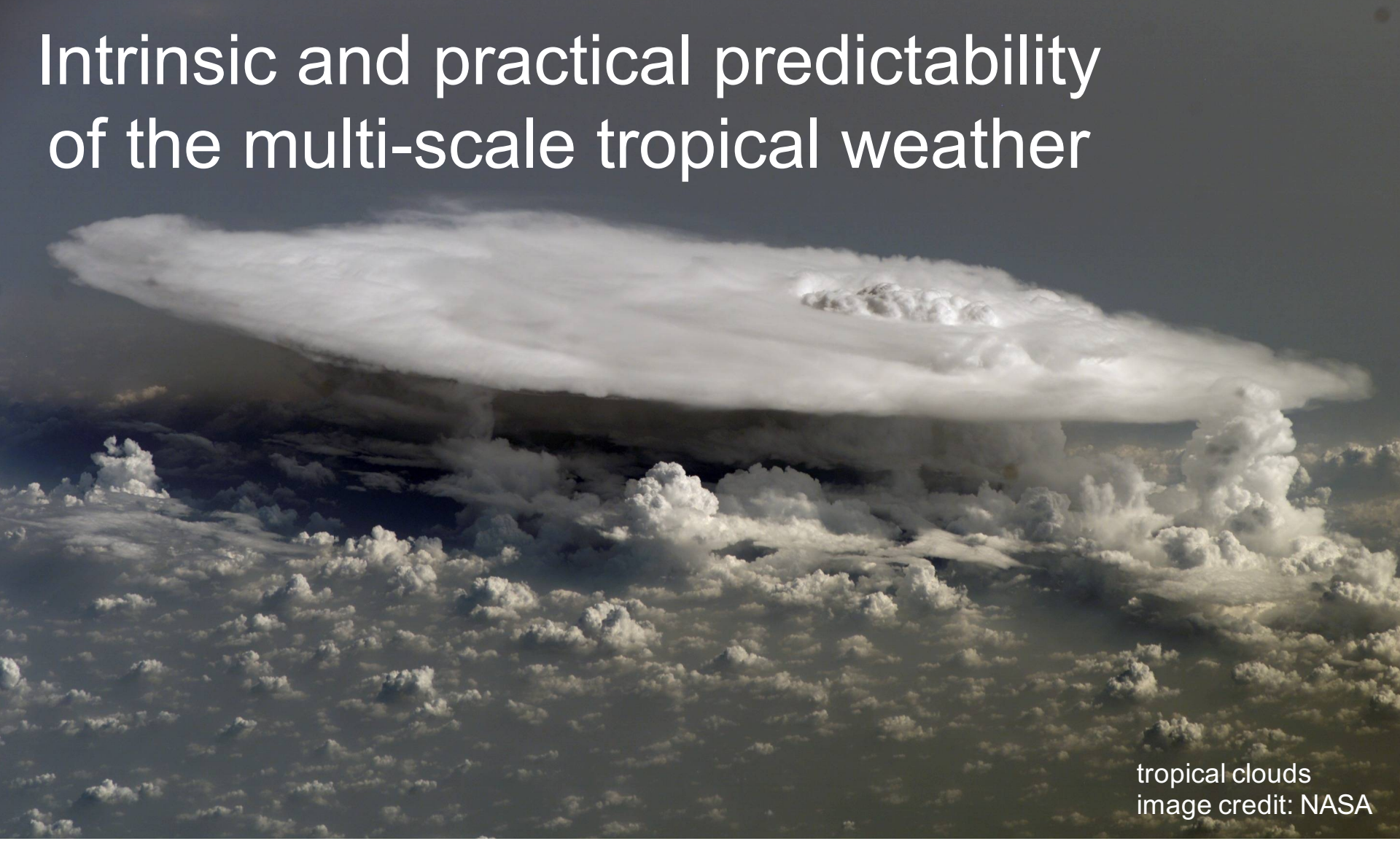
Intrinsic and practical predictability of the multi-scale tropical weather



tropical clouds
image credit: NASA

Yue (Michael) Ying and Fuqing Zhang

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Motivation and background

How predictable is tropical weather?

- Tropical weather is multi-scale: convective clouds, equatorial waves, MJO.

- Moist convective processes are responsible for amplifying small-scale error and intrinsically limit the predictability. (Melhauser and Zhang 2012; Tao and Zhang 2015; Sun and Zhang 2016)

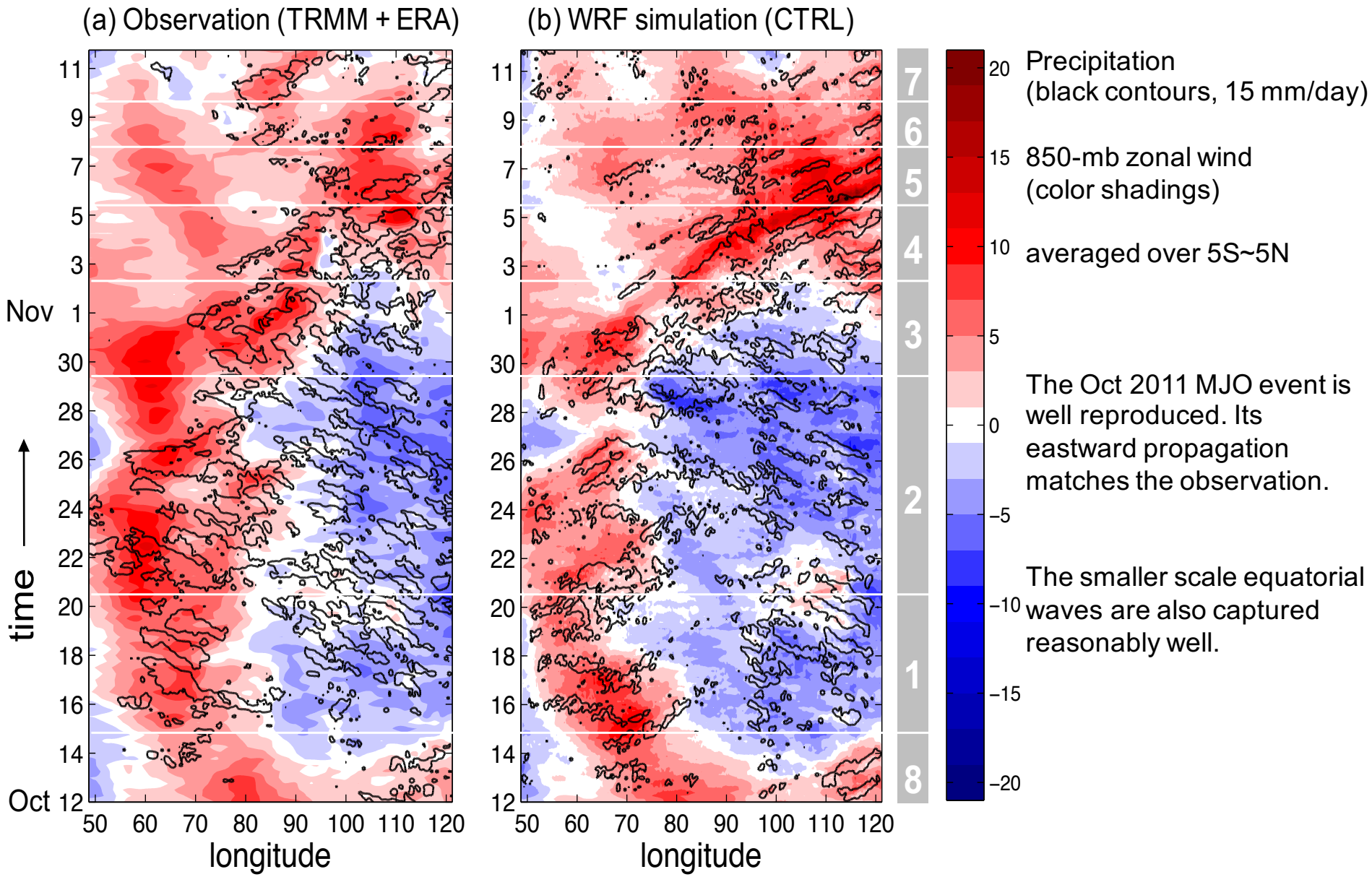
- What is the practical/intrinsic predictability of tropical weather at each scale?

