Dynamical constraints on ITCZ migration in planetary atmospheres using a moist GCM

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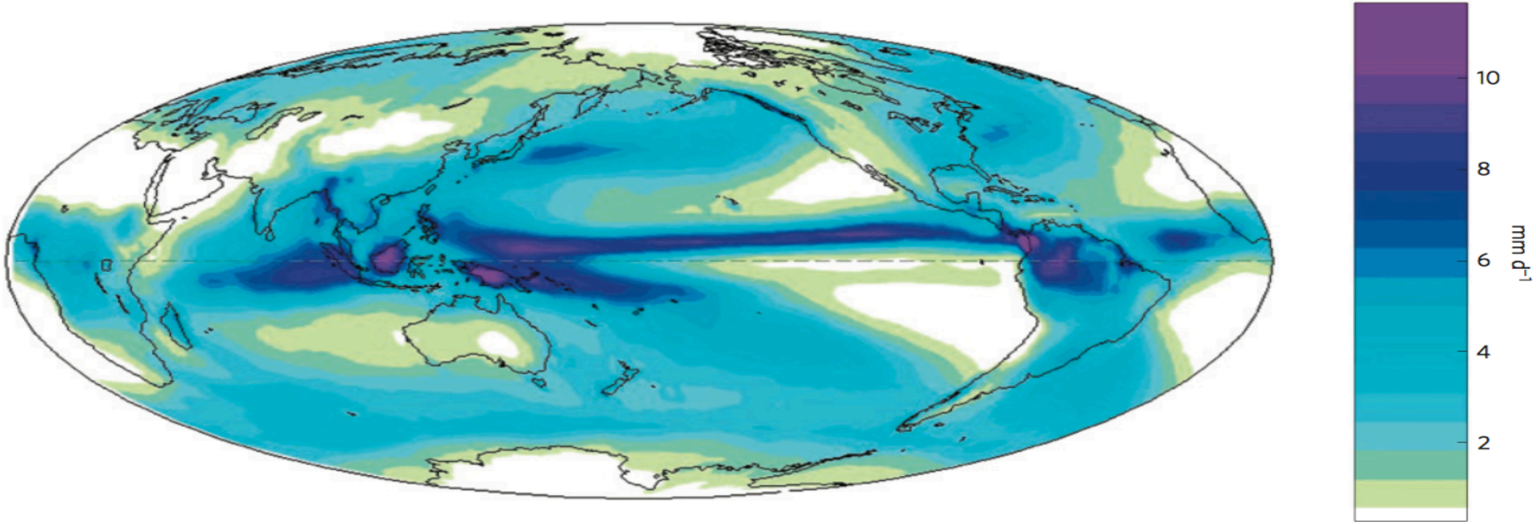
ITCZ on Earth

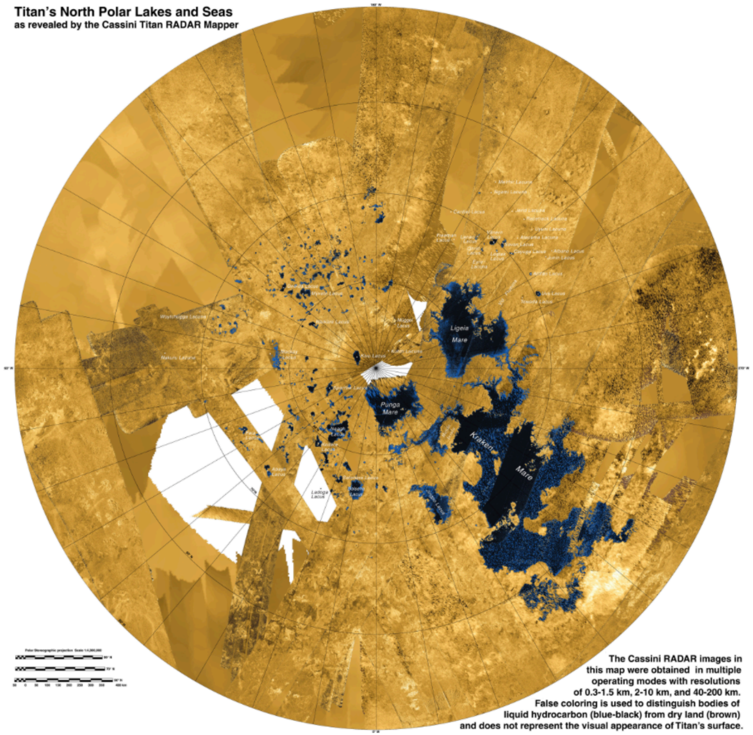
Observed annual-mean precipitation in 2013



(Frierson et al., 2013)

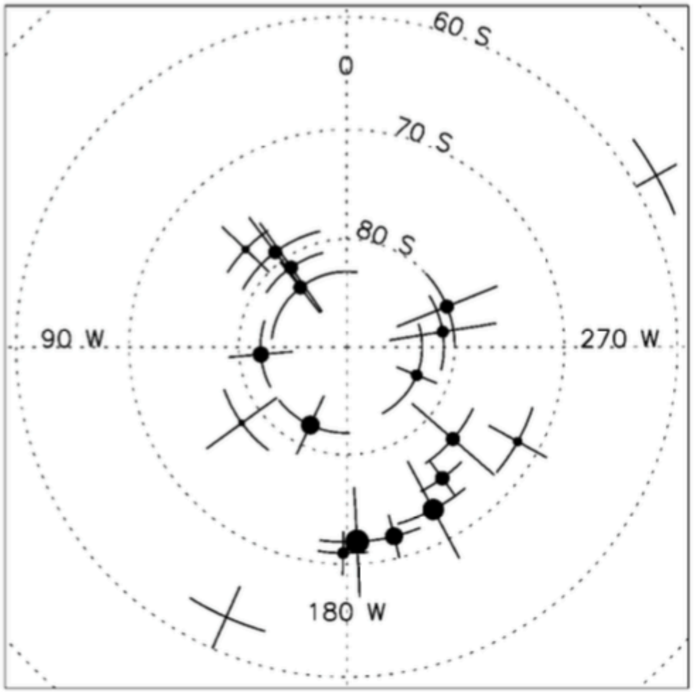
“ITCZ” on Titan reaches pole

North Polar Lakes



(Image source: NASA/ JPL/ ASI/ USGS)

