A summary of Session 2: Global/Regional Climate State in 2030 (Climate Change: Global Risks, Challenges and Decisions, 10-12 March 2009 in Copenhagen, Denmark)

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1. Introduction

As the inevitability of future warming becomes accepted, interest in adapting to climate change, particularly over the next few decades, has increased. This requires accurate regional climate predictions on a particularly difficult timescale, when the influence of initial conditions has faded, but the climate change signal is still weak. This session was motivated to discuss and review predictions of climate change and impacts on multiannual to decadal timescales, and prospects for future improvement.

There are 9 oral and 6 poster presentations which addressed such topics as decadal prediction, uncertainty, regional downscaling and impact assessment relevant to climate projections in the near-term future. Here we summarize points of the session mainly based on oral presentations and associated discussions.

2. Background

Prior to the oral presentations, Professor John F. B. Mitchell of UK Met Office/Hadley Centre gave introductory remarks on the session's background. He pointed out that (1) climate scientists recognize that some amount of warming is inevitable in the next few years, and therefore, (2) there is increased interest in adaptation. In order to realize more realistic adaptation strategies, (3) regionally detailed projections accompanied by quantitative assessment of their uncertainty are necessary. This is a challenging task. While (4) it is well-known that, over the next few decades, dependence of projections on socio-economic scenarios is weak, the relative contribution of natural, decadal climate variability on projection uncertainty is greater. Therefore, the science community is discussing the possibility of initialized projections, that is, observed information of the actual climate system of the recent past has to be used to set up the initial conditions for projections by the state-of-the-art climate models.

This introduces for the first time an initial-value approach similar to that used in seasonal and interannual predictions in climate projection problem. (5) There is a growing recognition for the need to calibrate climate projection models through interannual and shorter time scale prediction experiments, called seamless approach to prediction. Following this movement, (6) the Working Group for Coupled Modelling (WGCM) of World Climate Research Programme (WCRP) is proposing a new category of internationally coordinated climate projection experiment (CMIP5) focusing on the decadal predictions for the coming fifth assessment report (AR5) of IPCC. Not only climate projection community, but also seasonal prediction community has already expressing enthusiastic interest in participating such endeavor.

In parallel with the scientific interest in decadal predictions, many operational climate centres are interested in and some are already initiating (7) "climate services" to interested parties and society in general. Naturally for this kind of services to take effect, not only information on temperature and precipitation but also information with more direct impact on society, e.g., flood risk potential, crop yield projections, influence on fishery, are demanded.

3. Decadal climate prediction: challenges and opportunities

As a leading talk of contributed presentations, Dr. James Hurrell of National Center for Atmospheric Research, USA, gave a comprehensive overview on challenges and opportunities of decadal climate prediction.

While the scientific understanding of climate change is now sufficiently clear to show that climate change from global warming is already upon us, uncertainties remain, especially regarding how climate will change at regional and local scales where the signal of natural variability is large. Hurrell revisited the significance of decadal prediction for realizing more realistic adaptation strategies, and reemphasized that is the mixture of forced and natural climate variability that is to be predicted in this time range. Hurrell pointed out that a map of linear trend of 20th century surface air temperature shows regionally varying degree of warming, a considerable fraction of which should be affected by decadal climate variability. One of the well-known decadal climate variability is the Sahel rainfall, which showed a large decline from 1960s to 1980s with recovering tendency toward the beginning of 21st century. A dipolar tropical Atlantic sea surface temperature (SST) variability shows a close covariability with the decadal-scale Sahel rainfall changes. Likewise, North Atlantic SST variability appears to be linked to pan-Atlantic hydrological variability. Decadal to interdecadal variations in oceanic circulation is believed to play a crucial role in such SST variability in which both forced and natural components are important (Ting et al. 2008).

While the decadal prediction is of both societal and scientific interest, there are considerable challenges to be overcome. Some of the open questions are:

(1) To what extent decadal variability in ocean and atmosphere is predictable?

There are observational and model estimates of potential decadal predictability, and idealized model experiments are becoming available. At GFDL, an attempt has made to examine decadal predictability of meridional overturning circulation (MOC) in their climate model; in an idealized experiment a model's MOC time evolution could be followed for more than a decade even when atmospheric initial conditions are randomly perturbed. Examinations on other decadal phenomena are being conducted in many of climate modeling centres.

