Climate Prediction Center Stakeholder Meeting

24-26 September 2019

Performance Evaluations Improvement Requirements Development Updates

National Weather Service
National Oceanic and Atmospheric Administration
Department of Commerce

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National Weather Service
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OVERVIEW

NOAA's Climate Prediction Center (CPC) Stakeholder Meeting was held at the NOAA Center for Weather and Climate Prediction in College Park, Maryland from 24-26 September 2019. The meeting focused on five major aspects of the CPC's operationally delivered subseasonal to seasonal (S2S) climate prediction and monitoring products:

- Recent performance of CPC operational products
- New products to be released for the upcoming year
- New and improved products currently under development
- Feedback from stakeholders on recent product performance
- Feedback from stakeholders on their requirements for improved and new products and the products CPC currently has under development

The meeting featured ten plenary presentation sessions and nine discussion breakouts. In plenary sessions, the product producers briefed core partners on CPC products, their near-term evolution, and researches to improve existing and develop new products; the application partners showed how CPC products were used and what improvements desired. In breakouts, the needs of improvements to existing products and development of new products were discussed in depth. The meeting enhanced mutual understanding between CPC and core partners nationwide.

This volume is a collection of extended summaries of the presentations contributed by the meeting participants. The information will be used to improve the delivery and usability of the existing products (e.g., additional parameters, format change etc.) and inform development of new products and improvements to existing products.

CONTENTS

1. TEMPERATURE AND PRECIPITATION OUTLOOKS, HAZARD OUTLOOKS, AND DROUGHT OUTLOOK / DROUGHT MONITOR

Week-2 U.S. Hazards Outlook

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1. Background: Product evolvement

The Climate Prediction Center (CPC) has issued the U.S. Hazards Outlook for 17 years, which spans the 3-14 day lead time. As of early 2019, the day 3 to 7 lead time of the hazards forecast has been transferred to the Weather Prediction Center (WPC), which aligns with their time domain. Therefore, CPC forecasters and developers are able to focus more on improving and developing the 8 to 14 day (week-2) hazards outlook. The U.S. Hazards Outlook was originally in deterministic format until August 2014. Since 2014, CPC has used a phased approach to transitioning the forecast variables from a deterministic to a probabilistic format, since probabilistic forecasts are a more appropriate format than deterministic at the week-2 lead.

Currently the hazards variables available in probabilistic format are: much below normal temperatures, much above normal temperatures, excessive heat, heavy precipitation, heavy snow, and high winds. The shift to probabilistic format allows CPC to show increased chances for hazardous weather and climate conditions, which allows CPC to identify hazards at a longer lead than before. Previously, CPC forecasters would only be able to delineate higher probability hazards, which is less common at the week-2 lead. This allows CPC to support and improve the NWS mission of decision support services (DSS).

2. Product specification and evaluation

A U.S. hazards composite map (Fig. 1) is available that serves as a summary map of hazards that is not in a probabilistic format. It contains hazards that 1) have a moderate probability risk and 2) do not have yet an objective probabilistic tool associated with it (e.g. frozen precipitation, flooding). The probabilistic hazards outlook maps (Fig. 2) highlight the potential for increased chances of hazards of the aforementioned variables. The outlook is issued daily on weekdays. The CONUS and Alaska outlook is depicted on forecast maps, and Hawaii is covered in the text discussion. The text discussion also includes more details regarding the potential hazards and other hazards that may be a possibility but do not pass the criteria to designate them on a map at that time.

The probabilistic hazard maps indicate risk levels (slight, moderate, and high) of a hazard, which is associated with a forecast probability (20%, 40%, and 60%, respectively). The forecast probabilities are primarily based on objective forecast probabilities from the CPC extremes tool. This is the main guidance used by hazards forecasters to produce the outlook. The CPC extremes tool is post-processed model output, which is calibrated using paired reforecasts and observations over a long term (GEFS uses 25 years, ECMWF 20 years).

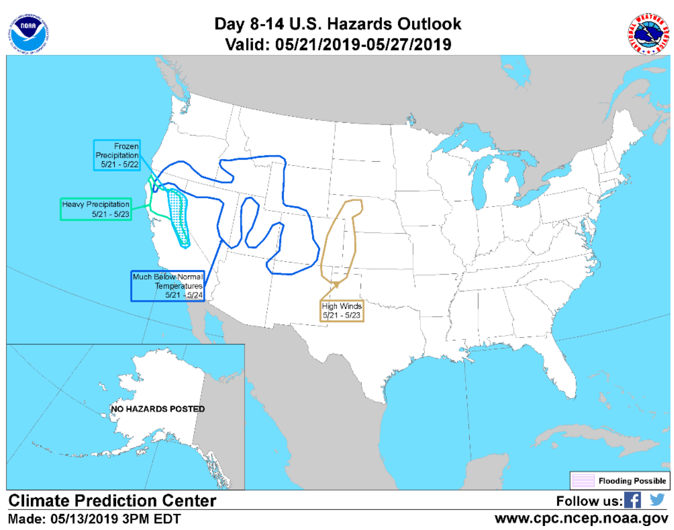

Fig. 1 Sample week-2 U.S. hazards outlook composite map.

Forecasts are somewhat subjective but based on objective tools. The hazards forecasters use various dynamical models, post-processed model guidance tools, and thresholds to produce the forecast. Thresholds used to identify possible hazards vary temporally, spatially, and situationally and are based on percentiles as well as actual values.

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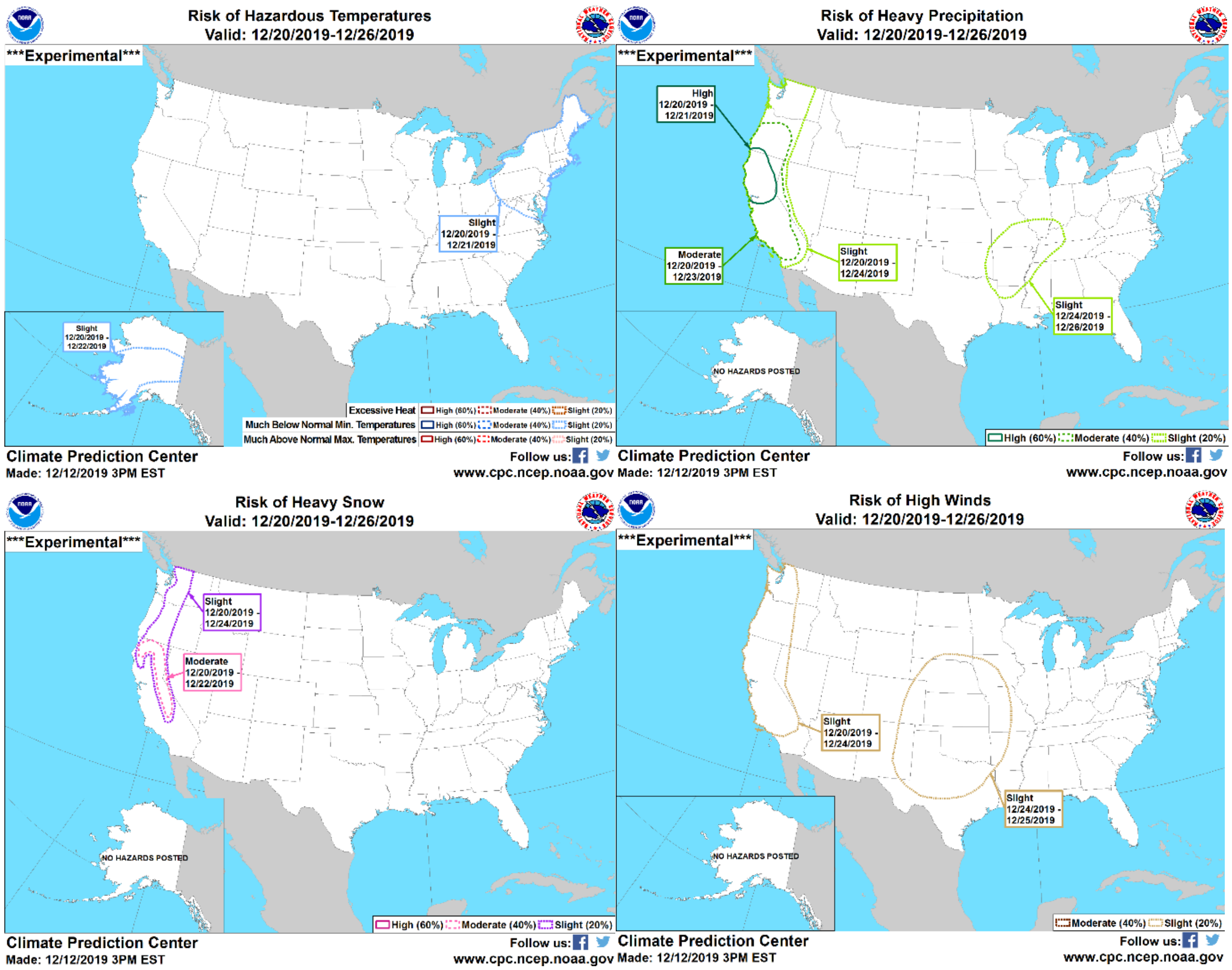

Fig. 2 Sample probabilistic outlook maps of hazardous temperature (top left), precipitation (top right), snow (bottom left), and wind (bottom right).

3. Issues and research for improvement

The subjective nature of the hazards outlook poses a challenge for trying to perform objective skill evaluation. The CPC plans to draft a strategy in the upcoming year to try to do an initial evaluation of the hazards. There are currently efforts to implement the NCAR-DTC Model Evaluation Tool (MET) at CPC, which may help facilitate producing objective skill results of the hazards outlook. This MET software creates objective verification and has a multitude of available formats of output as well as skill metrics. The hope is that this MET Tool, in conjunction with support from the MET team, will help facilitate objective skill results for the hazards outlook.

Additional future planned work includes developing a post-processed model guidance tool to support the probabilistic heavy snow forecast. In the future, the CPC plans to continue to include more hazards variables in probabilistic format in the outlook.

References

Ou, M., K. Pelman, M. Charles, and J. Gottschalck, 2015: CPC's new week-2 probabilistic hazards forecast and extremes tool. *Climate Prediction S&T Digest: NWS Sci. & Technol. Infusion Clim. Bull. Suppl., 39th NOAA Annu. Clim. Diagn. Predict. Workshop*, St. Louis, MO, 20-23 October 2014, 21-31, https://doi.org/10.7289/V5MW2F51

NOAA's Climate Prediction Center Stakeholder Meeting
College Park, MD, 24-26 September, 2019

Stratospheric Tools for Week 3-4 Temperature and Precipitation Outlooks

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1. Background

In September 2015, the Climate Prediction Center (CPC) began issuing experimental Week 3-4 temperature (T2m) and precipitation outlooks. The T2m outlooks have since become operational while precipitation outlooks remain experimental due to relatively modest forecast skill during the period. The source of skill in the T2m forecasts largely arises from tropical variability, including the Madden Julian Oscillation (MJO) and the El Niño Southern Oscillation (ENSO), along with the long-term trend. To continue improvements to the forecast skill, stratospheric sources could potentially provide additional new guidance, particularly during periods when the Tropics are quiet, such as during ENSO neutral conditions.

One source of potential new guidance is from the extratropical stratospheric circulation, or more specifically, the downward coupling between the stratosphere and troposphere. The ability of dynamical models to capture this coupling is currently limited, so an attempt to identify potential influences of the stratosphere on the troposphere was made by testing various indicators of stratospheric-tropospheric coupling into CPC's multiple linear regression (MLR) model. The MLR tool, which runs operationally and currently incorporates the MJO, ENSO, and a linear trend to predict Week 3-4 T2m and precipitation, was expanded to include a predictor characterizing the extratropical stratospheric circulation.

Tropical stratospheric variability, as indicated by the phase of the Quasi-biennial Oscillation (QBO), was also examined as a potential source of guidance. The QBO manifests itself in the tropical stratosphere and consists of downward propagating zonal wind anomalies that shift between easterly and westerly regimes every ~2 to 3 years. Recent research has shown that the QBO is capable of modulating the MJO's amplitude and its teleconnections around the globe (Wang *et al.* 2018; Yoo and Son 2016). As it is unclear how well this MJO/QBO relationship is captured in dynamical models, we tested the addition of the QBO as a predictor to CPC's phase model in order to see if additional T2m/precipitation skill could be obtained.

2. Evaluation of the stratospheric predictors

a. Extension of the MLR to include extratropical stratospheric-based predictors

Three types of extratropical stratospheric predictors were tested within the MLR framework and characterized as: 1) the strengthening/weakening of the stratospheric polar vortex, 2) leading patterns of zonal mean circulation throughout the stratosphere and troposphere, and 3) coupling between the stratospheric and tropospheric circulation; which are represented by red, green, and blue lines, respectively in Figure 1. Each stratospheric predictor was added separately to the original 3-predictor MLR (oMLR) to create an extended 4-predictor MLR (eMLR). Comparisons of the skill of the Week 3-4 T2m forecasts made from the oMLR and eMLR were examined to determine if the stratospheric predictors added appreciable skill to the forecast. Skill of the forecasts is assessed and compared two ways: 1) across the retrospective forecast period (1982-2014) at each grid point using the leave-one year out method and 2) across the real-time forecast period (2015-2019) for the continental United States/Alaska (CONUS/AK) for each forecast period.

During the 32-yr retrospective period, adding any of the stratospheric predictors to the MLR resulted in a statistically significant improvement in explained T2m variance during the winter months relative to the oMLR. During the 4+ year real-time period, daily Week 3-4 T2m forecasts were made using the eMLR and oMLR and were verified across the CONUS/AK using the Heidke Skill Score (HSS). Adding each

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stratospheric predictor provided periods of more skillful forecasts than the oMLR (Fig. 1). Interestingly, the improved forecast skill is not just confined to periods following sudden stratospheric warmings (SSW) events alone, but also show improved skill during other significant stratospheric events such as during the Oct-Nov 2016 period. As expected, the largest improvements in forecast skill tend to occur from late fall through early spring when the polar vortex is most active. The stratospheric predictor that yielded the best improvement relative to the oMLR characterized coupling between the stratosphere and the troposphere rather than just stratospheric variability alone, demonstrating about a 10% improvement in forecast temperature skill during the winter seasons (Table 1). Actually, only the coupling predictor showed improved scores during the real-time period, with the other two predictors having slightly lower HSS during both winter and throughout the year.

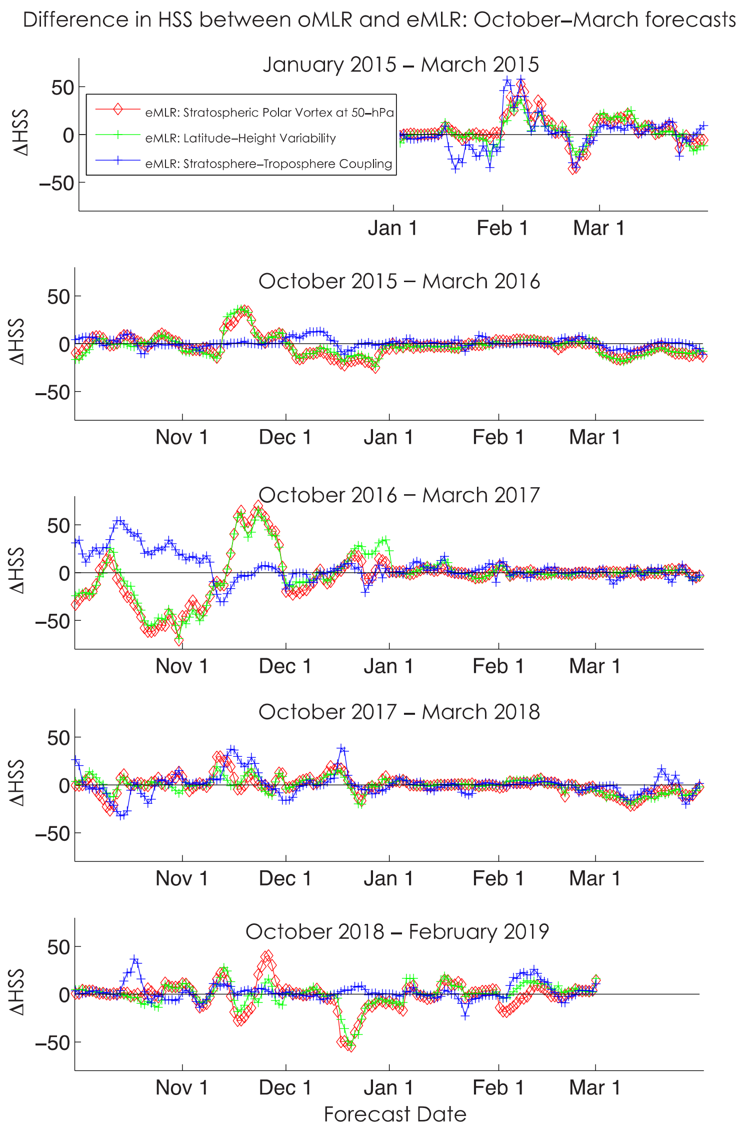

Fig. 1 Change in HSS between the original and extended MLR T2m forecasts for each forecast during the 2015-2019 real-time period. Positive values denote an improvement from the original MLR.

b. Extending the phase model to include the QBO as a predictor

The current version of the phase model incorporates the long-term trend along with the current phases of ENSO and the MJO as predictors. We tested a new version of the phase model which adds the current phase of the QBO as a predictor. For brevity, the two versions of the phase model are denoted as MJO|ENSO and MJO|ENSO|QBO, respectively. Both versions of the phase model were run with comparisons of their skill in forecasting Week 3-4 T2m and precipitation across CONUS/AK produced by the following two approaches: 1) during a retrospective period (1979-2017), using a leave-one-year-out cross validation approach, and 2) during a real-time forecast period (2011-2018), where the training data was derived from the 1981-2010 climate normal period. Skill is assessed using the HSS as above.

Predictor	ΔHSS all forecasts (% change)	ΔHSS Oct-Mar forecasts (%change)
Stratospheric Polar Vortex at 50-hPa	-0.96(-4%)	-1.06 (-5%)
Zonal mean stratosphere-troposphere variability	-0.56(-3%)	-0.74 (-4%)
Stratosphere-troposphere coupling	0.96(5%)	2.07 (11%)

Table 1 Change in the mean HSS between the original and extended MLR forecasts of T2m over the 2015-2019 real-time period. Positive values denote an improvement relative to the original MLR. Values in parentheses represent the fractional change in HSS relative to the mean HSS of the original MLR.

During the retrospective period, the MJO|ENSO|QBO phase model added ~3 to 5 points of skill for both T2m and precipitation across CONUS/AK, depending on the season, as compared to the MJO|ENSO phase model. Of particular note, T2m forecasts showed skill scores greater than 20 during autumn, improving on the MJO|ENSO phase model by ~50%. However, results from the 2011-2018 real-time period were less promising. For T2m, adding the QBO to the phase model actually decreased skill scores from 15.4 to 10.2. On the other hand, precipitation skill scores were slightly increased from 2.1 to 3.0. Interestingly, when skill

		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	Avg
T2m	MJO|ENSO|QBO	8.2	6.5	17.1	21.5	21.4	12.1	4.8	9.2	14.2	14.5	6.9	4.9	12.6
	MJO|ENSO	10.5	6.4	18.8	26.0	26.8	19.3	7.9	9.7	5.9	5.0	0.8	3.4	13.6
	ΔHSS	-2.3	0.0	-1.7	-4.5	-5.4	-7.2	-3.1	-0.5	8.3	9.4	6.1	1.6	-1.0
Precipitation	MJO|ENSO|QBO	4.7	2.6	2.1	0.7	4.0	3.2	3.8	5.5	9.2	7.4	1.6	0.3	3.7
	MJO|ENSO	1.4	-1.3	1.0	-0.1	2.3	0.9	1.6	4.9	6.9	7.9	2.3	1.1	2.2
	ΔHSS	3.3	3.9	1.1	0.9	1.6	2.3	2.2	0.6	2.3	-0.6	-0.7	-0.8	1.4

Table 2. Seasonal change in HSS between the original MJO|ENSO phase model and the MJO|ENSO|QBO phase model during ENSO neutral initializations for T2m and precipitation forecasts during the 2011-2018 real-time period. Values in red denote an improvement from the original MJO|ENSO phase model.

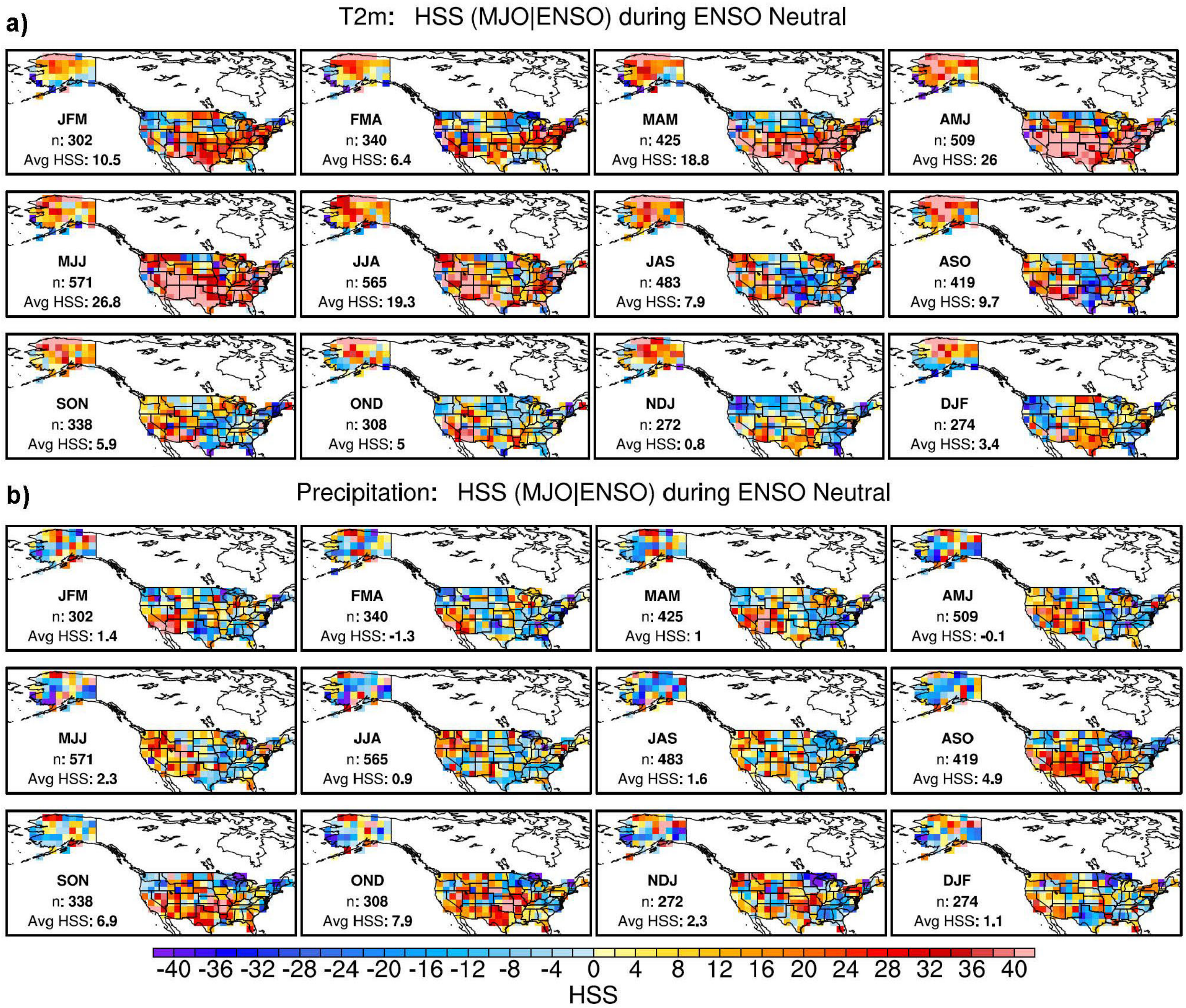

Fig. 2 HSS in the original MJO|ENSO phase model during ENSO neutral initializations for a) T2m and b) precipitation forecasts during the 2011-2018 real-time period. Sample sizes (n) and area-averaged HSS for each season are noted.

scores were only averaged during ENSO neutral initializations, the MJO|ENSO|QBO phase model showed more promise (Table 2). Specifically, the disparity in T2m skill scores decreased, with the MJO|ENSO|QBO phase model increasing its score to 12.6 and the MJO|ENSO model decreasing its score to 13.6. For precipitation, the scores were 3.7 and 2.2, for the MJO|ENSO|QBO and MJO|ENSO phase models, respectively. Separating by season, the MJO|ENSO|QBO phase model outperforms the MJO|ENSO phase model during the fall and winter months for T2m and during most months for precipitation (values highlighted in red in Table 2) during ENSO-neutral periods.

Figure 2 provides the regional and seasonal breakdown of HSS for the original MJO|ENSO phase model during ENSO neutral conditions (essentially just MJO forcing). For T2m, there is widespread positive skill during spring and summer, while for precipitation positive skill is mainly confined to the south and west during fall. Figure 3 provides the regional breakdown of the change in HSS (ΔHSS) between the MJO|ENSO|QBO and MJO|ENSO phase models, as a function of season. For T2m, most of the increase in skill occurs over Alaska along with locations mainly west of the Mississippi River during the fall and winter months. For precipitation, the maps are noisy, but some regions of enhanced skill may be seen in southwestern Alaska and along the lower Mississippi River Valley.

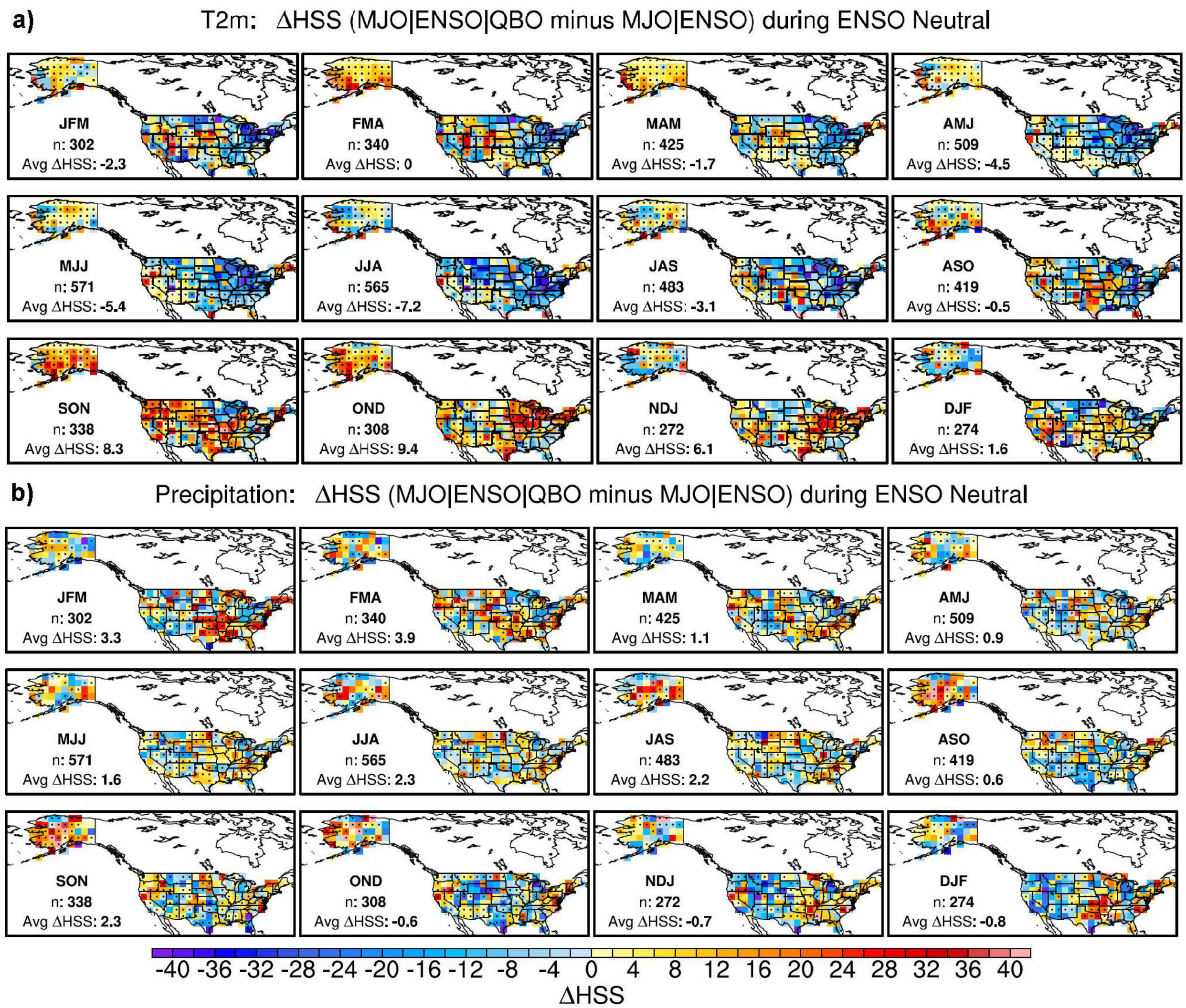

Fig. 3 Seasonal change in HSS between the original MJO|ENSO phase model and the MJO|ENSO|QBO phase model during ENSO neutral initializations for a) T2m and b) precipitation forecasts during the 2011-2018 real-time period. Positive values denote an improvement from the original MJO|ENSO phase model. Sample sizes (n) and area-averaged ΔHSS for each season are noted. Black dots indicate where and when the MJO|ENSO|QBO phase model has positive HSS.

3. Future research

a. MLR model

Given the 10% increase in HSS over the last 4.5 years of real-time forecasts, the extended MLR with stratosphere-troposphere coupling will be experimentally implemented and run throughout the winter 2019-2020. These forecasts will be made in addition to the operational MLR and will be made readily available to CPC forecasters.

b. Phase model

As noted in Section 2b, the QBO adds skill sporadically during certain seasons for particular regions during ENSO neutral conditions. This information could prove valuable, as when ENSO is in a neutral state, the current MJO|ENSO phase model often has little skill or even provides much forecast other than the trend. Also, because the cross-validation results were promising, additional monitoring of the potential of adding the QBO will be conducted. This is particularly true in light of recent research that shows the MJO/QBO relationship may be a phenomenon that has emerged in our current climate due to the warming of tropical sea surface temperatures (Klotzbach *et al.* 2019). Thus, when the climate normal period changes to 1991-2020 (at some point in 2021), there may be appropriate training data to capture the MJO/QBO relationship and thereby improve the real-time version of the phase model.

References

Klotzbach, P., S. Abhik, H. H. Hendon, M. Bell, C. Lucas, A. G. Marshall, and E. C. J. Oliver, 2019: On the emerging relationship between the stratospheric Quasi-Biennial oscillation and the Madden-Julian oscillation. *Sci Rep*, 9, 2981. https://doi.org/10.1038/s41598-019-40034-6

Wang, J., H.-M. Kim, E. K. M. Chang, and S.-W. Son, 2018: Modulation of the MJO and North Pacific storm track relationship by the QBO. *J. Geophys. Res.*: *Atmos.*, **123**, 3976-3992. https://doi.org/10.1029/2017JD027977

Yoo, C., and S.-W. Son, 2016: Modulation of the boreal wintertime Madden-Julian oscillation by the stratospheric quasi-biennial oscillation. *Geophys. Res. Lett.*, **43**, 1392-1398. https://doi.org/10.1002/2016GL067762

NOAA's Climate Prediction Center Stakeholder Meeting
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Prediction of Atmospheric Rivers

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1. Background

Atmospheric Rivers (ARs) are long, narrow, and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone (AMS glossary definition). These plumes of water vapor are typically detected using the following 2 criteria: 1) the intensity of integrated water vapor transport and 2) the geometric characteristics defined by total area and the length-to-width ratio such that the water vapor feature is sufficiently plume-like (see Figure 1).

Landfalling ARs that interact with the orography (*e.g.* the California coast) can lead to extreme precipitation events and flooding. In addition to heavy precipitation, ARs are also associated with extreme winds, accounting for up to 50% of surface wind extremes along the U.S. west coast (Waliser and Guan, 2017). While these features can cause destruction along the west coast of the United States, they can also benefit society - providing up to 50% of the water supply to regions of the western U.S. (*e.g.* Dettinger *et al.*, 2011). As such, skillful forecasts of ARs on subseasonal-to-seasonal (S2S) timescales would support many aspects of society, *e.g.* emergency management, water managers, shipping route designation, and agricultural practices.

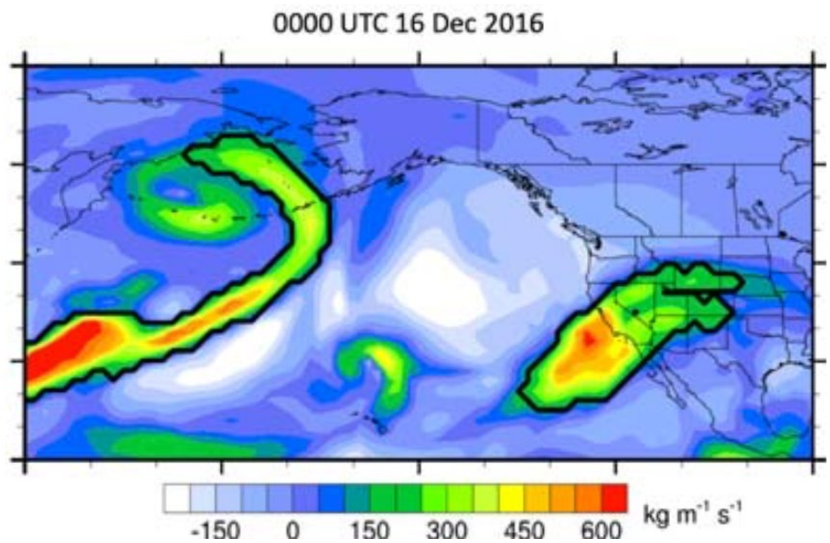

Fig. 1 Atmospheric Rivers (black outlines), based on vertically integrated vapor transport anomaly (shading), that impacted the US west coast in December 2016.

2. Product specification

The objective of the project is to develop/transition empirical guidance that predicts anomalous AR frequencies based on the Madden Julian Oscillation (MJO) and the Quasi-biennial Oscillation (QBO) using a methodology similar to that of Johnson *et al.* (2014). The AR detection scheme was originally developed at Colorado State University (Mundhenk *et al.* 2018). The product will be implemented to provide probabilistic forecasts of anomalous AR activity in support of the precipitation outlooks at Days 6-10, Days 8-14, and Weeks 3-4.

