GEWEX NEWS

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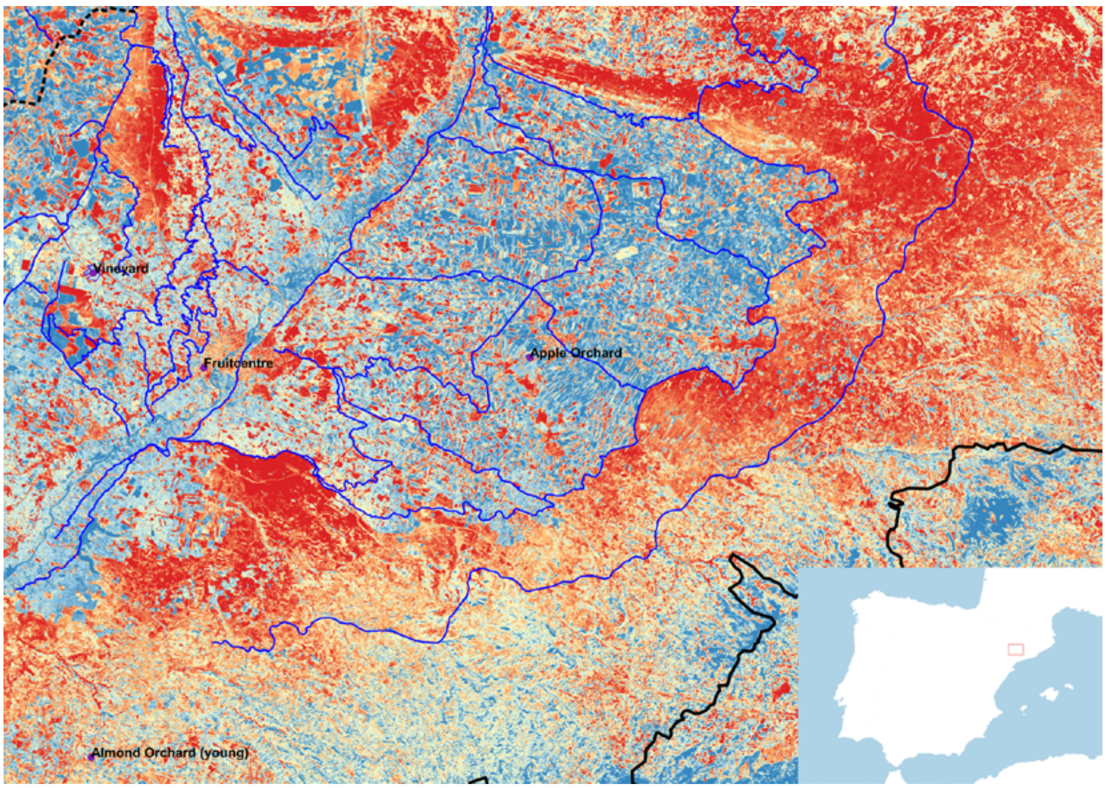
New Activity LIAISE Studies Human Influence on the Water Cycle



Land surface temperature (LST) over irrigated portions of Lleida, Spain, one of the areas under study in the new LIAISE activity, which aims to improve understanding of the impact of anthropization on the water cycle and land-atmosphere-hydrology interactions. It will also investigate the limitations of models representing the terrestrial water cycle in a semi-arid environment on the Iberian peninsula and contributes to the GEWEX-led WCRP Grand Challenge on "Water for the Food Baskets of the World." LST was obtained by sharpening Sentinel 2 and 3. Cool colors correspond to irrigated surfaces and the domain is approximately 100x100 km. The acquisition date is July 5, 2017. This image was produced within IRTA's Efficient Use of Water in Agriculture Program, and you can read more about LIAISE in Boone et al. on page 8.

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Challenges for WCRP and GEWEX in the Era of Earth System Science

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The International Geophysical Year (IGY) in 1957–58 was a watershed moment in Earth sciences, bringing together many disciplines and marking a major change in the study of Earth. What evolved out of the IGY was an appreciation that Earth was a dynamic system exemplified by the revolutionary new, emerging model of Earth plate tectonics. Today, we fully understand and embrace the concept of an Earth system that is complex with interactions occurring between its many components. The concept of Earth system science is now deeply rooted in our thinking, as expressed in the Bretherton report of the 1980's.

This system realization, however, represents challenges in organizing a science enterprise like that of the World Climate Research Programme (WCRP). It also is a major challenge for designing Earth observing systems, a point expressed the recent National Academies Decadal Survey report. Hints at a more integrative approach to address this challenge from an observing system perspective are expressed by the following most important priority identified by the hydrology panel organized for the decadal study: **H-1a Interaction of Water and Energy Cycles**––*develop and evaluate an integrated Earth system analysis.* The rationale of this objective recognizes that information of the future will ultimately come through some advanced system of models and observations fused together. The challenge is to develop such an advanced system and we are not there today, although elements of it are evolving. When it comes to climate science, there is a similar need to have an integrated system approach to couple the disciplinary parts together and we rely on Earth system models to achieve this synthesis. In both cases, the foundation for these integrative tools ultimately lies with adequate, quantitative representation of the physics and chemistry and of the basic processes of the system. This sentiment was recognized in the review of WCRP by the World Meteorological Organization (WMO), International Science Council (ICS), and the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO) (*https://council.science/cms/2018/08/WCRP_Report_full_screen_16112018.pdf*), which recommended that a critical capability of WCRP must be to sustain activities on processes across all time and space scales. GEWEX has from the outset been more process-centric in its approach rather than phenomenologically-centric, a point underscored in this newsletter with the report on the new Global Atmospheric System Studies (GASS) Panel initiative on the Impact of Initialized Land Temperature and Snowpack on Sub-seasonal to Seasonal Prediction (LS4P) and the meeting summary of the Upper Tropospheric Clouds and Convection Process Evaluation Study (UTCC PROES). The challenge for WCRP and GEWEX is to maintain a deep discipline expertise such as resides in the three Panels, while also providing a more integrative vision of the Earth system. There is no clear recipe for building such integration. The same challenges exists for WCRP, which must unify all aspects of Panel research while avoiding the arbitrary partitioning of the science that can create gaps in key areas.

How to Improve Regional Information for Extreme Weather, Climate and Hydrological Events: An Early Career Perspective

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Early Career Researchers (ECRs) recently published a perspective paper on major challenges and opportunities that arise in the study, understanding, and provision of regional information for Climate, Weather and Hydrological (CWH) extreme events (Langendijk et al., 2019; doi: 10.3389/fenvs.2019.00006). This topic is gaining societal relevance as the occurrence and impact of such events increases in the changing climate.

This perspective emerged from the discussions of the three-day Joint Young Earth System Scientists-Young Hydrologic Society (YESS-YHS) ECR Workshop, which was held alongside the Global Energy and Water Exchanges (GEWEX) Open Science Conference in Canmore, Canada in May 2018. The roughly 40 ECRs from 26 countries who attended the workshop identified three possible ways forward in the field: a stronger interaction between users and scientists, a collaborative modeling approach between the different modeling communities, and possible inclusion of unconventional data sources in scientific studies. By making strides in the three domains, the scientific community can gain improved quantification and prediction of extreme events, and deliver more useful and relevant regional information to users.

Furthermore the paper highlights the important role of ECRs in embracing the outlined pathways and addressing the longstanding challenges in the field, simultaneously providing great opportunities for ECRs to take a leading role in moving CWH sciences forward. By doing so, distinct challenges arise for ECRs, particularly to develop their careers in this highly interdisciplinary environment. Alternative approaches are required to evaluate scientific impact and excellence that correspond to the research needs of our generation. YESS and YHS encourage the global community to support and strengthen its involvement with ECR communities to move the field of interdisciplinary Earth system science forward in the coming years and to foster advances in the field of CWH sciences.

Reference

Langendijk, G.S., C. Aubry-Wake, M. Osman, C. Gulizia, F. Attig-Bahar, E. Behrens, A. Bertoncini, N. Hart, V.S. Indasi, S. Innocenti, E.C. van der Linden, N. Mamnun, K. Rasouli, K.A. Reed, N. Ridder, J. Rivera, R. Ruscica, B.U. Ukazu, J.P. Walawender, D.P. Walker, B.J. Woodhams and Y.A. Yılmaz, 2019. Three Ways Forward to Improve Regional Information for Extreme Events: An Early Career Perspective. *Front. Environ. Sci.*, 7:6, doi: 10.3389/fenvs.2019.00006.

H3S Members Network and Learn at the 2018 AGU Fall Meeting

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AGU H3S Chair

The 2018 American Geophysical Union Fall Meeting ringing in the organization's centennial year kept the Hydrology Section Student Subcommittee (H3S) bustling around Washington, D.C., in mid December. We focused on facilitating opportunities for Early Career Scientists (ECSs) to speak on a variety of topics, as well as continue their professional development in a welcoming environment. Our four pop-up talk session topics ranged from "Building Communities through Shared Experiences and Bridging Science and Policy for Change" to "Big Ideas in Hydrology: The Next 100 Years." H3S's town hall events brought out experts in non-academic fields to share their experiences in research outside the university. However, since we still like to enthusiastically share our current research and learn from each other, workshops on new technology, tools and concepts were presented and put to practice throughout the week. We also brainstormed with other ECS networks to pool our resources to create an active community and continue momentum beyond conferences and meetings. It was a busy week!

Even after a great 2018 and beyond the AGU Fall Meeting, we're excited for the coming year! We're planning on continuing our successful events held throughout the year, like bringing scientists and science communicators of all levels together to share their research through poem via Haiku Your Research on Twitter (@AGU_H3S). We're excited to hear your ideas for how H3S can add to the hydrology community and strengthen the international ECS network via Twitter or email (*Caitlyn.Hall@asu.edu*). Happy 2019!

What is the Role of GEWEX in R2O and O2R?

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Traditionally, GEWEX has emphasized the transition of research to operations (R2O). The operations to research (O2R) shift has not received as much attention, however. Here we offer a few ideas to make the R2O and O2R transitions more efficient and to strengthen GEWEX's role in this process, as summarized in Figure 1. Our purpose is not to make a comprehensive list; rather, we want to make short suggestions to stimulate further discussion in the GEWEX community.

Strategic Alignment of Research Programs. GEWEX, the Climate and Ocean Variability, Predictability and Change (CLIVAR) project, the World Weather Research Programme (WWRP) and similar groups should coordinate for true community Earth System Model (ESM) development and the associated data assimilation of all ESM components. This includes Numerical Weather Prediction (NWP), subseasonal to seasonal (S2S) prediction and longer-term climate time scales, as well as ecosystems, air and water quality, etc. This fully engages the academic community, government centers and the private sector, and should also include state and local programs in some manner. Absolutely no "stovepipe" efforts!

Strategic Plan. GEWEX and other national and international programs could support, literally, a 10-or-so-year proposal on ESM development where ego, territory and interest in promoting particular projects would not hinder the necessary cooperation. This would call for close collaboration among all entities at all levels, from students and early career scientists to program leaders, and strong connections among the academic community, government centers and the private sector. It would also provide opportunities for the next generation of Earth system scientists.

