Spatial Forecast Verification Methods

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Goal

Describe new methods for evaluation of spatial fields

Many methods have been developed in the context of high resolution precipitation forecasts, which may have application to aerosol predictions

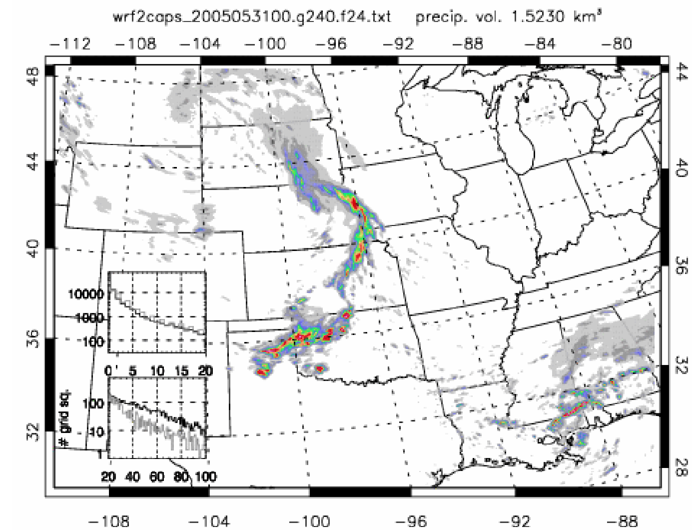
Context

- Motivation: Traditional verification approaches don't
  - Reflect observed capabilities of new (higher-resolution) modeling systems (generally with higher spatial resolution)
  - Provide diagnostic information about model performance (i.e., *what* was wrong)
- History: Most new spatial methods developed over the last 10-15 years
  - Initial methods published in early 1990s
  - Earliest "used" method published in 2000 (Ebert and McBride)
  - Beginning to be used operationally
- Initial development target: Mesoscale precipitation
- Other applications:
  - Clouds and Reflectivity
  - Jets and Low pressure systems (Mittermaier)
  - Convective storm characteristics (Clark)
  - Wind/RH
  - Climate/climatology
- Limitations: Typically requires gridded forecasts and observations

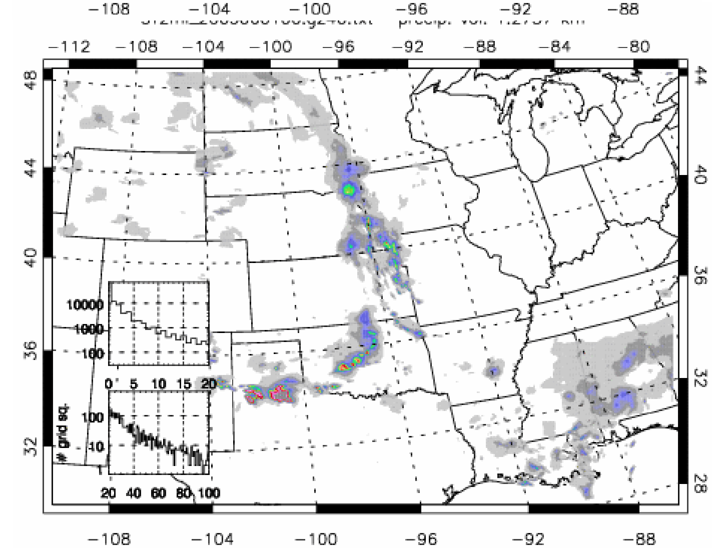
Spatial fields

Weather variables defined over spatial domains have **coherent spatial structure and features**

WRF model

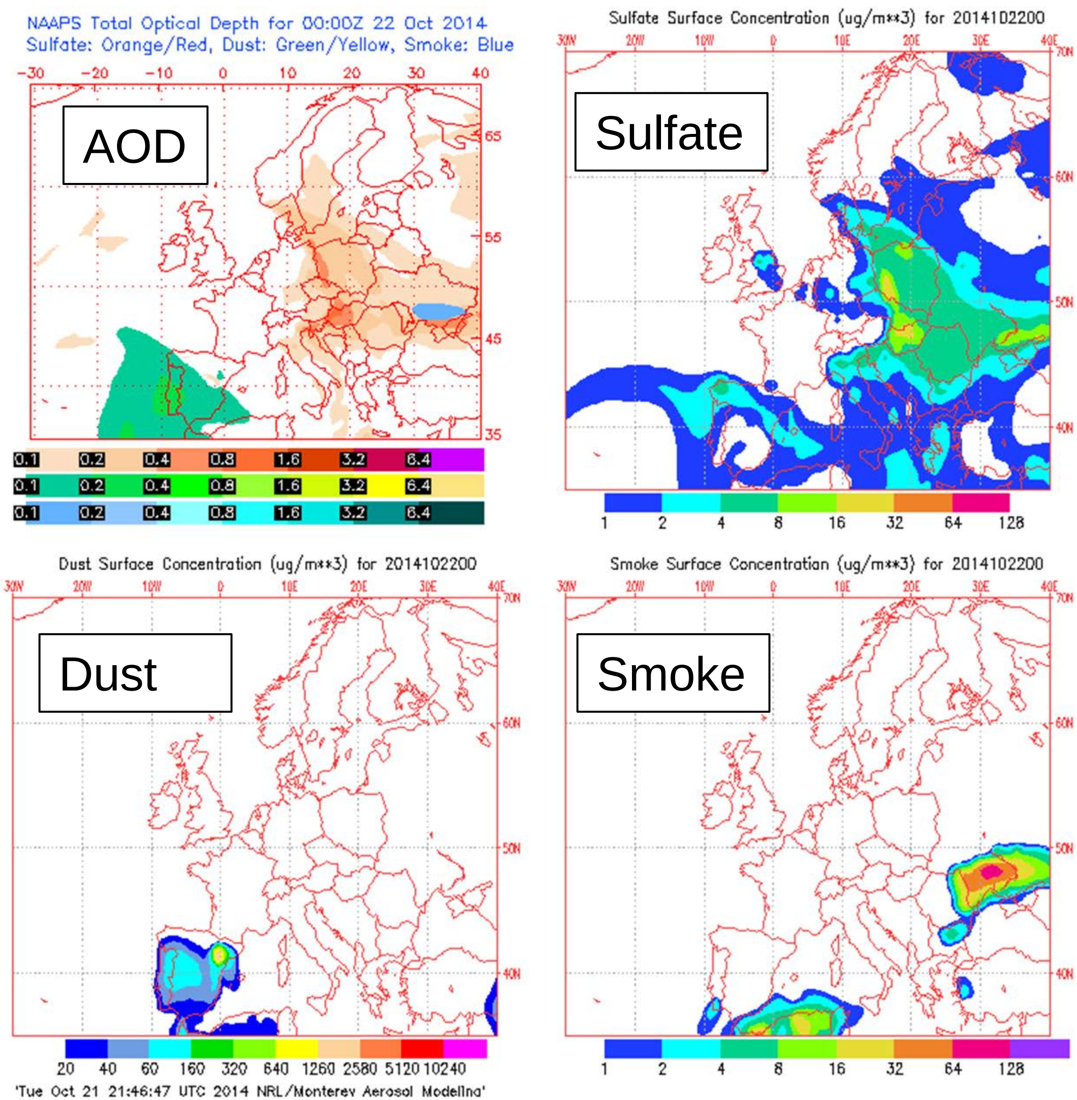


Stage II radar



Spatial fields

Weather variables defined over spatial domains have **coherent spatial structure and features**

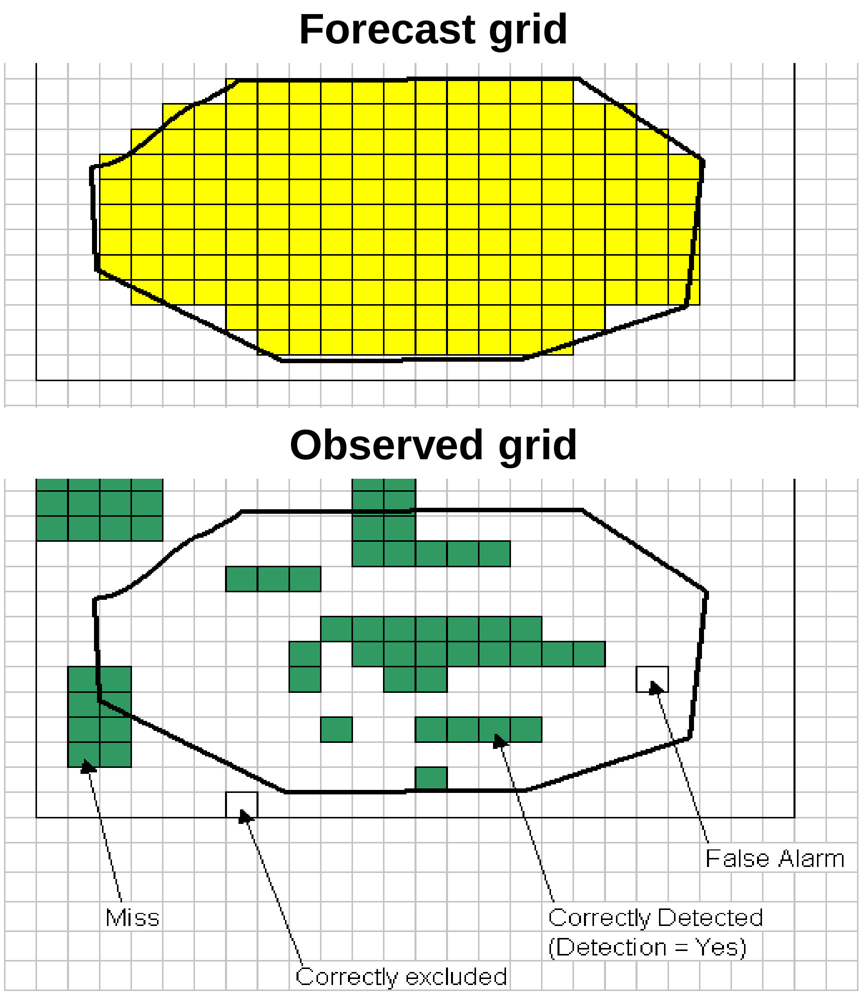


Matching two fields (forecasts and observations)

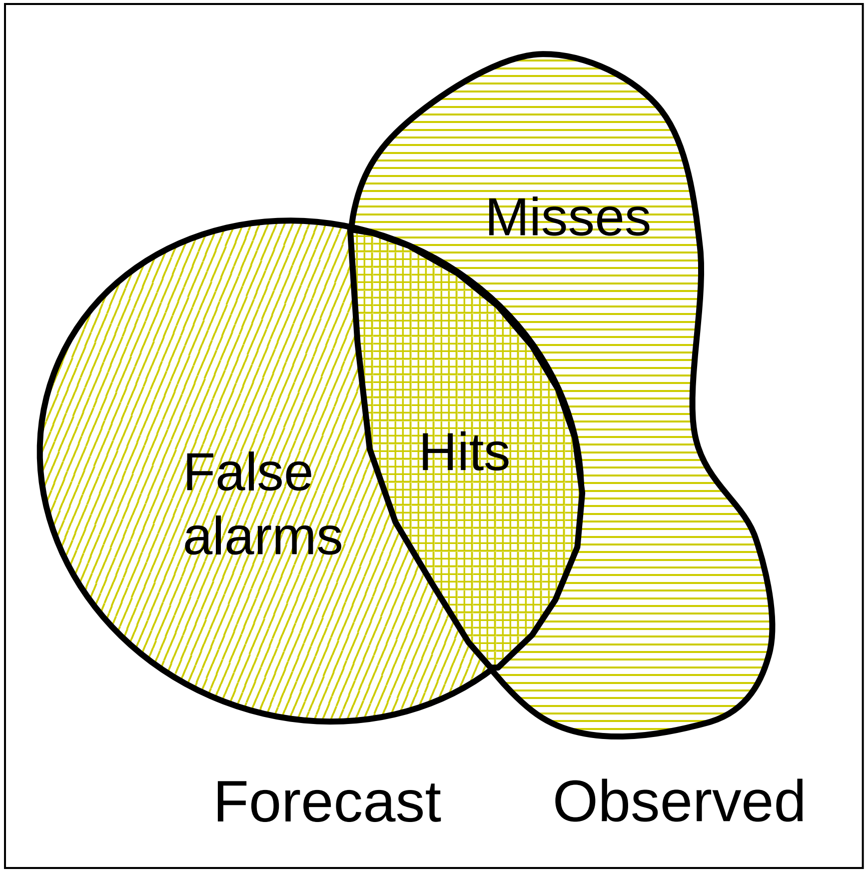
<u>Focus</u>: Gridded fields

Traditional grid to grid approach:

- Overlay forecast and observed grids
- Match each forecast and observation gridpoint



Traditional spatial verification measures

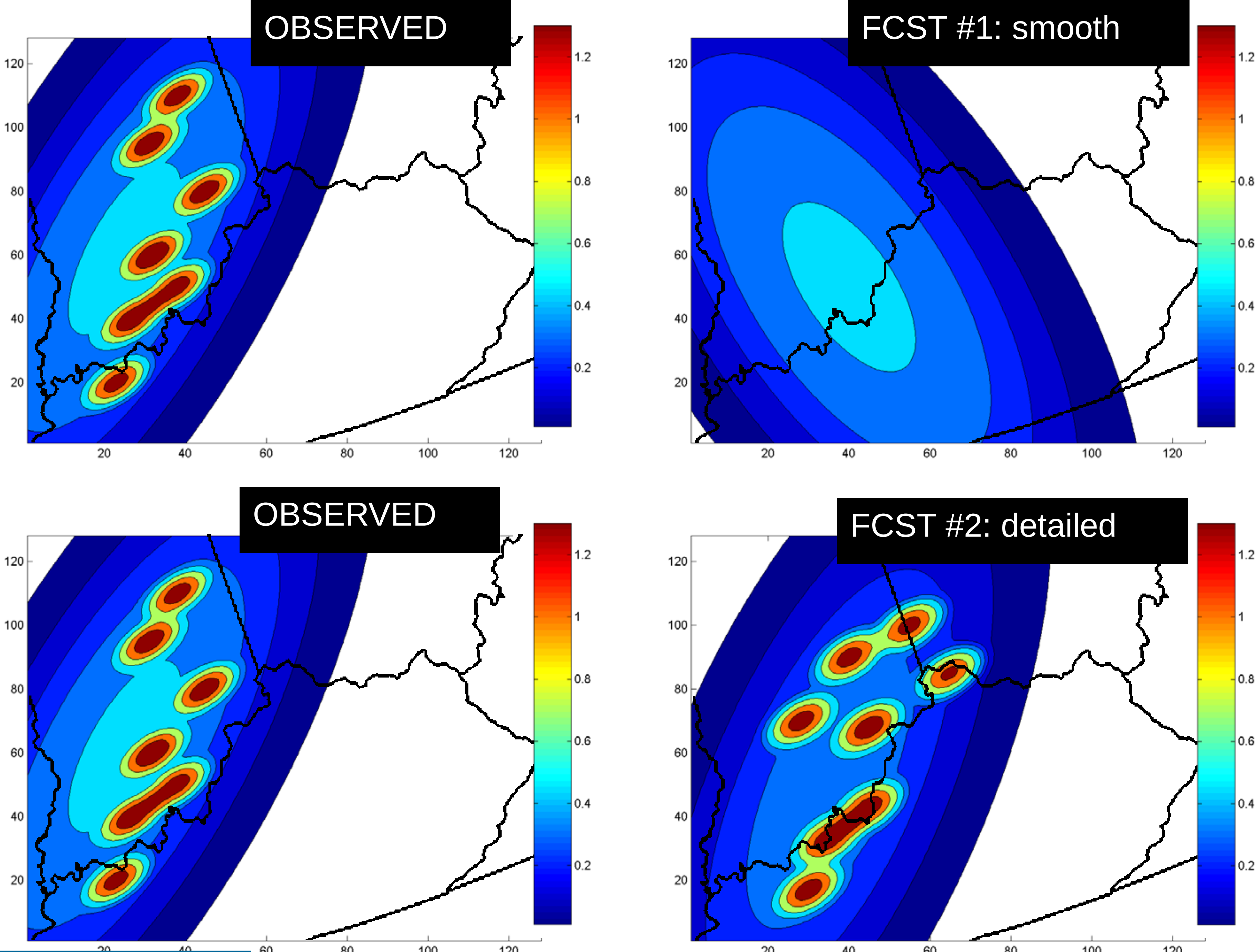


Contingency Table

		Observed	
		yes	no
Forecast	yes	*hits*	*false alarms*
	no	*misses*	*correct negatives*

Basic methods:

1. Create contingency table by thresholding forecast and observed values
   - *Compute traditional contingency table statistics: POD, FAR, Freq. Bias, CSI, GSS (= ETS)*
2. Directly compute errors in predictions
   - *Compute measures for continuous variables*: MSE, MAE, ME



From Baldwin 2002

“Measures-oriented” approach to evaluating these forecasts

Verification Measure	Forecast #1 (smooth)	Forecast #2 (detailed)
Mean absolute error	*0.157*	0.159
RMS error	*0.254*	0.309
Bias	0.98	0.98
CSI (>0.45)	*0.214*	0.161
GSS (>0.45)	*0.170*	0.102

From Baldwin 2002

What are the issues with the traditional approaches?

- "Double penalty" problem
- Scores may be insensitive to the *size* of the errors or the *kind* of errors
- Small errors can lead to very poor scores
- Forecasts are generally rewarded for being smooth
- Verification measures don't provide
  - Information about kinds of errors (Placement? Intensity? Pattern?)
  - Diagnostic information
    - What went wrong? What went right?
    - Does the forecast look realistic?
    - How can I improve this forecast?
    - How can I use it to make a decision?

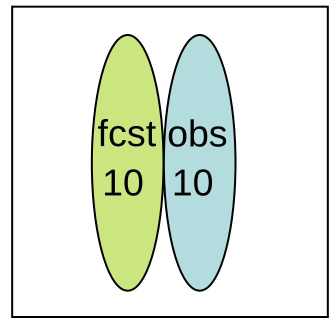
Double penalty problem

Traditional approach requires an ***exact match*** between forecasts and observations at every grid point to score a hit

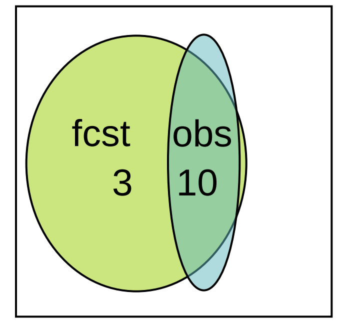
<u>Double penalty:</u>

(1) Event predicted where it did not occur => ***False alarm***

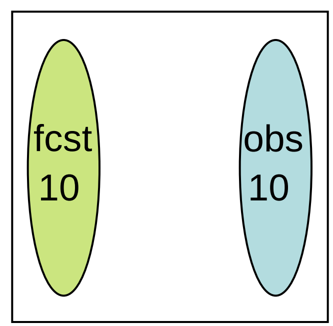
(2) No event predicted where it did occur => ***Miss***



Hi res forecast
RMS ~ 4.7
POD=0, FAR=1
TS=0



Low res forecast
RMS ~ 2.7
POD~1, FAR~0.7
TS~0.3



Summary: What are the issues with the traditional approaches?

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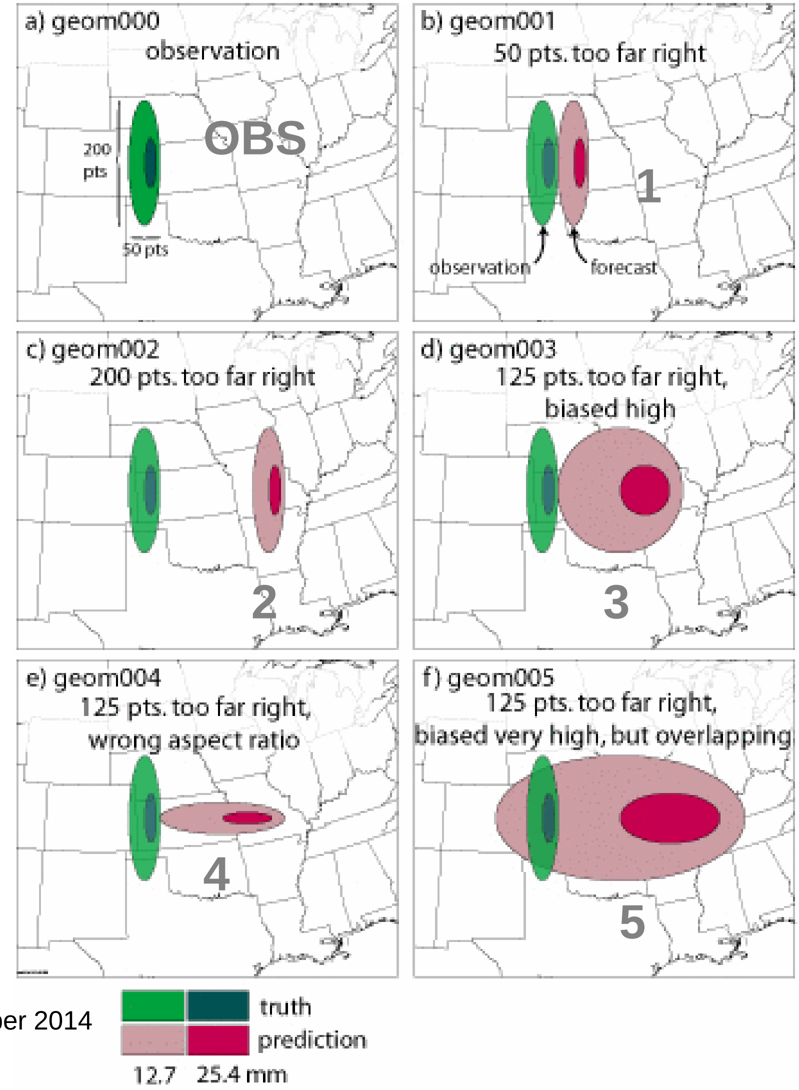
Traditional approach

Consider gridded forecasts and observations of precipitation

Which is better?