(2) What are the mechanisms of variability?

While observational and experimental assessments of predictability are valuable, better predictions should require better understanding of mechanisms for the predictability. It is important to distinguish predictability (i) forced by processes external to the physical climate system, such as anthropogenic radiative forcing, (ii) generated by internal processes, e.g., coupling among oceans, atmosphere, cryosphere and biosphere, and (iii) resulting from interactions of forced and natural variability. Also important is to determine level of predictability; the ocean should contain much of decadal memory in the climate system, but its relevance to regional atmospheric variables must be one of the key questions.

(3) Do we have the proper tools to realize the predictability?

In addition to characterizing the predictability, one must have (1) sustained observing systems to monitor the climate system, (2) advanced assimilation system to effectively initialize climate models, and (3) models good enough to reproduce modes of observed natural decadal variations. Several prospective attempts have already been report (Smith et al. 2007; Keenlyside et al. 2008), and many international groups are preparing for the next coordinated experiment for IPCC AR5.

4. Quantifying uncertainty

No prediction/projection is free from uncertainty, and it is of vital importance in any climate projection study to give quantitative measures to represent uncertainty associated with projections. There are different sources for uncertainty and their relative importance varies depending on variable and spatio-temporal scales of the projection.

4a. Quantifying uncertainty, interpreting ensembles and combining models with process understanding: An overview

Dr. David Stainforth (UK; London School of Economics) gave a thorough discussion on the importance of quantifying uncertainty, interpreting ensembles, and combining models with process understanding. He started by pointing out that most statements about the state of climate in 2030 are founded on the interpretation of complex climate models -- atmosphere/ocean global circulation models (AOGCMs). Although they are not perfect, much confidence in future projection of the Fourth Assessment Report of IPCC comes from estimates based on these models. This confidence comes from the facts that models are based on accepted physical principles and that they demonstrated ability to reproduce observed present and past climates.

Recent years have seen an increasing awareness and focus on the systematic study of uncertainty with such models. Notable experiments have included the climateprediction.net (Allen 1999; Allen and Stainforth 2002; Stainforth et al. 2005) experiment at Oxford University and the Quantifying Uncertainty in Model Predictions (QUMP) work at the UK Met Office (Murphy et al. 2004; Murphy et al. 2007). Both began by studying idealised doubled CO2 scenarios and have gone on to pursue simulations of the 20th and 21st century. Questions about how models, and particularly ensembles of models, should be interpreted have been discussed as far back as 2002 (Smith, 2002). More recently these debates have developed and extended (Stainforth et al. 2007; Allen et al. 2006; Murphy et al. 2007).

Dr. Stainforth proceeded to discuss the sources of uncertainty in statements about future climate with a focus on the identification of relevant information for societal decision makers. He presented a breakdown of uncertainty into five categories:

(i) forcing uncertainties,
(ii) microscopic initial condition uncertainty,
(iii) macroscopic initial condition uncertainty,
(iv) model inadequacy, and
(v) model uncertainty.

(i) Forcing uncertainties are those associated with external influences, both natural and anthropogenic, on climate such as greenhouse gas emissions, solar radiation, volcanic and anthropogenic emissions of aerosols, etc. In order to quantify these uncertainties a range of possible future scenario has to be covered.

Uncertainty associated with initial condition concerns how the prediction is affected by our imprecise knowledge of the current state of the system. The initial condition uncertainty in a classical sense (called (ii) microscopic) concerns that errors in the present state of the system, even at the smallest scale, eventually amplify in time and contaminate predictions. The prediction has to be made from an ensemble of initial conditions that represent uncertainty small scales, as is in practice in weather forecasting and seasonal to interannual climate predictions. On longer time scales, the system is subject to larger influence of changes in subsystems with large, slowly mixing, scales, such as oceans, land, and cryosphere. These systems are neither well observed nor understood. Efforts to better observe these climate subsystem are necessary for reducing the uncertainty.

(iv) Models are useful, but imperfect, can be inadequate in some cases. For example, processes known to be important for projection/prediction on question may be absent, e.g., ice sheet dynamics, atmospheric and oceanic chemistry, stratospheric circulation. Parameterized processes are unlikely to capture all the small-scale feedbacks in nature. Coarse resolution models may not be adequate to represent severe weather disturbances such as typhoons. Quantifying model inadequacy is a necessary, but hard task.

