Analysis and reduction of climate model systematic errors through a unified modelling strategy

Gill Martin and Sean Milton
Wilfran Moufouma-Okia and Richard Jones
Met Office, Exeter, UK

WGNE Workshop on Systematic Errors, 13th February 2007

Outline

- Techniques for resolving systematic errors
- Model development at the Met Office
- Examples of using a unified development strategy:
  - SST and ENSO
  - Asian summer monsoon
- Conclusions

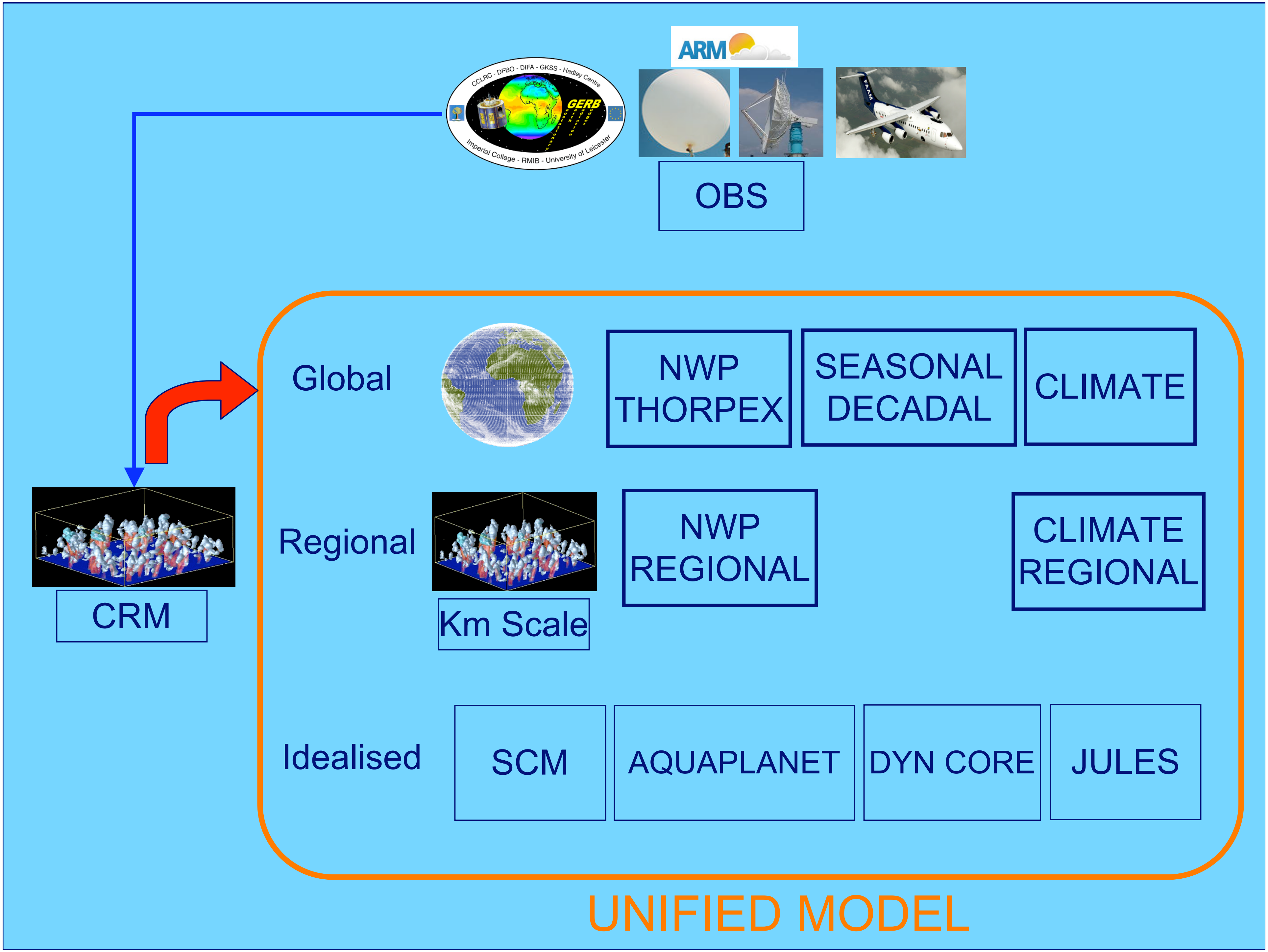
Techniques for resolving systematic errors

Various techniques are used in understanding and reducing climate model systematic errors:

- idealised models (single column model, aquaplanet, dynamical core)
- sensitivity tests designed to shed light on processes and investigate teleconnections
- “spin-up” tests to determine whether a systematic bias is the result of:
  - long-term feedbacks, e.g. through model drift
  - an immediate movement of the model away from the initial observed state and from which it does not recover.

Spin-up tests may suggest problems with a particular parametrisation scheme → potentially easier solution

Spin-up tests using climate models provide a parallel with numerical weather prediction (NWP) models


ARM
CCLRC - DFBO - DIFA - GKSS - Hadley Centre
GERB
Imperial College - RMIB - University of Leicester
OBS
Global
NWP
THORPEX
SEASONAL
DECADAL
CLIMATE
Regional
NWP
REGIONAL
CLIMATE
REGIONAL
CRM
Km Scale
Idealised
SCM
AQUAPLANET
DYN CORE
JULES
UNIFIED MODEL

Model development at the Met Office

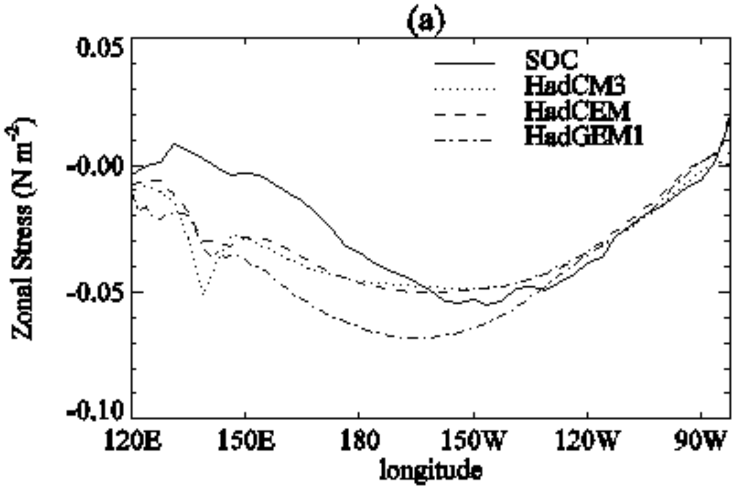
At the Met Office, the same model is used for both NWP and climate prediction. Each system brings a unique perspective to model development:

- NWP model
  - Higher resolution
  - Data assimilation
  - Direct comparison with observations
- Climate model
  - Shows how a parametrisation behaves in equilibrium and in combination with the rest of the model physics and dynamics
  - Coupled modelling: systematic errors in the atmosphere can feed back on the ocean

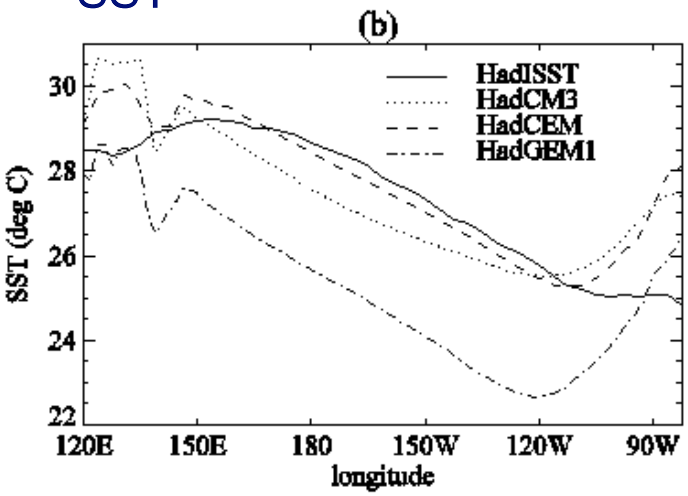
When systematic errors are shared between the daily forecast model and the climate model, a unified approach to model development is beneficial to both systems.

