TECHNICAL MEMORANDUM

513

# The value of targeted observations Part III: Influence of different weather regimes

Carla Cardinali, Roberto Buizza, Graeme Kelly, Melvyn Shapiro[1] and Jean-Noël Thépaut

Research Department

[1] NOAA Office of Weather and Air Quality

To be submitted for publication in Q.J.Roy.Meteor.Soc.

February 2007



European Centre for Medium-Range Weather Forecasts
Europäisches Zentrum für mittelfristige Wettervorhersage
Centre européen pour les prévisions météorologiques à moyen

**Series: ECMWF Technical Memoranda**

A full list of ECMWF Publications can be found on our web site under:
http://www.ecmwf.int/publications.html

library@ecmwf.int

**Abstract**

The value of targeted observations over the North Atlantic Ocean in the summer season is assessed for different meteorological flow regimes. It is shown that during tropical cyclone activity and particularly during tropical cyclone transition phase, removing observations in sensitive regions, indicated by singular vectors optimized on the 2-day forecast over Europe, degrades the skill of a given forecast more than excluding observations in randomly selected regions. The maximum downstream degradation computed in terms of, spatially and temporally averaged root mean square error of 500-hPa geopotential height is about 13%, a value which is 6 times larger than when removing observation in randomly selected areas. The forecast impact found by degrading the observational coverage in sensitive areas, for these selected periods, is similar to the impact found (elsewhere in other weather forecast systems) for the observational targeting campaigns carried out over the last years, and it is larger than the average impact obtained by considering a larger set of cases covering various seasons.

# 1. Introduction

In the past few years, field experiments have been organized to improve the short-range forecast accuracy in specific areas over land by deploying extra observations over specific ocean regions.The general conclusions from these campaigns (see, e.g., Langland 2005) were that, on average, targeted observations had positive but small impact, with maximum error reductions of about 10-15% (e.g. on mean-sea-level-pressure). These studies were anyhow affected on the design and execution by some major weaknesses: often there was poor matching between the target area identified by the methods and the area actually sampled by the extra observations (e.g. aircraft could not completely cover the identified area and sometimes observations were collected outside. Cardinali & Buizza 2003). Moreover, results had a low statistical significance due to the limited number of cases included in the targeting observational campaigns. Furthermore to assess the cost-benefit of targeting, a clean comparison between the impact of observations taken in objectively defined target and randomly selected areas was lacking, and the size of the target area and the number of extra observations varied substantially between cases.

To address these major weaknesses and provide a better estimate of the value of observations taken in localized target regions, extensive data assimilation experiments have been performed at ECMWF. The value of these supplemental observations has been evaluated in terms of the relative forecast error reduction in downstream regions: i) North-America for targeted observations taken in the Pacific Ocean, ii) Europe for targeted observations taken in the Atlantic Ocean. The present study is the third of the series of papers intended to investigate the value of targeted observations over North America and Europe (paper 2: Buizza et al. 2007, hereafter BCKT07) and the importance of observation cover over the oceans (paper 1: Kelly et al. 2007, hereafter KTBC07 )

The first paper (KTBC07) investigated the value of observations taken over the Pacific and the Atlantic Oceans for 2-day forecasts verified over North-America and Europe, respectively. The latitudinal extent considered was between 30°N and 80°N for both ocean basin experiments. KTBC07 also investigated the value of Pacific observations for medium-range forecast verified over Europe. KTBC07 concluded that, on average, (i) ocean data are important to minimise 2-day forecast errors over the US and Europe; (ii) the removal of observations over the Pacific has a very small impact on the medium-range (4-7 day) forecasts verified over Europe; (iii) results are strongly dependent on the data-assimilation system used to assimilate the observations.

The second paper (BCKT07) discussed the value of observations (six months are considered) taken in singular vector (SV) target areas over the ocean for the 2-day forecast verified over the downstream regions on land. The value (forecast impact) was compared to the value of observations taken in randomly selected regions and with the value of observing all the ocean regions. It has been found that if the baseline observing system is data rich over oceans (which is the situation today with the current data coverage), the impact of removing observations in sensitive areas e.g. over the Atlantic, will increase the 2 day forecast error (over Europe) by 2% compared with 1.7% for observation removed in random areas. In the second paragraph of this paper, the designed BCKT07 experiments will be described and the results summarized to provide the background of the further investigation here depicted. However, BCKT07 investigation, being based on a very large sample of days (183), could not exclude the possibility that a larger value of targeting SV areas occur during specific weather regimes developing on shorter temporal scales (few weeks instead of months). It was in fact noticed that a series of higher value of targeting occurred during Extra-tropical Transition (ET) or in association with Tropical Cyclones (TC). In particular, the tropical storm Cristobal (August 2002) was the first case capturing the attention on the subject. An interaction between a Rossby wave packet and the precipitation band along the east coast of North America associated with the tropical storm Cristobal (Fig 1 in Par.2) had a significant influence upon the formation of the European cut-off low and the extreme flooding on August 2002 in Central Europe. The targeting experiment showed a considerable forecast impact and consequently larger observational value with respect the BCKT07 results. Different periods have then been examined with meteorological developments that could largely affect Europe.

