PREDICTABILITY STUDIES WITH FASTEX DATA USING THE ECMWF IFS

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Summary: The Fronts and Atlantic Storm Track Experiment, FASTEX, took place during January and February 1997 and was in part aimed at addressing the predictability of Atlantic sector cyclones. Upstream dropsonde observations were taken in regions which were predicted as "sensitive" by singular vectors and other calculations. In this paper a brief summary will be given of the targeting method used. This process is here referred to as an example of "chaotic control" of the observing system aimed at improving the 1 to 3 day forecast over a specified region, in this case north-west Europe. Examples of the impact of these additional observations will be given from 5 re-run ECMWF forecasts. Questions concerning the potential vorticity structure and balance of the singular vector will be discussed briefly.

1. INTRODUCTION

Following a perception that the skill of short-range forecasts (up to 3 days ahead) of extra-tropical cyclones affecting north-west Europe could be increased by improving the analysis from which such forecasts are made, the FASTEX project was conceived; see Joly et al 1997 for further details of FASTEX. A goal of the experiment was to provide additional observations relating to the complete life-cycles of Atlantic storms. The experiment was a success in this regard in that 20 storms were observed by an international team of scientists during January and February 1997. FASTEX was composed of two components. The first related to predictability studies and involved taking so-called targeted observations in the western Atlantic sector whilst the second was directed towards a verification of short-range forecasts by taking observations of the mesoscale structure of the developed cyclone close to north-west Europe. In this paper a contribution to the predictability part of FASTEX will be described and the research to be discussed was carried out by the author, Andrea Montani, at the University of Reading, Roberto Buizza and Tim Palmer from ECMWF. Many of the results for individual cases to be discussed including the relevant figures are taken from Montani (1998). The forecast re-runs were carried out by Per Unden at ECMWF.

This research is directed toward demonstrations of controlling the observing system to minimize forecast error over a specified region at a specified prediction range. In the case of FASTEX this control was exerted by taking dropsonde profiles of atmospheric structure in regions where it was predicted that if there were to be an analysis error then this error would grow rapidly and diminish the forecast skill.

These additional, or targeted, data will reduce analysis errors in these regions thus preventing this diminution of skill.

2. CONTROL PROCESS

The process by which the observational network was controlled during FASTEX can be summarized as follows:

(i) Define a specified region, R_v, over which the forecast error is to be minimized. In the experiments described here this was chosen to be an area such as 0°W to 20°W and 50°N to 65°N. For FASTEX this area was used as it was the zone where further detailed observations of the cyclone were made thus providing verification data. However in general this might be chosen as north-west Europe where key forecast users might be located.

(ii) Define a time at which the forecast is required (hereafter $TEND$) and also specify the forecast range, ΔTF. The choice of forecast range will be influenced by a variety of factors to be discussed later. The time $TO = TEND - \Delta TF$ will be the time at which the additional observations are to be taken. In FASTEX the observations were collected via research aircraft which needed to be alerted a time period ΔTW prior to the nominal time of observation. This allowed time for aircrew preparation and flight planning. Hence the alert time was $TA = TO - \Delta TW$.

(iii) A high resolution (T213L19) operational ECMWF forecast was made from TA over the period up to $TEND$. Typical time-periods used in FASTEX were $\Delta TF = TEND - TO \sim 36 \rightarrow 48\ hr$ and $\Delta TW = 24\ hr$ thus giving the forecast period, $TEND - TA = 60 \rightarrow 72\ hr$.

(iv) A computation was made of the structures at observation time, TO, which would grow maximally over the forecast period into the specified region R_v. For this singular vectors, SVs, were used with a total energy norm at initial and final time i.e. the SVs have the maximum growth of total energy; see Palmer et. al 1997.

(v) The location of the leading SV at time TO is in a region, R_T, which became the target region in which to take additional dropsonde soundings through the atmosphere.

(vi) The aircraft was instructed to take these observations.