The project consists of collaboration between internal CPC participants (Laura Ciasto and Dan Harnos), who handle the transition of the products to the CPC operational framework, and external CSU participants (Elizabeth Barnes, Cory Baggett, Eric Maloney, and Kyle Nardi) who provided the original code and continue to explore the possibilities of extending/improving the empirical model.

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3. Experimental forecasts

Figure 2 shows an example of the Probabilistic 8-14 Day forecast of anomalous AR activity issued on September 2, 2019 when the QBO was in the westerly phase and the MJO was in phase 5. In addition to the AR probabilities (shading), the contours correspond to the 500-hPa height anomalies forecasted by the empirical model. The addition of the contours allows the forecaster to compare the circulation features with those from other tools such as the dynamical models. Since the beginning of the project, a key improvement to the product has been the expansion of the AR forecasts from the west coast to the entire continental US and Alaska. While much of the literature surrounding the mechanisms and impacts of ARs have focused primarily on the west coast, recent literature as well as research at CSU suggest that ARs may be skillfully predicted in other regions of the US.

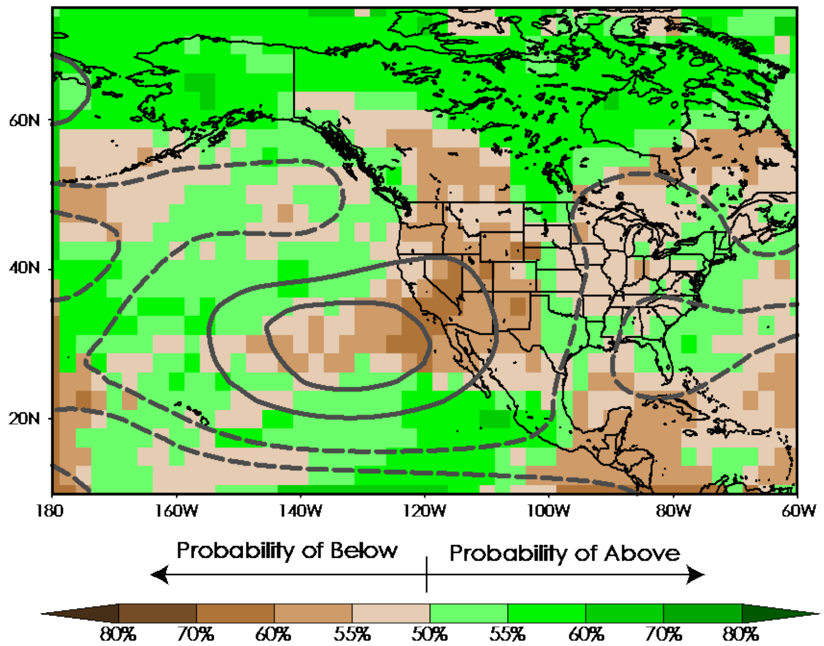

Fig. 2 An example of the Days 8-14 probabilistic AR activity forecast (shading) and 500-hPa geopotential height anomalies (contours) issued on September 2, 2019 and valid for September 10-16, 2019.

The product is currently running experimentally in real-time throughout the winter of 2019-2020 and will be verified using Heidke Skill Score.

References

Dettinger, M. D., F. M. Ralph, T. Das, P. J. Neiman, and D. R. Cayan, 2011: Atmospheric rivers, floods and the water resources of California. *Water*, **3**, 445–478. https://doi.org/10.3390/w3020445

Johnson, N. C., D. C. Collins, S. B. Feldstein, M. L. L'Heureux, and E. E. Riddle, 2014: Skillful wintertime North American temperature forecasts out to 4 weeks based on the state of ENSO and the MJO. *Wea. Forecasting*, ***29***, 23–38. https://doi.org/10.1175/WAF-D-13-00102.1

Mundhenk, B., E. A. Barnes, E. Maloney, and C. Baggett, 2018: Skillful empirical subseasonal prediction of landfalling atmospheric river activity using the Madden-Julian Oscillation and the Quasi-biennial Oscillation, *npj Clim. Atmos. Sci.*, 1:20177. https://doi.org/10.1038/s41612-017-0008-2

Waliser, D. and B. Guan, 2017: Extreme winds and precipitation during landfall of atmospheric rivers. *Nature Geosci.*, **10**, 179–183. https://doi.org/10.1038/ngeo2894

NOAA's Climate Prediction Center Stakeholder Meeting
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Sub-X Verification

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1. Background

The Subseasonal Experiment (SubX) is a multi-model subseasonal prediction project designed around operational needs to fill the "gap" that exists in our current prediction systems at the subseasonal timescale (*i.e.*, 2-weeks to months) (Pegion *et al.*, 2019). Seven global models have produced fifteen years of retrospective (re-) forecasts and more than two years of weekly realtime forecasts (began in 2017). The ongoing weekly forecasts provide guidance to the week 3/4 outlooks issued by the Climate Prediction Center (CPC) at the NOAA National Centers for Environmental Prediction.

The SubX database is a mix of models from operational centers and research centers. This combination gives us a unique opportunity to explore whether there is a discernible difference in skill between models from different centers. This work compares the skill of operational-based models and research-based models as part of an effort to evaluate and verify the SubX database.

2. Verification data

The verification dataset used for temperature over land is the CPC daily temperature dataset with horizontal resolution of 0.5x0.5 degree. This dataset provides daily maximum and minimum temperature, which are averaged to estimate the daily temperature. For precipitation over land, the CPC Global Daily Precipitation dataset (also at the resolution of 0.5x0.5 degree) is used. Each verification dataset is re-gridded to the coarser SubX models' resolution of 1x1 degree prior to performing model evaluations.

To verify the reforecast for each week, each model's lead time was calculated to best match the lead times in realtime; and if a model's forecast was not available, it was left out of the multi-model-mean estimate. The model climatology was estimated individually and removed. No further bias correction steps were taken.

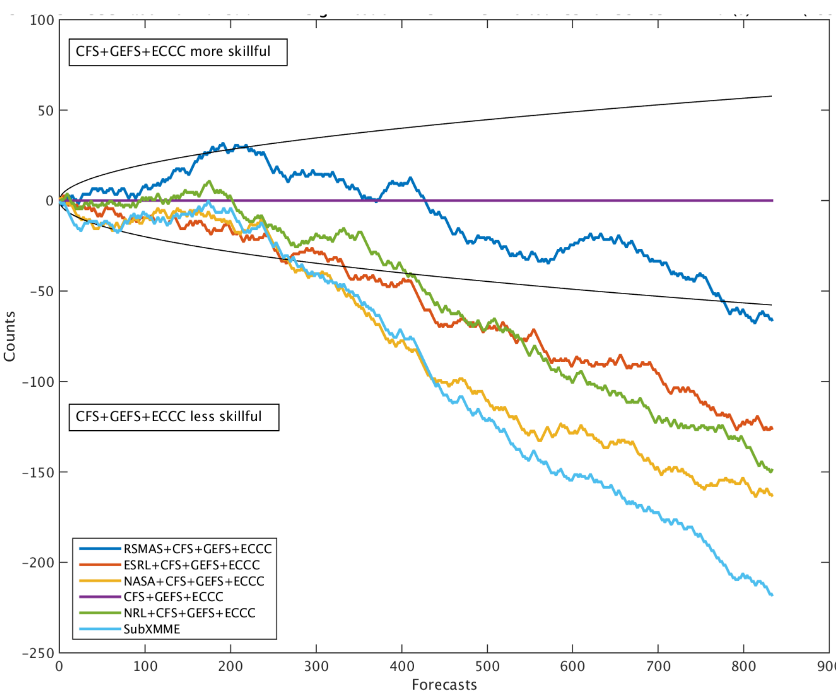

Fig. 1 Sign Test comparing week 3/4 precipitation reforecast HSS over CONUS and Alaska for all months across 1999-2014. Mulit-model combinations are compared to a multi-model mean of the operational-based models plus an additional model from a research center. Black curves show the 95% confidence interval. Walks between those curves are equally skillful to the operational-based MMM.

3. Verifications

Model verification is evaluated using the Sign Test to compare

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Heidke Skill Scores (HSS) for a two-category probabilistic forecast (an above/below normal forecast). Scores are estimated from the full hindcast period for all months (1999-2014, approx. 800 forecasts). HSS from a mini-multimodel-mean (MMM) comprised only of the models from operational centers (NCEP-CFSv2, EMC-GEFS, and ECCC-GEM) are compared to that same MMM plus a research-based model. The difference of the HSS yields either a positive or negative value that is assigned as a +1 or -1. Those 1s are cumulatively summed and displayed as a random walk (see Fig. 1). The smooth black curves delineate a 95% confidence interval. The legend identifies which multi-model mean is being compared with the operationally-based MMM. It may be tempting to compare the colored curves to each other, but this test is only providing a skill comparison between the operationally-based MMM and that same MMM plus one research-based model. The curves are displayed together only as a matter of convenience. The random walks (colored curves) that appear between the black curves indicate that comparison-MMM is equally skillful to the operational-based MMM at the 95% confidence level. In nearly all cases, adding a research-based model to the operationally-based MMM improves the forecast skill, as indicated by a random walk that emerges below the black curve. The SubXMME is the most skillful multi-model combination by this metric and the probability of success in being more skillful than the operationally-based MMM. Table 1 shows the probability of success of one MME outperforming another MME. For instance, the SubXMME is likely to provide a more skillful precipitation forecast approximately 63% of the time over the operationally-based MMM.

Model added to CFS+GEFS+ECCC:	**Probability of success over only CFS+GEFS+ECCC:**
SubX	63%
NASA+CFS+GEFS+ECCC	60%
NRL+CFS+GEFS+ECCC	59%
ESRL+CFS+GEFS+ECCC	58%
RSMAS+CFS+GEFS+ECCC	54%

Table 1 Probabilities of success based on the Sign Test in Figure 1.

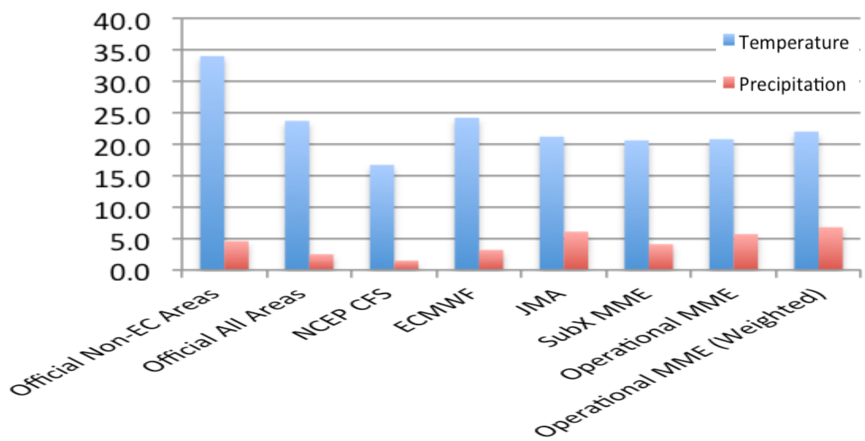

Fig. 2 HSS for a year of realtime forecasts (Sept 2018-2019). SubX models are uncalibrated. In some cases, the SubX models are outperforming or are equally skillful as the operational suite.

The weekly guidance from SubX is now verified alongside the operational tools. Figure 2 shows the HSS from Sept 2018- Sept 2019 for the operational week 3/4 tool suite and the SubX suite of models. It should be noted that the SubX models are not calibrated. Skill scores are shown for both temperature and precipitation and in some cases the uncalibrated SubX models are either outperforming or are equally skillful to the operational suite.

References

Pegion, K., B. P. Kirtman, E. Becker, D. C. Collins, E. LaJoie, R. Burgman, R. Bell, T. DelSole, D. Min, Y. Zhu, W. Li, E. Sinsky, H. Guan, J. Gottschalck, E. J. Metzger, N. P. Barton, D. Achuthavarier, J. Marshak, R.D. Koster, H. Lin, N. Gagnon, M. Bell, M. K. Tippett, A. W. Robertson, S. Sun, S . G. Benjamin, B. W. Green, R. Bleck, and H. Kim, 2019: The Subseasonal Experiment (SubX): A multimodel subseasonal prediction experiment. *Bull. Amer. Meteor. Soc.,* **100**, 2043–2060, https://doi.org/10.1175/BAMS-D-18-0270.1

NOAA's Climate Prediction Center Stakeholder Meeting
College Park, MD, 24-26 September, 2019

Development, Evaluation, and Experimental Implementation of an Updated Seasonal Temperature and Precipitation Forecast Consolidation

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1. Goal and background

At the time of this project's conception it had been known for some time that CPC could benefit from a new seasonal forecast consolidation that would serve as a 'first guess' for the forecaster, with the aim of improving forecast reliability and month-to-month consistency across forecast and forecasters. The existing consolidation, implemented in 2006, had the positive benefit of leading to increased forecast coverage and improved 'all forecasts' skill scores (Baxter 2017). However, this product had some drawbacks that limited its usefulness to CPC's forecasters. The black-box system made it difficult to understand and attribute forecast probabilities to one or more of the various input tools. Also, it used only climate division data (CD-102) over the CONUS. Finally, it was based only on legacy statistical tools derived a couple of decades ago and a single dynamical model input (CFS).

Since the implantation of the operational consolidation in 2006, there have been advances in model post-processing and calibration (Unger *et al.* 2009, Ou *et al.* 2016, and van den Dool *et al.* 2017) that have been implemented across many of CPC's operational forecast products and tools. This project was established to

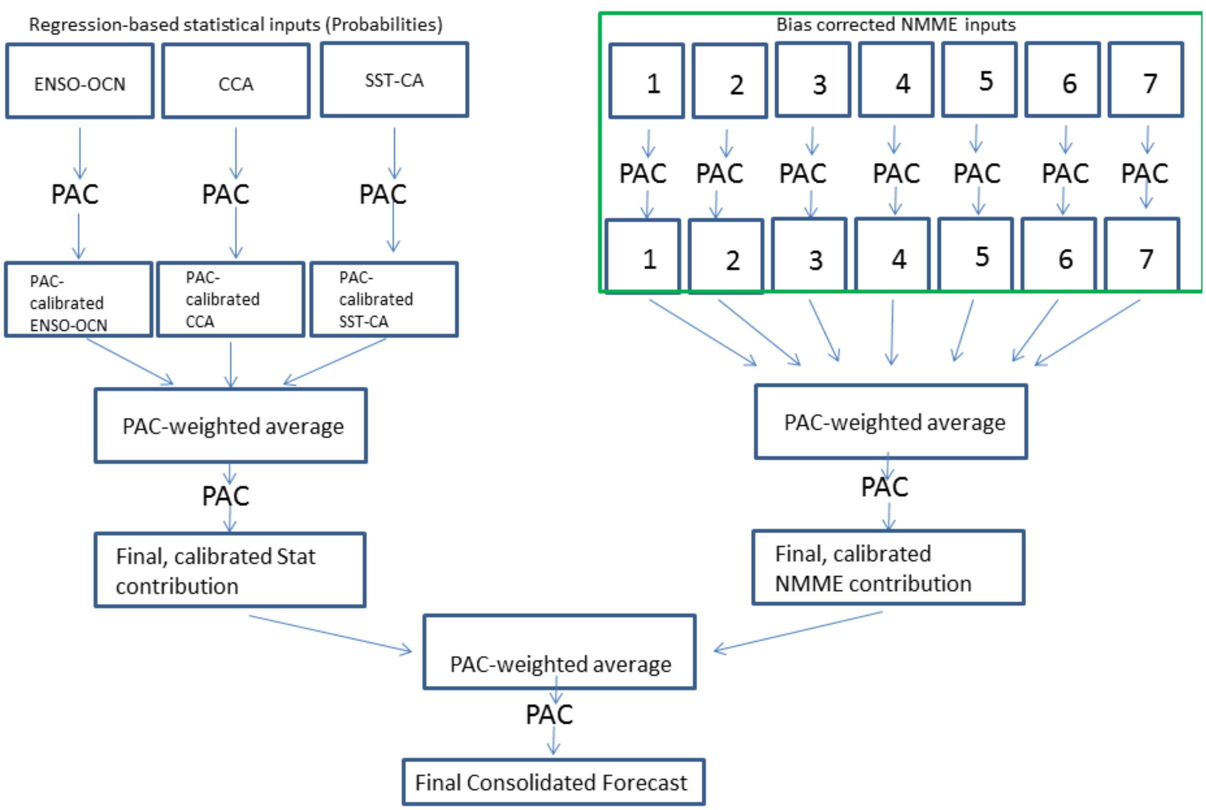

Fig. 1 Seasonal consolidation flowchart for both temperature and precipitation (for each lead, season, above/below tercile). The green box indicates process that currently executes operationally upstream of the consolidation. All other processes are included as part of this experimental consolidation process.

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apply a probability anomaly correlation (PAC) calibration to a new suite of empirical forecast tools (updated canonical correlation analysis, constructed analog based on sea surface temperatures, and a hybrid El Niño-Southern Oscillation/long term trends forecast tool), and consolidate those tools with the constituent models of the National Multi-model Ensemble (NMME) system, which have been PAC-calibrated in real-time since 2016. The PAC methodology, acting on probability anomalies, is analogous to traditional linear regression acting on temperature and precipitation anomalies themselves. The former minimizes the Brier score, while the latter minimizes the mean squared error.

2. Project overview

A project plan was developed in December 2017 and executed throughout the remainder of the fiscal year. The new consolidation flow chart is shown in Figure 1. The premise is to apply PAC calibration to each of the constituent models for both the statistical and dynamical model inputs, and then each stream, statistical (left) and dynamical (right), is combined by weighting based on the PAC coefficient (ranging from 0 to 1, which negative values set to 0). Because the combination of models is often more skillful than each model separately, the results at this point are expected to be underconfident. Therefore, a second pass PAC calibration will minimize the Brier score of the combination of forecast tools. This process is repeated to consolidation the statistical and dynamical forecast streams.

The software was developed to run and update in real-time and is trained on the independent hindcast data for each forecast tool when available from 1982-present. The training datasets utilized are GHCN+CAMS for

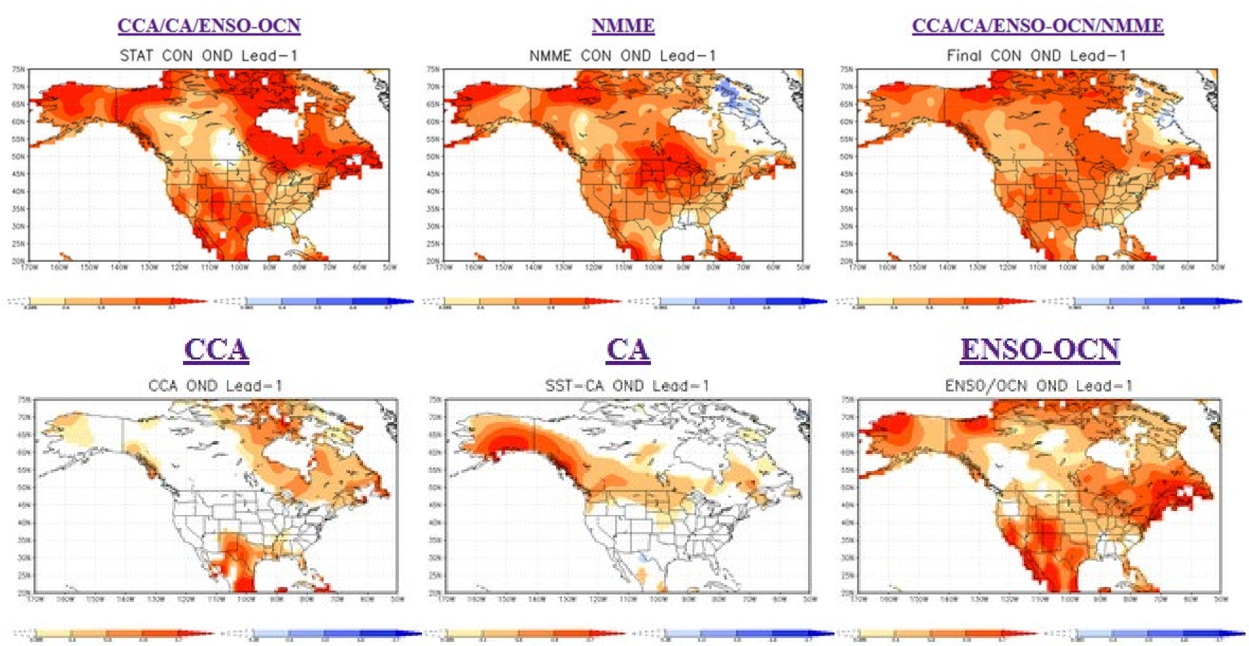

Fig. 2 Sample output graphics available to forecasters for the OND Lead-1 temperature forecast.

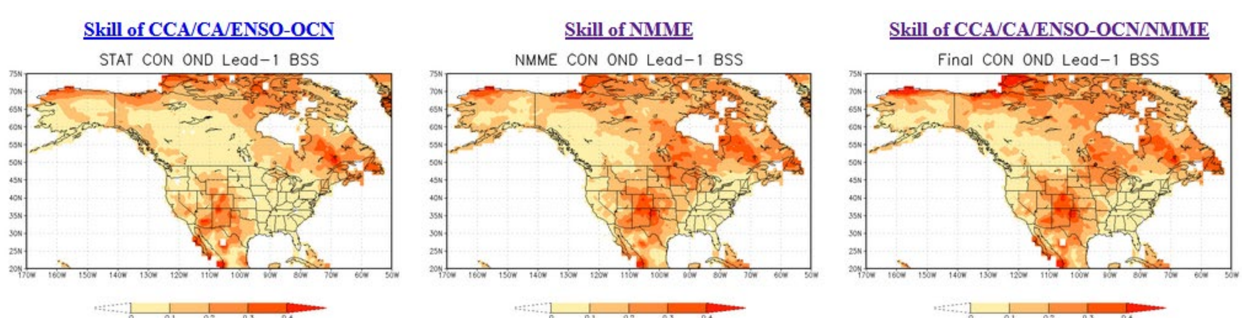

Fig 3 Sample historical Brier skill score (BSS) graphics output alongside the forecast graphics.

temperature and CPC's gridded precipitation reconstruction. Forecast probabilities and skill metrics are output and archived in real-time in both NetCDF and binary data formats, and forecast graphics are output and archived.

3. Results and accomplishments

The project plan was executed on schedule. A web interface was created where the forecaster can access the consolidation forecasts from both the NMME and statistical tools, and their final consolidation. An example of the graphics forecasters had access to for the September seasonal forecast cycle is shown in Figure 2. Importantly, forecasters can see whether contributions to the forecast are coming from statistical models or the NMME. The statistical model stream is further broken down into its three constituent models. Associated skill maps are displayed as well, where the average of the hindcast Brier skill score for above- and below-normal temperature probabilities is plotted for that lead and target season (Figure 3).

Evaluation of the consolidation was conducted by calculating the BSS for each lead and season as well as associated reliability statistics. The statistical and dynamical model components are compared to understand where the statistical guidance adds value to the state-of-the-art dynamical model guidance. Finally, some comparison is made to the current NMME guidance utilized by forecasters.

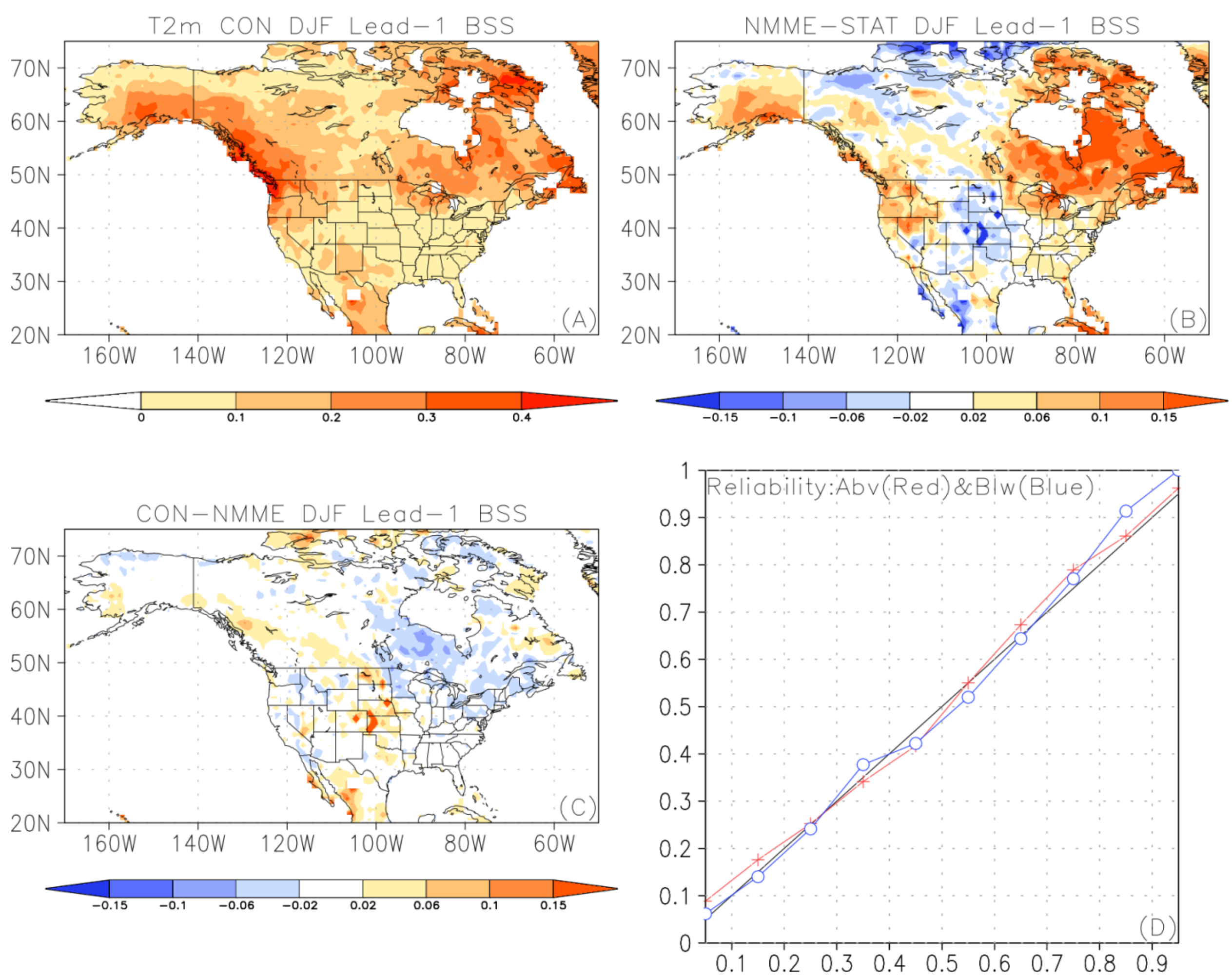

Fig. 4 Panel (a) shows the average Brier skill score (BSS) for Lead-1 above- and below-normal temperature forecasts for December-February (DJF). Panel (b) shows the BSS difference between the NMME stream and the statistical stream; Panel (c) shows the BSS difference between the final consolidation and the NMME stream. Reliability of the final consolidation is shown in (d), where the black diagonal line is perfect reliability.

The average BSS for Lead-1 temperature forecasts of December-February (DJF) is shown in Figure 4a. As expected, skill is modest across much of the CONUS, except where ENSO and long-term trends are most important. The difference between the average BSS of NMME model consolidation and the statistical model consolidation is shown is Figure 4b; the statistical models outperform the NMME only in low-skill areas over the central CONUS. Figure 4c shows the difference in BSS between the final consolidation and the NMME constituent; this can be thought of as the value added by the inclusion of the statistical guidance. There are areas where the statistical guidance clearly adds value, but it is mostly mixed. Figure 4d shows the reliability of above- and below-normal temperature forecasts from the final consolidation, respectively. As expected given this established methodology, the final consolidation is reliable across forecast probabilities. Figure 5 shows the same except for DJF Lead-1 precipitation forecasts. In this case, an obvious ENSO skill signature is seen, with the highest forecast skill over regions where seasonal precipitation is known to be more correlated to ENSO.

Finally, Figure 6 shows a more in-depth breakdown of tools for the Lead-1 DJF temperature forecast. This reveals that the addition of the statistical models maintains reliability while adding resolution (increasing the frequency with which larger probabilities are forecast). Additionally, it shows that the NMME as currently used by CPC forecasters is quite under confident. The second pass PAC calibration in this case increases the probabilities to match forecast skill.

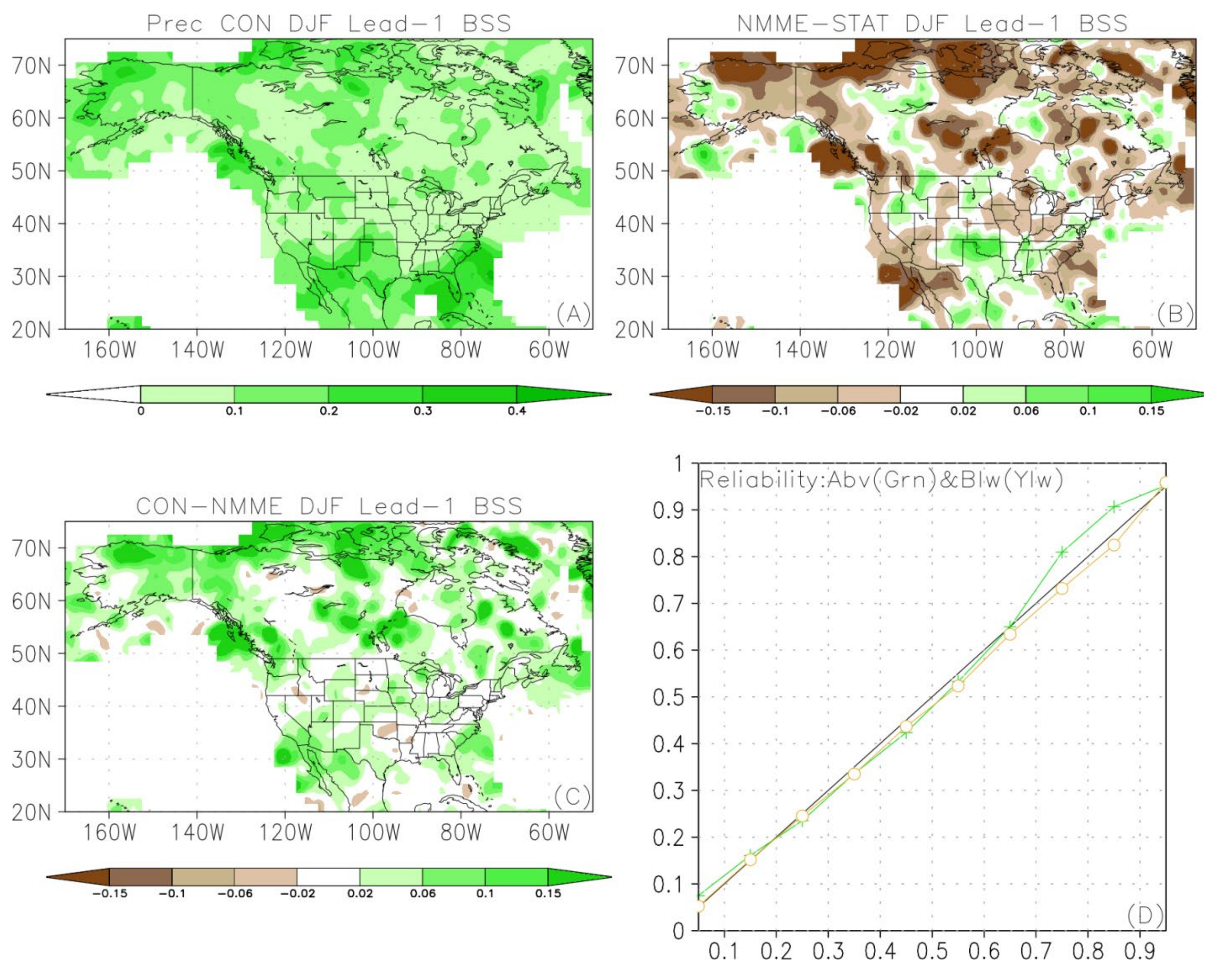

Fig. 5 Same as Figure 4 except for Lead-1 DJF precipitation forecasts. In this case, the statistical forecast tools generally enhance the skill of the forecast (Panel C).

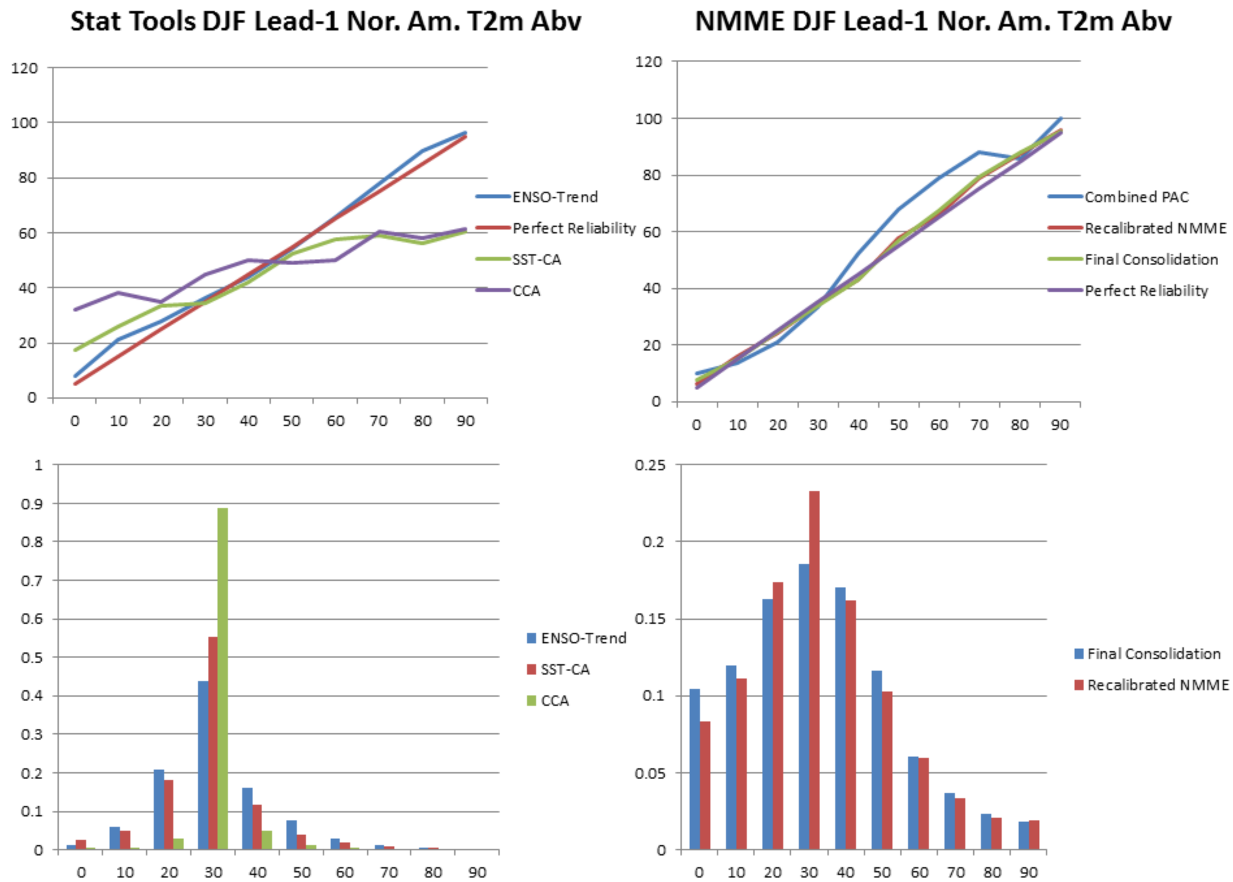

Fig. 6 This figure highlights the reliability and frequency of Lead-1 forecasts of above-normal temperatures for December-February from the statistical models (left) and the NMME and final consolidation (right). Importantly, the NMME as used by seasonal forecasters (blue line, upper right) is notably under confident.