This study investigates the influence of weather regimes in targeting, in particular the impact of targeting the North Atlantic Ocean to improve the 2-day weather forecast over Europe. The experiments are all based in summer and over the Atlantic during tropical cyclones activity and they are all characterized by the presence of formation of Tropical Cyclones (TC). In Section 2 the description of the experimentation performed and the model used is given, together with the regimes investigated in different years. The results described in terms of impact of targeting sensitive or randomly selected areas in the analysis and forecast are discussed in Section 3. Conclusions are provided in Section 4.

## 2. Experimental Design

In this Section a brief summary of the experiment design and conclusion of BCKT07 is presented. In fact, for a comprehensive picture of the investigation here described, it is necessary to be acquainted with the BCKT07 methodology and findings. The experiments performed, all in summer season, compare different years and duration of the tropical cyclones activity and the interaction with different mid-latitude flows. A description of the weather regime characteristics is also included.

### 2.1 BCKT07 experiments

The experiments conducted in BCKT07, summarized in Table 1, are the following: i) type-IN experiment, at each data-assimilation cycle observations are injected either in the target area defined using SVs, SVIN, or in randomly selected areas, RDIN. The reference experiment is SEAOUT, which does not include observation over the ocean. ii) Type-OUT experiment, at each data-assimilation cycle observations are removed either in the target areas, SVOUT, or in the randomly selected areas, RDOUT; the reference experiment SEAIN includes all observations (ECMWF operational suite). Following the discussion and results of BCKT07, only the type-OUT experiment can be used to provide an upper bound of the expected average impact that extra observations released in targeting campaigns would have, clearly under the assumption that the impact of removing information is symmetric to the impact of adding information in the same region.

| **Experiments** | **SVIN** | **RDOUT** | **SVOUT** | **RDOUT** | **SEAIN** | **SEAOUT** |
|---|---|---|---|---|---|---|
| **Description** | No data over oceans except in sensitivity areas | No data over oceans except in random areas | Data over oceans except in sensitivity areas | Data over oceans except in random areas | Data everywhere, as the operational suite | No data over oceans |

*Table 1: Description of the experiment performed in BCKT07*

BCKT07 concluded that observations taken in SV-target areas are more valuable than observations taken in random areas: i) by a factor 7.2 in winter and a factor 3.5 in summer when the verification area is North America (see Tab.2 in BCKT07, ratio between SVOUT and RDOUT); ii) by a factor 1.1 in winter and 2.2 in summer when the verification area is Europe (see Tab. 3 in BCKT07). It was undoubtedly found that the value of targeted observations depends on the region, on the season, and on the baseline observing system used as a reference and, as shown in KTBC07, on the data assimilation system used. If the baseline observing system is the one with observations over the ocean (SEAIN experiment), the average value of observations taken in SV-target areas is very small. The value was measured using the 2-day root-mean-square-error of 500-hPa geopotential height (rmse) averaged over the North America verification area: (125°W:90°W;35°N:60°N) when the North Pacific is targeted and averaged over Europe (10°W:25°E;35°N:60°N) when the North Atlantic is targeted. BCKT07 deduced that removing SV-targeted observations (SVOUT) increases the 2-day forecast error in the verification region by a maximum of 6.5% for the winter season (summer season is 2%) and over North America. While over Europe the rmse increases by 3% in the winter season (3.6% in summer). On the other hand, data-injection experiments indicated that if the baseline observing system is the one without observations over the ocean (SEAOUT experiment), then the average value of observations taken in SV-target areas is substantially higher (SVIN). In fact, SV-targeted observations are capable to reduce the 2-day forecasts error in the verification region (North America) from a minimum of 16% (summer season) to a maximum of 27.5% (winter season). Over Europe, in the winter season, the relative reduction is given by 19.1% and in summer is 28.6%. It is worth to notice that while in the Pacific the maximum forecast value is obtained in winter, over the Atlantic the situation is reversed and the maximum value is observed in the summer season.

In all experiments, ECMWF 12 hour 4D-Var data-assimilation system has been used (Mahfouf & Rabier 2000) at the resolution T511L60 (outer loop and forecast) and TL95TL159L60 (inner loops). The SVs and the corresponding target areas have been computed every 12-hour at the resolution T63L40, 48-hour optimization time interval, dry total energy norm and dry simplified physics (Buizza 1994). The experiments performed consist on degrading the data coverage either in SV or random regions. In this study, as mentioned above, only the type-OUT experiments are considered because they can provide the estimation of the expected average impact of targeting observations. In particular, they provide an upper bound of the average impact of targeting given the fact that the number of observations removed over the ocean in SV-regions is much larger than the number of observation released in real campaigns and the data-coverage degradation is systematically performed at every assimilation cycle (twice per day) and not few days per week (as field campaign).

The tropical storm Cristobal (August 2002) is the first case examined. All cases are synthesized in Table 2 for different TC seasons and ET episodes. In total 130 days have been examined but only 100 are included in Table 2. In fact, the examination performed on November 2002, month characterized by strong dynamical activity with Rossby way propagation and breaking associated with extreme events over Europe, has been excluded because the results were completely in line with BCKT07 findings.

