IITM Earth System Model
(IITM ESM)

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Outline

- **Main components and features of IITM ESM**
- **Improvements in IITM ESM**
  - **TOA energy imbalance**
  - **Improve simulation of mean monsoon rainfall over South Asia**
  - **Improve distribution of sea-ice concentration**
- **Future Plans**

Roadmap for Earth System Model (ESM) development

Start with an atmosphere-ocean coupled model with realistic mean climate

- Fidelity in capturing the global and monsoon climate
- Realistic representation of monsoon interannual variability
- Features of ocean-atmosphere coupled interactions
- …

Include components / modules of the ESM

- Biogeochemistry
- Interactive Sea-ice
- Aerosol and Chemistry Transport
- …

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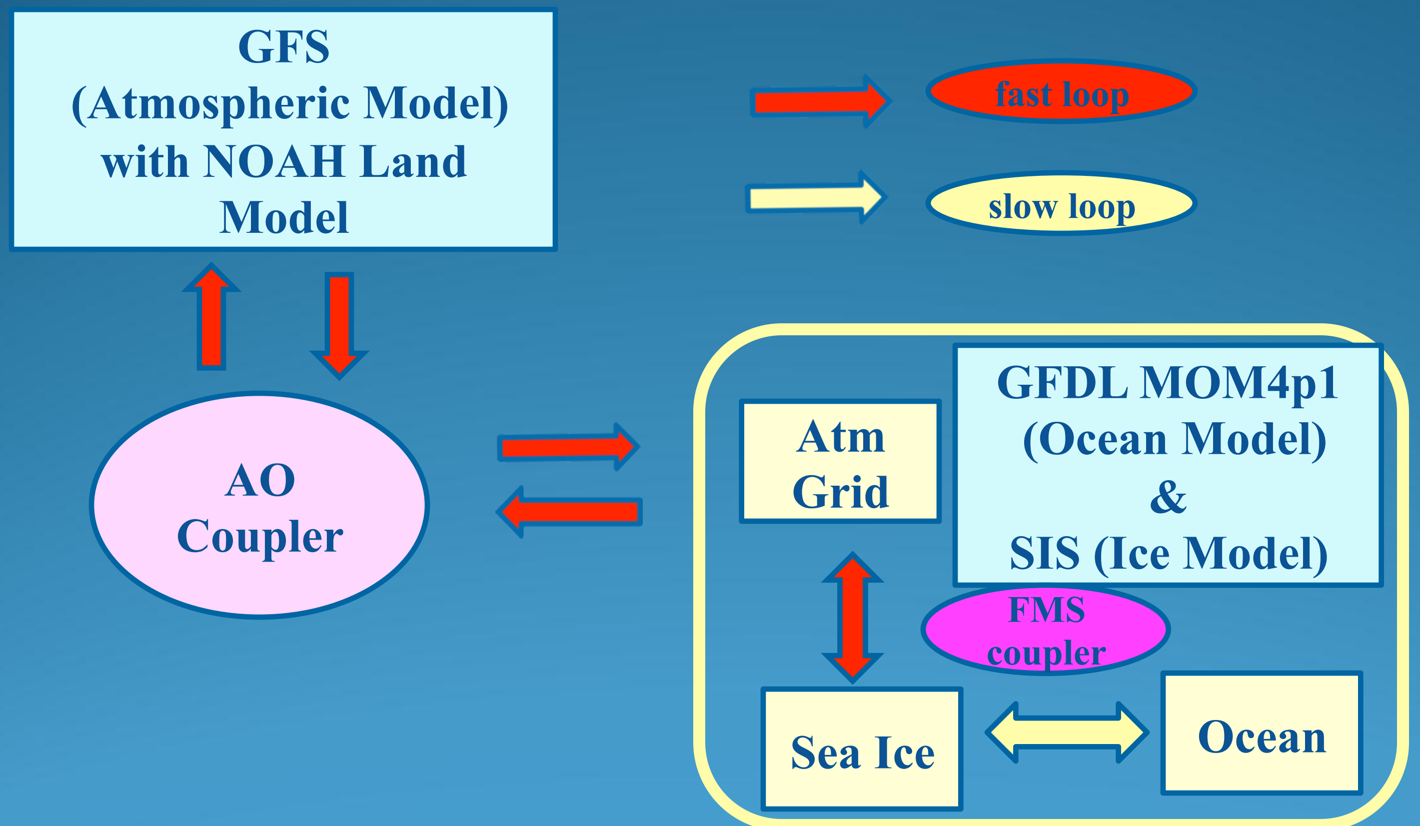
Schematic of IITM ESM



Scalability : 8 Simulation Year Per Day (SYPD)
: 7 SYPD with ocean BGC.

IITM Earth System Model (ESM1.0)
Based on Coupled Forecast System (CFS) T62L64

- **The Atmospheric Component : NCEP GFS (Global Forecast System) Model**
  (Courtesy : Dr. Shrinivas Moorthi, NCEP)

Horizontal resolution : T62

Spectral (spherical harmonic basis functions) with transformation to a Gaussian grid for calculation of nonlinear quantities and physics

Other supported resolutions from CFS :– T574, T382, T254, T190, T170 and T126

Vertical: 64 sigma – pressure hybrid levels

Sigma-Pressure hybrid coordinate system

Terrain following near the lower boundary

Constant pressure surfaces in the stratosphere and beyond

(15 levels below ~ 800 hPa and 24 levels above 100hPa.

NCEP GFS (Global Forecast System) Model

Model Physics

Nonlocal PBL scheme originally proposed by Troen and Mahrt (1986) and implemented by Hong and Pan (1996)

PBL height estimated iteratively from ground up using bulk Richardson number

Shallow convection parameterization

Massflux based shallow convection scheme based on Han and pan (2010)

Convection starting level is defined as the level of maximum moist static energy within PBL

- Cloud top is limited to 700 hPa

NCEP GFS (Global Forecast System) Model

Model Physics

Deep convection parameterization

- Simplified Arakawa Schubert (SAS) scheme (Pan and Wu, 1994, based on Arakawa-Schubert (1974)
- Modified Simplified Arakawa Schubert (SAS) scheme (Han 2010)

Large-scale condensation and precipitation

- The large-scale condensation and precipitation is parameterized following Zhao and Carr (1997)

Radiation

- Rapid Radiative Transfer Model

NCEP GFS (Global Forecast System) Model

Gases:

CO2 Distribution :

use prescribed global annual mean value

use observed global annual mean value

use observed monthly 2-d data table in 15° horizontal resolution

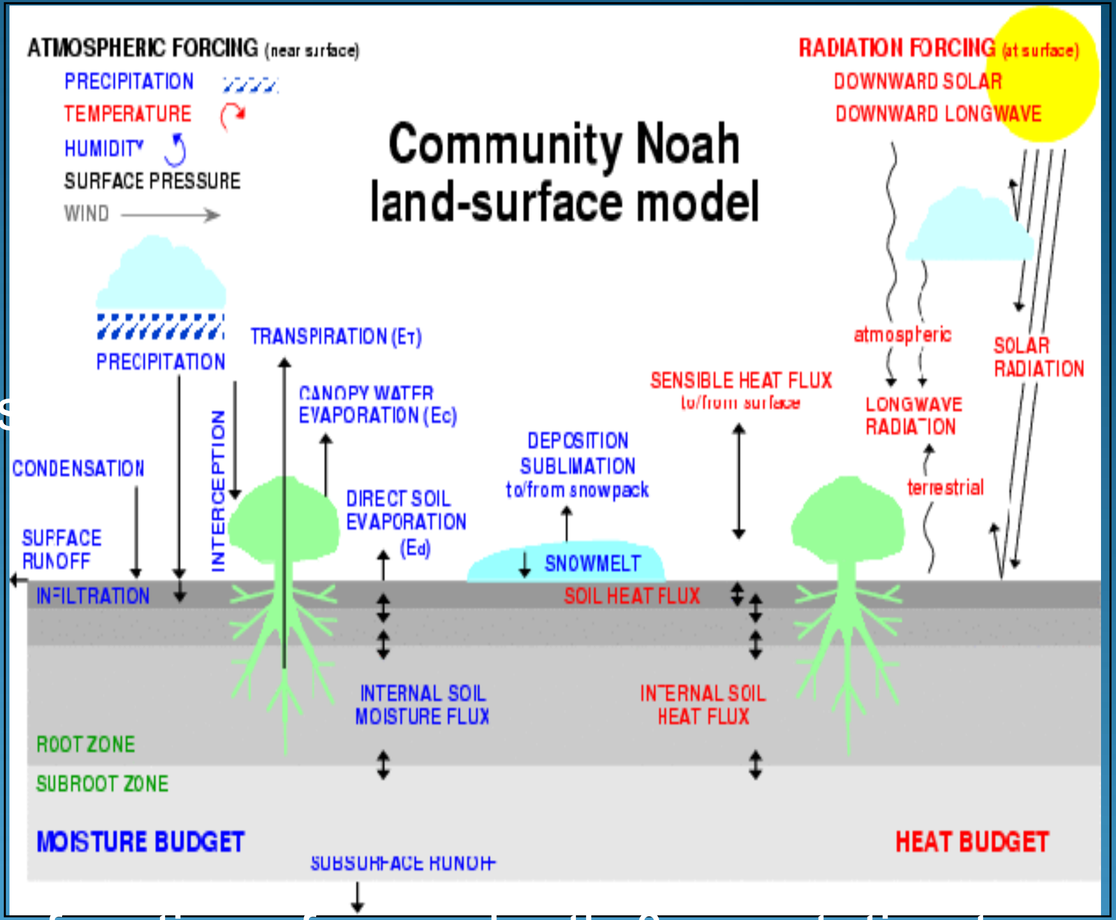
O3 Distribution : interactive or climatology

Rare Gases : (global mean climatological values)

CH4 - 1.50×10^{-6}	N2O - 0.31×10^{-6}	O2 - 0.209
CO - 1.50×10^{-8}	CF11 - 3.52×10^{-10}	CF12- 6.36×10^{-10}
CF22 - 1.50×10^{-10}	CF113- 0.82×10^{-10}	CCL4- 1.40×10^{-1}

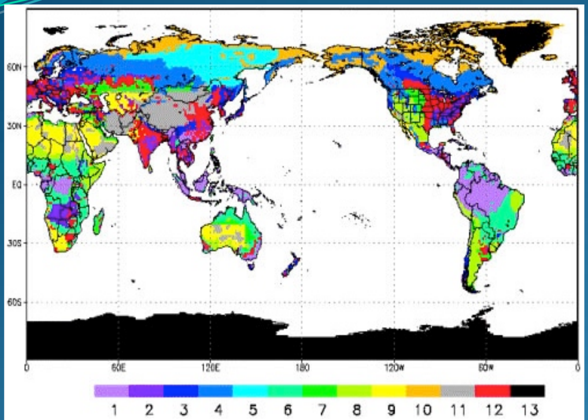
** all units are in ppmv

Noah land-surface model

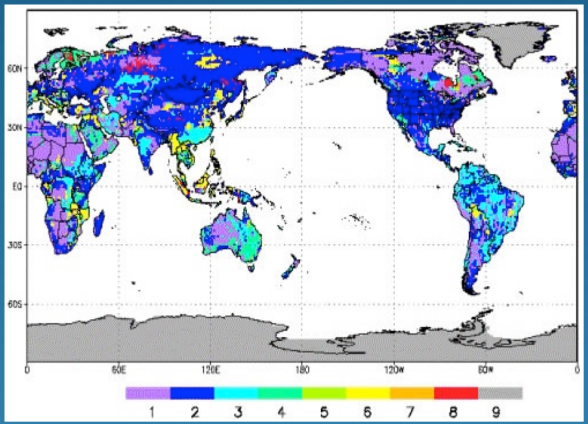


- Four soil layers :
  (10, 30,60, 100 cm thick).
- Vegetation (13) &
- soil (9) classes parameters
- Direct soil evaporation.
- Canopy interception.
- Patchy/fractional snow
- cover effect on surface
- fluxes; coverage treated as function of snowdepth & vegetation type.

