Met Office
Hadley Centre

# Understanding and evaluating monsoon processes in the MetUM

Gill Martin

*With contributions from Richard Levine, Andrew Turner, Stephanie Bush and members of the joint Met Office/NCAS-Climate Monsoon Working Group*

# Introduction

- The monsoons: still a challenge for modelling on a range of timescales.
- Known sensitivities:
  - convection and boundary layer parametrisation
  - cloud microphysics
  - land surface properties
  - orography
  - model resolution (atmosphere, ocean, horizontal, vertical)
  - coupled model SST biases
- What progress have we made?

# Typical monsoon errors

- South Asia:
  - excessive rainfall over the equatorial Indian Ocean and the Himalayan foothills and underestimation of rainfall over the Indian peninsula;
  - in coupled models, cold Arabian Sea SST bias reduces early season rainfall.
- East Asia:
  - weak intensity of the North Pacific subtropical high pressure region associated with anomalously weak southerly inflow and an underestimation of rainfall over eastern China and Korea.
- West Africa:
  - In coupled atmosphere-ocean models the rainfall tends to be biased to the south and underestimated over the Sahel, related to warm SST biases in the Gulf of Guinea;
  - atmosphere-only models fail to reproduce the seasonal north-south movement of the rain band even when forced by realistic SSTs.
- Australia:
  - monsoon rainfall over the northern land areas tends to be underestimated while that over the surrounding sea is overestimated. Over much of the inland region rainfall is overestimated.

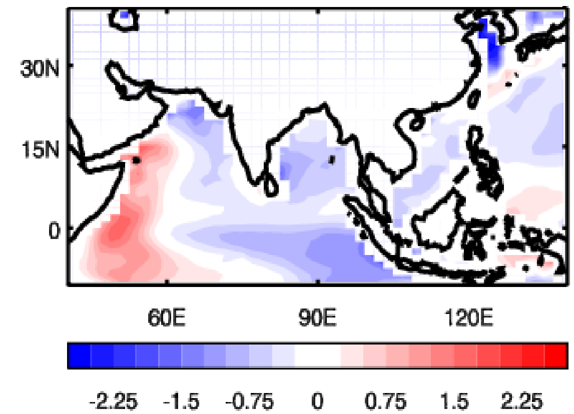
# Understanding model errors using sensitivity tests

- SST biases
- Orography
- Indian peninsula
- Changing the convection scheme
- Horizontal resolution
- Role of the land surface

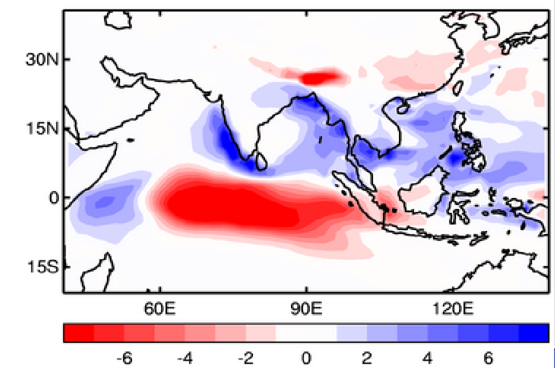
# Coupled model SST biases

- Coupled model has significant cold SST bias in N Indian Ocean (develops in winter) and in equatorial Indian Ocean (response to excessive equatorial convection)
- Cold SST bias in Arabian Sea reduces monsoon rainfall (up to 30%) and delays onset by weakening local evaporation.
- But equatorial rainfall is weakened over equator in coupled model (modulated by cooling SSTs) → slightly more rain over India.

SSTA (JJA): coupled

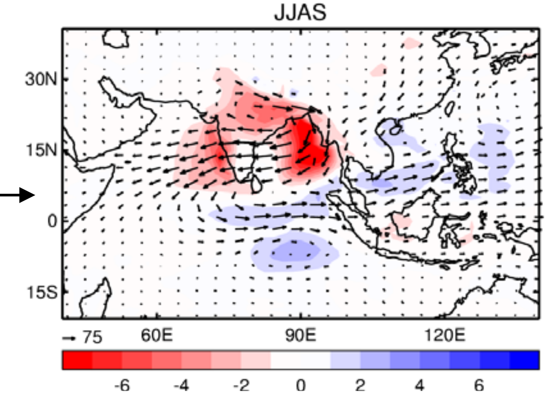


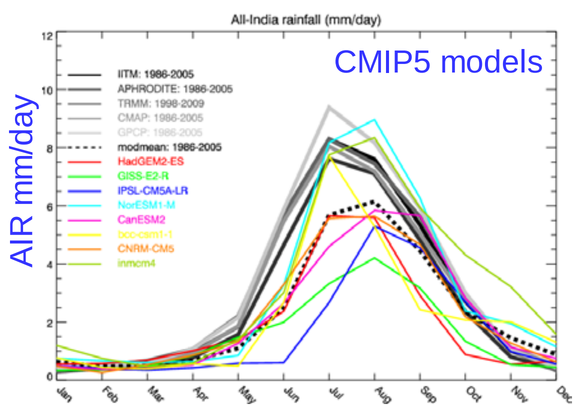

Rain (JJA): coupled - AMIP

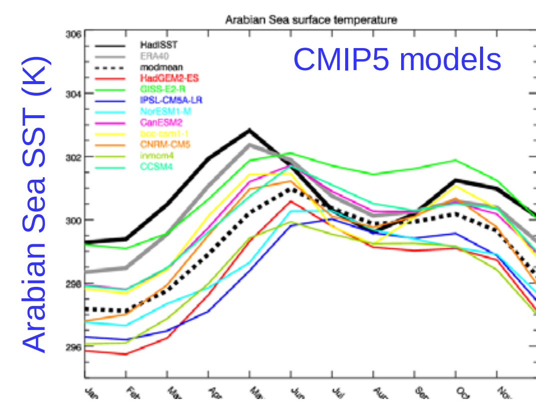



The effects of N Indian Ocean SST biases on HadGEM3-A (rainfall and vertically-integrated moisture flux) →