The type-OUT experiments are compared with the baseline system SEAIN, which assimilates the same observations as operational. Two different temporal scales are examined: a longer period of few weeks, type-All, and a shorter period of few days, type-ET. The period defined as 'All' includes the 'ET' period which is computed from the time the TC becomes Extra-tropical (30ºN) until it dampens plus three days to account for the possible remnant effects over Europe.

| **Periods** | **Aug02** | **Sep03** | **Aug05** | **Sep05** |
|---|---|---|---|---|
| **All** | 26July-16Aug | 1-21Sep | 10Aug-6Oct | |
| **ET** | 5-13Aug | 7-11Sep | 13-21Aug | 4-27Sep |

*Table 2: Description of the periods examined: type-All is indicative of the duration of the experiment and type-ET is relative to the particular time when the Extra-tropical transition takes place. Total number of days is 100*

## 2.2 Weather regimes

The periods examined in this work contain one or more episodes of tropical cyclone Extra-tropical transitions that interact with the particular large-scale circulation.

August 2002 (Aug02). During August 2002, many regions over central Europe were affected by heavy precipitation and flooding caused by a cut-off cyclone (Enomoto et al, 2006). The cyclone developed as a result of the propagation of a Rossby wave packet, initiated over Japan. The wave-packet propagation along the relatively weak sub-tropical jet was accompanied by wave-break and re-emission in the subtropics. In particular, there was an interaction between the Rossby wave packet and the precipitation band along the east coast of North America associated with the tropical storm Cristobal (Fig 1). Cristobal transitioned to an Extra-tropical cyclone on the 5th August, quickly intensified and weakened on the 10th. This interaction had a significant influence upon the formation of the European cut-off low and the extreme flooding on the 10-11 August 2002.

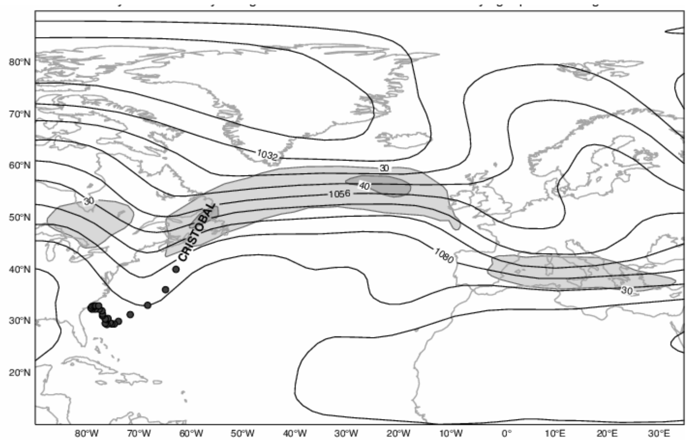


*Figure 1: 250-hPa geopotential height (grey contour) and wind speed (grey-shadow areas) averaged on Aug05 ET period. The black dots describe Cristobal evolution (black represent TC intensity).*

*September 2003 (Sep03)*. Fabian formed as tropical storm towards the end of August 2003 and it became Extra-tropical on the 7 and ET on the 8 September. Figure 2 shows the mean over the ET period (Table 2) of geopotential height and wind speed at 250 hPa. UKMO identified a series of poor forecasts of the cyclone as it landed over the UK (Sarah Jones, personal communication). For the period 3-9 September the verification cyclone was weaker than forecast (not shown).

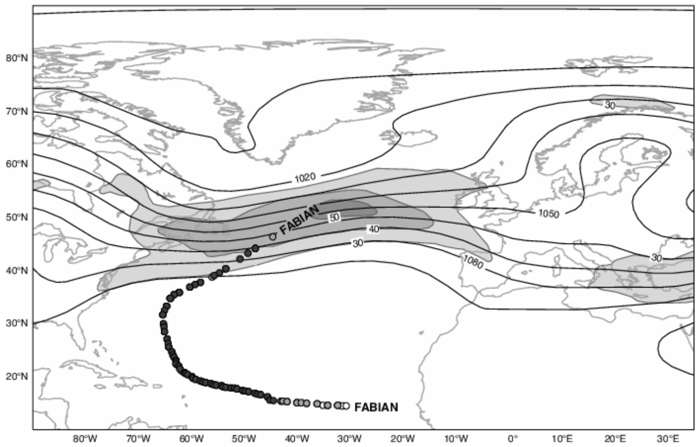


*Figure 2: 250-hPa geopotential height (grey contour) and wind speed (grey-shadow areas) averaged on Sep03 ET period. The dots describe TC Fabian evolution: black TC intensity and grey Tropical storm intensity*

While Fabian moved pole-ward, an upper-level wave developed northwest of the Atlantic. The confluence of the polar and sub-tropical jet at the bottom of the amplified upper trough (west of the TC) gave to Fabian a northeast acceleration which caused the downstream amplification of the secondary trough over Europe.

*August 2005 (Aug05)*. TC Irene formed on the 8 August 2005 and transitioned to Extra-tropical on the 13th and ET on the 18th, according to the NOAA National Hurricane Centre, when it was absorbed by a mid-latitude cyclone (Fig 3). In particular, Irene interacted with the mid-latitude flow when from a major sharp trough on the North America east coast a short-wave formed. During the next few hours the ET rapidly developed by deepening of about 35-hPa in one day. The explosive cyclone moved from the equator-wards to the pole-wards of the jet streak (not shown) and led to the downstream trough amplification and likely to the severe flooding in central Europe. Some weather prediction centers, e.g NOAA/GFS and FNMOC/NOGAPS disagreed on the medium-range forecast.

