Statistics of clusters of tropical convection in global cloud-resolving simulations of aqua-planet with SAM

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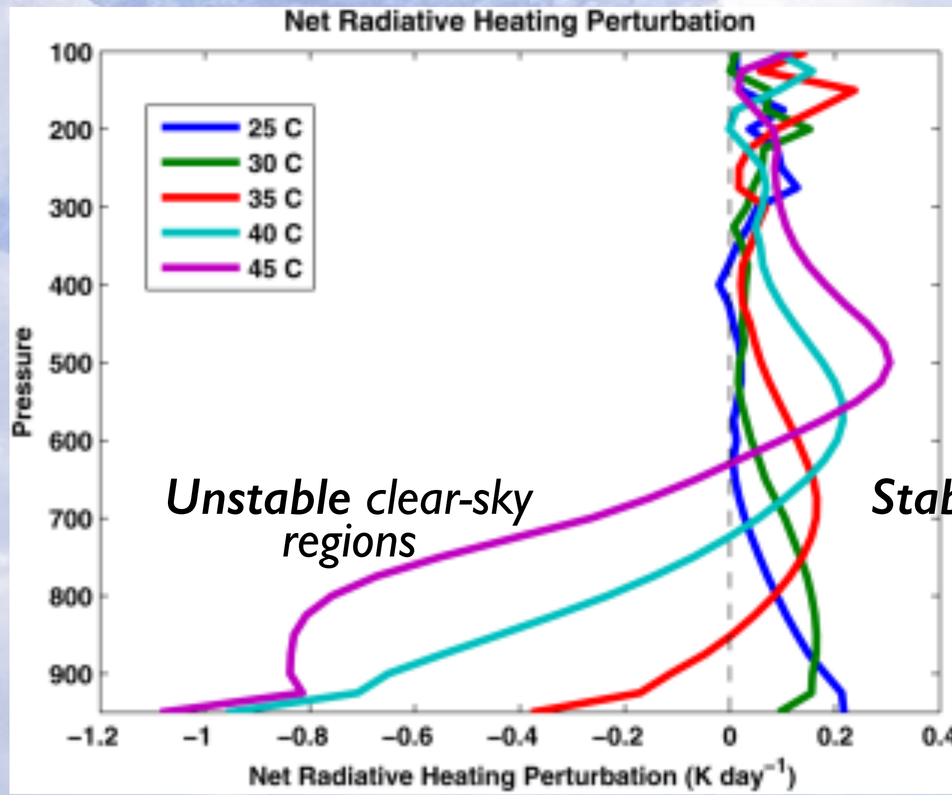
Evidence from paleoclimate reconstructions suggests that the tropical climate has been essentially stable with just a few degrees variations in SSTs

Radiative-Convective Instability
Change in radiative heating rates due to instantaneous uniform reduction of water vapor by 20%

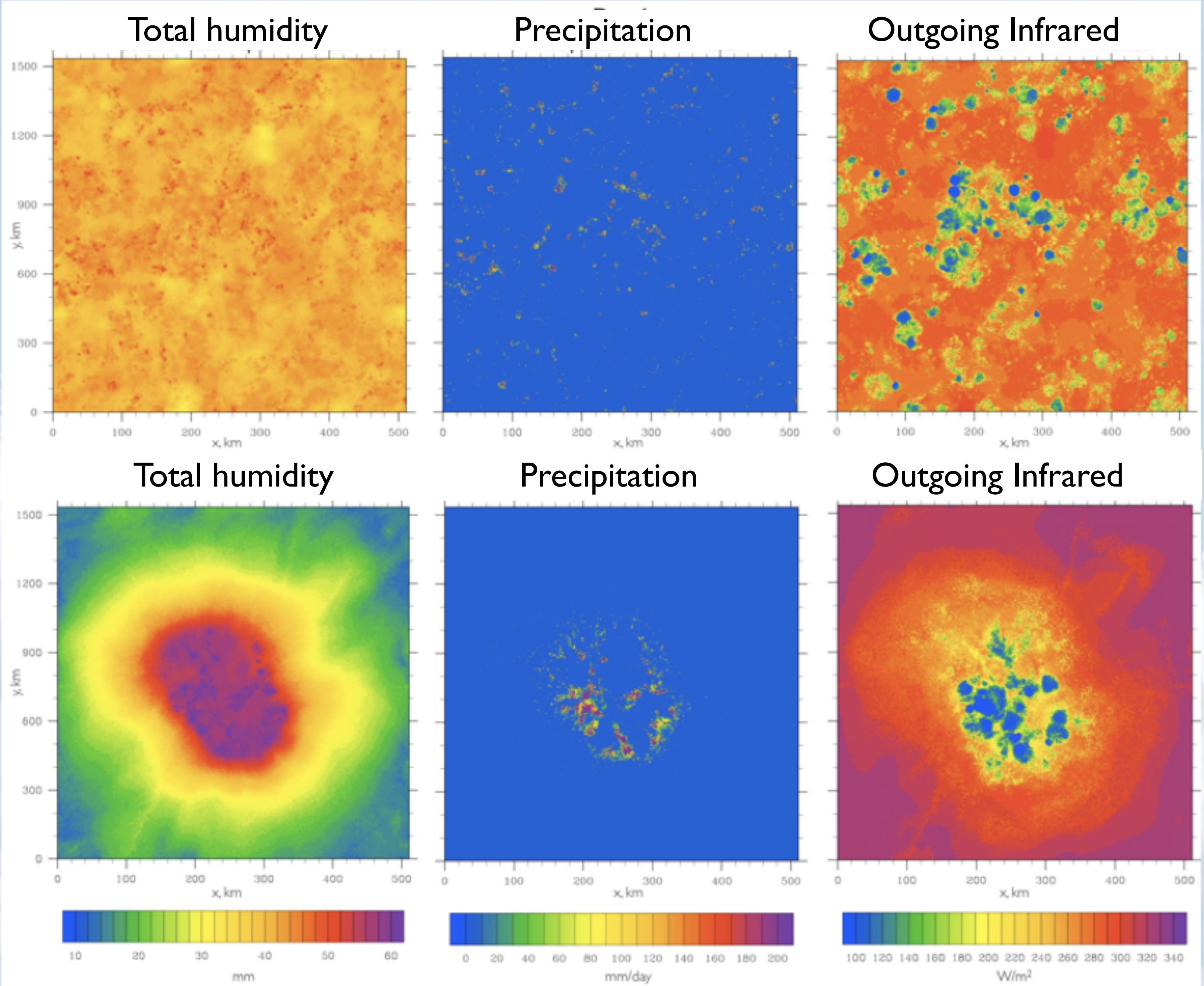


***Unstable** clear-sky regions*

***Stable** clear-sky regions*

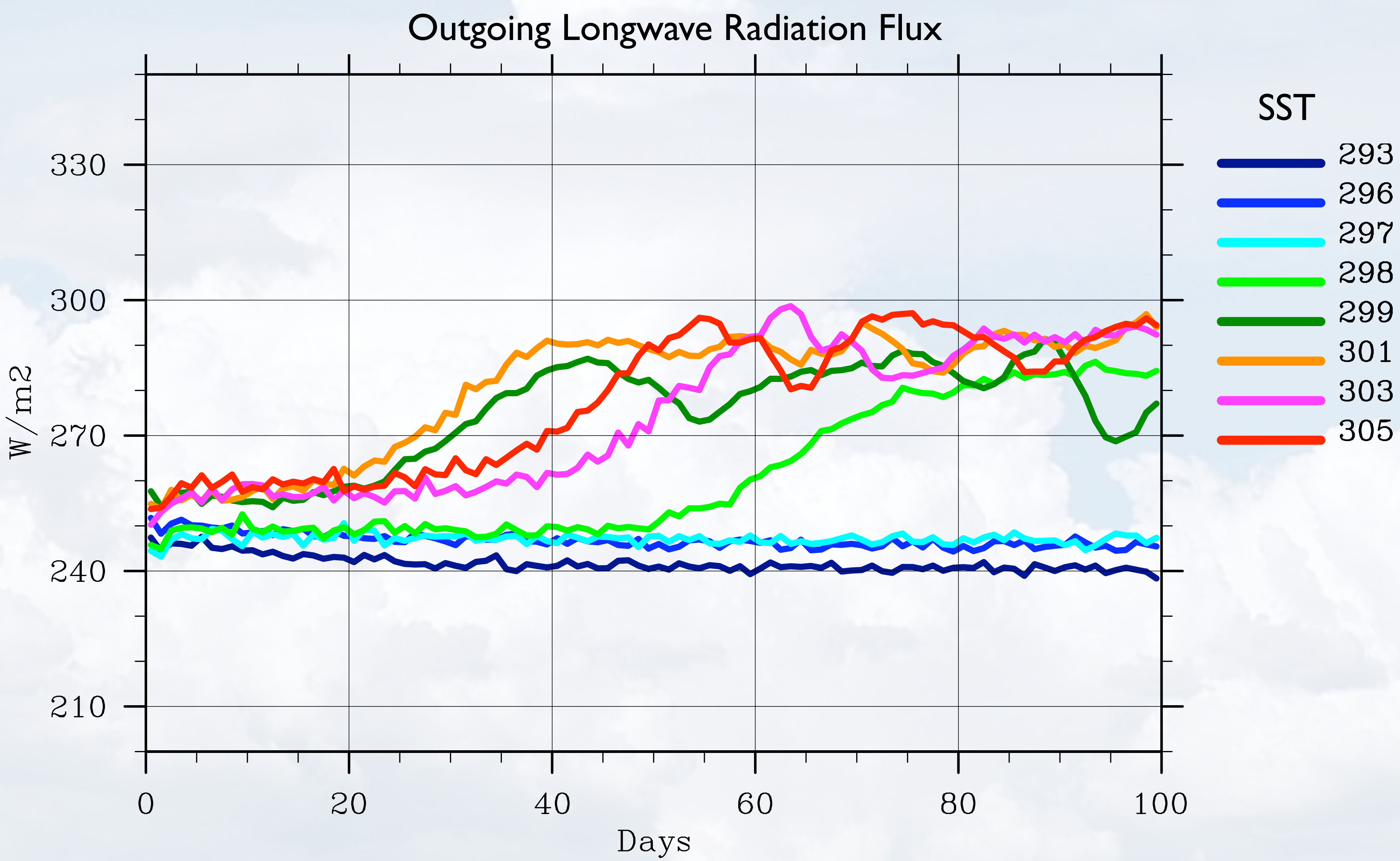
Emanuel et al (2014)

