2.2 Rainfall in the Mawddach catchment

Rainfall monitoring

Rainfall distribution is clearly an important controlling factor for catchment hydrological response. Field investigations were carried out to determine the extent to which rainfall distribution patterns varied across the Mawddach catchment:

- during individual storm events
- between different storm events

At the commencement of the project, a small number of raingauge stations were operated in and around the Mawddach catchment by the Environment Agency:

	Grid reference
Ffestiniog	716433
Arenig	839391
Drws y Nant	849269
Rhydymain	797238
Llyn Cynnwch	736204

Data from these stations has been used in studies of the 3 July 2001 Mawddach flood event (Barton, 2002).

Figure 2.33: Weather station at Coleg Meirion-Dwyfor, Dolgellau

To improve the coverage of meteorological data for the catchment, additional stations have been added: Automatic weather stations have been installed at Coleg Meirion-Dwyfor in Dolgellau (fig.2.33) and Aran Hall School, Rhydymain. These provide readings of temperature at 10 minute intervals, 10 minute averaged wind speed and direction, and tipping bucket raingauge event data.

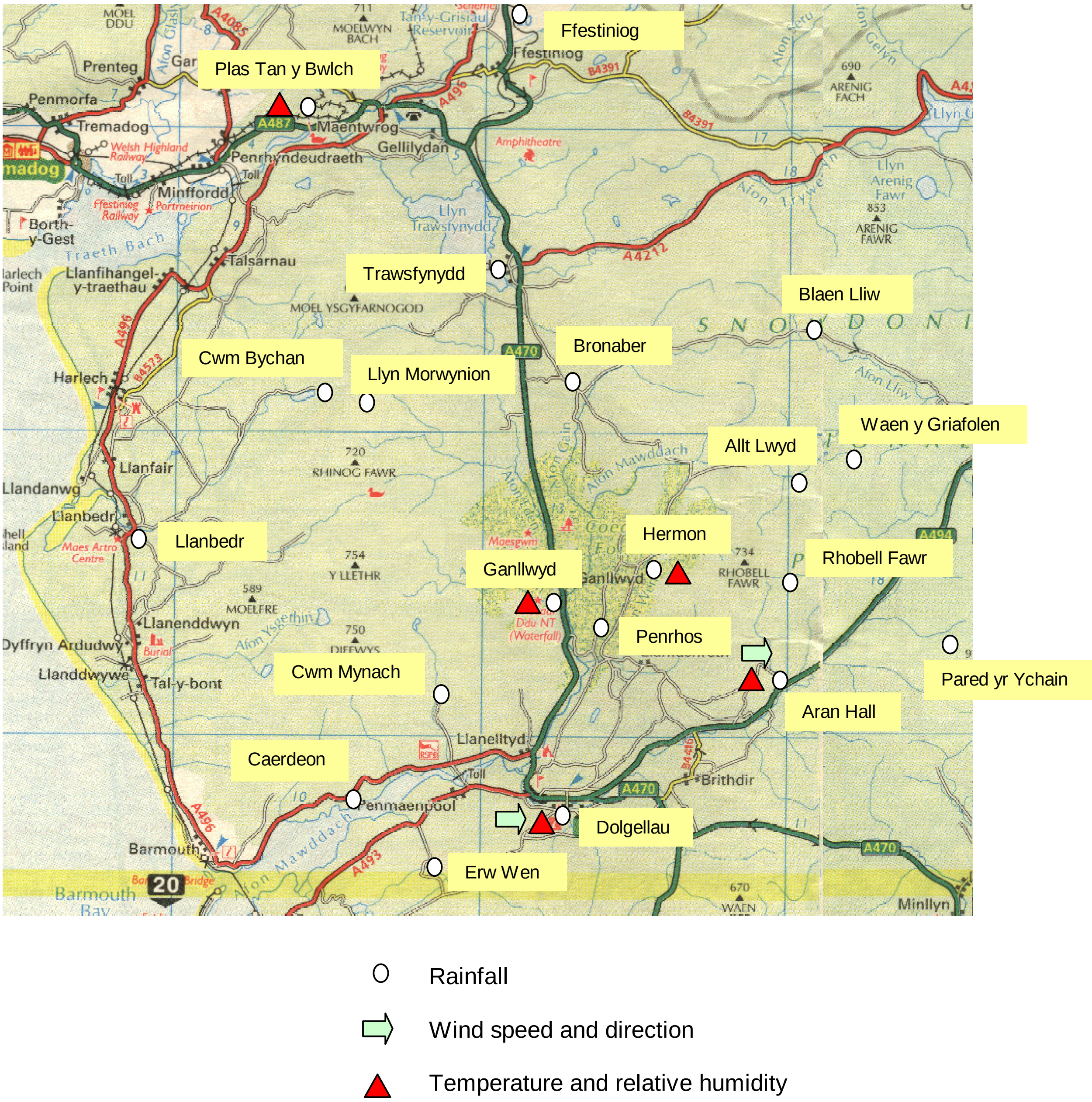

Figure 2.34: Meteorological recording sites

A pattern of 18 automatic rain gauges has been established across the Mawddach catchment and adjoining areas. The gauges are of the tipping bucket type, with event signals sent to an electronic data logger. Sites were chosen to fill gaps in the existing coverage, particularly for mountain terrain (fig.2.35). The distribution of additional recording sites in shown in figure 2.34.

Figure 2.35(a). Pared yr Ychain raingauge site, Aran mountains.

Figure 2.35(b). Llyn Morwynion raingauge site, Rhinog mountains.

Classification of rainfall patterns

Data was collected from the raingauge array for 28 storm events during the period August 2002 to February 2004. A 'storm event' was defined as a 24 hour period during which at least 15mm of rainfall was recorded by a raingauge within the Mawddach catchment. An isohyet map was plotted for each storm event. Meteorological Office synoptic charts were also obtained. Prevailing wind directions during all the storm events were from the westerly or southerly quadrants.

