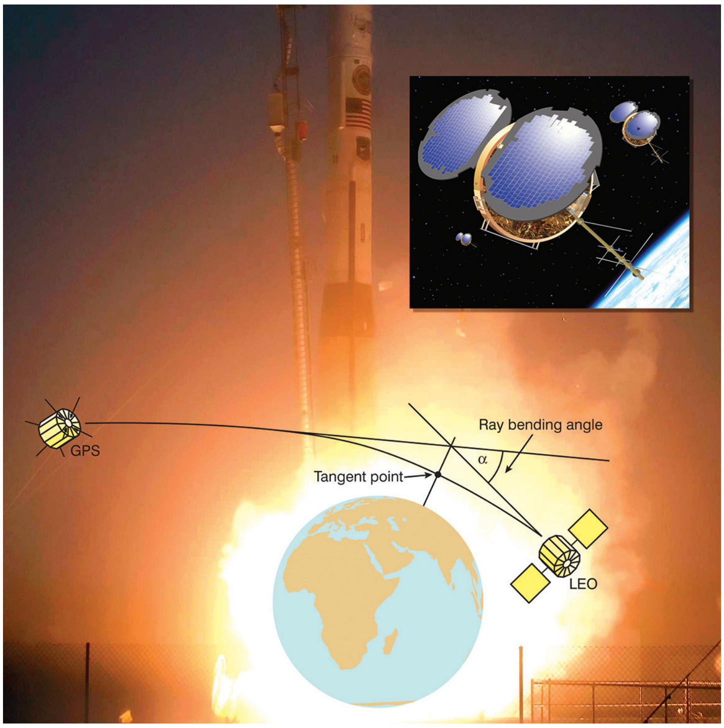
ECMWF Feature article

from Newsletter Number 111 – Spring 2007

METEOROLOGY

The value of targeted observations



Courtesy of the Orbital Science Corporation.

www.ecmwf.int/en/about/news-centre/media-resources

doi:10.21957/addpd17h4t

This article appeared in the Meteorolgy section of ECMWF Newsletter No. 111 – Spring 2007, pp. 11-20.

The value of targeted observations

Roberto Buizza, Carla Cardinali, Graeme Kelly, Jean-Noël Thépaut

In the past decade, field experiments have been organized to assess the impact of extra observations taken in some specific, case-dependent target areas identified using objective and subjective methods, on (mainly short-range) forecast accuracy. These campaigns, organized following a proposal at a workshop in 1995 (*Snyder,* 1996), were included, for example, in 1997 FASTEX (Fronts and Atlantic Storm-Track Experiment), in 1998 NORPEX (North-Pacific Experiment) and CALJET (California Land-falling JETs Experiment), in 1999 and 2000 the Winter Storm Reconnaissance Programs (WSR99 and WSR00) and in 2003 NATReC (North Atlantic THORPEX Regional Campaign). The general conclusions of these campaigns (see, e.g., *Langland,* 2005 for a review of issues in targeted observing) were that in most of the cases the impact of the targeted observations was positive, and that on average the impact was small, with maximum error reductions in some specific cases for variables such as mean-sea-level (msl) pressure of about 10–15%.

These studies were affected, by design and execution, by four major weaknesses.

- Poor matching between the target area identified by the method under investigation and the area actually sampled by the extra observations.
- Absence of a clean comparison between the impact of observations taken in objectively-defined target and randomly selected areas.
- Large variation of target areas and number of extra observations taken in the target area.
- Low statistical significance due to the limited number of cases, and biased case selection.

The study described here aims to address these four major weaknesses by comparing data-injection and data-denial experiments designed so that observations are injected or removed only in the target areas, and objectively-defined target and random areas have the same size. Furthermore, the impact of observations taken in objectively-defined target areas on downstream forecast errors, especially at forecast day 2, is analysed, and compared with observations taken in random or fixed areas with a similar size to the target areas. Finally, to be able to draw statistically significant conclusions with state-of-the-art assimilation systems, a very large number of cases (183, selected to cover different months of both warm and cold seasons) have been considered.

Data-assimilation and forecast experiments have been performed with the following version of the ECMWF system.

- Four-dimensional variational assimilation system, with a 12-hour cycling.
- Analysis resolution: outer loop T_L511L60, inner loops T_L159/T_L95L60.
- Forecast resolution: T_L511L60.

A detailed assessment of the experiments can be found in three companion papers prepared by staff at ECMWF: *Kelly et al.*(2007), *Buizza et al.* (2007) and *Cardinali et al.* (2007). Here only the key findings will be described.

Methodology and experimental design

Singular vectors (SVs) identify the perturbations growing during a finite time interval, called the optimization time interval, with the largest amplification rate measured using a defined norm (*Buizza & Palmer,* 1995). Following their successful use in the ECMWF Ensemble Prediction System, targeted SVs were used for the first time in January–February 1997 during the FASTEX field campaign (*Buizza & Montani,* 1999) to define regions where extra observations should be taken to reduce the forecast error in the verification region. Since then, SVs have been used to identify sensitive regions where targeted observations can be taken to reduce the forecast error.

Figure 1 illustrates the key concepts used in this paper to assess the value of targeted observations: T is the target area where observations should be taken to improve the day-*d* forecast inside the verification area Σ. Experiments have been run to assess the impact of ocean observations on the short-range forecast error over downstream regions (e.g. of observations located in the Pacific Ocean for forecasts verified over North America, and of observations located in the Atlantic Ocean for forecasts verified over Europe), and on medium-range forecast error over the whole northern hemisphere. For both sets of experiments, the ocean is defined as the area between 30°N and 80°N latitude, while the two verification regions have been defined as follows.

 doi:10.21957/addpd17h4t

- European verification area: 10°W:25°E, 35°N:60°N
- North-American verification area: 125°W:90°W, 35°N:60°N

For each verification area, three types of target areas are considered.

- ***SV-target areas:*** for each initial date and time (*d, h*), the SV-target area (which has always the same size) is defined using the ten leading SVs growing for two days [i.e. between (d, h) and (d+2, h)] with maximum final time total energy norm inside the verification region.
- ***SV-av-target areas:*** for each initial date and time (*d, h*), the SV-av-target area is defined using the mean taken over the whole period under investigation of all the (*d, h*) SV-target areas (with the same size as the SV-target area).
- ***Random areas:*** for each initial date and time (*d, h*), the random area has circular shape centred randomly over the ocean and with the same geographical size as the SV-target area.

