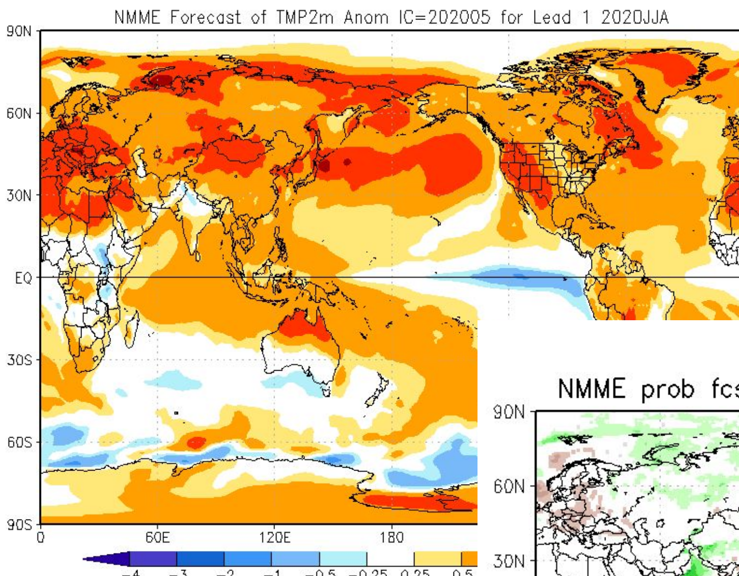
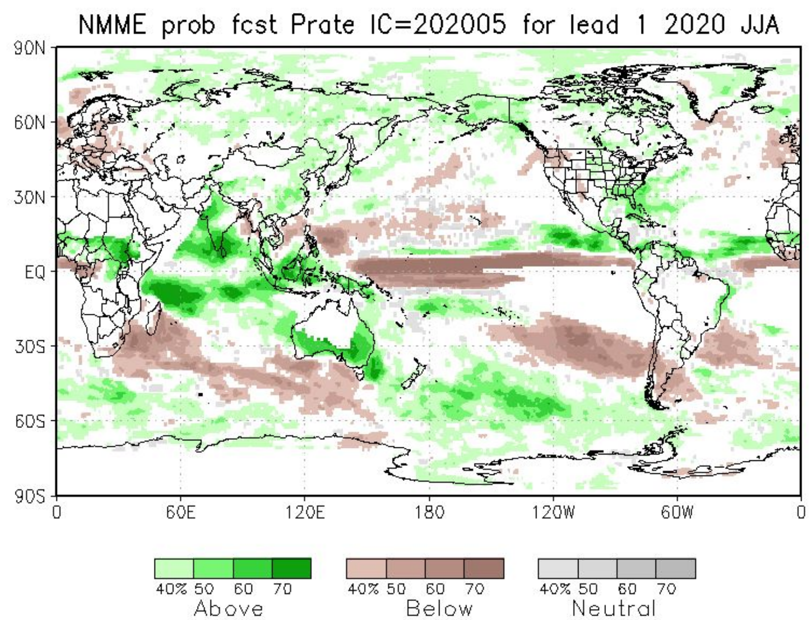
The North American Multi-Model Ensemble (NMME) Operational Phase

2019-2020 Annual Report





U.S. DEPARTMENT OF COMMERCE
National Oceanographic and Atmospheric Administration
Silver Spring, MD

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Summary

The North American Multi-Model Ensemble (NMME) continued to deliver benefits to the subseasonal-to-seasonal operational forecast entity within NOAA, the Climate Prediction Center (CPC), and to the larger research community. Overall data usage from the operational data delivery point remained stable, with about 3000 active users each month. Data was delivered on time for all months, though in one month there was a quality issue corresponding to a major component upgrade.

The system continues to produce skillful information that can be easily translated into official outlooks, with the modeling suite showing skill over the North America domain in almost every issuance since 2012, for both temperature and precipitation. Regionalized verifications, as well as those focused on specific seasons, have provided insight into what modes contribute to low-skill outlooks, feeding back from operations to research.

The number of products being derived from the NMME models is increasing, with several new applications under development by NOAA and other entities, showing how the research can feed into operational entities. The NMME model suite continues to evolve, as older models are retired and replaced with new models; model replacements from three modeling centers are planned for 2021. Understanding the dependencies and implementing some initial internal controls to document and track downstream dependencies, as well as informing users of the sustainable reliability, will be critical in the coming years.

Overview

History of NMME

The North American Multi-Model Ensemble (NMME; Kirtman et al. 2014) experiment is an unprecedented effort to improve seasonal operational predictions based on the leading North American climate models. The NMME project had an experimental phase (referred to here as NMME Phase I; August 2011-July 2012), which had a core activity of making multi-model (from the major US and Canadian modeling centers) seasonal predictions in real-time on the NOAA operational schedule. NMME Phase-II covered the period August 2012-July 2015 and focused on:

(i) Continued real-time forecasts and incorporating updated models;

(ii) Coordinated predictability research that identifies the benefit of the multimodel approach, examines how best to combine models, and guides model development and applications;

(iii) Developing an intra-seasonal protocol;

(iv) Continued and enhanced data distribution to facilitate use of NMME data.

NMME Phase-II was externally reviewed by a panel of experts that recommended that NMME Phase-II transition to an operational phase (August 2015-July 2018). Based on this review an “arrangement for cooperation” for the deployment and operation of the North American Multi-Model Ensemble (NMME) - Phase II Seasonal System, among the: National Centers For Environmental Prediction (NCEP), National Weather Service (NWS), National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce (DOC); Geophysical Fluid Dynamics Laboratory (GFDL), Office of Oceanic and Atmospheric Research (OAR), NOAA, U.S. DOC; Environment and Climate Change Canada (ECCC), Government of Canada; Climate Program Office, OAR, NOAA, U.S. DOC; Goddard Space Flight Center (GSFC), National Aeronautics and Space Administration (NASA); University Corporation for Atmospheric Research (UCAR) acting on behalf of the National Center for Atmospheric Research (NCAR); and University Of Miami was signed by all the partners.

The project report summarizes NMME related activities during 2019 and early 2020 of the NMME Phase-II operational deployment. The major results include (among other accomplishments): (i) Continued operational forecasts and data dissemination; (ii) Real-time evaluation of forecast quality; (iii) Developing the distribution of real-time daily data; (iv) Coordination of NMME/SubX Workshop; (v) Prediction and predictability research (i.e., special issue of Climate Dynamics, and over 300 peer reviewed publications using the NMME data.