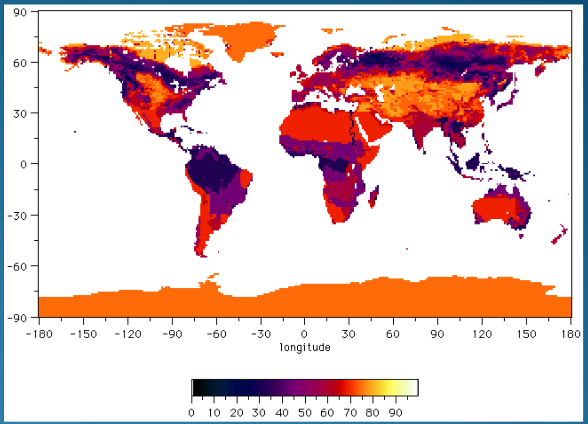
Land Data Sets



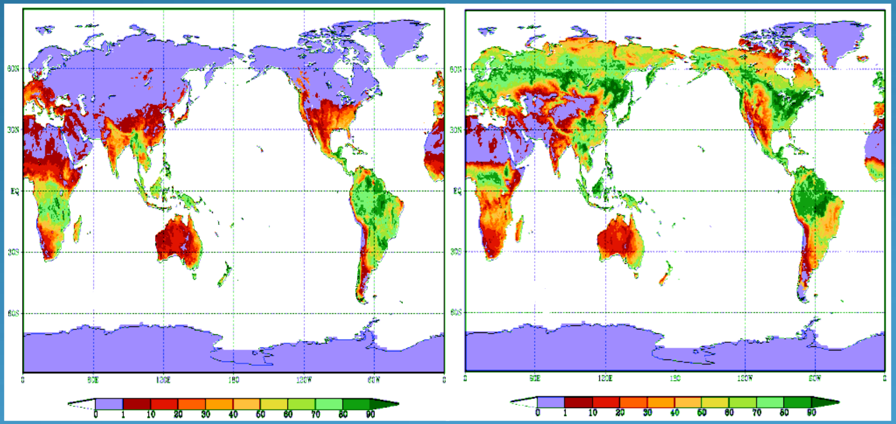
Vegetation Type
(1-deg, UMD)



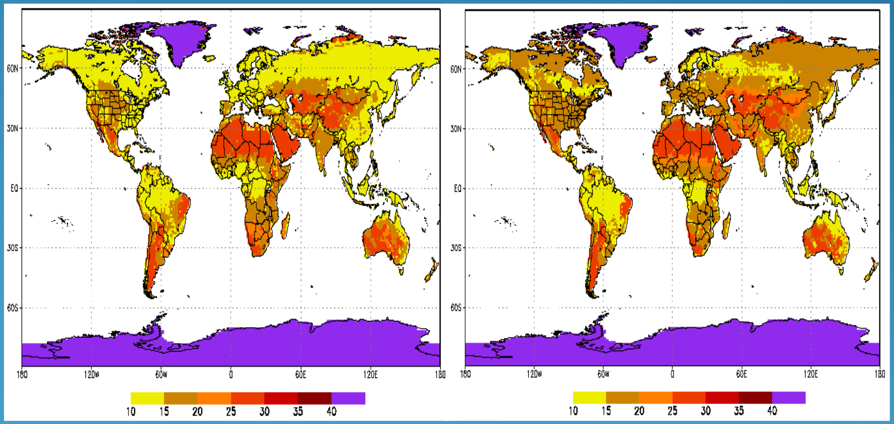
Soil Type
(1-deg, Zobler)



Max.-Snow Albedo
(1-deg, Robinson)



Green Vegetation Fraction
(monthly, 1/8-deg, NESDIS/ AVHRR)



Snow-Free Albedo
(seasonal, 1-deg, Matthews)

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Ocean and Sea-ice components

Ocean component :

- MOM4p1 (GFDL, Griffies et al. 2009)
- Horizontal resolution : 720x400 (~ 0.5deg) and 360x200 (~1deg)
- Vertical levels : 50 vertical levels from the surface to 5000 m
  27 levels in the upper 400 m of the water

Interactive ocean biogeochemisty component: TOPAZ model

Sea ice component :

- Sea Ice Simulator (SIS; GFDL, Delworth et al. 2006; Winton 2000)
- Dynamical sea ice model
- Three vertical layers, one snow and two ice
- Five ice thickness categories.

Coupling and Initialization

- The component models pass fluxes across their interfaces through an exchange grid system, which enforces the conservation of energy, mass, and tracers.

- The atmosphere, land, and sea ice exchange quantities such as heat and momentum fluxes every 10 min

- The ocean tracer and atmosphere–ocean coupling time step is 60 min.

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The IITM Earth System Model: Transformation of a Seasonal Prediction Model to a Long Term Climate Model

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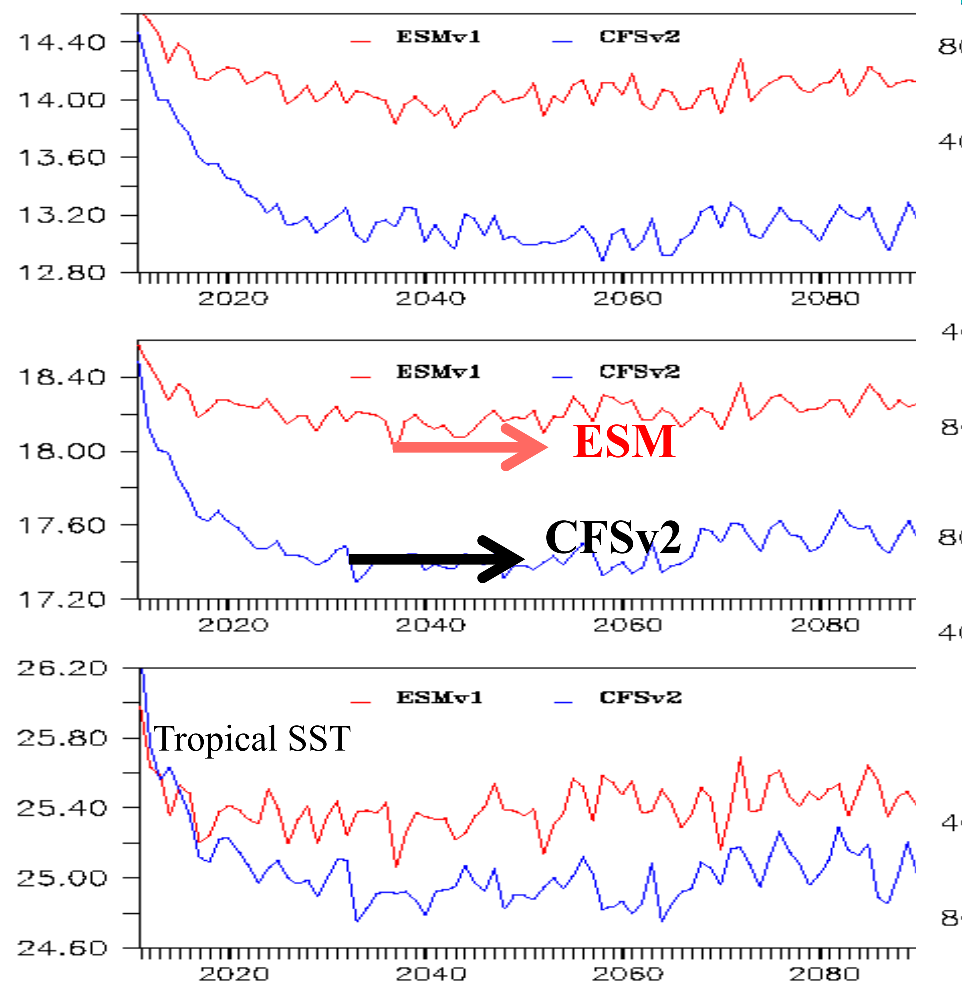
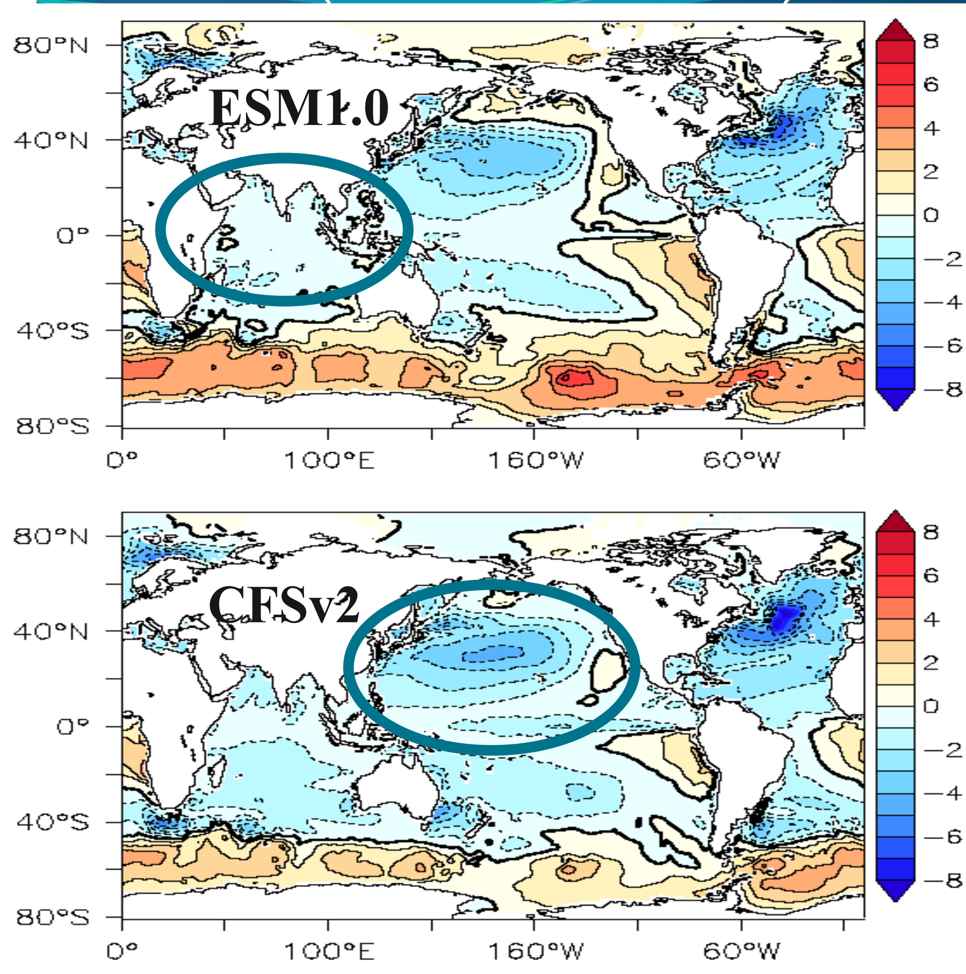
Global mean surface (2m) temperature



