On the Appropriateness of Spectral Nudging in Regional Climate Models

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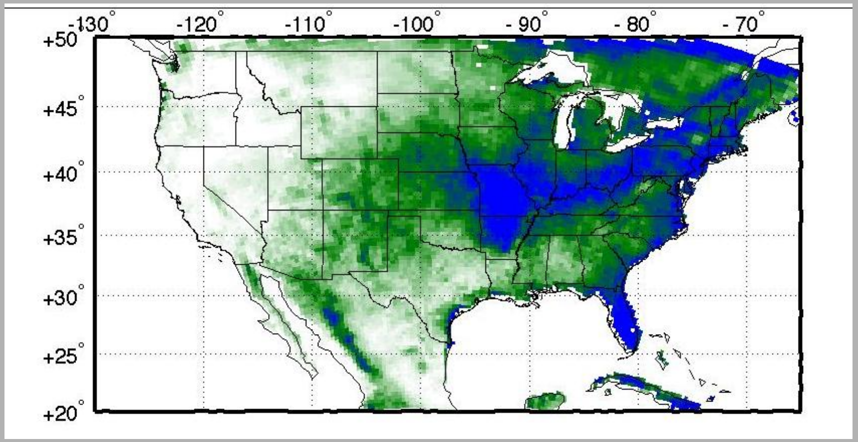

Dynamically Downscaled IPCC model (HadCM3) July precipitation using WRF with spectral nudging

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Dynamical Downscaling Types

from *Castro et al.* (2005)

	Examples
TYPE 1: remembers real-world conditions through the initial and lateral boundary conditions	Numerical weather prediction
TYPE 2: initial conditions in the interior of the model are "forgotten" but the lateral boundary conditions feed real-world data into the regional model	Retrospective sensitivity or process studies using global reanalyses
TYPE 3: global model prediction is used to create lateral boundary conditions. The global model prediction includes real-world surface data	Seasonal climate forecasting
TYPE 4: Global model run with no prescribed internal forcings. Couplings among the ocean-land-continental ice-atmosphere are all predicted	Climate change projection

Definition of RCM:

Initial conditions in the interior of the model are "forgotten" but the lateral boundary conditions feed data into the regional model

Type 2 dynamical downscaling and above

Some a priori expectations for RCM dynamical downscaling (Type 2 and above)

A RCM should:

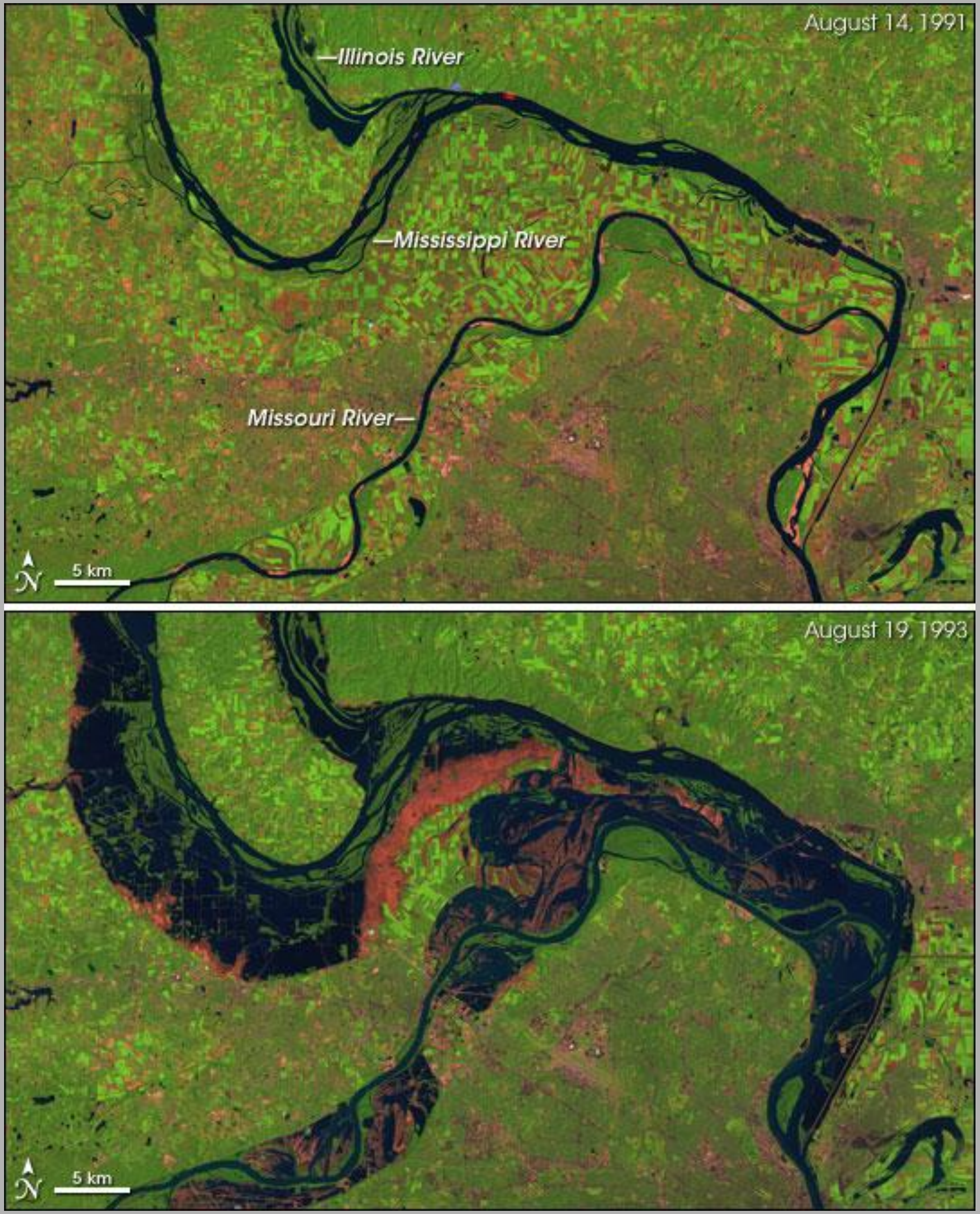
1. **Retain or enhance variability of larger-scale features provided by the driving global model (i.e. those on the synoptic scale)**

2. **Add information on the smaller scale because of increase in grid spacing, finer spatial scale data (e.g. terrain, landscape) and possibly differences in model parameterized physics.**

3. **Add information that is actually of value, as demonstrated by comparing RCM results with independent metrics (e.g. observations for Type 2)**

A good test case for a RCM…
The Great Flood of 1993 in central U.S.

Our RCM experiments focused on the month of May…look at results after two weeks of integration.



Regional Climate Model Experiments and Methods

***Castro et al.* (2005)**

Regional Atmospheric Modeling System (RAMS)

NCEP Reanalysis lateral boundary forcing.

