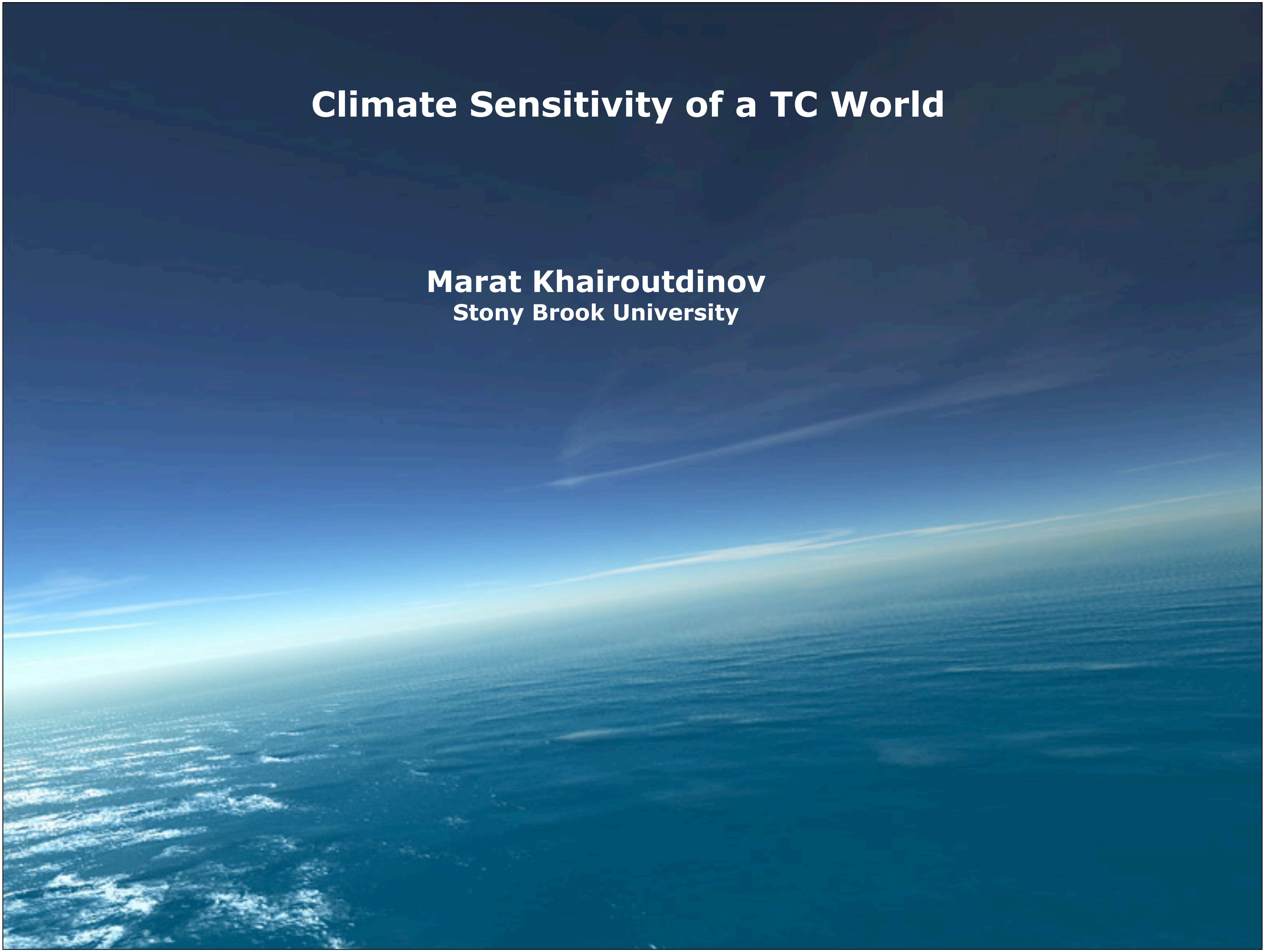

Climate Sensitivity of a TC World

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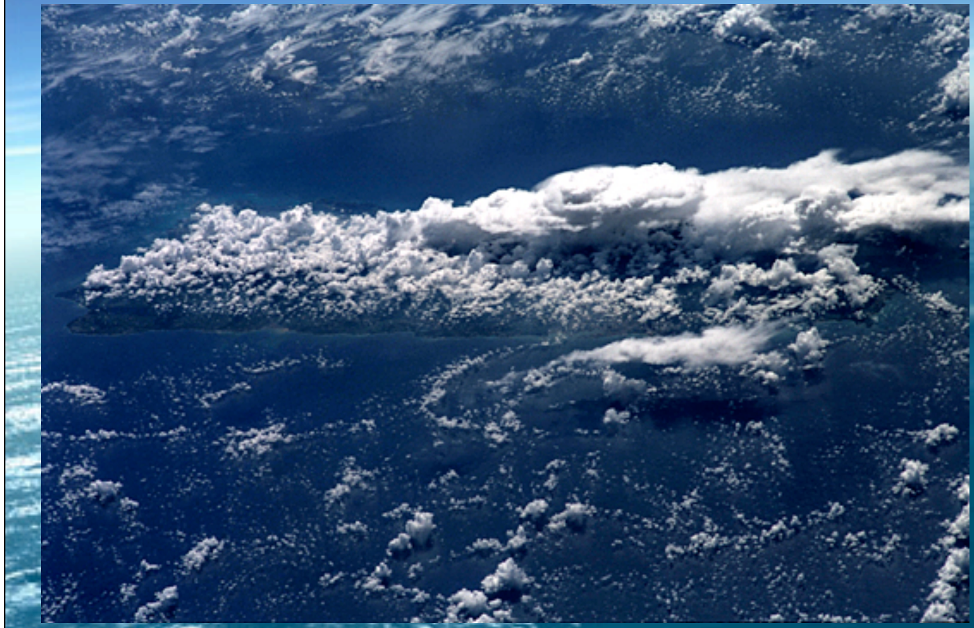
Motivation

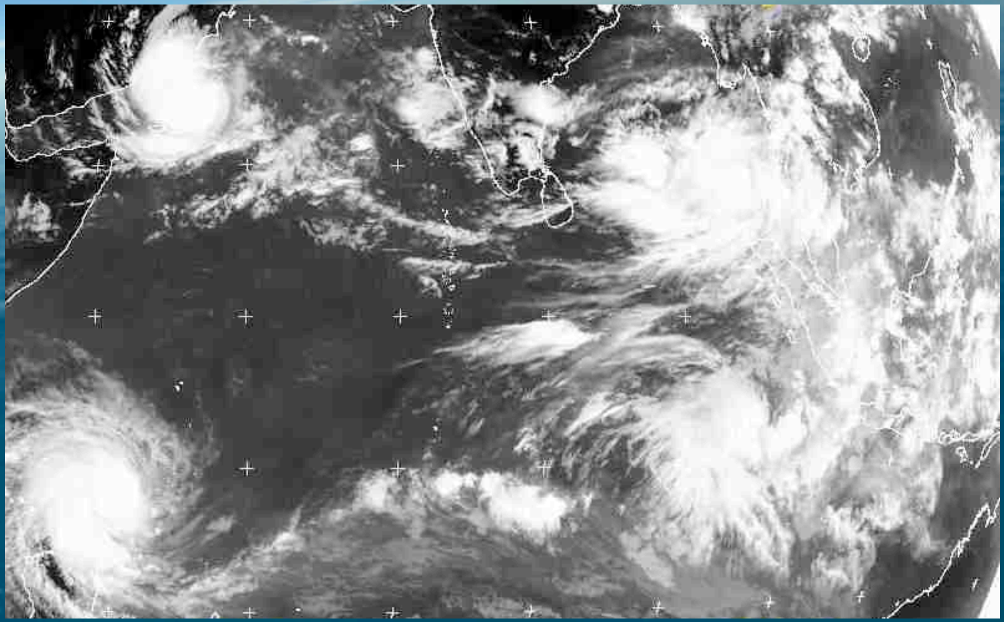
- Tropical convection tends to self-organize on wide range of scales much larger than the individual cloud elements, e.g., squall-lines, MCCs, tropical cyclones, MJO.
- Mechanisms and dependencies of self-organization are poorly understood.
- Self-organization of convection may modulate cloud feedbacks on climate.

The approach: Use cloud-resolving simulations of the radiative-convective equilibrium as the idealization of tropical atmosphere.