Self-Aggregation of Tropical Convection



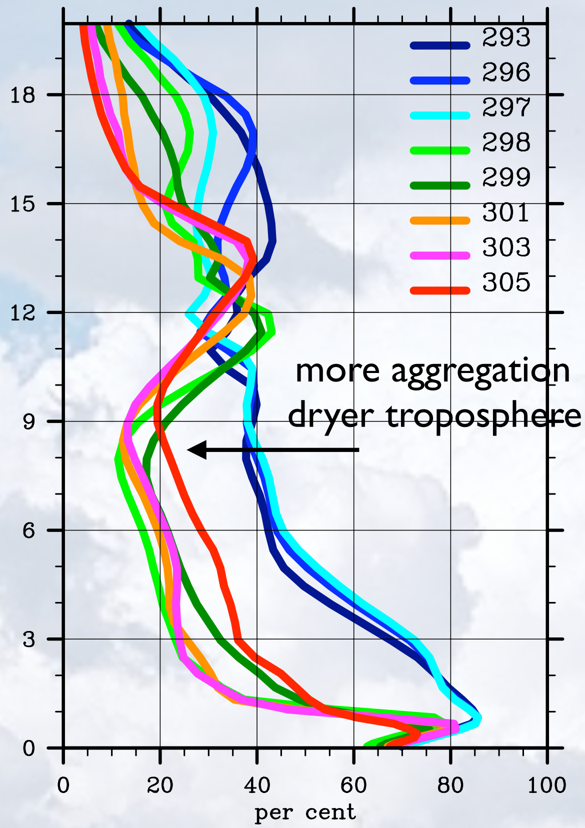
Self-aggregation of convection in RCE over large domain with no rotation

Dependence on SST: “On/off switch”

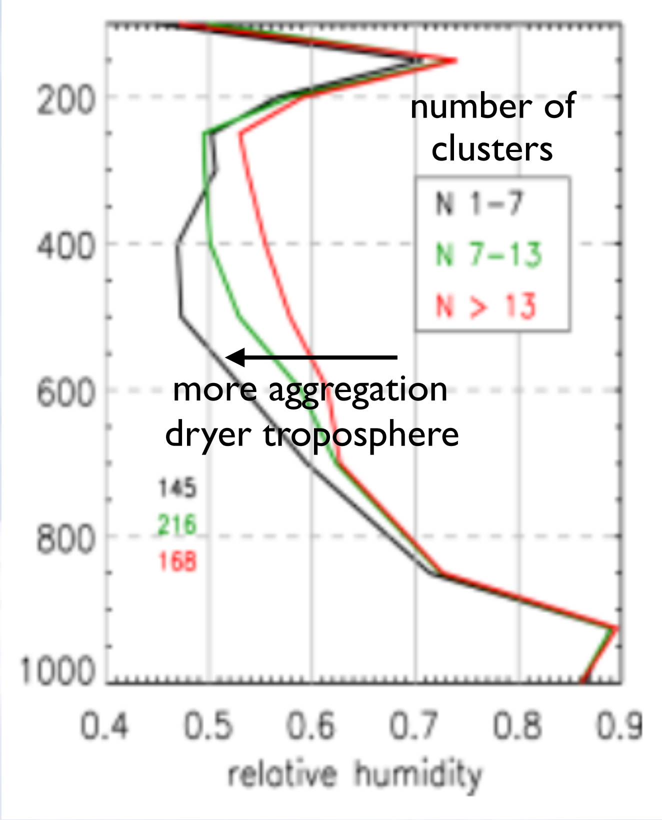


Khairoutdinov and Emanuel (2011)

**Aggregated-convection state has, on average,
drier troposphere
than random-convection state.
Dryer Atmosphere means smaller green-house effect,
that is cooler surface.**



SAM



OBS Tobin et al (2013)

Self-Organized Criticality (SOC) Hypothesis
(Khairoutdinov and Emanuel 2010)

Warmer SSTs
↓
Self-aggregation
↓
Drying of the Troposphere
↓
Reduction in Greenhouse Effect
↓
Cooler SSTs
↓
Disaggregation
↓
Re-moistening of the Troposphere

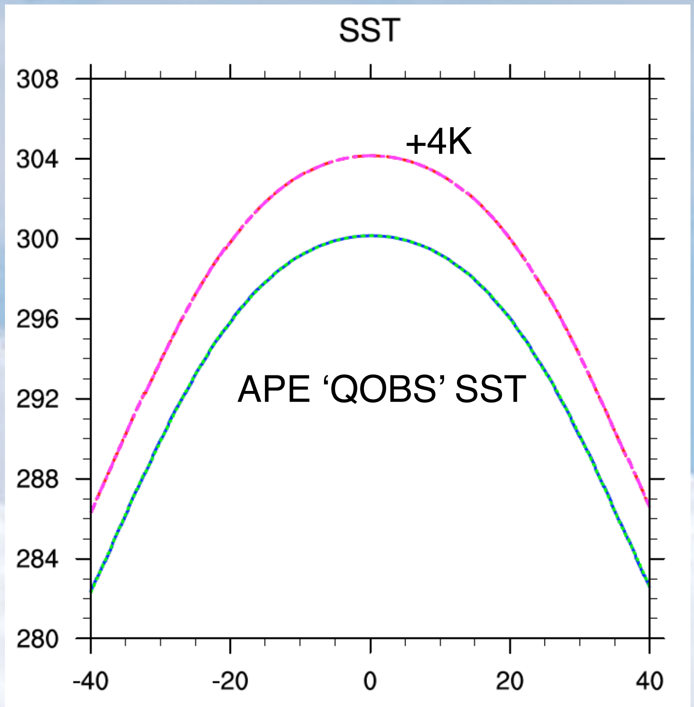
- **SOC Hypothesis: Tropical convection (and SST) is attracted to the transition critical state (critical SST) between mostly aggregated and mostly disaggregated regimes.**
- **Consequence: If tropical convection is currently indeed in near-SOC state, the climate sensitivity of Tropics to anthropogenic warming may be low (strong negative feedback due to aggregation of clouds).**

Cloud-resolving Near-Global™ simulation of equatorially-centered channel on Aquaplanet

Bretherton and Khairoutdinov (*JAMES* 2015)

