Monsoon Modelling Efforts at IITM-Pune

Suryachandra A. Rao
Indian Institute of Tropical Meteorology

Contributors: Group Members

Workshop on : Grand challenges in monsoon modeling:
Representation of processes in climate model

Towards Improved Simulations of Monsoon

Monsoon Mission

- **To improve the prediction skill of Indian Summer Monsoon Rainfall (Short range to long range) in dynamical coupled models**
- To build a working partnership between the academic and R & D Organizations, and to improve the operational monsoon forecast skill over the country.
- **To train researchers in India to work on various aspects of dynamical models**
- **Setup the HPC system for carrying out the above tasks**

ICTP Activities with MoES

- Towards Improved Monsoon Simulations (2016 @ ICTP)
- Modelling and Prediction of Asian Monsoons: Improving Physical Processes (2015 @ IITM)
- Challenges in Monsoon Prediction (2014 @ ICTP)
- Intrseasonal Monsoon Predictability and Prediction (2013 @ IITM)
- El Nino Southern Oscillation Monsoon in the Current and Future Climate (2012 @ ICTP)

Outline

- Identified systematic biases in simulation of Indian Summer monsoon
- Some attempts in reducing them
- Future roadmap

INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **34**: 1628–1641 (2014)
Published online 25 July 2013 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/joc.3791

Royal Meteorological Society

Improved simulation of Indian summer monsoon in latest NCEP climate forecast system free run

Subodh K. Saha,[a*] Samir Pokhrel,[a] Hemantkumar S. Chaudhari,[a] Ashish Dhakate,[a] Swati Shewale,[b] C. T. Sabeerali,[a] Kiran Salunke,[a] Anupam Hazra,[a] Somnath Mahapatra[a] and A. Suryachandra Rao[a]

[a] *Indian Institute of Tropical Meteorology, Pune, India*
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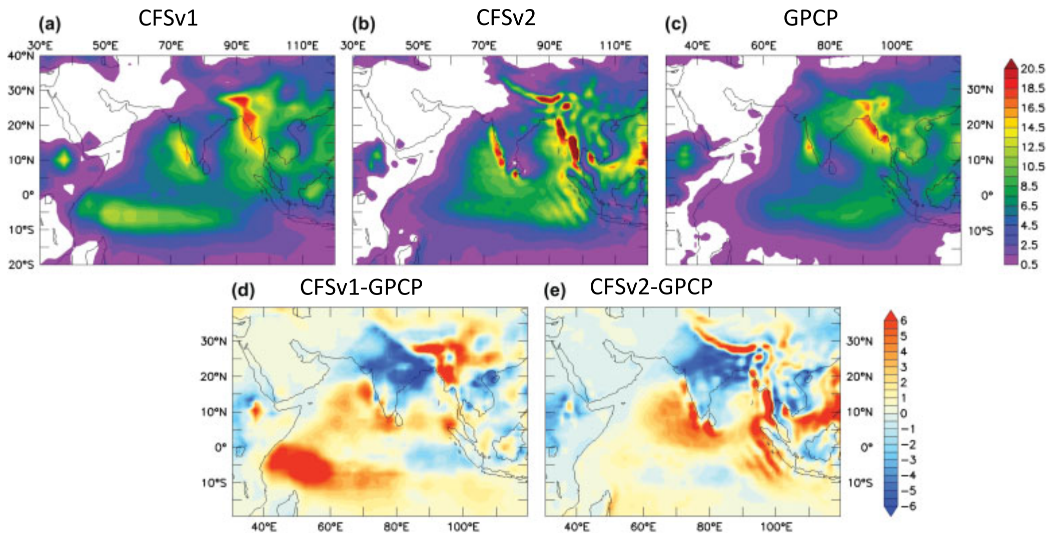
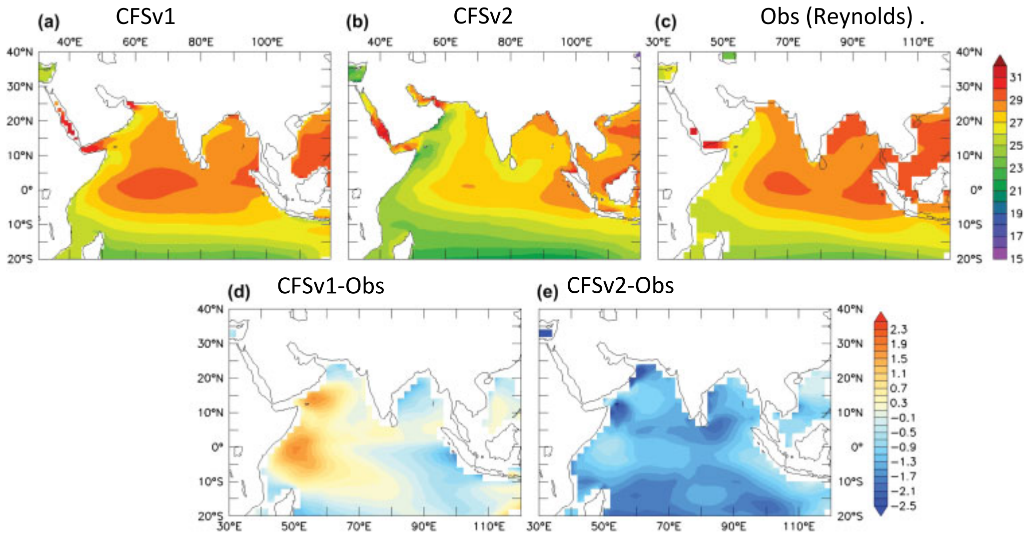
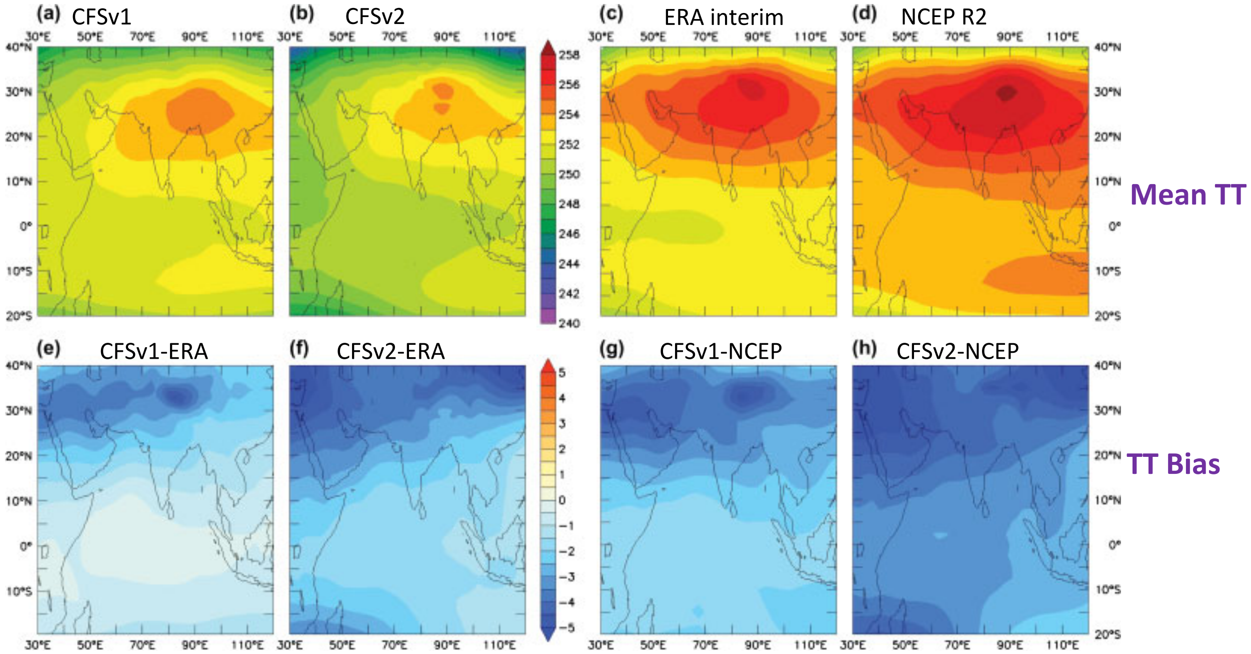
- Cold SST Bias in the tropics; Excessive Evaporation and Ocean Heat Transport
- Cold Troposphere: Underestimation of medium and high clouds
- Excessive Snow & Delay in Snow Melting: Lack of Detailed Snow dynamics
- Dry bias over tropical land regions: Excessive Convection over Oceans and cold SSTs in neighborhood
- Overestimation of ratio of Convective to Stratiform



