Atmospheric Predictability

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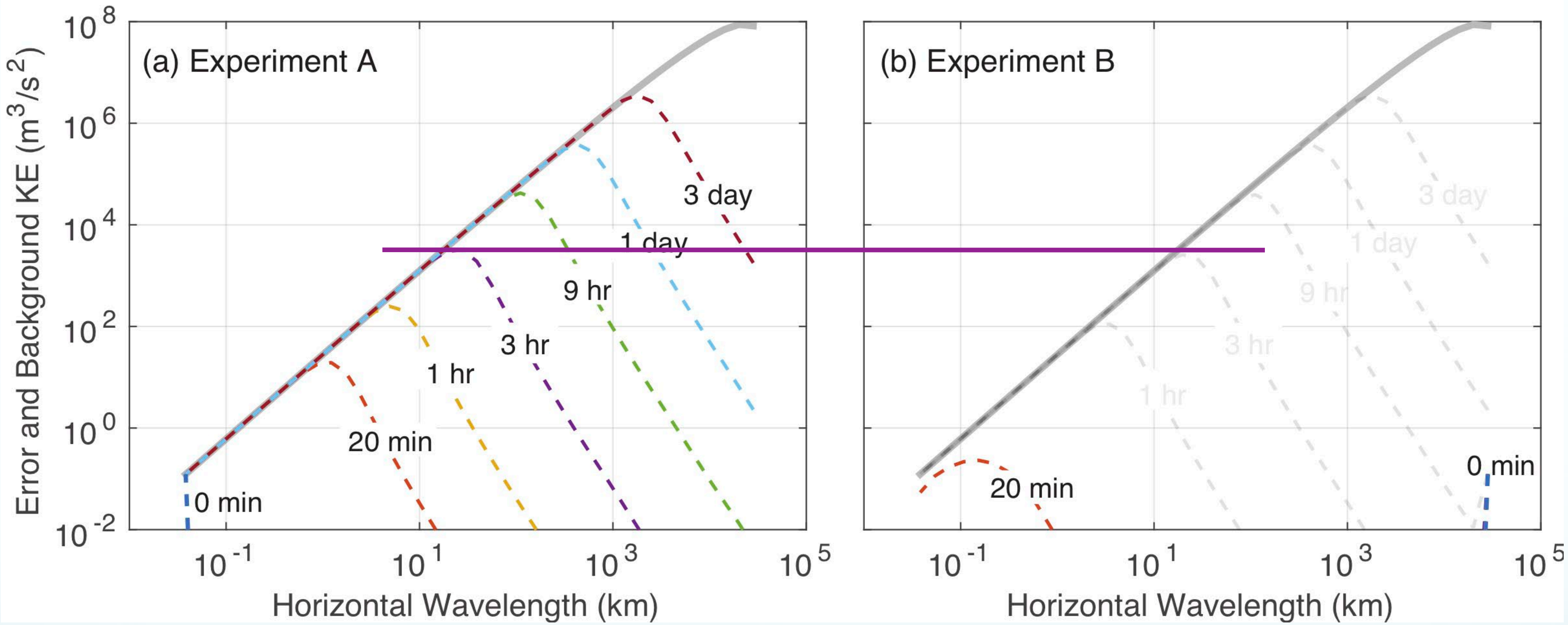
Initial-Condition Errors: Scale Sensitivities

Consider two *different* questions

- Is upscale error growth important?
  - (even if it is not exactly a "spectral cascade")
- Given initial errors of *fixed absolute magnitude*, does their *horizontal scale* influence predictability?

Lorenz’s 1969 Answer: Experiments A & B

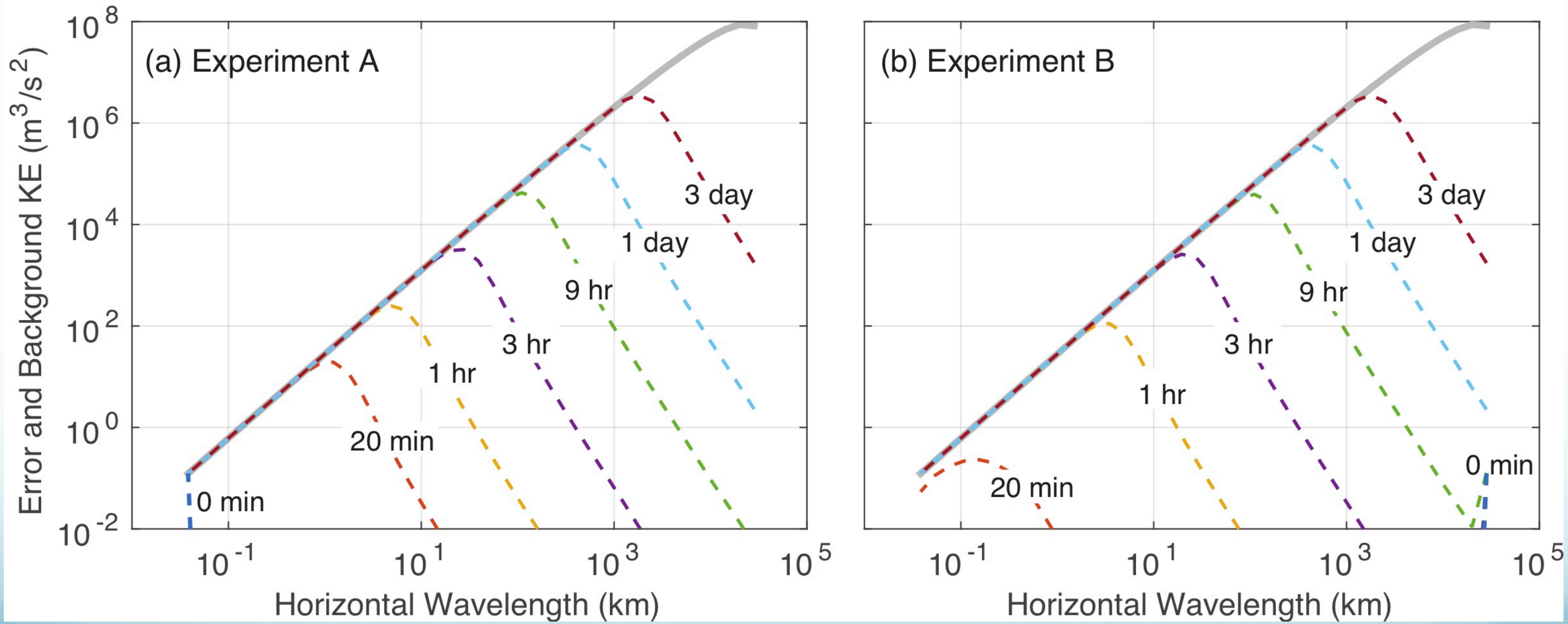
Modified spectral turbulence model (Durran and Gingrich 2014)



“Evidently when the initial error is small enough, its spectrum has little effect upon the range of predictability.”

