Predictability aspects of aqua-planet simulations with explicit convection

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Outline

- Conceptual framework: **predictability**
  - subtle, model dependent
    - when is a model good enough?
      - (when there's no Reality to worry about!)

- Model (NICAM, on Earth Simulator)
- Zonally symmetric aqua-planet runs
    - spinup sequence for showcase 3.5 km grid run
- Analysis and results

Introduction

- Predictability of atmospheric flow
  - a few days for dry baroclinic waves
  - mere minutes-hours for cumulus clouds
  - ? for moist large-scale flows (tropics, whole system) ?
- Usually cast as **growth of Δ(init. cond.)**
- Here (opportunistic): consider weather differences growing in parallel model runs after **resolution doublings** (with initial conditions interpolated to new grid)

"Predictability"

- A powerful, even arrogant claim...
- ...since ways of approaching it are inevitably model dependent
- especially for a fictional planet

Predicting the weather in model A with model B

A good B bad	A good B good
A bad B bad	A bad B good

"Predicting" the weather in model A using model B

A good B bad	A good, B good Lessons: science gold! a glimpse of fundamental predictability properties of real flow!
A bad B bad	A bad B good

"Predicting" the weather in model A using model B

A good B bad	A good, B good Clues: A & B simulations *similar, realistic by important measures*
A bad B bad	A bad B good

"Predicting" the weather in model A using model B

A good, B bad Lessons: limited by B's badness. Cannot make "predictability" claims :(	A good B good
A bad B bad	A bad B good

"Predicting" the weather in model A using model B

A good, B bad One clue: B-A diffs may appear at large scales directly (climate drift, not weather divergence)	A good B good
A bad B bad	A bad B good

“Predicting” the weather in model A using model B

A good B bad	A good B good
A bad, B bad DANGER A&B similar, so it can look like predictability is being addressed!	A bad B good

"Predicting" the weather in model A using model B

A good B bad	A good B good
A bad, B bad How would we know? 1. formulation badness • strong dep. on ?param? 2. performance badness	A bad B good

This study - opportunistic, with challenges

1. formulation badness?
   - e.g. strong dependence on uncertain params.
     - e.g. cumulus parameterization
       - *avoid, with global explicit convection!*

2. performance badness
   - How to assess on fictitious aqua-planet?

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The model

- Nonhydrostatic ICosahedral Atmosphere Model (NICAM)
  - grid spacing uniform over globe: **Δx = 14, 7, 3.5 km**
  - All interpolated to common 0.5º grid for this analysis
- SST: Neale-Hoskins **aqua planet** "control case"

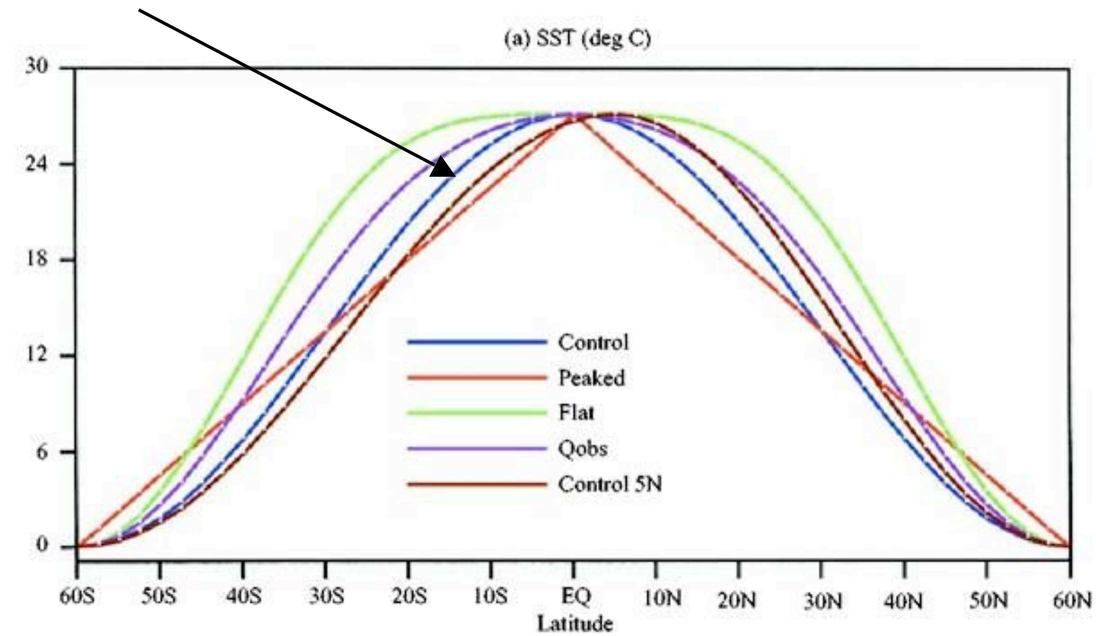
- **No cumulus parameterization**
- PBL scheme: M-Y level 2
- Microphysics: Grabowski 1998 2-cat (w/ice)
- Radiation: 2-stream adding, Nakajima 2000
  - every 10min at 14km, 5min at finer res.

Experimental design:

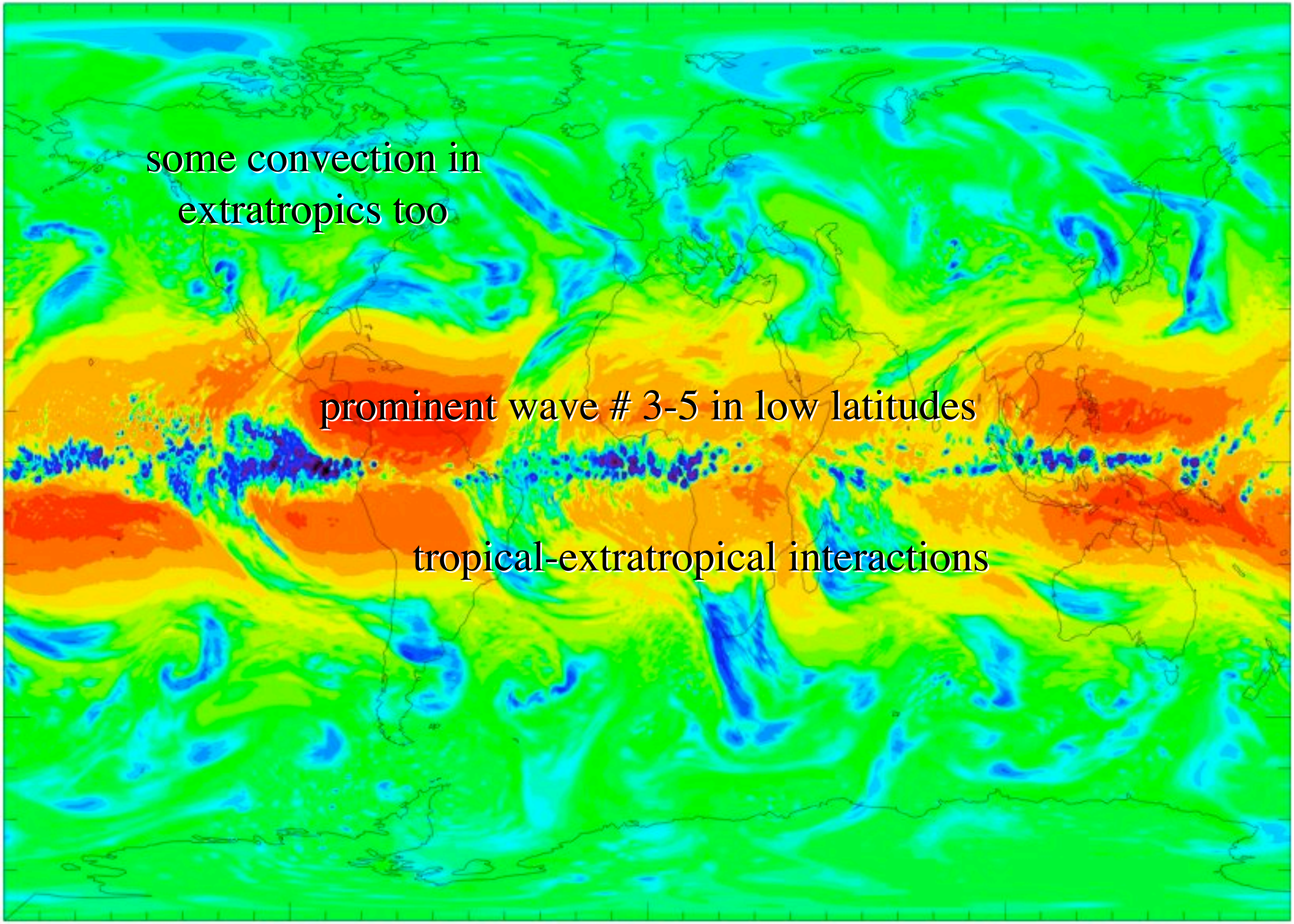
Aquaplanet … Neale and Hoskins (2000)

- radiation: equinox (no seasonal variability)
- zonally uniform SST

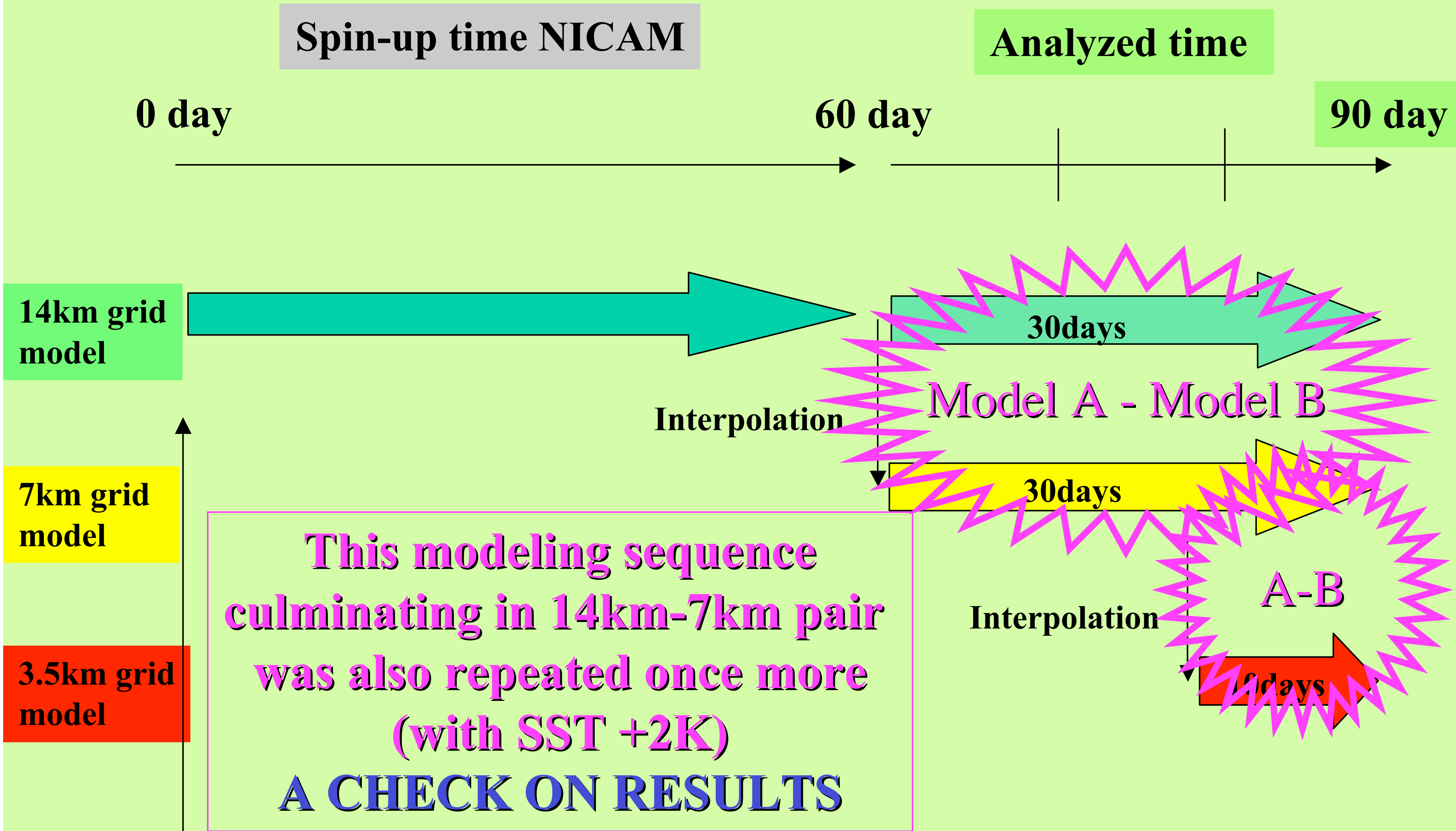
(Control)



OLR snapshot (continents for ref only)



