WWRP 2018 - 4
WCRP Report No. 11/2018

WWRP/WCRP Sub-seasonal to Seasonal Prediction Project (S2S) Phase II Proposal

(November 2018–December 2023)

WEATHER CLIMATE WATER

WORLD
METEOROLOGICAL
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WORLD WEATHER RESEARCH PROGRAMME

World Climate Research Programme

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WORLD METEOROLOGICAL ORGANIZATION

EDITORIAL NOTE

METEOTERM, the WMO terminology database, may be consulted at:
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NOTE

CONTENTS

This report builds on S2S Project Phase I Progress Report and the feedback received from reviewers and questionnaires/interviews, identifying current gaps in S2S research, transition to operations and in abilities to meet user requirements. It outlines plans for Phase II of the S2S Project.

1. SUMMARY OF S2S PHASE I

The World Weather Research Programme (WWRP) and the World Climate Research Programme (WCRP) Sub-seasonal to Seasonal Prediction Project (S2S) was launched in November 2013, with the primary goals of improving forecast skill and understanding the dynamics and climate drivers on the sub-seasonal to seasonal timescale (from 2 weeks to a season). The S2S project has a special emphasis on high-impact weather events, developing coordination among operational centres, and on promoting uptake of S2S information by the applications communities. S2S is one of three post-THORPEX activities of WWRP - along with the Polar Prediction Project (PPP) and the High Impact Weather project (HIWeather) - and is the first major joint research project between WWRP and WCRP. A key motivation of S2S was to capitalize on the expertise of the weather and climate research communities and WMO/WWRP/WCRP programmes - filling the gap between medium-range and seasonal forecasting - to address issues of importance to the Global Framework for Climate Services (GFCS).

The Implementation Plan for S2S (http://www.s2sprediction.net/file/documents_reports/S2S_Implem_plan_en.pdf) was written by a planning group that convened several times during 2011–2013 and was published in 2013. The plan proposed the following set of activities toward realizing the S2S project goals, to be carried out over a 5-year period initially, with the option of extension for a further 5 years:

- The establishment of a project Steering Group representing both the research and operational weather and climate communities, and an International Project Office to coordinate the day to day activities of the project and manage the logistics of workshops and meetings.
- The establishment of a multi-model database consisting of ensembles of sub-seasonal (up to 60 days) forecasts and supplemented with an extensive set of re-forecasts following TIGGE protocols.
- A major research activity on evaluating the potential predictability of sub-seasonal events, including identifying windows of opportunity for increased forecast skill with a special emphasis on events with high societal or economic impacts, and relevance to developing countries.
- A series of science workshops on sub-seasonal to seasonal prediction.
- Appropriate demonstration projects based on some recent extreme events and their impacts, in conjunction with the WWRP Working Group on Societal and Economic Research Application (SERA).

All the main activities foreseen by the Implementation Plan have been tackled to a significant degree. The signature achievement of S2S has been the creation of the S2S database of sub-seasonal forecasts (3 weeks behind real time) and re-forecasts, archived at the European Centre for Medium-Range Weather Forecasts (ECMWF) and the China Meteorological

Administration (CMA), and later on in the International Research Institute for Climate and Society (IRI) Data Library. The database was launched publicly in May 2015 and has inspired major research activity on S2S predictability, modelling, forecast verification and product development. Several regional S2S research activities have been established, including a major National Oceanic and Atmospheric Administration (NOAA) initiative in the USA, for which the S2S project may take some credit. The project has fostered S2S research by organizing/co-organizing 18 science workshops/sessions in the project's first 4 years, together with eight training courses. Six S2S sub-projects were established to coordinate research and to foster development of a global S2S climate & weather research community. A series of case studies has been carried out as part of the sub-project on extremes. The science findings are rapidly evolving, with the database launched only two years ago. To date, 22 articles have been published that use the S2S database. Several of the findings relate to the Madden-Julian Oscillation (MJO), a primary source of sub-seasonal predictability:

- The skill of MJO forecasts in 7 of 10 S2S models exceeds a bivariate correlation skill of 0.5 at 20-day lead, while only one model reaches that level after 30 days.
- MJO teleconnections over the North Atlantic are of realistic sign, but too weak in all the models.
- MJO skill is enhanced by up to a week during the easterly phase of the stratospheric Quasi-Biennial Oscillation (QBO) in several S2S models.
- Evidence from the S2S database forecast ensembles suggests that the severe cold spell that afflicted Western Europe in March 2013 was at least in part attributable to a strong MJO event propagating into the western Pacific.
- The skill of the S2S models to predict Euro-Atlantic weather regimes and their transitions has been assessed. Results indicate predictive skill up to about 3 weeks for the positive and negative North Atlantic Oscillations (NAO) phases, and up to about 16 days for the other weather regimes. The S2S models display skill to predict weather regime transitions up to about 16 days.

Coordination among operational centres fostered by S2S led the WMO Lead Centre in 2015 to begin a pilot real-time sub-seasonal MME prediction system for its members, taking advantage of the S2S database at ECMWF. The Lead Centre is able to routinely access the S2S database without the 3-week delay placed on public access. Further coordination across the WMO Global Producing Centres (GPCs) has taken place such that all of 11 operational centres now issue forecasts on Thursdays (including the four models with daily forecast starts); this compares with only 7 of 11 models at the project's outset and greatly facilitates the construction of multi-model ensemble forecasts.

The S2S project was born into a complex landscape of research and operational forecasting programmes and institutions within and external to WMO. The project has created a nexus between WCRP and WWRP, and is strongly linked to WMO- Commission for Basic Systems (CBS), and is well positioned in Phase II to make a significant contribution to the WMO Global Framework for Climate Service (GFCS).

2. GAP ANALYSIS

While Phase I of the S2S project can point to major achievements and important milestones during the first 4 years of the project to date, there is a clear recognition that much of the research, product development and uptake by the applications communities are still at quite early stages. Much remains to be done to fully realize the vision of sub-seasonal to seasonal timescale prediction both in terms of improving the skill of the forecasts, as well as creating forecast products to help inform user-decisions in the two weeks to a season range.

To provide a meaningful gap analysis to inform future plans, a questionnaire was developed to elicit feedback from the research, modelling and operational communities on research and modelling gaps, suggestions for coordinated numerical experiments and new sub-projects to address them, constraints faced in operational sub-seasonal forecasting, and gaps in forecast product development.

Eighteen responses were received covering a wide range of issues. Frequently mentioned research and modelling gaps include: land-surface processes and initialization; ensemble generation, including initialization, perturbation methods and stochastic physics; coupled data assimilation and the role of the ocean and sea ice on the sub-seasonal forecasts; stratospheric processes; and understanding model systematic errors and error growth. Some of the database and operational gaps raised include: need for more convenient and faster access to popular suites of variables, including ensemble means, model climatologies, indices, and map displays; need for multi-model calibrated forecast product development; desire for more extensive re-forecast sets (number of years and ensemble members) for verification and forecast calibration, and encouraging centres to harmonize re-forecasts; request for more ocean data including 3D fields, increased model horizontal and temporal resolution; and desire for real-time access.

While the feedback from the survey is broad, it highlights a number of upstream research and modelling gaps that need to be addressed in order to increase the skill of S2S forecasts, and downstream gaps in the database and forecast product development which need to be addressed in order to provide S2S forecast and verification products with socioeconomic value to users in the climate-service and business contexts.

