THE SUBSEASONAL TO SEASONAL (S2S) PREDICTION PROJECT DATABASE

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A database containing subseasonal to seasonal forecasts from 11 operational centers is available to the research community and will help advance our understanding of predictability at the subseasonal to seasonal time range.

Demands are growing rapidly in the operational prediction and applications communities for forecasts that fill the gap between medium-range weather (up to 15 days) and long-range or seasonal (3–6 months) forecasts. Skillful subseasonal to seasonal prediction (forecast range more than 2 weeks but less than a season) provides an important opportunity to inform decision-makers of, for example, changes in risks of extreme events or opportunities for optimizing resource management decisions. Although many challenges remain to make subseasonal forecasts sufficiently reliable, skillful, and tailored for users, a great return on investment in weather and climate science and model development is to be expected if the science and forecast products of subseasonal to seasonal prediction can be successfully connected to societal applications.

Weather-related hazards, including the slow onset of long-lasting events such as drought and extended periods of extreme cold or heat, trigger and account for a large proportion of disaster losses, even during years with other very large geophysical events (e.g., Haitian and Chilean earthquakes; Munich Re 2015). While many end users have benefited by applying weather and climate forecasts in their decision-making, there remains ample evidence to suggest that such information is underutilized across a wide range of economic sectors (e.g., Morss et al. 2008; Rayner et al. 2005; O'Connor et al. 2005; Pielke and Carbone 2002; Hansen 2002). This may be explained in part by the presence of "gaps" in our forecasting capabilities at the subseasonal time scale and in part by the complexity of processes and the numerous facets involved in decision-making. Developing countries are most affected by major gaps in access to forecasts and knowledge. The goal of the Subseasonal to Seasonal (S2S) Prediction Project and its associated database is to help fill these gaps.

THE S2S PROJECT. Subseasonal forecasting, bridging a gap between the more mature weather and climate prediction communities, is at a relatively early stage of development. Forecasting the day-to-day weather is often considered as an atmospheric initial-condition problem. Most of the current operational medium-range forecasting systems (forecasts up to day 15) are not coupled to an ocean model, although there can be an influence from ocean (e.g., Bender and Ginis 2000) and land conditions (e.g., Koster et al. 2010). Forecasting at the multiseason to multiannual range depends strongly on the slowly evolving components of the Earth system, such as the sea surface temperature. In between these two time scales is subseasonal to seasonal variability (defined here as the time range between 2 weeks and 2 months). Forecasting for this time range has so far received much less attention than medium-range and multiseason prediction despite the considerable socioeconomic value that could be derived from such forecasts. This time scale is critical for proactive disaster mitigation efforts. It is considered a difficult time range since the lead time is sufficiently long that much of the memory of the atmospheric initial conditions is lost and it is too short for the variability of the ocean to have a strong influence. However, recent research has indicated important potential sources of predictability for this time range, such as the Madden–Julian oscillation (MJO), the state of El Niño–Southern Oscillation (ENSO), soil moisture, snow cover and sea ice, stratosphere–troposphere interactions, ocean conditions, and tropical–extratropical teleconnections (see, e.g., review in Vitart et al. 2015).

The fundamental goals of the S2S Prediction research project are to improve forecast skill and understanding on the subseasonal to seasonal time scales and to promote its uptake by operational centers and by the applications community (Vitart et al. 2015). An extensive database containing subseasonal (up to 60 days) forecasts and reforecasts (sometimes known as hindcasts) has been created to enable research of operational pathways to accomplish these goals. It is modeled in part on The Observing System Research and Predictability Experiment (THORPEX) Interactive Grand Global Ensemble (TIGGE) database for medium-range forecasts (up to 15 days; Bougeault et al. 2010) and the Climate-System Historical Forecast Project (CHFP; http://wcrp-climate.org/index.php/wgsip-chfp/chfp-overview) for seasonal forecasts. The research is organized around a set of six topics (MJO, monsoons, Africa, extremes, teleconnections, and verification), each intersected by cross-cutting research and modeling issues and applications and user needs. The latest science plans of each subproject are available online (www.s2sprediction.net/static/documents#reports). Some of the main research questions include the following:

- What is the benefit of a multimodel forecast for subseasonal to seasonal prediction and how can it be constructed and implemented?
- What is the predictability of extreme events and how can we identify windows of opportunity for subseasonal to seasonal prediction?
- What is the best initialization strategy for a forecasting system that includes ocean, land, and cryosphere? What is the optimal way to generate an ensemble of subseasonal to seasonal forecasts?
- What is the impact of horizontal and vertical resolution of atmosphere and ocean models on subseasonal to seasonal forecasts?
- What are the origins of the systematic errors affecting subseasonal to seasonal forecasts?
- How well do state-of-the-art models represent tropical–extratropical teleconnections?
- What forecast quality attributes are important when verifying S2S forecasts and how should they be assessed?
- What are the current S2S forecasting capabilities for daily weather characteristics relevant to agriculture, water resource management, and public

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TABLE 1. Main characteristics of the 11 contributions to the S2S database, where time range is forecast lead time (days), resolution is longitude and latitude resolution (°) and the number after the letter L represents the number of vertical levels, ens size is the number of members in the real-time forecast ensemble, and freq is how often (frequency) the forecasts are run. Reforecasts (rfc; hindcasts) are run using the actual forecast model but for the past several years on the same (or nearby) calendar day as the forecast. The reforecast is used to calibrate the actual forecast. The rfc period is the number of years the reforecasts are run. In some centers, the number of reforecast years is fixed, but the list of years varies from year to year (e.g., reforecast years at ECMWF cover the past 20 years). The rfc freq is how often the reforecasts are run, and the rfc size is the number of ensemble members for reforecasts. Ocean coupling indicates if the atmospheric component is coupled to a dynamics ocean model. Sea ice coupling indicates if an active dynamical sea ice model is included or not.