Implications of Experiment B were largely overlooked.

Small *relative errors* in the large-scales can destroy predictability.



Influence of Scale: Lorenz Model

- Small relative errors in the large scales rapidly propagate down to the smallest resolved scale.
- Those small-scale errors subsequently propagate back upscale as if they had simply originated in the small scales.
  - Upscale growth is responsible for the finite limit to intrinsic predictability
- No easy way to diagnose the scale of the "original errors".

How relevant is the Lorenz model?

- It does not include
  - Baroclinic instability
  - Deep convection
  - Inhomogeneity and nonstationarity
- Nonlinear effects are incorporated only crudely.
- Incorrectly assumed $k^{-5/3}$ slope for the background KE spectrum at large-scales.
- *Deep Convection?*

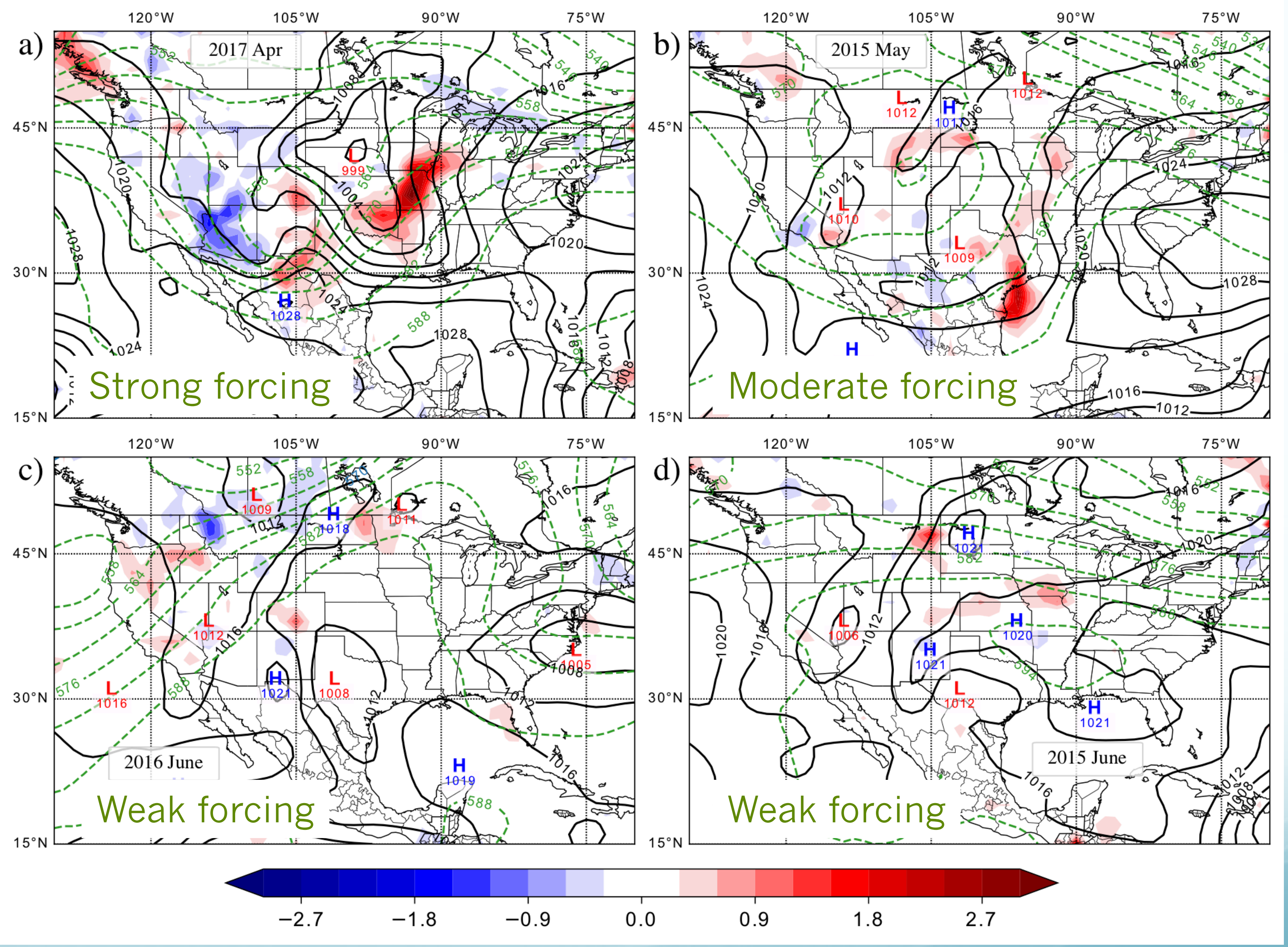
Error Growth in Observed Convective Systems

- Four cases: both weakly and strongly forced systems
  - 24-hr control simulations
  - WRF model, 2.5 km horizontal grid spacing
  - GFS analysis for initial conditions
  - Six ensemble simulations branch off each control at hour 6

- Different *background* perturbations among ensemble members in the near-surface moisture field
  - Monochromatic square wave in horizontal, random phase
    - **Small-scale ensemble**: *x* & *y* wavelengths 20 km (λ = 14 km)
    - **Large-scale ensemble**: *x* & *y* wavelengths 200 km (λ = 140 km)
  - Perturbation amplitude of *1% of control moisture field*
  - 1-km *e*-folding decay scale away from the surface