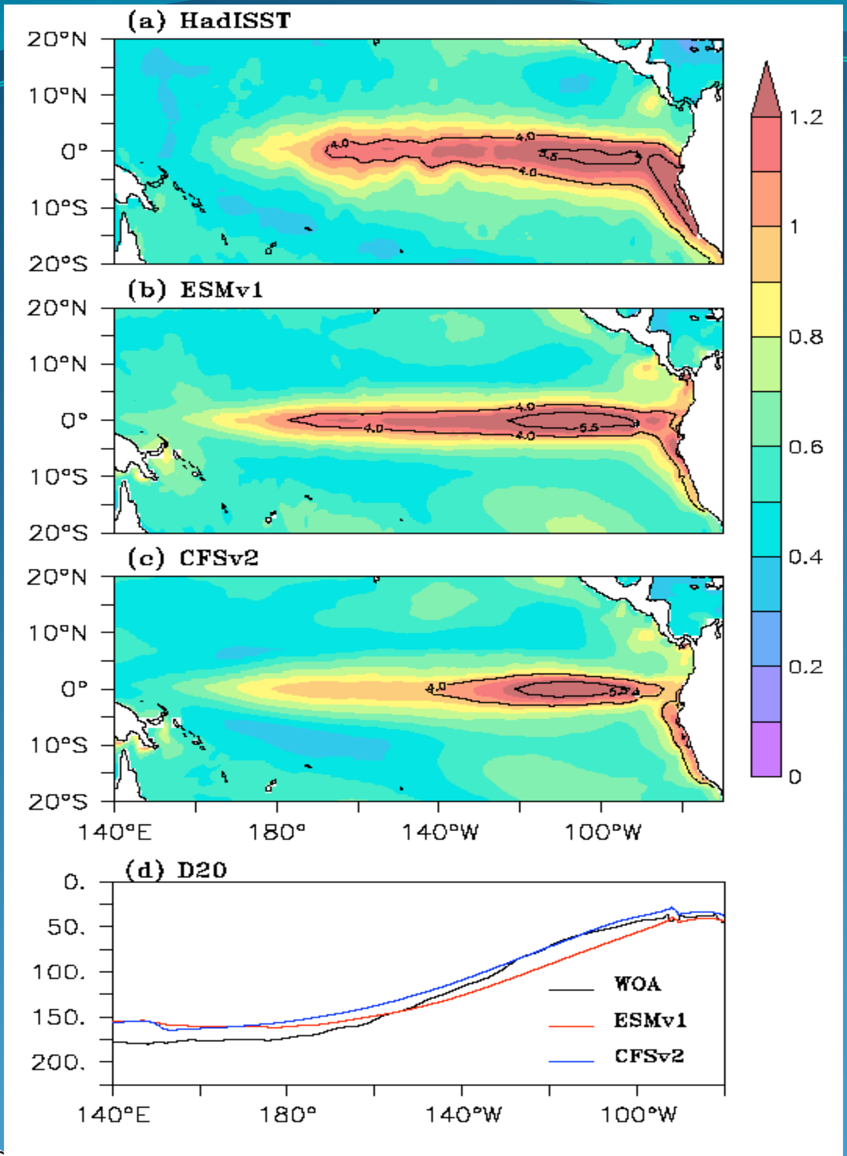
Annual mean SST difference (Model minus WOA)

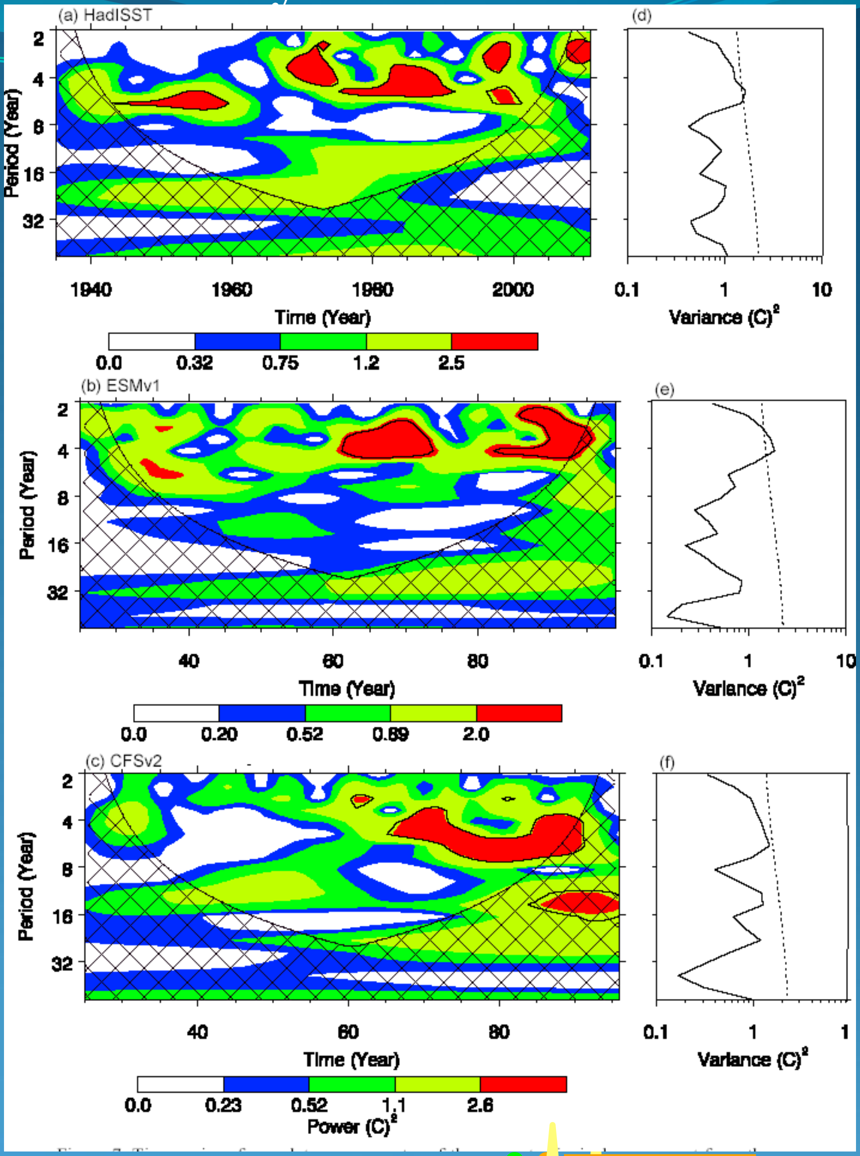


The drift in surface temperature and SST is minimum in IITM ESMv1 (red line) compared to CFSv2 (blue line).

