UNIVERSITY OF EXETER

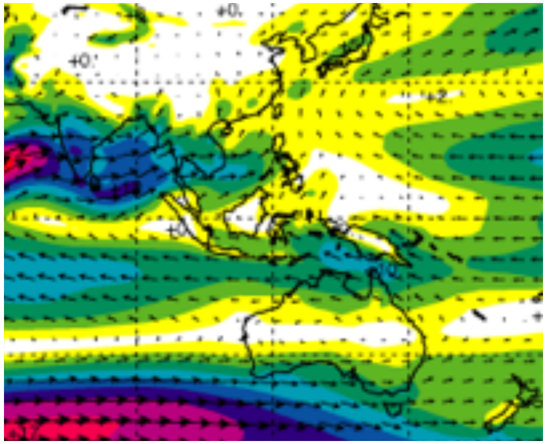
# Idealised modelling of the East Asian monsoon

Ruth Geen, Hugo Lambert, Geoff Vallis

# 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



Wind vectors and isotachs, 850hPa
www.ecmwf.int/s/ERA-40_Atlas

Western Ghats 28/05/10 (Arne Hückelheim)

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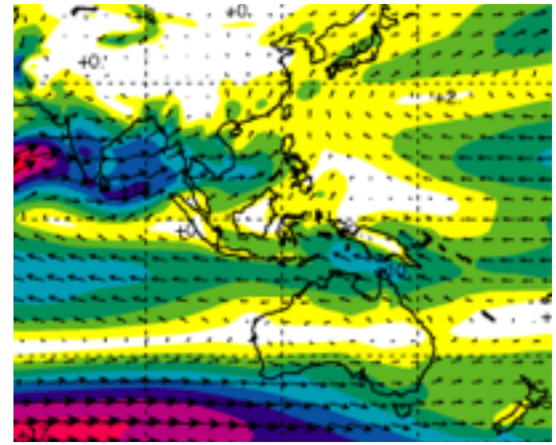

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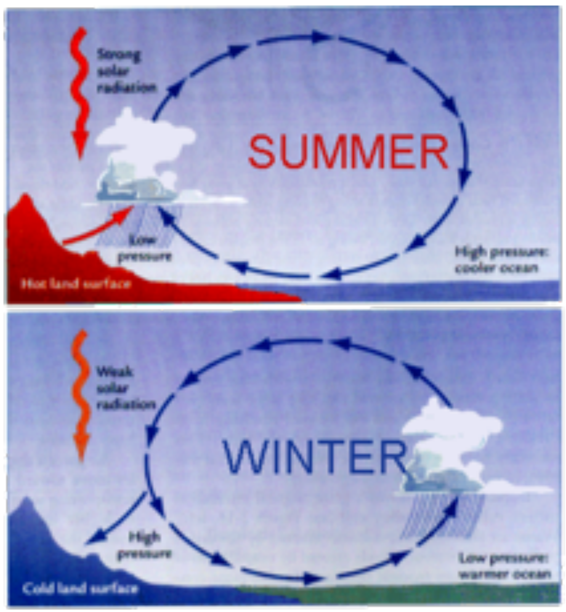
# ‘Classic’ views of the monsoon



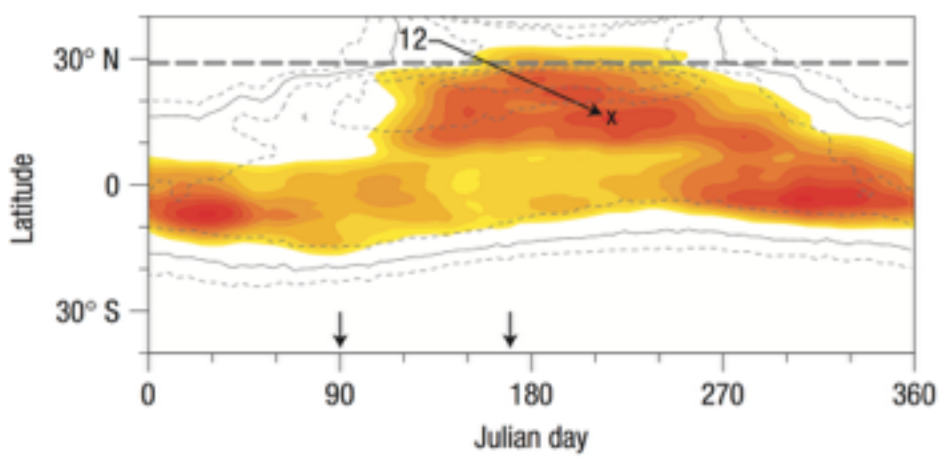

**Large scale sea breeze**

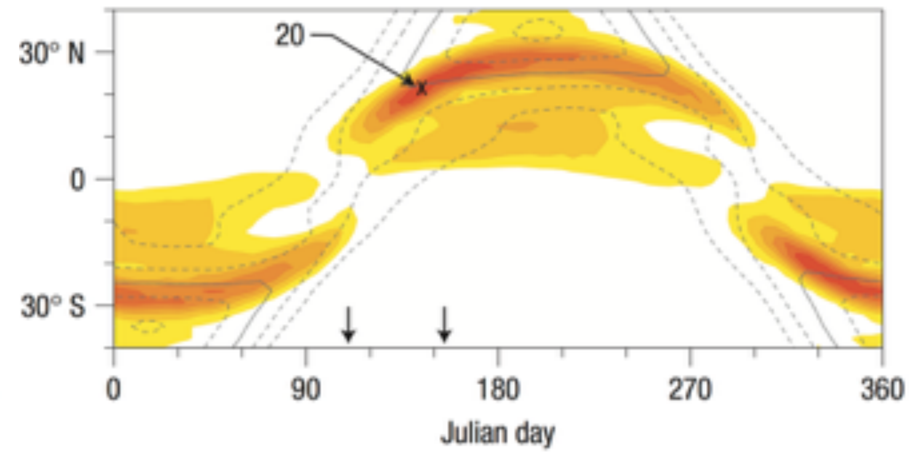

**Shifts in ITCZ over year**

+ Influences from SST patterns, Tibetan Plateau…

Diagrams from:
- https://wildcardweather.com/2014/09/07/monsoons-and-the-north-american-monsoon/
- http://monsoon.yale.edu/why-monsoons-happen/

