INFLUENCE OF THE TOPOGRAPHY OF THE EARTH SURFACE ON VERTICAL SOUNING OF THE TEMPERATURE PROFILE

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1. INTRODUCTION

In 1989, the 3l inversion procedure of the LMD was implemented in the Interactive System for Satellite Data Processing (ISYS) at the Institut für Meteorologie und Klimaforschung (IMK). In this connection, the scientific goal is to derive from satellite data high-quality atmospheric temperature and moisture fields for use in mesoscale models [Chédin et al. 1985b, 1989]. Therefore, the influence of the topography of the earth’s surface on the retrieved temperature profiles was investigated using the 3l inversion procedure [Pfister, 1992].

The mean elevation of the area observed on the surface of the earth represents an important parameter for the inverson procedure. Thus, various parameters influencing the inversion process are controlled by the ground pressure via the mean elevation. To avoid errors when interpreting the measured radiance values of the atmosphere and the surface of the earth in the radiative transfer calculation assuming a plane surface, a more detailed characterization of the topography of the earth’s surface is required too.

Originally, a digital elevation model with a resolution of 18×18 km² was used in the 3l inversion procedure. Hence, a sufficiently precise mean elevation and geomorphometric parameters for the description of surface roughness are not provided. For an objective analysis of a more precise mean elevation and the derivation of roughness parameters, a new digital elevation model with a resolution of 500×500 m² has been implemented into the 3l inversion procedure. Using a geomorphological procedure [Hobson, 1967] and the slightly modified topography rejection test [Pfister, 1992], areas with a high surface roughness can be localized and excluded before grouping the HIRS/2 spots into the 3l boxes [Pfister, Olesen, 1991].

2. CHARACTERISTICS OF THE SELECTED OVERPASSES

Two appropriate SATMOS NOAA-10 overpasses were chosen for the case studies, to assess the influence of elevation (NOAA-10, orbit: 18822, May 3, 1990, 7:34 UTC and orbit: 18857, May 5, 1990, 18:14 UTC). In both cases the area, for which the DLMS-DTED (Digital Land Mass System - Digital Terrain Elevation Data) were available, was covered completely by the two overpasses. The sub-satellite track passed centrally over this area. Thus, a relatively high differentiation of the topography of the earth could be
reached (up to 12 HIRS/2 spots/box). Besides, the two passes showed small cloudiness only and a convenient position of the calibration area.

Central Europe was influenced by a high pressure situation with the center over the North and Baltic seas. Only few convective clouds could be localized over Brittany and southeast France in the second case study. Some low clouds could be found in the southern part of the North Sea.

3. PROBLEMS ARISING WHEN INTERPRETING THE RESULTS

To verify the influence of a physical quantity, normally independent data are used. In this scientific study, no independent data are available.

The verification of the results with analysis and radiosonde data from the ECMWF could not be performed, because the analysis data were only available on a grid, with a spacing of 2.25 degree (~250 km). The analysis of the geopotential and the elevation on the grid nodes respectively only shows a schematic shape of topographic structures (flat land, mountains etc.). Fine structures in topography could not be resolved. Even the possibility to verify the results with radiosonde data could not be taken into account, as no radiosonde data were available in the regarded area at the time of the overpass (7:34 and 18:14 UTC).

Moreover, no studies were performed with synthetic elevation data, because the influence of the topography could only be modeled in a restricted manner. It is difficult to transfer the results to real case studies.

The examination of the results can only help to make the changes in the results plausible. For this, significant changes in the temperature profile will be connected with topographic structures of the earth surface and the topography rejection test. The temperature profiles of the standard 31 procedure and the modified 31 procedure will be compared, to evaluate the caused differences.

4. CASE STUDY ON THE SOUTHERN SIDE OF THE ALPS

The investigated 31 box (orbit: 18857, secant: 12, box: 67, 45.50° N, 10.34° E) is located on the southern side of the Alps over the town of Brescia in the north of Italy. The box partly covers the Alps and partly the plain of the Po river. The elevation determined by the standard 31 procedure is 920 m. The topographic situation of the box with the HIRS/2 spots is shown in Fig. 1. The box was declared as 'cloud-free'. By using the topography rejection and the variance test [Wahiche, 1984], the mean elevation was reduced from 920 m to 123 m. Thus, the percentage of the used spots decreased from 50% to 17%. The geographic position of the retrieval was slightly changed by the modified 31 procedure.

