Convection, Humidity, and Predictability in a Near-Global Aquaplanet CRM

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Goals of study

Use a near-global convection-resolving aquaplanet simulation:

1. To examine the growth of small humidity perturbations and the time scale on which they limit the predictability of large-scale tropical circulations (Lorenz 1969; Mapes et al. 2008)
2. To diagnose whether diabatic processes (surface energy fluxes and atmospheric column radiative cooling) have a positive feedback on maintenance of humidity anomalies and growth of small humidity perturbations, as they do in self-aggregation simulations, and if so, on what scales.

Mapes et al 2008: GCRM aquaplanet predictability study

- NICAM GCRM run 30 days from identical initial conditions with 7 km and 14 km horizontal grid (‘fraternal twin’ experiment)
- Growth of differences is a measure of potential predictability.

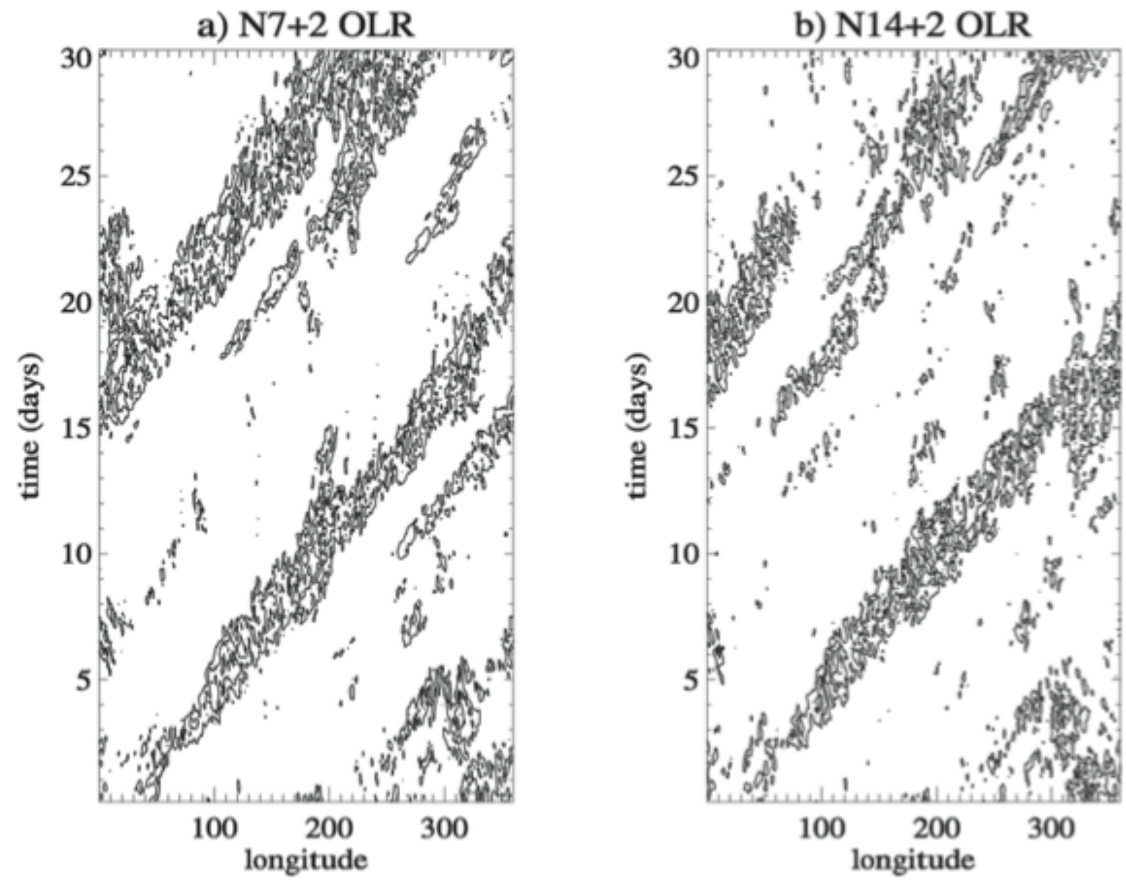
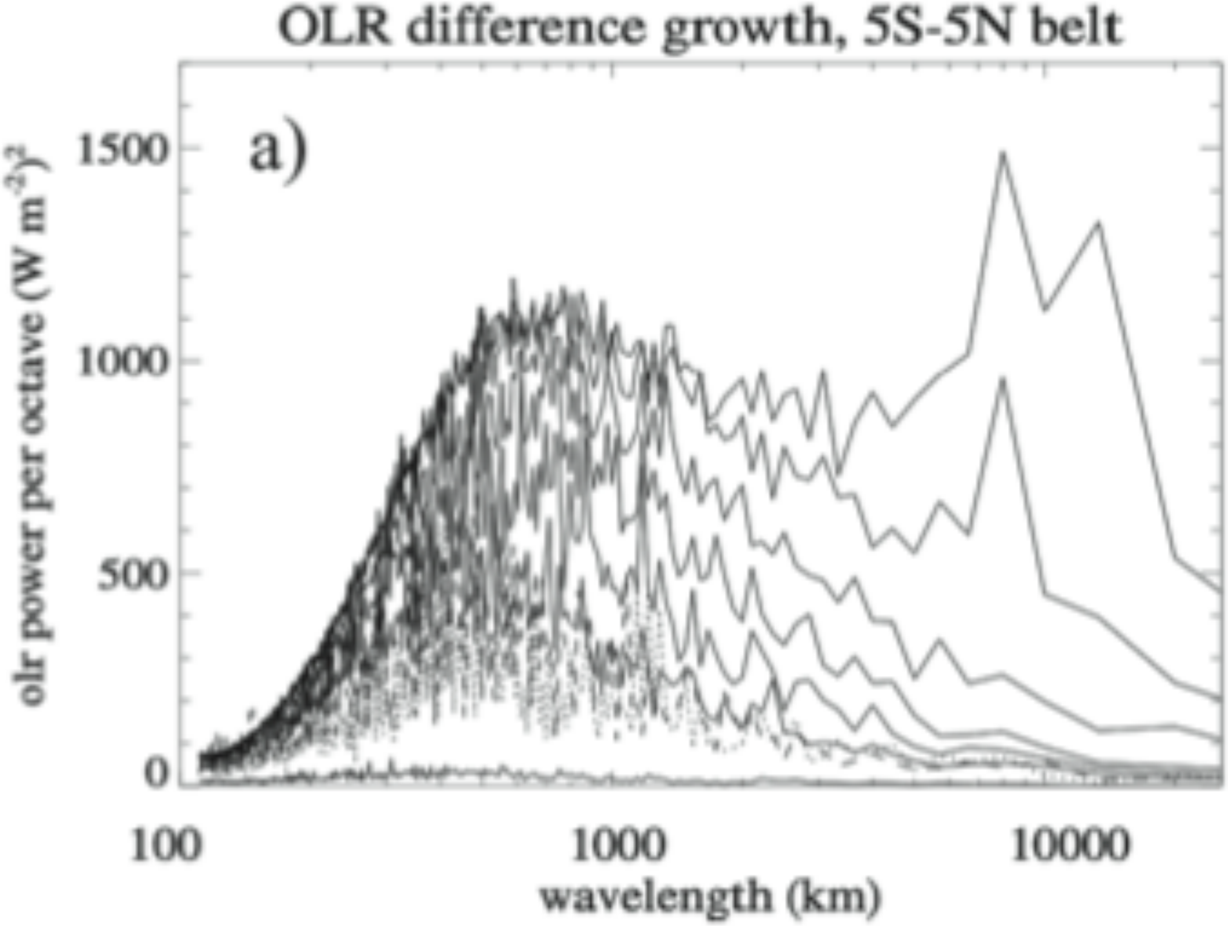