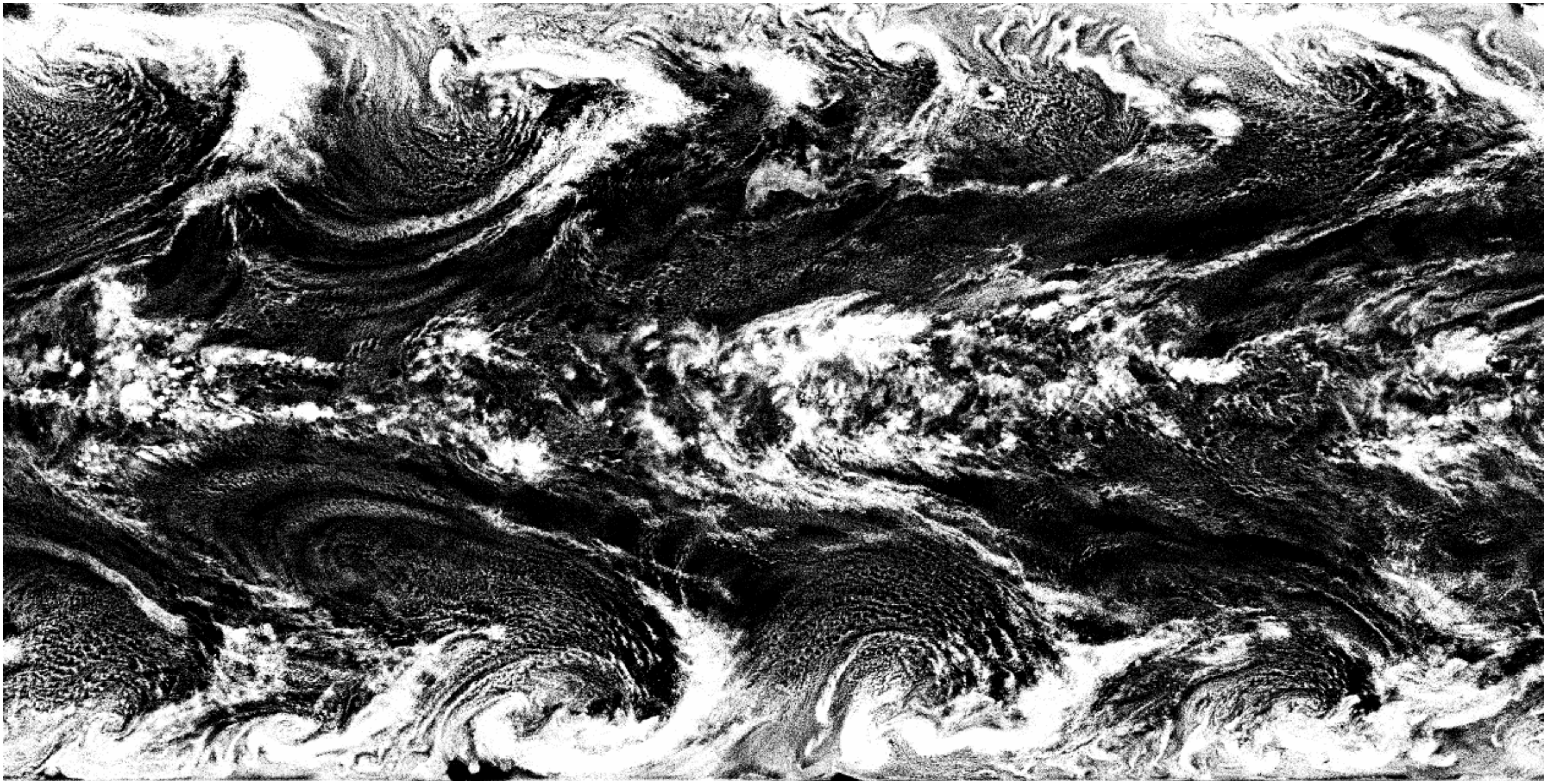
Set-Up

- **SAM 6.10.6; Single-Mom Micro; CAM3 radiation**
- **Zonally symmetric APE QOBS SST; CTL and +4K**
- **Domain: 20,480 x 10,240 km^2; top at 27 km**
- **$\Delta x=\Delta y=4$ km, zonally periodic**
- **Solid walls at N and S; equator at the center**
- **Perpetual Equinox**
- **Lat-varying insolation with diurnal cycle**
- **Lat-varying Coriolis parameter**
- **Spin-up from uniform state for 100 days with $\Delta x=\Delta y=20$km**
- **60-day continuation run with $\Delta x=\Delta y=4$ km**
- **Analyzed: last 40 days**



Cloud Cover

46° N

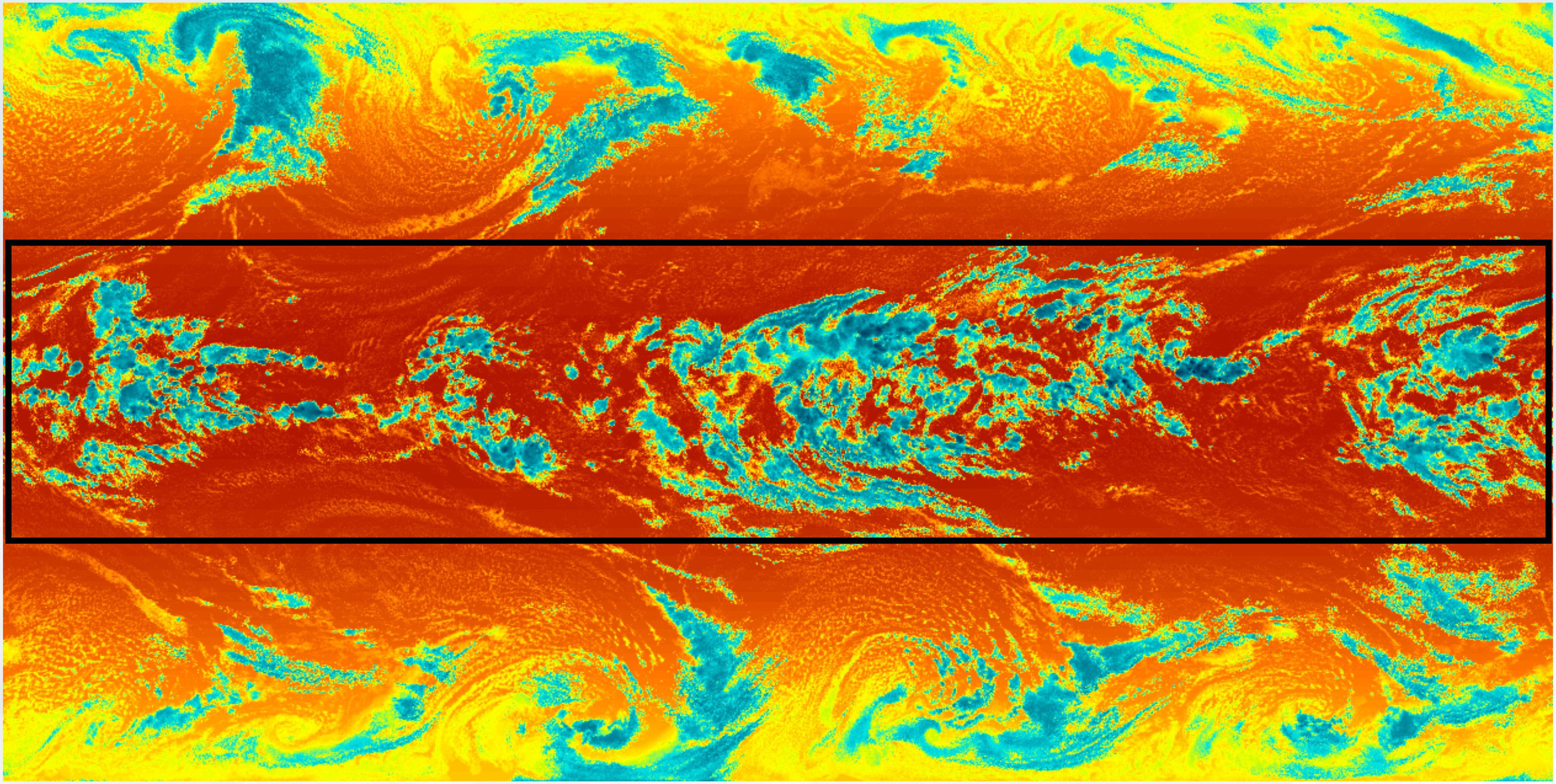


46° S

20480 km = 184° longitude

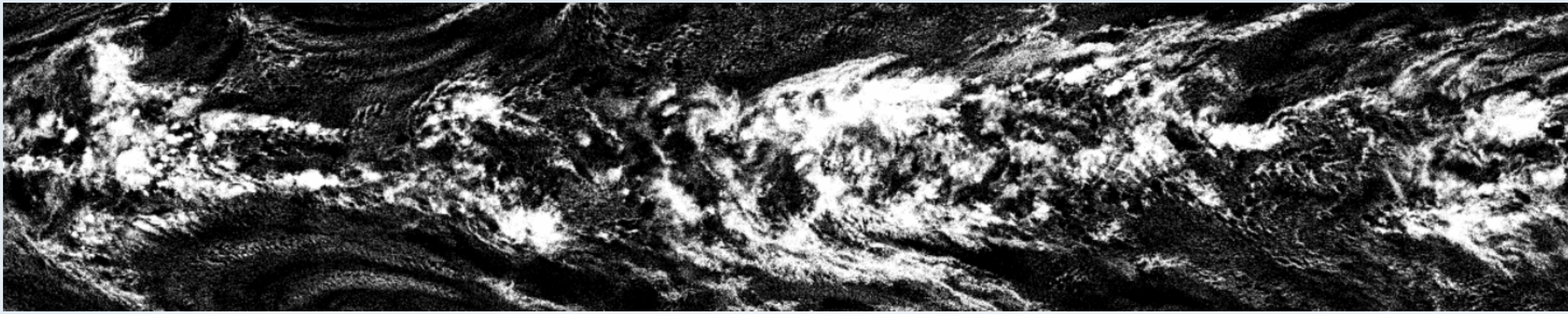
Brightness Temperature (Tb)