Significant reduction in cold SST bias in tropical IO and subtropical Pacific

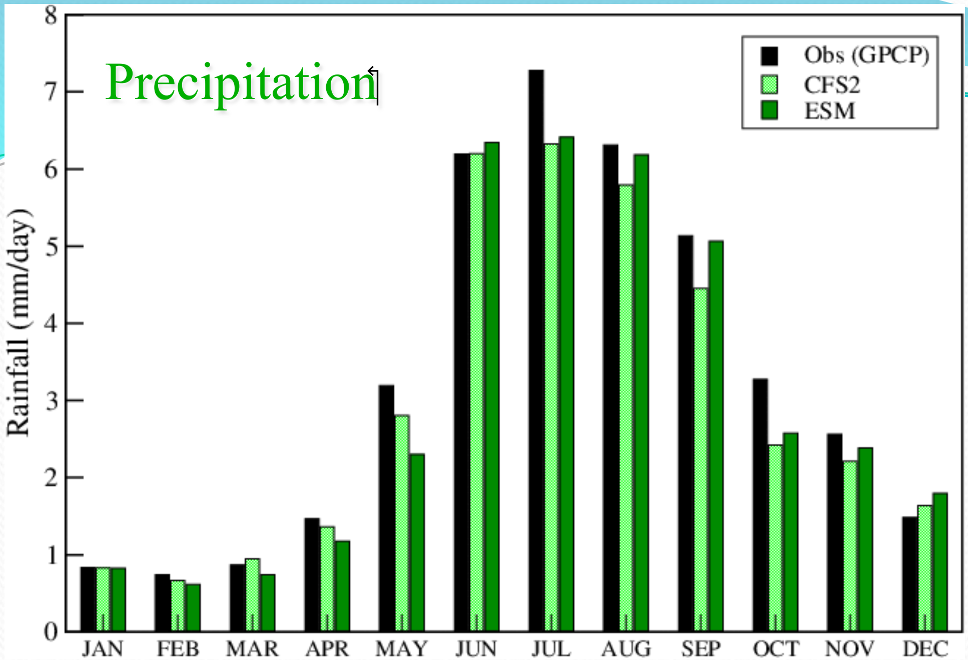
Inter-annual variability



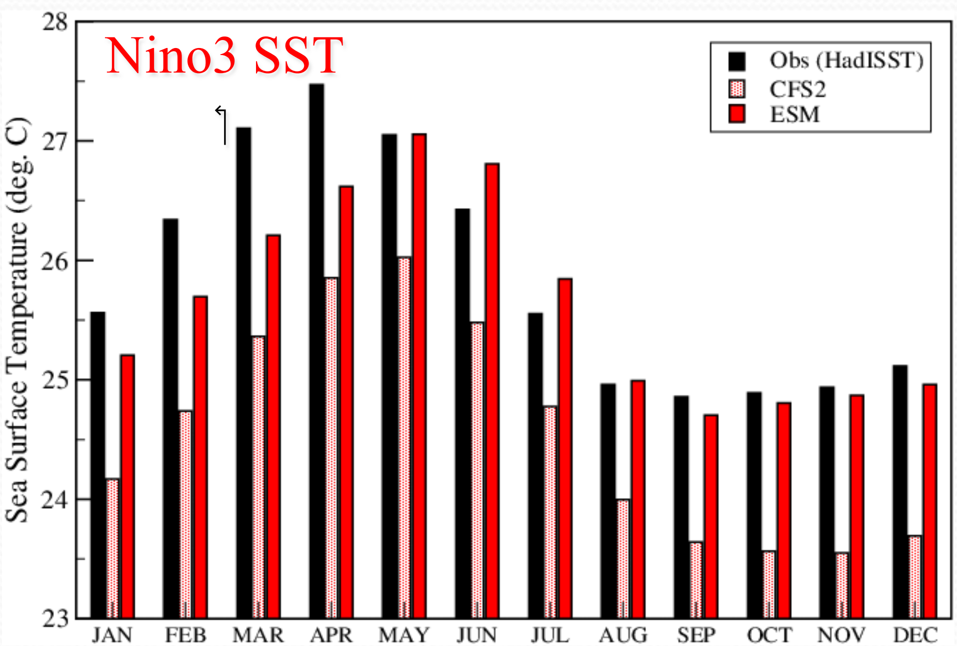


Precipitation

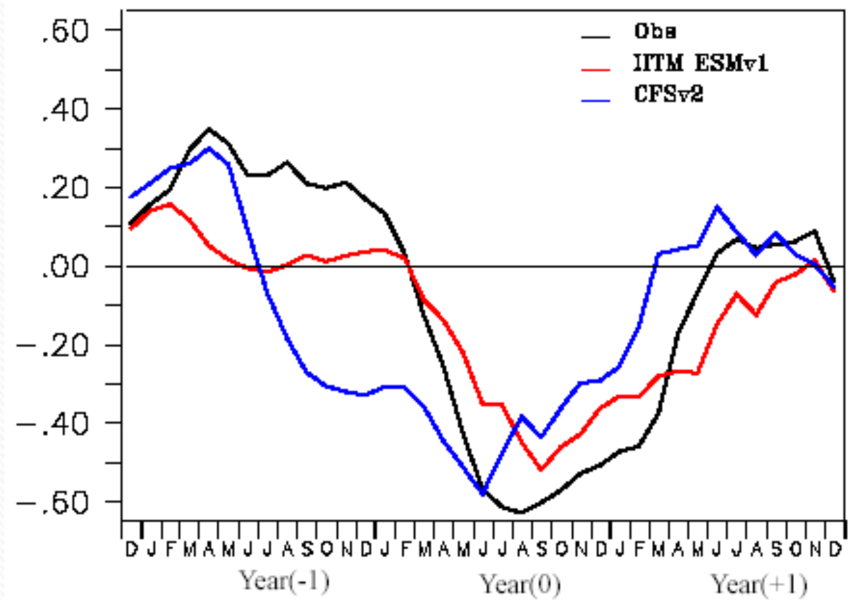
(5N-35N; 65E-95E)



Seasonal cycle of precipitation and Nino 3 SST is captured in ESM & CFSv2

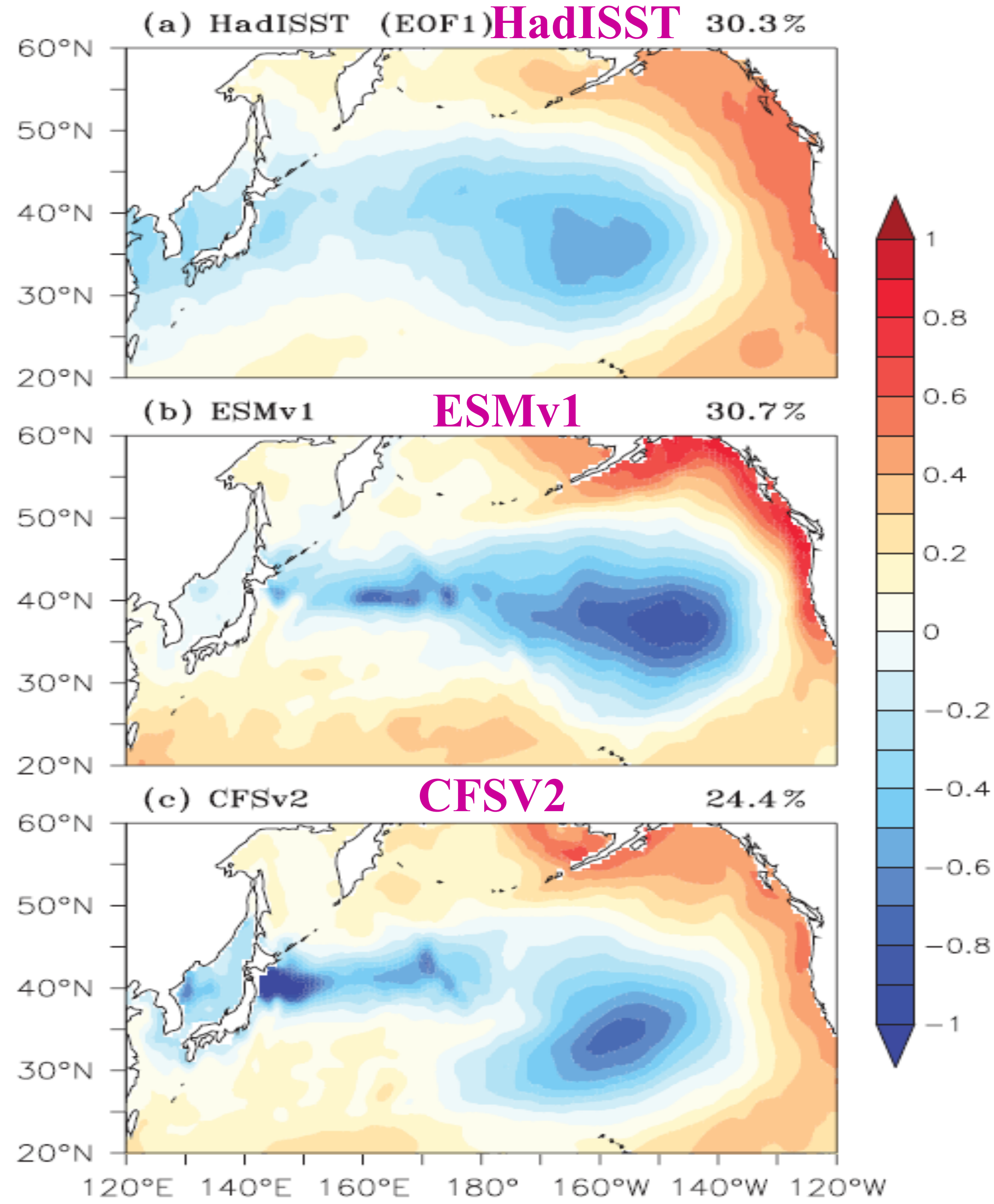


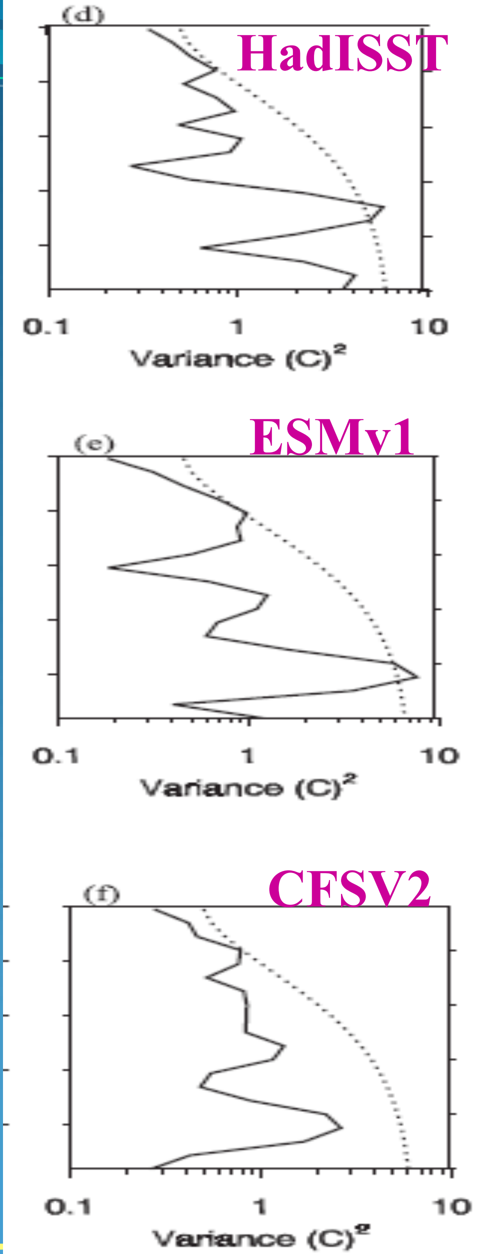
ENSO-Monsoon relationship



Lagged correlation between ISMR and Nino3 SST in the preceding/following months are captured well in IITM ESM as compared to CFSv2

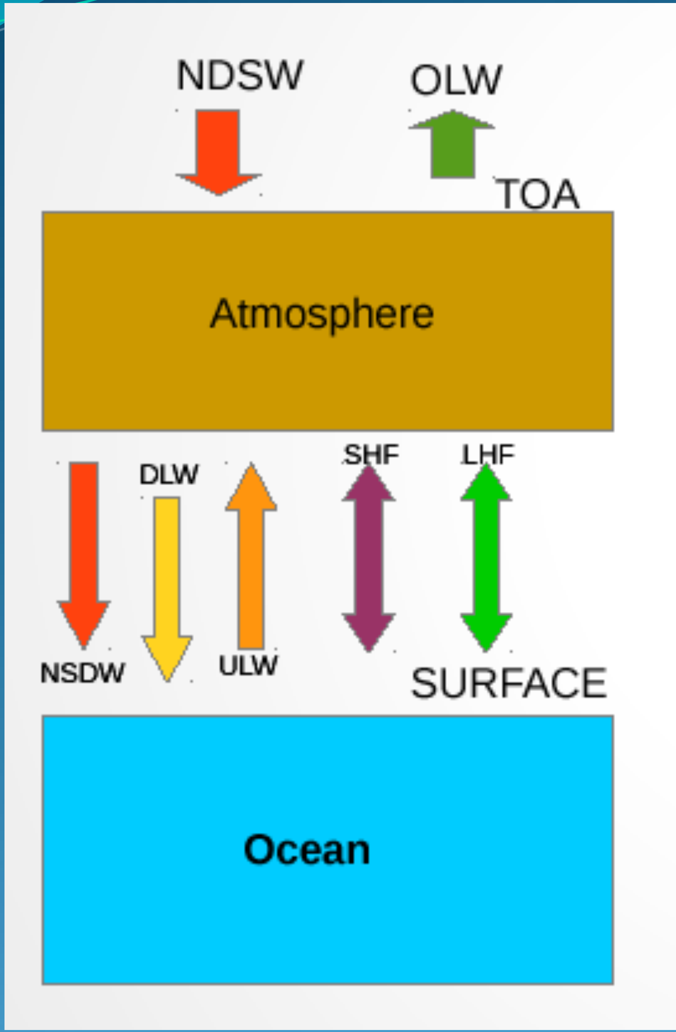
PDO - IITM ESM


(a) HadISST (EOF1)
HadISST
30.3%
(b) ESMv1
ESMv1
30.7%
(c) CFSv2
CFSV2
24.4%
60°N
50°N
40°N
30°N
20°N
120°E 140°E 160°E 180° 160°W 140°W 120°W
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1


