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# Synthesis and Integration: Challenges Facing the Next Generation Operational CFS

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## 1. Introduction

The Topical Collection on Climate Forecast System version 2 (CFSv2), a special volume of Climate Dynamics, was published in 2015. It includes 24 peer-reviewed papers, consisting of findings by the broader climate research and applications community together with NCEP scientists at the April 2012 CFSv2 Evaluation Workshop, organized by the NCEP Climate Prediction Center (CPC), the NOAA Climate Test Bed (CTB), the Center for Ocean-Land-Atmosphere Studies (COLA), and the NOAA Climate Program Office (CPO). The papers identify key model strengths, biases and deficiencies in predicting climate variables, simulating the modes of climate variability and phenomena and representing physical processes and their interactions. From the point of view of seamless weather-climate prediction, this summary synthesizes the challenges with regard to operational prediction requirements, predictability research prospects, and model fidelity and reliability; and integrates research and development needs for the guidance of next generation operational CFS development.

## 2. Operational prediction requirement

The NOAA Climate Prediction Center produces climate outlooks of surface temperature and precipitation from weeks to seasons in advance, which primarily depend on the impacts of ENSO, trends, antecedent soil moisture, and indicators of intraseasonal variability (that are weighted more for the week 2-4 forecast). The skill assessments of those critical components help to address the requirement for operational prediction improvement.

ENSO – Compared with the previous version of CFS, the NINO3.4 forecast has significantly improved in terms of reduced RMSE, amplitude bias and target month slippage, but the difference in correlation skill is not statistically field significant. (Barnston and Tippett)

Soil moisture – The bias changes with lead time, and there is a tendency to underrepresent the link between precipitation and antecedent soil moisture as strongly as in the real atmosphere. A long-term tendency to wet coupling east of the Rocky Mountains precludes the model from consistently predicting and maintaining drought over the continental U.S. (Dirmeyer; Roundy *et al.*)

MJO – Prediction skill varies seasonally with the lowest anomaly correlation during boreal summer and the highest during boreal winter, being useful out to 20 days (improved from CFSv1 of about 10-15 days). Forecast problems include too slow eastward propagation, the Maritime Continent barrier and weak intensity (Fig. 1). Air-sea coupling plays an important role for initiation and propagation. (Wang *et al.*; Fu *et al.*)

## 3. Predictability research prospects

The representation of predictability, an intrisic property of the climate system, is model dependent. It has been continuously improving in the past via advancing representation of physical, chemical and biological processes and coupling among land, ocean, atmosphere, cryosphere and biosphere in the model system.

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Prospects for an improved representation of predictability, which has the potential to improve skill, have been demonstrated by research using CFSv2.

Arctic Oscillation (AO) – CFSv2 forecasts can capture both the timing and amplitude of wave activity in the extratropical stratosphere at a lead time >30 days, and a statistically significant portion (20%) of the wintertime AO can be predicted up to 2 months in advance. Benefits from further improvement are expected as the model captures better the stratosphere-troposphere pathway. (Riddle *et al.*; Zhang *et al.*)