Basic model experiments that investigated sensitivity to domain size and grid spacing with standard lateral boundary nudging only.

Follow on experiments that investigated sensitivity to 4DDA internal nudging.

***Rockel et al.* (2008)**

CLM (or CCLM), climate version of German weather service COSMO model.

ECMWF ERA-40 Reanalysis lateral boundary forcing

Repeat basic model experiments of Castro et al. (2005)

Follow on experiments with spectral nudging.

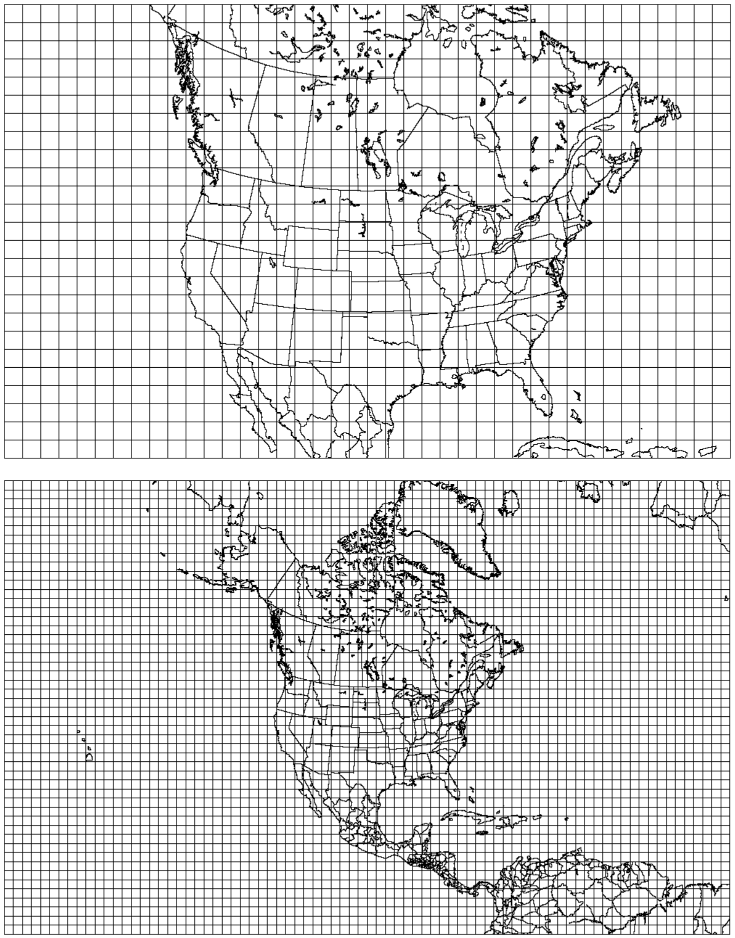

CASTRO ET AL.: DYNAMICAL DOWNSCALING USING RAMS

Figure 1. RAMS domains for model sensitivity experiments for Δx = 200 km.

Small Domain

Large Domain

3 nudging points used at lateral boundaries

Degradation of large-scale circulation features

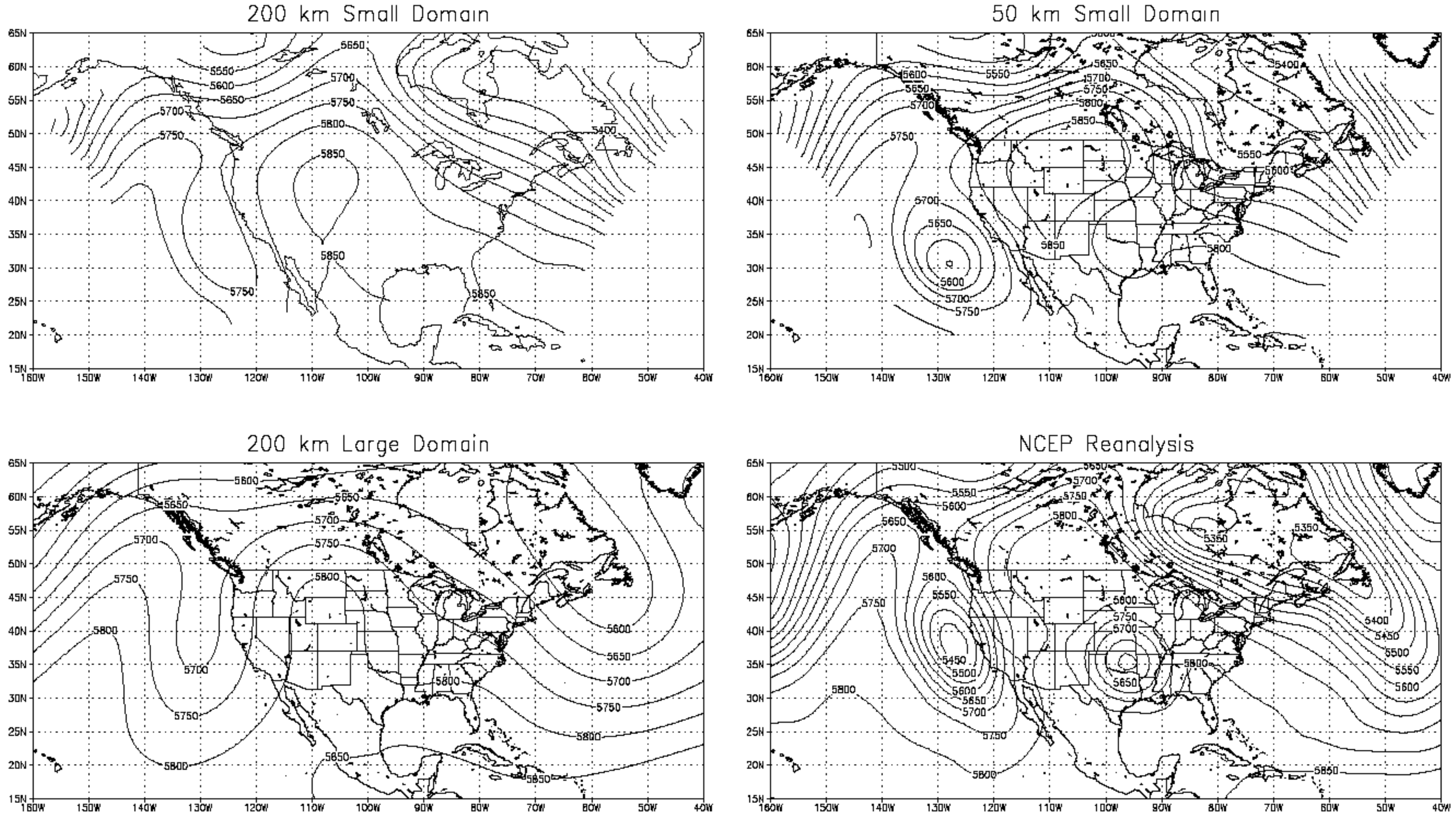
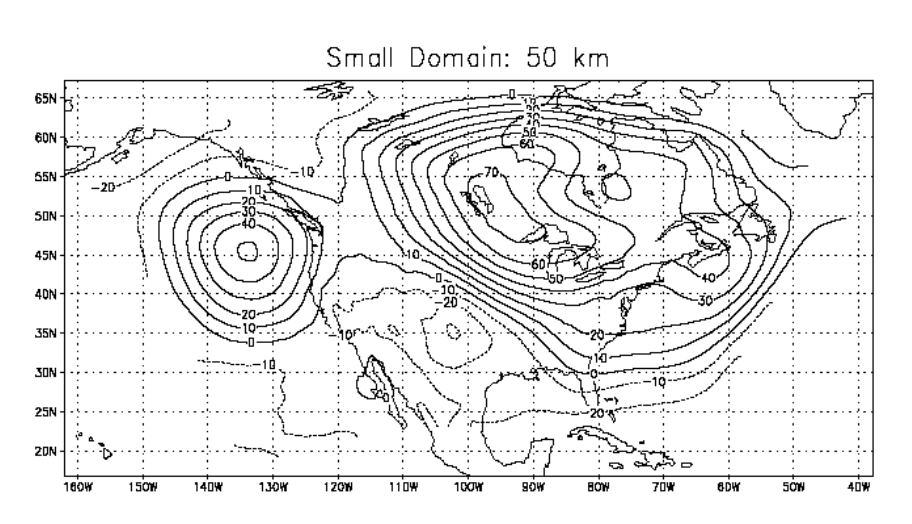