100 miles

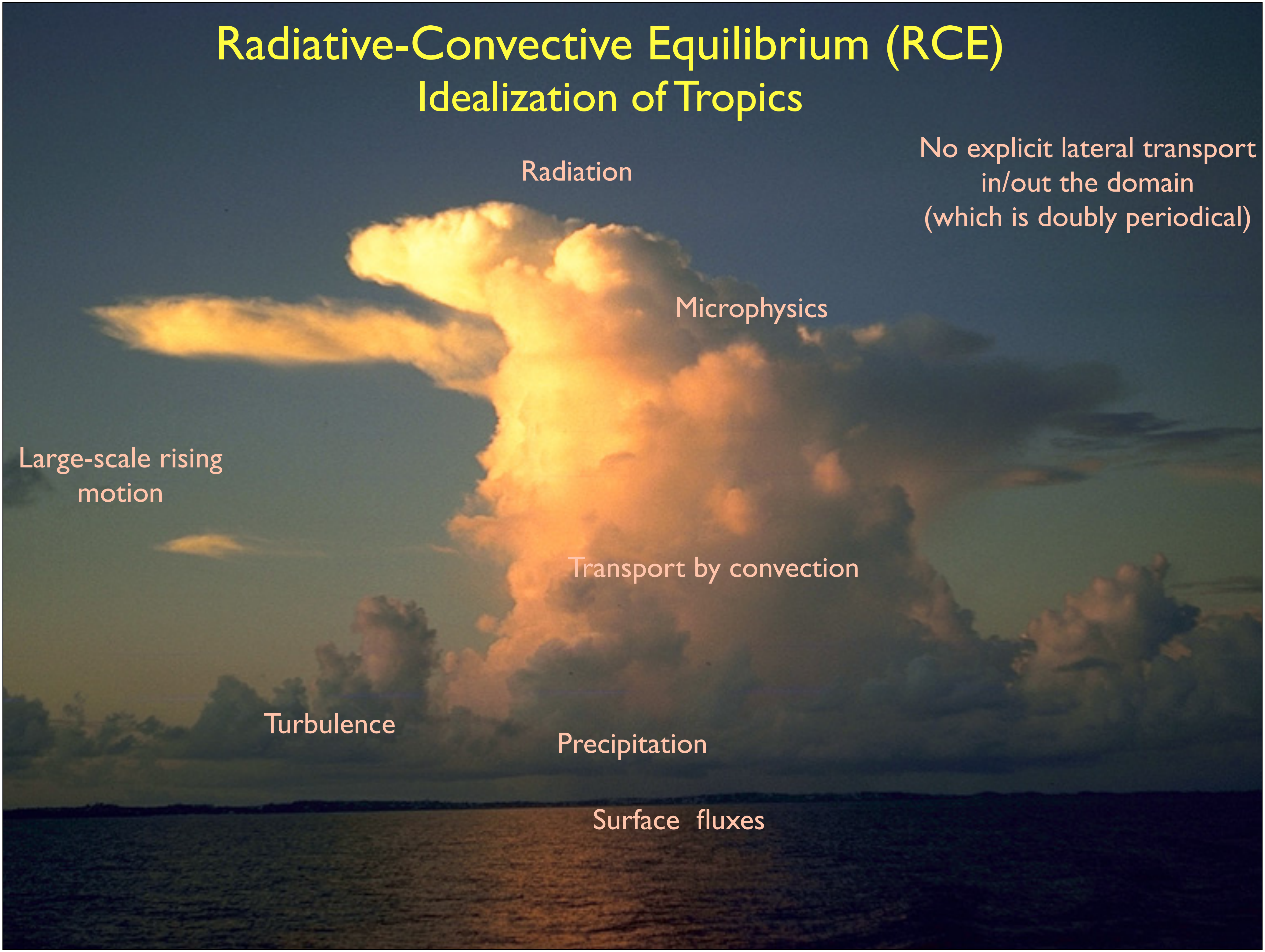


4000 miles



Radiative-Convective Equilibrium (RCE)

Idealization of Tropics



Radiation

No explicit lateral transport
in/out the domain
(which is doubly periodical)

Microphysics

Large-scale rising
motion

Transport by convection

Turbulence

Precipitation

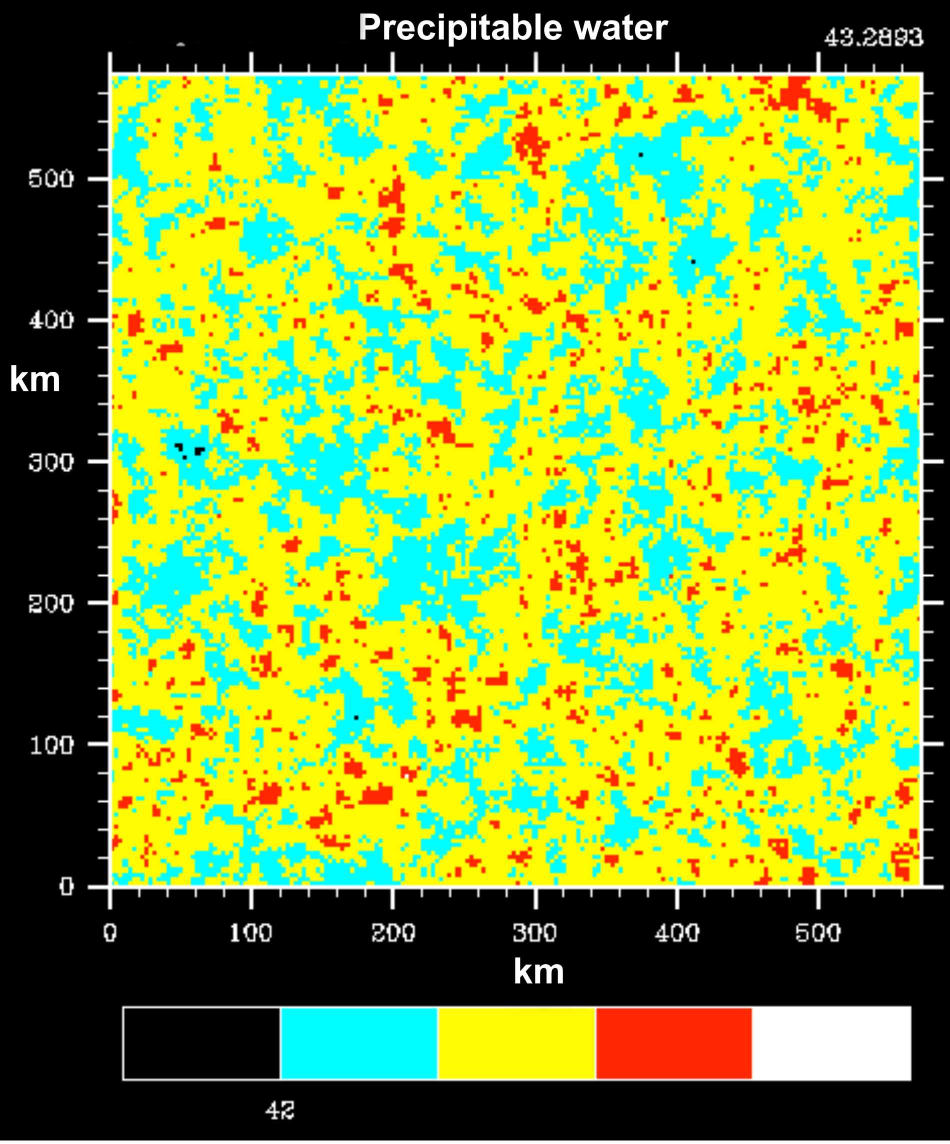
Surface fluxes

Self-aggregation of convection in RCE

Bretherton and Khairoutdinov (2005), Bretherton at al (2006)

