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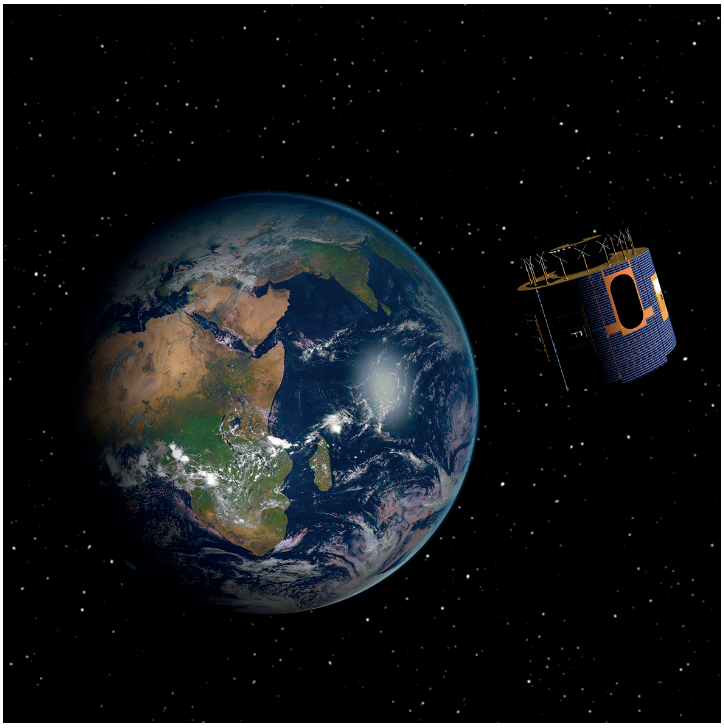
METEOROLOGY

Using ECMWF's new ensemble vertical profiles



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Using ECMWF's new ensemble vertical profiles

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ECMWF has developed a new product to show the vertical structure of the atmosphere at a point in ensemble forecasts (ENS). In June 2018, the new product was incorporated into ECMWF's web-based chart-viewing applications, which include ecCharts, clickable web charts and the Dashboard, to use and assess. Users can now examine vertical profiles of the atmosphere anywhere across the globe, at 6-hour intervals, up to a lead time of 120 hours. These can provide considerable assistance with many forecasting challenges, such as predicting cloud layers, layers of instability, precipitation type, wind gust penetration to the surface, propensity for supercells to develop, etc.

The history of this initiative is that ECMWF forecast users have for many years been asking to see vertical profiles of the atmosphere at points, in various different formats. *Ihász & Tajti* (2011) demonstrated ways of doing this for the ENS over Hungary, but for ECMWF, whose products cover the globe, 'big data' challenges had precluded progress until now. The new products are designed to address the various user requirements, and they were demonstrated for the first time at ECMWF's user meeting (UEF) in June 2018. Initial feedback was very positive, and monitoring statistics collated since then have shown substantial uptake, but ECMWF would very much welcome further feedback and requests for changes from users. These will be used to shape future improvements.

Data choices

For ECMWF, the production and visualisation of vertical profiles from the ensemble posed many technical challenges. The first was dealing with the huge data volumes involved while at the same time providing a responsive interactive service. This required careful preparation of the raw ensemble data:

- deriving required parameters on carefully selected model levels from ensemble and deterministic model outputs for all selected lead times
- preparing suitable point databases that would provide retrieval and plotting of a vertical profile for any given point in an acceptable time frame (2 to 5 seconds).

