Summary

A revised set of physical parametrizations for the IFS has been described. Apart from a general reduction of model temperature bias, the direct impact upon medium-range forecasts is small. However, there is a large impact upon the ability of the model to accurately capture many aspects of the tropical climate on seasonal timescales. The improved distribution of heating and TOAand surface energy budgets is of benefit to coupled ocean-atmosphere modelling at ECMWF and hence to forecasting on seasonal time-scales.

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Tubing: an alternative to clustering for EPS classification

Ensemble prediction generates huge amounts of data. The main problem for operational use is the design of manageable products for potential users. The daily output of the ECMWF operational Ensemble Prediction System (EPS) is a collection of forecasts, which are different possible realisations of the meteorological future. From this collection, any weather parameter probability distribution can be derived. 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.

On the other hand, end users are not necessarily satisfied solely with probabilities. They certainly appreciate *explanations*, designed to help them 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 why the probabilities of weather elements occur, by mentioning the various meteorological possibilities. This 'added value' 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 distribution of ensemble forecasts.

The problem is that the distribution of ensemble forecasts is rather difficult to interpret on a meteorological basis: it is almost impossible – in operational conditions – to catch the differences and similarities between 51 forecasts, even over a limited area. Different products have been designed in order to facilitate the forecasters interpretation. Some allow visualisation of specific aspects of the distribution, like the ensemble mean field used as a smooth forecast of the large scale pattern, or the ensemble spread indicating the uncertainty associated to the different meteorological features. Other products are based on an objective classification of ensemble members, indicating the main alternative meteorological patterns. The tubing method belongs to that last category and is proposed as an alternative to conventional clustering techniques.

The tubing algorithm

The idea of tubing is based on the following assumptions:

- Ensemble forecast distribution can generally be considered as monomodal.
- The verification is most likely to be found in the vicinity of the ensemble mean.

- Ensemble modes are generally not reliable: in case of multi-modality the verification is still more likely to be found near the ensemble mean than in the vicinity of ensemble modes.

The tubing is a method of classification of ensemble forecasts that suits monomodal distributions, gives large emphasis to the ensemble mean, and indicates a highly contrasted picture of the possible alternative scenarios.

Unlike conventional clustering methods, the tubing algorithm 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 reliable, these axes should represent the directions along which the verification is likely to deviate from the ensemble mean. The algorithm is illustrated figure 1:

- The *central cluster* is obtained by grouping a certain number of those members lying around the ensemble mean. The number of members depends on the tubing configuration, detailed in the next section.
- 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 another tube).

The central cluster mean field, similar to the ensemble mean field by construction, indicates the main meteorological option to follow in a deterministic approach, the large scale forecast which 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, which indicate the possible *deviations* from the main option.

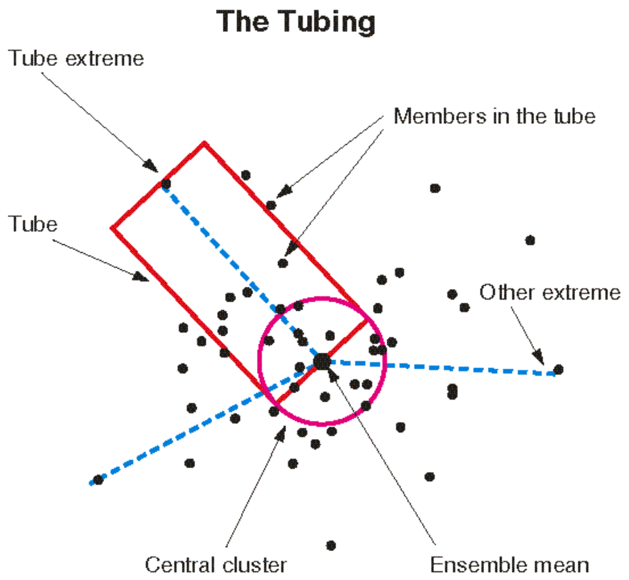

Figure 1: *Schematic representation of the tubing algorithm. The central cluster groups those members lying around the ensemble mean. The tubes are defined by their extremes, which are the most remote members from the ensemble mean.*

The tubing configurations

The main parameter of the tubing algorithm is obviously the condition limiting the population of the central cluster. Two main configurations can be distinguished, whether this limitation depends on the actual ensemble spread (spread dependent configuration) or on the expected, 'climatological' ensemble spread (seasonal dependent configuration).

