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The **G**lobal **E**nergy and **W**ater **Ex**changes (**GEWEX**) project is a core project of WCRP and is dedicated to understanding Earth's water cycle and energy fluxes at the surface and in the atmosphere. We are a network of scientists gathering information on and researching the global water and energy cycles, which will help to predict changes in the world's climate.

WCRP is co-sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the International Science Council (ISC). See www.wmo.int, www.ioc-unesco.org and council.science.

Disclaimer

Executive Summary

This report documents the proceedings of the 32nd Session of the Global Energy and Water cycle Exchanges (GEWEX) Scientific Steering Group (SSG), the annual meeting of scientists who guide the formation of GEWEX's scientific program as well as Chairs and Co-Chairs of the GEWEX Panels. The attendees reviewed the progress of GEWEX and its four Panels for the year 2019 and discussed the program's relevance today and tomorrow.

All four GEWEX Panels reported many undertakings in 2019. Activities ranged from installing new Panel members and the startup of new projects and initiatives to the development and marketing of products and the organization of meetings and workshops. Ongoing projects are advancing according to plan or have ended successfully. Working groups in all four Panels have published articles in major scientific journals, have articles under review at this time, or both. Discussions on how to proceed, what is lacking, other possible topics to explore and discussions on existing or possible obstacles resulted in new action items and recommendations.

In addition to its regular daily duties, activities of the International GEWEX Project Office (IGPO) focused on: i) finding collaboration partners and expanding its network in Central Asia, and ii) assisting with the promising start of reintroducing a Regional Hydroclimate Project (RHP) in the United States.

In anticipation of Phase IV (2023–2032) of GEWEX, a "Science and Applications Traceability Matrix" (SATM) is being assembled with input from all SSG and Panel members. The GEWEX SATM will provide traceability from WCRP strategies to core science, defined metrics, applications and programs. It will serve as the backbone of, and provide direction to, the revision of the GEWEX strategic plan and science questions for the coming years.

The meeting ended with a follow-up on last year's discussion on the concept of Process Evaluation Studies and how they should be incorporated in the GEWEX structure.

Contents

1. Introduction and Overview

This report summarizes the main developments in GEWEX during the year 2019 and includes the major items and recommendations from the 32nd Session of the GEWEX Scientific Steering Group (SSG-32).

The GEWEX SSG-32 meeting was hosted by the National Aeronautics and Space Administration (NASA)/Jet Propulsion Laboratory (JPL) at the Cahill Center for Astronomy and Astrophysics in Pasadena, CA, USA, from 27–31 January 2020. Besides GEWEX Scientific Steering Group (SSG) members and GEWEX Panel Co-Chairs, representatives from the U.S. Department of Energy (DOE), the European Space Agency (ESA), the Japan Aerospace Exploration Agency (JAXA), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), U.S. Global Change Research Program (USGCRP), United Nations Educational, Scientific and Cultural Organization (UNESCO), World Climate Research Programme (WCRP), WCRP's core programs and working groups and other collaborating partners of GEWEX participated in this meeting. The full list of participants can be found in Annex 1 and the agenda of this meeting in Annex 2.

Major results, goals and plans of GEWEX and each of its four Panels are expanded on in §1.1. Panel activities range from installing new Panel members and the startup of new projects, to ongoing projects, development and marketing of products and organizing meetings and workshops. The annual overall report of each Panel, which is based on the annual reports of the individual working groups within the Panel, is presented in §2. Each Panel was assigned two or three SSG members as rapporteurs. The rapporteurs reported on the development and progress of the Panel. Their findings are described in a rapporteur's report, shown in Annex 3.

GEWEX links to WCRP and WMO and their respective core projects and programs are presented in §1.2. The presentations of both WCRP and WMO focused on the transition they are going through and gave insight to their new Strategic Plans. Presentations from GEWEX's sister projects showed their recent achievements and plans for the near future. Information on the joint activities with GEWEX's sister project Climate and Ocean – Variability, Predictability and Change (CLIVAR) in the CLIVAR/GEWEX Monsoon Panel and developments with respect to WCRP's Grand Challenges (GC) on "Extremes" and "Water for the Food Baskets of the World" are covered in §1.4.

Interactions with other GEWEX sponsors and partners are described in §1.3. Their presentations focused on recent achievements and plans for the future and showed areas of interest where collaboration with GEWEX might be initiated or intensified.

This year's scientific talks concerned the influence of the human aspect on the water cycle and how big data can support smart infrastructure decisions. The second scientific talk dealt with the Earth Explorer mission for water cycle science, G-Class Hydroterra.

1.1. GEWEX and GEWEX Panels: Overview of Results, Goals and Plans

This section gives an overview of major results, goals and plans of GEWEX and the GEWEX Panels. The major activities for the GEWEX Panels are described in more detail in Section 2.0.

The GEWEX mission, in short, is the “quantitative understanding and prediction of the coupling of energy and water in the changing Earth system.” There are three major areas of research within GEWEX: Data and Assessments, Hydroclimatology, and Modeling and Prediction. GEWEX is made up of four different Panels, each consisting of several working groups, which explore these three areas. In addition, there are several cross-cutting activities within GEWEX: PROcess Evaluation Studies (PROES), the CLIVAR/GEWEX Monsoon Panel, the WCRP Grand Challenge (GC) on Extremes and the GC on Water for the Food Baskets of the World. The GEWEX Scientific Steering Group (SSG) shapes and monitors the course of GEWEX and briefs WCRP’s Joint Steering Committee (JSC). The SSG consists of 10 members, two Co-Chairs and ex-officio members of NASA, ESA, JAXA and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

In anticipation of Phase IV (2023–2032) of GEWEX, a “Science and Applications Traceability Matrix” (SATM) is being assembled with input from all SSG and Panel members. The GEWEX SATM will provide traceability from WCRP strategies, to core science, defined metrics, applications and programs. It will serve as the backbone of, and provide direction to, the revision of the GEWEX strategic plan and science questions for the coming years.

During the 2019 reporting period, the International GEWEX Project Office (IGPO), in addition to its regular daily duties and activities, focused on: i) finding collaboration partners and expanding its network in Central Asia, ii) assisting with the promising start of reintroducing a Regional Hydroclimate Project (RHP) in the United States, and iii) supporting the initiating RHP ANDEX with drafting its white book and moving towards becoming a full RHP.

The Global Atmospheric System Studies (**GASS**) Panel aims to improve the understanding of physical processes in the atmosphere and their coupling to atmospheric dynamics. The activities of GASS include facilitating and supporting international projects that use observations, process studies and numerical model experiments to develop and improve the representation of the atmosphere in weather and climate models. The GASS Panel has expanded with two new members in 2019, a representative of one of the WCRP Grand Challenges and an Early Career Scientist.

GASS has intensified communications with the Working Group on Numerical Experimentation (WGNE) and the World Weather Research Programme (WWRP) of the World Meteorology Organization (WMO). This development resulted in inputs to implement WCRP reforms in terms of organizing activities across WCRP and coordinate with WWRP and WGNE. Collaboration on several GASS projects also ensued. GASS has also increased its collaboration with the Atmospheric Radiation Measurement user facility of the U.S. Department of Energy (DOE ARM). Agreements on data use and hosting and some financial support for GASS meetings were made.

The four active GASS projects which are entering their productive stage are: Constraining Orographic Drag Effects (COORDE); Demistify: an LES and NWP fog DOE intercomparison; Impact of Initialized Land Temperature and Snowpack on Sub-Seasonal to Seasonal Prediction (LS4P) and Improving the Simulation of Diurnal and Sub-Diurnal Precipitation over Different

Climate Regimes. Experiments are submitted and first analysis are being performed. These projects are related to the top three errors from WGNE Systematic Error Survey Results Summary:

- Precipitation diurnal cycle, intensity and frequency
- Surface fluxes and temperature diurnal cycle
- Cloud microphysics

The fifth active GASS project, the GEWEX Atmospheric Boundary Layer Study 4 (GABLS-4), is in its final stage and is discussing follow-up activities. The GEWEX Upper Tropospheric Clouds and Convection Process Evaluation Study (UTCC PROES) and the GEWEX Aerosol Precipitation process study (GAP) are both GASS-affiliated projects. Their respective communities are active and making steady progress.

The second phase of the "Grey Zone" Project is one of two future GASS Projects. Its WGNE/GASS White Paper describes two partitions based on the Elucidating the Role of Clouds-Circulation Coupling in Climate (EUREC^{4}A) field campaign (January/February 2020) and phase III of the Global Atmospheric Research Program's Atlantic Tropical Experiment (GATE) field campaigns (summer 1974). The second upcoming GASS project is the Physics-Dynamics Coupling project. Its objective is to improve the understanding and numerical treatment of physics-dynamics coupling in atmospheric models. The prepared white paper is currently under revision.

The GEWEX Data and Analysis Panel (**GDAP**) guides the production and evaluation of long term, global atmospheric, surface water and energy budget products. Following through on the recommendations from the discussion on the identity of GDAP in 2018, GDAP is transitioning as planned. A new format is implemented after rescoping and consolidating activities. GDAP's science is process-oriented and focused on: i) the Earth Energy Imbalance (EEI) and climate sensitivity, ii) cloud dynamics and feedbacks, iii) global land-atmosphere interactions, iv) global energy and water cycle variability and v) precipitation extremes.

The mature products overseen by GDAP are the International Satellite Cloud Climatology Project (ISCCP), the Global Precipitation Climatology Project (GPCP), the Surface Radiation Budget (SRB), SeaFlux and LandFlux. The GEWEX Integrated Product and the ISCCP-Next Generation (ISCCP-NG) product were recently added to this list.

The GEWEX Integrated Product, released in 2019, supplies all energy and water cycle parameters from GEWEX-supported products and several ancillary fields at 1°, 3-hourly resolution, on an equal are grid, from 1998–2015. Future enhancements of this product are being considered. ISCCP-NG is an advanced new product to support cloud science. The goal of the first workshop held at EUMETSAT in Germany in October 2019 was to define the scientific scope and the technical contents and methods needed for ISCCP-NG based on the recently-enhanced observational capability of the geostationary meteorological satellite ring. At this successful workshop the next steps for the coming period were formulated.

GDAP sponsors several surface networks, namely the World Radiation Monitoring Center-Baseline Surface Radiation network (WRMC-BSRN), the International Soil Moisture Network (ISMN) and the Global Precipitation Climatology Centre (GPCC). WRMC-BSRN appointed a new director at the end of 2018 and is looking for a deputy director. The network is expanding and active, with candidate stations already operational and/or submitting at least one station to

archive file. At the Global Climate Observing System (GCOS) Joint Panel Meeting in Morocco in March 2019, WRMC-BSRN initiated a discussion with members from the Ocean Observations Panel for Physics and Climate (OOPC) to work towards the harmonization of best practices measuring the radiative components over land and ocean. In this context, WRMC-BSRN and OOPC organized a splinter meeting on land/ocean radiation community interaction at the annual European Geosciences Union General Assembly in April 2020. The goal of this meeting is to establish a dialog across the communities that measure surface solar and longwave radiation over land and sea.

In 2019, the Quality Assurance for Soil Moisture (QA4SM) open access online validation tool was launched, including data from ISMN. The funding of Research and Development activities of ISMN at TU Wien in Austria will continue under the new European Space Agency (ESA) Quality Assurance for Earth Observations (QA4EO) program until at least March 2021. The operational tasks of ISMN will be taken over by the International Centre for Water Resources and Global Change (ICWRGC), located in Koblenz, Germany.

GPCC increased its database with respect to the number of quality-controlled stations to 121.500 stations by integrating large datasets from, inter alia, Australia, Canada and Brazil. Additionally, GPCC regularly updated the quasi-operational monthly Monitoring Product and First Guess products (daily and monthly). The next release of the GPCC precipitation data product portfolio comprising daily, and monthly full data analyses is scheduled for March 2020.

GDAP's GEWEX Water Vapor Assessment (G-VAP) phase II is ongoing and its report is expected in the fall of 2020. The GDAP/GEWEX Cloud Assessment phase II is in its final stage and will end in 2020. The Frequent Rainfall Observations on GridS (FROGS) database was launched in 2019 to support the joint International Precipitation Working Group (IPWG)/GDAP Precipitation Assessment and the WCRP Grand Challenge on Extremes. It is composed of gridded daily-precipitation products on a common 1x1 degree grid to ease intercomparison and assessment exercises. The new Earth Energy Imbalance (EEI) assessment extends to the ocean reanalysis community, cryosphere and land. It is an assessment of the capability to document the EEI and its variability, including trends at various scales using various approaches, such as in situ, satellite and reanalysis. The scoping document is in under writing.

Looking forward, GDAP suggests the following activities for the near future: i) radiation and latent heat profiles assessment, ii) a Process Evaluation Study (PROES) based on the outcome of the GEWEX Integrated Product Workshop planned for March 2020 and iii) continental-scale land energy and water cycle closure assessment.

The science objective of the GEWEX Hydroclimatology Panel (**GHP**) is to understand and predict continental to local-scale hydroclimates for hydrologic applications. Addressing the water cycle at these scales allows us to better understand the many components of the system, from its physical to economic to social aspects. Panel membership expanded with six new members bringing more gender and geographic diversity. Within GHP there are four types of projects: Regional Hydroclimate Projects (RHPs), Cross-cut Projects (CCs), Global Data Centers (GDCs) and GHP Networks.

There are four active, three prospective and four envisioned RHPs. The Hydrological cycle in the Mediterranean Experiment (HyMeX), one of the four active RHPs, conducts monitoring and modeling of the Mediterranean coupled system and its variability and characteristics over the 2010–2020 period. The Pelagic Ecosystem Response to dense water formation in the Levant Experiment (PERLE), a HyMeX effort, launched a 2019 follow-up cruise field campaign in the

Eastern Mediterranean called PERLE2. PERLE-2 complements what was performed during the second Special Observing Period (SOP2) in the Levantine region. In 2020, HyMeX's final year, the program will conduct wrap-up actions and launch the Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) field campaign, which focuses on land surface interactions over the Iberian semi-arid environment.

The second active RHP, Global Water Futures (GWF), focuses on: 1) delivering new capability for providing disaster warning; 2) diagnosing and predicting water futures; and 3) developing new models, tools and approaches to manage water-related risks to multiple sectors for evidence-based responses to the world's changing cold regions. GWF funds over 39 projects in Canada that involve 162 faculty investigators from 15 universities, 60 observatories, 335 partners and 496 researchers hired in the first three years. Additionally, GWF supports four global programs: Future Earth, WCRP, UNESCO and WMO.

The third active RHP, Baltic Earth, studies Earth system science in the Baltic Sea region. The main areas of research and publication focus on 1) oxygen minimum zones in coastal seas; 2) new projections for the Baltic Sea region, including marine ecosystem and comprehensive uncertainty analysis of climate projections; and 3) detection and attribution of past (~1000 years) climate variability. This RHP is producing nine Baltic Earth Assessment Reports (BEARs) and has many other annual capacity building activities such as the Baltic Summer and Winter schools.

The initiating RHP PannEX centers on the Pannonian Basin in Europe. Its white book was published by WCRP in 2019 and is available online (https:// https://www.wcrp-climate.org/WCRP-publications/2019/WCRP-Report-No3-2019-PannEx-WB.pdf). While PannEX didn't succeed in obtaining funding from ESA in 2019, it did open up the opportunity to join efforts with DryPan, the team that did secure this funding.

The prospective RHP ANDEX focuses on the Andes Mountain range in South America. It is in the process of organizing and uniting a relevant research community and obtaining international support. In 2019, ANDEX organized a writing workshop in Quito, Ecuador, to assess the advancement of the white book and to define a timeline. Six chapters of the ANDEX White Book were sent to Frontiers-ES special edition for review. Additionally, ANDEX conducted a well-attended oral and poster session at the 2019 Fall meeting of the American Geophysical Union (AGU) and launched its website in this reporting period.

The Third Pole Environment Water Sustainability (TPE-WS) project is a prospective RHP intending to explore water sustainability in the Third Pole environment. The TPE-WS-team worked on its science plan and established different sub-groups. A proposal will be submitted shortly. The research priorities over the Third Pole regions are:

- Water-energy exchanges and transport based on observation (in situ and satellite);
- Mechanisms of and changes in the hydrological cycle;
- Regional and global modeling, especially improving modeling capacity and providing high resolution model products;
- Data assimilation and prediction of high-impact hydro-meteorological events and future changes in the hydrological cycle and water-energy exchanges.

TPE-WS's scientific activities in 2019 included three Intensive Observational Periods (IOP) of comprehensive ground and space observation from horizontal transects over the Third Pole region and the set-up of an observation network along the Yarlung Zangbo Grand Canyon.

The third prospective RHP is the Asian Precipitation Experiment (AsiaPEX), which is a follow-up of the Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction Initiative (MAHASRI). AsiaPEX concentrates on understanding Asian land precipitation. The project group submitted the first draft of its white book and held a kick-off workshop in Sapporo, Japan, in August 2019. The CLIVAR/GEWEX Monsoon Panel will be engaged in this project once the white book is approved.

Additionally, in 2019 many activities were initiated or continued from previous periods towards forming new research communities, which could lead to RHPs in the East African mountain range, Central Asian high mountains and New Zealand. Likewise, earlier initiatives to reintroduce a U.S. RPH on the water and energy cycle continue to take shape. The proposed approach for the Contiguous United States (CONUS) region is coupled modeling at convection permitting scales, combined with focused regional analyses, process studies and observations in western headwaters. The next steps are to form a writing team to develop a strategy white paper, which includes a needs assessment and the formulation of science questions and program goals and deliverables. Another priority in the coming period is to get the U.S. federal agencies interested and involved in this prospective RHP. The timeline includes a kick-off implementation workshop in the fall of 2020.

There is a topical connection between RHPs and Cross Cutting projects (CCs). Three CCs are coming to a close in 2020: The International Network for Alpine Catchment Hydrology (INARCH), the INTElligent use of climate models for adaptation to non-Stationary hydrological Extremes (INTENSE) and Near 0^{o}C Precipitation.

INARCH focused on understanding hydrological processes in alpine cold regions. Among many other highlights and key results, INARCH published invaluable mountain catchment hydrometeorological datasets from around the world through a special issue of *Earth System Science Data* and contributed to the WMO High Mountain Summit in Geneva, Switzerland, in October 2019. Its leaders are currently reflecting on how to proceed with its legacy.

INTENSE collected and analyzed sub-daily precipitation data and model outputs. The data has been added to the Global Precipitation Climatology Center (GPCC) global repository.

