GEWEX Hydroclimatology Panel (GHP)

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

1. Panel Activities

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

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

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

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

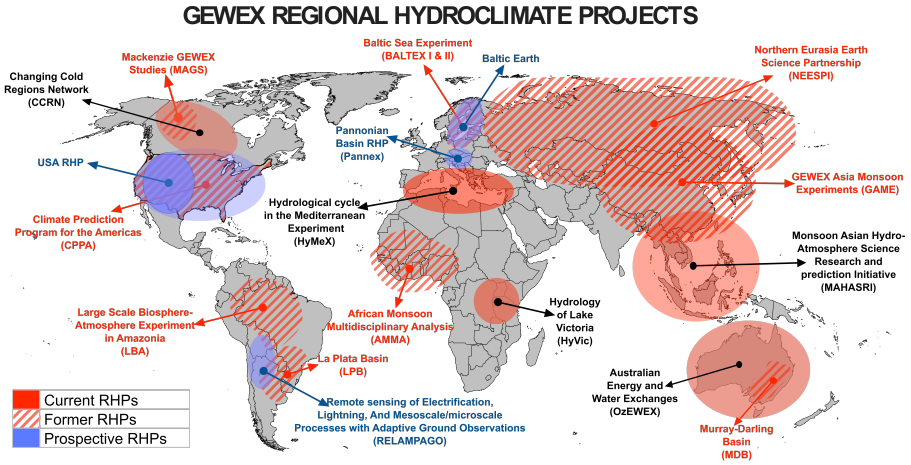

Figure 1: GHP Regional Hydroclimate Projects (RHPs)

2. New Projects in Place

GHP Regional Hydroclimate Projects (RHPs)

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

Active
- Changing Cold Regions Network (CCRN, Howard Wheater)
- HYdrological cycle in the Mediterranean Experiment (HyMex, Philippe Drobinski)

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

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

GHP Crosscutting Projects

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

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

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

3. New Projects and Planned Activities

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

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

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

Planned Activities

RHPs

HyMex

Plans for next five years:

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

MAHASRI

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

Crosscutting Projects

INTENSE

- Continued data acquisition and initiatives to update and expand the existing database and consideration given as to who will host the data and the development of new indices for sub-daily precipitation.
- Two publications are planned on the quality control of sub-daily precipitation. The first of these is on the site-specific rain gauge methods that have been applied in the UK. The second is on the further development of tests of spatial consistency with neighboring gauges and their application to produce a gridded 1-km hourly precipitation product for the UK. A more generic overview report is planned.
- International workshop planned in 2016 to include INTENSE partners (funded) and other interested parties (unfunded). This will take forward some of the questions and activities identified at the WCRP workshop that was held in Sydney, Australia in February 2015, in particular, the identification of indices for sub-daily precipitation.
- Construction and analysis of a comprehensive UK sub-hourly (10-15 minute) data set using UK rain gauge data is planned in conjunction with corresponding outputs from the UK Met Office high-resolution model for the southern UK. An associated paper will be written. A global scale analysis of the extreme precipitation-temperature relationship will be undertaken using sub-daily data sets gathered by INTENSE.

- Extreme value analysis methods will be applied to the quality controlled UK hourly precipitation data set and used to produce Intensity-Duration-Frequency (IDF) curves. This methodology will then be applied further to the sub-hourly UK data and global data sets as they become available.

- A session has been approved on high-resolution climate models at the UK Royal Meteorological Society annual conference and European Geophysical Union (EGU) General Assembly in 2016.
- A working group on very high-resolution models and common analyses of model outputs is under development.
- First analyses of global data observations and results.
- Preparation of INTENSE project website to include:
  - Project information
  - A central repository of INTENSE publications
  - The status of project activities
  - Access to data when it is available
  - Project related papers

