Subseasonal-to-Seasonal S2S Prediction Project

Newsletter No. 20

WCRP World Climate Research Programme
WWRP World Weather Research Programme

In This Issue…

News:

Topics:

1. What is S2S ?

To bridge the gap between medium-range weather forecasts and seasonal forecasts, the World Weather Research Programme (WWRP) and World Climate Research Programme (WCRP) launched a joint research initiative in 2013, the Subseasonal to Seasonal Prediction Project (S2S). The main goal of this project is to improve forecast skill and understanding of the subseasonal to seasonal timescale, and to promote its uptake by operational centres and exploitation by the applications communities.

Phase II of the S2S project began in January 2019 and will continue until 2023. A new set of scientific sub-projects has been developed, as outlined in the sidebar in next pages. Enhancements to the database will be made including access to the S2S ocean and additional models. The second phase will also include new research-to-operations activities and a real-time supplications initiative introduced in this edition of the newsletter.

S2S Phase II Proposal is available at http://s2sprediction.net/file/documents_reports/P2_Pro.pdf

S2S Forecasting for Wind Turbine Maintenance Scheduling

Jethro Browell (University of Glasgow) and Rosemary Tawn (TNEI Services Ltd)

Photo credit: Paul Anderson / Completed Turbine Tower No 11 on Scout Moor / CC BY-SA 2.0

The growth in awareness and skill of S2S forecasts over the past decade has led to the development of a wide range of application-focused capabilities. These span sectors including public health, agriculture, emergency services, and energy. In the energy sector, early applications focused on predicting supply from renewables (hydro, wind, solar) and demand for electricity and gas. Forecasts in the S2S range of two to six weeks ahead can be valuable to market participants who gain a competitive advantage from skilful predictions of supply, demand, and prices. Electricity network operators also benefit from improved situational awareness of potential stress events, such as wind droughts and extreme temperatures.

Beyond supply and demand, there is potential to reduce costs in the wind industry through more efficient maintenance: minimising downtime, maximising utilisation of human and material resources, and scheduling maintenance during periods of low potential power production.

In addition to regular servicing, a wind turbine's need for maintenance may be predicted weeks to months before wear becomes critical using sophisticated condition monitoring. Furthermore, some maintenance tasks require specialist skills and equipment, notably cranes, which must be hired weeks in advance and are only safe to operate in low wind conditions. Therefore, predictions of wind conditions on S2S time scales align with the timescales involved in maintenance planning and offer the potential to realise savings by minimising lost energy capture and idle time of personnel and equipment.

Research carried out as part of Rosemary Tawn's PhD investigated the potential value of incorporating S2S predictions into wind turbine maintenance scheduling in Scotland. Methods for post-processing S2S forecasts from ECMWF (made available via the S2S Prediction Project) were developed to produce site-specific probabilistic forecasts of weekly wind speed variability and a bespoke accessibility index. By incorporating these into a cost-loss decision-making framework it was possible to first, demonstrate how probabilistic forecasts may be used to inform decisions, and second, to quantify the value of using S2S forecasts in such an approach compared to climatology. The results depend on wind farm location and the relative price of electricity and crane hire; and the study identified the range of electricity prices where the hiring decision is sensitive to weather forecasts. While there is little difference in the hiring decision based on S2S forecasts and the climatology benchmark at most electricity prices, the repair cost per turbine is reduced at lower electricity prices.

The method used principal component analysis to identify significant large-scale weather patterns targeting relevant parameters, primarily wind speed. Then a linear model was used to 'scale down' to the site of interest and forecast a metric tailored to the decision problem using the principal components as explanatory variables and a job-specific metric derived from wind speed at the wind farm of interest as the target variable. Individual ensemble members were processed in this way to generate a probabilistic forecast, with an EMOS correction also applied to produce the final forecast. Finally, a cost-loss model considering expected lost energy given the forecast wind conditions and expected chance of successful maintenance work was employed to determine the benefit of the proposed model over a climatology-based approach.

2. Six sub-projects in S2S Phase II

The new research Phase II sub-projects will address issues related to sources of predictability, forecast system configuration, and model development. These sub-projects are 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).

1. **MJO and teleconnections**: This sub-project focuses on the representation of teleconnections and their modulation in S2S models. Metrics for assessing model teleconnections and diagnosing sources of errors in teleconnections will be applied.

2. **Land**: This sub-project investigates the impact of the observing system on land initialization and S2S forecasts, the representation of the coupled land/ atmosphere processes in S2S models, and contribution of anomalies in land surface states to extremes. It will work in concert with other relevant programs to pool resources and coordinate scientific studies (e.g. GEWEX/GLASS).

3. **Ocean**: This sub-project aims to evaluate the ocean feedbacks which directly influence sub-seasonal variability and prediction skill, the predictability influenced by pre-existing ocean state, the effect of low-frequency variability on S2S predictability, the impact of ocean mean state drift on S2S predictability, mechanisms which affect extreme ocean weather (heat waves) and their predictability.

