The implementation of the hydrological model CHyM in the new earth system model RegCM-ES

Fourth Workshop on Water Resources in Developing Countries: Hydroclimate Modeling and Analysis Tools | (smr 3125)

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OGS

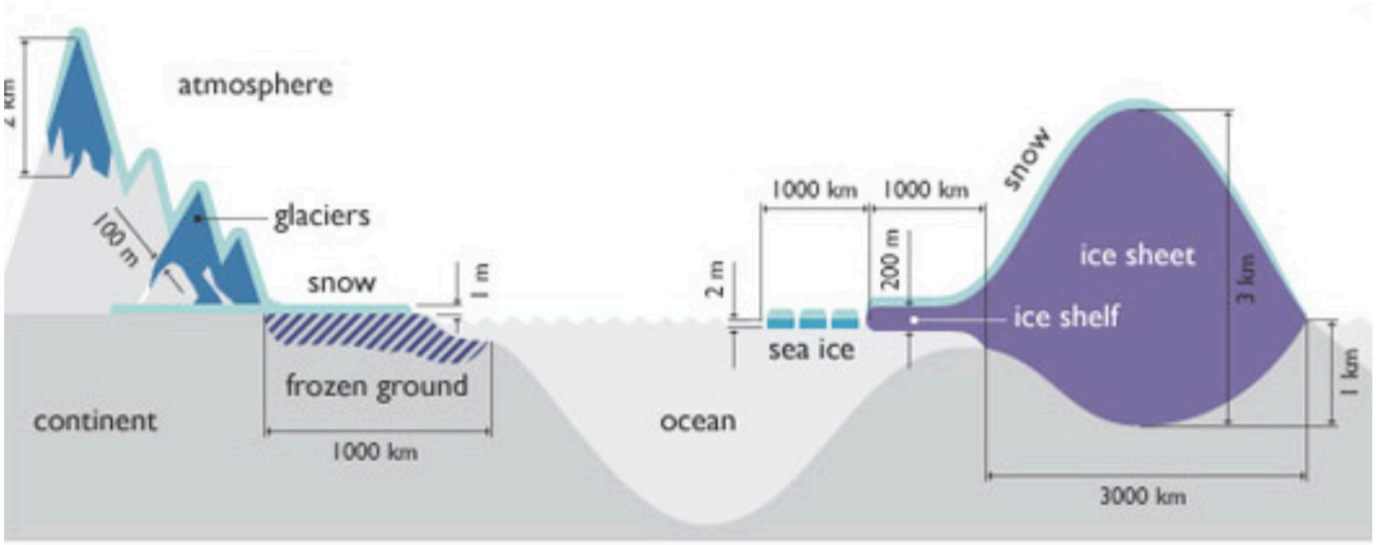
Earth System: Interactions of different components through positive and negative feedbacks

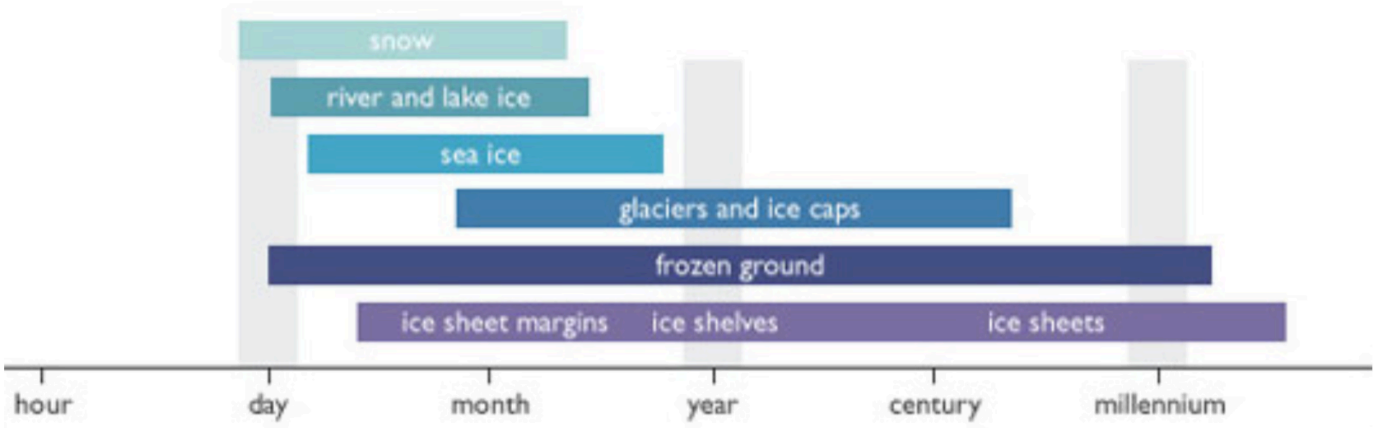
Different spatial and temporal scales

Important role on maintain an equilibrium

USRA, Earth System Science Education strategy, 2008

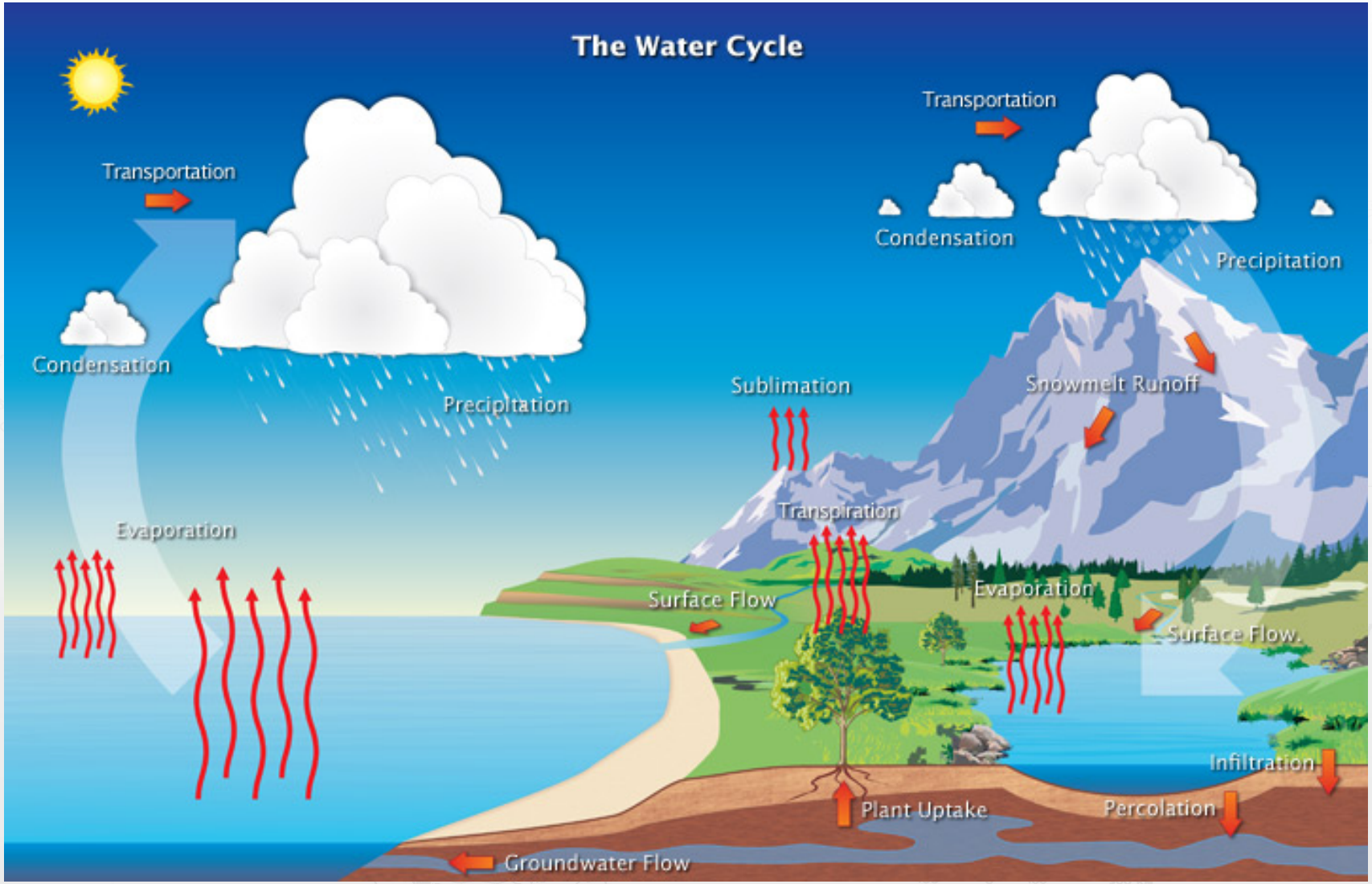
Earth System: response time under forcing





IPCC Report

Water Cycle



http://www.srh.noaa.gov/jetstream/atmos/hydrocycle_max.html

Water Cycle

Energy from the sun

Evaporation from soil, rivers, lakes and oceans

Transpiration

Condensation and formation of clouds

Gain enough mass → precipitation

Soil water or runoff → original surface reservoirs

Types of model coupling

1. Offline: The models run sequentially and the interactions among them are in one direction only (nesting between a global and a regional model)

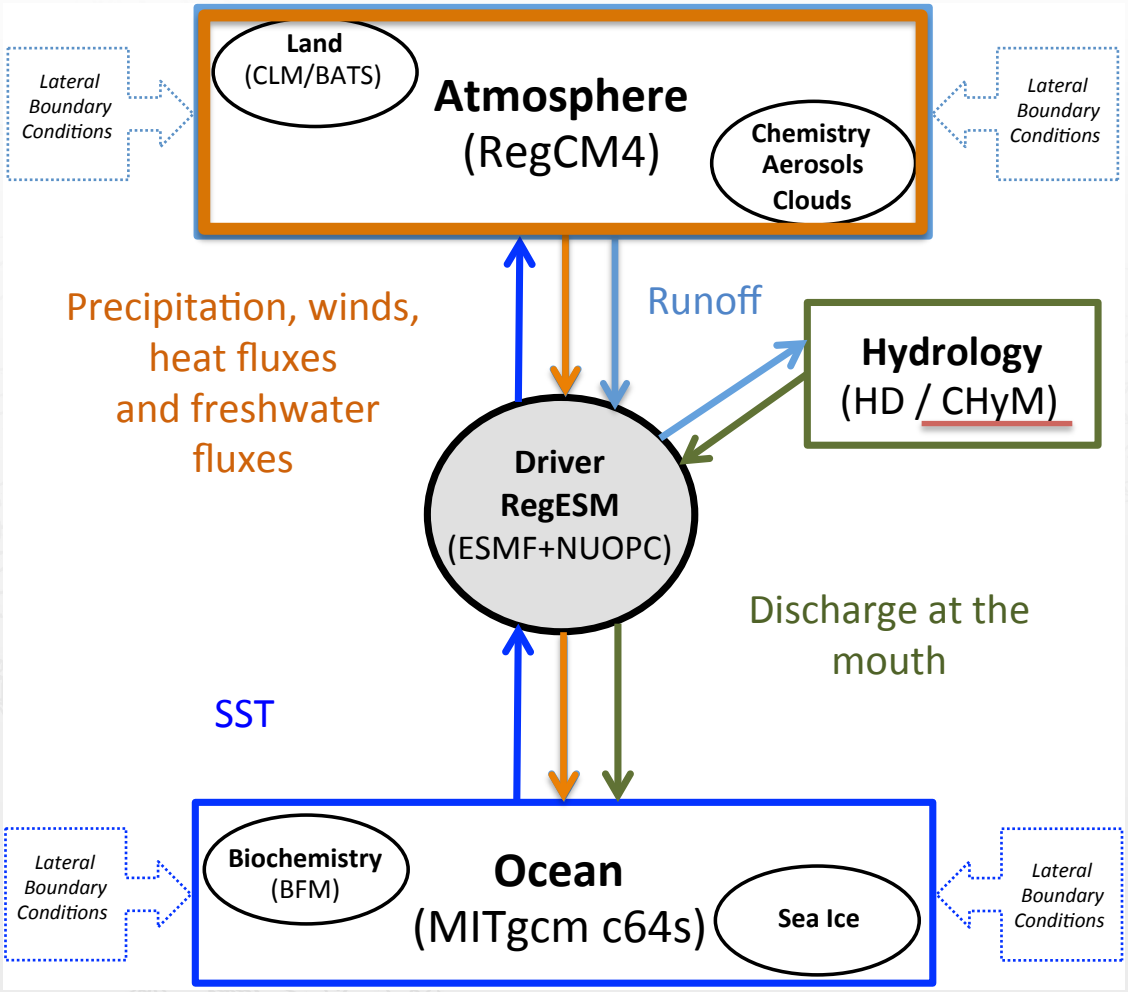
2. Online: The interactions between the model are in both directions and the feedback mechanisms are simulated (Fully coupled Earth System models)

General description of RegCM-ES

- State-of-the-art Regional earth system model (Atmosphere, Ocean, Land and River components)

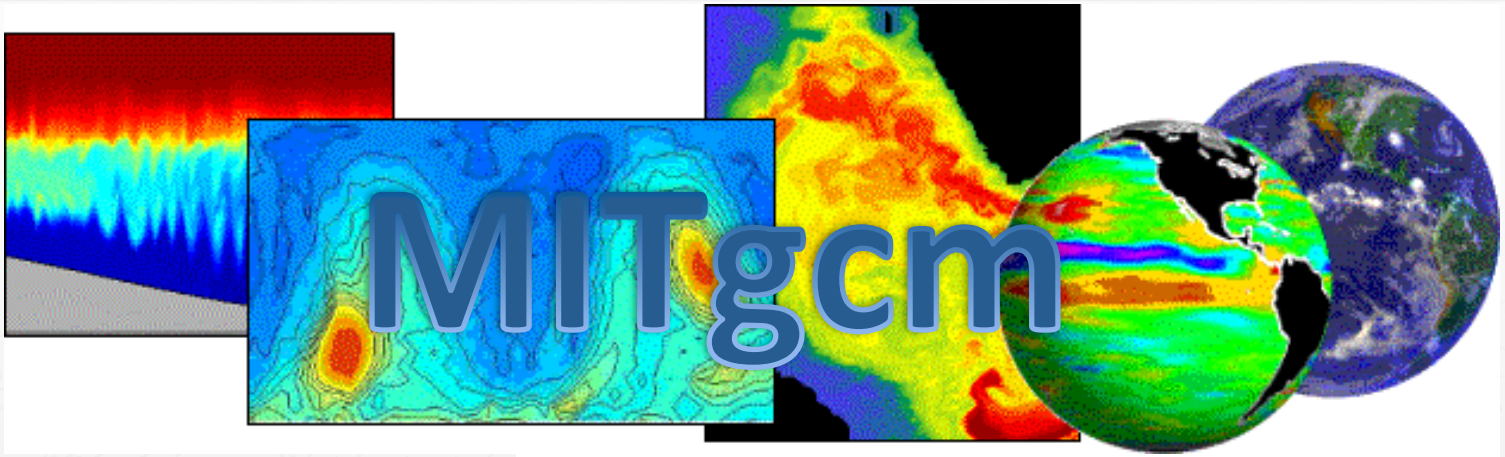
- Open source community model (source code distributed by the developers of the components and drivers)

General description of RegCM-ES



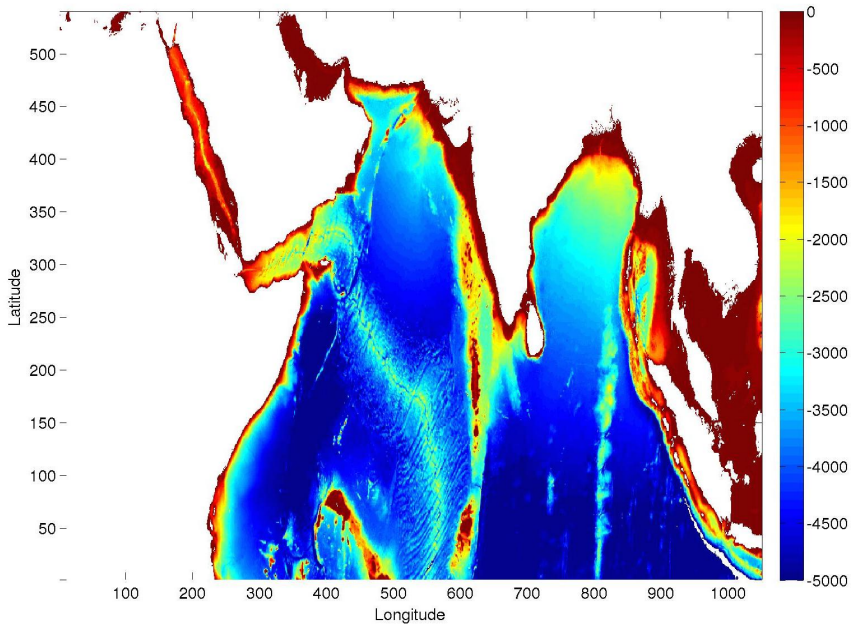
Sitz, L. E., **Di Sante, F.**, Farneti, R., Fuentes-Franco, R., Coppola, E., Mariotti, L., Reale, M., Sannino, G., Barreiro, M., Nogherotto, R., Giuliani, G., Graffino, G., Solidoro, C., Cossarini, C., and Giorgi, F. (2017). Description and evaluation of the eart system regional climate model (regcm-es). J. Adv. Model. Earth Syst.