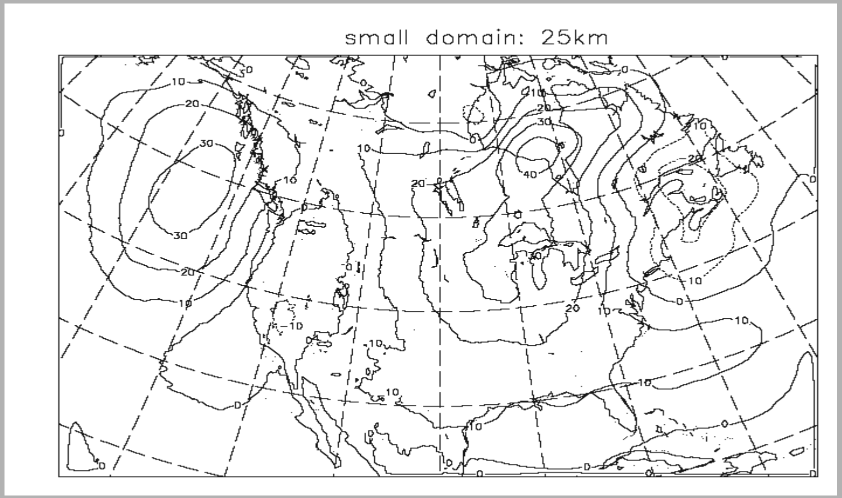
Figure 2. The 500-mbar height (m) on 0Z UTC, 12 May 1993, for indicated model basic experiments and NCEP Reanalysis.

Average 500-mb height difference (m) from driving reanalyses (last 15 days of simulation)

