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Predictability of cold drops based on ECMWF's forecasts over Europe

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Predictability of cold drops based on ECMWF's forecasts over Europe

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Cold drops are closed cyclonic eddies in the middle and upper troposphere that are separated from the main western stream. Being elliptically shaped with a diameter of hundreds of kilometres, they resemble miniature cyclones on satellite images. Within a cold drop the air mass is isolated from the cooler air of higher latitudes and it carries air substantially colder than its surroundings to the warm regions of lower latitudes. Cold drops are sometimes called upper-level lows (ULLs).

It is important to study cold drops because they can sometimes be responsible for severe weather affecting a region for a couple of days. They can occur at any time of the year and often bring high amounts of heavy rainfall. The unstable nature of cold drops provides perfect conditions for the formation of massive thunderstorms in summer (these can lead to flooding, or in rare cases, even tornadoes), and intense snowfall during winter. Synoptic studies of the cold drops have received less attention during the past decades than their importance would suggest.

We have studied the formation, development conditions, and synoptic and dynamical backgrounds of cold drops using ECMWF's ERA-Interim reanalysis. The first step was to develop an algorithm to recognize the cold drops. Then a statistical investigation determined the typical horizontal and vertical structures of the cold drops. For the 280 selected cases, predictability of the intensity and position of the cold core was investigated using ECMWF's high-resolution forecast (HRES). Also, based on ECMWF's ensemble forecast (ENS), a new type of ensemble plume containing four meteorological variables was developed to help forecasters predict the onset of a cold drop.

Life cycle of a cold drop

A classic cold drop has four development phases, starting with the ULL becoming isolated from the main airstream and ending with it dissolving or fusing with another stream (*Nieto et al.*, 2005). There are four phases: upper-level low, tear-off, cut-off and final phases.

- ***Upper-level low phase.*** For a cold drop to form, there have to be unstable waves inside the main airstream, where the temperature wave lags the geopotential wave (Figure 1a). This is the phase where the ULL is still behind the frontal cloud mass, so it shows as a clearly visible cloud trail on satellite images.
- ***Tear-off phase.*** The main meteorological process of this phase is the trough tearing off from the main airstream (Figure 1b). The wave amplitude gets higher ('the wave gets deeper'), followed by cold air detaching from the airstream in its southern regions. The bottom part of the ULL slowly isolates from the main stream, leading to a closed circulation in the upper troposphere.
- ***Cut-off phase.*** The isolation is completely finished in this phase, and the ULL is fully developed. The wind field shows the most advanced closed circulation at 500 hPa (Figure 1c).
- ***Final phase.*** Convection begins to develop in the ULL (except for its coldest parts). The upper air mass gets warmer by the convection and the ULL slowly decays (Figure 1d). In most cases, the ULL reattaches to the main westerly stream before dissolving completely (*ZAMG*, 2007).

The development of the cold drop usually takes 3–10 days. There are two kinds of cold drops, based on size and lifetime: 'small eddies' which last 2–4 days and 'big eddies' which can last up to 14 days. Larger eddies are usually more common than smaller ones.

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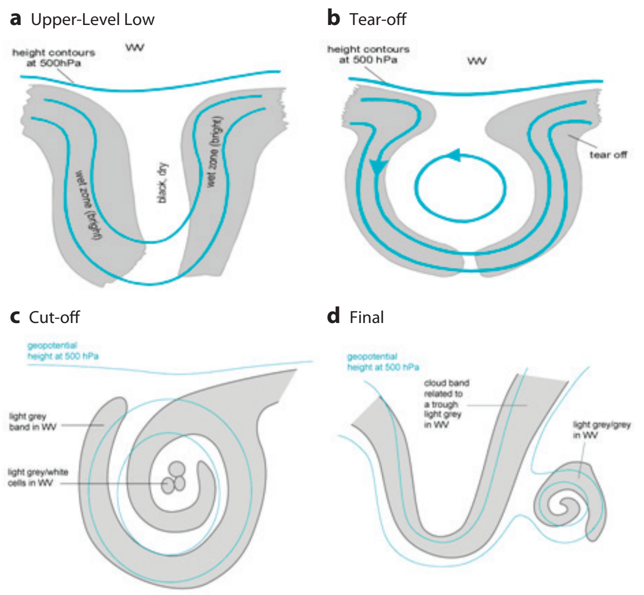

Figure 1 Phases of the cold drop: (a) Upper-level low, (b) tear-off, (c) cut-off and (d) final Phases (ZAMG, 2007).