A set of questions directed to an applications/service/donors/wider stakeholder audience of S2S was also created and used as a basis for a series of semi-structured interviews, led by the WWRP SERA Working Group. The identification and selection of interviewees was based primarily on existing relationships and research collaborations, as well as their convenience and availability to be interviewed. Eight phone and face-to-face interviews were carried out with stakeholders in agriculture (Australia, Uruguay), energy (Uruguay), transport (Canada), water management (Canada, USA), bushfire management (Australia), and humanitarian aid (global and Peru). Moreover, results from an online survey for the general public using 6-week forecasts (Finland) were used. It is recognized that the results of the interviews (except for the survey work conducted in Finland) are an illustrative and descriptive glimpse of user attitudes towards S2S forecast information, rather than a comprehensive and representative review. Despite this, the results offer insights which can help the S2S project in its further development aims. The main findings include:

- Current use/interest/availability/applicability of S2S information depends on the sector. The energy sector in Uruguay is very advanced in using S2S and probabilistic information. The humanitarian sector is actively trying to develop the use of S2S information. Most important lead time approximately two weeks for effective procurement of non-food items. Other sectors show clear interest, but current use and availability is minimal.
- Potential benefits of skilful S2S information are high, yet the following barriers hinder their realization: (i) Lack of accuracy/poor skill - high level of accuracy is required for many types of decision-making; (ii) Lack of post-processing - need for statistical post-processing techniques to calibrate forecast for reliable probabilities; (iii) Lack of forecast verification: request that forecasts always be provided with verification information; (iv) Lack of stability in forecast model output: instability/persistence of the rainfall in the forecasts prevented the use of the forecast, or they became reliable only close to the actual event; (v) Challenges in interpretation of probabilities - a large share of users struggle to interpret probabilities and can have low expertise in risk management; and (vi) It was also emphasized by the interviewees that weather is usually only one input into decision-making, so other inputs need to be considered that may be partially or completely independent of the weather forecast.
- Several areas for research and development were identified: (i) Improve forecast accuracy, forecasts of extremes, and calibration/verification of S2S forecasts; (ii) Develop flexible and adaptable services: e.g. can be tailored to user defined thresholds of interest, and/or that can be easily analysed/integrated with non-meteorological data; (iii) Provide data in accessible formats that can easily be added into apps/integrated with other information/added to decision support tools; and (iv) Focus on hydrology, and especially high-impact floods are created through water in rivers.
- Several Stakeholders/Sectors were identified as eager to engage in further collaboration: (i) The Red Cross Red Crescent Climate Centre is already engaged with WMO and would be interested in joining efforts for instance on S2S verification; (ii) The Department of Water Resources (DWR), Sacramento, California, USA is interested in engaging on S2S forecast pilots; (iii) In Australia, the agriculture sector is most exposed to climate and weather, hence most likely to engage/collaborate with research and development - other sectors that have a large sensitivity to climate that may be interested in engaging in service development include construction, transport, energy, water, oil and gas, mining; and (v) Opportunities exist to further examine, develop, and demonstrate S2S applications within Metrolinx, a large regional transit agency serving the Greater Toronto and Hamilton Areas in Ontario, Canada.

3. PROPOSAL FOR S2S PHASE II (NOVEMBER 2018–DECEMBER 2023)

A set of core activities is proposed to make maximum progress in filling the identified upstream and downstream gaps:

- S2S database enhancement
- Research activities (new sub-projects)
- Enhancing operational infrastructure and user applications

3.1 S2S Database enhancement

Work will continue to maintain and update the current S2S database at ECMWF, CMA and IRI. The S2S database will be enhanced in Phase II to improve the service to the users and address their main complaints in a S2S database survey which was done by ECMWF (see section 1.1. in the progress report). In particular, the speed of downloading the data should be improved thanks to the recent opening of the IRI Data Library, which should reduce the pressure on the ECMWF data server and also by the availability from the IRI data library of derived S2S products to save time and efforts to a large range of users. These new products will include model ensemble means and model climatology. It is also planned to create a verification and products interactive map rooms using IRI Data Library, contingent on resourcing.

Enhancements to the database will include the availability of more surface variables four times a day instead of only once a day (in particular the availability of 10-metre wind four times a day will be particularly useful for energy applications). Increasing spatial resolution will also be considered. Ocean variables which were listed in the original plans of the S2S project (S2S Implementation Plan) will be added to the S2S database. Finally, additional models, such as the extended-range forecasts from the Indian Meteorological Department, will be added to the database.

3.2 Research activities (sub-projects)

The new research sub-projects will address issues related to sources of predictability, forecast system configuration, and model development. These new sub-projects will be more oriented towards model experimentation than the Phase I sub-projects which were more about model assessment. Some of the new sub-project research plans will include coordinated experiments and also process studies in coordination with the Working Group on Numerical Experimentation (WGNE).

3.2.1 MJO prediction and teleconnections

This proposed research activity builds on the progress of the MJO sub-project and teleconnections sub-projects in Phase I. During Phase I much of the MJO research associated with the S2S sub-projects focused on the predictive skill for the MJO (e.g. Vitart, 2017), including: the relationship between predictive skill and model biases (e.g. Kim, 2017; Lim et al., 2017); and changes in basic state associated with the MJO (e.g. Marshall et al., 2016).

Whilst it is expected that much of this research activity will continue, within Phase II we propose two new foci for activity to be promoted within the S2S project, and in collaboration with the WGNE MJO Task Force, described below.

i) The relationship between the MJO and high-impact weather in the tropics/subtropics and the potential for predictive skill for these events at 2 weeks to 2 months lead time.

A number of studies have identified the relationship between the MJO and high-impact weather throughout the tropics (e.g. Jones et al., 2004; Chang et al., 2005; Xavier et al., 2014; Sossa et al., 2017), however little research has been carried out to evaluate the ability of operational S2S models to capture these relationships between the MJO and high-impact weather, or the implications for sub-seasonal predictive skill for these events. The S2S project will promote research to address the following related questions:

- How well do operational S2S models capture the observed relationship between the MJO and high-impact weather events?
- Does the relationship between the MJO and high-impact weather events lead to enhanced predictive skill for these events for particular phases of the MJO or whilst there is strong MJO activity?
- Can errors in the representation of the relationship between high-impact weather and the MJO be attributed to: e.g. errors in the model basic state; errors in the modulation of the large-scale environmental conditions associated with the MJO; and/or errors in the response of physical parametrizations to the MJO modulation of the environment?
- How well do S2S models capture tropical moisture exports, potential vorticity streamers, and their interactions, associated with extreme rainfall events in the tropics and subtropics?

This activity will benefit from links developed within the international community through e.g. the S2S Africa sub-project; the Years of Maritime Continent; and the WWRP High Impact Weather Project.

ii) Tropical-extratropical teleconnections associated with the MJO and the potential for extratropical predictive skill associated with the MJO.

The statistical relationship between the MJO and extratropical circulation patterns is well established (e.g. Matthews et al., 2004; Cassou et al., 2008; Mori and Watanabe, 2008). This relationship provides enormous potential for sub-seasonal predictive skill for the extratropical circulation and associated weather. Realizing this potential predictability requires a faithful simulation of these teleconnections by operational prediction models. For example, Vitart (2014) showed that prior to 2007 the ECMWF forecast monthly forecast system had lower predictive skill for the NAO when the MJO was active in the initial conditions than without an active MJO, likely because of the model’s loss of MJO amplitude. Following improvements in the model the ECMWF forecast skill has improved skill of the NAO when the MJO is active, realizing some of that potential predictability. However, S2S models still underestimate the strength of the extratropical response to the MJO (Vitart et al., 2017) which can impact on their skill for the weather variables (e.g. temperature and precipitation). Furthermore, a number of studies have identified the dependence of the MJO-extratropical teleconnections on both the propagation characteristics of individual MJO events (e.g. Yadav and Strauss, 2017); and the slowly varying basic state (e.g. Roundy et al., 2010). This research activity will address the following research questions which relate both to the observed MJO teleconnections to the extratropics and the predictive skill of operational S2S models.

- How does the teleconnection depend on the horizontal, vertical and temporal structure of the diabatic heating anomalies associated with the MJO?
- How do variations in the slowly varying background state effect the Rossby wave source and the subsequent Rossby wave propagation from the source region?
- How does the tropical circulation respond to the Rossby wave forcing from the extratropics?
- How does the tropical circulation, most especially the MJO, respond to forcing from the extra-tropical circulation (e.g. NAO).

