Medium-range forecasting with ensemble prediction products

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1. Introduction

Ensemble prediction generates huge amounts of data, expected to contain precious information on atmospheric predictability. The main problem when it comes to its operational use is to design suitable products to provide potential users with this information. The daily output of an operational Ensemble Prediction System (EPS) is a collection of forecasts, which are different possible realisations of the meteorological future. From this collection can be derived any weather parameter probability distribution, straightforward or through different statistical methods involving parametric adjustment or calibration. This set of distributions, provided they are reliable, should fulfil all operational requirements, since the probability of virtually any meteorological event can be extracted from them: simple events, such as the mere probability of significant precipitation; more complicated ones such as the probability of having at least one point over an area where the wind speed will exceed 20m/s some time during a period of 5 days. Information extracted from this set of probability distributions can also take more deterministic forms than probabilities, as shown figure 1: the median value of the distribution represents the best forecast available, the most likely to verify; a confidence interval around the median value adds some information on the uncertainty of a deterministic forecast based on the median value.

All users requirements could theoretically be fulfilled by a combination of these different forms of information (right part of figure 2). On the other hand, end users are not necessarily satisfied with probabilities or confidence intervals. They would certainly appreciate *explanations*, designed to help them to take their decisions from the probabilistic information. These explanations are not supposed to add any information to the probabilistic forecast, but to allow the end user to understand what the forecast *means* by mentioning the different meteorological possibilities and their consequences on the weather elements. This can only be the result of an *interpretation* of ensemble products by an experienced forecaster, able to understand for instance why a 20% probability of strong precipitation is associated with a given set of ensemble forecasts. The problem is that the distribution of meteorological situations is quite difficult to understand: it is almost impossible (in operational conditions) to catch the differences and similarities between 51 forecasts, even over a limited area. Different products derived from the direct output of the EPS have been designed to facilitate this interpretation. These products allow a forecaster to visualize specific aspects of the ensemble distribution (left part of figure 2):

- Mainly based on the interpretation of the *ensemble mean*, the deterministic component of the forecast is a description of the most likely meteorological conditions.
- The forecast uncertainty may be expressed by an indication of the *confidence* one should have in the deterministic forecast, based on the interpretation of the *ensemble spread* (e.g. standard deviation or "spaghetti" charts).
- The forecast uncertainty is more explicitly expressed by the description of meteorological *variants*, i.e. alternative, possible but less likely meteorological conditions, based on the interpretation of ensemble forecasts *classification* (e.g. clustering).

This paper describes a new method of classification of ensemble forecasts, the tubing, proposed as an alternative to conventional clustering methods, and designed to be the basis of the forecasters interpretation of the EPS data.

2. The tubing

The idea of the tubing is based on 3 main assumptions: (i) ensemble distributions can generally be considered as monomodal; (ii) the verification is most likely to be found in the vicinity of the ensemble mean; (iii) ensemble modes are not reliable, i.e. even in case of multimodality the verification is still more likely to be found nearby the ensemble mean than around the modes.

From these assumptions come the main characteristics of the tubing, a method of classification of ensemble forecasts (i) suitable with monomodal distributions, (ii) giving more emphasis to the ensemble mean and (iii) disregarding possible modes in the distribution. Unlike conventional clustering methods, the tubing does not group the members around hypothetical centroids, but along axes coming from the ensemble mean and reaching the extremes of the distribution. If the ensemble distribution is properly sampled and reliable, these axes should represent the directions in which the verification is likely to deviate from the ensemble mean. The algorithm is illustrated figure 3:

- The *central cluster* is a spherical cluster obtained by grouping those members lying around the ensemble mean. The radius of the central cluster is limited according to the season.
- The member which is the most remote from the ensemble mean is located. It becomes the first *extreme* and defines a *tube* grouping those members lying in the cylinder whose axis of symmetry goes from the ensemble mean to the extreme of the tube, and whose radius is the same as for the central cluster.
- The process is then iterated until all members are classified, with the following rule: a member belonging to a tube cannot become an extreme (but can still be classified in an other tube).

When classification is completed the central cluster members are averaged. The central cluster mean exhibits a smooth field, similar to the ensemble mean by construction, which indicates the main, large scale meteorological option to follow in a deterministic approach, since it is the most likely to verify.

The tubes are not averaged but represented by their extremes: since the tube members are not grouped around a centroid but along an axis, a tube mean does not make much sense. However the main information is not to be found in the extremes of the tubes themselves, but in the meteorological differences between these extremes and the central cluster, indicating the possible *deviations* from the main option.

