GEWEX

WCRP
World Climate Research Programme

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# 1. Introduction and Overview

This report summarizes the main developments in GEWEX during the year 2015 and includes the major items and recommendations from the 28th Session of the GEWEX Scientific Steering Group (SSG), which was hosted by Professor Sonia Seneviratne at the Swiss Federal Institute of Technology in Zürich (ETH, Zürich) from 25-28 January 2016. This session of the SSG addressed both responses to advice resulting from the latest WCRP Joint Scientific Committee (JSC) meeting and developments in WCRP and the global programs. Key activities included assessing progress towards new data sets and goals, and the actions required to advance the GEWEX Grand Science Questions and synthesize water and energy cycle science across the Panels.

## 1.1. Major Activities

In May 2015, IGPO launched the new GEWEX website at http://www.gewex.org with new and updated content, a new events calendar, social media integration and a mobile-ready version.

Details of the implementation plan for the WCRP Grand Challenge on Changes in Water Availability (*Water Availability for the Food Baskets of the World*) have been refined and will be presented at the JSC meeting in April 2016.

In preparation for the new modeling initiatives related to the 6th Phase of the Coupled Modeling Intercomparison Project (CMIP6) being planned by the WCRP climate modeling community, a dedicated GEWEX and Climate and Cryosphere (CliC) Project-sponsored land modeling workshop was held at ETH Zürich in October 2015. It provided, for the first time, an interface between the broad spectrum of land modeling communities to foster exchange and develop synergies.

A new GEWEX activity, the Process Evaluation Study (PROES), will take advantage of existing data sets to advance process understanding and representation in models, both through new efforts and in collaboration with existing groups and activities. Four GEWEX-PROES activities are currently in different phases of development and include: (i) an upper tropospheric clouds and convection process study, (ii) a radiation kernels study, (iii) an ice sheet surface mass and energy balance study and (iv) a mid-latitude storms study.

In October 2015, GEWEX and the European Space Agency (ESA) held a very successful conference on Earth Observation for Water Cycle Science in Frascati, Italy. Special emphasis was placed on new science avenues and observational requirements for water cycle science. One of the primary conclusions of the ESA-GEWEX Conference was that, although past single- or limited-parameter Earth observational missions have proven their usefulness, they are most likely not the best way forward in tackling climate change issues.

Major activities related to the GEWEX Panels are given below.

**Global Atmospheric System Studies (GASS) Panel** activities are continuing, however at the time of this SSG meeting, replacements for the GASS co-chairs had not been found and there is no report on GASS activities for the past year. However, four papers related to the

GASS-Year of Tropical Convection vertical structure and physical processes of the Madden-Julian Oscillation model evaluation project were published in the May 2015 issue of the Journal of Geophysical Research-Atmospheres. In addition, a GASS Panel and WCRP World Weather Research Program (WWRP)/THORPEX MJO Task Force paper on challenges in predicting and simulating the Madden-Julian Oscillation was published in the September 15th issue of the American Geophysical Union's Eos.

**GEWEX Data and Assessment Panel (GDAP)** activities are currently divided into two major areas: data products and product quality assessments. The individual and integrated GEWEX data products enable research related to the WCRP Grand Challenges on changes in water availability, clouds, climate sensitivity and potentially for climate extremes. Major objectives of the product quality assessments are to provide independent and transparent quality assurance for existing data records, to identify key limitations in data records to stimulate improvements, and to allow objective selections of appropriate data records. The aerosol optical depth assessment to evaluate trends over the last decade and satellite data-climate model comparisons is complete and the final report, "A Critical Review of the Efficacy of Commonly Used Aerosol Optical Thickness Retrievals: Literature Assessment," was presented at the 2015 GDAP meeting. New activities include contributions to the GEWEX Upper Tropospheric Clouds and Convection Process Evaluation Study (UTTC PROES), reprocessing ground-based precipitation radar data in support of several WCRP Grand Challenges and further developments of a methodology for uncertainty characterization for satellite-derived data sets.

The SeaFlux Project has produced a Climate Data Record for the period of 1988–2007. A validation study of the LandFlux product against 45 globally-distributed flux towers was undertaken (McCabe et al., 2015), providing the first comprehensive evaluation of the LandFlux data sets. In a parallel effort, findings from the ESA-funded Water Cycle Observation Multi-mission Strategy-EvapoTranspiration (WACMOS-ET) Project have also been published, supporting the research being undertaken by investigators within LandFlux (Michel et al., 2015 and Miralles et al., 2015).

The **GEWEX Hydroclimatology Panel (GHP)** is well on track since its reorganization with several new Regional Hydroclimate Projects (RHPs) initiated (Hydrology of the Lake Victoria Basin, HyVic, and the Australian Energy and Water Exchanges, OzEWEX), as well as new crosscutting activities, including mountain snow and ice hydrology, and atmospheric interactions (Alpine Research Catchment Hydrology, INARCH) and sub-daily precipitation (INTENSE). New RHP initiatives include alpine precipitation (MOUNTerrain) and the incorporation of the human dimension in land-atmosphere and hydrological modeling, in collaboration with the Global Land Atmosphere Panel (GLASS). The Northern Eurasia Earth Science Partnership Initiative (NEESPI) RHP concluded with a very successful conference highlighting its many achievements.

The Hydrological Cycle in the Mediterranean Experiment (HyMeX) RHP held a 5-year program review and workshop in Mykonos, Greece in September 2015. New knowledge related to the Mediterranean water cycle produced in the first 5 years of HyMeX has led to the publication of more than 260 articles in peer reviewed journals and four special issues.

Two crosscutting activities, the project focused on sub-daily precipitation (INTENSE) and the International Network for Alpine Research Catchment Hydrology (INARCH) Project, were active over the past year, holding workshops, collecting data and initiating new research activities. A number of potential crosscutting activities have made progress towards reaching

GHP project status, including the Alpine precipitation (MOUNTerrain) Project, which held a special session at the annual meeting of the American Geophysical Union in December 2016. A new GHP/GLASS crosscutting project that focuses on the inclusion of water management in large-scale models will be launched with a workshop in late 2016 at the Ebro River Basin in Spain. The location was chosen because it is within the HyMeX study area. The Ebro River Basin has lost two-thirds of its discharge in the past 50 years due to irrigated agriculture in the catchment.

The **Global Land/Atmosphere System Study (GLASS) Panel** supports improved estimates and representation of (land) states and fluxes in models, the interaction with the overlying atmosphere and maximizing the utilized fraction of inherent predictability.

GLASS has reached out to the GEWEX Hydroclimatology Project (GHP) regarding a number of activities, such as the new initiative to improve the representation of the impact of anthropized water resources in land surface and eventually fully-coupled Earth System Models (Harding et al., 2015). The Panel has links with Global Atmospheric System Studies (GASS) Panel through the Diurnal Land/Atmosphere Coupling Experiment (DICE, which is wrapping up and in publication phase) and the GEWEX Atmospheric Boundary Layer Study (GABLS4), and is working within the new GEWEX Soils and Water (GSW) Initiative. GLASS has also collaborated with groups outside GEWEX, such as the Climate and Cryosphere (CliC) Project (via ESMsnowMIP as a part of LS3MIP), and it continues to engage the Working Group of Numerical Experimentation (WGNE) on benchmarking and data assimilation activities.

The Global Soil Wetness Project 3 (GSWP3) is currently in the “fast-track” phase with seven institutes participating [National Centers for Atmospheric Research (NCAR), the Swiss Federal Institute of Technology (ETH), the University of Tokyo, Météo-France, the European Centre for Medium-range Weather Forecasts (ECMWF), the Royal Netherlands Meteorological Institute (KNMI), and the Japanese Meteorological Association (JMA)]. Six simulation sets have been submitted, and the first round of analysis and validation is under way.

The Local Land-Atmosphere Coupling (LoCo) Working Group (WG) is continuing work on diagnostics of land-atmosphere interactions and coupling across an array of scales and models. Over 25 recent papers have been produced by members of the WG focusing on aspects of LoCo, such as diagnostic development, soil moisture-precipitation coupling, cold process coupling, mesoscale processes and GCM/RA/CMIP applications. The LoCo WG has been collaborating with the U.S. Department of Energy’s Atmospheric Radiation Measurement (ARM) Program U.S. Southern Great Plains (SGP) campaign and has produced an ARM-supported data set for coupling studies over the SGP. In addition, a radiosonde campaign led by the LoCo WG was executed in the Summer of 2015 (15 June-31 August 2015 at the ARM-SGP Central Facility) with high temporal resolution sonde launches to augment the current ARM-SGP sonde launches for application to LoCo studies. This new data set will allow the array of LoCo diagnostics to be applied consistently to the same location in order to understand their hierarchy and to develop a classification system based on the metrics.

## 1.2. GEWEX Links to the WCRP Grand Challenges

WCRP identified six Grand Science Challenges to be addressed by the climate research community in the coming decade. These represent some of the most important and challenging scientific questions for addressing current research gaps. GEWEX is leading two of the six science challenges, and also has connections to the four others. During this reporting period,

GEWEX has further defined how the collective research efforts within its four Panels will address the Grand Challenges. This topic was a primary focus of the SSG meeting.

GEWEX is leading the **Grand Challenge on Understanding and Predicting Weather and Climate Extremes** and has developed an implementation plan that was published in the February 2015 issue of GEWEX News. While it is expected that the implementation plan will be a "living document" that will be updated as plans and ideas progress, the current focus is on what is believed to be doable over the next few years. For that reason, the main implementation strategy is focused on four core event types: (i) heatwaves, (ii) droughts, (iii) heavy precipitation and (iv) storms. All activities are broadly embedded within WCRP, and also within the CLIVAR and SPARC projects. They will build upon many existing activities that already have international community support and coordination in place, and that are also connected to the relevant research activities of the High Impact Weather Initiative within WCRP.

The individual and the integrated GDAP data products enable research related to three of the Grand Challenges: Clouds, Circulation and Climate Sensitivity; Changes in Water Availability; and potentially Understanding and Predicting Weather and Climate Extremes. The GDAP Integrated Product supports improved understanding of the interactions of clouds, aerosols, precipitation and radiation and their contributions to climate sensitivity.

GEWEX is also leading the Grand Challenge on Changes in Water Availability, now re-scoped as the **Grand Challenge on Water for Food Baskets of the World**, and the implementation plan for this will be presented to the JSC at its next meeting. This Grand Challenge is one of the highest societal priorities, and of great importance to governments and agencies that sponsor climate research.

A number of GASS Panel activities will contribute to the **Clouds, Circulation and Climate Sensitivity Grand Challenge**, including the Grey Zone, Weak Temperature Gradient, Low-cloud Feedbacks and Radiative Processes in Observations and Models projects. In addition, idealized modeling frameworks are needed to study the response of convection and climate over warm land surfaces. Two upcoming GASS projects could align with the **Grand Challenge on Water for Food Baskets of the World**: (i) the Clouds Above the United States and Errors at the Surface (CAUSES) warm bias project, with its focus on the coupling of energy and water cycles at the land-atmosphere interface over summertime land masses, and (ii) the HiRes crosscut project to evaluate water cycle processes in high-resolution models. GDAP can also contribute to this Challenge by providing past precipitation amounts and the distribution of rain rates.

For the **Grand Challenge on Understanding and Predicting Weather and Climate Extremes**, the GHP Changing Cold Regions Network (CCRN) RHP is studying the effects of land use changes and drainage on eastern prairie hydrology, flooding and drought, and developing a hydrological model for predicting these changes. The HYdrological cycle in the Mediterranean EXperiment (HyMeX) has a strong focus on hydrometeorological extremes (heavy precipitation, floods, heat waves, droughts). Within GDAP, the re-engineered GDAP products (1-degree, 3-hourly time steps) may allow detection of extremes and processes related to extremes in the data.

The GHP INTENSE project is focused on meeting the data requirements and examining trends, variability and processes associated with heavy precipitation and drought. Data collection activities will contribute information that could underpin detection and attribution

studies and model evaluation by collating and quality-controlling sub-daily precipitation data (providing data that is extensive in time and space). INTENSE is also examining how sub-daily precipitation extremes may be defined through the use of relevant indices that have to date only been established on daily timescales. Analysis of local scale thermodynamics and large-scale predictors will improve understanding and characterization of physical mechanisms leading to the occurrence of floods and droughts and the relationships between these events. By linking observations with the latest generation of climate models (and in particular the emerging high-resolution regional climate models), INTENSE will assess the deficiencies of models in the simulation of key processes and events.

The **Cryosphere in a Changing Climate Grand Challenge** is addressed by the CCRN Project within GHP. CCRN conducts focused analysis and modeling of cryospheric process responses to warming. Key areas are the biomes of the Rocky Mountains (including glacier processes), boreal forests, prairies and the sub-Arctic.

## 1.3. Goals and Plans for Major Activities for 2016

GEWEX is developing plans for a North American Regional Hydroclimate Project (RHP) and is holding a workshop entitled “Workshop for the Water Availability Challenge for North America: A New Regional Hydroclimate Project” on 3-5 May 2016 at USRA headquarters in Columbia, Maryland. The goal of the workshop is to bring members of the atmospheric, hydrological, biogeophysical and social science communities to design an integrated strategy for addressing climate-related water challenges that face the semi-arid and/or topographically complex western U.S. and Canada. For in this region, longstanding observational, modeling and water management challenges uniquely intersect. The workshop will explore creating an RHP that tackles water availability from different vantage points: high resolution subseasonal-to-seasonal forecasts, downscaling and evaluation of climate projections, mountain hydrology, in situ and remote sensing observations, land-atmosphere interactions, ecosystem science, socioeconomic and political impacts, vulnerability and adaptation and the intersection of water, energy, and people. GEWEX is also pursuing new regional activities in South America.

The role of human activities in modifying and controlling the continental water cycle has been recognized by WCRP as one of its Grand Challenges and also underlies the GEWEX Grand Science Questions. To better understand the mechanisms behind this challenge, the GHP and GLASS Panels are creating a crosscutting project focused on the inclusion of water management in large-scale models that will be launched with a workshop in late 2016 at the Ebro River Basin in Spain. The location was chosen because it is within the area of the Hydrological Cycle in the Mediterranean Experiment (HyMeX) RHP. The Ebro River Basin has lost two-thirds of its discharge in the past 50 years due to irrigated agriculture in the catchment.

The Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction (MAHASRI) RHP will conclude with a conference in Tokyo, Japan on 2-4 March 2016.

The Global Soil Wetness Project-3 (GSWP3) will begin Phase 2 during the first half of 2016. It is a part of the Land Surface, and Snow, Soil moisture Model Intercomparison Project (LS3MIP) under LMIP, which is endorsed as part of Coupled Model Intercomparison Project-6 (CMIP6).

In addition, a number of new activities are expected to develop under the GEWEX Process Evaluation Study (PROES).

## 1.4. Interactions (Especially with WCRP Sponsors and Partners)

The National Aeronautics and Space Administration (NASA) continues to strongly support the International GEWEX Project Office. The major U.S. government agencies have been supportive for the development of a U.S. RHP in the Western U.S./Canada.

ESA continues to be a strong supporter of GEWEX activities. In October 2015, ESA and GEWEX held a very successful conference on Earth Observations for Water Cycle Science in Frascati, Italy. HyMeX initiated an ESA-funded Water Cycle Observation Multi-mission Strategy-EvapoTranspiration (WACMOS-ET) project over the Mediterranean region. The Director of IGPO co-chairs the International Soil Moisture Working Group, one of the drivers in establishing the global soil moisture in situ network, and supports the ESA WACMOS as the Chair of the Advisory Board.

GDAP shares responsibility with the Global Climate Observing System (GCOS) for the Baseline Surface Radiation Network (BSRN), which is essential to set standards and to provide high quality radiation measurements for the evaluation of satellite data sets and climate models. The Alfred Wegener Institute (AWI) hosts the World Radiation Monitoring Center, which is the central archive of BSRN data. The archive contains approximately 700 years of BSRN station data, which are heavily used and cited in almost 1200 peer reviewed articles. The current Director of the World Radiation Monitoring Center (WRMC) is retiring and the GDAP Chair has not received a commitment from the Director of AWI that his organization will continue to support the archive.

BSRN is directly participating in the World Weather Research Programme Polar Prediction Project and several stations are a part of the International Arctic Systems for Observing the Atmosphere (IASOA) Radiation Working Group.

The Subseasonal to Seasonal Prediction Project (S2S) joint initiative of the World Weather Research Program is of interest to the GLASS Panel and a representative attends the S2S meetings on a regular basis.

The WMO Sustained, Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM) Initiative continues to host International Satellite Cloud Climatology Project (ISCCP) data processing at the National Oceanic and Atmospheric Administration's (NOAA) National Center for Environmental Information (NCEI), which is supported by several data centers (mostly space agencies) delivering the needed input data for ISCCP.

The International Soil Moisture Network (ISMN), which serves a large international scientific community through improvement of weather and climate models and remote sensing products, and support to agriculture applications, is coordinated by GEWEX/GDAP in cooperation with the Group of Earth Observation (GEO) and the Committee on Earth Observation Satellites (CEOS). The database is hosted by the Department of Geodesy and Geoinformation at the Vienna University of Technology (TU Wien). ISMN integrates 49 networks containing almost 2050 stations that have added over 8000 soil moisture data sets into the archive. It also contains historical soil moisture data sets dating back to 1952. Operational data sets are updated in near-real time. ISMN is rapidly growing and several new networks and data sets will be integrated in the near future, including China (Wuhan University), Korea and Romania. Further growth potential, such as the hundreds of soil

moisture stations operated by the Chinese meteorological service, was discussed at the GDAP annual meeting with Chinese representatives giving positive signals on a potential integration.

## 1.5. Outreach and Capacity-Building Activities

GEWEX is leading the WCRP Grand Challenge on Changes in Water Availability, which relates to the UNESCO International Hydrological Programme (IHP) goal to understand uncertainty and translate it back to water security. Future GEWEX activities within this Grand Challenge are planned with IHP, including co-hosting a summer school on water availability in 2017.

GEWEX is also exploring potential collaboration with the WMO Hydrology Climate Land Water Department and Regional Panels and the Climate and Cryosphere (CliC) Project. A connection to CliC has been proposed through the GABLS Stable Planetary Boundary Layer Project over the arctic region (GABLS4). In addition, ESMSnowMIP is a collaborative effort between CliC and GLASS. LS3MIP, a CliC and GEWEX project, is addressing core research questions of WCRP and is relevant to a large fraction of the WCRP activities.

GDAP shares responsibility with the Global Climate Observing System (GCOS) for the Baseline Surface Radiation Network (BSRN), which is essential to setting standards and providing high quality radiation measurements for the evaluation of satellite data sets and climate models.

GEWEX benefits greatly from its strong interactions with other WMO and WCRP initiatives. The Global Data Centers for precipitation, river runoff, and lakes/reservoirs (GRDC, GPCC and Hydrolare, respectively) are affiliated activities under GEWEX and are connected through a number of outside bodies to obtain meaningful data for application to research of interest to the broader climate research community.

Under GDAP, the Surface Radiation Budget Project (SRB) is participating in the WCRP Data Advisory Council (WDAC) Surface Fluxes Task. In addition, GDAP has presented a paper to WDAC on “Data Set Quality Assessments: Needs, Benefits, Best Practices and Governance,” which provides guidance for a more homogeneous approach towards assessments of data set quality. The GDAP chairman continues to be active in the WDAC obs4mips Task Team and supports the open data call.

GEWEX is working to identify links to new regional groups in Latin America that may require further support to broaden current activities into international studies that fit within the WCRP structure. The 2015 GEWEX SSG meeting was held in Medellin, Columbia and the SSG now has a new member from Columbia.

Cross collaboration opportunities between GEWEX and the integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) are being identified within the different GEWEX Panels. Under GHP, MAHASRI had collaborative activities with the Japanese iLEAPS and International Geosphere Biosphere Programme (IGBP) communities, as well as the Asian SPARC community. A new GHP-GLASS-iLEAPS project for the Saskatchewan River Basin is being investigated.

HyMeX and OzEWEX are collaborating with Earth2Observe and HEPEX in hydrological forecasting.

GEWEX and CLIVAR joint activities include the new JSC task group on extreme weather and climate, and the WCRP Monsoon Panel.

Continued collaboration with the Group on Earth Observations (GEO) is provided through the Director of IGPO, who has been active in the Integrated Global Water Cycle Observations (IGWCO) Project. In addition, the Director of IGPO serves on the Board of the FP7 Earth2Observe Project and the Board of the Helmholz Alliance as a user group representative.

There are many cross collaboration activities between the GEWEX Panels and other programs. GEWEX and iLEAPS collaboration is underway through the GLASS/GSWP3 Project. In addition, the Land-Use and Climate, IDentification of robust impacts (LUCID) activity is an iLEAPS-GLASS supported project. GLASS is also recruiting member(s) of iLEAPS to be actively involved in both the planning and analysis of its new carbon activity.

To encourage the involvement of young scientists in GEWEX/WCRP activities, IGPO has invited the Young Hydrologic Society (YHS) and the Young Earth System Scientists (YESS) Community to contribute one-half page in each issue of GEWEX News to advertise their activities. GEWEX also co-sponsored the Alpine Summer School on Land-Atmosphere Interactions in Valsavarenche, Italy in June 2015.

# 2. GEWEX Panel Status Report

## 2.1. GEWEX Data and Assessment Panel (GDAP)

Reporting Period: January 2015–December 2015
URL: http://gewex.org/GDAP.html
Chair(s) and term dates: Jörg Schulz (July 2014–March 2017);
Vice Chair: Matthew McCabe (January 2015–March 2017)

### 2.1.1. Panel Activities and Science Highlights

#### 2.1.1.1. GEWEX Data Sets

*2.1.1.1.1. ISCCP and Ancillary Data*

The full reprocessing to generate the International Satellite Cloud Climatology Project Version 2 (ISCCP V2) data set has not begun. The processing was transferred to the U.S. National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Information (NCEI) with the consequence that quality control and improvement of the input data became major work that lasted for a full year. Once the processing begins (likely in February 2016), NCEI should be able to process about 10 years per month. A "final" version of the ISCCP cloud products for 2007–2009 should be available soon.

The neural network High Resolution Infra Red Radiation Sounder (nnHIRS) product, a retrieval of temperature and humidity profiles, is essential to providing temperature and humidity profiles, as well as several surface parameters for the GEWEX Integrated Product (see Section 1.1.7). The Integrated Product has been completed for 1980–2014 and is available for the processing of other GEWEX products. Due to issues detected when using earlier versions of the nnHIRS product to compute long wave (LW) radiative fluxes, the latest version was adjusted to improve agreement with surface station temperatures and humidity. This version will soon be used by the Surface Radiation Budget Project (SRB). All other ancillary products needed for the provision of the integrated product have been completed for the entire time period (currently 1980–2014) and are online.

*2.1.1.1.2. SRB*

The Surface Radiation Budget Project (SRB) team continues to assess new nnHIRS and ISCCP HX data sets, make algorithm improvements and analyze test cases in preparation for production of the integrated data product. During the past year, two different versions of nnHIRS and ISCCP HX were received, and these were assessed by comparisons to other data sets and by running various cases through the SRB production system. The nnHIRS data sets were compared with ERA-I, the Modern-Era Retrospective Analysis for Research and Applications (MERRA), MERRA2 and the National Aeronautics and Space Administration (NASA) water vapor–MEaSUREs (NVAP-M) data sets. Near surface data parameters are compared against NOAA NCEI global surface weather station data sets. ISCCP HX, HGG and HGM data products were compared to ISCCP DX, D1 and D2. In addition, there were several other input and algorithm changes implemented as well. Included in these were the

implementation of the Max Planck Aerosol Climatology (MAC v1) and new ISCCP ancillary data sets, including ice, snow, ozone and surface types. Adjustments to various stages in the SRB production system were required to incorporate these changes. One additional input quantity is surface skin temperatures for the year 2007. SRB is testing the use of the land surface temperature product from LandFlux and the diurnal ocean surface skin temperature from the SeaFlux Project. Thus, SRB derives a 3-hourly blended global surface skin temperature input using these and the ISCCP HX skin temperature retrievals. This represents the next stage in energy flux integration. Several case studies were performed to evaluate the effect of these inputs on the SRB outputs. The resulting fluxes were compared to fluxes from the Baseline Surface Radiation Network (BSRN) sites and the fluxes now released by the Clouds and the Earth's Radiant Energy System (CERES) Mission for both top of atmosphere (TOA) and surface fluxes.

Although, other comparisons are ongoing, the results of these tests will be included as part of our uncertainty analysis for the latest SRB version. In general, the shortwave (SW) data products showed improvements relative to the previous version. However, the LW TOA and surface radiative flux data products have significantly larger differences relative to the surface measurements and CERES. Thus, SRB is still evaluating the new various cloud and ancillary data products and algorithm changes for issues. After completion of this assessment and further testing, SRB will be able to deliver both the SW and LW fluxes from the current nnHIRS and ISCCP HX data product versions. This should be completed in the next 1–2 months.

#### *2.1.1.1.3. GPCP*

Version 2.3 of the Global Precipitation Climatology Project (GPCP) data is in final testing. This new version fixes a few problems with cross-calibrations among satellites that had caused artificial shifts in the data. It also uses new Global Precipitation Climatology Centre (GPCC) full analysis. The plan is to release this new version in early 2016 to replace GPCP Version 2.2. The GPCP Monthly Interim Climate Data Record (ICDR) is produced within 10 days of the end of the month for climate diagnostics work.