4. **Aerosol**: This sub-project is a collaboration between S2S, WGNE and GAW. It aims to evaluate the benefit of interactive instead of climatological aerosols on sub-seasonal forecasts through a series of coordinated re-forecast experiment with and without interactive aerosols. The sub-seasonal predictability of aerosols will be assessed as well as their impact on sub-seasonal forecast skill scores.

5. **Ensembles**: This sub-project will study the influence of burst vs lagged ensemble initialization on the forecast spread using S2S database. It will also investigate the impacts of stochastic parameterizations and coupled initial perturbations on the sub-seasonal prediction, review the techniques for coupled initial perturbations which are under development in a few center (ECMWF, NCEP, BoM, and JMA).

6. **Stratosphere**: This is a joint sub-project between S2S and WCRP/SPARC/SNAP. Its main goals include: developing additional stratospheric diagnostics and investigating the use of DynVarMIP additional diagnostics to S2S models; Coordinating damping experiments to examine the dynamics of downward coupling studying the link to tropospheric dynamics.

3. Upcoming events

- **S2S Session at European Meteorological Society (EMS) Annual Meeting 2022,** *4—9 September 2022, Bonn, Germany https://www.ems2022.eu*
- **S2S Real-time Pilot Workshop,** *14-17 November 2022, online.*
- **S2S Session at American Geophysical Union (AGU) Fall Meeting 2022**, *12-16 December, Chicago, IL & online. agu.org/Fall-Meeting*
- **S2S Summit**, *3-7 July 2023, Reading, UK*

While the value for an individual turbine or wind farm is modest, across the lifetime of a fleet of wind farms we believe there is potential for significant efficiency saving to be made by incorporating S2S forecasts into maintenance planning in the onshore wind industry and that the opportunity may be greater still offshore where weather-driven accessibility is a major constraint – large waves prevent safe transfer of crew from vessels to wind turbines, for example. Even in Scotland, a part of the world with relatively low predictability on S2S timescales, we found value. Other regions may stand to benefit more. Full details of this work are available in our paper linked below, and we have also suggested some further reading for anyone interested in applications of S2S forecasts and weather and climate services in the energy sector.

Recommended reading:

- Tawn, R.; Browell, J.; McMillan, D. (2022). Subseasonal-to-Seasonal Forecasting for Wind Turbine Maintenance Scheduling. Wind, 2, 260–287, DOI: 10.3390/wind2020015
- White, C. J., *et al.*, (2022). Advances in the Application and Utility of Subseasonal-to-Seasonal Predictions, Bulletin of the American Meteorological Society, 103(6), E1448-E1472, DOI: 10.1175/BAMS-D-20-0224.1
- Weather and Climate Services for the Energy Industry, (2018). Eds. A. Troccoli, DOI: 10.1007/978-3-319-68418-5

Opportunistic Mixture Model for S2S Predictions of Temperature and Precipitation

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Introduction

In the summer of 2021, the S2S project launched a prize challenge to improve sub-seasonal to seasonal predictions using artificial intelligence. The competition attracted contributions by teams from various countries. The winning entry was proposed by CRIMS2S, a team of data scientists from the Computer Research Institute of Montreal, as well as weather experts from Environment and Climate Change Canada. This short article describes the approach used by CRIMS2S for the S2S challenge, as well as its performance on the proposed benchmark. Some baseline experiments made after the challenge ended are also reported.

S2S AI Challenge

Participants to the WMO S2S AI challenge were asked to produce bi-weekly probabilistic forecasts for surface temperature and precipitation for lead times of 3 to 6 weeks. The submitted models are to target CPC daily observations for the two target variables. A training set containing data for years 2000 to 2019 was provided to the participants. Hindcasts from ECMWF, ECCC and NCEP were provided, as well as the corresponding observations. The testing set was year 2020.

Proposed Model

The CRIMS2S team proposed an opportunistic mixture model to formulate the challenge forecasts. It consists of a weighted multimodel ensemble based on five predictions: ECMWF, ECCC and NCEP forecasts, postprocessed using ensemble model output statistics (EMOS); a prediction based on a Convolutional Neural Network (CNN) applied to ECMWF forecasts; and climatology.

The EMOS correction closely follows the standard procedure outlined in Gneiting et al. 2005, in which the forecast probability distribution follows a Gaussian distribution whose parameters are expressed linearly in terms of the ensemble mean and standard deviation. Precipitation is transformed by the 1/3 power to improve normality. To reduce the negative impacts of overfitting, weekly EMOS parameters are smoothed using a rolling 20-week window centered on the target forecast week. The weights of the mixture model are obtained by an additional CNN which uses the reference member of the ECMWF forecasts as input, and outputs weights for each of the five models. This design is intended to capture the overall weather state determined by the ECMWF forecasts, and then infer the relationship between the current conditions and the optimal weight for each model in the ensemble.

Both the postprocessing and the weighting convolutional neural networks have architectures that are largely inspired by ResNet (He et al. 2016), in that they are built with residual blocks containing skip connections. They contain two branches. The first is pooled down to a vector and is meant to represent the forecast globally. The second branch is meant to perform post-processing on the grid points. A fully detailed specification of the architecture is available in the source code[1].