(d)
HadISST
0.1 1 10
Variance (C)²
(e)
ESMv1
0.1 1 10
Variance (C)²
(f)
CFSV2
0.1 1 10
Variance (C)²

Improvements in IITM ESM

Energy Balance of the Coupled System



NDSW – Net downward Short wave radiation

OLW- Outgoing Long wave radiation

DLW- Downward Long wave (depends on T of Atm)

ULW – Upward long wave (depends on T of Ocean)

SHF – Sensible heat flux

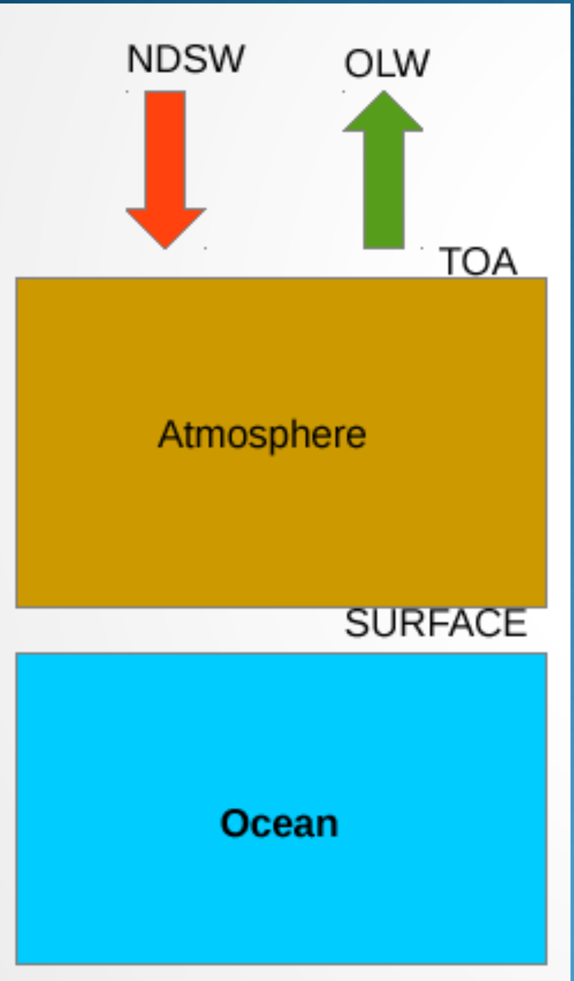
LHF – Latent heat flux

Surface Flux = NDSW – DLW +ULW +SHF+LHF

Net flux = TOA – Surface flux

Courtesy: Prajeesh

TOA Energy Balance



NDSW – Net downward Short wave flux at TOA

OLW – Outgoing Longwave flux (depends on layer temperature according to Stefan Boltzman law)

NDSW

Internal Energy (CpT) → **Incr. Temp**

Kinetic Energy (Winds)

(Friction)

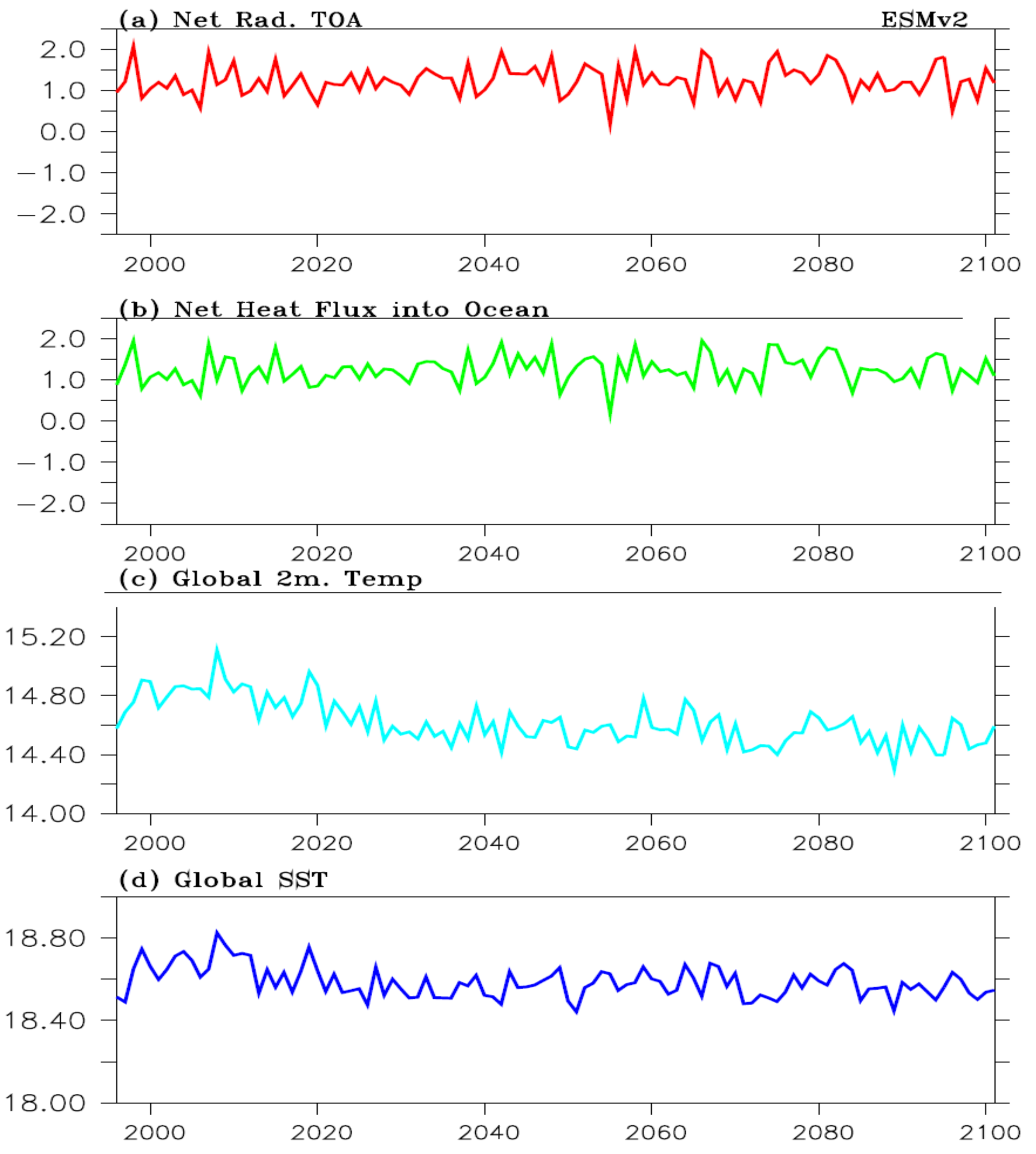
Missing in GFS

TKE dissipation heating (Han)

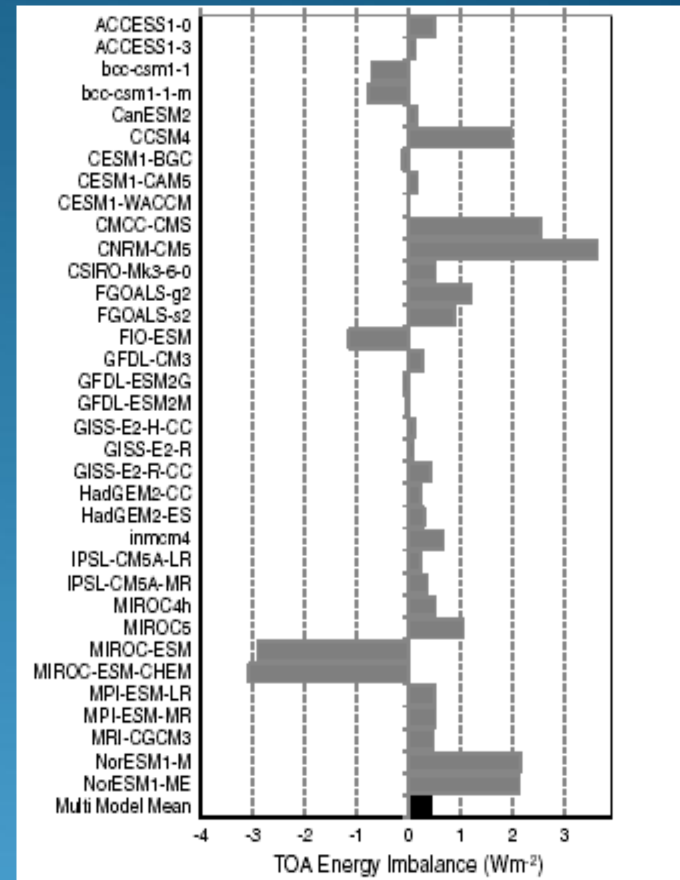
$$\varepsilon = \underbrace{-K_h \frac{g}{\theta_v}\frac{d\theta_v}{dz}}_{\text{buoyancy production}} + \underbrace{K_m \left|\frac{d\mathbf{u}}{dz}\right|^2}_{\text{shear production}}$$