RAMS



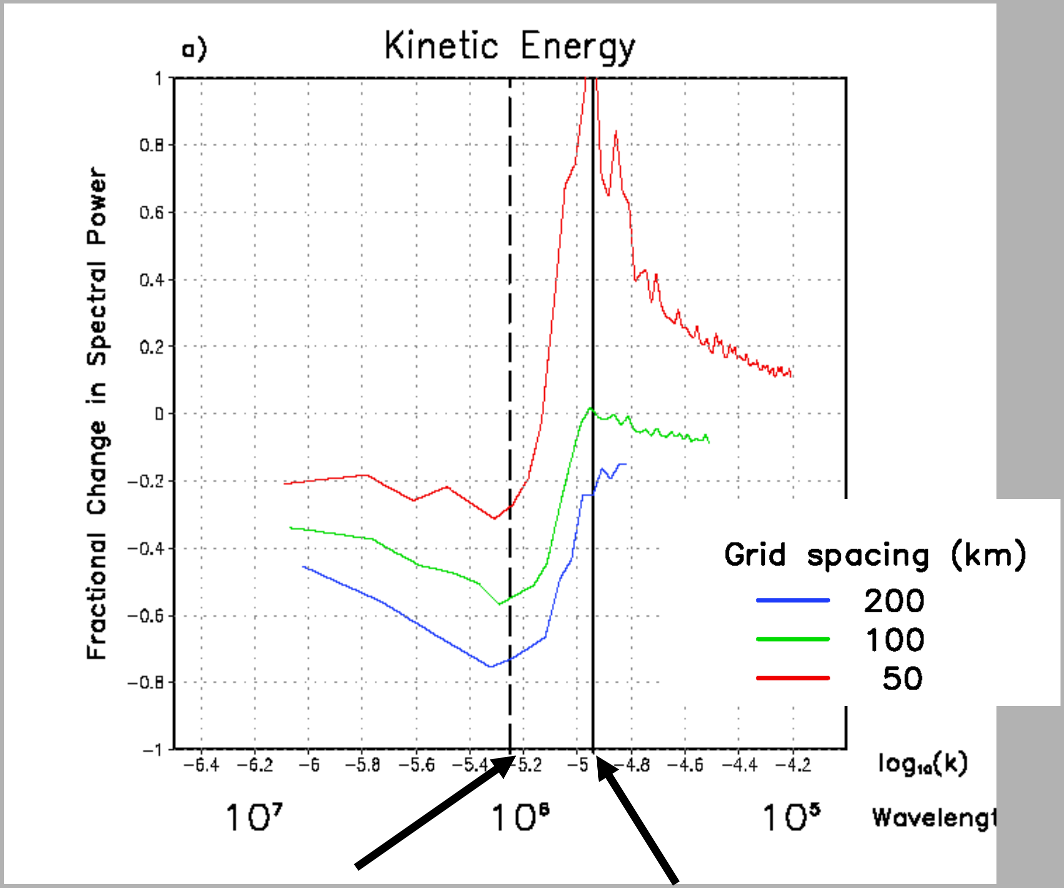
CLM



Fractional change in spectral power of kinetic energy: RAMS Model

RCM variability MORE than driving reanalysis.
VALUE RETAINED OR ADDED

RCM variability LESS than driving reanalysis.
VALUE LOST

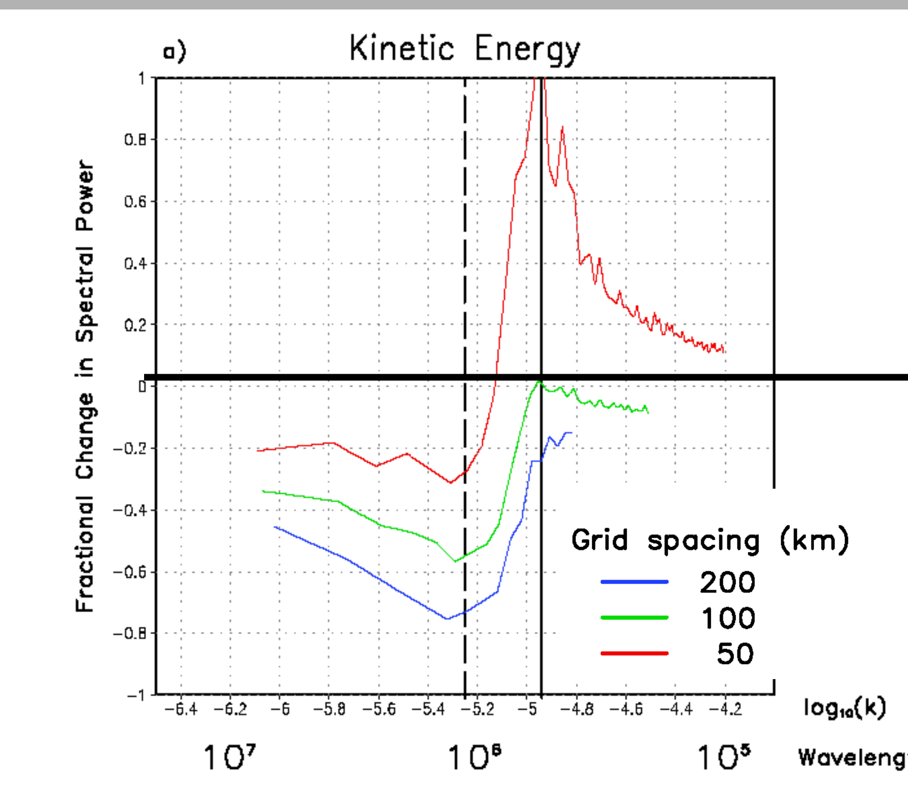


Shortest physically resolved wavelength in reanalysis (4Δx)

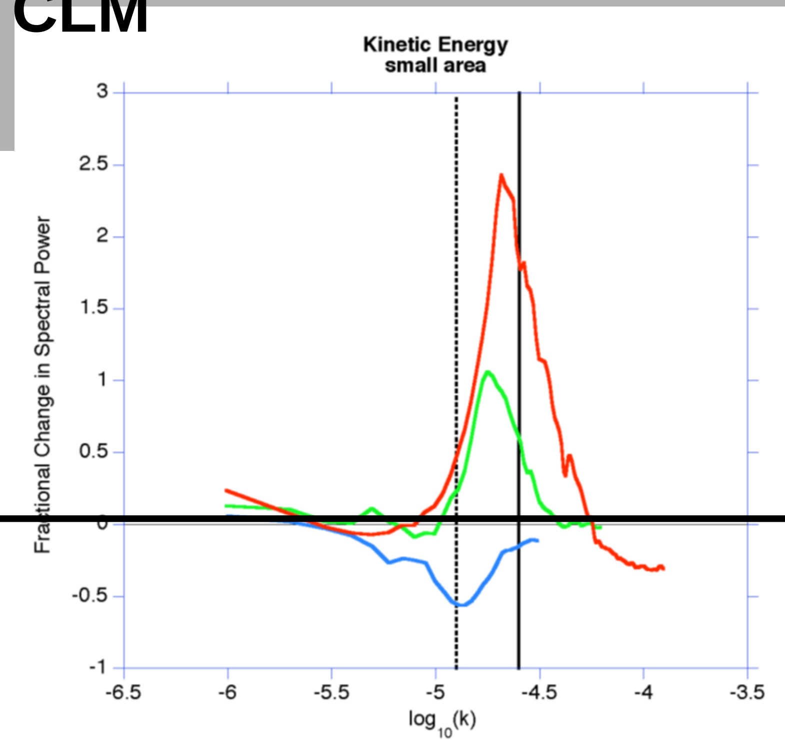
Nyquist frequency of reanalysis (2Δx)

Is the same behavior present in CLM?

RAMS



CLM



Grid spacing (km)