Figure 2 shows a schematic illustration of the six types of data-assimilations that have been performed.

- ***SEAIN:*** all observations available over the ocean have been used.
- ***SEAOUT:*** none of the observations available over the ocean have been used.
- ***SVIN:*** only observations available in the SV-target area have been used.
- ***SVOUT:*** all observations apart for the ones in the SV-target area have been used.
- ***RDIN:*** only observations available in randomly defined area have been used.
- ***RDOUT:*** all observations apart for the ones in randomly defined area have been used.

In experiments *SVIN* and *SVOUT,* at each data-assimilation cycle observations are either injected (*SVIN*) or removed (*SVOUT*) in the same target area defined using SVs (noting that SVs are updated every 12 hours). Similarly, in experiments *RDIN* and *RDOUT* observations are injected or removed in the same random area. For a limited subset of cases, the following experiment has also performed:

- ***SVavIN:*** as *SVIN* but always using only the observations available in the SV-av-target area, defined by averaging the SV-areas computed for each day of the period under investigation.

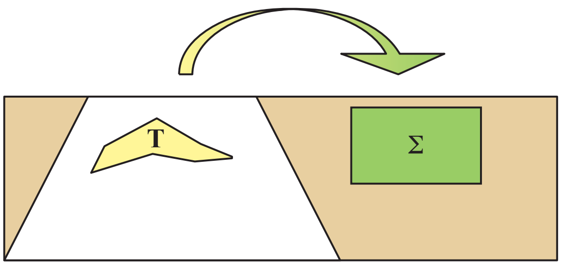


Figure 1 Schematic illustration of the concept of the 'value of targeted observations': the brown areas identify land, while the white regions identify the ocean. T is the target area (e.g. identified using singular vectors) where observations should be taken to improve the day-*d* forecast inside the verification area Σ.

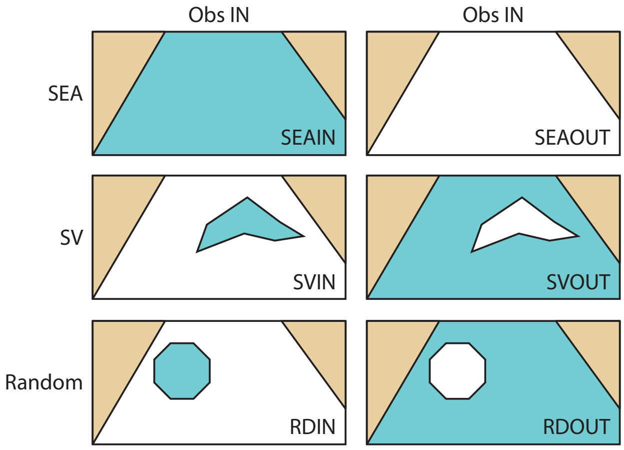


Figure 2 Schematic of the data-assimilation experiments: the brown areas identify land; the blue areas identify the areas where observations have been used, while the white areas identify the areas where observations are not used.

doi:10.21957/addpd17h4t

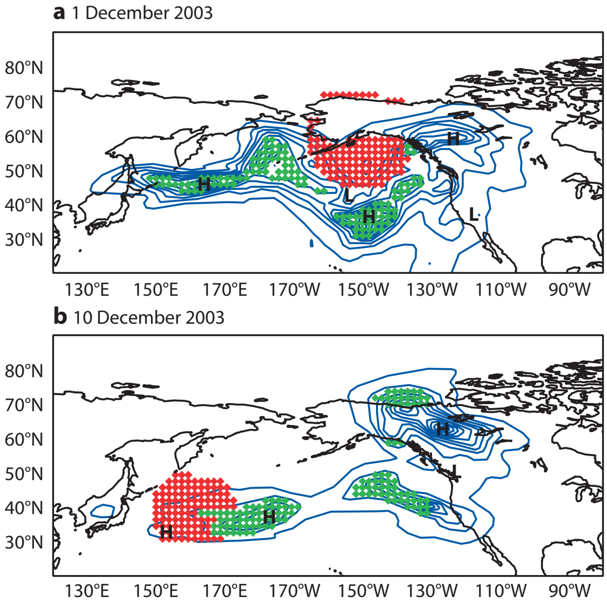


Figure 3 SV-target (green symbols) and random (red symbols) areas for the Pacific-North American region for 12 UTC on (a) 1 December and (b) 10 December 2003. The contour isolines show the weighted-average, vertically-integrated total energy of the ten leading SVs.

SV-based target and random areas

The SV-based target areas have been defined, as in *Buizza & Montani* (1999), by the weighted-average (with weights defined by the singular value), vertically-integrated total energy of the SVs. For each ocean basin, the SV-target areas have been defined as the 100 grid points over the ocean with the largest value of that measure. The SVs and the corresponding target areas have been computed every 12 hours, with a configuration very similar to the one used in the ECMWF Ensemble Prediction System but with a higher resolution: T63L40 resolution, 48-hour optimization time interval, total energy norm and (dry) simplified physics. The random areas have been defined to be approximately circular, with the centre of the circle randomly selected inside the ocean region of interest, and large enough to contain the same number of grid points as the SV-target areas.

Figure 3 shows two examples of SV-target and random areas used in the Pacific-North American *SVIN* and *RDIN* experiments started at 12 UTC on 1 and 10 December 2003. In the first case, the two areas do not overlap, while in the second case the two areas have some grid points in common over the western Pacific.

Value of observations taken in the Pacific or the Atlantic Oceans

The first of the three companion papers (*Kelly et al.,* 2007) discusses the importance of data over the ocean in a mean statistical sense and for individual cases. In order to help identify 'forecast busts' a subjective method has been developed to find a relationship between the forecast root mean square error (rmse) and 'synoptic pattern' differences. These questions have been addressed with experiments using both three- and four-dimensional variational data-assimilation (referred to as 3D-Var and 4D-Var) performed at fairly high resolution using the ECMWF system that was operational in June 2005 for two periods: winter 2003/04 (December 2003 to February 2004, 91 days) and summer 2004 (June to August 2004, 90 days).

The key conclusions that can be drawn from the *SEAIN* and *SEAOUT* experiments are the following.

