On the operational use of ECMWF forecast products

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1. Introduction

The rôle of the forecaster in the interpretation of the short range numerical weather prediction (NWP) products has long been well defined. The situation is not the same for the medium range. But can a forecaster really "understand" the medium-range NWP, at least in a sense that he is able to make useful interpretations or even modifications of the direct model output? Whatever the answer to the question, forecasters *are* working with NWP products and experience shows that they do it with some success. In spite of increased automatization, there will always be a need for human intervention or supervision when large economic or political risks are at stake.

Automatization relieves the forecaster from routine duties and enables him to concentrate on difficult or crucial forecasts. For many applications, NWP generated weather forecasts are already today issued automatically. To remove systematic errors in the near surface parameters, *adaptive techniques* (e.g. Kalman filtering) have been found to be useful (Persson, 1991):

-The filter can adapt easily to seasonal and model changes.

-There is no need for large historical data samples.

-New stations are easily integrated into the system (fig.1).

An adaptive filtering technique for an EPS system will use the unperturbed forecast for the updating of the correction equations, which are then applied to all members in the ensemble. This will enable the user to have forecasts for any weather parameter in probabilistic terms with systematic errors removed.

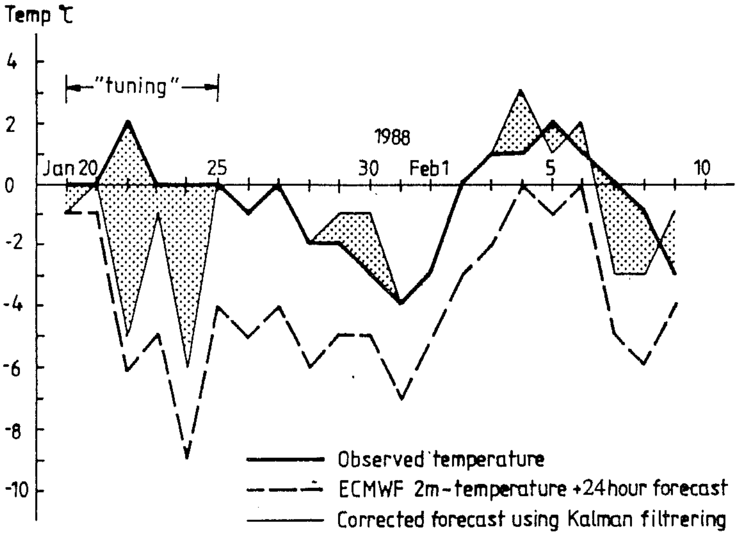

Figure 1: The start, initial tuning and the first two weeks of operation of a Kalman filter for the 24 h forecasted 2 m temperature for a location in Sweden in 1988.

To improve the interpretation in the medium range it must be realized that the subjective techniques applicable in the short range will mostly not work beyond D+3 when baroclinic waves are less predictable and the impact of analysis errors cannot easily be deduced. To interpret the medium range instead involves the understanding of dynamical concepts like group velocity, "downstream development" and the synoptics of planetary waves.

2. Subjective use

To help the forecaster in the short range there is a range of guidelines where later or additional observations (SYNOP, radar, satellite etc) play an important rôle. Since these do not work beyond 72 hours there has been an idea that the forecaster should rely on his experience to provide an independent judgement of the NWP. When this turned out to be counterproductive, the forecaster has been advised to accept the NWP and only add weather features or local effects.

But just reading off the NWP charts will tempt him to issue forecasts of scales that may not be predictable at a certain forecast range. In doing so he will not only convey an unrealistic accuracy of the forecast to the customer, he will also convey most of the frequent day-to-day differences in the forecast.

2.1 Consistency as indication of skill

During the 1980's it became customary for the medium-range forecaster to use the day-to-day agreement (consistency) between successive runs to form an opinion about the forecast:

-The D+5 from today is more reliable than normal if it resembles yesterday's D+6...

This sounds plausible, but consistency only correlates 0.1-0.3 with skill in the medium range, mainly because successive bad forecasts are also quite often consistent.

Several objective verifications during the 1980's failed to confirm any useful relation between day-to-day consistency and skill. Also subjective investigations (Tab.1) indicated that the skill of the forecasts hardly depended on whether they were consistently forecasted.