The main parameter of the tubing algorithm is obviously the condition limiting the size of the central cluster. For operational purposes this limitation is seasonal dependent so that the smoothness of the central cluster mean field varies little from day to day, the internal spread following the seasonal, slow variations of the meteorological uncertainty. The other advantage is that the number of tubes varies from day to day according to the actual ensemble spread, i.e. the actual meteorological uncertainty: there may be no tube at all, when the spread and the uncertainty are small, all members being grouped together in the central cluster, as well as plenty of tubes when the spread and the uncertainty are large. As shown in the table below, a simple confidence index based on the number of tubes, i.e. the number of possible meteorological variants, proves quite successful:

number of tubes	ensemble mean RMSE	confidence index	frequency
0-1-2	75 gpm	high	27%
3-4-5	84 gpm	normal	47%
>5	109 gpm	low	26%

Overall, the tubing provides a complete set of information :

- The central cluster mean field is the basis of the deterministic component of the forecast.
- The number of tubes gives the level of confidence of the deterministic forecast.
- The tubes extremes indicate the possible meteorological variants.

3. An example of meteorological interpretation based on the tubing

The usefulness of the tubing is discussed in this section on a forecast case study. The +144h EPS forecast based on 22/01/1997 had a large spread (84 gpm) over Western Europe. A ridge was forecast by the T213 model (as the EPS control, not represented since almost identical) to build up off Ireland and a consequent Northerly anticyclonic flow to establish over Britain and France (figure 4). The ensemble spread mainly related to the development of this ridge and its effects on the circulation over Western and Central Europe.

The tubing has been applied to this forecast with a 60 gpm threshold for the central cluster standard deviation (figure 5). The central cluster clearly supports the control forecast: with a 60 gpm threshold the averaged field is hardly smoothed, and the main synoptic features are still discernable. 4 tubes indicate different possible deviations from the main option:

- Tube 1: The Northerly flow might be more cyclonic and stronger over the British Isles.
- Tube 2: On the contrary the ridge might develop further into the continent.
- Tube 3: The ridge might evolve into a dipole with a cut-off low over SW Europe.
- Tube 4: A large scale cut-off low might affect the Eastern part of Western Europe.

The two first tubes indicate the main, larger possible deviations. At the opposite the last tube is not very different from the control forecast. The 3rd tube proves to indicate the "right" deviation from the ensemble mean: the verification pattern does not match the extreme of the tube itself, but can be subjectively localized somewhere between the ensemble mean and the extreme of the tube (see verification figure 11, bottom right).

Grid-point probabilities have been computed from the EPS distribution -without any parametric adjustment or calibration- to illustrate how the tubing can be interpreted by operational forecasters to complement "raw" probabilistic forecasts, by identifying the main possible meteorological variants. Significant rain probability (precipitation > 1mm/24h) ranges approximately from 10% to 60% over France (figure 6). Except over the Pyrenees region, where Northerly flows are likely to cause orographic precipitations, the risk of rain over the Western half of the country does not exceed 30-40%. The main synoptic pattern indicated by the central cluster leads indeed to dry anticyclonic conditions over this area. The 30-40% probability is mostly associated with the tendency represented by the tube 1: if the ridge does not develop as much as indicated by the main option, a secondary wave is likely to pass through at a stage or an other, leading to a rainy interval over the considered area.

Frost probabilities (T2m < -5C some time during the two nights surrounding the +144h time-step) indicate a significant risk of 20-30% over Northern Germany (figure 7), although a deterministic forecast based on the central cluster synoptic pattern would probably exclude it: a wet, cloudy weather is more likely to occur over this area with the North-Westerly cyclonic flow. The risk of frost is obviously associated with the tendency pointed out by the tubes 2 and 4, indicating a stronger ridge developing further over the continent and inducing anticyclonic, dry conditions over this part of Europe.

4. Summary

The tubing method has been designed to facilitate a human interpretation of the distribution of meteorological forecasts produced by the EPS, in order to complement on meteorological grounds the probabilistic forecasts generated from weather parameters probability distributions. The tubing condenses the information from the EPS by highlighting the main differences between ensemble forecasts. The forecast distribution is represented by (i) the central cluster mean, grouping those ensemble forecasts lying around the ensemble mean, indicating the most likely meteorological pattern, (ii) the extreme forecasts located on the edges of the distribution, whose differences from the central cluster mean indicate the possible meteorological deviations from the most likely forecast.