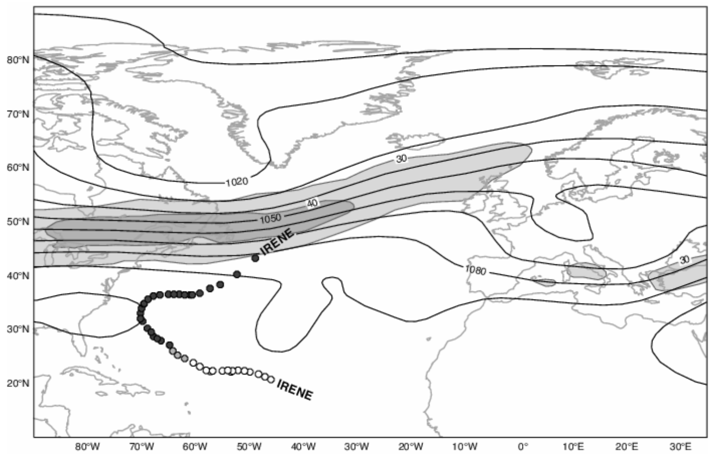


*Figure 3: 250-hPa geopotential height (grey contour) and wind speed (grey-shadow areas) averaged on Aug05 ET period. The dots describe TC Irene evolution and the colouring the intensity: black TC and grey Tropical storm intensity*

*September 2005 (Sep05)*. North Atlantic tropical cyclones activity was very high in September 2005. Four of them, Maria, Nate, Ophelia and Philippe became Extra-tropical on the 4, 8, 9 and 23 September 2005, respectively. This period was characterized by a zonal circulation, mainly affecting North of Europe, with less unstable flow compare with the other situations described above. Over the Atlantic, the maximum mean jet-stream speed was 30 $ms^{-1}$ (Fig 4). Only Maria and Ophelia interacted with the mid-latitude flow. In particular, the equatorial branch of the jet, embedded on a developing trough, moved Maria to higher latitudes (not shown). The cyclone moved North of Scandinavia regions. The transition only affected higher latitude than 60°. Instead, on the pole-ward trajectory of Ophelia, along the east coast of United States, the storm was absorbed by the upper westerly wave but instead of amplifying it lost energy (not shown). The remains of the storm only locally interact with the advancing short-wave trough with no consequences for Europe

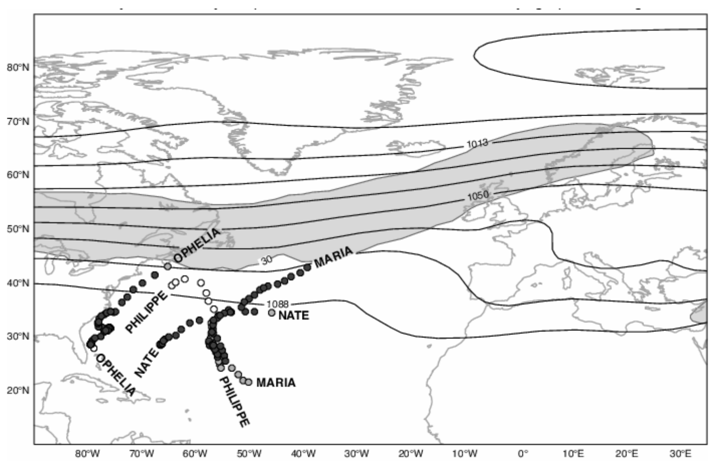


*Figure 4: 250-hPa geopotential height (grey contour) and wind speed (grey-shadow areas) averaged on Sep05 ET period. The dots describe Maria, Nate, Ophelia and Philippe TCs evolution are black for TC intensity and grey for Tropical storm intensity*

## 3. Results

The results described in this section compare the measured degradation of forecast impact among the different experiment types SVOUT, RDOUT and SEAIN for the 48-hour range and over the verification region. The impact of degrading the observations coverage in the assimilation is also provided by computing the loss of the degree of freedom for signal (DFS) that is measured at each cycle in the experiment types, SEAIN, SVOUT and RDOUT. The last investigation described in this section, compares the forecast error over the North Atlantic when observations are denied in SV target or randomly selected areas. If better observed sensitive regions improve the analyzed fields, some larger degradation on the very short-range forecast should be observed for the same fields in a larger area containing the sensitivity and the random regions as well.

### 3.1 Rmse evaluation

The forecast impact evaluation is measured in terms of averaged 48 hour rmse of the 500 hPa geopotential height. The rmse is averaged on the defined 'ET' periods (Table 2) and over the European (10°W:25°E; 35°N:60°N) verification area used to compute the singular vectors. The average for the 'All' and the BCKT07 periods are also shown for comparison. Aug05 (ET Irene), SVOUT suffers the maximum degradation of 12.9% relative to SEAIN (all current observations used). By contrast, SVOUT suffers the minimum degradation of 3.3% in Sep05 (Table 3). In general, RDOUT shows a very little degradation compared to SEAIN and in Sep03 case, taking out observation in random areas, actually improved the forecast by 3.9%. In the ‘ET’ periods, SV-target areas are more valuable than random areas by a maximum factor of 9 (Sep03) to a minimum of 2 (Sep05). On average, SV-target areas are 6 times more important to observe than random areas. It is worth noticing that all the studied periods, provide very consistent results with the exception of Sep05 which is characterized by a smaller difference between SVOUT and RDOUT. For this case, some considerations must be taken into account. The general circulation was different from the other cases being, in fact, strictly zonal and less dynamical unstable. Only two of the TCs transitioned to Extra-tropical: Maria which mainly affected Northern Europe (above 60 ) area that is not included in the verification area (when rmse are computed by including this region the forecast degradation is comparable to Aug02-05 and Sep03 cases, not shown) .For the other case, Ophelia had very local impact (east coast of North America) that did not much influence the downstream circulation over Europe.

