# Spatial Forecast Verification

**Verification Spinup for WRF Tutorial,**
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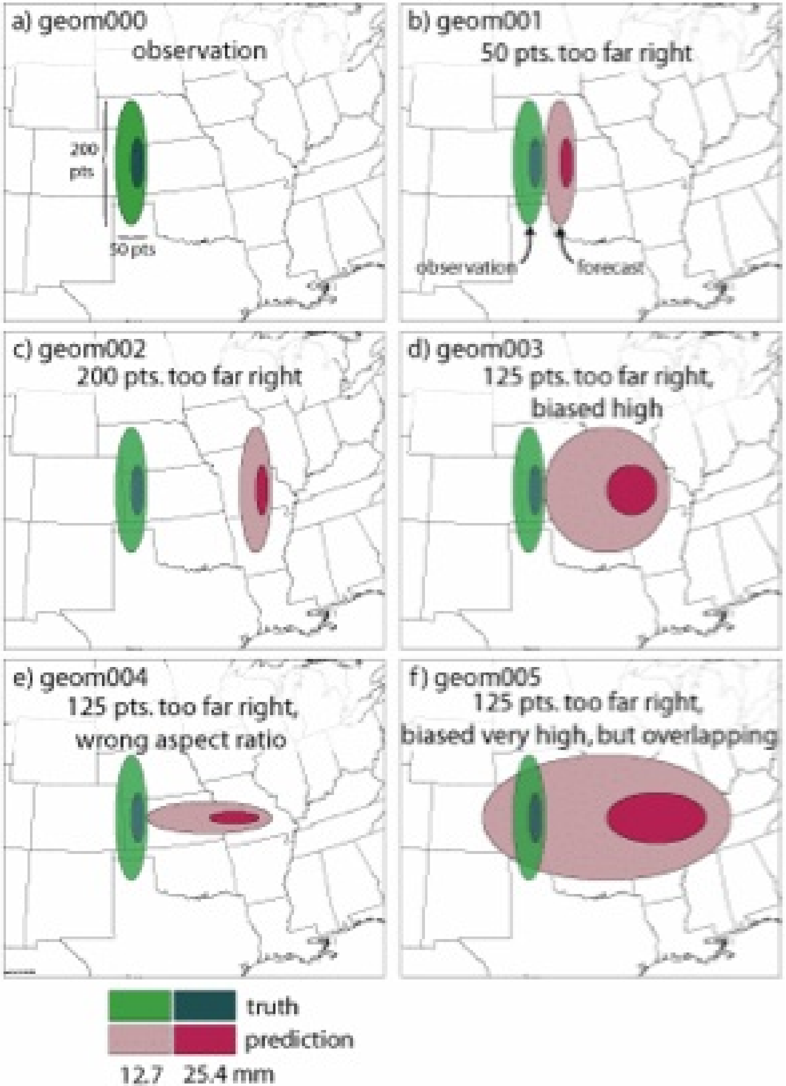
Photo by Everett Nychka

# Background and Motivation




## Traditional Approach

Based on comparing overlapping grid points...

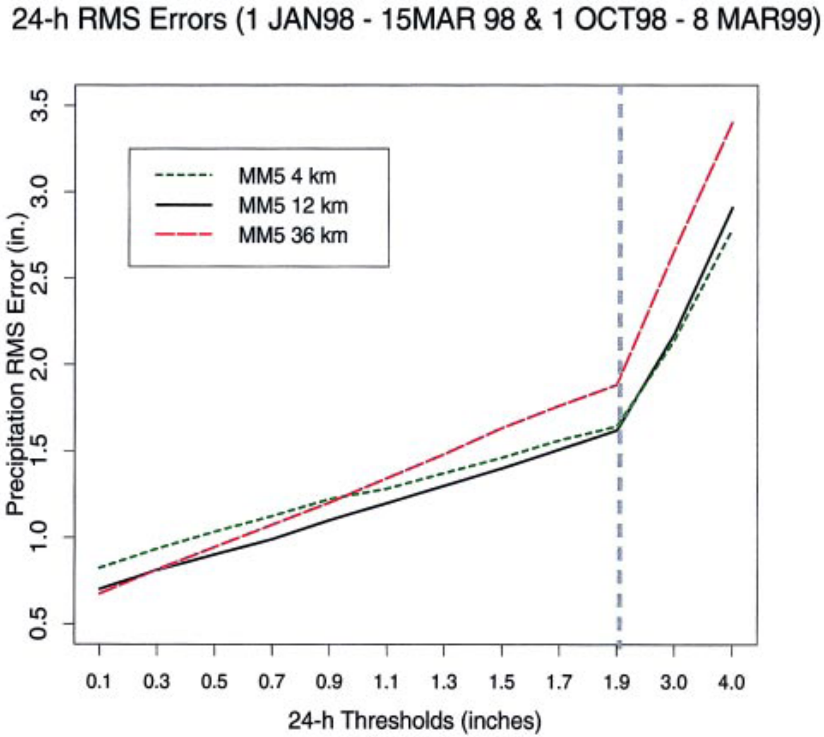
| Score | b–e | f |
|---|---|---|
| Correlation Coefficient | -0.02 | 0.2 |
| Probability of Detection | 0.00 | 0.88 |
| False Alarm Ratio | 1.00 | 0.89 |
| Hanssen-Kuipers | -0.03 | 0.69 |
| Gilbert Skill Score | -0.01 | 0.08 |

By these scores, forecast f is best.

Which is best for you?