JJAS



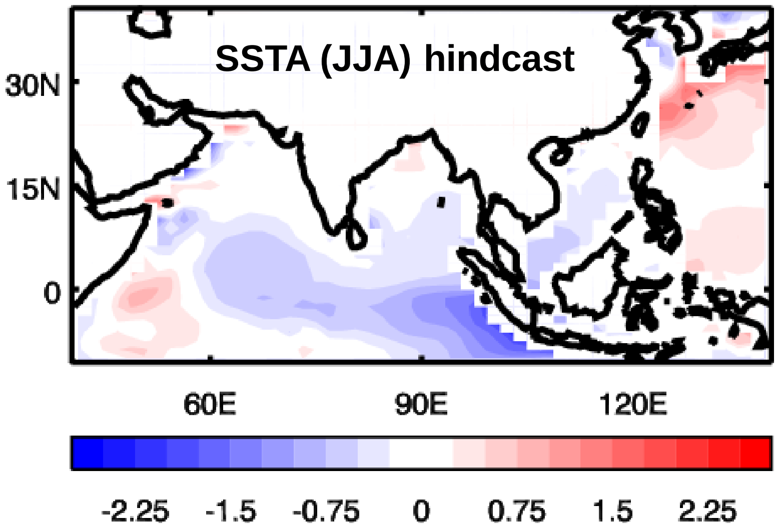






Richard Levine

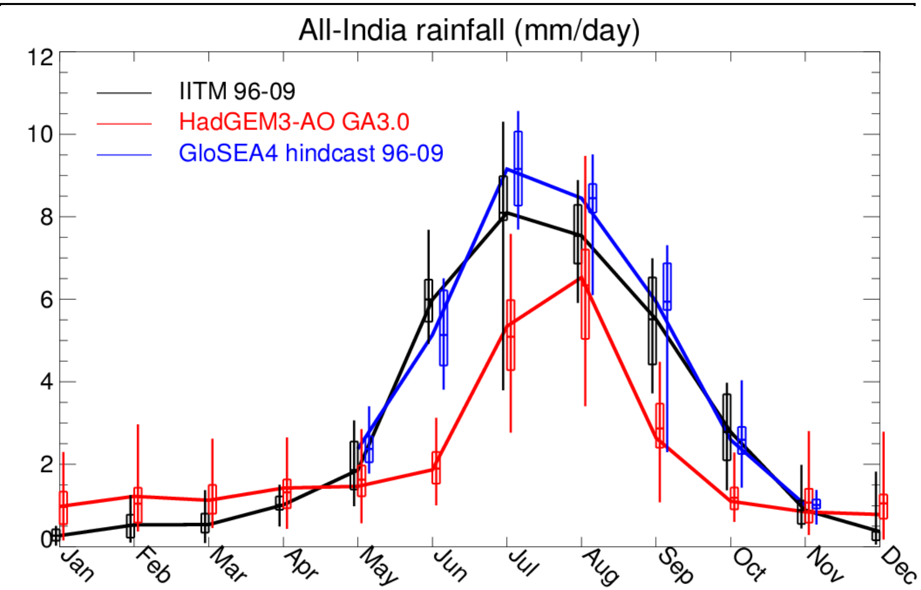
# Implications for seasonal hindcasts

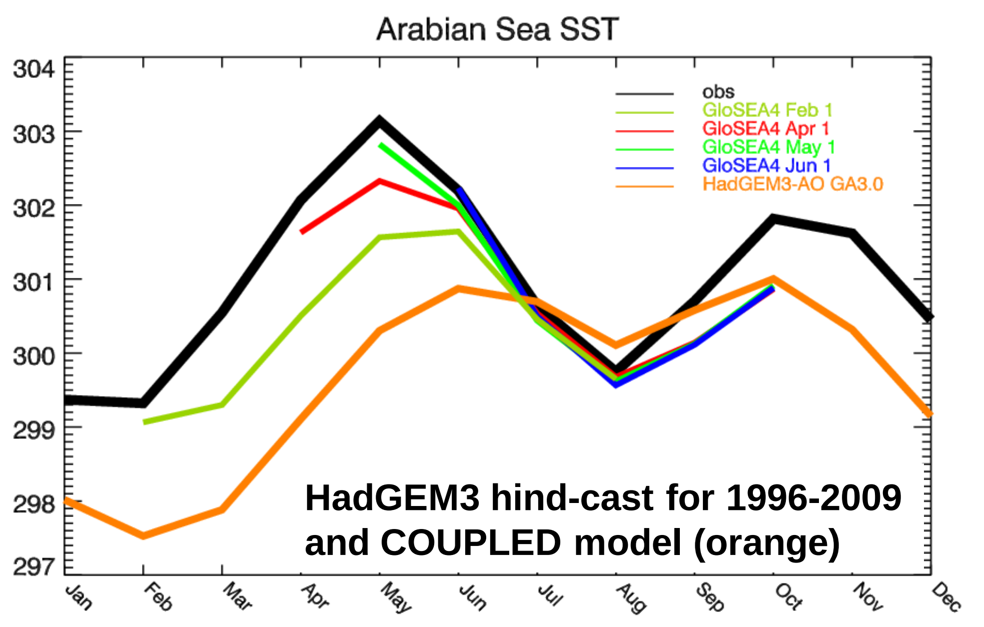



In hindcast (initialised in spring) the cold N Indian Ocean SST bias does not have time to develop, leaving equatorial SST bias to strengthen monsoon through enhanced temperature gradient.

→ preferred convection over equatorial Indian Ocean strengthens monsoon in seasonal model.

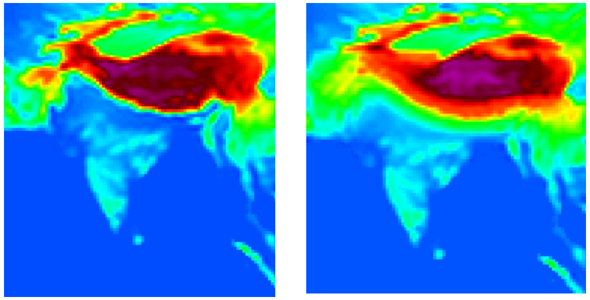
Illustrates the influence of SST biases on a range of timescales.



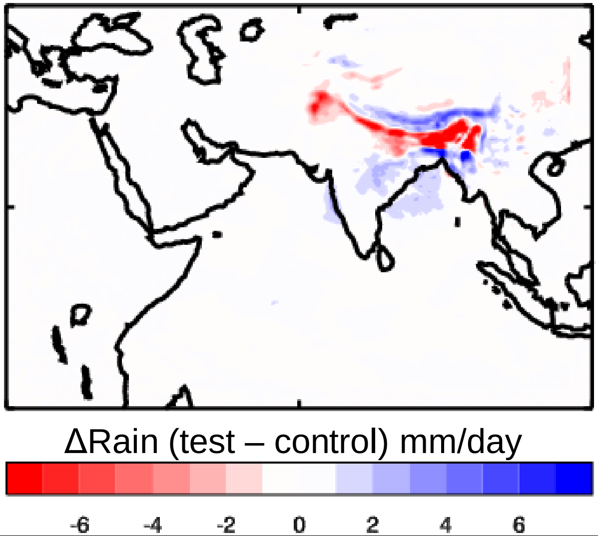
# Sensitivity to representation of Himalayan orography

Excessive Himalayan rainfall influences dry bias over Indian peninsula.

