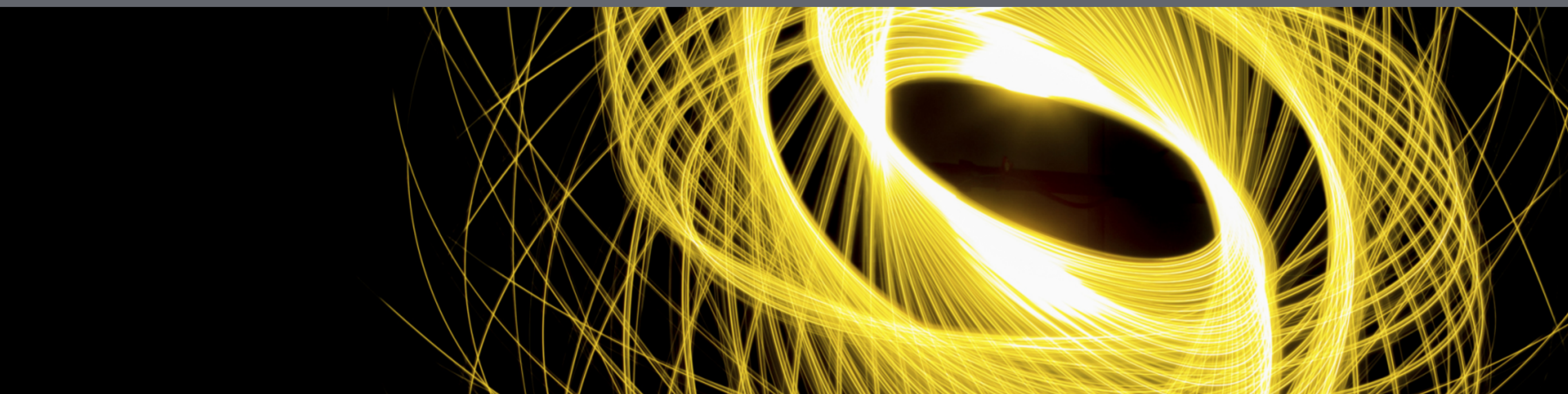
Dr Andy Turner, NCAS-Climate &
Department of Meteorology

University of Reading

# SYSTEMATIC MODEL BIASES IN THE SOUTH ASIAN MONSOON



ICTP Targeted Training Activity: Monsoons in a changing climate

31 July-4 August 2017

# OUTLINE

- CMIP5 performance for the Asian monsoon
- Arabian Sea as a source of bias
- Impact of coupling in CMIP5
- Parametrization uncertainty
- Role of resolution

Thanks to Fred Kucharski and J. Shukla for the invitation

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# MONSOON SIMULATION IN CMIP5

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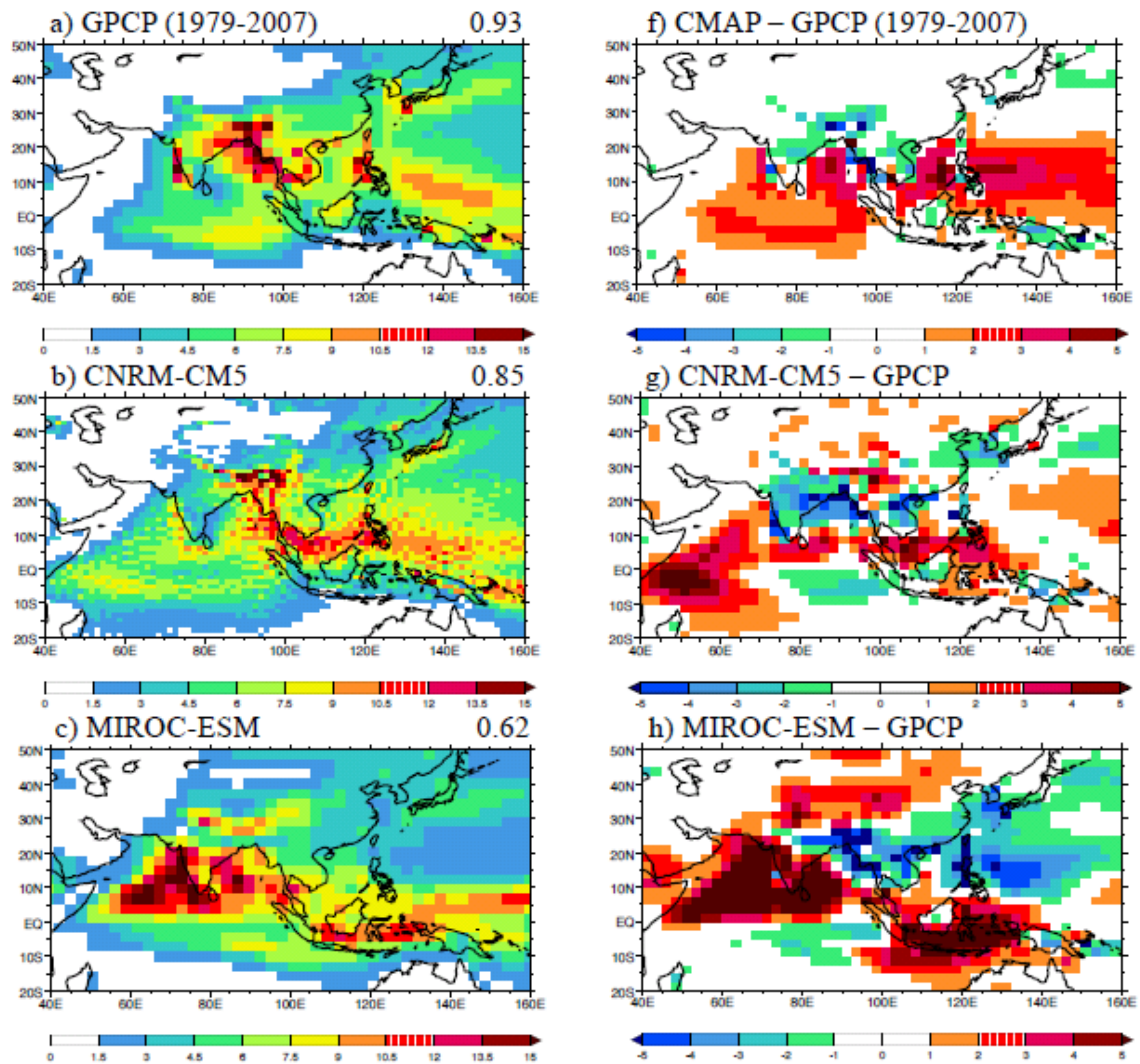
# MONSOON PRECIPITATION BIAS

- Large range of skill at simulating mean monsoon precipitation in CMIP5 & CMIP5 models
- Sperber *et al*. (2013)




**Mean JJAS precipitation (left) and bias versus GPCP obs (right)**

# CMIP PERFORMANCE FOR ASIAN MONSOON

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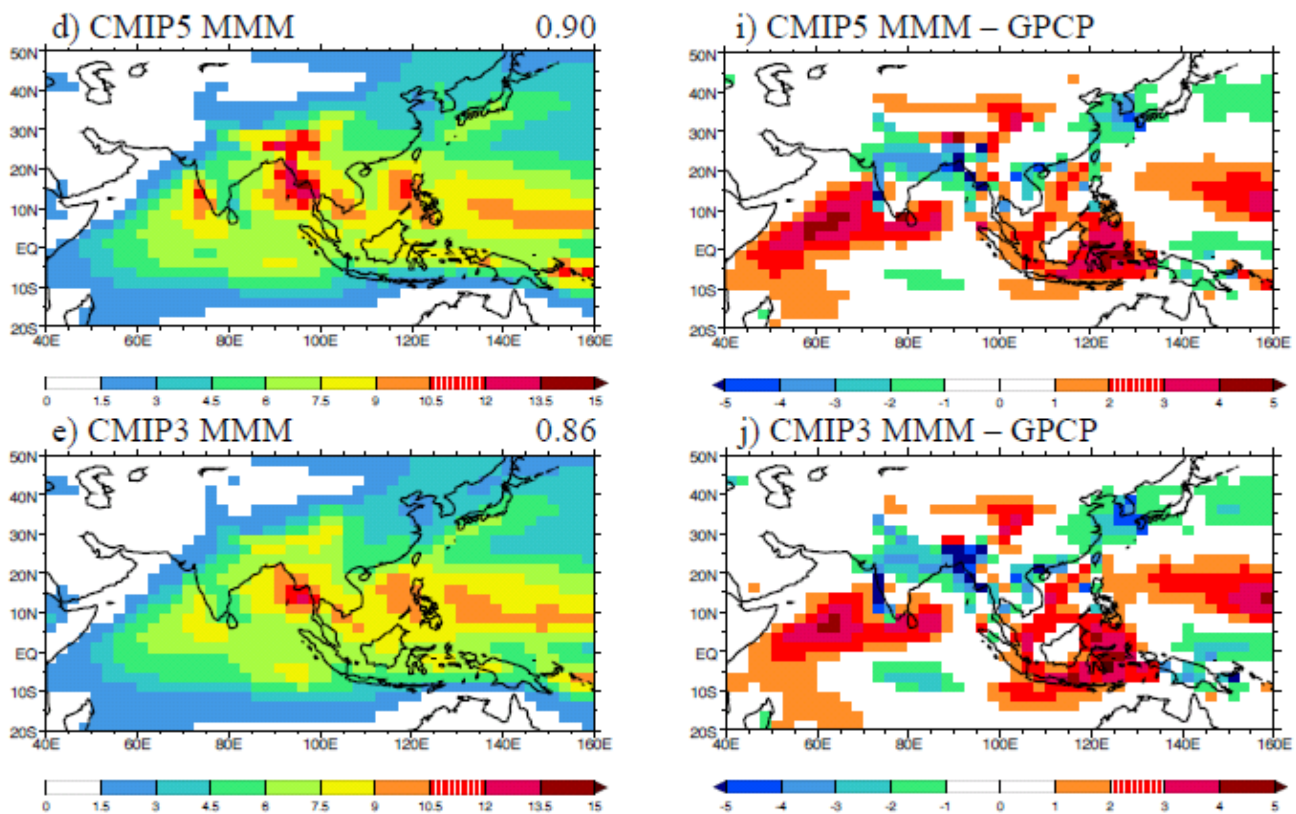
**Mean JJAS precipitation (left) & bias versus GPCP obs (right)**

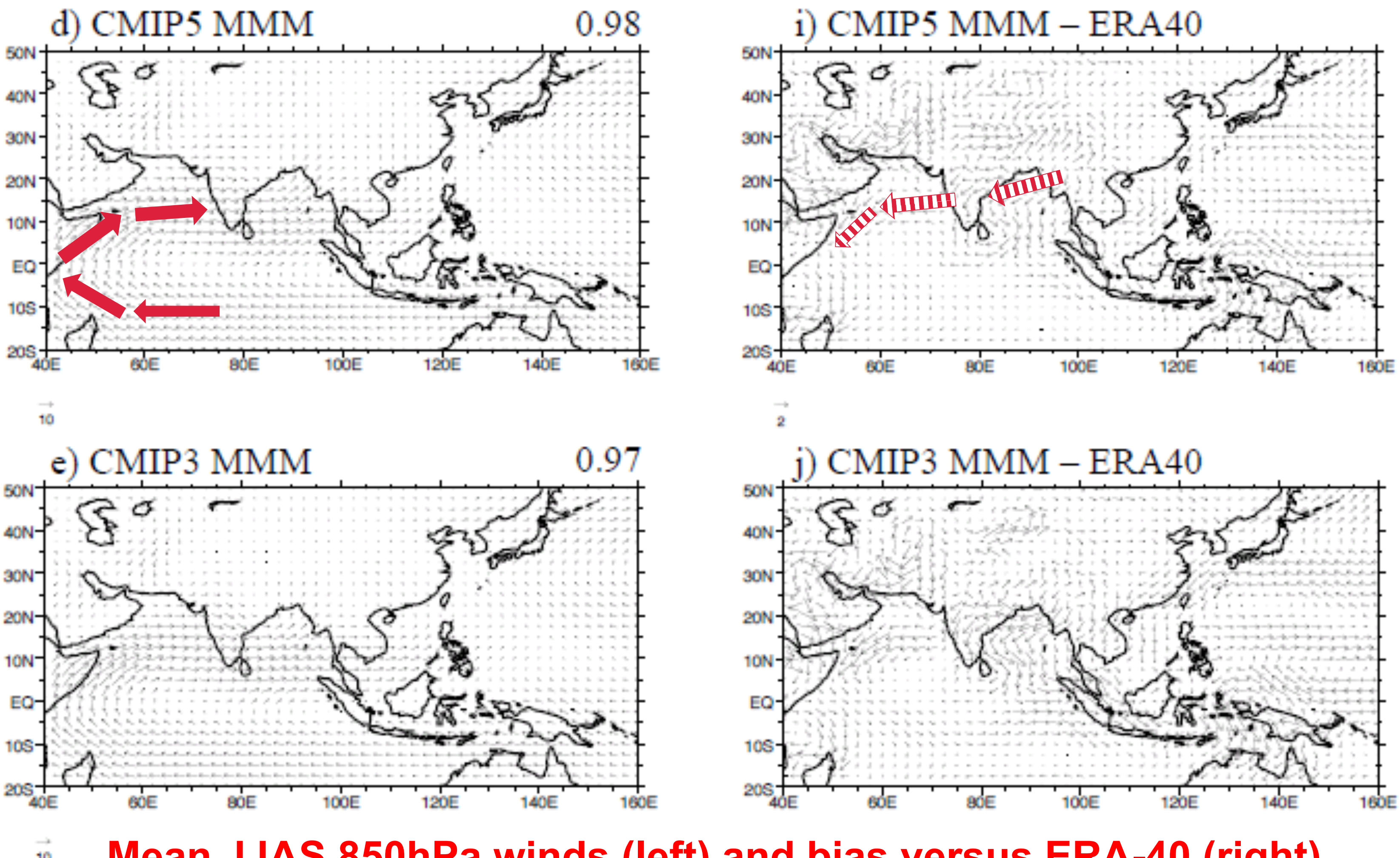
Sperber *et al.* (2013, *Clim. Dyn.*)