Blue colors - cold cloud tops

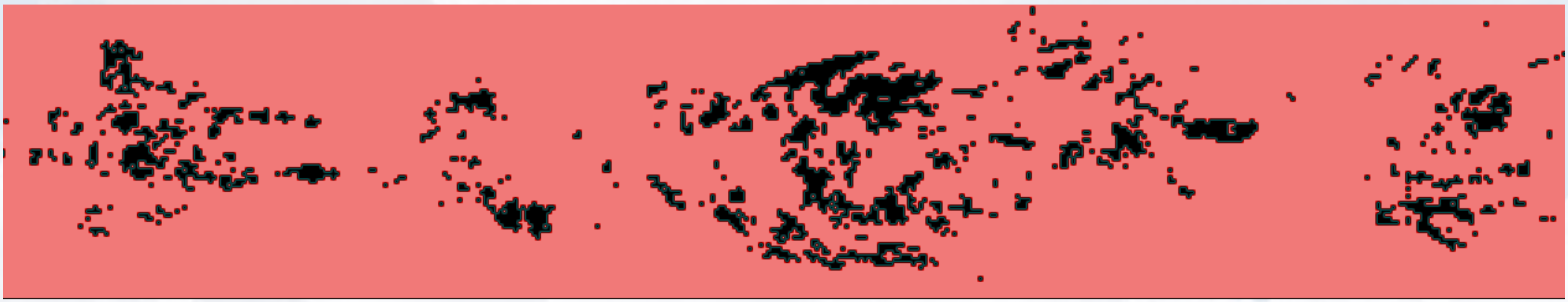


40 days of 3-hourly snapshots = 320 cloud scenes

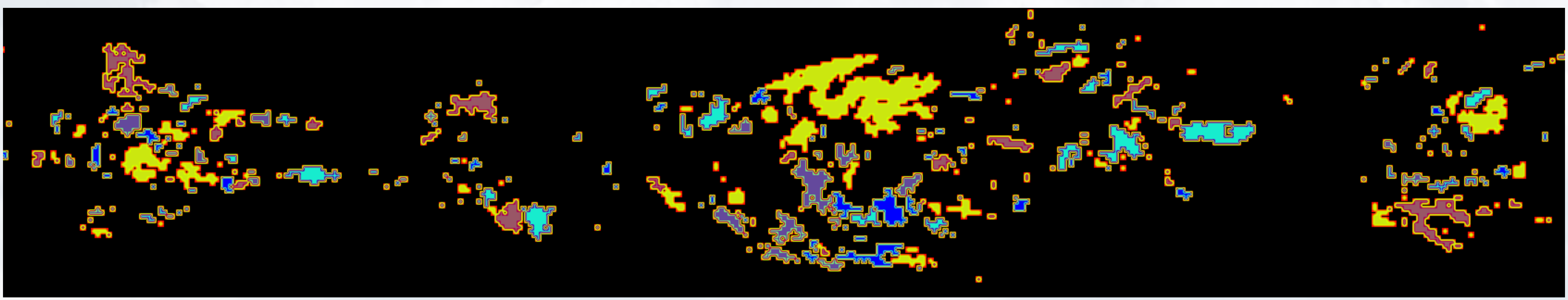
Cloud Cover 4-km grid



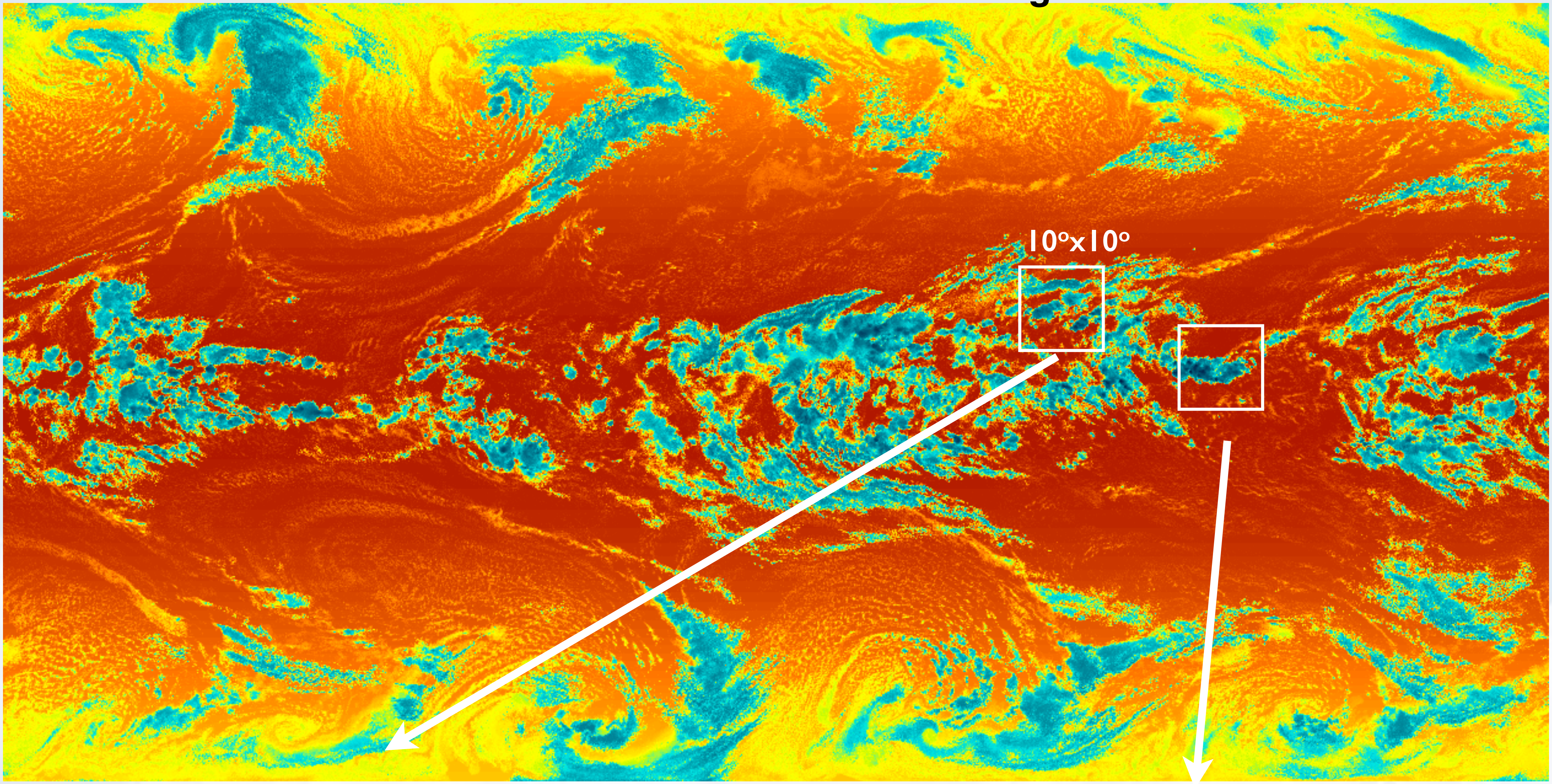
Tb<240K averaged over 50-km grid (to be comparable with CLAUS data)



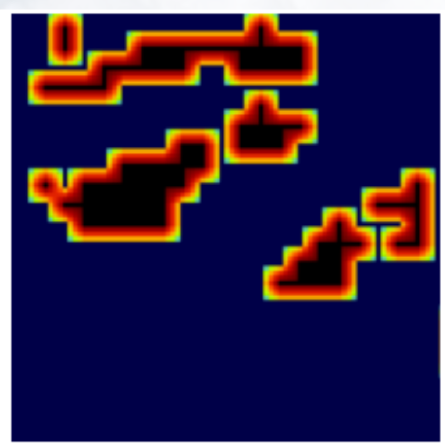
Identification of Individual Clusters



Statistics of Clusters in 10°x10° regions



N=6



Less Aggregated More

N=1

Tb < 240K, 50-km resolution

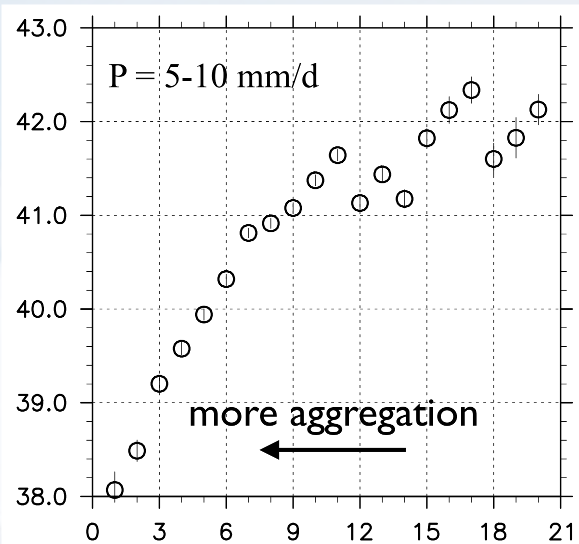
Following Tobin et al (2013)