Improving simulation of SST and ENSO

Zonal surface wind stress



SST



- HadGEM1 exhibits a marked cold bias in the equatorial Pacific.
- This is linked to an easterly bias in the climatological trade winds
- Niño-3 SST variability is 0.69 K in HadGEM1 vs 0.80 K in the HadISST dataset.
- The eastward shift of convection during El Nino winters is not captured by HadGEM1
- There is no evidence of a collapse of the Walker circulation in the zonal winds.
- This lack of response is likely to be associated with overly weak SST variability and the cold bias in the tropical Pacific.

Spin-up tests

Climate:

- 52-member ensemble of 5-day runs
- 1.875 x 1.25 deg resolution, L38
- Initialised from weekly ECMWF analyses spread through season (JJA or DJF)

NWP:

- Up to 90-member ensemble of 5-day forecasts
- 0.83 x 0.55 deg resolution, L38
- Initialised from UM analyses including data assimilation

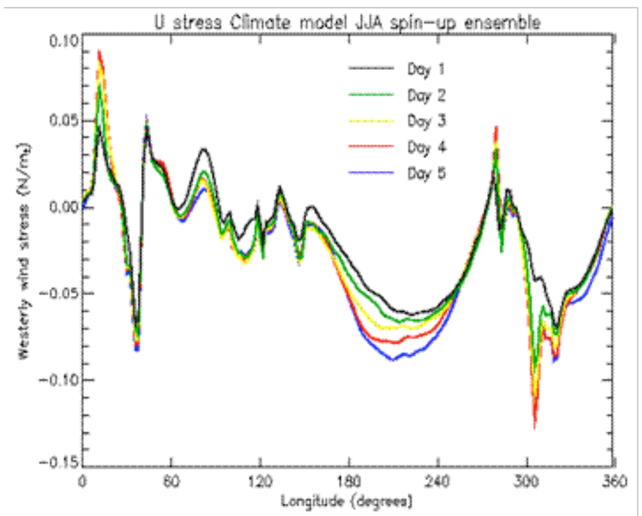
THORPEX:

- 10-member ensemble of 15-day forecasts
- 1.25 x 0.83 deg resolution
- Initialised from UM analyses including data assimilation

Spin-up of the error

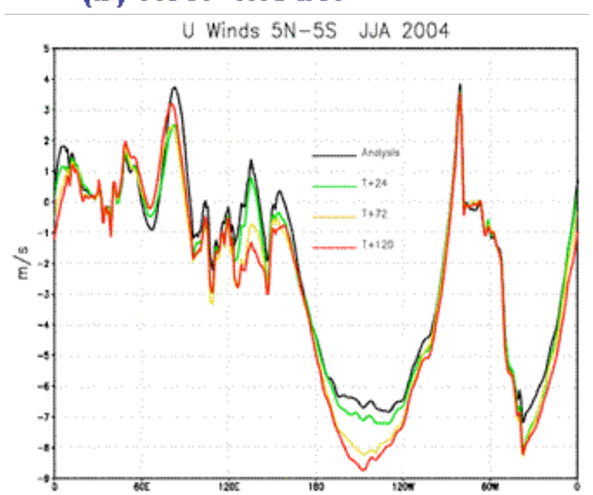
(a) Climate model

Zonal wind stress



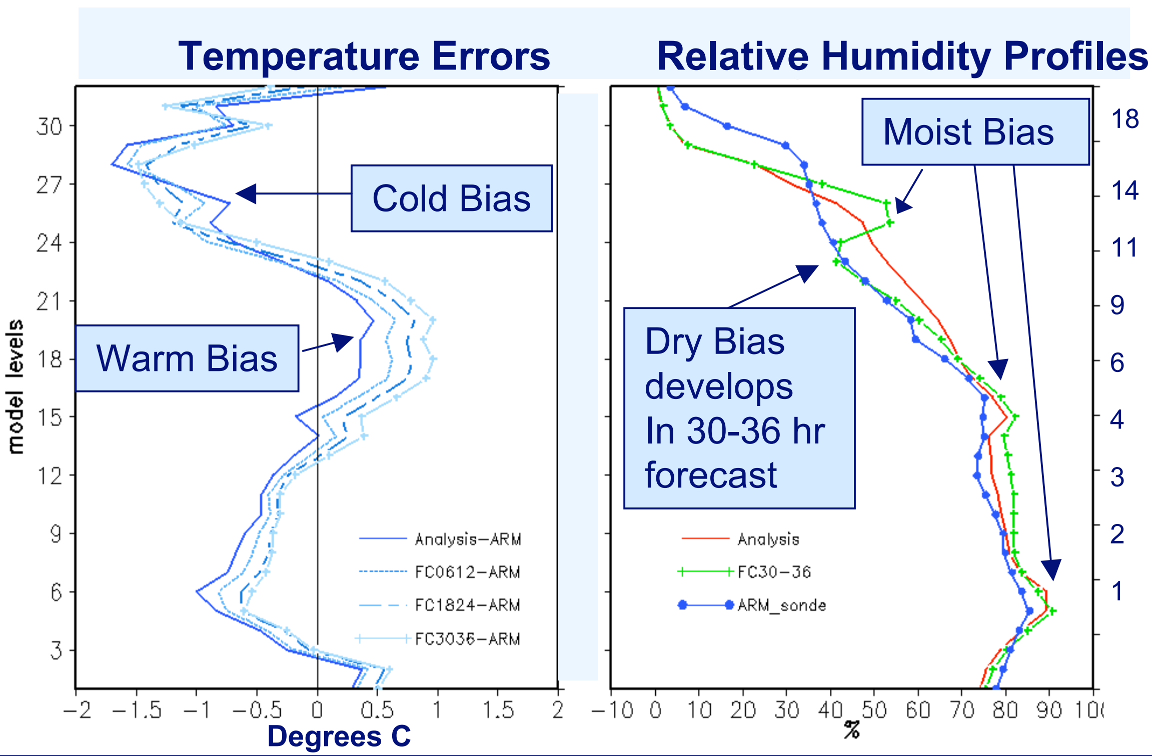
(b) NWP model

Zonal wind



- The increase in the low-level wind stress is seen in spin-up tests using the climate model and also in NWP tests.
- This suggests that this error occurs through an immediate response of the model parametrisations.
- The climatological results illustrate that the error then persists in equilibrium.

NWP spin-up verification (from Milton et al.)



Model vs. ARM Manus Is. Sonde - JAS 2003.

- Temperature and moisture biases evolve at upper levels
- Convection tends to terminate too low down
- Too much heat and moisture is detrained at once at the top of convection
- Suggests incorrect distribution of diabatic heating which could feed back on tropical circulation

Adaptive detrainment

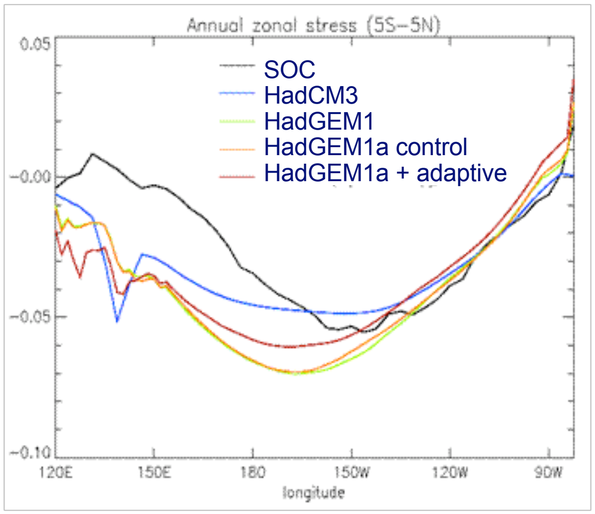
- An adaptive detrainment parametrisation has been developed which relates detrainment to the buoyancy excess of the parcel.
- This replaces the "forced detrainment" which only detrains when the buoyancy goes below a certain threshold (leading to step-changes in the mass-flux profile)
- Adaptive detrainment results in smoother mass-flux profiles more like those from CRMs.