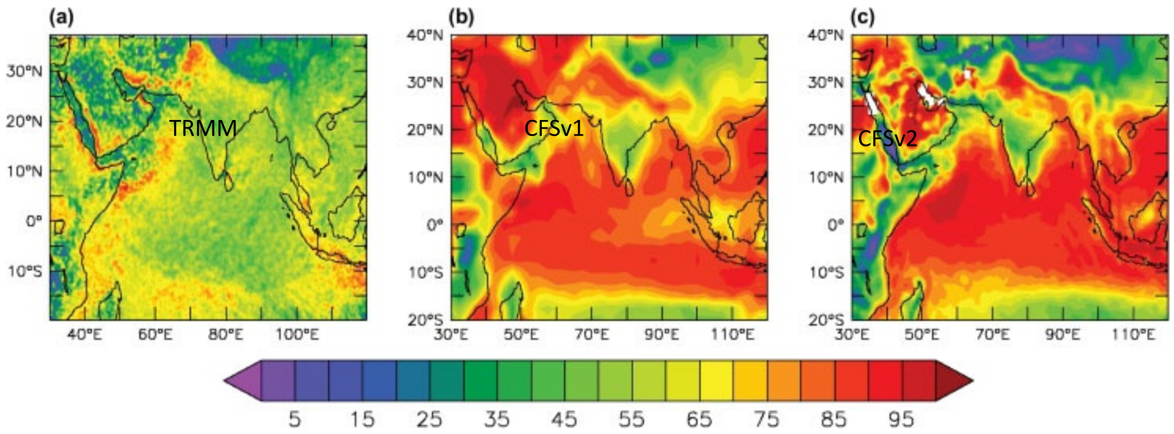
Seasonal (JJAS) averaged climatological mean rainfall



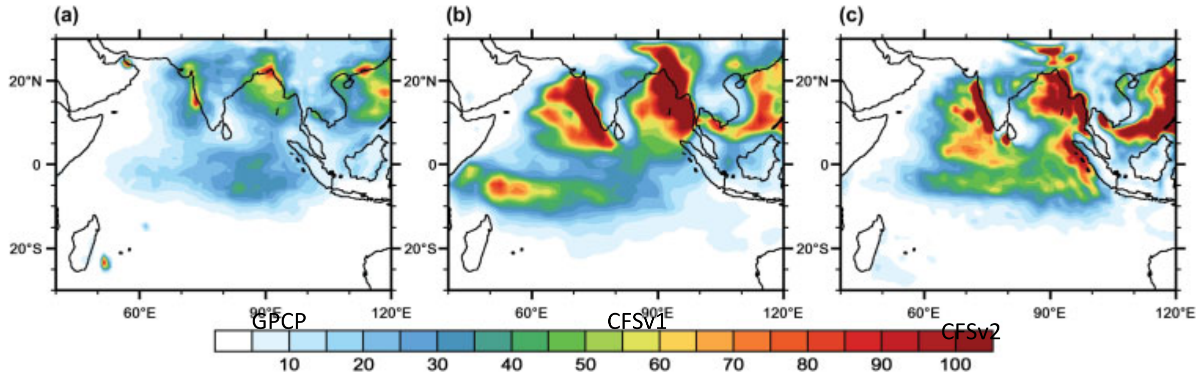
Seasonal (JJAS) averaged climatological mean SST



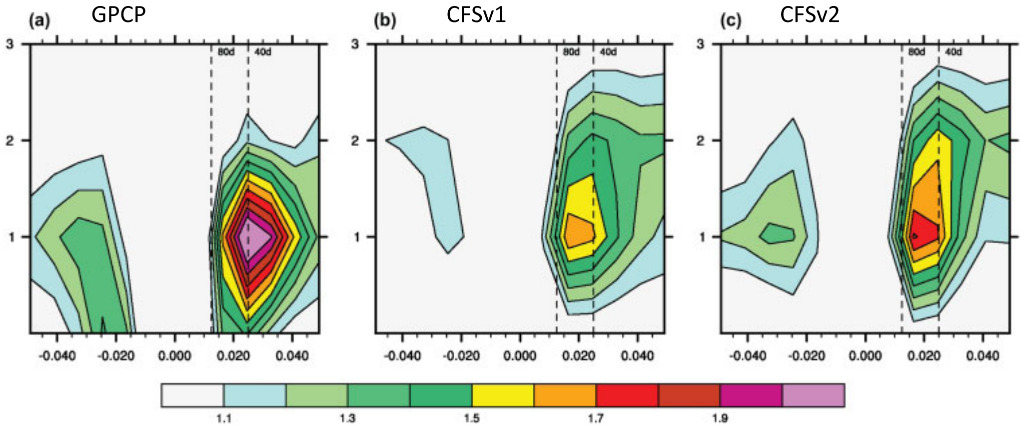
(a) CFSv1
(b) CFSv2
(c) ERA interim
(d) NCEP R2
(e) CFSv1-ERA
(f) CFSv2-ERA
(g) CFSv1-NCEP
(h) CFSv2-NCEP
Mean TT
TT Bias



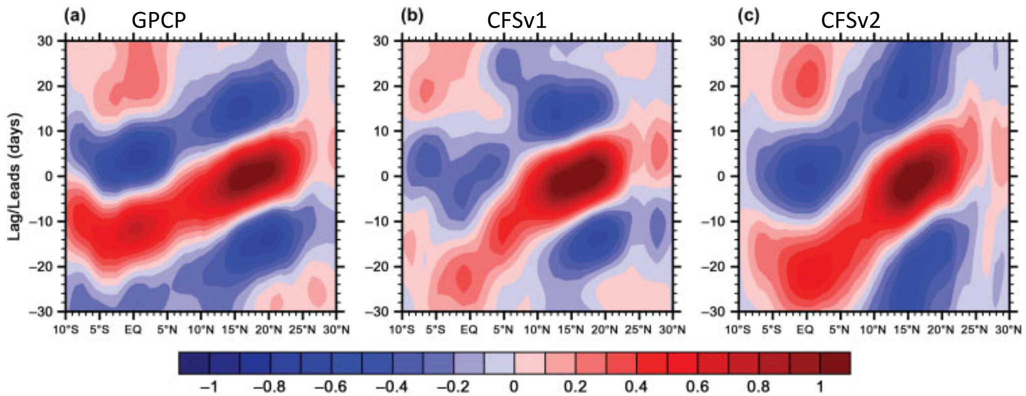
Ratio of JJAS averaged convective to total rainfall (in %).
(a) TRMM precipitation radar data, (b) CFSv1, (c) CFSv2.



ISO variance using 20–100 days filtered daily rainfall anomaly



Space–time spectra of daily JJAS rainfall averaged over 60E–110E



Northward propagation of ISOs using lead/lag regressed 20–100 d filtered rainfall anomaly during JJAS

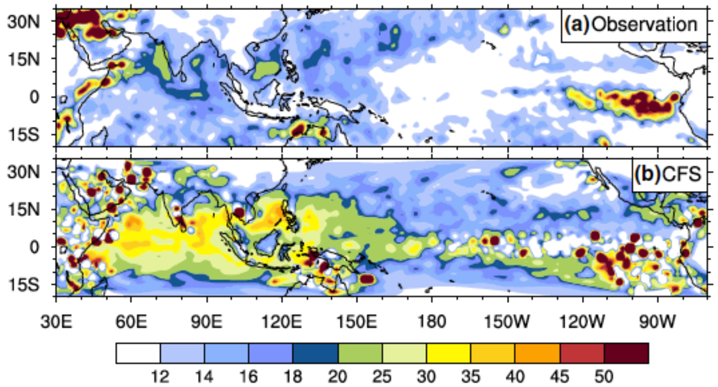
Clim Dyn (2016) 46:3287–3303
DOI 10.1007/s00382-015-2769-9

CrossMark

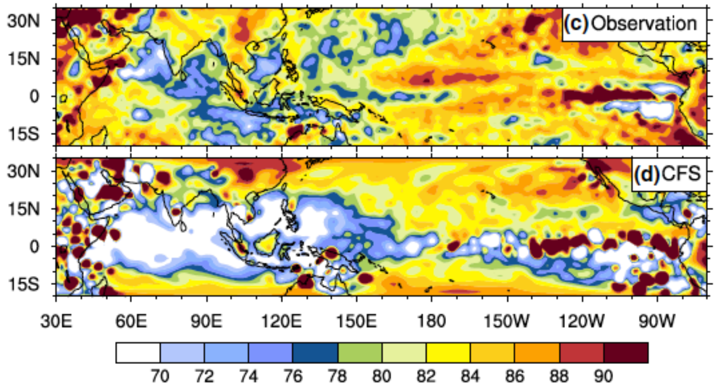
Diagnosis of boreal summer intraseasonal oscillation in high resolution NCEP climate forecast system

S. Abhik[1] · P. Mukhopadhyay[1] · R. P. M. Krishna[1] · Kiran D. Salunke[1] · Ashish R. Dhakate[1] · Suryachandra A. Rao[1]

- Simulated eastward Propagation of BSISO rapidly decays east of Maritime Continent
- Overestimation of 20-100 day variance
- Underestimation of 2-20 day variance

