Climate Models and Tropical Cyclones: Idealized Models of the Climatology of Cyclogenesis

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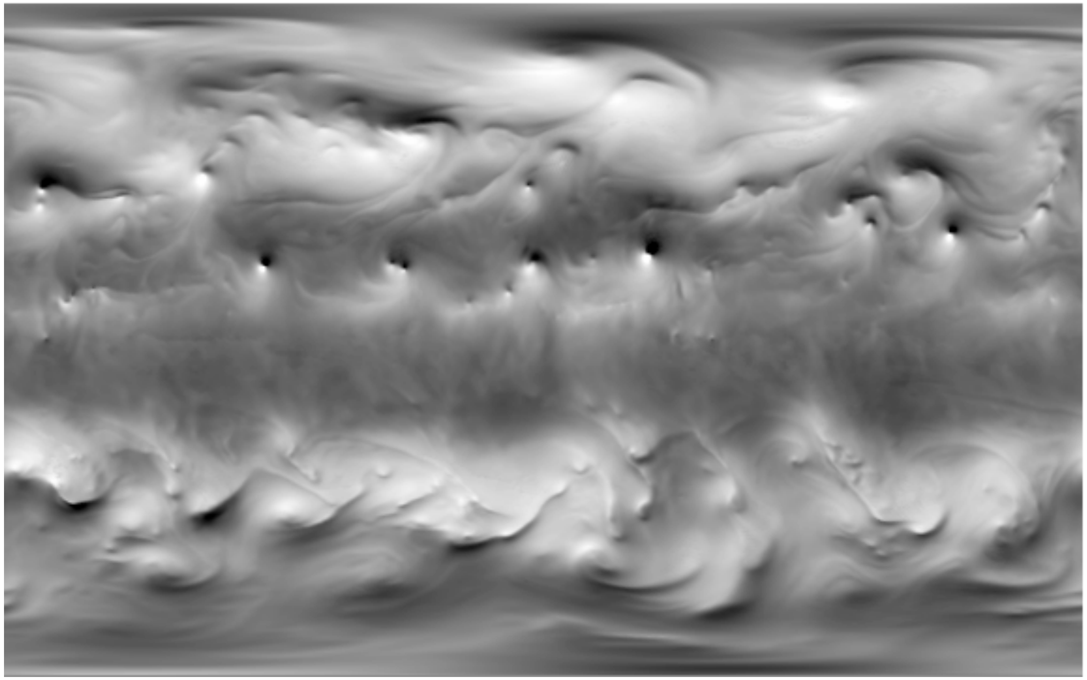
Bjerknes Lecture, AGU Fall 2016



Thanks to Ming Zhao, Tim Merlis, Andrew Ballinger, Wenyu Zhou

Claim:

we are poised for rapid progress in our understanding of the tropical cyclone climate based on simulation of tropical cyclones in global models

analogous to the transition in the 1970-80's in simulations of midlatitude baroclinic eddies in global models

(models are far from perfect but good enough that we feel justified in manipulating them to better understand the factors that control these storms)

All results here based on a single atmospheric model
HiRAM (Zhao, et al, J. Clim. 2009) with 25 or 50km resolution
but using geometries/boundary conditions
with different levels of idealization

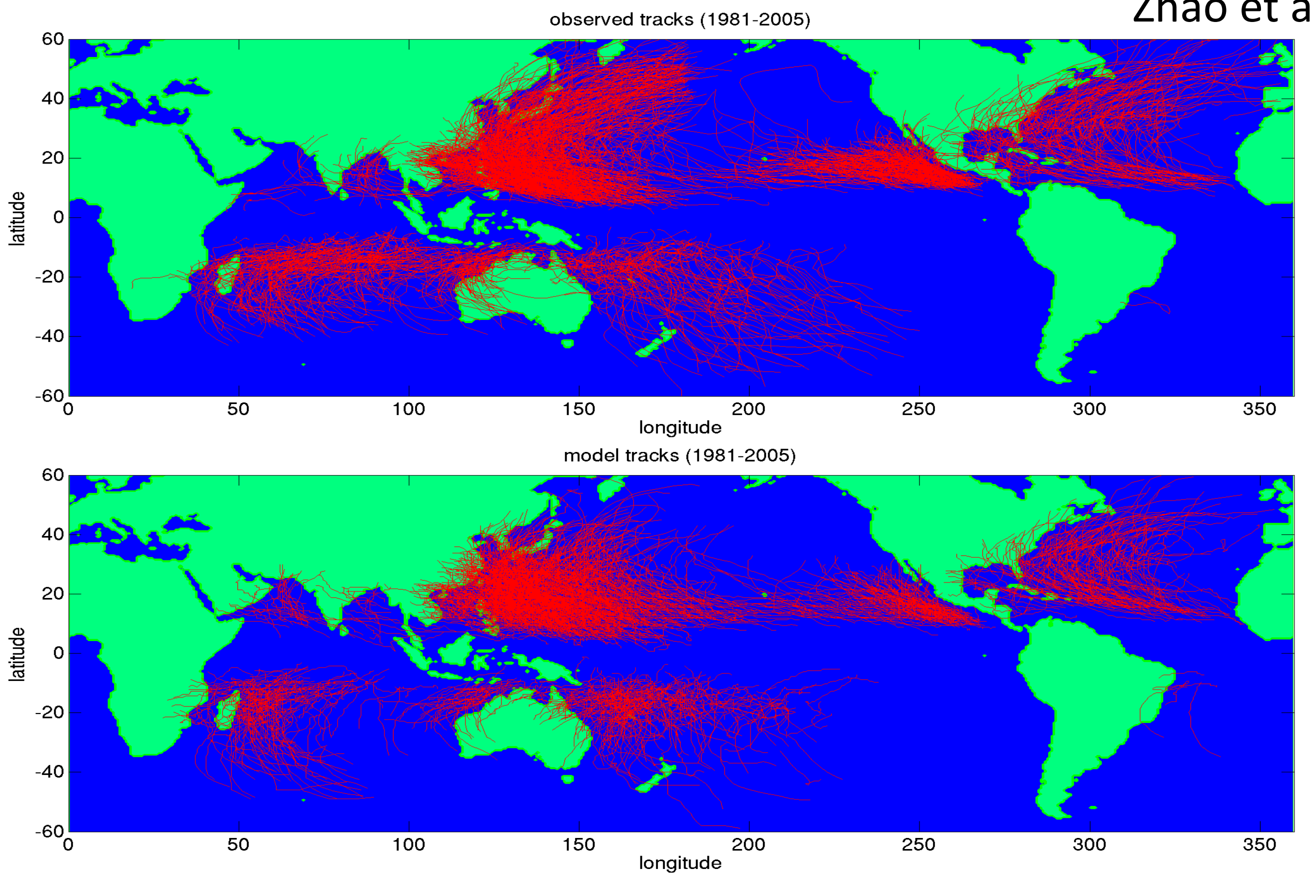
Realistic version
prescribed sea surface temperatures - SSTs

Aqua-planet:
zonally symmetric boundary conditions
slab ocean (Merlis et al, GRL, 2013)
fixed SSTs (Ballinger et al, JAS, 2015)

Spherical rotating radiative-convective equilibrium
uniform SSTs in latitude and longitude
(Merlis et al GRL 2016)

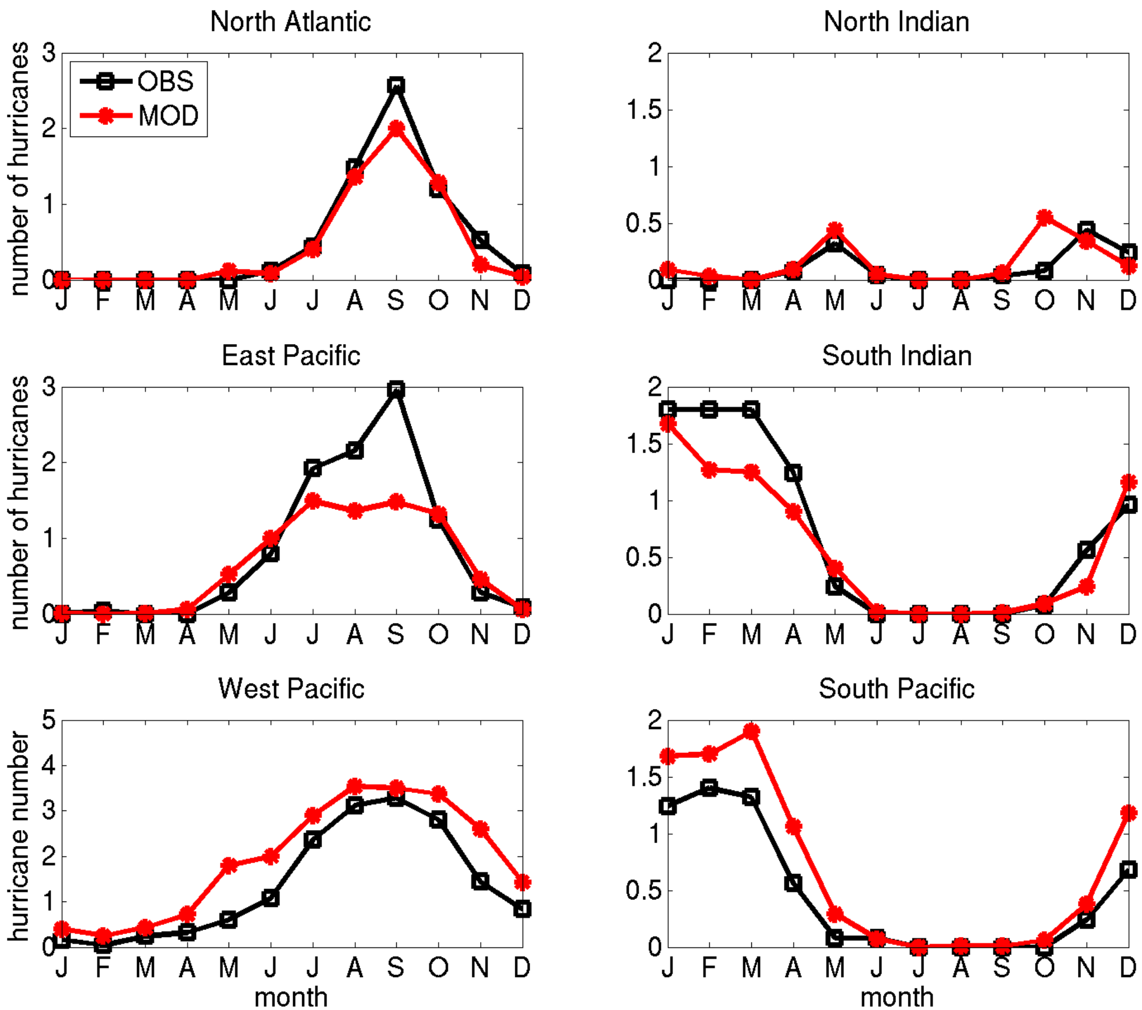
f-plane rotating radiative convective equilibrium:
fixed SSTs (Zhou et al, JAS, 2014)
slab ocean (Zhou et al, JAMES, 2017)

