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ADAPTIVE OBSERVATIONS AT NCEP: PAST, PRESENT, AND FUTURE

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1. INTRODUCTION

In this paper we provide an overview of activities related to the use of adaptive observations at the National Centers for Environmental Prediction (NCEP). First a brief summary is given on past developments (section 2). This is followed by a discussion on current activities related to the recent introduction of adaptive observations into the National Weather Service (NWS) operations in the framework of the Winter Storm Reconnaissance (WSR) program (section 3). Section 4 is devoted to a short discussion of the impact adaptive observations collected in the latest field program (Winter Storm Reconnaissance 2001, WSR01) had on forecast quality. A short description of planned activities is given in section 5, while section 6 offers some conclusions.

2. HISTORICAL OVERVIEW

Targeted observations, where data are collected in specific areas at specific times with the aim of improving the quality of preselected Numerical Weather Prediction (NWP) forecast features in the extatropics has only a short history (Toth et al. 2001). The idea was first dicussed publicly at a workshop in 1995 (Snyder 1996). Related research at several NWP centers has first organized around a major field program, the Fronts and Atlantic Storm Track Experiments (FASTEX, Joly et al. 1999). NCEP, in collaboration with Pennsylvania State University (PSU) scientists, contributed by developing the Ensemble Transform technique (ET, Bishop and Toth 1999), later superseded by the Ensemble Transform Kalman Filter technique (ETKF, Bishop et al. 2000; Majumdar et al. 2001a), along with adjoint and quasi–inverse linear techniques (Pu et al. 1997). In 1997 these techniques were used, in a collaborative effort with Massachusetts Institute of Technology (MIT) scientists, in real time during the FASTEX field experiments to identify observational areas for the release of dropsondes by manned aircraft. Results from the use of these adaptive observational techniques in FASTEX are reported in Toth et al. (1998), Szunyogh et al. (1999a), and Pu and Kalnay (1999).

The ET technique was further tested, along with an adjoint technique developed by the Naval Research Laboratory (NRL), in the following winter within the North Pacific Experiment (NORPEX, Szunyogh et al. 1999b; Langland et al. 1999). NCEP also participated in the California Landfalling Jets Experiment (CALJET, Ralph et al. 1998), and later in the Pacific Landfalling Jets Experiment (PACJET) regional field programs by providing experimental mesoscale adaptive observational guidance (Toth et al. 2000). The success of these early field experiments led to the establishment of the Winter Storm Reconnaissance field program in 1999 (Toth et al. 1999).The aim of the WSR program is to reduce forecast errors for significant winter weather events over the contiguous US and Alaska in the 24–96 hour lead time range through the use of adaptive observations over the data sparse northeast Pacific. For this purpose dropsonde data are collected by the Aircraft Operations Center (AOC) of the National Oceanic and Atmospheric Administration (NOAA) and the 53rd Weather Reconnaissance Squadron of the US Air Force (USAF), through the use of manned aircraft operating out of Honolulu, HI, and Anchorage, AL.

Verification results indicate that the majority of the targeted forecasts are significantly improved (Szunyogh et al. 2000; 2001). Based on these results WSR became a regular program (Toth et al. 2001). Recognizing the success and importance of wintertime adaptive observations, in January 2001 NWS made the WSR program operational. In the following section we discuss some details of the transition of the adaptive observational work from the research into the operational environment.

3. TRANSITION FROM RESEARCH INTO NWS OPERATIONS

As discussed by Toth et al. (2001) adaptive observations involves three major steps: (1) Selection of a targeting case, i. e., the identification of date/time and location of a threatening weather event for which forecasts are to be improved; (2) Identification of observational time and area from where extra observations can most benefit the forecast aspect defined in (1) above (sensitivity calculations); and (3) Collection of atmospheric measurements from the observational area defined in (2). Here we will discuss how the transition from research to operational mode is affecting each of the three major steps of adaptive observations in the WSR program.

