The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

1956-22

Targeted Training Activity: Seasonal Predictability in Tropical Regions to be followed by Workshop on Multi-scale Predictions of the Asian and African Summer Monsoon

4 - 15 August 2008

Monsoon ISV: modelling issues and influence of global warming

SLINGO Julia Mary

Centre For Global Atmospheric Modelling
Department of Meteorology
2 Earley Gate. Whiteknights, P.O. Box 243
RG6 6BB Reading
UNITED KINGDOM

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Modelling ISV and the Impacts of Climate Change

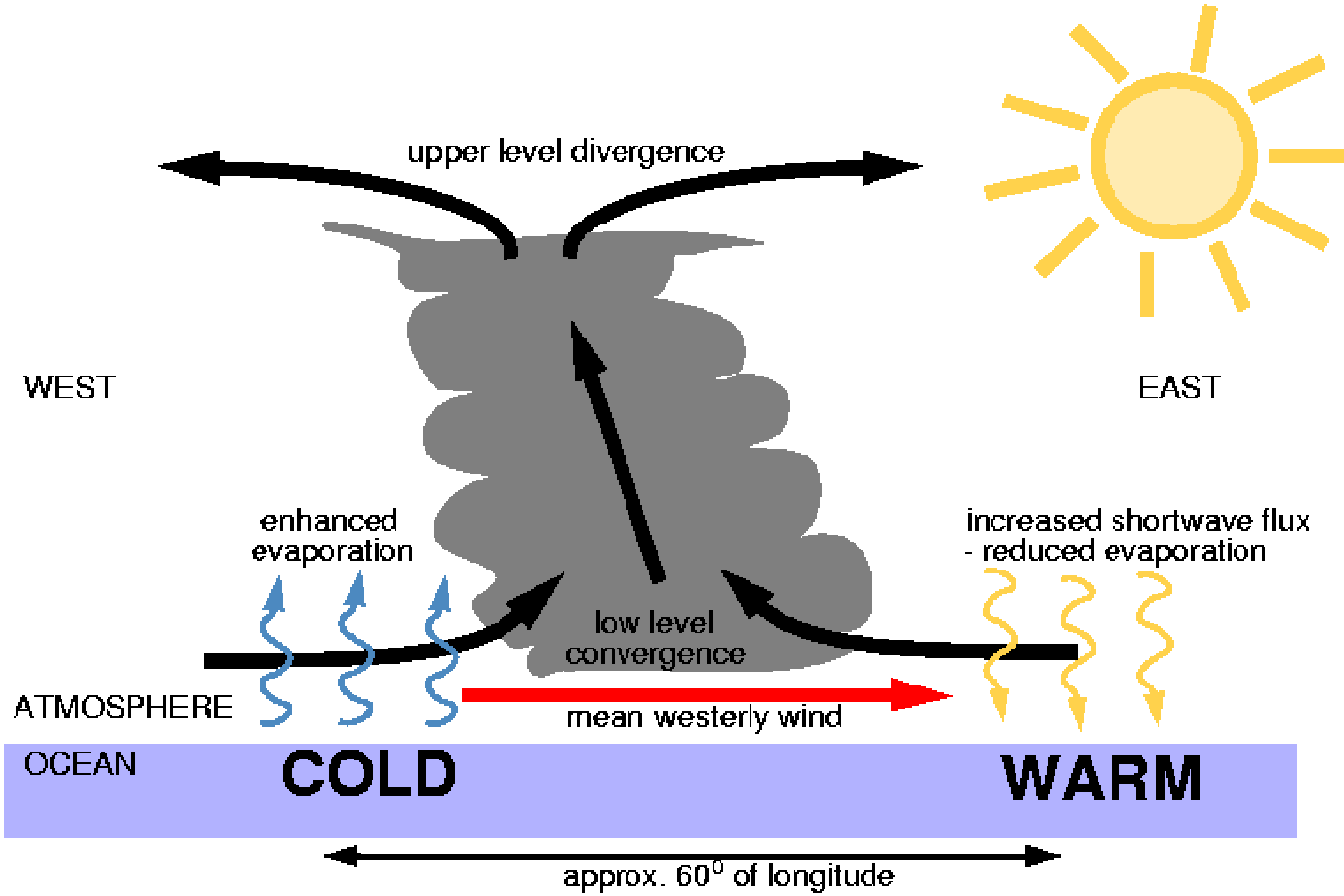
Julia Slingo, Dan Bernie, Nick Klingaman, Pete Inness, Pratap Mohanty, Andy Turner, Steve Woolnough, Gui-Ying Yang and the UK-HiGEM Consortium

Walker INSTITUTE

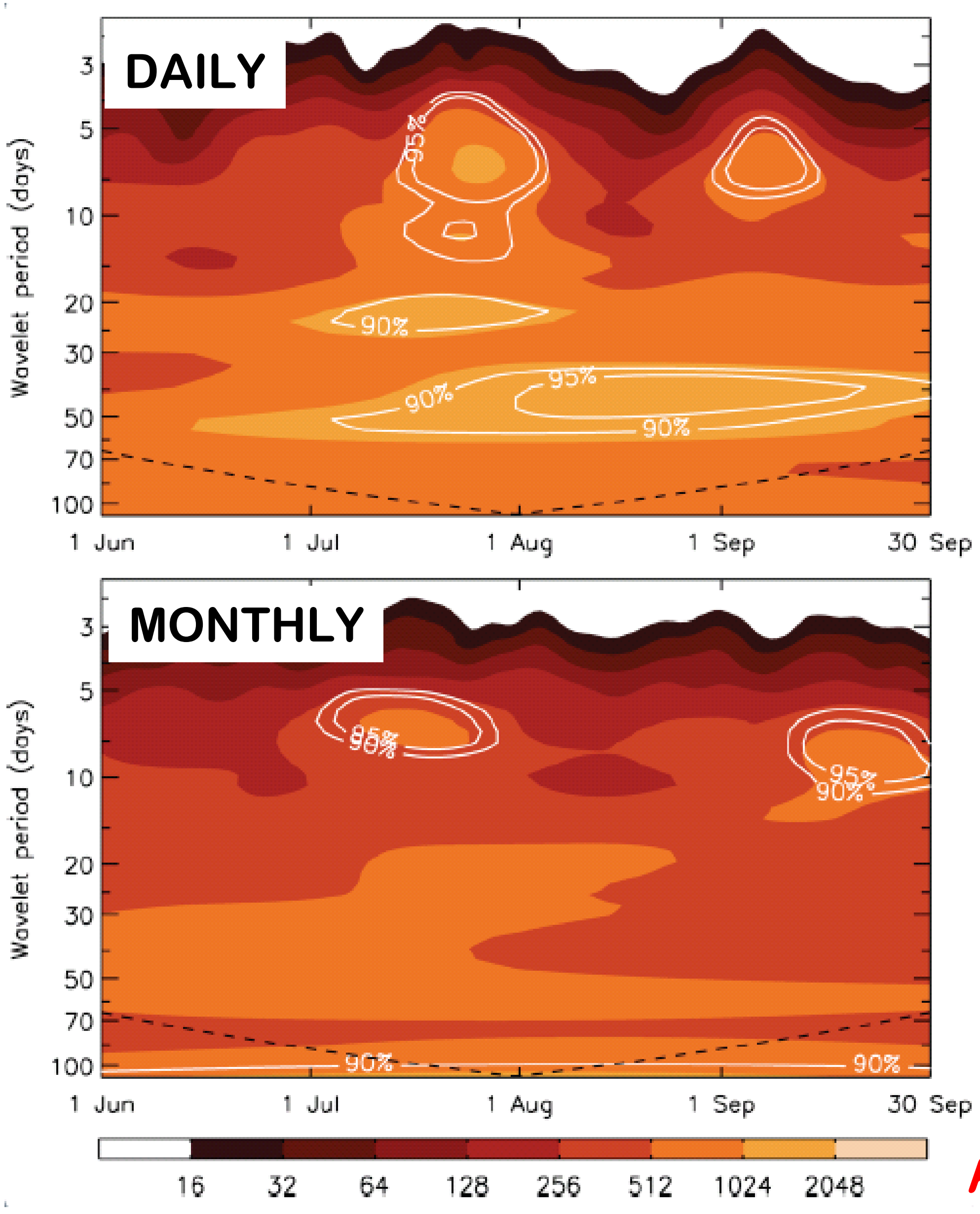
Outline

- Role of the ocean
  - Thermodynamic
  - Dynamic
- Influence of model resolution
- Organised convection and the coupling between physics and dynamics
- Monsoon ISV and climate change

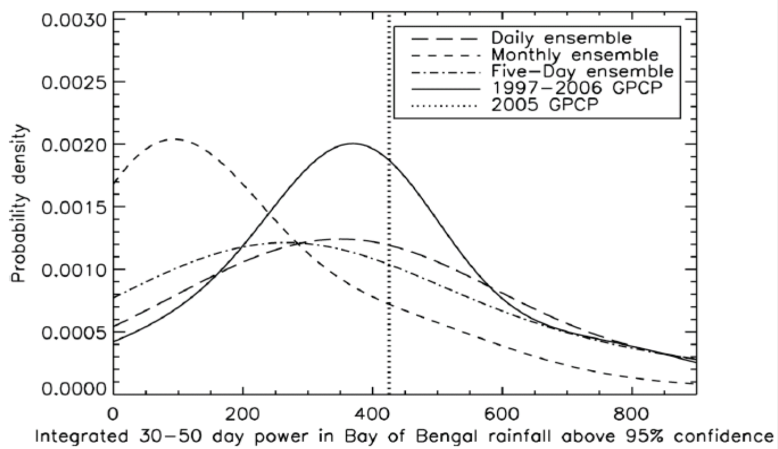
Air-sea interaction and the MJO



Increased power on intraseasonal timescales from high resolution SSTs



Wavelet analysis of simulated rainfall in all ensemble members

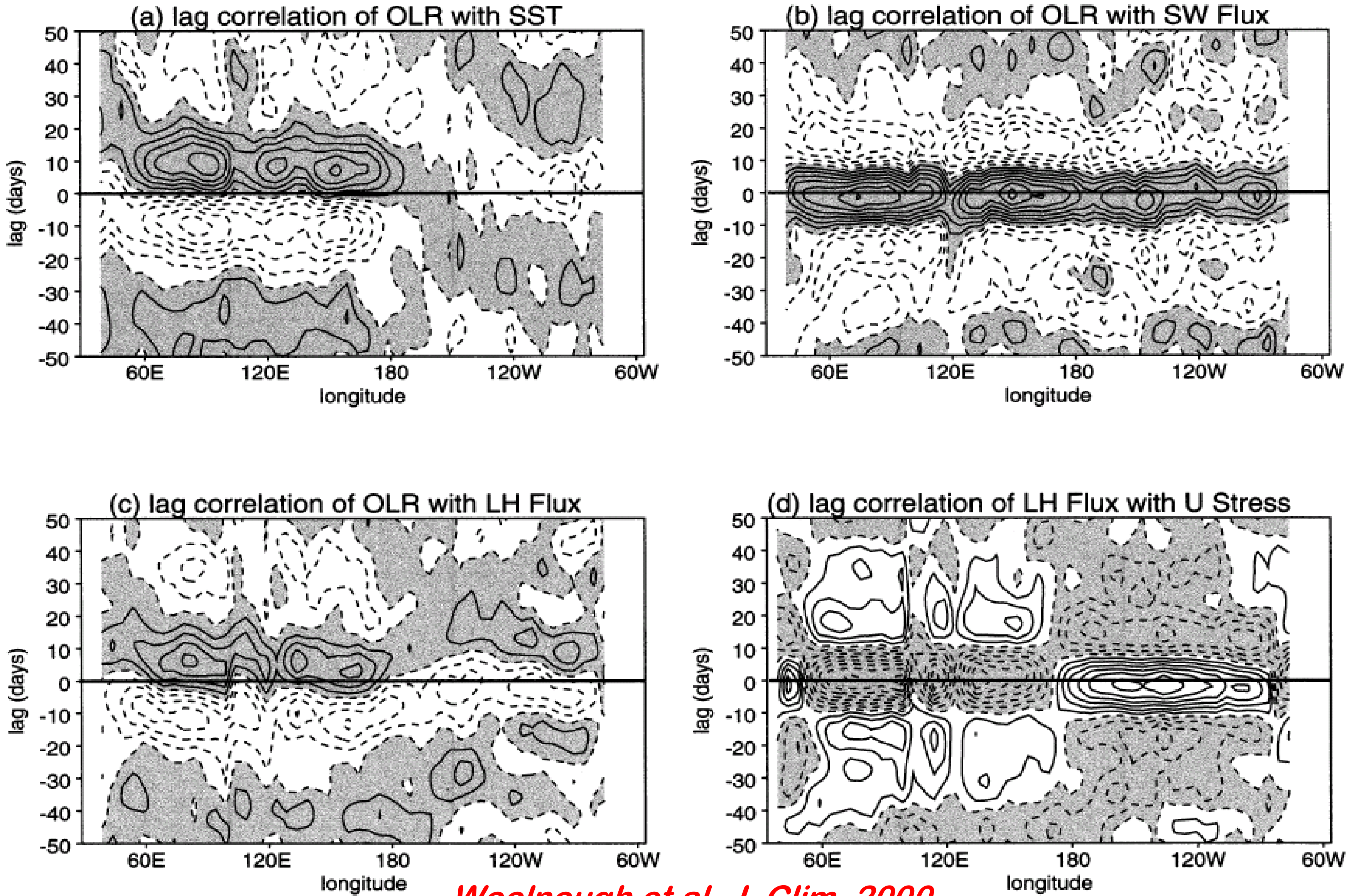


Probability-density function of the intraseasonal-power metric for all three ensembles, compared to high-resolution GPCP rainfall analyses.

Klingaman et al. 2008

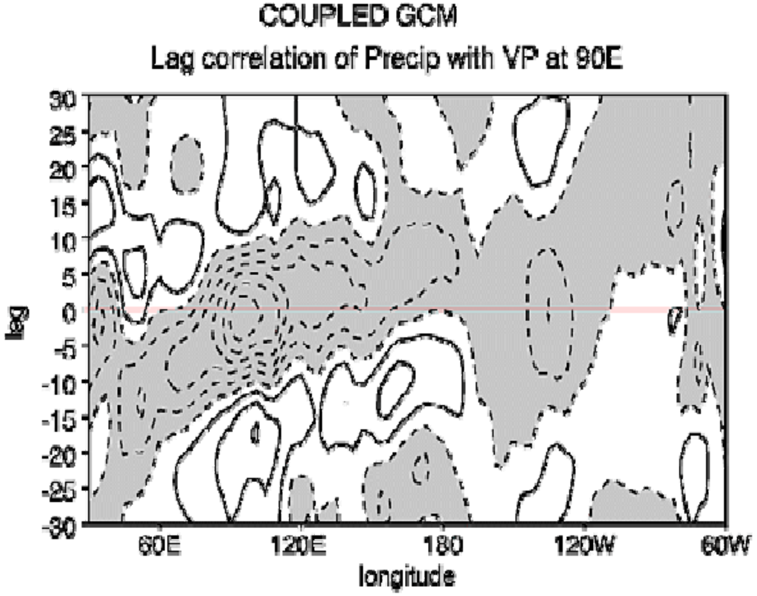
Some background – observed air-sea interaction

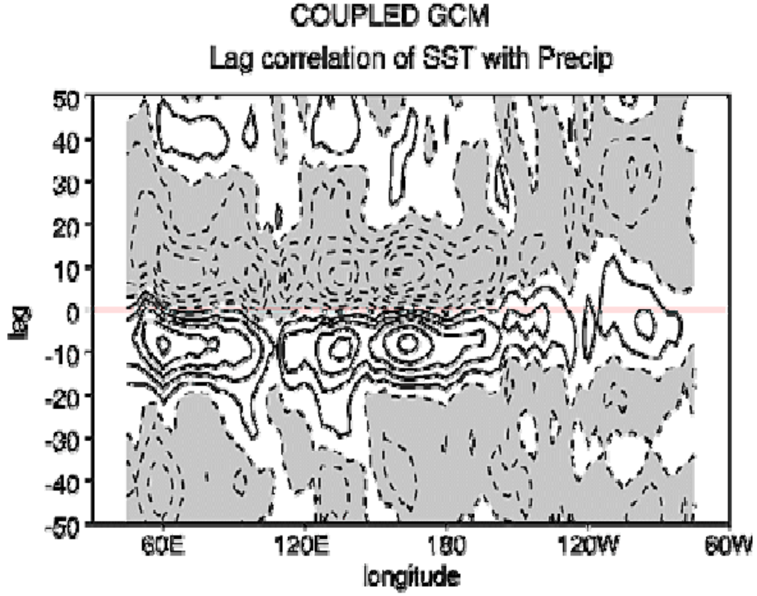
National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