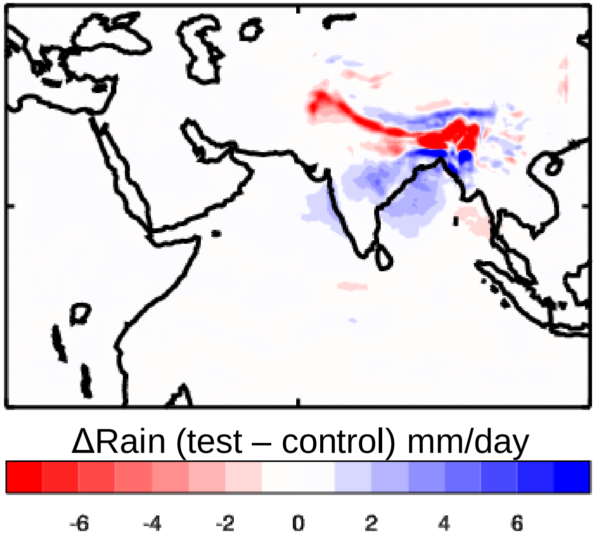


Smoothing southern Himalayan slopes in RCM

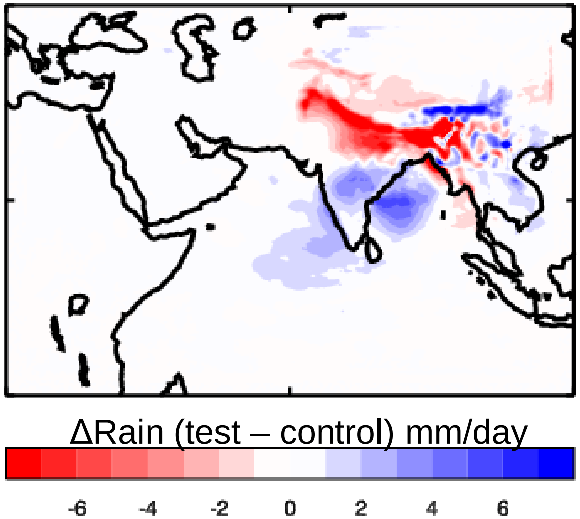
**test 1**
smoothing of mean orography, sub-grid-scale unchanged




**test 2**
smoothing of mean and sub-grid-scale orography




**test 3**
smoothing of mean orography, sub-grid-scale removed



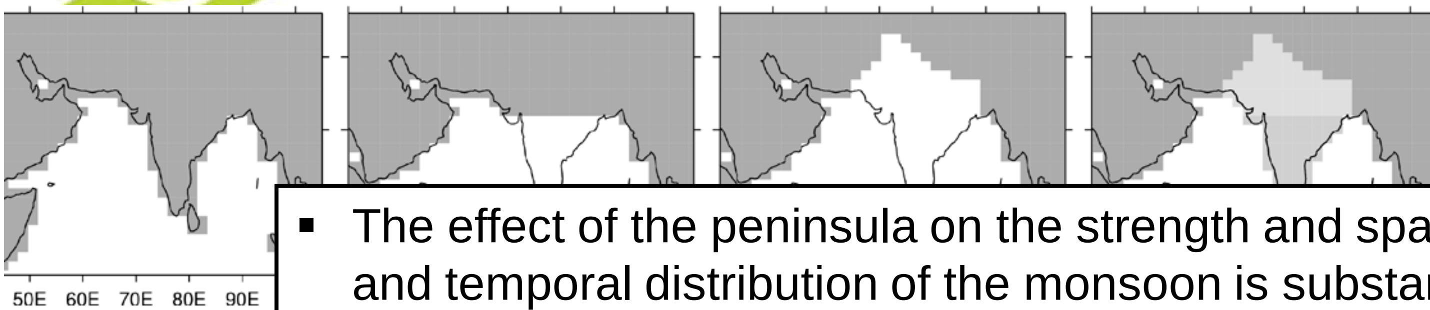

- Smoothing steep slopes results in reduced convergence - reduces Himalayan wet bias and moves rainfall to Central India and western Bay of Bengal (improvement)
- Sensitive to representation of both mean and sub-grid-scale variability of orography