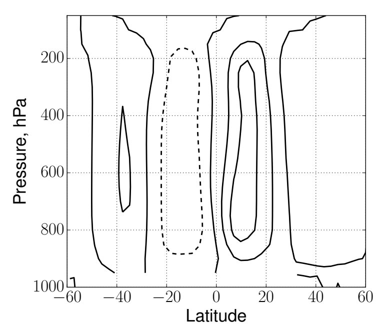
# Emerging view of the monsoon:
## Change in dynamical regime of NH circulation
## Feedbacks -> Fast onset

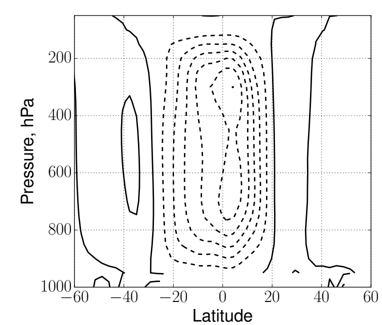



**Precipitation:** **Observations (70-100˚E)** **1m aquaplanet**

Bordoni and Schneider 2008:
Transition from eddy-driven (equinoctal) to thermally direct 'Held-Hou' (NH summer) Hadley cell



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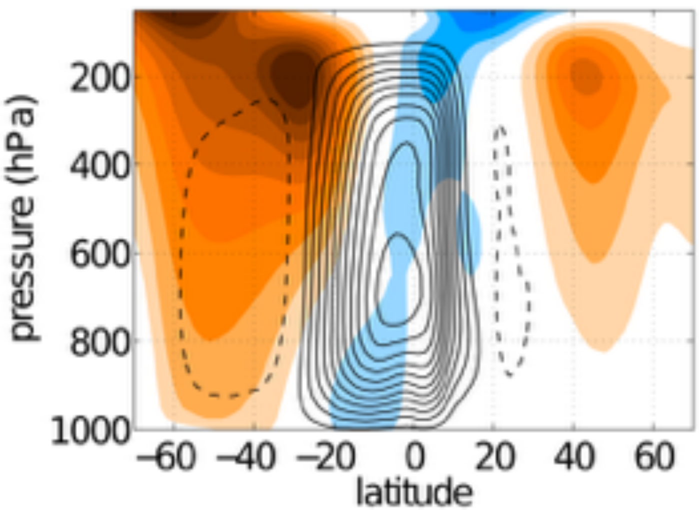
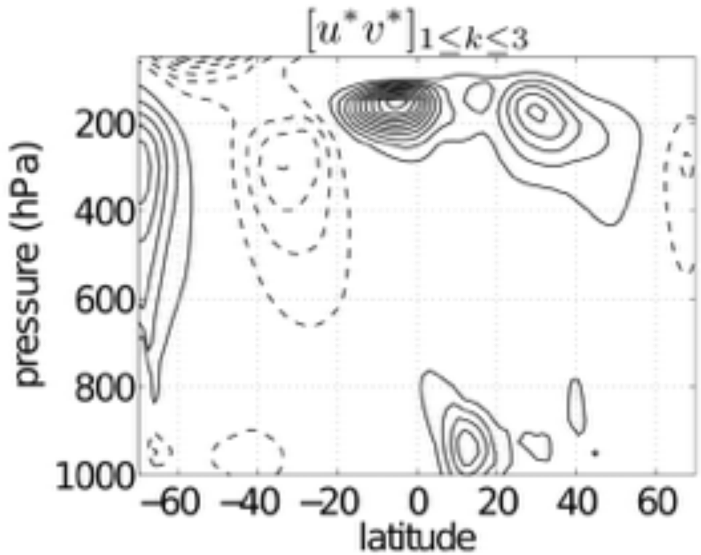



**Zonal wind and meridional overturning**




**Planetary scale eddy momentum flux**

**(ERA-Interim)**

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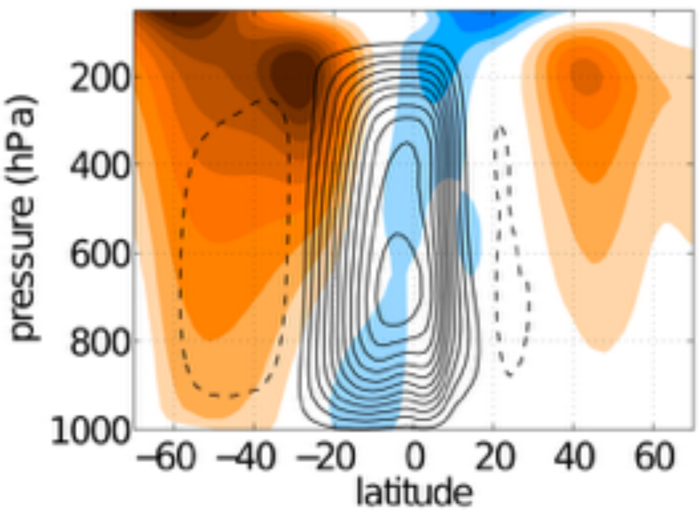


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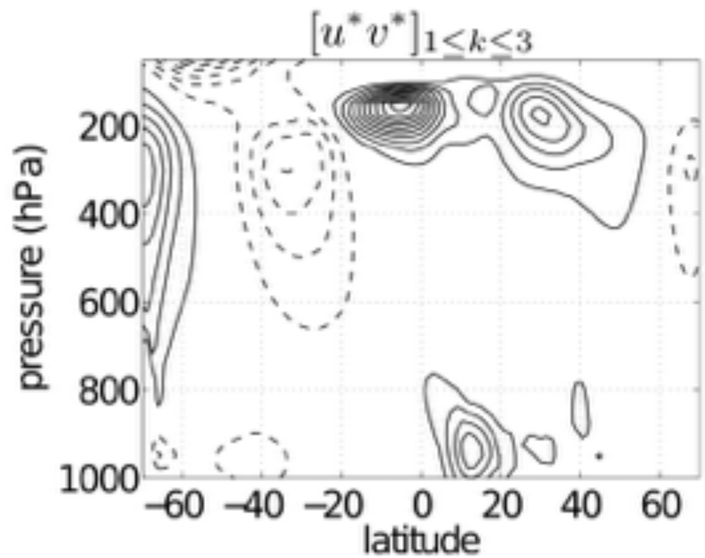