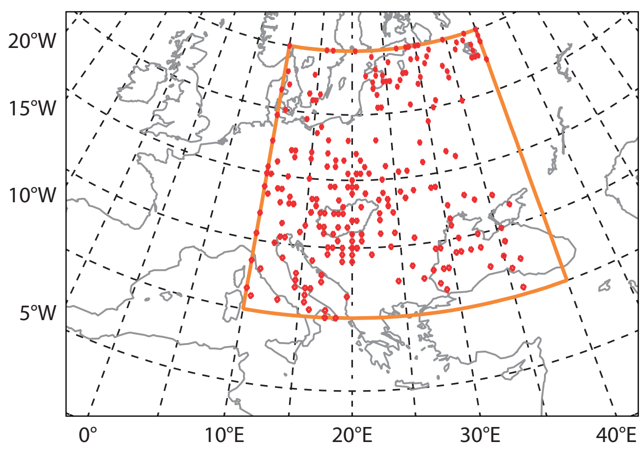

Figure 2 Centres (local minima) of 280 cold drops between 2002 and 2011.

The horizontal and vertical structure of cold drops

Because cold drops rarely occur at any specific geographical location, it is not easy to get a large sample of these events in order to examine their characteristics. Consequently, we decided to collect cold drops by developing an objective method for recognizing them. We used a two-step process.

- Several occurrences were collected when cold drops were identified by forecasters in the last ten years.
- The general characteristics of cold drops were determined by applying an objective method.

At first we gathered 70 cases from those submitted by synoptic meteorologists as cold drop situations between 2002 and 2011. These cases were studied daily at 6-hourly intervals, so this led to us having 280 different states. We used ERA-Interim to extract a few meteorological parameters such as temperature, geopotential, relative humidity and winds at standard pressure levels (850, 700, 500 and 400 hPa) to study the three-dimensional structure of the atmosphere. Since cold drops usually have small horizontal extensions and they rarely occur at any specific location, we chose a large area for our study. Figure 2 shows the study area and the core positions of the 280 cold drops studied between 2002 and 2011.

For the period between 1979 and 2008, we calculated the monthly average temperatures at 500 hPa from ERA-Interim. The core temperature of the cold drops was compared to the 30-year average along with the minimum and maximum monthly-mean temperatures for each month (Figure 3). It can be clearly seen that core temperature is always located below the monthly mean value. We can also see that cold drops do not have an absolute temperature threshold.

To have enough samples for a statistical analysis, we developed an algorithm for recognizing cold drops. The version used in this study was based on 500 hPa temperature, potential temperature at 2 PVU, and isentropic potential vorticity at 315 K.

Having found the core of the cold drops we explored their typical horizontal and vertical structures using a three-step process.

- Local minima of the temperature fields are determined at 400, 500, 700 and 850 hPa.
- Horizontal gradients (in °C/100 km) at distances of 100, 250, 500 and 700 km from the local minimum are calculated at each pressure level.
- Histograms are produced for each selected distance and pressure for the 280 cold drops.

An example of these histograms is shown in Figure 4. As expected the results indicate that the thermal gradient gets lower as we move further away from the core. This unique thermal structure of cold drops gives us a good way of distinguishing them from the cyclones in temperate zones, which are characterized by their large extent and thermal asymmetry (except in their cut-off phase). Another unique feature of cold drops is that their inner core is only apparent in the upper troposphere, while in the lower troposphere it is barely visible (as opposed to what occurs in temperate cyclones). This information can be used by the recognition algorithm to separate cold drops from cyclones.

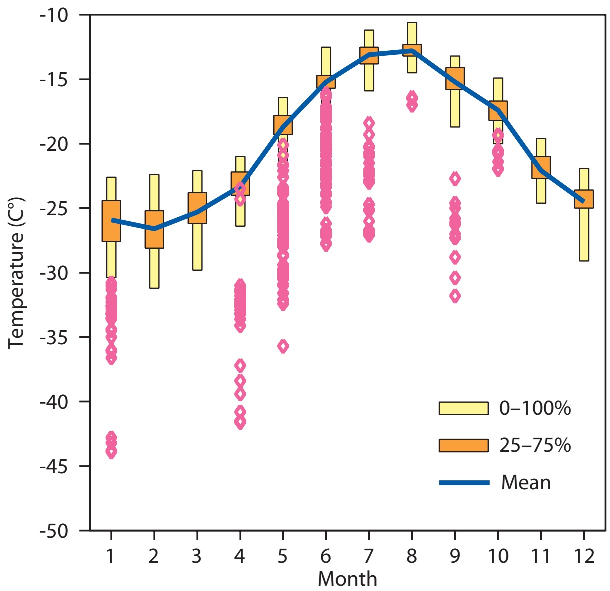

Figure 3 Monthly mean of the 500 hPa temperature (brown line) along with the corresponding coldest monthly mean (blue lines), and the warmest monthly mean (red lines) based on data from ERA-Interim for 1979 to 2008. Magenta dots show the minima of 280 cold drops.