- Large dry bias (India)/wet bias (WEIO)
- Incremental improvements only since CMIP3

# MULTI-MODEL MEAN WINDS

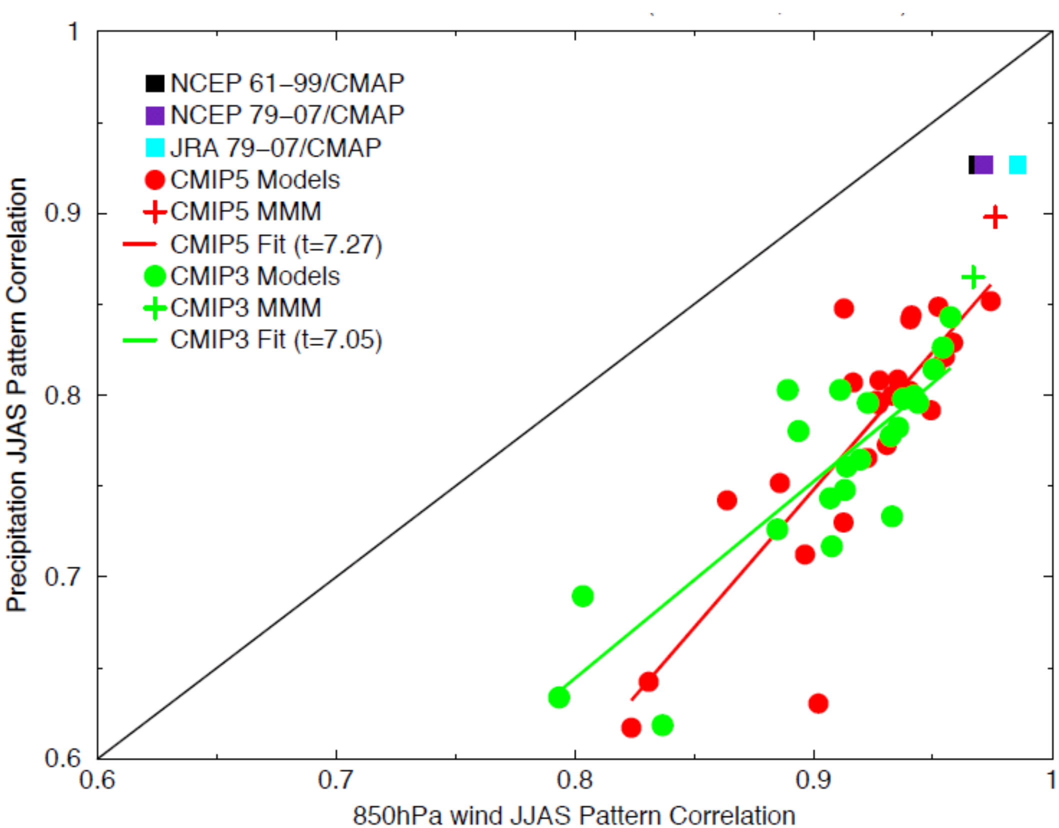
- Weak Somali jet in CMIP5 and CMIP3




**Mean JJAS 850hPa winds (left) and bias versus ERA-40 (right)**

# CMIP PERFORMANCE FOR ASIAN MONSOON

- Intimate link between monsoon circulation and precipitation biases
- Considerable effort still needed to improve coupled model performance
- Multi-model means outperform individuals




Sperber *et al*. (2013, *Clim. Dyn.*): Scatter diagrams of model pattern correlation skill for historical simulation of precip (y) and winds (x)

CMIP3 vs. CMIP5

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# ARABIAN SEA AS SOURCE OF BIAS

# SPRING TIME ARABIAN SEA COLD BIASES

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- CMIP5 models are too cold in winter and spring in northern Arabian Sea

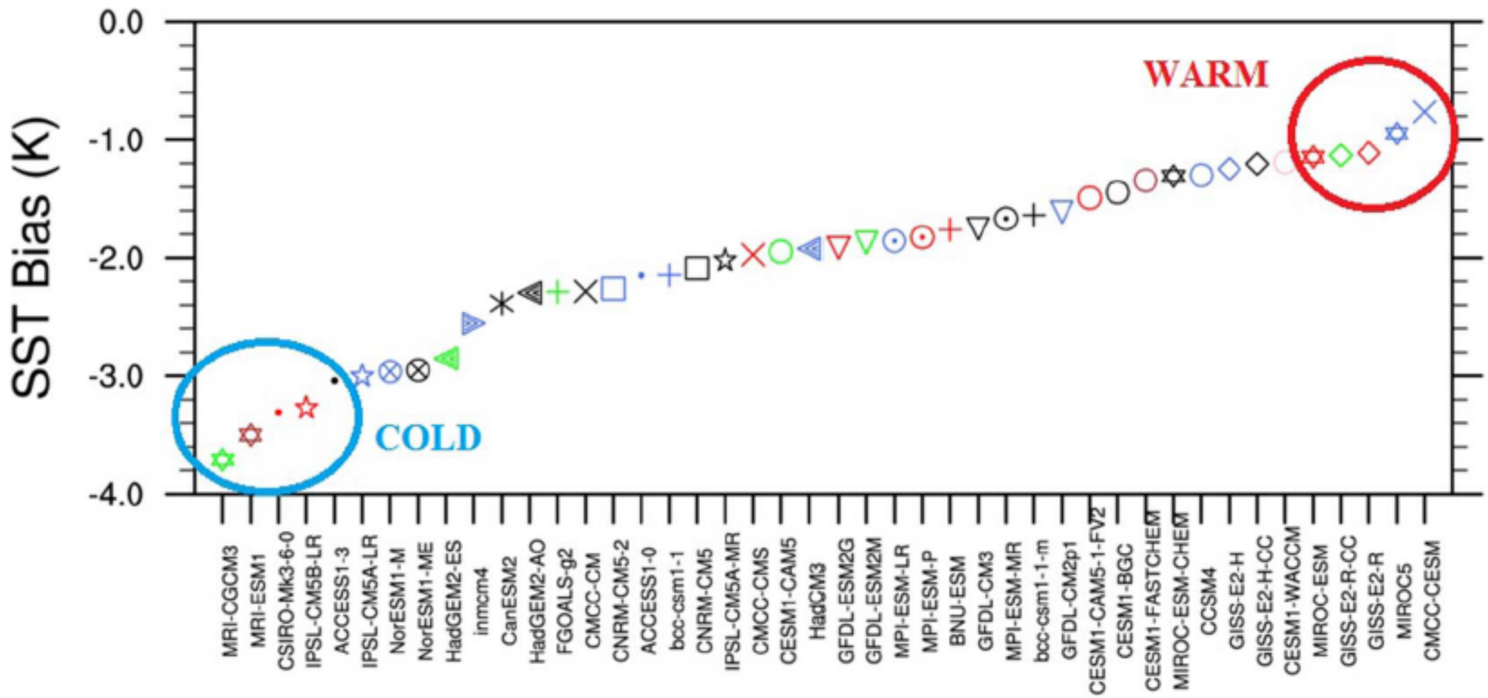
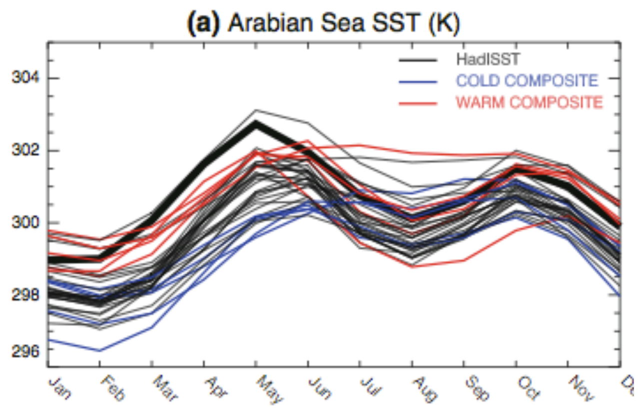


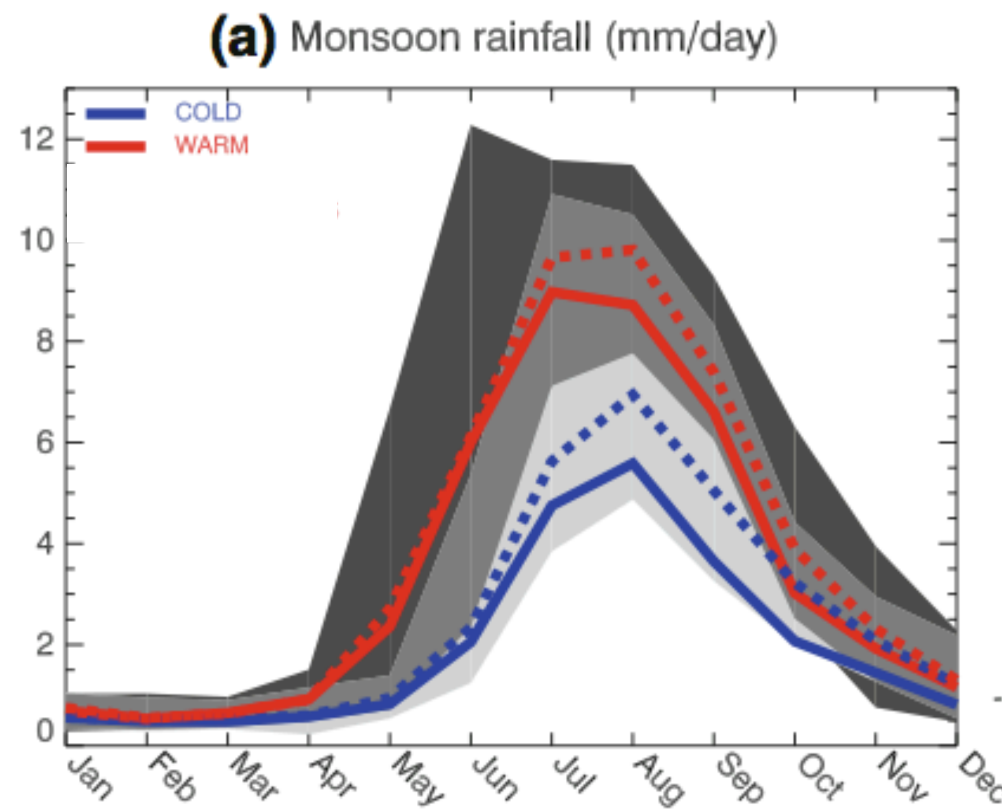

**Figure 1 | Arabian Sea SST bias.** Northern Arabian Sea (15°N–25°N; 60°E–70°E) spring season (March – May) SST bias (K) calculated for 44 CMIP5 models. The bias in historical all forcing simulations are computed with reference to fifty year (1951–2000) climatology of HadISST1.1. This figure is plotted using NCAR Command Language (NCL).