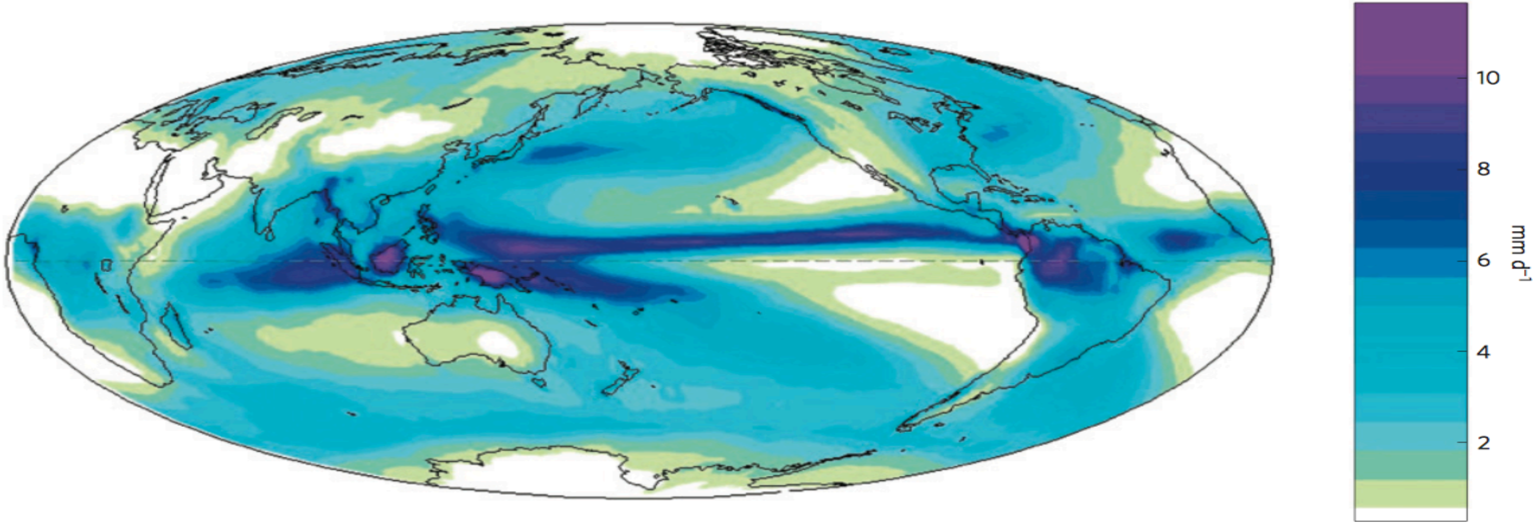
South Polar Clouds



(Bouchez and Brown, 2005)

ITCZ on Earth

Observed annual-mean precipitation in 2013

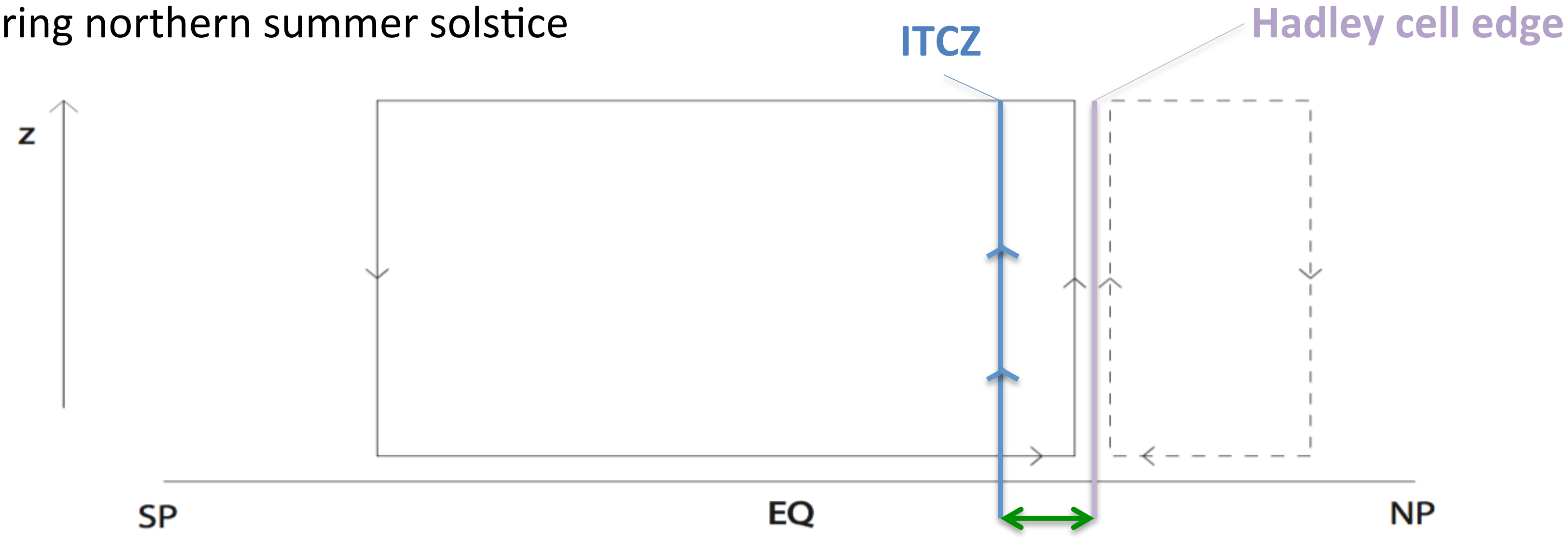


(Frierson et al., 2013)

Our question: Why doesn't Earth's ITCZ reach summer pole?