| | (SVOUT-SEAIN)/SEAIN (%) | (RDOUT-SEAIN)/SEAIN) (%) | (SVOUT-RDOUT)/SEAIN) (%) | SVOUT (m) | RDOUT (m) | SEAIN (m) |
|---|---|---|---|---|---|---|
| **ETAug02** 8 day | 8.1 | 1.4 | 6.7 | 13.0 | 12.1 | 12.0 |
| **ETSep03** 4 day | 6.0 | -3.9 | 9.9 | 17.3 | 15.7 | 16.4 |
| **ETAug05** 8 day | 12.9 | 2.1 | 10.8 | 11.6 | 10.5 | 10.2 |
| **ETSep05** 23 day | 3.3 | 1.5 | 1.8 | 11.6 | 11.4 | 11.2 |
| **All02** 21 day | 4.5 | 2.5 | 2 | 12.8 | 12.5 | 12.2 |
| **All03** 21 day | 1.5 | -2.7 | 4.2 | 13.7 | 13.1 | 13.5 |
| **All05** 57 day | 3.9 | 2.0 | 1.9 | 11.4 | 11.2 | 11.0 |
| **JJA04** 90 day | 3.6 | 1.6 | 2.0 | 10.6 | 10.4 | 10.2 |
| **DJF04** 90 day | 3 | 2.6 | 0.4 | 18.4 | 18.3 | 17.9 |

*Table 3: rmse over Europe for the 500 hPa geopotential height for the ET, All and BCKT07 summer (JJA) and winter (DJF) periods. 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 meters averaged over Europe.*

When *rmse* is averaged over longer periods than the type-ET, the value of targeting decreases; this is true either for the type-All experiments or the BCKT07 summer and winter ones. BCKT07 showed that over the Atlantic in winter there was very little difference (a factor 1.1) between degrading SV and random area and a larger factor 2.2 in summer. Moreover, degrading SV areas would, on average, degrade the forecast by 3% in DJF04 and 3.6% in JJA04 (Table 3). For the ‘All’ periods, an average forecast degradation of 3.3% is found in SVOUT, which is 2 times larger than observing random areas (RDOUT).

The assessment on the synoptic difference among SVOUT, RDOUT and SEAIN forecasts over the all periods are also performed. At 500 hPa , often, the type-OUT experiments show similar dynamical features with respect to the reference experiment, the main differences come from slightly displacement or intensification of the low pressure systems. The main diversification is observed for the MSL (Mean Sea Level) pressure fields. Figure 5 illustrates three cases with large rmse degradation and significant changes also in the surface fields. In the top panel of Fig 5 are shown (from left to right) the 48 hour 500 hPa forecast differences between SVOUT and RDOUT, the MSL pressure for SVOUT and RDOUT valid on 20020811 at