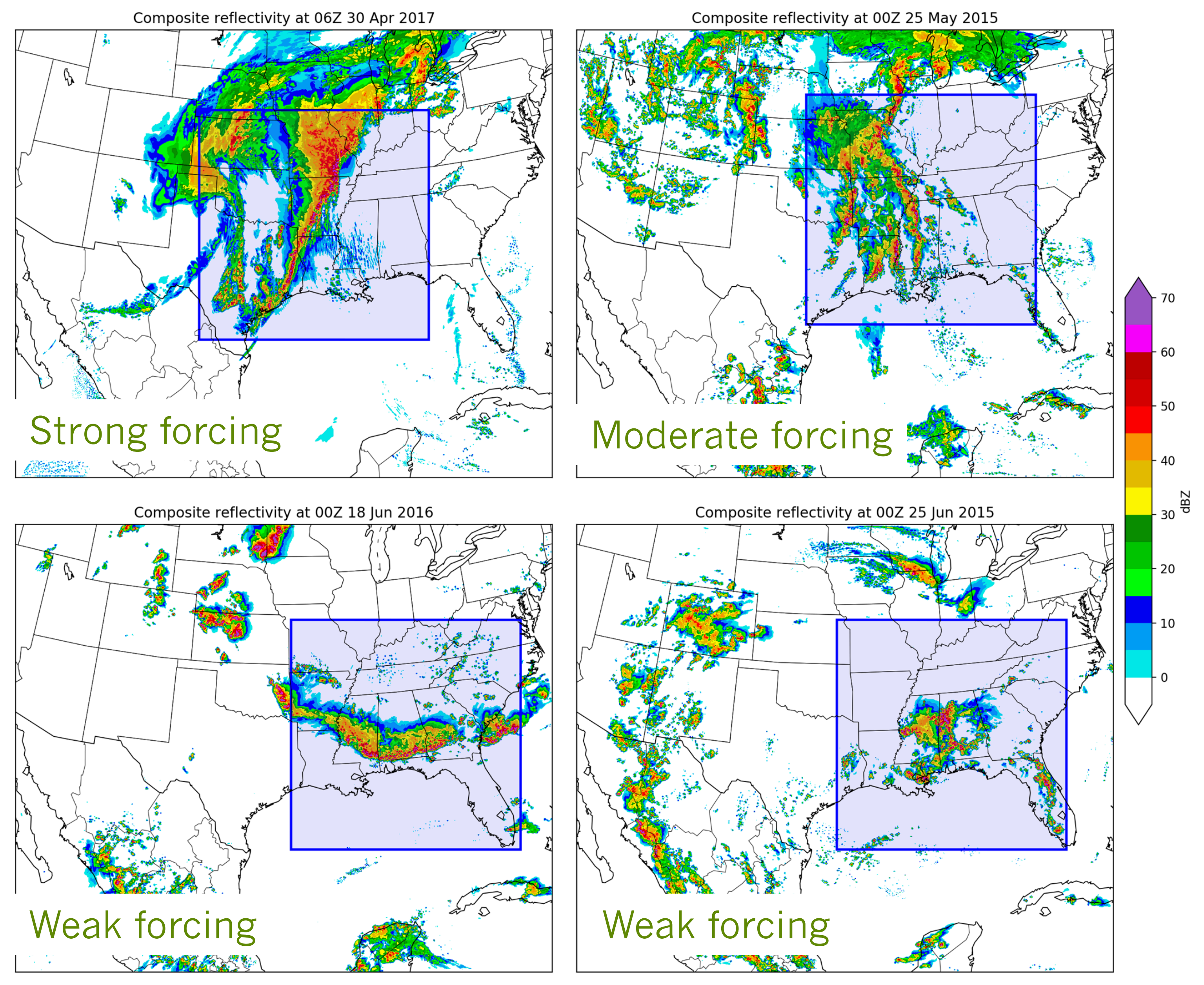
Synoptic Overview

- Sea-level pressure
- 500 hPa heights
- 500 hPa vertical velocity (contours)



Control Simulations

- Simulated composite reflectivity
- 12 hours after initialization from GFS
- Hour 6 in the ensembles
- 2.5 km horiz. resolution



Composite reflectivity at 06Z 30 Apr 2017

Strong forcing

Composite reflectivity at 00Z 25 May 2015

Moderate forcing

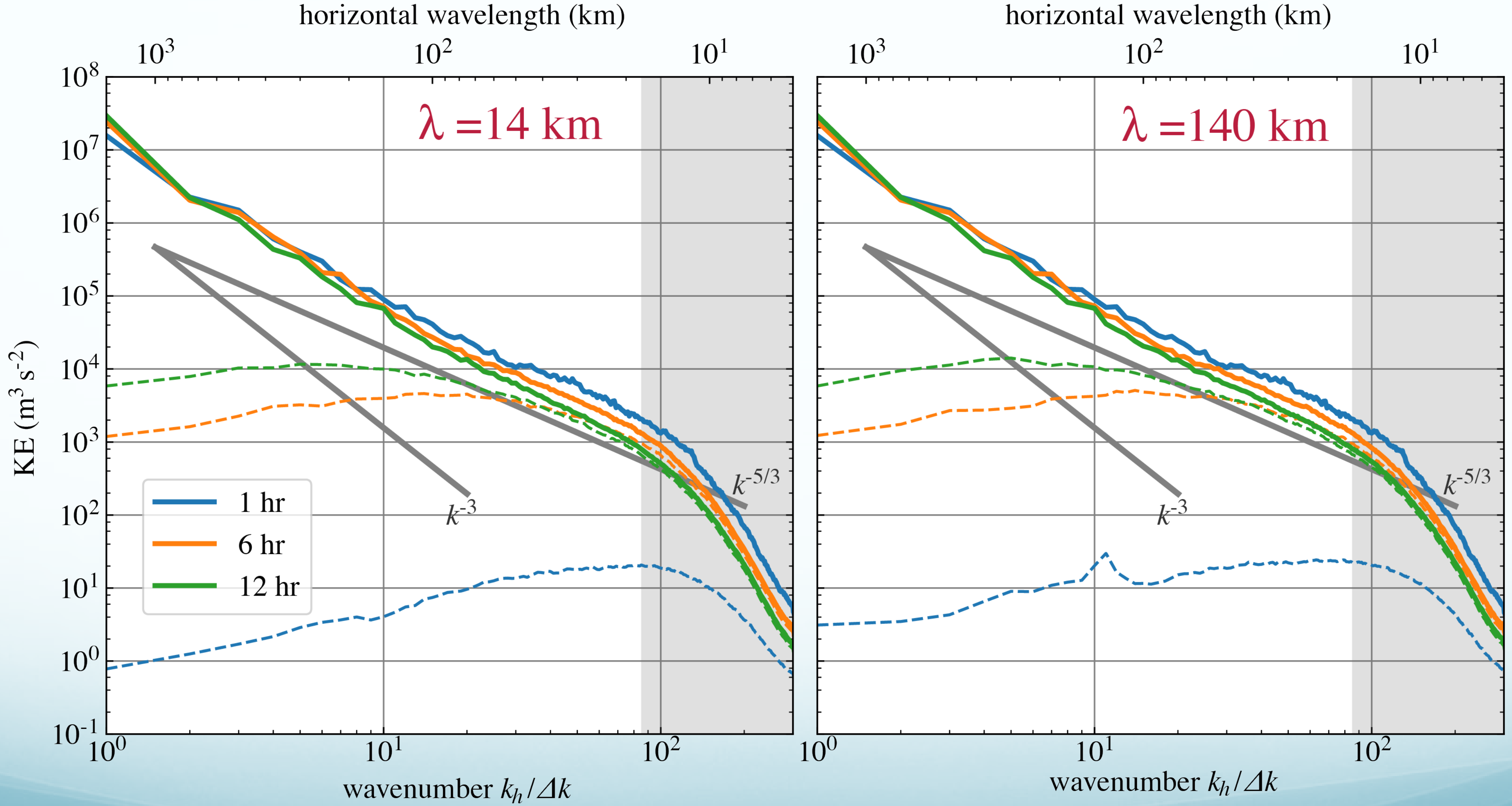
Composite reflectivity at 00Z 18 Jun 2016