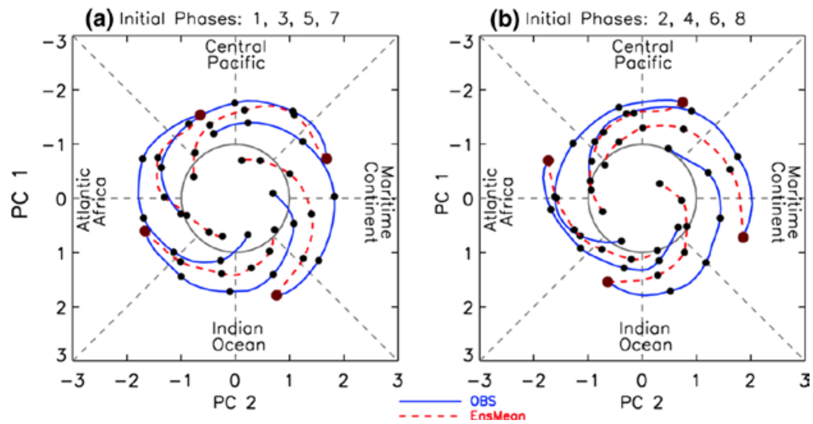


**Fig. 1** Phase diagrams of the composite forecast for initial conditions with strong MJO (amplitude>1). (a) Initial phases 1, 3, 5, and 7. (b) Initial phases 2, 4, 6, and 8. The composites are started from observed values and the dots indicate the locations every 5 days. Blue curves are observations and red curves are the composite of the forecast. (From Wang *et al.*)

Quasi-Biweekly Oscillation (QBWO) – Skillful QBWO prediction can reach ~10-15 days in winter hemisphere and does better in El Niño years. Overall, QBWO in CFSv2 exhibits a significant weakening tendency with lead time for all seasons. (Jia *et al.*)

Monsoons – CFSv2 is capable of simulating both the frequency and spatial structure of the northward propagating (from near equatorial Indian Ocean to the Indian subcontinent) intraseasonal oscillation of the Indian summer monsoon at pentad 3 and even pentad 4 lead (Fig. 2). In general, it can predict the Asian Indo-Pacific monsoon and North American monsoon precipitation patterns associated with ENSO reasonably well, while African monsoon precipitation forecasts have little skill, which could be related to low prediction skill of the tropical Atlantic SST. High-frequency, interactive ocean–atmosphere coupling plays a vital role in simulating the observed amplitude of variability and the relationship between precipitation and SST at the intraseasonal scale. (Abhulash *et al*; Zuo *et al*; Sharmila *et al.*)

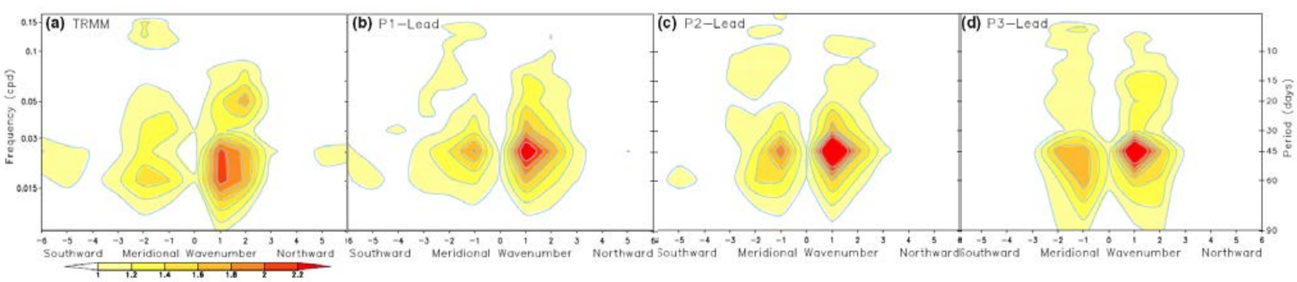


**Fig. 2** North-South wavenumber-frequency power spectrum over Indian region for rainfall from (a) TRMM observations and from (b)-(d) pentad 1-3 lead CFSv2 forecast. (From Abhilash *et al.*)

South Pacific Ocean Dipole (SPOD) – CFSv2 reproduces the SPOD, the dominant mode of the interannual variability in the South Pacific. It is significantly correlated with the southern annular mode (SAM) while the latter is also significantly correlated with the ENSO index. (Guan *et al.*)

### 4. Model fidelity and reliability

To provide users with reliable forecasts, particularly for precipitation and away from the El Niño region, model fidelity (the ability to represent physical processes accurately), proper calibration and quantification of uncertainties, are the keys to improve reliability.