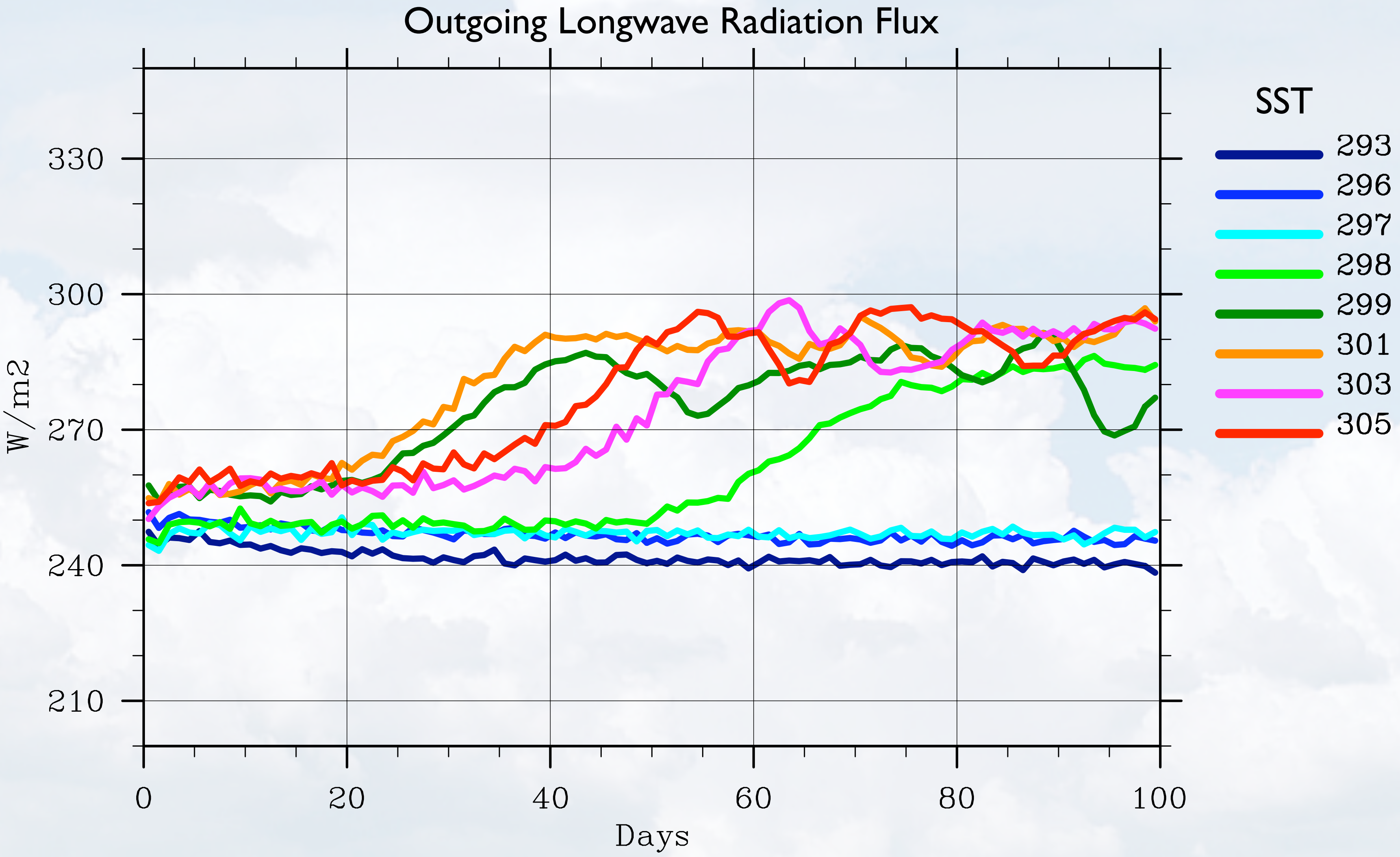
Domain should be large enough (at least 500 km)

What determines the scale of self-aggregation?



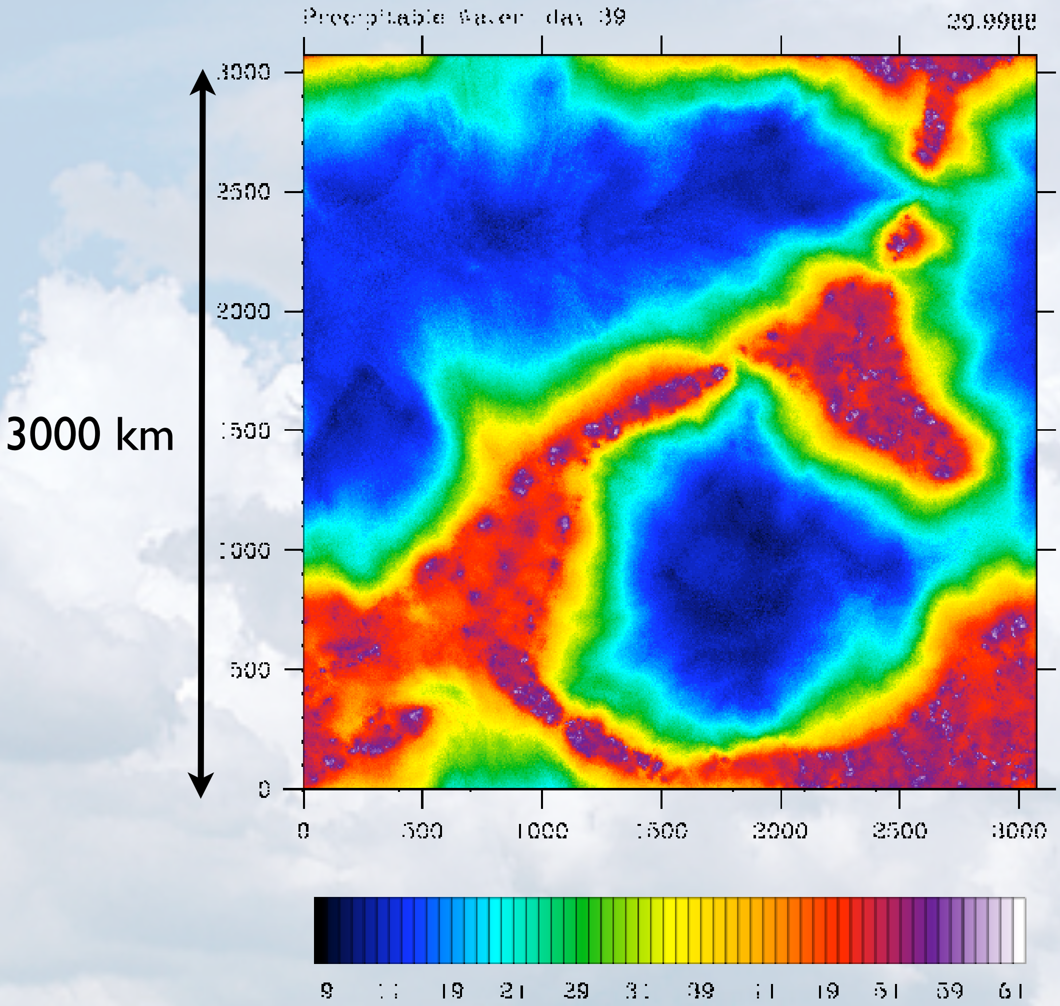
Self-aggregation of convection in RCE over large domain with no rotation

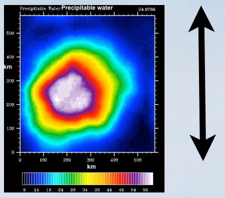
Dependence on SST: “On/off switch”

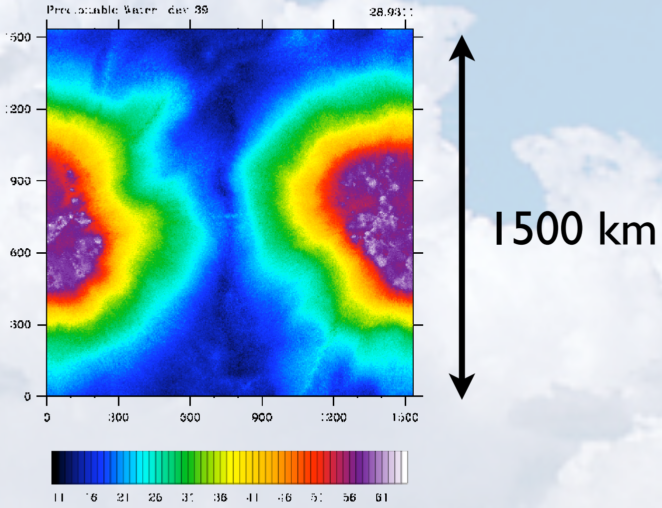


Khairoutdinov and Emanuel (2011)

There appears to be no limiting horizontal scale for self-aggregation, only the domain size.