#### *2.1.1.1.4. SeaFlux*

SeaFlux has produced a Climate Data Record (CDR) covering 1988–2007 that is similar to the SeaFlux 1.0 product delivered for the integrated product. The CDR contains extensions towards real time using the Special Sensor Microwave Imager/Sounder (SSMIS) instrument data. Major differences are the use of neural net derived winds, rather than the Cross-Calibrated Multi-Platform (CCMP) wind product, which has reduced the trend in global wind speed. Data obtained prior to1998 used a ship-of-opportunity-based reference data set and are not as high quality as the SeaFlux research vessel only data set.

Comparison activities show that both latent heat and sensible heat fluxes exhibit inter-product differences of 5-10 Wm-2 globally and 10-20 Wm-2 over the Southern Ocean. Several of the products show a moderate trend from the early 1990s, in contrast to the Objectively Analyzed Air-sea Fluxes (OAFlux) Project data and some reanalysis products. At the global scale, both humidity, temperature and wind speed differences appear to be important, and offsetting in some cases. Wind speed is in better overall agreement than humidity and temperature differences.

Further study shows that the structure in the retrieval atmospheric humidity (Qa) biases appear to be co-aligned with patterns of cloud weather states as defined using ISCCP cloud-top histograms. The largest biases in several of the Qa retrievals are aligned best with Global WS 7 (mostly clear, with thin boundary layer cloud). New ways for retrieval are being tried by using cloud information derived from the microwave instruments to distinguish between weather regimes.

*2.1.1.1.5. LandFlux*

The LandFlux Project has made good progress towards completion of Version 1 global land surface heat fluxes. Simulations covering the period 1984-2007 have been completed using four different methodologies, with latent heat (LE) fluxes produced at 3-hourly, 1-degree resolution for this period. Work is continuing on the development of a global sensible heat flux product (H) to be completed by mid-2016.

A validation study of the LandFlux product against 45 globally distributed flux towers was recently undertaken (see McCabe et al., 2015), providing a first comprehensive evaluation of the LandFlux data sets. In a parallel effort, findings from the European Space Agency (ESA) funded WAter Cycle Observation Multi-mission Strategy-EvapoTranspiration (WACMOS-ET) Project have also been published, supporting the research being undertaken by investigators within LandFlux (see Michel et al., 2015 and Miralles et al., 2015). An overview paper on global flux estimation is in the planning stages.

*2.1.1.1.6. Soil Moisture*

An International Space Science Institute (ISSI) Workshop was held in November in Bern, Switzerland with representations from across satellite soil moisture user community [national weather prediction, climate, and hydrology]. The goal of this workshop was to establish a common baseline for satellite soil moisture products and to identify the evaluation metrics and approaches that are needed to verify that products comply with these standards. The results of the meeting have been summarized and are currently detailed in a draft white book for satellite soil moisture validation. The white book will be discussed with a larger user community in a dedicated workshop to be held at the ESA European Space Research and Technology Centre in Noordwijk, The Netherlands on 28-29 April 2016.

Specific achievements include:

- All radiometer data products From NASA's Soil Moisture Active Passive (SMAP) Mission are now available at the National Snow and Ice Data Center
- New release of the ESA Climate Change Initiative-Soil Moisture (CCI SM) multi-satellite soil moisture data set for the period 1978-2014 (including SMMR, SSM/I, TMI, AMSR-E, WindSat, AMSR2, ERS 1/2-AMIand MetOp-A ASCAT)
- Signal-to-noise ratio (based on triple collocation) has been introduced as new evaluation metric for soil moisture product evaluation and intercomparison
- A Special Issue in the Journal of Applied Geodesy on the retrieval and validation of satellite soil moisture (with GDAP panel member W. Dorigo as guest editor): http://www.sciencedirect.com/science/journal/03032434/45/part/PB

*2.1.1.1.7. GEWEX Integrated Product*

Completion of an integrated product that uses common assumptions across the suite of GDAP products is expected in 2016. The integrated product is designed to ensure that geophysical signals and their covariance are tied to the data and products themselves rather than inconsistencies in their assumptions. Two different types of integration are planned:

1. Integration of GEWEX products in one collection, which will allow downloading the data from one location.

2. Integration by using the same ancillary files for all data sets and by using outputs from one product as input to another, as is done by using ISCCP data to construct SRB data. The strategy here has changed from using only those parts that can be proven to bring improvements to the individual products.

Performing (1) has proven to be very difficult, in particular using derived temperature and humidity profiles from HIRS as inputs to SRB and the SeaFlux and LandFlux schemes. SRB has used the HIRS products together with SeaFlux and LandFlux surface values along with the latest ISCCP and MAC-v1 aerosols to compute fluxes. SW fluxes look quite good and are ready for distribution but LW fluxes are biased positive (too large downwelling) with 7 $W/m^{-2}$ over oceans for a net 5 W/m2 bias globally. The HIRS products are not good in the lower atmosphere and close to the surface because there is no HIRS channel that is sensitive to it and water vapor is estimated basically from the differential absorption in window channel differences. Discussion is ongoing to use reanalysis instead, however, the MERRA data stopped at the end of 2015 and the MERRA 2 data needs to be better understood as some biases with BSRN station data have increased. The use of European Centre for Medium-Range Weather Forecasting (ECMWF) reanalysis could be of help with this.

Given the fact that the HIRS temperature and humidity retrievals have been tuned with surface stations (e.g., SeaFlux and LandFlux use their own near surface estimates).

Ancillary information such as ice edge are also critical in an integration process, however, different products have different sensitivities for this. The currently used definition of ice edge is less conservative than the sea ice product used by the ocean community. This can have a large impact on air-sea (up to changes of the global mean) and also radiation fluxes. Therefore, it might be better to use existing proved flagging from the individual products.

Basically all products are ready to produce data from 1998 onwards, with only SRB waiting for the ISCCP products to be finalized, and the need to make a decision on the use of temperature and humidity profiles for the LW fluxes.

### 2.1.1.2. GEWEX Data Quality Assessments

*2.1.1.2.1. Water Vapor Assessment*

The Fifth G-VAP meeting was hosted by the Space Science and Engineering Center at the University of Wisconsin on 4-5 November 2015. Attendees included participants from research institutes and universities (Colorado State University, Freie Universität Berlin, Lille University of Science and Technology, Vanderbilt University, University of Wisconsin), weather services (Agencia Estatal de Meteorología, Danish Meteorological Institute, Deutscher Wetterdienst, U.S. National Oceanic and Atmospheric Administration), the in situ measurement community

(NOAA) and space agencies [European Space Agency (ESA), European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)].

The main outcomes of the Fifth G-VAP Workshop were:

- A timeline for drafting the World Climate Research Programme (WCRP) report on G-VAP and for freezing the data archive was agreed upon, with the preliminary report to be ready in April 2016 and final draft in August 2016.
- The release of collocated data and data on common grid by G-VAP was endorsed under specific circumstances.
- The proposal to continue G-VAP beyond the acceptance of the WCRP report on G-VAP was well received and the participants are willing to support G-VAP in the future.

From this it is expected that the water vapor assessment will be finalized by the time of the 2016 GDAP meeting. At the meeting, GDAP will review the proposal for continued work on G-VAP, which would result in a biennial reporting of water vapor scientific findings relevant to GEWEX.

*2.1.1.2.2. Aerosol Assessment*

The aerosol assessment presented their final report, “A Critical Review of the Efficacy of Commonly Used Aerosol Optical Thickness Retrievals: Literature Assessment,” at the 2015 GDAP meeting. However, the report has not been published because it has not received clearance from the main author. GDAP will continue to work to clear this report that will mark the end of the aerosol assessment (unless aerosol product users request more activity from GDAP).

The AeroCom forum for aerosol global modeling and communications was formed by providers of the data for needed input (emissions) and for model evaluation, and reports also to GDAP through Stefan Kinne. The main goals of AeroCom are to understand the complexities in the aerosol component of global modeling (emissions to forcing) to use available aerosol data to constrain models. This will lead to close interactions and collaborations with the remote sensing communities to define harmonized model experiments to investigate and understand model behavior.

As a by-product the Max-Planck-Institute Aerosol Climatology (MAC) was developed and has continuously improved all spectral properties needed for radiative transfer including seasonality and decadal anthropologic change. The climatology gives access to climate impacts without detailed modeling. MAC-v2 was released and can be downloaded at: ftp-projects.zmaw.de/aerocom/climatology/MACv2_2015.

*2.1.1.2.3. Precipitation Assessment*

Key questions to address in the different assessment phases were identified. High priority is placed on the evaluation of the GPCP climatology in comparison with other selected precipitation products for the first interim report. The data sets participating at this stage include the Japanese Global Satellite Mapping of Precipitation (GSMaP), the NOAA Climate Prediction Center (CPC) MORPHing technique (CMORPH), and the CPC Merged Analysis of Precipitation (CMAP), but more data sets, including reanalysis results may be identified during 2016. The Global Precipitation Mission (GPM) radar, ground radar networks, and gauge analyses may be

also helpful if carefully analyzed with individual strengths and weaknesses in mind for assessing uncertainties from multiple angles. Meanwhile, the Precipitation Assessment team continues to identify questions to address in subsequent assessment cycles. Extreme precipitation is among the top priorities after the climatology.

Understanding and quantifying the potential uncertainties in the GPCP climatology is of urgent importance to address the budget closure issues of the integrated products.

The prioritized foci for the precipitation assessment remain as:

- Global and Regional Climatology (long-term mean and trend) – with a focus on regionally dependent sources of uncertainty.
- Time series analysis in the context of different modes of climate variability – Diurnal, intra-seasonal, seasonal, interannual, etc.
- Extremes – which could benefit from a new activity on ground-based radar data reprocessing
- Frozen Precipitation – Snow and mixed-phase precipitation
- Structural Errors – Errors that are not eliminated by temporal/spatial averaging

The data sets considered in the assessment may contain more than classical precipitation data sets, such as measurements to constrain precipitation [e.g., Gravity Recovery and Climate Experiment (GRACE) data in polar areas], surface salinity for long-term freshwater budget, soil moisture as potential rain gauge, and moisture transport derived from reanalysis. Suggestions were made to shorten the analysis and take the benefits from literature, however these comparisons are done in an inhomogeneous way. The GEWEX assessment can connect to CLIVAR through the use of climate model metrics to be applied to satellite data record. The topic of frozen precipitation will be linked with the Climate and Cryosphere Project (CliC).

Plans for the precipitation assessment were endorsed at the 2015 GDAP annual meeting with a request for more specific science questions. A workshop to define the questions around the first topic is planned for autumn 2016, possibly in combination with the next GDAP meeting. In addition, Chris Kummerow will establish needed connect with the GHP MOUNTerrain Project on rugged terrain precipitation.

#### *2.1.1.2.4. Soil Moisture Assessment*

The white paper on the identification of the evaluation metrics and approaches needed to verify if products comply with these standards will serve as baseline for the soil moisture assessment. A review of the white paper by GDAP is planned this year. While the interest and need for an assessment of the various products from satellite, reanalysis and models is there, the progress is hampered by the community taking a long time to reach agreements on how to do the evaluation.

### 2.1.1.3. Ground Based Observational Networks

#### *2.1.1.3.1. BSRN*

The Baseline Surface Radiation Network (BSRN) has a new project manager, Charles Long (NOAA) who was jointly approved by GEWEX and the Global Climate Observing System (GCOS). BSRN objectives are to:

- Monitor the surface short wave and long wave radiative components and their changes with the best methods and instrumentation currently available (Detailed observations)
- Provide accurate data for the calibration of satellite-based estimates of the surface radiative fluxes (global coverage)
- Produce high quality observational data for validating the theoretical computations of radiative fluxes by models climate prediction)
- Improve fundamental measurement capabilities with the goal to provide the highest possible quality data from continuously operated field sites
- BSRN has developed practices for instrumentation, calibration, and operation that fulfill highest specifications.

BSRN is a volunteer organization, with stations sponsored by host organizations and governments.

BSRN has six working groups:
- Infrared Working Group
- Long-Term Data Sets Working Group
- Archive Working Group
- Cold Climate Issues Working Group participates in polar prediction project
- Oceanic Working Group
- Uncertainties Working Group

In 2014, 59 Stations provided data to the BSRN Archive; five additional stations are planned, four are proposed, and six have been closed. The BSRN archive contains now approximately 700 years of station data. The data are heavily used and cited almost 1500 times without self-citations in almost 1200 peer reviewed articles.

*2.1.1.3.2. International Soil Moisture Network (ISMN)*

The International Soil Moisture Network integrates 49 networks containing about 2050 Stations that have put approximately 8000 soil moisture data sets (6500 last year) into the archive. Historical data sets reach back to 1952. Operational data sets are being updated in near-real time.

The ISMN is rapidly growing and several new networks and data sets will be integrated into it in the near future: e.g., China (Wuhan University), Korea, Romania. There is a large growth potential (e.g., the Chinese meteorological service operates hundreds of soil moisture stations). If these were shared through the ISMN, it would have an enormous scientific impact (most registered ISMN users come from China). Chinese representatives at the 2015 GDAP annual meeting in Xiamen, China gave positive signals on this topic.

The ISMN is a success story, serving a large international scientific community and important implications well beyond science, e.g. through improvement of weather and climate models (ESMs), improvement of remote sensing products, and support to agriculture applications. ISMN has good-value for money (costs are approximately 50-100k EUR/year). Financial support for 2009-June 2016 comes from the ESA Earth Observation Program funds for the Soil Moisture and Ocean Salinity (SMOS). A new funding source is being investigated.

*2.1.1.3.3. Global Precipitation Climatology Centre (GPCC)*

GPCC delivered a detailed report to the GEWEX Hydroclimatology Panel (GHP) and is therefore not repeated here. GPCC remains an important element in the construction of GPCP products.

### 2.1.2. New Projects in Place

None.

### 2.1.3. New Projects and Activities Being Planned

#### 2.1.3.1. Ground-Based Radar Data Records

Activities in radar data reprocessing are by far less mature than what is in place on satellite data, but 30 years ago we were in a similar state with regards to satellite data, when it was understood that satellite data can be used for more than weather forecasting or other real-time application.

GDAP plans to work towards a similar extension of the usage of radar data by coordinating and synthesizing activities. A first step should be, that even if we cannot now solve the problem of global radar data exchange (see Figure 1 for available radar systems), all operators of radar data should be approached to request that they store their radar data in a manner that someone can use at least 15 years from now. As this is cost intensive we need to show that there is a much bigger spectrum of potential usages for radar data.

NOAA has completed reprocessing for the period covering 2001-2012. The reanalyzed data are available at 1-km and 5-minute resolution. An important step in the process of generating the best possible precipitation estimates is to assess the bias in the radar-only product and to implement techniques for merging in situ data and providing the best bias-adjusted estimates. The Deutscher Wetterdienst (DWD) has completed reprocessing of DWD radar data (for Germany) from 2001, including statistical evaluation with a focus on extreme precipitation and the development of user-specific products for applications (e.g., hydrology, civil protection and agriculture).

Although this was attempted earlier with not much success GDAP will try again to start a new project that brings together scientists working on radar reprocessing, considering aspects of archiving, reprocessing, and exchanging radar data and the development of consistent radar precipitation databases for use in hydroclimatological studies. Potential leaders of such a project could be Andreas Becker (DWD) and Brian Nelson (NOAA). A first workshop is tentatively planned for 2017.

The existing reprocessed data holdings should be used by the Climate Extreme Grand Challenge and feedback should be provided to the project within GDAP.

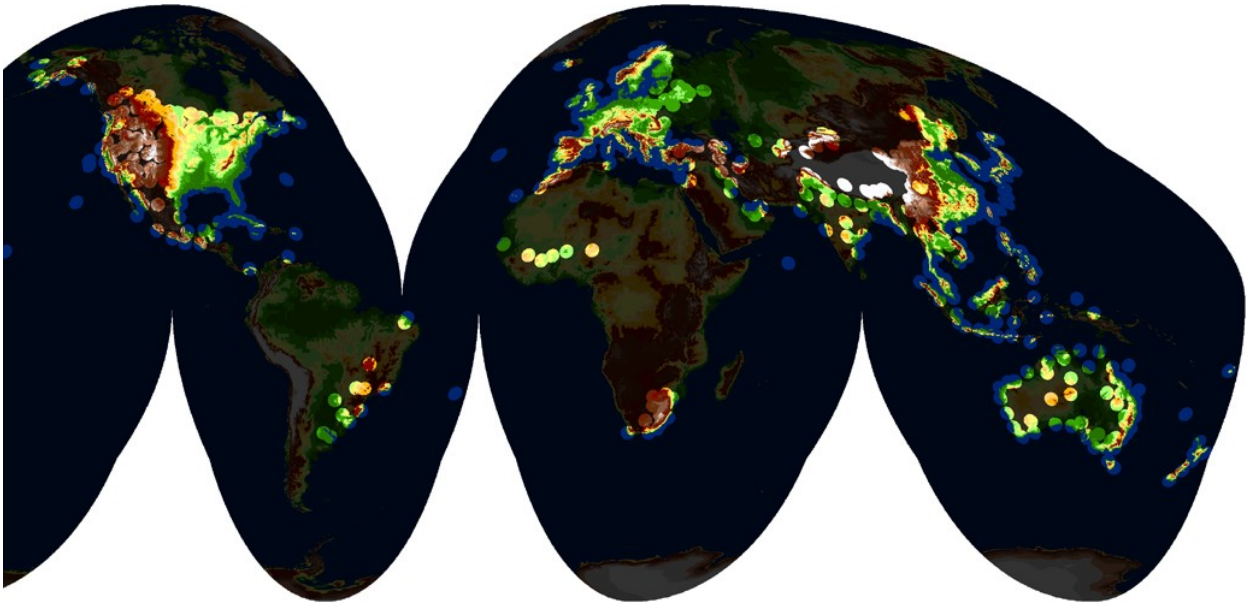

*Figure 1. Current weather radar coverage provided by national weather services (in Goode Homolosine projection). For computing the area illuminated by terrestrial weather radars, a maximum range of 200 km per radar device is assumed. The underlying database was established based on a web search of national weather services' web pages, web documents, and the WMO radar database http://wwr.dmi.gov.tr (which is quite incomplete, though, in comparison to the results shown in this figure). The figure shows that almost complete coverage is achieved for North and Central America, as well as Western and Central Europe. Good coverage is also available for the Middle East, South, Southeast and East Asia, and Australia. Large parts of Africa and South America remain uncovered, yet, as well as vast parts of Russia (although a new network with about 140 Doppler radars is planned to be established in Russia by 2018). Source: Heistermann et al., 2013: Technical Note: An open source library for processing weather radar data (wradlib). Hydrol. Earth Syst. Sci., 17, 863–871, 2013, www.hydrol-earth-syst-sci.net/17/863/2013/, doi:10.5194/hess-17-863-2013.*

#### 2.1.3.2. GEWEX UTCC PROES

The goal of the activities of the GEWEX Upper Tropospheric Clouds and Convection Process Evaluation Study (UTTC PROES) is to provide observational based metrics for a better understanding of climate related physical processes. One of the WCRP Grand Challenges is to determine the role of convection on cloud feedbacks. The UTCC PROES Working Group aims to gain a better understanding of the interconnection between the convection and the heating induced by the outflowing anvils. By widening the focus on the role of all cirrus clouds [linkage to Stratospheric Processes and their Role in Climate (SPARC)] another key question arises: how large are the relative cirrus contributions, in occurrence and in radiative heating, originating from convection and from in situ freezing driven by large-scale forcing?

At present the working group includes about 30 scientists. The first workshop was held on 16 November 2015 in Paris, France. Twenty participants presented and discussed feedback hypotheses and the resources to tackle the scientific questions: (1) cloud systems and atmospheric environment from observations, (2) Lagrangian transport to determine cirrus origin and life cycle, (3) process modeling and large-scale parameterizations and (4) radiative

transfer. The analysis of large-scale convective cloud systems shows that the size of these systems is strongly linked to their convective strength.

In a first step, we intend to build a synergetic database of high-altitude cloud systems to be used by the participants. In addition, a simulator of high-altitude cloud systems is being built for the evaluation of different formation schemes in climate models. Informal meetings will be held whenever the coordinators have the occasion (during conferences or visits); and a second official workshop is planned in fall 2016 in New York.

#### 2.1.3.3. Uncertainty Analysis

Uncertainty analysis is important in making GEWEX related products useful for answering the GEWEX science questions. Within Europe two distinct projects have begun that address the uncertainty characterization of satellite data records. One is Fidelity and uncertainty in climate data records from Earth Observations (FIDUCEO) and the other is the Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring (GAIA-CLIM) that addresses the uncertainty of surface based reference observations and their use to characterize satellite measurements. In addition, GEWEX data set producers and assessments have further addressed how uncertainty might be quantified in products and through comparisons with other data.

A recent workshop was held on uncertainties in water vapor measurement at 183GHz, where biases observed between measurements at 183 GHz and calculations using different radiative transfer models were discussed, including using either radiosondes (RAOBS) or short-range forecasts from Numerical Weather Prediction (NWP) systems. The three main objectives of the workshop were (1) describe the biases, trying to separate those biases are common to all approaches from those that may have been a result of a particular methodology; (2) identify and, where possible, quantify uncertainty in every component of the comparison; and (3) where possible to begin the process of attribution of the biases, which could in due course lead to their elimination. In order to address these ambitious goals, experts in the many different aspects were assembled, including specialists in RAOBS calibration, NWP models and data assimilation, instrument biases and radiative transfer models, both the models themselves and the underlying spectroscopy. Comparisons were also undertaken with other techniques for sensing humidity information such as Global Navigation Satellite Systems (GNSS), Differential Absorption Lidar (DIAL), Raman lidar and infrared (IR) radiances.

GDAP will continue to support such activities to achieve better overall uncertainty characterization of satellite derived data sets. ESA and EUMETSAT are planning a workshop on uncertainty characterization for satellite data sets in 2017.

### 2.1.4. Science Issues

#### 2.1.4.1. Ground-Based Radar Data Reprocessing

The following conditions are necessary for global climatological approaches that are based upon radar data.

- The archiving of raw and processed radar data by institutions that operate radar networks needs to be elevated to a similar level of commitment as obtained for (operational) satellite data. The Earth System Grid Federation (ESGF) success is a likely model for a distributed solution of such observation databases. However, the problem was somehow easier to

address with a set of models, where most dimensions are complete, than with observations that present many dimensions (e.g., temporal frequency, type of variable, vertical sampling, technique of measurement). Defining a minimum set of standards for observations, without duplicating the years of work in this area, would help create observations to be discoverable and searchable by everyone. This should include digital object identifiers (DOIs) or other unique data set identifiers. GEWEX may help to implement this through the World Meteorological Organization and in direct consultation with radar operators.

- Consistent reprocessing in terms of methodology of various types of radars starting with common precipitation radars (C, S-band radars) should be achieved. This requires an initial workshop that considers the existing approaches and initializes a process that may lead to a baseline similar to what is achieved for satellite data. It is expected that nomenclature from the satellite world could be transferred to the radar data reprocessing activities.
- Data and software exchange can be key for success and an initial workshop may provide a basis for agreements on this. Currently, radar data reprocessing or climatological evaluation of radar data is performed or under consideration by different weather services or institutes (e.g., DWD, Météo France, FMI, KNMI, KMI, Meteo Swiss, and NOAA). Within Europe some approaches to combine and unify radar data on an international scale by OPERA and BALTRAD exist but concentrate primarily on real time applications.

It is evident that this topic is a long-term activity because many of the conditions necessary for a successful generation of radar data climatologies do not exist today. However, the example of the evolution for satellite data shows that at a scale of 10 years very useful data sets may be developed.

#### 2.1.4.2. LandFlux

Developing a global sensible heat flux product is proving to be challenging, given the reliance on accurate and representative surface temperature data. The project requires the development of consistent surface temperature and radiation data to move forward with the integrated product. Identifying a robust and simple model for snow evaporation is also required for polar and related regions. Other science issues are highlighted in the referenced papers, but include consistency in forcing, model parameterizations and variable model performance with biome and land-cover type.

#### 2.1.4.3. Soil Moisture

The NASA Soil Moisture Active Passive (SMAP) Mission radar failed after collecting only two months of data. NASA now focuses on the ESA Sentinel-1, a two-satellite constellation carrying the C-SAR sensor, as the replacement for the SMAP radar. Funding of the International Soil Moisture Network, a satellite validation platform coordinated by GEWEX, was secured only until June 2016.

### 2.1.5. Contributions to the GEWEX Science Questions

The following table shows the general contribution of GDAP data products to the GEWEX science questions.

| GEWEX Science Questions | | GDAP Projects and Products | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | GPCP/GPCC Assessment | ISCCP | GVAP | GACP AEROCOM | SRB | EBAF | Landflux | Seaflux | Soil Moisture | Groundwater Storage | Integrated Product |
| Observation and Prediction of Precipitation | How well can precipitation be described | y | y | y | y | n | n | n | y | y | y | y |
| | How do changes in climate affect the characteristics | y | c | c | c | c | n | c | c | y | y | y |
| | How much confidence do we have in predictions | y | c | c | c | n | n | n | n | y | y | y |
| Global Water Resources | How do changes in the land surface and hydrology influence water resources? | n | n | n | n | c | n | c | n | c | c | c |
| | How does climate change impact water resource systems? | n | n | n | n | n | n | n | n | n | n | n |
| | How can new observations lead to improvement in management? | p | n | n | n | n | n | n | n | p | n | p |
| Climate Extremes | Observing system requirements? | y | y | y | y | y | y | y | y | y | y | y |
| | Modelling capabilities? | u | u | u | u | u | u | u | u | u | u | u |
| | Modelling processes involved in extremes? | y | y | y | u | u | u | u | u | u | u | u |
| | Improved early warning systems? | y | c | y | u | y | u | u | u | u | u | u |
| Energy and water Cycles | Can we balance the budget at TOA? | n | c | c | c | c | y | n | c | n | n | c |
| | Can we balance the budget at surface? | y | y | y | y | y | y | y | y | y | y | y |
| | Can we track the changes over time? | y | y | y | y | y | y | y | y | y | y | y |
| | Can we relate changes and processes? | p | y | y | p | p | p | p | p | p | p | y |
| | Cloud-aerosol-precipitation feedback | y | y | y | y | y | y | n | n | n | n | n |

*Table 1: Potential contribution of GDAP activities to GEWEX science questions; y = yes, n=no, c=contribute, u=unknown, p=potential.*

### 2.1.5.1. Observations and Predictions of Precipitation

GPCP and other data sets provide a baseline for addressing questions related to precipitation. The planned precipitation assessment will address some basic questions around the existing data sets. The Global Precipitation Mission (GPM) provides a new observational basis for tailored data sets addressing questions associated with PROES activities.