(vii) After FASTEX , and as reported in this paper, re-run forecasts were made incorporating these additional data to assess the impact on forecast skill. Various measures of skill are used here including surface pressure minima and 1000 mb and 500 mb root-mean-square height errors.

In the next section results of forecast re-runs including the additional dropsonde data for IOPs 9, 11, 12 and 17 of FASTEX will be discussed. These cases were chosen as they exhibited a large forecast error in region R_v at *TEND* . This error was in the surface pressure minimum that the cyclone in question attained in the verification region R_v . The results should be viewed in the light of several important characteristics of the control process being used. The additional data are in the form of dropsoundings which have different error characteristics to the normally assimilated radiosonde data. In addition it proved impossible to use geopotential data from the dropsoundings as the height of the dropsonde above the sea surface at the time of its final reading was not known. Therefore here only temperature, wind, and humidity information has been used. No attempt was made here to allow for these differences.

In addition the 3D var data assimilation system at ECMWF is such that the analysis increments are calculated at T63 resolution. Therefore the analysis increments cannot resolve any horizontal scales smaller than T63 so that higher resolution signals from observations are damped and averaged at T63. There is still an advantage however of using a high resolution T213 model but only for good observations in an area where the model background is accurate. For dropsonde data in the data sparse Atlantic sector this advantage is not so applicable. (P. Unden ECMWF: personal communication). It is in principle possible to carry out the analysis incremental component of the data assimilation system at higher horizontal resolution but such results are not reported herein.

3. FASTEX CYCLONE FORECASTS

Here we show results of including targeted observations in forecast re-runs for IOPs 9, 11, 12 and 17. Some detail will be given for IOP 17 to provide the appropriate background, other cases will be discussed in a more cursory way.

3.1 IOP 17

In fig 1 an analysis of surface pressure valid at 12Z on 19 February 1997 and a $\Delta TF = 42\ hr$ forecast valid at the same time is shown. Note that these include no FASTEX data of any type. The significant surface pressure error of 10 mb is obvious as is a positional error of the low. A calculation of the relevant singular vectors was made including the structure and singular values of the 5 most rapidly growing SVs. In fig 2 the temperature structure of the leading SV is shown at model level 13 which corresponds to a pressure of about 700 mb. It clearly defines a target zone R_T in which additional observations should be taken so that analysis error there can be reduced.