- With regard to the 4D-Var data denial experiments, the data from the Pacific is more important to reduce the two-day forecast error over North America (Figure 4) than the corresponding Atlantic oceanic data to reduce the two-day forecast error over Europe (Figure 5), although both denial experiments clearly show a downstream forecast degradation. The comparison of 4D-Var and 3D-Var experiments has indicated that removing oceanic data has a larger impact on downstream forecast accuracy if a 3D-Var assimilation system is used.
- In the 4D-Var system the influence of observations remains fairly local and mainly affects the immediate downstream region throughout the whole ten-day forecast range (Figure 6). In particular, on average there is a very little impact of removing observations in the Pacific on medium-range forecasts over Europe during winter (Figure 4), while the impact in summer is slightly larger (not shown, for further details see *Kelly et al.,* 2007). Similarly, removing observations in the Atlantic does not affect forecasts for the Pacific-North American region. Again, the comparison of 4D-Var and 3D-Var experiments indicates that the impact of removing oceanic observation is less local if a 3D-Var assimilation system is used.

doi:10.21957/addpd17h4t

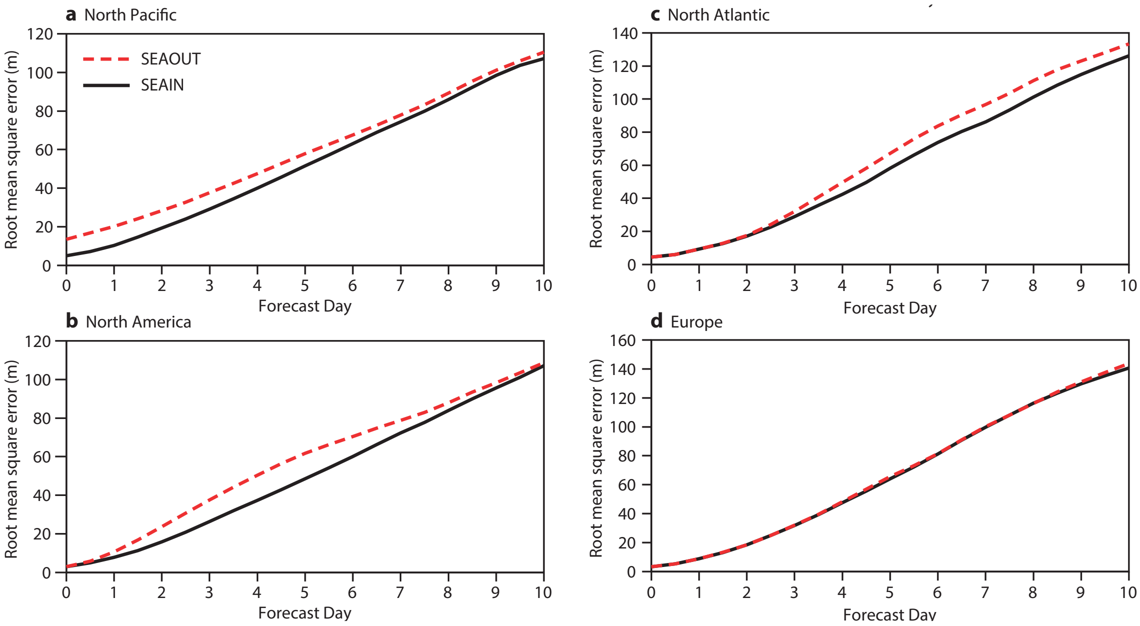


Figure 4 The rmse of mean 500 hPa geopotential height for up to day ten for *SEAOUT* and *SEAIN* for winter Pacific forecasts. Both experiments are verified using the ECMWF operational analysis. Verification regions are (a) North Pacific, (b) North America, (c) North Atlantic and (d) Europe (panels are ordered to reflect the downstream propagation of the impact of removing observations, starting from the North Pacific).

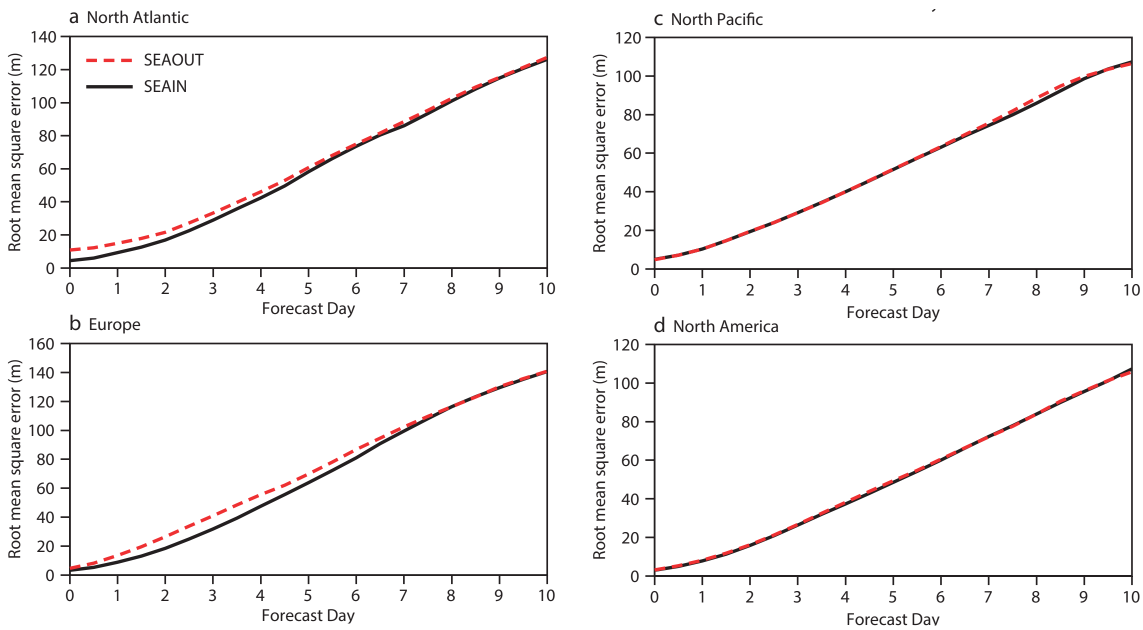


Figure 5 The rmse of mean 500 hPa geopotential height for up to day ten for *SEAOUT* and *SEAIN* for winter Atlantic forecasts. Both experiments are verified using the ECMWF operational analysis. Verification regions are (a) North Atlantic, (b) Europe, (c) North Pacific and (d) North America (panels are ordered to reflect the downstream propagation of the impact of removing observations, starting from the North Atlantic).