- Using perturbed ensemble simulation, we estimate predictability based on error growth.

Can we predict it well? (ongoing study)

- With the current observing network, model, and data assimilation techniques.

Control simulation using WRF, initialized with ERA-Interim



Precipitation
(black contours, 15 mm/day)

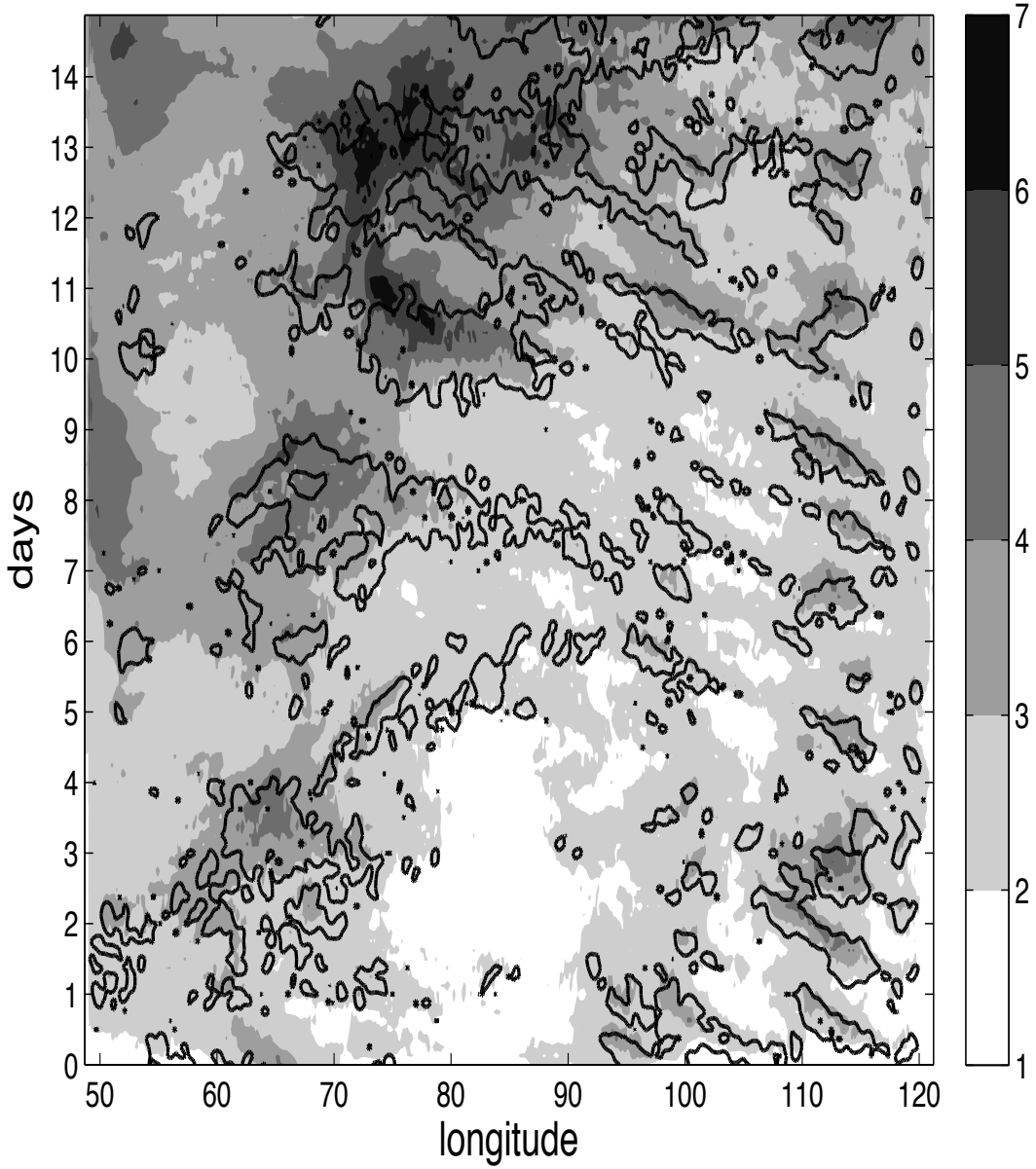
850-mb zonal wind
(color shadings)

averaged over 5S~5N

The Oct 2011 MJO event is well reproduced. Its eastward propagation matches the observation.

The smaller scale equatorial waves are also captured reasonably well.