In a spread dependent configuration, eg. central cluster variance limited to 50% of the total ensemble variance, the population of the central cluster varies little from day to day. The central cluster internal spread follows the variations of the ensemble spread, and so does the smoothness of the averaged field, high uncertainty resulting in a smoother field. On the other hand the number of tubes varies little from day to day.

In a seasonal dependent configuration, on the contrary, the smoothness of the central cluster mean field varies little from day to day, since the internal spread follows the seasonal, slow variations of the meteorological uncertainty. On the other hand the number of tubes varies from day to day according to the actual ensemble spread, ie. the actual meteorological uncertainty: there may be no tube at all, when all members are grouped in the central cluster, or plenty of them when the spread is especially large.

Both configurations apply similarly to agglomerative clustering algorithms. Aseasonal dependent limitation of the clusters standard deviation is applied for instance to the ECMWF operational clustering. This configuration appears indeed the most suitable for operational purposes, since it allows forecasters to directly link the number of possible meteorological variants – given by the tubes or the clusters – to the forecast uncertainty. The spread dependent configuration is rather suitable for verification purposes and case studies, since it allows one to visualize a given proportion of information (ie. of variance) from the ensemble distribution.

Tubing and clustering

The differences between clustering and tubing are fundamental: clustering algorithms focus on ensemble forecasts similarities, whereas tubing groups ensemble forecasts according to the fact that they *differ* similarly from the ensemble mean. To illustrate their differences the tubing and the operational ECMWF clustering algorithm have been applied to a 2-dimensional ensemble of 51 points randomly extracted from a Gaussian distribution. This idealised ensemble, although roughly monomodal, exhibits local sampling accumulations (figures 2 and 3). A similar

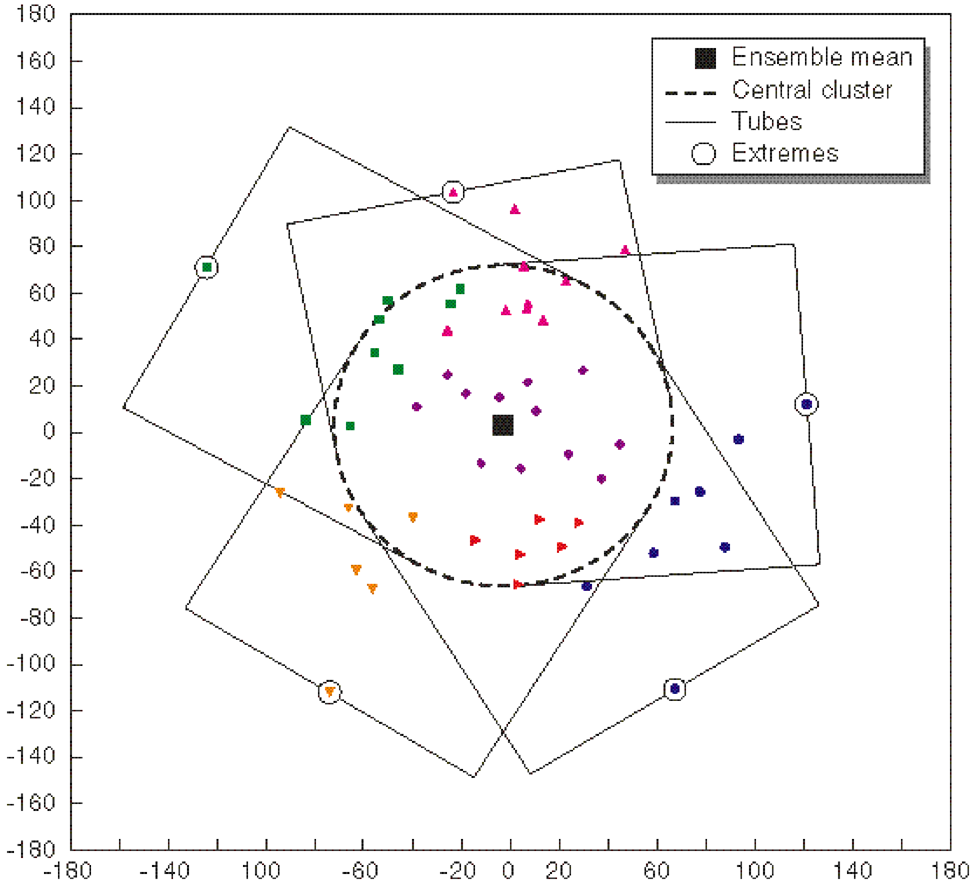

Figure 2: *Tubing applied to a 2-dimensional idealised ensemble extracted from a Gaussian distribution, giving a central cluster grouping 32 members and 5 tubes.*