Figures captions:

Figure 1: Hypothetical probability distribution of the minimum 2m temperature at one model grid-point, as it can be extracted from the EPS daily output. The median value, a confidence interval and a specific probability are represented:

- a deterministic forecast, based on the distribution median value, would be +2dg;
- the forecast uncertainty would be expressed by the -1dg/+4dg interval indicating 80% confidence (note that the interval is not necessarily symmetric, depending on the distribution);
- a 20% probability of frost represents the most complete information with respect to the risk of frost, but does not inform the user on other characteristics of the probability distribution.

Figure 2: Schematic representation of the proposed methodology for the use of the EPS output in operational weather forecasting. The right hand part represents the direct, automatic way to satisfy the user requirements. The left hand part represents the interpretative way, based on the use of different products by a forecaster. Both approaches are complementary.

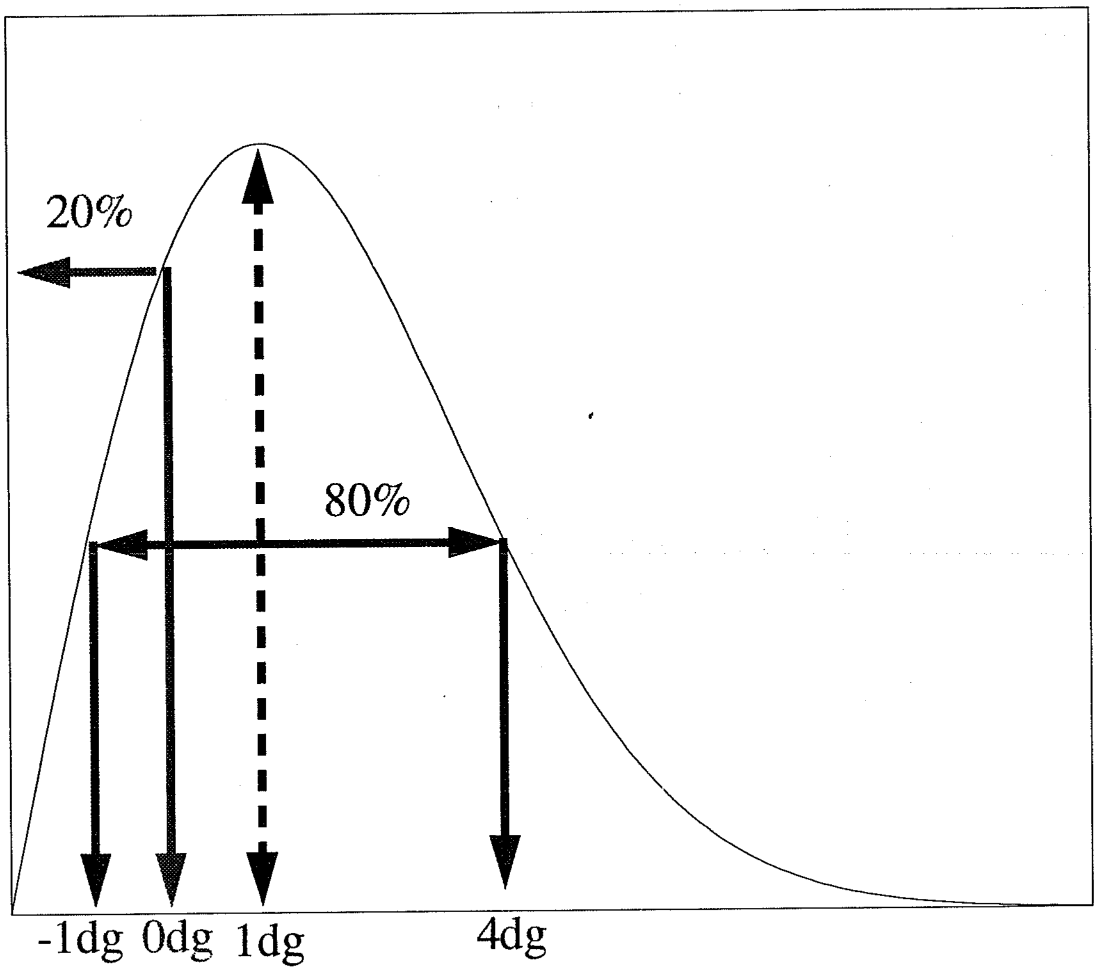
Figure 3: Schematic representation of the tubing algorithm. The *central cluster* groups those members lying around the ensemble mean. The *tubes* are defined by their *extremes*, which are the most remote members from the ensemble mean.