Weak forcing

Composite reflectivity at 00Z 25 Jun 2015

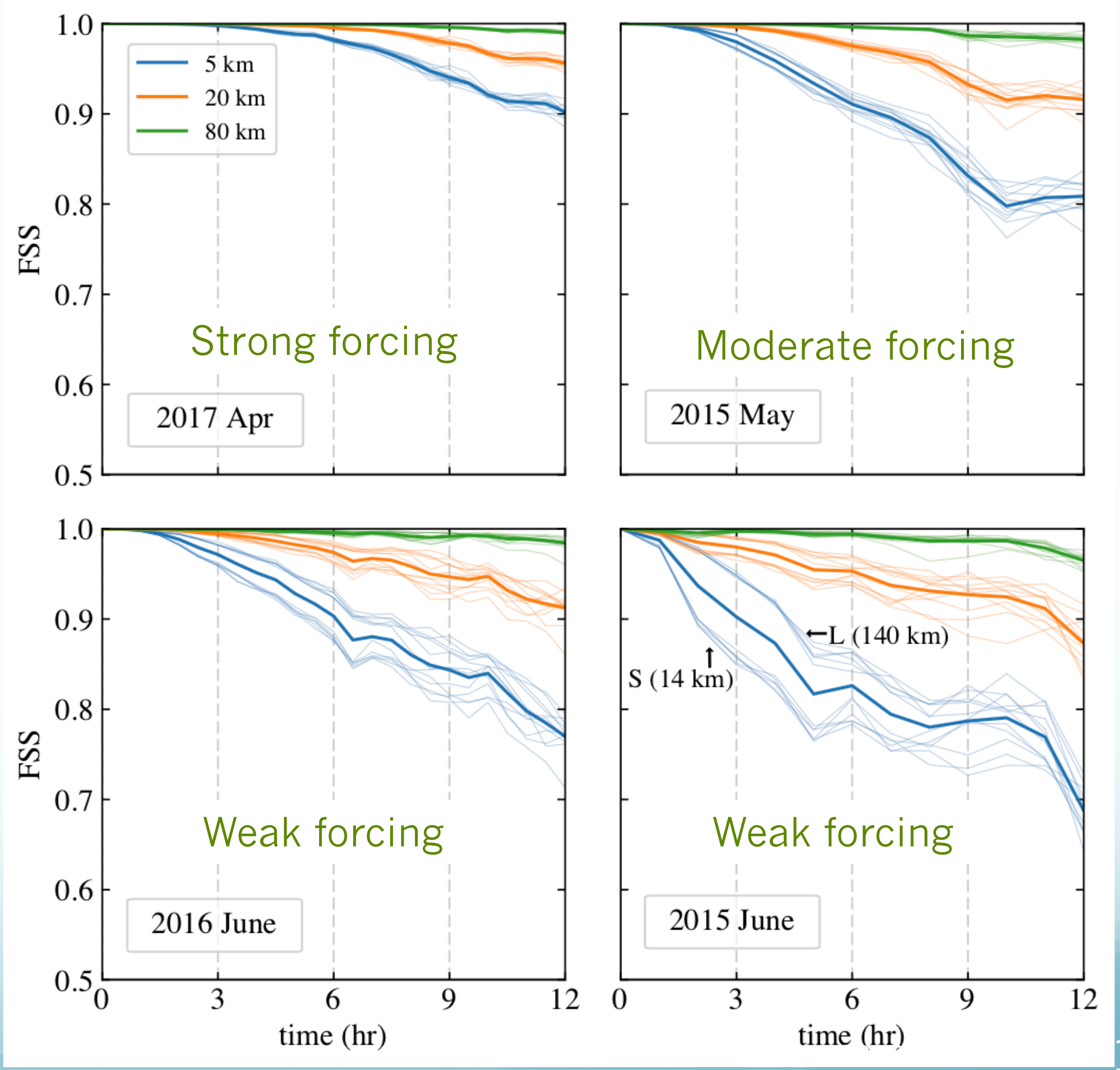
Weak forcing

Pertubation KE Growth: April 2017 Case



Fractions Skill Score

- 1 mm/hr precip threshold
- 5, 20, 80 km verification radii
- *Weak forcing:* 14-km perturbations grow faster than 140-km perturbations



Influence of Scale – Convective Systems

- Equal amplitude 1% humidity errors at 14 and 140 km produce:
  - Similar losses in predictability in strongly forced cases
  - More rapid error growth in weakly forced cases
- Short-wavelength errors influence convective initiation
  - Important in weakly forced cases
- Long-wavelength errors influence convective organization
  - Important in strongly forced cases

Implications for data assimilation on the mesoscale

- Characteristic velocities at wavelengths of 200-400 km are 5 times larger than those at 2-4 km.

- Equal improvements:

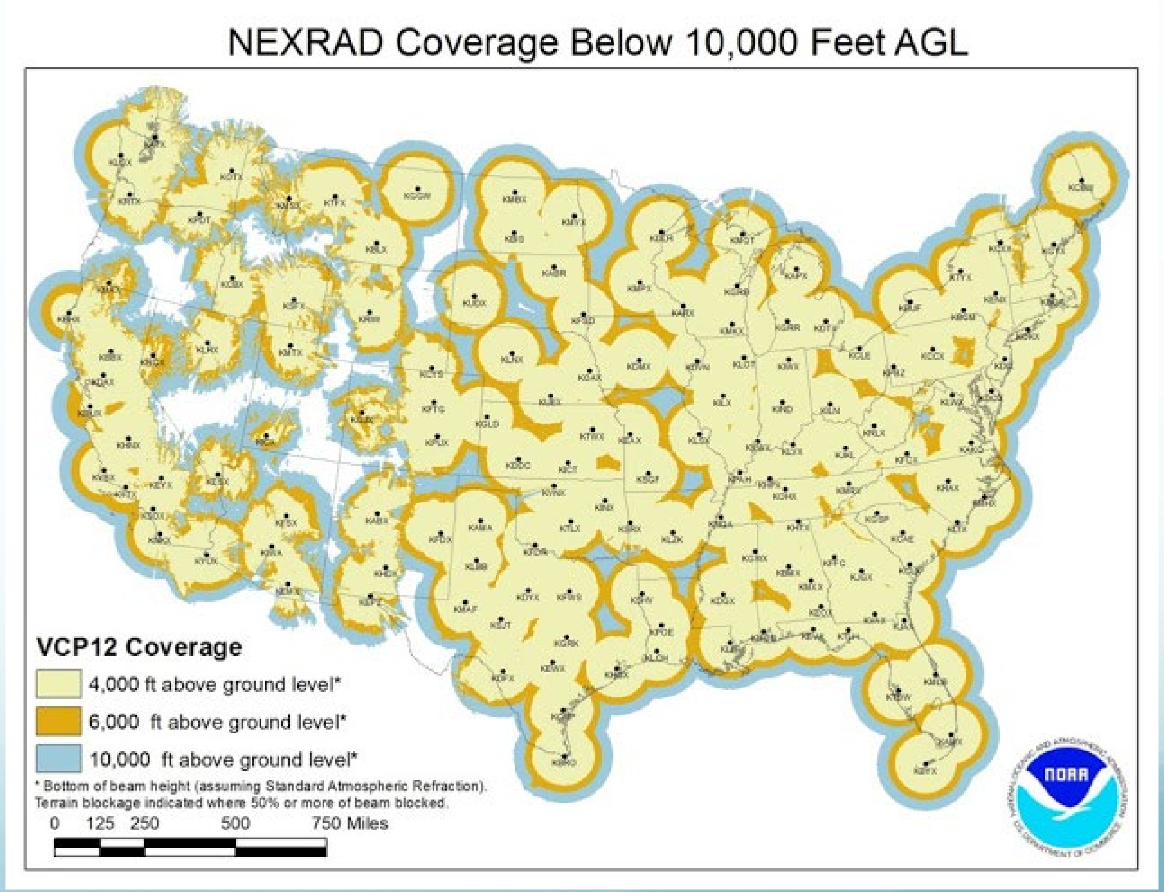
  (> 6-hr forecast)

