EXPERIENCES WITH TOVS MEASUREMENTS DURING ALPEX-1

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I. INTRODUCTION

It is not a simple task to evaluate the impact of satellite geopotential retrievals on meteorological analyses and forecasts correctly. The impact depends on (i) the capacity of the numerical model used, e.g., how it handles the data assimilation problem, (ii) the geographical region, i.e. whether it is data-rich or data-sparse and whether -for that region- the satellite measurements are made around synoptic standard observation hours or not, (iii) the meteorological situation, and finally (iv) the general organisation within a Meteorological Centre. The findings are, therefore, not unambiguous. The impact is generally considered to be marginal. There are cases with a definitely positive impact, others with a negative and again others with a negligible impact at least.

For a National Meteorological Centre (NMC) of Central Europe embedded in an area of a dense aerological network with distances between radiosonde stations of 100 to 200 km over land and with a coarse-mesh region as A of Fig. 1 and a fine-mesh one (grid distance less than 150 km) similar to region B satellite temperature retrievals are less important than in other geographical areas with data-sparse surrounding. Even with drastic changes of analysis products in the North Atlantic area D of Fig.1 as a result of satellite temperatures no significant and definite changes in the 24 hour geopotential.

Fig. 1: Areas of the NMC; A-coarse-mesh area, B- fine-mesh area, C- verification area, D- area of drastic changes in analyses due to SIRS data (after Kluge and Petzold 1978)
forecast for Central Europe (area C of Fig. 1) were observed (Kluge and Petzold 1978). Kluge's and Petzold's satellite input temperatures based on SIRS\(^1\) data with a rather coarse spatial resolution (at the surface about 200 km) caused as a rule only large-scale corrections in the geopotential fields of remote areas. These corrections gradually disappeared in the data-rich areas under the weight of the aerological information with the weather ships OWS R and L having played an essential role. The growing need to forecast subsynoptic scale processes and phenomena has again raised the problem of incorporating in the analysis and forecasting procedures satellite retrievals, and that of high spatial density as, for example, at present offered by the TOVS measurements. An NMC with its limited resources and possibilities has thoroughly to evaluate expense and benefit of each meteorological observational subsystem used including the corresponding technological aspects. If the present aerological network in Central Europe with a density of about 100 to 200 km distance between the stations is to be maintained in the future, satellite retrievals must add substantial mesoscale information to be considered in the technological run within a Central European NMC. A considerable number of aerological stations has, however, only a reduced sounding programme, i.e. one or two ascents per day. Satellite retrievals are beneficial already if they can satisfactorily trace temporary changes in the geopotential fields. The incorporation at the NMC could be either direct by its own receiving station or via teleconnections from a regional receiving station or indirect by corresponding meteorological products (e.g., analyses, forecasts) obtained at the competent Regional Meteorological Centre (RMC). As long as the question whether or not substantial mesoscale information is contained in TOVS data cannot definitely be answered case studies such as ALPEX are a suitable tool to tackle this problem. We have should, however, to emphasize that this question can adequately be answered only (i) by a comparison with verified mesoscale analysis products or (ii) if simultaneously high-spatial-density TOVS data (spot by spot) and mesoscale features, recognized by means of conventional observations are available, including TOVS data of the current operational systems with some spatial filtering. Generally, none of these conditions are met. Conventional analysis products of RMCs or NMCs do in general not contain meso- features. Hence, if differences between retrievals and analysis products with gridpoint distances of 150 km or 300 km occur they cannot directly be used as an evidence of mesoscale information in TOVS data unless they are manifested by further meteorological development. This study is a modest approach at our NMC to become familiarize with the sounding of single-spot TOVS measurements.

\(^1\)SIRS\(4\): Satellite Infrared Spectrometer, flown on Nimbus 3
Due to the lack of sufficient mesoscale verification means the evaluation is, however, restricted to the impact of the TOVS subsystems HIRS and MSU at a synoptic-scale analysis by comparing analysis products with the corresponding retrieval results. It is not the purpose of this paper to assess the influence of TOVS data on numerical models and forecasting.

