Online Tools for Assessing the Climatology and Predictability of Rainfall and Temperature in the Indo-Gangetic Plains Based on Observed Datasets and Seasonal Forecast Models

Working Paper No. 27

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

Andrew W. Robertson
Michael Bell
Rémi Cousin
Ashley Curtis
Shuhua Li

CGIAR

RESEARCH PROGRAM ON
**Climate Change,
Agriculture and
Food Security**

CCAFS

Working Paper

Online Tools for Assessing the Climatology and Predictability of Rainfall and Temperature in the Indo-Gangetic Plains Based on Observed Datasets and Seasonal Forecast Models

Working Paper No. 27

Andrew W. Robertson
Michael Bell
Rémi Cousin
Ashley Curtis
Shuhua Li

DISCLAIMER:

This Working Paper has been prepared as an output for Theme 2 under the CCAFS program and has not been peer reviewed. Any opinions stated herein are those of the author(s) and do not necessarily reflect the policies or opinions of CCAFS.
All images remain the sole property of their source and may not be used for any purpose without written permission of the source.

Abstract

Rainfall in the Northern India-Nepal-Bangladesh region is crucial for farmers, water managers and others in the region. Most precipitation falls predominantly during the south Asian summer monsoon season. The phase of El Niño-Southern Oscillation (ENSO) affects the monsoon as well as winter rainfall in some of the region, but the spring predictability barrier and weakness of ENSO-monsoon relationships lead to relatively low-to-moderate seasonal forecast skill in the region during summer. This report documents a set of tools developed to facilitate the analysis of the mean climate and the predictability of seasonal climate in the region and presents preliminary results for the summer monsoon season. These tools advance the tailoring of historical and forecast climate information for agriculture and increase the accessibility of the information via online map rooms to benefit stakeholders throughout the region.

About the author

Andrew W. Robertson is a research scientist at the International Research Institute for Climate and Society (IRI) at Columbia University. He currently leads IRI's climate group, which works on a number of climate prediction, observation and forecasting projects across the globe. His current work is focused on bringing climate information into regional projects that seek to demonstrate the value of climate risk management through targeted research, tool development and training and outreach. Contact: awr@iri.columbia.edu

Michael Bell is a senior staff associate at IRI. His research interests include examining rainfall variability in West Africa, and, more generally, the contributions of weather variability to climate. Contact: mb@iri.columbia.edu

Rémi Cousin is a staff associate at IRI. He works as part of the IRI Data Library team to develop new functionalities and enable climate information communication and dissemination to end users. Contact: remic@iri.columbia.edu

Ashley Curtis is a staff associate at IRI. She coordinates the Climate Program and contributes to research, education, and outreach efforts. In addition, she helps staff the International Federation of the Red Cross/Red Crescent Help Desk at IRI, contextualizing forecasts for disaster preparedness. Contact: acrutis@iri.columbia.edu

Shuhua Li is a senior staff associate at IRI. His research interests include one- versus two-tiered climate models, forecast verification and climate extremes. He also helps produce IRI's monthly seasonal forecasts. Contact: shuhua@iri.columbia.edu

Contents

Introduction

One of the goals of the Climate Change, Agriculture and Food Security (CCAFS) program is developing adaptive management in response to intraseasonal-to-interannual climate information through community-level participatory action research on climate risk management. The CCAFS project is preparing to select among a set of candidate sites at benchmark locations in India (Punjab or Haryana, and Bihar), Nepal and coastal Bangladesh (see map in figure 1). An assessment of seasonal predictability is needed at these locations to assess feasibility and inform the design of actionable seasonal climate information for participating rural communities.

Rainfall over the Northern India-Nepal-Bangladesh region derives predominantly from the south Asian summer monsoon (SASM) during the months of June to September and secondarily through wintertime mid-latitude "western disturbances" over northern India and Nepal. Tropical cyclones in the transition seasons occasionally impact

Figure 1. Location of study outlined in the black box

Bangladesh as well. Temperatures follow an expected seasonal progression while being strongly impacted by the monsoonal rainfall. They tend to peak during the early summer before monsoon onset before lowering due to decreased incident solar radiation because of monsoonal cloud cover and evaporation of monsoon rains. Mid-latitude cold air outbreaks in the winter half of the year and summer heat waves associated with monsoon breaks can have significant agricultural impacts.

ENSO exerts a long-established yet fickle impact on the SASM (Gadgil, 2003, Gadgil et al., 2011) as well as on the wintertime Northeast monsoon (Yadav, 2011) and winter rainfall in the western Himalayas (Yadav et al. 2009). However, the El Niño-Southern Oscillation (ENSO) spring predictability barrier together with the weakness and apparent non-stationarity of ENSO-monsoon rainfall relationships at regional spatial scales conspire to produce generally low-to-moderate forecast skill in modern global climate model (GCM)-based seasonal forecasts (Kulkarni et al., 2011). Certain daily characteristics of seasonal rainfall of relevance to agriculture, including the

number of dry days during the monsoon season and even the onset date of the monsoon, have been shown to be sometimes more seasonally predictable than the seasonal total of rainfall itself (Moron et al., 2006; Robertson et al., 2009).

