Operational Verification of Vertical Profiles at DWD

Ulrich Pflüger

Deutscher Wetterdienst, P.O.Box 100465, 63004 Offenbach a.M., Germany

1 Introduction

The operational upper-air verification at the Deutscher Wetterdienst uses all the available radiosonde stations over the integration domain of LM to verify the vertical structure of the forecasts. The parameters considered are geopotential, relative humidity, temperature, wind direction and wind speed.

In addition, so-called multi-level aircraft reports, which are created from aircraft observations from the ascent or descent flight phase are used for verification purposes. Each of the multi-level reports comprises of a group of at least 4 original single-level aircraft reports, which must be within a 20 km radius and a 15 minute interval from the lowest report in the group. Furthermore, the vertical spacing between successive reports may not exceed 55 hPa. These multi-level aircraft reports can be regarded as piecewise vertical profiles, and are treated like radiosonde profiles but considered separately in the verification. The parameters verified are temperature, wind speed and wind direction.

Vertically the atmosphere is divided into bins of 25 hPa below the 800-hPa level and of 50 hPa between the 800-hPa and 100-hPa levels. Above 100 hPa, the bins are bounded by the pressure levels 100, 70 ,50 ,30 , 20 and 10 hPa. Complying with the height, every observation, respectively every forecast increment is allocated to one bin.

2 Annual Mean Profiles of BIAS and RMSE

Figure 1a displays the profile of the annual mean error (bias, left column) and the annual root mean square error (rmse, right column) against all radiosonde data at 00 UTC within the LM domain for different forecast times (analysis, 12h, 24h, 36h, 48h) and different parameters (geopotential, relative humidity, temperature, wind direction and wind speed from top to bottom) for 2003. On the right side of each panel, the number of observations used in each bin is shown as a bar chart.

Figure 1b shows the same illustration but for verification time 12 UTC.

Figure 1c and Figure 1d are like Figure 1a and 1b but for the year 2002.

The comparison of the corresponding figures demonstrates that generally the annual mean profiles of bias and rmse do not change very much between the year 2002 and the year 2003.

The bias of geopotential reduces somewhat for both verification times and for all forecast times, except for the 48 h forecast below 600 hPa. Especially at verification time 12 UTC there is a negative bias of about 2 m in 2003. Changes in rmse are very small too, whereas with longer forecast times a rmse reduction of about 1 m has occurred.

Above 600 hPa, there are some changes in the bias of relative humidity. At verification time 00 UTC, the slight negative bias shifts to a positive bias, and at verification time 12 UTC, the slight positive bias increases clearly. The reduction of rmse of relative humidity above

400 hPa is ascribed to the implementation of a prognostic cloud ice scheme in October 2003. Since then there is a reduction of up to 10 % in the monthly mean profiles. Note that this is partly resulting form the smaller range of humidity values because, in contrast to the old scheme the ice scheme rarely produces relative humidity values close to 100 % at that height.

Between 600 hPa and 300 hPa, there is a slight decrease in the bias of temperature, while below 800 hPa in particular at verification time 00 UTC, the negative bias increases, compared to the year 2002. Rmse of temperature remains predominantly unchanged.

In 2002, the bias of wind direction was close to zero nearly everywhere above 700 hPa but in 2003 a negative bias up to 2 degrees has appeared. The rmse profiles of wind direction remain unchanged.

The bias of wind velocity has the same structure in 2003 as in the year before, but exhibits a slight tendency for a decrease. The rmse of wind velocity has decreased predominantly in the range of tropopause.

3 Time Series of Monthly Mean Profiles of BIAS and RMSE

In order to show both the seasonal and interannual variation of the bias and rmse, time series of the vertical distribution of the monthly bias (left column) and rmse (right column) and rmse are presented in Figure 2 to Figure 9 for each parameter. For lack of space and in favour of a comparison of verification against radiosonde data and verification against aircraft observations, only the verification time 00 UTC for 3 forecast times (analysis, 24 h and 48 h, from top to bottom) is shown. Because aircraft observations are only used below the 250 hPa level, the vertical range of the time series differs from that of the annual profiles in Figure 1a to Figure 1d.

Figure 2 displays the time series of the vertical profiles of the monthly geopotential bias and rmse against radiosonde data. It shows that the relatively small bias below 600 hPa in the annual mean (especially at 48 h forecast in the year 2003, see Figure 1a) has a strong seasonal variation with values less than -10 m in summer and up to +8 m during the rest of the year. Furthermore, the negative bias in summer is coupled with a relatively small rmse.

Figure 3 shows that in 2003 compared to 2002, there is an increase of the positive bias of relative humidity in the middle atmosphere during the autumn and winter months and a slight decrease of the negative bias during summer at forecast times 24 h and 48 h. This can also be seen in the profiles of the annual means as aforementioned. In the lower troposphere below 800 hPa, a positive bias during spring and summer months is found. It was larger in the year 2003 compared to 2002 The aforementioned decrease of rmse of relative humidity above 400 hPa due to the implementation of prognostic cloud ice in October 2003 is also evident in Figure 3.

Figure 4 displays the time series of the vertical profiles of the monthly temperature bias and rmse against radiosondes. Figure 5 is analogous but verifying against multi-level aircraft observations as described before. It is evident that the behaviour of bias and rmse of temperature against radiosondes and against aircraft data in the years 2002 and 2003 is very similar, and there are also no major differences between verification against radiosonde and verification against aircraft data. Compared to both observing systems, the middle troposphere of the LM simulations is to warm in the summer and too cold in the winter, while the lower troposphere is predicted too cold except for December 2002. Also, the rmse of temperature has similar variations with both observing systems, but is about 0.2 K greater in the verification against radiosonde data.