ITCZ is associated with ascending branch of Hadley cell

During northern summer solstice

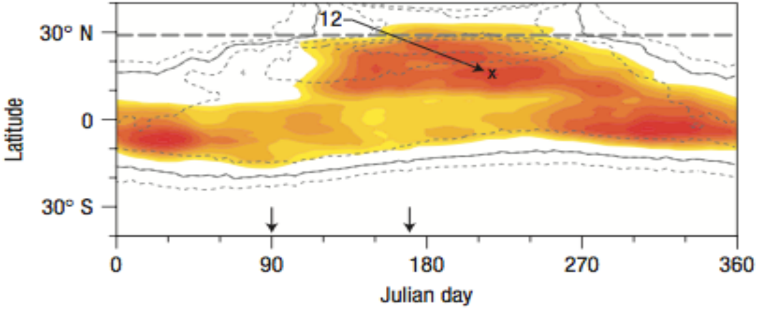


Hadley cell edge = latitude where meridional flow vanishes; well correlated with energy flux equator (Kang et al., 2008) and maximum zonal MSE in most of our aquaplanet simulations

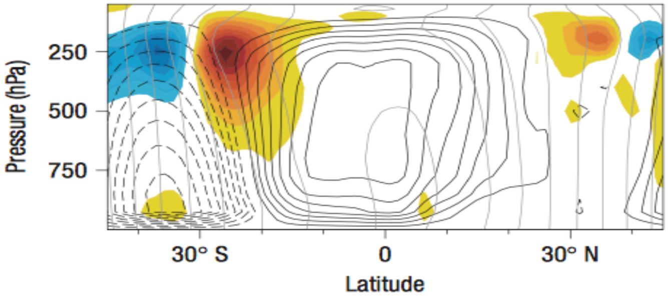
ITCZ = latitude of maximum zonal precipitation

Observations of Asian monsoon sector

Zonal mean precipitation



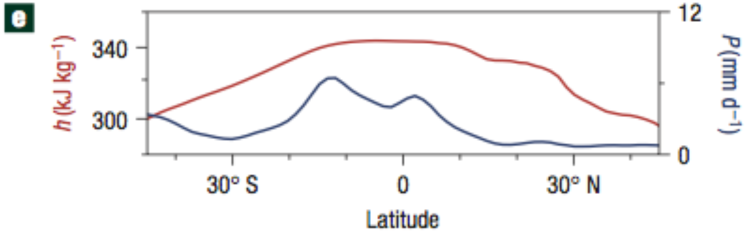
Zonal and time mean streamfunction



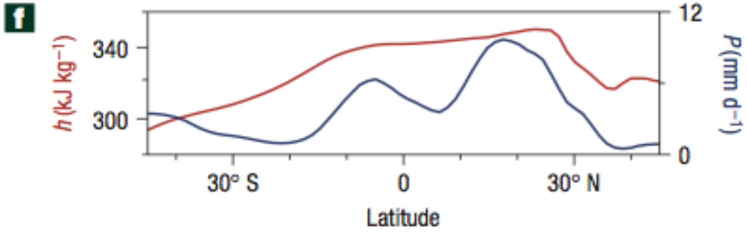
(Bordoni and Schneider, 2008)

Moist static energy (MSE) vs. precipitation

Equinox



Monsoon onset



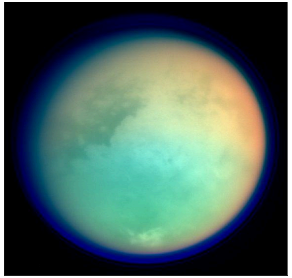
Thermodynamic arguments for ITCZ position on Earth

1) Convection and uplift generally occur over warmest surface waters, just equatorward of latitude of **maximum MSE** (Privé and Plumb, 2007) or at energy flux equator (Kang et al., 2008, 2009)
    - Continental distribution (Philander et al., 1996) and ocean heat transport (Frierson et al., 2013) help explain ITCZ's northern annual-mean position as a result of warmer waters north of equator

2) Surface **heat capacity** affects movement of ITCZ on Earth (Bordoni and Schneider, 2008; Donohoe et al., 2013)
    - Often invoked as part of explanation for far-reaching Hadley cells on Titan

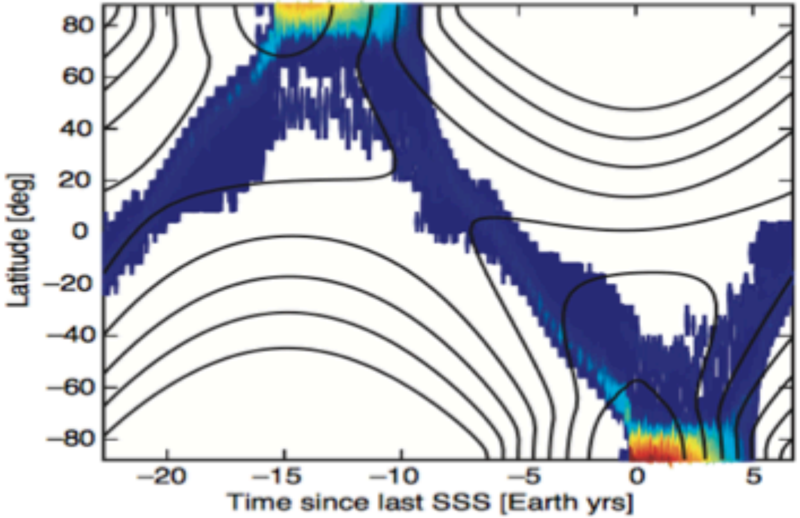
How do dynamics affect ITCZ position?