Model	Time range	Resolution	Ens size	Freq	Rfc[a]	Rfc period	Rfc freq	Rfc size	Ocean coupling	Sea ice coupling
BoM	Days 0–62	~2° × 2°, L17	33	Twice weekly	Fixed	1981–2013	Six per month	33	Yes	No
CMA	Days 0–60	~1° × 1°, L40	4	Daily	Fixed	1994–2014	Daily	4	Yes	Yes
ECCC	Days 0–32	0.45° × 0.45°, L40	21	Weekly	On the fly	1995–2012	Weekly	4	No	No
ECMWF	Days 0–46	0.25° × 0.25° days 0–10 0.5° × 0.5° after day 10 L91	51	Twice weekly	On the fly	Past 20 years	Two per week	11	Yes	No
HMCR	Days 0–61	1.1° × 1.4°, L28	20	Weekly	On the fly	1985–2010	Weekly	10	No	No
CNR-ISAC	Days 0–31	0.8° × 0.56°, L54	41	Weekly	Fixed	1981–2010	Every 5 days	1	No	No
JMA	Days 0–33	~0.5° × 0.5°, L60	25	Twice weekly	Fixed	1981–2010	Three per month	5	No	No
KMA	Days 0–60	~0.5° × 0.5°, L85	4	Daily	On the fly	1996–2009	Four per month	3	Yes	Yes
CNRM	Days 0–61	~0.7° × 0.7°, L91	51	Weekly	Fix	1993–2014	Two per month	15	Yes	Yes
NCEP	Days 0–44	~1° × 1°, L64	16	Daily	Fixed	1999–2010	Daily	4	Yes	Yes
UKMO	Days 0–60	~0.5° × 0.8°, L85	4	Daily	On the fly	1996–2009	Four per month	3	Yes	Yes

[a] There are two types of reforecasts: fixed and on the fly. In fixed reforecasts, some operational centers (e.g., NCEP) use the same version of their model ("frozen" version) to produce real-time S2S forecasts over a period of several years (typically 4–5 years). Therefore, the reforecasts are produced once, often before the first real-time forecast is produced, and used for several years to calibrate the real-time forecasts. In on-the-fly reforecasts, other operational centers (e.g., ECWMF) update their model version several times per year. To ensure model consistency between real-time forecasts and reforecasts, the reforecasts are produced continuously just before the real-time forecast they will be used to calibrate. For example, at ECMWF, every week a reforecast set is produced starting the same day and same month as the next real-time forecast (e.g., 1 Jan 2015) but for the past 20 years (1 Jan 1995–2014).

Table 2. The 3D parameters available on 10 pressure levels (1000, 925, 850, 700, 500, 300, 200, 100, 50, 10 hPa) from all models.

Name	Abbreviation	Unit	Frequency
Geopotential height	gh	gpm	Instantaneous once per day (0000 UTC)
Temperature	*t*	K	Instantaneous once per day (0000 UTC)
U velocity	*u*	m s^{-1}	Instantaneous once per day (0000 UTC)
V velocity	*v*	m s^{-1}	Instantaneous once per day (0000 UTC)

health, such as heavy rainfall events, dry spells, and monsoon onset and cessation dates?

- How well do we understand the fundamentals of predictability and dynamical processes of the subseasonal variability?

DESCRIPTION OF THE S2S DATABASE. The S2S database builds on the experience of creating the TIGGE database and can be seen as its extension to the longer forecast ranges. The S2S database includes near-real-time ensemble forecasts and reforecasts up to 60 days from 11 centers: the Australian Bureau of Meteorology (BoM), the China Meteorological Administration (CMA), the European Centre for Medium-Range Weather Forecasts (ECMWF), Environment and Climate Change Canada (ECCC), the Institute of Atmospheric Sciences and Climate of the National Research Council (CNR-ISAC), the Hydrometeorological Centre of Russia (HMCR), the Japan Meteorological Agency (JMA), the Korea Meteorological Administration (KMA), Météo-France/Centre National de Recherche Meteorologiques (CNRM), the National Centers for Environmental Prediction (NCEP), and the Met Office (UKMO). A key difference with the TIGGE database is that the S2S database includes reforecasts, whereas none are included in the TIGGE database. For short-range weather forecasts, model error is not usually so dominant that a reforecast set is needed, but for the subseasonal to seasonal range the model error is too large to be ignored. Therefore, an extensive reforecast set spanning several years is needed to calculate model bias. Such reforecasts in some cases can also be used to evaluate skill. The models are also generally different from the TIGGE models. For instance, S2S models can have the atmospheric component coupled to an ocean model and an active sea ice model (Table 1).

Because S2S is a research project, the real-time forecasts are only available with a 3-week delay. Table 1 displays the main characteristics of the S2S models. Tables 2–6 show the list of variables that have been requested for the S2S archive, which include standard variables at many pressure levels together with a large number of single-level variables, including thermodynamic, hydrological, and surface flux fields. However, some models are providing just a subset of the requested variables (the list of variables provided by each model can be found at https://software.ecmwf.int/wiki/display/S2S/Provided+parameters). Pressure-level fields are available in the stratosphere at 50 and 10 hPa to facilitate the diagnostic of sudden stratospheric warming events and their downward propagation. The frequency of archiving is once a day, except for maximum and minimum near-surface temperature and total precipitation, which are available four times a day (computed over 6-h periods). The data are archived in Gridded Binary 2 (GRIB2) format, and a conversion to Network Common Data Form (netCDF) will be made available. There are plans to add some oceanic variables in the near future from the coupled ocean–atmosphere models: sea surface salinity, depth of the 20° isotherm, heat content in the top 300 m, salinity in the top 30 m, horizontal (*U*) and vertical (*V*) surface current, and sea surface height. It is also planned to include sea ice thickness for the models that have a dynamical sea ice model.