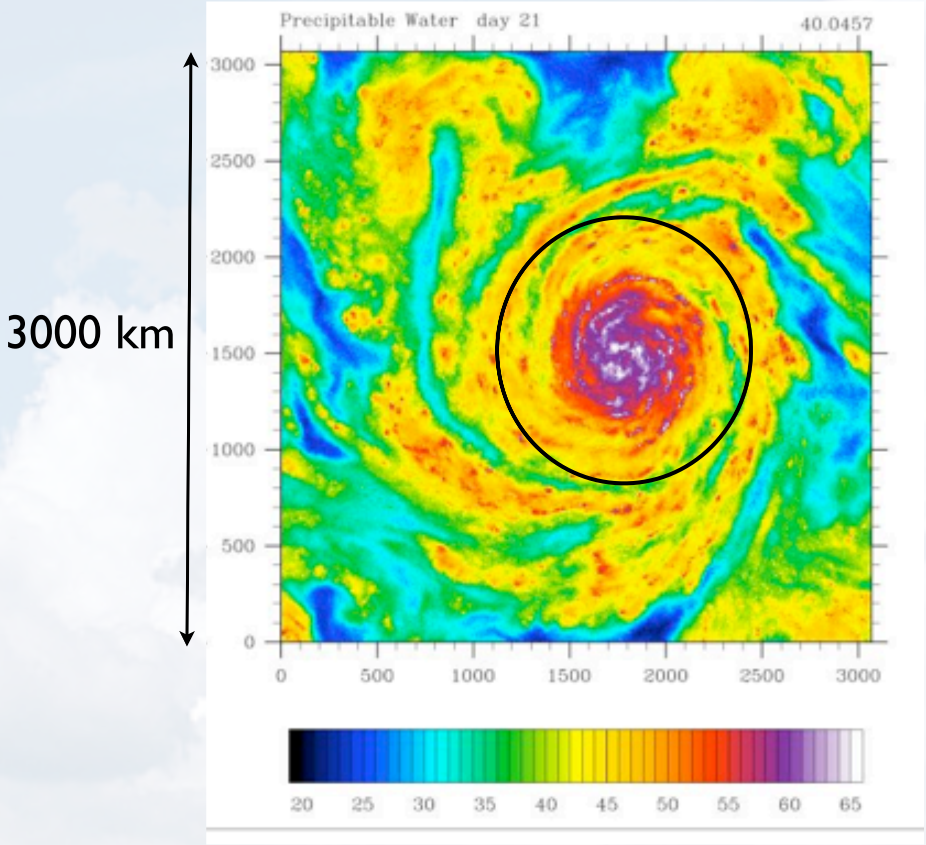




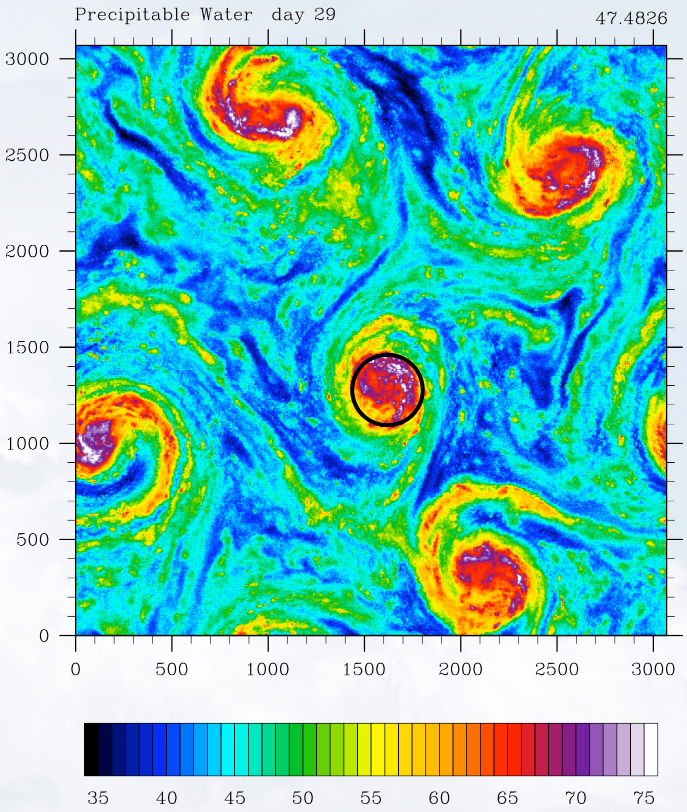
Rotation provides the horizontal scale

"TC Worlds"

$f \approx 5 \times 10^{-5} s^{-1}$



$f \approx 2 \times 10^{-4} s^{-1}$



$$Ro = \frac{V_{PI}}{Df} \sim 1$$

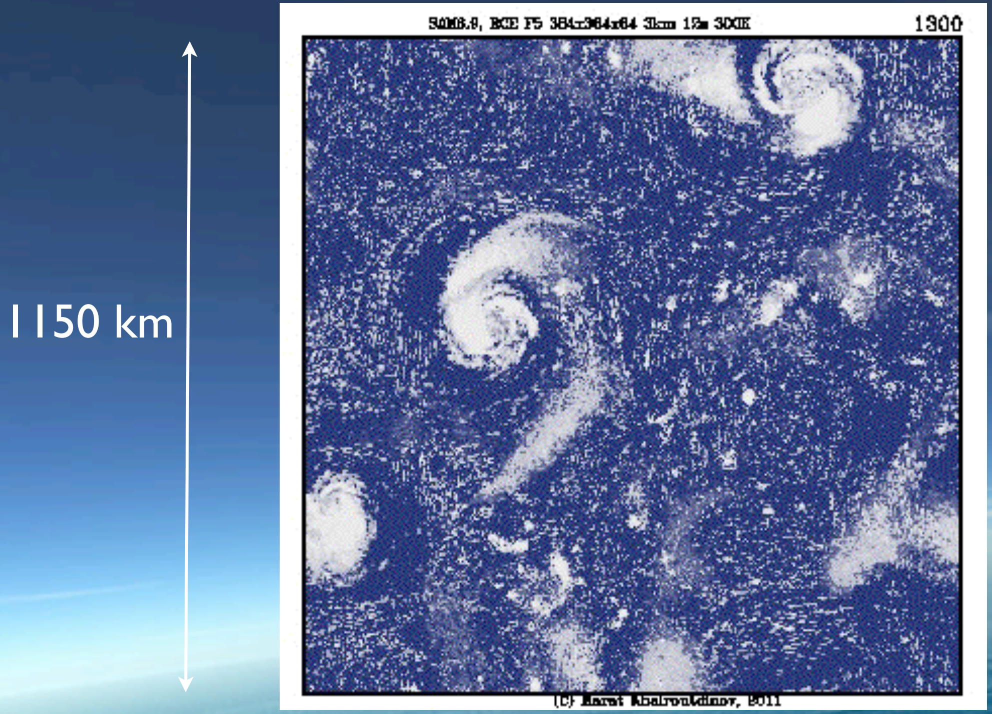
$$D \approx \frac{V_{PI}}{f}$$

Set-up

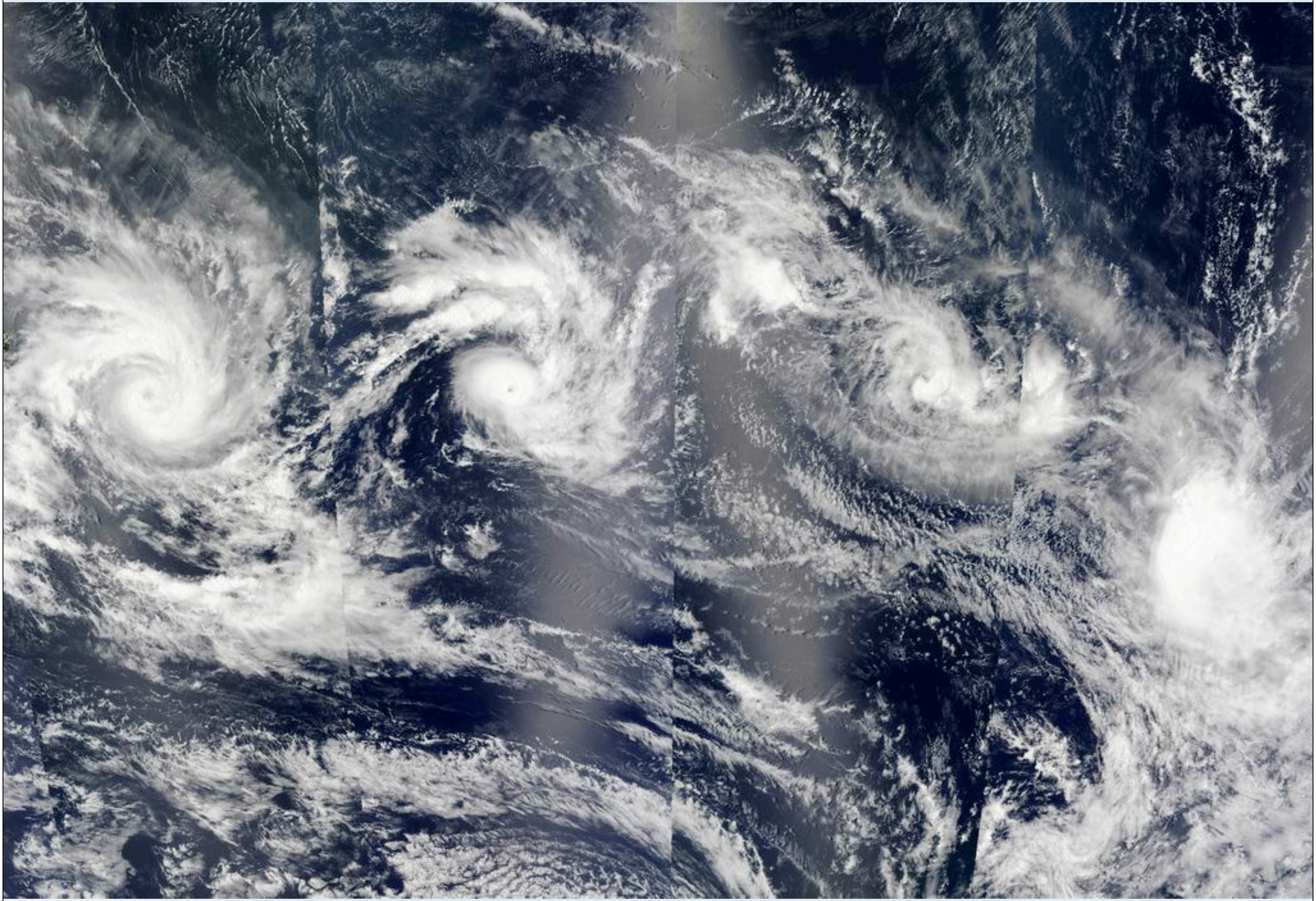
- System for Atmospheric Modeling (SAM; Khairoutdinov and Randall 2003)
- perpetual sun; prescribed SST (294, 297, 300, 303, 306 K)
- f-plane with Coriolis parameter: 5×10^{-4} s^{-1}
- RCE with no rotation: 384 x 384 x 28 km3; “TC World”: 2304 x 2304 x 28 km3
- Horiz. grid-spacing 3 km; vertical grid stretched, from 50 m to 500 m
- Duration: 100 days