Hierarchical Model Development (HMD). This approach can be a most efficient way to effectively connect R2O and O2R, i.e., the ability to test small parts such as process-level subroutines of an ESM first in isolation, then in progressive stages to connect the parts with increased coupling between the ESM components and HMD steps, all the way up to a complex fully-coupled ESM. The fully-coupled model would include components for the atmosphere, chemistry, aerosols, the ocean, waves, sea-ice, land hydrology, land ice and ecosystems, a subset of which (i.e., atmosphere-land) has traditionally addressed NWP needs through programs like GEWEX and its Global Atmospheric System Studies (GASS) and Global Land/Atmosphere System Study (GLASS) projects focused on Earth system processes, as well as GEWEX Hydroclimatology Panel (GHP) crosscutting projects.

A requirement for moving from one HMD step to the next includes appropriate metrics and benchmarks of ESM performance. But this process is not linear; it is iterative, in that more complex steps can provide information to be used at simpler HMD steps. This also includes understanding the spatial and temporal scale dependencies in ESMs and the need for consistency in solutions between higher-resolution and regional short-range versus global models for the medium- and extended-range, S2S and longer climate time scales.

Software Infrastructure. New infrastructure that allows for all the HMD steps to be connected efficiently is a necessity, and would allow for rapid tests of individual components at first, with all the following HMD steps up to the complex fully-coupled ESM. The speed at which this can be done is a measure of success, and this would greatly accelerate R2O and O2R and maximize computer use efficiency. Researchers could then become involved in the R2O and O2R process at any number of different HMD stages, depending on their interest and resources. This infrastructure also includes community access to an end-to-end system with a work flow equivalent to the operational environment. Major operational and research centers could take the lead with assistance from GEWEX on land-atmosphere interactions and other international programs such as CLIVAR and WWRP on other Earth system processes.

Data Sets. In addition to routine weather measurements, we have to leverage the truly vast amount of data sets from field programs and specialized observation systems to examine and understand Earth system processes, such as measurements of all ESM components, then use them to improve the corresponding model components. GHP and GEWEX Data and Analysis Panel (GDAP) efforts play an important role here. Satellite remote sensing is crucial for global measurements, particularly for data assimilation in models. Independent data sets then allow for model assessment at the process level, in addition to the usual precipitation, atmospheric profile, and low-level temperature, humidity and wind that typify NWP verification. These data sets are used for both process-level understanding and for model development, forecasting and evaluations. In particular, integrated data sets are needed to constrain models and help understand processes.

International Cooperation. Individual Panels within GEWEX and different programs such as GEWEX, CLIVAR, WWRP and the Working Group on Numerical Experimentation (WGNE) need to work together on a variety of activities, as weather and climate are connected and they simply have different Earth system spatial and time scales. Furthermore, GEWEX and other international programs need to get back to essential principles by examining all the aspects of the Earth system and making sure the components work together optimally in order to get the right answers for the right reasons.

O2R. To accelerate O2R, major operational centers are encouraged to make their models and data assimilation systems openly available, and even better, to provide the computing resources to the community for undertaking meaningful model development and testing.

This article was motivated by discussions with a number of scientists in the Earth system research and modeling community, among them Paul Dirmeyer of George Mason University and the Center for Ocean-Land-Atmosphere Studies (COLA) and Joseph Santanello of the National Aeronautics and Space Administration Goddard Space Flight Center (NASA GSFC), and was initially inspired by conversations with Alan Betts of Atmospheric Research.

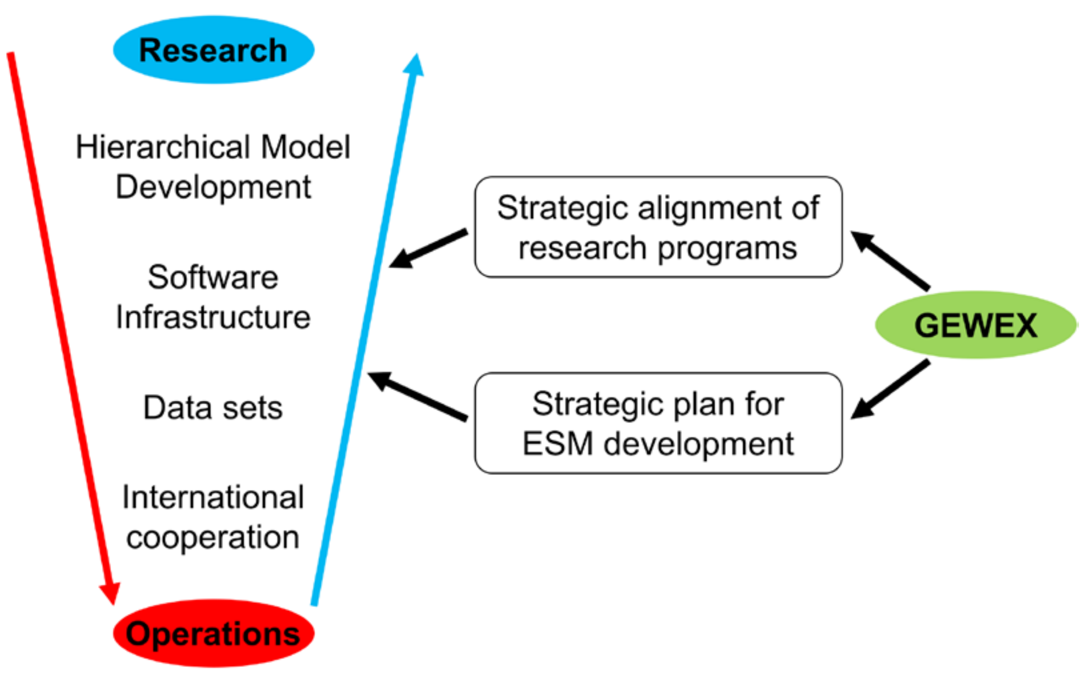

Figure 1. *Schematic illustration of the role of GEWEX in R2O and O2R.*

Current Challenges in Evapotranspiration Determination

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The following reflection on ET was initiated at an informal meeting in Canmore, Canada, during the 8th GEWEX Open Science Conference in May 2018. A subsequent e-mail discussion took place among a wider grouping, with inputs from Z. Su (University of Twente), A. Teuling (Wageningen University and Research), J. Vila (Wageningen University and Research), C. van Heerwaarden (Wageningen University & Research), V. Vionnet (University of Saskatchewan), H. de Bruin (Wageningen University & Research), P. Gentine (Columbia University), F. Bosveld (Royal Netherlands Meteorological Institute), A. Beljaars (European Centre for Medium-Range Weather Forecasts), F. Beyrich (German Meteorological Office), S. Seneviratne (Swiss Federal Institute of Technology in Zurich), J. Polcher (Laboratoire de Météorologie Dynamique), A. Boone (Centre National de Recherches Météorologiques), J. Edwards (UK Met Office), E. Blyth (Centre for Ecology and Hydrology), A. Martínez de la Torre (Centre for Ecology & Hydrology), S. Boussetta (European Centre for Medium-Range Weather Forecasts), B. van den Hurk (Royal Netherlands Meteorological Institute), P. Greve (International Institute for Applied Systems Analysis), Li Jia (Chinese Academy of Sciences), Q. Duan (Beijing Normal University), S. Kumar (National Aeronautics and Space Administration), T. Holmes (National Aeronautics and Space Administration), J. Wang (Georgia Institute of Technology), R. Padron (Swiss Federal Institute of Technology in Zurich), L. Gudmundsson (Swiss Federal Institute of Technology in Zurich), J. Groh (Leibniz Centre for Agricultural Landscape Research & Jülich Research Centre), A. Graf (Jülich Research Centre), H. Cleugh (Commonwealth Scientific and Industrial Research Organisation) and P. van Oevelen (GEWEX).

Evapotranspiration (ET) from soil and vegetation is a key part of the energy and water budgets and, with condensation, a process that links both explicitly. Accurate experimental determination of ET is a requirement, but it is challenging both in situ and remotely, introducing uncertainties for model parameterization development and validation. Furthermore its representation often ignores important processes for specific conditions. We list a number of issues that we consider to deserve further reflection, grouped under four main challenges. It is addressed to members of the main scientific communities concerned, namely meteorologists, hydrologists, soil physicists, plant physiologists, agronomists, land-surface modelers and remote-sensing researchers.

First Challenge: Defining and Understanding ET

While *actual evapotranspiration* (ETa or simply ET) refers to the amount of water vapor coming from any surface, not necessarily vegetated or well-watered, *potential evapotranspiration* (ETp) is the theoretical value if water limitation at the surface is removed, and *reference ET* (ET0) is the theoretical value without water limitation and replacing the existing vegetation with a standard grass crop. A closely related concept is the *atmospheric water demand*, which, according to the American Meteorological Society (AMS) glossary, is "the evapotranspiration that would be achieved from a well-aerated soil/plant surface at a field water-holding capacity."

Even though ETp can be a useful reference tool, there is a vast array of situations and related processes contributing to ET that are not taking place under such idealized conditions and yet are very relevant over the Earth's surface. For example:

- *Sublimation*: this transition takes place from areas covered (totally or partially) by snow and ice, including the intercepted snow by vegetation canopy. It is also relevant for wind-blown snow. Important factors to consider are the physical properties of surface snow, in particular hardness and roughness. Evaporation and sublimation may happen simultaneously when liquid water is present in the top layer of the snowpack.
- *Evaporation from free water surfaces*: this depends on an equilibrium term (dominated by radiation) and an advective term, controlled by the atmospheric vapor pressure deficit with respected to the surface, and the wind speed. In sunny and windstill conditions the first term may dominate. Ponds with shallow waters may be treated differently from larger and deeper water bodies. The importance of the energy storage term has yet to be analyzed.
- *Rainfall interception*: for canopies, the determination of the amount of intercepted water is a significant challenge, both to measure it experimentally and to parameterize it in models. Canopy structure and within-canopy resistances, which are usually calculated as a function of the leaf area index, play an important role for ET from intercepted water.
- *Nocturnal phase changes*: even though some applications neglect them, nocturnal ET values can be on the order of 10% of the total daytime values, both from soil evaporation induced by wind and from nocturnal plant transpiration sustaining the integrity of the vascular system. On calm, clear nights, condensation is common and may be a very significant contributor to the water budget of ecosystems in arid to humid regions. Moisture adsorption by bare soil taking place mostly during late afternoon and evening is another important process.
- *Plant transpiration*: water absorbed by roots is transported to the leaves by the vascular system. Water lost through the stomata generates the tension that maintains the filling of the xylem and cools the leaves to prevent overheat-

ing. This process depends mostly on atmospheric conditions and soil moisture availability. In models, it is often parameterized by assuming that leaves present a "resistance" to evaporation in addition to a resistance posed by the air. Many models assume the validity of the Monin-Obukhov similarity theory over the leaf surface, and use a "big-leaf" approach to calculate the transpiration of the canopy. Multi-source or multi-layer (generally two: vegetation and bare soil) approaches are available in some models as well. Different formulations exist to express the relation between stomatal conductance and soil moisture availability, which may depend on soil water potential, the root distribution and the hydraulic properties of the roots.

- *Evaporation from the soil*: evaporation of moisture from the soil is determined by the distribution of soil pore sizes and the humidity of the soil air within these pores, from the soil layer between the "evaporation front" and the soil surface. The pore size distribution depends on the soil texture, dry bulk density and organic matter contents as well as on biological activity. Hydraulic properties and soil water flow dynamics determine the amount of water reaching the evaporation front, where water vapor can be transported, via diffusion or convection, to the surface. Hydraulic models employ pedotransfer functions (PTFs) derived from soil databases, and these PTFs and the consequent hydraulic properties vary largely between models.