This report documents a set of web-based tools that has been developed to facilitate the analysis of the mean climate and the predictability of seasonal climate as well as some preliminary results for the summer monsoon season.

Datasets

Observed Data

Besides the necessity of access to historical records of the output of GCM forecast systems, tailored daily rainfall quantities forecasts require long data records of daily observed rainfall both to develop and test GCM regression tailored forecast systems. In the following, we make use of the APHRODITE daily rainfall dataset (1951–2007), which is a gauge-based gridded daily dataset compiled in Japan at a spatial resolution of 0.25 degree and 0.5 degree (Xie et al 2007). The dataset is based on World Meteorological Organization (WMO) Global Telecommunication System data, pre-compiled datasets as well as a new compilation of station data that includes data form Bangladesh, India and Nepal.

Over India, the India Meteorological 1 degree daily temperature dataset (Srivastava et al., 2008) is used for 1 Jan 1969 to 31 Dec 2005; it is produced from station observations over Northern India and interpolated to 1 degree grids (66.5E to 100.5E; 6.5N to 37.5N).

Over Bangladesh and Nepal, WMO Global Summary of the Day station data 1979-2011 is used. The CRU dataset (Mitchell et al., 2005) from the Climate Research Unit, University of East Anglia, provides mean monthly surface data (1901-2009) over global land areas, excluding Antarctica, interpolated from station data to 0.5 degree lat/lon for a range of variables. It is used for assessing General Circulation Model (GCM) seasonal forecast performance. The NASA POWER daily temperature data (1 Jan 1982 to 30 Sep 2012) is based upon reanalysis from the NASA GMAO GEOS-4 assimilation system (Bloom et al., 2005), available at 0.5 degree grids in South Asia (60E to 98E; 6N to 39N), and is used here for data comparison.

General Circulation Model Data

Extensive sets of GCM retrospective seasonal forecasts have recently been developed at IRI using multiple GCMs. These have been archived in the IRI Data Library (IRIDL), where similar sets of seasonal retrospectives from the National Oceanic and Atmospheric Administration's NCEP CFS models have also been archived. In all, hindcasts from about eight GCMs are available (about half of which are coupled atmosphere-ocean models) for the period 1982–present. In the second phase of tool

development, a new database of GCM retrospective forecasts was used, from the U.S. National Multi-model Ensemble (NMME) project. The models used are state-of-art coupled ocean-atmosphere GCMs from the NCEP CFS v2, NASA GMAO, GFDL CM2p1 and COLA RSMAS CCSM3. Seasonal forecasts from these models are publicly available online in the IRI Data Library at http://iridl.ldeo.columbia.edu/SOURCES/.Models/.NMME/, retrospectively for the period 1982–present, as well as in real time.
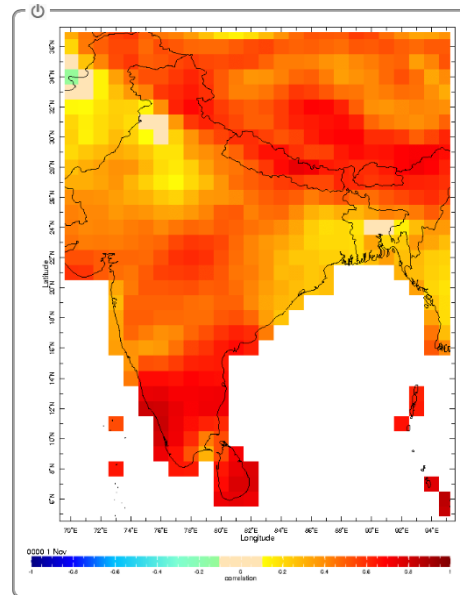
Tool Development

The following tools have been developed for the CCAFS-Asia region and can be accessed online at http://iridl.ldeo.columbia.edu/maproom/Agriculture/index.html:

1. *Historical temperature and precipitation map room:* this map room allows a user to easily calculate and visualize historical statistics of daily precipitation and temperature for a chosen calendar season of interest across Nepal, Bangladesh and Northern India. Some examples of the statistics for rainfall include the historical probability of getting less than a specified number of rain days within a growing season and the historical risk of dry spells (of user-chosen durations) within a critical crop stage. Statistics for temperature include average minimum or maximum daily temperature over the season, heating degrees days (summations of negative differences between the mean daily temperature and user-defined reference base temperature during the season), and the number of cold and hot days relative to a user-defined threshold. The mean temperature is defined as the average of the minimum and the maximum. An additional version of the maproom is available for Northern India based on IMD data, for data comparison purposes (note that this dataset is not available outside of India).

