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Earth System Initialization For Decadal Predictions

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Contents:

Introduction

Decadal predictions are of increasing scientific interest, but are also potentially a benefit to society. They fill the gap between the seasonal forecasts and climate change projections. The next few decades internal climate variations, in particular at regional scales, are expected to have a similar amplitude compared to regional expression of the anthropogenically forced global warming. The premise of decadal predictions is two fold: (i) the decadal internal fluctuations in the earth system are partly predictable and (ii) that by initializing the climate system with the best possible observed state we obtain better estimates of the anthropogenically forced response. The basis for (i) is observed long-term climate fluctuations, such as Pacific Decadal Variability and Atlantic Multidecadal Variability and the basis for (ii) is the climate drift the in current state-of-the-art climate models. Potential predictability studies, either diagnostically by looking at the variance of climate fluctuations or prognostically by performing idealized twin-experiments with models, indicate that over large parts of the ocean and land areas skilful predictions at the decadal time scales may be possible. Indeed, decadal predictions intialized from estimates of the true climate state have been published.

There is societal interest in these decadal predictions as well. Many investments in large scale infrastructure are made for decadal time scales. Knowing how climate will change regionally over those periods may help in making cost-benefit analyses of new investments. The probabilistic character of the predictions is potentially useful in risk analyses. Also, decadal predictions are generally obtained with models at higher resolution than traditional climate change experiments in which long spinups are needed to equilibrate the climate. Consequently, extremes may be better simulated in decadal prediction simulations.

Technically decadal predictions are a challenge. While seasonal forecasts are initialized from observed earth system states, climate projections generally follow on long term spinups of coupled earth system models. The methodology to produce decadal forecasts is at its infancy and draws from the seasonal prediction strategies: only a few studies in the literature have appeared, the data to initialize the models from is limited (in particular in the pre-ARGO period) and the verification is hampered by the relatively small time record of observations.

The workshop was directed at making an inventory of best practices and providing a roadmap to the challenges ahead to make skilful decadal predictions. The workshop had the following specific objectives:

- To make an <u>inventory</u> of initialization and perturbation techniques in earth system models; compare and contrast, where possible, forecast made with these different initialization strategies.
- To discuss the <u>effectiveness</u> of initialization and perturbation <u>techniques</u>.
- To <u>review the observing system</u> and available data for initialization: ocean, soil moisture, ice, snow, atmospheric composition.

The workshop gathered an international group of about 50 scientists (see list of participants) with a background in climate modeling, prediction strategies, ocean analyses, and climate observations. The workshop was organized around plenary presentations giving an overview of the problem, poster session and showcases with individual contributions and working group discussions on future directions. In the following a short description of the plenary talks is given and detailed recommendations are made based on discussions at the workshop. These recommendations can be summarized as follows:

- The relevant panels of the World Climate Research Program (WGSIP, GSOP, WGOMD, WGCM, basin panels) to take notice of detailed recommendations reported in this document.

- For WCRP-CLIVAR to expand on CMIP5 near-term predictions and set up a protocol for coordinated decadal prediction experiments to address initialisation issues mentioned in this report.

- To encourage twin and sibling experiments (i.e. attempt to predict output of another model) in order to study initialisation and perturbation techniques.

- To make analyses of earth system components available through CMIP5 data centres according to CMIP5 data management requirements, including error information.

- To set standards for verification following recommendations made in this report and make use of large climate events for guided verification.

- To maintain and extend the observing system of the earth system, with emphasis on ocean and sea ice observations, for initialisation and verification of decadal predictions

Summary of plenary presentations

All presentations can be viewed and downloaded from the Internet:
http://www. knmi.nl/samenw/easyint/index.html
Here we present a short review of the plenary presentations.

Session 1: General aspects of decadal predictions

G.Boer (CCCma). Overview of Decadal Potential Predictability
The motivation and premise of decadal predictions was discussed. The existence of long-time scales forms the basis of decadal predictions. A historic overview showed the growing interest a few decades ago to the large interest in the last few years. Two types of potential predictability studies can be distinguished: diagnostic and prognostic studies. A metric based on signal-noise shows that there is potential for predictability over large regions, in particular midlatitude oceans. The challenge is to identify the mechanisms associated with regions/modes of predictability, to assess “perfect model” and “potential” vs “actual” predictability, to investigate predictive *skill* of both forced and internally generated variability.