ITCZ on Titan



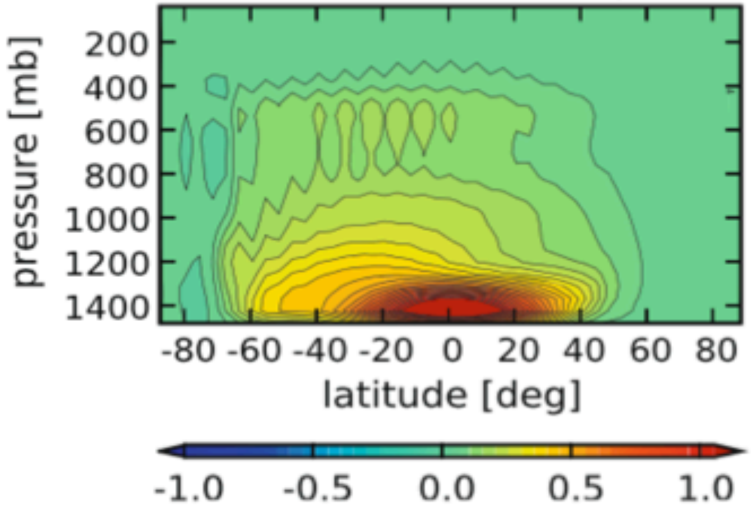
Titan ITCZ reaches pole during solstice, as part of a **global** Hadley cell

Zonal mean precipitation



(Mitchell et al., 2006)

Zonal and time mean streamfunction



(Mitchell et al., 2009)

$$\phi_H \propto \frac{1}{\Omega a}$$

Determined by TOA energy balance

(Held and Hou, 1980)

Use a moist convection aquaplanet GCM with a seasonal cycle

- Model developed by Frierson (2006) and Frierson (2007) using FMS spectral core
  - zonally symmetric, slab mixed layer ocean
  - no clouds or water vapor feedbacks
  - moist convection

- 3-D; 64 x 128 horizontal resolution; 25 vertical levels

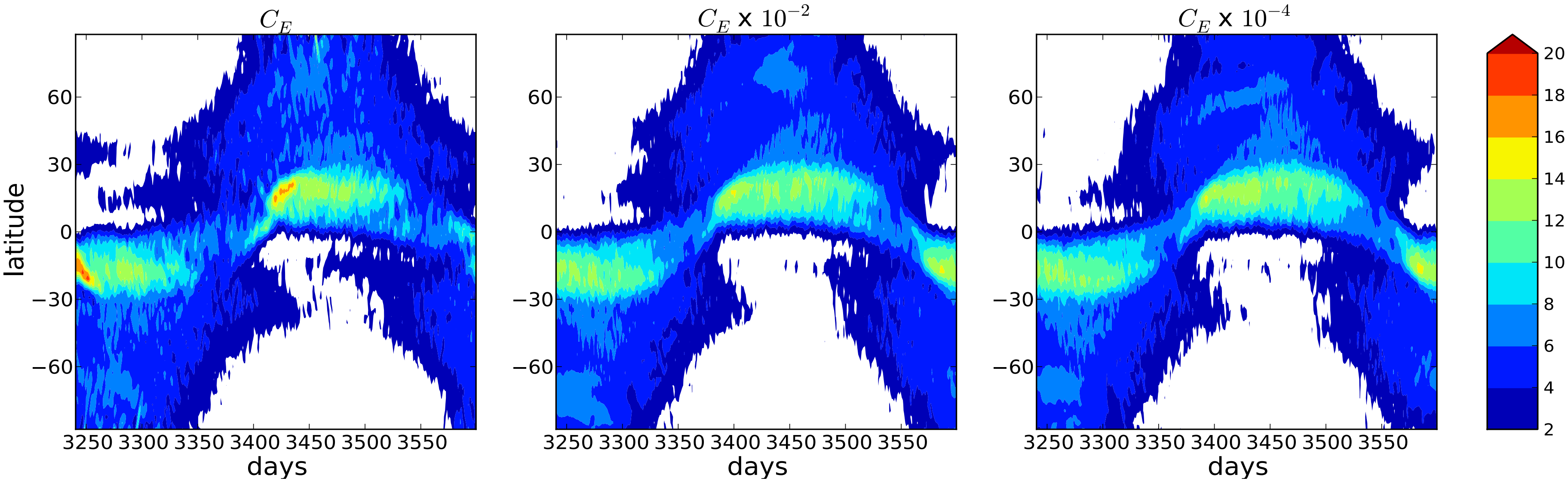
1) Simulations run for decreased **heat capacity** – keeping everything else Earth-like
   - 10-year seasonal runs where top-of-atmosphere insolation is empirical fit to Earth's current insolation (Hartmann, 1994)

2) Simulations run under **eternal solstice** forcing for 10 years

3) Simulations run with $\mathbf{\Omega = \alpha\Omega_E}$ for $\mathbf{\alpha}$ **= 4, 2, 1, 1/2 , 1/4 , 1/6, 1/8 , 1/16 , 1/32**