# Forecast Verification

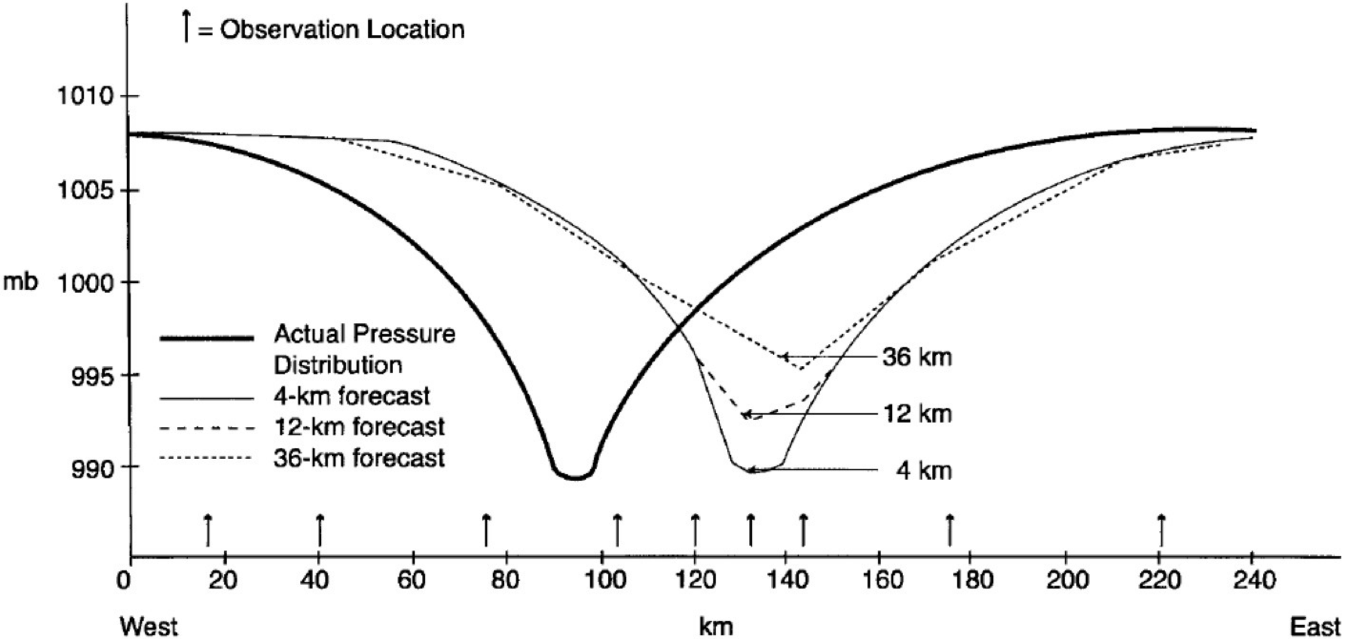
Mass *et al.*, 2002: Bull. Amer. Meteorol. Soc., **83**, 407–430.




“Decreasing grid spacing in mesoscale models to less than 10–15 km generally improves the realism of the results but does not necessarily significantly improve the objectively scored accuracy of the forecasts."

# Forecast Verification

Mass *et al.*, 2002: Bull. Amer. Meteorol. Soc., **83**, 407–430.




Timing error: Traditional ***grid-point to grid-point*** verification yields RMSE of 4.19-, 4.81- and 5.25- mb for 36-, 12- and 4-km, resp.