General description of RegCM-ES: MITgcm



- Non-hydrostatic
- Capability to simulate Atmosphere and Ocean fluid phenomena
- Open source code

http://mitgcm.org



Bathymetry from Smith and Sandwell, 1997

Challenges

BATHYMETRY

Choice of the domain

↓

Cleaned and adjusted the bathymetry

↓

Smooth steepest slopes through CA

Different tests using applications developed from scratch at ICTP (click_edit & ncEdit)

ICBC EXF

Interpolate over the MITgcm Curvilinear grid using ESMF library and NCL

↓

Tests of interpolation quality (complex land-sea mask)

General description of RegCM-ES: MITgcm

- Hydrostatic model (Giorgi et al. 1993a,b)

- Different Cumulus convection parametrizations for land and sea
- Ocean fluxes parametrization BATS (Dickinson et al 1993) and Zeng (Zeng et al. 1998)

- Land surface scheme BATS (Dickinson et al 1993), SUB-BATS (Giorgi et al 2003) and CLM (Oleson et al. 2008)

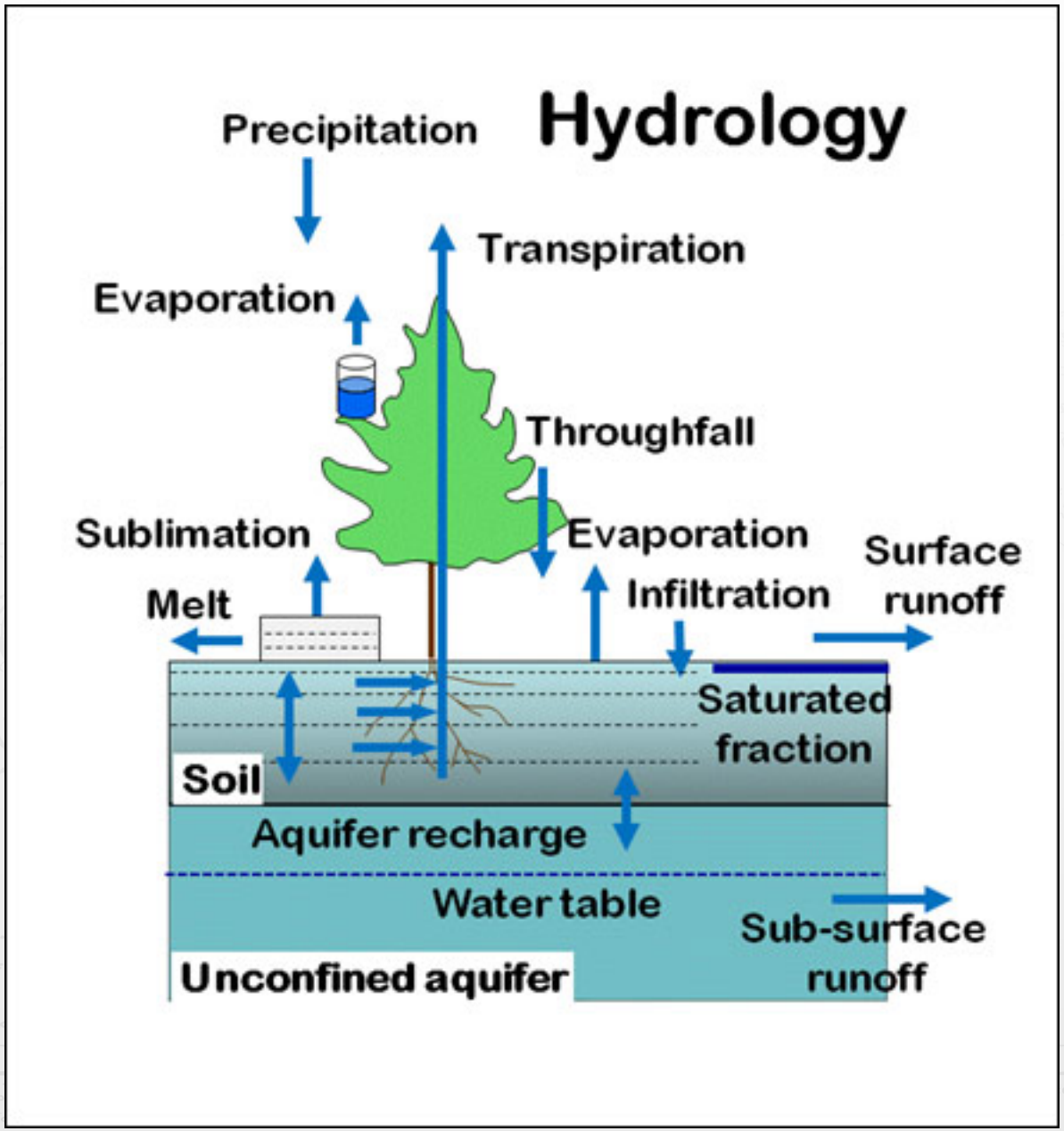
- Planetary boundary layer: Modified Holtslag, Holtslag (1990) and UW-PBL (O'Brien et al. 2011)

Recent improvements:

- CLM4.5 land surface scheme

- coupling with the MIT Ocean model (ESMF – Earth System Modeling Framework)

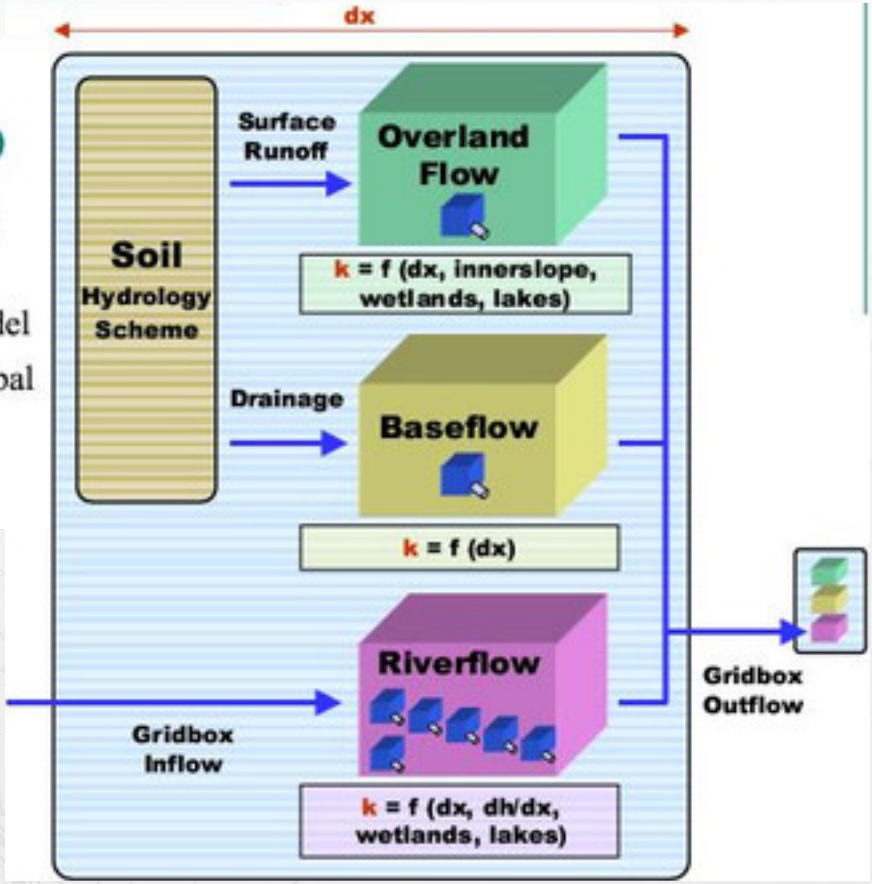
General description of RegCM-ES: CLM4.5



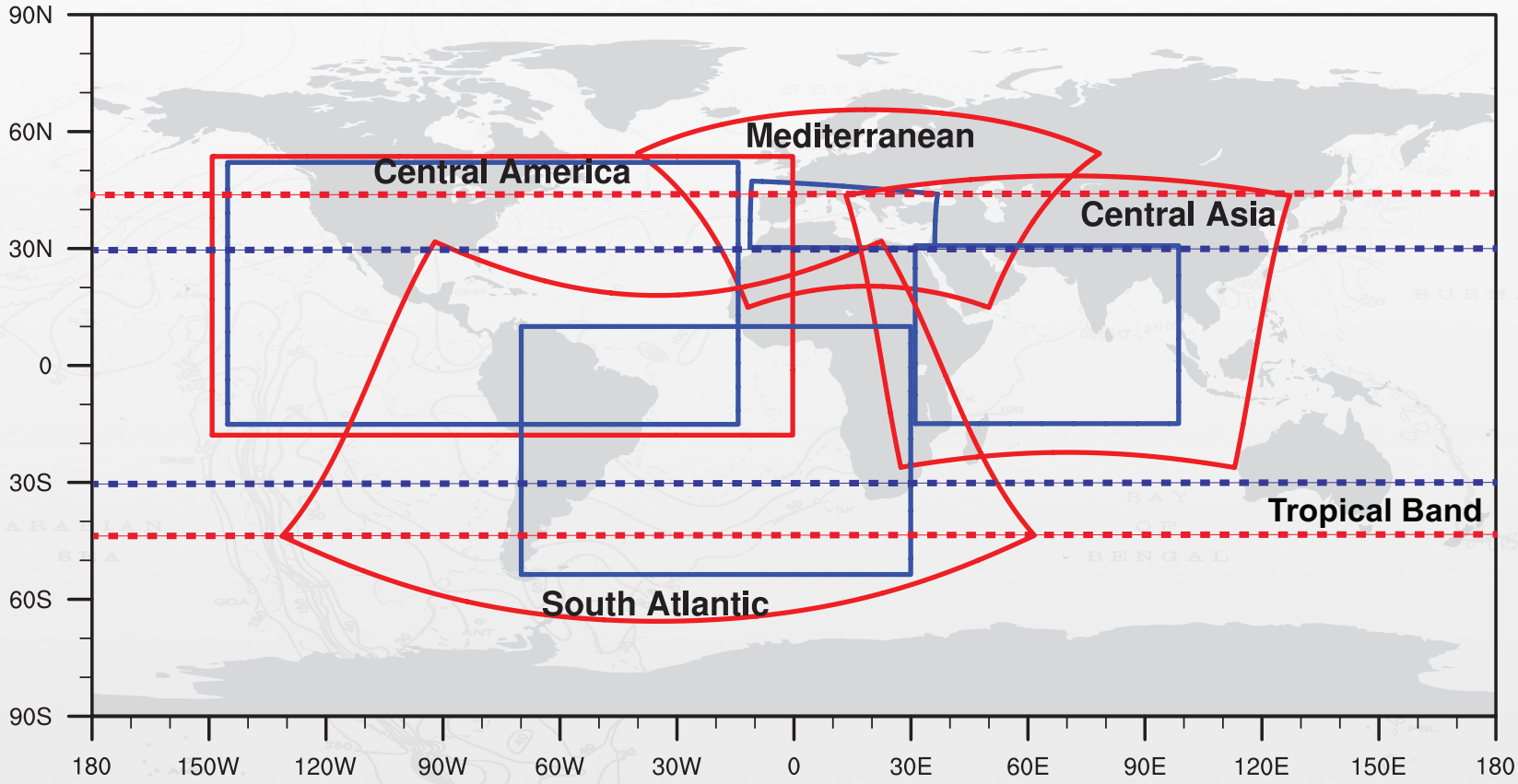
General description of RegCM-ES: HD

HD Model

- **(Hydrological Discharge)**
- **Hagemann & Dumenil (1998)**
- State of the art discharge model
- Applied and validated on global scale at 1/2 deg.
- Part of ECHAM5-MPI-OM



Testing RegCM-ES over selected domains



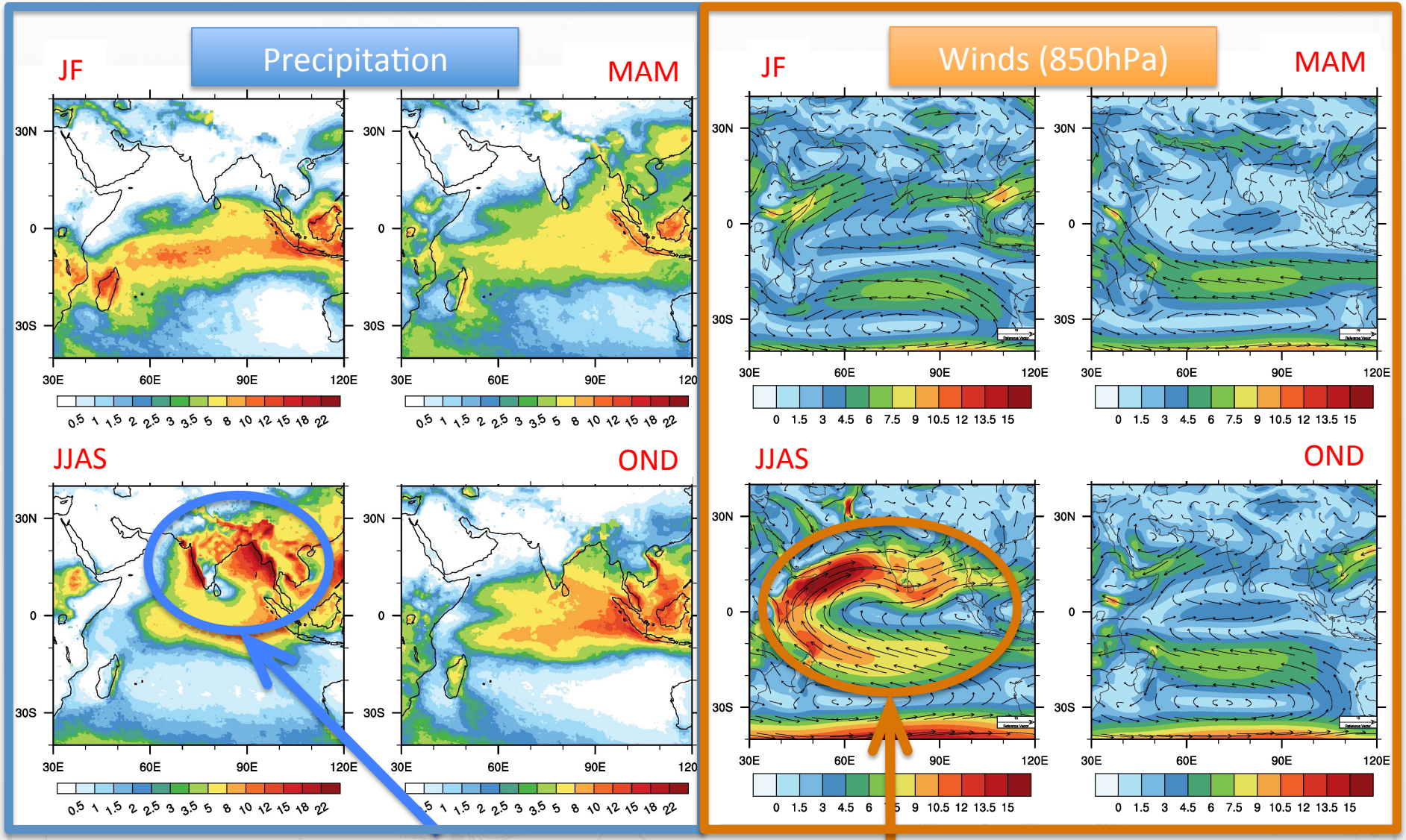
Why and when we need to use regional coupled models?

