Object-oriented verification: Application to ensemble precipitation forecasts

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Ensemble Forecasts - the primary NWP tool of the future?

Mean  Spaghetti Plots  Standard Deviation (uncertainty)
Or.... Probability information

COM_US prob of T2m<=32F(0C), 03H fcst from 09Z 26 OCT 2007
verified time: 12z, 10/26/2007
How can object-oriented techniques be applied to ensemble forecasts?

• Evaluation of ensemble mean forecasts (really just another deterministic forecast)
• Evaluation of spread of object parameters – does this relate to skill?
• Does the mean of the various object parameters from each member give a more accurate depiction of the event than any specific deterministic forecast?
• Might object-oriented approaches be applied to probability forecasts?
Object-oriented technique parameters:

- Areal coverage
- Mean Rain Rate
- Rain Volume of system
- Number of systems
- Displacement error
- Axis orientation
- Correspondence Ratio
- Correlation coefficients/RMSE
- Etc....
Methodology

- 6h 15-km grid precipitation forecasts over 60 h integration periods from TWO 8-member WRF ensembles run by Adam Clark for 72 cases were input into CRA and MODE.
- TWO ensembles – one with just mixed physics, the other with just perturbed I.C. and L.B.C.
- This results in $10 \times 16 \times 72 = 11,520$ evaluations (plots, tables....) from each approach.
Example of 6 hr precip forecast (left) and obs (right) with CRA-derived systems indicated.

Validation statistics for 20060407_24Z Valid gridpoints=25181  Threshold=0.25 in

<table>
<thead>
<tr>
<th>Forecast</th>
<th>&lt;0.25</th>
<th>≥0.25</th>
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<tbody>
<tr>
<td>&lt;0.25</td>
<td>21124</td>
<td>1891</td>
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<tr>
<td>≥0.25</td>
<td>1635</td>
<td>531</td>
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- Mean abs error = 0.1088 in/6 hr
- RMS error = 0.2526 in/6 hr
- Correlation coeff = 0.218
- Bias score = 1.118
- Probability of detection = 0.245
- False alarm ratio = 0.781
- Hanssen & Kuipers score = 0.163
- Equitable threat score = 0.084

Ebert and McBride, 2000
CRA Output for one “CRA” from Apr 6, 2007 18-24 hr forecast

wrfnew 18–24h fcst from 20060406_00z run

Stage IV 6hr accum ending 20060406_00+24h

CRA valid 20060406_00+24h

wrfnew 18–24h fcst from 20060406_00z run
(43.78°,−101.05°) to (46.60°,−91.98°)
n=1089   CRA threshold=0.25 in/6 hr

<table>
<thead>
<tr>
<th>Analyzed</th>
<th>Forecast</th>
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<tbody>
<tr>
<td># gridpoints ≥0.25 in/6 hr</td>
<td>583</td>
</tr>
<tr>
<td>Average rainrate (in/6 hr)</td>
<td>0.67</td>
</tr>
<tr>
<td>Maximum rain (in/6 hr)</td>
<td>3.19</td>
</tr>
<tr>
<td>Rain volume (km³)</td>
<td>0.92</td>
</tr>
</tbody>
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Displacement (E,N) = [−0.66°,−0.38°]

RMS error (in/6 hr) | 0.61 | 0.48 |
Correlation coefficient | 0.063 | 0.390 |

Error Decomposition:
- Displacement error | 0.142in² | 38.6% |
- Volume error | 0.000in² | 0.0% |
- Pattern error | 0.227in² | 61.5% |
- Conditional bias error | N.A | N.A.
Example of MODE output for one ensemble member
April 6 18-24 hour forecast from Mixed Physics/Dynamics ensemble
Same forecast but from mixed initial/boundary condition ensemble
One question that can be explored is:

Does the behavior of spread/skill measures of object-based parameters match that of traditional measures applied to full model domains?
Spread measures in CRA and MODE

- For the parameters of:
  - areal coverage,
  - mean rain rate,
  - rain volume,
  - number of systems,
  - and displacements

  standard deviations were computed as a function of time to compare trends to those found in Clark et al. (2008) for traditional ensemble spread measures.