Precipitation Near 0ºC

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

4. Science Highlights

RHPs

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

HyMex

After several years of preparation (writing international, implementation and operation plans), the collection of data began in 2010 to cover a 10-year period (Long Observation Period, LOP) including hydrometeorological and oceanic measurements from operational national weather and hydrological services, research hydrometeorological and oceanic observatories, and satellite data (Drobinski et al., 2014). Social impact data were also included (Llasat et al., 2013). An enhanced observation period (EOP) covering 2011-2015 was mainly dedicated to the hydrological monitoring of flash floods (Braud et al., 2014). Two special observation periods (SOP) were organized in fall 2012 and winter 2013 with heavy

instrumentation deployment (e.g., boundary layer pressurized balloons, instrumented ships, aircrafts, enhancement of ground based monitoring network, and radiosondes) dedicated to observations of heavy precipitation and flash floods (Ducrocq et al., 2014; Bousquet et al., 2015; Defer et al., 2015; Ferreti et al., 2015; Davolio et al., 2015; Jansà et al., 2015; Doerenbecher et al., 2015), and strong air-sea interaction and dense water formation (Estournel et al., in revision; Doerenbecher et al., 2015), respectively.

Cross-cuts

INTENSE

- Analysis of extreme hourly precipitation scaling with temperature using a new UK data set has shown an increase in precipitation intensities with temperature at around the rate prescribed by the Clausius-Clapeyron relation. An examination of the influence of indicators of large-scale circulation conditions has shown a dependency on the circulation regime. This work has been published in *Environmental Research Letters*.
- Further development of quality control (QC) procedures for sub-daily precipitation has been developed using the UK hourly data set. A two-part process was developed that may be used to automate the QC process, which involves: (i) identifying suspect rainfall amounts using >30 different site specific and multi-gauge tests and applying corresponding QC flags; and (ii) a "rule base" that may be used to apply either single QC flags or combinations thereof to mark suspected erroneous data.
- Quality controlled UK data has been used to create a gridded hourly rainfall product for the UK for 1991-2013. This is to be hosted online at the Centre for Ecology and Hydrology (CEH), together with the Gridded Estimates of Areal Rainfall (CEH-GEAR) daily gridded product. Sub-daily precipitation data has been collected for the US, Australia, Canada, Japan, Malaysia, UK, Netherlands, Singapore, and HadISD (UK Met Office sub-daily data set comprising precipitation and other variables). Data is now being received from Norway, Portugal, The Philippines and New Zealand. Contacts have been obtained for further countries and are being pursued.
- Additional QC has been undertaken on the US hourly precipitation data set as some issues with data quality were identified. This related to a change in the measurement resolution of rainfall amounts during the record. The knowledge gained has added to that derived from working with the UK data and will contribute to the need to develop widely applicable, standard quality control procedures for sub-daily data. Problems have also been encountered with the removal of zero precipitation hours, which need to be reinstated to allow investigation of the timing and persistence of extremes.
- An initial investigation of extreme hourly rainfall in the US that includes examining scaling with temperature and trends is currently ongoing.
- An initial examination of large-scale drivers of extreme precipitation has begun and is focusing on Europe, where good quality data is already available. Methods are being developed that will be applicable to other regions.
- An assessment of the extent to which convection-permitting climate models are needed for reliable future climate projections was conducted by an international team evaluating currently available model runs (paper submitted to *BAMS*).
- An assessment of hourly rainfall scaling with temperature in high resolution climate model runs was conducted which showed the same downturn at high temperatures as seen in observations (paper in press in *Nature Geoscience*).
- Sub-hourly precipitation from the same models is also being assessed

5. Science Issues

RHPs

MAHASRI

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

6. Contributions to the GEWEX Science Questions

a.) Observations and Predictions of Precipitation

RHPs

CCRN

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

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

HyMEX

- Significant progress in understanding the formation of heavy precipitating systems, notably over the Mediterranean Sea and the plains. These heavy rainfalls affect the coastal regions with strong impacts in southeastern France and northern Italy. The key role of the various mountain ranges and islands and storm processes themselves were highlighted
- HyMeX field campaign observations have helped to design, improve and evaluate new tools and methods of forecasting heavy precipitation and flash floods (e.g., the convection-permitting data assimilation and ensemble prediction systems)

