Modeling the Monsoon Circulation and Precipitation: CMIP5 biases and Future Plan

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Workshop - Monsoons: Past, Present and Future
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SAM biases in CMIP5 models

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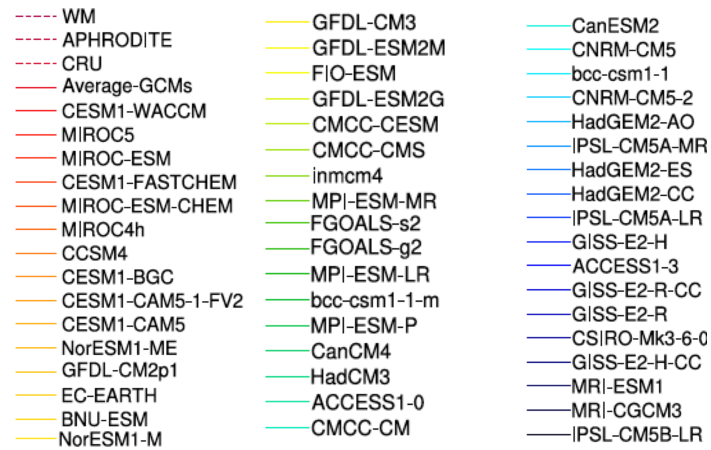
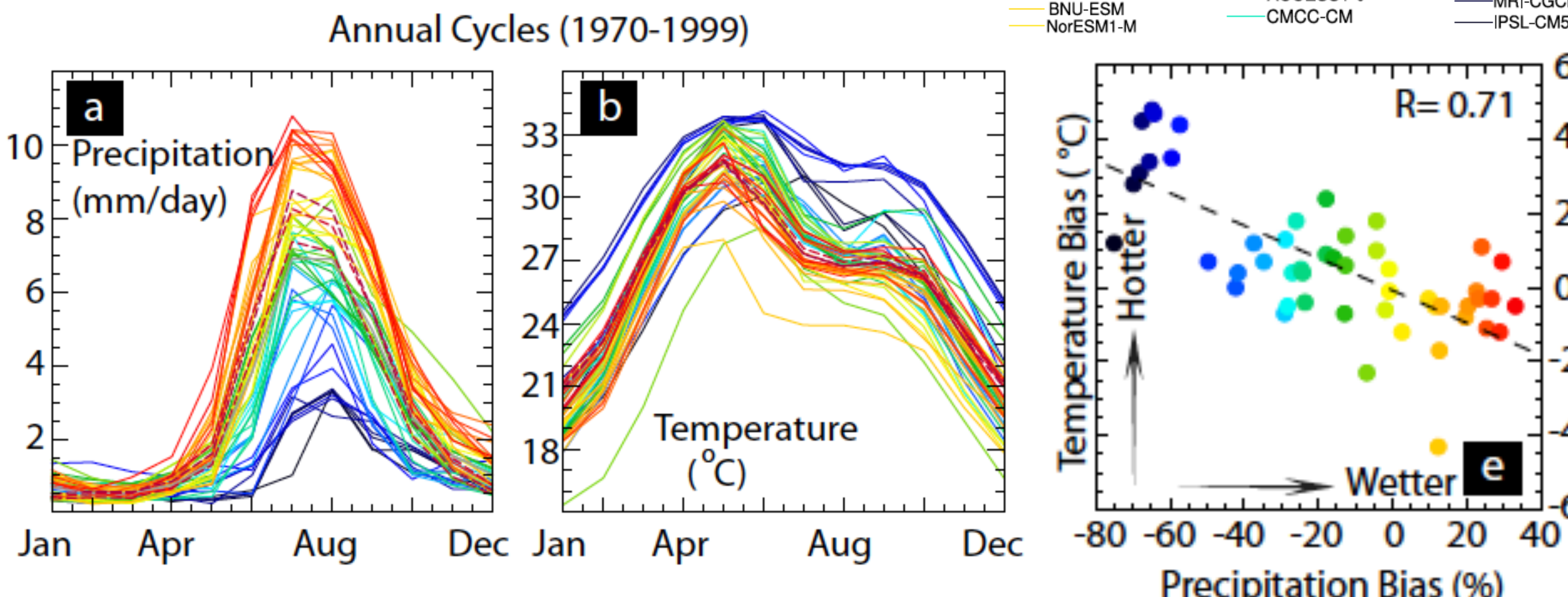
- Out of 50 CMIP5 GCMs, only 16 skillfully simulate annual precipitation to within 25% with maxima in July
- And only 20 skillfully simulate temperature to within 2^{o}C with maxima in May

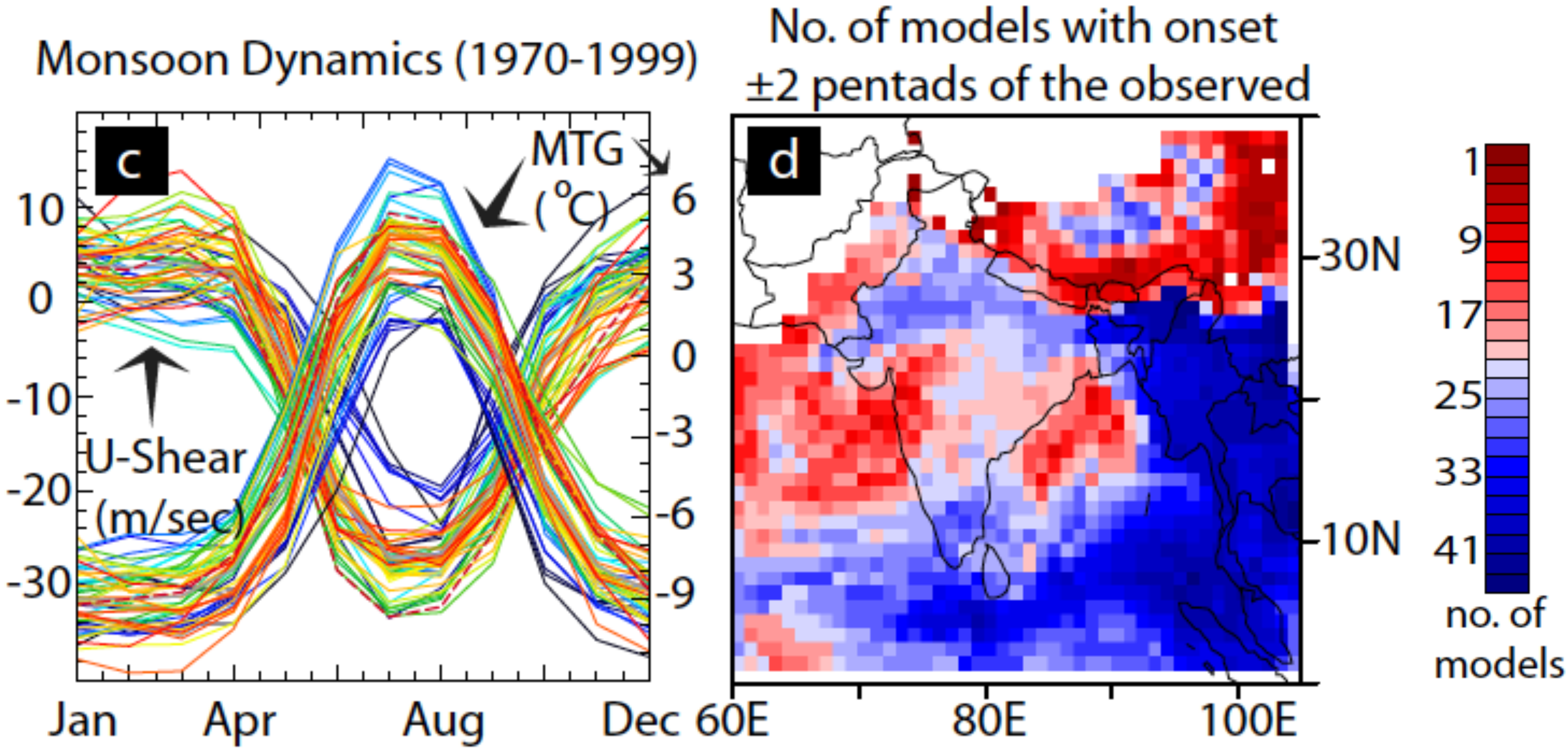




(Ashfaq et al. 2015 Clim. Dyn. Submitted)

SAM biases in CMIP5 models

- More than half of 42 GCMs are unable to simulate the monsoon onset timing to within 2 pentads of the observed onset timing over most (>60%) of the South Asian landmass