Fc	% skilful	Consist.	% skilful when cons.	corr. cons./skill
D+3	98	D+3/D+4	99	-.04
D+4	84	D+4/D+5	80	-.14
D+5	45	D+5/D+6	48	.07
D+6	34	D+6/D+7	45	.15
D+7	18	D+7/D+8	16	-.08

Tab.1 Subjective assement of consistency and skill of ECMWF forecasts during January-March 1993. (John Doyle, personal communication, 1993)

Day-to-day consistency mostly occurs when *yesterday's* forecast is unusually good. The practise to judge the skill of today's forecast from its consistency with yesterday's, is actually to make the confidence dependent on the skill of yesterday's forecast. This practise has had the effect that some forecasters are hesitant to issue forecasts beyond D+3.

It has, however, been found that the skill of *yesterday's* forecast correlates well with consistency. This does not motivate the use of consistency to assess the quality of yesterday's forecast. An unusually good D+6 from yesterday is normally not better than today's D+5. And since they look similar, there is nothing to gain.

75% of all D+5 are actually better than the D+6 from the day before. *The best choice in the long run is therefore to rely on the last forecast.* Yesterday's forecast can, however, indicate possible alternative solutions ("Poor Man's Ensemble Forecast") .

2.2 The necessity of a stable model climate

A certain degree of day-to-day inconsistency is a sign that the model has a stable climate and develops cyclones, blockings, fronts and cut-offs develop with the same frequency at every stage in the forecast But the systems become less and less predictable and beyond D+7 the forecast model can create realistic looking systems that never will occur.

Since the synoptic systems beyond D+7 appear as almost random features, it is no surprise that the changes in the forecast from day to day also appear almost random with sometimes immense jumps from one synoptic flow pattern to a completely different one. For shorter and more skilful forecasts the random element is smaller and the consistency therefore also higher.

If a stable model climate has these negative consequences, why is it not modified in a way that gradually dampens smaller-scale non-predictable systems? Such a model would actually appear more skilful in the longer forecast ranges. But small scale systems serve an important purpose in the energy balance between different atmospheric scales. Smoothing out these because they are not predictable, would make it difficult to forecast blockings for example.

There are also two other reasons why a stable model climate is necessary:

-Model climatological drifts indicate deficiencies in the simulation of the atmospheric processes which must be identified and solved.

-Any application of an EPS system demands that synoptic developments will occur with the same frequency at D+10 as D+1.

At present the ECMWF T213 model has an almost stable climate over the Northern Hemisphere, whereas on the Southern Hemisphere a minor, but significant increase of the eddy kinetic energy takes place.

2.3 The forecasters approach

Just because the NWP has to obey a stable climate, there is no reason why the forecaster should do the same. *He* must introduce a "climatological drift" of his own, by treating a D+6 forecast chart differently from a D+3. This is also what has been the case since weather forecasting started: a shorter forecast expresses more detail and extremes than a longer. So the medium range forecaster must introduce a "climatological drift" of his own, by treating a D+6 forecast chart differently from a D+3. He can do this by considering what scales are normally predictable at a certain time range.

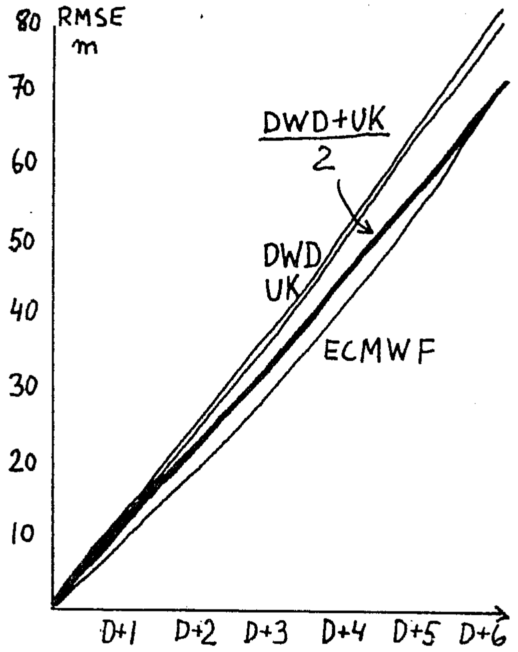

Figure 2: The RMSE for NH 500 hPa forecasts for ECMWF, UKMO and DWD Dec 1992 - Feb 1993 . A new "consensus" forecast, created as a mean of the UKMO and DWD, would score almost as good as the ECMWF forecast.

