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# Forecasting Research

Met O 11 Technical Note No. 18

Interpreting results

from

numerical models

by

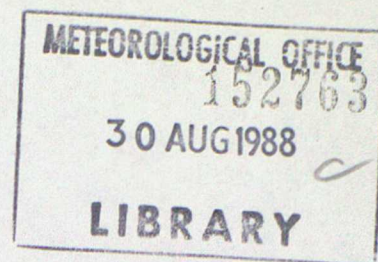
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August 1988

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MET O 11 TECHNICAL NOTE NO 18

INTERPRETING RESULTS FROM NUMERICAL MODELS

by

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LONDON, METEOROLOGICAL OFFICE.

Met.O.11 Technical Note (New Series) No.18

Interpreting results from numerical models.

02560988

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August 1988

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## Interpreting Results From Numerical Models

### 1. Introduction

1.1 Numerical weather prediction lies at the heart of any advanced forecasting system and the forecaster today is faced with the problem of interpreting the results from various models. The forecaster therefore needs to have some understanding of how each model works and what are its limitations. The object of this note is to provide basic information about the UK Meteorological Office global and fine-mesh models. The note has been kept brief and perhaps points to the need for a longer, descriptive reference manual designed specifically for the forecaster to complement the Scientific Paper No 41 (Bell and Dickinson, 1987). It is assumed that the reader has a knowledge of the main dynamical and physical processes at work in the atmosphere. A precise description of the numerical schemes used and of the physical parametrizations is not given here; this information is available in the Scientific Paper. Some of the more general points raised on resolution and parametrizations are applicable to large scale and limited area models used by other centres.

### 2. Resolution and grids

2.1 One of the most important factors in interpreting output from a numerical model is its resolution, particularly in the horizontal. This is especially important when comparing results from different models as the higher the resolution the smaller the scale that can be resolved. Physical processes, which largely determine the vertical structure of the model, are calculated separately at each grid point and give information for the grid square. The minimum width of frontal zones is also one grid length but other dynamical features, such as waves, are only meaningful if their wave-length is greater than three grid-lengths. Thus the amount of meaningful information that can be extracted from the model depends on the feature being assessed. Rainfall on a front may be accurate to nearly one grid length but waves on a front need to be larger than three grid lengths to be resolved adequately. It should also



be remembered that the modelling processes involved in solving the equations contain a certain amount of smoothing so that sharp discontinuities are smoothed.

2.2 The global model uses the smallest grid length compatible with providing global forecasts, given the available computing power and the cut-off times for various forecast products. The grid of the model is not uniform on the sphere but follows lines of latitude and longitude at intervals of  $1.5^\circ$  and  $1.875^\circ$  respectively. As the poles are approached the longitude lines converge and thus the East-West resolution increases. However, for computational reasons, this extra resolution cannot be used poleward of about  $60^\circ$  which is therefore where the effective East-West resolution reaches its maximum. At the equator the East-West resolution is about 200km and at  $60^\circ$  North or South it is about 100km. For the UK this resolution is not sufficient to provide detailed rainfall forecasts and so a fine mesh model is used with twice the horizontal resolution. With the computing power available, this higher resolution can only be used over a limited area. The boundaries of the fine mesh model are  $80^\circ$  West to  $40^\circ$  East and  $30^\circ$  North to  $80^\circ$  North. (See figure 1.) During a forecast, information at the boundaries is supplied by the global model.

2.3 In the vertical, the coarse mesh and fine mesh models have the same resolution. The model atmosphere is divided into 16 layers with winds and temperatures carried at 15 levels. (See figure 2.). Normalized pressure ( $\sigma$ -sigma) is used as the vertical coordinate as this helps in the application of boundary conditions at the surface ( $\sigma=1$ ) and at the top of the atmosphere ( $\sigma=0$ ). At the surface we have information such as surface pressure and temperature as well as the nature and elevation of the surface. Humidity is carried at each level apart from the top. Examination of figure 2 shows that the spacing of the levels is not uniform. Resolution is greatest near the surface in an attempt to model the more rapid, near-surface variations. Above the boundary layer, the resolution is more uniform, except near the tropopause where the resolution is increased to allow for the larger shears there. In the same way that horizontal information (e.g. winds or temperatures) are



representative of values over a grid square, information in the vertical is representative of values over a layer. Thus inversions in the models are usually less marked than those in the real atmosphere and small, but significant variations in the vertical may be absent altogether. This should be borne in mind when examining tephigrams derived from model grid point values. Model tephigrams are much smoother than those derived from radiosonde information.

2.4 A description of the various numerical schemes employed in numerical modelling is beyond the scope of this note. However, it is necessary to point out a major difference between the techniques used by the UK Meteorological Office and ECMWF. The global and fine-mesh models are grid point models; i.e. the equations are solved at intersections of lines of latitude and longitude using finite difference techniques. The model developed at ECMWF uses spectral techniques where the dependent variables have a prescribed spatial structure. The precise details of spectral methods is not important here but we do need to know the effective resolution for comparison between models. The present resolution of the model at ECMWF is described as T106 which is a measure of the truncation involved. This means that the shortest wave treated by the scheme is just under 400km in length which compares with the global model value of around 500 or 600 km (there is no precise value for grid-point schemes; all we can really say is that the two-grid length wave is treated badly). The physical processes in the ECMWF model are calculated on a different grid (effectively grid-point) with a resolution of about 125km which compares with a coarse mesh value of around 150km at mid-latitudes.