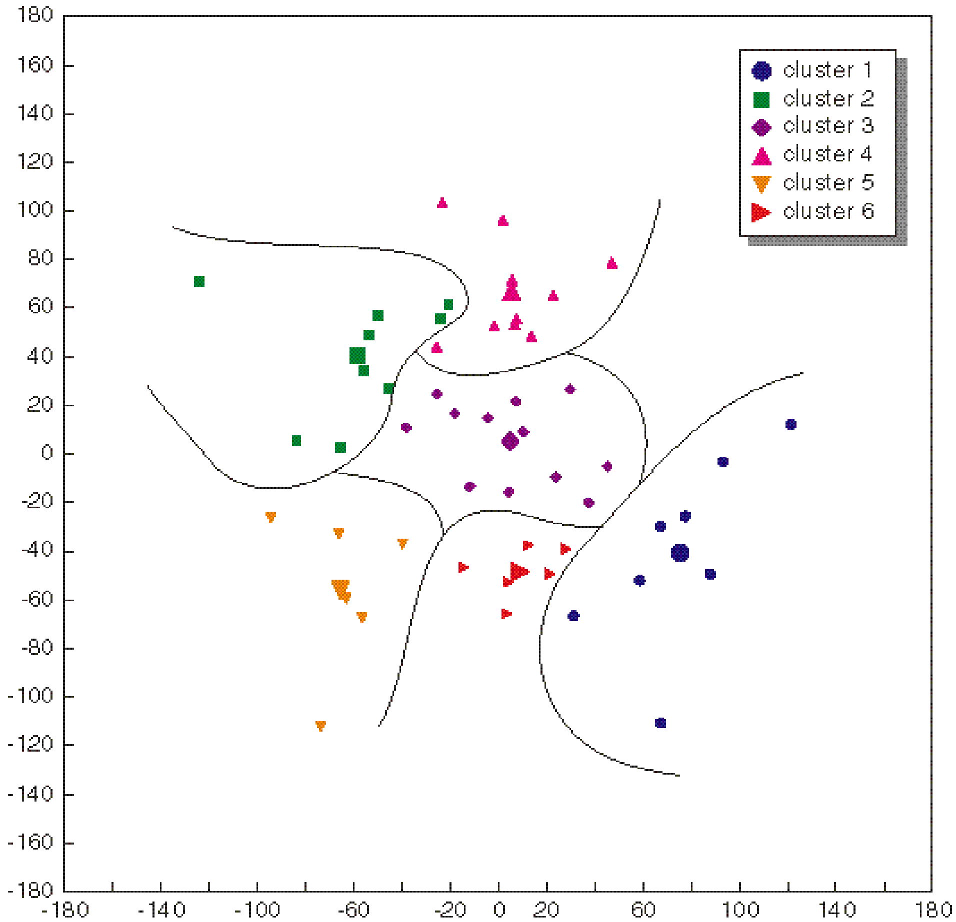

Figure 3: *Same as figure 2, but clustering algorithm. The clustering classification gives 6 clusters, grouping 8, 9, 12, 10, 6 and 6 members.*

configuration has been used to limit the population of the tubing central cluster and the Ward clusters (st. dev.<50 m).

The Ward algorithm is clearly not suitable for such a distribution: the boundaries between the clusters are arbitrary, often separating members very close to each other; the cluster centroids, close to each other and to the ensemble mean, give a poor representation of the ensemble distribution. On the contrary the tubing classification widely 'covers' the whole distribution by localising its centre and its extremes. The tubes boundaries appear as arbitrary as the clusters boundaries, but this should not be considered as a drawback since the tubes are not supposed to be averaged. The tube extremes indicate possible departures from the ensemble mean. Because they are extracted from the low density part of the distribution, tube extremes are very sample dependent compared with clustering centroids. This dependency, which should always be kept in mind when using the tubing product, is the price to pay in order to get more significant indications about the distribution of ensemble forecasts.

Meteorological interpretation based on the tubing classification

The usefulness of the tubing product is discussed in this section on a forecast case study. The +144h EPS forecast based on 22/01/1997 had a large spread (84 m) over Western Europe. Aridge 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.

