Spatial Forecast Verification:

Filter Methods: Examining model performance at different spatial scales

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Filter Methods

• Smoothing (e.g., FSS, Upscaling)
  – Neighborhood or “fuzzy” (Ebert 2008)
  – At what resolution does the model have skill?
  – Credit a forecast for being partially correct.

• Band-pass (e.g., Fourier, Wavelets)
  – How well does a model reproduce the spatial structure of the verification field?
  – Examine performance at different scales separately.
Filter Methods
Filter Methods

Fractions Skill Score (FSS)

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

Numerator is Fractions Brier Score (FBS)

Roberts and Lean (2008)

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# Filter Methods

Filter Methods

<table>
<thead>
<tr>
<th>Fuzzy method</th>
<th>Matching strategy*</th>
<th>Decision model for useful forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upscaling</strong></td>
<td>NO-NF</td>
<td>Resembles obs when averaged to coarser scales</td>
</tr>
<tr>
<td><strong>Minimum coverage</strong></td>
<td>NO-NF</td>
<td>Predicts event over minimum fraction of region</td>
</tr>
<tr>
<td>(Damrath 2004)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fuzzy logic</strong></td>
<td>NO-NF</td>
<td>More correct than incorrect</td>
</tr>
<tr>
<td>(Damrath 2004), joint probability (Ebert 2002)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fractions skill score</strong></td>
<td>NO-NF</td>
<td>Similar frequency of forecast and observed events</td>
</tr>
<tr>
<td>(Roberts and Lean 2007)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Area-related RMSE</strong></td>
<td>NO-NF</td>
<td>Similar intensity distribution as observed</td>
</tr>
<tr>
<td>(Rezacova et al. 2006)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Practically perfect hindcast</strong></td>
<td>NO-NF</td>
<td>Resembles a forecast based on perfect knowledge of observations</td>
</tr>
<tr>
<td>(Brooks et al. 1998)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pragmatic</strong></td>
<td>SO-NF</td>
<td>Can distinguish events and non-events</td>
</tr>
<tr>
<td>(Theis et al. 2005)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CSRR</strong></td>
<td>SO-NF</td>
<td>High probability of matching observed value</td>
</tr>
<tr>
<td>(Germann and Zawadzki 2004)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Multi-event contingency table</strong></td>
<td>SO-NF</td>
<td>Predicts at least one event close to observed event</td>
</tr>
<tr>
<td>(Atger 2001)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*NO-NF = neighborhood observation-neighborhood forecast, SO-NF = single observation-neighborhood forecast

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Filter Methods

Fig. courtesy of E Ebert.
Filter Methods

• In MET, Neighborhood methods are in grid-Stat tool. See MET documentation for specific filters.
• Can be cumbersome (many numbers for one filter).
• Choose filter that addresses the verification question of interest.
• See Ebert (2008) for a good summary and comparison of these techniques (and references).

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Band-pass Methods

- Fourier
  \[ Z(x) = \frac{1}{2} a_0 + \sum_{j=1}^{n} (a_j \cos(jx) + b_j \sin(jx)) \]

- Wavelets
  \[ Z(x) = \sum_{j,k} c_{j,k} \varphi(2^j x - k) + \sum_{j,k} d_{j,k} \psi(2^j x - k) \]
Band-pass Methods

Wavelets

Briggs and Levine (1997)

Fig. 6. A series of images in the data space comparing the analysis and forecast fields at each of the five successively finer orthogonal wavelet scales.

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Band-pass Methods

• Fourier
  – Skamarock (2004), MWR 132:3019-3032
  – Harris et al. (2001), J Hydrometeorol. 2:406-418
  – Tustison et al. (2001), JGR 106(D11):11775-11784
  – and many more…

• Wavelet
  – Briggs and Levine (1997), MWR 125:1329-1341
  – Casati et al. (2004). [In MET Wavelet tool]
Band-pass Methods

Wavelets: Practical considerations

• In MET, applicable only on dyadic grids (i.e., square grids of size $2^n$).

• If grid does not meet this, then must alter the grid in some way. For example,
  – Pad with zeros (or average),
  – Cut the domain down,
  – Fudge a little.

• Several choices for wavelets. Haar Wavelets are a good choice for precipitation (because of their discrete nature), but other choices might be better for other fields.
## Quick Contingency Table Review

<table>
<thead>
<tr>
<th></th>
<th>obs &gt; threshold</th>
<th>obs &lt; threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>forecast &gt; threshold</td>
<td>a hits</td>
<td>b false alarms</td>
</tr>
<tr>
<td>forecast &lt; threshold</td>
<td>c misses</td>
<td>d correct rejections</td>
</tr>
<tr>
<td>a + c</td>
<td>b + d</td>
<td>n = a + b + c + d</td>
</tr>
</tbody>
</table>

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Band-pass Methods

Intensity Scale (IS) (Casati et al., 2004)

1. Create binary fields for a threshold, and calculate MSE (denote, MSE(t)).
2. Apply wavelet decomposition to binary fields.
3. Calculate MSE for each threshold (t) and scale (j) (denote, MSE(t,j)),
4. Calculate IS Skill Score

$SS(t,j) = 1 - \frac{\text{MSE}(t,j)(n+1)}{\text{MSE}(t)_{\text{random}}}$
Band-pass Methods

In addition to MSE and SS, the energy squared (denote En2) is calculated. That is,

\[ En2(X) = \sum_{i=1}^{n} X_i^2 \]
Band-pass Methods

Also find the relative difference in $\text{En}2$ between the forecast and verification fields. That is,

$$\frac{[\text{En}2(F)-\text{En}2(O)]}{[\text{En}2(F)+\text{En}2(O)]}$$
Casati et al. (2004)

Forecast

Observation

Raw Data

Binary Data
Casati et al. (2004)

Binary Difference Field

Contingency Table Contributions
Casati et al. (2004)
Casati et al. (2004)

Intensity Skill Score (ISS) is equivalent to the Heidke Skill Score (HSS), but calculated at each threshold and scale.

HSS is an accuracy score corrected for random chance.
Spatial Forecast Verification

Filter Methods

- Do not provide displacement information.
- Two general types:
  - Band-pass
    - Potential to provide information about physical features for different scales of features (e.g., large-scale storm systems and small-scale convection).
    - Fourier Analysis
    - Wavelets
    - Other possibilities
  - Smoothing
    - No information about physical features.
    - Can say at which grid resolutions a forecast has skill.
    - Particular filter will address different verification questions.
Thank you...Questions?

References


See also, [http://www.ral.ucar.edu/projects/icp](http://www.ral.ucar.edu/projects/icp)