Organization of tropical convection and equilibrium climate sensitivity

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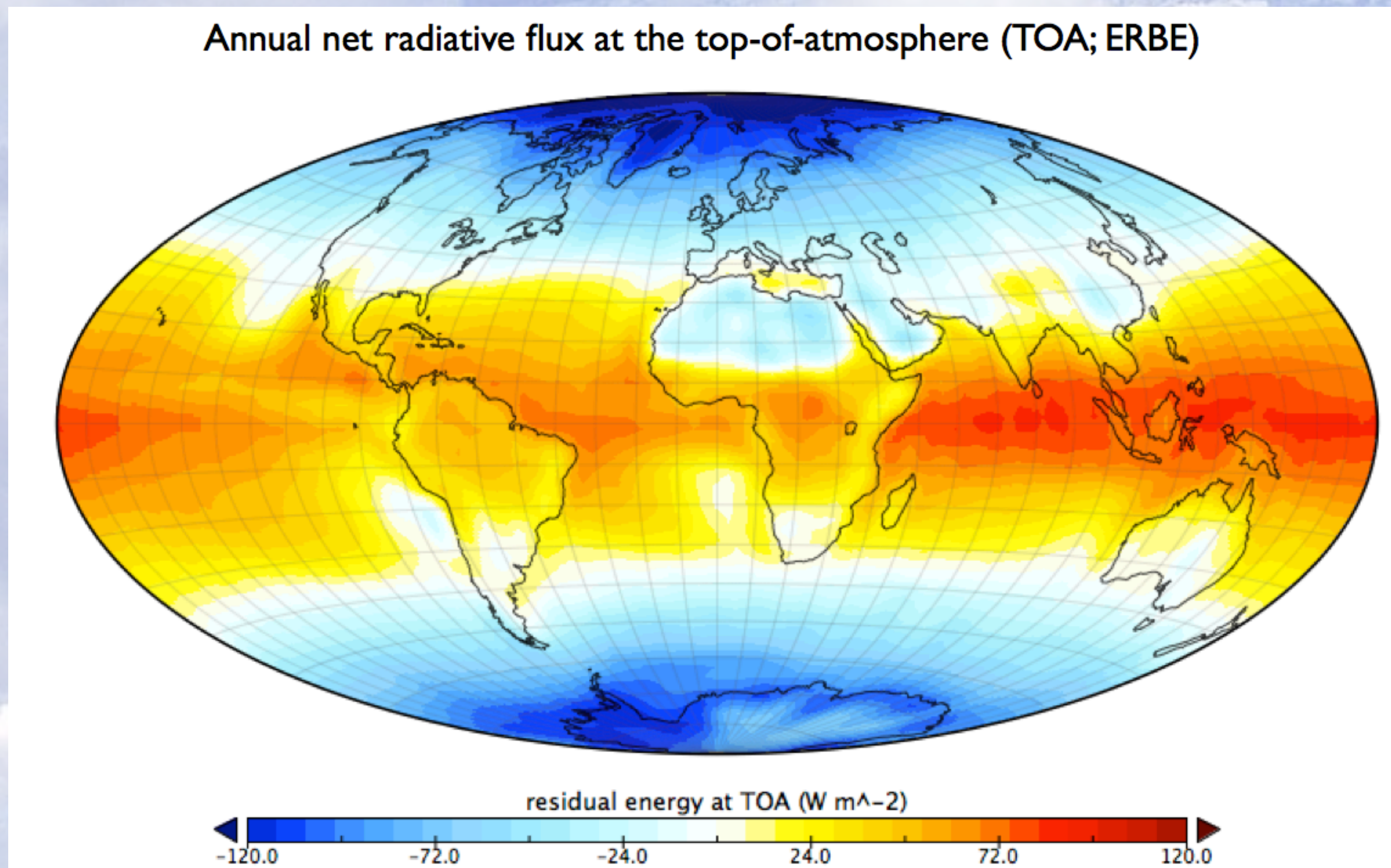
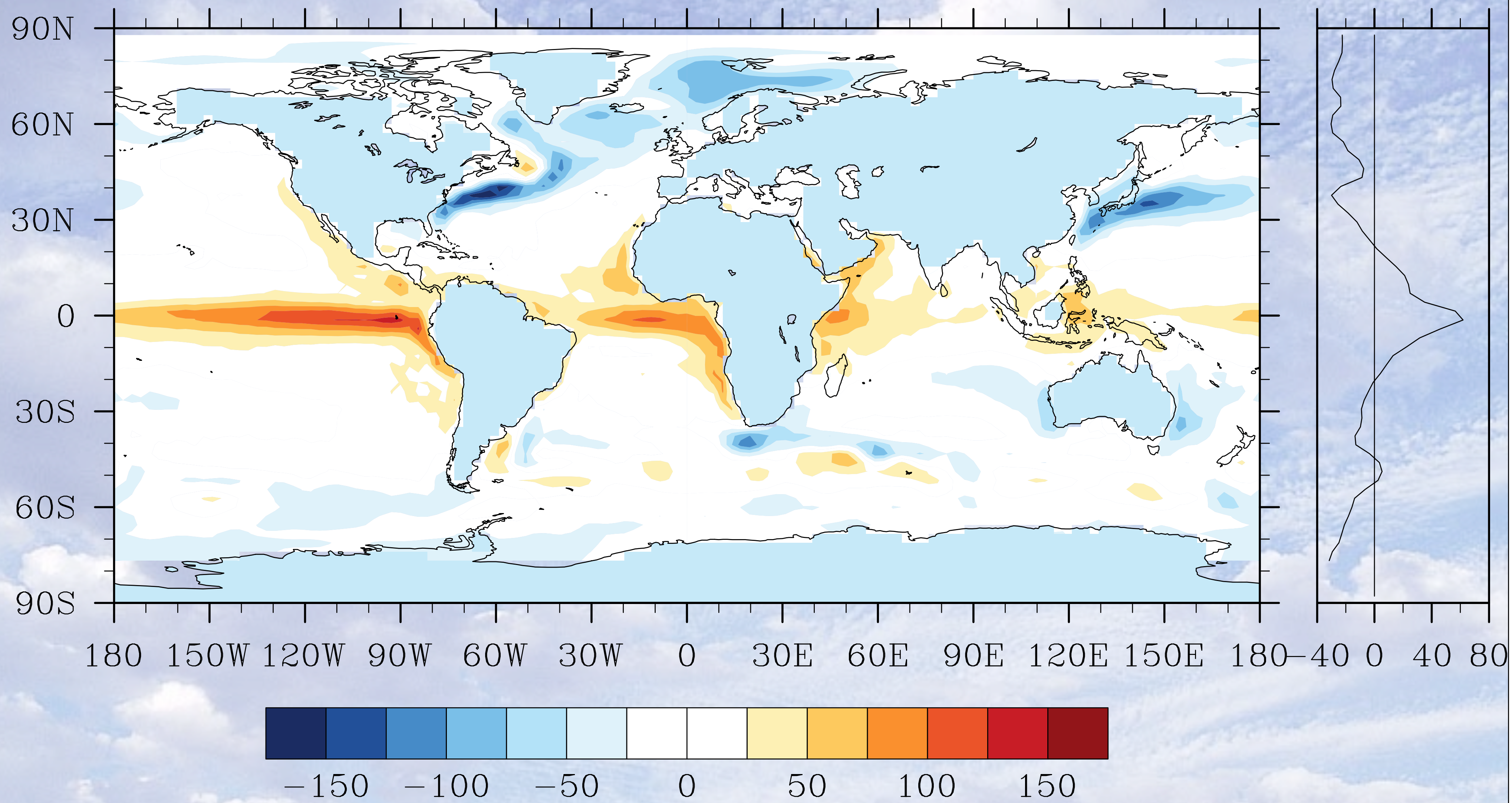
CMMAP
Reach for the sky.