Radiative-Convective Equilibrium with Rotation
“TC World”

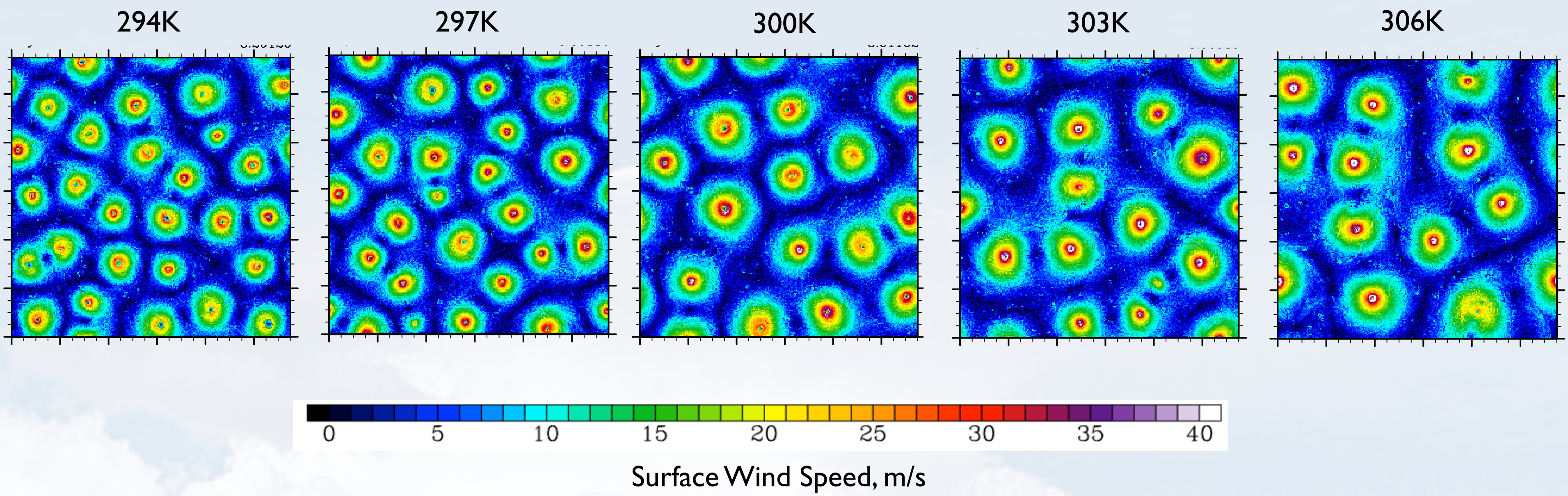
SST= 300K   f=5x10^{-4} s^{-1}

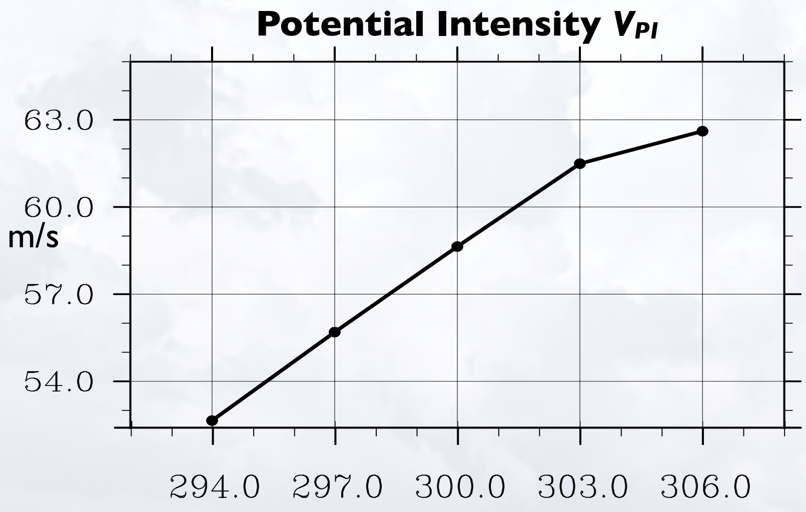


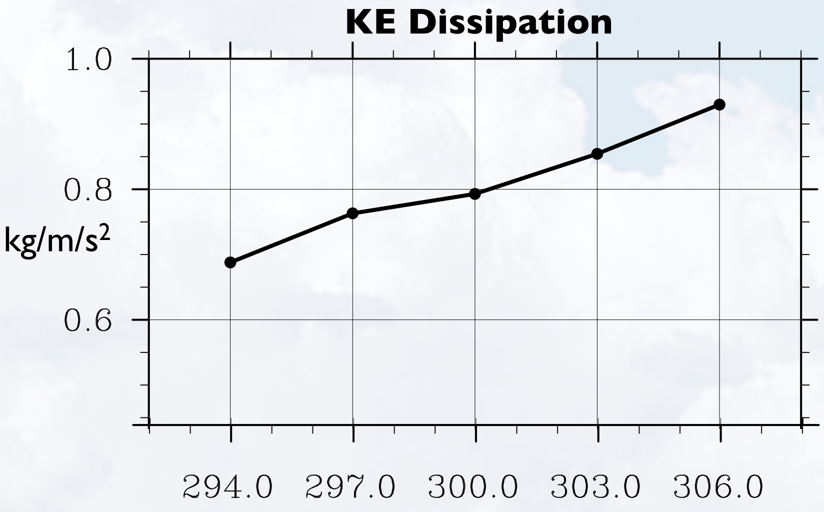
“TC World on Earth...”



In warmer TC World, TCs become larger, less frequent, but more intense.