Zhao et al, JAS, 2009



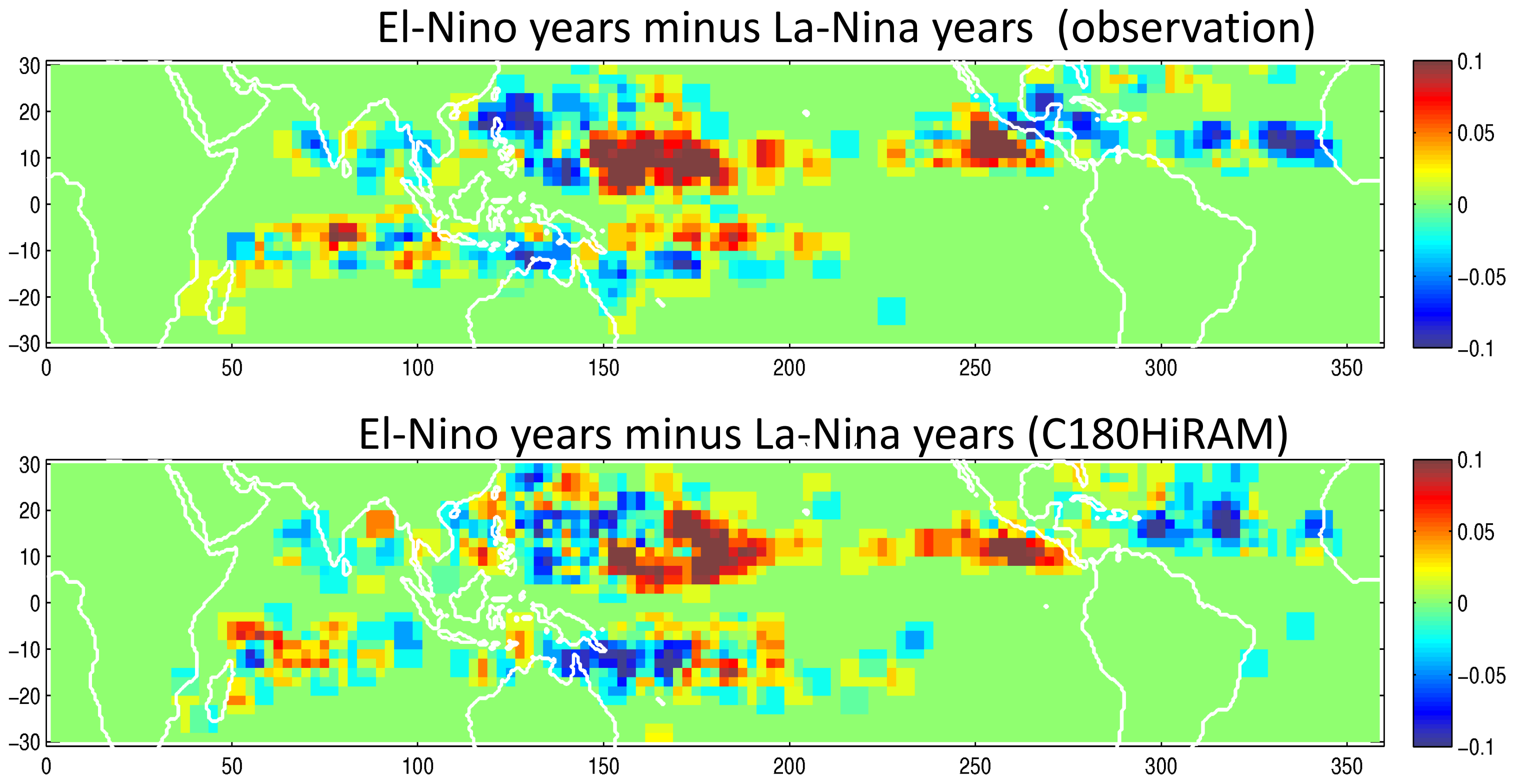
hurricane tracks (1981-2005) upper: obs, lower: model

Model captures the seasonal cycle of hurricane frequency over various ocean basins



Zhao et al, JAS, 2009

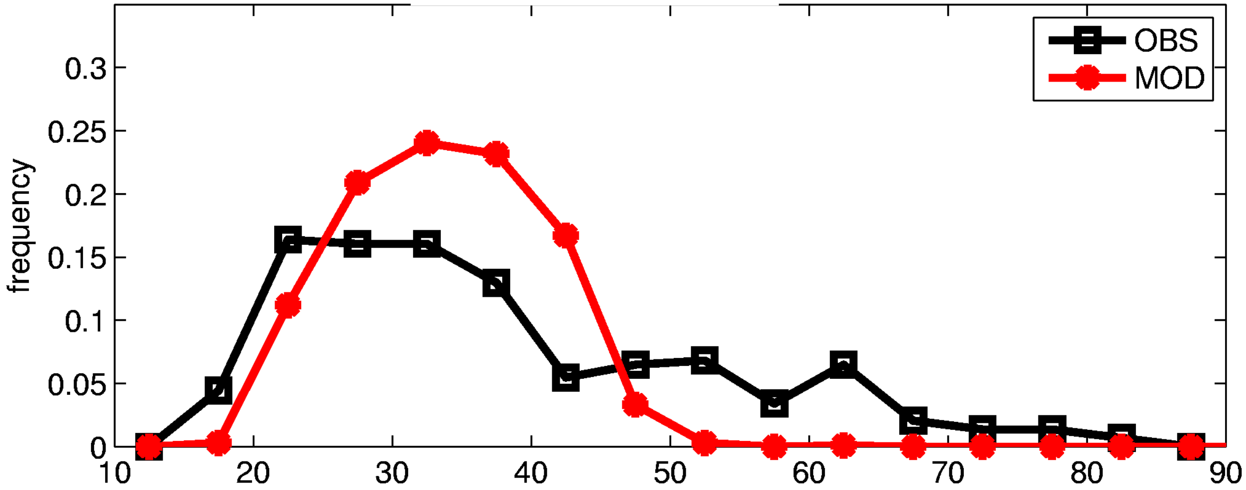
Model captures ENSO effect on hurricane genesis frequency



Zhao et al, JAS, 2009

Raw model output cannot be used to study intensity

N. Atlantic



pdf of max lifetime wind speed

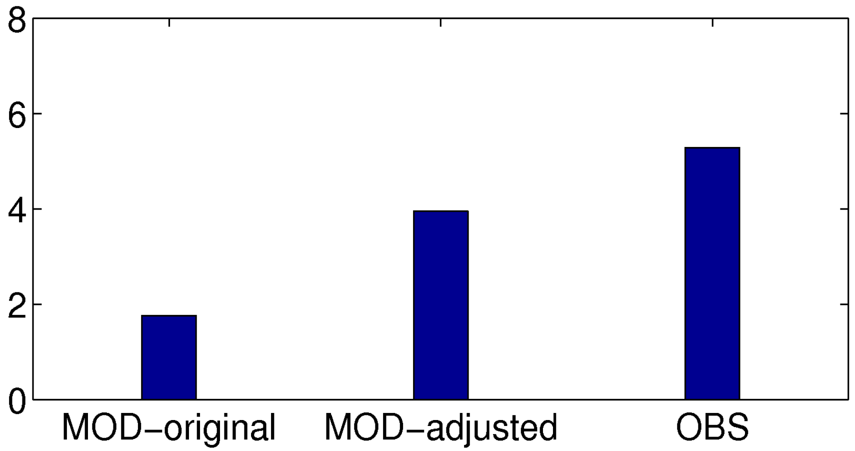
HIRAM (50km grid)

Observation

raw global model output cannot be used for quantitative info on intensity but a statistical adjustment captures observed variability of storm mean intensity

Mean intensity is obtained by averaging the maximum intensity of each storm over all TCs in given years

Change in mean intensity of Atlantic TCs La Nina minus El Nino



Zhao and Held, 2010, J. Clim

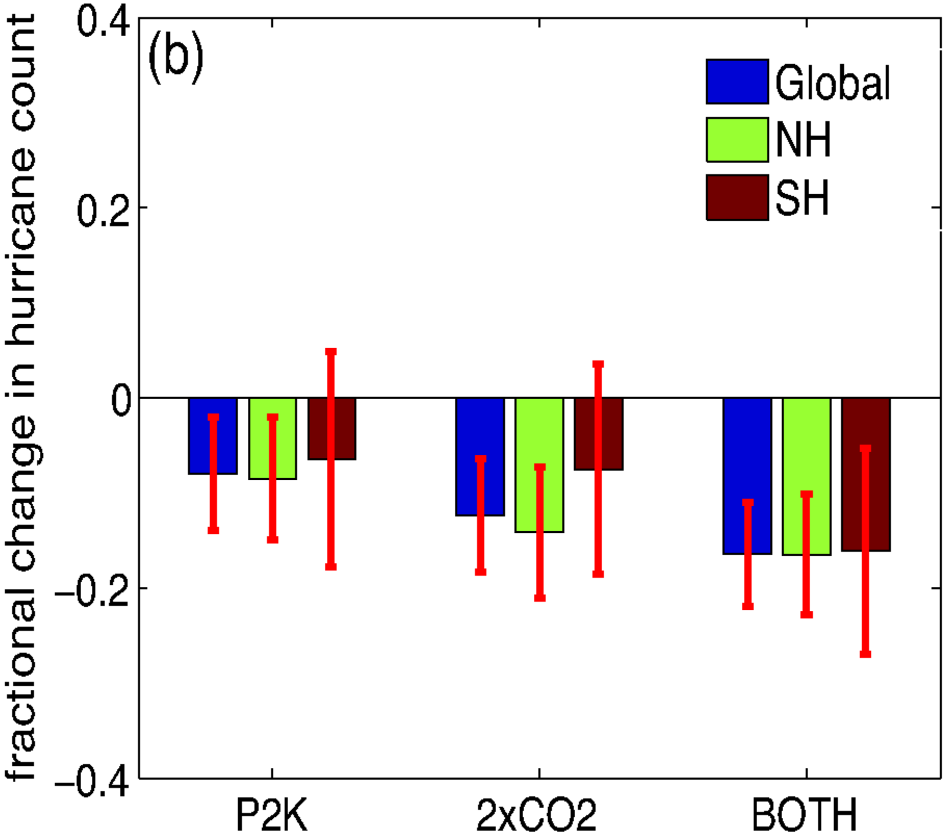
Global mean reduction is due in part to CO_2 increase with fixed SSTs

P2K: uniform SST increase of 2K
no change in CO2

2xCO2: double CO2
no change in SST

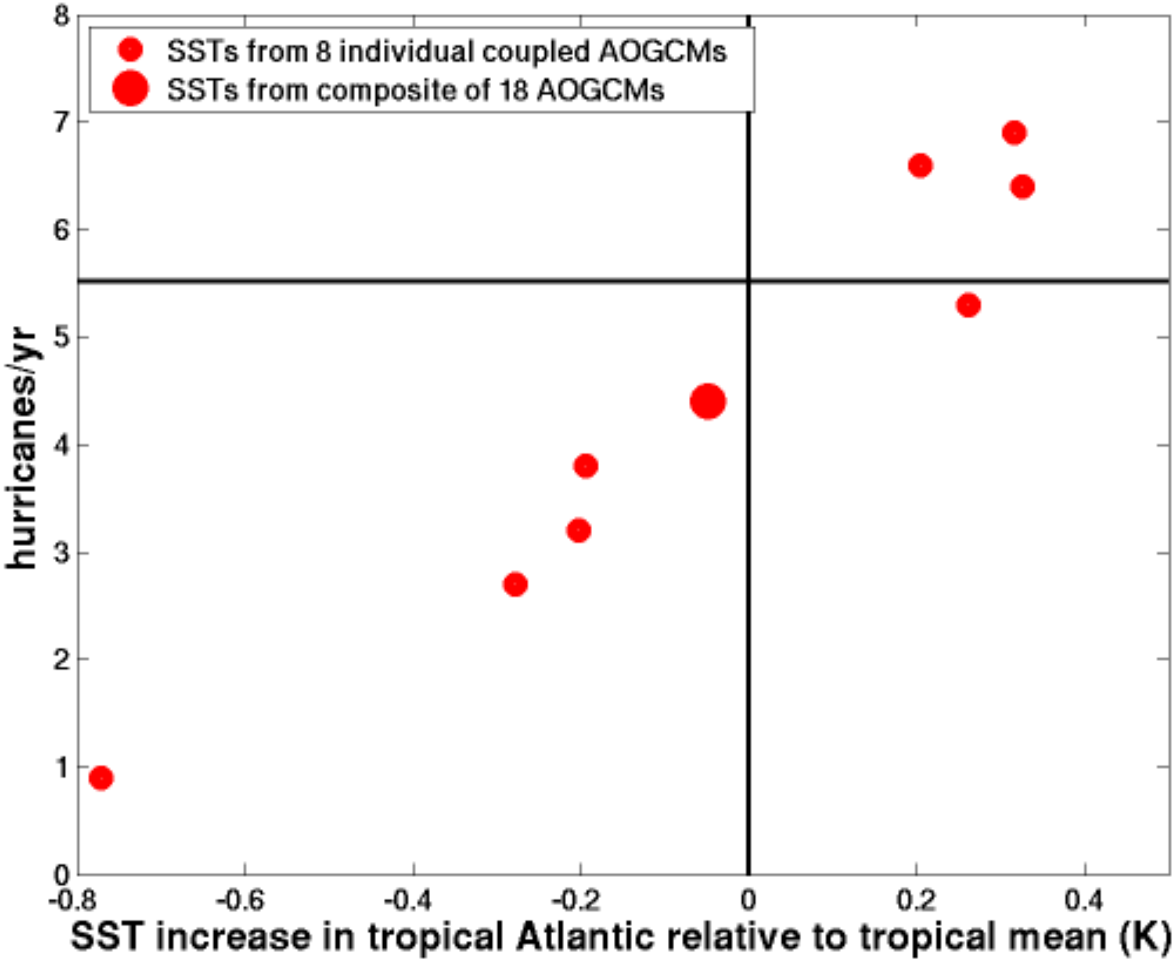
Contribute about equally to global mean reduction in frequency

