GHP Report for the GEWEX SSG-30 Meeting

GEWEX Hydroclimatology Panel (GHP)
Reporting Period: January 2017 – December 2017
Starting date:
End date (where appropriate):
URL:
Chair(s) and term dates: Jason Evans (2012-2019), Joan Cuxart Rodamilans (2017-2020)

Please report on the following:

1. **2-3 major panel accomplishments or significant contributions for the reporting period**

- Active RHPs (CCRN, HyMex, Baltic Earth) very productive. CCRN is in final stages and will likely be followed by a larger Canadian effort through their Global Water Futures initiative. Baltic Earth demonstrates considerable maturity as a new RHP, building on efforts of previous Baltex RHPs.
- A new RHP focused on the Pannonian Basin (PannEx), in its prospective phase, has progressed very significantly and has applied to the status of Initiating RHP. A new effort in South America (AndEx) has been proposed and is under development.
- The CC activities are very productive and there was an expression of interest in the GHP annual meeting to set a new one on the water cycle in the Third-Pole region.

2. **Panel activities**

The GEWEX Hydroclimatology Panel (GHP), has been organized around several Regional Hydroclimate Projects (RHPs) and a number of crosscutting (CC) science topics (and global data centres). The aim of GHP is especially focused on improving the knowledge about global climate change and its impacts at regional scales and to propagate that knowledge from one region to the other, then, synthesizing 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 http://www.gewex.org/pdfs/GEWEX_Science_Questions_final.pdf and the related WCRP Grand Challenges http://www.wcrp-climate.org/grandcha.shtml, are key to the strategy for implementation of the Panel activities. Discussions on a number of important issues that range from monsoons, to extremes and how to help coordinate the number of national/regional initiatives in those areas, have been fostered by the Co-Chairs. These include collaborations with groups including GDIS, GDAP, GLASS, CLIVAR, CliC and WGRC that have common interests in land-surface processes.

In addition, in keeping with the need to be responsive to the WCRP/GEWEX main challenges and scientific questions GHP has organized itself to address the GEWEX science questions 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 Cross-Cut projects allow GHP to propagate knowledge from one region to the other and synthesize results at the global scale. They also allow development and testing of applications developed with the new understanding that they deliver both science advances and applicable outcomes for stakeholders and services.

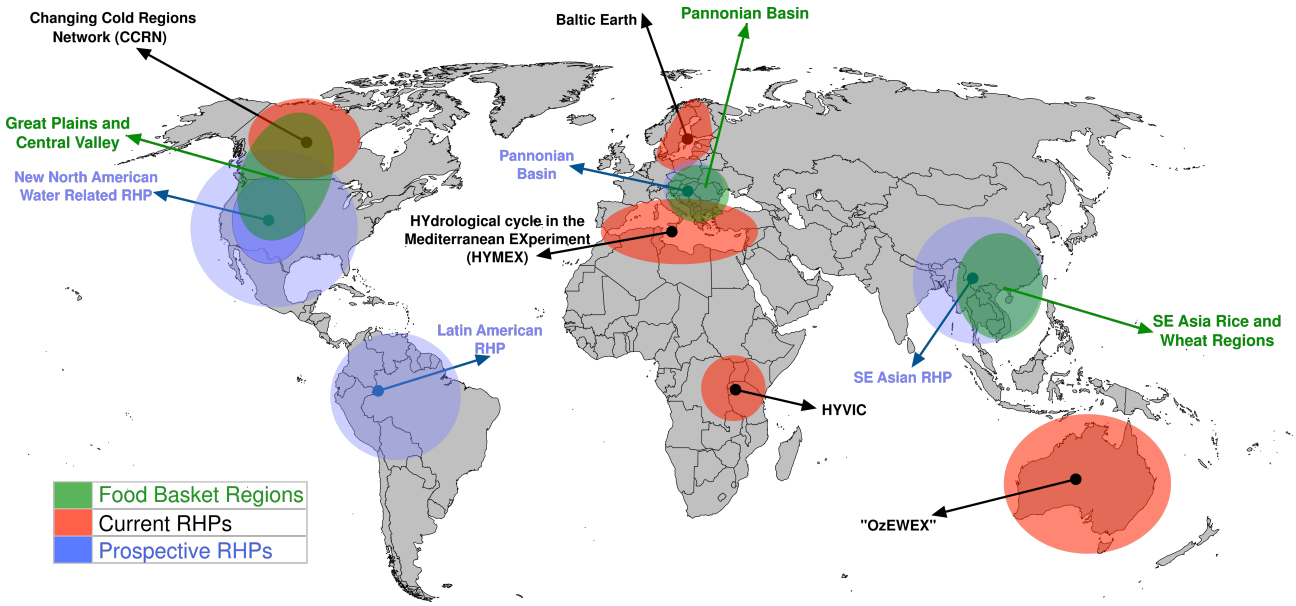

Figure 1: GHP Regional Hydroclimate Projects (RHPs) and Water for the Food Baskets of the World focus regions

GHP Regional Hydroclimatic Projects List

Currently active

- CCRN (Howard Wheater)
- HyMex (Philippe Drobinski)
- BalticEarth (Markus Meier)

Initiating

- OzEWEX (Albert VanDijk/Seth Westra)
- HyVic (Fred Semanzzi)

Proposed

- PannEx (Monika Lakatos/Ivan Güttler)
- AndEx (German Poveda/René Garreaud)

GHP Cross-Cut Projects List

Currently active

- INTENSE (Sub-daily precipitation) (H. Fowler)
- Cold/Shoulder Season Precipitation Near 0°C, (R. Stewart/P. Groisman)
- INARCH (Mountain Hydrology) (J. Pomeroy)

Proposed

- Including water management in large scale models (R. Harding/J. Polcher)

3. **New projects in place**

No new projects in place.

4. **New projects and activities being planned, including timeline**

New Projects

The Pannonian Basin RHP (PannEx) held its third workshop in Cluj-Napoca (Romania) in March in order to get feedback from local scientists on the draft white paper and garner further participation from the regions scientists. The White Book has been completed, comprising five Flagship Questions dealing with Agronomy, Air Quality, Sustainable Development, Water management and Education. Also a Science and Implementation plan has been put together. These two documents were presented in the GHP annual meeting in Kathmandu, where the chair of PannEx, M. Lakatos, applied for the status of Initiating RHP. The panel agreed to do so in view of the good progress of the action and proposes to the SSG that this status is accorded to PannEx. The action has now defined "Task Teams" so that the participants can tackle specific issues and proceed to apply for funding in open calls. A PannEx special session is planned at the European Meteorological Society (EMS) annual meeting to be held in Budapest, Hungary, 3-7 September 2018. A fourth workshop is planned as a side meeting to the EMS meeting.

The Andean RHP (AndEx) held its inception meeting at Medellin early December, hosted by Prof. German Poveda, and attended by a few scientists of the different Andean countries and two representatives of GEWEX. An agreement was reached to explore the setting of an RHP covering the Andes range and its surrounding areas with provisional title "ANDEX: a hydroclimate research program for the Andes" and first-term co-chairs G. Poveda (UNAL, Medellín, Colombia) and R. Garreaud (USC, Santiago, Chile).

An open workshop will be held in Santiago de Chile end of October 2018, in conjunction with the annual GHP meeting, to debate on the objectives following a draft White Book that will contain the following main issues: i) the hydroclimate of the Andes (paleoclimate, patterns and drivers) ; ii) climate and environmental change (trends, regional modelling, deforestation and land use changes, erosion) ; iii) high impact events (severe weather, flooding, droughts, landslides, extremes, disaster management, urban pollution); iv) cryosphere of the Andes (glaciers, seasonal snow cover, paramos, impact on water management, interaction with vulcano eruptions). Identification of available and supplementary observations and data are a need and a number of applications were listed (agriculture, energy production, access to fresh water, ...)

Planned Activities *(extracted from the annual reports)*

RHPs

CCRN

CCRN will be coming to an official end in March 2018. As we enter the final six months of the programme we are focused on incorporating scenarios of change into our regional MESH modelling of the Mackenzie and Saskatchewan River systems and examining projected future Earth system change and responses for the 21st century. We will be looking carefully at the results and feeding some of this back to our fine scale models to explore process interactions and feedbacks in more detail and gain further insights into system change. We have a workshop

planned for November 2-3 2017(http://ccrnetwork.ca/science/workshops/index.php) to examine the results, plan final model runs and analyses, and develop output products such as model datasets and papers for publication. Our final network symposium, The CCRN Finale, is planned for March 4-7, 2018, where the network will gather for the last time to review our accomplishments, to plan products and publications as a legacy of CCRN, to connect with key stakeholders and partner organizations, and to look to the future in follow-on initiatives (see below). We currently have our two special issues (ESSD and HESS) open for several months beyond the end date of CCRN, and will continue to populate these. We will also be developing a film documentary to showcase the observed Earth system changes, CCRN's science advancements (including projections of future change) and their societal relevance, and the legacy of this important research initiative.

