# 3.2 DETERMINING THE RESOLVED SPATIAL SCALES OF ETA MODEL PRECIPITATION FORECASTS

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## 1. INTRODUCTION

In this work, we attempt to discover whether the Eta model produces structure and spatial variability over a range of spatial scales in a manner consistent with observations. As the grid spacing of numerical weather prediction (NWP) models used in operations and research continues to decrease, while at the same time model numerics and physical parameterizations continue to become more sophisticated, one likely expects models to produce forecast fields that look more and more realistic. We illustrate this expectation with a hypothetical example. A tool for quantifying the spatial variability of a field over a wide range of scales is the Fourier power spectra. In Figure 1, the spectrum of a hypothetical observed field, such as precipitation or kinetic energy, is compared to spectra from hypothetical NWP models with different grid spacings. Here the variance of the observed field is shown to increase with increasing wavelength up to a certain scale, where it more or less levels off, similar to what has been found in spectral analysis of actual data (e.g., Errico 1985, Harris et al. 2001). NWP models are expected to underpredict

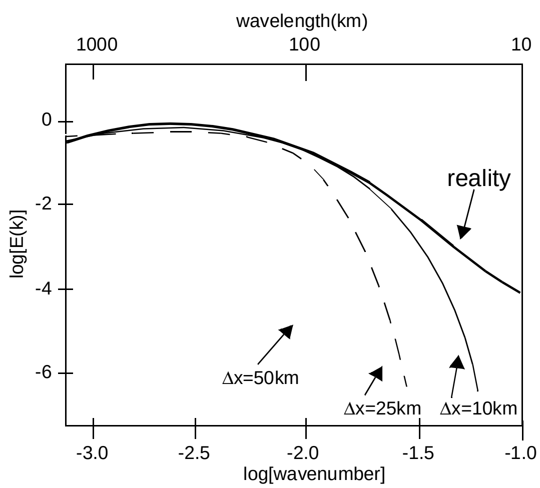


**Figure 1**: Hypothetical Fourier spectra for an observed field (thick solid), and NWP models with grid spacing of 10km (thin solid), 25km (long dashed), and 50km (short dashed).

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the structure of smaller scales because of the implicit smoothing properties of the finite differencing schemes, and explicit smoothing due to parameterized horizontal diffusion and vertical turbulent mixing. However, for larger spatial scales somewhat beyond the point where this smoothing affects the forecast fields, one expects the NWP model to simulate processes with similar variability as those observed. The effects of both implicit and explicit smoothing should be a function of grid spacing, therefore it is reasonable to expect the spatial structure represented by NWP models to expand to smaller and smaller scales as grid spacing decreases. This is displayed in Figure 1 by the different spectra from the hypothetical NWP models. The model with the coarsest grid spacing (50km) produces little variability at 2 Δx (100km) and variability that is reasonably similar to reality possibly near the 5-8 Δx point (~300km). As the model grid spacing decreases, the “gap” between reality and the NWP forecast is filled in, therefore, the structure of forecast fields should appear more realistic at smaller and smaller scales. In this work, we define “resolution” as the spatial scale where the forecast and observed spectra begin to diverge. In this hypothetical example, we would consider the model with Δx=25km to have a resolution of ~100km. Note the distinction between *resolution* and *grid spacing* (see recent correspondence on this issue by Pielke 2001 and others).

While this hypothetical example may decribe what is expected of NWP models, there is scant evidence (besides subjective impressions) to establish what range of spatial scales NWP models are actually predicting structure similar to that found in observed fields. Unfortunately, we do not have a history of analyses of this type to judge how forecast models have predicted spatial structure as they have evolved over time. Anthes (1983) advocated the verification of forecast “realism” in addition to traditional accuracy measures, through the use of analysis of spectra, structure function, etc. However, this concept has not been applied extensively across the NWP community. Recent work by Harris et al. (2001) with the ARPS model shows that the variability of forecast precipitation from that particular model agreed with observations for scales larger than approximately 5 Δx. However, we do not expect this "resolved scale" to apply in general to all NWP models, due to differences in numerics, physical parameterizations, data assimilation techniques, etc. The question remains, over what ranges of scales are NWP models predicting spatial variability in agreement with observations? Conversely, over what range of scales are NWP models significantly underpredicting the spatial structure?