- *Vertical and lateral transport of air moisture*: ET is measured at specific locations, but its value also depends on the state of the surrounding areas. Entrainment of air from the free atmosphere may significantly modify the near-surface atmospheric humidity (drying/moistening for wet/arid surfaces). Land surface heterogeneity may result in lateral advection processes that would humidify or dry the air above a location and consequently change ET compared to a homogeneous area. Moisture transport by terrain-induced slope flows should also be considered.

- *ET across scales*: depending on the application, ET is generally considered at a specific temporal and spatial scale. Available formulae do not explicitly take into account the scale, although these equations have often been derived under specific restrictions,usually locally and for the daily or monthly scales. As the spatial scale increases, there is a concomitant increase of the heterogeneity of the concerned area, and improved ways of accounting for this are an active area of current investigation.

Second Challenge: Measuring ET In Situ

ET can be estimated experimentally by a variety of methods, like those based on aerodynamic or atmospheric methods, which include the eddy-covariance and the flux-gradient methods plus scintillometry; those using the soil and plant water balance, like lysimeters, soil moisture monitoring or sap flow at the leaf level; or those based on the surface energy balance residual.

At local and short time-scales, water vapor fluxes are generally estimated using the *eddy-covariance method* (EC), by sampling the three components of the wind vector and water vapor concentrations at high frequency to compute water vapor fluxes at typical averaging periods between 10 minutes and one hour. This expensive, high-maintenance setup is normally found in the research context and rarely in operational settings. EC implicitly assumes local surface homogeneity and stationarity of the regime during the averaging period. The surface energy budget (SEB) shows a lack of closure in the range of 10-25% when turbulent heat fluxes are determined using the EC method. For some applications, closure is achieved by increasing both the sensible heat flux (H) and latent heat flux (LE) while maintaining the Bowen ratio.

ET can be estimated through the *flux gradient method*, where the flux is taken proportional to the vertical gradient of humidity. The proportionality coefficient depends on the wind and the atmospheric stability, and is determined using a similarity theory, usually restricted to homogeneous and stationary conditions. When one atmospheric measurement and one surface estimate are used to compute the flux, we refer to that as the "bulk aerodynamic method." If we assume that the proportionality coefficients are the same for heat and moisture, we can obtain the so-called Bowen ratio (H/LE) from the gradients of air temperature and water vapor pressure at two levels. With knowledge of net radiation (R_n) and ground heat flux (G) (see *the residual method* below), we can then obtain the values of H and LE.

Scintillometers estimate an area-averaged value of ET by analyzing the intensity fluctuations induced by turbulence on electromagnetic waves propagating over a path of 100 m to 10 km length. Optical scintillometers at visible or near infrared (NIR) wavelengths allow for the determination of H and then LE assuming the SEB closure. A combination of an optical and a microwave scintillometer allows for the direct estimation of LE. Monin-Obukhov similarity theory is used to derive H and LE from the temperature and humidity structure parameters, which are the primary turbulence parameters determined from the scintillation measurements.

The *residual method* estimates ET (or its equivalent, the latent heat flux, LE) using the values of the other three main terms of the SEB: R_n, G and H while assuming closure of the energy balance. R_n and G can be determined by direct measurements, while H may be measured with a sonic anemometer through EC, by the gradient method using air and surface temperatures (see below), or with the sigma-T method using fast thermocouples. The resulting ET error depends on the quality of the values of the other terms and it attributes all possible deficits of the SEB components to LE.

For many decades, ETp was estimated using an *evaporation pan*, measuring the water lost by a shallow circular basin with a free surface of water. Its use is decreasing as it ignores the contribution of the soil-vegetation system and it is not considered representative of its surroundings.

Agronomists and soil physicists use a variety of methods: i) a *lysimeter* determining the loss of water mass of a volume of soil and vegetation by weighting it, ii) *sap flow sensors* estimating the transpiration flux by measuring the speed of sap as the passage of a warm pulse heated somewhere below is detected, iii) *closed flux chambers* instantaneously measuring ET from leaves or the soil and iv) trying to establish correlations between soil moisture or water potential and ET. These techniques represent very diverse spatial and temporal scales.

Sometimes there is a need to *distinguish between evaporation and transpiration*, which may be determined by analyzing the isotopic composition of Deuterium and 18O in the condensed atmospheric water vapor, and for water at different depths of the soil. With relatively novel measurement techniques, profiles of isotopic composition can now be monitored continuously, providing information with much higher temporal resolution. Methods using microlysimeters below the plant canopy are under development.

EC and lysimeters are usually taken as the best ET estimates and the other methods are calibrated using them. Comparisons between the two have been made with inconclusive results, probably related to the different scales relevant to each method, although modern lysimeters with high-frequency weight measurements allow ET estimates at an hourly time resolution. Using the Bowen Ratio method to close the SEB equation for both EC and lysimeter measurements provides similar values for both systems.

New global observation networks are needed for Earth system monitoring and modeling. FLUXNET provides ET estimates basically using the EC method, and it still has large spatial gaps at the global scale. There are also time lags due to inappropriate weather conditions. Lysimeters are progressively becoming part of networks like the Integrated Carbon Observation System (ICOS) or the Terrestrial Environmental Observatories (TERENO).

Third Challenge: Parameterizing ET

Estimated values for ETp have been generated for more than half a century using simple empirical approaches relating air temperature and usually some insolation-related parameter. A number of them have been widely used since the proposal of Thornthwaite in 1948, initially for monthly values. Currently the Food and Agriculture Organization (FAO)-modified Hargreaves formula is recommended for ETp at the daily scale if only temperature and radiation are available.

The Penman-Monteith (PM) equation is the most widely used today, following Penman's initial formula in 1948, which was later expanded by Penman and Monteith to plant canopies. Based on the SEB equation, it makes a number of assumptions: i) the SEB is represented by only four terms (H, LE, G, R_n) that close the budget; ii) H and LE are proportional to the temperature and humidity gradients between the surface and the air above; iii) the conductances (or resistances) depend on surface layer theory and the vegetation and soil state; and iv) the saturating water vapor pressure is assumed to vary linearly with the temperature. Additionally, the net radiation at the surface is often expressed in terms of air temperature with subsequent modification of conductances. It is common to further simplify the equation by parameterizing G as a function of R_n.

The PM formulation implicitly assumes surface homogeneity and steady conditions. The extension to a vegetated surface was made by including a physiological conductance, essentially determined by the stomatal aperture in the conceptual framework of the "big leaf" model, where each canopy component has its own conductance and they are added in parallel.

The first of two very popular expressions for ETp conceptually evolving from PM is the Priestley-Taylor equation, which depends solely on net radiation and a coefficient 1.26 for well watered surfaces; that is, a limit of PM when aerodynamic resistance is large and surface resistance is small. The second is the PM FAO-modified in 1998 by Allen et al. for daily crop ET values, imposing specified values for the canopy surface resistance (70 sm^{-1}) and assuming neutrally stratified conditions and G=0.

An alternative approach, proposed originally by De Bruin in 1987, follows Makkink in considering that ET for a well-watered surface is well-represented by the shortwave radiation at the surface. He expanded the concept in 2016 with his co-authors, adding a correction factor that takes into account the dry air entrainment at the top of the atmospheric boundary layer.

Other estimates of ET are obtained by varying the coefficient of the Priestley-Taylor equation to represent the water stress of the surface, or by the use of two-source/two-layer models. These include the model introduced by Shuttleworth and Wallace based on PM in 1985, which considers separate equations for the canopy and the soil in the case of sparse canopies. These models have recently evolved to multi-layer models as developed by Verhoef and colleagues.

Complex soil-vegetation-atmosphere transfer models (SVAT) are used to compute ET, especially in numerical models of the atmosphere, with diverse degrees of complexity, relying heavily on the concepts described above. The SEB equation is the basis of their approach, which is equivalent to the PM equation without the surface temperature, since the latter is solved numerically. Soil evaporation and plant transpiration are usually estimated separately, with a multi-source model or a mosaic-tile approach in an attempt to represent surface heterogeneity. Vegetation can go from a simple “big leaf” model to canopy flow models. The modeling of canopy and aerodynamic resistances, the prescription of the soil and vegetation characteristics, the handling of snow and intercepted water, the coupling to runoff and the improved treatment of terrain heterogeneity are amongst the main challenges that SVAT modeling faces currently.

ET determination in numerical models is now facing the transitioning of weather models into convection permitting models that experience far more fast fluctuations near the land surface than models in which convection is parameterized. A thorough review is needed of whether conventional concepts, such as the Monin-Obukhov Similarity Theory (MOST), need to be improved for the next-generation models. Furthermore, models have to continuously improve their performances related to forecasting, data assimilation, trend analysis and climate projections.

Fourth Challenge: Estimating ET Remotely and at the Catchment Scale

Satellite remote sensing ET estimates normally use the approaches of PM, Priestley-Taylor or the residual method and make a number of further assumptions to obtain H, G or R_n, usually imposing the closure of the SEB. As mentioned above, parameterizing ET essentially as a function of solar radiation is also an option. The resulting values are compared with in situ ET estimates and calibrated accordingly.

To obtain the actual ET, normally a function is derived that varies between wet conditions-corresponding to ETp-and dry conditions when sensible heat flux prevails. Quantities like albedo, land surface temperature, surface roughness, soil moisture or some vegetation index are used. For heterogeneous vegetated surfaces, two-source energy balance (TSEB) approaches are common. There exist also purely empirical algorithms trained by data, using, for example, neural networks.

Satellite estimates of ET are given at the scale of the pixel, and some applications require information at much higher resolutions, such as the hectometer and subdaily scale. This is leading to the development of downscaling methods for most satellites.

The scale issue has a specific hydrological side, since hydrologists have traditionally analyzed the water budget at the catchment level, looking for closure at relatively large time scales (typically annual) and using the water balance as the basic methodology, with ET=precipitation−runoff, assuming that storage changes might be neglected at annual time scales. However, hydrological numerical models require estimations of ET at a higher time-space resolution. Annual catchment water budgets may be used as a calibration or validation method for other approaches.

To reflect on these ET-related subjects, a workshop is being organized for 7–9 October 2019 in Sydney, Australia, hosted by the University of New South Wales. It is intended to bring together specialists from different disciplines and provide a space for interaction and scientific progress on the subject. More information will be available at *https://www.gewexevents.org/events/determining-evapotranspiration/*.

Land Surface Interactions with the Atmosphere over the Iberian Semi-Arid Environment (LIAISE)

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Introduction

One of the largest challenges facing environmental science is understanding future changes in the terrestrial water cycle and the subsequent impact on water resources. It has also been recognized by international organizations such as the World Climate Research Programme (WCRP) that human activities are playing a key role in modifying the continental water cycle, and therefore must be accounted for in projections. As highlighted by the WCRP Grand Challenge on "Water for the Food Baskets of the World," this issue is especially critical in bread basket regions where water resources are already limited, such as the Mediterranean basin. Understanding the processes that drive the hydrological cycle in this region is a key aim of the international HYdrological cycle in the Mediterranean Experiment (HyMeX). Climate projections from the Coupled Model Intercomparison Project phase 5 (CMIP5) predict that the Mediterranean region will be a so-called climate change "hot spot" during the twenty-first century (Diffenbaugh and Giorgi, 2012). However, semi-arid regions are also hot spots for biases in climate model variables, in particular land surface temperature (LST) and components of the surface energy balance. The Mediterranean basin is also characterized by highly heterogeneous land cover in terms of both natural and anthropized surfaces, largely driven by the limited availability of soil moisture and the nature of the precipitation. Since rainfall is essentially limited to winter and mountainous areas, human management of the natural river systems is required to provide water for crops and an ever-increasing population. Dams and extraction for irrigation modify the amount and timing of the water flowing into the ocean. Irrigation is also known to significantly impact local atmospheric boundary layer (ABL) growth and structure, in addition to modifying near surface atmospheric conditions and increasing convective activity and clouds downwind of irrigated areas (e.g., Lawston et al., 2015). It also greatly enhances the aforementioned land surface (flux) heterogeneity.

