Improvements to the 2m temperature forecasts

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Introduction

Many users of ECMWF products have reported a severe cold bias in the 2m temperature forecasts in winter. The problem was particularly serious in the winter of 1995/1996, mainly as a result of the anomalous flow circulation with a persistent high pressure area over continental Europe. The standard verification with SYNOP observations has shown that the problem was more pronounced in areas below freezing than in areas above zero, as illustrated in Fig. 1 for Berlin. The latter suggests a possible link between the model bias and soil moisture freezing, a process that is currently not represented in the model. Daily verification with SYNOP data also shows that the night time temperatures are too low in all seasons, and correspondingly the diurnal cycle is too large.

The Research Department has investigated this problem extensively making use of operational and non-operational observations. With the help of tower observations covering the lowest two model levels (Cabauw, The Netherlands) it could be shown that for weak winds, a steep inversion develops in the model between the lowest model level (30m above the surface) and the layers above (140m and up). Such shallow inversions, with cold air near the surface and warm air aloft, do occur, but the model tends to produce them more frequently and with too large temperature gradients. Once such an inversion has formed, vertical diffusion by turbulence is suppressed and the lowest model level is completely decoupled from the upper air.

The second result from the diagnostic study is that the soil over continental areas tends to cool excessively. The soil temperature observations as received from some member states have been very useful in diagnosing the nature and magnitude of the problem. An example is given in Fig. 2 for an area in Germany. The comparison of 20 cm deep temperature observations with operational 24 hour forecasts clearly indicates the cold bias in the model, and it also shows the levelling-off of the observations at 0°C, whereas the model soil temperatures do not feel the 0° thermal barrier. It should be remembered that the land surface temperatures in the current scheme are the result of heating and cooling provided by the atmospheric model during the first guess computations (6 hour forecast). The seasonal evolution of the soil temperatures is determined by the model and by the seasonal evolution of the atmosphere during data assimilation, and no soil temperature observations are used directly.

Two conclusions emerged:

(i) The vertical diffusion of heat is too weak in stable situations allowing for too much decoupling between atmospheric and soil temperatures, and

(ii) soil moisture freezing, which was not represented in the model, plays a rather important role in the evolution of soil temperatures in winter. The latter is suggested by the nature of the 2m temperature errors in Fig. 1, but it is also rather obvious from time series of soil temperature observations in Germany (Fig. 2).

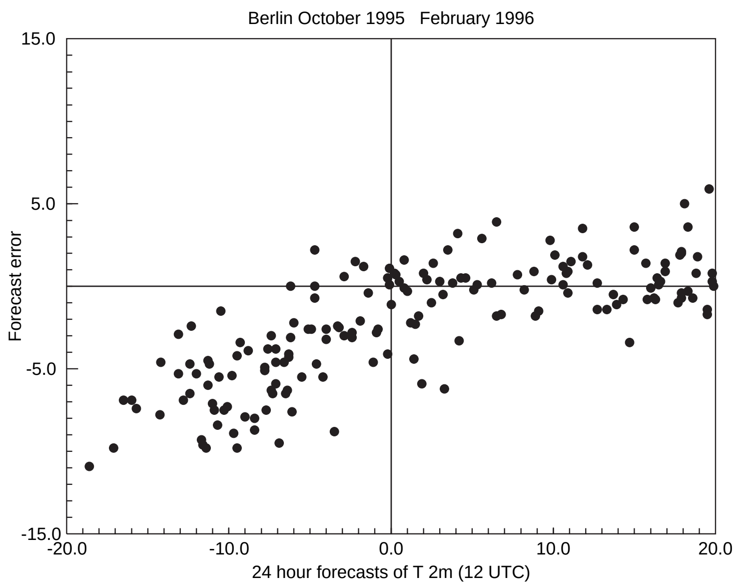

Fig. 1 Errors of 24 hour forecasts of 2m temperature at Berlin as a function of temperature.