Held and Zhao, J. Climate, 2011



When HiRAM is run with change in SSTs over 21st century simulated by 8 of world's climate models

Change in Atlantic Hurricane numbers correlated with warming in Atlantic SST relative to mean tropical warming

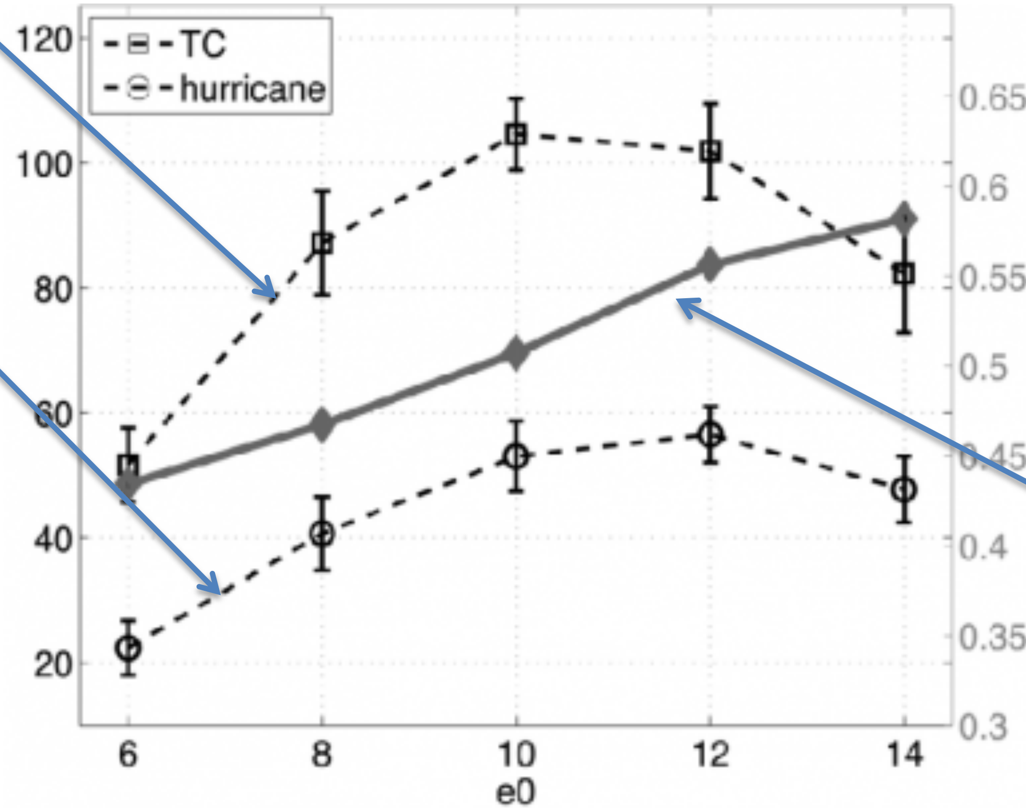


Effect of change in convection scheme on TCs in HiRAM

TCs

Zhao, Held, Lin JAS 2012

Hurricanes

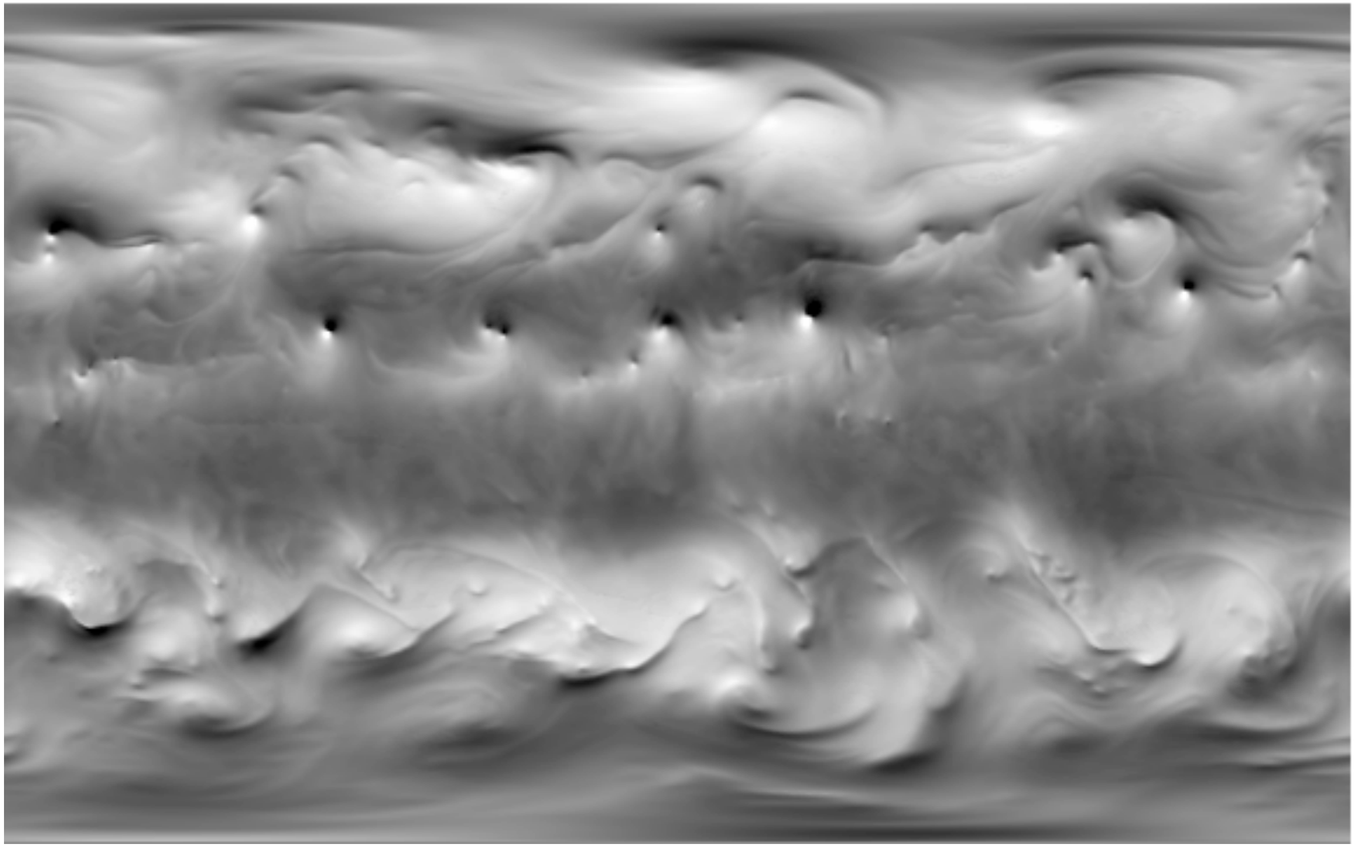


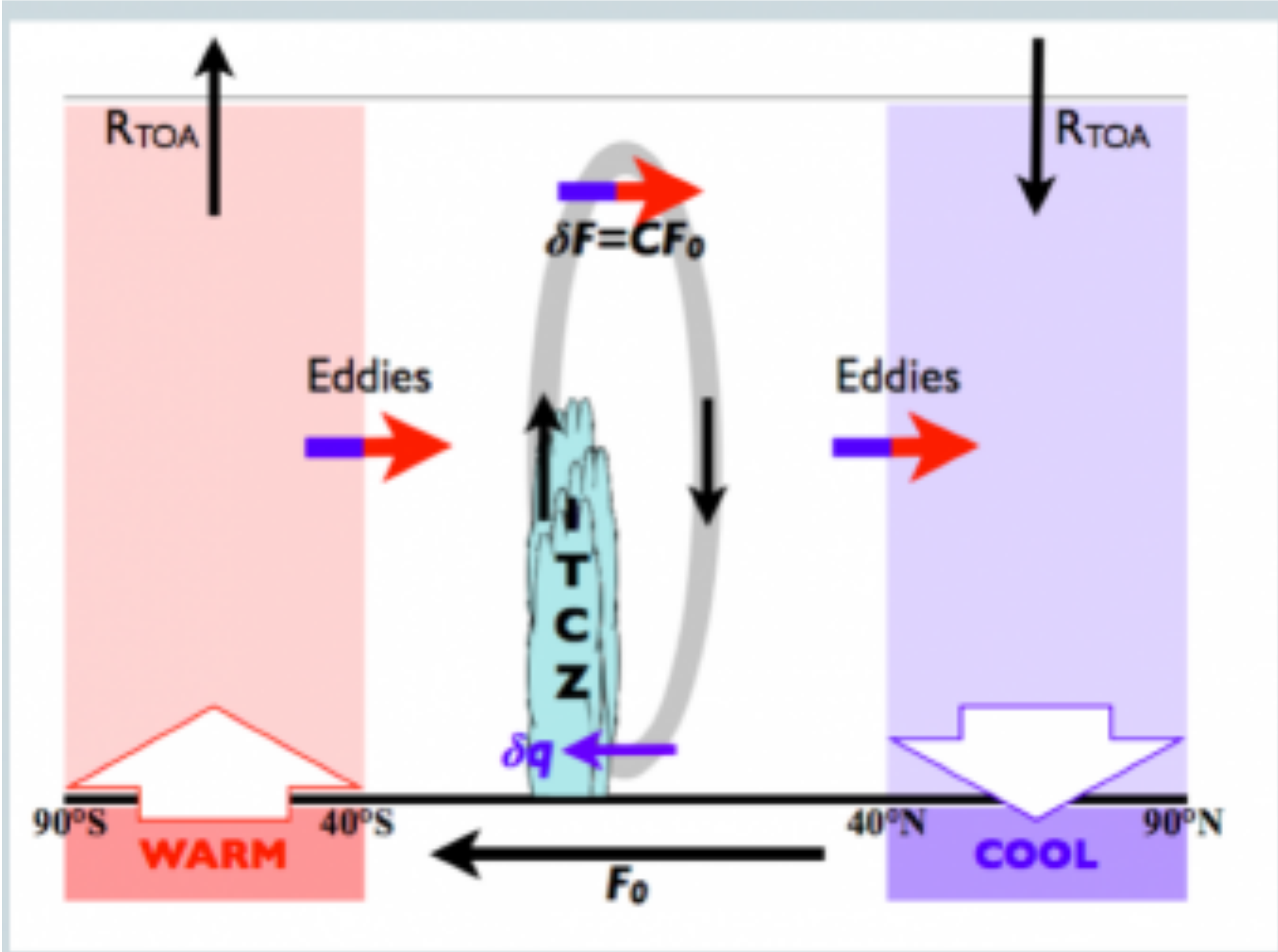
Hurricanes/TCs

Inhibiting parameterized convection =>

Aquaplanet over slab ocean (20m deep), 50km resolution, zonally symmetric climate, no seasonal cycle