The *Near 0^{o}C Precipitation* CC aimed at improving our understanding of future changes in hazardous cold and shoulder season precipitation and storms, especially occurring near 0^{o}C. Its main activities included i) the generation of a database containing records and related climate analysis from different regions, especially in the Northern Hemisphere and ii) numerical simulations with special focus on the microphysics and analysis of the Coupled Model Intercomparison Project (CMIP).

The *mulTi-scale transport and Exchange processes in the Atmosphere over Mountains – programme and eXperiment* (TEAMx) has been approved for GHP CC status in 2019. TEAMx aims to improve the understanding of atmospheric processes specific to mountainous regions, which heavily affect the exchange of momentum, heat and mass between the Earth's surface and the atmosphere. During this reporting period, TEAMx held its first community event, the first TEAMx Workshop, and defined the scope and scientific basis for its research program as described in the TEAMx White Paper.

The group on *Determining EvapoTranspiration* (ET) met in Sydney, Australia in October 2019 for the first time. Members created five working groups and are now considering organizing as either a GEWEX/GHP CC or alternatively as a PROcess Evaluation Study (PROES). Their second workshop originally planned for August 2020 is postponed to February 2021.

There are three Global Data Centers (GDCs) linked to GHP that collect and distribute important hydrology-related data: the Global Runoff Data Center (GRDC), the International Data Centre on Hydrology of Lakes and Reservoirs (HYDROLARE) and the Global Precipitation Climatology Center (GPCC). The activities of GPCC in this reporting period have already been described in the section on the GDAP Panel (pg. 4).

As of September 2019, the GRDC database holds world-wide discharge data for 9,927 stations in 161 countries featuring about 440,000 station-years of monthly and daily values with an average time-series length of 44 years, which GRDC has managed to acquire from 25 countries around the world. HYDROLARE currently holds water level data for 801 lakes and reservoirs in the world and counts 1420 stations. The value of these Global Data Centers should be properly recognized. They provide steady and reliable work. This might prove to be difficult in the near future, as personnel and financial resources become limited. The GHP GDCs are connected with other data networks through GDCs linked to GDAP and the Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) Data Center.

In 2019 there were no active GHP Networks. The HyMeX RHP might continue as such after its completion in 2020.

The Global Land/Atmosphere System Study (**GLASS**) Panel's objective is to improve the understanding of energy and water cycling on land and in the coupled land-atmosphere system and to improve representation of these processes in Earth system models. GLASS activities center on facilitating and supporting international projects that use observations, process studies and numerical model experiments to develop and to improve the representation of land and land-atmosphere systems in climate models.

In 2019, GLASS had eight active, one forthcoming and one project on hold.
These projects can be categorized in three groups from process to global scales.

Projects in the Process-Oriented Group
There are four projects classified as process-oriented within GLASS.

i) *Local Coupling Working Group* (LoCo), which focuses on land-atmosphere interactions at local to regional scales
ii) *Protocol for the Analysis of Land Surface Models (PALS) Land Surface Model Benchmarking Evaluation Project, phase 2* (PLUMBER2), which is a model comparison experiment that uses out-of-sample empirical models as benchmarks
iii) *GEWEX Soil and Water Initiative* (SoilWat), which brings together two research communities to improve the representation of soil and subsurface processes in climate models
iv) *Diurnal land/atmosphere Coupling Experiment/GEWEX Atmospheric Boundary Layer Study* (DICE/GABLS-4*)* is a joint GLASS-GASS experiment which studies 1-D interactions between land-surface and atmospheric boundary layer model experiments

LoCo's successful field campaigns with increased instrumentation focused on the Planetary Boundary Layer (PBL) and continued to promote the importance and the development of improved observations of the land-atmosphere system, particularly in the PBL. In this context, GLASS proposed the development and operation of multiple GEWEX/GLASS Land-Atmosphere Feedback Observatories (GLAFOs). These observatories should record long-term, high-frequency observations of soils, vegetation, surface fluxes and the planetary boundary layer.

The objectives of the GLAFOs, based on the *Land-Atmosphere Feedback Experiment* (LAFE), are to:

i) determine profiles of turbulent moments and fluxes and investigate new similarity relationships among gradients, variances, and fluxes;
ii) map surface momentum, sensible heat, and latent heat fluxes using a synergy of scanning wind, humidity, and temperature Light detection and ranging (Lidar) systems;
iii) characterize the diurnal cycle, transitions, the mesoscale and seasonal variability of the Planetary Boundary Layer (PBL), Land-Atmosphere feedback as well as the moisture and energy budgets; and
iv) verify Large Eddy Simulations (LES) and improve turbulence parameterizations in mesoscale models.

Projects in the Benchmarking Group

The Benchmarking group consists of PALS and the *International Land Model Benchmarking* (ILAMB) project. PALS, which has been relaunched as modelevaluation.org, is a web-based platform for evaluating and benchmarking computational models.

ILAMB developed a global benchmarking toolkit for climate model variables (seasonal to annual) and consolidated the location for datasets and diagnostics relevant to land and vegetation modeling communities. ILAMB is widely used by several modeling centers and intercomparison projects and is also used to analyze Coupled Model Intercomparison Project version 6 (CMIP6) vs. Coupled Model Intercomparison Project version 5 (CMIP5) models.

Projects in the Model Intercomparison Projects (MIP) Group

The third group consists of the Model Intercomparison Projects (MIP), which are closely tied to the activities and timeline of the Coupled Model Intercomparison Project (CMIP) of the WCRP Working Group on Coupled Modelling (WGCM):

i) *Global Soil Wetness Project, phase 3* (GSWP3), an ongoing terrestrial modeling activity that produces a long-term reanalysis and investigates the changes of the energy-water-carbon cycles through the 20th and 21st century. The project finalized and distributed the forcing dataset.
ii) *Land Surface, Snow and Soil Moisture MIP* (LS3MIP), which assesses the performance of current land surface modules of Earth System Models and quantifies land surface feedbacks in a changing climate. Several groups completed "Land-hist" experiments. Land-future experiments are underway.
iii) *Land Use MIP* (LUMIP), which focuses on understanding the impact of land use and land use change on climate. Simulations and analysis are ongoing as part of CMIP6.

1.2. GEWEX Links to WMO, WCRP and WCRP Core Projects

GEWEX's parent organization, WCRP, falls under the umbrella of the World Meteorological Organization (WMO) as well as IOC-UNESCO and the International Science Council as its three co-sponsors.

In terms of the relationship with WMO, the long-term goals mentioned in WMO's Strategic Plan (2020–2023) are to:

- Better serve societal needs: deliver authoritative, accessible, user-oriented information and services
- Enhance Earth system observations and predictions: strengthen the technical foundation for the future
- Leverage leadership in science to improve understanding of the Earth system for better services
- Enhance service delivery capacity of developing countries to ensure availability of essential information and services
- Realign the WMO structure strategically for effective policy- and decision-making and implementation

The WMO Research Board on Weather, Climate, Water and the Environment (Research Board) translates the strategic aims of WMO and the decisions of the Executive Council and Congress into overarching research priorities. The Research Board ensures the implementation and coordination of the research programs to achieve these priorities in accordance with the purposes of Organization. The Research Board is advised by the Scientific Advisory Panel (SAP), whose role is to provide forward-looking strategic advice on emerging challenges and opportunities.

To deliver on the long-term goals of the WMO Strategy, the Research Board advances scientific knowledge of the Earth system and policy-relevant science. At the same time, it aims to enhance the science-for-service value chain to ensure scientific and technological advances will improve predictive capabilities. Priorities of the Research Board for 2020/2021 are:

- to develop the concept of science-for-services and the value chain approach;
- to promote innovation in the regions and strengthening or improving capacity building in less developed countries and Caribbean, Pacific and Indian Ocean Small Island Developing States (SIDS);
- to foster an integrated and multidisciplinary research approach; and
- to mobilize resources through science funding and partnership.

WCRP, GEWEX's parent organization, coordinates international climate research and provides a reference framework for both individual researchers and national funding agencies. During the past 40 years, WCRP has reached major achievements. WCRP fundamentally advanced our understanding of the climate, helped the development of spatial and in situ observing systems, climate data processing and assimilation methods, improved computational facilities and enabled extraordinary developments in numerical coupled climate models, which established the basis for ongoing climate politics.

A review of WCRP and its programs in 2018 concluded that WCRP's current structure is not able to meet the challenges of the future. This conclusion led to the WCRP publication of the new strategic plan for the period 2019–2028 in 2019 (*https://www.wcrp-climate.org/images/documents/WCRP_Strategic_Plan_2019/WCRP-Strategic-Plan-2019-2028-FINAL-c.pdf*). The new strategic plan expressed the modernized vision of WCRP: "*A world that uses sound, relevant, and timely climate science to ensure a more resilient present and sustainable future for humankind.*" Accompanying this new vision is a more integrated approach to climate science and an updated mission to coordinate and facilitate international climate research to develop, share and apply the climate knowledge that contributes to societal well-being.

There are four defined scientific objectives: i) fundamental understanding of the climate system, ii) prediction of the near-term evolution of the climate system, iii) long-term response of the climate system and iv) bridging climate science and society. To achieve these objectives, a critical infrastructure needed to be in place. This critical infrastructure included:

- a hierarchy of simulation tools,
- sustained observations and reference datasets,
- need for open access, and
- high-end computing and data management.

The roadmap showing the path of transition to the agreement on the final implementation plan at the 43rd Joint Scientific Committee meeting in April 2022 requires:

- a transparent "bottom-up"-approach involving the entire community;
- identification of high-level science goals and questions, and the key actions required to reach them and to ensure strong "buy-in" from the community and interest of funding agencies; and
- identification of those elements of a new WCRP that are required to put the WCRP Strategic Plan into action, including: structures, milestones, deliverables, resources, measures of success and risk assessment.

Following this route will ensure a smooth transition without interruption into a WCRP that is fit for the challenges ahead. In the near term, the next steps will be taken at the WCRP High-level Science Questions and Flagship Workshop in Hamburg, Germany in February 2020 and the WCRP Elements and Structure Workshop in Washington, DC, USA in March 2020.

The WCRP budget consists of a $70K base to each Core Programme and $10K for each Grand Challenge. The travel budget for WCRP's Joint Planning Staff (JPS) is reduced by approximately 35%. For the transition and integration to the new structure, a fund of $125K is available in 2020. An additional $265K from WMO is dedicated to spending across three WMO programs (Urban, Social Science Engagement and High-Performance Computing), and allocations will be decided by the Research Board. JPS is actively working to increase the voluntary funding base with co-sponsors and has increased its proposal to the National Science Foundation (NSF).

Two of WCRPs core programs, the Climate and Cryosphere Project (CliC) and GEWEX, have the water and energy cycles in common. CliC serves as the focal point for climate science related to the cryosphere, its variability and change, and interaction with the broader climate system. Changes and interaction in cryosphere and cryospheric processes are associated with the water and/or energy cycle. CliC's Science Plan shows four general themes that provide the broad framework within which activities are developed.

These four themes are:

- Observing the cryosphere,
- Physical processes and dynamical understanding,
- Modeling the cryosphere, and
- Global and regional prediction and predictability.

The first three themes reflect where CliC and GEWEX are cross-cutting. GEWEX's GHP Panel includes several activities on high mountains and latitudes that interact with CliC. Within GEWEX's GLASS Panel, the GSWP3 and LS3MIP projects cooperate with CliC.

CliC leads the WCRP Grand Challenge (GC) on Melting Ice and Global Consequences. Its main science question is: "How will melting ice respond to, and feed back on, the climate response to increasing greenhouse gases, and what will the impacts be?" This GC focuses on three themes:

- Permafrost and the global carbon cycle
- Ice sheets, glaciers and rising sea level
- Sea ice and snow interacting with a changing climate.

The six activities associated with this GC consist of five MIPs and a synthesis of exisiting research about permafrost carbon and climate. The format of the research is suitable for assimilation by biospheric and climate models and will contribute to future assessments of the Intergovernmental Panel on Climate Change (IPCC).

Activities in 2019 include five Model Intercomparison Projects, 11 CliC activities and funding/sponsorship of, and/or participation at, workshops, major conferences and the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) School.

The mission of WCRP's core program "Climate and Ocean–Variability, Predictability, and Change" (CLIVAR) is to understand the dynamics, interaction and predictability of the climate system with emphasis on ocean-atmosphere interactions. Its overarching goal is to build a society resilient to environmental changes.

CLIVAR's Science Plan 2019–2028 identified three scientific priorities:

- Mechanisms of climate variability and change that require further investigation with the ultimate goal of better constraining the fluxes of energy and carbon in the climate system.
- Ocean processes that modulate climate variability and change for which open questions remain.
- Climate predictability challenges that exist over a broad range of space and time scales.

In addition to organizing and participating in numerous meetings and workshops, CLIVAR contributed ten articles to the *Frontiers Research* topic "OceanObs'19: An Ocean of Opportunity" in 2019. Its inputs for WCRP core project's integrated activities concentrated on several panels in the Third Pole Environment (TPE), ANDEX and GREENLAND projects.

CLIVAR has planned workshops, meetings and summer schools on different topics in the near future. Furthermore, a roadmap to sustained observations of the Indian Ocean 2020–2030 (IndOOS-2) will be launched. IndOOS-2 can provide a fit-for-purpose observing system that leads to improved weather forecasts, climate predictions and marine ecosystems understanding for the benefit of all. A new research focus is the Tropical Basin Interaction

(TBI). Its main goal is to clarify the complex two-way interaction between the tropical basins and to quantify the benefit to climate prediction.

Within the WCRP family, CLIVAR's Ocean Model Development Panel encourages closer connection with the Working Group on Seasonal to Interannual Prediction (WGSIP) to work on initialized predictions, both seasonal (up to 1 or 2 years) as well as decadal. Another emerging area is a liaison with Sub-seasonal to Seasonal (S2S) activities, which are planning to start looking at the validation of subseasonal prediction of ocean variables also.

The Coordination Office for WCRP Regional Activities (CORA) is a new WCRP support and coordination unit on regional activities. It has the mandate to:

- Identify opportunities, resources and partners to promote regional climate science and/to deliver regional information
- Assist in the integration and synergy of regional activities within WCRP and in cooperation with all its bodies
- Identify and review feasibilities and engage regional activities for climate science that address key challenges and objectives of WCRP
- Support scientific workshops, training and outreach

Current CORA activities include an online database on WCRP regional activities, taking an inventory on WCRP links to stakeholders and supporting GEWEX in the application for funding for a workshop in Central Asia. CORA is a member of the WCRP Task Team on Regional Activities. The completion of the online database on WCRP regional climate research and activities is in its final phase. The database is expected to go live in March 2020.

The Coordinated Regional Downscaling Experiment (CORDEX) objectives are to link regional expertise, build on prior experiences with regional simulations and processes, and to engage all forms of downscaling covering all major land masses and the Artic. Achievements in 2019 consist of meetings, conferences and workshops in Europe, Asia, Australia and South, Central and North America. Additionally, CORDEX contributed to the Intergovernmental Panel on Climate Change (IPCC) 1.5 report and chapters of the IPCC Assessment Report 6 and dozens of papers and contributions to national and regional reports.

Future challenges for CORDEX include:

- Conducting simulations at high resolutions in smaller domains than the CORDEX Domains. Collaboration with the High-Resolution Model Intercomparison Project has started
- Increasing the complexity of processes and interactions and inclusion of the effects of human decision making
- Increasing need for computing time
- Adapting models to the new generation of high-performance computers

The Stratosphere-Troposphere Processes and their Role in Climate (SPARC) core program of WCRP has three main science themes:

i) Atmospheric dynamics and predictability
ii) Chemistry and climate
iii) Long-term records for climate understanding

SPARC is organized through a bottom-up approach where activities are proposed by its community. Currently there are activities with focus on data records, analysis and evaluation, on model development and on networking. SPARC capacity-building activities include

organization of training schools, travel support opportunities for Early Career Researchers (ECRs) and involvement of those ECRs in activity leadership.

Recent achievements include, but are not limited to, organization of two successful summer schools, publication of two community papers on the predictability of the stratosphere and stratosphere-troposphere coupling on S2S timescales (SNAP) and making screened Water Vapour Assessment 2 (WAVAS-II) satellite datasets in homogenized format publicly available.

SPARC is working towards a new Implementation Plan for 2021–2025. Apart from mapping on to WCRP's strategy and implementation plans, it will show strong support for maintaining an atmospheric community within WCRP, which includes dynamics, composition and long-term changes. Additionally, it will encourage the community to support and lead initiatives of broader interest involving WCRP and non-WCRP groups.

SPARC activities for the near future involve preparation of the 5th Atmospheric Composition and the Asian Monsoon (ACAM) workshop and 4th ACAM training school, publication of the SPARC Reanalysis Intercomparison Project (S-RIP) and a new full SPARC activity focusing on process understanding: Stratospheric and Tropospheric Influences on Tropical Convective Systems (SATIO-TCS).

The World Weather Research Programme (WWRP) is WMO's international program for advancing and promoting research activities on weather, its prediction and its impact on society. It advances society's ability to cope with high-impact weather through research focused on improving the accuracy, lead time and utilization of weather prediction. WWRP is organized in projects, working groups and an expert team. Its implementation plan facilitates the realization of a research strategy developed along four Action Areas (urbanization, high-impact weather, water and evolving technologies) culminating ultimately in seamless prediction of the Earth system from minutes to months.

Within each Action Area, objectives are defined, and concrete activities outlined to ensure progress. Specifically, for the Action Area "Water", the objectives are to model and predict the water cycle for improved disaster risk reduction and resource management. This Action Area addresses the integrated water cycle, new in situ and remotely-sensed hydro-meteorological observations, precipitation processes and hydrological uncertainty.

There are opportunities for collaboration between WWRP and GEWEX. Although WWRP already supports the organization of GASS around process-oriented science challenges, there is room for improvement. Furthermore, both GEWEX Phase III (2013–2023) and the WWRP Implementation Plan (2016–2023) are in their final stages. This might be seen as an opportunity to mutually reprioritize research foci and identify emerging areas which overlap that would foster organic collaboration. Examples for these areas of collaboration are convective-permitting climate modeling, exa-scale computing and science methodologies, and Subseasonal to Seasonal (S2S) from the perspective of water management and land atmosphere interactions. Another of the intended outcomes of collaboration could be the advancement of an Earth system science framework in support of seamless prediction with benefits across time scales ranging from weather to S2S to climate.