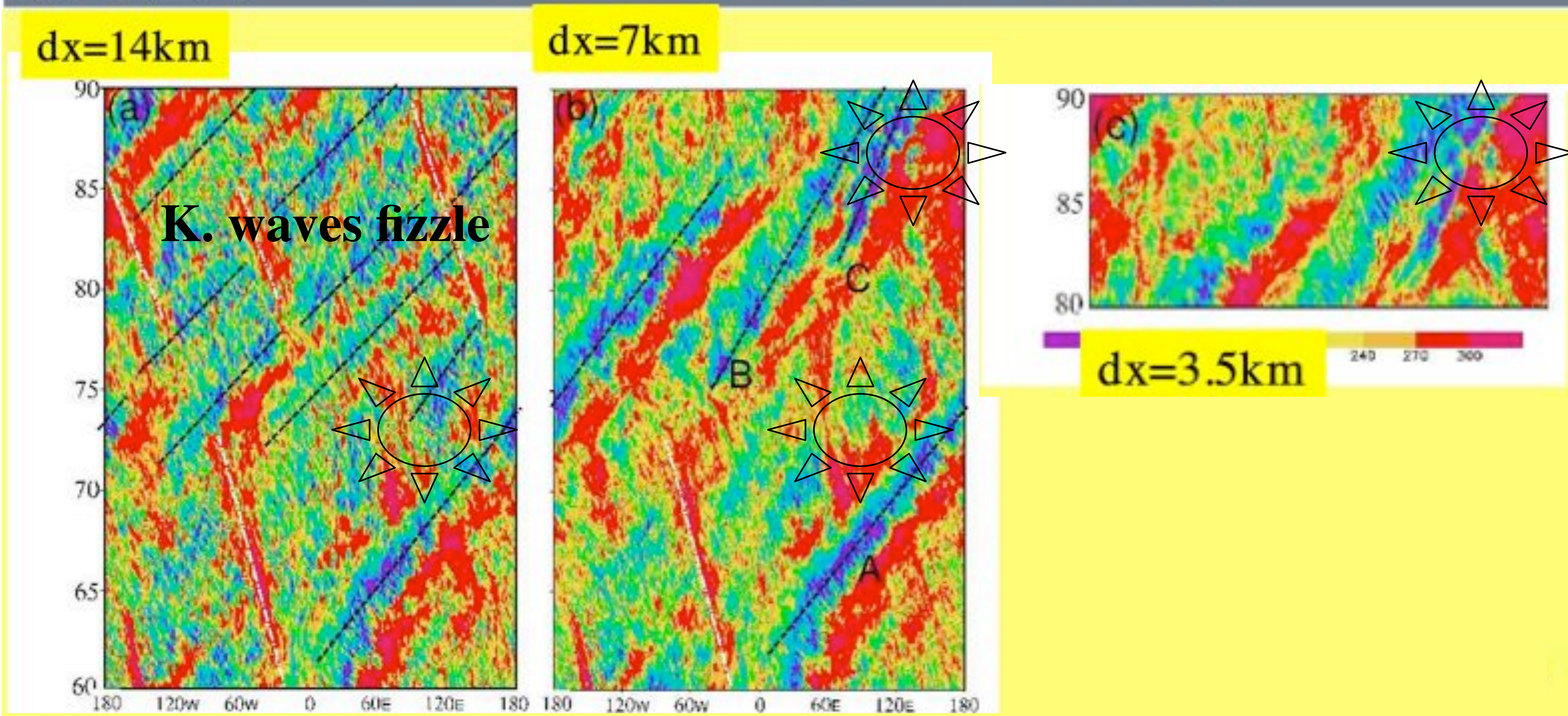
Aquaplanet experiments



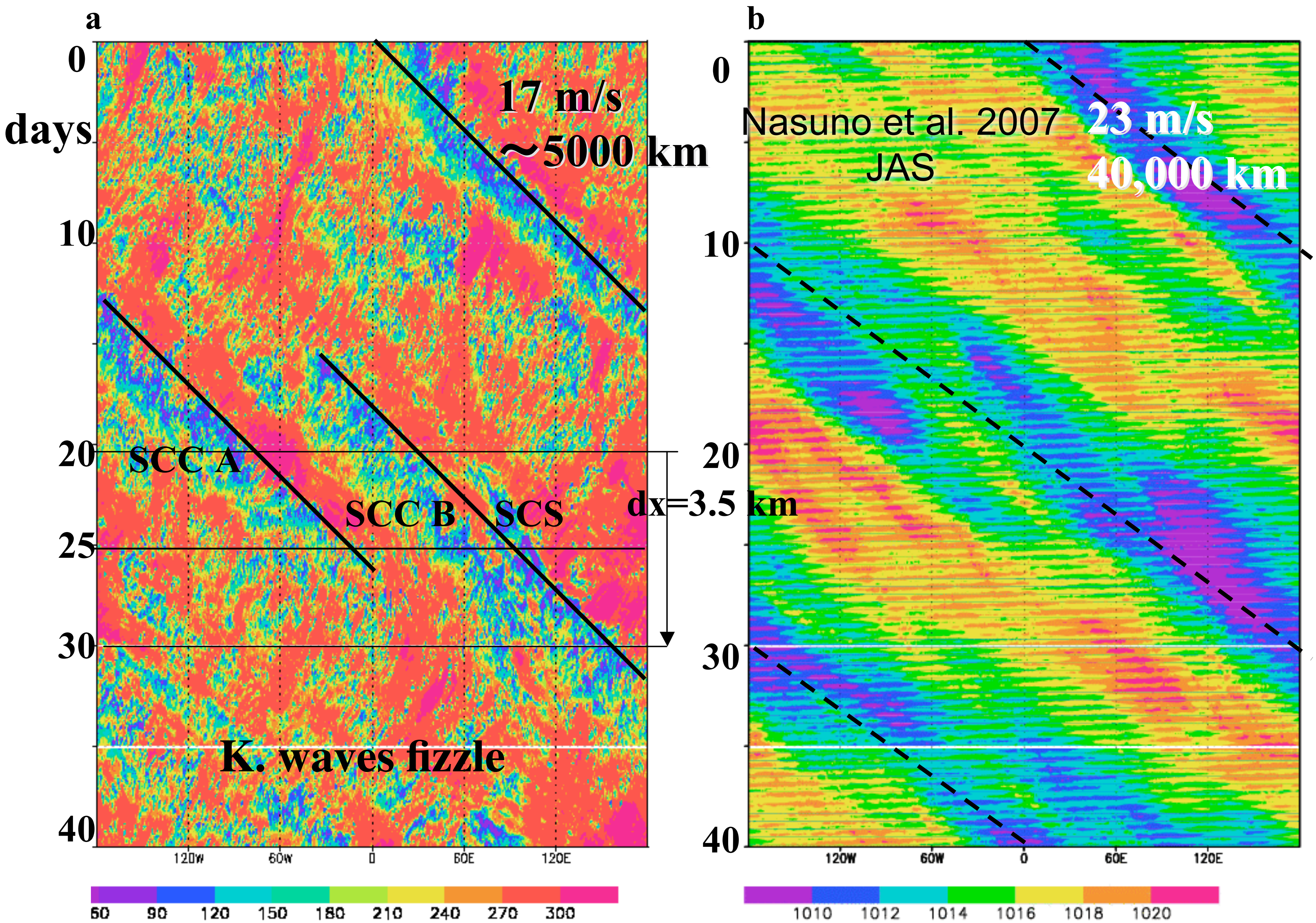
Initial condition: 3 year average of T42 AGCM

FRCGC Frontier Research Center for Global Change

Hovmoller diagrams of OLR (2S-2N)



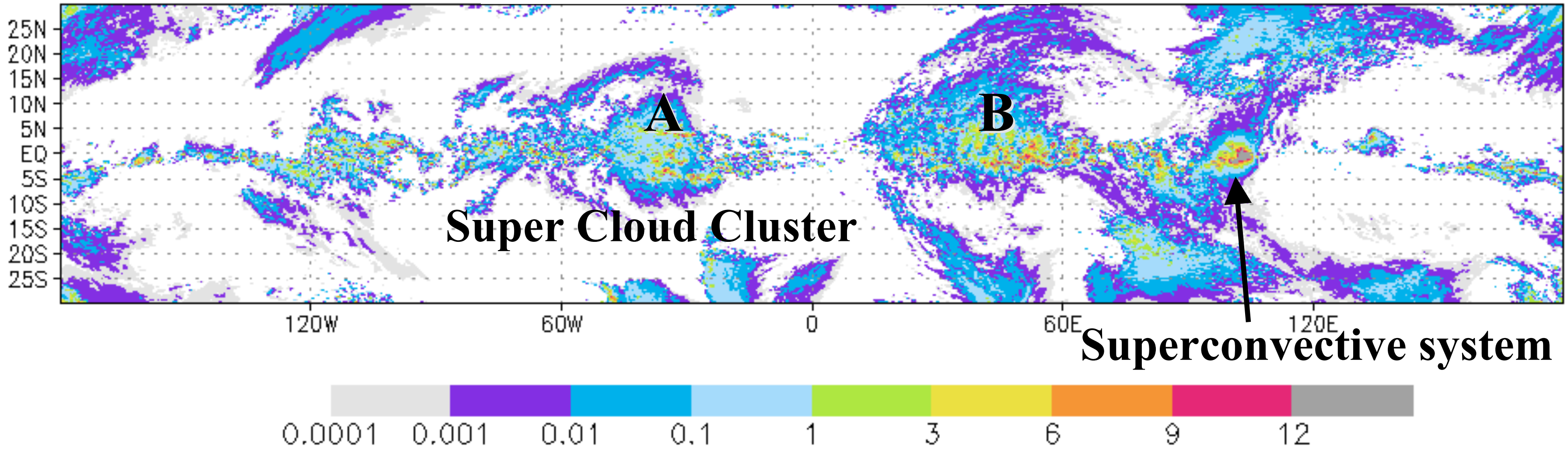
Nasuno et al. 2007 JAS



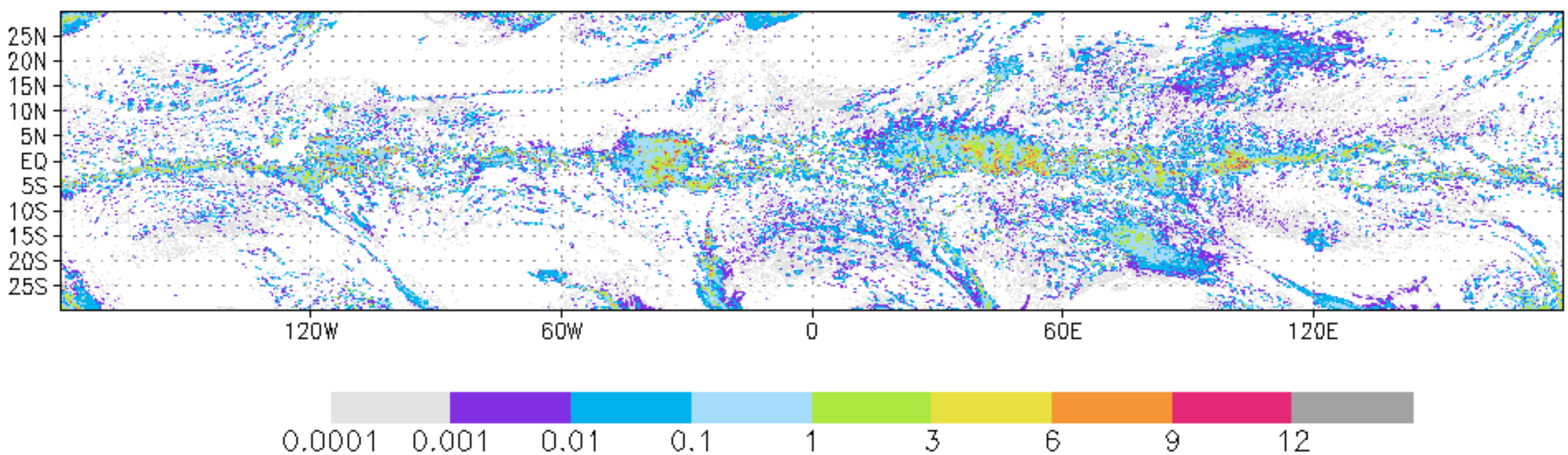
Hovmoller diagram of (a) outgoing long-wave radiation (OLR) at the top of the atmosphere (W m^{-2}) and (b) surface pressure (hPa). Solid (broken) lines in (a) ((b)) indicate eastward velocity of 17 (23) m s^{-1}.

3.5-km mesh aqua planet experiment (NICAM)

Ice water path (kg m $^{-2}$)

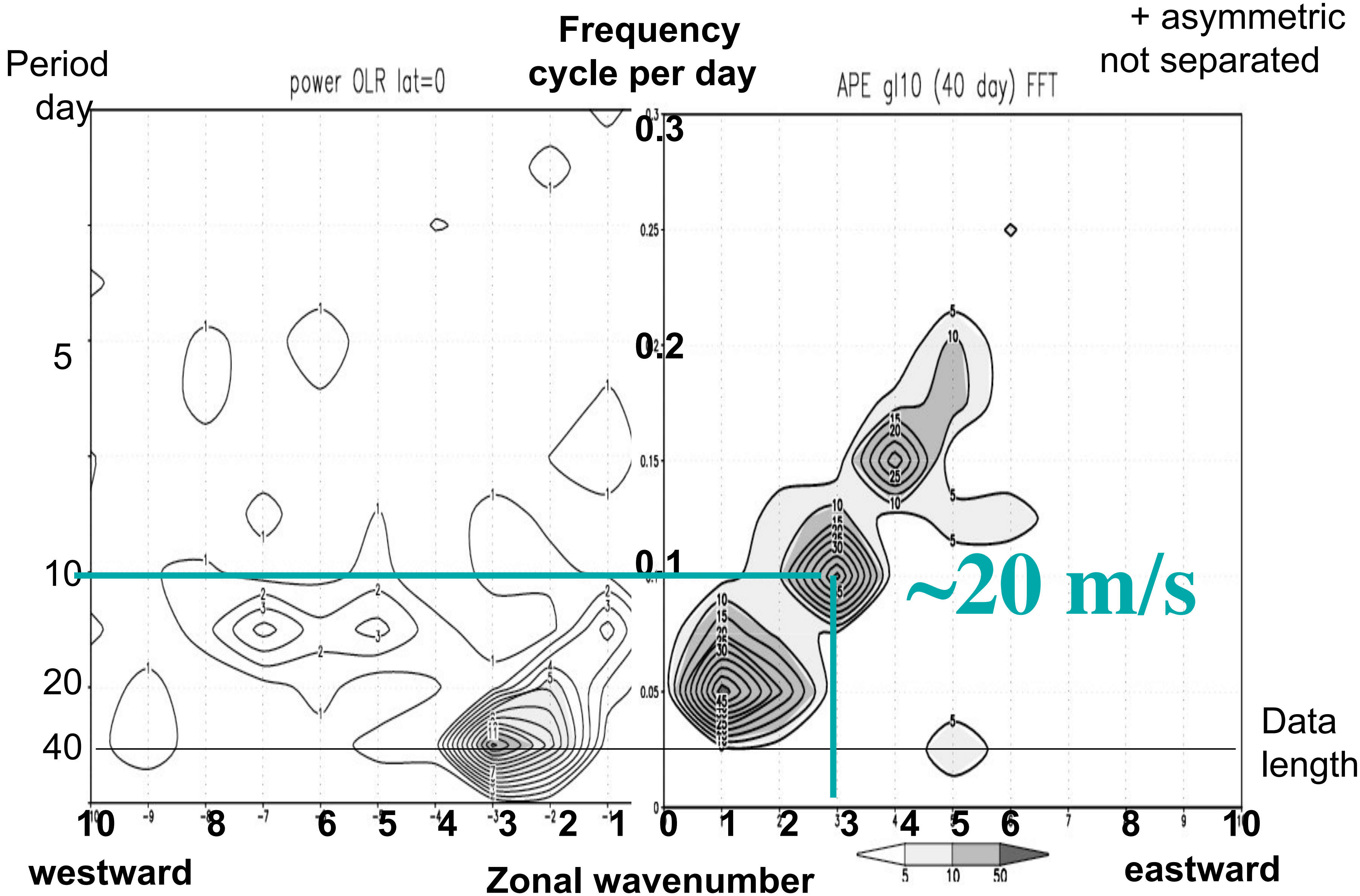


Liquid water path (kg m $^{-2}$)

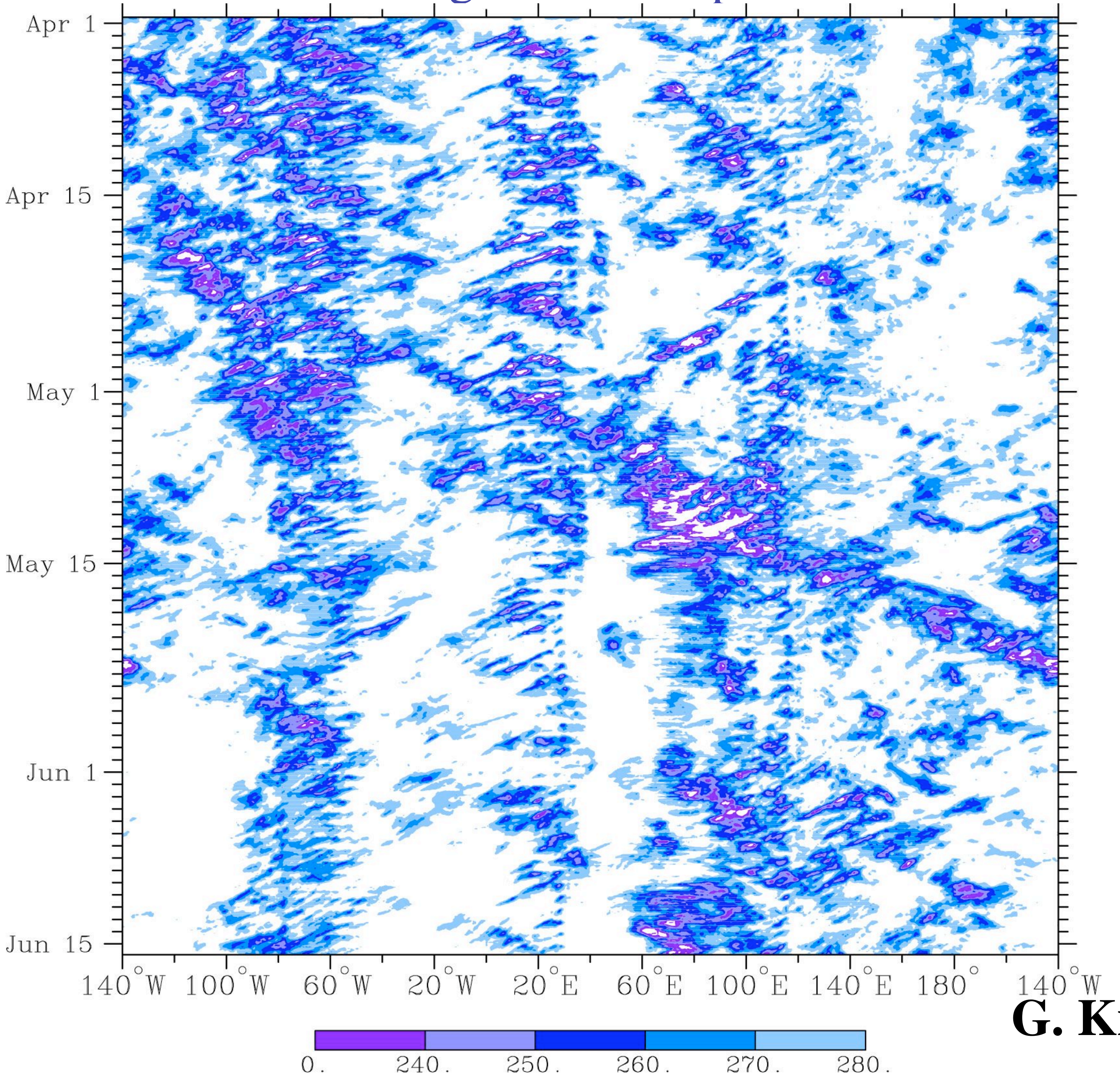


OLR (deviation from zonal mean) power (7 km)

Raw spectrum symmetric + asymmetric not separated



1998 CLAUS Brightness Temperature 5ºS-5º N



G. Kiladis

"Predicting" the weather in model A using model B

A good B bad	Want to say A good, B good 3.5 km good, 7 km good 7 km good, 14 km good *Is deep convection so inherently mesoscale that 14km is ~good enough?* *? what is the role of small-scale DOFs ?*
A bad B bad	

Storm-scale problems w/ under-resolved storms
late to start, then too strong

The Resolution Dependence of Explicitly Modeled Convective Systems

Morris L. Weisman, William C. Skamarock, and Joseph B. Klemp

ABSTRACT

...By varying the horizontal grid interval **between 1 and 12 km**, the degradation in model response as the resolution is decreased is documented and the processes that are not properly represented with the coarser resolutions are identified.