Fig. 1. Time-longitude sections of OLR averaged 10N–10S, for the $N7^{+2K}$ and $N14^{+2K}$ simulation pair. Contours are 180, 210, 240 W m^{-2}.

Scale dependence of perturbation growth

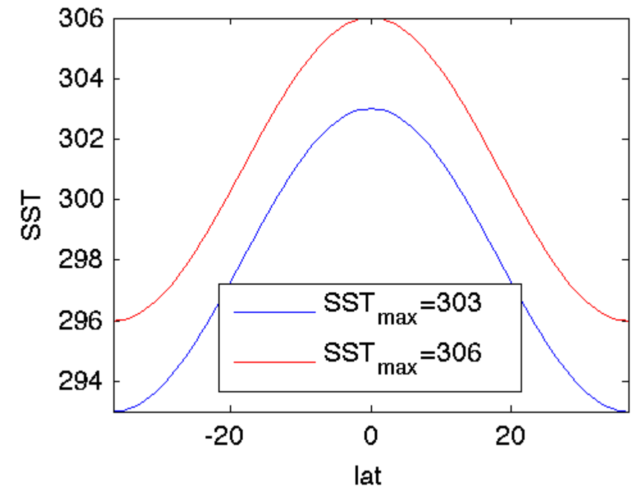


Perturbations grow simultaneously at all scales, saturating at:

λ = 500 km at 8 d,
3000 km at 16 d
longer at global scales.

Fig. 3. Squared differences of OLR between a) N7–N14 and b) N7^{+2K}–N14^{+2K} simulations, averaged over the 5N–5S belt, in the log-wavelength domain. The vertical axis is scaled to indicate power per octave, while the horizontal axis covers 8 octaves exactly. The rising sequence of lines represents times of 3h, 6h (dotted). 9h (dashed); then mean differences over 1d, 2d, 4d, 8d, 16d, 30d.

Marat vs. BlueGene



Last year: Round 1 (to Marat)

– several 16384 x 8192 km x 32 level CRM simulations (4 km resolution) on a zonally-symmetric aquaplanet

Equatorial beta-plane (36 S- 36 N)

Rigid N/S walls, periodic in E-W direction

Specified SST

Interactive radiation with diurnal cycle

Each run 100+ days

Results have obvious potential

Marat vs. BlueGene

- Last fall - Round 2 (to Marat):

  I suggest a sensitivity test to small humidity perturbations. Run is successfully completed and 2D results archived at UW.

- Last Nov-Dec – Round 3 (knockout by BlueGene)

  BlueGene RAID array suddenly fails. All 3D data is lost from all runs

  BlueGene decommissioned. Out of business!

The results shown here are some of what we can glean from the limited outputs salvaged from limited model runs. We have a proposal in for the computer resources to do these runs better with full archiving of results.

Setup of our simulations

- SST_{max} = 306 K run 100 days into statistical equilibrium (t=0)
- Two 18-day branched simulations:

  CTRL: continuation of above run

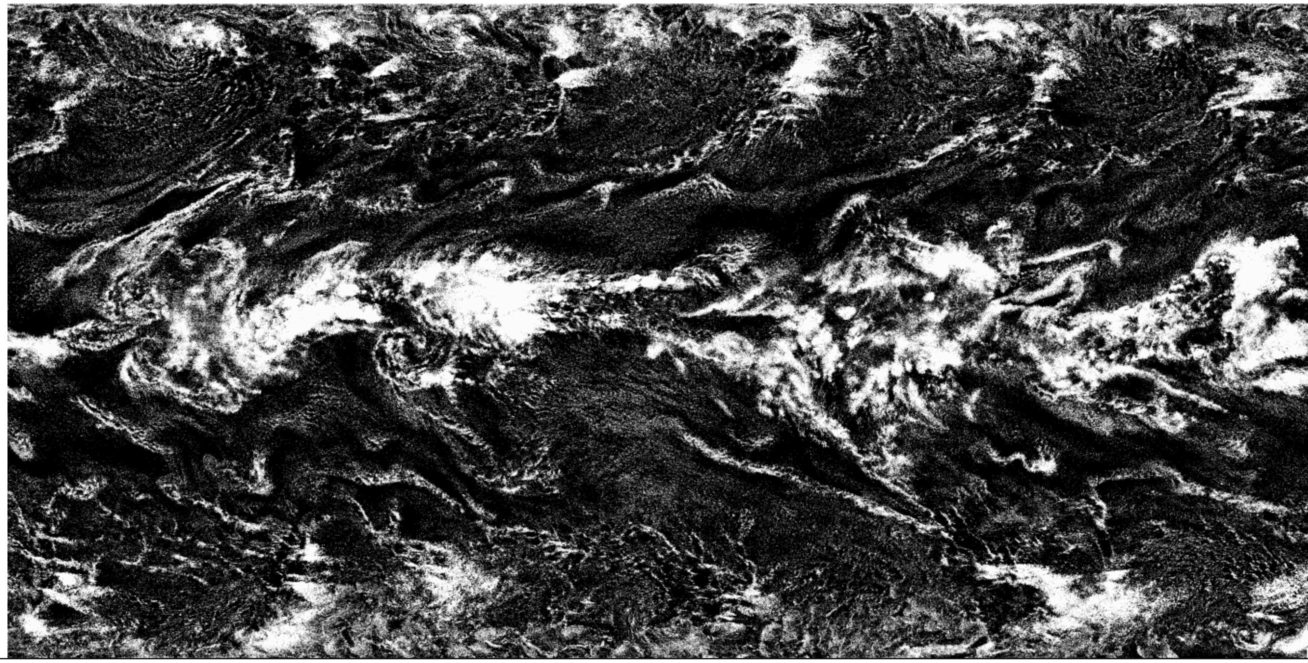
  PERT: small spatially white humidity perturbations at 630 hPa added to qt at t=0
- Convection, MSE and diabatic feedbacks in CTRL
- Perturbation growth (predictability) from DIFF = PERT-CTRL
- Fourier spectral and cospectral analysis in x of CTRL and DIFF