4. Summary

- CPC's legacy seasonal temperature and precipitation consolidation was over ten years old and did not provide enough information to the forecaster.
- The latest seasonal forecast tools, including constituent models from the NMME and newly derived empirical models, are consolidated and recalibrated using the probability anomaly correlation (PAC) methodology in the new product.
- The forecast consolidation occurs in two phases: the first in which statistical and dynamical tools are consolidated separately, and the second in which these two streams are consolidated (Figure 1).
- Real-time forecast graphics are available to forecasters, along with associated skill metrics (Figures 2 and 3).
- The new consolidation process produces more reliable forecasts from the NMME suite of models.
- The inclusion of statistical tools improves the forecast skill for precipitation in all seasons. For temperature the impact is less notable, though there is some evidence that forecast resolution improves (Figures 4, 5, and 6).
- Real-time forecasts are produced on a monthly basis as of Nov. 2018. Output can be found at http://www.cpc.ncep.noaa.gov/pacdir/ncca.html

References

Baxter, S., 2017: Evaluating CPC's operational seasonal temperature forecasts: Why aren't we beating a categorically warm forecast*? Climate Prediction S&T Digest: NWS Sci. & Technol. Infusion Clim. Bull. Suppl., 41st NOAA Annu. Clim. Diagn. Predict. Workshop*, Orono, ME, 3-6 October 2016, 61-63. https://doi.org/10.7289/V5JS9NH0

Ou, M., M. Charles, and D. C. Collins, 2016: Sensitivity of calibrated week-2 probabilistic forecast skill to reforecast sampling of the NCEP Global Ensemble Forecast System. *Wea. Forecasting,* **31**, 1093–1107. https://doi.org/10.1175/WAF-D-15-0166.1

Unger, D. A., H. van den Dool, E. O'Lenic, and D. Collins, 2009: Ensemble regression. *Mon. Wea. Rev.,* **137**, 2365–2379. https://doi.org/10.1175/2008MWR2605.1

van den Dool, H., E. Becker, L.-C. Chen, and Q. Zhang, 2017: The probability anomaly correlation and calibration of probabilistic forecasts. *Wea. Forecasting*, **32**, 199–206. https://doi.org/10.1175/WAF-D-16-0115.1

NOAA's Climate Prediction Center Stakeholder Meeting
College Park, MD, 24-26 September, 2019

Weekly Update of Monthly Outlooks

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1. Background

The Climate Prediction Center (CPC) currently issues monthly temperature and precipitation outlooks for the upcoming calendar month two times each month, once near the middle of the month, coincident with the release of the suite of seasonal outlooks, and an updated version released on the last day of the month. Changing anticipated climate conditions after the first monthly outlook release makes it necessary at times for substantial changes to be made as part of the updated monthly outlook release. Additionally, synoptic transients come into clear view for a zero-lead forecast which adds forecast information not available during the half month lead release. In these cases, a more frequent updating monthly outlook may be helpful to users. Moreover, stakeholders have expressed the need and benefit of a weekly update of the forecast temperature and precipitation outlook for the upcoming 30 days no matter the exact timing of the month.

2. Methods

Hindcast skill was calculated (temporal AC) for the CFSv2 for the 4 pre-determined, sub-monthly periods : 1) Days 1-3, 2) Days 4-7, 3) Days 8-14, 4) Days 15-30 and also the GEFS for the first 3 periods. The 30-day mean forecast f_w is calculated by aggregating the forecast values from each of the sub-monthly periods. This is done by weighting the sub-monthly forecasts by their hindcast AC skill:

$$f_w = \frac{1}{30}\sum_{n=1}^{4} d_n f_n AC_n$$

where d_n, f_n, and AC_n are the number of days, the forecast value, and the hindcast anomaly correlation skill of the nth sub-monthly period, respectively.

These results are compared to those calculated when using just the CFSv2. The training period for AC calculations was 1999-2010 for both models, and the verification period was 2011-2017. The anomaly correlation, Heidke skill score (HSS), and ranked probability skill score (RPSS), were all calculated and used as verification metrics. Probabilities are calculated by using the variance of the aggregated forecasts, calculated by accounting for the many correlation terms between the various sub-monthly periods. This variance is used to fit a Guassian distribution around the expected value (a power transformation is used for the precipitation data due to its non-normal distribution).

3. Results

It was demonstrated that using only the CFSv2 and calibrating by forecast sub-period (1-3 day, 4-7 day, 8-14 day, and 15-30 day) for a 30-day forecast yielded a small but systematic increase in forecast skill compared to calibration of the entire 1-30 day forecast period alone. There are two competing effects here: 1) averaging over time increases forecast skill by emphasizing the low-frequency state and smoothing over weather phenomena beyond the limit of predictability, but 2) imperfect models likely retain too much forecast signal relative to skill, especially at longer lead times. For a perfect model with very large ensemble size, one would expect that just using a simple 1-30 day average would be the best possible monthly forecast.

This result was expanded to assess whether aggregating sub-period forecasts from different sources would improve upon those from a single source (CFSv2). In this case, the GEFS model was used for the first 3 periods, which generally improved upon the sub-period-weighted CFSv2 and the raw CFSv2 in all metrics. The difference was most notable when using the HSS and RPSS metrics, although improvement is small or

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nonexistent during the summer (the scores are better in winter overall). The precipitation forecasts benefit the most from the sub-period calibration, while the temperature forecasts benefit most from the inclusion of the GEFS at earlier lead times. Figure 1 shows the summary scores as a function of month and the average over all months for precipitation and temperature.

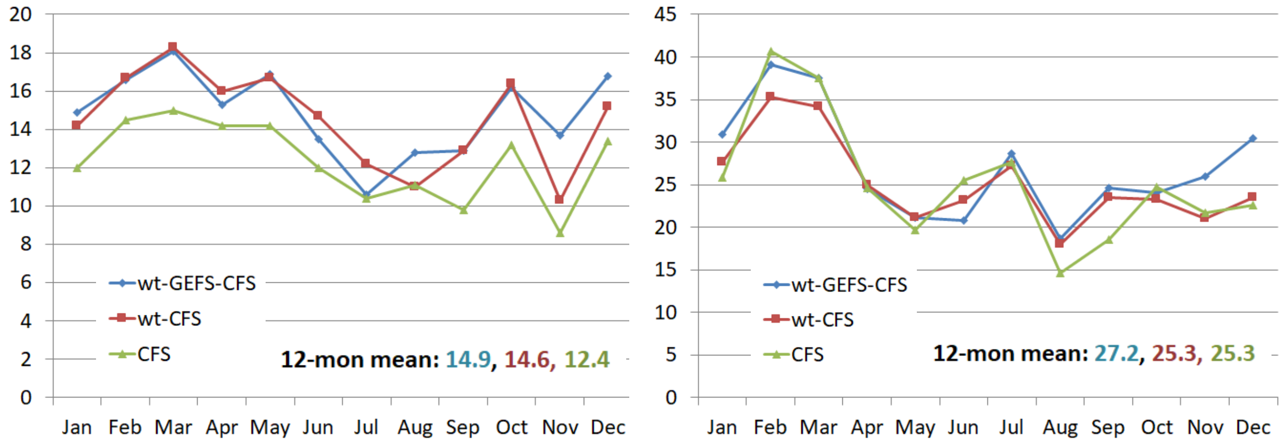

Fig. 1 Left: Precipitation HSS for by month the period 2011-2017 for the CFSv2, sub-period weighted CFSv2 (wt-CFS), and the combined GEFS-CFSv2 (wt-GEFS-CFS). Right: Same as left, but for temperature HSS.

4. Conclusions

Weekly updates to the 30-day forecast is feasible by aggregating calibrated sub-monthly forecasts using both CFSv2 as well as a GEFS-CFSv2 combination. Furthermore, weekly updates to a monthly forecast would also be possible by aggregating official forecast products, utilizing CPC's official Week-2 and Week 3-4 forecasts as well as a model forecast for the earliest periods. This would also ensure that the resultant 30-day forecast would be consistent with the continuum of official CPC forecast outlooks.

A path to operational implementation is readily available once the forecast probability of exceedance products are available for CPC's Week-2 and Weeks 3-4 official forecasts, as the calibrated model guidance is already produced operationally for Week-1. Some assumptions would have to be made with respect to the correlation between various forecast periods in order to yield an appropriate forecast distribution and thus reliable probabilities for the final 1-30 day forecast product. Another consideration would be the usefulness of the product, but discussions during a recent CPC stakeholder meeting found general support for the product, despite the likely elimination of CPC's current updated monthly forecast.

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Improve CPC Week 3-4 Precipitation Outlooks with Machine Learning Technologies

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1. Introduction

In recent years, the demand for sub-seasonal (*e.g.* Week 3-4) forecasts have been increasing steadily from many industries. However, operational forecasts on Week 3-4 time scale are relatively new and the forecast skills are quite low. The Week 3-4 precipitation and temperature forecast is one of the most challenging and toughest forecast. This is because current numerical weather models perform well up to about seven days in advance, and climate outlooks get more reliable as the time horizon extends from months to seasons. Sub-seasonal (*e.g.* Week 3-4) forecasts are in a middle ground, the memory in initial condition that impacts short-term weather is diminished after 7 to 10 days, while the impact of monthly and seasonal factors such as the state of El Niño, soil moisture, snow and sea ice etc. is not well established.

Benefiting from the great advance in machine learning technologies in recent years, the neural network techniques will be used to explore the predictability of the Week 3-4 precipitation and improve its forecasts. The neural network techniques do show some advantages over traditional statistical methods (*e.g.* the multiple linear regression): such as flexible algorithm that can account for complicated linear and non-linear relationships, spatial dependency and co-variability *etc*. in predictors and predictands, at the same time is able to handle big data easily and also improve training efficiency (Krasnopolsky 2013, Fan *et al.* 2019).

2. Methodology and data

By design, the neural network architecture used here is able to account for not only nonlinear impacts from big data correction, but also spatial dependency (*e.g.* pattern relationship) by training different predictors and predictands from all locations simultaneously, and the co-variability among the predictands by training different predictand variables simultaneously. Those learned statistical patterns and relationships from the NN training processes then are used by the NN to make the corrected forecasts at all locations. Therefore, this neural network architecture has the ability to extract more complicate and high level information hidden behind big data and allow the neural network algorithm to detect what are the most important forecast input variables and where these (group) points are located for mapping the target (predictand) points. This will allow the NN method to perform some forecast corrections, such as reversing wrong forecast patterns, which is impossible for the traditional method like multiple linear regression.

The data sets used for the NN training and testing usually are paired with predictor variables and predictand variables. The data set for predictors used here, such as the bias corrected Week 3~4 leading forecast total precipitation (P), mean 2 meter temperature (T_{2m}) and 500-hPa height (Z500) *etc*., are obtained from the NOAA Climate Forecast System (CFS) (Saha *et al.* 2006, 2014) for period Jan. 01, 1999 to Dec. 31, 2018. The data domain used in study here covers the Conterminous US (CONUS) only, has 1x1 degree spatial resolution and is on daily temporal resolution initialized at 4 different times (00Z, 06Z, 12Z and 18Z) per day. Auxiliary predictors, such as daily P, T_{2m} and Z500 climatologies, biases, latitudes, longitudes, elevations, station ID *etc.* on the same spatial-temporal resolutions, are also used.

The data set used for correspondent target variables (predictands) are the observed P from the gauge based daily CPC Unified Precipitation Analysis and the observed T_{2m} from the Global Telecommunications System (GTS) based daily maximum and minimum 2 meter temperature analysis (Chen *et al.* 2008, Shi personal communication, Fan *et al.* 2008). Both the above observed P and T_{2m} are converted to two weekly total and two weekly mean, and re-gridded to the same spatial-temporal resolutions as the above predictors.

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3. Results

In this study, one open question to be explored here is if the machine learning (*e.g.* the highly nonlinear neural network systems used here) technologies can add additional values and make meaningful improvement for the precipitation forecasts in the Week 3-4 time scale, when compared with the bias corrected CFS Week 3-4 forecasts as the inputs.

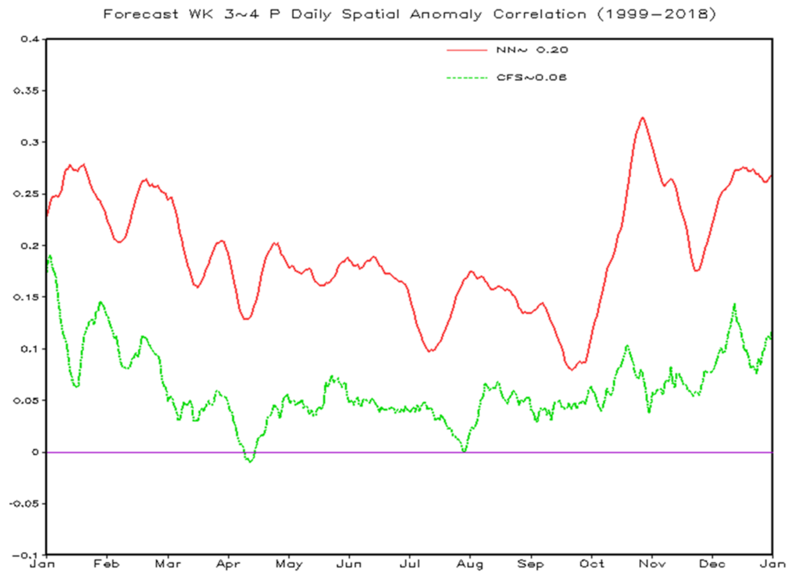

Fig.1 Mean time series of the daily Week 3-4 precipitation spatial anomaly correlation between the neural network (NN) forecasts and observations (red), the bias corrected CFS forecasts and observations (green) for the period between Jan. 01, 1999 and Dec.31, 2018.

In order to answer the above question, the twenty (1999-2018) years daily Week 3-4 precipitation (independent) forecast verifications are performed as follows: take out 3 years daily paired data from 20 years data pool sequentially, use the middle year only as the independent forecast (testing) dataset, the rest 17 years daily paired data as training dataset. For the year 1999 and 2018, only two years daily data is taken out and uses the far side year only as independent forecast (testing) dataset, and the rest 18 years daily data as the training dataset.

The daily mean spatial anomaly correlations averaged from the above 20 years independent Week 3-4 precipitation forecasts are show in the Figure 1. The results indicate that the neural network techniques indeed can make a solid and robust improvement for the Week 3-4 precipitation forecasts over the raw forecasts (*i.e.* bias corrected CFS inputs), while traditional methods, such as the multiple linear regression method, are hardly to improve the above Week 3-4 precipitation (no shown).

4. Summary

The neural network architecture used here not only benefits from the flexible NN algorithms, but also can take many advantages offered by the available big data. Therefore, it enables us to explore and extract more sophisticate pattern relationships and co-variabilities among the multiple dimensional predictors and predictands, and eventually helps us to improve the Week 3-4 precipitation forecasts.

Althrough the improvement on the Week 3-4 precipitation is encourging, the overall forecast skill (such as in terms of RMSE and AC skills) for the Week 3-4 precipitation prediction is still quite low, compared to the Week 2 and monthly climate outlooks. Since the NN forecasts here critically depend on the quality of the numerical forecast inputs, improving the numerical model itself (*i.e.* CFS) is one way to improve the Week 3-4 forecasts.

References

Chen, M., W. Shi, P. Xie, V. B. S. Silva, V. E. Kousky, R. Wayne Higgins, and J. E. Janowiak, 2008: Assessing objective techniques for gauge-based analyses of global daily precipitation. *J. Geophys. Res.*, **113**, D04110.

Fan, Y. and H. van den Dool, 2008: A global monthly land surface air temperature analysis for 1948–present. *J. Geophys. Res.*, **113**, D01103, doi:10.1029/2007JD008470

Fan, Y., C.-Y. Wu, J. Gottschalck, and V. Krasnopolsky, 2019: Improve CFS week 3-4 precipitation and 2 meter air temperature forecasts with neural network techniques. *Climate Prediction S&T Digest: NWS*

Sci. & Technol. Infusion Clim. Bull. Suppl., 43rd NOAA Annu. Clim. Diagn. Predict. Workshop, Santa Barbara, CA, 23-25 October 2018, 59-63. https://doi.org/10.25923/ae2c-v522

Krasnopolsky, V., 2013: The application of neural networks in the Earth system sciences. Neural Network Emulations for Complex Multidimensional Mappings, Springer, 200 pp.

Saha, S. and Coauthors, 2006: The NCEP Climate Forecast System. *J. Climate*, **19**, 3483-3517.

Saha, S. and Coauthors, 2014: The NCEP Climate Forecast System Version 2. *J. Climate*, **27**, 2185–2208. http://dx.doi.org/10.1175/JCLI-D-12-00823.1

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College Park, MD, 24-26 September, 2019

Alaska Spring River Break-up and Climate Prediction Center

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SUMMARY

Spring snowmelt and river ice break-up are important events in the annual environmental cycle over mainland Alaska. Ice jams form along the major rivers of Alaska almost every break-up season, and on rare occasions produce catastrophic flooding as water is impounded behind the jam. This occurred on the Yukon River at Eagle in 2009 (Fig. 1) and Galena in 2013. While there is a stochastic element involved, ice jam flooding is not a random phenomenon. There are communities at higher risk due to local river geometry such as sharp bends or obstructions jutting into the river. The second most important variable is weekly scale temperatures during April and May[1]. An earlier than average start to the diurnal thaw/freeze cycle allows for gradual snowmelt at low elevations and thermal weakening of river ice. By contrast, persistently colder than normal temperatures through April help maintain low elevation snowpack and ice strength, increasing the risk that ice jams will form.

Because of the prime importance of temperatures, the Climate Prediction Center provides critical guidance to the NWS Alaska-Pacific River Forecast Center and other partners both before and during the spring melt season. Pre-season identification of temperatures regimes likely to significantly tilt the ice jam threat risk (higher or lower), such as seasonal outlooks and model guidance are utilized to shape messaging to communities and preparedness by appropriate local, tribal and state organizations. Once the melt season is underway, 6-10 day, week 2 and week 3-4 guidance can provide important clues to break-up evolution in three to five weeks of the break-up season.

Fig. 1 Eagle, Alaska, May 2009. Photo courtesy NWS/APRFC

[1] Spring is climatologically dry over most of mainland Alaska, so precipitation during the melt season is rarely a significant factor. Unless extreme, the snow water equivalent of the end-of-winter snowpack is also of secondary importance.

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Alaska Heat and Climate Prediction Center

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SUMMARY

Alaska does not experience warm season temperatures and humidities typically associated with CONUS heat impacts. However, impacts from unusually high, prolonged temperatures do occur in Alaska, and in recent years have been increasingly widespread. Because of the diverse climates of Alaska, national centers like the Climate Prediction Center should coordinate with NWS Alaska Region and other partner organizations to issue timely and relevant notice of heat impacts.

Some of the societal impacts stems from the fact that buildings in Alaska are designed to retain heat. Central air conditioning is virtually unknown outside of large public buildings, and most homes do not have window systems that permit routine installation of box type air-conditioning units. And like many environmental conditions, impacts grow rapidly the longer the heat persists. Interior Alaska regularly experiences periods with highs in the 80s and even lower 90s, and alone are not especially impactful. However, when such temperatures co-occur with significant wildfire smoke, buildings rapidly heat-up as windows remain closed to keep out the smoke. In southcentral Alaska, the most populous region of the state, there is no expectation for temperatures to be in the 80s, so a population acclimatized to cool summers incurs impacts merely by the occurrence of these conditions.

Ecological impacts of prolonged heat are strongly dependent on antecedent conditions. For example, prolonged heat that immediately follows a period of convectively active weather in the Interior has greatly increased risk of seeing substantial wildfire growth. Similarly, prolonged heat followed by a still warm but convectively active period also as greatly increased chances for wildfire growth. Similarly, with the appropriate antecedent conditions, river water temperatures can rise high enough to produce fish kills of returning salmon, as happened in many parts of the state in July 2019 (Fig. 1).

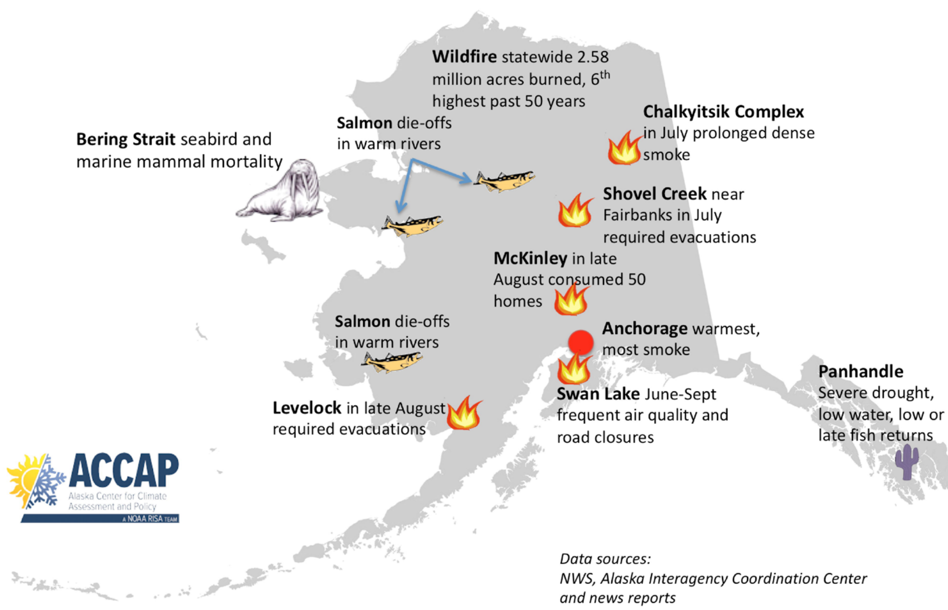

Fig. 1 Summer 2019 heat impacts

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NOAA's Climate Prediction Center Stakeholder Meeting
College Park, MD, 24-26 September, 2019

Use of CPC Prediction Products for Decision Support Services for Flooding in Central US in 2019

Doug Kluck

Regional (Central) Climate Services

NOAA's National Centers for Environmental Information

SUMMARY

Record wet conditions across most of the north central U.S. in 2019 led to long lasting and record flooding across throughout the Missouri and Upper Mississippi basins (Fig 1). Collaboration with and use of the Climate Prediction Center's (CPC) forecast information was an important piece of translating the hydro-climate situation to a broad group of stakeholders during the event. The stakeholder audience included local, state, tribal and federal government as well as private interests (agriculture, media, NGOs, transportation, energy, *etc*.) who received comprehensive and interpreted climate and hydrologic information. Beginning in March 2019 flooding became widespread with unusual antecedent and heavy precipitation for the two major basins. Continued very heavy precipitation through the rest of 2019 kept flooding and inundation at very high levels for much of the region and thus kept CPC directly involved with regional NOAA and partners.

Through NOAA's partnerships with the U.S. Dept of Agriculture and U.S. Army Corps of Engineers various regional climate services were provided with the aid of CPC outlooks and collaboration. For instance, numerous emails, webinars, conference calls, regional public briefing materials, and other forms of communication were used to translate complex outlook information to useful actionable support. More specific cases include webinars, summaries and email with the Mississippi Cities and Towns Initiative (about 80 mayors along the Mississsippi River), consultation with the U.S. Army Corps of Engineers and numerous email and correspondence with partners both internal and external to NOAA.

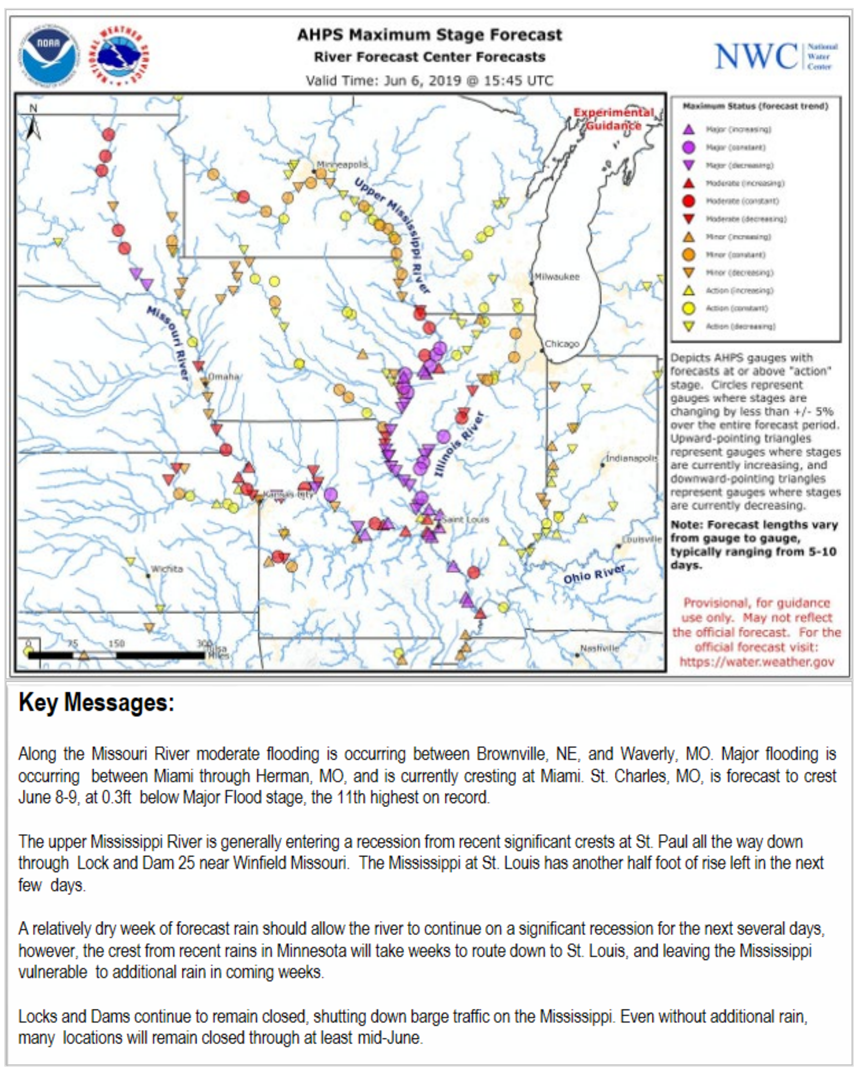

Fig. 1 River flood update for Upper Mississippi River on 6 June 2019.

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NOAA’s Climate Prediction Center Stakeholder Meeting
College Park, MD, 24-26 September, 2019

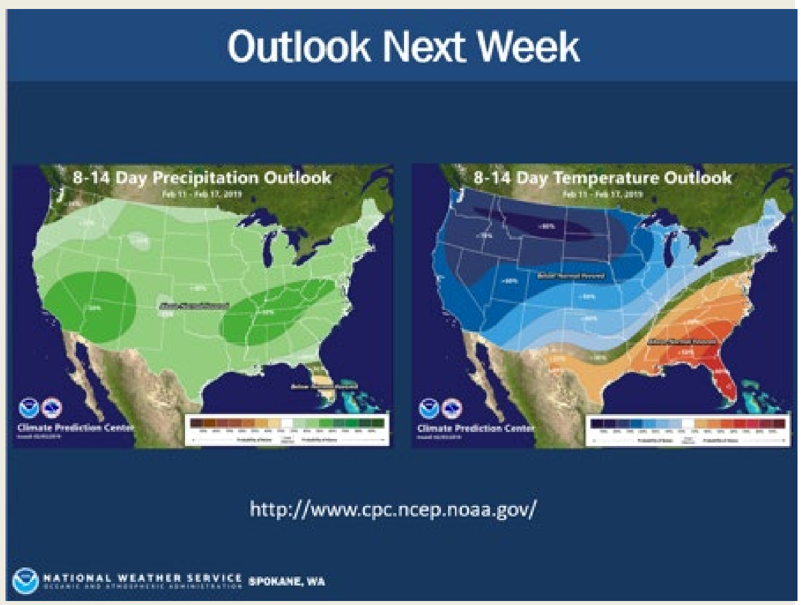
Western Region Partner Outreach Approaches with CPC Products

Andrea Bair
Climate Service Program
NOAA’s National Weather Service Western Region

SUMMARY

Climate Prediction Center (CPC) products and information are widely used in partner outreach at the local and regional levels in NWS Western Region (WR). Common types of Decision Support Services (DSS) where CPC products are used, include: partner emails, web briefings, in-person briefings, social media posts, local fact sheets, and Weather Stories. NWS WR offices were asked for examples of the various CPC products used in local DSS, and what partner decisions were informed from this information. The offices surveyed could not always determine exact partner decisions that were informed by CPC products, but they did express that CPC products are widely used to set the stage for many of the types of DSS activities mentioned above. There were some examples of when CPC information was specifically used for partner decisions included in the presentation (See one of them below). An overwhelming suggestion from the WR field offices, was that they really want to see new and more modern graphics from CPC that can be directly used in formal DSS activities.

Social Media - Spokane WFO *The temperature outlooks during February and March 2019 were heavily utilized through social media. Everyone wanted to know when will the cold end? In a mid-February Youtube weather and climate recorded briefing, Jerry Wilson, superintendent of operations from Idaho Transportation Department (ITD) District 1 utilized the 8-14 day outlook to make the decision to keep his plow trucks tooled for winter operations into mid-March. Most years, ITD-1 begins to convert some of their plow trucks to spring/summer maintenance trucks. It did not this year. With the outlook for continued cold and snowy conditions into mid-March, Jerry kept the plows on his trucks and used those plows through the last snow storm on March 12.*



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Use of CPC Outlooks to Inform the Transportation Sector in the Northeast

Ellen L. Mecray
Regional Climate Services – Eastern Region, NOAA/NESDIS/NCEI

SUMMARY

The NOAA/NWS/NCEP/Climate Prediction Center (CPC) is a valued partner for Regional Climate Services as information is offered to customers at regional to local scales. Regional Climate Services currently offers CPC information in the forms of webinars, quarterly seasonal outlook two-pagers, and event-specific (*e.g.* ENSO) briefings. In the Eastern Region, we consider the application of NOAA's information by economic sector. The example (below) is our work with the transportation sector. The National Centers for Environmental Information has invested in staff to build trusted relationships with federal and state Departments of Transportation (DOTs) across the Eastern Region. These relationships have led to sharing of NOAA information specific to their decisions around resilience planning, as well as operational choices based on the seasonal forecasts for the region. Specifically, the CPC's seasonal, and sub-seasonal, temperature outlooks are used by transportation officials to plan operation and maintenance budgets. The DOTs examine the outlooks to inform the purchasing of road salt for winter road safety, and for pothole repairs during the mid-season thaws. A recent use of CPC sub-seasonal information was the creation of the freeze-thaw map from the Northeast Regional Climate Center (Figure 1). The DOTs use these maps for decisions around opening and closing seasonal roads to heavy loads (NESDIS News & Articles 2017).

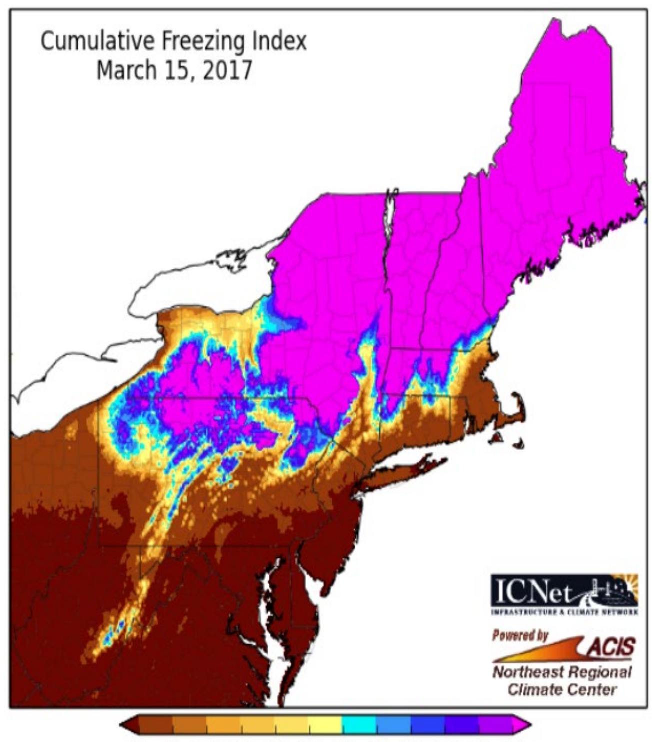

Fig. 1 Northeast Regional Climate Center's Roadway Freeze-Thaw interface shows portions of Maine (in blue to purple) where the cumulative freezing index has exceeded the 280°F-day threshold. That threshold, established by Minnesota DOT, is used as an indicator of freeze strengthening, and assists roadway managers in deciding when to remove load restrictions.