Traditional approach

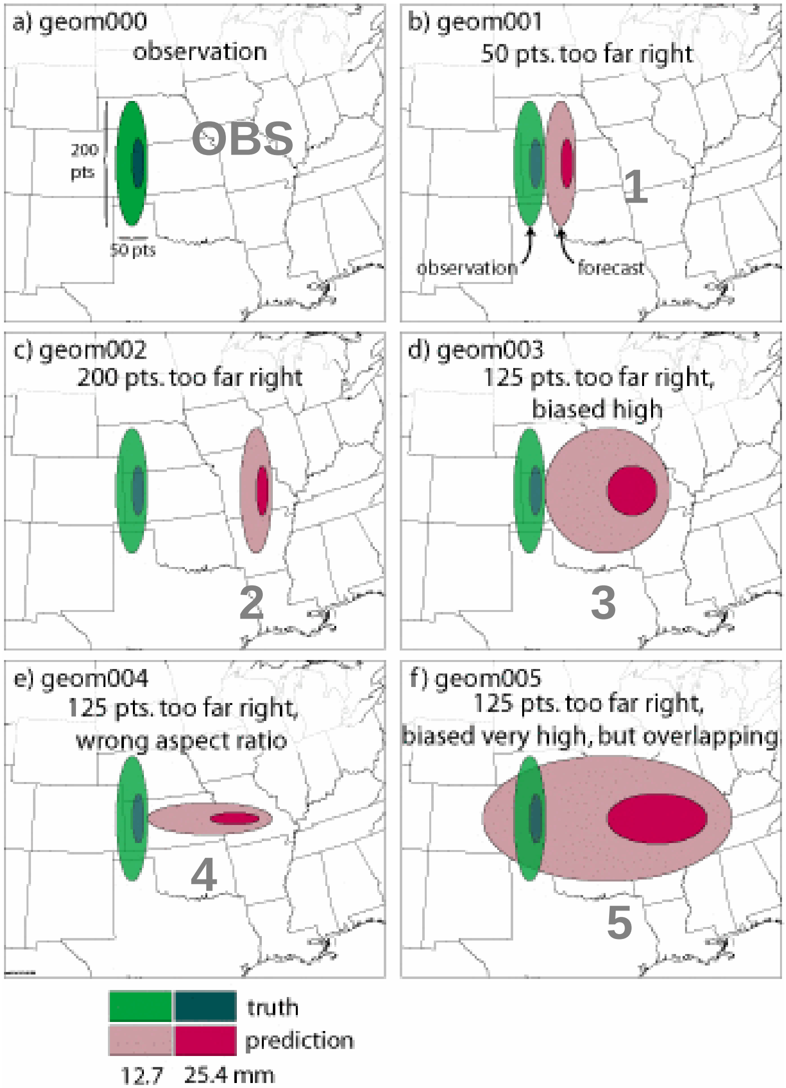
Scores for Examples 1-4:

Correlation Coefficient = -0.02
Probability of Detection = 0.00
False Alarm Ratio = 1.00
Hanssen-Kuipers = -0.03
Gilbert Skill Score (ETS) = -0.01

Scores for Example 5:

Correlation Coefficient = 0.2
Probability of Detection = 0.88
False Alarm Ratio = 0.89
Hanssen-Kuipers = 0.69
Gilbert Skill Score (ETS) = 0.08

Forecast 5 is "Best"



Summary: What are the issues with the traditional approaches?

- "Double penalty" problem
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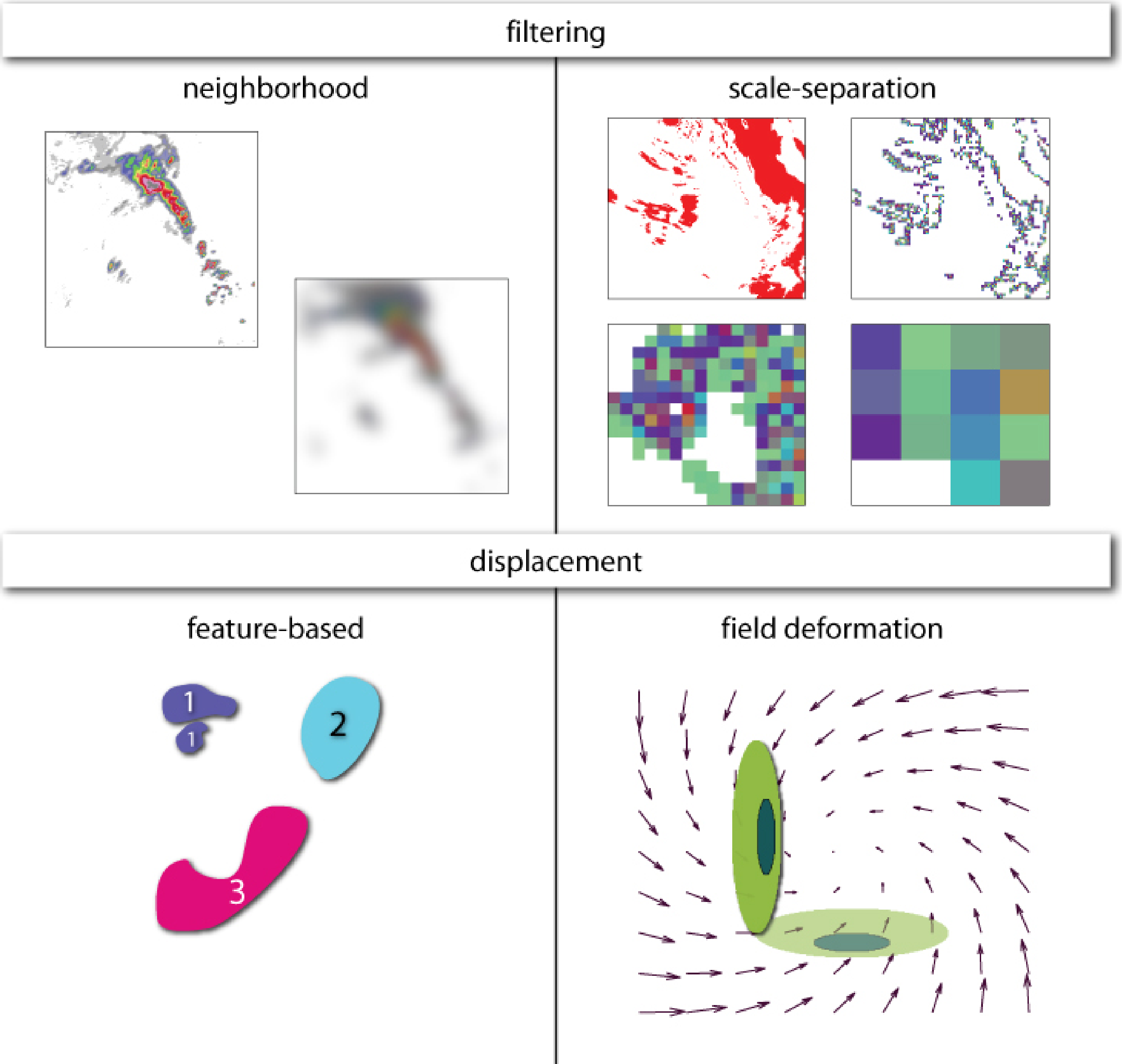
Spatial Method Categories

To address the issues described here, a variety of new methods have been developed



New spatial verification approaches

Neighborhood

Successive smoothing of forecasts/obs

Gives credit to "close" forecasts

Scale separation

Measure scale-dependent error

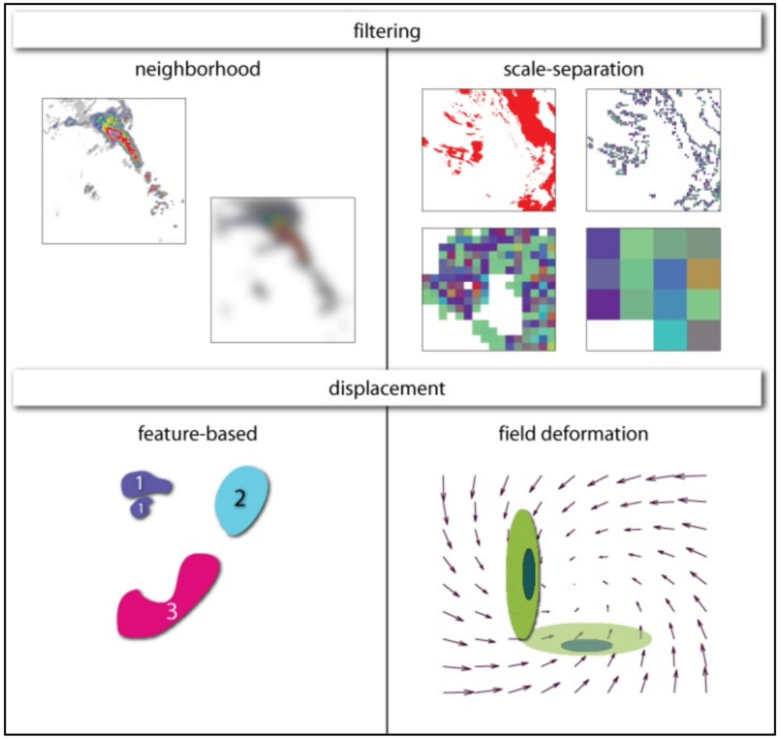
Field deformation

Measure distortion and displacement (phase error) for whole field

How should the forecast be adjusted to make the best match with the observed field?

Object- and feature-based

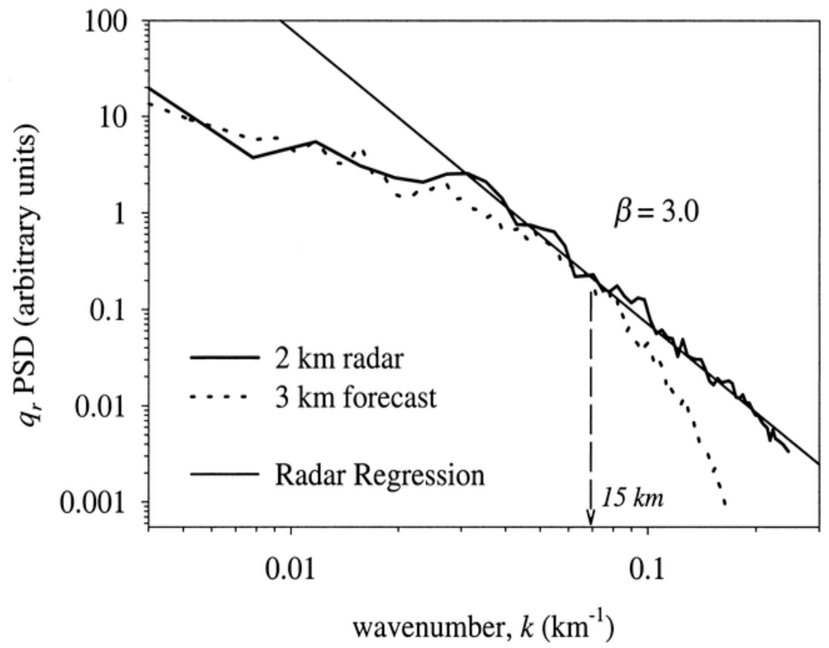
Evaluate attributes of identifiable features



Scale separation methods

- Goal:
  Examine performance as a function of spatial scale

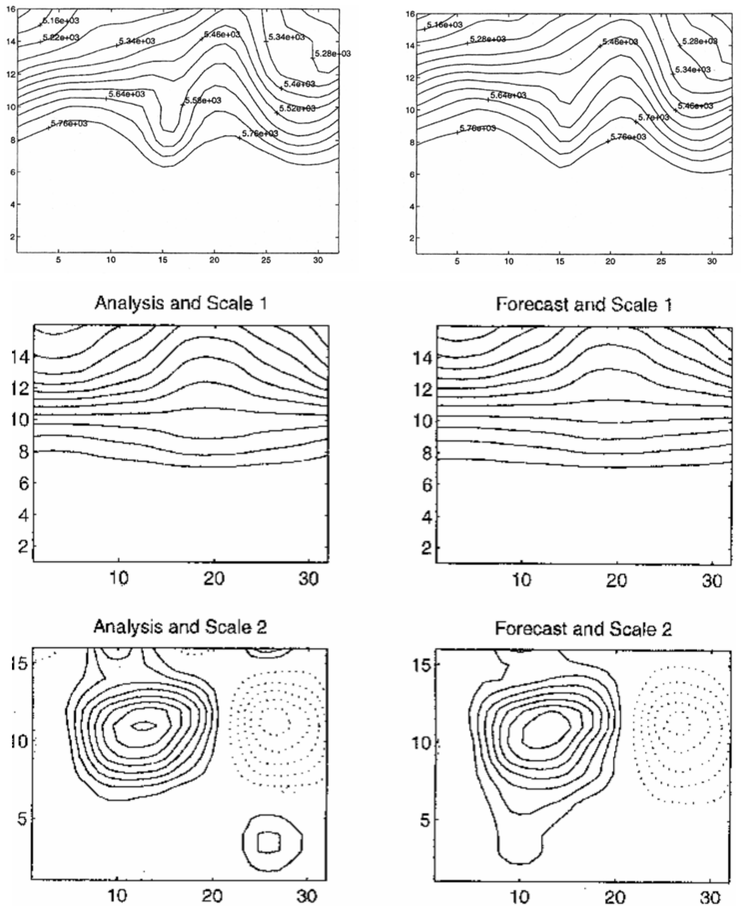
- Example: Power spectra
  - Does it look real?
  - Harris et al. (2001): compare multi-scale statistics for model and radar data