Minimize atmospheric energy loss – Bretherton et al. 2012

Energy Balance in IITM ESM

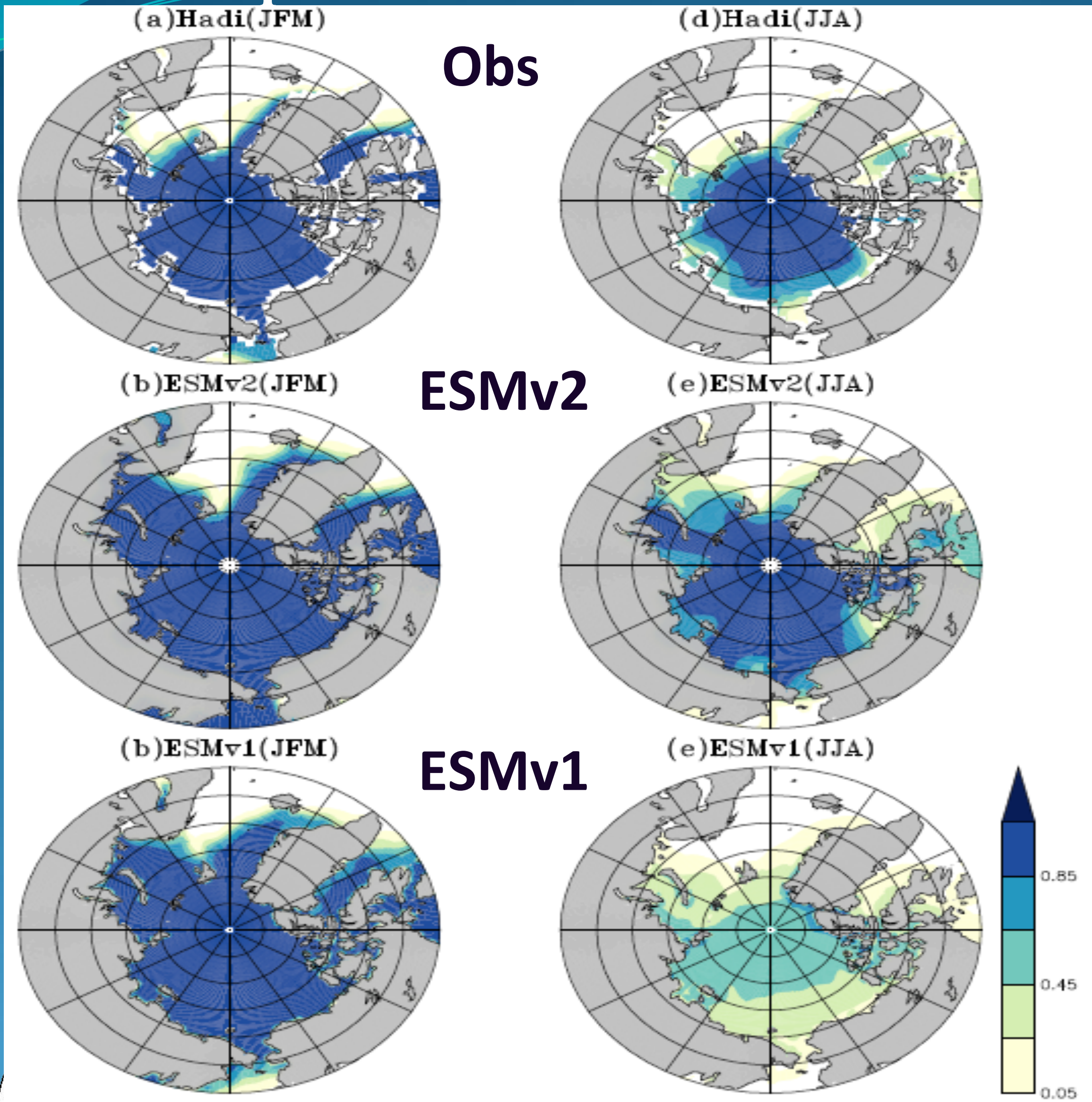


TOA Energy Imbalance (CMIP5 Models)

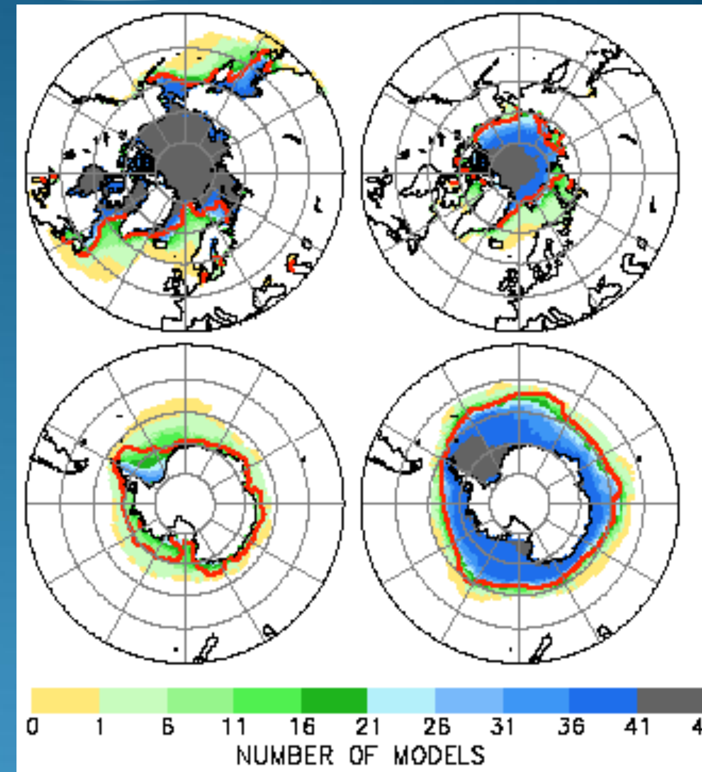


Preindustrial TOA (Wm^{-2}) Energy imbalance for CMIP5 Models (Forster et al., 2013)

Sea-Ice concentration in Summer Hemisphere in IITM ESMv2



Sea-Ice in CMIP5 models (IPCC AR5 Report)

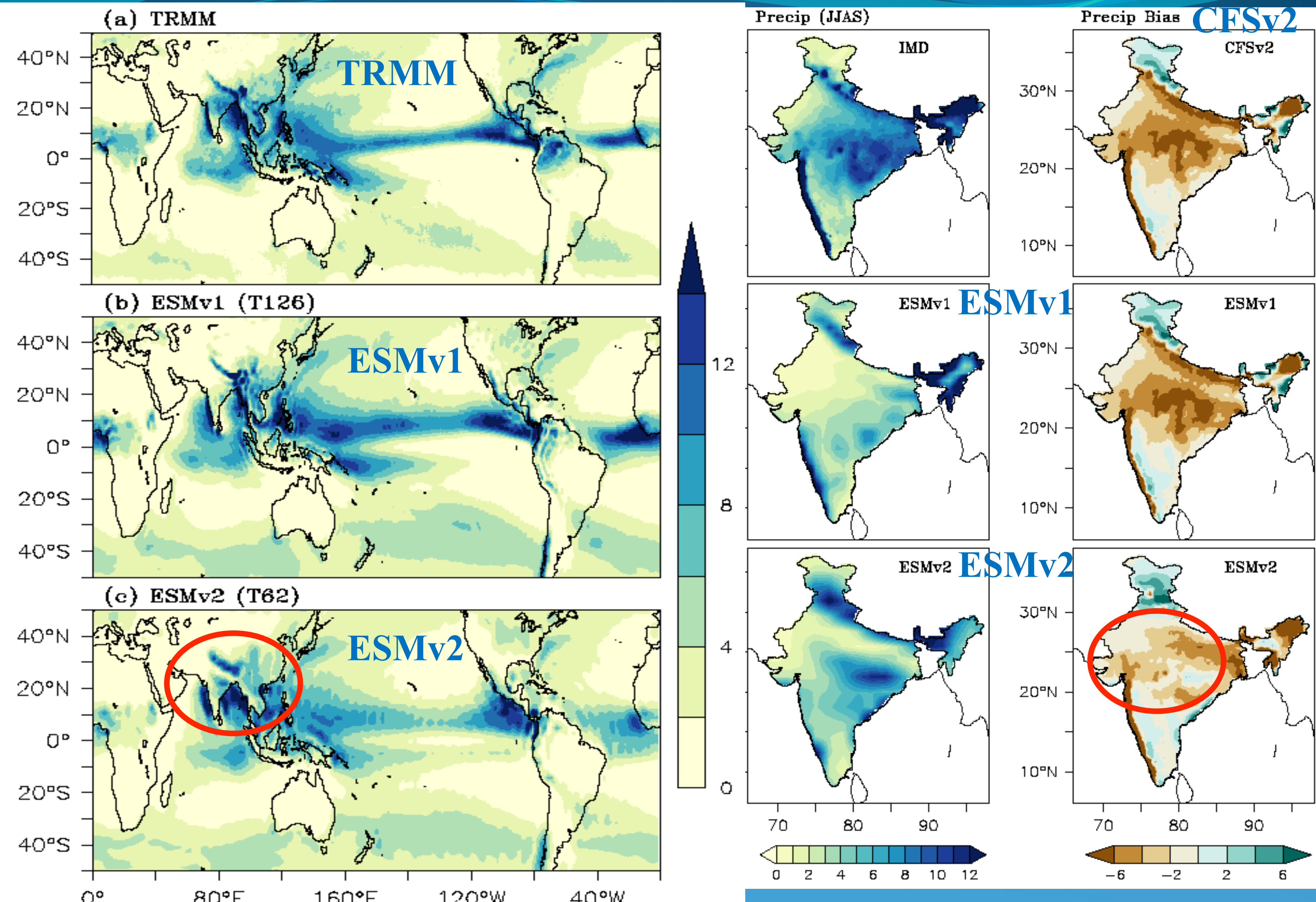


Depletion of NH sea-ice during Jan-Mar has reduced

SH sea-ice conc. during Jun-Aug has improved

Mean Monsoon Characteristics

Boreal summer monsoon (JJAS) precipitation (mm day^{-1})



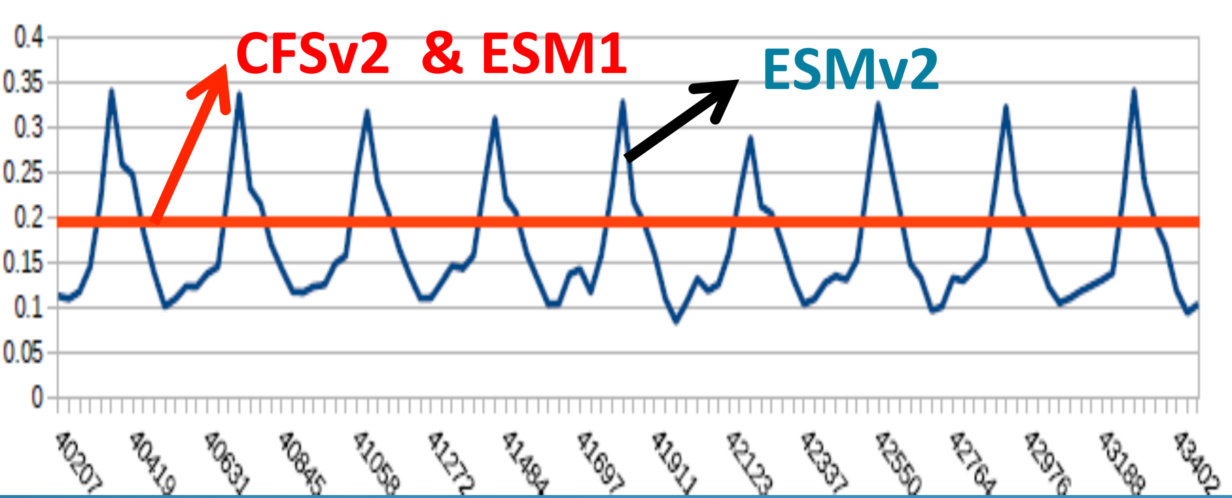
Mean Features of Hydrology in ESMv2

Water balance in ESMv2

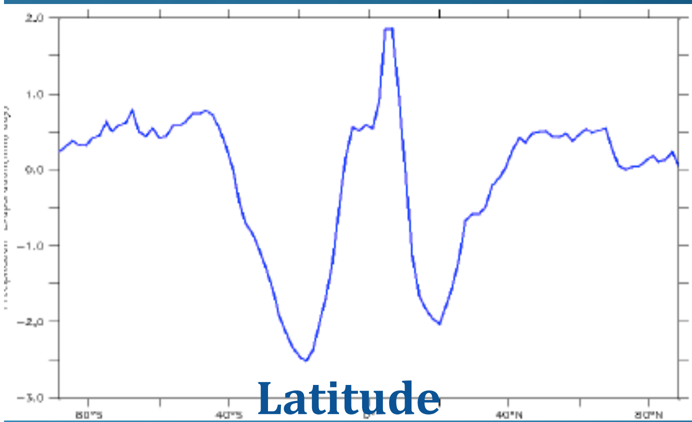
CFSv2 and ESMv1: Constant value of runoff was used in the Ice Model