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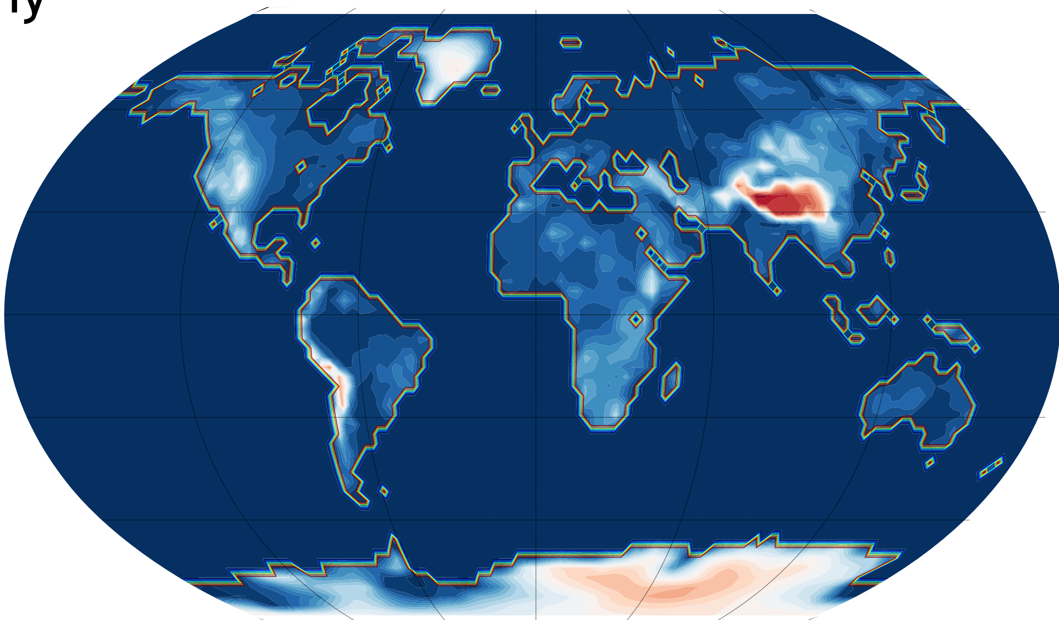
NB see also: Krishnamurti and Ramanathan 1982, Plumb and Hou 1992, Privé and Plumb 2006

# 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)?

or

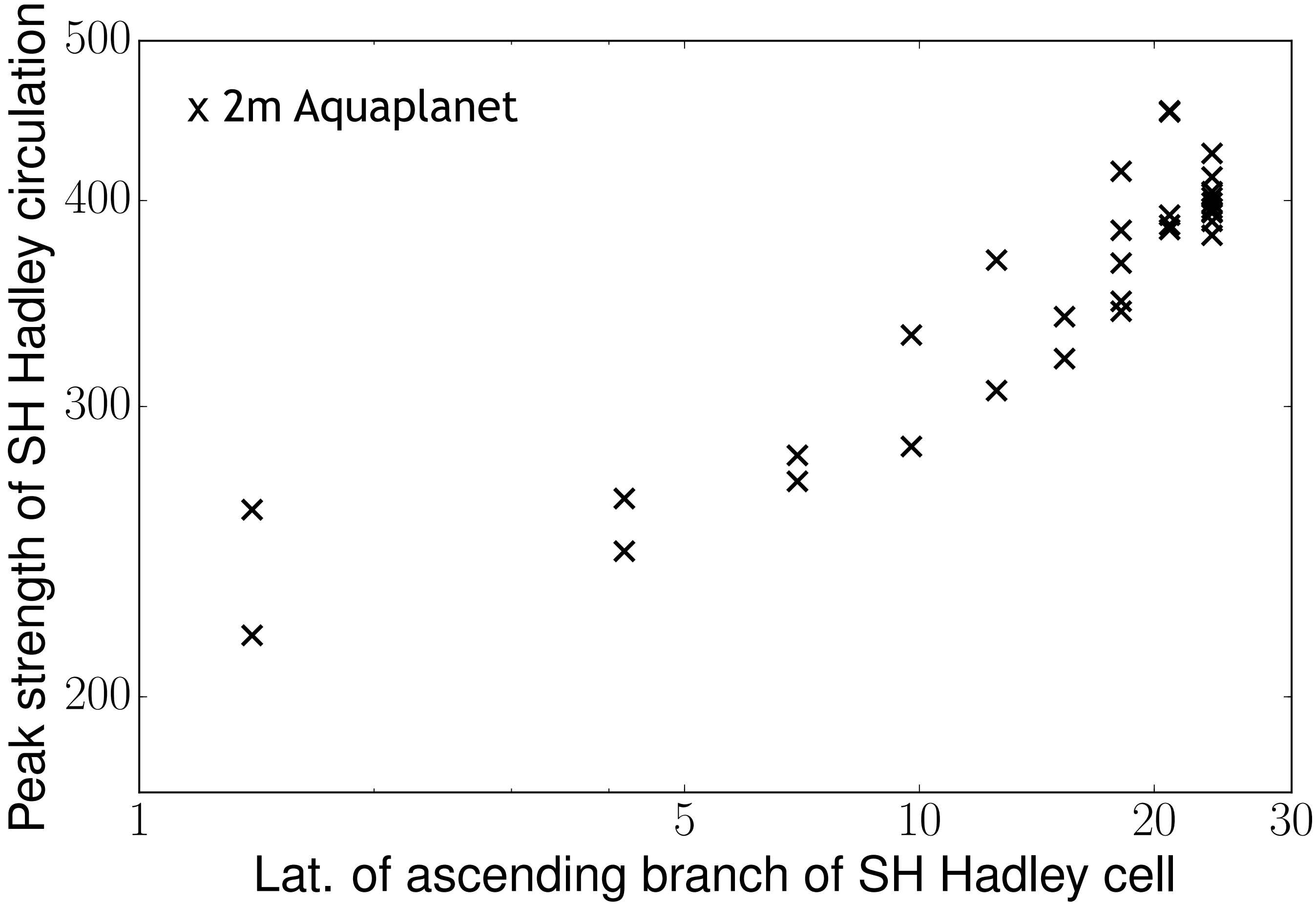
- A transition to a planetary scale wave, or sea breeze, dominated regime (cf. Shaw 2014)?

or

- Something else?

What is the **mechanism** that gives a fast monsoon onset?