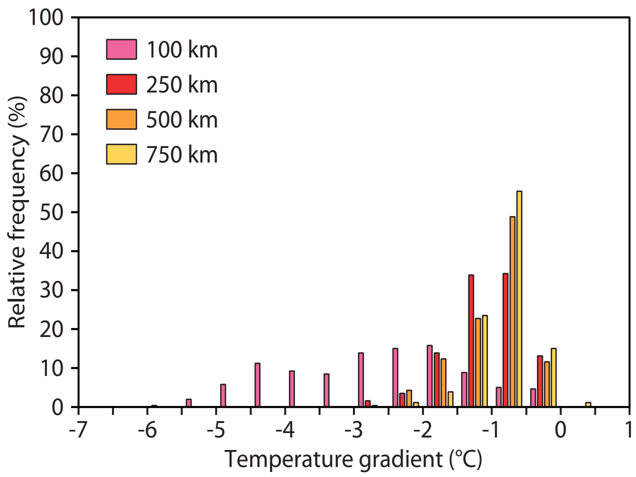

Figure 4 Histograms of the average horizontal temperature gradient (°C/100 km) around the centre of cold drops at 100, 250, 500 and 750 km at 400 hPa based on data from ERA-Interim for 1979 to 2008.

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Relationship among meteorological fields in cold drops

In this part of the work we extended the number of meteorological variables used for studying cold drops (*Gaál & Ihász,* 2014). The additional variables are 300 hPa wind speed, potential temperature at 2 PVU, isentropic potential vorticity at several levels including 315 K and 320 K, horizontal temperature advection at 500 hPa, and wind shear between 850 and 300 hPa. Here only two of the new meteorological variables are discussed: 300 hPa wind speed and potential temperature at 2 PVU.

Studying the connection between cold drops and jet streams, we found there is a very strong relationship between position of the cold core and structure of the jet stream. A typical lifecycle can be seen in Figure 5. As expected from thermal wind considerations, the jet stream is always located around the cold drop and we never see the wind maximum near the core. Before the tear-off phase the most intensive part of the jet stream quickly moves to the southern part of the wave. Then this maximum wind moves towards the northeast; this change causes a tearing of the drop. In most cases, due to further rotation of the cold drop, two intensive parts of the wind shear are visible: one to the left of the core and the other one to the right. For large cold vortices, three or four separated intensive parts of the jet stream can often be found. In the final phase of the lifecycle, when the cold drop joins to the main flow, an intensive part of the jet is always found towards the east. However, when the cold drop does not join to the main stream, it becomes stationary, typically with increased warming at the core and a decrease in the intensity of the jet stream.

As well as studying cold drops on standard pressure levels, it could be beneficial to apply 'pv-thinking'. Studying the relationship between the local minimum of the potential temperature at 2 PVU and position of the cold drops at 500 hPa, we found these two minima are typically very close to each other (Figure 6). If there is more than one cold core there are also more minima in the potential temperature at 2 PVU. We found that in the tearing phase, the pattern of the potential temperature at 2 PVU field is slightly behind that of the 500 hPa temperature with a delay of 12–18 hours.

Comprehensive study of several meteorological fields based on ERA-Interim, such as that just described, has two benefits. Firstly, good guidance could be provided for the successful prediction of cold drops using high-resolution and ensemble forecasts as we would have a better understanding of the typical relationships between various fields when cold drops occur. Secondly, it would be possible to recognise all cold drop cases in the European region during several decades for the whole reanalysis period.