2.5 From the above remarks, it would be expected that greater resolution results in better forecasts. There are many aspects of model performance which benefit from higher resolution. Certain features, such as the large shears near jets, need a short grid-length to model them adequately. In the case of jets, a horizontal grid-length of around 50km is desirable and this is less than that currently used in the fine mesh. Nonetheless, we do notice an improvement in the forecasting of jets in the fine-mesh and it is not too surprising that the coarse mesh



underestimates maximum wind speeds on most occasions, even in the analysis. Other small-scale features also benefit from high resolution but there is no guarantee that the fine mesh will give a better forecast than the global model on a particular occasion. The two models have separate analyses and different cut-off times. This usually means that the fine-mesh model does not have all the data that is available for use in the global model analysis for the same time. There are also occasions where because of its shorter grid-length, the fine mesh handles a particular feature differently which turns out to be wrong. As mentioned above (section 2.2), boundary conditions for the fine-mesh, limited-area model are provided by the global model forecast which starts from a data time 12 hours earlier since the fine mesh is run first for a particular data time and boundary conditions are also needed for the fine mesh assimilation. The solution from the global model will normally differ from the fine mesh so that a high diffusion zone is imposed on the fine mesh over several grid points near the boundaries to help smooth the values there. Moreover, near the fine-mesh boundaries the forecast will depend on the global model run which provided the boundary conditions. This may turn out to be significantly different from the global model run with the same data time as the fine mesh.

2.6 An important area where high resolution usually helps is in the physical parametrizations and the treatment of the surface. Processes that take place on or below that of the model grid-length and yet affect the larger scale, have to be modelled by assuming that the process is related in some way to the larger-scale variables (i.e. wind components, temperatures, humidity etc.). The processes we are describing here are those that we normally think of as producing weather (e.g. rain) and we know that the spatial variability of these processes is high. Thus the large scale variables will be more representative of conditions in the grid square as the grid-length decreases which in turn should result in more accurate parametrization.

### 3. Surface characteristics



3.1 Each grid point in the model is either land or sea. The land points are mostly described as temperate although there are arid land points to define desert regions, ice-covered points to define glaciated regions such as much of Greenland, and the land can also be snow-covered. Some sea points are designated as sea-ice points. Each grid point is assigned one of these types depending on the appropriate climatology each month (figures 10 to 21) and the surface type remains fixed during a forecast; e.g. land points do NOT change their classification during a forecast by accumulating snow or becoming frozen. Temperate and arid land points are also assigned a value for the albedo (ratio of reflected to incident solar energy) from a global dataset in which the type of vegetation for each grid square has been assessed. The albedo is used in radiation calculations (Section 5). Appropriate albedos are fixed for sea, snow and ice points. Sea surface temperature is analysed daily and remains fixed during a forecast.

3.2 In CFO there is a facility to intervene manually on the surface type. This is mainly used when the climatological snow cover used differs markedly from reality. This snow cover remains fixed during the forecast so it needs to be used with care, particularly in a coarse mesh 6 day forecast.

3.3 Each land point has a height difference (mostly above) from sea level. These values are derived from a high resolution (10') global data set and represent the mean value over a grid square. This mean value will be much lower in general than the highest point in a grid square especially in mountainous regions. A smaller grid length allows orography to be more accurately represented. However, even in the fine mesh model the orography over the British Isles (figure 3) is still unrealistic in places e.g. parts of Wales and the South West. Note also that valleys are too small to be represented on this scale so that important features such as the Great Glen and even the Forth-Clyde valley are not represented. The contouring in figure 3 implies more detail than exists within the model. In the model a cross-section West-East across Wales to East Anglia would look something like that shown in



figure 4. Figure 5 shows the orography for the whole fine mesh area and figures 6 to 9 show the orography used by the global model.

3.4 The data set used to obtain orographic height also contains information about land-cover. Using the information in this data set the percentage of land for each grid square is calculated and if it is more than half-covered it is designated as land and if it is less than half-covered it is designated as sea. Thus each point in the model is treated as land or sea and the model coastline lies midway between land and sea points. The coastline drawn on the fine-mesh grid in figure 1 is for illustrative purposes only. To show what the British Isles coastline really looks like in the fine mesh see figure 4. The global model coastline is obviously even less realistic with only about 16 grid points to represent the British Isles.

3.5 The above remarks concerning resolution are important when it comes to interpreting grid point values from the models and expecting these to represent specific locations. In most cases if individual station forecast elements are required from the models the relevant information should be post-processed in some way. If nearest grid point values are used without modification then the characteristics of the model grid point ought at least to be compared with the site for which a forecast is being made. The model elevation or surface type (the nearest grid point may actually be a sea point) may differ substantially from the forecast location and for example, the model screen temperature would be inappropriate if used unmodified. In the global model, grid-point values are averages over 20,000 square kilometers so to use unmodified values does not seem sensible. Post-processing, such as using MOS (model output statistics), would appear to be the best way of extracting forecast information for a particular site.

3.6 Much of local detail relates to the orographic variance and affects such things as wind, rainfall and temperature. Coastal points also have to be considered carefully. In the model, any grid point adjacent to a sea point will be affected to some extent by that sea point particularly if the wind is on-shore. However, the model cannot



capture the small-scale differences between say the coastal strip and inland locations sheltered from the effects of the sea.

#### 4. Boundary layer processes

4.1 The effects of surface friction and the exchange of heat and moisture between the atmosphere and the surface are calculated in the model boundary layer. In the global and fine mesh models the boundary layer can occupy the bottom 4 levels i.e. up to about 830mb.

4.2 Firstly the surface fluxes of momentum, heat and moisture are calculated using the variables from the model's lowest level (approx 25m) and the surface. For frictional effects different drag coefficients and roughness lengths are specified for land and sea points. In the fine mesh the roughness length over the sea also depends on wind speed to increase the frictional effect when there are strong winds. Exchange coefficients for heat and moisture also depend on whether the surface is land or sea.

4.3 Evaporation from the surface depends on the surface type. Over arid land there is no evaporation. The temperate classification in the model is used to represent all types of land surface except those covered by snow or ice and arid land. In the fine mesh model the ratio of actual/potential evaporation for each grid point over the UK is obtained from MORECS (Meteorological Office Rainfall and Evaporation Calculation System) and this value is used to modify the evaporation in the model. This is important in dry conditions, particularly in the summer months. At present the analysis of actual/potential evaporation is done once a week and is an average of the daily values for the week leading up to the analysis.