Reference

NESDIS News & Articles, 2017: NCEI's Data Helps DOTs in the Northeast conserve low-volume roads. [Available online at https://www.nesdis.noaa.gov/content/ncei%E2%80%99s-data-helps-dots-northeast-conserve-low-volume-roads]

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2. ENSO DIAGNOSTIC DISCUSSION, ARCTIC SEA ICE FORECASTS, GLOBAL TROPICS HAZARDS

NOAA's Climate Prediction Center Stakeholder Meeting
College Park, MD, 24-26 September, 2019

Diagnosing ENSO False Alarms in CFSv2

Wanqiu Wang, Michelle L'Heureux, Hui Wang, Zeng-Zhen Hu, Yan Xue, and Arun Kumar

Climate Prediction Center, NOAA's National Weather Service

1. Background

The National Centers for Environmental Predictions (NCEP) operational Climate Forecast System version 2 (CFSv2, Saha et al. 2014) was implemented in March 2011 and has been a major dynamical tool for the Climate Prediction Center (CPC) subseasonal to seasonal (S2S) climate predictions, including the prediction of El Niño-Southern Oscillation (ENSO). One issue in the CFSv2 forecasts is that it has a systematic bias to produce false alarms of ENSO events when observed sea surface temperature anomalies (SSTAs) in the central-eastern Pacific, as represented by the Nno3.4 or Niño3 indices, are relatively weak. This extended summary provides an analysis of the ENSO false alarm bias in CFSv2 and associated atmospheric feedbacks.

2. False alarms in CFSv2

Niño3.4 index from CFSv2 forecasts is shown in Fig.1 for 2012 to 2018. CFSv2 produced El Niño false alarm forecasts with Niño3.4 index anomalies greater than 0.5 K for 2012, 2014, and 2017 when observed SSTAs were near or below 0.5K. It is also noticed that the false alarms not only occurred in late spring to early summer but may occur in different months for different years. The 2012 false alarm is most clear in the forecast from June initial conditions, which will be the focus in this analysis. False alarm ENSO forecasts are also a common issue in the North American Multi-Model Ensemble (NMME), especially for 2012 for which all NMME models produced a false alarm (not shown).

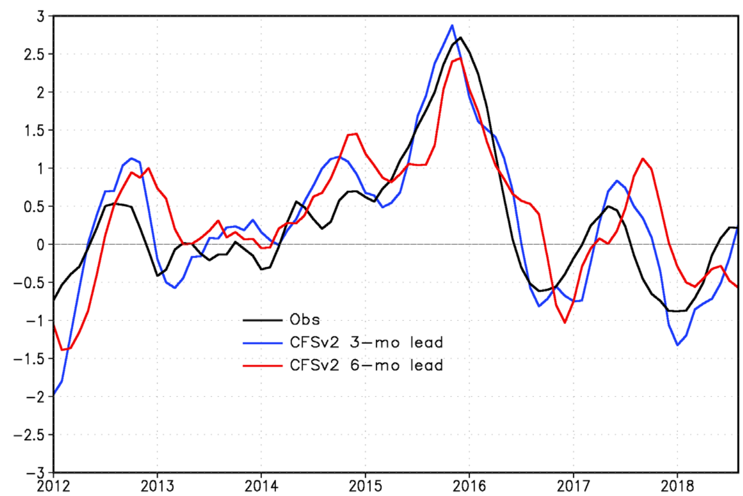

Fig. 1 Niño 3.4 index anomalies from CFSv2 forecasts at 3-month lead (blue) and 6-month lead (red) for 2012 to 2018. Observed values from the National Centers for Environmental Information (NCEI, Reynolds *et al.* 2007) are shown in black.

3. Relationships of Niño 3.4 with atmospheric variables

An ENSO false alarm forecast indicates that the balance among feedback processes in the model are not correctly represented. We will focus on atmospheric feedbacks. An ENSO false alarm may be due to the negative feedbacks related to surface heat fluxes that are too weak or positive feedbacks related to surface momentum fluxes that are too strong. To investigate possible feedbacks that may have contributed to the development of the false alarms in the CFSv2 forecast, we calculated relationships between Niño 3.4 index and related atmospheric variables. Figure 2 shows standard deviation of downward surface shortwave radiation flux (DSW) for 0.5-K

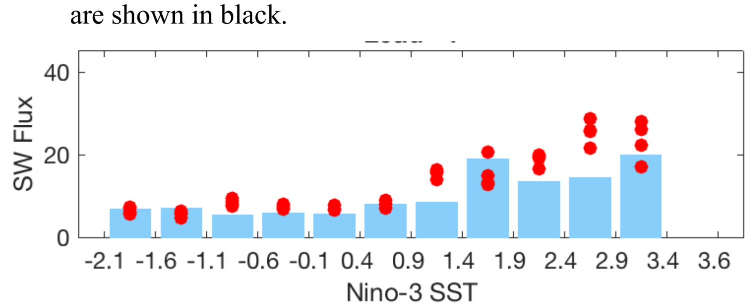

Fig. 2 Standard deviation of surface shortwave radiation flux (SW) for 0.5-K bins of Niño 3 index anomalies. Bars are from observations and red dots are 0-month CFSv2 forecasts for individual members.

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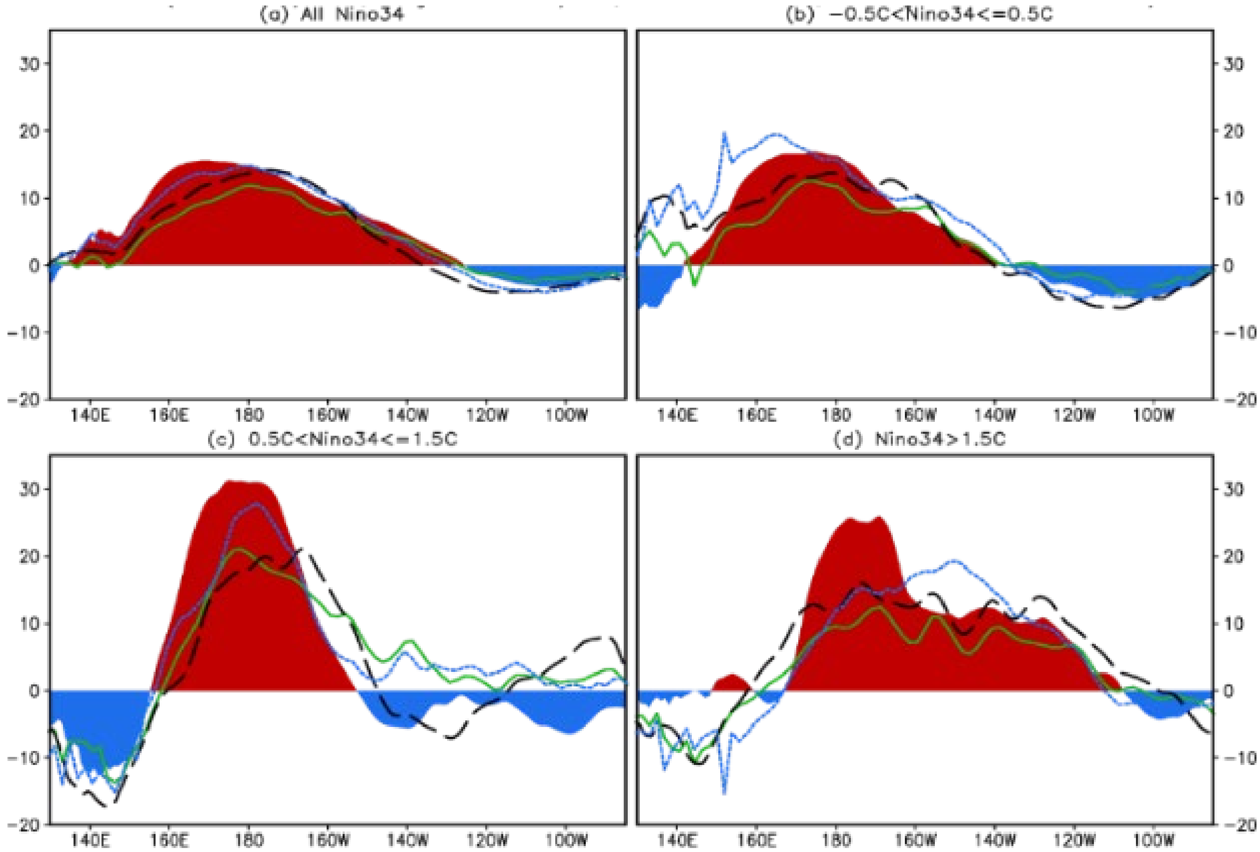


Fig. 3 Regression of 5°S-5°N zonal momentum flux (Taux) against the Niño 3.4 SST index. Shading is CFSv2 0-month forecast, and curves are from thee reanalyses: CFSR (blue), NCEP R2 (green), and NCEP R1 (black).

bins of Niño 3 index anomalies for observations (bars) and CFSv2 0-month forecast (red dots). It is seen that SW variability in CFSv2 is generally stronger than that in the observations.

A regression of 5°S-5°N zonal momentum flux (Taux) against the Niño 3.4 SST index is shown in Fig. 3 for three observational analyses (curves) and CFSv2 0-month forecasts (shadings). The CFSv2 produces stronger Taux than the observations in the tropical western-central Pacific when Niño3.4 is warm (Fig. 3c and Fig. 3d), suggesting a stronger positive wind-stress feedback in CFSv2.

To further look into the atmospheric response to SSTAs for individual cases, we analyze relationships between Niño 3.4 index and atmospheric fields in July. Scatter plots of Niño 3.4 index (x-axis) and outgoing longwave radiation (OLR), DSW, zonal momentum flux (Taux), and latent heat flux (LH) are shown in Fig. 4. CFSv2 values in Fig. 4 are forecasts from June initial conditions for July, when forecast SST errors are relatively small. We focus on the CFSv2 2012 forecast (plotted with yellow colors) which shows a clear ENSO false alarm. The CFSv2 produces larger amplitude of OLR and SW anomalies, indicating a stronger convection response and stronger negative SW feedback in CFSv2 than in observations. The difference in LH response between the CFSv2 and observation is small. The variable that is closely related to the development of the 2012 false alarm forecast of an El Niño event is Taux. The CFSv2 produced positive Taux in most individual members which would help enhance the existing warm SSTAs, resulting in a positive feedback between the atmosphere and ocean. The July 2012 Taux anomaly in the observation (solid large circle) is near zero and thus did not help to enhance the observed SST.

4. Impact of convection parameterization

The above analysis suggests that error in zonal momentum flux is a possible reason for the false ENSO alarm in CFSv2. Surface momentum flux can be influenced by different physical processes. We have carried out a set of Atmospheric Model Intercomparison Project (AMIP) simulations using the atmospheric

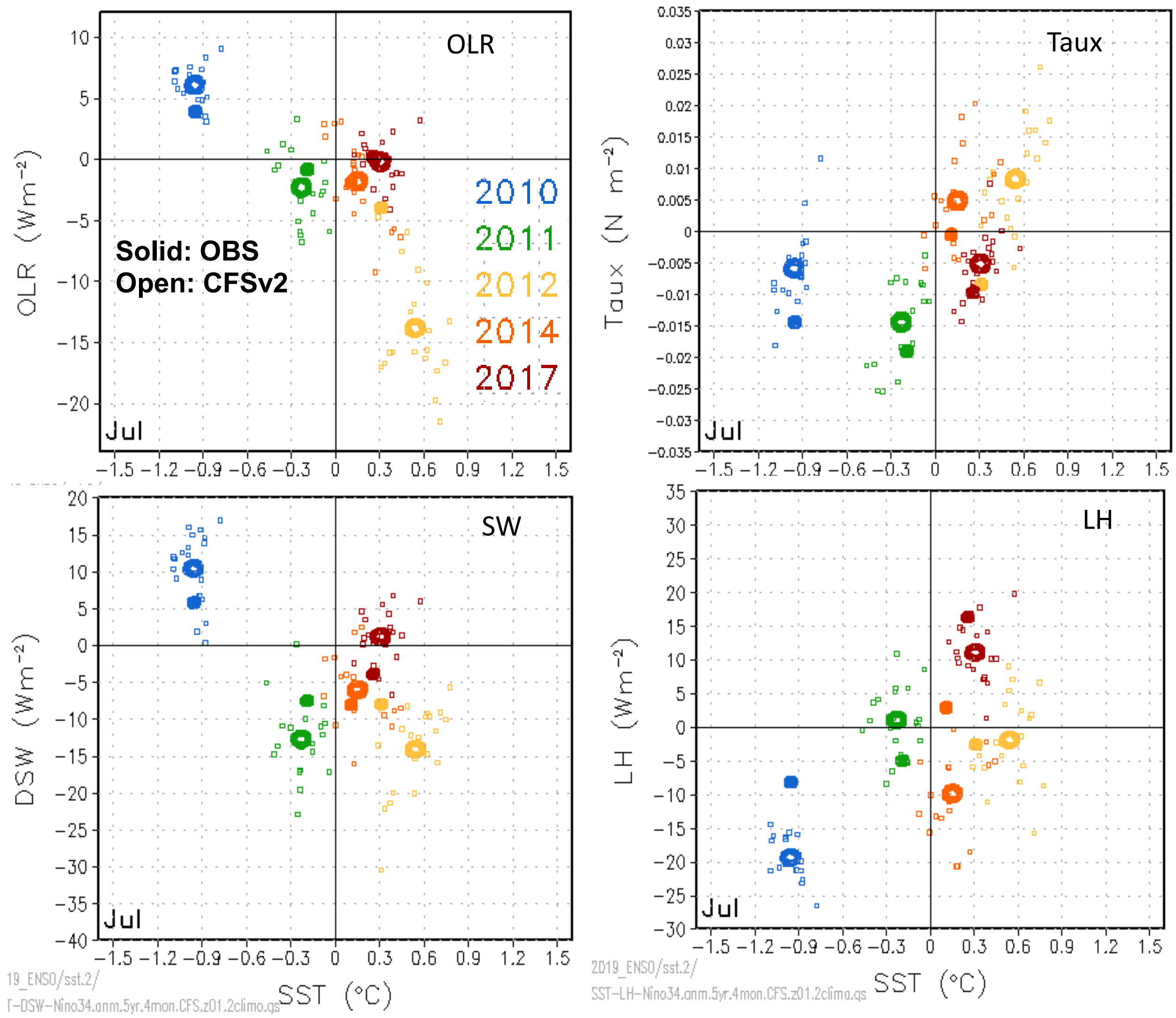


Fig. 4 Relationships between July Niño3.4 SSTAs (x-axis) and atmospheric variables (y-axis): OLR, DSW, zonal momentum flux (Taux), and latent heat flux (LH). Observations are shown with solid circles and CFSv2 forecasts with open circles. Individual forecast members are shown with small dots. Observed SST index is from the NCEI analysis, and observed atmospheric variables (OLR, DSW, Taux, and LH are from the ERA-Interim (ERA-I) analysis (Dee *et al.* 2011). Colors are used to represent different years. CFSv2 forecasts are from June initial conditions.

component, the Global Forecast System (GFS), with specified SSTs to evaluate the impact of convection parameterization schemes. AMIP runs are performed with three convection schemes: Simplified Arakawa-Schubert in CFSv2 (SAS), Relaxed Arakawa-Schubert (RAS), and Simplified Arakawa-Schubert v2 (SAS2). As shown in Fig. 5, Taux is too strong with SAS and SAS2 scheme and is quite reasonable with RAS compared to the observation, suggesting the strong impact of convection parameterization. This comparison suggests that using an alternative convection scheme such as RAS may help improve ENSO prediction with reduced false alarm bias.

5. Summary and conclusions

The ENSO false alarm is a systematic bias in the current NCEP climate forecast system (CFSv2). It is also a common issue in the NMME. Our analysis indicates that the ENSO false alarm is related to excessive convection response to existing weak warm SST anomalies, resulting in strong zonal momentum anomalies and positive wind-stress feedbacks. The strong zonal momentum response is possibly related to the

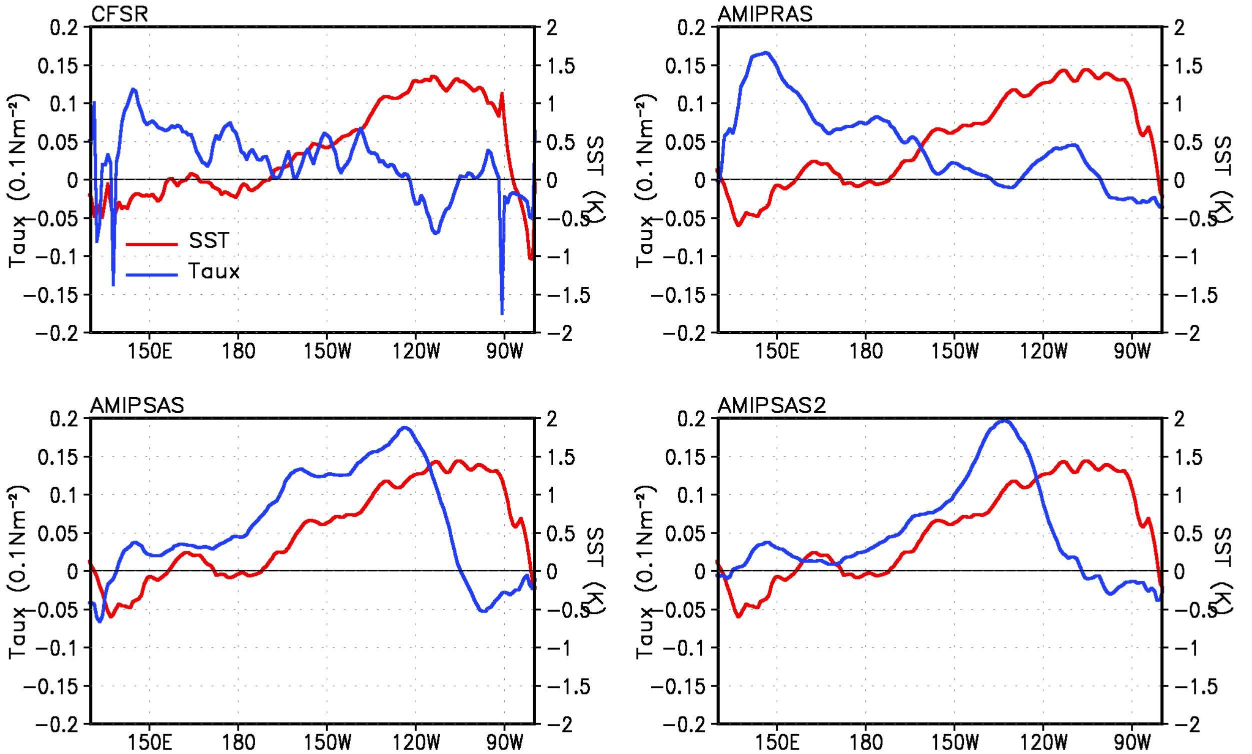


Fig.5 July 2012 SST and Taux anomalies (1ºS-1ºN average) from NCEP Climate Forecast System Reanalysis (CFSR) and AMIP runs with the CFSv2 atmospheric component.

convection parameterization scheme. The excessive convection response also results in larger amplitude of negative shortwave radiation feedback, which is an effect rather a cause of the ENSO false alarm.

Reference

Dee, D. P., and Coauthors, 2011: The ERA-Interim reanalysis: configuration and performance of the data assimilation system. *Quart. J. Roy. Meteor. Soc.*, **137**, 553–597. doi:10.1002/qj.828.

Reynolds, R. W., T. M. Smith, C. Liu, D. B. Chelton, K. S. Casey, and M. G. Schlax, 2007: Daily high-resolution-blended analyses for sea surface temperature. *J. Climate*, **20**, 5473-5496.

Saha, S. and Coauthors, 2014: The NCEP Climate Forecast System Version 2. *J. Climate*, **27**, 2185-2208. doi: abs/10.1175/JCLI-D-12-00823.1

NOAA's Climate Prediction Center Stakeholder Meeting
College Park, MD, 24-26 September, 2019

Afghanistan Impacts After Autumn 2018-Spring 2019 Precipitation

Justyn D. Jackson

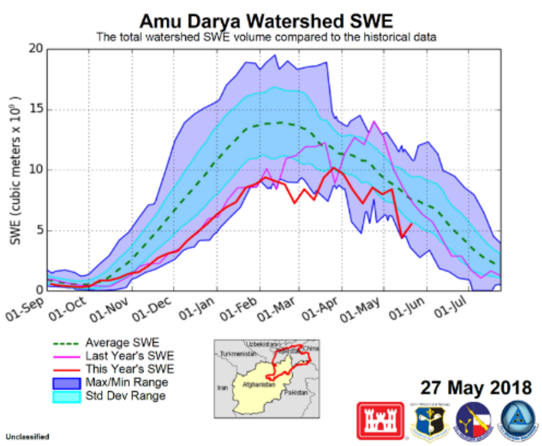
14th Weather Squadron, 557th Weather Wing, U.S. Air Force

1. Introduction

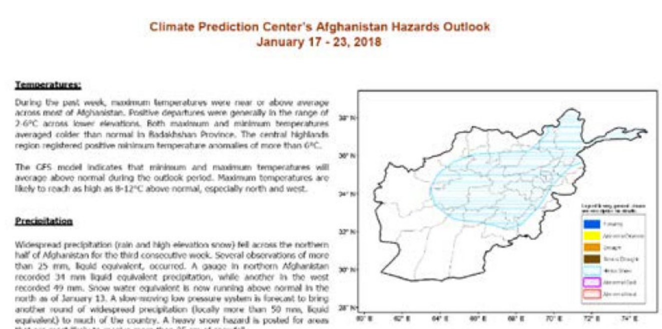
The Air Force's 14th Weather Squadron (14 WS) is the organization responsible for delivering climate information and services to the Department of Defense (DoD). Due to increasing demand for climate information, including drought and precipitation monitoring, the squadron seeks to identify avenues to best deliver decision-grade climate services, illustrated by a case study of the 2018-2019 Middle East and Southwest Asia winter and spring seasons.

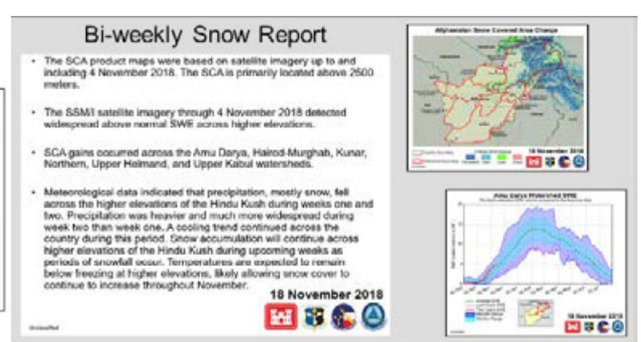
2. Case study

The vast majority of the Middle East and Southwest Asia experienced extreme drought conditions for the last several years, with little occurrence of widespread heavy precipitation, mountain snow, or subsequent significant spring snowmelt. These conditions were exacerbated by the 2017-18 La Nina, causing 275,000 people to be displaced and over 13 million being food insecure.



However, persistent upper-level ridging across Western Europe resulted in a very active storm track from the eastern Mediterranean Sea to the Himalayas during the winter of 2018-2019. The persistent synoptic pattern contributed to well above normal precipitation and an accumulation of near-record snow in mountainous watersheds. Members of the 14 WS Climate Monitoring, Analysis and Prediction/Projection team began to notice these conditions in November 2018. Products from the Climate Prediction Center, including Weekly Hazards Outlook, MJO Analysis and Forecasts, and ESNO predictions were incorporated into the analysis. The 14 WS began to discuss them in their specialized Afghanistan product suite (see below).





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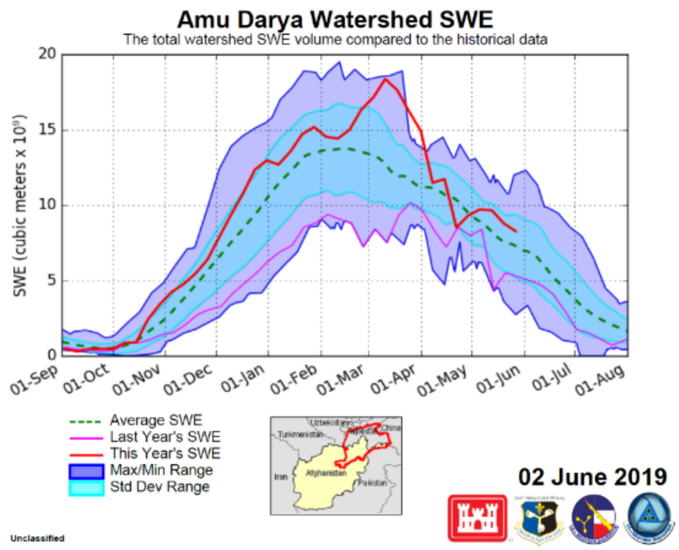
The high level of snow water equivalent (SWE) resulted in significant spring snowmelt and the same regions plagued by a multi-year drought suddenly experienced widespread and devastating flooding not seen in over a decade. The image on the right shows the Amu Darya Watershed SWE, with the red line indicating a near record amount.



An in-depth climate analysis revealed the persistent synoptic pattern can be linked to a weak El Niño event in the equatorial Pacific Ocean. Additionally, periods of anomalously wetter and drier than normal periods can be linked to the Madden Julian Oscillation. These impacts were well-anticipated and continued to be communicated by the 14 WS via climate monitoring and prediction team discussions, incorporation into the website product suite, and responding to several tailored support requests, thus providing environmental intelligence to analysts and decision makers.

The 2019 spring snow melt resulted in the worst flooding in 7 years, with 28 of 34 Afghanistan provinces being impacted. In several instances, excessive snow pack blocked roads, complicating the relief and recovery efforts.

3. Concluding remarks

The 14 WS looks forward to continuing to work with CPC and will leverage CPC sub-seasonal and seasonal products. Additional products that would be useful include longer range (2-4 week) Afghanistan outlooks, seasonal precipitation outlooks and seasonal precipitation performance probabilities, similar to those available on the CPC Africa desk website.

NOAA's Climate Prediction Center Stakeholder Meeting
College Park, MD, 24-26 September, 2019

Climate Prediction Center Experimental Arctic Sea Ice Outlooks

Wanqiu Wang[1], Yanyun Liu[1, 2], Thomas W. Collow[1], Arun Kumar[1], and David DeWitt[1]
[1]*Climate Prediction Center, NOAA's National Weather Service*
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1. Background

The Climate Prediction Center (CPC) produces seasonal and weekly sea ice outlooks. The seasonal outlook covers nine target months and the weekly outlook covers six target weeks. This extended summary provides a description of the forecast process, available forecast products, and an assessment of the forecast performance.

2. Forecast process

Seasonal predictions have been produced since March 2015 with March to October initial conditions each year while weekly predictions became available in May 2018. Beginning in November 2019, seasonal predictions are made starting in all months. The predictions are produced with a CPC experimental forecast system (CPCExp) modified from the operational Climate Forecast System version 2 (CFS, Saha *et al.* 2014) to reduce forecast bias. The atmospheric component in CPCExp is the 2007 version of the NCEP Global Forecast System (GFS). The oceanic component is the Geophysical Fluid Dynamics Laboratory Modular Ocean Model version 4 (MOM4, Griffies *et al.* 2004) before May 2018 and Modular Ocean Model version 5 (MOM5, Griffies 2012) starting May 2018.

One of the key initial conditions for sea ice predictions at sub-seasonal to seasonal time scales (S2S) is the sea ice thickness. The operational CFS uses initial conditions from the National Centers for Environmental Predictions (NCEP) Climate Forecast System Reanalysis (CFSR, Saha *et al.* 2010). The sea ice thickness from CFSR contains large errors compared to other observational analyses and satellite retrievals. The CPCExp forecasts are initialized from CFSR for the atmosphere and land surface. For seasonal sea ice predictions, initial conditions for ocean and sea ice are also taken from CFSR except for sea ice thickness which was taken from the Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS, Lindsay and Zhang 2006) for 2015 to April 2018 and from the CPC Sea ice Initialization System (CSIS) starting May 2018. The use of the PIOMAS sea ice thickness significantly improved the sea ice forecast compared to that from the operational CFS (Collow *et al.* 2015). For weekly predictions, initial conditions for both ocean and sea ice are taken from CSIS.

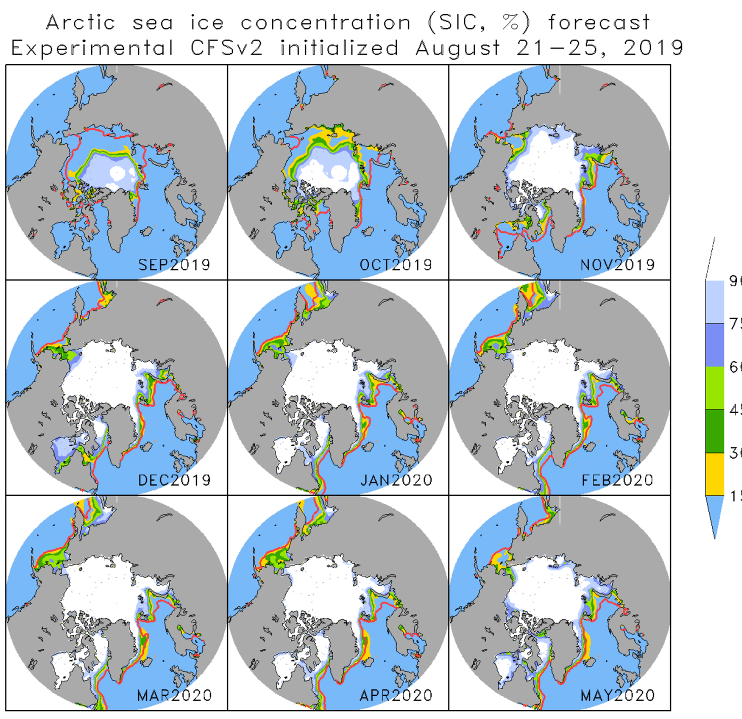

Fig. 1 Monthly ensemble mean sea ice concentration for nine target months from seasonal forecast initialized in August 2019.

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3. Sea ice predictions

Seasonal predictions are produced every month with 20 ensemble members. Historical forecasts of sea ice concentration from 2006 to the year before the forecast year are used to compute climatology for the correction of forecast bias which is defined as the mean differences between forecasts and observations from the NASA Team analysis (Cavalieri *et al.* 1996; available at ftp://sidads.colorado.edu/DATASETS). Weekly predictions are produced once a week and are initialized every Sunday. There are 16 ensemble members. Historical weekly forecasts of sea ice concentration from 2012 to the year before the forecast year are used to compute climatology for bias correction.

For both seasonal and weekly forecasts, sea ice concentration-based parameters are made available to the public, including (1) sea ice extent, (2) monthly/weekly mean sea ice concentration, and (3) first ice melt day (IMD) and ice freeze day (IFD). The IMD and IFD are calculated based on daily data. For each parameter, forecast uncertainties are provided based on ensemble spread. An example of monthly forecast sea ice concentration is shown in Fig. 1 for seasonal forecast from August 2019.

4. Assessment of sea ice forecast performance

A Heidke skill score (HSS) is used to assess the CPCExp sea ice forecast performance. The HSS is calculated based on the forecast of existence or non-existence of sea ice. Sea ice is considered to exist in the forecast or observation if the sea ice concentration is greater than 15%. The HSS is defined as

$$HSS = \frac{AC - AC_e}{AT - AC_e}$$

where AC is the area of correct forecast, ACe area of expected correct forecast based on observed climatology, and AT the total area of grid boxes being considered.

Comparisons between NCEP operational CFS and CPCExp of the HSS of monthly sea ice concentration from 2015-2018 seasonal forecasts are shown in Fig.2. Overall, CPCExp produces improved forecasts compared to the operational CFS, especially for the summer period from June to September for which the CFS skill is mostly negative. It is also noted that both CFS and the CPCExp have difficulties in predicting sea ice during freeze-up seasons. Similar comparisons for weekly forecasts between CFS and CPCExp are given

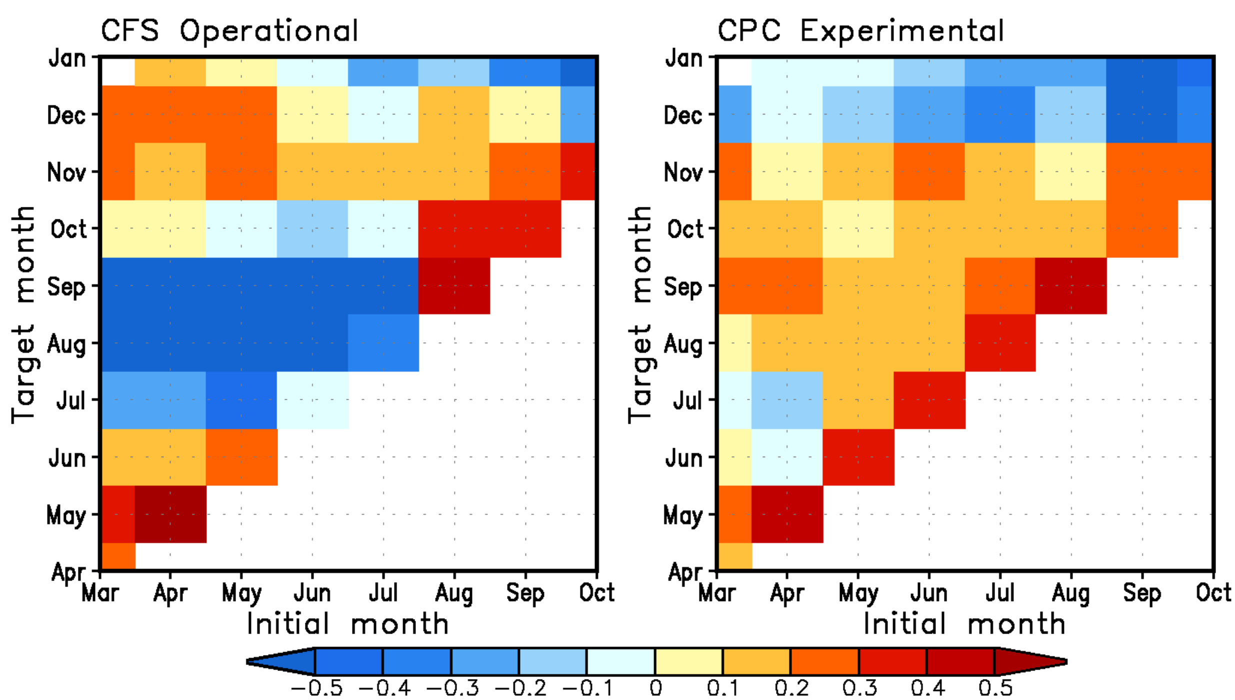

Fig. 2 HSS of monthly mean sea ice seasonal forecasts from 2015 to 2018 for Arctic regions.

in Fig. 3. It is clear that the CPCExp forecast is consistently better than CFS operational for both sea ice melt and sea ice freeze-up seasons.