There are a variety of users that demand forecasts containing realistic spatial variability across a wide range of scales. For example, forecasters at the Storm Prediction Center (SPC) are often faced with the problem of determining the likely mode of convection (e.g., squall line, bow echo, isolated celluar convection) up to 72h in advance. Explicit guidance from NWP models containing realistic spatial precipitation patterns, even with errors in timing and phase, would be of considerable value to these forecasters. Managers of operational forecasting units are interested in obtaining information on the spatial structure of NWP forecasts to help in deciding on their investment in communications and mass storage. They do not want to waste bandwidth by obtaining, for example, 10km grids when grids with 40km spacing might contain practically the same information and require 1/16th the number of bits. Hydrologists are interested in the small-scale spatial and temporal variability of precipitation, which is important for flood prediction and modeling land-atmosphere interaction. Certainly, the motivation exists for examining the spatial structure of forecast fields.

In this work, we will examine different measures of spatial structure as a function of scale in forecast fields from NWP model forecasts, comparing these measures to those found in observed fields, following the work of Harris et al. (2001). In particular, 3h accumulated precipitation fields from NCEP's operational Eta model, which runs at 12km grid-spacing with the Betts-Miller-Janjic (Janjic 1994) convective scheme, are compared to an experimental version of the Eta running at NSSL (hereafter KF), with 22km grid-spacing and the Kain-Fritsch (Kain and Fritsch 1993) convective scheme. In addition, forecast precipitation fields from experimental runs of the WRF model (Skamarock et al. 2001) at 22km (hereafter WRF22; 28 vertical mass coordinate levels, Kain-Fritsch convection, NCEP 3 class cloud microphysics, MRF PBL) and 10km (WRF10; 35 mass coordinate levels, Kain-Fritsch convection, NCEP 5 class microphysics, MRF PBL) which were running at NCAR are also compared. Observed precipitation fields are obtained from the operational 4km national hourly "Stage II" analysis available at NCEP (Baldwin and Mitchell 1998). Fourier power spectra, structure function, and moment-scale analyses will be used to analyze the spatial variability of forecast fields by each of these models. Due to space constraints, in this paper we will focus on Fourier spectra from a recent case. There are several factors separating the operational Eta from the experimental KF, WRF22, and WRF10 runs (numerics, convective parameterization, cloud microphysics, grid spacing, explicit horizontal diffusion, PBL, etc.). For the conference, the impact of many of these factors on the spatial structure will be examined by comparing the results from off-line Eta and WRF model runs.

## 2. SPECTRAL ANALYSIS RESULTS

To make the analysis easier to perform, forecasts were linearly interpolated to the same 4km grid as the observed rainfall analysis. This was done so the same domain could be compared on a regular grid. While the interpolation will introduce some smoothing, the effect should be small over the scales at which the models are running (10-22km) since the interpolation is made to a smaller grid spacing. The impact of this interpolation on the resulting analysis will be addressed at the conference presentation. A 311x451 subset of the grid, centered approximately at 40N 97W was used for these analyses. Across this region, the spatial variation of topography is relatively small and likely quite similar between reality and the various NWP models. This choice was made in order to focus on spatial structures that might be generated by the physical and dynamical processes in the models, in a region that is most likely free from the influence of orographically forced circulations. Figure 2 shows the observed and forecast precipitation from the various runs of the Eta and WRF models over this domain. The case that was chosen for this analysis was from a 3-6h forecast beginning at 1200 UTC 4 June 2002. At this time, there was a surface cyclone located in northeast Iowa with a cold front trailing southwestward across Kansas, northwest Oklahoma, and the Texas panhandle. The cold front was progressing southeastward and heavy rainfall was observed in the vicinity of this front. As shown in Figure 2, each model predicted significant rainfall in the vicinity of the observed precipitation, although there are considerable differences in the spatial variability exhibited by these precipitation fields. These results are shown mainly as an example and we caution that results from one case should not be taken as a general rule for every event. Fields from the early part of a forecast are most likely affected by spin-up problems, so these results may be quite different from those found at later forecast hours. For the conference presentation, we will show the ensemble average of analyses of several cases and a wide range of forecast times.