This activity will benefit from links developed with the Year of Tropical –Mid-latitude Interactions, Teleconnections sub-project, and the Working Group on Subseasonal to Interdecadal Prediction (WGSIP) Initiative Interaction/Teleconnection between tropics and extratropics.

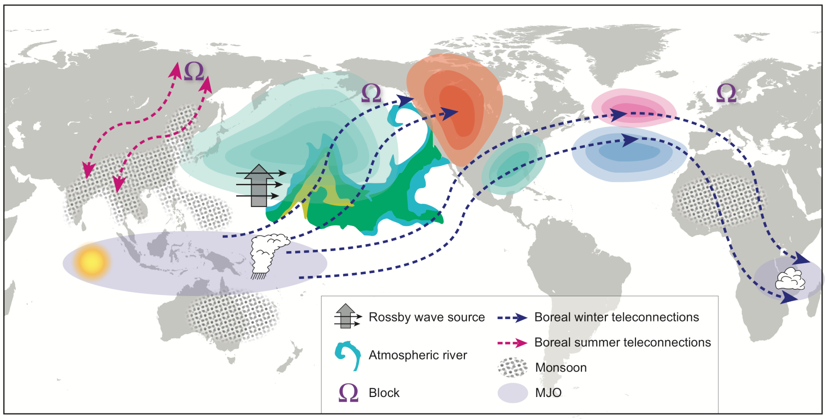

Figure 1. Atmospheric teleconnection in the northern hemisphere associated with the MJO diabatic heating, which favour the development of Rossby wave sources a from which Rossby waves can propagate into the mid-latitudes and interact with the circulation anomalies there. Under certain conditions these circulation anomalies of the mid-latitudes can feed back onto the subsequent evolution of the convective activity of the tropics (i.e. new MJO phases and breaks in the Indian summer monsoon precipitation).

Source: From Stan et al. (2017)

3.2.2 Land initialization and configuration

Land initialization and configuration (includes soil moisture, snow cover and depth, and possibly vegetation states). Land surface states affect surface heat, moisture and radiative fluxes to the atmosphere, and can have a great impact on the evolution of the diurnal cycle, which then affects longer timescales. Because land states evolve slowly compared to the state of the free atmosphere, they can provide a source of predictability on timescales extending from a few days to several weeks (Figure 2). For such potential predictability to be realized as improved prediction skill, models of land and atmosphere must properly represent the coupled processes that determine feedbacks between the two components, and forecasts need to be initialized with accurate, representative land surface states.

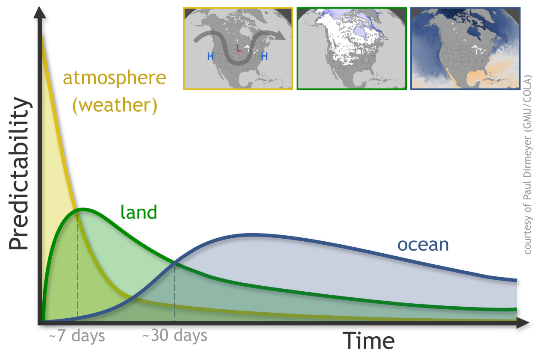

Figure 2. Impact of atmosphere, land and ocean on predictability as a function of lead time. This figure suggests that land is likely to play an important role for sub-seasonal prediction.

Source: https://www.climate.gov/sites/default/files/Fig1-Initial-State-Of-AtmosphereV12_1240.png

Proposed studies

This sub-project will work in coordination with the Global Energy and Water Exchange/Global Land Atmosphere System Study (GEWEX/GLASS), Data Assimilation and Observing Systems (DAOS), EartH2Observe and WGSIP SNOWGLACE to both investigate the fidelity of model representations of land-atmosphere interactions, and how S2S forecasts may be improved by taking better advantage of the information contained in land surface states. Several questions will be addressed in this sub-project:

- What is the impact of the observing system on land initialization and S2S forecasts?
- How well are the coupled land/atmosphere processes represented in S2S models?
- How might anomalies in land surface states contribute to extremes?

Investigation of the diurnal cycle would require at a minimum 6-hourly (and ideally 1-3 hourly) S2S model output for selected near-surface fluxes, states and 2-D atmospheric fields (e.g. PBL depth), but could greatly aid the identification of problems in forecast models and inform model development.

The possibility exists for setting up coordinated modelling experiments to investigate such questions with carefully-designed sensitivity studies, leveraging expertise gained by modelling efforts in GEWEX/GLASS and WGSIP. EartH2Observe has developed a multi-model land surface hydrologic analysis (Schellekens et al., 2017) that can serve as a validation dataset, or even a source of initialization fields for surface hydrologic variables provided the proper precautions are taken (cf. Koster et al., 2009). There are also current and planned field campaigns (e.g. LAFE, HyMex, RELAMPAGO, and a possible new North American water-related regional hydroclimate project in GEWEX) that could greatly inform model evaluation. The Local-Coupled modeling (LoCo) effort in GEWEX/GLASS has developed a number of metrics to assess coupled land-atmosphere behaviour in nature and models that can be brought to bear. Efforts to operationalize true assimilation of land-surface data have begun with snow cover and are extending to snow mass and soil moisture, with particular emphasis on remote sensing data streams. Vegetation properties attainable in real time from satellite are the next target (including leaf area index, greenness and other multi-spectral quantities) because they affect surface water, energy, momentum and carbon budgets as well as aerosols.

3.2.3 Ocean and sea ice initialization and configuration

Sub-seasonal to seasonal prediction is now routinely performed with coupled models because coupling of the atmosphere to the ocean is thought to become important for lead times longer than two weeks, contributing, for example to predictability of monsoon variations (e.g. Hendon et al., 2012) and the MJO (e.g. Woolnough et al., 2007). Sub-seasonal prediction of regional SST variations, marine heat waves, and variations in near-surface currents is also of direct interest for a wide range of activities and enterprises including, management of fisheries, offshore mining activities, ocean transportation, and anticipating coastal impacts resulting from wave activity and inundation. Sea ice is also considered as part of the coupled ocean system. Sub-seasonal prediction of sea ice has wide potential application as well but its potential has not yet been widely investigated.

This sub-project will work in coordination with WGSIP, DAOS, and PDEF (Predictability, Dynamics, Ensemble Forecasting) Working Groups to promote improved sub-seasonal predictions though improved initialization of the ocean-sea ice state and depiction of key ocean and sea-ice processes that provide predictability at sub-seasonal timescales. The project will also promote improved understanding and prediction of sub-seasonal variations of the ocean and sea ice, including marine heat waves and sea-ice extremes.

Proposed studies

(1) What are the ocean-atmosphere coupled processes that directly drive/influence sub-seasonal variability and how well are these processes depicted in S2S models? What role does ocean model resolution play? As well as assessing hindcast output, some coordinated case study hindcasts can be developed that will provide ocean model output with sufficient temporal and spatial resolution in order to assess how well key processes are depicted such as the diurnal cycle of the mixed layer in the warm pool which is thought to play a key role in evolution of the MJO. An example from Shinoda et al. (2013) of the diurnal cycle of SST in the equatorial Indian Ocean during supressed phase of the MJO is shown in Figure 3. The COAMPS model used in

this example has 0.5 m vertical resolution in the mixed layer and so well represents the strong diurnal variations in the suppressed phase. Assessing the depiction and prediction of this kind of variability across the full range of S2S models will provide insight into the resolution required to enhance forecast skill of the MJO.