Experiments and Results

Table 1 contains the RPSS against climatology for the proposed model (Conv. Weighting). We add a baseline where all 5 input models are weighted equally instead of dynamically using a neural network (Equal Weights). We performed a regression study where we computed scores for a forecast built only from the ECMWF forecast, corrected via EMOS (ECMWF EMOS) and the convolutional network (ECMWF CONV). Finally, we score the bias-corrected ECMWF forecast which was used as a baseline during the competition.

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[1] https://github.com/crim-ca/crims2s

Model	Area	Surface temperature		Total precipitation		Mean
		Weeks 3-4	Weeks 5-6	Weeks 3-4	Weeks 5-6	
Conv. Weighting (challenge winning entry)	90N-30N	0.099	0.044	0.027	0.013	0.046
	30N-30S	0.101	0.064	0.042	0.026	0.058
	30S-90S	0.037	0.011	0.029	0.016	0.023
	Global	**0.090**	**0.046**	**0.030**	**0.017**	**0.046**
Equal Weighting	90N-30N	0.099	0.056	0.027	0.015	0.049
	30N-30S	0.105	0.064	0.044	0.028	0.060
	30S-90S	0.030	0.004	0.039	0.020	0.023
	Global	**0.090**	**0.051**	**0.031**	**0.019**	**0.047**
ECMWF EMOS	**Global**	**0.080**	**0.022**	**0.019**	**0.007**	**0.032**
ECMWF CONV	**Global**	**0.072**	**0.015**	**0.005**	**-0.010**	**0.020**
ECMWF Benchmark	**Global**	**0.045**	**0.000**	**-0.011**	**-0.041**	**-0.002**

Table 1: RPSS score of different models on the S2S AI Challenge dataset.

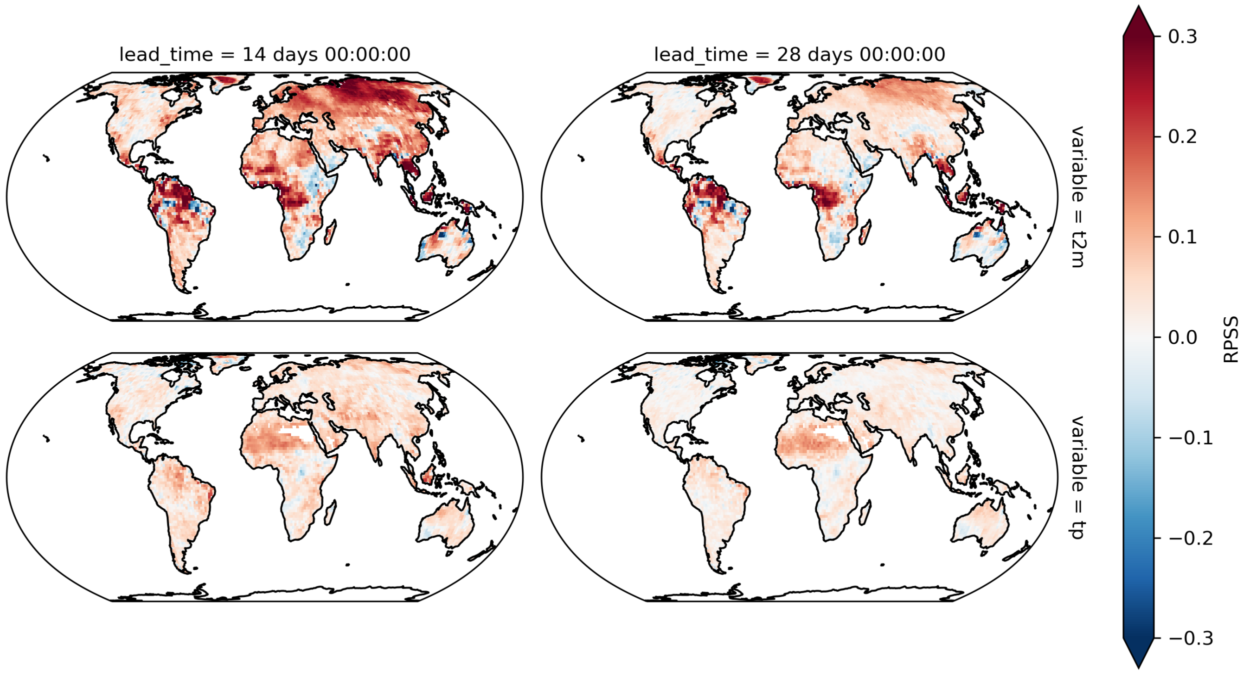

Fig. 1: RPSS for the convolutional weighting model. The upper row shows the score for surface temperature, while the lower row shows the score for precipitation forecast. The left column shows the score for weeks 3-4, while the right row shows the score for weeks 5-6.

While the mixture model was successful in the challenge, the equal-weighted mean of the five input models performs slightly better than the mixture model for 2020 (Table 1). This implies that the backbone of the approach lies in the individually postprocessed dynamical model outputs and their combination. Future work is needed to establish the pertinence of convolutional models for multi-model blending.