The current representation of anthropization in land surface models (LSMs) and therefore within global climate models (GCMs) is in a relatively nascent stage and urgently needs attention if we are to make accurate future projections of water resources and modifications to the global water cycle

(Harding et al., 2015). The understanding of the impact of anthropization and its representation in models have been inhibited due to a lack of consistent and extensive observations. Here we present the plans for a project which will bring together ground-based and airborne measurements with modeling studies to improve our understanding of key natural and anthropogenic land processes and the subsequent feedbacks with the Mediterranean boundary layer and basin-scale hydrological cycle. These observations will provide the opportunity for a number of community modeling experiments to move forward within GEWEX, helping to highlight gaps in our knowledge and identify current model deficiencies within land surface processes and land/atmosphere interactions.

Objectives and Science Questions

The overall objective of this new activity, the Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) project, is to improve our understanding of the impact of anthropization on the water cycle in terms of land-atmosphere-hydrology interactions, and the limitations of models to represent all aspects of the terrestrial water cycle in a semi-arid environment on the Iberian peninsula. These include: i) the influence of heterogeneity in land cover, including large irrigated areas, on area-averaged surface fluxes of momentum, heat and moisture; ii) the consequence of land/atmosphere interactions on local initiation of precipitation and boundary layer evolution; iii) the interactions between soil moisture, reservoirs and groundwater in both natural and irrigated regions; iv) the impact of changes in runoff generation owing to anthropogenic effects and its influence on stream flow and reservoir storage; and v) the ramifications of human influences on the future evolution of the water cycle. The main science questions can be summarized as:

1. What are the key natural and anthropogenic semi-arid surface processes that modulate or control infiltration and runoff and govern turbulent fluxes and their spatial heterogeneity?
2. How does anthropization impact boundary layer development, mesoscale circulations and potentially precipitation recycling over this region via feedbacks with the atmosphere?
3. What is the sustainability of ground water and reservoirs in the face of expanding agricultural and farming activities, especially in light of projected future warming and drying over this region?

The study domain for LIAISE is the Ebro basin in northeastern Spain, which is bound to the north by the Pyrenees and to the south by the Iberian System. Surface heterogeneity has grown due to the presence of human society, which has been altering the hydrological cycle and the landscape mainly through intense agricultural activity. The bulk of the basin runoff is generated in the Pyrenees region, therefore infrastructure has been built to store and transport water from the mountainous areas to the agricultural fields. Most of the water used for agriculture, approximately 75%, is stored in reservoirs while the rest is maintained by the snow pack in the mountains. This infrastructure has increased agricultural production and dramatically enlarged irrigated areas. In addition, agricultural fields in the headwater region have been abandoned, which leads to the expansion of forests, increasing evapotranspiration and decreasing river flow. Therefore, the human component of the Ebro system cannot be avoided in any study that aims to understand the water cycle of a basin driven by meteorological and hydrological processes.

Strategy

The overall strategy for LIAISE is to take a multidisciplinary approach consisting of utilizing a suite of LSMs and hydrological and meteorological models that will employ remotely-sensed data or data assimilation strategies to prescribe input parameters and conduct evaluations. It can be summarized as follows:

1. A network of surface energy budget (SEB) observing stations will be installed within an approximately 10 km radius centered over the Urgell and Plà d'Urgell (Lleida) region of the Ebro basin. This area is selected since it encompasses several representative Mediterranean land cover types: irrigated cereal crops (corn, alfalfa), non-irrigated crops (wheat and other cereals), irrigated fruit trees (pear, apple), irrigated poplar plantations, natural grasses and baresoil, non-irrigated fruit trees (olives, almonds) and a lake used for irrigation. The land sites will also include soil moisture, temperature and vegetation monitoring data. This location will also allow us to benefit from the dense local meteorological station and radar data from the Spanish State Meteorological Agency (AEMET) and the Meteorological Service of Catalonia (SMC), along with an existing extensive observation site run by the Institute of Agrifood Research and Technology (IRTA), which includes weighing lysimeters in apple orchards. This network will enable us to evaluate the ability of LSMs to simulate fluxes, especially evapotranspiration, over irrigated sites and to contrast the fluxes with those from natural surfaces. These sites will be maintained at least through entire growing season as part of the Intensive Observation Period (IOP) from early April through September 2020.
2. A 15-day Special Observation Period (SOP) is planned for mid July 2020, when contrasts between irrigated and natural surfaces are at their maximum. During the SOP, the SEB network will be complemented by extensive measurements of the lowest 4 km of the atmosphere using captive balloons, frequent radio-sounding releases, a UHF wind profiler, lidars and up to five flights by the French Office of Aircraft Instrumented for Environmental Research (SAFIRE)/ATR42 aircraft. Measured atmospheric fluxes and state variables will be used in conjunction with fully coupled, non-hydrostatic mesoscale models to study the impact of irrigation on the spatial variability of the ABL, the basin scale circulation and water budget and interactions between the irrigated and natural surfaces.
3. During the observational campaign, a 5-day period will be identified during the dry down of soil moisture in the spring. Throughout this period, radiosondes will be launched at regular periods to add to atmospheric and flux profiles along a 50 m mast. These data will be used to study the

impact on interactions with the lower part of the boundary layer and the contrast in the surface fluxes between the sites with natural dry down and the irrigated sites. A number of LSMs will be confronted with the data to help understand the limitations identified by Ukkola et al. (2016).

4. Several LSM-hydrological modeling platforms will be tested over this region. The improved understanding and representation of evaporation from irrigated surfaces and their high resolution mapping by satellite data will be incorporated into models, which include new parameterizations for dams, rivers and canals, groundwater and reservoirs. Extensive discharge and dam release data will be obtained from the basin authority, the Hydrographic Confederation of the Ebro, through its real-time data portal, Sistema Automático de Información Hidrológica (SAIH). The focus will be on better understanding the exchanges between the different components of the water cycle.

5. Two measurements from the ATR42, high resolution land surface temperature and soil moisture estimates from the GLObal navigation satellite system Reflectometry Instrument (GLORI), will be used alongside state-of-the-art soil moisture products based on downscaled data such as that from the Soil Moisture and Ocean Salinity (SMOS) and Soil Moisture Active Passive (SMAP) missions. This data will be used for assimilation into LSMs and/or evaluation alongside in situ soil moisture observations from an existing Ebro Observatory network and measurements from irrigation-monitoring companies. The use of high-resolution remotely-sensed data from both satellites and aircraft along transects crossing swaths of irrigated and non-irrigated land with concomitant surface observations will permit a multi-scale modeling approach going from the parcel to the regional scale. An example of the detection of irrigated zones over this region using remote sensing is shown in Figure 1 (*see cover*).

6. The improved coupled LSM-hydrological model systems that include anthropogenic effects will be used in conjunction with statistically downscaled new high-resolution regional climate data as part of the European-Mediterranean Coordinated Regional Climate Downscaling Experiment (EuroMed-CORDEX) project in order to provide estimates of the evolution of water resources over this region.

7. Field-scale actual and potential evapotranspiration will be evaluated using two-source energy balance (TSEB) models, which combine thermal observations from Sentinel-3 satellites and optical observations from Sentinel-2 satellites. The methodology for combining Sentinel-3 and Sentinel-2 data to obtain high-resolution ET is currently being researched in the Sentinels for Evapotranspiration (SEN-ET) project (*http://esa-sen4et.org/*).

Summary and Outcomes

To the authors' knowledge, this is the first international project which will focus on the human impact on the water and energy cycle in a semi-arid environment for which the models are advanced enough to explicitly account for dams, irrigation methodologies, river flow, ground water interactions, vegetation phenology and atmospheric feedbacks. These models are sophisticated enough to exploit remotely-sensed data as input or to use data assimilation strategies, but despite recent advances, water management is either quite simple or nonexistent in most LSMs. This was evident during the GEWEX Hydroclimatology Panel (GHP)-Global Land/Atmosphere System Study (GLASS) Workshop on Including Water Management in Large Scale Models (Harding et al., 2015). So we seek to improve the representation of anthropization in the LSM component of Earth system models. LIAISE addresses the GEWEX Science Questions and contributes to WCRP's Grand Challenges, notably how a warming world will affect available fresh water resources globally, specifically in the food basket regions, and how it will change human interactions with these resources and their value to society. Another key GEWEX Science Question addressed by LIAISE pertains to improving our understanding of the effects and uncertainties of water and energy exchanges in the current and changing climate and how to convey this information to society. The improvement of the representation of anthropogenic effects in models will form the foundation for water resource impact studies under future climate change. These results will be communicated to water management services within the Ebro basin. A comprehensive database, consisting of surface-based and aircraft measurements of surface and hydrological fluxes and states and properties of the ABL, will be integrated into the Mediterranean Integrated STudies at Regional And Local Scales (MISTRALS)/HyMeX database, which can accessed upon request by interested researchers. This database of observations will form the basis for a number of international modeling experiments that will cut across many areas of interest to GEWEX, ranging from the ability of LSMs to capture soil moisture dry down, the representation of heterogeneity and how this interacts with the atmospheric boundary layer, the impacts of human influence on land surface fluxes and land/atmosphere interactions and the impact of human influence of the terrestrial water cycle of semi-arid environments.

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COnstraining Orographic DRag Effects (COORDE)

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Introduction

Mountains play a vital role in the predictability of the atmospheric system at both weather and climate timescales. While the large-scale (>*O*(100 km)) mountains are well resolved in models used for climate projection, seasonal forecasting and numerical weather prediction, small-scale (<*O*(100 km–10 km)) mountains are generally not. These small-scale mountains have the ability to generate gravity waves that grow in amplitude as they propagate vertically, decelerating the flow in the stratosphere. They also deflect flow near the surface, therefore acting as a drag on the atmosphere both locally and remotely. The importance of representing these processes in atmospheric models for the large-scale circulation is now well known. As a result, they are approximated in models through parameterizations that have, thus far, relied mostly on idealized modeling and linear theory. The accuracy of these parameterizations is highly uncertain in models, as was highlighted by the Working Group on Numerical Experimentation (WGNE) Drag project (Zadra et al., 2013). They showed that, while the total parameterized surface stress was roughly similar across models, the magnitude of the contributing components varied greatly across models at similar resolutions.

Owing to the difficulties in directly measuring gravity wave momentum fluxes and the drag that arises from the non-linear interactions with orography near the surface, there are very few constraints on the magnitude and spatial distribution of orographic drag processes. This leads to an ambiguity in the contributing processes and a lack of understanding of both the regime and scale dependence of orographic drag. Following the success of the WGNE Drag project, and motivated by its findings, a new project jointly led by the Met Office and the European Centre for Medium-Range Weather Forecasts and endorsed by GEWEX's Global Atmospheric System Studies (GASS) Panel and WGNE has now been launched. The project, COnstraining Orographic DRag Effects (COORDE), aims to understand and constrain the effects of parameterized and resolved orographic drag through the "*COORDE*-nation" of different modeling groups.