(2) What aspects of the ocean initial state provide predictability for sub-seasonal to seasonal timescales? This activity will encompass intercomparison of ocean initial states so to provide insight into current capability to capture key oceanic features that are providing predictability. The role of model ocean mean-state drift and its impact on depiction and prediction of sub-seasonal variability also should be addressed in order to guide forecast system development

(3) What are the mechanisms and predictability of sub-seasonal marine variability, especially focusing on near–surface variations, ocean fronts, upwelling, and extreme events, such as ocean heat waves, that are relevant of fisheries and coral bleaching? The impact of ocean model resolution for depiction of these events should be addressed in order to guide forecast system development. Case study prediction of some key marine heat wave events that, for instance, resulted in the recent bleaching of the Great Barrier Reef, should be coordinated across several modelling centres in order to assess current capability and to highlight key deficiencies that are acting to limit predictive skill.

(4) What is the current capability to make sub-seasonal prediction of sea ice, which can be assessed with the S2S hindcast datasets? What is the sensitivity of forecast skill and predictability to initial state? What are the key processes driving sub-seasonal variations of sea ice and how are these key processes represented in the S2S models?

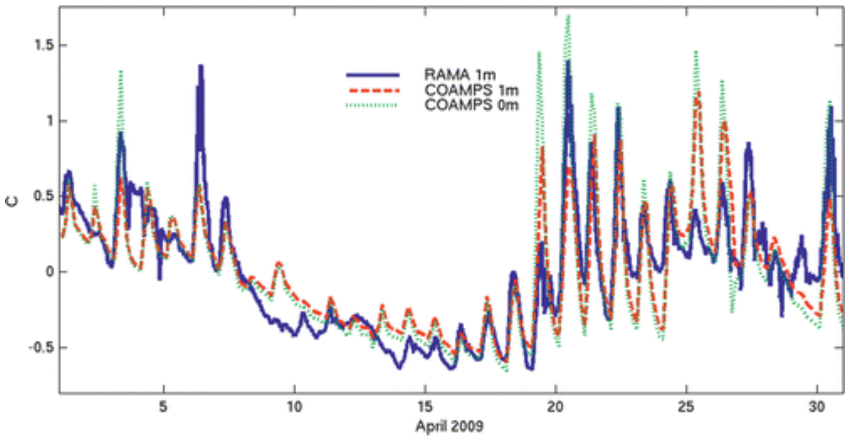

Figure 3. Observed and simulated near surface temperature variation in the equatorial Indian Ocean during transition from the convective (5-18 April) to the suppressed (20-30 April) phase of the MJO (from Shinoda et al., 2013). The COAMPS model has .5 m resolution in mixed layer and can well depict the diurnal variation of SST during suppressed phase of the MJO.

3.2.4 Ensemble generation

For predictions on all timescales, initial perturbations among an ensemble (representing our estimates of uncertainty in observing different components of the Earth System) grow with lead time and provide an estimate of uncertainty in forecast outcomes. For reliable forecasts, the forecast uncertainty needs to be representative of observed outcomes. In practice, however, it is generally agreed that ensemble prediction systems (EPSs) on S2S timescale do not have enough spread among ensemble members, and consequently, are overconfident (see example in Figure 4). Therefore, efforts need to be made to improve the representation of uncertainty in initial conditions (using methods such as singular vector, bred vector, lagged averaging) or to develop methods (such as stochastic parameterization) to enhance spread during model integration.

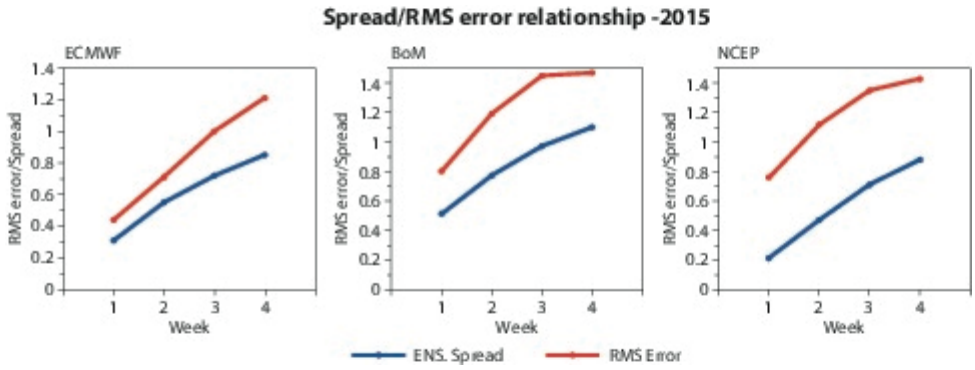

Figure 4. Evolution of MJO ensemble spread (blue lines) and Root mean square Error (RMSE) (red lines) as a function of lead time (in weeks) for the all the ECMWF (left panel), BoM (middle panel) and NCEP (right panel) real-time ensemble forecasts produced in2015. The RMSE has been calculated using ERA Interim.

Although operational sub-seasonal EPSs are based on our current state of knowledge, the influence of initialization and ensemble configuration on a sub-seasonal timescale is neither well understood nor well researched. As one of the foci for the next phase of the S2S project, research on the ensemble generation techniques need to engage in addressing following challenges:

- Optimal initial-perturbation strategies for the sub-seasonal timescale have not been systematically studied.
- In the sub-seasonal timescale, the many models suffer from over-confident predictions. The reason for the discrepancy between the observed and forecast spread may be result from both random and systematic errors, in contrast to short-range predictions in which the random error is dominant; the relative importance of the different causes is not well understood.
- For certain regimes (e.g. MJO, tropical cyclone), there might be skill improvement from initial perturbations of the ocean in addition to the atmospheric perturbations, however, the coupled initialization techniques are in their infancy and have not been fully researched.
- While stochastic parameterizations schemes have the potential to improve forecast performance, little research on their impact on this timescale has been conducted.

With this in mind, and with the availability of the S2S database and the possibility of additional coordinated forecast experiments, we propose tackle the above-mentioned challenges. The research agenda will be developed in close collaboration with the PDEF Working Group and WGNE.

Proposed studies

(1) Study the influence of forecast configuration strategies, including initialization strategies used in the current generation of S2S prediction systems (burst and lagged ensemble) on the forecast spread.
(2) Benchmark the spread-error relationship in the current generation of S2S prediction systems.
(3) Explore the impacts of coupled initial perturbations on the sub-seasonal prediction, and develop techniques of coupled initial perturbations.
(4) Investigate the impact of stochastic parameterizations for the sub-seasonal prediction.

3.2.5 Atmospheric composition

It is widely recognized that both natural and anthropogenic aerosols are crucial in the radiative balance and that the direct effect in cloud-free regions can be substantial and impact variables such as surface temperature and winds (e.g. Yu et al., 2006; Bellouin et al., 2005). The aerosol direct effect consists of the sum of two phenomena: scattering/absorption of incoming solar radiation and absorption/emission of long-wave radiation. Aerosols also serve as cloud condensation nuclei and affect cloud properties such as the cloud life cycle, the optical properties and the precipitation activity of clouds (indirect effect). Aerosol particles also impact air quality and represent a serious public health issue, as shown by recent particulate matter (PM) pollution events in western Europe and China (Wang 2014; Sun 2014).

The role of aerosols in the Earth's radiation balance has been investigated by the climate modelling community since the early 1990s (e.g. Crutzen, 1990; Coakley, 1992; Hansen, 1992). However, in Numerical Weather Prediction, state-of-the-art operational models are still using climatology which can describe the average effect of aerosols on the radiative balance. This is due to the fact that there has been so far no definite proof that sophisticated aerosol schemes are needed and the cost of running a full integrated aerosol system at the high resolution of current NWP systems is considered at the moment prohibitive. In order to assess the impact of prognostics aerosols on NWP forecasts, the Working Group on Numerical Experimentation (WGNE) coordinated a set of experiments. Results (Remy et al., 2015) showed that the impact of the dust aerosols on surface temperature and winds was noticeable, even though the synoptic situation was not much affected by the radiative forcing of the prognostic aerosols. Similar conclusions were also reached by (Colarco, 2014).

