ECMWF Feature article

from Newsletter Number 129 – Autumn 2011

METEOROLOGY

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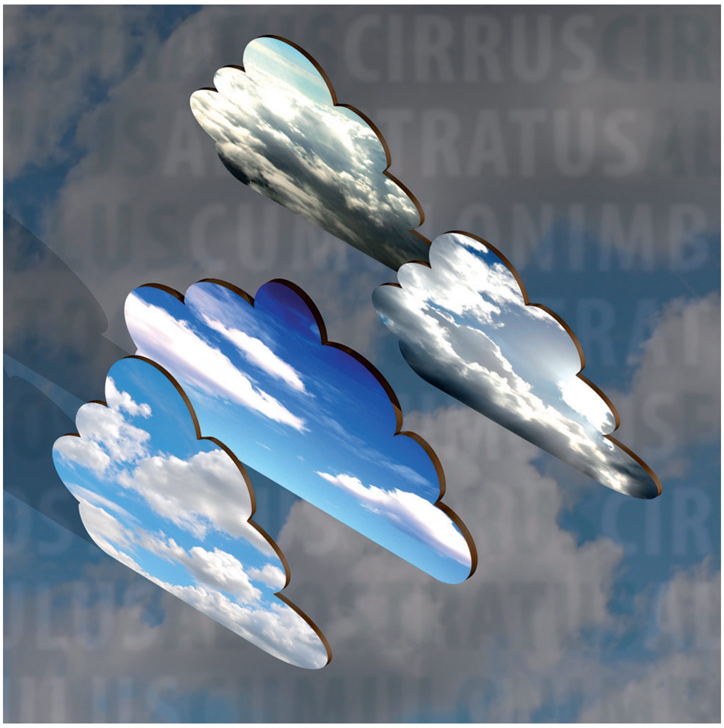

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doi:10.21957/tzs8ekmh

This article appeared in the Meteorology section of ECMWF Newsletter No. 129 – Autumn 2011, pp. 25–29.

Use of ECMWF's ensemble vertical profiles at the Hungarian Meteorological Service

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The Hungarian Meteorological Service has made extensive use of ECMWF's deterministic and ensemble forecasts since 1994 when Hungary became a Co-operating State of ECMWF. Several locally-developed tools have been used operationally to extract information from the ECMWF forecasts. For example, based on data from the EPS (Ensemble Prediction System), these tools are used for clustering EPS members for the Central European domain, deriving a wide range of probability forecasts (among others EPS histograms), displaying several types of the EPS plumes (ECMWF, 2010), and performing ensemble calibration (*Ihász et al.*, 2010).

Deterministic vertical profiles based on the ALADIN/HU limited-area model and ECMWF global model have been used for a long time. In 2009 we started to plan the development of a new tool to visualize the vertical distribution of probabilistic forecasts for temperature, humidity, and wind speed and direction. These new products were verified on standard pressure levels and 62 EPS model-level fields for a one-year period (April 2010 to March 2011). Also a few case studies have been performed to prove the usefulness of this new tool in different weather situations.

The new visualization tool was implemented for standard pressure levels in May 2011 and it was introduced for 62 EPS model level fields in July 2011.

In this article we describe the use of ensemble vertical profiles and the way in which they can be verified. In addition, the usefulness of the ensemble vertical profile is illustrated with three case studied.

Use of ensemble vertical profiles based on standard pressure levels

Ensemble forecasts of temperature, relative humidity and horizontal wind components are currently available every three hours up to 144 hours (and 6 hours from 144 to 360 hours) with a horizontal resolution of 0.25° by 0.25° (*Buizza et al.*, 2010). This data is available from MARS (Meteorological Archival and Retrieval System) and also it is disseminated by ECMWF. At the Hungarian Meteorological Service programs use ECMWF's GRIB API grib decoder software and ECMWF's MAGICS++ software (*Siemen & Lamy-Thépaut*, 2010) to manipulate the data.