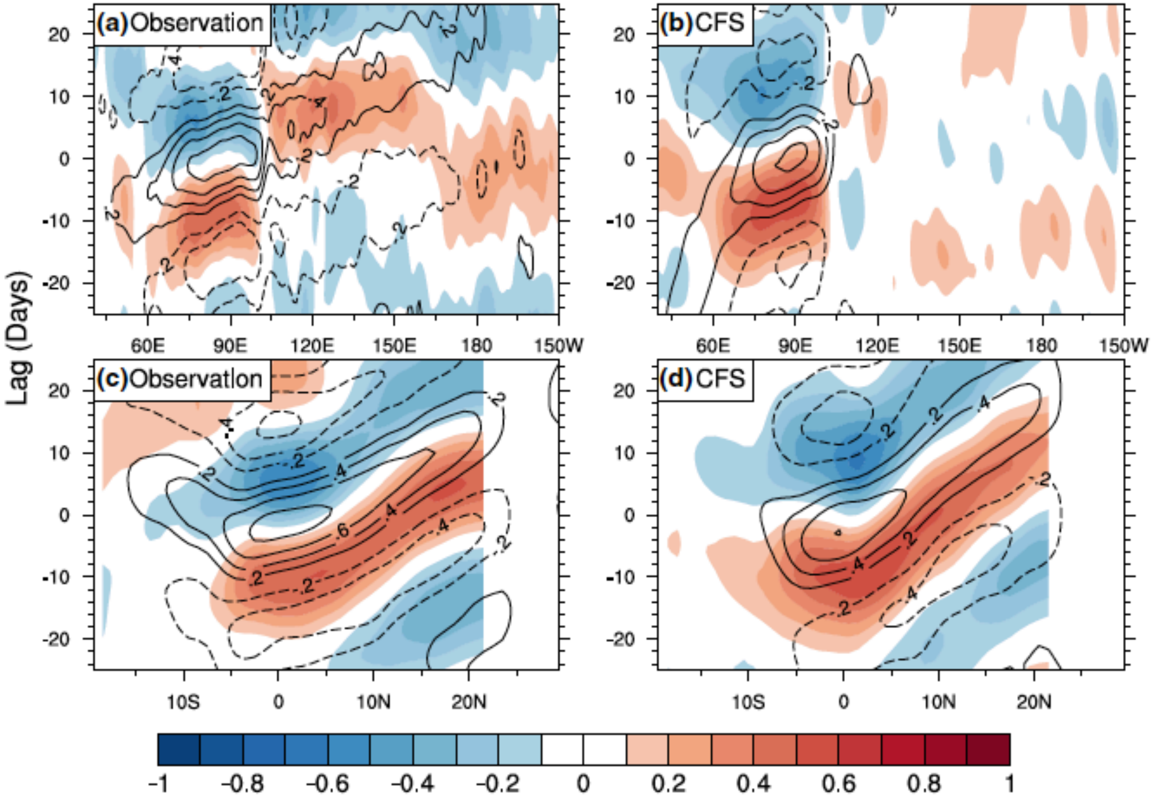


Ratio of Total variance and
20-100 day variance



Ratio of Total variance and
2-20 day variance

Propagating Characteristics of BSISO



Eastward Propagation

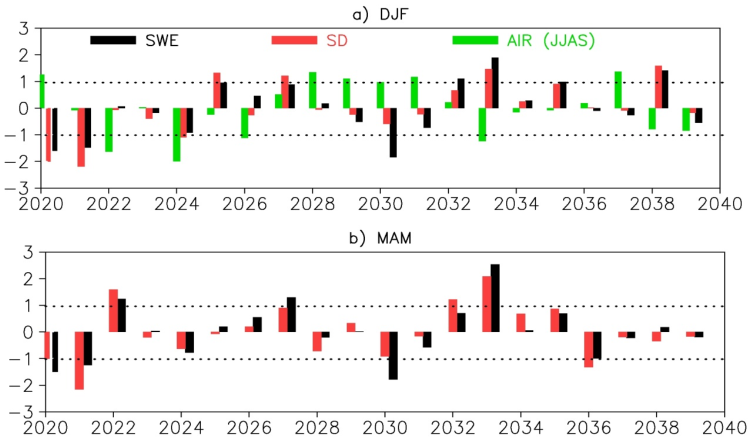
Northward Propagation

SST (Shaded)
Precip (Contour

Influence of Eurasian snow on Indian summer monsoon in NCEP CFSv2 freerun

Ref: Saha Subodh K., S. Pokhrel , H S Chaudhari, 2013: Influence of Eurasian snow on Indian summer monsoon in NCEP CFSv2 freerun, Climate Dynamics, 41: 1801-1815.

Snow and Rainfall Indices

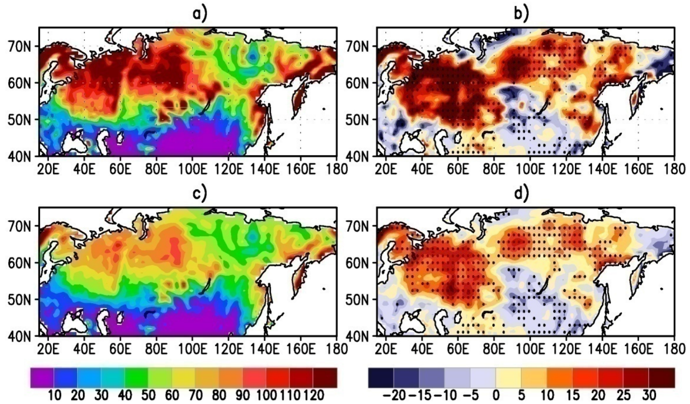


Normalized anomaly of area averaged snow over western Russia (box in Fig. 3c) and all India rainfall from CFSv2. a) Rainfall during monsoon (JJAS; green), SWE (black) and snow height (red) during winter (DJF). b) SWE (black) and snow height (red) during spring (MAM). Anomalies are normalized by their own standard deviation

- **Strong and weak snow years are identified based on normalized snow over west Eurasian region**
- **Composite approach is used to quantify the dry bias over India caused by bias in the mean snow over Eurasia.**

Ref: Saha et al. 2013

Snow Depth (cm) in Composites



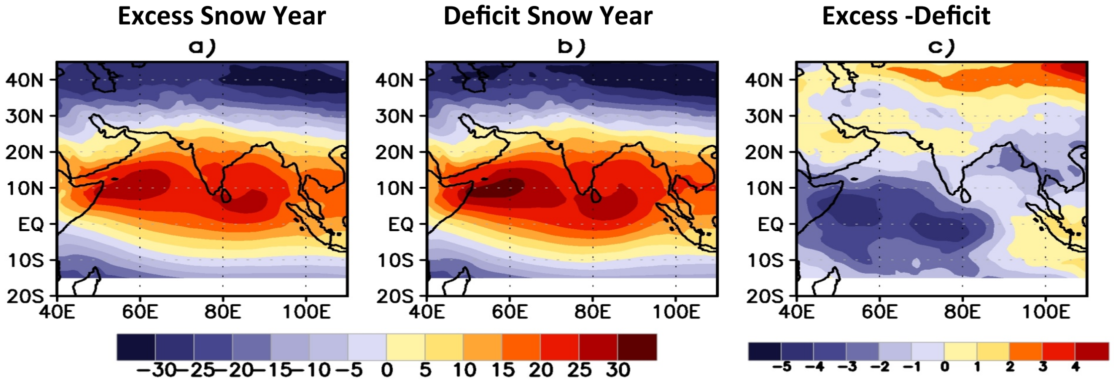
Strong year composite of DJF averaged a) SWE (in mm) and c) snow depth (in cm) from CFS. Strong minus weak year b) SWE and d) snow depth. Area with significant difference (C95 %) are stippled.

- **Difference between strong and weak snow years over west Eurasian region is comparable to the climatological mean bias over the same region.**

- **Difference in the ISMR based on same composite may be due to excess snow over Eurasia.**

Ref: Saha et al. 2013

Zonal Wind Shear (U850 – U200)

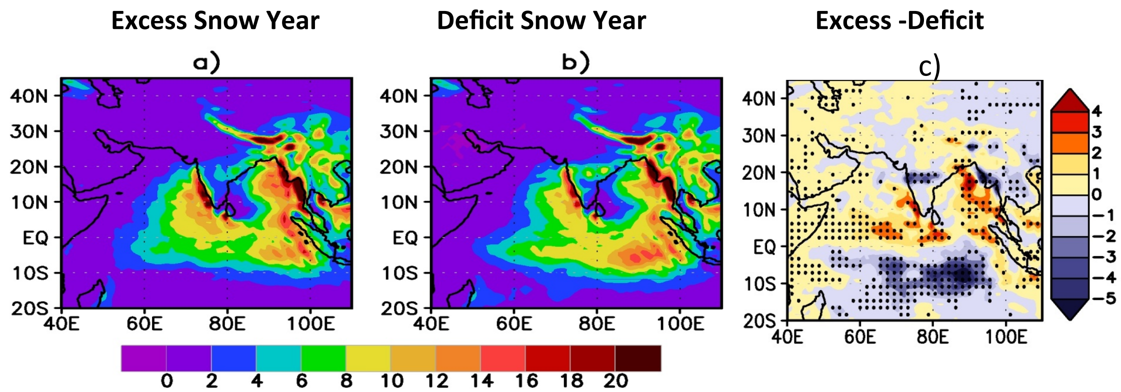


Composite of JJAS averaged zonal wind shear (U850 - U200 in m s-1) during a) strong snow year, b) weak snow year and c) strong-weak snow year from CFS. Area with significant difference (95 %) are stippled

- **Vertical wind shear is weaker during excess snow year, which suggest indirect influence on the northward propagation of ISOs.**