Figure 6 and Figure 7 display the same as Figure 4 and Figure 5 but for the wind velocity. A comparison of Figure 6 left column (bias of wind velocity against radiosondes) with Figure 7 left column (bias of wind velocity against multi-level aircraft measurements) shows in the lower troposphere big systematic differences between the verification against the two observing systems. While the bias against radiosondes is negative below 950 hPa the bias against multi-level aircraft measurements is positive below 850 hPa. The monthly variation of the bias is similar in both cases but the numerical values are shifted. Above 850 hPa a negative bias exists with similar variations in both cases, with the negative bias against aircraft observations being a little bit stronger.

The reason for the difference in the bias at low levels is possibly due to the accuracy of the measurement of wind speed depending on the flight attitude of aircraft. Figure 11 (WMO No. 958, 2003) shows the combined effect of pitch and roll at an airspeed of 150kt. For definition of roll/pitch angle see Figure 10. Thus, with 5 degrees pitch angle and 10 degrees roll angle, a wind vector error of some 2kt (1m/s) can be expected regardless of the true wind vector. At 300kt airspeed, the wind error doubles to 4kt (2m/s). The observation error increases with increasing aircraft roll angle at a given pitch angle. Below 850 hPa, aircraft are turning frequently (large roll angle) and have in parallel the strongest climb and descent rates (large pitch angle). In the LM data assimilation the pitch and roll angles are not yet taken into account, so aircraft measurements with relatively great observing errors may be used and could cause perhaps this behaviour of bias. Below 500 hPa the rmse of forecasts against aircraft observations is about 0.5 m/s larger than that against radiosondes.

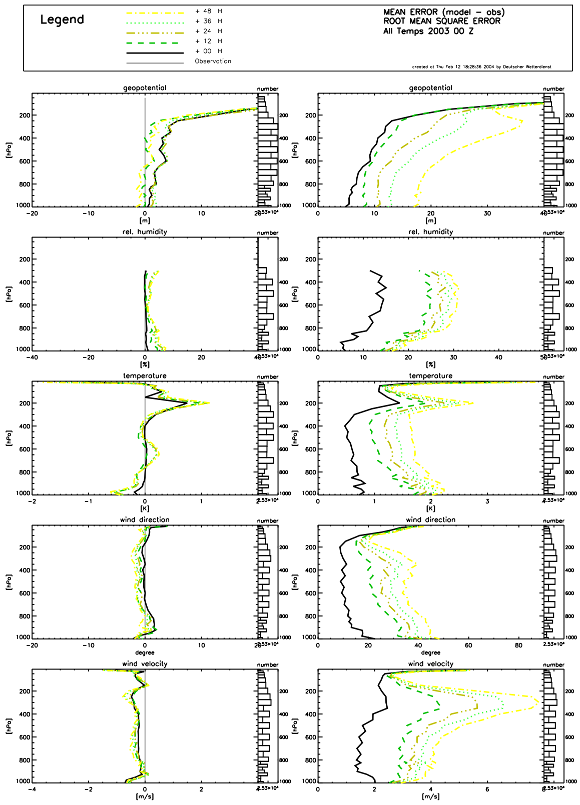
The bias of wind direction forecasts (Figure 8,9 left columns) against radiosondes and aircraft observations does also have different signs below 950 hPa (negative with radiosondes and positive with aircraft measurements), with the bias against aircraft observations being stronger than the bias against radiosondes.

Below 800 hPa rmse of wind direction forecasts (Figure 8,9 right columns) is about 5 degrees lower at verification against radiosondes, whereas above 800 hPa at least at 48 h forecast, rmse is lower at verification against aircraft measurements.

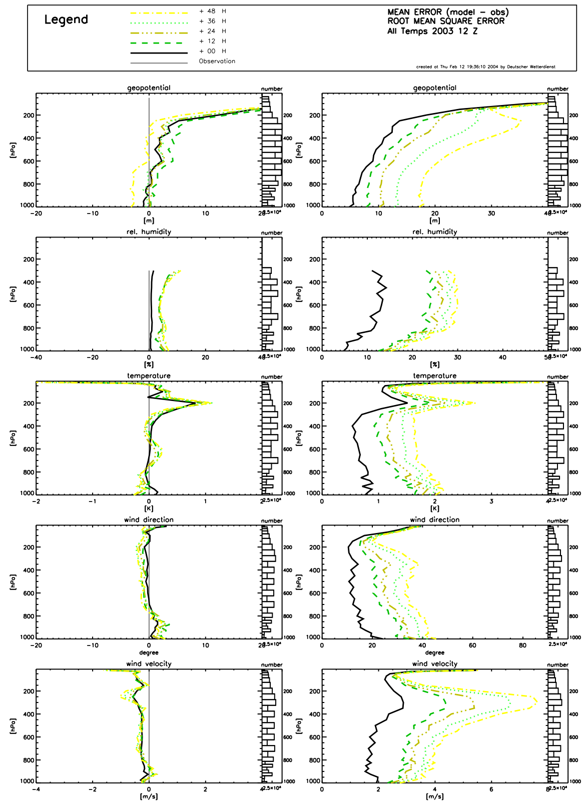
4 References

WMO No. 958, 2003: Aircraft Meteorological Data Relay (AMDAR) Reference Manual.