The regression study indicates that the ECMWF forecast corrected with a convolutional network does not perform as well as the same forecast corrected with EMOS. However, the errors of both corrected models are not fully correlated, which justifies keeping the two versions in the model ensemble.

As a way to perform introspection, we study the relative weights given to the input models by the mixing CNN. Figure 2 shows the relative weight given to the climatology by the mixing CNN. A higher weight indicates that the CNN gave less weight to the various dynamical models after optimization. The figure conforms to many of our expectations: the relative weight of climatology is higher for precipitation than it is for temperature. The relative weight of climatology increases with the lead time.

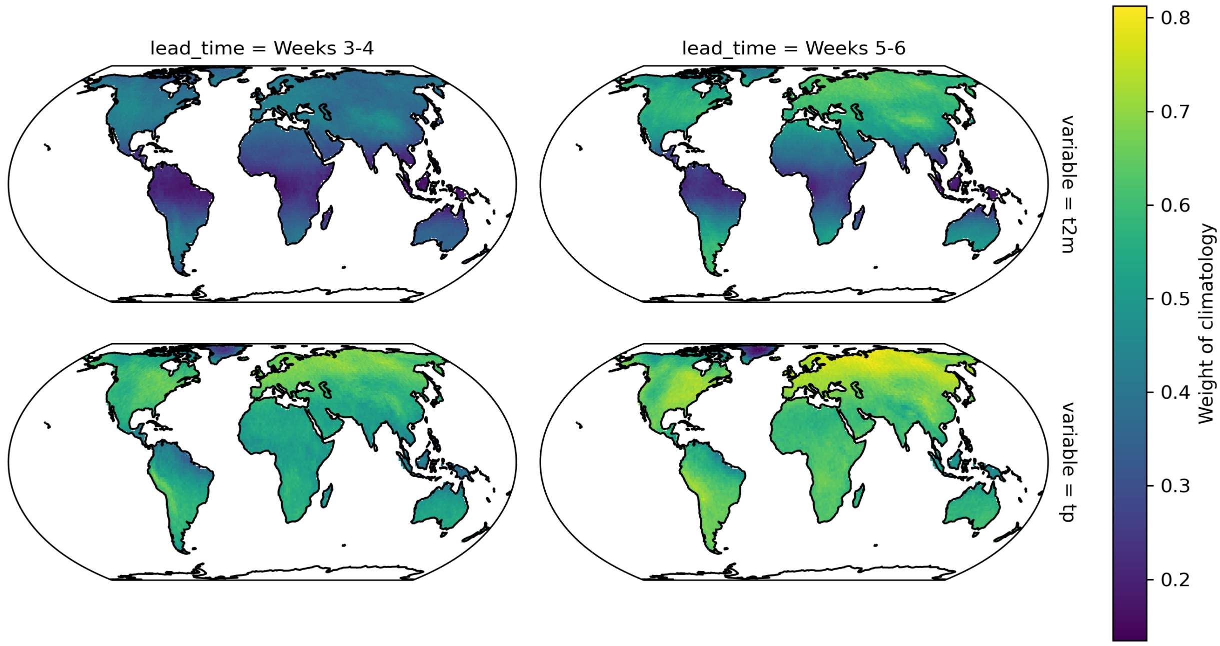

Fig. 2: Relative weight of climatology with respect to the other input models.

Conclusion

This article presented the submission that the CRIMS2S team made to the S2S AI Challenge organized by the S2S project. It proposes to blend the three input forecasts (postprocessed using various methods) and climatology optimally with a convolutional neural network. Experiments performed after the challenge showed that, within the proposed experimental benchmark, a simple average of the five corrected models performs similarly to the more complex convolutional weighing model. Consequently, future work should prioritize demonstrating the pertinence of a convolutional weighting approach within an S2S context. Additionally, other network architectures could be explored that are able to exploit the expected skill from teleconnections.

Recommended readings

- Gneiting, T., A. E. Raftery, A. H. Westveld, and T. Goldman, 2005: Calibrated Probabilistic Forecasting Using Ensemble Model Output Statistics and Minimum CRPS Estimation. *Mon. Weather Rev.*, **133**, 1098–1118, https://doi.org/10.1175/MWR2904.1.

- He, K., X. Zhang, S. Ren, and J. Sun, 2016: Deep Residual Learning for Image Recognition. *2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, Las Vegas, NV, USA, IEEE, 770–778.

WMO S2S Prediction Project Website Makeover

Hyung-Jin Kim, Inja Jeon, Imgook Jung, Sangwon Moon (APEC Climate Center, S2S ICO)

S2S ICO hosted by the APEC Climate Center/Korean Meteorological Administration is proud to announce that the WMO S2S Prediction Project website has been significantly improved to reflect the protocols of S2S Prediction Project Phase II and requests from the steering committee. In this major makeover, ICO upgraded the overall layout, contents, and functionality of the S2S website. Users can now more easily access S2S scientific sub-projects and regional activities at the front page with enhanced visibility and consistency among menus/sub-menus. In addition, it allows the leaders of each subproject and regional activity to provide more project-oriented information through improved management systems. S2S ICO will keep updating contents and information to enhance user experience. We hope users to find it useful for their research and operational works.