Relationship between biases in precipitation and monsoon dynamics

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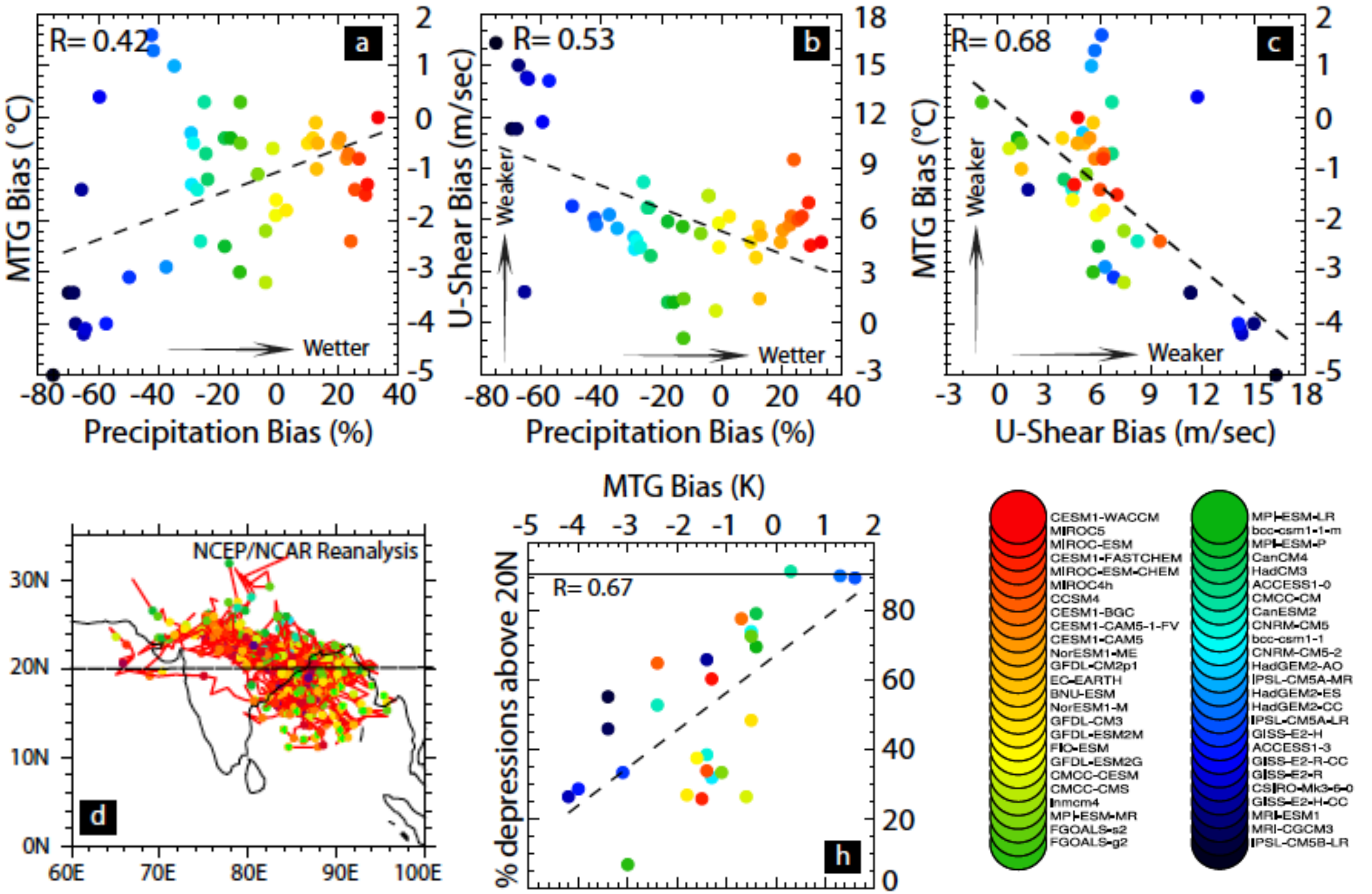
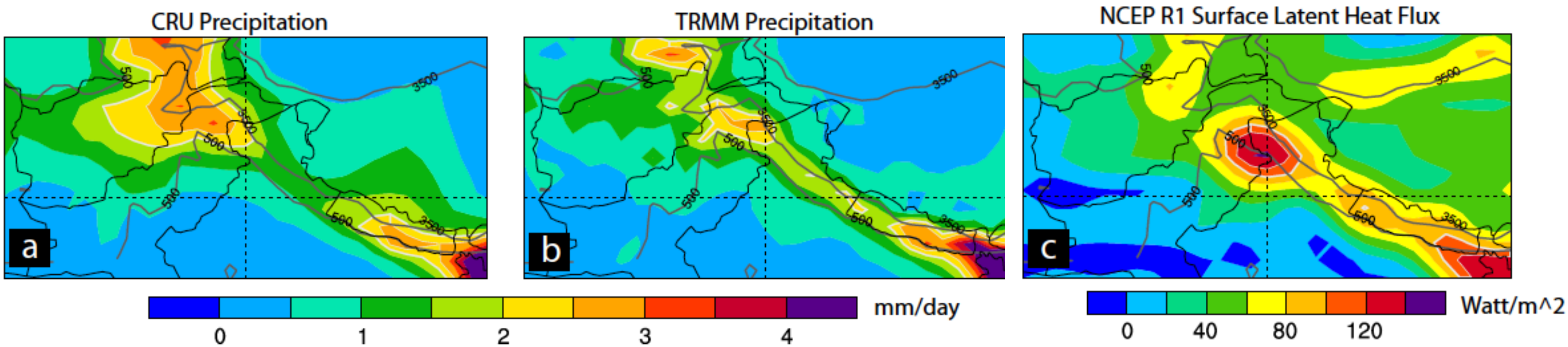


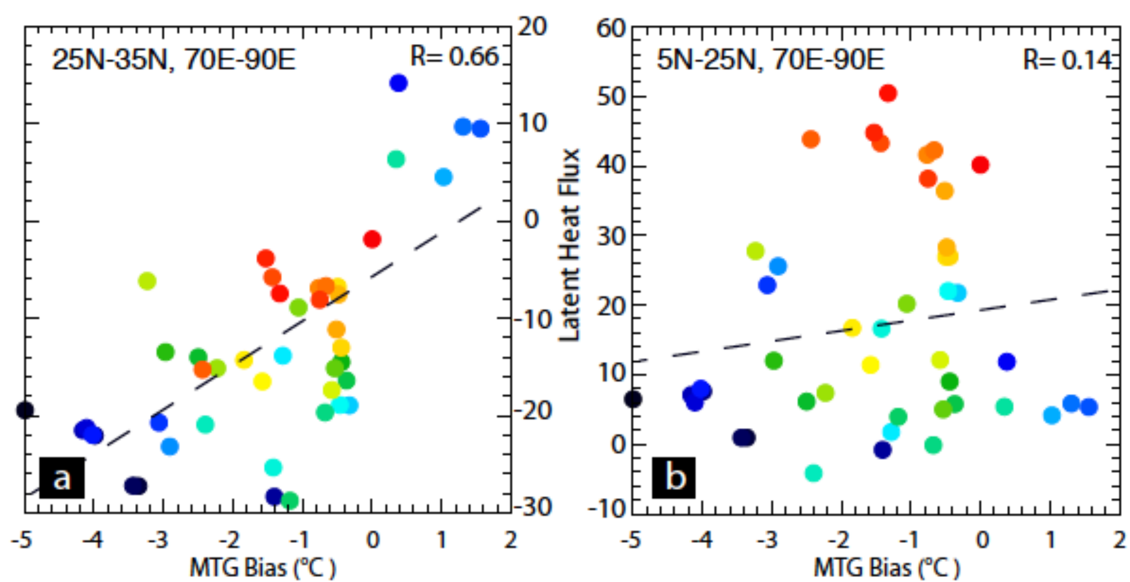
Role of pre-monsoon biases in MTG biases

- Pre-monsoon precipitation occurs over the Himalayas and Karakoram range, resulting in large latent heat flux along the slope

Mar-April-May Precipitation and Latent Heat Flux



- Most GCMs produce pre-monsoon precipitation north of the Himalayas at elevation > 3500 m in the form of snowfall
- So GCMs have large negative latent heat flux bias



Does higher resolution help?

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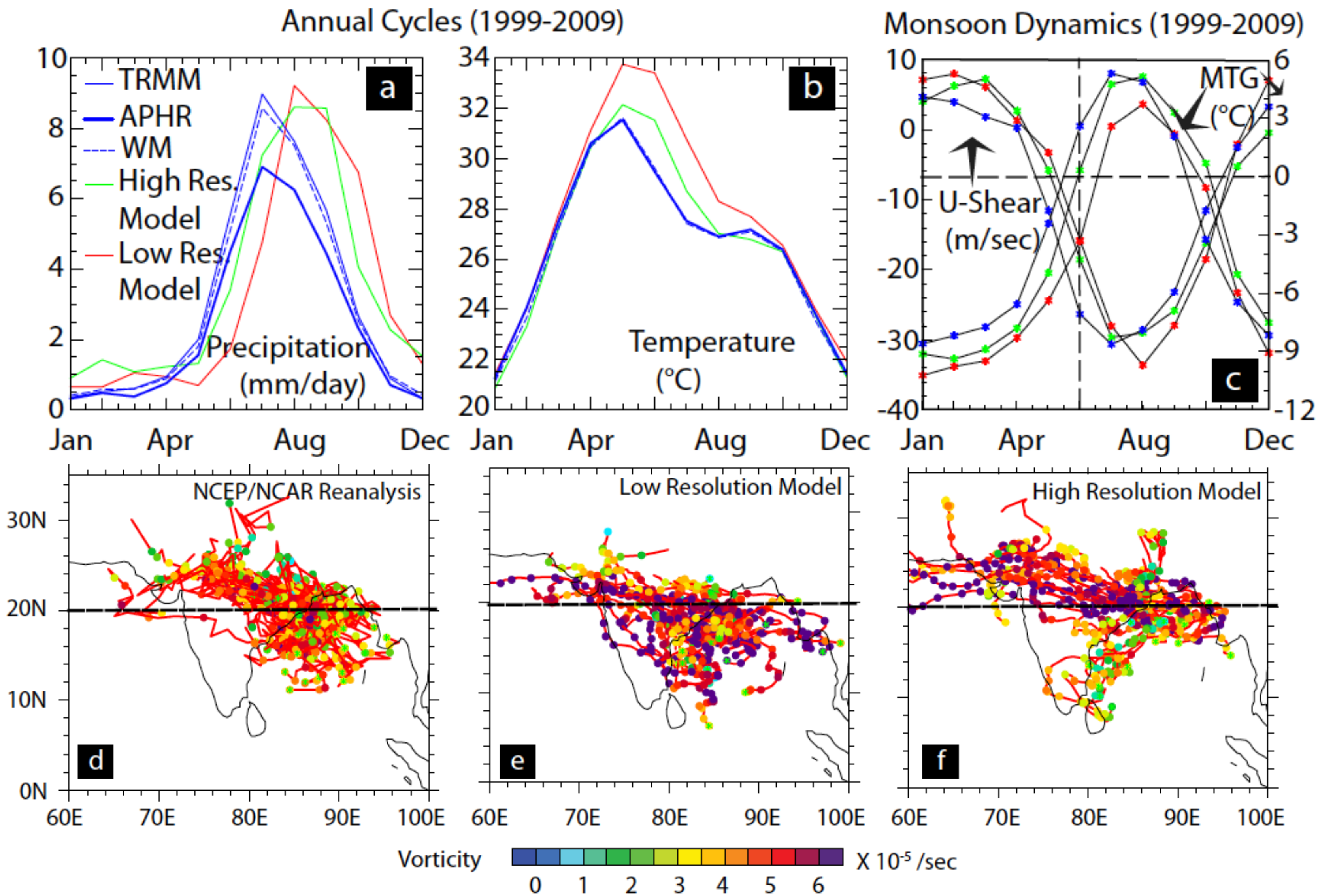
- Comparison of CAM simulations at T85 and T341 resolution