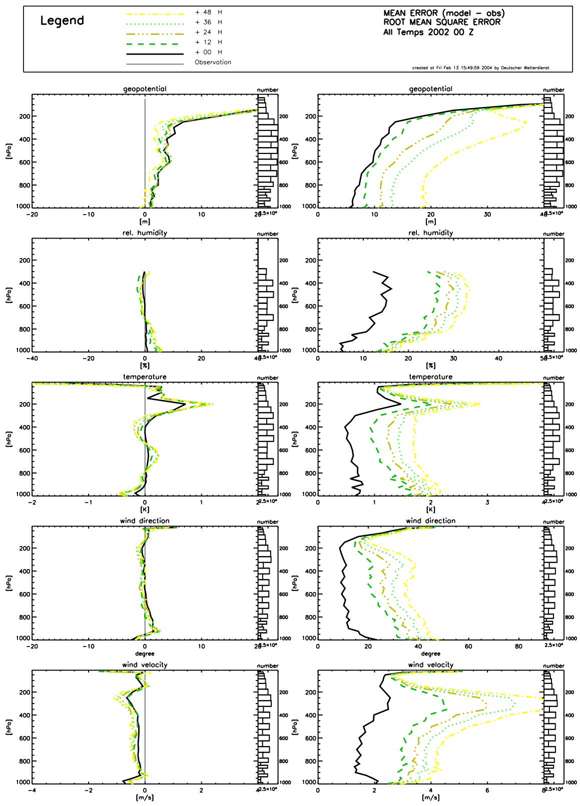
1a: 2003 00 UTC



1b: 2003 12 UTC



1c: 2002 00 UTC



1d: 2002 12 UTC

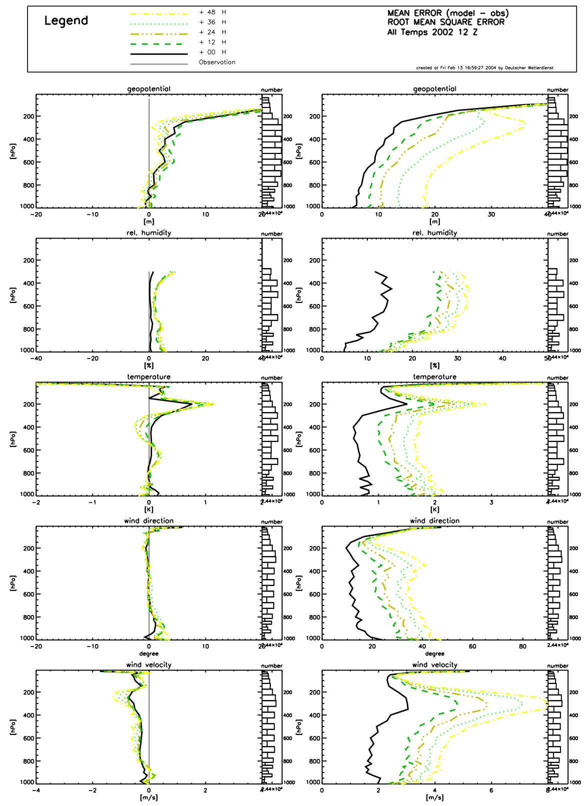


Figure 1: Vertical profiles of annual mean of bias (left column) and rmse (right column) at all radiosonde stations for different forecast times of LM runs at DWD. 1 a: 2003 00 UTC, 1 b:2003 12 UTC 1 c: 2002 00 UTC 1 d: 2002 12 UTC. From top to bottom at each column: geopotential, relative humidity, temperature, wind direction and wind velocity.