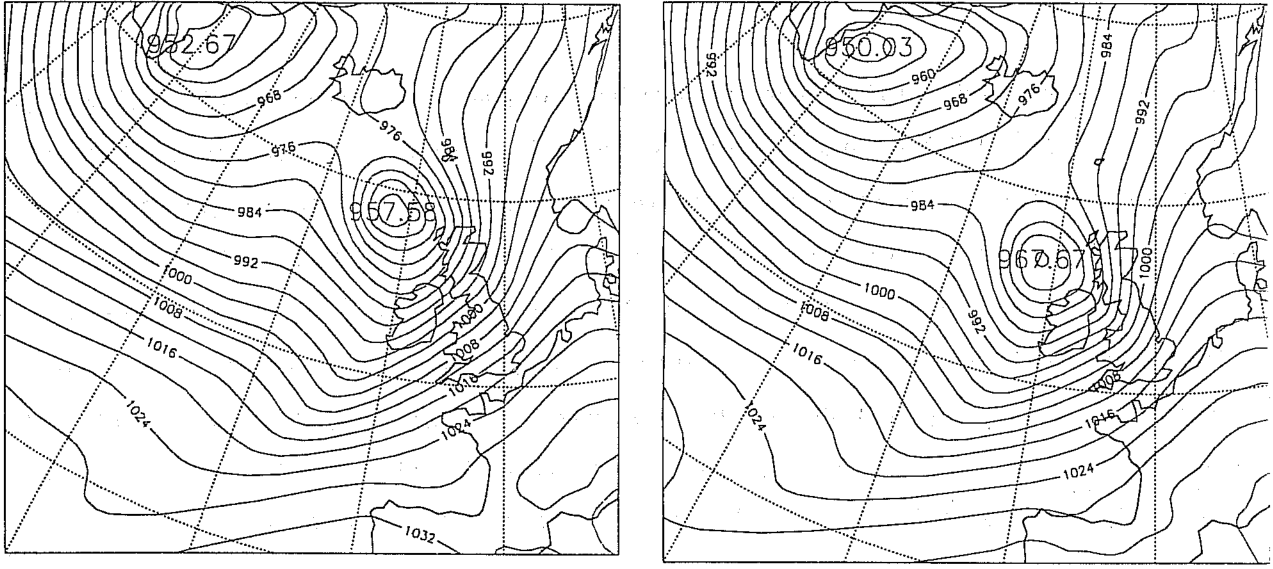


Fig. 1: On the left is the mean sea-level pressure distribution at 12Z on 19 February 1997 corresponding to IOP 17, with no FASTEX data included. On the right is a 42 hour forecast valid at the same time, again with no FASTEX data being used. The substantial 10 mb error is apparent.

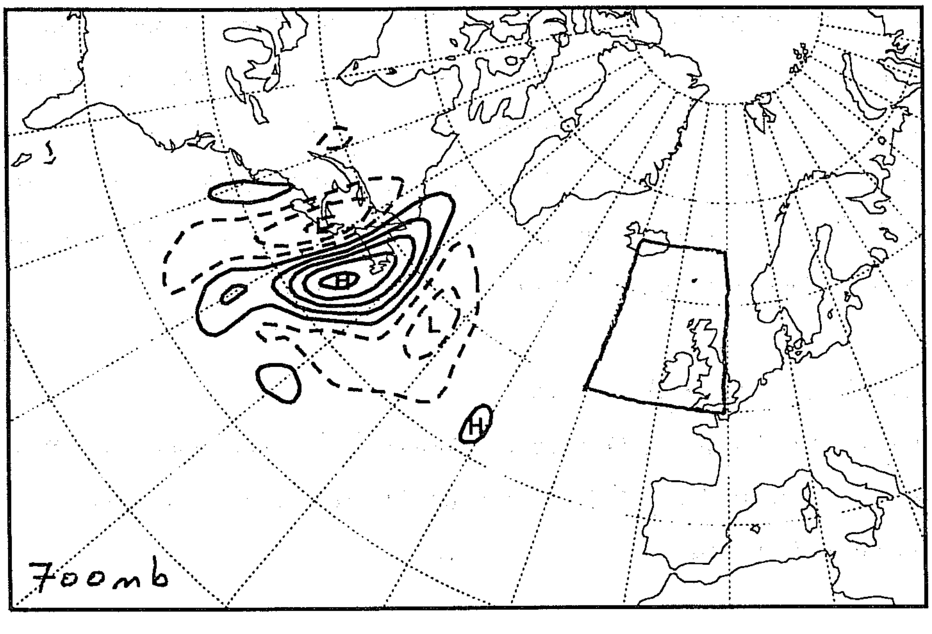
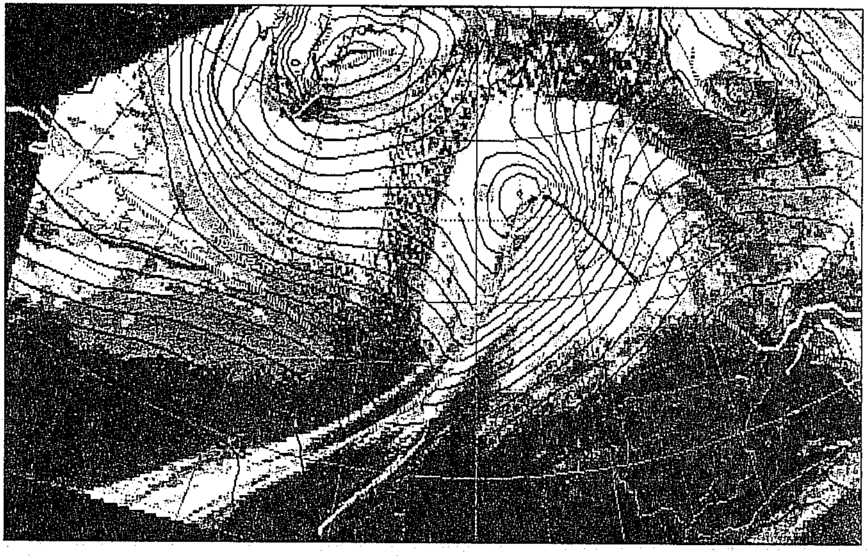


Fig. 2: The temperature structure of the leading singular vector at around 700 mb. This structure grows rapidly over the 42 hour period into the down stream target area, shown as a box near UK.

