CHAPTER 9 — NUMERICAL WEATHER PREDICTION

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9.1 Operational models

The Meteorological Office operational models are increasingly sophisticated but their output should always be interpreted cautiously. Familiarity with strengths and weaknesses is vital.

9.2 Summary of types of numerical models

(i) Climate models describe the general behaviour of the troposphere and stratosphere over long periods of time.
(ii) Operational synoptic models are used for day-to-day weather forecasting. They may cover a domain that is global (GM) in extent, or may be restricted to a more limited area (LAM). Their resolution is such that they can describe the state and behaviour of synoptic-scale weather systems.
(iii) Mesoscale models (MM) are used for forecasting localized weather variations, especially those forced by topography, over a domain about the size of the UK.
(iv) Specialized models are research tools for investigating the physics of such phenomena as fog, cumulonimbus clouds, stratocumulus, low-level turbulent flow, etc. or larger-scale phenomena such as individual cyclones and the long-wave flow pattern.

Cullen (1993)

9.3 Guide to NWP Interpretation

Asynoptic data are assimilated with model forecast fields to give the best possible estimate of the initial state of the atmosphere (e.g. 4-D variational assimilation).

Lorenc et al. (1991)

9.3.1 Limits of resolution

(i) LAM grid-point spacing of 50 km effectively defines frontal position accuracy (i.e. at 15 kn this represents nearly 2 hours of movement). In practice, the frontal position will be aided by information on orientation from surrounding grid points.
(ii) Frontal waves need at least three grid lengths in order to be adequately represented; such features can occasionally be missed as a result.
(iii) More often a wave will be developed, but with uncertainty as to position and amplitude.
(iv) Artificial smoothing within the model and resulting from contouring algorithms will reduce sharpness of angles/discontinuities.
(v) Satellite imagery may provide evidence of the development of a frontal wave through the widening of the frontal band and other characteristics.

9.3.2 Precipitation

(i) It is important in forecasting the distribution and type of precipitation to deduce surface frontal positions and apply conceptual models.
(ii) The 850 hPa WBPT is useful here (Bradbury, 1977); the front, warm or cold, is likely to be situated just on the warm side of a tight WBPT gradient.
(iii) Because of frontal slopes, the frontal position at 850 hPa may not coincide with the surface frontal position.
(iv) Generally surface cold fronts coincide well with the warm side of the 850 hpa WBPT gradient because of the steeper frontal slope and the tendency for a nose of cold air to override the warm air at the surface, whereas surface warm fronts tend to be slightly back from the 850 hPa position (though not as far as the 1:150 slope would suggest) **(Fig. 9.1)**.
(v) Occlusions are positioned along ridges of WBPT.
(vi) Troughing in the forecast surface isobaric pattern is a more definitive indication of frontal surface position.
(vii) The position of a certain value WBPT isopleth may be linked to, say, a surface front, cloud sheet edge, etc. which may, in the short term anyway, be related to the movement of that isopleth.
(viii) Consistency is important in positioning surface fronts from frame to frame. A good guide in this respect is to use the ASXX chart to position fronts on the T+0 initializing frame and the FSXX to position fronts on the T+24 frame and to fill in intermediate frames accordingly.

(ix) Any differences between a precipitation forecast by the model and that expected from subjective assessment should be reconciled with, for example, WBPT analysis and checking LAM T-ϕs or global model 700 hPa RH fields against relevant satellite imagery and actual T-ϕs.

Bradbury (1977)