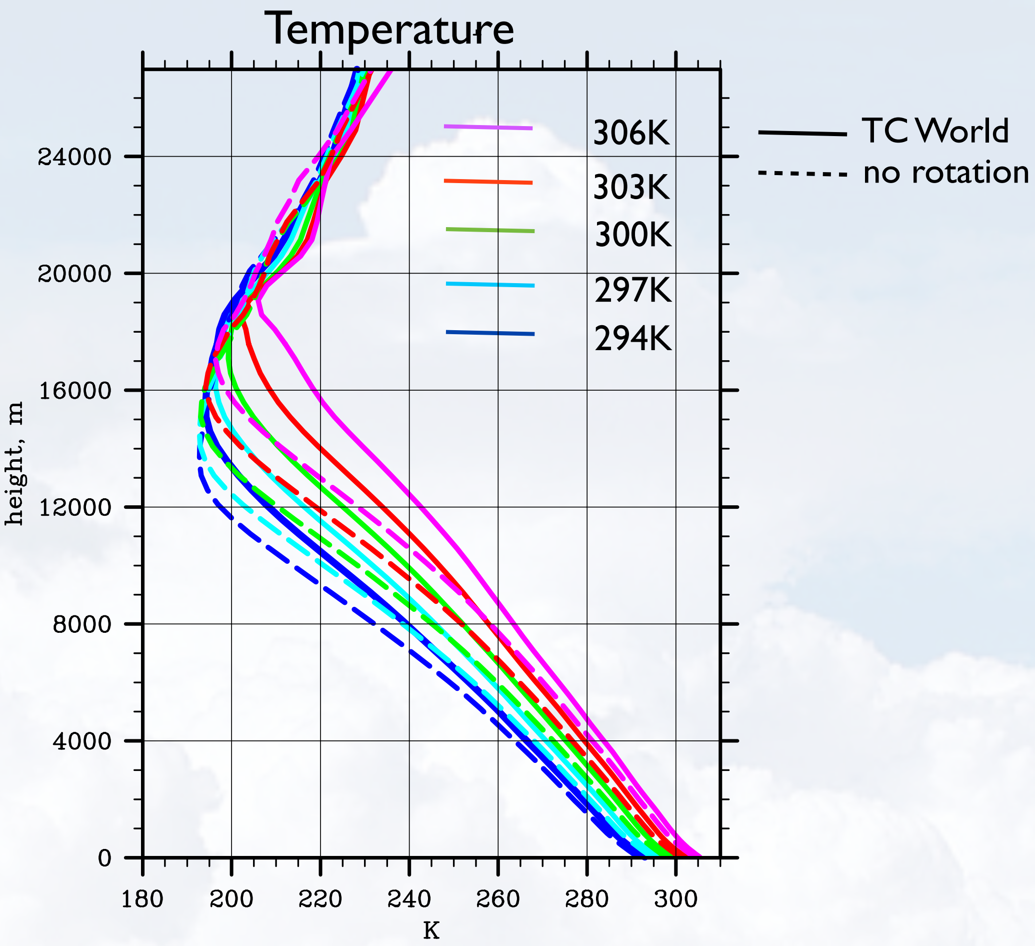




TC size: $D \approx \frac{V_{PI}}{f}$

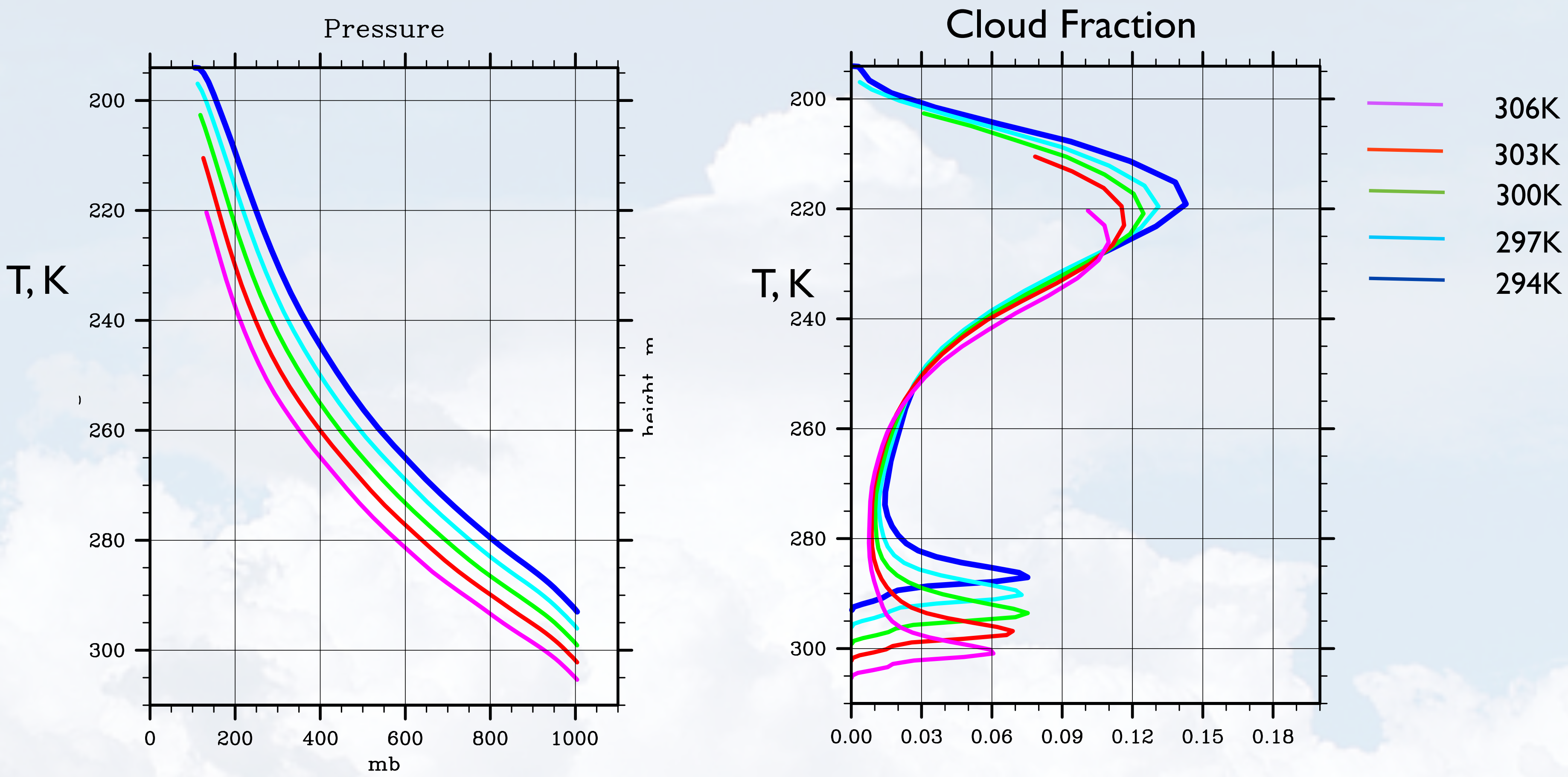
#TC per unit area: $f^2 V_{PI}^{-2}$

Power dissipation per TC: V_{PI}^3



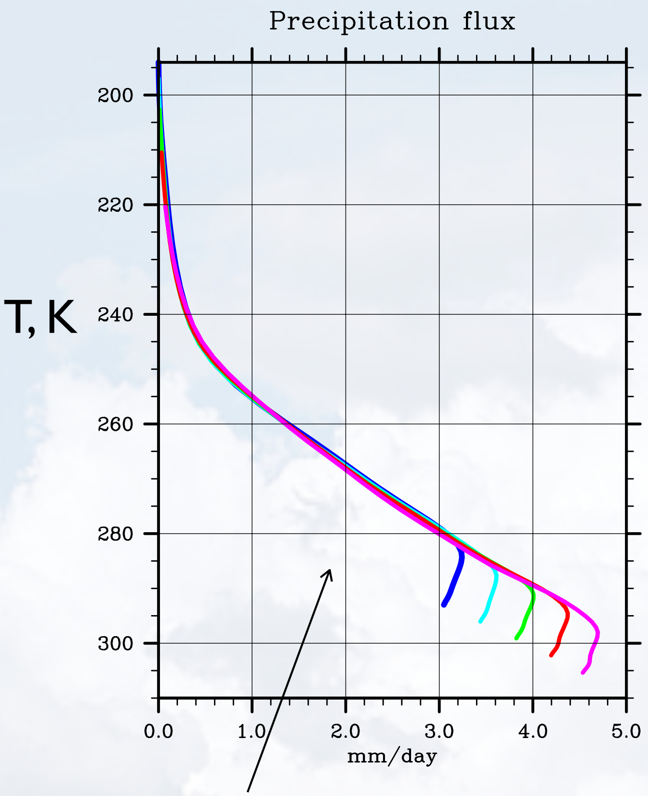
As SST increases, the tropopause becomes higher and

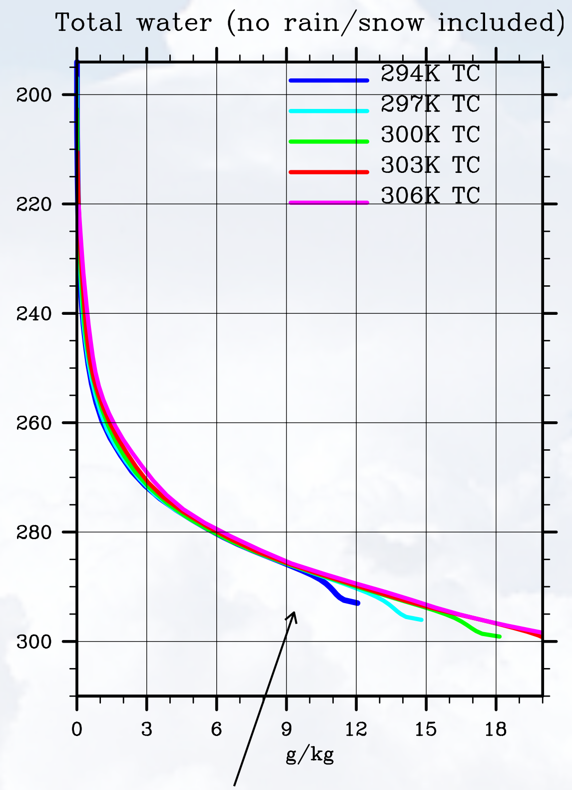
- with no TCs, tropopause temperature stays constant;
- in “TC World”, tropopause becomes warmer;