For this IOP there were a variety of flights in the western Atlantic and in figure 3 we show a relevant satellite picture and the flight tracks and location of additional FASTEX observations. It can be seen that both the Gulfstream GIV and Lear flights coincided with the target zone implied by figure 2.

FASTEX IOP17 Meteosat Infrared image 06Z 19/02/97 Low 41



FASTEX IOP17 Low 41 15Z 17/02/97 - 15Z 19/02/97

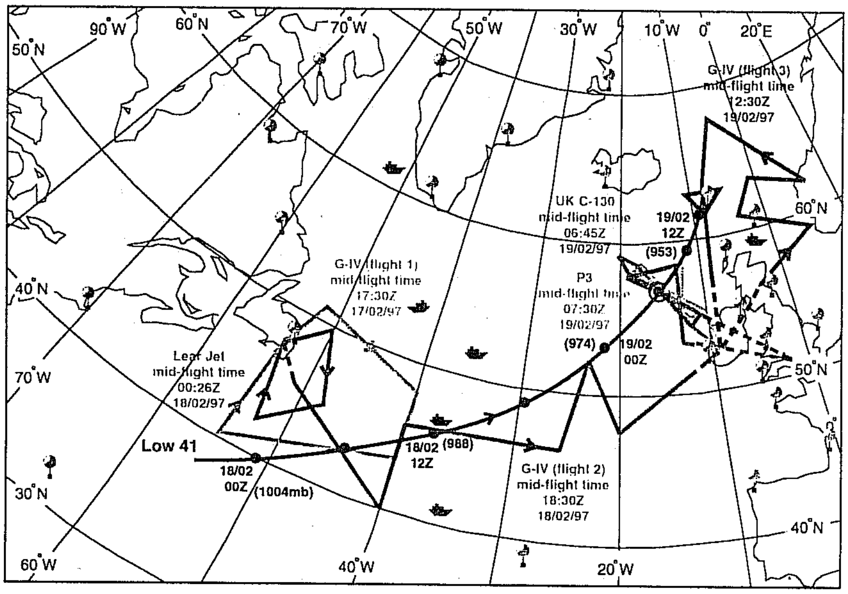


Fig. 3: A satellite image at 06 Z on 19 February 1997 and the tracks of the aircraft which took extra observations of this case.

In the first re-run experiment carried out the GIV, dropsonde (22 soundings distributed over the entire flight track) data were incorporated in the forecast from 18Z on 17 February 1997 using a ± 3 hr time window. In fig 4 we show the surface pressure map for this re-run and it indicates that the pressure minimum error has been significantly reduced to 3 mb. The location has been altered in a less significant way. From a human forecaster's viewpoint this represents a substantial "synoptic" improvement.

