

# The sensitivity of hurricane frequency to ITCZ changes and radiatively forced warming in aquaplanet simulations

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# Tropical cyclone frequency questions

- How does tropical cyclone genesis depend on large-scale circulation and thermodynamic environment?
- Should we generally expect a reduction in number of tropical cyclones with warming (or an increase with cooling)?

*“Existing modelling studies also consistently project decreases in the globally averaged frequency of tropical cyclones by 6-34% [by 2100].”*

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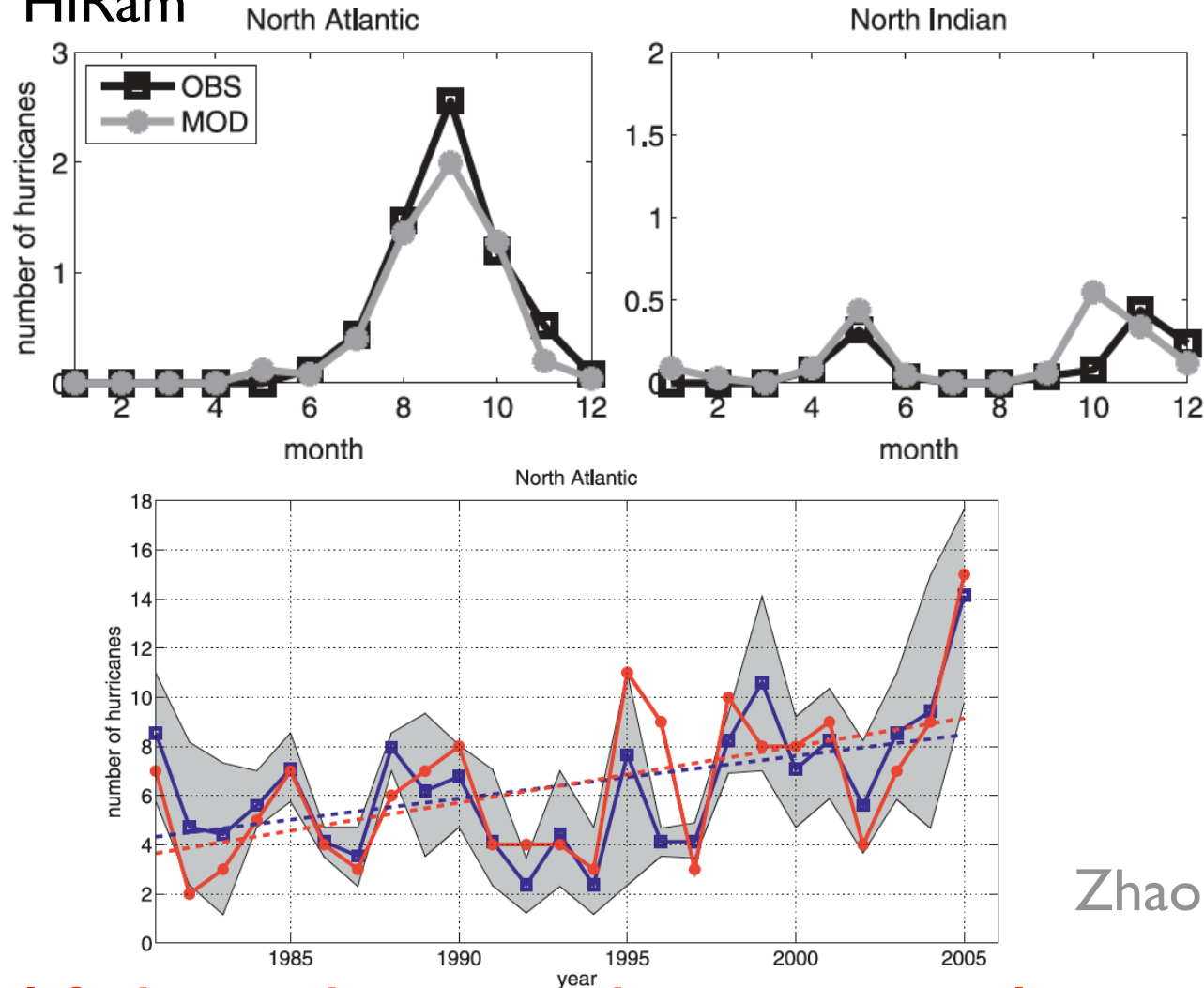
*“Existing modelling studies also consistently project decreases in the globally averaged frequency of tropical cyclones by 6-34% [by 2100].”*

**Large uncertainty in basin-scale projections.**

# Approach:

Take a high-resolution aGCM that simulates TC genesis...

GFDL's 50-km 'HiRam'

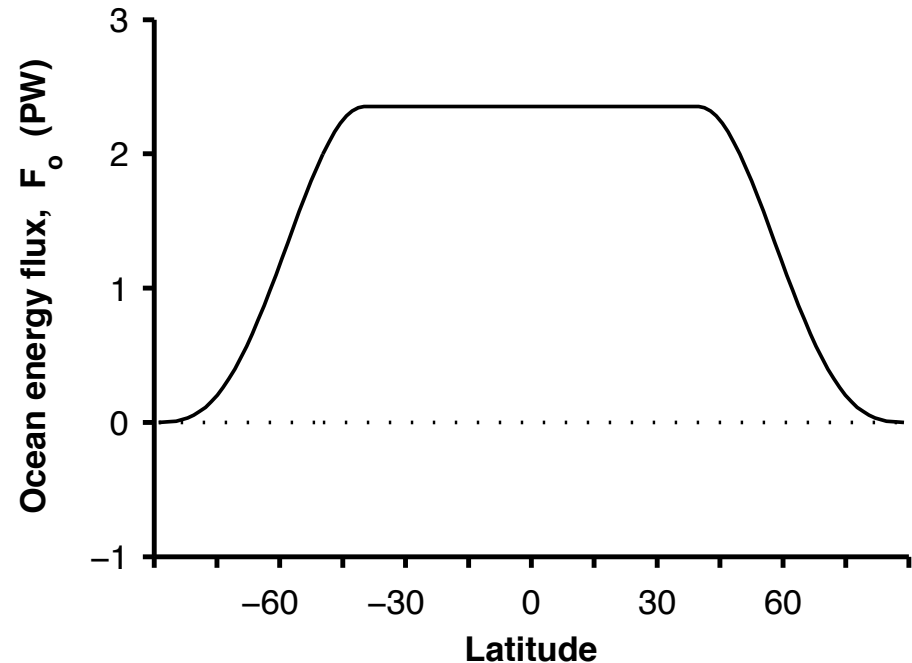
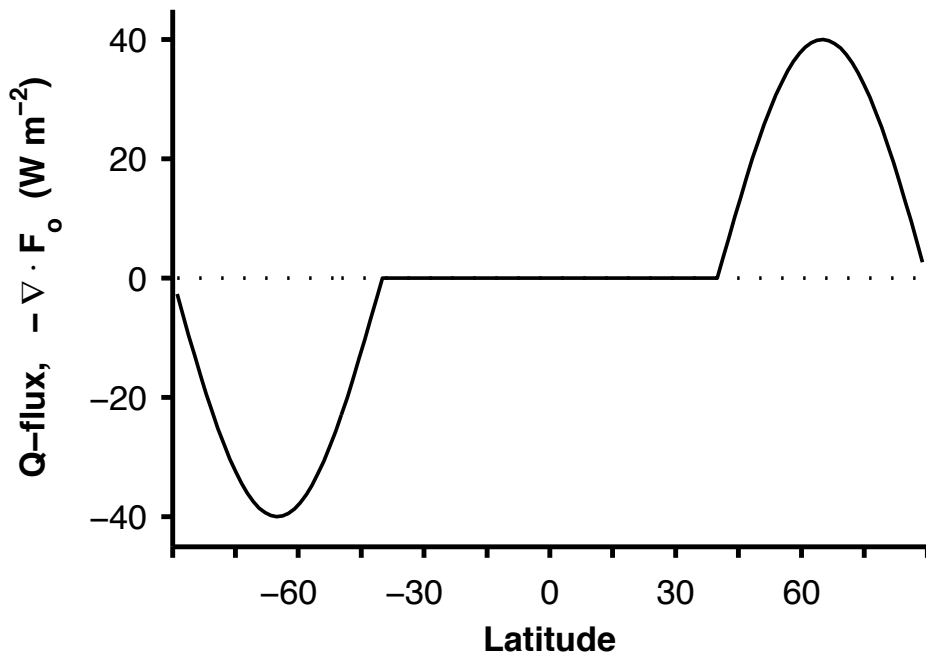