# Forecast Verification: High vs. Low Resolution

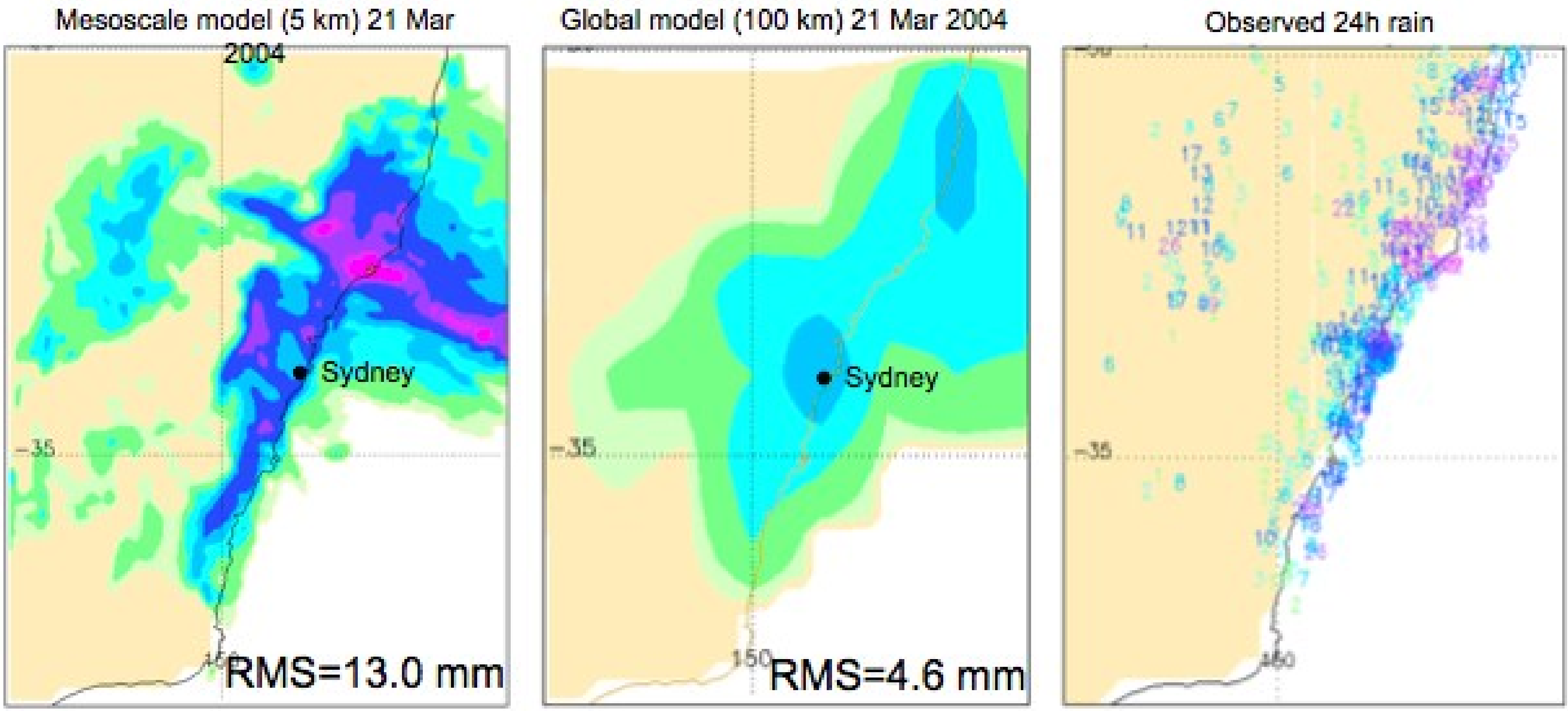
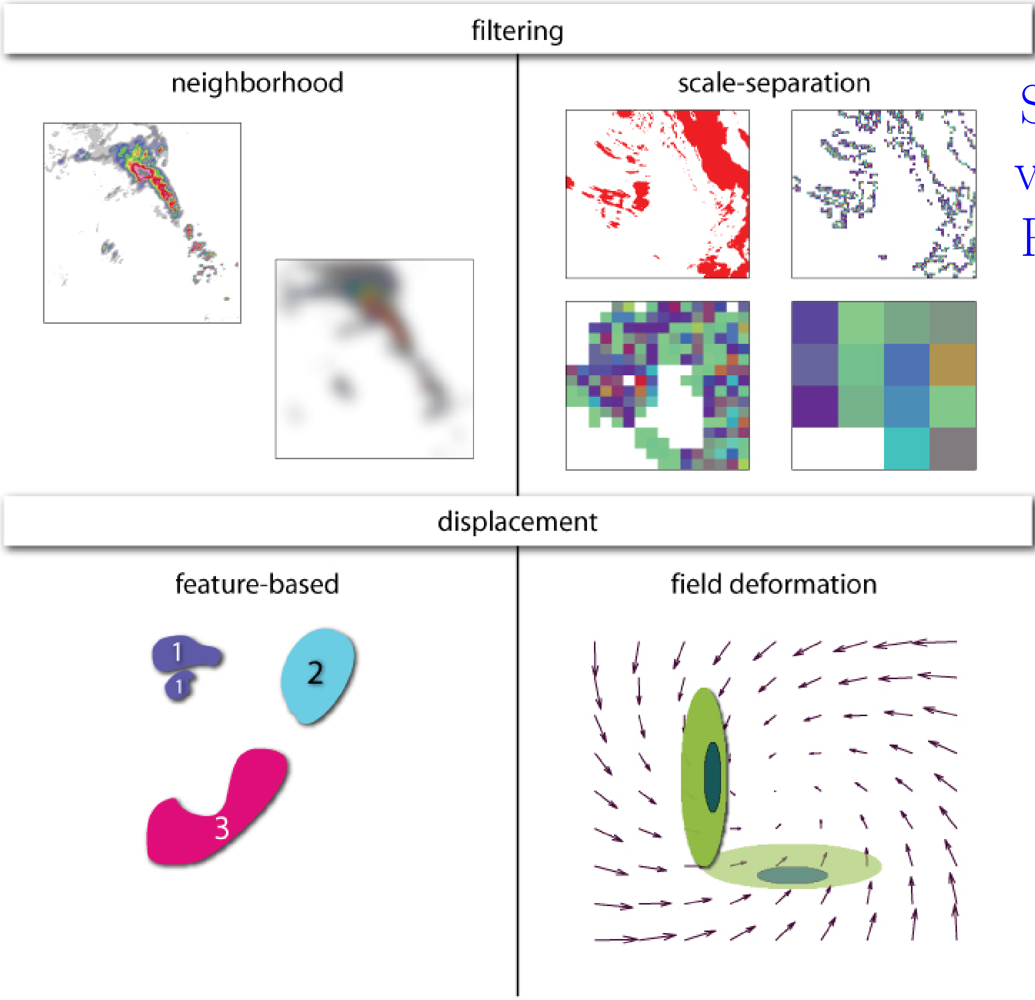



Fig. from E.E. Ebert

Which forecast would you prefer to use?

# Spatial Forecast Verification Methods

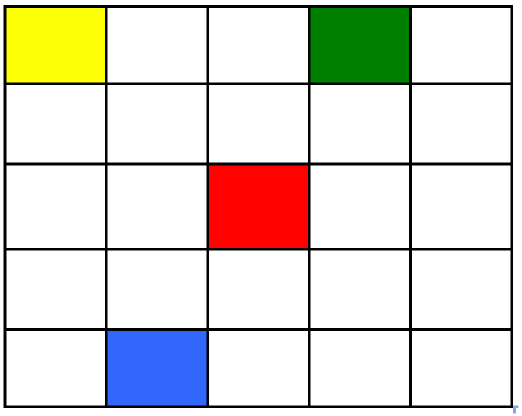



Spatial forecast verification Inter-Comparison Project (ICP)

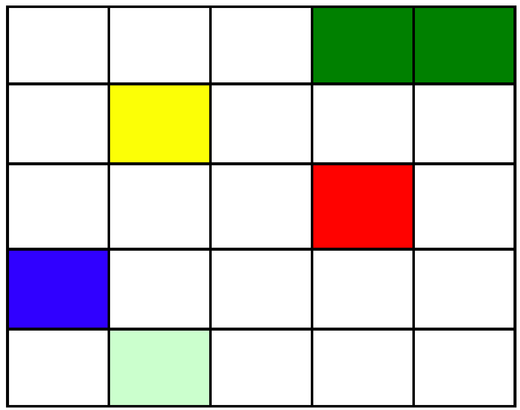
# Filter Methods : Neighborhood

Neighborhood of length 5 around a grid square (center square).