The GPCC precipitation analysis products based on in situ observed data in near real-time, as well as non real-time; contribute by improving the observational precipitation data sets (Becker et al., 2013). A combination of GPCC daily analysis with the satellite-based HOAPS data set for 1988-2008 has been completed, and is in process for the Full Data Daily Analysis (V.1) for 1988-2013. In the future an update of the combined data set on a yearly basis is planned.

The envisaged activities on radar precipitation will further strengthen the ability to address questions associated with the Climate Extremes Grand Challenge.

### 2.1.5.2. Global Water Resource Systems

GDAP products do not contribute very much in this area. However, soil moisture data sets may be used to address the question of how changes in land surface and hydrology influence water resources.

#### 2.1.5.3. Changes in Extremes

Documenting changes in climate extremes requires high temporal resolution data sets. The collection of GEWEX data sets could be analyzed in that respect. Surface radar could be a new source for analyzing precipitation extremes but the work needed to bring the data into a state for analysis should not be underestimated (see above). Surface temperature extremes may be easier to address as new data records on surface temperature are being made employing geostationary satellite instruments that provide better space-time sampling.

On the *in situ* side, the GPCC new daily precipitation analyses (First Guess Daily, Full Data Daily) and the underlying daily precipitation data will help to investigate changes in precipitation extremes (Schamm et al., 2014).

#### 2.1.5.4. Water and Energy Cycles

All GDAP products contribute to all of the questions related to the analysis of water and energy cycles. The question of tracking changes over time or better computing trends in cycle components are a major challenge. This is not only because of the limited length of most satellite data time series but also due to the fact that many existing GEWEX data sets, and also some new products, use suboptimal inputs of measured satellite radiances. Activities in creating so called Fundamental Climate Data Records, currently mostly pushed by international global reanalysis activities, need to be strengthened to make substantial progress.

The non real-time products Global Precipitation Climatology and Full Data Reanalysis help to determine the average precipitation over land for the period 1951-2000 (Schneider et al., 2014). Based on the continuously enlarged and improved GPCC data base new and improved versions of the non real-time products will be released in the future.

### 2.1.6. Key Science Questions for the Next 5-10 Years for a Land-Atmosphere Project

The role GEWEX data sets in the initialization of decadal predictions would be particularly interesting if this became a Grand Challenge.

### 2.1.7. Specific Activities Contributing to the WCRP Grand Challenges

#### 2.1.7.1. Provision of Skillful Future Climate Information on Regional Scales (Includes Decadal and Polar Predictability)

Most GDAP products are 1-degree, 3-hourly resolution and may not be suitable for many regional studies. Things like a radar precipitation climate data record would change that picture, but it is a challenge. To create useful data sets for regional scale applications, a better set of requirements is needed (e.g., what variables are needed and at what resolution and accuracy).

BSRN is directly participating in the polar prediction project (http://www.polarprediction.net/yopp.html). Several BSRN stations are part of the International Arctic Systems for Observing the Atmosphere (IASOA) Radiation Working Group.

#### 2.1.7.2. Regional Sea-Level Rise

GDAP is developing the link with CLIVAR Global Synthesis and Observations Panel (GSOP) in the Ocean Heat Concept activities to bring together TOA radiation and Ocean Heat Content estimates.

#### 2.1.7.3. Cryosphere Response to Climate Change

The CliC PROES on ice mass balance may create the need for new tailored data sets for GDAP to handle.

#### 2.1.7.4. Improved Understanding of the Interactions of Clouds, Aerosols, Precipitation, and Radiation and Their Contributions to Climate Sensitivity

The GDAP Integrated Product data sets were specifically created to test covariance and climate sensitivity

ISCCP is engaged in CFMIP and the usage of atmospheric motion vectors in analysis of storm tracks. Interactions of clouds, aerosols, precipitation and radiation, and their contributions to climate sensitivity was part of GDAP studying onset of precipitation and the impact of aerosols regarding this question. Progress is slow while global data sets are still being developed.

As this Grand Challenge has no observational component yet, GDAP is interested in supporting it with the prediction and analysis of tailored data sets.

#### 2.1.7.5. Past and Future Changes in Water Availability

GDAP shall contribute to all activities related to fostering the understanding of processes and model evaluation using the existing data sets but also to create problem specific data sets and in particular utilize those from the GPM mission.

#### 2.1.7.6. Science Underpinning the Prediction and Attribution of Extreme Events

The activity on radar-based precipitation is clearly addressing the needs of this Grand Challenge. Extremes are addressed in the precipitation data sets (e.g., Lockhoff et al., 2014) and it would be interesting to perform similar analysis with individual products and the integrated product. A discussion regarding the data needs to elaborate on this is needed for preparing tailored data sets for this GC.

### 2.1.8. Cooperation with Other WCRP Projects

#### 2.1.8.1. WCRP Data Advisory Council (WDAC)

*2.1.8.1.1. Surface Flux Team*

SRB is participating in the new WDAC Surface Fluxes Task Team led by Carol-Anne Clayson and Brian Ward. This group will cover land, ocean, ice, biogeochemical, heat, moisture, momentum, turbulent, radiative fluxes utilizing in situ, and remote sensing observations. Terms of Reference were proposed to WCRP but needed more focus and will be reiterated at the next WDAC meeting in April 2016.

*2.1.8.1.2. Quality Assessment Best Practices*

GDAP has presented a paper on “Data Set Quality Assessments: Needs, Benefits, Best Practices and Governance” (see Annex I) to WDAC, which has been reviewed across the WCRP programs. The paper provides guidance for a more homogeneous approach towards assessments of data set quality and is expected to be endorsed at the next WDAC in April 2016.

### 2.1.8.2. Joint Workshop with CLIVAR on Air-Sea Energy Exchange

Key questions addressed by the workshop:

- What are the magnitude and the uncertainties of our estimates of the Earth's energy imbalance (EEI), and how does it vary over time?
- How can we improve validation requirements for and from climate models and reanalysis systems to improve estimates of EEI?
- How can we better constrain the surface energy fluxes and their spatio-temporal variations at regional scale?
- How are TOA net radiation and ocean heating rate distributed in space and time?

Key elements for GDAP:

- Complement GSOP inventory of surface flux products “assessment”-type information regarding strengths and weaknesses of the various flux products, in an effort analogous to the “Climate Data Guide” (NCAR/UCAR, USA)
- Quantify different types of uncertainties of surface fluxes, their correlation structure, sensitivity to uncertain parameters and satellite retrieval schemes to improve the usefulness of global flux products.
- Develop an innovative ensemble approach to generate multiple realizations of flux surface products, combining the individual strengths of existing data sets, the latest knowledge in bulk formulations and associated input data, and the most recent efforts in re-processing flux data sets of climate quality (e.g. ESA CCI)
- Exploit integral constraints along with statistical approaches using reconstruction of probability density functions for surface fluxes to check consistency of Net Heat Flux product components on a series of regional "Cages” (ESA-OHF)
- Develop a community-led flux platform to share, access and inter-compare easily 6 different sets of flux climatologies, and their input data (e.g. different SSM/I data streams), thereby fostering close collaboration between different communities, as well as new ways of combining in situ measurements and flux data

#### 2.1.8.3. Evolving Connection to obs4mips

The GDAP chairman continues to be active in the WDAC obs4mips Task Team and supports the open data call. Currently, only GPCP is available via the ESGF and ISCCP via the CFMIP activity including a data set simulator. The data call remains open until 31 March 2016 and all GEWEX data set projects are encouraged to submit data to obs4mips. LandFlux has indicated a submission already but for some groups there are still issues with the reformatting of data towards the obs4mips grid and format that may present a challenge to data producers. In addition to the GEWEX data set, some products participating in GEWEX cloud and water vapor assessments are already present or indicated for obs4mips. One issue is that although the CMIP experiments are defined the data needs for some of them remain not well known. More communication between CMIP and obs4mips is initiated via the CMIP panel chair (Veronika Eyring) to create more contacts of individual MIP leaders and data set providers.

#### 2.1.8.4. Connect to WMO SCOPE-CM Activities on ISCCP–Geostationary Surface Albedo

The WMO Sustained, Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM) initiative continues to host ISCCP data processing at NOAA NCEI, which is supported by several data centers (mostly space agencies) delivering the needed input data for ISCCP. Other links between GEWEX data sets and SCOPE-CM could not be fostered during 2015. However, SCOPE-CM will open a discussion in 2016 about what new projects requiring international collaboration should start. A hot candidate is certainly precipitation because GPCP needs a similar set of inputs as ISCCP and within Europe new initiatives towards global precipitation climate data records will be funded by EUMETSAT from 2017 onwards.

#### 2.1.8.5. Reporting to the International Radiation Commission

GDAP and BSRN reported to the International Radiation Commission (URC) in 2015 as part of the IUGG Conference in Prague. However, not much feedback was received on GDAP from the presentation. IRC still considering the reporting style with no decision expected in 2016.

### 2.1.9. Workshops/Meetings Held

- Joint workshop on uncertainties at 183 GHz (29–30 June 2015, Paris, France)
- GDAP Annual Meeting (29 Sep–1 Oct 2015, Xiamen, China)
- Workshop CONCEPT-HEAT (28 Sep–1 Oct 2015, Exeter, UK)
- Fifth GEWEX Water Vapor Assessment Workshop (4–5 November 2015, University of Wisconsin, Madison, USA)
- ISSI Workshop on soil moisture (November 2015, Bern, Switzerland)
- First GEWEX UTCC PROES Workshop (16 Nov 2015 in Paris, France)

### 2.1.10. Workshops/Meetings Planned

- Participation in Sixth Session of WDAC (7–8 April 2016, NOAA NCEI, Asheville, USA)
- 14th BSRN Science and Review Workshop (26-29 April 2016, Canberra, Australia)

- ESA CCI Soil Moisture User Workshop (28-29 April 2016 at ESA ESTEC)
- Second GEWEX UTCC PROES Workshop (fall 2016, New York, NY, USA)
- GDAP Annual Meeting (October/November 2016, Washington D.C)
- Kickoff workshop for precipitation assessment (October/November 2016, Washington, DC)
- A first workshop bringing together experts in the field of radar reprocessing (2017, Europe or USA)
- ESA-EUMETSAT workshop on uncertainty characterization in satellite data records (2017, Europe)

### 2.1.11. Other Meetings Attended on Behalf of GEWEX or GDAP

Project results have been presented at a number of international meetings including EGU, IUGG, ESA Earth Observation for Water Cycle Science conference, MODSIM and AGU.

### 2.1.12. Issues for the SSG

#### 2.1.12.1. Maintenance of the BSRN Archive at the World Radiation Monitoring Center

The current Director of the World Radiation Monitoring Center (WRMC, http://bsrn.awi.de/), Dr. Gert König-Langlo, is retiring as of May, 2017. The WMRC is the central archive of the Baseline Surface Radiation Network (BSRN) data. WRMC and the BSRN Archive have been hosted at the Alfred Wegener Institute following the endorsement of an agreement of (and attendant funding from) the AWI Director, Dr. Peter Lemke, in 2007. Gert König reported to GDAP that so far he has not received any promise from the current AWI Director, Prof. Dr. Karin Lochte, to provide the required post-doc position, etc. after his retirement to continue the WRMC/BSRN Archive. A well-trained and excellent person ready to take over is available: Dr. Amelie Driemel, who is already working for the WRMC/BSRN as data curator. Thus Gert König is asking for a letter of support to convince the director of AWI, Prof. Dr. H.C. Karin Lochte (http://www.awi.de/en/aboutus/organisation/management.html), to host the World Radiation Monitoring Center of the Baseline Surface Radiation Network (http://www.bsrn.awi.de/) beyond his retirement in May 2017.

Gert König suggests that the more letters of support sent from WMO persons of import, such as the BSRN Project Manager, the GDAP Chair (as BSRN Science Chair), Carolin Richter (as the Director of the GCOS Secretariat), Stefan Rösner (as the German GCOS coordinator), Peter van Oevelen (as Director of the GEWEX Project Office), Dawn Erlich (as assistant to the GEWEX director) and as many others of note as we can muster to convince Dr. Lochte and AWI that their continued hosting of the BSRN Archive is very much appreciated and needed.

GDAP proposes that a support letter from GEWEX signed by the GEWEX chairs, GEWEX Office Director, the GDAP Chair and BSRN Project Manager be sent to the Director of AWI. In addition, we should request support letters from the users of BSRN data (e.g., producers of the SRB data set and similar).

If AWI decides not to continue the archive we will have to find another organization to host it, and in the process could possibly lose all the progress that Gert König and his crew have accomplished since 2007, including the Pangea data base distribution system, BSRN Toolbox software for data quality assessment and data extraction, and the excellent web site they have built and maintained. If we cannot get an endorsement and agreement from AWI in place

before then, we will have to look for an alternate host during the upcoming BSRN Workshop in Canberra on 26-29 April 2016, in case a renewed endorsement from AWI does not happen prior to Gert König's retirement.

### 2.1.13. List of Key Publications


Gruber, A., C.-H Su, S. Zwieback, W. Crow, W. Dorigo, and W. Wagner, 2016. Recent advances in (soil moisture) triple collocation analysis. *International Journal of Applied Earth Observation and Geoinformation*, 45, Part B, pp 200-211, doi:10.1016/j.jag.2015.09.002

McCabe, M.F., A. Ershadi, C. Jimenez, D.G. Miralles, D. Michel and E.F. Wood, 2015. The GEWEX LandFlux project: evaluation of model evaporation using tower-based and globally gridded forcing data. *Geosci. Model Dev. Discuss*. 8(8): 6809-6866.

Michel, D., C. Jiménez, D.G. Miralles, M. Jung, M. Hirschi, A. Ershadi, B. Martens, McCabe MF, Fisher JB, Q. Mu, S.I. Seneviratne, E.F. Wood and D. Fernaìndez-Priet, 2015. The WACMOS-ET Project–Part 1: Tower-scale evaluation of four remote sensing-based evapotranspiration algorithms. *Hydrol. Earth Syst. Sci. Discuss*. 12(10): 10739-10787.

Miralles, D.G., C. Jiménez, M. Jung, D. Michel D, A Ershadi, M.F McCabe, M. Hirschi, B. Martens, A.J. Dolman, J.B. Fisher, Q Mu, S.I. Seneviratne, E.F. Wood and D. Fernaìndez-Priet, 2015. The WACMOS-ET Project–Part 2: Evaluation of global terrestrial evaporation data sets. *Hydrol. Earth Syst. Sci. Discuss.* 12(10): 10651-10700.

Raschke, E., S. Kinne, W.B. Rossow, P.W. Stackhouse, Jr., and M. Wild, et al., 2015: Comparison of radiative energy flow in observationl datasets and climate modeling [accepted to *J. Clim.*]

Stackhouse, P.W., Jr., A.J. Soja, J.C. Mikovitz, T. Zhang, A. Tsvetkov and D.J. Westberg, 2015. Long-term radiation budget variability in Northern Eurasia: potential for assessing variability during the fire season (submitted *ERL*, Sept. 2015).


This list may not be comprehensive.

### 2.1.14. List of Members and Term Dates

*Chair and Vice-Chair:*
Joerg Schulz 2014–2017 (Chair) Jörg Schulz (July 2014–March 2017)
Matthew McCabe 2015–2017 (Vice-Chair)

*Members:*
Wouter Dorigo (2013–2017)
Carlos Jimenez (2010–2017)
Christian Kummerow (2014–2017)
Andrew Heidinger (2012–2016)
Felix Landerer (2013–2015)
Norman G. Loeb (2005–2015)
Hirohiko Masunaga (2010–2017)
Axel Schweiger (2008–2015)
Sonia Seneviratne (2008–2015)

B.J. Sohn (2007–2015)
Claudia Stubenrauch (2007–2016)
Susan Van den Heever (2008–2015)
Tianjun Zhou (2011–2017)

*Proposed Candidates for 2016-2019:*
Ali Behrangi (NASA JPL), precipitation, link to extremes GC
Myoung Hwan Ahn (Ehwa University, Korea) remote sensing expert
Shinya Kobayashi (JMA, Japan) reanalysis, data assimilation
Diego Miralles (University Gent, Belgium) land surface fluxes, GLEAM model
Rémy Roca (LEGOS, France) energy and water cycle science
Mathew Rodell (NASA GSFC) water budget, water storage
Philip Stier (Univ. Oxford, UK) global modeling, radiative transfer, data
Nick Schutgens (Univ. Oxford, UK) data assimilation, data, modeling, radiative transfer
Christopher Taylor (Centre for Ecology and Hydrology, UK) land surface modeler with increasing interest in observations

## 2.2. GEWEX Hydroclimatology Panel (GHP)

Reporting period: January 2015–December 2015
URL: http://www.gewex.org/panels/gewex-hydroclimatology-panel/
Chair(s) and term dates: Jan Polcher (2011–2015), Jason Evans (2012–2016)

### 2.2.1. Panel Activities

The GEWEX Hydroclimatology Panel (GHP) has been organized around several Regional Hydroclimate Projects (RHPs) and a number of crosscutting science topics. The aim of GHP is focused on improving the knowledge of global climate change and its impacts at regional scales and to propagate that knowledge from one region to the other, then synthesize the results at the global scale.

The objectives of GHP are to contribute effectively to the leading role that GEWEX plays in the hydrological sciences and related modeling activities. The GEWEX Science Questions (GSQs, http://www.gewex.org/pdfs/GEWEX_Science_Questions_final.pdf), and the related WCRP Grand Challenges (http://www.wcrp-climate.org/grand-challenges), are key to the strategy for implementation of Panel activities. The GHP Co-Chairs have fostered discussions on a number of important issues, ranging from monsoons to extremes and how to help coordinate the number of national/regional initiatives in those areas. These include collaborations with groups including the Global Drought Information System (GDIS), the Global Data and Assessments Panel (GDAP), the Global Land/Atmosphere System Study (GLASS), the Climate and Ocean Variability, Prediction and Change Project (CLIVAR), the Climate and Cryosphere (CliC) Project, and the WCRP Working Group on Regional Climate (WGRC) that have common interests in land-surface processes.

In addition to being responsive to the WCRP/GEWEX main challenges and scientific questions, GHP is organized to address the GSQs from a regional and integrated perspective. The driving premise for this approach is that only at the regional scale can the water cycle be addressed from its physical to human and socioeconomic aspects. The RHPs (Figure 1) are an essential tool in this endeavor as they bring together various disciplines on the water issues of greatest importance to the advancement of the GSQs.

The GHP Crosscutting Projects allow the propagation of knowledge from one region to another, and the synthesizing of results at the global scale. They also allow the development and testing of applications that deliver both science advances and applicable outcomes for stakeholders and services.

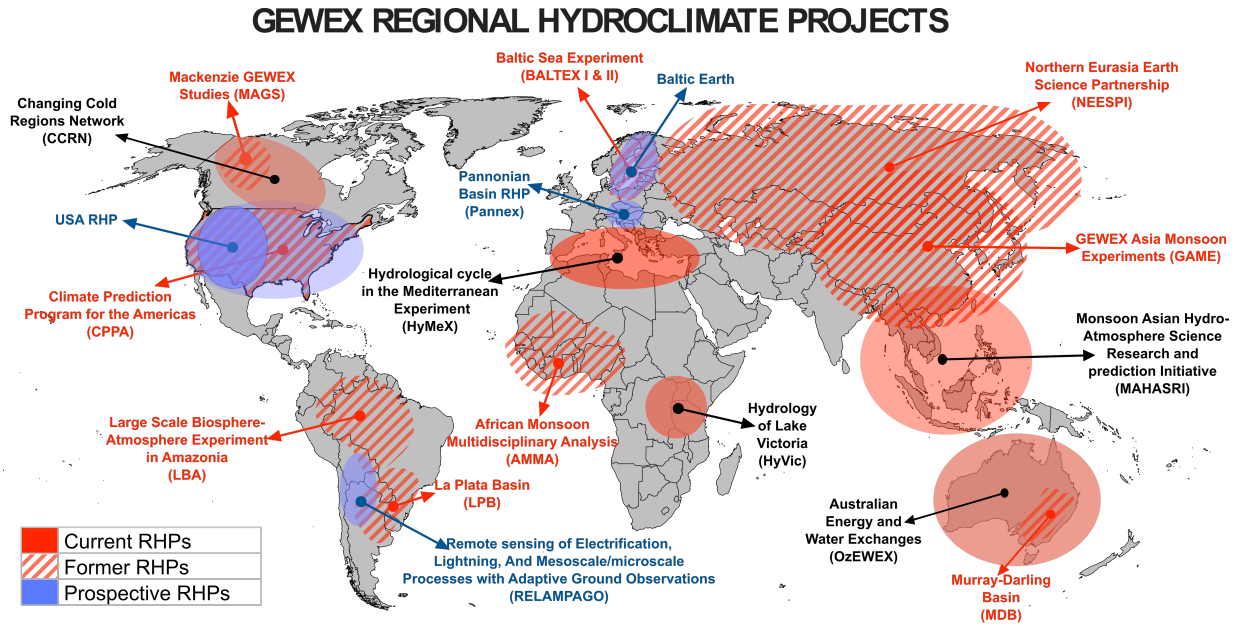


*Figure 1: GHP Regional Hydroclimate Projects (RHPs)*

### 2.2.2. New Projects in Place

#### 2.2.2.1. GHP Regional Hydroclimate Projects (RHPs)

Recently Closed
- Northern Eurasia Earth Science Partnership Initiative (NEESPI, Pavel Groisman)

Active
- Changing Cold Regions Network (CCRN, Howard Wheater)
- HYdrological cycle in the Mediterranean Experiment (HyMex, Philippe Drobinski)
- Monsoon Asian Hydro-Atmosphere Science Research and prediction Initiative (MAHASRI, Jun Matsumoto) (Ends March 2016)

Initiating
- Australian Energy and Water Exchanges (OzEWEX, Albert VanDijk)
- Hydrology of Lake Victoria Basin (HyVic, Fred Semanzzi)

Proposed
- Pannonian Basin Experiment (PannEx, to be determined)
- Baltic Earth (Markus Meier)

#### 2.2.2.2. GHP Crosscutting Projects

Active
- INTENSE (Sub-daily precipitation) (Hayley Fowler)
- Cold/Shoulder Season Precipitation Near 0°C (Ronald Stewart/Paval Groisman)
- INARCH (Alpine Research Catchment Hydrology) (John Pomeroy)

Proposed
- MOUNTerrain (Mountainous terrain precipitation) (James Renwick)
- Including water management in large scale models (Richard Harding/Jan Polcher)

Potential
- Seasonal hydrologic prediction (HEPEX, Andrew Wood)
- GDAP integrated product regional evaluation

### 2.2.3. New Projects and Planned Activities

Two regional studies (one in Australia, OzEWEX, and the other in Africa, HyVic) that had been developing as prospective RHPs were raised to Initiating RHP Status by the GHP in December 2015. Two crosscutting projects (Cold/Shoulder Season Precipitation Near 0°C and INARCH - Mountain Hydrology) were also approved as crosscutting.

The Pannonian Basin RHP (PannEx) held its first workshop in order to gauge interest from local scientists in this project. Response was very good and a core group of participants were brought together to produce a white paper and garner further participation from the regions' scientists, and may include a workshop in the summer of 2016 in Budapest. This will likely result in moving PannEx towards Initiating RHP status in 2016 or 2017.

The potential crosscut on water management in large-scale models is progressing with a workshop planned in September 2016 and a formal application for GHP crosscut is likely this year as well.

#### 2.2.3.1. Planned Activities: RHPs

*HyMex*

Plans for next five years:

The HyMex science plan will be revised, based upon the recent 5-year review of achievements and the identification of work that has not been completed. The revised plan will include more scale continuum in object-oriented studies (i.e., dense water formation and ocean circulation, Mediterranean cyclones, heavy precipitation systems, flash floods), and more integrated transdisciplinary studies, such as water resources, droughts and impacts, water-cycle and renewable energy resources, flash-floods and social vulnerabilities and attempts to integrate forecasting of heavy precipitation, flash-floods and impacts. These research studies should support a water cycle related regional climate assessment at the end of the HyMeX Project in 2020. These studies will benefit from the European Space Agency (ESA) Water Cycle Multi-mission Observation Strategy Mediterranean (WACMOS-MED) Project to produce a new integrated satellite database of the Mediterranean water cycle in all Earth components over a multi-decadal period. This could be seen as a contribution to both GHP and GDAP. Finally, a few strategic actions are to be supported in the next 5 years and include field campaigns in the Eastern-Mediterranean focusing on aerosol, water vapor feedbacks on precipitation and associated hydrology, and the documentation of Levantine intermediate waters of the Mediterranean Sea. They also include the MED-CORDEX-2 preparation and organization, the support to a flash floods and social impacts information and analysis platform. Securing data collection over the 10-year period and the outreach of the HyMeX research results are also of high priority for the next 5 years.