Zhao et al. (2009)

...and simplify boundary conditions to isolate sensitivities.

# Aquaplanet slab ocean lower BC with imposed cross-equatorial ocean heat flux

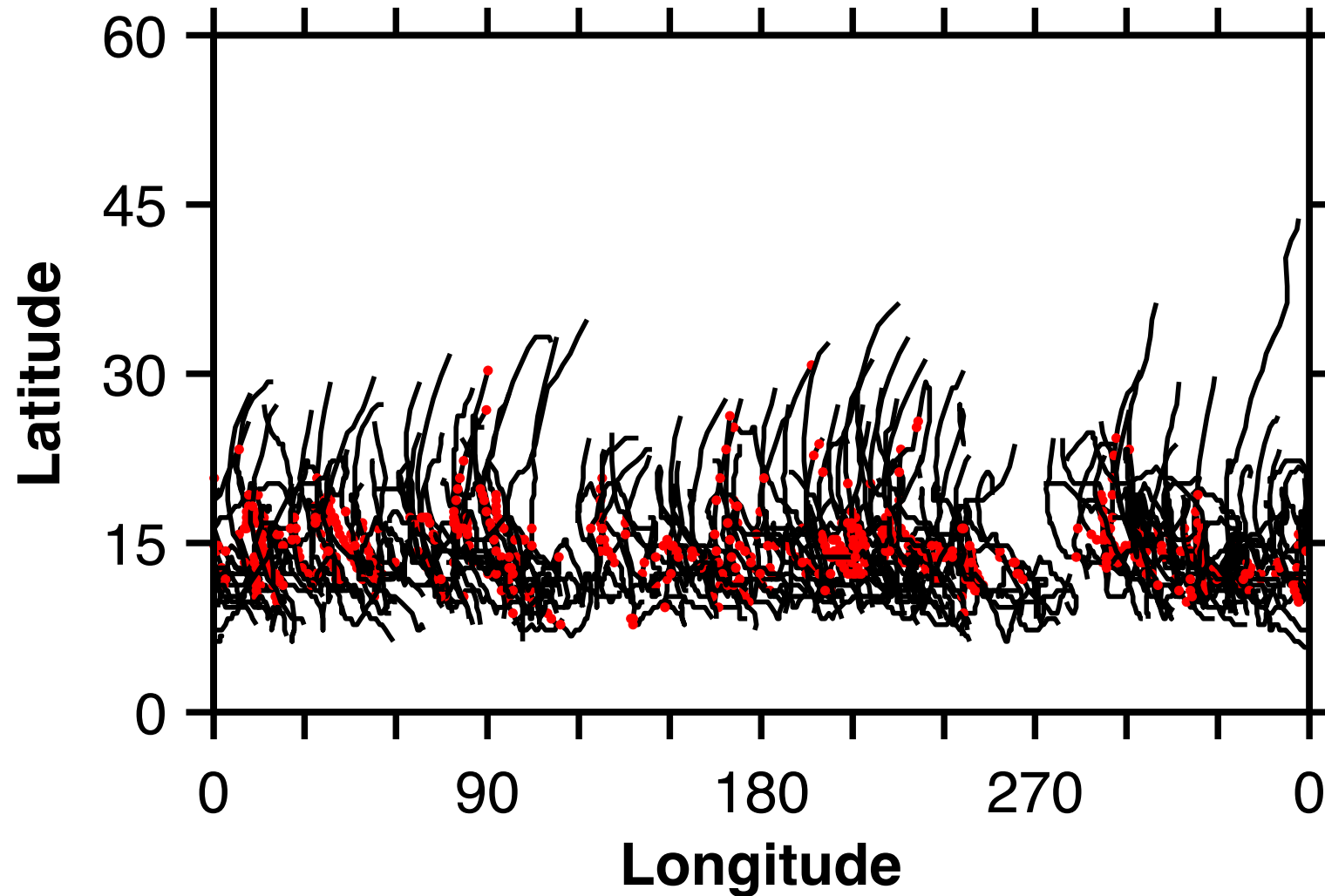
aGCM identical to that used with comprehensive boundary conditions



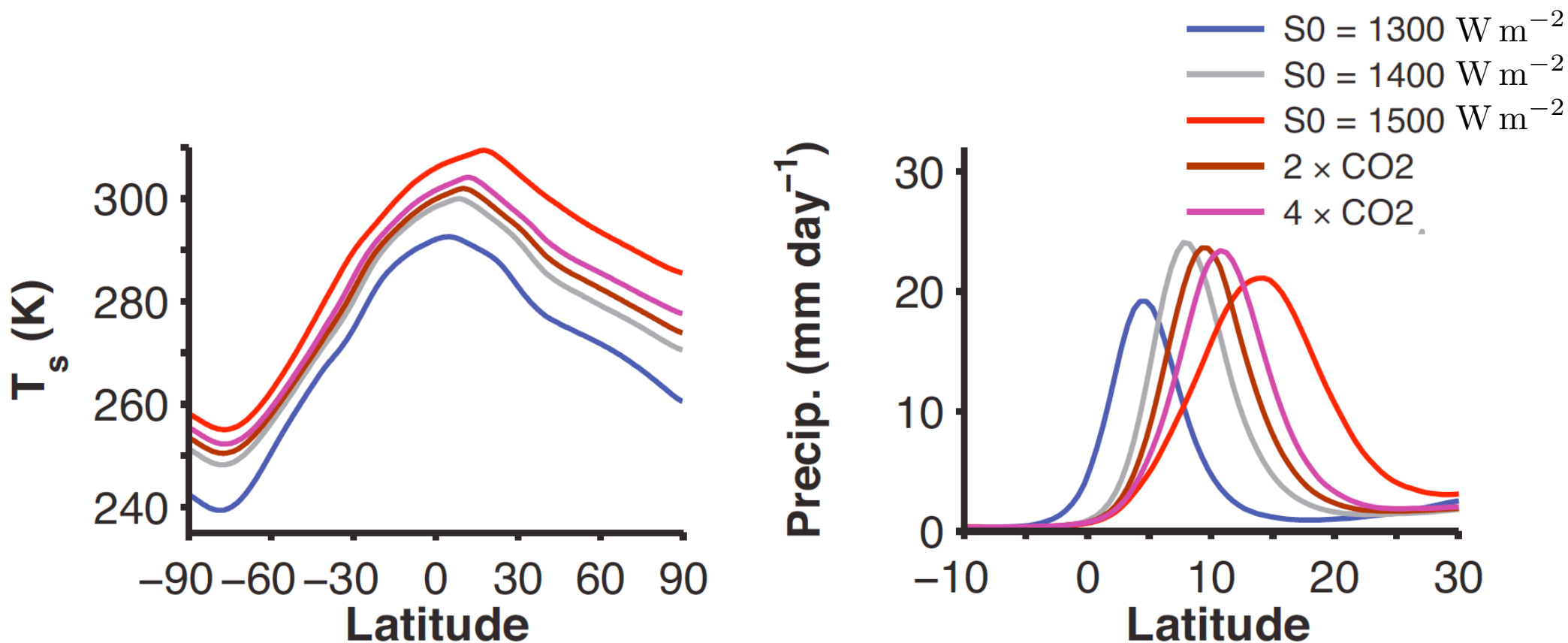
Kang, Held, et al. (2008, 2009, 2012)