No improvement in latent heat flux bias

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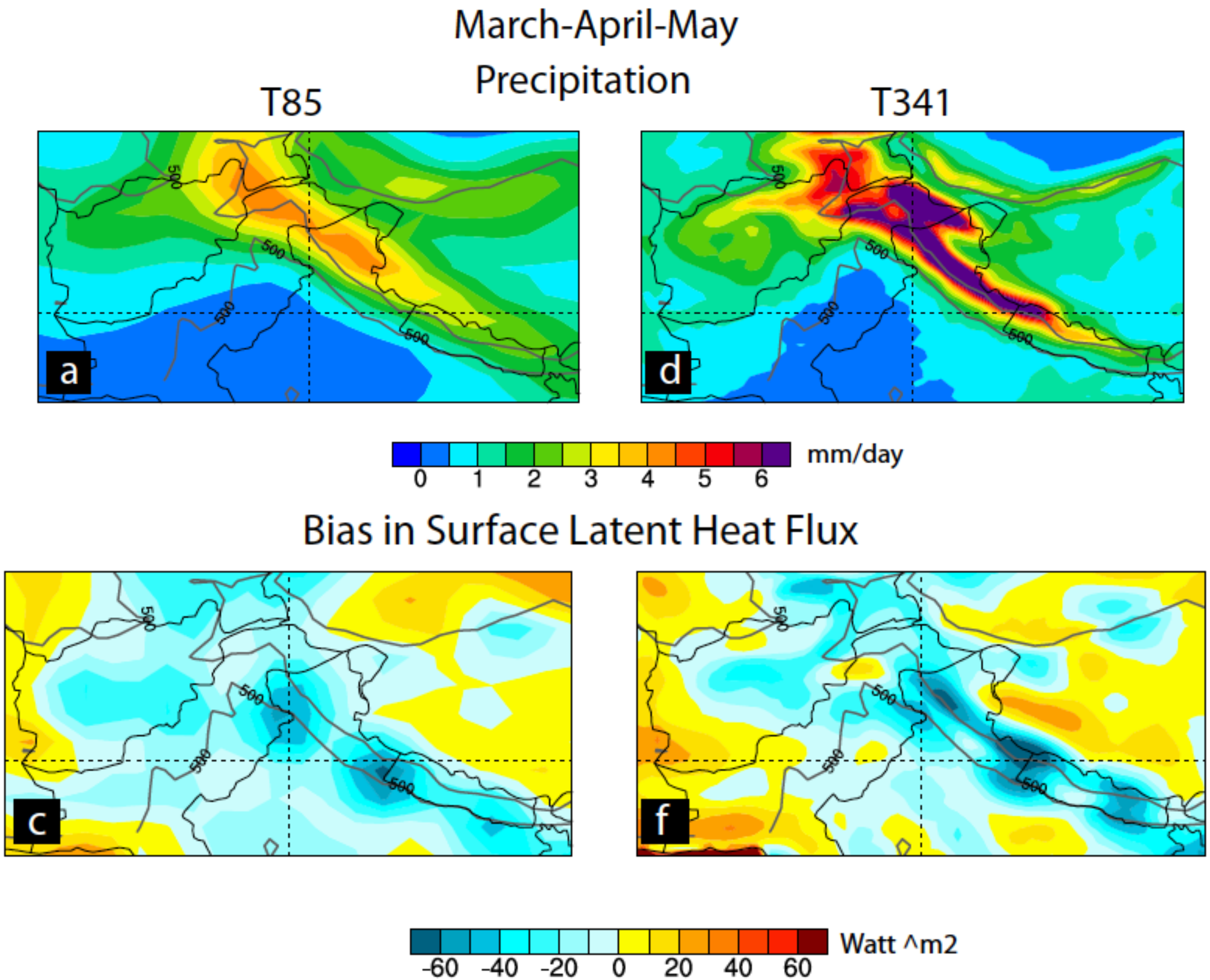
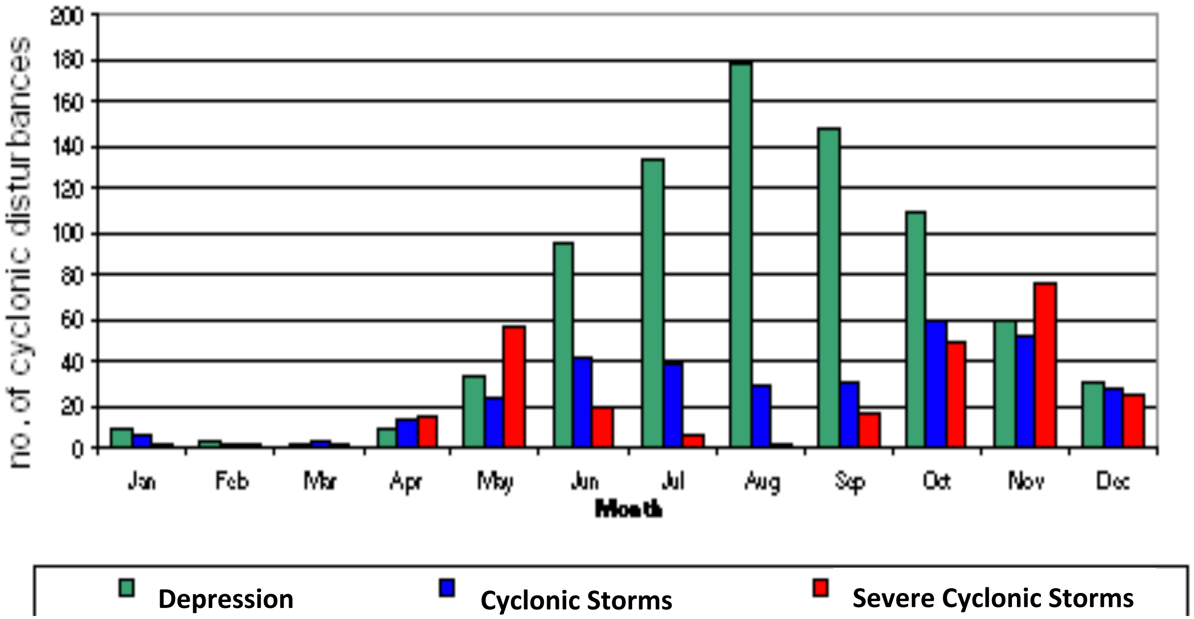


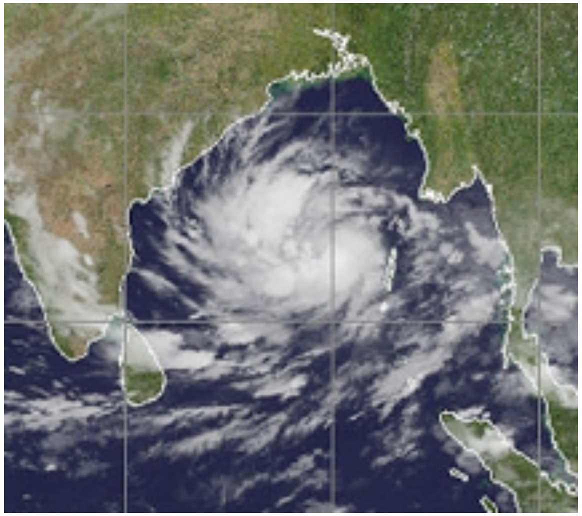
- Improvement in MTG at T341 is due to a larger cold bias over the ocean