Merlis, et al, GRL, 2013

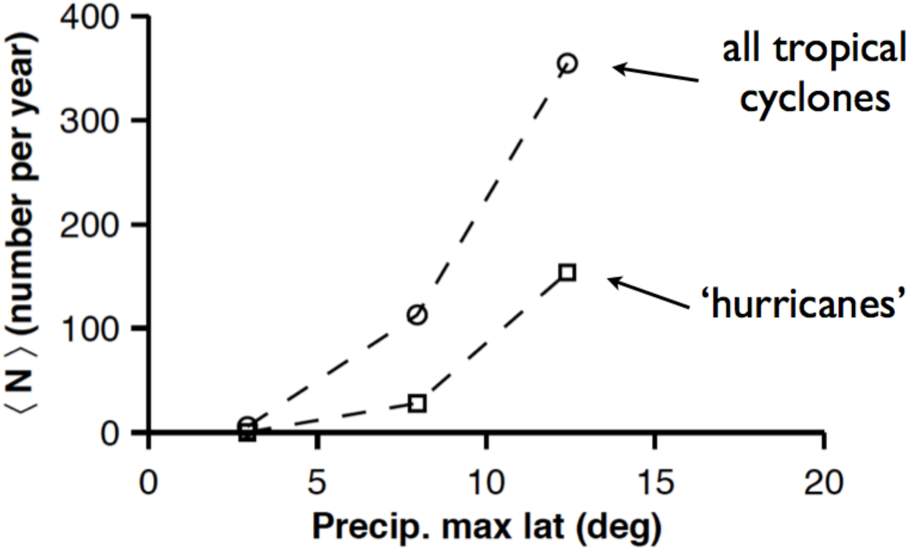




RTOA
RTOA
δF=CF0
Eddies
Eddies
ITCZ
δq
90°S
40°S
40°N
90°N
WARM
COOL
F0

Merlis, et al, GRL, 2013

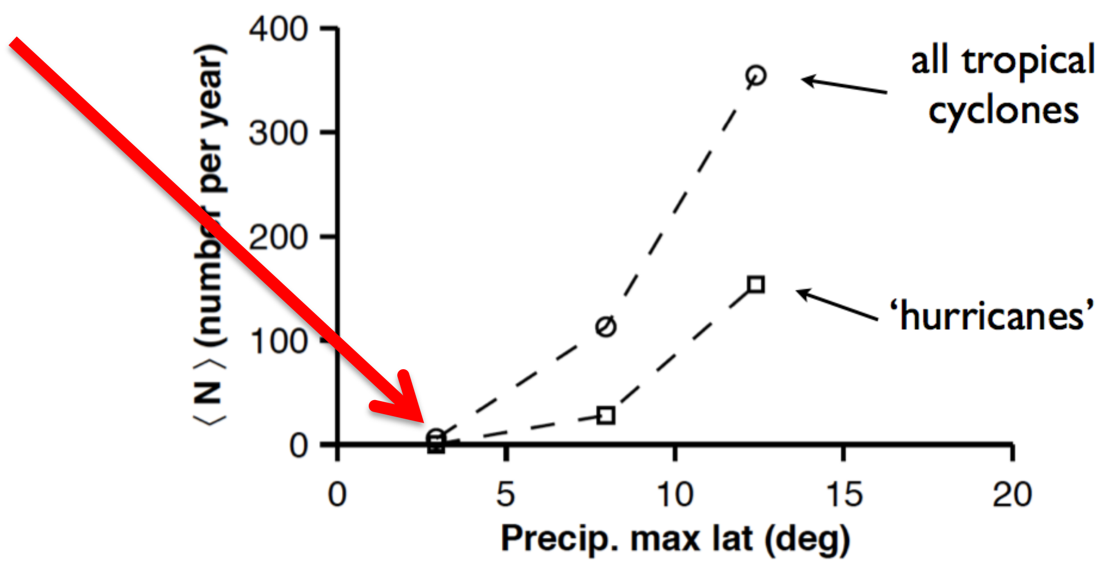
Moving ITCZ by changing prescribed cross-equatorial "oceanic" energy flux



Poleward ITCZ more favorable for cyclogenesis.

Merlis, et al, GRL, 2013

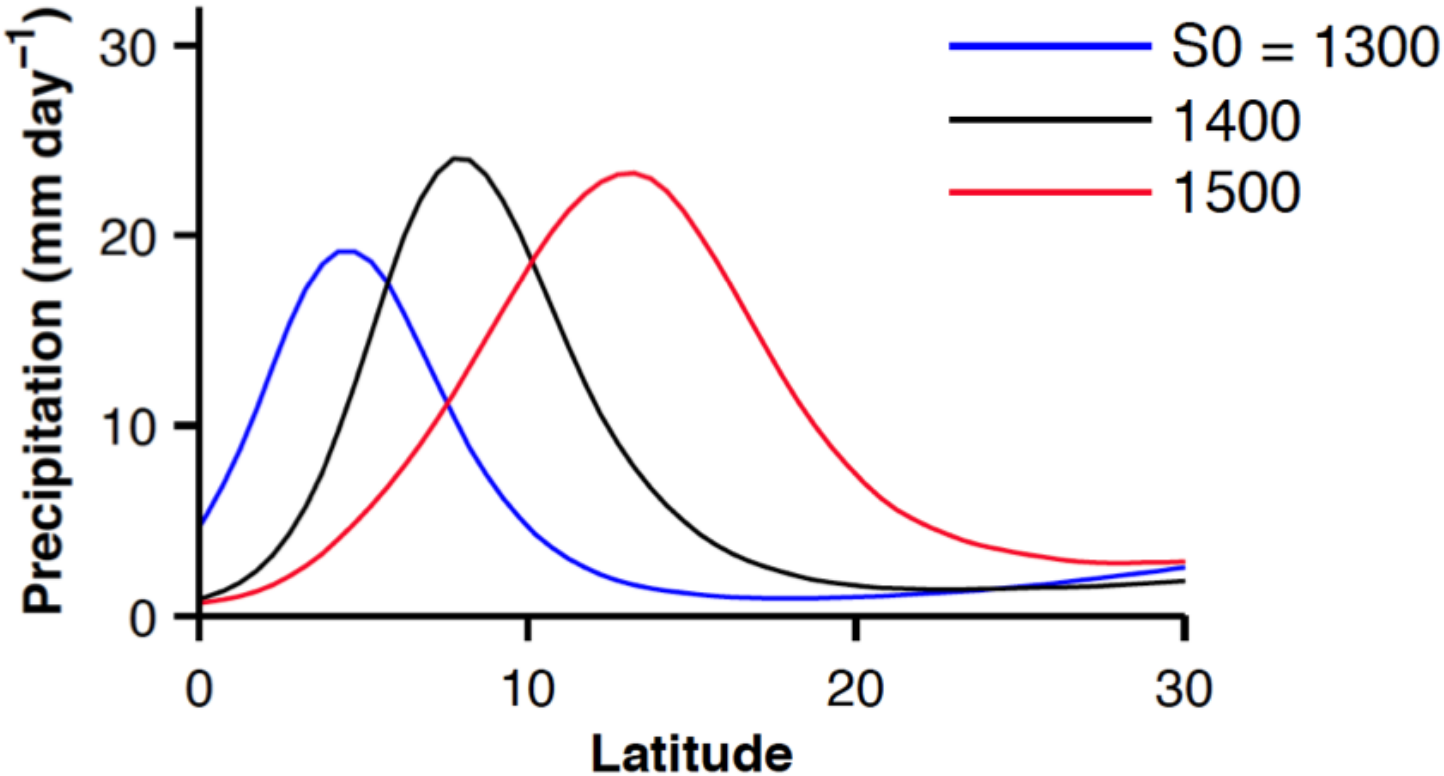
Moving ITCZ by changing prescribed cross-equatorial "oceanic" energy flux



Poleward ITCZ more favorable for cyclogenesis.

Tim Merlis et al, GRL 2013

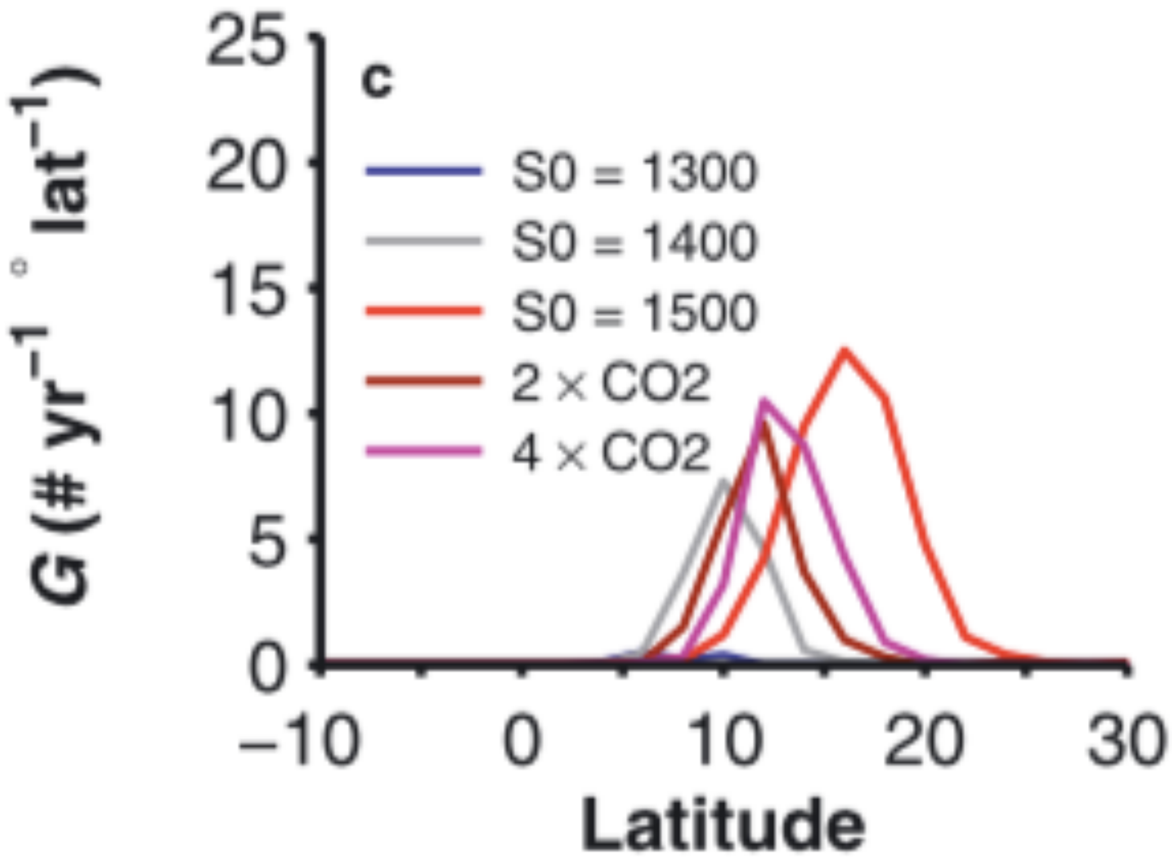
Precipitation



ITCZ & TC genesis shifts poleward with warming!