  from reducing IC errors at

  2-4 km below *50%*

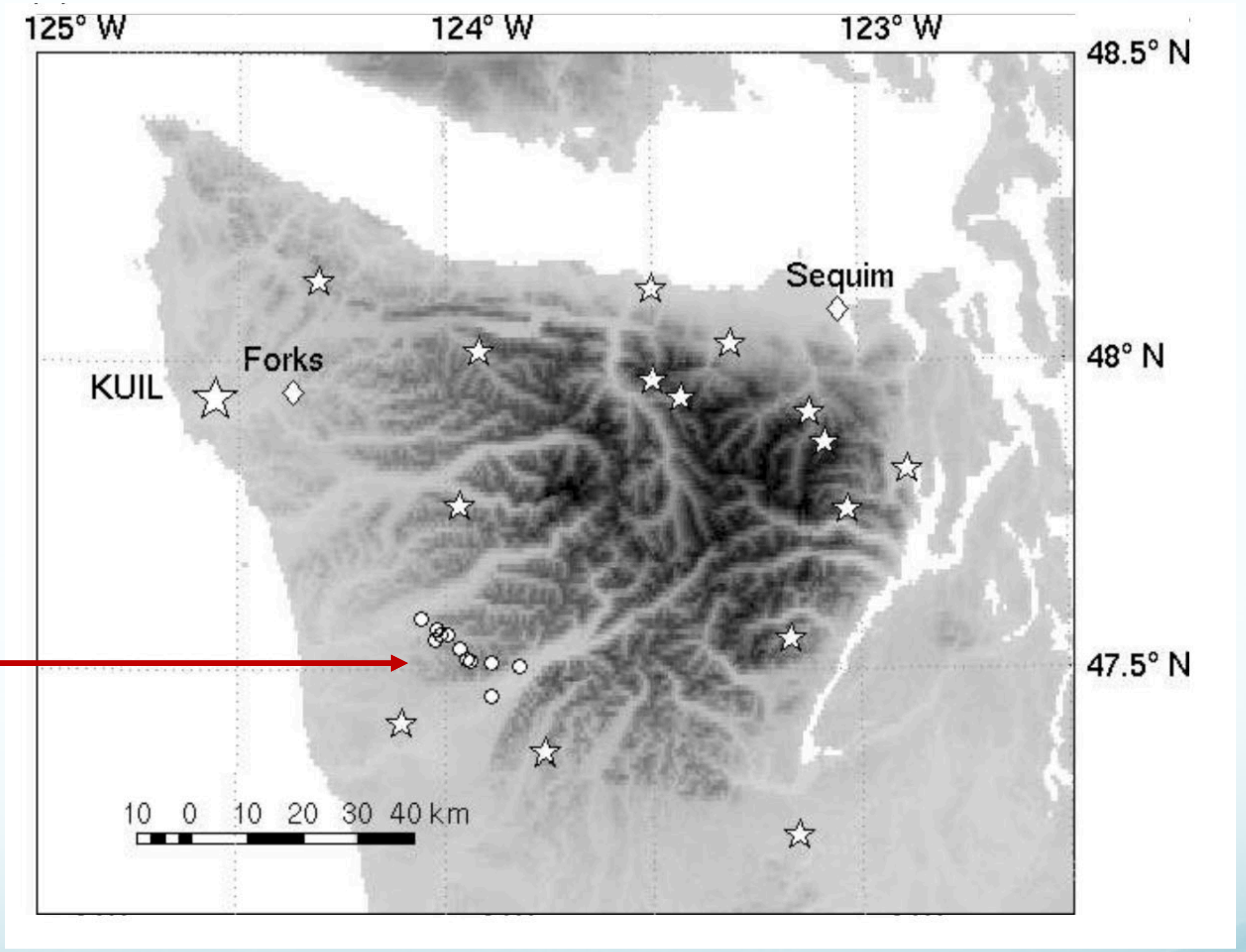
  200-400 km below *10%*

  (equal absolute errors in KE')