South Asia CORDEX domain experiment

The Indian Summer Monsoon (ISM)

- Climatology
- Intraseasonal oscillations (ISV)
- Interannual variability (IAV)

Climatology of the ISM

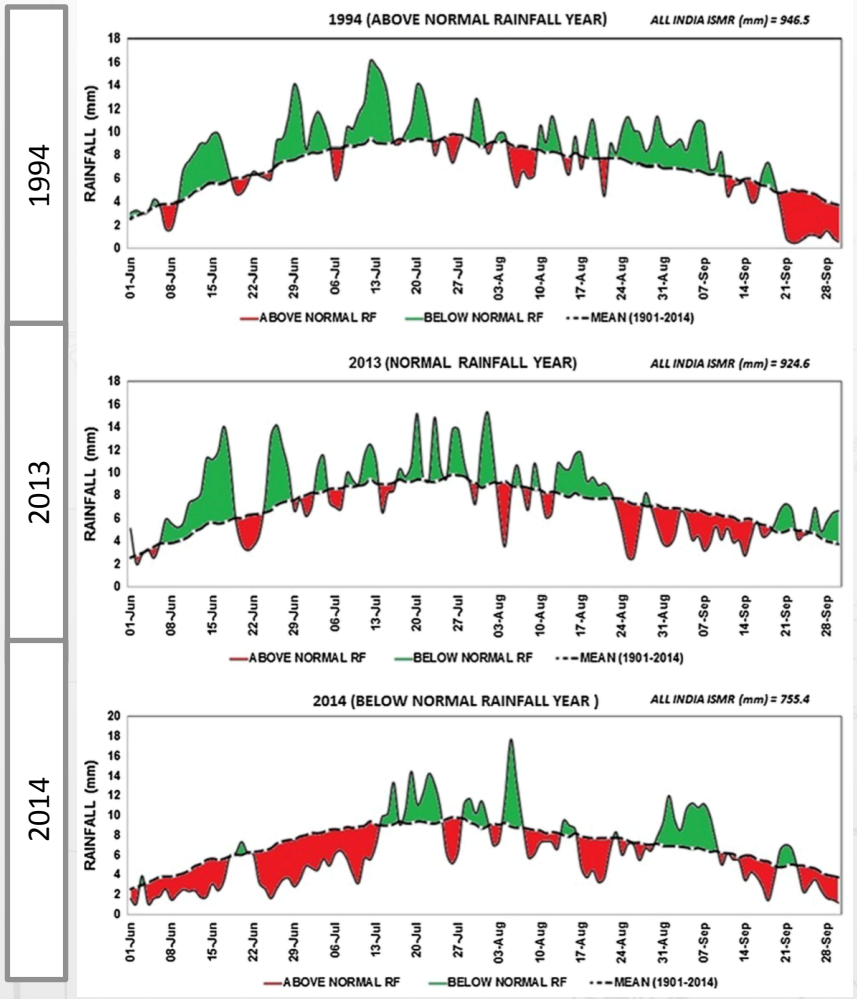


Large Increase in precipitation and runoff

Low Level Jet

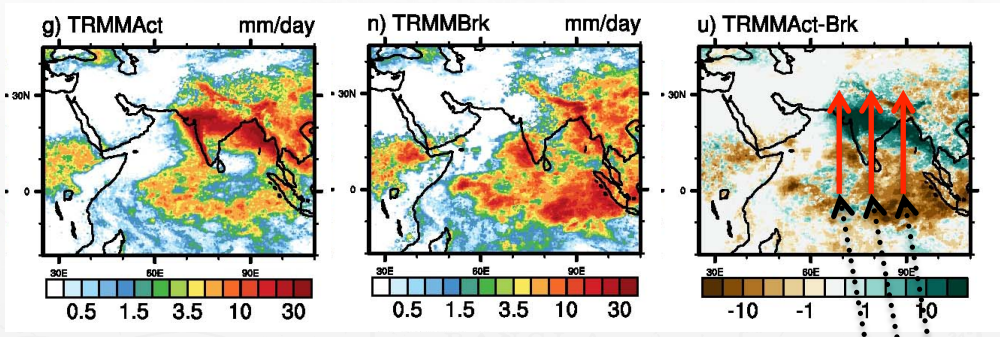
Intraseasonal oscillations of the ISM

Rainfall

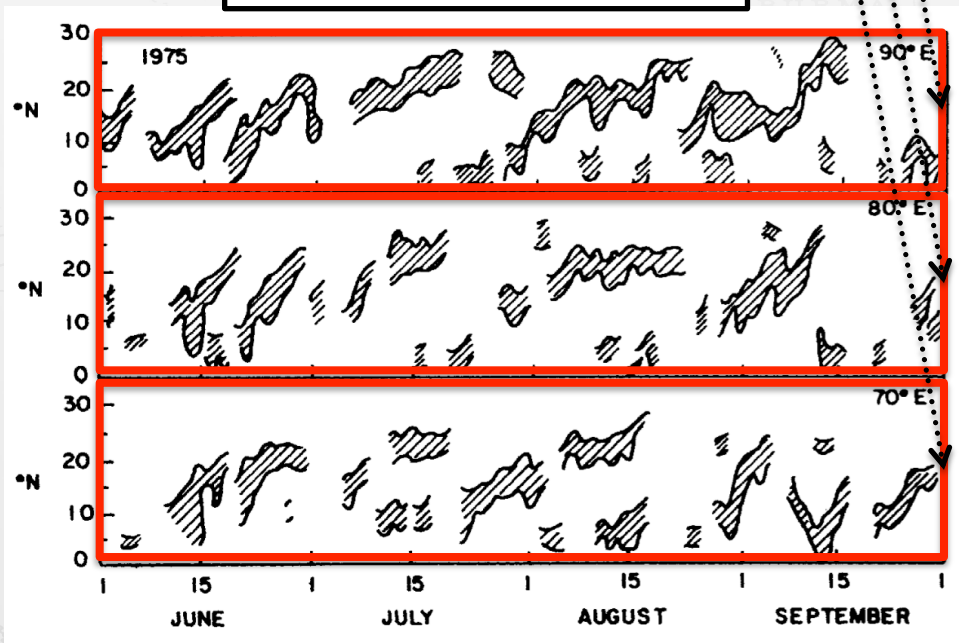


Pai et al. [2016]

Composite of break/active



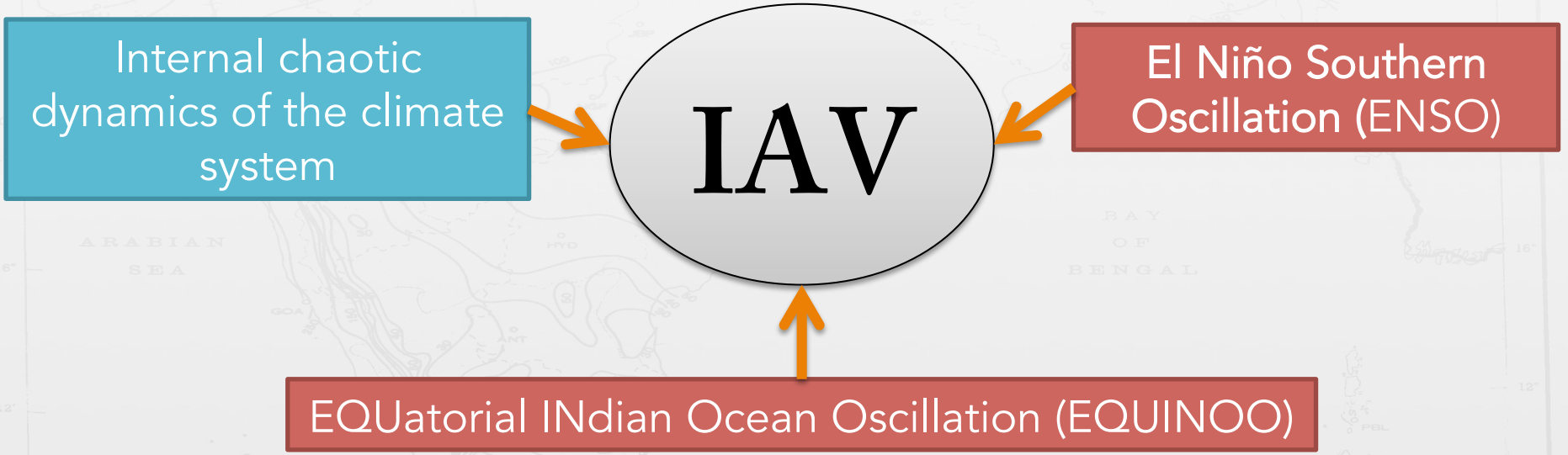
Maximum cloud zone



Goswami [1994]

Interannual variability of the ISM

The Indian summer monsoon is characterized by large year-to-year variations in the total amount of rainfall over the Indian continent.



Scientific objectives

- Develop an instrument that is able to realistically reproduce the mean state of the ISM and variability on its two main scales: the intraseasonal and the interannual (RegCM-ES);

- Improve the hydrological cycle simulation in the coupled system implementing a new ad-hoc developed hydrological model important for a more realistic freshwater discharge into the ocean over the BoB;

- Use the developed instrument to study the external forcings that influence the variability of the ISM;

Motivations

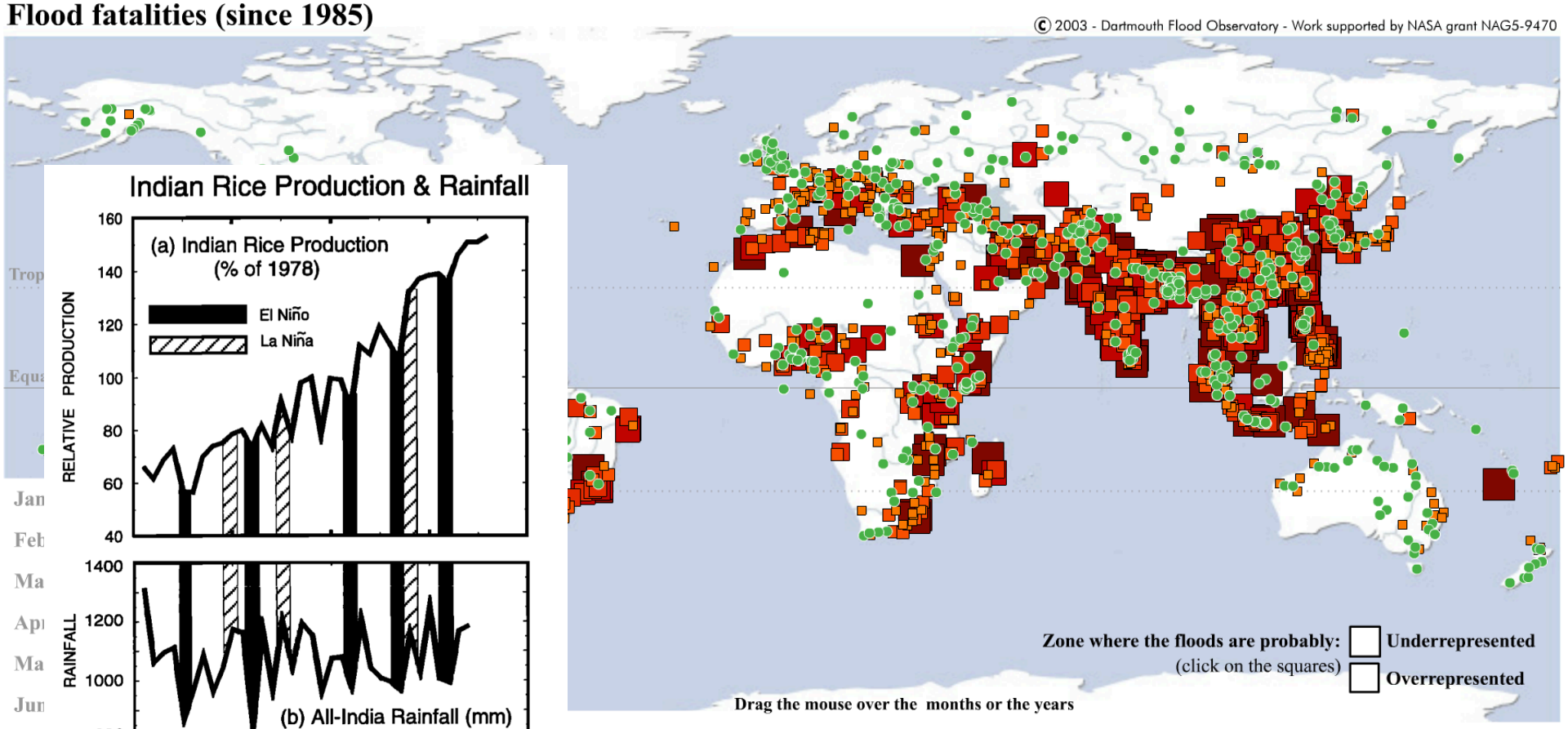
- To correctly simulate the interannual and the intraseasonal oscillation (ISO) of the Indian monsoon it is necessary to use a coupled atmosphere-ocean model as supported by different studies (Fu et. al 2002 ; Fu et al. 2007; Ratnam et al. 2008; Seo et al. 2009; Samala et al. 2013)

- Precipitation and river discharge well exceed the evaporation in the Bay of Bengal making this area the region with more fresh water in the Indian Ocean

- Socio-economic implications

Motivations: Socio-Economic implications

Flood fatalities (since 1985)