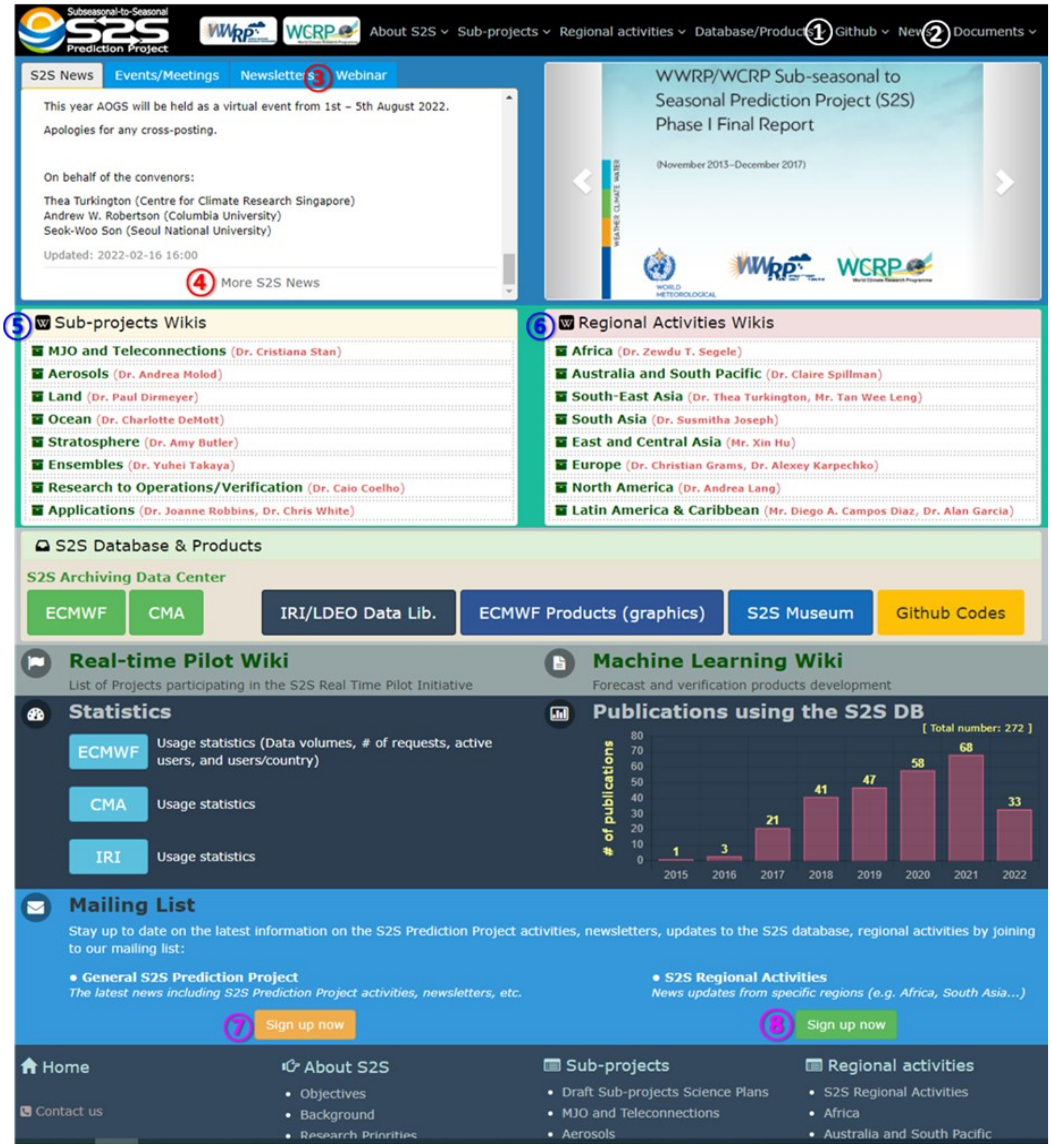

Fig. 1: The front page of the WMO S2S Prediction Project website (http://s2sprediction.net)

The website contains new features as follows.

① Additional S2S Githubs for “S2S R2O Tools” and ‘Diagnostic Tools” opened to systematically collect and manage program codes relevant to research, operations, and applications on S2S times scales. Users are welcome to contribute to these Githubs by either directly uploading program codes along with corresponding descriptions or simply redirecting to their local resources. For those who are willing to join the S2S Github, please feel free to email apccs2sico@gmail.com.

② Adding up sub-menus of “Model Reference Papers” and “SG/LG resources (restricted to SG/LG members only)” in “Documents” tab to list up reference papers for participating models and to share important documents between steering committee members, respectively.

③, ④ “Webinar” and “More S2S News” tabs created to make webinar and news more visible.

⑤, ⑥ Rearranging and renaming “Science Sub-project Wikis” for 8 sub-projects and creating “Regional Activities Wikis” for 8 regional activities to support the modelling and scientific issues of the S2S Prediction Project.

⑦, ⑧ Separating the regional activity mailing list from the general mailing list to manage regional activities more systematically and efficiently, and also to facilitate regional communications.