*MAHASRI*

The final MAHASRI conference is set for 2-4 March 2016.

### 2.2.3.2. Planned Activities: Crosscutting Projects

*INTENSE*

- Continued data acquisition and initiatives to update and expand the existing database and consideration given as to who will host the data and the development of new indices for sub-daily precipitation.
- Two publications are planned on the quality control of sub-daily precipitation. The first of these is on the site-specific rain gauge methods that have been applied in the UK. The second is on the further development of tests of spatial consistency with neighboring gauges and their application to produce a gridded 1-km hourly precipitation product for the UK. A more generic overview report is planned.
- International workshop planned in 2016 to include INTENSE partners (funded) and other interested parties (unfunded). This will take forward some of the questions and activities identified at the WCRP workshop that was held in Sydney, Australia in February 2015, in particular, the identification of indices for sub-daily precipitation.
- Construction and analysis of a comprehensive UK sub-hourly (10-15 minute) data set using UK rain gauge data is planned in conjunction with corresponding outputs from the UK Met Office high-resolution model for the southern UK. An associated paper will be written. A global scale analysis of the extreme precipitation-temperature relationship will be undertaken using sub-daily data sets gathered by INTENSE.
- Extreme value analysis methods will be applied to the quality controlled UK hourly precipitation data set and used to produce Intensity-Duration-Frequency (IDF) curves. This methodology will then be applied further to the sub-hourly UK data and global data sets as they become available.
- A session has been approved on high-resolution climate models at the UK Royal Meteorological Society annual conference and European Geophysical Union (EGU) General Assembly in 2016.
- A working group on very high-resolution models and common analyses of model outputs is under development.
- First analyses of global data observations and results.
- Preparation of INTENSE project website to include:
    - Project information
    - A central repository of INTENSE publications
    - The status of project activities
    - Access to data when it is available
    - Project related papers

*Precipitation Near 0ºC*

Preparation of a paper on freezing precipitation events over North America and most of Northern Eurasia is in its final stage. Immediately upon its completion, an overview paper will be prepared to review all current tendencies in near 0°C precipitation and related phenomena. Separately, efforts will be continued to assess tendencies in precipitation near 0°C and related phenomena as projected by global and regional climate models (cf., Thériault et al., 2015).

### 2.2.4. Science Highlights

#### 2.2.4.1. RHPs

*MAHASRI*

- High predictability of the 2011 severe Thai flood was revealed by applying statistical downscaling to the coupled general circulation model (Imada et al., 2015).
- The long-term changes in extreme rainfalls in Bangladesh and western Japan were analyzed and an increase in heavy precipitation was not found (Endo et al., 2015, Otani and Kato, 2015)
- Delayed withdrawal of autumn rainy season over central Vietnam was detected in the early 1990s (Nguyen-Le and Matsumoto, 2015)
- Drying trends and increases in heat waves in Mongolia due to the recent rainfall decrease was revealed (Erdenebat and Sato, 2015; Xia et al., 2015)
- Based upon the long-term data rescue of sea level pressure data, multi-decadal variation of the Pacific-Japan teleconnection patterns in the western North Pacific was revealed (Kubota et al., 2015)

*HyMex*

After several years of preparation (writing international, implementation and operation plans), the collection of data began in 2010 to cover a 10-year period (Long Observation Period, LOP) including hydrometeorological and oceanic measurements from operational national weather and hydrological services, research hydrometeorological and oceanic observatories, and satellite data (Drobinski et al., 2014). Social impact data were also included (Llasat et al., 2013). An enhanced observation period (EOP) covering 2011-2015 was mainly dedicated to the hydrological monitoring of flash floods (Braud et al., 2014). Two special observation periods (SOP) were organized in fall 2012 and winter 2013 with heavy instrumentation deployment (e.g., boundary layer pressurized balloons, instrumented ships, aircrafts, enhancement of ground based monitoring network, and radiosondes) dedicated to observations of heavy precipitation and flash floods (Ducrocq et al., 2014; Bousquet et al., 2015; Defer et al., 2015; Ferreti et al., 2015; Davolio et al., 2015; Jansà et al., 2015; Doerenbecher et al., 2015), and strong air-sea interaction and dense water formation (Estournel et al., in revision; Doerenbecher et al., 2015), respectively.

#### 2.2.4.2. Cross-cuts

*INTENSE*

- Analysis of extreme hourly precipitation scaling with temperature using a new UK data set has shown an increase in precipitation intensities with temperature at around the rate prescribed by the Clausius-Clapeyron relation. An examination of the influence of indicators of large-scale circulation conditions has shown a dependency on the circulation regime. This work has been published in Environmental Research Letters.
- Further development of quality control (QC) procedures for sub-daily precipitation has been developed using the UK hourly data set. A two-part process was developed that may be used to automate the QC process, which involves: (i) identifying suspect rainfall amounts using >30 different site specific and multi-gauge tests and applying corresponding

QC flags; and (ii) a “rule base” that may be used to apply either single QC flags or combinations thereof to mark suspected erroneous data.

- Quality controlled UK data has been used to create a gridded hourly rainfall product for the UK for 1991-2013. This is to be hosted online at the Centre for Ecology and Hydrology (CEH), together with the Gridded Estimates of Areal Rainfall (CEH-GEAR) daily gridded product. Sub-daily precipitation data has been collected for the US, Australia, Canada, Japan, Malaysia, UK, Netherlands, Singapore, and HadISD (UK Met Office sub-daily data set comprising precipitation and other variables). Data is now being received from Norway, Portugal, The Philippines and New Zealand. Contacts have been obtained for further countries and are being pursued.
- Additional QC has been undertaken on the US hourly precipitation data set as some issues with data quality were identified. This related to a change in the measurement resolution of rainfall amounts during the record. The knowledge gained has added to that derived from working with the UK data and will contribute to the need to develop widely applicable, standard quality control procedures for sub-daily data. Problems have also been encountered with the removal of zero precipitation hours, which need to be reinstated to allow investigation of the timing and persistence of extremes.
- An initial investigation of extreme hourly rainfall in the US that includes examining scaling with temperature and trends is currently ongoing.
- An initial examination of large-scale drivers of extreme precipitation has begun and is focusing on Europe, where good quality data is already available. Methods are being developed that will be applicable to other regions.
- An assessment of the extent to which convection-permitting climate models are needed for reliable future climate projections was conducted by an international team evaluating currently available model runs (paper submitted to BAMS).
- An assessment of hourly rainfall scaling with temperature in high resolution climate model runs was conducted which showed the same downturn at high temperatures as seen in observations (paper in press in Nature Geoscience).
- Sub-hourly precipitation from the same models is also being assessed

### 2.2.5. Science Issues

#### 2.2.5.1. RHPs

*MAHASRI*

- Past and future changes of extreme rainfall
- Multi-scale interactions on intra-seasonal, synoptic, and diurnal cycles, and mid-latitude-tropical interactions on monsoon heavy rainfall
- Atmospheric and hydrological processes of severe floods and their predictions
- Decadal or multi-decadal changes of ENSO and monsoon rainfall
- Importance of coastal rainfall on water and energy cycle in the maritime continent
- Interannual and long-term variations of regional monsoon onset and withdrawal

### 2.2.6. Contributions to the GEWEX Science Questions

#### 2.2.6.1. Observations and Predictions of Precipitation

*RHPs*

*CCRN*

- Individual research progress on atmospheric circulation patterns, instabilities for generating convection, large-scale forcing for drought, precipitation phase changes, winter precipitation extremes, surface hydrologic changes, and runoff, with a number of journal submissions and draft manuscripts based on these studies
- A comprehensive investigation of the June 2013 extreme weather and flooding events that affected southwestern Alberta and downstream areas, including a number of submissions to a special issue of Hydrological Processes dealing with meteorological and hydrological aspects
- Focal examination of extreme events (floods, fires, droughts) affecting the CCRN region from 2009–2011 with publications forthcoming

*MAHASRI*

- Improvement of satellite derived Global Satellite Mapping of Precipitation (GSMaP) data by considering orographic shallow cloud precipitation (Shige et al., 2014, Yamamoto and Shige, 2015)
- Predictability of mature monsoon season in 2011 Thailand flood case was examined, and skillful results were obtained when statistical SVDA related SST anomaly was applied to CGCM and its results were statistically downscaled in Indochina (Imada et al., 2015)
- Examination of diurnal and seasonal variations of rainfall, squall and hail characteristics in the pre-monsoon season in northeastern Bangladesh (Choudhury et al., 2015)
- Evaluation of TRMM and surface rainfall observations, and large rainfall underestimation was evaluated over the Meghalaya Plateau in Northeast India, the rainiest place in the world (Terao et al., 2015)

*HyMeX*

- Significant progress in understanding the formation of heavy precipitating systems, notably over the Mediterranean Sea and the plains. These heavy rainfalls affect the coastal regions with strong impacts in southeastern France and northern Italy. The key role of the various mountain ranges and islands and storm processes themselves were highlighted
- HyMeX field campaign observations have helped to design, improve and evaluate new tools and methods of forecasting heavy precipitation and flash floods (e.g., the convection-permitting data assimilation and ensemble prediction systems)
- Seamless analysis of the heavy precipitation event of the HyMeX Intensive Observation Period-12, which extended from Spain to Italy during SOP-1 was performed. One study compares simulations from numerical simulation models with either explicit or parameterized convection, as well as regional climate models
- Heavy precipitation was characterized in a more bottoms-up approach with respect to the affected population and economy sectors in Spain, France, Italy and Greece
- Local social studies in southern France investigated the evolution of urban management policies with respect to floods and model mobility/transportation

*Crosscutting Projects*

*INTENSE*

- Collation of global sub-daily precipitation data (see Section 1 for a summary of progress)
- Development of procedures for the quality control of sub-daily precipitation data has been undertaken for the UK. Future work will examine how the methods developed can be applied for widely in the context of global data acquisition (see above and Section 1)
- Existing work examines how large-scale predictors and local-scale thermodynamics drive intense precipitation. This knowledge will be applied to assess which information from coarse-scale models can be used as predictors of intense precipitation

*Near 0°C*

- Found an increase in cold season precipitation around 0°C in several humid Arctic regions (Alaska, Norway, European Russia)

### 2.2.6.2. Global Water Resource Systems

*RHPs*

*CCRN*

- Completion of assessments and inventories of change at many Water, Ecosystem, Cryosphere and Climate (WECC) Observatories and across the CCRN domain
- Analysis of large-scale hydrological model performance for the Saskatchewan and Mackenzie basins. Identification of key challenges – input uncertainty, permafrost, cold region lakes and wetlands, mountain hydrology, prairie hydrology, anthropogenic water management. Work initiated to address these
- Progress with assimilation of remotely sensed data to constrain large scale hydrological models
- Extension of previous work on vulnerability analysis of water resource systems in the SaskRB; now includes risk-based hydro-economic analysis for Saskatchewan

*MAHASRI*

- Global high resolution cropping pattern data sets (SACRA) of satellite derived crop calendars of major crops were developed using satellite NDVI data (Kitsuki and Tanaka, 2015)

*HyMeX*

- Water management issues, droughts, heat waves and related impacts have also been addressed at several spatial scales, at catchment scale, notably in Morocco and Spain, but also at the whole Mediterranean scale.
- These activities cover in part GEWEX Land-Atmosphere System Studies (GLASS)
- Dams network management in North Africa was modeled and allowed the estimation of their impact on water resources and their evolution in climate change constrained by offer/demand equilibrium
- Studies showed the role of groundwater memory to precipitation deficit and its impact on hydrological droughts.

- Other studies analyzed the strong interlink between precipitation deficit, vegetation phenology and soil moisture variability on heat waves, droughts and wildfires. They showed that the dryness of the soil can contribute up to 40% on the severity of heat waves and abundance or deficit vegetation can respectively mitigate or otherwise increase by about 10% the severity of heat waves
- Assimilation of vegetation characteristics (LAI, NDVI, etc.) showed significant improvement on drought forecasting
- Droughts were also characterized by indices defined in a bottom-up approach at the Ebro basin scale

#### 2.2.6.3. Changes in Extremes

*RHPs*

*CCRN*

- Regional-scale synthesis of Earth system change through analysis of federal and provincial hydroclimatic data sets, remotely sensed data products, climate model reanalysis, and radar, rawinsonde, and lightning detection observations, as well as an integrated literature review of past change over the CCRN domain
- Individual research progress on atmospheric circulation patterns, instabilities for generating convection, large-scale forcing for drought, precipitation phase changes, winter precipitation extremes, surface hydrologic changes, and runoff, with a number of journal submissions and draft manuscripts based on these studies
- A comprehensive investigation of the June 2013 extreme weather and flooding events that affected southwestern Alberta and downstream areas, including a number of submissions to a special issue of Hydrological Processes dealing with meteorological and hydrological aspects
- Initial work towards an interdisciplinary examination of the 2014 forest fires in the Northwest Territories, involving contributions from university and government organizations

*MAHASRI*

- Dramatic increase of frequency and intensity of hot extremes since the late 1990s was detected around Mongolia (Erdenebat and Sato, 2015).
- Long-term trends in daily rainfall were examined in Bangladesh for the period 1950 to 2008, and no significant increase was detected in heavy extreme rainfall, although total rainfall amount showed increasing trend at some stations (Endo et al., 2015)
- Sharp decrease in precipitation and heavy rainfall during the mature Baiu season in late June was detected in the northern Kyushu Island, southwestern Japan in the 2000s (Otani and Kato, 2015)

*HyMeX*

- The evolution of heavy precipitating systems with climate change has also been investigated. In relation with the GEWEX cross-cutting activity on sub-daily precipitation extremes (INTENSE), observations and regional climate simulations show that all across the Mediterranean, the number and intensity of the Mediterranean episodes increase with global warming, limited to a few percent per degree of warming
- Regarding heat waves and droughts, the new climate projections confirm longer dry periods and more frequent heat waves in the Mediterranean with global warming

*Crosscutting Projects*

*INTENSE*

- Initial work has been undertaken on observed changes in sub-daily US precipitation extremes. It is planned that this analysis will be performed on additional global data sets where data quality and length allow

*Near 0°C*

- We consider some of phenomena related to precipitation near 0°C as human-related extremes and found changes in several of them (Bulygina et al., 2015; Groisman et al., 2015a,b)

### 2.2.6.4. Water and Energy Cycles

*RHPs*

*CCRN*

- Use of soil moisture monitoring networks for improving observation of soil freeze-thaw processes and evaluation of soil moisture scaling properties at resolutions applicable to the NASA Soil Moisture Active Passive (SMAP) mission, up scaling of energy and water balance components from point- to field-scales, and evaluation of wetlands and soil moisture using RADARSAT-2 in prairie and taiga–tundra eco-regions
- An important development for the network is that Li, working with NCAR, is producing 4-km Weather Research and Forecasting model climate simulations for the entire CCRN domain (14 years historical simulations, plus pseudo warming simulations of future climate). This provides comparative data for Themes' B, C and D modeling and large-scale climate analysis. Similarly, collaboration with Sushama's Canadian Network for Regional Climate and Weather Processes (CNRCWP) provides access to the regional climate model CanRCM5, based upon the Canadian Land Surface Scheme (CLASS), which provides a platform for coupled modeling and additional simulations for large scale analysis

*MAHASRI*

- Studies of stable water isotopes, such as Jasechko et al. (2013) in Nature and Good et al. (2015) in Science, where the partition of evapotranspiration was investigated. An observational study with new vapor isotope measurement over a paddy field in Japan was also conducted, and confirmed that the transpiration fraction was well controlled by evolution of LAI. The global mean transpiration fraction was estimated to be 62% (Wei et al., 2015)
- Long-term evapotranspiration (ET) was estimated by satellite regressed with in situ eddy covariance measurement and meteorological datasets over dry land East Asia from 1982 through 2009. Ecosystem ET showed decreased trends over 61% of the DEA region during this period, especially in most regions of Mongolia and eastern Inner Mongolia due to decreased precipitation. Water balance (the difference between precipitation and ecosystem ET) decreased substantially during the summer and growing season (Xia et al., 2015)

- The effects of surface water runoff on the interannual sea surface temperature (SST) variations in the northern Bay of Bengal were detected (Nagura et al., 2015)
- Using satellite-derived EXAM solar radiation data, the three main budgets (i.e., radiation, heat and water budgets, of the land surface simulation was found to be improved; Kotsuki et al., 2015)
- Multi-site real-time data management server system FluxPro was created for the energy, water and carbon dioxide flux densities by in situ eddy covariance measurements (Kim et al., 2015)

*HyMeX*

- The long-term water and energy budget of the Mediterranean Sea and catchment were established. The variability and trends were also analyzed
- The study was based on direct simulations and data assimilation experiments

### 2.2.7. Contributions to the WCRP Grand Challenges

#### 2.2.7.1. Cryosphere response to climate change

*CCRN*

Projection results will be used to address regional scale effects on land and water resources, using the large-scale models developed in Theme C. This includes the change in river flows for the Saskatchewan, Peace-Athabasca and Mackenzie River Basins, and effects of climate change for specific ecosystems.

Whether future changes cross ‘tipping points’ in Earth system behavior, leading to further extremes and dramatic system changes, such as deglaciation, permafrost disappearance and terrestrial ecosystem transition will be determined. Outputs from this analysis will thus be used to identify global climatological controls on broad regional water resource response, and hence to enable specific design, operational or policy development problems under climate change to be addressed in Theme E. To address this issue, specific analyses will be carried out utilizing future conditions along with threshold guidance on conditions needed to trigger a fundamental shift.

#### 2.2.7.2. Improved understanding of the interactions of clouds, aerosols, precipitation, and radiation and their contributions to climate sensitivity

*CCRN*

Specific scientific contributions will involve the assessment of large and synoptic scale atmospheric circulation patterns as they relate to observed temporal and spatial trends and variability (including extremes) in the hydroclimate over the study region. In addition, studies will be undertaken to understand the mechanisms that link the regional water and energy response to large-scale forcings. This includes the role of the orographic barrier in amplifying the region’s climate sensitivity to upstream large-scale forcings. Statistical techniques and diagnostic studies will be carried out to examine the coupled mode of variability between low-frequency forcings, such as SST anomalies, large-scale circulation patterns and warm-season synoptic activities.

Changes in large-scale atmospheric circulation will be assessed from CMIP5 and other projections. There subsequent effects on the continental synoptic activities and associated heat and moisture transports which affect critically regional temperature and precipitation responses will be assessed from the downscaled projections.

*MAHASRI*

Sea level rise in the Pacific coast of Japan is due to SST increase of the Kuroshio region in the south of Japan (Takahashi, et al., 2015), which is linked to past and future changes in water availability (with connections to water security and hydrological cycle.

### 2.2.7.3. Past and future changes in water availability

*CCRN*

Use of soil moisture monitoring networks for improving observation of soil freeze-thaw processes and evaluation of soil moisture scaling properties at resolutions applicable to the NASA Soil Moisture – Active Passive (SMAP) mission, upscaling of energy and water balance components from point-to field-scales, and evaluation of wetlands and soil moisture using RADARSAT-2 in prairie and taiga–tundra eco-regions.

Progress has also been made on the quantification of effects of uncertainty in driving variables, and new methods to accommodate this, and in the assimilation of other satellite products in the large-scale hydrological models, in particular GRACE (in collaboration with Natural Resources Canada, NRCan)

Individual research progress on atmospheric circulation patterns, instabilities for generating convection, large-scale forcing for drought, precipitation phase changes, winter precipitation extremes, surface hydrologic changes, and runoff, with a number of journal submissions and draft manuscripts based on these studies.

Regional-scale synthesis of Earth system change through analysis of federal and provincial hydro-climatic data sets, remotely sensed data products, climate model reanalysis, and radar, rawinsonde, and lightning detection observations, as well as an integrated literature review of past change over the CCRN domain.

Various improvements to CLASS and issues under development, including lakes, wetlands, snow/ mountain hydrology, frozen soils and infiltration, prairie hydrology, water management, coupled land-surface–groundwater, glacier dynamics, and linkage between hydrology, climate, and vegetation.

Setup and evaluation of the MESH hydrological model over both the Mackenzie and Saskatchewan River basins, with several key focal issues identified for future work, including input uncertainty, soil depth and permafrost initialization/representation, wetlands, and water management—channel hydraulics may be a major limiting factor for basin-scale modeling of the Mackenzie.

An important development for the network is that Li, working with NCAR, is producing 4km WRF climate simulations for the entire CCRN domain (14 years historical simulations, plus pseudo warming simulations of future climate). This provides comparative data for Theme B, C

and D modeling and large-scale climate analysis. Similarly, collaboration with Sushama's CNRCWP provides access to the regional climate model CanRCM5, based on CLASS, which provides us with a platform for coupled modeling and additional simulations for large scale analysis

Theme/work package D1:

Studies will be undertaken to understand the mechanisms which link the regional water and energy response to large-scale forcings. This includes the role of the orographic barrier in amplifying the region's climate sensitivity to upstream large-scale forcings. Statistical techniques and diagnostic studies will be carried out to examine the coupled mode of variability between low-frequency forcings such as SST anomalies, large-scale circulation patterns and warm-season synoptic activities.

Another focus will be on precipitation. Studies include the occurrence of precipitation extremes from droughts to heavy precipitation including variability and simultaneous occurrence. The regional and larger scale factors leading to such events will be determined. The factors leading to the changing occurrence of winter precipitation will be examined. As well, changes in the occurrence of extreme precipitation rates will be determined over some areas and linked with the large and regional scales forcing factors.

Theme/work package D2:

Research on future conditions over the domain has given some indication of future states and interactions although with a great deal of uncertainty. In general, results predict continued increase in temperature – more in the cold season and at higher elevations. They also expect an overall increase in precipitation, but with considerable spatial and temporal variability. Northern regions are projected to see more increases in precipitation than southern regions of the study area, which has potentially huge implications for water resources. In parallel, there is a projected increase to in the frequency, intensity and duration of future droughts including more hot droughts. Overall, future water cycle related variability remains a huge knowledge gap.

Given the determination and understanding of changing conditions over the region, it is critical to assess how future conditions will evolve, in particular factors affecting water resources and ecosystems. Validated models from Theme C will be a critical basis for addressing this issue including our degree of uncertainty. Projections of future conditions over the region will be developed by CCRN (4 km WRF pseudo-warming) and others will be obtained (CanRCM5 projections, with improved CLASS algorithms and explicit representation of feedbacks).

Theme/work package D3:

Changes in the large-scale atmospheric circulation will be assessed from CMIP5 and other projections. There subsequent effects on the continental synoptic activities and associated heat and moisture transports which affect critically regional temperature and precipitation responses will be assessed from the downscaled projections. The initial focus will be on projections of temperature, precipitation, and their variation. Key focal points will be on regional and local scale temperature changes and variations of prolonged summer hot periods, and extension of above freezing conditions. In terms of precipitation, the focus will be on the development of drought, heavy precipitation, extreme precipitation rates, as well as the changing phase of precipitation.

Theme/work package D4:

The projection results will be used to address regional scale effects on land and water resources, using the large-scale models developed in Theme C. This includes the change in river flows for the Saskatchewan, Peace-Athabasca and Mackenzie River Basins, and effects of climate change for specific ecosystems.

We will determine whether future changes cross 'tipping points' in Earth system behavior, leading to further extremes and dramatic system changes, such as deglaciation, permafrost disappearance and terrestrial ecosystem transition.

Outputs from this analysis will thus be used to identify global climatological controls on broad regional water resource response, and hence to enable specific design, operational or policy development problems under climate change to be addressed in Theme E. To address this issue, specific analyses will be carried out utilizing future conditions along with threshold guidance on conditions needed to trigger a fundamental shift.

*MAHASRI*

The new land surface model with hydrological human activities, HiGWMAT, has shown that for RCP8.5, 13 of 26 global regions would see unprecedented hydrological drought levels by 2050. In that scenario, the western United States could see historical drought levels as early as 2017, while the Mediterranean region would see unprecedented drought by 2027 (Satoh et al., 2015).

Future water stress changes as a function of increasing global mean temperature and future socio-economic scenario based on IPCC2000 SRES-based datasets were re-valuated globally. Trends in the total population under high water stress (defined as when the annual water withdrawal divided by the annual water availability is higher than 0.4) now and in the future (total HWSP) and the population exposed to high water stress in the future but not now (add_HWSP) were found to be dependent on differences in each scenario, not the global mean temperature increase (Kiguchi et al., 2015).

#### 2.2.7.4. Science underpinning the prediction and attribution of extreme events

*CCRN*

- A comprehensive focal investigation of the June 2013 extreme weather and flooding events that affected southwestern Alberta and downstream areas, including a number of submissions to a special issue of Hydrological Processes dealing with meteorological and hydrological aspects. See progress updates by Kochtubajda, Li, Pomeroy, Stewart, Szeto, Thériault.
- Focal examination of extreme events (floods, fires, droughts) affecting the CCRN region from 2009–2011 with publications forthcoming. See progress updates by Hanesiak, Kochtubajda, Stewart, Szeto.
- Initial work towards an interdisciplinary examination of the 2014 forest fires in the Northwest Territories, involving contributions from university and government organizations. See progress updates by Baltzer, Bonsal, Johnstone, Kochtubajda, Quinton, Stewart, Turetsky.