- Seamless analysis of the heavy precipitation event of the HyMeX Intensive Observation Period-12, which extended from Spain to Italy during SOP-1 was performed. One study compares simulations from numerical simulation models with either explicit or parameterized convection, as well as regional climate models
- Heavy precipitation was characterized in a more bottoms-up approach with respect to the affected population and economy sectors in Spain, France, Italy and Greece
- Local social studies in southern France investigated the evolution of urban management policies with respect to floods and model mobility/transportation

Crosscutting Projects

INTENSE

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

Near 0°C

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

b.) Global Water Resource Systems

RHPs

CCRN

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

MAHASRI

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

HyMEX

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

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

c.) Changes in Extremes

RHPs

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

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

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

Crosscutting Projects

INTENSE

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

Near 0°C

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

d.) Water and Energy Cycles

RHPs

CCRN

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

MAHASRI

- Studies of stable water isotopes, such as Jasechko et al. (2013) in *Nature* and Good et al. (2015) in *Science*, where the partition of evapotranspiration was investigated. An observational study with new vapor isotope measurement over a paddy field in Japan was also conducted, and confirmed that the transpiration fraction was well controlled by evolution of LAI. The global mean transpiration fraction was estimated to be 62% (Wei et al., 2015)
- Long-term evapotranspiration (ET) was estimated by satellite regressed with in situ eddy covariance measurement and meteorological datasets over dry land East Asia from 1982 through 2009. Ecosystem ET showed decreased trends over 61% of the DEA region during this period, especially in most regions of Mongolia and eastern Inner Mongolia due to decreased precipitation. Water balance (the difference between precipitation and ecosystem ET) decreased substantially during the summer and growing season (Xia et al., 2015)
- The effects of surface water runoff on the interannual sea surface temperature (SST) variations in the northern Bay of Bengal were detected (Nagura et al., 2015)
- Using satellite-derived EXAM solar radiation data, the three main budgets (i.e., radiation, heat and water budgets, of the land surface simulation was found to be improved; Kotsuki et al., 2015)
- Multi-site real-time data management server system FluxPro was created for the energy, water and carbon dioxide flux densities by in situ eddy covariance measurements (Kim et al., 2015)

HyMEX

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

7. Contributions to the WCRP Grand Challenges

a.) Provision of skillful future climate information on regional scales

b.) Regional sea-level rise

c.) Cryosphere response to climate change

CCRN

Projection results will be used to address regional scale effects on land and water resources, using the large-scale models developed in Theme C. This includes the change in river flows for the Saskatchewan, Peace-Athabasca and Mackenzie River Basins, and effects of climate change for specific ecosystems.
Whether future changes cross 'tipping points' in Earth system behavior, leading to further extremes and dramatic system changes, such as deglaciation, permafrost disappearance and terrestrial ecosystem transition will be determined. Outputs from this analysis will thus be used to identify global climatological controls on broad regional water resource response, and hence to enable specific design, operational or policy development problems under climate change to be addressed in Theme E. To address this issue, specific analyses will be carried out utilizing future conditions along with threshold guidance on conditions needed to trigger a fundamental shift.

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

CCRN

Specific scientific contributions will involve the assessment of large and synoptic scale atmospheric circulation patterns as they relate to observed temporal and spatial trends and variability (including extremes) in the hydroclimate over the study region. In addition, studies will be undertaken to understand the mechanisms that link the regional water and energy response to large-scale forcings. This includes the role of the orographic barrier in amplifying the region's climate sensitivity to upstream large-scale forcings.
Statistical techniques and diagnostic studies will be carried out to examine the coupled mode of variability between low-frequency forcings, such as SST anomalies, large-scale circulation patterns and warm-season synoptic activities.
Changes in large-scale atmospheric circulation will be assessed from CMIP5 and other projections. There subsequent effects on the continental synoptic activities and associated heat and moisture transports which affect critically regional temperature and precipitation responses will be assessed from the downscaled projections.

MAHASRI

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

e.) Past and future changes in water availability

CCRN

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

Progress has also been made on the quantification of effects of uncertainty in driving variables, and new methods to accommodate this, and in the assimilation of other satellite products in the large-scale hydrological models, in particular GRACE (in collaboration with Natural Resources Canada, NRCan)
Individual research progress on atmospheric circulation patterns, instabilities for generating convection, large-scale forcing for drought, precipitation phase changes, winter precipitation extremes, surface hydrologic changes, and runoff, with a number of journal submissions and draft manuscripts based on these studies.