II. RETRIEVALS FROM THE ALPEX DATA AND COMPARISON WITH NUMERICAL ANALYSES PRODUCTS

Let us now discuss the experiences made with TOVS data of the ALPEX period of 4 and 5 March, 1982. The TOVS data were made available on magnetic tape by the Cooperative Institute for Meteorological Satellite Studies (CIMSS) of the Space Science and Engineering Center of the University of Wisconsin Madison and included all HIRS/2- and MSU-messurements of two consecutive orbits on 4 March at about 1200 and on 5 March 1982 at about 0000 UTC. Additionally, the tape contained fast computer programmes for transmittance calculations with the corresponding coefficients. For further details see Weinreb et al. 1981.

The synoptic situation was characterized by a low-pressure system of 975 hPa, over the northern North Sea and southern Norway (4 March 0000 UTC) which weakened to 995 hPa and moved to the Gulf of Finland (5 March 0000 UTC). At the same time, a wave disturbance at the frontal system of this depression moving from Central France to the Gulf of Genoa developed into a separate low-pressure system with 1010 hPa making way for a ridge of high pressure over Western and part of Central Europe. Fig. 2, according to the analysis of the European Centre of Medium Weather Forecasting (ECMWF) showing the 500/1000 hPa thickness of 4 March, 1200 UTC (full lines) and 5 March, 0000 UTC (dashed lines) demonstrates this meteorological development. The tongue of cold air over Britain and Northern France, shifting eastwards, extended up to the Mediterranean.

The following discussion concentrates on the analysis of the boxes D10 and D17 of Fig. 2 where TOVS data of both days were available. The dimension of D10 with 10 scan lines and of D17 with 17 scan lines are 2400 km x 400 km and 2400 km x 700 km. Marked thickness changes from 4 to 5 March are within D17 and lesser ones are within D10. Temperature retrievals were made for each spot with 56 HIRS and 11 MSU spots per scan line using (i) only the HIRS channels 1 to 8 (HIRS), (ii) only the MSU channels 2 to 4, and (iii) both data sets (HIRS + MSU). MSU channel 1 and the HIRS channels within the 4.3 um region were deliberately omitted to avoid the problems connected with the unknown microwave surface emittance of the ground and the scattered light at 4.3 um.
Fig. 2: 500/1000 hPa thickness analysis of the European Centre of Medium Weather Forecasting (ECMWF) of 4 March, 1200 UTC (----) and 5 March, 0000 UTC (---) (from Rizzi 1984). The discussion in the paper is concentrated of the boxes D10 and D17.
The MSU data were already 'limb-corrected' based on a regression technique that takes into account viewing angle, surface reflectivity, atmospheric liquid water content and antenna pattern.

The total number of individual spots were 560 HIRS- and 35 MSU spots for D10 and 952 HIRS- and 50 MSU-spots for D17 with 15 to 20 HIRS spots per one MSU measurement. Fig. 3 contains for region D10 the changes of the 500/1000 hPa thickness from 4 to 5 March 1982 as difference charts, in Fig. 3a for the numerical analysis, based solely on conventional meteorological observations without satellite data, of the Central Forecasting Office of the Meteorological Service of the GDR (NMC of the GDR), and in Figs.3b to 3d for the analysis from HIRS data only (3b), HIRS plus MSU dat (3c), and MSU retrievals only (3d). The first guess differed only modestly from the solution by 20 gpm on 4 March and by 40 gpm on 5 March. These differences are within the error limit of indirect temperature sounding tech-

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**Fig. 3:** Thickness changes (5 March - 4 March) of the 500/1000 hPa layer in the region D10 according to

- a) the numerical analysis of the Central Forecasting Office of the GDR (NMC of the GDR)
- b) HIRS data only
- c) HIRS plus MSU data
- d) MSU data only
niques. A substantial improvement of the first guess can, therefore, not be expected. High-level cloudiness (pc 300 hPa) was estimated with 68 and 23 per cent on 4 and 5 March, and cloudless conditions with 24 and 43 per cent. The meteorological situation in D10 is characterized by small temporal change and small thickness gradients. There are, according to the numerical analysis, only two regions with thickness changes greater than 4 gpm. These changes are best reflected by the analysis of the MSU retrievals. For HIRS plus MSU data the analysis is similar to the numerical analysis for 4 March, but there are larger differences on 5 March resulting in a more detailed structure in the thickness change map 3c compared with 3a. The meteorological situation of D10 is, however, not appropriate for definite conclusions.