Forecast



Verification



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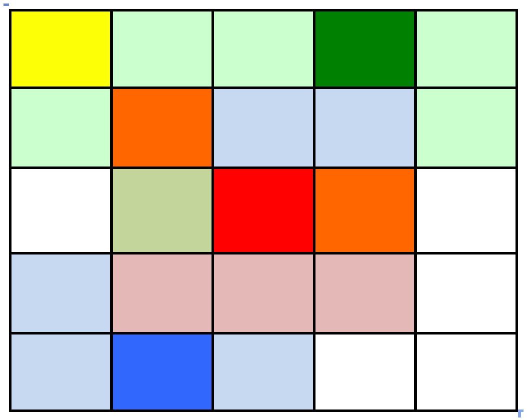
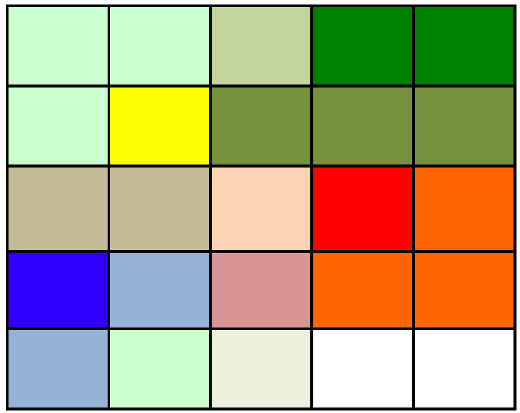
Forecast



Verification

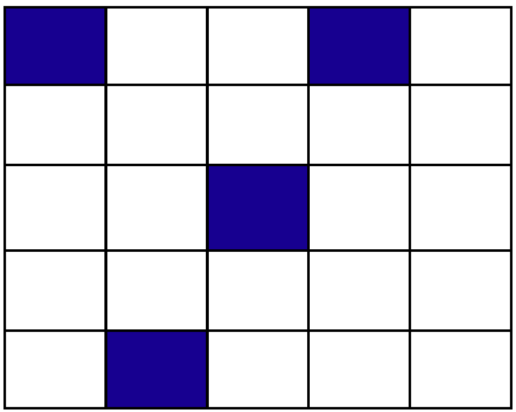


Smoothed (in some way) over a neighborhood of length 3.

# Filter Methods : Neighborhood

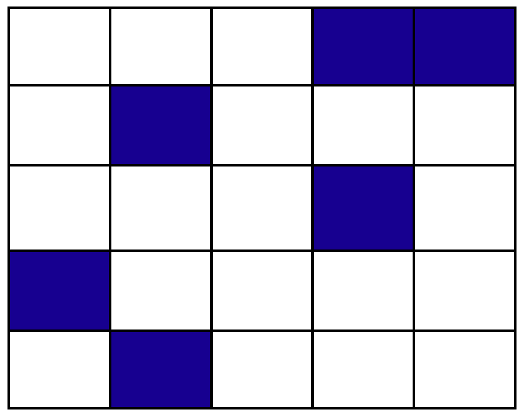
Neighborhood of length 5 around a grid square (center square).

Forecast



4/25

Verification



6/25

Event-based smoothing.

# Filter Methods : Neighborhood

For a spatial field, $\boldsymbol{X} = [x_{ij}]$, the smoothed field, $\tilde{\boldsymbol{X}}$, at each point $\tilde{x}_{ij}$ is given by

$$\tilde{\boldsymbol{X}} = [\tilde{x}_{ij}] = \left[ \sum_{k=1}^{n} \sum_{l=1}^{n} x_{kl} K_{\lambda} \left( x_{ij} - x_{kl} \right) \right],$$

where $x_{kl}$ are the neighbors of $x_{ij}$ (including $x_{ij}$), $K_{\lambda}$ is a non-increasing function called a kernel with smoothing parameter $\lambda$ that determines the amount of smoothing. For example, for neighborhood smoothing (i.e., the average value over the nearest $n^2$ grid points) with neighborhood length $n$,

$$K_{\lambda} = K_{n} = 1/n^2.$$

# Filter Methods : Neighborhood

## Convolution smoothing with kernel $\boldsymbol{K}$ and smoothing parameter $\lambda$.

We can write

$$\tilde{\boldsymbol{X}} = [\tilde{x}_{ij}] = \left[\sum_{k=1}^{n}\sum_{l=1}^{n} x_{kl} K_\lambda (x_{ij} - x_{kl})\right]$$

$$= \boldsymbol{X} * \boldsymbol{K}_\lambda,$$

where $*$ denotes the convolution operator.

# Filter Methods : Neighborhood

Convolution smoothing with kernel $\boldsymbol{K}$ and smoothing parameter $\lambda$.