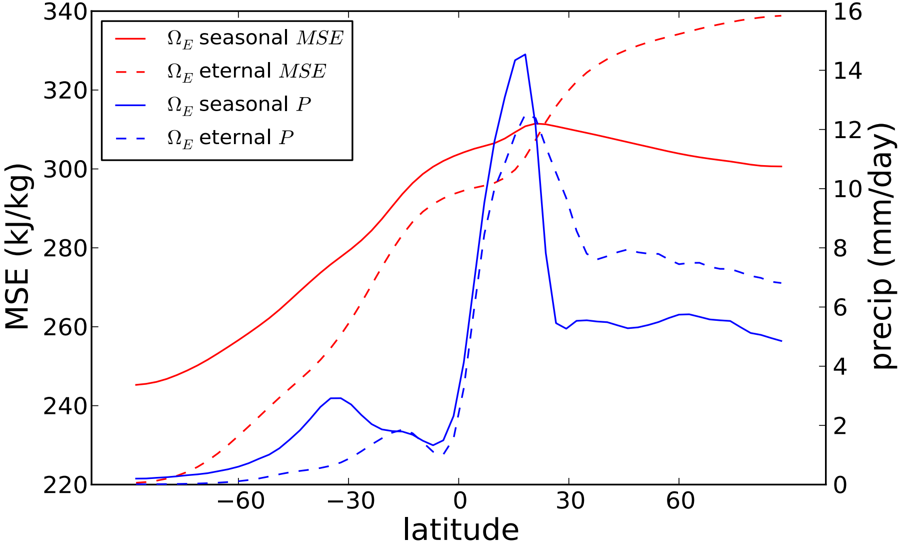
Decreased heat capacity has minimal effect on ITCZ migration

Zonal mean precipitation (mm/day)