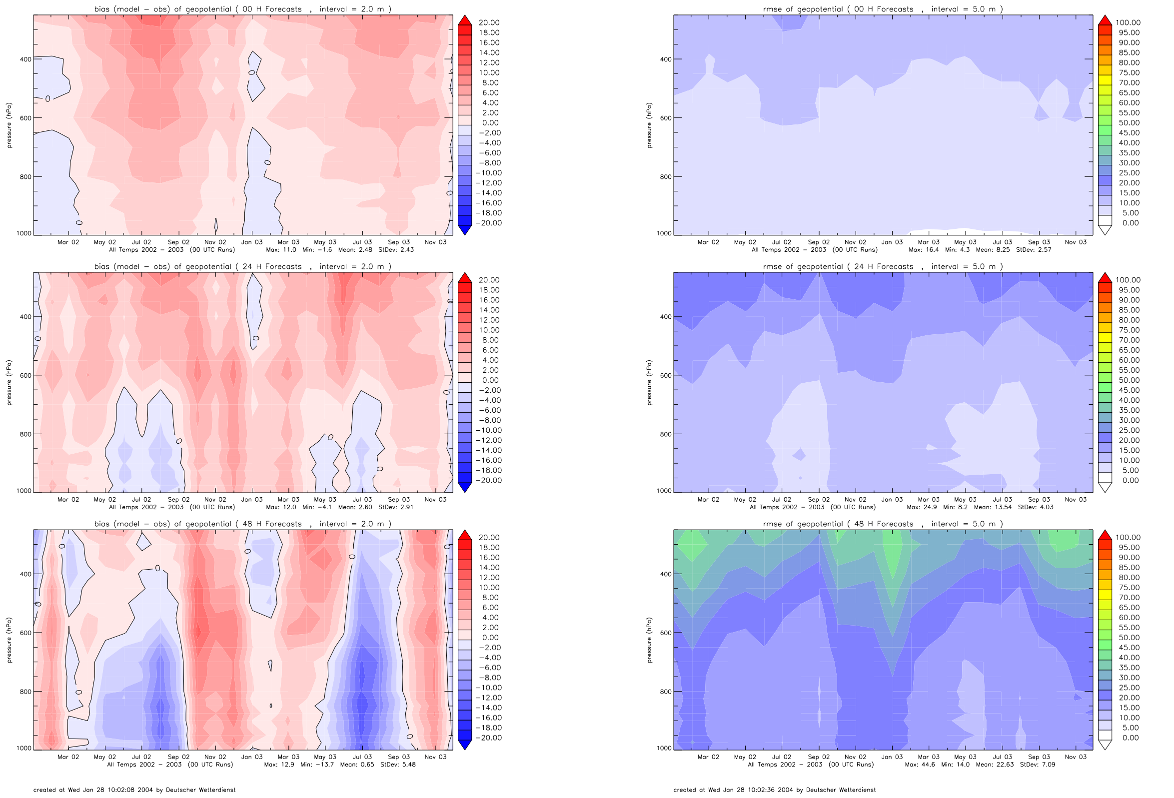


Figure 2: Time Series (January 2002 - December 2003) of gepotential bias (left column) and rmse (right column) against radiosonde data based on monthly mean profiles for 00 UTC LM runs at DWD. From top to bottom: Analysis, 24 h, and 48 h forecast.

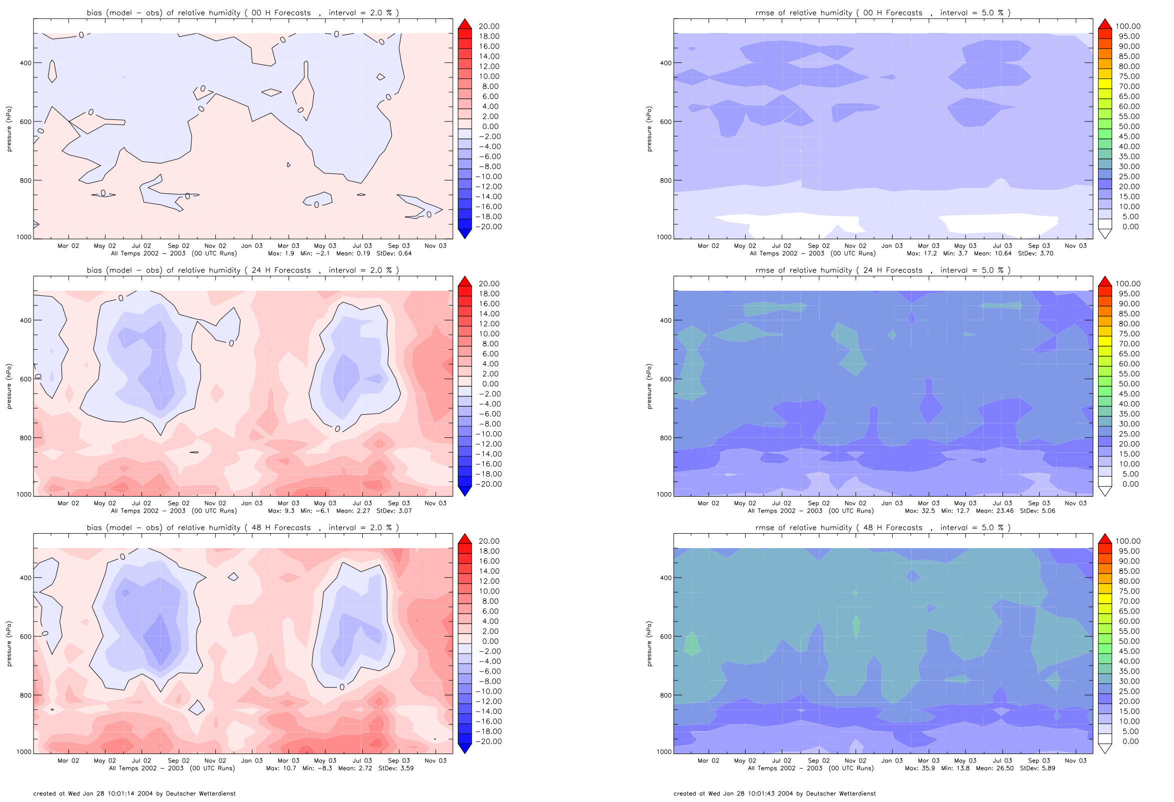


Figure 3: Time Series (January 2002 - December 2003) of relative humidity bias (left column) and rmse (right column) against radiosonde data based on monthly mean profiles for 00 UTC LM runs at DWD. From top to bottom: Analysis, 24 h, and 48 h forecast.