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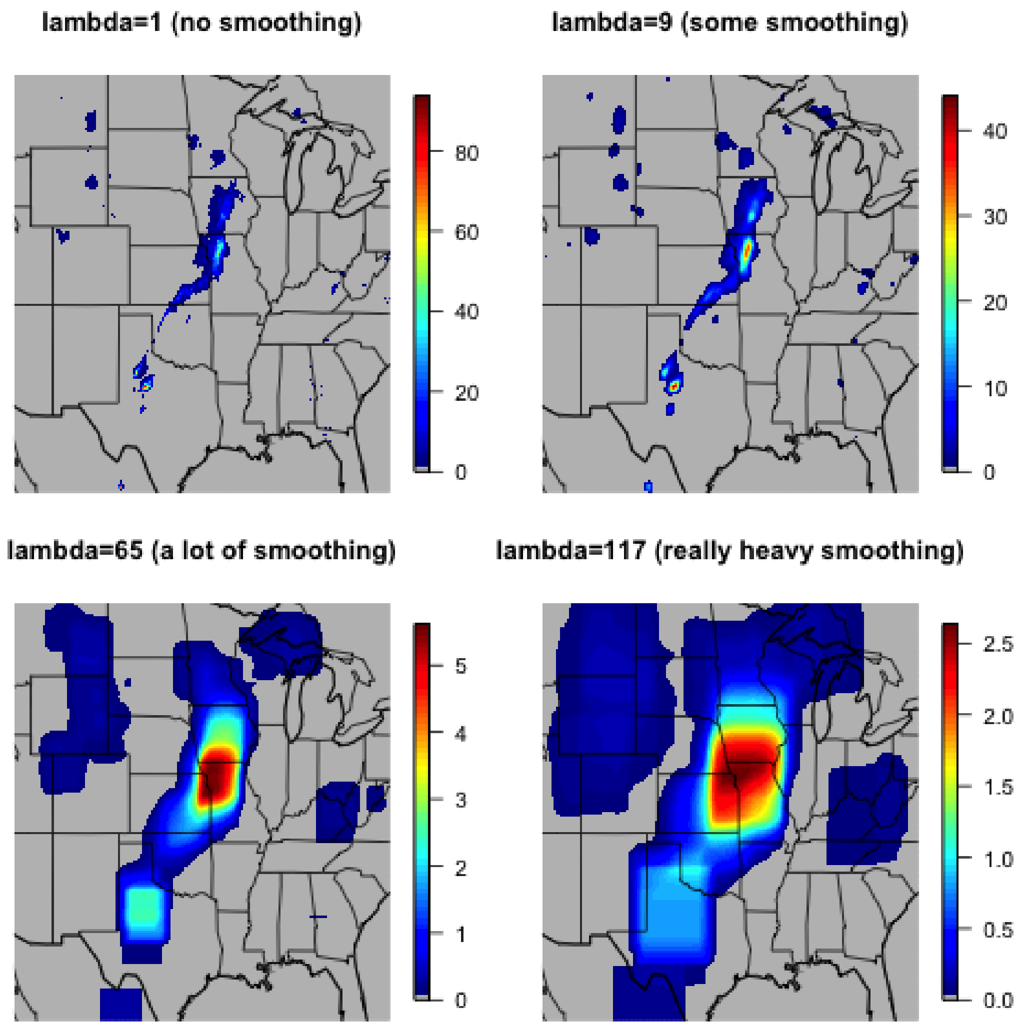
Fast computation with convolution theorem and FFT.

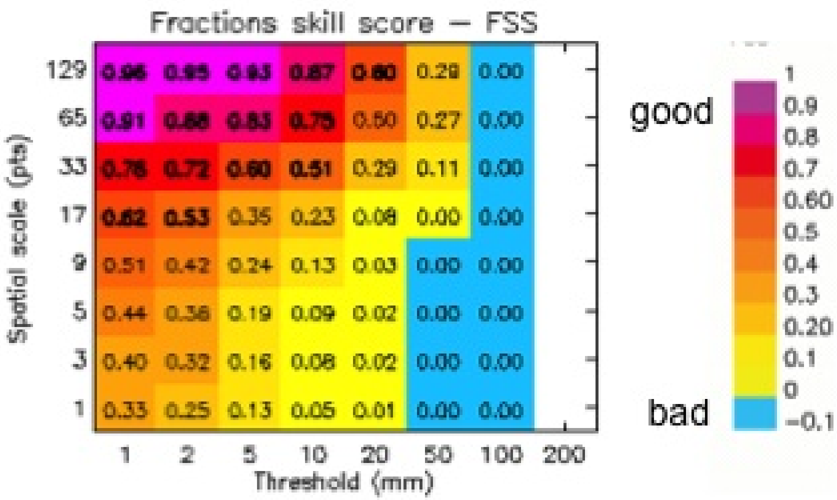
$\boldsymbol{X} * \boldsymbol{K}_\lambda = \mathcal{F}^{-1} (\nu \mathcal{F}(\boldsymbol{X}) \cdot \mathcal{F}(\boldsymbol{K}_\lambda))$

# Filter Methods: Neighborhood

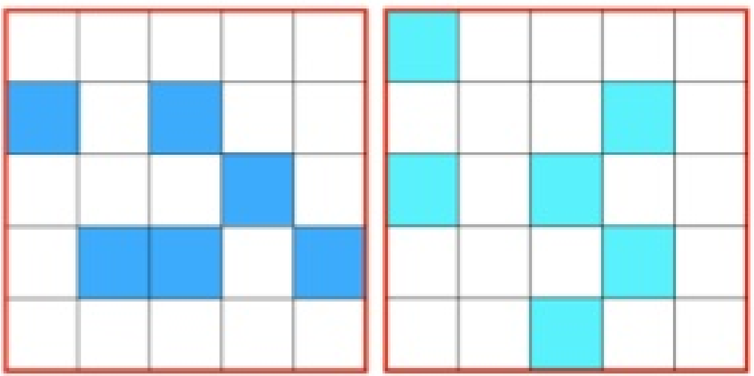



Note that color scales differ!

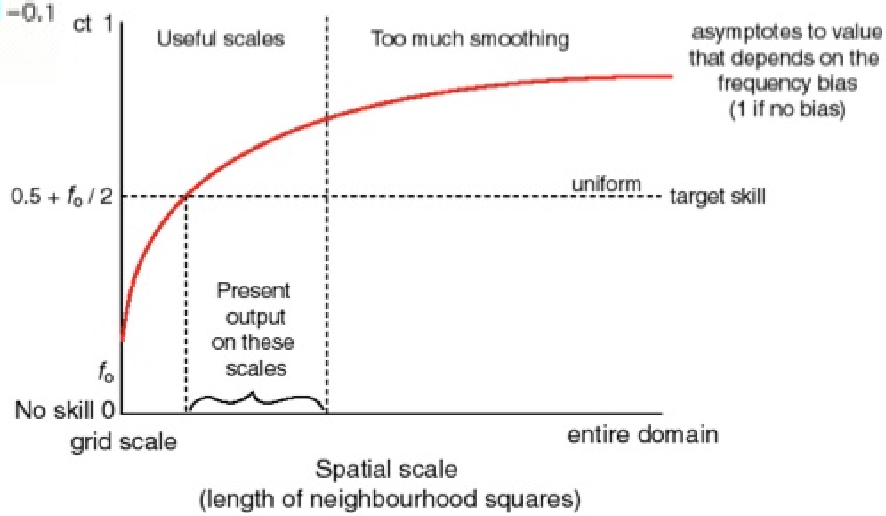
# Filter Methods: Neighborhood (Ebert, 2008)