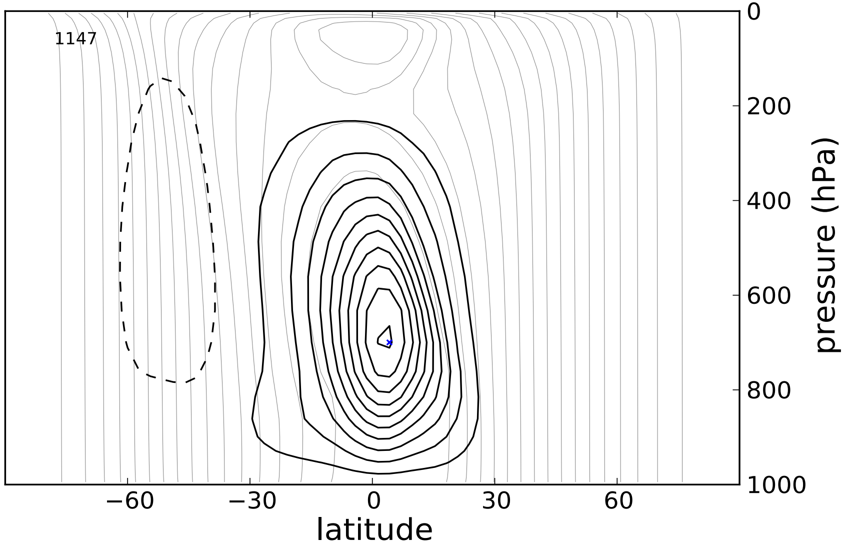


Maximum MSE condition fails in eternal solstice case

Zonal/time mean precipitation and MSE

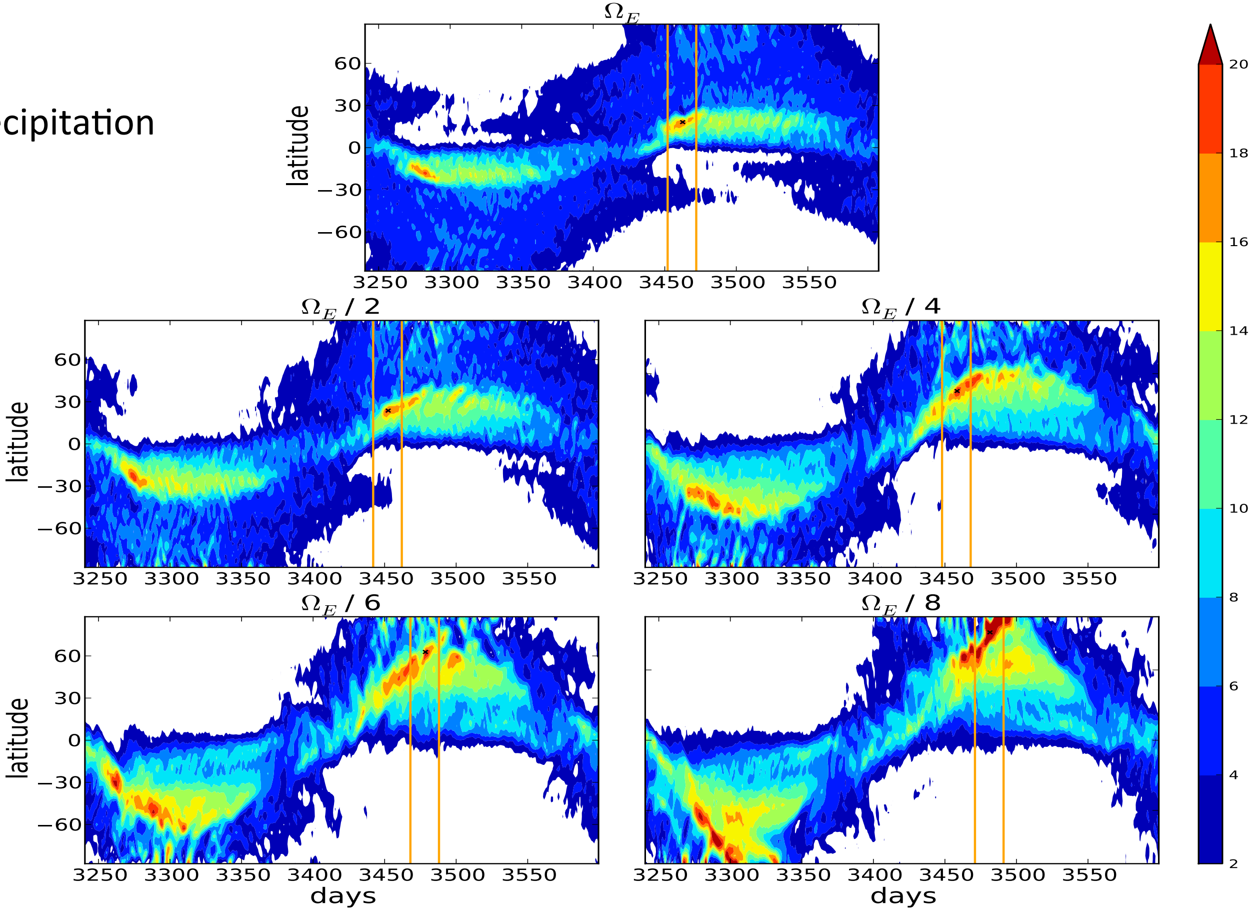


Zonal and time mean streamfunction

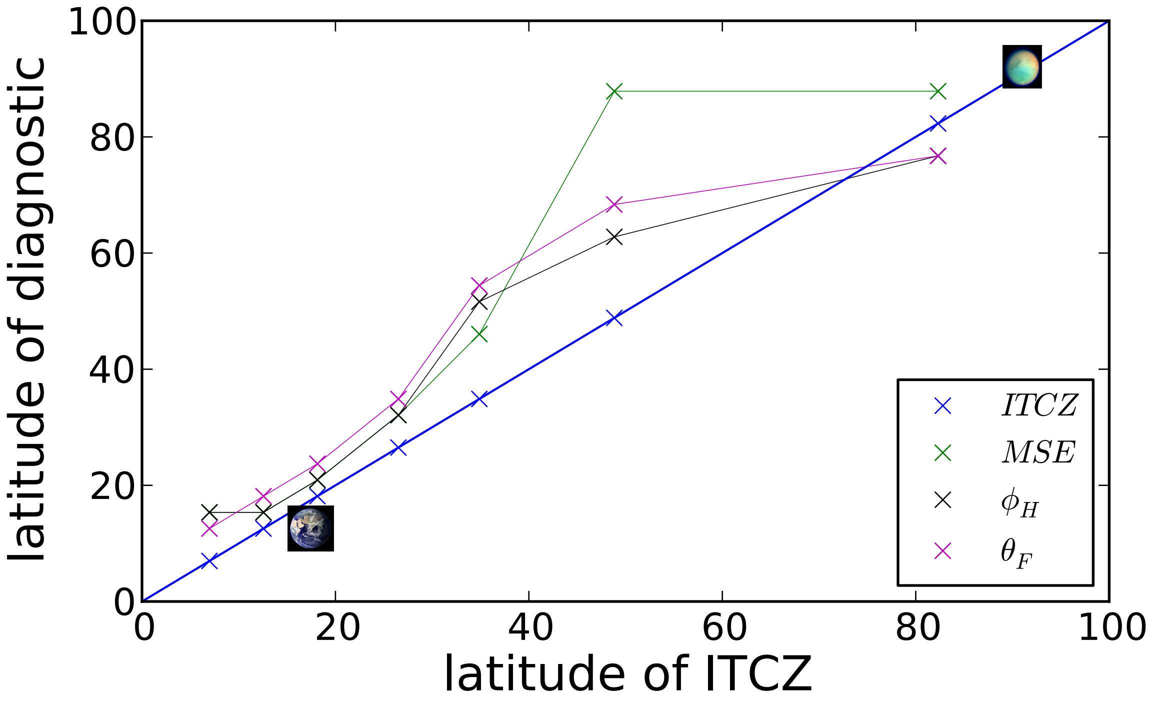


Decreasing rotation has major effect – ITCZ reaches pole beyond $\Omega_E/8$