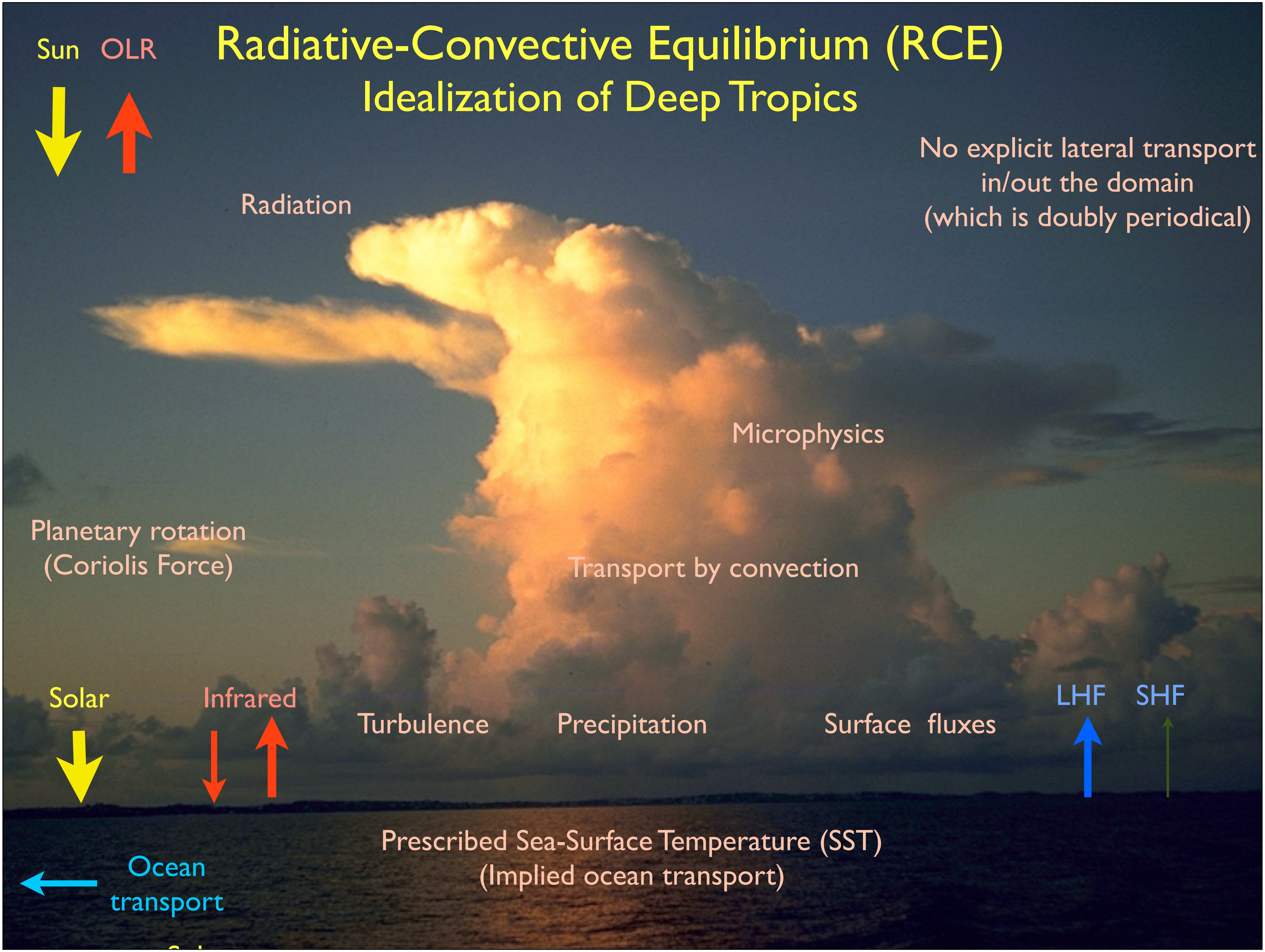
NSF

Qs: How stable is the tropical climate with respect to external forcing such as warming due to increasing greenhouse gases?
What is the role of organized convection? In particularly tropical cyclones?



Implied Ocean Heat Uptake (CERES & ERA40)





Radiative-Convective Equilibrium (RCE)
Idealization of Deep Tropics
Sun
OLR
Radiation
No explicit lateral transport
in/out the domain
(which is doubly periodical)
Microphysics
Planetary rotation
(Coriolis Force)
Transport by convection
Solar
Infrared
Turbulence
Precipitation
Surface fluxes
LHF
SHF
Prescribed Sea-Surface Temperature (SST)
(Implied ocean transport)
Ocean
transport

Radiative-Convective Equilibrium with rotation

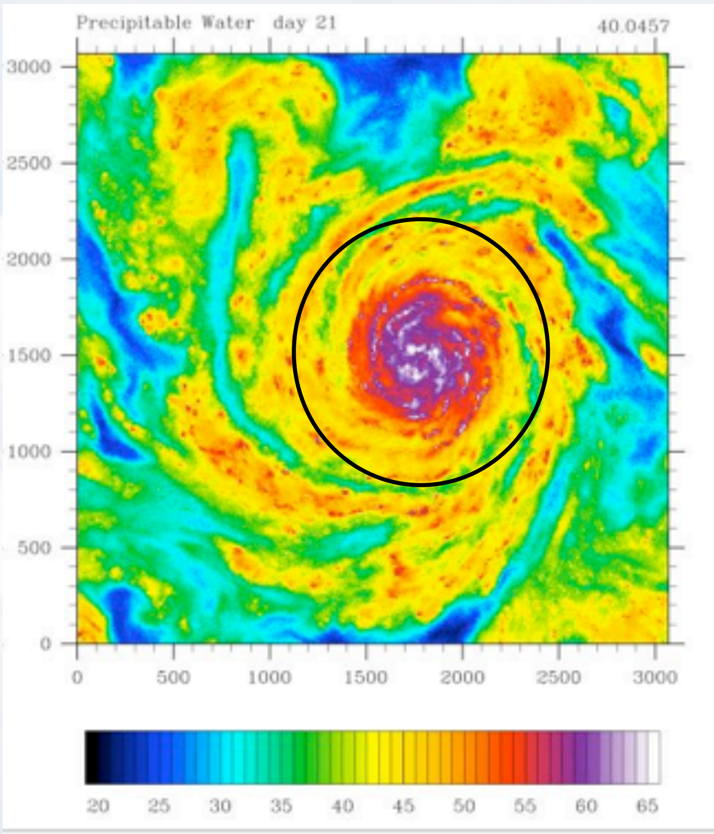
"TC-World"

