tant source of predictability on numerical weather prediction timescales. There are strong feedbacks between precipitation and evaporation, and between turbulent heat transport in the atmosphere and heat transfer in the soil and snow. The drag exerted by the surface on the atmosphere also has a strong impact on the atmosphere; however, the partitioning of the land surface drag between the orographic and boundary layer components differs considerably based on recent model intercomparison project results. There are even significant differences in the surface stress diurnal cycle among operational models. Large-scale circulations are sensitive to these parameterizations on forecast spatial and temporal scales; thus the need for improving the basic underpinning of such schemes was recommended. In terms of surface turbulent fluxes, research on extremes has shown that a dry anomaly in the soil is a necessary (but not sufficient) condition for a heat wave, and that there is predictability on the sub-seasonal timescale which is probably not fully exploited yet by state-of-the-art models. Another aspect of the boundary layer is the simulation of low clouds, which has strong implications for forecasting at all time ranges, and particularly for climate change. The difficulty is that such clouds interact strongly with small-scale turbulence, which is unresolved in current numerical weather prediction models. The subtropical stratocumulus-to-cumulus transition over subtropical oceans was highlighted as an area where improvements are needed in global models. Finally, the challenges of describing the processes that occur in the Arctic, specifically in the Arctic boundary layers, and their importance for the interaction with the surface were highlighted. The main challenges are surface heterogeneity, cloud radiative interactions and the frequently strong stably stratified boundary layer. These issues are being addressed, in part, by international boundary layer-surface model intercomparison projects, such as the GEWEX-sponsored GEWEX Atmospheric Boundary Layer Study (GABLS) Project that uses recent field campaign data.

The Seminar concluded with sessions on data assimilation, uncertainty and verification. There is an obvious synergy between verification and assimilation, because model errors can often be isolated through the systematic confrontation of the model with observations in the data assimilation system. This is increasingly the case with modern satellite observations that are sensitive to hydrometeors. Examples were shown of systematic errors that have an impact on the feedbacks relevant for El Niño forecasts. Talks were given on the estimation and representation of model error in ensemble systems and the modeling of meteorological processes in the transport of tracers. Finally, the application of linear models in 4-dimensional variational data assimilation was presented. The physical processes were shown to be important, but the limitations were illustrated too. For very high resolution, it may be necessary to consider alternative data assimilation techniques.

Erland Källén, the ECMWF Director of Research, closed the Seminar by noting that remarkable progress has been made in the modeling of the physical processes in the atmosphere and that exciting prospects for the coming years were offered at the meeting. Presentations and summaries are available at: *http://www.ecmwf.int/en/annual-seminar-2015*.

HyMeX Midterm Program Review and Perspectives—Report of the 9th HyMeX Workshop

Mykonos, Greece
21–25 September 2015

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The Hydrological Cycle in the Mediterranean Experiment (HyMeX; Drobinski et al., 2014) is a 10-year (2010–2020) GEWEX Hydroclimatology Panel (GHP) Regional Hydroclimate Project (RHP). Its objectives are to: (i) improve the understanding of the water cycle, with emphasis on extreme events, by monitoring and modeling the Mediterranean coupled system (atmosphere-land-ocean), its variability (from the event scale to the seasonal and interannual scales) and characteristics over one decade in the context of global change; and (ii) evaluate societal and economical vulnerability, and adaptation capacity to extreme meteorological and climate events.

The HyMeX 10-year Long Observation Period (LOP) began in 2010 and includes hydrometeorological and oceanic measurements from operational national weather and hydrological services, research hydrometeorological and oceanic observatories, and satellite (Drobinski et al., 2014) and social impact data (Llasat et al., 2013). The 2010–2015 Enhanced Observation Period (EOP) was primarily dedicated to the hydrological monitoring of flash floods (Braud et al., 2014). Two Special Observation Periods (SOPs) were organized in late 2012 and early 2013 with instrumentation deployment dedicated to heavy precipitation and flash floods (Ducrocq et al., 2014; Ferreti et al., 2014; Jansà et al., 2014; Bousquet et al., 2015; Davolio et al., 2015; Defer et al., 2015; Doerenbecher et al., 2015) and strong air-sea interaction and dense water formation (Estournel et al., in revision; Doerenbecher et al., 2015), respectively. Dedicated science teams were set up to organize and coordinate research activities in HyMeX (e.g., on water vapor, lightning, microphysics, flash floods, regional climate modeling, vulnerabilities), combining collected data and numerical modeling in the various Earth components at different time and space scales. For regional climate modeling, HyMeX has a joint initiative with the Mediterranean Coordinated Regional Climate Downscaling Experiment (Med-CORDEX, Ruti et al., 2015).