Perturbed simulation using TIGGE ECMWF 15-day forecast



Precipitation
(black contours, 15 mm/day)

RM-DTE (m/s)
(gray shadings)

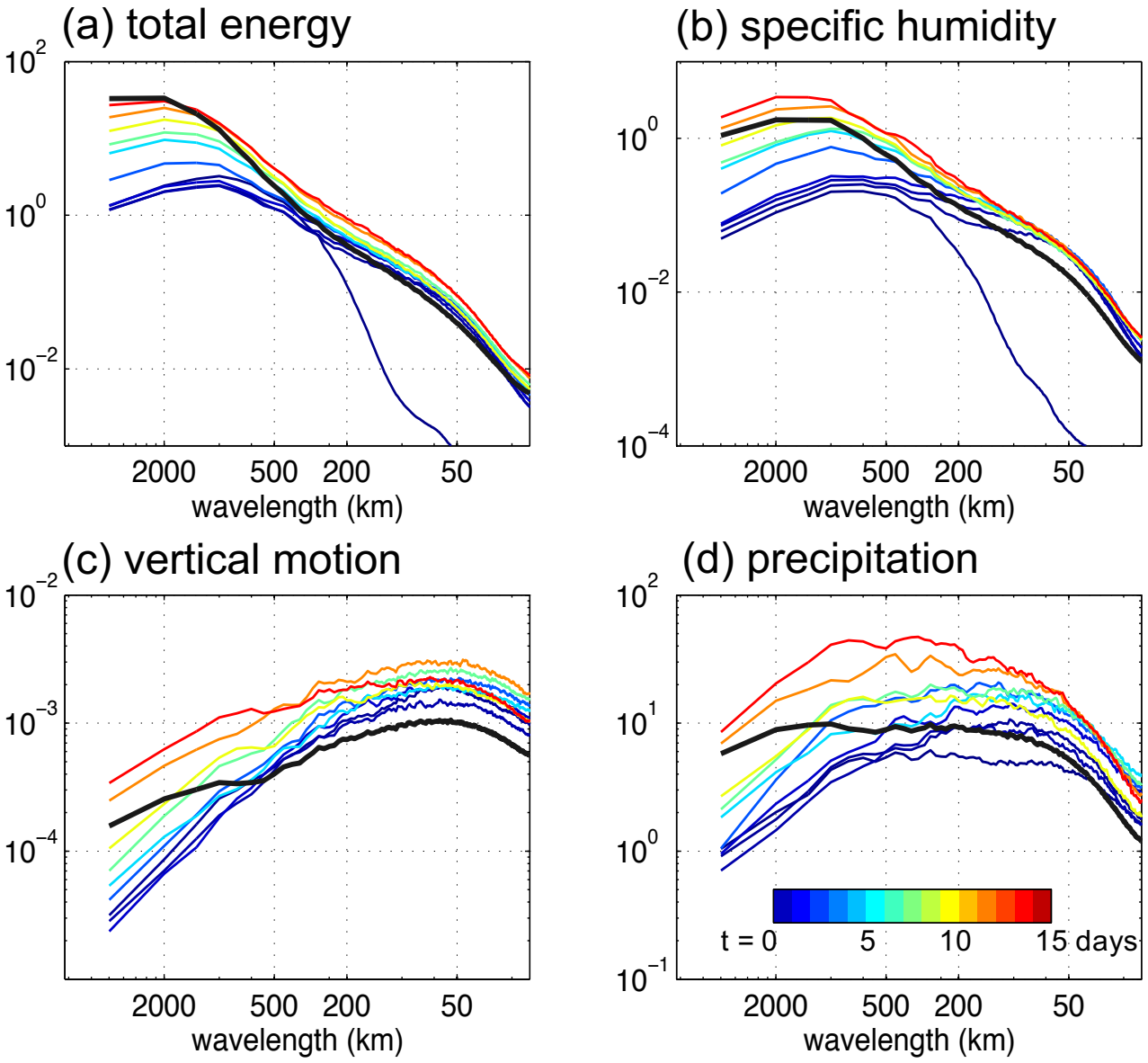
averaged over 5S~5N

The perturbation (error) grows in time.

Error is mostly located near convective events.

At some point, the DTE (error power) is as large as the total energy (reference power), this is when we lose practical predictability.

Spectral power of error and reference state



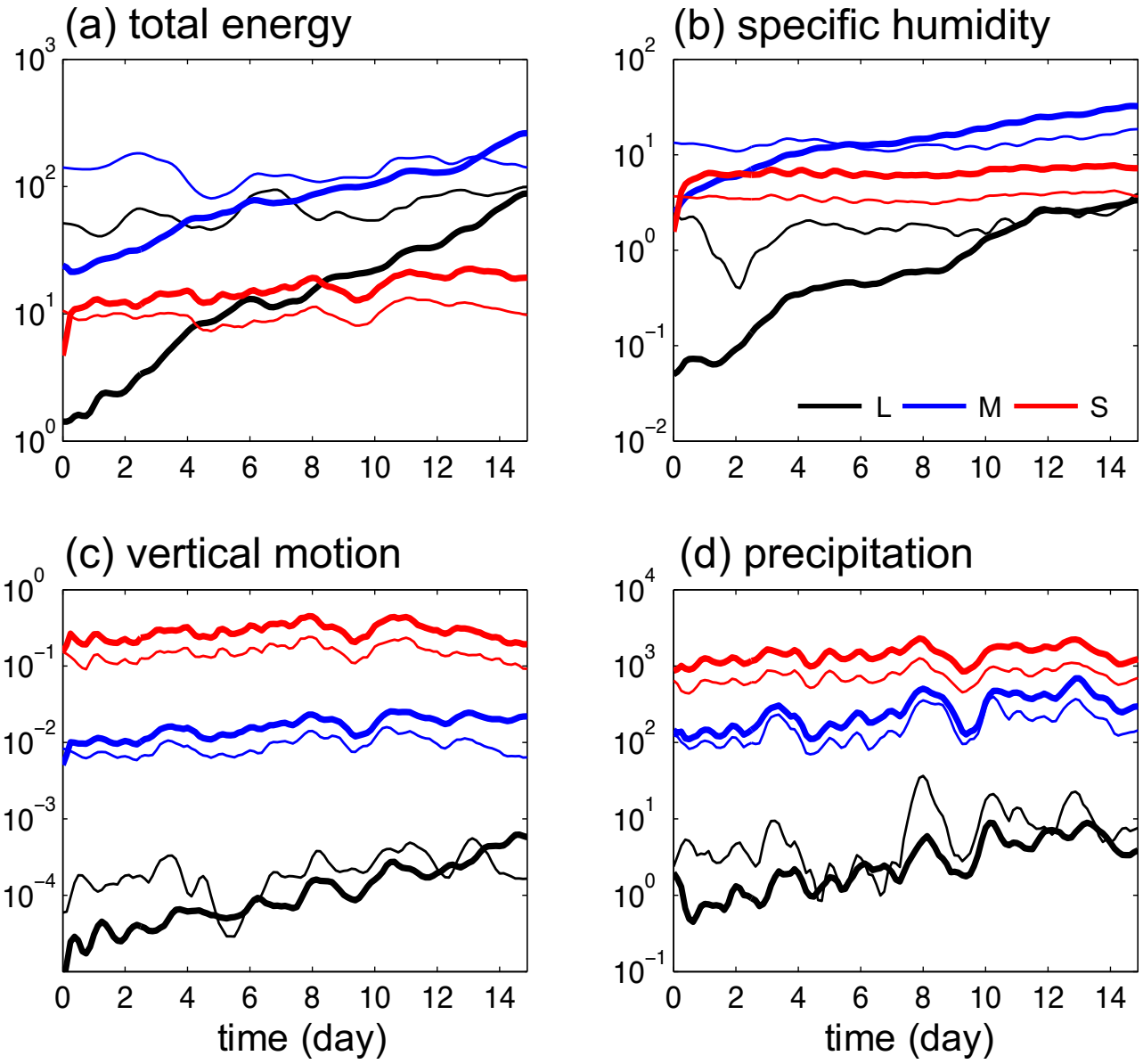
error power (colored lines)
reference power (black lines)