As for NWP, all the operational S2S models contributing to the S2S database use climatological aerosols. However, recent studies suggest a strong modulation of aerosols by the Madden Julian Oscillation which is a major source of predictability in the tropics at the sub-seasonal to seasonal time range (e.g. Figure 5) and that the MJO-related intra-seasonal variance accounts for about 25% of the total AOT variance over the tropical Atlantic (Tian et al., 2011) primarily through its influence on the Atlantic low-level zonal winds (Figure 6). Guo et al. (2013)

indicated that dust in this region is strongly influenced by the MJO-modulated trade wind and precipitation anomalies, with anomalies lasting as long as one MJO phase, whereas smoke is less affected.

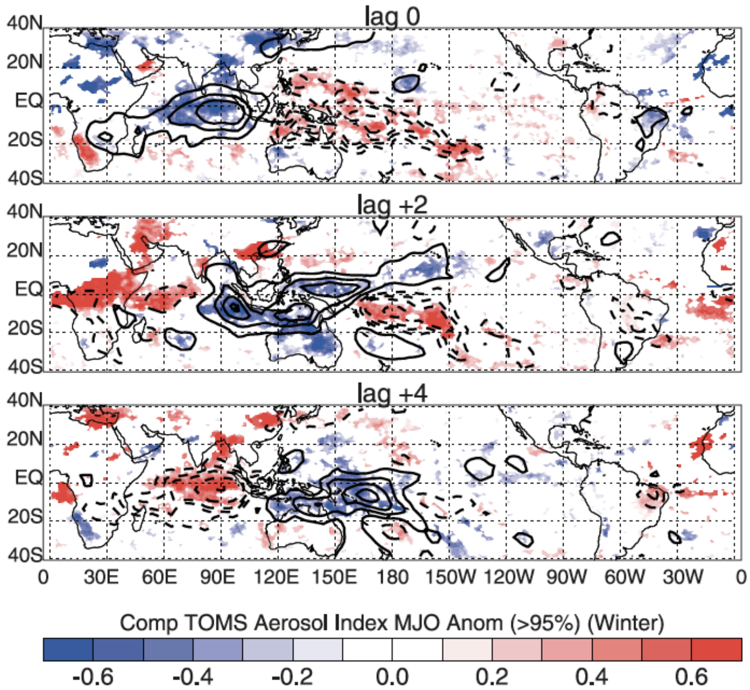

Figure 5. Composite maps of the TOMS Aerosol Index anomalies (colour shading) associated with the MJO indicated by the CMAP rainfall anomalies (contours). TOMS AI anomalies are only plotted if they exceed 95% confidence limit using a Student's t-test. Lags are in pentads. Note that the correlation between precipitation and TOMS AI tends to be negative. A similar diagram using MODIS Aerosol Optical Thickness (AOT) shows a weak positive correlation. See Tian et al. (2008) for discussion.

These studies suggest that the MJO can represent an important source of predictability for aerosols at the sub-seasonal to seasonal timescale which is not represented in current operational S2S systems which make use of climatological aerosols. This impact of the MJO on the aerosol distribution is likely to feed back on the atmospheric circulation. The use of climatological aerosols instead of prognostic aerosols may be an important gap in S2S forecasting system. Besides the potential feedbacks of natural and anthropogenic aerosols on the atmospheric dynamics and the skill of the forecast on sub-seasonal scales, aerosols often have serious impacts on air quality and human health. Skilful S2S forecasts of air quality could be of great socioeconomic benefit, e.g. over SE Asia associated with forest fires, in the meningitis belt of the Sahel, and South Asian cities.

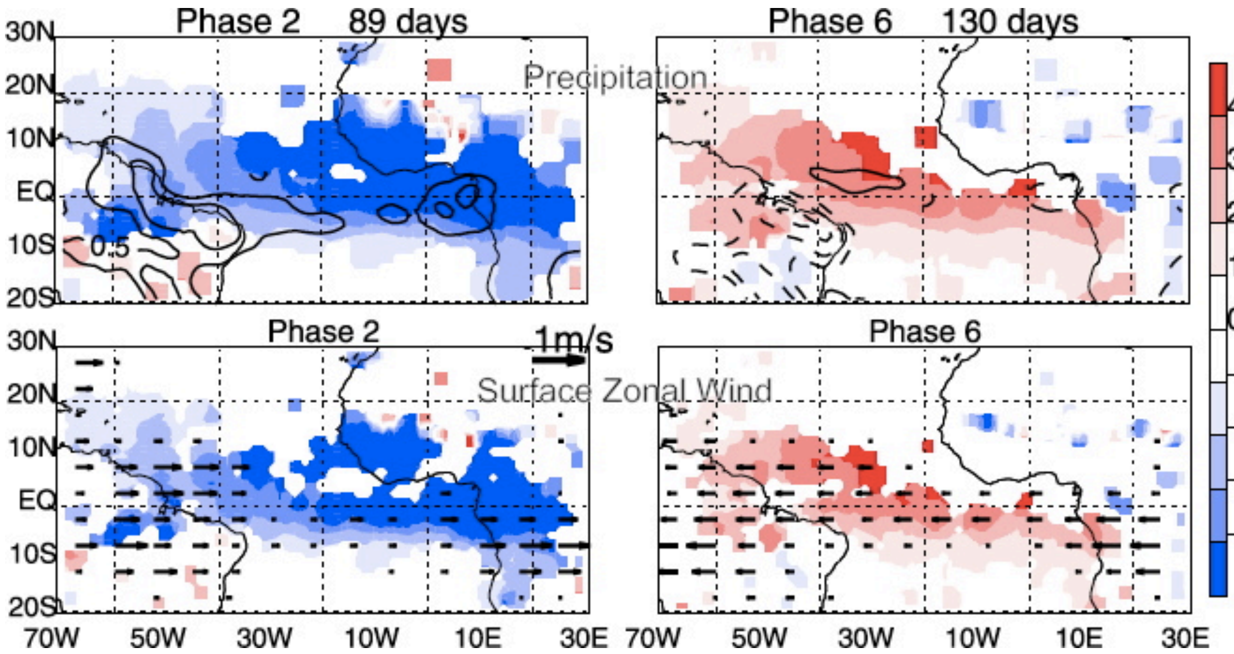

Figure 6. (Upper 2 panels) Composite maps of boreal winter MJO-related MODIS AOT anomalies (multiplied by 100) (coloured areas) and TRMM 3B42 precipitation anomalies (mm day -1) (contours) over the tropical Atlantic region for MJO phases 2 and 6 as defined in Tian et al. (2011). Only AOT anomalies above a 90% confidence limit are shown. Solid contours indicate positive precipitation anomalies, while dashed contours indicate negative precipitation anomalies at a 0.5 mm day^{-1} interval. (Lower 2 panels), same except for NCEP/NCAR low-level (averaged from 925 hPa to 700 hPa) zonal wind anomalies (m s^{-1}).

Proposed studies

The main goal of this sub-project will be to assess the benefits of using prognostic aerosols rather than the climatology used in the current operational S2S models. The main scientific questions which will be addressed include:

(1) What is the impact of prognostic (vs climatologically specified) aerosol loading in the atmosphere on S2S forecasts via its effects on radiation?

This will include assessing the impact of prognostic aerosols on model systematic errors and on model probabilistic forecast skill scores. This would build on the case study coordinated by WGNE (see description in the previous section), although the approach here could be more systematic than case studies.

(2) What level of complexity is needed?

As mentioned above, the cost of current aerosol models, which include often dozens of species is prohibitive. For instance, at ECMWF, the inclusion of a prognostic aerosols scheme with only 8 species would increase the cost of the S2S forecasts by about 50%. Therefore, it would be important to determine which species play the most important role at the S2S timescale and which ones can be neglected. This would help design more affordable aerosol models for S2S forecasts. This would also include assessing the number of source regions and scavenging mechanisms needed in the simulation.

(3) What is the predictability of aerosols (e.g. dust) at the S2S timescale, and what would be the value of these forecasts for applications?