100

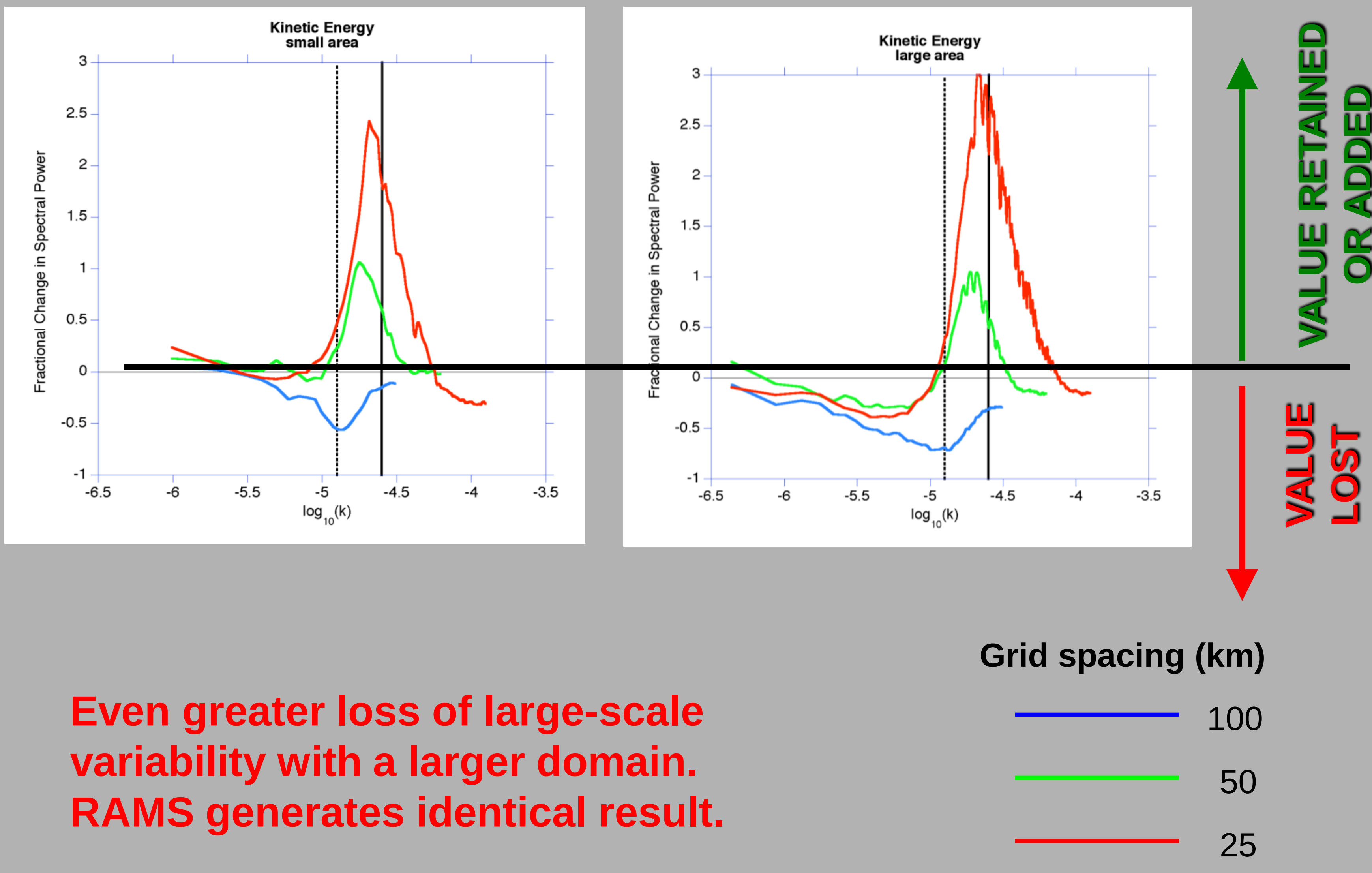
50

25

VALUE RETAINED OR ADDED

VALUE LOST

CLM: Small vs. Large Domains



Even greater loss of large-scale variability with a larger domain. RAMS generates identical result.

Spectral nudging in brief

We apply at scales greater than 4Δx of driving global model

Form of nudging coefficients for a given model variable in spectral domain:

$$\sum_{j=-J_a,k=-K_a}^{J_a,K_a} \eta_{j,k}\left(\alpha_{j,k}^{a}(t)-\alpha_{j,k}^{m}(t)\right)e^{ij\lambda/L_\lambda}e^{ik\phi/L_\phi}$$