Hemispheric asymmetry can be viewed as (i) 'perpetual summer'  
(ii) an idealization of the cross-equatorial ocean heat flux  
(iii) a representation of inhomogeneous radiative forcing agents  
(e.g., sulfate aerosols).

# Explicitly simulated (& tracked) “hurricanes”



# Perturbed radiation (unchanged ocean heat flux)



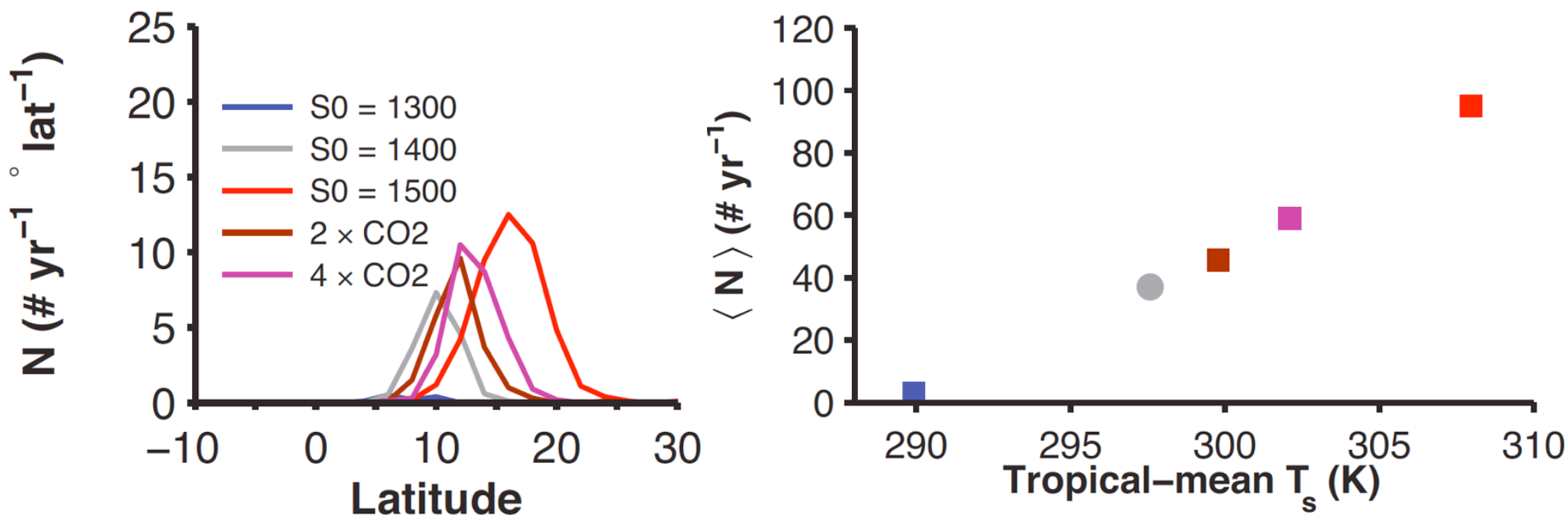
Mean climate becomes more hemispherically asymmetric through inhomogeneous radiative feedbacks.

*Known sensitivity to representation of clouds (i.e., GCM dependent):*

Kang et al. (2009), Zhang et al. (2010), Frierson & Hwang (2012)

# Perturbed radiation (unchanged ocean heat flux)

Genesis shifts poleward with ITCZ and amplifies

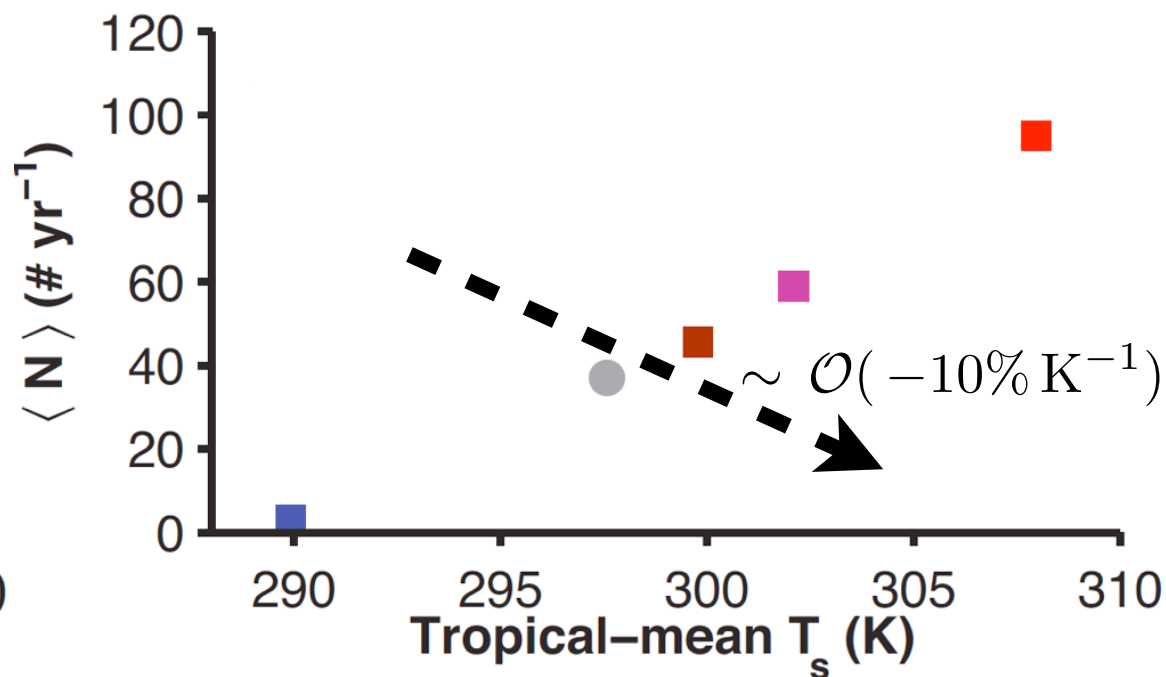
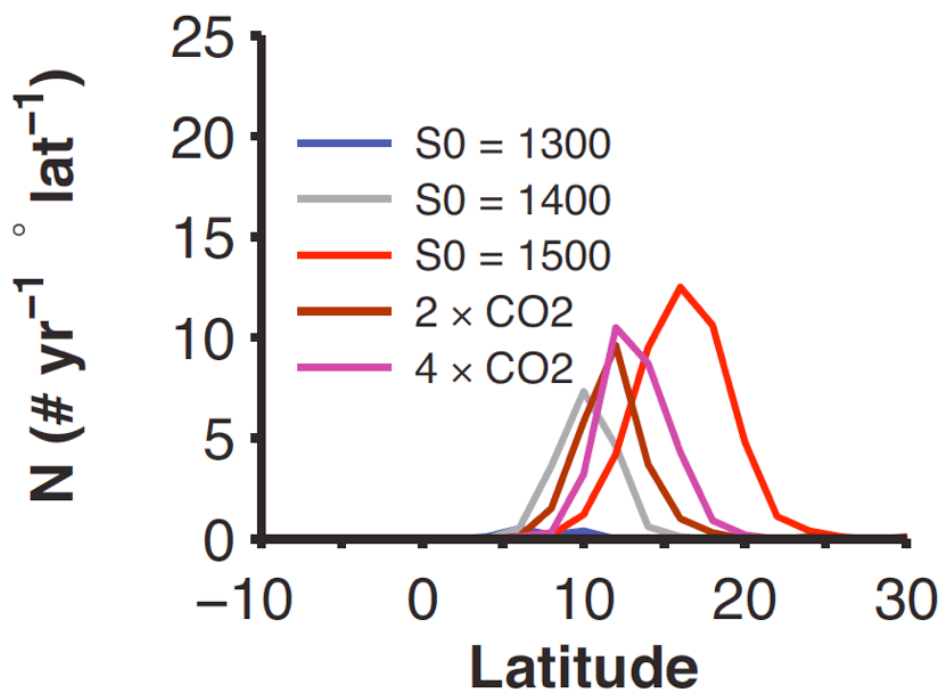