Theme/work package D1:

Specific scientific contributions will involve the assessment of large and synoptic scale atmospheric circulation patterns as they relate to observed temporal and spatial trends and variability (including extremes) in hydro-climate over the study region.

Another focus will be on precipitation. Studies include the occurrence of precipitation extremes from droughts to heavy precipitation including variability and simultaneous occurrence. The regional and larger scale factors leading to such events will be determined. The factors leading to the changing occurrence of winter precipitation will be examined. As well, changes in the occurrence of extreme precipitation rates will be determined over some areas and linked with the large and regional scales forcing factors.

Theme/work package D3:
Key focal points will be on regional and local scale temperature changes and variations of prolonged summer hot periods, and extension of above freezing conditions. In terms of precipitation, the focus will be on the development of drought, heavy precipitation, extreme precipitation rates, as well as the changing phase of precipitation.

Theme/work package D4:
We will determine whether future changes cross 'tipping points' in Earth system behavior, leading to further extremes and dramatic system changes, such as deglaciation, permafrost disappearance and terrestrial ecosystem transition.

*MAHASRI*

Since the rate of temperature increase at the beginning stage of recent heat wave (HW) was found to be sensitive to the soil moisture condition, it is suggested that the recent drier soil conditions played a role in enhancing the frequency and intensity of HWs and localization round Mongolia (Erdenebat and Sato, 2015).

*INTENSE*

The INTENSE project is focused on meeting the data requirements and examining trends/ variability and processes associated with the core Grand Challenge events of "heavy precipitation" and "drought."

Data collection activities will contribute information (overarching theme: document) that could underpin detection and attribution studies and model evaluation by collating and quality controlling sub-daily precipitation data (providing data that is extensive in time and space). INTENSE is also examining how sub-daily precipitation extremes may be defined through the use of relevant indices that have to date only been established on daily timescales.

Analysis of local scale thermodynamics and large-scale predictors will improve understanding and characterization of physical mechanisms leading to the occurrence of floods and droughts (Overarching theme: understand), and the relationships between these events.

By linking observations with the latest generation of climate models (and in particular the emerging high-resolution regional climate models) INTENSE will assess the deficiencies of models in the simulation of key processes and events. It will contribute valuable information as to the types of events that current models can provide credible and robust simulations for, and

where high-resolution models offer added value compared with coarse resolution models (overarching theme: simulate).

### 2.2.8. Cooperation with Other Projects

The International Network for Alpine Research Catchment Hydrology (INARCH) is a spin-off GHP project from CCRN, led by Professor John Pomeroy. INARCH recently held an inaugural workshop in Kananaskis, Alberta, Canada, at which CCRN was represented by the principal investigator, Professor Howard Wheater and several other network co-investigators. A report on the INARCH workshop was provided to GEWEX. CCRN and INARCH are closely linked and share many common research priorities and objectives. Professors Wheater and Nazemi are contributing to the GHP crosscut on representation of anthropogenic water management in large-scale models.

MAHASRI has collaborated with the Japanese Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) and International Geosphere Biosphere Programme (IGBP) communities, as well as the Asian SPARC related community.

HyMEX and OzEWEX are collaborating with the Earth2Observe (EU project) and HEPEX in hydrological forecasting.

HyMEX initiated an ESA funded Water Cycle Observation Multi-mission Strategy-EvapoTranspiration (WACMOS) project over the Mediterranean region.

INTENSE has connections with the WCRP Grand Challenge on Extremes.

### 2.2.9. Workshops/Meetings Held

*CCRN*

- Workshop on the 2014 Northwest Territories Fires – Developing a Research Framework (12–13 January 2015, Yellowknife NT)
- Theme A workshop, Conceptual Models of Change (22 January 2015, Hamilton ON)
- Modeling Change in Cold Regions Workshop (28–30 September 2015, Saskatoon SK)
- CCRN Third Annual General Meeting (1–4 November 2015, Saskatoon SK)

*MAHASRI*

- 36th Congress and International Seminar, “Meteorology and Climate” (25-28 February 2015, Gauhati University, India)
- Indo-Japan Joint Workshop on Natural Disaster and Human Activity in the Northeastern Indian Subcontinent. Cooperating Atmospheric scientists, Geographers and Social scientists for disaster and Human Activities in South Asia, North Eastern Hill University (2 March 2015, Shillong, India)
- Asian monsoon Hydroclimate–Review of MAHASRI and Beyond (4-5 March 2015, Nagoya, Japan)
- The Fourth International Workshop of Climatic Changes and Their Effects on Agriculture in Asian Monsoon Region (GRENE-CAAM Workshop) (10-12 March 2015, Hanoi, Vietnam)
- International Session on Asian monsoon Hydroclimate (24-28 May 2015, JpGU at Chiba, Japan)

- AOGS2015 “AMY 2015 Session” (2-7 August 2015, Singapore)
- APHW HS session on Asian monsoon hydroclimate (2-7 August 2015, Singapore)

*HyMeX*

- HyMeX workshop (21-25 September 2015, Greece)

*OzEWEX*

- Soil Water Estimation and Evaluation workshop (March 2015)
- Australian Climatic Natural Hazards (May 2015, Adelaide)
- Annual OzEWEX Workshop (2 December 2015, Brisbane)

*INTENSE*

- A workshop was hosted at The Royal Society in London in January 2015 to present research on sub-daily rainfall and to discuss how it might be used in practice and to develop policy. This focused on outputs from the Using Observational Evidence and Process Understanding to Improve Predictions of Extreme Rainfall Change (CONVEX) project and was attended by about 100 academics and stakeholders.
- Research on UK hourly extremes has resulted in consultancy work for UK Water Industry Research (UKWIR) on the potential effect of changes in intense rainfall on urban drainage. This has resulted in a journal paper (see below) and an UKWIR guidance document, which was presented at a water industry stakeholder event in London in April 2015.

### 2.2.10. Workshops/Meetings Planned

*CCRN:*
Cold Regions Hydrological Model training workshop, March 2016
CCRN Fourth Annual General Meeting, November 2016

*MAHASRI:*
March 2-4(5), 2016: International Science Conference on MAHASRI at Tokyo, Japan
March 6-8, 2016 The Fifth International Workshop on Climatic Changes and Their Effects on Agriculture in Asian Monsoon Region” in Fukushima, Japan

*HYMEX:*
HyMex workshop in mid-2017

*OzEWEX:*
Annual workshop, dates and location TBD

*INTENSE:*
Planned international workshop in 2016 to include INTENSE partners (funded) and other interested parties (unfunded). This will take forward some of the questions/activities identified at the WCRP workshop in Sydney in Feb 2015, in particular, identification of indices for sub-daily precipitation.

*Precipitation near 0ºC:*
Meetings within EGU April, Japan Geosciences Union Annual Meeting May, CLIVAR Open Science Conference September

*Including water management in large scale models:*
Workshop 28-30 September 2016, Gif-sur-Yvette

*GHP Panel:*
The next GHP Panel meeting will be held jointly with GLASS from 3-5 October 2016 in Gif-sur-Yvette, France

### 2.2.11. Other Meetings Attended on Behalf of GEWEX or GHP

MAHASRI workshop, Nagoya, Japan, March 2015
WCRP Grand Challenge 1 writing session, Paris, March 2015
WGRC annual meeting, Norwich, England, December 2015

### 2.2.12. List of Key Publications


Bhatt, B. C., S. Sobolowski and A. Higuchi, 2015. Simulation of diurnal rainfall variability over the maritime continent with a high-resolution regional climate model, *Journal of the Meteorological Society of Japan*, doi:10.2151/jmsj.2015-052. (Accepted)

Bousquet O., Berne A., Delanoë J., Dufournet Y., Gourley J.J., Van-Baelen J., Augros C., Besson L., Boudevillain B., Caumont O., Defer E., Grazioli J., Jorgensen D.J., Kirstetter P.E., Ribaud J.F., Beck J., Delrieu G., Ducrocq V., Scipion D., Schwarzenboeck A., Zwiebel, J., 2015. Multiple-frequency radar observations collected in southern France during the field phase of the Hydrometeorological Cycle in the Mediterranean Experiment (HyMeX). *Bull. Amer. Meteorol*. Soc., 96, 267–282.

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Davolio S., Ferretti R., Baldini L., Casaioli M., Cimini D., Ferrario M.E., Gentile S., Loglisci N., Maiello I., Manzato A., Mariani S., Marsigli C., Marzano F.S., Miglietta M.M., Montani A., Panegrossi G., Pasi F., Pichelli E., Pucillo A., Zinzi A., 2015. The role of the Italian scientific community in the first HyMeX SOP: an outstanding multidisciplinary experience. *Met. Zeit*., in press.

Defer E., Pinty J.P., Coquillat S., Martin J.M., Prieur S., Soula S., Richard E., Rison W., Krehbiel P., Thomas R., Rodeheffer D., Vergeiner C., Malaterre F., Pedeboy S., Schulz W., Farges T., Gallin L.J., Ortéga P., Ribaud J.F., Anderson G., Betz H.D., Meneux B., Kotroni V., Lagouvardos K., Roos S., Ducrocq V., Roussot O., Labatut L., Molinié G, 2015. An overview of the lightning and atmospheric electricity observations collected in Southern

France during the HYdrological cycle in Mediterranean EXperiment (HyMeX), Special Observation Period 1. *Atmos. Meas. Tech.*, 8, 649-669.

Doerenbecher A., Basdevant C., Drobinski P., Bernard F., Durand P., Cocquerez P., Verdier N., Vargas A., 2015. Low atmosphere drifting balloons: platforms for environment monitoring and forecast improvement. *Bull. Amer. Meteorol. Soc.*, in revision.

Drobinski P., Ducrocq V., Alpert P., Anagnostou E., Béranger K., Borga M., Braud I., Chanzy A., Davolio S., Delrieu G., Estournel C., Filali Boubrahmi N., Font J., Grubisic V., Gualdi S., Homar V., Ivancan-Picek B., Kottmeier C., Kotroni V., Lagouvardos K., Lionello P., Llasat M.C., Ludwig W., Lutoff C., Mariotti A., Richard E., Romero R., Rotunno R., Roussot O., Ruin I., Somot S., Taupier-Letage I., Tintore J., Uijlenhoet R., Wernli H., 2014. HyMeX, a 10-year multidisciplinary program on the Mediterranean water cycle. *Bull. Amer. Meteorol. Soc.*, 95, 1063-1082.

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Endo, N., J. Matsumoto, H. Hayashi, T. Terao, F. Murata, M. Kiguchi, Y. Yamane and Md. Shah Alam, 2015. Trends in precipitation characteristics in Bangladesh from 1950 to 2008. SOLA, 11, 113-117. Doi:10.2151/sola.2015-027.

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Jansà A., Campins J., Picornell M.A., Guijarro J.A., 2014: Heavy rain and strong wind events over Spain during HyMeX SOP1. *Thetys*, 11, 25-38.

Jasechko, S., Sharp, Z. D., Gibson, J. J., Birks, S. J., Yi, Y., Fawcett, P. J. Terrestrial water fluxes dominated by transpiration. *Nature,* 496, 347–350 (2013).

Kiguchi, Y. Shen, S. Kanae, and T. Oki, 2015. Reevaluation of future water stress due to socio-economic and climate factors under a warming climate, *Hydrol. Sci. J.*, 60, 14-29. DOI: 10.1080/02626667.2014.888067.

Kim, W. et al. and 37 co-authors, 2015. FluxPro as a realtime monitoring and surveilling system for eddy covariance flux measurement, *Journal of Agricultural Meteorology*, 71, 32-50.

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Kubota, H., Y. Kosaka, and S.-P. Xie, 2015. A 117-year long index of the Pacific-Japan pattern with application to interdecadal variability, *Int. J. Climatol*, in press.

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Nagura, M., T. Terao and M. Hashizume, 2015. The role of temperature inversions in the generation of seasonal and intraseasonal SST variability in the far northern Bay of Bengal. *J. Climate*, 28, 3671-3693.

Otani, K. and K. Kato, 2015. Decrease in Baiu precipitation and heavy rainfall days in late June of the 2000s in northwestern Kyushu, western Japan. *SOLA*,11,10-13 (doi:10.2151/sola.2015-003).

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Wei, Z., K. Yoshimura, A. Okazaki, W. Kim, Z. Liu, and M. Yokoi, 2015. Partitioning of evapotranspiration using high frequency water vapor isotopic measurement over a rice paddy field, *Water Resour. Res.*, doi:10.1002/2014WR016737.

Xia J, S. Liang S, J. Chen, W. Yuan, S. Liu S, L. Li, W. Cai, L. Zhang, Y. Fu, T. Zhao, and others, 2014. Satellite-based analysis of evapotranspiration and water balance in the grassland ecosystems of dryland East Asia", PloS One, 9, e97295.

Yamamoto, M. K. and S. Shige, 2015. Implementation of an orographic/nonorographic rainfall classification scheme in the GSMaP algorithm for microwave radiometers. *Atmos. Res.*, 163, 36-47, http://dx.doi.org/10.1016/j.atmosres.2014.07.024.

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### 2.2.13. List of Members and Term Dates

*Co-chairs:*
Dr. Jan Polcher (4-year appointment 2011-2015 with option for additional 4-years)
Dr. Jason Evans (4-year appointment 2012-2016 with option for additional 4-years)

*Members:*
Dr. Li Yaohui (3-year appointment February 2013/16 with option for additional 3 years)
Prof. Kei Yoshimura (3-year appointment February 2013/16 with option for additional 3 years)
Prof. Joan Cuxart Rodamilans (3-year appointment February 2014/17 with option for additional 3 years)
Dr. Silvina Solman (3-year appointment February 2014/17 with for additional 3 years)
Dr. Nicole Van Lipzig (3-year appointment February 2014/17 with option for additional 3 years)
Prof. Hamma Yacouba (3-year appointment February 2013/16 with option for additional 3 years)
Dr. Craig Ferguson (3-year appointment February 2015/18 with option for additional 3 years)
Dr. Christel Prudhomme (3-year appointment February 2015/18 with option for additional 3 years)
Dr. Ben Zaitchik (3-year appointment February 2015/18 with option for additional 3 years)

## 2.3. Global Land/Atmosphere System Study (GLASS)

Reporting period: 1 January 2015–31 December 2015
URL: http://www.gewex.org/glass.html
Chair(s) and term dates: Aaron Boone (2013–2016); Michael Ek (2015–2018)

### 2.3.1. Panel Activities

"Support improved estimate and representation of (land) states and fluxes in models, the interaction with the overlying atmosphere, and maximize the utilized fraction of inherent predictability."

The aim of GLASS is to promote community activities that improve our best estimates and the model representation of state variables (e.g., soil moisture) and fluxes (e.g., evaporation), or to improve our understanding of land/atmosphere feedbacks and the role of land surface in predictability. To achieve these, GLASS is organized into three themes: (1) Benchmarking, (2) Model Data Fusion (MDF), and (3) Land-Atmosphere Coupling (LAC). The concept of model benchmarking (rather than validation) enables the modeling community to identify the current strengths and weaknesses of models in relation to their required applications. This is a big shift of focus for the modeling community and considerable work and discussions have been engaged on the definitions of the a priori metrics that a model needs to achieve. The GLASS Protocol for the Analysis of Land Surface models (PALS) Land Surface Model Benchmarking Evaluation Project (PLUMBER) directly addresses this theme with the goals of demonstrating this approach to benchmarking for the community. As of the writing of this report, a second paper (Houghten et al., 2016) is under review on the results of this project. A paper published last year (Best et al., 2015) has served as a community-wide reference on the subject and an example that is applicable to land surface models. Many of the GLASS panel members participated and have co-authored both of these international efforts.

The second theme of Model Data Fusion (MDF) brings data assimilation and parameter estimation techniques to both the initial value problem and to constrain the bounds of unknown parameters by using historical data sets. In the past, land data assimilation has been limited to restrictions in observational data of the land components (e.g., soil moisture), however new satellite data provides an opportunity to explore more advanced data assimilation techniques. The Project for the Intercomparison of Land Data Assimilation Schemes (PILDAS) directly addresses this theme of GLASS, with connections between the GEWEX Hydroclimatology Panel (GHP), The GEWEX Data Assessments Panel (GDAP) and GLASS with regards to Phase 3 of the Global Soil Wetness Project (GSWP3) and Phase 2 of the Analyse Multidisciplinaire de la Mousson Africaine (AMMA) Land Surface Model (LSM) Intercomparison Project (ALMIP2), and a new potential GHP-GLASS project with the Integrated Land-Ecosystem-Atmosphere Processes Study (iLEAPS) for the Saskatchewan River Basin.

The third theme, Land-Atmosphere Coupling (LAC), aims at understanding the physical interactions between the land and the atmosphere and how feedbacks can change the subsequent evolution. While the GLACE1 and GLACE2 projects demonstrated regions of the globe and situations where the land can have a significant impact on atmospheric evolution, they also highlighted large differences between modeling systems. The goal of the Land Surface, Snow and Soil Moisture Model Intercomparison Project (LS3MIP) is to provide a comprehensive assessment of land surface-, snow-, and soil moisture-climate feedbacks, and diagnosing systematic biases in the land modules of current Earth science models (ESMs)

using constrained land-module only experiments. The solid and liquid water stored at the land surface has a large influence on the regional climate, its variability and its predictability, including effects on the energy and carbon cycles. Therefore, GLASS will help to facilitate two aspects of land/atmosphere coupling, the first being to understand the physical processes while the second will strive to understand how both land and atmospheric parameterizations interact. The focus is at both the process/local level (Local Land-Atmosphere Coupling Working Group, LoCo) and the global behavior of the coupling (Global Land-Atmosphere Coupling Experiment, GLACE). This understanding will help to maximize the inherent predictability of the coupled land/atmosphere system.

In summary, GLASS currently has a good mix of established and new projects, each of which adheres well to the three GLASS themes (MDF, Benchmarking, LAC). GLASS has reached out to the GEWEX Hydroclimatology Project (GHP) regarding a number of activities (such as the new initiative to improve the representation of the impact of anthropization water resources in land surface and eventually fully coupled Earth System Models, Harding et al., 2015), has forged links with the Climate and Cryosphere (CliC) Project (via ESMsnowMIP as a part of LS3MIP), has links with Global Atmospheric System Studies (GASS) Panel through Diurnal Land/Atmosphere Coupling Experiment (DICE) (which is wrapping up and in publication phase) and the GEWEX Atmospheric Boundary Layer Study (GABLS4), is working within the new GEWEX Soils and Water (GSW) Initiative and continues to engage the Working Group of Numerical Experimentation (WGNE) on benchmarking and data assimilation activities.

### 2.3.2. Science Highlights

#### 2.3.2.1. GSWP3 (Hyungjun Kim)

The pilot stage of the Project Phase Global Soil Wetness 3 was initiated in autumn 2014. GSWP3 is currently in the “fast-track” phase with seven institutes participating (National Centers for Atmospheric Research (NCAR), the Swiss Federal Institute of Technology (ETH), the University of Tokyo, Meteo-France, the European Centre for Medium-range Weather Forecasts (ECMWF), the Royal Netherlands Meteorological Institute (KNMI), and the Japanese Meteorological Association (JMA)]. Six simulation sets have been submitted, and the first round analysis and validation is under way. The goal is to test the forcing within a subset of the land surface models in order to identify any issues (which in turn, could result in changes or updates to the input forcings). This is a critical step, as the model simulations should have the best possible forcing data as inputs. Phase 2 will begin during the first half of 2016 (the official runs). GSWP3 is a part of the Land Surface, Snow, and Soil moisture Model Intercomparison Project (LS3MIP) under LMIP (which is endorsed as part of Coupled Model Intercomparison Project, CMIP6). New or updated components being considered for this project include:

- To maintain the consistency with CMIP6, conduct a long-term retrospective experiment (EXP1) that extends the proposed simulation back to 1850 (as opposed to the original proposition of 1870), and future simulations (EXP2) that span the period 2015-2100 using multiple projected future climate scenarios from CMIP6 ScenarioMIP. This would include some interesting global trends in hydrology, but is also long enough for carbon processes considering land use/cover changes (LULCC).

- Use carbon models to explore/attribute possible carbon-related effects or changes in ecosystem functions. This could provide a bridge to the terrestrial carbon cycle modeling

community. GLASS will recruit member(s) of iLEAPS to be actively involved in both the planning and analysis of the carbon component of GLASS.

- Explore uncertainties in model physics, forcings, and parameters by assessing the large set of ensemble combinations, and propose an optimal set as a land reanalysis. Extensive sets of observations including both in situ (e.g., discharge and soil moisture) and satellite remote sensing products (i.e., terrestrial water storage) will be aggressively exploited.

The standard forcing data of EXP1 is generated combining spectral nudging dynamic downscaling and bias correction techniques. Twentieth Century Reanalysis is spatio-temporally disaggregated to 3-hourly T248 resolution using a global spectral model. Multiple in situ measured surface variables (i.e., precipitation, short-/long-wave downward radiation, and air temperature) are used to reduce intrinsic biases of the downscaled reanalysis fields. A “white paper” (experimental protocol) and the list of variables are being updated with an inter-community contribution component. Work on this document has been ongoing with input from participants of the project. It will be distributed to the participating modeling groups before launching the actual phase (March 2016).

The second phase of the Intersectoral Impact Model Intercomparison Project (ISI-MIP) adopted the GSWP3 EXP1 forcing data as one of standard model input data sets, and it will be circulated among key contacts within the carbon community to get their buy-in before the project begins. This will enable both carbon and water and energy cycle land surface models to be included, and simultaneously evaluated in them (e.g., the hydrology of carbon models and vice-versa).

#### 2.3.2.2. GLASS/GABLS DICE Experiment (Martin Best, John Edwards)

The GLASS/GABLS Diurnal Coupling Experiment (DICE) experiment began in 2013. The first DICE workshop was held during 14-16 October 2013 at the UK Met Office (UKMO) in Exeter and subsequent workshops were held at the GEWEX science conference from 14-18 July 2014 at The Hague and in Toulouse from 20-22 May 2015. This project involves the GABLS and GLASS members running fully coupled SCMs at the CASES 99 experiment (which was the GABLS2 project) and controlling for surface fluxes vs. atmospheric forcing in each component to isolate the impact of land-atmosphere coupling in the models over the full diurnal cycle (stable and unstable PBLs). Stages 1 (offline land surface), 2 (fully coupled) and 3 (column models forced by surface fluxes) are complete and analyses are currently being undertaken with a view to having three draft scientific papers ready for circulation to participants within the next couple of months. In addition, the hope is that a number of studies will be undertaken with these data by other DICE participants on the various coupling diagnostics that have been developed, with the subsequent scientific papers forming a special collection of a journal.

#### 2.3.2.3. LoCo and the SGP Testbed (Joe Santanello)

The LoCo Working Group (WG) has continued to grow over the last year and is actively continuing work on diagnostics of land-atmosphere interactions and coupling across an array of scales and models. Over 25 recent papers have been produced by members of the working group focusing on aspects of LoCo, such as diagnostic development, soil moisture-precipitation coupling, cold process coupling, mesoscale processes, and GCM/RA/CMIP applications. A wide net has been cast in developing coupling metrics and producing maps, but it is recognized

that now is the time to reel in these efforts, and synthesize them to get at more science-driven questions of coupling (i.e., a “LoCo Metrics Toolkit” by Ahmed Tawfik based on a compilation of LoCo coupling indices by Paul Dirmeyer). Additionally, the LoCo WG has been collaborating with the U.S. Department of Energy’s Atmospheric Radiation Measurement (ARM) Program US Southern Great Plains (SGP) campaign and has produced an ARM-supported data set for coupling studies over the SGP. In addition, a radiosonde campaign led by the LoCo WG was executed in the Summer of 2015 (15 June-31 August 2015 at the ARM-SGP Central Facility) with high temporal resolution sonde launches to augment the current ARM-SGP sonde launches for application to LoCo studies. These new data set will allow the array of LoCo diagnostics to be applied consistently to the same location in order to understand their hierarchy and to develop a classification system based on the metrics.

#### 2.3.2.4. PALS and Benchmarking (Gab Abramowitz)

The Protocol for the Analysis of Land Surface models (http://pals.unsw.edu.au) has progressed to a more advanced version that includes gap filling, empirical benchmarks, and automated metrics along with a large suite of FLUXNET data. PALS was designed to analyze in a standard way uploaded single site model simulations with site observations. Extensions to other data sets and the development of benchmarking tests are under development. For example, implementation of the Manabe Bucket Model and the Priestly-Taylor approach to flux estimation has been performed in order to use as standard benchmarks of the ‘goodness’ of current LSMs. The joint GHP-GLASS project PLUMBER has been conceived to demonstrate benchmarking through PALS (see the next item). Discussions are under way for including two-dimensional (ideally for specific well-instrumented and documented basins which implies developing links with GHP and GDAP) case studies within PALS potentially under the auspices of a future follow-on intercomparison project.

#### 2.3.2.5. PLUMBER (Martin Best, Gab Abramowitz)

The PALS Land Surface Model Benchmarking Evaluation Project (PLUMBER) is a benchmarking activity that uses the PALS system. Data acquired in conjunction with GHP for 20 FLUXNET sites was used to evaluate an array of land surface models and comparing metrics vs. that of simple formulations (bucket model, P-M, and simple regressions). Many GLASS member groups participated in this initial stage of PLUMBER, and results have been presented at conferences and an overview paper (co-authored by many GLASS panel members) was published in 2015 (Best et al., 2015) and another paper (also co-authored by several GLASS panel members) is currently under review for the Journal of Hydrometeorology. Analysis will continue into 2016, but the active modeling phase of this project has concluded.