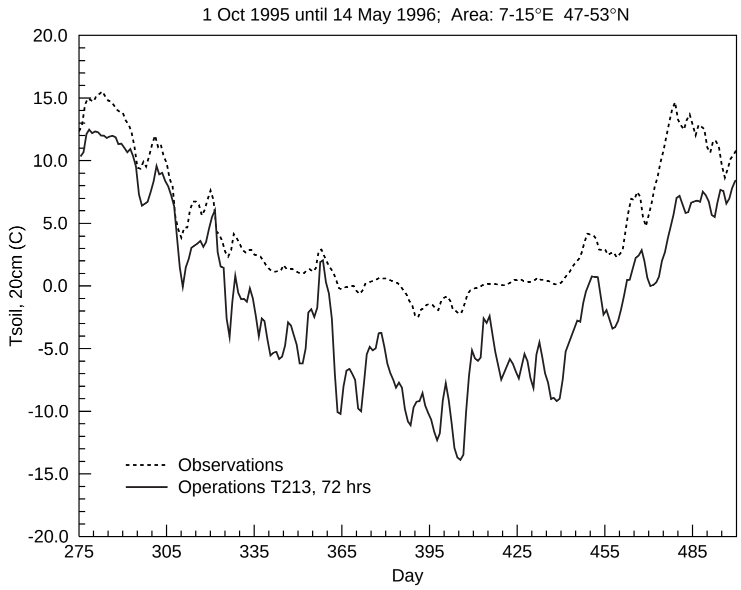

Fig. 2 Time series of observed soil temperatures (20 cm deep) compared with 72 hour forecasts of the operational ECMWF model in an area over Germany. The time axis is day number counted from 1-1-95; day 275 corresponds to 1 October 1995 and day 500 corresponds to 14 May 1996. The area includes about 100 SYNOP stations.

Model changes

In order to improve the model, a package of three changes has been prepared for operational implementation. It consists of:

(i) increased turbulent diffusion of heat in the stable boundary layer,

(ii) introduction of soil freezing, and

(iii) increased skin layer conductivity.

The increased turbulent diffusion spreads the surface cooling over a deeper atmospheric layer leading to less cold surface temperatures, the soil freezing slows the soil temperature drop near freezing, and the higher skin layer conductivity increases the coupling of the radiative surface temperature with the underlying soil and reduces the amplitude of the diurnal temperature cycle. All three changes have a considerable impact on the near surface temperatures, but soil moisture freezing is the dominant effect as far as the seasonal evolution of soil temperatures is concerned. This is illustrated by a simple calculation, which shows that the amount of energy necessary to freeze/thaw 1 m3 of wet soil, would cool/warm this soil by 49 K if the phase transition was not taken into account.

Effect on seasonal time scales

The changes, discussed above, affect the seasonal evolution of soil temperatures and would need a long data assimilation experiment to test. Such experiments are very demanding on computer resources. As a cheap alternative to data assimilation, long integrations are used at T63 resolution in which the model atmosphere above the boundary layer is relaxed towards the analysis. In this way the synoptic situation of the winter of 1995/1996 could be reproduced realistically with a single long integration. First it was verified that the control run with relaxation towards the analysis, reproduced the cold bias problem and then experiments were carried out with the changes described above. The long experiments at T63 resolution start from 1 October 1995 and finish in May 1996 in order to run through a freezing and melting season.

Results from the long relaxation integrations are shown in Figs. 3 and 4 for an area in Germany. The operational model and the revised model are compared with observed temperatures at screen level and with observed soil temperatures both averaged over the same domain. It is clear that the revised model alleviates the 2m cold bias and that the soil temperature evolution is much closer to the observations. Sensitivity experiments with different parts of the new parametrization have shown that about half of the improvement on the day time 2m temperatures in winter comes from the increased turbulent diffusion; the other half is due to the introduction of freezing. About three quarters of the improvement of deep soil temperatures can be attributed to the effect of soil freezing and the remaining part to increased turbulent diffusion. The skin layer conductivity has no impact on the seasonal temperature evolution, it only affects the night time temperatures and the amplitude of the diurnal cycle.