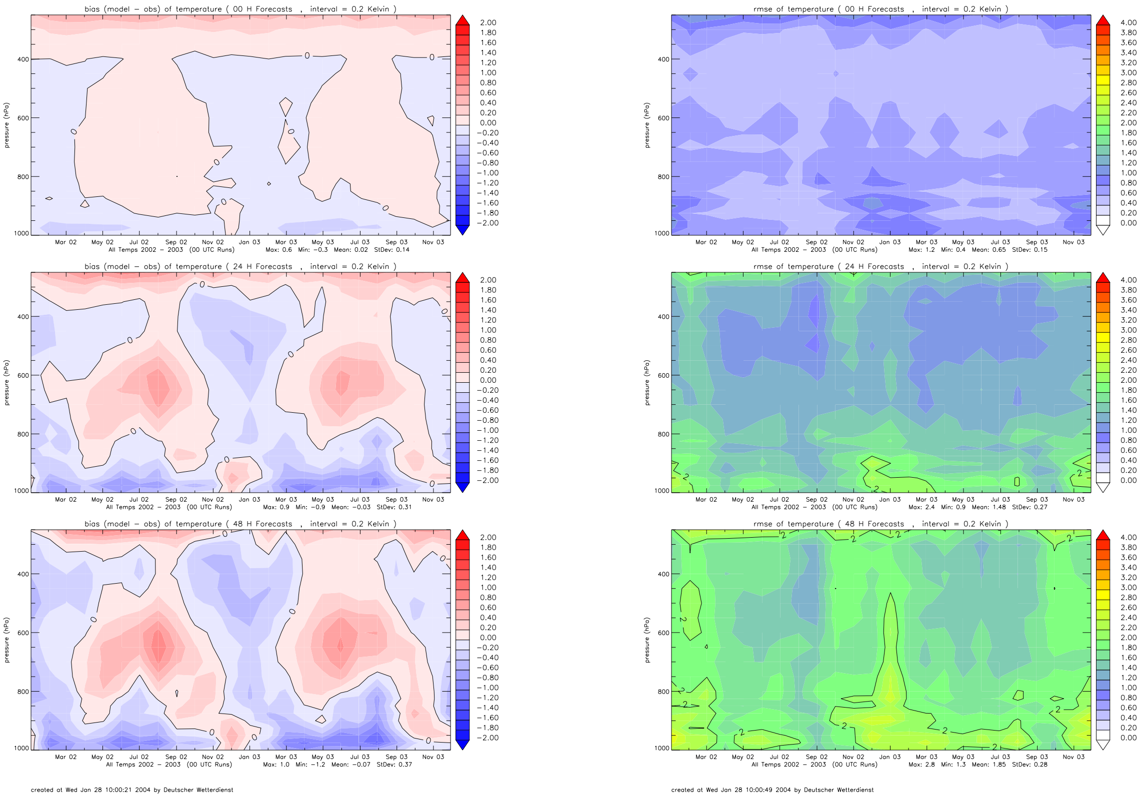


Figure 4: Time Series (January 2002 - December 2003) of temperature bias (left column) and rmse (right column) against radiosonde data based on monthly mean profiles for 00 UTC LM runs at DWD. From top to bottom: Analysis, 24 h, and 48 h forecast.

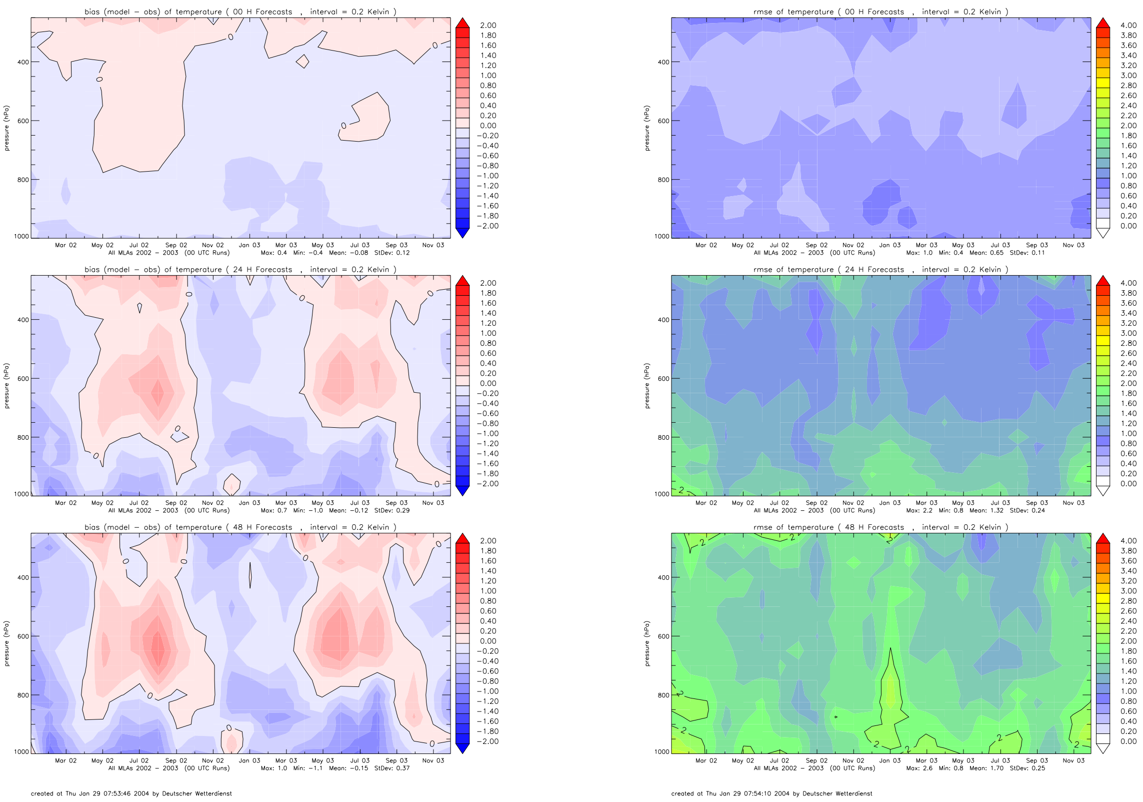


Figure 5: Time Series (January 2002 - December 2003) of temperature bias (left column) and rmse (right column) against aircraft data based on monthly mean profiles for 00 UTC LM runs at DWD. From top to bottom: Analysis, 24 h, and 48 h forecast.