2. *Probabilistic ENSO-phase composites of seasonal-average rainfall anomalies:* This map room allows the historical impact of El Niño and La Niña to be quickly assessed for Nepal, Bangladesh and Northern India, in terms of three characteristics of precipitation. They are (a) the historical probability of above-normal, near-normal and below-normal tercile-category seasonal precipitation conditional upon ENSO state; (b) the historical mean of the seasonal frequency of daily precipitation above/below a selected threshold conditional upon ENSO state; (c) the historical seasonal mean daily precipitation intensity (above a selected daily precipitation threshold) conditional upon ENSO state.

3. *Probabilistic ENSO-phase composites of temperature anomalies*: This maproom allows the historical impact of El Niño and La Niña on temperature to be quickly assessed. Three different products are available: (a) seasonal average temperature, for daily average, daily minimum and maximum temperature (T_{avg}, T_{min}, T_{max}), for (a) South Asia from the GSOD station dataset, and (b) India for the IMD gridded dataset; (c) the frequency of days

with T_{avg}, T_{min}, T_{max} above/below a chosen temperature threshold from the GSOD. In each case the maps show the historical probability of getting the below-normal or above-normal tercile category of temperature, given a particular phase of ENSO. The maproom is applicable to any season (i.e. set of consecutive calendar months) of choice, such as for a cropping season. If the ENSO situation and forecast, for example updated monthly from the CPC/IRI ENSO Update indicates high likelihood of a La Nina or El Nino event persisting, these map rooms could be used to inform crop choice.

4. Anomaly correlation "skill" maps of precipitation and temperature from individual GCMs: A set of maprooms was developed to calculate and display the anomaly correlation skill of the individual NMME models for precipitation and temperature for any chosen season. The GCM hindcasts were interpolated spatially onto the 0.5-degree grid of the APHRODITE data for precipitation, and CRU TS3p1 for temperature. Maps are shown for 3-month averages at 1-month lead, thus for example, for the July–September season for forecasts initialized on June 1. Figure 2 shows the Dec–Feb temperature skill of the CFSv2

initialized on Nov 1, for hindcasts for 1982-2011.

forecasts made on Nov 1, of each year 1982–2011. This map shows very high skill levels over southern India and the Himalayas, while skills are low over northern India and Bangladesh.

5. Experimental downscaled forecast maprooms: New maprooms for experimental downscaled seasonal forecasts were built for APHRODITE seasonal precipitation total and seasonal mean CRU TS3p1 temperature. This product is based on the ECHAM4.5 atmospheric GCM's response to statistical forecasts of sea surface temperature (available at http://iridl.ldeo.columbia.edu/SOURCES/.IRI/.FD/.ECHAM4p5/.Forecast/.ca_sst/). The maprooms downscale the GCM's simulations of precipitation and near-surface temperature using the IRI Climate Predictability Tool (CPT; available at http://iri.columbia.edu/climate/tools/cpt). The maprooms provide the downscaled real-time forecast, along with anomaly correlation skill maps.

Clicking a location on the map brings up a time series of past forecast performance, as well as the real-time forecast presented as a probability of exceedance. Figure 3 shows an example of the maproom output for Jan–Mar 2013 temperature (T_{avg}) forecast made from a GCM initialized on 1 Dec 2012. A point over Nepal was selected in the bottom panels. In this case, the ENSO condition is neutral, and the forecast anomaly is very weakly positive. This is reflected in the forecast probabilities of exceedance (bottom left panel, red) being very close to the historical distribution (blue). The observations at this point (bottom right panel, blue) show a warming trend since about 1990 that is not reflected in the model hindcasts, which may indicate a deficiency of the latter.
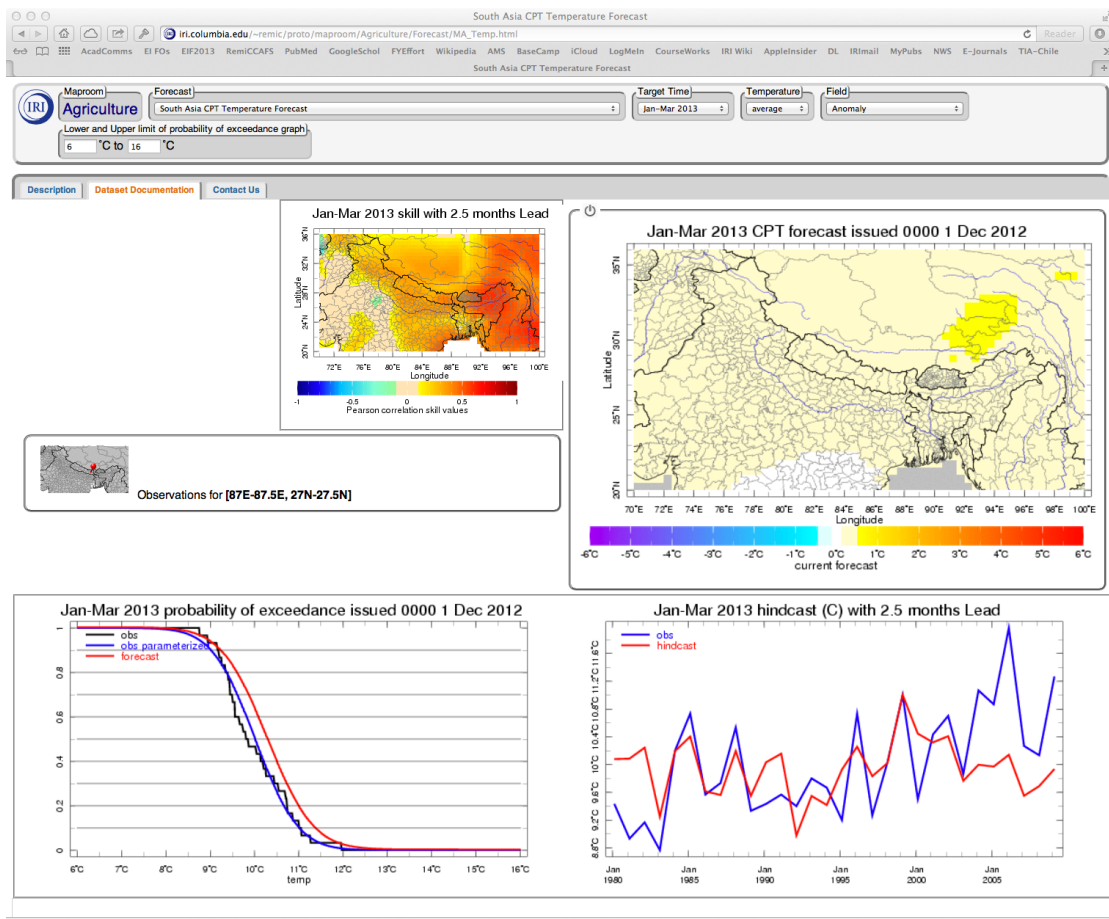