As CCRN is ending, we note a relatively new programme that is ramping up and in many respects following on from, and expanding upon, some of the activities and scientific issues being addressed in CCRN. The Global Water Futures (GWF; www.globalwaterfutures.ca) Project is a $143 Million, seven year (2016–2023), University of Saskatchewan-led research initiative that has an overall mission to improve disaster warning, predict water futures, and inform adaptation to change and risk management. GWF is the largest investment of its kind in university-led water research and aims to provide global leadership in water science for cold regions and to address the strategic needs of the Canadian economy in adapting to change and managing the risks of uncertain water futures and extreme events. Its geographic focus will include not only the Mackenzie and Saskatchewan River Basins, but a number of other major watersheds across all of Canada, while its science focus will expand to include water quality, social science, health, and water governance.

We envision our linkage to the GEWEX Hydroclimate Panel continuing through this major new initiative, under the leadership and direction of Distinguished Professor John Pomeroy, who was co-PI for CCRN. The CCRN secretariat staff has been expanded to manage this large and complex programme, and will benefit from including many of the same support and management staff, thus retaining continuity and experience. Most of the CCRN core team and collaborators are also actively involved in GWF and its activities.

HyMex

Preparation of MED-CORDEX2

The 10th HyMeX workshop was the opportunity to discuss the implementation of the MED-CORDEX flagship pilot studies (FPS) which can be seen as the follow-up if the first MED-CORDEX exercise (Ruti et al., 2016). There are 3 MED-CORDEX FPS. One FPS is dedicated to convection and is shared between MED-CORDEX and EURO-CORDEX. It aims at investigating convective-scale events, their processes and their changes in a few key regions of Europe and the Mediterranean using convection-permitting RCMs. The second MED-CORDEX FPS focuses on air-sea interactions, with special emphasis on the role of small scale ocean processes and waves. The third MED-CORDEX FPS is dedicated to the role of the natural and anthropogenic aerosols in the Mediterranean region.

Future field campaigns

Three campaigns are also planned in the frame of HyMeX, to complement the already conducted fields experiments in the frame of the Enhanced Observation Period (Braud et al., 2014) and Special Observation Periods (SOP1, Ducrocq et al., 2014; Ferretti et al., 2014 and SOP2, Estournel et al., 2016) (see Drobinski et al., 2014 for a full overview). The field experiments in preparation are (Fig. 3):

- EXAEDRE to be conducted in September 2018 on atmospheric electricity in complement to what has been performed during SOP1 (Defer et al., 2015)
- PERLE oceanic experiment to be conducted in October 2018, February 2019 and June-July 2020 in complement to what has been performed during SOP2 (Estournel et al., 2016) but in the Levantine region in the Eastern Mediterranean
- LIAISE to be conducted between April 2020 and March 2021 which focuses on land surface interactions over the Iberian semi-arid environment

Figure 3: Location of the future field campaigns planned in the frame of HyMeX.

Baltic Earth

INTEGRAL

Several of the European nations are investing in the Integrated Carbon Observation System (ICOS). The overall aim of ICOS is to provide European-wide carbon dioxide and other greenhouse gas (GG) concentration and flux data, but integration for the Baltic Sea region has not been pursued, and the added value of ICOS and related infrastructure for the Baltic Sea ecosystem assessment has not been exploited at all. INTEGRAL will

- Integrate the different data streams of ICOS and related infrastructure in the pan-Baltic area
- Provide best charts of seasonal carbon dioxide and GG flux over the Baltic Sea, including advanced remote sensing approaches

- Integrate the carbon system into a high resolution 3D-model, which will allow for a better description of the biogeochemical coupling of eutrophication and deoxygenation
- Demonstrate the added value for a better biogeochemical ecosystem status description of the Baltic Sea
- Advise the implementation of ICOS in the southeastern countries of the Baltic, and actively promote components strengthening the value for Baltic Sea ecosystem status assessment
- Develop, in close interaction with stakeholders, the strategy for a better, cost efficient monitoring approach for the Baltic Sea by integration of ICOS and related data

OzEWEX

2017 Australian Climate and Water Summer Institute

Scheduled over a six week period from 11-23 December 2017 and 7 January – 2 February 2018. 16 applicants were selected to attend the institute. The 2017/18 event will focus on the following five themes:

- Forecasts – using weather, climate and water forecasts to benefit economy, society or environment.
- Droughts – quantifying and predicting the economic and environmental impacts of drought.
- Floods – improving flood risk assessment and warning, increasing flood resilience, and supporting emergency response.
- Water Sharing – quantifying available water resources, increasing the benefits of water use for people and environment.
- Data integration – integrating observation networks, remote sensing, and modelling through data discovery, data fusion and assimilation.

HyVic

HyVic was designed to focus on the Lake Victoria basin involving the 5 countries of Burundi, Rwanda, Kenya, Tanzania and Uganda belonging to the East African Community (EAC) regional economic union. Indeed the funds for the Feasibility Study that led to the establishment of HyVic were provided by the EAC. However, it is clear now that the most viable strategy is for HyVic to serve a larger group of regional alliance nations, the IGAD (Intergovernmental Authority on Development) comprising the nations of Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan and Uganda. HyVic has been invited through Fredrick Semazzi to be funded for providing scientific oversight for ICPAC, which is under IGAD. This means that HyVic has to take on larger regional responsibility that includes Djibouti, Eritrea, Ethiopia, Somalia, South Sudan and Sudan which are not included in its present mandate. The composition of HyVic panel must also reflect the expanded geographical region. Thus HyVic will be reconfigured (and renamed) to reflect this expanded mandate. This will involve development of a new science plan and reapplication to GHP for RHP status.

Cross-cut Projects

INTENSE (sub-daily precipitation)

Continued data acquisition and initiatives to update and expand the existing database. Thought given to where to host data collection and calculation of new indices for sub-daily precipitation. Talks are developing with ECA&D among others. Data will be held at an approved data centre (probably DWD) where freely distributable, and sub-daily seasonal/monthly indices will be developed for all stations. Other station metrics will also be calculated such as diurnal cycle or precipitation-temperature scaling relation. The indices will be made available to the public through a dedicated web site, which will also indicate data availability and links to data providers and licensing arrangements etc. Publications are planned on analysing the indices.

A further publication is planned on the quality control of sub-daily precipitation assessing the further development of tests of spatial consistency with neighbouring gauges and their application to produce a gridded 1km hourly precipitation product for the UK. Developing this towards a generic software package which can be applied internationally (including assessment of existing methods from Met Services). These will be quality controlled using methods developed on UK data (and adapted to local circumstances using the CLIMDEX daily indices).

Planned analysis include: Global scale analysis of trends in sub-daily extreme precipitation; Working collaboratively with Andy Prein at NCAR on CPM and observations over the US, trying to understand the role of thermodynamics and dynamics in driving sub-daily precipitation extremes; Extreme value analysis methods will be applied to the quality controlled UK hourly precipitation dataset and used to produce Intensity-Duration-Frequency (IDF) curves to support design and planning decisions. This methodology will then be applied further to the sub-hourly UK data and global datasets as they become available; First analyses of data observations from around the world and first global results; First analyses of large-scale drivers of sub-daily extreme precipitation across multiple geographical regions.

Further develop the working group on very high resolution models and common analyses of model outputs – progress was made on this at the INTENSE September meeting. A CORDEX Flagship Pilot study has been approved on convection-permitting model comparison over a common domain. The study domain is the European Alps and Mediterranean. The project will propose a set of common model diagnostics to align with observed indices being calculated.

Initiation of efforts to explore how sub-hourly in situ and satellite observations can help each other. Remote sensing should be useful because of its spatial coverage and in situ can be a great source to assess satellite performance at each point. Assessing the diurnal cycle of remotely sensed precipitation estimates using stations where and when available. The scaling differences (point versus grid) is another important topic that needs further exploration.

INARCH (mountain hydrology)

- Participate in snow model comparisons at sites where inputs can measured/defined through links with GLASS (Richard Essery).
- Reduce measurement uncertainty by implementing WMO SPICE recommendations for solid precipitation measurements at all sites and making contact with Global Cryosphere Watch for how to further improve measurement quality

- Develop a downscaling toolbox by examining various techniques for statistical, dynamical and medium complexity downscaling.
- Continue climate sensitivity comparative analysis of various alpine basins using "standard virtual basin" modelling to compare the response of snowcover, snowpack, glaciers and hydrology to variations in temperature and precipitation in various climate regimes.
- The ESSD Special Issue will continue to receive submissions until 6 April, 2018, while other journals will be approached for a special INARCH issue on mountain snow and ice hydrology that includes references to downscaling, processes and diagnosis of climate change impacts.
- Updates to the INARCH website (http://www.usask.ca/inarch/) will include a downscaling toolbox with a link to methods, as well as metadata for catchments and links to DOI data. A technical document is being planned with UNESCO on "Best Practices in Instrumenting Mountain Research Catchments," as is a policy-relevant publication with UNESCO on "Risks to World Water Security from Changing Mountain Snow and Ice Hydrology."