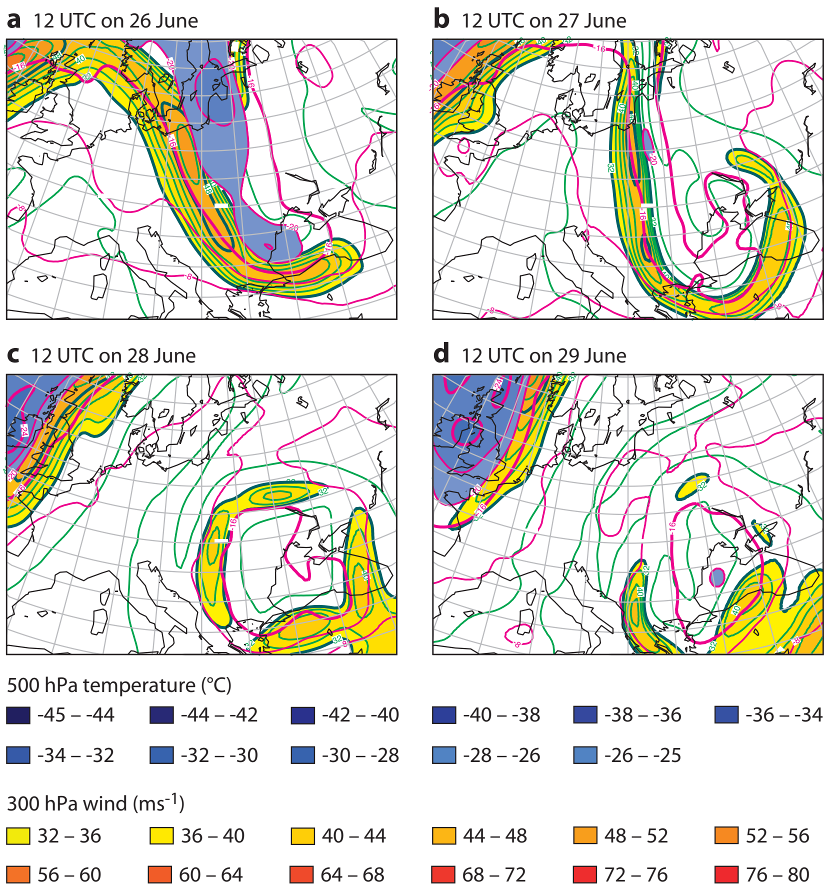

Figure 5 300 hPa wind and 500 hPa temperature at 12 UTC on (a) 26 June, (b) 27 June (c) 28 June and (d) 29 June 2011 using ECMWF's high-resolution forecast.

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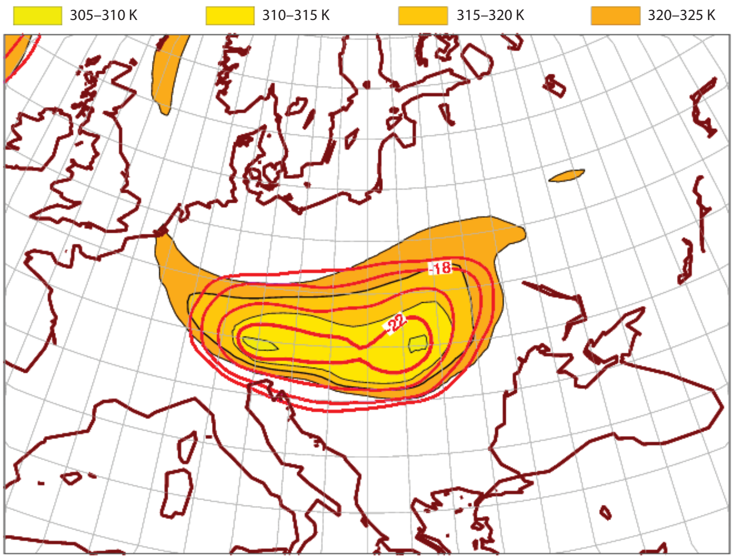

Figure 6 Potential temperature at 2 PVU (shading and black isopleths) and 500 hPa temperature (red isopleths) at 12 UTC on 2 July 2011 using ECMWF's high-resolution forecast.

New ensemble plumes for supporting recognition of the cold drops

Predicting cold drops using numerical weather prediction models is not an easy task. So it is worthwhile using ECMWF's ensemble forecast alongside the high-resolution forecast. At the Hungarian Meteorological Service a wide range of the ensemble-based graphical products are used in operations, among them plumes, meteograms, spaghetti and probability maps. As a result of our investigation of the cold drops we developed new tools using a variety of meteorological fields to support the better recognition and forecast of the cold drops. We developed two new types of ensemble plume diagram. One contains three variables: 500 hPa temperature, isentropic potential vorticity at 320 K and potential temperature at 2 PVU. The other one contains four variables: in addition to the previous three variables, the 300 hPa wind speed is also included.