This study will include assessing the ability of S2S models to simulate the modulation of aerosols by the MJO and other sources of sub-seasonal to seasonal predictability. A main motivation of this sub-project is to assess the impact of prognostic aerosols on the S2S forecasts, but the sub-seasonal to seasonal prediction of the aerosol concentration itself can represent a very valuable source of information for applications such as meningitis and air quality. This study would link with the WMO SDS-WAS, which has performed a similar study but for short and medium-range forecasting. It would also link with groups running off-line aerosol transport models, to explore using forecast/re-forecast data in the S2S database to drive these models off-line. These models typically need high-resolution 6-hourly fields, but downscaling approaches may be feasible.

This sub-project will explore the possibility of performing coordinated experiments to address the above questions. In these experiments, the full scope of an "active" simulation would include:

- Generation of aerosol abundance in the atmosphere from source regions (e.g. wind blowing over deserts, sea salt - more from storm regions)
- Precipitation scavenging and general gravitation fall out
- Advection in between the above two
- And then its impact is only on radiation

Currently few operational and research centres are currently able to produce S2S simulations with "active aerosols" (defined here as prognostics aerosol loading for the purpose of radiation impacts - not cloud-aerosol interactions). A first step would to contact the centres who participated to the WGNE case study experiment to assess if it is possible to use these models for extended-range forecast experiments.

3.2.6 Stratosphere

Sub-seasonal to seasonal (S2S) predictability derives from climate processes that evolve on timescales of weeks to months. S2S predictive skill derives from forecast models faithfully simulating and predicting these processes. Stratospheric variability impacts the troposphere on approximately these timescales, making the stratosphere a potentially important source of S2S prediction skill (NAS, 2016; NRC, 2010). The S2S Prediction Project (Vitart et al., 2017) seeks to promote and improve S2S predictions by identifying sources of predictability and understanding systematic model errors that are acting to limit forecast skill. Given the observed impact of the stratosphere on the troposphere, creating a sub-project focused on the stratosphere would be valuable.

In collaboration with S2S during Phase I, the Stratospheric Network for the Assessment of Predictability (SNAP), which is a WCRP/SPARC initiative, focused on the predictability of extreme stratospheric polar variability, especially stratospheric sudden warmings (SSW), and the coupling to the troposphere (Tripathi et al., 2015). Predictability of SSW was demonstrated into the sub-seasonal range but stratospheric model biases and predictability of tropospheric planetary wave were found to limit predictive skill of SSW. In order to fully tap into the predictability that the stratosphere may provide for the troposphere in the sub-seasonal range and several key questions need to be addressed:

- *Quantification and understanding of coupling*. What are the mechanisms of vertical coupling that act to promote tropospheric variability at S2S timescales (both in polar regions and in tropics)? How well are these mechanisms depicted in S2S models? What is their contribution to predictability of the troposphere at S2S timescales? What is the role of model resolution?
- *Model biases*. What are key systematic errors in the stratosphere in the S2S models and where are these common across the ensemble? How do model biases impact coupling to the troposphere? How are they acting to limit predictive skill?
- *Initial conditions and ensemble generation*. What is the quality of the stratospheric initial conditions in S2S models and how is it impacting S2S skill?
- *Whole atmosphere diagnostics*. What additional data output is required in order to better diagnose the stratosphere and its impact on the troposphere in the S2S models?

The Stratospheric Network for the Assessment of Predictability (SNAP) is a WCRP/SPARC initiative which seeks to understand the role of the stratosphere in tropospheric predictability. In its first phase, SNAP used targeted model simulations to investigate the predictability of the stratosphere on sub-seasonal timescales (Tripathi et al., 2015). The second and current phase of SNAP is focused on evaluating model ensemble forecasts from the S2S project to better determine the role of stratospheric processes on improving tropospheric forecasting skill. A sub-project focused on the stratosphere would therefore strengthen the link between S2S and SNAP, and promote research and collaboration between these two groups.

SNAP is already working to coalesce S2S projects focusing on the role of the stratosphere in an overview paper led by Ms Daniela Domeisen. There are 13 research projects from 20 researchers around the world focused on various aspects of both upward and downward coupling between the troposphere and stratosphere. Each project uses S2S output to evaluate topics such as the role of the Quasi-Biennial Oscillation on Madden-Julian Oscillation predictability, the predictability of surface climate following stratospheric final warming events, or the role of weak or strong polar vortex events in tropospheric predictability. While many of the projects will also produce individual publications, the SNAP S2S paper will provide a broad overview on how both the tropical and extratropical stratosphere may contribute to prediction skill in the S2S models.

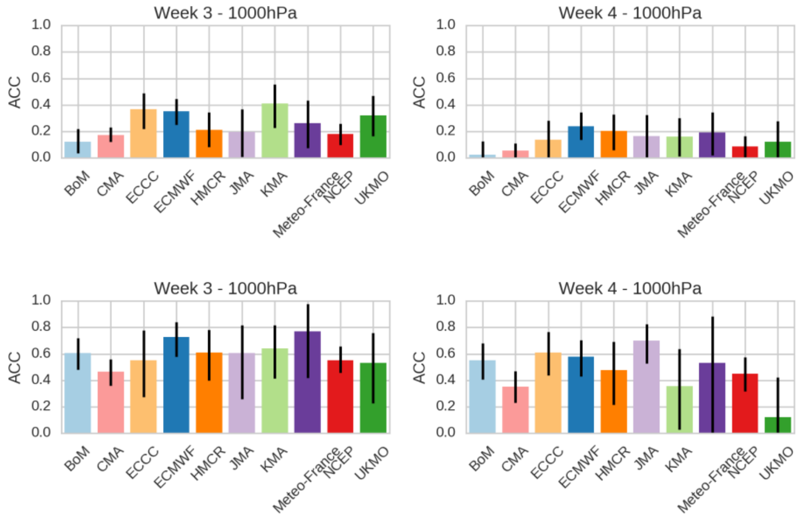

Figure 7. Anomaly Correlation Coefficient for NAM1000 at week 3 or week 4 lead time following (top row) neutral stratospheric vortex or (bottom row) weak stratospheric vortex conditions. Here the state of vortex is based on NAM100.

For example, Figure 7 shows the prediction skill of the 1000 hPa Northern Annular Mode for week 3 or week 4 in the S2S models, for either neutral stratospheric vortex conditions (top row), or weak vortex conditions (bottom row). It is clear that for most models, skill is higher following weak vortex conditions. Similar results are found following strong vortex conditions. In other words, extremes in the polar stratosphere can improve tropospheric winter climate prediction, during weeks notoriously difficult to skilfully predict. The figure also highlights that there is considerable difference in the size of this gain in skill between the models and a clear priority of the SNAP work will be to quantify and understand the origin of these differences.

Proposed studies

- Continue and complete initial community paper on stratosphere-troposphere coupling in S2S models.
- Collaboration with the SPARC Data Assimilation Working Group, the WWRP Probability, Dynamics and Ensemble Forecasting (PDEF) group, and the S2S Teleconnections Project on this topic.
- Develop proposed set of diagnostic output/additional levels for the stratosphere and stratosphere-troposphere coupling which would help further analysis of S2S models through a community survey.
- A session at the forthcoming SPARC General Assembly (September 2018) which focuses on the impact of the stratosphere on predictability on the S2S timescale.
- A community meeting at the SPARC General Assembly (September 2018) to solicit ideas for additional S2S experiments that could yield insight into the questions posed above. One possible line of experiments might look at nudged model runs similar to those used by Hitchcock and Simpson (2014).

3.3 Enhancing operational infrastructures and user applications

One of the overarching goals of the S2S project is to promote the uptake of S2S forecasts by operational centres and by the applications communities and end users. The major component of the Phase II will be devoted to this goal, recognizing that, while much progress has been made, there is much to be done in order to translate improved understanding of predictability and prediction skill into useful forecast information. Two sub-projects will be developed, the first addressing specific research-to-operations needs, and the second directed toward fostering uptake of S2S forecasts in applications more generally.