Current status of NMME

For 2019-2020, the NMME consisted of the CFSv2, 2 models from Environment and Climate Change Canada (ECCC), 2 models from Geophysical Fluid Dynamics Laboratory (GFDL), 1 from University of Miami (UM), 1 from National Aeronautics and Space Administration (NASA). The models from ECCC were updated in August of 2019, to include the CanSIPSv2, which consists of two models, the CanCM4i and GEM-NEMO. While CanCM4i is a climate model, which is upgraded from CanCM4 of the previous CanSIPSv1 with improved sea ice initialization, GEM-NEMO is a newly developed numerical weather prediction (NWP)-based global atmosphere–ocean coupled model (Lin et al. 2020). No other changes were made to the constituent models during 2019-2020.

Meeting Operational Needs

The NMME continued to be a valued element in the process of making monthly and seasonal outlooks at CPC. The data has been delivered routinely, and the final output products have been delivered 100% of the time, continuing to demonstrate the robustness of the systems and processes in place. The output is used in many ways, from being referenced qualitatively by the forecasters to quantitative interrogation and integration.

NCEP’s operational system requires that the NMME-Phase II system deliver timely and reliable seasonal forecast products. To meet such a requirement the NMME Phase-II system intends to uses the following approach:

The operational NMME Phase-II is a product-based system. The metric of system reliability is based on the timeliness of delivery of the NMME products rather than the availability of the individual participating models. The operational NMME Phase-II will deliver timely, reliable products by including prediction systems from the NCEP and ECCC operational centers (reliability is 99% for NWS operational systems). Participants deliver timely real-time forecasts following NCEP operational launch schedules as specified in the NMME protocol. To evaluate whether the NMME Phase-II System is meeting its operational service system requirements, NCEP/CPC tracks the following metrics regularly:

Timeliness

On-time delivery is necessary for NMME Phase-II forecasts and products to be of most use by the forecasters at CPC and around the world.

Criteria

The baseline for timeliness is NWS’s 99% on-time product delivery requirement. Note that product delivery within 15 minutes of the published delivery time is considered on time. Additionally, CPC tracks the number of users accessing the data and the timeliness of the data delivery.

Report

The CPC operational products that utilize the NMME were delivered on time 100% for all initial condition months during the January 2019 through June 2020 period, which surpasses the 99% on-time requirement. It should also be noted that in the reporting period all of the individual models were provided by the monthly processing deadline.

Approximately 3000 users access CPC’s central NMME page, with an additional 1500 accessing the NMME data through the CPC international desk. Work is underway to track usage statistics for CPC’s FTP site where the numerical data is served. The ability to track that was broken in 2016 during a system migration.

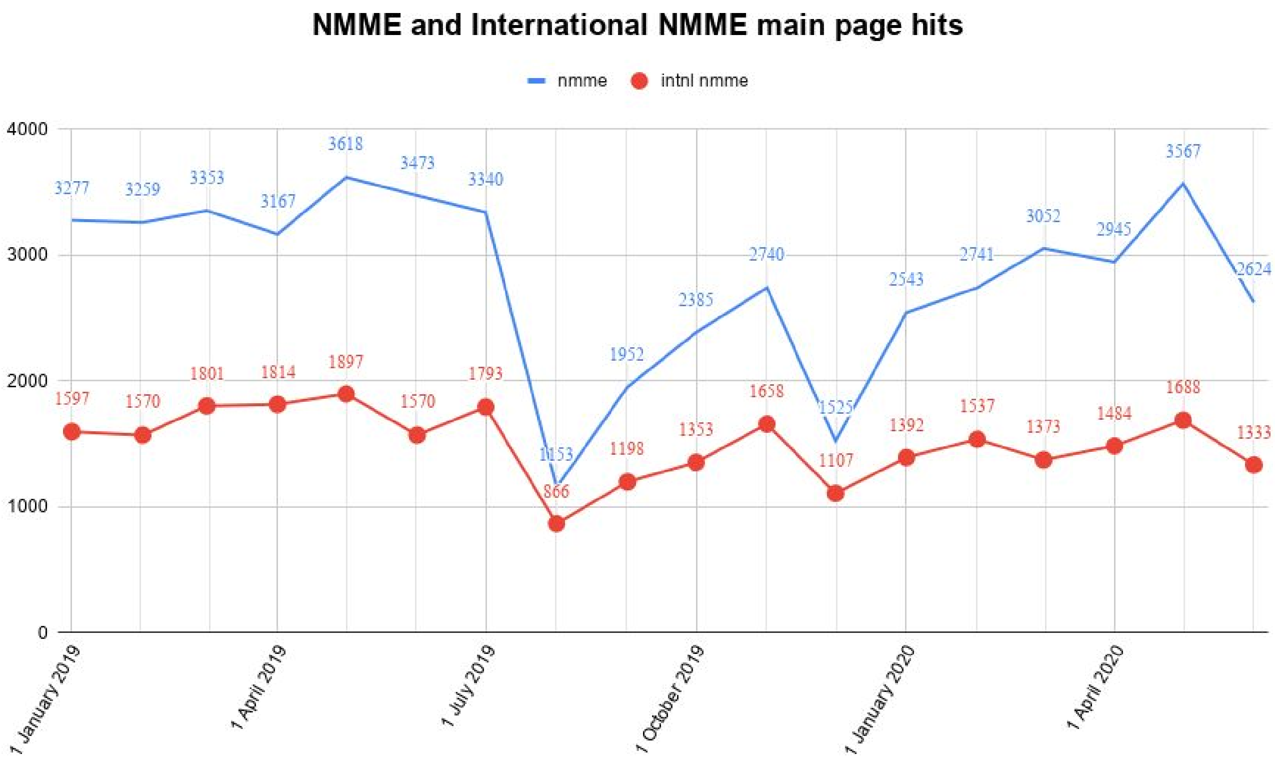

Figure 1: Website hit statistics for CPC's main NMME page and the International Desk NMME landing page.

Skill

NCEP/CPC intends to prepare annual reports on the NMME System-II product timeliness and skill based on the relevant operational metrics. Reports will be made available to all participating centers and their sponsors.

Criteria

CPC tracks the anomaly correlation for the North America Region and CONUS. Additionally, CPC calulcates Heidke Skill Scores (HSS)and Ranked Probability Skill Score (RPSS) for global fields, as part of CPC's international desk work. The governing agreement for the NMME specifies that in addition to these metrics, CPC should also be evaluating (for each model mean and the grand ensemble mean) Root Mean Square Error, Variance, and Biases, as well as Brier Scores

Additionally, some work on assessing the modes of variability associated with each outlook was undertaken by CPC staff. That work could better help forecasters understand sources of skill/error from the NMME suite.

Report

CPC maintains real-time verification metrics web pages available at the following URLs:

http://www.cpc.ncep.noaa.gov/products/NMME/verif/index.html
http://www.cpc.ncep.noaa.gov/products/NMME/prob/rpss.probindex.html
https://www.cpc.ncep.noaa.gov/products/international/nmme/verif/nmme_all_verif.shtml
(updated annually)

The latest temperature verifications are included in the figures. The modeling suite had trouble identifying the cold events over the central CONUS during the winter months of early 2019, but the skill over North America was positive. That continued for most outlooks with initial conditions in early 2020. That prompted some of the work to assess what modes are contributing to the skill of the system.