(v) Climatic processes can be represented in models in different ways, e.g., different parameter values, different parameterization schemes, and different resolutions. What are the most useful parameter values and model versions to study within the available model class? What is the range of possibilities? Model uncertainty associated with these should be quantified, e.g., by perturbed-physics ensembles (Murphy et al. 2004; Stainforth et al. 2006).

An appropriate exploration of the above uncertainties should be valuable in informing policy and business decisions; as well as directing model development and observational campaigns to maximise the production of relevant information in the future. However, the experiments necessary for such an appropriate exploration requires a dynamic ensemble design constructed to balance the relative roles of the different sources of uncertainty. Furthermore, the judgment of these relative roles is best done in the context of the decision or policy framework in which the information is destined to be used. There is therefore substantial value in dialogue between the climate modellers and the decision makers; a dialogue which could substantially influence the experimental design.

4b. Influence of future air-pollution mitigation strategies on climate by 2030

Silvia Kloster of European Commission, Institute for Environment and Sustainability, Italy, discussed the problems related to climatic influences of anthropogenic aerosols.

The combustion of biomass and fossil fuels leads to emissions of greenhouse gases as well as air pollutants. While greenhouse gases, particularly CO2, warm the planet, aerosols have an overall cooling effect, by blocking incoming solar radiation and modifying the properties of clouds. According to the recent Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007) the overall negative radiative forcing of aerosols between pre-industrial and present day times is about 48% of that of the positive forcing by long-lived greenhouse gases, hence the observed temperature increase of 0.76 degC would have been substantially larger without aerosols. As well as impacting climate, aerosols cause a variety of adverse health impacts. In Western Europe and North America in the last decades legislations were introduced to reduce aerosol emissions and to improve air quality. Air pollution has also become a major concern in developing countries, facing increasing urbanization, mobilization and industrialization, leading to the introduction of new legislations worldwide.

Dr. Kloster showed how reducing aerosol emissions world-wide by 2030 can influence global and regional climate based on an experiment by an atmospheric general circulation model, ECHAM5-HAM (Stier et al. 2005), including aerosol microphysics and aerosol cloud microphysics (Lohmann et al. 2007) coupled to a mixed-layer ocean model. They used the 'maximum feasible reduction (MFR)' scenario for air pollutants prepared by the International Institute for Applied System Analysis (IIASA; Cofala et al. 2007). This scenario assumes a full implementation of today's most advanced end-of-pipe emission control technologies worldwide, whereas energy changes according to SRES-B2, leading to a substantial reduction of anthropogenic global annual mean aerosol emissions (SO2: -76%; black carbon: -43% ; organic carbon: -57%). They noted that some of these technologies are very expensive, and may also in future be too expensive for full implementation.

To identify the effects of increasing greenhouse gas concentrations (CO2, CH4, N2O, stratospheric and tropospheric O3) and decreasing aerosol emissions, they performed four equilibrium experiments using greenhouse gas concentrations and aerosol emissions for present-day (2000) and for the near future (2030) according to the SRES-B2 scenario for greenhouse gases and MFR for aerosol emissions:

1. CONTROL: 2000 greenhouse gas concentrations, 2000 aerosol emissions
2. GHG: 2030 greenhouse gas concentrations, 2000 aerosol emissions
3. AE: 2000 greenhouse gas concentrations, 2030 aerosol emissions
4. GHG&AE: 2030 greenhouse gas concentrations, 2030 aerosol emissions.

Increasing GHG concentrations ('GHG minus CONTROL') results in a global annual mean equilibrium temperature increase of 1.20 degC. The equilibrium temperature response due to decreasing aerosols ('AE minus CONTROL') of 0.96 degC is globally less than that from increasing GHGs, but is concentrated in the Northern Hemisphere, where most of the source regions are located. The combined effect of increasing GHGs and decreasing aerosols (GHG&AE minus CONTROL leads to a global increase of the equilibrium surface temperature by 2.18 degC, and to more than 4 degC in vast regions of the Northern Hemisphere. Thus a combined assessment of future aerosol and greenhouse gas emissions indicates potentially rapid increases in the surface temperature in the coming decades. In the admittedly extreme case of achieving the 'maximum feasible reduction' of aerosol emissions by 2030 the global annual mean warming caused by the reduction of aerosols is comparable to that caused by increasing greenhouse gas concentrations.