Reference power follows -5/3 slope for TE and humidity, while for w and precipitation, more power is distributed in small scales.

Small-scale error grows fastest, saturates within 1 day.

Large-scale error takes more than 10 days to saturate.

Error growth in time at L, M, S scales



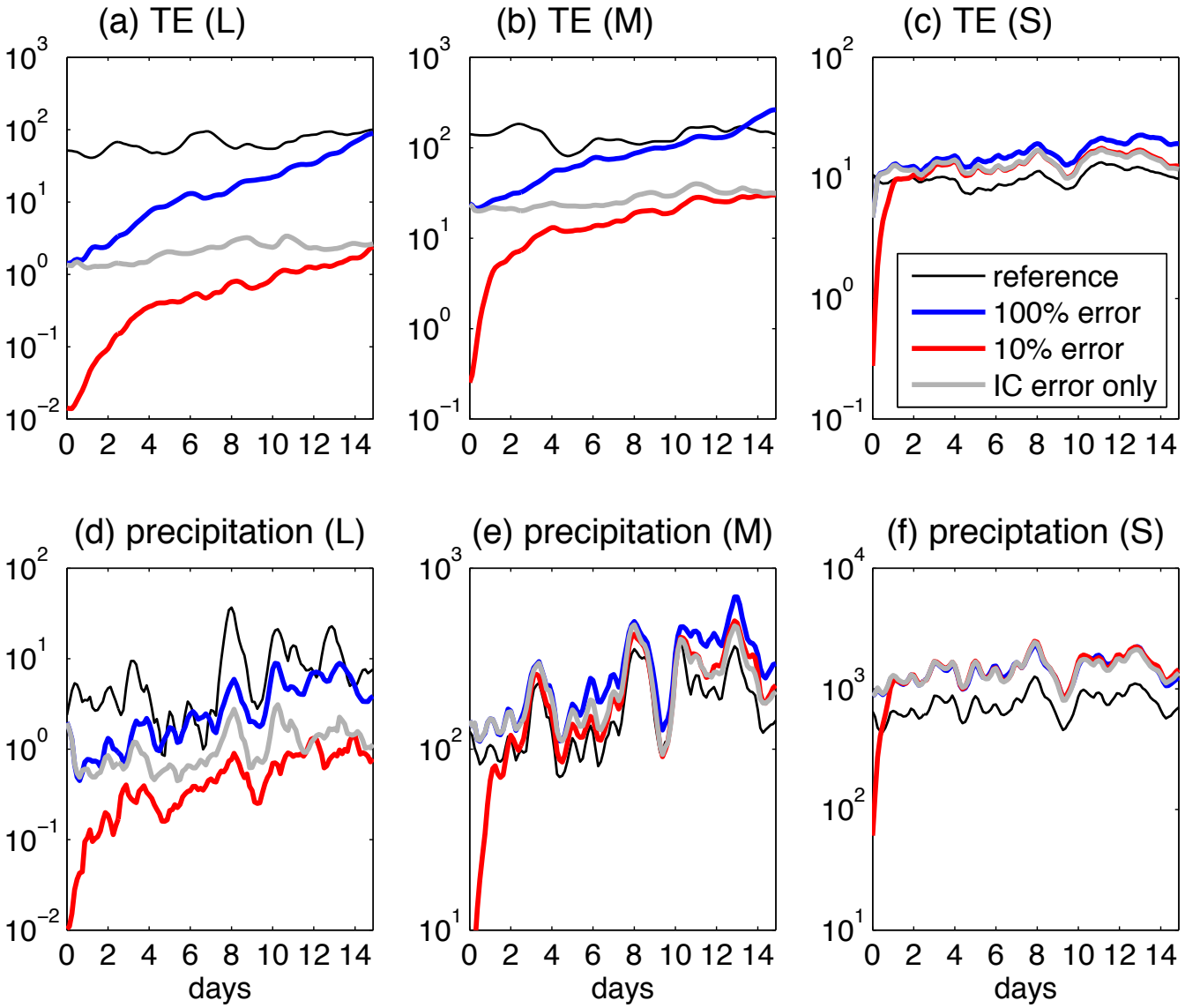
L (> 2000 km)
M (200 ~ 2000 km)
S (< 200 km)

reference power (thin)
error power (thick)

Practical predictability is about
10 days for L scale,
5 days for M scale,
< 1 day for S scale,
for TE and humidity.

For w and precipitation,
< 1 day for M and S scale,
< 5 days for L scale.