The used HIRS/2 spots and the corresponding elevation matrices of the box are shown in Tab. 1. The number of the mean layer temperature could increased from 37 to 39. Figure 2 shows the corresponding guess and retrieved profiles before and after the
modification of the 3l procedure. The resulting differences in the temperature profile between the standard- and the modified 3l procedure are represented in Fig. 3 for clarification.

By the significant reduction of the mean elevation of about ~800 m, the surface pressure increased from 904.3 to 997.2 hPa. With this new surface pressure, a new initial guess was determined by pattern recognition in the TIGR data set. In addition a new regression data set was extracted from TIGR for the correction of the influences of water vapor and surface emissivity (HIRS/2 chn. 8,18,19) as a function of the new mean elevation [Chédin, Scott, 1985a].

An increase in temperature in the whole troposphere after the modification (Fig. 3) is clearly visible. This trend can also be found in the HIRS/2 and MSU channels, which contribution functions peaking in the tropospheric range. The surface temperature was also increased by 3.4 K after the 3l modification.

A look at the resulting geographic position of the remaining HIRS/2 spots and the corresponding representative elevation assigned to the 3l box will make the unsatisfactory compromise in the standard 3l procedure evident. The geographic position of the retrieval determined by the standard 3l version was located on the southern side of the Alps. With the new computed elevation (123 m, before 920 m) and with the topography rejection test, the evaluated geographic position of the retrieval is now shifted in the plain of the Po river.

By use of a more characteristic physical data set the final retrieval describes the situation corresponding to the geographic position more reliably.

5. CASE STUDY ON THE NORTH SEA

By using the new elevation model, the possibility to identify coastal areas will be significantly improved. Thus, the surface property 'sea' or 'land' can be better assigned to the 3l box.

The box examined is located exactly on the coastline (orbit: 18857, secant: 10, box: 47, 52.56° N, 4.93° E). For this case study, it should be noted that it is difficult to detect the coastline accurately (Netherlands), because the coastal area is coarse dissected and parts of the land surface are below the main sea level. In the standard 3l procedure, the surface property of the box will be classified as 'land' (43% of water) compared with the modified 3l procedure where the surface property of 'sea' is assigned. If the threshold of 70% of water in the whole box (i.e., all HIRS/2 spots are taken into account!) will be exceeded, the box will be classified as 'sea'. By changing the surface property, also different emissivities are taken into account. The topographic situation of the box is shown in Fig. 4.

Concerning the small change in elevation from 0 to 1 m, the originating differences in the temperature profile could only result in a modification of the surface property. In accordance with the surface property different thresholds are set in the cloud detection.
algorithm [Wahiche, 1984; Chédin, 1988]. In this case study, the box was declared as ‘clear’ in both 3I versions. By the use of the new elevation model, the number of HIRS/2 spots used for the inversion process could be increased by one spot, i.e., from 17% to 25%, caused by the changed surface property. In Tab. 2, the used HIRS/2 spots and the corresponding elevation matrices of the box are shown. The modified number of HIRS/2 spots in the box causes a new geographic position of the final retrieved profile as well as different brightness temperatures, which are included in the inversion process. In this case study, all of the 39 possible mean layer temperatures are computed. The change of the surface pressure is unimportant. A new guess profile from the TIGR data set was determined corresponding to the new brightness temperatures and the changed surface property. The channel used for the inversion process in the lower troposphere shows a temperature trend similar to the retrieval profile. A distinct temperature decrease could be detected in the lowest troposphere. This was a result of the new surface property assigned to the 3I box and the used brightness temperatures. The original and the modified guess and retrieval profiles are shown in Fig. 5. The differences between the retrieval profiles are represented in Fig. 6.

The brightness temperatures in HIRS/2 channel 14(950 hPa) and channel 6(800 hPa), used for the inversion process to calculate the temperature profile, decreased by 0.5 K and 0.16 K respectively. Also the used brightness temperature of the MSU channel 2(700 hPa) decreased by 3 K. Determine the surface temperature, the same decreasing trend in the used brightness temperatures of HIRS/2 channels 8(corrected for H2O, surface) and 10(900 hPa) can be found (chn.8 1.6 K, chn. 10 0.9 K) [Wahiche, 1984], [Flobert, 1988]. Thus the newly computed surface temperature for ‘sea’ decreased by 3 K.

Also in this case study, the positive impact of the elevation model can be noticed. The results ‘better represent reality.