$$\text{FSS} = 1 - \frac{\sum_{i=1}^{N} (P_{\text{fcst}} - P_{\text{obs}})^2}{\sum_{i=1}^{N} P_{\text{fcst}}^2 + \sum_{i=1}^{N} P_{\text{obs}}^2}$$



Fraction = 6/25 = 0.24 Fraction = 6/25 = 0.24




Fractions Skill Score (Roberts and Lean, 2008)

# Filter Methods: Scale Separation

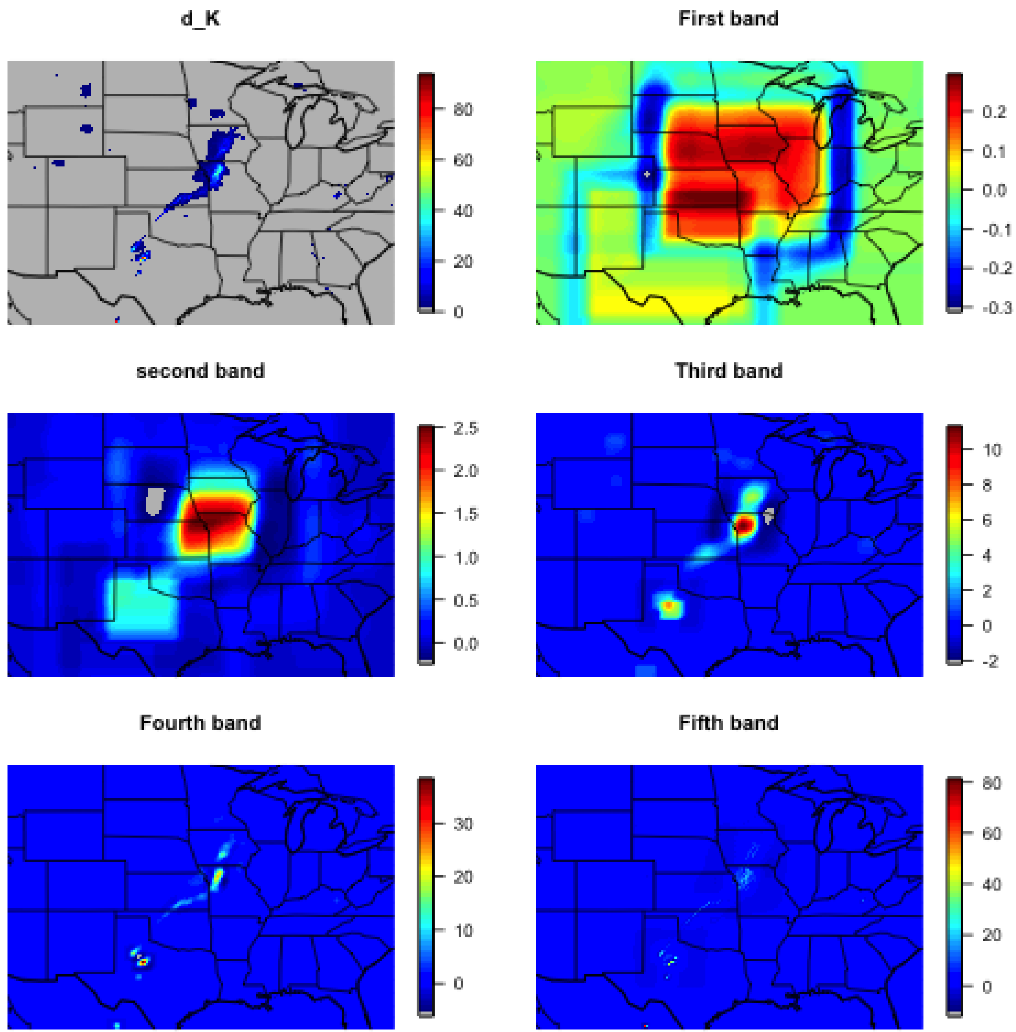
Let $\infty = \lambda_0 > \lambda_1 > \cdots > \lambda_K = 0$. Then $\lambda_0$ results in a lot of smoothing, and $\lambda_K$ in no smoothing. Define $\boldsymbol{d}_0 = \boldsymbol{X}$ and:

$$\boldsymbol{d}_m = \boldsymbol{X} * \boldsymbol{K}_{\lambda_m} - \boldsymbol{X} * \boldsymbol{K}_{\lambda_{m-1}}$$

$$= \boldsymbol{X} * \left(\boldsymbol{K}_{\lambda_m} - \boldsymbol{K}_{\lambda_{m-1}}\right) = \boldsymbol{X} * \boldsymbol{K}'_{\lambda'}$$

$\boldsymbol{d}_m$ are called detail fields.