Figure 3. Example of the downscaled temperature forecast maproom.

In addition to these project-specific products, a recently developed Verification Portal is available on the IRIDL (http://iri.columbia.edu/climate/forecast/verification) that documents the skill of the multi-model IRI Net Assessment seasonal forecasts of seasonal-average precipitation and temperature for the period 2001–2011.

Results

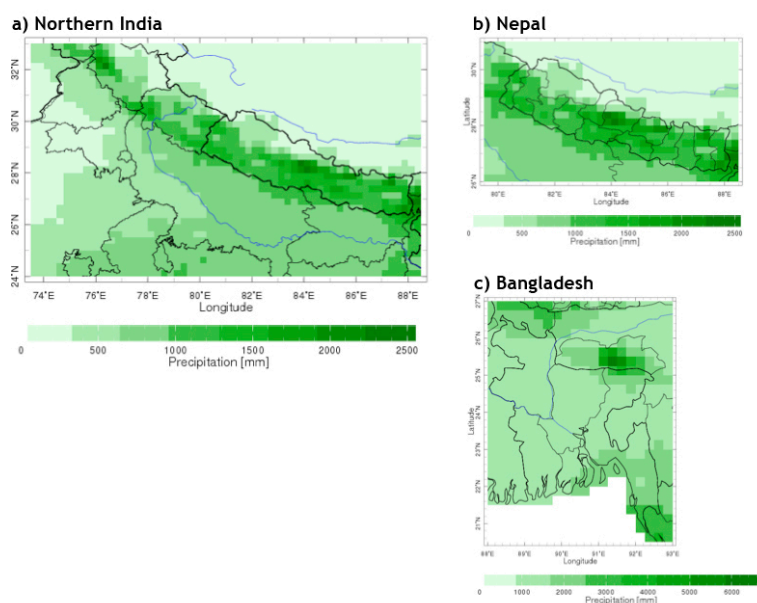## Mean Precipitation Climatology

Figure 4. JJAS mean seasonal total precipitation climatology (1951-2007) from the 0.25-degree APHRODITE dataset. Units in millimeters.

An example of the historical precipitation map room is illustrated in figure 4. It shows the June–September (JJAS) mean seasonal total precipitation climatology (1951–2007) for the three target regions. A strip of higher rainfall extends along the Himalayan escarpment over Nepal while seasonal rainfall totals over Bangladesh are largest. This map room enables mean historical amounts of rainfall to be calculated and displayed for an arbitrary seasonal window at daily resolution. It also allows various spell statistics of daily rainfall to be calculated in place of the seasonal total as well as exceedance probabilities—for example the ability to compute the probability of exceeding two dry spells of a week or longer within the specified seasonal window.