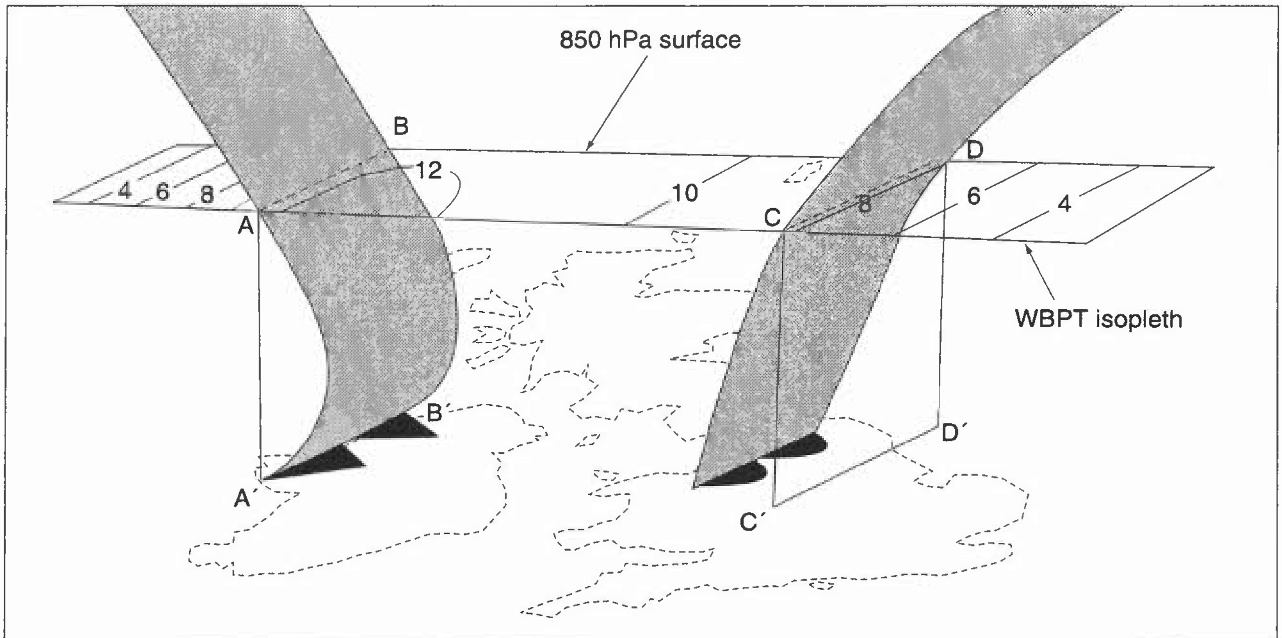

Figure 9.1. Cold- and warm-frontal positions at 850 hPa coinciding with the warm side of the WBPT gradients, given by AB and CD, respectively. These positions projected down onto the surface are A′B′ and C′D′. A′B′ gives a good estimate of surface cold-frontal position because of the cold air 'nose' overriding warm air at the surface. C′D′ is somewhat ahead of the surface warm front, but not as far ahead as a 1:150 slope would suggest because frontal slope is steeper near the surface.

9.3.2.1 Shower forecasts

(i) The convection scheme is based on parcel theory (4.2.1) ; output rain rates are averaged over a grid box so heavy showers are designated mean rate 0.5 mm h^{-1} or more.

(ii) In order to model the effect of different concentrations of condensation nuclei in continental and oceanic air masses, showers are diagnosed according to strict criteria:
showers develop if cloud depth >1.5 km over sea
>4.0 km over land
if (land or sea) cloud-top temperature <−10 °C, then critical depth is 1.0 km.

These may only just fail to be reached, so checking against the actual or forecast T-ϕs is important. The output may point to something overlooked. Correct or not, the model evolution is always internally consistent. Check accumulated as well as actual rates of precipitation.

9.3.2.2 Phase

(i) The UM differentiates between phases of the precipitation, based on temperature of the first model level.
(ii) Snow probabilities are based on the mean temperature at the 1000–850 hPa thickness and should be corrected for the height of the ground above sea level **(Fig. 9.2)**.
(iii) Beware of the situation where cold air at the surface is undercutting warm (e.g. use Hand's method, 5.10.1.3).
(iv) Beware, too, of the poor vertical resolution of representative forecast tephigram, especially in the boundary layer.
(v) A downdraught scheme allows snow to reach the ground on some occasions, even when wet-bulb temperatures are several degrees above zero.
(vi) An arbitrary limit of 2 °C is set for precipitation to be output as snow.
(vi) Current boundary layer and convective schemes have led to unrealistic temperature profiles near intense cold pools.