Results from quasi-three-dimensional squall-line simulations for midlatitude-type environments suggest that resolutions of 4 km are sufficient to reproduce much of the mesoscale structure and evolution of the squall-line-type convective systems produced in 1-km simulations. **The evolution at coarser resolutions is characteristically slower, with the resultant mature mesoscale circulation becoming stronger than those produced in the 1-km case.** It is found that the slower evolution in the coarse-resolution simulations is largely a result of the delayed strengthening of the convective cold pool, which is crucial to the evolution of a mature, upshear-tilted convective system. The relative success in producing realistic circulation patterns at later times for these cases occurs because the cold pool does eventually force the system to grow upscale, allowing it to be better resolved. **The stronger circulation results from an overprediction of the vertical mass transport produced by the convection at the leading edge of the system, due to the inability of the coarse-resolution simulations to properly represent nonhydrostatic effects.**

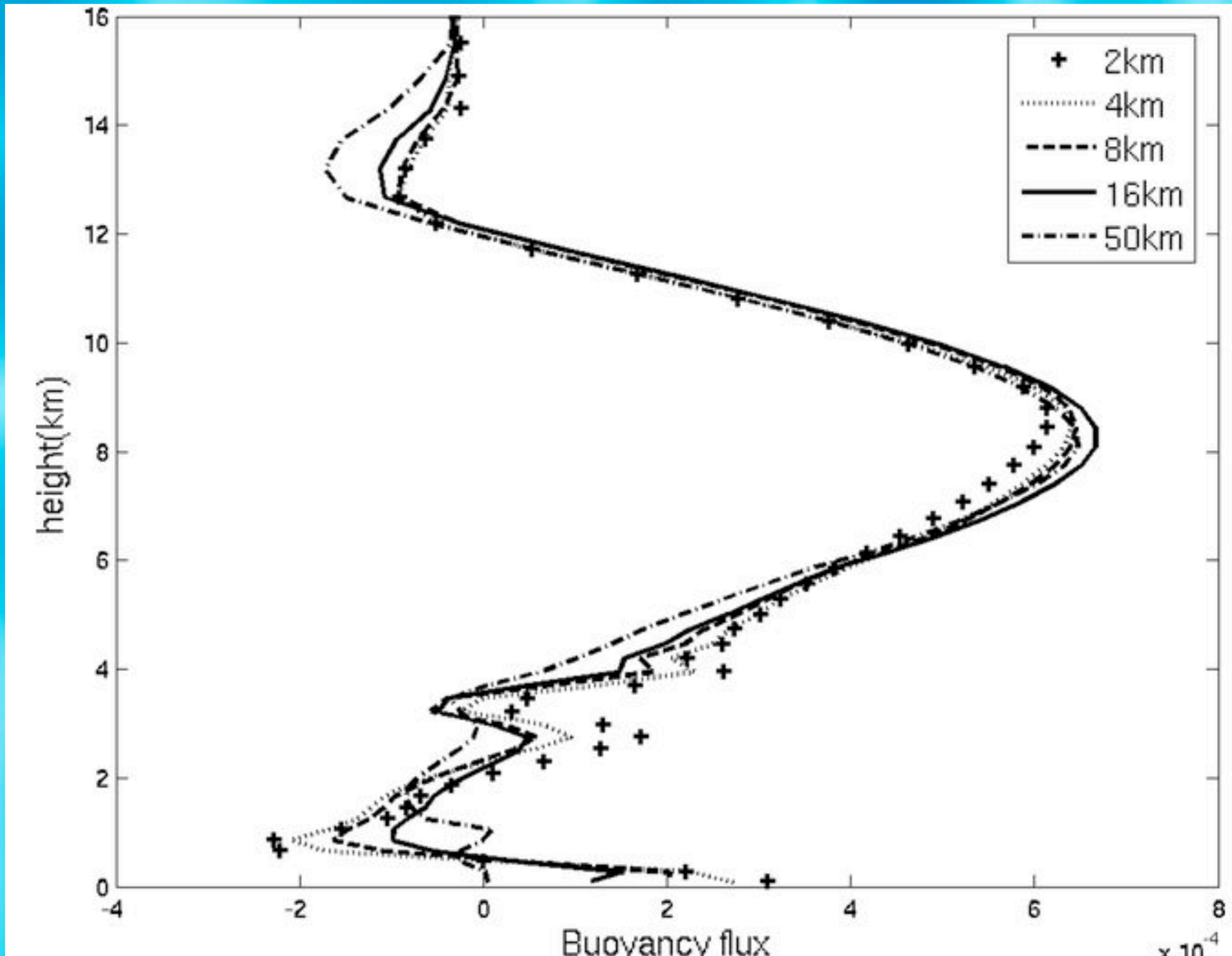
A statistical view

Sensitivity of Radiative–Convective Equilibrium Simulations to Horizontal Resolution. Olivier Pauluis and Stephen Garner

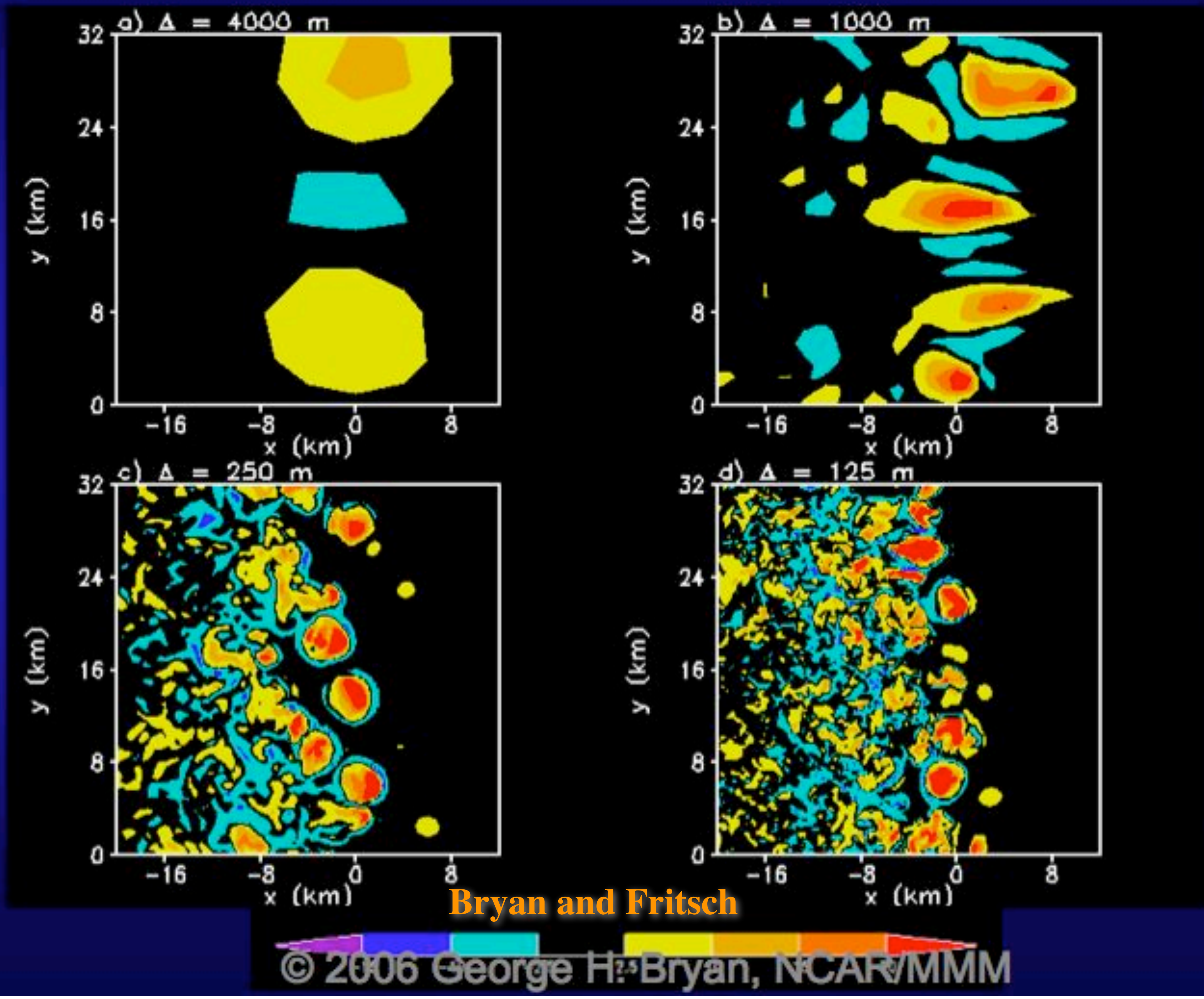
ABSTRACT

An idealized **radiative–convective equilibrium is simulated for model resolutions ranging between 2 and 50 km**. The simulations are compared based upon the analysis of the mean state, the energy and water vapor transport, and the probability distribution functions for various quantities. It is shown that, at a coarse resolution, the model is unable to capture the mixing associated with shallow clouds. This results in a dry bias in the lower troposphere, and in an excessive amount of water clouds. **Despite this deficiency, the coarse resolution simulations are able to reproduce reasonably well the statistical properties of deep convective towers.** This is particularly apparent in the cloud ice and vertical velocity distributions that exhibit a very robust behavior...the vertical velocity of an ascending air parcel is determined by its aspect ratio, with a wide, flat parcel rising at a much slower pace than a narrow one. This **theoretical scaling law... is used to renormalize the probability distribution functions for vertical velocity, which show a very good agreement for resolutions up to 16 km.** This new scaling law offers a way to improve direct simulations of deep convection in coarse resolution models.

A statistical view



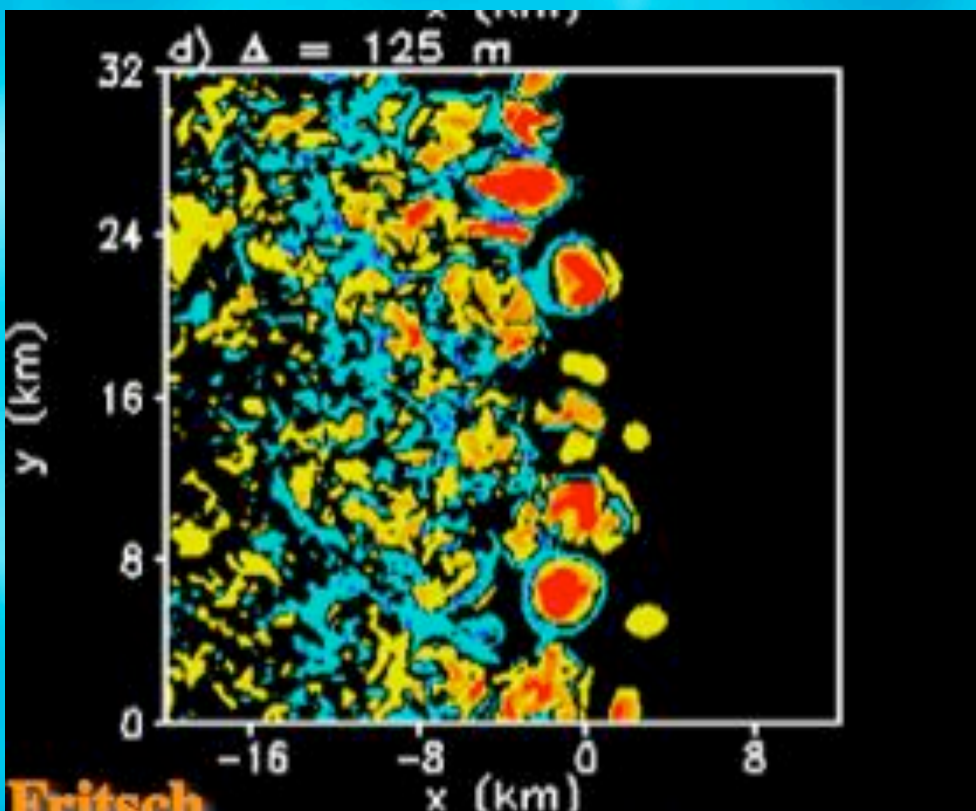
Vertical velocity (w) at z = 5 km, t = 5 h

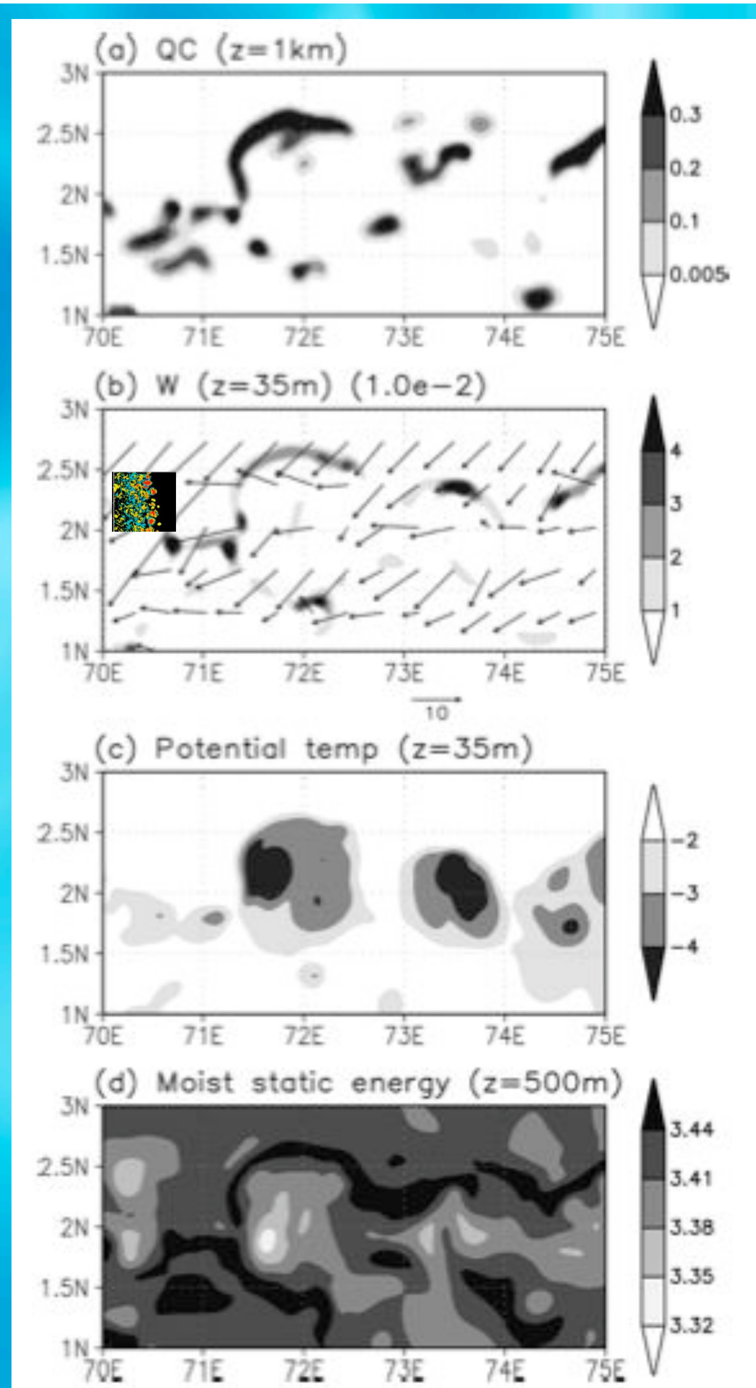


Bryan and Fritsch

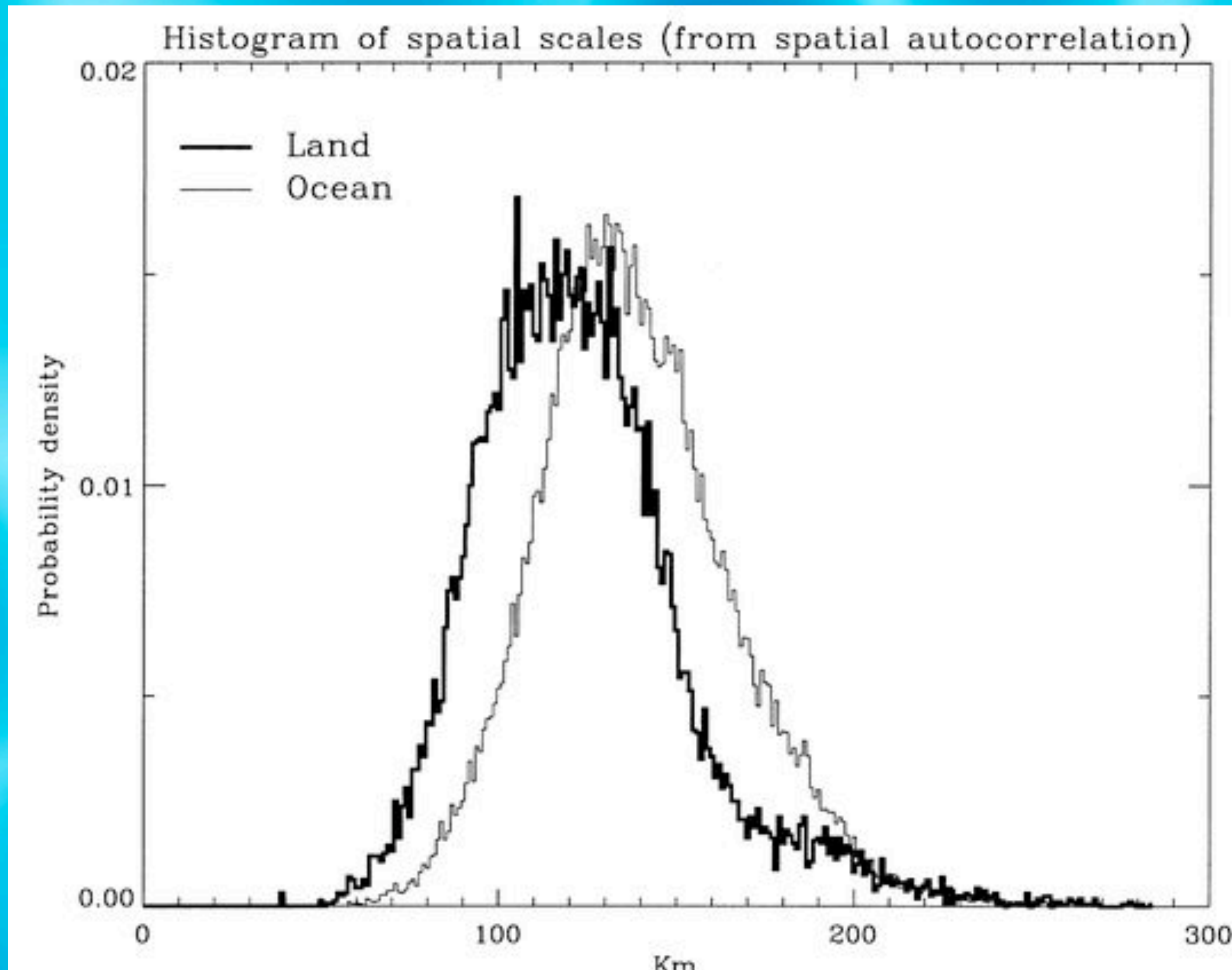
Fine enough? How about 2x, 4x?