Tropical cyclones in Bay of Bengal

- 8 out of the 10 deadliest TCs in recorded history have occurred in BoB



Source: Indian Meteorological Department



Source: NOAA/UW-CIMSS

A meridional dipole in BoB TC activities

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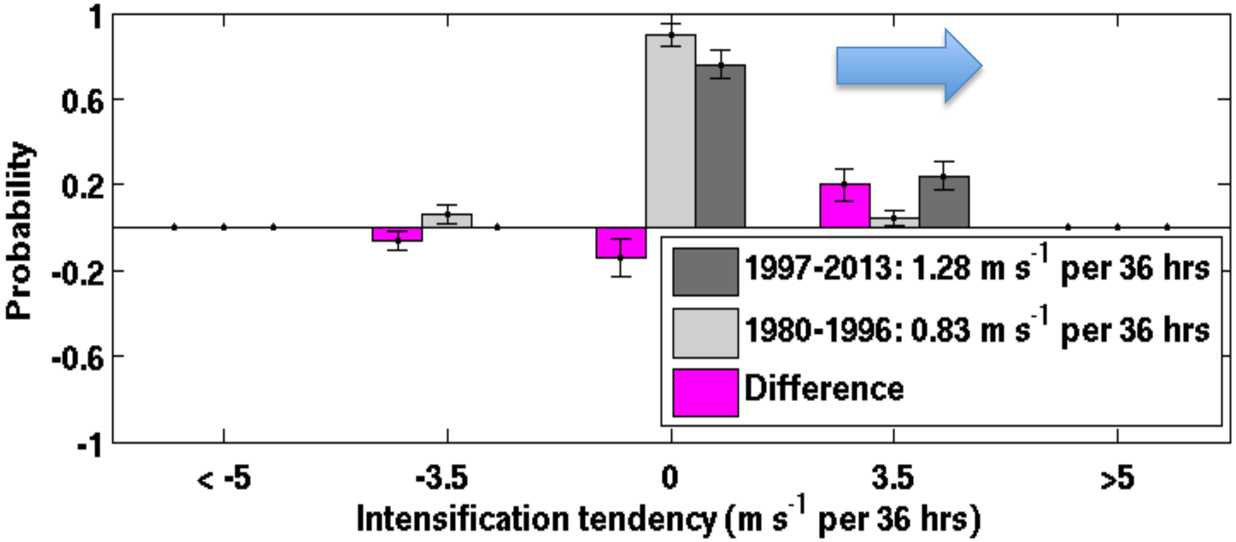
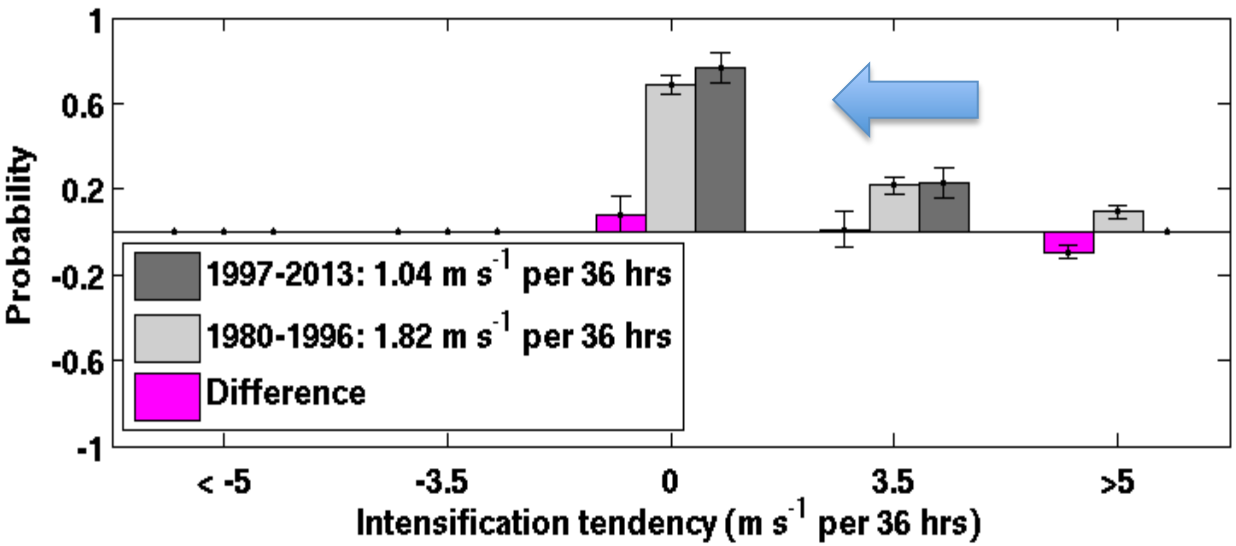


Northern Bay

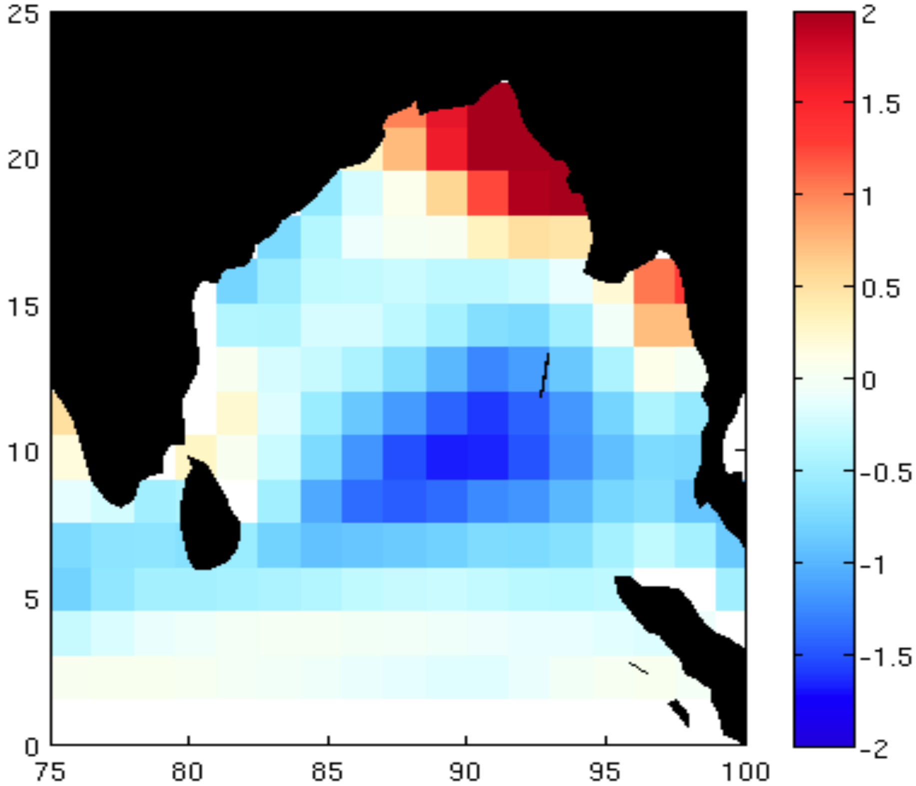


Southern Bay

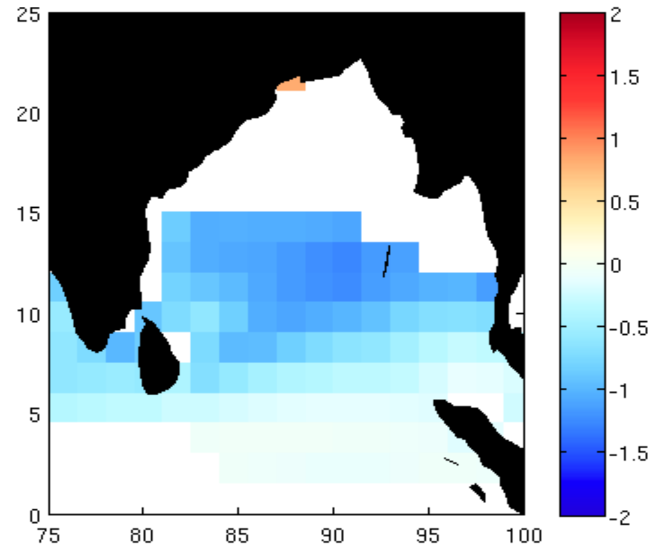
(Balaguru et al. 2015, in prep)

