IRI’s new Forecasting system and Introduction of PyCPT tools For Regional Forecasting

Nachiketa Acharya
nachiketa@iri.columbia.edu
IRI began routinely providing calibrated user-oriented seasonal climate forecasts since the late 1990s based on a 2-tiered multi-model ensemble dynamical prediction system.
### Advances in Real-time IRI’s Probabilistic Seasonal Forecasting

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<tr>
<th></th>
<th>Old IRI forecast</th>
<th>New IRI forecast</th>
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<tr>
<td><strong>GCM used (Predictors)</strong></td>
<td>2-tier (uncoupled) ECHAM 4.5, CCM3.6, COLA, GFDL, CFSv2</td>
<td>1-tier (coupled) NMME models</td>
</tr>
<tr>
<td><strong>Observed data used (Predictand)</strong></td>
<td>Precip: CMAP Temp: CAMS</td>
<td>Precip: CPC-CMAP Temp: GCHN updated</td>
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<td>2.5 degree grid</td>
<td>1 degree grid</td>
</tr>
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<td><strong>Calibration method</strong></td>
<td>• Pattern-based correction of ensemble means - PC Regression based on tropical precip EOFs - Spread estimate from historical forecasts with forecast SST • Equal weighting of corrected models • Parametric forecast probabilities (T - Gaussian, P - transformed Gaussian)</td>
<td>Extended Logistic Regression (Non-Gaussian) at grid point level.</td>
</tr>
<tr>
<td><strong>Dry mask</strong></td>
<td>Forecast are only produced when the climatology being more than 30 mm precipitation in any given season</td>
<td>Forecast are only produced when the at least 10% of the training sample are non-zero.</td>
</tr>
<tr>
<td><strong>Making Flexible forecast</strong></td>
<td>Used mean and SD of the forecast, then use parametric approach</td>
<td>Integrated part of the ELR method</td>
</tr>
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</table>

New system of seasonal forecast has been operational from April, 2017.
NMME datasets

The North American Multi-Model Ensemble (NMME) is a multi-model, seasonal forecasting system consisting of coupled models from North American modeling centers. This data contains global, 12-month forecasts of 13 key variables.

The NMME contributors are NOAA’s National Centers for Environmental Prediction (NCEP), NOAA’s Geophysical Fluid Dynamics Laboratory (GFDL), the National Center for Atmospheric Research (NCAR), NASA’s Goddard Space Flight Center (GSFC), and Canada’s Centre for Climate Modeling and Analysis (CCCma). The models include The Community Climate System Model version 4 (CCSM4), the Climate Forecast Model version 2 (CFSv2:2011), the Canadian Coupled Model versions 3 and 4 (CanCM3, CanCM4), the Global Environmental Multiscale/Nucleus for European Modeling of the Ocean (GEM/NEMO), and the Goddard Earth Observing System Model version 3 (GEOS-3).

NMME data is daily or 6-hourly with a 1° by 1° spatial resolution. Most NMME datasets have 10 realizations for each variable. Variables include the following: by model and variable name (“N/A” denotes variables that are not available).

<table>
<thead>
<tr>
<th>Variable</th>
<th>CCSM4</th>
<th>CESM1</th>
<th>CPSv2-2011</th>
<th>CanCM3</th>
<th>CanCM4</th>
<th>FIOOBL 01</th>
<th>GEOS-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation rate</td>
<td>pr</td>
<td>pr</td>
<td>pr</td>
<td>pr</td>
<td>pr</td>
<td>pr</td>
<td>pr</td>
</tr>
<tr>
<td>Daily Maximum</td>
<td>Tasmx</td>
<td>Tasmx</td>
<td>Tasmx</td>
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<td>Tasmx</td>
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<tr>
<td>Surface Air</td>
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<tr>
<td>Temperature</td>
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<tr>
<td>Daily Minimum</td>
<td>Tasmx</td>
<td>Tasmx</td>
<td>Tasmx</td>
<td>Tasmx</td>
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<td>Tasmx</td>
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<tr>
<td>Surface Air</td>
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<tr>
<td>Temperature</td>
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</tr>
<tr>
<td>Zonal surface</td>
<td>STX</td>
<td>STX</td>
<td>STX</td>
<td>STX</td>
<td>STX</td>
<td>N/A</td>
<td>STX</td>
</tr>
</tbody>
</table>