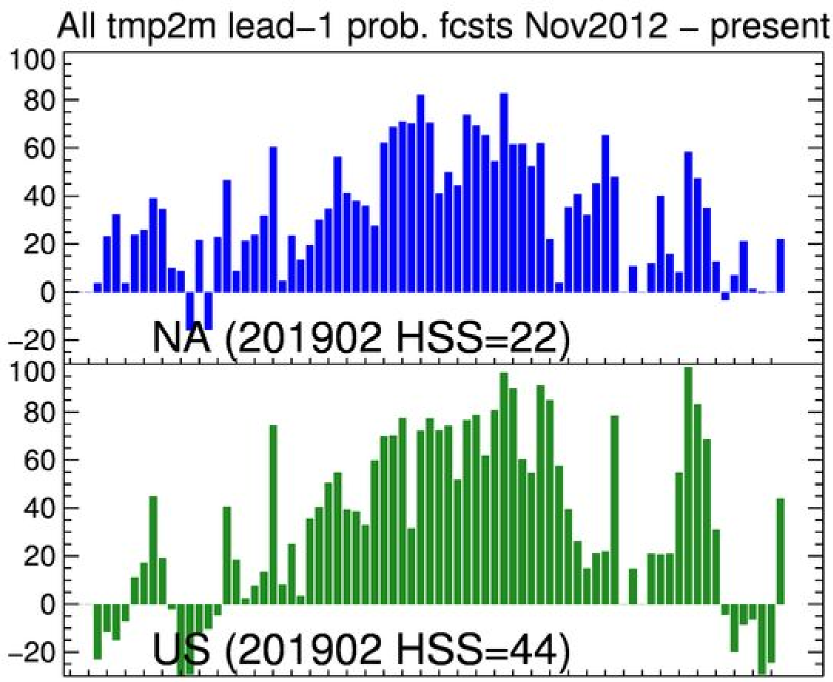

Figure 2: Heidke Skill Score (HSS) of 2-meter temperature for the NMME mean for each month from 2012- July of 2019.

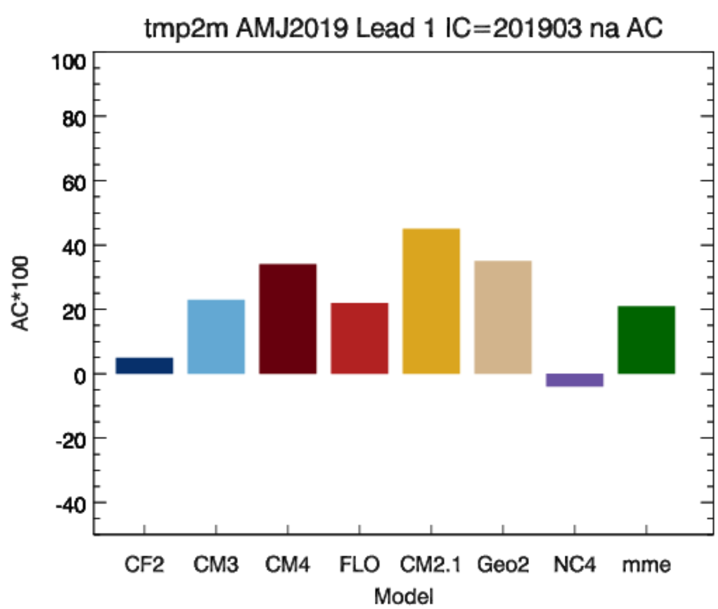

Figure 3: Anomaly Correlation (AC) of 2-meter temperature for the individual model means, and NMME mean over North America, for the season April-May-June of 2019.

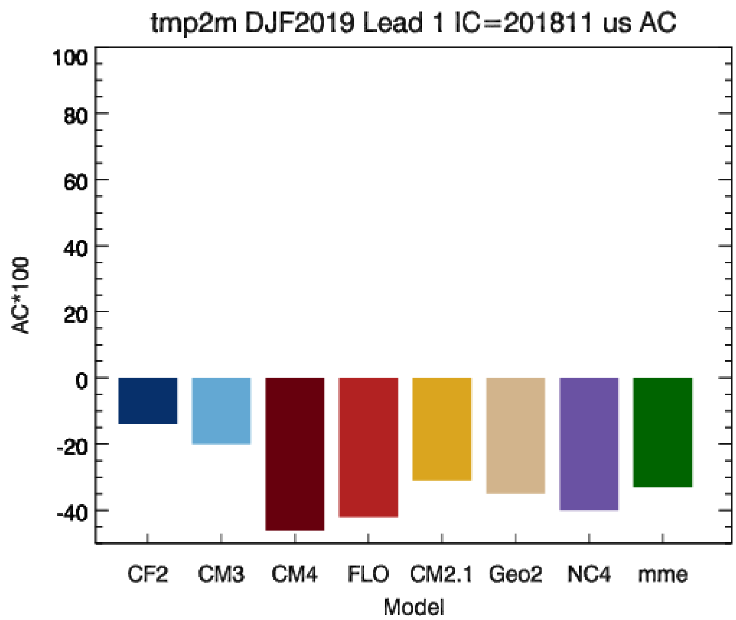

Figure 4: Anomaly Correlation (AC) of 2-meter temperature for the individual model means, and NMME mean over CONUS, for the season Dec-Jan-Feb of 2019-2020.

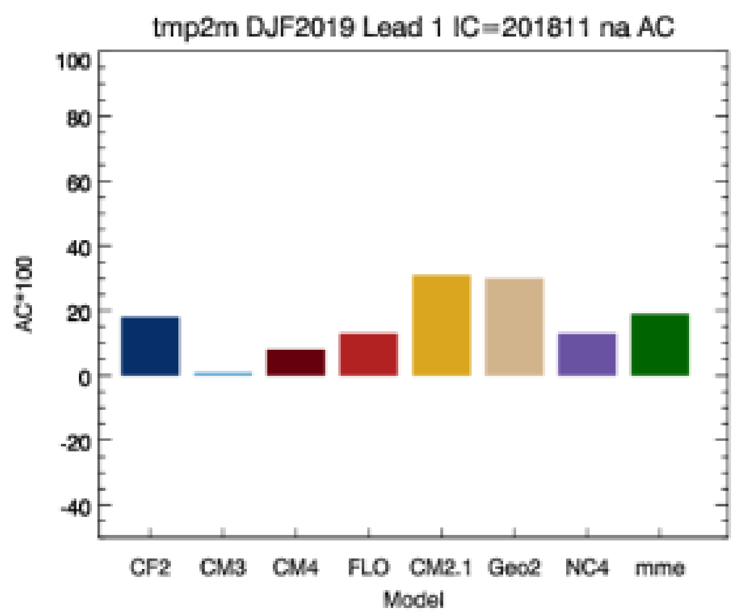

Figure 5: Anomaly Correlation (AC) of 2-meter temperature for the individual model means, and NMME mean over North America, for the season Dec-Jan-Feb of 2019-2020.