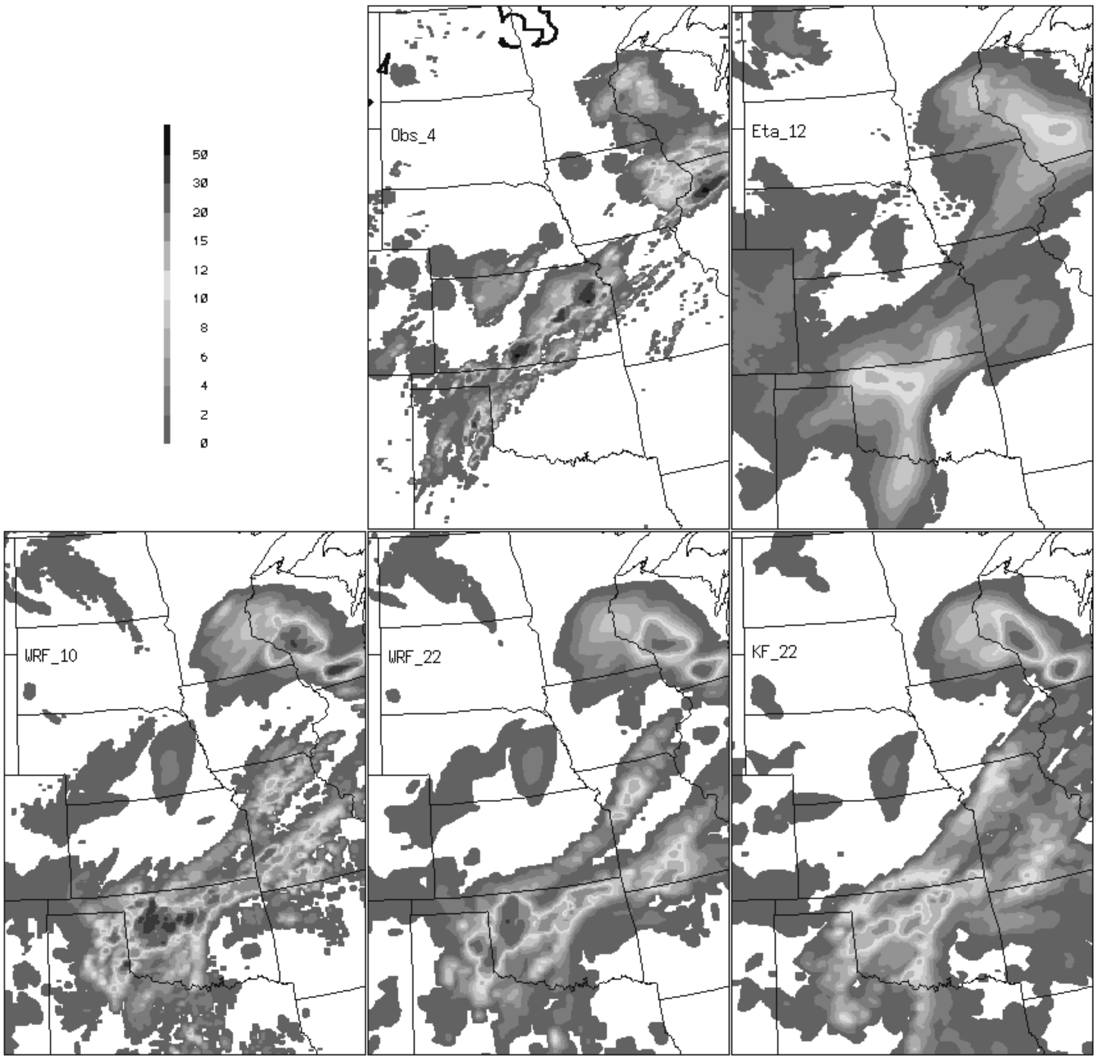


**Figure 2:** 3h accumulated precipitation (mm) valid 1800 UTC 04 June 2002. Top center: observed precipitation from the NCEP Stage II analysis. Top right: 3-6h 12km Eta forecast. Bottom left: as in top right except 10km WRF forecast. Bottom center: 22km WRF. Bottom right: 22km KF.

The Fourier spectra for each precipitation field displayed in Figure 2 were produced using the Errico (1985) technique. This method performs a 2-D Fourier transform to determine the spectral coefficients. The spectral coefficients are multiplied by their complex conjugate to produce the 2-D variance spectrum, this is converted to 1-D by an annular average of the spectra. This averages out any anisotropy that may exist in the fields, we are not assuming the fields are isotropic but this technique allows for easier comparison of the different spectra.

Figure 3 shows the resulting spectra. The figure in the top left corner shows all models and the observed field plotted together. Here, the observed field displays the greatest spatial variability across the widest range of scales (down to ~10km). The WRF10 is very similar to the observed spectrum to approximately 30km wavelength, where it quickly drops off. The spectra next closest to the observed are from the WRF22 and KF runs, which are very similar. These spectra agree closely with the observed down to a scale of approximately 100km, then quickly drop off at smaller scales. Finally, the spectrum from the operational Eta is least similar to the observed, starting to diverge from the observed spectrum at fairly long wavelengths and consistently dropping off as the spatial scale decreases.