NCAR/NOAA/WMO Workshop on S2S Science and Applications, Boulder, Colorado, July 11-15, 2022

Aneesh Subramanian (University of Colorado) and

A one-week workshop on "The Science of Subseasonal to Seasonal (S2S) Predictions and Applications" was held July 11-15, 2022 at the National Center for Atmospheric Research in Boulder, Colorado. The workshop was primarily intended for students and lecturers who participated in the 2021 NCAR/ASP summer colloquium, which was held virtually due to the COVID pandemic-related restrictions. The workshop brought together experts from academia and operational centers including climate and weather forecasting experts, hydrologists, oceanographers, program managers from federal (NOAA) and regional program agencies (e.g., California Department of Water Resources, Western States Water Council), research centers (e.g., NCAR, IRI, CW3E), and international participants from various institutes and universities (e.g., NCEP, ECMWF, JMA-MRI, University of Reading, Australia Bureau of Meteorology). Recent advancements in S2S prediction science and their applications for water resource management, energy management and state-of-the-art techniques to identify sources of skill on S2S timescales were presented during the workshop.

The workshop featured latest research from domestic and international experts on the fundamental processes leading to S2S predictability such as the Madden-Julian Oscillation, El Niño Southern Oscillation, processes related to the stratosphere, and atmospheric interactions with the ocean, land and cryosphere. It provided the participants with an integrated conceptual understanding of earth system processes that influence S2S predictions, numerical modeling, initialization strategies, machine learning and ensemble configuration and applications of S2S-predictions. The workshop also included two afternoons of breakout discussion sessions and presentations from program managers. The participants discussed challenges and future research directions for improving S2S prediction skills. Many important directions for future work were highlighted by the students and lecturers including increased research on multiscale and multi-(earth system)-component diagnostics to identify unique sources of S2S predictability in the earth system.

The lectures were complemented by an excursion to one of Boulder's hydroelectric facilities in the Canyon (Boulder Canyon Hydro) and reservoirs (Barker Reservoir in Nederland). The excursion gave the students an opportunity to learn about the local hydroelectric facilities that supply energy and water to the region and how they are managed (including how S2S forecasts are used for their management).

Fig. 1: Students and water management engineer having a conversation (left) about water resource management at the Barker reservoir (shown on the right)

The key highlights of the workshop presentations were the student fellow presentations on the ongoing work based on the five hands-on tutorials of the 2021 summer school:

- Hydrology application to the Oroville dam and 2018 Japan floods
- US West Coast Precipitation forecasts
- Weather-typing with IRI's PyWR diagnostic package
- Flow-dependent verification of S2S forecasts
- S2S predictions using machine-learned teleconnection patterns

The workshop was supported by NCAR's Education, Engagement and Early Career Development center, the Mesoscale & Microscale Meteorology Laboratory, the Climate and Global Dynamics Laboratory and NOAA's Weather Program Office. Additional funding from WMOs subseasonal-to-seasonal project allowed several international early career scientists to attend.

The agenda and slides can be accessed from the workshop websites:

https://www.cgd.ucar.edu/events/2022/asp-colloquia/

https://www.cgd.ucar.edu/events/2021/asp-colloquia/

Recordings are available on the YouTube channel.

Harmonizing Intraseasonal Climatologies

Ángel G. Muñoz, Xandre Chourio, Kyle Hall, Andrew W. Robertson
(International Research Institute for Climate and Society (IRI). The Earth Institute at Columbia University)

The calculation of both observed and forecast “climatologies” are a key building block for the climate research and services communities. It helps to define reference states in observations and models, to compute and analyze deviations from that reference state (i.e., anomalies), and to correct certain systematic errors in models.

A climatology is the expected -or average- value of the variable of interest for a particular location and averaging period; e.g., a weekly climatology corresponds to the expected value of each one of the weeks of the year in a certain period (say, 1999-2010). When dealing with forecast climatologies, the calculations need also to consider initial times (when the forecast is produced), target periods (the actual periods being forecast) and lead times (the time between the target period and the initial time, or how far in advance the forecast is produced). For the sake of simplicity -but without losing generality- the rest of this contribution focuses on daily climatologies; pentad, weekly, bi-weekly climatologies and so on can be constructed from daily ones by averaging or accumulating, depending on the case of interest.

The simplest method, called “naïve” (Tippet et al., 2018), to compute a forecast climatology is to just average hindcasts with the same start time, target period and lead time from all years available in the hindcast. For example, to compute the daily forecast climatology of Valentine’s Day (target), all Feb 14th in the hindcast period (e.g., 1999-2010) need to be averaged, keeping the same start time and lead time fixed. The calculation can be repeated, as needed, for all start times and lead times of interest.

The *naïve approach* is easy to compute, but if some start times are not available in the hindcast, the method will not be able to produce a climatology and hence forecast anomalies. This problem tends to happens when the operational forecast schedule does not coincide with that of the hindcast. A different method is needed in such cases.