4.4 Changes are made to the surface temperature of land points as a result of evaporation and the flux of sensible heat. In the fine mesh model there is also a heat flux from the ground. This is obtained by modelling the temperature of 4 layers in the soil. The bottom layer (at



around 1.5m) is given a temperature appropriate for the time of the year and the temperatures of the other layers are solved using heat balance equations. At the surface a balance is obtained between the radiative flux and the heat flux from the ground. This is important when the radiational cooling is strong as without the soil model the surface cools too freely and the surface temperature becomes too cold by several degrees. Over ice and snow-covered land points the heat diffusion coefficient between the surface and the first soil layer is reduced to try and model the insulating effects of snow and ice. The heat diffusion coefficient for a particular point may therefore be inappropriate if, for example, snow accumulates in reality but not during a forecast. At present the heat diffusion coefficient is not changed if the ground becomes frozen so there will be too large a heat flux from the ground in these circumstances.

4.5 The turbulent mixing between the bottom layers and the rest of the boundary layer depends on the stability of each layer. Once a stable layer is reached the mixing is suppressed. No mixing takes place above the fourth layer (approx. 830mb) even in unstable conditions when the convection scheme operates instead.

## 5. Radiation

5.1 The vertical temperature structure of the model, including the surface temperature, changes because of the effects of incoming solar radiation and the long wave radiation emitted. Seasonal and diurnal effects are taken into account by the model depending on the position of the sun relative to a particular grid-point. The albedo of the surface governs the amount of solar radiation that is reflected and depends on the type of surface (see section 3).

5.2 Climatological radiation (global model)



5.2.1 The humidity and cloud inferred by the model are not used in this radiation scheme. Instead zonally averaged climatological values of mean daily heating and cooling rates are used which already take into account climatological cloudiness. The solar heating is also modified by the time of day to allow for the diurnal cycle. However, there is no diurnal variation of cloudiness.

5.2.2 From the above remarks, it follows that in conditions of either full or no cloud cover, the performance of the radiation scheme will be at its worst. Forecast minimum temperatures on clear nights will have a warm bias due to the assumed partial cloudiness and forecast maximum temperatures on a sunny day will have a cold bias. In cloudy conditions, the converse applies assuming that all other aspects of the forecast are correct.

### 5.3 Interactive radiation (fine mesh)

5.3.1 This is a more complex scheme which takes into account the cloud inferred by the model. Four cloud types are catered for - layered cloud at high, medium and low levels and convective towers. Clouds are inferred from the relative humidity within a layer; liquid water or ice are not stored by the model. Due to the computational expense of the scheme, calculations are done only every three simulated hours with the effects averaged over that period. The accuracy of this radiation scheme is dependent on the cloud forecast by the model. However, if the cloud forecast is good then a better simulation of the surface temperature can be expected, particularly in conditions of full or no cloud cover. Use of the interactive scheme also requires taking into account the flux of heat between the surface and deeper soil layers. (See section 4.4)

## 6. Large scale (dynamic) precipitation

Large scale or dynamic precipitation is produced by the model when a layer becomes supersaturated as a result of convergence or radiational cooling. Excess moisture is removed as precipitation. When precipitation



falls into a layer that is not saturated a proportion of the precipitation is evaporated into that layer. Phase changes between rain and snow are allowed for depending on the temperature of the layer. Whenever evaporation, condensation or phase changes take place, appropriate changes are made to the temperature of a layer.

## 7. Deep convection

7.1 The deep convection scheme is based on parcel theory, modified by entrainment and detrainment. The scheme assumes that in unstable conditions, in each grid box there is an ensemble of buoyant convective plumes of varying characteristics which entrain air from the environment and ascend until they are no longer buoyant. The environment is modified by the effects of entrainment and detrainment. In the fine mesh model the final detrainment is split over two layers, the top cloud layer and just above. This is to prevent excessively dry conditions being produced above the model's boundary layer. This split final detrainment does not appear to have a significant effect above the tropopause.

7.2 The bottom of the model layer where convection begins is taken as the base of the cloud. Convection ends when the plumes are no longer buoyant which is in the layer where convective effects are negligible. The cloud top is taken as the bottom of this layer.

7.3 In the fine mesh model convective clouds have to attain a certain depth before precipitation is produced. In both models the calculated cloud water content must exceed a certain minimum value. The critical depths of cloud used in the fine mesh are based on research data and are 4km over land and 1.5km over the sea. However, if the cloud top temperature is -10 degrees C or colder then the minimum depth is 1km to allow for ice-crystal growth through the Bergeron-Findeisen process.

7.4 As with large scale precipitation, snow (rain) is melted (freezes) when it reaches a layer with a temperature above (below) 0°C and the temperature of the environment cools (warms) accordingly. Below



cloud base a proportion of the rain (but not snow) is allowed to evaporate into the environment.

7.5 It should be noted that showers are not advected in the model. Showers released over warm seas in winter will not spread to adjacent land areas. Low level air may be moistened and warmed sufficiently to allow showers to develop over land in some situations.

7.6 Since one of the principal uses of the fine mesh is to provide rainfall forecasts, the performance of the deep convection scheme is of vital importance and it is also the scheme criticised most frequently. Deep convection schemes were developed originally for use in global modelling where the effects of tropical convection are important in terms of the general circulation. In higher latitudes convection tends not to be as organised in general. Thus part of the problem lies in the nature of convection itself and part with our perception of the weather and rainfall. Convective elements embedded within frontal zones do not appear to matter as much (unless there is very heavy rain) than when they are scattered in otherwise dry conditions. Scattered showers (i.e. most places dry!) are, by the nature of the parametrization scheme, difficult to model since presumably the large scale conditions averaged over a grid box may be relatively dry and with little or no dynamical forcing present. Reducing the grid-length ought to help but new problems will arise as the model grid-length approaches the scale of individual showers when the parametrization approximation will no longer be strictly valid. The fine mesh appears to be more successful when showers are more widespread but it can be sensitive to humidity errors which may occur because of analysis errors or the use of unrepresentative data.

## 8. Analysis and initial conditions

8.1 A continuous assimilation cycle is used to produce starting conditions for the model forecasts. In the coarse mesh, data is analysed every 6 hours using data 3 hours either side of the analysis hour (00Z, 06Z, 12Z and 18Z). The fine-mesh assimilation consists of a 3-hourly assimilation cycle, starting from interpolated coarse-mesh data 12 hours



before the required forecast time and using data 1½ hours either side of the analysis hour (e.g. 03Z, 06Z, 09Z and 12Z for the 12Z analysis/forecast run). Observations are used to correct a background field which is just a 6 hour forecast (3 hours for the fine mesh) from the previous assimilation. A description of the analysis and quality control of observations can be found in Atkins and Woodage (Met Mag 1985 p227). It is worth noting that surface temperatures (i.e. screen temperatures from land stations, ships etc.) are not used as they are often unrepresentative of conditions on the scale of the model grid. For the same reason, wind and humidity surface observations are not used over land, including coastal and island stations.