Trends in BoB TC activities related to monsoon onset

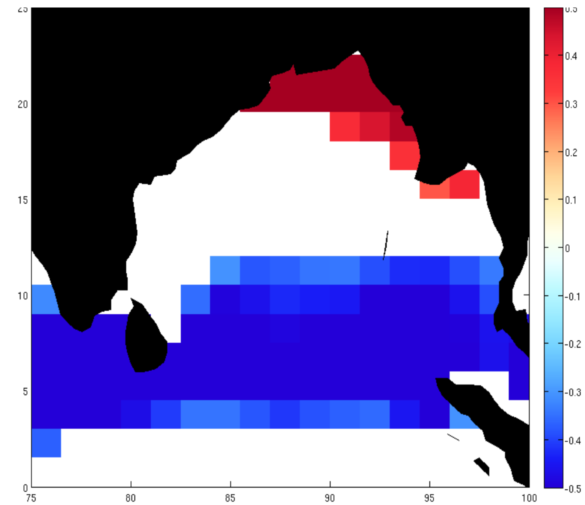
Changes in GPI



Changes in shear



Correlation between MTG and GPI



ENSO and monsoon onset

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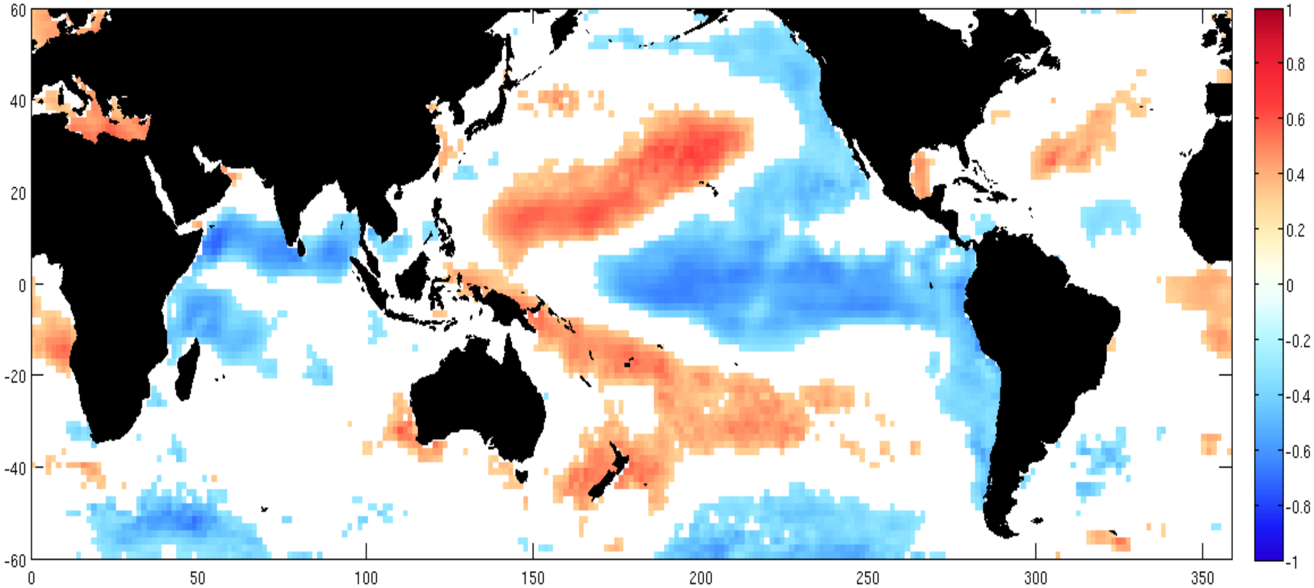
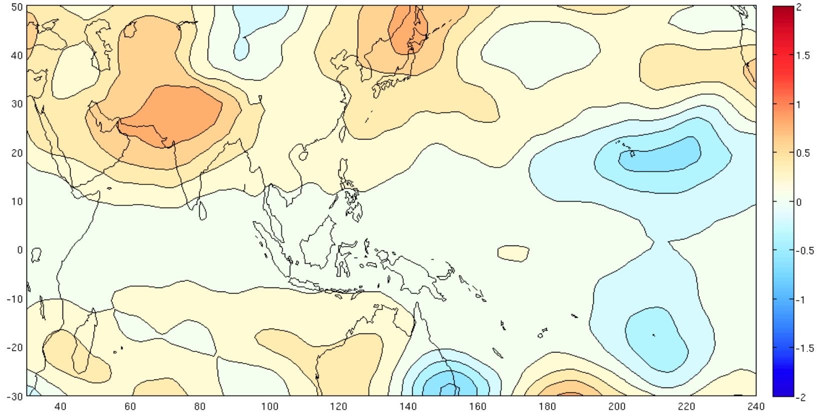
Correlation between MTG and SST (1980-2013)



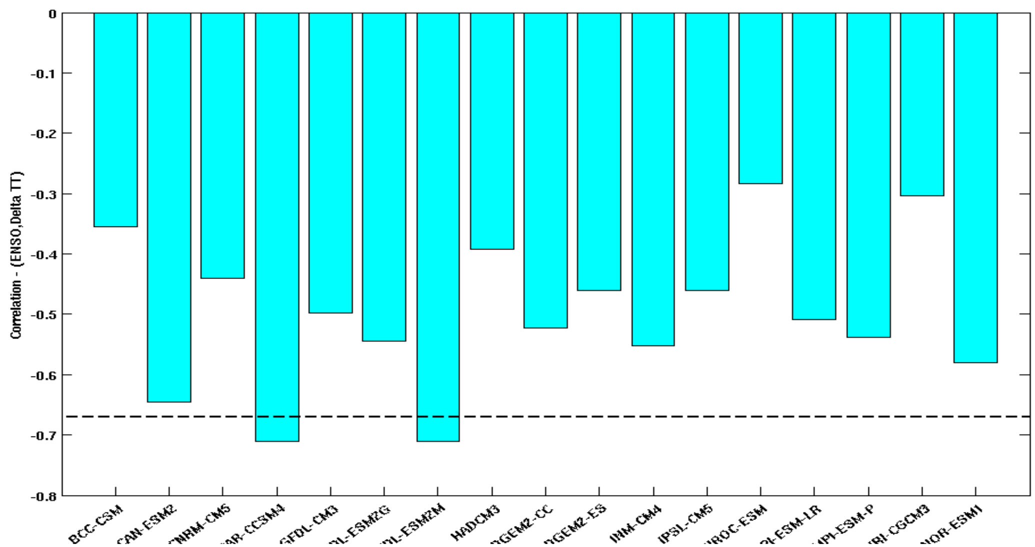
A shift towards La Nina-like SST pattern post 1997 favors earlier monsoon onset



Changes in MTG

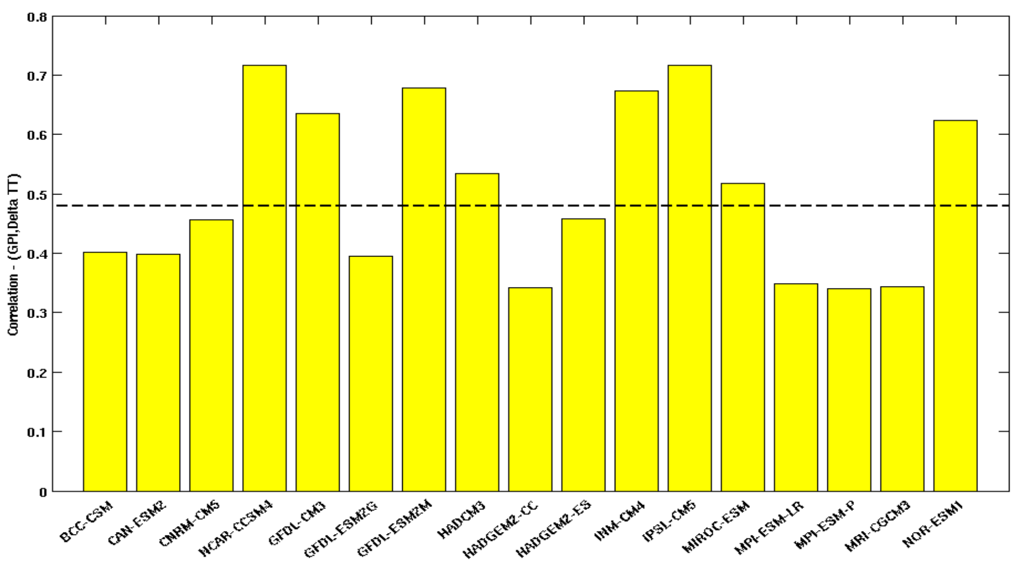
Gill-type response to diabatic heating (Rodwell, M. J. and B. J. Hoskins, 1996; Su, H., Neelin, D. and Meyerson, J. E., 2002)

CMIP5 models captured the ENSO-monsoon onset-TC relationship



From CMIP5 historical simulations for 1850-2005

Correlation coefficients (ENSO, MTG)



Correlation coefficients (MTG, GPI)

Future work

- Simulations of Asian monsoon using two variable resolution modeling frameworks:
  - DOE Accelerated Climate Model for Energy (ACME) with the Spectral Element dynamical core and regionally refined grids at ¼ to 1/8 degree resolution over the U.S. and Asia (AMIP and CMIP style) with various combinations of forcings

  - Using the non-hydrostatic MPAS with regionally refined grids down to 4 km resolution over the U.S. and Asia (AMIP style only)

Model for Prediction Across Scales (MPAS)

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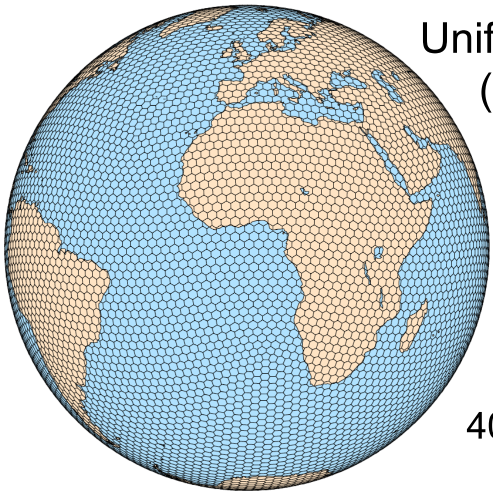
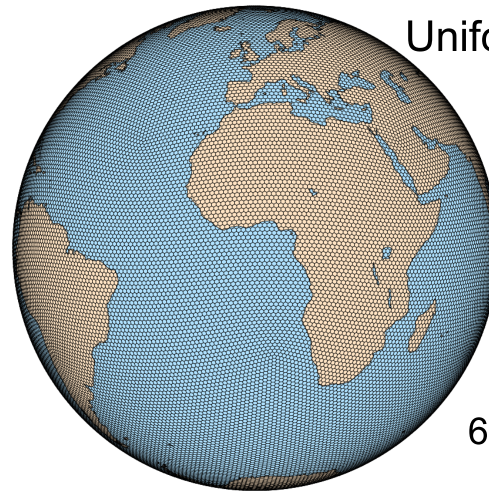