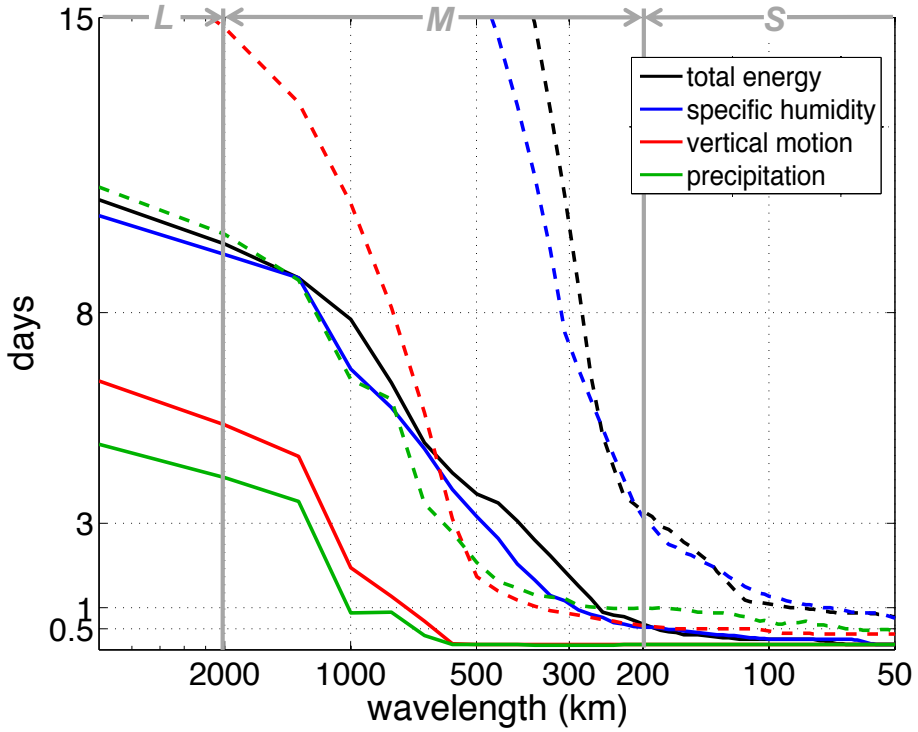
Intrinsic predictability estimated with reduced error

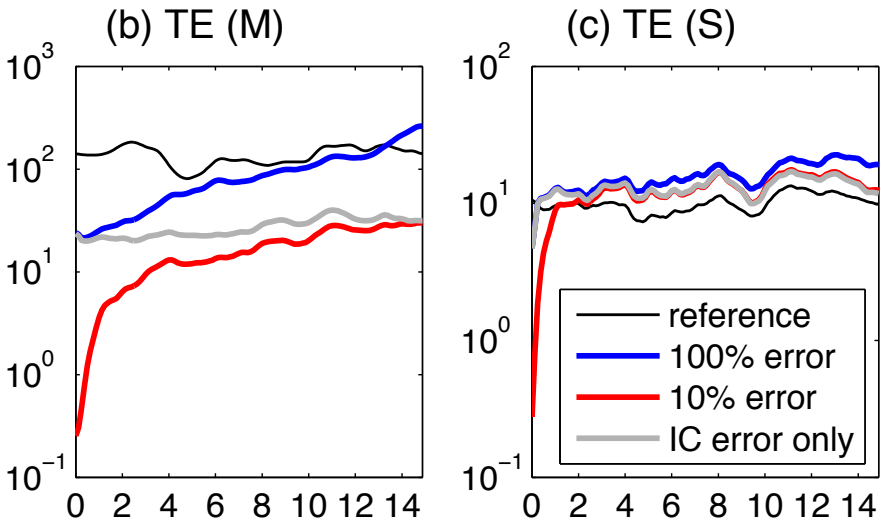


blue: original perturbed runs
red: IC/LBC error reduced to 10%
gray: 100% error only in IC

At large scales, reducing error extends the predictable horizon, but at small scales the extension is limited.

Practical (solid) and intrinsic (dashed) predictability limits





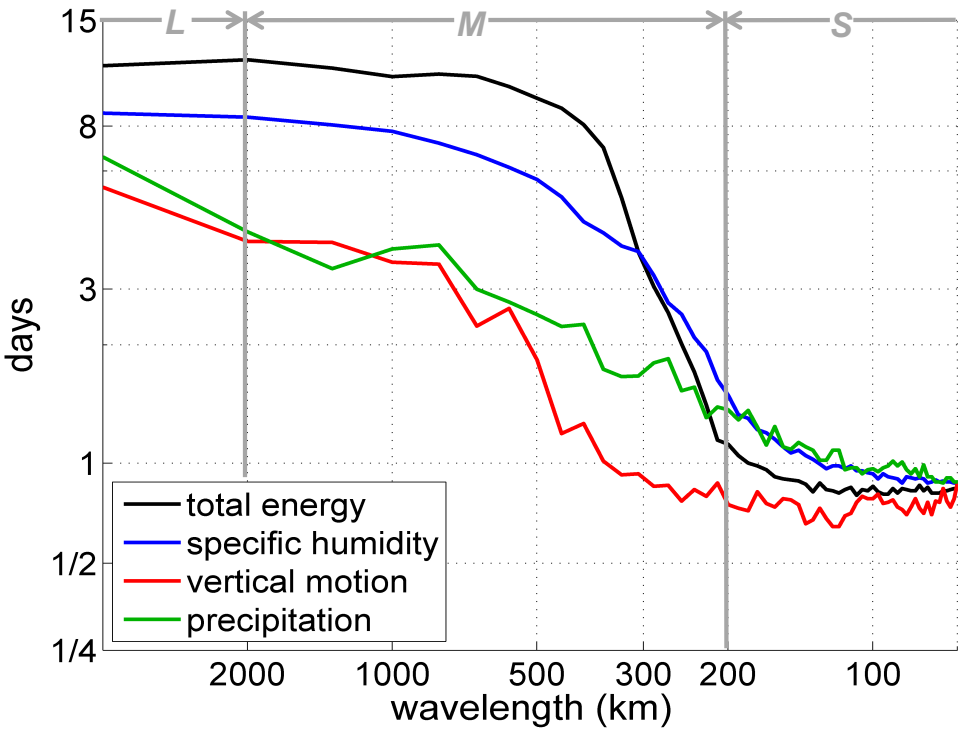
Practical predictability limit:
The time it takes 100% error to reach reference power