Ref: Saha et al. 2013

Rainfall

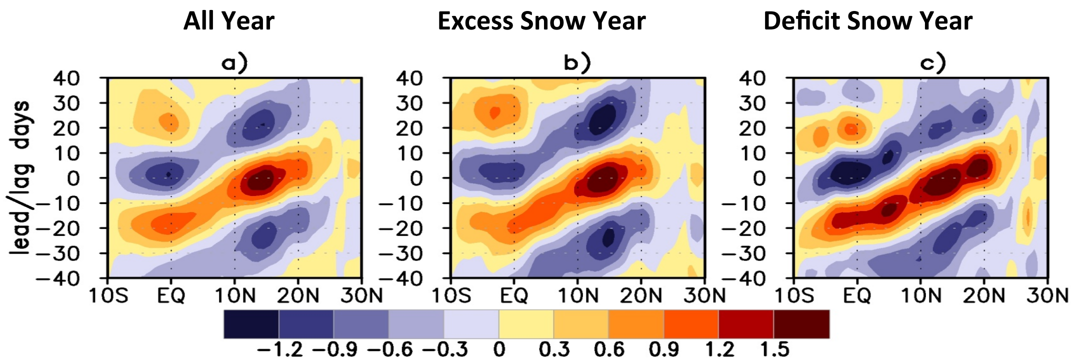


Composite of JJAS averaged zonal rainfall (in mm/day) during a) strong snow year, b) weak snow year and c) strong-weak snow year from CFS. Area with significant difference (95 %) are stippled

➢ **Part of ISMR bias in CFSv2 may be improved by reducing winter/spring snow bias over Eurasia.**

Ref: Saha et al. 2013

Northward Propagation



Northward propagation of ISOs using lead/lag regressed 25–90 days filtered JJAS rainfall anomaly from CFSv2. Using rainfall of a) all year, b) strong snow year and c) weak snow year from CFSv2

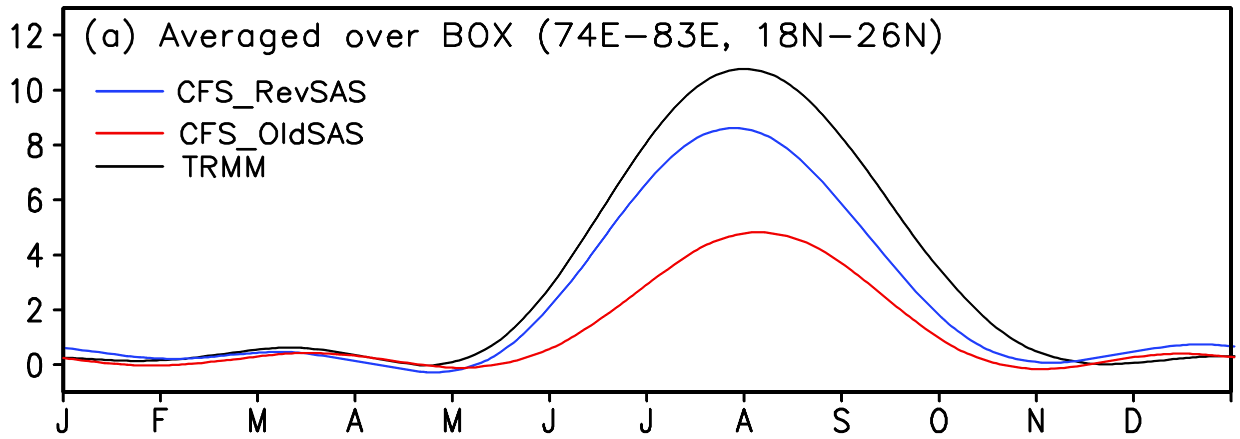
- **As mean rainfall is linked with ISOs, improvement in the Eurasian snow may also improve monsoon ISOs in CFSv2.**

Ref: Saha et al. 2013

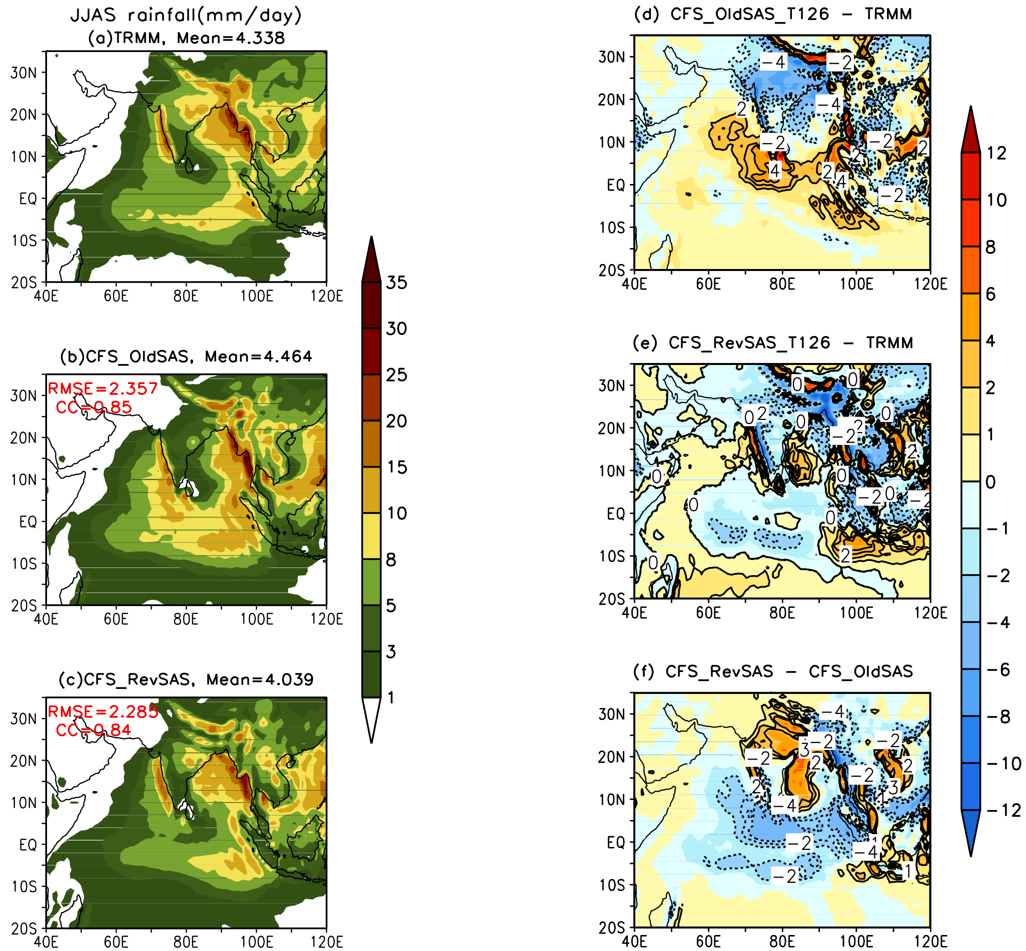
Improvements Due to Parametrization

The impact of revised simplified Arakawa–Schubert convection parameterization scheme in CFSv2 on the simulation of the Indian summer monsoon

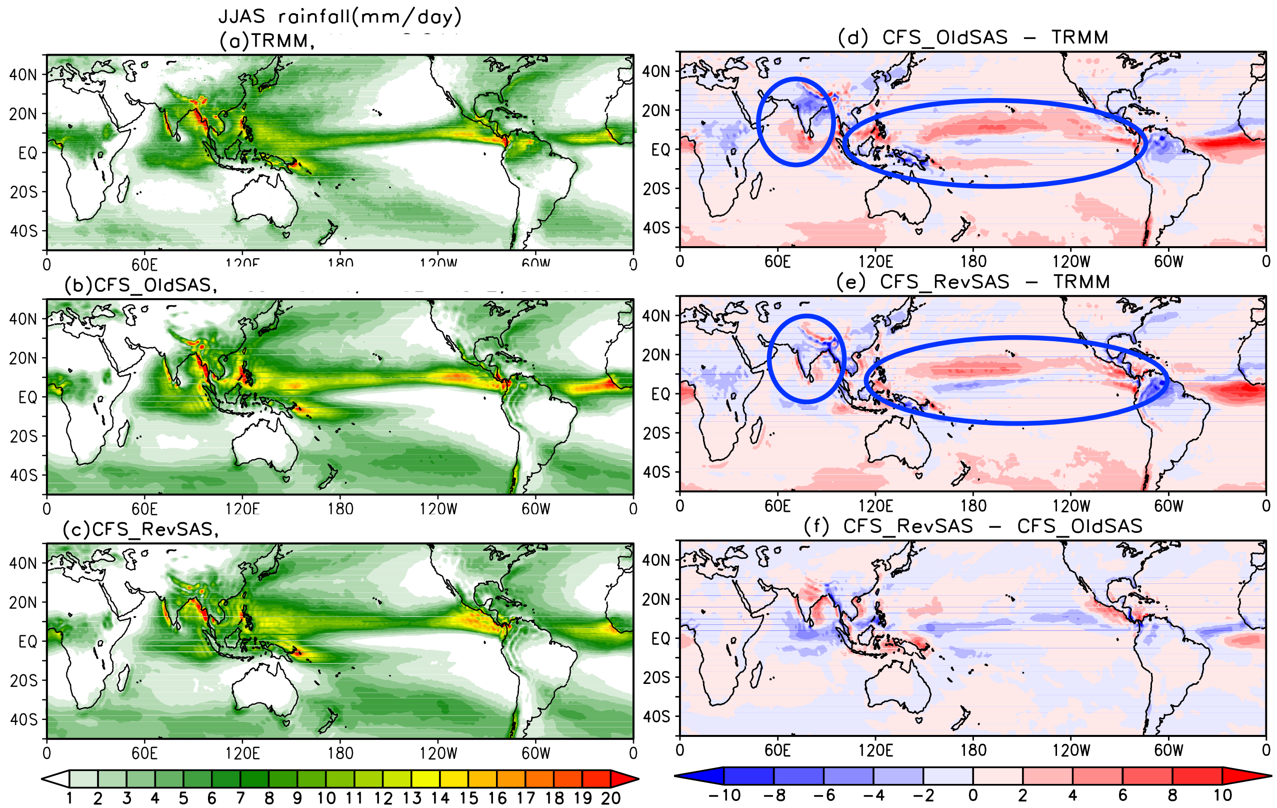
Malay Ganai · P. Mukhopadhyay ·
R. Phani Murali Krishna · M. Mahakur