Examination of the set of iohyet maps revealed three principal rainfall distribution patterns. These have been termed rainfall distribution **Types A1, A2** and **B**. Every frontal storm event recorded during the project conformed to one or other of these three basic patterns. It should be noted, however, that convective thunderstorm activity shows more randomness and cannot be assigned to an A-B pattern.

Rainfall distribution Type A1

Rainfall is concentrated in the area of Coed y Brenin and Rhobell Fawr, giving a single zone of maximum rainfall near the centre of the catchment. Isohyets appear as ellipses extended on a WNW – ESE axis.

A typical storm event of type A1 occurred on **8 November 2002**. Isohyet patterns for the storm are illustrated in fig.2.36.

Synoptic charts for the period 8-9 November 2002 are given in fig.2.37. The area of low pressure A remains stationary to the south east of Greenland, whilst low B tracks from the north of Scotland towards the Dutch coast. Early in the morning of 8 November a wedge of warm air is drawn towards low B, creating a depression with warm and cold front structure.

Local meteorologocal charts for Wales for the period 11:00h to 14:00h, 8 November, are given in fig.2.38. The warm front crosses the Mawddach catchment around 11:00h with a N-S orientation, followed around 13:30h by the cold front with orientation NNE-SSW. Low level wind directions within the warm sector have an average orientation between westerly and west-south-westerly.

Heavy rainfall commences as the warm front approaches, with maxima below and to the rear of the front where a warm air conveyor will be ascending with the west-south-westerly air flow. Rainfall is concentrated in the central area of the catchment, with local maxima in the areas of the mountains Diffwys and Rhobell Fawr.