## 9. Use of Model Forecasts

9.1 The fine-mesh model usually produces realistic precipitation forecasts. However, rather than use these directly, it is better to try and understand the main developments first and then to reconcile the differences between the precipitation expected and that produced by the model. Other forms of output, such as relative humidity charts, model tephigrams, vertical velocity, thermal advection, etc may need to be examined. Later data or information from other sources such as satellite imagery or radars may reveal significant faults in the early stages of the forecast.

9.2 Continuity in successive forecasts will usually result in a greater degree of confidence and in general, the latest forecast is likely to be the most accurate. However, convergence towards the true state is not guaranteed and any significant differences between model forecasts should be assessed and the reasons for these differences understood before the earlier solution is put to one side.

9.3 One of the most useful diagnostic produced from the models is the 850mb wet-bulb potential temperature ( $850\text{mb}\theta_w$ ).  $\theta_w$  is conserved under adiabatic processes in the atmosphere and is therefore a useful indicator of air-mass and thus frontal position. (See Bradbury, Met. Mag. 1977) for a description of the uses of  $\theta_w$  analysis.) The warm edge



of the boundary of strongest  $\theta_w$  gradient is often associated with boundaries deduced from surface observations. The 850mb surface appears to be the optimum level for  $\theta_w$  analysis since it is hardly influenced by diurnal variations over land but low enough to be representative of the lower tropospheric air-mass. However, there are situations where  $\theta_w$  at other levels adds useful information e.g. cold air near the surface in winter over-ridden by warm air aloft, warm fronts at levels above 850mb.

9.4 In recent years, the fine mesh has proved its worth in helping to forecast snow. Snow probability lines (80%, 50% and 20% at MSL) based on forecast values of the 1000-850mb thickness suggested by Boyden are added to the precipitation output. There are limitations in the use of this parameter (see Davies and Hammon, Met. Mag. 1986) but in the first instance it is the most useful predictor available. Some forms of fine mesh output print snow symbols if the lowest level in the model (approximately 25m above the ground) is below 0°C and this has proved useful in highlighting the possibility of snow over high ground or when warm air over-rides cold air.

9.5 Grid-point surface winds from the fine mesh need to be used carefully. From the remarks made in section 3.5, grid-point winds are average values over a grid square which will not possess the orographic variance which influences surface winds in reality. This is true not only of valley winds but even for funnelling on the scale of the Dover Straits and adjacent areas of the Channel and Southern North Sea. Furthermore, gustiness is not available from the model and has to be inferred. Vertical wind profiles may be of some help in showing wind speeds near to the surface.

9.6 When comparing model forecasts which differ, the forecaster has to decide on which solution to follow or whether a compromise is needed. In general, since forecast errors grow with time there is a tendency to accept the latest forecast. Differences between model forecast can usually be traced to different starting conditions but it is not straightforward to identify the significant differences in real time.



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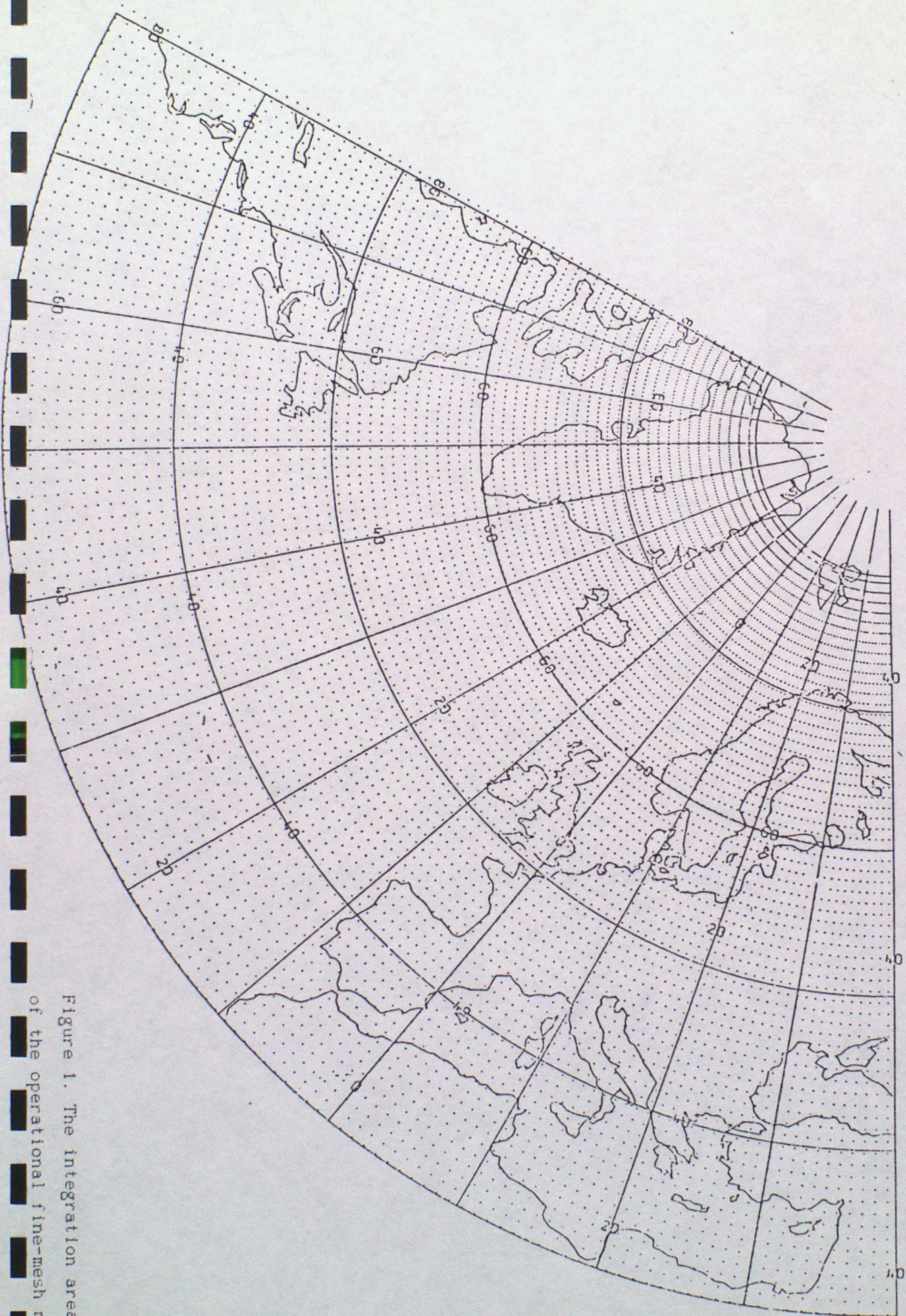