There are considerable uncertainties in future scenarios of aerosol emission, roles of different species of aerosols in direct radiative and indirect cloud feedbacks. It is demonstrated that aerosols do pose comparable importance to greenhouse gases in the assessment of climate in 2030.

4c. Physical mechanism and quantitative assessment of the planetary boundary layer feedback in the climate system

There are feedbacks in climate system that have not been understood well. Their understanding is crucial for reducing uncertainty in climate projections. Cloud feedback and aerosols are well-known examples, but there are much more. Dr. Igor Esau Bjerknes Centre, Norway, pointed out that planetary boundary layer feedback is another overlooked example.

During a few last decades, the daily minima, Tmin, in the surface air temperature (SAT) has increased faster than the SAT maxima, Tmax, which led to persistent decreasing of the diurnal temperature range, DTR = Tmax - Tmin. The general circulation climate models (GCMs) do not reproduce this essential feature and predict approximately the same change rates of change for Tmax and Tmin. Contrary to the usual assessment of the DTR reduction through the cloud damping on Tmax, the planetary boundary layer (PBL) feedback hypothesis put forward here proposes the DTR reduction through the amplification of the Tmin response on the climate change in shallow stably stratified PBL. This physical mechanism has not been properly accounted for in GCMs, first of all, due to lack of the models' vertical resolution. The daytime Tmax is associated with deep convective PBL (h ~ 1000 m), whereas Tmin with much shallower nocturnal stable (NS) PBL (h ~ 200 m) and the long-lived stable (LS) PBL (h ~ 30-50 m). It is conceivable that one and the same variation in the surface heat balance stronger affects shallow NS and LS PBL than deep convective PBL. Until recently the PBL theory was not accurate on prediction of the NS and LS properties and the first of all their depth. It resulted in generally overestimated NS and LS PBL depth. This study applies the modern PBL theory to derive theoretical estimates of the variations in the SAT associated with the stable and convective PBLs. The theoretical estimation are supported with ERA-40 and observational data. It suggests explanation of the observed asymmetry in the Tmax and Tmin trends. To characterize the role of the trend asymmetry in the climate system, a concept of local and general PBL feedbacks, by analogy with definitions currently used in the theory of climate, is introduced. Besides the strengths of feedbacks (considered in the standard approach), the study deals with response time scales of different mechanisms. The proposed concepts are applicable to different climate analyses from the global change to the local variations caused by changes in the land use.

5. High resolution modelling

In order to help regional adaptation decisions, projection of regional details is necessary, and resolution of global climate models is inadequate in many regional impact assessment studies. Global models, such as those used in CMIP3 model intercomparison project referred extensively in IPCC AR4 (IPCC 2007), can reproduce reasonably well climate features on large scales (global and continental), but their accuracy decreases when proceeding from continental to regional and local scales because of lack of resolution. This is especially true for surface fields, such as precipitation, surface air temperature and their extremes, which are critically affected by topography and land use. In many applications, particularly related to the assessment of climate-change impacts, the information on surface climate change at regional to local scale is fundamental. Although there are attempts at higher resolution global modeling, they require considerable computer resource, and regional downscaling is a more practical strategy. To bridge the gap between the climate information provided by global models and that needed in impact studies, several approaches have been developed. The most popular approaches are (i) statistical downscaling, i.e., identification of statistical relationships between large-scale fields and local surface climate elements, and (ii) dynamical downscaling, i.e., nesting of a fine scale limited area model (or Regional Climate Model, RCM) within the global model. The latter approach is more correct from a physical point of view, but is much more demanding on computer resources. There are quite a few on-going international activities on regional high-resolution modelling, and we had up-to-date progress reports from European and US groups.

5a. CECILIA Project: a high resolution regional climate change modelling for central and Eastern Europe

Tomas Halenka (Charles University in Prague, Czech Republic) introduced the CECILIA (Central and Eastern Europe Climate Change Impact and VulnerabiLIty Assessment) project for high-resolution regional modeling to assess climate change signals in central and Eastern Europe.