Flow chart of new forecast methodology

NMME model 1
- Observed dataset
- Calibration

NMME model 2
- Observed dataset
- Calibration

NMME model 9
- Observed dataset
- Calibration

MME + Spatial Smoothing

Final Forecast
IRI’s New Calibration Method

**Logistic Regression**
Logistic regression is well known and widely used as a probability forecast method.

\[
\ln \left( \frac{p}{1-p} \right) = f(x)
\]

Where \( p \) is the (cumulative) probability of not exceeding the quantile \( q \)

\[
p = Pr\{V \leq q\}
\]

- **Logistic Regression**
  - Logistic regression (LR), a nonlinear regression method where probability itself can be considered as the predictand rather than a measurable physical quantity, is an alternative model for Gaussian approach.
  - Logistic Regression is a Machine Learning algorithm which is used for the classification problems, it is a predictive analysis algorithm and based on the concept of probability.
  - Unlike linear regression, no need to fulfill assumptions of linearity, normality and homoscedasticity.
Modification of LR Method

\[
\ln \left(\frac{p}{1-p}\right) = f(x) + g(q) \quad \text{Where} \quad f(x) = b_0 + b_1\bar{x}_{\text{ens}} \\
g(q) = b_2q
\]

Limitations:

- Probabilities of different categories estimated by fitting separate equations for selected predictand quantile thresholds \(q\), yielding a collection of threshold probabilities rather than full forecast probability distributions.
- However, the most problematic consequence of separate equations for different predictand thresholds is that forecasts derived from the different equations are not constrained to be mutually consistent.

Extending Logistic Regression:

- Extending LR (ELR) by including the predictand threshold as an additional predictor (link function \(g\) itself function of the quantile \(q\)), allows the derivation of full predictive distributions to avoid the problem of potentially incoherent forecast probabilities (Wilks, 2009).
- Cumulative probability for a smaller predictand threshold cannot be larger than the probability for a larger threshold.

Spatial Smoothing of final forecast: why & how?

Smoothing with Kernel function (Gaussian) with a rectangle of size 9 by 9.
Hindcast Skill Map (1982-2010)


Seasonal Forecasts

Seasonal forecasts of temperature and precipitation.

This map shows the IRI seasonal forecasts in both the traditional tercile format as well as a flexible format that enables any quantile of the forecast distribution to be selected. Please see the main IRI Seasonal Forecasts page for detailed information about the NMME-based forecast system. Additional tabs on this page display maps of observed climatological percentile values by season, as well as the forecasts and climatologies of individual NMME models. The Older Forecasts tab contains discontinued products.

Hindcast Skill Map

**Precipitation Seasonal Hindcast Skill**

Seasonal skill score based on the historical performance of each calibrated NMME model and their multimodel ensemble (1982-2010).

**Temperature Seasonal Hindcast Skill**

Seasonal skill score based on the historical performance of each calibrated NMME model and their multimodel ensemble (1982-2010).

Rank probability Skill Score:

\[
RPSS = 1 - \frac{RPS_{\text{forecast}}}{RPS_{\text{reference}}}
\]

\[
RPS = \sum_{\text{cat}=1}^{\text{Ncat}} \left( P_{\text{cum}}^{F(\text{cat})} - P_{\text{cum}}^{O(\text{cat})} \right)^2
\]

Skill scores display maps of a season when and when (based on months of the year and for which seasonal skill scores) the hindcast seasonal forecasts have the potential to provide useful information, based on hindcasting.

Skill scores definitions:

- **RPSS**: Rank Probability Skill Score (RPS); Epstein (1969) Murphy (1989, 1977), Weigel et al. (2007). RPSS are used to quantify the error in which the calibrated tercile category predictions are improved compared to climatological frequencies. RPSS values tend to be small, even for skillful forecasts. The approximate relationship between RPSS and correlation being such that a RPSS value of 0.1 corresponds to a correlation of about 0.4 (Tippett et al. 2010).

References:


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DJF-2020 forecast


Flexible forecast format

Overview

Starting in April 2017, the Flexible precipitation seasonal forecast product is based on a re-calibration of model output from the U.S. National Oceanographic, and Atmospheric Administration (NOAA) North American Multi-Model Ensemble (NAME). This includes the ensemble seasonal prediction systems of NOAA’s National Centers for Environmental Prediction, Environmental and Climate Change Canada, NOAA’s Physical Fluid Dynamics Laboratory, NASA, NCAR and CSIRO’s University of Miami. The output from each NAME model is re-calibrated prior to multi-model ensemble to form reliable probability forecasts. The forecasts are now presented on a 1-degree latitude-longitude grid.