The latest precipitation verifications are included in the figures. The modeling suite continues to score lower for precipitation than for 2-meter temperature, consistent with most other global models. The April-May-June 2019 scores were positive and quite good. CPC's verification codes failed during Summer of 2019, as they were run manually. Staff have since been allocated to make the appropriate fixes, as well as fully flesh out the suite of metrics required.

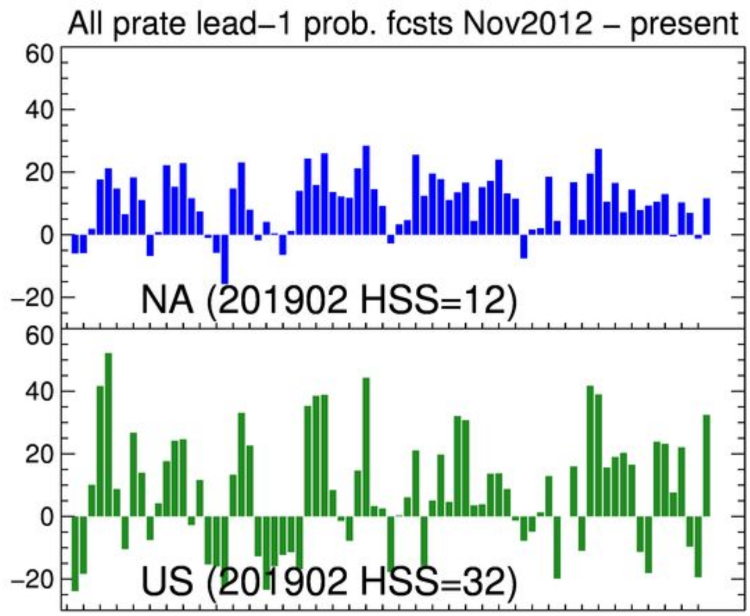

Figure 6: Heidke Skill Score (HSS) of precipitation rate for the NMME mean for each month from 2012- July of 2019.

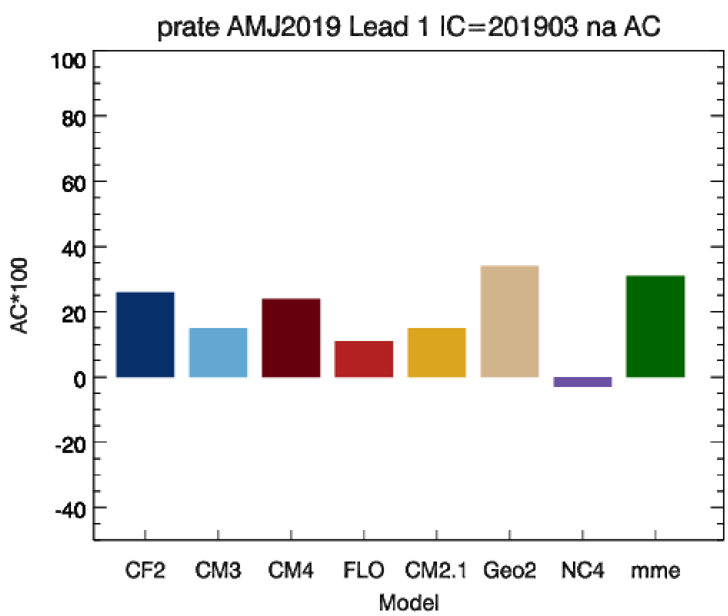

Figure 7: Anomaly Correlation (AC) of precipitation rate for the individual model means, and NMME mean over North America, for the season April-May-June of 2019.

Community Engagement

As the operational center, providing the data to the public, CPC needs reliable methods of contact and communication.

Criteria

An official NMME email address, will be set up to receive feedback such as complaints, requests, and comments.

Report

Ncep.cpc.nmme.production @noaa.gov was established and can be used to provide guide feedback directly to CPC staff about the monthly production.
ncep.cpc.nmme.notifications@noaa.gov can be used to disseminate relevant information to any user that has asked to be included in that email list. Typical announcements range from production problems to seminar announcements and model upgrade schedules.
NMME monthly calls continued, encompassing report outs from operations and presentations on research related to the NMME project and seasonal outlooks for many parameters.

Meeting Research Needs

Evaluating the Modeling System

Evolution of the NMME system

The NMME was designed to evolve as old models were retired and new models joined the ensemble. This study examines the assumption that prediction skill will increase as the system evolves, focusing on 2 m temperature, precipitation rate, and sea surface temperature prediction. The common reforecast period of 1982–2010 is studied for four configurations of the NMME, approximately representing the operational model suites of 2011, 2012, 2014–2018, and 2019–present. “NMME1,” active from 2011-2012, includes seven models, CFSv1, CFSv2, CCSM3, ECHAMa, ECHAMf, GEOS5, and CM2.1, for a total of 79 ensemble members. “NMME2,” 2012-2014, is comprised of six models, CFSv2, CCSM3, GEOS5, CM2.1, CanCM3, and CanCM4, with 70 ensemble members. “NMME3,” 2014-2019, has seven models, CFSv2, GEOS5, CM2.1, CanCM3, CanCM4, CM2.5-FLOR, and CCSM4, for 98 ensemble members. Finally, “NMME4,” initiated in 2019, has seven models, CFSv2, CM2.1, CM2.5-FLOR, CCSM4, GEOSS2S, CanCM4i, and GEM-NEMO, for 92 total members.

Substantial improvement in temperature prediction over both land and ocean is observed, with little change in global precipitation prediction. Land surface temperature prediction by the NMME improves with each new suite, even as the highest anomaly correlation from an individual model remains the same. Sea surface temperature prediction at longer leads has improved over much of the globe, with the notable exception of the central-eastern tropical Pacific, where prediction skill has declined.