Near 0°C Precipitation

- We submitted proposals to U.S. and Russian funding agencies to support our further activity on the Cross-cut Project keeping in mind that we shall need to (a) go into more details of near-0°C precipitation events and associated perils (changes in timing, intensity, and spatial pattern, handling the inhomogeneity in the data); (b) modify and complete our analyses for those countries, where synoptic information about freezing events is not readily available (first of all, for East Asia countries); and (c) assess the impact of perils associated with the near 0°C precipitation and project their changes in the next decades.
- A concerted effort continues to be made to quality control Canadian operational near 0°C regions and to utilize this information to characterize these regions. This includes the many types of precipitation as well as the associated state variables. It is intended that, once complete, this dataset will form the basis of a journal article and also be made available to everyone via a web portal.

5. Science highlights

- Fine scale model advancements have included improvement in process representation within the Cold Regions Hydrological Model (CRHM; www.usask.ca/hydrology/CRHM.php), and enhanced computational efficiency and landscape representation within the next generation Canadian Hydrological Model (CHM; http://ccrnetwork.ca/science/workshops/summer-2017-modelling-workshop/files/marsh_ccrn_modelling2017.pdf), both developed at the University of Saskatchewan's Centre for Hydrology. CRHM has been set up and applied at selected WECC observatories for long-term historical runs and diagnosis of hydrological change. Cordeiro et al., 2017; Mahmood et al., 2016; Krogh et al., 2017; Rasouli et al., 2014) and further papers are in development.

- CCRN have made major advancements in regional climate, land surface, and hydrological model development and applications. This work has involved close collaboration and a strong partnership with Environment and Climate Change Canada (ECCC) to help them incorporate improvements into their research and operational models. Our main focus is the ECCC Canadian LAnd Surface Scheme (CLASS), Modélisation Environmentale Communautaire (MEC) – Surface and Hydrology (MESH), and Canadian Terrestrial Ecosystem Model (CTEM) models. The main effort has concentrated on developing and improving large-scale MESH models of the Mackenzie and Saskatchewan River systems, and within this, improving the representation of various processes such as permafrost, wetlands, hydrodynamics and large lakes, and snow processes, and also exploring ways of better handling spatial discretization (especially in mountainous terrain) and in particular, the effects of water management—CCRN is strongly linked to a GEWEX cross-cut project on including water management in large scale models. Various other activities have supported this work, which has progressed well to the point where we have working models in place for both major basins and we are in the midst of running future climate simulations and incorporating scenarios of landscape and ecological change. These activities were reviewed and discussed in detail at a recent modelling workshop (www.ccrnetwork.ca/science/workshops/summer-2017-modelling-workshop).
- CCRN have focused on in-depth analyses of recent extreme events in western Canada. This includes the 2013 Calgary flood (http://ccrnetwork.ca//science/2013-Alberta-flood), summer flooding in the prairies (http://ccrnetwork.ca//outputs/information-products/2014-assiniboine-flood), severe dry conditions in 2015 (Szeto et al., 2016) and 2017, extreme wildfires (Northwest Territories (2014), Saskatchewan (2015), Fort McMurray (2016), British Columbia and southern Alberta (2017), and more). This has included analyses from a variety of perspectives (climate, ecology, hydrology, modelling, etc.) and scales (continental to regional and local).

- Assessment of the extent to which very fine resolution convection-permitting climate models are needed for reliable future climate projections by an international team has evaluated currently available model runs and published a paper in BAMS in early 2017 (DOI: 10.1175/BAMS-D-15-0004.1).
- Paper published in GRL on the spatial scales of rain cells in connection to the super Clausius-Clapeyron (CC) scaling of rainfall intensities. An analysis of rain radar data using a cloud tracking algorithm has been performed. The results show that only large convective cells produce super CC scaling. Also a remarked increase in convective cell size is found for high humidity (dew point temperatures), which is needed to sustain the super CC scaling (Lochbihler et al.; DOI: 10.1002/2017GL074857).

- We found significant changes in the frequency of freezing rain precipitation occurrence over the extratropical regions of the Northern Hemisphere. In the Arctic and sub-Arctic, step-wise increases in their occurrence in the last decade have been found and in the south decreases have been observed (Groisman et al. 2016, Environ. Res. Lett.).
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6. Science issues

7. **Contributions to developing GEWEX science; fit into GEWEX imperatives**
8. **List contributions to the GEWEX Science Questions and plans to include these.**
    - **Observations and Predictions of Precipitation**

RHPs

CCRN

- There has been much 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. Bonsal et al. (2017), Brimelow et al. (2017), Kochtubajda et al. (2017), Zhang et al. (2017)
- Measurements, correction and evaluation of precipitation datasets. Pan et al. (2016), Scaff et al. (2015), Smith et al. (2017)
- Assessments of various precipitation products and remotely sensed observations, including GPM, and characterization and regionalization of precipitation and drought characteristics over western Canada, with several papers in draft. Asong et al. (2015, 2016, 2017), Khaliq et al. (2015), Masud et al. (2015), Wong et al. (2017)
- A major CCRN effort was centered on a comprehensive focal examination of the extreme weather and flooding in southern Alberta in June 2013, focusing on meteorological, hydrological, and water management aspects of the flood. This has led to a collection papers being published in a special issue of Hydrological Processes. (See http://ccrnetwork.ca//science/2013-Alberta-flood for further details, information products and links to all published papers.)
- Focal examination of extreme events (floods, fires, droughts) affecting the CCRN region from 2009–2017 with several papers published and others forthcoming. Publications include those listed above and: Blouin et al. (2016), Brimelow et al. (2014, 2015), Masud et al. (2016), Szeto et al. (2015)

HyMex

In 2015-2016, a number of inter-model studies systematically analyzed the ability of regional climate models to reproduce precipitation using HyMeX data (including satellite) but also cloud resolving models (e.g. NWP) operated in the frame of HyMeX (Khodayar et al., 2016, Rysman et al., 2017) and their sensitivity to ocean / atmosphere feedback on the continent (Panthou et al., 2017, Cavicchia et al., 2017) and the sea (Lebeaupin Brossier et al., 2015). A similar approach has been taken in the context of particular phenomena, in particular Mediterranean cyclogenesis (Flaounas et al., 2015a, b).

Baltic Earth

- A coupling of atmosphere and ocean can improve the dry biases for different regional climate models but not always; but particularly for summer heavy precipitation over central Europe. Ho-Hagemann HTM, Gröger M, Rockel B, Zahn M, Geyer B, Meier HEM, 2017. Effects of air-sea coupling over the North Sea and the Baltic Sea on simulated summer precipitation over Central Europe. Climate Dynamics 48:1-26, March 2017
- Liisi Jakobson, Erko Jakobson, Piia Post, and Jaak Jaagus 2017. Atmospheric teleconnections between the Arctic and the Baltic Sea regions. Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2017-37, 2017 (under review)
- Liga Bethere, Juris Sennikovs, and Uldis Bethers 2017 Climate indices for Baltic States from principal component analysis. Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2017-34, 2017

- Julia Jeworrek, Lichuan Wu, Christian Dieterich, and Anna Rutgersson 2017. Characteristics of convective snow bands along the Swedish east coast. Earth Syst. Dynam., 8, 163-175, https://doi.org/10.5194/esd-8-163-2017, 2017

INTENSE

- Collation of global sub-daily precipitation data (see section 1 above 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 more widely in the context of global data acquisition (see above and also see section 1)
- Existing work is examining 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.

Precipitation near 0°C

- Datasets are being carefully produced that document precipitation near 0°C.
- Initial assessments of projections are being made and limitations in model physics have been identified and steps have been and continue to be taken to rectify these.