Discussion

April 2017. Climate Forecast Discussion for May-July through Aug-Oct

The SSI forecast shows El Niño development by Jul-Sep, reaching moderate strength by the fourth and final running forecast season of Aug-Oct. A positive IOD event exists throughout the four forecast seasons, and becomes somewhat stronger by the fourth season. The tropical Atlantic remains near to slightly above average SST throughout all four seasons.

Slightly enhanced probabilities for below-normal precipitation are predicted in northern South America during May-Jul, progressively strengthening and expanding to include more of northern South America by Jul-Sep, and persisting into Aug-Oct. A similar scenario of strengthening chances for below-normal is predicted for Indonesia throughout Jun-Aug, and for eastern Australia over the course of all four forecast periods. By Aug-Oct season, the region leaning toward below-normal in eastern Australia expands northward to join Indonesia.

A tendency toward above-normal temperature is predicted in a general manner over much of the globe for all four forecast seasons, with a few exceptions such as a small region in west-central North America, some of the U.S. Canadian Arctic, during the first two seasons. Probabilities for abovenormal are strongest in Greenland and northeastern Canada during the second, third and fourth seasons, and in varying parts of Europe and South America during the course of the four seasons.

Precipitation Flexible Seasonal Forecast

This seasonal forecasting system consists of probabilistic precipitation seasonal forecasts based on the full estimate of the probability distribution. Please refer to our licensing agreement for permission to use any IRI forecast material. Probabilistic seasonal forecasts from multi-model ensembles through the use of statistical reconciliation, based on the historical performance of those models, provide reliable information to a wide range of climate risk and decision-making communities, as well as the forecast community.

The flexibility of the full probability distributions allows to deliver interactive maps and point-wise distributions that became relevant to user-defined needs.

The default map shows globally the seasonal precipitation forecast probability (colors between 0 and 1) of exceeding the 50th percentile of the distribution from historical 1980-2010 climatology. The forecast shown is the latest forecast made (e.g. Dec 2017) for the next season to come (e.g. Jan-Mar 2018). Four different seasons are forecasted and it is also possible to consult forecasts made previously. The forecasts are directly compared with the climate unadjusted seasonal model as probabilities of exceeding (or non-exceeding) of every 5th percentile of the climatological distribution. The specific quantile (in steps of 5 percentile points) can then be selected. The user can also specify a quantitative value in physical units (here seasonal total precipitation in mm) for probability of exceeding or non-exceeding. The final probability maps are smoothed spatially with a bell point Gaussian smoother.

Clicking on a point on the map will show the local probability of exceeding and probability distribution of the forecast (given) together with the climatological distribution (black).

The distribution of seasonal rainfall may often be approximated by a normal distribution, especially when considering only years when it actually rained. But there can be a significant number of years in the sample when rainfall is 0. This translates to situations where the probability of rainfall to be just above 0 is less than 10%, which are represented by the vertical lines at 0 mm in the distribution graph.

Colors Scale

Color scales are colors indicating that the distribution of the forecast tends towards drier (shades of brown) or wetter (shades of blue) conditions than normal (mean). Older Forecasts

Older forecasts can be found in the last tabbed entry of this section. Forecast made from February 2017 use the same SSI method only the presentation of the local pie chart was done, and the local yel was not shown. Forecasts made from July 2012 to March 2017 are discontinued and used a different methodology to obtain the full distribution of the forecasts.

Change in temperature, precipitation, and other climate elements can be inferred from the temperature and precipitation related to the forecast.
IRI’s Experimental Precipitation Sub-seasonal Forecasts


**Subseasonal Forecasts**

Subseasonal forecasts of precipitation and temperature.

This section is dedicated to subseasonal forecasts, i.e., that bridge the gap between medium range weather forecasts (up to 10 days) and seasonal climate predictions (above 1 month). They are issued at different frequencies (from daily to once or twice a week) and forecasting values with lead times from 1 to about 40 days, depending on the Global Forecasting Center (GFS). The availability of forecast products in the subseasonal-to-seasonal time range offers an unprecedented opportunity to develop intra-seasonal forecast information that other forecasts can't, in association with increased lead time compared to medium range weather forecasts, and with higher temporal resolution than seasonal forecasts that give an overview of an upcoming season (3 months). For instance, subseasonal forecasts may allow delivering relevant information about key climate characteristics such as the timing of the onset of a rainy season for agriculture, the risk of extreme rainfall events or heat waves in regards to public health.