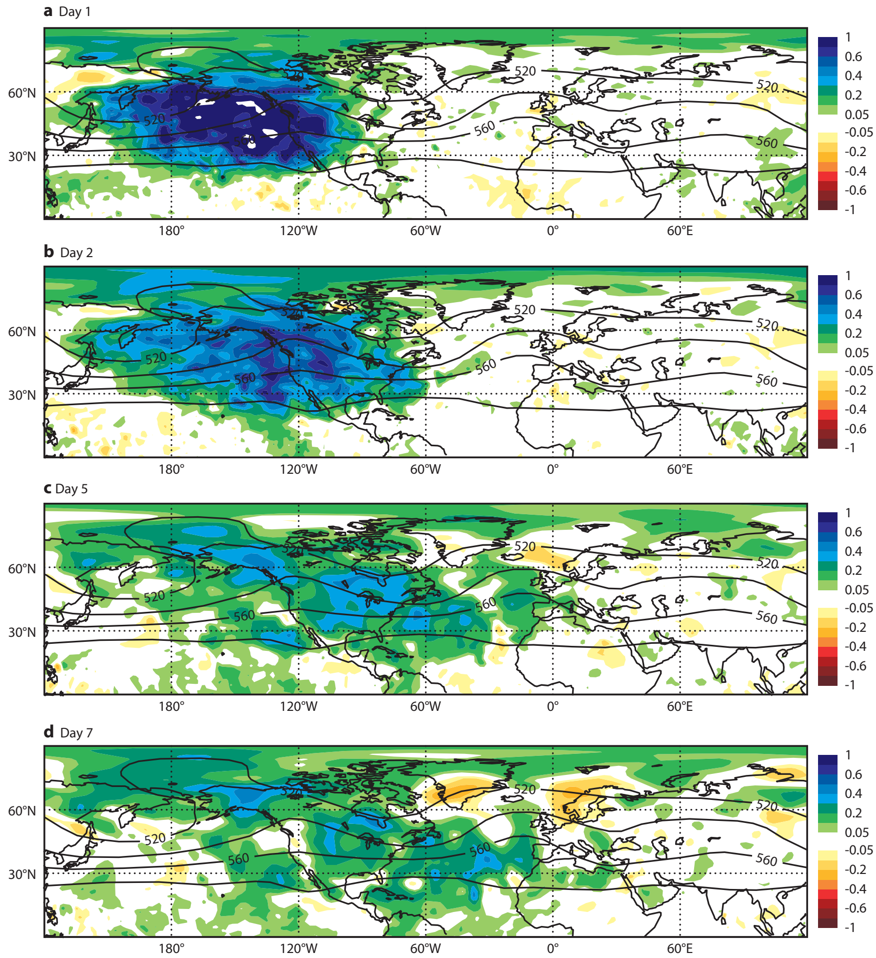


Figure 6 Normalized rmse differences between *SEAIN* and *SEAOUT* for winter Pacific forecasts for (a) day 1, (b) day 2, (c) day 5 and (d) day 7. Blue-purple show the negative impact and yellow-black the positive impact of *SEAOUT*.

- In a few, selected cases the impact of removing oceanic data can be very large and detectable on 500 hPa geopotential synoptic maps. In particular, a detailed synoptic evaluation performed for the Atlantic-European region has indicated that large synoptic differences between the 48-hour forecasts of *SEAIN* (the experiment using all oceanic data) and *SEAOUT* (the experiment removing all oceanic data over the Atlantic) could lead to forecast rmse differences of more than 15 m at 500 hPa at day 2 in a small number of cases (16% in winter and 14% in summer). The Pacific *SEAOUT* experiments have a much larger effect than the Atlantic ones. The impact remains relatively small in summer.

The fact that denying observations in 3D-Var has a larger impact than in 4D-Var should be interpreted with care. Figure 7 displays an idealistic representation of the analysis accuracy as a function of the number of observations (all units and numbers are arbitrary). 4D-Var and 3D-Var should give the same results in terms of analysis accuracy when there are no observations and when there are infinitely many observations (the assimilation system should not matter anymore if infinite observations are assimilated). The experience, backed up by many impact studies performed in the past, suggests that the analysis improvement in case of 4D-Var is likely to follow the blue curve, while a less performing system (e.g. 3D-Var) will follow the red curve.

Figure 7 shows that going for example from 0 to 25 observations will lead to a 0.26 improvement in 3D-Var (red vertical bar) against 0.39 (blue dotted vertical bar) in 4D-Var. It has indeed been demonstrated and documented in *Thépaut* (2006) that in the sole presence of surface pressure observations, 4D-Var was outstandingly better than 3D-Var, indicating a much sharper curve (analysis improvement as a function of number of observation) in a data void context. The experiments reported here are performed in a system overwhelmed by observations (in particular satellite data), which probably corresponds to a regime of around 150 observations in the idealistic context. Although 4D-Var is clearly better than 3D-Var in our experimental framework, the incremental gain (loss) achieved by adding (denying) an overall limited number of observations will be higher in 3D-Var than in 4D-Var (red and blue vertical bars around 150 observations: increment of 0.017 for 4D-Var against 0.048 for 3D-Var).

doi:10.21957/addpd17h4t

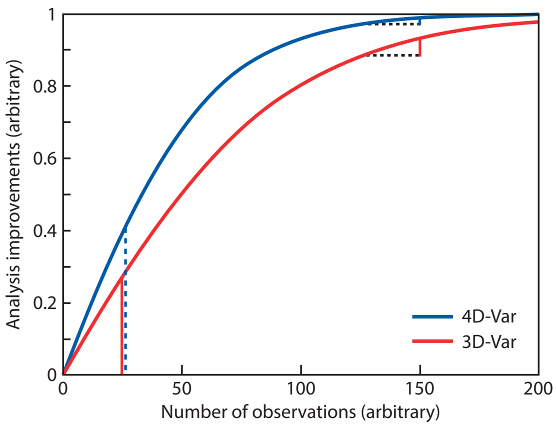


Figure 7 Idealistic representation of the analysis improvement as a function of the number of assimilated observations (numbers and units are arbitrary) for 4D-Var and 3D-Var. The vertical full red bars represent the improvement of the 3D-Var analysis when one goes from zero to 25 observations, and from 125 to 150 observations. The vertical dotted blue bars represent the same quantities for 4D-Var.