In the first year (1999) of the WSR program, researchers at the Environmental Modeling Center (EMC) of NCEP, in collaboration with PSU scientists, carried out the first two steps of adaptive observations, case selection, and sensitivity calculations. The program became operationally oriented in 2000, hence the case selection task was taken up

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by forecasters at the Hydrometeorological Prediction Center (HPC) of NCEP. Sensitivity calculations were still carried out by the developers of the method at PSU and EMC. During the WSR 2000 (WSR00) program the first author provided training to Senior Duty Meteorologists (SDM) of the NCEP Centeral Operations (NCO) with respect to the targeting procedure on a daily basis. Another change introduced in anticipation of a subsequent operational implementation was the use of predesigned flight tracks. To drastically reduce the work load related to daily flight planning activities sensitivity calculations were carried out for a number of predesigned flight tracks. Results from the new sensitivity product facilitated the rapid selection of the optimal flight pattern. With these changes the WSR00 program can be considered as the first phase of the transition process.

In January 2001 the WSR program became operational at the US NWS. The WSR01 program constitutes the second phase of the transition into operations, which involved the following changes: (1) Transition of all necessary software from EMC to NCO; (2) Formalizing the case selection process by establishing a mechanism for NCEP Service Centers (beyond HPC) and NWS Weather Forecast Offices (WFOs, through a focal point in their region) to provide their input; (3) Assembly and prioritization of case selection requests by the SDM; (4) Sensitivity calculations for the selected cases initiated by SDM (and not EMC, as before); (5) Evaluation of the results and final decision making by the SDM as to whether or not to deploy aircraft and if so along what predesigned flight track(s). The decision, as in earlier years, is transmitted to Chief, Aerial Reconnaissance Coordination, All Hurricanes (CARCAH) who acts as an intermediary between NCEP and the aircraft facilities. To assist the work of the SDM meteorologist two interactive scripts have been also developed and operationally implemented. To ensure a smooth transition the training provided by EMC to SDM resumed on a more intense basis during the WSR01 program.

As part of the third and last phase of the transition from research into operations, the first author will provide a refresher training course to SDM in the fall of 2001. After this training it is expected that the SDM personnel will be ready to carry out their adaptive observational duties on their own (though EMC will be ready to offer advice in case the need arises).

The new task of the selecting significant winter weather forecast cases fits naturally into the routine of operational forecasters at HPC (who, because of their wide scope of interest, provide WSR requests on a regular basis), and at other forecast units (who contribute occasionally). Daily interaction between HPC and EMC personnel during the WSR00 and WSR01 programs guarantees a smooth transition process in this aspect of targeting. As for the sensitivity analysis and decision making part, SDM meteorologists, whose daily core activities include data quality control and forecast quality assurance, are well positioned and motivated to take up the new responsibilities.

4. WSR01 RESULTS

The impact of the adaptively collected dropsonde data on the quality of the targeted forecasts can be assessed by running an analysis/forecast cycle from which all targeted data are excluded, parallel to the operational cycle that uses all data, including those taken adaptively (Szunyogh et al. 1999). In this section preliminary verification results are presented for the WSR01 program, based on a comparison of error reduction statistics for forecasts from the operational vs. the parallel cycles. Additional results can be found at the WSR01 web site: http://sgi62.wwb.noaa.gov:8080/ens/target/wsr2001.html and in Majumdar et al. (2001b).

4.1 *Verification statistics*

The preliminary verification results for the WSR01 program are presented in Table 1. Note that the operationally implemented version of the sensitivity calculation codes contained a bug that rendered the results unreliable. The problem was recognized and circumvented 28 January 2001. Therefore the first 5 flight days before 28 January are omitted from Table 1 and results are shown only for the remaining 13 flight days.