At present, these maproom includes experimental subseasonal forecasts of weekly and biweekly precipitation and temperature terciles and above median) based on the multi-model ensemble of individual forecasts issued every Saturdays through the SubX real-time database and every Thursday through the delayed S2S database.

### SubX Forecasts

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<tr>
<th>Precipitation Median Probability Forecast</th>
<th>Temperature Weekly Probability Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibrated Subseasonal Two-category precipitation real-time forecasts</td>
<td>Calibrated subseasonal tercile categories temperature forecasts</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Precipitation Biweekly Probability Forecast</th>
<th>Temperature Weekly Probability Forecast (LELR)</th>
<th>Precipitation Flexible Biweekly Forecast</th>
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<tbody>
<tr>
<td>Calibrated Subseasonal Two-category temperature precipitation forecasts</td>
<td>Subseasonal tercile categories temperature forecasts with pattern-based calibration</td>
<td>This subseasonal forecasting system consists of probabilistic precipitation forecasts based on the full estimate of the probability distribution.</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Temperature Biweekly Probability Forecast</th>
<th>Temperature Flexible Biweekly Forecast</th>
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<tbody>
<tr>
<td>Calibrated Subseasonal Tercile categories precipitation real-time forecasts</td>
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</table>
Next Generation (NextGen) Regional Forecasting

The use of an objective seasonal forecast procedure which is defined as a traceable, reproducible, and well-documented set of steps that allows the quantification of forecast quality, are preferred and recommended by the World Meteorological Organization in their recent seasonal forecast guidance.

The Next Generation (NextGen) seasonal forecast system is a systematic and **objective approach**. It enables calibration, combination, and verification of objective climate forecasts from the state-of-the-art general circulation models (GCM) of the North American Multi-Model Ensemble project.
Climate Predictability Tool

CPT is designed to produce statistical forecasts of seasonal climate using either the output from a GCM, or empirical predictors, of the outputs from GCM.

- Developed and maintain by Dr. Simon Mason.
- CPT available for Windows 95+ and Linux Batch version.

Features:
- Model training
- Validation
- Verification
- Flexible forecasts
Climate Predictability Tool: Approaches

<table>
<thead>
<tr>
<th>Predictor (X)</th>
<th>Predictand (Y)</th>
<th>Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Empirical</strong></td>
<td></td>
<td></td>
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<tr>
<td>Observations</td>
<td>Observations</td>
<td></td>
</tr>
<tr>
<td><strong>Dynamical</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model output</td>
<td>Observations</td>
<td></td>
</tr>
</tbody>
</table>

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NextGen Approach

- Need to run CPT multiple times.
- We need a system which produce skill maps and forecasts for multiple models in a single run.
- Solution: PyCPT
Why PyCPT?

1. In brief: to simplify our life!
2. Automate downloading datasets
3. Automate calibration and skill assessment
4. Automate forecast generation
5. Automate model ensembling
PyCPT is a Python library that provides an interface and extra functionalities to IRI's Climate Predictability Tool (CPT), a widely used research and application Model Output Statistics/Prediction toolbox.
The Climate Predictability Tool (CPT) is a software package for constructing a seasonal climate forecast model, performing model validation, and producing forecasts given updated data. Its design has been tailored for producing seasonal climate forecasts using model output statistics (MOS) corrections to climate model output.

[Image]

[Link]
https://bitbucket.org/py-iri/iri-pycpt/src/master/
PyCPT: Installation

- For Linux users:
  - The user will need to install Anaconda (Python3), the Climate Predictability Tool (batch version) and the Python extension of CPT (PyCPT).

- For Window users:
  - install a Virtual Machine with all needed packages and use PyCPT Ubuntu
  - Any recent (< 2 years) Intel Processor should be able to run a Virtual Machine. The PC should have at least 4GB of RAM installed, but preferably more than 8GB. You should have at least 20GB of free space to install the virtual machine and software.