Richard Levine

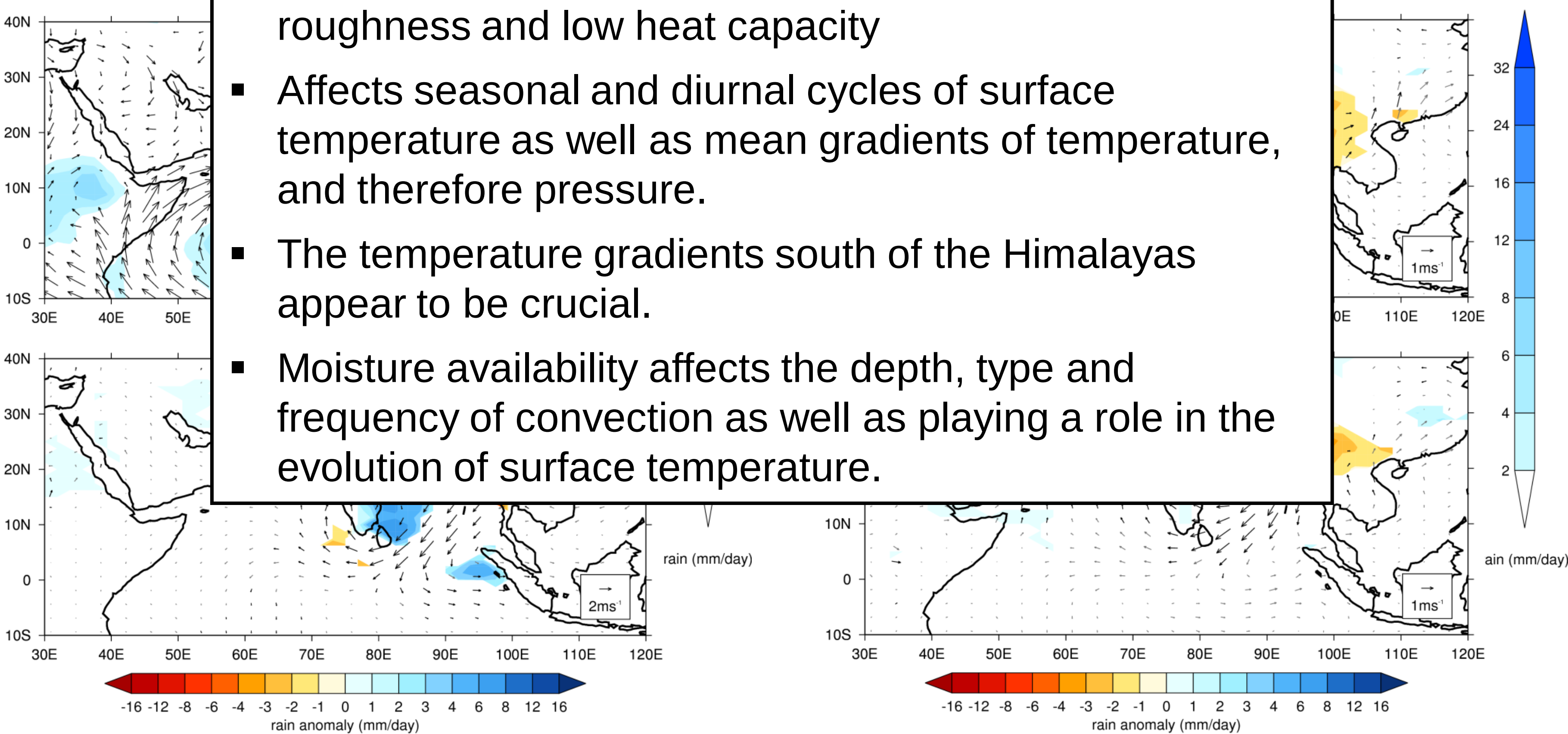
# The role of the Indian peninsula

*Turner, Martin and Levine, submitted to Climate Dynamics*



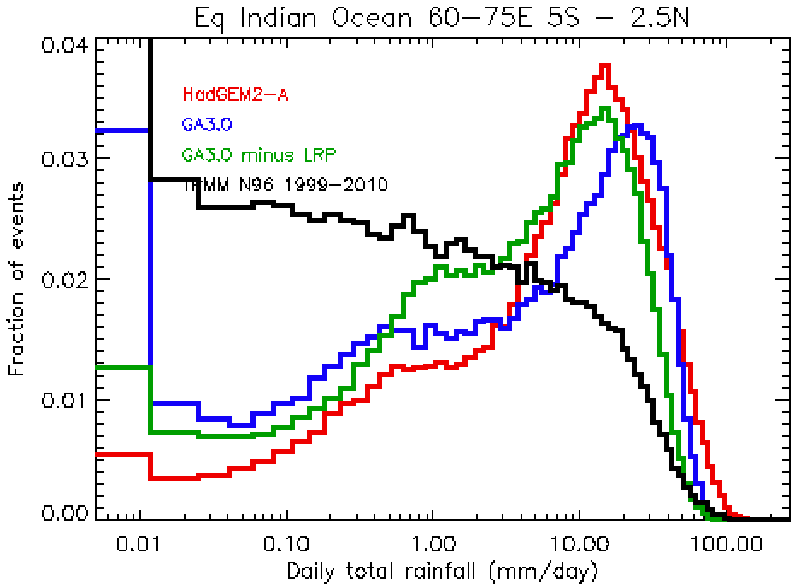

- Replace Indian peninsular land with sea
- /without
  aphy

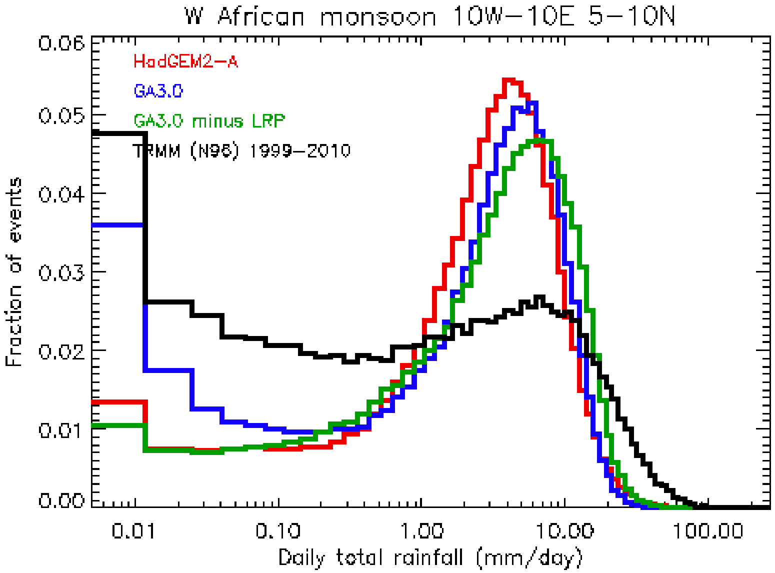
- The effect of the peninsula on the strength and spatial and temporal distribution of the monsoon is substantial.
- Land and orography affect the flow through both surface roughness and low heat capacity
- Affects seasonal and diurnal cycles of surface temperature as well as mean gradients of temperature, and therefore pressure.
- The temperature gradients south of the Himalayas appear to be crucial.
- Moisture availability affects the depth, type and frequency of convection as well as playing a role in the evolution of surface temperature.

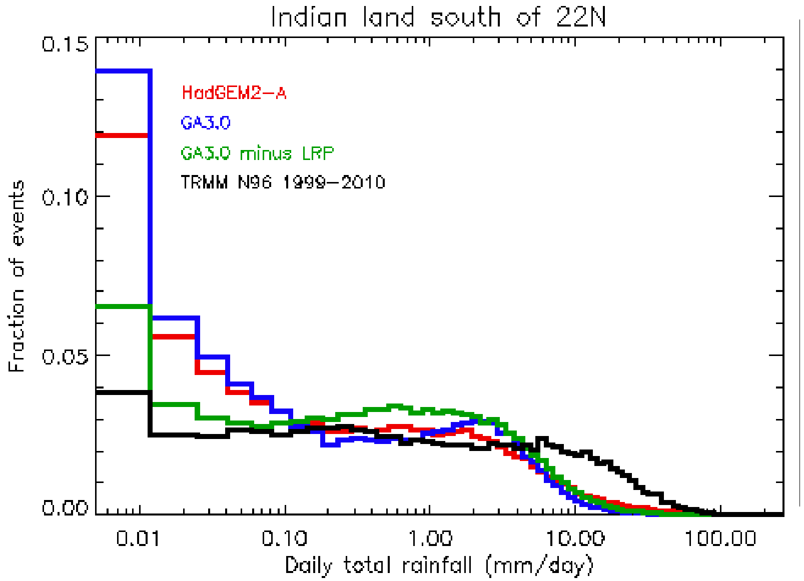


# Convective behaviour

## Daily timescales




- Daily rainfall spectra more peaked in the model than in TRMM.
- Lack of spread in daily rainfall totals, over land and sea.
- Important to examine impact of changing parametrisations on a range of timescales.