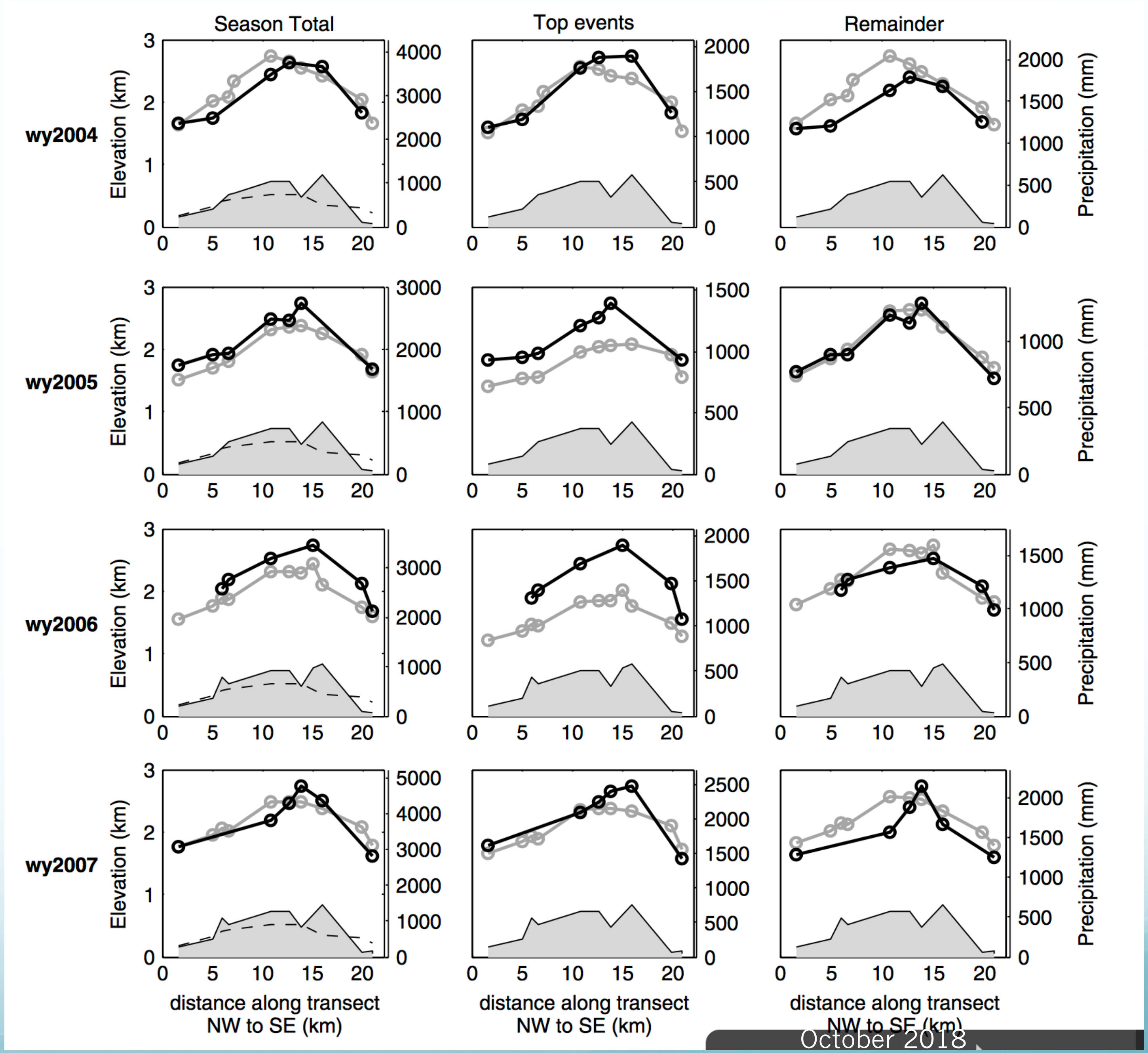


Predictability and Microphysics

Fine-scale rain gauge network across ridge



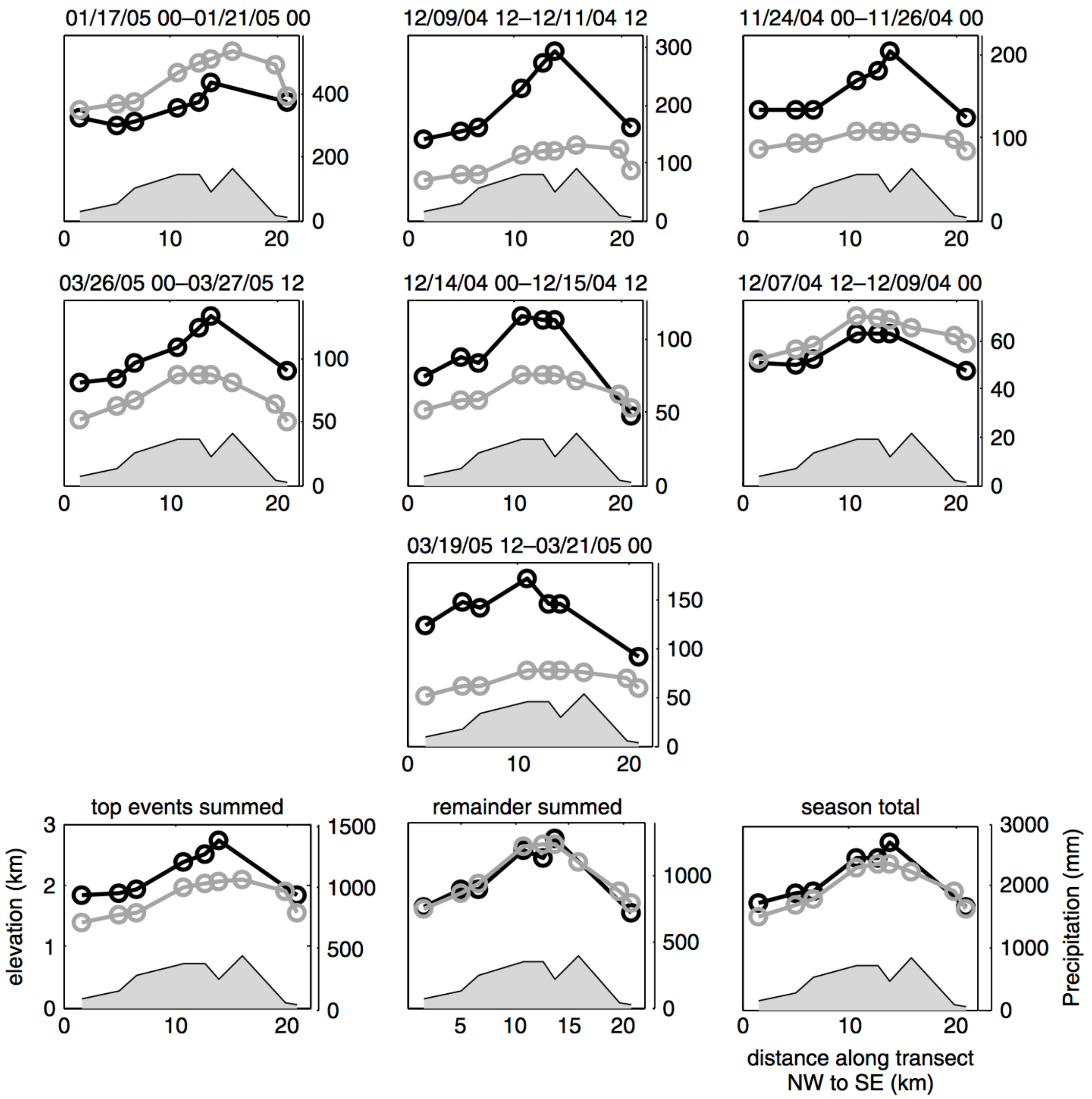
MM5 vs Rain Gauges



Black: observations

Gray: MM5 forecast

MM5 vs Rain Gauges WY 2005



Black: observations

Gray: MM5 forecast

Predictability and "Physics"

Don't test a family of physics parameterizations in simulations using single deterministic initial condition!