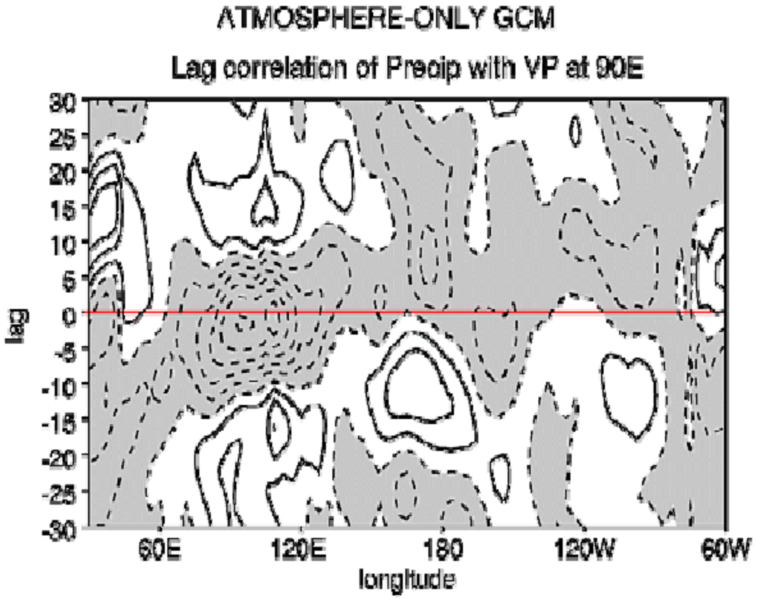


Woolnough et al. J. Clim. 2000

Some background – modelled air-sea interaction



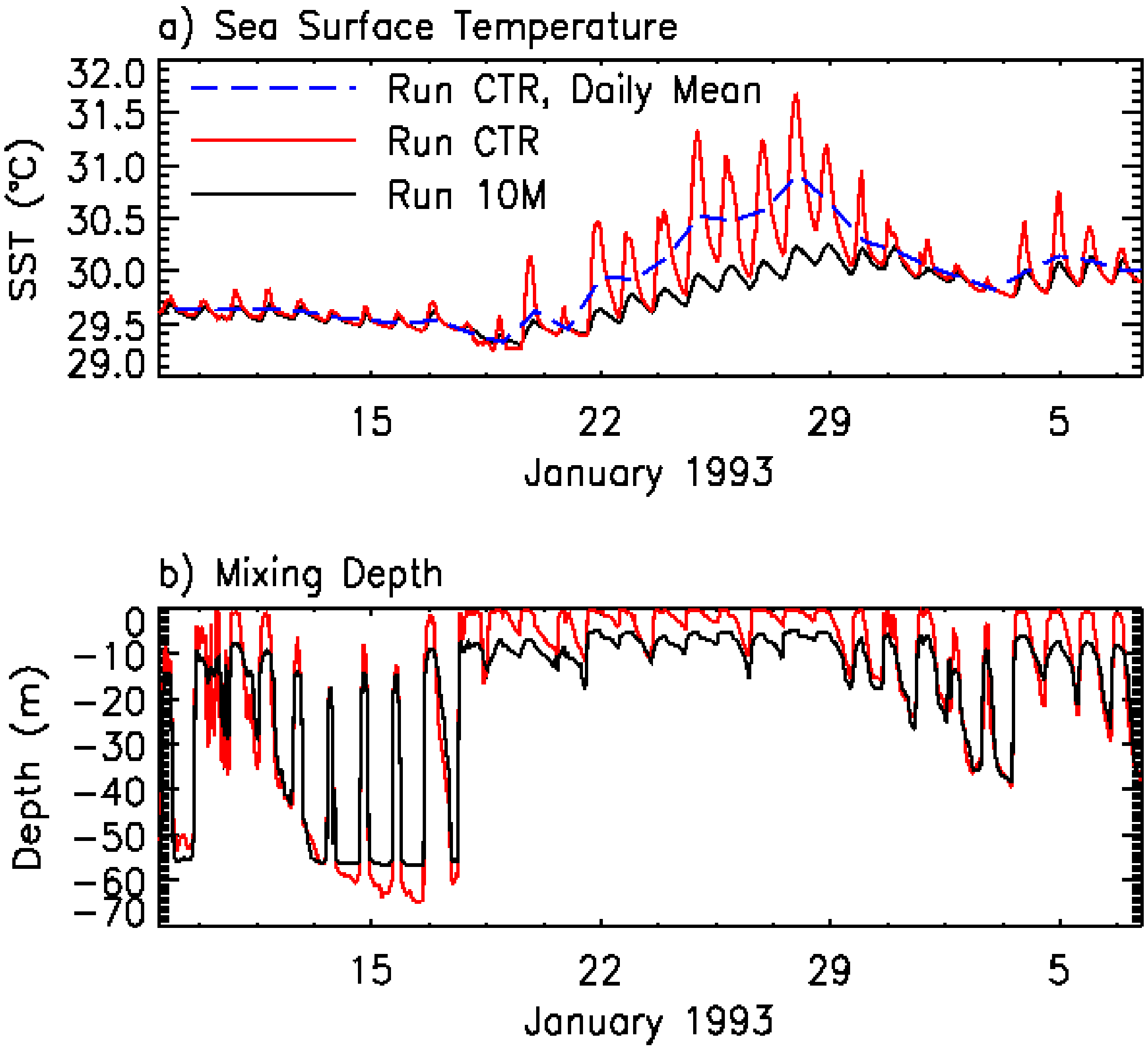




CGCM has a propagating convective signal compared with standing oscillation in AGCM. Coherent variations in SST in CGCM in agreement with observations, *provided* the mean state (i.e. eastward edge of Warm Pool) is realistic

Inness and Slingo J. Clim. 2003
Inness et al. J. Clim. 2003

Mixed layer model studies of the diurnal cycle: Sensitivity to vertical resolution



- 1m resolution (CTR) gives good simulation of diurnal and intraseasonal variability
- 10m resolution of most ocean models will not resolve diurnal variability of SST
- Intraseasonal variability is ~0.4°C less than CTR
- Implies 40% underestimate of the strength of air-sea coupling

Bernie et al. J. Clim. 2005

Influence of well-resolved upper ocean on the MJO

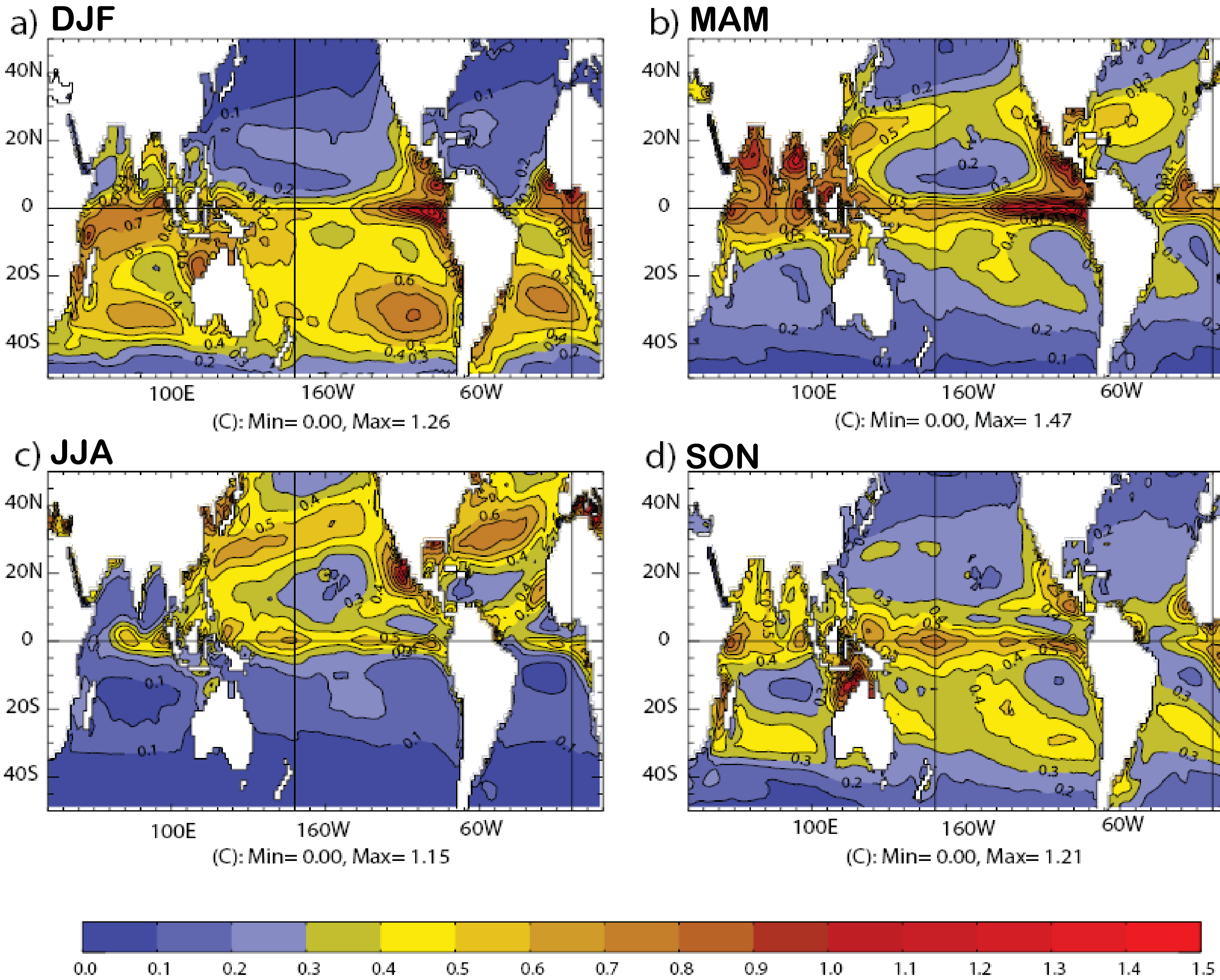
National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

- N48L30 HadAM3 coupled to L300 ORCA2 with 1 meter resolution in near surface ocean
- Two 50-year simulations: 3-hourly coupling vs. daily coupling
- 3-hourly coupling gives improved tropical Pacific mean state, ocean currents and seasonal cycle

Bernie et al. Clim. Dyn. 2008

Walker INSTITUTE

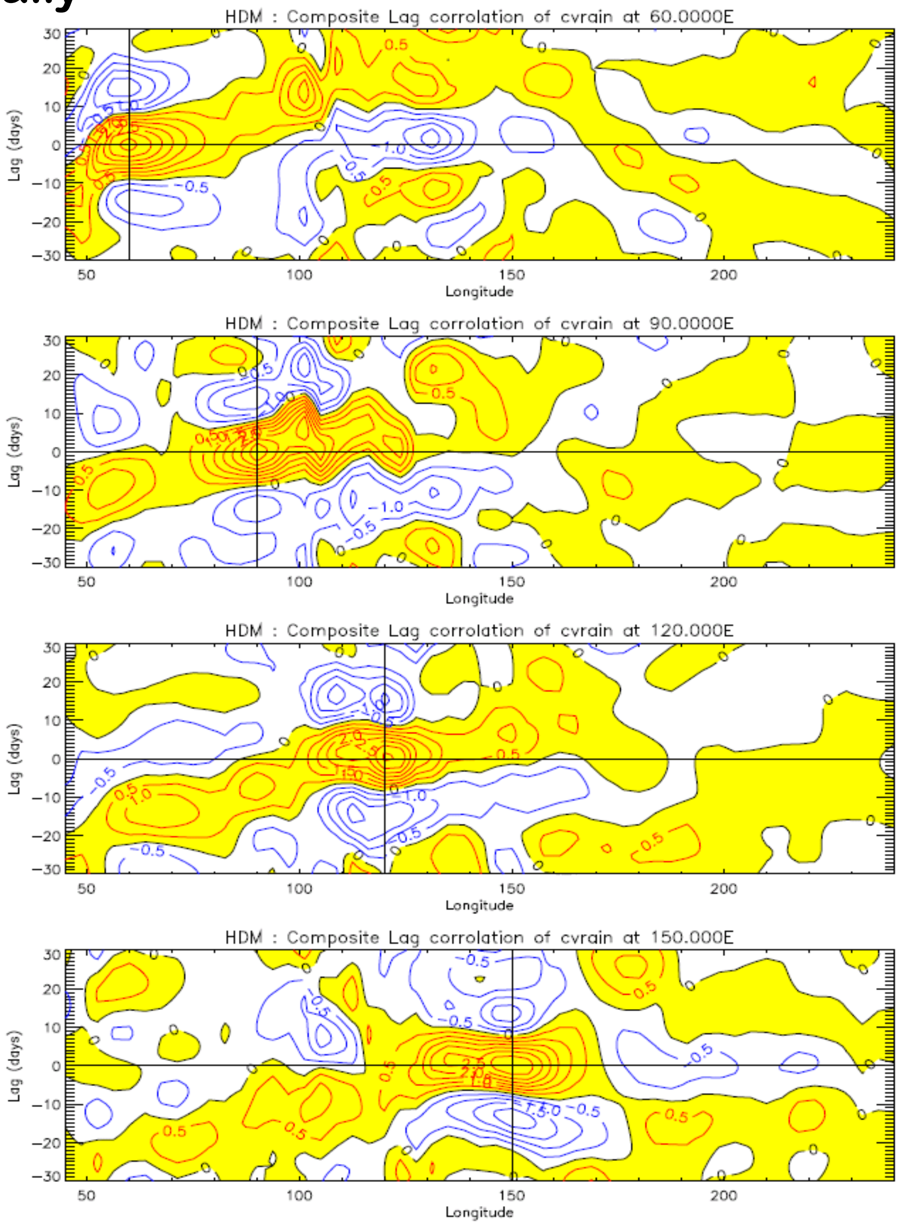
Amplitude of SST diurnal cycle in HadOPA (L300)



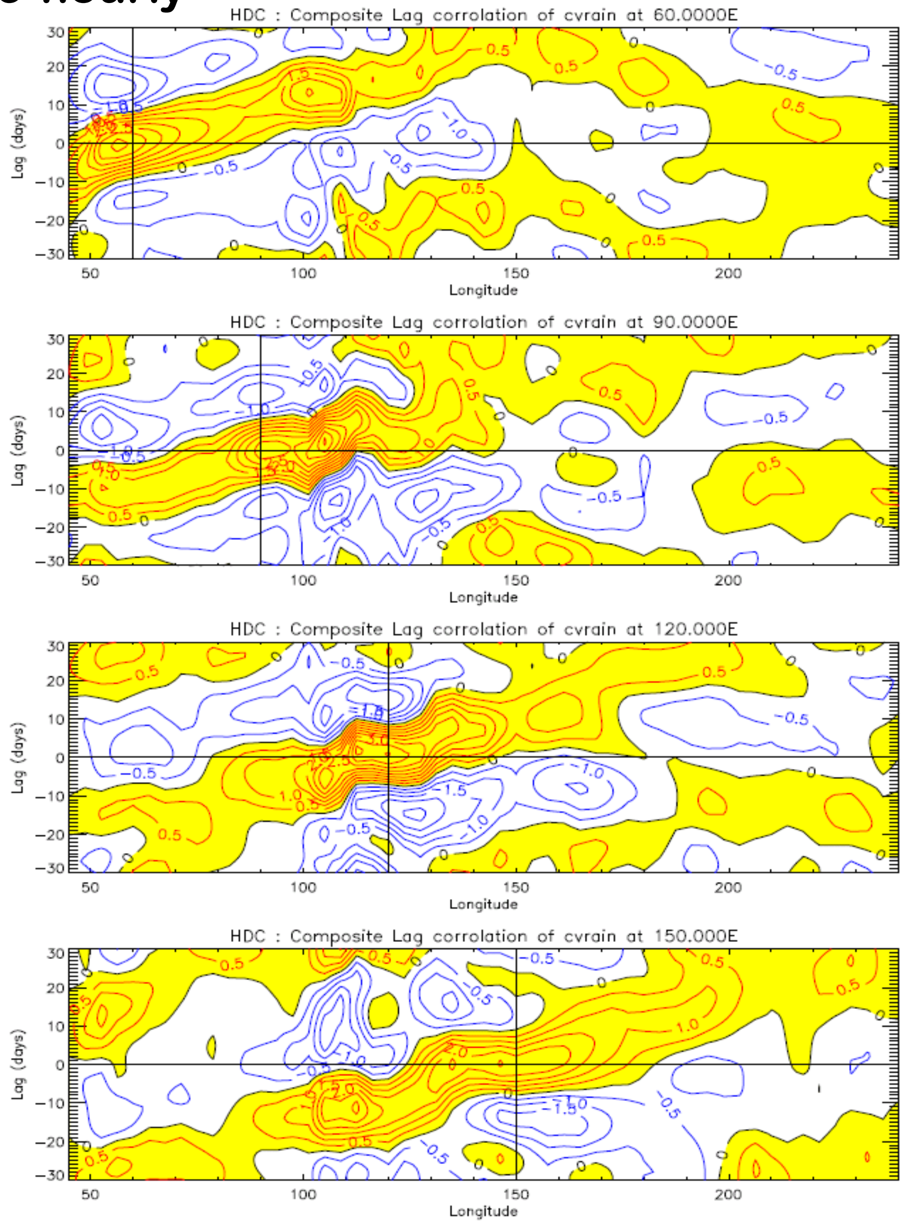
Bernie et al. Clim. Dyn. 2008

Lag-lead composites of MJO precipitation for various base points across the Indo-Pacific Warm Pool