Water Vapor

More aggregation ⟷ Dryer troposphere

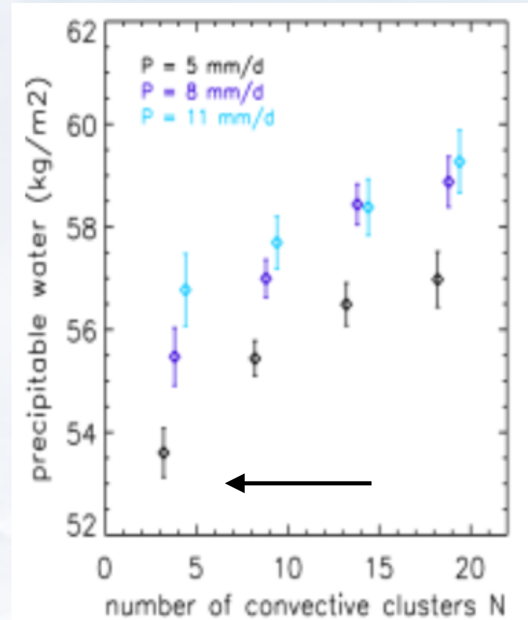
precipitable water

mm



number of clusters

CRM

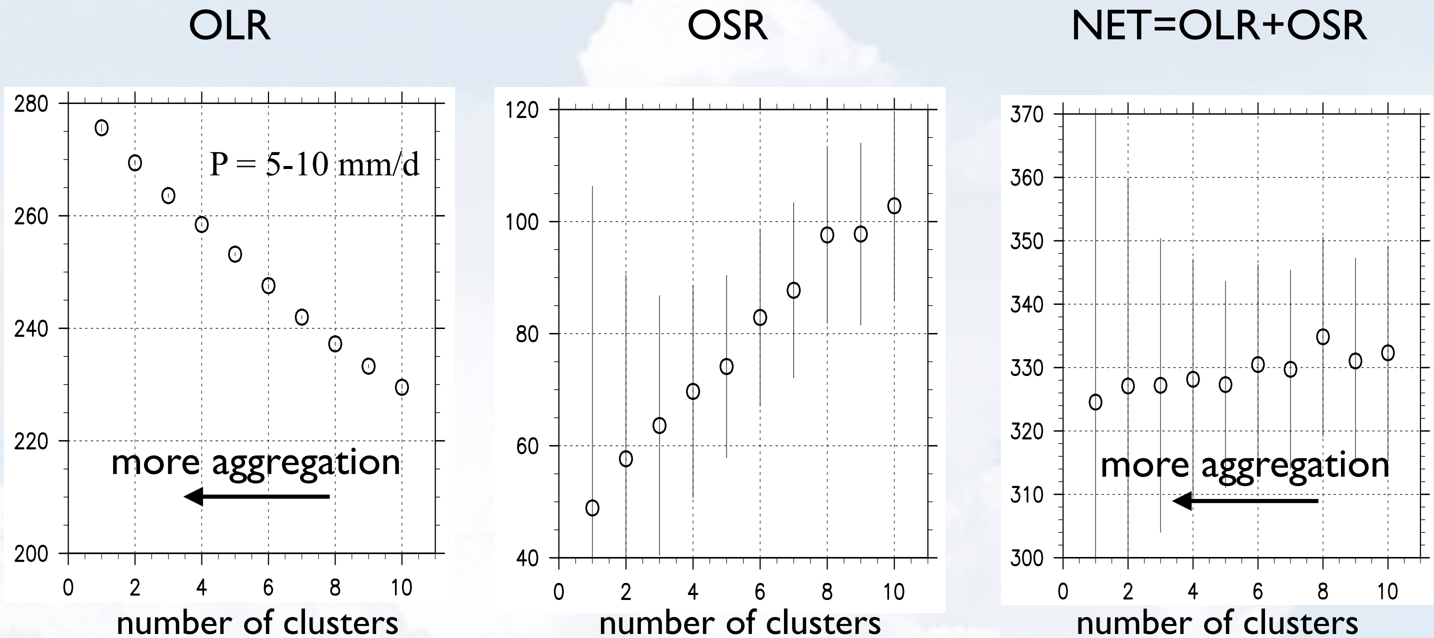


SSM/I

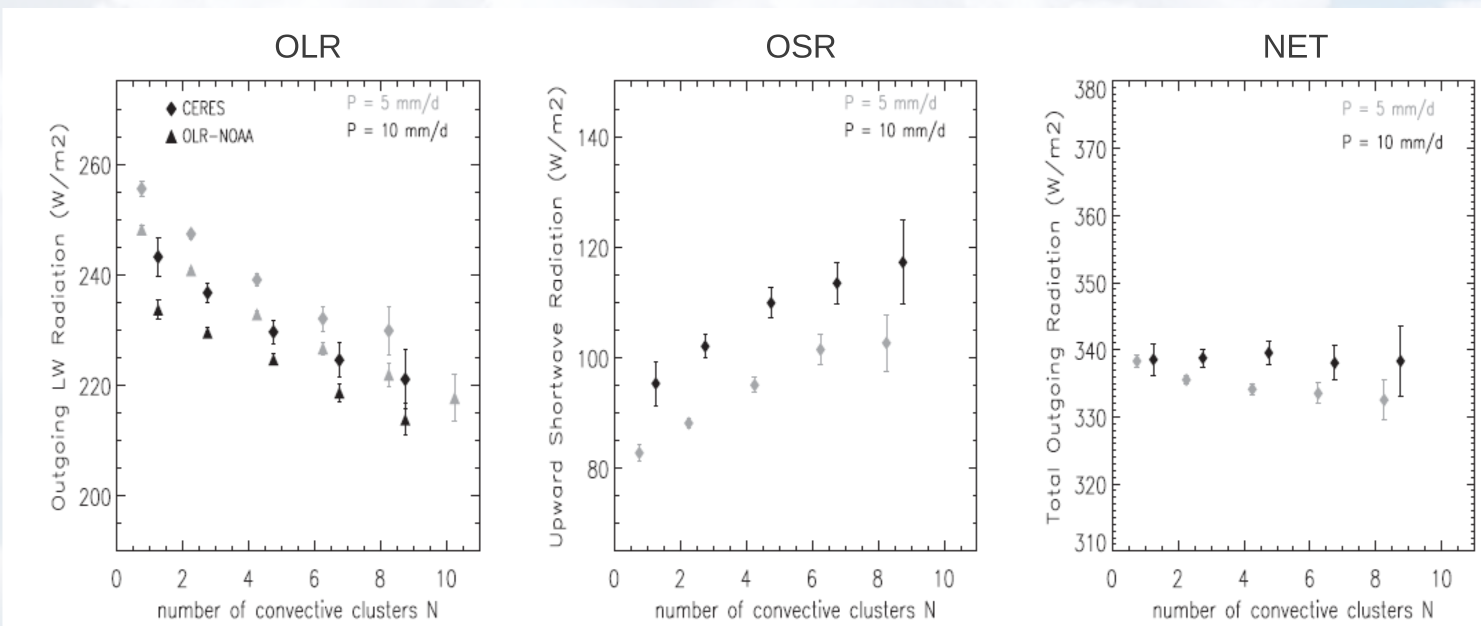
Tobin et al (2012)

Outgoing Radiation

No strong effect of aggregation on net **outgoing** radiation



Near-Global CRM

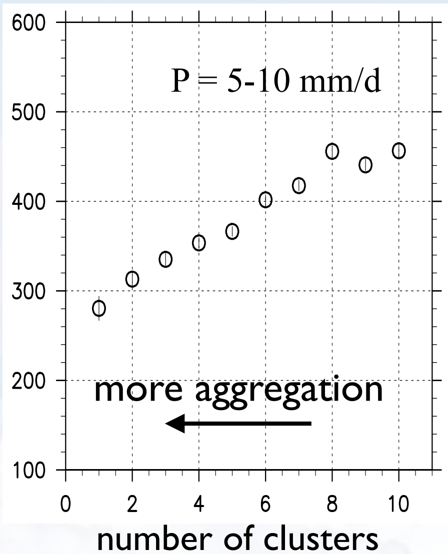


Tobin et al

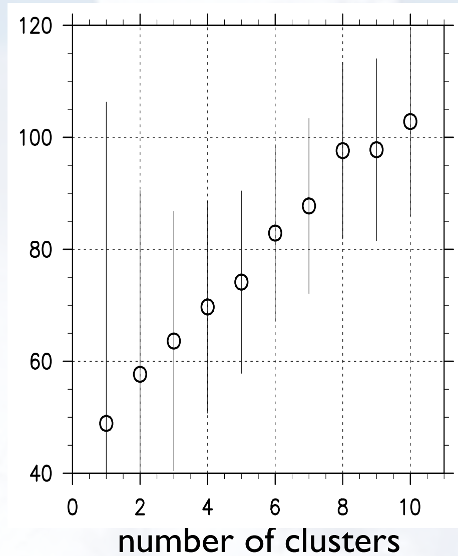
Absorbed Radiation

Strong effect of aggregation on net **absorbed** radiation and, hence, on climate?

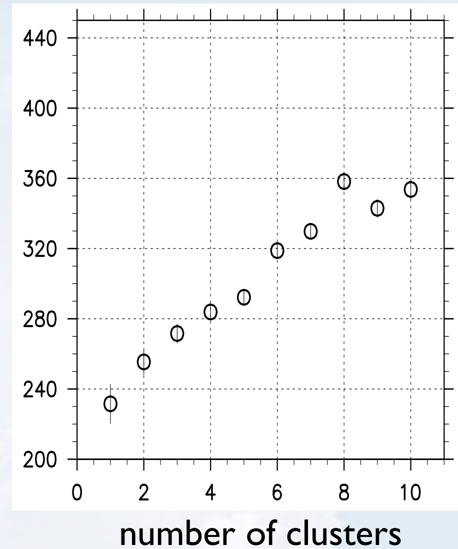
Incoming Solar Rad (ISR)



OSR



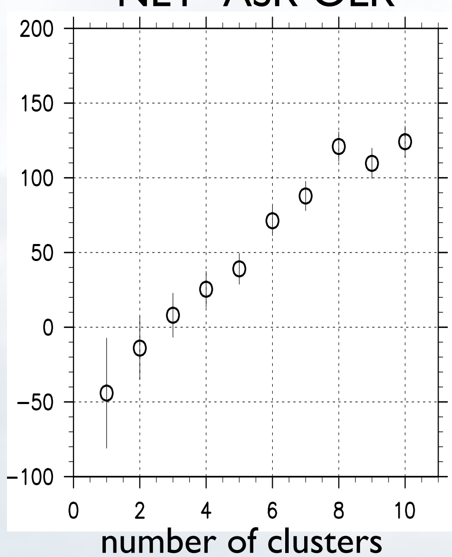
ASR=ISR-OSR



Near-Global CRM

Aggregated convection is more often nocturnal?