Project Aims

- *Expose differences in orographic drag parameterization formulation between models*: Understanding how and why models differ in their parameterized drag contributions requires knowledge of the underlying parameterizations. Taking stock of the various parameterization formulations and which processes they account for has been the first phase of this project. With this information, we hope to inform the results of the model inter-comparison and to uncover the diversity of parameterizations currently used in models.
- *Understand impacts of differences in orographic drag parameterizations for modeled circulation*: Previously, the WGNE drag project and other studies have diagnosed and compared the stresses from parameterized orographic drag. Here, we wish to understand the implications of differences in parameterized drag, and its interaction with the resolved dynamics, for model circulation.
- *Quantify contribution of parameterized orographic drag to model error*: Attributing systematic model errors to particular processes can be challenging due to, firstly, the complex (often non-linear) interactions between various processes and, secondly, non-local impacts of certain processes. However, by running short-range experiments initialized from analysis, the interaction between processes remains relatively linear and the errors remain localized to their source. Through running low resolution model experiments in this manner, we hope to identify and attribute systematic model errors to orographic processes.
- *Use high resolution simulations to quantify drag from small-scale orography in order to evaluate and constrain orographic drag parameterizations*: Measuring orographic drag over large extended mountain ranges is extremely difficult. Numerical weather prediction centers are now entering an era where they are able to realistically model the atmosphere using comprehensive high resolution simulations, and are doing so routinely. Harnessing this capability by modeling the non-linear fluid dynamics around complex orography using various high-resolution models will help us to constrain and validate current orographic drag parameterizations.
- *Understand differences between the impacts of resolved and parameterized orographic drag across models*: Generating a spread of different responses to parameterized and resolved orographic drag through our model intercomparison will give us an indication of the uncertainty in both. A deeper understanding of the reasons behind this spread will be sought, with the cooperation and input of participating members.

Method

In order to address the aims outlined above, the project proposes a model intercomparison that seeks to quantify the impact of small-scale resolved orography and parameterized orographic drag on the circulation over complex mountainous regions. Our main regions of interest are the Middle Eastern mountainous region (see Figure 1 on next page) and the Himalayas.

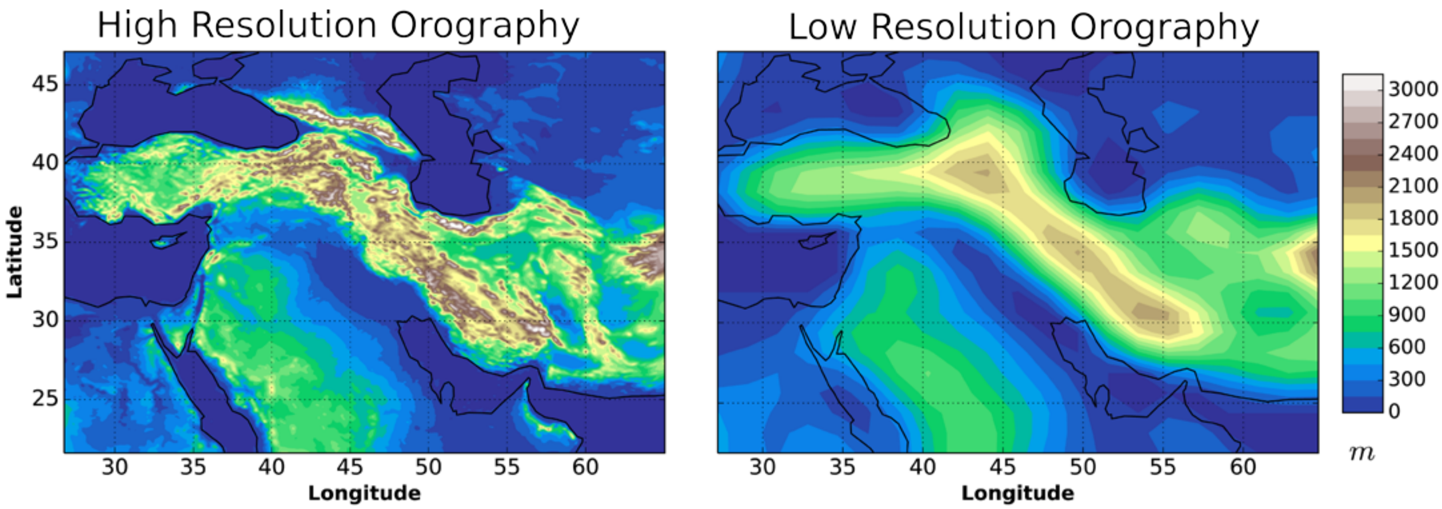

***Figure 1**: Orographic height over the Middle East region, used in the high resolution (4 km) Met Office Unified Model (MetUM) experiments with (left) high resolution and (right) low resolution orography.*

As a means of separating the small-scale contributions of resolved orographic drag to the atmospheric circulation from the larger-scales, we propose the use of a method employed in van Niekerk et al. (2018), briefly outlined here. Two sets of short-range 24 hour forecast experiments initialized from analysis over the period 1–14th January 2015 are used. In the first set, two high resolution (<10 km) experiments are performed: one with high resolution orography and one with low resolution (O(100 km)) smoothed orography. The difference between these two experiments will give an estimate of the impact of small-scale orography that is typically unresolved in climate and seasonal prediction models. In the second set, two low resolution experiments are performed: one with the orographic drag parameterization turned on as standard and one with parameterized orographic drag turned off. The difference between these two experiments will then give the impact of parameterized orographic drag. By comparing the supposedly-equivalent circulation impacts of small-scale resolved orography with that of parameterized orographic drag, it is possible to verify and constrain the parameterization schemes. An example of the "high resolution orography" and "low resolution orography" that is prescribed in the high resolution Met Office model over the Middle East is given in Figure 1.

This simple method has proven useful for identifying deficiencies in the orographic drag parameterizations employed in both the Met Office Unified Model (MetUM) and the European Centre for Medium-Range Weather Forecasts Integrated Forecasting System (ECMWF IFS). The MetUM high resolution experiments are performed using the limited area model at a horizontal resolution of 4km and the MetUM low resolution experiments use the global model at a resolution of 150 km. The ECMWF IFS high and low resolution experiments are performed with the global model at a resolution of 9 km and 125 km, respectively. The impact on the zonal winds at the end of the 24 hour model integration, averaged over all the forecasts from 1–14th Jan 2015 and longitudinally averaged over the Middle East, is shown in Figure 2. The left panel shows the impact from the small-scale resolved orography, as defined above, and the right panel shows the impact of turning on the parameterized orographic drag. While there are some differences in the impact of the resolved orography, potentially due to the dynamic formulation or horizontal resolution of the two models, the most striking difference is in the impact of the parameterized orographic drag of these two models. The MetUM produces far more deceleration at low levels compared with the ECMWF IFS and, using the impact of the resolved orography as a reference, this low-level deceleration appears to be excessive in the MetUM. Conversely, the upper-level deceleration between 15 km–22 km from parameterized orographic drag appears to be insufficient in both models, but, again, the MetUM compares less well with the resolved orographic impacts.

Further investigation of the low resolution simulations with parameterized orographic drag (i.e., the standard configuration of the low resolution MetUM and the ECMWF IFS) reveals that the lack of parameterized orographic drag in the lower stratosphere leads to the winds becoming excessively westerly within that region relative to analysis. This method has, therefore, allowed us to identify a circulation error that is common to both models and begs the question of whether or not it is present in other models.

With these types of experiments performed across a range of models and model resolutions, along with further analysis to explain why models differ so greatly in their parameterized drag impacts, a deeper understanding of missing parameterized processes and/or dependencies will be sought.

Next Steps

The question of whether or not the systematic lack of (resolved or parameterized) orographic gravity wave drag in the lower stratosphere, seen in both the MetUM and ECMWF IFS at low horizontal resolutions, is present in other models at similar resolutions will be addressed using our proposed modeling framework. If we find that all the models exhibit this error, this motivates the need for a joint effort in reducing it. On the other hand, if we find that only some models exhibit this error, investigation into the particulars of these models compared with the others will likely shed some light on the problem.

In addition to the analysis of the impacts of resolved and parameterized orographic drag on the winds, diagnostics of the vertical and horizontal distribution of parameterized wind tendencies from the various orographic and boundary layer drag parameterizations are requested. This will help us to determine not only how models are partitioning their total drag into various processes, as had already been done in the WGNE Drag project, but also where the parameterized drag is being deposited. What is more, since the total wind response to parameterized orographic drag shown in Figure 2 is a combination of the parameterized drag tendencies and the resolved dynamics tendencies, these diagnostics will help us to understand the interactions between parameterized drag and the resolved flow.

Another, perhaps more subtle, path of investigation is to understand the differences in the resolved orographic impacts. From Figure 2, it is evident that there are differences between the MetUM and ECMWF IFS in both the magnitude and distribution of the resolved orographic impacts. With several models performing similar experiments across a range of high resolutions (between 10 km to 1.8 km), the agreement in resolved orographic impacts can also be ascertained.