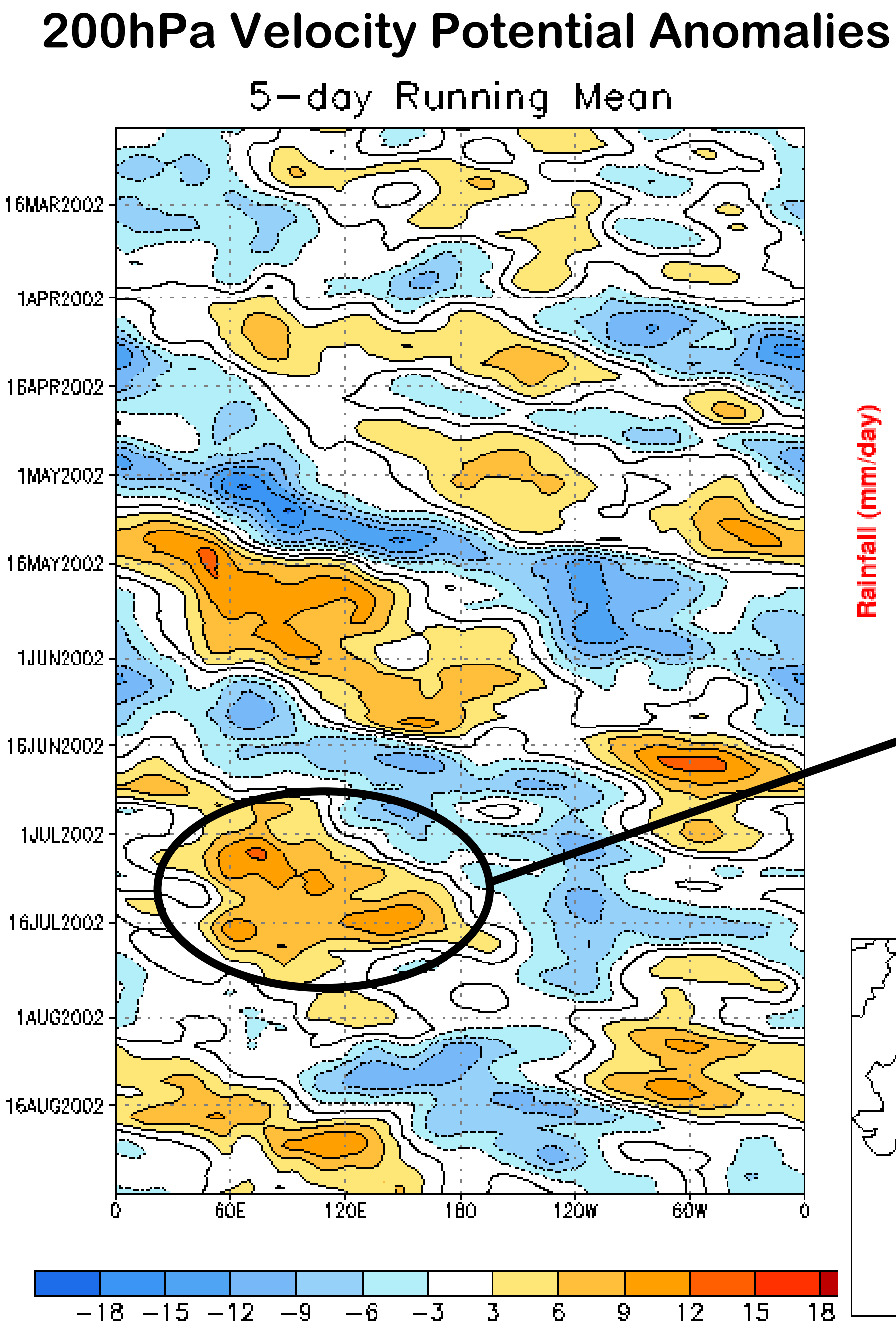
Daily

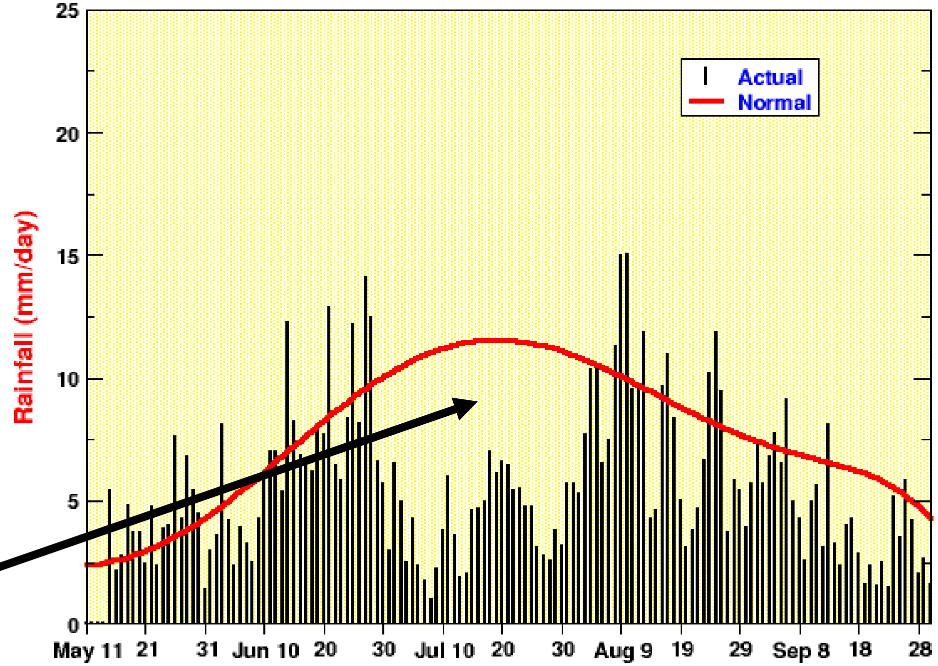


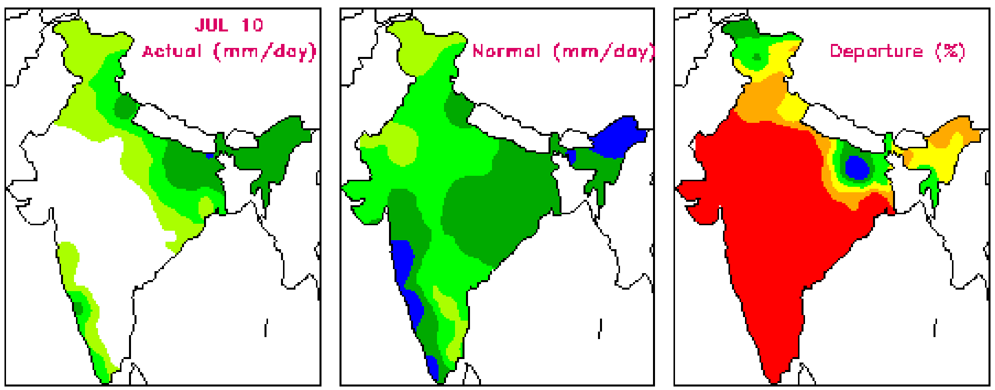
3-hourly



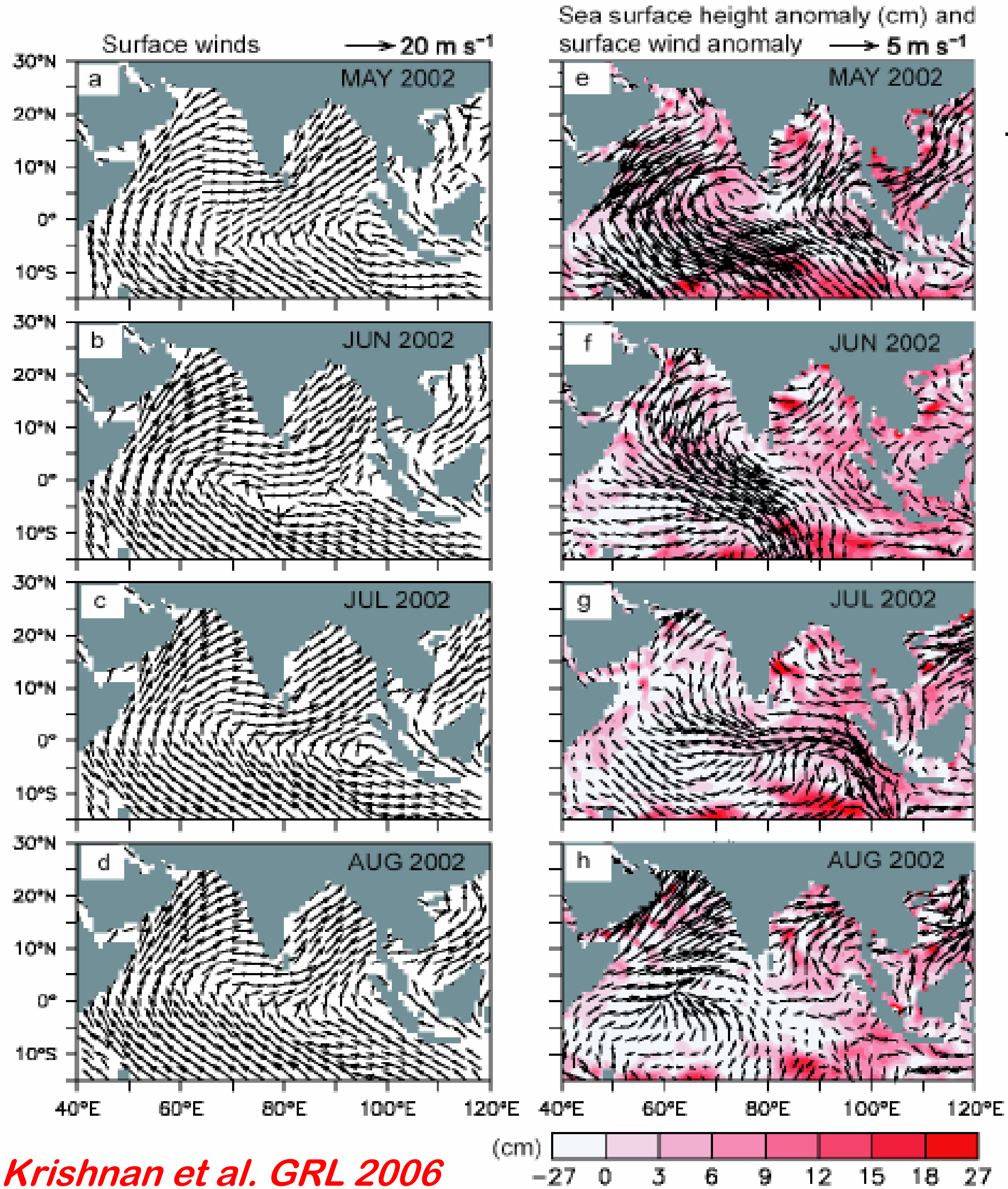
MJO Activity: 2002







Saith and Slingo IJC 2006

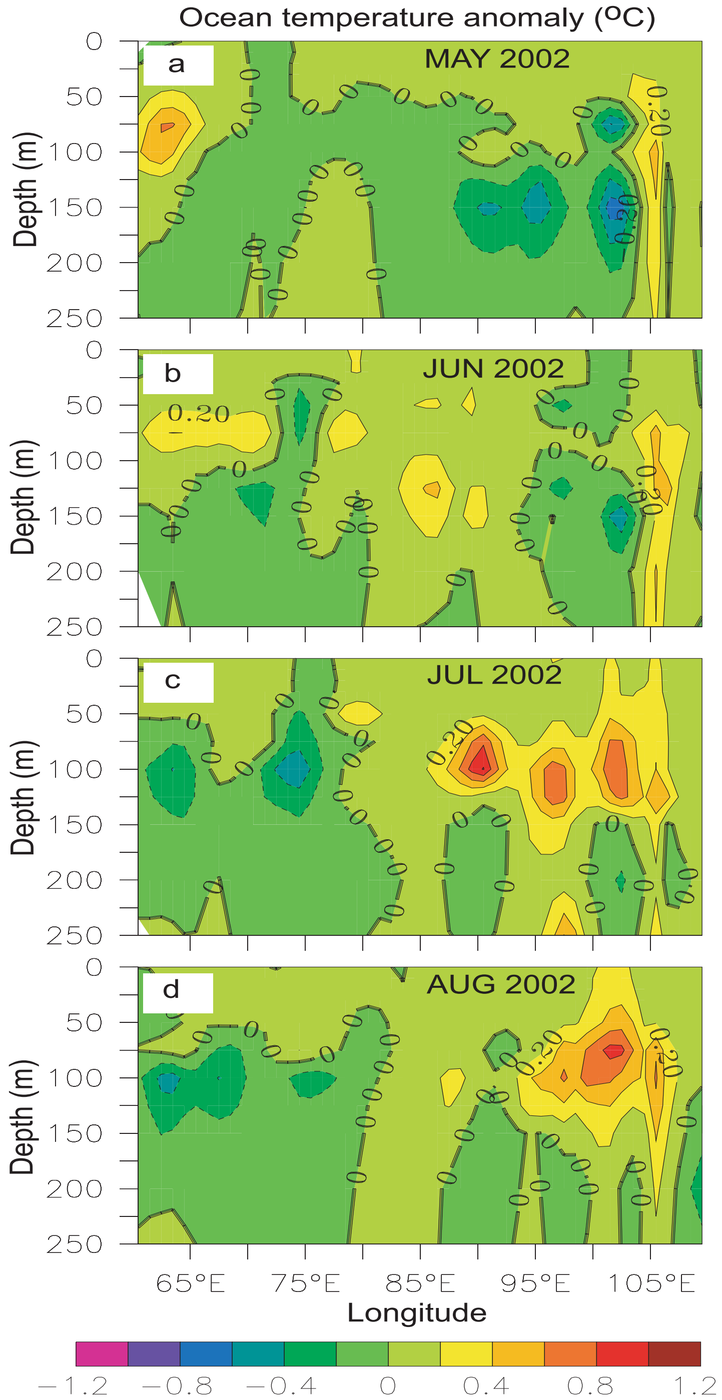


Krishnan et al. GRL 2006

July 2002 Monsoon Break:

Evolution of surface winds and sea surface height

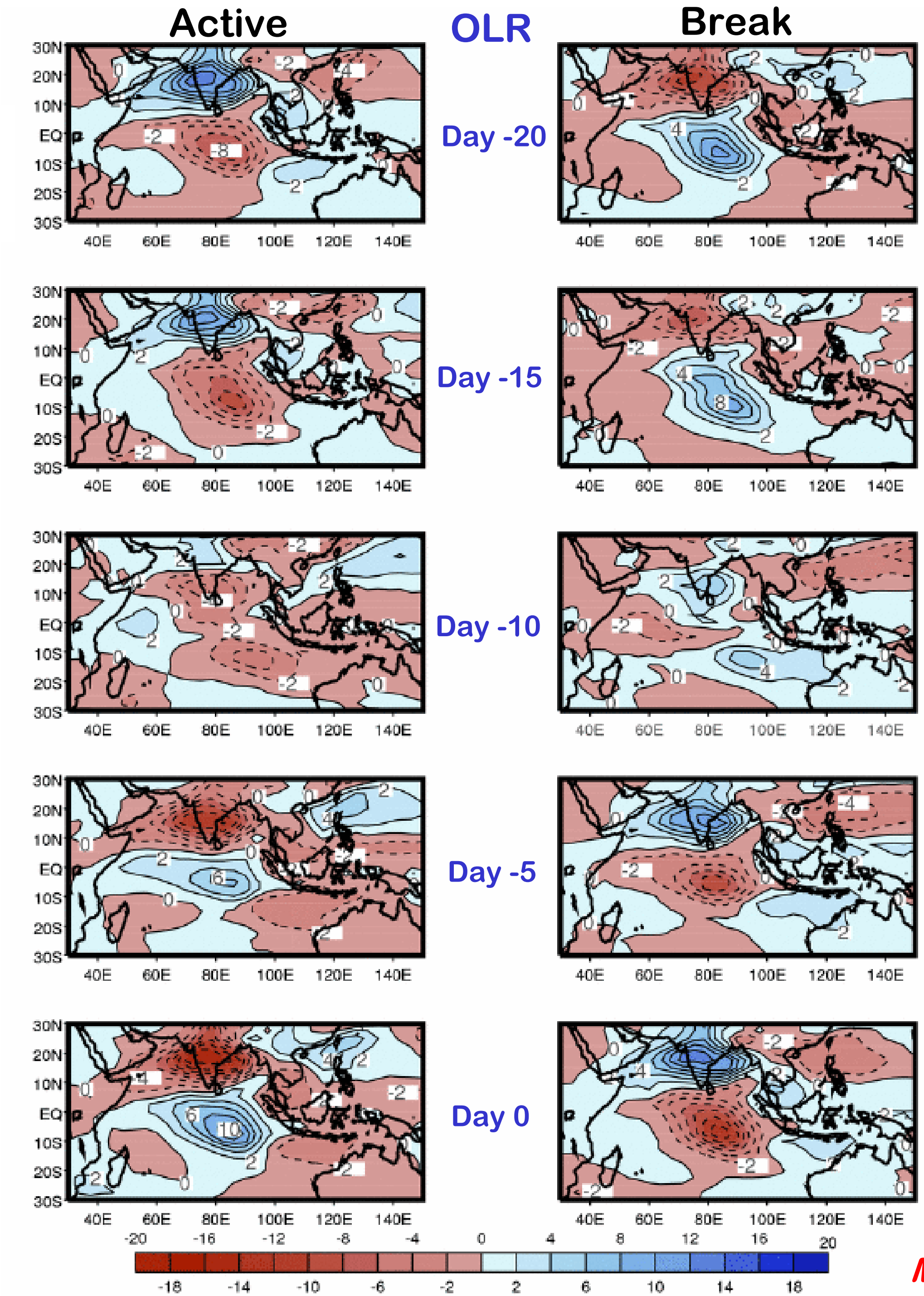
- Westerly wind event associated with the passage of the MJO produces downwelling ocean Kelvin waves and positive SSH anomalies in eastern Indian Ocean.
- Kelvin wave activity subsequently propagates north and south along coasts.



July 2002 Monsoon Break: Equatorial Indian Ocean Temperature Anomalies

- **Build up of heat in Eastern Indian Ocean through oceanic response to westerly wind anomalies associated with the MJO.**
- **Accumulation of heat in Eastern Indian Ocean acts to prolong monsoon break conditions?**

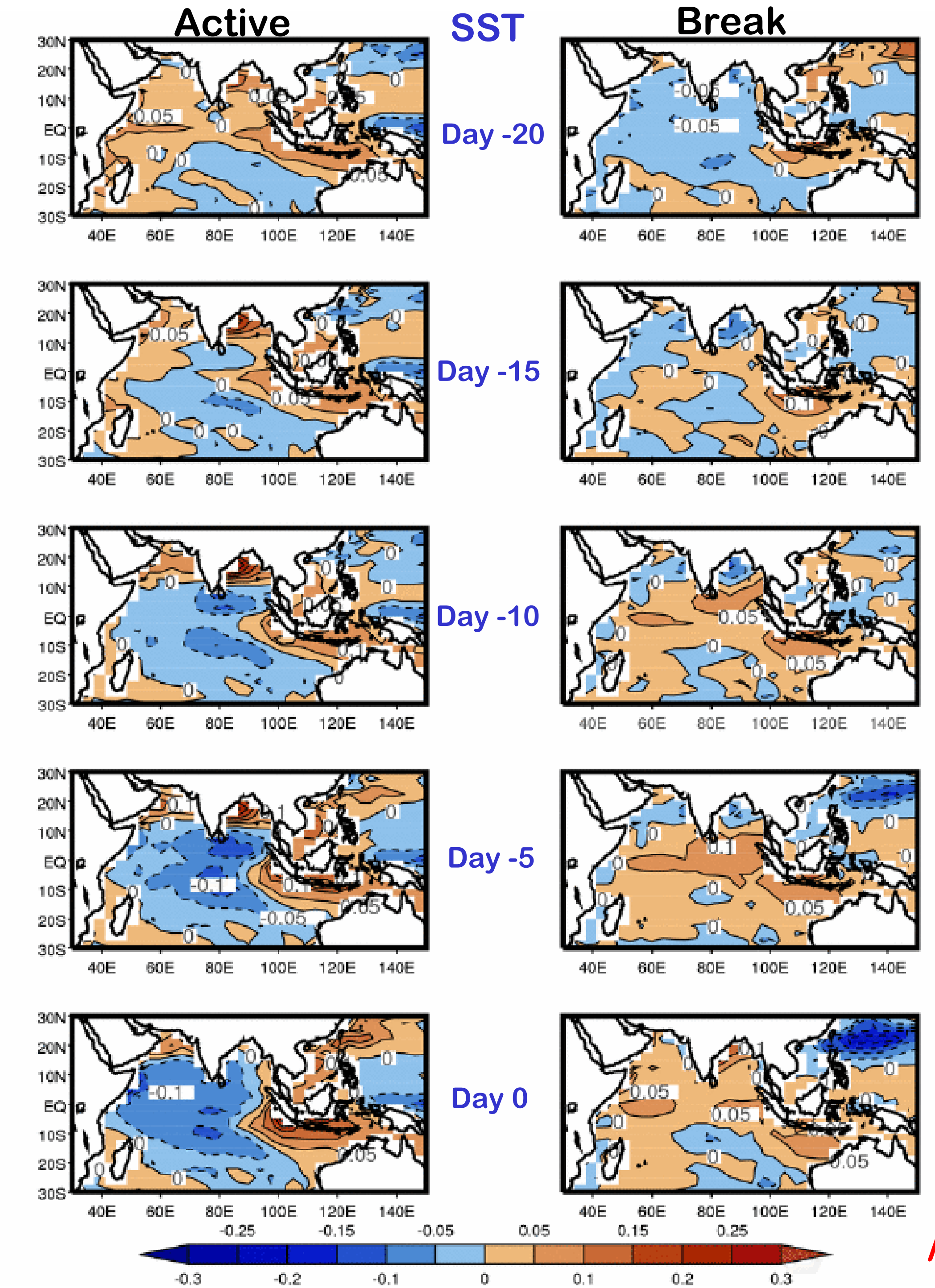
Krishnan et al. GRL 2006



Analysis of Active-Break cycles in 100-year HadCM3 and the role of the Indian Ocean

- Composite evolution of active and break cycles defined in terms of OLR dipole index (Vecchi)
- Observed quadrapole structure of convective anomalies is reasonably captured
- Model shows northward and eastward propagation of convective anomalies

Mohanty et al., in prep.



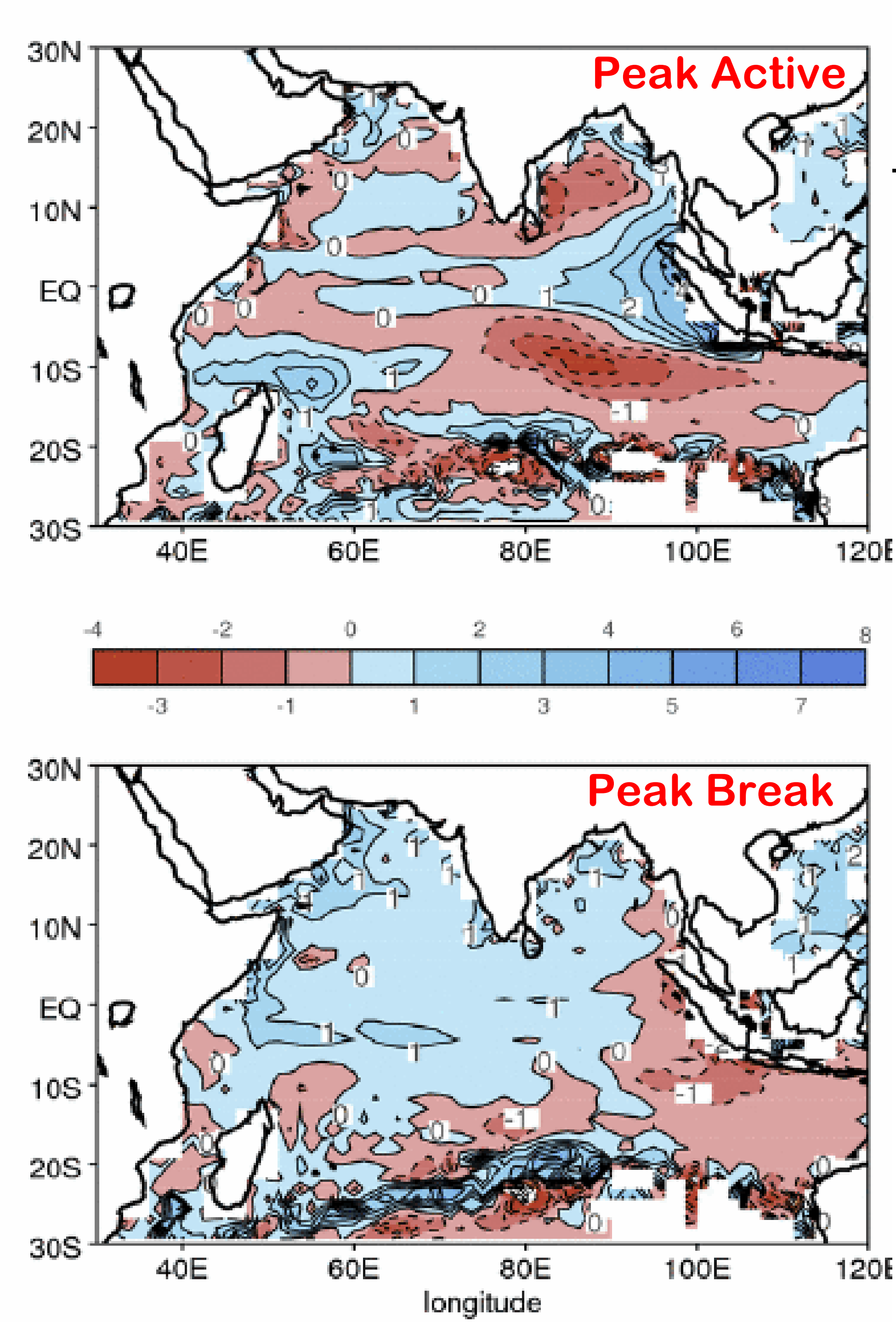
Analysis of Active-Break cycles in 100-year HadCM3 and the role of the Indian Ocean

- Composite evolution of SST anomalies associated with active and break cycles
- Active phases show coherent SST anomalies across the Indo-Pacific Warm Pool consistent with observations
- Break phases suggest that SST plays a less important role – at least in this model?

Mohanty et al., in prep.

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Walker INSTITUTE



Analysis of Active-Break cycles in 100-year HadCM3 and the role of the Indian Ocean

- Composite anomalies in the depth of the 20C isotherm for peak active (upper) and break (lower) phases
- Active phase suggests large dynamic adjustment of the equatorial ocean

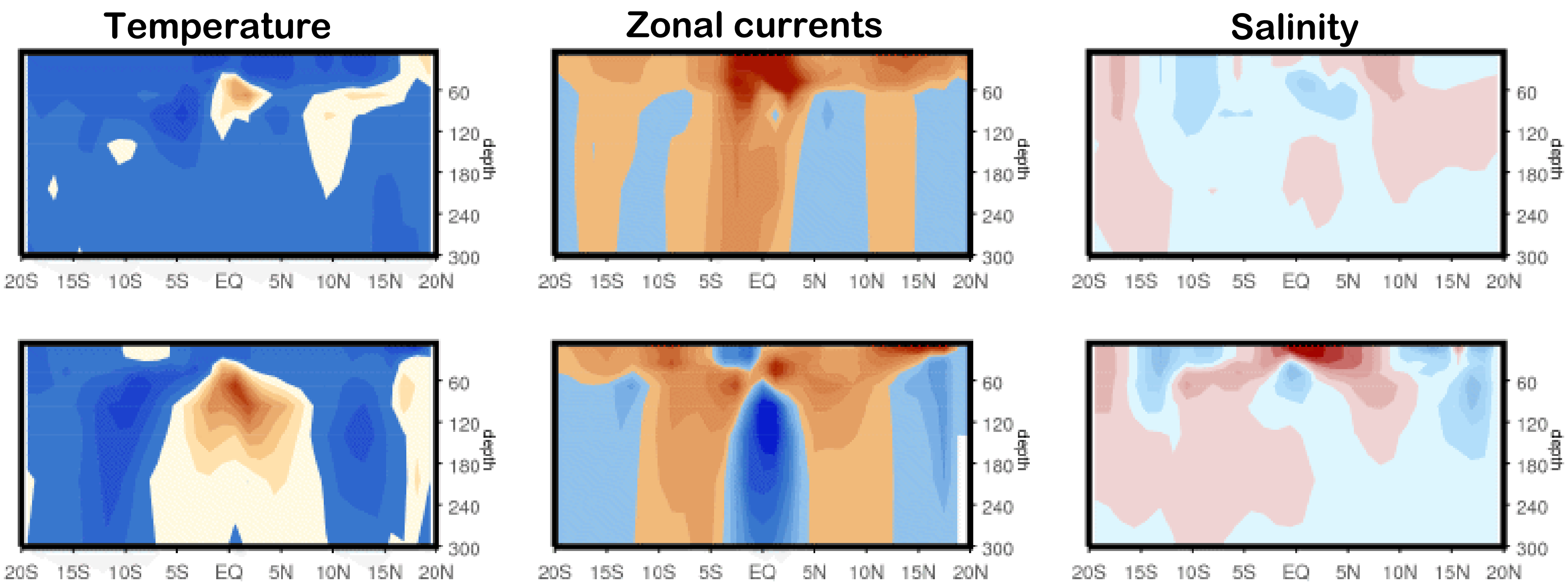
Mohanty et al., in prep.

Active-Break cycles in 100-year HadCM3: Role of the Indian Ocean

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Vertical profiles of the difference, Active minus Break, for the West and East Indian Ocean

West IO



East IO

Changes in mixed layer structure and dynamic adjustment of the ocean lead to differing responses in temperature and zonal currents

Walker INSTITUTE

Mohanty et al., in prep.

Summary: Ocean-Atmosphere Coupling and ISV

- Increasing evidence that upper ocean variability plays a key role in defining the propagation characteristics and amplitude of ISV.

- In many regions this is dominated by the thermodynamic response of the upper ocean, but there may be an important role for fast dynamical adjustment, especially in the Indian Ocean during the boreal summer.

- That being the case, coupled models require a much improved representation of the upper ocean.