5. Summary and discussions

Sea ice predictions have been produced routinely with the CPC experimental forecast system (CPCExp). While the CPCExp predictions are significantly improved compared to that from the NECP operational CFS, the skill of the forecast system may be further enhanced with improved post-processing and a better assimilation system for sea ice initialization. The current predictions are produced with a mean bias correction for sea ice concentration. An alternative bias-correction algorithm based on the mapping between forecast and observed sea ice concentration as well as the SST conditions is being developed, which is expected to help further reduce errors in the sea ice predictions. The current CPC sea ice initialization system (CSIS) only assimilates observed sea ice concentration. Additional information of observational estimates of sea ice thickness will also provide more accurate initial sea ice conditions for the predictions.

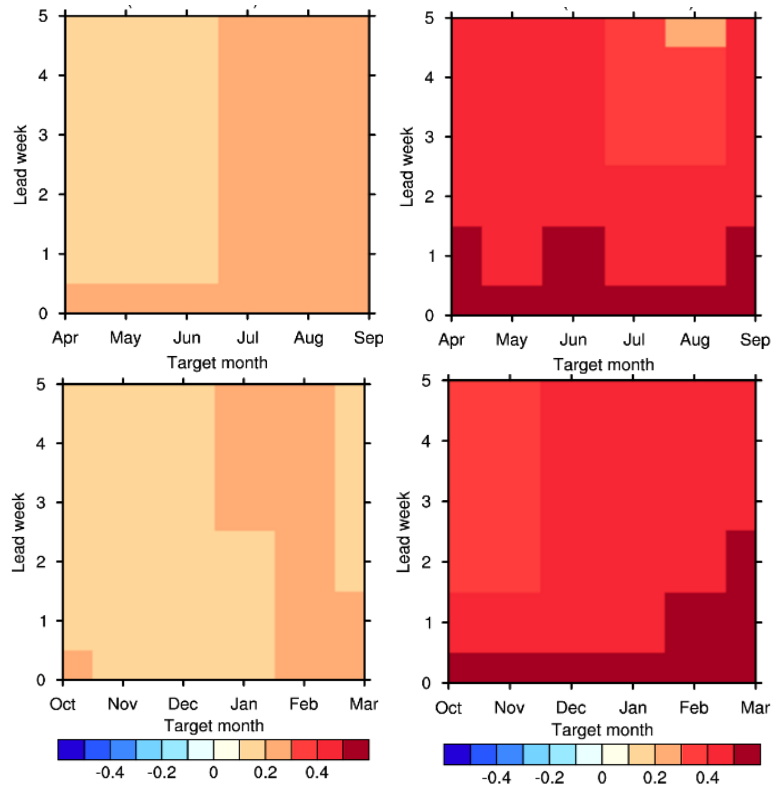

Fig. 3 HSS of weekly mean sea ice weekly forecasts from 2012 to 2018 for Arctic regions. Left panels: Operational CFSv2. Right panels: CPCExp.

References

Cavalieri, D. J., C. L. Parkinson, P. Gloersen, and H. J. Zwally, 1996 (updated yearly): Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data. [1980-2015]. NASA Distributed Active Archive Center at National Snow and Ice Data Center, Boulder, Colorado USA.

Collow T. W., W. Wang, A. Kumar, J. Zhang, 2015: Improving Arctic sea ice prediction using PIOMAS initial sea ice thickness in a coupled ocean-atmosphere model. *Mon. Wea. Rev.*, **143**, 4618-4630, doi:10.1175/MWR-D-15-0097.1

Griffies, M., J. Harrison, R. C. Pacanowski, and A. Rosati, 2004: Technical guide to MOM4. *GFDL Ocean Group Tech. Rep. No. 5*, NOAA/Geophysical Fluid Dynamics Laboratory, 337 pp. [Available online at www.gfdl.noaa.gov/~fms.]

Griffies, S. M., 2012: Elements of the Modular Ocean Model (MOM) (2012 release). *GFDL Ocean Group Tech. Rep. No. 7*, NOAA/Geophysical Fluid Dynamics Laboratory, 631pp.

Lindsay, R. W. and J. Zhang, 2006: Assimilation of ice concentration in an ice-ocean model. *J. Atmos. and Ocean. Tech.*, **23**, 742-749. doi: 10.1175/JTECH1871.1

Saha, S., and Coauthors, 2014: The NCEP Climate Forecast System Version 2. *J. Climate*, **27**, 2185-2208. doi: abs/10.1175/JCLI-D-12-00823.1

Saha, S., S. Moorth, H. Pan, and Coauthors, 2010: The NCEP Climate Forecast System Reanalysis. *Bull. Amer. Meteor. Soc.*, **91**, 1015-1067. doi: 10.1175/2010BAMS3001.1

Develop Improved Seasonal and Week 3/4 Sea Ice Outlook

Thomas W. Collow[1], Yanyun Liu[1, 2], Wanqiu Wang[1], Arun Kumar[1], and David DeWitt[1]

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[2]*Innovim, LLC, Greenbelt, MD*

1. Background

One of the key factors that affect sea ice predictions at sub-seasonal to seasonal time scales (S2S) is the sea ice thickness. Unrealistic initial sea ice thickness is a major reason for erroneous sea ice prediction from the National Centers for Environmental Predictions (NCEP) operational Climate Forecast System (CFS, Saha *et al.* 2014), which is initialized from the NCEP Climate Forecast System Reanalysis (CFSR). The Climate Prediction Center (CPC) developed a reconfigured sea ice experimental forecast system (CPCExp) using initial sea ice thickness from the Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS, Lindsay and Zhang 2006), together with modifications to the model physics to reduce systematic forecast bias. CPC started producing seasonal sea ice predictions for a nine-month target period in 2015. While the use of the PIOMAS sea ice thickness significantly improved the sea ice forecast compared to that from the operational CFS (Collow *et al.* 2015), there are two disadvantages in using the PIOMAS data to initialize CPCexp, i) inconsistency of the ocean model (PIOMAS and CFSv2 use different ocean models with different sea ice thickness categories that require interpolation), and ii) reliance on an external and non-operational source for data. To ameliorate these issues, CPC has developed an in-house sea ice analysis product for initializing sea ice outlooks, known as the CPC Sea Ice Initialization System (CSIS). In this extended summary, we provide a description of the CSIS and its evaluation against PIOMAS, CFSR, and CryoSat-2 satellite retrieval.

2. The CPC Sea ice Initialization System (CSIS)

The CSIS sea ice analysis is produced with the Geophysical Fluid Dynamics Laboratory Modular Ocean Model version 5 (MOM5, Griffies 2012). The MOM5 is run starting on 1 January 2005 forced by prescribed atmospheric near surface fields. Observational analyses of sea ice concentration (SIC) and sea surface temperature (SST) are assimilated as daily observations following the approach of Lindsay and Zhang (2006). The assimilation of both SST and SIC uses a nudging method with the final values calculated as a weighted average of values from observations and model integration. Sea ice in MOM5 is described with 5 thickness categories. Sea ice concentration is first changed in the lowest thickness category. If needed, the residual difference is removed from the next lowest category and so on until the total amount changed equals the nudged value. Newly added sea ice is initially assigned a

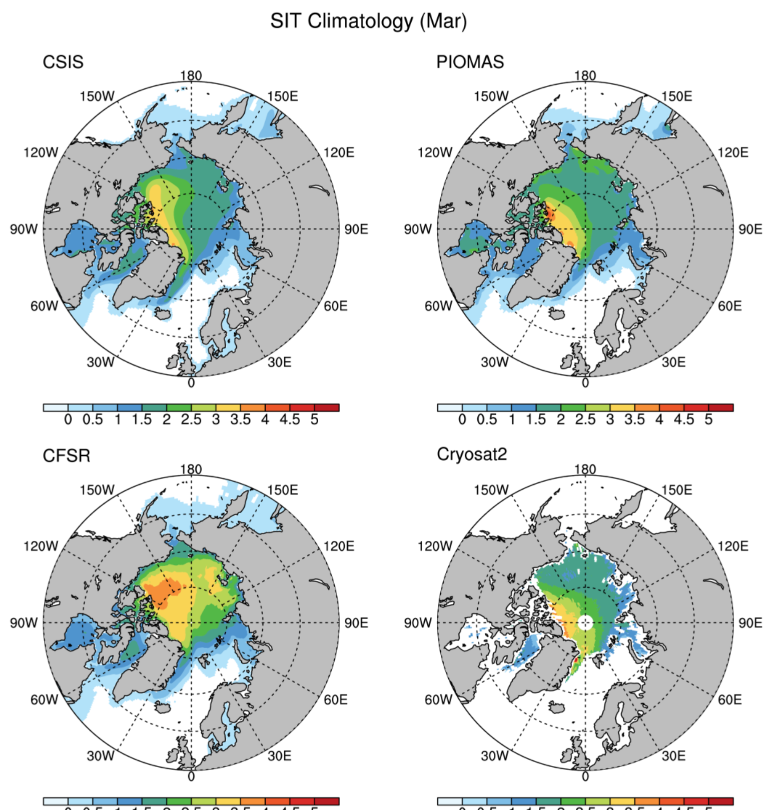

Fig. 1 2012-2018 average of March sea ice thickness (m).

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sea ice thickness of 0.30 m. Due to the constraint that the CSIS is to provide initial conditions for real-time forecasts, CFSR atmospheric forcing (Saha *et al.* 2010), National Centers for Environmental Information (NCEI) SST (Reynolds *et al.* 2007), and NASA Team SIC (Cavalieri *et al.* 1996, available at ftp://sidads.colorado.edu/DATASETS) are used as the observational data sources. Other datasets were also tested experimentally, with the above configuration having ideal performance.

3. Assessment of sea ice thickness from CSIS

Sea ice thickness from CSIS is compared with other observation analyses including CFSR, PIOMAS, and CryoSat-2. Figure 1 compares 2012-2018 average of March sea ice thickness (SIT). Spatial pattern of SIT in PIOMAS and CryoSat-2 is characterized by relatively large SIT to the north of Greenland and the Canadian Arctic Archipelago, and smaller SIT in other regions. The CSIS produces a pattern similar to that in PIOMAS and CryoSat-2, although the sea ice over parts of the Beaufort Sea appears to be too thick. In contrary, there exists a large positive SIT bias in CFSR compared to PIOMAS and CryoSat-2 in most of the Arctic regions. This bias led to errors in sea ice prediction from CFS that was initialized from CFSR (Collow *et al.* 2015).

In addition to the mean bias, SIT errors in interannual anomalies also exist in CFSR. One example of SIT anomaly errors and its impact on sea ice forecasts is shown in Fig. 2. In May 2017, both PIOMAS (Fig. 2b) and CSIS (Fig. 2c) produced negative SIT anomalies over most of the Arctic regions, while SIT anomalies

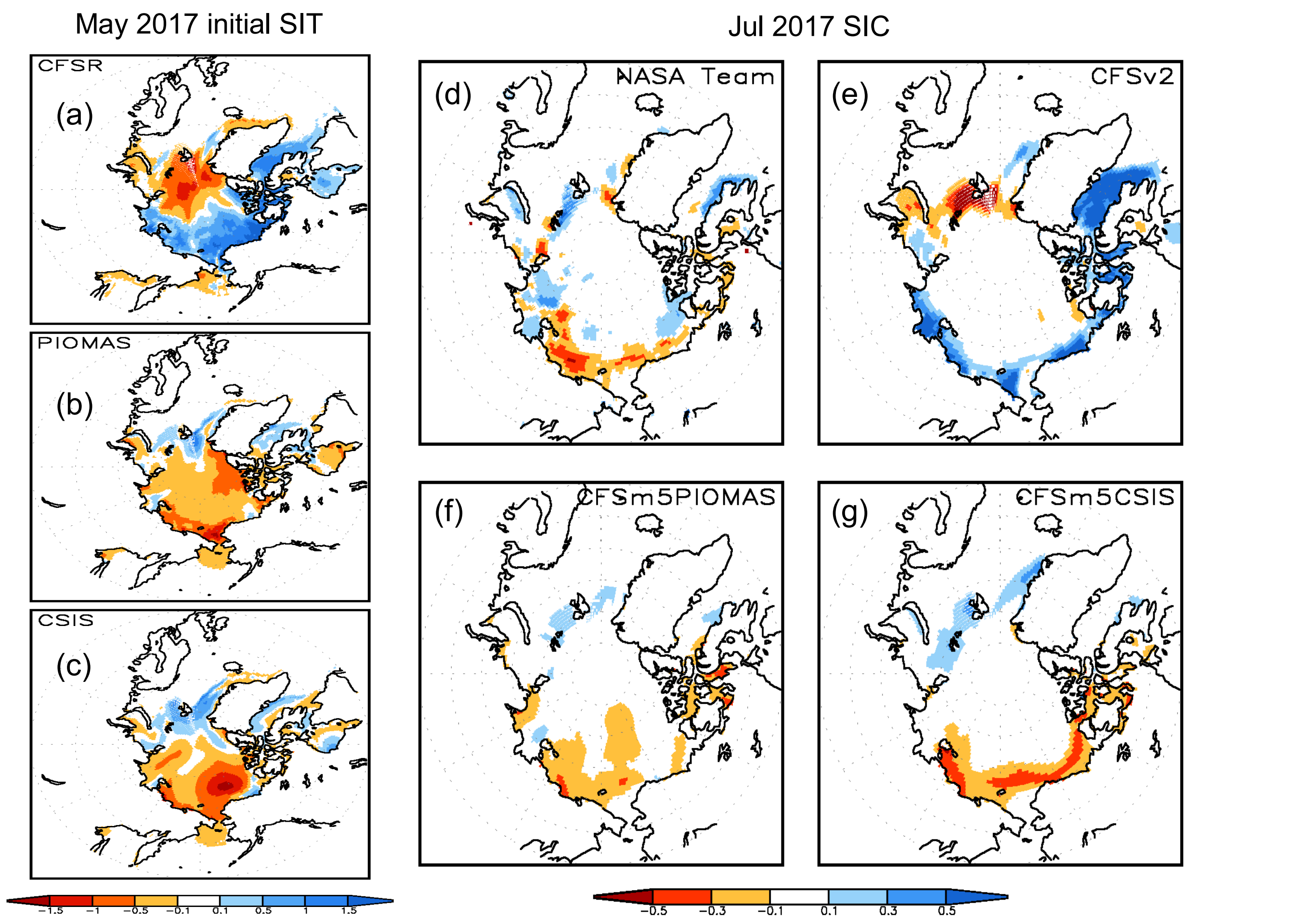


Fig. 2 (a) May 2017 sea ice thickness anomalies from CFSR, (b) as in (a) except for PIOMAS, (c) as in (a) except for CSIS, (d) observed July 2017 sea ice concentration anomalies, (e) CFSv2 forecast July 2017 sea ice concentration anomalies initialized in May 2017 with CFSR sea ice thickness in (a), (f) as in (e) but for forecast with CFSm5 initialized with PIOMAS, and (g) as in (f) except with initial sea ice thickness from CSIS.

from CFSR (Fig. 2a) show a clear dipole pattern with positive anomalies in the Pacific side and negative anomalies in the Atlantic side. When used as initial conditions in the CPCExp, these May 2017 SIT conditions result in dramatic differences in the forecast of July 2017 SIC. Forecasts of July SIC with both PIOMAS and CSIS May initial SIT (Fig. 2f and Fig. 2g) compared well with the NASA Team observational estimate (Fig. 2d). However, the forecast with CFSR initial sea ice thickness (Fig. 2e) failed to capture. Forecasts for shorter time scales (weeks 3 and 4) initialized from CSIS also significantly improve over that from operational CFS (not shown).

4. Conclusions

Evaluations of the CPC Sea ice Initialization System (CSIS) have shown that (1) the sea ice thickness from CSIS is reasonable compared to the sea ice thickness from PIOMAS and CryoSat-2, and (2) initialization with the CSIS sea ice thickness results in much improved sea ice predictions compared to those from operational CFS. The current version of CSIS does not assimilate any observed sea ice thickness. It is expected that the SIT accuracy in CSIS will be further improved with the inclusion of observational sea ice thickness information in the initialization system.

References

Cavalieri, D. J., C. L. Parkinson, P. Gloersen, and H. Zwally, 1996 (updated yearly): Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data. [1980-2015]. NASA Distributed Active Archive Center at National Snow and Ice Data Center, Boulder, Colorado USA.

Collow T. W., W. Wang, A. Kumar, J. Zhang, 2015: Improving Arctic sea ice prediction using PIOMAS initial sea ice thickness in a coupled ocean-atmosphere model. *Mon. Wea. Rev.*, **143**, 4618-4630, doi:10.1175/MWR-D-15-0097.1

Griffies, S. M., 2012: Elements of the Modular Ocean Model (MOM) (2012 release), *GFDL Ocean Group Tech. Rep. No. 7*, NOAA/Geophysical Fluid Dynamics Laboratory, 631pp.

Lindsay, R. W. and J. Zhang, 2006: Assimilation of ice concentration in an ice-ocean model. *J. Atmos. and Ocean. Tech.*, **23**, 742-749, doi: 10.1175/JTECH1871.1.

Reynolds, R. W., T. M. Smith, C. Liu, D. B. Chelton, K. S. Casey, and M. G. Schlax, 2007: Daily high-resolution blended analyses for sea surface temperature. *J. Climate*, **20**, 5473-5496.

Saha, S., and Coauthors, 2014: The NCEP Climate Forecast System Version 2. *J. Climate*, **27**, 2185-2208. doi: abs/10.1175/JCLI-D-12-00823.1

Saha, S., S. Moorth, H. Pan, and Coauthors, 2010: The NCEP Climate Forecast System Reanalysis. *Bull. Amer. Meteor. Soc.*, **91**, 1015-1067, doi: 10.1175/2010BAMS3001.1

NOAA's Climate Prediction Center Stakeholder Meeting
College Park, MD, 24-26 September, 2019

Delayed Indian Southwest Monsoon

Justyn D. Jackson

14th Weather Squadron, 557th Weather Wing, U.S. Air Force

1. Introduction

The Air Force's 14th Weather Squadron (14 WS) is the organization responsible for delivering climate information and services to the Department of Defense (DoD). Due to increasing demand for climate information, including drought and precipitation monitoring, the squadron seeks to identify avenues to best deliver decision-grade climate services, illustrated by a case study of the delayed onset of the southwest monsoon over the Indian subcontinent and surrounding areas and the resulting extended drought.

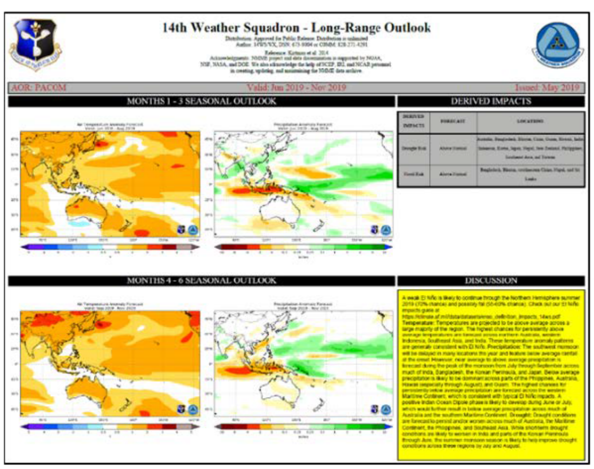
2. Case study

The 2018 southwest monsoon season was nearly normal in terms of its arrival. However, some locations experienced well below rainfall, including the Chennai area. The image on the right shows a much smaller Puzhal Lake on April 21, 2109 resulting from this lack of monsoon rains. In early May of 2019, 14 WS personnel began to track the increasingly dry conditions and delayed onset of the southwest monsoon.

In addition to locally created products, the CPC collaborative Global Tropics Hazards and Benefits Outlook (GTHB, https://www.cpc.ncep.noaa.gov/products/precip/CWlink/ghazards/), South Asia International Desk website (https://www.cpc.ncep.noaa.gov/products/international/sasia/sasia.shtml), and MJO and OLR products (https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/mjo.shtml) were used in creating 14 WS long range outlooks.

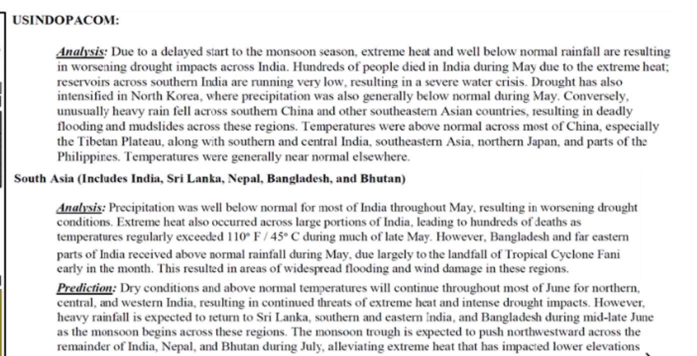
The May issuance of the 14WS Long Range Outlook (LRO) (on the left below) and Monthly Climate Assessment (on the right below) products included the first discussion of the delay in the onset of the southwest monsoon, extreme heat, continued below average rainfall, and worsening drought across India.

LRO issued May 2018



"The southwest monsoon will be delayed in many locations this year and feature below average rainfall at the onset."

Monthly Climate Assessment issued May 2019



USINDOPACOM:

Analysis: Due to a delayed start to the monsoon season, extreme heat and well below normal rainfall are resulting in worsening drought impacts across India. Hundreds of people died in India during May due to the extreme heat; reservoirs across southern India are running very low, resulting in a severe water crisis. Drought has also intensified in North Korea, where precipitation was also generally below normal during May. Conversely, unusually heavy rain fell across southern China and other southeastern Asian countries, resulting in deadly flooding and mudslides across these regions. Temperatures were above normal across most of China, especially the Tibetan Plateau, along with southern and central India, southeastern Asia, northern Japan, and parts of the Philippines. Temperatures were generally near normal elsewhere.

South Asia (Includes India, Sri Lanka, Nepal, Bangladesh, and Bhutan)

Analysis: Precipitation was well below normal for most of India throughout May, resulting in worsening drought conditions. Extreme heat also occurred across large portions of India, leading to hundreds of deaths as temperatures regularly exceeded 110° F / 45° C during much of late May. However, Bangladesh and far eastern parts of India received above normal rainfall during May, due largely to the landfall of Tropical Cyclone Fani early in the month. This resulted in areas of widespread flooding and wind damage in these regions.

Prediction: Dry conditions and above normal temperatures will continue throughout most of June for northern, central, and western India, resulting in continued threats of extreme heat and intense drought impacts. However, heavy rainfall is expected to return to Sri Lanka, southern and eastern India, and Bangladesh during mid-late June as the monsoon begins across these regions. The monsoon trough is expected to push northwestward across the remainder of India, Nepal, and Bhutan during July, alleviating extreme heat that has impacted lower elevations and improving drought conditions across these regions.

"Due to a delayed start to the monsoon, extreme heat and well below normal rainfall are resulting in worsening drought impacts across India."
"…heavy rainfall is expected to return to Sri Lanka and southern and eastern India during mid-late June as the monsoon begins"

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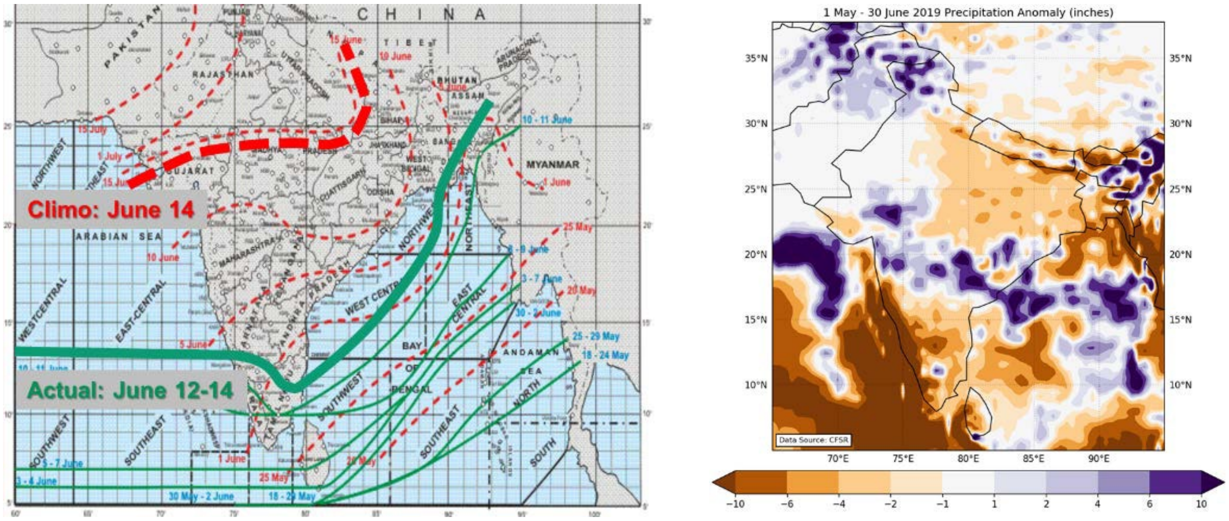

According to the India Meteorological Department in their graphics above, the onset of the southwest monsoon (left panel) was delayed about 2 weeks, with the green line showing the location of the monsoon boundary on 12-14 June compared to the climatological norm shown in the red line. Precipitation anomalies (right panel) exceeded 4-10 inches below normal over much of India through the end of June 2019.

The extended period of below average rainfall, excessively high temperatures, and delayed onset of the southwest monsoon rainy season resulted in hundreds of heat related deaths and significant water shortages.

3. Concluding remarks

The 14 WS looks forward to continuing to work with CPC and will leverage CPC products. Additional products that would be useful would be longer range (week 3-4) temperature and precipitation outlooks on the International Desk website and an updated GTHB for week 3 and 4.

Use of GTH by JTWC: General Overview and Use Case

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Joint Typhoon Warning Center, Pearl Harbor, Hawaii

1. Introduction

The Joint Typhoon Warning Center (JTWC) is a U.S. Department of Defense (DOD) meteorological and oceanographic forecasting command jointly staffed by U.S. Navy and U.S. Air Force personnel. The organization's mission is to provide analysis, forecast and decision support to enable DOD and other decision makers to plan, prepare and protect against the threat of tropical cyclones (TCs), tsunamis and other weather impacts. JTWC forecasts TC formation, track, intensity and wind radii in the Pacific and Indian Ocean basins for its U.S. Government customers.

JTWC is pursuing extended-range TC formation forecasting through participation in the Global Tropics Hazards (GTH) and Benefits Outlook process and its own two-week forecasting effort, with three primary objectives. First, the organization seeks to increase lead-times for the first notice of potential TC formations. Prior to recent extended-range forecasting efforts, the first notifications of potential TC formations that JTWC provided to its customers were discussions of invest areas classified in Significant Tropical Weather Advisory bulletins. These bulletins classify the potential for TC formation within a 24-hour forecast period. JTWC's second objective for extended-range TC prediction is to provide consistent, well-timed TC formation guidance in Significant Tropical Weather Advisories. By identifying potential TC formation areas early, JTWC strives to improve the timing and accuracy of short-lead forecasts. JTWC's third objective for extended-range TC formation prediction is to improve the accuracy of initial warnings for TCs by extending the opportunity to gather and evaluate guidance prior to formation.

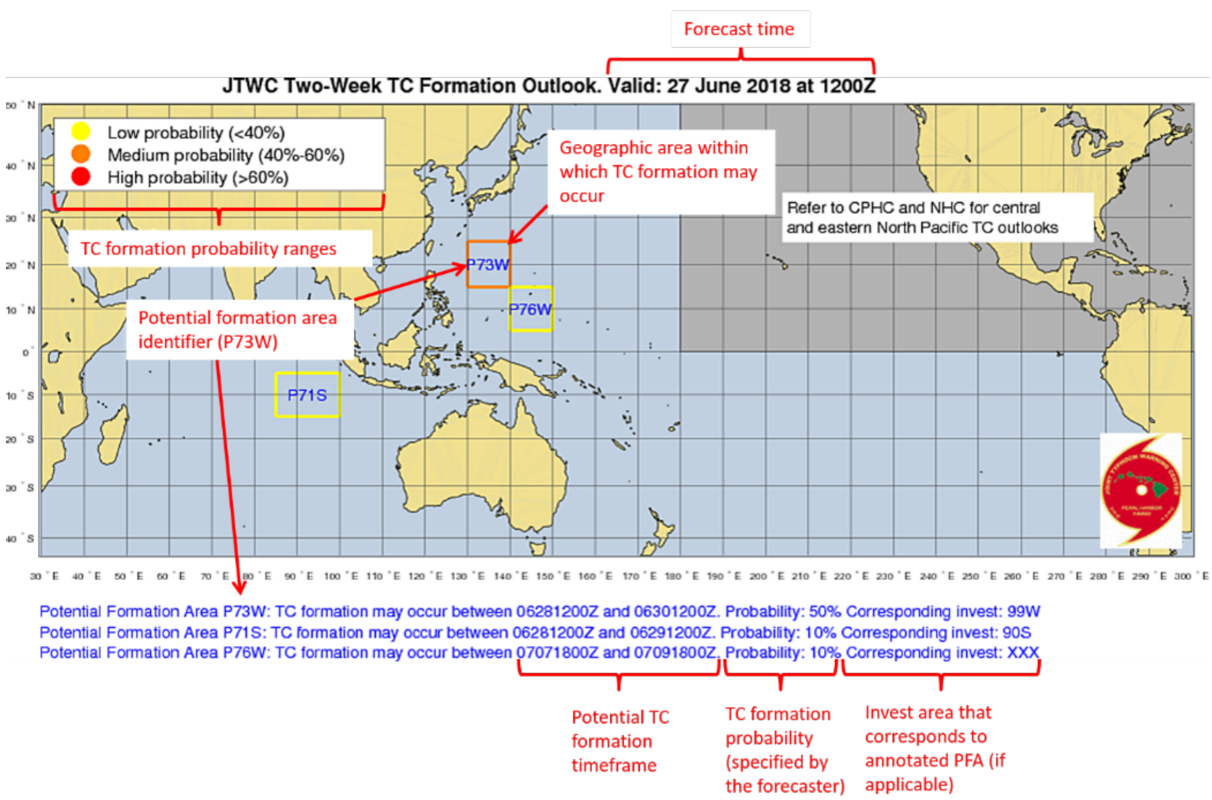

Fig. 1 Example AOR-scale JTWC two-week TC formation outlook graphic.

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JTWC has participated in weekly GTH telephone conference calls since 2010. JTWC forecasters discuss the latest GTH outlook each Wednesday during in-house TC forecast discussions, and the organization provides a link to the GTH outlook from its websites. After several years of successful, weekly collaboration with the Climate Prediction Center (CPC) through participation in the GTH process, JTWC initiated a project to produce two-week TC formation forecasts for situational awareness among the organization's forecasters and staff members. That project's success prompted JTWC to transition the two-week outlooks into operational products for its external customers. JTWC began issuing Two-Week TC Formation Outlooks to DOD partners on 01 July 2018. The products specify locations and times at which TCs may form within the JTWC area-of-responsibility (AOR). Two-week outlooks consist of an AOR-scale graphic (Figure 1) and detail graphics for each identified potential formation area (PFA). JTWC produces and distributes these outlooks at least twice daily through the organization's DOD and Collaboration websites. Forecasters consider a wide range of data to determine the geographic areas, timeframes and probabilities for TC formation depicted in the outlooks. Information shared at GTH conference calls and the GTH forecast product itself are among the most important data points considered during the forecast process.

2. Use case

JTWC forecasters apply information shared in the GTH conference calls and forecast products to set and adjust the PFAs depicted in the organization's Two-Week TC Formation Outlooks. The GTH is particularly useful for the period from late-week 1 through week 2, when dynamical models may not yet indicate formation but large-scale patterns such as the Madden-Julian Oscillation (MJO) and equatorial wave activity are expected to induce environmental conditions that support TC formation. Super Typhoon (STY) 30W (Kong-Rey) from 2018 illustrates applicability of the GTH to the JTWC Two-Week TC Formation Outlook forecasting process. STY 30W, which intensified to an estimated peak of 140 knots, threatened DOD installations in Guam, Okinawa and South Korea between September 28, 2018 and October 6, 2018. Early forecasts for potential TC formation and track, prior to formation, were essential to effective planning and resource protection.

The GTH product issued on September 19, 2018, depicted a moderate confidence area in the week 2 forecast for the area within which STY 30W would eventually form (Figure 2). At the time, the MJO signal was weak and numerical forecast model solutions were mixed. The GTH outlook provided the first notification of the developing TC threat near Guam to JTWC's customers, and prompted JTWC forecasters to

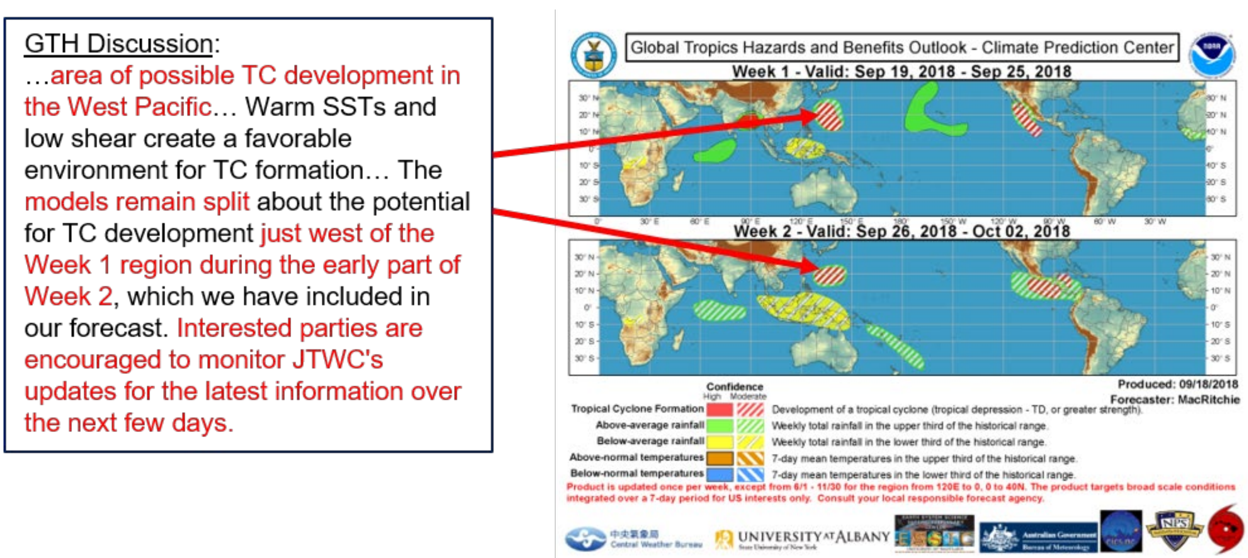

Fig. 2 GTH Outlook graphical product from September 19, 2018. The moderate confidence area in the western North Pacific, week 2 forecast corresponds to the area within which STY 30W would eventually form.

monitor the area for possible incorporation into JTWC's Two-Week TC Formation Outlook. On September 23, 2018 at 0000Z, 5 days prior to TC formation, JTWC forecasters designated a corresponding PFA in the two-week outlook.