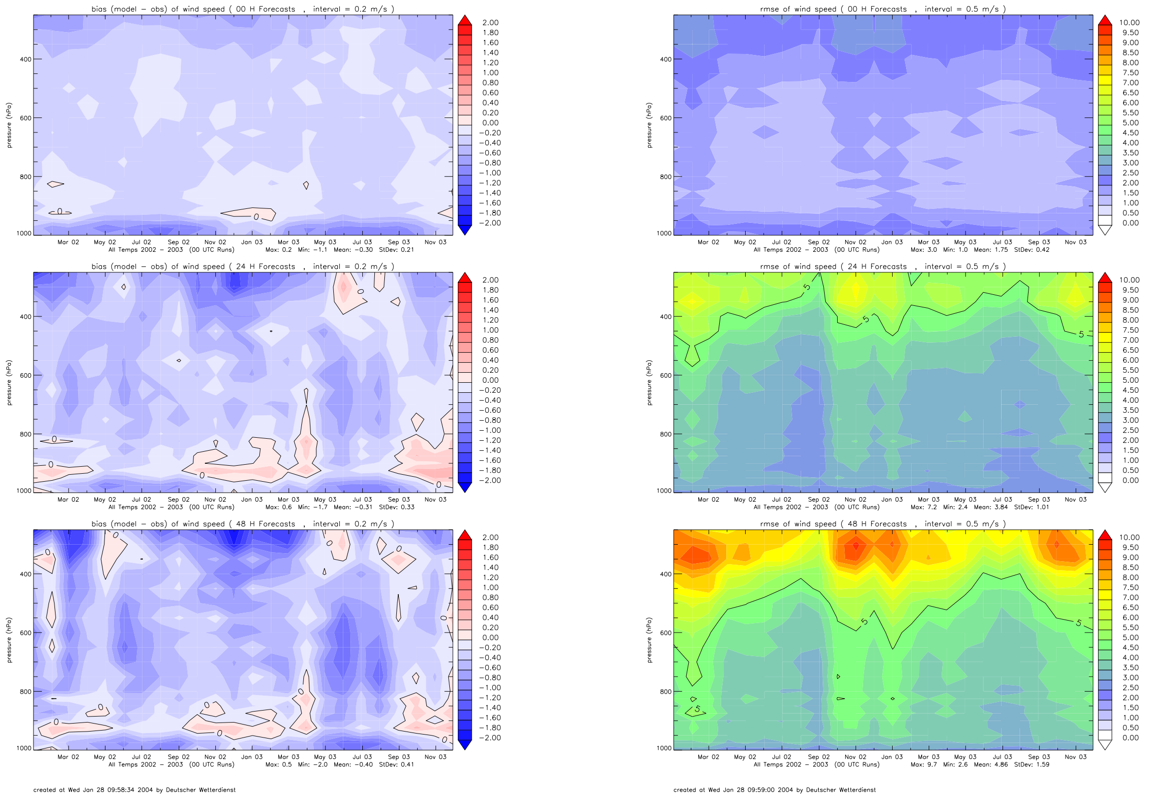


Figure 6: Time Series (January 2002 - December 2003) of wind speed bias (left column) and rmse (right column) against radiosonde data based on monthly mean profiles for 00 UTC LM runs at DWD. From top to bottom: Analysis, 24 h, and 48 h forecast.