- Future plans include a detailed analysis of the upper ocean behaviour in HiGEM with 1/3 degree ocean

Recent and future developments in UK Climate Models

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

	HadCM3 1998	HadGEM1 2004	HiGEM1 2006	NU-GEM 2007/8	HiGEM2 2009/10
Atmosphere	~300km 19 levels	~150km 38 levels	~90km 38 levels	~60km 38 levels	~40km 60-70 levels
Ocean	1.25^0 x 1.25^0 20 levels	1^0 x 1^0 ($1/3^0$) 40 levels	$1/3^0$ x $1/3^0$ 40 levels	$1/3^0$ x $1/3^0$ 40 levels	$1/4^0$ x $1/4^0$ 50+ levels
Integration Length	1000s IPCC AR3	100s IPCC AR4	100s	10s	Seasonal to Decadal Prediction
Relative Computing Power	1	10	100	Earth Simulator	HECToR Met Office

Met Office

HiGEM

日英気候共同研究
UK-Japan Climate Collaboration

Walker INSTITUTE

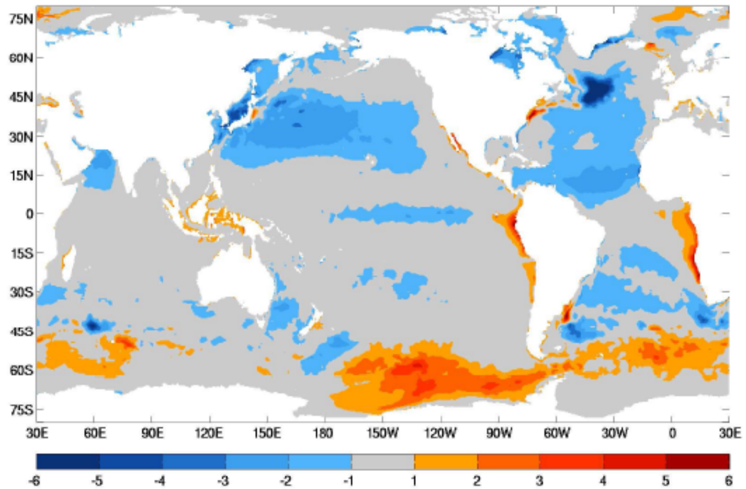
Resolution improves annual mean biases

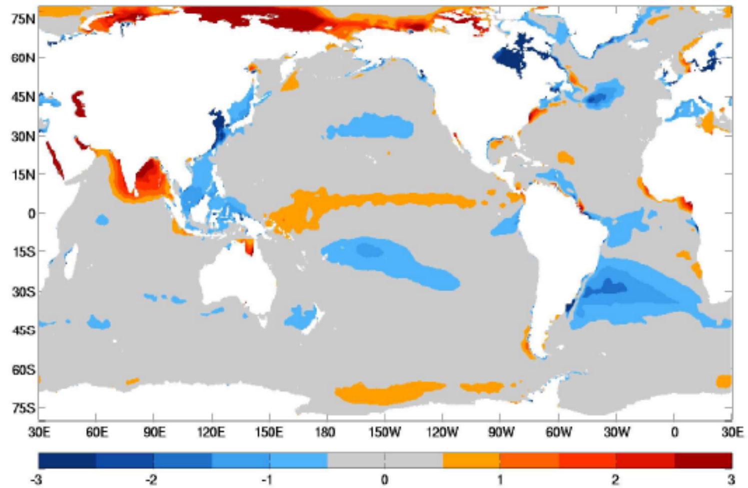
National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Sea Surface Temperature