$\alpha_{j,k}^{a}(t)$ **Fourier expansion coefficients of variable in driving larger-scale model (*a*)**

$\alpha_{j,k}^{m}(t)$ **Fourier expansion coefficients of variable in the regional model (*m*)**

$\eta_{j,k}$ **Nudging coefficient. Larger with increasing height.**

Change in spectral power of KE and MFC with internal nudging in RAMS

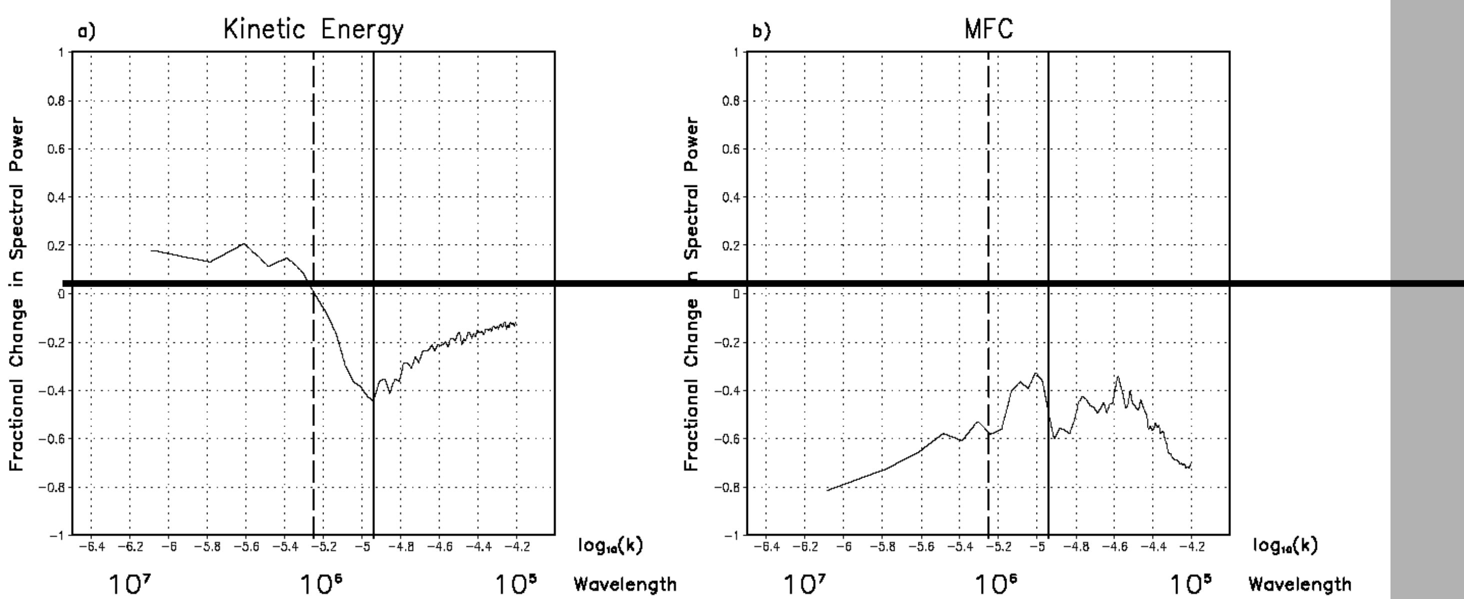
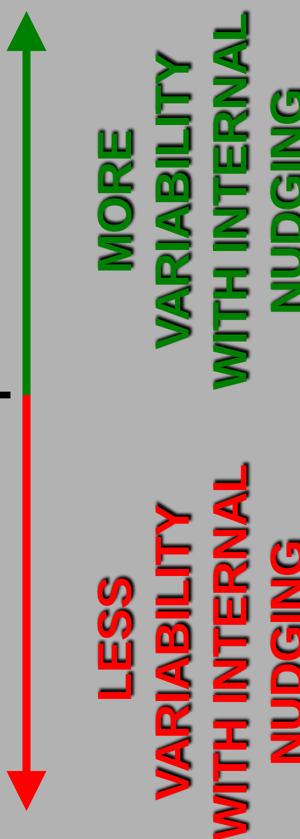
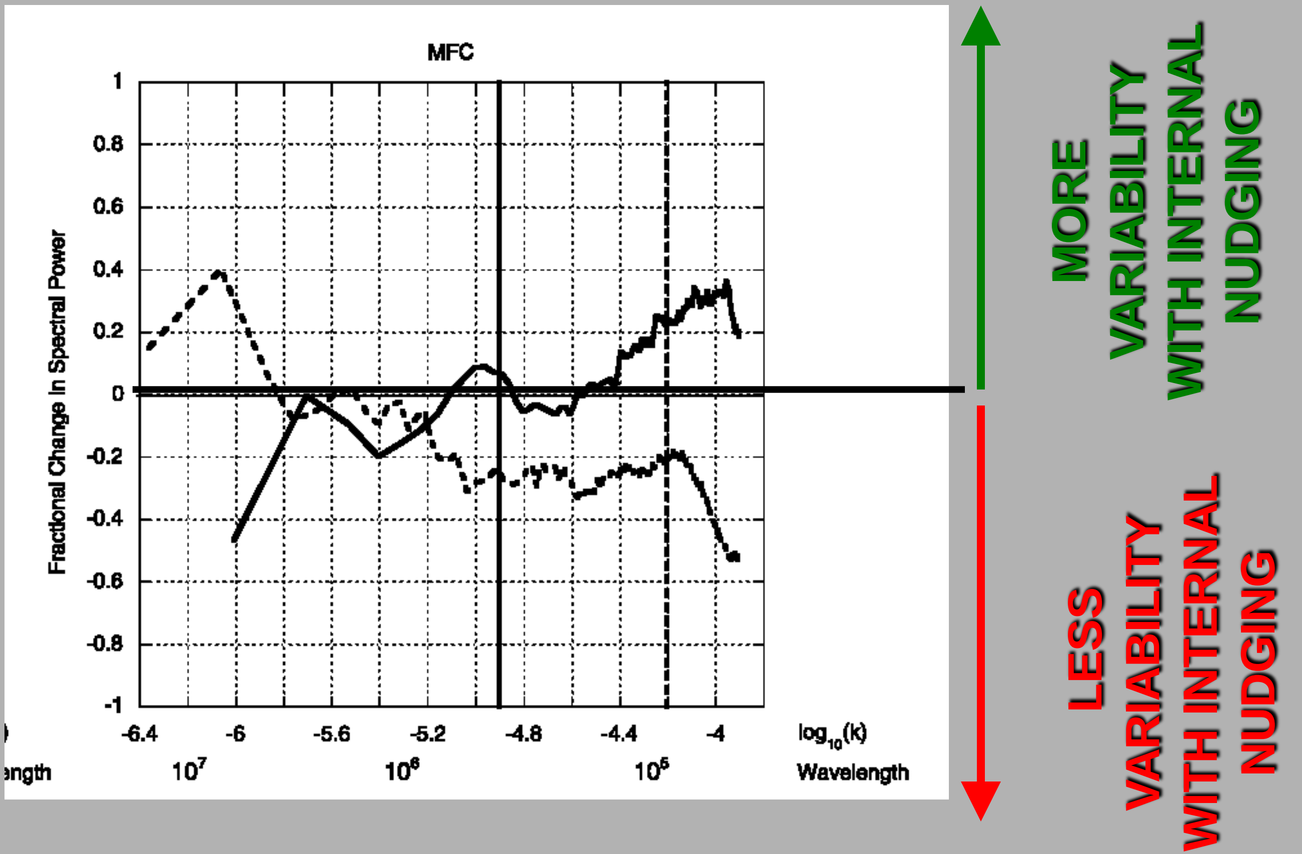