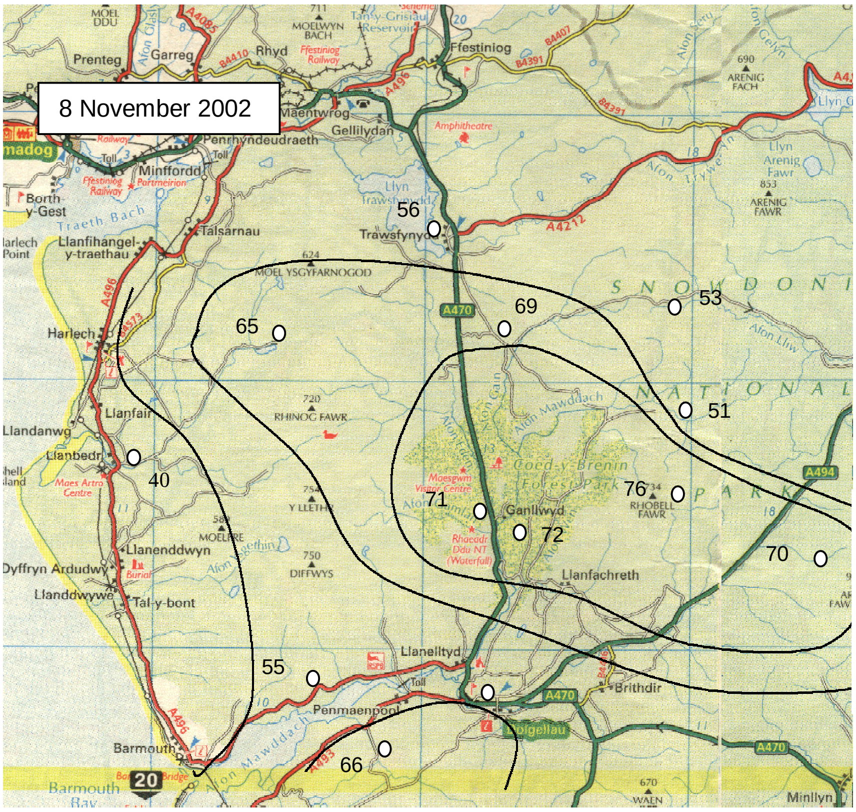

Figure 2.36: Type A1 rainfall distribution pattern. Total storm rainfall isohyets, 8 November 2002

