ADAPTIVE OBSERVATIONS AT NWS:
THE WINTER STORM RECONNAISSANCE PROGRAM

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1  SAIC at NCEP
1) ATMOSPHERIC OBSERVATIONS

TRADITIONAL AND ADAPTIVE APPROACHES

2) TARGETED OBSERVATIONAL TECHNIQUE

FCST CASE SELECTION, SENSITIVE AREA, DATA COLLECTION

3) PAST PROGRAMS

EIGHT RESEARCH & OPER. PROGRAMS BETWEEN 1997–2002

4) WINTER STORM RECONNAISSANCE 2001 PROGRAM

OPERATIONALLY IMPLEMENTED AT NWS; POSITIVE RESULTS

5) PLANS

EXPAND WSR PROGRAM IN TIME/SPACE; THORPEX RESEARCH
CURRENT PRACTICE:

Most observations are taken

1) At fixed times and locations (in situ obs)

2) As opportunities arise (aircraft ascent/descent; satellite overpass)

3) Based on FEATURE (hurricane, heavy precip & its environment)

ADAPTIVE APPROACH:
Obs. taken adaptively to maximize analysis and/or forecast impact

TARGETED OBSERVATIONS

IMPROVE PARTICULAR FCST FEATURE:

Eg, 3–day precip fcst over ne US

QUESTION: Can targeting observations improve fcst performance?

PROBLEM: Fcst feature

may not exist at observation time
may undergo major changes till verification time =>

Feature based technique is not applicable at longer lead times
1) How to select fcst feature?
   a) Uncertainty/information content in fcst
   b) Societal impact: Is uncertainty tolerable?

2) How to identify sensitive area to be observed?
   (i) Adjoint sensitivity calculations
   (ii) Ensemble transform technique

3) How to take observations?
   (i) Dropsondes released from manned aircraft
   (ii) Unmanned aircraft
   (iii) Balloons
   (iv) Satellite

4) How to evaluate technique?
   (i) Data impacts desired fcst feature?
   (ii) Impact positive (ie, fcst improved)?
   (iii) Societal impact – Cost effective?
CASE 1:
Decision time: 2001020100
Observation time: 2001020300
Verification time: 2001020500
Longitude: 123W
Latitude: 48N
Priority: HIGH
Comments: nw precip
GOAL:
Try to reduce expected fcst error at time $t_2$, location $V(\text{erif})$

PROBLEM:
Locate sens area where extra obsv. at $t_1$ best achieve goal

METHOD:
Based on nonlinear ensemble – Bishop and Toth, 1996
Ensemble Trasform Kalman Filter – Bishop and Majumdar, 2000

Variance = uncertainty under standard observational network

TRANSFORM ENSEMBLE to see effect of extra observations
Variance = uncertainty with extra obs. added at location X
MOVE X to see if variance at $t_2$ optimally reduced at Verif area

TRANSFORMATION:
Linear combination of ensemble perturbations – SVD in vector space of ensemble perturbations at $t_1$ and $t_2$
COMPUTATIONALLY VERY EFFICIENT
FORECASTERS: List of significant fcst events: Time, Lat/Lon

PRIORITIZE

Objective guidance can be developed based on ensemble

SDM: Sensitivity computations for each event:

General guidance
Best flight tracks
Expected data impact

Based on results and priority of each event and available resources,

DECIDE WHETHER TO FLY, AND WITH WHICH PLANE(S)