- Nasuno et al. 2007





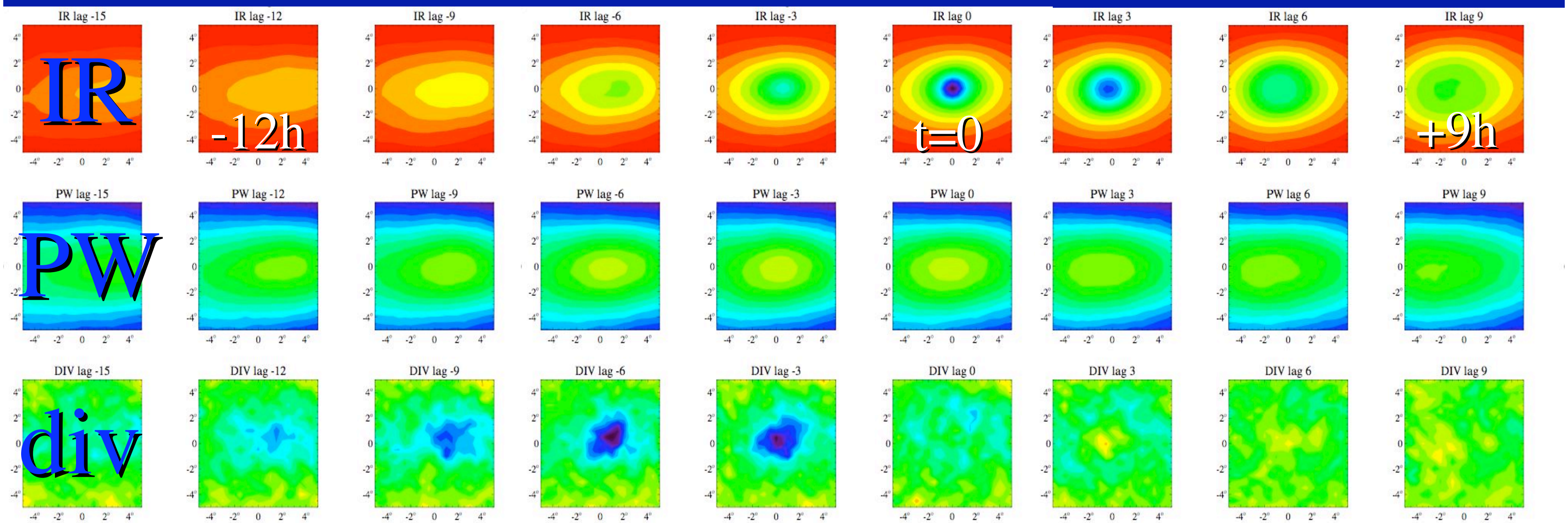
Dominance of mesoscale



- Ricciardulli and Sardeshmukh 2002 - from cloud top (IR)
  - cloud image pixels were selectively sampled and collected in regular 0.35° × 0.7° latitude–longitude boxes at 3-hourly intervals

Dominance of mesoscale II:
(100s km, many hours scales)

Composite 10x10 deg 3-hourly evolution of IR, PW, 10m divergence around 1st appearance of cold clouds (< 210K) on 0.5 deg grid



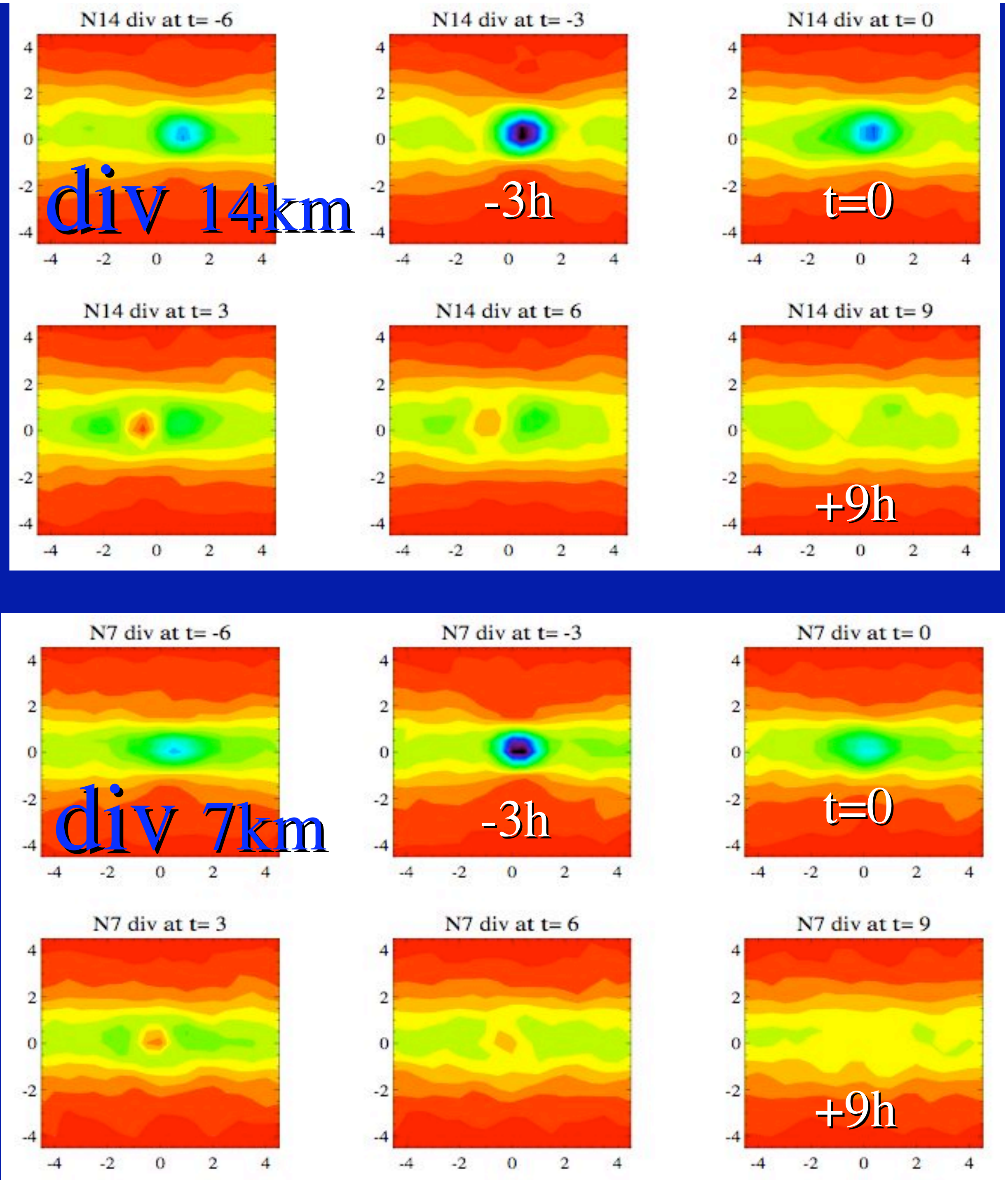
Meso scale & lifetime clear even in this equal-weight composite

(strong rotation cases excluded)

Mapes Milliff Morzel in prep.

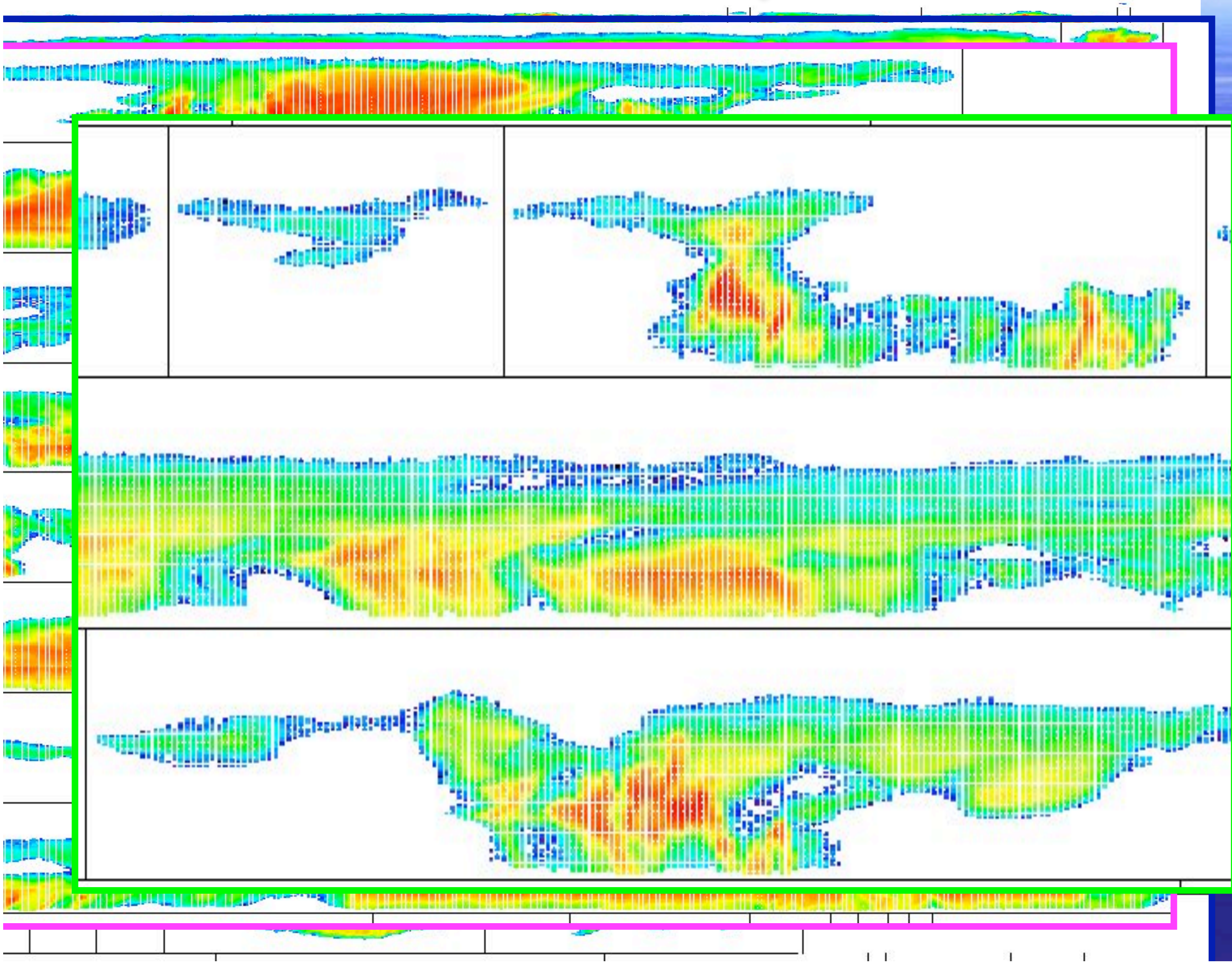
NICAM cloud clusters

- Divergence
- As in obs: 3 hourly 0.5 degree model data, 10x10 deg composite around cold IR cloud top appearance



Mesoscale org. *ubiquitous* in deep convection

Cloudsat: an unbiased sample from the Asian monsoon



connected cloud objects sorted by top height

true aspect ratio

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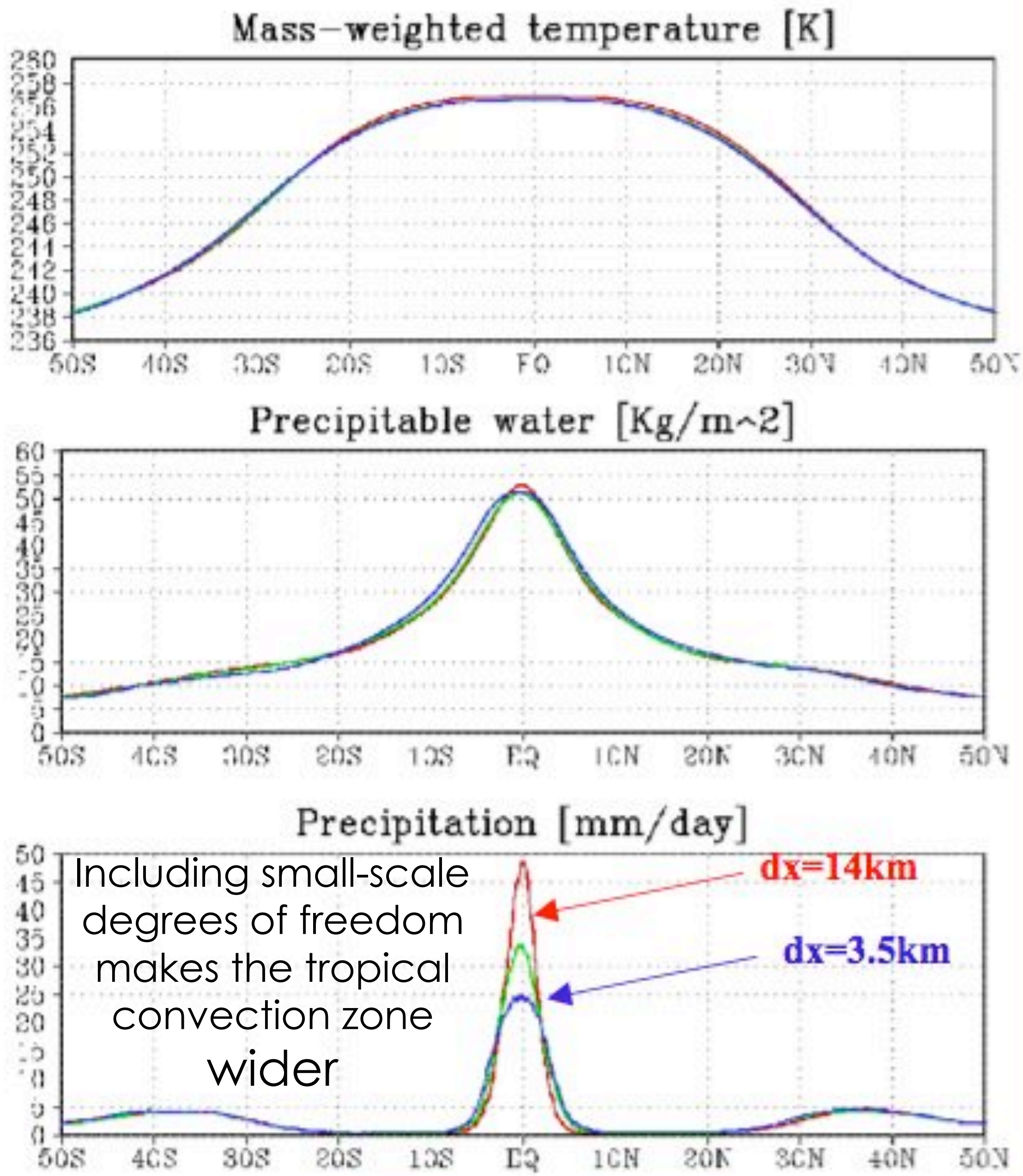
A bad B bad	