- **Global Water Resource Systems**

RHPs

CCRN

- Completion of inventories and assessments of Earth system change at many WECC observatories and across the CCRN domain. Baltzer et al. (2013), Bash and Marshall (2014), Bonsal et al. (2017), Connon et al. (2014), DeBeer et al. (2015, 2016), Demuth et al. (2014), Dumanski et al. (2015), Ehsansadeh et al. (2014), Harder et al. (2015), Hayashi and Farrow (2014), Ireson et al. (2015), Maillet et al. (2017), Mamet et al. (2017), Marshall (2014b), Patankar et al. (2015), Paznekas et al. (2015), Quinton and Baltzer (2013b), Shi et al. (2015), Shook and Pomeroy (2015), Spence et al. (2015), Yang et al. (2014b).
- 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 with a number of draft papers underway and some recent publications. Much of this work (at various stages of development) had been reviewed and synthesized at a recent workshop (see http://ccrnetwork.ca//science/workshops/summer-2017-modelling-workshop). Hassanzadeh et al. (2014, 2015), Mekonnen et al. (2014), Nazemi and Wheater (2014a, 2014b, 2015a, 2015b), Haghnegahdar and Razavi (2017).
- Progress with assimilation of remotely sensed data to constrain large scale hydrological models, and examination of scaling effects in the models (Yassin et al., 2017).
- Extension of previous work on vulnerability analysis of water resource systems in the SaskRB – now includes risk-based hydro-economic analysis for Saskatchewan. Hassanzadeh et al. (2015)

HyMex

The EartH2Observe project which contributes to HyMeX has produced a new atmospheric forcing data set (E2OFD) from satellite Earth Observations (EO) to drive land surface models (LSM). It is at 0.25° resolution, over the ERA-I re-analysis period and includes the new and original rainfall estimates MSWEP (Beck et al., 2017). The product is global but its quality over

the Mediterranean region has been analysed within HyMex. For the Iberian Peninsula a higher resolution (5 km) forcing data set was also developed by the Observatori de l'Ebre and serves as a refence (SAFRAN-IP). The ORCHIDEE simulations forced with EartH2Observe and a WRF based downscaling of the ERA-I re-analysis were used to analyse the uncertainty propagation due to the forcing. This demonstrated that the high resolution of E2OFD provides details which are also produced by the dynamical downscaling thus confirming that E2OFD brings added value. Comparing the discharge of some of the large rivers contributing to the Mediterranean sea shows that the difference between both forcing (E2OFD and WRF) is smaller that systematic errors of the land surface model caused by missing processes : human control of the water cycle. The analysis of the major droughts which have occurred over the IP in the last 30 years demonstrated that the ability of LSMs to reproduce them does not depend on the resolution of the forcing. This comparison with SAFRAN-IP confirmed the quality of the E2OFD forcing data set (see GSQ4). This drought analysis also demonstrated the difficulty in choosing metrics to define these climatic and hydrological extremes. This is a topic which will require more detailed analysis within the HyMex community and is the focus of a specific Science Team. ORCHIDEE has been used to assimilate river discharge in order to determine where the largest errors occur in the simulated continental water balance. It has demonstrated that over the Mediterranean region the largest errors are found over irrigated areas because these human controls on the water cycle are not yet simulated.

There are several difficulties in the use of satellite observations for studying the Mediterranean region. For instance, due to coastal contamination, EOs have many issues over this region. Elevation over mountains is another factor impacting the quality of EOs. Furthermore, there exist a multiplicity of datasets for a same variable (e.g. precipitation) and it is difficult for a user to know which one he should be using. Finally, the datasets are not coherent to each other and therefore, the Mediterranean water cycle budget is not closed when using the EOs. The ESA WACMOS-MED project, which complements the eartH2Observe project and which focuses on the Mediterranean region, has the goal to provide to the scientific community with an integrated satellite dataset monitoring, in a coherent way, the water cycle over the continents, ocean and in the atmosphere. Several datasets have been gathered for each one of these water cycle components: precipitation, evaporation, runoff, ground water storage, atmospheric humidity, etc. We first analysed the budget closure of the EO datasets, build a best consensus EO dataset by combining them (Fig. 4). This first combined dataset has then been used to characterize the seasonality and the long-term trends over large Mediterranean basins (Pellet et al. 2017). Comparison with ERA-Interim analysis from the ECMWF shows that the purely satellite dataset has very similar features to ERA-I, but no model is used in our EO dataset. Second, an original merging procedure has been developed to integrate all the satellite datasets in a more hydrologically coherent way by constraining the water cycle budget closure (Pellet et al. 2018). Validation has been performed using several in situ data. This integrated dataset will be made available to the scientific community, in particular the HyMeX community. It is been tested and validated in several contexts, for a better modelling of the runoff, or for a better forecast of river discharges from satellite observations.

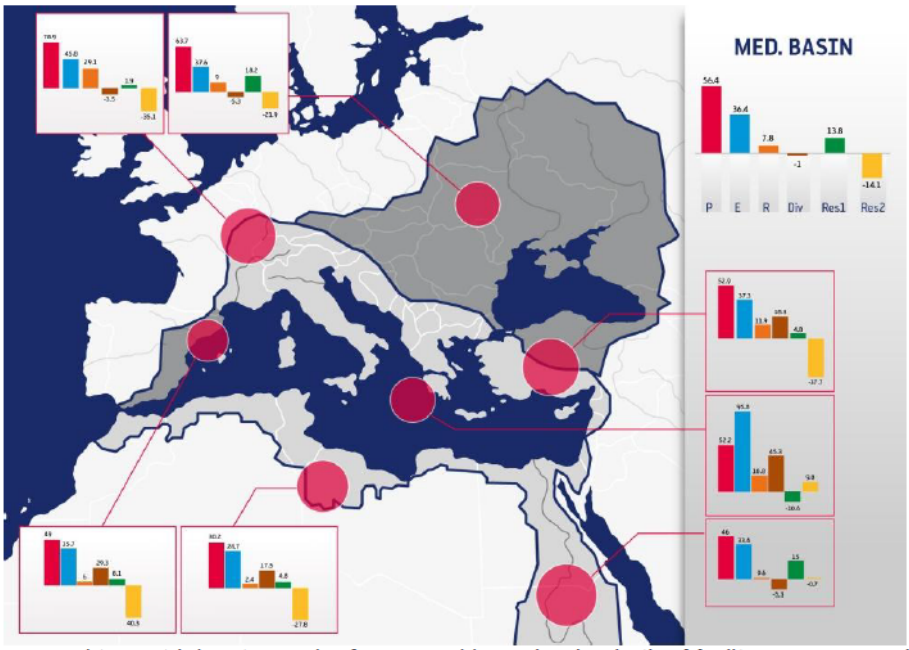


Figure 4: Mean annual terrestrial water cycle, for several large basins in the Mediterranean, as observed by our combined satellite observations dataset..

- **Changes in Extremes**

RHPs

CCRN

- Regional-scale synthesis of Earth system change through analysis of federal and provincial hydro-climatic datasets, 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. See http://www.ccrnetwork.ca/science/workshops/theme-d-workshop-2016/index.php for a summary of a past workshop where this work was presented and discussed.
- 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. See website link above.
- A major CCRN effort was centered on a comprehensive focal examination of the extreme weather and flooding in southern Alberta in June 2013, focusing on meteorological, hydrological, and water management aspects of the flood. This has led to a collection papers being published in a special issue of Hydrological Processes. (See http://ccrnetwork.ca//science/2013-Alberta-flood for further details, information products and links to all published papers.)
- Focal examination of extreme events (floods, fires, droughts) affecting the CCRN region from 2009– 16 with several papers published and others forthcoming. Initial work towards an interdisciplinary examination of the 2014 forest fires in the Northwest Territories, involving contributions from university and government organizations. Relevant publications include those listed above and: Brimelow et al. (2014, 2015), Masud et al. (2016), Szeto et al. (2015)
- CCRN will continue to focus on conducting detailed analyses of recent extreme events (floods, droughts, wildfires) in our geographic domain, including the recent short but severe

drought in 2015, the sequence of devastating wildfires in parts of the region from 2014–2017, local prairie flooding in several of the past years, hazardous winter precipitation and severe summer weather and hail that has affected several cities in the past year, and examination of the chain-of-events leading up to these events.

HyMex

Scaling extreme precipitation with temperature

The capacity of the atmosphere to store water vapor increases with temperature according to the Clausius-Clapeyron law (CC, 7%/°C). Several studies have hypothesized that the evolution of extreme rainfall intensity in future climate will be mainly controlled by this amount and will therefore increase by about 7%/°C. Since then, various studies have focused on the relationship between extreme rains and temperature, and show that this relationship does not necessarily follow the law of CC and depends on many factors. Within HyMeX, and in the frame of the GEWEX cross-cutting activity on sub-daily precipitation, research has focused on the relationship between temperature and extreme rainfall for the Mediterranean region in order to (i) verify whether this relation follows the C-C scaling (both in observations and simulations); (ii) to better understand the mechanisms driving the formation of extreme precipitation and (iii) to analyze how these processes will be modified in the future. Drobinski et al. (2016) show that the daily intensity of extreme precipitation increases with the daily temperature of the surface at low temperatures and decreases at high temperatures. This "hook shape" can be attributed to several factors: (i) reduction of the duration of rainfall events at high temperatures, (ii) different synoptic situations leading to extreme precipitation, (iii) decreasing precipitation efficiency and vertical moisture transport. Drobinski et al. (2017) have also shown using the HyMeX / MED-CORDEX simulations that in a future climate the range of temperatures over which the daily intensity of extreme precipitation increases with daily temperature rises and that the rate at which the intensity of precipitation decreases at high temperatures decreases. Nevertheless, a large part of the temperature-extreme precipitation relationship in the future can be found by correcting the relation to the climate present by Clausius-Clapeyron law. But this correction can only be applied if the relative humidity remains constant between the present and the future. This discovery is quite counter-intuitive because this region warms up and dries up at one of the highest rates on the globe. Drobinski et al. (2017) advocates that the Mediterranean Sea is an immense source of moisture which makes it possible to counterbalance the effect of continental aridification. Figure 5 summarizes these findings.