OBSERVA-TIONS		***FORECAST CASE***				***VERIFICA-TION***		
Date	***Flight***	***LT***	***LA***	***LO***	***PR***	***SP***	***W***	***SM***
010128	21	48	36	91	H	+	+	+
		72	39	77	H	–	0	–
010131	20, 31	24	50	124	L	+	+	+
		48	50	124	M	+	–	0
		108	35	96	L	+	_	0
010201	20, 35	24	50	124	M	+	+	+
		96	30	87	L	+	–	0
010203	34	48	48	123	H	+	+	+
010204	21, S	36	48	124	L	+	–	0
		96	35	95	H	+	+	+
		24	21	158	E	+	+	+
		48	32	142	E	+	+	+
010205	37	96	35	88	M	+	+	+
010206	9	72	36	91	M	+	0	+
		96	40	80	M	+	+	+
010207	8	48	42	123	M	–	–	–
		72	39	86	H	0	+	+
010210	E	24	21	157	E	+	+	+
		48	21	157	E	0	+	+
		72	21	157	E	0	+	+
010217	45	36	39	124	M	+	+	+
		48	41	91	L	–	+	0
010219	46	24	40	122	H	+	+	+
010220	37	48	39	121	M	–	+	0
		72	36	76	M	–	+	0
010226	F	24	35	112	L	+	–	0
		48	35	92	L	–	+	0

Table 1. WSR01 flight days (column 1, yymmdd), flight track numbers (col. 2, S for SCATCAT, E for experimental, and F for Ferry flight track), corresponding forecast cases (lead time (LD) in hours, col. 3, latitude (LA) and longitude (LO) of center of verification region, cols. 4–5, priority (PR,

H, M, L, and E for High, Medium, Low, or Experimental, col. 6), and forecast verification (SP, W, and SM for surface pressure, tropospheric winds, and summary measure, cols. 7–9).

The first two columns in Table 1 mark the flight days (flights were always centered around 0000 UTC time) and flight track(s). As seen from the table, on three occasions two flights were requested in order to cover a geographical area larger than that feasible with only one plane. Flight tracks with numbers below/above 30 indicate tracks originating and terminating in Alaska/Hawaii.

Columns 3–6 identify the targeted forecast features. Time is expressed in terms of forecast lead time from the targeted observational time (column 1) while the location is given as the latitude/longitude position of a 1000 km radius disc. Altogether there were a total of 27 verification cases, including 6 cases that the forecasters marked as high priority (column 6). Six other cases were considered experimental since they were verifying out of the WSR domain of the continental US and Alaska, 4 over Hawaii and 2 over the Pacific. Note that in most cases flight(s) were requested to improve forecasts for two or more forecast features. Verification features associated with a flight were sometimes as far apart as the west and east coast of the US in space, and 3 days in lead time.

Columns 7–9 contain the main results of this study. Positive/negative (zero) signs indicate whether the operational forecast, started from an analysis using the targeted data, performed better/worse than (similar to) its parallel counterpart that made no use of the targeted data. The verification procedure follows that used in Szunyogh et al. (2000), and is based on surface pressure and tropospheric wind (1000–250 hPa) observations within the preselected verification region in a 6–hour time window around the verification time. The last, 9th column provides a summary measure based on the surface pressure and wind results. The results reveal that in the majority of the cases the targeted data improved the quality of the forecasts in the intended area. Clear overall forecast improvement is observed in 16 of the 27 preselected verification cases while the results are neutral on 9 occasions (Table 2). It is important to note that the forecasts were improved in 5 of the 6 high priority cases.

In 2 cases overall performance was degraded by the use of targeted data. To understand why this can happen we should note that data assimilation algorithms are statistical schemes that guarantee improved performance due to better data coverage only in an expected sense, averaged over many cases (Szunyogh et al. 1999). The difference between the number of imporved (16) vs. degraded (2) forecasts for the WSR01 program is statistically highly significant (at the 0.001 level, see last column in Table 2). Despite the major logistical changes associated with the transition of the adaptive observing methodology from a research into an operational environment the overall results for the WSR01 program are similar to those from earlier programs (Toth et al. 2001). Forecasts are improved in 60–70% of all cases and the average rms error reduction in the preselected verification regions is on the order of 10% (not shown).