In the region of central and Eastern Europe the need for high resolution studies is particularly important. This region is characterized by the northern flanks of the Alps, the long arc of the Carpathians, and smaller mountain chains and highlands in the Czech Republic, Slovakia, Romania and Bulgaria that significantly affect the local climate conditions. The primary objectives of EC Project CECILIA is to integrate results from different previous and ongoing modelling activities and approaches to provide the basis for very high resolution climate change impact and vulnerability assessment in important human activity sectors and natural ecosystems. However, it is prohibitive to cover all the sectors in their complexity, so that some key areas have been targeted. For example, the flood and drought conditions which occurred in recent summers over the region highlight the importance of the hydrologic cycle and water management in the Elbe and Danube river catchments in response to changes in the occurrence of precipitation extremes. Impacts on agriculture and forestry influencing the economy of countries in the region will be studied with emphasis on the main productions in the area. The 2003 heat wave demonstrated the importance of studies of the health impacts of extreme conditions that would also lead to considerable changes in air quality, both regionally and in major urban centres.

A resolution sufficient to capture the effects of these topographical and associated land-use features is necessary. It has been demonstrated that neither resolutions 50 nor 25 km used in FP6 Integrated Project ENSEMBLES is sufficient to capture necessary details in this region. That is why 10 km resolution has been introduced in CECILIA. The main goal of regional climate modelling activities in CECILIA project is to produce simulations on targeted domains for a past period (1961-1990) driven by ERA40 reanalysis used for validation of the models as well as for a reference period (1961-1990) and scenario time slices (2021-2050 and 2071-2100) based on ENSEMBLES 6FP EC IP A1B GCM simulations. Two models are used as source of driving fields over six target areas, ALADIN-Climate family using stretched climate change transient run by ARPEGE/Climat for ENSEMBLES project, RegCM family using RegCM transient ENSEMBLES run for whole Europe in 25km resolution driven by transient run of ECHAM5. Results of model validation and climate change signal based on these simulations will be presented with emphasis to the regional details of targeted areas as well as examples of impact studies using these high resolution scenarios runs.

The project contains studies on hydrology, water quality, and water management (focusing at medium-sized river catchments and the Black Sea coast), air quality issues in urban areas (Black Triangle -- a polluted region around the common borders of the Czech Republic, Poland and Germany), agriculture (crop yield, pests and diseases, carbon cycle), and forestry (management, carbon cycle). The high spatial and temporal resolution of dense national observational networks at high temporal resolution and of the CECILIA regional model experiments will uniquely feed into investigations of climate change consequences for weather extremes in the regions under study. Comparison with the results based on statistical downscaling techniques will also be provided. Statistical downscaling methods for verification of the regional model results will be developed and applied, and assessments of their use in localization of model output for impact studies will be performed.

5b. A multi-member, high-resolution, transient simulation of 20th and 21st century climate in the United States

Dr. Noah Diffenbaugh of Purdue University, USA, and his colleagues are currently conducting a suite of high-resolution climate model simulations for the United States. This nested experiment covers the full continental United States at 25 km horizontal resolution, with five GCM-generated ensemble members covering 1951-2100 in the A1B emissions scenario. This is one of the first attempts at century-scale, high-resolution, multi-member climate change projection for any continental area. This unique dataset will help generate predictions of the magnitude, pattern, and uncertainty of changes in the climate of the United States over the next two decades.

The high-resolution climate model experiment uses RegCM, a hydrostatic, sigma coordinate, primitive equation nested climate model originally derived from the National Center for Atmospheric Research (NCAR)/Pennsylvania State University Mesoscale Model (version 4, MM4). The latest version of RegCM (RegCM3) has been developed at the Abdus Salam Institute for Theoretical Physics (ICTP) in Trieste, Italy (Pal et al. 2007). Large-scale boundary conditions are provided to 25-km RegCM by the NCAR Community Climate System Model (CCSM3), an AOGCM with 150 km resolution.

Three-dimensional model outputs are archived at sub-daily intervals, and the dataset offers a unique opportunity to assess possible changes in weather and hydrological extremes on a continental scale. A preliminary analysis suggested (i) that severe heat stress appears imminent in the next two decades in much of the United States, (ii) that "physically uniform" near-term projections reveal physically-consistent but spatially diverse response, (iii) that effect of differences in initial conditions was not superficially clear, which can be a short-coming of experimental approach, and (iv) that response of mean state and of critical thresholds are not necessarily linear, even on short time-scales.