Figure 1. The integration area  
of the operational fine-mesh model



Number	Full-level	Half-level
15	0.025	0.013
14	0.065	0.042
13	0.125	0.098
12	0.190	0.156
11	0.250	0.228
10	0.310	0.273
9	0.390	0.350
8	0.490	0.433
7	0.590	0.552
6	0.690	0.630
5	0.790	0.754
4	0.870	0.827
3	0.935	0.914
2	0.975	0.956
1	0.997	0.994

Figure 2. The  $\sigma$ -levels used by the operational forecast models.



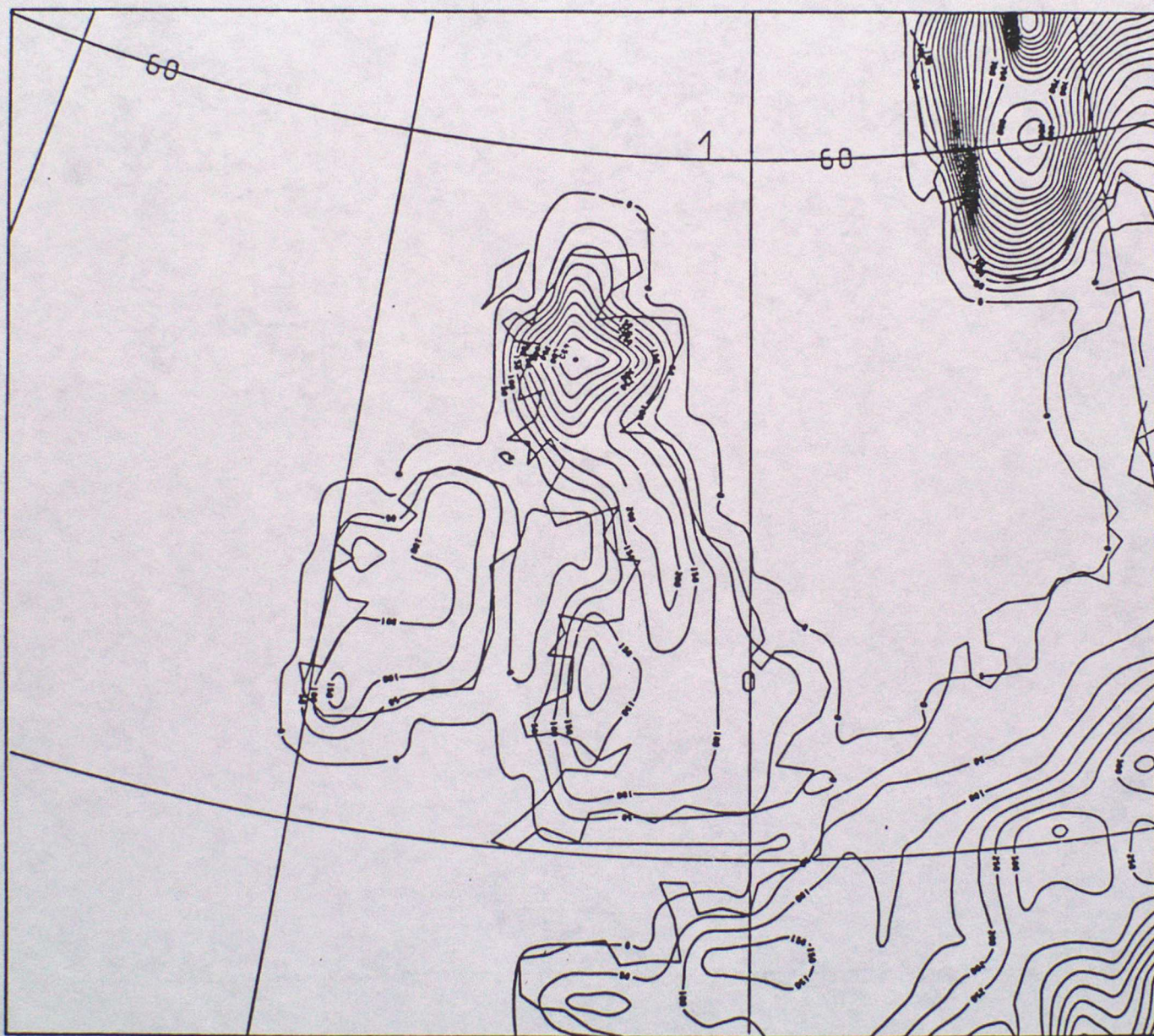
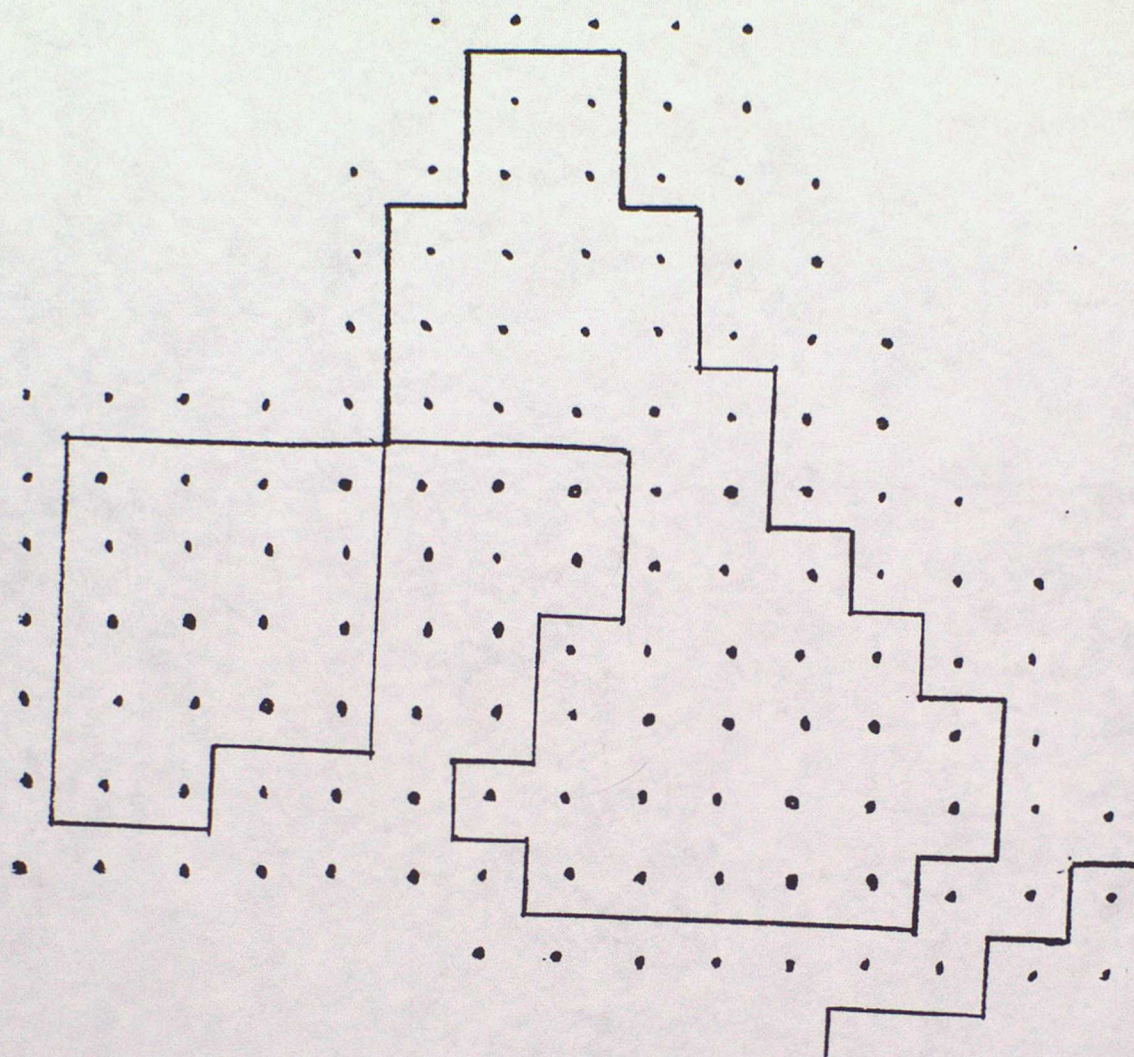