A feature often observed for a wide variety of atmospheric fields that manifests itself in Fourier power spectra is the presence of scale invariance (Harris et al. 2001) across a range of scales. Scale invariance, or simple scaling, is where the energy spectrum follows a power law: $E(k) \propto k^{-\beta}$ where β is defined as the s*pectral slope*. This is evident on a log-log plot of E(k) versus k as a region where the specturm follows a fairly straight line. The spectral slope is an indicator of the smoothness of a field (Davis et al. 1996) where higher

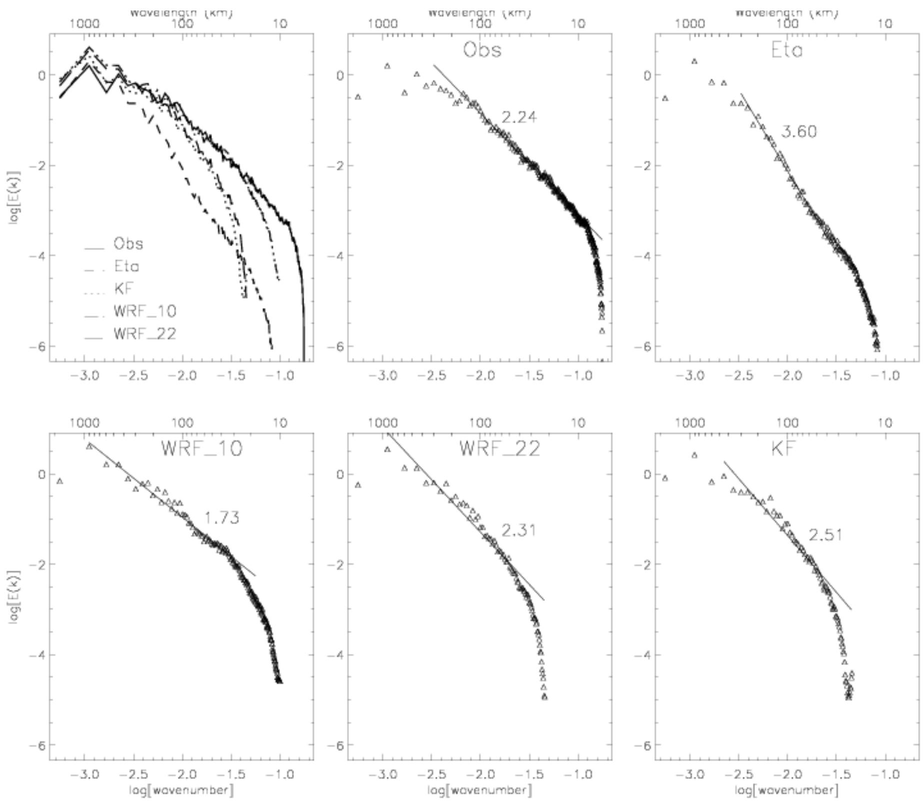


**Figure 3:** Spectra of precipitation fields shown in Figure 2. Top left: observed, Eta, KF, WRF10, and WRF22 spectra. Top center: observed spectra with spectral slope. Top right: as top center except 12km Eta. Bottom left: 10km WRF. Bottom center: 22km WRF. Bottom right: 22km KF.

values of $\beta$ indicate a smoother, more organized spatial structure. For each spectrum in Figure 3, the range of scales over which simple scaling exists was determined subjectively, and the spectral slope was found by a least-squares fit to the spectrum across that range of scales. On the individual plots in Figure 3, the value of $\beta$ is provided along with the line that fit the spectrum in the range of scales where simple scaling was found. In this case, the WRF10 is not as smooth, the WRF22 and KF are similar to, and the Eta is much smoother than the observed field. While there are many factors that contribute to uncertainty in the estimation of these spectral slopes (see Davis et al. 1996), it is clear from both the spectral analysis and visual inspection of the forecast fields that the operational Eta model field contains much less spatial variability than the observed field.

## 3. CONCLUDING REMARKS

In this work, we will continue to compare the spatial variability of model forecast and observed fields. The results from the WRF22 and KF are quite similar, which may not be surprising considering their similar grid spacing and convective schemes. The impact of decreasing the grid spacing in the WRF from 22 to 10km is consistent with expectations, while the result of decreased grid spacing between the 22km KF and 12km operational Eta is certainly not.

For the conference, results from generalized structure function and moment-scale analysis of precipitation fields will be presented, following Harris et al. (2001). Structure function supplies much of the same information that spectral analysis provides, indicating the amount of smoothness and organization in the structure of the field. However, structure functions are better able to deal with the nonlinear character of atmospheric processes (Marshak et al. 1997). Moment-scale analysis provides information on the intermittency of a field, that is the sparseness of rainfall of different amounts (beyond zero intermittancy: rain/no-rain). The combination of these analyses will provide a more complete quantitative picture of the structure of forecast fields.

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