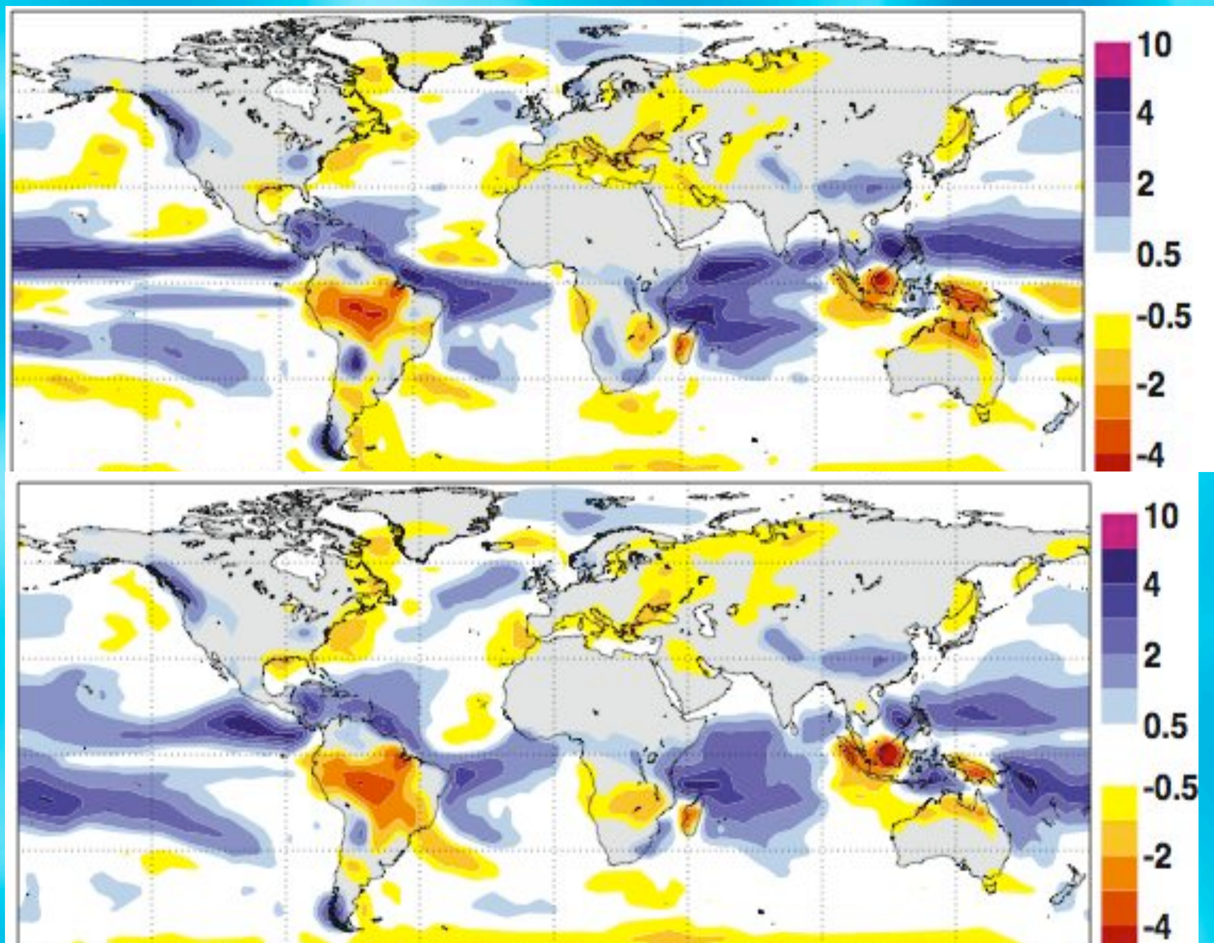
APE: resolution dependency of precipitation



Tomita et al. (2005,GRL)

- Temperature, precipitable water: converged
- The maximum precipitation decreases as dx decreeases from 14km to 3.5km

Including small-scale degrees of freedom makes tropical convergence zone wider



ECMWF model

with stochastic backscatter scheme (Berner and Palmer, pers. comm.)

fine scales: just add noise ?

What's "good enough" for large-scale "predictability" interpretations (A good / B good)?

- *A is good* cuz 3.5km global is best yet
- B's mean flow should be similar
- Variance & spectrum of B's large-scale fluctuations should be like A's
- Diff growth after 7 -> 3.5 doubling should be similar to that after 14 -> 7
- Diff growth in 2 realizations of 14 -> 7 pairs should be similar

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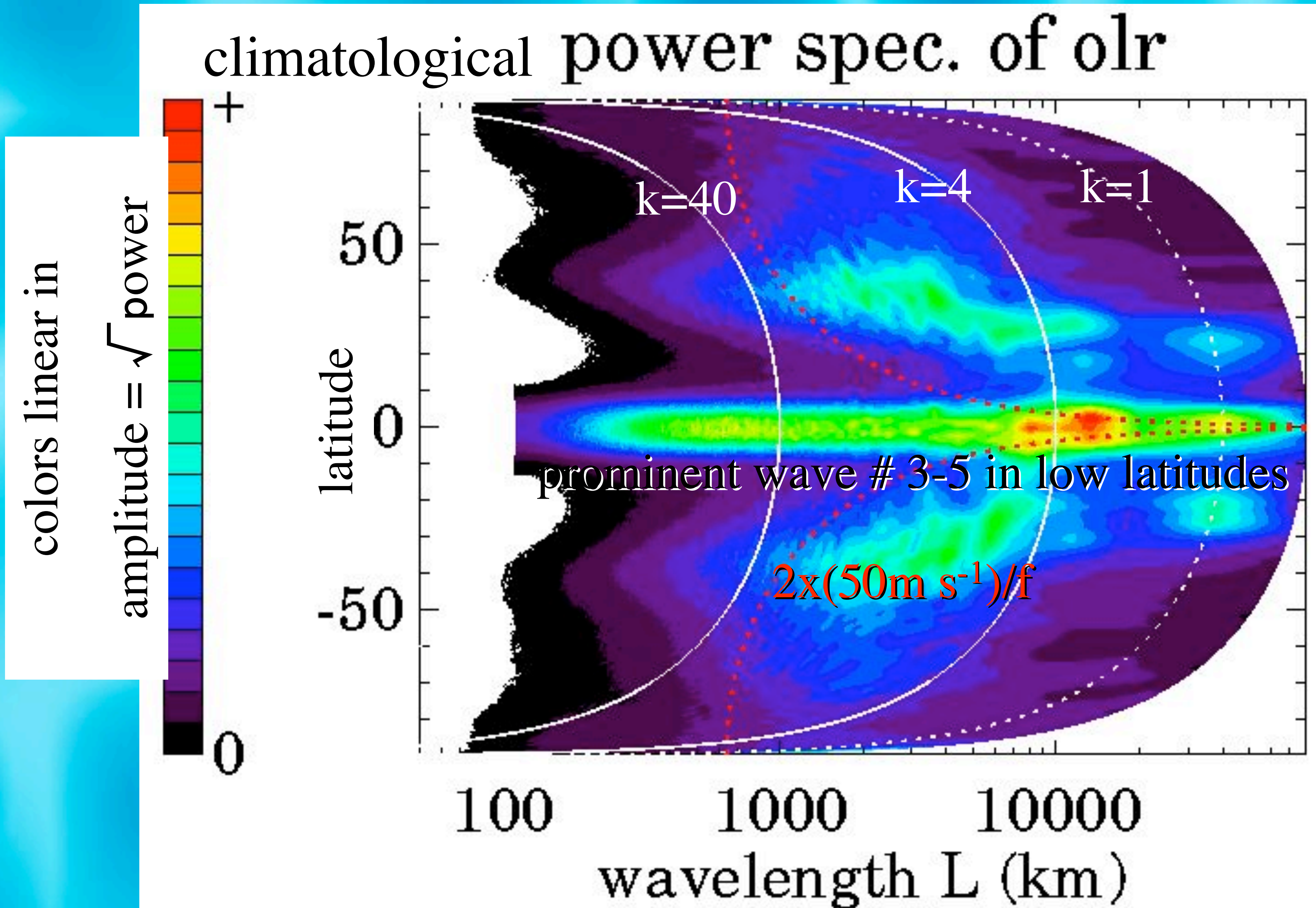
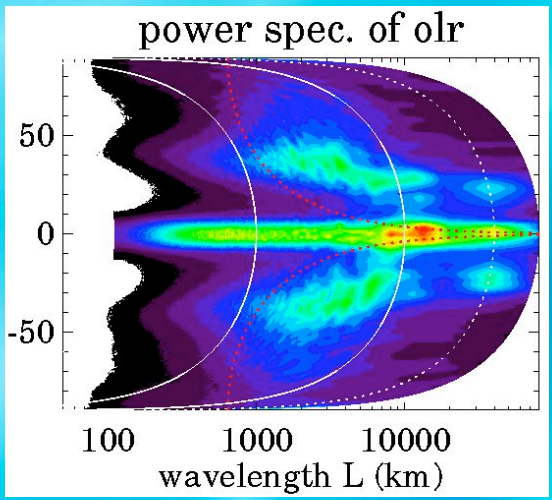
A diagnostic space



Calculus of difference growth

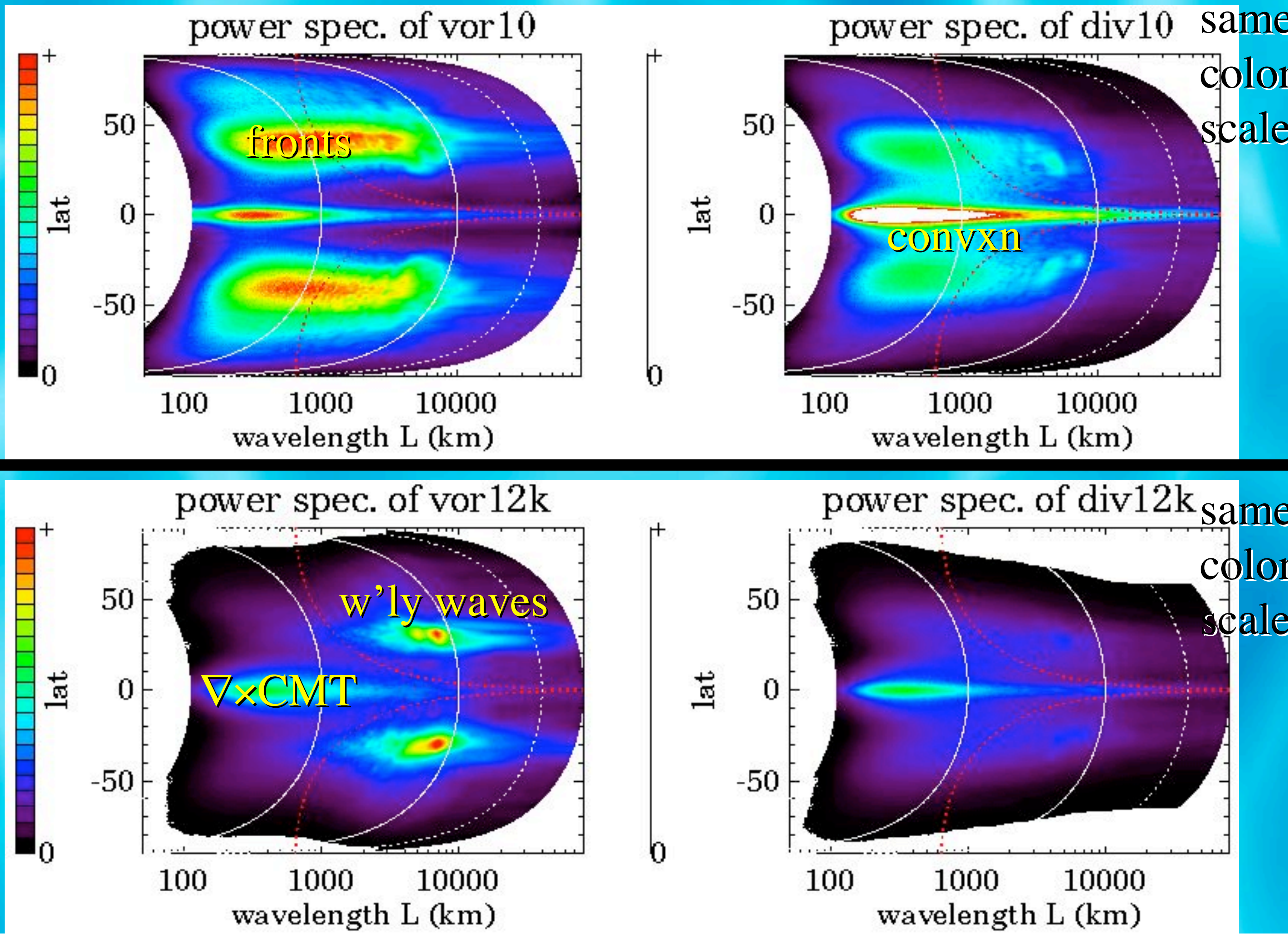
- **Initial** difference field is very small
  - just interpolation error
- **Expectation of squared difference** grows with time to become

2x this pattern as differences saturate (statistically)

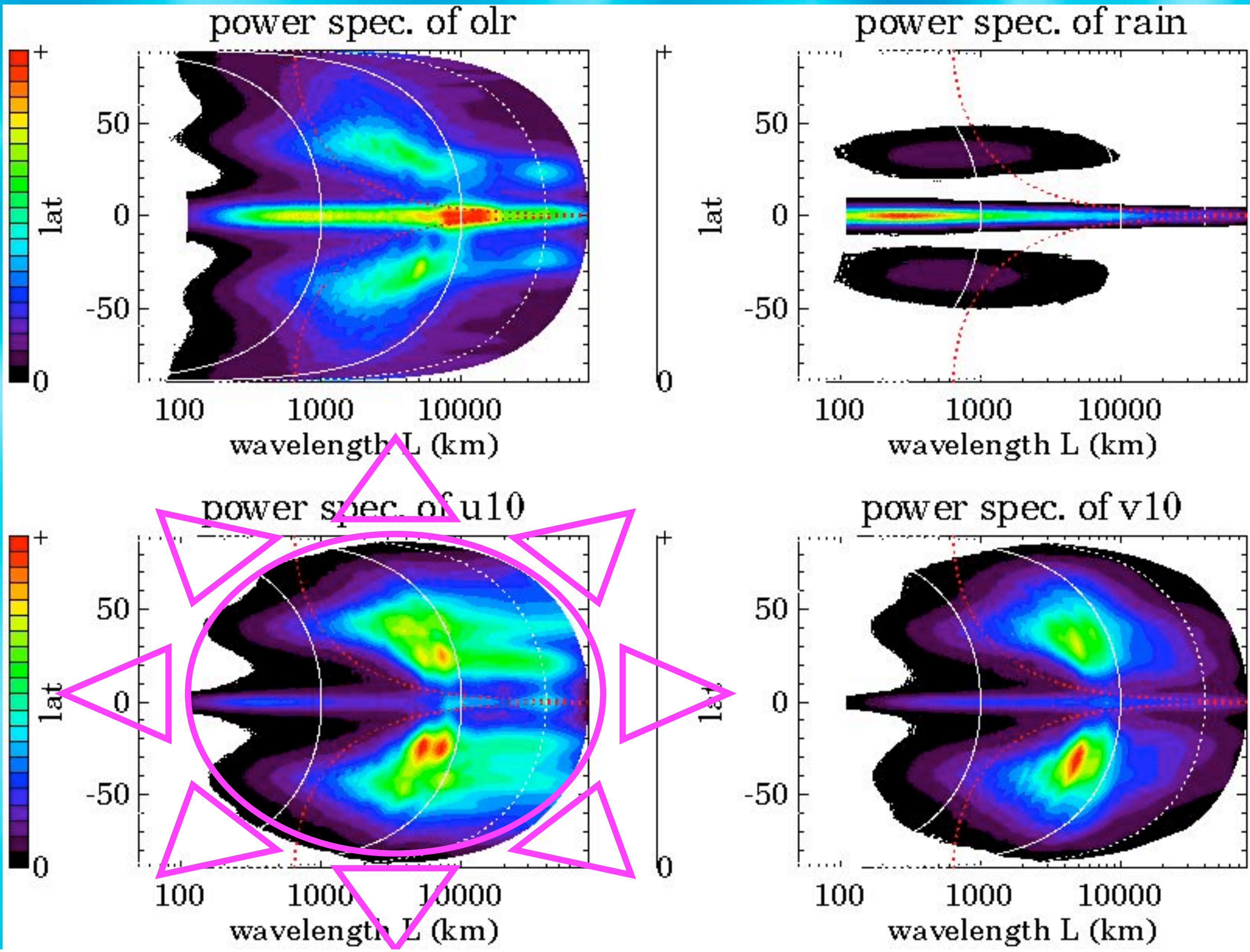


(all runs have similar clim. variance pattern)