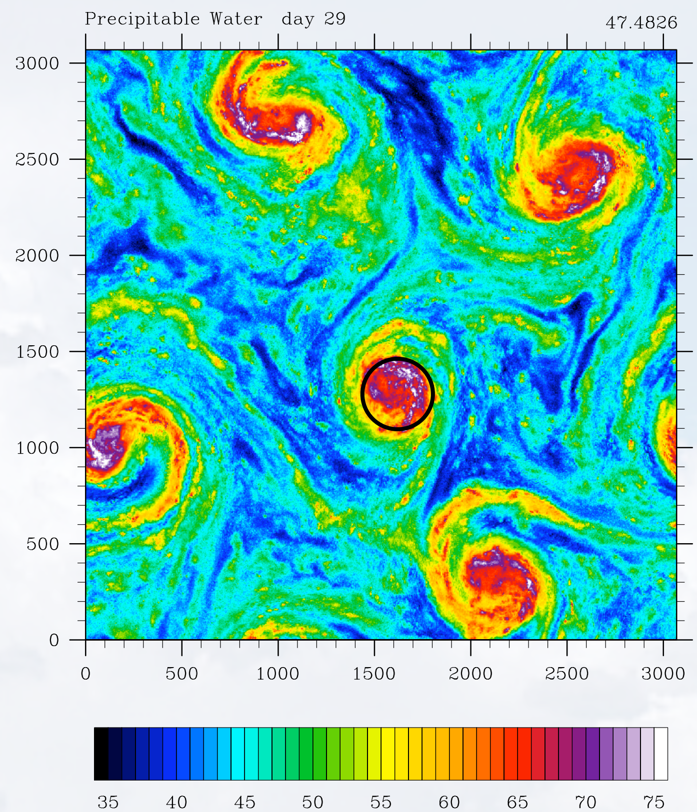
$$D \approx \frac{V_{PI}}{f}$$

Speedup rotation x4 times

$f \approx 5 \times 10^{-5} s^{-1}$ → $f \approx 2 \times 10^{-4} s^{-1}$

3000 km





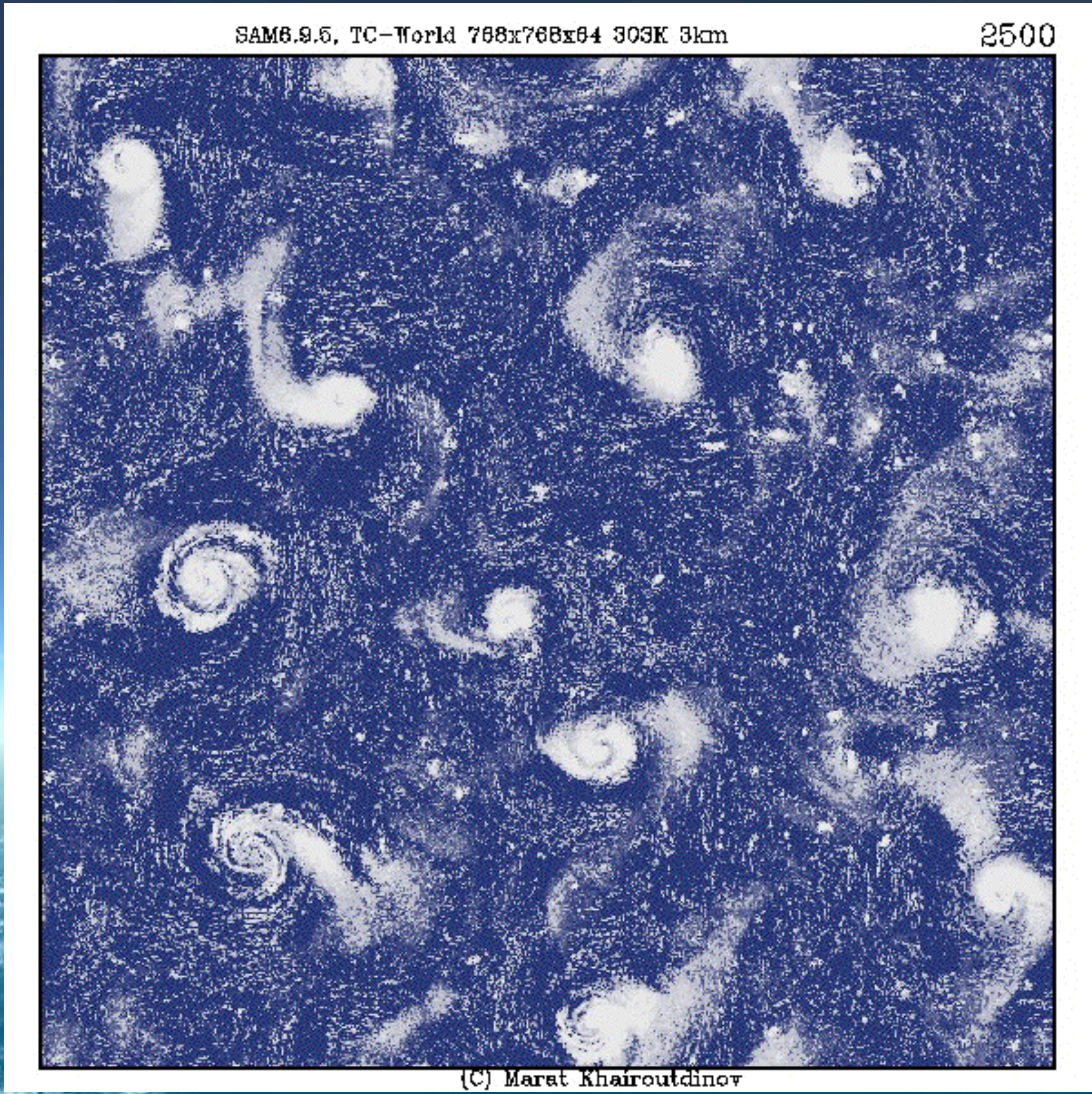
Set-up

- System for Atmospheric Modeling
- perpetual sun; prescribed SST (21, 24, 27, 30, 33, 36 ^{o}C)
- f-plane with Coriolis parameter: 5×10^{-4} s^{-1}
- RCE with no rotation: 388 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 about 100 days