Typically, number of TCs decreases with uniform warming with realistic boundary conditions

But in this aqua-planet configuration, the number increases because ITCZ and genesis move poleward



Tim Merlis, et al – GRL 2013

Typically, number of TCs decreases with global warming with realistic boundary conditions

But in the aqua-planet configuration, the number increases because ITCZ moves poleward

Understanding this result has at least 3 distinct parts
-- how does the ITCZ move with warming
-- how does the TC number change with ITCZ latitude
-- how does the TC number change with warming with fixed ITCZ latitude

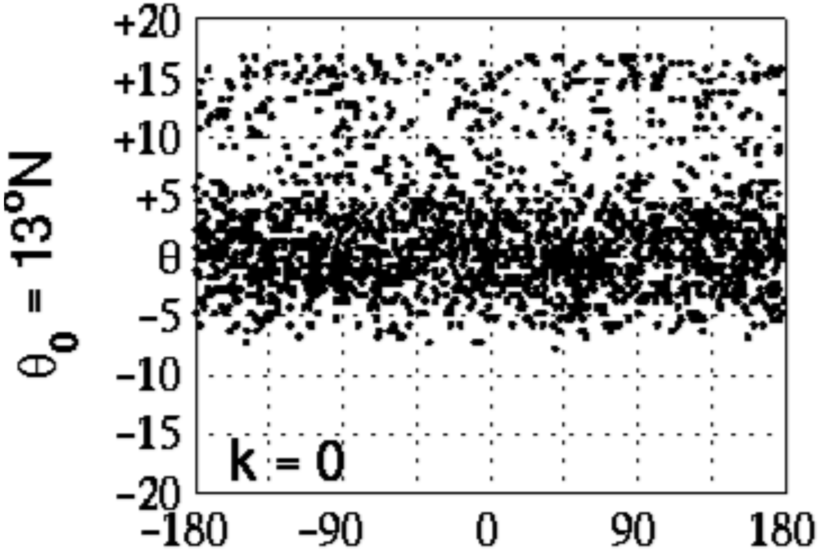
$$N = f(\ Q, T) = g(\ ITCZ(Q, T), T)$$

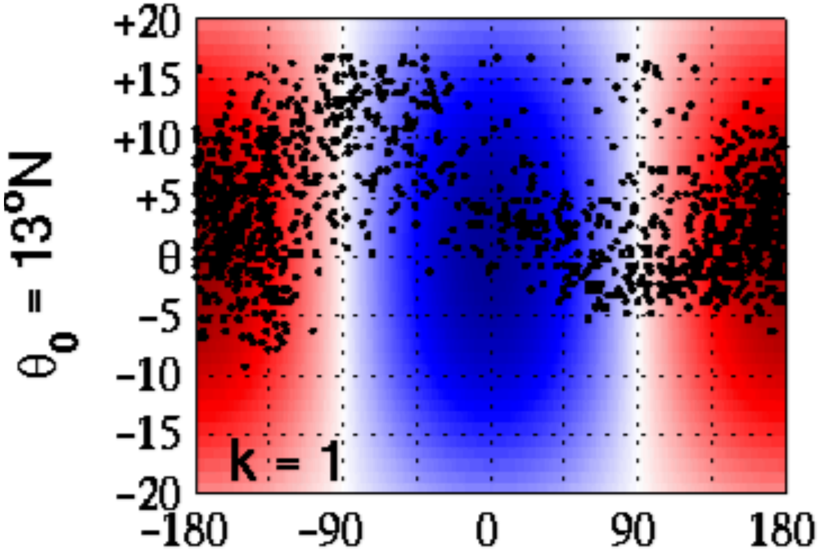
$$\frac{\partial f}{\partial T} > 0; \quad \frac{\partial g}{\partial T} < 0$$

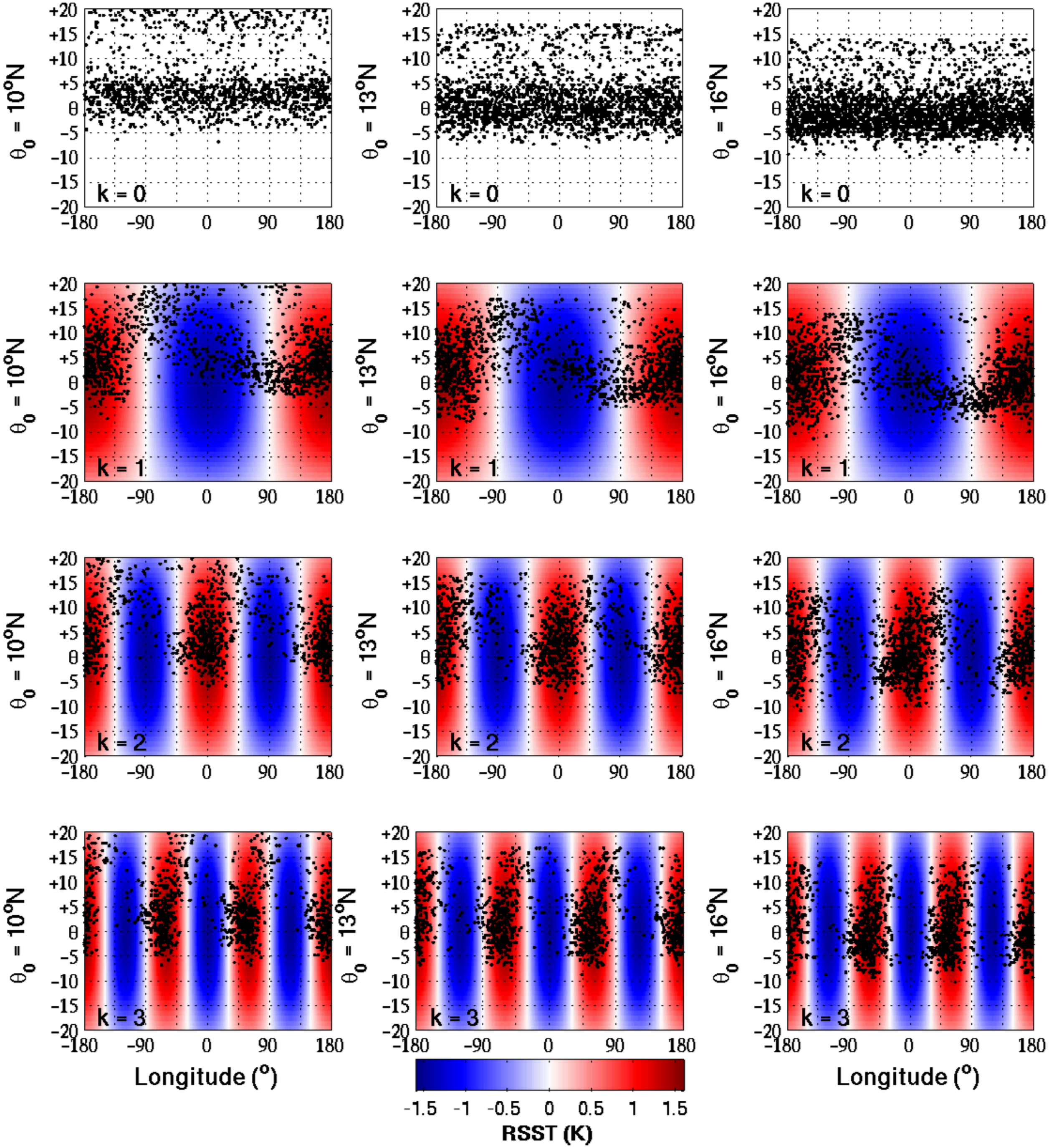
adding zonal variations

$SST = SST_0(y) + (1.5K)*\sin(kx)$

Andrew Ballinger, in prep







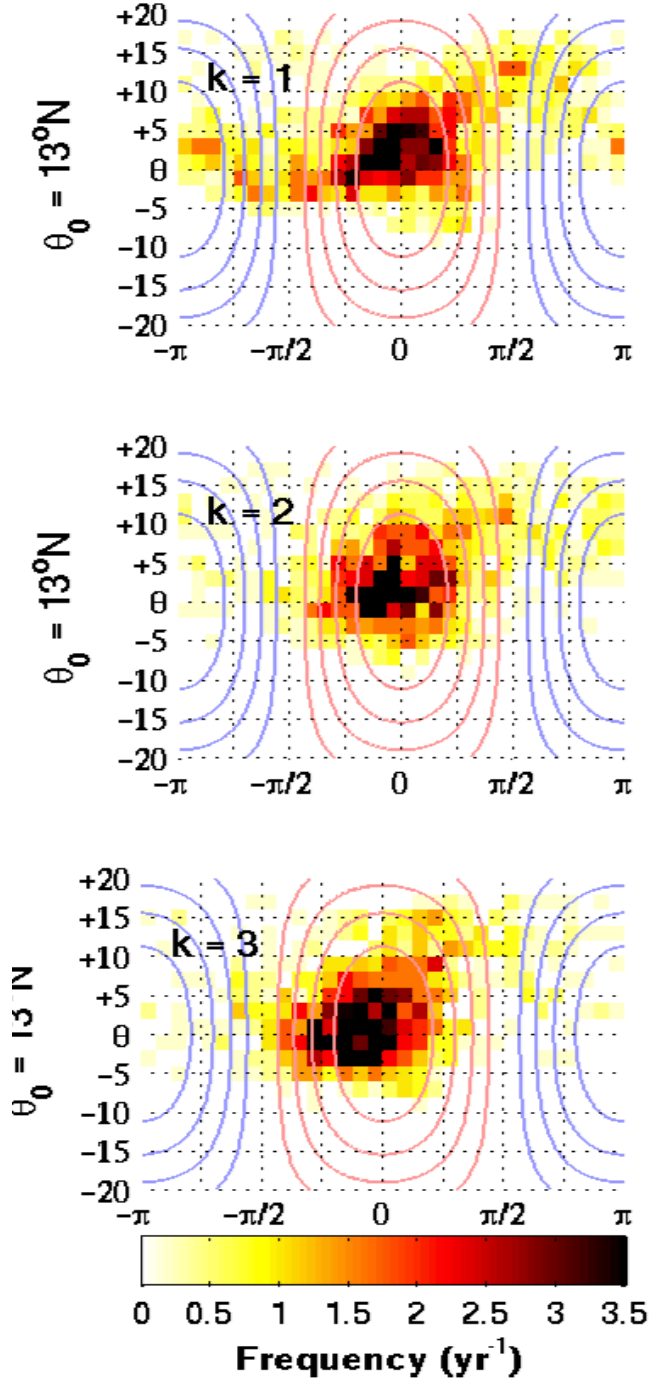
θ0 = 10°N
θ0 = 13°N
θ0 = 16°N
k = 0
k = 1
k = 2
k = 3
Longitude (°)
RSST (K)