In Figs. 4 to 6 500/1000 hPa thickness analysis products are shown for the region D17, in (a) and (b) of the numerical analysis of the ECMWF and of the NMC of the GDR (b), and based on HIRS data only (c), HIRS plus MSU data (d), and MSU data only (e). Figs. 4 and 5 are for 4 and 5 March, respectively, and Fig. 6 shows the thickness change of 5 March minus 4 March. The first-guess thickness differs from the 'solution' (NMC numerical analysis) with, on the average, 65 gpm and 84 gpm on 4 and 5 March remarkably, high cloudiness was estimated to be 60% on 4 March and 47% on 5 March, and cloudless spots to be 37% for both days.

Note the different numerical analyses of ECMWF and of the NMC in subsynoptic scale (Fig. 7). With regard to the analysis on the basis of the retrievals we would like to point out that the isolines could be drawn only after some spatial filtering. The meteorological situation in D17 is dominated by a trough with southward movement, recognised also in the difference maps (Figs. 6a and b) with negative amounts in the centre and especially in the southern part of D17, and positive amounts in the western part. With regard to 'satellite products' the thickness maps based solely on HIRS data are most difficult to interpret. This is due to the large variability of the retrieval results as temperature sounding with infrared channels only is most complicated in case of high cloudiness. The trough displacement can, however, be identified especially in the difference chart 6c. The combined use of HIRS plus MSU data furnishes extreme deviations from the numerical analysis in the western part of D17 on 4 March with strong thickness gradients. Both data sets are probably not well adapted and a preselection to identify questionable measurements was not made so that in some cases instabilities occurred in the retrieval procedure. Nevertheless, the trough displacement can be recognised in the difference chart 6d. Best agreement with the numerical analysis, i.e. for both days and, therefore, also for the meteorological development is obtained using MSU retrievals only. The agreement is within the limit defined by the ECMWF's and the NMC's numerical analysis (Fig. 7). Both, the southeastward displacement of the trough and the thickness increase to the west are well reflected. We emphasize once again that, strict-
Fig. 4: 500/1000 hPa thickness chart of 4 March 1982, 1200 UTC for region D17 according to a) ECMWF numerical analysis
b) NMC of the GDR numerical analysis
c) HIRS data only
d) HIRS plus MSU data
e) MSU data only
Fig 5: As for Fig. 4, but for 5 March 1982, 0000 UTC
Fig. 6:
Thickness changes (5 March - 4 March) of the 500/1000 hPa layer in the region D17 according to

a) the ECMWF numerical analysis
b) the NMC of the GDR numerical analysis
c) HIRS data only
d) HIRS plus MSU data
e) MSU data only
Fig. 7: Difference charts of 500/1000 hPa thicknesses, NMC minus ECMWF numerical analysis (top), NMC analysis minus analysis from MSU data (bottom)

a) 4 March 1982, 0000 UTC

b) 5 March 1982, 1200 UTC
Fig. 7c: Differences of 5 minus 4 March. Zero and +4 gpdm differences were not unambiguous for the numerical analyses and were, therefore, partly not drawn.

ly speaking, verification is not possible and that the impact of retrieval on meteorological analysis and forecasting must be evaluated by means of appropriate numerical models. To shed some more light on the characteristics of TOVS retrievals Fig. 8 presents the 500/1000 hPa thickness of one single scan line, the most southern scan line of D17. Given are the first guess (+++), the NMC numerical analysis (---), and retrievals of HIRS (---), HIRS plus MSU (---), of limb corrected MSU (---), as well as of MSU measurements assuming a ground emittance of \( \varepsilon = 1 \) (\( \varepsilon \rightarrow \)) and \( \varepsilon = 0.5 \) (---).

The numerical analysis shows a sharp thickness decrease up to spot number 8 with 5360 gpm and a steady increase afterwards. The HIRS-only-retrievals are randomly grouped around the first guess with large thickness differences between neighbouring spots. Too large deviations from the first guess are attributed to the cloudiness estimates in accordance with the results of numerical experiments (Güldner and Spänkuch 1989). Information on mesoscale phenomena can hardly be extracted. The addition of the MSU information to the HIRS channels does not eliminate the large discontinuities from spot to spot but indicates roughly the thickness variation with its minimum. The MSU retrievals are most similar to the numerical analysis, large discrepancies between neighbouring spots do not occur and the thickness minimum is well reflected. The thickness differences between retrievals with \( \varepsilon = 1 \) and \( \varepsilon = 0.5 \) are a function of the scan angle and can be as great as 2 gpdm. The thickness retrievals with limb-corrected MSU data are similar but they
Fig. 8: 500/1000 hPa thickness along a scan line
are higher by about 5 to 7 gpdm due to the additional atmospheric attenuation having been taken into account.