This new visualization tool can provide a quick overview of the complexity of forecasts of meteorological variables in the vertical. One can easily see the levels and layers where small and high probabilities occur, and interactions between different variables can easily be recognized by operational forecasters. Time evolution of probabilities is also easily studied.

It is important to note that even ensemble vertical profiles based on standard pressure level fields are very useful for viewing probabilistic information, but they could not be support the recognition of all the required details in some specific weather situations. For example, in the case of a winter inversion in the lower troposphere, the vertical profile derived from the three lowest standard pressure levels (1000, 925 and 850 hPa) could not describe the fine vertical structure. ECMWF's numerical models use a hybrid co-ordinate system containing a lot of model levels in the lower troposphere, so use of all the model-level data would be beneficial.

Use of an ensemble vertical profiles based on model levels

Having encouraging results from an ensemble of vertical profiles based on 11 standard pressure levels between 1000 and 100 hPa, the next step was to develop a similar tool based on 62 EPS model levels. However, , it is important to be aware that EPS model-level fields are not archived in MARS, but the latest two forecasts are available from the FDB (Forecast Data Base). In addition, EPS model-level fields are available via ECMWF dissemination system.

At the Hungarian Meteorological Service the EPS model-level fields have been archived for the Central European domain with 0.25° by 0.25° horizontal resolution since April 2010. Consequently it was possible to compare standard pressure level and model-level forecasts over quite a long period. After solving a few technical tasks, ensemble vertical profiles based on model-level fields became available in the same two main types as developed for standard pressure levels. To see detailed vertical structures, the program can easily change the vertical interval depending on what is of interest to the forecaster. Two main types of visualization were developed using the EPS forecasts:

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- Probability forecasts of temperature and dew point in the vertical (Figure 1).
- Probability of the wind speed and wind direction shown as a wind rose (Figure 2).

These two types could also be combined.

62 level EPS fields are used for temperature, dew point and wind components from the operational dissemination. The area chosen covers all Hungary and some neighbouring regions, and the ensemble vertical profiles are generated for a few predefined location by using time-critical job on ecgate (ECMWF's Member State server). In addition, products can be generated locally within our meteorological service. Consequently vertical profiles can be made for any location of interest to the forecaster. Generating these products needs only a couple of minutes.

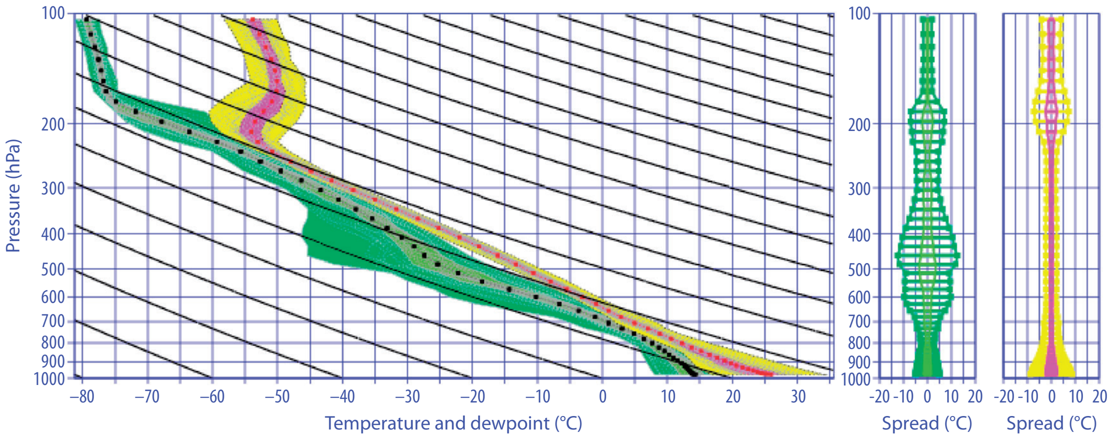

Figure 1 84-hour ensemble forecast of temperature and dew point on model levels. The forecast was issued at 00 UTC on 17 July 2011 for Budapest. The colours indicate ranges of probability. For dew point the green part shows 0–25% and 75–100%, and avocado shows 25–75%. For temperature the yellow part shows 0–25% and 75–100%, and magenta shows 25–75%. In subsequent figures of a similar kind, the diagrams are simplified by using pressure/temperature rectangular axes and not including the dry adiabats. Note that in reality 2% of all cases are outside the EPS range.