Webster et Al 1999

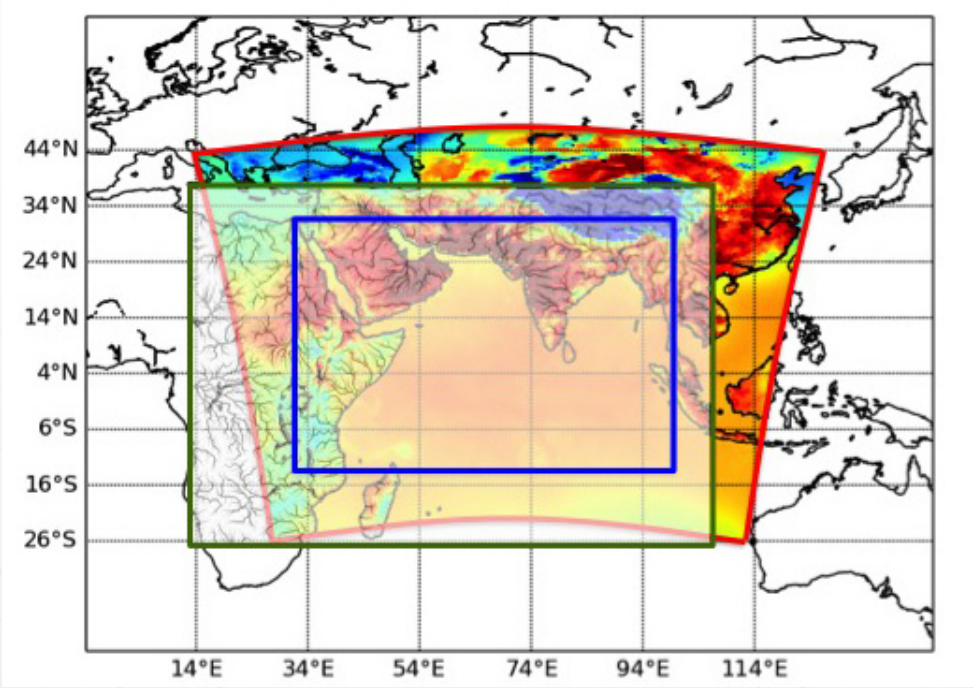
http://www.dartmouth.edu/~floods/archiveatlas/floodfatalities.htm

South Asia experimental design

ATM:
Horizontal spatial Res. 50km
ICBC ERA Interim reanalysis 0.75°

OCN:
Horizontal spatial resolution 0.16°
ICBC MOM global integration 0.25° and ORAP reanalysis 0.25°

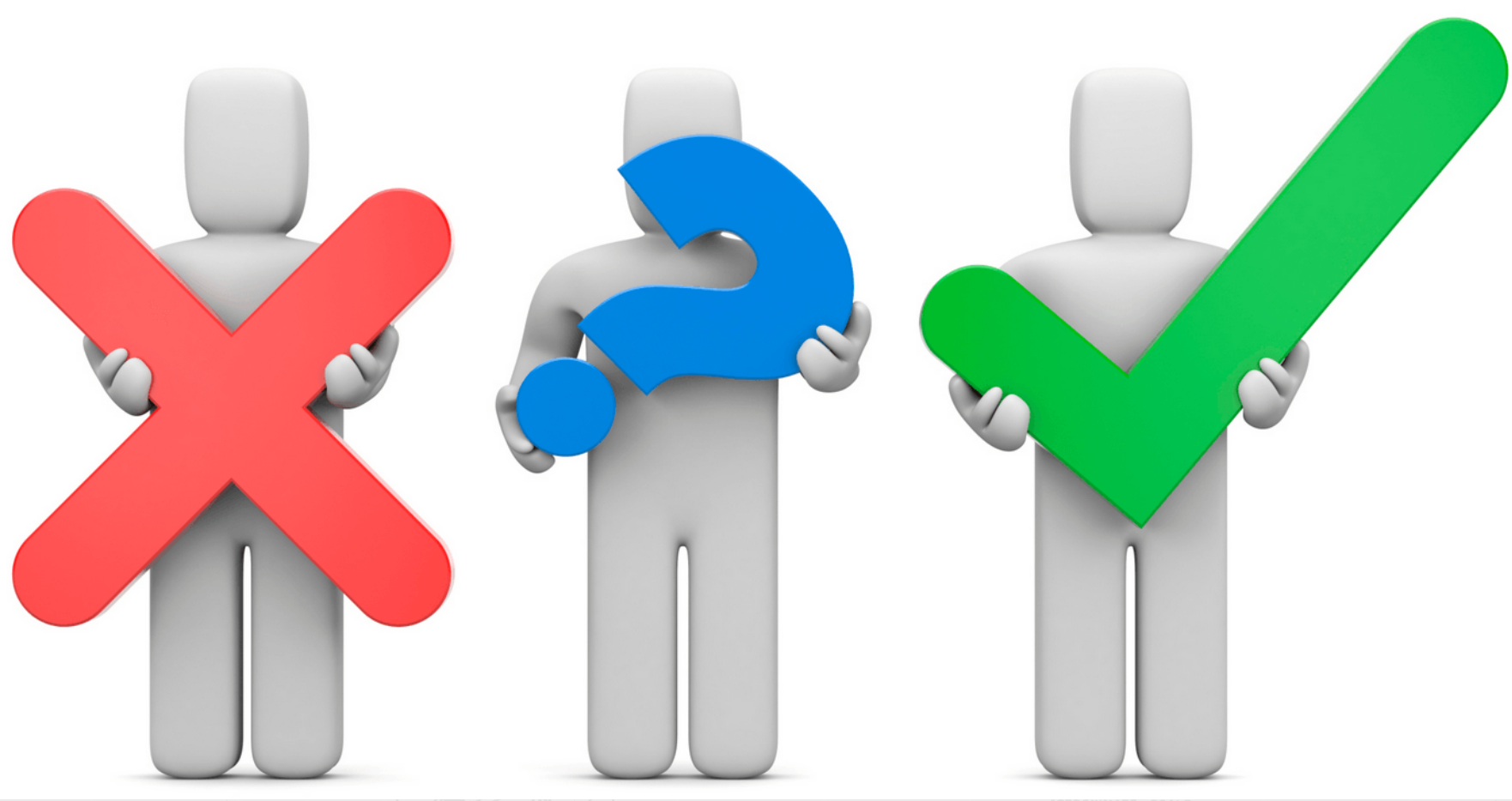
HYD:
Horizontal spatial resolution 0.5° HD and 0.12° CHyM



Simulation Acronym	Convective schemes	Ocean model ICBC	Hydrological model
RCM-Em	Emanuel		
RCM-Tk	Tiedtke		
ESM-Em	Emanuel	MOM (GOCM)	HD
ESM-TkHD	Tiedtke	ORAP5 (Reanalysis)	HD
ESM-TkCH	Tiedtke	ORAP5 (Reanalysis)	CHyM

29 years simulated (1979-2007)

Results



Results

- Ocean Validation
- Freshwater validation
- Precipitation Climatology
- Intraseasonal oscillations (ISV)
- Interannual variability (IAV)

Results: Ocean validation

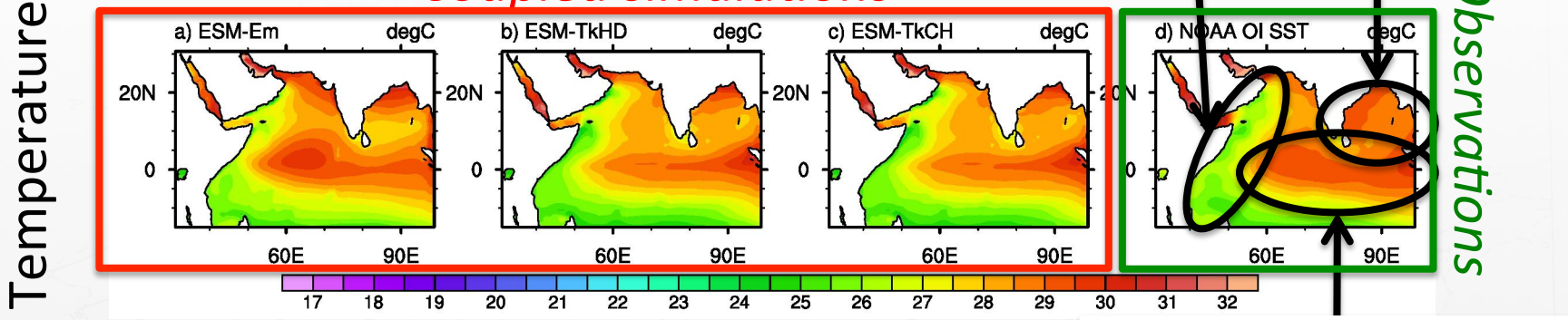
BoB warm pool

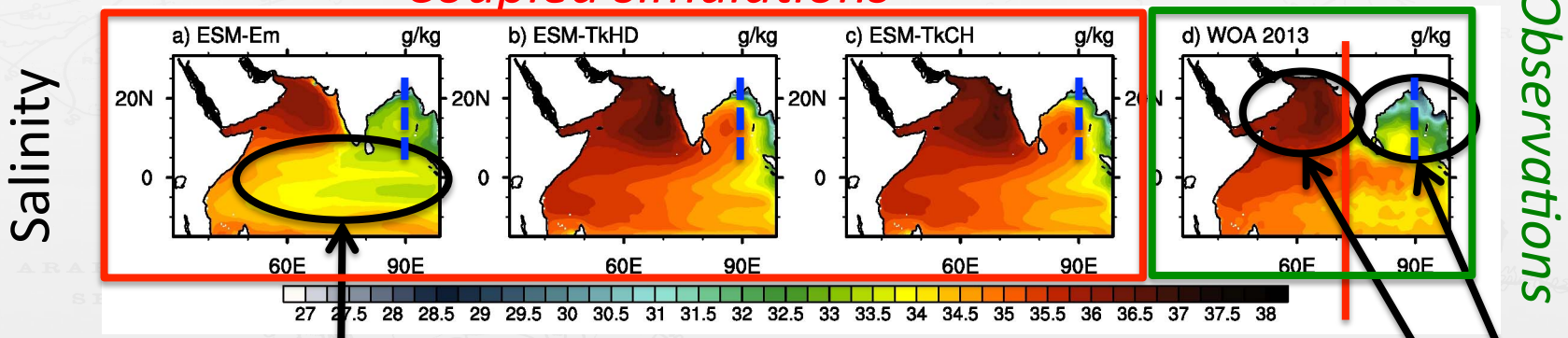
Somali current

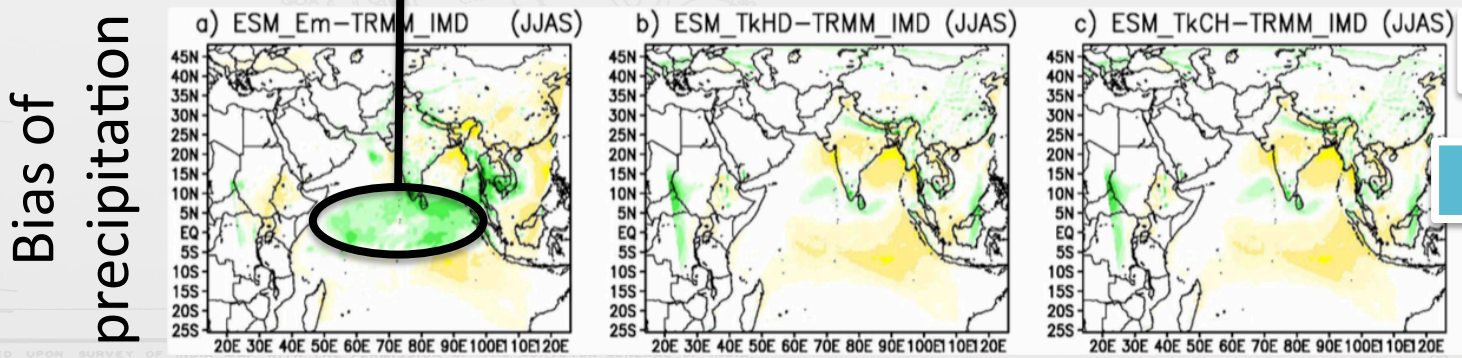
Equatorial warm pool

Very low salinity

Very high salinity



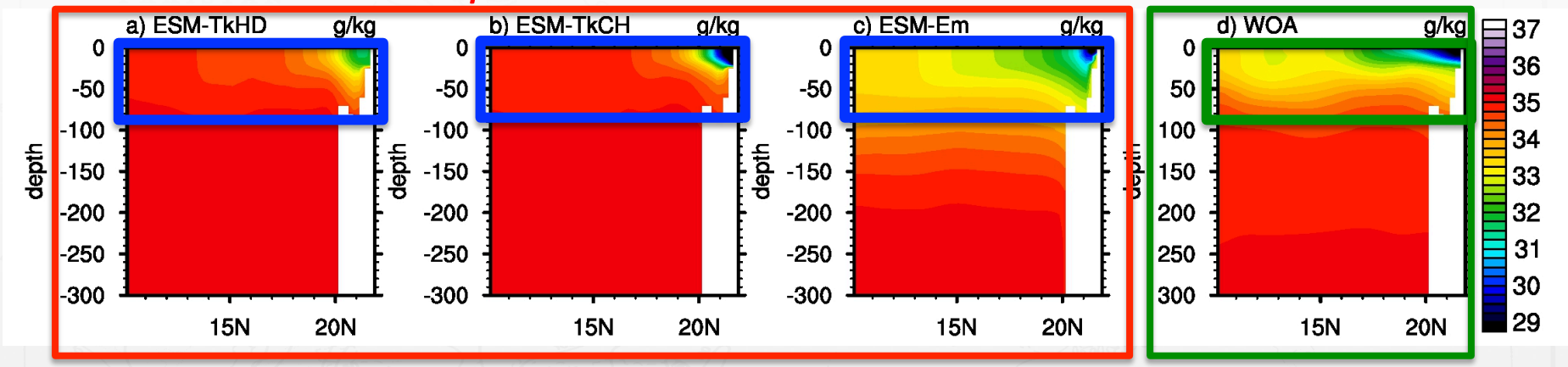




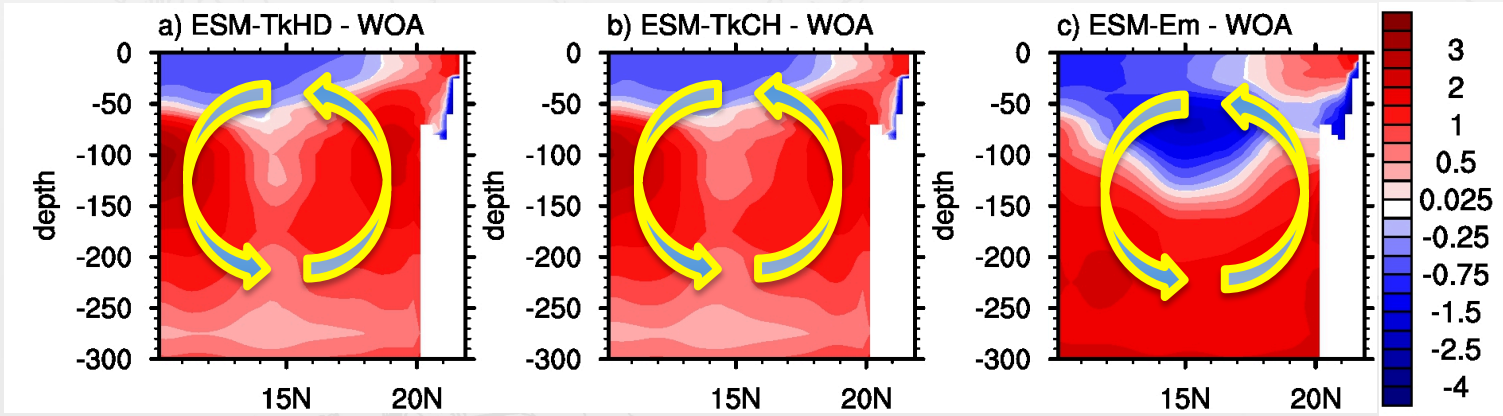
Results: Ocean validation

Salinity transect at 90°E (in the middle of BoB)