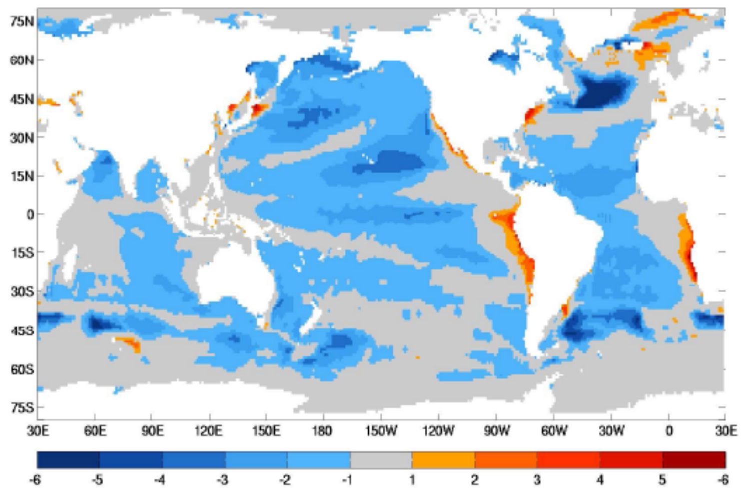
Sea Surface Salinity

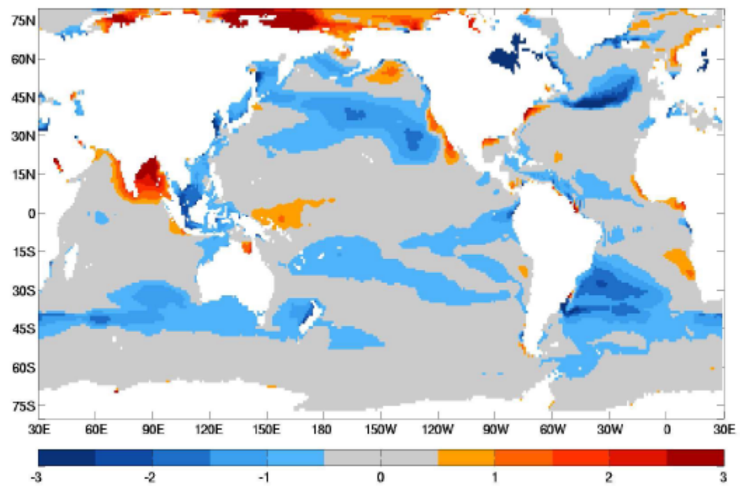
HiGEM



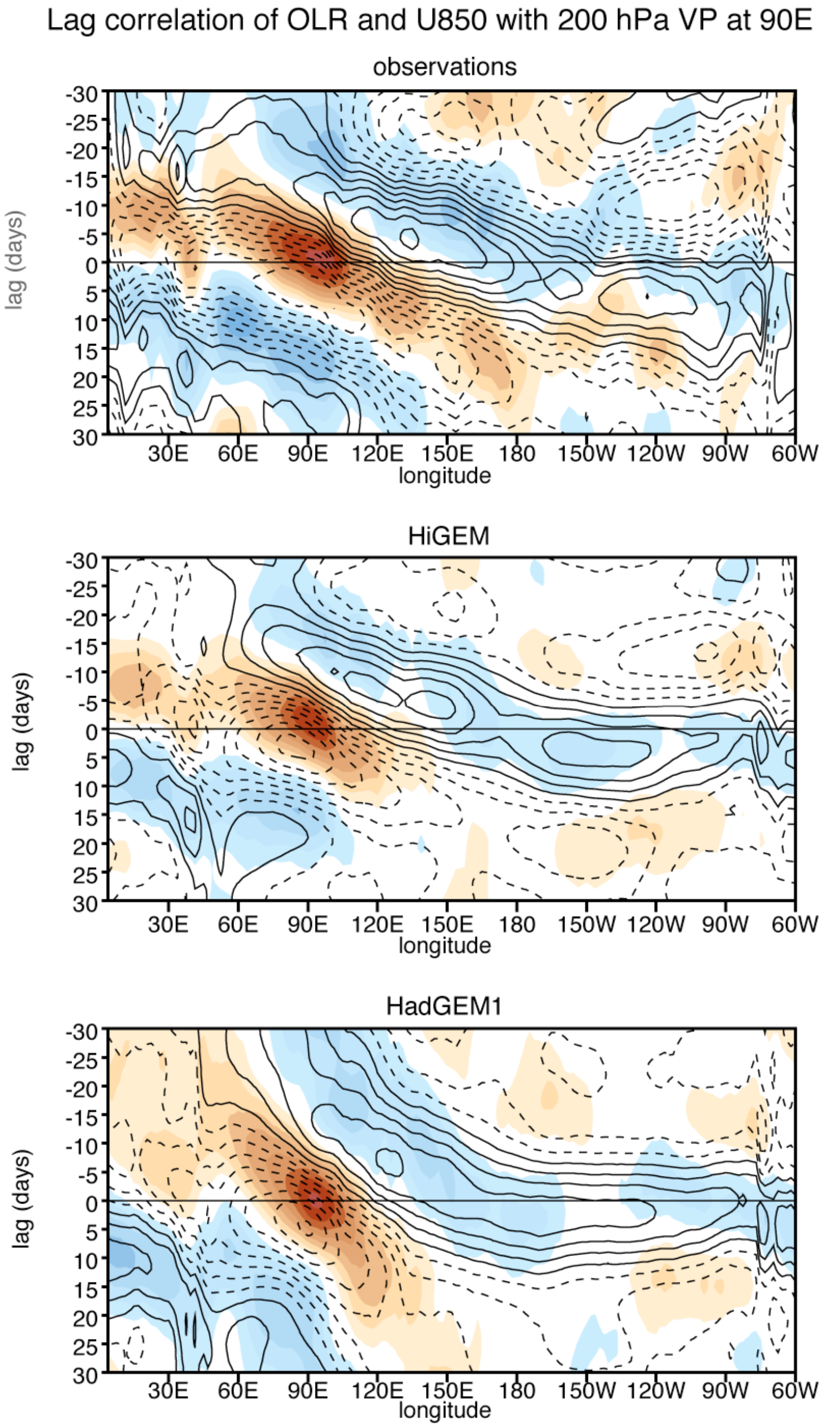


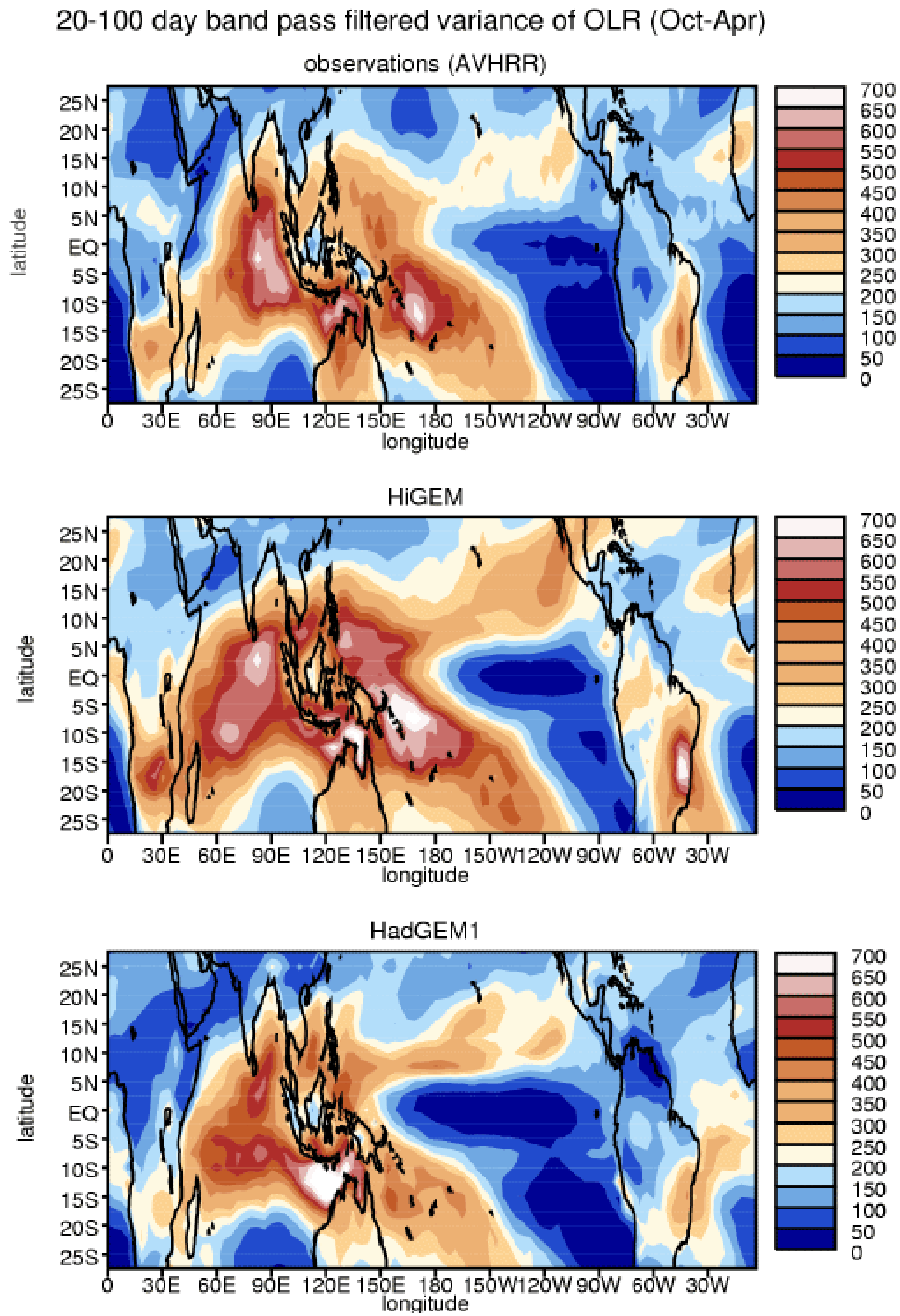
HadGEM





Walker INSTITUTE



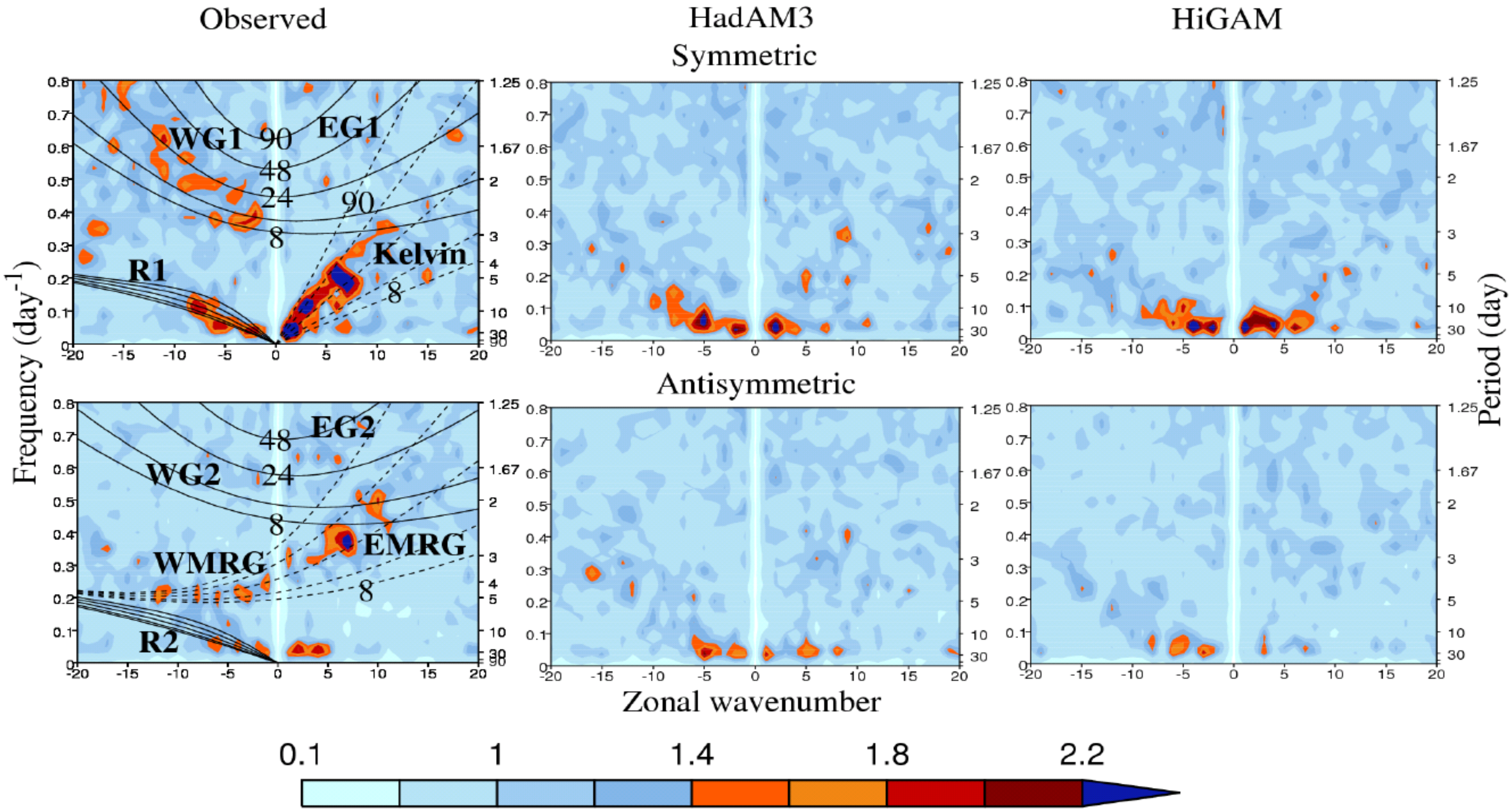


Courtesy of Pete Inness

Convectively Coupled Equatorial Waves

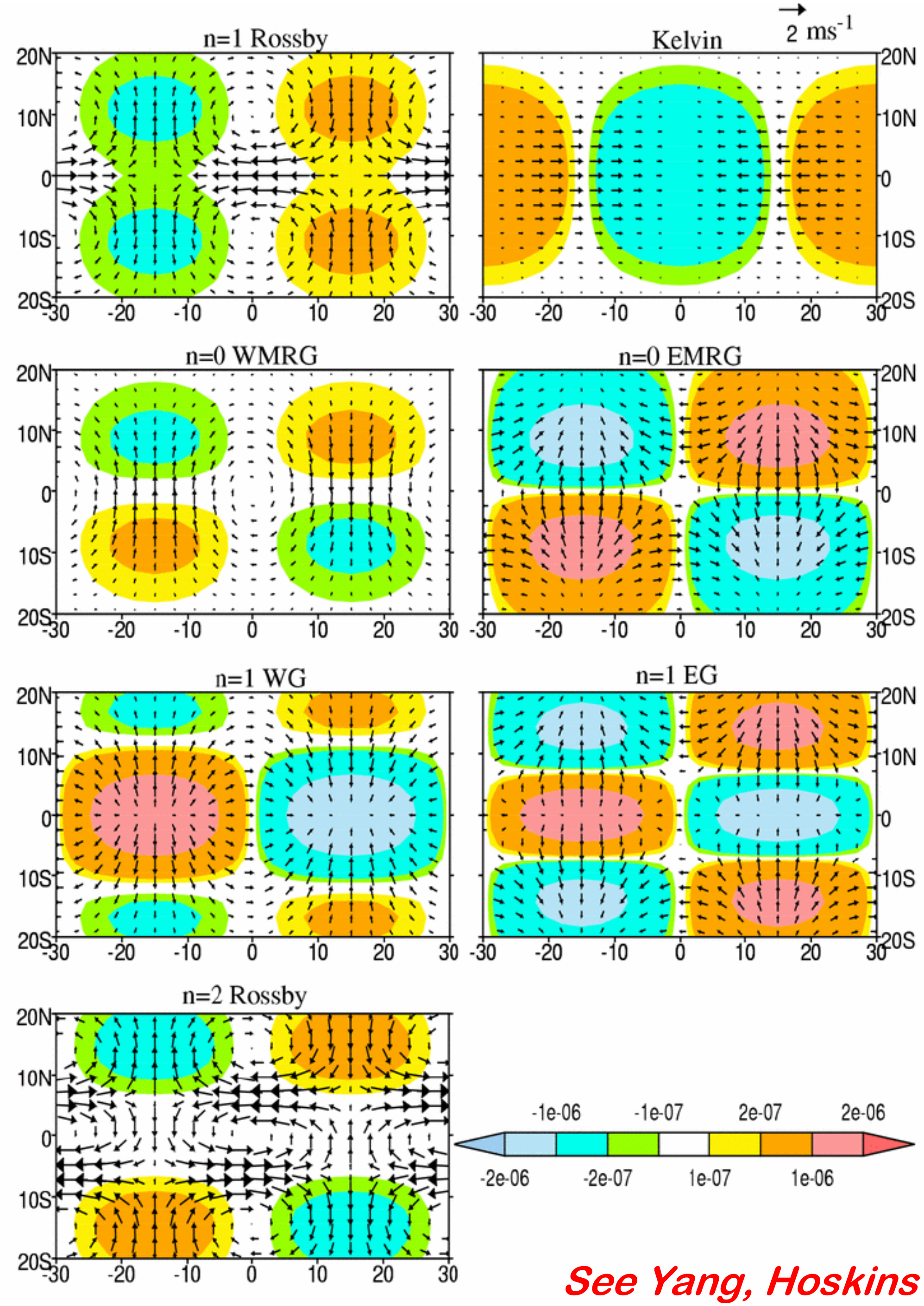
National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Space-time spectra for summer of 1992



Model resolution: N144 (~100km)

Yang, Slingo and Hoskins, Submitted to J. Clim.



Convectively coupled equatorial waves

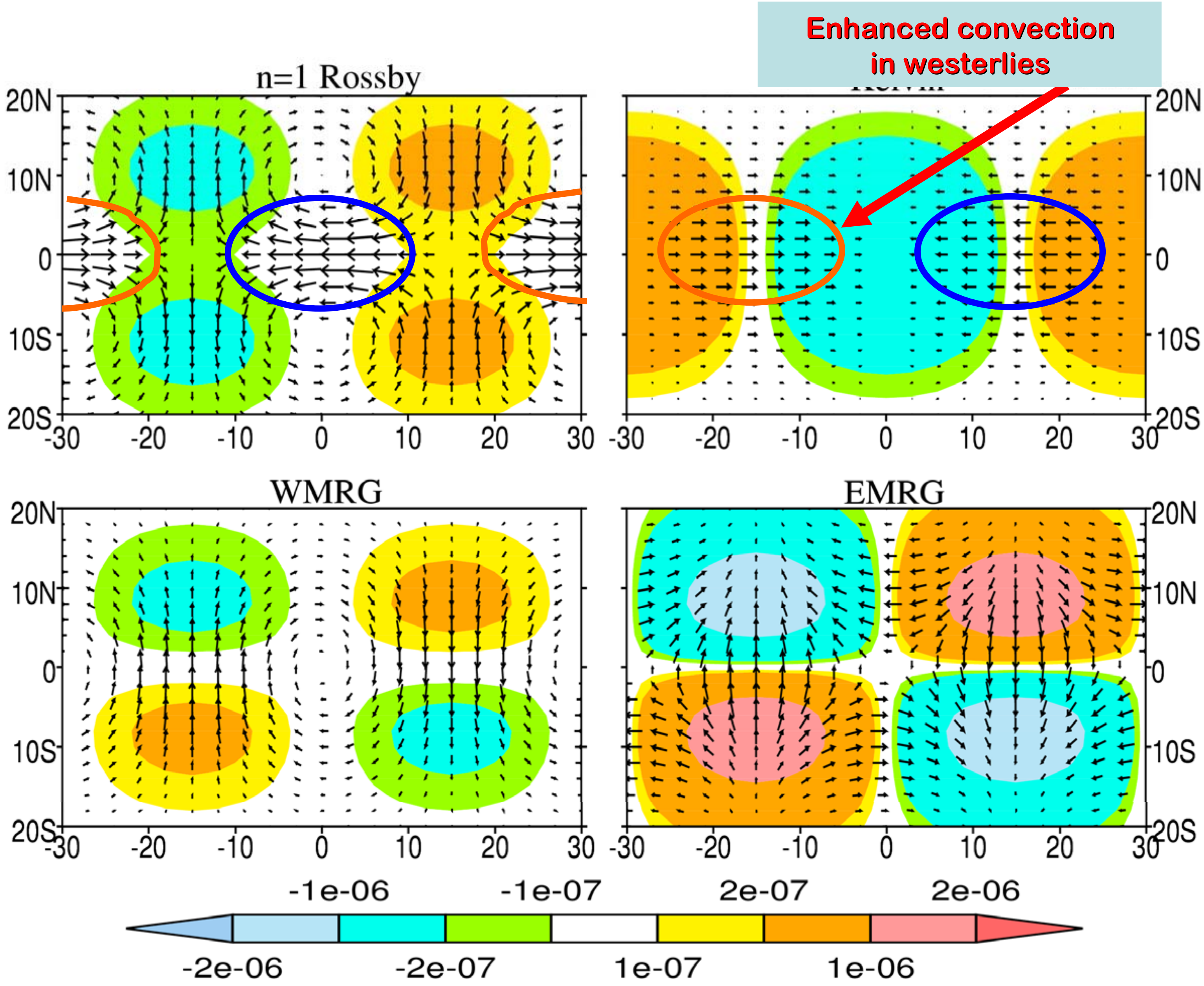
Wind/divergence solutions of theoretical equatorial wave equation on a b-plane, after Matsuno (1966).

Spatial scale assumes zonal wave no. 6 and meridional trapping (y_0) of 6^0.

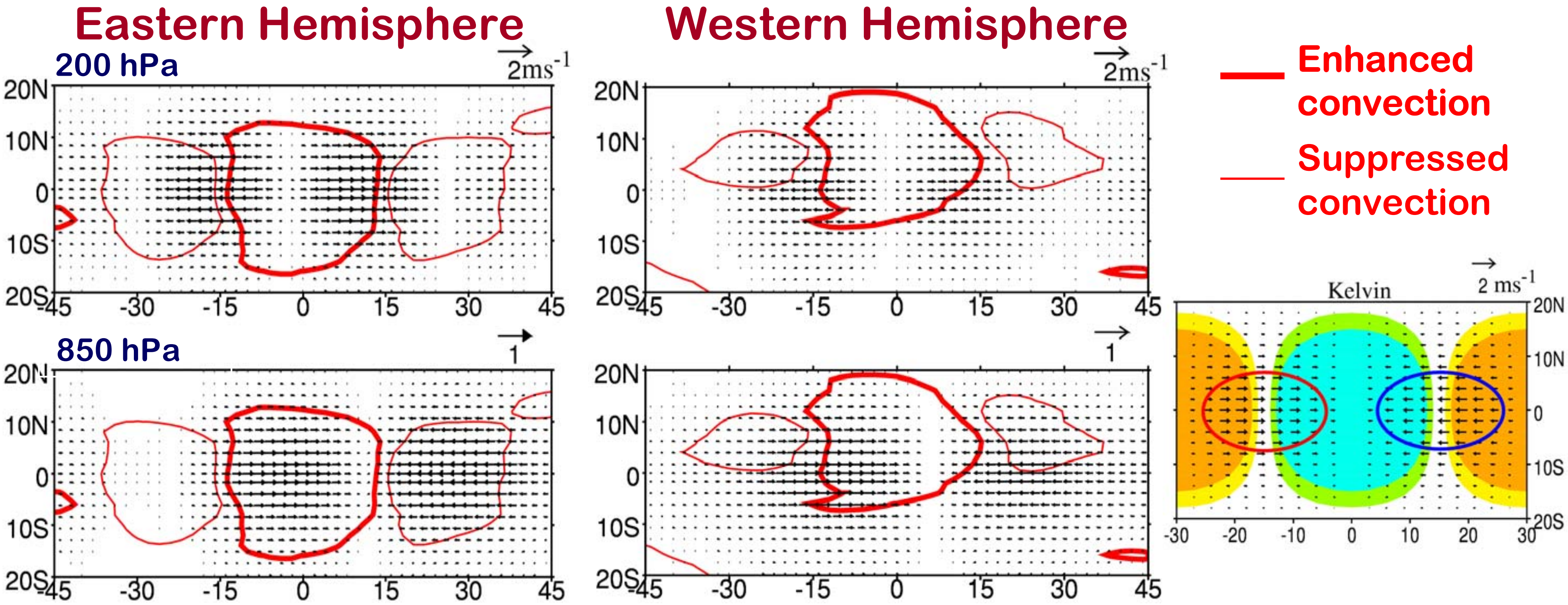
If winds represent lower tropospheric flow, then green/blue shading corresponds to regions of convection.

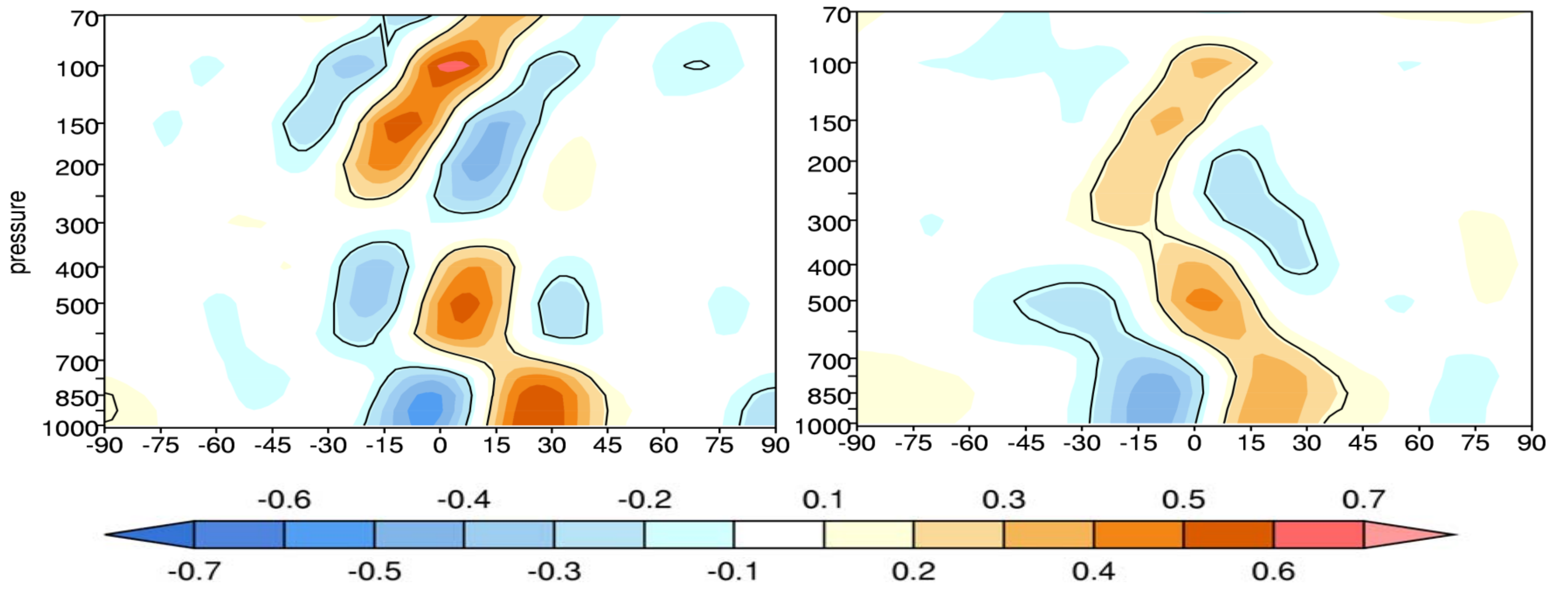
See Yang, Hoskins & Slingo, 2003, 2007a,b,c: J. Atmos. Sci.

WISHE working in equatorial waves?