Value of observations in SV-based target areas

The second of the three companion papers (*Buizza et al.,* 2007) discusses some fundamental questions about the value of targeted adaptive observations: what is the 'value' of observations taken in target regions identified using SVs compared to the value of observations taken in randomly chosen regions? Is it important that SV-target regions are identified using the most recent analysis and forecast, or can an SV-av-target region be used? Does the 'value' of observations depend on the region?

Figure 8 compares the average rmse of *SVIN, SVavIN* and *RDIN* with the two reference forecasts *SEAOUT* and *SEAIN* for both the Pacific and Atlantic experiments. Similarly, Figure 9 compares the average rmse of *SVOUT* and *RDOUT* with the two reference forecasts for the two regions. The following three general conclusions can be drawn from the comparison of forecasts started from the seven types of experiments run for winter 2003/04 and summer 2004.

- Observations taken in SV-target areas are more valuable than observations taken in random areas, with the difference depending on the region, the season and the baseline observing system used as a reference.
- It is important that the daily set of singular vectors is used to compute the target areas. Experiments run for the Pacific-North American region for winter 2003/04 indicated that observations taken in a fixed target area identified considering the average of all the daily SV-target areas would have a smaller value than observations taken in the daily SV-target areas (while *SVIN* experiments have an average a 27.5% smaller error than *SEAOUT*, *SVavIN* experiments have a 20.9% smaller error, see Table 1). However, this would have to be mitigated against the cost of deploying a daily targeting strategy.
- The value of observations taken in SV-target areas defined using SVs optimized for a two-day period starts decreasing after forecast day 3 because the impact of the targeted observations moves outside the verification region after that time.

In particular, results have indicated that:

- ***If the baseline observing system is data void (i.e. no observations) over the ocean, then the average value of observations taken in SV-target areas is fairly high.*** Consider the value measured using the rmse of 500 hPa geopotential height forecasts (Tables 1 and 2). These results indicate, for example, that SV-targeted observations are capable of reducing the two-day average forecast error in the verification region by 27.5% in winter 2003/04 for SV-targeted Pacific observations with forecasts verified over North America (compared to 15.7% for randomly targeted observations); this corresponds to 13.5 hours of forecast gain.
- ***If the baseline observing system is data rich (i.e. with all observations) over the ocean, then the average value of observations taken in SV-target areas is very small.*** In terms of the rmse of the 500 hPa geopotential height forecasts, the results indicate, for example, that removing SV-targeted observations increases the two-day average forecasts error in the verification region by 4.0% in winter 2003/04 for SV-targeted Pacific observations and forecasts verified over North America (compared to 0.5% for randomly targeted observations); this corresponds to two hours of forecast gain.

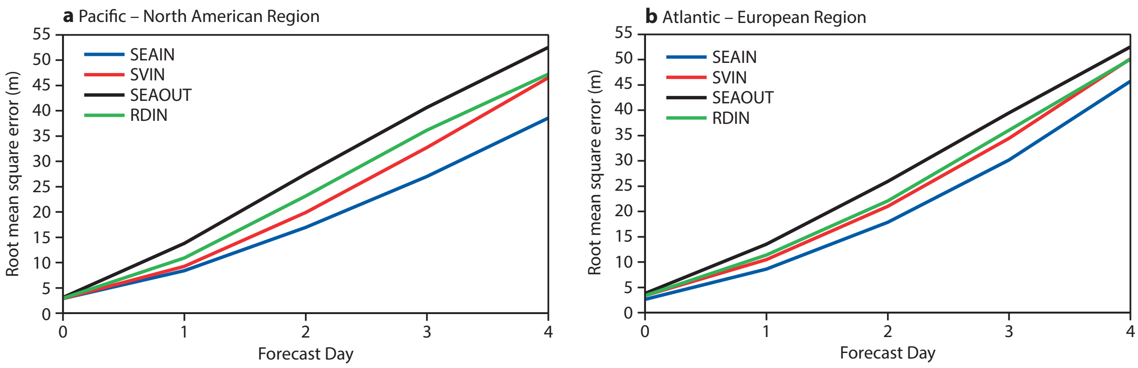


Figure 8 Average rmse of 500 hPa geopotential height forecasts of experiments *SEAIN, SEAOUT, SVIN* and *RDIN* run for (a) Pacific-North American region and (b) Atlantic–European region for winter 2003/04.

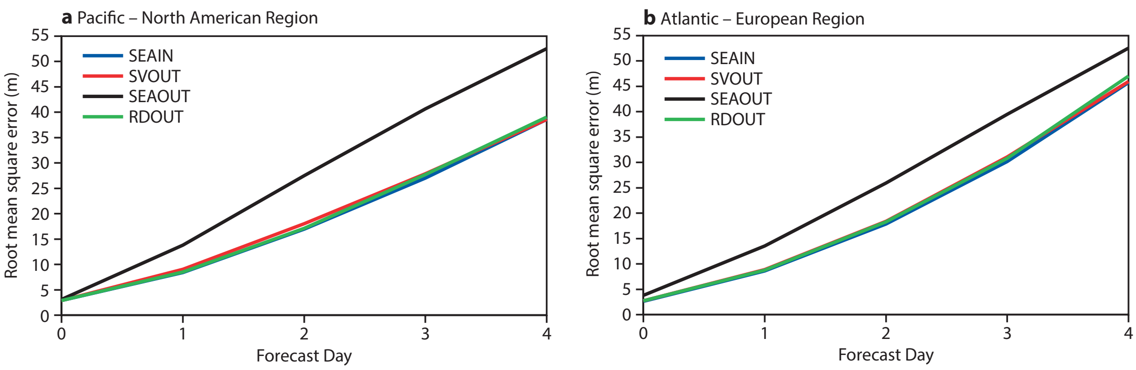


Figure 9 Average rmse of 500 hPa geopotential height forecasts of experiments *SEAIN, SEAOUT, SVOUT* and *RDOUT* run for (a) Pacific-North American region and (b) Atlantic–European region for winter 2003/04.