A trivial, but efficient way to improve on the NWP is by simple averaging of 2-4 forecasts valid for the same time, either from different runs from the same model (fig. 2) or the same run from different models (fig. 3).

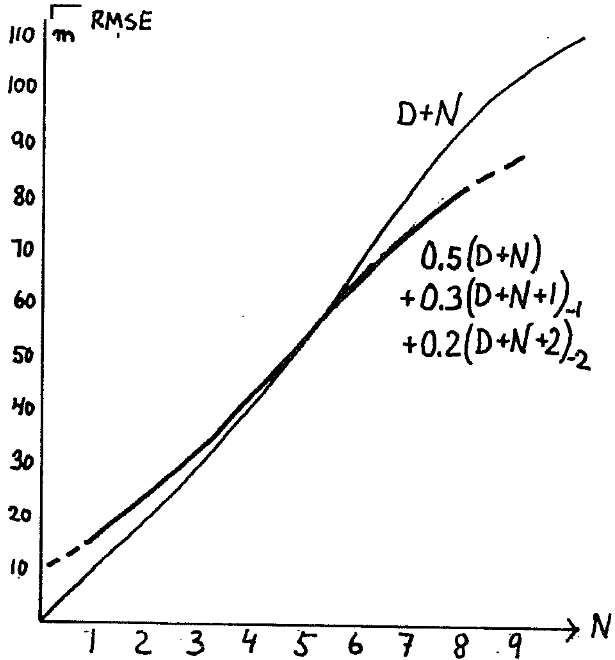

Figure 3: The RMSE of a smoothed "consensus" forecast constructed as a pure average of the last three ECMWF verifying on the same date, compared with the scores for the most recent one.

Any smoothing of non-predictable synoptic features should thus be done in the post-processing. We will come back to how this can be achieved, but first let us explore how the day-to-day differences can be used in a productive way.

2.4 How to make use of day-to-day forecast differences

It is useful to compute the difference between today's and yesterday's ECMWF forecast and trace the differences back to their sources. Experience shows that most forecast differences originate from data dense areas and improve the forecast. If the forecaster can have this confirmed in real time it will further increase his confidence in the forecast. When the differences originate from areas with little or low-quality data, he can consider whether the D+5 belongs to the 25% which are worse than yesterday's D+6.

2.5 Downstream development

To assess a D+5 forecast of a cyclone wave, we therefore have to look at not only where the wave originated, but also from where possible influences might have originated. A development further upstream might affect the downstream system.

The synoptic phenomenon of *downstream development* has been known since the 1930's: a strong cyclogenesis over the western Atlantic is followed 1-2 days later by an amplified ridge over Iceland and 1-2 days later by a low deepening over the North Sea (Riehl et. al., 1952). This chain of events is often part of a fundamental dynamic process, *energy dispersion,* whereby weather systems can interact over long distances through propagation of energy (Rossby, 1945, 1949a, 1949b). Usually energy does not propagate with the same speed as the weather system, but faster, by the *group velocity* (Holton, 1992, Simmons, 1985).

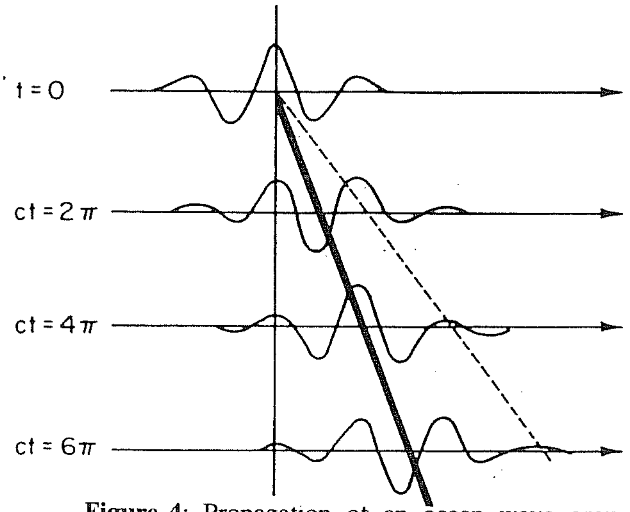

Figure 4: Propagation of an ocean wave group. Heavy line shows group speed, dashed line phase speed (from Holton, 1992).