ESMv2: Runoff calculated from Land Model & discharged into the nearest ocean point

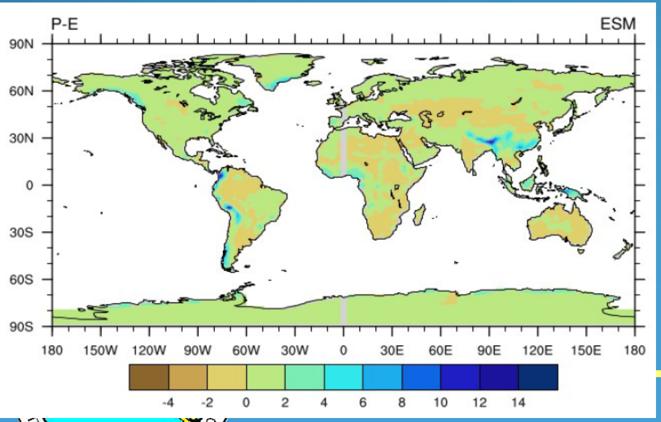
Runoff (kg m^{-2} s^{-1})



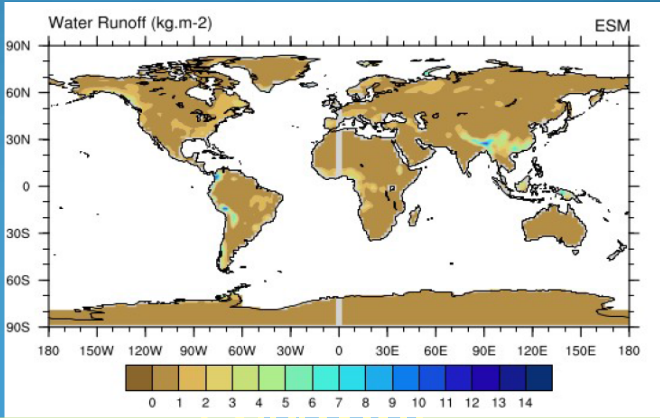
Zonal mean (P-E) in mm



Precipitation minus Evaporation



Runoff from Land Model

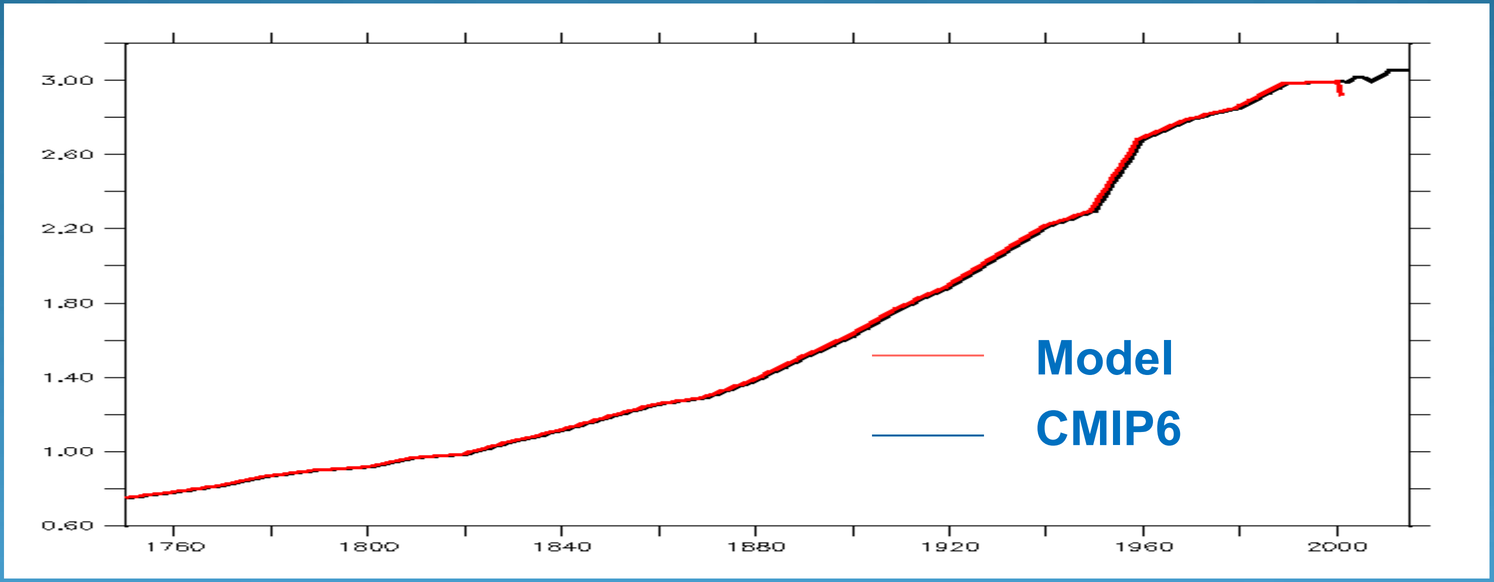


Hydrology statistics

Total Runoff from Land = 1.06×10^9 kg s^{-1}

Total Water Discharge into Ocean = 1.06×10^9 kg s^{-1}

Mean features of land-use/land cover changes implemented in ESMv2

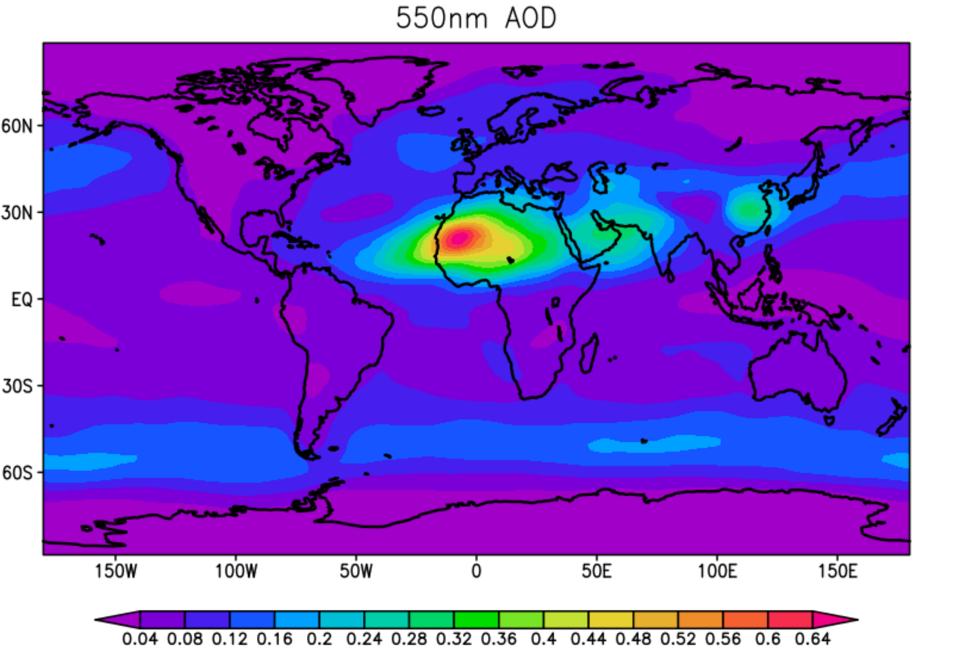


Percentage change in Crops, CMIP6 (Hurtt et al., 2015)

Courtesy: Sandeep, CCCR

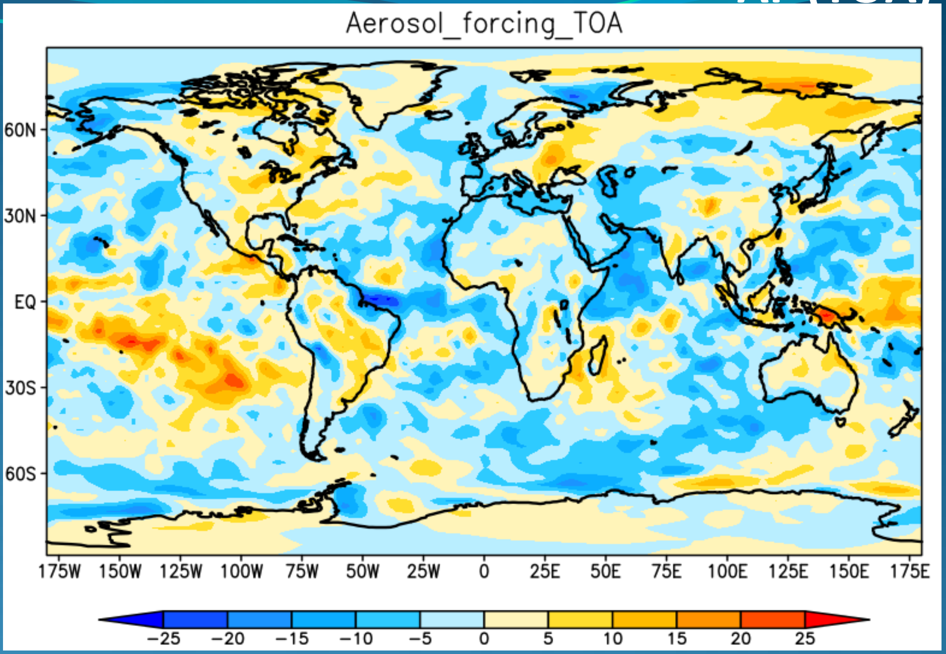
Aerosol forcing in IITM ESM

Prescribed time-varying aerosol distributions in IITM ESM from CMIP

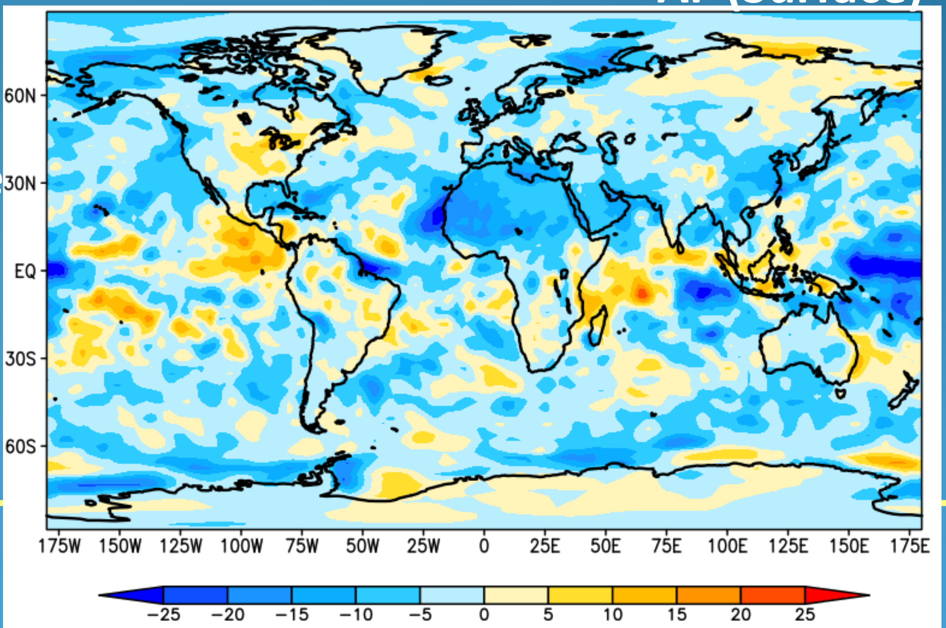


Data Courtesy : Bjorn Stevens, Stefan Kinne
(Max Planck)