The data-denial experiments do not replicate precisely the impact that adding extra observations taken in targeted regions may have on forecast accuracy, but in our view they can be used to estimate the potential average impact that they may have. In the (strong) hypothesis that the characteristics (type, quality, content of information) of future extra observations is similar to the characteristics of the observations removed, the data-denial experiments provide an upper bound of the expected average impact that extra observations may have.

The fact that, for the Pacific, the value of observations taken in SV-target is smaller in summer, and the difference between the value of observations taken in the SV-target versus random areas is also smaller in summer, is possibly due to the characteristics of the SVs (*Buizza & Palmer,* 1995). In winter, the amplification rate spectrum of SVs is steeper, which makes it easier to separate the leading ten from the others, in particular from the directions spanned by the random area. Furthermore, in winter the SVs are more localized in the storm track region, again making their location more ‘different’ from the location identified by the random areas. Finally, it is worth remembering that the SVs have been computed with a simplified, dry tangent forward and adjoint physics, which may make their computation less accurate in summer, a period during which moist processes play a bigger role than in winter.

These values could be compared to the reduction of the 48-hour forecast error of the ECMWF high-resolution forecast between 1995 and 2005: over North America, the rmse of the 500 hPa geopotential height was reduced from about 25 to 16 m (i.e. by ~36%), while over Europe the rmse was reduced from about 24 to 15 m (i.e. by ~37%). In other words, development of the observation network and ECMWF data assimilation and forecasting system led to a forecast error reduction of about 3.6–3.7% per annum. ***Thus, the average impact of SV-targeted observations in the case of a data-rich baseline observing system over the ocean is comparable to the annual forecast error reduction of the ECMWF high-resolution forecast.***

 doi:10.21957/addpd17h4t

Experiment	Root mean square error (rmse)	
	Winter 2003/04	Summer 2004
SEAOUT	27.49 m	16.57 m
SEAIN	16.96 m	11.96 m
SVIN	19.93 m	13.90 m
RDIN	23.18 m	14.61 m
SVOUT	18.06 m	12.20 m
RDOUT	17.11 m	11.81 m
SVavIN	21.75 m	–
Measure of impact	**Normalised rmse differences (predictability gain)**	
	Winter 2003/04	**Summer 2004**
(SEAIN-SEAOUT) / SEAOUT	38.3% (18.8 h)	27.8% (13.5 h)
(SVIN-SEAOUT) / SEAOUT	27.5% (13.5 h)	16.0% (7.8 h)
(RDIN-SEAOUT) / SEAOUT	15.7% (7.7 h)	11.8% (5.7 h)
(SVavIN-SEAOUT) / SEAOUT	20.9% (10.3 h)	–
(SEAIN-SVOUT) / SEAOUT	4.0% (2.0 h)	1.3% (0.7 h)
(SEAIN-RDOUT) / SEAOUT	0.5% (0.3 h)	-1.1% (-0.4 h)
(SVOUT-SEAIN) / SEAIN	6.5%	2%
(RDOUT-SEAIN) / SEAIN	0.9%	-1.5%

Table 1 Average value of observations taken in different target areas, measured using the rmse of the two-day forecasts of 500 hPa geopotential height over North America. The upper part of the table gives the rmse (metres) of the forecast experiments. The lower part shows the normalized differences in rmse (percent) between pairs of experiments, with the normalization done using the rmse of the *SEAOUT* experiment for all but the last two rows where the rmse of *SEAIN* has been used. The corresponding change in predictability in hours is given in brackets.

Experiment	Root mean square error (rmse)	
	Winter 2003/04	Summer 2004
SEAOUT	25.98 m	17.96 m
SEAIN	17.87 m	10.25 m
SVIN	21.02 m	12.82 m
RDIN	22.10 m	13.04 m
SVOUT	18.40 m	10.62 m
RDOUT	18.33 m	10.40 m
SVavIN	–	–
Winter 2003/04	**Normalised rmse differences (predictability gain)**	
	Winter 2003/04	**Summer 2004**
(SEAIN-SEAOUT) / SEAOUT	31.2% (15.0 h)	42.9% (21.7 h)
(SVIN-SEAOUT) / SEAOUT	19.1% (9.2 h)	28.6% (14.5 h)
(RDIN-SEAOUT) / SEAOUT	14.9% (7.2 h)	27.3% (13.8 h)
(SVavIN-SEAOUT) / SEAOUT	–	–
(SEAIN-SVOUT) / SEAOUT	2.0% (1.0 h)	2.1% (1.0 h)
(SEAIN-RDOUT) / SEAOUT]	1.7% (0.8 h)	0.8% (0.4 h)
(SVOUT-SEAIN) / SEAIN	3.0%	3.6%
(RDOUT-SEAIN) / SEAIN	2.6%	1.6%

Table 2 Average value of observations taken in different target areas, measured using the rmse of the two-day forecasts of 500 hPa geopotential height over Europe. The upper part of the table gives the rmse (metres) of the forecasts experiments. The lower part shows the normalised differences, in percent, between pairs of experiments, with the normalization done using the rmse of the *SEAOUT* experiment for all but the last two rows where the rmse of *SEAIN* has been used. The corresponding change in predictability in hours is given in brackets.

Weather regime sensitivity of the value of targeted observations

The third of the three companion papers (*Cardinali et al.,* 2007) discusses the sensitivity to the atmospheric flow of targeted observations taken in the Atlantic for forecasts verified over Europe. Four different periods characterized by different large-scale circulation during the tropical cyclones season have been examined: A02 (26 July to 16 August 2002), S03 (1 to 23 September 2003), A05 (13 to 21 August 2005) and S05 (4 to 27 September 2005). Results based on *SEAIN, SEAOUT, SVOUT* and *RDOUT* experiments for these four periods indicate the following.

- The value of targeted observations is sensitive to the interaction of tropical disturbances with the mid-latitude flow, with targeted observations capable of reducing the forecast error by up to 13%, when error is measured in terms of averaged rmse of the 500 hPa geopotential height over the verification area.
- SV-based targeted observations in sensitive regions of North America computed by using energy norm and dry singular vectors are on average six times more valuable than a target randomly selected areas over the ocean.

doi:10.21957/addpd17h4t

The maximum forecast response to targeted observations is detected when extra-tropical transitions take place and the large-scale flow over the Atlantic is non-zonal and rather unstable. It should be also kept in mind that a rmse reduction smaller than 15 m (~40%) does not generally bring substantial synoptic forecast differences at tropospheric levels but can provide some significant changes to the surface pressure field as was shown for August 2002 and 2005 (see *Kelly et al.,* 2007).