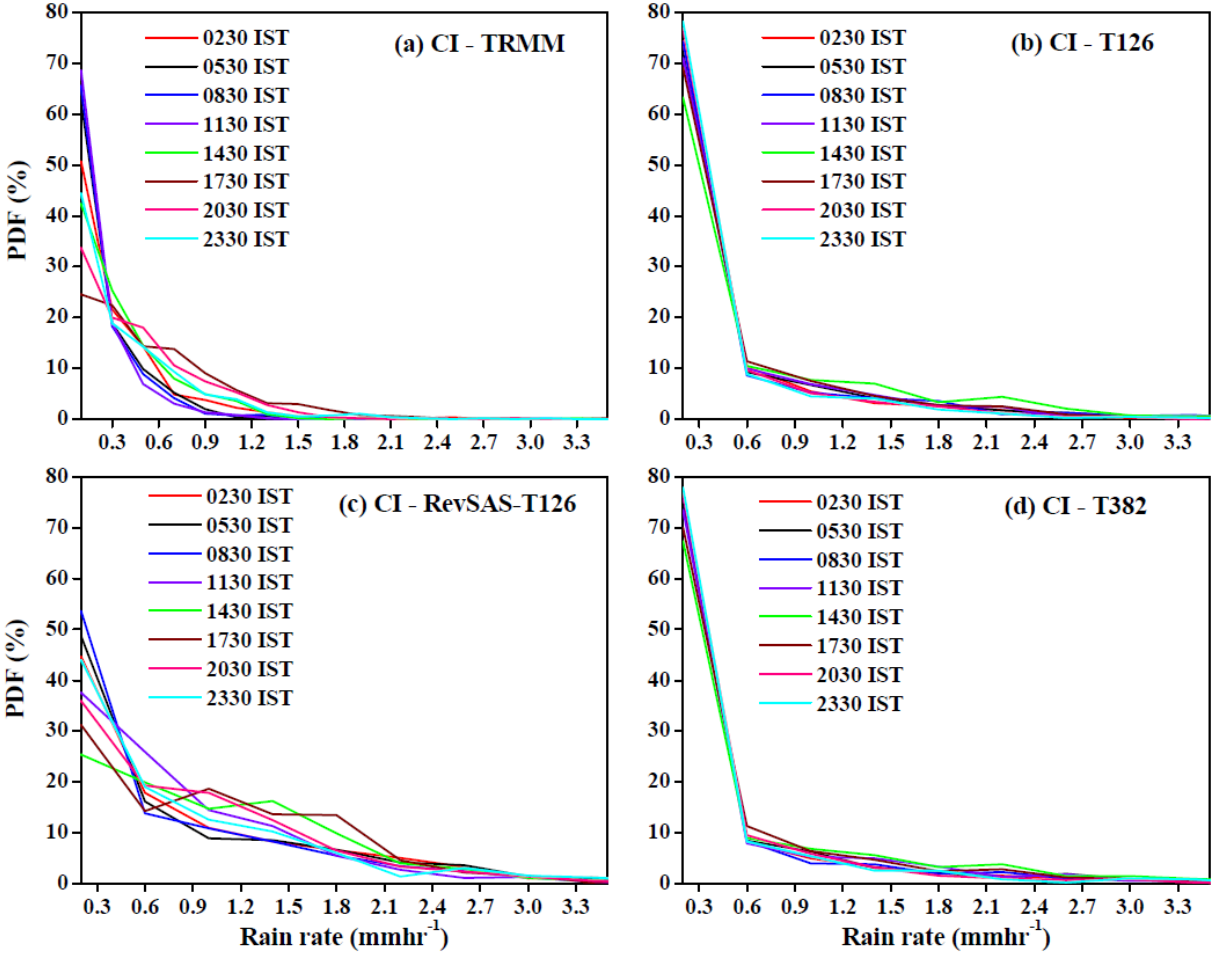
The smoothed climatology is computed from the first three harmonics of the daily climatology and annual mean.



Ganai et al., (2015)



Rainfall 15 years JJAS daily data



(a) CI - TRMM
(b) CI - T126
(c) CI - RevSAS-T126
(d) CI - T382
0230 IST
0530 IST
0830 IST
1130 IST
1430 IST
1730 IST
2030 IST
2330 IST
PDF (%)
Rain rate (mmhr^{-1})

INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **35**: 4738–4755 (2015)
Published online 8 April 2015 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/joc.4320

RMetS
Royal Meteorological Society

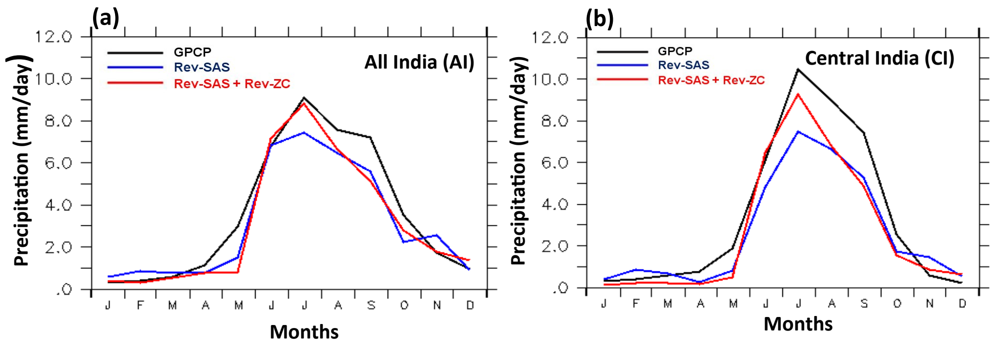
Impact of revised cloud microphysical scheme in CFSv2 on the simulation of the Indian summer monsoon

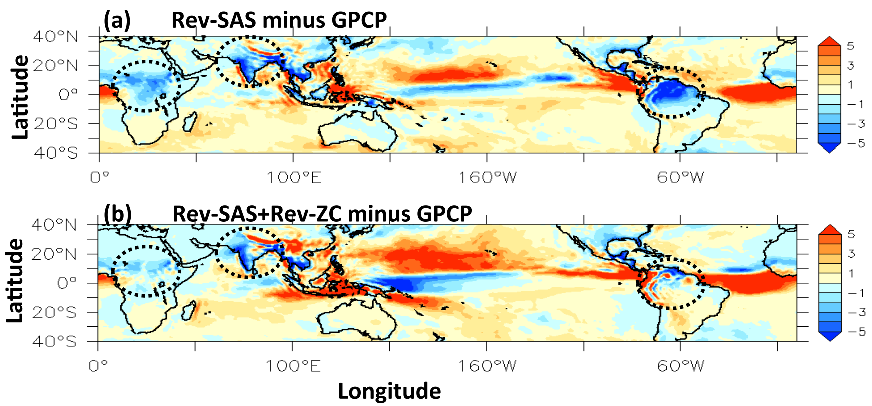
Anupam Hazra,* H. S. Chaudhari, S. A. Rao, B. N. Goswami, A. Dhakate, S. Pokhrel and S. K. Saha
Indian Institute of Tropical Meteorology, Pune, India

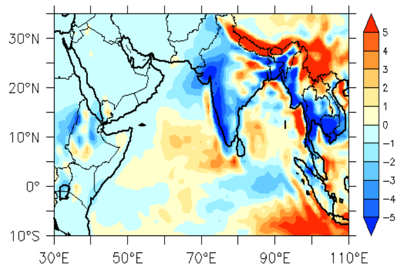
- ***Better representation of cloud microphysical processes (auto conversion and accretion) in the warm phase and mixed phase of cloud results in reduced SST and tropospheric bias hence results in better simulation of ISMR***

Cloud microphysics – Convective parameterization in CFSv2

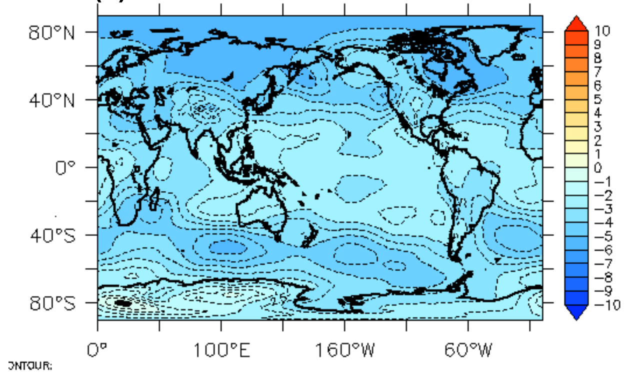
Ganai et al. (2014) have shown that revised SAS with deep convection can be a potentially better parameterization scheme for CFSv2 in simulating ISM rainfall variability.