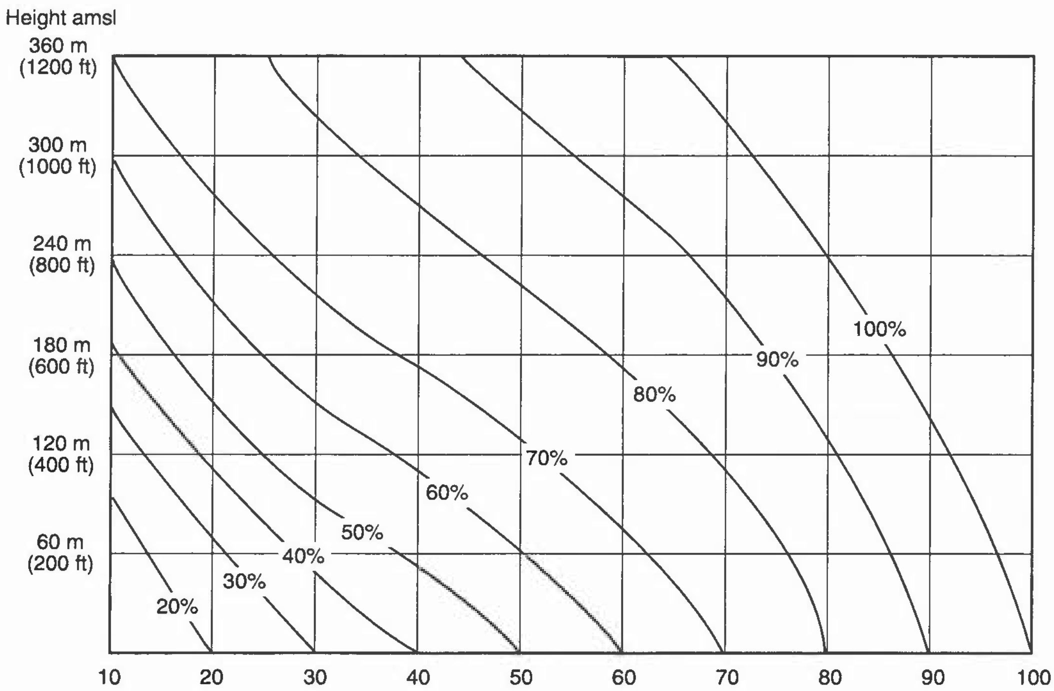

Figure 9.2. Diagram to adjust snow probability at sea level for different elevations, e.g. 20% probability at MSL represents 50% probability at 150 m AMSL.

9.3.2.3 Cloud water and dynamic precipitation

(i) Cloud water is included as a model variable, distributed between liquid and solid phases according to temperature.
(ii) Precipitation is generated by coalescence in warm clouds with the seeder–feeder mechanism modelled (5.9.5).
(iii) For dynamic rain a rate of 4 mm h^{-1} is required to produce the heavy rain symbol.
(iv) Evaporation of dynamic precipitation falling through unsaturated air is rain-rate dependent; cloud water can be advected in the GM and LAM leading to possible moisture convergence and rainfall intensification.

Davies & Hammon (1986) **Hall (1991)**

9.3.3 Surface boundary conditions

Surface hydrology includes effects of plant canopies and sub-soil characteristics; surface albedo depends on soil, canopy type, fractional vegetation cover, snow cover and temperature. Insulating effects of snow cover are modelled.

9.4 Model characteristics

9.4.1 General comments

(i) Generally the model handles cyclogenesis well; there is little evidence of systematic problems; trough disruption situations account for most errors, the model failing to capture the fine balances involved, and producing spatial and temporal errors.
(ii) Systematic under-forecasting of winds near jet cores for World Area Forecast output is noted.
(iii) Surface winds — normally too strong over land in the LAM; a little too weak in the MM.
(iv) Vertical velocity — very high grid box mean velocity often associated with intense convection; possibly due to excessive feedback between convection scheme and large-scale motion.

9.4.2 Rainfall

(i) Main problems during summer months are due to poor representation of moisture and weakly defined forcing functions.
(ii) Spurious light rain is sometimes found from shallow boundary layers driven by radiative cooling of the cloudy layer, due to lack of vertical resolution which does not allow compensating entrainment of air from above the boundary layer.

(iii) The possibility of low cloud/drizzle should not be ruled out when light rain is forecast.
(iv) The model has a tendency to change shower distribution from run to run; forecasters should treat shower symbols as indicating areas of instability that may trigger showers.
(v) Over-forecasting of showers with a high 850 hPa θ_w may be due to too high θ_w or early encroachment of instability from the south or south-west.
(vi) Under-forecasting of dynamic rain is often associated with too rapid decay of precipitation on weakening, slow moving fronts and/or poor humidity analysis (MM is better at retaining moisture).