A simple example of group velocity is seen in ocean waves. The longer the ocean wave, the greater the phase speed. It can be easily demonstrated, by a simple interference of superimposed sine waves, that this yields a group velocity that is lower than the phase speeds of individual waves (fig.4). Every 5-10th wave is therefore stronger or weaker.

Seamen have for long times known about the "Seventh Wave" and learned to avoid it when they are about to leave or enter a boat at open sea. Its existence is due to the fact that the energy of the waves move with the group velocity, which for ocean waves is slower than their phase speed. In the atmosphere it is generally the opposite: the shorter the wave the faster it moves. Long waves may even be stationary or move westward (retrogress). This leads, as can be shown by interference of superimposed sine waves, to a group velocity which is *greater* than the phase speed of the waves (fig. 5). This has consequences for our understanding of both the atmosphere and the NWP model.

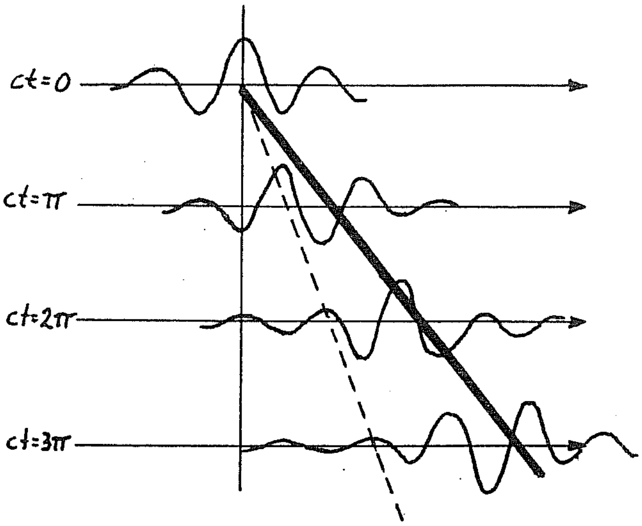

Figure 5: Propagation of an atmospheric wave group. Notations as in fig. 4. The group velocity is larger than the phase speed of any individual wave, "downstream development".

The discovery of energy dispersion in the 1940's marked a scientific break with the Bergen School concepts where atmospheric waves were (and still are) seen as closed systems, developing according to their internal properties. Tor Bergeron tried to modernize the Bergen school model by incorporating the concept of energy dispersion. In the chapter on weather forecasting in Godske et. al. (1957) he wrote:

> *"The [Chicago School] model introduced the idea of dispersion and group velocity - the energy in a train of waves being propagated not with their phase speed, which is less than the wind speed, but with the group velocity, which is greater. Attention is centred, in this new line of attack, not on the propagation of matter, for instance in the form of outbreaks of cold and warm air, but on the propagation of waves and atmospheric states, and thus of energy, through matter."*

At some weather services in Europe and the US, group velocity discussions were performed from the 1940's to the 1980's. Downstream development events were followed on *trough-ridge* or "Hovmöller Diagrams" (Kurz,1977,1990). A cyclogenesis e.g. over the British Isles, appeared more likely if it was a link in a chain of upstream amplifications from the Pacific, over the US to the Atlantic (fig.6 and 7.).