Can be fully automated for other observing systems

WSR PREDESIGNED FLIGHT TRACKS

NWS Seminar, Silver Springs, July 24 2002
**OVERVIEW OF FIELD PROGRAMS**

<table>
<thead>
<tr>
<th>PROGRAM</th>
<th>TIME PERIOD</th>
<th>OBS.AREA</th>
<th>VERIF.AREA</th>
<th>Details</th>
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<tbody>
<tr>
<td>WSR2000</td>
<td>Jan–Febr 2000</td>
<td>NE–Pacific</td>
<td>CONUS, AL</td>
<td>Training of operational personnel</td>
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<tr>
<td>WSR2001</td>
<td>Winter 2001</td>
<td>NE–Pacific</td>
<td>CONUS, AL</td>
<td>Operational implementation</td>
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<tr>
<td>PACJET</td>
<td>Winter 2001</td>
<td>NE–Pacific</td>
<td>W–US</td>
<td>Meso–scale research program</td>
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<td>WSR2002</td>
<td>Winter 2002</td>
<td>NE–Pacific</td>
<td>CONUS, AL</td>
<td>Fully operational</td>
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<tr>
<td>THORPEX–TOST</td>
<td>Winter 2003</td>
<td>Atlantic &amp; Pacific</td>
<td>– Obs. system tests</td>
<td></td>
</tr>
</tbody>
</table>
Based on: WSR 2000 & earlier field programs

New element: Transition into operations

Collaborative effort:
Forecast feature  Sensitive area  Aircraft operations
Regions => HPC => EMC/SDM => AOC/USAF Reserve

Each mission:
Requested by field/HPC forecasters to support critical weather forecasts
Operational needs
Among predisigned flight tracks, best is selected objectively
SDM training
Dropsonde flight missions carried out by AOC & USAF Reserve

Total of 17 missions, 360 dropsondes:
8 NOAA G–IV (from Honolulu) and
10 USAF C–130 (from Anchorage) flights

All data used operationally

Data impact evaluation:
Near real time parallel assimilation. fcst cycle with dropsonde data excluded:
CASE 1:
Observation time: 2001020300
Verification time: 2001020500
Longitude: 123W
Latitude: 48N
Priority: HIGH
Comments: nw precip
TOHT ET AL.: TARGETED OBSERVATIONS

Expected forecast error reduction in verification region (VR) due to adaptive observations around any grid point.

Case 1  Obs. time: 20001020300  Verif. time 20001020500  VR: 48N, 123W, 1000km radius  Verif. var.: u,v,t
PSU-NCEP ETKF based on 35-member 20001020100 combined ensemble. Best flight tracks: 34 33 19

(NWS Seminar, Silver Springs, July 24 2002)
Signal Variance for u,v,t Flight 34. Observation time 2001020300, 2001020100 ensemble.
TOTH ET AL.: TARGETED OBSERVATIONS

NWS Seminar, Silver Springs, July 24 2002
Targeted Observations

2001020300 (+00 hrs)

2001020500 (+48 hrs)

2001020312 (+12 hrs)

2001020512 (+60 hrs)

2001020400 (+24 hrs)

2001020600 (+72 hrs)

2001020412 (+36 hrs)

2001020612 (+84 hrs)

Operational surface pressure — control surface pressure (contour interval = 0.5 mb)
<table>
<thead>
<tr>
<th>DATE/FLIGHTS</th>
<th>VERIFICATION</th>
<th>CENTER OF</th>
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<td>N</td>
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<tr>
<td>010303 P</td>
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</table>
TOTAL OF 27 FORECAST VERIFICATION CASES:
IMPROVEMENT 20
NEUTRAL IMPACT 3
DEGRADATION 4
RESULTS STATISTICALLY SIGNIFICANT AT 0.1% – 5% LEVEL

FIG. 2: RMS error of 24–84 hours targeted surface pressure forecasts, measured against observations within predefined verification regions over the west coast, Hawaii, and the eastern US, with (horizontal axis) and without (vertical axis) the use of dropsonde data for the 27 Winter Storm Reconnaissance Program 2001 cases.

FIG. 3: Same as Fig. 2 except for wind vector errors integrated for the 1000–250 hPa layer.
WINTER STORM RECONNAISSANCE PROGRAM

January 22 – March 20, 2002

BASED ON: Earlier field programs

NEW ELEMENT: Fully Operational

COLLABORATIVE EFFORT:
Forecast feature Sensitive area Aircraft operations

Regions => HPC => SDM => AOC/USAF Reserve

EACH MISSION:
Requested by field/HPC forecasters to support critical weather fcsts Operational needs

Among predisigned flight tracks, best is selected objectively SDM personnel trained

Dropsonde flight missions carried out by AOC & USAF Reserve

TOTAL OF 22 MISSIONS, 500–600 DROPSONDES:
18 NOAA G–IV (from Anchorage & Honolulu) and
7 USAF C–130 (from Honolulu) flights