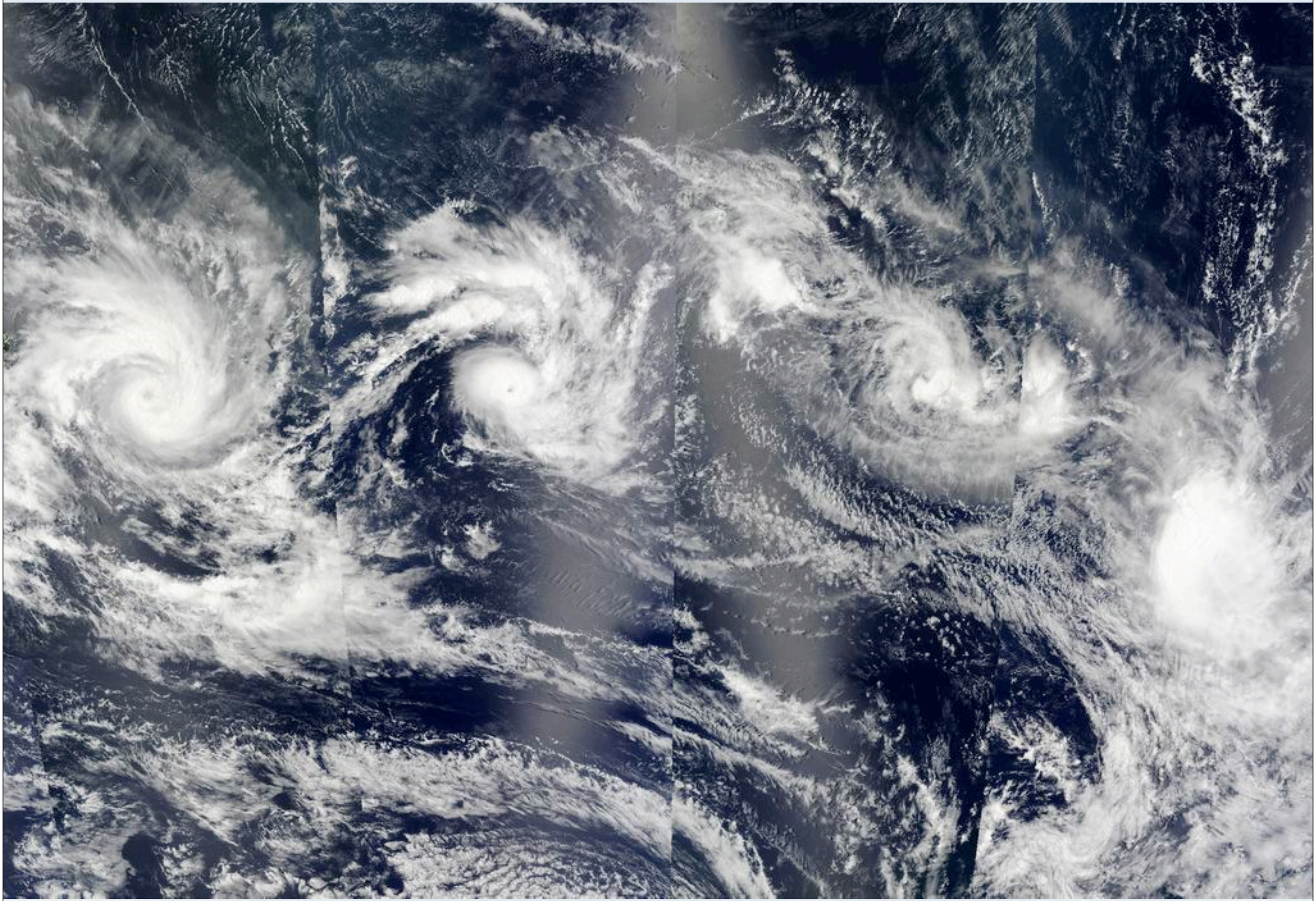
Radiative-Convective Equilibrium with Rotation

"TC World"

SST= 303K $\quad f=5\times10^{-4}\ s^{-1}$



“TC World on Earth...”



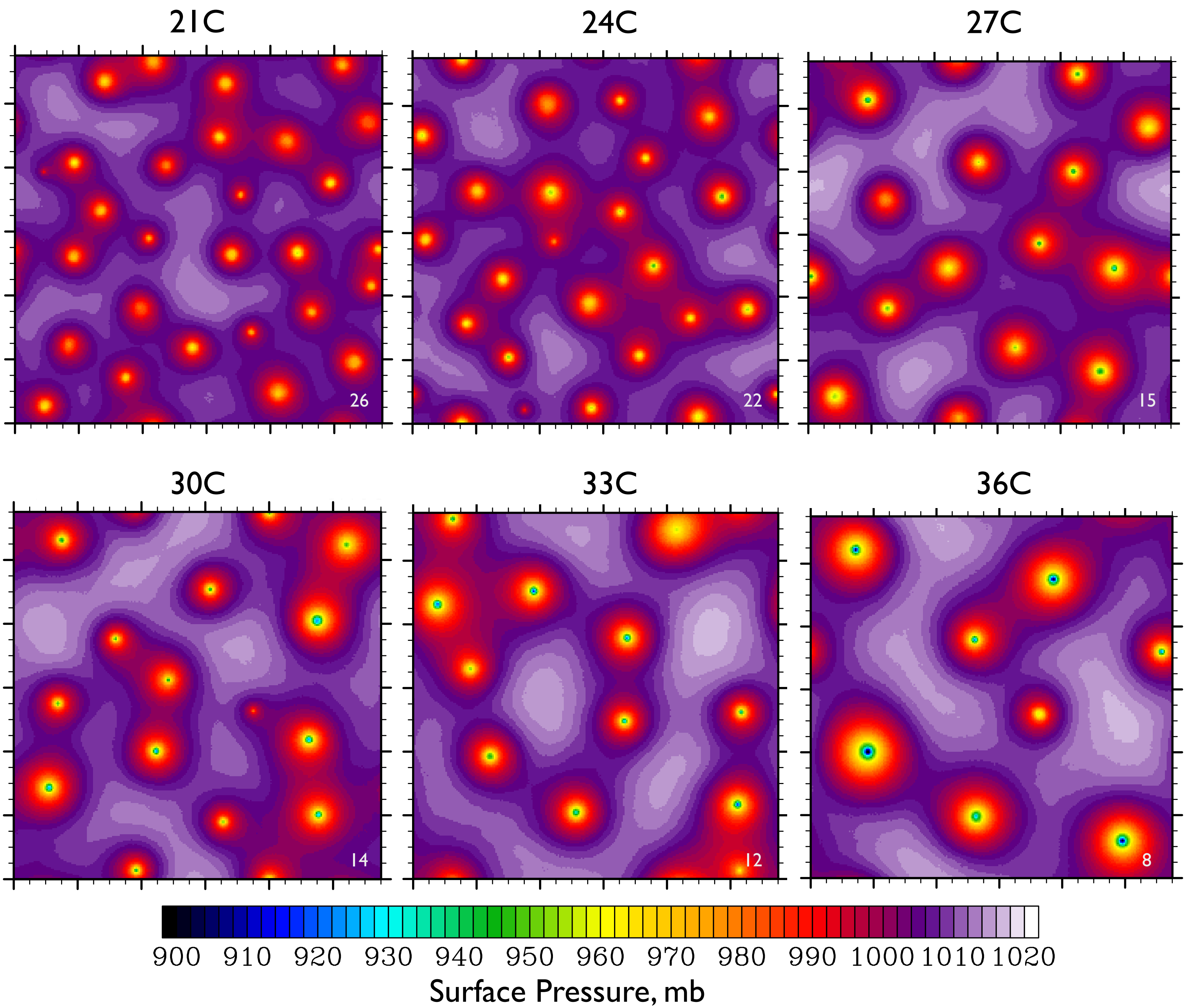

21C
24C
27C
30C
33C
36C
26
22
15
14
12
8
900
910
920
930
940
950
960
970
980
990
1000
1010
1020
Surface Pressure, mb

Table 1. TC-World simulation statistics. Here N_{TC} is the average number of tropical cyclones; V_{PI} the TC's potential intensity; KE is the average kinetic energy per unit area; KE/N_{TC} is the average kinetic energy per unit area per TC; PR/N_{TC} is precipitation rate per unit area per TC.