Temperature Dataset Comparison

As an example of candidate sites at benchmark locations in India, a specific grid box (near 26.5N, 80.5E) in Northern India has been chosen in order to compare interannual variability of temperature mean, maximum, and minimum, based on CRU, IMD and NASA data sets (figure 5). The time-series over the common period 1982-2005 displays those temperature quantities for the winter season December-February (DJF). Note that the NASA POWER is based upon reanalysis, and it indicates

'systematic' warm bias relative to the other two data sets. Therefore, the POWER temperature quantities minus 2.0 (hereafter referred to as POWER-2) are applied in the time-series plots.
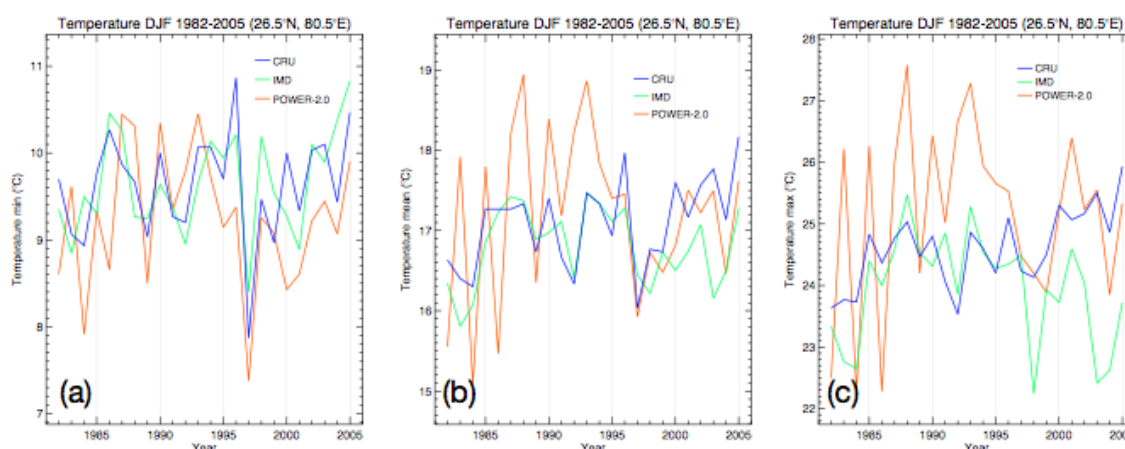

Figure 5: Comparison of temperature datasets for a gridbox near 26.5N, 80.5E, for (a) Tmin, (b), Tmean, and (c) Tmax, averaged over the DJF season. Two degrees C was subtracted from the NASA Power.

The time-series of temperature quantities for DJF 1982-2005 compare well between CRU and IMD for mean or minimum, and relatively not so well with POWER-2. For maximum temperature, however, IMD appears to be closer to POWER-2 with each other than with CRU. The POWER-2 data also indicate more frequent and larger interannual variation than the other two, especially prior to the mid-1990s.

Summer Rainfall Predictability

The historical probability of seasonal precipitation anomalies during El Niño and La Niña events is shown in figure 6 over Northern India and Nepal for the JJAS season (1951–07) in terms of seasonal rainfall total, rainfall frequency and mean rainfall intensity on wet days. The maps in figure 6 show the probability of receiving rainfall in the below-normal tercile category during El Niño events (top) and the below-normal tercile category during La Niña events (bottom), both of which correspond to the "canonical" ENSO pattern over South Asia during summer. While there is a general historical tendency for this ENSO-related signature, it is only a moderate tendency with tercile-category probabilities generally in the range 0.4–0.6 and present a noisy spatial pattern. There are more elevated probabilities in the case of rainfall frequency, reaching 0.6–0.7, while rainfall intensity shows the weakest signal. Over the study regions, Punjab and Haryana regions show a strong enhanced probability of

drought during El Niño for rainfall frequency. Meanwhile higher rainfall intensities are more likely during La Niña events over Nepal and northern Bangladesh.
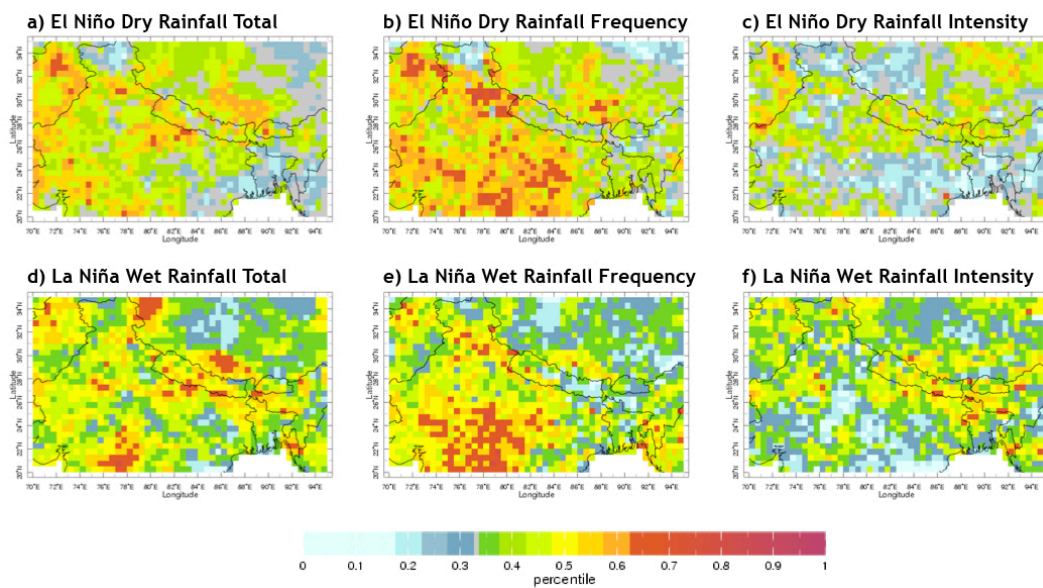