To plot, say, a 10-day meteogram for a point is relatively straightforward: one only needs about 1,400 data values. To plot vertical profiles for the same time window potentially requires about 800 times more data! Coupled with the need to reference the whole globe at 18 km resolution, access can become very slow, and indeed the problem becomes intractable. This is a good example of a big data challenge where the derivation and presentation of information present in the raw data requires careful thinking. Our approach has been to ensure good performance by cutting down the amount of data used while preserving the most important aspects of the forecast. One option was to use only pressure level data. For winds this is acceptable. However, for thermodynamic variables we would have distorted the picture of the atmosphere as represented by the model. For example, critical information such as the presence of thin cloud layers beneath inversions would have disappeared, whilst unrealistic instabilities would have been created where the atmosphere in the model is actually stable. Instead we chose to show all available model levels up to about 700 hPa in order to retain everything in the all-important lower troposphere, then every other level from about 700 to 100 hPa, where structure is less critical, and to discard anything above about 150 hPa, which is of little relevance to surface weather. We have also limited lead times to 5 days. This is because there is less benefit in overlaying profiles from the increasingly disparate synoptic patterns one sees at longer lead times: the plots would just become confusing. Together these measures enabled an 80% reduction in data volume. This makes it possible to deliver a new set of ensemble profiles to the computer screens of users in around 3 seconds.

Visualisation

The second challenge was to show multiple profiles from ENS together in a meaningful way. We wanted to show the key variables measured by radiosondes (temperature, dewpoint, wind speed and wind direction) and also the critical relationships between those variables, such as dewpoint depression and vertical wind shear. Meanwhile ECMWF's Strategy calls for continued improvements in the prediction of severe weather. Whilst some convective hazards cannot yet be explicitly represented by the Integrated Forecasting System (IFS), ensemble vertical profiles can give very useful pointers

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on whether there is a risk of such hazards. In particular, CAPE (convective available potential energy) and CIN (convective inhibition) and their juxtaposition are of fundamental importance. The vertical profile chart layout has been designed with these considerations in mind. The charts now include four key components. These are illustrated in Figure 1, which shows a winter time case at day 5 near the Antarctic Peninsula:

- A thermodynamic diagram, in the current implementation a tephigram (top left), is used to show temperature and dewpoint ranges at different levels within ENS. Specifically we delineate, with differently shaded bands, the minimum, median and maximum, and the 25th and 75th percentiles of the temperature and dewpoint distributions at each level, in a way that mirrors the use of box-and-whisker plots on meteograms.
- A similarly styled panel (top right) is used to show the range of dewpoint depression values found on different model levels. In the same panel we also show wind flags from HRES at standard pressure levels. Showing them in this panel is not because winds relate directly to dewpoint depression but for plotting convenience.
- In part because showing wind barbs from 52 runs is not viable, the vertical vector wind distribution from ENS is plotted as a hodograph (bottom left), using one line for each ENS member and one colour for each of a range of levels, with warmer colours denoting low levels and colder ones denoting upper levels. Only data from standard pressure levels are shown. The radial wind speed scale varies to span the value range represented, with certain values (20, 50, 100 m/s) highlighted to aid quick interpretation.
- Simple box-and-whisker plots (bottom right) are used to show distributions of most unstable CAPE for three different categories of CIN. These three categories were selected to denote, respectively, when CAPE is likely to be released (CIN < 50 J/kg), when CAPE may be released (50 J/kg ≤ CIN < 200 J/kg), and when CAPE release is not expected (CIN ≥ 200 J/kg). This addresses difficulties that often occur when viewing CAPE fields in isolation; for example, very high values can sometimes be seen where convection is not really possible, and thus false alarms can arise. Scaling for CAPE varies according to the full range of values present, with 200, 500, 1000, 2000 and 5000 J/kg highlighted. The user should note that ECMWF provides most unstable CAPE in the lowest 350 hPa of the atmosphere, whilst CIN is the minimum found in the same atmospheric layer. Therefore, CAPE and CIN provided as a model output are not necessarily computed for the same departure levels. Nevertheless, CIN can be used qualitatively as an indicator of the likelihood of convective initiation. Thus, the CAPE diagram provided within this product should be used for a rough estimate of how easily CAPE might be released.

In each of the panels described above, we also show the high-resolution forecast (HRES thick solid line) and Control forecast (dashed line) as on meteogram products. At present, as with meteograms, it is not possible to link data from one particular ENS member across the four panels. Nevertheless, we believe that the new product will prove extremely valuable for assessing many different aspects of atmospheric structure as modelled by the IFS.