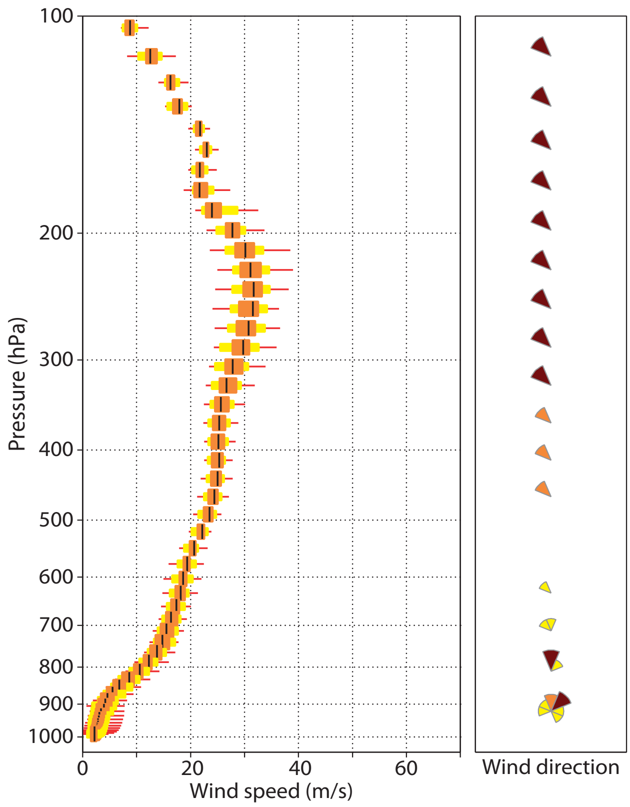

Figure 2 84-hour forecast of ensemble wind speed and wind rose based on model levels. The forecast was issued at 00 UTC on 17 July 2011 for Budapest. The colours indicate ranges of probability. For wind speed (left panel) yellow shows 10–25% and 75–90%, and orange shows 25–75%. For the wind rose (right panel) yellow shows less than 5%, orange shows between 5% and 25%, and brown shows more than 25%. Note that in reality 2% of all cases are outside the EPS range.

Verification of ensemble forecasts on standard pressure levels

Many methods of verifying ensemble forecasts are available, but most of them are typically used for local weather elements (e.g. 2-metre temperature, precipitation and wind speed). In this case, however, we want to assess the quality of the ensemble vertical profiles – this can be achieved using Talagrand diagrams and the area under the Relative Operating Characteristic (ROC) curves. Ensemble forecasts at 00 UTC were verified for an area defined by a rectangle covering the territory of Hungary. Here we will give some examples of the verification results based on Talagrand diagrams.

Talagrand diagrams give a measure of how well the ensemble spread of the forecast represents the variability of the observations, though they give no indication of the skill of the forecasts. In an ideal system the long-term distribution in the diagram should be flat. If the distribution is slightly U-shaped, this indicates that the ensemble spread is too small with many observations falling outside the extremes of the ensemble (i.e. over-representation of cases when the verification falls outside the ensemble and under-representation when it falls in the centre of the ensemble). However, a J-shape or L-shape indicate that the system has a bias: a J-shape shows systematic underestimation and L-shape shows systematic overestimation.

Talagrand diagrams were produced for all standard pressure levels and displayed together. They were calculated for temperature, wind speed and humidity for one year (April 2010 to March 2011) (*Tajti*, 2011). As well as verification of the individual ensemble members, verification of the ensemble mean is also applied and results are easily displayed in the vertical. Verification results will now be presented for two important meteorological elements: temperature and relative humidity.