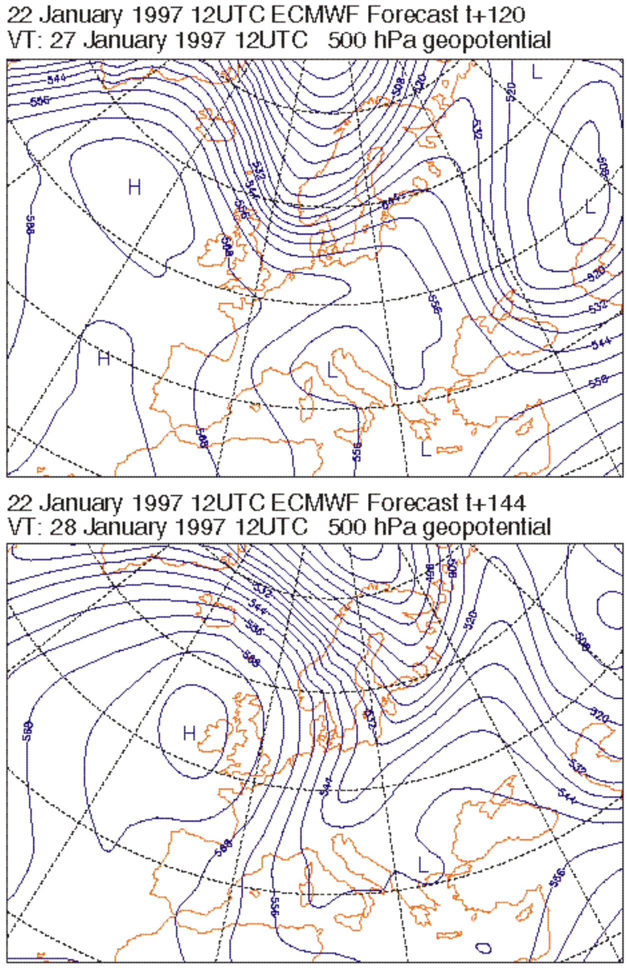

***Figure 4:** T213 ECMWF model +120h/+144h forecast based on 22nd January 1997, 500 hPa height.*

Tubing

The tubing classification has been applied to this forecast with a 60 m threshold for the central cluster standard deviation (figure 5). The central cluster clearly supports the control forecast: with a 60 m threshold the averaged field is hardly smoothed, and the main synoptic features are still discernable. Four 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 Central Europe.

The two first tubes indicate the main, larger possible deviations. At the opposite extreme 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 5, bottom right).

Figure 6 shows all the members grouped along the first tube axis, together with the control and the closest member to the ensemble mean: from the closest member to the central cluster boundaries, located 104 m from the ensemble mean, exhibiting a rather anticyclonic North-Westerly flow, through gradually more cyclonic patterns, up to the extreme at 190 m. It is noticeable that some members, eg. the 5th one, do not fully support the tube tendency given by the extreme. As in any classification, the loss of information can only be compensated by an increase in resolution, ie. an increase of the number of tubes, obtained by limiting the size of the central cluster. But this would be at the expense of the conciseness that is of primary importance for operational use in a forecasting office.

Clustering

AWard clustering has been applied to the same situation, giving 5 clusters with a similar configuration (figure 7). The second, most populated cluster, exhibits more or less the same pattern as the control or the tubing central cluster, whereas the 1st and the 3rd ones seem to support the 2 first tubes options, although not as strikingly as the tubes extremes. The 4th and the 5th clusters support more clearly