The experiences with the ALPEX data confirm, by and large, the results of the numerical experiments. This single case study is, however, not suitable to draw any definite conclusion. The outcome can only be taken as an indication to the information content of the TOVS subsystems. It is, however, worth mentioning that the most reliable product has been achieved by measurements only from MSU which needs by far the least troublesome numerical data handling. The noise in the HIRS retrievals can only be eliminated by directly taking into account the horizontal correlation (Ledsham and Staelin 1978), or by clear-column radiance-calculations including horizontal correlation as proposed by Prata (1985). Prata's proposal does, however, not reduce the numerical expenditure but transforms the necessary calculations only in the preparatory phase.

We conclude this Chapter with Table 1 where for D17 the rms $\sigma(\varphi)$ and systematic deviation $E(\varphi)$ from the 'solution' (NMC numerical analysis) are compiled for thicknesses $\rho_i/1000$ hPa at standard pressure levels $\rho_i$. Given, too, are $\sigma(\varphi)$ and $E(\varphi)$ of the first guess for both days. There is no gain of HIRS data against the first guess for 850/1000 hPa and 700/1000 hPa thicknesses. MSU data provide already some gain for 700/1000 hPa thicknesses in $\sigma(\varphi)$ as well as in $E(\varphi)$. For $\rho_i = 500$ hPa and 300 hPa we find considerably smaller random and systematic deviation by a factor of 2 to 3 from the numerical analysis for MSU data than for HIRS data. Using both data sets (HIRS plus MSU) we obtain $\sigma(\varphi)$ and $E(\varphi)$ values between HIRS and MSU results, probably caused by adaptation.

III. CONCLUSIONS

Although only a very limited TOVS data set of total spatial resolution (spot by spot) was used for the present investigation some useful experiences for a data-rich geographical region were made. The most promising result is the similar information of the current microwave sounding unit (MSU) for 500/1000 hPa thicknesses compared with the numerical analysis that uses solely conventional meteorological observations. Due to insufficient information on the lower atmospheric layers in MSU data this is not true for the 850/1000 hPa and 700/1000 hPa thicknesses. In account of the better vertical resolution obtained by adding some more microwave channels of improved spectral resolution, some improvement is expected from the Advanced Microwave Sounding Unit AMSU of the NOAA polar orbiting satellites soon in operation. As cloudiness does not severely disturb the radiative transfer of microwave radiation, there is no need for cumbersome cloud elimination procedures as in case of temperature sounding with infrared channels. Temperature retrievals of single-spot HIRS measurements are pretty noisy and need, additionally to
Table 1: Mean $E(\sigma \phi)$ and rms deviation $\sigma(\sigma \phi)$ in gpm of estimated layer thicknesses from the NMC numerical analysis $\phi_{AN}$ $\phi$ above 1000 hPa for standard pressure levels $p_i$ using different TOVS measurements. Region D17 for 4 and 5 March, 1982. The corresponding deviations of the first guess $\phi_{FG}$, are also included.

<table>
<thead>
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<th>$p_i$ (hPa)</th>
<th>4 March 1982, 1200 UTC</th>
<th>5 March 1982, 0000 UTC</th>
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<tr>
<td></td>
<td>$\phi - \phi_{AN}$</td>
<td>$\phi_{FG} - \phi_{AN}$</td>
</tr>
<tr>
<td>850</td>
<td>19.5</td>
<td>13.3</td>
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<tr>
<td>700</td>
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<td>32.2</td>
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<td>500</td>
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<td>850</td>
<td>21.8</td>
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<td>300</td>
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<td>HIRS plus MSU</td>
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<td>850</td>
<td>17.3</td>
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the cloud elimination, spatial filtering. This spatial filtering can mask existing subsynoptic features. The HIRS measurements with their high spatial density do not yield analysis products of reliable mesoscale structure as the horizontal resolution power of sounding systems is intimately related to their vertical resolution power. For passive sounding systems the vertical resolution power is, however, generally limited. Mixing of MSU and HIRS measurements is anticipated to supply best accuracy but further efforts are needed to improve adaptation.

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