# Regime change behaviour?




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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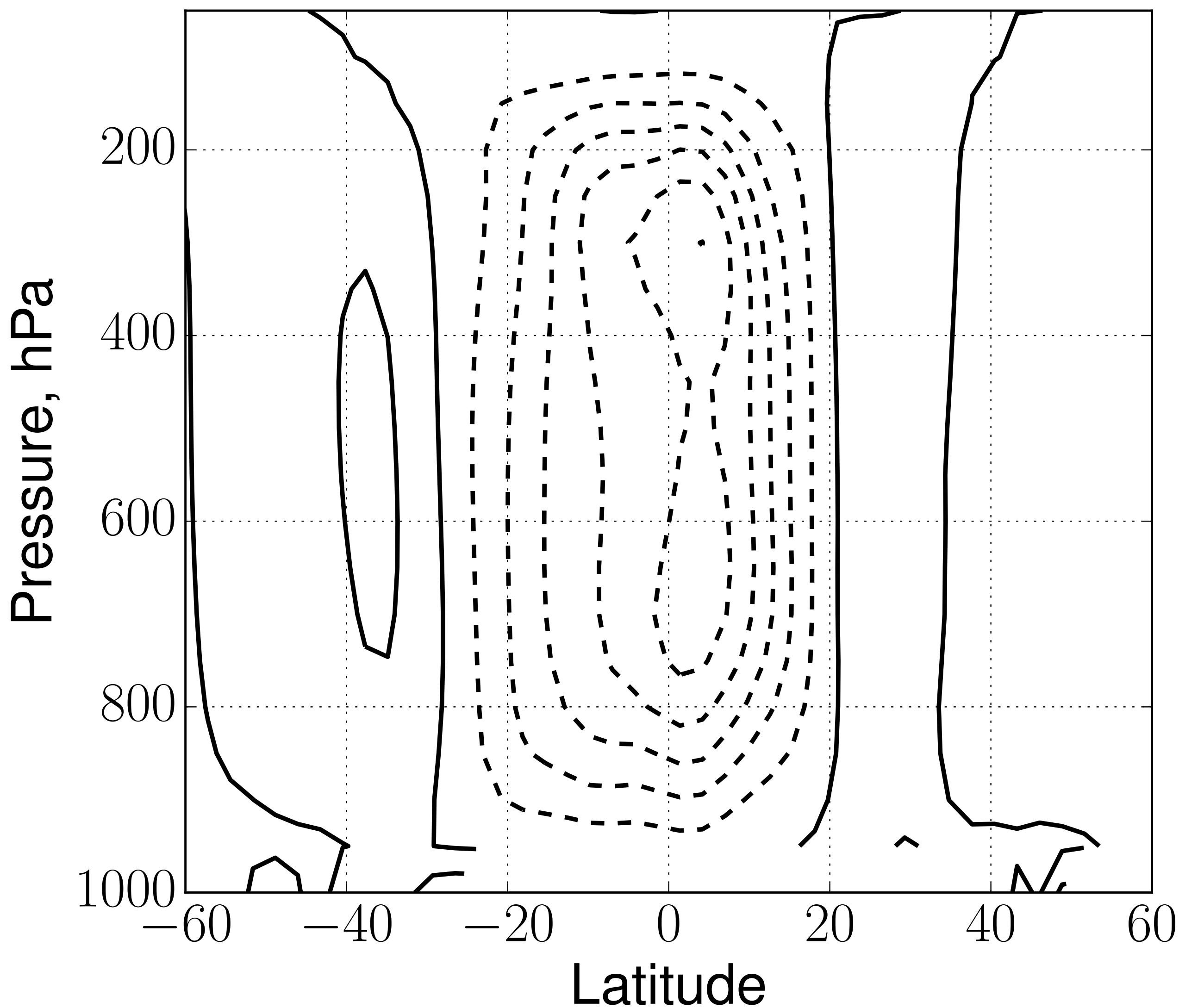


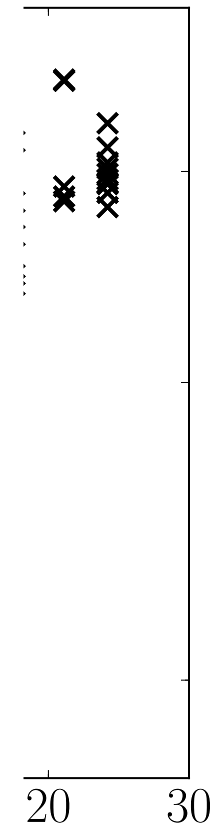


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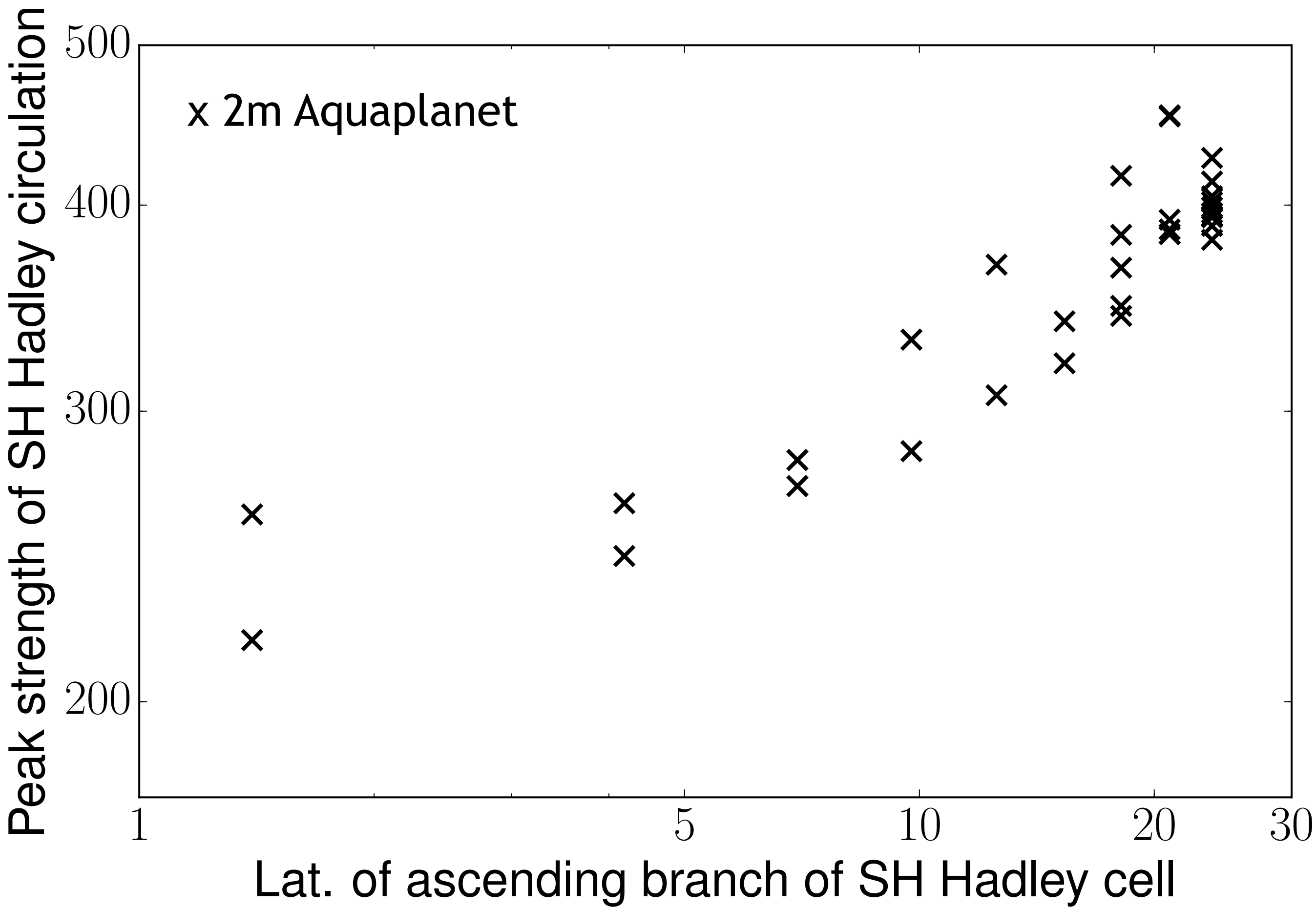