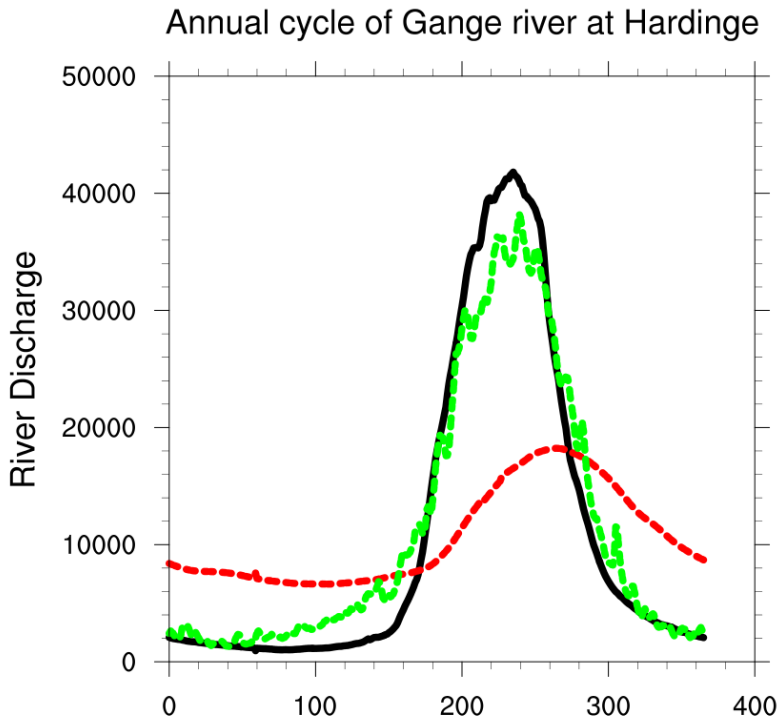
Coupled simulations *Observations*

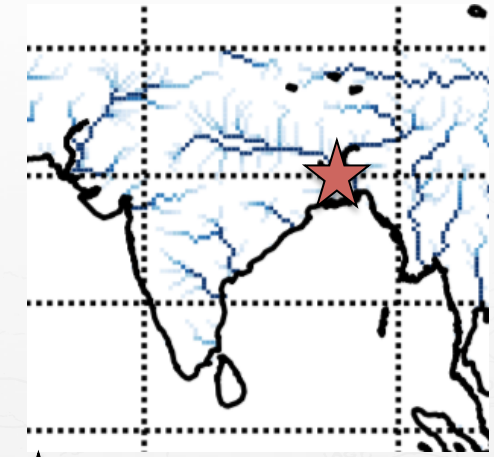


Bias of Temperature transect at 90°E (in the middle of BoB)



Results: freshwater validation





Hardinge station

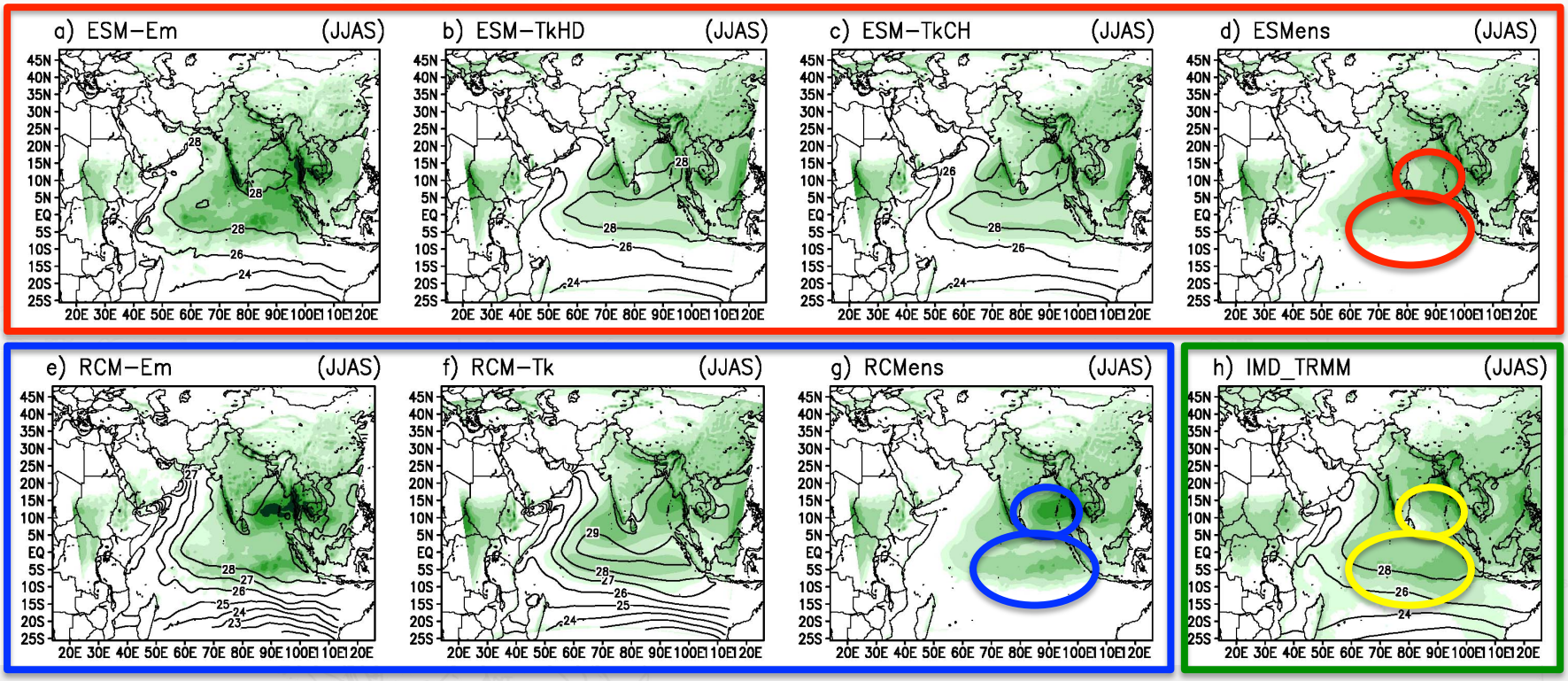
Observations

CHyM model

HD model

Results: precipitation climatology

ESMs experiments

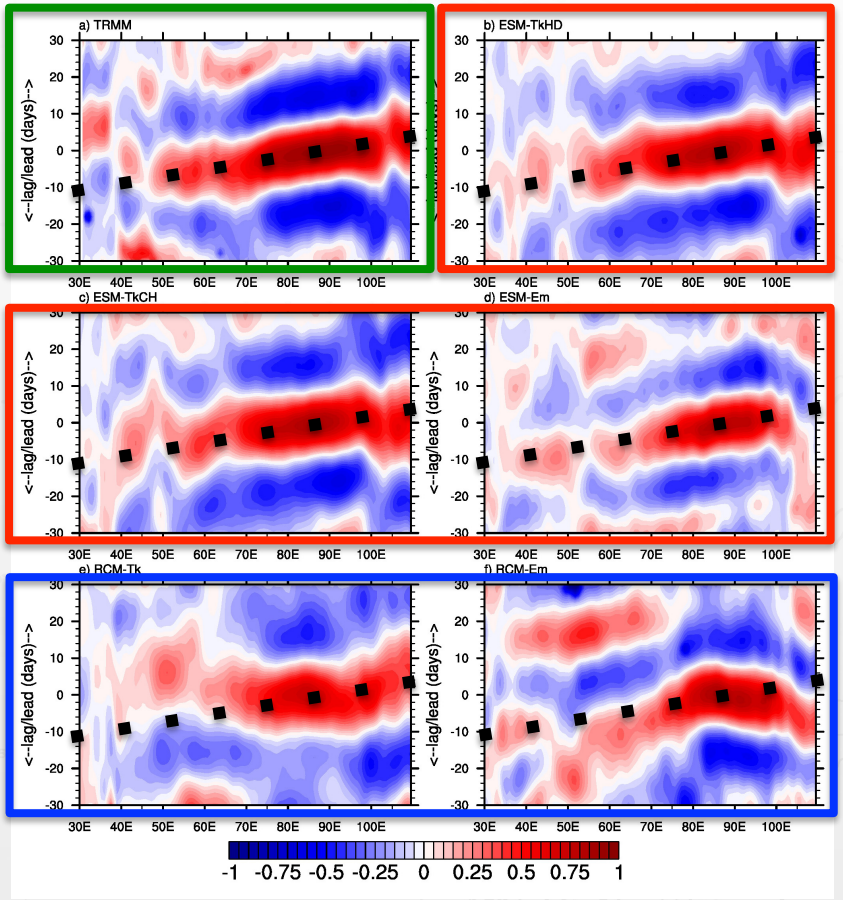


RCMs experiments

Observations

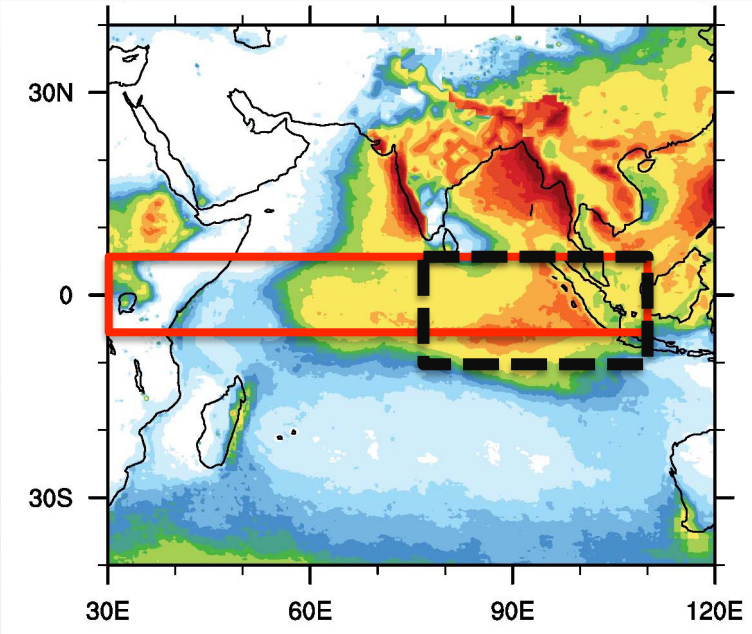
Results: intraseasonal oscillations

OBS



ESMs

RCMs

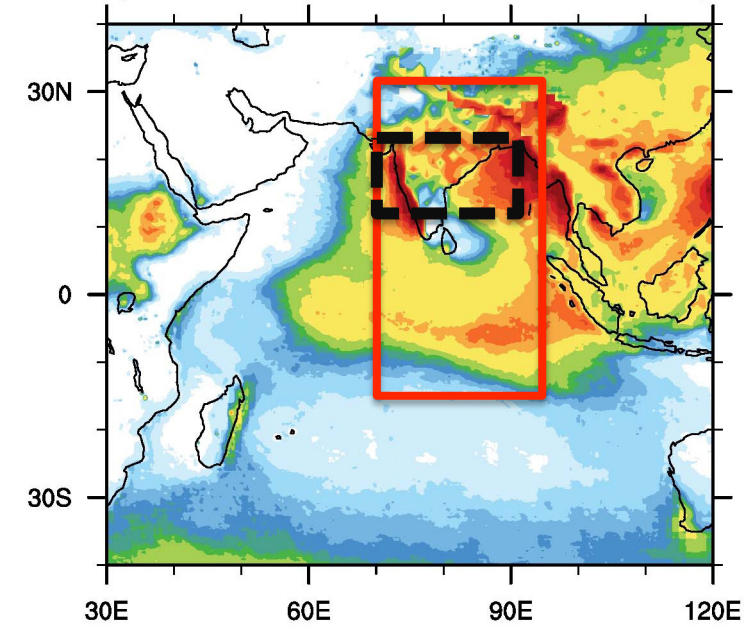


Lat average vs box average

Eastward propagation of rainfall

Sabeerali et al. [2013]

Results: intraseasonal oscillations

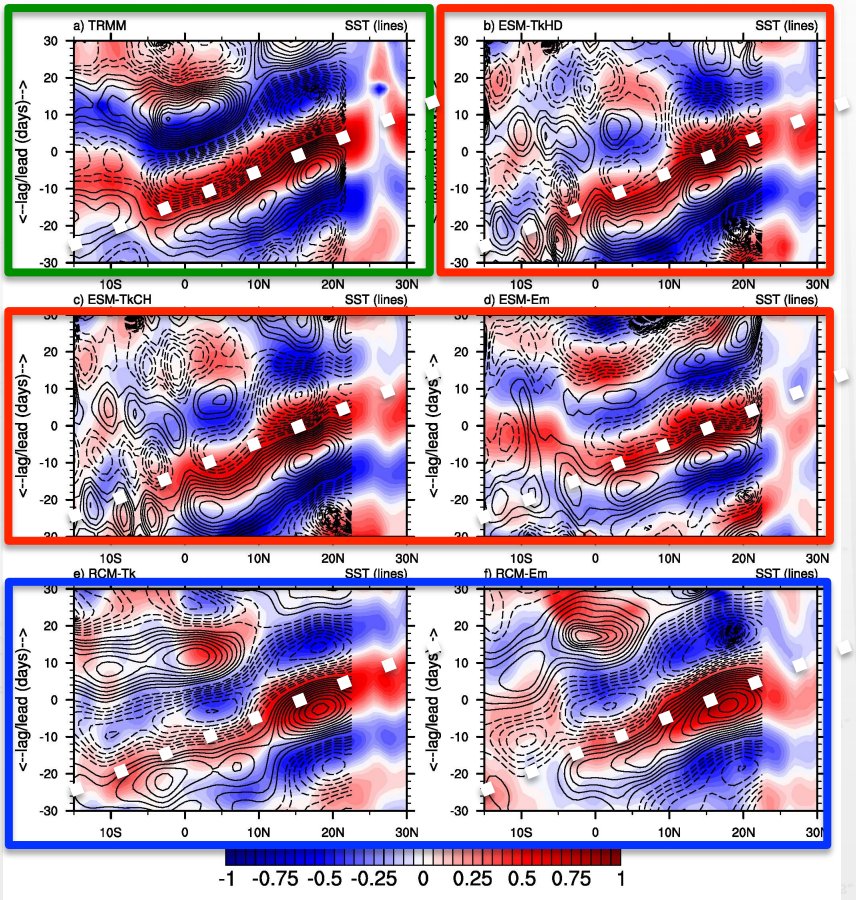


Lon average vs box average

OBS

ESMs

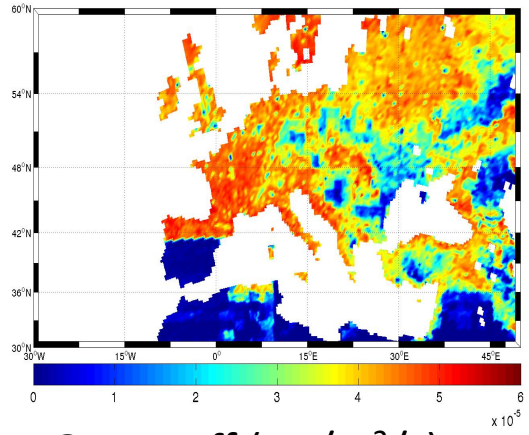
RCMs



Northward propagation of rainfall

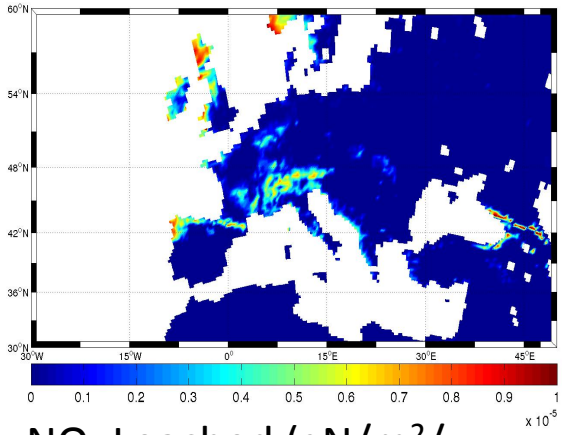

What's Next

Potential future development in RegCM-ES/BFM (with F.Di Sante and S.Rateb)