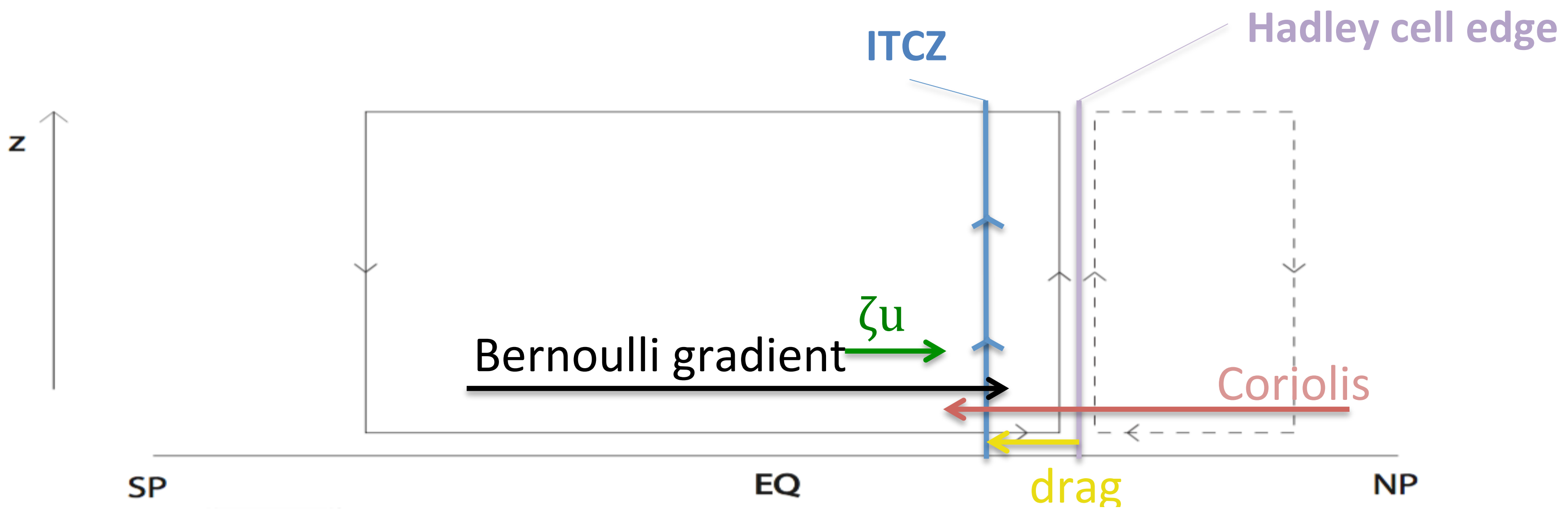
Zonal mean precipitation



ITCZ vs. other diagnostics



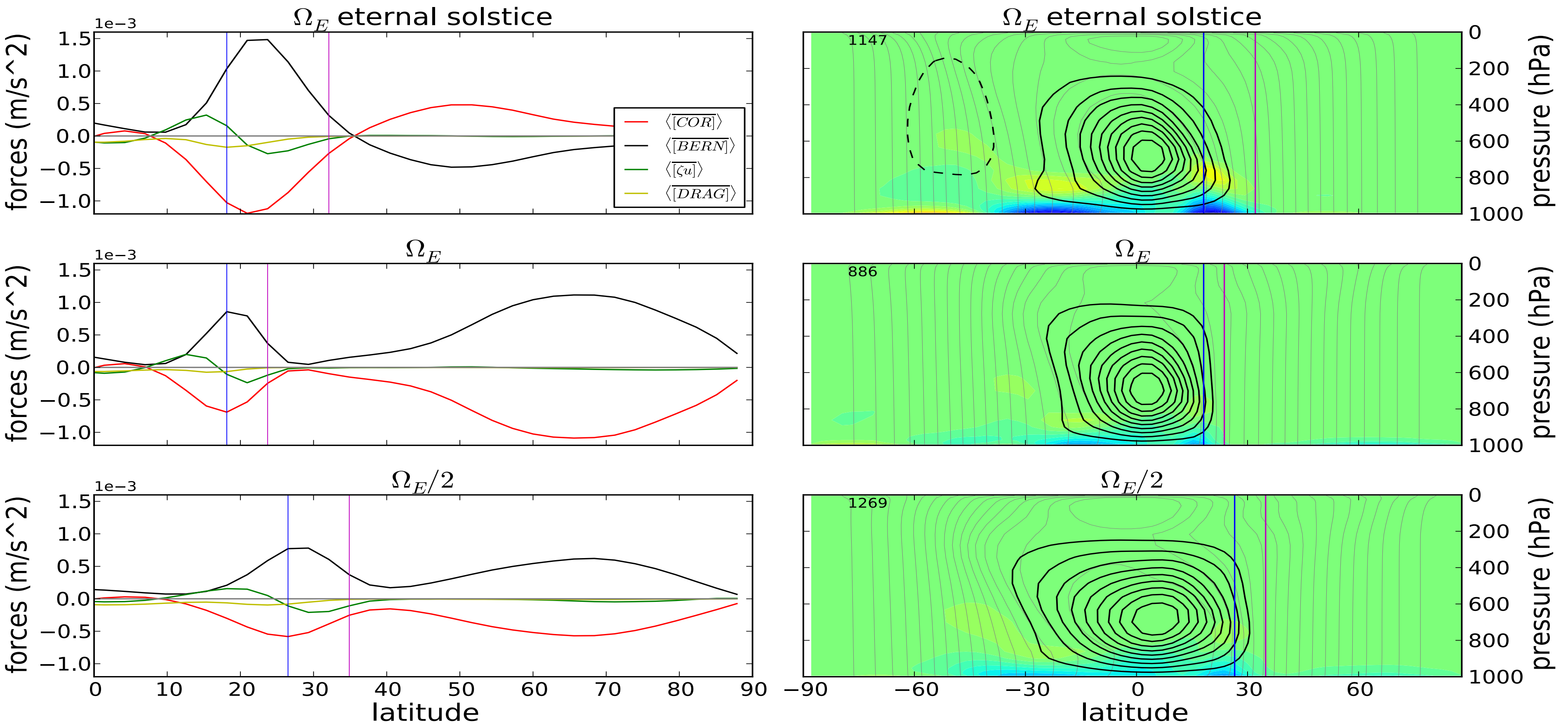
Boundary layer forces



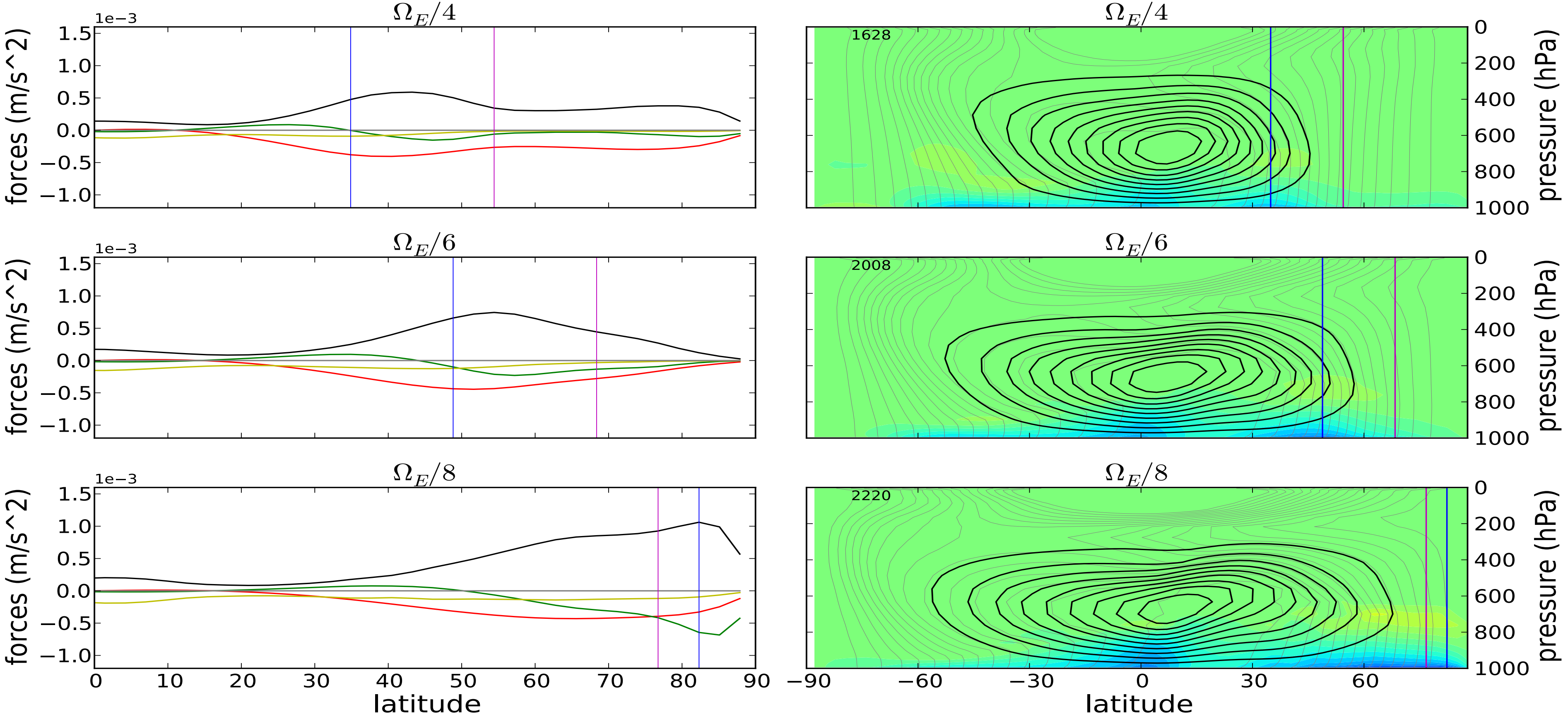
$$\frac{\partial\overline{[B]}}{\partial y} + f\overline{[u]} + \overline{[\zeta u]} \approx -\epsilon\overline{[v]}$$