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

Various improvements to CLASS and issues under development, including lakes, wetlands, snow/ mountain hydrology, frozen soils and infiltration, prairie hydrology, water management, coupled land-surface–groundwater, glacier dynamics, and linkage between hydrology, climate, and vegetation.
Setup and evaluation of the MESH hydrological model over both the Mackenzie and Saskatchewan River basins, with several key focal issues identified for future work, including input uncertainty, soil depth and permafrost initialization/representation, wetlands, and water management—channel hydraulics may be a major limiting factor for basin-scale modeling of the Mackenzie.

An important development for the network is that Li, working with NCAR, is producing 4km WRF climate simulations for the entire CCRN domain (14 years historical simulations, plus pseudo warming simulations of future climate). This provides comparative data for Theme B, C and D modeling and large-scale climate analysis. Similarly, collaboration with Sushama's CNRCWP provides access to the regional climate model CanRCM5, based on CLASS, which provides us with a platform for coupled modeling and additional simulations for large scale analysis

Theme/work package D1
Studies will be undertaken to understand the mechanisms which link the regional water and energy response to large-scale forcings. This includes the role of the orographic barrier in amplifying the region's climate sensitivity to upstream large-scale forcings. Statistical techniques and diagnostic studies will be carried out to examine the coupled mode of variability between low-frequency forcings such as SST anomalies, large-scale circulation patterns and warm-season synoptic activities.
Another focus will be on precipitation. Studies include the occurrence of precipitation extremes from droughts to heavy precipitation including variability and simultaneous occurrence. The regional and larger scale factors leading to such events will be determined. The factors leading to the changing occurrence of winter precipitation will be examined. As well, changes in the occurrence of extreme precipitation rates will be determined over some areas and linked with the large and regional scales forcing factors.

Theme/work package D2
Research on future conditions over the domain has given some indication of future states and interactions although with a great deal of uncertainty. In general, results predict continued increase in temperature – more in the cold season and at higher elevations. They also expect an overall increase in precipitation, but with considerable spatial and temporal variability. Northern regions are projected to see more increases in precipitation than southern regions of the study area, which has potentially huge implications for water resources. In parallel, there is a projected increase to in the frequency, intensity and duration of future droughts including more hot droughts. Overall, future water cycle related variability remains a huge knowledge gap.

Given the determination and understanding of changing conditions over the region, it is critical to assess how future conditions will evolve, in particular factors affecting water resources and ecosystems. Validated

models from Theme C will be a critical basis for addressing this issue including our degree of uncertainty. Projections of future conditions over the region will be developed by CCRN (4 km WRF pseudo-warming) and others will be obtained (CanRCM5 projections, with improved CLASS algorithms and explicit representation of feedbacks).

Theme/work package D3
Changes in the large-scale atmospheric circulation will be assessed from CMIP5 and other projections. There subsequent effects on the continental synoptic activities and associated heat and moisture transports which affect critically regional temperature and precipitation responses will be assessed from the downscaled projections. The initial focus will be on projections of temperature, precipitation, and their variation. Key focal points will be on regional and local scale temperature changes and variations of prolonged summer hot periods, and extension of above freezing conditions. In terms of precipitation, the focus will be on the development of drought, heavy precipitation, extreme precipitation rates, as well as the changing phase of precipitation.

Theme/work package D4
The projection results will be used to address regional scale effects on land and water resources, using the large-scale models developed in Theme C. This includes the change in river flows for the Saskatchewan, Peace-Athabasca and Mackenzie River Basins, and effects of climate change for specific ecosystems.

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

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

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

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

f.) Science underpinning the prediction and attribution of extreme events

CCRN
- A comprehensive focal investigation of the June 2013 extreme weather and flooding events that affected southwestern Alberta and downstream areas, including a number of submissions to a special issue of *Hydrological Processes* dealing with meteorological and hydrological aspects. See progress updates by Kochtubajda, Li, Pomeroy, Stewart, Szeto, Thériault.
- Focal examination of extreme events (floods, fires, droughts) affecting the CCRN region from 2009–2011 with publications forthcoming. See progress updates by Hanesiak, Kochtubajda, Stewart, Szeto.