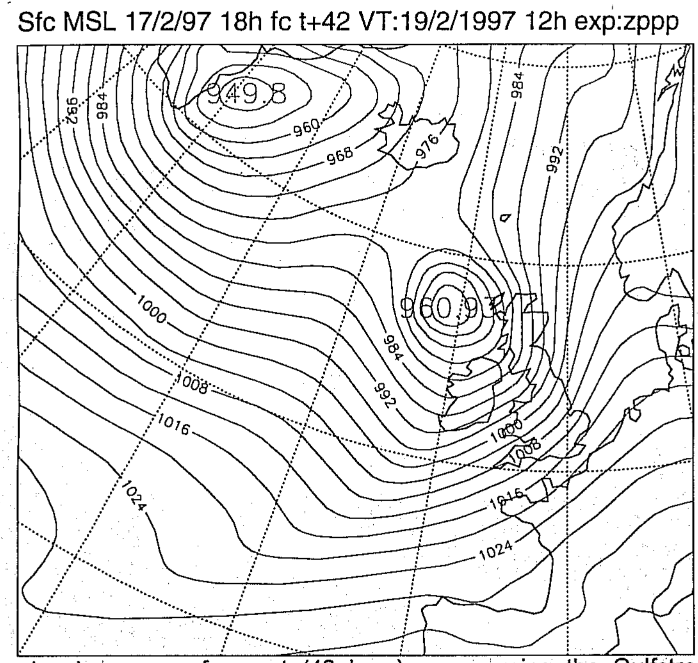


Fig. 4: Mean sea-level pressure forecast (42 hour) re-run using the Gulfstream dropsonde data as additional observations at analysis time. Comparing with Figure 1 we see that the original forecast error has been substantially removed.

To assess more objectively the skill of the forecast in figure 5 the root-mean-square geopotential error at 1000 mb is shown for the control case and for the dropsonde re-run for four verification regions: North Atlantic, Europe, Northern Hemisphere, and North Pacific. The clear forecast error reduction when the dropsonde data are included is evident.

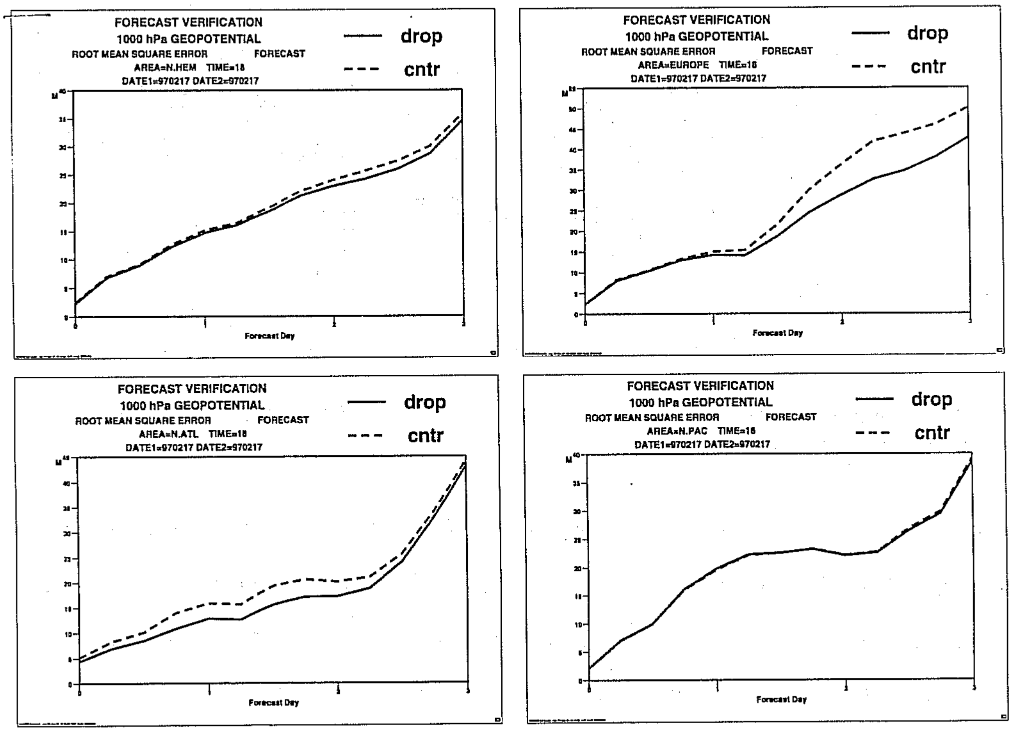


Fig. 5: Root mean square errors at 1000 mb for the four areas - Northern hemisphere, Europe, North Atlantic and North Pacific - comparing the forecast without the dropsonde data (marked "cntr") to the one with the Gulfstream data included (marked "drop").