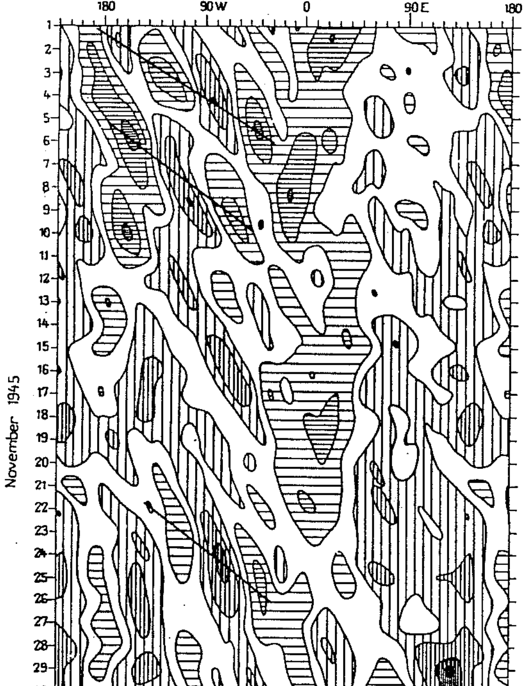

Figure 6: A trough-ridge diagram at 500 hPa from autumn 1945 (Hovmöller, 1948). Occurrences of "downstream developments" indicated by lines.

Hovmöller diagrams were used to study the characteristics of the global circulation models (Smagorinsky et. al., 1965 ,Miyakoda et. al., 1972). In the late 1970's the concept of energy dispersion saw a revival by a series of elegant theoretical papers (for example Hoskins, Simmons and Andrews, 1977). WMO has recently published an monograph on the subject (Phillips, 1990). During recent years dynamical meteorologists have started to look at the synoptic implications of energy dispersion (Chang and Orlanski, 1993).

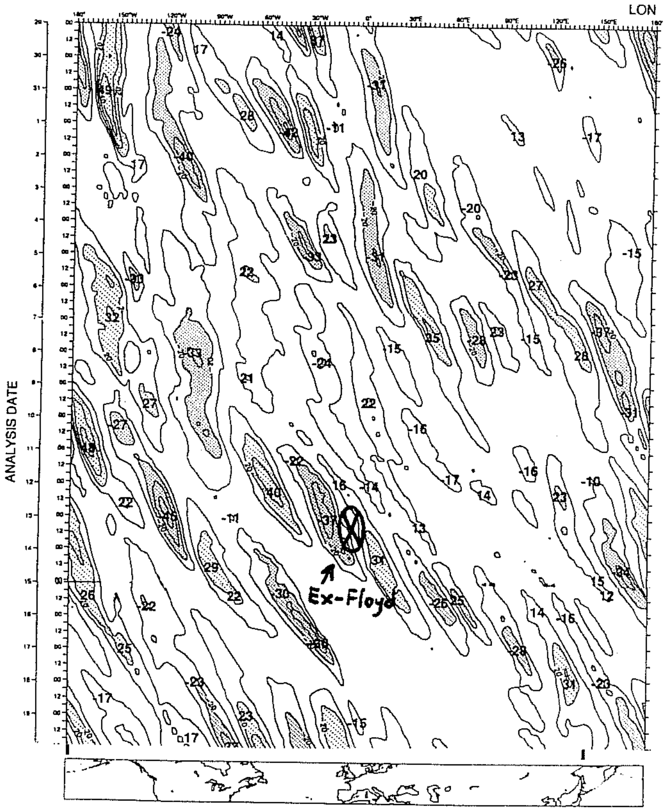

Figure 7: The 250 hPa v-component 29.8-20.9 1993, averaged between latitudes 35 and 60 N, plotted in a Hovmöller diagram (as suggested by Chang and Orlanski, 1993) .

Hovmöller diagrams of the V-components in the jet-level reveal strikingly occurrences of downstream propagation of energy. From fig. 7 it can be seen that a violent storm, "Ex-Floyd", which hit western Europe on 13 September 1993, was to some extent related to a cyclogenesis over the Pacific one week earlier.

Similar diagrams can be plotted for the ECMWF forecasts and reveal the dependence of developments over Europe around D+5 on upstream developments some days earlier.

3.7 The requirements on the area of display

A practical consequence of the fact that energy can travel faster than the systems is to consider if the geographical area presented to the forecaster is sufficiently large. Let us take the area in fig. 8 as an illustrative example. They represent a typical area of display for European weather services: Europe, the North Atlantic and Newfoundland.