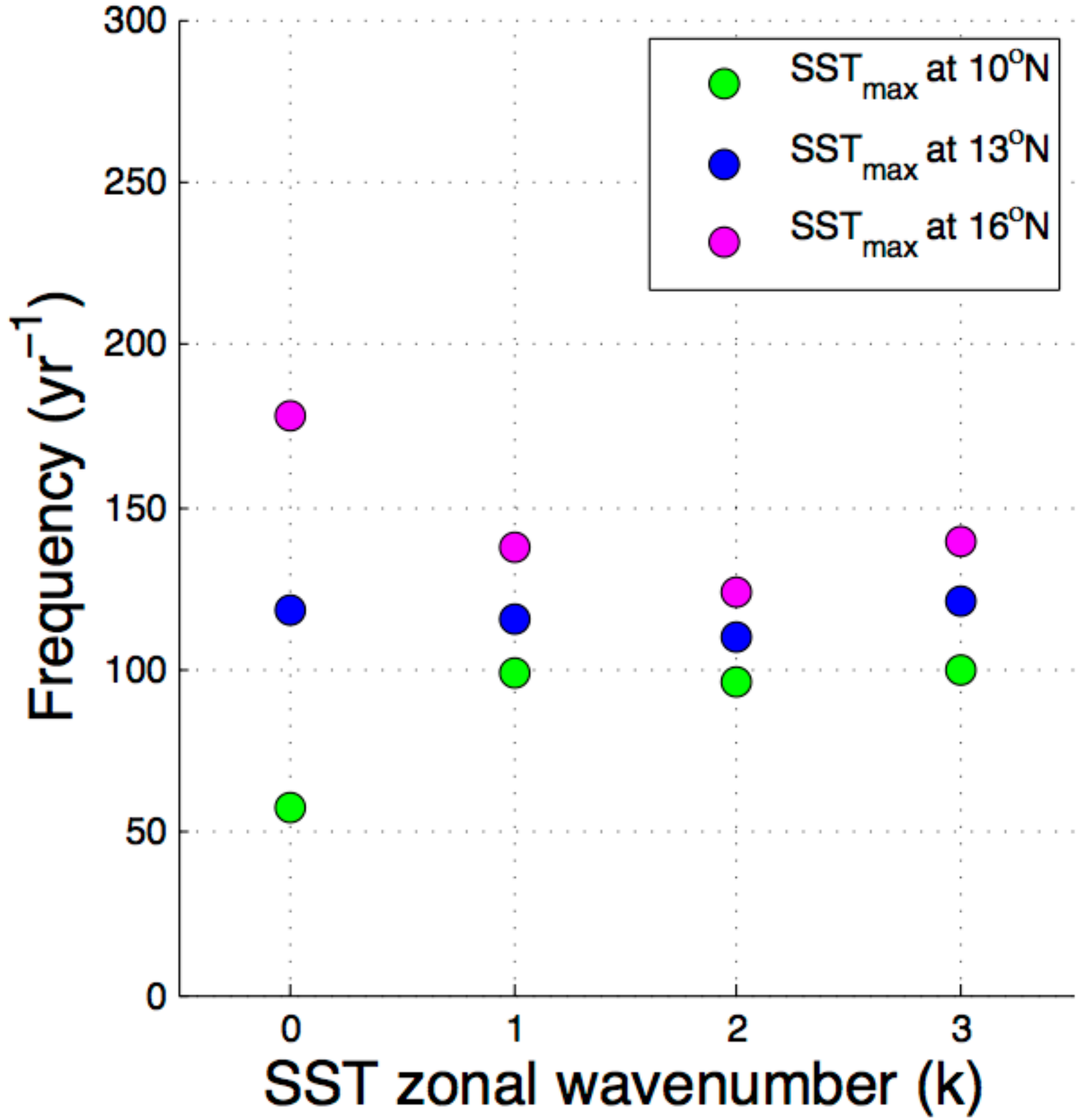
Genesis frequency

k = 1

k = 2

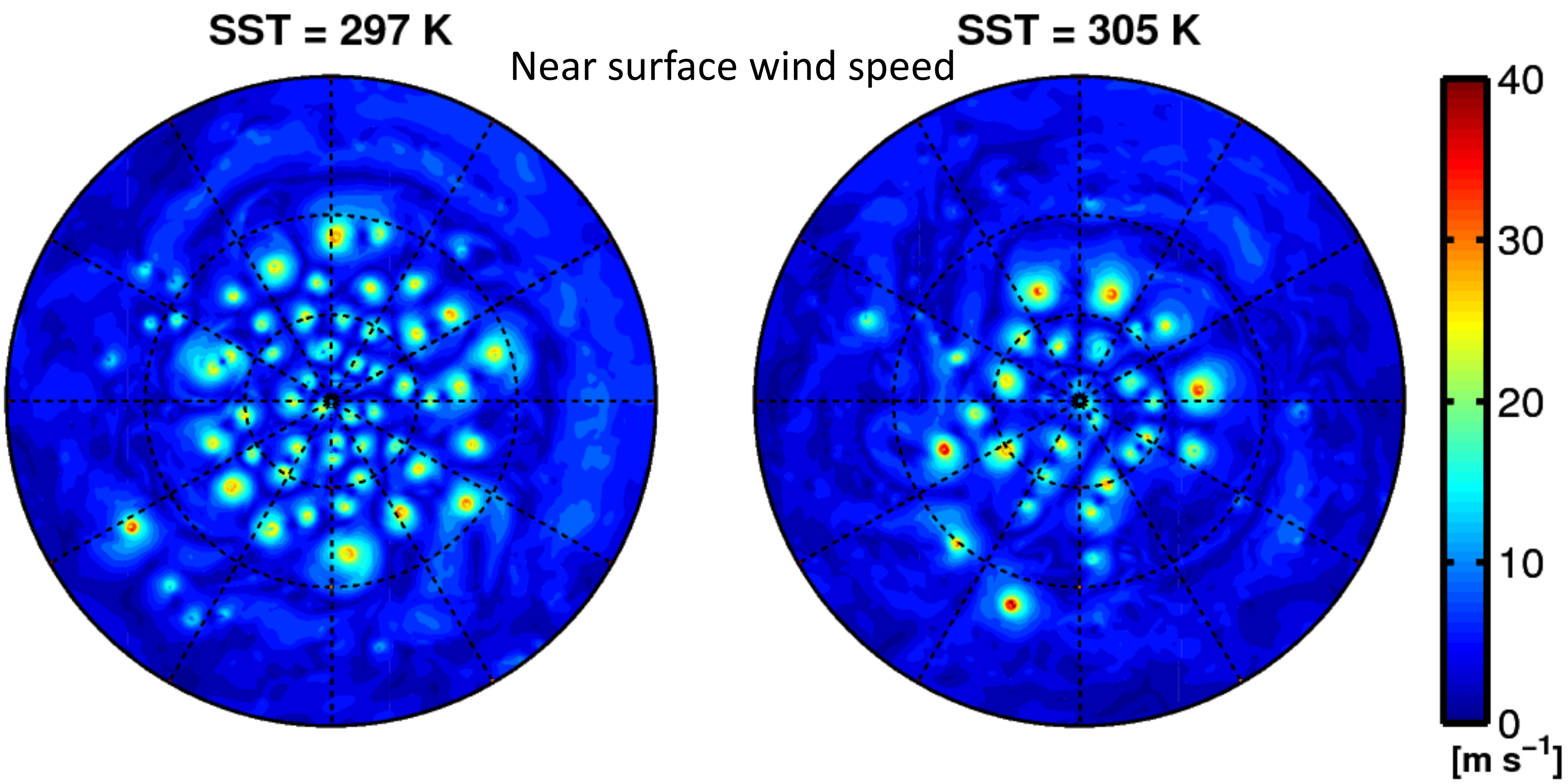
k = 3





300
250
200
150
100
50
0
Frequency (yr^{-1})
0
1
2
3
SST zonal wavenumber (k)
SST_{max} at 10^{o}N
SST_{max} at 13^{o}N
SST_{max} at 16^{o}N

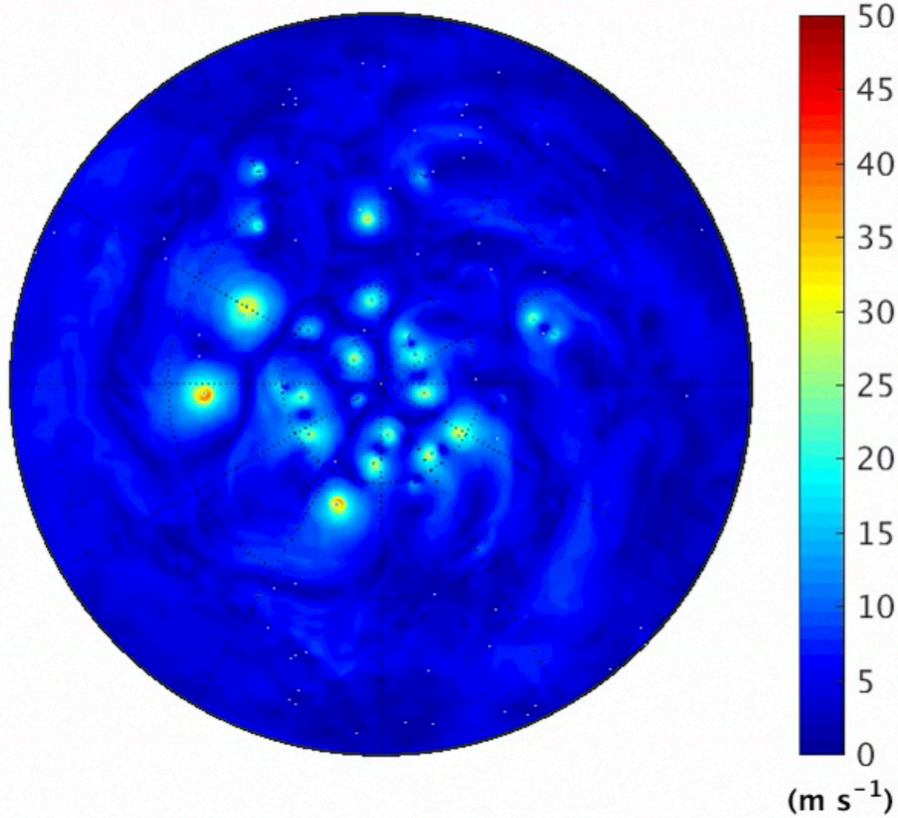
Rotating radiative-convective equilibrium on a sphere
Uniform SSTs – Uniform insolation
(eliminates midlatitude baroclinic eddies)



tropical genesis => beta drift => polar accumulation

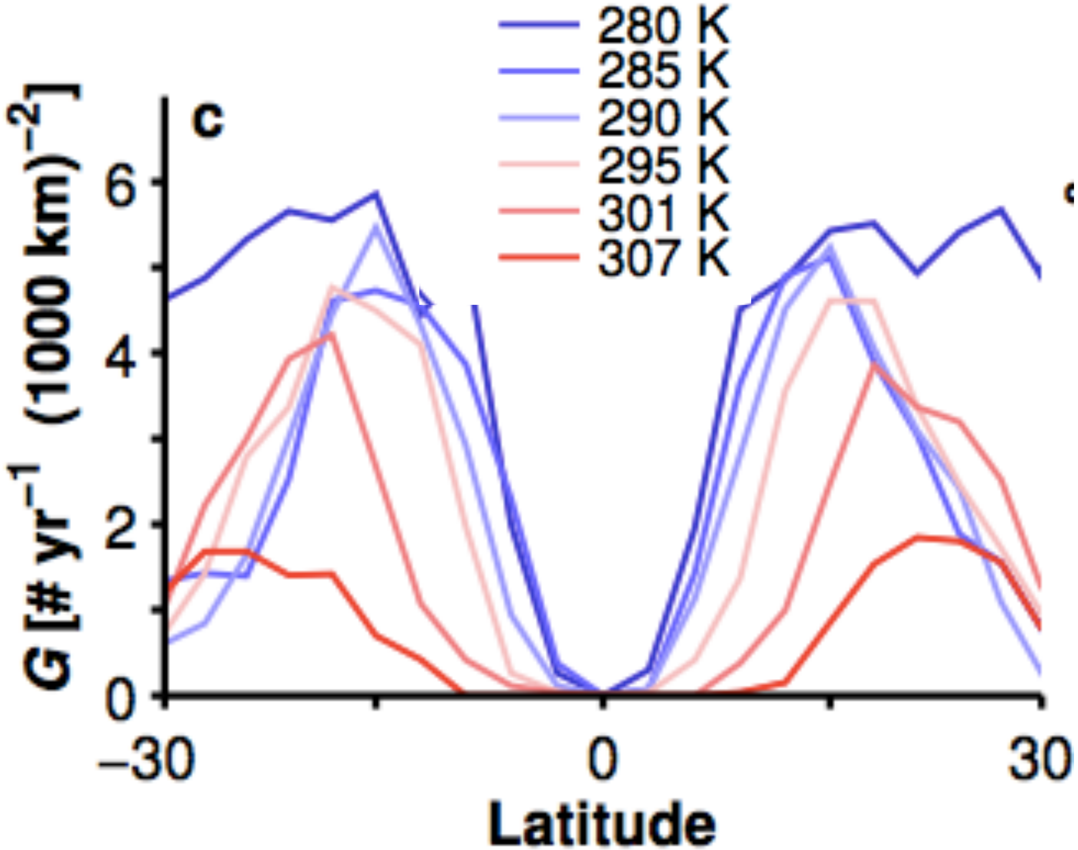
Merlis, et al GRL,2015

SST = 307K



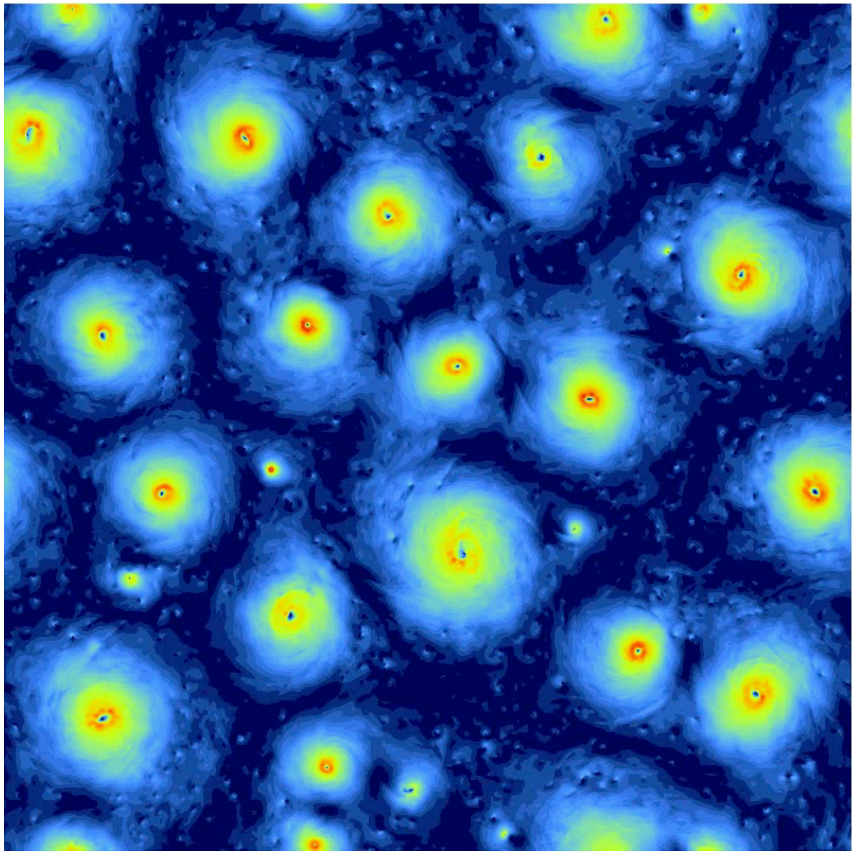
Merlis, et al 2015

TC decreases as temperature increases in rotating radiative-convective equilibrium