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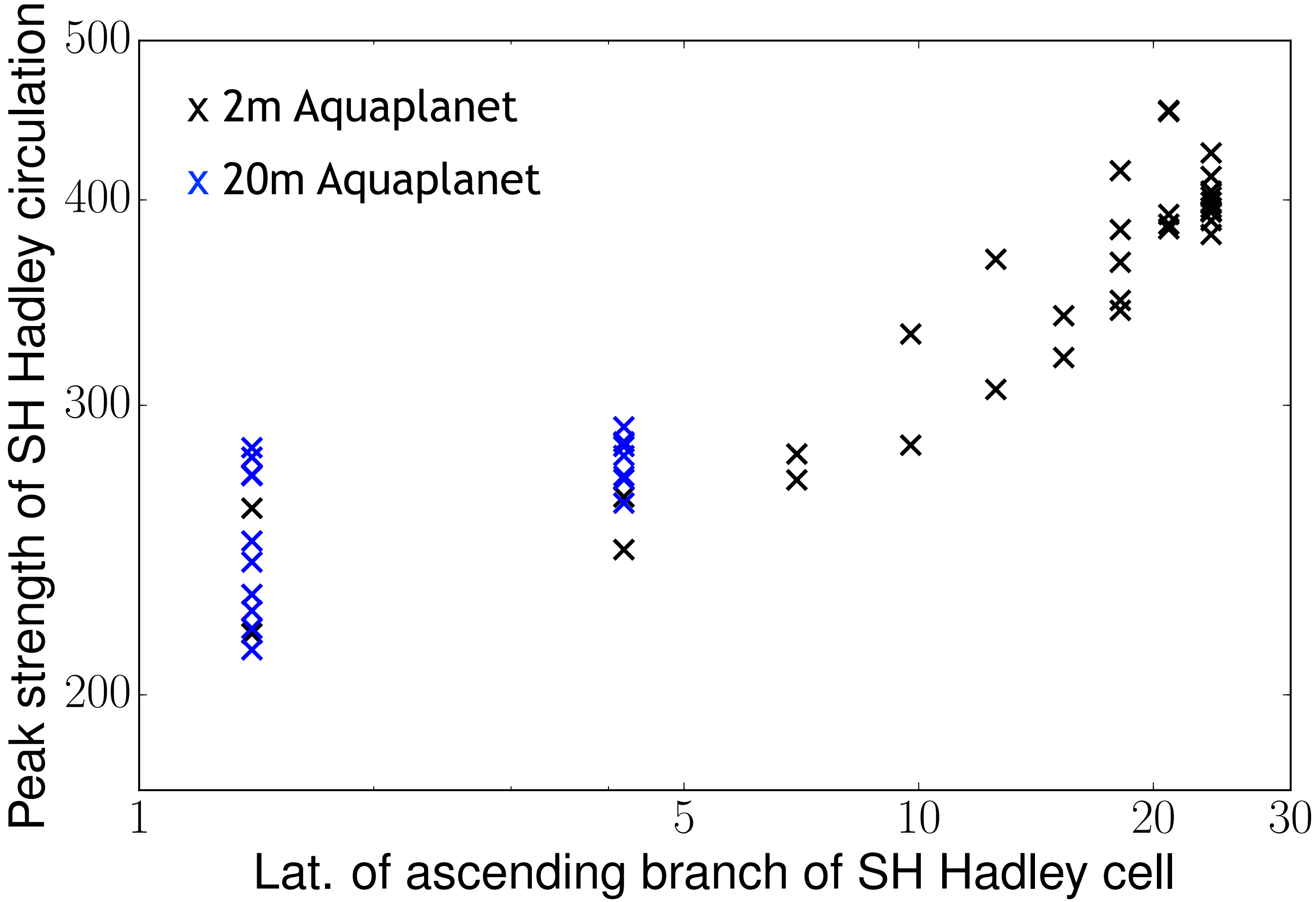