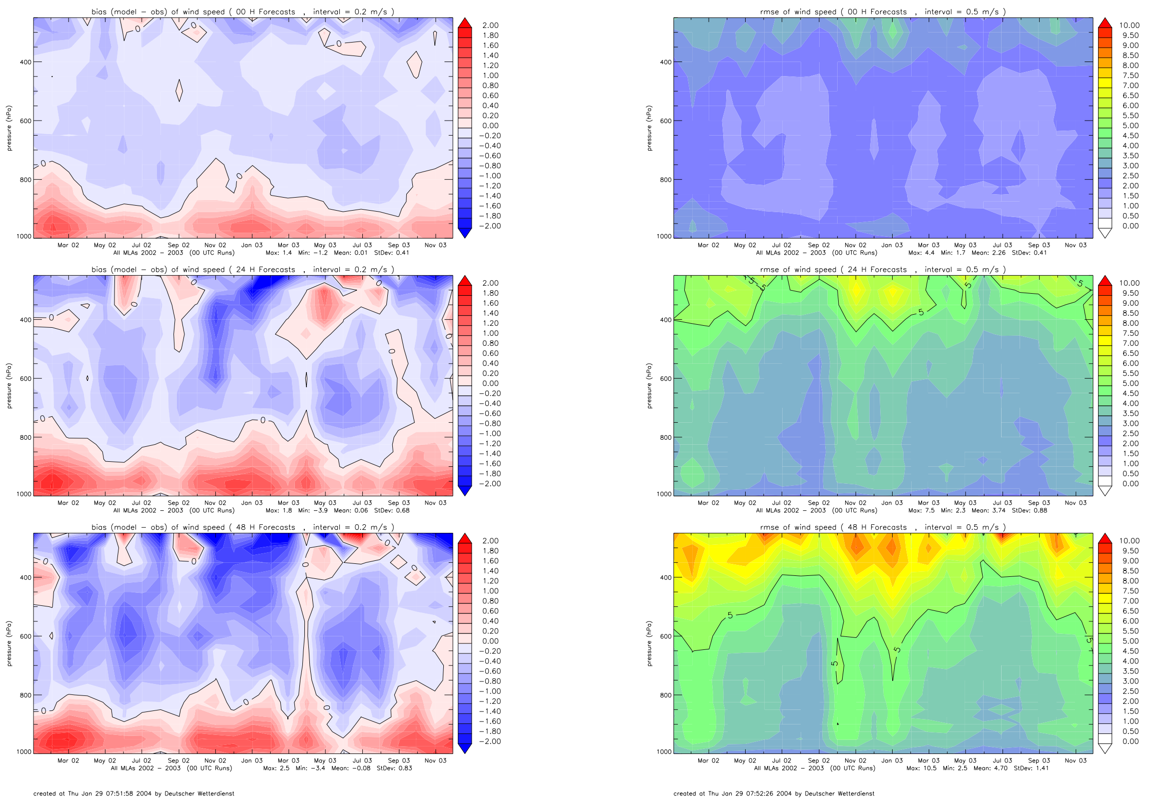


Figure 7: Time Series (January 2002 - December 2003) of wind speed bias (left column) and rmse (right column) against aircraft data based on monthly mean profiles for 00 UTC LM runs at DWD. From top to bottom: Analysis, 24 h, and 48 h forecast.

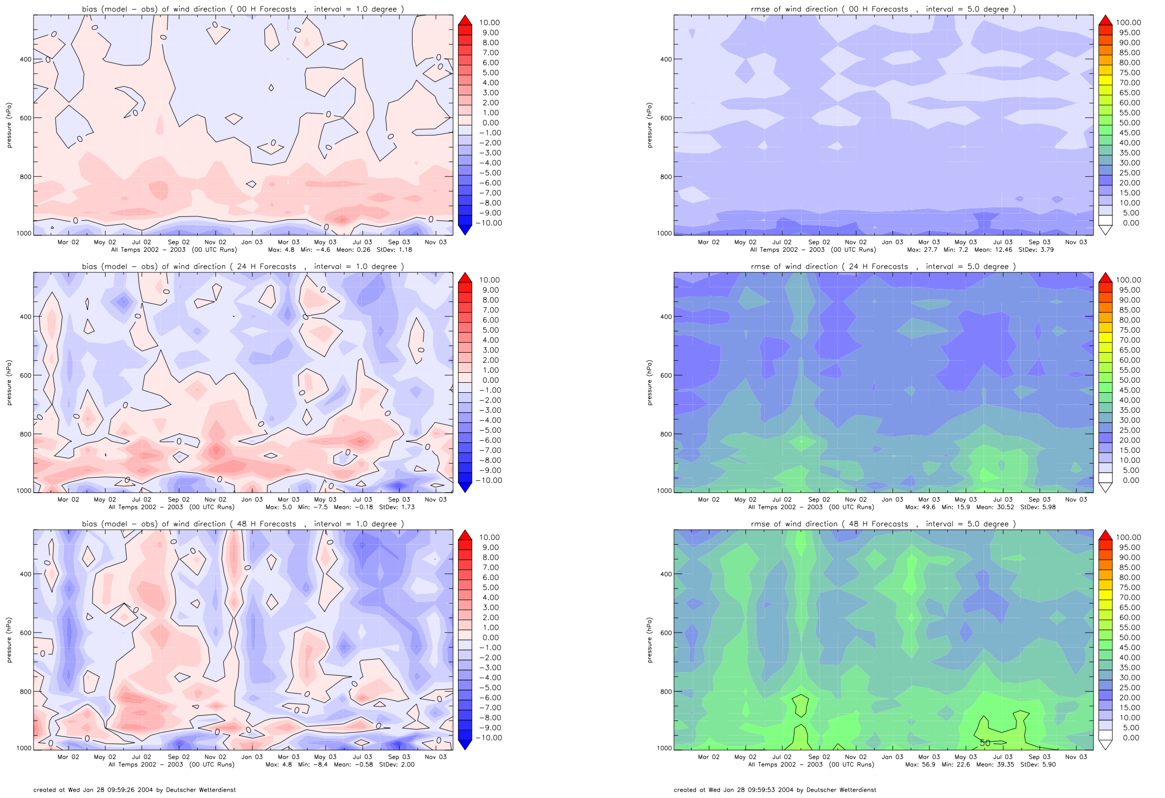


Figure 8: Time Series (January 2002 - December 2003) of wind direction bias (left column) and rmse (right column) against radiosonde data based on monthly mean profiles for 00 UTC LM runs at DWD. From top to bottom: Analysis, 24 h, and 48 h forecast.