6. Impact assessment

Climate change signals given by climate models should be subject to impact assessment programmes for the establishment of realistic adaptation strategies. Uncertainties not only in climate model results but also in impact models and in interpretation procedures have to be carefully taken care of. In many cases, impact studies require climate signals with temporal and spatial scales much finer than what can be given by very high resolution models, so that sometimes usage of statistical "downscaling" tools cannot be avoided. Uncertainty associated with such procedure should not be overlooked.

6a. ACQWA Project: exploring issues of water in vulnerable mountain regions

Mountains are recognized as particularly sensitive physical environments with populations whose histories and current social positions often strain their capacity to accommodate intense and rapid changes to their resource base. Dr. Martin Beniston of University of Geneva, Switzerland, introduced ACQWA (Assessing Changes in the Quantity and Quality of WAter in vulnerable mountain regions) project of the 7th Framework Programme of the EU to address water issues in mountain regions. The project aims to assess the impacts of a changing climate, focusing on the quantity and quality of water originating in mountain regions, particularly where snow- and ice melt represent a large, sometimes the largest, streamflow component. An increasing number of observations related to glacier retreats, permafrost reduction and snowfall decrease have been observed in many mountains, suggesting that climate modifications may seriously affect streamflow regimes, in turn threatening the availability of water resources, increasing the downstream landslide and flood risk, impacting hydropower generation, agriculture, forestry, tourism and water-dependent ecosystems. As a consequence, socio-economic structures of populations living downstream will be also impacted, calling for better preparedness in developed countries and strategies to avoid the exacerbation of the already conflicting situation in many developing countries, like those in Central Asia and South America.

The goal of the project is to use advanced modelling techniques to quantify the influence of climatic change on the major determinants of river discharge at various time and space scales, and analyse their impact on society and economy, also accounting for feedback mechanisms. The focus will be on continuous transient scenarios from the 1960s up to 2050. In comparison to many existing studies, the limitation of the modelling horizon to mid of the 21st century allows to develop more realistic assessment of the progressive impact on the social, economical and political systems, which we expect to evolve typically in an adaptive mode on shorter time scales than the centennial ones, eventually shifting to new equilibria when forced abruptly.

Environmental and socio-economic responses to changes in hydrological regimes will be analyzed in terms of hazards, aquatic ecosystems, hydropower, tourism, agriculture, and the health implications of changing water quality. Attention will also be devoted to the interactions between land use/land cover changes, and changing or conflicting water resource demands. Integration of the information from all these sectors and the impacts on economies will feed into a quantitative model of water use incorporating supply and demand. Supply is conceived as having physical inputs (from the regional climate models) as well as societal inputs based on property, price, and regulatory factors. Demand reflects population evolution, price, and economic activity.

The resulting integrated model will permit the construction of scenarios and allow the evaluation of various policy options for adaptation and mitigation, both within the EU and in other mountain regions where opportunities and stresses will arise as water resources change.

6b. Climate indices for the prediction of European agricultural production in 2020 and 2040

As has been discussed in earlier sections, the near-term predictions and associated impact assessments depend on how well we can extract climate change signals out of uncertainties due to natural decadal variability on regional scales. One of the concerns is whether or not a climate change signal will be apparent at these relatively short time scales. Dr. Neil MacKellar of Danish Meteorological Institute presented an analysis on feasibility on using EU ENSEMBLES regional climate projection project (www.ensembles-eu.org) for in an assessment of agricultural production in 2020-2040. Regional climate model (RCM) projections are used to derive indices for use in simulating future agricultural yields for Europe. The data are sourced from a subset of the simulations produced under the ENSEMBLES project. This subset includes various RCMs forced by two global climate model transient projections for the 21st century under the IPCC SRES A1B scenario. Proportional changes in a number of climate parameters, including temperature, precipitation and evapotranspiration, as well as the Palmer Drought Severity Index are calculated on a 50 km grid. Two time slices are considered: 2011-2030 and 2031-2050. The mean climate of these time slices is used as estimates of probable change in 2020 and 2040 respectively, relative to the 1961-1990 baseline climate.

It is found that there exist some clear regional signals despite spread between models. As for temperature, climate change signals amplify from 2020 to 2040, but not for rainfall indices. The impact of inter-decadal variability on rainfall indices can be a stumbling block in the near-term assessments. However, it is reported that there found slightly better agreement between models on wet/dry spell indices than mean rainfall. It is pointed out that considering changes in rainfall characteristics rather than just rainfall amount may be important, and that its consequences in the context of agricultural modeling should further be clarified.