The S2S database is a database of "opportunity," which means that the forecasts have not been produced specifically for the S2S project following an agreed-upon protocol. Table 1 highlights differences in model setup between the operational centers. The main differences between real-time forecasts from different centers include the following:

- The forecast time range varies from 32 to 60 days.
- The horizontal resolution of the atmospheric model varies from several-hundred-kilometer resolution to about 30 km.
- The ensemble size varies from 4 to 51 members. This reflects a difference in strategy between operational centers. The centers producing a low number of ensemble members typically produce forecasts in lag mode (combining ensemble members from different start dates to produce an ensemble forecast).

Table 3. The 3D parameter available on seven pressure levels (1000, 925, 850, 700, 500, 300, 200) from all models.

Name	Abbreviation	Unit	Frequency
Specific humidity	*q*	kg kg^{-1}	Instantaneous

Table 4. The parameter available at 500 hPa.			
Name	**Abbreviation**	**Unit**	**Frequency**
Vertical pressure velocity	*w*	Pa s^{-1}	Once per day

- The frequency of initializing forecasts varies. Some models are run in burst mode on a subweekly basis with a large ensemble size (e.g., ECMWF, BoM, ECCC), whereas other models are run in continuous mode on a daily basis with a smaller ensemble size (e.g., NCEP, UKMO, CMA, KMA).
- Some models have an atmosphere component coupled to an ocean and a sea ice model (e.g., UKMO, NCEP, CNRM, CMA), while others use a combination of persistence of initial conditions and climatology to define the oceanic and sea ice boundary conditions (e.g., JMA, ECCC).

The configuration of the reforecasts also varies greatly between the models:

- Some models have a reforecast set covering a period exceeding 30 years (e.g., JMA, BoM), while other reforecast sets span a much shorter number of years (e.g., NCEP, UKMO).
- Some reforecasts are produced progressively "on the fly" (as at ECMWF), while others are computed all at once prior to operational implementation (e.g., BoM, NCEP).
- The ensemble size can vary from just 1 member (e.g., CNR-ISAC) to 33 members (BoM).
- Some models have reforecasts produced on a daily basis (e.g., NCEP), some on a subweekly basis (e.g., BoM, ECMWF), and some on a monthly basis (e.g., CNRM).

There is much greater diversity between the various S2S forecast systems than in other databases for medium and seasonal time ranges [e.g., TIGGE, European Multimodel Seasonal to Interannual Prediction (EUROSIP), CHFP]. Very different strategies are currently in use. For example, some centers take advantage of their seasonal and climate systems, while other centers employ systems used for weather forecasting. This highlights the current lack of consensus on the best practice for subseasonal prediction, unlike for medium-range and seasonal forecasting and diversity of priorities of operational centers. One of the goals of the S2S project is to make recommendations on the optimal configuration of subseasonal systems. The S2S database will enable these issues to be addressed by clustering the models sharing similar characteristics (e.g., coupled ocean–atmosphere models vs atmosphere-only models and lag vs burst initialization) and comparing their forecast skill scores.

Despite the differences in system setup, there are enough commonalities between them to make intercomparisons or multimodel combinations possible. For instance, almost all of the S2S systems produce real-time ensemble forecasts every Thursday and have reforecasts covering the period 1999–2010. Therefore, it is possible to create a multimodel combination of the S2S models every Thursday, calibrated using the common period 1999–2010.

The database is currently updated routinely with near-real-time forecasts and reforecasts from nine data providers, namely, JMA, NCEP, BoM, ECMWF, UKMO, CMA, CNRM, CNR-ISAC, and HMCR. Data from ECCC and KMA will be available soon. The S2S database is hosted by two archiving centers, ECMWF and CMA, and was opened to the public on 6 May 2015 at ECMWF via the Data Portal and ECMWF web Application Programming Interface (API) and in November 2015 at CMA. Users can register, visit the data portal, and browse the contents of the database, and they are encouraged to use the ECMWF web API to download data in batches.

By the end of 2015, about 300 users from 42 countries had registered and had already executed over 200,000 requests to extract about 30 TB of data from ECMWF. ECMWF and CMA are working together closely to ensure the timely synchronization of the two databases. The S2S database at ECMWF can be accessed online (at http://apps.ecmwf.int/datasets/data/s2s; http://s2s.ecmwf.int) for the reforecasts. The S2S database at CMA can be accessed at http://s2s.cma.cn/.

At CMA, about 22 TB of forecast and reforecast data have been collected from ECMWF. S2S data are archived on tapes in the Meteorological Archive and Retrieval System (MARS) (same archiving system as at ECMWF) and also stored in a large online storage system with a preprocessed unified form. The CMA data portal, like the ECMWF data portal, provides descriptions of the models from the different centers and S2S data parameters, in addition to the data download service. Two ways of searching and accessing the data are supported: free text search and faceted search. The method of downloading data is through a "data cart," similar to an online "shopping cart." All

Table 5. The following parameter is available only at 320 K.			
Name	**Abbreviation**	**Unit**	**Frequency**
Potential vorticity	pv	K m^2 kg^{-1} s^{-1}	Once per day

the S2S data can be accessed by hypertext transport protocol (HTTP) currently and Open-Source Project for a Network Data Access Protocol (OPeNDAP) in the near future. The S2S data in GRIB2 format can be directly downloaded at CMA, and data in netCDF format can be obtained through online conversion.