Rotating Radiative Convective Equilibrium

Identical model except for f-plane doubly-periodic geometry and homogeneous forcing and SSTs



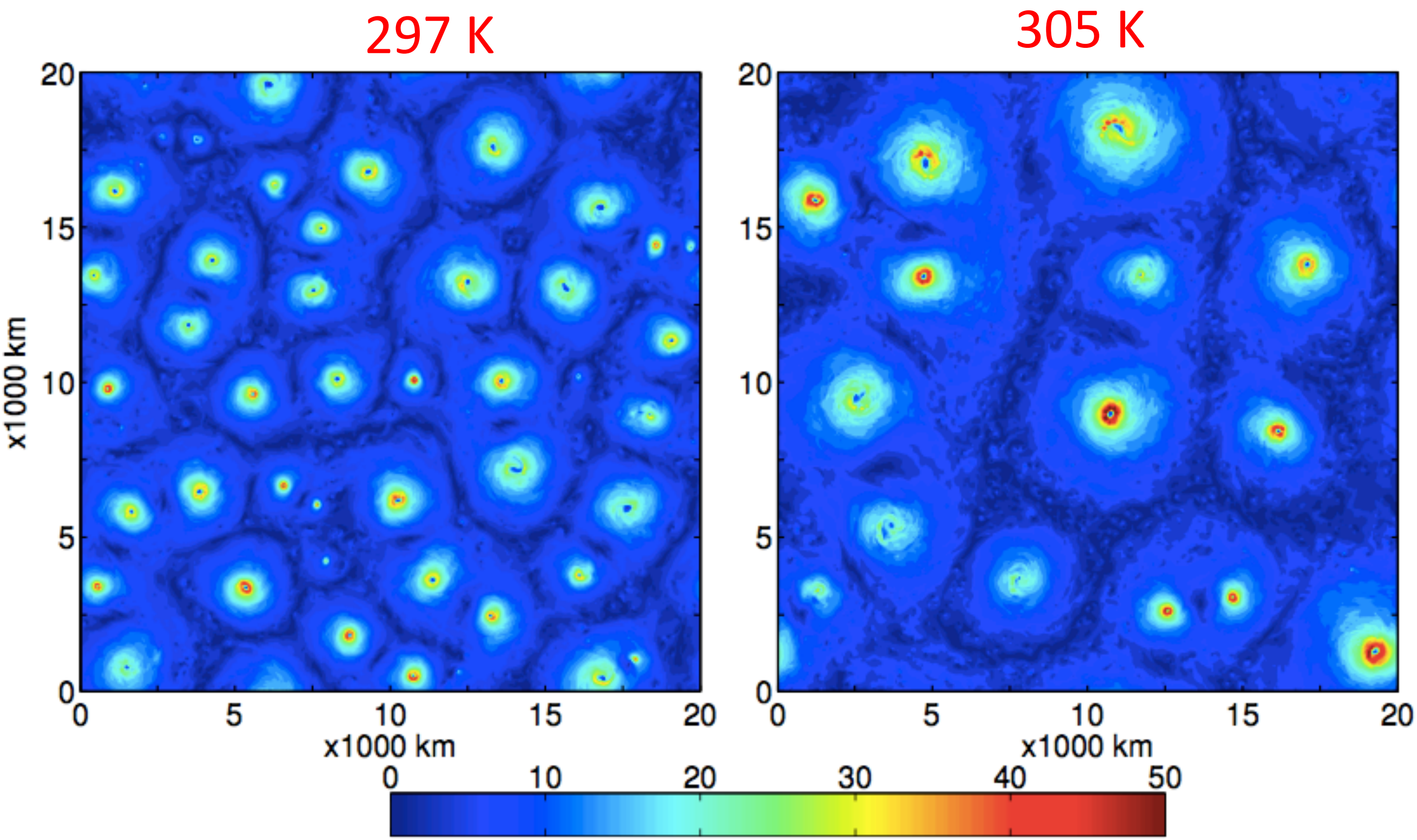
Surface wind speed

Also referred to as "TC World" and "Diabatic Ekman Turbulence"

Zhou et al , 2014, JAS

Lots of interesting parameter dependencies:

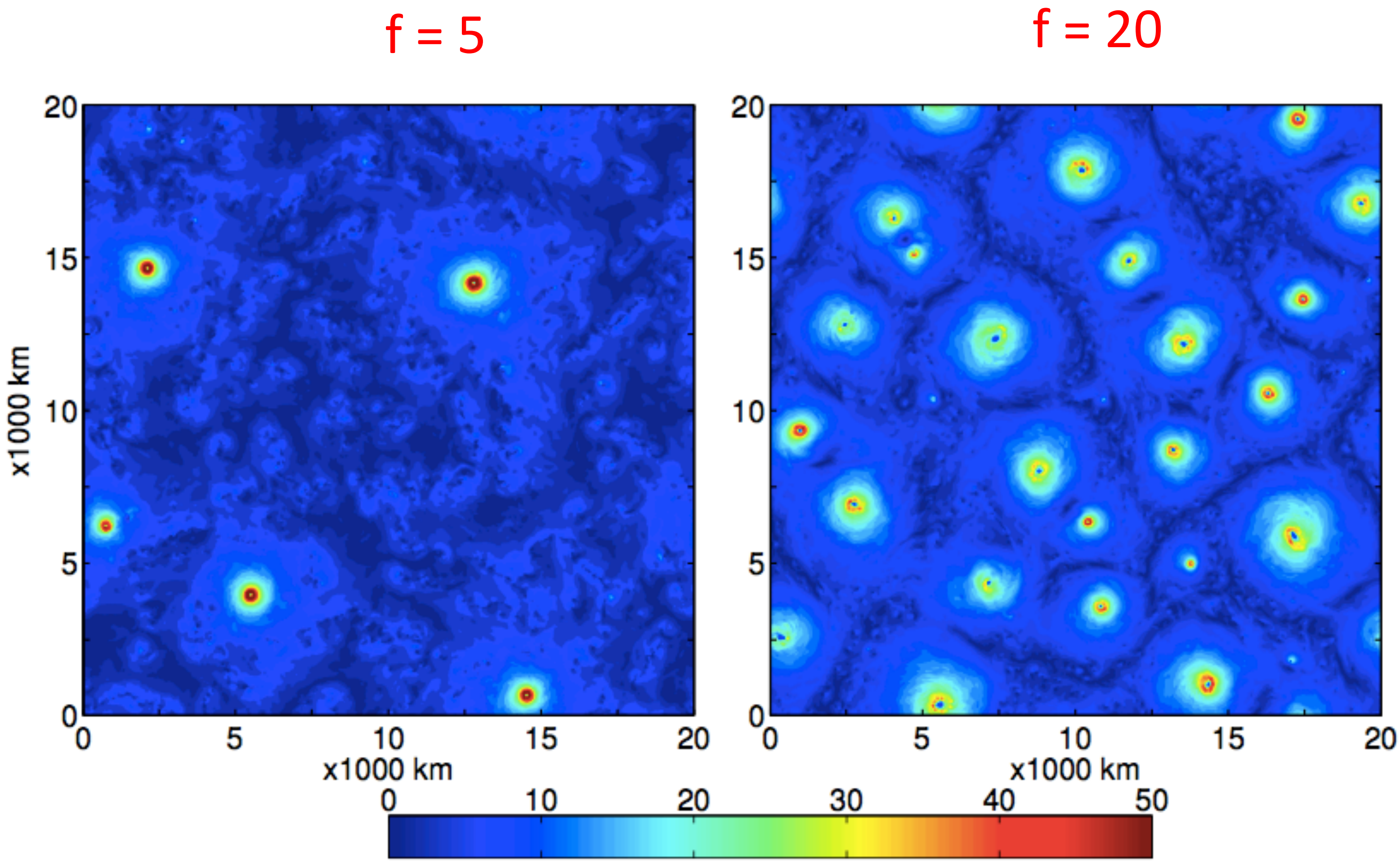
distance between storms increases with SST: NH/f ?, u/f ?*



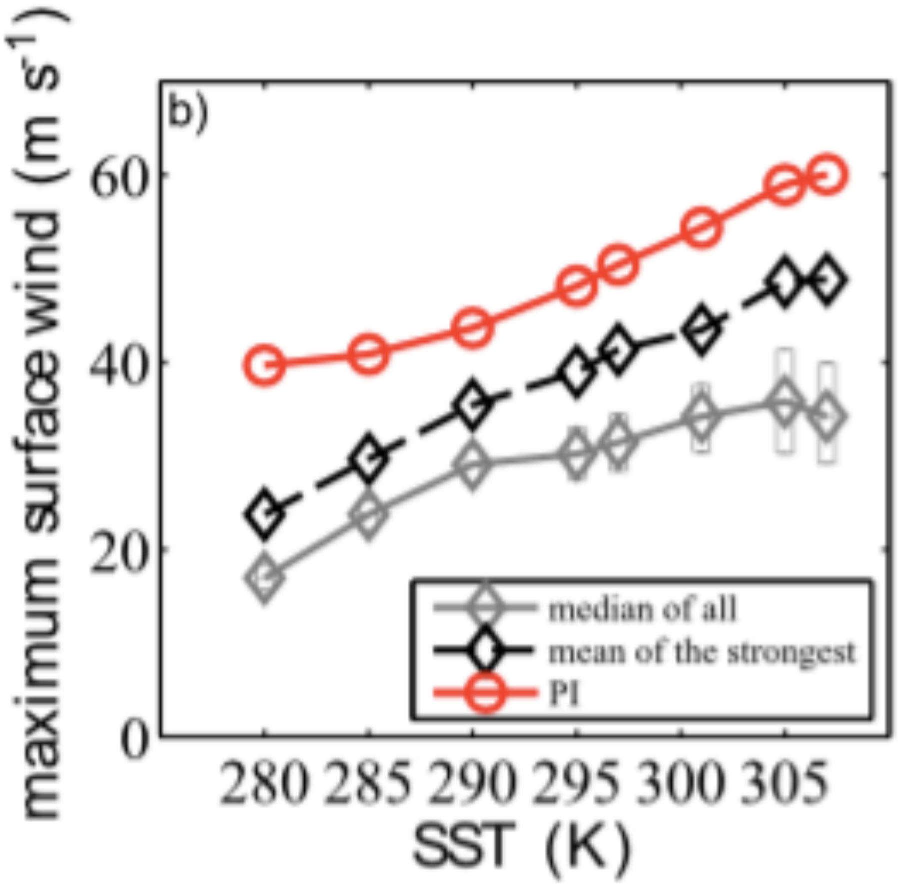
Wenyu Zhou et al, J. Atmos. Sci 2014

Lots of interesting parameter dependencies:

distance between storms decreases with rotation rate: NH/f ?, u/f ?*



Wenyu Zhou et al, J. Atmos. Sci 2014

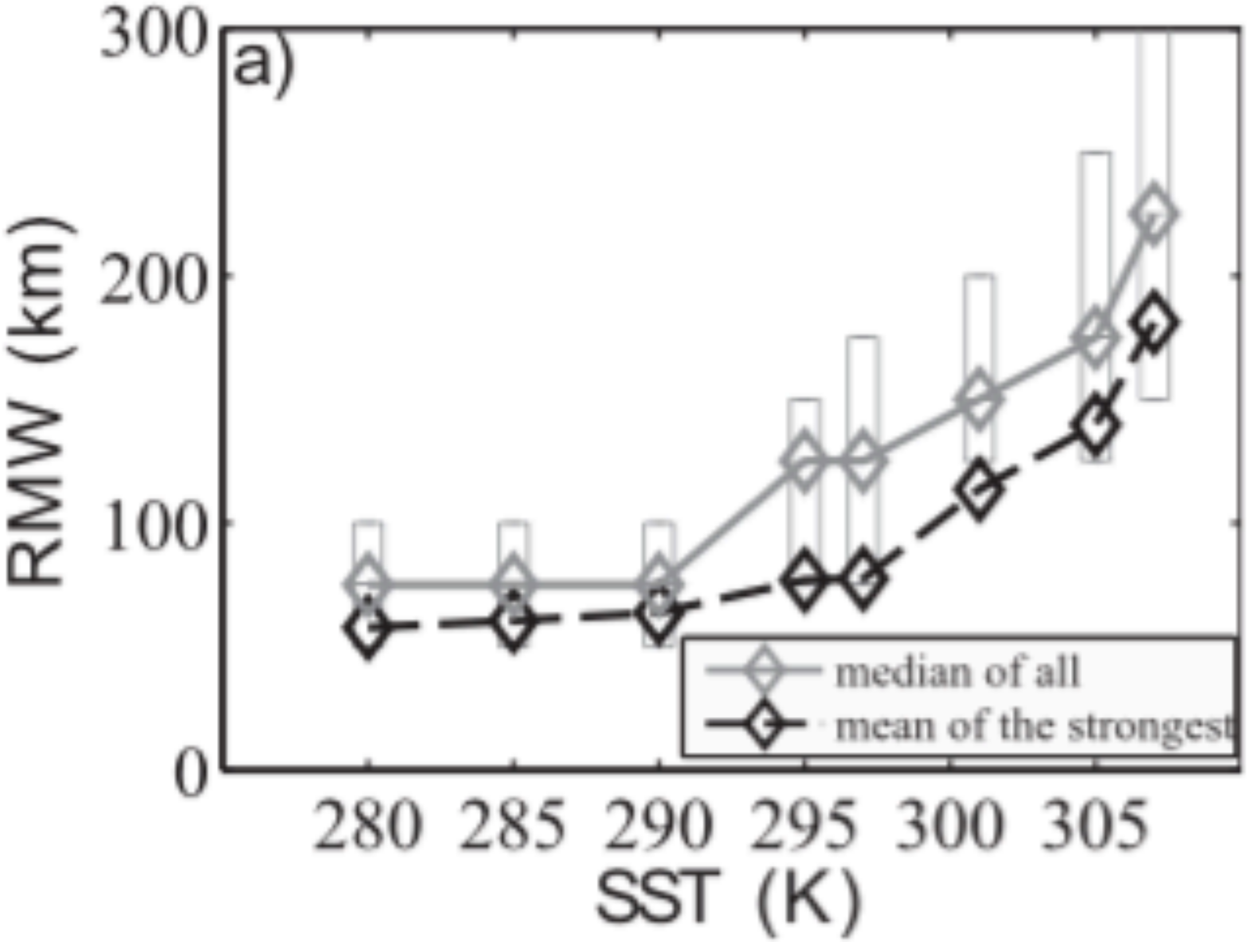


Potential Intensity:

$$C_D V^3 \sim Q(\Delta T / T) \sim C_H V(k^* - k)(\Delta T / T)$$

$$\Rightarrow V^2 \sim (C_H / C_D)(k^* - k)(\Delta T / T)$$

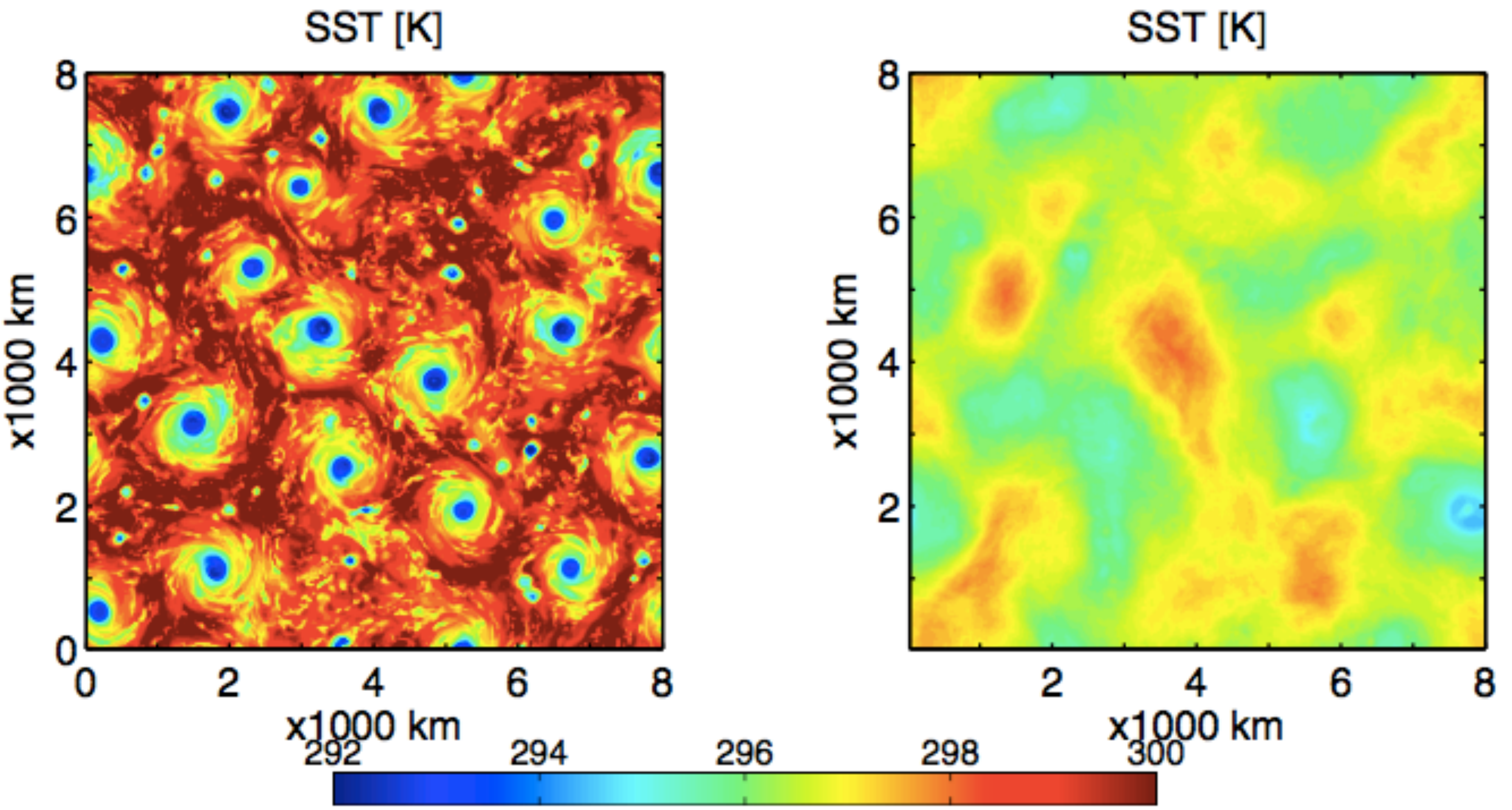
Radius of maximum winds



Rotating radiative-convective equilibrium on an f-plane with a slab ocean of depth H (energetically closed – prognostic SSTs)

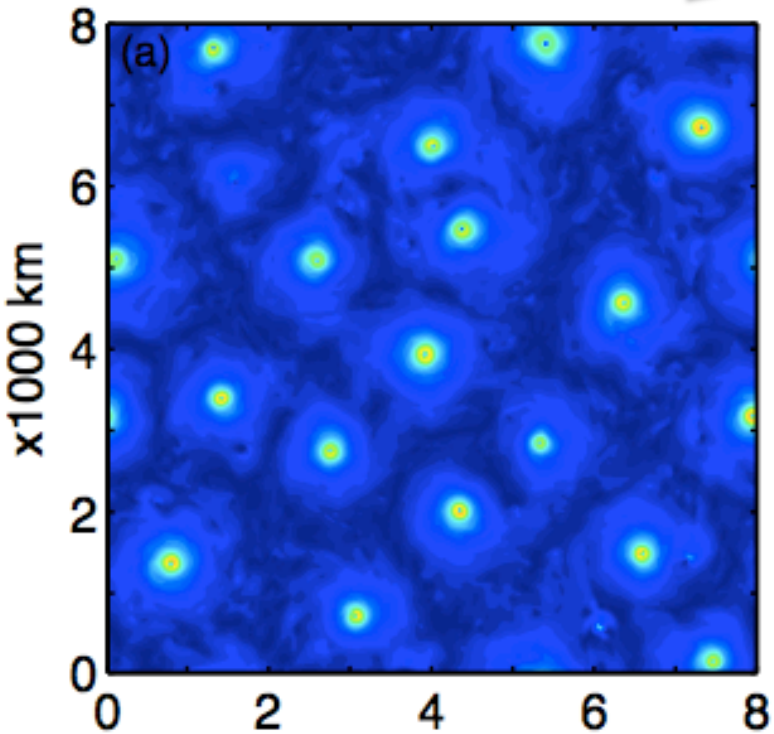
H = 0.1 m

H = 20 m

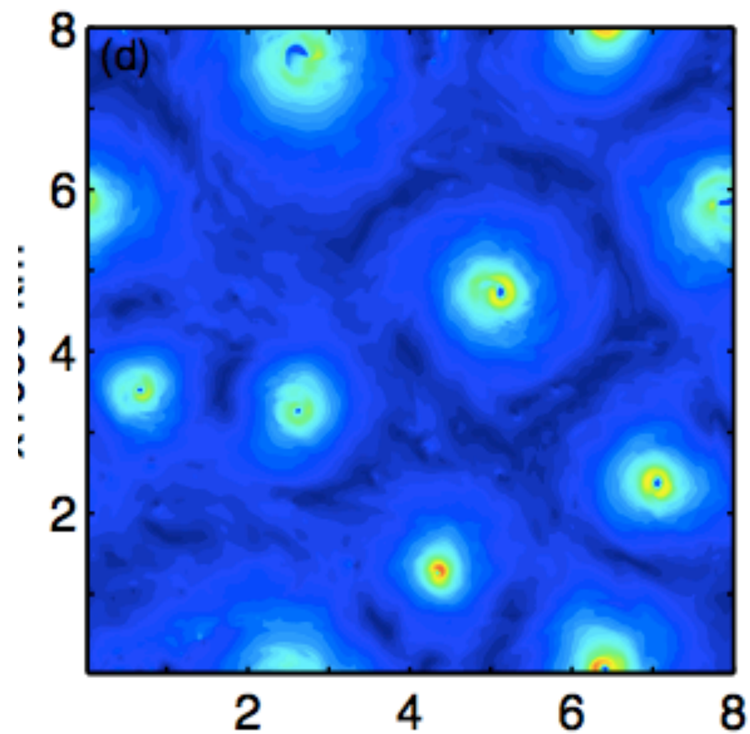


Even as energy content of “ocean” – the depth of the slab -- approaches zero,
tropical storms survive and fill domain

Depth = 0.1 m



Depth = 20 m



There is great opportunity for a new generation of scientists
with solid foundations in both
tropical cyclone (TC) research and in global climate modeling
to increase our
fundamental understanding of the TC climatology
and improve our
simulations and predictions of its variability and sensitivity