From Sandeep & Ajayamohan (2014) *Scientific Reports*

# SST BIASES & LINK TO RAINFALL

- CMIP5 models with cold winter/spring Arabian Sea have a weakened seasonal cycle of rainfall, later onset



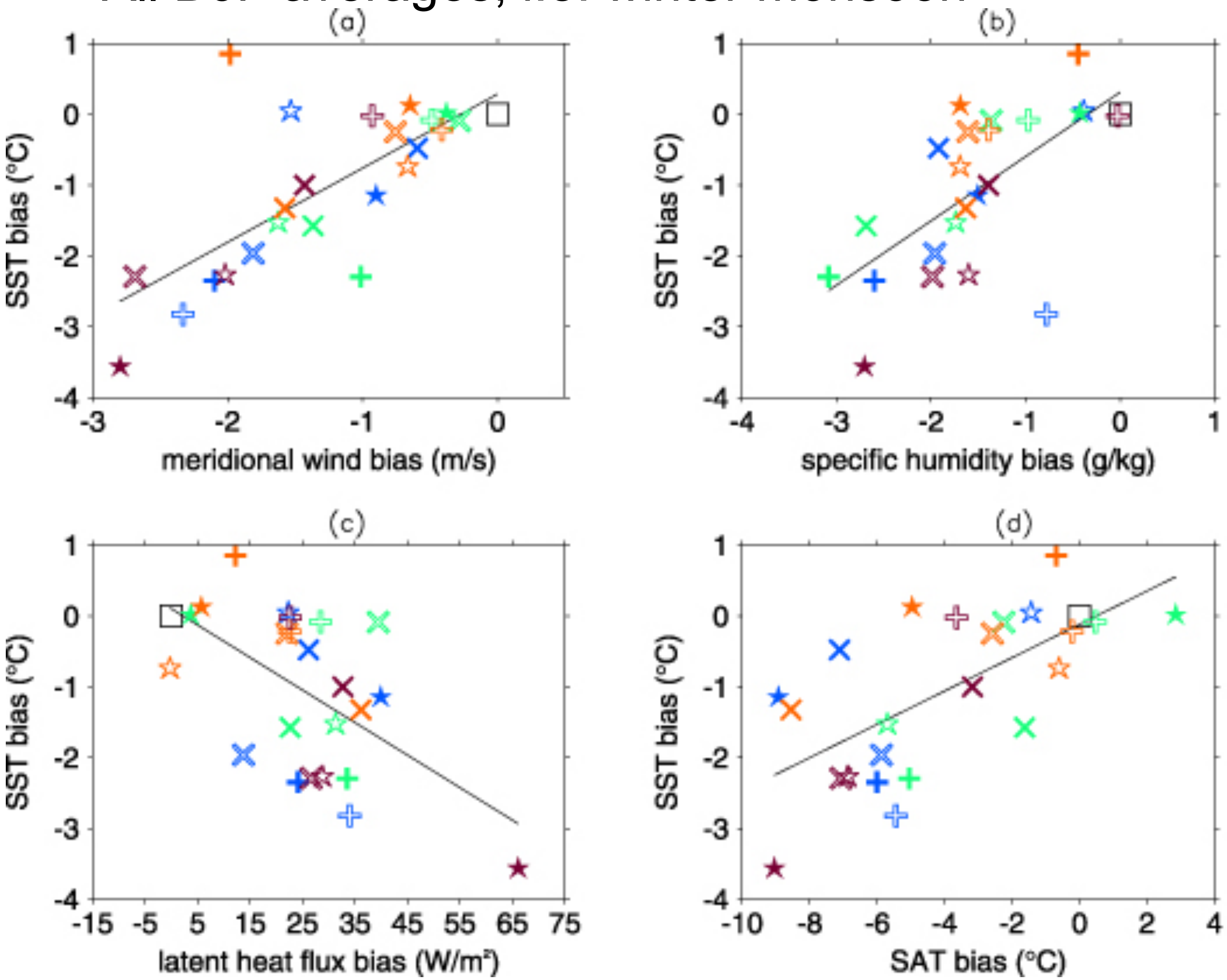




Levine, Turner, Marathayil & Martin (2013, *Clim. Dyn.*)

# MODEL BIAS: ARABIAN SEA IN WINTER

- Links to Arabian Sea cold biases
- All DJF averages, i.e. winter monsoon

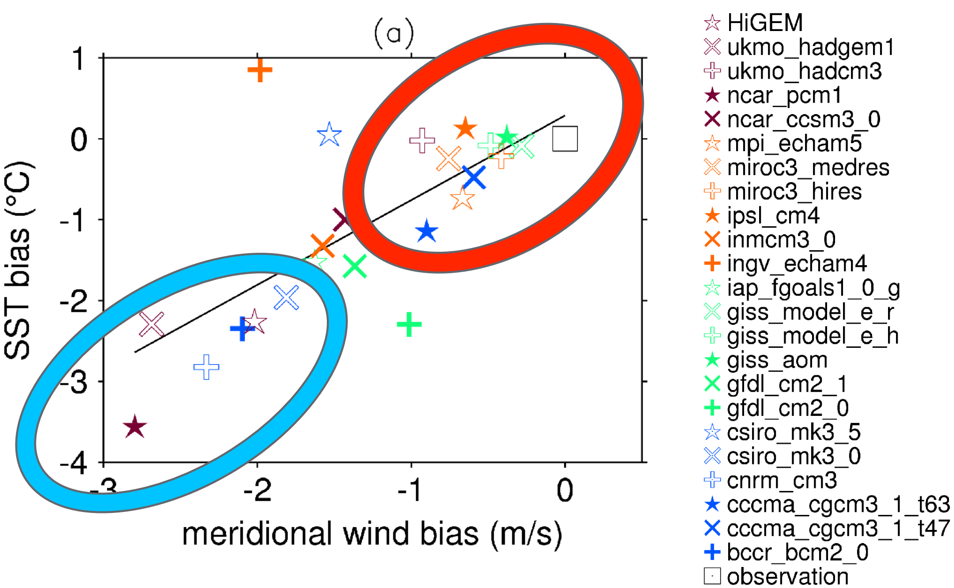
Marathayil/Turner/ Shaffrey (2013, *ERL*)

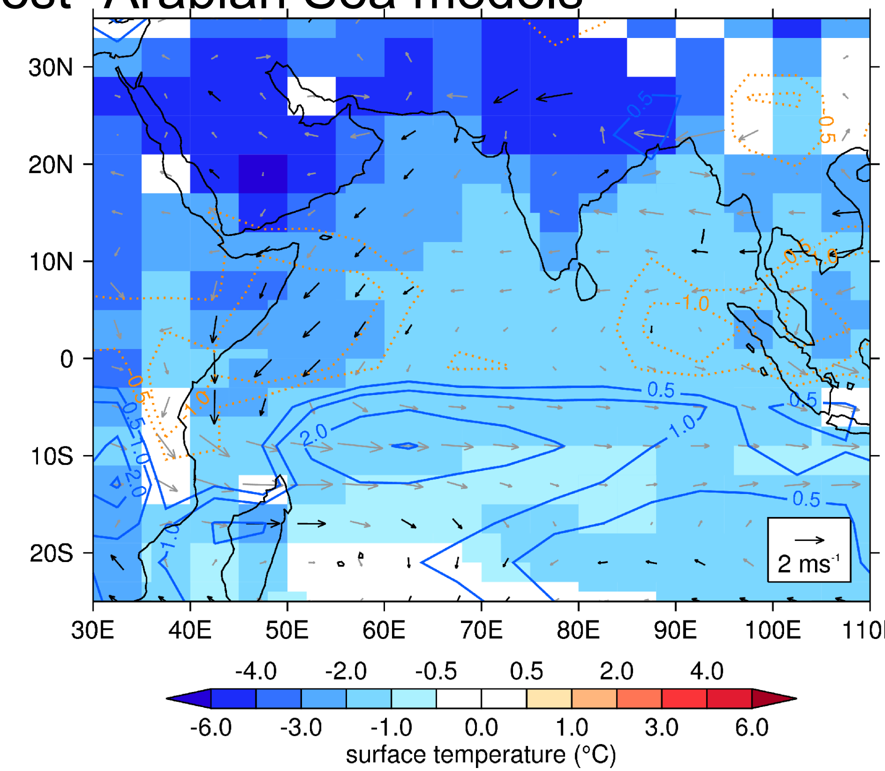



- Northern Arabian Sea SST cold biases linked to excess winter monsoon winds
- Excess LH flux lost to the atmosphere
- Yet air over north AS is too dry
- Advection of cold dry air across north coast of Arabian Sea

# CONNECTION OF ARABIAN SEA COLD BIASES

- Composite of “coldest” minus “warmest” Arabian Sea models
- DJF average
- Linked series of coupled biases




Marathayil/Turner/Shaffrey (2013, *ERL*)

# IMPACT OF COLD BIASES ON MONSOON

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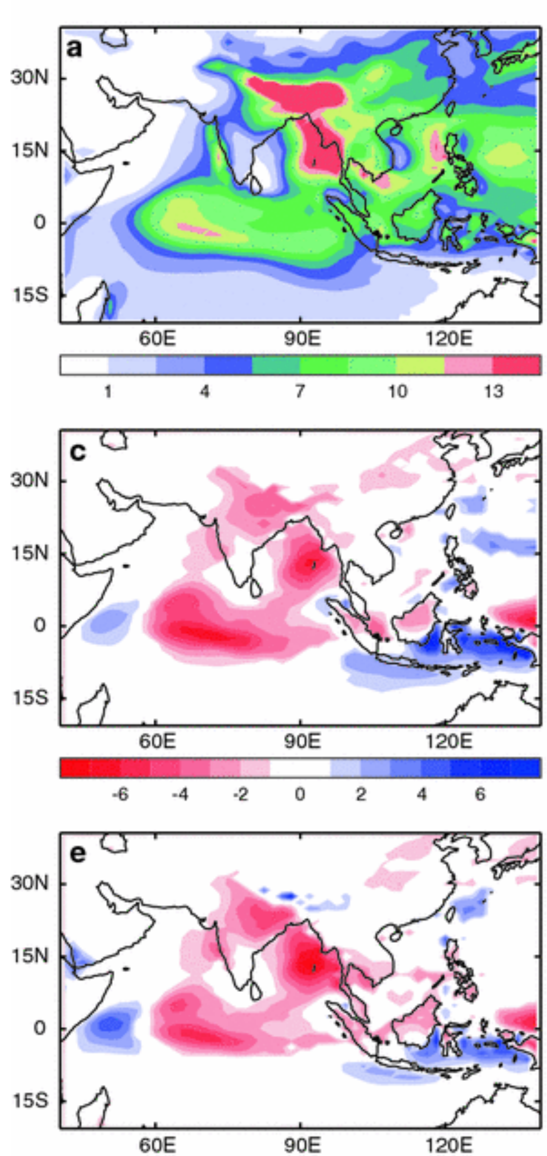
**HadGEM3-AGCM mean state**

**Difference in coupled simulation**

**AGCM when forced with coupled SST**




Comparison of monsoon rainfall in:

- AGCM
- CGCM
- AGCM forced with SSTs from the CGCM

From Levine & Turner (2012) *Climate Dynamics*

# ISOLATE ROLE OF LOCAL SST

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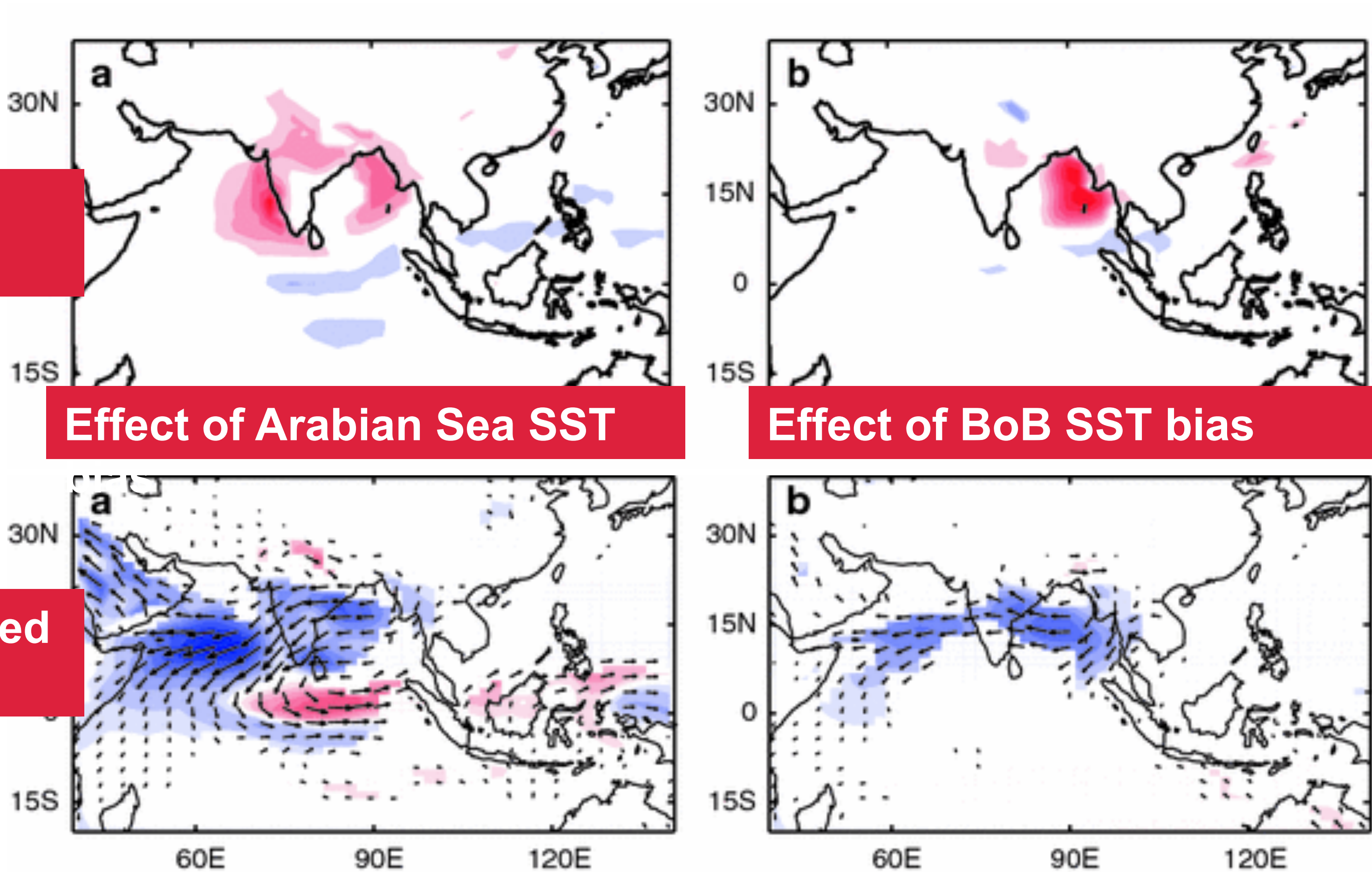
Rainfall change

Vector/speed change

Effect of Arabian Sea SST

Effect of BoB SST bias




From Levine & Turner (2012)
*Climate Dynamics*

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# IMPACT OF COUPLING IN CMIP5

# AMIP JJAS MEAN MONSOON

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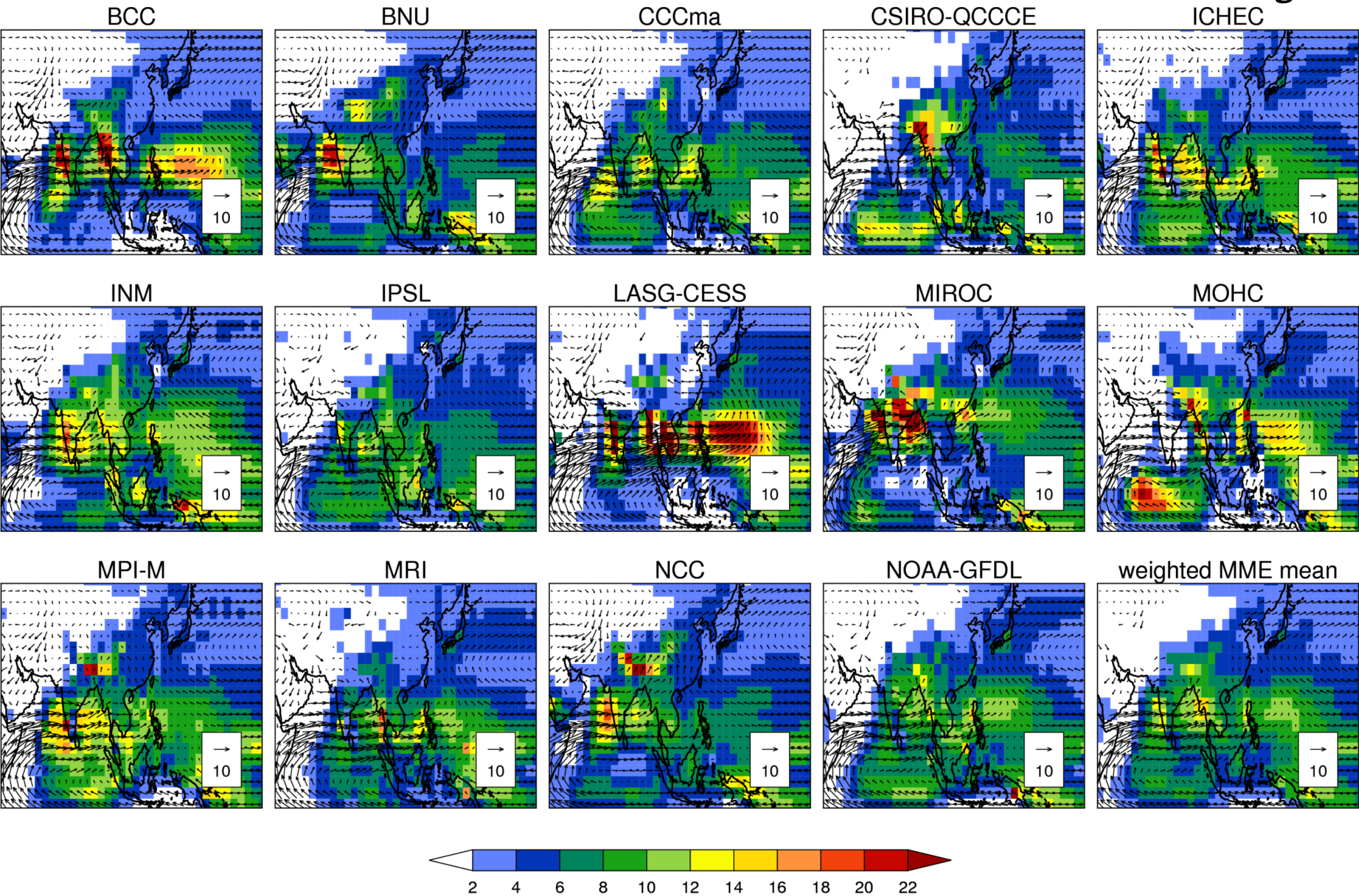

# COUPLED JJAS MEAN MONSOON

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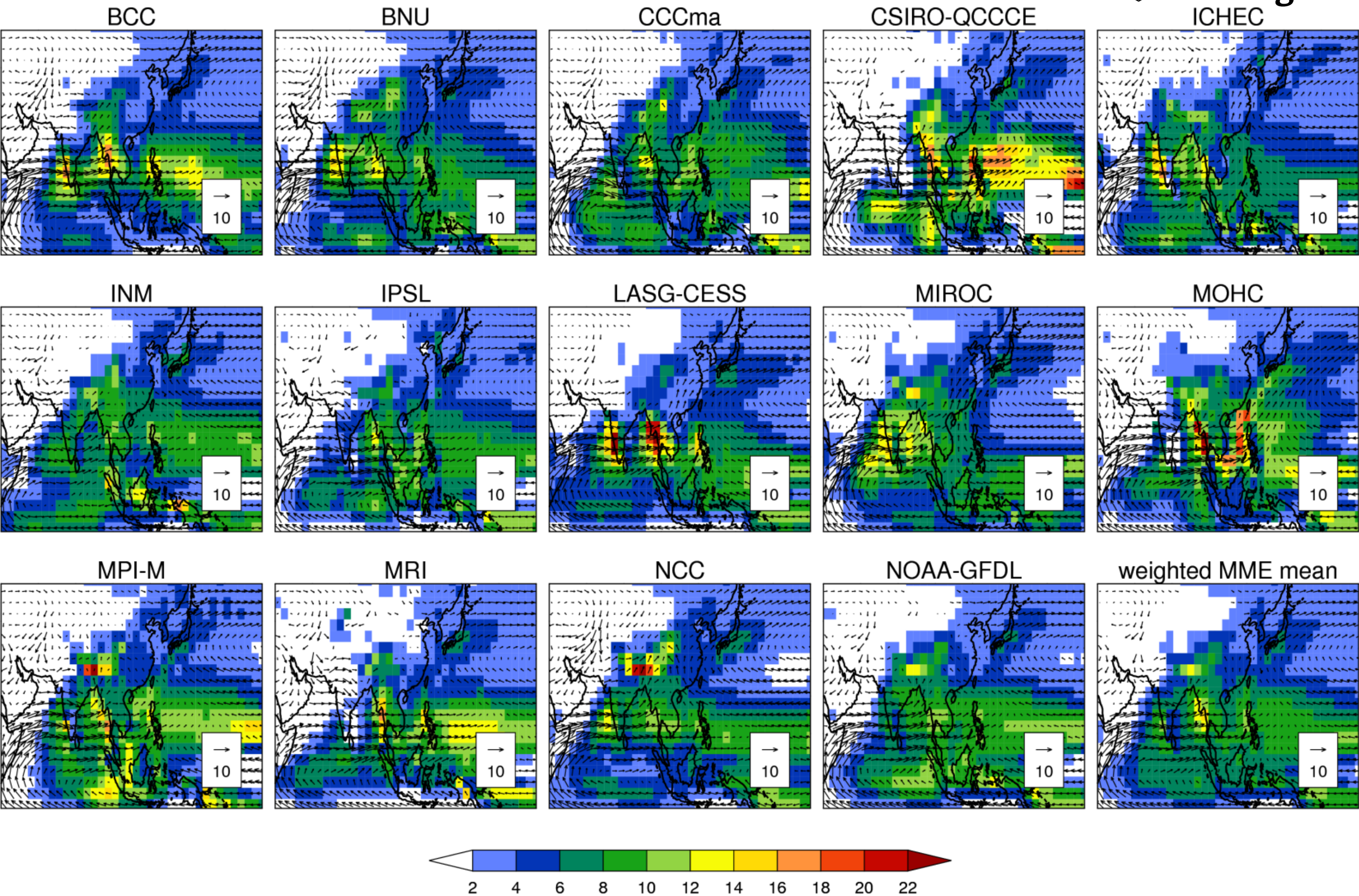
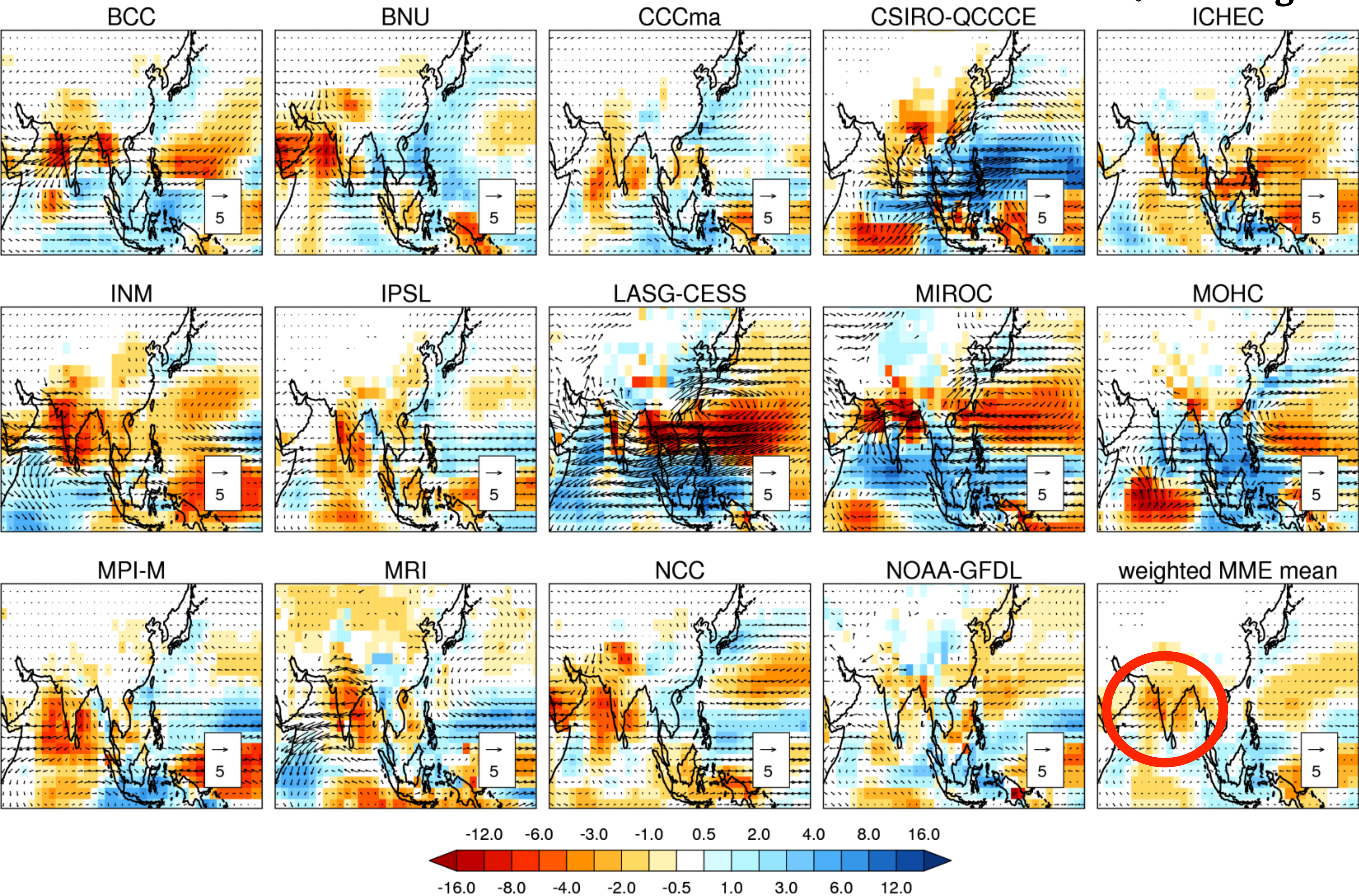
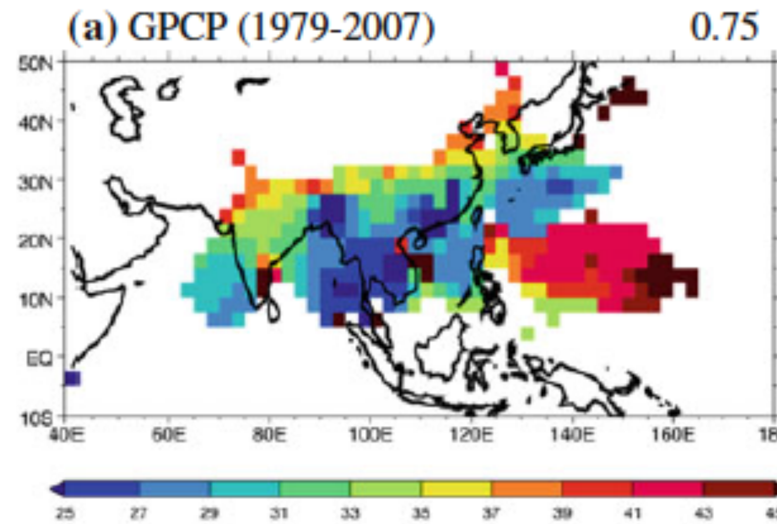