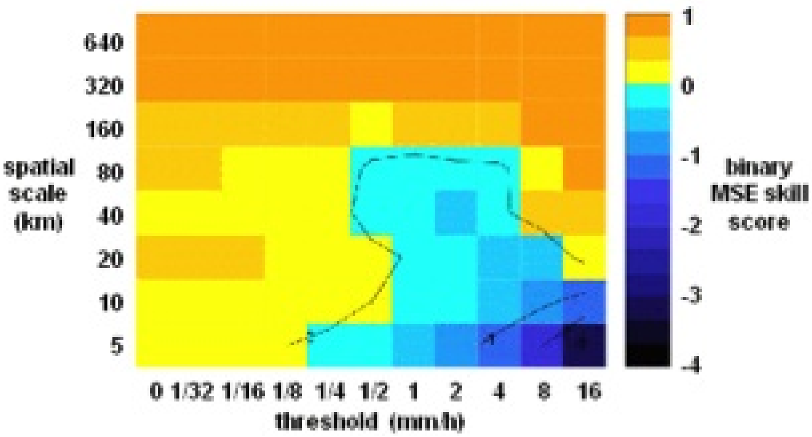
# Filter Methods: Scale Separation




Color scales differ!

Physically meaningful scales?

# Filter Methods: Scale Separation




Examples of bandpass filters:
Fourier, Wavelets,
Power spectra
(Harris *et al.*, 2001)

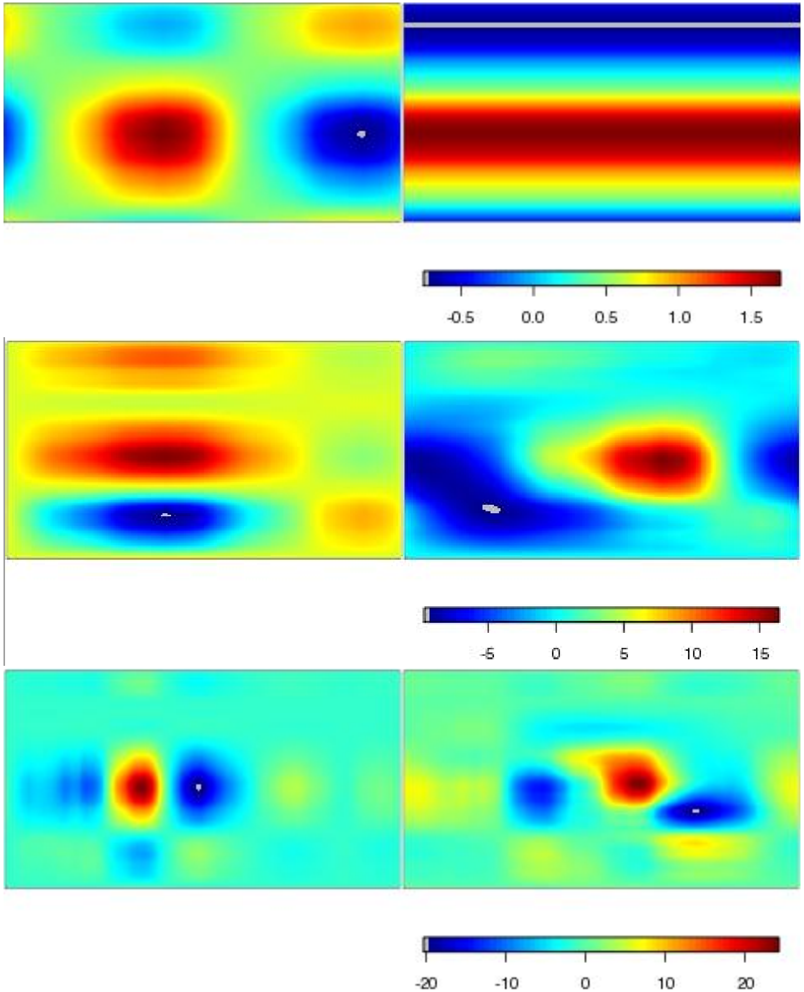
Wavelet detail fields (Briggs and Levine, 1996)

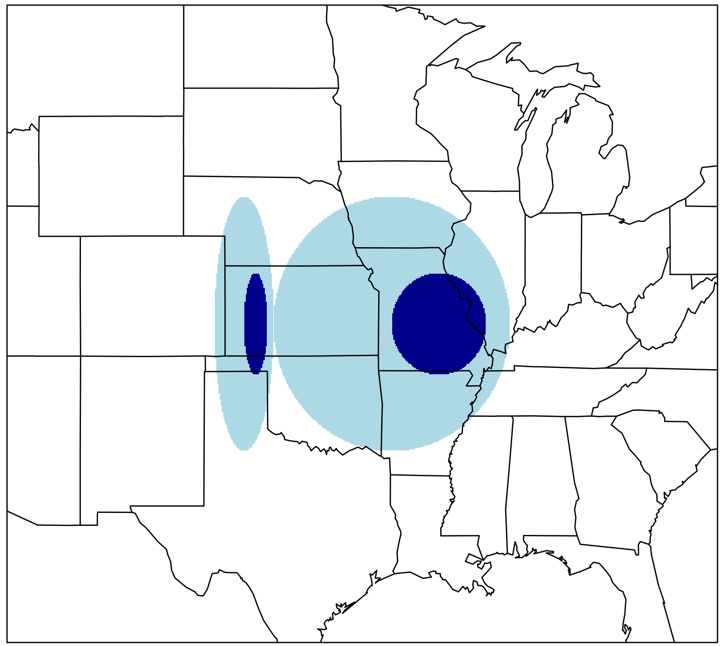
Intensity Scale (IS): (Casati *et al.*, 2004) (wavelets applied to binary event fields)

Multi-scale variability (Zapeda-Arce *et al.*, 2000; Harris *et al.*, 2001; Mittermaier 2006; Marzban and Sandgathe, 2009; Hering and Genton, 2011)