Sensitivity regions are believed to indicate dynamically active regions which are very important to identify. Denying observations in sensitive areas is therefore expected to produce a larger loss of information content than in random areas, being the maximum effect when full flow-dependent structure functions are used. Anyhow, the observation departures propagated back in time by the adjoint model to the beginning of the assimilation window do provide a similar effect in the covariance evolution. Also a larger observation influence loss is observed in all experiments where data has been denied in sensitive areas. While examining the short-range forecast, it has been noticed that 12-hour geopotential height forecast error measured over the Atlantic, which includes both sensitive and random regions where data were denied, is larger for those experiments where observations are missing in sensitive regions. Poorer first-guest fields are clearly determined by the poorer analysis quality.

Overall, this study validates and confirms the hypothesis on which targeting of sensitivity regions are based. Table 3 shows that, although on average over many cases the impact of SV-based targeted observations on two-day forecast of 500 hPa geopotential height is 3.3%, in selected cases of extra-tropical transitions the value increases to be 12.9%. Figure 10 shows three cases with large rmse degradation and significant changes in the surface fields.

Cases	Degradation Relative to SEAIN (%)			Absolute Forecast Error (m)		
	(SVOUT–SEAIN) / SEAIN	(RDOUT–SEAIN) / SEAIN	(SVOUT–RDOUT) / SEAIN	SVOUT	RDOUT	SEAIN
Extra-tropical cases						
August 2002 8 day	8.1	1.4	6.7	13.0	12.1	12.0
September 2003 4 day	6.0	-3.9	9.9	17.3	15.7	16.4
August 2005 8 day	12.9	2.1	10.8	11.6	10.5	10.2
September 2005 23 day	3.3	1.5	1.8	11.6	11.4	11.2
All cases						
2002 21 day	4.5	2.5	2	12.8	12.5	12.2
2003 21 day	1.5	-2.7	4.2	13.7	13.1	13.5
2005 57 day	3.9	2.0	1.9	11.4	11.2	11.0
Seasons						
Summer 2004 90 day	3.6	1.6	2.0	10.6	10.4	10.2
Winter 2003/04 90 day	3	2.6	0.4	18.4	18.3	17.9

Table 3 Average rmse over Europe for the two-day forecasts of 500 hPa geopotential height computed for the extra-tropical cases analyzed in *Cardinali et al.* (2007), all cases discussed in the three companion papers, and the two seasons discussed in *Buizza et al.* (2007). The first three columns give the percentage of degradation relative to *SEAIN* of *SVOUT, RDOUT* and (*SVOUT–RDOUT*) and the last three columns the absolute forecast error in metres are averaged over Europe.

 doi:10.21957/addpd17h4t

Figure 10(a) shows, from left to right, the 48-hour 500 hPa forecast differences between *SVOUT* and *RDOUT,* the msl pressure for *SVOUT*, and msl pressure for *RDOUT* valid at 12 UTC on 11 August 2002. At 500 hPa the differences of 31 m are due to a stronger intensification and time shifting of the low system, amplified by the interaction with Tropical Cyclone Cristobal; the msl pressure in *SVOUT* presents a minimum of 1000 hPa whilst in *RDOUT* it is 995 hPa. Rejecting observations in a sensitive area causes a disruption of the surface pressure field whilst *RDOUT* surface field stays similar to *SEAIN* (not shown). This period was characterized by heavy precipitation with flooding in parts of Central Europe. The accumulated forecast precipitation over 48 hour from 00 UTC on 9 September for *SVOUT* and *RDOUT* shows very different patterns but similar intensities (not shown).

Figure 10(b) depicts a case valid at 00 UTC on 11 September 2003 (forecast started at 00 UTC on 9 September) during the Fabian extra-tropical transition. Removing observations in sensitive areas first lessens the low pressure system (moving northwards) northwest of England by 6 hPa (not shown) and 12 hours later some changes occur in the displacement and intensity of the low pressure system over Germany (second and third columns, respectively).

Figure 10(c) is related to the Irene transition into the extra-tropical flow. Large differences are observed north of Scandinavia in the msl pressure fields between *SVOUT* and *RDOUT* (not included in the rmse verification region) with a 7 hPa maximum difference. This time, denying observations in a sensitive region creates a surface pressure system which is too deep. On average for all periods, differences of 20 m are observed in the troposphere and sometimes there are corresponding significant changes to the pressure distribution at the surface.

Target field campaigns tend to investigate the impact on forecasts of extreme weather events (that very often do not occur). Also the size of the target and verification area change at every observational campaign. The results presented here suggest that it would be preferable to target more continuously during specific weather situations as, for example, extra-tropical cyclone transitions.