NO_3 Runoff ($gN/m^2/s$) = dissolved nitrate in surface runoff (RegCM4.6.1/CLM 4.5)

+



NO_3 Leached ($gN/m^2/s$)=subsurface loss of nitrate dissolved in soil water (RegCM4.6.1/CLM 4.5)

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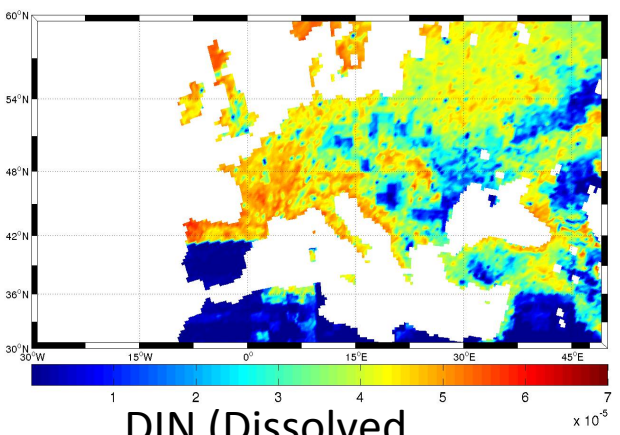
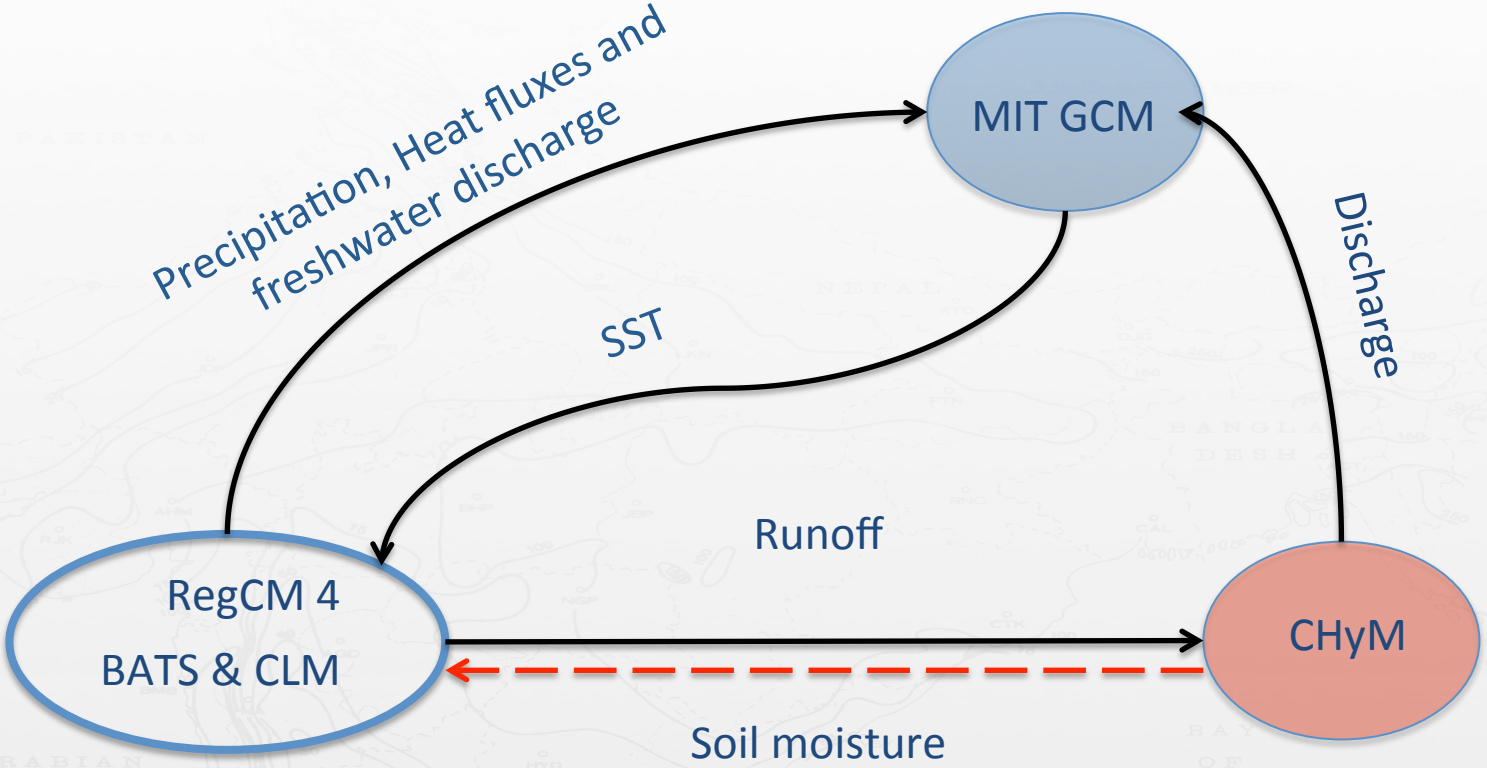


DIN (Dissolved inorganic nitrogen in the soil)

DIN+River Discharge = CLM4.5+ HD(or CHym)

Online transport of nitrogen (and carbon) by the rivers towards the sea

Idea based on Nevison, C., P. Hess, S. Riddick, and D. Ward (2016), Denitrification, leaching, and river nitrogen export in the Community Earth System Model, J. Adv. Model. Earth Syst., 8, 272–291, doi:10.1002/2015MS000573.


Precipitation, Heat fluxes and freshwater discharge
MIT GCM
SST
Discharge
Runoff
RegCM 4
BATS & CLM
CHyM
Soil moisture

Prespectives

- The powerful instrument implemented for this project, over the South Asia region, will allow to study more in deep the coupled phenomena linked with the two main scales of variability of the Indian Summer Monsoon.

- The implementation of RegCM-ES over regions where we have similar coupled mechanisms (as for example eastern tropical Africa and south-east Asia) will be of great interest, moreover, if we consider the possible impact of the climate warming on that mechanisms, the coupled model is absolutely necessary to perform climate projections over that regions.

- The new Hydrological model CHyM opens the doors to the possibility of simulates a more realistic representation of soil moisture (really important for the triggering of the convection) through the interactions with the land model.

Summary and conclusions

- Our analysis confirm what found in the previous studies, namely the necessity of using a coupled system to simulate the Indian Summer Monsoon variability

- The implementation of the CHyM model leads to large improvements on simulating river discharges over the study area and show an added value in the representation of the salinity over the BoB that is partially hidden by the not accurate representation of the ocean dynamic over the Bay of Bengal (low resolution, kpp vertical mixing scheme)

- RegCM-ES allows to study the complex coupled phenomena that are related to the large scale forcing (ENSO) on the ISMR. The understanding of these phenomena may leads to an increase of predictability of the monsoon with a very high impact on socio-economic aspects of the region

References

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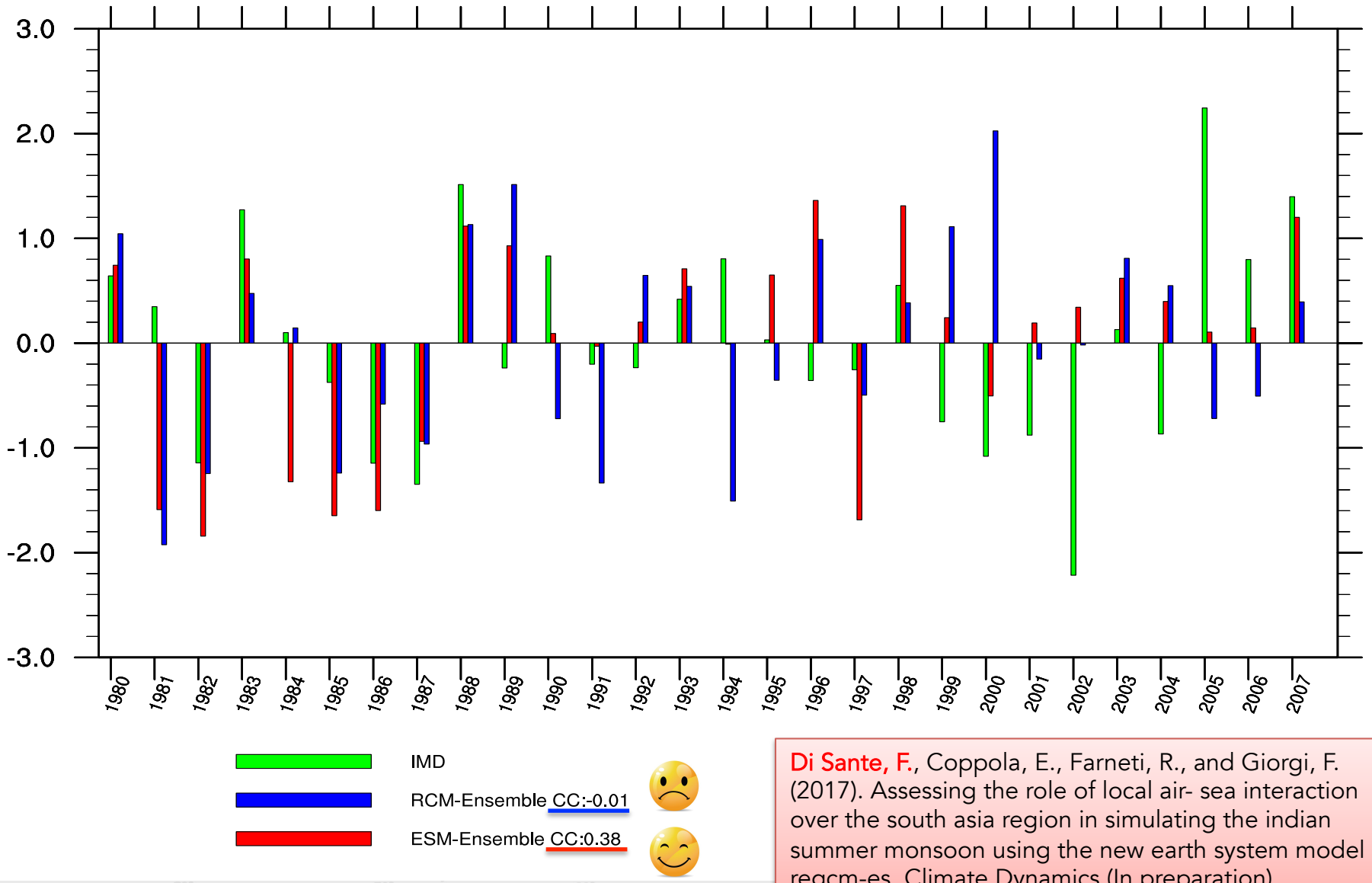
Results: interannual variability



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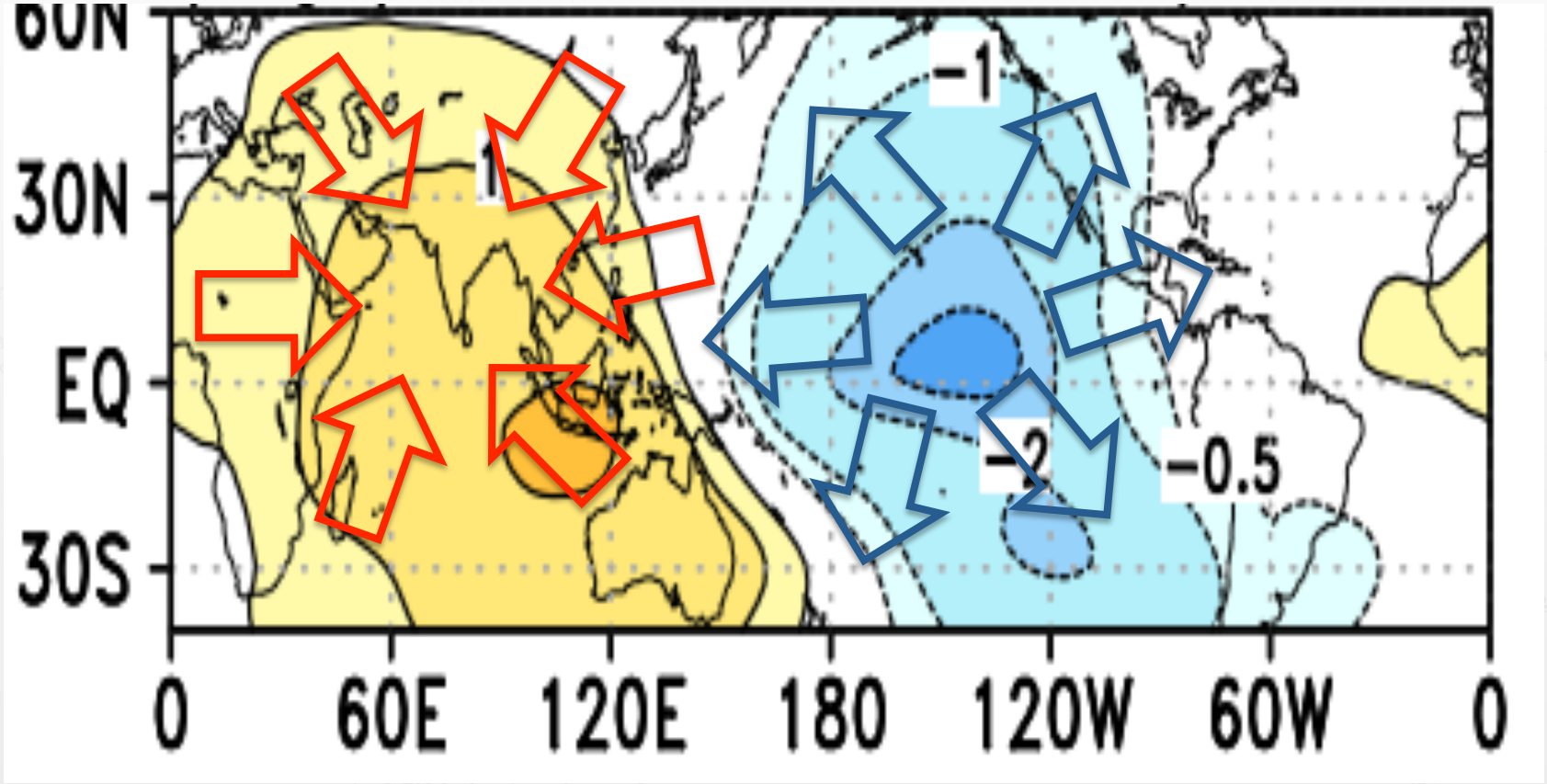
Results: ENSO forcing on ISM (direct effect during JJAS)