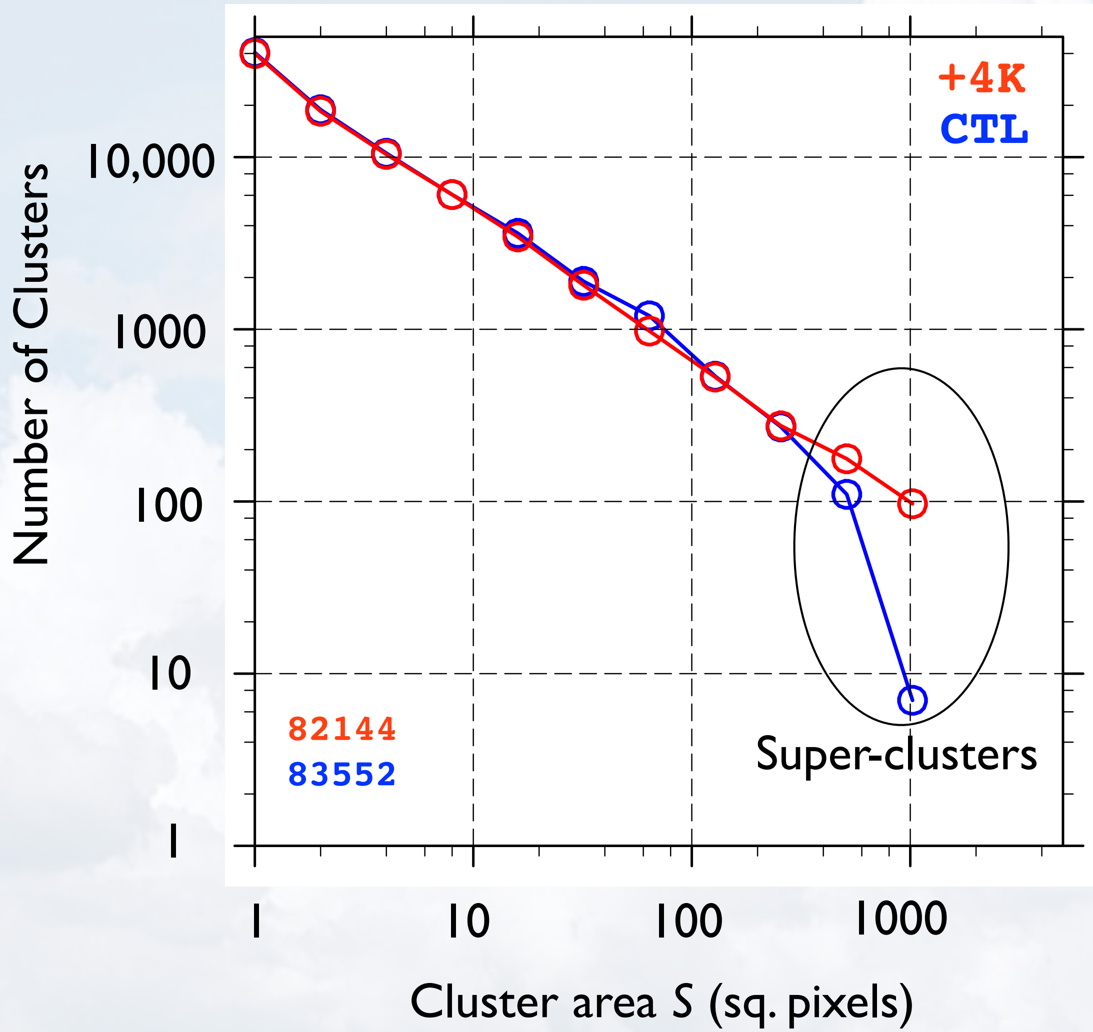
NET=ASR-OLR



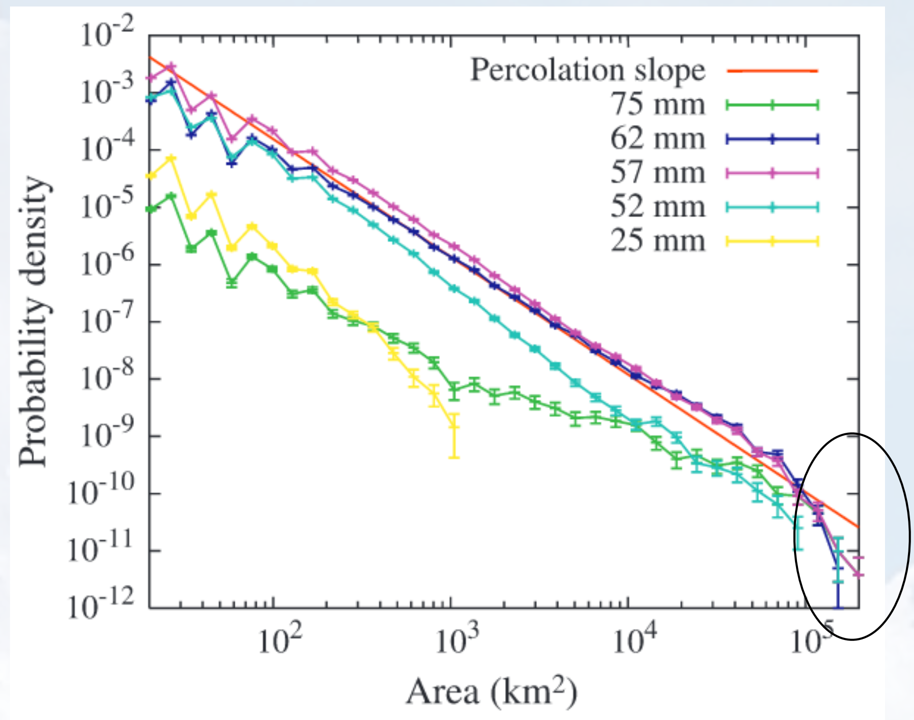
Strong net cooling by aggregated convection (no cancelation of LW by SW)

PDF of Cluster Area

Near-Global



Observations



Peters et al (JAS, 2009)

Large increase (by a factor of 10) of number of super-clusters in warmer climate.
Virtually no change in number of small and medium clusters.

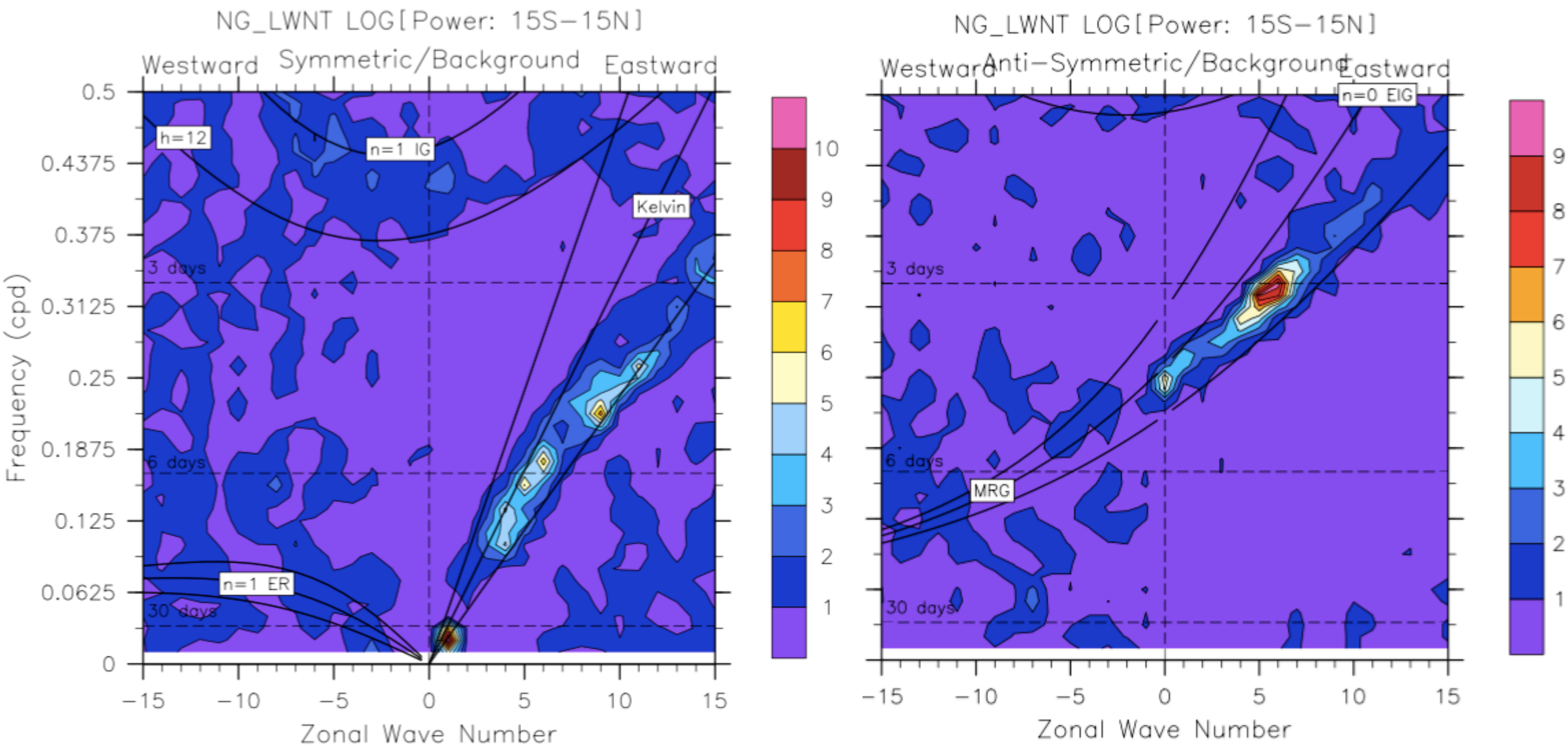
Cloud-resolving Near-Global™ simulation of equatorially-centered channel on Aquaplanet