Figure 3.

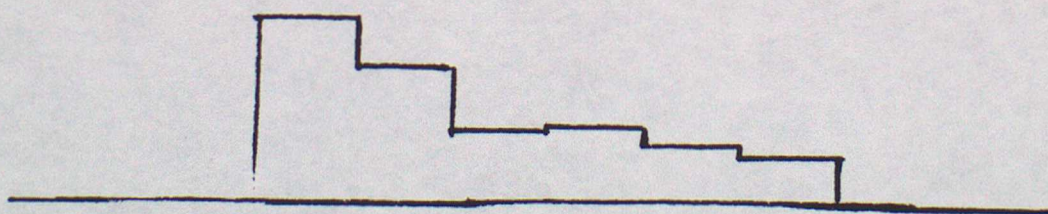
OPERATIONAL FINE-MESH OROGRAPHY (M.)

FINE-MESH F/C MAIN RUN





Fine-mesh land points for U.K. with implied coastline.



Cross section from Wales to East Anglia.

Figure 4.





Figure 5. Fine mesh model orography. Contour interval = 200m



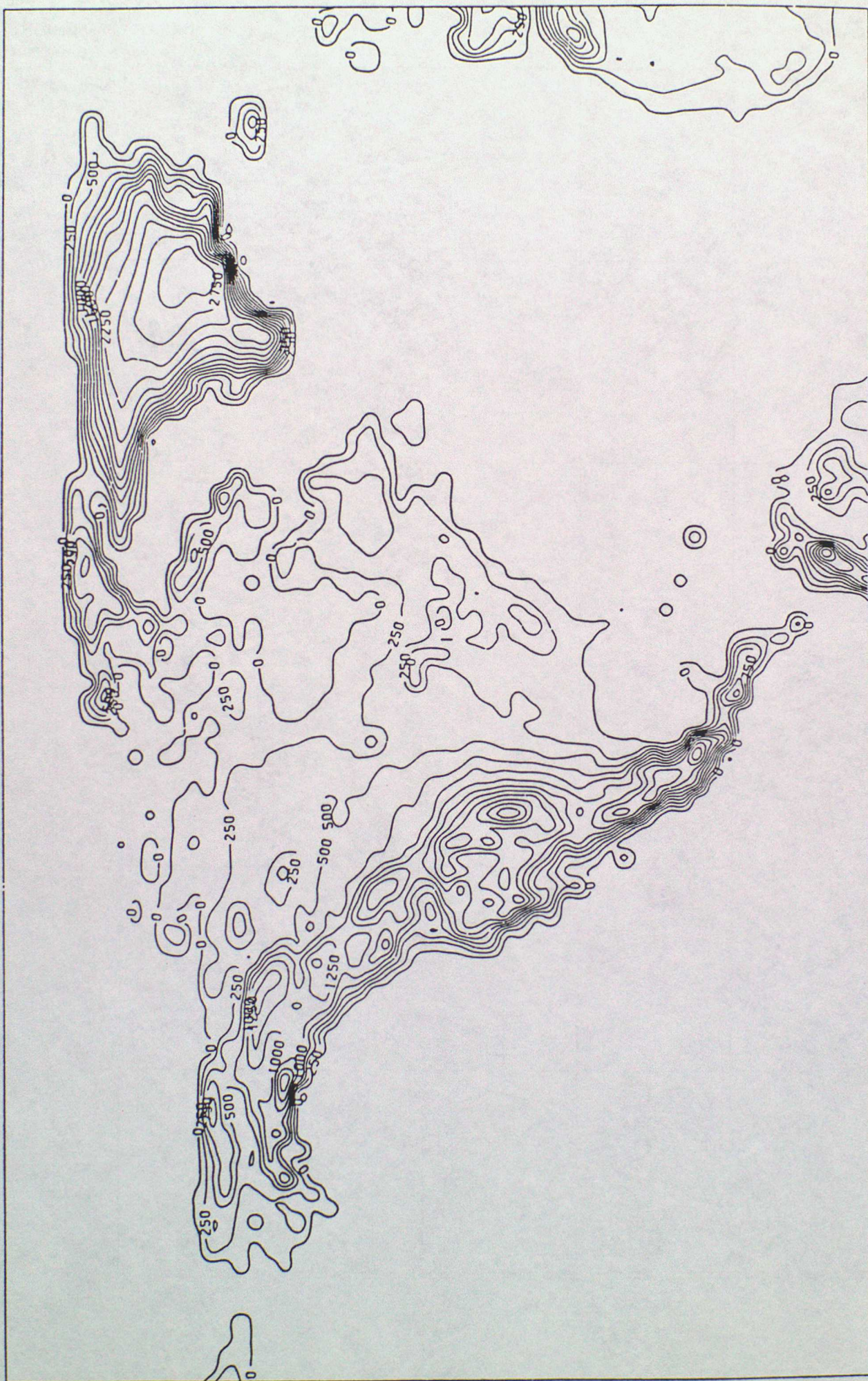


Figure 6. Global model orography.