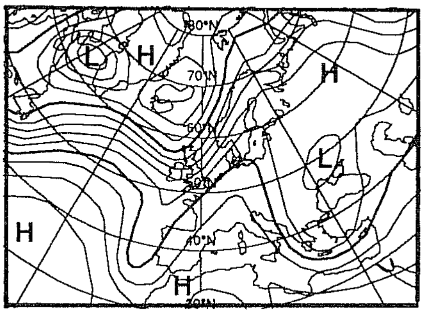

Figure 8: The usual map area for medium range forecast, though only suitable for short range considerations (up to +48 hours).

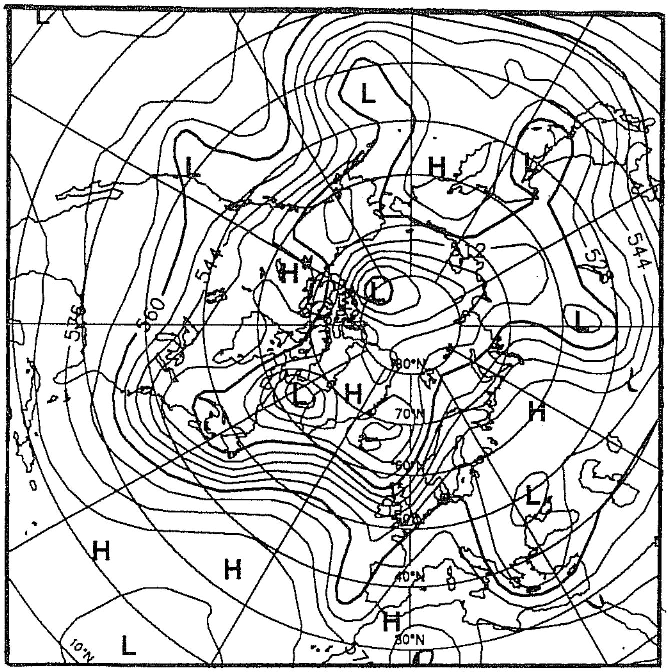

Figure 9: A suitable area for a medium range NWP display.

A normal polar front cyclone with a typical phase velocity of 20 longitude degrees/day will take about 3 days to move from the western boundary to Europe. This is hardly within the medium-range. Even worse: since the typical atmospheric group velocity is 25-30 longitude degrees/24 hours, any influences from the Newfoundland area will reach Europe within three days.

To have a chance to understand a D+5 forecast for Europe a medium range forecaster has to look at the North American continent and most of the Pacific (fig.9).

3.8 The rôle of jet-streams

All baroclinic systems are accompanied by an upper level jet in a quasi-balance, with "left exit" and "right entrance" being favourable regions for cyclonic developments. Generally the thermal contrasts in a developing cyclone weaken as the flow draws its energy from the available potential energy. A less common development is when *the baroclinicity increases while a storm develops*. This occurs when a strong polar front jet penetrates into the next downstream cyclone (fig. 10) or when the subtropical jet extends northward.

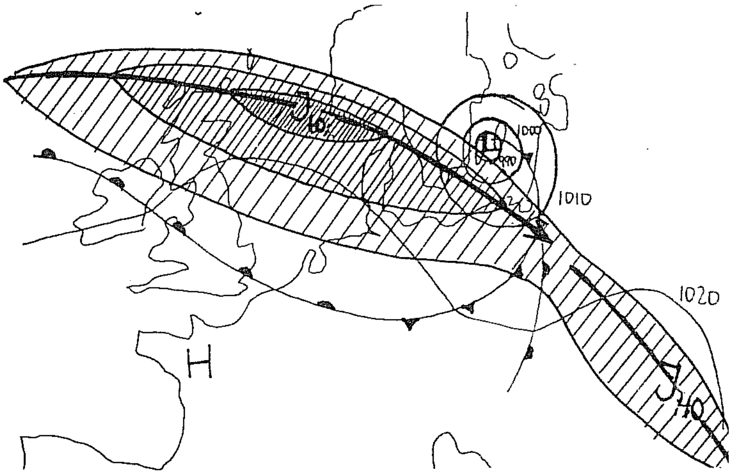

Figure 10: The typical synoptic situation when an external jet-streak moves into a downstream cyclone. On this situation, 23 July 1985, a severe storm developed over the Baltic in a couple of hours time.