ALL DATA USED OPERATIONALLY

DATA IMPACT EVALUATION:
Parallel assimil. fcst cycle with dropsonde data excluded, see later at:
## SUMMARY OF TARGETED OBSERVATIONS RESULTS

<table>
<thead>
<tr>
<th>SIGNAL</th>
<th>MOD/VERIFICATION</th>
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<td>sp</td>
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<tr>
<td>FASTEX</td>
<td>7+1–0</td>
</tr>
<tr>
<td>NORPEX</td>
<td>8–2</td>
</tr>
<tr>
<td>CALJET</td>
<td>3+1–1</td>
</tr>
<tr>
<td>WSRP–99</td>
<td>21+4–0</td>
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<tr>
<td>WSRP–00</td>
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<tr>
<td>WSRP–01</td>
<td></td>
</tr>
</tbody>
</table>

% SUCC.: 81–94 87–95 81 73 91 84

STAT. SIGN.: * * * *

1) Max. signal is in verif. area in most cases – 12–84 hrs lead time, Continental US + Alaska
2) Moderately sensitive areas contribute less
3) Nonsensitive areas virtually have no impact
4) Forecasts improve in 70–90% cases
5) 10–20% average error reduction in verif area
6) Targeted forecasts gain 12–24 hrs in lead time

TECHNOLOGY TRANSFERRED INTO OPERATIONS

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Average pattern of sensitivity in initial conditions to errors in a 36–hour forecast over the west coast for the 15 Winter Storm Reconnaissance Program 1999 cases in 36–hr forecasts (top, shades of blue). The surface pressure impact of the dropsonde data (red dots) is shown in black contours at initial time (top, contour interval is 0.1 mb, starting at 0.2 mb), and at 36–hr lead time (bottom, first contour is at 0.8 mb). Note that the maximum average forecast impact of the targeted data is within the area of preselected verification regions (averaged location shown as a blue ellipsoid), right over the area of large (greater than 2.5 mb) control surface pressure forecast error shaded in pink.
Signal from real targeted areas amplifies much more than that from adjacent, less sensitive areas (significant difference at 0.5% level, Wilcoxon rank sum test).

For null cases signal outside of verification area over that within verification area is much larger than that for real cases (significant difference at 0.5% level, Wilcoxon rank sum test).

Based on 11 out of 14 FASTEX cases.
RMS error (measured against observations) of 2–day surface pressure forecasts with (horizontal axis) and without (vertical axis) of dropsonde data for the 10 NORPEX–98 cases (top) where the NCEP targeted guidance was used, over western north America (230–260 E, 30–60 N). On the bottom panel errors for all other days in the NORPEX–98 period (January 16 – February 27, except for missing data on Febr. 16, 17 and 19, where no flights were taken) are shown with crosses whereas the NCEP flight days are repeated with dots.

**2–day surface pressure fcsts improved 7 out of 8+2 cases (statistically significant at 10% level)**

**NCEP flight days have higher skill than all other days (or other flight days); statistically significant at 5% level**
RMS error (upper panel) of surface pressure forecasts with (continuous lines) and without (dashed lines) dropsonde data for the 12 WSR2000 cases, over the US (25–50N, 125–70W), West coast (25–50N, 125–100W), Eastern US (25–50N, 100–70W), and Alaska (55–70N, 165–140W). RMS error reduction (lower panel) in surface pressure over western half of Northern Hemishpere extratropics due to winds and temperature, or separately winds only or temperature only targeted dropsonde data for the 12 WSR2000 cases. The sum of the separate winds and temperature only error reduction values is also shown.
Average reduction in 48–hr surface pressure forecast error for 15 Winter Storm Reconnaissance Program 1999 cases (top, shades of red, %), along with the average 48–hr control surface pressure forecast error (black contours). Note that the use of the dropsonde data reduced forecast errors on average by 10–20% over the area of maximum forecast errors within the average location of the verification regions at 48–hr lead time (blue dashed ellipsoid). In comparison, improvements in the Northern Hemispheric observing system produced a 10% rms error reduction in 2–day 500 hPa reanalysis forecasts during the most recent 25 years (bottom right).
QUALITATIVE COMPARISON OF ENSEMBLE TRANSFORM AND ADJOINT SENSITIVITY RESULTS, JAN. 25 2000 STORM