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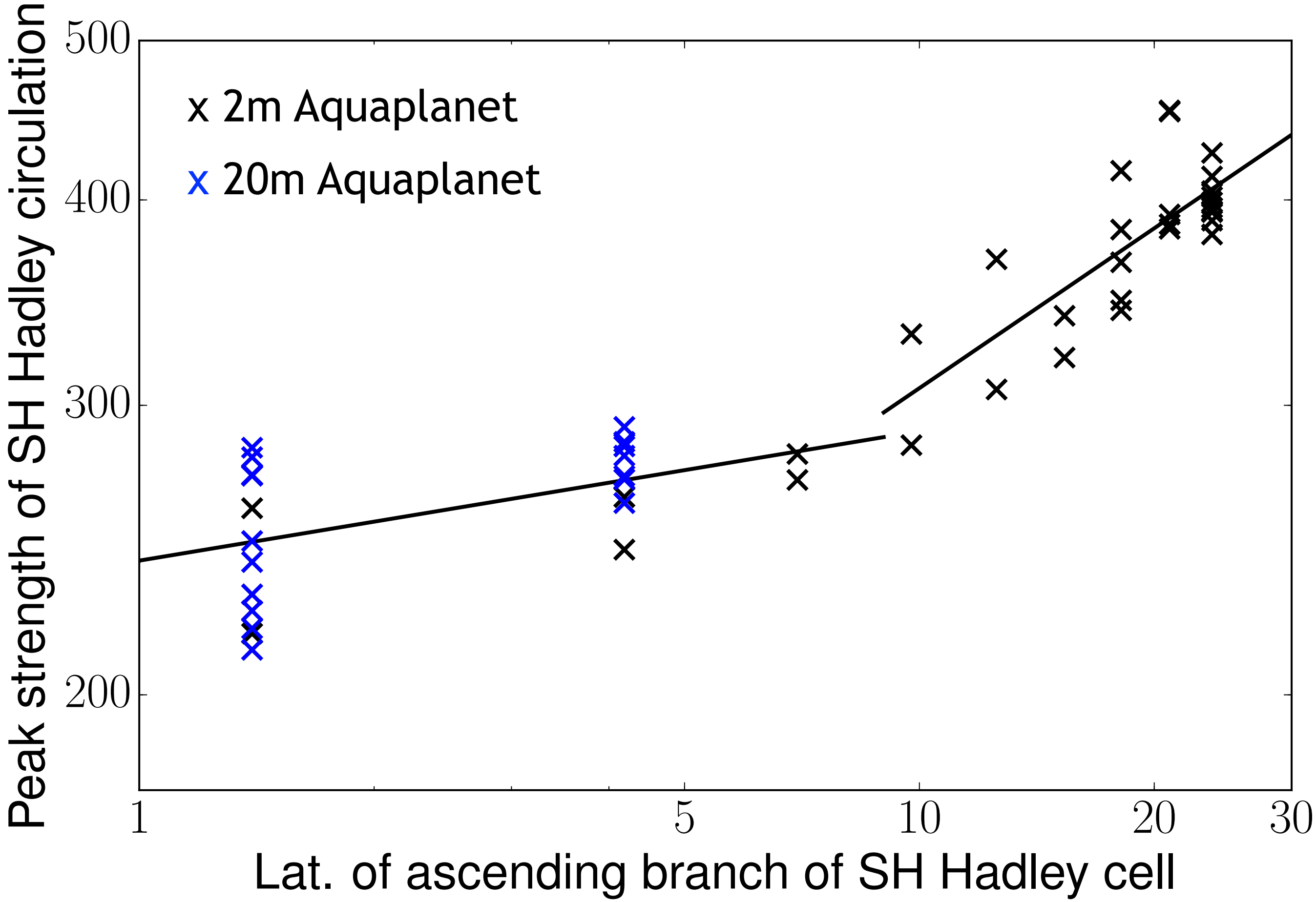


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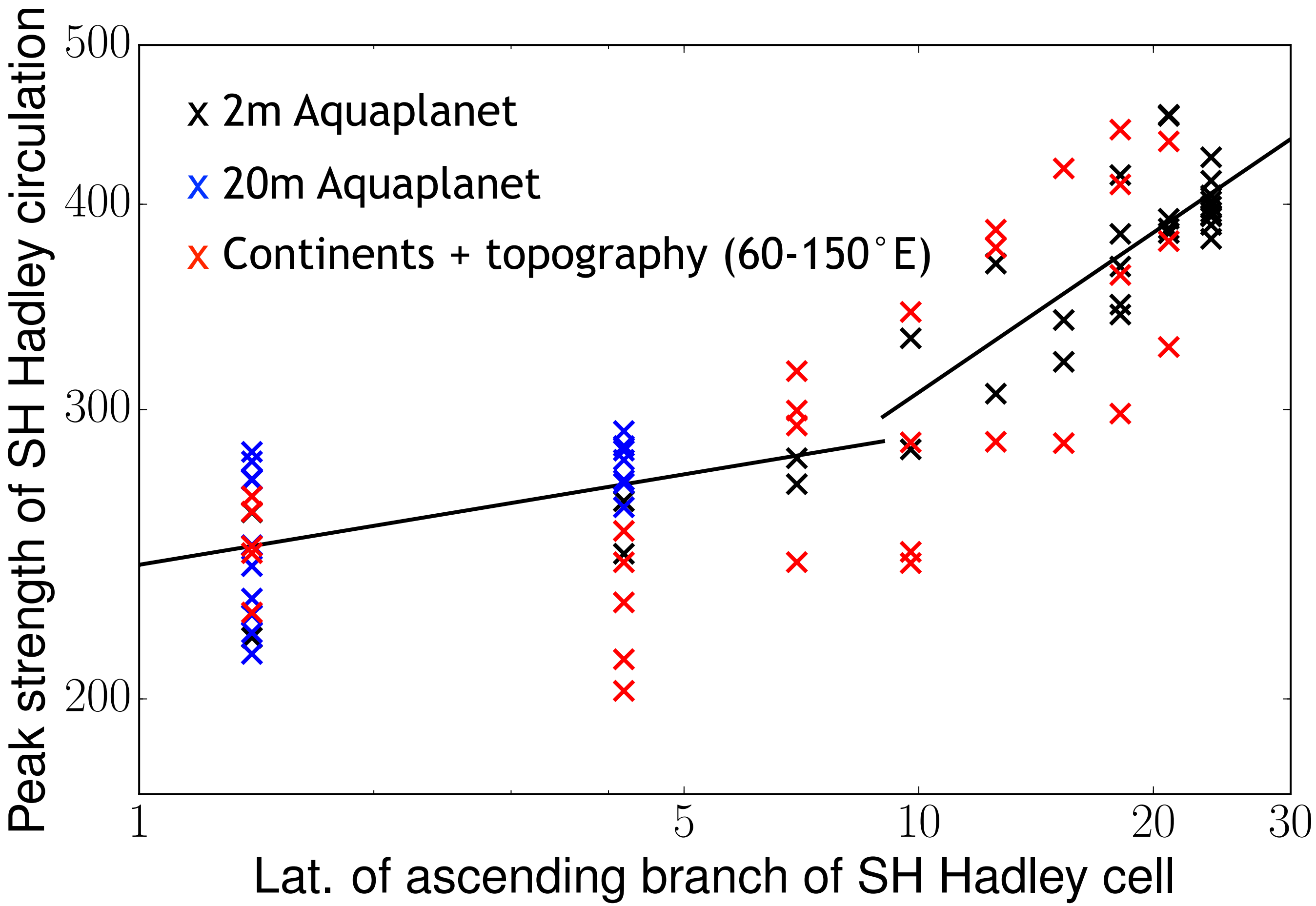


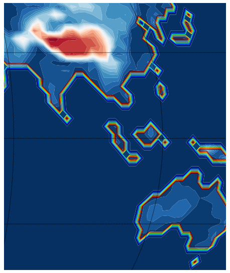

The strength of the cross equatorial Hadley cell is proportional to its Northward extent.