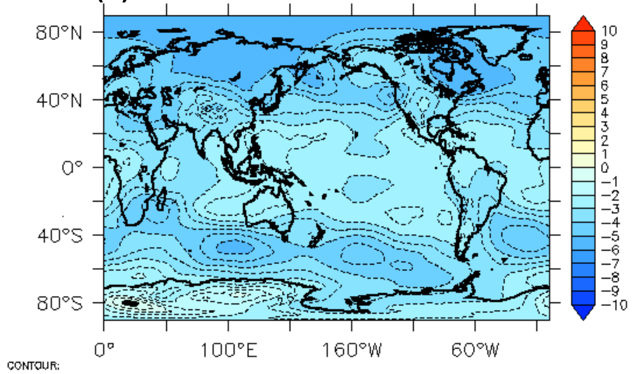




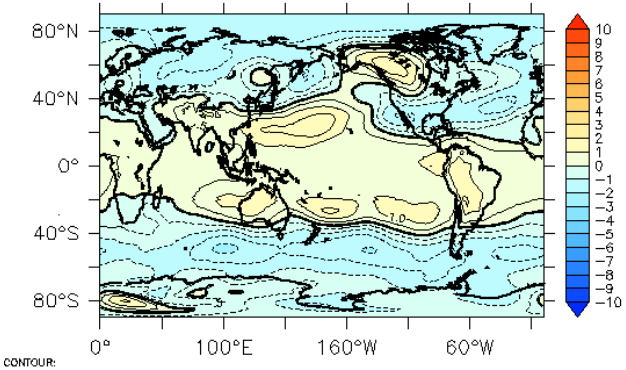
(a) TT bias with SAS+ZC



(b) TT bias with Rev-SAS+ZC



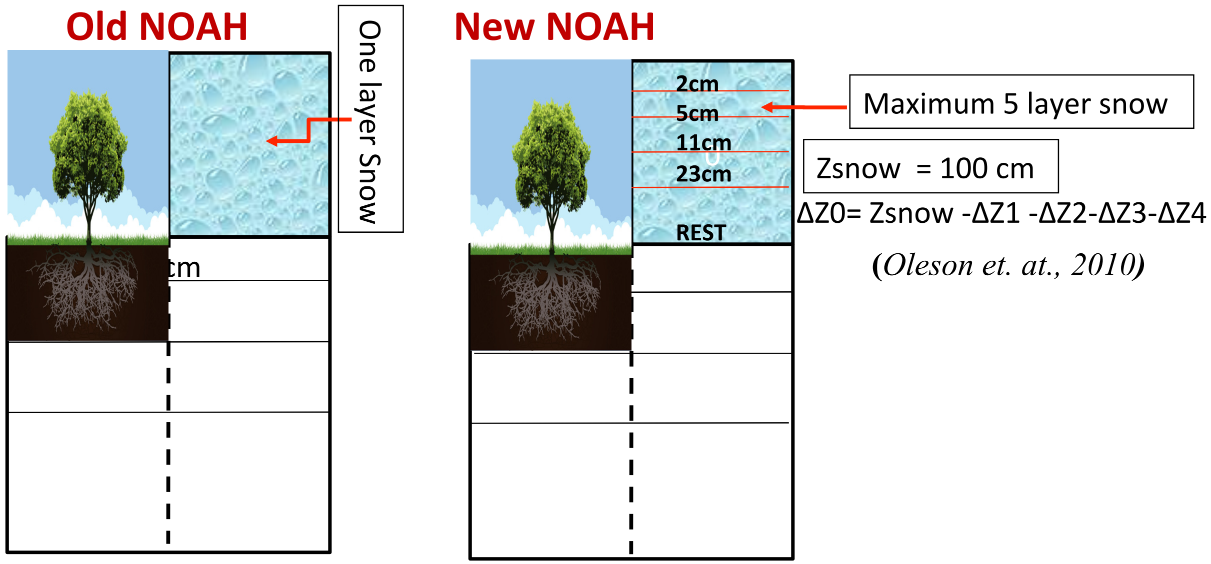
(c) TT bias with Rev-SAS + r2ZC



- **A.** **Improvement of physical processes (e.g. Microphysics, Convection, Land surface, Radiation, PBL etc.) are important for better forecast.**
- **B.** **Integration of different component of physical processes are also similarly crucial.**
- **C.** **Basic research for understanding the individual process rates are important.**
- **D.** **Need 2-moment microphysical parameterization to account aerosol effect in Global climate model.**

Development of Snow Physics in NOAH LSM

Subodj Saha, Samir Pokhrel, Hemant Choudhary, Anupam Hazra, etc.



Net energy at surface is given by

$$FNET_{surf}=(1-\alpha)S\downarrow+L\downarrow-\sigma T_s^4-G-H-LH$$

Where α is albedo, $S\downarrow$ is downward shortwave, $L\downarrow$ is downward longwave, σT_s^4 is longwave emitted, G is ground heat flux, H is sensible heat flux, LH is latent heat flux.

Developments in Noah LSM

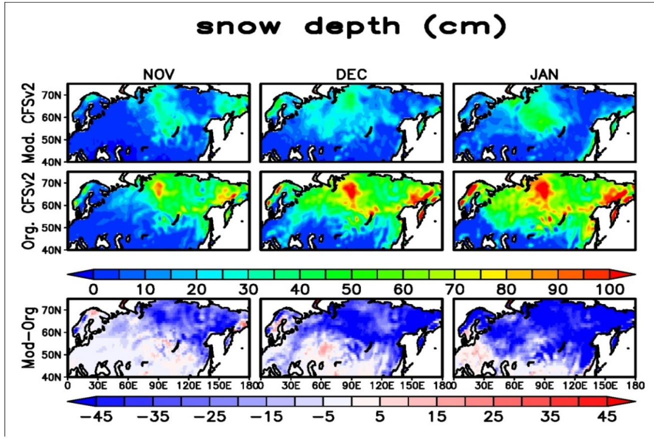
Old Noah	New Noah
1) Snow thermal conductivity (λ) is only a function of snow density (ρsno) and is given by $\lambda = 0.11631 \times 0.328 \times 10^{2.25}\rho_{sno}$	Snow thermal conductivity (λ) of each layer is function of thermal conductivity of air that trapped in snow and that of ice and snow density (*Jordan 1991*). It is given by $\lambda_i = \lambda_{air} + \left(7.75 \times 10^{-5}\rho_{sno,i} + 1.105 \times 10^{-5}\rho_{sno,i}^2\right)(\lambda_{ice} - \lambda_{air})$
2) Bulk method used for heat conduction through snow (snow is blended with first soil layer)	Discrete snow layers (maximum 5) and soil layer are used for calculation of heat and moisture transfer. (*Oleson et. at., 2010*)
3) No compaction/snow morphology	Three types of compaction is added (*Anderson* 1976) 1. Destructive metamorphism 2. Overburden due to load pressure 3. Melting
4) No explicit representation of ice, liquid water and air in the snow	Explicit representation of ice, liquid water and air in the snow

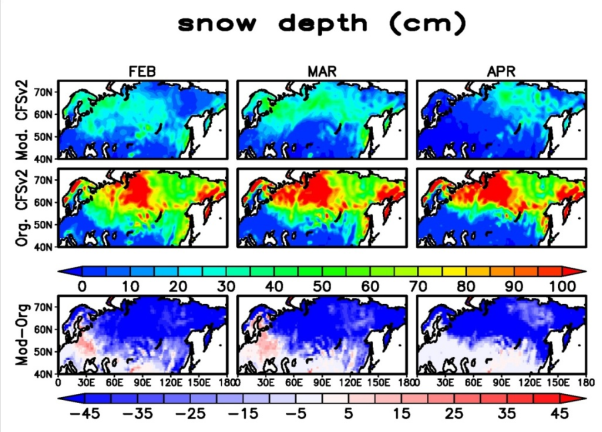
Developments in Noah LSM

Old Noah	New Noah
5) Snow melting/refreezing depends on bulk temperature and available energy	Melting can take place at the bottom or top snow layer. Snow melt water infiltrate through snow layer (which also depends on water holding capacity) and adds to the top soil layer
6) No combination/subdivision	If snow layer become thicker/thinner that prescribed maximum/minimum limit, snow layer subdivision/combination are based on Jordan (1991) according to certain rule

Major Achievements during 2014-2015

ILS is incorporated in CFSv2, which involves incorporation of five prognostic variables into ESMF, initial conditions, restart file





- **A preliminary result from the simulation of one year it is evident that amount of snow is much reduced in new version of CFSv2**
- **There is further scope to improve snow depth simulation using new schemes (continuing)**

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2015JD024629

Key Points:

- Compare the simulation and prediction skills of AISMR at two atmospheric horizontal resolutions
- AISMR variance and prediction skill are better represented in the high-resolution CFSv2
- Improved simulation of mean climate and IOD-ISM teleconnection in high resolution is reported