1.3. GEWEX Interactions with Sponsors and Partners

The National Aeronautics and Space Administration (NASA) relies on the science community to identify and prioritize leading-edge scientific questions and the observations required to answer them. One principal means by which NASA's Science Mission Directorate engages the science community in this task is through the National Research Council (NRC). The NRC conducts studies that provide a science community consensus on key questions posed by NASA and other U.S. government agencies. The broadest of these studies in NASA's areas of research are the decadal surveys. These decadal surveys look 10 or more years ahead into the future and prioritize research areas, observations and notional missions to make those observations. In the 2017 Decadal five observation systems were suggested:

i) Aerosol and Clouds
ii) Convection and Precipitation (1 and 2 combined are ACCP)
iii) Mass Change
iv) Surface Biology and Geology
v) Surface Deformation and Change

The disciplinary science programs are encouraged to engage with large advisory groups, like GEWEX and IPCC.

The Earth Venture (EV) class of NASA projects consist of low-cost, Principal Investigator (PI)-led, competed orbital and sub-orbital missions that are built, tested and launched in short time intervals. The focused missions and investigations uniquely address different components of the Earth to accommodate new and emergent scientific priorities. The EV class includes Earth Venture Instruments (EVI); Earth Venture Sub-orbital (EVS) and Earth Venture Missions (EVM). In response to the 2017 Decadal Survey, NASA's first EVM involved a new instrument, Libera, to maintain the 40-year data record of the radiation balance.

Subjects of interest to GEWEX in this context are ACCP, measurements of winds and cloud boundary layer. The planetary boundary layer is important across all four GEWEX Panels.

The Earth Observation Program of the Japanese Aerospace Exploration Agency (JAXA) holds many opportunities for GEWEX. JAXA developed "The Grand Plan for Water Cycle Observations by Satellites". Its objective is to utilize Japanese satellite observations to contribute to policy regarding adaptation and actions combatting the impacts of climate change and operational applications to provide information on water-related disasters and numerical weather prediction.

The new mission "Global Observation SATellite for Greenhouse gases and Water cycle" (GOSAT-GW) has been approved, carrying the Total Anthropogenic and Natural emissions mapping SpectrOmeter-3 (TANSO-3) and Advanced Microwave Scanning Radiometer-3 (AMSR3) instruments. Its objective is to produce a long-term continuous data record and to enhance operational utilization of near real-time data. TANSO-3 will improve observation capability of greenhouse gases from GOSAT-2.

The Global Satellite Mapping of Precipitation (GSMaP) has extended its real-time version GSMaP_NOW to the whole globe beginning in June 2019. A review paper of the Global Precipitation Mission (GPM)-era GSMaP products will appear in March 2020.

JAXA developed the global hydrological simulation system "Today's Earth" with satellite data as inputs under the joint research with University of Tokyo. Over 50 hydrological variables simulated through three different experiments are accessible through the web page:

https://www.eorc.jaxa.jp/ theme/water/. The Japan Meteorology Agency implemented the Himawari aerosol algorithm (L2, L3) provided by JAXA in its operational system. Data assimilation of the Himawari aerosol started in January 2020.

The European Space Agency (ESA) and GEWEX share an interest in fostering robust Earth Observation (EO) capabilities. In November 2020, ESA and GEWEX will jointly organize the Earth Observation for Water Cycle Science Workshop in Versailles, France.

ESA has an array of funded EO missions, including Earth Explorer 9, Far-infrared-Outgoing-Radiation Understanding and Monitoring (FORUM) and the Copernicus program, which has a suite of new missions that includes Anthropogenic CO_2 Monitoring (CO_2M), Polar Ice and Snow Topography (CRISTAL), Passive Microwave Radiometer, Sea Surface Temperature and ICE concentration through Passive Microwave Radiometer (CIMR), Land Surface Temperature Mission (LST), Hyperspectral Imaging Mission (CHIME) and L-band SAR Mission (ROSE-L).

- TRUTHS, Phase A/B1
- ARCTIC Weather Satellite
- ALTIUS, Phase E
- Proba-V extension and 2 small satellites
- Small missions: Two SCOUTS and 2-4 PHI-sat missions

At this time, ESA has 15 satellites in operation and 25 satellites under development. ESA is preparing for the future missions Sentinels Next Generation A/B1, the Aeolus follow-on, Earth Explorer-10 and Next Generation Gravity Mission with NASA. There are three candidates for the Earth Explore 10: i) Harmony, a bistatic Synthetic Aperture Radar (SAR) as passive follower of Sentinel-1; ii) Daedalus, which explores the mesosphere and the lower thermosphere and Ionosphere and iii) Hydroterra, a Geostationary C-band SAR, with science focused on daily water cycle.

ESA's past and future Science and Technological Flagships consist of:

i) Gravity field and steady-state Ocean Circulation Explorer (GOCE; 2009 -2013): understanding of the gravity field
ii) Soil Moisture Ocean Salinity (SMOS; 2009): global observations of soil moisture over land and salinity over oceans
iii) CryoSat (2010): measuring the thickness of polar sea ice and monitoring changes in the ice sheets that blanket Greenland and Antarctica
iv) SWARM (2013): dedicated to unravelling the magnetic field
v) Aeolus (2018): acquire profiles of Earth's wind on a global scale
vi) Cloud Aerosol and Radiation Explorer (EarthCARE; 2021): understanding of the role that clouds and aerosols play in reflecting incident solar radiation back out to space and trapping infrared radiation emitted from Earth's surface
vii) Biomass Explorer (2022): maps on carbon storage and changes in the world forests
viii) Fluorescence Explorer (FLEX; 2023): will map vegetation fluorescence to quantify photosynthetic activity
ix) FORUM (2025)

The cooperation of ESA and the new Research and Innovation Framework Programme or the European Union (EC-RTD) resulted in a Joint Planning Working Group (JPWG), a common scientific Agenda and Flagship Actions on Sea Level and Costal Hazards, Polar regions, Extreme Events, and Water & Food systems and climate adaptation.

ESA focuses on four science clusters: Polar Science, Ocean Science, Carbon and Water Cycle Science. The objectives of these science clusters are to bring together different expertise, data and resources with synergy; promote networking, collaborative research and foster international collaboration and lastly, to contribute to a stronger European research area in close collaboration with European and international partners.

The mission of the National Oceanic and Atmospheric Administration (NOAA) is to understand and predict changes in climate, weather, oceans and coasts; to share that knowledge and information with others and to conserve and manage coastal and marine ecosystems and resources. Its current priorities are to reduce the impact of extreme weather and water events (Weather Act) and to increase the sustainable economic contributions of fishery and ocean resources (Blue Economy). The four goals in NOAA's strategic plan are: i) explore the marine environment; ii) detect changes in the ocean and atmosphere; iii) make forecasts better and iv) drive innovative science.

The mission of the NOAA Climate Program Office (CPO) is to advance scientific understanding, monitoring and prediction of climate and its impacts to enable effective decisions. CPO has three major components, namely: i) Earth System Science and Modeling (ESSM), ii) informing decisions and iii) communication, education and engagement.

Since the 1990s, NOAA has contributed to GEWEX directly via the GEWEX Continental-Scale International Project (GCIP), the GEWEX America Prediction Project (GAPP), and the Climate Prediction Program for the Americas (CPPA) programs.

In Fiscal Year 2019–2021, CPO and NOAA's Climate Variability and Predictability (CVP) funded ten projects on "Observing and Understanding Upper-Ocean Processes and Shallow convection in the Tropical Atlantic Ocean". In this same period, co-funded with the National Science Foundation (NSF), DOE and NASA, five new Climate Process Teams (CPTs) started, focusing on Atmosphere (2), Ocean (1) and Land (2). These CPTs aim to accelerate the improvement of coupled models, data assimilation systems and model components.

The NOAA Modeling, Analysis, Predictions and Projections Program Mission (MAPP) Model Diagnostic Task Force developed process-oriented diagnostics (PODs) that enable targeted model testing and accelerated improvement. The CPO/MAPP Drought Task Force supported research to improve drought understanding, monitoring and prediction in the National Weather Service and the National Integrated Drought Information System.

Looking forward, the foci of CPO/ESSM are:

- Urban Atmosphere
- Climate-Fish: Process-level understanding of changing ocean conditions that directly affect marine species and fisheries
- Drought Complex Interactions
- Climate Sensitivity
- Developing Boundary Layer (BL) datasets to improve BL processes in models
- Explaining Climate Extreme Events

To better align CPO, NOAA and community capabilities to address climate risks, four CPO risk area teams have been formed based on four targeted climate risks: Extreme Heat, Marine Ecosystems, Coastal Inundation and Water Resources.

The U.S. Climate Modeling Summit (USCMS) brings together representatives from federal agencies, USGCRP, and major "CMIP-class" climate model development centers and from operational prediction programs. The objective of this annual summit is to enhance coordination toward a common national climate modeling strategy and to enhance communication with the broader modeling community. The theme of 2020 USCMS Meeting is aerosol-cloud interaction.

The Intergovernmental Hydrological Programme (IHP) of the United Nations is devoted to water research and management, and related education and capacity development. It stimulates and encourages hydrological research and assists member states in research and training activities.

At present, an estimated 3.6 billion people live in areas that are potentially water-scarce for at least one month per year (WWDR, 2018[1]; Burek et al., 2016[2]), while floods have accounted for 47% of all weather-related disasters since 1995, affecting 2.3 billion people (WWDR, 2018[1]). According to *The Global Risks Report 2020*[3], the top five risks in terms of likelihood are:

i) Extreme weather
ii) Climate action failure
iii) Natural disasters
iv) Biodiversity loss
v) Human-made environmental disasters

The main objective of IHP's current, eighth phase (IHP-VIII, 2014–2021) is to put science into action required for water security. IHP-VIII acts at the science-policy nexus to help meet today's global water challenges. It focuses on six thematic areas:

i) water-related disasters and hydrological changes;
ii) groundwater in a changing environment;
iii) addressing water scarcity and quality;
iv) water and human settlements of the future;
v) ecohydrology, engineering harmony for a sustainable world; and
vi) water education, key to water security.

These thematic areas in turn are driven by three axes:

i) Mobilizing international cooperation to improve knowledge and innovation to address water security challenges.
ii) Strengthening the science-policy interface to reach water security at local, national, regional and global levels.
iii) Developing institutional and human capacities for water security and sustainability.

Different approaches are utilized, including:

- Source-to-Sea and Climate Action: it defines key flows found within a source-to-sea system, describes six steps to guide analysis and planning and presents a framework for elaborating a theory of change

[1]UNESCO (2019), *The United Nations World Water Development Report 2018: Nature-based Solutions for Water*, ONU, New York, https://doi.org/10.18356/dc00fb4d-en.
[2] Burek, P. et al. (2016) Water Futures and Solution – Fast Track Initiative (Final Report), IIASA Working Paper WP-16-006.pdf. IIASA, Laxenburg, Austria
[3] World Economic Forum (2020), *The Global Risks Report 2020*. Geneva, Switzerland.

- Climate Risk Informed Decision Analysis (CRIDA), where first the vulnerability domain is determined, then the climate domain is mapped onto the vulnerability domain and finally the climate risks are determined to project performance
- African, Latin American and Caribbean countries flood and drought monitors designed to strengthen the capacity in these regions for near real-time monitoring and seasonal forecasting to raise awareness of the imact of floods and droughts on vulnerable and disadvantaged groups
- The water disaster platform to enhance climate resilience in Africa. This project will establish a flood early warning system and will build capacity for better preparation in managing recurrent flood events within the region, moving from crisis management to a risk management approach
- A web-based drought monitoring platform
- An assessment of snow glacier and water resources in Central Asia focusing on strengthening the resilience of Central Asian countries by enabling regional cooperation to assess high altitude glacio-nival systems to develop integrated methods for sustainable development and adaptation to climate change
- Providing a key platform to develop a global knowledge base on climate-human interactions, particularly related to water resources

The United States Department of Energy (DOE)-sponsored research on the Energy Exascale Earth System Model (E3SM) demonstrated that Super Parameterization (SP) is a successful strategy for convective-scale modeling. For the SP-E3SM, a 28 km global grid and Cloud-Resolving Models (CRMs) with 64 internal columns and with the CRM ported to GPUs was used. SP-E3SM improved the simulations of the precipitation diurnal cycle and the Mesoscale Convective Systems (MCSs) precipitation, although biases are still large in summer.

The DOE-sponsored research on Atmospheric Rivers (ARs) showed that ARs induced large anomalies of precipitation with hydrologic impacts in western United States. AR frequency explains over 40% of interannual variance of water availability in coastal western U.S. ARs sharpen the runoff seasonality.

The Precipitation Metrics Workshop organized by DOE in 2019 was inspired by the lack of objective and systematic benchmarking of, and the need to improve precipitation simulated by, Earth System Models. Baseline metrics are a limited set of observed characteristics to be used for model benchmarking. They only require observed and simulated precipitation data. Data is divided into Tier 1 (global and annual mean) and Tier 2 (regional and seasonal) and is to be applied to a common set of simulations. Exploratory metrics often require more than just precipitation data. To meet the needs of different user communities, the benchmark used diverse aspects of precipitation.

The third Atmospheric River Tracking Method Intercomparison Project (ARTMIP) workshop in 2019 defined four new Tier 2 experiments and identified gaps and priorities:
- Consider going beyond existing AR detection algorithms from 2D to 3D structure.
- Develop open-source computational framework to facilitate implementation of existing and new AR detection algorithms.
- Conduct research to determine the different flavors of ARs and detection method.
- Conduct basic research on the dynamics and lifecycle of ARs.
- Objective and physics-informed clustering of AR detection algorithms.

The Decadal Vision Strategic Plan 2014 of the Atmospheric Radiation Measurement Climate Research facility (ARM) of the DOE is drawing on input from the community and ARM staff to update its long-term plan that identified five focus areas:

i) establish observation modeling “mega sites” at the Southern Great Plains (SGP) site and in the arctic;
ii) produce routine high-resolution simulations over ARM sites;
iii) continued focus on measurement excellence:
iv) enhance data products and processes:
    iv.1. specifically called out aerosol instruments, scanning radars, and frozen precipitation;
    iv.2. develop UAS/TBS capabilities and review possible G-1 replacement;
v) strengthen interactions with the user community.
    v.1. continue to improve the discoverability of ARM data;
    v.2. improve the characterization and communication of data quality;
    v.3. use DOIs to better link data to background information;
    v.4. integrate ARM data with other BER measurements and simulations;

The U.S. Global Change Research Program (USGCRP) coordinates global change research and advances science across the U.S. government. It uses research results and products to inform decisions and responses to a changing climate. USGCRP delivers mandated products (e.g., the quadrennial National Climate Assessment), promotes international cooperation on global change research, and coordinates U.S. activities with the programs of other nations and international organizations. The Integrated Water Cycle Group (IWCG), part of USGCRP, coordinates and integrates global relevant water cycle research and advances capabilities and infrastructure that support water cycle observation, modeling and predictability at a range of scales. Additionally, IWCG develops approaches to apply and translate our understanding, inform decisions surrounding preparedness and resilience and pursues interagency and end-to-end approaches across the USGCRP.

In 2019, USGCRP established the U.S. GEWEX office to support U.S. interagency efforts focused on federal water and energy cycle research that align scientifically with GEWEX. The coordination of interagency activities is facilitated through regular discussions and meetings of program managers from the various USCGRP agencies interested in science relevant to GEWEX by providing communication and infrastructure to support these activities. In addition, the U.S. GEWEX office provides interaction with the research community and vice versa: it provides a point of contact for this community to share and learn about U.S. agencies’ activities related to GEWEX, and to support connection and coordination across science and activities. The U.S. GEWEX office is currently managed by the program managers of NASA and DOE.

In 2019, the initial plans and activities of the U.S. GEWEX office were:

i) Science Planning Exercise: Focus Areas were developed and mapped to activities of GEWEX, WCRP and other U.S. programs during agency discussions
ii) Building on interagency coordination and activities already underway, e.g., the U.S. Climate Modeling Summit and Precipitations Metrics Community Effort of DOE
iii) Kick-starting land-atmosphere interactions, with multiple agencies funding projects and a series of seminars by GEWEX scientists, e.g., the LoCo Perspective, NOAA’s Bedrock-to-Boundary Layer Effort and Update on the Land-Atmosphere Feedback Experiment (LAFE), the briefing on a potential U.S. RHP at USGCRP, etc.
iv) Engaging the community, e.g., town halls at AGU and the American Meteorological Society (AMS) Meeting

The outlook for 2020 shows a continuation of the discussion with the community on the science questions. The need for close coordination with GEWEX science and activities remains, as it is important to synthesize and create synergy with the current work focusing on communication and exchange between scientists of the national and international communities. Undertakings are most successful if they are driven by the community. It is therefore beneficial to express science needs and near-term goals in order for agencies to work together to find the necessary resources or host workshops.

1.4. GEWEX Outreach and Capacity-Building Activities

GEWEX is leading the WCRP Grand Challenge (GC) on Changes in Water Availability, *Water for the Food Baskets of the World*. The water cycle is the main driver for food production. The warming climate pushes the water cycle into unknown territory and the terrestrial water cycle is not natural anymore. It is a matter of urgency to understand the new state of the water cycle and food production, where natural and anthropogenic processes interact.

The Research Applications Laboratory of the National Center for Atmospheric Research (NCAR/RAL) has several projects related to this topic. At the 2019 AGU Fall Meeting, a town hall was organized on “Irrigation Modelling in Land Surface Models (LSM)”, resulting in the potential formation of a group to try and coordinate the efforts underway in many Earth system modeling groups.

The main challenges in modeling agriculture in Earth System Models (ESMs) are:

- crop species evolve and crop growth models are not static;
  - complex agriculture management practices, including rotation and double crops, fertilization, irrigation, and tile drainage;
- varying scales, from field to regional; and
- differing impacts of various irrigation techniques on soil moisture.

In April 2020, the Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) will launch a field campaign that will bring ground-based and airborne measurements together with modeling studies, including assimilation of remotely sensed data. GEWEX is advised to engage the different Panel communities: GLASS in order to coordinate crop and irrigation modeling in LSM’s, GLASS/GASS for coupling studies over managed land areas, and GHP for interaction with regional climate research and the Evapotranspiration CC. Additionally, a proposal for a conference in 2021, *Advancing our Understanding of the Role of Irrigation and Water Management in the Earth System*, was suggested.

Interaction with CliC, CLIVAR and CORDEX is recommended.

In its current form, the GEWEX/CLIVAR Global Monsoon Panel (GMP) was established after the 2014 GEWEX Open Science Conference in the Netherlands. Both CLIVAR and GEWEX recognized a general need for a more global view of monsoons, better coordination of monsoon research and sharing knowledge and best practices. The overarching goals of GMP are to advance understanding of monsoon variability and improve its prediction with observations and modeling as the cornerstones of research activities. These goals are supported by four sub-objectives:

- enhanced emphasis on linkages across scales and physical processes;
- seeking new methods to enhance monitoring, advance diagnostics and improve models;

- development of more elaborated process studies coordinated with modeling activities, e.g., the Coupled Model Intercomparison Project Phase 6 (CMIP6);
- empowering the next generation of scientists around the world to advance our knowledge of monsoon systems, particularly in key regions of interest.