Uniform Low Resolution
(ULR ~120 km)

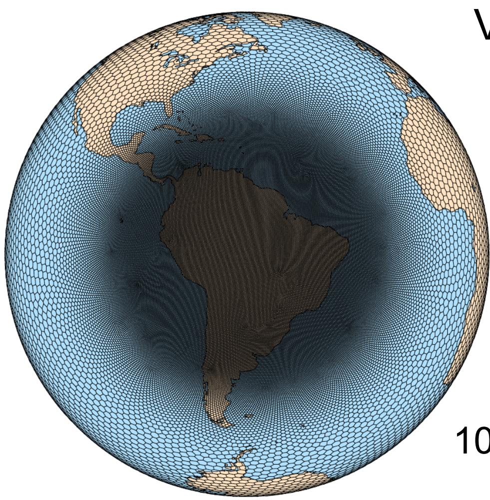
40,962



Uniform High Resolution
(UHL ~30 km)

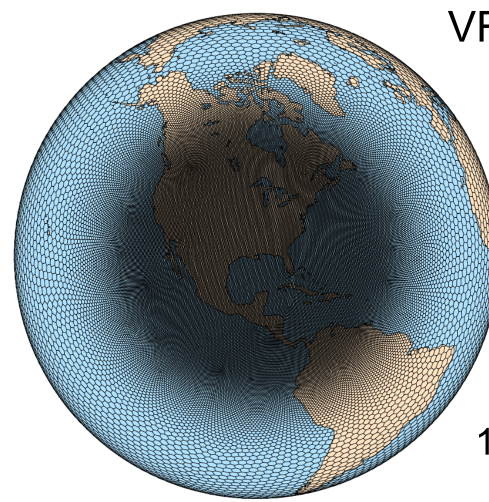
655,362

Variable Resolution – South America
VR 120 km → 30 km



102,402

Variable Resolution – North America
VR 120 km → 30 km



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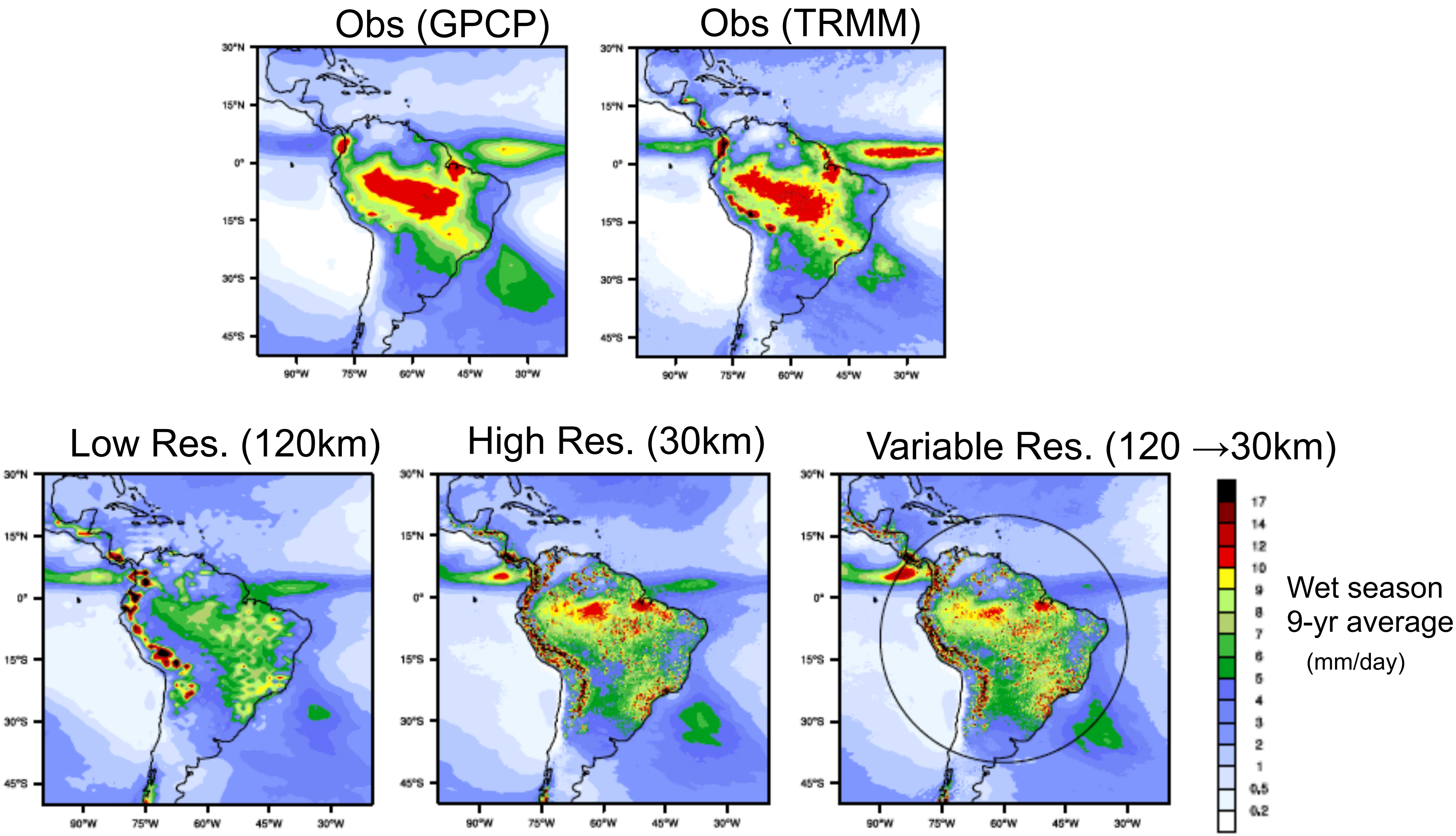
Same CAM4 physics parameterizations for all simulations

(Sakaguchi et al. 2015 J. Climate)

Precipitation in South America



Model skill of VR compared to UHR

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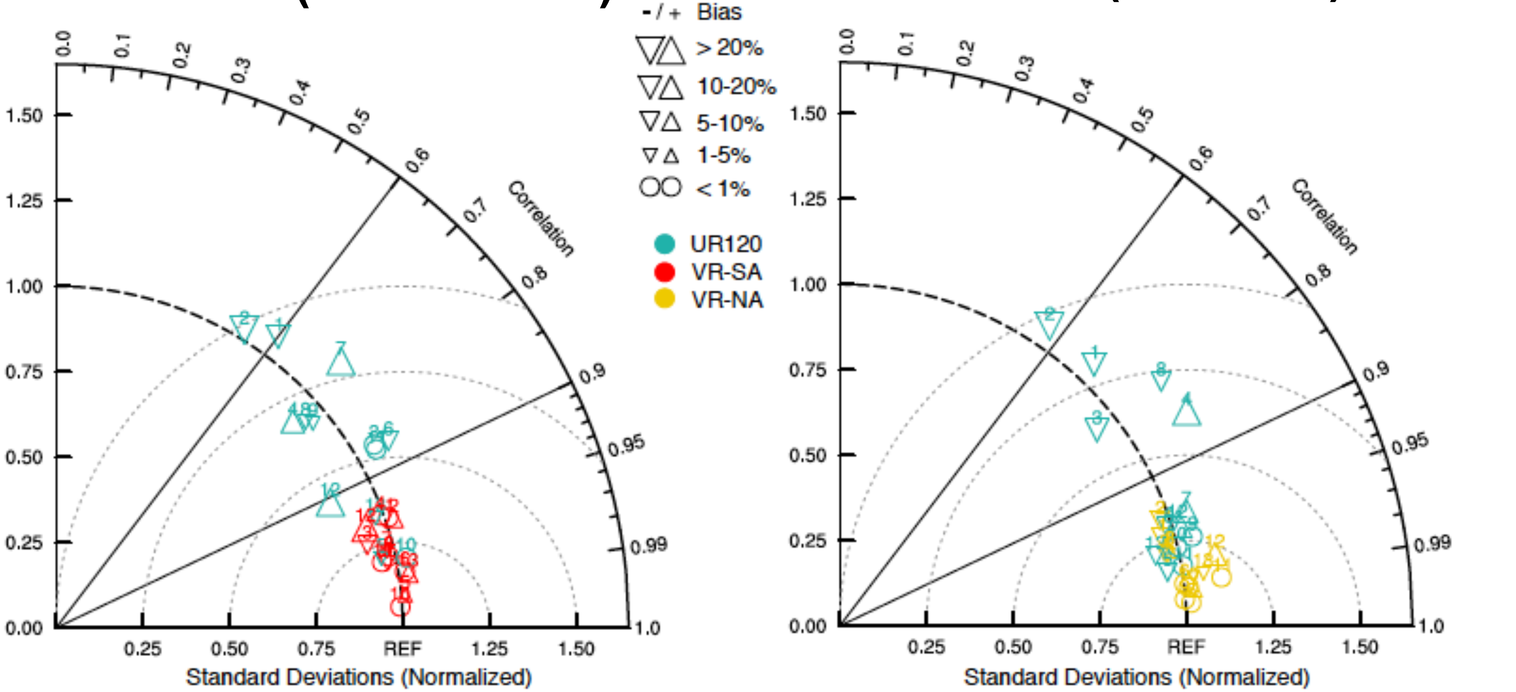
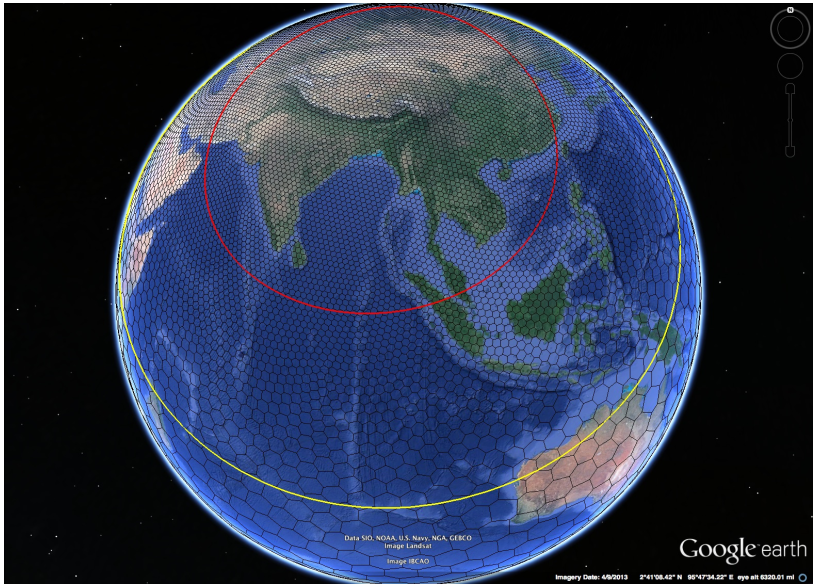
S. America (wet season) / N. America (summer)