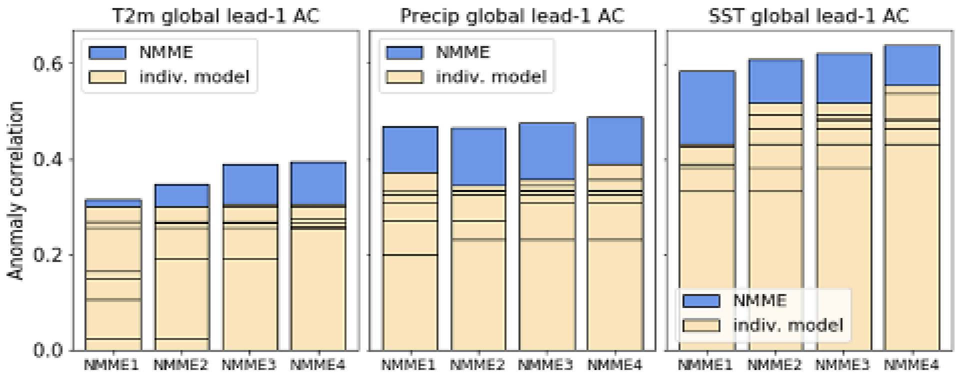

Figure 8: Annual average lead-1 seasonal global anomaly correlation for the four NMME combinations for T2m (right), precipitation (center), and SST (right). Blue bars show the multi-model mean anomaly correlations; yellow bars are individual model average anomaly correlations. (Becker et al. 2020)

Research informing real-time prediction: Excessive Momentum and False Alarms in Late-Spring ENSO Forecasts

The unforecast stalled growth of the El Niño-Southern Oscillation (ENSO) of 2014 and 2017 raises questions about the reliability of the coupled models used for forecast guidance. This study analyzed the skill and reliability of forecasts of the Niño 3.4 tendency (3-month change) in the North American multimodel ensemble (1982–2018). Forecasts initialized April–June (AMJ) have "excessive momentum" in the sense that the forecast Niño 3.4 tendency is more likely to be a continuation of the prior observed conditions than it should be. Models tend to predict warming when initialized after observed warming conditions and cooling when initialized after observed cooling conditions.

Excessive momentum appears in AMJ forecast busts and false alarms including the 2014 one. In some models, excessive momentum appears to be related to model formulation rather than initialization. A concerning trend is that four of the nine years with AMJ forecast busts occurred in the last decade. The authors of this study note that From a pragmatic standpoint, excessive momentum in late-spring coupled model ENSO forecasts is simply another model bias and should be amenable to correction by statistical methods.

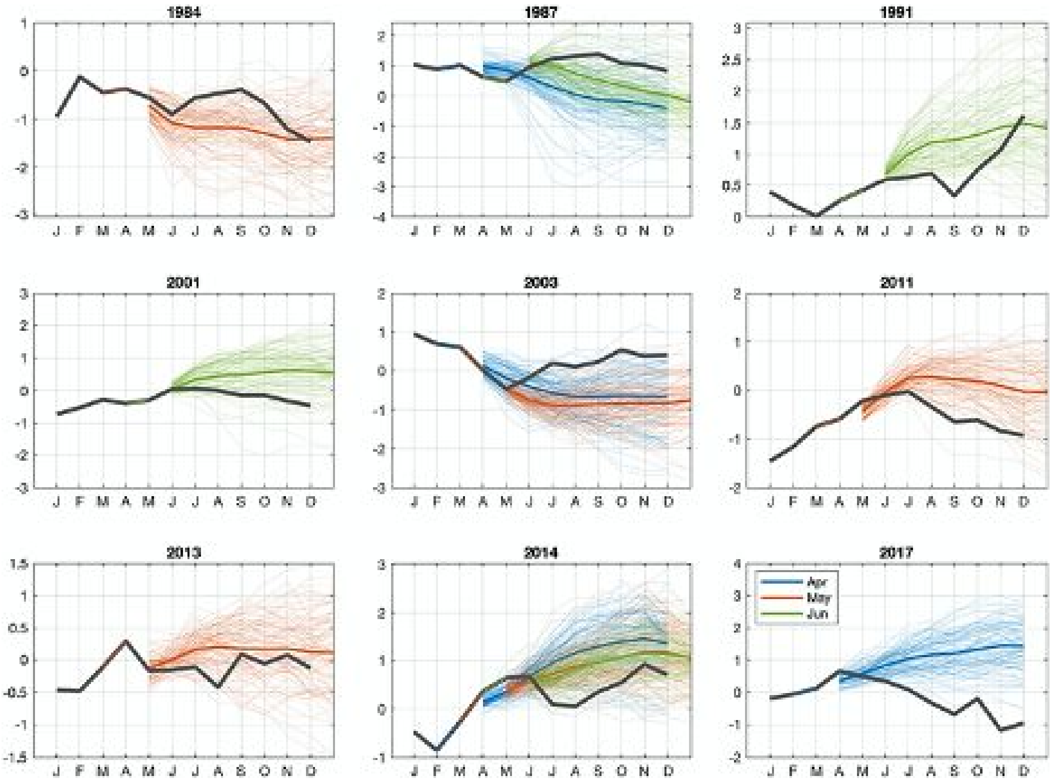

Figure 9: False alarm years (1984, 1987, 1991, 2001, 2003, 2011, 2013, 2014, and 2017) in which the forecast probability of the wrong sign of the 3-month tendency exceeded 80% for April–June starts. The black curves are observed monthly values of the Niño 3.4 index with 1-month prior tendencies highlighted in the same color as the corresponding forecast. The colored curves are forecast values with heavy lines for the North American multimodel ensemble mean and light lines for North American multimodel ensemble members. Note the differing vertical scales. (Tippet et al. 2020)

NOAA Line Office Applications

National Marine Fisheries Service NMME research & development

A team from the NMFS assessed the skill of seasonal sea surface temperature (SST) forecasts in the California Current System (CCS) using output from Global Climate Forecast Systems in the North American Multi-Model Ensemble (NMME), and described mechanisms that underlie SST predictability. The CCS is a biologically productive Eastern Boundary Upwelling System that experiences considerable environmental variability on seasonal and interannual timescales. Given that this variability drives changes in ecologically and economically important living marine resources, predictive skill for regional oceanographic conditions is highly desirable.

A simple persistence forecast provides considerable skill for lead times up to ~4 months, while skill above persistence is mostly confined to forecasts of late winter/spring and derives primarily from predictable evolution of ENSO-related variability. Specifically, anomalously weak (strong) equatorward winds are skillfully forecast during El Niño (La Niña) events, and drive negative (positive) upwelling anomalies and consequently warm (cold) temperature anomalies. This mechanism prevails during moderate to strong ENSO events, while years of ENSO-neutral conditions are not associated with significant forecast skill in the wind or significant skill above persistence in SST. Aa strong latitudinal gradient in predictability within the CCS is found; SST forecast skill is highest off the Washington/Oregon coast and lowest off southern California, consistent with variable wind forcing being the dominant driver of SST predictability. These findings have direct implications for regional downscaling of seasonal forecasts and for short-term management of living marine resources.