GMP consists of three regional Working Groups (WG): i) WG on Asian-Australian Monsoons, ii) WG on American Monsoons and iii) WG on African Monsoons. In addition to the ongoing activities of the three WGs related to S2S databases and models in the context of monsoons, highlights in this reporting period are the publication of an article on the 2016 Interaction of Monsoon Precipitation and Convective Organization, Atmosphere, Surface and Sea (INCOMPASS) field campaign in India in the *Quarterly Journal of the Royal Meteorological Society* in August 2019, the organization of the Advanced School and Workshop on American Monsoons in São Paulo, Brazil and other cross-panel and cross-regional activities. The members of GMP and the WGs interacted with WMO/WWRP and the WCRP core programs on several levels. For GEWEX specifically, discussion with the GASS co-chair on connecting to diurnal cycle project took place at the Global Monsoon Panel meeting held during the 2019 AGU Fall Meeting. Other possible links are the GHP CC INTENSE and some of the GHP RHPs looking at physical processes, like AsiaPEX. These connections and possible areas of collaboration will be explored in the coming period. To engage all concerned stakeholders, a discussion paper on the future evolution of the International CLIVAR Monsoon Project Office and its activities is under review.

GEWEX participates in the WCRP Grand Challenge (GC) on *Weather and Climate Extremes*. Droughts, heatwaves, heavy precipitation and storms are the four main extremes, which are researched using four overarching themes:

i) *Document* deals with documenting and assessing past changes in extremes. Examples of database development are the Rainfall Estimates on Gridded Network (REGEN), a global land-based gridded dataset of daily precipitation from 1950–2016; HadEX3, a gridded extremes indices dataset from 1901-2016; and the Global Sub-Daily Rainfall Dataset (GSDR).

ii) *Understand* looks at the relative roles of large-scale, regional and local scale processes, as well as their interactions, for the formation of extremes.

iii) *Simulate* questions if models are able to reliably simulate extremes and their changes and how this can be evaluated and improved. It uses both statistical methods and storylines to understand and quantify risks.

iv) *Attribution* researches the contributors to observed extreme events and to changes in frequency and intensity of the observed extremes. One of the challenges is the human role in some wet extremes.

Achievements attributed to the Weather and Climate Extremes GC are the support it created for compound events, and the ongoing collaboration with GDAP/IPWG, which led to the development of the FROGS database and *Environmental Research Letters* special issue. Additionally, the Climate Model Intercomparison Project (CMIP) is strongly influenced by the research requirements of extremes, and the training of young scientist at the WCRP Summer School (2014) and the Nanjing Fall School (2019).

With the possible discontinuation of the Expert Team on Climate Change Detection and Indices (ETCCDI), there is no central point where activities on extremes are coordinated. An option to overcome this shortcoming is to add a WCRP core project on extremes. A core project on extremes would relate to all four WCRP themes. Extremes are vital for useful near-term predictions and will form a clear bridge to society. Long-term changes influence the carbon cycle and cost long-term climate change damage versus mitigation costs. The Nanjing University of Information Science & Technology is willing to support a project office.

One of this year's scientific talks concerned the influence of human impacts on the water cycle and how big data can support smart infrastructure decision. The second scientific talk dealt with G-Class Hydroterra, an Earth Explorer mission to observe and understand the rapid processes of the water cycle over land.

2. GEWEX Panel Status Reports

2.1. Global Atmospheric System Studies Panel (GASS)

Full Panel Name (Acronym) : Global Atmospheric System Studies Panel (GASS)
Reporting Period : 01 January–31 December 2019
Starting Date : 2018
End Date (where appropriate) : N/A
URL : www.gewex.org/panels/global-atmospheric-system-studies-panel

Membership

Chair(s) and Term Dates : Xubin Zeng, 2017–Present
Daniel Klocke, 2017–Present

Members and Term Dates : Sandrine Bony, 2019–Present
Ian Boutle, 2018–Present
Irina Sandu, 2018–Present
Martin S. Singh, 2019–Present
Shaocheng Xie, 2018–Present
Yongkang Xue, 2018–Present
Claudia Stubenrauch (leading UTCC PROES)
Eric Bazile (leading GABLS-4)

Panel Objectives, Goals and Accomplishments during Reporting Period

Overall Panel Objective(s)

The Global Atmospheric System Studies (GASS) Panel facilitates and supports the international community that carries out and uses observations, process studies and numerical model experiments with the goal of developing and improving the representation of the atmosphere in weather and climate models. Primarily, GASS coordinates scientific projects that bring together experts to contribute to the development of atmospheric models.

List of Panel Goals

Adjust yearly

- Work with existing project leaders to reach their yearly goals.
- Launch the Grey-Zone II project and Dynamics-Physics Coupling project.
- Develop the panel by adding one Young Earth System Scientists Community (YESS) member and one other member.
- Plan pan-GASS conference for 2021.
- Develop the questionnaire to survey climate and NWP modeling centers about their priorities in addressing deficiencies in represented processes.

List of Key Results

Adjust yearly with respect to goals

- Four projects are entering the productive phase. Experiments are submitted and first analyses are being performed.
- Two affiliated projects (Upper Tropospheric Clouds and Convection Process Evaluation Study, UTCC PROES, and GABLS-4) are making progress.
- Two new panel members have been recruited (see above).
- Intensive communication occurred with WGNE and WWRP and GASS provided input to implementing WCRP reforms in terms of organizing modeling activities across WCRP and coordinating with WWRP and WGNE.

Other Science Highlights

Not part of the 2–3 major accomplishments

Constraining Orographic Drag Effects (COORDE, drag)

- At resolutions of 80–100km, most of the models exhibit insufficient or misplaced orographic gravity wave drag in the lower stratosphere with respect to the resolved drag obtained from the km-scale simulations.
- There is a large spread in magnitude and spatial distribution of the parameterized orographic drag across models.
- Some of the models exhibit surprising resolution sensitivities in their orographic drag parametrizations.

Demistify (fog)

- Representation of cloud droplet sedimentation is essential for NWP fog simulation.
- Small changes in fundamental parametrizations are more important to fog development than aerosol.

Diurnal Cycle of Precipitation (DCP)

- Developed experiment plan and procedure for both Single Column Models (SCM)/Cloud-Resolving Models (CRM)/Large Eddy Simulation (LES) modeling and Global Climate Model (GCM)/ ESM modeling.
- Created necessary case library that contains both forcing and evaluation datasets for process studies using process models.
- Performed SCM runs with the U.S. DOE E3SM for all the selected cases to test forcing strategies for further refinement and generate initial diagnostics for the group to discuss.
- Start to receive SCM/CRM/LES results from participating modeling groups.

Impact of Initialized Land Temperature and Snowpack on Sub-seasonal to Seasonal Prediction (LS4P, surface and sub-surface temperature)

- Based on multi-model ensemble mean, the significant impact of Tibetan Plateau spring land surface and sub-surface temperature on global summer precipitation is confirmed.
- Two workshops were held to discuss LS4P's progress and report major results.
- Two articles were published in the *GEWEX Quarterly* to report LS4P activities.

Upper Tropospheric Clouds and Convection Process Evaluation Study (UTCC PROES)

- Cloud system analysis allows process studies by relating anvil properties to convection and provides new observational metrics to further constrain model parameterizations.
- The emissivity structure of mature convective systems changes with convective depth, with more surrounding thin cirrus.

GEWEX Atmospheric Boundary Layer Study 4 (GABLS-4)

- Better simulation of the low-level jet in many models (compared to the previous GABLS experiment) thanks to a turbulent kinetic energy scheme and a height of the first level of about 3m.
- For the LES, to reduce the differences or the uncertainties in the LES results, it is necessary to use a resolution about 1m for the horizontal and the vertical directions.

Panel Activities during Reporting Period

List of Panel Activities and Main Result

COORDE (drag)

- All high-resolution experiments have been performed, data has been submitted and analyzed.
- All experiments with and without parameterized drag at resolutions of 80–100km have been performed. Data has been submitted and analyzed.
- The results have been communicated to contributors via email exchanges.
- The second phase, which involves looking at parameterized drag at intermediate resolutions (~40km), has been initiated and most of the model data has been submitted.

Demistify (fog)

- 12 participating models submitted results for stage 1.
- An analysis of submitted results was undertaken by the principal investigator and circulated between project members for discussion and planning for the next steps.

DCP (diurnal cycle of precipitation)

- The GCM/ESM part of the project is in preparation.

LS4P (surface and sub-surface temperature)

- Conducted Task 1, Task 2, and Task 3 experiments and analyzed preliminary results.
- Most modeling groups have submitted their results, which confirm the land surface and sub-surface temperature effect on S2S precipitation prediction.

UTCC PROES (Upper Tropospheric Clouds and Convection Process Evaluation Study)

- Bulk microphysical properties of ice clouds, such as fall speed and ice crystal size distribution, strongly impact the lifetime and the radiative effects of these clouds. More realistic bulk ice schemes, when integrated into the Laboratoire de Météorologie Dynamique Global Climate Model (LMDZ GCM), seem to lead to more realistic anvil size growth with convective depth.
- The working group brings together scientists from several communities: satellite observations, radiative transfer and transport modeling, as well as small-scale process and climate modeling.

GABLS-4 (GEWEX Atmospheric Boundary Layer Study)

- Drawing a conclusion for the interaction with surface requires more experiments with better control of the surface characteristics for all the models.
- The LES manuscript on GABLS4 was submitted in December 2019, and another general paper on GABLS-4 is in preparation.

List of New Projects and Activities in Place and Main Objective(s)

- No new projects launched.
- In close interaction with the Grey Zone 2 project and Dynamics-Physics coupling project lead scientists to move these projects forward.

List of New Projects and Activities Being Planned, including Main Objective(s) and Timeline, Lead(s)

- Second Phase of the "Grey Zone" Project based on the EUREC^{4}A and Phase III of the GATE field campaigns WGNE/GASS White Paper on Scale-Awareness, Stochasticity, and Convective Organization

  Objective: It is designed to have two parts: 1) a focus on shallow convection, and 2) an exploration deep convection.
  Leads: Lorenzo Tomassin, Rachel Honnert, George Efstathiouk, Adrian Lock, Pier Siebesma
  This project represents another excellent partnership between WGNE and GASS. The first phase was already a joint WGNE/GASS activity, while we take the next step as a GASS/WGNE joint project. This project is also related to the WCRP CFMIP project and has gone through iterations with international programs (WGNE, WWRP) and the GASS community. It will be launched after the EUREC^{4}A campaign in mid 2020.
- Physics-dynamics coupling

  Objective: To improve the understanding and numerical treatment of physics-dynamics coupling in atmospheric models.
  Leads: Hui Wan and Ben Shipway
  Timeline: The white paper has been prepared. We plan to launch it in 2020.
- There are early discussions about a follow-up to the GABLS projects, potentially in collaboration with GLASS around the MOSAiC campaign.
- After the EUREC^{4}A campaign, a project on convective momentum transport is being envisaged following COORDE.
- An analysis of diurnal cycle of precipitation simulated by CMIP6 models is being planned as part of DCP. This work will be done in collaboration with scientists at the Program for Climate Model Diagnosis and Intercomparison (PCMDI). The goal is to provide an assessment of current climate model capability to capture the diurnal cycle of precipitation over different climate regimes, which can be used as a benchmark for the current GASS diurnal cycle of precipitation project. The analysis is expected to be completed by May 2020.

Science Issues and Collaboration during Reporting Period

Contributions to Developing GEWEX Science and the GEWEX Imperatives

a. Datasets
   - All data relevant to GASS projects (forcing data, model output and validation data) will be available to the community. DOE ARM is willing to host GASS data. Currently this is being tested with data from the Demistify project.
   - The LS4P data bank has also been established at the TPE Big Data Center.

b. Analysis
   - GASS projects are expected to develop new analysis tools and software that will be available to the community.

c. Processes
   - GASS projects are about process understanding and model treatment (e.g., precipitation, clouds, surface fluxes, coupling surface to atmosphere, aerosols, dynamics-physics coupling).

d. Modeling
   - GASS projects aim to improve different aspects of atmospheric models and related processes.

e. Application
   - GASS projects intend to improve both weather and climate models.

f. Technology Transfer
   - GASS projects intend to transfer improved model treatments to weather and climate centers.

g. Capacity Building
   - The GASS email list includes 500+ people (from graduate students to senior scientists in developed and developing countries). All GASS project white papers are circulated on this email list. Junior scientists and scientists with limited resources are also encouraged to participate in GASS projects.

Contributions to the GEWEX Science Questions and Plans to Include These

a. Observations and Predictions of Precipitation
   - Three existing GASS projects directly address precipitation: the precipitation diurnal cycle, LS4P and GAP.
   - Two projects to be launched in 2020 will also address precipitation: the grey zone project and the physics-dynamics coupling project.

b. Global Water Resource Systems
   - One GASS project (LS4P) is directly related to the global water resources systems.

c. Changes in Extremes
   - All GASS projects aim to improve weather and climate models, including their capability for studying weather and climate extremes.

d. Water and Energy Cycles

- All GASS projects aim to improve weather and climate models, including their capability for studying the water and energy cycles. For instance, in UTCC PROES, upper tropospheric clouds play a crucial role in the climate system by modulating the Earth's energy budget and heat transport. These clouds are most abundant in the tropics, where they often form as cirrus anvils from convective outflow, building mesoscale systems. The radiative heating of the thinner cirrus within the anvils may be critical to cloud climate feedback.

Other Key Science Questions

List 1–3 suggestions that you anticipate your community would want to tackle in the next 5–10 years within the context of a land-atmosphere project

- GASS does not have overarching "key science questions" for the next 5–10 years. Three projects list such questions and they are provided below.
  - How realistic are the high-resolution simulations of orographic processes using observations? How can we develop the seamless orographic drag parametrization formulation?
  - How does land surface temperature (LST)/subsurface temperature (SUBT) over global high mountain regions (including the Tibetan Plateau, Rocky Mountains and other high mountains) affect the global precipitation at S2S scales?
  - The strong stable boundary layer is still a challenge for LES (to reduce the uncertainties) and for flux measurement.

Contributions to WCRP, Including Current Grand Challenges

Briefly list any specific areas of your panel's activities, particularly those related to the Grand Challenges "Extremes" and "Water for the Food Baskets", that are not covered under 2.

- GASS LS4P and precipitation diurnal cycle projects address precipitation that is directly related to "Water for the Food Baskets".
- All GASS projects aim to improve weather and climate models, enabling the modeling study of weather and climate "Extremes".
- UTCC PROES contributes to the WCRP Grand Challenge on Clouds, Circulation and Climate Sensitivity.

Cooperation with Other WCRP Projects, Outside Bodies and Links to Applications

e.g., CLIVAR, CliC, SPARC, Future Earth, etc.

- WGNE, SPARC, S2S Prediction Project, CFMIP and Monsoon panel.
- Develop a survey in collaboration with WGNE and GLASS to gather information from NWP and climate modeling centers about deficiencies in process representations to prioritize future projects.

Workshops and Meetings

List of Workshops and Meetings Held in 2019

Meeting title, dates and location

- Four highly efficient videoconferences attended by GASS Panel members were held on 30 April, 17 June, 16 September and 12 November 2019. For one videoconference, we invited the GLASS Co-Chair Mike Ek to join us. We also invited the GDAP Co-Chairs to join us for other videoconferences, but their schedule didn't work out. Each meeting agenda is similar, and the agenda on 12 November 2019 included: updates on the WGNE (including the WCRP modeling white paper) and WWRP meetings, CORDEX, each GASS project, the dynamics-physics coupling white paper and the grey-zone project; discussions on Annual Reporting Templates, Pan-GASS meeting in 2021 and other GASS meetings in 2020, and the next video-conference; and open discussions.
- Understanding Clouds and Precipitation meeting (UCP2019), Berlin, Germany, in February 2019. Including a preparatory meeting for the grey-zone II project.
- LS4P Workshop during AGU Fall Meeting in December 2019, San Francisco, USA
- LS4P Workshop, July 2019, in Nanjing, China
- COORDE results were presented at an Innsbruck University seminar in November 2019, a Reading University seminar 2019, the WCRP 40 Years symposium at the 2019 AGU Fall Meeting, and during the opening talk of the International Conference on Mountain Meteorology in September 2019
- UTCC PROES results were presented at the International Union of Geodesy and Geophysics (IUGG) meeting, July 2019, Montreal, Canada.

List of Workshops and Meetings Planned in 2020 and 2021

Meeting title, dates and location and anticipated travel support needs

- Continue to have regular videoconferences with panel members.
- Improvement and calibration of clouds in models, Toulouse, France, in June 2020. Including a grey-zone II workshop.
- Fourth International GEWEX/GASS/LS4P and TPEMIP Workshop in USA or China, in September 2020,
- A session on "Diurnal Cycle of Precipitation in Observations and Weather and Climate Models" will be organized at the Asia Oceania Geosciences Society (AOGS) 2020 annual meeting, 28 June–4 July 2020, in Hongcheon, Korea.
- COORDE results will be presented at a Reading University seminar in January 2020, at a University of East Anglia seminar in January 2020 and at the EGU meeting in May 2020.
- 4th UTCC PROES workshop, 9–11 September 2020, New York, USA
- Pan-GASS meeting in 2021 (exact time, location, and local hosts TBD).

Other Meetings Attended on Behalf of GEWEX or Panel in 2019

- WWRP, Geneva, Switzerland, in October 2019: D. Klocke gave a GASS update.
- WGNE, Offenbach, Germany, in September 2019: D. Klocke gave a GASS update and discussed collaborations.
- GEWEX Water Vapor Assessment workshop, June 2019, Madrid, Spain: representing UTCC PROES.
- ISCCP-NG workshop, October 2019, Darmstadt, Germany: representing UTCC PROES.