Figure 6. Historical probability of seasonal anomalies during the different ENSO phases for the JJAS season. The top three panels show the probability of below normal tercile precipitation during El Niño. The bottom three panels show the probability of above normal tercile precipitation during La Niña. The left panels compare total JJAS precipitation, the middle panels show the number of days where it rains greater than one millimeter and the right panels show the average rainfall intensity on wet days (1951-2007). The ENSO state is dictated by seasonal average sea surface temperature in the NINO3.4 region.

The ENSO associations with rainfall characteristics shown in figure 6 indicate potential predictability of the latter based on the established predictability of the former, although the seasonality of ENSO events is such that their predictability reaches a minimum in April and May, (known as the ENSO spring predictability barrier). The skill of the IRI Net Assessment forecasts for July-September (JAS) seasonal precipitation amounts for forecasts issued in mid-May are shown in figure 7.
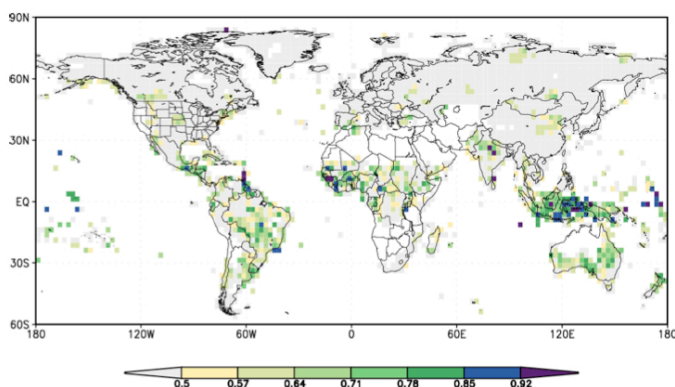

Figure 7. Skill of IRI Net Assessment JAS precipitation amount forecasts for 2001-2011 using generalized relative operating characteristic.

IRI's Verification Portal has many means of measuring and comparing skill of IRI's forecasts. The method displayed in figure 7 is the generalized relative operating characteristic (ROC) skill score. These forecasts show modest some skill over the Punjab/Haryana region but none over Nepal and Bangladesh.

To analyze in more detail the performance of GCM forecasts over South Asia, figure 8 shows maps of the Pearson anomaly correlation coefficient between the hindcasts of JAS precipitation amount (i.e. forecasts made retrospectively) and the APHRODITE data. These hindcasts were started from initial conditions on June 1 of each year over the 1982–2007 period, and figure 5 shows the results for five different GCMs. Two of the GCMs stand out as exhibiting high positive correlations over the CCAFS-relevant regions, namely the CFSv2 (figure 5b) and ECHAM-MOM (figure 5d), for Punjab, Haryana and Nepal respectively; these two models will be considered in more detail in the following figure. None of the five models perform well over Bangladesh.
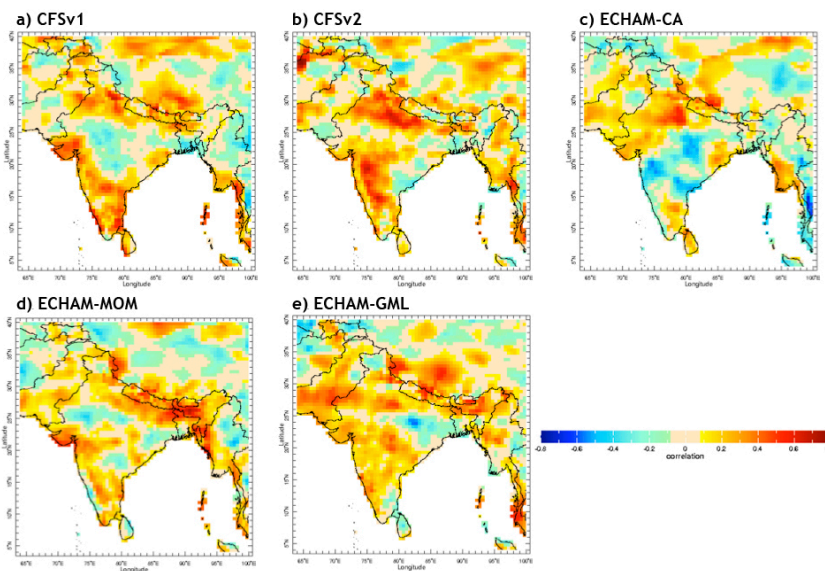

Figure 8. Pearson correlation coefficient between APHRODITE JAS seasonal precipitation and 1982-2007 retrospective GCM hindcasts initialized on June 1 of each year. The performance of five different GCMs is shown.