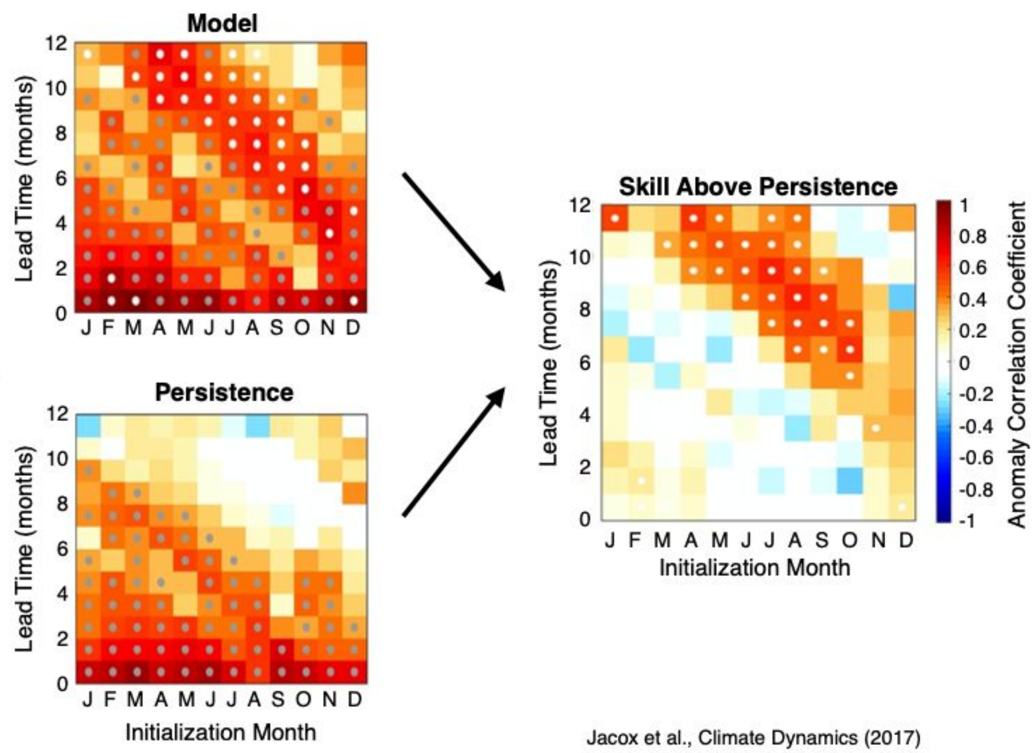

Figure 10: SST skill grids for the NMME ensemble mean (top), persistence (bottom), and the difference (right). Initialization month is on the x-axis, lead time is on the y-axis, and anomaly correlation coefficient is in color. The zero-lead forecast is for the month of initialization (e.g., the lower left corner of each grid represents a forecast of January's monthly mean SST, initialized at the beginning of January). Gray dots indicate significant skill while white dots indicate significant skill above persistence (95% confidence level). (Jacox et al. 2019)

National Ocean Service NMME research & development

The incidence of coastal flooding is rapidly increasing, especially along the US East Coast, as sea levels rise. Prediction of these events are currently limited to weather timescales, but a probabilistic outlook on subseasonal to seasonal timescales is currently under development using NMME predictions. In collaboration with members of the National Ocean Service, University of Miami scientists are developing a coastal flooding prediction model based on multiple linear regression of NMME 850hPa winds and sea level pressure (SLP) with coastal tide gauge records.

The subset of NMME models used in this study, comprising the NCAR-CCSM4, CanCM4i, GEM-NEMO, and CFSv2, are found to represent observed correlations between global U850 and observed non-tidal residual (NTR) data at several stations, including Sewell's Point, VA, Charleston, SC, and San Francisco, CA. Observed SLP-NTR correlations are also reproduced by the models.

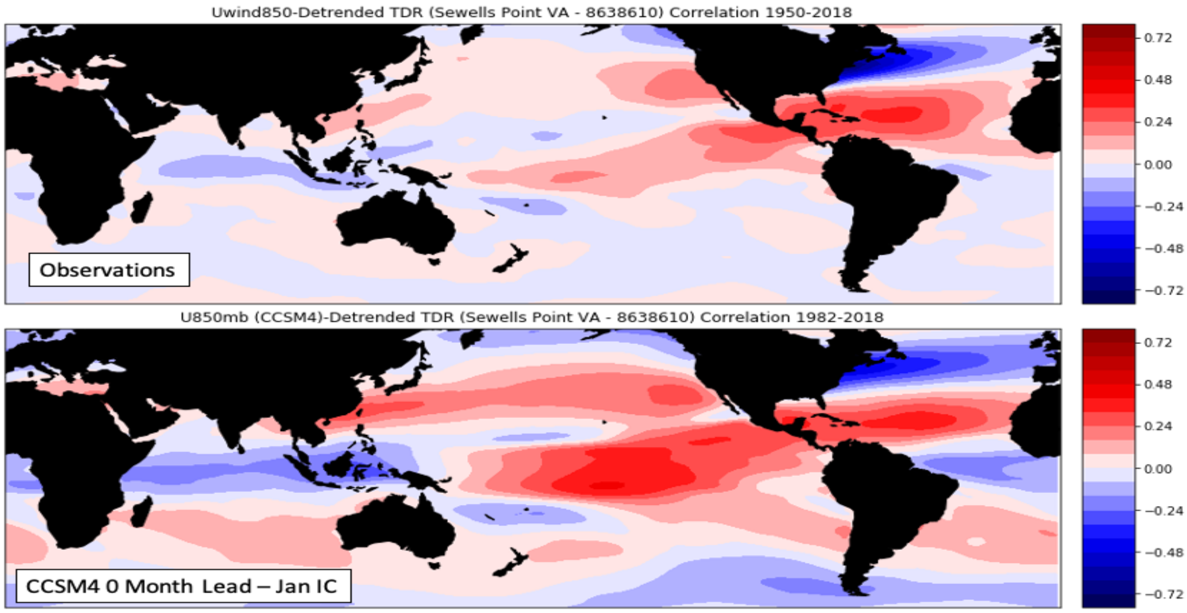

Figure 11: Correlation between 850hPa U wind and non-tidal residual gauge observations at Sewell's Point, VA in observations (top) and CCSM4 0-month lead monthly predictions (bottom).

NMME Research, Development, Application, and Outreach

The primary reference paper for NMME, Kirtman et al. (2014, BAMS), has been cited approximately 390 times per Web of Science, qualifying as a "highly cited paper." The bulk of these citations are in the meteorology/atmospheric science sector, but many are classified as "multi-disciplinary," water resources, and engineering. Google Scholar citations, which include non-peer-reviewed sources, number more than 500.