Figure 9. Average fractional change in spectral power ($\Delta S(k)_{frac}$) versus $\log_{10}(k)$ and wavelength for (a) column-averaged kinetic energy and (b) column integrated moisture flux convergence (MFC), Follow-on 1 (internal nudging). The dashed black line indicates k^*_{max}, and the solid black line indicates $k^*_{Nyquist}$. k in units of m^{-1}. Wavelength in units of m.



Tradeoff of internal nudging at all wavelengths: weaken variability at small scales where we want the regional model to add information.

Spectral nudging in CLM preserves the small-scale variability, so it's better!

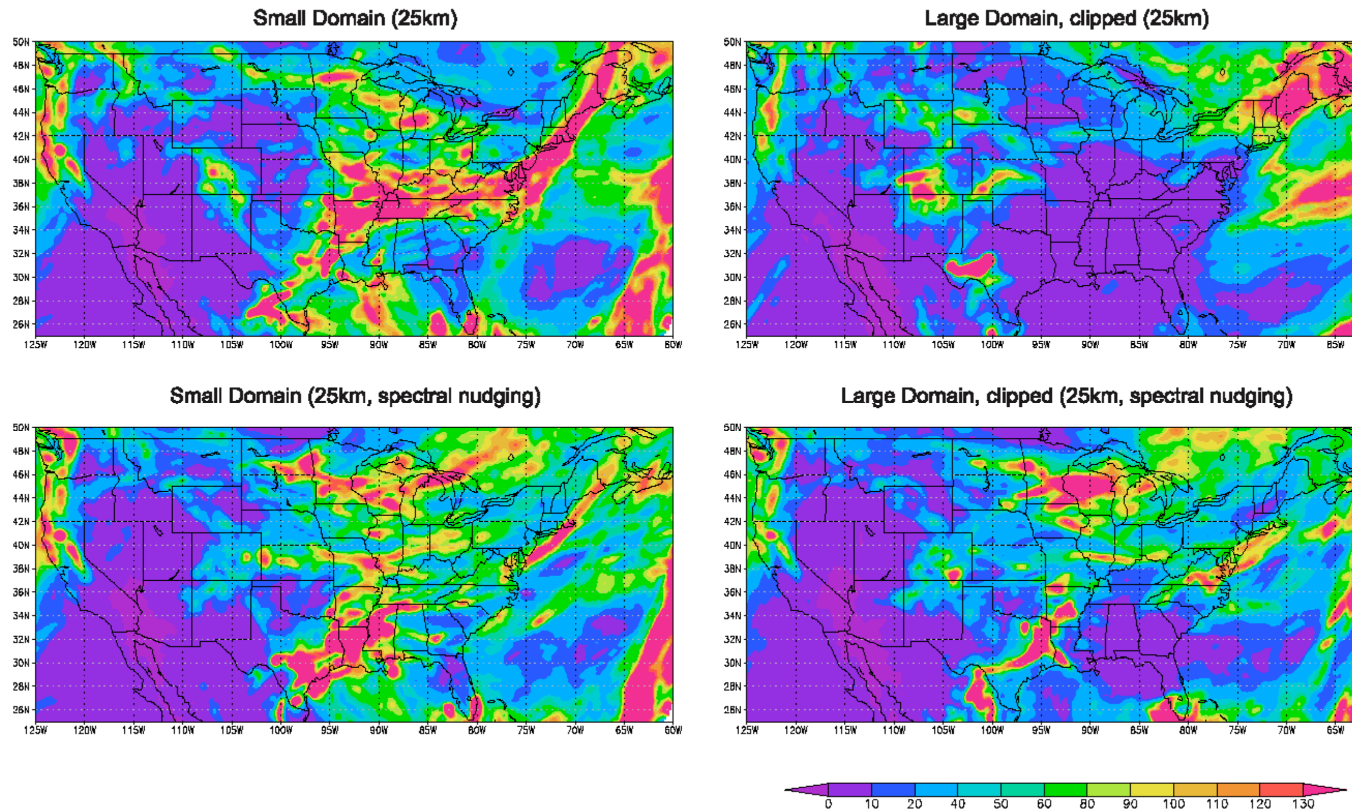


Small domain

Large domain

Δx = 25km

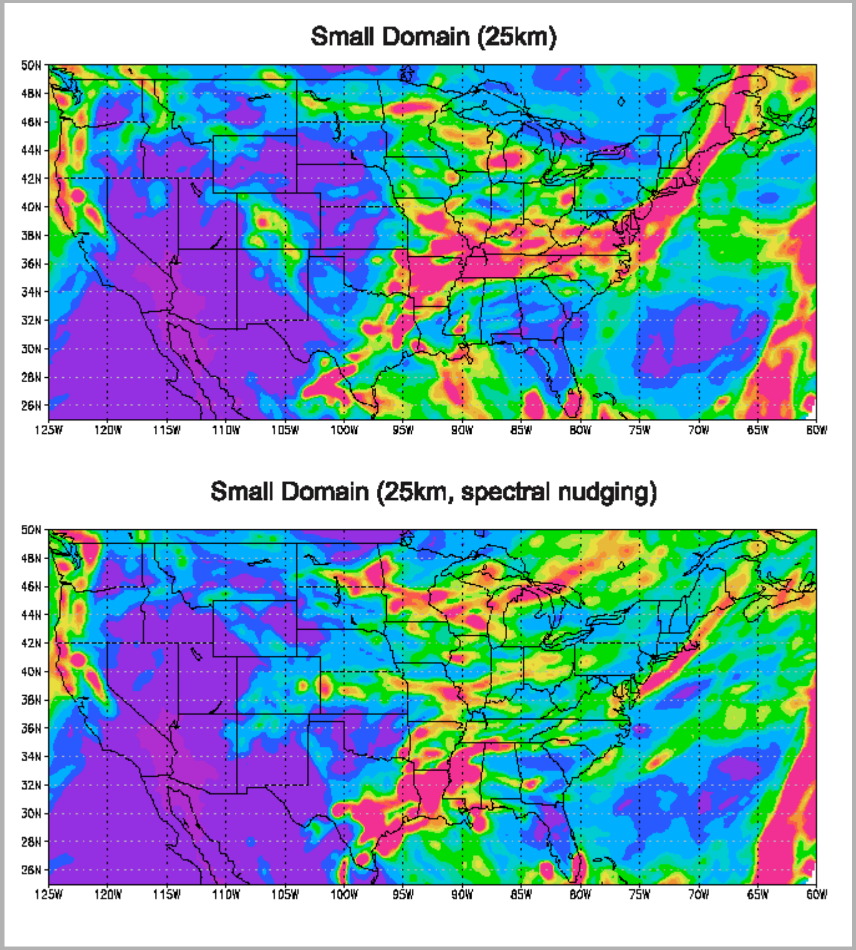
CLM Precipitation for various model configurations

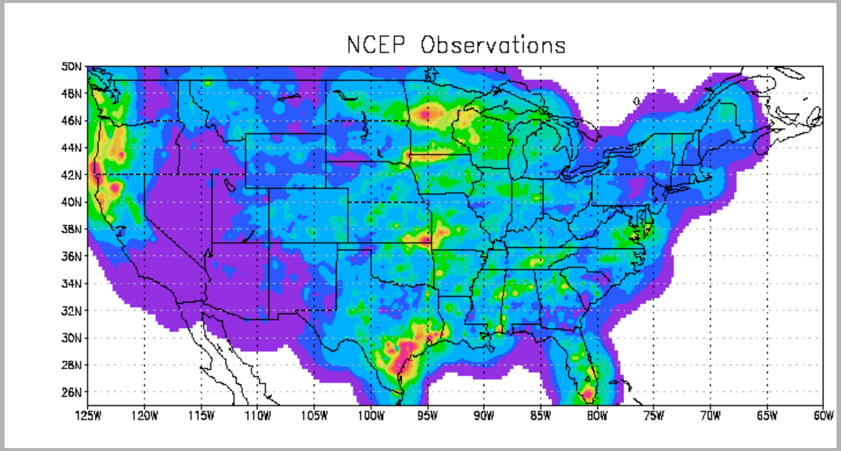


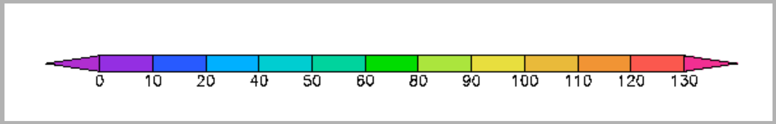
Units: mm

Figure 6. Precipitation results from CLM simulations for the second half of May 1993 without and with spectral nudging in the top and bottom rows, respectively.

CLM Precipitation comparison with observations for small domain







Units: mm

How have we applied these lessons to produce seasonal climate forecasts and climate change projections using WRF?

Assumption: exactly the same behavior will exist for Type III and Type IV dynamical downscaling

June precipitation solutions for one ensemble member (mm day^{-1})