Reference: Maidens, A.V. and S.H. Derbyshire, 2006: Improving mass flux profiles in the Gregory-Rowntree convection scheme using adaptive detrainment. *Submitted to Q.J. Royal Meteorol. Soc.*

Impact of adaptive detrainment on low-level wind and SST

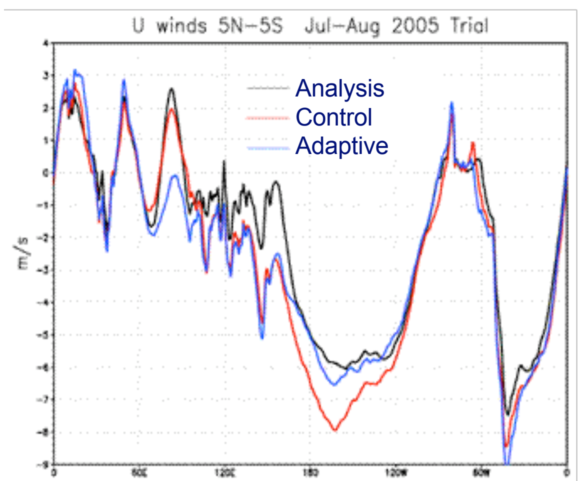
(b) Climate model

Zonal wind stress

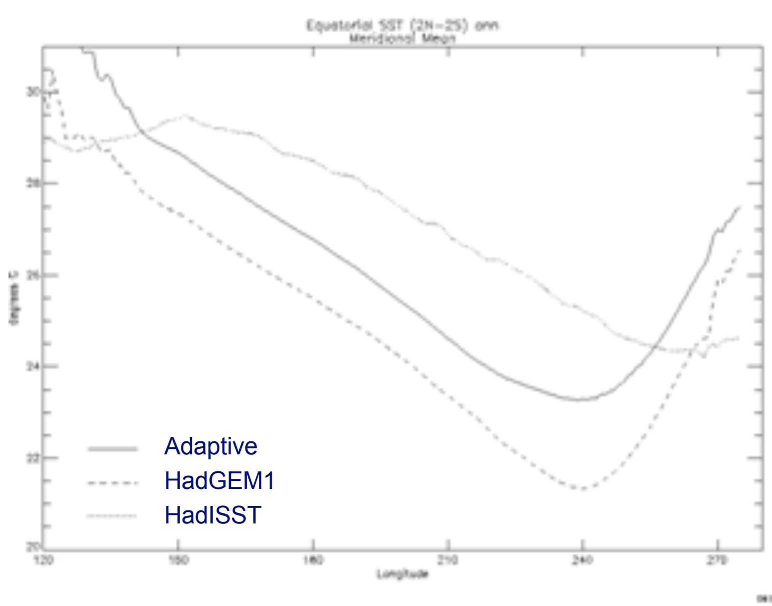


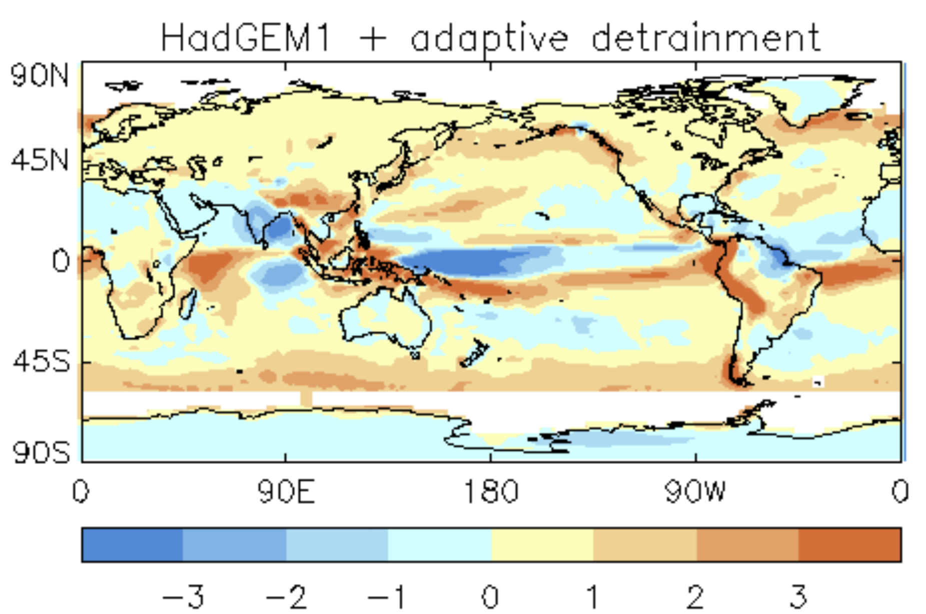
(a) NWP model

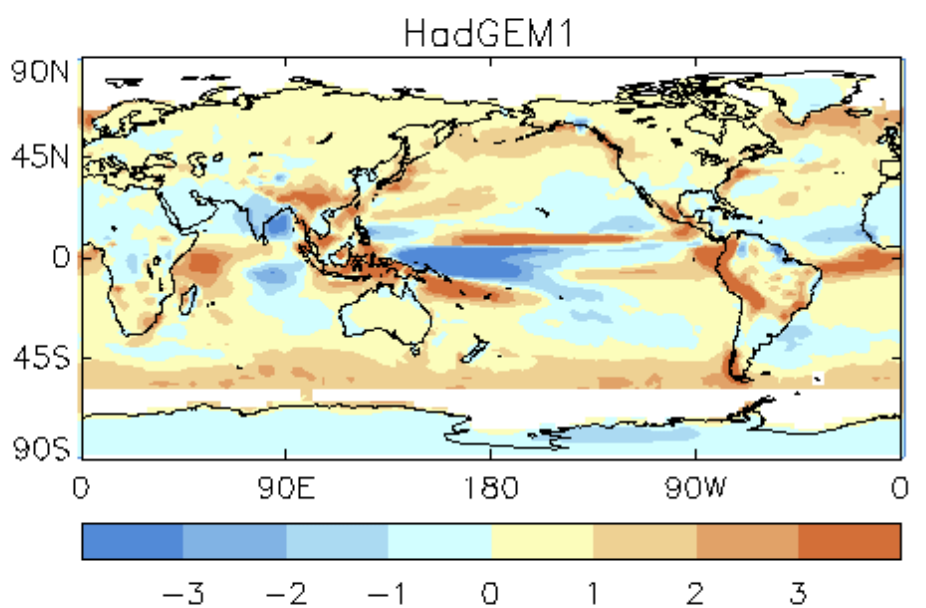
Zonal wind



- Tests of adaptive detrainment in NWP and climate models show reduced low-level wind biases
- There is a corresponding improvement in the Pacific cold SST bias