Analysis of Control Run

day 7

CLD

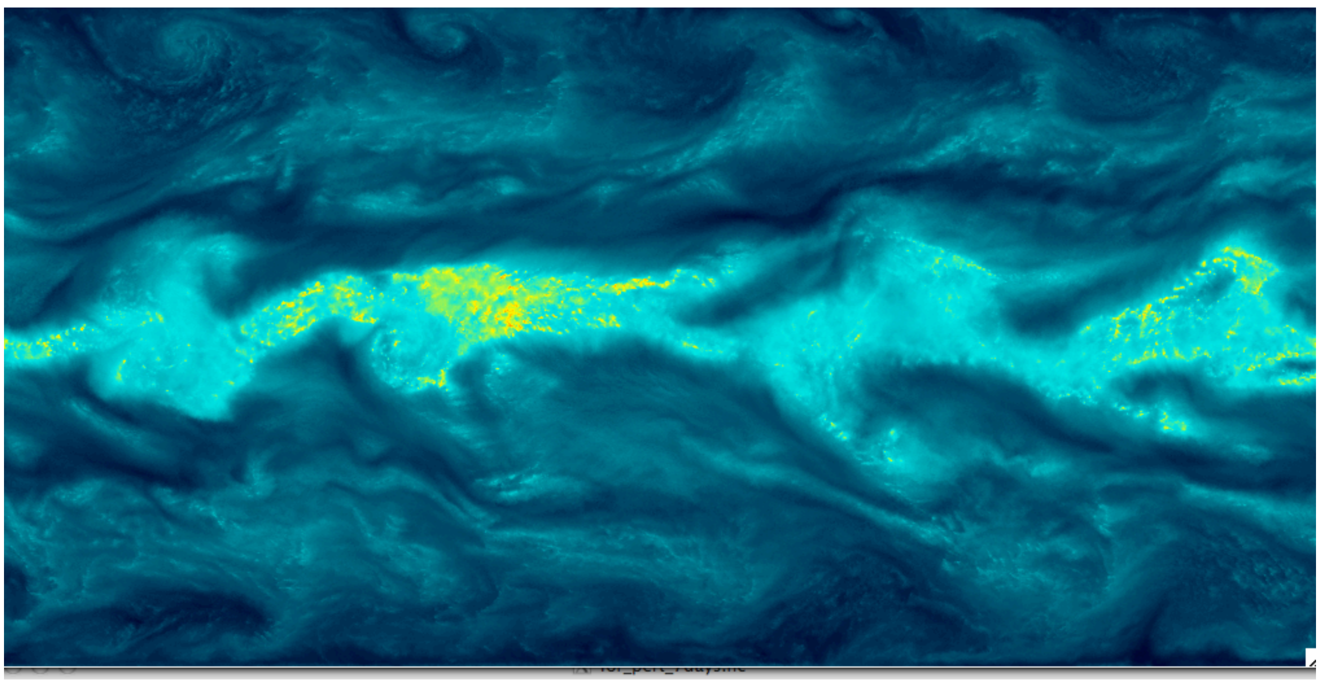
Control



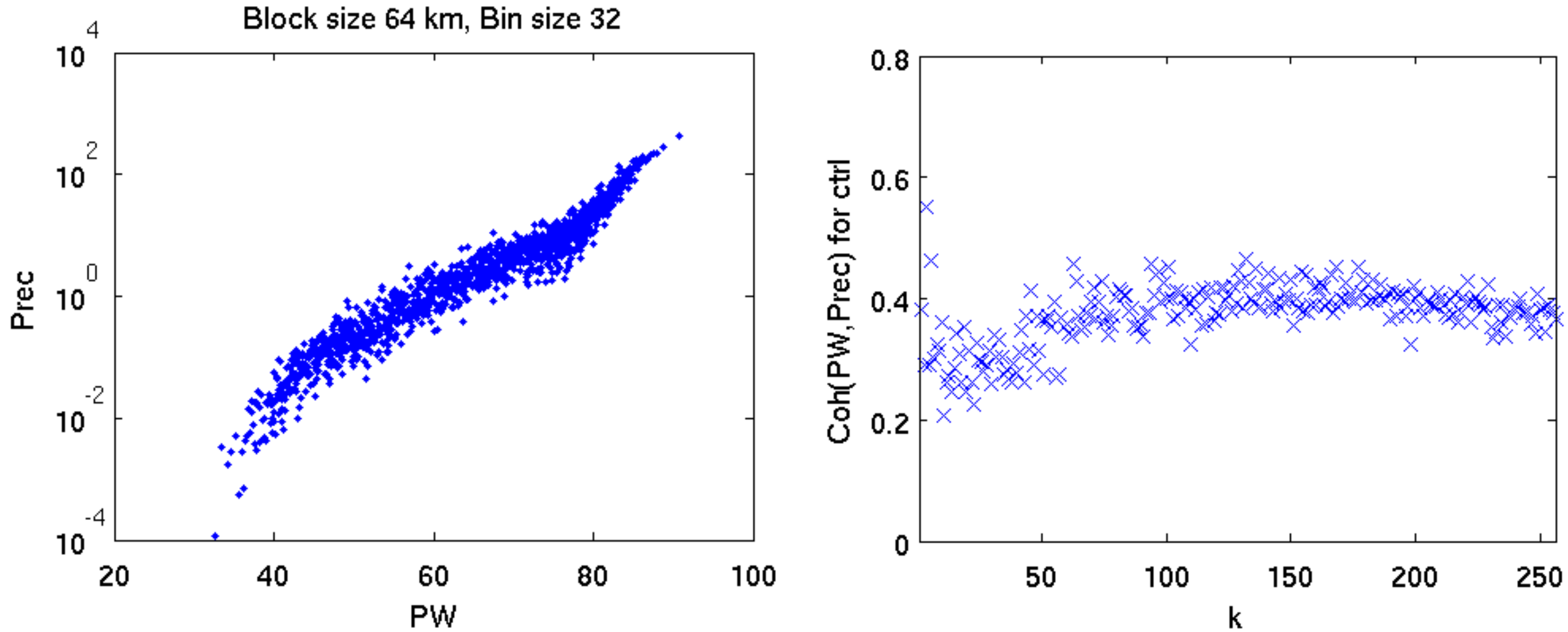
day 7

PW

Control



Precipitation vs. Water Vapor Path, 10S- 10N



More rainfall in humid columns, as expected,
over a large range of scales k = 16384/λ

Diabatic feedbacks in control run