Publications during Reporting Period

List of Key Publications

- Ek, M., and X. Zeng, 2019: What is the Role of GEWEX in R2O and O2R? p. 3–4, *GEWEX News*, Vol. 29, Quarter 1, 2019.
- Xue, Y., A. Boone, and T. Yao, 2019: Remote Effects of High Elevation Land Surface Temperature on S2S Precipitation Prediction: First Workshop on LS4P and TPEMIP. p. 14–16, *GEWEX News*, Vol. 29, Quarter 1, 2019.
- Stubenrauch, C., and the GEWEX UTCC PROES Working Group: Process Evaluation Study on Upper Tropospheric Clouds and Convection: 2018 Highlights. p. 16–17, *GEWEX News*, Vol. 29, Quarter 1, 2019.
- Klocke D., W. Schubotz, A. Wing, B. Stevens, U. Lohert, and A. Macke, 2019: UCP2019: Understanding Clouds and Precipitation. p. 8–9, *GEWEX News*, Vol. 29, Quarter 2, 2019.
- Xue, Y., W. K.-M. Lau, T. Yao, and A. Boone, 2019: Remote Effects of Tibetan Plateau Spring Land Surface Temperature on Global Summer Precipitation and its S2S Prediction: Second Workshop on LS4P and TPEMIP. p. 8–10, *GEWEX News*, Vol. 29, Quarter 4, 2019.
- Couvreux, F., and co-authors, 2020: on GABLS-4 LES intercomparison, under review.

2.2. GEWEX Data and Analysis Panel (GDAP)

Full Panel Name (Acronym) : GEWEX Data and Analysis Panel (GDAP)
Reporting Period : 01 January–31 December 2019
Starting Date : 2018
End Date (where appropriate) : N/A
URL : https://www.gewex.org/panels/gewex-data-and-analysis-panel/

Membership

Chair(s) and Term Dates : Rémy Roca (2016–Present)
Tristan L'Ecuyer (2016–Present)

Members and Term Dates : Eui-Seok Chung (2019–Present)
Wouter Dorigo (2013–Present)
Seiji Kato (2017–Present)
Chris Kummerow (2014–Present)
Hirohiko Masunaga (2010–Present)
Isable Trigo (2017–Present)
Tianjun Zhou (2011–Present)

Panel Objectives, Goals and Accomplishments during Reporting Period

Overall Panel Objective(s)

Assess the current state of the observational capability to document the global water and energy cycle elements with emphasis on the consistency and the GEWEX Science Questions fitness-for-purpose with a climate driven focus and emphasis on satellite-based datasets. Sponsor ground-based references networks. Trigger new international initiative in support of the GEWEX Science Questions and the panel activity.

List of Panel Goals

Adjust yearly

- Renew the panel membership.

List of Key Results

Adjust yearly with respect to goals

- One new member has joined the panel.

Other Science Highlights

Not part of the 2–3 major accomplishments

- -

Panel Activities during Reporting Period

List of Panel Activities and Main Result

- Continuation of the GDAP identity elaboration.
- Release of the Integrated Product (IP) dataset.
- Consolidation of the land surface activity (see IP project and Toledo meeting to come).
- Teleconference in October 2019/2019 annual GDAP Meeting held in January 2020.
- Kick-off of the International Satellite Cloud Climatology Project Next Generation (ISCCP-NG) project in Darmstadt.
- Significant Progress on the Precipitation Assessment.

List of New Projects and Activities in Place and Main Objective(s)

- -

List of New Projects and Activities Being Planned, including Main Objective(s) and Timeline, Lead(s)

- Assessment of EEI to start in 2020.

Science Issues and Collaboration during Reporting Period

Contributions to Developing GEWEX Science and the GEWEX Imperatives

a. Datasets
   - See the Integrated Product project report.
   - See the GPCC project report.
   - See the BSRN project report.
   - see the ISMN project report.

b. Analysis
   - -

c. Processes
   - -

d. Modeling
   - -

e. Application
   - -

f. Technology Transfer
   - -

g. Capacity Building
   - -

Contributions to the GEWEX Science Questions and Plans to Include These

a. Observations and Predictions of Precipitation
   - See the Precipitation Assessment project report.

b. Global Water Resource Systems
   - -

c. Changes in Extremes
   - See the Precipitation Assessment project report.

d. Water and Energy Cycles
   - See the GEWEX Water Vapor Assessment Project (G-VAP) report.

Other Key Science Questions

List 1–3 suggestions that you anticipate your community would want to tackle in the next 5–10 years within the context of a land-atmosphere project

- -

Contributions to WCRP, Including Current Grand Challenges

Briefly list any specific areas of your panel's activities, particularly those related to the Grand Challenges "Extremes" and "Water for the Food Baskets", that are not covered under 2.

- -

Cooperation with Other WCRP Projects, Outside Bodies and Links to Applications

e.g., CLIVAR, CliC, SPARC, Future Earth, etc.

- -

Workshops and Meetings

List of Workshops and Meetings Held in 2019

Meeting title, dates and location

- DOE Precipitation metrics meeting, Washington, July 2019.
- ISCCP–NG, Darmstadt, Germany, October 2019.

List of Workshops and Meetings Planned in 2020 and 2021

Meeting title, dates and location and anticipated travel support needs

- Integrated Product and Land Surface, Toledo, Spain, March 2020 (support already requested and granted).
- The GDAP 2020 Annual Meeting, October 2020.

Other Meetings Attended on Behalf of GEWEX or Panel in 2019

- -

Publications during Reporting Period

List of Key Publications

- Multiple contributions to the GEWEX newsletter

2.3. GEWEX Hydroclimatology Panel (GHP)

Full Panel Name (Acronym) : GEWEX Hydroclimatology Panel
Reporting Period : 01 January–31 December 2019
Starting Date :
End Date (where appropriate) : N/A
URL : https://www.gewex.org/panels/gewex-hydroclimatology-panel/

Membership

Chair(s) and Term Dates : Joan Cuxart, 2017–Present
Francina Dominguez, 2019–Present

Members and Term Dates : Craig Ferguson, 2015–Present
Xin Li, 2016–Present
Sylvester Danuor, 2017–Present
Ivana Stiperski, 2019–Present
Paola Arias, 2019–Present
Li Jia, 2019–Present
Vidya Samadi, 2019–Present
Ali Nazemi, 2019–Present
Andreas Prein, 2019–Present

Panel Objectives, Goals and Accomplishments during Reporting Period

Overall Panel Objective(s)

To understand and predict continental to local-scale hydroclimates for hydrologic applications by concentrating on improving our understanding of environmental water and energy exchanges at the regional scale and from an integrated perspective.

List of Panel Goals

Adjust yearly

- The GEWEX Hydroclimatology Panel (GHP) aims to understand and predict continental to local-scale hydroclimates for hydrologic applications. GHP concentrates on improving our understanding of environmental water and energy exchanges at the regional scale and from an integrated perspective. Addressing the water cycle at the regional scale allows us to better understand the many components of the system, from its physical to economic to social aspects. There are four types of projects within GHP that allow us to do this:
  i) Regional Hydroclimate Projects (RHPs) are an essential tool in understanding and predicting hydroclimates, as they bring together various disciplines on water-related issues.
  ii) Cross-Cutting Projects (CC) allow GHP to propagate knowledge from one region to another and synthesize results at the global scale. They also facilitate the development and testing of applications derived from this new understanding.
  iii) Global Data Centers collect and distribute important hydrology-related data.
  iv) GHP Networks provide continuity to concluding projects in GEWEX and also to welcome activities that have a regional aspect and are not currently structured as an RHP.

List of Key Results

Adjust yearly with respect to goals

- Mature RHPs [HyMeX, Baltic Earth and Global Water Futures (GWF)] have mainly reached their scientific objectives, characterizing more deeply, with new observations and modeling exercises, parts of the hydrological cycle in their regions. Additionally, these mature RHPs are managing to transfer the new knowledge into applications for weather and climate. HyMeX is finishing its last planned activities, with the semi-arid irrigated experiment LIAISE planned for 2020. Baltic Earth has been very active this past year, concentrating on the improved understanding of its region with a strong focus on biogeochemical and marine processes and some current work related to regional climate system modeling in the Baltic Sea area. During the past year, GWF continued to successfully engage researchers in Canada and the United States with its focus on observations within river basins throughout the region and hydrologic/atmospheric modeling initiatives. At the initiating status, PannEx is organizing itself into Task Teams, it is likely that their research questions will be revisited in the coming year to more closely align with the team's activities.
- There are three groups that are in the process of applying for RHP status: AsiaPEX, TPE and ANDEX. AsiaPEX aims to better understand Asian land precipitation. This group is in the process of finalizing its science plan and aims to begin activities in early 2020. TPE-WS is an initiative to explore the water sustainability in the Third Pole Environment. The TPE-WS team is working on its science plan and will then submit the full proposal. ANDEX aims to improve our understanding and prediction of climate and hydrology along the Andes cordillera.
- Cross-Cuts: The "Precipitation near 0ºC in the changing environment" project has just ended with the generation of a database with records and related climate analysis coming from different regions, especially from the Northern Hemisphere. The INTENSE CC focused on sub-daily precipitation is coming to an end. The data acquisition has been completed, along with climatological studies and high-resolution modeling. The INARCH CC focused on mountain hydrology, continues to be very active, and we now have the potential to integrate ANDEX and TPE, once these are full working RHPs. The TEAMx CC has applied for a Cross-Cut status. This CC focuses on multi-scale transport and exchange in the atmosphere over mountains. The team is organized and active, with a memorandum of understanding, review papers and a workshop, and the goal for an intensive field campaign in 2023 focusing on the European Alps.
- The Global Runoff Data Center (GRDC) and Global Precipitation Climatology Centre (GPCC) maintain their activities, with less information reaching the panel about HYDROLARE on lakes and reservoirs.

Other Science Highlights

Not part of the 2–3 major accomplishments

- We welcomed six new members into the GHP panel: Vidya Samadi from Clemson University, Li Jia from the Lab of the Division of Earth Observation for the Water Cycle (EO-Water) in the Institute of Remote Sensing and Digital Earth (RADI) of the Chinese Academy of Sciences, Ali Nazemi of Concordia University, Andreas Prein of NCAR, Ivana Stiperski of the University of Innsbruck and Paola Arias of the Universidad de Antioquia.
- After the 2019 GHP Meeting, Jason Evans stepped down as Co-Chair of GHP after seven years of leadership. Francina Dominguez has been appointed as the new Co-Chair of GHP.
- Silvina Solman has ended her service as Panel member after her second three-year term.

Panel Activities during Reporting Period

List of Panel Activities and Main Result

- Baltic Earth: The main areas of study and publications from the Baltic Earth group have focused on the following topics: 1) oxygen minimum zones in coastal seas, as many coastal seas suffer from expanding bottom-water deoxygenation and hypoxia primarily because of excessive nutrient loads from land; 2) new projections for the Baltic Sea region including the marine ecosystem and comprehensive uncertainty analysis of climate projections; and 3) detection and attribution of past (~1000 years) climate variability.
- GWF: The coordinated analysis continues with modeling and observations of changing land, ecosystems water and climate for eight large river basins that cover most of Canada and part of the U.S.. During the reporting period, GWF held five different meetings with water managers, GWF Operations Team, the Canadian National Streamflow Forecasting, a national discussion on water security and its Second Annual Open Science Meeting. GWF approved 6 new Indigenous community water research projects.
- HyMeX: This RHP is approaching its end in 2020 after intense activity, both experimental and by numerical simulation, in the Mediterranean basin. Analysis of the campaigns continues, while an experimental and modeling effort over semi-arid terrain with irrigation (LIAISE) is being organized and will take place in 2020. The community indicates its willingness to continue working together.
- PannEx: This RHP was granted initiating status at the end 2017. During the past year, its White Book was published by the WCRP in March 2019 (https://www.wcrp-climate.org/WCRP-publications/2019/WCRP-Report-No3-2019-PannEx-WB.pdf), and all of the nine task teams have consolidated and grown. It was noted that some of the science teams have been more active than others, and perhaps the science questions will be re-visited. While PannEx was not successful in obtaining funding from the European Space Agency, this opened an opportunity to join efforts with the team that was awarded funding (DryPan) and representatives from DryPan will attend the PannEx workshop in 2020.
- Near 0ºC precipitation: This CC is focused on improving our understanding of future changes in hazardous cold or shoulder season precipitation, especially occurring near 0°C. The CC ended this year. The main effort was producing reliable datasets in different regions that can be used for the analysis of near 0°C precipitation. They compiled a dataset of more than 1,500 long-term time series (40 years of data), and climatology studies have either been finished or are underway and particular effort has been devoted to Canada.
- INTENSE: This is a community effort to collect and analyze sub-daily precipitation data and model outputs through the GHP cross-cut. The data acquisition has concluded at this point with more than 25,000 hourly data records worldwide. The database has been transferred to Deutscher Wetterdienst (DWD) and will be given to Copernicus. There is collaboration with the climate modeling teams at ETH Zurich and the UK Met Office to set up first convection permitting resolution model comparison study for the European domain at 2.2 km. Progress has been made towards developing a blended radar-gauge-satellite precipitation product for the UK at 1 hr, 1 km resolution, with the methodology finalized. There have been numerous publications in high-impact journals including *Nature*, and Hayley Fowler, the principal investigator, will contribute to the IPCC report.

- INARCH: This CC is devoted to increasing the understanding and prediction of the alpine cold regions hydrological processes, with an eye towards defining consistent measurement strategies. There are currently 26 INARCH research basins in the Americas and Eurasia. There was an INARCH special issue in *Earth System Science Data* covering hydrometeorological data from mountain and alpine research catchments. Additionally, INARCH focused on the development of a downscaling methodology toolbox in collaboration with NCAR.

List of New Projects and Activities in Place and Main Objective(s)

- See below.

List of New Projects and Activities Being Planned, including Main Objective(s) and Timeline, Lead(s)

- New RHPs on the horizon:
  - ANDEX, a prospective hydroclimate research project for the Andes. ANDEX aims to improve our understanding and prediction of climate and hydrology along the Andes cordillera. In doing so, ANDEX will integrate atmospheric and hydrologic models, and assimilate local and remotely-sensed data products. The first five chapters of their white book have been submitted for peer-review in *Frontiers in Earth Sciences*, and the community continues to come together with special meetings and sessions at AGU and EGU meetings.
  - The Water Security side of TPE is in the process of organizing as an RHP. The main lines under consideration are the water-energy exchanges and transport mechanisms as observed and modeled, the study of the changes in progress in the hydrological cycle, and the societal impact of extreme events. TPE is looking for regional cooperation through the establishment of the Pan-TPE program in cooperation with the neighboring countries. The focus is essentially on the impacts of the Pan-TPE changes on regional sustainability under the dual influences of humanity and nature, and the environmental uncertainty under the westerly monsoon interplay. They are also in the process of writing their science plan and formally applying for RHP status.
  - AsiaPEX is the third proposed RHP. Focusing on understanding Asian land precipitation, AsiaPEX will apply for RHP status shortly. Many in-person meetings and their Kick-Off Conference in Sapporo, Japan in September 2019 have been successful. They are planning a 2020 field campaign.

- Cross-Cutting Activities:
  - TEAMx is a new Cross-Cut initiative focused on atmospheric processes specific to mountainous regions that heavily affect the exchange of momentum, heat and mass between the Earth's surface and the atmosphere. They have formally applied for CC status.
  - EvapoTranspiration (ET) is a potential Cross-Cut focused on the subject of evapotranspiration. The group held a workshop on "Determining Evapotranspiration" in Sydney in October of 2019. As the action is refined, it remains to be seen if it takes the form of a CC or of a PROES.

Science Issues and Collaboration during Reporting Period

Contributions to Developing GEWEX Science and the GEWEX Imperatives

Datasets

- The active RHPs (HyMeX, Baltic Earth and GWF) maintain their datasets and generate new ones as their activities progress, either with new campaigns or with the expansion of their networks. PannEx is still in the initial phase and datasets are being defined.
- Cross-cuts also produce new datasets: i) INTENSE has completed a database on sub-daily precipitation and has obtained complementary numerical model data; ii) INARCH is compiling data from the 26 basins that form the network; and iii) Precipitation near 0ºC has gathered observational data from the northern hemisphere, together with congruent numerical model data.
- Data Centers on precipitation and runoff report continuous feeding of their databases, whereas no new information is available from HYDROLARE on basin water levels.

Analysis

- Most projects use the same basic information inputs: analysis of existing databases, generation of data in experimental campaigns to study a specific process and numerical modeling to have a comprehensive description of the processes in place, while always checking against available observational information.

Processes

- As described above, each project focuses on some particular aspects. Precipitation extreme events and the role of the sea surface waters is the dominant issue in HyMeX, the functioning of the Baltic Sea region as a complex biogeochemical Earth system is Baltic Earth's main focus, similar to GWF, which was more oriented to changing land, ecosystems, water and climate. Cross-Cuts as described above tackle specific processes in a transregional perspective, so far mostly devoted to precipitation (sub-daily, in mountains or near 0ºC).

Modeling

- Due to the variety of purposes that the different GHP actions have, many kinds of model types and simulation strategies are used. In the study of processes, detailed modeling is used at short time scales, including single-column modeling, large-eddy simulation and high-resolution mesoscale modeling. In reference to climate studies, they range from regional models with various techniques and time scales to global Earth system modeling at the century scale. Impact of severe weather events are usually studied with mesoscale models, often taking advantage of operational forecasting systems.

Application

- The overall objective of the GHP actions is to generate databases and methodologies that can be of use to the organizations that study the Earth system, many of them being meteorological and hydrological services providing direct service to society.

Technology Transfer

- Databases, model comparisons and parameterization testing have a direct impact on the day-to-day operational activities of weather and climate modeling centers; for instance, in the generation of improved reanalysis, observed timeseries and expected trends.

Capacity Building

- In most of the GHP actions, capacity building is a high priority, firstly because of the continuous improvement of the scientific and technical capabilities of the personnel involved and secondly because there is a sustained flow of Ph.D. subjects related to the actions that contribute to the maintenance, renewal and eventual growth of the related scientific community.

Contributions to the GEWEX Science Questions and Plans to Include These

Observations and Predictions of Precipitation

Those provided by HyMeX, GWF, INTENSE, INARCH, Precipitation near 0º and GPCC are usually obtained from national services, but also from research networks. PannEx will contribute to this subject as well as they progress.

Global Water Resource Systems

In addition to precipitation (listed in the previous point), INARCH and GWF have a well-defined hydrological component, also covered by the GRDC data center on runoff. PannEx plans to work intensively on water management at the basin scale.

Changes in Extremes

The study of the occurrence and trends of extremes in the present climate is practiced by all GHP projects. The INTENSE CC is particularly focused on this aspect. The future changes are usually studied in the frame of regional climate modeling, by specific studies or through coordinated actions, such as in CORDEX.

Water and Energy Cycles

Most RHPs do not devote an equivalent effort to all parts of the energy and water cycles. Concerning the water cycle, precipitation is well addressed in general, while only some RHPs analyze the hydrological part. Evapotranspiration is not a subject of organized research to date, which is a well-detected limitation and will be tackled by the ET CC if it comes to fruition. Concerning the energy cycle, measurements are well-treated in GEWEX under GDAP, while the reflection at the regional scale could be much deeper in GHP, either observationally or numerically.