- Clark et al. (2008) found spread & skill initially may have been best in mixed physics ensemble vs. IC/LBC one, but spread grew much faster in the IC/LBC one, and it performed noticeably better than mixed physics ensemble at later times (after 30-36 h) in these 120 h integrations.
Areas under ROC curves for both ensembles (Clark et al. 2008)

**Skill initially better in mixed ensemble but IC/LBC becomes better after hour 30-36**
(b) 6–hr accumulation periods

Variance continues to grow in IC/LBC ensemble but levels off after hour 30 in mixed ensemble. MSE always worse for mean of mixed ensemble – and performance worsens with time relative to IC/LBC ensemble.
Spread Ratio also shows dramatically different behavior with increasing spread in IC/LBC ensemble but little or no growth in mixed ensemble after first 24 hours.
Observed Rain Volume (solid line) has peaks at hours 6, 30, 54, etc.

Amplitude of diurnal signal is reduced in IC/LBC ensemble (runs used NMM-KF-Ferrier)

Volumes are overestimated by many of the mixed ensemble members
Questions:

• Do the object parameters show the different behaviors between the Mix and IC/LBC ensembles?

• Do the object parameters show an influence from the diurnal trends in observed precipitation?
Rain Rate Standard Deviation (in.) – mean usually around .5 inch

Diurnal signal not pronounced, only weak hint of IC/LBC tendency to have increasing spread with time – and only in MODE results.

Wet times in blue.
Standard Deviation of Rain Volume (km$^3$) – MODE values multiplied by 10 (mean ~ 1)

No diurnal signal, hard to see different trends between 2 ensembles
Areal Coverage
Standard Deviation
(number of points above .25 inch) –
Mean ~ 800 pts

CRA results show both ensembles with growing spread, and IC/LBC having faster growth

NOTE: CRA approach uses obs-pred CRAs; MODE just uses pred. objects
No clear diurnal signal, both CRA & MODE show max in 24-48 h
No diurnal signal, no obvious differences in behavior of Mix and IC/LBC.
Other questions:

• Is the mean of the ensemble’s distribution of object-based parameters a good forecast (better than those in an ensemble mean)?
• Does an increase in spread imply less predictability?
• How should a forecaster handle a case where only a subset of members show an object?

These questions have been examined using CRA.
Mix Ensemble – in general, slight positive bias in rain rate, with Probability Matching forecast slightly less intense than mean of rates from members (PM usually better but not by much). Only during 06-18 period does observed rate not fall within forecasted range.

IC/LBC – usually too dry with rain rate (at all hours except 06-18), Probability Matching forecast exhibits much more variable behavior, again its performance is comparable to mean of rates of members.
Notice that at all times, the observed rain rate falls within the range of values from the full 16 member ensemble – indicating potential value for forecasting.
Mix Ensemble – clear diurnal signal, usually too much rain volume except at times of observed peak, when it is too small. Probability Matching equal in skill to mean of member volumes.

IC/LBC Ensemble – also clear diurnal signal, less volume than Mix ensemble, Probability Matching usually a little wetter but generally comparable to mean of members.
NOTE: Even with all 16 members, there are still times when observed volume does NOT fall within range of predictions --- not enough spread (indicated with red bar)
Percentage of times the observed value fell within the min/max of the ensemble

- **Rate - Mix**
- **Volume - Mix**
- **Volume - IC/LBC**
- **Rate - IC/LBC**
- **Areal Coverage**
- **IC/LBC**
- **Mix**

Day

Successful Forecasts (%)
Skill (MAE) as a function of spread (> 1.5*SD cases vs < .5*SD cases)

CRA applied to Mix Ensemble (IC/LBC similar)

- Vol big SD
- Vol low SD
- Rate*10 low SD
- Rate*10 big SD
- Area/1000 big SD
- Area/1000 low SD

Time
• It thus appears that total system rain volume and total system areal coverage of rainfall show a clear signal for better skill when spread is smaller.

• Rain rate does not show such a clear signal – (especially when 4 bins of SDs are examined).

• *Perhaps average rain rate for systems is not as big a problem in the forecasts as areal coverage (and thus volume)?* Seems to be ~5-10% error for rate, 10-20% for volume, 10-20% for area.
Summary

- Ensemble spread behavior for object-oriented parameters may not behave like traditional ensemble measures.
- Some similarities but some differences also in output from CRA vs MODE.
- Some suggestion that ensembles may give useful information on probability of systems having a particular size, intensity, volume.
Future Work

• How can location information best be determined from ensembles?
• Can lack of spread in the object-oriented parameters be improved entirely with addition of reasonable number of members?
• How well does a forecast of object parameters based on probability information perform?
• How will results differ based on grid spacing -- 4 km vs 20 km ensemble output will be explored
Acknowledgments

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