Idealised modelling of the East Asian monsoon

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Background - Asian monsoon

- Key features: seasonally reversing winds accompanied by intense precipitation
- Variability is linked to drought and floods affecting a large fraction of the world’s population
- Many aspects of monsoon behaviour are still unclear, e.g. controls on the onset, variability, and links to the wider climate system

→ Look at basic dynamics in an idealised modelling context
Background - Asian monsoon

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‘Classic’ views of the monsoon

Large scale sea breeze  
Shifts in ITCZ over year

+ Influences from SST patterns, Tibetan Plateau...

Diagrams from:
- http://monsoon.yale.edu/why-monsoons-happen/
Emerging view of the monsoon: Change in dynamical regime of NH circulation
Feedbacks -> Fast onset

Precipitation: Observations (70-100°E)
1m aquaplanet

Bordoni and Schneider 2008: Transition from eddy-driven (equinoctial) to thermally direct ‘Held-Hou’ (NH summer) Hadley cell
Emerging view of the monsoon: Change in dynamical regime of NH circulation

Feedbacks -> Fast onset

Shaw 2014: Transition from a zonally symmetric (equinoctial) to planetary wave dominated (NH summer) background state
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NB see also: Krishnamurti and Ramanathan 1982, Plumb and Hou 1992, Privé and Plumb 2006
Model: GFDL-MiMA
(Model of an idealised Moist Atmosphere)

- GFDL model spectral dynamical core
- Currently using T42 resolution + 40 sigma levels
- Idealised moist physics and convection (cf. Frierson et al. 2006)
- RRTM radiation scheme (Jucker et al., In prep)
- Simple parameterisations of land + topography (thanks to Stephen Thomson)
- ERA land mask and topography
- Mixed layer ocean
- NB - no clouds
Experiments

- Aquaplanets: 2m and 20m mixed layer depths
- Flat, idealised continents (2m mixed layer depth for land, 20m for ocean)
- Aquamountains (20m mixed layer depth)
- Continents + mountains + AMIP derived q-fluxes: “Earth”
Questions...

In our hierarchy of experiments do we see evidence for a change in regime in the Asian monsoon region?

If so, which regime change is it:

- A transition to a near angular momentum conserving cell related to ITCZ shifts (cf. Bordoni and Schneider 2008)?
- A transition to a planetary scale wave, or sea breeze, dominated regime (cf. Shaw 2014)?
- Something else?

What is the mechanism that gives a fast monsoon onset?
The strength of the cross equatorial Hadley cell is proportional to its Northward extent. Beyond ~10°N the ratio of strength to width increases.
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Regime change behaviour?

The strength of the cross equatorial Hadley cell is proportional to its Northward extent. Beyond $\sim 10^\circ$N the ratio of strength to width increases. Consistent behaviour is observed in the monsoon region in the Earth-like experiment.
What is the ‘monsoon regime’?

Zonal momentum budget (150 hPa)

\[
\frac{\partial \bar{u}}{\partial t} = f\bar{v} + \text{mean state advection} + \text{eddy advection} - \frac{\partial \Phi}{\partial x} - \mathcal{F}
\]

- Coriolis force
- Geopotential gradient
- Damping
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Zonal momentum budget (150 hPa)

\[
\frac{\partial \bar{u}}{\partial t} = f \bar{v} + \text{mean state advection} + \text{eddy advection} - \frac{\partial \Phi}{\partial x} - \nabla \cdot \mathbf{v}
\]

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\[
\frac{\partial \bar{u}}{\partial t} = f\bar{v} + \text{mean state advection} + \text{eddy advection} - \frac{\partial \Phi}{\partial x} - X
\]

Coriolis force \( \sim -v \frac{\partial \bar{u}}{\partial y} \)

Geopotential gradient

Damping

Expectations from recent studies:

Bordoni and Schneider 2008: **Decrease** in magnitude of **transient eddy advection**. **Strong Coriolis** and **mean state advection** in close balance.

Shaw 2014: **Increase** in magnitude of transient + stationary eddy advection (indicating strong role for **planetary scale wave** activity).
Zonal momentum budget (150 hPa)

Continents + topography

\[ \frac{\partial \Phi}{\partial x} \]

- Development of cross-equatorial cell can be seen in \( f\bar{v} \).
- This is balanced by transient and stationary eddy momentum flux convergence.
- \( f\bar{v} \) is not in balance with mean state advection.
Zonal momentum budget (150 hPa)

2m Aquaplanet

\[
\frac{\partial \bar{u}}{\partial t} = f \bar{v} + \text{mean state advection} + \text{eddy momentum flux convergence}.
\]

- Development of cross-equatorial cell can again be seen in \( f \bar{v} \).
- Here this is balanced by mean state advection and transient eddy momentum flux convergence.
- Fourier analysis shows strong low wavenumber activity in summer.
Zonal momentum budget (150 hPa)

Continents + topography (60-150°E)

- Looking locally over the Asian continent, $fv$ and geopotential gradient are dominant.
- The ageostrophic wind (large south of 20°N) is balanced by mean state advection and transient eddy momentum flux convergence - similarities with shallow aquaplanet.
Summary

‘Knowns’

- Once the ITCZ passes ~10°N, the overturning cell strengthens significantly.

- The ITCZ can be moved poleward by warming of the NH, e.g. the continent warms in summer + warm SSTs develop in Northern Indian Ocean.

- Zonal geopotential gradients are in balance with meridional wind. Warming of the continent relative to ocean is balanced by enhanced low level north and eastward flow along coast, further extending the cross equatorial Hadley cell.

- Land-sea contrast triggers this transition in the continent + topography simulation.

‘Maybes’

- Upper level easterlies may shield upper branch from synoptic scale eddies, so cell is closer to thermally direct.

- Northward advection of MSE by the low level flow may act as a positive feedback, pushing the ITCZ further North.

- Equatorial, planetary scale waves may be a response to the upper level easterlies, or may be a feedback onto the circulation e.g. from diabatic heating in the ITCZ.