6c. Modelling crop yield distribution as affected by extreme events

Climate-risk in agriculture has been evaluated by characterizing the probability density function (PDF) of crop yields. Yield distribution has in fact important implications for modelling crop insurance programs, production decisions under uncertainty, and risk-efficient farm planning. The expected increase in mean temperature and extreme events frequency is likely to modify the present yield distribution with important repercussion on the local and global economy. On these premises, Dr. Marco Moriondo (University of Florence, Italy) presented a framework to assess climate change impact on yield distribution at European scale, which represents a basis to test adaptation options in agriculture. As a first step a specific modelling approach to account for climate extreme impact on yield was calibrated and validated. These events may have a dramatic impact on final production when they occur during key development stages of the crop, and their effect should be consequently carefully considered. The yield PDFs for wheat sunflower and maize were then calculated for the present period (1975-2005) and future periods (2030-2060; 2070-2100) at European scale using 50x50 km gridded meteorological data to drive CROPSYST crop growth simulation model.

Daily meteorological data driving the simulations (Tmin, Tmax, rainfall and global radiation) on a grid scale of 50x50 km were provided by MARS project (http://agrifish.jrc.it/marsstat/default.htm) for the time-slice 1975-2005 and were used to calibrate a LARS-WG stochastic weather generator for each grid point. The calibrated version of LARS WG was then used to produce stochastically 100 years of daily meteorological data for each grid point for the present and future periods to be used as input variables of CROPSYST. The relevant crop yield data for the present and future periods were then simulated and their statistical distribution was analysed.

The results indicated that in the present period generally crop yield has a non normal distribution being negatively or positively skewed according to the crop growth conditions. Areas where the general climate conditions were suitable for a crop showed a negative skewness (elongated tail to the left, where yields are close to their maximum potential) whereas where the conditions were less favourable, the skewness was positive (elongated tail to the right, where yields are strongly reduced closer to 0). Gumbel and Lognormal function generally fitted better when skewness was positive while Logistic better performed when skewness was negative. In future periods both mean climate and extreme events change the PDFs with a different degree of impact in northern and southern Europe.

7. Summary

In the session titled “Global/Regional Climate State in 2030” (Session 2) challenges and issues related to the near-term projection have been discussed. Out of these discussions the following two points should be emphasized.

1. The need for high resolution modelling to predict regional climate change and impacts

Until recently, much of the modelling of climate change was directed at establishing a human effect on climate and showing that such effects are likely to be large in the future. It is now generally accepted that there has been a human influence on climate, and that there is likely to be substantial change over the next few decades, even with significant reductions in emissions. As a result, attention has begun to focus on adaptation to climate change, which requires reliable predictions of local changes in climate. This will require a huge improvement in our modelling capability, including high resolution to resolve the smaller scale features of climate. This is in addition to the ongoing need for improved representation of the physical and biological climate feedbacks.

Over the next two or three decades, natural variations will remain comparable to the emerging climate change signal, and hence it is important that natural models of variability are well represented in models. Amongst other things, this will require increased resolution in global models. Indeed, even at longer timescales, this will be necessary if we are to predict the changes in extreme events as anthropogenic warming progresses. This is in addition to any local downscaling needed to provide information for the assessment of climate impacts. In order to reduce uncertainty arising from natural climate variability, a coordinated experiment is planned in the international research community to pursue impact of initializing models by observations of recent decades.

2. The need for an agreed approach to producing probabilistic predictions, and how to interpret them.

Given the range of climate responses evident in the simulations assessed in the recent IPCC Assessment, it is no longer adequate to use results from a single model to provide guidance on climate change. Quantifying uncertainty in climate projections is of vital importance in formulating adaptation and mitigation stragtegies. Ensembles of opportunity such as that considered in IPCC assessments give some indication of the range of uncertainty, but the frequency distribution of results may not be a good estimate of the probability distribution of climate change. A number of approaches have been tried out, each with strengths and weaknesses, but there is no agreed approach to developing probability distributions of future change. This remains an area of active research. One thing is certain - a large number of simulations will be required to define the distribution of uncertainty, and this will require a large increase in computing resources

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