Contour interval - 250 m





Figure 7. Global model orography (continued). Contour interval : 250 m



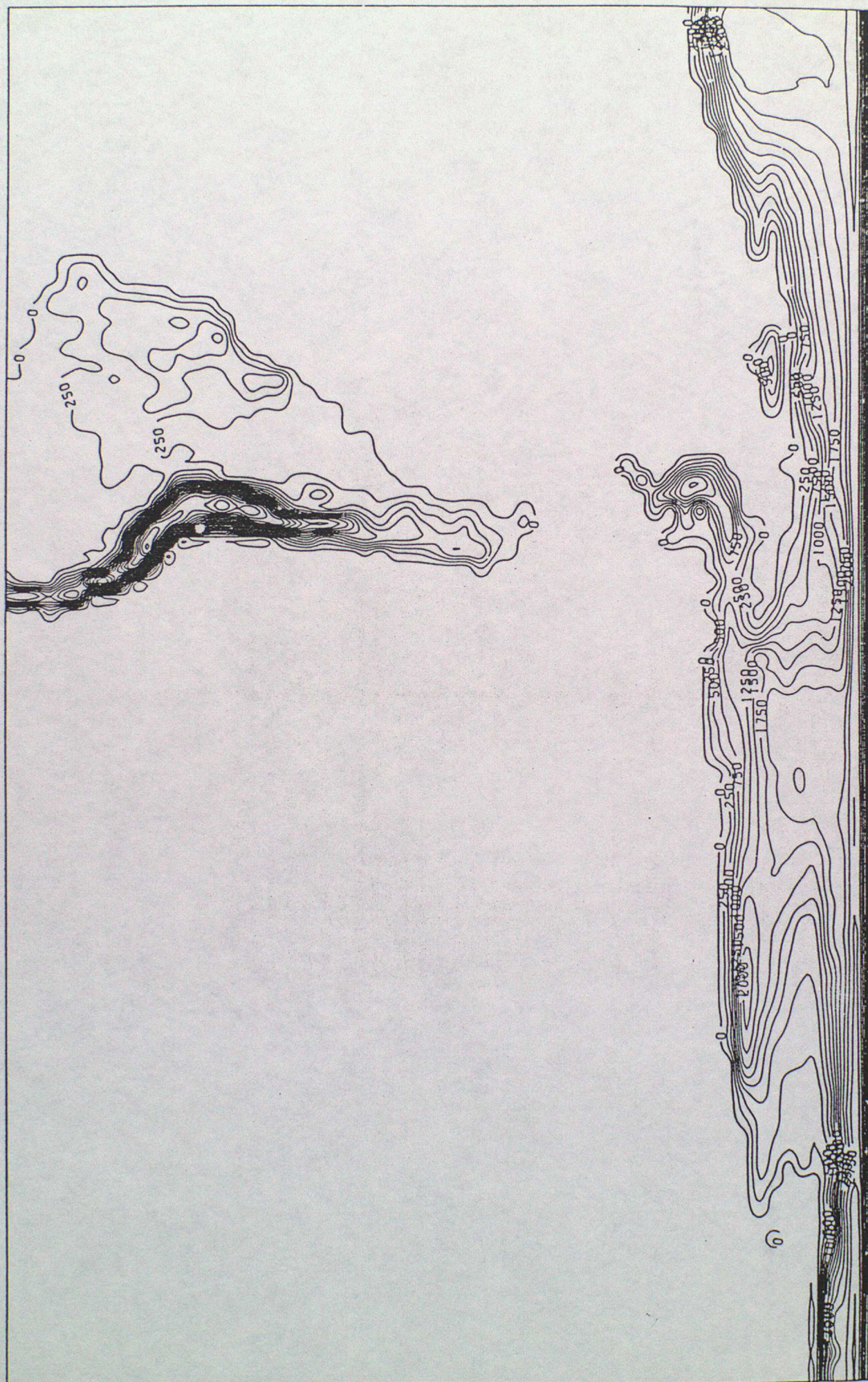


Figure 8. Global model orography (continued). Contour interval = 250 m



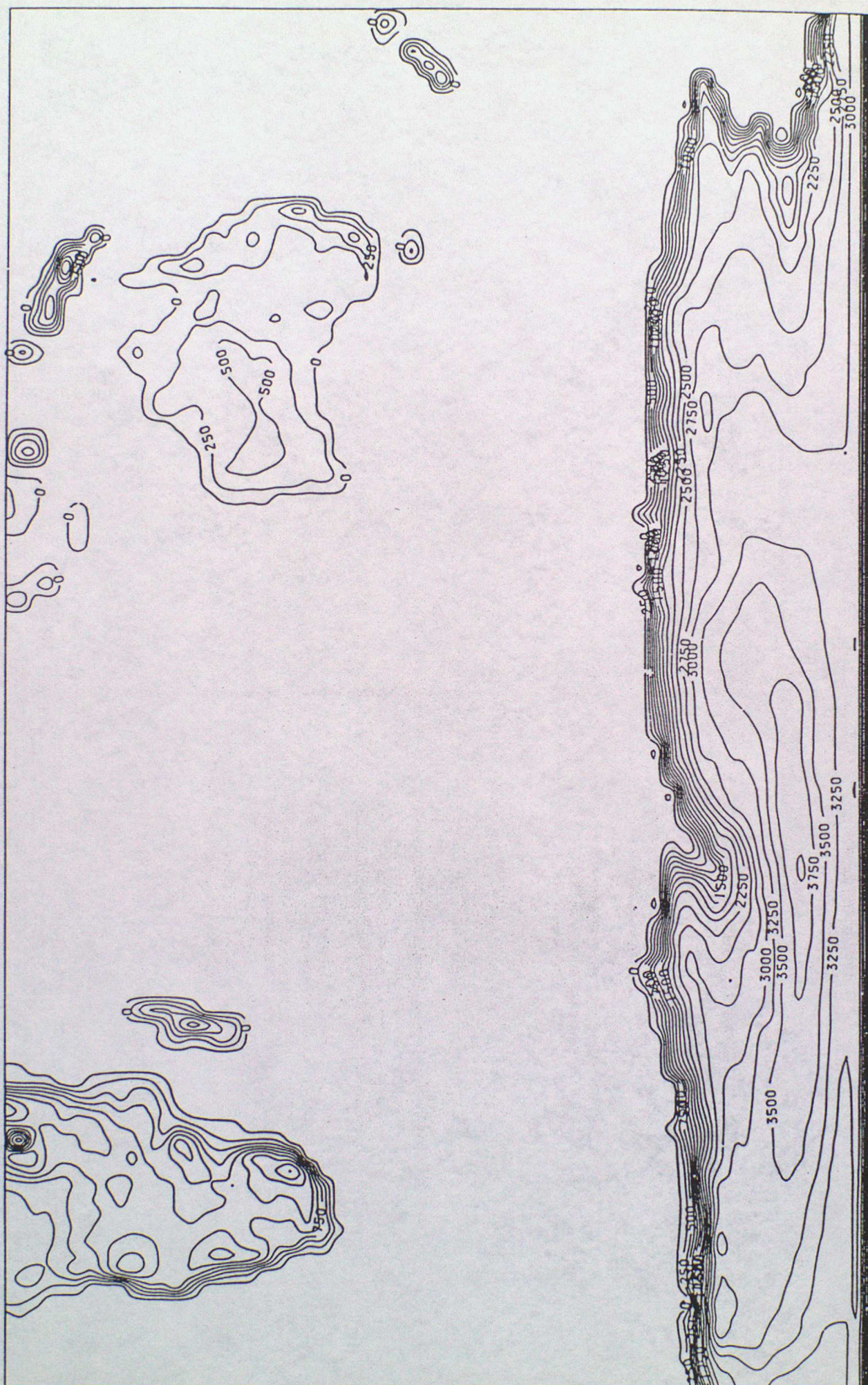


Figure 9. Global model orography (continued). Contour interval = 250 m





Figure 10. JANUARY SURFACE TYPES.

Temperate land=⊙ ; Sea-ice=Δ ; Land-ice=▽ ; Arid-land=◻ ; Snow covered land=\*





Figure 11. FEBRUARY SURFACE TYPES.

Temperate land=⊙; Sea-ice=∧; Land-ice=△; Arid-land=□; Snow covered land=✱





Figure 12. MARCH SURFACE TYPES.

Temperate land=○ ; Sea-ice=△ ; Land-ice=Δ ; Arid-land=□ ; Snow covered land=\*





Figure 13. APRIL SURFACE TYPES.

Temperate land=⊙;Sea-ice=^;Land-ice=Δ;Arid-land=□;Snow covered land=\*





Figure 14. MAY SURFACE TYPES.

Temperate land=⊙ ; Sea-ice=△ ; Land-ice=▲ ; Arid-land=◻ ; Snow covered land=✱