The usefulness of these new tools can be demonstrated using a case study. On 2 July 2011 a cold drop travelled across Hungary – Figure 7 shows the ensemble plume based on four variables. We can see the strong U-shape on the second forecast day of the 500 hPa temperature (bottom panel), showing a high probability of about an 8 °C drop in 24 hours and a similar rise after the passing of the cold drop. A corresponding change can be seen in the potential temperature at 2 PVU (top panel). The change in isentropic potential vorticity of 320 K (lower middle panel) is the opposite of that found for the other two variables, so these three can support the recognition of cold drops. As already mentioned, the behavior of the 300 hPa wind speed (upper middle panel) is not usually synchronized in space with that of the other three variables but it can provide some useful information.

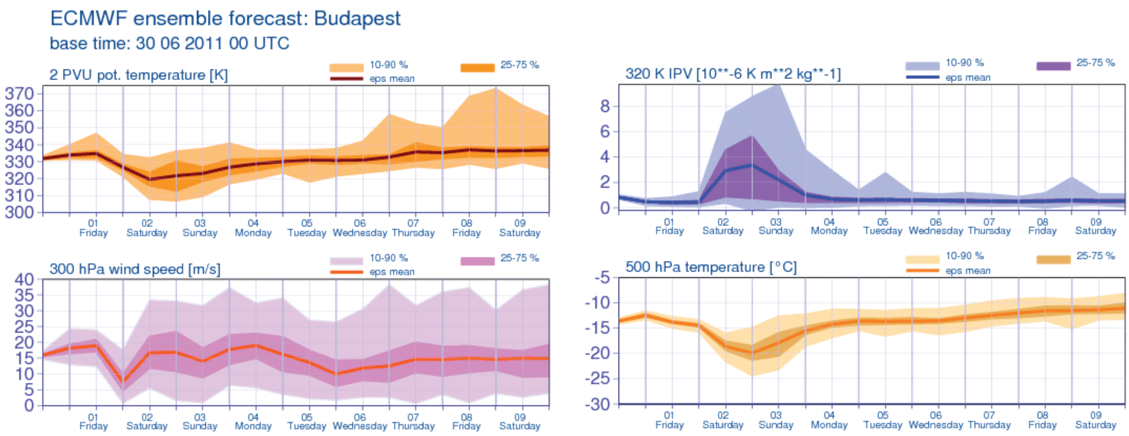

Figure 7 Ensemble plume, containing potential temperature at 2 PVU, 300 hPa wind speed, isentropic potential vorticity at 320 K and 500 hPa temperature for Budapest, based on ECMWF's ensemble forecast starting at 00 UTC on 30 June 2011.

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Summary and outlook

Because cold drops rarely occur at any specific geographical location, it is not an easy task to acquire a large sample of cases to study and summarize the typical characteristics of cold drops. Consequently, we collected information about cold drops from a large area and developed an objective method for their recognition.

As well as determining the general characteristics of the horizontal and vertical structure of cold drops, several new methods were developed for studying them with a view to providing guidance about the forecasting of cold drops. The two most important aspects are usage of the ensemble and high-resolution forecasts on isentropic levels. For operational practice, use of the ensemble forecast alongside the high-resolution forecast can provide very valuable additional information because the intensity and position of the cold drops are quite often uncertain. In addition to applying standard pressure level fields, potential temperature at 2 PVU and isentropic potential vorticity fields are also useful as they provide information about features of the cold drops that are not apparent on pressure levels. An objective process for detecting cold drops is required that is able to reliably distinguish them from cyclones. Our results so far make this a very real and achievable goal.

One of our plans is to identify the areas that have a potential for the formation of cold drops based on ensemble forecasts. In the future, we would like to run further tests with our detection algorithm for cold drops to study the last 30 years of cold drops, and we would also like to carry out further experimentation about the forecasting of cold drops.

Further reading

Gaál, N. & **I. Ihász,** 2014: Evaluation of the cold drops based on ERA Interim and ECMWF's ensemble model over Europe. *Időjárás* (accepted for publication)

Nieto, R., L. Gimeno, L. Torpe, P. Ribera, P. Gallego, R. Garcia-Herrera, J.A. Garcia, M. Nunez, A. Redano & **J. Lorente,** 2005: Climatological features of cutoff low systems in the Northern Hemisphere. *J. Climate*. 3085–3012.

ZAMG, 2007: Manual of synoptical and satellite meteorology: Conceptual models and cases studies. http://www.zamg.ac.at/docu/Manual/

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