On September 25, 2018 at 0600Z, JTWC classified the 24-hour formation potential for STY 30W's precursor disturbance as "low" on the Significant Tropical Weather Advisory, 66 hours prior to formation. JTWC subsequently upgraded these classifications to "medium" and "high" 42 hours and 15.5 hours prior to formation, respectively. Concurrently, the GTH product issued on September 26, 2018, depicted a corresponding high confidence area and presented a concise reference to JTWC's forecast input in the accompanying write-up (Figure 3).

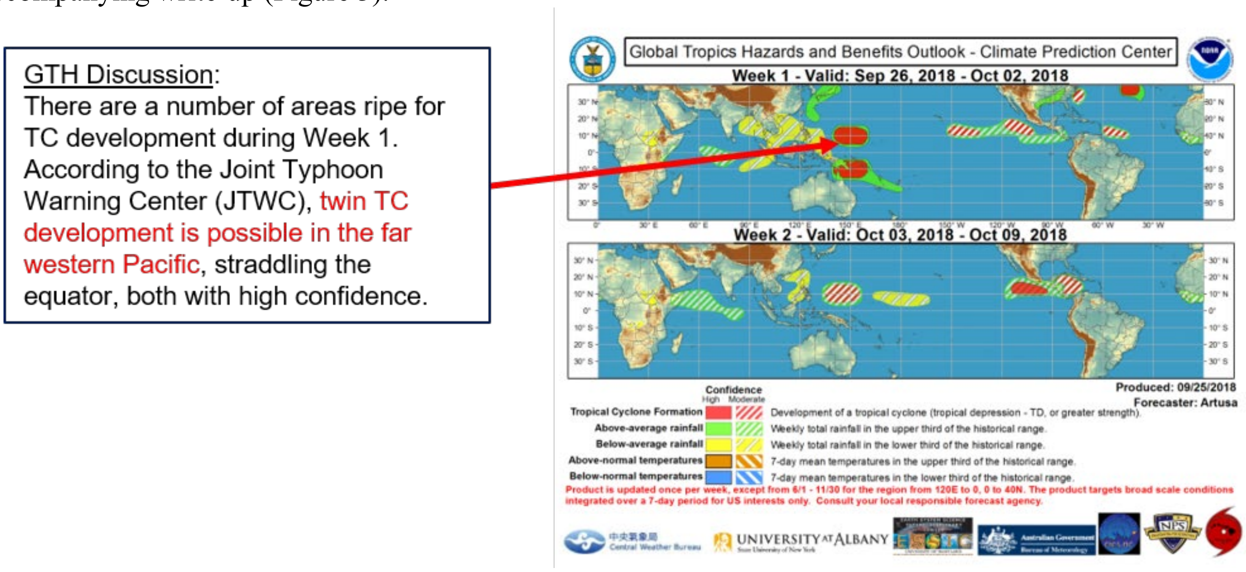

Fig. 3 GTH Outlook graphical product from September 26, 2018. The high confidence area in the western North Pacific, week 1 forecast corresponds to the area within which STY 30W would eventually form.

The GTH outlooks, JTWC Two-Week TC Formation Outlooks and JTWC Significant Tropical Advisories provided JTWC's customers 8 days advanced notice of potential TC formation and a clear, consistent progression toward higher confidence in TC formation prior to the high visibility, high potential threat event. JTWC's extended-range forecasting objectives to increase pre-formation first notice lead-times and to provide consistent and well-timed guidance in Significant Tropical Weather Advisories were fulfilled. The third objective, to improve the accuracy of initial warnings for newly-formed TCs by extending the opportunity to gather data prior to formation, was also fulfilled. Forecast position errors for the first JTWC track forecast were approximately 78 nautical miles at day 4 and 56 nautical miles at day 5, compared to the 2018 western North Pacific basin season averages of approximately 155 nautical miles and 220 nautical miles at those lead times. The first several JTWC forecasts correctly indicated that the system would track to the south of Guam after formation and toward Okinawa by day 5. Highly accurate initial forecasts enabled effective and appropriate resource protection decisions in both locations (Figure 4).

3. Feedback / wishlist

As the use case presented in this summary demonstrates, the GTH outlook and the associated, collaborative forecast process support JTWC's objectives for extended-range TC forecasting in their current format. However, JTWC proposes a few enhancements of the GTH product that could improve the overall customer experience. These enhancements include identifying the expected onset time for conditions annotated into the GTH map, providing interactivity with features designated on the GTH map (e.g., clickable overlays), and presenting automated product verification statistics through the GTH webpage. JTWC also supports extension of the outlooks into week 3, which could further increase customer notification lead times and provide a basis for earlier designation of PFAs on JTWC's Two-Week TC Formation Outlooks.

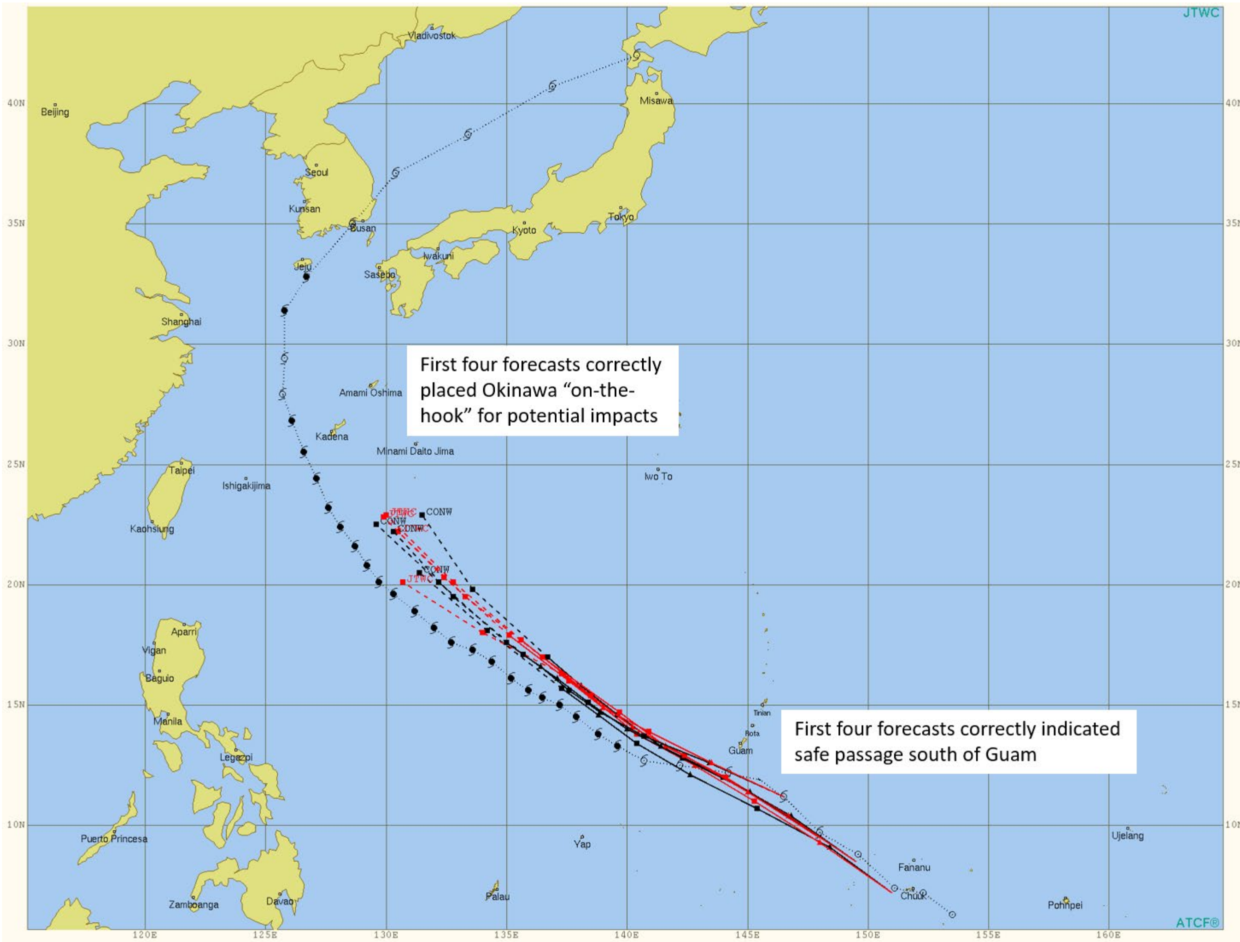

Fig. 4 STY 30W (Kong-Rey) 2018, first four JTWC (red) and corresponding multi-model consensus (black) track forecasts (28 Sep 2018 0000Z – 28 Sep 2018 1800Z); Connected TC symbols represent the verifying TC best track, as displayed in the Automated Tropical Cyclone Forecasting (ATCF) system (Sampson and Schrader 2000).

Reference

Sampson, C.R. and A.J. Schrader, 2000: The Automated Tropical Cyclone Forecasting System (version 3.2). *Bull. Amer. Meteor. Soc.*, **81**, 1231–1240.

NOAA's Climate Prediction Center Stakeholder Meeting
College Park, MD, 24-26 September, 2019

Applications of Climate Prediction Center Products to Support International Security Operations: Case Study for the Northwest Indian Ocean Region, March-May 2018

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1. Introduction

The US and its partner nations conduct international security operations around the globe. These include operations on land, at sea, and in the air — for example, anti-piracy and humanitarian assistance / disaster relief (HADR) operations. Planning for these operations occurs at multiple time scales, including subseasonal to seasonal (S2S) leads. Many long lead plans are difficult to revise at short leads. So skillful predictions at leads of two weeks and longer are extremely useful. Subseasonal to seasonal (S2S) analyses and predictions of environmental conditions from the Climate Prediction Center (CPC) and other operational support centers are extremely valuable in planning these operations, in managing the risks and opportunities associated with these operations, and in assessing those conditions and their operational impacts after they have occurred.

Planning by the international security community relies on a wide range of S2S environmental analyses and predictions that span from the sea floor to the top of the atmosphere. Some of the most important environmental variables include ocean surface winds and waves, ocean currents, land and ocean surface temperature, middle and upper tropospheric temperature and winds, relative and specific humidity, cloud amounts and levels, precipitation, soil moisture, and indicators of storm activity, drought, and flooding.

The planning for international security operations occurs at lead times of years to hours. Many of the most important operational decisions are made at S2S lead times (months to weeks). At these lead times, there is still time to make substantial changes in the allocation and deployment of people, ships, planes, ground vehicles, relief supplies, and other equipment and materials.

The northwest Indian Ocean (NWIO) region is an example of an area in which international security operations are especially active and CPC's S2S products are especially useful. This large region includes both ocean and land areas — for example, the northwest Indian Ocean, Arabian Sea, Gulf of Aden, the eastern Sahel, Horn of Africa (HOA), and the Arabian Peninsula. The US and many of the other nations involved in international security operations in the NWIO region are located far from the NWIO. So S2S and longer lead planning is especially important for operations in this region.

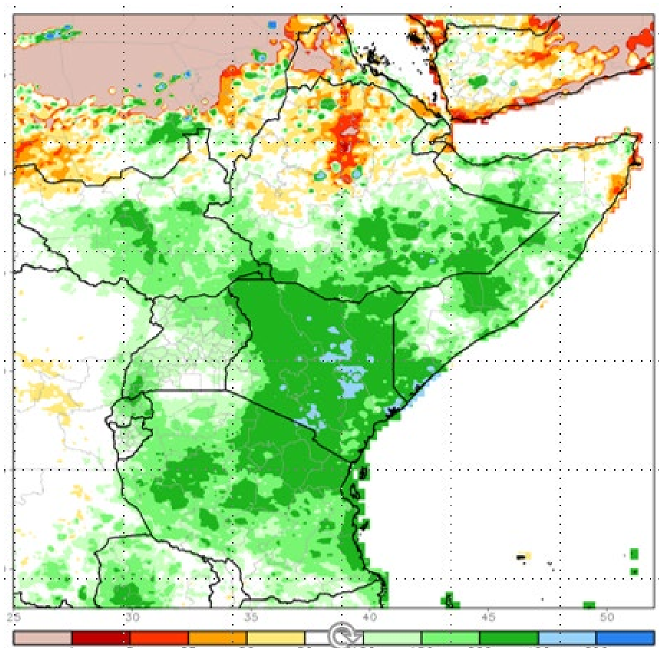

Fig. 1 Percent of normal rainfall in the HOA and nearby areas during 01 March – 09 May 2018. Figure shows an ARC2 product provided by CPC at: http://www.cpc.ncep.noaa.gov/products/international/africa/africa.shtml

For this case study, I have synthesized the results for a number of international security operations in the NWIO region, with a focus on the

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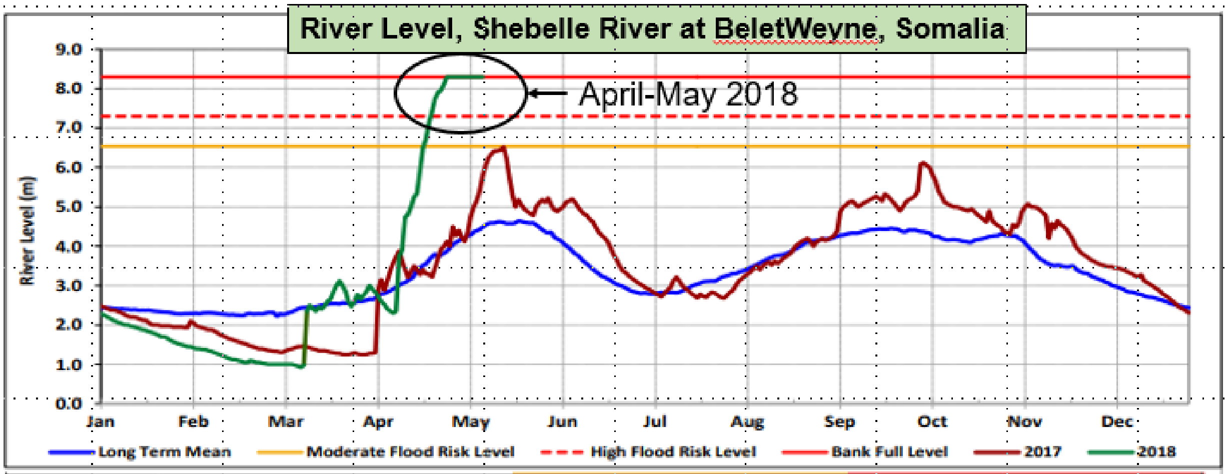

Date	Observed River Level (m)	Moderate Flood Risk Level (m)	High Flood Risk Level (m)
08 May 2018	8.30	6.50	7.30

Fig. 2 Level of the Shebelle River at BeletWeyne, Somalia, in January-May 2018 compared to 2017 and several river level benchmarks. Figure from the Somalia Flood Watch, 08 May 2018 at: http://www.faoswalim.org/resources/site_files/Flood_Watch_Bulletin_08052018-Eng.pdf

most common results. This synthesis is based on climate research and research-to-operations (R2O) work done at the Naval Postgraduate School (NPS) with: (a) atmospheric and oceanic scientists at operational centers that provide climate support services for international security operations; and (b) planners and decision makers for these operations. This case study is representative of many other international security cases around the globe.

2. Observed conditions in the NWIO region, March-May 2018

March-May 2018 was a period in which the NWIO region experienced anomalously strong rainfall, flooding, tropical cyclone (TC) activity, and high ocean surface winds and waves. These extreme conditions had significant impacts on planning and conducting a number of operations, especially anti-piracy and HADR operations involving surface vehicles, ships and small boats, and aircraft. Figure 1 shows the percent of normal rainfall for 01 March – 09 May 2018 for the HOA and nearby areas. Note the large area in which 150-600 percent of normal rainfall occurred.

The heavy rainfall indicated by Figure 1 led to extensive flooding in much of the HOA. One representation of this flooding is shown in Figure 2, which shows the level of the Shebelle River in Somalia during April-May 2018. The flooding in the HOA led to major and prolonged international HADR operations and societal disruptions during April-May 2018.

The NWIO region tends to have a very small number of tropical cyclones (TCs) in a year. But in May 2018, two TCs occurred in the NWIO — TC Sagar on 16-20 May 2018 and TC Mekunu on 21-27 May 2018. Sagar tracked into the Gulf of Aden and Mekunu into the southern Arabian Peninsula (Figure 4). Both TCs produced heavy rainfall over land, extended the flooding from the prior heavy rainfall in March-April 2019, and

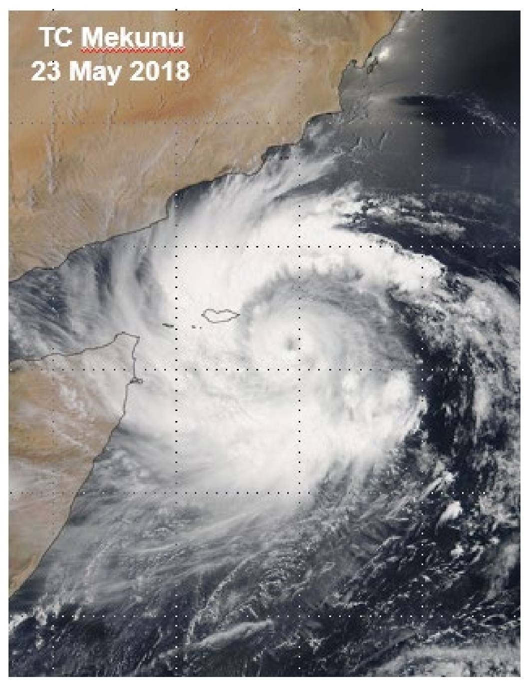

Fig. 3 TC Mekunu, in the NWIO region, 23 May 2018. Figure from NASA at: https://visibleearth.nasa.gov/view.php?id=144122

Fig. 4 Tracks of TC Sagar and TC Mekunu, in the NWIO region, May 2018. Figures from: https://en.wikipedia.org/wiki/Cyclone_Sagar and https://en.wikipedia.org/wiki/Cyclone_Mekunu

contributed to the need for extensive international HADR and other operations in the NWIO region. Over the ocean, the two TCs forced ship operations to divert away from the forecasted TC tracks, disrupting the maritime components of the HADR, anti-piracy, and other international security operations.

3. S2S support for operations in the NWIO region, March-May 2018

One example of the types of S2S products used for planning international security operations in the NWIO is the precipitation forecast for Mar-May 2018 shown in Figure 5. This figure shows a forecast from the International Research Institute for Climate and Society (IRI). Similar products from CPC based on CFS and other CPC forecasting systems, as well as products from other centers, are widely used in planning and assessing international security operations. Figure 5 is representative of a common type of S2S forecasts: a categorical forecast for the probability of a variable (precipitation, in this case) occurring in each of three

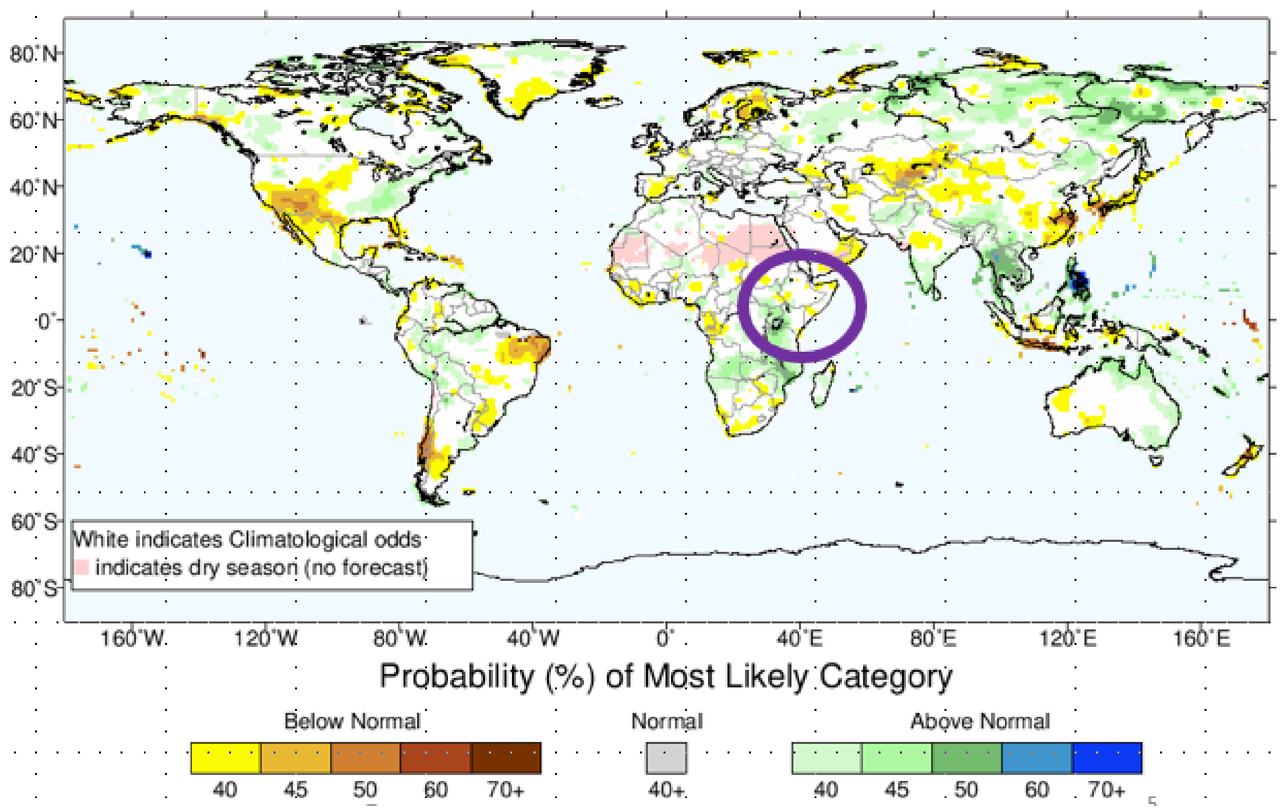

Fig. 5 IRI multi-model probability forecast of S2S precipitation for March-May 2018 (issued in February 2018). Figure from: https://iri.columbia.edu/our-expertise/climate/forecasts/seasonal-climate-forecasts

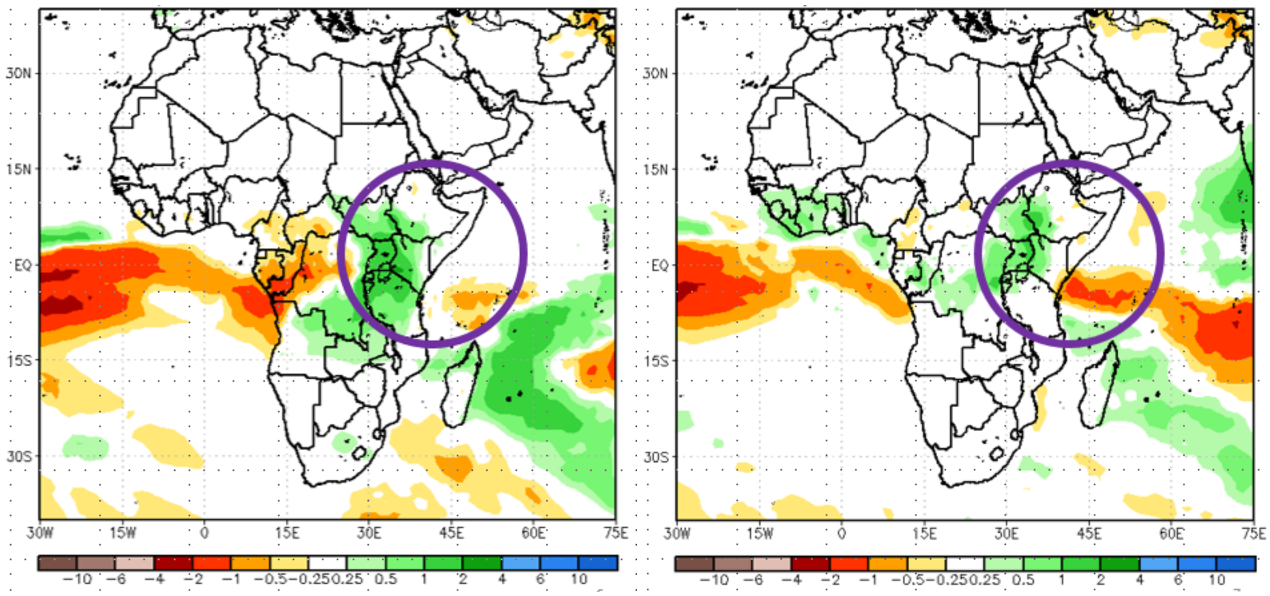

Fig. 6 NMME S2S precipitation anomaly forecast (mm/day) for April 2018 (left) and May 2018 (right), with initial condition March 2018. Figure from: http://www.cpc.ncep.noaa.gov/products/international/nmme/previous_ nmme_ forecasts.shtml

tercile categories, with a relatively long valid period (three months, in this case). The pros and cons of such longer lead S2S products are relatively well understood by the atmospheric and oceanic scientists who support that international security planning. Note that the forecast in Figure 5 did not provide a clear indication of the anomalously high precipitation observed in the HOA and nearby regions (compare the forecast for the purple circled area to the observed results in Figure 1).

Figure 6 shows examples of S2S precipitation forecasts used for planning NWIO region operations (mean lead times of two and six weeks, respectively). These forecasts provided relatively good indications of the observed high precipitation in April and May 2018 in southwestern HOA but not elsewhere in HOA (for example, eastern Kenya, southeastern Ethiopia, Somalia).

Atmospheric and oceanic scientists that support international security operations are aware of the importance of accounting for climate variations when developing their climate support products and services. For the NWIO region, some of the most important climate variations are the Madden-Julian Oscillation (MJO), Indian Ocean Dipole (IOD), and El Niño – La Niña (ENLN). These variations can have large impacts on the variables of interest described in section 1. For example, MJO activity can substantially enhance or suppress TC activity in the NWIO. So MJO, IOD, and ENLN analyses and predictions from CPC and other sources are commonly used in developing support products for NWIO operations. For example, MJO related products from CPC, such as the MJO weekly update product and the Global Tropics Hazards and Benefits (GTHB) product, are routinely used to develop support products for NWIO region temperature, precipitation, flooding, ocean surface winds and waves, and TC activity.

For March-May 2018, MJO activity and its impacts on TC activity in the NWIO were especially important. Figure 7 shows predictions and analyzed observations of MJO activity for early April to early June 2018. Note that MJO phases 1-2, with relatively high amplitude and anomalously strong convection in the NWIO region, occurred during much of May 2018. TC Sagar and TC Mekunu formed during phases 1 and 2 (on 16 and 21 May 2018, respectively) and intensified during phase 2 (the second half of May 2018). Note that the observed MJO had higher amplitude and propagated faster than predicted. The under-prediction of the amplitude contributed to an under-prediction by scientists supporting NWIO operations of the probability of TC formation and intensification, especially at leads greater than one week.

For March-May 2018 in the NWIO region, CPC's GTHB products generally did well in predicting anomalous precipitation and TC activity (see for example Figure 8). However: (a) the moderate confidence in

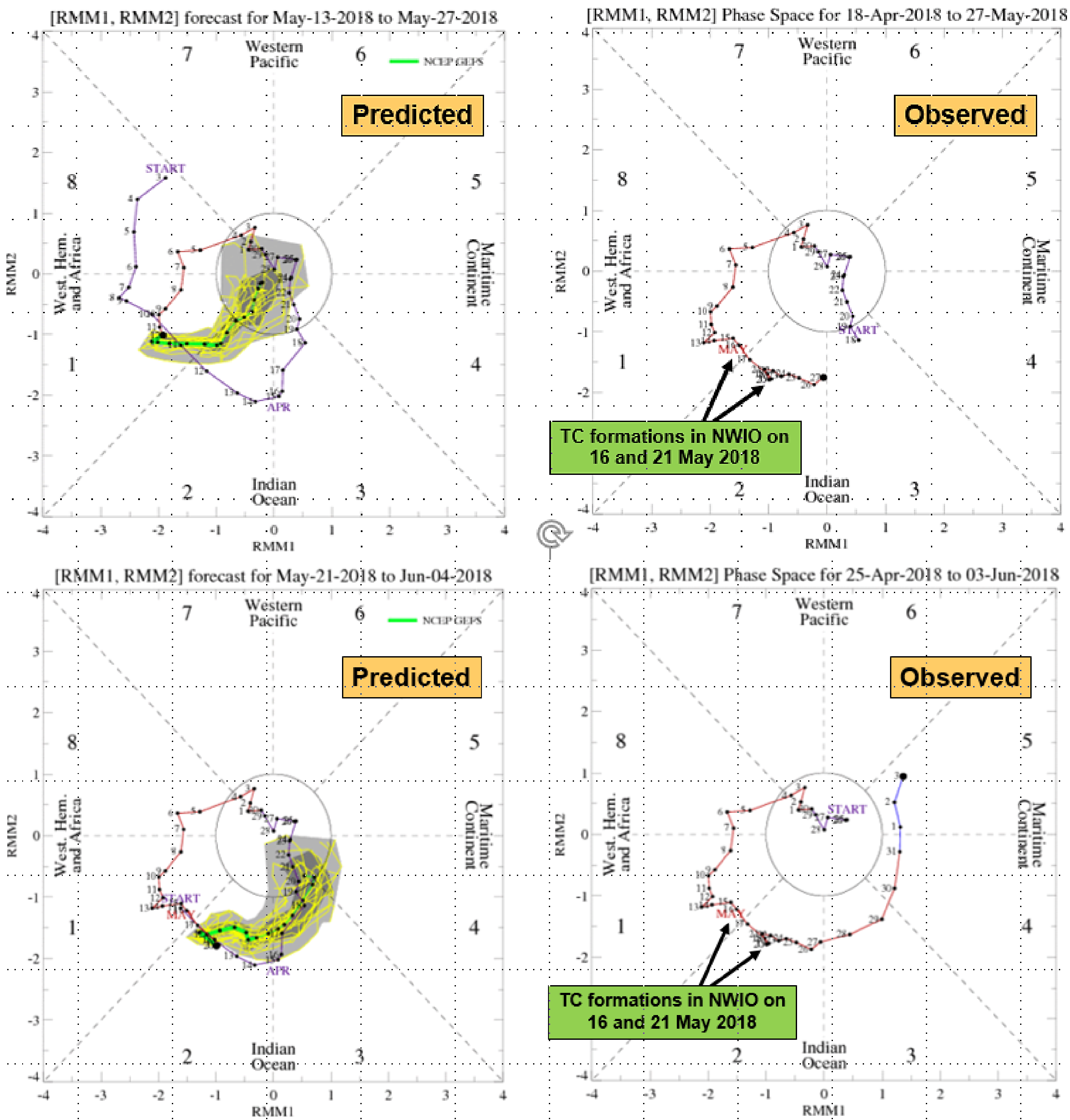

Fig. 7 Predictions and observations of MJO amplitude and phase from CPC MJO weekly updates. The left panels are predictions, top for 13 – 27 May 2018 and bottom for 21 May – 04 June 2018. The right panels are observations, top for 18 April – 27 May 2018 and bottom for 25 April – 03 June 2018. Figures from: https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/mjo.shtml

those predictions was somewhat inconsistent with strength of the anomalous precipitation and TC activity; and (b) the TC activity was predicted well only at short leads (one week or less). This inconsistency and difficulty in longer lead forecasting of TC formation affected the accuracy of predictions made by scientists supporting NWIO operations — in particular, by contributing to under-predictions of the probabilities of anomalously high precipitation and of TC formation and intensification, especially at leads greater than one week.

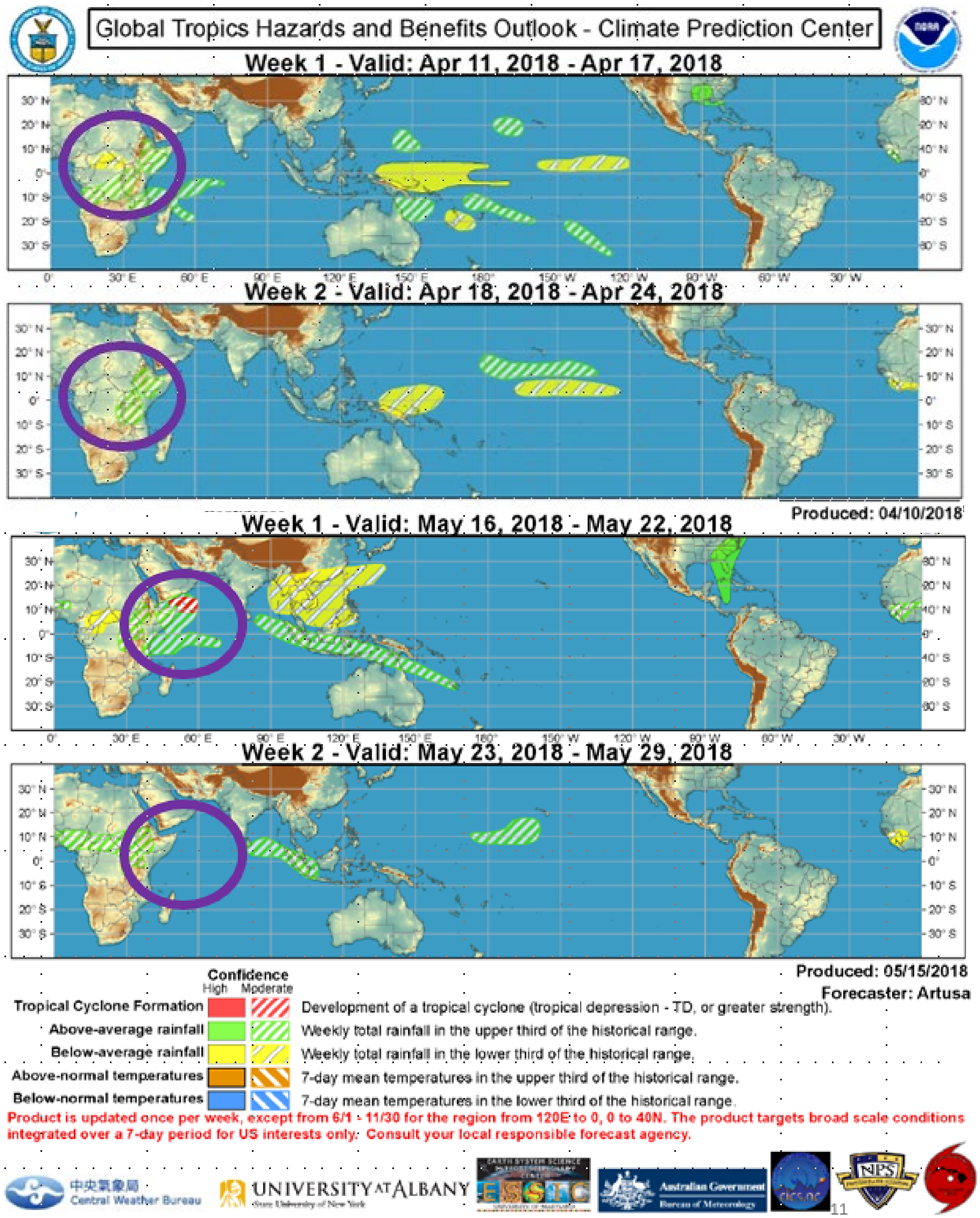

Fig. 8 GTHB products for valid periods spanning 11-24 April 2018 (top two panels) and 16-29 May 2018 (bottom two panels). The purple circle indicates the general area in which anomalously high precipitation and TC activity occurred during these periods.
Figures from: https://www.cpc.ncep.noaa.gov/products/precip/CWlink/ghazards/index.php

4. Summary, discussion, and recommendations

CPC's S2S analysis and prediction products are well regarded and commonly used by many scientists who support international security planning and assessment, especially in regions where locally generated products are scarce (*e.g.*, the NWIO). These products do have shortcomings that are typical of many S2S products (*e.g.*, lower skill at longer leads and in predicting short term events, low spatial / temporal resolution, and limited number of analyzed and predicted variables). However, these products are still very useful, especially in the absence of better alternatives.