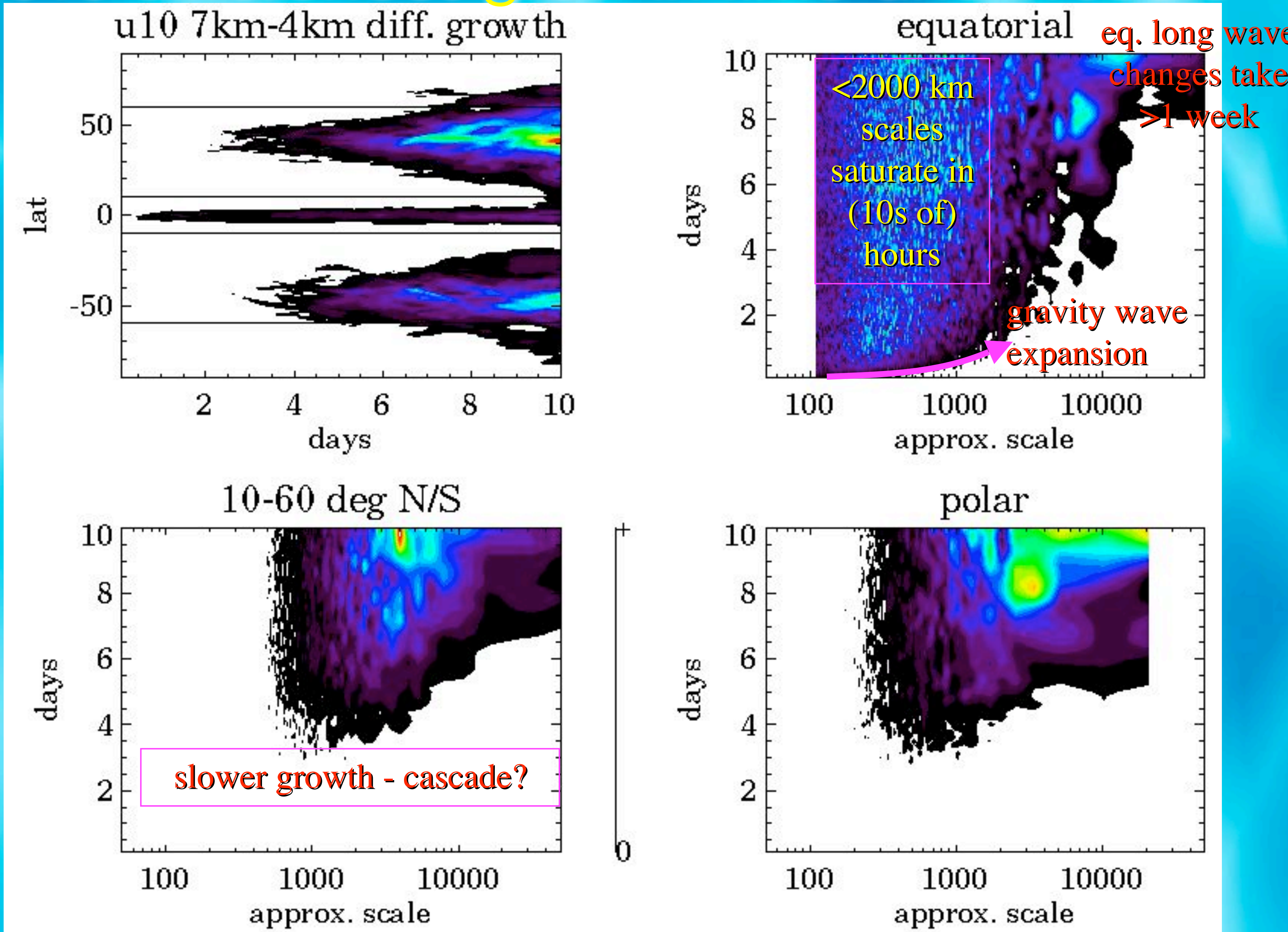
different fields, different variances



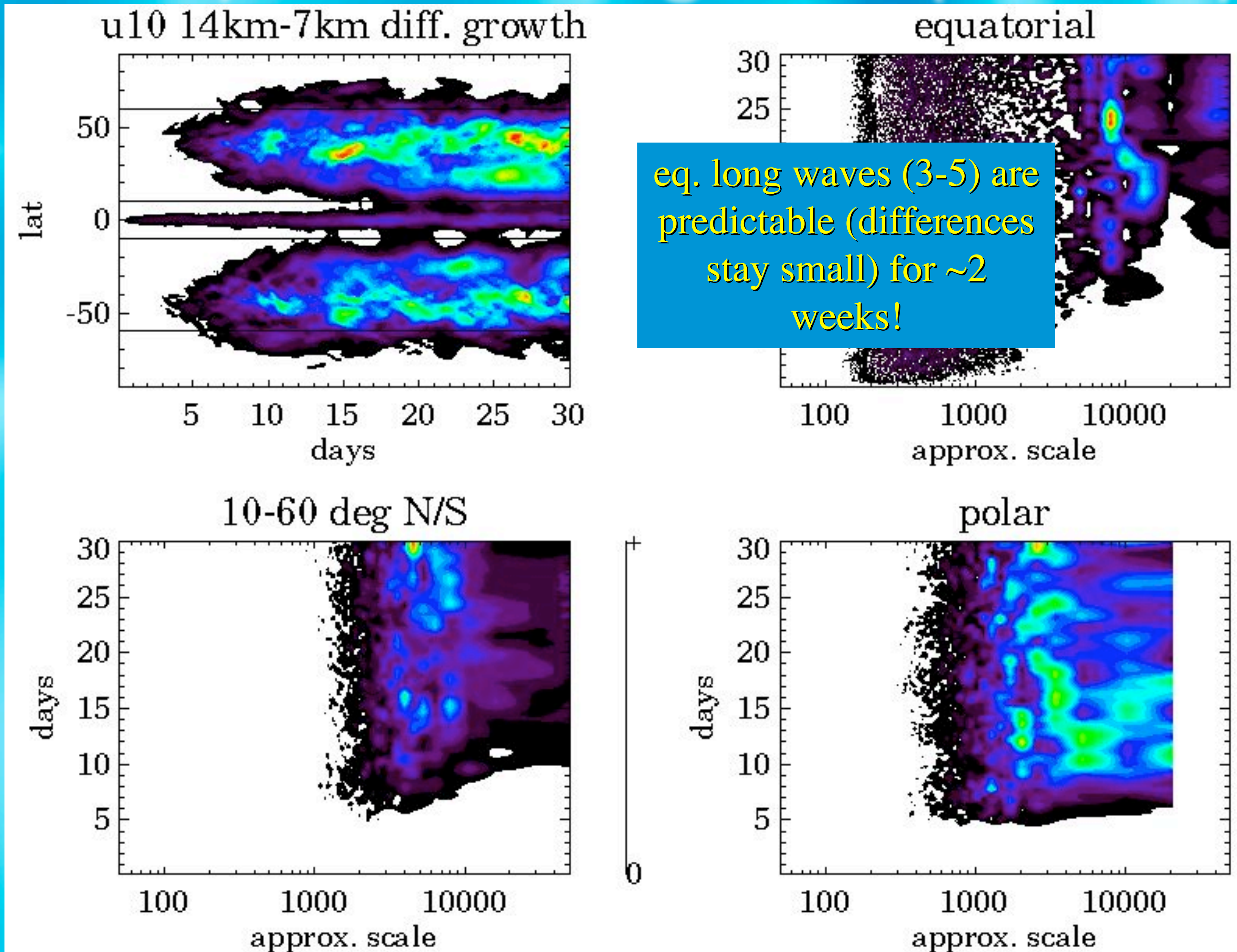
Clim. power spectra for other variables



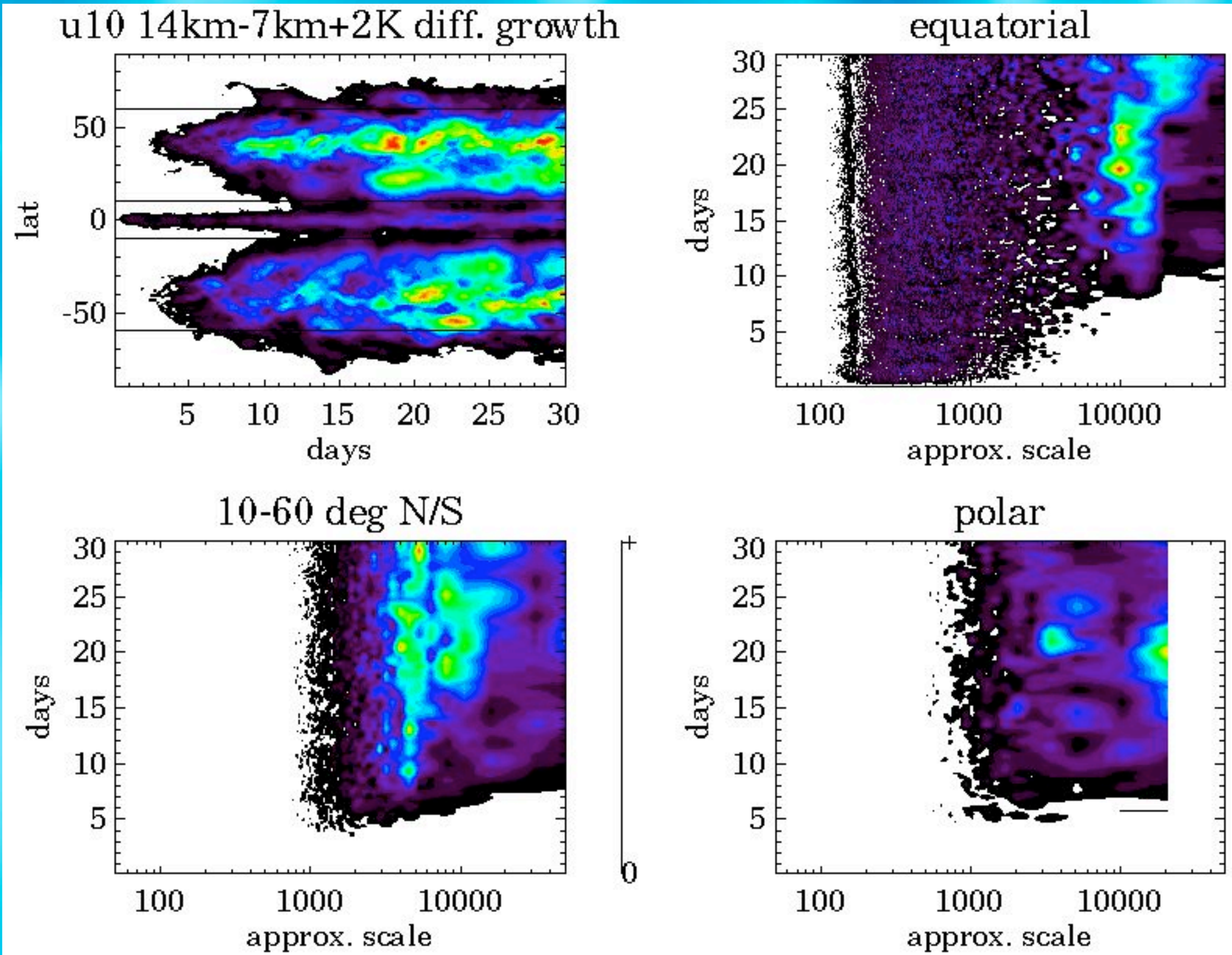
u10 differences grow in time and in scale



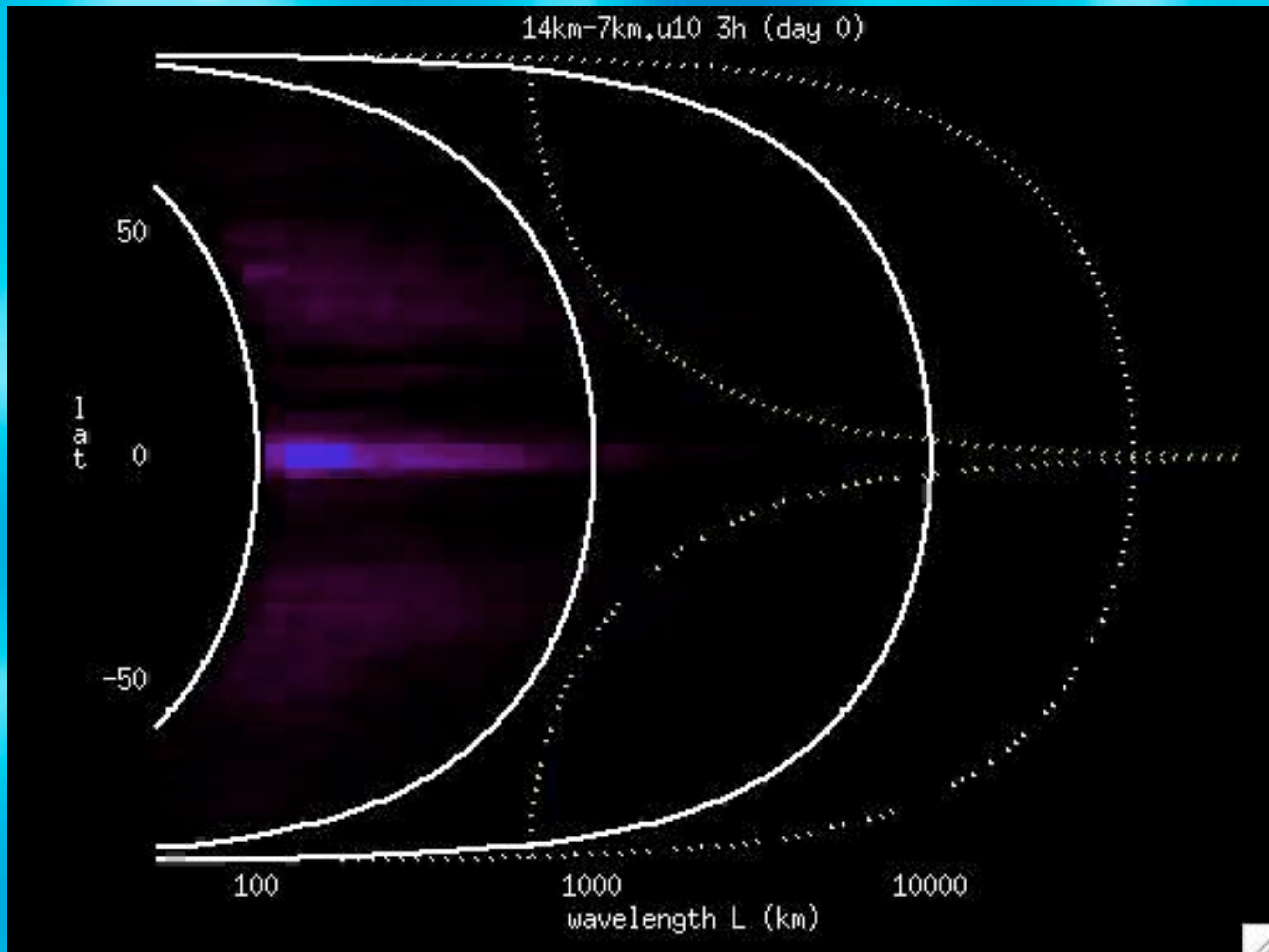
30 days of u10 diff growth (14-7 km)

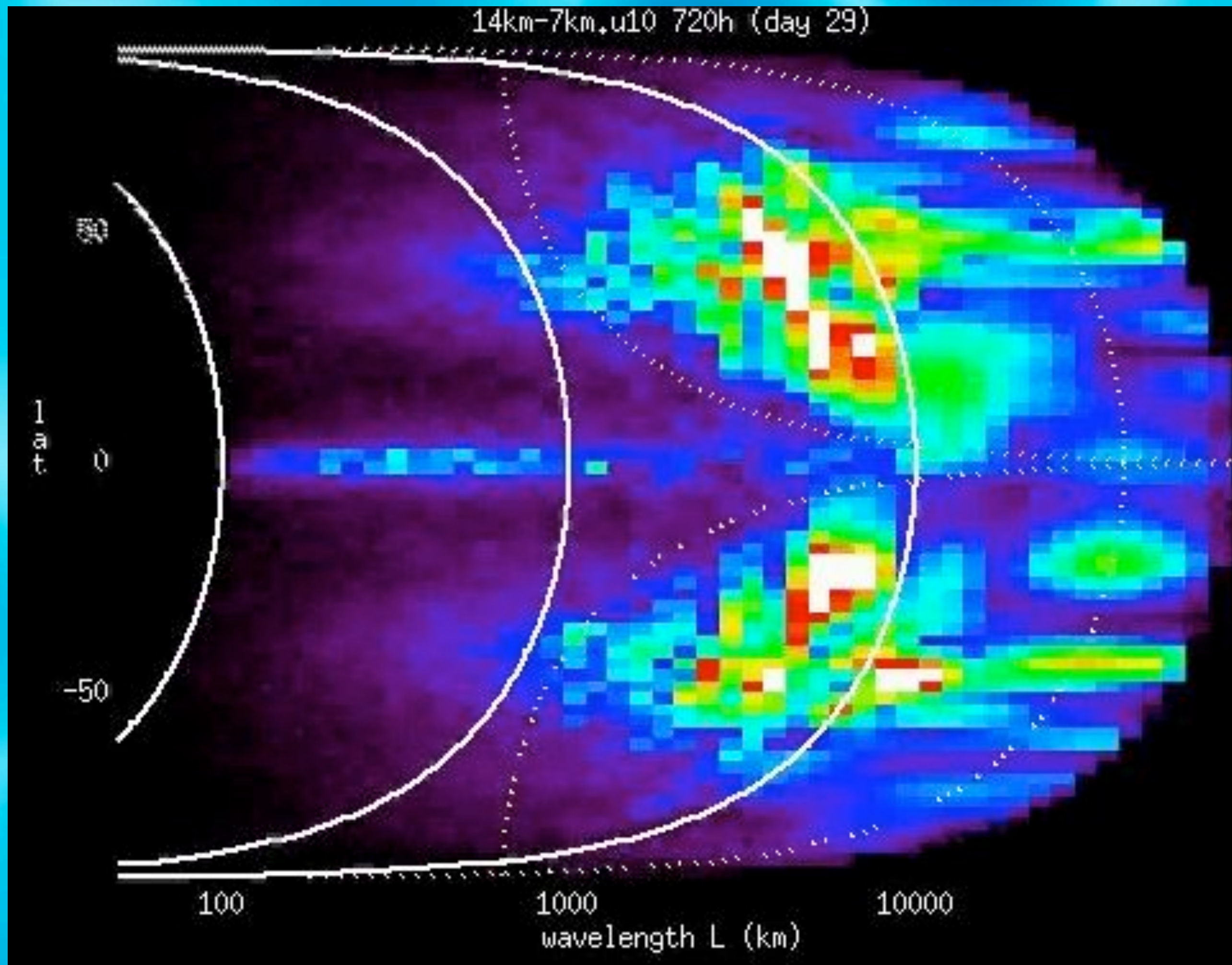


An independent 30d sample (+2K run pair)