For details: [https://bitbucket.org/py-iri/iri-pycpt/wiki/Home](https://bitbucket.org/py-iri/iri-pycpt/wiki/Home)
PyCPT: Example plots

Domain

EOF maps

Skill maps
#NextGen Maproom: Example of Meteo Rwanda

http://maproom.meteorwanda.gov.rw/maproom/Climatology/Climate_Forecast/Forecast.html
# NextGen Maproom: Example of Meteo Rwanda

Precipitation Flexible Seasonal NextGen Forecast

NextGen is a systematic general approach for designing, implementing, validating and verifying objective climate forecasts. It involves the identification of decision-relevant variables by the stakeholders, the analysis of these variables' relationship with climate drivers through a combination of observations, regional climate models, and statistical relationships, and the selection of the models and predictors (or models and observational) for those key relevant variables. NextGen helps select the most dynamical models for the region of interest through a process-based evaluation, and automates the generation and verification of tailored multi-model, statistically calibrated predictions at seasonal and sub-seasonal scales.

The system takes advantage of the expertise of forecasters and local scientists at the country's national meteorological service and universities to maximize predictive skill and tailoring of the climate services generated by the process. Rather than focusing on probabilities of above normal, normal, and below normal categories of total rainfall or mean temperature, NextGen also provides probabilities of exceeding (or not) particular thresholds of interest in the decision-making process, thus enabling users to forecast with the same system both mean and extreme values.

The models employed in this forecast are from the suite of the North American Multi-Model Ensemble (NAMM) and the predicted is rainfall from the Climate Hazards Group Infrared Precipitation with Station Data (CHIRPS). The default map shows, for the latest forecast made, the median value of the seasonal rainfall total forecast in the season. Users can use the field menu to express the forecast in different ways, as follows:

- **Rainfall**: most likely seasonal total rainfall
  - *Anomaly*: deviation in mm of the most likely seasonal total rainfall predicted by the hindcast (1982-2009) from the baseline (1961-1990) rainfall
  - *Percent of Median*: deviation in percentages of the most likely seasonal total rainfall from the median of the most likely seasonal total rainfall predicted by the hindcast (1982-2009)
  - *Probability of non-exceeding a Percentile*: forecast probability of seasonal total rainfall to be below/above the historically observed (1982-2009) chosen percentile
  - *Probability of non-exceeding a Precipitation amount*: forecast probability of seasonal total rainfall to be below/above the chosen rainfall amount

The Layers button, shown when mousing over the map, will reveal inactive layers on the map.

Clicking on the map will reveal information about the location clicked, as well as the full forecast distribution at that given location, compared with the historical distribution. Cumulative full distribution of the forecast (red) together with the climatological distribution (blue and black) for the forecast in view on the map shows under *Probability of Exceedance*, as well as the CDF probability distribution under *Probability Distribution*. 
Challenges in producing forecast

- Non-availability of GCMs in real time.
- GCM’s version changes.
- Need update PyCPT scripts.

<table>
<thead>
<tr>
<th>Models</th>
<th>hindcast</th>
<th>forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMC1-CanCM3</td>
<td>1981-2010</td>
<td>Jan2011-current</td>
</tr>
<tr>
<td>CMC2-CanCM4</td>
<td>1981-2010</td>
<td>Jan2011-current</td>
</tr>
<tr>
<td>NCEP-CFSv2</td>
<td>1982-2010</td>
<td>March/Apr 2011-2017</td>
</tr>
<tr>
<td>NCAR-CESM1</td>
<td>1980-2010</td>
<td>July-2016-April-2017</td>
</tr>
<tr>
<td>COLA-RSMAS-CCSM4</td>
<td>1982-2010</td>
<td>2011-current</td>
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<tr>
<td>NASA-GMAO</td>
<td>1981-2010</td>
<td>2011-Jan2018</td>
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<td>NASA-GEOSS2S</td>
<td>Feb 1981-Jan 2017</td>
<td>Nov 2017-current</td>
</tr>
<tr>
<td>GFDL(3)</td>
<td>1982-2010</td>
<td>2011-current</td>
</tr>
</tbody>
</table>
Concluding Remark

- ELR based non-Gaussian calibration method introduced in the real-time seasonal forecast at IRI.
- It is a more robust method compared to other calibration method based on the Gaussian assumption for precipitation.
- For regional forecast, NextGen system is introduced by IRI by the recommendation of WMO.
- PyCPT is the tool for NextGen where CPT can run multiples times in a single run.
- Very easy to use through Jupyter notebook.
- PyCPT keep on updating based on user’s feedback and GCM availability.

Thanks!