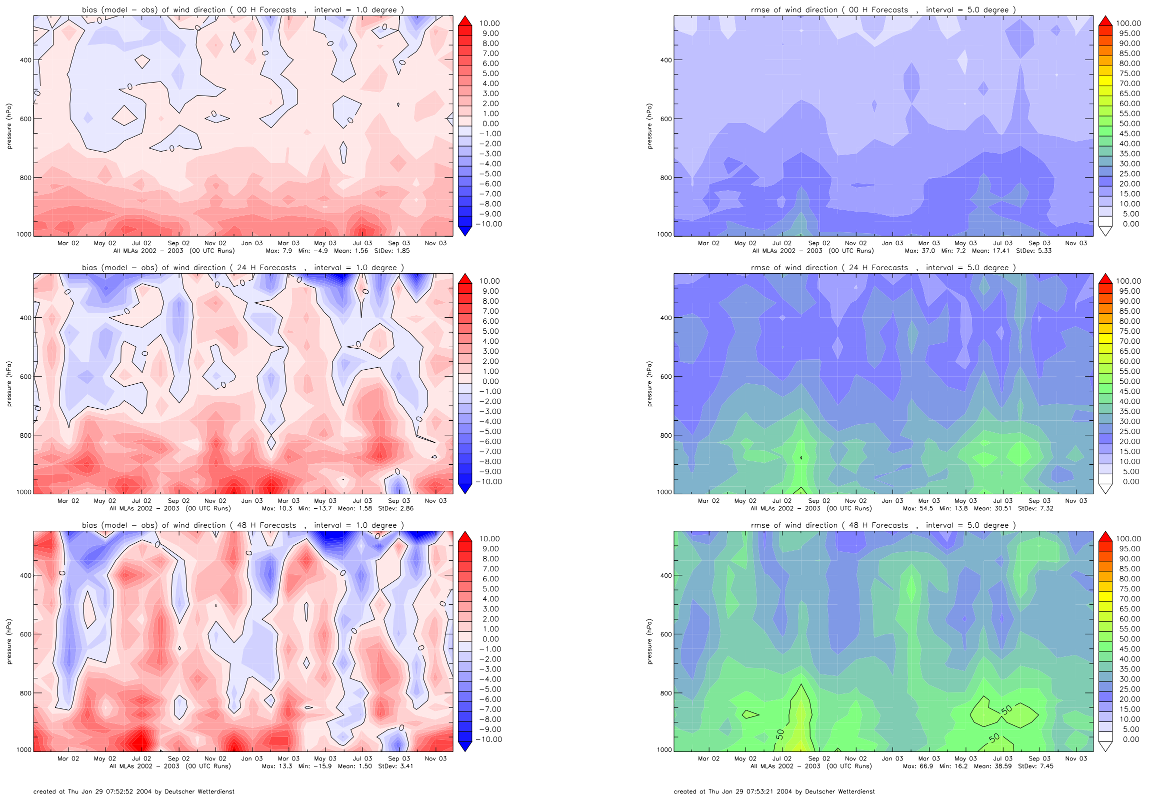


Figure 9: Time Series (January 2002 - December 2003) of wind direction bias (left column) and rmse (right column) against aircraft data based on monthly mean profiles for 00 UTC LM runs at DWD. From top to bottom: Analysis, 24 h, and 48 h forecast.

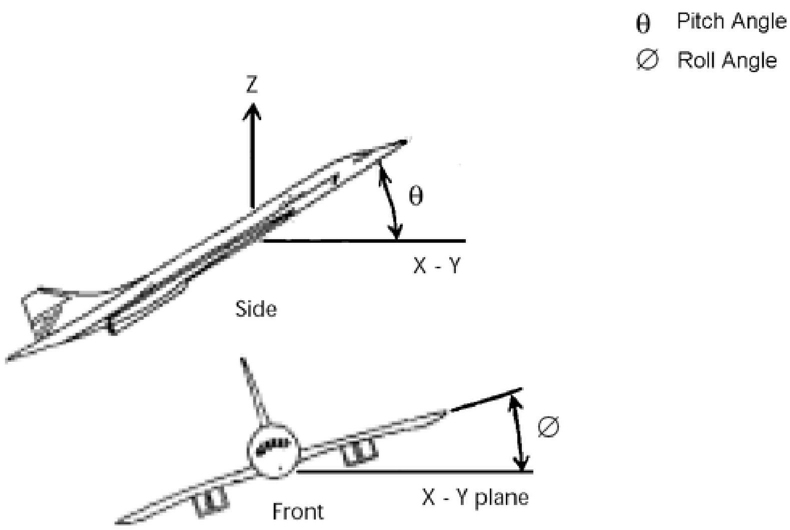


Figure 10: Aircraft reference axes and altitude angles (from WMO No. 958, 2003).

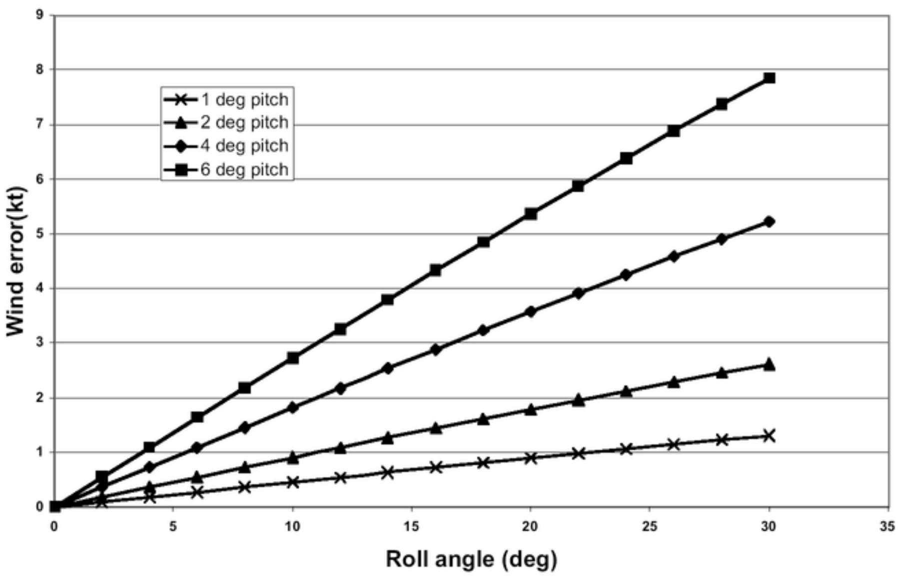


Figure 11: Effect of pitch/roll angle on wind speed at airspeed 150 Kt (from WMO No. 958, 2003).