3.2 Other FASTEX cases

Four additional cases were considered: IOP 17 with the Lear dropsondes, IOP 9, IOP 11, and IOP 12. All revealed a positive impact of including the targeted dropsonde data except at 1000 mb for IOP 12. In figure 6 we here reproduce a figure from Unden et. al. 1997 which considers all the 5 cases and plots a scatter plot of 1000 mb and 500 mb root-mean-square height errors for forecasts with and without the inclusion of the additional dropsondes for forecast time-periods 48, 60, and 72 hr verifying over Europe. The substantial positive impact of the dropsonde data is evident although, as noted previously, there are some negative impact points on the plot in fig 6. Also plotted on fig 6 are the results (with crosses) for a pre-FASTEX case in which the known forecast error was projected onto the leading SVs so that an estimate of the actual analysis error could be made. The re-run forecast for this case then involved removing the error from the analysis and finding the forecast impact. In effect these points indicate a theoretical maximum to the beneficial impact any such observing system might have if properly located. It is encouraging that the FASTEX cases sometimes achieve a positive impact close to this theoretical maximum.

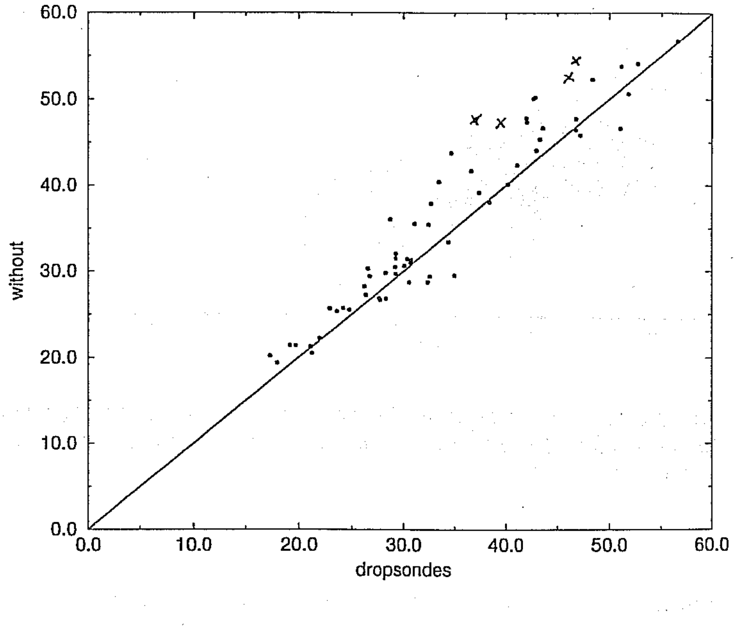


Fig. 6: A scatter plot for all the five re-run forecasts of the 1000 mb and 500 mb root-mean-square height errors. These are plotted to compare the errors for forecasts with and without the inclusion of the additional dropsondes for forecast time-period 48, 60 and 72 hour verifying over Europe. (Figure taken from Unden et. al. 1997) Also shown with crosses are the results of a pre-FASTEX case indicating an estimate of the maximum beneficial impact the extra data could have made.

4. POTENTIAL VORTICITY AND BALANCE

It is interesting to speculate upon the relationship of the SV-generated target zone to any significant dynamical features in the flow in that area. Synoptic-dynamical meteorological theory suggests that cyclogenesis is related to potential vorticity (PV) anomalies embedded in the flow both at tropopause level and also throughout the troposphere; the latter having arisen from prior diabatic processes. Prior to

FASTEX it had been speculated that the SV target zones would probably not bear any special relationship to dynamically significant zones. However it appears that usually this is not the case and the target zones are often near strong PV gradients or PV anomalies. More research is being carried out on this aspect. Also other cases, such as that of the forecast of ex-hurricane Lili, seem to imply that sensitive regions are near to the dynamically active development zones (see Browning et. al. 1998 for further details).