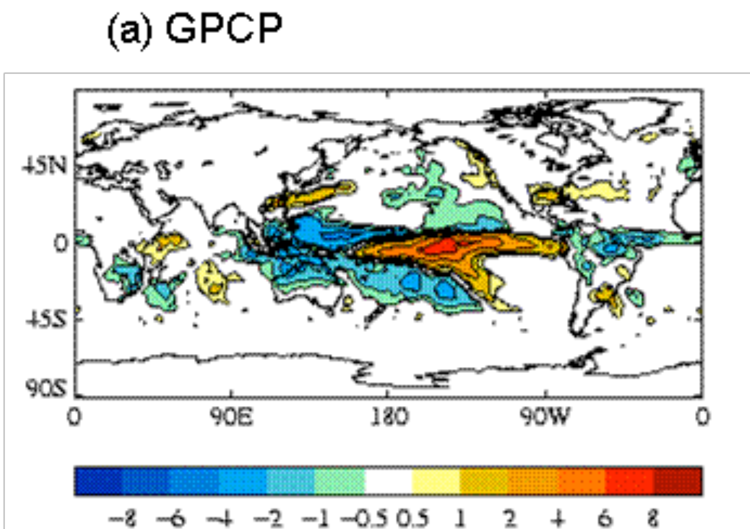




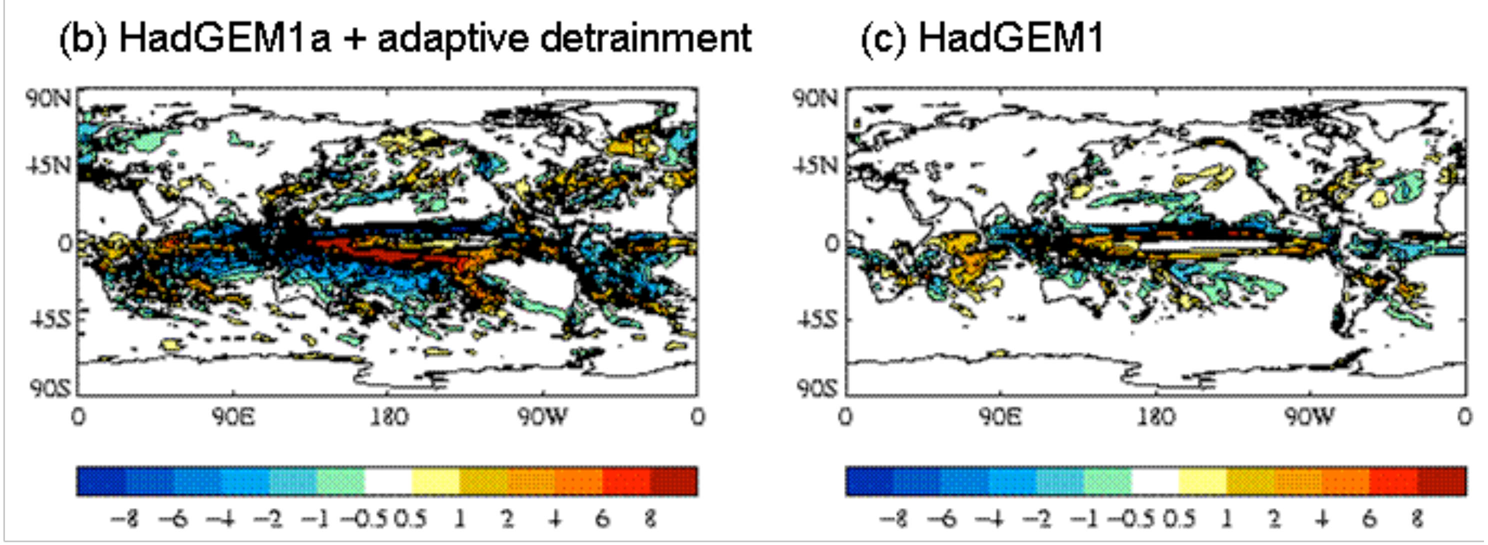
Impact of adaptive detrainment on annual mean total precipitation biases

- Improved in the Pacific
- Similar errors in Maritime Continent region and Indian Ocean

Precipitation anomalies during El Nino events



- ENSO variability is not increased but there is an improvement in the response of the precipitation to El Nino SSTs



Summary of ENSO and SST example

- Comparisons of NWP forecasts with observations have suggested problems with the diabatic heating distribution
- Tests of the new adaptive detrainment parametrisation have shown improvements in both NWP and climate models
- Problems with mean SSTs and ENSO SST variability remain, but the joint approach has been beneficial in reducing some aspects of the systematic error

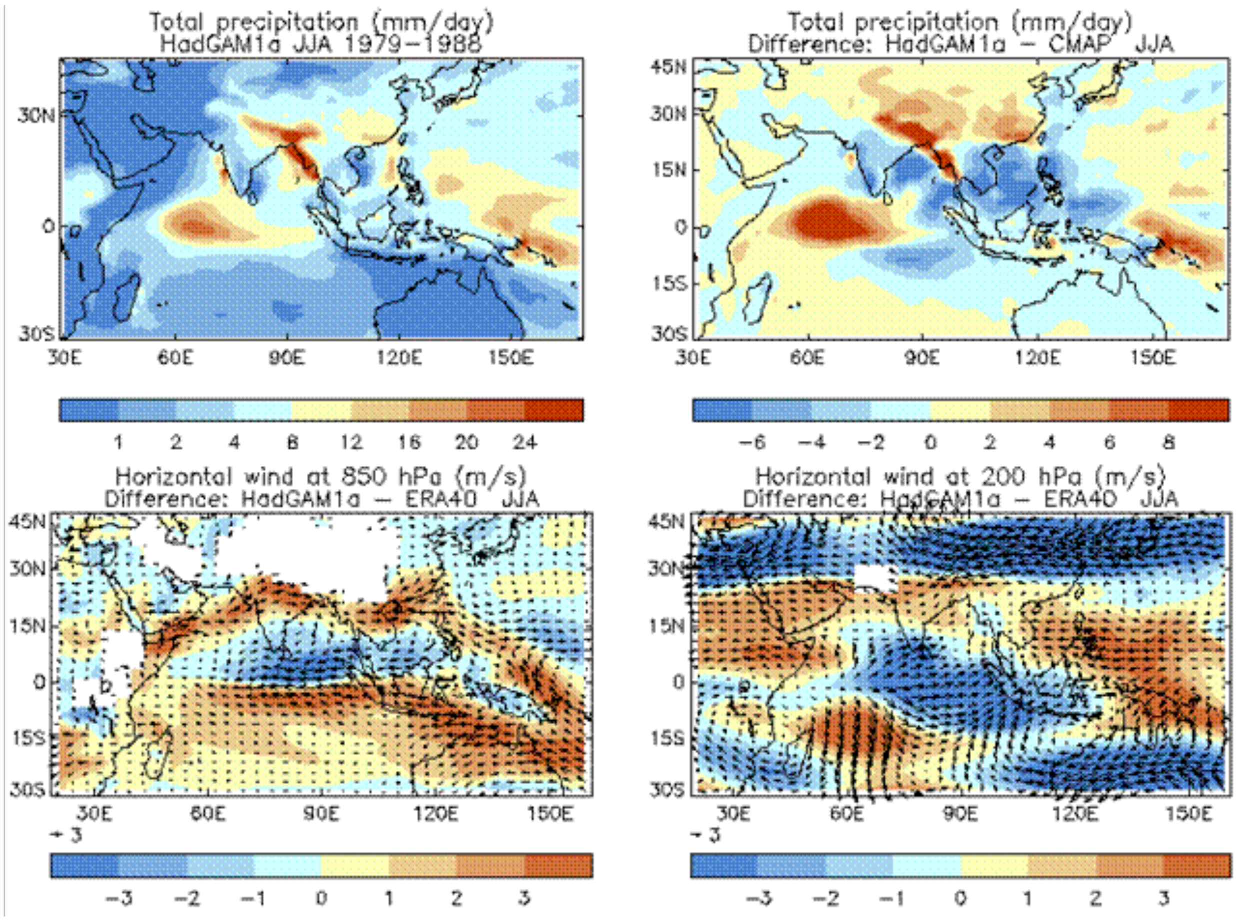
Improving the Asian summer monsoon simulation

- The Asian summer monsoon exhibits a marked dry bias in precipitation over India.
- This has implications for regional climate change modelling and for seasonal forecasting for the region.
- The errors are present in the atmosphere-only model and in the coupled model, with small differences occurring in the coupled model through corresponding adjustment of the SSTs.
- This error pattern is reproduced in the model on a range of time and space scales.