6. CONCLUSIONS AND FURTHER OUTLOOK

Application of a high-resolution digital elevation model in the 3I inversion procedure must be judged favorably in any case, as resolution of fine topographic structures is impossible with the original elevation model (resolution ~18 km). As a result of the increased accuracy in the determination of the elevation of the HIRS/2 spots, a more precise and more representative mean elevation characterizing the area observed can be assigned to the 3I box following the topography rejection test, cloud and variance tests. In spite of a small change of elevation of a few meters only, the calculated retrieval profile can be modified using other coefficient data sets (correction of the influences of water vapor and emissivity, cloud tests, etc.). Excessive elevation values like those obtained with the old elevation model are avoided.

An analysis of the impact of the topography on the 3I process of the two overpasses is shown in Tab. 3 and 4. The two overpasses characterized by a different location of the calibration areas.
In more than half of all possible 3I boxes covering the DTED area, the mean elevation was determined without rejection of the HIRS/2 spots depending on the geographic position of the boxes. Using the topography rejection test, one or several HIRS/2 spots were eliminated from about 40% of the boxes observed due to the roughness of the surface of the earth. Depending on the position of the overpasses, up to 6% of the boxes were singled out completely by means of the topography rejection test. Most of these boxes were found to be located above the Alps (Tabs. 3 and 4).

Due to the more precise elevation of the box the number of mean layer temperatures calculated by the 3I procedure was adapted. The maximum changes are found to occur predominantly in the periphery of mountains. The surface pressure is calculated either from the mean elevation of the box or from the forecast data. Hence, the accurate determination of mean elevation is of crucial importance, as the surface pressure considerably affects the selection of an initial guess from the TIGR data set and, thus, of the new guess profile.

Since the TIGR data set contains the actual 'physical' a priori information, it is reasonable to determine the initial guess for the sounding process as precisely as possible. For more than 32% of all boxes, another atmospheric situation was taken from the TIGR data set using the digital elevation model. This percentage seems to be small, however, it must be kept in mind that a pressure grid of 19 possible surface pressures is available for the determination of the initial profile. The guess profile and the retrieved profile of the middle troposphere were found to differ by up to 5 K under cloud-free conditions, i.e., 'cloud-free' before and after 3I modification. When approaching the upper troposphere, these differences are reduced. At higher elevations, the computed profile shifts towards the warmer side for compensation. In the lower troposphere, i.e., at ground level, an analog tendency towards compensation is observed.

Due to the influence of the new elevation model or the topography rejection test, atmospheric situations can be found which were characterized as 'cloudy' in the modified 3I process and as 'cloud-free' in the standard 3I procedure. This may be attributed to the cloud tests, which were controlled by various regression coefficients. Visual comparisons with the AVHRR satellite recordings do not help to find out in an unambiguous manner, which method produces the better results.

By means of the new digital elevation model, the coastal areas can also be determined more precisely. Hence, the surface property of 'sea' or 'land' can be better assigned to the 3I box. This is also of crucial importance for the selection of the guess profiles in the TIGR data set (surface emissivity).

As a result of the topography rejection test with the separation of those HIRS/2 spots that indicate a high variation of the topographic structure of the surface and due to the more realistic characterization of the earth surface by the new elevation model, the geographic position of the retrieval within the box observed tends to be shifted towards an area of smaller elevation.

To sum up, it must be noted that the application of a high-resolution digital eleva-
tion model considerably supports the inversion process by means of the more precise mean elevation and the topography rejection test in a topographically structured area [Pfister, 1992]. By integration of this independent physical information, the results of the 3l procedure are improved to a small extent only. In some cases, however, significant improvements are achieved in comparison to the desired accuracy of temperature profiles of 1 K.

7. REFERENCES

Chédin, A.

Chédin, A., Scott, N.A.

Chédin, A., Scott, N.A., Anderson, E., Flobert, J.F.

Chédin, A., Scott N.A., Wahiche, C., Moulinier, P.

Flobert, M.J.-F.
1988, Analyse tridimensionale de la structure de l’atmosphère par sondage vertical satellitaire, Interêt pour la prévision du temps, Thèse de docteur, Université Paris VI.

Hobson, R.D.

Pfister, A.
Pfister, A., Olesen, F.-S.