References

Weyn, J.A.. and D.R. Durran, 2018: The scale dependence of initial-condition sensitivities in simulations of convective systems over the Southeastern US. *Q. J. R. Meteorol. Soc.*, 2018;1–18. https://doi.org/10.1002/qj.3367

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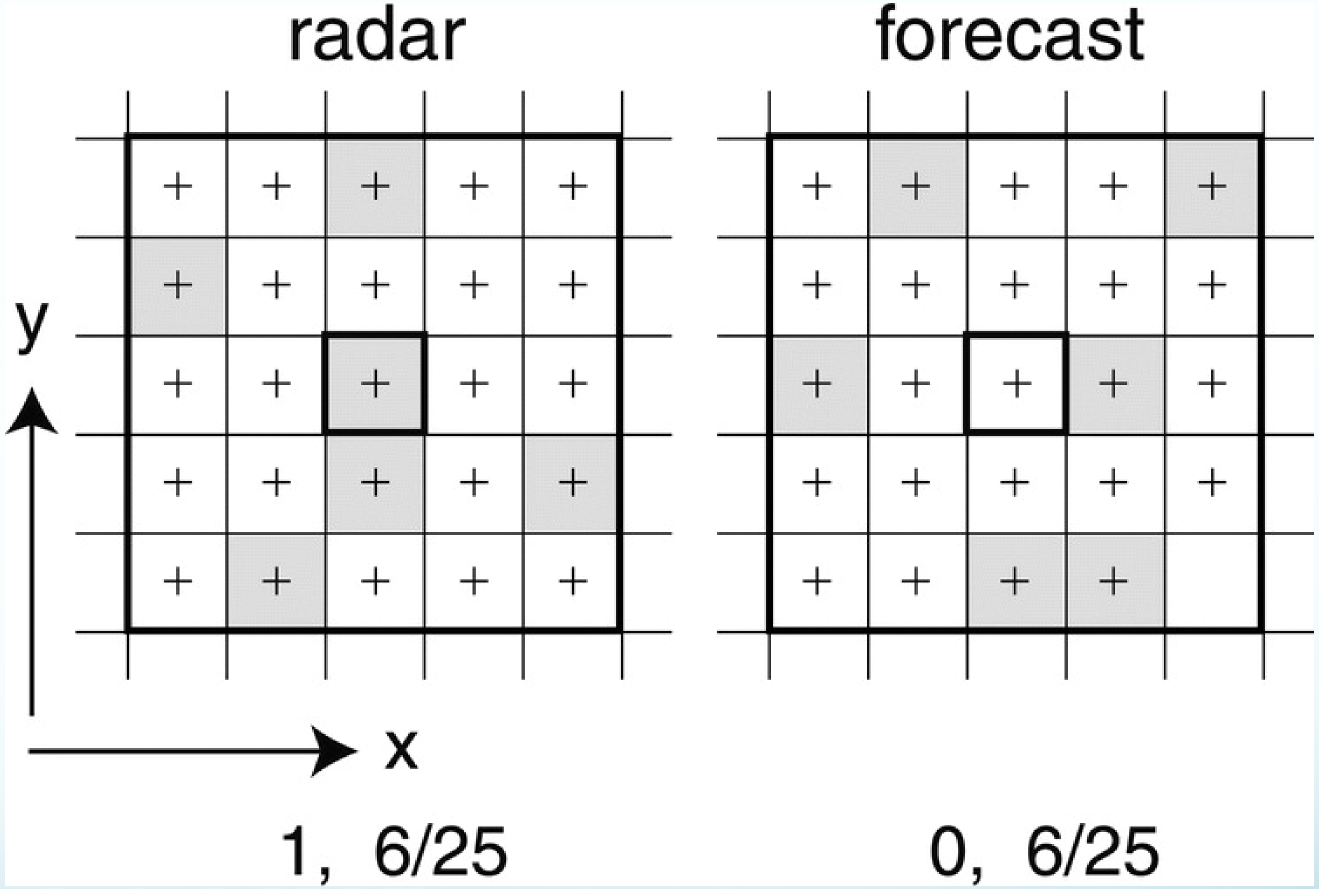
Minder, J.R., D.R. Durran, G.H. Roe and A.M. Anders, 2008: The climatology of small-scale precipitation over the Olympic mountains: Patterns and processes. *Q. J. R. Meteorol. Soc.*, **134,** 817-839.