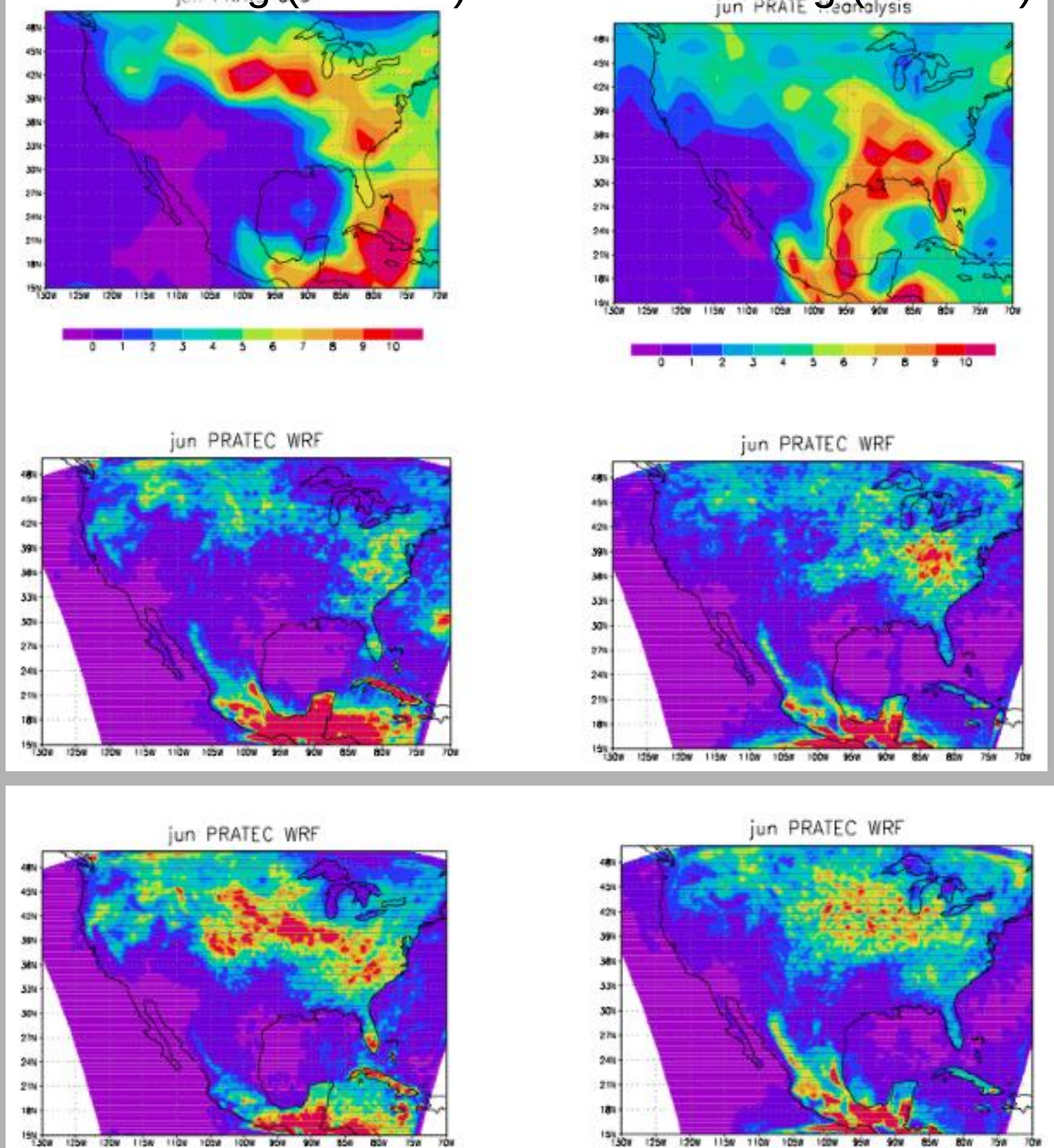
CFS member
Downscaling (TYPE 3)

NCEP Reanalysis:
Downscaling (TYPE 2)

Original
Global model

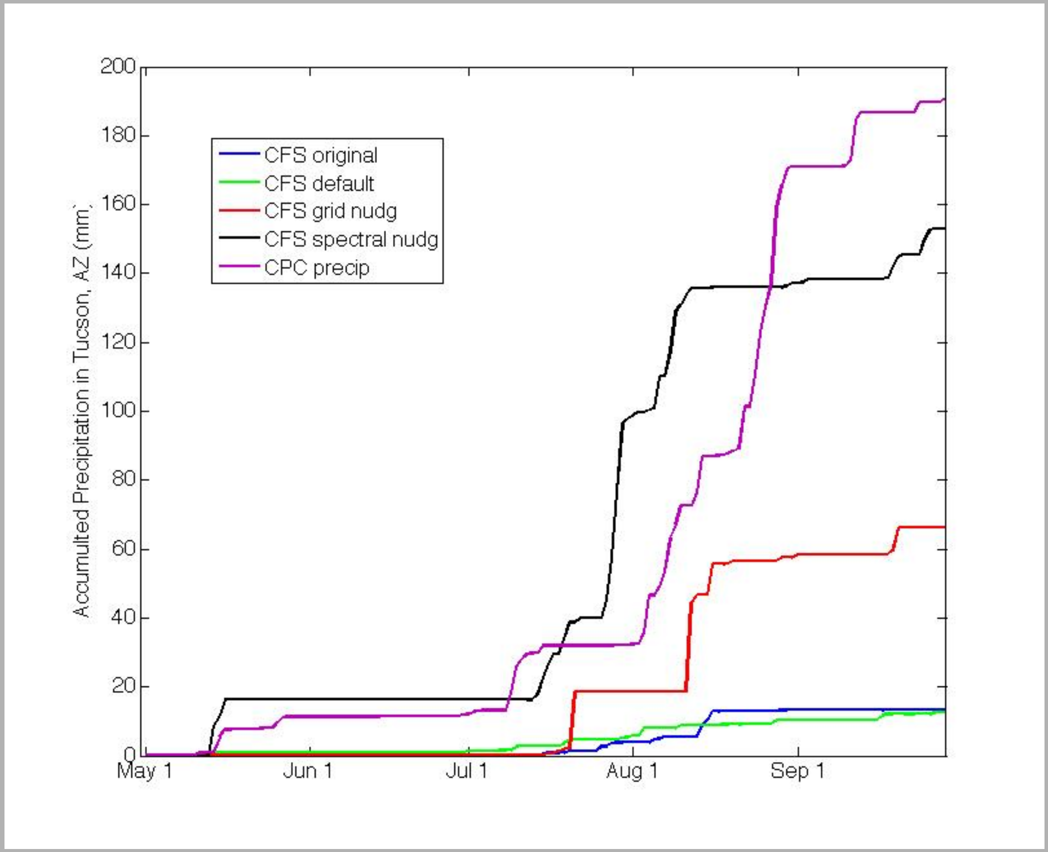
WRF
Lateral boundary
nudging only

WRF
Spectral nudging



1993 Summer precipitation Tucson, AZ

Single CFS ensemble member initialized in May



WRF downscaled simulation with spectral nudging gives best result!

Original CFS model <u>and</u> WRF-CFS downscaled with no interior nudging HAVE NO MONSOON!

Conclusions

•The results for CLM reported in *Rockel et al.* (2008) are similar to those found in the RAMS study by *Castro et al.* (2005) for basic experiments using nudging only in a lateral boundary sponge zone. In both models, there is a loss of large-scale variability with increasing domain size and grid spacing.

•Internal nudging can alleviate loss of large-scale variability in both RCMs.

• Spectral nudging yields less reduction in added variability of the smaller scales than grid nudging and is therefore the preferred approach in RCM dynamic downscaling. WRF experiments confirm this for higher order downscaling types (Types III and IV).

•Results suggest the effect to be largest for physical quantities in the lower troposphere (e.g. moisture flux convergence, rainfall)

Additional comments

•The utility of all regional models in downscaling primarily is not to add increased skill to the large-scale in the upper atmosphere, rather the value added is to resolve the smaller-scale features which have a greater dependence on the surface boundary.

•However, the realism of these smaller-scale features needs to be quantified, since they will be altered to the extent that they are influenced by inaccurate downscaling of the larger-scale features.

• Though spectral nudging currently presents the best “solution” to ensure variability is retained on the large-scale, we don’t have good explanations as to what causes the loss of variability at the large-scales without it. Should be an area of future study…