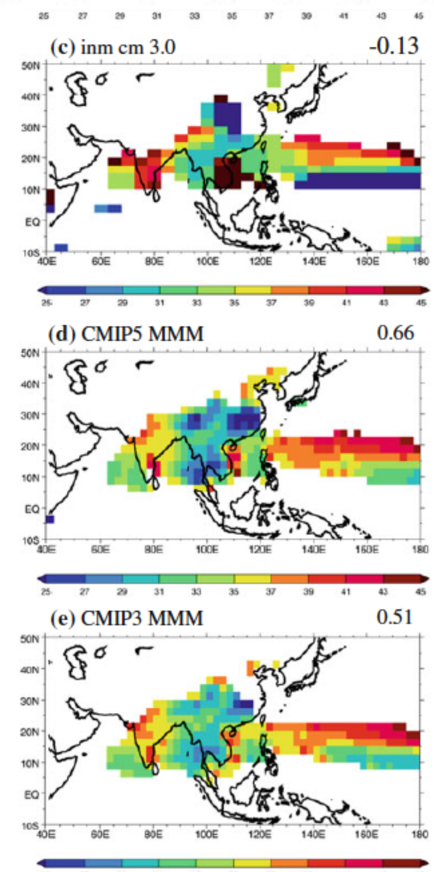
# COUPLED-AGCM MEAN



# CMIP5 ONSET PERFORMANCE

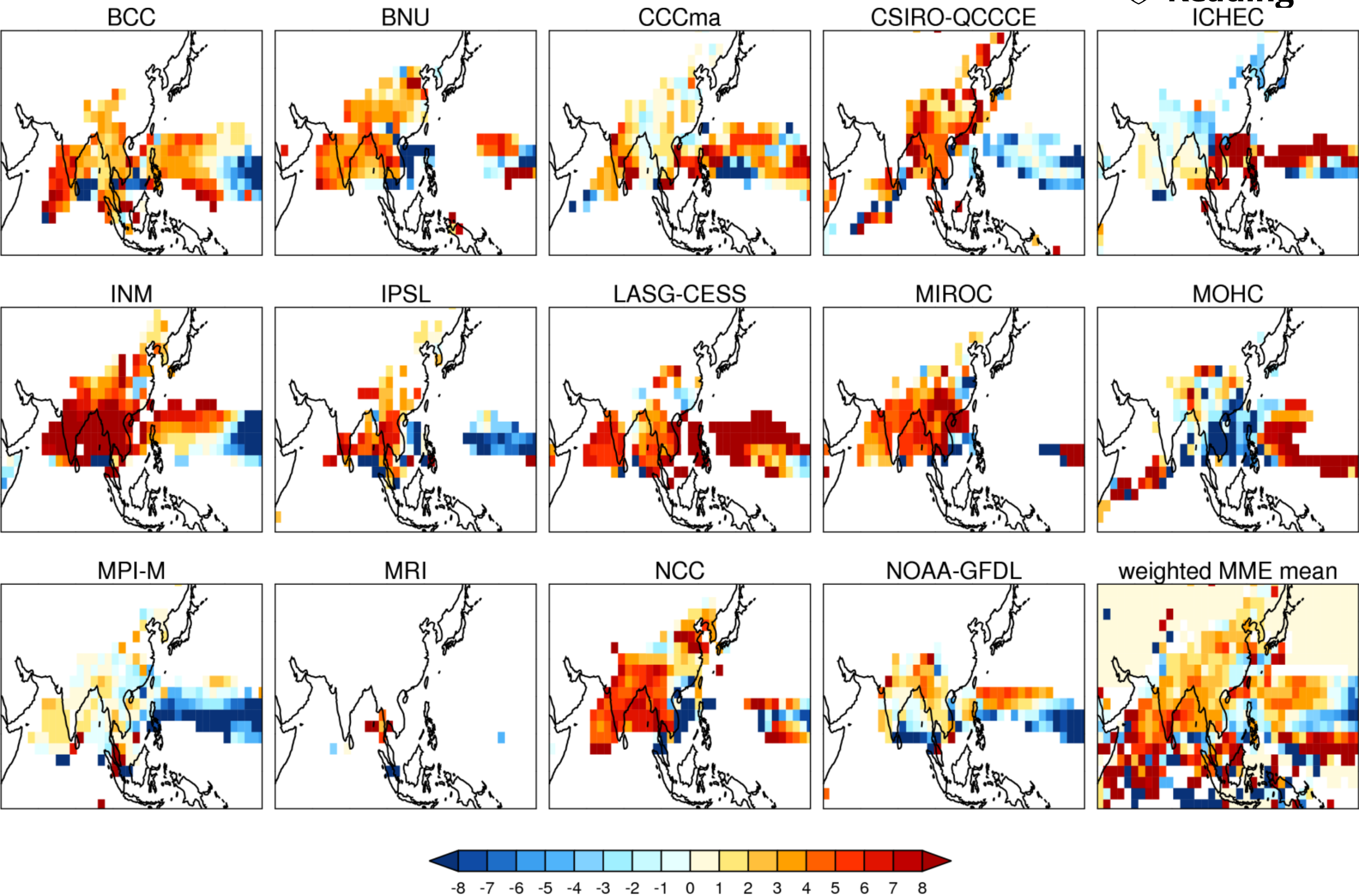
- Monsoon progression to the NW across much of the Asian monsoon domain
- “Wang & LinHo metric” for onset pentads
- Some models perform awfully
- CMIPx multi-model mean gets the right idea but systematically late




Sperber *et al.* (2013, *Clim. Dyn.*)

# CGCM MINUS AMIP ONSET



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# PARAMETRIZATION UNCERTAINTY

# CONVECTIVE PARAMETRIZATION

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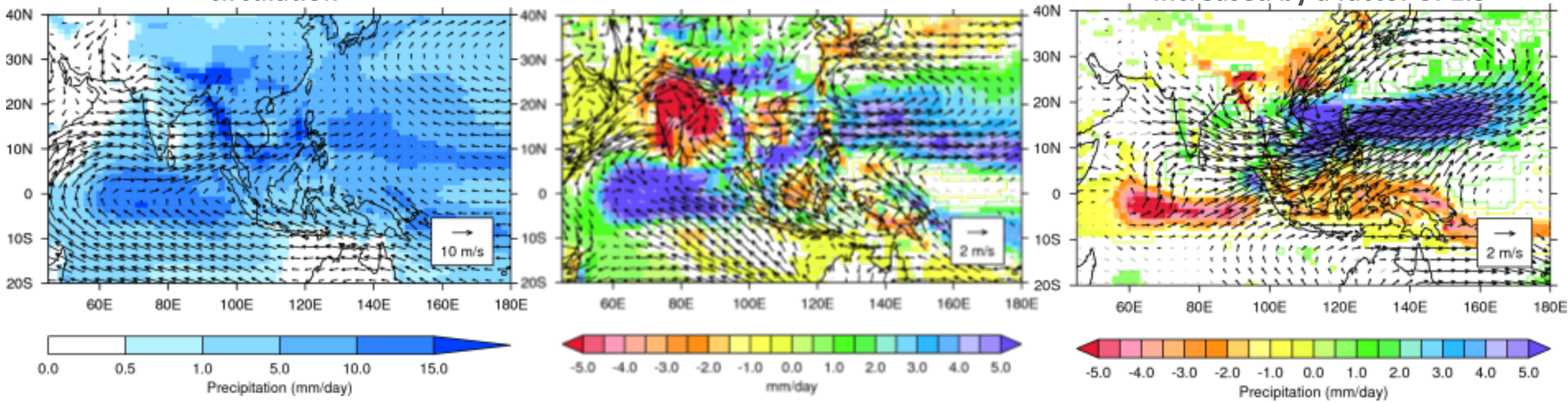
UM JJAS precipitation and 850 hPa circulation

Bias: GPCP and ERA Interim

Mid-level and Deep Entrainment increased by a factor of 1.5




- Increasing the convective entrainment rate tends to improve ISV (e.g. Klingaman et al.; Hirons et al., 2012; Del Genio et al., 2012)
- Increasing convective entrainment globally decreases several biases while increasing others (Kim et al. 2011)
- Changing the entrainment rate has a dramatic impact on distribution of monsoon rainfall, but doesn't solve the fundamental bias

Bush *et al.* (2014, QJRMS)