Many of the atmospheric and oceanic scientists who routinely use CPC S2S products for international security applications are limited in their ability to give feedback to CPC due to security factors and their heavy workloads. However, the S2S needs of international security users are similar to those of many other users (for example, improved outlooks for weeks 2-4, improved spatial and temporal resolutions, increased number of predicted variables, improved skill assessments). The following recommendations to CPC are intended to help international security users improve the S2S products and services that they provide based on CPC products.

1. Improve the navigation for the CPC site to make it easier for users to find S2S products (*e.g.*, the GTHB product) for user selected variables, regions, and lead times.
2. Develop a prominent education and documentation page to: (a) help atmospheric and oceanic professionals who use these products understand how they are developed, and their strengths and weaknesses; and (b) to provide insights on these products from CPC staff (*e.g.*, product X is generally good for temperature and precipitation but not for TCs in the NWIO).
3. Provide product archives and regularly updated operational skill metrics to help users get more familiar with products, to determine the weight to give to products in their decision making, and to create S2S analyses and assessments. An analogy: In baseball, a team manager uses al player's batting averages to determine when to put a player up to bat. Users of CPC products are like baseball managers in needing to know the past performance of CPC products before using those CPC products to develop their own products.
4. When possible and skillful, include text discussions of how events are predicted to evolve within a valid period and region (for example, the evolution of a high precipitation event within the one week valid period of a week 1 or 2 outlook).
5. Work with providers of S2S support for international security applications to identify high priority improvements of CPC products (for example, high priority climate variations, variables, regions, and lead times). One example of a climate variation on which to focus improvements efforts is the IOD. Some examples of potential variables to focus on are ocean surface winds and waves, clouds, and soil moisture. Some examples of potential regions to focus on are: (a) the northern Indian Ocean and nearby land regions of HOA, southwest Asia, and southeast Asia; (b) the western North Pacific, including the South China Sea, East China Sea, Philippine Sea, and nearby land regions; (c) the eastern Mediterranean Sea and nearby land regions.

3. GLOBAL OBSERVING PRODUCTS, OCEAN MONITORING PRODUCTS, INTERNATIONAL DESK PRODUCTS, FOOD SECURITY

NOAA's Climate Prediction Center Stakeholder Meeting
College Park, MD, 24-26 September, 2019

CORe (Conventional Observational Reanalysis) for Climate Monitoring

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1. Background

One of the missions of CPC is to deliver real-time climate monitoring products and information to describe the current state of Earth System, particularly related to the variability in its atmospheric and terrestrial components. To achieve this mission, CPC provides real-time climate monitoring products that provide support for wide-ranging activities, for example, monitoring environmental conditions for the development of hurricanes in the Atlantic; monitoring of El Niño-Southern Oscillation (ENSO) in tropical Pacific; placing current evolution of climate in a historical context *etc*.

CPC's real-time climate monitoring products rely on model based data assimilation system, specifically the NCEP-NCAR Reanalysis (also known as the Reanalysis-1 or the R1). R1 was a pioneering effort that was made operational in 1995 and continues to be the basis of all real-time atmospheric monitoring products at CPC. Since 1995, the atmospheric model and data assimilation procedures have seen tremendous advances, which have not been incorporated in R1. Further, R1 is a legacy system and its continued maintenance is proving to be difficult task.

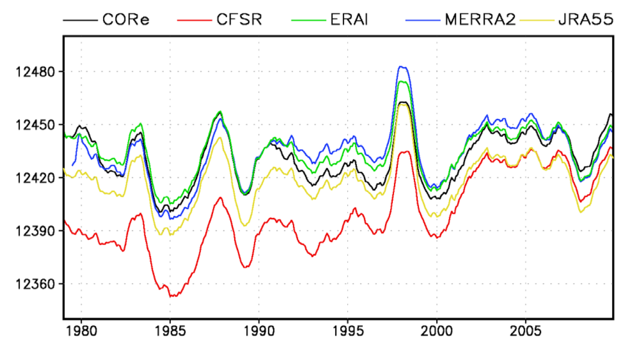

Fig. 1 Zonally averaged 200 hPa height at the equator for various reanalysis: CORe (black), CFSR (red), ERAI (green), MERRA2 (blue) and JRA55 (yellow). Note that while CFSR is an outlier before 2000, the performance of CORe (without use of satellite data) is similar to other modern generation reanalysis, *e.g.*, ERI-I, MEERA2 and JRA55.

Towards exploring the possibility of replacing the R1, in past few years CPC evaluated the performance of the Global Forecast System (GFS) Conventional Observations Reanalysis (CORe). This effort, supported previously by the CPO, demonstrated that the performance of CORe, even without the use of satellite data, was at par with the monitoring products based on R1 (Fig. 1). This is because of advances in the atmospheric model and the data assimilation system that were part of the data assimilation infrastructure used in the "proof of concept" run of the CORe.

2. Current status

Encouraged by the performance of CORe, this project aims to make CORe operational at NCEP and consider the phasing out of R1. However, since our initial effort was with the Global Spectral Model GFS (GSMGFS) based CORe, on the suggestion from the CPO and NWS the leadership, we needed to make a major shift to an assimilation infrastructure for CORe based on the next generation of atmospheric forecast system, *i.e.*, the FV3GFS, and our recent efforts focused on the reestablishing such a capability.

The scope of this effort is to eventually implement an operational climate monitoring reanalysis system based on CORe, *i.e.*, a reanalysis based on conventional data alone. The implementation will require (a) completion of reanalysis over the historical period starting from 1950-present, and (b) implementation for its real-time continuation. Currently work is under way in setting up and testing assimilation scripts on NOAA research computing and running several reanalysis streams. As various reanalysis streams mature, we will evaluate the performance of the FV3GFS based CORe against other existing reanalysis products and will work towards the operational implementation of CORe.

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Use of CPC Gauge-based Precipitation for RMA Crop-Insurance Program

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U.S. Department of Agriculture, Risk Management Agency

1. History into rainfall index program

The Agricultural Risk Protection Act of 2000 (ARPA) directed Federal Crop Insurance Corporation (FCIC) to develop a pasture, rangeland, and forage program as one of the highest research and development priorities. Risk Management Agency (RMA) issued a statement of objectives (SOO) in January 2004, stated that "…RMA is seeking improvements to existing crop insurance programs and the development of new and innovative approaches for providing improved forage coverage and risk management protection…" Based on the SOO, RMA had four different contracts with three different contractors to develop a forage program to cover grazing losses. All these contracts came back with some type of weather-based program to insure grazing losses. Throughout the development phase, RMA ended up canceling two of the contracts leaving only the Rainfall and Vegetation program. The Vegetation program was maintained until 2016, at which time it was pulled because of the education and participation hurdles. The Pasture, Rangeland, Forage (PRF) rainfall program was the first program that utilized the NOAA CPC data set. Since the development of the PRF program, we have added two additional programs that utilize the same data set, which is the Annual Forage program and Apiculture program. For 2019, the total liability of these crops is about $2.9 billion, with about $671 million in premium.

2. Rainfall index program's overview

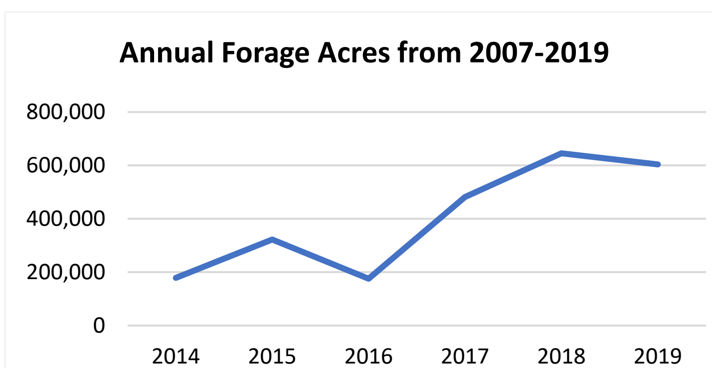
The Rainfall Index (RI) Pilot Crop Insurance Program is an area plan of insurance based on the historical rainfall for specific two month time periods. The two month time periods are called Index Intervals. A producer must select at least two index intervals but may select up to six index intervals depending on the program. The Rainfall programs that RMA offers utilize a numbered grid system. The grids are based on NOAA CPC 0.25 degree x 0.25 degree of longitude and latitude. Indemnities are payable when the final grid index falls below the historical average for the two months for that index interval. NOAA Climate Prediction Center Daily Precipitation data sets are used to establish historical and present values.

RMA determines an insurance value per acre referred to as the County Base Value (CBV) for each of the programs. For example, under the PRF program, we offer four different CBVs based on the intended use and irrigation practice. Producers can adjust the CBV by applying a productivity factor from 60% to 150%.

Indemnities are payable when the final grid index for an insured interval falls below the historical average and is below the coverage level selected by the producer. Coverage levels of 5% increments between 70% and 90% are offered.

a. Annual Forage Program

The Annual Forage (AF) Pilot Insurance Program is designed to provide insurance coverage on annually seeded acreage that is planted for forage or fodder. Similar to the other Rainfall products that RMA offers, the AF program was designed to help protect a producer's operation from the risks of forage loss due to the lack of precipitation. AF is offered in all counties in the states of Colorado, Kansas, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, and Texas.



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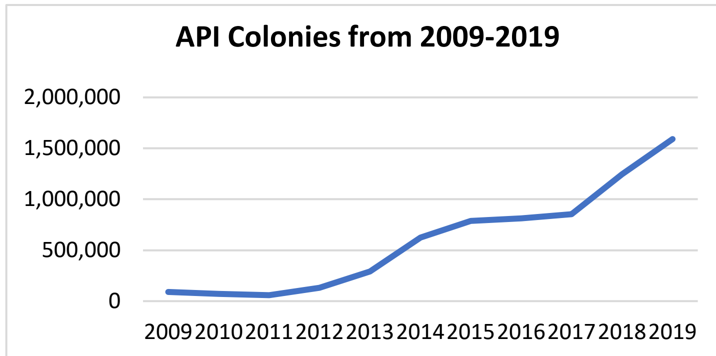
AF 2019 Highlights:

- Total Premium 38 Million and 151 million in liabilities
- 1,479 policies earning premium with total acres insured around 604 thousand acres

b. Apiculture (API) Program

Apiculture Pilot Insurance Program (API) provides a safety net for beekeepers' primary income sources – honey, pollen collection, wax, and breeding stock. Apiculture systems consist of different types of plants or crops. They often contain mixtures of different species, each with varying habits of growth and seasons, precipitation requirements, and other climate conditions necessary to maintain plant growth over extended periods of time. API was designed to provide maximum flexibility to cover these diverse situations. API is available in the 48 contiguous states.

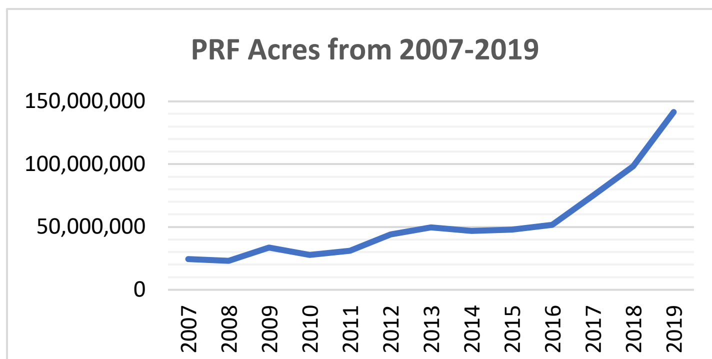


API 2019 Highlights:

- Total Premium 49 Million and 223 million in liabilities
- 3,059 policies earning premium with total colonies insured around 1.5 million

c. Pasture, Rangeland, Forage (PRF)

Pasture, Rangeland, and Forage (PRF) Pilot Insurance Program is designed to provide insurance coverage on pasture, rangeland, and forage acres. PRF was designed to help protect a producer's operation from the risks of forage loss due to the lack of precipitation. It is not designed to insure against ongoing or severe drought, as the coverage is based on precipitation expected during specific intervals only. PRF is available in the 48 contiguous states with the exception of a few grids that cross international borders.



PRF 2019 Highlights:

- Total Premium 584 Million and 2.6 billion in liabilities
- 31,981policies earning premium with total acres insured around 141 million

3. Data concerns

For 2019, the RI program is among the top 5 programs for RMA in both terms of liabilities and indemnities paid. The importance of the NOAA CPC data set is crucial to the success of these three programs RMA offers. Anything NOAA CPC can do to maintain the data set or increase the accuracy of the data will benefit both RMA and the producers that purchase these programs. These programs have become a crucial risk management tool for bee and livestock producers.

4. Feedback and wishlist

Since the Rainfall program is in the top 5 programs that RMA offers, below are some suggested items for NOAA CPC to consider.

- Could NOAA CPC add more data points especially in the Western states

   - Keep in mind RMA historical data will need to be updated since RMA uses the historical data to rate these programs

- Strengthen and document the Quality Control (QC) process to reduce the number of errors

   - It is important once RMA releases the data that nothing changes, so the QC process needs to be accurate and catch the majority of the errors before being released
   - Keep in mind that we have insurance companies that have access to the same data set, so we must have only one version of the data set
   - NOAA CPC should look at incorporating other variables such as radar to verify accuracy of results
   - NOAA CPC should provide documentation on how the QC process works so people can review *i.e.* somewhere on the NOAA CPC website

- Strengthen Cooperative Observer Program (COOP) network

   - Need to get more daily observers to maintain/strengthen the data set
   - NOAA CPC should look at long-term solutions to replace COOP networks if they don't believe it is feasible to maintain them

- Importance of the data

   - More education with other NOAA offices to explain the importance of the NOAA CPC data set to RMA

      - Hearing from regional offices that it is okay for COOPs to report monthly vs. Daily

   - Some Regional offices don't realize the importance and impact of this data set to RMA

- Expanding the grid system to include grids that fall mostly in Mexico and Canada

   - We have producers that would like to purchase these programs but since these grids mostly fall into Mexico and Canada, we don't offer insurance for these grids.

Stakeholder Use Case: USDA Office of the Chief Economist

Mark D. Brusberg

USDA Office of the Chief Economist/World Agricultural Outlook Board

1. Introduction

USDA's Office of the Chief Economist (OCE) has enjoyed a decades-long partnership with the Climate Prediction Center (CPC) under an agreement dating back to the late 1970s establishing the Joint Agricultural Weather Facility (JAWF). The role of JAWF was to bring meteorologists from both USDA and the NWS together to monitor global weather for the purposes of assessing its impacts on foreign agricultural production. This mission was forged by the need to prevent a recurrence of incidents such as the "Great Grain Robbery", when a drought experienced by the then Soviet Union went undetected, ultimately having a negative impact on the United States economy after undocumented purchases of grain depleted our own reserves (Powers, 2015). The creation and operation of JAWF was detailed in a separate Subsidiary Agency Agreement (SIA) under the broader reaching USDA/NOAA Memorandum of Understanding, detailing specific tasks and responsibilities of each agency under the agreement, including the physical location of NWS meteorologists at USDA's Washington, DC, headquarter complex.

Much has changed during the years since the formation of JAWF, including a major shift toward offsite support from CPC rather than a physical presence; however, while the technological improvements have made the transfer of information more efficient, there is still a great deal of interaction between the meteorologists. Additionally, the partnership has grown over the years to include other agencies that have also become dependent on CPC products and services, with which, as outlined in the aforementioned SIA, JAWF is tasked as a lead supporting organization.

2. User cases of significant impact

The following examples detail some of the products and services provided by CPC in support of the JAWF partnership and their importance to USDA operations.

a. Global weather data

As per the aforementioned SIA, JAWF is designated as a lead agency responsible for identifying, and facilitating the transfer of weather and climate data from NOAA to USDA as needed. For the purposes of OCE, the majority of this information is available through the World Meteorological Organization (WMO) and made available daily to JAWF's USDA meteorologists. In turn, the meteorologists use this data for operational support of the World Agricultural Supply and Demand Estimates (WASDE) report. Activities using the data range from briefing decision makers on current situations to developing crop yield models. An example of this can be seen in Fig. 1, which is a depiction of both excessive heat and crop stage of development modeled using temperature data obtained from CPC.

Other uses of the data involve identifying analog years for comparison of yield response to drought, periods of excessive moisture, and other factors that can impact crop yield potential. The global data file available daily from CPC is one of the sources of information mentioned in the Introduction as being of use to other USDA agencies.

b. The Weekly Weather and Crop Bulletin (WWCB)

The WWCB is a weekly publication designed to keep the agricultural sector apprised of weather and crop developments both foreign and domestic. The publication has appeared in one form or another dating back to 1872, when it was published by the Signal Service of the U.S. War Department (Hughes, 1972). The

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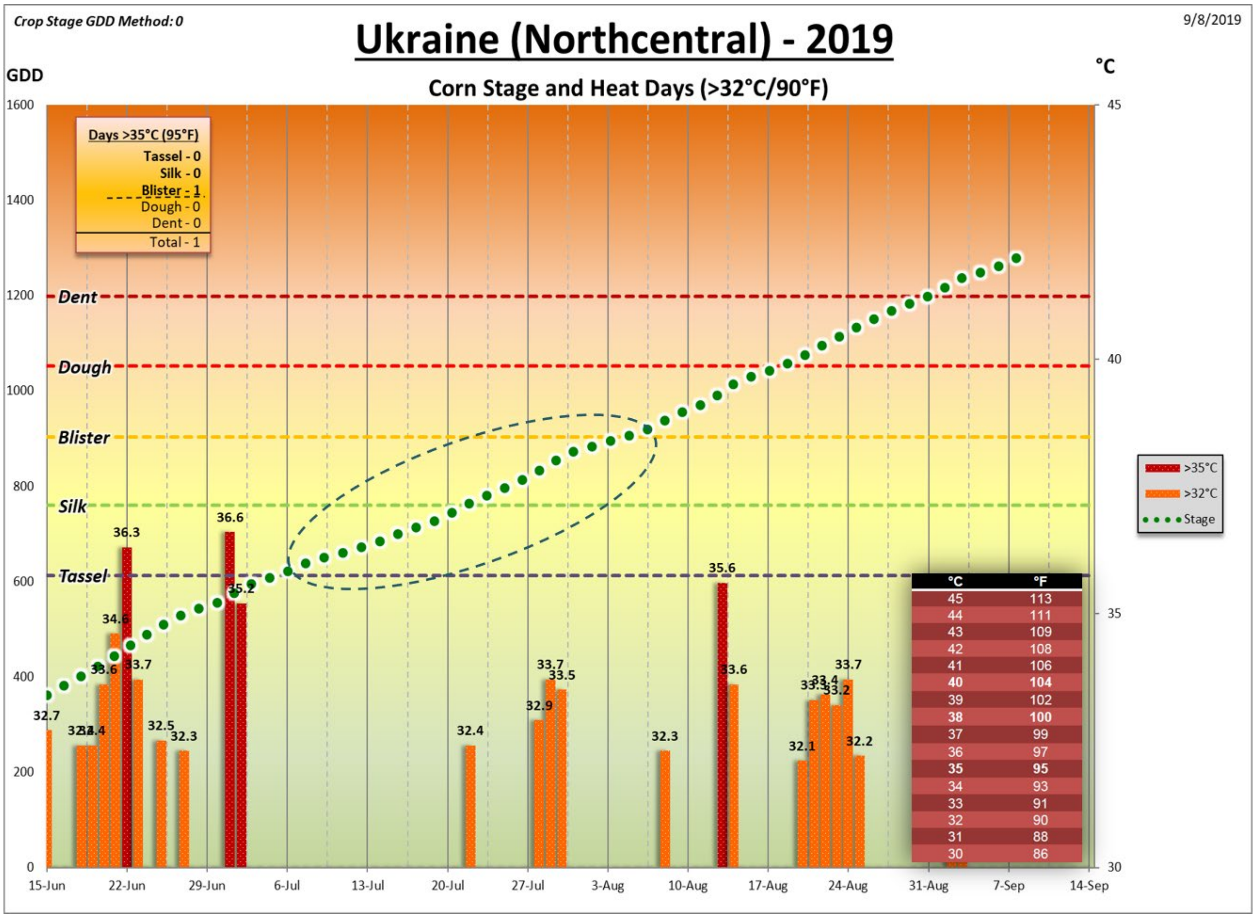

Fig. 1 Depiction of stressful temperatures on corn during various modeled stages of growth determined by Growing Degree Day (GDD).

responsibility for publishing the WWCB was assigned to JAWF in 1978 and process has undergone several significant changes to take advantage of new technologies, in particular the Internet and the advent of electronic publishing. Even after the physical departure of NWS meteorologists, CPC has played a huge role in the production of the WWCB, in particular by providing:

- Formatted tabular data of select cities across the U.S. and globally;
- Maps of U.S. and International precipitation and temperatures; and
- Maps of calculated parameters such as Growing Degree Days.

The aforementioned maps undergo a manual quality control process by meteorologists at CPC to remove bad stations from the analyses. In many cases, data need to be manually corrected and analyses need to be regenerated – an example of this is illustrated in Fig. 2, which underscores the continued need for editing capabilities to correct errors in data received through the Global Telecommunication System.

c. Outlook products

Although not used operationally to make decisions, the USDA meteorologists make frequent use of the current suite of sub-seasonal to seasonal outlook products as a way of informing OCE's analysts on potential weather events that could influence other decision makers and, in turn, commodity markets. In addition, USDA meteorologists reference the Monthly and Seasonal Drought Outlooks as a companion to the U.S. Drought Monitor (USDM) when briefing USDA staff and others on potential expansion or removal of drought.

NOTE: When used or referenced in publicly available materials (example: the 6-10 Day Outlook is referenced in the daily Agricultural Weather Highlights, along with other NWS forecast products:

https://www.usda.gov/oce/weather/pubs/Daily/TODAYSWX.pdf), separate credit is given to NWS as the originator of this and other forecast information.

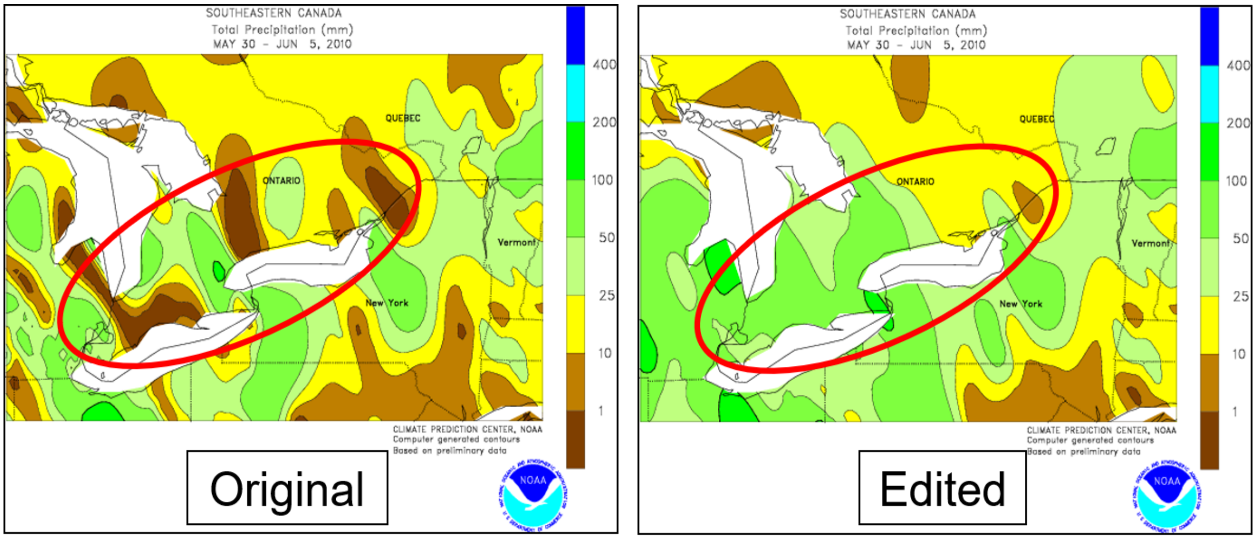

Fig. 2 Example of edited versus non-edited maps as created for use in the Weekly Weather and Crop Bulletin.

d. Other climate products

Other products provided by CPC which are vital to the routine operations of OCE include:

- Products generated for use in creating the U.S. Drought Monitor, such as the calculated regional blend drought indicator maps;
- Information regarding the El Niño / Southern Oscillation (ENSO) Phenomenon; and
- Information on other teleconnections impacting global weather patterns such as the Madden Julian Oscillation and Northern Atlantic Oscillation.

In the case of ENSO, the USDA meteorologists closely follow the potential development of active phases as some areas report significant impacts on agriculture. For example, there is a strong correlation between ENSO and the weather in Argentina's summer growing areas (Fig. 3), which is extremely useful in creating scenarios for the potential for drought (La Niña) versus abundant rainfall (El Niño).

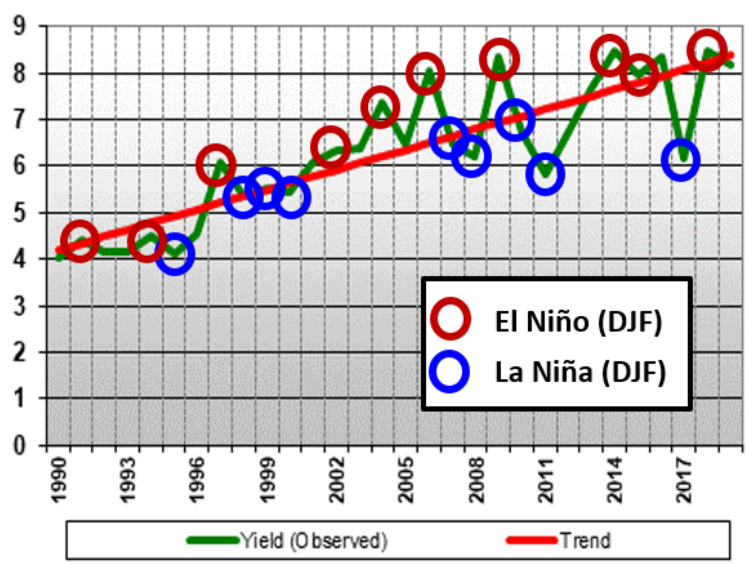

Fig. 3 Depiction of correlation between Argentine corn yields (metric tons / hectare) and ENSO (yield data available from USDA/Foreign Agricultural Service: https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery).

3. Recommendations for improvements / additional products

The following is a listing of recommendations for activities covered by the current partnership:

- Coordination with the National Centers for Environmental Information on data quality issues, more frequent updates of the station library and normals, and validation of gridded products;

- Timed releases of the Outlook Products more closely adhered to (often late);
- Development of scenario analyses for regional anomalies (example: if a cooler-than-normal fall is forecast for the upper Midwest, what is the likelihood for an early season-ending freeze?);
- Development of metrics for defining the beginning / ending of drought, possibly through collaboration with other research organizations;
- Creating an interactive regional drought blend portal, possibly in partnership with the National Drought Mitigation Center, for allowing users to create their own regional drought blend indicators; and
- A complete overhaul of ENSO website, including:
    - Improved user friendliness (better flow between pages, printable graphics, etc.);
    - Easily identifiable links to partners (IRI) or other related products like the ENSO blog;
    - Updating informational charts to reflect more recent information; and
    - Describing known relationships between ENSO and other phenomena (NAO and MJO).

Reference

Hughes, P., 1972: A century of cooperation. *Weekly Weather and Crop Bulletin*, Special Centennial Edition, 2-4.

Powers, R. C., 2015: The Great Grain Robbery of 1972. Earthzine.org. https://earthzine.org/the-great-grain-robbery-of-1972/.

NOAA's Climate Prediction Center Stakeholder Meeting
College Park, MD, 24-26 September, 2019

Global Ocean Monitoring Products in CPC

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1. Introduction

Ocean plays a crucial role in regulating global climate variability, and thereby, influences the various facets of society, such as predictions of drought and flooding, marine ecosystems, transportations, food security *etc*. Ocean's influence on the Earth system extends from weather to climate on sub-seasonal, seasonal, interannual, decadal and centennial time scales. Synthesis of state of global oceans helps society to mitigate and adapt to vulnerability to weather and climate extremes that are influenced by oceanic variability, and advance understanding and prediction of droughts, floods, and water resources. Since 2005, the Climate Prediction Center (CPC) has collaborated with NOAA Ocen Observations and Monitoring Division (OOMD) to develop and disseminate real time ocean data sets and monitoring products to the user community with goals to (a) provide a scientific basis for making informed decisions to either mitigate or to take advantage of the consequences resulting from the ocean climate variability [*e.g.*, El Niño-Southern Oscillation (ENSO)], (b) enable science and improve understanding of ocean climate variability and its causes, (c) keep a pulse of slowly evolving changes in the ocean conditions and (d) assess benefits of NOAA´s extensive investment in global ocean observing program. The following sections will introduce three ocean monitoring products provided by the CPC.

2. Global ocean monitoring product

2.1 Global ocean monitoring websites

CPC develops and maintains two websites to deliver real-time ocean monitoring and prediction products. One is the Global Ocean Data Assimilation System (GODAS) website (http://www.cpc.ncep.noaa.gov/products/GODAS), the other is the Ocean briefing website (https://origin.cpc.ncep.noaa.gov/products/GODAS/ocean_briefing.shtml#Global). The GODAS website offers data download of NCEP GODAS (Behringer and Xue, 2004) pentad and monthly data sets that can be used for improved understanding of the ocean climate variability and to validate model outputs. Users can obtain the background of GODAS data sets in the "Introduction" and their statistics performance in the "Validation against observations" section of the website. The GODAS website also contains animations and plots for climatology and anomalous fields of various oceanic variables over different basins of the global ocean, and covers time scales from weekly to interannual to decadal. Users can obtain the visualized historical and real-time ocean climate information, including SST, ocean heat content, air-sea exchanges of heat, momentum and fresh water, sea level, mixed layer depth, subsurface temperature and currents. The real-time GODAS updates are routinely used to support CPC ENSO diagnostic and seasonal outlooks.

The Ocean briefing website provides a comprehensive view of recent evolution of ocean state and associated atmospheric conditions, and global SST prediction products using various real-time reanalysis data sets. Users can also monitor real-time update of ocean and atmospheric conditions associated with climate variations, such as ENSO, Indian ocean dipole (IOD), Pacific decadal oscillation (PDO), North Atlantic Oscillation (NAO), *etc*., and download important climate indices from this website.

2.2 Monthly ocean briefing

CPC initiated "Monthly Ocean Briefing" (MOB) in 2007 to provide the user community a monthly summary of the recent evolution of the global ocean and related climate variations, and forecasts and verification of recent ocean predictions. This synthesis assessment is disseminated via a PowerPoint

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presentation and conference call around the 8-12th day of each month. CPC also solicits feedbacks on the ocean briefing, and includes additional analysis as needed to address unique topical areas of interest, for example, ENSO status and prediction, ocean conditions associated extreme events (such as Marine heat wave, hurricanes), bias in NCEP GODAS and CFSR and their potential impact on CFSv2 predictions, impact of changes in ocean observing system on uncertainty among ocean reanalysis. The historical archives of MOB PPTs since 2007 are available from the GODAS website.

2.3 Real-time Ocean Reanalysis Intercomparison Project (RTORA-IP)

Ocean reanalysis (ORA) data set play an important role in seasonal predictions and climate studies because ORA provides (1) initial conditions for operational dynamical seasonal prediction models, (2) valuable information for real-time ENSO monitoring, and (3) historical context for climate variability analysis, such as ENSO, IOD, NAO, *etc*. The Tropical Pacific Observing System (TPOS) is one of the major observation sources which are assimilated in the operation ocean data assimilation systems to produce ORAs. A rapid decline of the TAO array took place during 2012-2013 (Fig.1). This degradation of the Tropical Atmosphere Ocean (TAO) moored array raised a serious concern whether the temporal variation in observing system influence the quality of ORA and ENSO prediction skills. Following the recommendation from the TPOS 2020 workshop in 2014, CPC initiated the RTOA-IP to collect and to quantify uncertainties in ORAs from various operational centers from all over the world (Xue *et al.* 2017). The goals of the projects are to:(1) deliver ensemble ocean monitoring products in real-time, (2) quantify uncertainties in the ocean state estimation in support of ENSO monitoring and prediction, (3) monitor the influences of ocean observations on constraining uncertainties in ocean reanalyses, and (4) assess how the NCEP ORAs (GODAS and CFSR) compare with other state of the art ORAs.

CPC routinely collect an ensemble of monthly temperature analysis in the upper 300m from seven ORAs that cover the period from 1979 to present, and a second ensemble of nine ORAs from 1993 to present. For the first ensemble, anomalies were calculated with the 1981-2010 climatology, and available plots show the anomalies of individual ORAs, the ensemble mean (signal), the ensemble spread (noise), and the signal-to-noise ratio for each month from January 1979 to present (http://www.cpc.ncep.noaa.gov/products/GODAS/multiora_body.html). For the second ensemble, anomalies were calculated with the 1993-2013 climatology, and the plots show the anomalies for each month from January 1993 to present (http://www.cpc.ncep.noaa.gov/products/GODAS/multiora93_body.html). Users can access the real-time ocean heat content in the upper 300m, depth of 20 degree isotherm (d20) as well as temperature anomalies at different latitude, longitude and depth sections to monitor ENSO status and project the potential impact of subsurface fluctuations on ENSO evolution. In addition, data for ENSO precursors are available in the web sites.