	VERIFICATION			
MEASURE	***Wins***	***Losses***	***Neutral***	***Signif.***
Surf. Pr.	18	6	3	0.01
Winds	19	6	2	0.01
Summary	16	2	9	0.001

Table 2. Summary verification results for WSR01 based on the number of positive (wins), negative (losses) and neutral targeting data impact cases in Table 1. The level of statistical significance is shown in righthand column.

4.2 *A typical example*

As a typical example, Fig. 1 shows the time evolution of the analysis/forecast signal of the targeted dropsonde data collected around 0000 UTC 7 February 2001. Note that the forecast signal associated with the impact of targeted data generally exhibits strong downstream development along the upper level jet (hence the choice of 250 hPa geopotential height in Fig. 1) and can influence vast areas in space in a short period of time. Due to the strong downstream development, the signal typically travels considerably faster than the synoptic features themselves, at an average speed of 30 degrees longitude per day (Szunyogh et al. 2001).

Downstream development is well demonstrated in the case of Fig. 1. Data were collected in the area of 155W–170W and the leading edge of the main signal reached 130W by 24, and 80W by 48 hour lead time. It is interesting to note that it is the leading edge of the signal where systematic forecast improvements are typically observed whereas under certain flow regimes the results can be more mixed in the areas behind it (Szunyogh et al. 2000). This is also the case in our example where the forecast is slightly degraded over the west coast verification region at 48 hour lead time (well behind the leading edge) while considerably improved over the eastern half of the continent, including the east coast verification region, at 72 hour lead time (within the area of the leading edge, see Fig. 2).

5. PLANS

Adaptive observations is a dynamically evolving field. It took merely six years from the time its concept emerged to its operational implementation at the US NWS. The fast evolution of the field naturally involves changes. On a few occasions in the WSR01 program, for example, experimental targeting was carried out to explore the possibility of extending the spatial coverage of the WSR program to cover the Hawaiian Islands and areas of maritime interest in the northeast Pacific. NCEP wants to be prepared for scientific, observational and other changes in the future and intends to play, through continued collaboration, an integrating role in the area of adaptive observations. In this section we describe some plans related to these efforts.

5.1 *Ensemble data*

The sensitivity calculations discussed earlier are based on a set of nonlinear ensemble forecasts (Bishop and Toth 1999; Bishop et al. 2001). It follows that larger and/or more skilful sets of ensemble forecasts lead to improved targeting guidance (Toth and Szunyogh 1997; Szunyogh et al. 1999). In the WSR01 program ensembles combined from NCEP (Toth and Kalnay 1997) and