Results in *increased* hurricane frequency in warmer climates.



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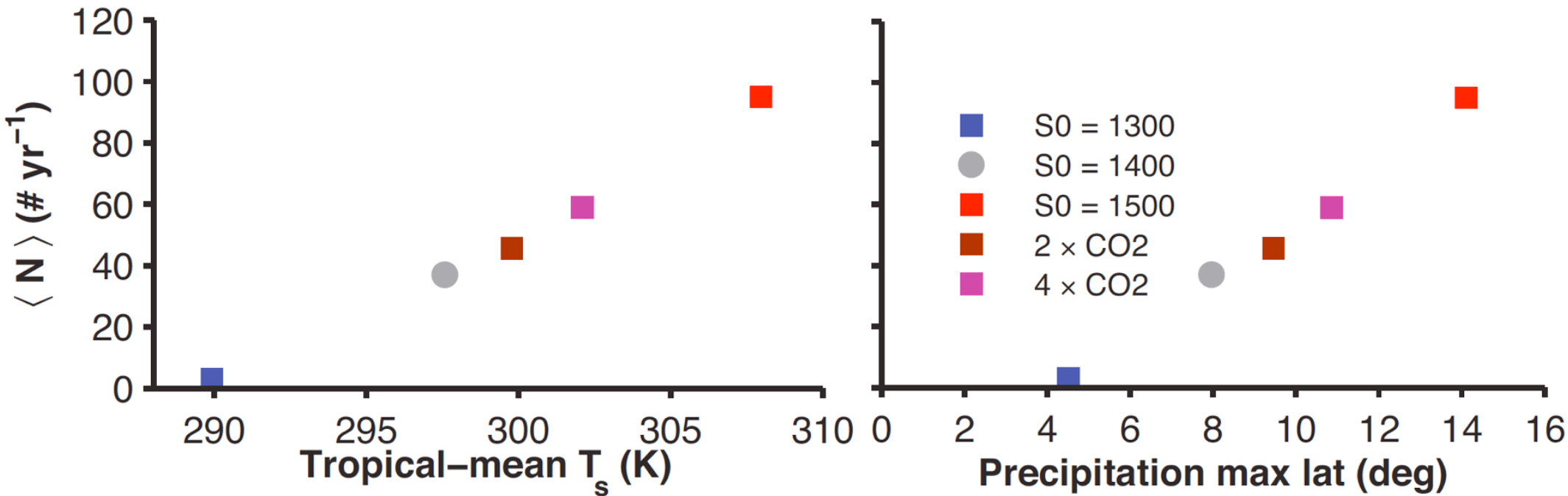


Results in *increased* hurricane frequency in warmer climates.

(Typical projection is *decreased* global TC frequency.)

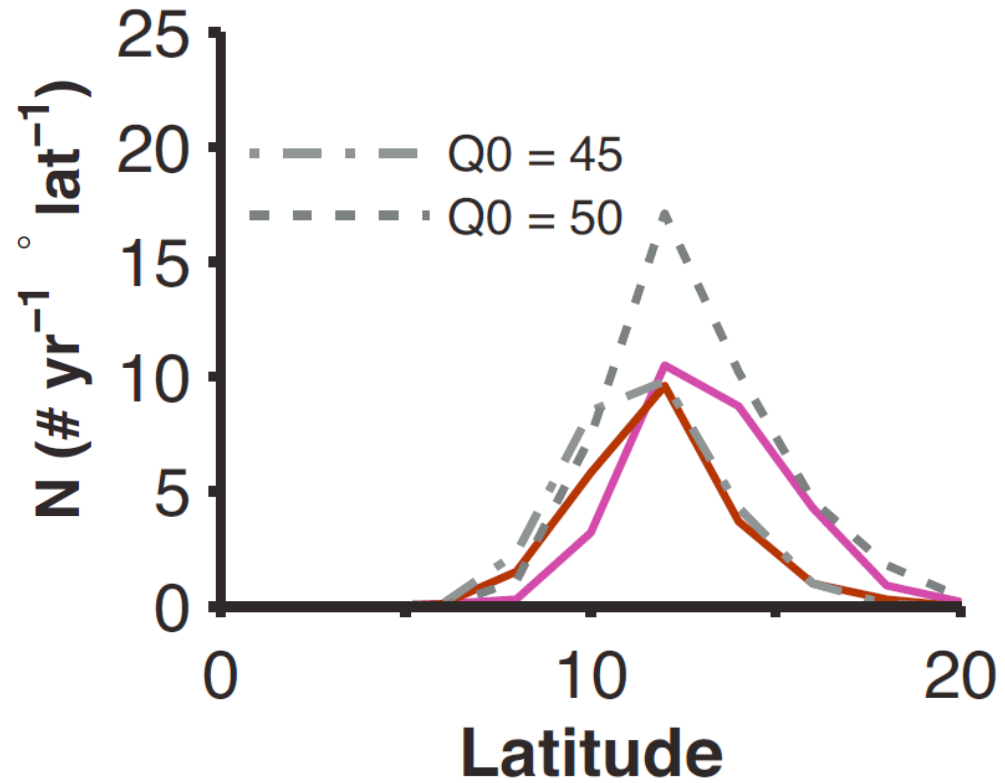
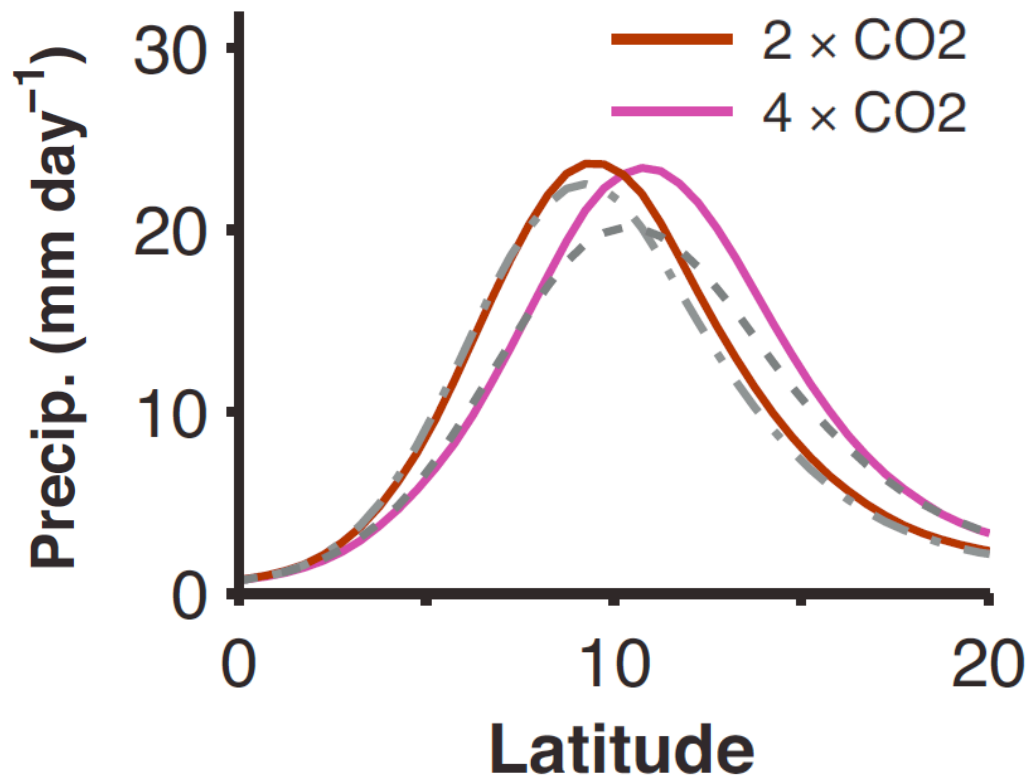
# Perturbed radiation (unchanged ocean heat flux)