Other Key Science Questions

List 1–3 suggestions that you anticipate your community would want to tackle in the next 5–10 years within the context of a land-atmosphere project

- Monitor water-use over land and introduce water-management in models
- Characterize evapotranspiration properly through observations and in models
- Strengthen effective community work regionally (through RHPs) and across regions (through CCs and other actions), improving communication and harmonizing the way tools are used

Contributions to WCRP, Including Current Grand Challenges

Briefly list any specific areas of your panel's activities, particularly those related to the Grand Challenges "Extremes" and "Water for the Food Baskets", that are not covered under 2.

- Most GHP projects contribute to the "Weather and Climate Extremes" Grand Challenge by database building, campaigning and modeling.
- "Melting Ice and Global Consequences" is an important subject for Baltic Earth and GWF and it will be for ANDEX and TPE-WS if they become RHPs.

- "Regional Sea Level Change and Coastal Impacts" is a main item for Baltic Earth in general and for HyMeX essentially on severe weather impacts.
- "Water for the Food Baskets of the World" is an issue that is being considered in the new actions, such as PannEx, or the actions in an exploratory phase like ANDEX or the Western USA RHP.
- "Carbon Feedbacks in the Climate System" is explored in Baltic Earth, which has a very important biogeochemical component.
- "Near-Term Climate Prediction" is considered, but normally handled within other core projects such as CORDEX.
- "Clouds, Circulation and Climate Sensitivity" are usually taken into account in modeling studies within RHPs.

Cooperation with Other WCRP Projects, Outside Bodies and Links to Applications
e.g., CLIVAR, CliC, SPARC, Future Earth, etc.

- Within GEWEX: cooperation is sustained with the other Panels (GDAP, GASS and GLASS).
- Within WCRP: by its regional nature over land, there is interaction with CliC related to the GHP activities in high mountains and high latitudes. Cooperation with CORDEX is increasing as each RHP is interested in performing regional climate studies.
- The new AsiaPEX RHP will strengthen collaborations with the CLIVAR Monsoon Panel.
- With Future Earth: there are contacts with the research action iLEAPS in the building of an activity related to evapotranspiration.

Workshops and Meetings

List of Workshops and Meetings Held in 2019

Meeting title, dates and location.

- 2019 GHP–ET CC Meeting, October 2019, Sydney, Australia
- See individual Working Group reports.

List of Workshops and Meetings Planned in 2019 and 2020

Meeting title, dates and location and anticipated travel support needs.

- 2020 GHP meeting and Pan-GEWEX meeting, Versailles, France, October 2020
- See individual Working Group reports.

Other Meetings Attended on Behalf of GEWEX or Panel in 2019

- There was a session on European RHP at the European Meteorological Society (EMS) conference in Lyngby. Denmark, co-chaired by Joan Cuxart and representatives of PannEx, Baltic Earth and HyMeX. It was mostly attended by PannEx scientists, with a few HyMeX and Baltic Earth participants too.
- Co-chair Joan Cuxart attended the 5th PannEx Workshop in Novi Sad, Serbia
- See individual Working Group reports.

Publications during Reporting Period

List of Key Publications

- See individual Working Group reports.

2.4. Global Land/Atmosphere System Study (GLASS)

Full Panel Name (Acronym) : Global Land/Atmosphere System Study Panel
Reporting Period : 01 January–31 December 2019
Starting Date : N/A
End Date (where appropriate) : N/A
URL : https://www.gewex.org/panels/global-landatmosphere-system-study-panel/

Membership

Chair(s) and Term Dates : Mike Ek, 2015–Present (member 2009–Present)
Kirsten Findell, 2019–Present (member 2018–Present)

Members and Term Dates : Gab Abramowitz*, 2008–Present
Eleanor Blyth^, 2011–Present
Souhail Boussetta, 2018–Present
Nathaniel Chaney, 2019–Present
Martyn Clark, 2017–Present
Paul Dirmeyer^, 2000–Present
John Edwards^, 2014–Present
Craig Ferguson^, 2011–Present
Chiel van Heerwaarden, 2012–Present
Samiro Khodayar Pardo, 2019–Present
Hyungjun Kim*, 2010–Present
Sujay Kumar, 2015–Present
David Lawrence*, 2014–Present
Aude Lemonsu, 2017–Present
Pere Quintana Seguí^, 2017–Present
Joshua Roundy, 2016–Present
Joseph Santanello*, 2011–Present
Anne Verhoef*, 2018–Present
Kun Yang, 2017–Present

** GLASS Project Lead*
^ GLASS Liason to relevant initiative

Panel Objectives, Goals and Accomplishments during Reporting Period

Overall Panel Objective(s)

- Encouragement of land modeling developments by coordinating the evaluation and intercomparison of the new generation of land models and their applications to scientific queries of broad interest, including the proper representation of land-atmosphere interactions with focus on the role of land.
- To develop a protocol for evaluating experiments to address the central question, “does my land model describe the processes in the climate system sufficiently well?”
- To develop an optimal system to create global land datasets in which information is extracted from both land models and sophisticated observations.
- To estimate the contribution of memory in the land system to the overall predictability of regional atmospheric phenomena at seasonal time scales.

List of Panel Goals

Adjust yearly

- SoilWat: Improve the understanding and representation of soil physics and groundwater flows in land and climate models. Processes and parameters of interest include hydraulic pedotransfer functions (PTFs), thermal PTFs, the impact of different PTFs on the water and energy balance, the impact of soil structure on surface evaporation, the viability of using vegetation characteristics as a surrogate for soil structure.
- PLUMBER: Prepare quality-controlled data and lauch PLUMBER2 experiment for 200–300 FLUXNET site locations.
- PALS/modelevaluation.org: Provide a simple-to-use workflow environment to allow the land model community to gauge model performance against a suite of standard reference tests at a variety of temporal and spatial scales and for a variety of process representations.
- ILAMB: Expand the suite of datasets incorporated into ILAMB; expand the usage and utility of the ILAMB suite of diagnostics; develop methods to incorporate uncertainty; apply ILAMB diagnostics to CMIP6 output.
- LUMIP: Coordinate multi-model assessment of the impacts of land use and land cover change (LULCC) as part of CMIP6. Develop metrics for assessment of model skill in simulating impacts of LULCC on climate and biogeochemical cycles.
- LoCo: Promote the importance and development of improved observations of the land-PBL system; pursue the adoption of LoCo metrics by operational NWP and climate centers; expand the reach of LoCo techniques and processes beyond warm season and 1-D column assumptions.
- GSWP3: Produce updated forcing for land experiments for LS3MIP.
- LS3MIP: Begin land-hist experiments.

List of Key Results

Adjust yearly with respect to goals

- Soil structure and PTFs: Simone Fatichi, Dani Or, Robert Walko, Harry Vereecken, Michael Young, Teamrat Ghezzehei, Tomislav Hengl, Stefan Kollet, Nurit Agam, Roni Avissar; Soil structure: an important omission in Earth System Models; accepted by *Nature Communications*.
- PLUMBER2 and PLUMBER-Urban are underway, hosted by modelevaluation.org.
- ILAMB used to assess CMIP6 models; found a general and broad improvement in models that participated in both CMIP5 and CMIP6.

- Land-use Harmonization version 2 (historical and future land use change scenarios for use by all CMIP6 modeling groups) completed. Paper is under review.
- LoCo: Successful field campaigns with increased instrumentation focused on the PBL have led to an effort to push for GEWEX/GLASS Land-Atmosphere Feedback Observatories (GLAFOs) with a common set of instruments collecting consistent, long-term observations at climatologically diverse locations.
- GSWP3: forcing for LS3MIP's EXP1 (land-hist) has been updated and EXP2 (land-future) is in beta version. Simulations are underway.

Other Science Highlights

Not part of the 2–3 major accomplishments

The global pattern of changes in dry season water availability is extremely likely influenced by human-induced greenhouse gas emissions. (Padrón et al, sumbitted.)

Panel Activities during Reporting Period

List of Panel Activities and Main Result

- SoilWat: Multiple survey projects investigating the scope of process representation in land models.
- PLUMBER: Quality assurance and quality control on land forcing data from 200–300 FLUXNET sites is nearing completion, including energy balance correction.
- PALS: Has been relaunched as modelevaluation.org, a web-based platform that is more versitile and no longer limited to land models. Hosted the PLUMBER-MIP; PLUMBER2 and PLUMBER-Urban are underway.
- ILAMB widely utilized.
- LUMIP Workshop at Aspen Global Change Institute in September 2019 was productive; progress and plans for more than 20 manuscripts were discussed.
- GSWP3 and LS3MIP: Updated naming convections for land variables for ALAM/GLASS and cf-convention. Modeling groups have begun testing and running land-hist and LFMIP simulations.

List of New Projects and Activities in Place and Main Objective(s)

The NOAA-DOE Climate Process Team (CPT) on Coupling Land and Atmospheric Subgrid Parameterizations (CLASP) has begun work at multiple institutions. The goal is to understand how improved communication of heterogeneity from the land model to the atmospheric model influences boundary layer processes and the development of convection within climate models.

List of New Projects and Activities Being Planned, Including Main Objective(s) and Timeline, Lead(s)

- LIAISE (Aaron Boone, Martin Best, et al.). Summer 2020 Iberian Peninsula campaign that will focus on land-atmosphere (L-A) interactions, including surface (soil moisture, surface fluxes) and atmospheric (PBL) observations, aircraft and ground measurements. Also contains an Anthropocene (irrigation) component. This project should have (will have) broad GEWEX participation.
- The NASA PBL Incubation Study Team selections were made and include Joe Santanello. There will be a community PBL Workshop sometime in mid-late May 2020 in Washington, D.C. or the Jet Propulsion Lab hosted by this study team but open to the whole community to help steer the effort.

Science Issues and Collaboration during Reporting Period

Contributions to Developing GEWEX Science and the GEWEX Imperatives

Datasets

- Quality-controlled land model forcing data for 200–300 FLUXNET sites
- Use of GEWEX-supported datasets in ILAMB
- Land use change datasets developed for LUMIP
- GSWP3 long-term retrospective experiment 1 (GSWP3-EXP1) and long-term future climate (EXP2) forcing data

Analysis

- LUMIP: Wide range of analysis projects on impacts of land cover and land use change on climate and biogeochemistry.
- Observed changes in dry season water availability attributed to human-induced climate change.

Processes

- Improved understanding of land processes, land-atmosphere coupling and impacts on climate and weather.

Modeling

- Land model process improvements stems from work on all the GLASS projects.
- Many GLASS projects are closely tied to CMIP6 modeling work.

Application

- -

Technology Transfer

- ILAMB, PALS/modelevaluation.org and LoCo's land-atmosphere coupling metrics

Capacity Building

- LoCo WG has many early career scientists working on land-atmosphere interaction issues.

Contributions to the GEWEX Science Questions and Plans to Include These

Observations and Predictions of Precipitation

- Improved land-based process representation and land-atmosphere feedbacks in models will ultimately lead to better prediction of precipitation.
- LFMIP experiment will show how variabiliy of soil mositure and snow are coupled with regional precipitation.

Global Water Resource Systems

- GSWP3-EXP1 and EXP2 (land-hist and land-fut of LS3MIP) will provide long-term changes of water availability globally.

Changes in Extremes

- GSWP3-EXP1 and EXP2 (land-hist and land-fut of LS3MIP) will provide a large simulation set to be used for extreme analysis on various terrestrial hydrology variables.
- LS3MIP will provide a large simulation set to be used for extreme analysis on various terrestrial hydrology variables.

Water and Energy Cycles

- Better representation of land processes and land-atmosphere interaction improves water and energy treatment in models.
- GSWP3-EXP1 and EXP2 (land-hist & land-fut of LS3MIP) will depict a century-long water and energy balance in global scale.

Other Key Science Questions

List 1–3 suggestions that you anticipate your community would want to tackle in the next 5–10 years within the context of a land-atmosphere project

- The role of soil evaporation in the climate system and how to model it reliably
- Incorporation of land-atmosphere coupling diagnostics into ILAMB
- Incorporation of all forms of land management in models
- The impact of human interventions (e.g., groundwater pumping, irrigation) on surface energy and water cycles
- The impact of groundwater on climate variability

Contributions to WCRP, Including Current Grand Challenges

Briefly list any specific areas of your panel's activities, particularly those related to the Grand Challenges "Extremes" and "Water for the Food Baskets", that are not covered under 2

- Many GLASS projects (e.g., LUMIP, GSWP3, LoCo) are interested in impacts of agricultural activities on climate as well as vulnerabilities of agriculture due to climate change.

Cooperation with Other WCRP Projects, Outside Bodies and Links to Applications

e.g., CLIVAR, CliC, SPARC, Future Earth, etc.

- Many GLASS projects are strongly linked with CMIP6 efforts.
- GSWP3 and LS3MIP cooperate with CliC.

Workshops and Meetings

List of Workshops and Meetings Held in 2019

Meeting title, dates and location

- 2019 GLASS Panel Meeting, 6–8 August, Boulder, CO, USA
- LUMIP Workshop at Aspen Global Change Institute, September 2019

List of Workshops and Meetings Planned in 2020 and 2021

Meeting title, dates and location and anticipated travel support needs

- Sessions at EGU, AGU and at the PAN-GEWEX meeting
- Land Modeling Summit planned for September 2020 will have strong GLASS representation
- 5th International Conference on Hydrology and Earth System Science for Society, June 15–19, 2020, Saskatchewan, Canada

Other Meetings Attended on Behalf of GEWEX or Panel in 2019

- GEWEX evaporation workshop that took place from 8–10 October 2019 in Sydney, Australia (organized by Joan Cuxart, Toby Marthews, Jason Evans and Anne Verhoef; attended by Or and Verhoef)
- AMS and AGU sessions on PBL from space, both led by Santanello and others
- NASA Planetary Boundary Layer Incubation Community Forum Townhall meeting at AGU Fall 2019 Meeting attended by Santanello and others

Publications during Reporting Period

List of Key Publications

— Fatichi, S., D. Or, R. Walko, H. Vereecken, M. Young, T. Ghezzehei, T. Hengl, S. Kollet, N. Agam, R. Avissar. Soil structure: an important omission in Earth System Models. Accepted by *Nat. Commun*.

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Annex 2: GEWEX SSG 32 Agenda

Monday January 27

09:00 – 09:30 Opening, Welcome, Introduction – Peter van Oevelen / Graeme Stephens
09:30 – 10:00 Co-Chair Report on GEWEX – Jan Polcher / Graeme Stephens
10:00 – 10:30 JSC Report on WCRP and Implementation Plan – Detlef Stammer
10:30 – 10:45 GEWEX Panel Highlights GHP – Francina Dominguez / Joan Cuxart
10:45 – 11:00 GEWEX Panel Highlights GDAP – Rémy Roca / Tristan L'Ecuyer
11:00 – 11:30 Break
11:30 – 11:45 GEWEX Panel Highlights: GASS – Xubin Zeng / Daniel Klocke
11:45 – 12:00 GEWEX Panel Highlights: GLASS – Mike Ek / Kirsten Findell
12:00 – 12:15 WWRP – Michael Morgan
12:15 – 12:30 SPARC – Judith Perlwitz (Remote)
12:30 – 14:00 Lunch
14:00 – 14:20 NASA – Hal Maring
14:20 – 14:40 JAXA – Misako Kachi
~~14:40 – 15:00 EUMETSAT – Jörg Schulz~~
15:00 – 15:20 NOAA – Jin Huang
15:20 – 16:00 Space Agency Round Table – Moderators: Graeme Stephens / Jan Polcher
16:00 – 16:30 Break
16:30 – 16:45 CORDEX – Bill Gutowski
16:45 – 17:00 CLIVAR – Sonya Legg (Remote)
17:00 – 17:15 CLIC – Helene Seroussi
17:15 – 17:30 UNESCO – Anil Mishra
17:30 – 18:00 Discussion

Tuesday January 28

08:45 – 09:00 ESA – Michael Rast / Diego Fernandez (Remote)
09:00 – 09:15 CORA – Wiebke Schubotz / Paul Bowyer (Remote)
09:15 – 09:30 GC Extremes – Gabi Hegerl (Remote)
09:45 – 10:00 Monsoon Panel – Rupa Kumar Kolli
10:00 – 10:15 DOE – Ruby Leung
10:15 – 10:45 Break
10:45 – 11:00 USGCRP – Jennifer Arrigo
11:00 – 12:00 GDAP Panel Presentation – Tristan L'Ecuyer / Rémy Roca
12:00 – 12:40 New Initiatives (5 min each):

- Precip – Christian Jakob
- TPE – Bob Su
- South America – Germán Poveda
- Central Asia – Peter van Oevelen

12:40 – 14:00 Lunch
14:00 – 15:00 GASS Panel Presentation – Xubin Zeng / Daniel Klocke
15:00 – 16:00 GLASS Panel Presentation – Kirsten Findell / Mike Ek
16:00 – 16:30 Break
16:30 – 17:30 GHP Panel Presentation – Francina Dominguez / Joan Cuxart
17:30 – 18:00 Discussion

Wednesday January 29

~~08:30 – 08:45 iLEAPS – Eleanor Blythe (Remote)~~
08:45 – 09:00 Report of WMO/JPS – Mike Sparrow (Remote)
09:00 – 09:45 Quantifying Human Aspects of the Water Cycle – Newsha Ajami (Remote)
09:45 – 10:30 Hydroterra – Steve Hobbs
10:30 – 11:00 Break
11:00 – 11:30 U.S. RHP – Tim Schneider
11.30 – 12:00 GC on Water for the Food Baskets – Jan Polcher / Peter van Oevelen
12:00 – 13:30 Lunch
13:30 – 21:00 Afternoon Work Retreat and Dinner – Pick up from auditorium

Thursday January 30

09:00 – 09:30 GDAP Rapporteurs Report – Zhongbo Su and Mike Bosilovich
09:30 – 10:00 GLASS Rapporteurs Report – Germán Poveda and Qingyun Duan
10:00 – 10:30 GASS Rapporteurs Report – Christian Jakob and B.J. Sohn
10:30 – 11:00 GHP Rapporteurs Report – Paul Dirmeyer, Gabi Hegerl and Gianpaolo Balsamo
11:00 – 11:30 Break
11:30 – 12:30 Discussion and "Finalizing" SATM – Leads: Graeme Stephens / Jan Polcher
12:30 – 14:00 Lunch
14:30 – 15:00 SATM Discussion – Leads: Graeme Stephens / Jan Polcher
15:00 – 15:30 Meeting Wrap-Up
15:30 – 16:00 IGPO Report + SSG-31 Actions and Recommendations – Peter van Oevelen
16:00 – 16:30 SSG-32 Actions and Recommendations – Lead: Peter van Oevelen
16:30 – 16:45 AOB – Lead: Peter van Oevelen
17:00 Meeting Close

Annex 3: Rapporteur Reports on GEWEX Panels

Global Atmosphere System Study (GASS)
Rapporteurs: B.J. Sohn and Christian Jakob

1.1. Overview
We congratulate the Co-Chairs for their excellent work over the past 12 months. They have built on the good foundation produced last year and all the early projects are maturing well. There are several new projects under consideration.