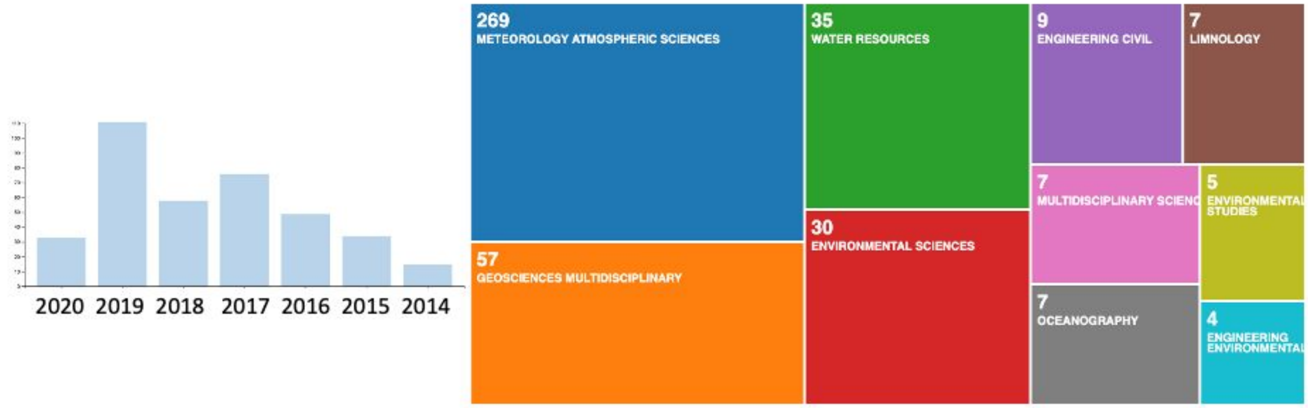

Figure 12: Citations per year (left) and discipline category for publications citing Kirtman et al. 2014 (right). Data from Web of Science.

The CIMAS NMME team queried NMME users via email, asking for information on published and ongoing research, prediction applications, and outreach and communications. The response was substantial and wide-ranging, including US government research and operations, international meteorological organizations, US and international private sector applications, and academia. It is not expected that this survey would be comprehensive, but rather provide some high-level illustrations of the various uses of NMME.

Examples of the use of NMME realtime seasonal predictions by the US government are wide-ranging. In addition to the many NOAA Climate Prediction Center applications (see other sections), Ray Kiess, Senior Climate Scientist for the US Air Force's 14th Weather Squadron, said "the NMME continues to be the primary S2S prediction model used by the USAF's 14th Weather Squadron, the sole AF unit dedicated to climatology support." Kevin Kodama of the NWS Honolulu Forecast Office responded to the query, saying "I lean heavily on the [NMME] forecasts when developing seasonal outlooks for county and state drought meetings as well as fire weather briefings. I also use the graphics for our wet season (Oct-Apr) and dry season (May-Sep) rainfall outlooks. The projected SST anomalies also help illustrate upcoming conditions related to tropical cyclone activity."

NMME seasonal predictions inform many current and developmental forecast systems, including NASA's Hydrological and Forecast Analysis System (NHyFAS) hydrological forecasts. Bering Sea seasonal forecasts, a joint project of the University of Washington, AFSC, PMEL, and ESRL, funded by CPO/MAPP and NMFS/IEA, use NMME climate predictions to drive regional dynamical downscaling. The International Research Institute for Climate and Society (IRI) uses NMME extensively for disease prediction, including Aedes-born disease, malaria, and meningitis, while the University Corporation for Atmospheric Research (UCAR) publishes S2S climate outlooks for watersheds based on NMME.

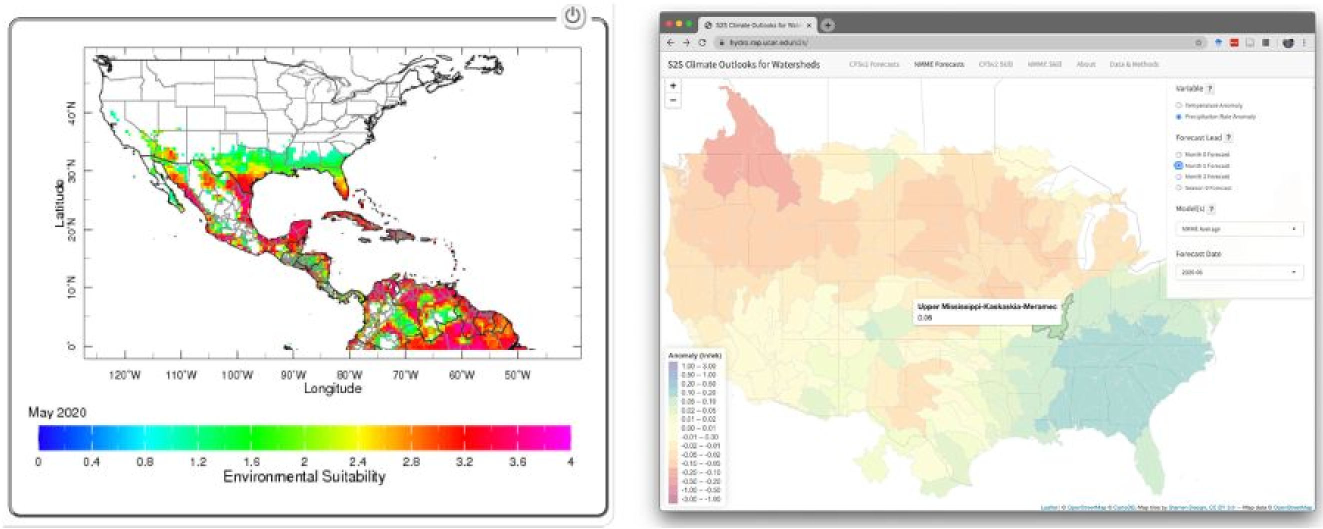

Figure 13: Left: Aedes-borne disease environmental suitability (IRI; https://aedes.iri.columbia.edu/). Right: S2S outlooks for watersheds (UCAR, https://hydro.rap.ucar.edu/s2s/).

NMME partner organizations IRI and NOAA Goddard Fluid Dynamics Laboratory (GFDL) have made substantial contributions to both research and applications. The IRI bases their seasonal forecasting system on NMME, and generates a seasonal climate briefing every month that employs NMME output. As part of the NextGen system, IRI has developed a Python interface for CPT, called PyCPT. Both CPT and PyCPT are being extensively used around the world to generate calibrated NMME forecasts. The IRI has published at least 24 NMME-related peer-reviewed studies. GFDL uses forecast data from one of GFDL's NMME models, FLOR, to generate and provide guidance to CPC and NHC in advance of their seasonal Atlantic Hurricane Outlooks. They regularly use NMME in outreach and communication, submit forecasts to the Arctic sea ice outlook each summer, and contribute to NOAA's seasonal ENSO forecasts. At least 20 publications have resulted directly from GFDL's commitment to the NMME.