$$\overline{[B]} = \overline{[\Phi]} + (\overline{[u]}^2 + \overline{[v]}^2)/2$$

Boundary layer forces



Boundary layer forces



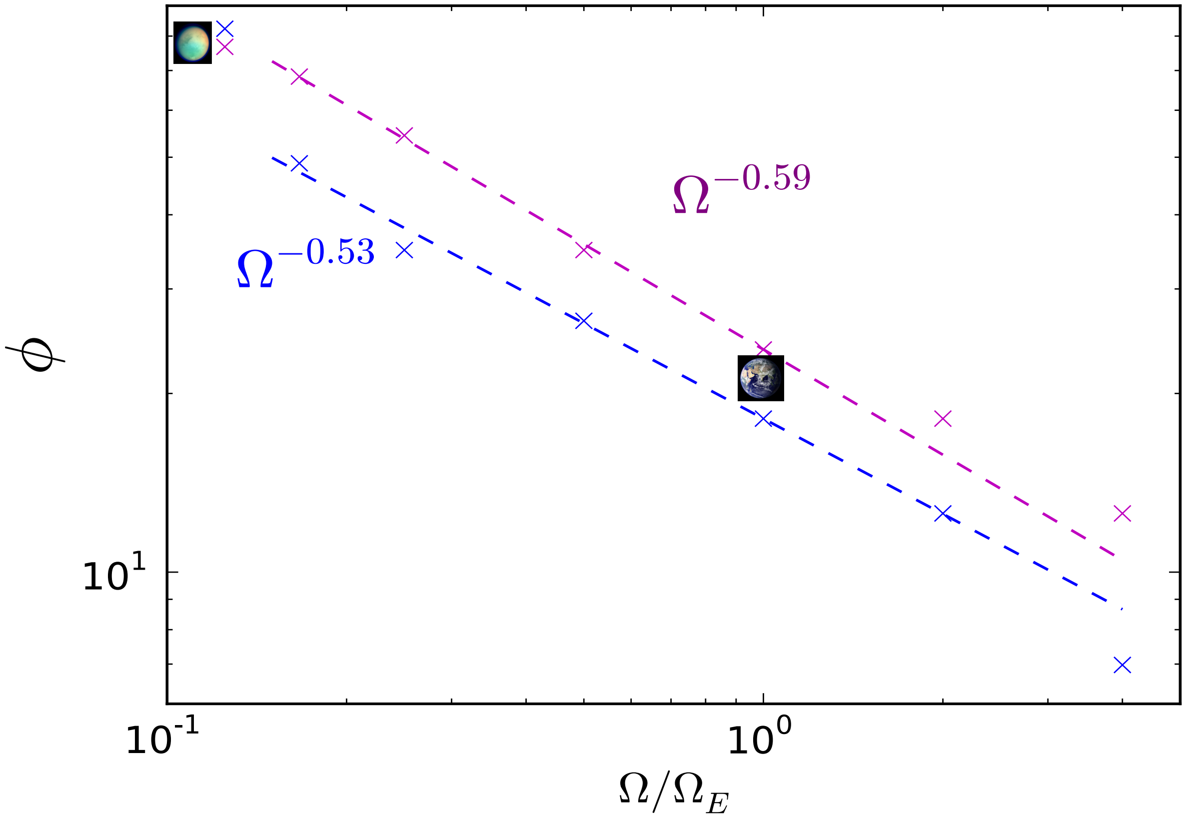
Summary

- Controls on Earth's ITCZ are still unclear and most of the literature has focused on thermodynamic mechanisms as well as on the planet Earth, so we have approached the problem from a planetary perspective and with an emphasis on dynamics

- We find that surface temperature/MSE and heat capacity do not always control ITCZ position, and that rotation rate and/or radius are the dominant controls in an aquaplanet context

- We examine boundary layer dynamics and find the ITCZ migration to be well correlated with friction and other forces.

ITCZ and energy flux equator scale according to power law



$$\phi_H \propto \Omega^{-\frac{2}{3}}$$

(Caballero et al., 2008)