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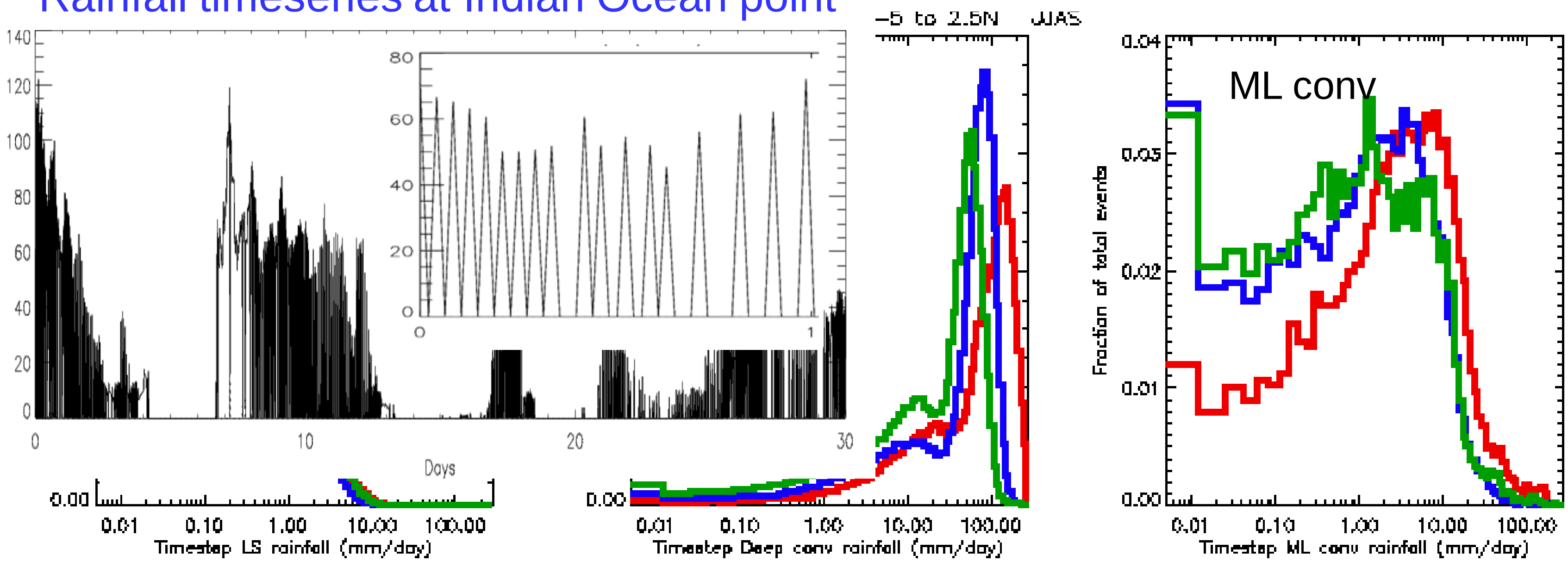
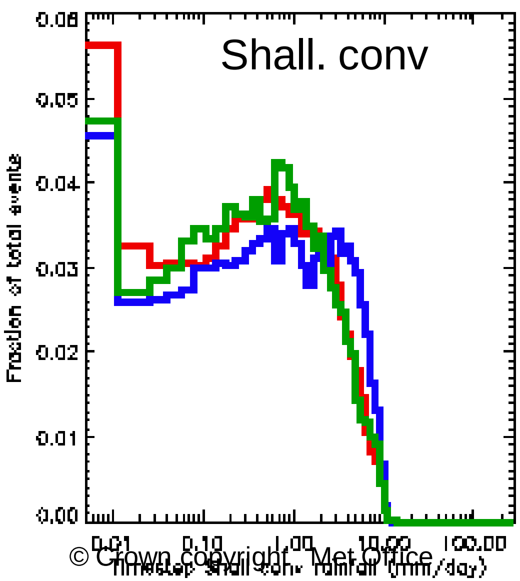
# Timestep behaviour of convection

Rainfall timeseries at Indian Ocean point




Number of events
Fraction of events

| | |
|---|---|
| GA5 #95.1 | 90 |
| with 1hr CAPE ts | 90 |
| 1hr CAPE and 1.5xE | 90 |

Sensitivity tests suggest that the dominance of high intensity events over Indian Ocean affects the moisture flux into the Indian region.

Indications are that models require a “flatter” spectrum of rainfall intensity, with more frequent moderate intensity events.

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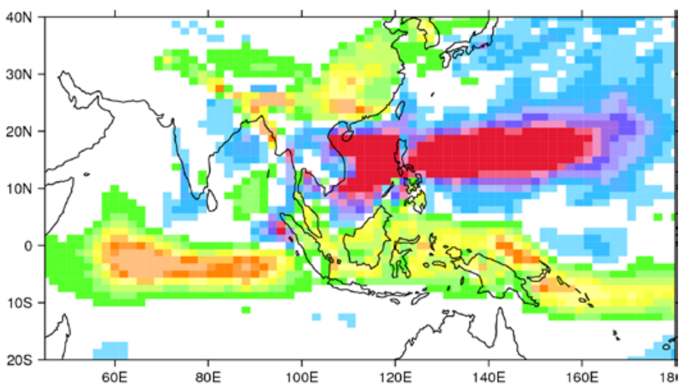
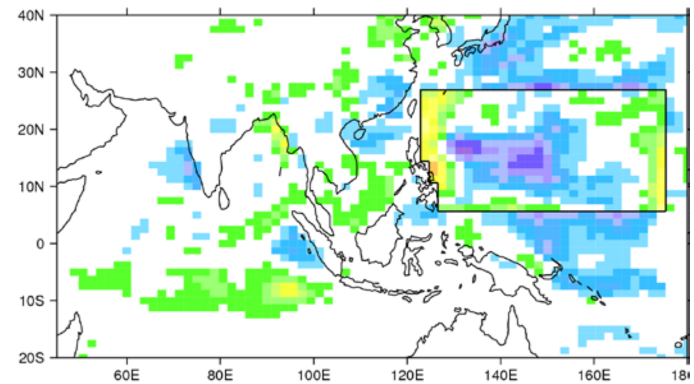
# Separating local versus remote effects