3.3.1 Research to Operations (R2O) and S2S forecast and verification products development

The operational global producing centres have been the backbone of S2S, and the transition of S2S research efforts and developments to operations will be a fundamental aspect to be addressed in the second phase of the S2S project. Such transition will require efforts in two important aspects:

(a) Pursue research for testing and developing methodologies for calibration, multi-model combination, verification and generation of forecast products.

(b) Coordination with the relevant WMO technical commissions to define the standards and protocols for operational implementation and exchange of S2S forecasts such that by the end of the Phase II of the S2S, the infrastructure related to the data exchange to support research can be transitioned into the operational domain. Such coordination will be done through the Inter-Programme Expert Team on Operational Predictions from Sub-seasonal to Longer time Scales (IPET-OPSLS). The goal will be to finalize the transition by the end of Phase II of S2S so that the WMO Lead Centre for Long-Range Forecast Multi-Model Ensemble (LC-LRFMME) can obtain the S2S forecasts directly from the WMO GPCs and develop the capability for delivering S2S forecasts and re-forecasts, independently of the S2S research database developed in Phase I of the S2S project. This data exchange is envisioned to follow the paradigm of what is currently done for the seasonal forecast exchange among GPCs.

Proposed activities

This sub-project would work in coordination with IPET-OPSLS and the Joint Working Group on Forecast Verification Research (JWGFVR), on the following proposed activities:

- Promote the development and intercomparison of different methodologies for forecast calibration, multi-model combination, verification, and forecast formats (e.g. probability of threshold exceedance). This will build on the work of the current (Phase I) S2S Verification and Products sub-project. The use of artificial intelligence and machine learning techniques for model post-processing and downscaling will be promoted.

- Make recommendations for operational centres to harmonize their real time and re-forecast set-ups to facilitate S2S forecast calibration, multi-model combination and verification. Great progress has been made in S2S Phase I to harmonize the S2S real-time forecasts issued by the 11 S2S partners. All of them issue now a real-time forecast every Thursday. However, there is still no convergence between the partners on how to produce re-forecasts. The re-forecasts in the S2S database are following very different protocols, which makes model intercomparison and multi-model combination very challenging. A key outcome of this activity will be to propose a protocol for S2S re-forecasts. The NOAA SubX project which is already using a common re-forecast set-up, will be an important resource to help define this protocol.
- Work with IPET-OPSLS to: (a) develop standards to define criteria for the designation of GPCs for S2S Predictions; and (b) establish standards for data exchange and delivery of S2S hindcasts and real-time forecasts to the WMO LC-LRFMME in support of the objectives of the Global Framework for Climate Services (GFSC), Regional Climate Centres (RCCs), National Meteorological and Hydrological Services (NMHSs) and Severe Weather Forecast Demonstration Projects (SWFDPs). The envisioned deliverables will be the formalization of the designation criteria and data exchange standards in the WMO (Global Data Processing and Forecasting System) GDPFS manual.

3.3.2 Real-time pilot for S2S applications research and demonstrations "S2S-SERA"

Significant progress has been made in seasonal forecasting to provide skilful and actionable forecasts which are also responsible: each current and new forecast product needs to be accompanied by verification statistics that clearly demonstrate the attributes of the forecast required by the specific user or sector. We also need to demonstrate potential usefulness of the forecasts over a recent period during extreme weather/climate anomalies were observed. In addition to progress in seasonal forecasting, applications model development has also taken place, providing strong evidence that commodities such as dry-land crops as well as flows in major river systems, and conditions conducive to severe weather development, are predictable on a seasonal timescale. These progress and experiences in seasonal forecasting activities can benefit S2S plans and objectives. This pilot project aims to demonstrate the social and economic value and other benefits in S2S forecasts through real-time production of forecasts, including tailored forecasts. Such forecasts can be developed for certain user groups such as those involved with derivative trading in the commodity market, the energy and humanitarian sectors, agriculturalists, reservoir managers, and marine ecosystem managers.

Tailored forecasting should be used as a platform for integrated fundamental and applied research. Some tailored forecasts on seasonal timescales have already been used to build links between climate model output and climate related variables such as river flows and dry-land crop yields. For example, Figure 8 shows an example of predicting seasonal flows into Lake Kariba (on the border between Zimbabwe and Zambia); similar models could be developed for monthly values since monthly observed data are available, but weekly flows typical of the standard S2S timescale may require a different approach.

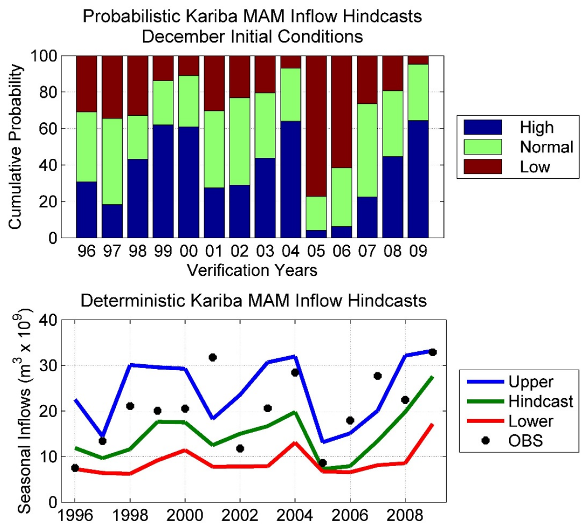

Figure 8. Forecasts of Lake Kariba inflow, using a statistical link between predicted low-level atmospheric circulation and observed inflows.

Hydroelectricity production might support irrigation, but also reduce water availability for irrigated food production. It is therefore important to produce skilful S2S forecasts of inflows, lake levels and risks involved with letting water out for downstream management and use. There is a need to identify and find additional time series of commodities related to S2S and seasonal-to-interannual climate variations such as livestock numbers and production, food prices following extreme events, and other high value agricultural commodities such as horticultural products. In addition to land-based tailored products, we can also aim to develop application models for the oceanic community, i.e. for large marine ecosystems such as the Benguela Current Large Marine Ecosystem.

While seasonal forecasts in the tropics have had a strong focus on rainfall, S2S temperature forecasts, which are often found to be more skilful, may have great benefit, including benefits for areas prone to flash floods as a result of snowmelts. Temperature forecasts should also be able to provide useful information on heat waves and their duration. Additional sectors affected by temperature changes need to be identified.

Promoting the uptake of S2S forecasts to help inform socio-economic decision-making is a complex and multifaceted task, yet critical, task if S2S forecasts are to be of value to society. The decision-making situations that S2S forecasts can inform are various, but some examples include civil protection or humanitarian aid agencies preparing for a high-impact weather event, or improved agricultural production or reservoir management. Real-world demonstrations are needed to spur broader uptake, and it is well accepted that these must be developed through research partnerships between forecast producers and users. The interviews carried out by the WWRP SERA Working Group found a high degree of interest in the potential use of skilful S2S forecasts. However, several barriers to their uptake were identified, including insufficient forecast skill, lack of post-processing to the decision-making context, lack of forecast verification, and challenges in interpretation of probabilities and communicating forecast uncertainty. Several areas for research and development were identified, including forecast accuracy/calibration/verification, developing flexible and adaptable services: e.g. can be tailored to user defined thresholds of interest, and/or that can be easily analysed/integrated with non-meteorological data, and providing data in accessible formats that can easily be added into apps/integrated with other information/added to decision support tools.