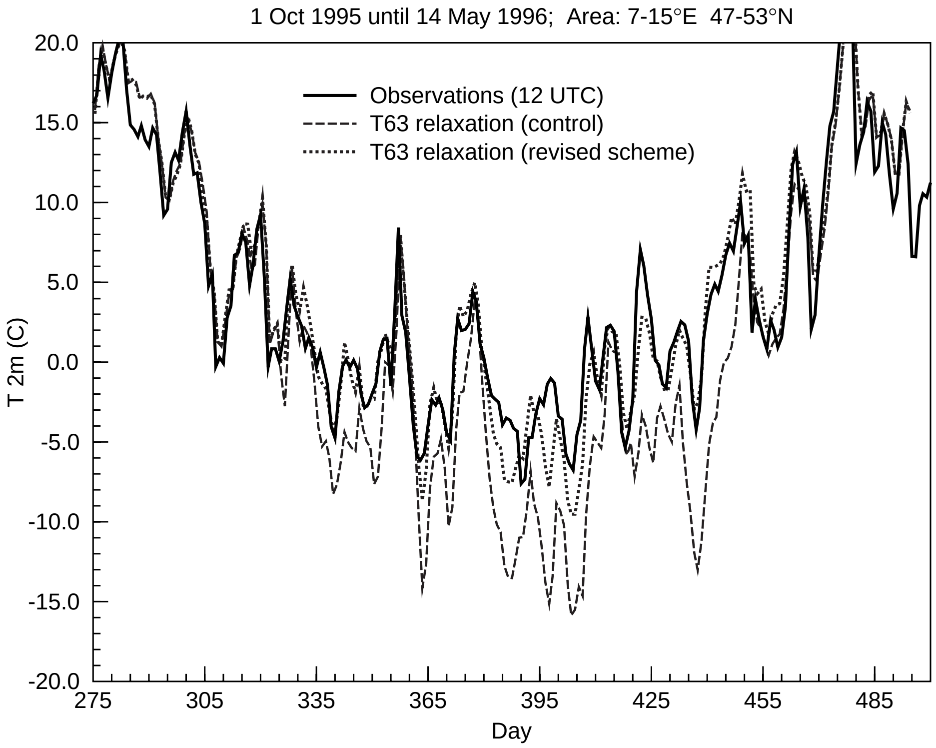

Fig. 3 Area averages (7-15E 47-53N) of 12z temperatures at 2 m from long runs at T63 resolution with relaxation towards the analysis above the boundary layer compared with observations.

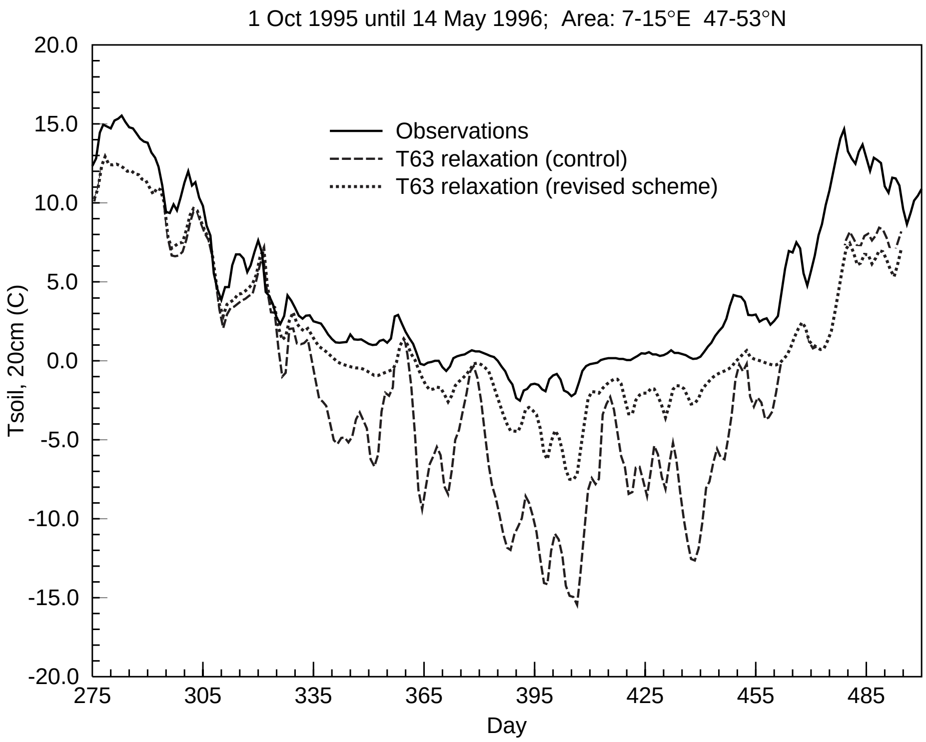

Fig. 4 Area averages (7-15E 47-53N) of soil temperatures (20 cm deep) from long runs at T63 resolution with relaxation towards the analysis above the boundary layer compared with observations.