MSE budget: Let h‘ denote perturbation of MSE from zonal mean and <> a mass-weighted column-integral:

$$L\, dPW'/dt \approx d<h'>/dt = THF' + RAD' + hadv'$$

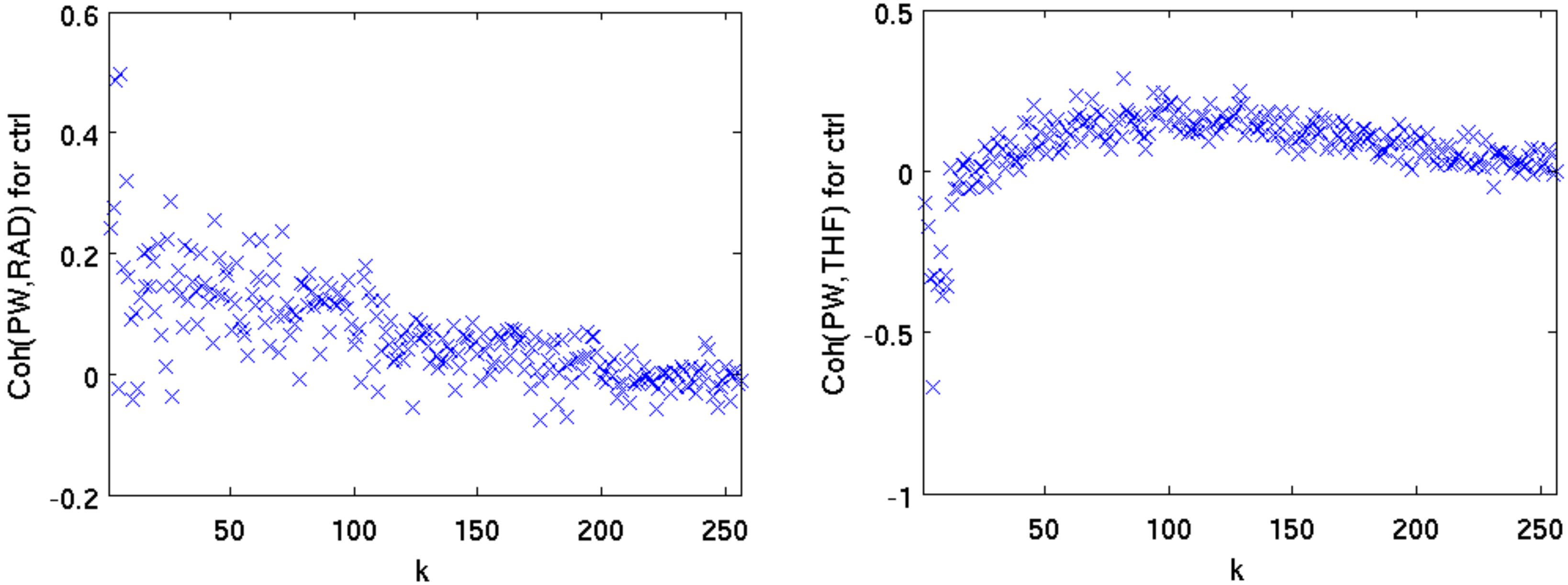
The approximation $<h'> \approx L\, dPW'$ is most accurate in the tropics where WTG justifies neglect of $<c_p T'>$.