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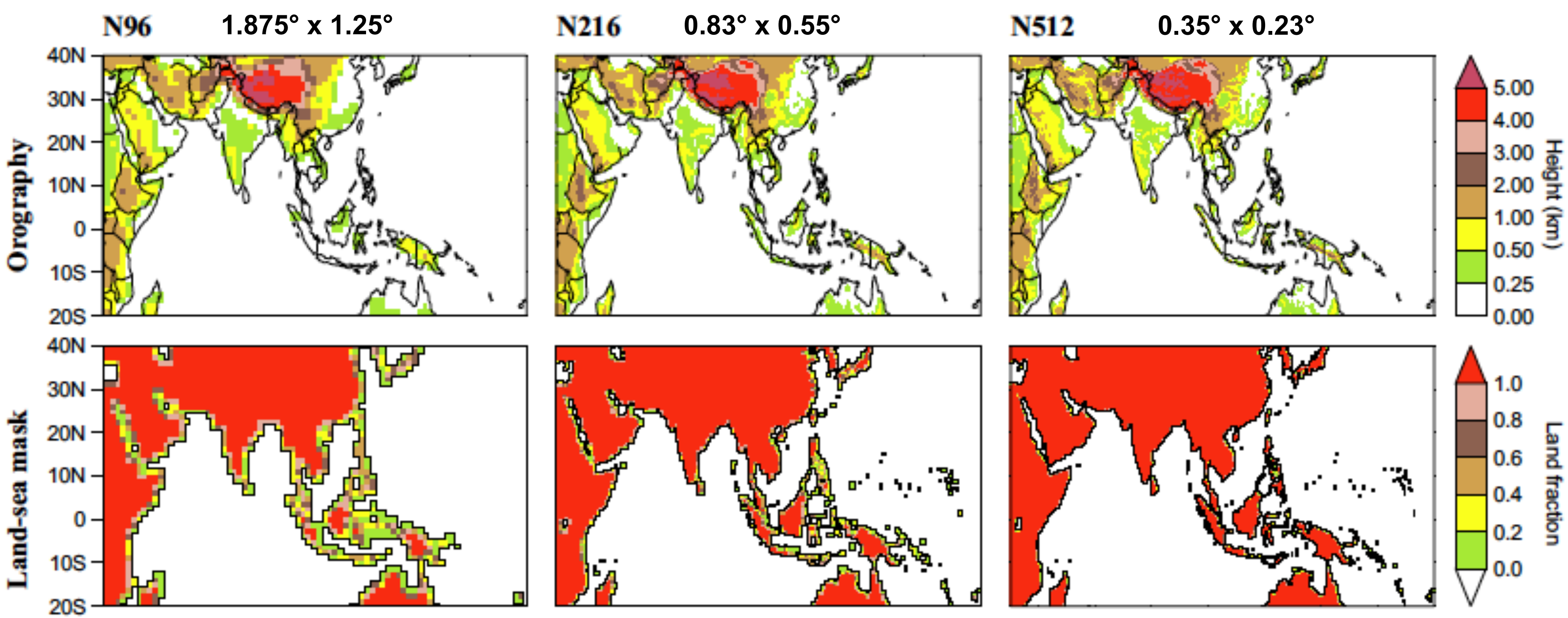
# ROLE OF RESOLUTION

# ROLE OF RESOLUTION

- Potential for better resolved processes
- Less to be achieved by sub-gridscale parametrizations




Johnson *et al*. (2016, *Clim. Dyn.*)

# IMPACT OF RESOLUTION ON RAINFALL

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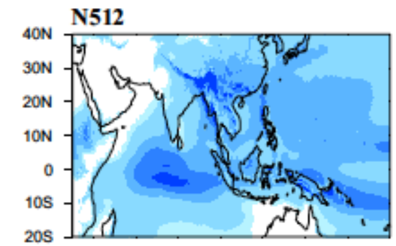
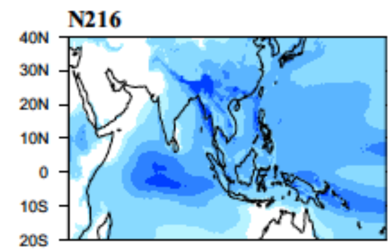
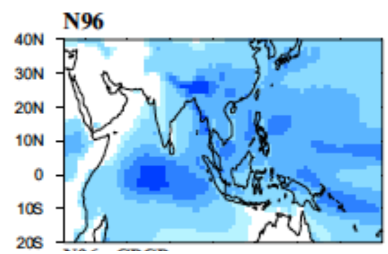
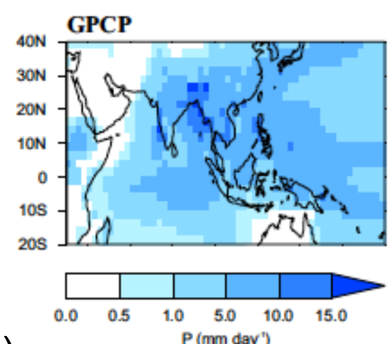
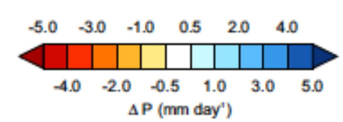
- For the Asian monsoon region as a whole, increasing resolution at these scales doesn't appear to improve simulation




Johnson *et al*. (2016, *Clim. Dyn.*)

# RESOLUTION & DEPRESSIONS

- In these simulations, resolution does not seem to change number of LPS (not shown)
- Rainfall associated with LPS does increase

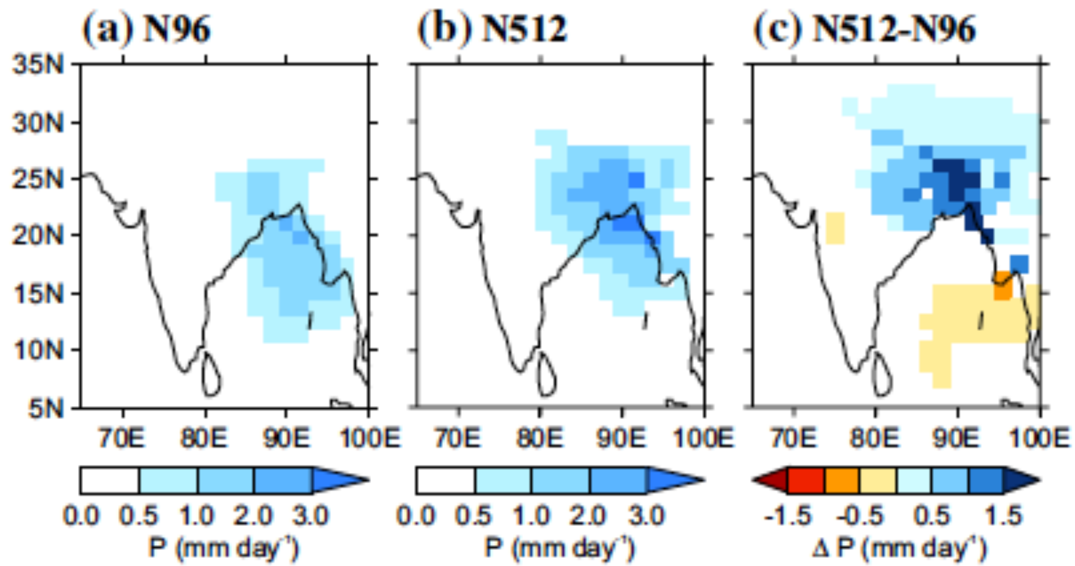



**Fig. 7** Climatological, ensemble averaged JJAS precipitation attributed to monsoon LPS in the **a** N96 configuration of the MetUM on its native grid and **b** N512 configuration of the MetUM interpolated to the N96 grid. **c** Difference between **b** and **a**. Only points significant by a Mann–Whitney rank sum test are shown. The *colour scale* ranges to $\pm 1.5$ mm day$^{-1}$, while the scale on Fig. 3, which shows the total JJAS precipitation change with resolution, ranges to $\pm 5$ mm day$^{-1}$

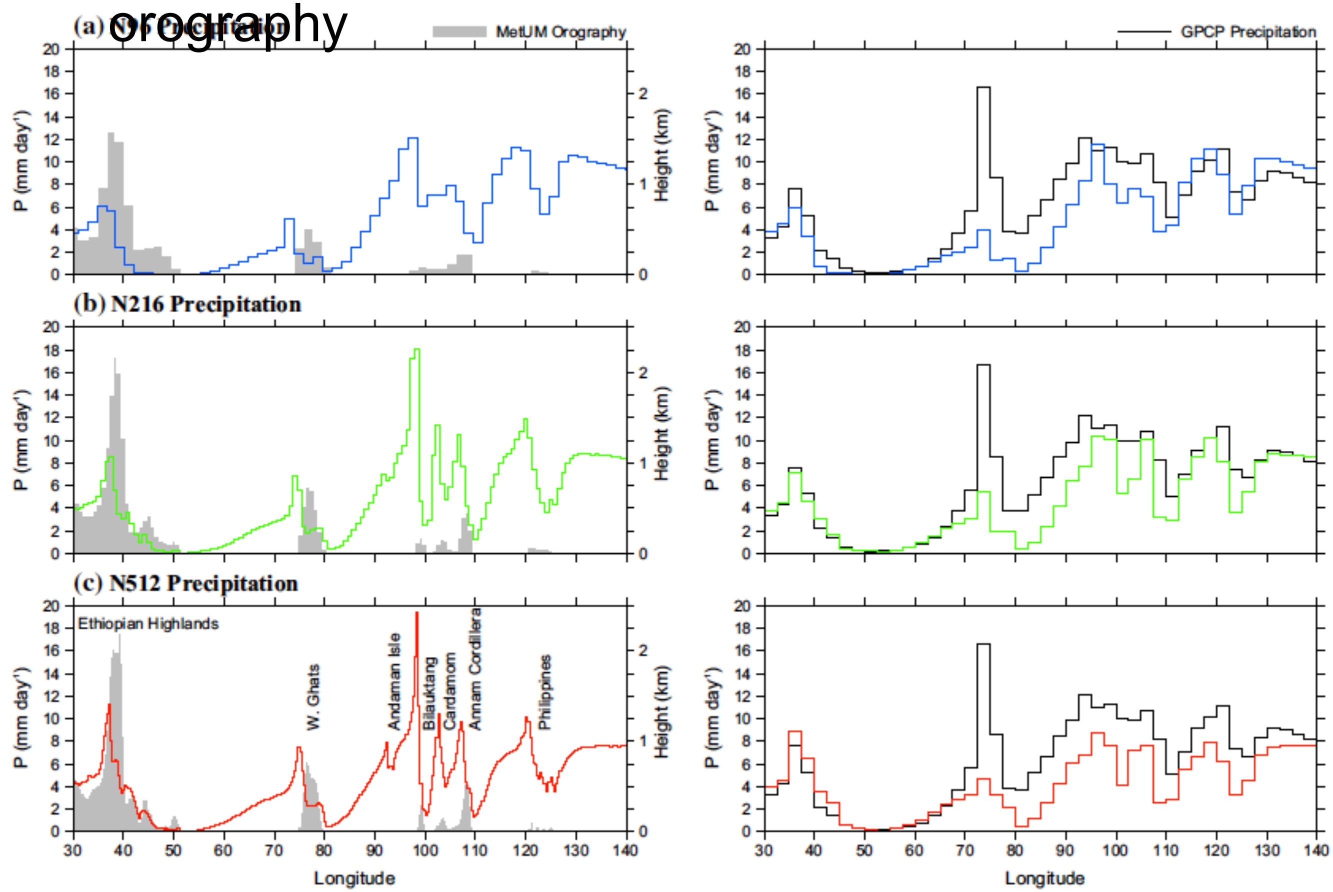
Johnson *et al*.
(2016, *Clim. Dyn*.)

# RESOLUTION & OROGRAPHY

- 11-13°N mean
- Clear increase in rainfall peaks associated with steep orography, but still failing to match observations