Fig. by Shapiro
1) **EXPAND OPERATIONAL WSR PROGRAM**

a) Cover full winter (4 instead of 2 mos.)

b) Fold East Coast Winter Storm program under WSR

c) Establish West Coast mesoscale program under WSR

2) **THORPEX RELATED RESEARCH**

a) Study adaptive obs approach on larger (global) domain

b) Explore targeting longer (4–6–day) range fcst

c) Test use of new LIDAR wind, aerosonde, driftsonde obs.

d) Compare traditional vs. adaptive approach in OSSEs

e) Refine sensitivity analysis – increase resol./ens. members

f) Automate case selection based on ensemble fcst

g) Study economic impact
1) ATMOSPHERIC OBSERVATIONS

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EXPAND WSR PROGRAM IN TIME/SPACE; THORPEX RESEARCH
4) CAN AN ENSEMBLE PREDICT VARIATIONS IN FCST UNCERTAINTY?

REPHRASED QUESTION:
What are the typical variations in foreseeable forecast uncertainty? What variations in predictability can the ensemble resolve?

METHOD:
Ensemble mode value to distinguish high/low predictability cases
Stratify cases according to ensemble mode value –
Use 10–15% of cases when ensemble is highest/loewest

DATA:
NCEP 500 hPa NH extratropical ensemble fcstsfors March–May 1997
14 perturbed fcsts and high resolution control

VERIFICATION:
Hit rate for ensemble mode and hires control fcst
THE UNCERTAINTY OF FCSTs CAN BE QUANTIFIED IN ADVANCE

HIT RATES FOR 1–DAY FCSTs

CAN BE AS LOW AS 36%, OR AS HIGH AS 92%


1–2% OF ALL DAYS THE 12–DAY FCST CAN BE MADE WITH MORE CONFIDENCE THAN THE 1–DAY FCST

AVERAGE HIT RATE FOR EXTENDED–RANGE FCSTs IS LOW – VALUE IS IN KNOWING WHEN FCST IS RELIABLE
Relative measure of predictability (colors) for ensemble mean forecast (contours) of 500 hPa height
ini: 2000102700 valid: 2000102800 test: 24 hours

Probability (%) 8 16 22 29 35 44 54 62 74 91
Measure of predictability (%) 10 20 30 40 50 60 70 80 90 100

Relative measure of predictability (colors) for ensemble mean forecast (contours) of 500 hPa height
ini: 2000102700 valid: 2000110400 test: 192 hours

Probability (%) 7 10 10 11 12 12 14 15 22 29
Measure of predictability (%) 10 20 30 40 50 60 70 80 90 100

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WHAT MAKES FCSTS BETTER / MORE USEFUL?

1) More / better quality data
   – within 25 years:
     10% 2D error reduction, 6–hr gain

2) Improved analysis schemes
   – within 6 years:
     10% 5D AC improvement, 12–hr gain

3) Better fcst models

4) Use of ensembles:
   25–30% 5D Brier score imprvm., 24–hour gain

Control forecast always predicts same level of reliability whereas ensemble indicates flow dependent level of reliability.
IMPROVEMENTS IN DATA ONLY
Reanalysis Forecast 500 mb Height RMS

Northern Hemisphere

10% ERROR REDUCTION IN 25 YEARS

IMPROVEMENTS IN DATA + ASSIMILATION + MODEL
NCEP 5-Day Forecast Anomaly Correlations
Operational vs Reanalysis (UPDATED for 1998)

10% IMPROVEMENT IN 6 YEARS

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Pattern Anomaly correlation (PAC, upper panel) and RMS error (lower panel) of surface pressure forecasts with (continuous lines) and without (dashed lines) dropsonde data for the 12 WSR2000 cases, over the US (25±50N, 125–70W), West coast (25–50N, 125–100W), Eastern US (25–50N, 100–70W), and Alaska (55–70N, 165–140W).