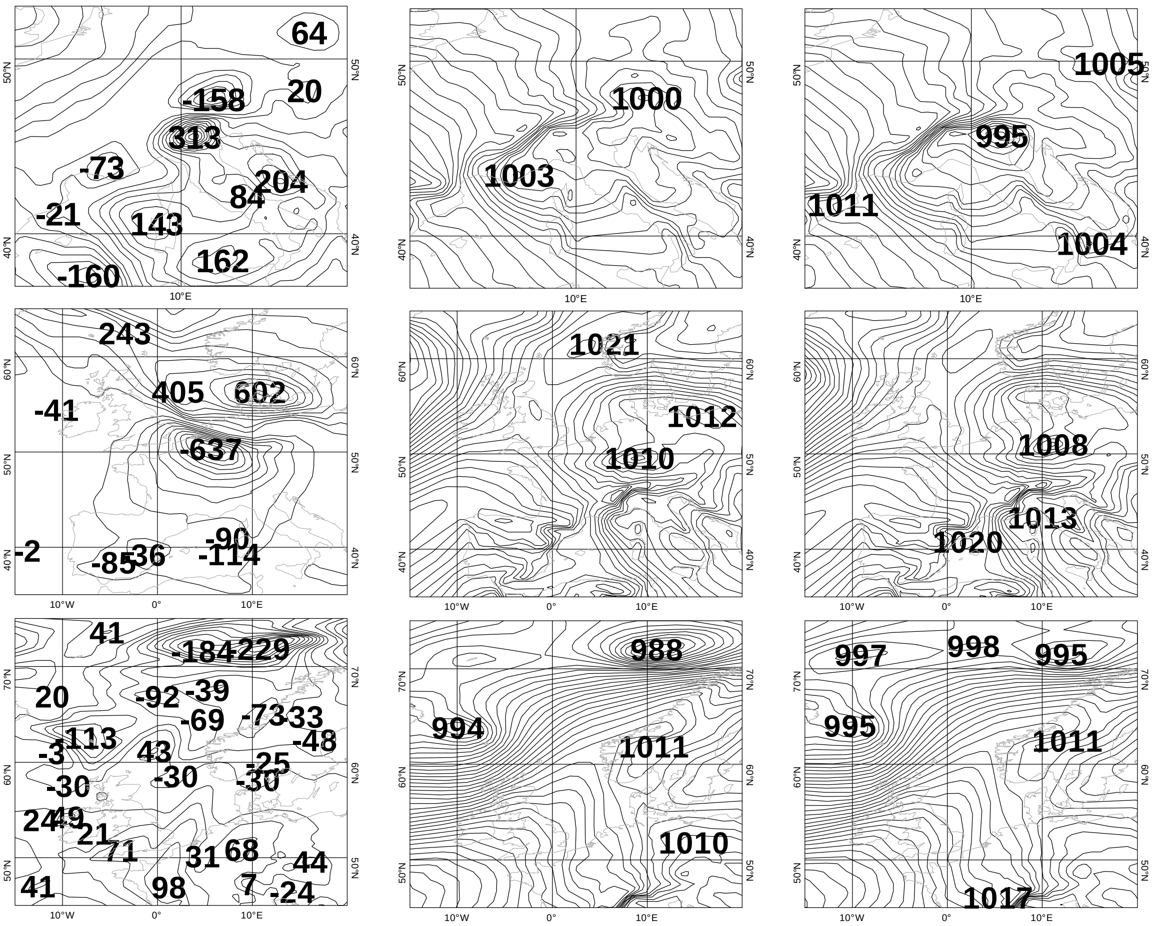


*Figure 5: 48 hour forecast of the 500-hPa geopotential height differences between SVOUT and RDOUT (first column), the MSL pressure for SVOUT (second column) and RDOUT (third column) valid on a) 20020809 at 12 UTC (top panel) , b) 20030909 at 00 UTC (mid panel) and c) 20050821 at 00 UTC (bottom panel)*

12 UTC. At 500 hPa the differences of 31 m are due to both, larger intensification and time shifting, of the low system amplified by the interaction with TC Cristobal; the MSL in SVOUT presents a minimum of 1000 hPa whilst in RDOUT is 995 hPa. Rejecting observations in 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 strong precipitation with part of central Europe flooded. The cumulated forecast precipitation over 48 hour from the 9 September at 00 from SVOUT and RDOUT shows very different pattern but similar intensity (not shown). The middle panel depicts a case valid on 20030911 at 00 UTC (forecast started on 9 September at 00 UTC) during Fabian Extra-tropical transition where removing observations in sensitive areas first lessen the low pressure system (moving northwards) northwest of England by 6 hPa (not shown) and 12 hour later some changes apply in the displacement and the intensity of the low pressure system over Germany (middle panel second and third column, respectively). The bottom panel of Fig 5 is related to 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), the maximum difference is 7 hPa. This time, deny observations in sensitive region create a too deep surface pressure system.

On average for all periods, differences of 20 m are observed in the troposphere corresponding sometimes to significant changes on the pressure distribution at the surface

## 3.2 DFS

The Degree of Freedom for Signal (DFS) or information content (Hoaglin and Welsh. 1978, Purser and Huang, 1993 and Cardinali et al.2005) is computed for all periods. At each cycles the observations influence in the assimilation system is computed by finding the diagonal elements of the Influence matrix which is strictly related to the analysis covariance matrix. The trace of the