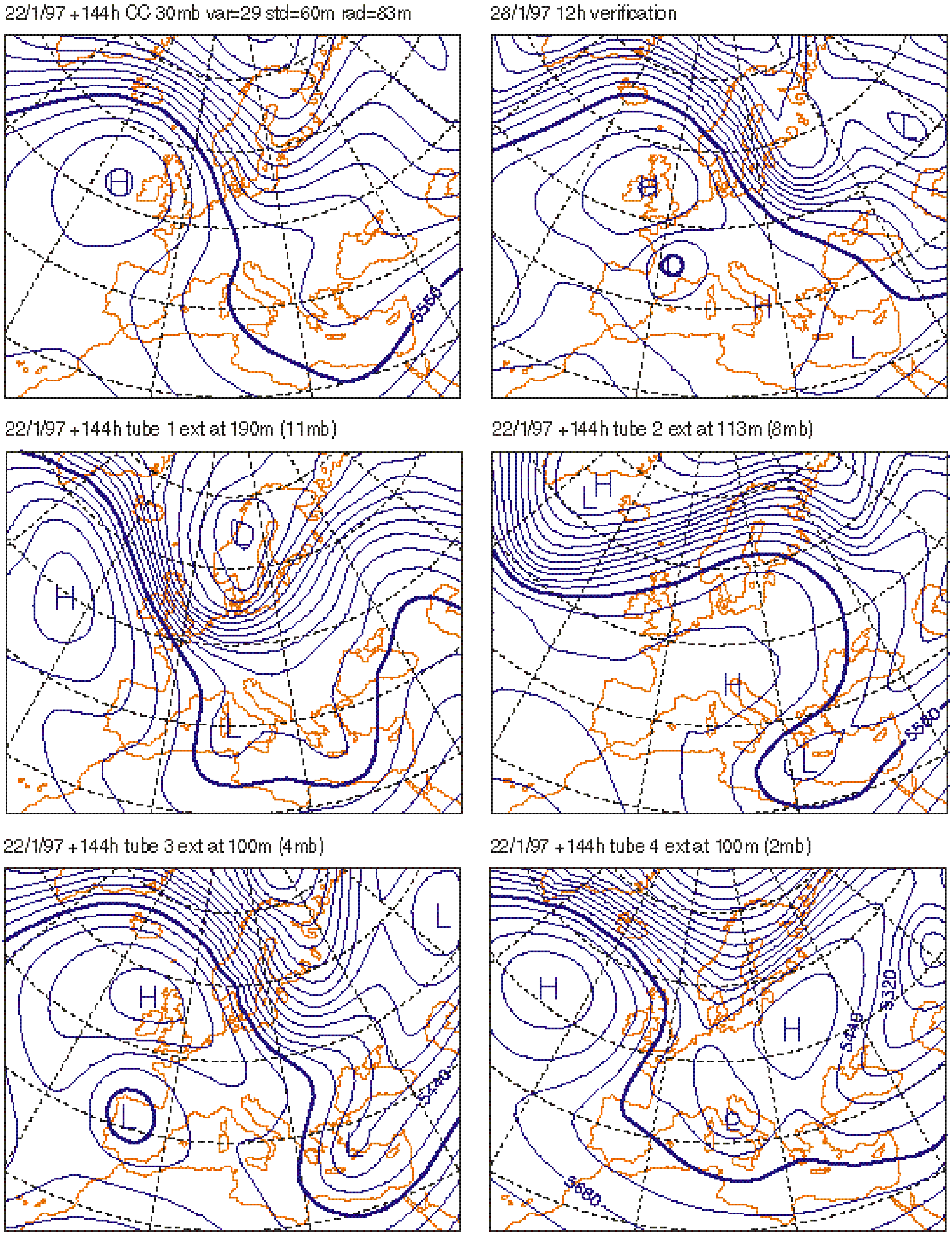

Figure 5: *Tubing applied on the EPS based on 22nd January 1997, +144h. The central cluster standard deviation was limited to 60 m. Western Europe, 500 hPa height.*

the first tube tendency. The tube 3 and tube 4 tendencies are not represented by the clustering classification.

The clusters look more similar than the tubes extremes. This similarity, commonly reported by forecasters, is not only due to the 'smoothing effect' when averaging different fields (although it should not have such an impact if clustering only reflected 'natural' modes) but also to the distribution being monomodal, leading the centroids to lie around the ensemble mean rather than along the edges of the distribution (see section 4).

Probabilities

Grid-point probabilities have been computed from the EPS distribution to illustrate how the tubing product can be interpreted by operational forecasters to complement probabilistic forecasts, by identifying the main possible meteorological variants. Significant rain probability (precipitation > 1 mm/24h) ranges approximately from 10% to 60% over France (figure 8). Except over the Pyrenees region, where Northerly flows are likely to cause orographic precipitation, 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 some stage, leading to a rainy interval over the considered area.

Frost probabilities (T2m < -5°C some time from +120h to +168h) indicate a 20 – 30% risk over Northern Germany (figure 9), although a deterministic forecast based on the central cluster synoptic pattern would probably exclude it: 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.