Climate model biases in the Asian Summer Monsoon

Model Precipitation

Precipitation bias



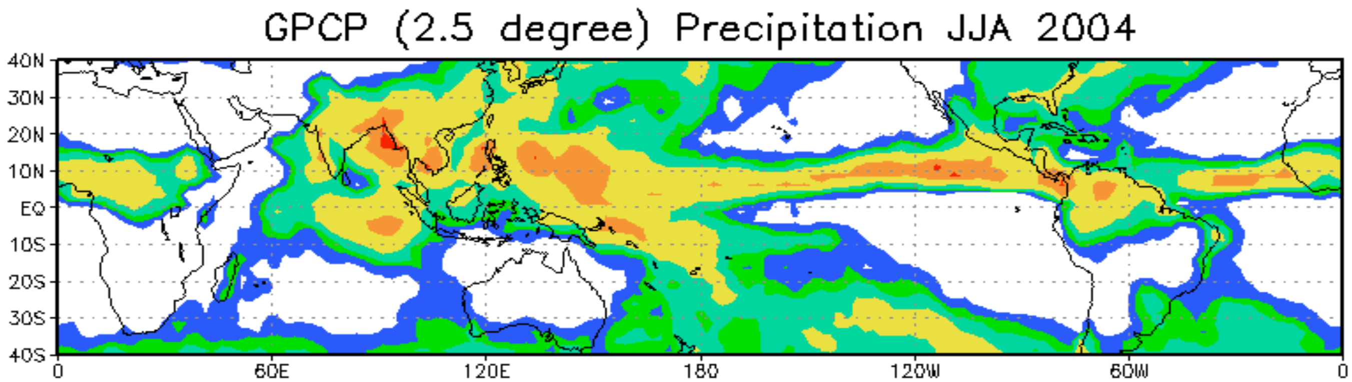
850 hPa wind bias

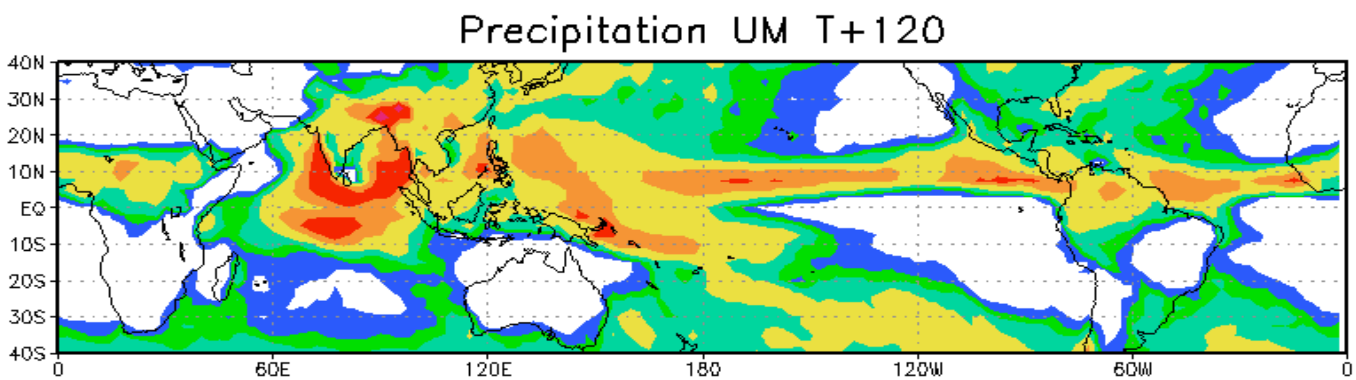
200 hPa wind bias

Contours indicate windspeed biases

- Too little rain over Indian subcontinent, East Asia, and Maritime Continent
- Excessive precipitation over the equatorial Indian Ocean, east coast of the Bay of Bengal and Himalayan foothills
- Anomalous anticyclonic circulation over Indian region at 850 hPa
- Anomalous cyclonic circulation at 200 hPa

NWP model summer precipitation vs GPCP

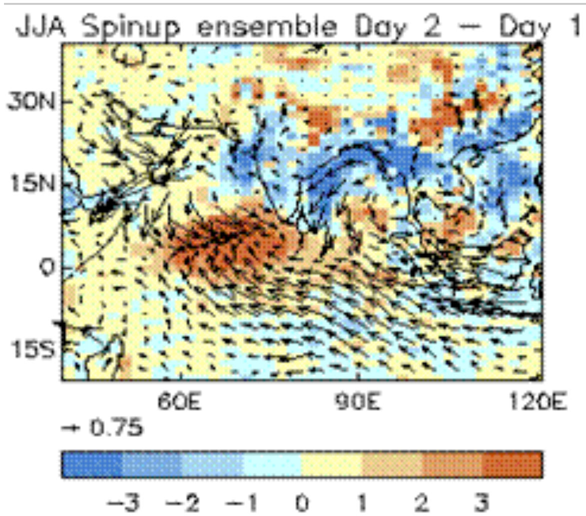


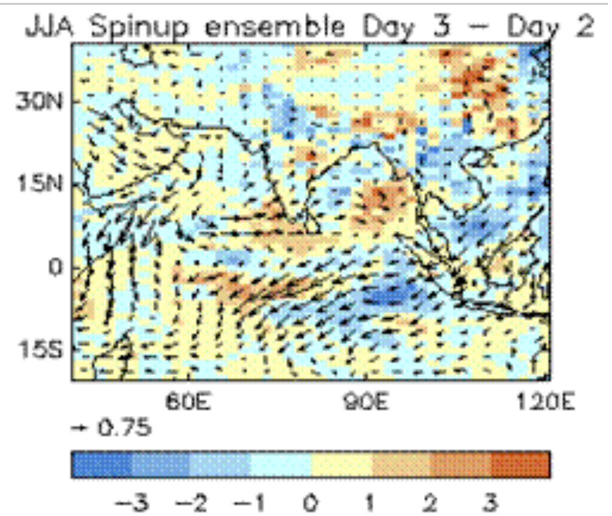


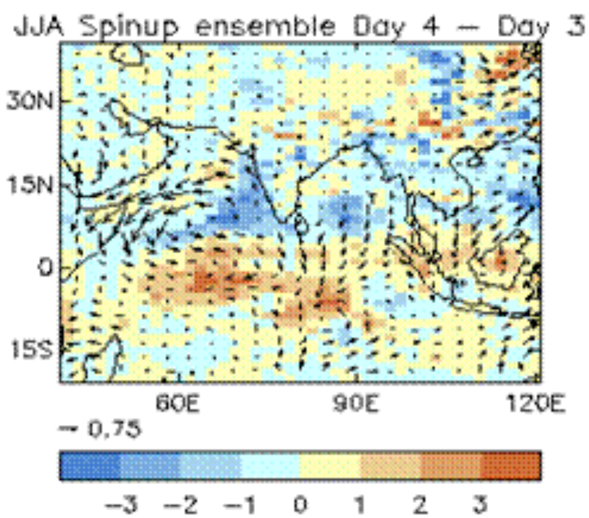
N216/L38

- Similar precipitation distribution to climate model
- Smaller rainfall bias over India on this timescale