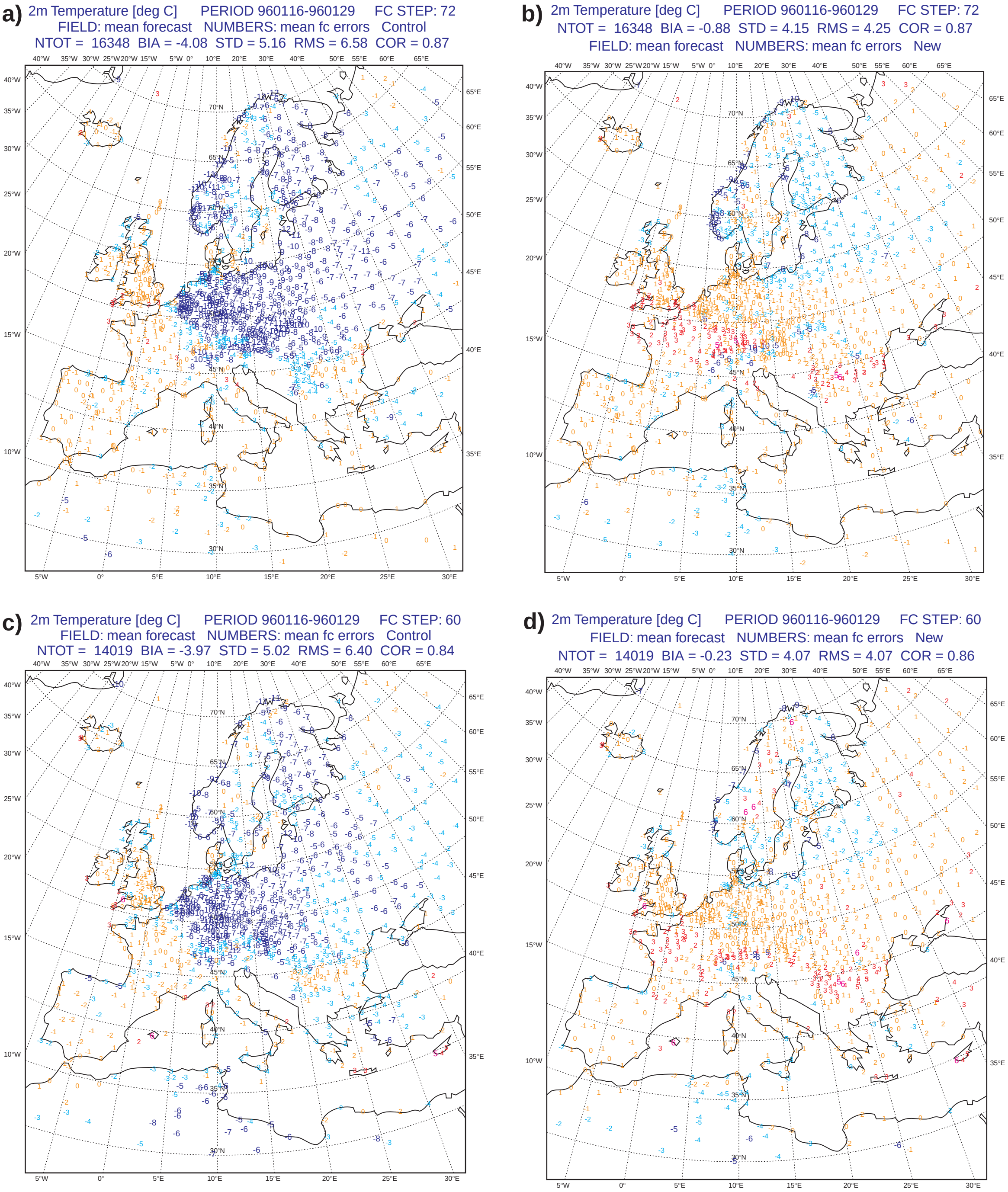

Fig. 5 Temperature errors at the 2 m level averaged over all 72 (a,b) and 60 (c,d) hour forecasts from the data assimilation experiment with the revised model (Figs. b,d) compared with the control experiment (Figs. a,c). The printed numbers are the mean errors at SYNOP stations for forecasts with initial dates between 16 and 29 January 1996.

Effect on 10 day forecasts

In order to investigate the impact on the diurnal temperature cycle and on the day and night time 2m temperature forecasts, data assimilation/forecast experiments were performed at T106 resolution for January and April 1996. Both experiments were initialized with soil temperatures from the long relaxation runs.