Compact relationship between hurricane frequency and temperature & ITCZ latitude



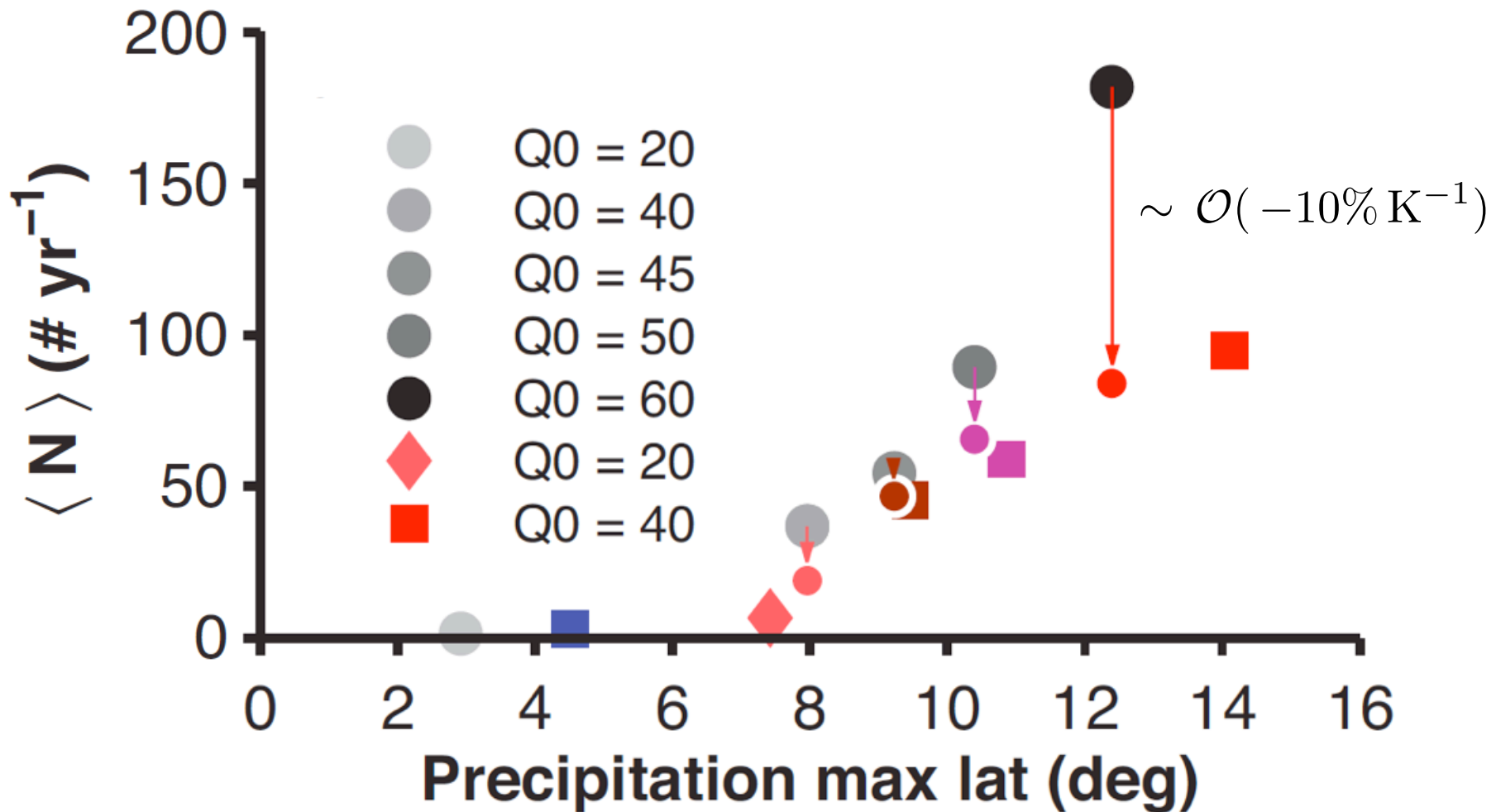
Increase consistent with shift in ITCZ latitude, which we can isolate by manipulating the ocean heat transport.

# Perturbed ocean heat transport & radiation



Reduction in hurricane frequency with warming  
*if* ITCZ position is unchanged.