Beyond ~10°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)**

$$\frac{\partial \overline{u}}{\partial t} = \underbrace{f\overline{v}}_{\text{Coriolis force}} + \underbrace{\begin{matrix}\text{mean state}\\\text{advection}\end{matrix}}_{\sim -\overline{v}\frac{\partial \overline{u}}{\partial y}} + \begin{matrix}\text{eddy}\\\text{advection}\end{matrix} - \underbrace{\frac{\partial \overline{\Phi}}{\partial x}}_{\text{Geopotential gradient}} - \underbrace{\overline{\mathcal{F}}}_{\text{Damping}}$$

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Coriolis force

$$\sim -\overline{v}\frac{\partial \overline{u}}{\partial y}$$

Geopotential gradient

Damping

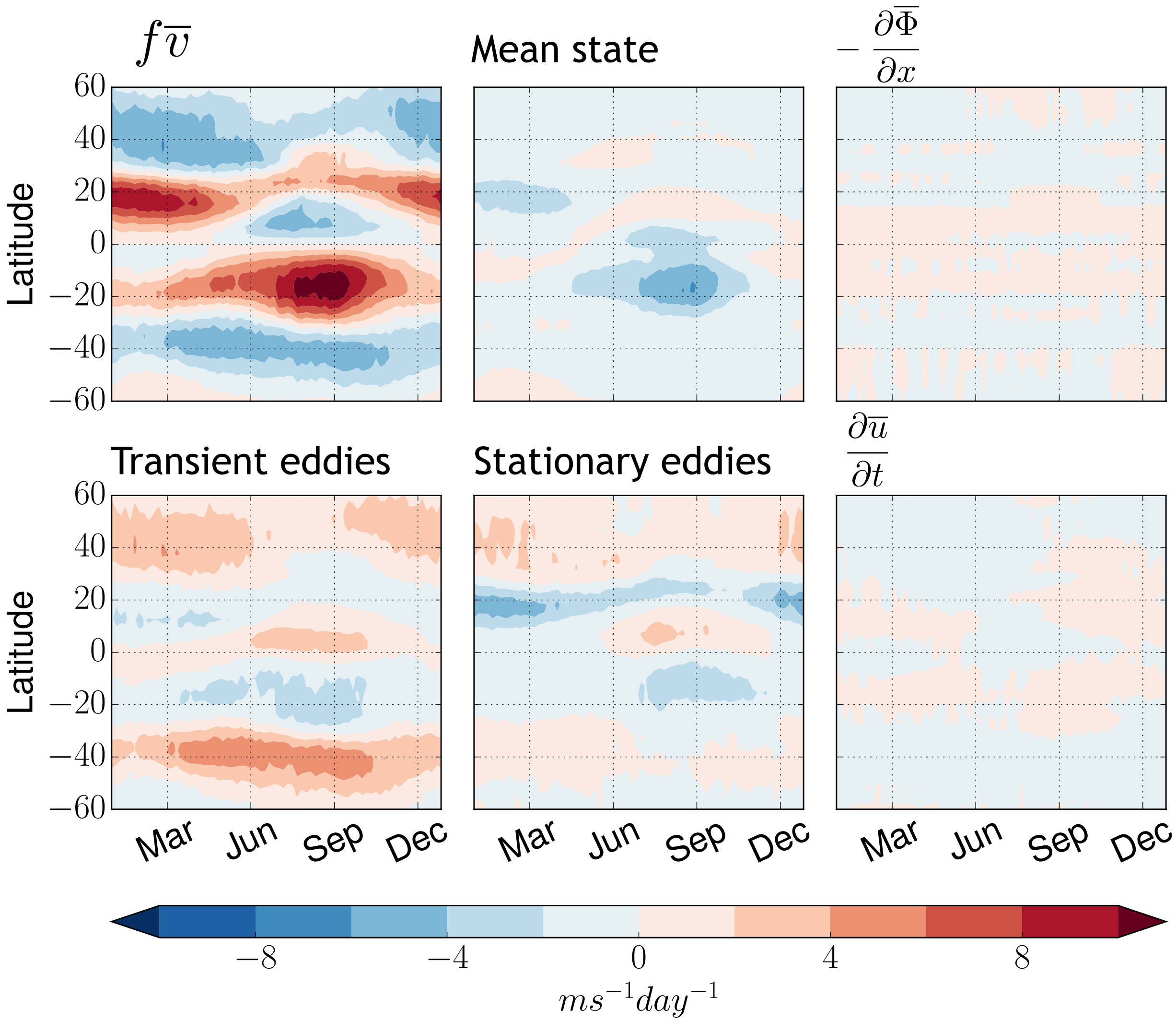
Expectations from recent studies:

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)