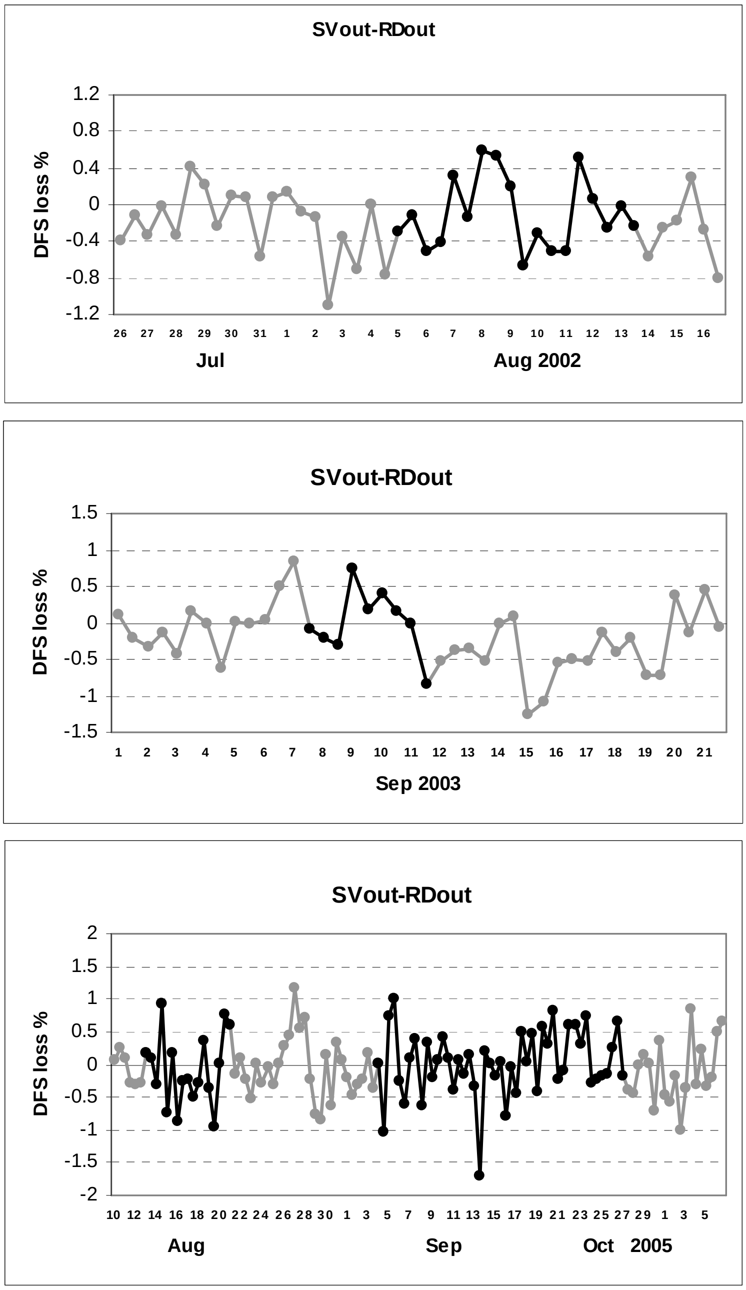


*Figure 6: DFS loss relative to SEAIN experiment of SVOUT experiment compared to RDOUT. a) Aug 02 type-All period, b) Sep03 type-All period and c) Aug05 and sep05 type All period. The black line highlights the type-ET periods.*

Influence matrix gives the value of all observations in the analysis that is the amount of information extracted from the observations or degree of freedom for signal.

Denying observations in sensitivity areas is expected to produce larger loss of information content than in random areas because sensitive areas are supposed to locate dynamically active regions important to observe. This of course is true if a fully flow dependent background covariance matrix is used able to adapt to different synoptic situations. In practice, at ECMWF, only some modification of the variance of the background error is allowed. Figure 6 shows the percentage of DFS loss between SVOUT and RDOUT. Measurements in the stratosphere are not taken into account. The percentage is relative to the DFS of SEAIN experiment. SVOUT negative values mean that the DFS in SVOUT is smaller than the DFS in RDOUT. This would imply that taking the observation out from SVs regions diminishes the information content more than removing the observations in random areas. The total DFS loss in SVOUT with respect to RDOUT for the type-All experiments is -7.7% for Aug02, -7.3% for Sep03 and -4.6% for Aug-Sep05. In terms of number of cases for the all periods, SVOUT presents 70% cases with larger DFS loss than RDOUT for Aug02 and Sep03 and 53% for Aug-Sep05. Clearly, there is a systematic DFS loss in all cases examined when observations are denied in sensitive areas. This result brings to the attention the importance of the tangent linear dynamics in the temporal interpolation of the observation information as a different mechanism to be compared with incorporating dynamics in the covariance evolution. In fact, as above specified, no full covariance evolution is applied in the 4D-Var assimilation system but still observations in sensitive and dynamically more instable regions have more influence than in randomly selected regions. This is due first to the fact that observation departures are calculated at the real observation time and second that the departure are propagated by the adjoint model back in time to the begin of the assimilation window. It is not in fact a coincidence that the last period examined Aug-Sep05 characterized by a zonal circulation with less unstable flow shows smaller DFS loss in SVOUT with respect the other periods.

### 3.3 Short-range forecast trend

Over the experiments time, the 12-hour difference between SVOUT and RDOUT has been compared in terms of the root mean square forecast error of the 500-hPa geopotential height averaged over the North Atlantic region (Fig 7). If the lack of observations in SV defined areas increases the analysis errors more than the lack of observations in randomly selected regions, similarly on the short range and over the Atlantic, SVOUT would present larger forecast error than RDOUT. In Fig 7 the difference of the rmse of the type-OUT experiments is shown for August and September 2005. The point distribution shows larger positive differences on the first half of the period, these differences disappear toward the end. All studied periods show similar trend which is also illustrated in Fig 7 by the linear regression of the rmse difference sample. Initially the maximum difference is 0.5 m. The error difference decreases and vanishes after day 50.

Similar results are obtained for BCKT07 type-OUT experiments in summer and in winter (not shown). Besides, the type-IN experiments performed in BCKT07 show smaller short-range forecast error in SVIN than RDIN over North Atlantic and North Pacific oceans: re-injecting the observation in SV locations provides less degraded first guest field over the oceans. SVOUT (SVIN) 12 hour forecast has initially larger (smaller) errors than RDOUT (RDIN), over sometime the error difference decreases likely due to the growing of some other error sources.