Indian summer monsoon rainfall simulation and prediction skill in the CFSv2 coupled model: Impact of atmospheric horizontal resolution

Dandi A. Ramu[1], C. T. Sabeerali[1,2], Rajib Chattopadhyay[1], D. Nagarjuna Rao[1], Gibies George[1], A. R. Dhakate[1], K. Salunke[1], A. Srivastava[1], and Suryachandra A. Rao[1]

[1]Program for Seasonal and Extended Range Prediction of Monsoon, Indian Institute of Tropical Meteorology, Pune, India,
[2]Center for Prototype Climate Modeling, New York University Abu Dhabi, Abu Dhabi, United Arab Emirates

- Improved Monsoon Simulation by
  - Reducing cold bias in tropics
  - Enhancing tropospheric temperature over tropical oceans
  - Improved telecommections

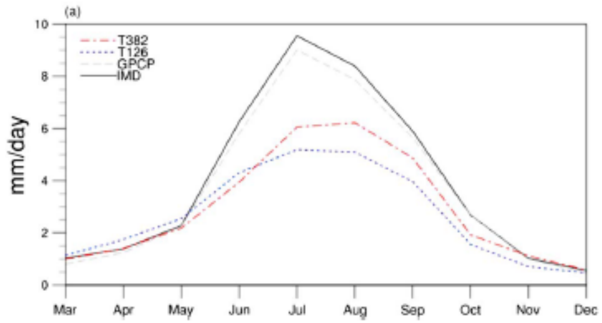
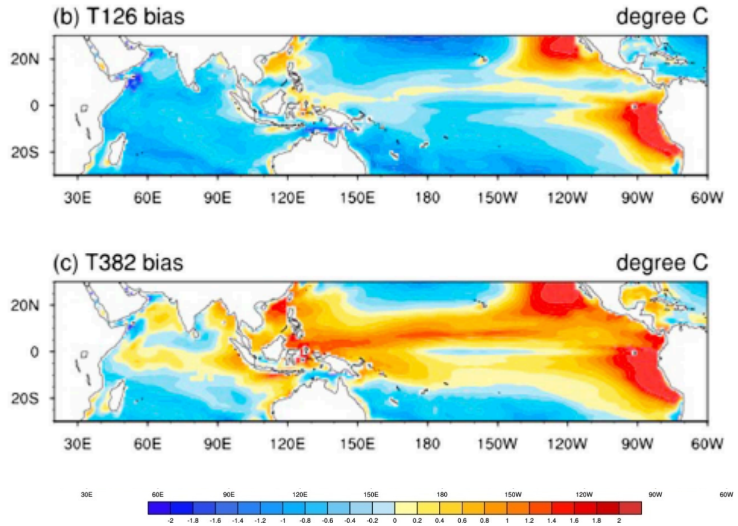
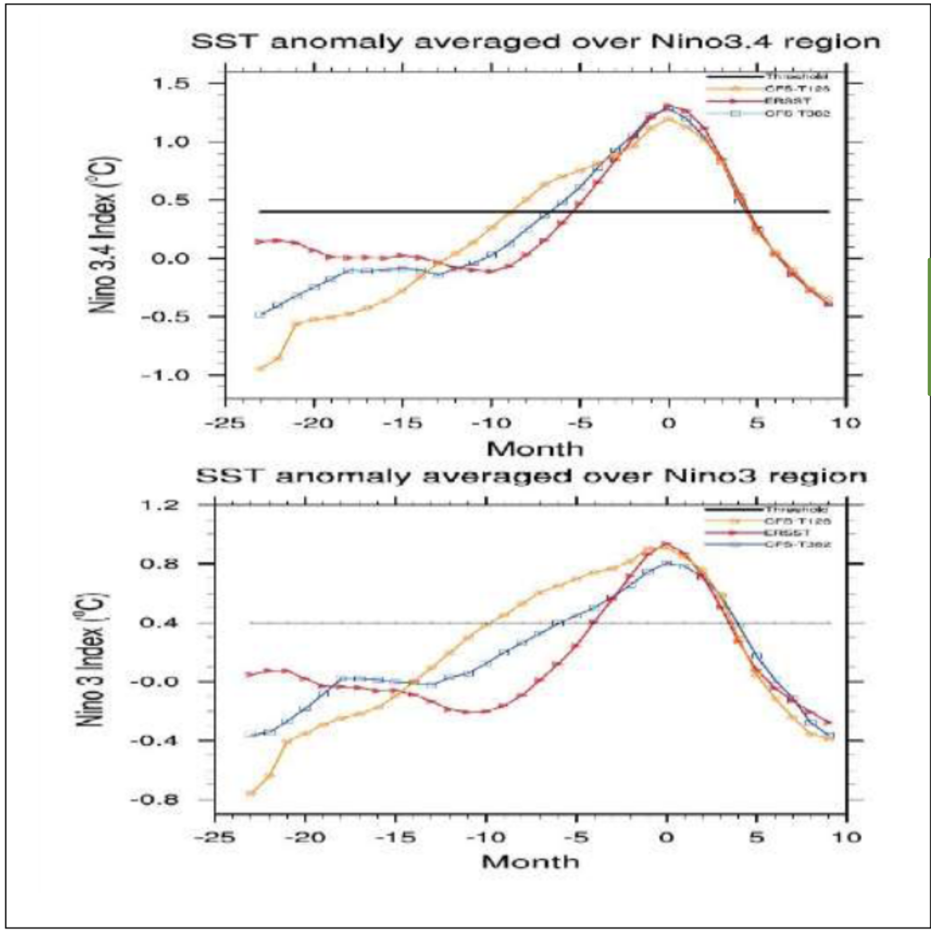


Figure 1. Annual cycle of Indian landmass rainfall simulated in T382 and T126 hindcast runs along with observations.





Improved Simulation of ENSO evolution in High resolution model

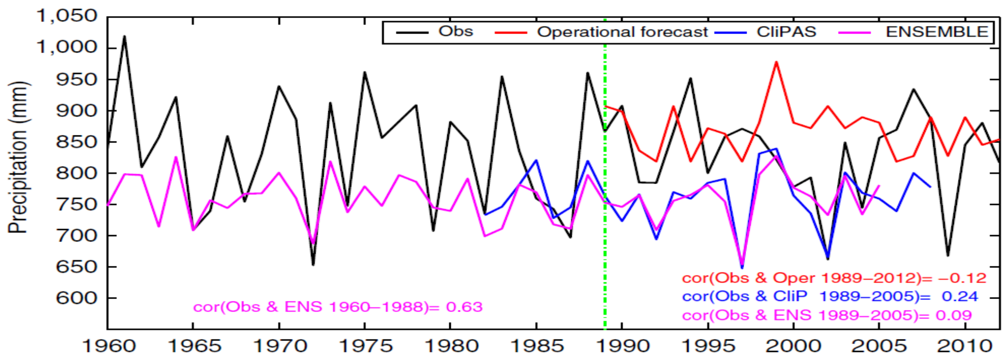
ENSO evolution is Better in high resolution model

(Unit : degree Kelvin) (a) **Upper Tropospheric Temperature**	Observations (degree Kelvin)	T126 (degree Kelvin)	T382 (degree Kelvin)
North Box (5N-35N,40E-100E)	251.4	250.2	251.7
South Box (15S-5N, 40E-100E)	249.1	248.6	250.2
TT Gradient (NB-SB)	2.3	1.6	1.5
(b) Seasonal Mean and Standard Deviation of rainfall over Indian landmass and Nino 3.4 index			
	Observations	T126	T382
AISMR JJAS Mean Rainfall (mm/day)	7.5	4.6	5.3
AISMR JJAS Standard Deviation (mm)	0.6	0.4	0.5
Nino 3.4 Standard deviation	0.7	0.6	0.7

Teleconnections	Observations	T126	T382
AISMR vs NINO3.4 (1981-2008)	-0.46	-0.74	-0.78
CIR vs EIOD (1981-2008)	-0.38	+0.47	+0.33
d) After excluding 7 years of common failure			
	Observations	T126	T382
AISMR vs NINO3.4 (21 years)	-0.61	-0.72	-0.83
CIR vs EIOD (21 years)	-0.43	+0.59	+0.26
e)Accumulated Rainfall and standard deviation(STD: in parenthesis) in mm			
Accumulated AISMR and STD (mm)	Observation(IMD) 918.3(77.4)	T126 566.1(50.7)	T382 643.6(67.0)
Accumulated AIR and STD in June (mm)	187.8(25.4)	129.3(14.6)	118.3(17.9)
Accumulated AIR and STD in July (mm)	296.1(41.2)	160.9(22.5)	187.8(24.4)
Accumulated AIR and STD in AUG (mm)	260.2(27.9)	158.0(16.9)	193.1(25.0)
Accumulated AIR and STD in SEP (mm)	177.1(34.2)	118.9(16.9)	146.2(19.8)

Impact of the developments on ISMR Seasonal Prediction

	ORIG	NEWSAS
AILR (IMD)	0.30	0.37
AILR (GPCP)	0.34	0.52
NINO 3.4	0.55	0.56
NINO 3	0.54	0.58
NINO 4	0.50	0.48
IOD E	0.49	0.61
IOD W	0.59	0.33