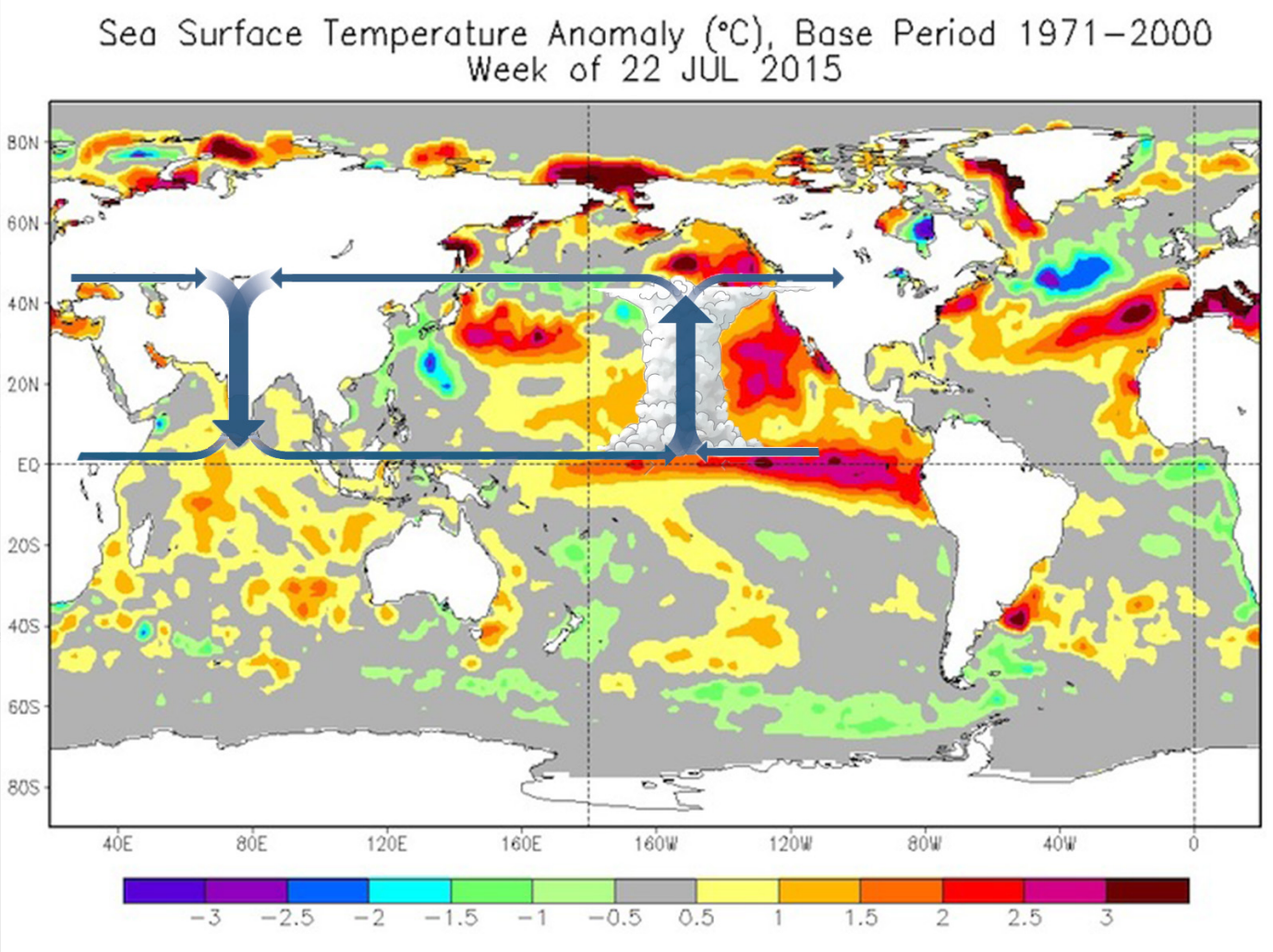
Regression maps (OBS) of Niño3.4 (JJAS) onto 200 hPa velocity potential



Thanks to Fred Kucharski for the Figure

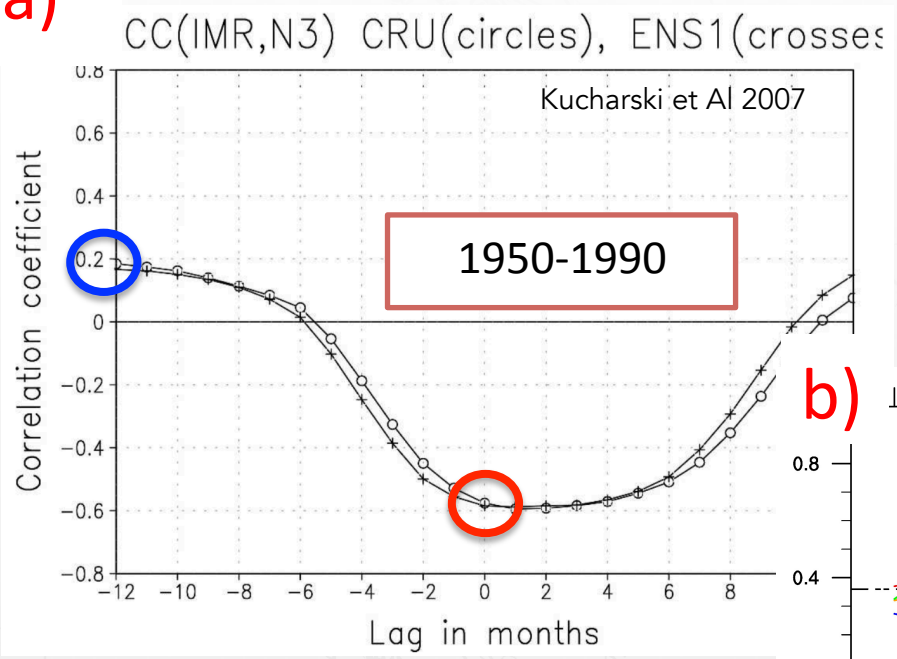
Results: ENSO forcing on ISM (direct effect during JJAS)

Atmospheric teleconnection between ENSO and ISMR

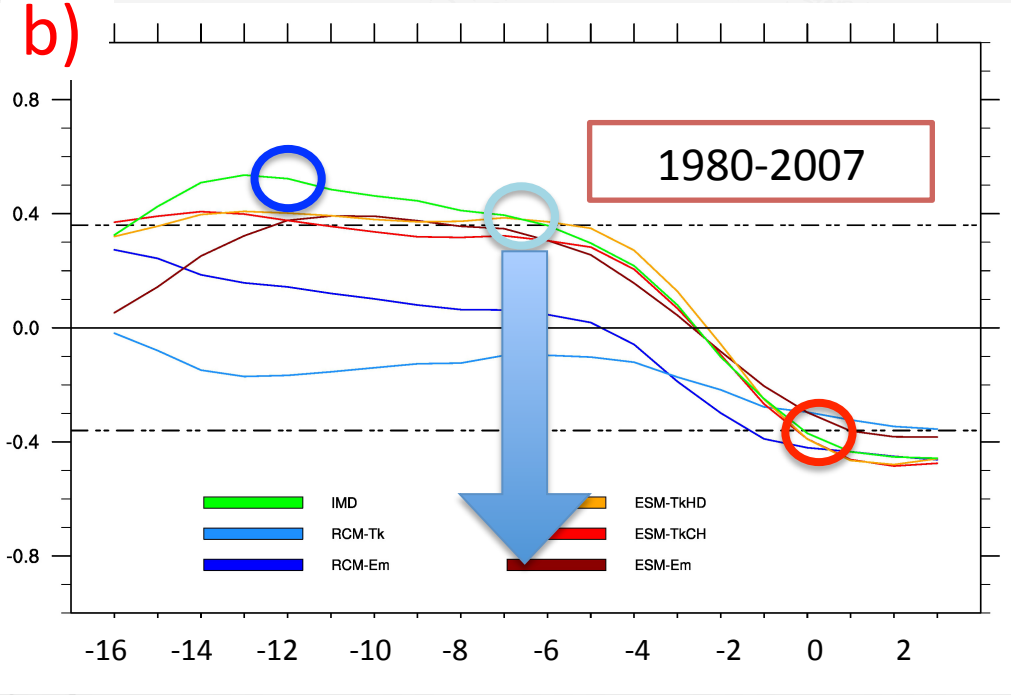


Results: ENSO forcing on ISM (delayed effect)

a)

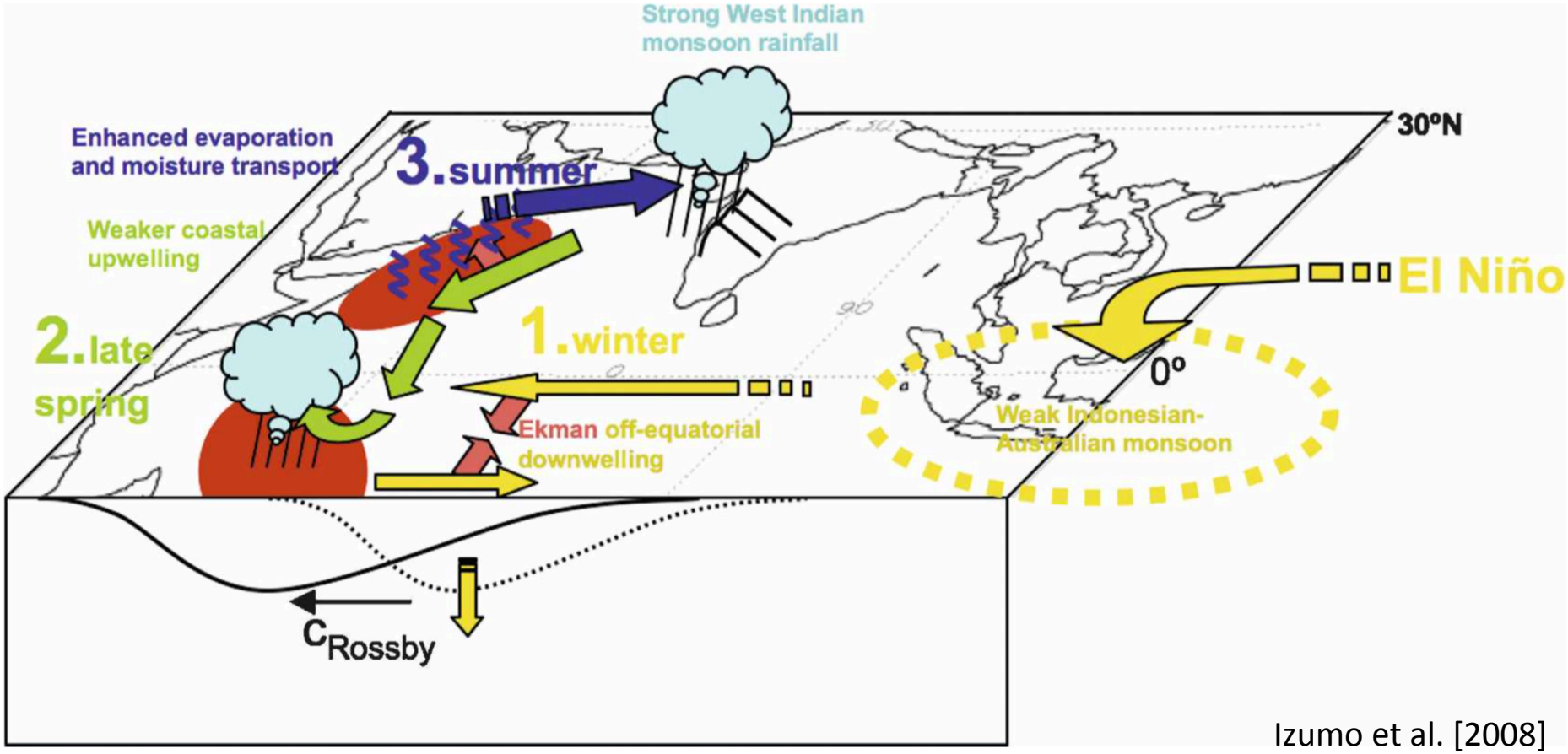


b)



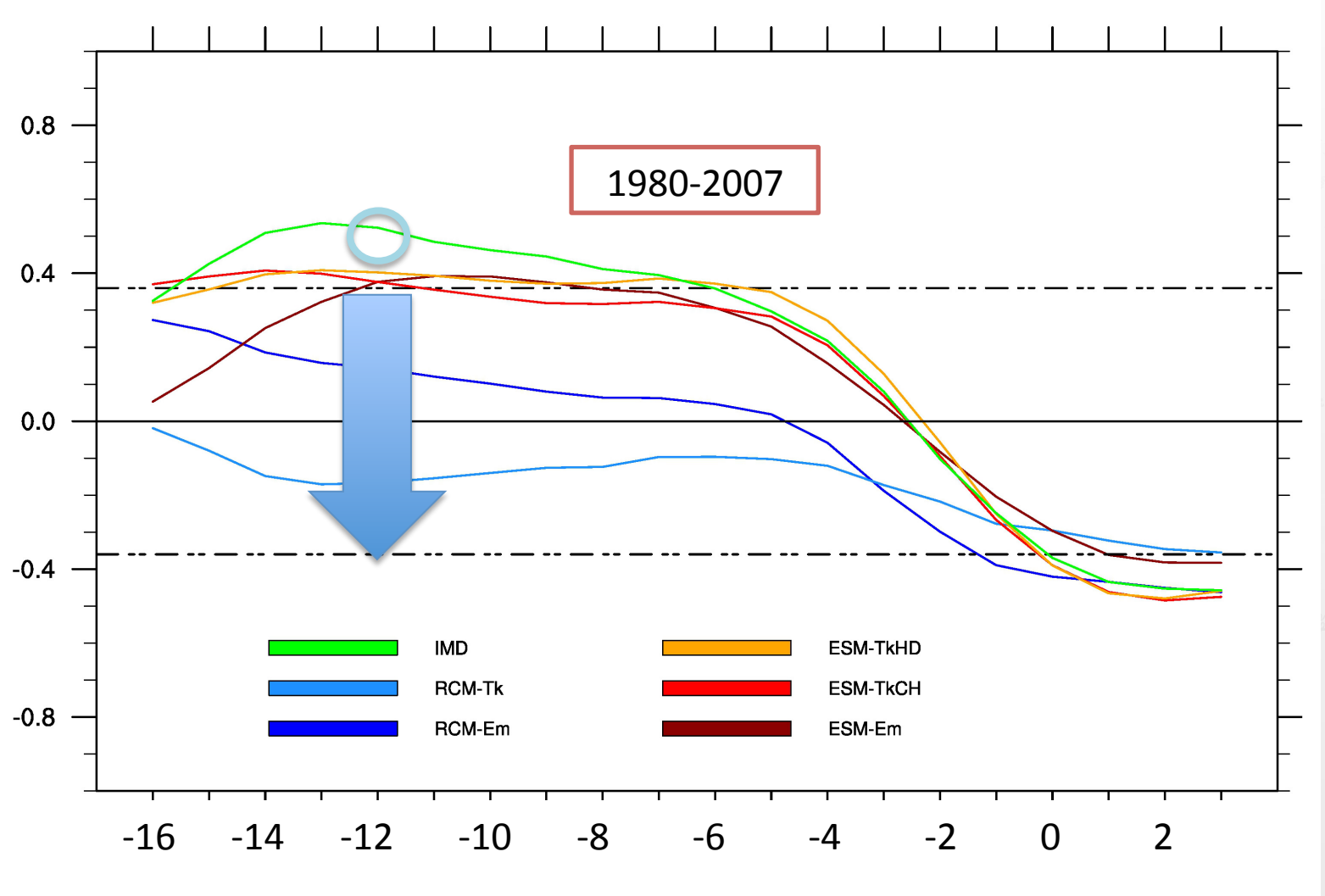
Results: ENSO forcing on ISM (delayed effect from NDJF)

Starting from previous winter…..