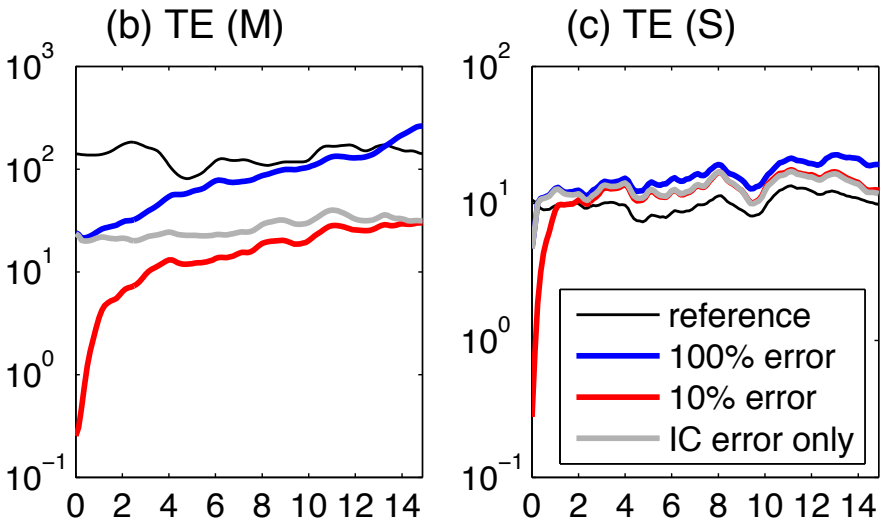
Intrinsic predictability limit:
The time it takes 10% error to reach reference power

At M scale, the practical predictability limit transitions from very short (at S) to very long (at L).

At L scale, the intrinsic predictability limit is much longer than practical limit. But at S scale, they are comparable.

Error growth time scale, transition at ~300 km



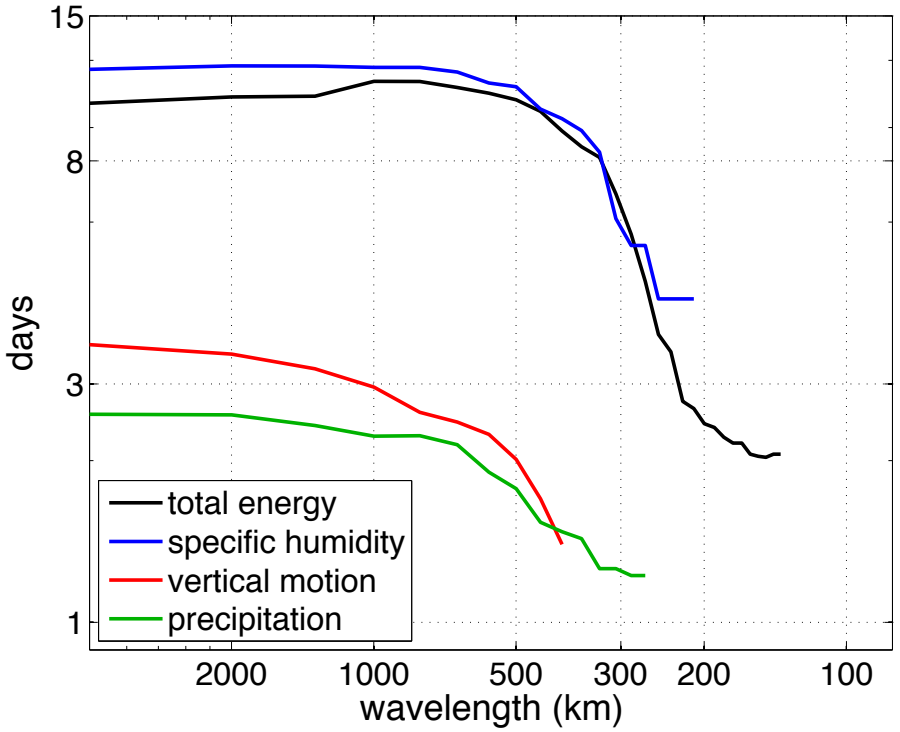


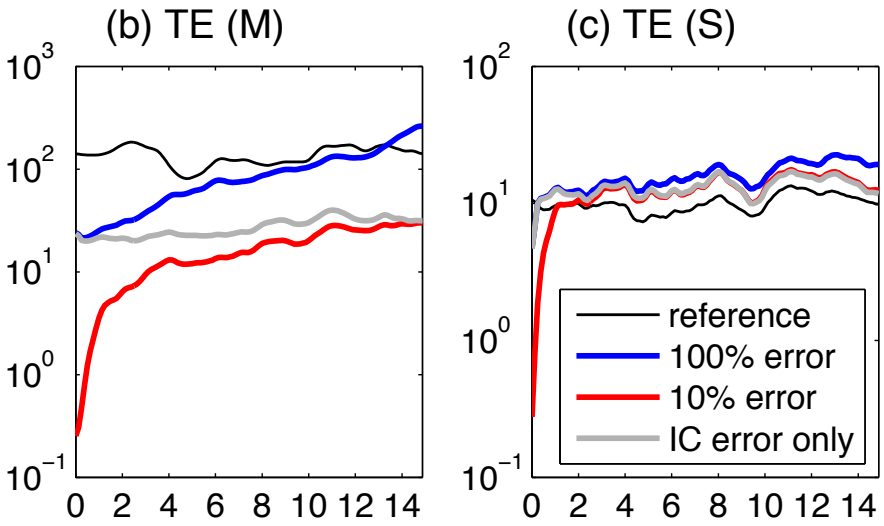
Error growth time scale:
The time it takes for 10% error to grow to 100% error level.

How fast error grows is linked to predictability limit.

At ~300 km, the transition from slow to fast growth happens, indicating the characteristic scales for the convective systems that helps amplify error?