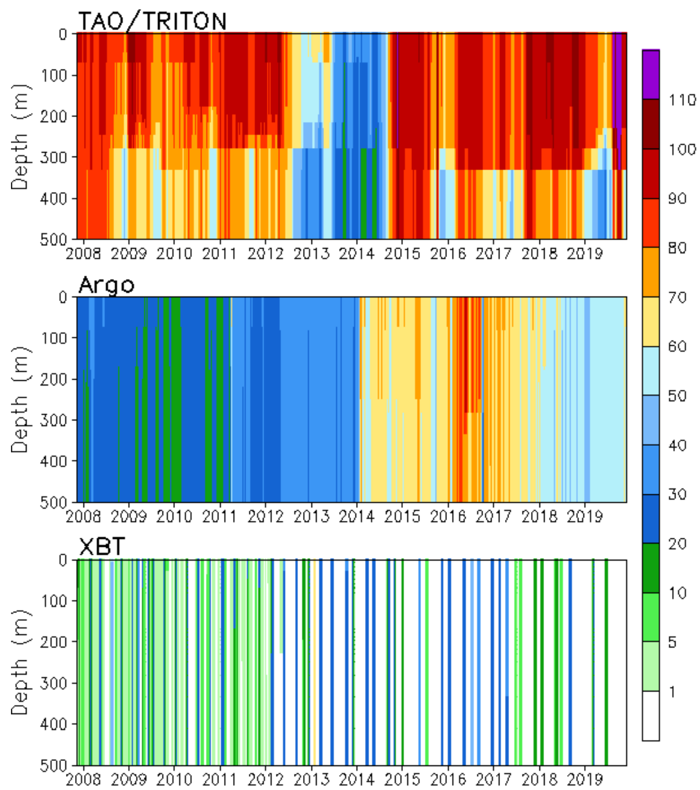

Fig. 1 Time variations of daily temperature profile number per pentad accumulated in the central-eastern equatorial Pacific [170°E-80°W, 3°S-3°N] as a function of depth from TAO moored array (upper panel), Argo (middle panel) and XBT (bottom panel).

(https://www.cpc.ncep.noaa.gov/products/GODAS/insitu/anum_zt.gif)

The ensemble spread and the signal-to-noise ratio allow users to quantify uncertainty in the reanalysis data. For example, Figure 2 displays the d20 anomalies in May 2018. All of the ocean

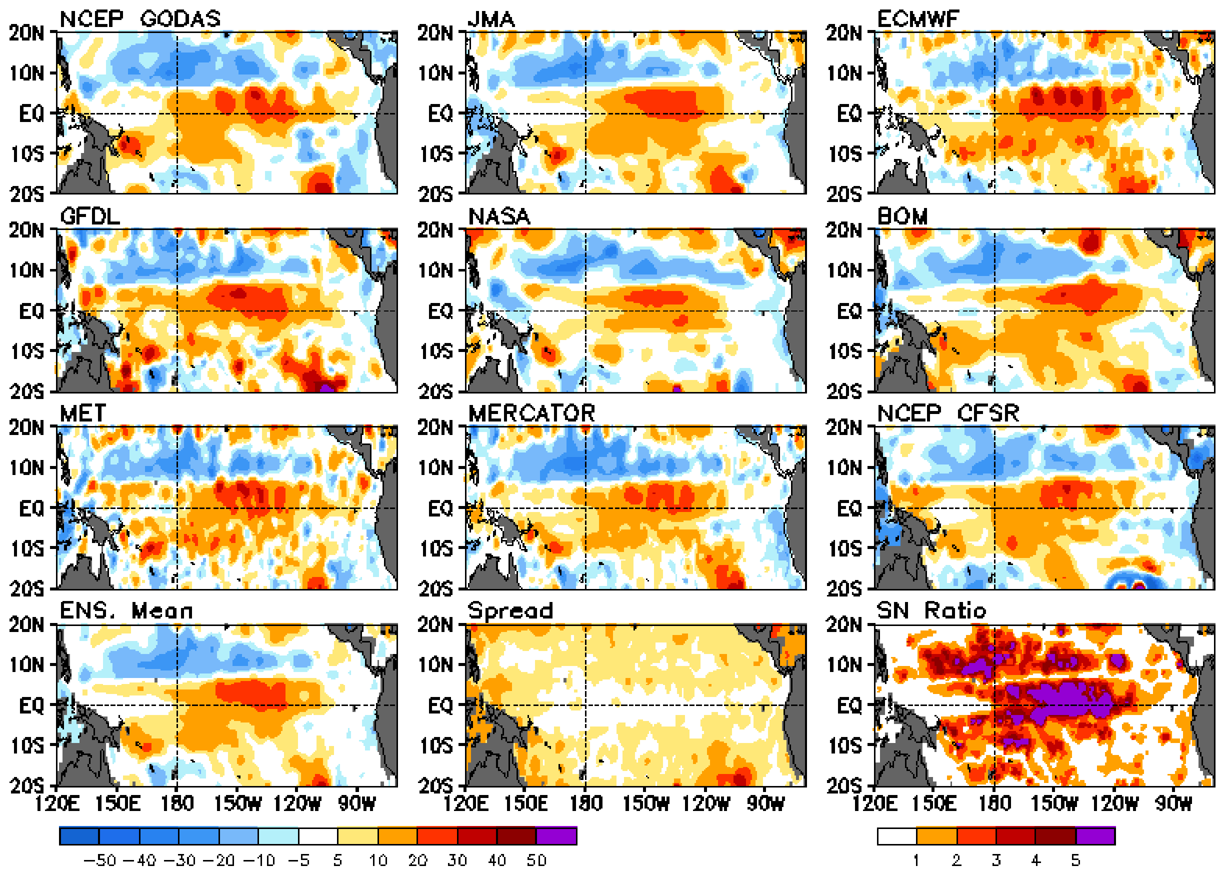

Fig. 2 D20 anomaly in May 2018 from nine operational ocean reanalyses (upper three rows). The ensemble mean (bottom left) provides the best estimation of climate signal. Spread provide a measure of uncertainties in our knowledge of climate signal, while the signal to noise ratio (SN Ratio), defined as the ratio of the ensemble mean and ensemble spread, provides the robustness of the climate signal.

(https://www.cpc.ncep.noaa.gov/products/GODAS/multiora93/pac/d20/d20_pac_xy_201805_9mem.gif)

reanalysis show a consistent pattern with positive (negative) d20 anomalies presenting across the equator (northern off-equatorial region). This is the typical d20 preconditions associated with the onset of El Nino events. The small spread near the equator indicates the high confidence of ocean estimates in representing climate signals. Large signal to noise ratio (>2) suggests the signals are robust.

CPC also routinely updates the spatial distribution and temporal evolution for numbers of observed temperature profiles (moored array, Argo floats and XBTs) in real time. This allows us to monitor the linkage between the spread among ORAs and the available observations. It is expected that availability of ocean observations, by providing stronger constraint on the ocean analysis, should lead to larger signal relative to analysis uncertainty. By identifying the regions where analysis uncertainties are large, the ensemble spread also helps us to identify the needs for enhancing ocean observing systems and improving the quality of ocean data assimilation schemes (Xue *et al.* 2017). These monitoring products also provide a strong support for the framework of TPOS 2020 (http://tpos2020.org/) project on the design of the future tropical Pacific observing system.

References

Behringer, D., and Y. Xue, 2004: Evaluation of the global ocean data assimilation system at NCEP: The Pacific Ocean. *Eighth Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Ocean, and Land Surface*, Am. Meteorol. Soc., Seattle, WA.

Xue, Y., and Co-authors, 2017: A real-time ocean reanalyses intercomparison project in the context of tropical pacific observing system and ENSO monitoring. *Clim. Dyn.*, **49**, 3647–3672.

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College Park, MD, 24-26 September, 2019

Upgrading Ocean Monitoring Products to Hybrid Global Data Assimilation System (Hybrid GODAS)

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1. Background

An ongoing partnership between Office of Ocean Observing and Monitoring Division (OOMD)/Office of Atmospheric Research (OAR) and the Climate Prediction Center (CPC)/NCEP/NWS focuses on the development and dissemination of real-time ocean monitoring products to the global user community. The real-time ocean products developed by CPC rely critically on the ocean observing system supported and maintained by the OOMD - real-time ingestion of those observational data into the NCEP ocean data assimilation system provides a synthesis of the current state of the global oceans and real-time monitoring of ocean climate variability on different time-scales. The current suite of CPC products, however, relies on a legacy ocean data assimilation system – Global Ocean data Assimilation System (GODAS) – that was made operational in 2003. GODAS is based on a univariate 3D-VAR approach and does not utilize advances in data assimilation methods after 2003, for example, ensemble data assimilation based approaches that can also provide error estimates. GODAS infrastructure is also based on GFDL MOM3 while the latest ocean model from GFDL is MOM6, which has gone through three upgrades. Further, GODAS is not capable of assimilating data from the current generation of observational platforms, *e.g.*, salinity from Argo, and satellite altimetry.

The scope of this project is to utilize the next generation of ocean data assimilation system at NCEP that is currently under development in the Environmental Modeling Center (EMC). This ocean data assimilation system will:

- Utilize GFDL MOM6;
- Be an ensemble based data assimilation approach with flow dependent error covariance characteristics. Assimilation system can also provide error estimates in the analysis;
- Have the capability to assimilate salinity, satellite sea surface temperature and altimetry; and
- Utilize a multivariate data assimilation approach that will maintain better dynamical balance between ocean temperatures, salinity in the analysis.

2. Current status

CPC, working with EMC, has already tested the initial performance of the Hybrid GODAS based on a pilot run and found its performance is better than the GODAS (Fig. 1). The infrastructure for the Hybrid GODAS is under further development in EMC for its operational implementation. When operational, CPC will replace the recurrent suite of real-time ocean monitoring capability based on the Hybrid GODAS products.

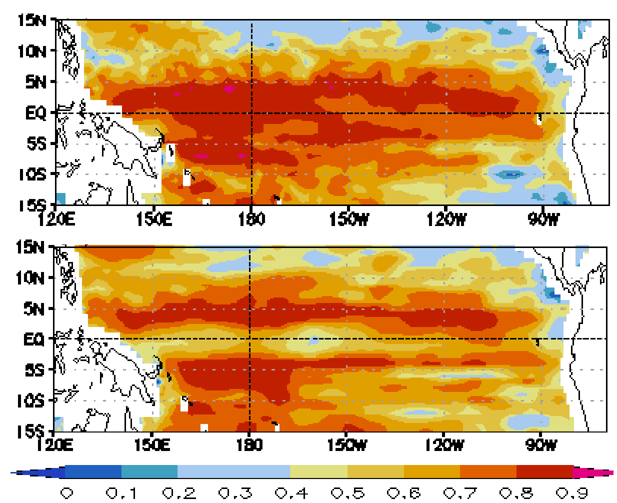

Fig. 1 Anomaly correlation between the ocean currents based on Hybrid GODAS (top panel) and GODAS (bottom panel) with the observation based estimate. Higher values of anomaly correlation between model based estimate and observation indicate a better performance and is the case for Hybrid GODAS.

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The International Desks of the Climate Prediction Center

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1. Background

Recognizing that many developing countries do not have sufficient capacity to meet the requirements for climate services, NOAA through the International Desks at the Climate Prediction Center (CPC) conducts a strong international program that develop and deliver routine climate products tailored to the needs of the international community. In particular, the International Desks support various government and international programs, including the USAID humanitarian mission namely Famine Early Warning System Network (FEWS NET) managed by Food for Peace (FFP), and the Disaster Risk Reduction Program manage by the Office of Foreign Disaster Assistance (OFDA). Other domestic programs supported include the U.S. Department of Agriculture (USDA) global crop supply and demand, the Department of Defense humanitarian support for security in the developing world, and the Department of State (DoS) Capacity Development Program.

2. Products and services

The primary functions of the desks are to continuously monitor weather and climate patterns around the world and to disseminate these in the form of bulletins or briefings via the CPC International Desks website (Fig. 1) and through e-mail distribution lists (Thiaw and Kumar 2015). The International Desks operational weather and climate products are derived from NCEP observational data and model outputs and seamless forecasts from short range weather to seasonal climate outlooks. In the following, we summarize the content of the CPC International Desks website.

The website features real time operational products for the World Meteorological Organization (WMO) Regional Association (RA) IV, which encompasses North America, Central America, and the Caribbean; post

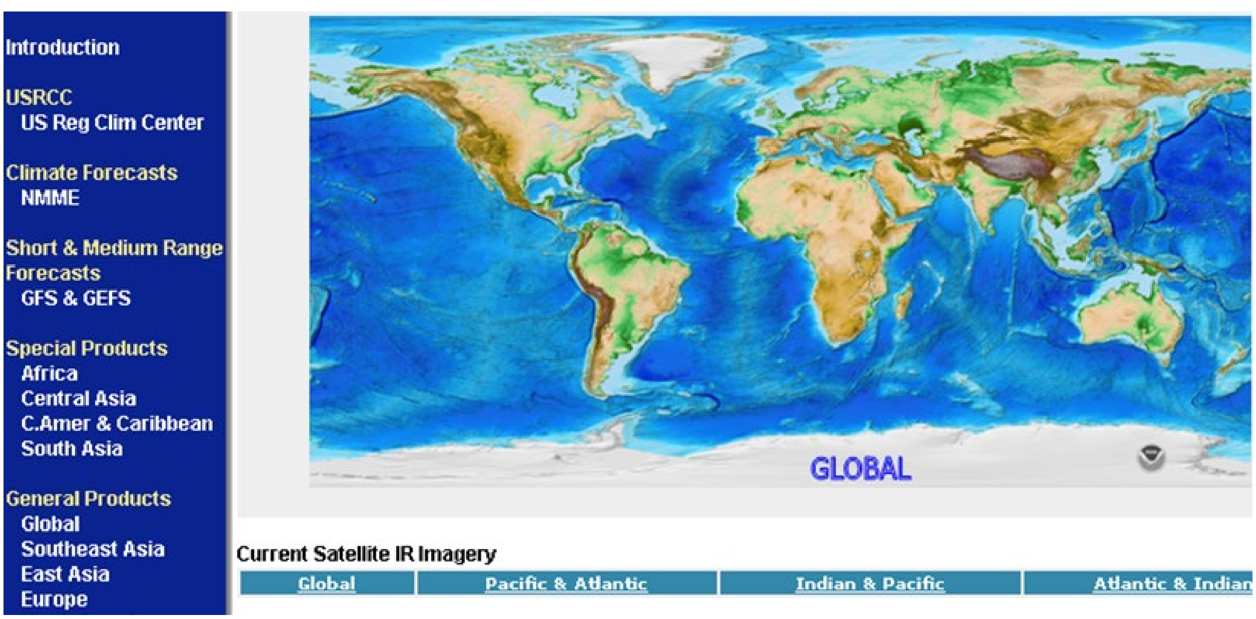

Fig. 1 The International Desks website. Regionalized NCEP products are made available over each geographical region through the clickable maps or through the menu on the left of the page. Expert assessment products are also available for Africa, Central America – Caribbean regions, and Central Asia.

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processed forecasts from the North American Multi-Model Ensemble (NMME) and the NCEP Global Forecast System (GFS) and Global Ensemble Forecast System (GEFS); products specifically targeted for the USAID FEWS NET with focus on Africa, Central Asia, Central America-Caribbean region, and South Asia. Global and regionalized products are also made available to include Southeast Asia, East Asia, Europe, North America, and South America.

The NMME models include the NCEP CFSv2, the Canadian CanCM4i and GEM-NEMO, the NOAA GFDL and GFDL-Flor, the NASA GEOS5v5, the NCAR CCSM4, and the ensemble mean which consists of an average of the 107 individual members from all 7 contributing models to the NMME. The forecast include monthly and seasonal post processed sea surface temperature, air temperature, and precipitation forecasts expressed in both deterministic and probabilistic terms from one month lead (target month or season is the first month or season following the month initial conditions data were taken from) to five months lead (Fig. 2). Historical model performance for all target months and seasons along with model verifications are

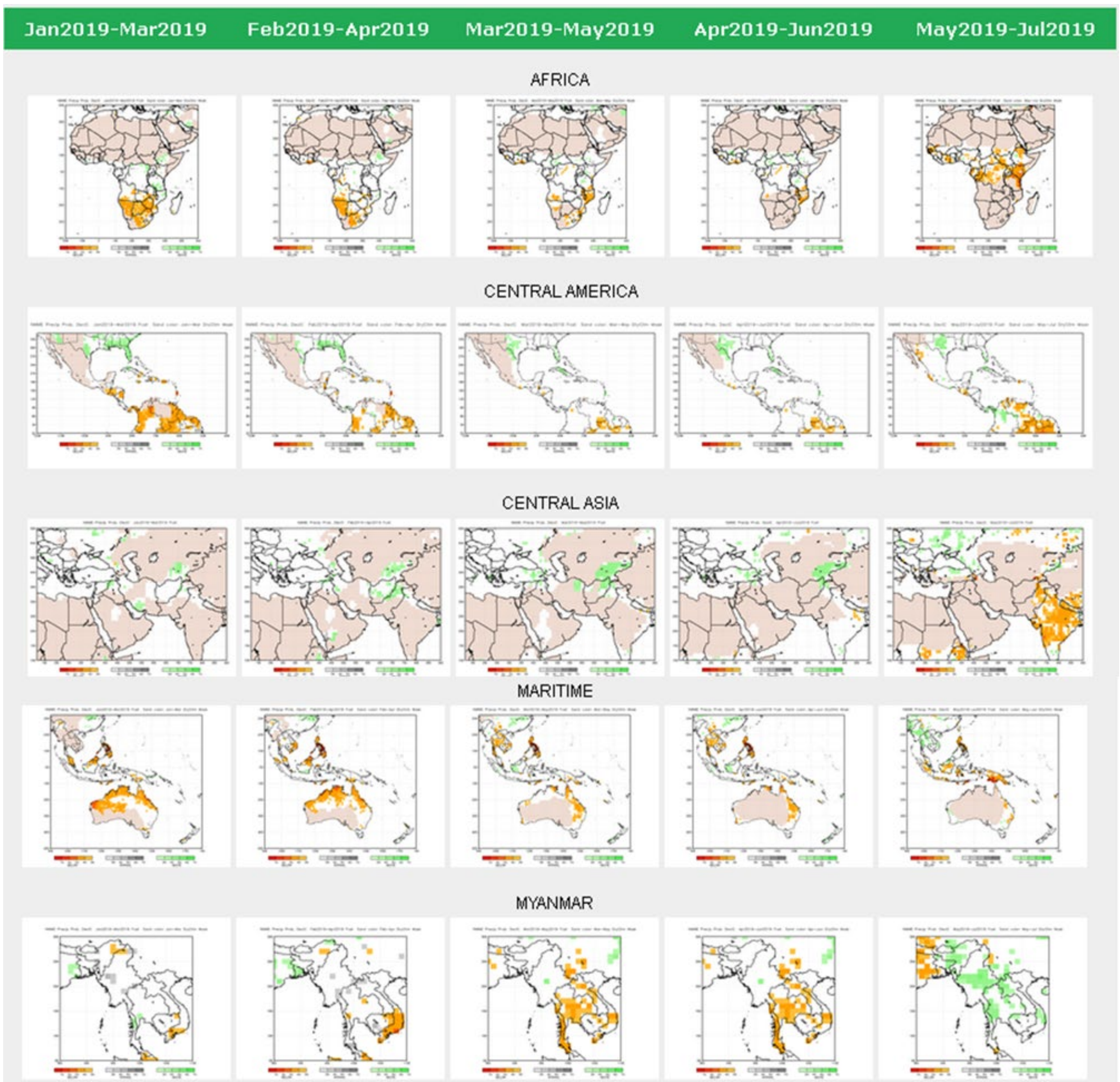

Fig. 2 Post processed NMME seasonal precipitation forecasts over different parts of the world, expressed in term of three category probability forecasts for above-average, near-average, and below-average rainfall.

also posted. The NMME forecasts are used to support WMO Regional Climate Outlook Forums (RCOF) around the world and also to support FEWS NET scenario development for the monitoring and projection of food security outcomes in many parts of the world.

Similarly, the GFS and GEFS post processed forecasts include air temperature and precipitation forecasts from day1, *i.e.* 24 hour forecast to day 16, week-1 and week-2 forecasts (Fig. 3). These forecasts include probability of exceedance of temperature and precipitation at various threshold values and are important tools for the forecasting of extreme events. In particular the GFS and GEFS model guidance are used in the preparation of regional week-1 and week-2 outlooks in support of the global tropics hazards outlooks.

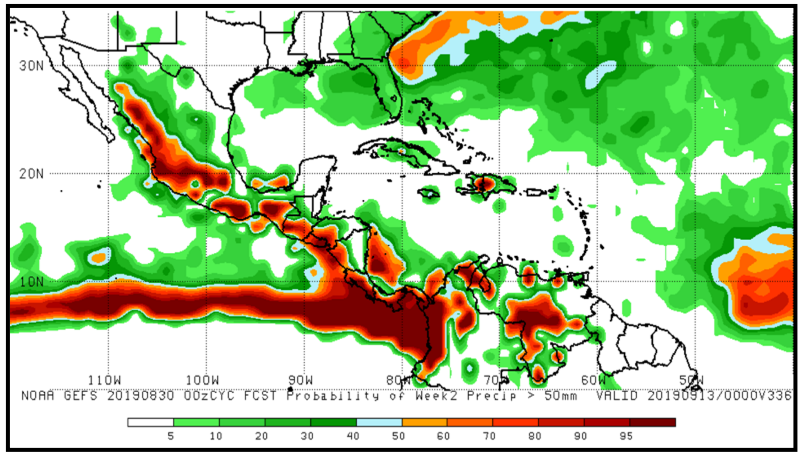

Fig. 3 Post processed NCEP GEFS week-2 precipitation forecasts over the Central America – Caribbean region, expressed in terms of probability of exceedance of 50 mm rainfall, valid 13 September 2019.

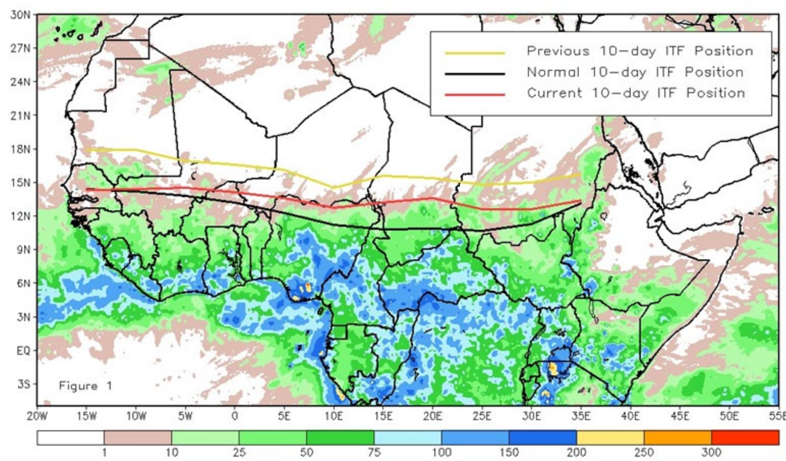

Fig. 4 Satellite rainfall estimate version 2 (RFE2) overlaid with the position of the intertropical front (ITF) representing the northern limit of the area of maximum rainfall in Africa north of the equator, 21 – 31 October 2019.

Climate monitoring is an important activity of the Desks. The NCEP various datasets including the NCEP reanalysis and Global Data Assimilation System, the CPC gridded temperature data, the daily and monthly gauge analysis such the CPC unified and the land only precipitation data (PREC-L), satellite derived rainfall estimates such as the Rainfall Estimate version 2 (RFEv2), the African Rainfall Climatology version 2 (ARC2), CMORPH, *etc.*, form a basis for the monitoring of the global climate system. Spatial maps and time series are generated on a daily basis to monitor the evolution of the most recent climate events up to about 180 days. This information is extremely useful for depicting the onset and evolution of meteorological drought or the monitoring of flood events. Satellite rainfall estimates are also used to derive as sets of products that help further monitor current conditions and outlooks into the future. For Africa, these products include the delineation of the Intertropical Front (ITF) a unique feature of the West African monsoon to indicate the strength of the monsoon season (Fig. 4); the seasonal performance probability that helps project the outcome of a rainy season about half way into the rainfall season.

The monitoring products combined with the GFS, GEFS and NMME model guidance are powerful tools for informed decision making in food security and disaster risk management. For instance, the monitoring of the evolution of the climate over the past several months enables the depiction of areas that have been experiencing drought or flooding. Then the model guidance is used to assess the evolution of conditions into the future. This assessment in turn enables the drawing of hazards polygons indicative of droughts or floods, and using GIS, shapefiles and raster files are generated and made available to the users of the information (Thiaw and Kumar 2015). In the case of food security for instance, the shapefiles and raster files are overlaid with other food security indicators including livestock health, market prices, livelihood, conflict, *etc.*, to generate food security outlooks. The food security outlooks serve as a basis for developing a contingency plan to mitigate the impacts of the hazards (drought or flooding) on the livelihood of vulnerable people.

3. Summary

For more than two decades, NOAA has been working with sister agencies with specific interest in the developing world to support the U.S. government humanitarian mission in areas that are challenged by natural disasters such as droughts, floods, tropical cyclones, *etc.*, and considered economically vulnerable because of shortage of food or safe drinking water. In particular, the International Desks provide domestic and international agencies with access to real-time NCEP operational weather and climate forecasts and monitoring products for any given region of the world. A website has been created and maintained for this purpose. The CPC International Desk also provides support to many domestic and international programs, including the USAID's FEWSNET and Disaster Risk Reduction (DRR) Program, WMO RCOFs. More recently, the International Desks has been working to provide support to the health sector through research and development and establishing relationship with this sector. The International Desks are working to improve week-2 and week-3&4 forecasts and to tailor these forecasts to the needs of the stakeholders including food security, disaster risk reduction, and health.

Acknowledgements. Appreciation is expressed to the CPC International Desks Team: Vadlamani Kumar, Endalkachew Bekele, Miliaritiana Robjhon, Steven Fuhrman, Pierre-Honore Kamsu-Tamo, Sarah Diouf, Ibrahima Diouf, and Alima Diawara.

Reference

Thiaw, W. M., and V. B. Kumar, 2015: NOAA's African Desk: Twenty years of developing capacity in weather and climate forecasting in Africa. *Bull. Amer. Meteor. Soc.*, **96**, 737-753, doi:10.1175/BAMS-D-13-00274.1

Regional Hazard Outlooks for Food Security

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[2]*Innovim LLC, Greenbelt, MD*

1. Background

Since the mid-1980s, the Climate Prediction Center (CPC) has been providing support to the United States Agency for International Development (USAID) Famine Early Warning Systems Network (FEWS NET). Support began with the provision of – 10-day weather reports from the Global Telecommunication Systems (GTS) stations; 10-day African weather summaries issued three times a month; daily, 10-day and monthly satellite rainfall estimates; and seasonal rainfall forecasts. Analysis evolved into the production of regional hazard outlooks for food security. The regional hazard outlook is a short weather and climate document that highlights hazards over a given region in both graphical and text formats. Currently, the hazard outlooks cover 5 regions. These include Africa, Central America, Hispaniola, Central Asia, and Afghanistan. The outlook has a weekly time scale and focuses primarily on flood and drought at different classifications. The hazard outlooks process is operational, cyclical, evidence-based, and collaborative.

2. Process and tools

The regional hazard outlook process consists of several steps. It begins with an in-depth climate monitoring of the region. Analyses focus on areas that exhibit food security vulnerability. Rainfall and temperature anomalies over the past week to few months are analyzed to monitor the progress of abnormal climatic conditions. Drought monitors and agro-climatic information are analyzed to assess potential impacts on the ground. Model guidance tools are, then, used to evaluate future evolution of weather systems, which may affect current conditions over the target region. An initial draft is prepared and is shared with partners. This is followed by a teleconference call with partners and users, where current conditions are discussed, and stakeholders' feedback is leveraged to adjust and calibrate previously issued draft. The hazard outlooks are finalized and are released on Wednesday of the week. The outlooks are integrated onto the FEWS NET food security outlook. Details on the process are found in Thiaw and Kumar, 2015.

3. The 2019 March-May eastern Africa drought

To illustrate the regional hazard outlooks process, drought that developed over eastern Africa during the 2019 March-May rainfall season is considered. From the beginning of March to late April, a delayed onset to the rainfall season, which was followed by poorly distributed rain, had led to large moisture deficits and abnormal dryness over a wide area of eastern Africa. This included South Sudan, southern Ethiopia, southern Somalia, northern Uganda, and Kenya. During the ensuing week of 28 April – 4 March 2019, dry weather pattern with limited rain continued over the region.

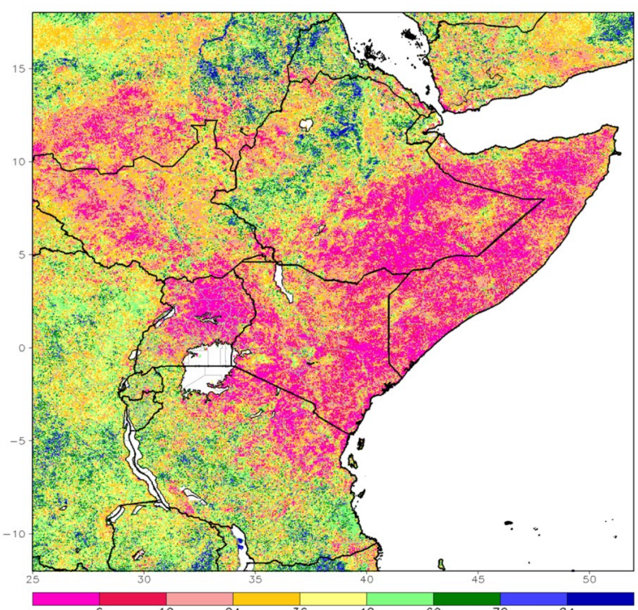

Fig. 1 Vegetation Health Index (VHI) in %, valid during the week of 23–29 April 2019. VHI values below 40% indicate poor conditions.

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Rainfall anomalies over the previous seven and thirty days indicated widespread, drier-than-average conditions throughout South Sudan, Uganda, southern Ethiopia, Somalia, and Kenya. Cumulative rains since 1 March were less than 50 percent of average over many areas. Drought monitor as Standardized Precipitation Index (SPI) exhibited drought-like conditions over parts of Ethiopia, Kenya, and Somalia. Vegetation products such as Normalized Difference Vegetation Index (NDVI) anomaly (not shown) and Vegetation Health Index (VHI) (Fig. 1) displayed very poor and well below-average conditions.

The low values of VHI denoted significant negative impacts on agriculture. Moreover, short-term rainfall forecasts from model guidance tool and regional rainfall outlook suggested drier-than-average conditions to continue during the subsequent week. An empirical seasonal performance probability outlook also indicated that the likelihood for the March-May rainfall season to finish below 80 percent of average was high. Thus, drought was expected to occur or to continue over parts of Ethiopia, Kenya, and Somalia, due to the combined effects of reported, abnormally high temperatures and persistent rainfall deficits, which had already adversely impacted pastoral and agropastoral conditions over many areas (Fig. 2).

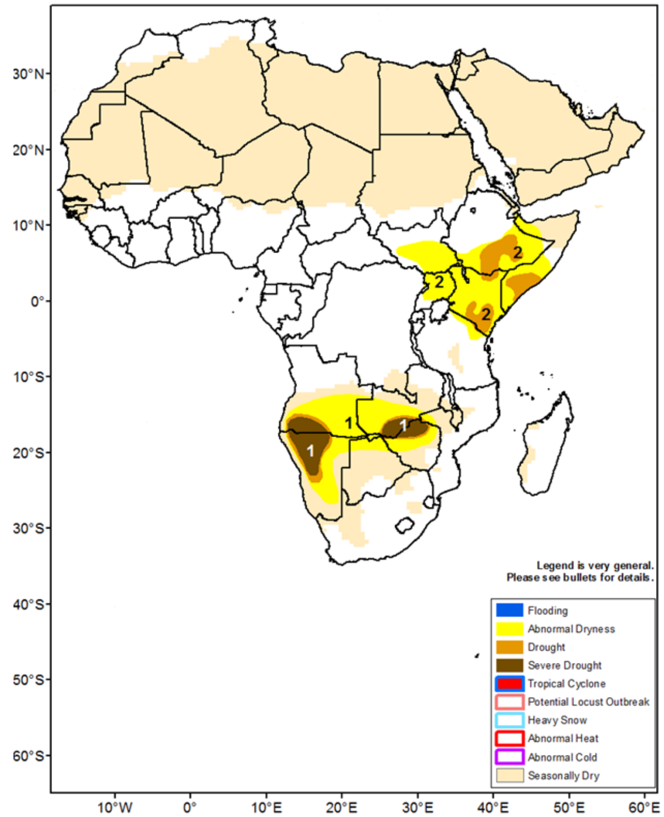

Fig. 2 Africa hazards outlook for food security, valid during the week of 9 – 15 May 2019.

4. Research for improvement

The Standardized Precipitation Evapotranspiration Index (SPEI) is an extension of the SPI. It takes into account both precipitation and potential evapotranspiration and captures the impact of increased temperature on atmospheric evaporative demand. Effort is being undertaken to produce monthly SPEI as an additional monitor to improve drought monitoring and support for the United States Agency for International Development (USAID)-sponsored Famine Early Warning Systems Network (FEWS NET). Preliminary evaluation of SPEI has showed that the variability of SPEI was consistent with that of SPI over drought-prone areas of eastern Africa during the period of 1979-2018. However, SPEI indicated more severe droughts relative to SPI from 2009-2013, period during which de-trended surface temperatures were abnormally high. This, therefore, supported the premise that increased temperature enhanced evapotranspiration and exacerbated droughts.

References

Thiaw, W. M., and Kumar, V. B., 2015: NOAA's African Desk: Twenty years of developing capacity in weather and climate forecasting in Africa. *Bull. Amer. Meteor. Soc.*, **96**, 737-753. doi:10.1175/BAMS-D-13-00274.1.

APPENDIX

PHOTO GALLERY

Stakeholder User Cases

CPC Operation & Research

Questions & Answers

Breakout Discussions