Set-Up

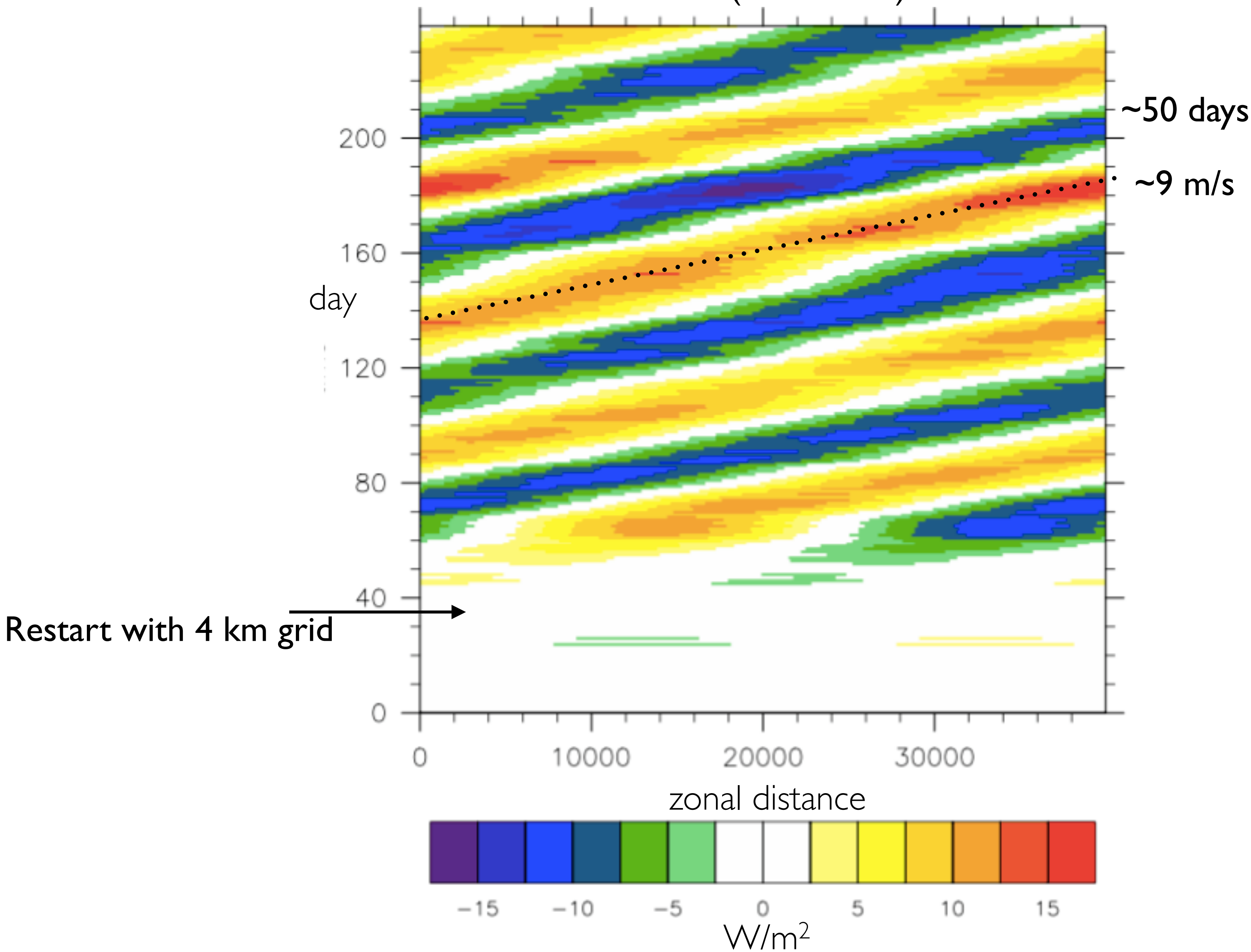
- Constant SST=300K;
- Domain: 40,000 x 10,240 km^2; top at 27 km
- $\Delta x=\Delta y=20$ km and 4 km, zonally periodic
- Constant insolation: 651 W/m2, cosz=52 degrees

RCE on SST=300K Near-Global Aquaplanet

20km, 240 days

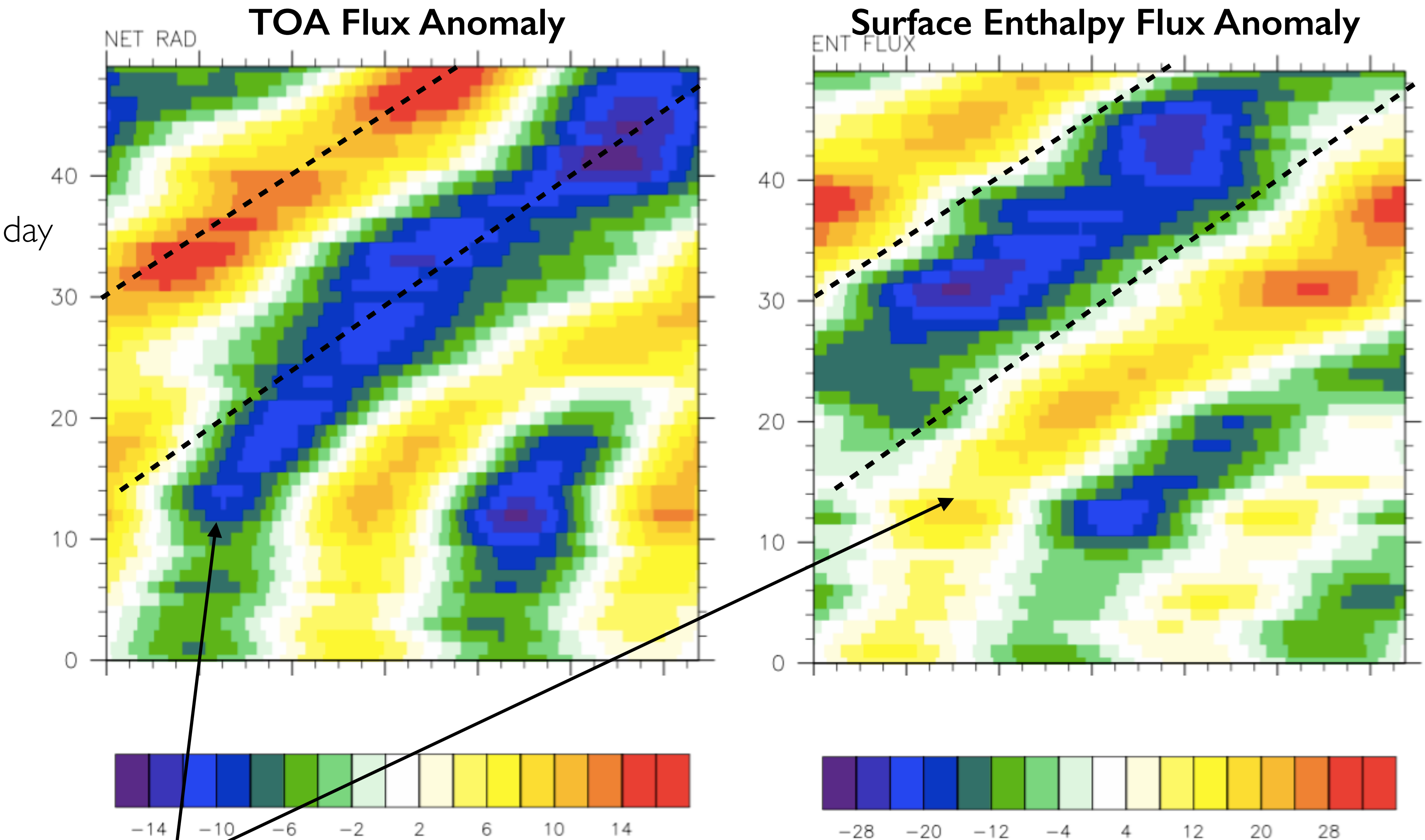


Constant SST=300K, Δx=20 km
OLR Wave-1 (15°S-15°N)



RCE on SST=300K Near-Global Aquaplanet

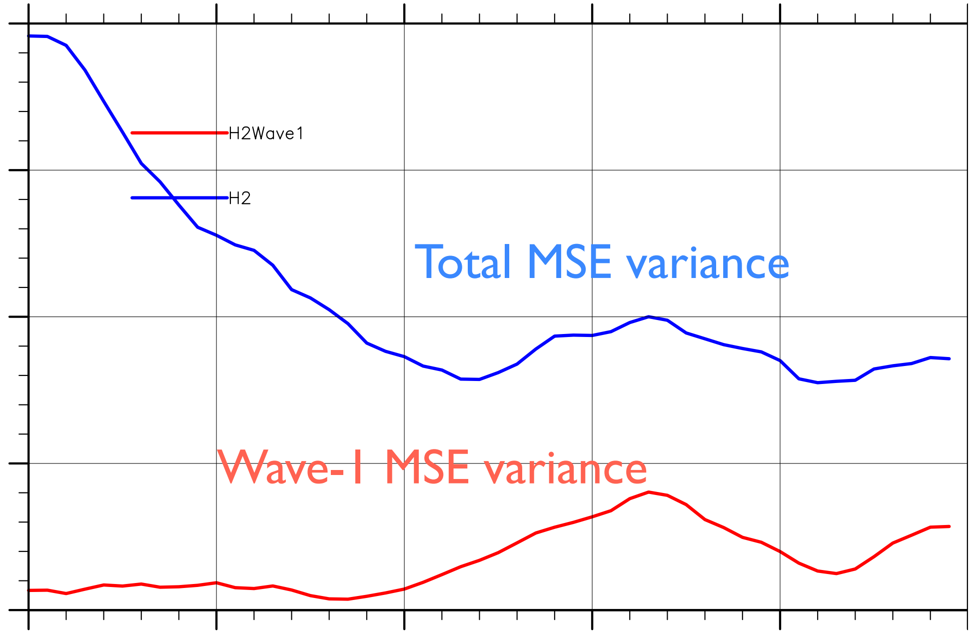
4 km simulation (Filtered Wave-1)



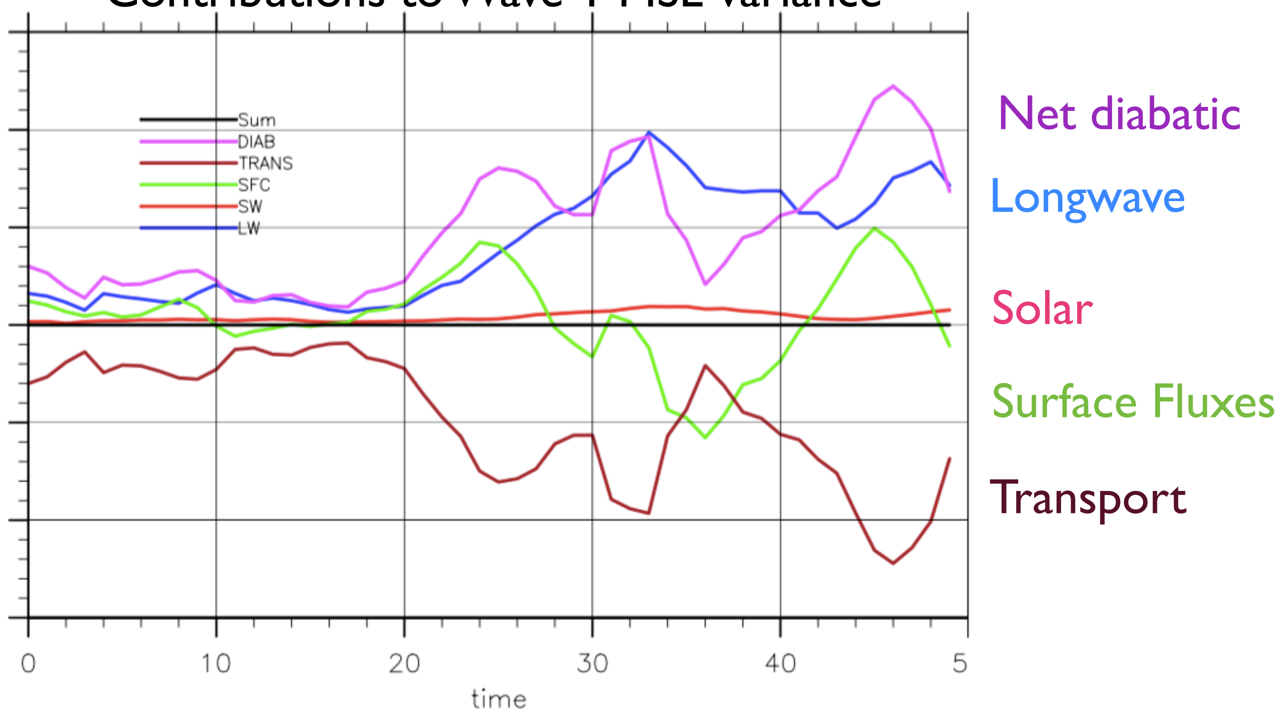
MJO initiation: both radiative cooling and surface fluxes are important.