Climate model spin-up tests



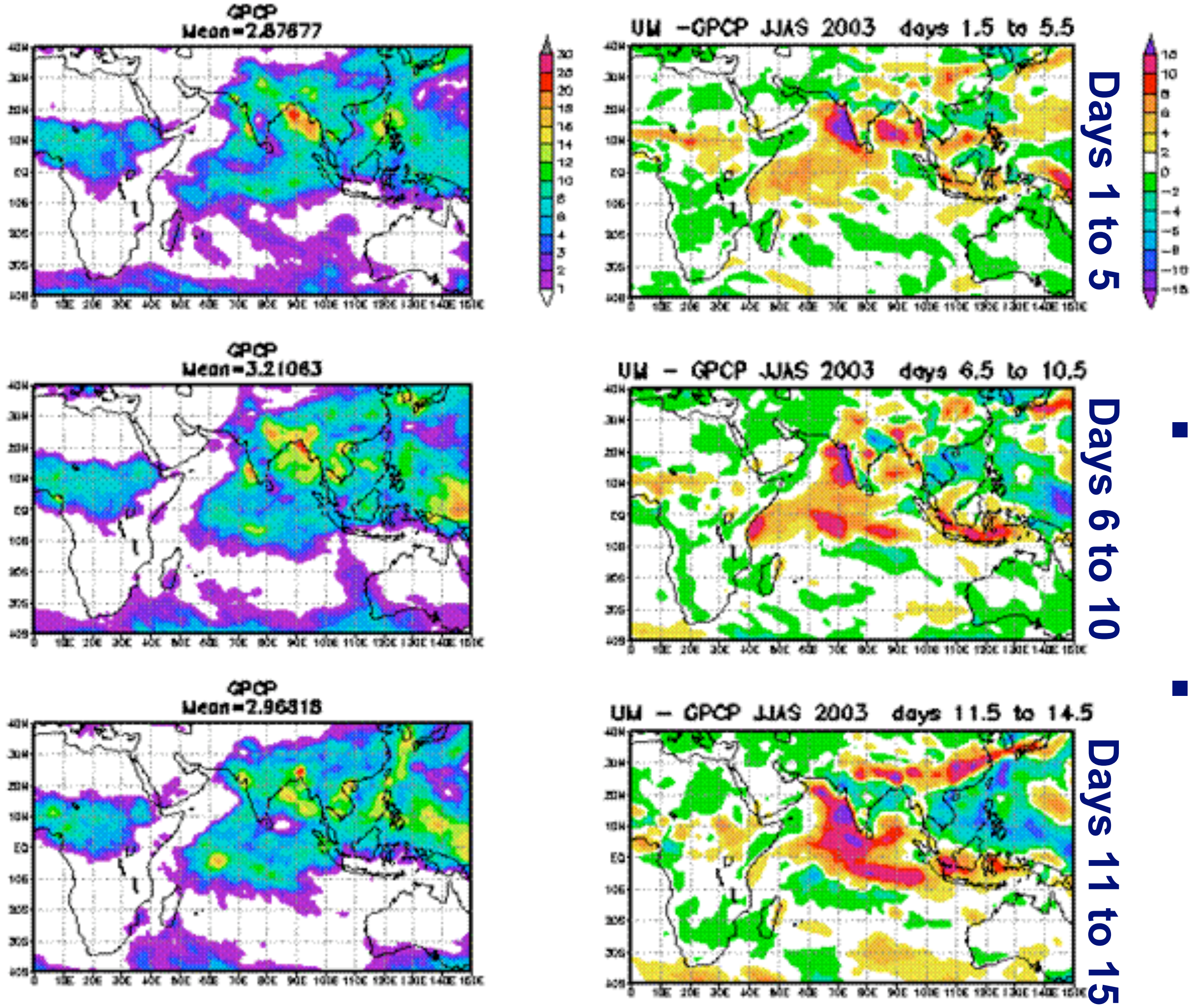




- Plots show spin-up of 850 hPa winds (arrows) and precipitation (contours)
- The positive precipitation bias over the equatorial Indian Ocean spins-up in the first day or two

15-day NWP THORPEX runs for JJA 2003

GPCP | UM - GPCP

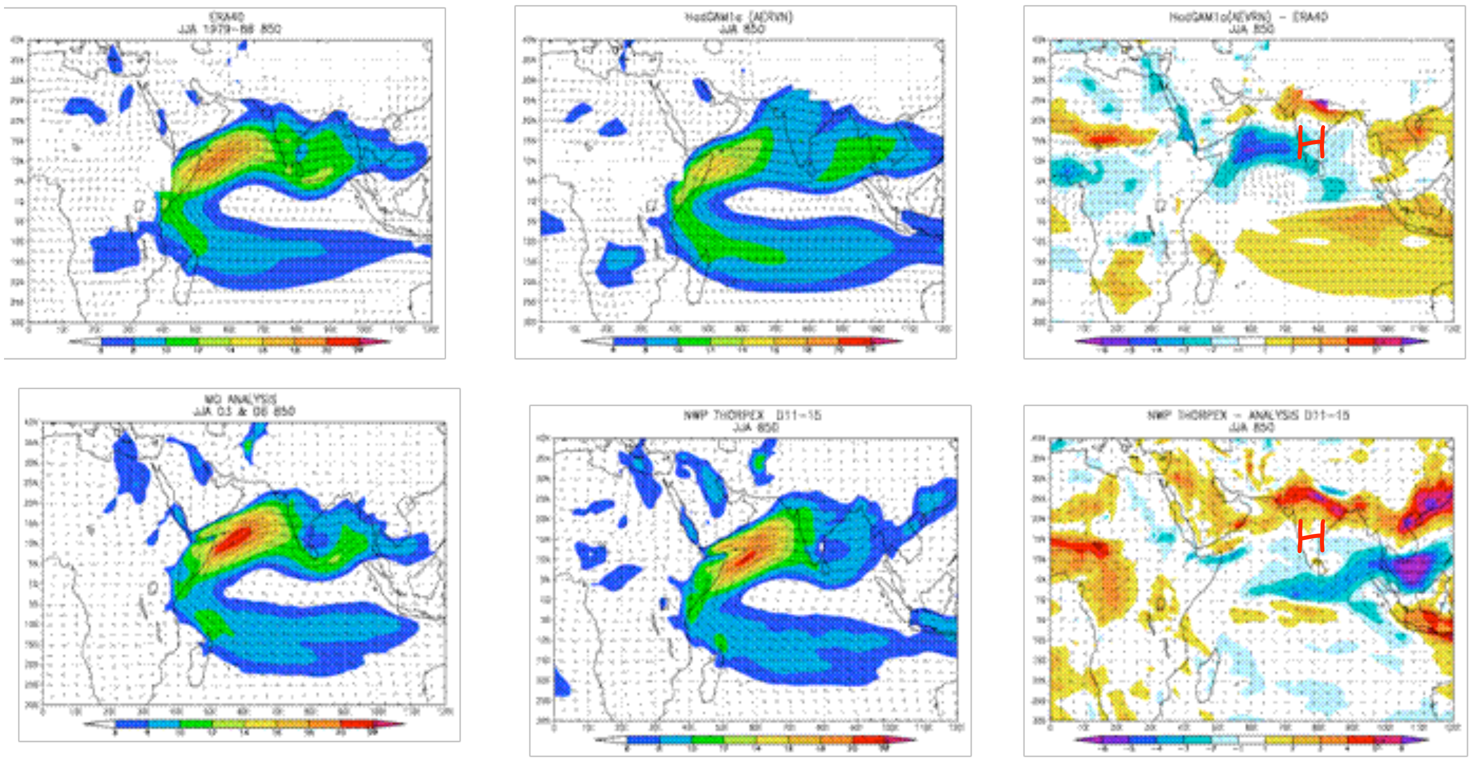


- Rapid development of positive precipitation biases over the Indian Ocean.
- The deficit over India develops over the order of 10-15 days.