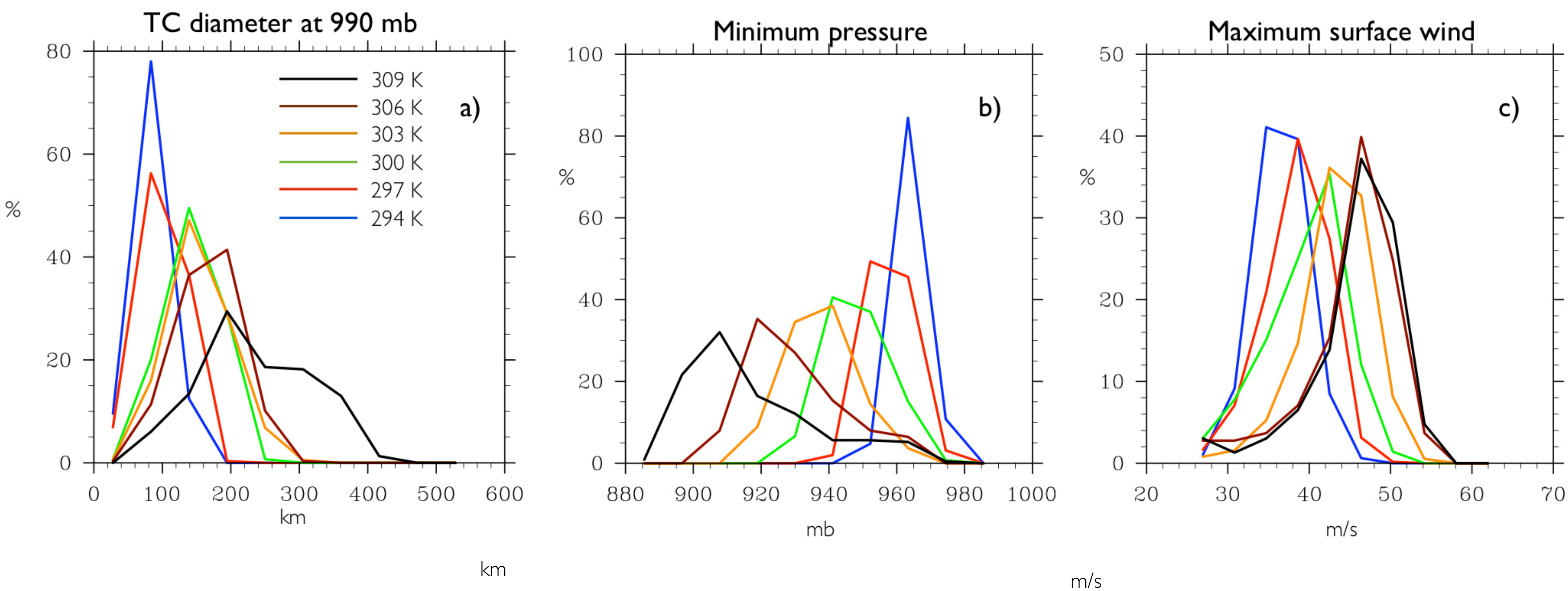
SST, °C	21	24	27	30	33	36
N_{TC}	26	22	15	14	12	8
V_{PI}, m/s	52.6	55.7	58.6	61.5	62.6	63.8
KE, J/m²	0.34	0.38	0.43	0.45	0.46	0.49
KE/N_{TC}, J/m²	0.014	0.017	0.029	0.032	0.038	0.061
PR/N_{TC}, mm/day	0.12	0.15	0.25	0.30	0.38	0.60

The average number of TCs monotonically decreases with increasing SST.

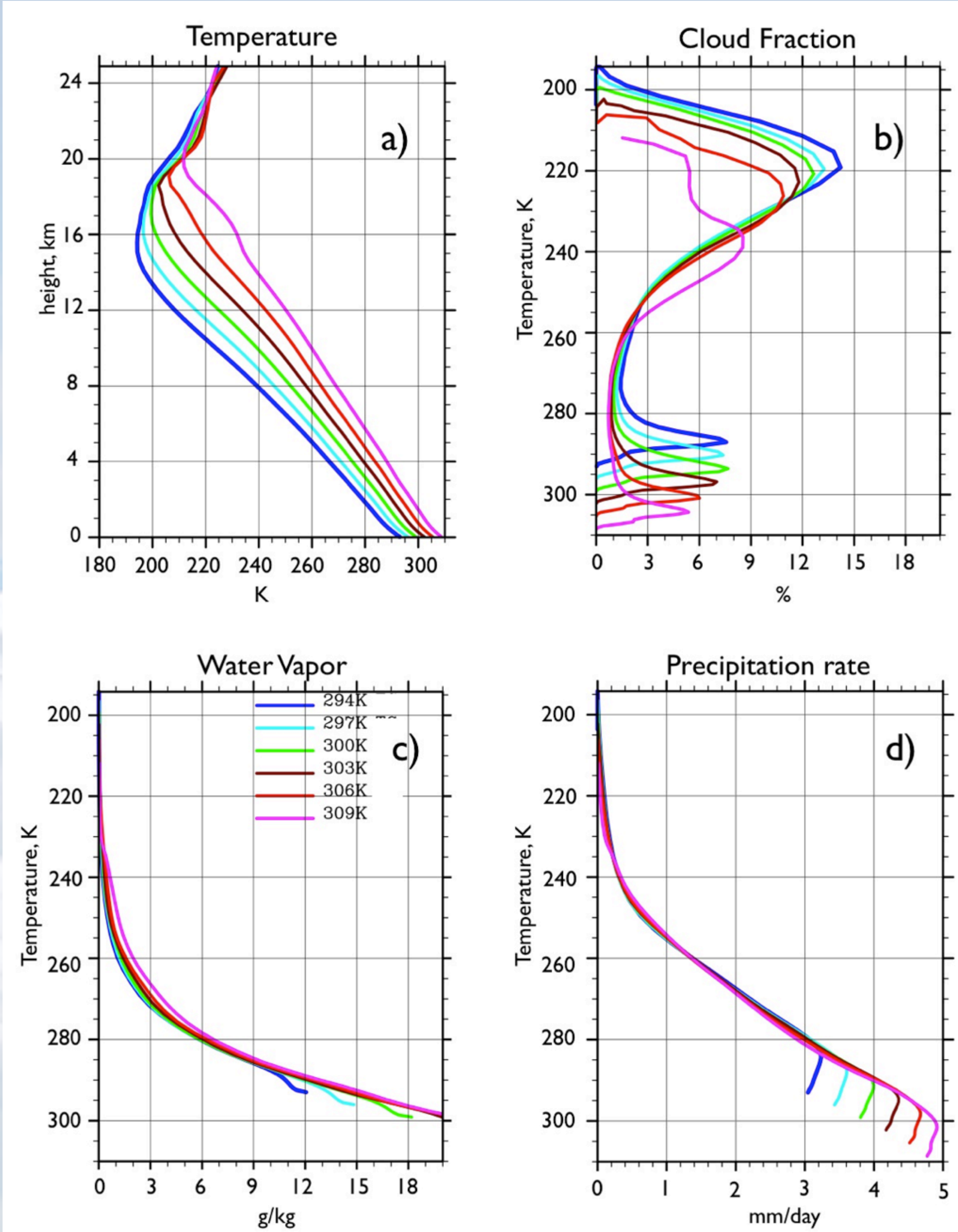
The average kenetic energy per TC shows a tendency to roughly double every 6 °C of SST increase.