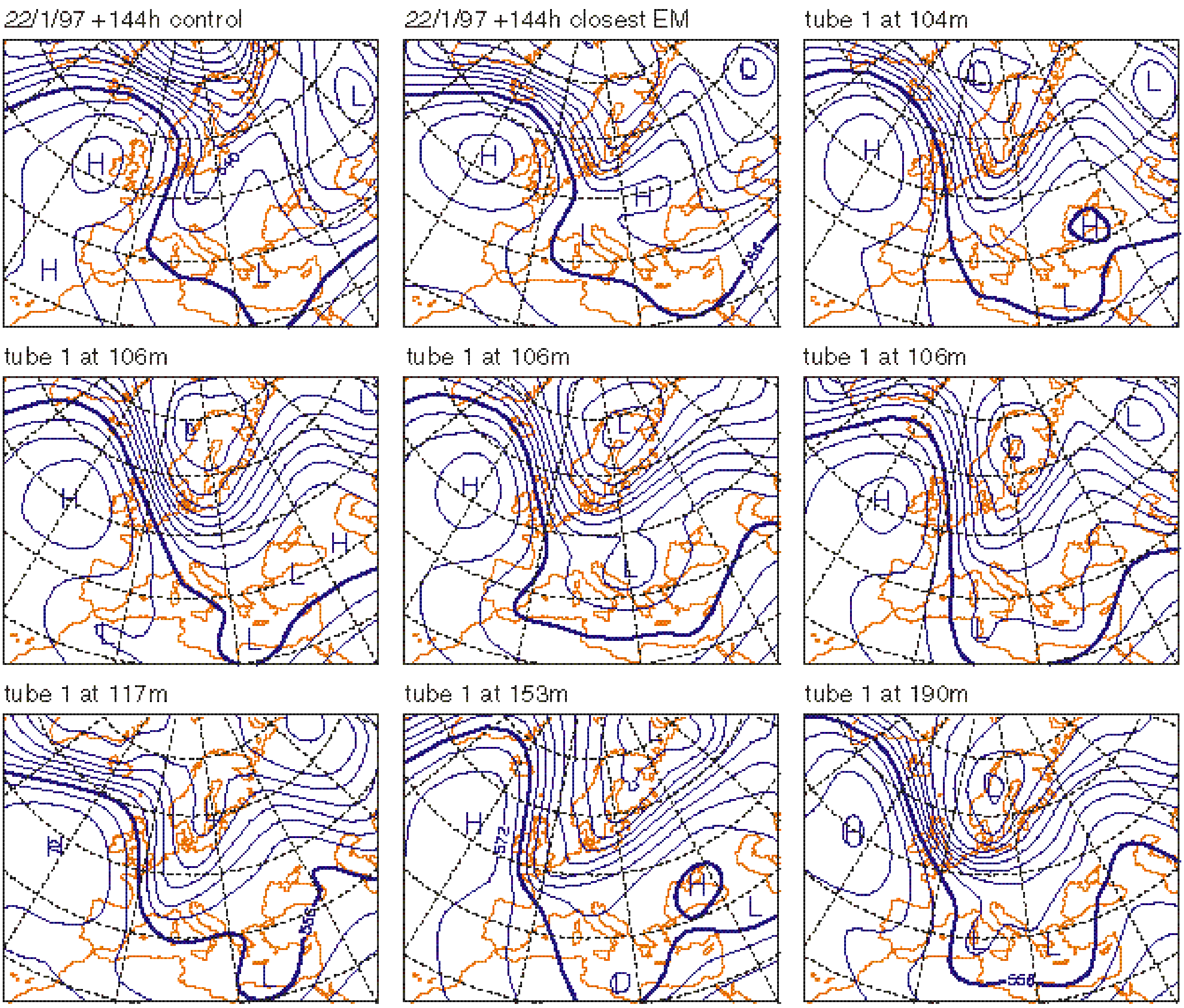

Figure 6: Ensemble forecasts grouped along the axis of the first tube.