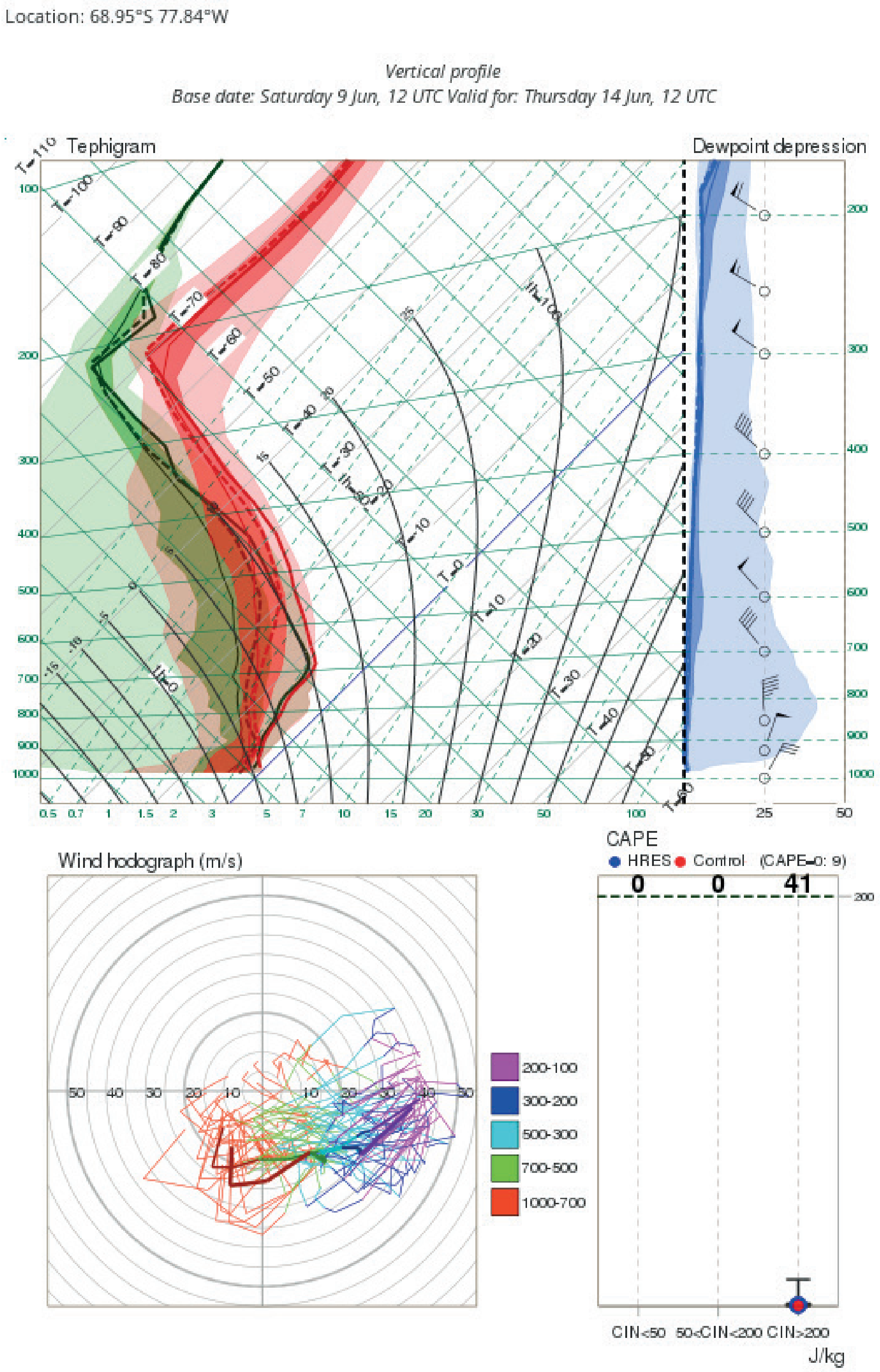

Figure 1 Example vertical profile chart for T+120h from the southern hemisphere winter. Some interesting features of this product are: (i) marked vertical wind shear in HRES and ENS, on the hodograph, implying thermal gradients and a front in the vicinity. Using standard techniques, one can visualise the frontal orientation and the approximate frontal speed of movement. (ii) HRES is something of an outlier solution, having more of an incursion of warmer air than virtually all ENS members at 700 hPa. (iii) Whilst most members are close to saturation through deep layers, which probably relates to the presence of a strong front, some have a very dry low to mid troposphere, probably because of the incursion of dry, cold Antarctic air poleward of any front. (iv) In this case most members (82% + HRES + Control) show very small, non-zero values of CAPE. It looks, based in part on the HRES and Control profiles, that this is elevated rather than surface-based instability, within the frontal cloud. Relatively high convective inhibition (CIN) would have to be overcome for this to be released, but forced dynamical uplift, commonly associated with fronts, may be able to do this.

Surface pressure assumption