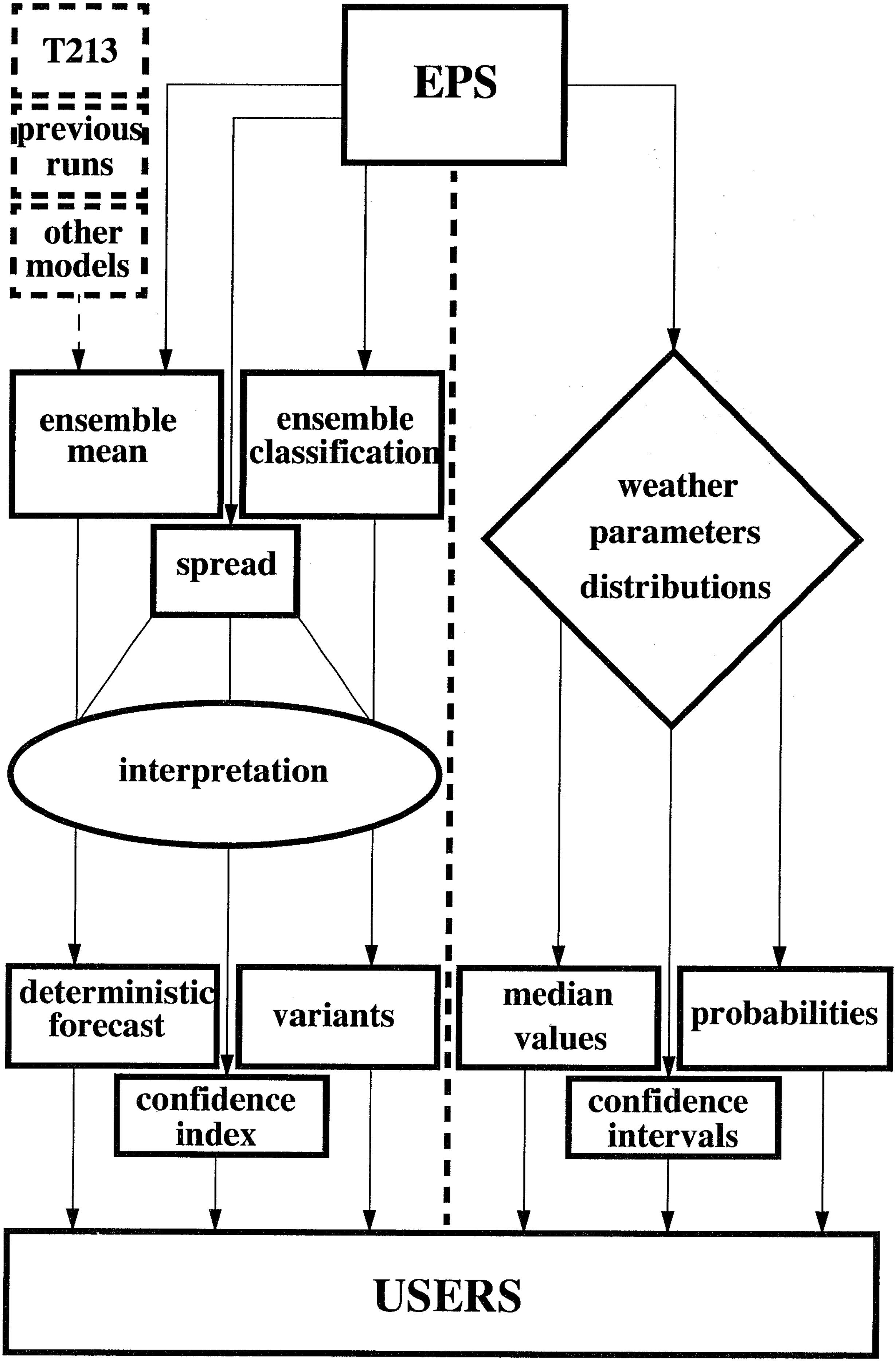
Figure 4: T213 ECMWF model +120h/+144h forecast based on 22th January 1997. Z500hPa.

Figure 5: Tubing applied on the EPS based on 22th January 1997, +144h. The central cluster standard deviation was limited to 60gpm. Western Europe, Z500hPa.