Kelvin wave and T_b field regressed on equatorial T_b

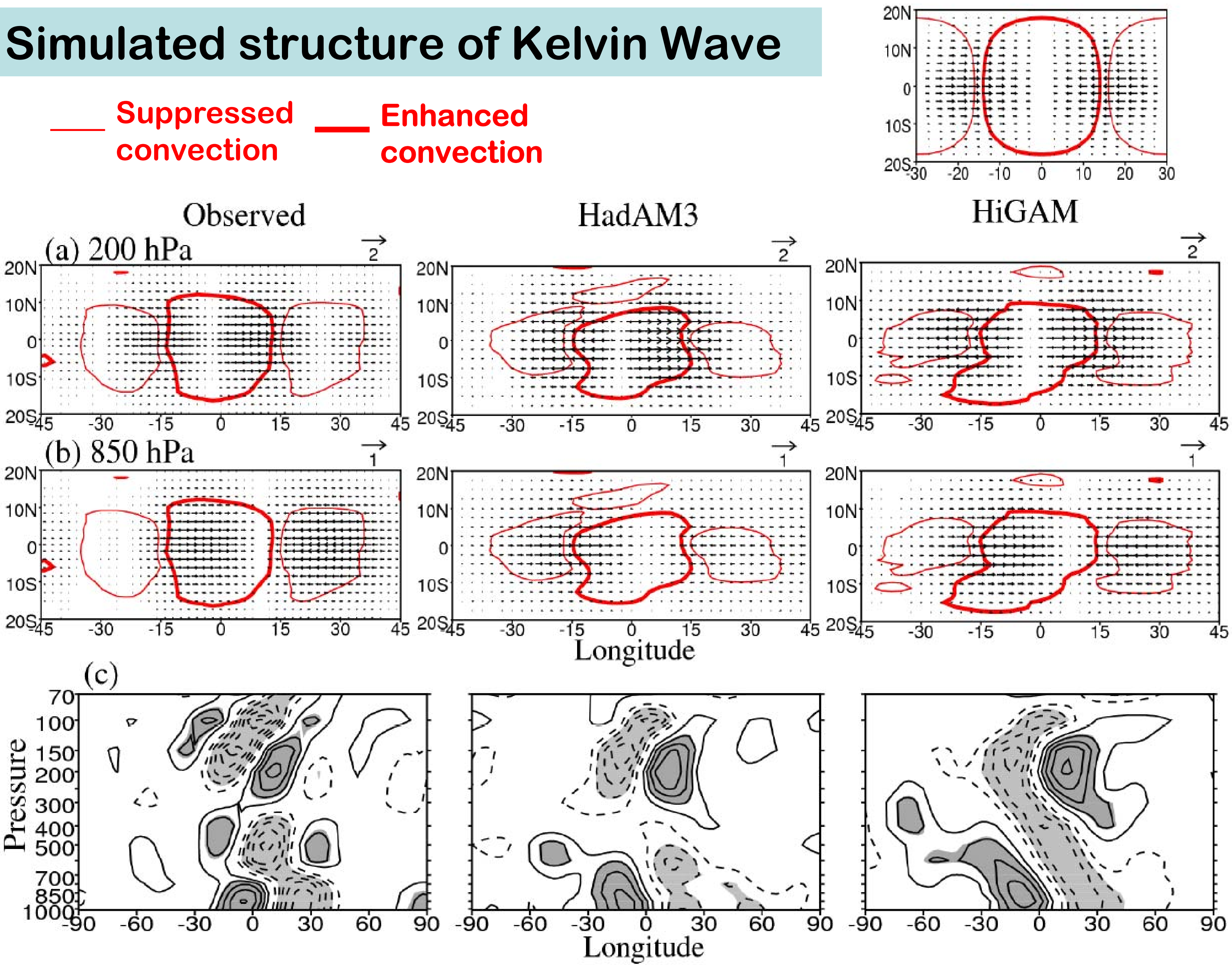




Correlation between equatorial brightness temperature, T_b and zonal wind, u

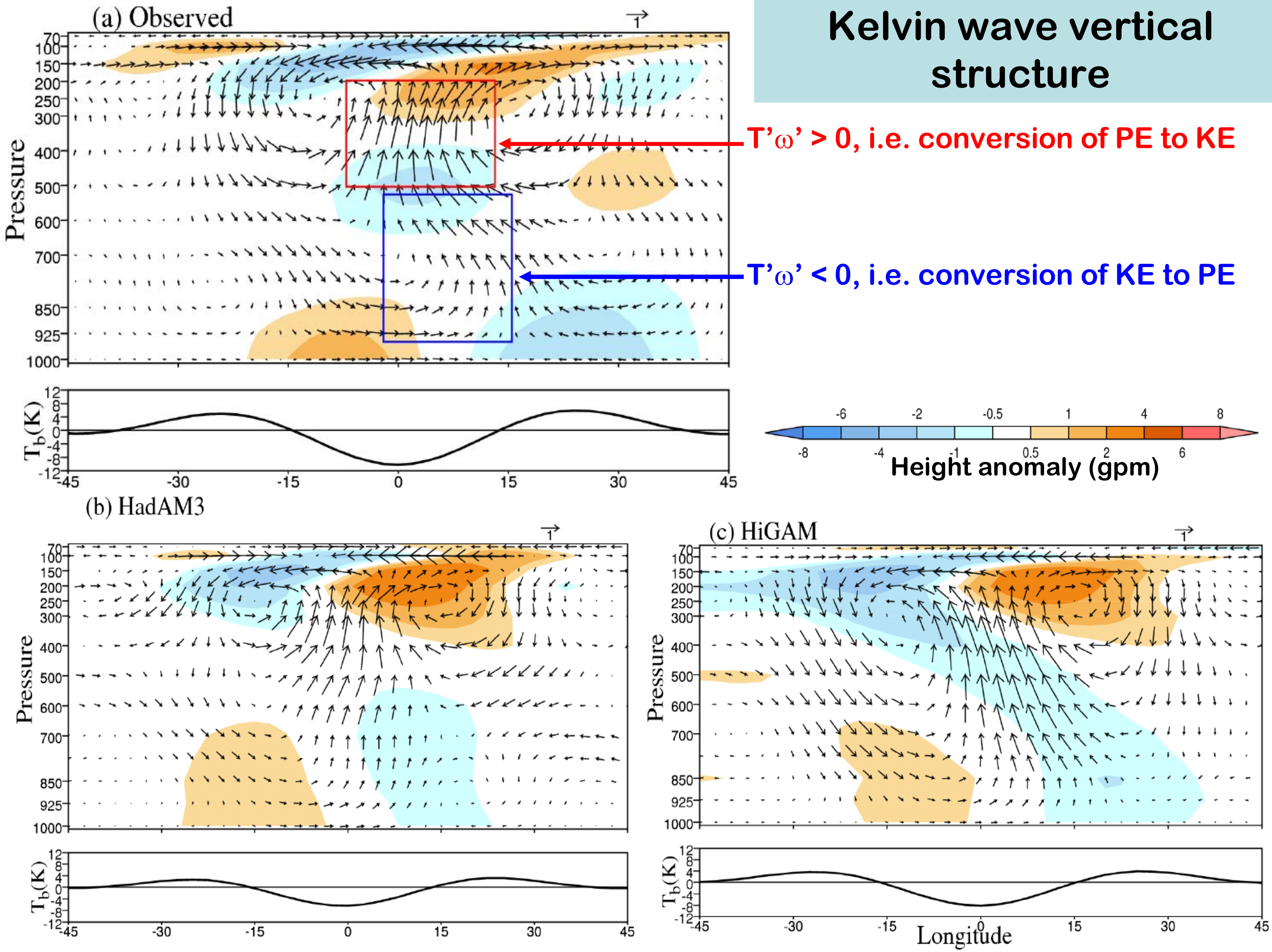
Simulated structure of Kelvin Wave

Suppressed convection — Enhanced convection



Yang, Slingo and Hoskins, Submitted to J. Clim.

Kelvin wave vertical structure



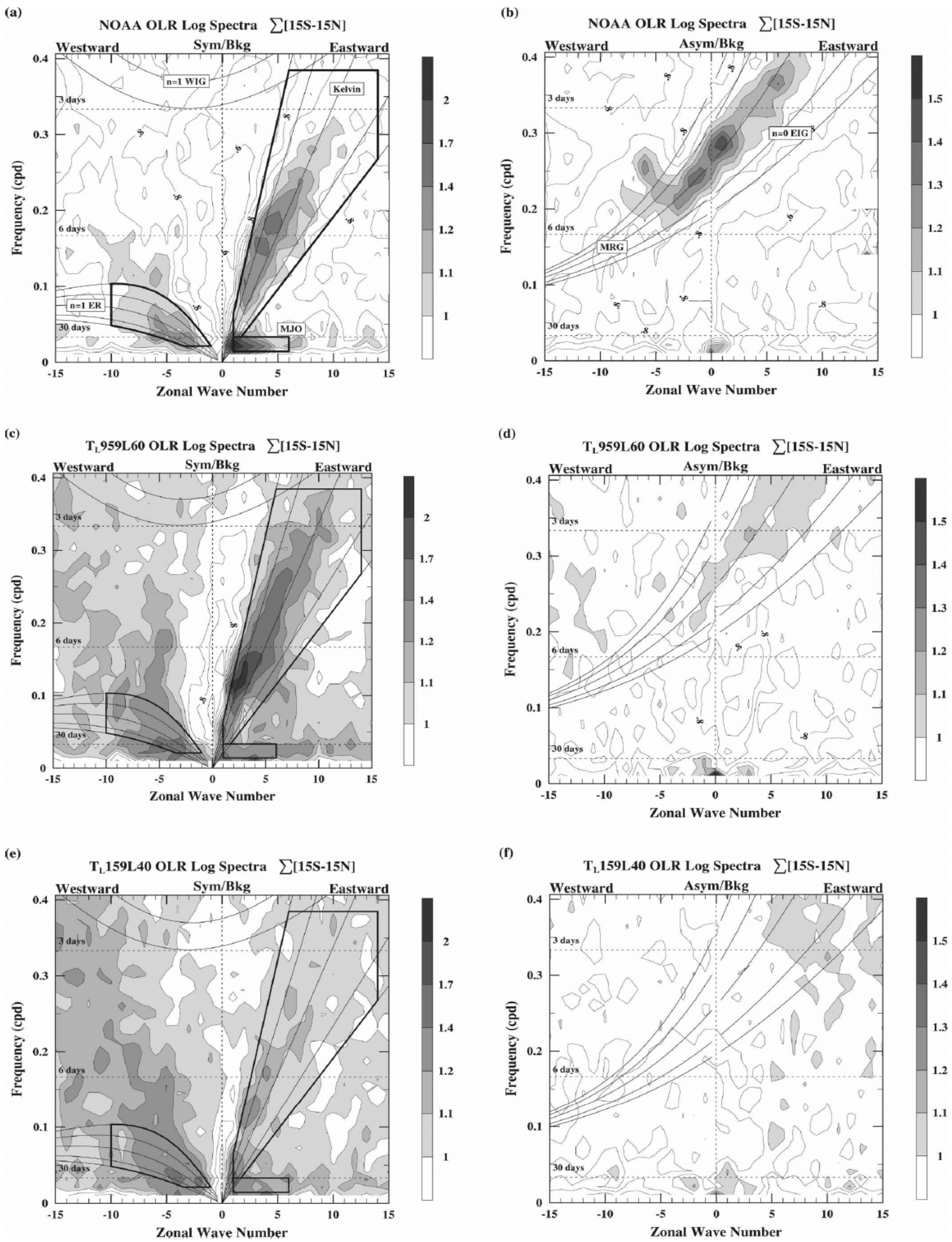
Summary of modelled equatorial waves

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

- Dynamical equatorial waves are simulated but the coupling of these waves with convection tends to be weak, especially in the vicinity of the equator.
- Model fails to capture the positive feedback between equatorial zonal winds and convection in the Kelvin (and R1) wave. Suggests lack of WISHE mechanism in model?
- Poor vertical structure of the simulated Kelvin wave indicates that the observed energy cycle, in which the upper tropospheric wave is amplified by convection, is missing in the models.
- The next step is to pin down those aspects of the moist physics that contribute to the poor dynamical coupling and energy cycles in the model.

Walker INSTITUTE

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL



Simulations of CCEW and ISV in the MRI/JMA 20km AGCM

- Equatorial Kelvin Wave captured better at high resolution. Other waves are still poor
- MJO is not improved despite better Kelvin Wave activity

From Rajendran et al., J. Clim. 2008

Walker INSTITUTE

Cascade:
Cloud System Resolving Modelling of the Tropical Atmosphere

NCAS-Climate, Reading
Department of Meteorology, Reading
Environmental Systems Science Centre, Reading
School of Environmental Sciences, UEA
Institute of Atmospheric Science, Leeds
Met Office, Exeter

Cascade Workplan

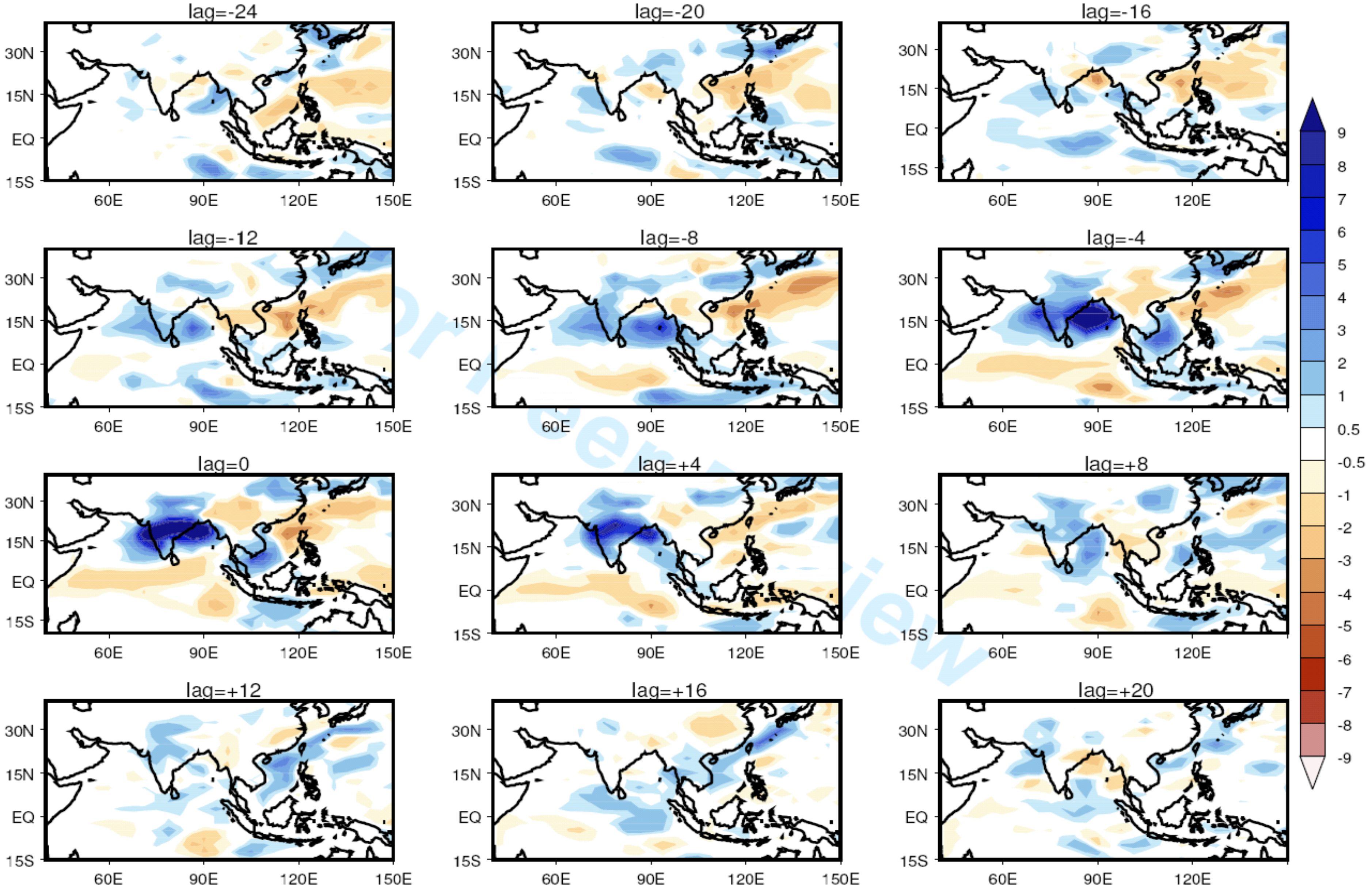
- Develop modelling framework for large domain (up to 100^0 longitude by 30^0 latitude), high resolution (1-2 km) simulations.
- Perform numerical case studies of organised convection over West Africa and the Indo-Pacific Warm Pool.
- Evaluate these simulations using advanced satellite and in situ observations of cloud structures.
- Analyse the simulations in terms of scale-dependent energy and momentum budgets.
- Use idealised case studies to explore the links between convection and equatorial wave modes.
- Bring this new understanding into the development of new representations of tropical convection for global weather and climate models.