- Initial work towards an interdisciplinary examination of the 2014 forest fires in the Northwest Territories, involving contributions from university and government organizations. See progress updates by Baltzer, Bonsal, Johnstone, Kochtubajda, Quinton, Stewart, Turetsky.

Theme/work package D1
Specific scientific contributions will involve the assessment of large and synoptic scale atmospheric circulation patterns as they relate to observed temporal and spatial trends and variability (including extremes) in hydro-climate over the study region.

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

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

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

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

INTENSE
The INTENSE project is focused on meeting the data requirements and examining trends/ variability and processes associated with the core Grand Challenge events of "heavy precipitation" and "drought."
Data collection activities will contribute information (overarching theme: document) that could underpin detection and attribution studies and model evaluation by collating and quality controlling sub-daily precipitation data (providing data that is extensive in time and space). INTENSE is also examining how sub-daily precipitation extremes may be defined through the use of relevant indices that have to date only been established on daily timescales.

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

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

8. Cooperation with Other Projects

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

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

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

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

INTENSE has connections with the WCRP Grand Challenge on Extremes.

9. Workshops/Meetings Held

CCRN

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

MAHASRI

- 36th Congress and International Seminar, "Meteorology and Climate" (25-28 February 2015, Gauhati University, India)
- Indo-Japan Joint Workshop on Natural Disaster and Human Activity in the Northeastern Indian Subcontinent. Cooperating Atmospheric scientists, Geographers and Social scientists for disaster and Human Activities in South Asia, North Eastern Hill University (2 March 2015, Shillong, India)
- Asian monsoon Hydroclimate–Review of MAHASRI and Beyond (4-5 March 2015, Nagoya, Japan)
- The Fourth International Workshop of Climatic Changes and Their Effects on Agriculture in Asian Monsoon Region (GRENE-CAAM Workshop) (10-12 March 2015, Hanoi, Vietnam)
- International Session on Asian monsoon Hydroclimate (24-28 May 2015, JpGU at Chiba, Japan)
- AOGS2015 "AMY 2015 Session" (2-7 August 2015, Singapore)
- APHW HS session on Asian monsoon hydroclimate (2-7 August 2015, Singapore)

HyMeX

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

OzEWEX

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

INTENSE

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

10. Workshops/Meetings Planned

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

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

HYMEX
HyMex workshop in mid-2017

OzEWEX
Annual workshop, dates and location TBD

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

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

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

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

11. Other Meetings Attended on Behalf of GEWEX or GHP

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

12. List of Key Publications

Bhatt, B. C., S. Sobolowski and A. Higuchi, 2015. Simulation of diurnal rainfall variability over the maritime continent with a high-resolution regional climate model, *Journal of the Meteorological Society of Japan*, doi:10.2151/jmsj.2015-052. (Accepted)
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Doerenbecher A., Basdevant C., Drobinski P., Bernard F., Durand P., Cocquerez P., Verdier N., Vargas A., 2015. Low atmosphere drifting balloons: platforms for environment monitoring and forecast improvement. *Bull. Amer. Meteorol. Soc*., in revision.

Drobinski P., Ducrocq V., Alpert P., Anagnostou E., Béranger K., Borga M., Braud I., Chanzy A., Davolio S., Delrieu G., Estournel C., Filali Boubrahmi N., Font J., Grubisic V., Gualdi S., Homar V., Ivancan-Picek

B., Kottmeier C., Kotroni V., Lagouvardos K., Lionello P., Llasat M.C., Ludwig W., Lutoff C., Mariotti A., Richard E., Romero R., Rotunno R., Roussot O., Ruin I., Somot S., Taupier-Letage I., Tintore J., Uijlenhoet R., Wernli H., 2014. HyMeX, a 10-year multidisciplinary program on the Mediterranean water cycle. *Bull. Amer. Meteorol. Soc*., 95, 1063-1082.

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13. List of Members and Term Dates

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

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