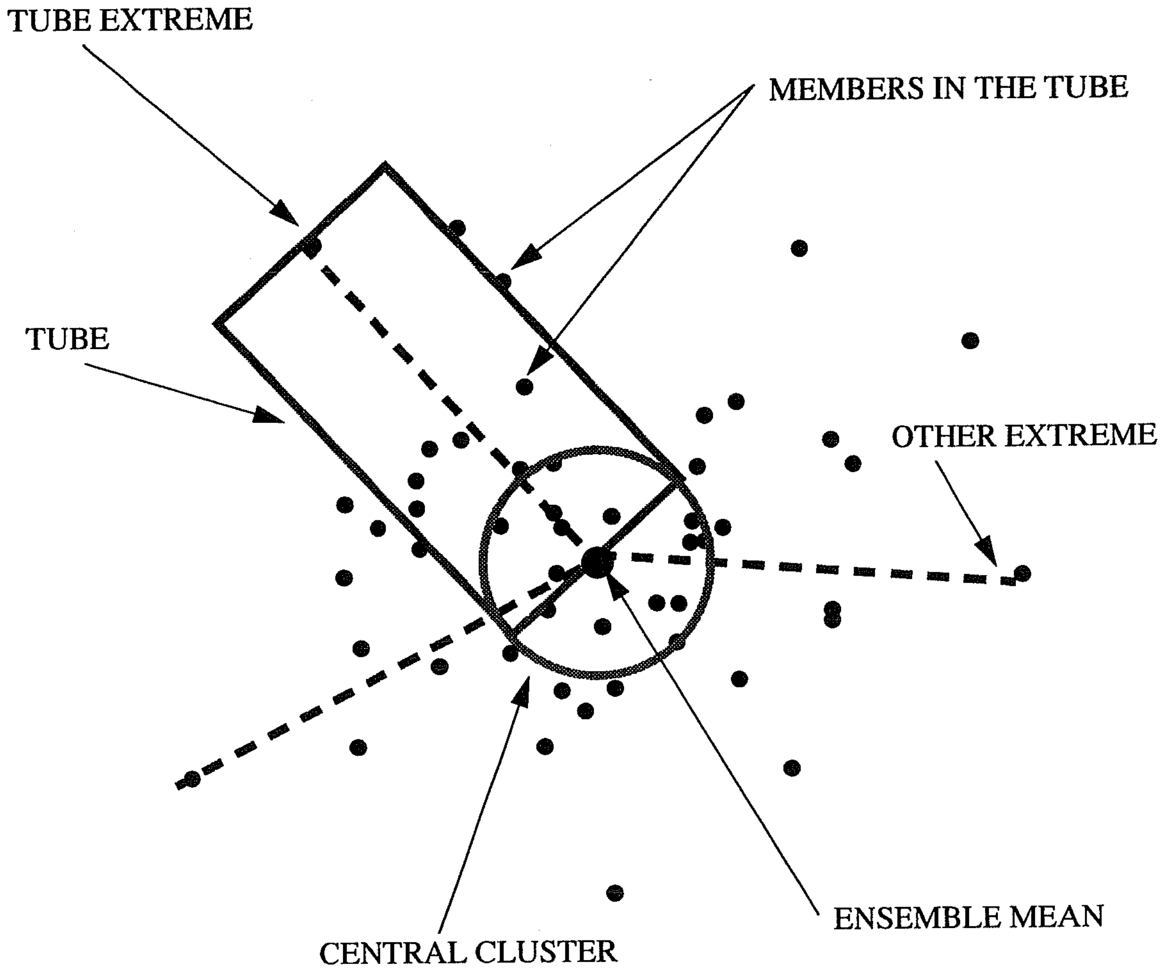
Figure 6: EPS probability of precipitation above 1mm/24h. 22th January 1997, +144h.

Figure 7: EPS probability of 2m temperature below -5C. 22th January 1997. +120h to +168h.