IC error memory time scale



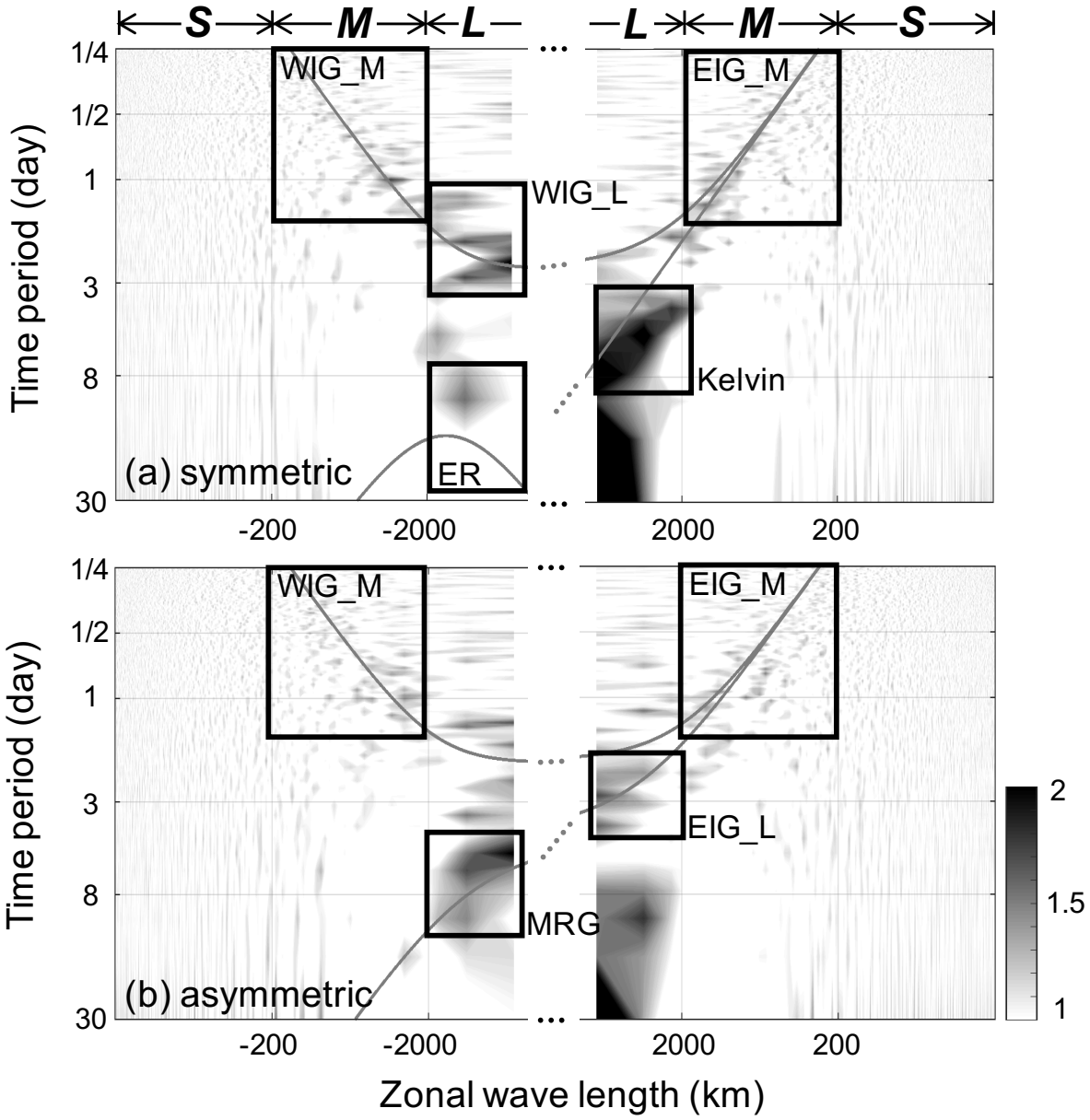


How long does the error in IC last in time, before the correct LBC relax the solution to control run.

For variable/scale that has slower error growth (longer predictability), the IC error memory is also longer.

May also depend on domain size.

Convectively coupled equatorial waves at each scales



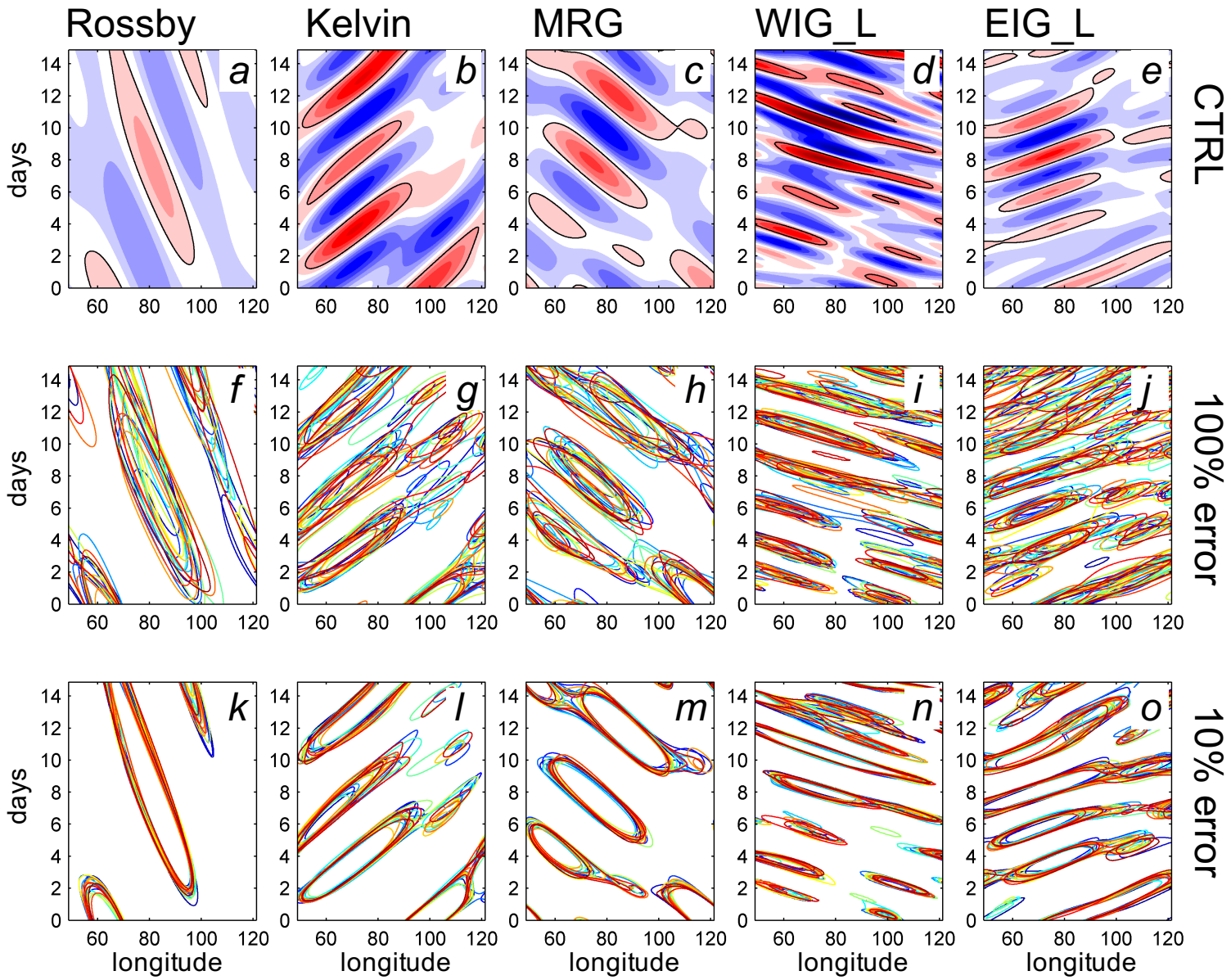
At L scale, the dominating signals are the n = 1 WIG, n = 0 EIG, n = 1 ER, Kelvin, and MRG waves.