The ECMWF model tends to under-forecast the pressure fall in the "left exit" and "right entrance" with about 2 hPa/24 hours on average, in several cases up to 10 hPa/24 hours in cases of jetstreams with phase speeds of 10 longitude degrees or more per 24 hours (Piriou, C. and A.Maas, personal communication, 1993). The reason for this under-forecasting is not quite understood. It might be due to numerical smoothing of small scale horizontal divergence to avoid computational problems.

The forecaster should be on alert when a jetstreak is forecast to "break away" and move downstream. Depending on where the jet penetrates the downstream low, an explosive storm may develop. Great day-to-day forecast differences may occur in connection with such developments.

3.9 Large scale synoptics

A general rule in weather forecasting is to associate any forecasted event with a scale as large as possible and disregard scales that are normally not predictable at the forecast range under consideration.

Aviation forecasters, making 2-12 hour cloud, turbulence and visibility forecasts, concentrate on turbulent, radiative and convective processes; *short range forecasters,* looking 12-36 hours ahead, are more concerned with the position and intensity of fronts, trough lines and baroclinic systems. Consequently *medium range forecasters,* are pre-occupied with the movements of the large scale patterns and try to acquire a feeling for and experience of the synoptics and kinematics of the large scale flow (fig. 11). For example the general retrogressive or progressive movement of a large section of the hemispheric flow is generally forecast with skill. For Europe a progressive movement indicates maritime influence (fig. 12), whereas retrogression indicates continental influence (fig. 13).

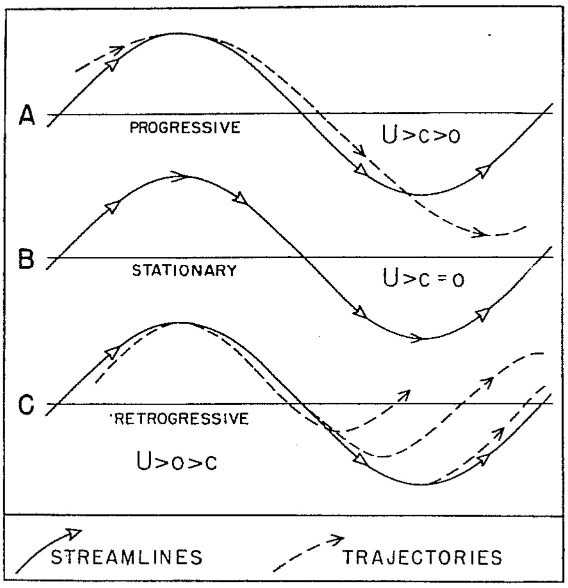

Figure 11: The relation between streamlines (isohypses) and trajectories(from Petterssen, 1956). For progressive phase speeds the trajectory is more latitudinal.

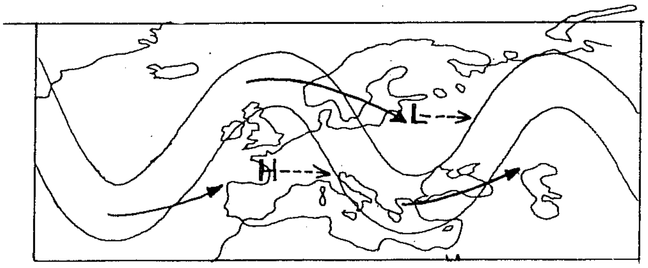

Figure 12: A kinematic illustration of how a progressive wave band creates a westerly (maritime) influence over Europe.

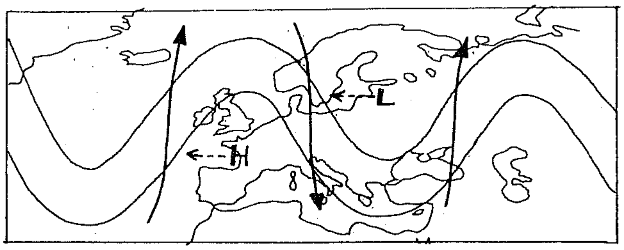

Figure 13: Same as fig. 12, but for a retrogressive wave band, creating a meridional (continental) influence over Europe.

Relying on the predictive skill of different scales during different forecast ranges, the forecaster will realize that there is more consistency from one day's forecast to the next that meets the eye. He should thus feel more confident about the NWP output.

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