Comparison of NWP model at 15 days with model climatology and ERA40

ERA40

HadGAM1a Climate

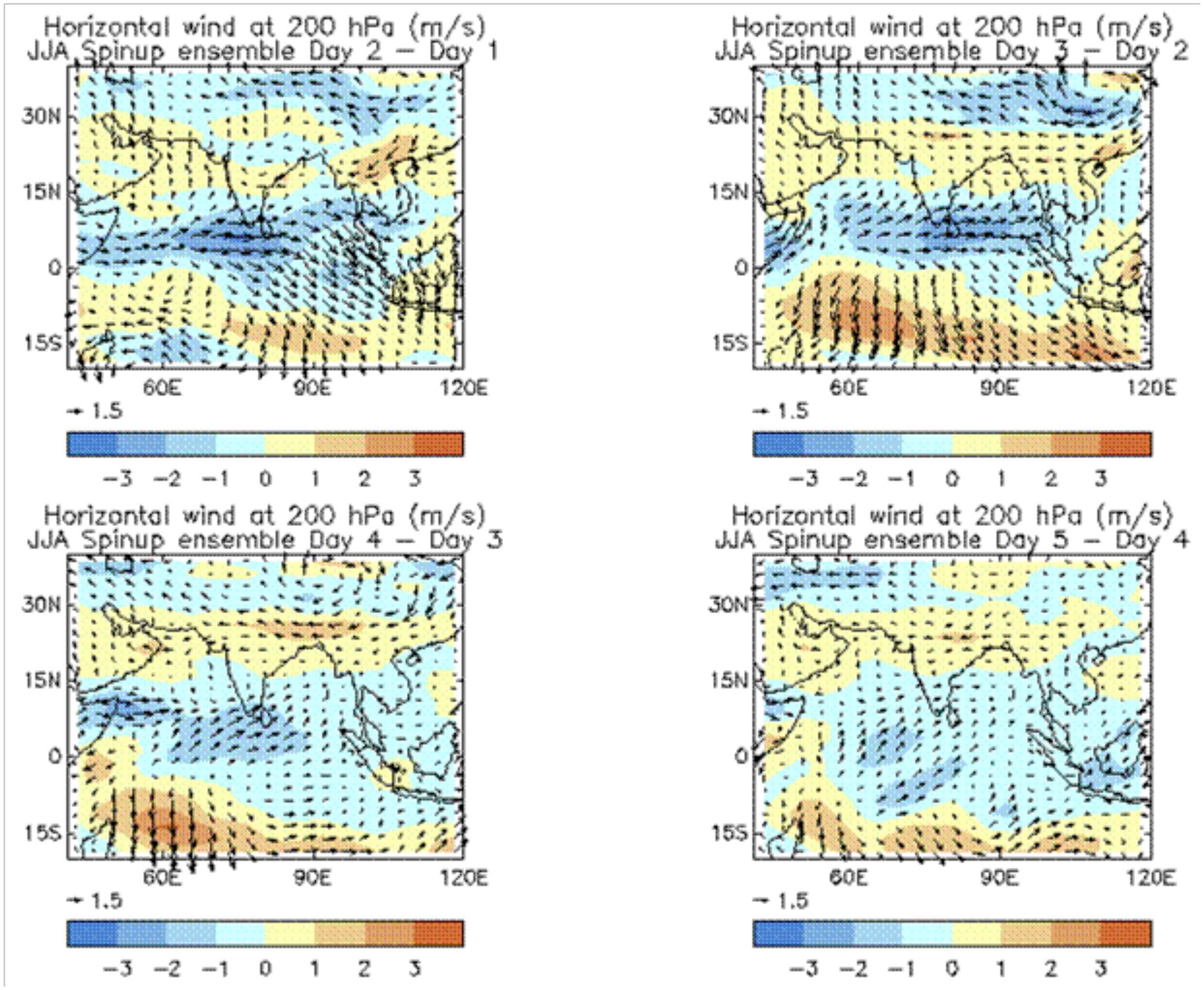


UM analysis

10 Summer N144 THORPEX case studies

- The low-level winds spin up an anomalous anticyclonic circulation over India at 850 hPa in 10-15 days which matches the climate model systematic error.

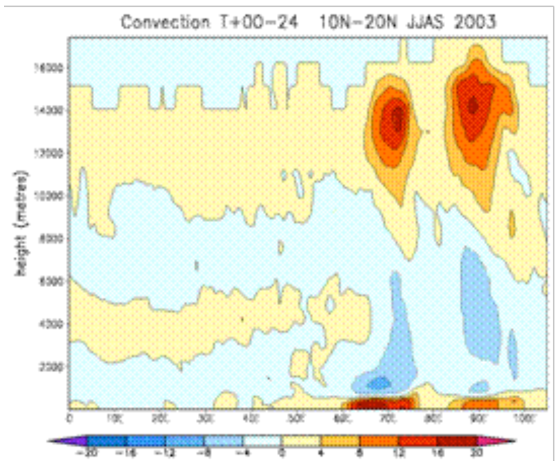
Climate model spin-up of 200 hPa winds



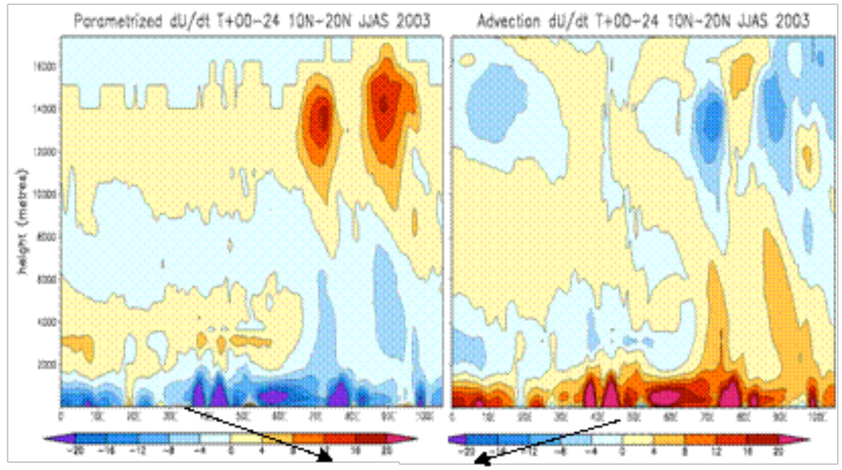
- Immediate spin down of the upper level winds
- Anomalous divergence over the equatorial Indian Ocean

Analysis of U momentum balance in NWP runs

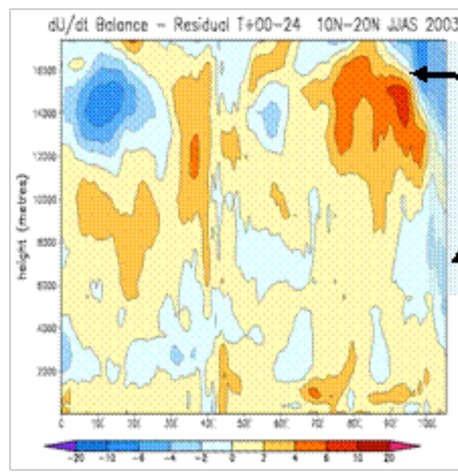
Convective Increments



Components in U momentum Balance



- Examination of the wind increments in the first 24 hours of forecast runs suggests that excessive momentum transport by convection results in drag at upper levels which is not balanced by advection.



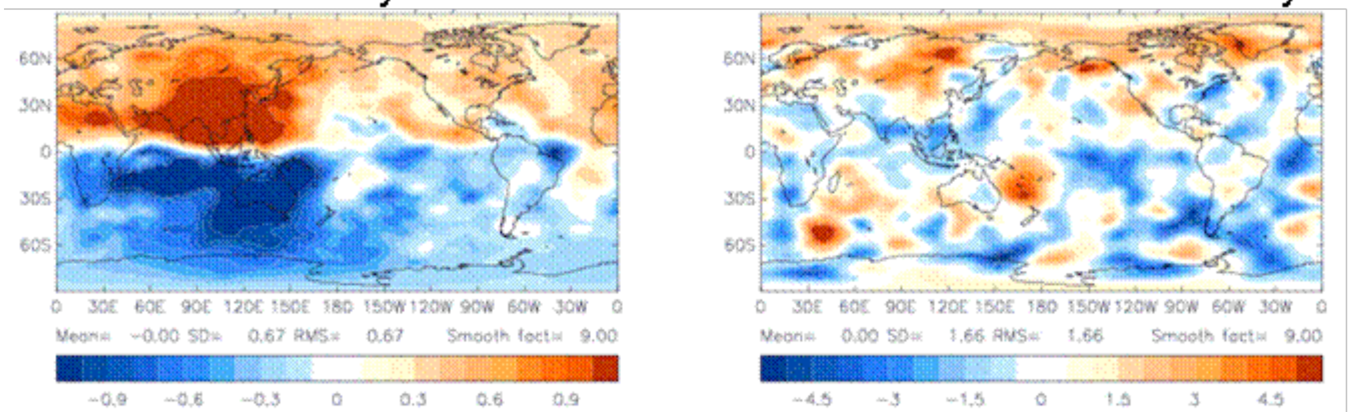
Westerly Residual

4-6 m/s/day

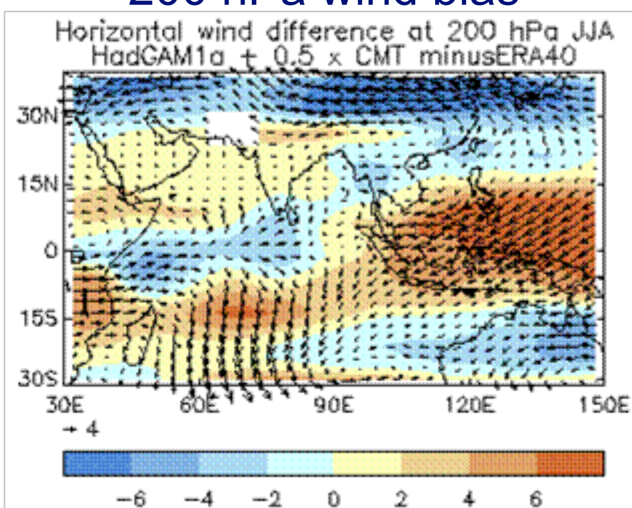
Tests of 0.5 x Convective Momentum Transport