The precipitation per TC also roughly doubles every 6 °C of SST increase.

TC-World Statistics

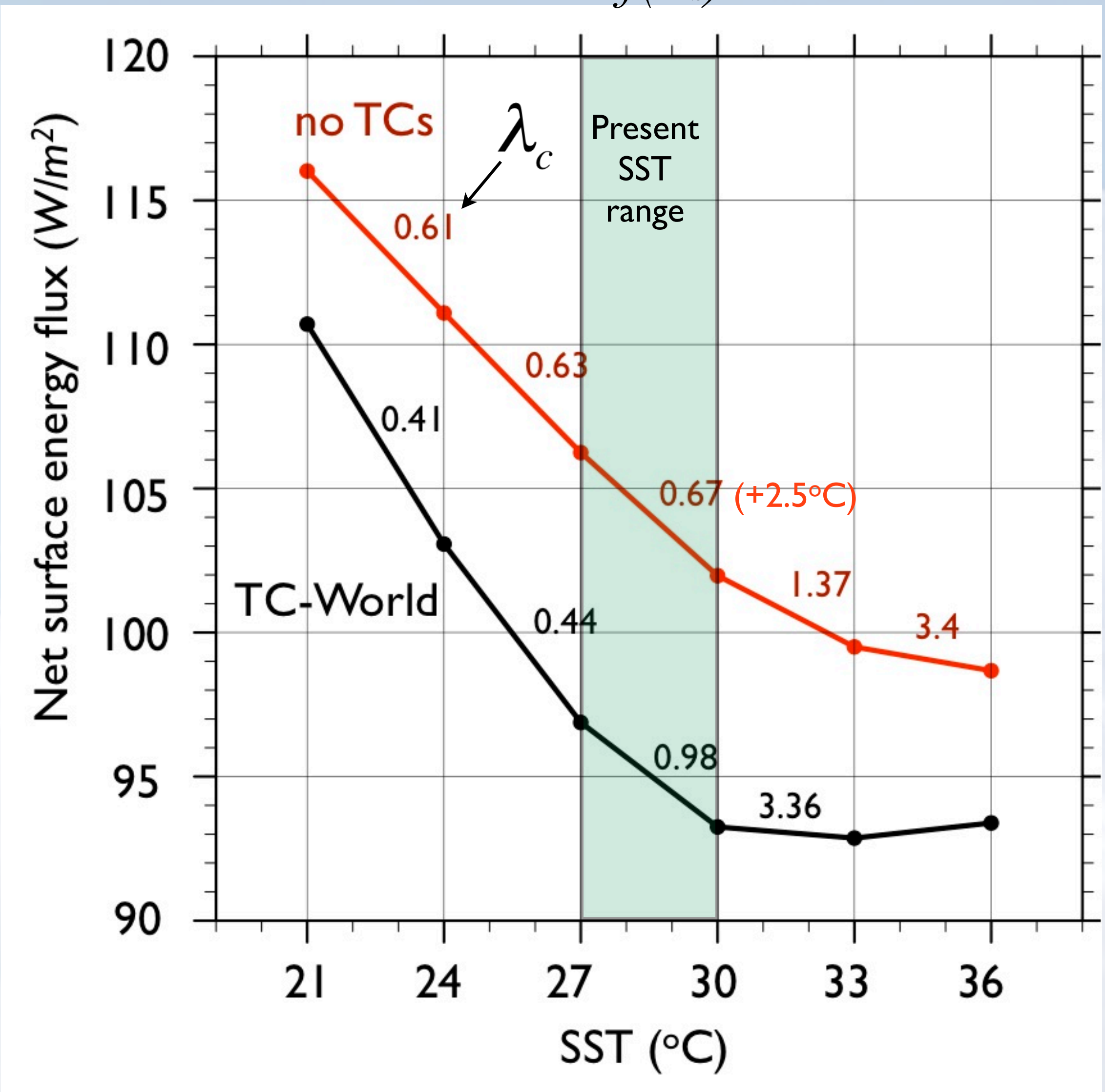


The hurricanes in the warming world may become more intense, deeper, and larger.


Temperature
a)
height, km
K
Cloud Fraction
b)
Temperature, K
%
Water Vapor
c)
294K
297K
300K
303K
306K
309K
Temperature, K
g/kg
Precipitation rate
d)
Temperature, K
mm/day