To address this problem, a “triangular” method was proposed by Pegion et al. (2019). In this approach, a moving average with a 30-day triangular kernel (weighting function) on the naïve climatology is used, centered on the target day. For example, the climatological day March 15th has contributions from the previous and following 15 days, following a triangular weighting with the maximum weight located on March 15th. This method is the one used by the Subseasonal Experiment (SubX) project, as described by Pegion et al. (2015).

Compared to the naïve one, the triangular approach is a non-local method in the sense that the climatology (and hence anomaly) calculation uses information that depends not only on the target day, but also a “neighborhood” of 15 days on each side. A non-local generalization is presented here for the first time, called “harmonic”.

The harmonic method fits a Fourier series to the naïve climatology to produce the smoothed daily time series. After testing with multiple truncations to identify the configuration that best capture the characteristics of local seasonal cycles, the final climatology uses N=16 harmonics for total precipitation (tp), and N=6 harmonics for 2-meter temperature (2t), where N is the number of harmonics. Here, the truncation is determined by finding the value of N for each variable that minimizes the spatially-averaged Root Mean Square Error (RMSE) between the harmonic and the triangular methods. A RMSE comparison considering a daily climatology produced via a simple 5-day running average as reference is also used for comparison purposes between the methods.

An example comparison between the approaches is presented in Figure 1 (for only the ECMF, NCEP and UKMO models, but climatologies have been computed for all models, see below). As it might be expected, the value of the harmonic method as a non-local (annual) approach tends to be seen in those models for which the start times are scarcer, such as the UKMO model.

As expected, the accuracy of each method will depend on the number of hindcast years being used (better accuracy for larger number of hindcast years), and on the variance of the forecast anomaly of the variable of interest (better accuracy for lower variance).

Daily climatologies using the naïve, triangular and harmonic approaches discussed above have been computed by the International Research Institute for Climate and Society (IRI) for 10 models in the S2S Prediction Project Database and three different observational datasets, and the results are publicly available in the IRI Data Library (Figure 2). It is left to each user of these products to decide which one is better, depending on the particular research and application case of interest.

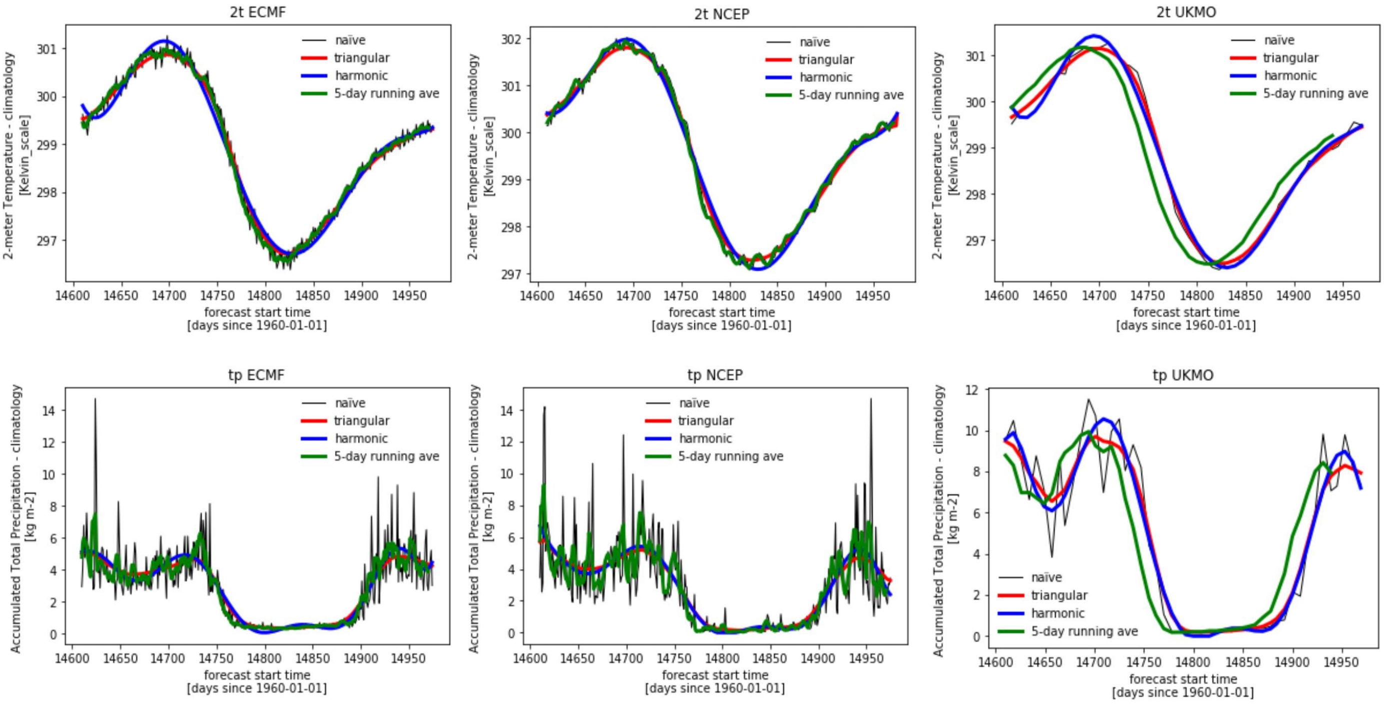

Fig. 1: Comparison between the naïve (black), triangular (red), harmonic (blue) and 5-day running-average (green) methods, for 2-meter temperatures (2t, upper row) and total precipitation (tp, lower row) as represented in the ECMF, NCEP and UKMO models. An arbitrary tropical location is used in this example.