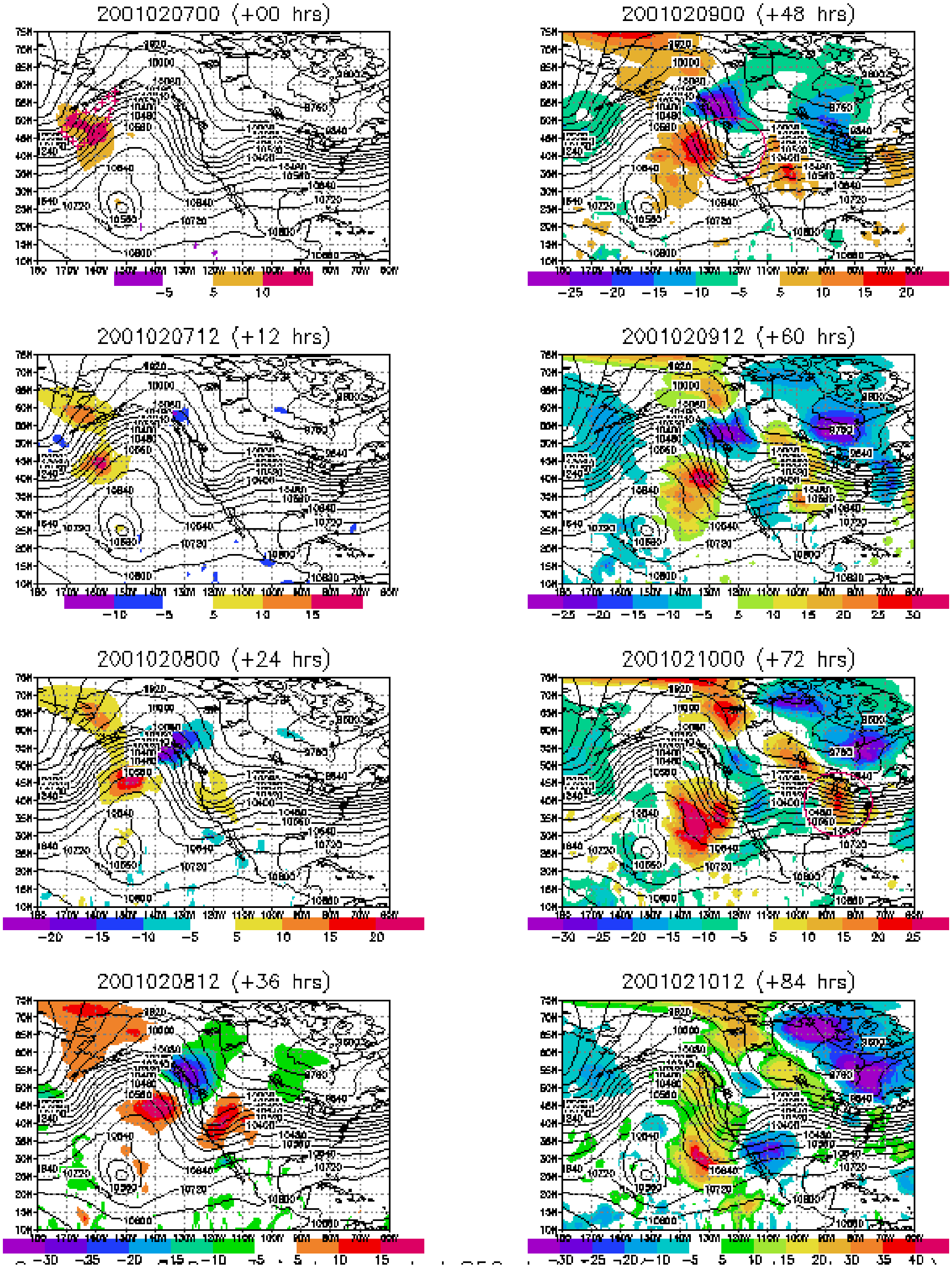