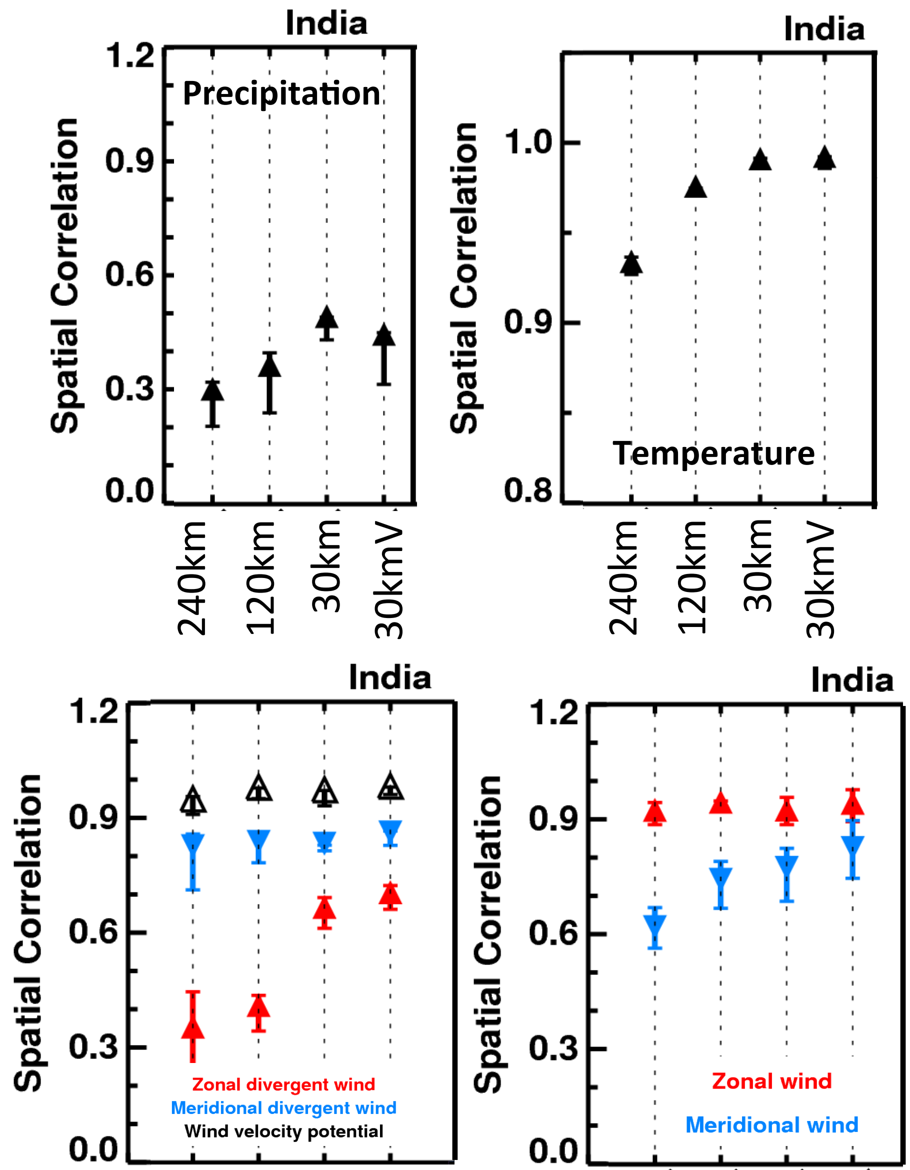


1: total precipitation
2: grid-scale precipitation
3: subgrid-scale (convective) precipitation
4: cloud cover fraction
5: precipitable water
6: surface evaporation
7: surface sensible heat flux
8: surface downward solar radiation
9: air temperature at 2 m height
10: geopotential height at 500 hPa level
11: wind vector at 200 hPa level
12: wind vector at 850 hPa level

VR can reproduce UHR in the high resolution regions

Resolution effects on SAM simulations





MPAS non-hydrostatic model

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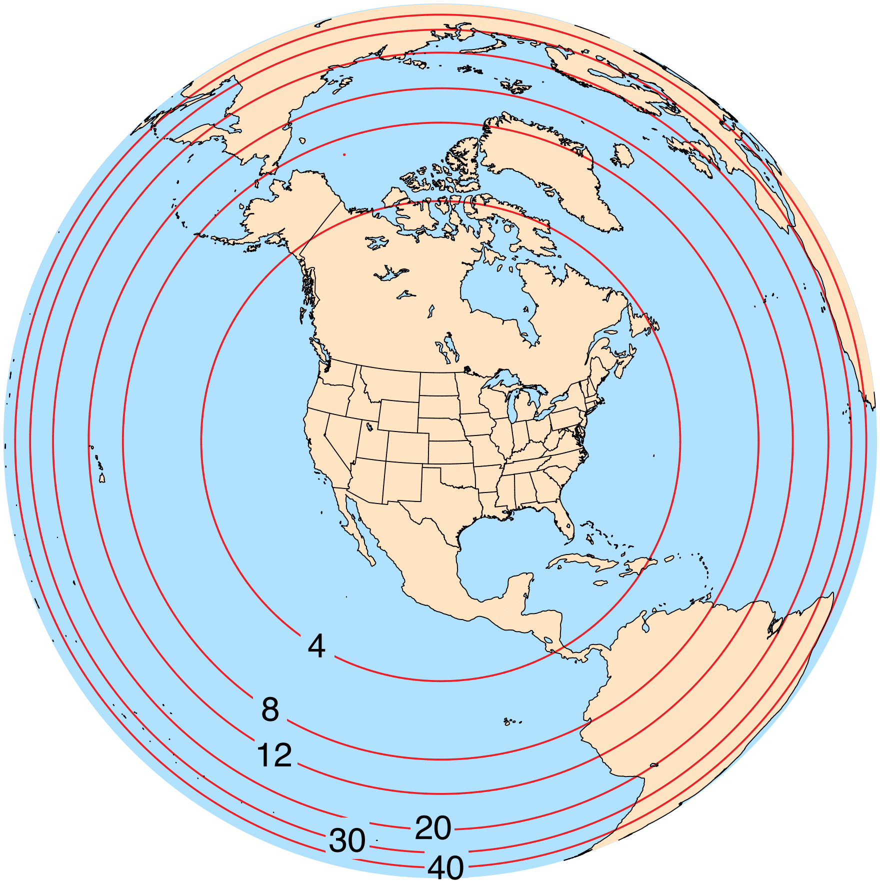
MPAS mesh mean cell spacing (km)



3-50 km mesh, Dx contours 4, 8, 12, 20, 30 40 km
approximately 6.85 million cells
68% have < 4 km spacing
(158 pentagons, 146 septagons)

<u>(Grell and Freitas, 2014, ACP)</u>

- Stochastic approach from Grell and Devenyi, 2002.
- Scale aware by adapting the Arakawa et al approach (2011).
- Transitions to precipitating shallow scheme as grid spacing decreases.
  - At very high resolution (dx < 3km) parameterized convection becomes much shallower – cloud tops near 800 mb (down from 200-300 mb).
  - Temperature & moisture tendencies decrease as resolution increases.