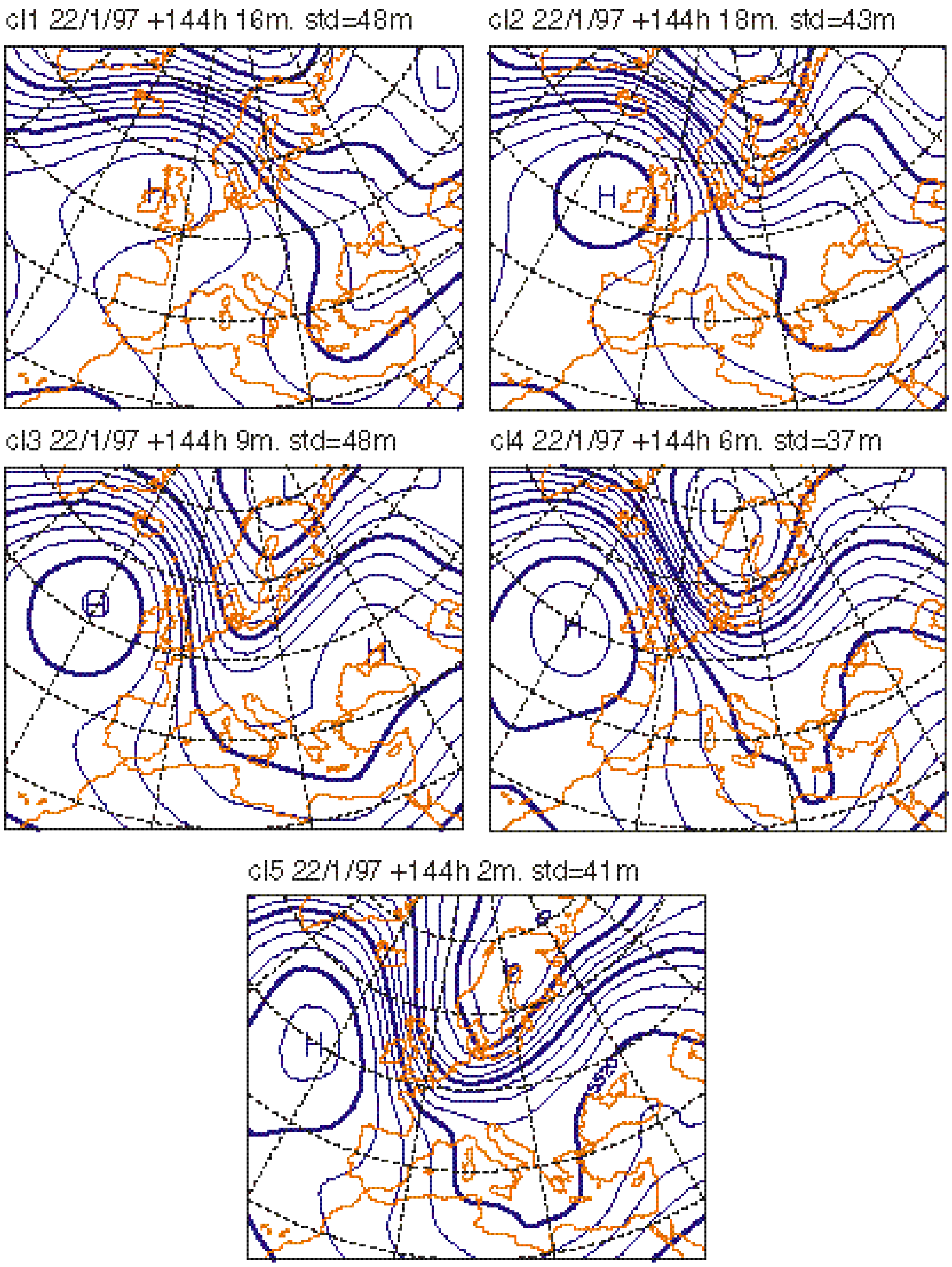

Figure 7: *Same as figure 5, but for a Ward clustering.*

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 the probabilistic forecasts generated from weather parameters probability distributions. 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.

Unlike conventional clustering methods, tubing is not designed to pick out alternative scenarios from a multimodal distribution. The underlying assumption is that ensemble distribution is generally monomodal, and distribution modes, when they exist, are spurious effects of sampling. The overwhelming performance of the ensemble mean, whatever the forecast distribution, is the basis on which the method was built. Still, tubing is an effective method of classification even when distributions are multi-modal, although it obviously emphasizes in this case the central part of the distribution at the expense of the existing modes, merely represented as possible deviations of the main central cluster pattern.

Tubing is indeed a method for *visualising* the forecast distribution, rather than a way of classifying arbitrarily ensemble members. One could object that the construction of the tubes assumes somehow an 'axial' multi-modality around the ensemble mean. As a matter of fact the tubes only give a condensed representation of the outer,