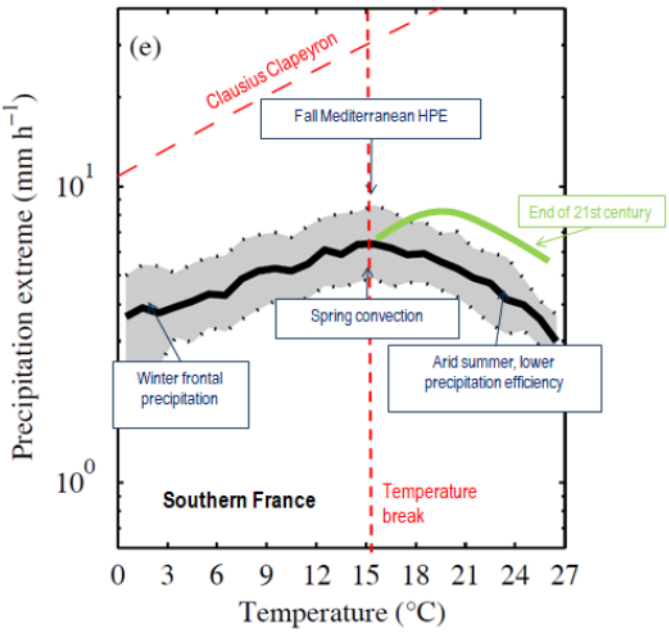


Figure 5: Scaling of precipitation extremes and temperature: processes and evolution in cliùate change. Source: Drobinski et al. (2016, 2017).

Heat waves, droughts and climate change

The effect on heat waves of vegetation fertilization in a context of climate change has been studied in the frame of HyMeX. Stomata bind water, carbon, and energy cycles. To enable photosynthesis, stomata open to assimilate carbon dioxide, and simultaneously release water vapor. In turn, the surface cools down as energy is converted to latent heat, the most effective form of temperature regulation in the absence of water stress. When the atmospheric concentration of CO2 increases, with the assimilation of CO2 given, the evapotranspiration of the vegetation is reduced. This greater water efficiency results in an increase in feedback on the water balance, carbon and energy at the surface. Lemordant et al. (2016) show that the fertilization of vegetation by an increased concentration of atmospheric CO2 can mitigate the heat waves at mid-latitudes by mobilizing the preserved water thanks to greater water efficiency before the onset of the heat wave. However, the aridity of the soil at the end of the summer in the Mediterranean is generally exacerbated because a greater vegetation cover "overcompensates" the greater water efficiency (Fig. 6). These results highlight the potential role of vegetation fertilization by atmospheric CO2 as a mitigator of extreme hydrological events and as an enhancer of summer droughts. These results can have important implications for the future of agriculture, water resource management and ecosystem health.

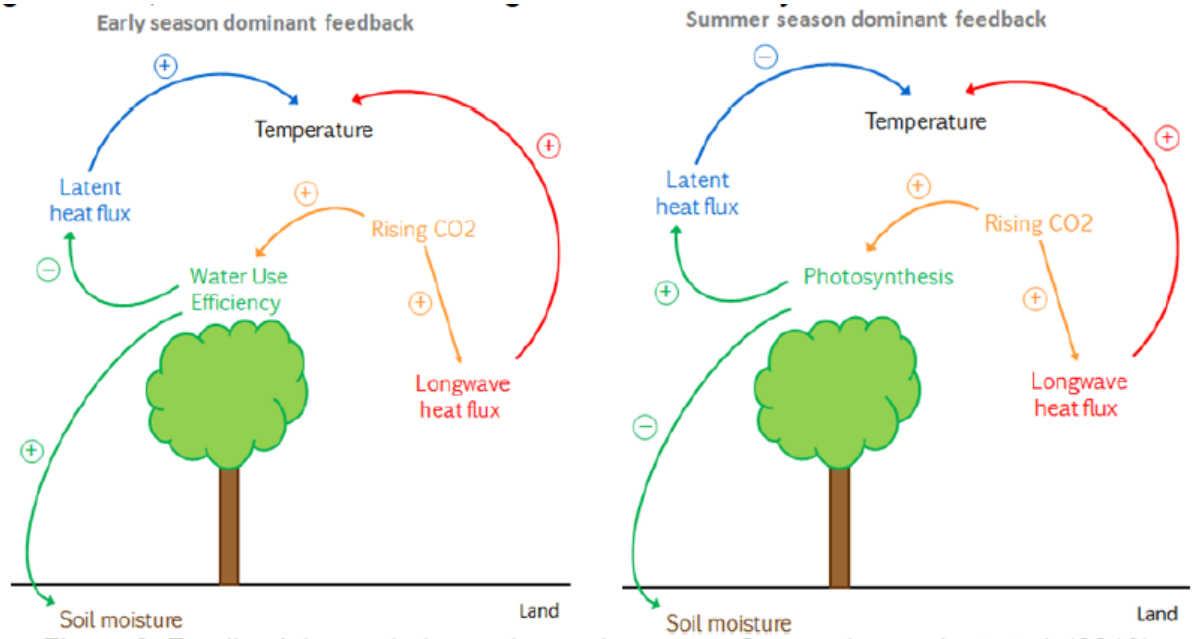


Figure 6: Feedback loops during spring and summer. Source: Lemordant et al. (2016).

Baltic Earth

- Egidijus Rimkus, Edvinas Stonevicius, Justinas Kilpys, Viktorija Maciulyte, and Donatas Valiukas 2017. Drought identification in the eastern Baltic region using NDVI. Earth Syst. Dynam., 8, 627-637, https://doi.org/10.5194/esd-8-627-2017, 2017
- Ari Venäläinen, Mikko Laapas, Pentti Pirinen, Matti Horttanainen, Reijo Hyvönen, Ilari Lehtonen, Päivi Junila, Meiting Hou, and Heli M. Peltola 2017. Estimation of the high-spatial-resolution variability in extreme wind speeds for forestry applications. Earth Syst. Dynam., 8, 529-545, https://doi.org/10.5194/esd-8-529-2017, 2017
- Anton Y. Dvornikov, Stanislav D. Martyanov, Vladimir A. Ryabchenko, Tatjana R. Eremina, Alexey V. Isaev, and Dmitry V. Sein 2017. Assessment of extreme hydrological conditions in the Bothnian Bay, Baltic Sea, and the impact of the nuclear power plant "Hanhikivi-1" on the local thermal regime. Earth Syst. Dynam., 8, 265-282, https://doi.org/10.5194/esd-8-265-2017, 2017

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 datasets where data quality and length allow.

Precipitation near 0°C

- Precipitation near 0°C leads to many impacts and so the whole effort is contributing to the study of changing extremes.
- We found significant changes in the frequency of freezing rain precipitation occurrence over the extratropical regions of the Northern Hemisphere. In the Arctic and sub-Arctic, step-wise increases in their occurrence in the last decade have been found and in the south decreases have been observed (Groisman et al. 2016, Environ. Res. Lett.).

- **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, 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 ecoregions. Adams et al. (2015), Burns et al. (2016), Champagne et al. (2016), Djamai et al. (2015), Manns et al. (2015), Rowlandson and Berg (2015), Rowlandson et al. (2015), Roy et al. (2016, 2017), Williamson et al (2017).
    - An important development for the network is that Li, working with NCAR, has produced 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 modelling and large scale climate analysis. Similarly, collaboration with ECCC provides access to the regional climate model CRCM4, which provides us with continuous future forcing data to the end of the 21st century. Driving datasets and the progress of WRF runs were presented and discussed the most recent CCRN modelling workshop

HyMex

Ocean / atmosphere interactions on precipitation and water balance in regional climate models

The possible role of ocean circulation in the "connection" of a strong mistral in the northwestern Mediterranean with an intense rainfall event in southern France in November 1999 was analyzed (Lebeaupin-Brossier et al., 2015). These two events are both controlled by intense air-sea fluxes and are separated by a week. From an atmospheric point of view, these two events can be considered totally uncorrelated and independent. Using HyMeX/MED-CORDEX simulations, it has been shown that cyclonic ocean circulation is a key element, which can trap important sea temperature anomalies over several days. In the investigated situation, the mistral induces a rapid cooling of the sea surface temperature in the Gulf of Lion and a strong evaporation due to the strong wind. This cold anomaly is trapped in the cyclonic vortex in the Gulf of Lions and lasts for more than a week. This directly affects the following intense precipitation episode with less energy supplied to the location of the cold anomaly and more evaporation near the coast, thus modulating the location and quantities of precipitation on land. This case-study work has been generalized to all the extreme precipitation simulated over 20 years (duration of HyMeX/MED-CORDEX simuations) and to cases documented within HyMeX in a multi-model approach along the Spanish, French, Italian and Croatian coastlines (Berthou et al., 2015, 2016, 2017)