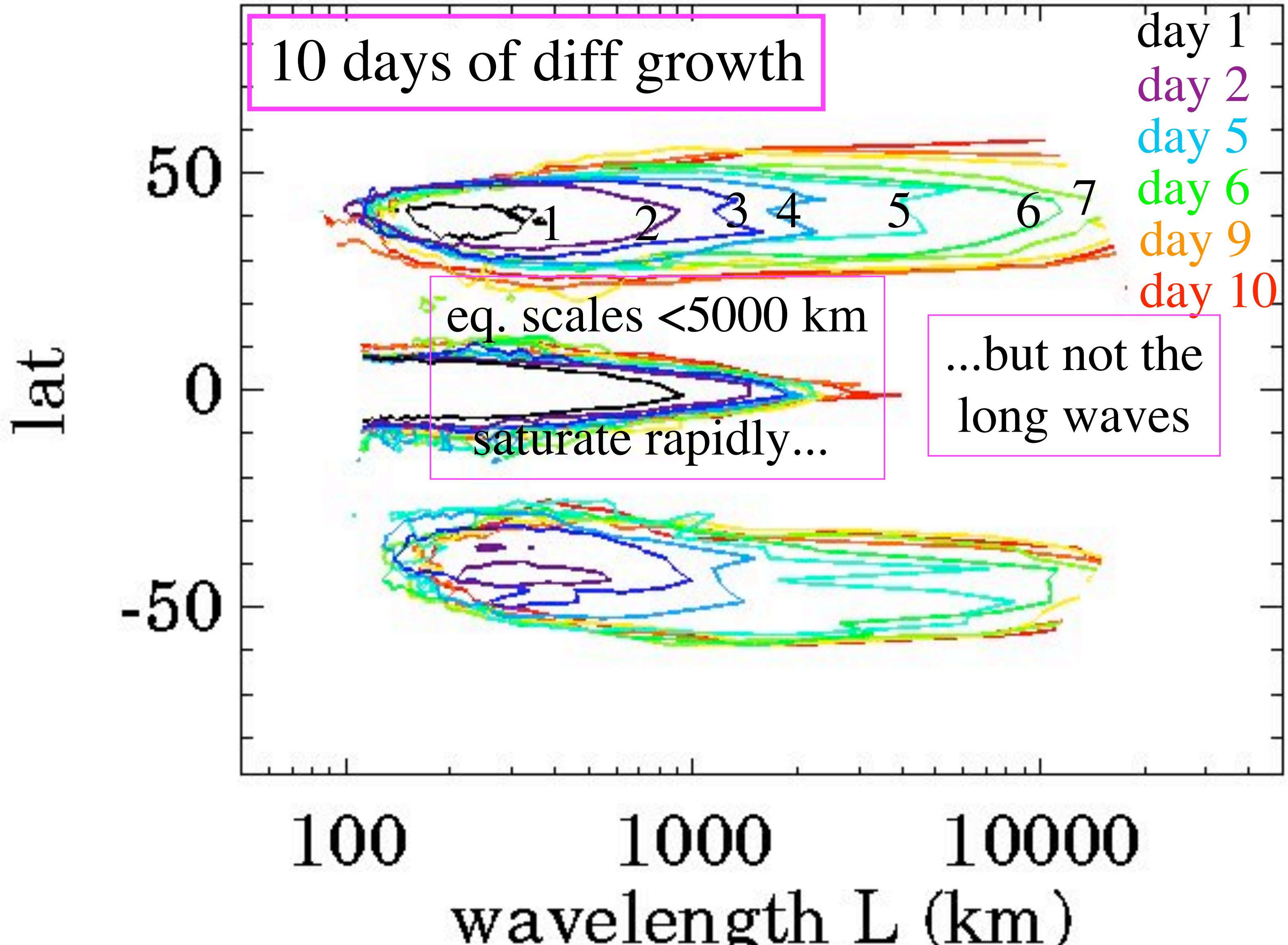


u10 differences power growth animation

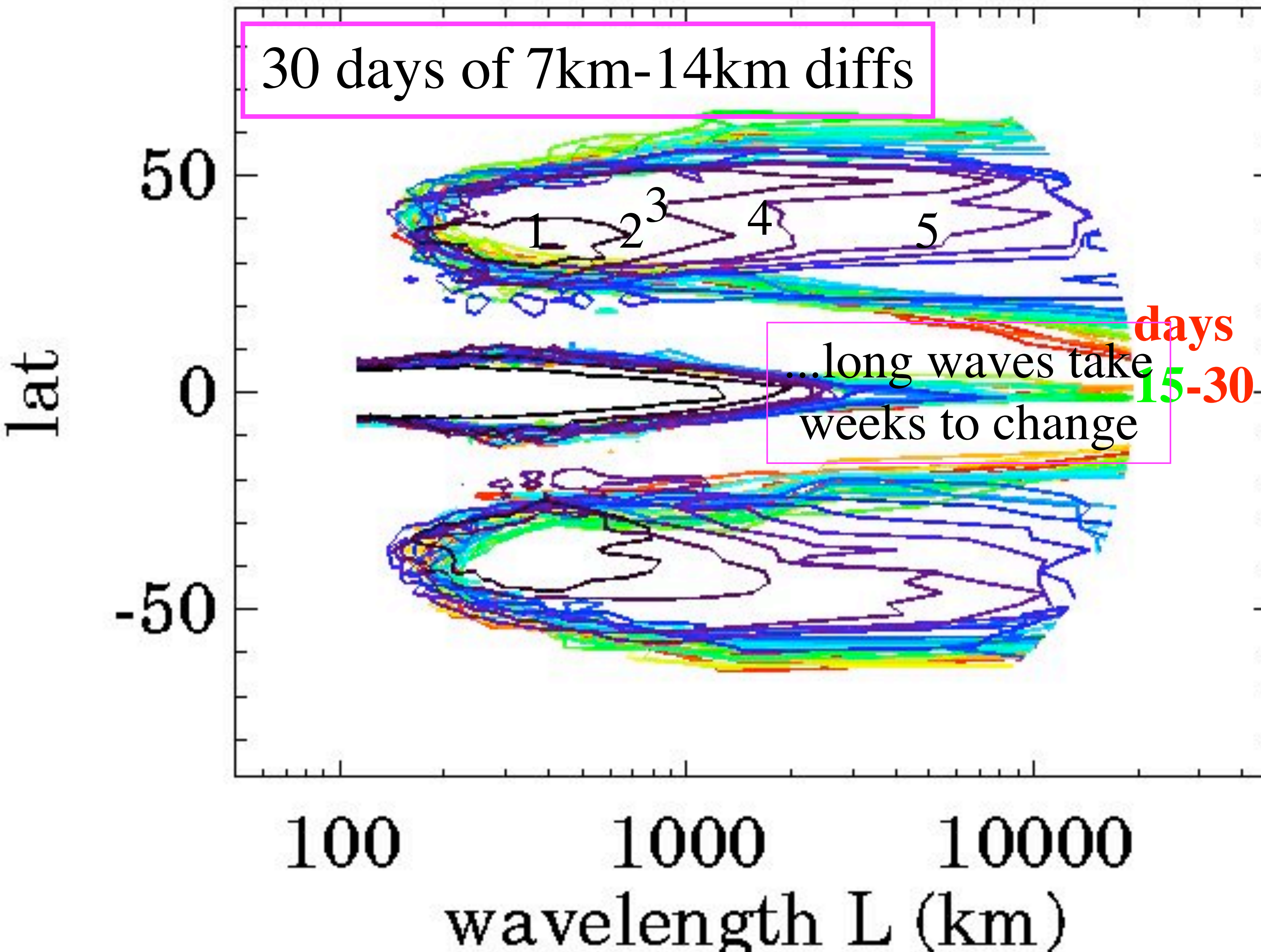



14km-7km,u10 720h (day 29)
50
lat
0
-50
100
1000
10000
wavelength L (km)