Figure 3 shows the Talagrand diagrams for forecasts of temperature on standard pressure levels in 2010 for two forecast ranges (36 and 132 hours). It can be seen that the forecasts are quite good around the mid-troposphere for both time steps. However, a systematic overestimation(L shape – warm bias) is found at lower levels at short time ranges but it disappears at longer time ranges. In the lower stratosphere a systematic underestimation (J shape – cold bias) is found.

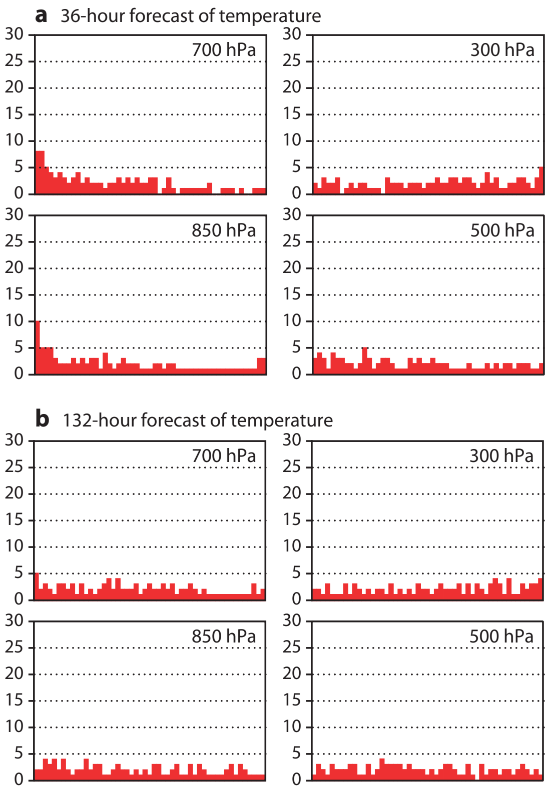

Figure 3 Talagrand diagram for (a) 36-hour and (b) 132-hour forecasts of temperature at 850, 700, 500 and 300 hPa in 2010.

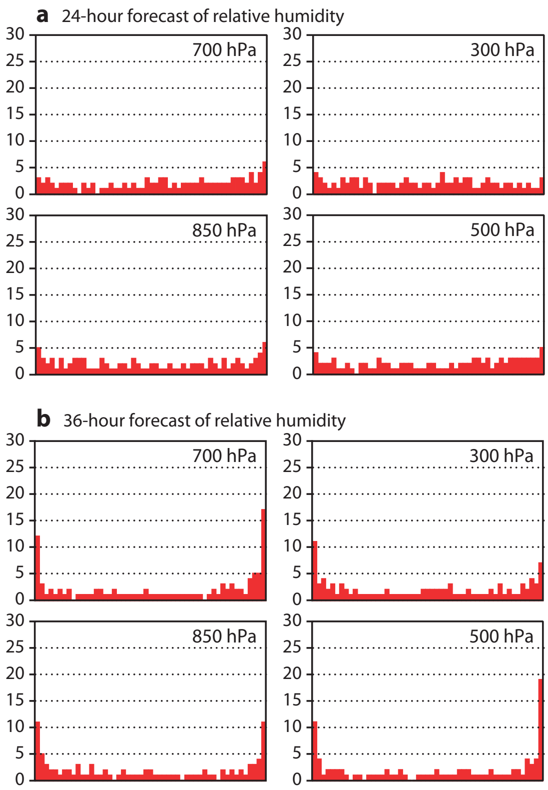

Figure 4 Talagrand diagram for (a) 24-hour and (b) 36-hour forecasts of relative humidity at 850, 700, 500 and 300 hPa in 2010.