Fine-scale precipitation processes

A special issue in the Quarterly Journal of the Royal Meteorological Society (Ducrocq et al, 2016) presents a wide range of studies exploiting the exceptional dataset of observations and model outputs collected during SOP1. This Special issue consists of a series of 31 papers, including several papers on process understanding for several IOPs. These IOP studies showed that a major ingredient for heavy precipitation is the conditionally unstable, low-level marine flow impinging the mountainous coastal regions bordering the western Mediterranean Sea, associated with lifting that lead to the triggering of deep convection at the same place during several hours. The lifting mechanisms mostly result from the interactions of the low-level circulation with the orography and with sometimes the convective systems themselves (Davolio et al, 2016; Scheffknecht et al, 2016; Barthlott et al, 2016; Barthlott and Davolio, 2016, Duffourg et al. 2016; Röhner et al, 2016). They include orographic lifting, pre-existing convergence lines (dynamically or orographically induced), cold pool (possibly, but not necessarily, resulting from evaporative cooling) and contributions of topographical flows (e.g., gap winds and barrier jets) (Fig. 8). Often they interplay and combine and can also occur over the Sea. The origin of the moisture over the Mediterranean Sea is quite diverse (Duffourg and Ducrocq, 2013) and

originates from (i) evaporation from the Mediterranean Sea, (ii) transport from the North Atlantic Ocean and (iii) transport from North Africa. Chazette et al (2016) highlighted a tropical origin of high water vapor content associated, whereas Röhner et al (2016) identified the eastern North Atlantic and the Mediterranean Sea as moisture uptake regions.

Droughts characterization, propagation and related processes

Drought affects different aspects of the continental water cycle, from precipitation (meteorological drought), to soil moisture (agricultural drought), streamflow, lake volume and piezometric levels (hydrological drought). The spatial and temporal scales of drought, together with its propagation through the system must be well understood.

A method has been developed for detecting and classifying meteorological droughts over the whole Mediterranean basin (extreme dry spells) in terms of spatial coverage, duration and occurrence (Fig. 9) (Raymond et al., 2016), which were then associatde with "typical" atmospheric circulation patterns (Raymond et al., in revision). This method also allows the evaluation of the capacity of the regional climate simulations HyMex/MED-CORDEX to reproduce drought characteristics (Raymond et al., In revision) with a view to studying their evolution in the context of climate change. Indices are often used to characterize different aspects of drought, built on precipitation (SPI), soil moisture (SSMI), streamflow (SSI) and water table depth. Other indices, such as SPEI, may combine several drought related variables. These indices allow to analyse the temporal scales of drought and its spatial patterns. The objective of the work conducted in the frame of HyMeX and funded by eartH2Observe project is to investigate how sensitive land-surface model (LSM) simulations are to the forcing dataset and model structure, with a focus on drought. Global and a local datasets at different resolutions are used to run LSM simulations. The global dataset is the eartH2Observe dataset (0.25°), which is based on ERA-Interim. The local dataset is the SAFRAN meteorological analysis system (in two versions at 5 km and 30 km). The LSMs used are SURFEX (using the multi-layer diffusion and 3-layer force-restore versions) and LEAFHYDRO. Standardized indices of the relevant variables are produced for all the simulations performed. Their analysis shows how differently drought propagates through the system in the different forcing-model combinations and how similar are spatial and temporal scales of drought. The results of this study will be useful to understand the applicability of global datasets for local studies on drought and to better understand the related uncertainties.

Baltic Earth

- Liisi Jakobson, Erko Jakobson, Piia Post, and Jaak Jaagus 2017. Atmospheric teleconnections between the Arctic and the Baltic Sea regions. Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2017-37, 2017 (under review)
- Liga Bethere, Juris Sennikovs, and Uldis Bethers 2017 Climate indices for Baltic States from principal component analysis. Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2017-34, 2017
- Ho-Hagemann HTM, Gröger M, Rockel B, Zahn M, Geyer B, Meier HEM, 2017. Effects of air-sea coupling over the North Sea and the Baltic Sea on simulated summer precipitation over Central Europe. Climate Dynamics 48:1-26, March 2017

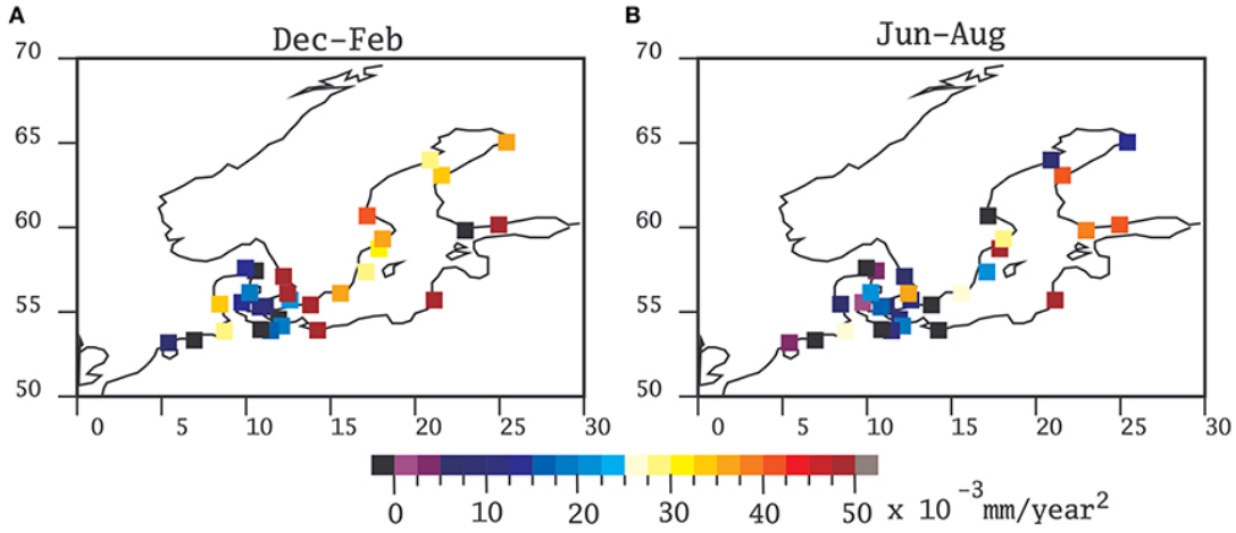
9. Other key science questions that you anticipate your community would want to tackle in the next 5-10 years within the context of a land-atmosphere project (1-3 suggestions)

10. **Briefly list any specific areas of your panel's activities that you think would contribute to the WCRP Grand Challenges as identified by the JSC (not covered under 9).**
    - **Regional Sea-Level Rise**

Baltic Earth

Hünicke B, Zorita E 2016: Statistical Analysis of the Accerleration of Baltic Mean Sea Level Rise, 1900-2012 Front. Mar. Sci., 22, July 2016

- Globally, sea level is expected to accelerate
- An acceleration for the Baltic Sea was tested statistically since 1900
- Acceleration was found to be mostly positive but very low and statistically not significant
- Absolute values due to acceleration would only add some cm to the expected rise of up to 1m at 2100



Acceleration of the annual mean sea-level in the Baltic Sea tide-gauges estimated in the period 1900–2012 in wintertime (A) and summertime (B) by the method gtols (see paper)

- Meier HEM, Hoglund A, Eilola K, Almroth-Rosell E, 2017. Impact of accelerated future global mean sea level rise on hypoxia in the Baltic Sea. Clim Dynam 49(1-2):163-172, July 2017
- Svenja E. Bierstedt, Birgit Hunicke, Eduardo Zorita, and Juliane Ludwig 2017. A wind proxy based on migrating dunes at the Baltic coast: statistical analysis of the link between wind conditions and sand movement. Earth Syst. Dynam., 8, 639-652, https://doi.org/10.5194/esd-8-639-2017, 2017
- Algimantas Česnulevičius, Regina Morkūnaitė, Artūras Bautrėnas, Linas Bevainis, and Donatas Ovodas 2017. Intensity of geodynamic processes in the Lithuanian part of the Curonian Spit. Earth Syst. Dynam., 8, 419-428, https://doi.org/10.5194/esd-8-419-2017, 2017
- Nils H. Schade 2017. Evaluating the atmospheric drivers leading to the December 2014 flood in Schleswig-Holstein, Germany. Earth Syst. Dynam., 8, 405-418, https://doi.org/10.5194/esd-8-405-2017, 2017

- **Cryosphere response to climate change (including ice sheets, water resources, permafrost and carbon)**

CCRN

- Projection results are 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 behaviour, leading to further extremes and dramatic system changes, such as deglaciation, permafrost disappearance and terrestrial ecosystem transition. Local scale assessments have begun in Theme B with several publications (Pomeroy et al. (2015b), Rasouli et al. (2014, 2015), Krogh et al. (2017), and planned CRHM historical and future diagnostic modelling (see http://www.ccrnetwork.ca/science/workshops/crhm-workshop-2016/index.php)
- 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.
- Glaciological studies, including mass and energy balance, glacier hydrology, and development of ice dynamic routines for local to regional-scale models are being conducted, crossing many of our thematic areas. See http://www.ccrnetwork.ca/science/WECC/index.php for information on the glaciological research at several of our WECC observatories. Bash and Marshall (2014), DeBeer et al. (2016), Demuth et al. (2014), Ebrahimi and Marshall (2015), Marshall (2014a, 2014b), Samimi and Marshall (2017).