Monsoon ISV and Climate Change

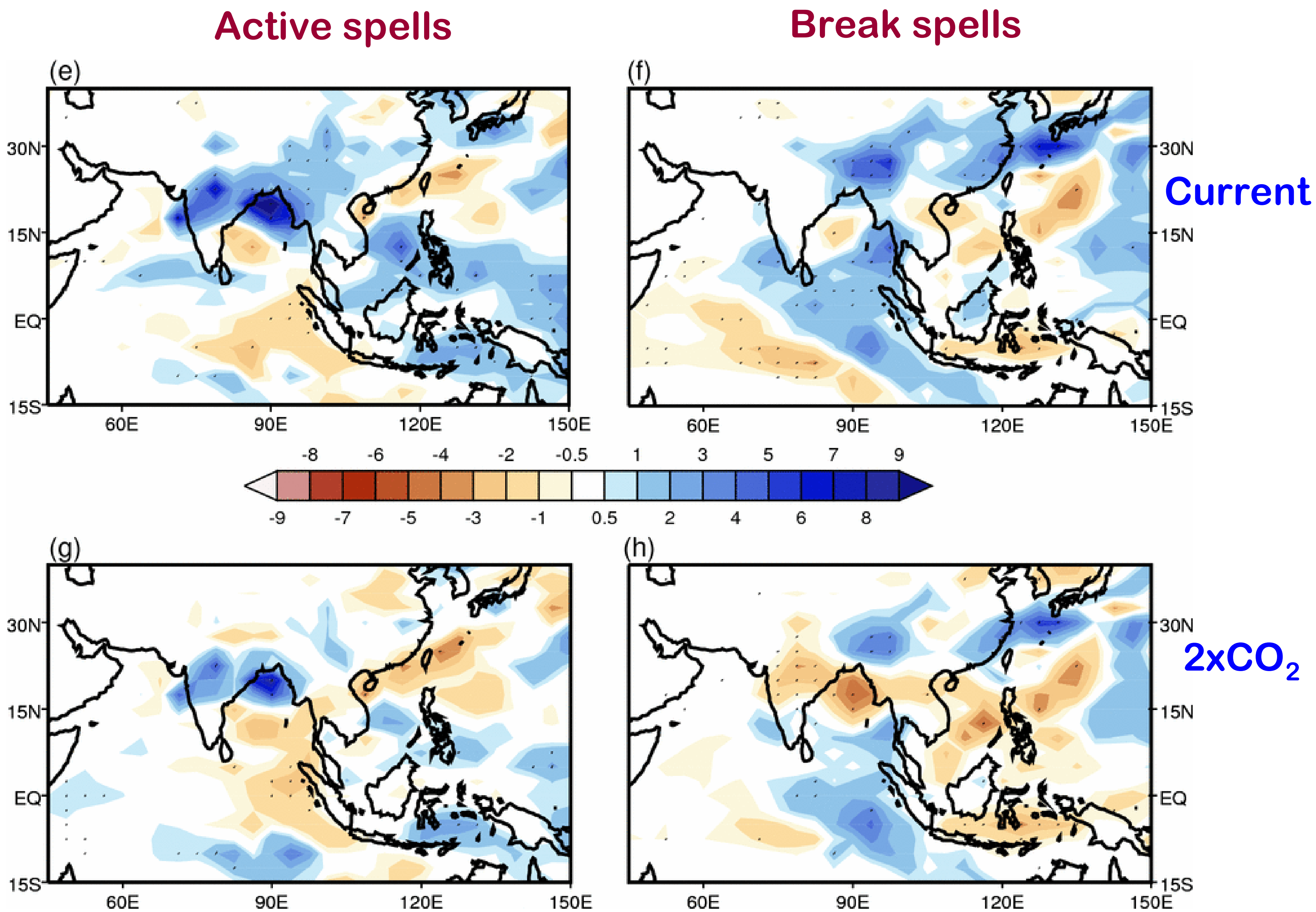
- Hadley Centre coupled model HadCM3:
  - Atmosphere 3.75° x 2.5° x 30 levels
  - Ocean 1.25° x 1.25° x 20 levels
- 100-year pre-industrial control integration
- 100-year (stable) 2xCO_2 integration

Composite evolution of active cycle of the ISM

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

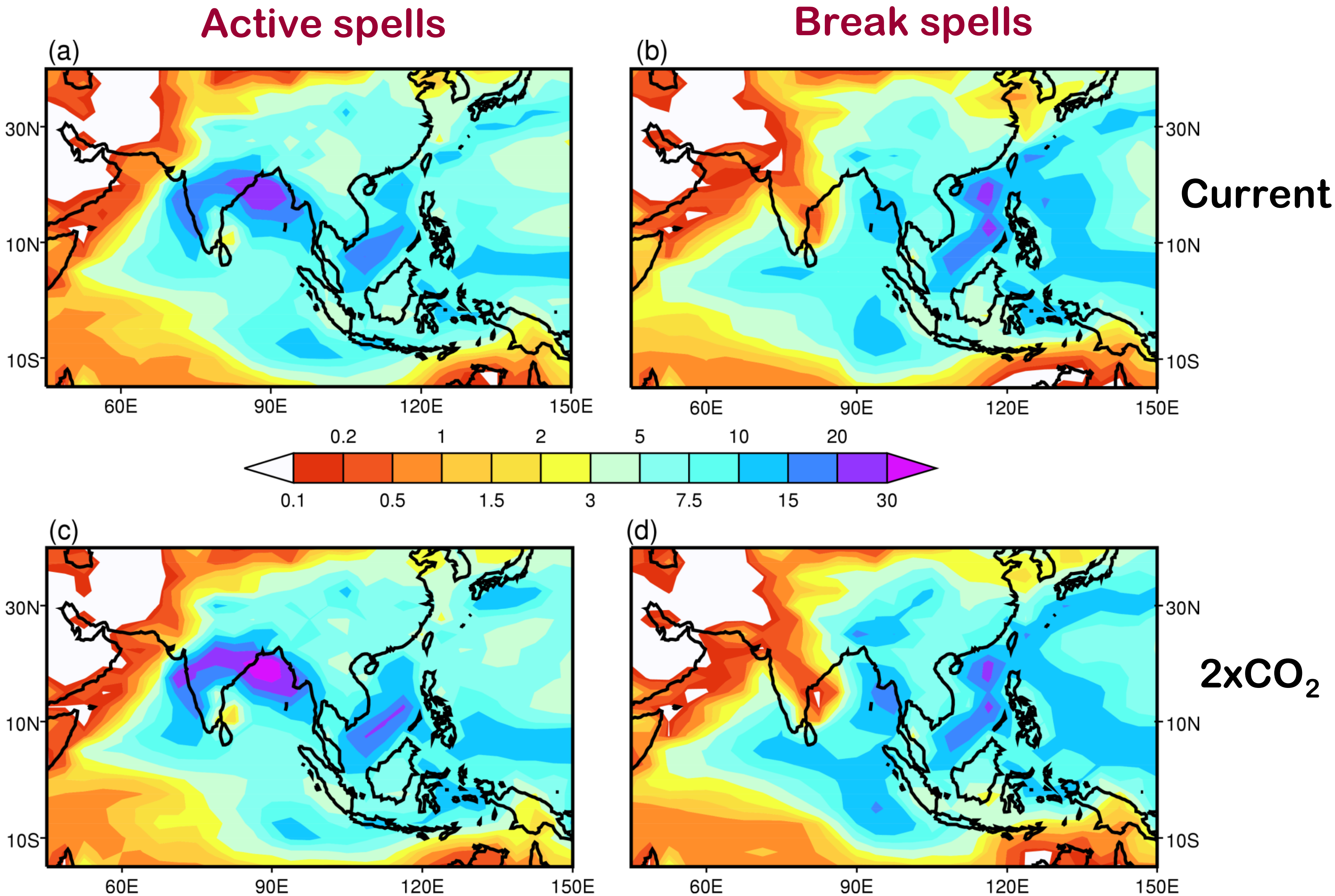


Rainfall Anomalies (mm/day) during active and break phases

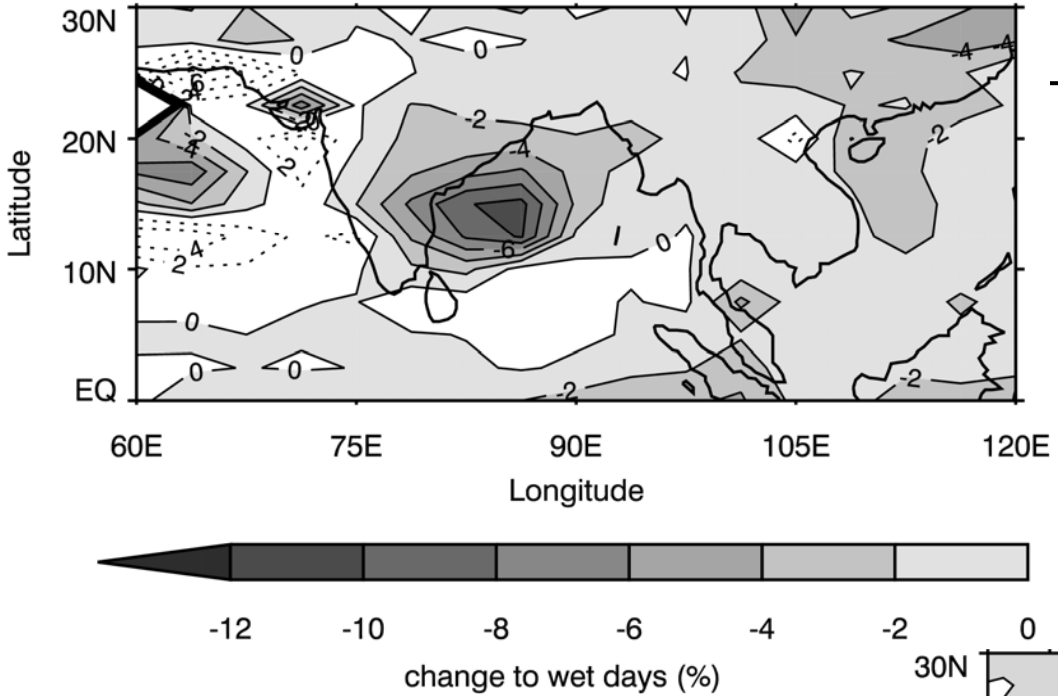


Turner & Slingo, QJRMS (Sub.) 2008

Absolute changes in rainfall during active and break phases

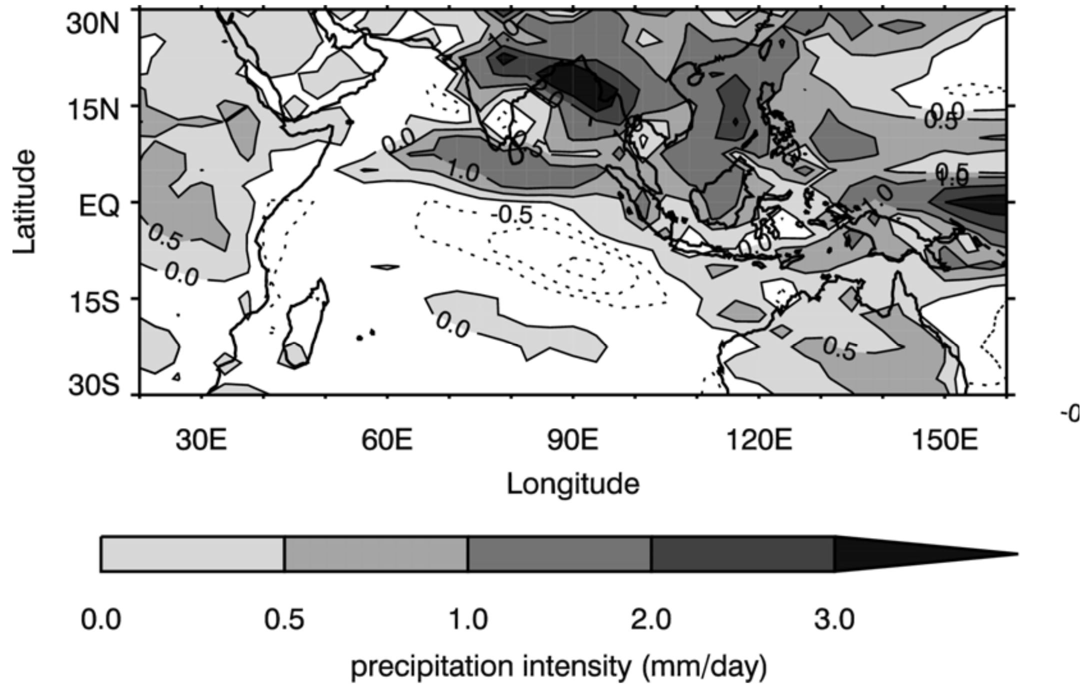


Monsoon breaks may become more severe – impacts on agriculture



Changing nature of Indian rainfall with climate change:

Impact of 2xCO2 on number of rain days and rainfall intensity

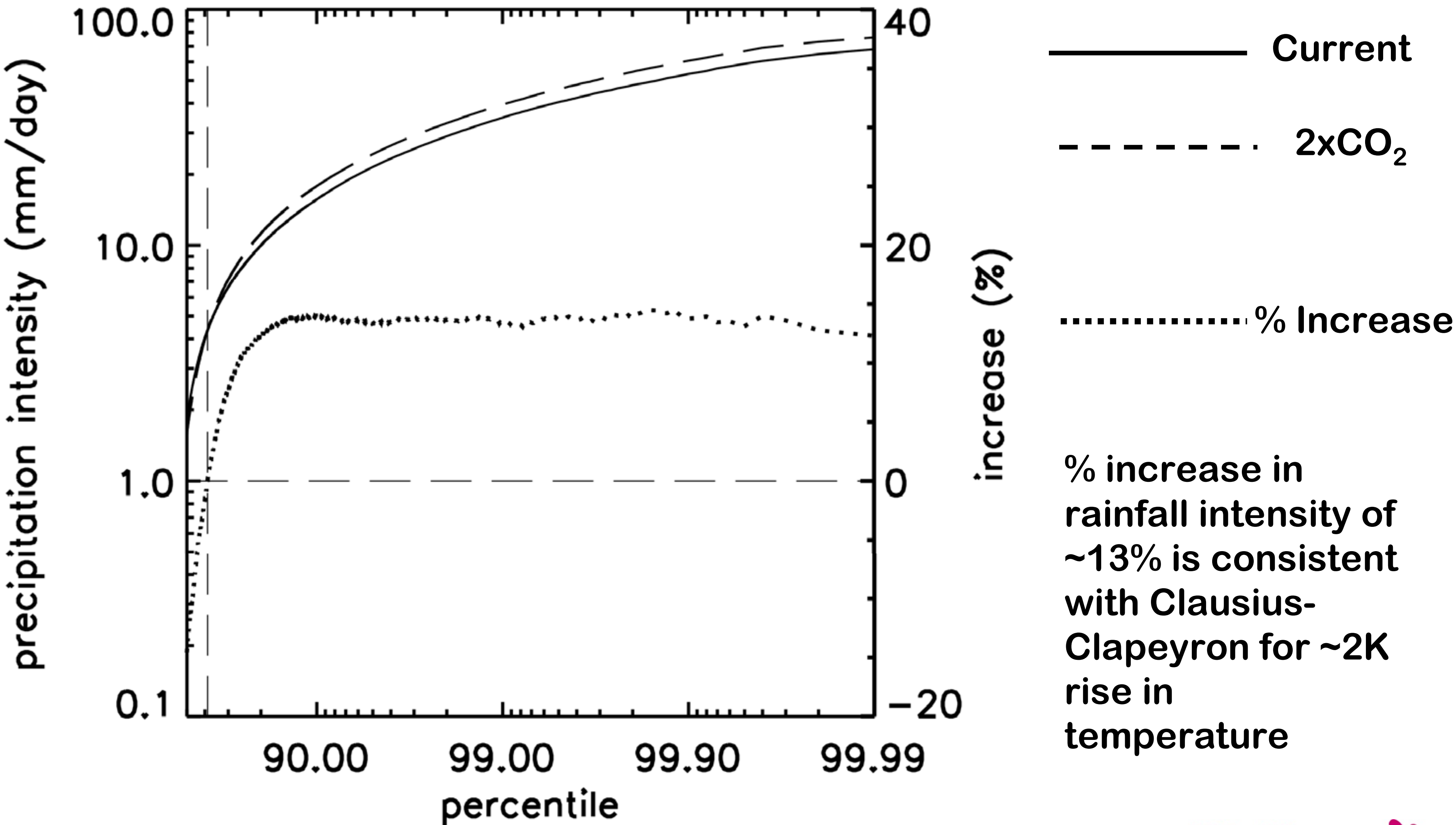


- **Decrease in number of rain days**
- **Increase in rain intensity on days when raining**

Turner & Slingo, QJRMS (Sub.) 2008

Changes in the intensity of extreme Indian daily rainfall with climate change

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL



1 in 10 1 in 100 1 in 1,000 1 in 10,000

% increase in rainfall intensity of ~13% is consistent with Clausius-Clapeyron for ~2K rise in temperature

Turner & Slingo, QJRMS (Sub.) 2008

Walker INSTITUTE

Concluding Remarks

- **New results suggest that climate change may increase the severity of monsoon breaks and the intensity of extreme rainfall events. Both have serious implications for the vulnerability of Indian society**

- **More skillful simulations and more confident predictions of ISV are urgently needed.**

- **What's needed for to achieve this goal:**

  - **Improved representation of the upper ocean to capture the thermodynamic coupling on intraseasonal timescales**

  - **Better understanding and simulation of the dynamic adjustment of the ocean to ISV**

  - **Probably higher resolution in both the atmosphere and ocean, especially if it improves the mean state.**

  - **Better understanding and simulation of the coupling between physics and dynamics in organised tropical convection**