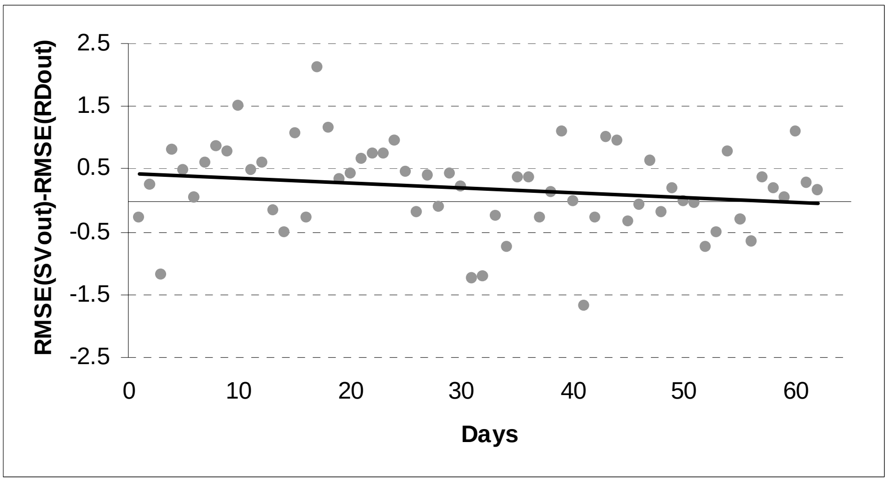


*Figure 7: 12-hour forecast rmse difference between SVOUT and RDOUT in meters averaged over North Atlantic and for Aug05 and Sep05 periods.*

## 4. Conclusion

The sensitivity to the atmospheric flow of targeted observations taken in the Atlantic for forecast verified over Europe has been investigated. Four different weather situations have been selected, characterized by different large-scale circulation during the tropical cyclones season, for August and September and for different years. It is noted that the forecast impact is sensitive to the interaction of tropical disturbances with the mid-latitude flow and targeting can reduce the forecast degradation by a maximum of 13% in terms of averaged root mean square error of the 500-hPa geopotential height over the verification area. In particular, results show that targeting North Atlantic sensitive regions computed by using energy norm and dry singular vectors is on average 6 times more valuable than target randomly selected areas over the ocean. The maximum forecast response is given when Extra-tropical transitions take place and the large-scale flow over the Atlantic is not zonal and unstable. It should be also kept in mind that a root mean square error reduction smaller than 15 m (~40%) does not bring in general substantially synoptic forecast difference as shown in Kelly et al 2006 at tropospheric levels but for instance can provide some significant changes on the surface pressure field as was shown for August 2002 and 2005.

Sensitivity regions are believed to indicate dynamically active regions very important to measure. Denying observations in sensitive areas is therefore expected to produce a larger loss of information content than in random areas, being the effect maximum 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 similar effect of covariance evolution and larger observation influence loss is observed in all experiments where data have been denied in sensitive areas.

On the short-range forecast or first-guess, 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. Results (Table 3) have shown that averaging over many cases, the impact of SV-based targeted observations on 2-day forecast of 500 hPa geopotential height is 3.3%, but selected cases of Extra-Tropical Transitions the value is 12.9%. The results are in line with the measured forecast impact over the verification area of the real targeting campaigns that took over in these last few years (Langland 2005) either over the North Pacific or in North Atlantic. These findings can provide target guide line; in particular they suggest that rather than play target field campaigns on the forecast indication of some extreme weather impacts (that very often do not occur) and change all the time size of the target and verification area, it would be preferable to target more continuously during specific weather situations as e.g. Extra-tropical transition, to improve somehow larger size verification region downstream. Some further investigation should be performed to compare the value of observing Extra-tropical transition of tropical cyclones to the value, here assessed, to observe sensitive areas during tropical cyclones transition in mid-latitudes.

**Acknowledgement**

The authors are very thankful to Sarah Jones for providing all Extra-Tropical Transition cases investigated herein. The authors are very grateful to Fernando Prates for the valuable discussion on the synoptic situations and to the THORPEX community who encouraged and support the study.

## References

Buizza, R., 1994: Sensitivity of Optimal Unstable Structures. *Q. J. R. Meteorol. Soc.*, **120**, 429-451.

Buizza, R., C. Cardinali, G. Kelly, and J.-N. Thepaut, 2007: The value of targeted observations Part II: the value of observations taken in singular vectors based target areas. *Q. J. Roy. Meteorol. Soc.*, submitted. Also available as ECMWF RD Technical Memorandum number 512.

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

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

Hoaglin, D.C. and R E Welsh, 1978: The hat matrix in regression and ANOVA. *Am.Stat.*, **32**, 17-22 and Corrigenda 32, 146.

Kelly, G, J-N Thepaut, R. Buizza and C. Cardinali, 2007: The value of targeted observations Part I: the value of observations taken over the oceans. *Q. J. Roy. Meteorol. Soc.*, submitted. Also available as ECMWF RD Technical Memorandum number 511.

Langland, R. 2005: Issues in targeted observing. *Q. J. R. Meteorol. Soc.*, **131**, 3409-3425.

Mahfouf, J. F. & F. Rabier, 2000: The ECMWF operational implementation of four-dimensional variational assimilation. Part I: experimental results with improved physics. *Q. J. R. Meteorol. Soc*., **126**, 1171-1190.

Enomoto, T., W. Ohfuchi, H. Nakamura, and M. A. Shapiro, 2006: Remote effects of tropical storm Cristobal upon a cut-off cyclone over Europe in August 2002. *Meteor*. *Atmos. Phys*., in press.

Purser, R.J. and H. L.Huang, 1993: Estimating effective data density in a satellite retrieval or an objective analysis. *J.Appl.Meteorol.*, **32**, 1092-1107.