#### 2.3.2.6. LUCID (Andy Pitman and Nathalie de Noblet-Ducoudré)

Several papers were published during the period of 2012-2014 that summarized the LUCID and LUCID-CMIP5 results. The effects of land cover change on temperature and rainfall extremes in multi-model ensemble simulations have been studied, along with the effect of anthropogenic land-use and land-cover changes on climate and land carbon storage. Some analyzes are continuing with LUCID and LUCID-CMIP5 runs. Two papers have been submitted that focus on the impacts of future land-use changes on monsoon areas throughout the globe, and on the impacts of historical land-use change in western Africa. Some of the main findings are that LULCC matters at the regional scale even though it may not be visible at the global

scale, the differences in the land surface model parameterizations explain one-half to two-thirds of the inter-model dispersion, and that differential amounts of forests removed explain approximately one-third of the inter-model dispersion.

Since the launch of the LUMIP Project, LUCID has been in a transitional phase with few interactions with scientists that contributed to past LUCID experiments. The main actions that LUCID was involved in during 2015 were:

- Continuing analysis on initial LUCID and LUCID-CMIP5 runs. Four papers are either about to be submitted or were just submitted (Quesada et al., just submitted to PNAS; Lejeune et al., about to be submitted; Quesada et al. about to be submitted; Sy et al., in prep.). Those analysis do not result from large coordinated actions but from isolated scientists who asked for the models' outputs;

- Discussion with EURO-Coordinated Regional Climate Downscaling Experiment (CORDEX) community to try and design LUCID-EURO/CORDEX simulations;

- Contribution to LUMIP scientific committee.

- An exploration of issues around land over change and land-atmosphere coupling strength

In terms of future actions:

- The LUCID Project would like to gauge the interest of the CORDEX community because the downscaling of future scenarios of global climate change need to be combined with scenarios of regional LUC, specially if those regional climates are meant to be used for impact studies. Several discussions occurred last year to prepare the EURO-CORDEX community to carry out regional European simulations with different land-use scenarios. This will finally happen this year (2016) and a first meeting is scheduled on 25 January 2016 in Hamburg, Germany). A wiki page has been set up (https://wiki.gerics.de/luc/) and the simulation protocol will hopefully be decided within 1-2 months (before the end of February 2016).

- There may be linkages between GSWP3 and the land cover treatment in the 20 C simulations and LUCID efforts that will be investigated. Discussions were initiated at the LandMIP meeting in Zürich (November 2015).

- To diagnose potential teleconnections in our climate models, additional regional simulations have been proposed and those would be run by three climate models in the context of the LUC4C European project [IPSL, Hadley Centre and ECEARTH-LPJguess]. It is hoped that within LUCID-LUMIP, more models will become involved.

- Further analysis has lead to several conclusions, which should be relayed to the community studying land cover change. The implications of all of these were already known. Land cover change experiments need to: (i) be run with large ensembles—at least 5–10 (any single realization of a land cover change is unreliable); (ii) be run with the knowledge of the land-atmosphere coupling (without this knowledge the results can vary due to the coupling; masking any real signal); and (iii) use field significance testing at a minimum. (For example for LUMIP, this means any experiments have to be methodologically rigorous which is computationally demanding but that is what the LUCID

results suggest. It will be tempting to ignore this and just do single simulations—we think this needs to be resisted).

#### 2.3.2.7. GLACE-CMIP5 (Sonia Seneviratne and Bart vd Hurk)

The goal of this project is to investigate effects of changes in soil moisture content and soil moisture-climate coupling in global CMIP5 projections. Six groups are participating in the simulations (GFDL, IPSL, ECHAM, CESM and EC Earth, as well as ACCESS since 2014). The analysis and the experimental design are coordinated by ETH and KNMI. Future phases of experiments are considered, including some investigating the joint effects of changes in soil moisture verses changes in CO2 concentration for plant transpiration. Highlights show a large impact of projected soil moisture changes on changes in daily mean and max temperature, including hot extremes. Effects on precipitation changes are less clear, and additional analyses will be conducted to investigate the underlying feedbacks and associated effects on the water balance (E-P). Six papers are currently under preparation or submitted: A. Berg et al.: T-P correlation (J. Climate, 2015), W. May et al.: Effects on monsoons (Climate Dynamics, 2015), R. Lorenz et al.: Impacts on extreme indices (submitted to JGR), A. Berg et al.: Aridity study (draft completed), S. Seneviratne, M. Hirschi: Land-atmosphere coupling hot spots, S. Seneviratne, V. Brovkin, et al.: Climate feedback analysis. The currently planned CMIP6 experiment LS3MIP ("Land Surface, Snow and Soil Moisture MIP") builds in part on the GLACE-CMIP5 framework (e.g. Seneviratne et al., 2014).

#### 2.3.2.8. PILDAS (Rolf Reichle)

The launch of the Project for the Intercomparison of Land Data Assimilation Schemes (PILDAS) was delayed until 2015. The experimental design is essentially complete, and a pilot study by the project lead to use two land surface models (LSMs) with one DA algorithm in NASA's Land Information System (LIS) was developed. However, this portion of the project had been delayed by new modifications to the ALMA convention made by the GLASS panel (requiring a considerable effort to update software). Phase-1 will still be focused on operational centers (rather than specific research projects), synthetic observations, and different DA algorithms with different LSMs for a 1/8-degree domain over the Southern Great Plains (US). Later phases will focus on coupled DA systems and actual satellite observations from SMOS and SMAP. GLASS will take the experimental plan and initial results to WGNE to entice other centers that are not currently listed to participate. Currently, Patricia de Rosnay (ECMWF) and Wade Crow (USDA) made some progress in that they obtained PILDAS forcing data from NASA/GMAO and were working to set up their systems to read the forcing data and generate their versions of the "truth" data set, with their expected completion time of this phase sometime in the winter or spring.

#### 2.3.2.9. ALMIP2 (Aaron Boone)

The 2nd AMMA Phase 2 Land MIP was launched in Spring 2012. In all, 22 LSMs, five hydrological models, and one evapotranspiration model are all included in this phase. In this experiment, the focus is on a much higher spatial resolution (mesoscale: 5 km) than in ALMIP1 (regional scale: 0.5 degree), to focus on the subtle hydrology and vegetation processes that dominate there (occasionally very large rooting depths which access water in near surface aquifers, soil crusting, lateral transfer processes, strong variability in surface runoff), and to enable use of high resolution satellite data. The period covers four years, where the forcing is

coming from a blend of in situ and NWP/radar/Landsat/other satellite data. ALMIP2 takes advantage of observational data along a meridional transect from the AMMA-CATCH network, which cuts across a zone with a large gradient in surface characteristics and rainfall. The project will give recommendations on the parameterization of runoff scaling and potentially missing or poorly parameterized processes, which are key to the functioning of the West African land surface. This project is now in analysis and publication phase: a proposal for a special collection of papers has been accepted by the Journal of Hydrometeorology: 10 papers will be submitted in 2016: currently, 2 papers are about to be submitted, and most should be submitted by summer 2016. Parts of this project will possibly be folded into the LoCo activities.

#### 2.3.2.10. GABLS4 (GASS/GLASS): GLASS Liaison – J. Edwards

Within the GEWEX Atmospheric Boundary Layer Study (GABLS), intercomparison studies are carried out for boundary layer parameterization schemes used by numerical weather prediction and climate models. Under stable stratification, models still have large biases, which depend on the parameterizations used for boundary and surface layers. In the GABLS4 case, the aim is to study the interaction of a boundary layer with strong stability (Ri>>1) with a surface with a low conductivity and a high cooling potential, such as snow (glacier). The case is based on observations at the Antarctic Plateau at Dome C. This intercomparison concerns Land-Snow Surface Models, Single Column Models and Large Eddy Simulations. GLASS panel member John Edwards is participating in this project and is acting as the GLASS liaison. This project began in the latter part of 2015 and is on going.

### 2.3.3. Projects Being Launched

2.3.3.1. PILDAS was delayed until 2015, and is finally getting started. The principal investigator (PI) of this project has been very busy as part of the SMAP science team. But with the SMAP launch in January 2015, the PI had more time in 2015 re-vitalize PILDAS during 2015. The initial pilot experiment at NASA-GSFC with the PI and Sujay Kumar (also at NASA) should lead to the larger community experiments, now with some activity by ECMWF and USDA. There is interest in this project (especially from WGNE), and thus the panel has continued to strongly encourage the PI to continue with this project, despite the delays.

2.3.3.2. The LoCo-SGP Testbed Project (Ferguson, Santanello, Gentine, Findell, and Shaocheng Xie) was proposed to the Department of Energy (DOE) Atmospheric Research Program. Three GLASS panel members (Ferguson, Santanello, and Gentine) were successful in securing radiosondes from DOE for an IOP for summer, 2015. The ARM Climate Research Facility supported a LoCo working group-led enhanced frequency radiosonde campaign this summer of 2015 (15 June to 31 August 2015) at the ARM Southern Great Plains Central Facility (CF). For twelve days the operational launch schedule at the CF was augmented by daytime hourly radiosondes with 3-hourly trailer (10-minute lagged) radiosondes—a total of (14) additional radiosondes/day. The data will be useful for: forcing single column model experiments such as DICE; assessment and refinement of the PBL daytime transition in models; evaluating the “LoCo Metrics Toolkit;” and directing the instrument reconfiguration at ARM-SGP to better support high-resolution modeling.

2.3.3.3. CMIP6-Endorsed MIPs: Land Surface, Snow and Soil Moisture (LS3MIP). The goal of the LS3MIP experiment is to provide a comprehensive assessment of land surface, snow, and soil moisture-climate feedbacks, and diagnosing systematic biases in the land modules of current ESMs using constrained land-module only experiments. Snow cover is an essential component of the Earth System that interacts with the atmosphere and the surfaces it covers (land, ice, sea ice). It is also an important source of (positive) feedbacks within the climate system. A WCRP/CliC Initiative was proposed in 2013 for an ESM-SnowMIP intercomparison program as a contribution to the WCRP Grand Challenge Cryosphere in a Changing Climate. The experimental design of the GLACE-CMIP5 study, carried out with a limited CMIP5 ensemble with prescribed SSTs (AGCMs) and vegetation, is used as blueprint for the second set of proposed LS3MIP experiments. The new LS3MIP experiments will allow a full quantification of soil moisture-climate feedbacks in the CMIP6 models and provide reference diagnostics for the evaluation of the CMIP6 ESMs, which will be of key relevance for the application of constraints to reduce uncertainties in projections.

2.3.3.4. GSWP3: The official launch for the Global Soil Wetness Project Phase 3 is planned for early 2015. See GSWP3 in Section 1. Panel activities and Section 4. Science Highlights for further details.

### 2.3.4. New Projects and Activities Planned

2.3.4.1. LoCo-SGP Testbed. In order to grow Department of Energy (DOE) Land/Land-Atmosphere research programs based on community feedback and through collaboration between LoCo PI's (Ferguson, Santanello, Gentine), ARM, and the NASA NEWS program, a new data product called ARM Best Estimate (ARMBE)-Land has been produced for the SGP Central Facility (Lamont, OK) which includes land states, fluxes, near-surface measurements, and PBL profiles co-located, and along with an ARM-SGP reconfiguration (reduced domain of 100x100 km with a focused 30x30 km inner (LES) grid) and a LoCo-SGP Testbed proposal for a Land-Atmosphere Feedback Experiment (LAFE) in summer 2016, this brings together LoCo metrics and the ARMBE data. This suggests an investigation of additional site suitability for other LoCo studies, e.g. India (monsoon), AMMA, and Cabauw, as suggested by the GEWEX SSG in 2012.

2.3.4.2. Discussions have been initiated with Howard Wheater (University of Saskatchewan) on a potential GHP-iLeaps-GLASS-CliC Cold Season Processes Project. This project would use observational data from the Changing Cold Regions Network (CCRN) (http://www.ccrnetwork.ca/). CCRN will integrate existing and new experimental data with modelling and remote sensing products to understand, diagnose and predict changing land, water and climate, and their interactions and feedbacks, for this important region. CCRN will use a network of world-class observatories to study the detailed connections among changing climate, ecosystems and water in the permafrost regions of the Sub-arctic, the Boreal Forest, the Western Cordillera, and the Prairies. CCRN will integrate these and other data to understand the changing regional climate and its effects on large-scale Earth system change and the region's major rivers - the Saskatchewan, Mackenzie and Peace-Athabasca. So, this project could potentially help improve land surface, Carbon and hydrological processes in a region, which is very sensitive to climate change. A proposal is being prepared by GLASS and iLEAPS panel members on how such a merged project can address the core issues of GEWEX and iLEAPS. If this progresses, this proposition will then be discussed with H. Wheater (in 2016).

2.3.4.3. The role of human activities in modifying and controlling the continental water cycle has been recognized by WCRP as one of its Grand Challenges and also underlies the GEWEX Grand Science Questions. To better understand the mechanisms behind this challenge, the GHP and GLASS panels are creating a crosscutting project focused on the inclusion of water management in large-scale models. This project will be launched with a workshop in late 2016 at the Ebro River Basin in Spain. The location was chosen because it is within the area of the GEWEX Regional Hydroclimate Project (RHP) called the Hydrological Cycle in the Mediterranean Experiment (HyMeX). The Elbro River Basin has lost two-thirds of its discharge in the past 50 years due to irrigated agriculture in the catchment. Plans for the new GEWEX crosscutting project include: (1) defining a program of research that addresses the four key gaps identified above; (2) developing a coherent action plan that integrates the current rather disparate activities in this area; and (3) linking modeling development to regional case studies through the RHP projects. See Harding et al., 2015, GEWEX News, 27 (4), 6-11.

2.3.4.4. The soil science community has been exploring ways to broaden disciplinary participation and foster collaboration in addressing important societal challenges where soil is a key component (beyond the traditional agricultural scope). In 2012, the Soil Systems and Critical Zone Processes (SSCZP) Technical Committee was established jointly by the Hydrology and Biogeosciences sections of the American Geophysical Union (AGU). This committee has since organized conferences to involve other disciplines. During this period the leadership within GEWEX became more proactive in addressing a fundamental element mostly missing in its activities related to global water and energy exchanges, namely subsurface water and its related processes at both global and regional scales. This is particularly relevant to GLASS. The GEWEX International Scientific Conference held in The Hague, The Netherlands in 2014, provided an ideal forum for exploring these topics of mutual interest to GEWEX and the soil community, and to develop plans for an initiative promoting the synergistic inclusion of soil and near-surface water flows into some of the GEWEX activities. This initiative is called the GEWEX Soils and Water (GSW). To better coordinate all these activities, two major events will be organized in 2016. The first, the Austin International Conference on Soil Modeling, will be held March 29–1 April 1 2016 in Austin, Texas, and will focus on establishing an International Soil Modeling Consortium. The second event will be an exploratory workshop held in Leipzig, Germany to identify and prioritize topics and establish working teams and a timeline for next steps of the GSW. See Or et al., GEWEX News, 2015, 25 (3), pages 8-9 for more details.

### 2.3.5. Science Issues

2.3.5.1. The LS3MIP science details are being finalized: A document was circulated among a number of the GLASS panel members in December 2014. The objectives of LS3MIP respond to each of the three CMIP6 overarching questions: what are regional feedbacks and responses to climate change, what are the systematic biases in the current climate models, and what are the perspectives concerning the generation of predictions and scenarios. Further details were also discussed at the LandMIP meeting in Zürich in October 2015.

2.3.5.2. The definition of ‘local’ vs. ‘non-local’ coupling and representation of each by the array of LoCo diagnostics is a non-trivial issue. This will be addressed directly by the SGP Testbed data set and diagnostic intercomparison and will include the effect on coupling metrics of spatial and temporal scales.

2.3.5.3. Forcing height used to force the PILDAS experiments still needs to be examined and resolved (either 2 or 10 m, or lowest atmospheric model level). There is not an optimal best solution at the moment, as some models have only one available.

2.3.5.4. LUCID has highlighted the importance to impound upon the land cover change modeling community the important of a minimum number of ensembles (and associated with this, the use of statistical significance testing).

### 2.3.6. Contributions to GEWEX Science Questions

GLASS contributes most directly to the following GEWEX Imperatives.

#### 2.3.6.1. Develop diagnostic approaches to improve process-level understanding of energy and water cycles in support of improved land and atmosphere models.

- Identify feedbacks and the interactions among different processes, and build confidence in their replication in models (GLACE, LoCo).
- Spin-up activities in advanced diagnostics through a joint pan-GEWEX effort/workshop (GRP, GLASS, GHP, and others).
- Develop metrics to aid benchmarking activities for both un-coupled and coupled modeling activities (PLUMBER, DICE)
- With the current and expected increasing complexity of land models in terms of various hydrologic and vegetation treatments, model optimization (i.e., parameter estimation approaches) will continue to be relevant to GLASS efforts (through Model Data Fusion).
- Investigate alternative representations of sub-grid processes in land surface schemes (heterogeneity).
- Develop improved understanding of climate variability and change on land surface properties, including soils, vegetation and hydrological processes, and an associated modeling capability (GSWP3, ALMIP2, GSW).
- Investigate the scope for development of next generation land surface models with improved representation of subsurface hydrology, including groundwater processes; identify suitable areas for their evaluation.
- Improved representation of cold season land surface, Carbon and hydrological processes (potential CCRN project)

#### 2.3.6.2. Improve global and regional simulations and predictions of precipitation, clouds, and land hydrology, and thus the entire climate system, through accelerated development of models of the land and atmosphere.

- Coordinate the construction of a global land reanalysis system, building on ongoing and preparatory activities in LandFlux, GSWP3, GLDAS and operational weather centers.
- Develop a framework and infrastructure for evaluation of land-atmosphere feedbacks. This should include the development of more quantitative estimates of uncertainty in the land condition and how this uncertainty propagates through to the atmosphere (e.g., PBL, convection, water and energy, carbon). This objective will be advanced in conjunction with the Processes Imperative in developing diagnostics.
- Organize coordinated intercomparison experiments for a range of model components in state-of-the-art land models, especially with regard to: groundwater hydrology; surface water treatment (snow, river routing, lakes, irrigation, and dynamic wetlands); vegetation phonology and links between carbon and water; and Land Data Assimilation systems (follow-up to the PILDAS initiative).
- Evaluation of these land model components will also have to be considered in their interactive (coupled) context with the PBL, while taking into account and developing more quantitative measures of uncertainty in the land parameters and states will enable more robust evaluation of data assimilation systems.

### 2.3.7. Contributions to the GEWEX Grand Science Questions

#### 2.3.7.1. How can we better understand and predict precipitation variability and changes?

*The GLASS activities below address the linkages of precipitation (and its accuracy) to land surface processes and LSM predictability.

Related current GLASS activities:

- GLACE – Land/soil moisture impact on precipitation and predictability (POC: Sonia; 1 and 2 complete; CMIP in progress), LS3MIP to begin within CMIP6 framework.

- LoCo – Regional/Local Process-Level Quantification of land-PBL interactions and impact of land surface on precipitation (POC: Joe)

- ALMIP2 – Specific precipitation event studies and heterogeneity issues in soil moisture-precipitation feedbacks (POC: Aaron, nearly complete)

- PILDAS – Land DA of soil moisture; multivariate-coupled DA (precipitation and soil moisture) in a future phase (POC: Rolf)

- GSWP3 – Precipitation as a key forcing for 20th Century simulations – this effort should quantify the error bounds on the 'land reanalysis' generated due to precipitation uncertainty (POC: Hyungjun)

Benchmarking – How does precipitation uncertainty impact offline and coupled model evaluation – spread of LSM physics vs. spread due to precipitation errors (POC: Martin, Gab)

Future activities:

- Incorporation of new satellite products (GPM, SMOS, SMAP) into these efforts more explicitly.

#### 2.3.7.2. How do changes in the land surface and hydrology influence past and future changes in water availability and security?

*Water Use, Resources, and Sustainability issues are at the heart of this challenge. How can GEWEX be positioned to meet this challenge given the current structure and makeup, currently focused on modeling groups and model intercomparisons with loose ties only (at best) with water resource and planning communities? Current activities are trying to answer various aspects of the science issues here (e.g. soil moisture and drought in a changing climate), but not yet at the stage of integrating the entire terrestrial water budget. GRACE is the only current tool we have in this regard, but is very limited in space and time scales such that regional and diurnal studies and models cannot be improved or assessed using this dataset. Carbon, ecosystem, cryosphere, ground water, and distributed hydrology models are not traditionally GEWEX activities – but fully integrated Earth System and Land models are the future so we need to be forward thinking. It seems this challenge is really the overarching challenge of all land hydrology for climate studies.

As a result, this challenge also intersects directly with other entities (iLEAPS, iLAMB, CliC, DMIP, LULCC). This challenge might boil down to coordinating model development from previously disparate disciplines and applications, and based on CMIP5 results in terms of the limitations and sensitivities to the land hydrology (e.g., LUCID recent results).

Related current GLASS activities:
- LUCID1/2 (POC: Andy Pitman)
- ALMIP1/2 (POC: Aaron Boone)

- PILDAS/SMAP (Data analysis of surface and root zone soil moisture will be critical to link with GRACE)

#### 2.3.7.3. How does a warming world affect climate extremes, and especially droughts, floods and heat waves, and how do land area processes, in particular, contribute?

*This continues to be a 'hot topic', e.g. how will the frequency and location of extremes change due to 'x' amount of warming in the future? The NASA Energy and Water Cycle Study (NEWS) chose 'Extremes' as one of it's core integration projects, and could be looked at as a model both of what and what not do, and what can be learned by a limited subset of the community (material available online). Model evaluation and benchmarking becomes critical here as well. Most models are tested offline and only for average conditions, and once into extreme realms of forcing or states tend to behave much differently. Recent LSM calibration/parameter estimation studies suggest that a vastly different set of parameters (lookup tables) is required for extremes vs. average conditions. As observational data improves (e.g. challenge #1), this is no guarantee the models will behave better as a result. DA and Calibration studies should be a focus here. Calibration is a weak component of GLASS currently and should be expanded under 'Model Data Fusion'. You can learn a lot about model behavior and limitations that way, especially in concert with DA.

Related current GLASS efforts:

- PILDAS – Data analysis with calibration for improved soil moisture representation during extreme conditions.

- LoCo - quantification during extremes to get at model behavior and how LSMs impact the persistence of droughts/floods and feedbacks. Seasonal drought prediction needs a lot of improvement with the emphasis on the land impact (http://www.climatecentral.org/news/lack-of-warning-on-2012-us-drought-reflects-flaws-in-forecasting-14823/)

- ALMIP2 - inherently encompasses dry extremes/feedbacks over AMMA with monsoon precipitation.

- GLACE2-CMIP is examining impact of soil moisture on extremes in CMIP5 (IPCC report just out on the subject).

Benchmarking - should look at model performance stratified by regime (e.g., PLUMBER)

Future activities:

- CORDEX-GLASS collaboration possibly needs to (a) exist and (b) accelerate to answer these questions in the context of climate model predictions.

#### 2.3.7.4. How can understanding of the effects and uncertainties of water and energy exchanges in the current and changing climate be improved and conveyed?

This seems to be the most traditional GEWEX-type challenge in that it promotes a lot of activities in the current panels and relies on the strengths of the current makeup. What this

challenge also shows is how much more work needs to be done in quantifying and improving water and energy cycle prediction in models of all scales and types. Results and improvements as a result are felt throughout the remaining three challenges, WCRP, and other communities as well. In order to close the land surface energy balance, we need to address all the issues and model evaluation and development listed in this challenge, and it will require SMOS/SMAP, GPM, GRACE, etc. to get right.

Related current GLASS efforts:

- GSWP3 – Land reanalysis and sensitivity of surface fluxes to forcing uncertainties including radiation.

- LoCo – Determining Processes; How are land and PBL fluxes quantified and interact with each other.

- PILDAS – Constraining LSMs with observations for improved land surface energy balance.

Benchmarking – Asses land surface energy balance in models vs. empirical models, and evaluating the 'goodness' of a model prediction.

Future activities:

- GLASS-GDAP – Improve connection between SRB, LandFlux and GLASS modeling and prediction and consistency between data products and models.

- Anthropogenic Influences on the Global Water Cycle initiative: better characterize and prediction the impact of the human imprint on the water cycle

### 2.3.8. Key Science Questions for the Next 5-10 Years for a Land-Atmosphere Project

2.3.8.1. The impact of the land surface, soil moisture and vegetation (interactive phenology), and L-A coupling on Seasonal/Drought Prediction.

2.3.8.2. A common modular interface for LSMs (new ALMA), such that different models and components can be more easily transferred to other's platforms, intercompared, and swapped. This would also include a common land-atmosphere coupling modularity such that different atmospheric and land models can be intercompared in order to evaluate the impact of each on the coupling results. Improved Benchmarking methods/tools/datasets for the community as a whole

2.3.8.3. Pressing Model developments/improvements: Improved cold season processes (interactions between permafrost and greenhouse gas emissions), ground water interactions, anthropogenic processes (irrigation, aquifer uptake, crop harvest, improved LULCC), and the LSM "grey zone" (in anticipation of ever-higher resolution research and NWP applications: lateral fluxes of mass and energy.)