Several private sector entities responded to the query. LDC uses NMME data to understand the risks in weather and related impacts on agriculture production, DTU Fishforecasts makes bluefin tuna predictions based on NMME, and others, including Rain & Hail and Prescient Weather, consult the NMME internally for various purposes. Some US and international energy sector corporations rely on NMME-based seasonal outlooks for energy use forecasts.

Many international meteorological services and research centers around the world utilize the NMME. Kobi Mosquera of the Instituto Geofísico del Perú commented that "NMME products are fundamental for the prevention of the El Niño impacts in Perú." Ben Noll of New Zealand's NIWA said "We consider the NMME along with 11 other climate models (ECMWF, UKMET, etc) to create our outlooks. An in-house validation exercise that we have been compiling since 2014 shows the NMME is the best long-term performer for our region for temperature. For rainfall, it is tied for 4th best."

The NMME research community is engaged and active. The first NMME/SubX Science Meeting was held in College Park, MD, in September 2017, with over 100 attendees and approximately 80 abstracts. A second meeting was planned but is on hold due to current events. The NMME team has an ongoing monthly research and operations telecon series. Topics range from verification of operational forecasts to model diagnostics to applications development.

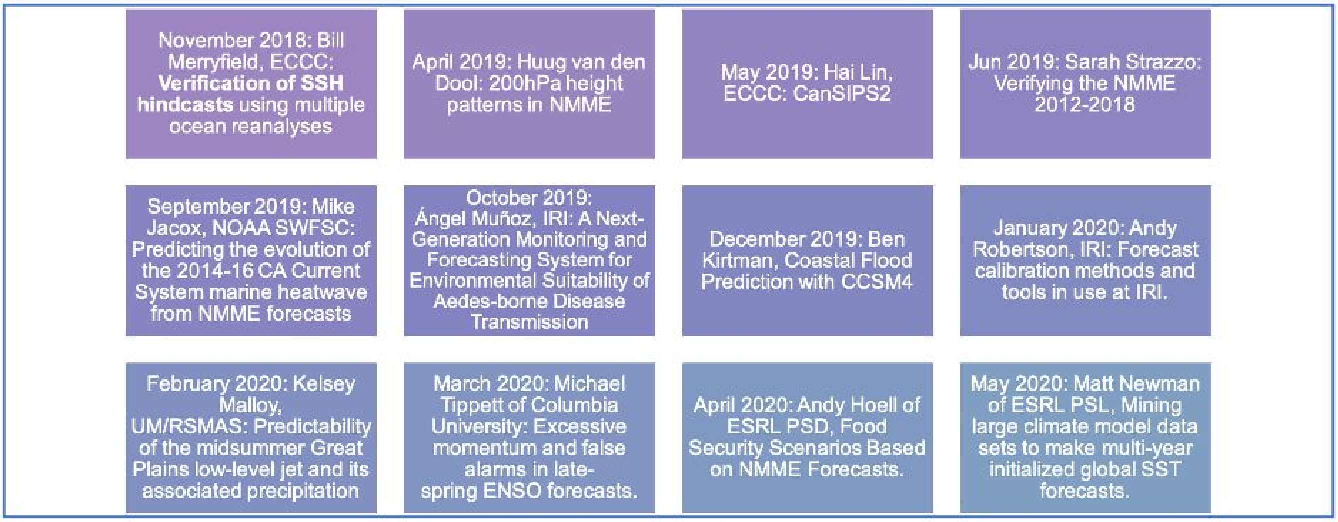

Figure 14: Recent NMME telecons.

Data distribution

IRI Data Library

The IRI data library serves hindcasts and realtime monthly-mean data. It is updated each month as model forecasts are released.

	Unique visitors	Number of visits	Pages	Hits	Bandwidth
2019	14,318	26,044	12,035,292	12,297,025	12146 GB
2018	12,693	21,872	5,102,053	5,367,875	4389.59 GB
2017	17,948	22,259	5,070,317	5,220,171	5930.93 GB
2016	6,296	11,077	5,970,776	6,007,297	4398.27 GB

Table 1 - Statistics about data access via the IRI data library.

Countries			Unique visitors	Number of visits	Pages	Hits	Bandwidth
	Brazil	br	6,396 (44.7%)	11,634 (44.7%)	5,432,967	5,434,774	316.63 GB
	United States	us	3,890 (27.2%)	7,077 (27.2%)	3,210,510	3,402,232	8944.21 GB
?	Unknown	unknown	2,223 (15.5%)	4,044 (15.5%)	1,878,730	1,899,080	1862.91 GB
	South Korea	kr	1,264 (8.8%)	2,298 (8.8%)	1,073,393	1,073,739	256.73 GB
	Italy	it	199 (1.4%)	362 (1.4%)	168,900	169,505	206.82 GB
	Greece	gr	113 (0.8%)	205 (0.8%)	95,351	96,142	9.89 GB
	Denmark	dk	46 (0.3%)	85 (0.3%)	39,462	39,541	140.07 GB
	China	cn	39 (0.3%)	71 (0.3%)	31,972	34,138	408.38 GB
	New Zealand	nz	16 (0.1%)	29 (0.1%)	13,657	13,837	493.57 GB
	France	fr	14 (0.1%)	25 (0.1%)	11,069	12,078	3.81 GB
	Iran	ir	14 (0.1%)	25 (0.1%)	10,097	13,110	44.43 GB
	Spain	es	10 (0.1%)	19 (0.1%)	8,203	9,446	25.83 GB
	Indonesia	id	9 (0.1%)	16 (0.1%)	6,527	8,646	18.93 GB
	European country	eu	9 (0.1%)	17 (0.1%)	6,000	9,488	691.93 MB
	Peru	pe	7 (0.0%)	13 (0.0%)	5,349	6,413	15.29 GB
	Others		69	124	43105	74856	398.53 GB

Figure 15 - Statistics about web hits on IRI's data library servers, including breakdown into country of origin as mapped by domain.

Daily data at NCEI

The daily resolution of monthly forecasts are available at NCEI for a subset of models. This represents a much higher temporal resolution than the operational datastream, potentially resulting in novel research users.

NMME

Model	Grid/Scale	Period of Record	Model Cycle	Output Timestep	Data Access Links
CCSM4	Global, 1°	01Jan2011 - Present	1/day	Daily	HTTPS TDS ERDDAP
CFSV2-2011	Global, 1°	01Jan2011 - Present	1/day	6-hourly	HTTPS TDS ERDDAP
CanCM3	Global, 1°	01Jan2011 - Present	1/day	Daily	HTTPS TDS
CanCM4	Global, 1°	01Jan2011 - Present	1/day	Daily	HTTPS TDS
GEOS-5	Global, 1°	01Jan2011 - Present	1/day	Daily	HTTPS TDS
GEM/NEMO	Global, 1°	01Nov2019 - Present	1/day	Daily	HTTPS TDS

Table 2 - Listing of model characteristics and download methods for those stored at NCEI

References

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