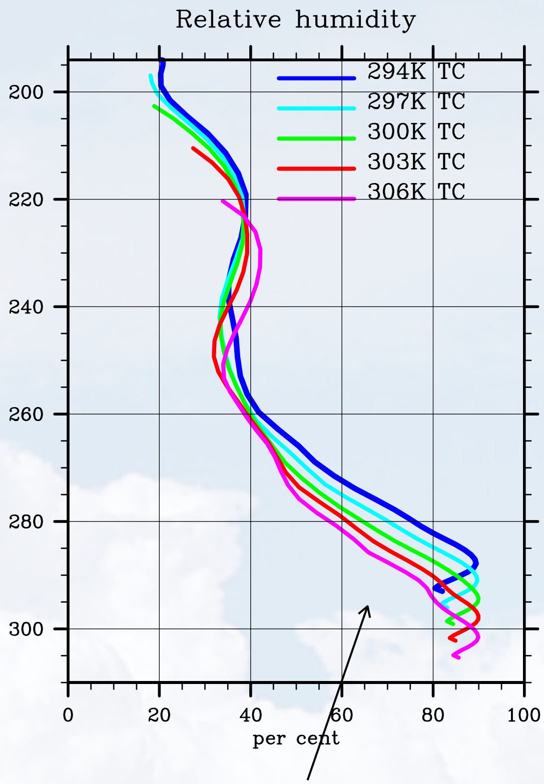


The outflow temperature in simulated hurricanes tends to be invariant of SST (recall Hartmann's FAT hypothesis for deep tropical convection). FAT tends to increase thermodynamic efficiency of converting heat into KE in TC World. However, FAT doesn't seem to work at warmest SSTs, when thermodynamic efficiency decreases.

Couple other little ‘nuggets’ to explain....







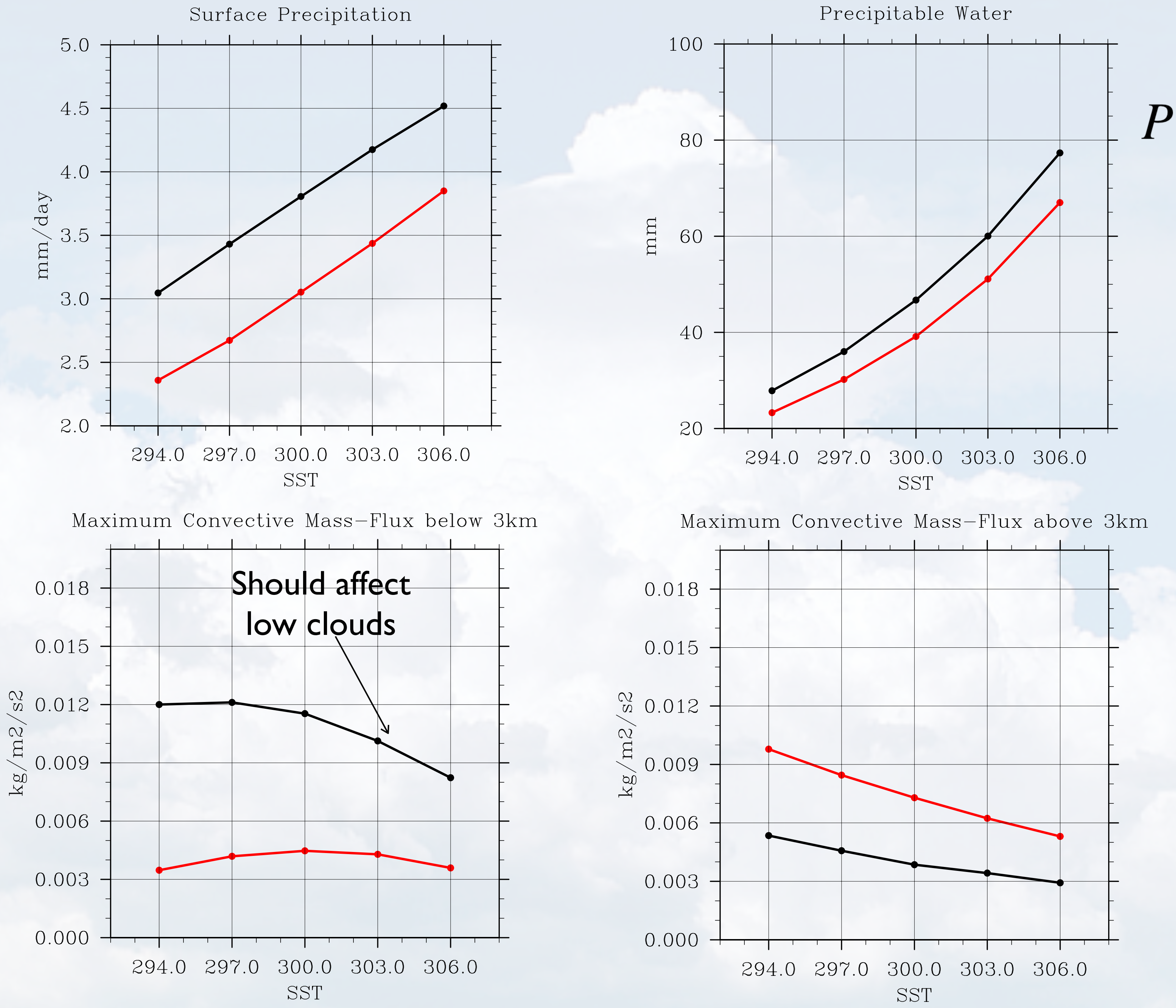
Precipitation rate is the function of temperature only (above PBL). But why?!

...and so is the water vapor, but not because the RH is invariant of T

(RH depends on pressure too)

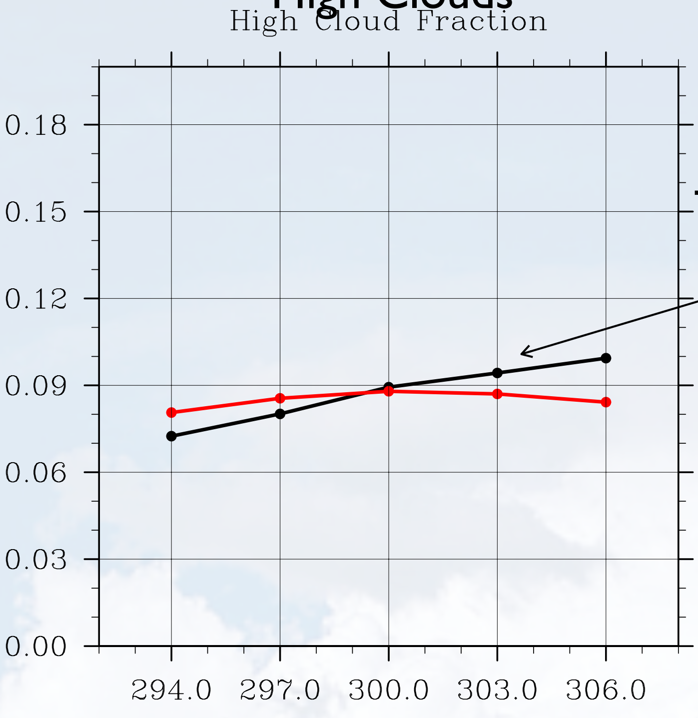
Because of similarity, one would expect then that the surface precipitation is a linear function of SST

