Sources of sub-seasonal predictability (including model uncertainty)

A. Sources of predictability

Are all the major sources of predictability currently included in S2S models?

Overall the sources of predictability have been properly identified in the Seamless Prediction of the Earth System WWOSC book[i] (MJO, ENSO, snow cover and sea ice, stratosphere-troposphere interaction, extra-tropics tropics, teleconnections, ocean conditions and soil moisture) and most of them are represented to some degree in S2S models. On potential source of predictability on these timescales which is not currently represented in the ECMWF system is from atmospheric aerosols including dust and volcanic aerosols. It would be good to identify the existing status of ECMWF prediction system sources of predictability and their modelling. In the case of aerosols/dust we should consider research about

a. Prediction of aerosol impacts;
b. Direct effects, particularly e.g. West Africa, China, India (dust, anthropogenic, fires …);
c. Feedbacks and dynamics.

Are the main sources of predictability well represented?

We have seen progress in S2S prediction for the MJO, monsoon, stratospheric variability, but need further progress for teleconnections both between extra-tropics and tropics and between the extra-tropical stratosphere and troposphere. ECMWF should assess if it is fully exploiting predictability from the land surface and sea-ice. The S2S science is relatively new and we could actually underestimate the potential extra-tropical predictability.

How can we estimate the limit of predictability at the sub-seasonal timescale? How much improvement can we realistically expect in the coming 10 years?

In view of providing quantified answers to these questions we need to make progress in a number of areas:

1. On S2S timescales it will important to develop better understanding flow dependent predictability and predictive skill (e.g. is the spread flow dependent enough);
2. To make assessments about potential predictability from perfect model experiments it would be useful to compare estimate of potential predictability of different EPSs;
3. Do initial conditions capture the uncertainty relevant for S2S timescales – consistent perturbation strategies?

B. Model developments

ECMWF should continue to improve its physics package taking in account the accurate representation of the modes of variability and the mean state, recognizing the importance of the latter for teleconnections. More specifically it is suggested to assess the importance of the following processes and model innovations (in no particular order):

a. Air-sea coupling and vertical ocean resolution;
b. Diurnal cycle over land;
c. Gravity waves and orographic and non-orographic drag;
d. Land-surface processes;
e. Closing energy and momentum budgets;
f. Data assimilation for S2S – particularly coupled data assimilation in the tropics (e.g. fluxes).

<u>What model developments are more likely to improve the prediction of tropical sub-seasonal variability?</u>

A general improvement in parameterization of convective processes such as convective downdraughts, cold pools, rain re-evaporation, prognostic precipitation microphysics, convective momentum transport and others will improve the vertical heating and moistening profiles, associated with convection, and may improve the coupling between the large-scale circulation and the convection, e.g. the vertical tilt in diabatic heating profiles and sensitivity of precipitation to large-scale moisture have been shown to be important for a good MJO representation in climate models.

Diurnal cycle in sea surface temperature and air-sea fluxes has an important influence on upper ocean heat content, low level atmospheric moistening and tropical convection over the ocean. Enhanced vertical resolution in the ocean mixed layer may resolve some of these processes, but approaches to parameterize the diurnal cycle processes could also be explored. Diurnal cycle of convection over the Maritime continent is a complex interaction between land-sea breezes, island orography and radiation. Better representation of these processes can not only improve the diurnal cycle representation but also its interaction with the MJO propagation across the Maritime continent.

Improved representation of model uncertainty, especially relating to convection schemes can help build more reliable ensemble forecasting systems. Stochastic schemes in convection and other model physics processes can model uncertainty in our parameterizations or unrepresented sub-grid scale processes and hence, builds a better probabilistic modeling system.

<u>What model developments are more likely to improve the representation of stratospheric processes?</u>

Since extra-tropical stratospheric variability is determined largely by the interaction of the mean circulation with upward propagating Rossby waves, improving its prediction relies upon improving the representation of both of these aspects in models. For the mean circulation, the key unknown in models is the representation of gravity wave drag, since this is generally poorly constrained by observations. There are a number of recent or imminent observational campaigns such as DEEPWAVE[ii] the DFG funded project MS-GWaves[iii] and the FP7 project ARISE2[iv] that might provide additional insight to help constrain these schemes. There is also a strong drive to address this problem within WGNE and SPARC through the Drag Project[v] with a workshop at ECMWF in September 2016. There is some evidence that trace gas distributions, in particular ozone, might also play a role in determining some stratospheric biases.