A third challenge arising when combining data from different model runs is variations in surface pressure. Potentially the greatest impact would be seen on thermodynamic diagrams which use pressure as a vertical co-ordinate. The 1,000 hPa level could be at the surface in one ENS member, well below for another and well above for a third. This makes percentile computation and display extremely challenging. We have taken a pragmatic approach by assuming, for the purposes of plotting, that the ENS mean surface pressure at a given lead time is representative for all members, which means that the data stored for a given model level, for each ENS member, will always be mapped to the same pressure level. The fact that we only make lead times up to T+120h available renders this assumption quite reasonable, because spread in mean sea level pressure is mostly small compared to the vertical scale gradations on a tephigram. Figure 2 shows that, in winter over Europe, the difference between the minimum and the maximum surface pressure at day 5 within ENS is on average between about 10 and 20 hPa.

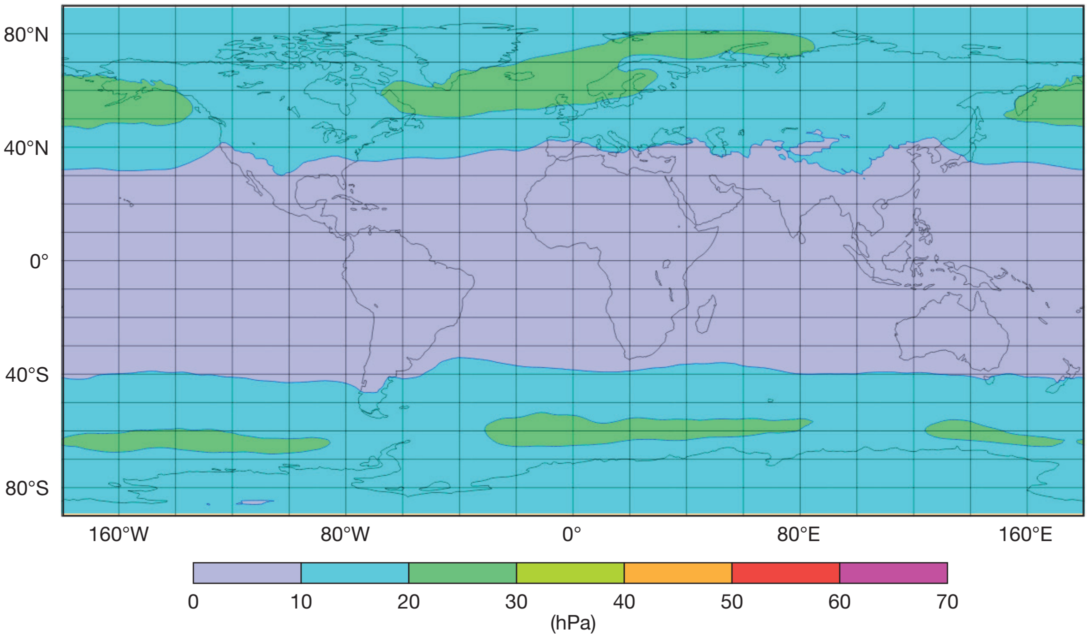

Figure 2 Approximate average difference in mean sea level pressure between extreme ENS members during the 2017/2018 northern hemisphere winter, at T+120h.