Proposed activities

A real-time pilot sub-project is proposed in order to further address this stakeholder feedback (several aspects are addressed by the R2O proposed sub-project). To be credible with stakeholders, .the proposed pilot recognizes that demonstrations of forecast applications need to include issuing forecasts in real time, in addition to assessments over a hindcast period and previous events. This sub-project - dubbed "S2S-SERA"—will build upon the stakeholder survey carried out by SERA, to co-develop a set of demonstration projects in partnership with users spanning the GFCS priority areas, representing both developing and developed countries. This activity will catalyze research on demonstrating S2S forecast value by making the near-real-time forecasts available only for a limited period of time, e.g. 2019-2020, emphasizing a concerted preparation phase beforehand. It could be designed to overlap with other "Years of" programmes, and coordinated activities (e.g. a competition) could be organized.

It is recognized that the simple provision of real-time data will not be sufficient to promote user uptake of S2S forecast information. Co-developed applications often produce bespoke tools and services, which address the needs of specific users. There is insufficient time and resources to implement products for all users who could potentially benefit from S2S forecast information. Therefore, the real-time pilot will aim to work with existing partners and projects identified through the SERA-led stakeholder interview work and the S2S steering group. The real-time pilot will then look to determine how to make S2S forecast information usable, by working with selected/interested users, and establish guiding principles that could be picked up and used by NMHS's who wish to pull through S2S research into operational products now and in the future. Through preparative work with the selected users, we will identify what is required in order to make the forecast data usable and how this varies between users in different sectors, different organizations within a sector and organizations with different levels of weather and climate data experience. For instance, would certain users prefer raw forecast information? Do they have capacity to do their own analysis of the information? Do they require a product/tool to translate the forecast information into something usable? How would they want to engage with the information? How should uncertainty, skill and reliability be described/integrated? Once the data is available in real time, user engagement will be essential. This continued engagement will assess how the available data is used and whether it is useful, meets user requirements and has led to positive changes in the way decisions are made.

The S2S database was designed at the beginning of the S2S project. Because S2S data is a commercial product for some of the operational centres participating to the S2S project, it was agreed to make the S2S real-time data available with a delay of 3 weeks. This decision was also supported by the fact that it is a research and not an operational database. However, it is planned to revisit this decision at the beginning of Phase II and propose to reduce this delay by a week or 2, pending the approval of all the centres participating to this project. It is also planned to propose a real-time pilot which consists in making the S2S data available as close as possible to real time during a limited period of time (1 or preferably 2 years) for a limited number of users. A reduced set of derived variables (e.g. weekly mean forecast anomalies of total precipitation, T2m, uv10m, MSLP, z500) might also be proposed for wider availability.

In order to generate scientifically based forecasts that are useable, e.g. understandable and actionable forecast formats and analysis results, incorporating decision-making needs into the research and forecast system development process is paramount. Such an objective may be best achieved by making use of existing long-term partnerships between weather and seasonal forecast producers and/or product developers, and various groups of end users. The partnership should together assess the fit between science and decision-making and coproduce knowledge and tools for the optimized use of S2S forecasts. This will require strong linkages with sector-specific research programmes (e.g. H2020 for energy).

The Global Framework for Climate Services (GFCS) has a focus on developing countries and particularly the African continent. Phase II activities will advance this objective, the sub-seasonal range being of key interest in the African context of rain-fed agriculture (e.g. season onset and cessation, dry spells and heavy rain events). During Phase I a number of Africa-focused projects aligned with the objectives of the Africa sub-project of S2S – though the emphasis until now has been more at the seasonal timescale. A number of new projects are now beginning that have a more explicit element on sub-seasonal prediction. These projects, which include W2-SIP (WISER), ForPAc (SHEAR) and SWIFT (GCRF) will coordinate on training, product development and evaluation and exploit the proposed Phase II real-time demonstration phase to trial products.

This real-time pilot activity will be an opportunity to promote discussions on the ethical issues in the provision of S2S forecasts.

4. WORKSHOPS AND TRAINING ACTIVITIES

The proposed second phase of the S2S project will include the organization of training courses and workshops as in Phase I. In particular, two international S2S workshops will be organized during the period 2018-2023. These workshops will cover the whole spectrum of research and application activities in S2S. In addition, several specialized workshops covering one of the sub-project topics will be organized as was done in Phase I (e.g. the workshop on extreme events at the International Research Institute for Climate and Society, Columbia University, in December 2016). In addition, sessions on S2S will be organized at conferences such as AGU, EGU, IUGG as in Phase I. It is proposed to dedicate one at the AGU session (possibly the one in December 2019) to the use of analytical and simplified models studies for a better understanding of S2S prediction, most especially of weather regimes.

The second phase of the S2S project will also include training courses (about once a year), including in collaboration with the International Centre for Theoretical Physics (ICTP) and S2S-ASEAN. It is planned to keep the similar level of training activities as in Phase I. An important objective of these training activities is to provide supporting documentation to help enhance the utility of the S2S database. It is also very important to engage early career scientists. Therefore, it is proposed to organize a summer school for early career scientists which will cover all the thematics of the S2S book (to be published in 2018). S2S also plans to promote the visit of early career scientists in operational centres.

5. LINKAGES

A number of linkages have been established during the first phase of the S2S project, most especially with CBS, WGNE, PPP/YOPP, HIW, SPARC, GEWEX, the Joint WWRP/WGNE Working Group on Forecast Verification Research, DAOS, PDEF and WGSIP. It is planned to continue interacting with all these groups and all the research sub-projects mentioned above will be developed in strong collaboration with other groups. For instance, the sub-project on Stratosphere (section 3.2.6) is a joint initiative with SPARC and its membership will include members from both groups. The sub-project on ocean initialization and processes (section 3.2.3) will be an opportunity to link with the ocean community and CLIVAR. Strong collaboration with WGSIP will be maintained, mostly through three WGSIP projects: teleconnections project which has strong synergies with the S2S sub-project on MJO and teleconnections, SNOWGLACE which has strong synergies with the sub-project "land initialization and processes" and the shock/drift project which is relevant to three S2S sub-projects: "Ocean initialization and processes", "land initialization and processes" and "ensemble generation". Collaboration could also be established with the WCRP Grand Challenge on Extremes to assess the modulation of S2S events by climate variability, which is in great public demand. In addition, stronger links with the SERA group will be established in Phase II with the creation of an S2S-SERA sub-group to get better feedbacks from the end-user community. Special attention will also be dedicated to establish stronger connections with the Global Framework with Climate Services (GFCS) and the Global Data-Processing and Forecasting System (GDPFS), which will be particularly relevant for the Real-time pilot for S2S applications research and demonstrations proposal (section 3.3.2).

The second phase of the S2S project having a strong focus on model improvements, stronger interaction will be established with field campaigns, such as the year of Maritime Continent (YMC) and Year of Polar prediction (YOPP) which represent unique opportunities to assess the impact of improving the observing system on sub-seasonal forecasts. To facilitate this interaction, an expert on observing system could be added to the S2S membership which is currently lacking this expertise.

Key supports for S2S activities are the funded research programme activities. S2S has benefitted from the strong support of the NOAA's Climate Program Office (Modeling, Analysis, Prediction and Projections program - MAPP) and National Weather Service which have both initiated multi-year research priorities on S2S predictability and forecasting since 2014. In particular, S2S is planning to leverage on the NOAA SubX project for the real-time pilot in Phase II. S2S will also benefit from the support of other funded activities: the Belmont project Interdec which assesses the impact of MJO teleconnections on high latitude seasonal and decadal variability, and the new Horizon 2020 project S2S4E which will investigate the use of S2S information for the energy sector. A new Horizon 2020 call on S2S and S2D has recently been announced for 2020 (Advancing climate services (seasonal to sub-seasonal (S2S) and seasonal to decadal (S2D) forecasting; climate services prototypes) which could provide a strong support for the S2S activities in Phase II, most especially for the research-to-operation activities.

6. OUTREACH AND COMMUNICATIONS

Effective and consistent communications will be vital to the success of S2S Phase II. The S2S International Project Office will work together with WMO's communications department to develop communications products, to ensure consistency of messaging, and to maximize outreach to targeted audiences.

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