### 2.3.9. Contributions to the WCRP Grand Challenges

#### 2.3.9.1. Provision of skillful future climate information on regional scales (includes decadal and polar predictability)

- GSWP3, ALMIP2
- Benchmarking (defining skillful), MDF (improved prediction and skill), and LAC (process-level improvement in land-atmosphere coupling)
- LUCID interactions with CORDEX have been proposed

#### 2.3.9.2. Regional Sea-Level Rise

- None

#### 2.3.9.3. Cryosphere response to climate change (including ice sheets, water resources, permafrost and carbon)

- Links to GABLS4 experiment and stable PBL coupling.
- ESMsnowMIP component of LS3MIP will address coupling between the atmosphere and the cryosphere (namely snow covered areas)
- Possible new project based on CCRN interactions

#### 2.3.9.4. Improved understanding of the interactions of clouds, aerosols, precipitation, and radiation and their contributions to climate sensitivity

- None direct, but L-A Coupling theme addressing the soil moisture-precipitation feedbacks.
- Improved aerosol emissions in regional to large scale models could possibly be assisted within the contact of GSW (better soils data and processes)

#### 2.3.9.5. Past and future changes in water availability

- GSWP3, GLACE (CMIP), and GPM/GRACE/SMOS/SMAP synergy
- LAC (process-level improvement in water and energy cycle feedbacks)
- Improved understanding of land-surface and hydrological processes in semi-arid zones where water resources are already limited (ALMIP2)
- The human imprint on the hydrological cycle within the new Anthropogenic Influences on the water cycle initiative (GHP+GLASS)

#### 2.3.9.6. Science underpinning the prediction and attribution of extreme events

- See above with respect to GEWEX Challenge #3 (strongest contribution from GLASS is here?)
- Benchmarking (model goodness during extreme conditions), MDF (data assimilation and model calibration during extremes), and LAC (improvements in coupling leading to improved predictability of extreme events from local to global scales)

### 2.3.10. Cooperation with Other Projects

2.3.10.1. A connection to CliC has been proposed through the GABLS Stable PBL Project over the arctic region (GABLS4). In addition, ESMSnowMIP (of LS3MIP) is a collaborative effort between CliC and GLASS. A suitable GLASS representative for both cold processes and stable PBLs has yet to be identified, however.

2.3.10.2. Better integration between GEWEX and iLEAPS is tentatively underway through collaboration on the GSWP3 project. There is a potential for further interactions within a new project based on the CCRN (as mentioned, still in the planning phase). Discussions on experiment design, protocols (such as variables of interest to study/report, appropriate units, etc.), and input data sets (time length covered) are underway. In addition, LUCID is an iLEAPS-GLASS supported project.

2.3.10.3. LS3MIP is addressing core research questions of the WCRP and is relevant for a large fraction of the WCRP activities. It is initiated by two out of four WCRP core projects (CliC and GEWEX) and directly related to three WCRP Grand Challenges (Cryosphere in a Changing Climate, Changes in Water Availability, and Climate Extremes).

2.3.10.4. The main objective of Subseasonal to Seasonal Prediction Project (S2S) (joint initiative of WWRP and WCRP) is to bridge the gap between medium-range weather forecasts and seasonal forecasts by improving forecast skill and understanding of the sub-seasonal to seasonal timescale, and to promote its uptake by operational centers and exploitation by the applications communities. P. Dirmeyer attends the S2S meetings on a regular basis (either in person or via telecon) on behalf of the GLASS panel. This action has been undertaken owing to the potential contribution of the land surface to predictability on the S2S timescales. P. Dirmeyer has noted that there are now 9 models in the ECMWF data server, so it is a good time for people to use these data and initiate studies if they are interested in multi-model analysis of operational models regarding land-atmosphere interactions and land surface model behavior.

2.3.10.5. Paul Dirmeyer is currently the co-chair of the WCRP/GEWEX-CLIVAR monsoon panel, in addition to being a GLASS panel member. The 2015 panel meeting was originally programmed for the GEWEX conference in Paris in November (which was canceled owing to the tragic events the week before). However, in the meantime an article appeared in CLIVAR Exchanges on the importance of land-atmosphere interactions within monsoons, by Y. Xue and P.A. Dirmeyer (see List of key publications, LAC (GCM/RA/CMIP Coupling Applications)). A. Turner (monsoon panel co-chair) and P. Dirmeyer are making tentative plans to have a workshop on monsoon land-atmosphere interactions, likely in 2017.

### 2.3.11. Workshops/Meetings Held

- Joint GLASS/GABLS - DICE Workshop, 20-22 May 2015, at Météo-France, Toulouse, France
- 2015 GLASS Panel Meeting, 18-19 May 2015, at Météo-France, Toulouse, France.
- LandMIP Meeting (LS3MIP/GSWP3/GLACE and LUMIP/LUCID), October 2015, Zürich, Switzerland.
- Alpine Summer School on Land-Atmosphere Interactions. 22 June–1 July 2015, Valsavarenche, Valle d'Aosta, Italy.

### 2.3.12. Workshops/Meetings Planned

- The GEWEX-SoilWat (GSW) initiative Workshop. Leipzig, Germany, June 28-30, 2016: hosted by UFZ
- GHP and GLASS are creating a crosscutting project focused on the inclusion of water management in large-scale models. Workshop to be held in late 2016 at the Ebro River Basin in Spain.
- 2016 GLASS Panel Meeting, co-hosted by GHP: Joint GLASS-GHP meeting, Gif sur Yvette, France, 3-5 OCT 2016.)
- Pan-GLASS Conference is proposed for (tentatively in autumn) 2016 to be combined with the next Pan-GASS meeting. Likely to be held/hosted in Europe.
- GSWP3 Workshop, Tokyo, Japan (tentatively).

### 2.3.13. Other Meetings Attended on Behalf of GEWEX or GLASS

- GEWEX Hydroclimatology Panel Meeting—Entebbe, Uganda, 16–19 November. (attended by C. Ferguson)

- WGNE (Mike Ek, Ex-Officio WGNE panel member as GLASS co-chair) provided a briefing on GLASS projects on model testing/evaluation and data assimilation of particular interest to the WGNE panel, i.e. land model benchmarking (PALS-PLUMBER), land-atmosphere interaction (DICE, with links to GASS), local coupled land-atmosphere modeling (LoCo), and land data assimilation (PILDAS).

### 2.3.14. Issues for the SSG

None.

### 2.3.15. List of Key Publications

**GEWEX**

Boone, A. and A. Beljaars, 2015. Summary of the ECMWF Annual Seminar. *GEWEX News*, 27(4), 19-20.

Ek, M. and A. Boone, 2015. GLASS Panel Meeting Summary, 18-19 May, Toulouse. *GEWEX News*, 25(3), 16-18.

Guillod, B., D. G. Miralles, A. J. Teuling and S. Seneviratne, 2015. Soil moisture-precipitation coupling: reconciling spatial and temporal perspectives. *GEWEX News*, 27(4), 13-16.

Harding, R., J. Polcher, A. Boone, M. Ek, H. Wheater, and A. Nazemi, 2015. Anthropogenic Influences on the Global Water Cycle - Challenges for the GEWEX Community. *GEWEX News*, 27(4), 6-8.

**LAC (SM-Precipitation Coupling)**

Guillod, B. et al., 2015. Reconciling spatial and temporal soil moisture effects on afternoon rainfall. Nat. Commun. 6:6443 doi: 10.1038/ncomms7443. (Pos/Neg SM-P Feedbacks)

Rieck M., C. Hohenegger, P. Gentine (2015).The effect of moist convection on thermally induced mesoscale circulations. *QJRMS.*

**LAC (Mesoscale Modeling)**

Santanello, J.A., S. Kumar, C. Peters-Lidard, and P. Lawston, 2015. Impact of Soil Moisture Assimilation on Land Surface Model Spinup and Coupled Land-Atmosphere Prediction. *J. Hydromet*. (Submitted April 2015).

Lawston, P., J. A. Santanello, and B. Zaitchik, 2014. Impact of Irrigation Methods on LSM Spin-up and Initialization of WRF Forecasts. *J. Hydromet*., (Accepted February 2015).

**LAC (GCM/RA/CMIP Coupling Applications)**

Dirmeyer, P. A., Z. Wang, M. J. Mbuh and H. E. Norton, 2014. Intensified land surface control on boundary layer growth in a changing climate. *Geophys. Res. Lett*., 41, 1290-1294, doi: 10.1002/2013GL058826.

Dirmeyer, P. A., G. Fang, Z. Wang, P. Yadav and A. Milton, 2014. Climate change and sectors of the surface water cycle In CMIP5 projections. *Hydrol. Earth Sys. Sci*., (submitted).

Dirmeyer, P.A., J. Wu, H. E. Norton, W. A. Dorigo, S. M. Quiring, T. W. Ford, J. A. Santanello Jr., M. G. Bosilovich, M. B. Ek, R. D. Koster, G. Balsamo, and D. M. Lawrence, 2016. Confronting weather and climate models with observational data from soil moisture networks over the United States. *J. Hydrometeor*., (in revision).

Couvreux F. et al., 2015. Representation of daytime moist convection over the semi-arid Tropics by parametrizations used in climate and meteorological models. *Q.J.R. Meteorol. Soc. (2015) DOI:10.1002/qj.2517.*

Santanello, J.A., J. Roundy, and P. Dirmeyer, 2015. Quantifying the Land-Atmosphere Coupling Behavior in Modern Reanalysis Products over the U.S. Southern Great Plains. *J. Climate*, 28, 5813-5829.

Xue Y. and P. A. Dirmeyer, 2015. Land-atmosphere interactions in monsoon regimes and future prospects for enhancing prediction. CLIVAR Exchanges newsletter - a special issue on the Monsoons. 19, 28-32.

**LAC-Land Cover Change (LUCID)**

Quesada B., N. Devaraju, N. de Noblet-Ducoudré, A. Arneth, 2016. Monsoon rainfall teleconnections in response to future land use and land cover changes. *PNAS submitted*

Quesada B., A. Arneth, N. de Noblet-Ducoudré, 2016. Biophysical effects on future land-use and land-cover changes: a global climate picture. To be submitted

Lejeune Q., E. Davin, S. Seneviratne, 2016. Comparative assessment of mid-latitude land-cover change effects on temperature in historical LUCID and CMIP5 simulations. To be submitted

Sy S., N. de Noblet-Ducoudré, J.-P. Boisier, B. Sultan, O. Ndiaye, A. Th. Gaye, to be submitted: 'Role of historical anthropogenically-induced land-cover change on the surface climate of West Africa: *Results from the LUCID Intercomparison Project*'

Hirsch, A.L., A.J. Pitman, J. Kala, R. Lorenz and M. Donat, 2015. Modulation of land use change impacts on temperature extremes via land-atmosphere coupling over Australia. *Earth Interactions*, 19, 1-24, doi: 10.1175/EI-D-15-0011.1

Lorenz, R., A.J. Pitman, A.L. Hirsch and J. Srbinovsky, 2015. Intraseasonal versus interannual measures of land-atmosphere coupling strength in a global climate model: GLACE-1 versus GLACE-CMIP5 experiments in ACCESS1.3b, *J. Hydrometeorology*, 16, 2276-2295.

Lorenz, R. and A.J. Pitman, 2014. Effects of land-atmosphere coupling strength on impacts from land cover change experiments in Amazonia. *Geophysical Research Letters*, 41, 5987–5995, doi: 10.1002/2014GL061017.

Hirsch, A.L., A.J. Pitman and *J. Kala*, 2014. The role of land cover change in modulating the soil moisture-temperature land-atmosphere coupling strength over Australia. *Geophysical Research Letters*, 41, 10.1002/2014GL061179.

**Benchmarking**

Best, M.J., G. Abramowitz, H. Johnson, A.J. Pitman, A. Boone, M. Cuntz, B. Decharme, P.A. Dirmeyer, J. Dong, M. Ek, V. Haverd, B.J.J.M van den Hurk, G.S. Nearing, B. Pak, C. Peters-Lidard, J.A. Santanello Jr., L. Stevens, N. Vuichard, 2015. The plumbing of land surface models. *J. Hydrometeor.*, 16, 1425-1442. doi: http://dx.doi.org/10.1175/JHM-D-14-0158.1

Haughton, N., G. Abramowitz, A. J. Pitman, D. Or, M. J. Best, H. R. Johnson, G. Balsamo, A. Boone, M. Cuntz, B. Decharme, P. A. Dirmeyer, J. Dong, M. Ek, Z. Guo, V. Haverd, B. J. van den Hurk, G. S. Nearing, B. Pak, C. Peters-Lidard, J. A. Santanello Jr., L. Stevens, and N. Vuichard, 2016. The plumbing of land surface models: why are models performing so poorly? *J. Hydrometeor.* (submitted).

### 2.3.16. List of Members and Term Dates

The GLASS Terms of Reference have been presented at the panel meetings in 2011 and 2012, and were ratified by the GEWEX SSG. These TORs include term limits on chairs of 4 years, staggered in 2-year intervals for continuity of leadership. Two main categories of panel members have been established and without term limits: Experienced Scientists (including project leads) and Young Scientists, as well as a protocol for new members of each category that they attend the next panel meeting and establish their interest and relevance to the panel activities. Template letters signed by GEWEX/Sonia Seveviratne and Graeme Stephens have also been developed to welcome new panel members and to thank departing members for their service.

*Co-chairs:*
Aaron Boone (CNRM/Météo-France) (2013– 2016)
Michael Ek (NOAA/NCEP) (2015–2018)

*Members:*
Joe Santanello (NASA/GSFC)
Hyungjun Kim (Univ. Tokyo)
Rolf Reichle (NASA/GSFC)
Martin Best (UKMO)
Paul Dirmeyer (George Mason Univ.)
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Patricia de Rosnay (ECMWF)
Sonia Seneviratne (ETH)
Gab Abramowitz (UNSW)
Craig Ferguson (SUNY, Albany)
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Annexes: 1. List of Participants
2. Agenda
3. Report of the GEWEX Data and Assessments Panel

# Annex 1: List of Participants

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# Annex 2: Agenda

### Monday, 25 January 2016

| | | | |
|---|---|---|---|
| 8:30 | 8:50 | Registration | |
| 9:00 | 9:10 | Opening and Welcome | S. Seneviratne, G. Stephens, P. van Oevelen |
| 9:10 | 9:20 | Logistics | S. Seneviratne, P. van Oevelen |
| 9:20 | 10:30 | Chairs Report | S. Seneviratne, G. Stephens |
| 10:30 | 11:00 | Break | |
| 11:00 | 12:30 | WCRP and JSC, Outreach/CB | G. Brasseur, D. Carlson, B. Lee |
| 12:30 | 14:00 | Lunch | |
| 14:00 | 14:25 | CLIVAR | D. Stammer |
| 14:25 | 14:50 | WMO-CCI, CHy and GFCS | R.K. Kolli |
| 14:50 | 15:15 | ESA | M. Rast |
| 15:15 | 15:40 | iLEAPS | H.C. Hansson |
| 15:40 | 16:15 | Break | |
| 16:15 | 16:40 | WWRP | S. Jones |
| 16:40 | 17:15 | JSC Action Items | G. Stephens, S. Seneviratne, P. van Oevelen |
| 17:30 | | Adjourn | |
| | | | |
| **18:30** | **21:00** | **Reception** | |

### Tuesday, 26 January 2016

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|---|---|---|---|
| 8:30 | 10:00 | GHP Panel - Science | J. Polcher/J. Evans |
| 10:00 | 10:30 | Break | |
| 10:30 | 12:00 | GLASS Panel – Science | A. Boone |
| 12:00 | 12:25 | CliC | G. Krinner, L. Hislop (TBC) |
| 12:25 | 12:40 | New Member Presentation | N. De Noblet |
| 12:40 | 13:50 | Lunch | |
| 13:50 | 15:20 | GDAP Panel - Science | J. Schulz/M. McCabe |
| 15:20 | 15:50 | Break | |
| 15:50 | 16:15 | WGNE | A. Zadra (TBC WEBEX) |
| 16:15 | 16:35 | NASA | J. Entin (TBC WEBEX) |
| 16:35 | 16:55 | LandMIP Workshop | S. Seneviratne |
| 16:55 | 17:30 | UNESCO | A. Mishra |
| 17:30 | | Adjourn | |

**Wednesday, 27 January 2016**

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|---|---|---|---|
| 8:30 | 9:00 | Extremes Grand Challenge | S. Seneviratne, L. Alexander |
| 9:00 | 9:15 | ETCCDI | L. Alexander |
| 9:15 | 10:00 | Water Grand Challenge | G. Stephens, P. van Oevelen |
| 10:00 | 10:30 | Discussion WCRP GCs | G. Stephens, S. Seneviratne |
| 10:30 | 11:00 | Break | |
| 11:00 | 11:45 | GEWEX PROES | G. Stephens |
| 11:45 | 12:30 | GEWEX Soil and Water | D. Or, P. van Oevelen |
| 12:30 | 14:00 | Lunch | |
| 14:00 | 14:30 | GDAP Panel – Action Items/GCs | J. Schulz, M. McCabe |
| 14:30 | 15:00 | GHP Panel – Action Items/GCs | J. Polcher, J. Evans |
| 15:00 | 15:30 | GLASS Panel – Action Items/GCs | A. Boone |
| 15:40 | 16:10 | Break | |
| 16:10 | 16:30 | SPARC | F. Tummon |
| 16:30 | 17:15 | Other WCRP Activities (WDAC/WMAC/Regional/Monsoon) | D. Carlson, B. Lee, others (TBC) |
| 17:15 | | Adjourn | |

**Thursday, 28 January 2016**

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|---|---|---|---|
| 8:30 | 9:00 | Rapporteur Report GHP | P. Webster, X. Li |
| 9:00 | 9:30 | Rapporteur Report GDAP | L. Alexander, R. Uijlenhoet, M. Zhang |
| 9:30 | 10:00 | Rapporteur Report GLASS | R. Anyah, N. de Noblet |
| 10:00 | 10:30 | GASS Report and Discussion | G. Stephens, P. van Oevelen, B. Holtslag (TBC) |
| 10:30 | 11:00 | Break | |
| 11:00 | 11:45 | IGPO Report and SSG-27 | P. van Oevelen |
| 11:45 | 12:30 | GEWEX Regional Activities – Africa/Latin America/US | R. Anyah, P. van Oevelen, G. Stephens |
| 12:30 | 14:00 | Lunch | |
| 14:00 | 14:30 | ETH Presentation | P. Greve |
| 14:30 | 15:00 | GEWEX Regional Activities – Asia Discussion | P. Webster, B. Lee, G. Stephens |
| 15:00 | 15:30 | Meetings, Travel Support, ECS | P. van Oevelen |
| 15:30 | 16:00 | Break | |
| 16:00 | 16:30 | Draft Actions and Recommendations SSG-28 | P. van Oevelen |
| 16:30 | 17:00 | Next Meeting, AOB | P. van Oevelen, S. Seneviratne, G. Stephens |
| 17:00 | | Adjourn | |

# Annex 3: Report of the GEWEX Data and Assessments Panel

## Data Set Quality Assessments: Needs, Benefits, Best Practices and Governance

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Peter Gleckler, Lawrence Livermore National Laboratory
and many WCRP contributors hereby deeply acknowledged

## 1. Introduction

This document addresses the need for systematic assessments of the quality of data sets used in various applications such as climate services as well as climate science, including their use in the evaluation of climate model performance. The purpose of this document is to initiate a discussion within WCRP as to how the core projects, working groups and WCRP Grand Challenges can initiate data set quality assessments in a more coherent way, ensuring that the outcomes of assessments are beneficial for their own activities and also for activities across WCRP.

The scope of this discussion paper is limited to a description of the general benefits, high level practices, and potential governance structures for data set quality assessments. Detailed best practices are not included as part of this document because they depend too much on the actual physical system and data sets that are being assessed. The document is entirely based on experience garnered from conducting data set quality assessments for more than two decades within several WCRP core projects.

The document provides a brief description of the background from which the need arises and a short, but not exhaustive history of data set assessments as they were performed in GEWEX, CLIVAR, SPARC and elsewhere. It then lists the currently known types of assessments and the benefits that were drawn from them. The last set of sections proposes high-level best practices and addresses funding needs and governance issues.

## 2. Background

Climate variability and long-term changes in climate pose significant challenges to societies. The availability and communication of climate information through climate services significantly supports prevention of economic setbacks and humanitarian disasters. In addition, climate services play a critical role in national development planning, managing development opportunities and risks, and in mitigating and/or adapting to changes in climate. To provide authoritative information to all of these areas it is necessary to develop the best possible understanding of the quality of climate observations and derived products. Formalized, impartial, data set quality assessments are one way to analyze the fitness-for-purpose of climate data sets and can play a crucial role in the acceptance process of climate data products for climate services.

Comprehensive assessments of the physical science basis of climate change conducted by the

Intergovernmental Panel on Climate Change (IPCC) refers to detailed scientific assessments of observations of various aspects of the climate system, with dedicated consideration of specific areas such sea level change, biogeochemical cycles, clouds and aerosols, and regional climate phenomena. Measurements are used to assess the status of the climate and to evaluate climate model simulations for the past to build confidence in model projections for the future. The use of measurements throughout the IPCC report is based on peer-reviewed publications about the individual climate data records (CDRs) and sometimes on comparison of CDRs. The IPCC Working Group I report (IPCC, 2013), in particular chapter 2, provides comparison of a limited number of data records whereby the selection of particular CDRs depends on the expert knowledge of the authors. Only in one case does the IPCC refer to a publication related to a WCRP GEWEX assessment, which is the cloud data set assessment (Stubenrauch et al., 2013). IPCC assessments reveal important geographical and temporal gaps in observations, understanding of system processes, and confidence in observations and projections themselves. However, IPCC assessments could, and should, make much more extensive use of community-wide assessments of the quality of existing CDRs, which could be provided under the leadership of WCRP, in particular the WCRP Data Advisory Council (WDAC).

A specific activity to facilitate the comparison of satellite observations with climate model data is the Observations for Model Intercomparisons (Obs4MIPS) initiative that makes observational data products more accessible for comparisons (Teixera et al., 2014). Obs4MIPS has organized a collection of well-established and documented data sets that have been organized according to the 5th Coupled Model Intercomparison Project (CMIP5) model output requirements and made available through the Earth System Grid Federation (ESGF). The technical alignment of data sets and model output fields is a key element that facilitates the comparison of model data and observations. In addition, Obs4MIPS has created a standardized documentation that is of particular relevance for model evaluation.

The Obs4MIPS activity was initiated by NASA but there are opportunities for contributions from a broader community. The broadening of the community is organized under the umbrella of WDAC by the establishment of a specific Obs4MIPS task team. Ferraro et al. (2015) have summarized the status of the evolution of Obs4MIPs in support of CMIP6. One particular challenge that arises from extending this activity is the management of many more data sets, including multiple data sets for the same model output field and their quality assurance. This calls for a process that allows the provision of information about the quality of data sets included in the Obs4MIPS portfolio. Data set quality assessments, if performed efficiently, could be an attractive activity that provides this information in a systematic way for the full Earth system. Thus, it is important to consolidate standards and high-level practices across WCRP for CDR assessments.

Alongside WCRP activities, space agencies have started a collaborative effort to formulate a so-called architecture for climate monitoring from space (Dowell et al., 2013). This should facilitate the development of an end-to-end system capable of delivering the necessary space-based observations for climate monitoring from space. One of the initial steps was to establish an inventory of CDRs of Essential Climate Variables (ECVs) as defined by the Global Climate Observing System (GCOS). Such an inventory can be used to analyze gaps in this value chain, starting from satellite measurements and ranging to the information provided to decision/policy makers as outlined in the architecture (Dowell et al., 2012). This includes the production and evaluation of CDRs, which require a careful assessment of the scientific quality so as not to provide wrong or misleading information downstream. The joint CEOS-CGMS Working Group Climate has started to consider how such quality assessments may be conducted and who could contribute to them. It is obvious that a multitude of differently organized research

structures may be able contribute but leadership of WCRP through WDAC may be envisaged for this undertaking.

Comprehensive data set quality assessments are critical to move science forward in a systematic way. Trenberth et al. (2014) stated that: "*Originally the task was getting a single time series of an ECV. Now there is a proliferation of multiple datasets purporting to be "the correct one". Many are created for specific purposes but all differ, often substantially, and the strengths and weaknesses or assumptions may not be well understood or well stated. Consequently, assessments are required to evaluate these aspects and to help improve the datasets.*"

In a cycle of quality assessment and reprocessing of data sets, the analysis of data products in direct comparison to reference data, with respect to their consistency with other data sets, e.g., in representing a part of the energy or water cycle, and/or in comparison with model output data always reveals differences that point to particular weaknesses in certain data sets. More importantly, this can also point to limitations in our capability to perform measurements with the required accuracy and/or sampling. In addition, assessments reveal limitations in our understanding of the measurement process in general, that is, the assignment of traceable uncertainties and our understanding of physical processes that are essential to convert measurements into derived data products. This is particularly true for satellite data sets.

Assessment activities often bring together a critical mass of research groups that analyze deficits and work on improvements of methodology to analyze measurements and the improvement of these measurements, e.g., by defining new satellite missions that address specific deficits in our knowledge.

The following outline for data quality assessments is based partly on experiences gained from the GEWEX Data and Assessments Panel (GDAP; formerly the GEWEX Radiation Panel), described in Kummerow et al. (2012), and from similar SPARC and CLIVAR activities.

## 3. History of Quality Assessments

GEWEX promotes the assessment of existing data products to adequately characterize each product and its strengths and limitations for various uses. GDAP conducted several data assessments that were related to the establishment of an observations-based estimate of the energy and water cycle over the last decade.