Making improvements to the generation and propagation of Rossby waves is also linked to many aspects of tropospheric variability, including diabatic heating from tropical convection and the mean state in the extra-tropics.

The lack of a complete theory for how stratospheric anomalies couple to the troposphere limits our ability to understand: if and why stratosphere-troposphere coupling is too weak in most models. Making use of the S2S database and other long hindcast sets of sub-seasonal forecasts will help to develop this understanding, since the sub-seasonal is the most natural one for this coupling.

Above 40km there is also a limited amount of data which the models can assimilate and so the initial state may be poorly constrained. Future measurements from ADM-Aeolus may help to improve stratospheric initialization and hence predictability.

<u>What model development is more likely to improve the prediction of land and cryosphere processes?</u>

In the coming decade we expect more model components for land (and water) included in the forecasting systems and the complexity will increase in existing components. However, introducing a dynamical treatment of a process instead of a climatological treatment will have the potential to increase the model climate error. The goal is that the error reduction by the dynamical treatment (random component) will be larger than the increase in the error in the mean climate (systematic). We will need to have a good balance between complexity of land surface schemes and usefulness for prediction system.

More attention is needed for the initialisation of these components (data assimilation) and consistence between initialisation of real-time forecasts and re-forecasts.

Other components that will likely help are:

- Proper representation of the model uncertainties;
- Land surface tile for urban areas;

<u>What model development is more likely to improve the teleconnections (non-stationary, speed of propagation?</u>

First the mean state is recognized to control the Rossby-wave source terms, the pathway of the teleconnections and eddy mean flow interaction, so the mean state needs to be well represented.

The second step would be to disentangle the role of the tropical heating vs. the intrinsic mid-latitude variability in determining the amplitude and persistence of mid-latitude modes of variability. Models should capture the observed statistics of wave-breaking and blockings in order to properly represent the observed amplitude and persistence of tropical-mid-latitude teleconnections, and this should be quantified during the model development process. Models should capture the observed phasing and amplitude of the organized convection in the tropics, with accurate vertical and horizontal distributions of heating.

ECMWF should explore the representation of extra-tropical to tropical teleconnection pathways including direct interactions e.g. the interactions between monsoon and mid-latitude systems producing heavy precipitation events over the Himalayas.

C. What kind of experimentation of could help investigate these issues?

There are multiple experimental and diagnostic approaches for investigating S2S issues.

1. Nudging and bias correction experiments, to assess the importance of tropical extra-tropical teleconnections and the sources of errors in their representation
   i. Bias corrections based on fixed forcing from a nudging experiments to improve the basic state and explore the impact on teleconnections pathway;
   ii. Relaxation of limited regions to observations to explore of tropical forcing in extra-tropical variability (e.g. relaxation over Maritime Continent);
   iii. Combination of the above two techniques.

2. To extend existing initial error tendencies using analysis increments to identify the flow dependence of error development
3. Process studies to
   i. assess the role of particular sources of predictability (e.g. time depend vs aerosol/sea-ice climatology),
   ii. explore the sensitivity to errors in the representation of key physical process by performing physics perturbation experiments (e.g. orographic parametrization) and assessing the impact of model improvements on S2S prediction during the development of the schemes
4. Linear Inverse Model (LIM). LIM are known to have good skill in S2S time scales. It permits to identify and diagnose sources of predictability and stochastic forcing. The comparison of LIM constructed from reanalyses and model output (e.g. forecast) could be a powerful diagnostic tools. The possibility of developing LIM from model statistics and different lead times to explore the sensitivity to the changing basic state should be explored.

D. Is the representation of model uncertainty well addressed in sub-seasonal EPS?

The representation of model uncertainty through the development of stochastic parametrization schemes is a powerful tool. ECWMF should consider

1. Closer integration between development of model components and the stochastic parameterization;
2. Exploring the representation of uncertainty in ocean/sea-ice/land-surface;
3. Improved understanding of impact of stochastic parametrization on the model climate;

The S2S database provides and additional resource to explore the issue of model uncertainty through the analysis of Multi-Model Ensembles

---

[i] Seamless Prediction of the Earth System: from minutes to months, WMO 2015. http://library.wmo.int/pmb_ged/wmo_1156_en.pdf

[ii] https://www.eol.ucar.edu/field_projects/deepwave

[iii] https://ms-gwaves.iau.uni-frankfurt.de/index.php/gravity-waves-in-the-atmosphere

[iv] http://arise-project.eu/arise-project.php

[v] http://collaboration.cmc.ec.gc.ca/science/rpn/drag_project/