EXAMPLES OF USE OF THE S2S DATABASE. *Multimodel prediction.* To monitor the S2S forecasts, a basic set of products has been developed, including ensemble mean anomalies for a few meteorological parameters and some atmospheric indices. These products are generated routinely at ECMWF

Table 6. List of single-level parameters.

Name	Abbreviation	Unit	Frequency
10-m *u*	10u	m s^{-1}	Instantaneous once per day (0000 UTC)
10-m *v*	10v	m s^{-1}	Instantaneous once per day (0000 UTC)
CAPE	cape	kg^{-1}	Daily average
Skin temperature	skt	K	Daily average
Snow depth water equivalent	sd	kg m^{-2}	Daily average
Snow density	rsn	kg m^{-3}	Daily average
Snowfall water equivalent	sf	kg m^{-2}	Accumulated once per day
Snow albedo	asn	%	Daily average
Soil moisture top 20 cm	sm20	kg m^{-3}	Daily average
Soil moisture top 100 cm	sm100	kg m^{-3}	Daily average
Soil temperature to 20 cm	st20	K	Daily average
Soil temperature top 100 cm	st100	K	Daily average
Surface air max temperature	mx2t6	K	Instantaneous four times per day
Surface air min temperature	mn2t6	K	Instantaneous four times per day
Surface air temperature	2t	K	Daily average
Surface air dewpoint temperature	2d	K	Daily average
Sea surface temperature	wtmp	K	Daily average
Sea ice cover	ci	Proportion	Daily average
Surface pressure	sp	Pa	Instantaneous once per day (0000 UTC)
Mean sea level pressure	msl	Pa	Instantaneous once per day (0000 UTC)
Total cloud cover	tcc	%	Daily average
Total column water	tcw	kg m^{-2}	Daily average
Total precipitation	tp	kg m^{-2}	Accumulated four times per day
Convective precipitation	cp	kg m^{-2}	Accumulated once per day
Northward turbulent surface stress	nsss	N m^{-2} s	Accumulated once per day
Eastward turbulent surface stress	ewss	N m^{-2} s	Accumulated once per day
Water runoff and drainage	ro	kg m^{-2}	Accumulated once per day
Surface water runoff	sro	kg m^{-2}	Accumulated once per day
Land–sea mask	lsm	Proportion of land	Instantaneous once per day (0000 UTC)
Orography	orog	gpm	Instantaneous once per day (0000 UTC)
Soil type	slt	Categorical	Instantaneous once per day (0000 UTC)
Top net thermal radiation	ttr	W m^{-2} s	Accumulated once per day
Surface latent heat flux	slhf	W m^{-2} s	Accumulated once per day
Surface net solar radiation	ssr	W m^{-2} s	Accumulated once per day
Surface net thermal radiation	str	W m^{-2} s	Accumulated once per day
Surface sensible heat flux	sshf	W m^{-2} s	Accumulated once per day
Solar radiation downward	ssrd	W m^{-2} s	Accumulated once per day
Surface thermal radiation downward	strd	W m^{-2} s	Accumulated once per day

from each individual forecast system and for a multimodel combination. Figure 1 shows an example of multimodel prediction of 2-m temperature anomalies from three S2S models, along with the verification. This figure shows that a cold event in the northeastern United States and Canada in February 2015 was well predicted for days 12–18. These S2S products are available online (at www.ecmwf.int/en/research/projects/s2s/charts/s2s/) to support the S2S community, with a 3-week delay.

The strong March 2015 MJO event. The S2S dataset can be used to assess the performance of current state-of-the-art subseasonal to seasonal forecasting systems to predict recent extreme events. For instance, 2015 witnessed an exceptional MJO event in March; it exhibited record amplification resulting in the largest amplitude ever recorded (above four standard deviations; Marshall et al. 2016) and triggered the formation of twin tropical cyclones, one on each side of the equator. The amplification was promoted by the unusually warm waters near the date line (Marshall et al. 2016), which preceded the development of strong El Niño conditions in the eastern Pacific later in the year. The surface westerly winds that developed in the western Pacific as a result of this March MJO event with twin cyclones likely enhanced the development of the strong El Niño later in the year. It is encouraging to see that all the models and the multimodel combination (black line in Fig. 2a) forecasted a strong MJO event more than 2 weeks in advance (Fig. 2a). Most models also predicted the occurrence of an MJO event 3 weeks in advance (black line in Fig. 2b), although the amplitude is generally underestimated, and no ensemble member predicted such a strong amplitude event.

This record-strength MJO event also contributed to the formation of Tropical Cyclone Pam, which intensified to category 5 strength and hit the islands of Vanuatu in the South Pacific on 13 March with devastating effects. Around 15 people were killed and many buildings were destroyed. The cyclone was the second strongest on record in the southern Pacific, second only to Zoe (2002). It is regarded as the worst natural disaster in Vanuatu's history. The cyclone formed on 6 March east of the Solomon Islands and was classified as a tropical storm on 9 March.