- **Improved understanding of the interactions of clouds, aerosols, precipitation, and radiation and their contributions to climate sensitivity**

CCRN

- Specific scientific contributions 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
- In addition, studies are 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 sea surface temperature anomalies, large-scale circulation patterns and warm-season synoptic activities. Armstrong et al. (2015), Asong et al. (2015), Brimelow et al. (2014, 2015), Khaliq et al. (2015), Kochtubajda et al. (2016, 2017), Liu et al. (2016), Masud et al. (2015), Szeto et al. (2015).
- Changes in the large-scale atmospheric circulation are assessed from CMIP5 and other projections. Their 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.

Baltic Earth

- Lehmann, A., K. Höflich, P. Post, K. Myrberg, 2017. Pathways of deep cyclones associated with large volume changes (LVCs) and major Baltic inflows (MBIs) J Mar Syst 167:11-18, March 2017
- Liisi Jakobson, Erko Jakobson, Piia Post, and Jaak Jaagus 2017. Atmospheric teleconnections between the Arctic and the Baltic Sea regions. Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2017-37, 2017 (under review)
- Liga Bethere, Juris Sennikovs, and Uldis Bethers 2017 Climate indices for Baltic States from principal component analysis. Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2017-34, 2017
- Jaak Jaagus, Mait Sepp, Toomas Tamm, Arvo Jarvet, and Kiira Moisja 2017 Trends and regime shifts in climatic conditions and river runoff in Estonia during 1951–2015. Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2017-24, 2017
- Julia Jeworrek, Lichuan Wu, Christian Dieterich, and Anna Rutgersson 2017. Characteristics of convective snow bands along the Swedish east coast. Earth Syst. Dynam., 8, 163-175, https://doi.org/10.5194/esd-8-163-2017, 2017
- Ho-Hagemann HTM, Groger M, Rockel B, Zahn M, Geyer B, Meier HEM, 2017. Effects of air-sea coupling over the North Sea and the Baltic Sea on simulated summer precipitation over Central Europe. Climate Dynamics 48:1-26, March 2017
- Camenisch C, Keller K, Salvisberg M, Amann B, Bauch M, Blumer S, Bradzil R, Bronnimann S, Buntgen U, Campbell BMS, Fernandez-Donado L, Fleitmann D, Glaser R, Golzalez-Rouco F, Grosjean M, Hoffamnn R, Huhtamaa H, Joos F, Kiss A, Kotyza O, Lehner F, Luterbacher J, Maughan N, Neukom R, Novy T, Pribyl K, Raible C, Riemann D, Schuh M, Slavin P, Werner JP, Wetter O, 2016: The 1430s: A cold period of extraordinary internal climate variability during the early Sporer Minimum with social and economic impacts in north-western and central Europe. Clim Past 12:2107–2126
- Barkhordarian, A., H. von Storch, E. Zorita, and J. Gomez-Navarro, 2016: An attempt to deconstruct recent climate change in the Baltic Sea Basin. Journal of Geophysical Research - Atmospheres, November 2016

    - **Past and future changes in water availability (with connections to water security and hydrological cycle)**

CCRN

- Use of soil moisture monitoring networks for various objectives (see above under GSQ4) 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 NRCan)
- Various atmospheric research activities contribute to this Grand Challenge, described above under GSQ1 and GSQ2
- 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 MESH over both the Mackenzie and Saskatchewan River basins, with several key focal issues identified for ongoing work, including input uncertainty, soil depth and permafrost initialization/representation, wetlands, and water management. Model development is at the stage where it these are ready for future simulations.
- 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 are a critical basis for addressing this issue including our degree of uncertainty. Projections of future conditions over the region are being developed by CCRN (4 km WRF pseudo-warming) and others will be obtained (CRCM4 projections, with improved CLASS algorithms and explicit representation of feedbacks). Asong et al. (2015, 2016, 2017), Khaliq et al. (2015), Masud et al. (2015), Yassin et al. (2017).
- Changes in the large-scale atmospheric circulation are assessed from CMIP5 and other projections. Their 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. Asong et al. (2015), Bonsal et al. (2017), Khaliq et al. (2015), Masud et al. (2015), Stewart et al. (2015).

- **Science underpinning the prediction and attribution of extreme events**

CCRN

- Specific scientific contributions 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 is 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. Asong et al. (2015, 2016, 2017), Bonsal et al. (2017), Brimelow et al. (2014, 2015, 2017), Dumanski et al. (2015), Khaliq et al. (2015), Kochtubajda et al. (2016, 2017), Liu et al. (2016), Masud et al. (2015), Pomeroy et al. (2016a, 2016b), Scaff et al. (2015), Schubert et al. (2016), Shook et al. (2015), Stewart et al. (2015), Szeto et al. (2015).
- Key focal points are on regional and local scale temperature changes and variations of prolonged summer hot periods, and extension of above freezing conditions. A focal examination of changes around the zero degree Celsius isotherm is ongoing. In terms of precipitation, the focus is on the development of drought, heavy precipitation, extreme precipitation rates, as well as the changing phase of precipitation
- We are in the process of determining whether future changes cross ‘tipping points’ in Earth system behaviour, leading to further extremes and dramatic system changes, such as deglaciation, permafrost disappearance and terrestrial ecosystem transition. Local scale assessments have begun in Theme B with several publications (Pomeroy et al. (2015b), Rasouli et al. (2014, 2015)), Krogh et al. (2017), and planned CRHM historical and future diagnostic modelling (see www.ccrnetwork.ca/science/workshops/crhm-

workshop-2016/index.php and http://ccrnetwork.ca//science/workshops/summer-2017-modelling-workshop)

Baltic Earth

- Egidijus Rimkus, Edvinas Stonevicius, Justinas Kilpys, Viktorija Maciulyte, and Donatas Valiukas 2017. Drought identification in the eastern Baltic region using NDVI. Earth Syst. Dynam., 8, 627-637, https://doi.org/10.5194/esd-8-627-2017, 2017
- Ari Venalainen, Mikko Laapas, Pentti Pirinen, Matti Horttanainen, Reijo Hyvonen, Ilari Lehtonen, Paivi Junila, Meiting Hou, and Heli M. Peltola 2017. Estimation of the high-spatial-resolution variability in extreme wind speeds for forestry applications. Earth Syst. Dynam., 8, 529-545, https://doi.org/10.5194/esd-8-529-2017, 2017
- Anton Y. Dvornikov, Stanislav D. Martyanov, Vladimir A. Ryabchenko, Tatjana R. Eremina, Alexey V. Isaev, and Dmitry V. Sein 2017. Assessment of extreme hydrological conditions in the Bothnian Bay, Baltic Sea, and the impact of the nuclear power plant "Hanhikivi-1" on the local thermal regime. Earth Syst. Dynam., 8, 265-282, https://doi.org/10.5194/esd-8-265-2017, 2017

INTENSE

The INTENSE project is focussed on i) meeting the data requirements, and ii) 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 characterisation 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 highresolution models offer added value on the projected change signal compared with coarse resolution models (overarching theme: simulate).

- **Near-Term climate prediction**

CCRN

- Our work on all future assessments of change is based on various climate model projections and forecasts, such as CMIP5, NARCCAP, CORDEX, but we are directly contributing to the development of climate forecasts. Our WECC observatories provide excellent validation datasets for model downscaling, bias correction, and other activities aimed at improving RCM performance and developing related products.

Baltic Earth

Liga Bethere, Juris Sennikovs, and Uldis Bethers 2017 Climate indices for Baltic States from principal component analysis. Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2017-34, 2017

- **Carbon feedbacks in the climate system**

CCRN

- Activities at some of our WECC observatories, in particular the Boreal Ecosystem Research and Monitoring Sites (BERMS), focus on the spatial and temporal variability in the boreal forest's water and carbon balance, and their sensitivity to climate variability and change. Long-term, high-quality, and intensive observations of water, carbon, and energy fluxes at several towers in different forest stands provide exemplary opportunities to observe and understand the carbon balance and feedbacks with the climate system. Work has examined the net annual ecosystem carbon exchange from CO2 flux measurements and partitioned it between gross ecosystem photosynthesis and ecosystem respiration.
- We have conducted preliminary analyses of the CTEM model, focusing on our BERMS sites, and will utilize the model to simulate different ecosystems, particularly around the boreal–prairie transition zone.