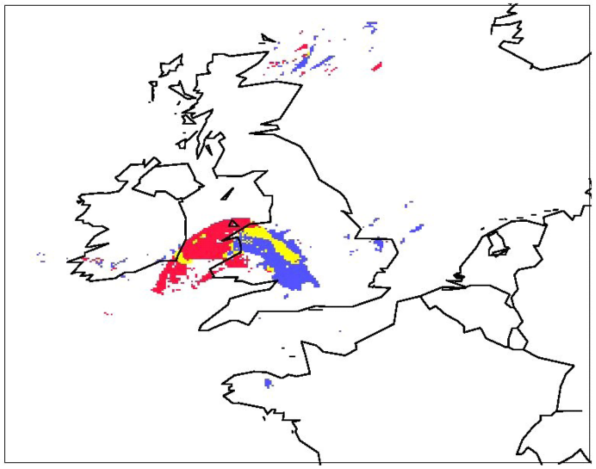
From Harris et al. 2001

Scale decomposition

- Wavelet component analysis
  - Briggs and Levine, 1997
  - Casati et al., 2004
- Examine how different scales contribute to traditional scores

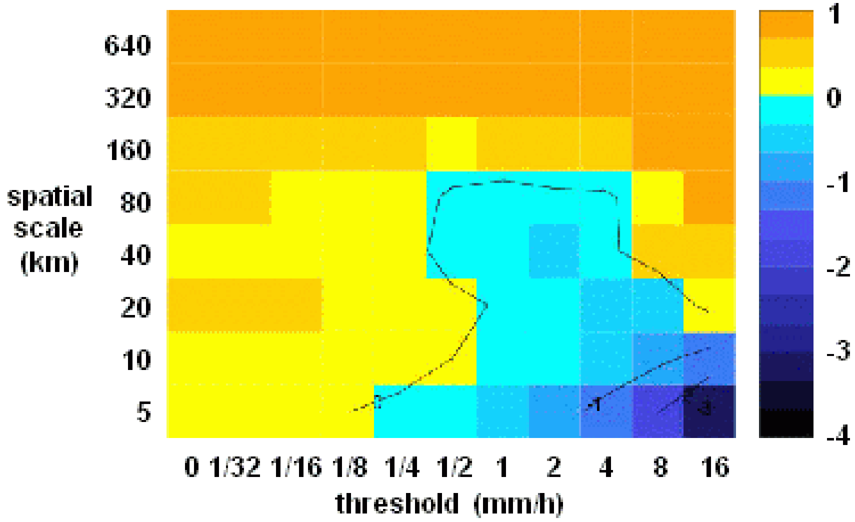


Scale separation methods



- Intensity-scale approach (Casati et al. 2004)
  - Discrete wavelet
  - Estimate performance as a function of scale
- Multi-scale variability (Zapeda-Arce *et al.* 2000; Harris *et al.* 2001 Mittermaier 2006)
- Variogram (Marzban and Sandgathe 2009)

MSE Skill Score

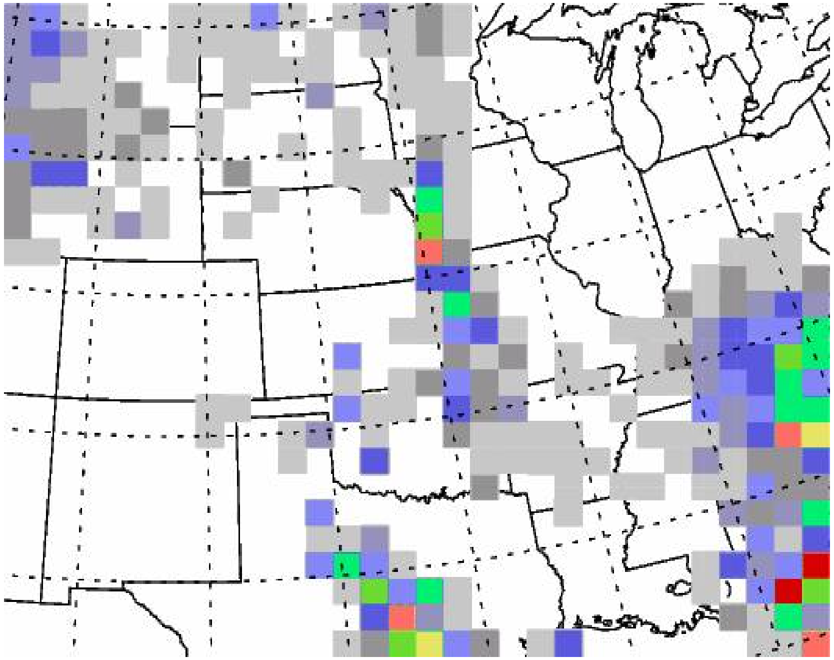


Neighborhood verification

<u>Goal:</u>

Examine forecast performance in a region; don't require exact matches

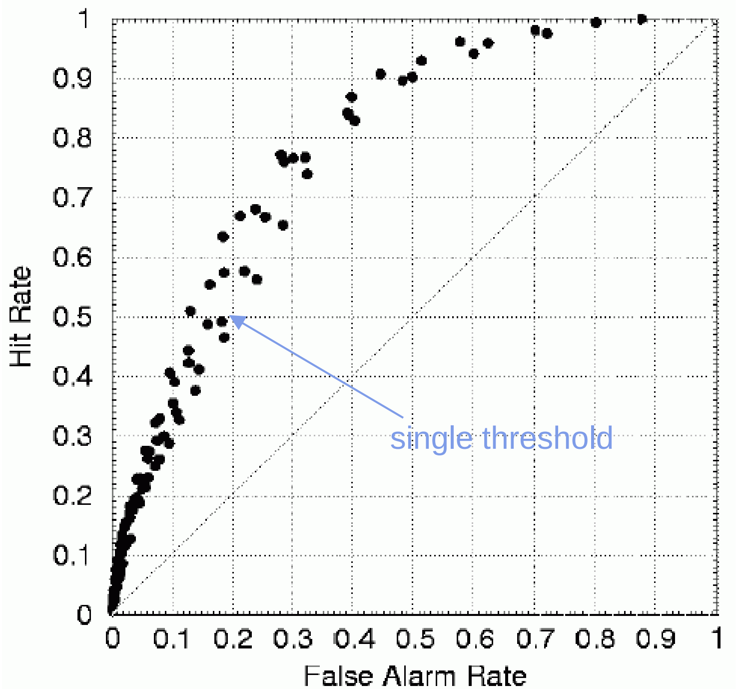
- Also called "fuzzy" verification
- Example: Upscaling
  - Put observations and/or forecast on coarser grid
  - Calculate traditional metrics
- Provide information about scales where the forecasts have skill



Neighborhood methods

Examples :

- Distribution approach (Marsigli)
- Fractions Skill Score (Roberts 2005; Roberts and Lean 2008; Mittermaier and Roberts 2009)
- Multiple approaches (Ebert 2008, 2009) (e.g., Upscaling, Multi-event cont. table, Practically perfect)

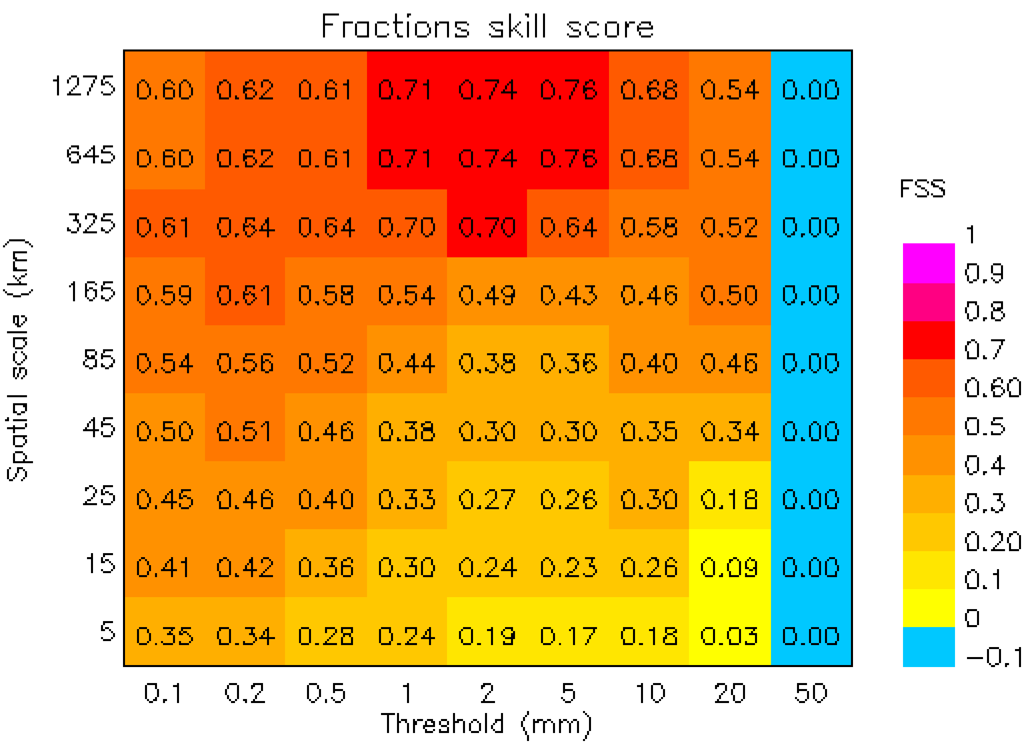


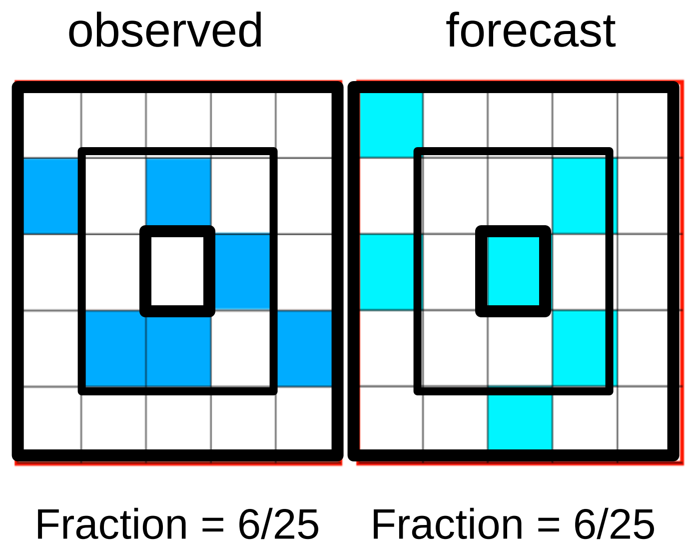
Atger, 2001

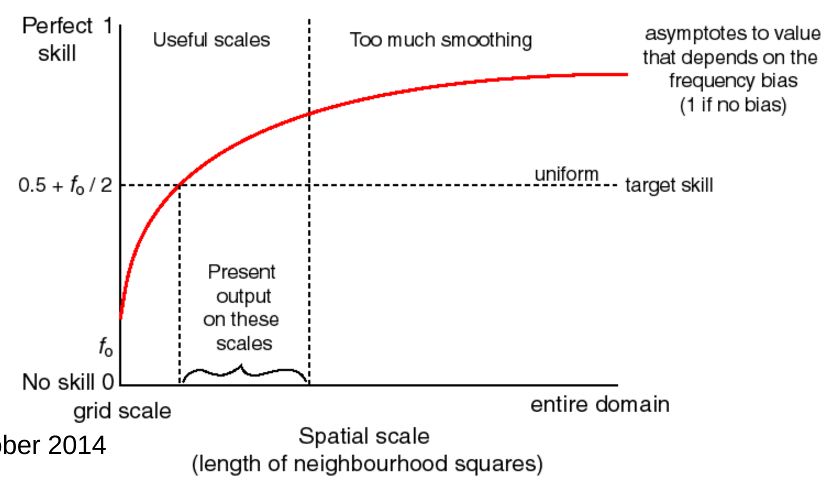
Ebert (2007; Met Applications) provides a review and synthesis of these approaches