D. Smith (UKMO) Overview of decadal predictions
This presentation focused on prognostic decadal predictions. After discussing motivation for decadal predictions, practical issues such as dealing with model bias, limited observations in the analyses and ensemble generation was discussed. It was noted that a lot of skill comes from global warming. Actual decadal predictions produced by different groups of the global mean temperature, Atlantic and Pacific were shown and compared to observations. These show that indeed, skill can be found at decadal time scales (in addition to skill from global warming alone and tested against a statistical model). The value of idealized experiments was discussed, for instance for observing system design. Finally, it was noted that CMIP5 and IPCC AR5 will receive a lot of attention, while decadal predictions are still in development. Care should be taken in communicating the results.

Session 2: The observing system for decadal predictions

D.E. Harrison (NOAA/PMEL) The Ocean Observing System and Decadal Predictions.
Historical data set of ocean observations was shown to be sparse, even for upper ocean temperature until recently. ARGO improved matters, but tropics and high latitudes are still sparsely sampled. It was shown that temperature is best sampled, but in the deep ocean it is still very limited. Because of the sparseness and uncertain covariance statistics, efforts to create analyses of the historical ocean have taken different approaches. Historical data clearly document decadal variability with 20-yr shallow temperature trend amplitudes comparable to or larger than 50-yr trends. But multi-decadal world-ocean average trend estimates of heat content are affected by changes in observing system, metadata/depth correction issues and methods of analysis. Deep ocean and full-suite-variables only via repeat hydrography available. The observations show clear ventilation patterns and variability evident, but poorly observed. Technology is needed for further

improvements. Satellite agencies are trying to sustain proven sensors and do more on ocean color, surface topography, sea ice, SSS, & reprocessing and operational issues. The Observing System community faces many national funding challenges.

L.-A. Breivik (NMI) Remote sensing of the cryosphere
Challenges in global sea ice monitoring were discussed. Sea ice is poorly defined, but passive microwave measurements and navigational charts can give estimates of ice extend. There are, however, substantial errors in the estimates. There is very limited information on thickness and flux of ice. New altimeters, Icesat (precision 2 cm) and Cryosat 2, will deliver information on ice thickness. Uncertainties in snow estimates include obscuration by dense liquid water clouds and rain, inaccuracy in the atmospheric correction, obscuration by forests, inability to map the water equivalent of partially wet snow cover, mapping snow in topographically-rough areas. Nevertheless SMMR, SMM/I and AVHRR and MODIS can be used to monitor snow. The different satellite instruments offer opportunities for decadal predictions, but for hindcasts data is very limited.

D. Smith, representing O. Boucher (UKMO) Atmospheric composition and aerosols
The impact of aerosols was reviewed. Globally, there seems to be a small negative trend. Regionally large trends found that are well correlated to emissions. In Europe aerosol concentrations decrease, in eastern Asia they increase. In Europe visibility is increased (less fog) and there is some evidence for impact on rainfall, primarily through changes in circulation rather than through the indirect aerosol effect. Tropospheric aerosol and ozone radiative forcings are significant, vary regionally on timescales of decades and are therefore highly relevant to decadal climate prediction. For hindcasts, satellite data, GEMS / MACC reanalysis and climate simulations can be used. For forecasts RCP scenarios are recommended. Finally stratospheric aerosols should be taken into account as well.

A. Koehl (Univ. Hamburg) Overview of re-analysis
The presentation focused on ocean synthesis, which are made available by CLIVAR-GSOP. The basis of combining statistical information and a dynamical ocean model to interpolate data from sparse ocean observations was discussed. The different techniques were discussed and it was advocated to produce error estimates. Furthermore, we need a variety of modeling and assimilation concepts if we want to learn about epistemic uncertainty. Different analyses were compared for heat content resulting in: similar assimilation concepts seem to lead to similar answers. Good agreement was found among the OI/3D-Var syntheses that replicate the XBT bias problem. GECCO disagrees but filters the bias. For heat transport: little agreement among the syntheses, except in the equatorial and northern Pacific; good agreement was found among the adjoint syntheses K7 and GECCO estimates

M. Balmaseda (ECMWF) Critical assessment of producing analyses
Uncertainties in important climate variables in ocean reanalyses remain large. The reanalysis are difficult to validate. Different examples of uncertainties were shown. In order to address the uncertainties in ocean reanalyses there is a need to consolidate assimilation methodology, improve atmospheric fluxes, work on quality control and improve ocean models. The (coupled) initialisation problem was further discussed. It was shown that: initialization shock does not imply loss of skill, balanced initialization does not imply anomaly initialization, anomaly initialization has problems when there are strong non-linearities, one-tier and two-tier anomaly initialization can be quite different. Finally, it is suggested to try statistical corrections to dynamical models (flux correction).