Cloud deficiencies – Large discrepancies were found in modeled low-level clouds: too much over the interior and too little over oceans, especially marine stratocumulus clouds in the eastern Pacific and Atlantic Oceans. Problems were also identified in modeling cloud properties, e.g. the distribution of cloud optical depth (Fig. 3), cloud fraction, liquid water path and ice water path *etc.*, which have significant impact on both Earth's radiation budget and atmospheric heating. (Yoo and Li; Yoo *et al.*; Zhang *et al.*)

Atmospheric mode bias – Examination of the climate mean, variability, and dominant patterns of the Northern Hemisphere winter revealed that bias in stationary waves emanating from the tropics into both hemispheres can be attributed to a lack of latent heating associated with a precipitation deficit over the Maritime continent. (Peng *et al.*)

Oceanic condition deviation –

1. Weakened Atlantic Meridional Overturning Circulation (AMOC): A major reduction of the upper ocean salinity in the northern North Atlantic weakens the AMOC significantly. A potential source of the excessive freshwater is the quick melting of sea ice. (Huang *et al.*; Bombardi *et al.*)

2. Cold summer tropical Indian Ocean (IO) SST bias: This may be attributed to deeper-than-observed mixed layer and smaller-than-observed total downward heat flux in the tropical IO. The CFSv2 simulation is vitiated by the presence of a basin-wide systematic positive bias in evaporation (mainly due to humidity bias), which is found to control a significant portion of the cold SST bias. (Pokhrel *et al.*; Jiang *et al.*)

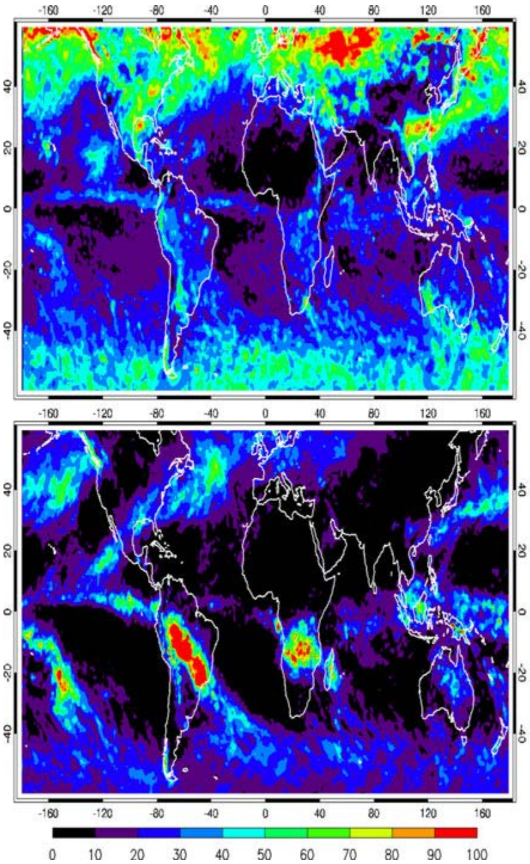


**Fig. 3** Total cloud optical depth (COD) from the MODIS-CL (top) and the GFS model (bottom) during January 2007, showing the modeled COD over storm track region and subtropical region is less than that from the passive sensor and is overestimated for deep convective clouds. (From Yoo and Li)

Multiple-ocean Analysis Ensemble (MAE) initialization – The structural uncertainty in the ocean initial conditions impacts the reliability of seasonal forecasts. MAE improves ENSO seasonal forecast reliability in warm, neutral and cold cases. (Zhu *et al.*)

Calibration and combination – Properly calibrated probabilistic forecasts possess sufficient skill and reliability to contribute to effective decisions in government and business activities that are sensitive to subseasonal-to-seasonal climate variability. (Dutton *et al.)*

## References

Topical Collection on Climate Forecast System Version 2 (CFSv2) (2015), *Climate Dynamics*, ISSN: 0930-7575 (Print) 1432-0894 (Online) *http://link.springer.com/journal/382/topicalCollection/AC_0c8dce90d46a2a6b4e60584773e8daf1*.

**List of Contents:**

Preface to CFSv2 topical collection (Jin Huang, Annarita Mariotti, Jim Kinter, Arun Kumar)

Impact of land-atmospheric coupling in CFSv2 on drought prediction (Joshua K. Roundy, Craig R. Ferguson, Eric F. Wood )