Nicholass (1993)

9.4.3 Snow

(i) Frozen precipitation is defined as melted or frozen depending on whether the layer temperature is above or below being <0 °C.
(ii) Chart symbols depend on temperature at the lowest level; snow/rain mixture possible if rate is high enough for temperature to be lowered to 0 °C before all snow melts. Output symbol is then snow, the temperature being held at 0 °C; thus lowering of freezing level by melting snow is modelled.
(iii) Snow probability lines are derived from 1000–850 hPa thickness adjusted for MSLP; they are a better indicator of snow than using symbols directly.
(iv) Probabilities are based on past frequencies of rain or snow compared to the observed thickness, and take into account that the wet-bulb freezing level is normally lower than the dry-bulb freezing level, and the fact that wet snow can fall when both are a few hundred metres above the surface. This is not the case for snow symbols in association with dynamic precipitation.
(v) Probabilities work best in unstable, showery situations when the 1000–850 hPa thickness represents a homogeneous air mass:
    the 20% line suggests rain/sleet,
    80% mostly snow
    50% often indicates a mixture of type and requires interpretation as to wind direction, proximity to sea, intensity, etc.
(vi) Widespread and heavy dynamical precipitation often turns to snow even with 20% or less probabilities if low-level air has a long land track over the UK or a short sea track from the continent.
(vii) Probabilities are significantly affected by height above sea level (150 m can change 20% to 50% probability, **Fig. 9.2**).

9.4.4 Temperature errors

(i) The GM and LAM tend to be too slow at warming cold air masses advecting over warmer surfaces — 500 hPa contour errors as high as 20 dam by T+96 have occurred; result — over-forecasting of snow at lower levels in polar maritime outbreaks.
(ii) Nested models within UM system tend to underestimate freezing-level height from summer to autumn — and overestimate for rest of year.
(iii) Under anticyclones, lowest layers often too cold, giving misleading MOS (2.12) from GM.

9.4.5 Humidity errors

(i) Initialized model ascents sometimes poorly represent observed moisture structure.
(ii) Humidity quality control is likely to reject information if it is significantly different from background, but intervention can support or bogus humidity observations to improve analysis.
(iii) Relative lack of model vertical resolution a problem on forecast ascents. For example, top of frontal cloud appears to be near 600 hPa.

9.4.6 Pressure over mountains

(i) Analysis and forecasts of sea-level pressure over mountainous areas is a problem. Indeed, there is no completely satisfactory way of deducing PMSL at high-level stations.
(ii) Uniform lapse rate of 6.5 °C km^{-1} from sigma level 4 (to avoid spurious effects from surface temperatures) to PMSL is assumed.
(iii) Observed PMSL is higher than the model when surface is cold. During a hot day, overland heat lows will appear deeper than model. This does not necessarily imply that the surface observations are correct.