Wahiche, C.
1984, Contribution au problème de la détermination de paramètres météorologiques et climatologique à partir de données fournies par les satellites de la série TIROS-N, Impact de la couverture nuageuse, Thèse de docteur-ingénieur, Université Paris 7.
Figure 1: Case study on the southern side of the Alps: The figure shows the topographic position of the 3l box (orbit: 18857, secant: 12, box: 67, 45.50° N, 10.34° E), which partly covers the Alps and partly the plain of the Po river. The numbers below the HIRS/2 spots are the HIRS/2 line and spot numbers. The HIRS/2 spot (68,38) is located in the northern part of lake Garda, the HIRS/2 spot (69,38) in the southern part. The bluish and violet colored HIRS/2 spots are spots, singled out by the topography rejection test. These spots are not taken into account for further processing. The HIRS/2 spots rejected by the variance test are not explicitly shown. The inversion procedure takes into account two HIRS/2 spots only ((69,35),(69,37)), the position of which is located in the plain of the Po river.

Figure 2: Case study on the southern side of the Alps: Guess profiles M and the corresponding retrieval profiles R before and after the modification of the 3l procedure (orbit: 18857, secant: 12, box: 67). The two profiles above show the situation before, the two profiles below show the situation after modification of the 3l procedure. The geographic position of the profiles in the diagram is given on right of the type of the profiles (M,R). On the basis of the significant reduction of the elevation, a new guess profile was determined from the TIGR data set. The result is a new computed temperature profile, which is considerably warmer.

Figure 3: Case study on the southern side of the Alps: Temperature differences between the retrieved profiles of the standard and the modified 3l procedures (orbit: 18857, secant: 12, box: 67). The use of the new elevation model causes a significant increase in temperature in the middle troposphere (1 K). The mean elevation of the box is now 123 m in comparison to 920 m. For more details see Fig. 2.

Figure 4: Case study on the North Sea: The figure shows the topographic situation of the 3l box (orbit: 18857, secant: 10, box: 47, 52.56° N, 4.93° E). In the standard 3l procedure, the surface property of the box will be classified as 'land' (43% of water), compared with the modified 3l procedure surface classified as 'sea' (89% of water). The newly determined elevation is changed from 0 m to 1 m. For more details see Fig. 1.

Figure 5: Case study on the North Sea: Guess profiles M and the corresponding retrieval profiles R before and after the modification of the 3l procedure (orbit: 18857, secant: 10, box: 47). The reduction of temperature in the lowest troposphere can clearly be seen, caused by a change of the surface property of the box ('land' > 'sea'). For more details see Fig. 2.

Figure 6: Case study on the North Sea: Temperature differences between the retrieval profiles R of the standard and the modified 3l procedures (orbit: 18857, secant: 10, box: 47). The reduction of temperature in the lowest troposphere (up to ~0.9 K) it clearly visible. It is caused by the change of the surface property of the 3l box and the corresponding brightness temperatures. For more details see Fig. 2.
PFISTER, A. ET AL. INFLUENCE OF THE TOPOGRAPHY OF THE EARTH SURFACE ...

Table 1: Case study on the southern side of the Alps: The two boxes located on the left show the used HIRS/2 spots and the corresponding elevation matrix, used by the standard 31 procedure (orbit: 18857, secent: 12, box: 67). The boxes on the right show the remaining spots and the new elevation matrix used by the modified 31 procedure. In case of the standard 31 procedure, 50% of the HIRS/2 spots will be used, in the modified 31 procedure only 17%. The remaining HIRS/2 spots are singled out by the variance and the topography rejection test. The computed mean elevation was changed from 920 m to 123 m. The elevation is given in m.

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Table 2: Case study on the North Sea: The two boxes located on the left hand side show the used HIRS/2 spots and the corresponding elevation matrix used by the standard 31 procedure (orbit: 18857, secent: 10, box: 47). The boxes on the right hand side show the remaining spots and the new elevation matrix used by the modified 31 procedure. By using the new elevation model, the number of spots could be increased by one spot from 17% to 25%. The remaining spots were rejected by the cloud tests. The elevation was changed from 0 m to 1 m. Elevations are given in m. The explanation of the symbols is given in Tab. 1.

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<td>(58.63%)</td>
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<td>Number of completely rejected boxes by the topography rejection test</td>
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Table 3: Analysis of the high-resolution topography for orbit: 18822, May 3, 1990, 7:34 UTC. For more details see section 6.

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<td>Number of completely rejected boxes by the topography rejection test</td>
<td>21</td>
<td>(6.27%)</td>
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Table 4: Analysis of the high-resolution topography for orbit: 18857, May 5, 1990, 18:14 UTC.

361
Fig. 1

Fig. 4
Fig. 2

Fig. 3
TECHNICAL PROCEEDINGS OF
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