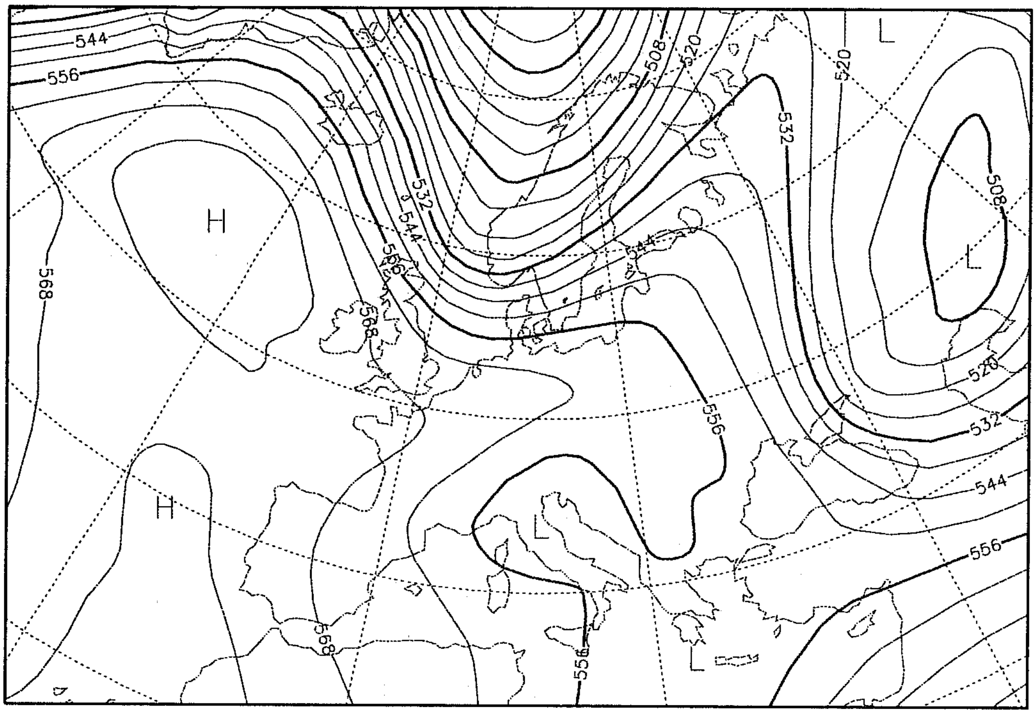

20%
80%
-1dg
0dg
1dg
4dg


T213
previous runs
other models
EPS
ensemble mean
ensemble classification
spread
interpretation
weather parameters distributions
deterministic forecast
variants
confidence index
median values
probabilities
confidence intervals
USERS