MJO propagation: radiation maintains MJO, while surface enthalpy fluxes are shifted 1/4 of wavelength from center of MJO to facilitate its eastward propagation.

Evolution of MSE variance, SST=300K, Δx=4km



Contributions to Wave-1 MSE variance



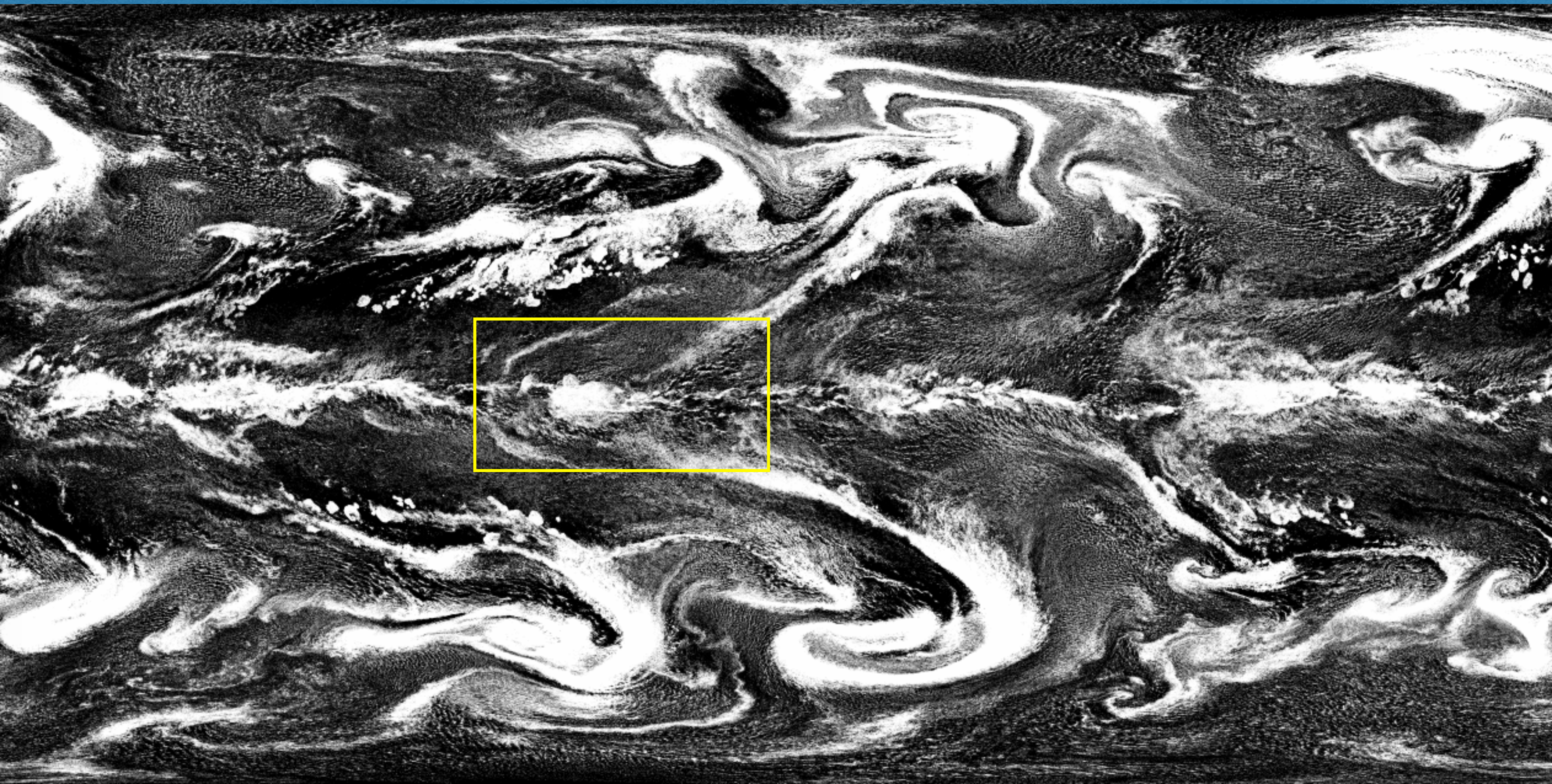
Global RCE over Aquaplanet

Lat-Lon grid: Δx = 4 km (EQ), Δt=10s

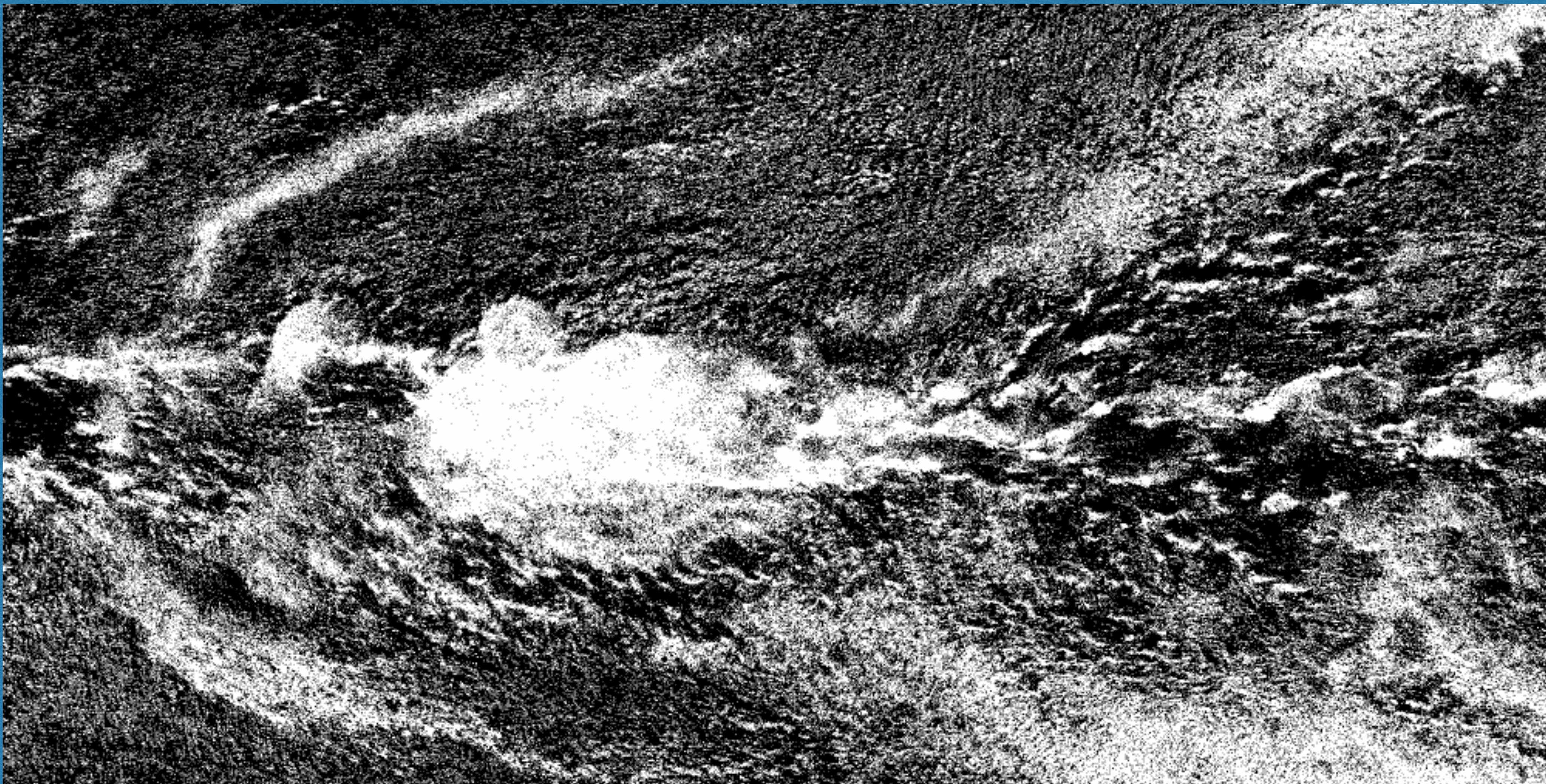
10240 x 5120 x 34 grid

Performance: 1 wall-clock hour/simulated day (5120 cores)

89.5º N



89.5º S



Take-home Message

- Aggregation or clustering of convection in Tropics can increase in warmer climate, which can be a powerful negative feedback on global warming.