Izumo et al. [2008]

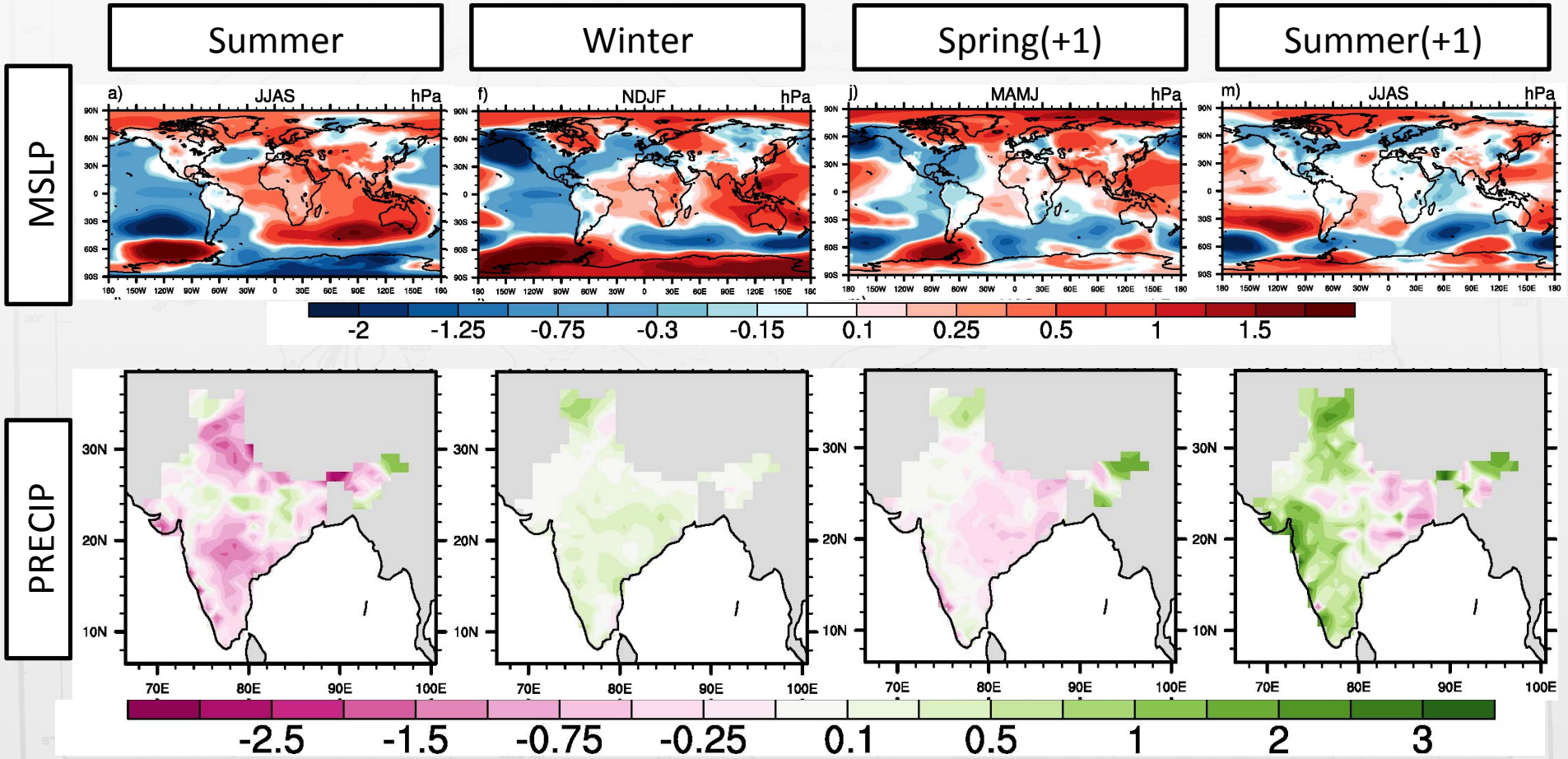
Results: ENSO forcing on ISM (delayed effect from JJAS)



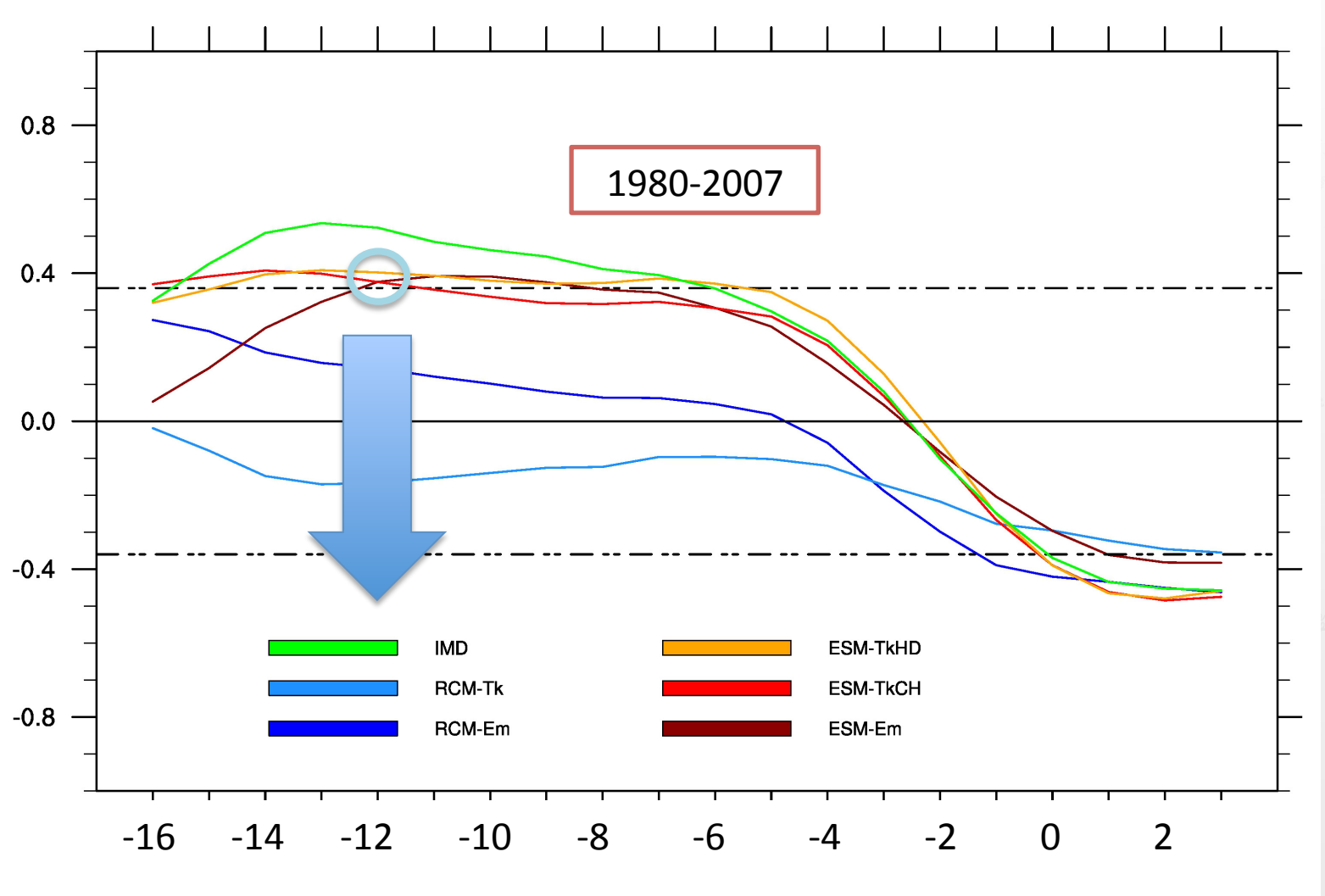
Results: ENSO forcing on ISM (delayed effect from JJAS)

Starting from previous summer.....

Regressed maps (OBS) of Niño3.4 (JJAS)

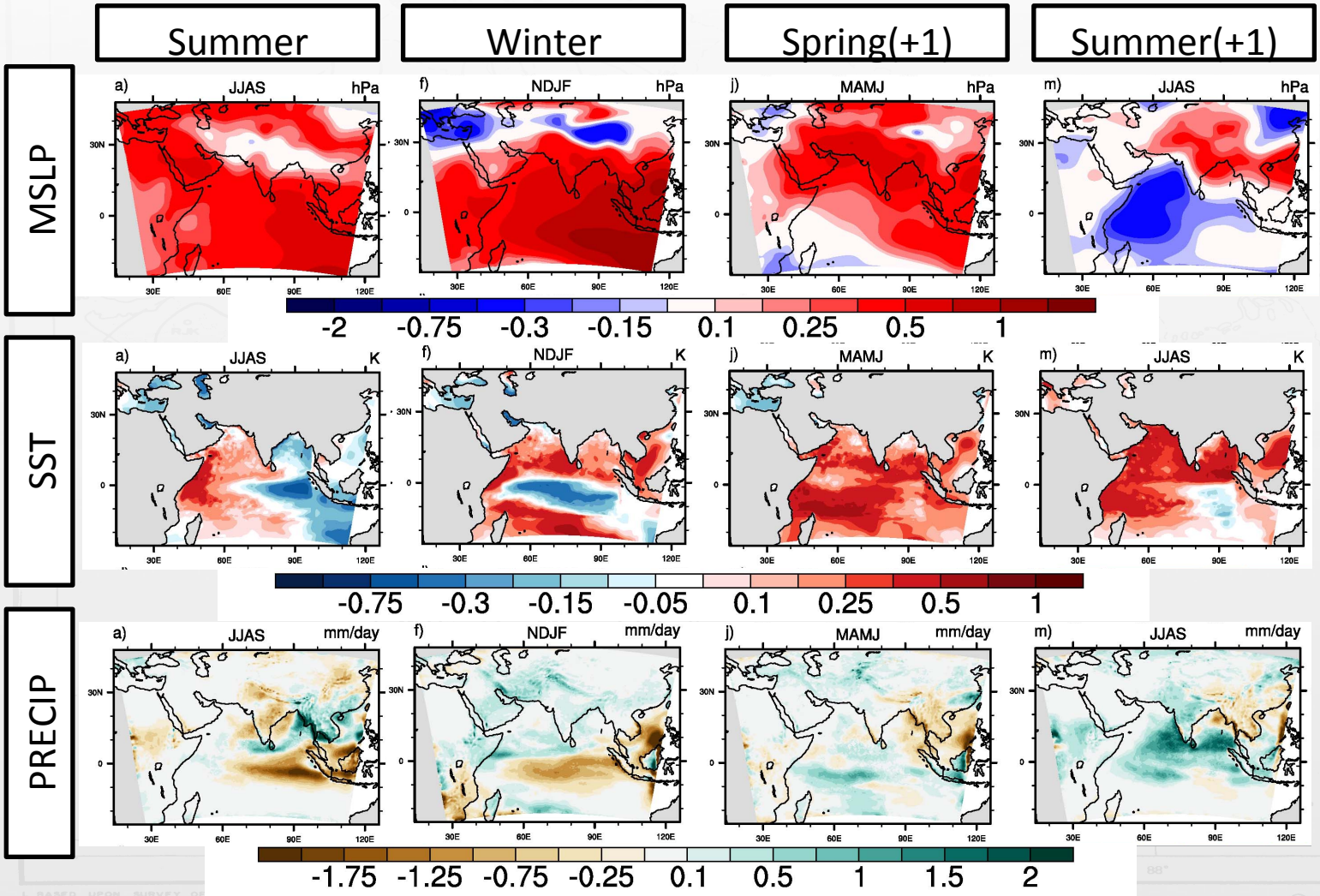


Results: ENSO forcing on ISM (delayed effect from JJAS)



Results: ENSO forcing on ISM (delayed effect from JJAS)

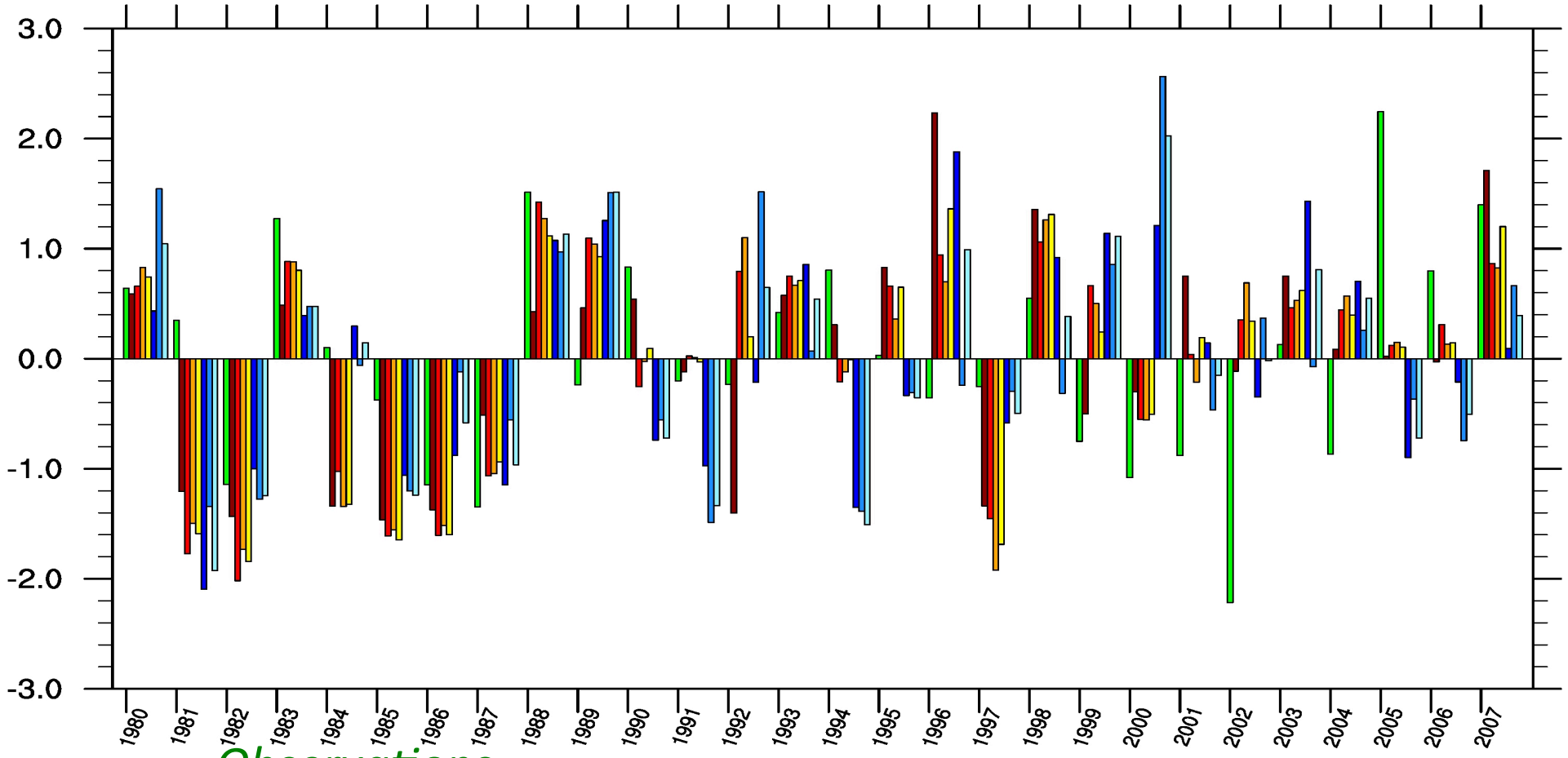
Starting from previous summer.....



Regressed maps (ESM-TkHD) of Niño3.4 (JJAS)

Di Sante, F. and et al. (2017). One-year lead-time predictability of indian summer monsoon due to delayed enso impact. Nature Geoscience (In preparation).

Results: interannual variability



Observations

IMD

RCM-Ensemble CC:-0.01

RCM-Tk CC:-0.04

RCM-Em CC:0.01

Standalone

ESM-Ensemble CC:0.38

ESM-TkHD CC:0.34

ESM-TkCH CC:0.37

ESM-Em CC:0.36

Coupled