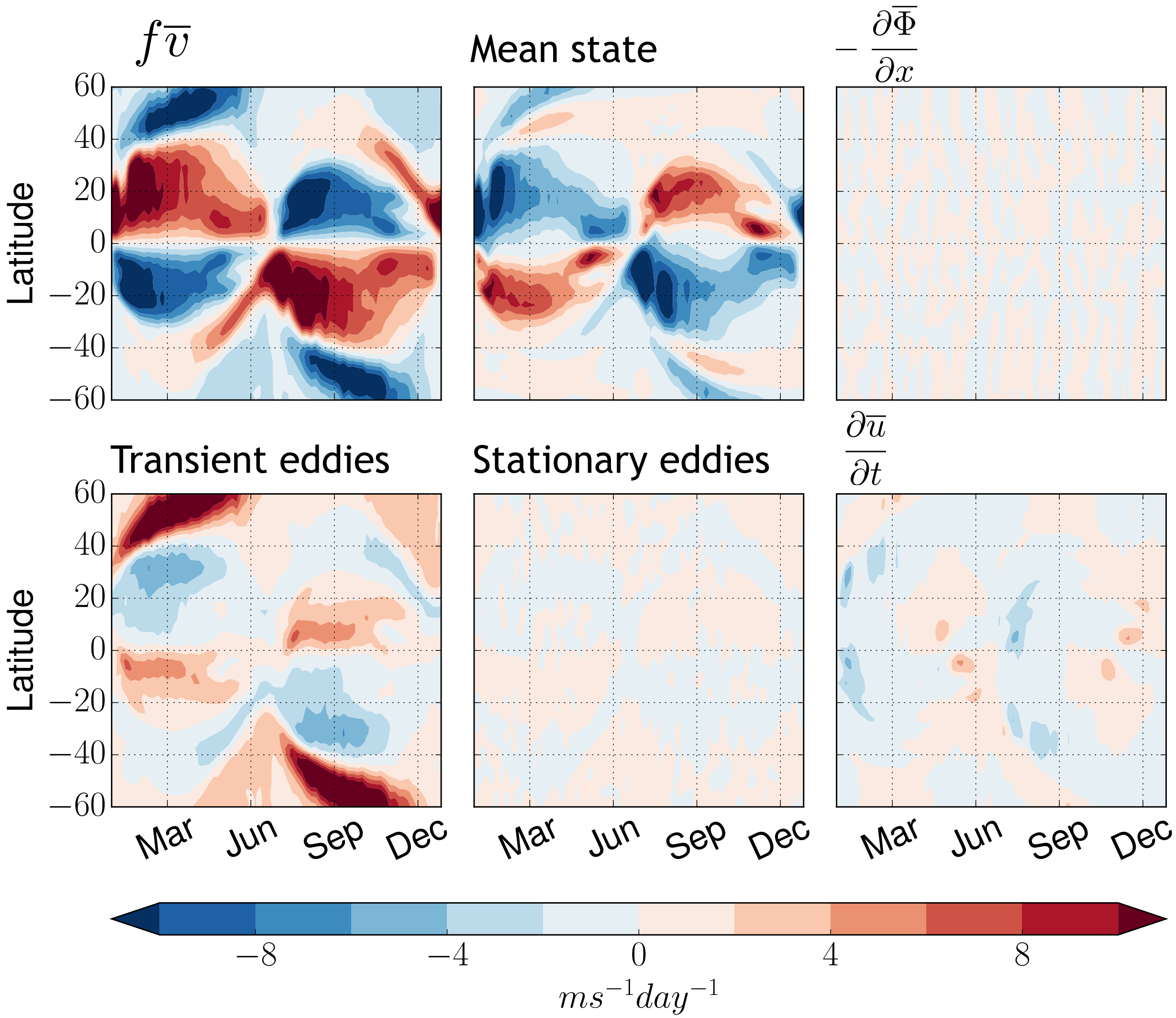
## Continents + topography




- Development of cross-equatorial cell can be seen in fv.
- This is balanced by transient and stationary eddy momentum flux convergence.
- **fv is not in balance with mean state advection.**

# Zonal momentum budget (150 hPa)

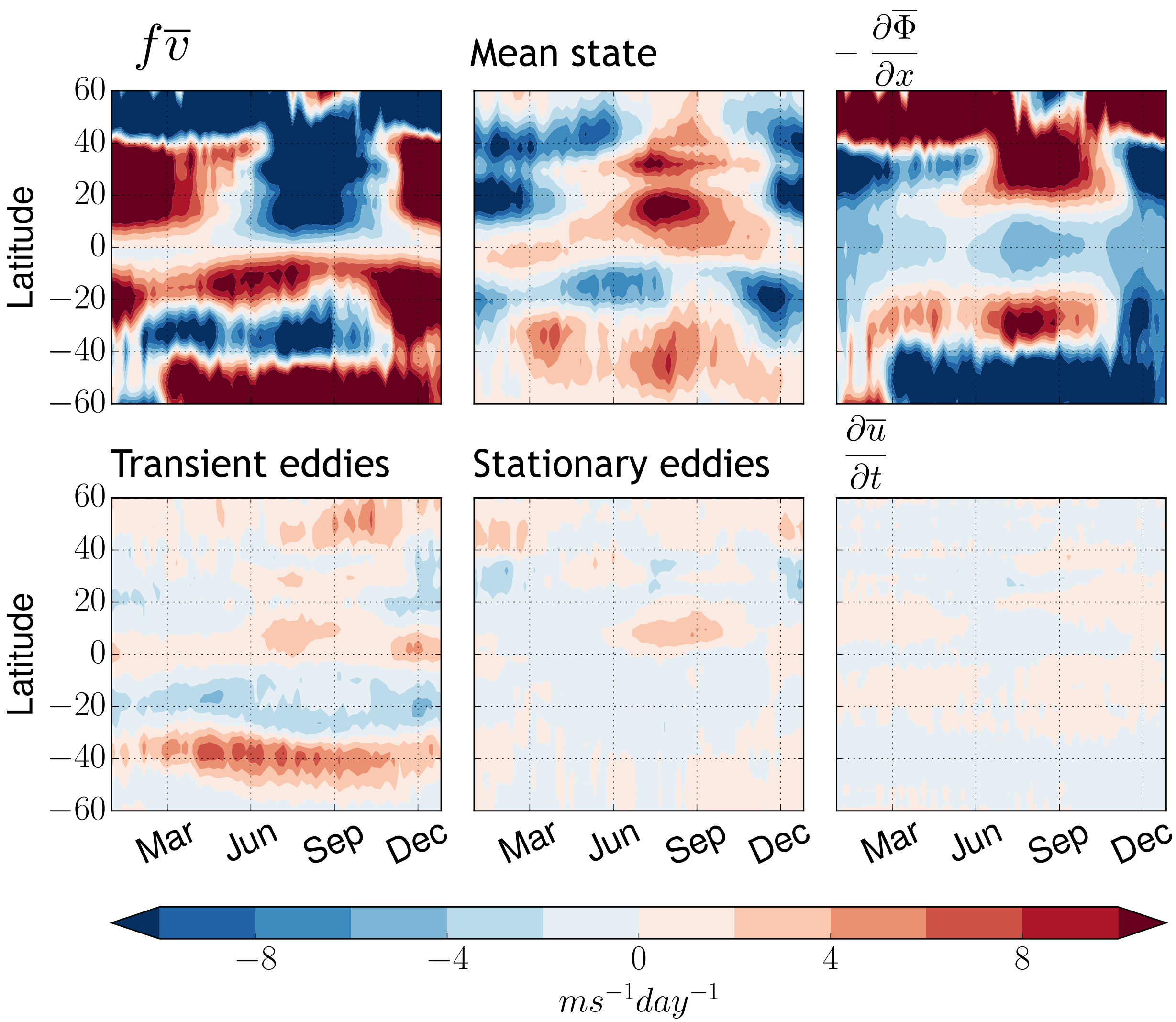
## 2m Aquaplanet

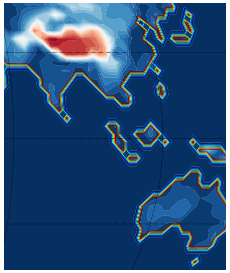



- Development of cross-equatorial cell can again be seen in fv.
- Here this is balanced by **mean state advection and transient eddy momentum flux convergence.**
- Fourier analysis shows strong **low wavenumber** activity in summer.

# 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.