The 2m temperature errors are shown for SYNOP locations averaged over 14 consecutive 60 and 72 hour forecasts in January with the old and the new scheme respectively (Fig. 5). A large portion of the systematic errors in operations is eliminated with the new scheme. Area averaged biases are reduced from -4.0° to -0.2° at night and from -4.1° to -0.9° for the midday forecasts. The impact on forecast performance of the large scale weather patterns (e.g. expressed by anomaly correlation of 500 and 1000 hPa fields) is small. This is because the near surface temperature biases are limited to a very shallow layer with negligible implications for the large scale height fields or synoptic developments.

April gives a slightly different picture. The daytime temperature bias over central Europe has already disappeared because of the solar heating. The improvement is mainly in the night time temperatures and in the amplitude of the diurnal cycle. This is illustrated by time series of consecutive 54, 60, 66 and 72 hour forecasts for South and Northern Europe, averaged over all SYNOP locations (Fig. 6). The new scheme reduces the amplitude of the diurnal temperature cycle and produces better night time temperature forecasts. The impact during this season is due to the revised vertical diffusion and the increased skin layer conductivity.

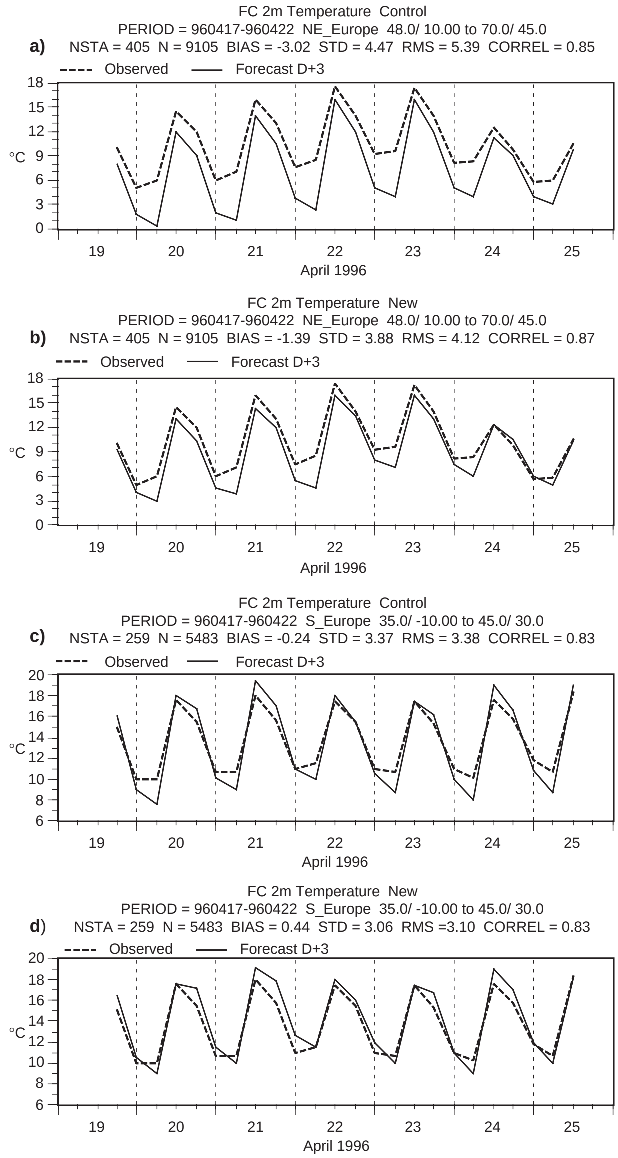

Fig. 6 Diurnal cycles of 54, 60, 66 and 72 hour forecasts (black) compared with observations (red) for North-East Europe (a,b) and Southern Europe (c,d). These are results from T106 data assimilation/forecast experiments that were initialised with soil temperatures from their corresponding T63 relaxation runs. Figs. a and c correspond to the control experiment, Figs. (b) and (d) correspond to the new model version with revised vertical diffusion, soil moisture freezing and increased skin layer conductivity.

Conclusions

The model changes described above will bring a considerable improvement of the 2m temperature forecasts over land in winter and of the night-time temperatures in summer. They were introduced into operation with the migration of the data assimilation/ forecasting system to the new computer (September 1996). The impact on forecast performance of the large scale weather patterns (e.g. expressed by anomaly correlation of 500 and 1000 hPa fields) is small.

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