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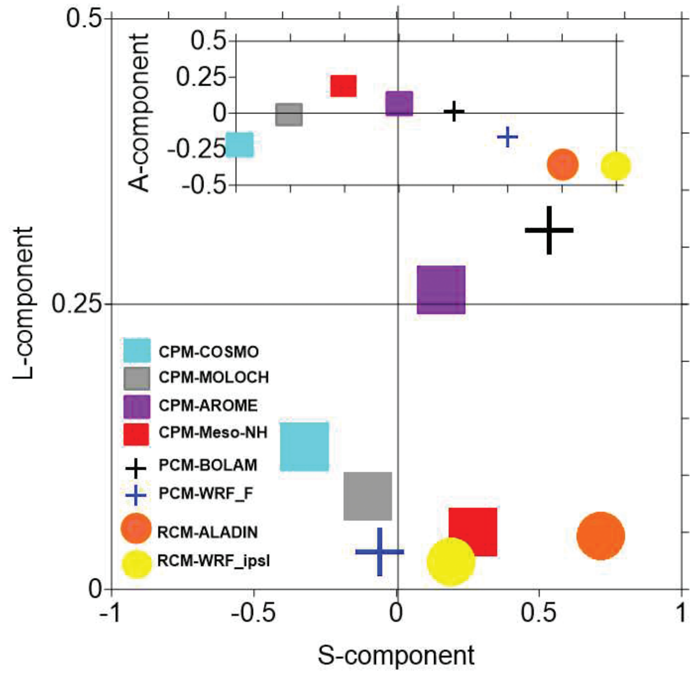
5-Year Review of HyMeX Achievements

More than 130 scientists from 11 countries participated in the 9th HyMeX Workshop to review the progress of HyMeX and define the remaining 5 years of the Project. With regard to the GEWEX Grand Challenges, HyMeX studies have led to significant progress in understanding the formation of heavy precipitating systems, notably over the Mediterranean Sea and the plains. Heavy rainfall in the coastal regions can have strong impacts in southeastern France and northern Italy, and show the key role of mountain ranges and islands. HyMeX field campaign observations have helped to design, improve and evaluate new tools and methods of forecasting heavy precipitation and flash floods (e.g., convection-permitting data assimilation and ensemble prediction systems). The figure on this page shows the seamless analysis of a heavy precipitation event in IOP-12, which extended from Spain to Italy during SOP-1. Numerical model simulations are compared with explicit Convection-Permitting Models (CPMs), Parameterized Convection Models (PCMs), or Regional Climate Models (RCMs). Heavy precipitation is characterized in a more bottoms-up approach with respect to the affected population and economic sectors in Spain, France, Italy and Greece. Studies in southern France investigated the evolution of urban management policies with respect to floods and model mobility/transportation. The evolution of heavy precipitating systems with climate change has also been investigated. In relation to the GEWEX crosscutting activity on subdaily precipitation extremes, observations and regional climate, HyMeX simulations show that the number and intensity of precipitation episodes across all of the Mediterranean increase by a few percent per degree of global warming.



Structure (S), Amplitude (A), Location (L) for the 24-hour (11 October 2012, 0600 UTC to 12 October 2012, 0600 UTC) mean precipitation simulation over northwestern Mediterranean (heavy precipitation event of IOP-12 that extended from Spain to Italy). The colored markers refer to the models (CPMs, PCMs, RCMs). The diagnostics are shown with respect to the CPMs ensemble mean upscaled to a coarser model resolution (approximately 20 km). Source: S. Khodayar, KIT, Germany.

Water management issues related to droughts, heat waves and other impacts have been addressed at several spatial scales (e.g., catchment scale in Morocco and Spain, and large scale for the entire Mediterranean region). The figure on page 22 shows how large yearly precipitation anomalies are "remembered" for 1-2 years into the future by the groundwater table, which suggests that the water table has more memory than soil moisture. These activities were covered in part in the GEWEX Land-Atmosphere System Studies (GLASS) Panel, where the network management of dams in North Africa was modeled, allowing for the estimation of the impact of dams on water resources and their evolution in climate change constrained by offer/demand equilibrium. These studies showed the role of groundwater memory in precipitation deficit and its impact on hydrological droughts. Other studies analyzed the strong interlink between precipitation deficits, vegetation phenology and soil moisture variability on heat waves, droughts and wildfires. Soil dryness can contribute to the severity of heatwaves by up to 40%. Abundance or scarcity in vegetation can respectively mitigate or otherwise increase the severity of heatwaves by about 10%. Assimilation of vegetation characteristics (e.g., Leaf Area Index, Normalized Difference Vegetation In-

Participants at the 9th HyMeX Workshop.

dex) showed significant improvement on drought forecasting. Droughts were also characterized by indices defined in a bottoms-up approach of the Ebro River Basin scale. New climate projections confirm longer dry periods and more frequent heat waves in the Mediterranean with global warming.