## Changing the convective entrainment rate locally

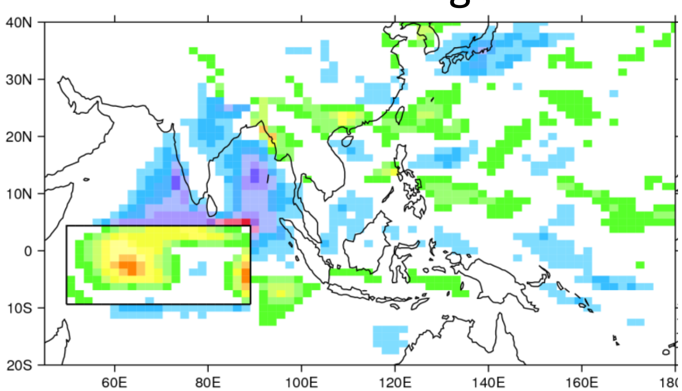
Global Change




Western Eq Pacific Change




WEIO Change





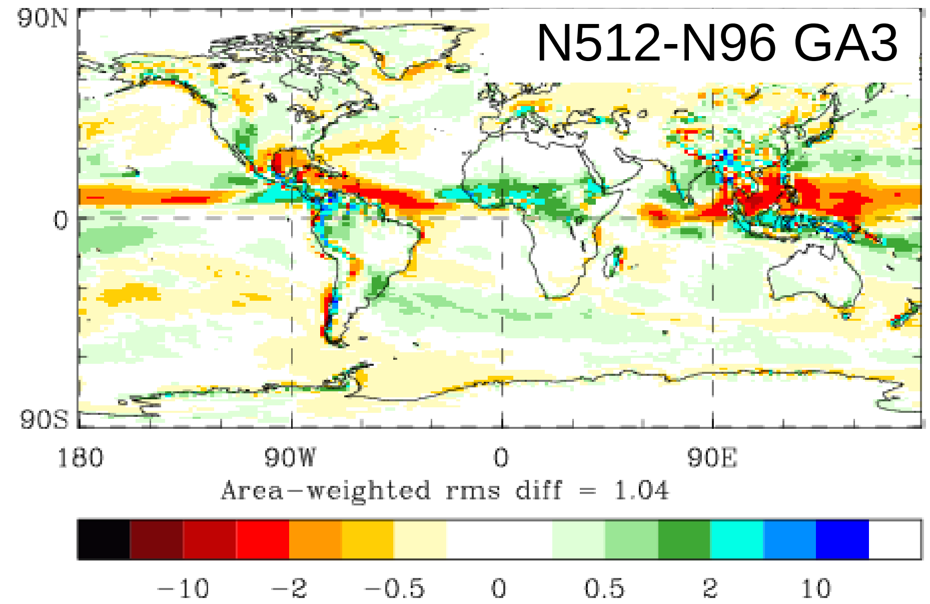
mm/day

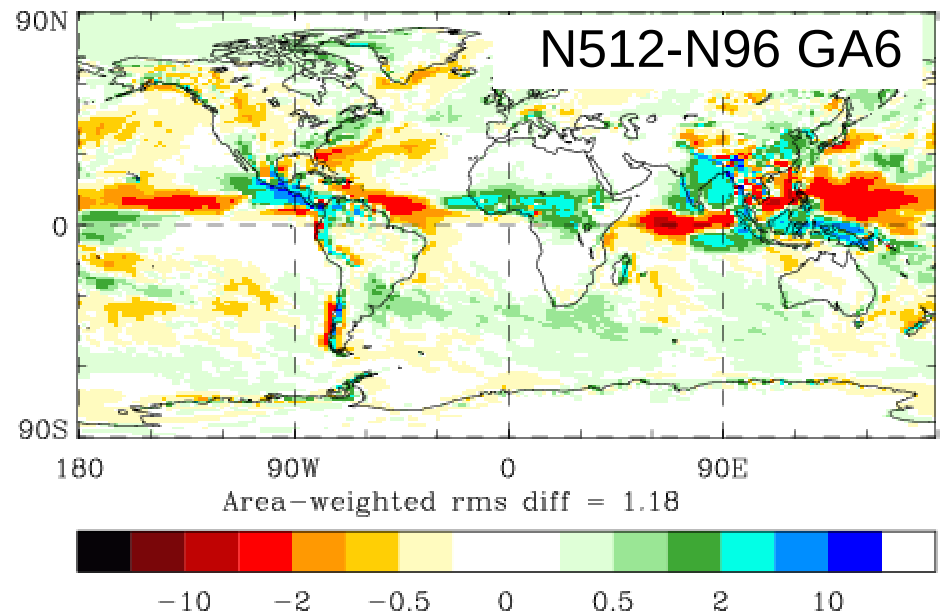
- Increasing the entrainment rate leads to increased moistening, ascent and precipitation in the WEP and reduced precipitation in the WEIO.
- Decreased WEIO precipitation leads to more moisture in the Somali Jet and increased rainfall over India.
- The change in the WEP is locally-driven, with only small impacts on the surrounding regions.