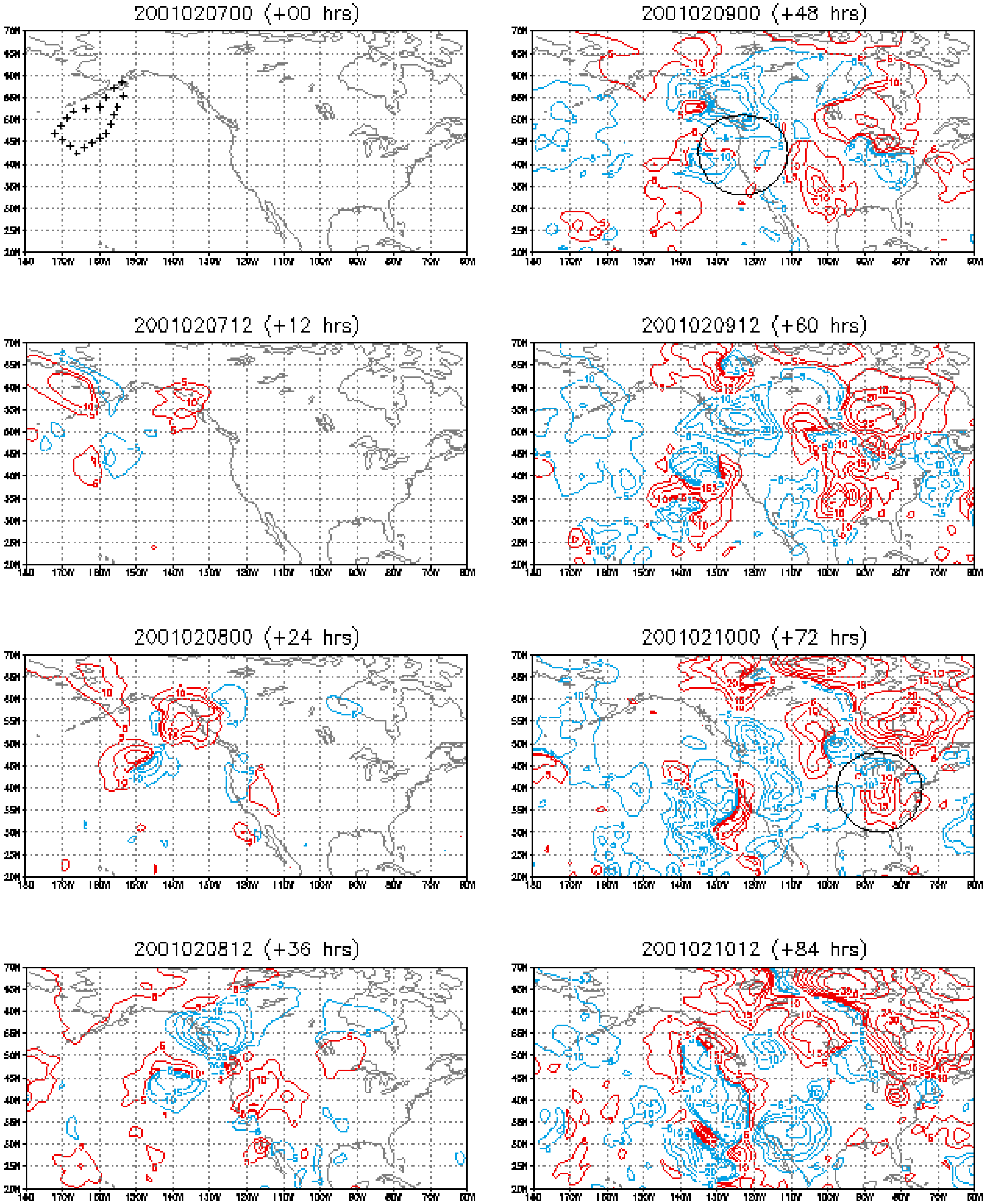