Fractions skill score

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





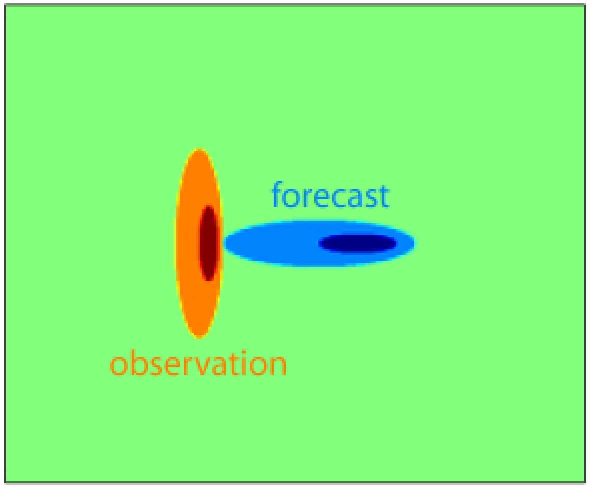


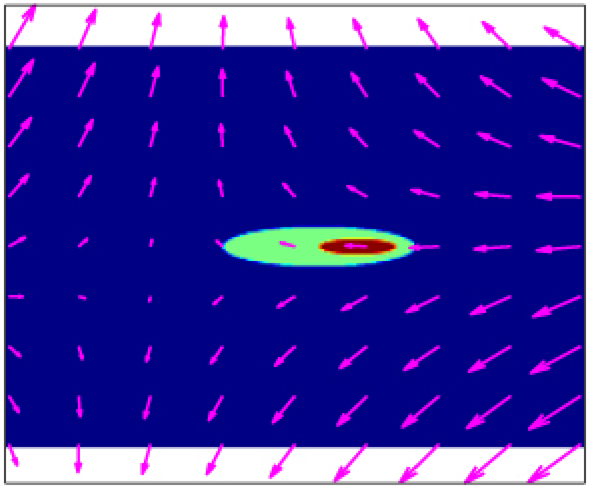
(Roberts 2005; Roberts and Lean 2007)

Field deformation

Goal:

Examine how much a forecast field needs to be transformed in order to match the observed field

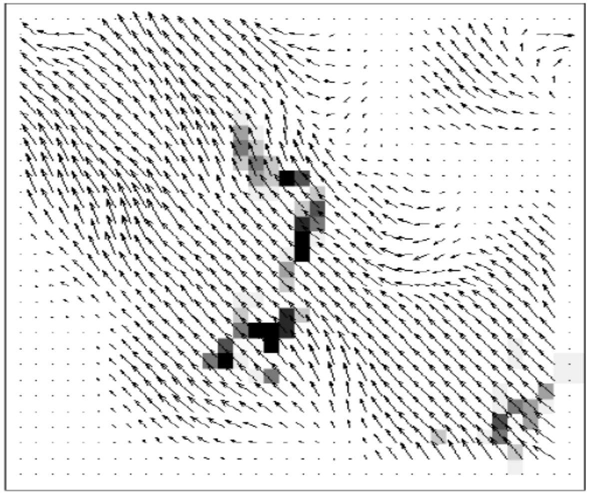




Field deformation methods

<u>Example methods :</u>

- Forecast Quality Index (Venugopal *et al*. 2005)
- Forecast Quality Measure/Displacement Amplitude Score (Keil and Craig 2007, 2009)
- Image Warping (Gilleland et al. 2009; Lindström *et al.* 2010; Engel 2009)

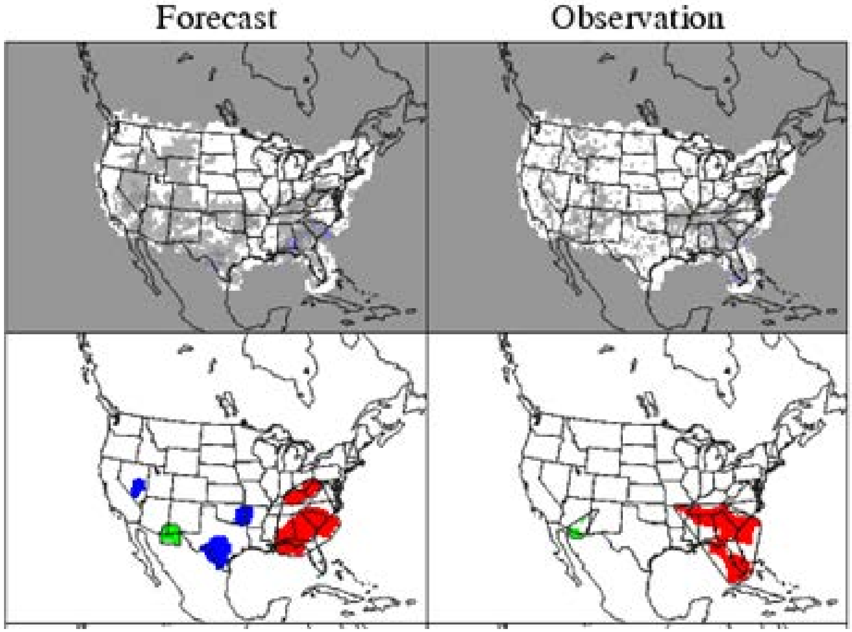


From Keil and Craig 2008

Object/Feature-based

Goals:

1. Identify relevant features in the forecast and observed fields
2. Compare attributes of the forecast and observed features



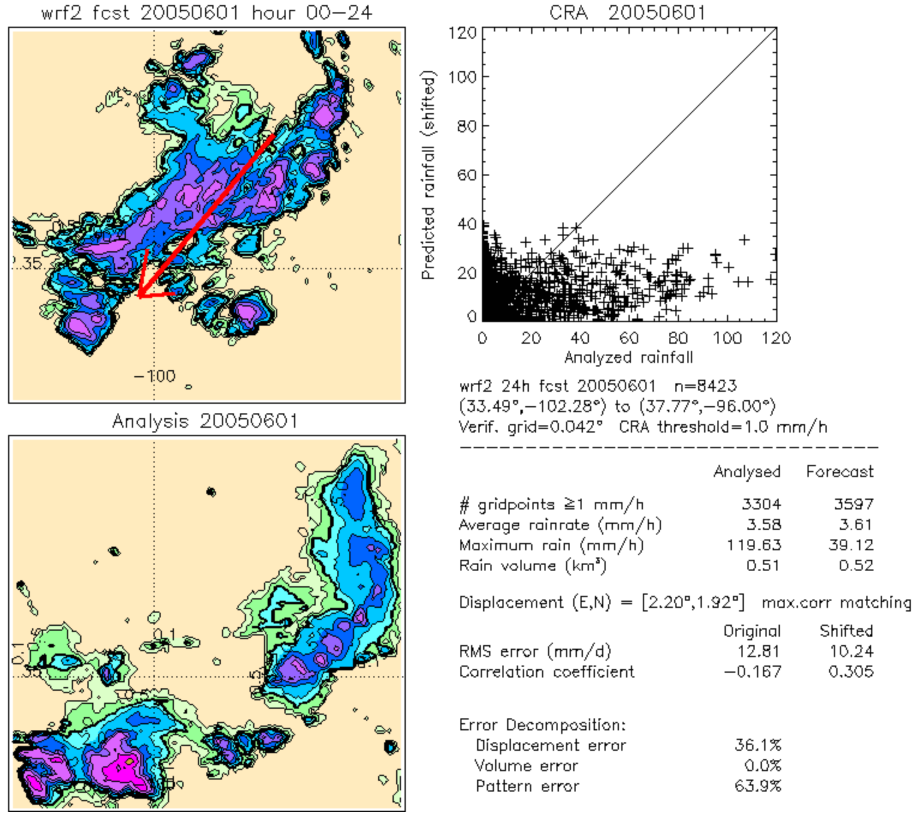
MODE example

Object/Feature-based

Example methods:

- Cluster analysis (Marzban and Sandgathe 2006a,b)
- Composite (Nachamkin 2005, 2009)
- Contiguous Rain Area (CRA) (Ebert and Gallus 2009)
- Procrustes (Micheas *et al.* 2007, Lack *et al.* 2009)
- SAL (Wernli *et al.* 2008, 2009)
- MODE (Davis et al. 2005,2009)

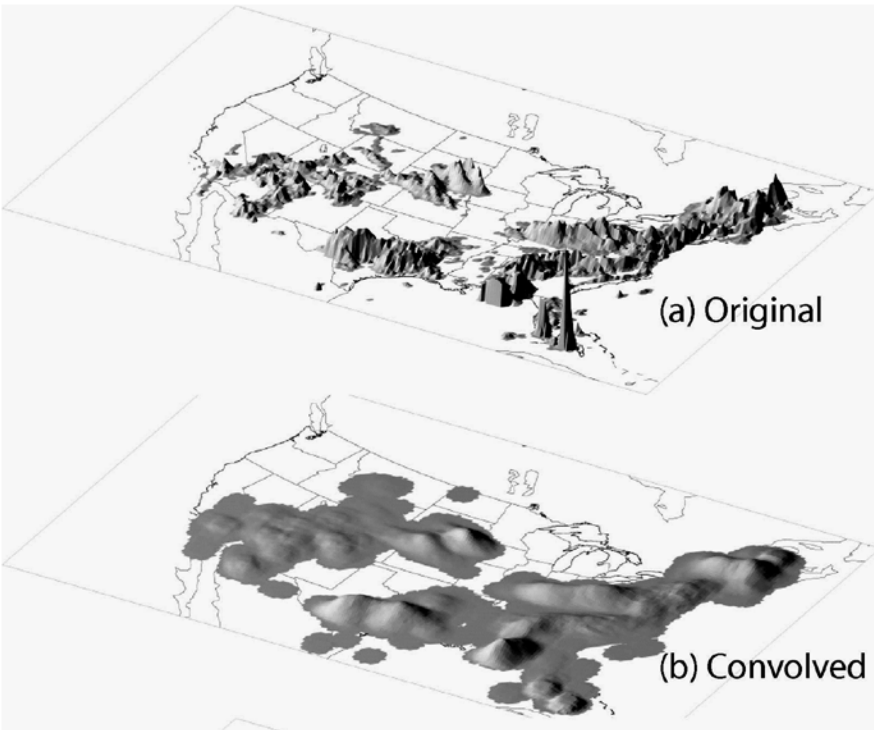
CRA example (Ebert and Gallus)