Source: Bill Skamarock

Precipitation in the mesh transition region

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MPAS 50-3 km mesh,
Grell-Freitas convection scheme
3 day 12h forecast valid at
2013-05-21_12:00

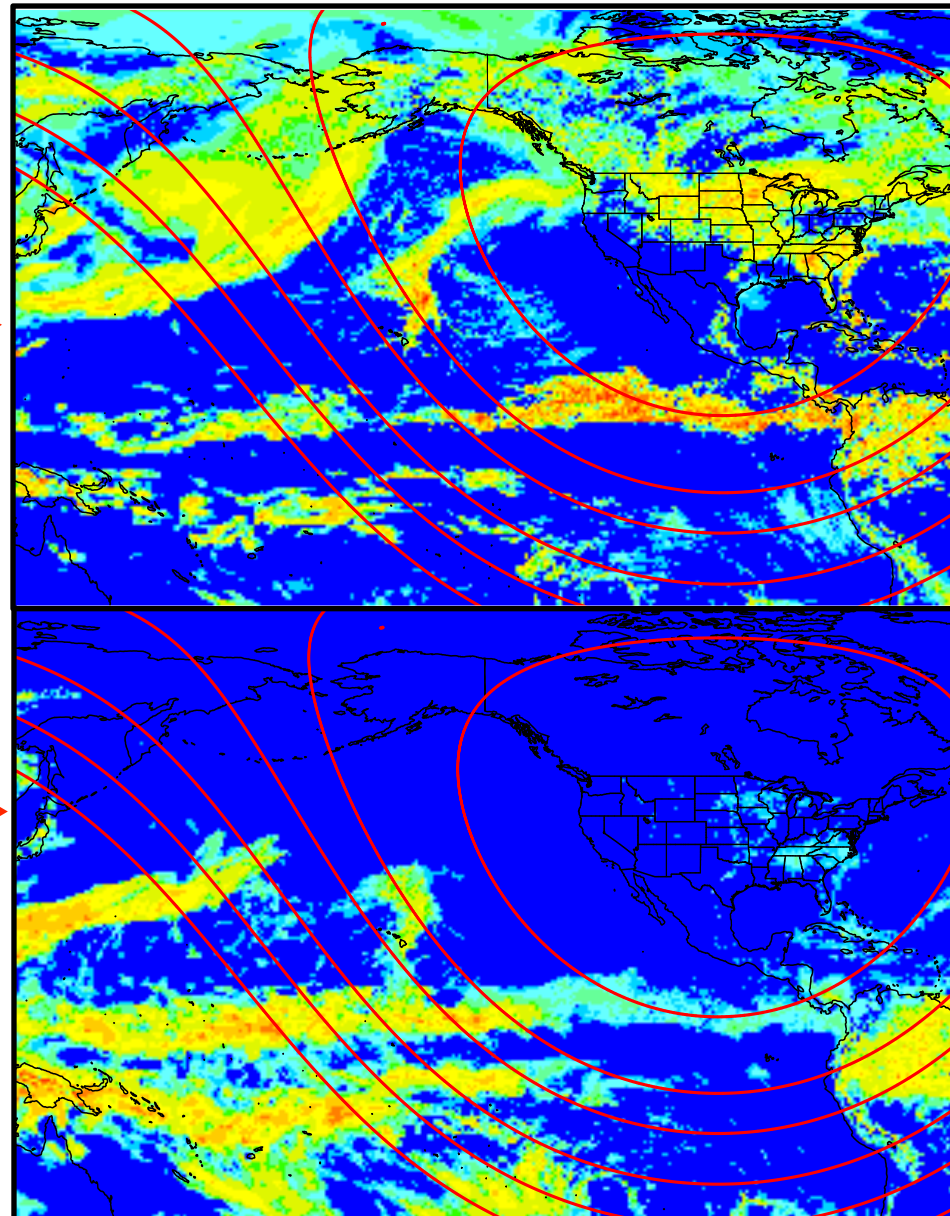
Explicit precipitation
(resolved on the mesh)

Mesh spacing
(4, 8, 12, 20, 30 40 km)

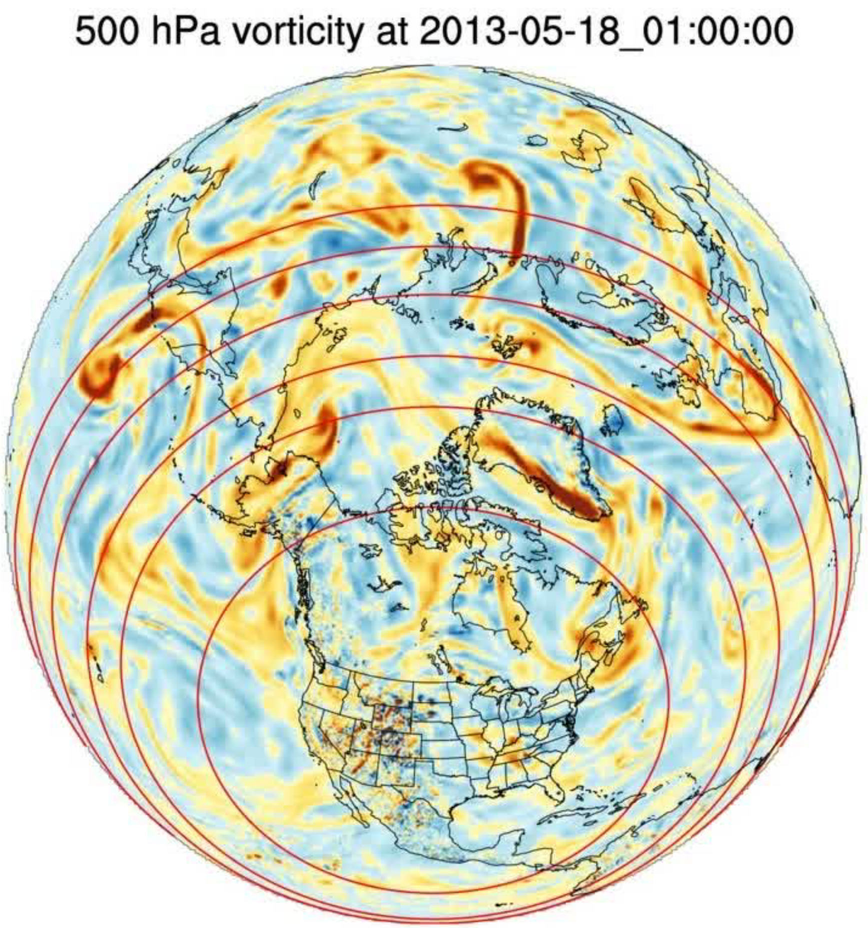
1 2 4 8 10 25 50 100 200 400
Accumulated precipitation (mm)

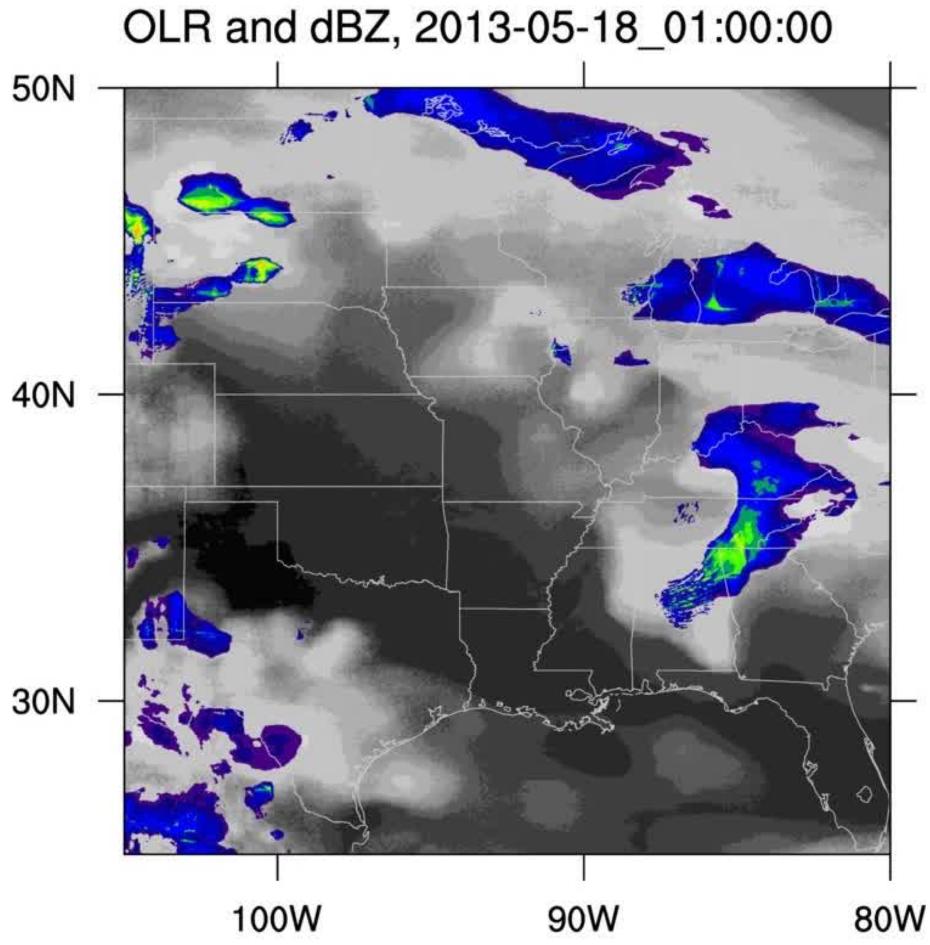
Convective precipitation
(from the convection scheme)

GF convection scheme gradually turns off as mesh spacing transitions to convection-permitting scales.



3-day forecast test





Summary

- A large number of CMIP5 models produce significant biases in simulating the SAM precipitation and temperature
- Biases in precipitation are related to biases in monsoon dynamics (MTG and wind shear)
- Biases in monsoon circulation correlate with biases in pre-monsoon surface latent heat flux in the Himalayas
- High resolution may or may not improve simulations
- The ENSO-monsoon onset-TC relationships are well captured by CMIP5 models
- Global variable resolution models are useful tool for testing impacts of model resolution
- Non-hydrostatic global variable resolution models are now feasible for convection permitting modeling to support investigations of monsoon science questions