Three quality assessments were finalized: precipitation (Gruber and Levizzani, 2008), radiation fluxes (Raschke et al., 2012), and cloud properties (Stubenrauch et al., 2012, Stubenrauch et al., 2013). Several others are ongoing: aerosol properties, turbulent fluxes over the oceans (SEAFLUX) and land surfaces (LANDFLUX), as well as water vapor. The motivation for these assessments has developed from studying the limits of applicability of a GEWEX data record (precipitation) to real multi-data record comparison exercises (e.g. on radiation, clouds, water vapor, and heat fluxes). All quality assessments were done to determine which data product is best suited to a particular purpose or how a data product could be developed to become applicable in energy and water cycle studies at different space and time scales. Most of the GEWEX assessments concentrate on satellite-derived data records with the exception of the precipitation assessments that also consider rain gauge data because they are used to calibrate satellite precipitation data records.

Prior to the GEWEX activities, an assessment was performed by SPARC, focusing on upper troposphere/lower stratosphere (UTLS) water vapor (Kley et al., 2000) with the goal of analyzing and assessing long-term changes in UTLS water vapor, with an emphasis on the observed increase of water in the stratosphere. SPARC is currently working on an update of this assessment using the improved knowledge and observations from the past 10 years.

The assessment activities of GEWEX and SPARC cover only a small fraction of CDRs needed to fully characterize changes in the Earth system but may function as a nucleus for more extensive systematic assessment activities in other domains. In addition to GEWEX and SPARC, assessment activities have also started in other areas, in particular the oceanic research community. For instance, the International Ocean Color Coordination Group (IOCCG) sponsored by the Scientific Committee on Oceanic Research (SCOR) and the Global High Resolution Sea Surface Temperature (GHRSST) Climate Data Record Technical Advisory Group, with their associated CEOS so called virtual constellations on Ocean Color Radiometry and Sea Surface Temperature, have started to develop coordination structures in which data record assessments can be performed.

The Climate and Ocean: Variability, Predictability and Change (CLIVAR), in particular through the Global Synthesis and Observations Panel (GSOP), has long been promoting and coordinating assessments of various data sets including:

- In situ data sets of sub-surface ocean temperature through the efforts of the International Quality Controlled Ocean Database (IQuOD) [www.iquod.org]. New data sets of sub-surface salinity and oxygen are foreseen
- Satellite products used for climate studies, such as ocean surface wind, air-sea fluxes (Josey, 2006, Yu et al., 2012, www.oceanheatflux.org)
- Ocean synthesis products, including inter-comparison efforts through the Ocean Reanalysis Intercomparison project (ORA-IP) Joint intercomparison of ocean synthesis & forward model simulation and the EU COST project Evaluating Ocean Syntheses [www.eos-cost.eu].

Members of the CLIVAR community have been actively involved in quality and consistency assessments of ocean vector wind measurements as coordinated by the International Ocean Vector Wind Science Team for ocean surface wind stress measurements from different satellite platforms (Ku-, C-, and L-band scatterometers), and in assessments of satellite measurements of sea surface salinity by the salinity remote sensing community (SMOS, Aquarius, SMAP).

CLIVAR has routinely used these data sets to advance our understanding of the ocean-atmosphere interactions and in particular the role of the ocean. More recently, CLIVAR has established a new research focus on “Consistency between planetary energy balance and ocean heat storage (CONCEPT-HEAT)” aiming to better close the Earth’s energy budget. In particular, the CONCEPT-HEAT initiative aims to reconcile different and independent estimates of energy flows derived from independent observing systems, including Argo buoys, in-situ networks, models and satellites, with different sampling capability and accuracy. This innovative initiative will provide new insight into diverse independent data sets related to energy flows, thereby providing scientists with a unique holistic insight.

Discussions among representatives from different communities facilitated by the CEOS-CGMS Working Group Climate revealed many commonalities in current activities, e.g., emerging similar practices of providing estimates of uncertainty, but also important differences, in particular in the specific aims of assessment activities.

## 4. Assessment Types and Potential Benefits

Data record diversity can be confusing for users and without the proper background information and understanding of the limitations of available data there is a danger that these data may be incorrectly used or misinterpreted. On the other hand, users need to realize that it is often difficult to define a single best CDR. CDRs are instead most often complementary in nature with varying strengths and weaknesses depending on the nature of the application and depending on the observing system used to construct the CDR. For instance, the retrieval of basic cloud properties depends on the sensor channel wavelengths as demonstrated in the cloud assessment of Stubenrauch et al., 2013.

The primary goal of a quality assessment is to highlight differences and limitations of CDRs and, if possible, to justify all aspects of the assessment. Such assessments should become part of the peer-reviewed literature (open access journals preferably) and be distributed as widely as possible, e.g., in ECV inventories, commentary meta-data tools, web portals, etc.

Panels such as GDAP currently consider two types of assessments that are valuable to user communities:

1. Development of review articles on CDRs considering specific science aspects extending from process understanding to trend analysis, specific geophysical variables (e.g., GCOS ECVs), or topics of importance for IPCC climate assessments. Such review articles could be written by a group of selected experts and reviewed by the panel members not involved in writing the article and journal reviewers. The results can be of immediate use, for instance to IPCC report authors. This also avoids the restrictive approaches on data selection for IPCC reports and provides balanced and peer-reviewed judgment of existing knowledge
2. Dedicated CDR quality assessment projects that perform a scientific analysis of existing CDRs and publish the results in peer-reviewed literature.

Type 1 assessments may follow cycles of IPCC assessments and can also point to the need for a type 2 assessment, e.g., if the available information for a review article is insufficient and/or incomplete.
Type 2 assessments should not be viewed as static but rather as dynamic activities that are ongoing and provide outputs at regular intervals, e.g., every 2 years. The reporting should contain updates resulting from updated and/or new CDRs, as well as consideration of specific topics, e.g., precipitation in mountainous regions that is hard to observe.

CDR quality assessments are beneficial to science, applications, as well as CDR providers. For the science and user communities, assessments:

- Provide independent and transparent quality assurance of CDRs;
- Endorse the use and credibility of CDRs for a broader community;
- Identify key limitations in CDRs to stimulate improvements; and
- Allow objective selections of appropriate CDRs.

For the data record providers, the assessments:

- Provide background information on available CDRs;
- Provide easy access to data in a common user-friendly format; and
- Establish reference data test-beds and tools for external evaluations that can be reused.

In addition, as many CDRs source data from multiple satellite programs, the data quality assessments also contribute to an assessment of the strengths and weaknesses of the current observing system. This provides useful guidance on development needs of the future observing system, which is, for example, part of the CEOS-CGMS WG Climate tasks.

## 5. High Level Best Practices

Generalization of assessment best practices is sometimes impractical and may not be useful. However, converging on common practices in some areas can ensure a similar level of evaluation of the quality of CDRs. These records may cover various aspects of the Earth climate system and may include many types of measurements (ground-based, satellite-based, in-situ and derived products that may combine measurements from multiple sources) as well as data from reanalyses. To make assessments comparable it is important to agree on some high level principles:

1. While assessments should include the creators of the CDRs being assessed, the assessment team needs to extend well beyond that group so as to avoid data products being evaluated favorably by the developers to encourage data use.
2. Assessments need to target well-developed expectations of CDRs such as those documented in GCOS-143 or those encapsulated in the GCOS Climate Monitoring Principles. By ensuring that each assessment targets these key requirements on CDRs, each assessment will have a similar structure and the user community will develop clear expectations of what assessments will encompass. However, the structure should not be so restrictive as to prevent the publication of results unique to the assessment. Every assessment must, at the very least, document the scientific utility of the CDR being assessed as well as the characterization of uncertainties in the CDR.
3. A lexicon of best practices to create CDRs also including practices on data comparisons and nomenclature used for characterizing uncertainties
4. Metrics to assess how far best practices have been followed.

These four principles should be adhered to any group performing an assessment.

1. Under general procedures, it is understood that each assessment should be hosted by a scientific body to whom the group performing the assessment reports, and who would be responsible for the assessment report. As mentioned above, the assessment is tasked to conduct objective and independent evaluations and inter-comparisons. It is advantageous to involve the scientists that created the CDRs so that sufficient background information on the instruments providing the measurements, applied methods, and underlying assumptions and limitations can be captured in detail and conveyed to the user. However, to ensure independence, independent experts need to be included in the assessment team to prevent biases in the reporting of results for specific CDRs, e.g., by selection of a particular comparison metric, reference data, or physical range of parameters. Although this is not easy, various groups have achieved such level of independence through various processes, such as reporting to a governing panel/project or via external review.

Another aspect of involving product developers in an assessment is the tendency to broaden

the goal of the assessment from its original intent of informing the user community, to one of using the assessment itself as a diagnostic to help investigators improve their respective data products. Although this is a clear benefit for the data producers and may ensure their participation, it has been found that while these two objectives are compatible, they should always be kept distinct in the assessment so as to keep the assessment manageable. Thus, in general, a data quality assessment should concentrate on providing information to the science and user community first, and then move to updates of the various data sets considered outside of the assessment.

2. As a general structure, an assessment of climate data records should always cover the following elements:

- A survey of available CDRs with their related background information;
- A quantitative intercomparison against reference data (especially if data of higher accuracy and/or maturity are available), if available, to elucidate the strengths and weaknesses of the CDRs being assessed;
- Comparisons of different CDRs at different temporal and spatial scales. GDAP has found that including model and reanalyses data sets in the comparisons is often useful in that it immediately incorporates the needs of an eventual user community;
- Recommendations for intended CDR uses and identification of areas for which data should not be applied;
- Open, full, and easy access to the assessment report and all examined CDRs1 and methods.

Some data will not be hosted in one place because of high data volumes. Thus, easy access is fulfilled if the data are readily accessible via Internet without needing special permission.
With regard to the last item, it has been found that even if the validation data, procedures, and previously assessed data are archived for interim use, comprehensive assessments are critical to move the field forward in a systematic way.

Furthermore assessments should include:

- A dedicated, motivated, and respected expert or group of experts to lead the effort;
- Assessment team members with individual, but complementary, specialized knowledge;
- Regular team meetings – open and closed workshops;
- A centralized data repository created specifically for the assessment (e.g., validation data or common gridded products) that can be used to facilitate assessments with new products or new versions of existing products.

3. A charter of best practices to ensure coherent use of nomenclature should be developed and hosted by a sub-group of WDAC. Such a lexicon would need to be coordinated with other bodies such as GCOS and the CEOS-CGMS Working Group Climate. Such a development could benefit from on-going initiatives such as QA4EO and related projects such as the European QA4ECV project.

4. A procedure to assess the extent to which best practices have been followed in generating the CDRs is useful in the survey of available CDRs and also helps to keep the assessment activity manageable by concentrating on CDRs of a certain maturity. Progress on such metrics, for example based on the work published by Bates and Privette (2012), has been made in projects such as the European Union project CORE-CLIMAX (CORE-CLIMAX, 2015).

In addition to the described best practices, each assessment needs to have a strategy for the dissemination of its results and how to make an impact on the scientific community. The

classical way of peer-reviewed publications and a WCRP report remains important because it ensures a proper review. However, the WCRP core project web appearance should put stronger emphasis on assessment activities and results. Data catalogues from data providers could be enhanced with tools providing commentary meta-data for a data set, e.g., those developed in the EU CHARMe project. These can point to assessment results and also databases used in the assessment. In addition, the Obs4MIPS platform can also serve as a good means to disseminate the results, at least for those data sets of potential use in climate model evaluation. Finally, other suitable online platforms such as the NCAR Climate Data Guide can be used for better dissemination to the community.

## 6. Needs for Funding

Past and current assessment activities usually relied on pure voluntary efforts, and thus can take considerable time to finish and can even collapse without strong leadership. Within GDAP several assessments took a very long time (>10 years), a timespan far too long to address the needs of such assessments. Full funding of assessment activities is out of the scope of most funding agencies, however, ideally some seed funding for centralized activities, e.g., on a centralized data depot and initial workshops should be provided to establish the assessment. A good recent example is the setup of the GEWEX water vapor assessment, for which ESA sponsored an initial workshop and EUMETSAT is funding central activities for about two years through its Climate Monitoring Satellite Application Facility (CM SAF). This allows the assessment to advance and keeps the participants together and active.

It is recognized that funding practices strongly differ across the globe but the membership of WDAC, including the CEOS-CGMS WG Climate (representing space agencies), can certainly help to improve the situation if convincing cases for assessments are brought forward. Such cases could be taken up by existing national and international programs, such as the NOAA Climate Data Record Program, NASA Measures, ESA Climate Change Initiative, EUMETSAT SAFs, and other initiatives.

## 7. Governance Practices

A couple of relevant questions related to the governance of assessments are:

- Who should initiate an assessment?
- Who should organize it?
- Who should undertake the assessment?
- Who should evaluate quality assessments?

Currently, there is no overall coordination of data record quality assessments related to GCOS ECVs; energy, water, and matter cycles; or other topics of importance to the IPCC. Assessments are often initiated and performed by specific scientific or other organizational bodies that represent both users and developers. The aims of these assessments range from providing objective information to the scientific community about the status of data records to more ambitious goals such as making trend estimates and using the data record comparison as a means to find or create the best data record for a specific purpose. Data record assessments are much more common in communities and bodies that work with satellite data compared to those related to in situ data records.

It is suggested to initiate data record quality assessments by any scientific or organizational

body that identifies a need for such an assessment. However, the assessment then needs a ‘harbor in which to anchor', to ensure support and an independent review.

Within WCRP the Core Projects may task relevant panels or groups of experts to act as initiator, organizer, and reviewer of data record quality assessments following the model set out here For assessments requested from outside, e.g. from the CEOS-CGMS Working Group Climate, WCRP should play a critical role in performing them; WDAC could become the known receiver of such requests and can help to channel it within WCRP. WDAC could also play an important role for developing a prioritization of assessment needs to guide funding agencies in their support of assessments.

The organization of an assessment is best placed at the level of panels or activities within WCRP core projects, because this is the place where scientific knowledge is concentrated and lead scientists for assessments can most easily be identified.

Scientific groups undertaking assessments should be formed in an open way to assure broad participation, however, attention should be paid to the selection of data records so as not to end up with only once-off activities that are of limited value to users. The scientists leading the assessment need to report to the group overseeing the particular activity/panel at regular intervals, e.g., annually. This group, for example a core project's Scientific Steering Group (SSG) would then report to the WCRP Joint Steering Committee (JSC).

Organization of assessments will not be restricted to WCRP since other domain/topic-specific bodies (e.g., CGMS working groups as ITWG, IPWG, CEOS Virtual Constellations) exist that may organize their own assessments.

The role of WDAC should be to oversee assessments performed within and outside of WCRP, in particular pointing out where assessments potentially lack in critical areas for science, the IPCC, and climate services. The WDAC membership is ideally positioned to do this in coordination with GCOS and the space sector. WDAC could establish an inventory of assessments that could be provided to various bodies such as the WCRP JSC.

By identifying area where assessments are lacking, WDAC can also act as the initiator of data quality assessments, which may, at a later stage, be performed by WCRP core projects. WDAC should also be active in supporting the funding of data quality assessments since this is vital to ensure the success of these assessments. In addition, WDAC could organize the collection and publication of best practices for climate data record generation.

## 8. Governance

This Annex provides an outline for data quality assessments explaining the needs, benefits, high level best practices, and a potential light governance structure. It is mostly based on experiences from the GEWEX Data and Assessments Panel, but also refers to more recent discussions among space agencies on the architecture for climate monitoring from space where quality assurance is a very important topic.

WDAC is invited to take note, discuss, provide feedback, and lay out a way forward.

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# Annex 4: Acronyms and Other Abbreviations

| | |
|---|---|
| AGU | American Geophysical Union |
| ALMIP2 | Land Surface Model Intercomparison Project (CMIP) |
| AMMA | Multidisciplinary Analysis of the African Monsoon |
| ARM | Atmospheric Radiation Measurement (U.S. Department of Energy) |
| ARMBE | ARM Best Estimate |
| AWI | Alfred Wegener Institute |
| BSRN | Baseline Surface Radiation Network |
| CAUSES | Clouds Above the United States and Errors at the Surface |
| CCI SM | Climate Change Initiative-Soil Moisture (ESA) |
| CCMP | Cross-Calibrated Multi-Platform |
| CCRN | Changing Cold Regions Network |
| CDR | Climate Data Record |
| CEH-GEAR | Centre for Ecology and Hydrology Gridded Estimates of Areal Rainfall |
| CEOS | Committee on Earth Observation Satellites |
| CERES | Clouds and the Earth's Radiant Energy System |
| CFMIP | Cloud Feedback Model Intercomparison Project |
| CGMS | Coordination Group for Meteorological Satellites |
| CLASS | Canadian Land Surface Scheme |
| CLiC | Climate and Cryosphere Project |
| CLIVAR | Climate and Ocean – Variability, Predictability, and Change (WCRP Core-Project) |
| CMAP | CPC Merged Analysis of Precipitation (NOAA) |
| CMIP | Coupled Model Intercomparison Project (WCRP) |
| CMORPH | CPC MORPHing technique (NOAA) |
| CONVEX | Research Project on Observational Evidence and Process Understanding to Improve Predictions of Extreme Rainfall Change |
| CORDEX | Coordinated Regional Climate Downscaling Experiment (WCRP) |
| CPC | Climate Prediction Center (NOAA) |
| DIAL | Differential Absorption Lidar |
| DICE | Diurnal Land/Atmosphere Coupling Experiment |
| DOE | Department of Energy |
| DOIs | Digital Object Identifiers |
| DWD | German Weather Service |
| ECMWF | European Centre for Medium-range Weather Forecasts |
| ECVs | Essential Climate Variables |
| EEI | Earth's energy imbalance |
| EGU | European Geophysical Union |
| ESA | European Space Agency |
| ESGF | Earth System Grid Federation |
| ESMs | Earth science models |
| ET | Evapotranspiration |
| ETH | Swiss Federal Institute of Technology in Zürich |
| EUMETSAT | European Organization for the Exploitation of Meteorological Satellites |

| | |
|---|---|
| EXP1 | Long-term retrospective experiment |
| FE | Future Earth |
| FIDUCEO | Fidelity and uncertainty in climate data records from Earth Observations |
| FMI | Finnish Meteorological Institute |
| FOCI | Frontiers of Climate Information (WCRP) |
| FPS | Flagship Pilot Study (FPS) |
| GABLS | GEWEX Atmospheric Boundary Layer Study |
| GAIA-CLIM | Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring |
| GC | Grand Challenge (WCRP) |
| GCOS | Global Climate Observing System |
| GDAP | GEWEX Data and Assessment Panel |
| GDIS | Global Drought Information System |
| GEO | Group of Earth Observation |
| GERICS | Climate Service Center Germany |
| GEWEX | Global Energy and Water Cycle Exchanges (WCRP Core-Project) |
| GFCS | Global Framework for Climate Services |
| GHP | GEWEX Hydroclimatology Panel |
| GHRSST | Global High Resolution Sea Surface Temperature |
| GNSS | Global Navigation Satellite Systems |
| GLACE | The Global Land–Atmosphere Coupling Experiment |
| GLASS | Global Land/Atmosphere System Study |
| GPCC | Global Precipitation Climatology Centre |
| GPCP | Global Precipitation Climatology Project |
| GPM | Global Precipitation Mission |
| GRACE | Gravity Recovery and Climate Experiment |
| GSFC | Goddard Space Flight Center (NASA) |
| GSMaP | Global Satellite Mapping of Precipitation (JMA) |
| GSOP | CLIVAR Global Synthesis and Observations Panel |
| GSQs | GEWEX Science Questions |
| GSW | GEWEX Soils and Water |
| GSWP3 | Global Soil Wetness Project 3 |
| G-VAP | GEWEX Water Vapour Assessment |
| HEPEX | Hydrologic Ensemble Prediction EXperiment |
| HIRS | High Resolution Infra Red Radiation Sounder |
| HOAPS | Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data |
| HyMeX | Hydrological Cycle in the Mediterranean Experiment |
| HyVic | Hydrology of Lake Victoria Basin |
| IASOA | International Arctic Systems for Observing the Atmosphere |
| ICDR | GPCP Monthly Interim Climate Data Record |
| ICSU | International Council for Science |
| IDF | Intensity-Duration-Frequency |
| IGBP | International Geosphere Biosphere Programme |
| IGPO | International GEWEX Project Office |
| IGWCO | Integrated Global Water Cycle Observations |
| iLAMB | International Land Model Benchmarking |
| iLEAPS | integrated Land Ecosystem-Atmosphere Processes Study |
| INARCH | Alpine Research Catchment Hydrology |

| | |
|---|---|
| INTENSE | INTElligent use of climate models for adaptatioN to non-Stationary hydrological Extremes |
| IOC | Intergovernmental Oceanographic Commission (of UNESCO) |
| IOCCG | International Ocean Color Coordination Group |
| IPCC | Intergovernmental Panel on Climate Change (WMO, UNEP) |
| IQuOD | International Quality Controlled Ocean Database |
| IR | Raman lidar and infrared |
| ISCCP | International Satellite Cloud Climatology Project |
| ISI-MIP | Intersectoral Impact Model Intercomparison Project (CMIP) |
| ISMN | International Soil Moisture Network |
| ISSI | International Space Science Institute |
| IUGG | International Union of Geodesy and Geophysics |
| JMA | Japanese Meteorological Association |
| JSC | Joint Scientific Committee (WCRP) |
| KMI | Belgium Meteorological Institute |
| KNMI | Royal Netherlands Meteorological Institute |
| LAC | Land-Atmosphere Coupling |
| LAFE | Land-Atmosphere Feedback Experiment |
| LAI | Leaf Area Index |
| LE | Latent heat |
| LEGOS | Laboratoire d'Etudes en Géophysique et Océanographie Spatiales |
| LIS | Land Information System (NASA) |
| LoCo WG | Local Land-Atmosphere Coupling Working Group |
| LSM | Land Surface Model |
| LS3MIP | Land Surface, and Snow, Soil moisture Model Intercomparison Project |
| LUCID | Land-Use and Climate, IDentification of robust impacts |
| LULCC | Land Use Cover Changes |
| LUMIP | Land Use Model Intercomparison Project (CMIP) |
| MAC v1 | Max Planck Aerosol Climatology version 1 |
| MAHASRI | Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction |
| MDF | Model Data Fusion |
| MERRA | Modern-Era Retrospective Analysis for Research and Applications |
| MESH | MEC – Surface and Hydrology |
| MOUNTerrain | GEWEX Mountainous Terrain Precipitation Project |
| NASA | National Aeronautics and Space Administration |
| NEESPI | Northern Eurasia Earth Science Partnership Initiative |
| NCAR | National Centers for Atmospheric Research |
| NCEI | National Center for Environmental Information |
| NDVI | Normalized Difference Vegetation Index |
| nnHIRS | neural network High Resolution Infra Red Radiation Sounder |
| NOAA | National Oceanic and Atmospheric Administration (USA) |
| NRCan | Natural Resources Canada |
| NWP | Numerical Weather Prediction |
| OAFlux | Objectively Analyzed Air-sea Fluxes |
| Obs4MIPS | Observations for Model Intercomparisons |

| | |
|---|---|
| ORA-IP | Ocean Reanalysis Intercomparison project |
| OzEWEX | Australian Energy and Water Exchanges |
| PALS | Protocol for the Analysis of Land Surface models |
| PannEx | Pannonian Basin Experiment |
| PI | Principal Investigator |
| PILDAS | Project for the Intercomparison of Land Data Assimilation Schemes |
| PLUMBER | Land Surface Model Benchmarking Evaluation Project (PALS) |
| POC | Point Of Contact |
| Qa | Atmospheric humidity |
| RAOBS | Paposo Lower Site Radiosondes |
| RHPs | Regional Hydroclimate Projects |
| PROES | Process Evaluation Study |
| S2S | Subseasonal to Seasonal Prediction Project |
| SACRA | global data sets of satellite-derived crop calendars for agricultural simulations |
| SCOPE-CM | Sustained, Coordinated Processing of Environmental Satellite Data for Climate Monitoring |
| SCOR | Scientific Committee on Oceanic Research |
| SGP | Southern Great Plains (USA) |
| SMAP | Soil Moisture Active Passive (NASA) |
| SMOS | Soil Moisture and Ocean Salinity (ESA) |
| SPARC | Stratospheric Processes and their Role in Climate |
| SRB | Surface Radiation Budget Project |
| SSCZP | Soil Systems and Critical Zone Processes |
| SSG | Scientific Steering Group (GEWEX) |
| SSMIS | Special Sensor Microwave Imager/Sounder |
| SST | Sea Surface Temperature |
| THORPEX | The Observing system Research and Predictability Experiment |
| TOA | Top Of Atmosphere |
| TU Wien | Vienna University of Technology |
| UCAR | University Corporation for Atmospheric Research |
| UKMO | UK Met Office |
| UKWIR | UK Water Industry Research |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| UNFCCC | United Nations Framework Convention on Climate Change |
| URC | International Radiation Commission |
| USDA | United States Department of Agriculture |
| UTLS | Upper Troposphere Lower Stratosphere |
| UTTC | Tropospheric Clouds and Convection (PROES) |
| WACMOS-ET | Water Cycle Observation Multi-mission Strategy-EvapoTranspiration |
| WCRP | World Climate Research Programme (WMO, IOC and ICSU) |
| WDAC | WCRP Data Advisory Council |
| WECC | Water, Ecosystem, Cryosphere and Climate (CCRN) |
| WGIR | Working Group on Information for Regions (WCRP, to be approved) |
| WGNE | Working Group of Numerical Experimentation |

| | |
|---|---|
| WGRC | Working Group on Regional Climate (WCRP) |
| WMO | World Meteorological Organization |
| WRMC | World Radiation Monitoring Center |
| WWRP | World Weather Research Program |
| | |
| YESS | Young Earth System Scientists Community |
| YHS | Young Hydrologic Society |

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