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For relative humidity the situation is more complex. There are typical features in the diurnal and seasonal scales; also there are some characteristic changes with the forecast time range. Figure 4 shows the Talagrand diagrams for forecasts of relative humidity for two short forecast ranges (24 and 36 hours). In terms of the annual average near to the surface, relative humidity is typically overestimated during the night as illustrated by the results for the 24-hour forecasts. However, especially at short time ranges, the spread is underestimated around noon – see the results for 36-hour forecasts. In addition, the spread at 700 hPa is underestimated but in the lower stratosphere overestimation is found. As already mentioned there is a seasonal variability too, so it is useful if users or potential users are aware of the reliability of the forecacting system and influences of the model upgrades.

Three case studies

The use of the ensemble vertical profiles will now be illustrated by three case studies associated with situations where there is summer convection, winter inversion and cold vortex in the middle troposphere.

Summer convection

In operational practice it is often necessary to estimate the type, vertical extent and base of cloudiness from profiles of temperature and humidity. Studying the EPS vertical profile we can assess the area of high vertical instability and thereby estimate the type of cloud formation in different layers. In addition, the ensemble vertical profiles can be used to derive ensemble meteograms containing convective indices (e.g. Convective Available Potential Energy (CAPE), wind shear between 500 hPa and 10 m, and average relative humidity between 850 and 500 hPa) that indicate whether severe events, such as heavy thunderstorms, are likely to occur. Also regions where turbulence might occur can be assessed from the wind shear.

On 16 August 2010 the weather of the Carpathian basin was determined by low pressure with a few local minima. In the morning a few thunderstorms occurred in the western part of Hungary and, due to the large-scale intensive convection, severe thunderstorms appeared in the eastern part in the afternoon. A red warning and an alarm of severe events were issued to the public. The ECMWF ensemble forecast provided useful early warning of this situation (Figure 5a) even though there was high uncertainty in the wind speed and dew point in the layer between 850 and 300 hPa. The very short-range (12 hour) ensemble forecast indicated low uncertainty in the temperature throughout the troposphere but higher uncertainty about the wind direction in the lower stratosphere and dew point around the tropopause (Figure 5b). Indeed, there are two relatively narrow regions (around 600 and 200 hPa) where there is a high uncertainty in the dew point.

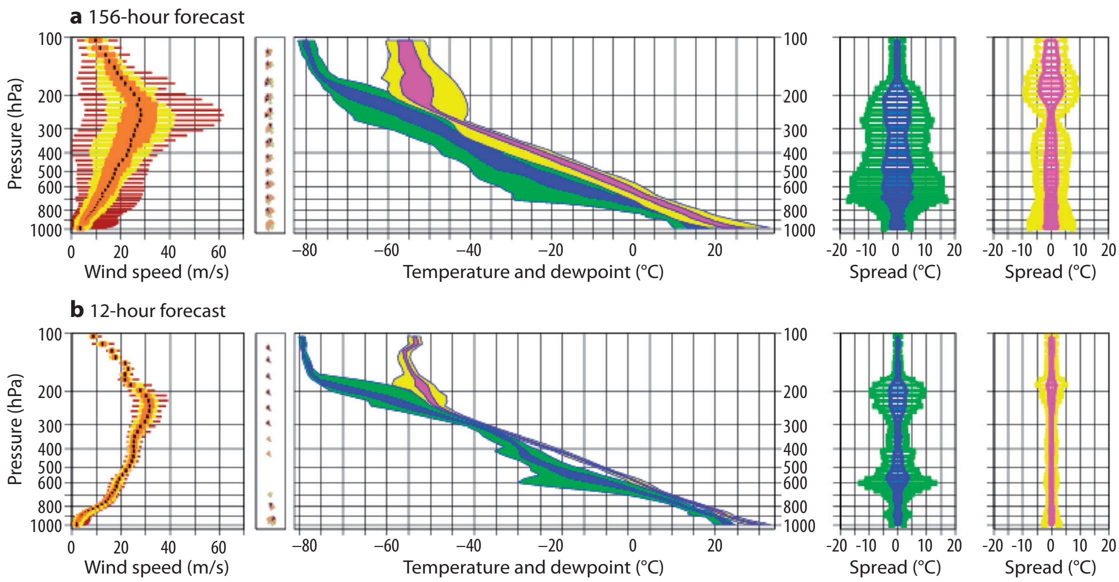

Figure 5 (a) 156-hour forecast issued at 00 UTC on 10 August 2010 and (b) 12-hour forecast issued at 00 UTC on 16 August 2010 of the ensemble wind speed, temperature and dew point based on model levels for Budapest. The colours have the same meaning as in Figures 1 and 2.