Session 3: Forecast strategy for decadal prediction systems

L.E. Smith (LSE, Oxford Univ.) Fundamentals of initialisation of non-linear systems
Different assimilation techniques were reviewed in a mathematical framework. It was shown that climate predictions suffer from large model biases, which hampers models to stay close to the observed trajectory of climate variability. A new technique, shadowing, was introduced. The technique keeps the model close to its attractor, but may not work well when biases are large, as in

climate models. The community clearly needs to work on model bias. Finally, skill from ENSEMBLES predictions were shown. Despite problems mentioned before, the runs show skill beyond the seasonal time scales.

N. Keenlyside (IFM Geomar) Overview initialisation techniques
First mechanisms and sources of memory were shown, taking interannual and decadal variations in the Pacific and Atlantic as example. Then the model bias was discussed and different methods to deal with it, such as a postriori bias correction, anomaly initialisation, flux correction and model improvement. A survey was presented of the different methods that were used (initialisation technique, analyses data). 19 combinations were found. Examples of the results were shown of different ways to initialise and produce forecasts. It was suggested to use perfect model experiments to further understand initialisation methods. CMIP5 will give us insight in many issues.

B. Kirtman (RSMAS) Overview of perturbation techniques
Skillful decadal predictions may be possible if a deterministic mechanism produces low frequency fluctuations and if the coupled system is properly initialized. To quantify the uncertainty, PDFs are produced, which implies that ensembles must be generated by perturbing the initial states in coupled models. Different perturbation methods were discussed: atmosphere only perturbations, which probably underestimate uncertainty of coupled system, and ocean perturbations. Two methods were highlighted: stochastic optimals and bred vectors. Both methods are designed to lead to optimal growth of perturbations. Examples were shown and issues, such as choice of the norm, were discussed. Finally different examples of prediction experiments were shown.

<u>Session 4: Windows of opportunity</u>

H. Drange (Univ. Bergen) Memory in the ocean
First importance of ocean memory in coupled system was discussed. Mechanisms that generate memory are slow adjustment times (advective, Rossby waves,..), subduction/stratification (anomalies shielded from atmosphere), salinity advection and the large heat capacity in general. Examples from the North Atlantic were shown from observations, forced ocean model runs and idealized forcing experiments. Especially, decadal fluctuations in the subpolar gyre have been clearly observed and may provide a testcase for guided verification of decadal predictions. It was stressed the signals were primarily oceanographic.

G.J. van Oldenborgh (KNMI) Large climate events in the 20th century
Large climate events were discussed. First it was shown that the largest climate event is global warming, leading to good skill in temperature in decadal forecast runs. The fluctuations around the trend of the global mean temperature are not predicted well by the ENSEMBLES decadal, but regional skill can be obtained, in particular in the North Atlantic for temperature and Sahel for precipitation. Large decadal fluctuations such as the AMO and PDO were further discussed.

Recommendations from working groups

Three discussion sessions were held on main issues of initialization for decadal predictions. These sessions were on Initialization, Perturbation and Verification. Each working group was charged to address:

- Best Practices & Options
- Key issues and challenges
- Roadmap to address the challenges

<u>Initialization Working Group</u>

Best practices & options
Best practices with a focus on ocean initialization was discussed. In general initialization techniques can be separated into full initialisation and anomaly initialisation and in coupled or uncoupled mode:

	Full	Anomaly
Uncoupled	GSOP GODAE Seasonal	
Coupled	C-4Dvar EnKF OI with CGCM NCEP rean	1-tier 2-tier (nudging)

The different strategies all have pro's and con's. There may not be a March 2010 universal solution. At least there is a need to assess and evaluate these methods systematically.

Nudging of anomalies from other reanalysis may not the best, but a practical solution to study sensitivities and to get started. Coupled initialization methodologies are probably the long term solution, but they are more difficult to start with.

For producing analyses and evaluation, use all available observations unless there is a good reason not to.