200 hPa streamfunction

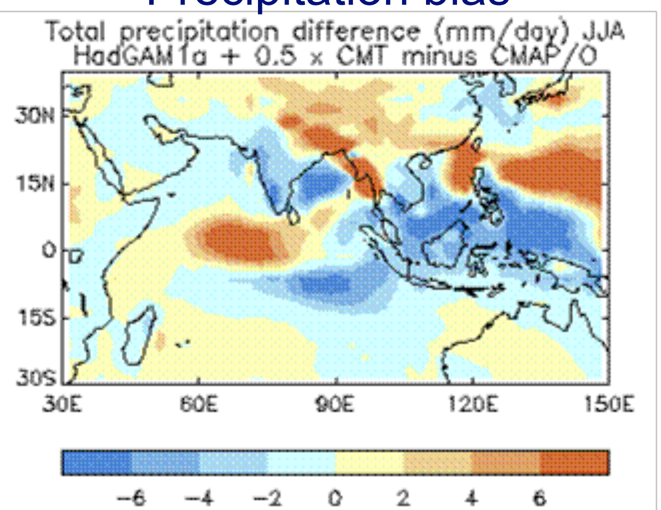
NWP model – analysis | NWP model + 0.5xCMT – analysis



200 hPa wind bias



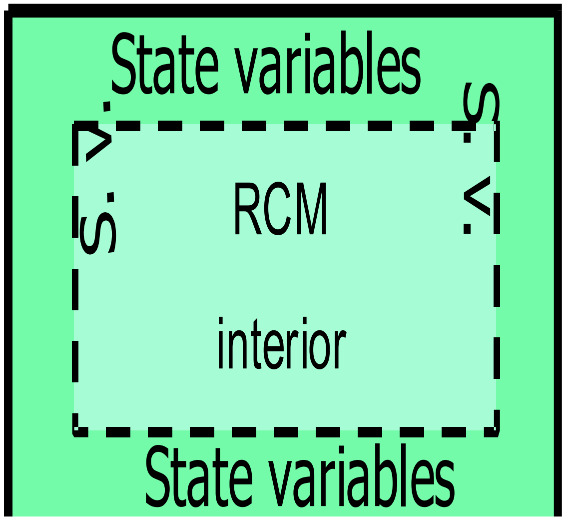
Precipitation bias



- Improvements in upper level flow in NWP
- Reduced bias in 200 hPa winds in climate run
- Slight improvements in precipitation over India in both forecast and climate tests.

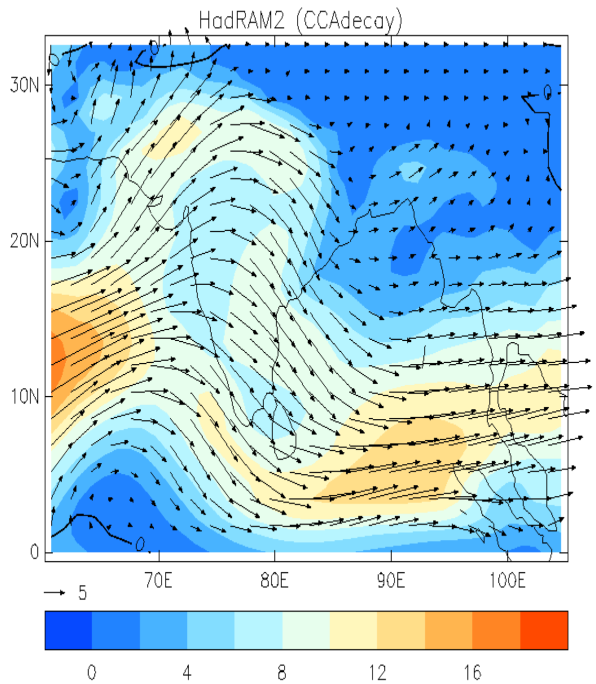
HadRAM2 regional climate modelling system

- Spatial resolution: 1.875x 1.25° and 38 vertical levels
- Dynamical and physical settings are identical to climate version
- HadRAM2 is driven at the lateral boundaries by quasi-observed atmospheric conditions from ERA40 every 6 hours
- Ocean conditions: prescribed from AMIPII SST/SICE;
- Simulation length: 5 months (from the 01/05/80 to 01/10/80). The first month is considered as a spin up and discarded from the analysis.
- Model domain: 30 x 33 grid points including a 4-point relaxation zone where information from the driving state variable are smoothly transmitted toward the RCM interior domain.

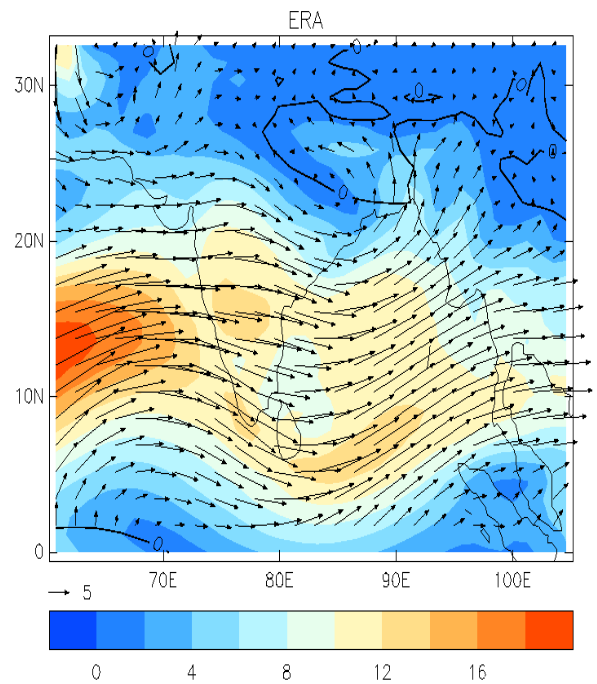


HadRAM2 monsoon circulation at 850 hPa - August

HadRAM2



ERA40



- The regional model isolates errors which develop locally in the Indian region
- It captures the anomalous anticyclonic circulation over India
- We are currently investigating the influence of orography and land surface conditions on this anomalous circulation

Summary of Asian Summer Monsoon example

- Comparison of the spin-up of this error in NWP and climate models and with observations has indicated problems with excessive convective momentum transport to upper levels
- Applying a reduction factor to this parametrisation improves the upper level winds and precipitation over India in both models
- Problems remain with other precipitation and circulation biases in the region
- These are being addressed using a range of techniques and a range of models

Conclusions

- The Met Office benefits from using the same basic model for a wide range of space and time resolutions
- We can make use of this to examine systematic errors at a range of spatial and temporal scales.
- Although problems remain with the rainfall distribution in both forecast and climate models, the use of joint analysis and sensitivity testing has proved invaluable in improving our understanding of the errors and suggesting possible solutions

Related poster presentations

- Sean Milton et al., Systematic Errors in Parametrizations in Global NWP : Evaluation Against Observational Data and Budget Studies
- Chris Dearden, The Sensitivity of HadGAM1 Dynamics to the Vertical Structure of Tropical Heating
- Jane Strachan et al., Exploring Systematic Errors in the Maritime Continent Region in an Atmospheric GCM
- Len Shaffrey et al., Systematic Errors and SST Biases in HiGEM
- Keith Williams et al., Initial tendencies of cloud regimes in the Met Office Unified Model
- Jon Petch et al., The Role of SCMs and CRMs for Investigating Biases in NWP and Climate Models
- Andy Brown et al., Combining Top-Down and Bottom-Up Approaches to Improve Boundary Layer Parametrization for NWP and Climate