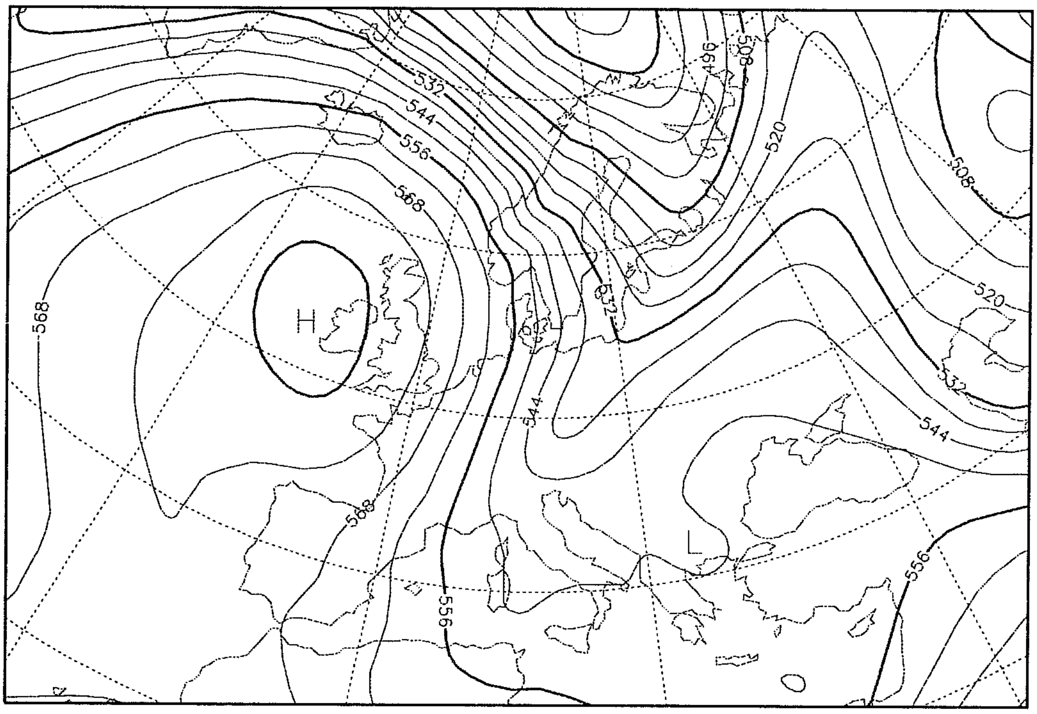
THE TUBING


TUBE EXTREME
MEMBERS IN THE TUBE
TUBE
OTHER EXTREME
CENTRAL CLUSTER
ENSEMBLE MEAN

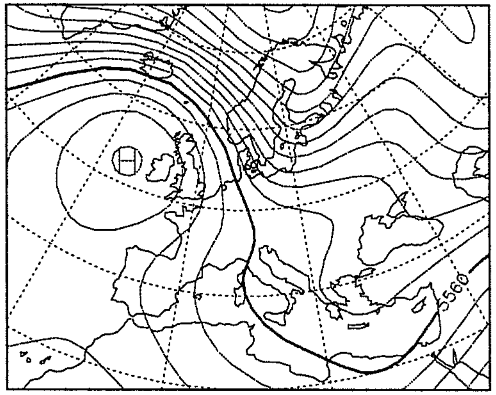
Wednesday 22 January 1997 12z ECMWF Forecast t+120 VT: Monday 27 January 1997 12z
500 hPa geopotential



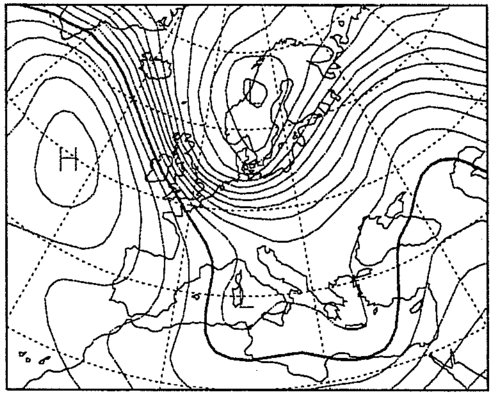
Wednesday 22 January 1997 12z ECMWF Forecast t+144 VT: Tuesday 28 January 1997 12z
500 hPa geopotential



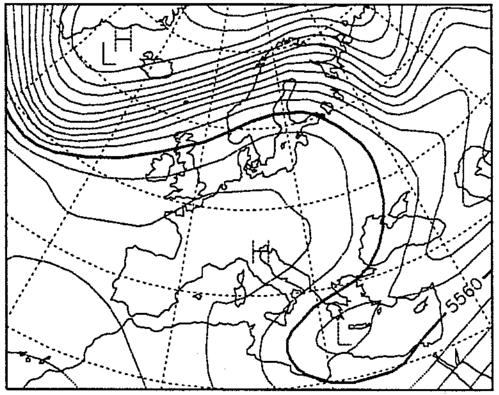
22/1/97 +144h CC 30mb var=29 std=60m rad=83m



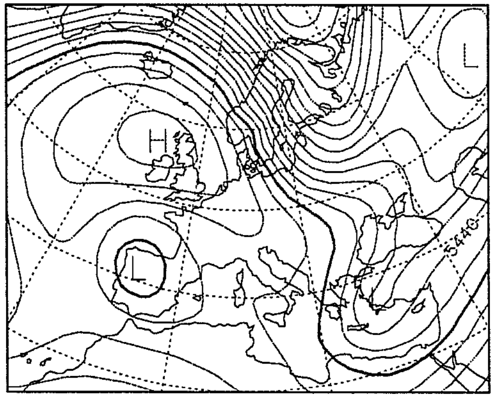
22/1/97 +144h tube 1 ext at 190m (11mb)



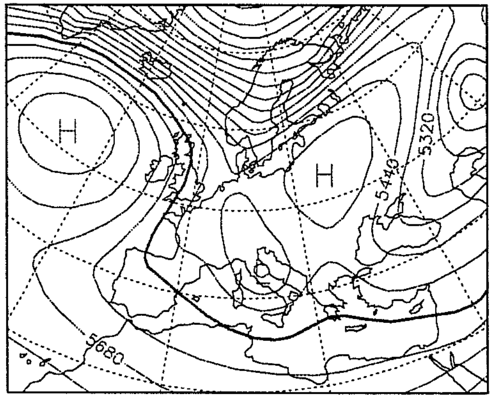
22/1/97 +144h tube 2 ext at 113m (8mb)



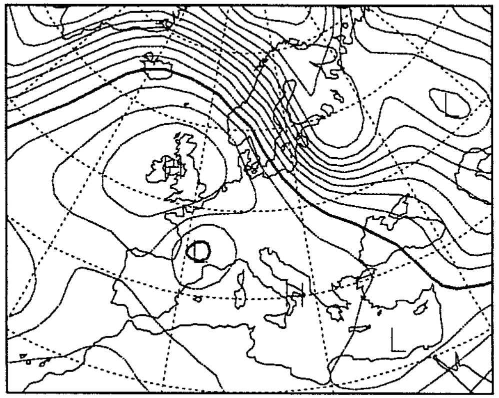
22/1/97 +144h tube 3 ext at 100m (4mb)