AF (TOA)



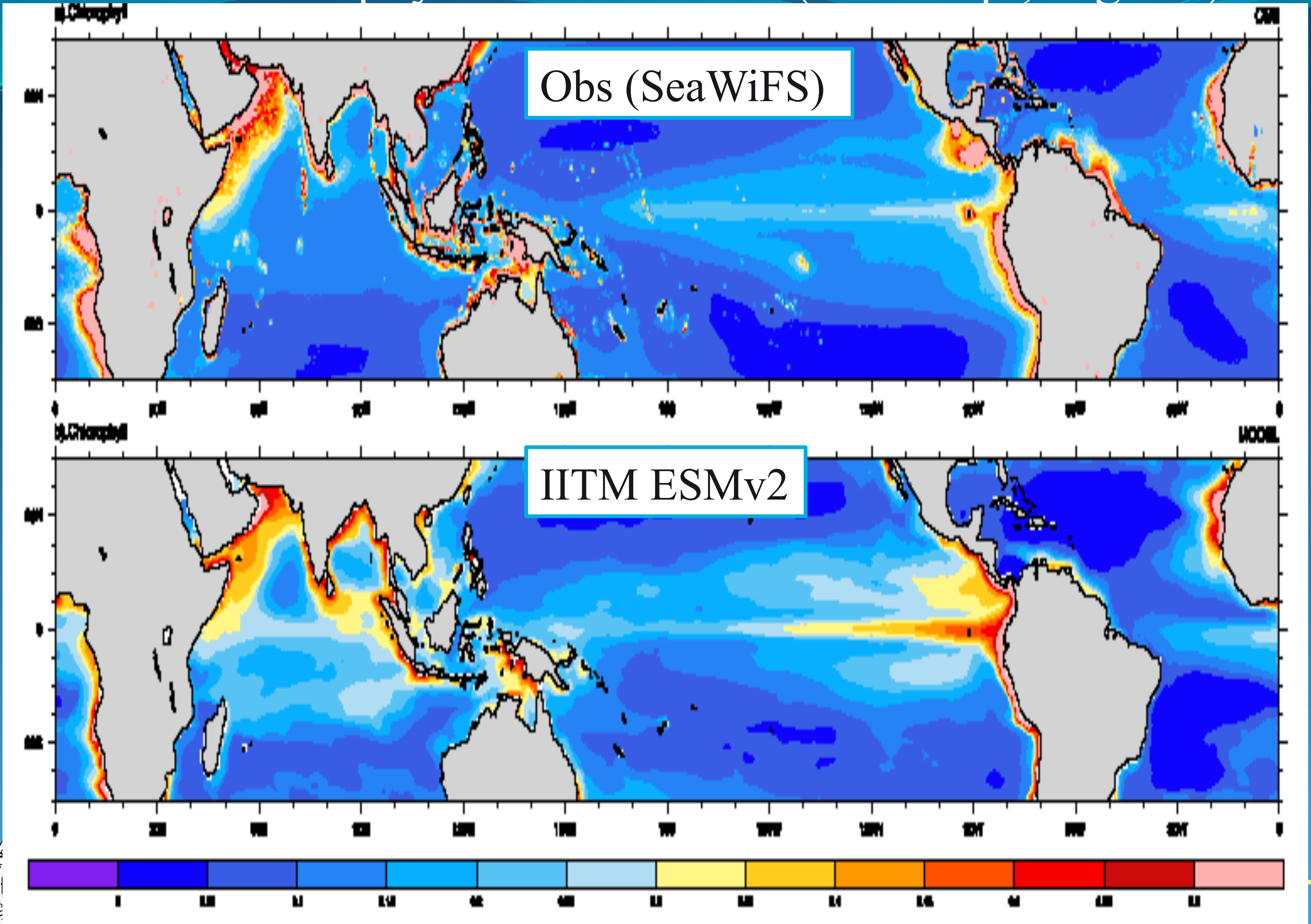
AF (Surface)



Aerosol TOA forcing (total sky)= -0.9

Courtesy: Ayantika, CCCR

Chlorophyll Concentration (June-Sept, Mg m^{-3})



Courtesy: Sandeep, CCCR

Summary

IITM ESMv1

- The first version of ESM has been successfully developed at CCCR-IITM by incorporating MOM4P1 (with ocean biogeochemistry) component in CFSv2. Major improvements are seen in the ESM simulation vis-à-vis CFSv2 :

  - **Significant reduction of cold bias of global mean SST by ~0.8^{o}C**
  - **ENSO & PDO are robust and spatially more coherent in IITM ESM**
  - **ENSO and monsoon links are well-captured**
  - **The IITM Earth System Model: Transformation of a Seasonal Prediction Model to a Long Term Climate Model. Swapna et al. (BAMS, 2015).**

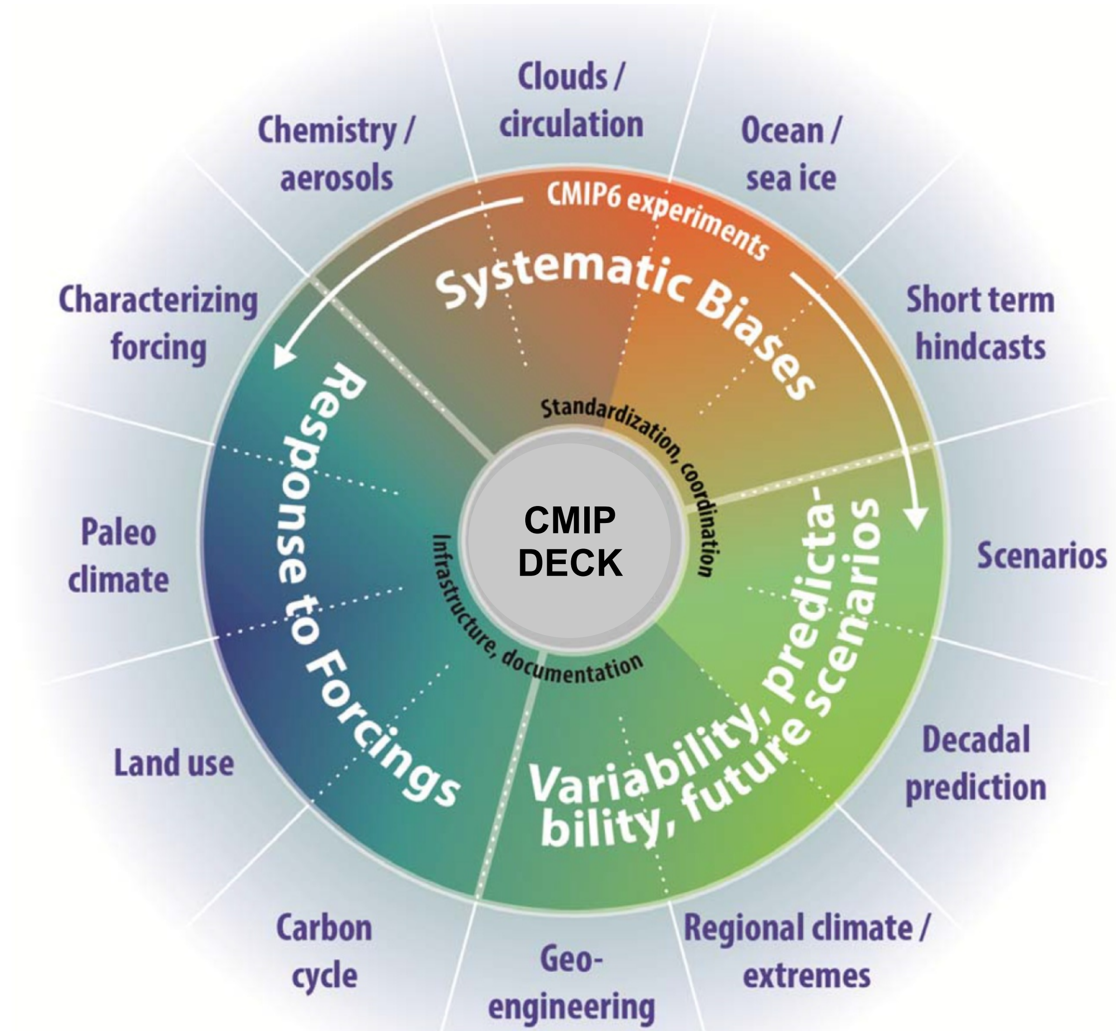
Improvements in IITM ESMv2

- ➢ **Reduced the TOA energy imbalance**
- ➢ **Improved the mean precipitation over Asian region**
- ➢ **Included land use land cover changes**
- ➢ **Included time-varying aerosol concentration**
- ➢ **Corrected the hydrology imbalance**
- ➢ **Improved representation of ocean BGC**

CMIP6 Schematic

Initial proposal for the CMIP6 experimental design has been released

Meehl et al., 2014: Climate Model Intercomparisons: Preparing for the Next Phase, Eos Trans. AGU, 95,77-84.



CMIP6 Concept:

A Distributed Organization under the oversight of the CMIP Panel

"DECK":

Development

Evaluation

Characterisation of

Klima (German for 'climate')

Plan for CMIP6

-

Plan for CMIP6 Exp : IITM will be contributing to the DECK & CMIP6 experiments:

1. a multi-hundred year pre-industrial control simulation;
2. a 1%/yr CO2 increase simulation to quadrupling to derive the transient climate response;
3. an instantaneous 4xCO2 run to derive the equilibrium climate sensitivity;
4. CMIP6 historical simulations
5. AMIP run

Global Monsoon MIP (T126 Atm; 0.5 deg Ocean)

Thank you