Case study

A vigorous supercell produced large hail, very strong winds and heavy rain that caused a lot of damage along the storm's path over north-western Bulgaria in the afternoon hours on 15 May 2018. The affected region was on the eastern flank of an upper low centred over Italy (Figure 3a). The co-location of high instability and significant deep-layer wind shear (also Figure 3a) favoured well-organised deep moist convection. The severe thunderstorm was initiated over the far north-west of Bulgaria and travelled eastwards producing a swathe of intense lightning activity (Figure 3b) and other convective hazards.

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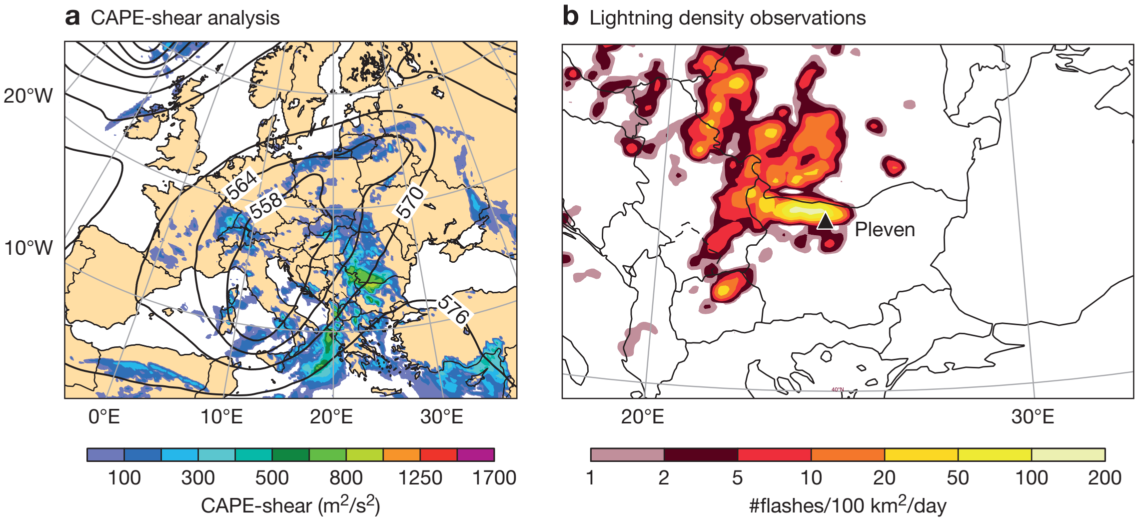

Figure 3 The plots show (a) the ECMWF analysis of 500 hPa geopotential height (contours, in decametres) and CAPE-shear (shading) valid for 12 UTC on 15 May 2018 and (b) ATDnet lightning density observations on 15 May 2018. Bright colours represent high values of lightning density associated with the supercell. The city of Pleven is marked on the map.

Figure 4 shows the new ensemble vertical profile forecast product for a lead time of 108 hours, valid for 12 UTC on May 15, for the city of Pleven, where the supercell caused havoc in the late afternoon. At this lead time, 14 members have CAPE=0 (top right on the panel), so in those members' representations deep moist convection is not possible and they are not shown within the CAPE/CIN plot. Meanwhile 9 members predict moderate to high CAPE from a few hundred to about 1000 J/kg, with CIN less than 50 J/kg. In all these 9 members, it would be relatively easy for the CAPE to be released and convection initiated, e.g. due to diurnal heating. The member with the most CAPE, almost 1200 J/kg, is also in this category. The second CIN category is populated with 14 members and CAPE values are of the order of a few hundred J/kg. As CIN is higher, between 50 and 200 J/kg, more substantial uplift would be required for convection to be triggered. Thirteen members belong to the third CIN category, and these have quite low CAPE (less than 400 J/kg). For these ENS representations convection would be very unlikely even if CAPE values were larger. HRES and Control forecasts, represented by blue and red dots respectively, also belong to this category, and show just a tiny amount of CAPE. In this forecast the risk of deep moist convection is arguably about 46% ((9+14)/50), although HRES and control runs do not support that outcome.