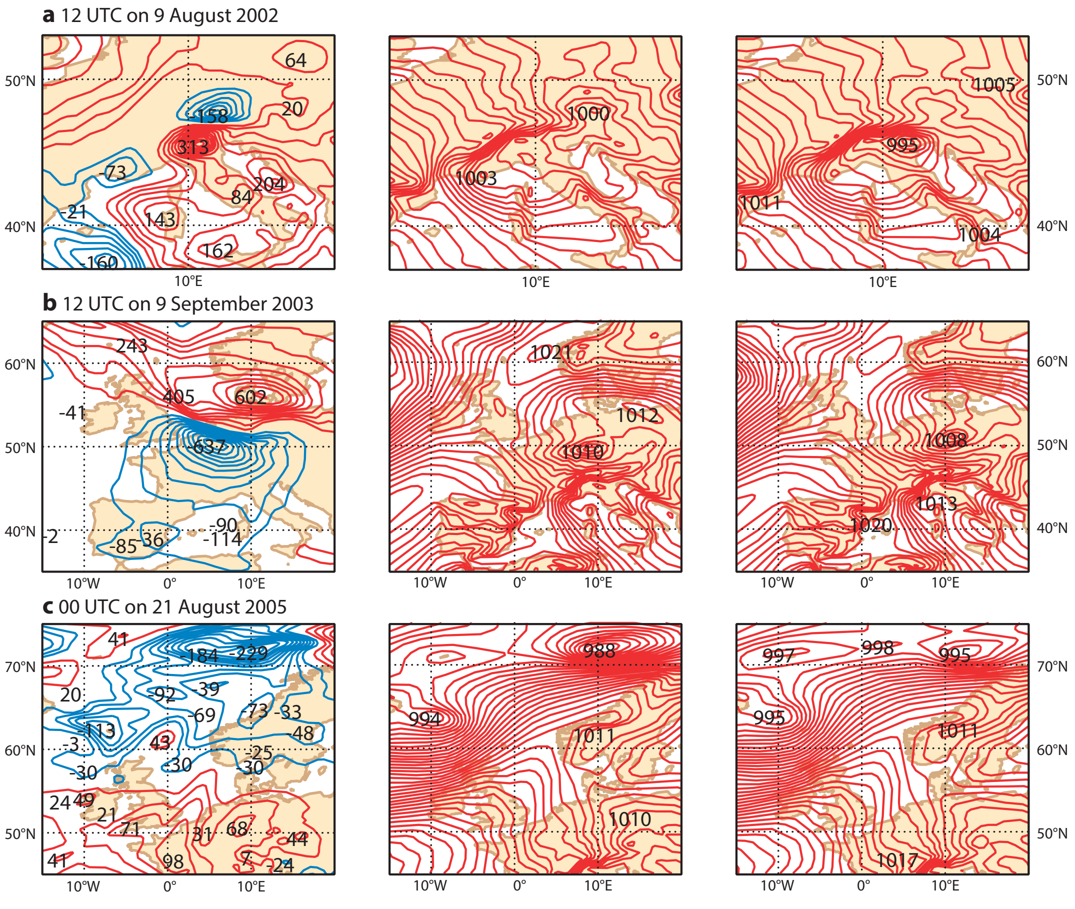


Figure 10 48-hour forecast of the 500-hPa geopotential height differences between *SVOUT* and *RDOUT* (first column), msl pressure for *SVOUT* (second column), and msl pressure for *RDOUT* (third column) valid at (a) 12 UTC on 9 August 2002, (b) 00 UTC on 9 September 2003 and (c) 00 UTC on 21 August 2005.

A framework to investigate the value of targeted observations

This study has provided an updated estimate of the potential value of targeted observations. In addition it proposes a framework that could be applied to (a) study the value of other objective targeting methodologies and (b) investigate their sensitivity to the data-assimilation system used to assimilate the extra observations. In particular, this framework could be used:

- To investigate whether using moist SVs would increase the value of observations taken in SV-target areas, and increase the difference between the value of observations taken in SV-target and random areas in the summer.
- To study the sensitivity of the value of targeted observations taken over land from higher quality observation platforms, capable to provide more accurate data both in cloud-free and cloud-covered areas. High quality data in the right place could have a non-negligible impact. However, such experiments, if they were to show too little impact, could be criticized as being unrepresentative on the grounds that observation removal is taking place over regions where error growth characteristics are rather different than those over the oceanic storm track.
- To compare the value of observations taken in SV-based target regions with observations taken in areas objectively identified using other methodologies (*Majumdar et al.,* 2006) so as to assess whether these other methodologies can lead to a better use of targeted observations.
- To further assess the forecast degradation caused by data-denial in target areas during other cases of extra-tropical cyclone transitions.

One of the interesting outcomes of this study is the local nature of data denial when 4D-Var is used to assimilate the data. The propagation of the analysis error downstream reduces rapidly, and little effect on any European forecasts was detected from the Pacific denial experiments. This result is an indication of the superiority of 4D-Var over the previous 3D-Var assimilation system, and a proof of its robustness and capacity to compensate for the lack of accurate observations.

doi:10.21957/addpd17h4t

Further Reading

Buizza, R. & **T.N. Palmer,** 1995: The singular-vector structure of the atmospheric global circulation. *J. Atmos. Sci.,* **52,** 1434– 1456.

Buizza, R. & **A. Montani,** 1999: Targeting observations using singular vectors. *J. Atmos. Sci.,* **56,** 2965–2985.

Buizza, R., C. Cardinali, G. Kelly & **J.-N. Thépaut,** 2007: The value of targeted observations Part II: the value of observations taken in singular vectors-based target areas. *ECMWF Tech. Memo. No. 512* (submitted to the *Q. J. R. Meteorol. Soc*.).

Cardinali, C. & **R. Buizza,** 2003: Forecast skill of targeted observations: a singular-vector-based diagnostic. *J. Atmos. Sci.,* **60,** 1927–1940.

Cardinali, C., S. Pezzulli & **E. Andersson,** 2005: Influence-matrix diagnostic of a data assimilation system. *Q. J. R. Meteorol. Soc.,* **130,** 2767–2786.

Cardinali, C., R. Buizza, G. Kelly, M. Shapiro & **J.-N. Thépaut,** 2007: The value of targeted observations Part III: weather regimes influence. *ECMWF Tech. Memo. No. 513* (submitted to the *Q. J. R. Meteorol. Soc.*).

Kelly, G. 1997: Influence of observations on the operational ECMWF system. *WMO Bulletin,* **46,** 336–341.

Kelly, G., A. McNally, J.-N. Thépaut & **M. Szyndel,** 2004. Observing System Experiments of all main data types in the ECMWF operational system. *In Proc. of the Third WMO Workshop on the Impact of Various Observing Systems on NWP Alpbach, Austria, 9–12 March 2004.*

Kelly, G., J.-N. Thépaut, R. Buizza, & **C. Cardinali,** 2007: The value of targeted observations Part I: data denial experiments for the Atlantic and the Pacific. *ECMWF Tech. Memo. No. 511* (submitted to the *Q. J. R. Meteorol. Soc.*).

Langland, R.H., 2005: Issues in targeted observing. *Q. J. R. Meteorol. Soc.,* **613,** 3409–3425.

Majumdar, S.J., S.D. Aberson, C.H. Bishop, R. Buizza, M. Peng & **C. Reynolds,** 2006: A comparison of adaptive observing guidance for Atlantic tropical cyclones. *Mon. Wea. Review,* **134,** 2354–2372.

Snyder, C., 1996: Summary of an informal workshop on adaptive observations and FASTEX. *Bull. Amer. Meteorol. Soc.,* **77,** 953–961.

Thépaut, J.-N., 2006: Assimilating only surface pressure observations in 3D and 4D-Var. *In Proc. of the ECMWF/GEO Workshop on Atmospheric Re-analysis,* ECMWF, 19–22 June 2006.

doi:10.21957/addpd17h4t