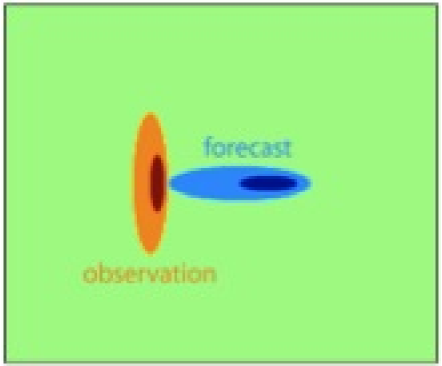
# Filter Methods: Scale Separation

## Wavelets



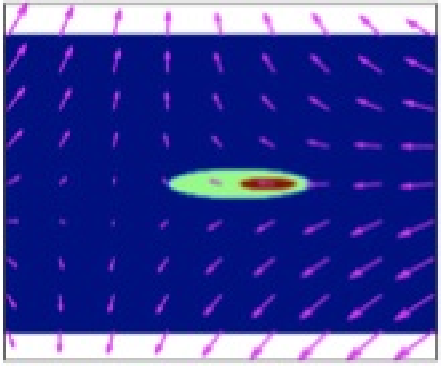



# Displacement Methods: Field deformation

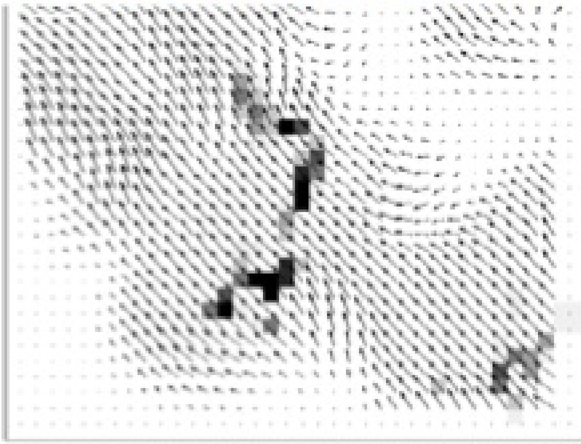



(Image) Metrics: Forecast Quality Index (FQI), (Venugopal *et al.*, 2005)

Baddeley's $\Delta$ metric (Gilleland, 2011; Schwedler and Baldwin, 2011)



From Keil and Craig 2008



$\text{metr}_V$ (Zhu et al., 2011)

Field morphing techniques: Optical Flow (e.g., Keil and Craig, 2009)

Image Warping (e.g., Gilleland, Lindström and Lindgren, 2010)

# Displacement Methods: Field Deformation

## Field Deformation Methods: Image Warping

Verification field $V$ (Finn), at each grid point $(x, y)$, is equal to the forecast field (Johan) at a mapping $(W_x, W_y)$ of $(x, y)$ plus error.

$$V(x, y) = F(W_x(x, y), W_y(x, y)) + \varepsilon(x, y)$$

# Displacement Methods: Field Deformation

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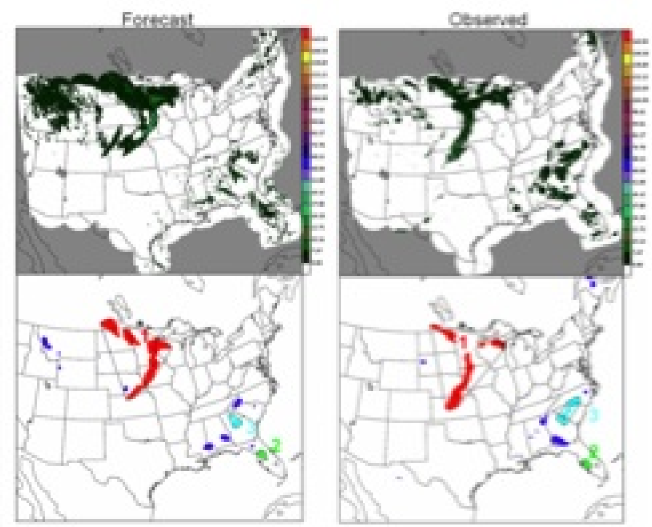
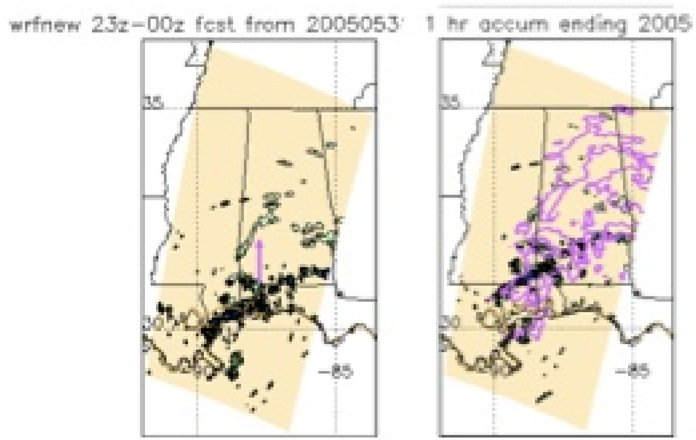
$$V(x, y) = F(W_x(x, y), W_y(x, y)) + \varepsilon(x, y)$$

Estimation of warp function parameters (i.e., control point locations) by way of optimizing a likelihood function.

# Displacement Methods: Feature based




MODE example 2008 CRA: Ebert and Gallus 2009

CRA (e.g., Ebert and McBride, 2000; Ebert and Gallus, 2009), MODE (e.g., Davis *et al.*, 2006, 2009), Procrustes (Lack *et al.*, 2009), SAL (e.g., Wernli *et al.*, 2008, 2009), Cluster Analysis (Marzbahn and Sandgathe, 2006a,b; Marzbahn et al. (2007, 2008), Composite (e.g., Nachamkin, 2006, 2009)

# Final Remarks

`http://www.ral.ucar.edu/projects/icp`

- Spatial Forecast Verification Methods Inter-Comparison Project (ICP)
- See ICP web page under the *References* and *Special Collection* sections for full references from these slides.
- A continuation of the ICP is about to commence.
- Participation in the ICP is encouraged. Sign up to receive emails at the web site.
- `SpatialVx` is a new R software package for spatial forecast verification techniques. The current version is minimal (neighborhood approaches only), but the next iteration will be out soon, and will be considerably more comprehensive. Look for an accompanying user manual to follow.