The hodograph plot allows us to assess how the wind changes with height in the 52 IFS runs, and how much uncertainty in the wind speed and direction there is in all these layers. In this example, near surface winds (red colour lines) are weak, with an easterly component in some members including HRES, which is shown with the wind flags on the dewpoint depression plot. In the mid- to high troposphere the uncertainty in the wind speed and direction increases but overall a westerly component is dominant. Thus deep-layer wind shear could be quite substantial (above 20 m/s). This means that, if convection is initiated, it could readily become well organised. The ensemble tephigram also shows the moisture content in the boundary layer and its uncertainty.

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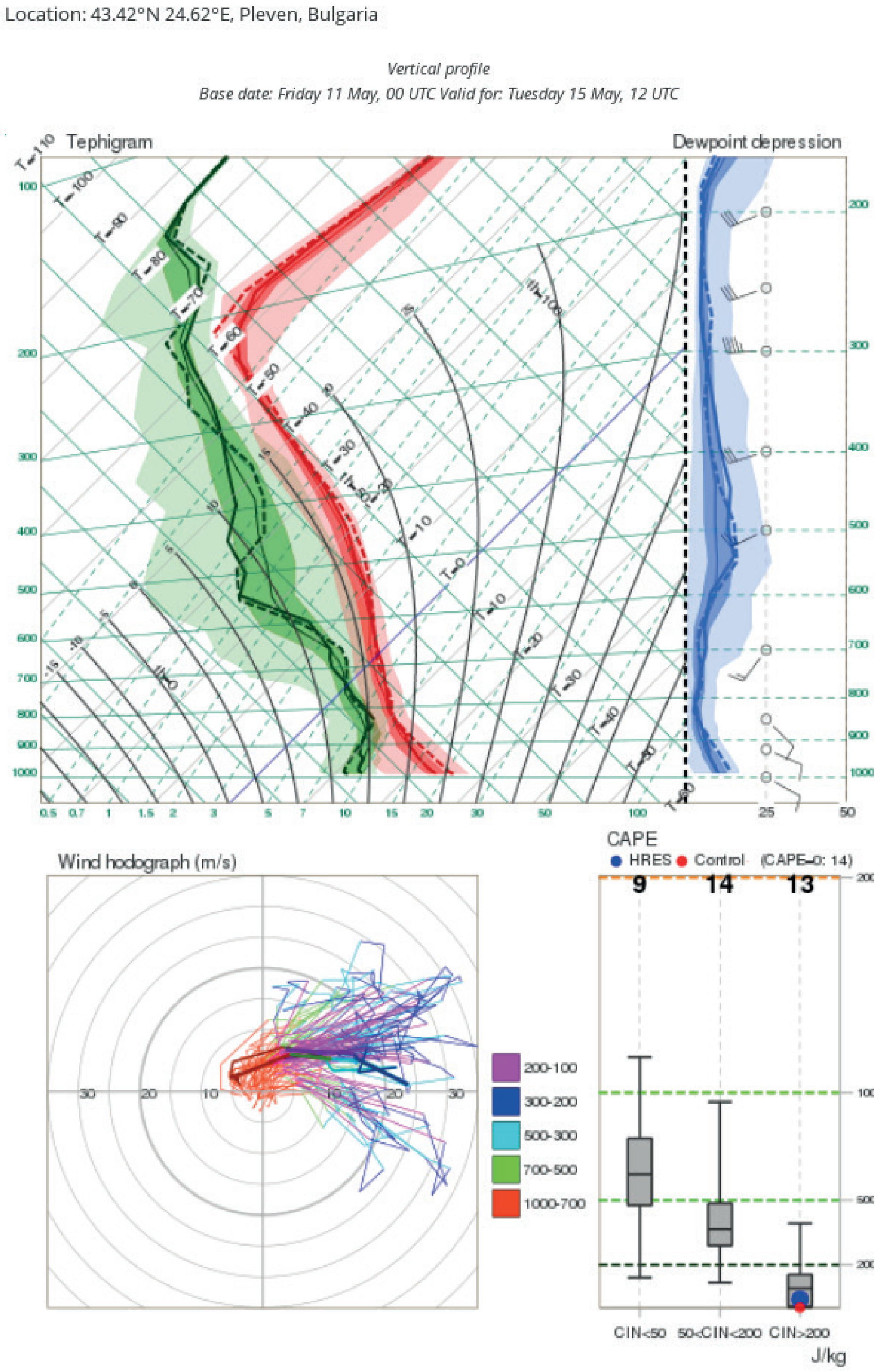