Another measure of predictability

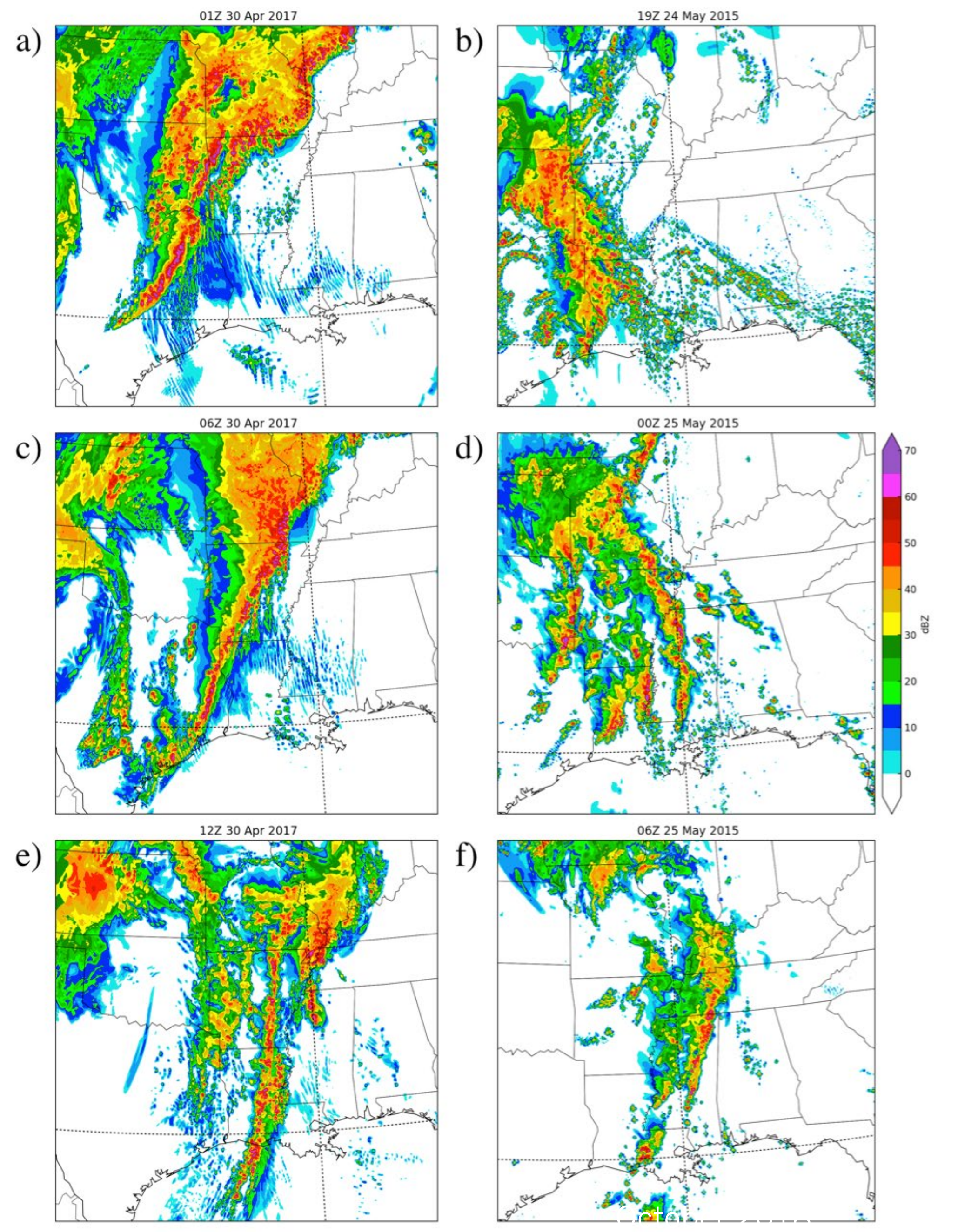
Fractions skill score

(Roberts and Lean, *MWR*, 2008)



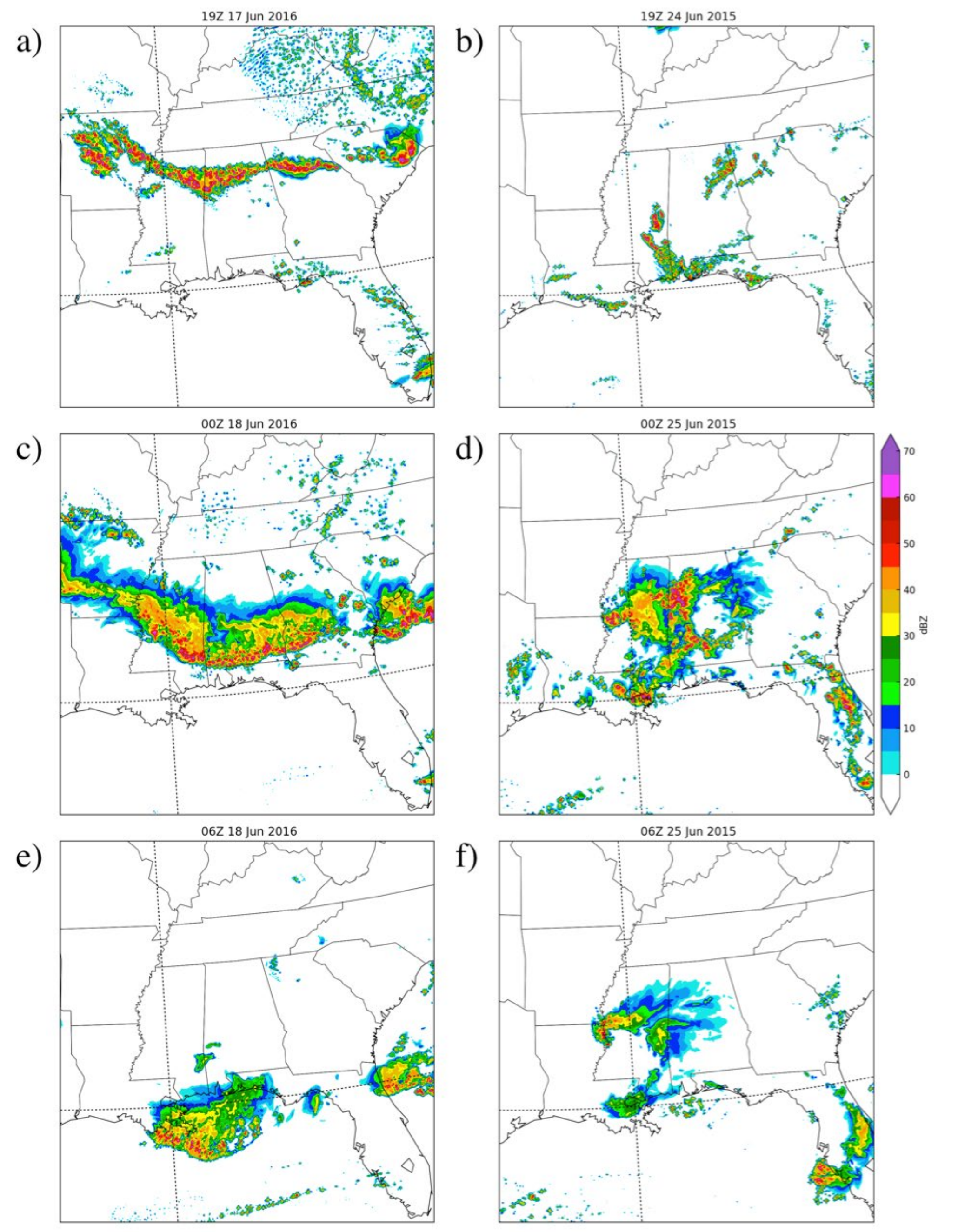
Strong/Moderate Forcing

Synthetic radar reflectivity



Weak Forcing

Synthetic radar reflectivity



Implications for data assimilation: I

Parseval's relation

$$\int_S u^2(x)\,dx = \int_{-\infty}^{\infty} \hat{u}(k)\hat{u}^*(k)\,dk$$

KE in wavenumber band *(k_1, k_2)*

$$E(k_1, k_2) = \int_{k_1}^{k_2} \hat{u}(k)\hat{u}^*(k) + \hat{v}(k)\hat{v}^*(k)\,dk$$

Implications for data assimilation: II

- $k^{-5/3}$ KE spectrum

$$\frac{E(k_1, k_2)}{E(k_3, k_4)} = \frac{\lambda_1^{2/3} - \lambda_2^{2/3}}{\lambda_3^{2/3} - \lambda_4^{2/3}}$$

- Ratio of velocities in 200-400-km band to those in 2-4-km band is 0.21
- Which is the easier goal?
  Reduce errors at 200-400 km below 10%
  Reduce errors at 2-4 km below 50%

Error saturation (KE'/KE) in layer $10 < z < 12$ km

- Similar errors at 12 hr in all cases
- Small-scale errors produce more saturation at 6 hr in the weakly forced cases
  - More variation in CI