Recognizing that there are significant risks and opportunities for society arising from changes in the climate, the European Climate Observations, Modeling and Services (ECOMS) initiative was formed in 2012. ECOMS has ensured close cooperation across climate-related projects in Europe and beyond, and has identified priorities for climate modeling and climate services.

ECOMS is led by three major European projects: European Provision of Regional Impacts Assessments on Seasonal and Decadal Timescales (EUPORIAS), Seasonal-to-Decadal Climate Prediction for the Improvement of European Climate Services (SPECS), and the North Atlantic Climate (NACLIM). The end of this four-year-long program was marked with an international conference. The conference presented and reviewed scientific advances, discussed what the next scientific advances will be, and made recommendations for priorities in the field of climate science for climate services for societal benefit.

OVERVIEW. The conference began with overview presentations to set the scene. Several speakers stressed the importance of climate science in the Intergovernmental Panel on Climate Change (IPCC) process, and the United Nations Framework Convention on Climate Change’s (UNFCCC) 2015 Paris Agreement.

Funding bodies provide significant investments for climate research, observations, and climate services. The European Commission (EC) has invested billions of euros into climate-related research. Previous EC funding programs have focused on developing excellent science, which is still recognized as essential, but current programs place more emphasis on innovation, economic growth, and harnessing knowledge to provide effective solutions. The EC, through its Copernicus program...
for European Earth observations, is developing a climate change service to pull through research and development to operational services giving access to information for monitoring and predicting climate change to support adaptation and mitigation. Climate science is an essential component.

The Met Office’s chief scientist (conference host) discussed scientific challenges: “we know that we are taking the planet into uncharted territory and our work is not yet done.” The Paris Agreement was “the end of the beginning and now the real work can start.” Can scientists provide society with information about what climate variations and changes may occur, where and with what implications? Central to this is our ability to understand and predict climate extremes at sufficient resolution, and to develop the tools, based on credible high-resolution models and large ensemble simulations, for assessing the impacts and the envelope of risks.

The UN’s World Meteorological Organization and the Global Framework for Climate Services (GFCS) are instrumental in coordinating actions worldwide. The GFCS is developing a Climate Services Information System to provide data and products to assist in decision-making. Of concern is sustaining observing networks and resolving large differences between observational datasets. The GFCS is undertaking pilot studies in eight countries to develop and use climate services effectively.

The IPCC comprehensively, objectively, openly, and transparently assesses the scientific and technical information. Scientific challenges for their next (Sixth) Assessment Report include assessing past and future regional changes, particularly for extreme events, such as droughts and trends in Arctic sea ice, and improving near-term predictions on multiannual time scales.

The World Climate Research Programme (WCRP) aims to determine the predictability of climate and the effects of human activities on climate. The Paris Agreement was reached in large part because of the knowledge provided by the scientific community. The focus of research now must evolve from “making the case” for anthropogenic climate change to the development and dissemination of regional information to minimize risks and build resilience. A smart end-to-end information system is needed that integrates knowledge from different disciplines to provide climate services to meet societal needs.

**OCEAN OBSERVATIONS.** Ocean observations in NACLIM (www.naclim.eu) focused on the North Atlantic Ocean, which is one of the most important drivers for global ocean circulation and its variability on time scales beyond the interannual. Global climate variability is, to a large extent, triggered by changes in the North Atlantic sea surface state. By monitoring relevant ocean parameters, such as sea surface temperature, sea ice distributions, and heat fluxes, the observational program in NACLIM provided a reference basis for numerical models for climate predictions and economic impact studies.

Key results presented included a new climate record of Arctic and Antarctic ice surface temperatures, covering high-latitude seas, sea ice, and ice cap surface temperatures based on satellite infrared measurements. Additionally, ocean volume flux time series were extended and are now able to address interannual variability. Flux correction in coarse-resolution climate models was found to be valuable for reducing the model biases, and initializing models with the upper Arctic stratification was identified as being essential for the predictive skill of models regarding both the freshwater storage and sea ice volume. Simulating these two parameters is important for realistically stratifying the North Atlantic Ocean.

**CLIMATE PREDICTIONS.** This discussion focused on the SPECS project (www.specs-fp7.eu) and collaborations between scientists during SPECS and EUPORIAS. The collaboration usefully illustrated the scientific challenges posed by the development of climate services.

A large number of climate model experiments and analyses of climate data have been undertaken and are available via the public SPECS data repository as part of the Earth System Grid Federation (ESGF), through numerous scientific publications, and as factsheets on the SPECS website. The factsheets provide entry-level information about the technical and scientific aspects of climate prediction, something previously lacking. They were driven by questions raised by the EUPORIAS partners and users and will be built upon by some WCRP initiatives. The climate prediction experiments showed that climate prediction is both an initial-value and a boundary-forced problem, and stronger links should be built between the climate prediction, weather forecasting, and climate change communities. The experiments suggested that observational uncertainty should be taken into account in a more formal way.