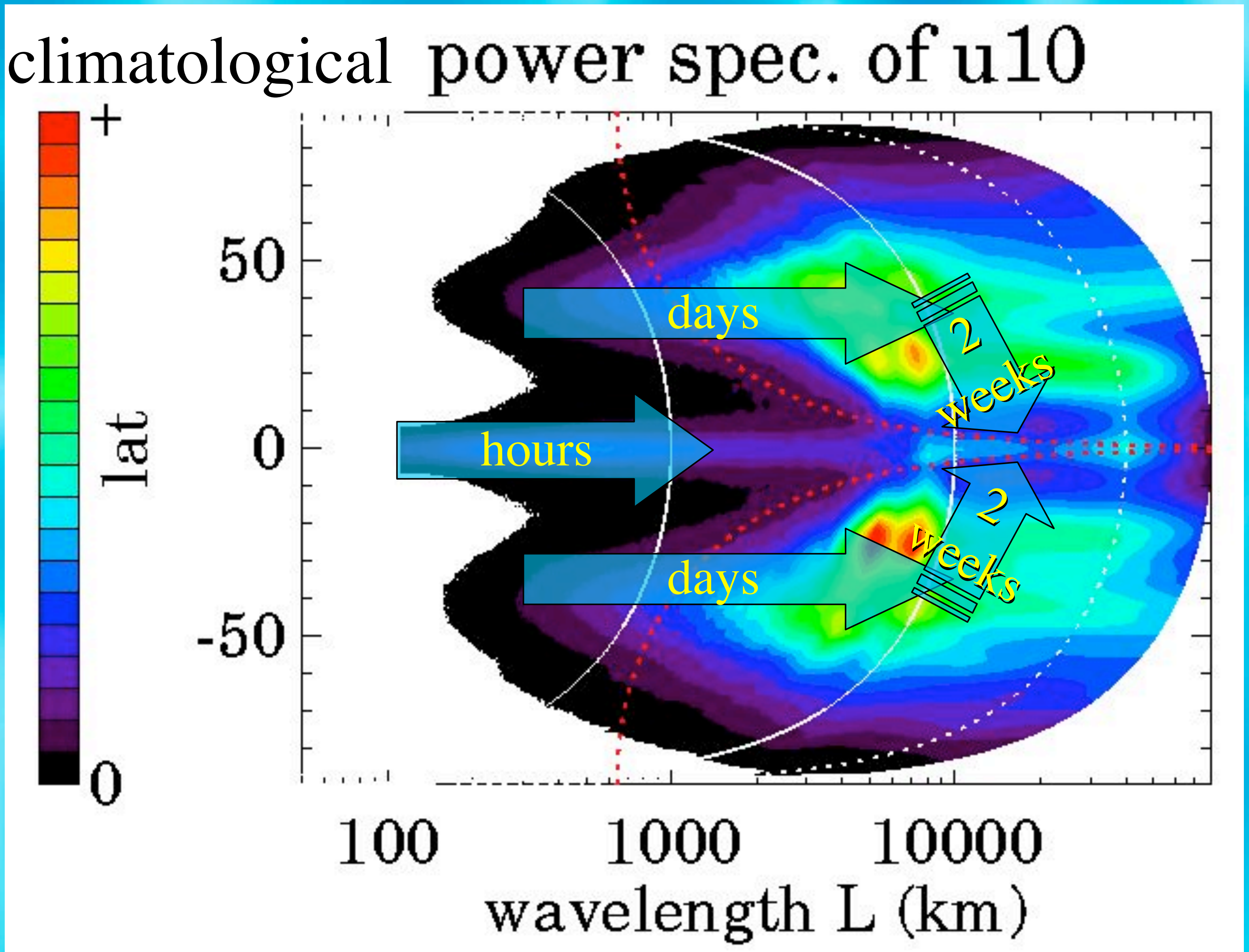
u10 diff growth isochrones



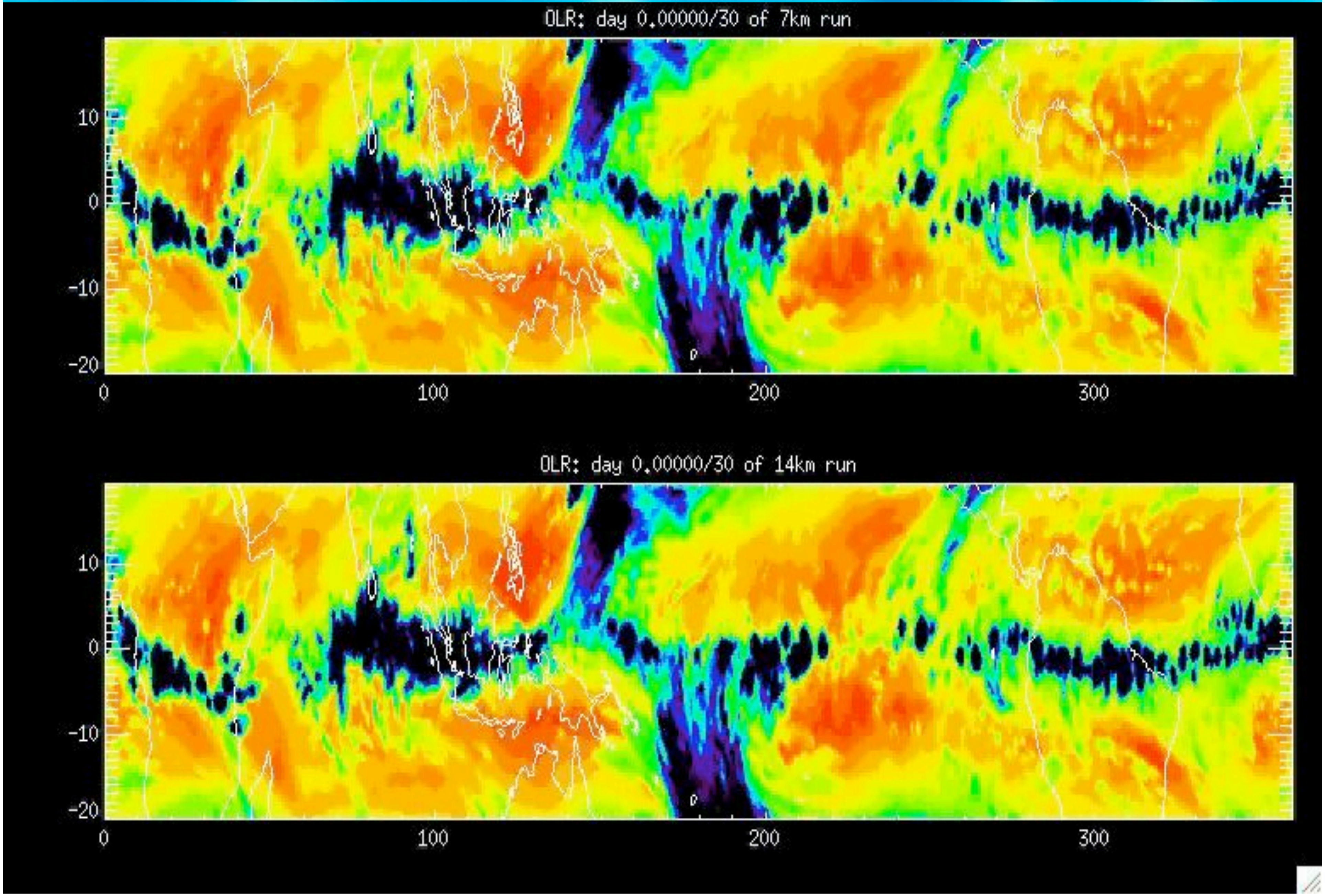
u10 diff growth isochrones



schematic of "error" growth



OLR animation

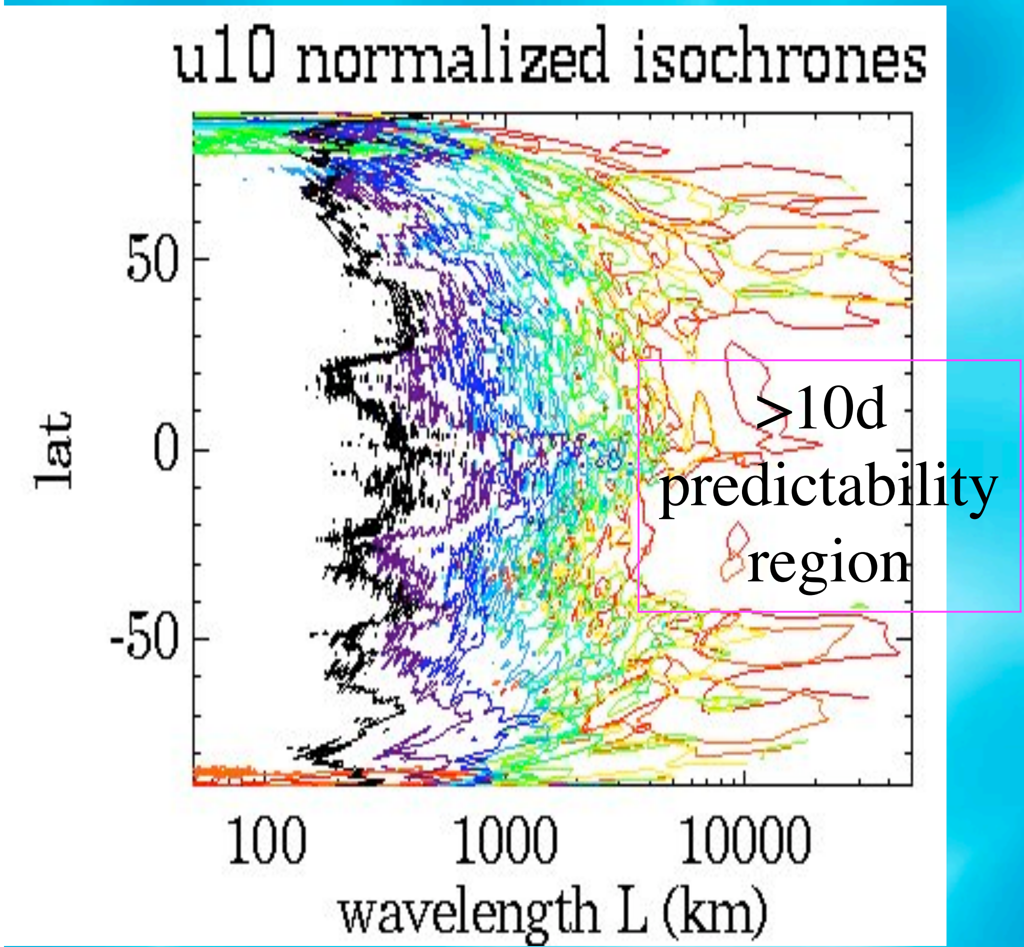


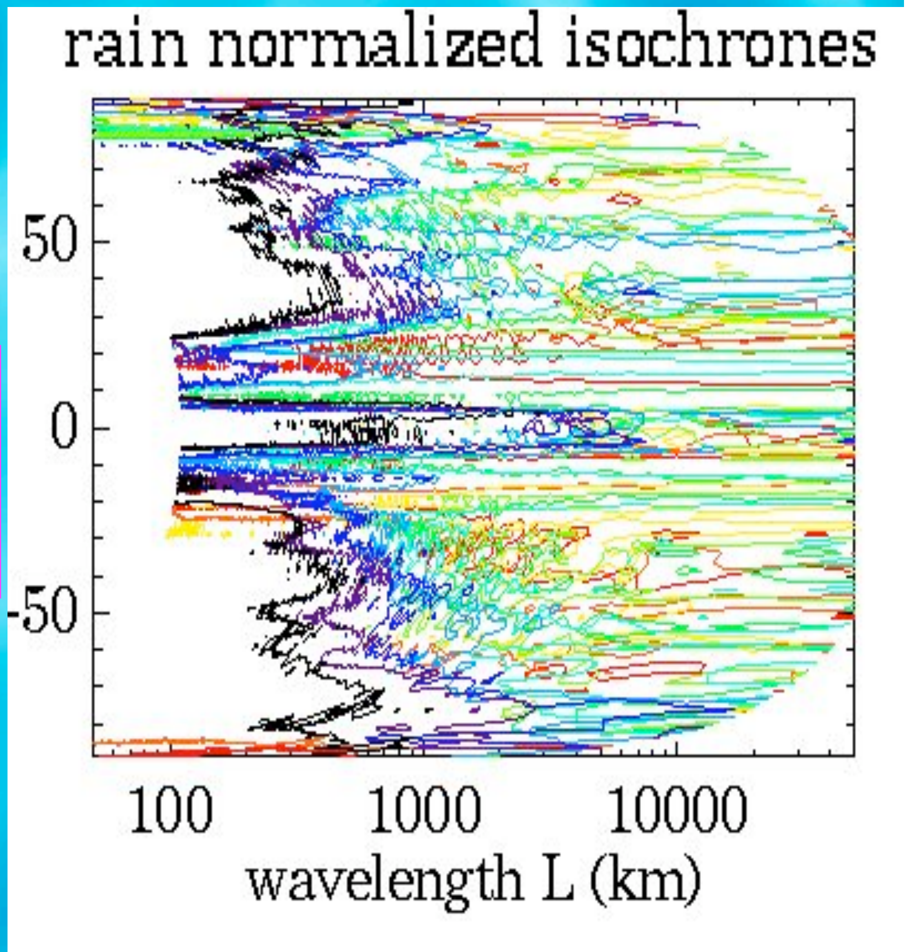
Summary

In this model:

- Convective details diverge quickly
  - hours to a day or two
  - triggers midlatitude geostrophic cascade
- Midlatitude diffs grow upscale
  - ~ a week
- Long tropical Kelvin waves exhibit up to 2 *weeks* of predictability
  - immune to upscale diff. growth in tropics
  - limited more by extratropical interactions

Normalize for background var. structure
(variance of "forecast error")/ (climatological variance)





Nasuno et al. 2007

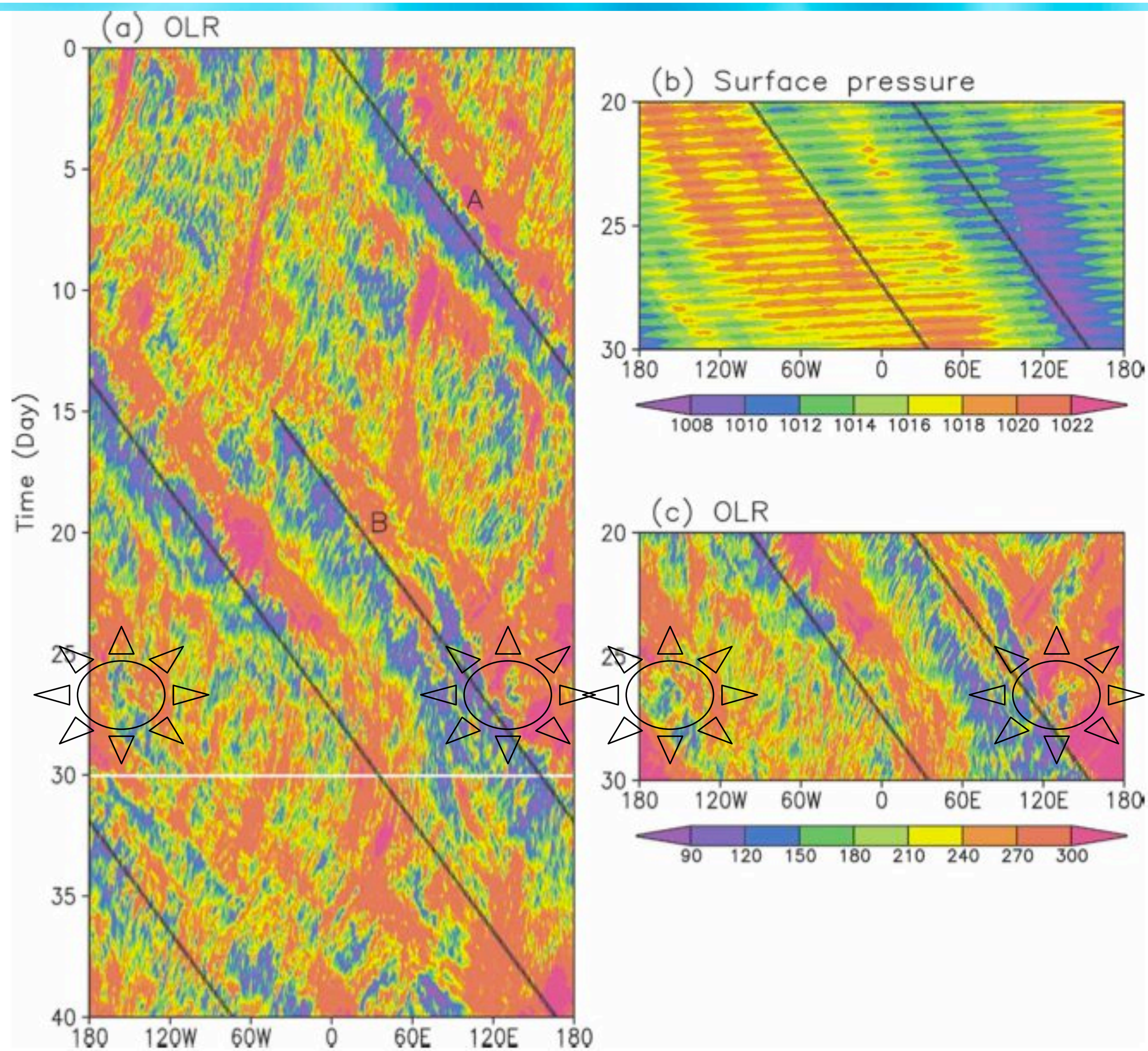
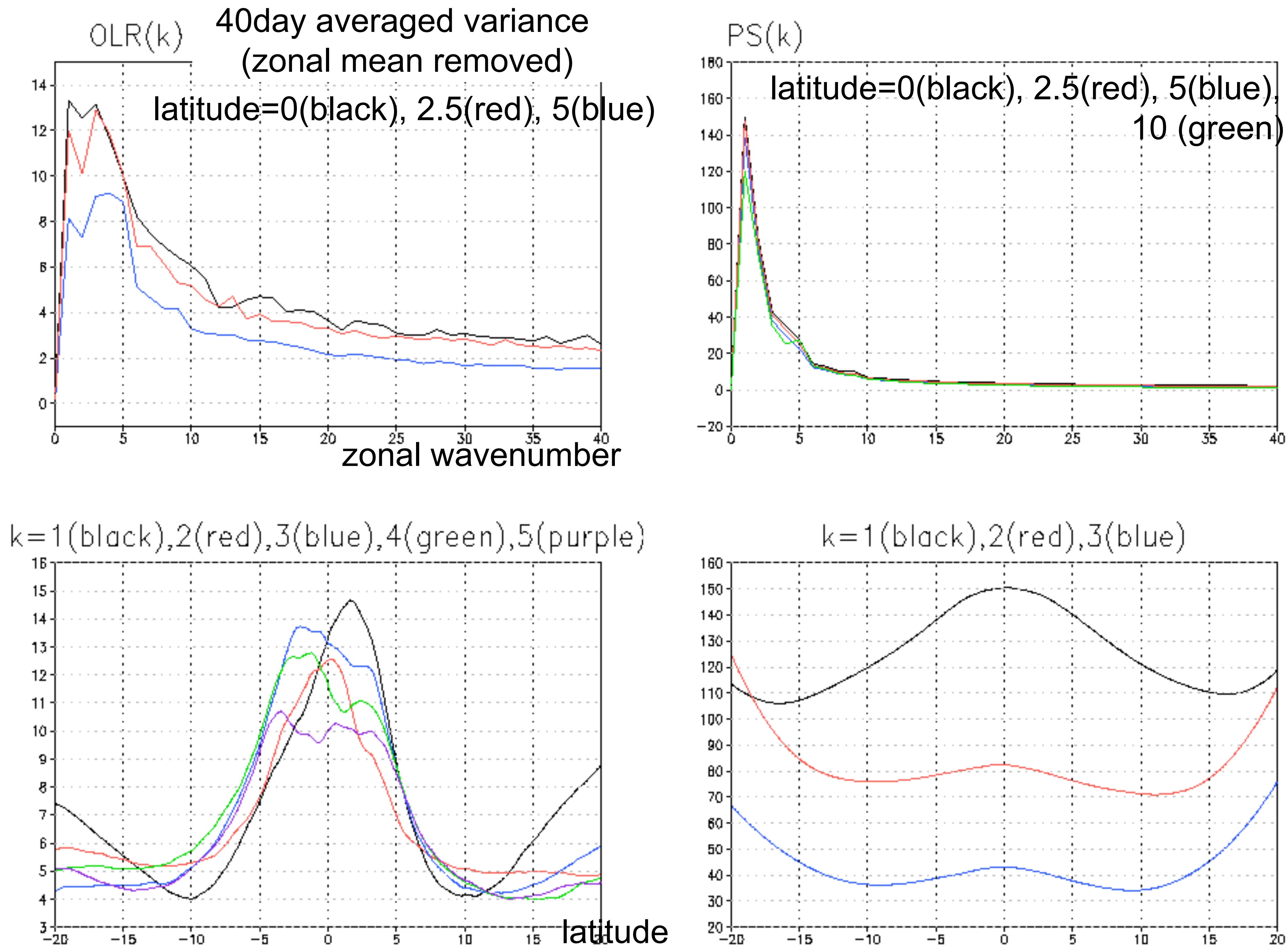


FIG. 3. Hovmöller diagram of (a) OLR (W m^{-2}) in the 7-km run, (b) surface pressure (hPa), and (c) OLR in the 3.5-km mesh run, averaged between 1°N and 1°S. Black lines indicate eastward velocity of 17 m s^{-1}.


40day averaged variance
(zonal mean removed)
latitude=0(black), 2.5(red), 5(blue)
OLR(k)
PS(k)
latitude=0(black), 2.5(red), 5(blue),
10 (green)
zonal wavenumber
k=1(black),2(red),3(blue),4(green),5(purple)
k=1(black),2(red),3(blue)
latitude

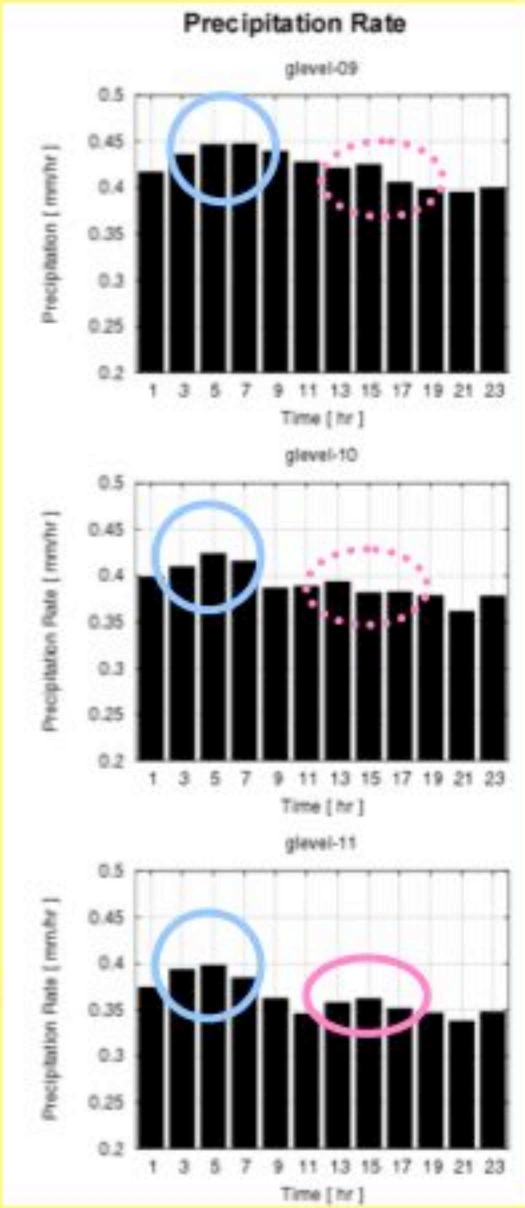
Diurnal cycle

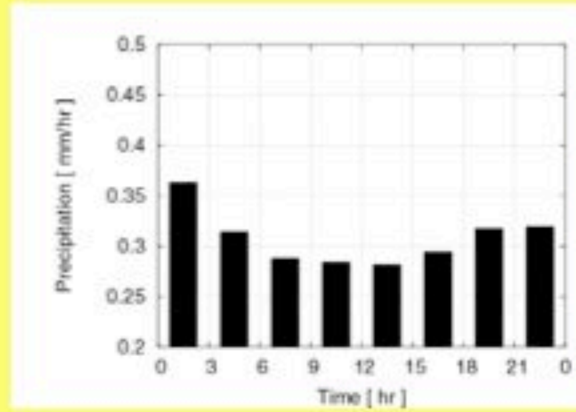
南緯10度～北緯10度

gl-09
(~14km)

gl-10
(~7km)

gl-11
(~3.5km)





CCSR/NIES AGCM (T42)