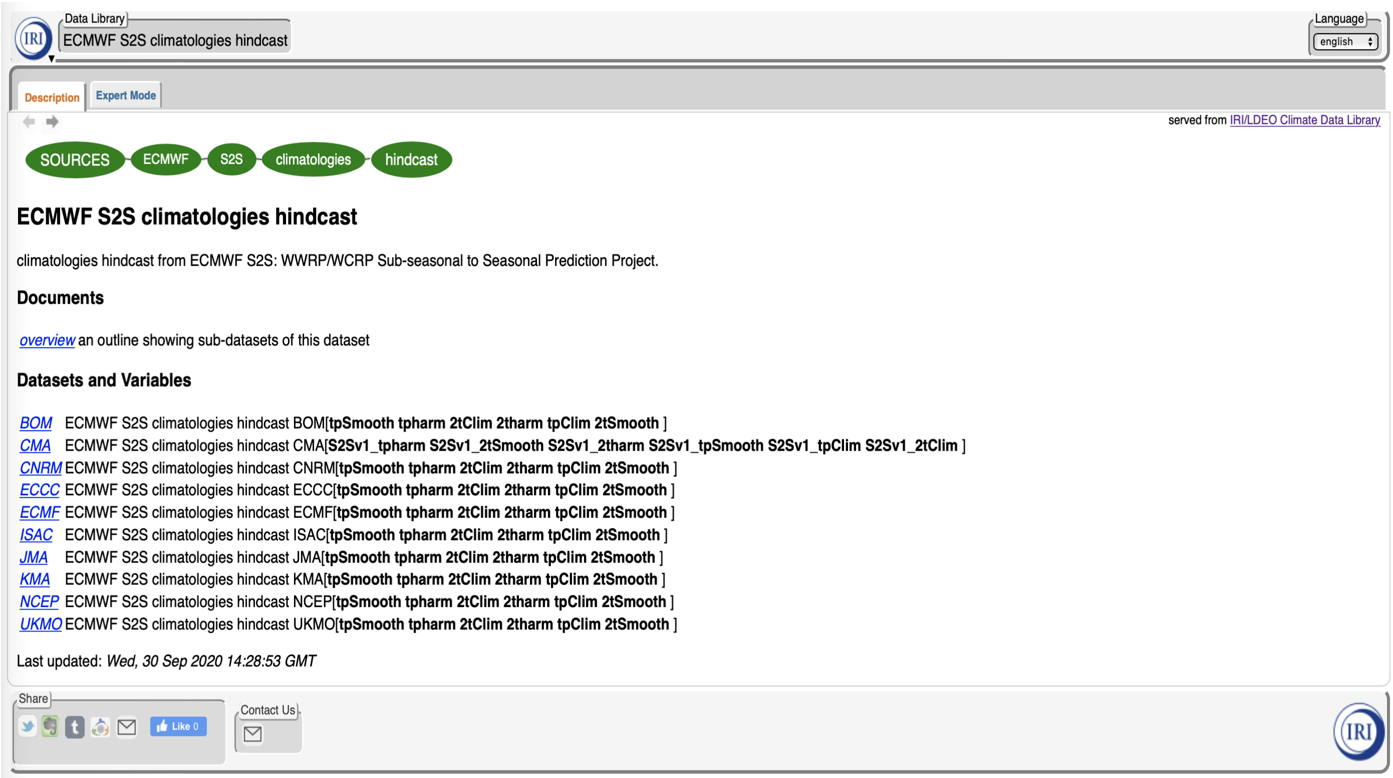

Fig. 2: IRI Data Library site with the daily climatologies for total precipitation (tp) and 2-meter temperature (2t) computed using the naïve (Clim), triangular (Smooth), and harmonic (harm) methods.

References

- Tippett, M. K. *et al.* (2018) 'Sources of bias in the monthly CFSv2 forecast climatology', *Journal of Applied Meteorology and Climatology*, 57(5), pp. 1111–1122. doi: 10.1175/JAMC-D-17-0299.1.
- Pegion, K. *et al.* (2019) 'The subseasonal experiment (SUBX)', *Bulletin of the American Meteorological Society*. American Meteorological Society, 100(10), pp. 2043–2060. doi: 10.1175/BAMS-D-18-0270.1.

Call for articles for the S2S Newsletter

S2S ICO welcomes the submission of articles to the S2S Newsletter related to research in a diverse range of S2S subprojects or on recent events for a "State of the Climate". The S2S Newsletter is published every four months.

Please contact Ms. Inja Jeon, at the S2S ICO, at alliswell1122@apcc21.org with any submissions to the S2S newsletter.

S2S ICO based in APCC in Busan, Republic of Korea

The S2S International Coordination Office (ICO) is located at the **APEC Climate Center (APCC)** in Busan, Republic of Korea.