Let [] = zonal average. Variance budget (Wing and Emanuel 2013):

$$L\, d[PW'PW']/dt \approx [PW'THF'] + [PW'RAD'] + [PW'hadv]$$

… can be partitioned by scale using cross-spectral analysis

Cross-spectra in the control run



- Some correlation of RAD’ and PW’ at large scales
- Slight positive correlation of PW’ and THF’ at mesoscale wavenumbers, with surprising negative correlations at global scales
- Correlations of Prec’, RAD’ and THF’ with PW’ much weaker than in CRM self-aggregation runs.

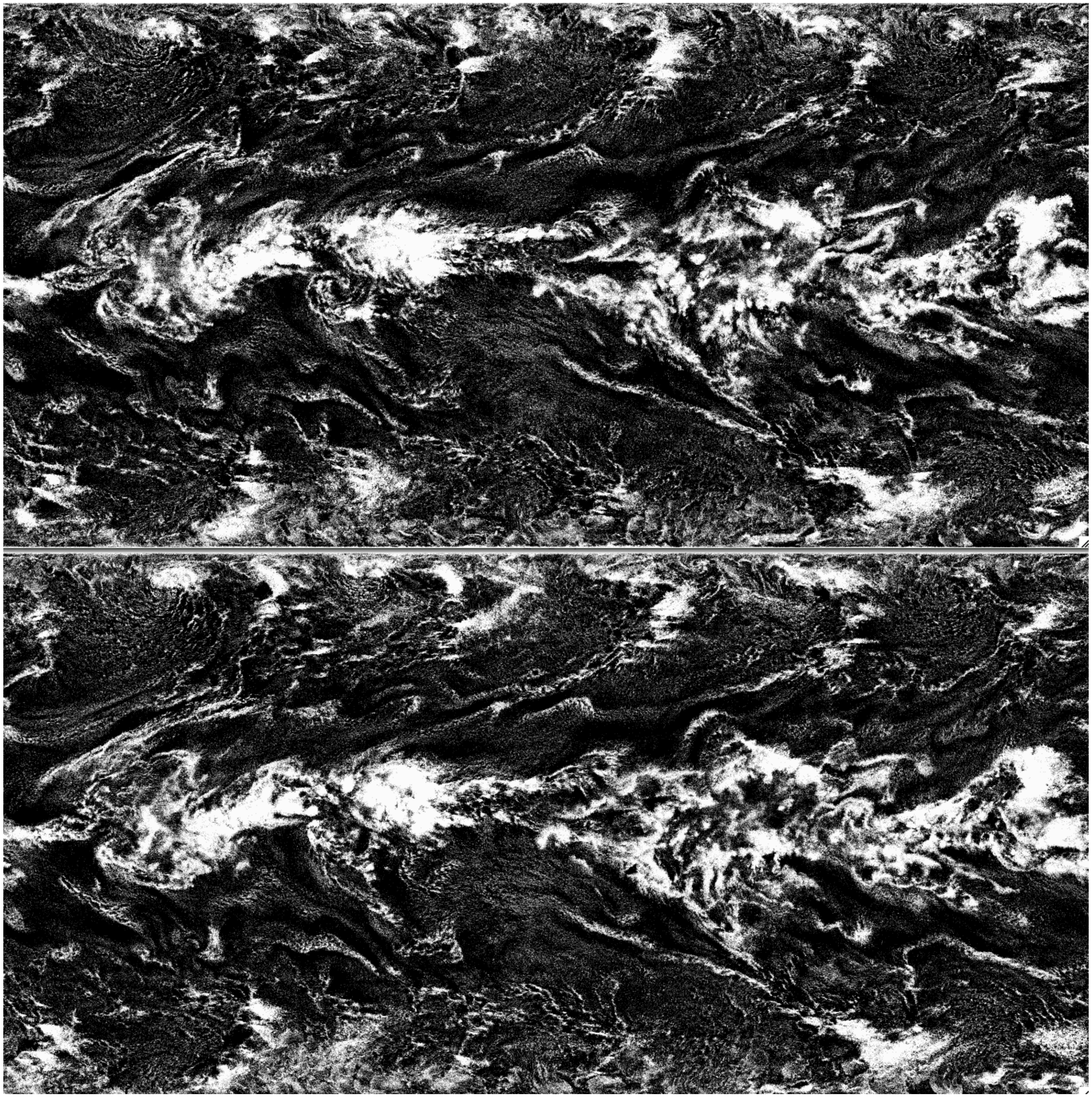
Growth of Humidity Perturbations

day 7

CLD

Control

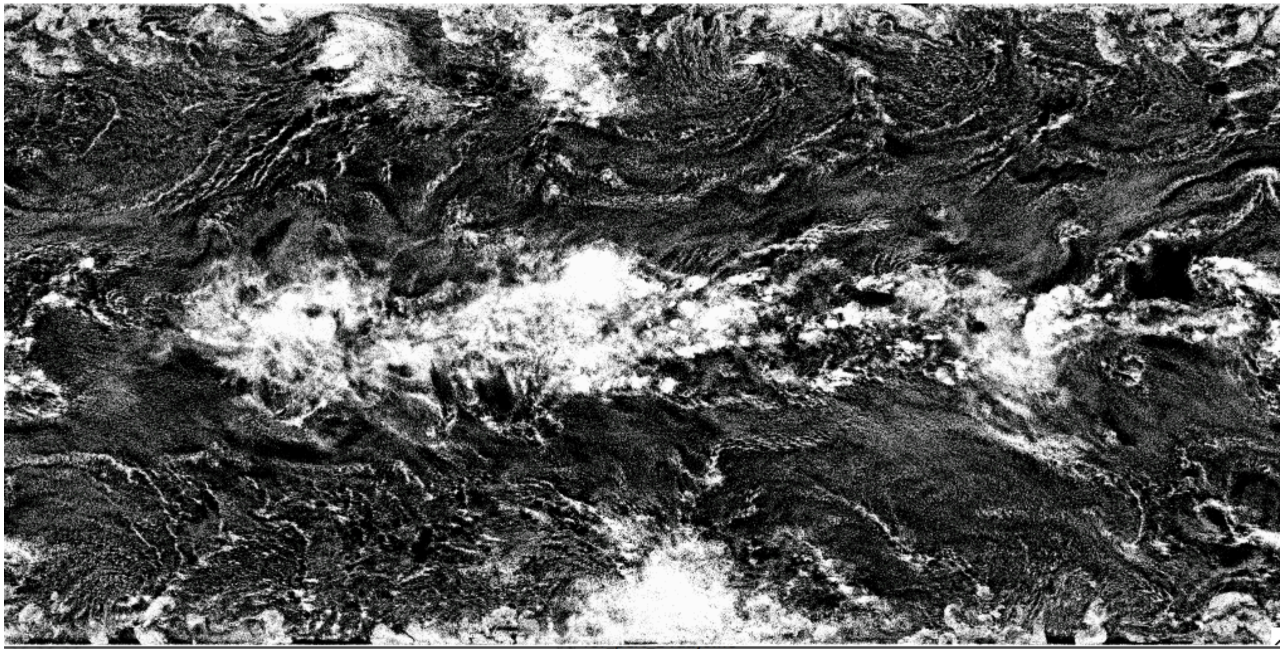
Perturbed



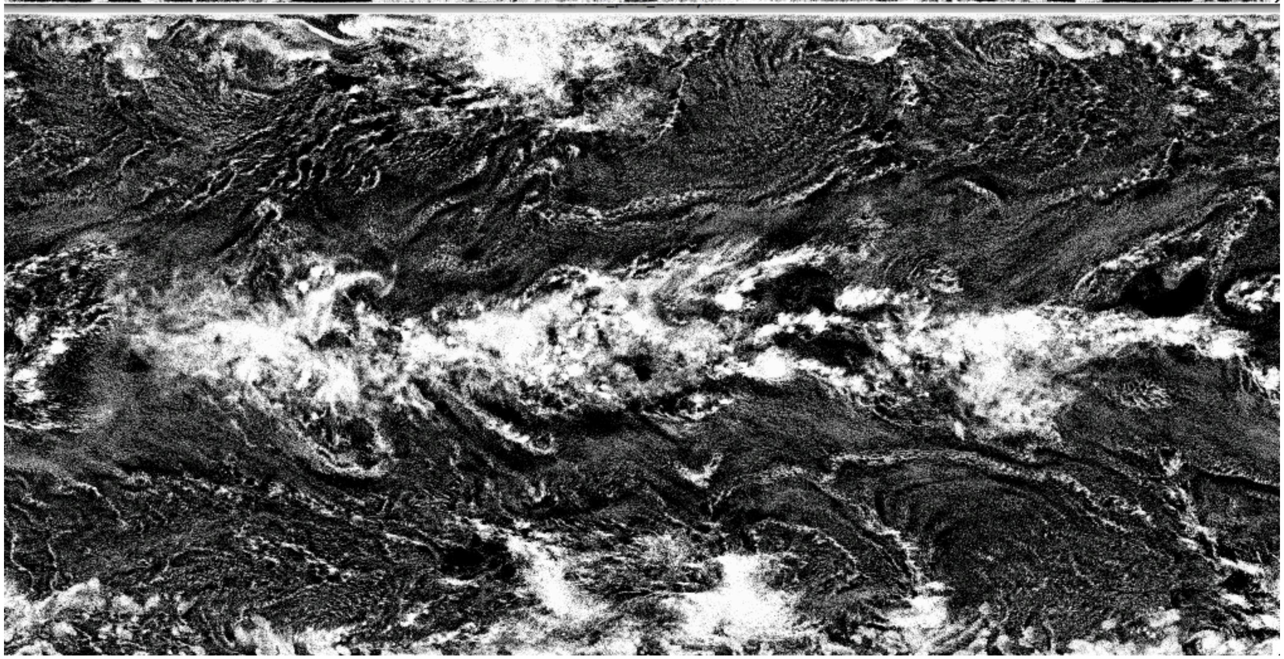
day 14

CLD

Control

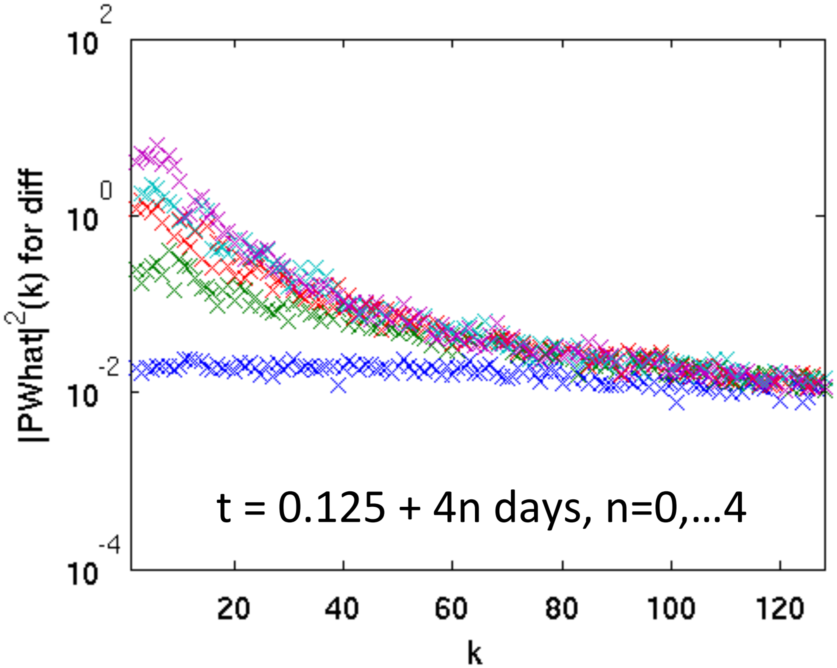


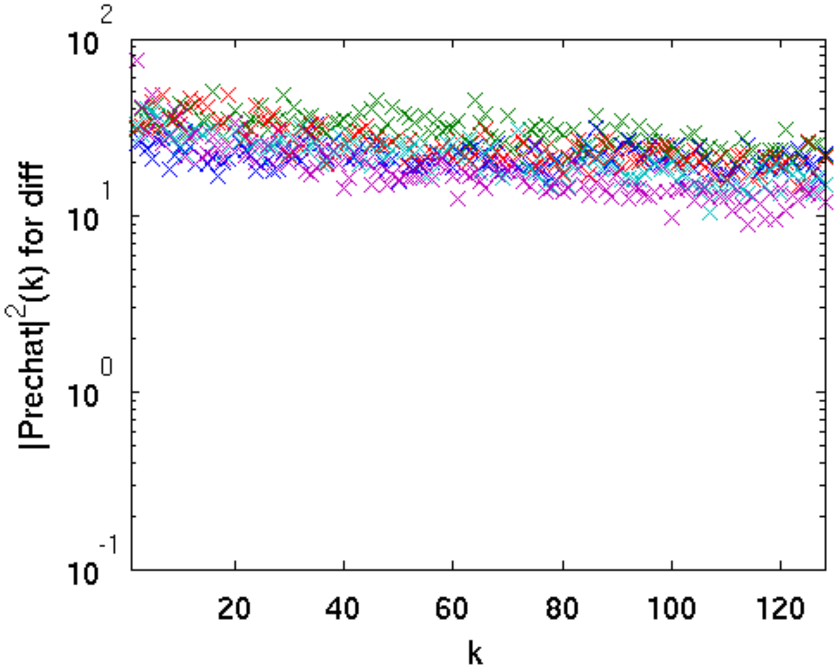
Perturbed



Tropical perturbation growth – all fields

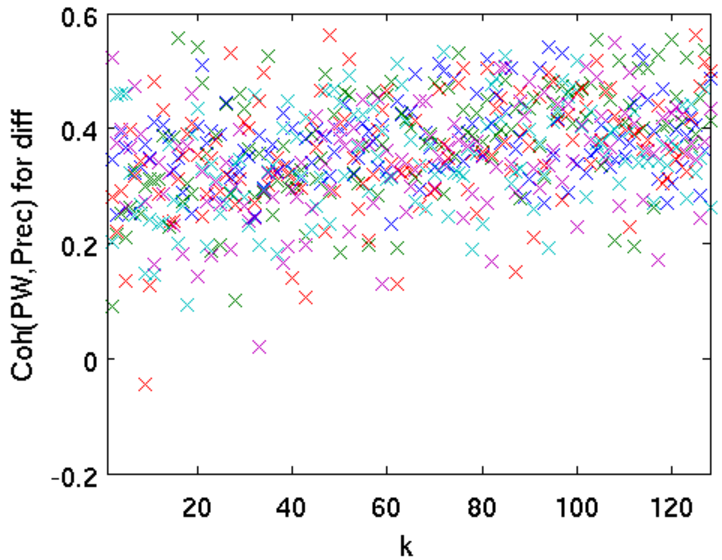
- Low wavenumbers take longest to saturate (> 16 d)
- Instantaneous precip differences have a whitish spectrum