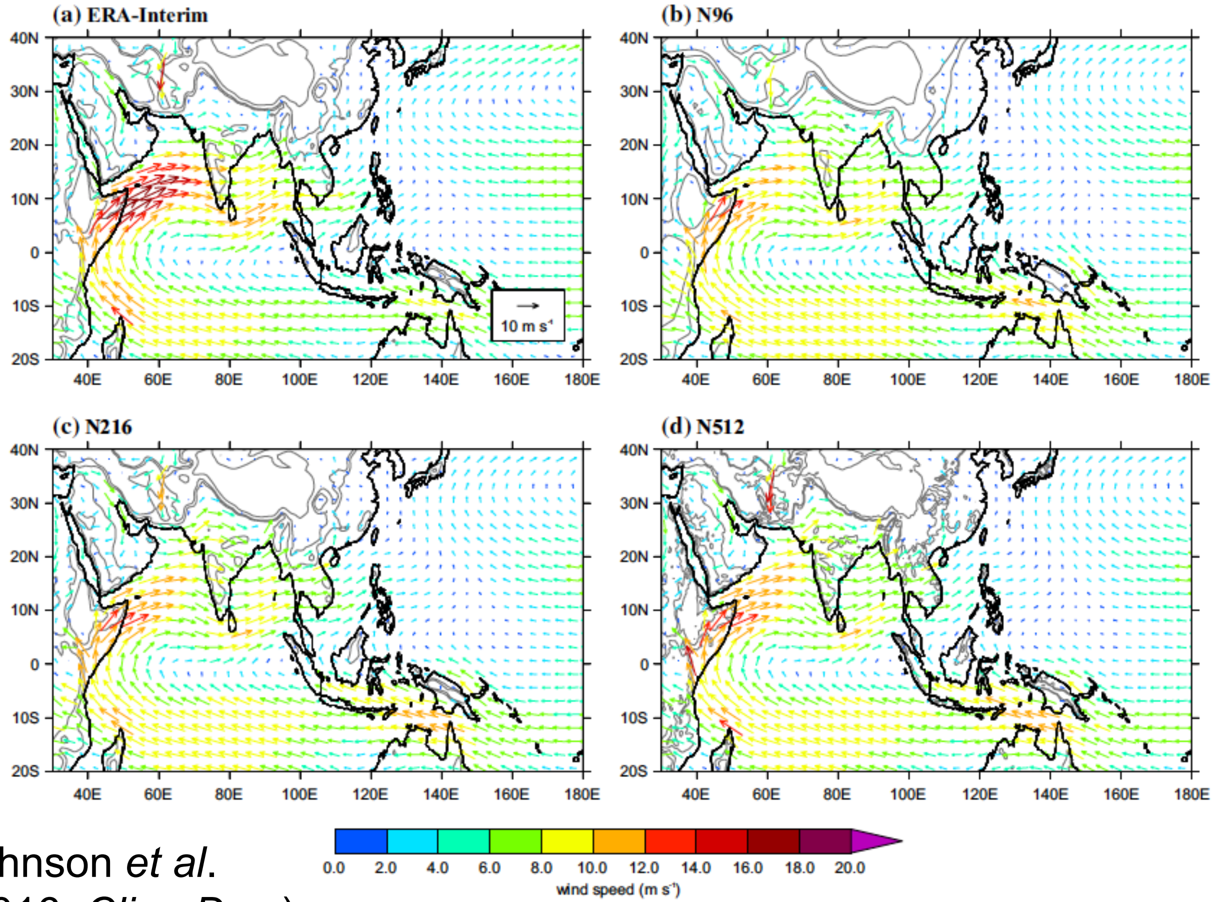
Left: native model grid rainfall with orography

Right: model rainfall on GPCP grid




Johnson *et al.* (2016, *Clim. Dyn.*)

# RESOLUTION & MONSOON FLOW

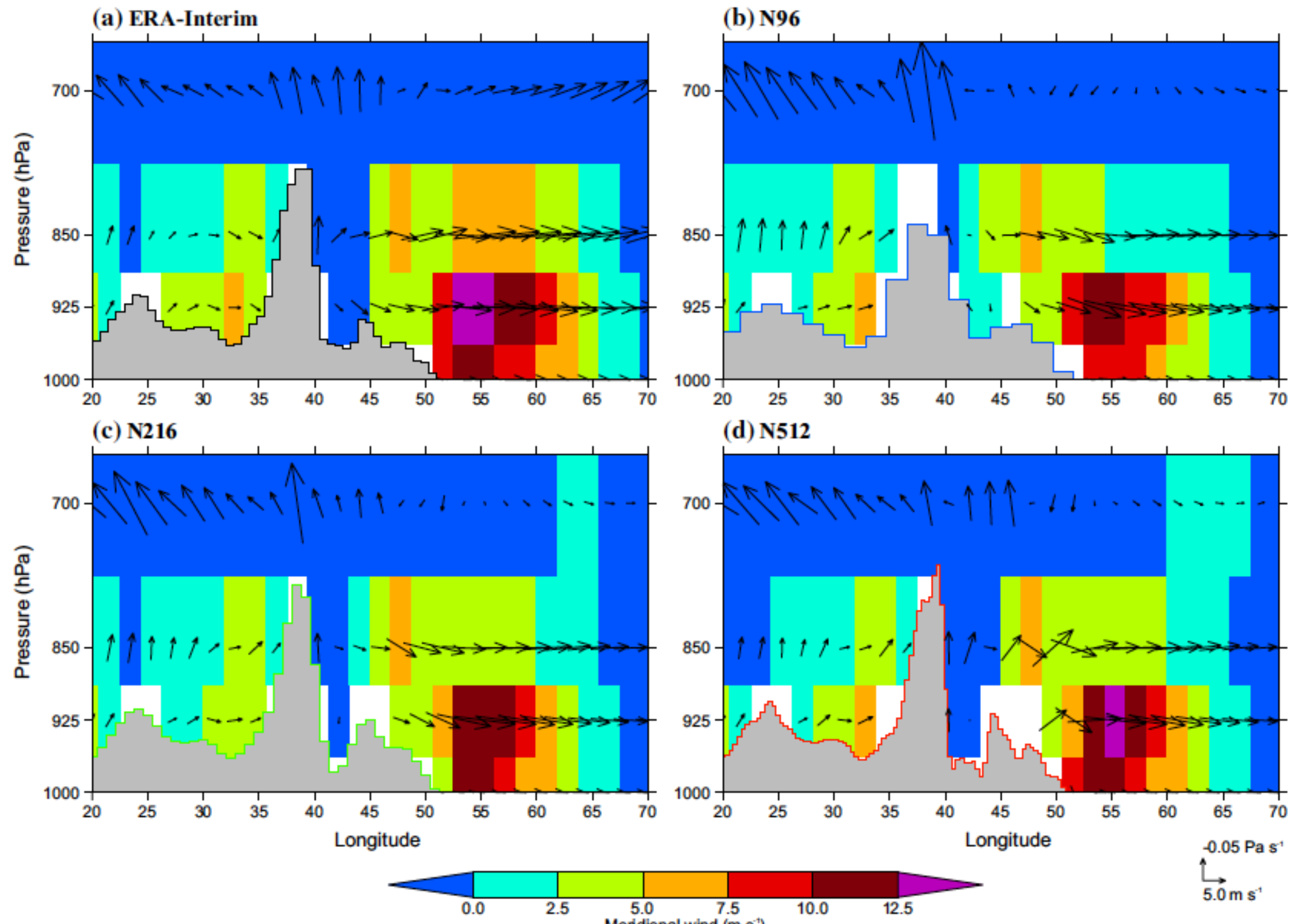



- Clear and systematic impact of resolution in increasing speed of Somali jet
- But N512 resolution still slower than reanalysis

Johnson *et al.* (2016, *Clim. Dyn.*)

# RESOLUTION & MONSOON FLOW

- 10-15°N east/ west cross-section
- Meridional flow shown shaded
- East African Highlands better resolved by N216 resolution
- High resolution improves both zonal flow and meridional cross-equatorial flow




Johnson *et al*. (2016, *Clim. Dyn*.)

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# SUMMARY & OUTLOOK

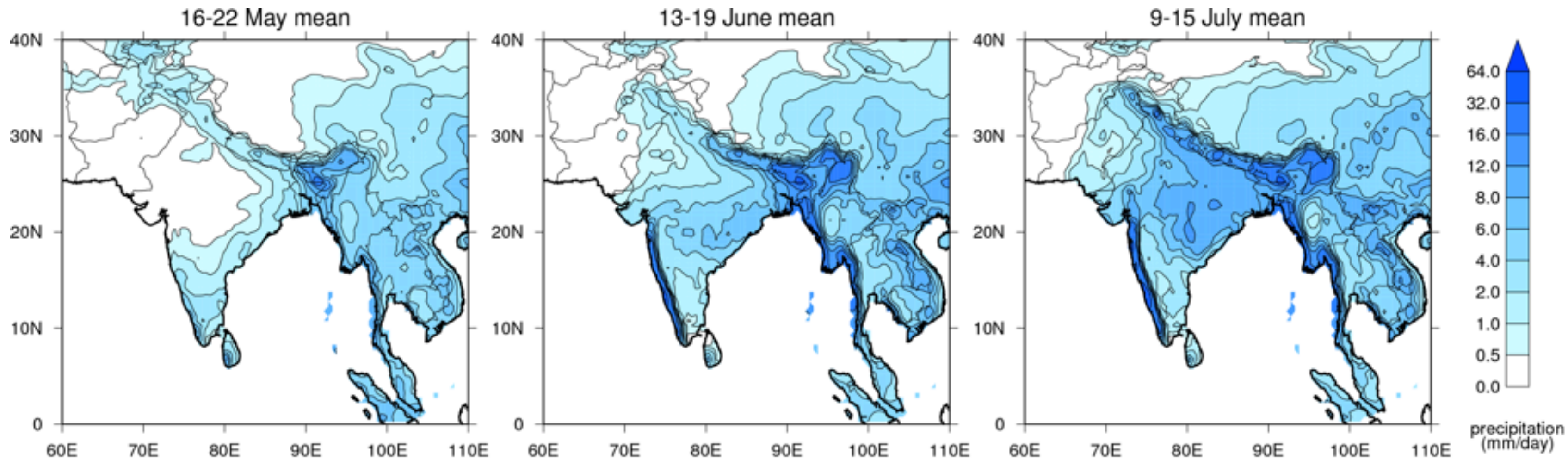
- CMIP models capture the basic features of monsoon, including NW onset propagation
- Large dry biases coupled to weak monsoon winds
- Coupled models seem to perform worse than AMIP models due to cold SST biases developing in the Arabian Sea
- Distribution of tropical (& Asian monsoon) rainfall is sensitive to the *detail* of convective parametrization
- Resolution improves some features of the monsoon, but at typical GCM scales it does not solve the bias problem

# THANK YOU!

See:

- Sperber et al. (2013) Climate Dynamics
- Marathayil *et al*. (2013) Environ. Res. Letts.
- Levine and Turner (2012) Climate Dynamics
- Levine et al. (2013) Climate Dynamics
- Johnson et al. (2016) Climate Dynamics
- Bush et al. (2015) QJRMS

# Spatial variations in the monsoon



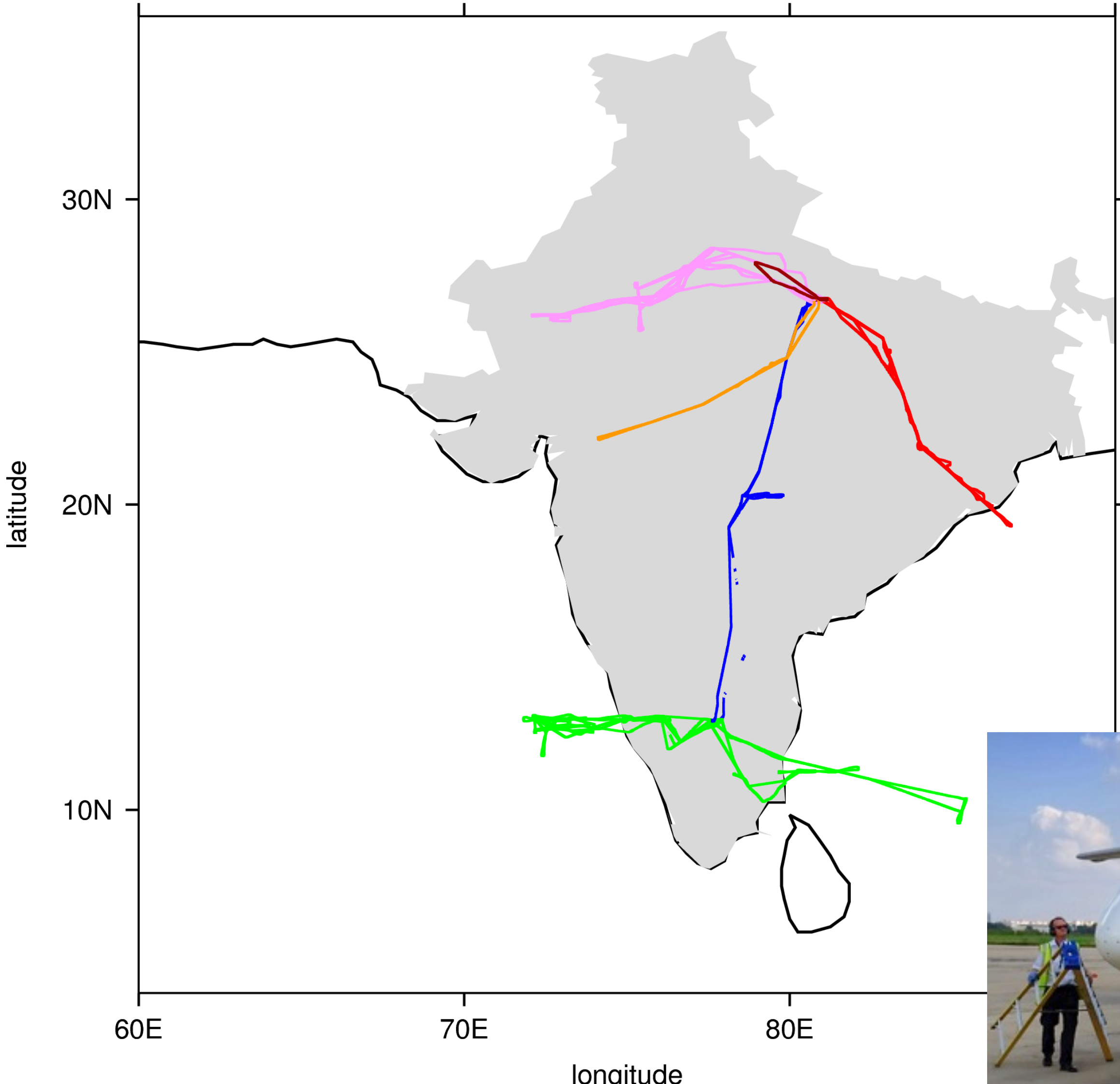

Overall INCOMPASS flight strategy:

① To sample spatial contrasts across northern India in the pre-monsoon and as the onset progresses

② To sample contrasts across southern India in the mature monsoon

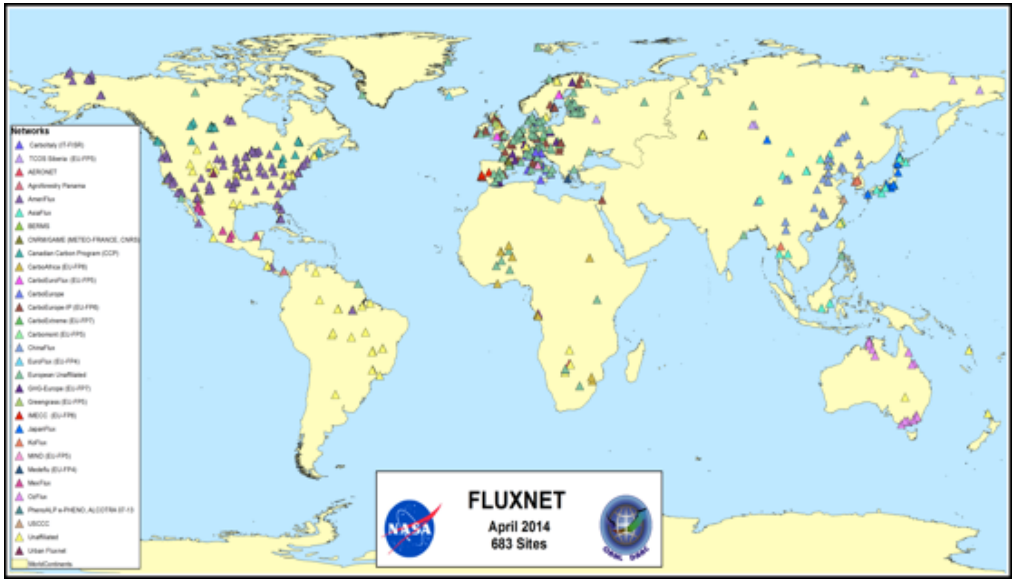
# INCOMPASS
# field campaign May-July 2016

INCOMPASS project
part of the NERC/MoES Monsoons Programme 2015-2018

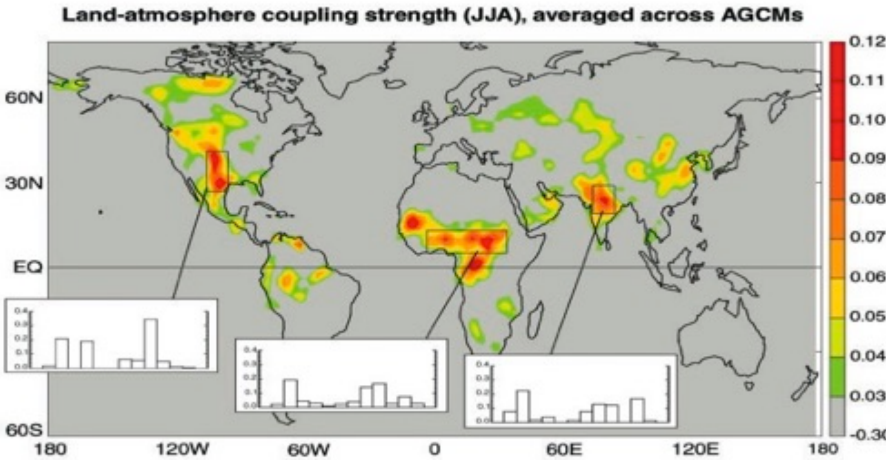


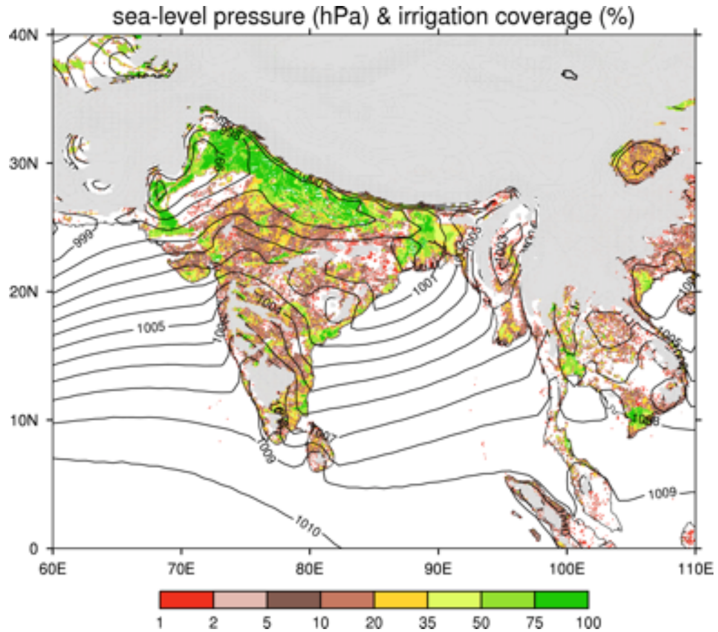

# Surface flux observations

INCOMPASS project
part of the NERC/MoES Monsoons Programme 2015-2018




(Koster et al., Science, 2004)




- Huge area equipped for irrigation in northern India
- Evidence in models for strong coupling between land and atmosphere in this region
- Contrasts between wet and dry soils

Despite all these factors, measurements of the land and its interaction with the atmosphere are sorely lacking

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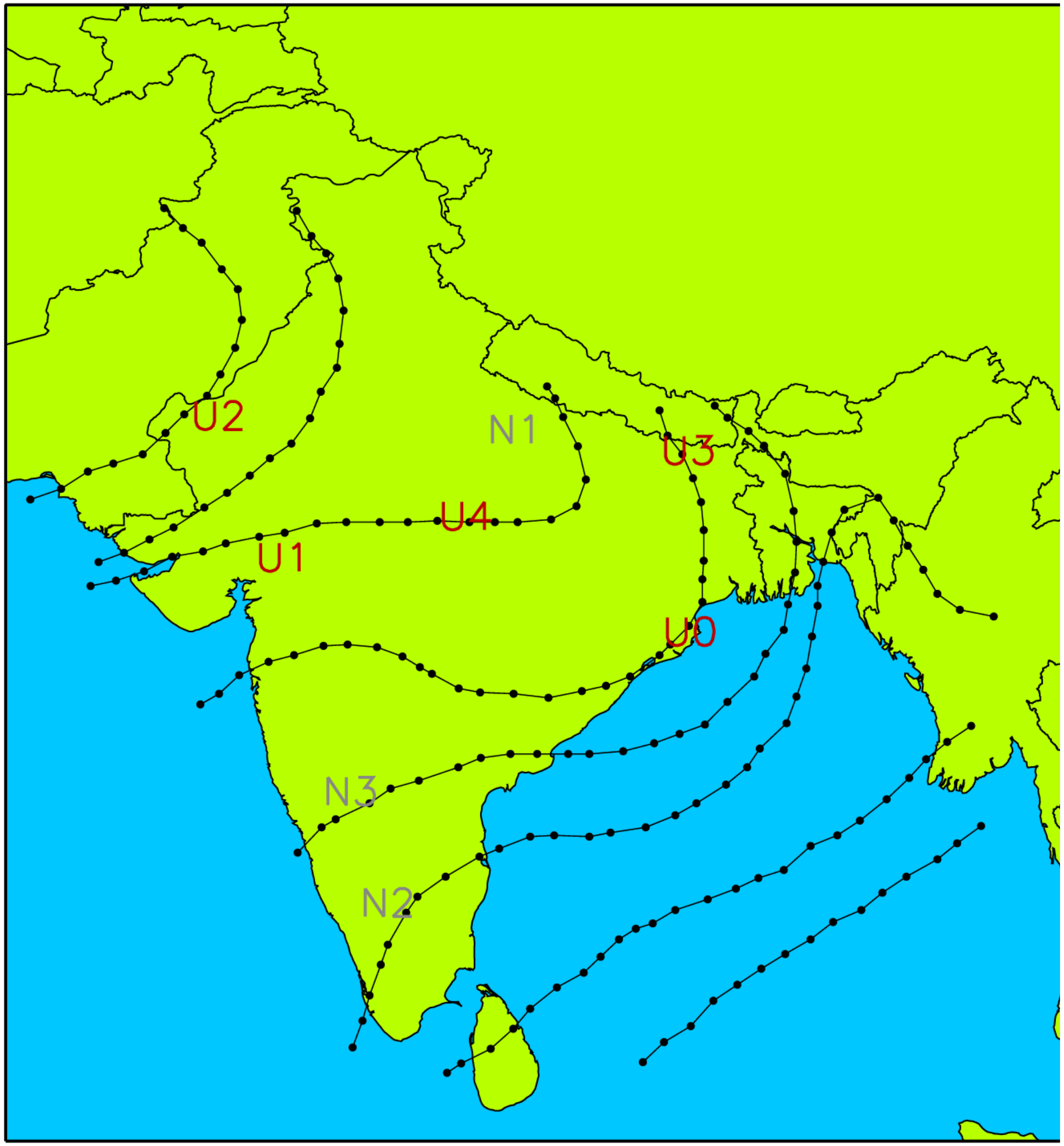
INCOMPASS project

part of the NERC/MoES Monsoons Programme 2015-2018

# Flux towers

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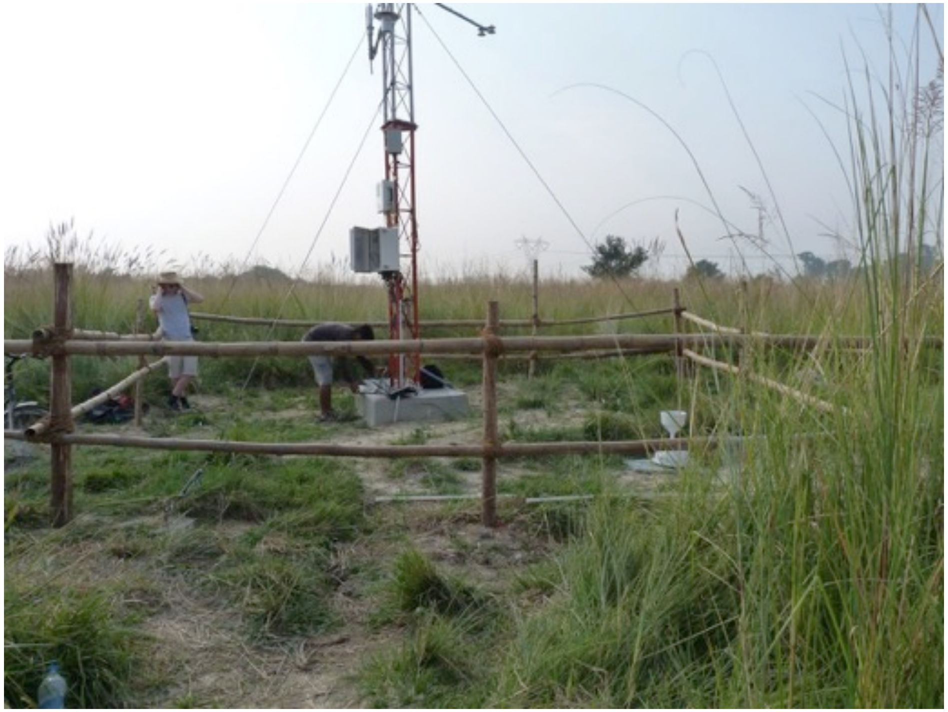
# IIT-Kanpur supersite (~85km from LKO)



Flux tower: permanent installation; surface flux data sent via mobile network to UK

Lidar ceilometer: permanent installation; test data have successfully tracked height of cloud base

Microwave radiometer: permanent, has begun testing

Radiosonde receiving station: intensive observations during July 2016