Figure 9 shows similar correlation maps but for the full JJAS season for hindcasts made on May 1 using the CFSv2 (top) and ECHAM-MOM (bottom) models. The results for seasonal total rainfall (left column) are similar to those in figure 8 for the reduced season. Breaking the seasonal rainfall into rainfall frequency (middle) and intensity (right) components suggests slightly better performance for rainfall frequency.
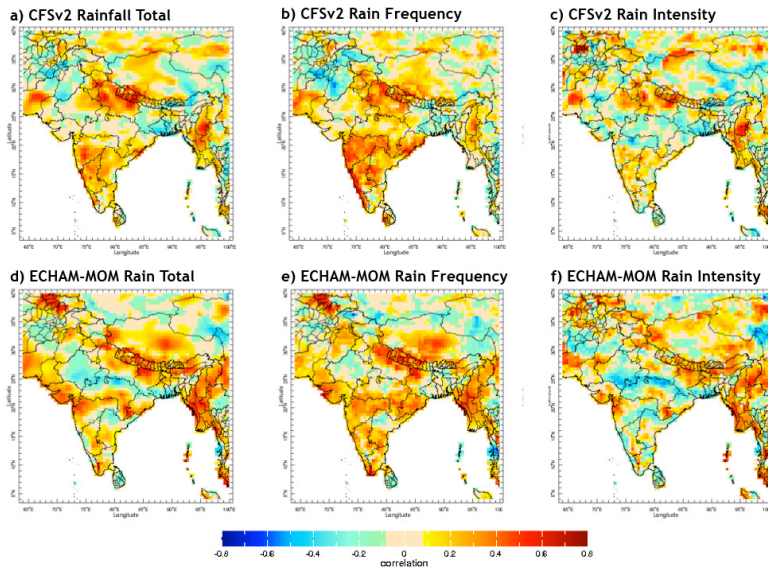
Figure 9. Same as figure 5 but for retrospective forecasts for JJAS seasonal precipitation for the CFSv2 model (top) and ECHAM-MOM (bottom).

The maps in figures 8 and 9 suggest promising GCM performance over the Punjab/Haryana region in CFSv2 and over Nepal and Bihar in ECHAM-MOM. To determine the extent to which this is reflected in actual hindcast skill, figure 10 shows cross-validated skill scores of CFSv2 and ECHAM-MOM models in terms of Pearson correlation (top) and ROC area for the below-normal tercile category. The maps again validate the models against APHRODITE 0.5-degree data using the closest GCM gridbox value and thus represent a crude spatial downscaling. Some cross-validated hindcast skill is evident for all the CCAFS regions except Bangladesh.
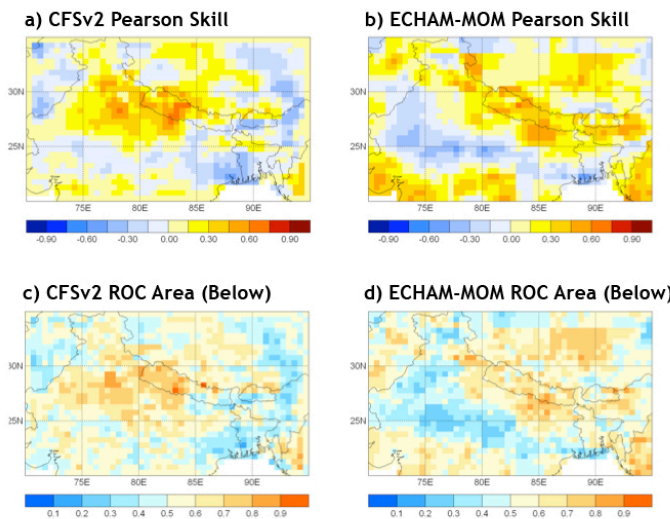
Figure 10. Cross-validated skill scores of CFSv2 and ECHAM-MOM models for hindcasts of JJAS seasonal total precipitation. Upper panels show Pearson anomaly correlation while lower panels show the area below the ROC curve for the below-normal tercile category.

A more sophisticated regression-based spatial downscaling was not found to improve the skill levels presumably due to the modest strength of the predictive relationship coupled with the relatively short training period under cross-validation—here 21

18

years. It should be noted that the maps in figures 6–10 are not strictly comparable because of the different ranges of years considered in each case, which can make a substantial difference in the case of the South Asian monsoon where sampling variability is high and the ENSO-monsoon relationship is known to be period-dependent. Whether this is a result of simple sampling variability or true non-stationarity is still under debate.

Conclusion

A new suite of maproom tools has been developed for CCAFS regions of South Asia that enable rainfall and temperature climatological characteristics, seasonal predictability, and downscaled seasonal forecasts to be accessed and analysed from an agronomic perspective. Some modest seasonal predictability of summer monsoon precipitation is found over the Punjab/Haryana region in the CFSv2 model and over Nepal and Bihar in ECHAM-MOM model. There is some evidence of slightly enhanced predictability of rainfall frequency compared to seasonal rainfall total, but the difference is not pronounced over the project regions. There is no evidence of any summer monsoon predictability over Bangladesh from the analyses reported here.