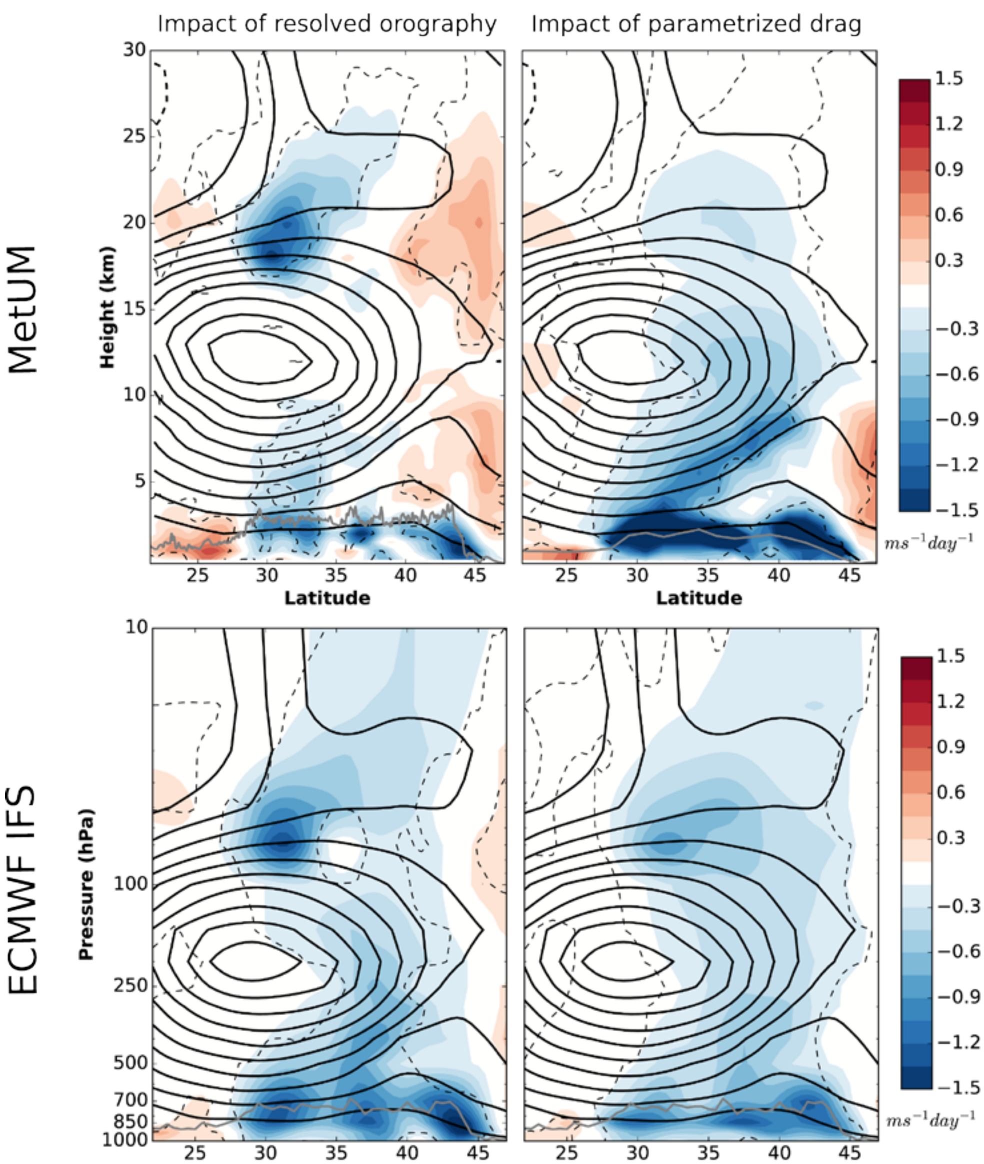

__Figure 2__: The impact of (left column) resolved orography and (right column) parameterized orographic drag on the zonal winds (colored contours) after 24 hours of model integration, longitudinally averaged over the Middle East region. The top row shows results from the MetUM and the bottom row shows results from the ECMWF IFS. Block line contours are the longitudinally averaged zonal winds in the low-resolution simulations with parameterized orographic drag. Reproduced from van Niekerk et al., 2018.

Participation

There are currently ten centers (12 models) participating: Environment Canada, National Oceanic and Atmospheric Administration, China Meteorological Administration, Deutscher Wetterdienst, Japan Meteorological Agency, Meteo-France, National Center for Atmospheric Research, Korea Institute of Atmospheric Prediction Systems, European Centre for Medium-Range Weather Forecasts and Met Office. The first model output is due at the end of January 2019 and results will begin to be generated in spring 2019. Late participation is welcome, and for more information please contact Annelize van Niekerk (*Annelize.van-Niekerk@metoffice.gov.uk*) and Irina Sandu (*Irina.Sandu@ecmwf.int*).

You can also see *https://osf.io/37bsy* for further details.

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Meeting/Workshop Reports

Remote Effects of High Elevation Land Surface Temperature on S2S Precipitation Prediction: First Workshop on LS4P and TPEMIP

Washington, D.C., USA
8–9 December 2018

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The kickoff workshop for the "Impact of initialized land temperature and snowpack on sub-seasonal to seasonal prediction" (LS4P) Initiative and "Third Pole Experiment Multi-Model Intercomparison" (TPEMIP) Project was held just prior to 2018's annual American Geophysical Union meeting. Subseasonal to seasonal (S2S) prediction, especially the prediction of extreme climate events such as droughts and floods, is scientifically challenging and has substantial societal impacts and economic consequences. Despite the substantial progress that has been achieved in recent decades, the prediction skill for precipitation anomalies in spring and summer months has remained stubbornly low. The GEWEX/Global Atmospheric System Study (GASS) LS4P initiative put forward a new approach that complements sea surface temperature (SST), snow and soil moisture research by suggesting the effect of land memory in terms of the land surface/subsurface temperature (LST/SUBT) on S2S prediction. Most land-atmosphere interaction studies have focused on the local effect, while the possible remote effects of large-scale LST/SUBT anomalies in geographical areas upstream on S2S prediction have largely been ignored. The LS4P project intends to address the question of the impact of the initialization of large scale LST/SUBT and snow pack, including aerosols in snow, in climate models on the S2S prediction over different regions. East Asia has been selected as the focus area in the first phase because of the presence of the high elevation Tibetan Plateau (TP) and large-scale snow cover there, in addition to a significant amount of available observational data from the Third Pole Experiment (TPE). This provides an ideal geographical location for the first phase experiment. Regional Earth system (multi-sphere) modeling for the Third Pole region and its impact on the adjacent regions at different scales is also one of TPEMIP's main focuses.

Participants of the First Workshop on LS4P and TPEMIP

The workshop, held in Washington, D.C., USA with 36 participants from different institutions around the world and U.S. government agencies, was very productive with five sessions and many inspiring presentations. GEWEX, GASS, TPE and the University of California, Los Angeles (UCLA) sponsored the event. TPE and the National Science Foundation (NSF) provided financial support. Dr. Peter van Oevelen of the International GEWEX Project Office, GASS Co-Chair Dr. Xubin Zeng, Dr. Ailikun of the TPE Project Office and World Weather Research Programme (WWRP)/WCRP Subseasonal to Seasonal Prediction Project co-Chair Dr. Andrew Robinson expressed their support for the respective projects that they are leading for this workshop, and they also presented summaries of related research. Dr. Jennifer Saleem Arrigo of the U.S. Global Change Research Program presented a multi-federal agency effort, the Climate, Water, and Energy Exchanges (CWEX) program. CWEX facilitates U.S. inter-agency research seeking to enhance predictive understanding of the water cycle and energy fluxes of the changing Earth and global climate system, and to coordinate interactions with relevant efforts of WCRP, such as GEWEX. Dr. Vijay Tallapragada of the National Centers for Environmental Prediction (NCEP)/the National Oceanic and Atmospheric Administration (NOAA), Constantin Ardilouze of Meteo France, and Dr. Qi Tang of the Lawrence Livermore National Laboratory (LLNL)/U.S. Department of Energy (DOE) provided presentations or gave introductions on their respective institutions' relevant S2S research. Dr. Randy Koster of the Goddard Space Flight Center (GSFC)/National Aeronautics and Space Administration (NASA) introduced current soil moisture research and suggestions to the LS4P experimental design.

Studies on the LST/SUBT effect as well as aerosols in snow were presented and discussed in the workshop. After preliminary studies explored the relationship between spring LST/SUBT anomalies and the summer precipitation anomaly in downstream regions in North America and East Asia (Xue et al., 2016, 2018; Diallo et al., 2019), a number of studies have been carried out on this issue. Dr. Yuhei Takaya of the Meteorological Research Institute (MRI), Dr. Zhaohui Lin of the Institute of Atmospheric Physics (IAP) and Dr. Myung-Seo Koo of the Korea Institute of Atmospheric Prediction Systems (KIAPS) reported their initial tests on the LST/SUBT effect on East Asian S2S prediction. Since the LS4P initiative was approved by GEWEX in spring 2018, eight institutions including the Australian Bureau of Meteorology (BOM), Environment and Climate Change Canada, National Meteorological Center/the China Meteorological Administration, IAP/Chinese Academy of Sciences (CAS), the Indian Institute of Tropical Meteorology (IITM), MRI/Japan Meteorological

Agency (JMA), KIAPS/the Korea Meteorological Administration (KMA) and UCLA have provided preliminary LS4P results, which were presented at the workshop. These models' results show a consistent relationship between their May 2003 2 meter temperature (T2m) bias over the TP and June 2003 precipitation bias in many parts of the world. For instance, the models with warm bias in May T2m in the TP also have a wet bias in June precipitation over the region to the south of the Yangtze River. The workshop also reported on the observed global June precipitation difference between warm and cold TP spring T2m years. The results between these two (observation and model bias) are very consistent, as shown in Figure 1 for the eastern part of Asia, with similar results for many other their activities were reported by Dr. Xin Li of the Institute of Tibetan Plateau Research and Dr. Ping Zhao of the Chinese Academy of Meteorological Sciences, respectively. TPE has four data centers and their four websites provide about 2,000 data sets covering glacier, permafrost, snow aerosol and near surface flux information, include data from a soil moisture and temperature network in the TP. TIPEX-III has established multiscale land-surface and planetary boundary layer (PBL) observation networks over the TP and a tropospheric radiosonde network over the western TP. Drs. Li and Zhao indicated that they will provide data services for LS4P and TPEMIP. Data availability and the TPE database for the storage of our projects' model outputs are two of the main reasons

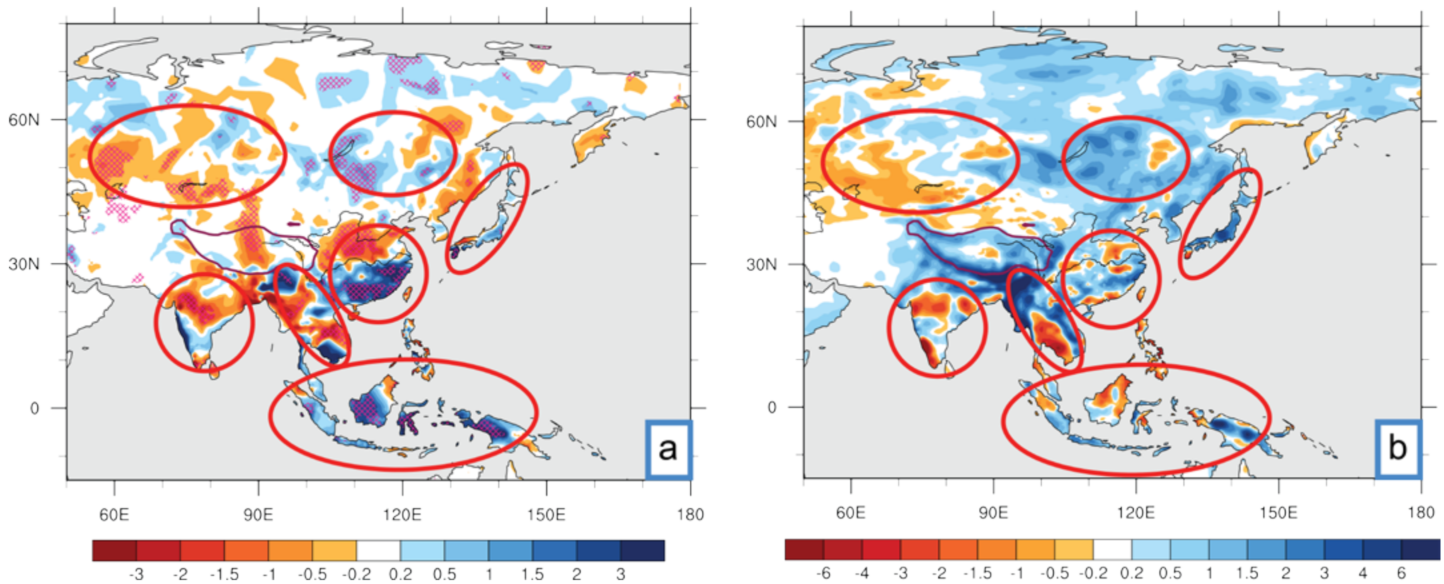

***Figure 1**. Comparisons of relationship between May T2m temperature in Tibetan Plateau and June precipitation from observed anomalies and model biases. Figure 1(a): Observed June precipitation difference between warm and cold years in May 2m Temperature (T2m) over the Tibetan Plateau. The anomaly year's selection is based on whether the year's May absolute T2m anomaly is larger than 0.5 standard deviation of May climatology. (b) Multi-model ensemble mean June precipitation bias when models have a warm bias over TP. Every model has a large T2m bias over the Tibetan Plateau area. For the model with negative T2m bias, the precipitation bias is multiplied by -1 to be included in the composite. The red circles highlight hot spots.*

parts of the world, suggesting a possible global remote effect of TP spring LST/SUBT on summer precipitation in many areas. Dr. Hailan Wang of GSFC/NASA reported that their model bias over the TP affects their model's simulation of the North American droughts.