Location: 43.42°N 24.62°E, Pleven, Bulgaria

Vertical profile
Base date: Friday 11 May, 00 UTC Valid for: Tuesday 15 May, 12 UTC

Figure 4 Vertical profile chart for the city of Pleven in northern Bulgaria affected by the severe thunderstorm on 15 May 2018. The forecast lead time is 108 hours, the valid time is 12 UTC on 15 May.

Access to plots and data

The new vertical profile product is available in ecCharts (Figure 5), clickable web charts and the Dashboard. In the ecCharts application, it can be accessed through the menu item 'Views/Vertical profiles window', which opens a separate, movable window on top that displays ensemble vertical profiles for any point selected on the background map. Vertical profiles are displayed for a given forecast valid time, hence changing the valid time for the background map triggers a new profile request for the selected time. Note that ecCharts maps have 3-hourly time steps whilst vertical profiles are only available on 6-hourly time steps. The vertical profile window displays a message if there is no vertical profile available for the selected lead time.

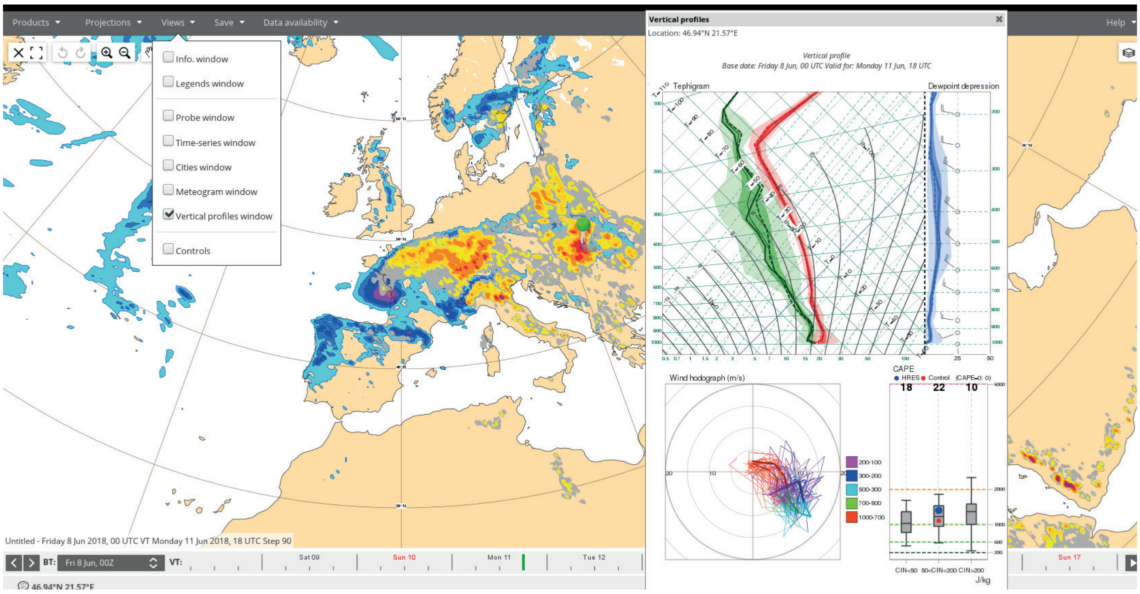

Figure 5 ecCharts interface showing a vertical profile for a selected point. The vertical profile window is added from the menu by clicking on 'Views' - 'Vertical profiles window'. Clicking on the background chart thereafter will generate vertical profile plots for the new selected location.