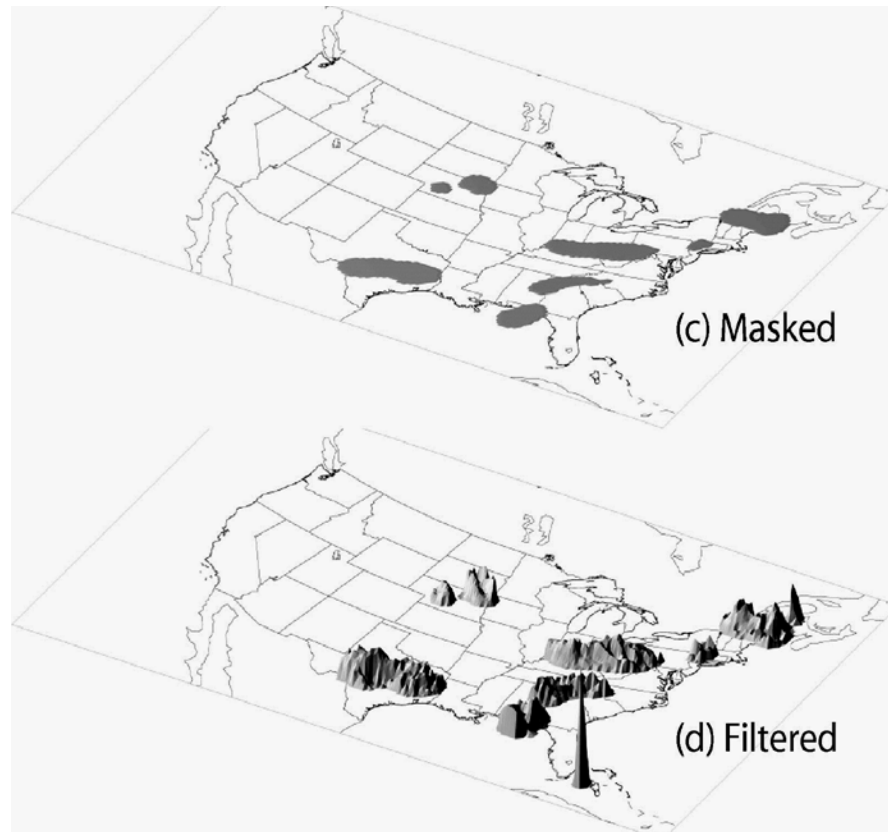


The CRA method measures displacement and estimates error due to displacement, pattern, and volume

MODE – Method for Object-based Diagnostic Evaluation

MODE Object identification



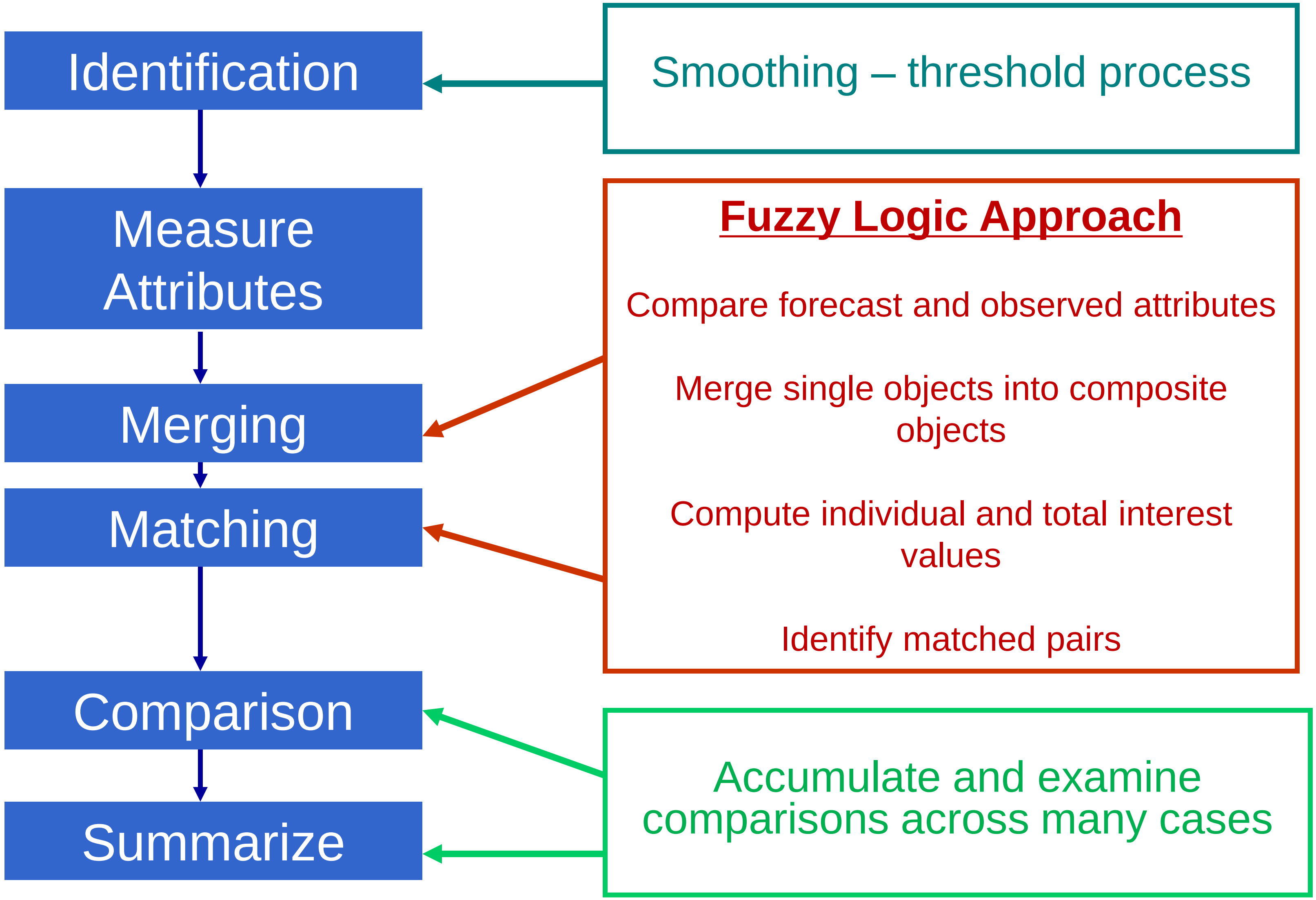


Two parameters:

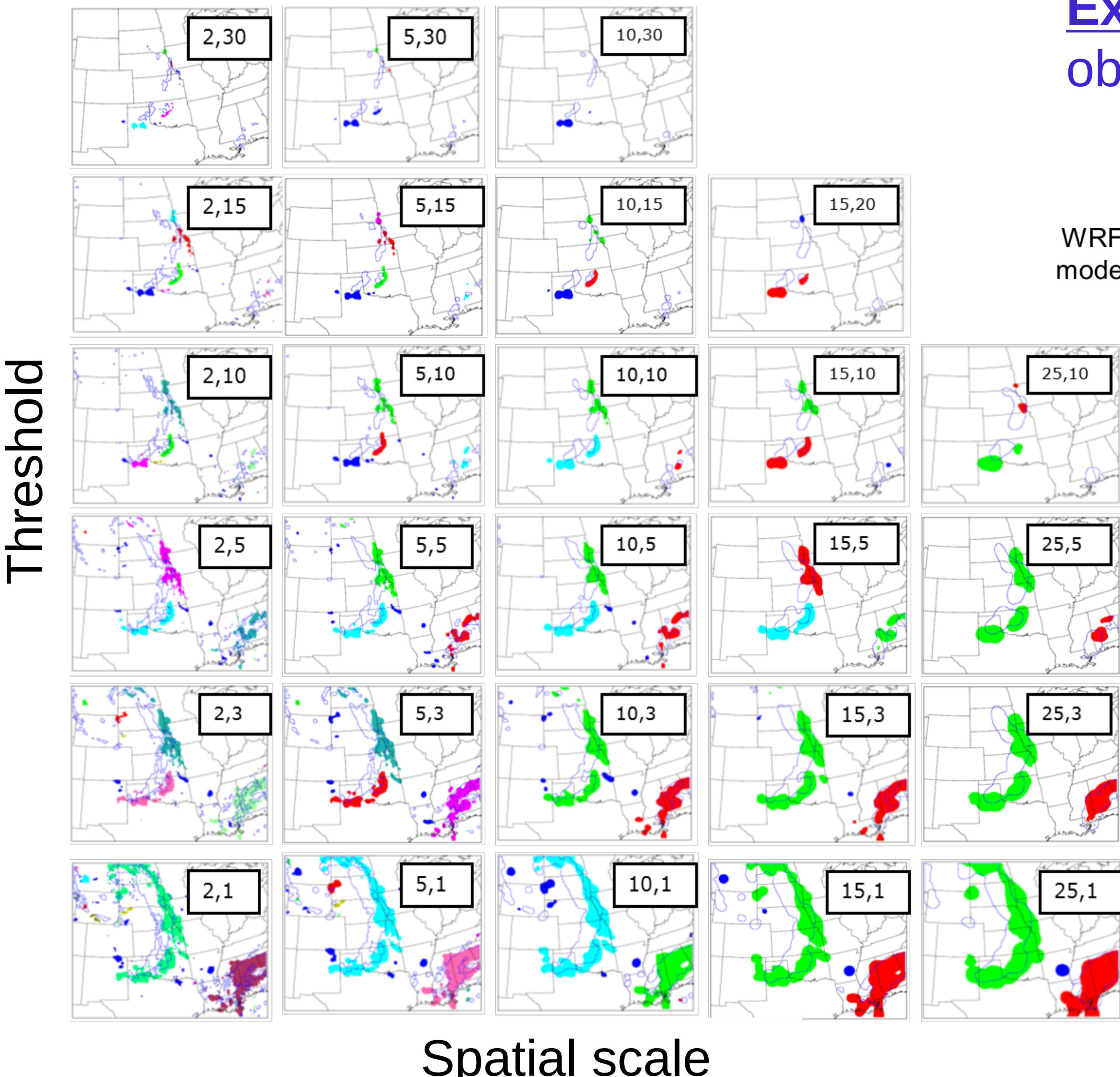
1. Convolution radius
2. Threshold

Davis et al., *MWR*, 2006; 2009

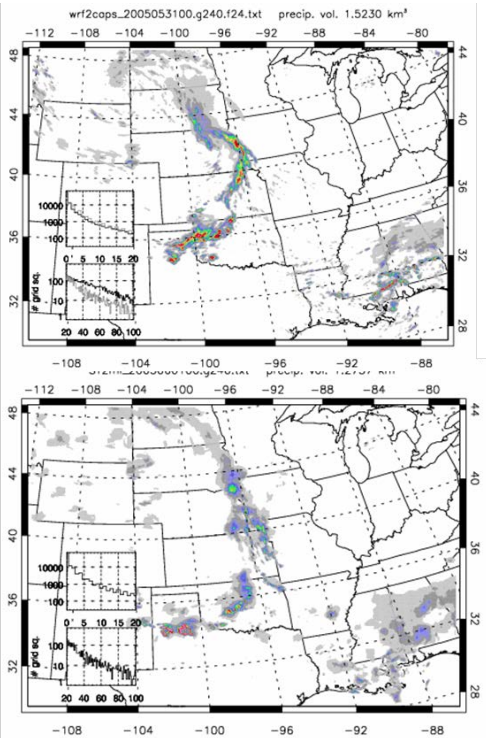
MODE methodology



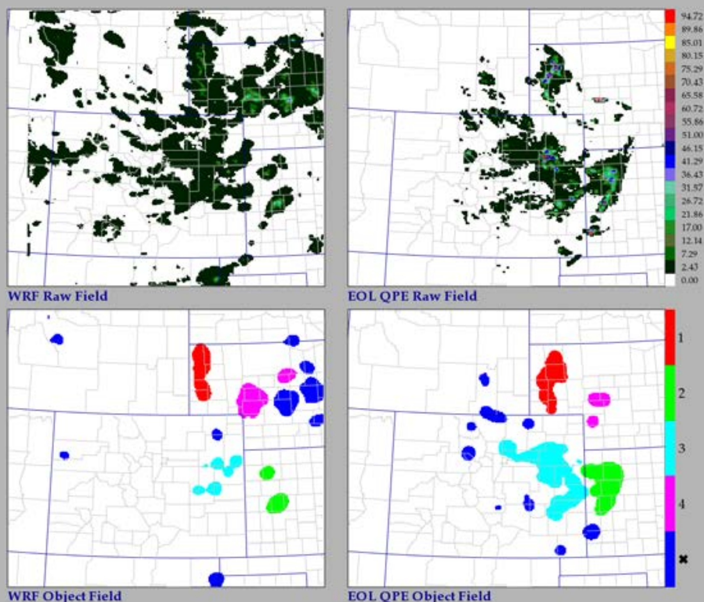
Example: MODE object definitions



WRF model



MODE Example: Summer 2014 QPF experiment (STEP)