The accuracy of the results is dependent on the quality of the observational datasets used, which is a nontrivial issue for daily precipitation and temperature data. For daily precipitation, we have relied on the APHRODITE station-based gridded product, which extends over monsoonal Asia. For daily temperature there are fewer large scale observational datasets available, although numerical weather prediction model reanalysis datasets provide a potential alternative. For this reason, we compared three daily temperature datasets over India, which is the most data-rich region due to the IMD products. For interannual variability our results (figure 5) showed that there are still large errors in the NASA POWER reanalysis product, while the CRU and IMD compare quite closely. However the CRU is a monthly product.

Several extensions for future work are suggested:

- Some of these maprooms already extend over SE Asia. Contingent on the availability of observed daily precipitation and temperature data, they could be extended to other regions.
- It would be valuable to extend the dataset comparison study to include the GSOD station data and other reanalysis products. The ENSO composites that use the GSOD and IMD temperature data do not agree closely, and this should be resolved.
- The GCM skill maproom could be extended to a probabilistic verification measure, as well as to allow the forecasts at multiple lead time to be viewed.
- The forecast maprooms are still a prototype, and consider only seasonal averaged quantities. These could be extended to consider some of the daily characteristics of precipitation and temperature that are available in the

historical monitoring maproom. They could also be extended to consider the multi-model average of the NMME coupled models.

•

References

Bai, J, X. Chen, A. Dobermann, H. Yang, K.G. Cassman, and F. Zhang, 2010: Evaluation of NASA Satellite- and Model-Derived Weather Data for Simulation of Maize Yield Potential in China. Agron. J., 102, 9-16, 10.2134/agronj2009.0085.

Bloom, S., A. da Silva, D. Dee, M. Bosilovich, J.-D. Chern, S. Pawson, S. Schubert, M. Sienkiewicz, I. Stajner, W.-W. Tan, M.-L. Wu, Documentation and Validation of the Goddard Earth Observing System (GEOS) Data Assimilation System - Version 4, Technical Report Series on Global Modeling and Data Assimilation, NASA/TM-2005-104606, Vol. 26, 2005.

Gadgil, S., 2003: The Indian monsoon and its variability. Ann. Rev. Earth Planet. Sci., 31:429–467, 2003.

Gadgil, S., M.N. Rajeevan, L. Zubair, and P. Yadav, 2011: Interannaul varaition of the South Asian Monsoon. In "The Global Monsoon System: Research and Forecast, 2nd Edition", Chang, C.-P., Y. Ding, N.-C. Lau, R. H. Johnson, B. Wang, and T. Yasunari, Eds., World Scientific Series on Asia-Pacific Weather and Climate, Vol. 5, World Scientific Publication Company, 608 pp. April 2011.

Mitchell, T. D., P. D. Jones. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. Int. J. Climatol. 25, 2005

Moron, V., A. W. Robertson and M. N. Ward, 2006: Seasonal predictability and spatial coherence of rainfall characteristics in the tropical setting of Senegal. Mon. Wea. Rev., 134, 3246-3260.

Robertson, A. W., V. Moron, and Y. Swarinoto, 2009: Seasonal predictability of daily rainfall statistics over Indramayu district, Indonesia. Int. J. Climatology, 29, 1449-1462.

Srivastava, A. K., M. Rajeevan, and S. R. Kshirsagar, 2008. Development of a high resolution daily gridded temperature data set (1969-2005) for the Indian region. NCC Research Report 8, National Climate Centre, India Meteorological Department, Pune, India, 15 pp.

Xie, P., A. Yatagai, M. Chen, T. Hayasaka, Y. Fukushima, C. Liu, and S. Yang (2007). A gauge-based analysis of daily precipitation over East Asia, J. Hydrometeorology, 8, 607-627.

Yadav RK, Rupa Kumar K, Rajeevan M. 2009. Increasing influence of ENSO and decreasing influence of AO/NAO in the recent decades over northwest India winter precipitation. J. Geophys. Res. 114: D12112, DOI: 10.1029/2008JD011318.

Yadav, R. K. (2011), Why is ENSO influencing Indian northeast monsoon in the recent decades?. Int. J. Climatology. doi: 10.1002/joc.2430

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is a strategic initiative of the Consultative Group on International Agricultural Research (CGIAR) and the Earth System Science Partnership (ESSP), led by the International Center for Tropical Agriculture (CIAT). CCAFS is the world's most comprehensive global research program to examine and address the critical interactions between climate change, agriculture and food security.

For more information, visit www.ccafs.cgiar.org

Titles in this Working Paper series aim to disseminate interim climate change, agriculture and food security research and practices and stimulate feedback from the scientific community.

International Research Institute
for Climate and Society
EARTH INSTITUTE | COLUMBIA UNIVERSITY

Earth System
Science Partnership

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture
Consultative Group on International Agricultural Research

CGIAR

RESEARCH PROGRAM ON
Climate Change,
Agriculture and
Food Security

CCAFS