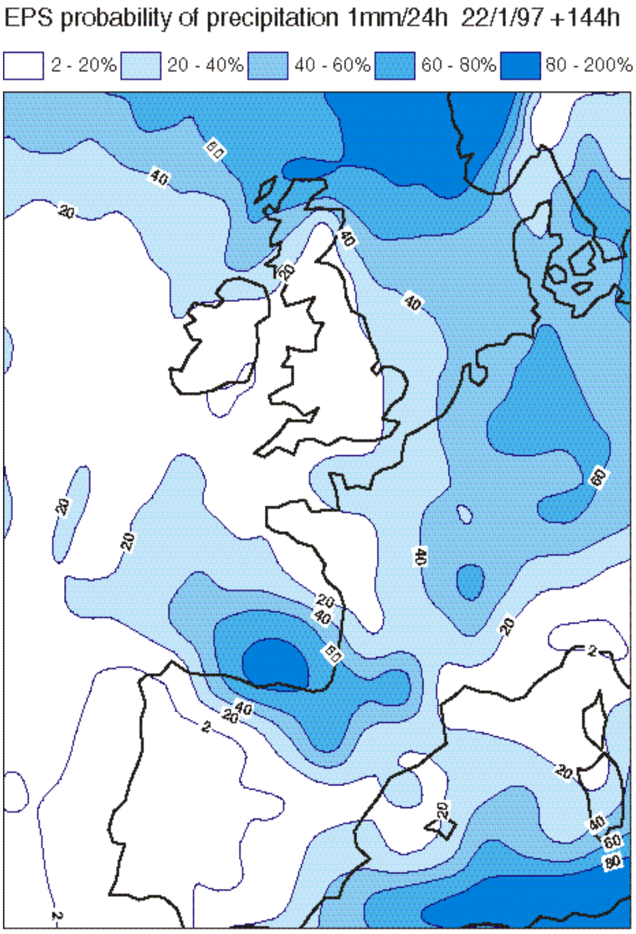

Figure 8: *EPS probability of precipitation above 1 mm/24h, 22nd January 1997, +144h.*

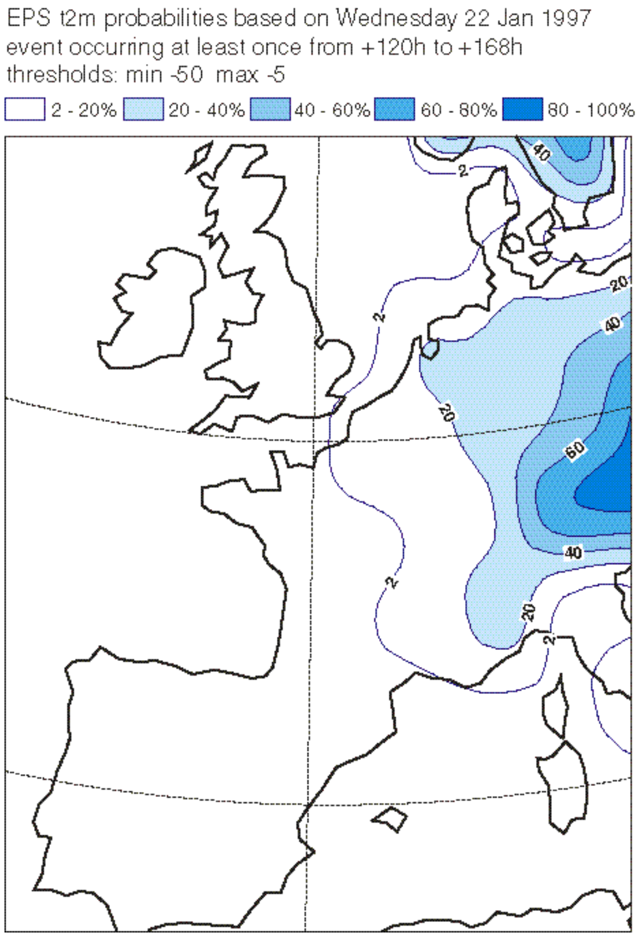

Figure 9: *EPS probability of 2 m temperature below -5°C, 22nd January 1997, +120h to +168h.*

sparse part of the distribution: as soon as a direction is sampled by an ensemble forecast outside the central cluster, a tube will represent this direction or a close one. Nevertheless, the question of the significance of all these directions may be addressed. Empty, long tubes – i.e. containing only the extreme or, much less frequently, several members grouped together around the extreme – are notably questionable, because they artificially 'fill the gap' between the central, dense part of the distribution and one or several isolated members, somehow assuming the distribution to be continuous when there is no evidence nor theoretical reason for that. If the distribution modes were indeed reliable – which they are not on average – tubing should be avoided in those situations when the distribution is clearly discontinuous. ❑

Frédéric Atger

Summary of ECMWF Technical Memorandum 225

Simulation of fog with the ECMWF prognostic cloud scheme

João Teixeira

A prognostic cloud scheme has been operational at ECMWF since 1995. In this paper the performance of the cloud scheme in simulating fog is assessed. A case study is performed with the one-column version of the ECMWF model in order to analyse how the model reproduces the main mechanisms of fog generation and dissipation. Aclimatology of the model's fog is produced using data from the ECMWF Re-Analysis (ERA) and compared with climatological data. High resolution (T213L31) operational forecasts with the prognostic cloud scheme are compared with synoptic reports of visibility for Europe. In this context the relation between fog and temperature, on the one hand, and fog and wind speed, on the other, is explored in some detail.

The comparison between the simulated and the observed visibility, in the one-column model case study, shows that the evolution of fog is properly simulated. The analysis of the behaviour of the different parametrized physical