Winter inversion

Having a wintertime inversion is quite typical in the Carpathian basin. During inversion situations the accurate forecasts of temperature and humidity in the lowest 1.5 km are quite important for determining the type of precipitation, particularly freezing rain and frozen rain as these have a strong influence on traffic conditions. In addition, correctly estimating the top of the inversion could help with forecasting these dangerous events as well as the occurrence of fog. Incorrect forecasts during wintertime inversion situations can also have a strong influence on energy consumption because the maximum temperature could differ by 8–10°C depending on the amount of cloudiness.

ECMWF forecasts have improved significantly in the last decade, but there are still a few cases when increasing or decreasing the strength of the inversion is not well captured. In these cases strong biases can appear in the maximum and minimum 2-metre temperatures due to the absence of the low-level cloudiness. The 36-hour deterministic forecast for 00 UTC on 31 January 2011 predicted a clear sky across Hungary, but actually there were low-level clouds everywhere. The inversion was quite well predicted, but less humidity was forecast than happened. In this situation it very useful having the ensemble vertical profile to provide guidance about the probability of the low-level cloudiness connected to the inversion (Figure 6). Note that the dew point changes very rapidly in the vertical.

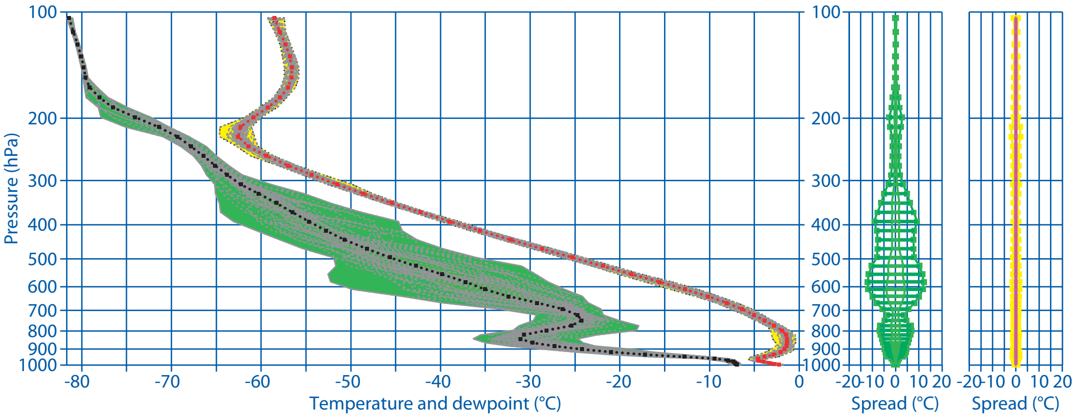

Figure 6 36-hour forecast of temperature and dew point based on model levels. The forecast was issued at 00 UTC on 31 January 2011 for Budapest. The colours have the same meaning as in Figure 1.