Stephanie Bush

# Sensitivity to model resolution

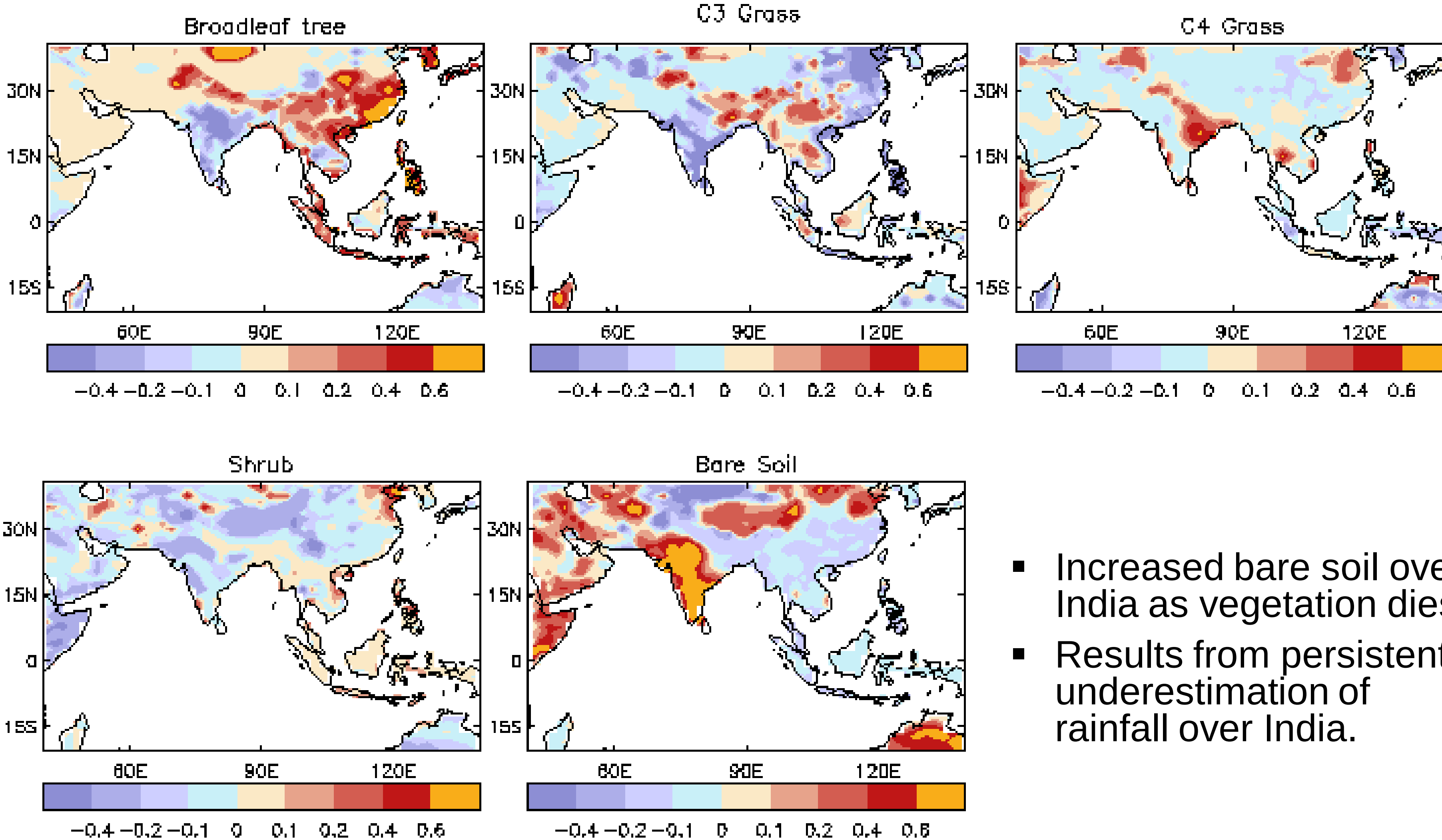
- Indian rainfall shows little sensitivity to change between N96 (1.875º x 1.25º) and N216 (0.83º x 0.56º)
- Similarly small sensitivity to change between N216 and N320 (0.56º x 0.375º)
- Changes are smaller than those seen for changing model physics.
- Latest configuration (with ENDGame dynamics): N512 has substantially more monsoon rainfall compared with N96.
- Appears to be related to increased frequency and better track of monsoon depressions.
- Impacts of increased resolution are configuration-dependent!



# Impact of vegetation distribution

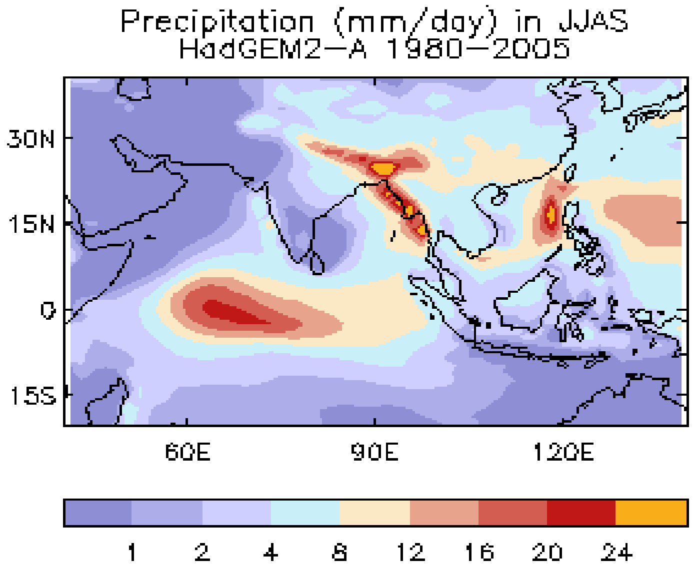
Differences between HadGEM2-ES modelled and "observed" vegetation

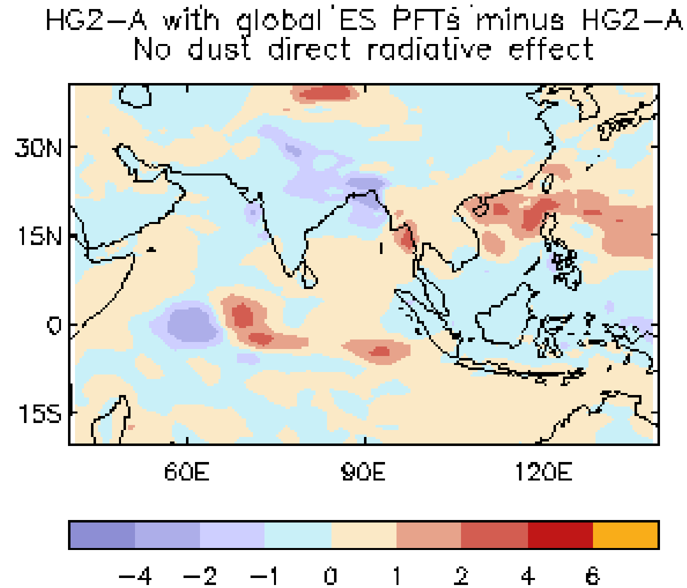


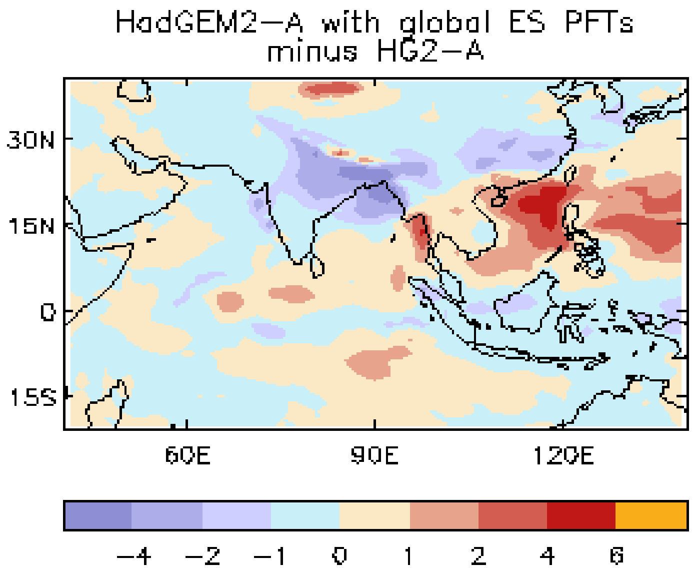

- Increased bare soil over India as vegetation dies.
- Results from persistent underestimation of rainfall over India.