The importance of process-based forecast quality assessments was shown, along with examples that used climate extremes in sea ice extent, ocean thermodynamics, and land surface variables. These
cases demonstrated that no single forecast system is perfect. Instead, forecast systems are complementary in representing climate phenomena differently. Multisystem predictions, including dynamical and statistical–empirical systems, are needed to provide reliable and accurate climate information. Traceable postprocessing that includes downscaling and bias adjustment is fundamental to maximizing the benefits of forecast information. However, postprocessing cannot replace the benefits produced by improving the models and forecast systems to address problems like forecast initial shock and drift.

Central to SPECS has been the public release of information and solutions. While the data produced are publicly available using a standard created by the SPECS project, a range of functions has been created and provided using the open-source language R, along with associated training.

**CLIMATE SERVICES.** Presentations and discussions about climate services, particularly from the EUPORIAS project (www.euporias.eu), emphasized the importance of close engagement between the developers of a climate service and the intended users, ideally to “coproduce” the service. An extensive analysis of users in Europe has been conducted by the EUPORIAS project, including 80 in-depth interviews and an online survey. The analysis highlighted some of the perceived barriers to the use of climate predictions in Europe, such as the reliability and accuracy of the forecasts, usable information, relevance, and accessibility of the information.

The importance of regional information in climate impact studies was discussed. An example shown was in the Alps, where the climate change trend from global model projections is the opposite of that found in regional model projections. Downscaling global seasonal predictions to finer spatial resolution using a dynamical climate model for a region covering the Great Horn of Africa was also shown. Although the large-scale signal was not deteriorated by the downscaling, there is no evidence that the downscaling had a positive impact on the skill of the predictions for this region.

Tools to analyze, postprocess, bias correct, and downscale climate prediction data have been developed and discussions emphasized that having good and open access to data and tools is a prerequisite for the development of an effective climate service community.

Climate impact modeling was discussed, with examples shown for hydrological models simulating seasonal river flow in Europe (often with more skill than the skill shown for precipitation in Europe), and variations in crop yields and river flows under a changing climate.

The session finished with a discussion of the challenges of presenting the confidence level associated with climate predictions. Users appear to prefer graphical representations that they are familiar with even when the objective understanding, as measured in a decision laboratory experiment, is lower than for other kinds of representations.

**FORWARD LOOK.** Major scientific developments have been made, including developing and delivering useful services based on the science, but there is still a long way to go. The conference identified gaps in knowledge and highlighted several potential priorities categorized below as observations, resolution, predictions, and user engagement. The conference noted that the move toward developing climate services for societal benefit must not be at the expense of the development of the underlying science that underpins such services.

**Observations.** There is continued need to improve observational records and ensure that observational activities are sustained, with benefits for evaluating models, assessing baselines, and monitoring the climate. The conference highlighted significant differences between observational datasets, with some datasets not capturing variability well.

**Resolution.** Global climate model resolution needs to be increased dramatically to reduce biases in models and to understand and predict climate extremes. This requires new forms of collaboration in the community, and the software, tools, and hardware necessary to support this also need to be developed. Much higher computing power is required, along with a substantially larger base of technical specialists to develop better models capturing the processes and resolution sufficiently.

**Predictions.** Predictions of the climate for the coming months and years have enormous potential for assisting a wide range of decision-makers. While forecasts for the coming weeks and seasons are operational, the multiannual time scale is largely a research activity. There is an urgent need to better understand users’ needs, and to develop and disseminate the forecasts to address such needs. Case studies demonstrating benefits would facilitate progress. However, assessing the value of climate services is complicated, often because decisions are rarely based solely on climate information. There are challenges in communicating uncertainty, but users should be aware that forecasts are probabilistic and that the reliability of those.
probabilities should be verified. Failing to properly communicate the uncertainty can have consequences, as a false sense of certainty can lead to maladaptive decision-making and a loss of trust in forecast providers.

User engagement. The services are often inadequate for users’ decisions. The underpinning scientific capability and knowledge should not be oversold (nor undersold) and strengths and limitations must be articulated. Many users struggle to understand or use climate model output. Reasons include technical challenges, data formats, irrelevant variables, inadequate uncertainty estimations, and errors in the data; so how can climate predictions be more useful and useable for users? Multidisciplinary teams will help, along with improvements to information systems, improvements to engagement with users, and developing the capacities and capabilities of both the providers and the users. Good communicators and translators are needed to bridge from the science through the services to better inform decisions, but also to feed back the user requirements to the scientists to develop different models and forecasts. Strong collaborations are now starting to develop between researchers, service providers, and end users, and these efforts have the potential to be highly beneficial to both the climate science community and society at large.

The above priorities, and other outcomes, from the conference will be taken forward in a larger follow-on to ECOMS. Called Climateurope (www.climateurope.eu), this activity is creating a managed network that includes climate science communities, funding bodies, providers, and users to coordinate and support the knowledge base (primarily in Europe, but extending globally as far as possible) and to enable better management of climate-related risks and opportunities.

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