Key issues and challenges

- How to validate ocean reanalysis?
- How to validate/evaluate the initialization?
- What to initialize? Processes, variables, modes?
- Which is the Observing System needed for decadal predictions? (Amount of deep ocean observations?)
- Initialization of other components of the Earth System
  - Land (permafrost, soil moisture, snow…)
  - Ice
  - Carbon, CFC, Oxygen

Roadmap to address challenges:

- Define relevant metrics for evaluation of predictions for unified evaluation criteria.
- Make a catalogue and easy-accessible data archive of independent observations for validation (if possible through CLIVAR or CMIP5 archives):
  - Observations that have proved relevant in understanding processes which are not assimilated (overflows, salinity, mooring data…)
  - Independent observations (velocities, transports): useful to evaluate assimilation techniques.
- Exploit existing Ocean Reanalysis efforts
  - Closer look at spatial structure and co-variability to extract coherent signals
  - Put the existing ocean reanalysis in the CMIP5 database
- Consolidate existing DA techniques
  - Perform coordinated prediction experiments
  - Use Argo period + sub-sampling to evaluate and improve the capability of the DA systems.
  - Provide error covariance formulation
  - Self consistency diagnostics
  - Verification with independent data (velocities, transports…)
    - Liaise with the GODAE community
- Predictability and initialization studies and Observing System Design:
  - Find predictable signals
  - Find sensitive areas/regions that should be better observed
  - From models: perform growing modes diagnostics
  - From observational studies: modes, transitions, **windows of opportunity**

  - OSEs and OSSEs
  - Siblings rather than twin experiments
- Consider the possibility of a XX century historical ocean re-analysis
  - To make use of the XX-C atmospheric reanalysis, SST
  - Tide gauges and sea level reconstructions
  - Heat content reconstructions
  - Continue data mining and QC.
  - Regional signatures
- Consider the possibility of initialization of different time scales with different spatial scales
- Ice impacts: use last 3-4 years to:
  - Study impact of ice initial conditions in climate
  - Assess ice model and ice initialization
- Liaise with the Carbon/Oxygen/CFC community
  - Ocean reanalysis
  - Decadal earth system predictions
- Sample Initial Uncertainty
  - Ice conditions
  - Land conditions
  - SST reconstructions

<u>Perturbation Working Group</u>

Best practice & options:
- Use ensembles (high priority)
  - It is unclear how large of ensemble is needed – this may be dynamic
  - Quantitative assessment of whether spread is sufficient
  - Investigate use of lagged forecasts to improve quantification of the forecast pdf
- Probe ocean initial conditions uncertainty (high priority)
  - Use different oceanic reanalysis,
  - Add noise to observations and redo analysis
- Idealized experiments to assess analysis strategies (high priority)
  - Agree on a common set of questions to be addressed in coordinated idealized experiments; such as:
    - (i) how reliable is the analysis error?
    - (ii) sub-sampling + prediction experiments

Key issues and roadmap to meet challenges:
- Probe uncertainty in the forcing, in particular tropospheric aerosols (high priority)
- Probe uncertainty in other earth system components (land and seaice) (priority)
- Develop simple methodologies for ocean initial condition perturbations: (high priority)
  - design an experimental protocol
- Address model uncertainty/errors: (high priority – long term)
  - perturbed physics
  - stochastic physics
  - multi-model and sensible use of same initial conditions and different climate models
  - Does model improvement lead to smaller uncertainty?
- Perform common idealized prediction experiments (priority)
  - Agree on common set of questions for coordinated experiments; such as sources and mechanisms for predictability
- Encourage work on theoretical methodologies (high priority)
  - Need a coherent theoretic framework for quantifying what is a good perturbation technique
- Capitalize on lessons learned in seasonal-interannual prediction (decadal hindcasts and forecasts should be analyzed at the seasonal timescale) (high priority)
  - Assess seasonal forecast quality using decadal forecasts
  - Seamless research – relating short term errors to model bias
- Work with WCRP to ensure the accessibility of the oceanic reanalysis data (high priority)

- Engage the traditional oceanographic community in these issues (high priority)

Verification Working Group

Best practice & options

- Uncertainties should be quoted on all measures including skill scores, reanalysis, and forecasts
- Check mean state and variability of multi-decadal experiments against observations, preferably a large 20c3m ensemble
- Aggregate spatially into regions or modes to improve signal/noise ratios.
- Use robust skill measures
- Compare skill in experiments initialised from observations against other (eg 20c3m) experiments
- Number of ensemble members should be adequate for the purpose of the experiment (more than 3 as advocated by CMIP5).
- Compare skill to baseline statistical models (eg trends and persistence) and combine model and complex statistical models to derive skill scores