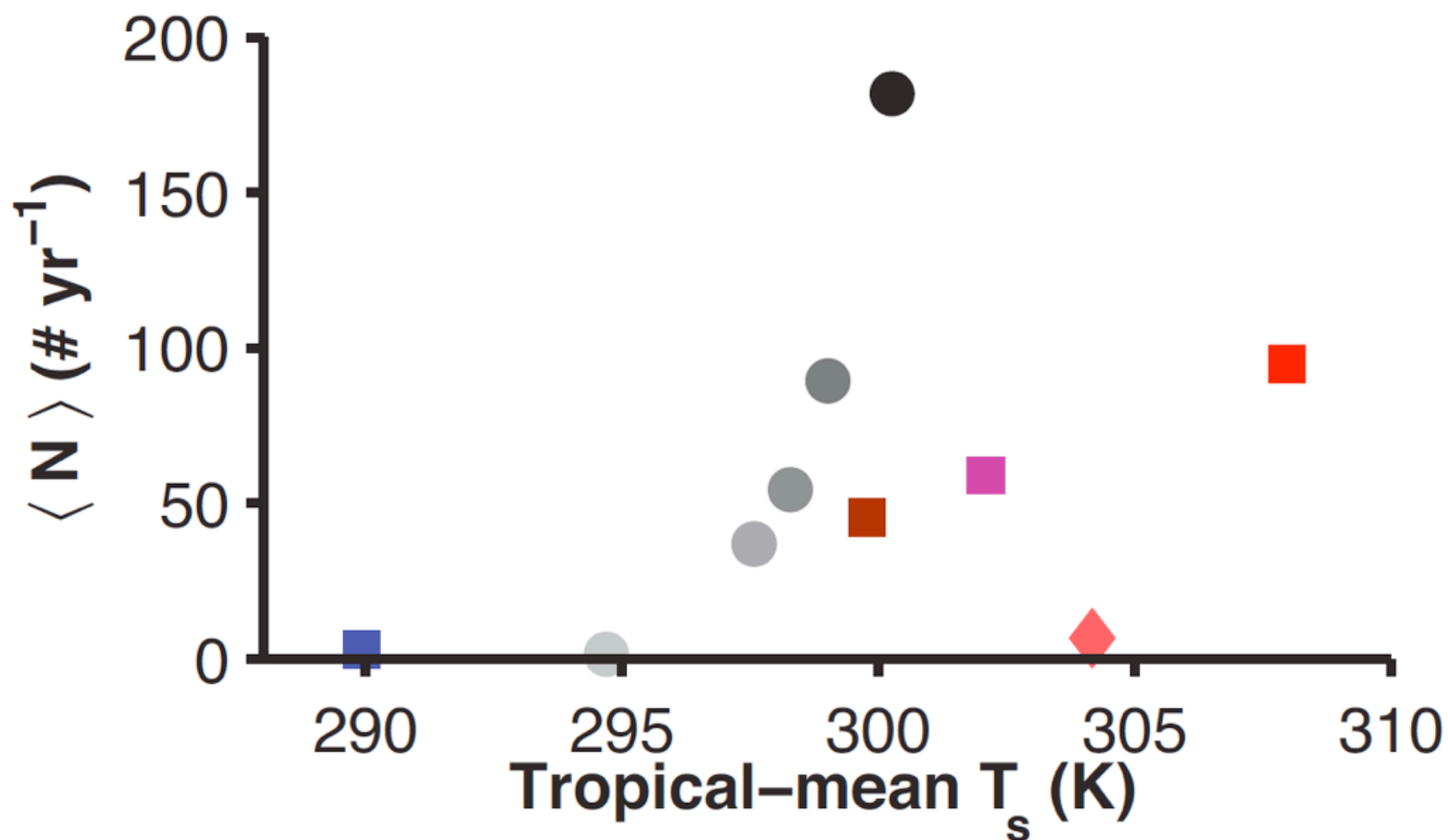
# Perturbed ocean heat transport & radiation



Simple estimate for change in frequency with warming  
*when comparing climates with similar ITCZ latitude:*

$$\tilde{N} = N_{\text{ref}} \exp(-0.10\delta T)$$

# Perturbed ocean heat transport & radiation



Temperature in isolation does not account for full set of simulation results.

# Recap of Hurricane Sensitivity

Fractional change in global number of hurricanes under...

Uniform warming:

$$\frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \langle T_s \rangle} \approx -\frac{10\%}{\text{K}}$$

ITCZ shifts:

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Shift in ITCZ per degree warming (fixed asymmetry):

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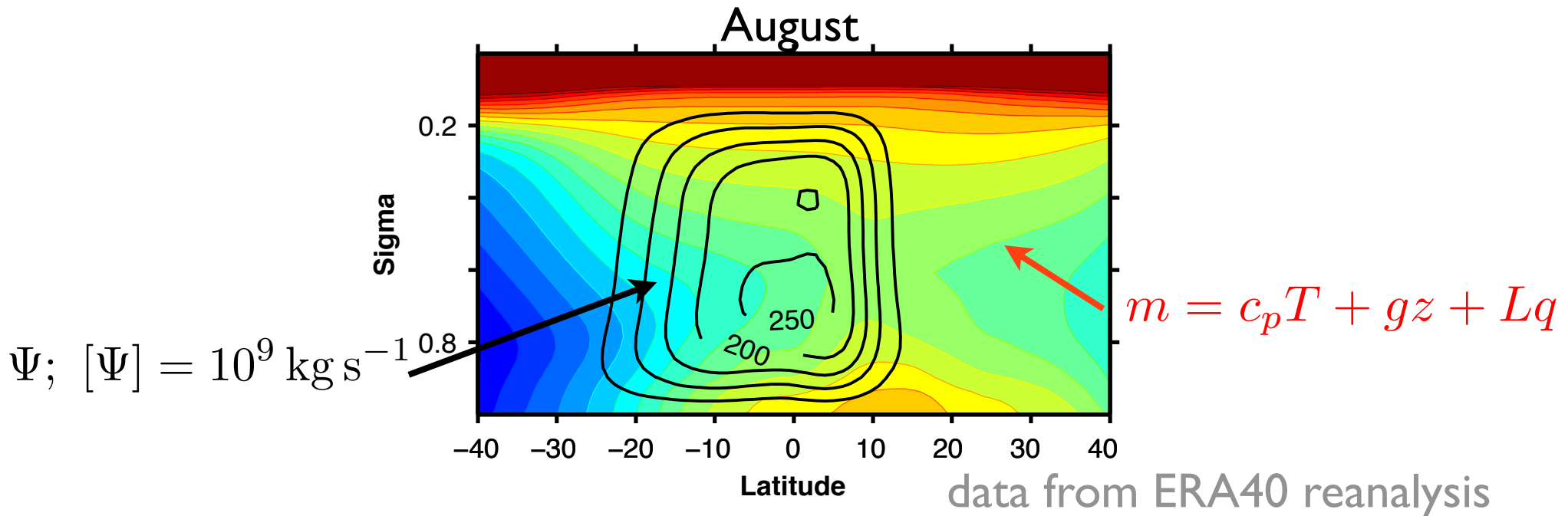
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These sensitivities do not vary substantially between solar and GHG forcing.

# Hadley circulation changes are important



TOA energy balance (not SST) is the basis for cross-equatorial Hadley circulation theory.

Lindzen & Hou (1988), Kang & Held (2012), Merlis et al. (2013)

# Hurricane Working Group

Fractional change in global number of hurricanes under...

**Uniform warming:** 
$$\frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \langle T_s \rangle} \approx -\frac{10\%}{\text{K}}$$

+2K, 2xCO<sub>2</sub> experiments are a useful for this sensitivity...  
though may minimize circulation shifts.

Are patterned SST anomaly experiments useful for probing hemispheric asymmetry?