The new knowledge related to the Mediterranean water cycle produced in the first 5 years of HyMeX has lead to the publication of more than 260 articles in international peer-reviewed journals and four special issues. About 400 researchers from 20 countries, as well as more than 110 Masters students, 70 PhD students and 20 post-docs have worked or are still working on HyMeX projects. In addition, HyMeX has contributed to the organization of four summer schools on severe weather and integrated water and society studies.

Planning for the Next 5 Years

Plans for HyMeX include more object-oriented studies with scale continuums (i.e., dense water formation and ocean circulation, Mediterranean cyclones, heavy precipitation systems, flash floods) and integrated transdisciplinary studies (e.g., water resources; droughts and impacts; water cycle and renewable energy resources; flash floods and social vulnerabilities and integrated forecasting of heavy precipitation, flash-floods and impacts). These studies will support a water cycle related regional climate assessment in 2020. HyMeX studies will benefit from the European Space Agency Water Cycle Observation Multi-mission Strategy (WACMOS)-MED Project to produce a new integrated satellite database of the Mediterranean water cycle over a multi-decadal period. Finally, discussions at the Workshop identified several strategic actions to be supported in the upcoming years, including field campaigns in the eastern Mediterranean focused on aerosols, water vapor feedbacks on precipitation and associated hydrology, and the documentation of Levantine intermediate waters of the Mediterranean Sea. These also include MED-CORDEX-2 preparation and organization and support for a flash floods and social impacts information and analysis platform. Securing data collection over the 10-year period and the outreach of the HyMeX research results are also of high priority.

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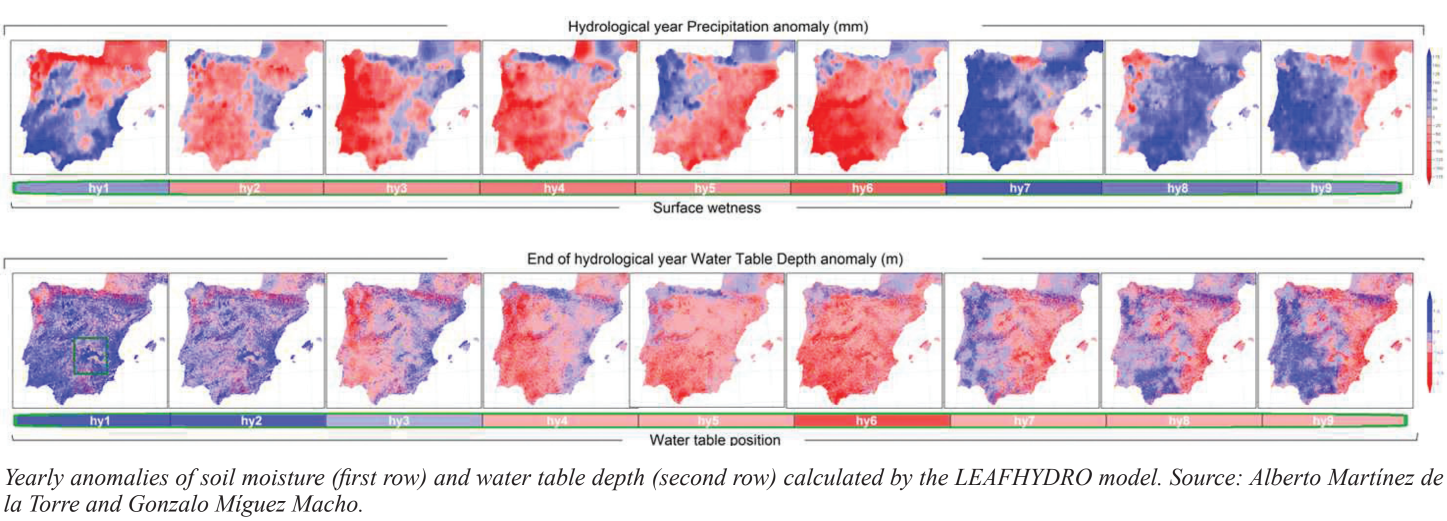

Yearly anomalies of soil moisture (first row) and water table depth (second row) calculated by the LEAFHYDRO model. Source: Alberto Martínez de la Torre and Gonzalo Míguez Macho.