Key issues and challenges

- (Time-varying) biases
- Extract maximum valid information from a small number of data points (eg 10 5-yr periods)
- Lack of ocean/ice data to verify against, uncertainties in reanalyses
- Dealing with the skill due to external forcing eg volcanoes, solar
- Separating the skill due to external forcing and initial conditions
- Assessing skill improvement of initialize from uninitialized models
- Dealing with expectations of users, communicating uncertainties and value of forecasts

Roadmap to address challenges

- Education of users community to the value of hindcasts
- Provide to users clearly distinguished calibrated forecast from model output
- Consider innovative application of datasets beyond that which the data set were designed
- Improvements to ocean reanalysis
- Maintain a sufficient observing system

Appendix 1

Participants

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3. Robert Burgman RSMAS USA
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Invited speakers (14 incl organising committee)

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43 George Boer CCCma Canada

44 Lars-Anders Breivik NMI Norway

45 Helge Drange Univ Bergen Norway

46 Lenny Smith LSE/Oxford Univ. United Kingdom

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48 Wilco Hazeleger KNMI The Netherlands

49 Noel Keenlyside IFM-GEOMAR Germany

50 Ben Kirtman RSMAS USA

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52 Geert Jan van Oldenborgh KNMI The Netherlands

53 Bernadette Sloyan CSIRO Australia

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55 Laurent Terray CERFACS France

Appendix 2

Agenda

Wednesday 4 November 2009
Introduction
09:30-10:00 Registration, *Coffee/Tea*
10:00-10:15 Welcome and logistics
10:15-10:30 Goals and scope of the workshop

General aspects of decadal predictions
10:30-11:15 Overview of decadal potential Predictability (G. Boer, CCCma)
11:30-12:15 Overview of decadal predictions (D. Smith, UKMO)
12:30-13:30 *Lunch*

The observing system for decadal predictions
13:30-14:00 The ocean (E. Harrison, NOAA)
14:00-14:30 Cryosphere (L.-A. Breivik, NMI)
14:30-15:00 *Coffee/Tea*
15:00-15:30 Atmospheric composition & aerosols (D. Smith, UKMO)
15:30-16:00 Overview of re-analyses (A. Köhl, Univ Hamburg)
16:00-16:30 Critical assessment of producing analyses (M. Balmaseda, ECMWF)
16:30-18:00 Poster session and drinks

Thursday 5 November 2009
Forecast strategy for decadal prediction systems
9:30-10:15 Fundamentals of initialisation of non-linear systems (L. Smith, LSE)
10:15-11:00 Overview initialisation techniques (N. Keenlyside, IFM-GEOMAR)
11:00-11:30 *Coffee/Tea*
11:30-12:15 Overview perturbation techniques (B. Kirtman, RSMAS)
12:15-13:30 *Lunch*

13:30-15:00 Showcases
Decadal hindcast and prediction experiments with a coupled atmosphere-ocean GCM, MIROC *(*M. Ishii, JAMSTEC) Preliminary tests at IPSL (J. Mignot & E. Guilyardi, IPSL/LOCEAN) Estimation of optimal perturbations for decadal climate predictions *(*E. Hawkins, Univ Reading)

Windows of opportunity
15:00-15:30 Memory in the ocean (H. Drange, Univ. Bergen)
15:40-16:00 Large climate events in the 20th century (G.J. van Oldenborgh, KNMI)

16:00-17:30 Discussion break out groups
Break out: Moderator: M. Balmaseda, ECMWF
Rapporteur: R. Haarsma, KNMI
Break out: Moderator: B. Kirtman, RSMAS
Rapporteur: L. Terray, CERFACS
Break out: Moderator: B. Sloyan, CSIRO
Rapporteur: G.J. van Oldenborgh, KNMI
17:30-18:00 Short report chairs on progress in plenary
Dinner in Utrecht

Friday 6 November 2009
9:00-10:30 Continue discussions, directed at new, challenging, innovative aspects
10:30-11:00 *Coffee/Tea*
11:00-12:00 Plenary discussion new research directions initialisation
12:00-13:00 Plenary discussion new research directions perturbation
13:00-14:00 *Lunch*

14:00-15:00 Plenary discussion new research directions verification
15:00-15:30 Concluding remarks
15:30-17:00 *Adjourn and drinks*

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