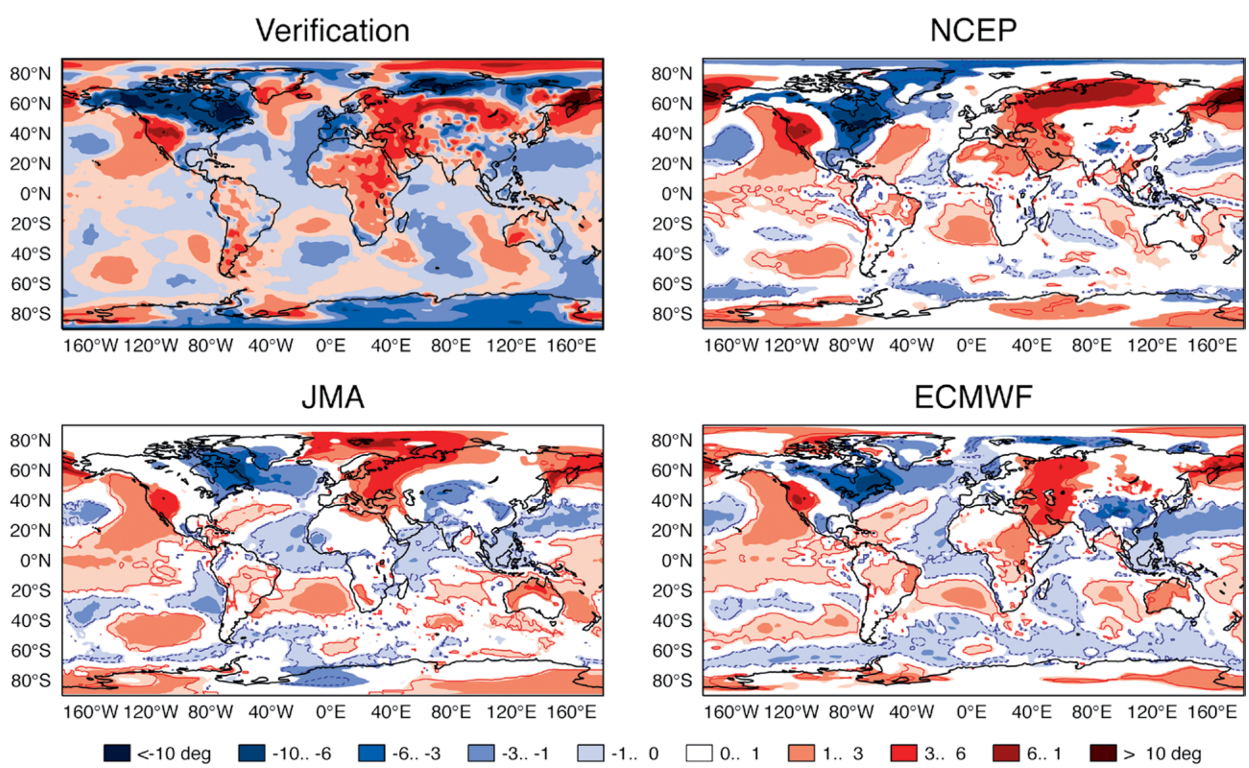

Fig. 1. Multimodel comparisons. A possible use of the database is to make comparisons between the outputs of different forecasting centers. The figure shows forecasts of 2-m temperature anomalies from three S2S ensemble-mean forecasts and a verification panel based on the ECMWF interim reanalysis (ERA-Interim; Dee et al. 2011). The forecast start date is 22 Jan 2015 and the forecast range is days 12–18. The areas where the ensemble forecast is not significantly different from the ensemble climatology, according to a Wilcoxon–Mann–Whitney test (e.g., Wonacott and Wonacott 1977), are blanked.

Previous studies (e.g., Vitart 2009) have demonstrated that state-of-the-art extended-range forecasting systems can simulate the modulation of tropical cyclone activity by the MJO, with an increased risk of tropical cyclone activity over the southwestern Pacific when the MJO is in phases 6 and 7. To assess the skill of the S2S models to predict the probability of a tropical cyclone hitting Vanuatu, tropical cyclones have been tracked in each ensemble forecast member from CMA, JMA, NCEP, ECMWF, and BoM using the algorithm described in Vitart et al. (1997). Figure 3 shows the probability of a tropical cyclone strike within a 300-km radius for the multimodel combination of the five real-time forecasts starting on 19 and 26 February 2015 and verifies it during the weekly period 9–15 March 2015 when Pam hit the islands of Vanuatu. Figure 3 suggests that this event had some extended-range predictability, with the multimodel combination indicating an increased risk of tropical cyclone strike probability in the vicinity of Vanuatu (indicated by a black dot in Fig. 3) 2–3 weeks in advance. The multimodel also predicted the possibility of a tropical cyclone strike in the western Pacific, which is consistent with the twin tropical cyclone genesis associated with the strong MJO event of March 2015. The multimodel forecast from 26 February also predicted an increased risk of tropical cyclone strike east of Madagascar and over the northwestern coast of Australia, which could correspond to Tropical Storm Haliba (7–10 March 2015) and Tropical Cyclone Olwyn (8–14 March 2015), respectively.

MJO teleconnections in the northern extratropics. Accurate predictions of MJO events are not sufficient for successful subseasonal forecasts. The ability to predict the impact of MJO events on the global circulation is crucial. By acting to excite the North Atlantic Oscillation (NAO), the MJO affects European weather (Cassou 2008; Lin et al. 2009) and North Atlantic significant ocean wave heights (Marshall et al. 2015). Cassou (2008) and Lin et al. (2009) showed that the probability of a positive phase of the NAO is significantly increased about 10 days after the MJO is in phase 3 (phase 3 + 10 days) and is significantly decreased about 10 days after the MJO is in phase 6 (phase 6 + 10 days). The probability of a negative phase of the NAO is decreased (increased) about 10 days after the MJO is in phase 3 (phase 6). The impact of the MJO on two other Euro-Atlantic weather regimes, the Atlantic Ridge and Scandinavian blocking, is much weaker.

Vitart and Molteni (2010) showed that a set of ECMWF reforecasts using cycle 32R3 displayed realistic MJO teleconnections over the northern extratropics, consistent with the observed impacts (Cassou 2008; Lin et al. 2009). Lin et al. (2010) further found that the MJO has a significant impact on the intraseasonal NAO skill scores using the ECCC model. This section evaluates whether the MJO teleconnections in the northern extratropics are adequately simulated in the reforecasts from the S2S database. We do this by forming 500-hPa geopotential height composites 10 days after an MJO is in phase 3 for all cases when the predicted MJO has an amplitude larger than one standard deviation. Only the reforecasts covering the period from January to April have been considered.