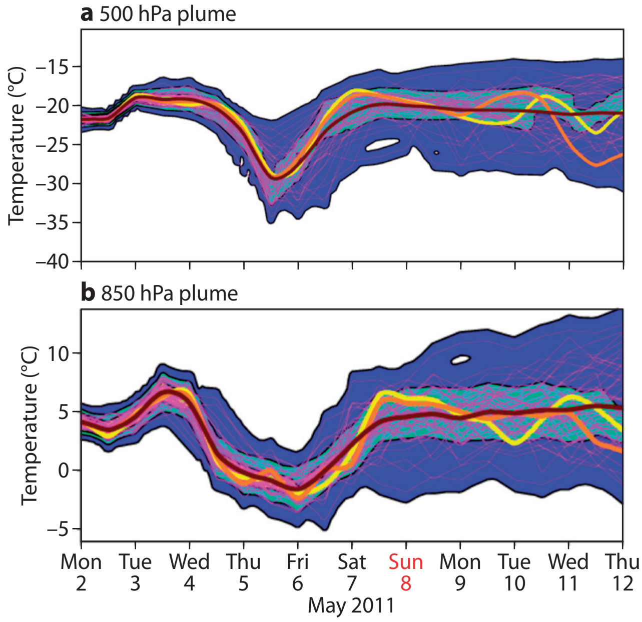

Figure 7 Standard 10-day ensemble temperature plume on (a) 500 hPa and (b) 850 hPa. The forecast was issued at 00 UTC on 2 May 2011 for Budapest. Ensemble mean is brown, deterministic model is yellow, and control model is orange.

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Cold vortex in the middle troposphere

The successful forecast of the position and intensity of the cold vortex in the middle troposphere is a real challenge, especially in medium-range forecasts. In these circumstances, the weather can be very changeable; for example intensive showers and thunderstorms are quite typical in some regions but at the same time sunny and calm weather is found not far away. Around 5 May 2011 such a weather situation appeared as can be seen in the temperature plume at 500 hPa (Figure 7a) – the uncertainty is quite high. In contrast, cooling occurred much earlier at 850 hPa (Figure 7b). The ensemble vertical profile based on model-level fields provided a better localization of uncertainties in the vertical (Figure 8).

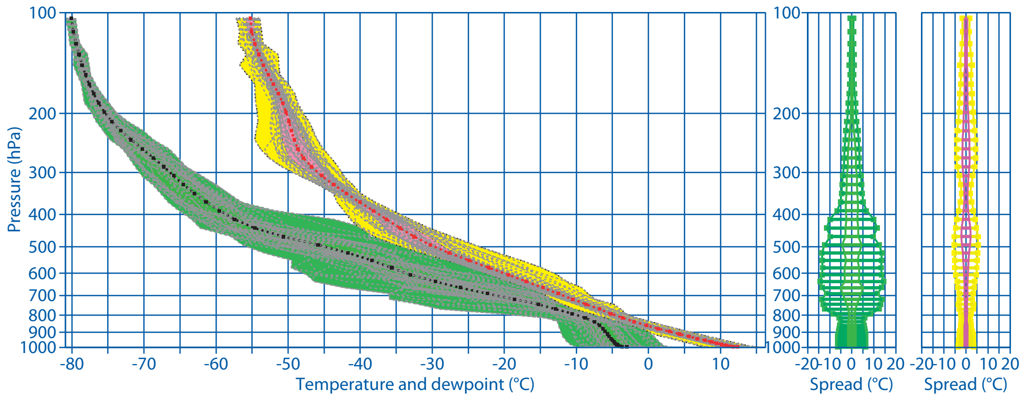

Figure 8 84-hour forecast of temperature and dew point based on model levels. The forecast was issued at 00 UTC on 2 May 2011 for Budapest. The colours have the same meaning as in Figure 1.

Overview and further developments

A new visualization tool, displaying an ensemble vertical profile, was developed at the Hungarian Meteorological Service. This enables ensemble vertical profiles of temperature, humidity, wind speed and wind rose to be generated operationally for pre-defined locations in addition to places of particular interest to forecasters because of the specific weather situation. The profiles have been created from forecasts of the 62 EPS model levels as well as using data from standard pressure levels.

Forecasters have found that having access to these profiles is of value in interpreting EPS output. The new tool provides a quick overview of the vertical structure of all important meteorological variables and interconnections among the variables. Based on such information, important meteorological situations, such as winter inversions and summer convective cases, can be better predicted.

We plan to investigate the improvement in the ensemble vertical profiles when the planned increase in the number of the ensemble model levels takes place in 2012.

Further reading

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