At M scale, the n = 1 and n = 2 WIG and EIG are dominant.

At S scale, the signal is noisy and with wide range of time frequency and zonal wavenumber.

We filter the simulated precipitation for each wave type and evaluate their corresponding error growth…

Large scale waves, practical predictability can be improved

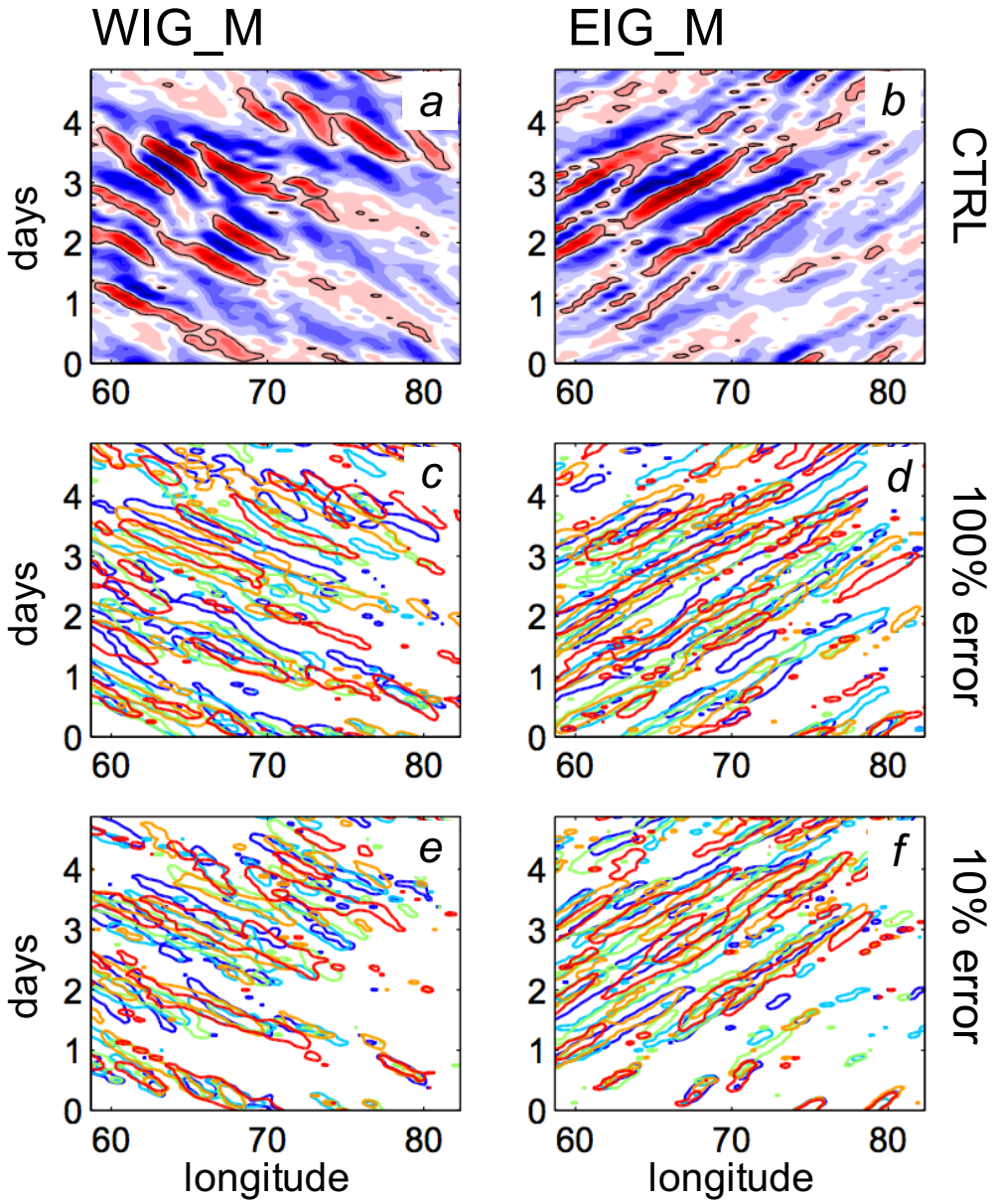


precipitation averaged over 0~5N

spaghetti plots of contours from 20 members

reducing the error in IC/LBC decrease the error in simulated precipitation

M scale waves, reaching intrinsic predictability limit



At smaller scale, the rapid error growth associated with moist convection pose an intrinsic limit in predictability.

At this scale, reducing IC/LBC error won't help decreasing error in simulation.

The errors remain saturated.

Concluding remarks

What is the practical/intrinsic predictability of tropical weather at each scale?

At large scale (> 2000 km), current practical predictability is ~10 days for u, v, T, q, and ~5 days for w and precipitation. Corresponds to Rossby, Kelvin, MRG, and large-scale IG waves.

At intermediate scale (200 ~ 2000 km), the active IG waves cause rapid error growth and reduce practical predictability to 5 days for u, v, T, q.

At small scale (< 200 km), the error saturates within 1 day.

Reducing error can improve predictability at L and M scales, but S scale is still intrinsically unpredictable.