$$N = SW - LW - LHF - SHF = Q$$

$$N = f(T_s)$$



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

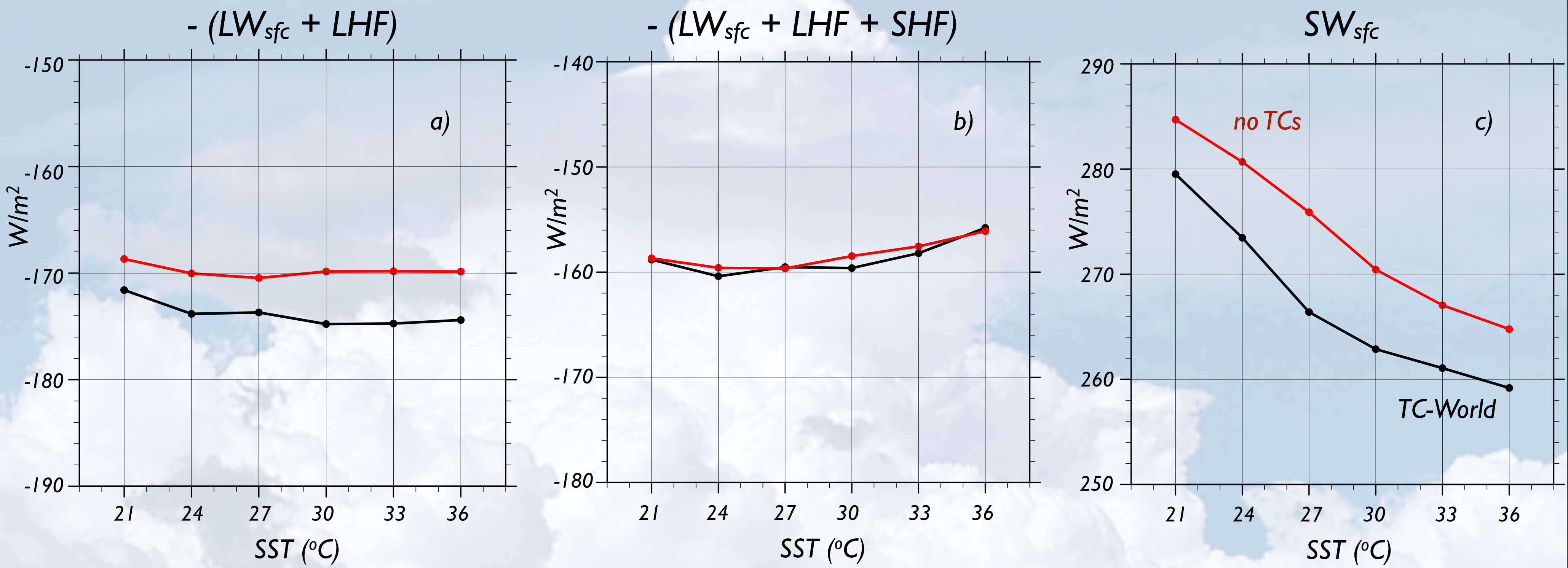
Let $\dfrac{dQ}{dT_s} \approx 0$ Then $\dfrac{1}{\lambda_c} = -\dfrac{dN}{dT_s}$

- Colder-than-present climate:
  - Constant climate sensitivity
  - TCs - negative feedback on warming

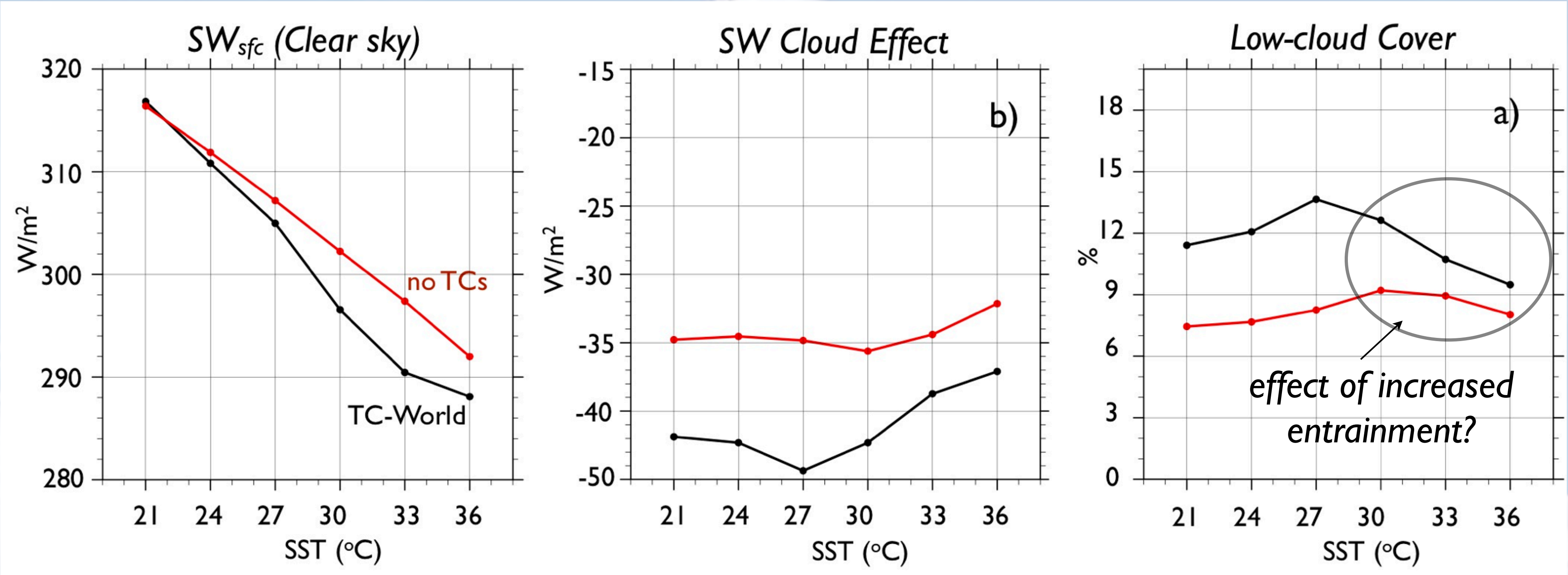
- Warmer-than-present climate:
  - Increasing climate sensitivity
  - TCs - amplify warming
  - Q should increase to keep RCE in stable regime (low sensitivity)
  - Increase in Q means even warmer higher latitudes

What determines the slope of $N = f(T_s)$?

Surface Energy Balance: $N = SW - (LW + LHF + SHF)$



Is it absorption of solar radiation by water vapor that maintains stability of the Tropics?