Figure 15. JUNE SURFACE TYPES.

Temperate land=⊙; Sea-ice=Λ; Land-ice=△; Arid-land=◻; Snow covered land=×





Figure 16. JULY SURFACE TYPES.

Temperate land=⊙; Sea-ice=△; Land-ice=▽; Arid-land=□; Snow covered land=\*





Figure 17. AUGUST SURFACE TYPES.

Temperate land=○ ; Sea-ice=△ ; Land-ice=▽ ; Arid-land=□ ; Snow covered land=\*





Figure 18. SEPTEMBER SURFACE TYPES.

Temperate land= $\bigcirc$  ; Sea-ice= $\Delta$  ; Land-ice= $\nabla$  ; Arid-land= $\square$  ; Snow covered land= $*$





Figure 19. OCTOBER SURFACE TYPES.

Temperate land=⊙ ; Sea-ice=△ ; Land-ice=▽ ; Arid-land=▣ ; Snow covered land=\*





Figure 20. NOVEMBER SURFACE TYPES.

Temperate land=⊙ ;Sea-ice=△ ;Land-ice=◻ ;Arid-land=◻ ;Snow covered land=✕





Figure 21. DECEMBER SURFACE TYPES.

Temperate land=○; Sea-ice=△; Land-ice=◻; Arid-land=◻; Snow covered land=\*