Figure 4 shows that the models generally capture the spatial pattern of the teleconnection but tend to overestimate the intensity of the MJO teleconnections

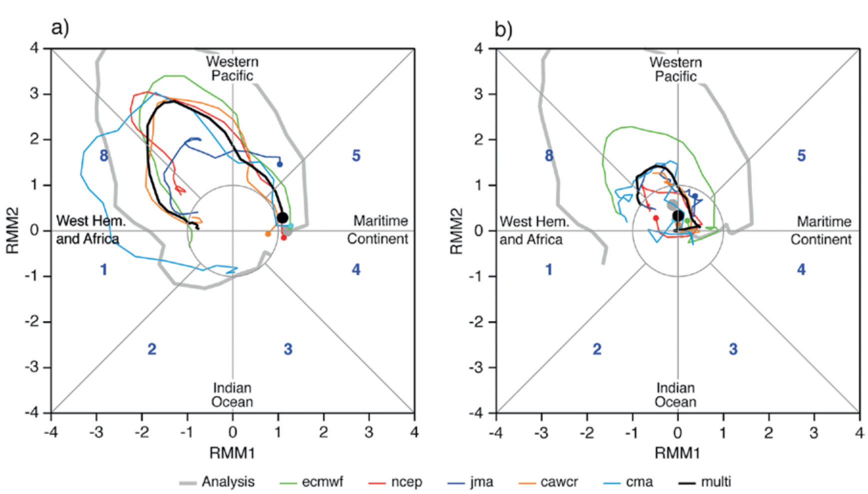

Fig. 2. Phase diagram showing MJO index forecasts from five S2S systems. Forecasts are initiated on (a) 5 Mar and (b) 26 Feb 2015 and are represented in colored lines. The gray and black thick solid lines represent the verification and the multimodel ensemble, respectively. The MJO index is based on a combined EOF analysis using fields of near-equatorially averaged 850- and 200-hPa zonal wind and outgoing longwave radiation (Wheeler and Hendon 2004). The Real-time Multivariate MJO series 1 (RMM1) and RMM2 give information on the location of the MJO: Indian Ocean (quadrants 2 and 3), Maritime Continent (quadrants 4 and 5), western Pacific (quadrants 6 and 7), and Western Hemisphere (quadrants 8 and 1). The amplitude of the MJO is represented by the distance to the center, and the inner circle represents one standard deviation.

in the North Pacific and underestimate its projection onto the positive phase of the NAO over the North Atlantic basin. This underestimation could be explained by the analysis being based on a single observed realization, whereas the model composites are averaged over several ensemble members. Since not a single ensemble member reproduced the intensity of the teleconnection in the North Atlantic sector as strongly as in the analysis, it follows that underestimation of the MJO impact over the Atlantic is a real deficiency, common to several models (Vitart and Molteni 2010). The underrepresentation of the MJO impact over the Euro-Atlantic sector is likely to limit the predictability and predictive skill over the North Atlantic and Europe in the subseasonal time range and therefore is an important aspect to be analyzed.

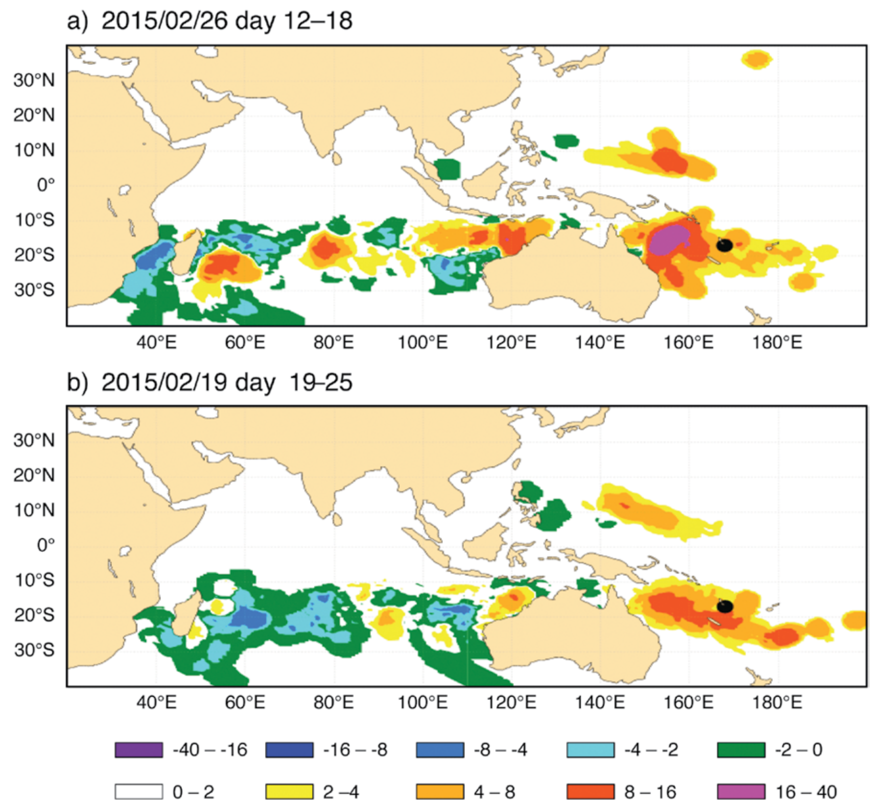

Fig. 3. Probability anomalies of a tropical storm strike within a 300-km radius from the multimodel ensemble (combination of ECMWF, NCEP, CMA, JMA, and BoM forecasts). The forecasts were initialized on (a) 26 Feb and (b) 19 Feb 2015 and cover the weekly period 9–15 Mar 2015, which corresponds to a forecast range of days 12–18 in (a) and days 19–26 in (b). The black dot in each panel represents the location of landfall of Tropical Cyclone Pam over Vanuatu.