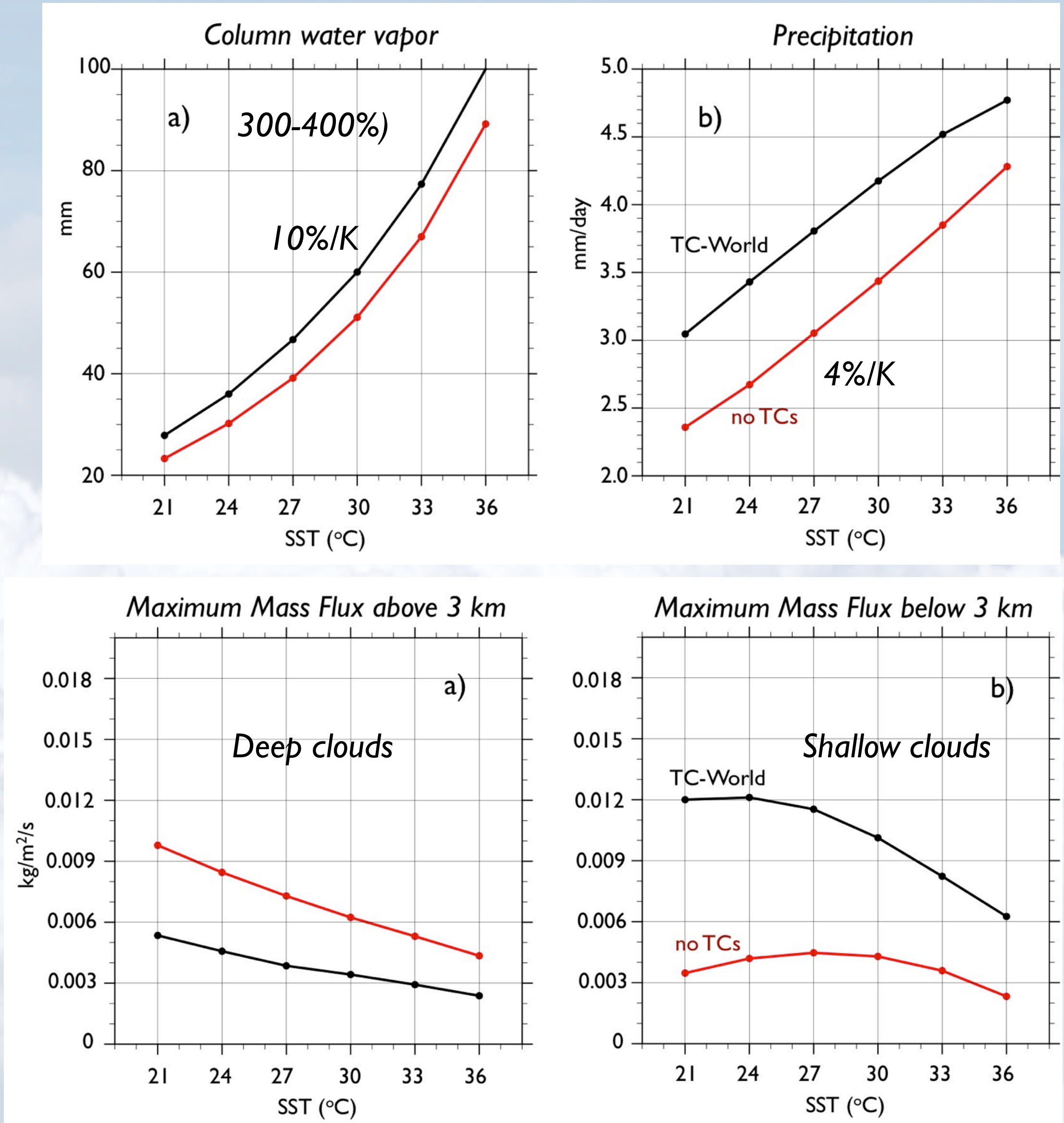


- The principle driver behind negative feedback to SST increase is the increased absorption of solar radiation by the water vapor;

- The effect of clouds, in particular, low-level clouds, is to increase climate sensitivity of RCE.

Why number of TCs should decrease in warmer climate?

"Thermodynamic argument (TA)" (e.g., Betts 1998; Held and Soden 2006)



$$P \propto M_c q$$

Mass-flux per TC is about constant or increasing (is it?). The total mass flux in TC-World should decrease due to TA. Then the number of TCs should decrease.

Summary

- The size and intensity of TCs monotonically increase with increasing SST. The minimum pressure also has a tendency to monotonically decrease with rising SST.

- The average number of TCs decreases with increasing SST.

- The equilibrium climate sensitivity, assuming constant implied ocean heat transport, has the tendency to increase with increasing SST.

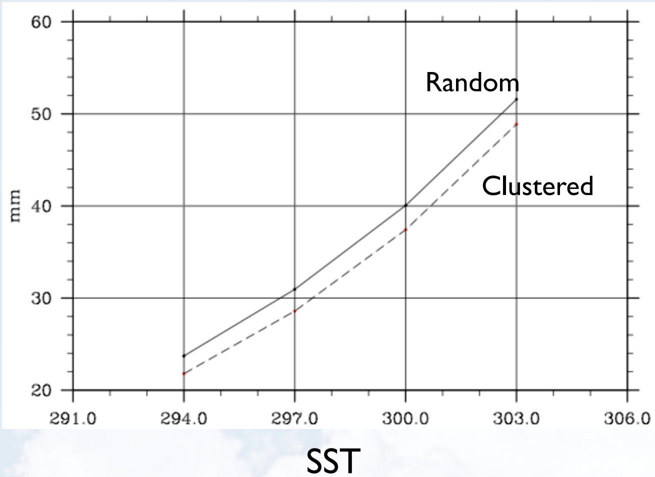
- For the colder-than present range of SSTs, the TCs tend to provide negative feedback to SST warming; however, at warmer-than-present SSTs, the TCs tend to amplify the SST warming.

- There is virtually no sensitivity to SST of the sum of latent heat flux and the net longwave radiative flux at the surface;

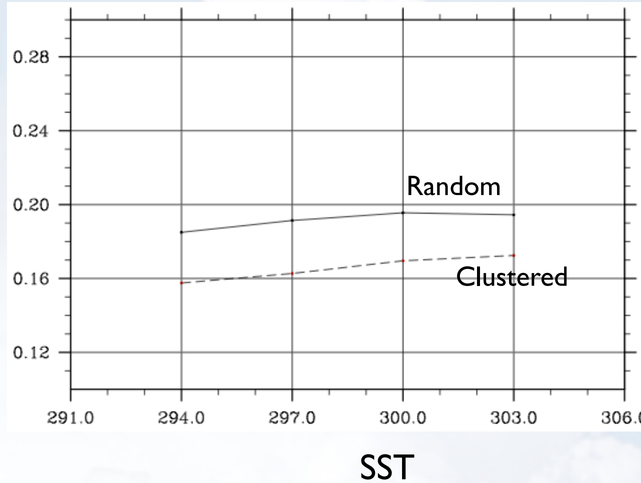
- The principle driver behind negative feedback to SST increase is the increased absorption of solar radiation by the water vapor;

The effect of deep-convection clustering on Radiative-Convective Equilibrium over wide range of SSTs

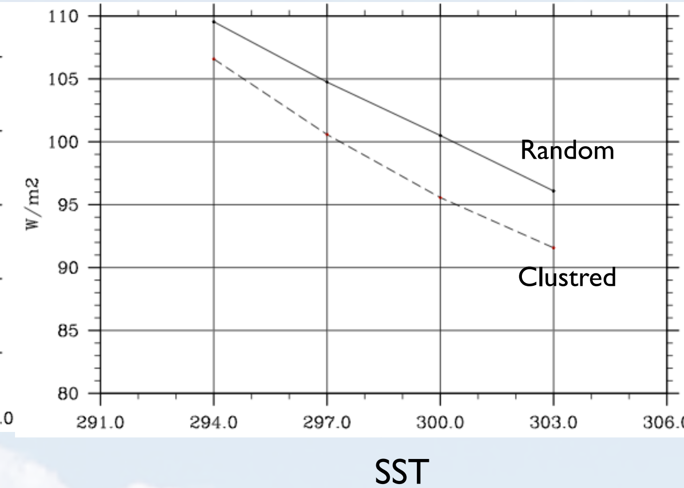
Precipitable water



Cloud cover



TOA Flux



- **Clustering of convection in RCE tends to dry out the troposphere, which reduces green-house effect of water vapor, increases OLR and would cool the SSTs (consistent with the obs study by Tobin et al 2012);**
- **Thus, clusters may help to keep the tropical SSTs cooler;**
- **Assuming constant implied ocean transport, in RCE, clusters could cool the SSTs by as much as 3 K;**
- **Big issue: How clusters change with warming climate?**
- **Need bigger computational domain (beyond three decades of scales);**