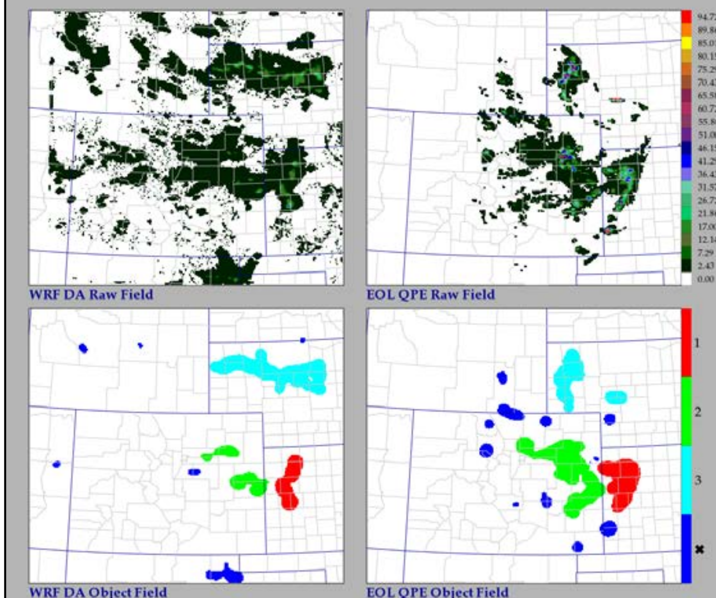


WRF vs. EOL QPE

Valid August 10, 2014 00h — **Radius** 6
Lead 03h — **Threshold** >=1.000

	Simple Objects	Cluster Objects	Simple Area	Cluster Area	Unmatched Area	10 %	50 %	90 %
Fcst	18	4	5,021	3,094	1,927	0.06	1.65	10.18
Obs	16	4	7,079	5,833	1,246	0.00	1.31	21.22

Cluster	Area (F/O)	Centroid Distance	Overlap Area	Symmetric Difference	50 % (F/O)	90 % (F/O)	Total Interest
	858 / 1,149	12.76	424	1,583	2.01 / 2.83	7.68 / 34.91	0.99
	536 / 1,477	13.82	267	1,746	1.75 / 4.22	14.18 / 26.82	0.93
	666 / 2,813	8.39	327	3,152	1.21 / 2.17	5.32 / 18.35	0.85
	1,034 / 394	11.74	263	1,165	2.20 / 17.70	14.13 / 78.17	0.93



WRF DA vs. EOL QPE

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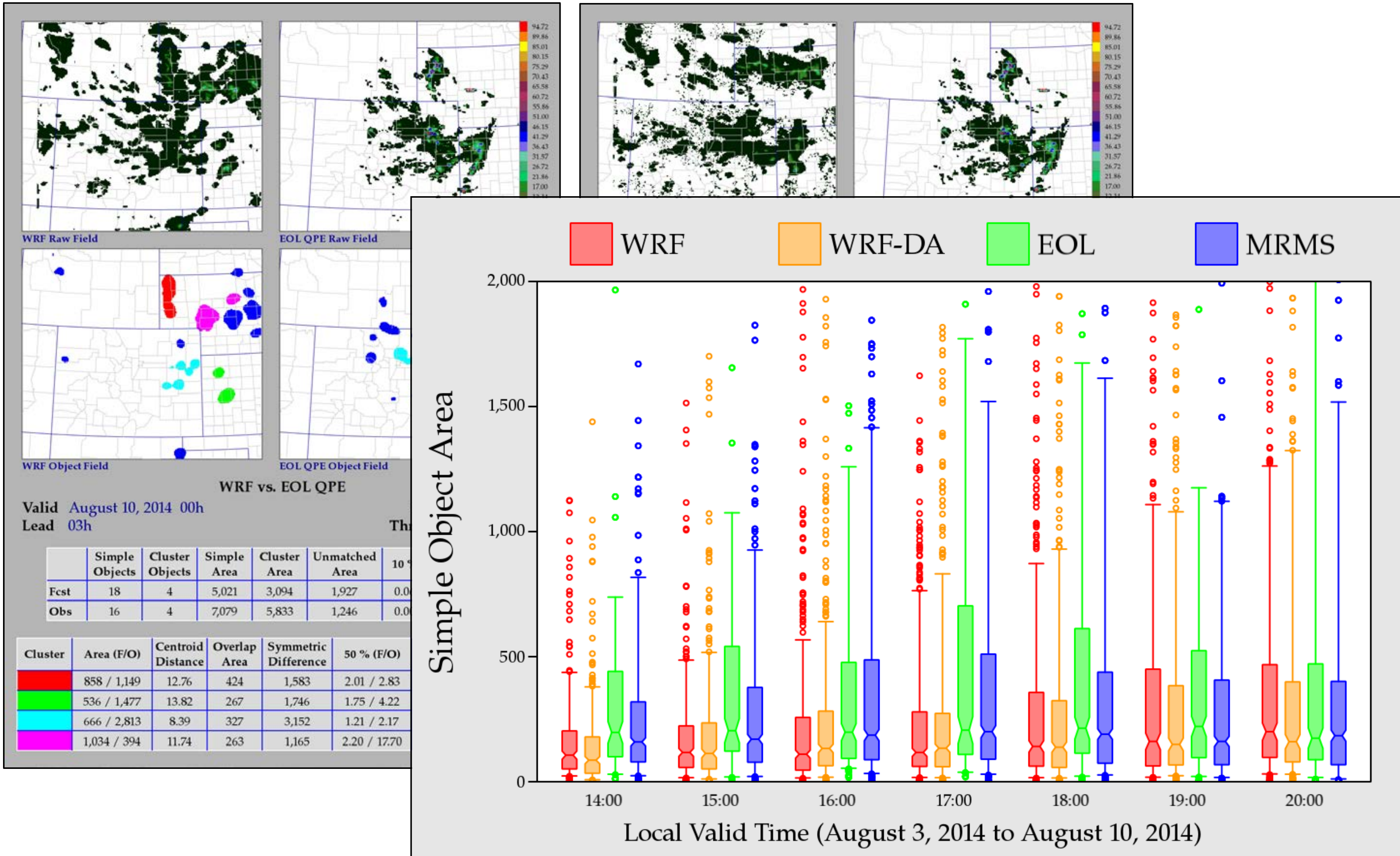
	Simple Objects	Cluster Objects	Simple Area	Cluster Area	Unmatched Area	10 %	50 %	90 %
Fcst	10	3	5,042	4,404	638	0.09	1.58	10.00
Obs	16	3	7,079	5,698	1,381	0.00	1.31	21.22

Cluster	Area (F/O)	Centroid Distance	Overlap Area	Symmetric Difference	50 % (F/O)	90 % (F/O)	Total Interest
	909 / 1,477	6.74	738	1,648	1.42 / 4.22	12.24 / 26.82	0.97
	919 / 2,794	9.58	777	2,936	1.35 / 2.18	4.66 / 18.37	0.93
	2,576 / 1,427	38.01	406	3,597	1.90 / 3.66	11.60 / 40.19	0.95

MODE Example: Summer 2014 QPF experiment (STEP)



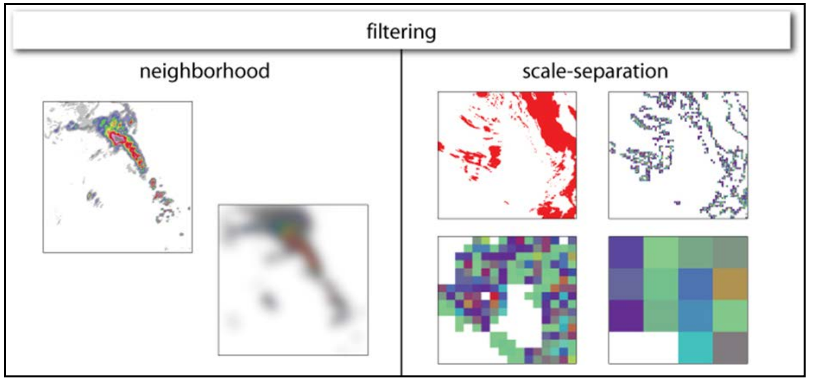
Method intercomparison projects

- First International Intercomparison Project (2006-2011)
  - Participants applied methods to a variety of cases:
    - Geometric
    - Real precipitation cases from US Midwest
    - Modified real cases (e.g., known displacements)
  - Summarized in several publications in *Weather and Forecasting* and *Bulletin of the AMS* (see reference list at http://www.rap.ucar.edu/projects/icp/index.html)
- Second International Intercomparison Project: MesoVICT ("Mesoscale Verification in Complex Terrain")
  - Focus:
    - Precipitation and wind in complex terrain (Alps region)
    - Ensemble forecasts and analyses
  - Kick-off workshop Oct 2-3, 2014 in Vienna, Austria
  - Web site: http://www.ral.ucar.edu/projects/icp/

Method strengths and limitations: Filtering methods

Strengths

- Accounts for
  - Unpredictable scales
  - Uncertainty in observations
- Simple – ready-to-go
- Evaluates different aspects of a forecast (e.g., texture)
- Provides information about scale-dependent skill



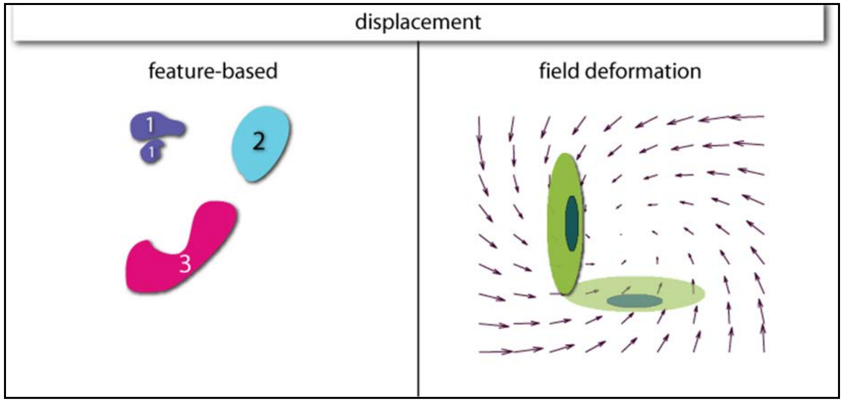
Limitations

- Does not clearly isolate specific errors (e.g., displacement, amplitude, structure)

Method strengths and limitations: Displacement methods

Strengths

- Features-based
  - Gives credit for close forecast
  - Measures displacement, structure
    - Provides diagnostic information
- Field-deformation
  - Gives credit for a close forecast
  - Can be combined with a field comparison significance test



Limitations

- May have somewhat arbitrary matching criteria
- Often many parameters to be defined
- More research needed on diagnosing structure