OTHER ACTIVITIES. The above examples give a flavor of the potential scope for research that the database offers. This database will also help to assess the potential of current operational S2S systems to forecast the extreme events around the globe, which are discussed in the *BAMS* special report "Explaining Extreme Events of 2015 from a Climate Perspective," and other events that have led to major humanitarian aid responses. Three important aspects of the S2S database—namely, that it contains 1) an archive of real-time forecasts (delayed 3 weeks) and 2) accompanying reforecast sets, and 3) that these outputs are from World Meteorological Organization (WMO)-recognized systems used currently for operational forecasts—make it a uniquely powerful tool for improving operational forecasts and exploring and prototyping decision support elements based on S2S forecast information. The WMO Lead Centre for Long-Range Forecast Multi-Model Ensembles (LC-LRFMME) will have access to the S2S database and will obtain the real-time forecasts *without* the 3-week embargo, enabling national meteorological and hydrological services to utilize real-time forecast information in a few years' time once the necessary research has been done to estimate and document skill and approval has been obtained by WMO. The S2S database will augment the resources available to developing countries to enable the research in early warning system products. The S2S project is using the database to train young scientists from developing countries to access the data, perform the necessary research, and collaborate with international experts.

CONCLUSIONS. The S2S database, a key component of the World Weather Research Programme (WWRP)/World Climate Research Programme (WCRP) Subseasonal to Seasonal Prediction Project science plan, is currently open to the public. It contains reforecasts and also near-real-time subseasonal to seasonal forecasts from all the major operational centers. This database represents an important tool to advance our understanding of the subseasonal to

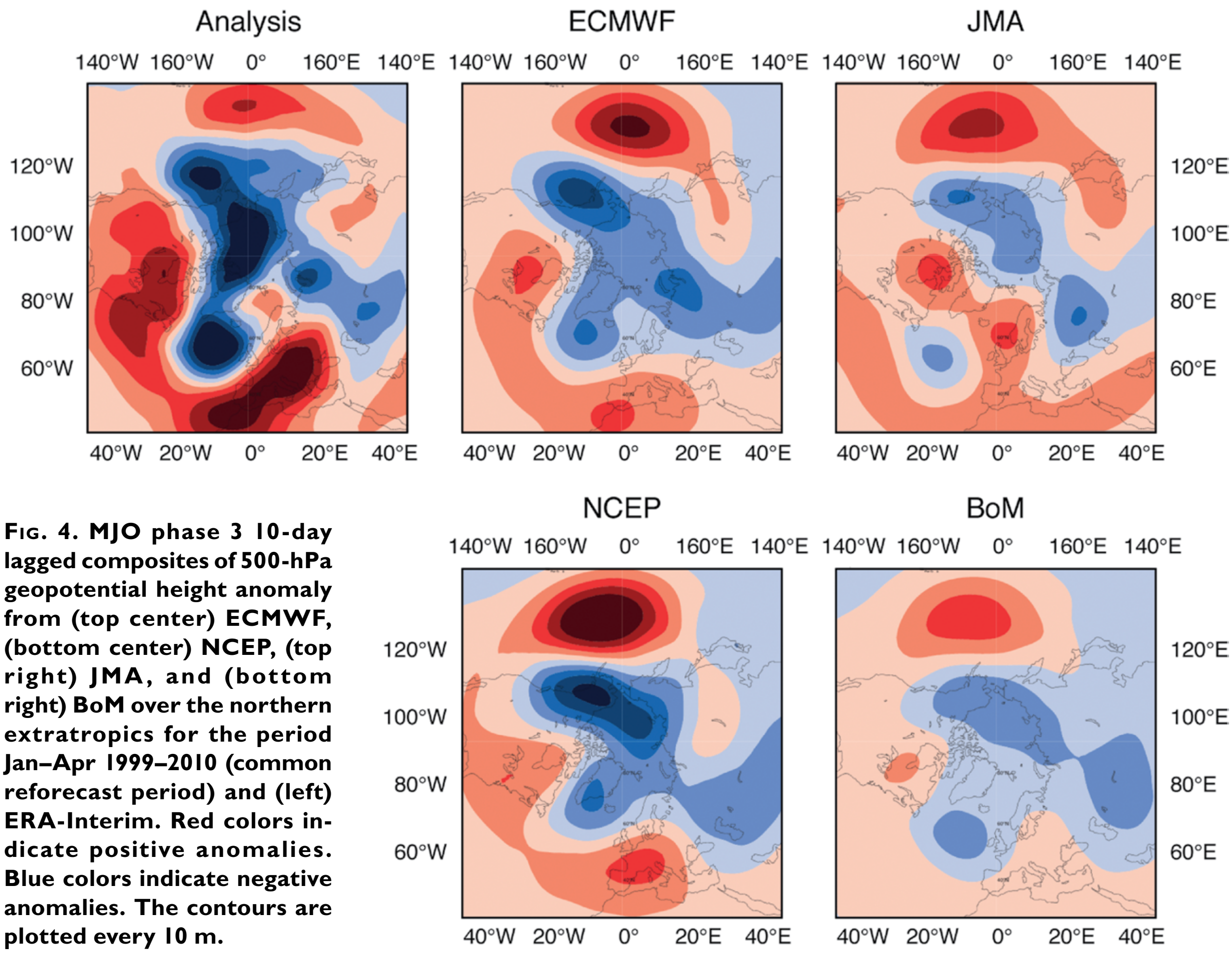

Fig. 4. MJO phase 3 10-day lagged composites of 500-hPa geopotential height anomaly from (top center) ECMWF, (bottom center) NCEP, (top right) JMA, and (bottom right) BoM over the northern extratropics for the period Jan–Apr 1999–2010 (common reforecast period) and (left) ERA-Interim. Red colors indicate positive anomalies. Blue colors indicate negative anomalies. The contours are plotted every 10 m.

