Uncertainty in Operational Atmospheric Analyses

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Objectives/ of Study

1. Quantify the uncertainty (differences) in current operational analyses of the atmosphere – height, temperature, winds

2. Consider implications of analysis uncertainty for NWP and plans for the future global observing network

Analysis differences are a proxy for actual analysis error, which cannot be precisely quantified
Significance of Analysis Uncertainty/Error

• Quality of NWP forecasts from short to medium-range
• Extended-range NWP?
• Short-range climate forecasts?
• Quality of forecast verification
• Accuracy of climate monitoring
Question asked to a prominent climate scientist: “Given that there are differences between various atmospheric temperature re-analyses, does that uncertainty affect your ability to detect global climate trends?”

Answer: ”There is only one correct analysis of the atmosphere and that is the one that we will use”
Causes of Analysis Differences and Error

• Gaps/deficiencies in global observing network
• Errors /bias in observation data
• Choices in observation selection
• Observation quality control decisions
• Different and imperfect data assimilation techniques
• Errors in background forecast
Methodology

- Use multi-year, multi-model archive of operational analyses and forecasts, developed at NRL for research and diagnostic studies
- Quantify and examine differences in atmospheric analyses, trends over time …
- Examine systematic (monthly/seasonal) patterns
Surprisingly sparse literature on the topic of atmospheric analysis uncertainty and error

“Some aspects of the improvement in skill of numerical weather prediction, 2002: A.J. Simmons and A. Hollingsworth, QJRMS.”
ECWMF / Met Office
Analyses of 500hPa height

Simmons and Hollingsworth (2002)

From 12UTC analyses, 12Dec 2000 to 12 March 2001

Analyses shown to be more similar in regions with in-situ observations (esp. radiosondes)
Analyses from NCEP, ECWMF, UKMO, CMC, FNMOC
00UTC: 1Feb 2008 to 30Apr 2008

Wei et al. (2010)
Time-averaged spread over the average anomaly

In general, smaller analysis spread in locations with in-situ observations (esp. raodiosondes, aircraft)
Indication that assimilation of high-quality in-situ observations (radiosondes, aircraft data) reduces analysis uncertainty more than assimilation of satellite observations (radiances and feature-track or scatterometer winds)
Smaller analysis uncertainty (<1K) where radiosonde data are provided
Larger uncertainty (1-2K) between analyses where satellite data predominates

UNCERTAINTY BETWEEN ANALYSES CAN BE LARGER THAN SHORT-RANGE "FORECAST ERROR"!!
2011: same pattern still in place!
[Many new radiance data have been added during 2007-2011]

Root-Mean Square of Analysis Differences: 500mb Temperature

Langland and Maue 2011
Analyses from NCEP, ECWMF, UKMO, CMC, CMA
00UTC: 1OCT 2010 to 30Sep 2011

Hamill (WGNE, Dec 2011)

Time-average of daily spread (sample standard deviation) of analyses about their daily mean

“Analyses, assumed to be unbiased, do exhibit substantial bias Implications for ensemble perturbations (may be too small)”
300mb Wind Speed (2010)  GFS / ECMWF

Root-Mean Square of Analysis Differences: 300mb Wind Speed

Note the very significant effect of in-situ wind observations:
Radiosondes and Commercial Aircraft

Langland and Maue 2011
Siberian Radiosonde Stations
A key component of the global observing network

vdor@starlink.ru
Raob launch in Siberia
Unicertainty in atmospheric upper-tropospheric wind analyses is substantially lower in locations where radiosonde data is provided. The blue-shaded areas are locations where raobs provide soundings twice-daily (00z and 12z). Station 70414 provides data only at 12z, so the associated reduction in analysis error at that location is mitigated, but still significant.
500mb ht root mean square analysis differences
South Polar Region: ECWMF | GFS

Langland and Maue 2011
Data Overview—CIMSS/UW Polar/LeoGeo Winds

Geostationary winds—orange
LeoGeo winds—purple (operational in Nov 2010)

Assimilated at NRL, but not all other centers
About 19 million observations assimilated in global domain each day in NAVDAS-AR [4d-Var]

28 Apr 2012 [00, 06, 12, 18 UTC]

High observation density does not guarantee analysis quality!!
Question

Why is analysis uncertainty over oceanic regions still much larger than over North America and Europe, despite the addition of massive amounts of radiance data? [Now as much as 90% of all assimilated data.]

Basic patterns of analysis differences and analysis uncertainty in 2012 remain similar to those reported in 2002.
Do the analysis differences shown in these studies have implications for design of the global observing network?
Summary

Availability of radiosonde and aircraft data appear to substantially reduce uncertainty in upper-air analyses of temperature and wind.

Analysis uncertainty is larger where the analysis relies primarily on radiance observations.

What new observing instruments and variables are most-needed to reduce analysis uncertainty?

Where is the greatest need to reduce the current magnitude of analysis uncertainty? Polar regions? Oceanic storm tracks?
Data count in 2° x 2° lat/lon bins

The largest density of observations is due to in-situ data [radiosondes, aircraft, land-surface and ocean-surface observations]