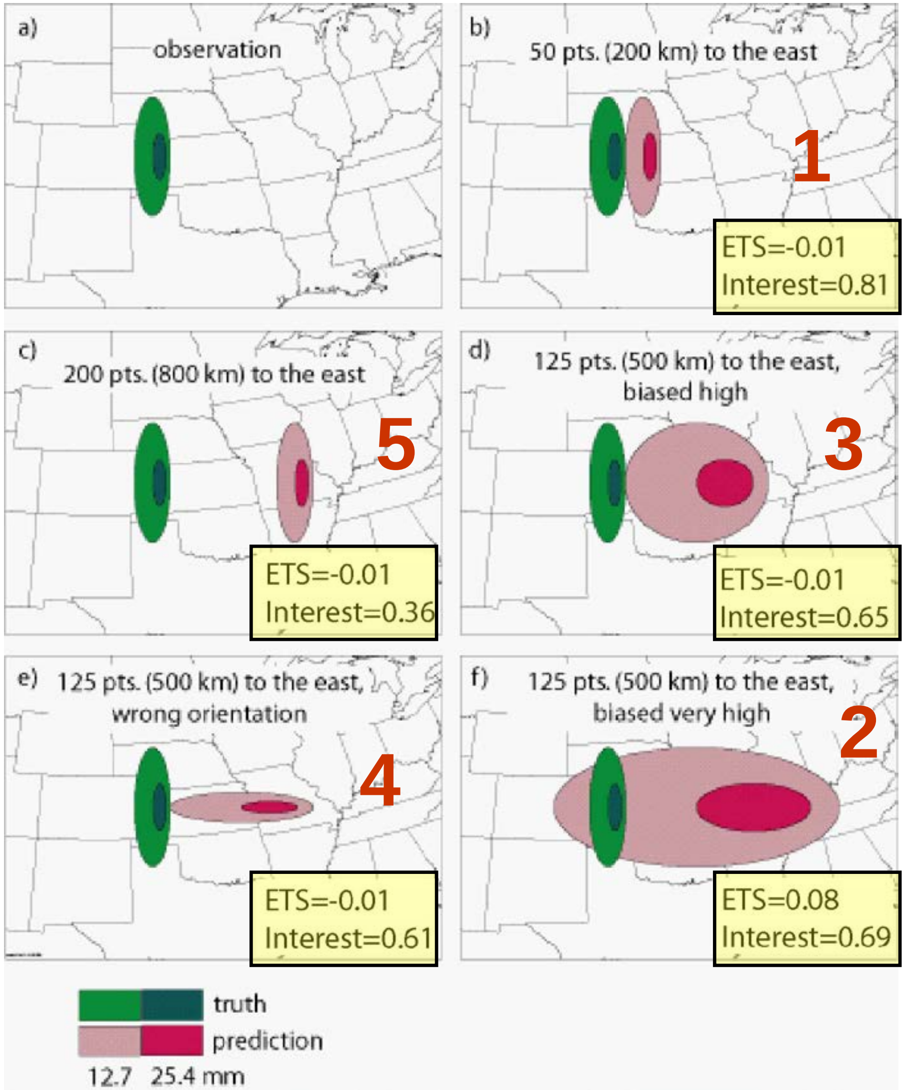
What do the new methods measure?

	Method	Scale-specific errors	Scales of useful skill	Structure errors	Location errors	Intensity errors	Hits, misses, false alarms, correct negatives
	Traditional	No	No	No	No	Yes	Yes
Filter	**Neighborhood**	Yes	Yes	No	Sensitive, but no direct information	Yes	Yes
	Scale Separation	Yes	Yes	No	Sensitive, but no direct information	Yes	Yes
Displacement	**Field deformation**	No	No	No	Yes	Yes	No
	Features-based	Indirectly	No	Yes	Yes	Yes	Yes, based on features rather than gridpoints

Back to the earlier example… What can the new methods tell us?

<u>Example:</u>

- MODE "Interest" measures overall ability of forecasts to match obs
- Interest values provide more intuitive estimates of performance than the traditional measure (ETS)
- Warning: Even for spatial methods, Single measures don't tell the whole story…

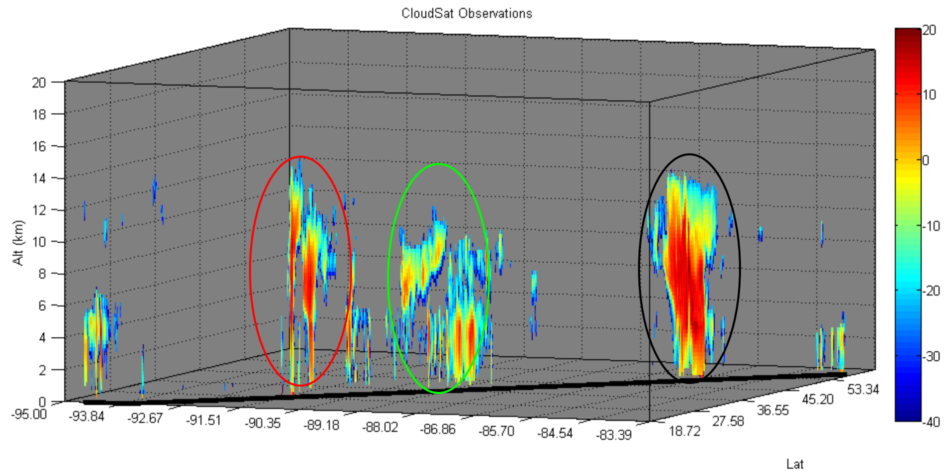


Application to other fields

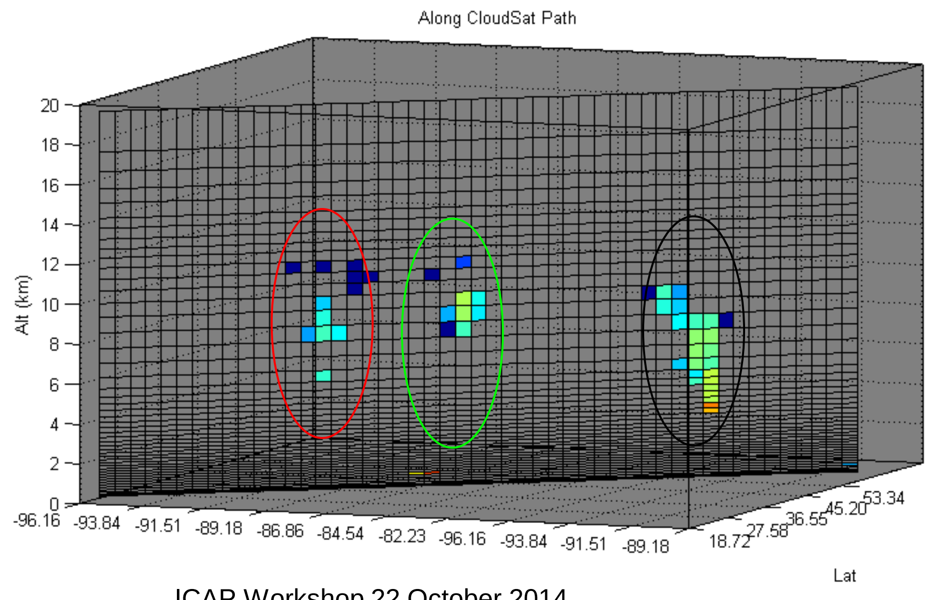
- Methods have been commonly applied to precipitation and reflectivity
- New applications
  - Wind
  - Cloud analysis
  - Vertical cloud profile
  - Satellite estimates of precipitation
  - Tropical cyclone structure
  - Ensemble
- Time dimension can also be included (see Fowler presentation)

Cloud-Sat Object-based Comparison: Along Track

CPR reflectivity

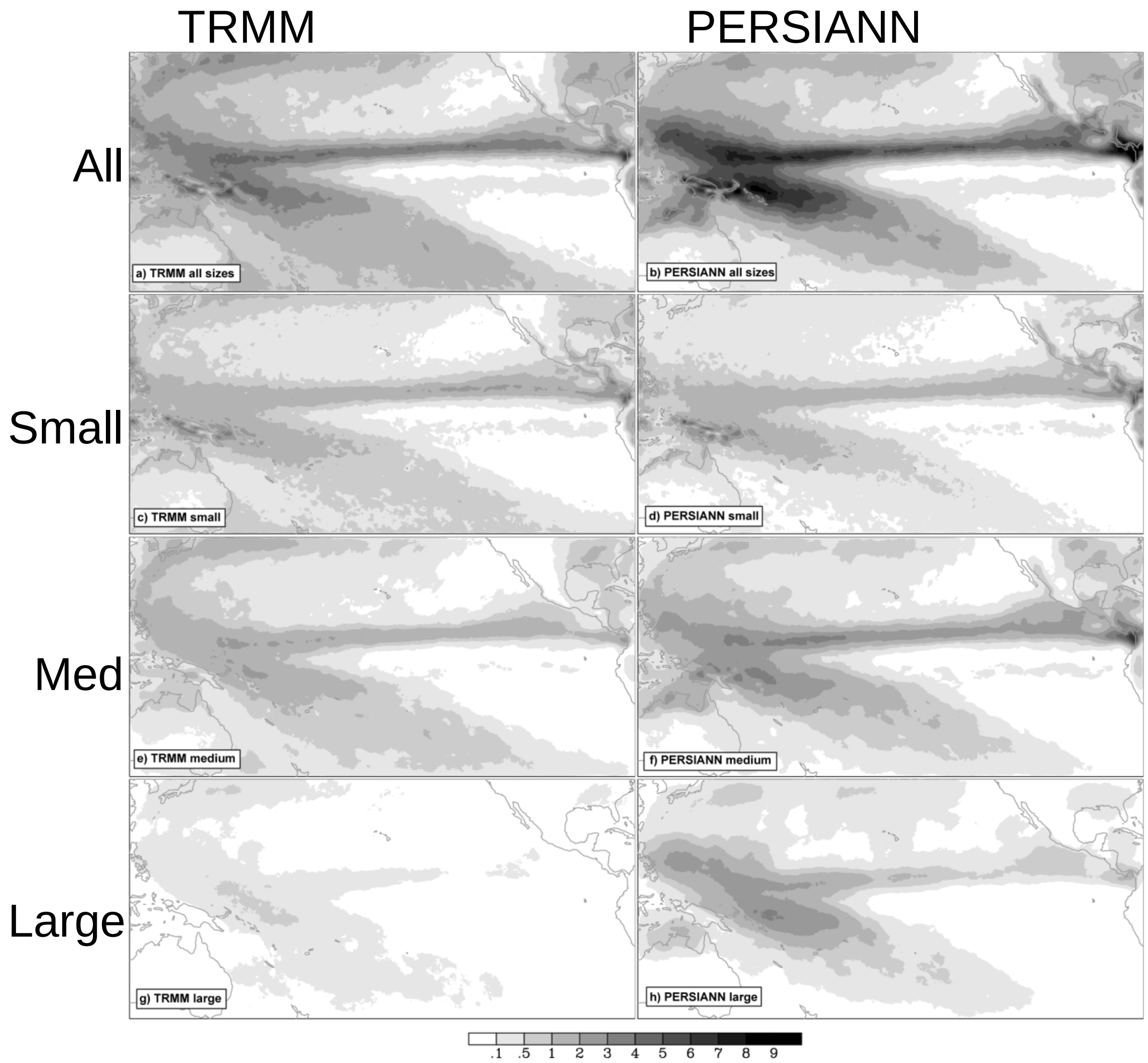


RUC reflectivity



Satellite precipitation estimates

Skok et al. (2010)
Object counts



Conclusion

- New spatial methods provide great opportunities for more meaningful evaluation of spatial fields
  - Feed back into forecast or product development
  - Measure aspects of importance to users
- Each method is useful for particular types of situations and for answering particular types of questions
- Methods are useful for a wide variety of types of fields
- For more information (and references), see http://www.rap.ucar.edu/projects/icp/index.html

Method availability

- Neighborhood, Intensity-Scale, and MODE methods are available as part of the Model Evaluation Tools (MET)
  - Available at http://www.dtcenter.org/met/users/
  - Implemented and supported by the Developmental Testbed Center and staff at NCAR/RAL/JNTP
- Software for other methods may be available on the ICP web page

  http://www.ral.ucar.edu/projects/icp/index.html

  or directly from the developer