seasonal time range that has been considered for a long time as a "desert of predictability." Use of this database by the research community can include

- assessing the average forecast skill of subseasonal to seasonal predictions in a statistical way through the large number of reforecasts and near-real-time forecasts;
- assessing the potential predictability of the S2S models and identifying forecast windows of opportunity;
- performing case studies to assess the skill of the model during a specific period or event;
- identifying sources of predictability, dynamical processes, and their impact on the forecast skill scores (e.g., sudden stratospheric warmings, MJO and its teleconnections, sea ice, soil initial conditions);
- assessing the models' capability to represent these key dynamical processes that are sources of subseasonal predictability so as to guide ongoing model development;
- assessing the benefit of a multimodel approach on subseasonal time scales and estimating the effective ensemble size of the multimodel ensemble as in Pennell and Reichler (2011) for climate models;
- assessing the representation of model uncertainty in the current operational systems;
- assessing the potential benefit of subseasonal to seasonal forecasts in applications; and
- comparing the strategies for model initialization (e.g., burst vs lag ensemble initialization).

Work is ongoing to extend the list of oceanic and sea ice variables and to improve the conversion of the data into netCDF. There are also plans to automatically compute some products from the database (e.g., MJO, NAO, ENSO, sudden stratospheric warming indices, weather regimes, and tropical cyclone tracks) and to make them available to the community to avoid multiple computations of the same indices. For example, the International Research Institute for Climate and Society at Columbia University also plans to make available a user-oriented subset of products from the S2S database hosted at ECMWF and CMA.

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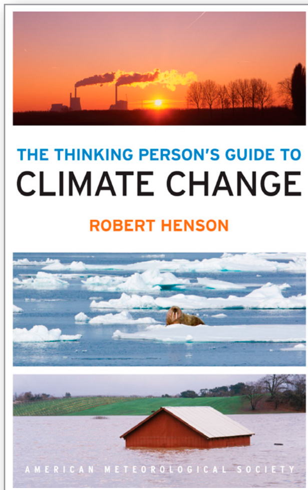

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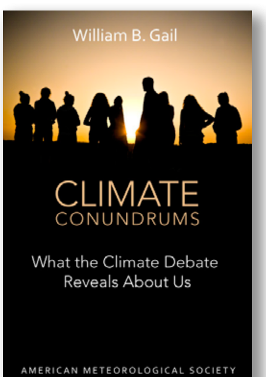

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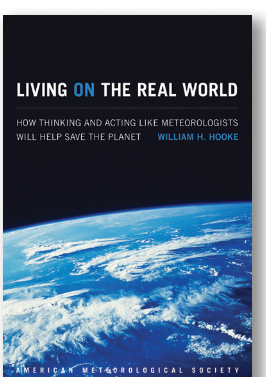

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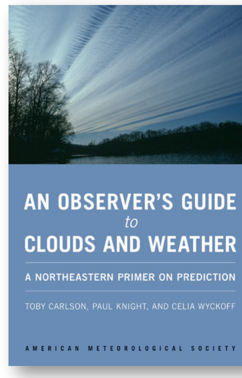

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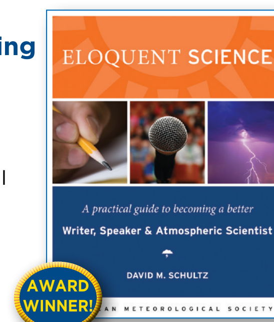

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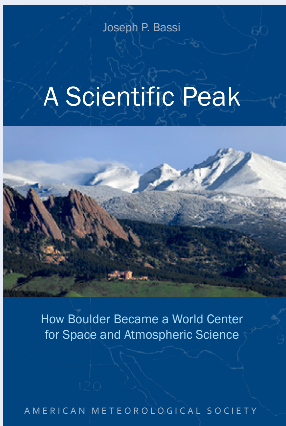

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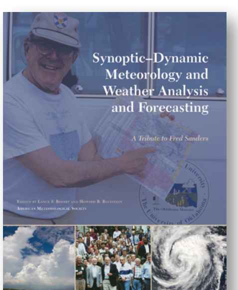

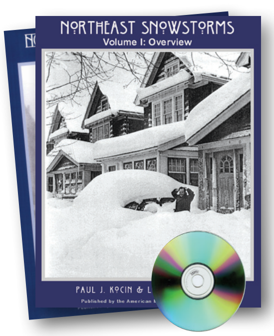

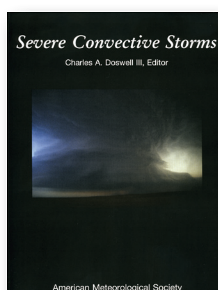

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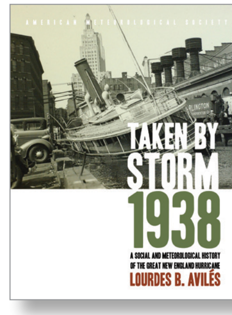

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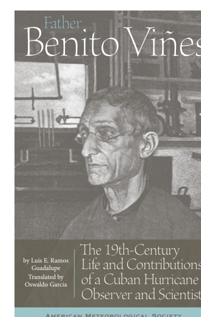

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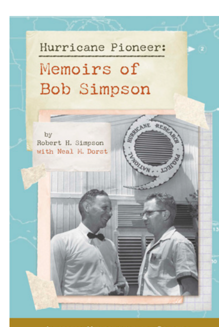

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