*Martin and Levine (2012)*
*Earth System Dynamics*

# HadGEM2-A with ES vegetation




- Atmosphere-only models show reduced rainfall when vegetation distribution from Earth System model is used.
- Dust production is increased significantly when the ES model's vegetation is applied.
- Removing the dust radiative impact reveals that most of this comes from the change in atmospheric stability due to the increased dust.

# Future challenges

- Representation of flow and rainfall over steep orography:
  - What does it really look like? Are the observations good enough?
- Coupled model SST biases – feedback on monsoon climatology, variability and teleconnections, even in seasonal forecasts
  - Is increased horizontal resolution in atmosphere <u>and</u> ocean required?
  - Linked to atmosphere parametrisation problems (e.g. equatorial Indian Ocean)
- Model resolution
  - Increased resolution doesn't always help – need to manage expectations!
- Model complexity
  - May require more complex processes to simulate complex feedbacks (esp for projections)
  - BUT need to reduce basic model systematic biases in order to avoid feedbacks which may increase, rather than reduce, the uncertainty in tropical climate change.

# Future challenges [cont.]

- Land-atmosphere interactions
  - Cover a range of time and space scales
  - Local and remote influences
  - Magnitude and sign of feedbacks may vary between different time and space scales
  - How important are these for the different monsoon systems?
  - Is the influence of the land surface masked in models by the dominance of atmospheric parametrisations?
  - How well do we know the actual land surface characteristics and how they vary?
  - Adding more complexity (e.g. interactive vegetation) can give unexpected results; we need to solve our basic errors first.
- Convective behaviour:
  - Parametrisations produce over-intense and intermittent deep convection
  - Lack of variability, across timescales.
  - Lack of knowledge of scale interactions, in models and observations

# Future challenges [cont.]

- Convective behaviour [cont.]
  - Require sub-daily observations to be more widespread and readily available (and reliable!)
  - Require more detailed analysis of model behaviour on a range of timescales, including sub-daily
  - Require model intercomparison at the timestep level (similar to MJO-TF diabatic processes activity)
  - Models at grey-zone resolutions are of limited use:
    - ✓ provide information on the effects of poor diurnal cycle in parametrised runs
    - ✗ produce locally intense rainfall with unrealistic feedbacks on dynamics, land surface, etc…
    - ✗ Require targeted parametrisation development if to be used as interim measure
  - Exploratory work now being done at ~100m resolutions
    - Requires further parametrisation development/tuning

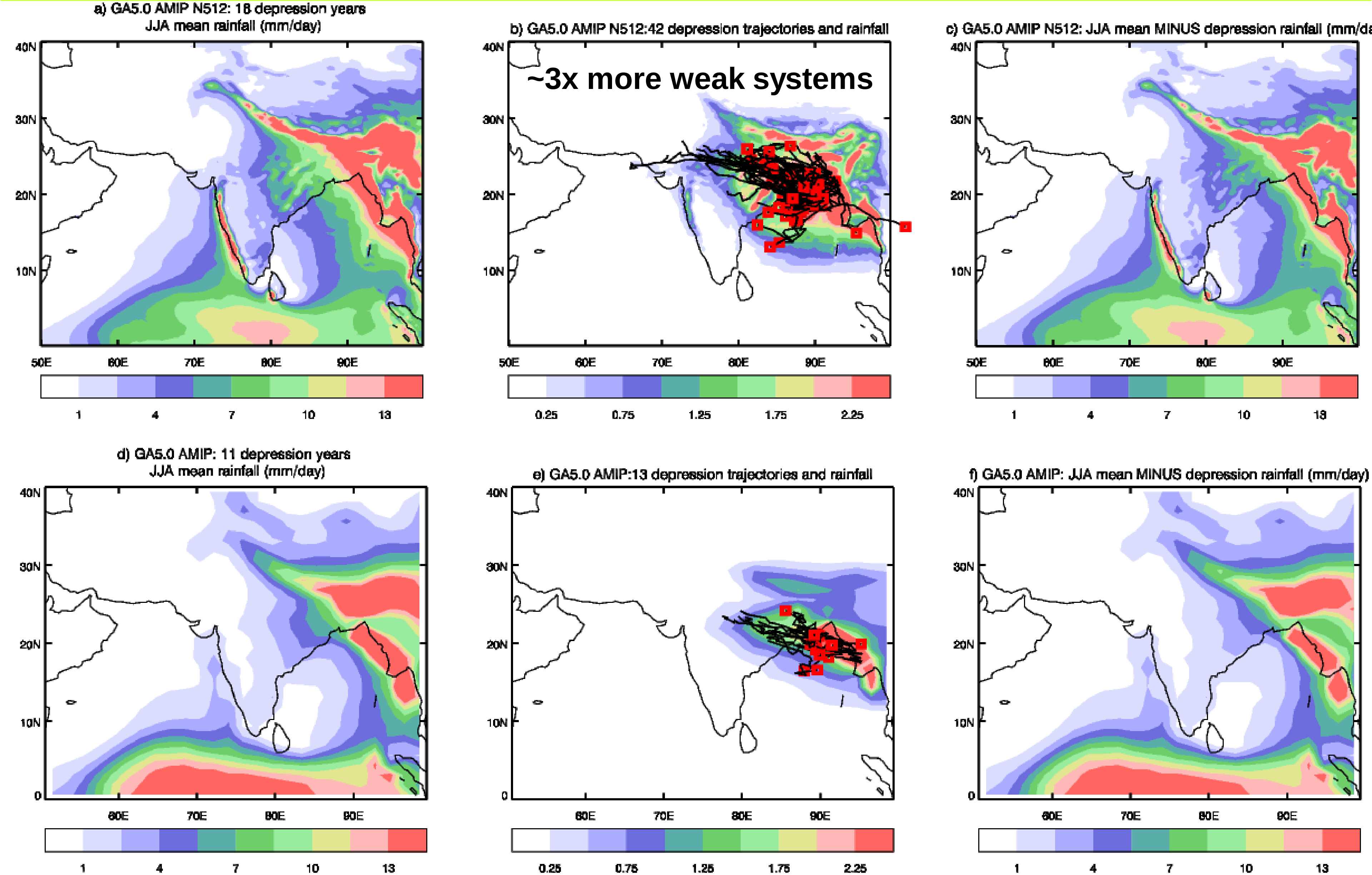
# Questions and answers

# Monsoon depressions: N512 vs N96

total rainfall in years with depressions

trajectories and rainfall contribution

total minus depression rainfall



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