Fig. 1. Impact of targeted observations collected around 0000UTC 7 February 2001 as shown by the difference between operational and parallel 250 hPa geopotential height analyses and ensuing forecasts (shades). The circulation pattern prevailing at the time of observations is superimposed as contours.

ECMWF (Molteni et al. 1996) have been used at 2.5 degree latitude/longitude resolution. Plans call for the introduction of 1 degree resolution ensemble data and for experimentation with the introduction of ensembles from



2001020700 (+00 hrs)

2001020900 (+48 hrs)

2001020712 (+12 hrs)

2001020912 (+60 hrs)

2001020800 (+24 hrs)

2001021000 (+72 hrs)

2001020812 (+36 hrs)

2001021012 (+84 hrs)

Fig. 2. Impact of targeted observations collected around 0000UTC 7 February 2001 on the quality of ensuing 250 hPa geopotential height forecasts. Red solid (dotted blue) lines indicate areas where the forecast improved due to the use of targeted data.

other centers (Canadian Meteorological Center, Houtekamer et al. 1996; Fleet Numerical Meteorology and Oceanography Center, Rennick 1995). The possible use of even higher resolution regional ensembles (e. g., Du and Tracton 2001) will also be considered.

5.2 *Mesoscale targeting*

The WSR program, as seen from Table 1, is concerned with improving forecasts in the 24–96 hour time range, on synoptic spatial scales. Targeting, however, can be applied on mesoscales, in the 12–24 hour time range as well. Winter storm reconnaissance flights, for example, have been carried out routinely in this context, directed subjectively by the HPC, for a number of years for east coast winter storms. As noted earlier, successful objective mesoscale targeting experiments were carried out in the CALJET and PACJET field programs (Ralph et al. 1998; Toth et al. 2000). Based on these positive experiences in these field experiments the objective tools developed for the WSR program will be generalized to facilitate their use in mesoscale targeting as well. Work is under way to fold the mesoscale targeting activities at NCEP under a unified WSR program.

5.3 *Adaptive observations on the global scale*

The general concept of adaptive observations can be applied over any geographical area (Toth et al. 2001). New in situ (e. g., aerosondes, Holland et al. 2001a; or driftsondes, Langland et al. 2001) and satellite (e. g., LIDAR wind) measurements can be used selectively over areas from where data have the best chance for enhancing the analysis or forecast products in an economical fashion (e. g., Holland et al. 2001b; Emmitt and Toth 2001). NCEP is actively involved in the planning phase of The Hemispheric Observing System Research and Predictability Experiment (THORPEX, Langland et al. 2001). One of the main objectives of THORPEX is to develop new and adaptive observational strategies over the Northern Hemisphere extratropics. NCEP’s long term goal in this respect is the development of an automated adaptive obervational program that, based on ensemble forecast guidance, can (1) detect forecast problem areas; (2) identify associated data sensitive areas; and (3) deploy available observational resources for the collection of targeted data anywhere over the globe, with the aim of reducing the theat of significant forecast failures.

5.4 *Economic value of targeted observations*

The costs of adaptive observations, such as the collection of dropsonde measurements, can be substantial. Are the economic benefits derived from improved forecasts sufficiently large to offset and surpass these costs? A careful analysis of the costs of current and future adaptive (and traditional) observations, related to the potential benefits they can provide through improved weather forecasts, is required to answer this important question. Collaborative research in the framework of THORPEX can substantially contribute to our understanding of the economic benefits of forecasts in general and of targeted forecasts in particular.

6. CONCLUSIONS

In this paper we reviewed past developments that led to the establishment and operational introduction of the Winter Storm Reconnaissance program at the US NWS. The program is based on experience accumulated in adaptive observational research field experiments.

The smooth transition of the new targeted observational procedures from the research into the operational environment has been ensured by careful planning. In particular, we note the following four areas: (1) Special procedures and products were developed to drastically reduce flight planning time (through the use of predesigned flight tracks) and assist sensitivity analysis and decision making (through the introduction of interactive scripts) in the operational setting. (2) The new tasks of case selection (weather forecasters at HPC and other operational forecast units within the NWS) and sensitivity analysis and decision making (Senior Duty Meteorologist at NCO) were assigned to personnel with a background and job experience that well prepared them for their new roles. (3) Training was introduced early on and was practically oriented; and (4) The operational implementation was carried out in phases.

The second of the three phases of the operational implementation took place, as planned, in the winter of 2001. Forecast verification results indicate that the transition of the adaptive observational procedures form research to operations has been successful. The operational WSR01 targeted forecast verification results are similar to those from past research field programs. Forecast errors are reduced in 60–70% of all targeted cases, on average by an amount of 10%. This is a significant improvement in terms of NWP verification statistics, corresponding approximately to a 12–hour gain in lead time (Toth et al. 2001). In other words, with the use of targeted observations a forecast issued, for example, at 48 hour lead time is as skillful as one issued without such data at a shorter 36 hour lead time.

With the aid of higher resolution and more ensemble forecasts an extension of the WSR adaptive observational program is being considered for the mesoscales in the coming years and for the global scales in the longer term. Additional related plans include a careful analysis of the costs and societal benefits associated with the collection of adaptive observations.

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