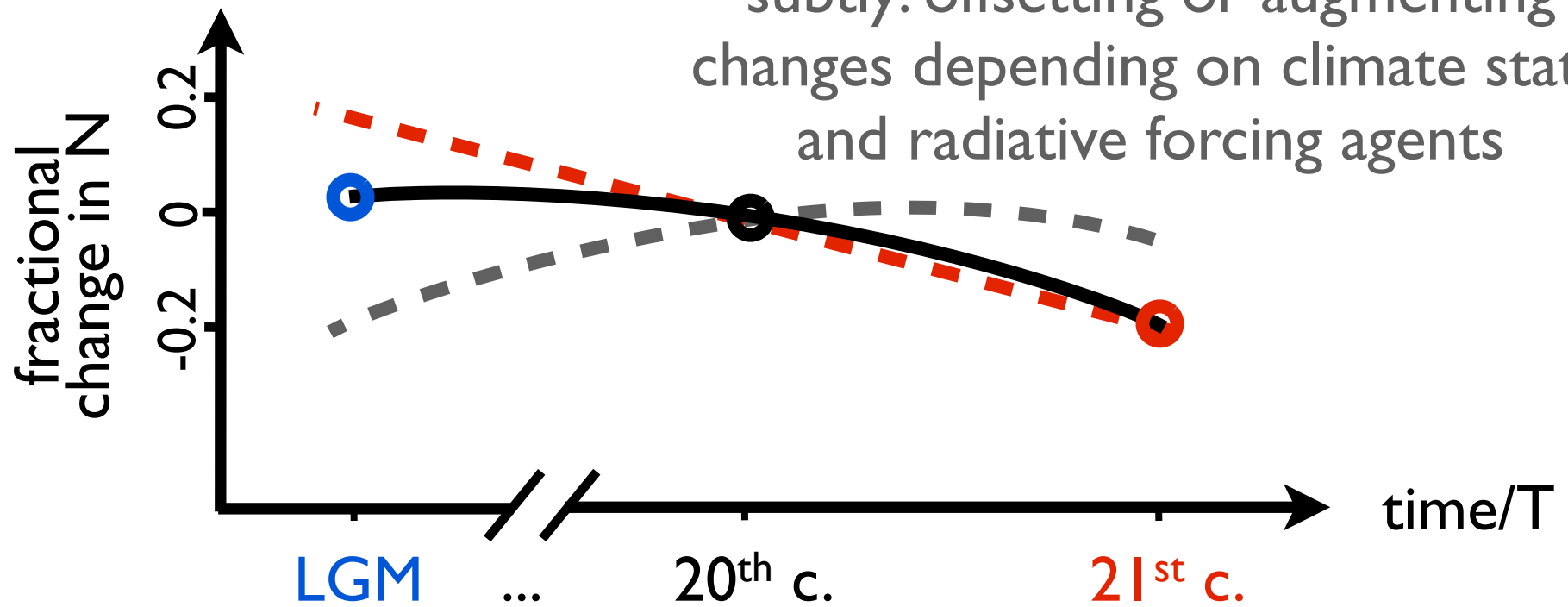
**ITCZ shifts:** 
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(NH sulfate aerosol reduction and AMOC variability & changes)