1.2. Objectives
GASS aims at supporting the international community in parameterizing and modeling various atmospheric processes based on our understanding from observations, for improving weather and climate simulations and prediction.

1.3. Status
The five projects introduced last year are now maturing. They are:

- Surface drag and momentum transport (COORDE), led by Irina Sandu
- Impact of initialized land temperature and snowpack on sub-seasonal to seasonal prediction (LS4P), led by Yongkang Xue
- Demistify: An LES and NWP fog DOE intercomparison, led by Ian Boutle
- Improving the simulation of diurnal and sub-diurnal precipitation over different climate regimes, led by Shaocheng Xie
- GEWEX Atmospheric Boundary Layer Study (GABLS-4), led by Eric Bazile

There are two projects currently under the PROES banner that have begun to affiliate themselves with GASS. Those are:

- GEWEX Upper Tropospheric Clouds and Convection Process Evaluation Study (UTCC PROES), led by Claudia Stubenrauch
- GEWEX Aerosol Precipitation (GAP) process study

In addition, GASS is planning to launch another two projects in the near future:

- Phase 2 of the “Grey Zone” Project
- A project on physics-dynamics coupling

GASS is successfully collaborating with key groups outside GEWEX. In addition to the ongoing interaction with WGNE and WWRP, GASS is engaged in discussions with SPARC around the UTCC and COORDE projects and with the Monsoon Panel about potential future collaborations. A connection to CFMIP has been established, which needs further strengthening in the future.

1.4. Vision
Continue current GASS activities while strengthening contributions to GEWEX science objectives by adding new projects and enhancing communications with WGNE and WWRP, and by pursuing collaboration with other groups in WCRP.

1.5. Future
After a spin-up phase, GASS plans to further expand its activities and collaborations including contributions to the WCRP Grand Challenges in Weather and Climate Extremes; Water for the Food Baskets; Clouds, Circulation and Climate Sensitivity; and Near-Term Climate Prediction.

1.6. Key Results

- Five projects are maturing.
- The relationship with PROES is being clarified.
- Two new projects are under construction.
- The Panel has been extended.
- Communication with WGNE and WWRP is ongoing and has expanded to other groups in WCRP, such as SPARC and the Monsoon Panel.

1.7. Issues

GASS continues to stress the bottom-up approach to project development. While this has been a good approach to get the ball rolling, it is important to balance it with a way of identifying gaps that need to be filled and individuals and groups who could lead efforts in those areas. The current projects are mostly weathe-r and seasonal prediction-oriented, and it is important for the future to prioritize projects that align with the overall GEWEX and WCRP strategy. We repeat our recommendation from last year to charge a few Panel members with identifying potential gaps and proposing solutions.

It is unclear to us what makes the LS4P project a good fit for GASS. It seems that this is largely an S2S project, which may require some expertise in the area of atmospheric teleconnections. The latter is not usually associated with GASS, but is more the realm of CLIVAR and SPARC. We recommend discussing the future of this project with its leads, CLIVAR, SPARC and S2S to identify where its best home may lie and how GASS can best contribute to its success.

We are pleased to see that the integration of the PROES activities into the Panels, which we recommended last year, is making progress. In fact, it is becoming quite apparent that the distinction between a PROES and a project run by a Panel is becoming less and less clear. It is hard to see a difference in scope and purpose between, say, the diurnal cycle project and the GAP project. We therefore recommend to fully integrate any new PROES activities, such as GAP, into GASS as one of its projects. Existing PROES, such as UTCC, could simply be phased out while being loosely affiliated with one or more Panels.

The diurnal cycle project is very far-reaching and ambitious and has our full support. We recommended last year to have a special presentation on this project at the GEWEX SSG. As this was not possible this year, we repeat this recommendation for next year, so that we can advise GASS more concretely on how to handle this large project.

We express some concern about the plan to use the GATE simulations in the new Grey Zone project. While iconic, this dataset lacks modern observations, which could be highly useful in themselves in studying grey zone interactions. Rather than disrupting community enthusiasm by removing GATE, we recommend potentially adding a third case to the Grey Zone, which is built on more recent field studies, such as TWP-ICE, GO-AMAZON or DYNAMO.

Machine learning is increasingly promoted as a new technique for parametrization. Rather than establishing a special GASS project in this space, we recommend that GASS encourages groups that are engaged in this research to participate in the existing GASS projects so that they i) have access to the resources of GASS and ii) can immediately compare their results and interact with the existing approaches. This should be very beneficial for future developments in both machine-learned and traditional parametrizations. It might be useful to

identifying an additional Panel member from the machine-learning community to build this new connection.

We welcome the expansion of the GASS Panel and support the plan to add a YESS member, the PROES leads and the leads of future projects. It is important to maintain some independent members on the Panel, which you have. We support the Chairs in their effort to balance gender, geography, scientific merit and willingness to contribute.

GASS has made great progress in building connections to other programs. Additional ones need to be carefully managed so as to not overwhelm the group's activities. It would be good to strengthen and maybe even formalize the WWRP connection. This could be through an existing (or new) Panel member being assigned the specific role as WWRP liaison. This way the task is clearly defined, and the Co-Chairs do not become overwhelmed with meeting attendance and travel. Similar but more informal arrangements could be made with SPARC, CFMIP and the Monsoon Panel.

We are very pleased to see the plan for a 2021 Pan-GASS Meeting. This will be a very important meeting that should include a discussion on major gaps and DOE issues and how to address them.

We repeat our recommendation from last year for GASS to carry on the excellent work of the last 12 months and not become distracted by the uncertain path forward for the WCRP structure. The science you do is too important!

GEWEX Data and Analysis Panel (GDAP)
Rapporteurs: Michael Bosilovich and Bob Su

1.1. Accomplishments and Activities

- Good participation in meetings (GCOS, ISCCP-NG, GAP, Precipitation Metrics)
- Successful Panel meeting (increased science presentations)
- BSRN: New director, EGU splinter, GCOS action
- On Going Assessments: Integrated Water Vapor, Precipitation and Earth's Energy Imbalance
- Extremes Precipitation Special collection at *Environmental Research Letters*
- Integrated Budget Project data is available and shows some encouraging results

1.2. Emerging Science Questions

- EEI: trends in CERES, extending to ocean reanalyses (OHC) and scoping and assessment have begun since meeting last week
- A continental scale land energy and water cycle closure assessment
- Differing lag relationships in tropical water vapor products to El Niño (uncertainty analysis in the G-VAP assessment)
- Panel-derived questions are being articulated by Rémy and Tristan, following the GDAP Panel meeting

1.3. 2019 Review: Science Issues

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1.4. For Improvement

- Increase the visibility of the Integrated Product project data beyond the GEWEX Newsletter (tweet it from the rooftops!).
- Traceability and climate data quality should be part of the criteria in data analysis (an example of evaluation is the use of System Maturity Matrix, e.g., Su et al., 2018[4]).
- Some of the reports are thinly populated (e.g., Integrated Product). Encourage the Panel to provide as much info as possible.
- Some efforts may need to be developed to engage users of the GEWEX datasets, e.g., for FROGS, capacity building courses may help to reach a large user community.

1.5. For SSG Consideration

SSG Meeting Format:

- More time for science presentations from the Panels, rather than just the highlights.
- Set time aside for rapporteurs and Panel Chairs to have a one-on-one discussion, for example, parallel breakouts, to dig into details of the report.

[4] Su, Z., W. Timmermans, Y. Zeng, J. Schulz, V.O. John, R.A. Roebeling, P. Poli, D. Tan, F. Kaspar, A.K. Kaiser-Weiss, E. Swinnen, C. Toté, H. Gregow, T. Manninen, A. Riihelä, J.-C. Calvet, Y. Ma, and J. Wen, 2018. An Overview of European Efforts in Generating Climate Data Records, *Bull Am Meteorol Soc*, *99*(2), 349-359.

1.6. GDAP Questions to SSG

- Link with GCOS: actions for Rémy to write out a paragraph, Peter van Oevelen and SSG to take to JSC.
- Integrated Product: the integration is a significant and time-consuming effort.
- ISCCP-NG L1 to be coordinated by the Coordination Group for Meteorological Satellites (CGMS) and the Sustained, Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM) group: what kind of governance is expected for L1, inclusive of WCRP and GEWEX?
- EEI assessment: moving toward including reanalyses in the effort. In terms of whom to contact in the realm of the atmosphere and ocean, Mike Bosilovich notes that the Task Team for Intercomparison of Reanalyses (TIRA) might be helpful (could invite an EEI presentation to TIRA telecon). CLIVAR Ocean Reanalysis Assessment group (not sure who is current lead) might also be useful.
- Hard time getting MSWEB (? Princeton for example), restricted data policy. What's the best way to work with academia and others with restrictive access? If the work is publicly-funded work, there might be something to be done.

1.7. Summary and Actions

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GEWEX Hydroclimatology Panel (GHP)
Rapporteurs: Paul Dirmeyer, Gianpaolo Balsamo and Gabi Hegerl

1.1. Overview
Congrats to Joan and Francina (and Jason) for extending the Panel membership (6 new members!). Much good work has been reported, and the capacity building brought by GHP actions is extremely effective at engaging expertise. All are well-documented.

There are promising new RHPs of great interest for current water cycle challenges in ocean-land-atmosphere strongly-coupled regions with current emphasis toward orography (e.g., ANDEX, AsiaPEX, TPE), which have high interest for Numerical Weather Prediction (NWP) and climate water cycle challenges.

Existing RHPs are delivering many datasets that feed into spinoff activities, also with operational applications (e.g., HyMeX into European reanalysis)–these are success stories. There is good diversity in RHPs to engage different communities.

The RHPs are potentially well braced by the Cross-Cut (CC) initiatives that tackle specific questions of high relevance and interest (e.g., TEAMx is particularly very well structured). Links with global datasets of relevance in GDAP are appreciated.

1.2. Objectives
As stated, “to understand and predict continental to local-scale hydro-climates for hydrologic applications by concentrating on improving our understanding of environmental water and energy exchanges at the regional scale and from an integrated perspective.”

1.3. Status
RHPs: Baltic Earth is concluding; HyMeX climaxing this year with the LIASE field campaign in the Ebro basin; PannEx and GWF are underway. Prospective new elements include: ANDEX, TPE, AsiaPEX. Each expands nicely beyond traditional GEWEX topics, acknowledging the larger Earth system and human impacts thereon.
CCs: Near 0°C has ended; INARCH and INTENSE are ongoing, TEAMx has been approved; ET is germinating. GDCs: GPCC, GRDC and HYDROLARE continue to serve their missions well.
Networks: currently no groups with this status.

1.4. Vision
The RHPs are the flagships for GEWEX science: they have historically garnered the highest profile outside our immediate field and often receive the most coverage in the scientific press. The RHP process has evolved and modernized, but has been growing away from its original emphasis on actual field campaigns (LIAISE is one obvious exception). This may well be a response to the ever-tightening budgets lying in contrast to the expense of field campaigns. Remote sensing, “virtual” observations from reanalyses of ever-increasing quality and “big data” analysis techniques are being used to fill the void. Is this a trend we want? Even limited ground truth data are very valuable to evaluate and take best advantage of remotely-sensed and reanalysis data.

The Panel finds the growing emphasis on processes-based understanding in all programs to be very encouraging, showing scientific maturation of many of the GEWEX-related topics which

previously focused heavily on quantification, monitoring and budget closure. The topics and adding important value to previous activities and cross cuts do a good job of covering relevant subject matter, but we feel each tends to take a rather individualized approach with sub-optimal communication and cross-fertilization. It is the role of GHP to facilitate integration, synchronization and establishment of common strands.

1.5. Future

There is a very good mix of mature, rising and nascent projects currently in the GHP portfolio in RHPs and crosscuts. Such an even distribution is essential for the health of GHP.

Down the road, RHPs are envisioned for Central Asia and East Africa; these are difficult areas with weak infrastructure, historically. What can be done to adapt the GHP/RHP playbook for such regions? Africa in particular is a hotspot for all manner of climate issues, and a hole in the RHP list should not remain here any longer than necessary. Liaising with experts that have been involved in shaping the AMMA campaign may help in navigating the infrastructural and diverse capacities challenges.

There has long been interest to revitalize a Continental U.S. (CONUS)-centered RHP that can take advantage of growing U.S. infrastructure, innovations in instrumentation and process understanding, and the natural gradients in temperature, rainfall, elevation and biomes that could enable water and energy “transects” in the vein of ecological transects. The establishment of a U.S. GEWEX Program Office by USGCRP means the time to revisit this prospect is now.

Cross cuts are strong in number and impact, but wholly focused on water cycle elements. Is the energy cycle becoming neglected? Is this actually a problem or just perception?

1.6. Key Results

GHP Panel membership has been reinvigorated with six new members, and careful attention to diversity in gender, geography, expertise and career stage.

Current RHPs span the range from nascent to complete.

- HyMeX will have its final field campaign (LIAISE) this summer. This has been a highly productive and successful effort to study the Mediterranean coupled system (atmosphere-land-ocean) and its variability on a range of space- and time-scales in the context of global change.
- The Global Water Futures project in Canada is in its early stages. This is well-supported and spans mid-latitude to arctic climatic zones ultimately to predict water futures, improve disaster warning and inform adaptation and risk management in a changing climate.
- Baltic Earth has ended its active science phase and now is producing nine Baltic Earth Assessment Reports (BEARs). This has a number of follow-on activities planned.
- PannEx failed to secure EU funding, but a related proposal, “DryPan”, will be able to pick up some of the slack, so PannEx will move ahead. A white book was published in early 2019.
- ANDEX is in the process of amalgamating the relevant scientific community in South America and obtaining international support. White book chapters have been drafted and submitted for peer review.
- TPE-Water Sustainability focuses on the Tibetan Plateau. Its leaders are working on a science plan, and sub-groups have been established. A proposal is expected soon, but the ongoing Land Surface For Prediction (LS4P) in GASS crosses over with TPE geographically.

- AsiaPEX will focus on understanding Asian land precipitation, with an emphasis on Southeast Asia and drainage basins of the Bay of Bengal. It will apply for RHP status soon.

Current crosscuts include:

- INTENSE, which focuses on the analysis of sub-daily observed and modeled precipitation. INTENSE has linked with GPCC, providing its data to their repository. This activity will end in 2020.
- The Near 0°C Precipitation crosscut aims to improve understanding of future changes in hazardous cold/shoulder season precipitation and storms, especially occurring near the freezing mark. It has generated a database for northern hemisphere events and conducted numerical simulations with special focus on microphysics and analysis of CMIP data. This crosscut is also ending.
- INARCH focuses on hydrological processes in alpine cold regions. It has clear potential for links with the ANDEX RHP, the Third Pole Environment (TPE) effort, the proposed TEAMx (see below) and perhaps a Western U.S. RHP, should it come about. It also ends in 2020, but a follow-on is being contemplated.
- TEAMx has been approved as a new crosscut. Its focus is turbulent exchange processes of momentum, heat and mass (water, CO_2 and aerosols) induced by mountains. This effort centers on microphysics, high-resolution observations and modeling with consideration of the range of scales involved.
- An effort called Determining ET may apply for either crosscut or PROES status. It is an activity focusing on advancing the understanding and determination of evapotranspiration.

Three data centers report to GHP:

- The Global Precipitation Climatology Center (GPCC) is a longstanding element of GHP. The database of quality-controlled stations in the archive has grown to more than 121,500 stations. GPCC regularly updates a quasi-operational monthly monitoring product and produces monthly and daily “first guess” products. All are blended gridded products, as many data suppliers prohibit distribution of their raw data.
- The Global Runoff Data Centre (GRDC) database now holds data from nearly 10,000 stations in 161 countries featuring about 440,000 station-years of monthly and daily values, with an average time-series length of 44 years. Similar redistribution constraints on data from certain suppliers affect usability for research, although all data are quality assured by GRDC. This is a highly valuable dataset.
- International Data Centre on Hydrology of Lakes and Reservoirs (HYDROLARE) holds water level data for over 800 lakes and reservoirs from over 1400 stations worldwide.

There are currently no GHP Networks, but HyMeX may continue as a Network after the end of its RHP period.

1.7. Issues

The balance of current efforts continues to be skewed toward components of the water cycle, with the energy cycle under-represented. This point was also raised in GEWEX SSG-31, but little seems to have been done in the last year to address this. The ET crosscut is one effort that will begin to tackle this, but this imbalance should be addressed. Underpinning this is also the consideration of balance closures for both water and energy, which is an area where stronger cooperation with GDAP could be of assistance. GDAP datasets could be better utilized for both RHPs and CCs.

How well are the lessons learned in one of the GHP projects transmitted to inform the new projects? The GHP approval process for RHPs helps in this regard, as does application of the wisdom of Panel members to guide various GHP actions. A synthesis across the history of GHP efforts (i.e., a review publication) authored by current and past GHP members would be tremendously enlightening and useful, serving as a synthesis document across the decades. Modernization of data archiving and services is an issue across our field. This impacts several aspects of GHP efforts:

- The Data Centers must update to modern standards of archiving, documentation, provision of metadata and digital object identification (DOI), as growing pressure from funding agencies and publishers are driving this trend. Online service of data with querying, sub-setting and findability, accessibility, interoperability, and reusability (FAIR) data standards are the future. Basic server-side computation, invokable from client-side scripts in various programming languages and analysis environments, is also highly desirable and would make the data open to the growing market of cloud computing and analysis (cf., CMIP6 data handling). GPCC seems to be making the most progress in this area.
- Likewise, data from historical and current RHPs are archived and largely accessible online, but mainly with 20th century standards and technologies. How can past, present and future data be made available in the cloud, with server-side computaion capabilities, FAIR data standards, DOI registration and data producer credit, etc.? There are initiatives that are looking after data mining and preservation of the sort needed for RHP data.
- Is GHP still the right place for GDCs? There is a history that may not be defensible anymore–would GDAP be a more appropriate home for GDCs in GEWEX?
- The wealth of hydrological data collected in RHPs and CCs is of interest to future global coupled environmental reanalysis. Is this link explored enough to benefit from infrastructural advances in climate data centers?