The Dashboard facility can provide access to all available forecast base times and lead times in a convenient way. To display them on the Dashboard, one needs to create a 'New Vertical profile' widget by using the 'Add new widget' menu item. Once a widget is created, it can be configured to any co-ordinate. Hovering over the widget will display time controls at the bottom left of the widget panel, as in meteograms and EFI/CDF plots, where users can easily navigate through available forecast base times and lead times. Users could, for example, create many widgets displayed side by side for data points that they are often interested in (Figure 6).

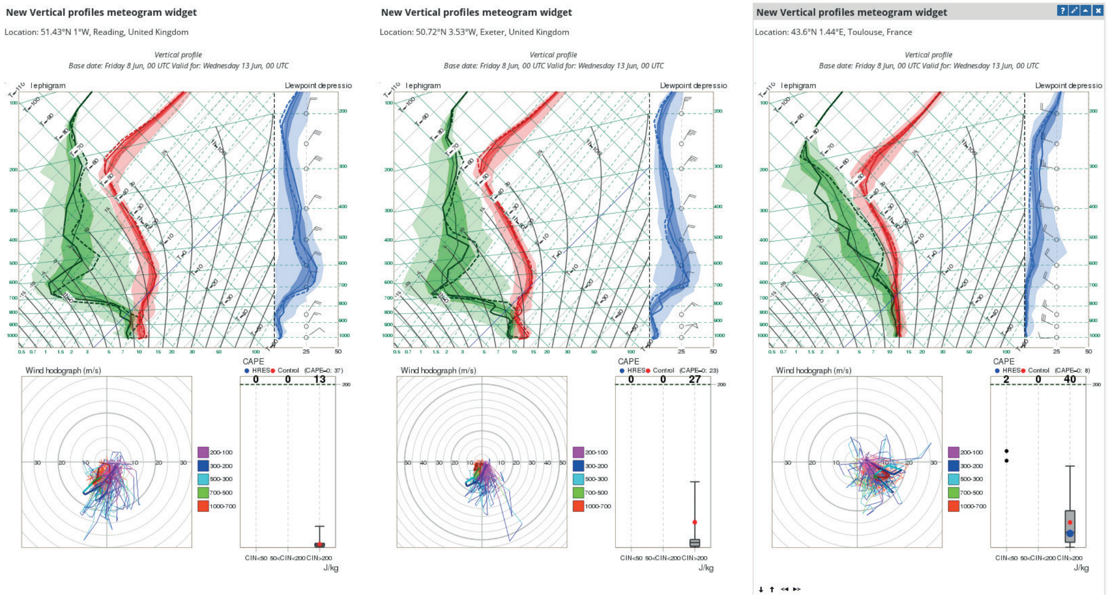

Figure 6 Dashboard interface showing three vertical profile plots side by side. Hovering over a vertical profile window calls up control buttons in the bottom left corner (visible in the third panel), where the user can control the base times and lead times available for this specific plot. Note also that a 'control widget', added through the Dashboard menu, could be used to change base times and lead times of all vertical profile plots on the page simultaneously. This interface provides the user with side-by-side comparisons, as well as allowing them to quickly scan through different lead times.

In addition to ecCharts and Dashboard access, vertical profile plots are also now included as an option on the standard clickable web charts, alongside the classical meteogram and EFI/CDF plot options that have been available for some time. Some users may be interested in accessing data files directly, to incorporate ECMWF vertical profiles into their own applications. To enable this, the data files for a given point will be provided via an ECMWF Web API that functions in a similar way to meteograms and that delivers output in JSON format. Note that vertical profile databases are kept online for 7 days (14 cycles), which is similar to meteograms.

For more information on ecCharts, visit: *https://confluence.ecmwf.int/display/ECCHARTS*

Further Reading

Ihász, **I.** & **D. Tajti**, 2011: Use of ECMWF's ensemble vertical profiles at the Hungarian Meteorological Service, *ECMWF Newsletter* **No. 129**, 25–29.

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