Another aspect of interest is to elucidate the mechanism by which the SV grows in amplitude so rapidly. A calculation has been made of the PV structure of the SV for IOP 17 and a zonal cross- section is given in figure 7. (Note that the sign of the anomalies is arbitrary.)

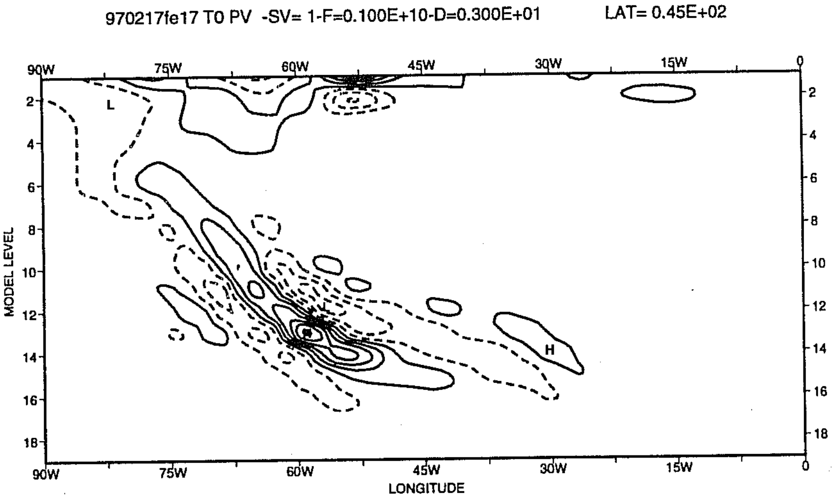


Fig. 7: A zonal-vertical cross-section at 45°N showing the perturbation potential vorticity structure of the leading singular vector. Note that model level 9 is approximately at the tropopause, level 13 at 700 mb and level 15 at 850 mb.

It is clear that the SV is composed of a baroclinically sloping set of PV anomalies dominated by a tripole structure with peak amplitude just below about 700 mb. There is very little amplitude within the boundary layer but there is some significant amplitude at tropopause level. This perturbation PV will amplify if, and only if, there are background PV gradients and this amplification is mostly confined to tropopause level. However even in the absence of PV amplification a change in vertical tilt of such anomalies will imply a substantial growth of other quantities such as temperature and vorticity. This "venetian blind" effect relies on the "unshielding" of the individual components of the tripole anomaly pattern (see Badger 1997). The interaction between this unshielding and perturbation PV amplification at the tropopause is currently being investigated.

Another aspect of SV structure relevant to the dynamical interpretation of their growth is the extent to which they are in balance. One might imagine a balance involving either geostrophy or a more complete non-linear form. The relevance of the balance of SVs is that ideas about their growth have assumed that they satisfy such a balance condition. An initial calculation of the balance condition suggests that the curvature terms, included in non-linear balance, are small and furthermore that the linear or geostrophic balance is only satisfied at around the 60% level. The thermal component in the thermal wind balance is larger than the vorticity component. Further research is being carried out on this question.

5. CONCLUSIONS

In FASTEX additional observational data were taken in target zones defined by SV calculations. These data, when included in ECMWF forecast re-runs, gave a significant reduction in root-mean-square error of the height of pressure surfaces. These results open up the possibility that there may be substantial benefits to be gained by exerting a significant degree of control over the observing system so that observations are taken in so-called sensitive zones. An example of how this might operate is that if the radiosonde network were to be automated at some future point then SV calculations could suggest when and where soundings were needed to be taken so as to reduce subsequent forecast error. In addition controllable satellite instruments, such as cloud lidar, could be switched-on only in such zones thus conserving power for future events. A further possibility is that pilotless aircraft may be available in future which could be directed to target zones to release dropsoundings as required.

It is important, however, to note that such sensitivity calculations can only be performed if the forecast trajectory from which they are calculated has at least a modest level of skill. This in turn relies on the maintenance of at least the current baseline of observations. What is being advocated in controlling the observing network is that additional observing platforms, should they come available, be deployed in a controllable and indeed controlled fashion.

6. REFERENCES

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