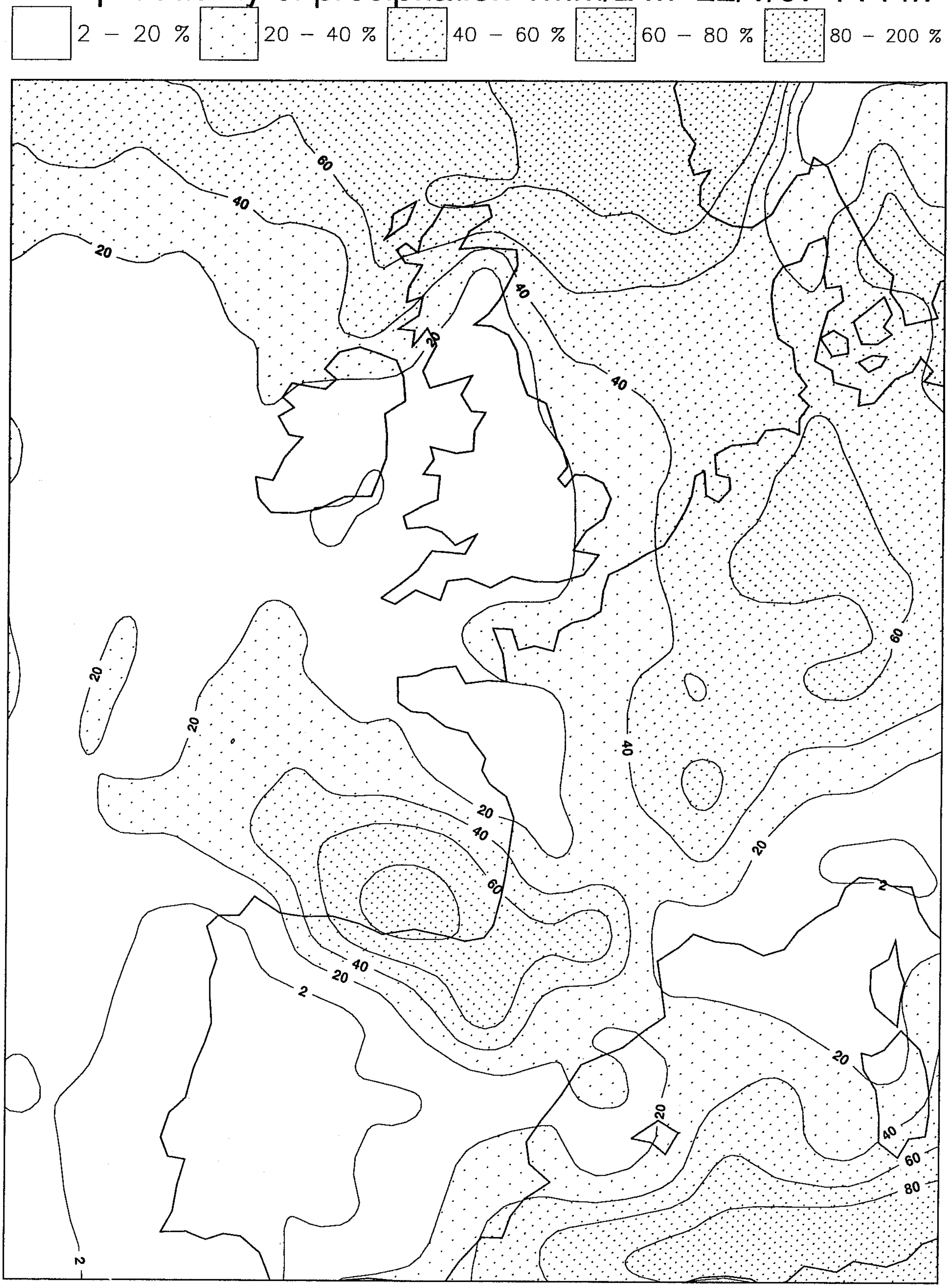
22/1/97 +144h tube 4 ext at 100m (2mb)



28/1/97 12h verification



EPS probability of precipitation 1mm/24h 22/1/97 +144h



EPS t2m probabilities based on Wednesday 22 Jan 1997 event occuring at least once from +120h to +168h thresholds: min -50 max -5

☐ 2 – 20 % ░ 20 – 40 % ░ 40 – 60 % ▒ 60 – 80 % ▓ 80 – 100 %