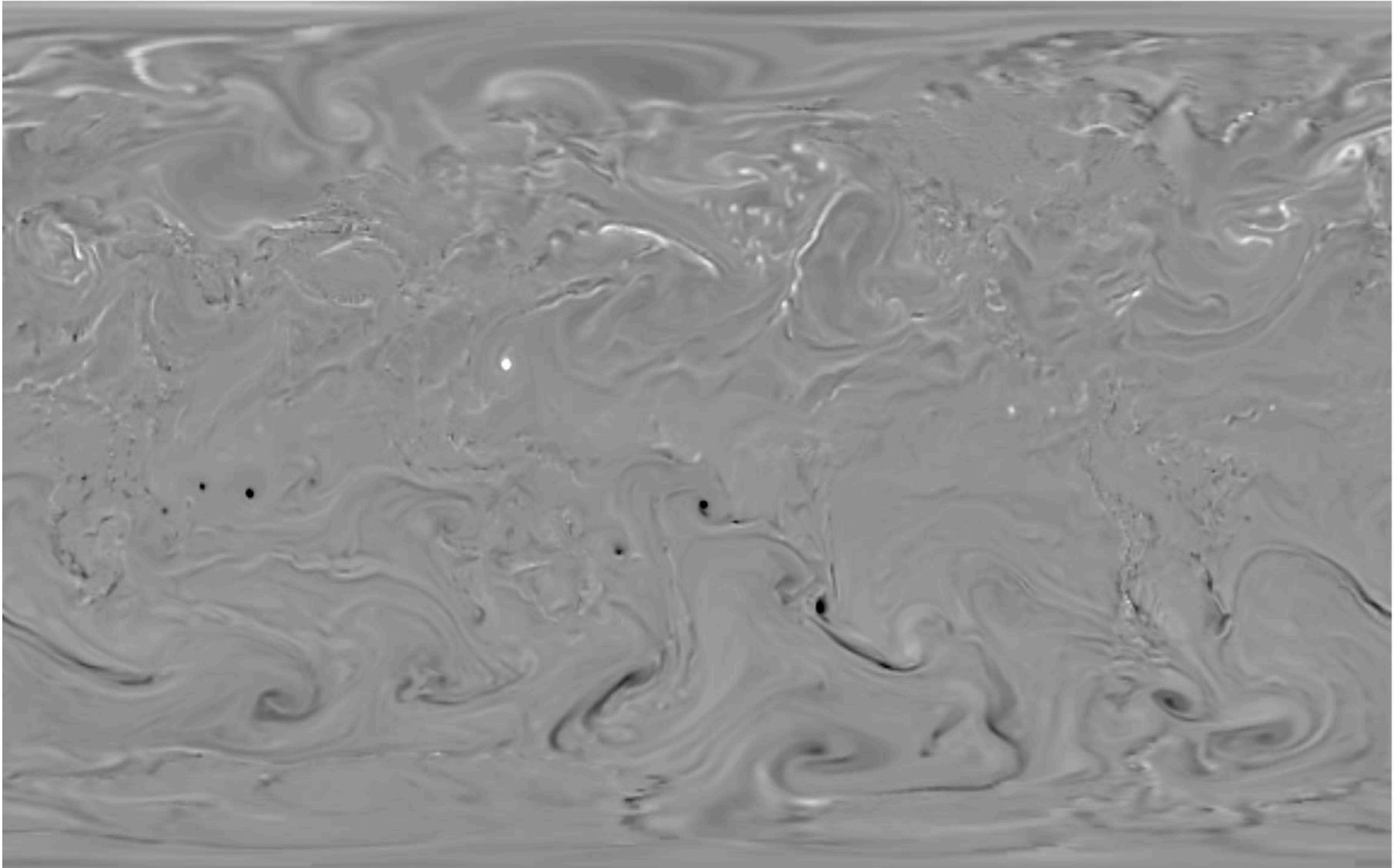
# Schematic of global TC frequency

“Thermodynamic” changes monotonically reduce TC freq. with warming

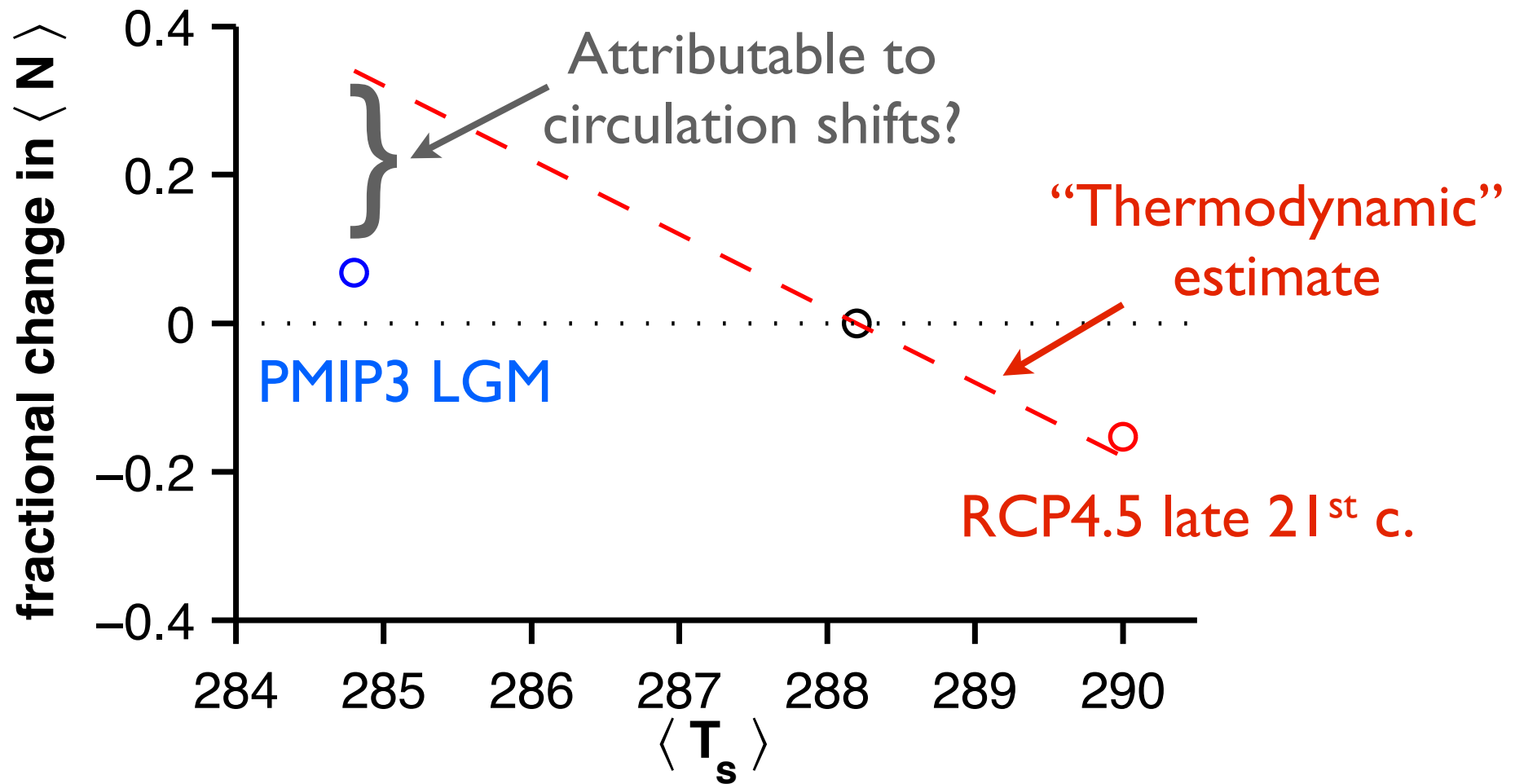
“Dynamic” changes may behave more subtly: offsetting or augmenting changes depending on climate state and radiative forcing agents



# LGM SST simulation: 850 hPa vorticity

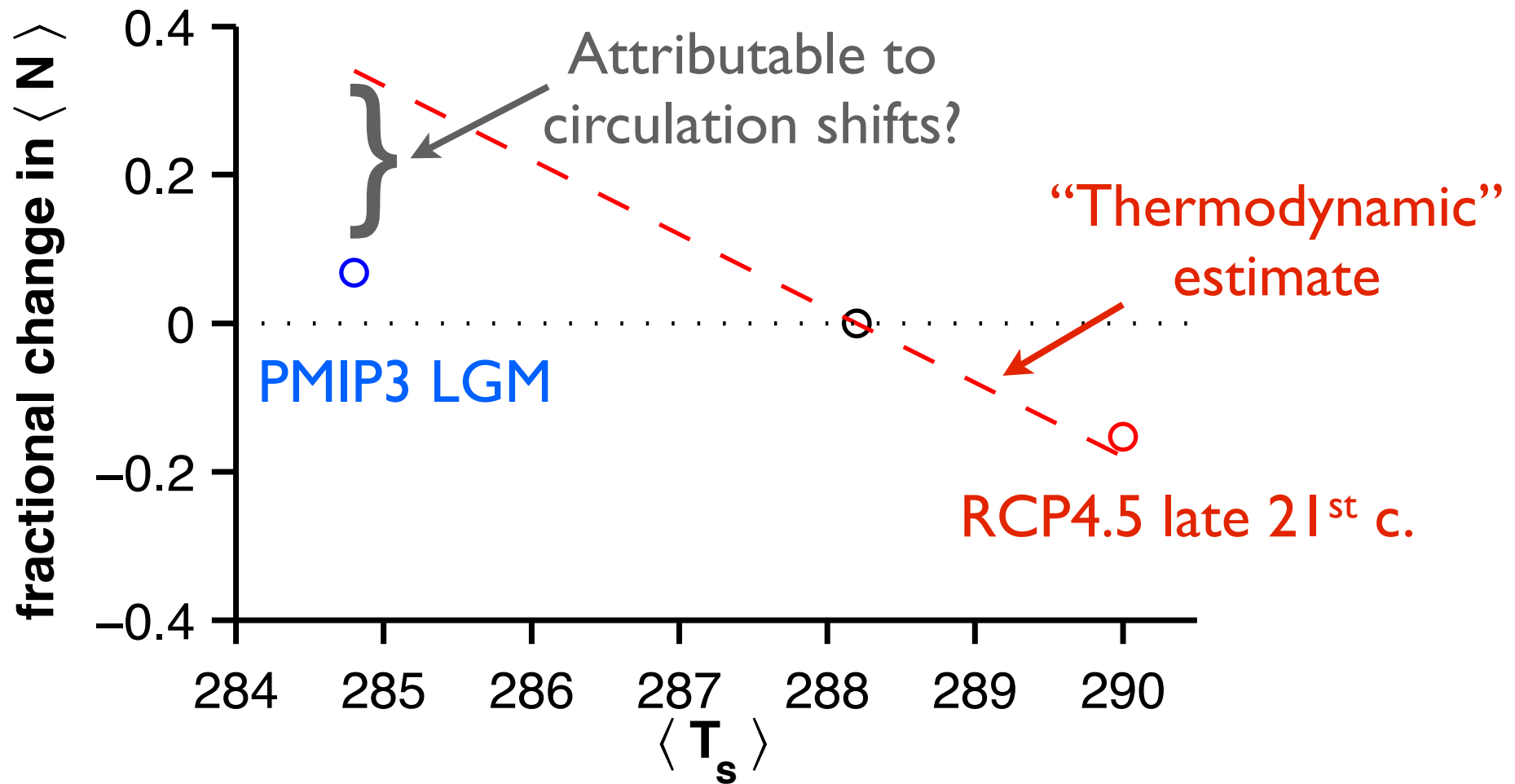


# Preliminary results in comprehensive HiRam simulations (CMIP5/PMIP3 SSTs)



Multi-model ensemble-mean SST anomalies

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Thank you!