The influence of routine rawinsonde observations on 3-7 day weather forecasts over North America and Europe

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Snow and Rain in USA, 24 Nov 04

East Asian rawinsondes assimilated at 00 UTC Nov 21 affected the 3.5 day NCEP GFS precipitation forecast by nearly 1 cm in places.
Motivation

- A NOAA THORPEX goal: accelerate improvement of 3-7 day precipitation forecasts.

- 1. Understand how observations benefit 3-7 day forecasts over a large sample of cases.

- 2. Identify whether adaptive sampling strategies can predict quantitatively how these observations change forecasts, in different flow regimes.
Methodology

• Three Parallel T126 NCEP GFS forecasts are run every day from slightly different analyses (same first guess):
  (a) Operational
  (b) Rawinsondes denied from E.Asia
  (c) Rawinsondes denied from E. North America

• 1. Are “signals” associated with downstream baroclinic development or other dynamical processes over the Northern Pacific and Atlantic? (Upstream development?)

• 2. Are Ensemble Transform Kalman Filter (ETKF) predictions of signal variance evolution associated with similar non-linear atmospheric processes, and do they have quantitative skill in various flow regimes?
Is the NCEP GFS signal associated with Downstream Development?

Observations lowered Z500(m) Obs increased Z500(m)

California Cold Snap last week.

Signal from Asian obs travelled 90°, reached CA within 48h.

Observations acted to deepen 500hPa trough forecast by >30m in NE America at +72h.

160° propagation in 3 days?!
500 hPa vorticity signal travelled 80-100°, reaching SE Europe within 3 days.

Rapid amplification of signal between 72-84h. N.American observations acted to increase the forecast vorticity substantially in the downstream trough region.

Is the NCEP GFS signal associated with Downstream Development?

Reduced vorticity (10⁻⁵ s⁻¹) Increased Vorticity
ETKF (Bishop et al. 2001)

Used annually during NWS Winter Storm Reconnaissance Programs (Majumdar et al., MWR 2002), and by UK Met Office during 2003 A-TReC.

Utility of ETKF as a targeted observing strategy for tropical cyclone surveillance is being tested (Aberson and Wu talks)
ETKF uses $P^f = Z^f Z^{fT}$

Kalman Filter error statistics equations to produce error covariances for the routine observational network:

\[
Pr = Pf - Pf Hr^T (Hr Pf Hr^T + Rr)^{-1} Hr Pf
\]

Update forecast error covariance matrix for $q^{th}$ set of targeted observations:

\[
Pq = Pr - Pr Hq^T (Hq Pr Hq^T + Rq)^{-1} Hq Pr
\]

ETKF predicts “signal covariance” $S^q$: reduction in forecast error covariance for $q^{th}$ deployment of adaptive observations:

\[
S^q = Pr - Pq = M Pr(t_a) Hq^T (Hq Pr(t_a) Hq^T + Rq)^{-1} Hq Pr(t_a) M^T
= Zr(t_v) T^r Cq \Gamma q (\Gamma q + I)^{-1} Cq^T T^r Zr^T(t_v)
\]

“Signal variance” = diagonal of $S^q$. This uses a LINEAR COMBINATION of ensemble perturbations valid at $t_v$
ETKF

ETKF estimates forecast error covariance matrix based on ensemble perturbations appropriate for a particular observational network: $P = ZZ^T$

ETKF predicts “signal covariance” $S^q = \text{reduction in forecast error covariance due to rawinsonde obs}:

$$S^q = Pr - Pq$$

$$= M Pr(t_a) Hq^T (Hq Pr(t_a) Hq^T + Rq)^{-1} Hq Pr(t_a) M^T$$

$$= Zr(t_v) Tr Cq \Gamma_q (\Gamma_q + I)^{-1} Cq^T Tr^T Zr^T(t_v)$$

“Signal variance” = diagonal of $S^q$. Uses a LINEAR COMBINATION of ensemble perturbations $Zr^T(t_v)$
NCEP GFS
Signal: square root of vertically integrated perturbation energy

\[ 0.5 \left[ u'^2 + v'^2 + \frac{c_p}{T_r}(T'^2) + R_d T_r \left( \frac{P'^s}{P_r} \right)^2 \right] \]
Initial (+00h) increment in ETKF signal variance and NCEP signal differ considerably.

ETKF prediction of variance of energy signal

Despite this, ETKF and NCEP maps give maxima at similar locations, even out to 5 days.
Summary

• Signal propagation over Atlantic and Pacific is often associated with downstream baroclinic development along the storm track, supporting Szunyogh et al.’s results (MWR 2000, 2002).

• Need to identify relative roles of convergence of ageostrophic geopotential flux, baroclinic and barotropic conversion terms in converting and transferring eddy energy downstream. Expect high baroclinic energy conversion east of rawinsonde sites: would more observations be useful in these regions? At what levels?
Future Work

• To what extent are ETKF signal variance predictions skillful in flow regimes of varying non-linearity, zonality etc?
• Can the ETKF be used to advise on deployment of offshore observations? Targeted satellite obs?
• Investigate full life cycles of baroclinic cyclones, perhaps extend to 7-14 days.
• Extend to tropical cyclones (Wu, Aberson)
• NCEP GFS signals for European and N.American forecasts will continue to be updated daily on http://orca.rsmas.miami.edu/~majumdar/thorpex/