Another data issue is how to enhance value for long-term climate change monitoring. This would include carry-ons to observational networks in RHPs. Something that would be very useful is metadata from GDCs on instrument and processing changes that may introduce spurious jumps or trends, so that they can be recognized and accounted for more readily, or a version of the dataset that is useful for long-term trends.

The GWF provides good coverage for the North American component of the cryosphere as well as water resources. INARCH, ANDEX and TPE are relevant here too, but piecemeal and not cross-coordinated. How can the cryosphere as a whole be better covered geographically to monitor and study rapid changes related to global climate change? How can CliC be engaged better? CliC and GEWEX/GHP could be equal partners to link up various cold regions and frozen water reservoir monitoring and links to water (and energy) research (Helene Seroussi of JPL gave a presentation on CliC). This issue was also raised last year–has there been progress?

How can engagement with NWP centers be enhanced? This goes both ways–how can NWP centers better help GHP efforts (for instance, supporting plans during Intensive Observation Period campaigns), and how could NWP centers better uptake recommendations arising from GHP's actions and findings?

How well do the GHP efforts link to the hydrology community [e.g., the Hydrologic Ensemble Prediction Experiment (HEPEX) or the Global Flood Partnership]? This mirrors issues going up the WCRP and WWRP chain of organization, but the linkages are best made at the grassroots level like through individual GHP efforts.

It will be valuable to link the GHP efforts into the Extremes Grand Challenge more strongly, particularly if the activity on extremes transitions into a long-term activity. INTENSE already links well and may serve as a model; many of the other GHP strands are very relevant.

Global Land/Atmosphere Study (GLASS)
Rapporteurs: Qingyun Duan and Germán Poveda

1.1. Overview

- A strong focus on WCRP Grand Challenges and GEWEX Science Questions.
- Enthusiastic panel—a lot of projects (eight current and one on hold)
- Projects with long legacies: GSWPs, PALS, iLAMB, PLUMBERs, etc.
- Relatively new projects such as SoilWat and LoCo are producing exciting results.
- Extensive links to, and collaborations with, other programs including WWRP, CMIP6, iLEAPs, and other GEWEX Panels such as GASS, GDAP, etc.

1.2. Goals and Objectives

To improve understanding of energy and water cycles on land and in the coupled land-atmosphere system; to improve representation of these processes in Earth system models. To develop a protocol for evaluating experiments to address the central question, "does my land surface model describe the processes in the climate system sufficiently well?"

Overall Objectives:

- Encouragement of land modeling developments by coordinating the evaluation and intercomparison of the new generation of land models and their applications to scientific queries of broad interest, including the proper representation of land-atmosphere interactions with a focus on the role of land.
- To develop a protocol for evaluating experiments to address the central question, "does my land model describe the processes in the climate system sufficiently well?"
- To develop an optimal system to create global land datasets in which information is extracted from both land models and sophisticated observations.
- To estimate the contribution of memory in the land system to the overall predictability of regional atmospheric phenomena at seasonal time scales.

1.3. Comments/Questions

- Very nice progress in diverse topics. List of new projects and activities in place and main objective. List of new projects and activities being planned, including main objective(s) and timeline.
- Contributions to developing GEWEX science and the GEWEX Imperatives.
- Disappointing that Budyko does it better than models, while being so simple.
- Soil moisture in mountainous terrain?
- Scaling issues of soil moisture?
- Scale-free equation for infiltration?
- Too much emphasis on models (low on theory)
- Human effects on water management irrigation?
- How about the cryosphere?
- Coupling between water, energy and carbon budgets
- U.S.-centric (more international!)
- The issue of scaling from flux tower site measurements to predictions over river basins
- Little or no mention of groundwater (infiltration, interaction with surface waters)
- More emphasis on the coupling between water, energy and carbon budgets?

1.4. A General Reflection to GEWEX

- Too much interest in rainfall, and deservedly so
- Interest in soil moisture and ET, and deservedly so
- Streamflows are hardly mentioned, though they are a fundamental component of the water balance equation and the Earth climate system.
- Measurements are routine, reliable and easy.
- River basins constitute a physical and mathematical filter of rainfall's high frequency variability.
- Streamflows integrate all water balance processes inside the river basin (precipitation, evapotranspiration, soil moisture, ground water=surface water, vegetation, etc.).
- Long way to go to fully understand runoff generation. Peak river flows, and floods! Climate change and LULCC
- Effects of human activity on streamflows
- Plenty of practical water resource planning and management and societal issues.

Annex 4: Acronyms and Other Abbreviations

Click for a list of acronyms and abbreviations related to climate research.

ACAM	Atmospheric Composition and the Asian Monsoon
ACCP	Aerosols, Clouds, Convection and Precipitation
ACPC	Aerosols, Clouds, Precipitation and Climate
AGU	American Geophysical Union
ALMIP2	Land Surface Model Intercomparison Project (CMIP)
AMMA	Multidisciplinary Analysis of the African Monsoon
AMS	American Meteorological Society
ARM	Atmospheric Radiation Measurement (U.S. Department of Energy)
ARMBE	ARM Best Estimate
ARTMIP	Atmospheric River Tracking Method Intercomparison Project
AWI	Alfred Wegener Institute
BSRN	Baseline Surface Radiation Network
CAUSES	Clouds Above the United States and Errors at the Surface
CC	Cross-Cut Project
CCI SM	Climate Change Initiative-Soil Moisture (ESA)
CCMP	Cross-Calibrated Multi-Platform
CCRN	Changing Cold Regions Network
CCSM	Community Climate System Model
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
CESM	Community Earth System Model
CFMIP	Cloud Feedback Model Intercomparison Project
CGMS	Coordination Group for Meteorological Satellites
CLASP	Coupling Land and Atmospheric Subgrid Parameterizations
CLASS	Canadian Land Surface Scheme
CliC	Climate and Cryosphere Project (WCRP Core 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)
CNRM	Centre National de Recherches Météorologique (National Center for Meteorological Research)
COLA	Center for Ocean-Land-Atmosphere Studies
CONUS	Continental United States
CONVEX	Research Project on Observational Evidence and Process Understanding to Improve Predictions of Extreme Rainfall Change
CORA	Coordination Office for WCRP's Regional Activities
CORDEX	Coordinated Regional Climate Downscaling Experiment (WCRP)
CPC	Climate Prediction Center (NOAA)
CPO	Climate Program Office (NOAA)
CPT	Climate Process Teams

CPPA	Climate Prediction Program for the Americas
CRCM	Canadian Regional Climate Model
CRHM	Cold Region Hydrological Model
CRM	Cloud-Resolving Models
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTEM	Canadian Terrestrial Ecosystem Model
DECK	Diagnostic, Evaluation and Characterization of Klima experiment
DCP	Diurnal Cycle of Precipitation (GASS project)
DIAL	Differential Absorption Lidar
DICE	Diurnal Land/Atmosphere Coupling Experiment
DOE	Department of Energy
DOIs	Digital Object Identifiers
DWD	Deutscher Wetterdienst (German Weather Service)
E3SM	Energy Exascale Earth System Model
EBAF-4	Energy Balanced and Filled (EBAF) Top-of-Atmosphere (TOA) Edition-4.0
ECA&D	European Climate Assessment and Dataset
ECCC	Environment and Climate Change Canada
ECMWF	European Centre for Medium-range Weather Forecasts
ECVs	Essential Climate Variables
EEI	Earth's Energy Imbalance
EGU	European Geophysical Union
EMS	European Meteorological Society
EO	Earth Observations
EO-Water	Division of Earth Observation for the Water Cycle (Chinese Academy of Sciences)
ERA-Interim	ECMWF Re-Analysis (ERA)-Interim
ESA	European Space Agency
ESGF	Earth System Grid Federation
ESMs	Earth System Models
ET	Evapotranspiration
ETCCDI	Expert Team on Climate Change Detection and Indices
ETH	Swiss Federal Institute of Technology in Zürich
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EUREC^{4}A	Elucidating the Role of Clouds-Circulation Coupling in Climate field campaign
EV	Earth Venture
EVI	Earth Venture Instruments
EVM	Earth Venture Missions
EVS	Earth Venture Sub-orbital
EXAEDRE	Exploiting new Atmospheric Electricity Data for Research and the Environment
EXP1	Long-term Retrospective Experiment
FAIR	Findability, Accessibility, Interoperability, and Reusability
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 (HyMeX)

FROGS	Frequent Rainfall Observations on GridS database
GABLS	GEWEX Atmospheric Boundary Layer Study
GAIA-CLIM	Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring
GAP	GEWEX Aerosol and Precipitation project
GAPP	GEWEX America Prediction Project
GATE	Global Atmospheric Research Program's Atlantic Tropical Experiment
GC	Grand Challenge (WCRP)
GCIP	GEWEX Continental-Scale International Project
GCM	Global Climate Model
GCOS	Global Climate Observing System
GDAP	GEWEX Data and Assessment Panel
GDC	Global Data Center
GDIS	Global Drought Information System
GEO	Group of Earth Observation
GERICS	Climate Service Center Germany
GEWEX	Global Energy and Water Exchanges (WCRP Core Project)
GFCS	Global Framework for Climate Services
GHP	GEWEX Hydroclimatology Panel
GHRSST	Global High-Resolution Sea Surface Temperature
GLACE	The Global Land–Atmosphere Coupling Experiment
GLASS	Global Land/Atmosphere System Study
GNSS	Global Navigation Satellite Systems
GOSAT-GW	Global Observation SATellite for Greenhouse gases and the Water cycle
GPCC	Global Precipitation Climatology Centre
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Mission
GRACE	Gravity Recovery and Climate Experiment
GSDR	Global Sub-Daily Rainfall Dataset
GSFC	Goddard Space Flight Center (NASA)
GSMaP	Global Satellite Mapping of Precipitation (JMA)
GSOP	Global Synthesis and Observations Panel (CLIVAR)
GSQs	GEWEX Science Questions
GSW	GEWEX Soils and Water
GSWP3	Global Soil Wetness Project 3
GSWP3-EXP1	Global Soil Wetness Project 3 long-term retrospective Experiment 1
GSWP3-EXP2	Global Soil Wetness Project 3 long-term future climate Experiment 2
G-VAP	GEWEX Water Vapor Assessment
GWF	Global Water Futures
HEPEX	Hydrologic Ensemble Prediction Experiment
HESS	Hydrology and Earth System Sciences
HIRS	High Resolution Infra-Red Radiation Sounder
HOAPS	Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data
HYDROLARE	International Data Centre on Hydrology of Lakes and Reservoirs
HyMeX	Hydrological Cycle in the Mediterranean Experiment
HyVic	Hydrology of Lake Victoria Basin
IASOA	International Arctic Systems for Observing the Atmosphere
ICDR	Monthly Interim Climate Data Record (GPCP)

ICPAC	Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Centre
ICSU	International Council for Science
ICWRGC	International Centre for Water Resources and Global Change
IDF	Intensity-Duration-Frequency
IGAD	Intergovernmental Authority on Development
IGBP	International Geosphere Biosphere Programme
IGPO	International GEWEX Project Office
IGWCO	Integrated Global Water Cycle Observations
IHP	Intergovernmental Hydrological Programme
ILAMB	International Land Model Benchmarking
iLEAPS	integrated Land Ecosystem-Atmosphere Processes Study
INARCH	International Network for Alpine Catchment Hydrology
INCOMPASS	Interaction of Monsoon Precipitation and Convective Organization, Atmosphere, Surface and Sea field campaign
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
IOP	Intensive Observation Period
IPCC	Intergovernmental Panel on Climate Change (WMO, UNEP)
IPSL	Institute Pierre Simon Laplace
IPWG	International Precipitation Working Group
IQuOD	International Quality Controlled Ocean Database
IR	Raman lidar and infrared
ISC	International Science Council
ISCCP	International Satellite Cloud Climatology Project
ISCCP-NG	Next Generation 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
JAXA	Japan Aerospace Exploration Agency
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
LIAISE	Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment
LIS	Land Information System (NASA)
LMDZ GCM	Laboratoire de Météorologie Dynamique Global Climate Model

LoCo	Local Land-Atmosphere Coupling
LoCo WG	Local Land-Atmosphere Coupling Working Group
LS3MIP	Land Surface, and Snow, Soil moisture Model Intercomparison Project
LS4P	Impact of Initialized Land Temperature and Snowpack on Sub-seasonal to Seasonal Prediction
LSM	Land Surface Model
LST	Land Surface Temperature
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
MAPP	Modeling, Analysis, Predictions and Projections Program Mission
MDF	Model Data Fusion
MEaSURES	Making Earth System Data Records for Use in Research Environments
Med-CORDEX	Mediterranean Coordinated Regional Downscaling Experiment
MERRA	Modern-Era Retrospective Analysis for Research and Applications
MESH	Modélisation Environmentale Communautaire (MEC)–Surface and Hydrology
MIP	Model Intercomparison Project
MOSAiC	Multidisciplinary drifting Observatory for the Study of Arctic Climate
MOUNTerrain	GEWEX Mountainous Terrain Precipitation Project
NARCCAP	North American Regional Climate Change Assessment Program
NASA	National Aeronautics and Space Administration
NEESPI	Northern Eurasia Earth Science Partnership Initiative
NCA	National Climate Assessment
NCAR	National Centers for Atmospheric Research
NCAR/RAL	Research Applications Laboratory of the National Center for Atmospheric Research
NCEI	National Center for Environmental Information
NCEP	National Center for Environmental Prediction
NDVI	Normalized Difference Vegetation Index
nnHIRS	neural network High Resolution Infra-Red Radiation Sounder
NOAA	National Oceanic and Atmospheric Administration (USA)
NRC	National Research Council
NSF	National Science Foundation
NWP	Numerical Weather Prediction
OAFlux	Objectively Analyzed Air-sea Fluxes
Obs4MIPS	Observations for Model Intercomparisons
OOPC	Ocean Observations Panel for Physics and Climate
ORA-IP	Ocean Reanalysis Intercomparison project
ORCHIDEE	Organizing Carbon and Hydrology In Dynamic Ecosystems
ORNL	Oak Ridge National Laboratory
OzEWEX	Australian Energy and Water Exchanges
PALS	Protocol for the Analysis of Land Surface models
PannEx	Pannonian Basin Experiment
PCMDI	Program for Climate Model Diagnosis and Intercomparison

PBL	Planetary Boundary Layer
PERLE	Pelagic Ecosystem Response to dense water formation in the Levant Experiment
PI	Principal Investigator
PILDAS	Project for the Intercomparison of Land Data Assimilation Schemes
PLUMBER	PALS Land Surface Model Benchmarking Evaluation Project
PMM	Precipitation Measurement Mission
POC	Point of Contact
POD	Process-Oriented Diagnostic
PROES	Process Evaluation Study
PTF	Pedotransfer Functions
Qa	Atmospheric humidity
QA4EO	Quality Assurance for Earth Observations
QA4SM	Quality Assurance for Soil Moisture
RADI	Institute of Remote Sensing and Digital Earth (Chinese Academy of Sciences)
RAOBS	Paposo Lower Site Radiosondes
RCM	Regional Climate Model
REGEN	Rainfall Estimates on Gridded Network database
RHPs	Regional Hydroclimate Projects
S-RIP	SPARC Reanalysis Intercomparison Project
S2S	Subseasonal to Seasonal Prediction Project
SACRA	Global datasets of satellite-derived crop calendars for agricultural simulations
SAFRAN-IP	Système d'Analyse Fournissant des Renseignements Atmosphériques à la Neige for the Iberian Peninsula
SAR	Synthetic Aperture Radar
SATIO-TCS	Stratospheric and Tropospheric Influences on Tropical Convective Systems
SATM	Science and Applications Traceability Matrix
SCM	Single Column Model
SCOPE-CM	Sustained, Coordinated Processing of Environmental Satellite Data for Climate Monitoring
SCOR	Scientific Committee on Oceanic Research
SGP	Southern Great Plains ARM site (USA)
SMAP	Soil Moisture Active Passive (NASA)
SMOS	Soil Moisture and Ocean Salinity (ESA)
SoilWat	GEWEX Soil and Water Initiative
SOP	Special Observation Period
SP	Super Parameterization
SPARC	Stratospheric Processes and their Role in Climate (WCRP Core Project)
SRB	Surface Radiation Budget project
SSC	Scientific Steering Committee
SSCZP	Soil Systems and Critical Zone Processes
SSG	Scientific Steering Group (GEWEX)
SSMIS	Special Sensor Microwave Imager/Sounder
SST	Sea Surface Temperature
SUBT	Subsurface Temperature
SWOT	Surface Water and Ocean Topography satellite

TANSO-3	Total Anthropogenic and Natural emissions mapping SpectrOmeter-3
TEAMx	mulTi-scale transport and Exchange processes in the Atmosphere over Mountains – programme and eXperiment
THORPEX	The Observing system Research and Predictability Experiment
TIRA	Task Team for Intercomparison of Reanalyses (WCRP)
TOA	Top Of Atmosphere
TPE	Third Pole Environment
TPE-WS	Third Pole Environment–Water Sustainability
TU Wien	Vienna University of Technology
UCAR	University Corporation for Atmospheric Research
UCI	University of California, Irvine
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
UNSW	University of New South Wales, Sydney, Australia
URC	International Radiation Commission
USDA	United States Department of Agriculture
USGCRP	U.S. Global Change Research Program
USRA	Universities Space Research Association
UTLS	Upper Troposphere Lower Stratosphere
UTTC	Tropospheric Clouds and Convection (PROES)
WACMOS-ET	Water Cycle Observation Multi-mission Strategy-EvapoTranspiration
WAVAS-II	Screened Water Vapour Assessment 2
WCRP	World Climate Research Programme (WMO, IOC and ICSU)
WDAC	WCRP Data Advisory Council
WECC	Water, Ecosystem, Cryosphere and Climate (CCRN)
WG	Working Group (CLIVAR/GEWEX Global Monsoon Panel)
WGIR	Working Group on Information for Regions (WCRP, to be approved)
WGNE	Working Group of Numerical Experimentation
WGRC	Working Group on Regional Climate (WCRP)
WGSIP	Working Group on Seasonal to Interannual Prediction
WMO	World Meteorological Organization
WMO SPICE	World Meteorological Organization's Solid Precipitation Intercomparison Experiment
WRMC	World Radiation Monitoring Center
WRF	Weather Research and Forecasting
WWRP	World Weather Research Programme
YESS	Young Earth System Scientists Community
YHS	Young Hydrologic Society

The
World Climate Research Programme (WCRP)
facilitates analysis and prediction of Earth system change for use in a range of practical applications of direct relevance, benefit and value to society.