$$P \propto q_{PBL} M_c$$



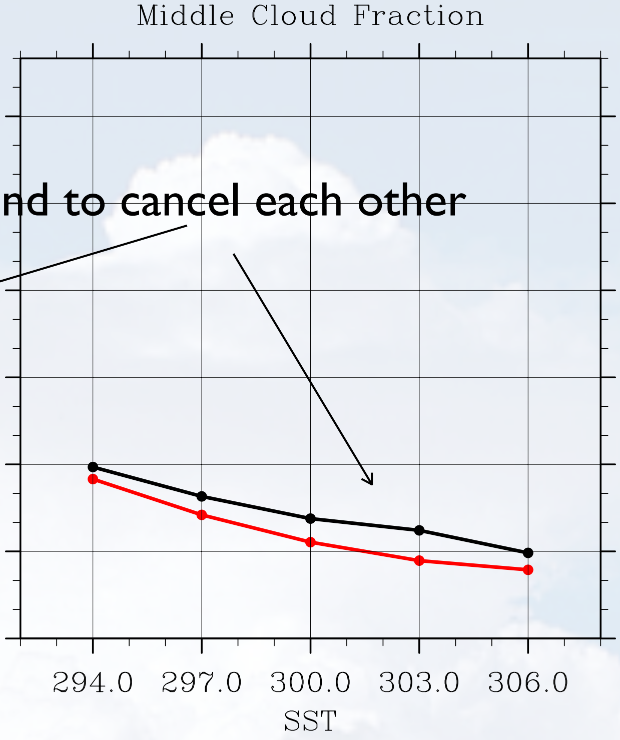
Should affect low clouds

High Clouds

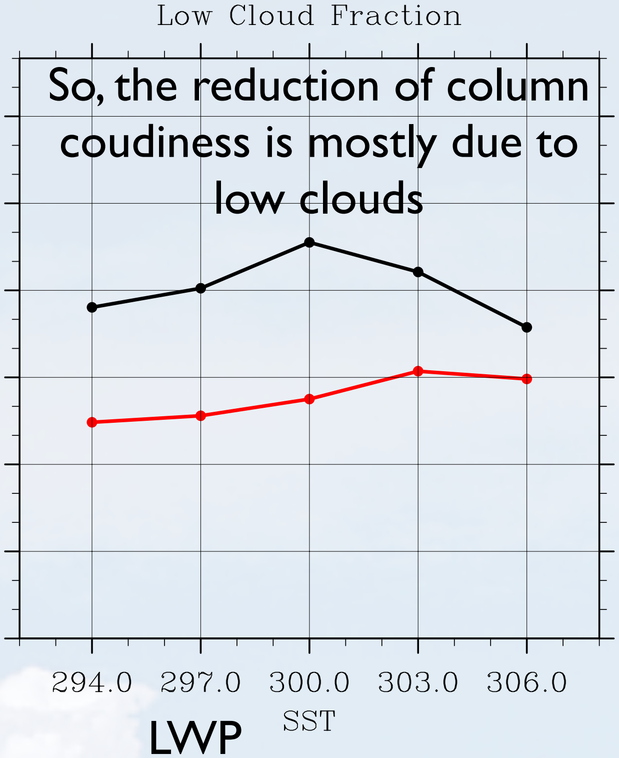


Tend to cancel each other

Mid Clouds

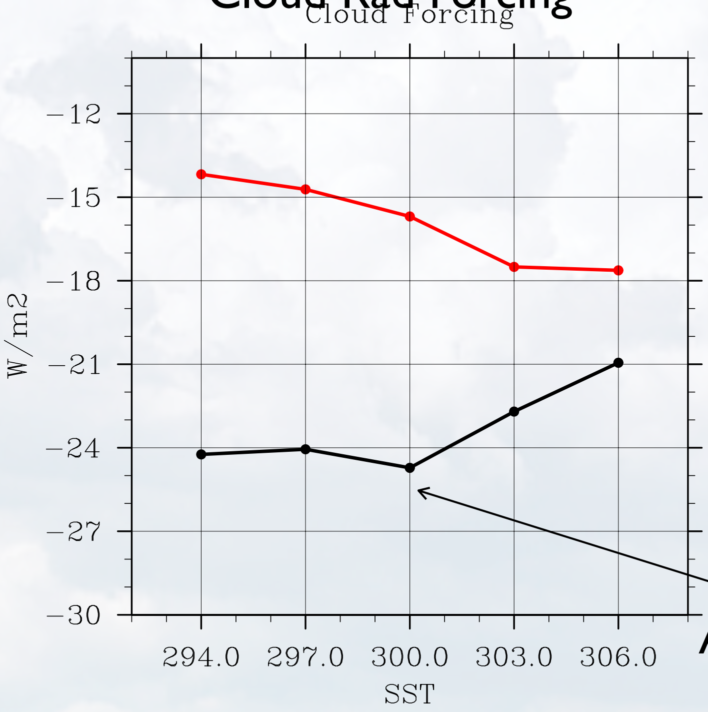


Low Clouds



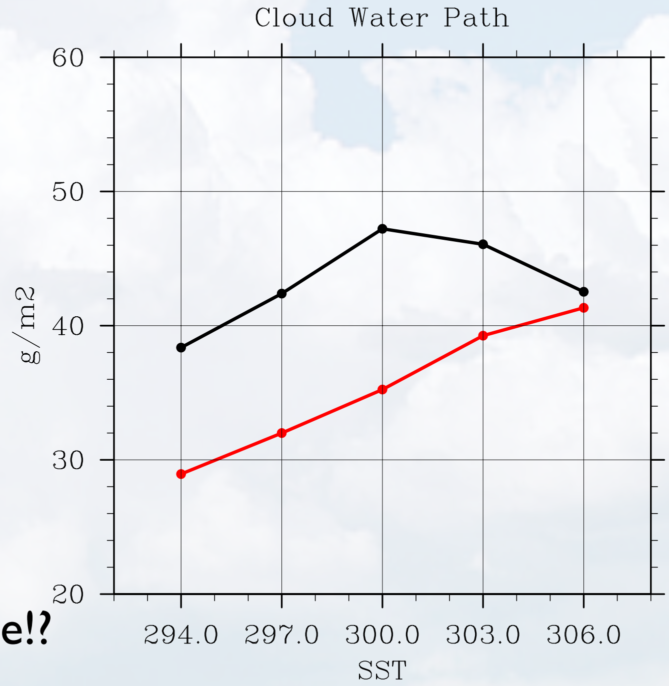
So, the reduction of column coudiness is mostly due to low clouds

Cloud Rad Forcing

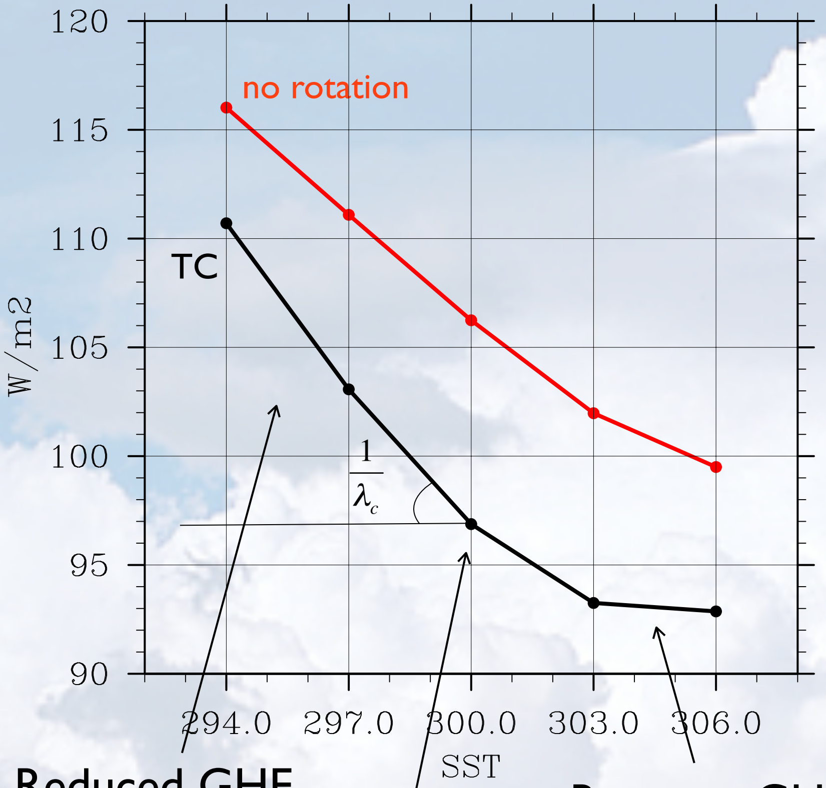


Abrupt regime change!?

LWP



Net TOA Imbalance *N* = *(ASW-OLR)*



Reduced GHE in TC World

Regime shift

Runaway GHE in TC World?!

RCE TOA balance:

$$N - Q + F \approx 0$$

N - Net TOA imbalance

Q - Implied ocean transport

F - Implied forcing (e.g. 2xCO2)

$$\frac{dN}{dT_s} - \frac{dQ}{dT_s} + \frac{dF}{dT_s} \approx 0$$

$$\frac{dF}{dT_s} = \frac{1}{\lambda_c}$$

λ_c- climate sensitivity

$$\boxed{\frac{1}{\lambda_c} = -\frac{dN}{dT_s} + \frac{dQ}{dT_s}}$$

For frozen implied ocean transport,
TCs may reduce or amplify the climate sensitivity of RCE depending on temperature. As TC world warms up, the climate sensitivity dramatically increases to the point of getting close to a ‘runaway’ climate change.

Summary

Cloud-resolving RCE simulations suggest that

- Tropical convection has a tendency to cluster or self-aggregate. There could be non-linearity or even on-off behavior associated with relatively modest SST changes
- The TCs in warming world may become stronger and larger in size, but less frequent.
- The aggregated state (with TCs) may substantially reduce or substantially increase sensitivity to the forcing (due to CO2 increase) with warmer temperatures conducive of ‘runaway’ greenhouse effect.
- Shallow convection may be the key to climate sensitivity of Tropics.