Some presentations explored the source of the spring LST/SUBT anomalies. Dr. William Lau of the University of Maryland (UMD) showed that aerosols in TP snow may trigger large spring LST anomalies there, and Dr. Mike Burke of the University of Arizona also demonstrated the effect of snow on T2m. Dr. Yang Zhang of Nanjing University suggested that the linkage between TP spring snow and LST anomaly may be related to the Arctic Oscillation.

The TPE and the Third Tibetan Plateau Atmospheric Scientific Experiment (TIPEX-III) have conducted extensive and comprehensive measurements over the TP for decades and why we selected East Asia as the focus of the first phase. In addition, satellite data applications for the TP area have been reported by Dr. Shunlin Liang of UMD.

The workshop attendees decided to change the project acronym name from the initial designation of "ILSTSS2S" to the more concise "LS4P." The workshop participants also discussed future prospects of the LS4P plan. One major task is to demonstrate the potential of using LST/SUBT for S2S prediction, which will include the following: i) Earth system model (ESM) experiments for selected regions and seasons to test the LST/SUBT effect (the first phase focuses on the TP LST/SUBT anomaly impact on surrounding Asian regions; in the second and third phase, ESMs will be used to identify Rocky Mountain and Andes Mountain LST/SUBT effects, respectively); ii) Data analyses to show the relationship between T2m/LST and precipitation for different major mountains and to identify hot spots over the globe where LST has significant impacts [a Tibetan Plateau Oscillation Index (TPO) will be proposed]; iii) The demonstration of regional climate model (RCM) dynamic downscaling effects on S2S prediction; iv) The improvement of land model physics and the refining of the land model LST/SUBT initialization strategy; v) The identification of the source of LST/SUBT anomalies and other mechanisms. Moreover, we will explore the role of snow and aerosols in snow with LST/SUBT in S2S prediction.

Major activities for 2019 were also discussed.

1. A paper will be submitted to Geoscientific Model Development to present the LS4P project early in the year.
2. We will accept model results for May T2m and June precipitation until May 31, 2019. The results will be for the year 2003 and for model climatology, if model climatology is available.
3. Most model results for the first stage sensitivity experiment are expected to be done by about August 31, 2019. A paper with multi-model results will be submitted to a journal early in 2020, and a special issue with relevant research from each group will be prepared by that time.
4. An LS4P and TPEMIP regional modeling group workshop will be held in summer 2019 in Nanjing, China. Nanjing University will host this workshop and limited travel support will be available. The announcement will be distributed soon.
5. A Tibetan Plateau Oscillation Index (TPO) that suggests a global impact of TP LST/SUBT will be proposed and a paper will be submitted in summer 2019.
6. A session in the next American Geophysical Union (AGU) Fall Meeting or American Meteorological Society (AMS) Annual Meeting will be proposed.

The LS4P workshop information and relevant materials can be found at the UCLA website, *https://ls4p.geog.ucla.edu*, and on the GEWEX website at *https://www.gewexevents.org/events/ilstss2s-kickoff-workshop-by-invitation-only/*.

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Process Evaluation Study on Upper Tropospheric Clouds and Convection: 2018 Highlights

Paris, France
22–23 October 2018

Claudia Stubenrauch[1] and the GEWEX UTCC PROES Working Group

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The GEWEX Upper Tropospheric Clouds and Convection Process Evaluation Study (UTCC PROES) working group was created in 2015 to ultimately advance our knowledge of the climate feedbacks of Upper Tropospheric (UT) clouds (*GEWEX News*, May 2017). As large-scale modeling is necessary to identify the most influential feedback mechanisms, it is important that the relevant cloud processes are well represented in climate models. Therefore, the UTCC PROES goals are to:

- Understand the relation between convection, cirrus anvils and radiative heating, and
- Develop observational diagnostic methods to probe processes that detrain UT clouds from convection.

The working group brings together scientists from several communities: satellite observations, radiative transfer and transport modeling, as well as small-scale process and climate modeling. 30 participants were hosted by the Sorbonne University in Paris for the 2018 UTCC PROES Workshop last October. During the two-day event, participants discussed observational analyses of mesoscale convective systems, water vapor and convective transport, process studies, climate variation and feedbacks, as well as parameterizations and model diagnostic studies.

On the first day, results from complementary observations were presented, which gave an interesting perspective on synergetic studies. Transport studies and the possibility of diagnosing convective transport were also examined. Vertical velocity is an important variable in process and climate modeling and it requires observations to be evaluated. The proposed National Aeronautics and Space Administration (NASA) D-Train mission will provide valuable insight, if the project is selected. The second day featured exciting observational studies coupled with modeling on cloud feedbacks to different climate modes, and on the role of convection in the maintenance of tropical margins. The last part of the meeting was dedicated to climate model sensitivity studies. Presentations are available at the UTCC PROES website (*https://gewex-utcc-proes.aeris-data.fr/*) and at the GEWEX website (*https://www.gewexevents.org/events/utcc-proes-workshop/*).

Participants gave very positive feedback on continuing the UTCC PROES meetings, as they also foster collaboration. A potent synergy with the Stratosphere-troposphere Processes And their Role in Climate (SPARC) project was also discussed. Beyond ongoing and new collaborations on this topic, we foresee writing a review article and promoting process-oriented cloud system diagnostics as an additional constraint in the evaluation of model parameterization.

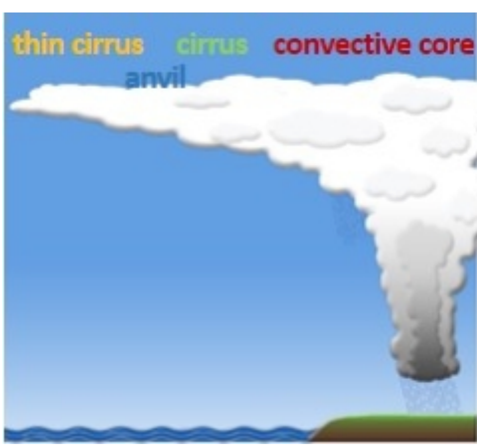
Participants of the 3rd UTCC PROES workshop, hosted by the Sorbonne University in Paris, France

Cirrus radiative heating in the upper troposphere is critical to UT cloud climate feedback. Climate warming will lead to changes in convective intensity and depth, as well as in cloud coverage and emissivity structure of the anvils. The resulting modified upper tropospheric heating then affects large-scale circulation. A first step towards understanding lies in exploring the link between convective strength and radiative heating induced by the cirrus anvils.

To tackle this issue, the UTCC PROES strategy is based on a cloud system concept using hyper-spectral infrared sounder data, as these are also sensitive to the thinner parts of the anvils. By using two independent variables (cloud pressure and emissivity), this methodology is able to relate the anvil properties to the processes shaping them. So far, a database of these UT cloud systems covering 2003 to 2017 exists. The analysis of the UT cloud systems demonstrated that deeper convection leads to relatively more thin cirrus within larger anvils. As the thinner parts of the anvils are hypothesized to heat the atmosphere, this relative thin cirrus increase may have a far-reaching impact on the feedback to climate warming. We are now in the process of adding complementary data, particularly the vertical dimension of the cloud systems from active radar and light detection and ranging (LiDAR) observations and the atmospheric environment from meteorological reanalyses. The radiative heating rates deduced from these narrow track observations are being laterally expanded across the UT cloud systems. This is achieved by powerful deep learning techniques that use artificial neural networks. The vertical structure and heating rates are eventually predicted using cloud and atmospheric properties from infrared sounders and meteorological reanalyses. First results are very promising.

As the UT cloud system approach allows us to link anvil properties to convection (Figure 2a), it can be used for a process-oriented evaluation of general circulation model (GCM) parameterizations of convection, detrainment and microphysics. Therefore a satellite observation simulator has recently been built and the UT cloud system analysis has been adapted to GCM resolution. As an illustration, Figure 2b shows the impact of new bulk ice schemes (coherently linking bulk ice fall speed, v_m, and effective ice crystal size, D_e) on the increase of anvil size with increasing convective depth for the Laboratoire de Météorologie Dynamique General Circulation Model (LMDZ). More realistic bulk ice schemes seem to lead to more realistic anvil size growth with convective depth.

This cloud system concept can also be applied to cloud resolving model (CRM) simulations in order to advance the understanding of the relation between convection and cirrus radiative heating.



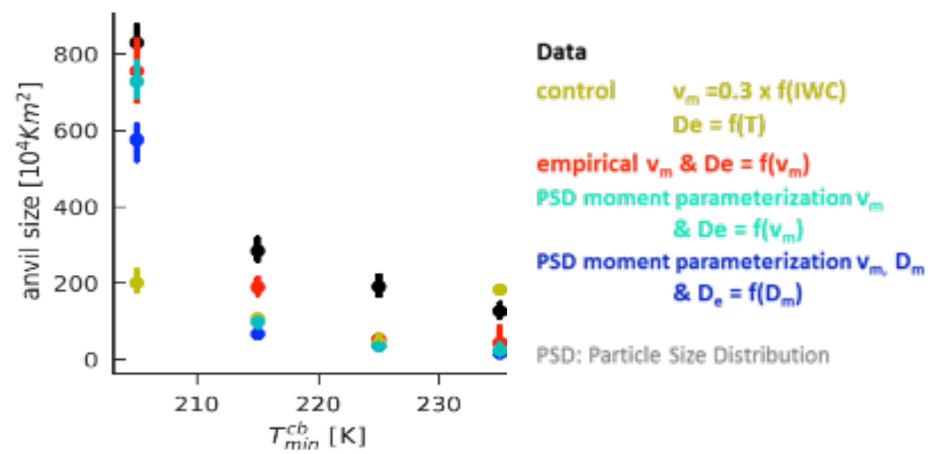


Figure 2a *(left): Scheme of a UT cloud system, with convective core (ε_{cld} > 0.98), cirrus (0.98< ε_{cld} <0.5) and thin cirrus anvil (0.5 > ε_{cld} > 0.1).* ***Figure 2b*** *(right): Anvil size as function of convective depth (given as minimum temperature within the convective core, with decreasing T^{Cb}_{min} corresponding to increasing convective depth), from observations and GCM simulations using different bulk ice schemes. More realistic fall speeds, adapted from existing parameterizations (red, turquoise and blue), better follow the behavior of the observations (Stubenrauch et al., submitted to* J. Adv. Model. Earth Syst.*, 2019).*

"Water for the Food Baskets of the World" AGU 2018 Side Meeting

Washington, D.C., USA
12 December 2018

Andreas F. Prein[1], Roy Rasmussen[1], Fei Chen[1], Peter van Oevelen[2] and Graeme Stephens[3]
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The GEWEX-led "Water for the Food Baskets of the World" (WFB) WCRP Grand Challenge focuses on climate change impacts on global freshwater availability, specifically in the food basket regions of the world. The main goal is to understand changes of the water cycle due to human interactions with freshwater resources such as irrigation and reservoir management (GEWEX, 2019). A multi-disciplinary approach that combines climate research and hydrological, agricultural and social science is essential to address this question.