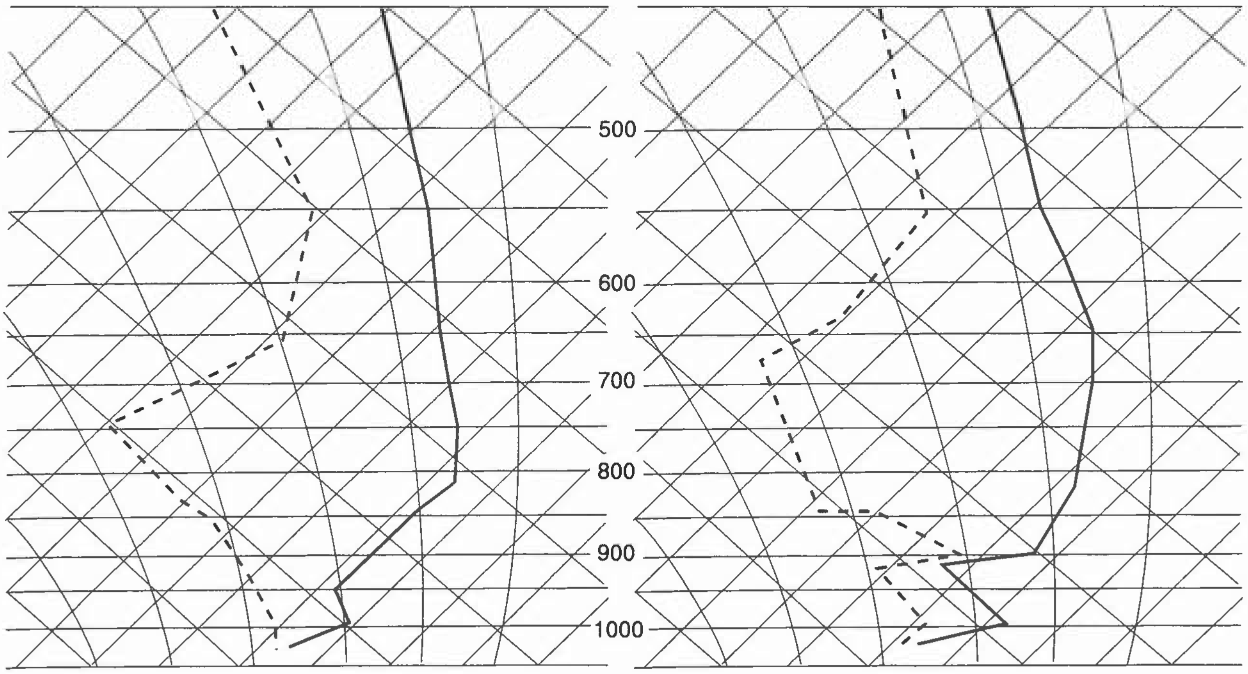

Figure 9.3. A tephigram from the initial fields of the old 15-level fine mesh (left) compared to its counterpart as measured by radiosonde. Note that although the general shape is correct, the model has completely failed to represent the sharp, moist inversion at 900 hPa.

9.4.7 T-ϕs

(i) Temperature of the lowest level is that of model ground (or sea); temperature at a model level represents mean temperature of a layer.
(ii) Thus, inversions are usually less well defined and the height will be in error when compared to the real atmosphere **(Fig. 9.3)**.
(iii) Real value of the T-ϕ may be to indicate stability and moisture changes with time at different levels.

See 5.9.8.

McCullum et al. (1995)

9.5 Guidance, confidence and verification

(i) The Synoptic Review (SR) will generally appraise the model output, with comments on the shortcomings of analysis and implications for subsequent development.
(ii) Major changes from run to run should be treated with caution.
(iii) Simple verification can include comparison of reported surface pressures with T+6 or T+12 forecasts, agreement giving confidence in subsequent evolution.
(iv) Actual versus forecast rainfall distribution can be compared; if T+6 is realistic, confidence in T+12, etc. frames will be high. The model output, anyway, should not be dismissed too hastily.
(v) Meteosat imaging is particularly useful (except during eclipses!) as it will be available at standard verification times.

9.5.1 Using Global Model output

(i) The 850 hPa WBPT allows direct comparison of the (lower-resolution) GM and LAM output. Differences, e.g. in timing, should be noted and the SR consulted.
(ii) If no specific guidance offered, the situation should be monitored for early indications of development.
(iii) The 700 hPa charts show RH at 19% intervals — mark the 76% isopleth; within this area extensive medium-level cloud and some rain is likely. The 95% line is indicative of likely medium to heavy precipitation.
(iv) The 500 hPa thickness and contour charts allow assessment of thermal advection and likely forcing for development .

(v) The 300 hPa chart has isotachs at 20 kn intervals; highest winds are slightly underestimated because the 90 km resolution is less able to cope with the large shear values around jets.
(vi) By better understanding of the model atmosphere, the dynamical processes and the features governing surface evolution, the better position the forecaster will be in a good position for extrapolating errors which become apparent early in the forecast run.
(vii) The output also allows the routine study of the 3-D relationship between the movement and development of upper and surface features.

9.5.2 Global compared to LAM

(i) The greater resolving power of the LAM will handle waves and jets more realistically (but has led to less-accurate handling of certain features) and should outperform the GM in highly developmental situations.
(ii) The GM has a later run time and may receive vital data missed by the LAM. The GM may also benefit from later intervention on the analysis.
(iii) SR will offer guidance as to which model has the preferred solution.

9.5.3 Mesoscale compared to LAM

(i) Mesoscale precipitation fields add little to LAM; by restricting diffusion to smaller scales MM allows sharper features and more active precipitation areas;
(ii) spurious signals can result due to problems with the initialization scheme for cloud and moisture;
(iii) assimilation includes humidity from surface observations with intention of improving fog treatment.

McCullum et al. (1995)

9.5.4 Model Output Statistics (2.12)

9.5.5 Ensemble forecasting (11.7)

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