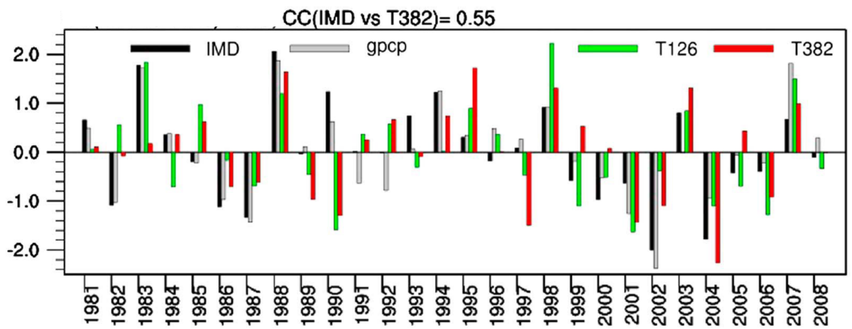


IMD operational model skill for 1989-2012 period is -0.12

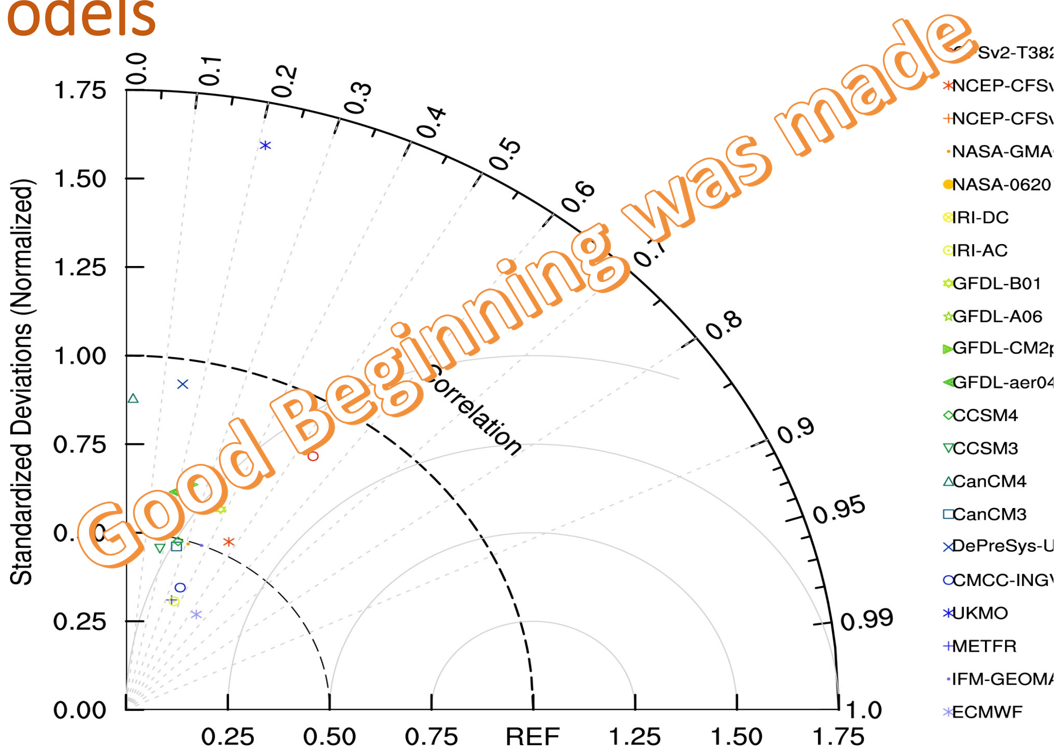
Wang et al., (2015)

High resolution model skill for 1982-2008 period is 0.55

Ramu et al., (2016)



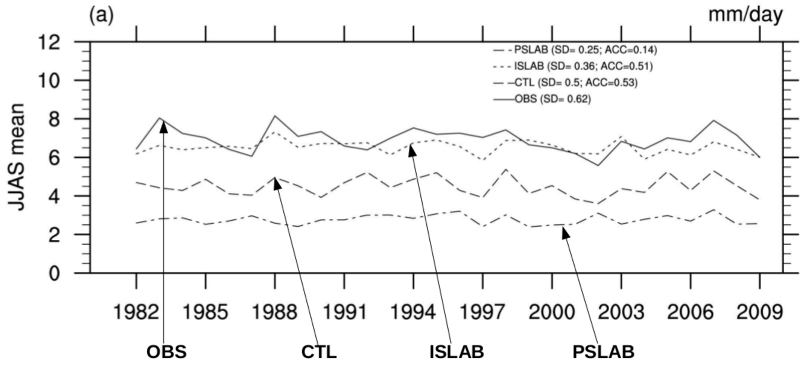
Monsoon Seasonal Prediction Skill in US (NMME) and Europe (ENSEMBLE) Models



Improvement is needed in Indian Ocean Dynamics

RMetS
Royal Meteorological Society
ATMOSPHERIC SCIENCE LETTERS
Atmos. Sci. Let. (2015)
Published online in Wiley Online Library
(wileyonlinelibrary.com) **DOI:** 10.1002/asl.599

George et. al., 2015



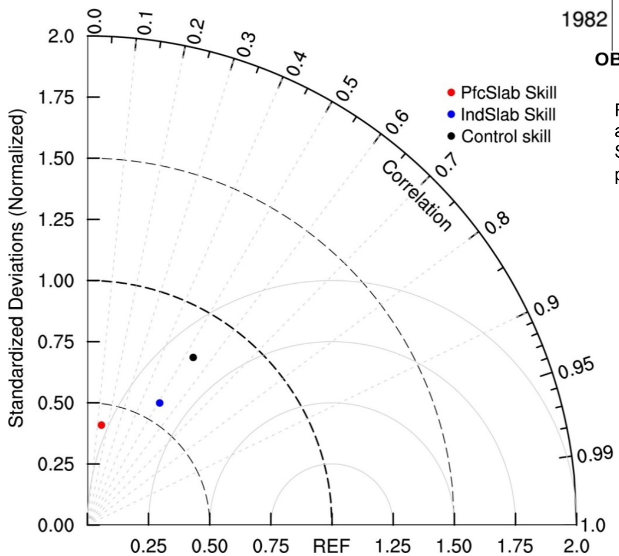
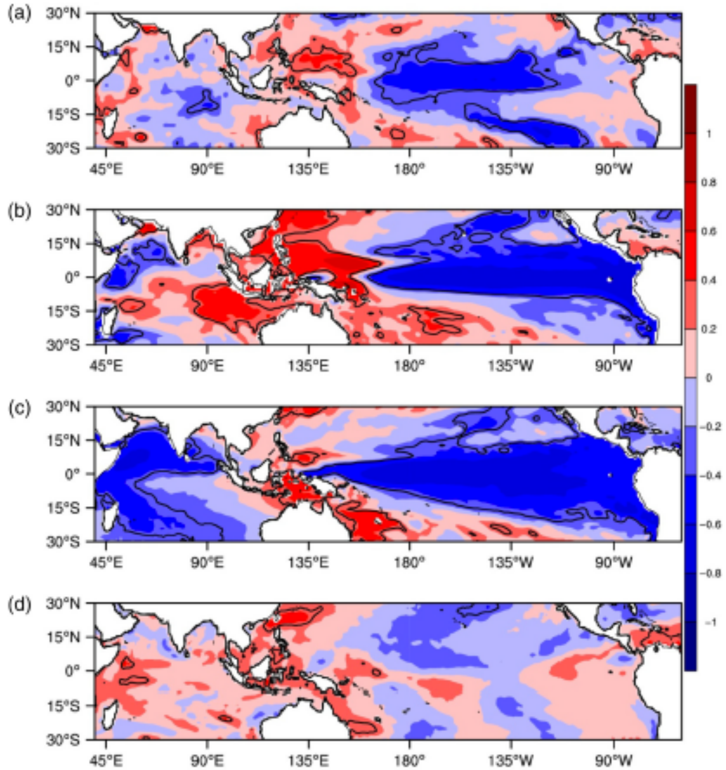


Figure: All India Summer Monsoon Rainfall (AISMR) time series observed and simulated by CFSv2 CTL run, ISLAB run and PSLAB run. Interannual Standard Deviation (SD) and Anomaly Correlation Coefficient (ACC) are provided in the legend.

Experiment	Mean	SD	ACC
OBS	6.9	0.62	Ref
CTL	4.5	0.5	0.53
ISLAB	6.5	0.36	0.51
PSLAB	2.8	0.25	0.14

Improvement of the Indian Ocean coupled dynamics is essential for further improvement of the AISMR prediction skill in CFSv2.

In appropriate teleconnections in Indian Ocean.



Observation

CFS T126

ISLAB

PSLAB

Future Directions

- Resolution and appropriate improvements in parametrization schemes should go hand in hand
- Improvement of Ocean Parametrization Schemes
- Improved teleconnections
- Dynamical Core should be modified to accommodate very high resolution challenges
- Better initial Conditions through better assimilation Techniques: Coupled data Assimilation

Thank You

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ICTP: Dr. Fernando Quevedo, Dr. Fred Kucharaski, Lisa Iannitti

COLA/GMU: Prof. Shuklat