A side meeting on this topic was organized on 12 December 2018 during the fall meeting of the American Geophysical Union (AGU). The goals of the meeting were to foster community engagement and to develop strategies for future projects and collaborations. The 23 participants spanned a wide range of disciplines including weather and climate modeling, agricultural modeling, hydrology and impact modeling. Three kickoff presentations introduced and motivated the central activities in the WFB Grand Challenge.

Currently, about 70% of global freshwater is used in agriculture (van Oevelen et al., 2018). Average annual growth rates of food production consistently declined over the past 50 years, whereas global population exponentially increased over the same period. These trends are expected to continue into the future, increasing the stress on water resources and agriculture. Modeling these changes is very challenging due to the interplay of food demand, agro-economics, water supply and climate change. Furthermore, our understanding of the human impact on the past water cycle is limited. Producing actionable science that is relevant to farmers, stakeholders and policymakers will demand close collaboration and integration of these groups.

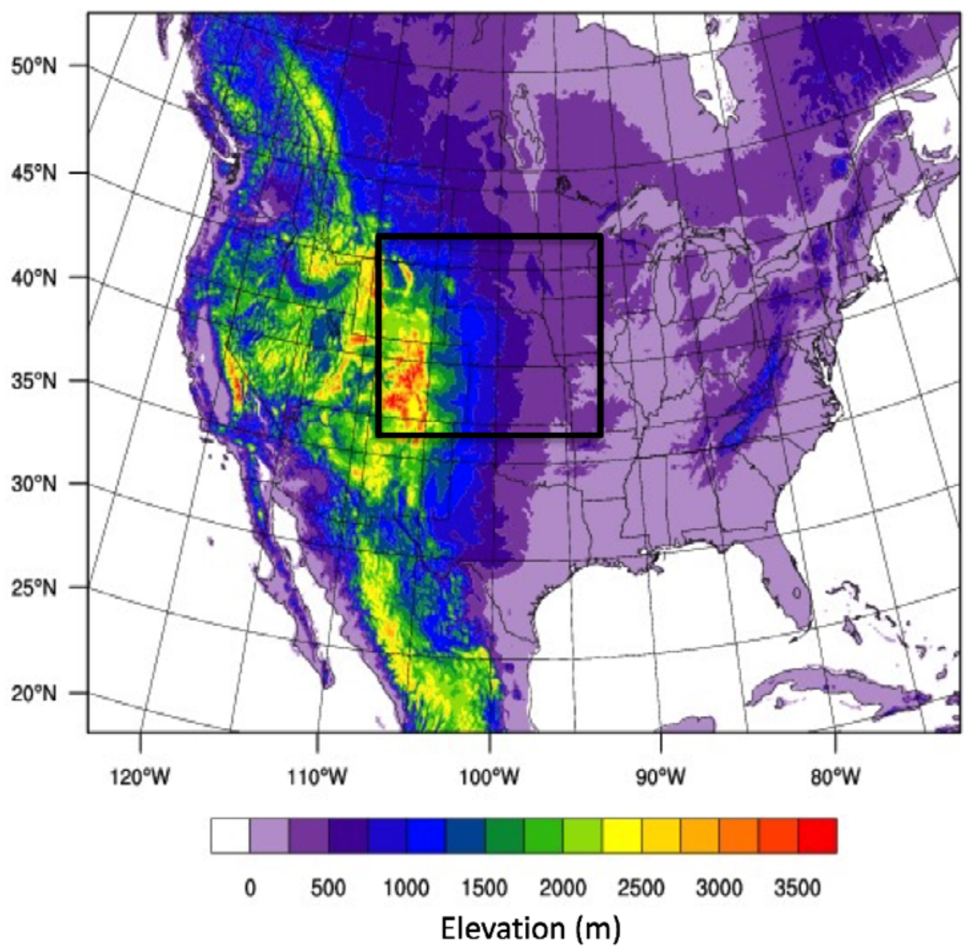

Figure 1. *Approximate location of the two 50-year convection-permitting historic simulations (black box).*

Realistically modeling the human impact on the water cycle demands adequate understanding of the natural water cycle. This requires a realistic representation in models of precipitation characteristics such as amount, intensity, frequency, variability and phase on regional and local scales. Convection-permitting climate models, which operate on horizontal grid spacings of ≤4 km, substantially improve all of the above characteristics compared to coarser resolution models (Prein, 2018). Therefore, convection-permitting models will be central in assessing the impacts of human activities on the natural water cycle in the WFB Grand Challenge.

Another important research area is the inclusion of dynamic agricultural modeling in climate simulations (Chen et al., 2018). Among the many challenges are complex agricultural management practices and scale differences between field-scales and model grid-cells. Recent applications of the Weather Research and Forecast-Crop (WRF-Crop) model (Liu et al., 2016) to regional scales reveal many challenges in transitioning crop and irrigation modeling from field to regional scales. The regional calibration of crop and irrigation model parameters can help to bridge these scale differences. Additionally, integrating agriculture management data is key to constraining agriculture model solutions. A full closure of the water budget in long-climate integrations is necessary to connect irrigation with slow-varying water cycle components such as underground water and reservoirs. Enhanced collaborations, particularly within the Agricultural Model Intercomparison and Improvement Project (AgMIP) community, are already being established to facilitate these efforts (Rosenzweig et al., 2012; Ruane et al., 2015).

Planned Initial Activities within the WFB Grand Challenge

The initial activities of the WFB Grand Challenge will be tailored towards developing modeling capabilities and establishing collaborations among different disciplines (e.g., atmospheric science, agricultural science, hydrology). The central U.S. will be used as a focus region due to its importance for U.S. and global food production, the occurrence of major changes in agricultural practices and intensity over recent decades and the availability of meteorological and agricultural datasets, which allow for proper model evaluation.

Two 50-year-long regional convection-permitting (~4 km model grid spacing) climate simulations will be performed focusing on a central U.S. domain (Fig. 1), one with and one without human effects on agriculture and hydrology. These two experiments will provide insights into agricultural impacts on the weather and climate of the central U.S. as well as the regional water cycle. The ultimate goal is to build modeling capabilities that can be used to predict future human-climate interactions with the water cycle on seasonal to centennial scales.

Important considerations for the setup of these simulations were discussed at the meeting, including the use of spectral nudging and potential constraints of the lateral boundary conditions. Using dynamic agricultural models such as WRF-Crop and incorporating socioeconomic impacts in the simulations were identified as important capabilities to add. The participants suggested further collaboration with agriculture modeling communities (e.g., AgMIP) regarding the adoption of agricultural land-use and management-practice change in WFB simulations. Employing a model testbed to develop and evaluate modeling systems without the need for large computational resources would encourage the inclusion of the larger modeling community. Furthermore, developing efficient ways to collect and share observational datasets was identified as a priority.

Next Steps

The GEWEX office will update the WFB webpage and organize bi-monthly webinars or conference calls to maintain and grow community involvement and knowledge exchange. A white paper (*https://www.wcrp-climate.org/images/documents/grand_challenges/GC_gsq_water_v5.pdf*) on the WFB Grand Challenge will be updated and shared with the community. A town hall meeting will be held at the European Geosciences Union (EGU) General Assembly 2019 in Vienna, Austria, and a WFB workshop will be organized in late 2019.

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Article Submissions to *GEWEX NEWS*

Do you have an idea for a *GEWEX News* article on scientific research results or other information related to GEWEX activities? E-mail us at *gewex@gewex.org* with your suggestion. Contributions of 1-2 pages (800-1600 words) are sought, and we require at least one figure or image. The graphic should be sent as a separate, high-resolution file, and not be embedded in your document.

GEWEX/WCRP Calendar

For the complete Calendar, see http://www.gewex.org/events/

18–21 March, 2019—Seventh International Conference on Remote Sensing and Geoinformation of Environment—Paphos, Cyprus

25–28 March 2019—CMIP6 Model Analysis Workshop—Barcelona, Spain

1–4 April 2019—Workshop on Predictability, Dynamics and Applications Research Using The International Grand Global Ensemble (TIGGE) and S2S Ensembles—Reading, UK

7–12 April 2019—European Geosciences Union—Vienna, Austria

24–26 April 2019—Aerosols, Clouds, Precipitation, and Climate (ACPC) Initiative Meeting 2019—Nanjing, China

24–26 April 2019—Global Land Programme: Fourth Open Science Meeting Transforming Land Systems for People and Nature—Bern, Switzerland

6–10 May 2019—Fortieth Session of the World Climate Research Programme (WCRP) Joint Scientific Committee (JSC)—Geneva, Switzerland

13–17 May 2019—2019 Living Planet Symposium—Milan, Italy

15–17 May 2019—Annual Science Meeting of the Global Water Futures Program—Saskatoon, Canada

20–24 May 2019—Twelfth Hydrological Cycle in Mediterranean Experiment (HyMeX) Workshop—Split, Croatia

27–31 May 2019—International Young Scientists School and Conference on Computational Information Technologies for Environmental Sciences (CITES-2019)—Moscow, Russia

28–31 May 2019—Workshop on Correlated Extremes—New York, New York, USA

29–31 May 2019—Twenty First Working Group on Subseasonal to Interdecadal Prediction (WGSIP)—Moscow, Russia

3–5 June 2019—Fifth PannEx Workshop: Building PannEx Task Teams to Address Environmental Needs in the Pannonian Basin—Novi Sad, Serbia

3–6 June 2019—Computational Information Technologies for Environmental Sciences (CITES-2019)—Moscow, Russia

10–14 June 2019—Tutorial and Workshop: Future Physics for Global Atmospheric Models—Boulder, Colorado, USA

13–14 June 2019—Eighth GEWEX Water Vapor Assessment (G-VAP) Workshop—Madrid, Spain

19–21 June 2019—Twelfth International Precipitation Conference (IPC12) and the Soroosh Sorooshian Hydrometeorology Symposium—Irvine, California, USA

7–9 July 2019—International GEWEX/GASS/LS4P and TPEMIP Regional Modeling and Aerosol in Snow Workshop—Nanjing, China

8–18 July 2019—Twenty Seventh International Union of Geodesy and Geophysics (IUGG) General Assembly—Montréal, Canada

8–18 July 2019—GlacierMIP Meeting at the Twenty Seventh IUGG General Assembly—Montréal, Canada

15–17 July 2019—Third International Surface Working Group (ISWG)—Montréal, Canada

15–19 July 2019—Paracon International Workshop on Convection Parameterization and GASS Project Side Meeting—Exeter, UK

28 July–2 August 2019—Asia Oceania Geosciences Society (AOGS) Sixteenth Annual Meeting—Singapore

28 July–2 August 2019—Fifteenth Atmospheric Chemistry Colloquium for Emerging Senior Scientists (ACCESS) and Gordon Research Conference in Atmospheric Chemistry (GRC)—Upton, New York, USA

21–23 August 2019—High Resolution Climate Modeling: Perspectives and Challenges—Zurich, Switzerland

21–23 August 2019—Third GEWEX Workshop on Convection-Permitting Climate Modeling—Zurich, Switzerland

4–7 September, 2019—Sixteenth International Conference on Environmental Science and Technology (CEST2019)—Rhodes, Greece

8–12 September, 2019—International Mountain Conference—Innsbruck, Austria

9–13 September, 2019—European Meteorological Society (EMS) Annual Meeting 2019—Copenhagen, Denmark

9–13 September, 2019—Soil Moisture Validation and Application over Highlands Workshop—Fairbanks, Alaska

24–27 September, 2019—Future Earth Water Future Conference: Towards a Sustainable Water Future—Bengaluru, India

GEWEX NEWS

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