Baltic Earth

- Ahlgren J, Grimvall A, Omstedt A, Rolff C, Wikner J, 2017 Temerature, DOC level and basin interactions explain the declining oxygen concentrations in the Bothnian Sea. J Mar Syst 170:22-30, January 2017
- Sveden J., Walve, J., Larsson, U., Elmgren, R., 2016: The bloom of nitrogen-fixing cyanobacteria in the northern Baltic Proper stimulates summer production. J Mar Syst 163:102-112, November 2016
- Almroth-Rosell, E., M. Edman, K. Eilola, H.E.M. Meier, J. Sahlberg, 2016: Modelling nutrient retention in the coastal zone of an eutrophic sea Biogeosciences 13:5753-5769, October 2016

11. Cooperation with other WCRP projects (CLIVAR, CliC, SPARC), outside bodies (e.g. IGBP) and links to applications

CCRN

- The International Network for Alpine Research Catchment Hydrology (INARCH; http://www.usask.ca/inarch/index.php) is a GEWEX Cross-cut project that is an international spin-off from CCRN, led by Distinguished Professor John Pomeroy. CCRN and INARCH are closely linked and share many common research priorities and objectives. A workshop will be held February 8-9, 2018, in Zugspitze, Germany, that members of CCRN will attend.
- The Cold/Shoulder Season Precipitation Near 0oC project is a GHP cross-cut project that addresses multiple aspects of precipitation phase transitions, and is led by CCRN investigators. There are many areas of overlap between these projects; in particular, CCRN is conducting a detailed assessment of changes in the 0°C isotherm, with objectives that are directly linked to this project.
- Another GHP cross-cut project is focused on Including water management in large scale models, and is led by several CCRN investigators, including the Principal Investigator. Considerable progress on this issue has been achieved through CCRN studies, and both initiatives have goals to include newly developed reservoir schemes into models, such as MESH.

HyMex

- CLIVAR: HyMeX aims at understanding the variability and trend of the regional climate in interaction with the Mediterranean Sea, and thus contributes to the specific MedCLIVAR program, chaired by Piero Lionello, member of the HyMeX ISSC.
- CORDEX: The regional climate modeling group of HyMeX is at the origin of the selection of the Mediterranean region as an official domain of the CORDEX program. The coordinator of the MED-CORDEX project is Paolo Ruti, who chairs with Samuel Somot the HyMeX regional climate modelling group.
- HyMeX is also endorsed by WWRP and its subprogram THORPEX. Véronique Ducrocq, co-PI of the HyMeX programme, is the HyMeX representative at the WWRP scientific committee.

Precipitation near 0°C
Much of this activity in Canada has been carried out in connection with the Canadian RHP CCRN (Changing Cold Regions Network) and with Environment and Climate Change Canada. The near 0°C region has many hydrologic, ecological and societal impacts.
In the U.S., France, and the Russian Federation, this activity is carried out in close cooperation with the International Belmont Forum Project "The ARCTIC-ERA (ARCTIC climate change and its impact on Environment, infrastructures and Resource Availability)."
Although this activity is relevant to CliC and CLIVAR as well, no linkage has been established.

12. Workshops/meetings held

CCRN

- Fall 2017 modelling workshop, Coast Hotel, Canmore, AB, November 2-3, 2017
- Wolf Creek Research Basin 25th Anniversary Science Summit, Gold Rush Inn, Whitehorse, YT, September 28-29, 2017
- Modelling workshop, National Hydrology Research Centre, Saskatoon, SK, June 19-20, 2017
- Scenarios of change workshop, National Hydrology Research Centre, Saskatoon, SK, March 20-21, 2017

- 10th HyMeX workshop, Barcelona, Spain (~160 participants) : 3-7 July 2017

- 1st Baltic Earth Conference "Multiple drivers for Earth system changes in the Baltic Sea region" in Nida, Lithuania, June 2016.
- 23-28 April 2017: EGU General Assembly 2017, Vienna, Austria. Baltic Earth Session on Climate change and its impacts in the Baltic and North Sea regions: Observations and model projections is based on the work of the recently published regional BACC II (Baltic Sea region) and NOSCCA (North Sea region) climate change reports
- 29-31 March 2017: Baltic from Space: Joint ESA-Baltic Earth Workshop on remote sensing applications in the Baltic Sea region, Helsinki, Finland
- 7-8 February 2017: Baltic Earth Workshop on "Coupled atmosphere-ocean modeling for the Baltic Sea and North Sea", Leibniz Institute for Baltic Sea Research Warnemünde (IOW), Germany
- 28 August – 4 September 2017: International Baltic Earth Summer School on Climate change in the Baltic Sea region, Askö Laboratory, Trosa, Sweden.

- The INTENSE project held a community-building workshop in Newcastle, UK from 13th-15th September 2016 “Sub-daily rainfall extremes: data, processes and modelling”. Participants agreed on a first set of sub-daily precipitation indices and a draft was circulated to all participants and members of the ETCCDI team in early October 2016 for comment. A paper is planned on the grand challenges in understanding sub-daily precipitation extremes.
- INTENSE ran a session at EGU 2017 titled “Development of climate datasets: homogenization, trends, variability and extremes, including sub-daily timescales”. This was co-convened with Xiaolan Wang, Enric Aguilar, Rob Roebeling and Petr Stepanek. Hayley Fowler also gave an invited talk on INTENSE at EGU 2017.

13. **Workshops / meetings planned. Include travel support needs anticipated (for WCRP). Include tentative meetings planned up to 2 years (for IGPO planning purposes)**

CCRN

Our final network symposium, The CCRN Finale, is planned for March 4-7, 2018, where the network will gather for the last time to review our accomplishments, to plan products and publications as a legacy of CCRN, to connect with key stakeholders and partner organizations, and to look to the future in follow-on initiatives

- 11th HyMex workshop , 29 May - 2 June 2018, Lecce, Italy

- MedCordex-Baltic Earth Workshop in March 2018
- 2nd Baltic Earth Conference in Helsingor, June 2018
- A Baltic Earth Workshop on “Multiple drivers of Earth system changes in the Baltic Sea region”, Fall-winter 2018
- “Precipitation new 0C” have a near 0°C session at the 2018 GEWEX Open Science Conference, as well as at the forthcoming AGU Annual Meeting in New Orleans (December 2017) and at the Annual JpGU Conference (Makuhari, Chiba, Japan, in May 2018).

14. **Other meetings that were attended on behalf of GEWEX or your Panel**

***** The Third Pole Science Summit (TPSS): TPE-CSTP-HKT (Third Pole Environment-China Society of Tibetan Plateau-the organizing committee of the 2017 Himalayan-Karakorum-Tibet workshop) Joint Conference was held in Kunming, China from 10 to 12 July, 2017. GEWEX chair P. van Oevelen and GHP co-chair J. Cuxart were present.

*GHP annual meeting held together with TPE: the joint Workshop was held in Kathmandu, Nepal from 17 to 19 October, 2017. In total, the workshop received 48 scientists, 14 from GHP, 14 from TPE and 20 from Nepal.

* Kick-off meeting of AndEX in Medellín (Colombia) 2-5 december 2017. GEWEX chair P. van Oevelen and GHP co-chair J. Cuxart were present.

15. **Issues for the SSG**

* PannEx: GHP proposes that it becomes an Initiating RHP after the completion of the WB and of the Science and Implementation plan.

- HyVic: Efforts in East Africa remain fragmented and fluid. International funding has backed several projects and closer collaboration with WWRP is being sought. A larger regional perspective (beyond Lake Victoria) is being pushed through IGAD (Intergovernmental Authority on Development) and ICPAC (IGAD Climate Prediction and Applications Centre). A successful way forward remains elusive. Advice/suggestions welcome.
- OzEWEX: Have not been successful in attracting funding to support RHP research activities. As a result they have failed to meet some RHP criteria and will likely have their RHP status removed at the next GHP meeting. They have been able to find funding for networking type activities (annual workshop, water and climate summer institute) – these activities are well attended and vibrant, and it would be good to maintain a GEWEX/GHP connection. One proposal, for SSG feedback, is to establish a new type of activity within GHP – a GHP network – that would need to meet the RHP criteria relevant for networking/capacity building only.
- Efforts for a RHP type activity in the USA have stalled. Any suggestions welcome.

Panel membership/leadership

- Need a new panel member for the USA. Suggestions welcome.
- GHP will need a new co-chair in just over a year (preferably from outside Europe). Suggestions welcome.

16. List of key publications (*where appropriate*)

17. List of members and their term dates (including changes) where appropriate:

A./Prof. Jason Evans – co-chair - 2013-2020
Dr. Joan Cuxart Rodamilans – co-chair - 2017-2020*
Dr. Nicole van Lipzig - 2014-2019
Dr. Silvina Solman - 2014-2019
Prof. Christel Prudhomme - 2015-2020
Dr Ben Zaitchik - 2015-2017
Dr Craig Ferguson - 2015-2020 (GLASS rep)
Prof. Sylvester Danour - 2016-2018*
Prof. Xin Li - 2016-2018*