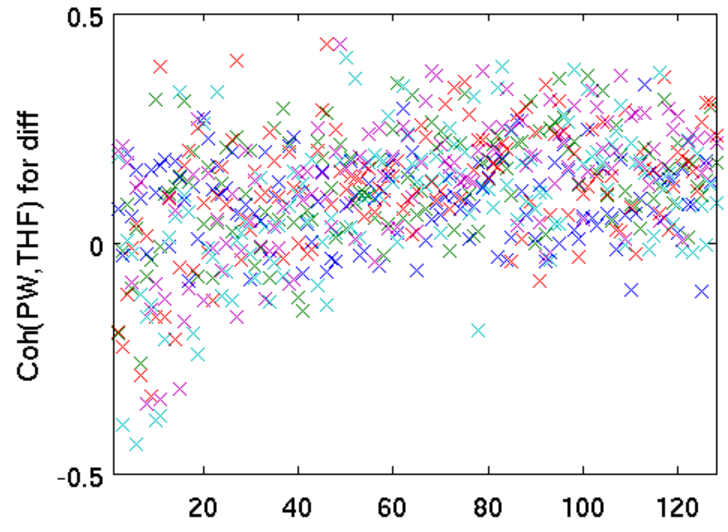


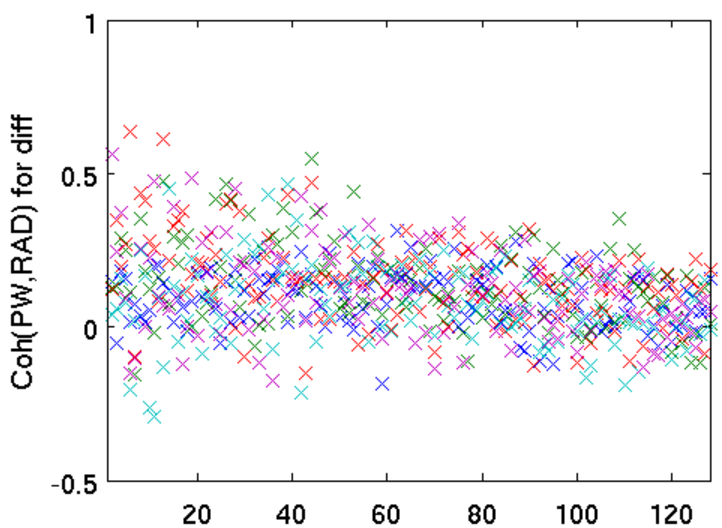


Coherence between fields in tropical perturbation growth

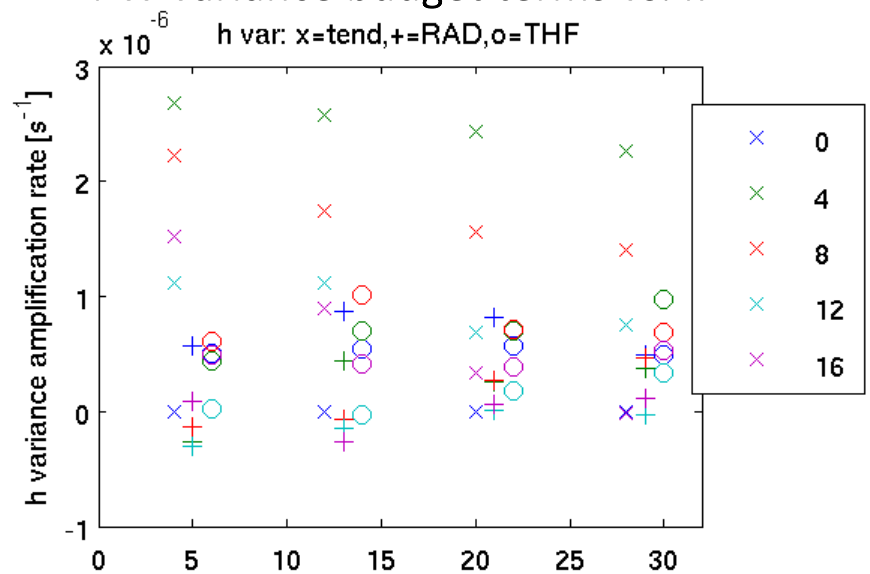
- Results similar to zonal perturbations in control run
- Both RAD and THF contribute modestly to growth of PW perturbations





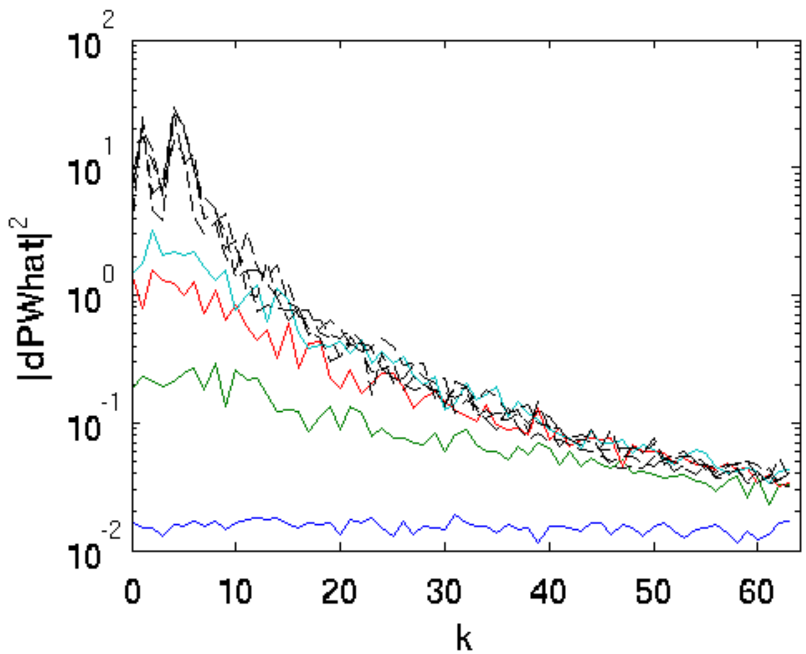


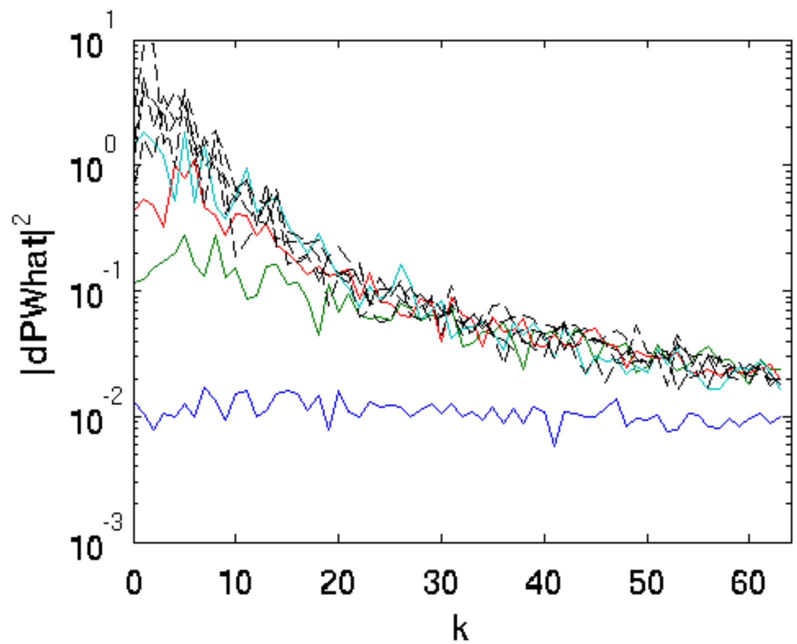
PW variance budget terms vs. k



Tropical vs. midlat PW perturbation growth

- ~5 day e-folding time of large-scale PW perturbations
- At 12 days, midlat PW perturbations saturated but tropics still retain substantial predictability at global scales.





Conclusions

- Near-global CRM is an expensive but simple idealized tool
- Diabatic processes amplify humidity anomalies but advectively driven anomaly growth is a stronger driver in this simulation
- Potential predictability may be longer in tropics than extra-tropics due to weaker shear (even without ocean coupling).