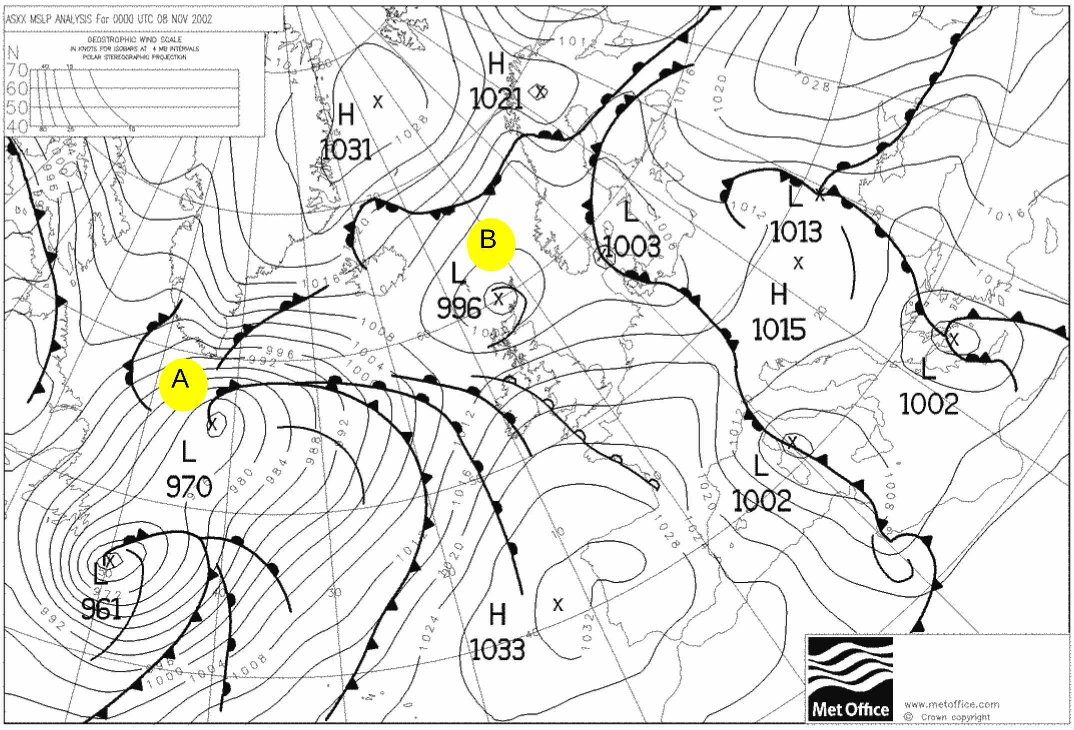

Figure 2.37(a) . Synoptic chart, 00:00h 8 November 2002

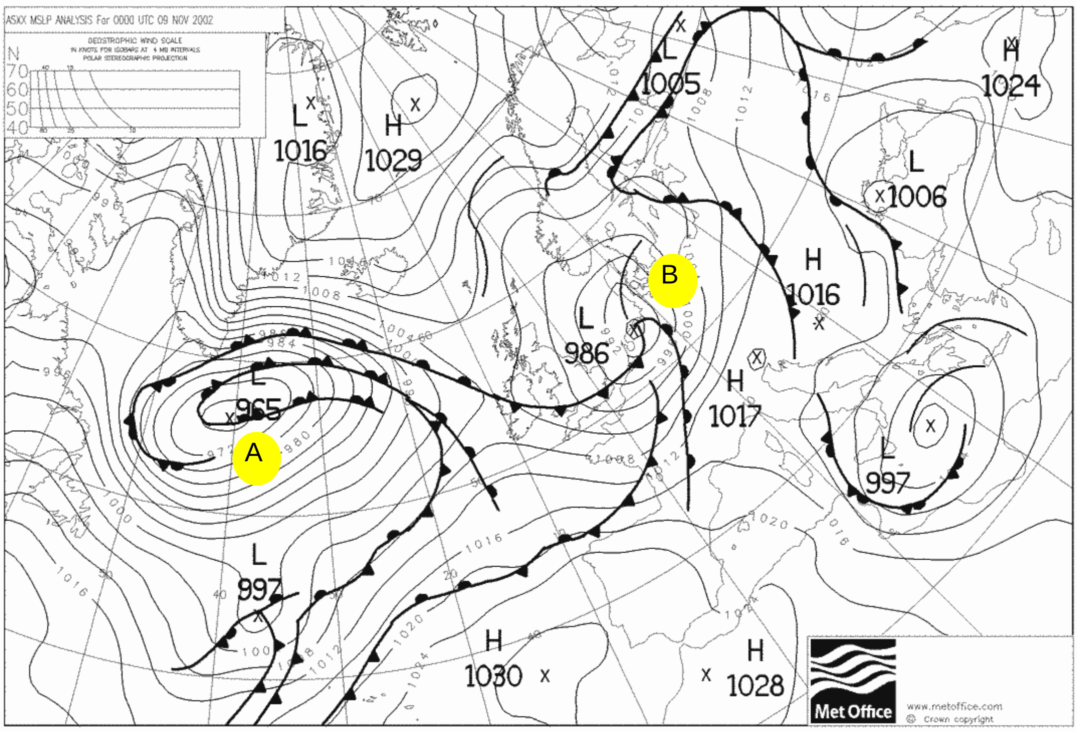

Figure 2.37(b) . Synoptic chart, 00:00h 9 November 2002

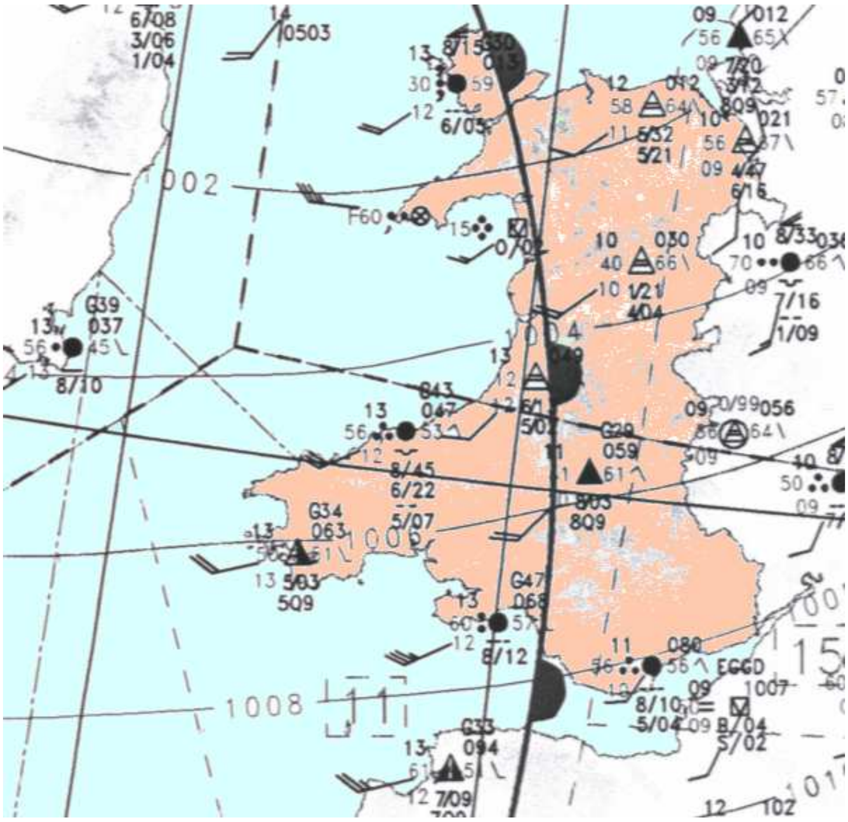

Figure 2.38(a). Regional meteorological chart: 11:00h 8 November 2002

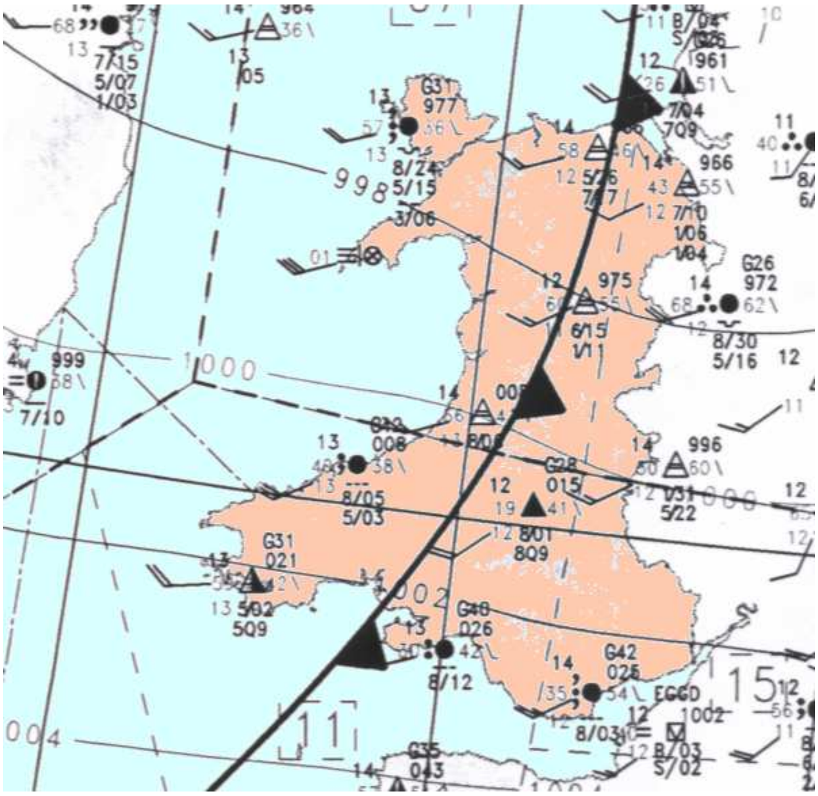

Figure 2.38(b). Regional meteorological chart: 14:00h 8 November 2002

The dominant regional airflow direction on 8 November is aligned with the Mawddach estuary(fig.2.39). It is conjectured that the mid altitude warm airmass in the conveyor ascends over Rhinog Fawr, Diffwys and Rhobell Fawr, initiating precipitation above these mountains. Low level airflows are forced to rise at the valley heads in Coed y Brenin, leading to saturation and condensation. Rainfall enhancement by the seeder-feeder mechanism occurs where rain drops descend through this saturated valley air, concentrating the maximum rainfall in the centre of the catchment.

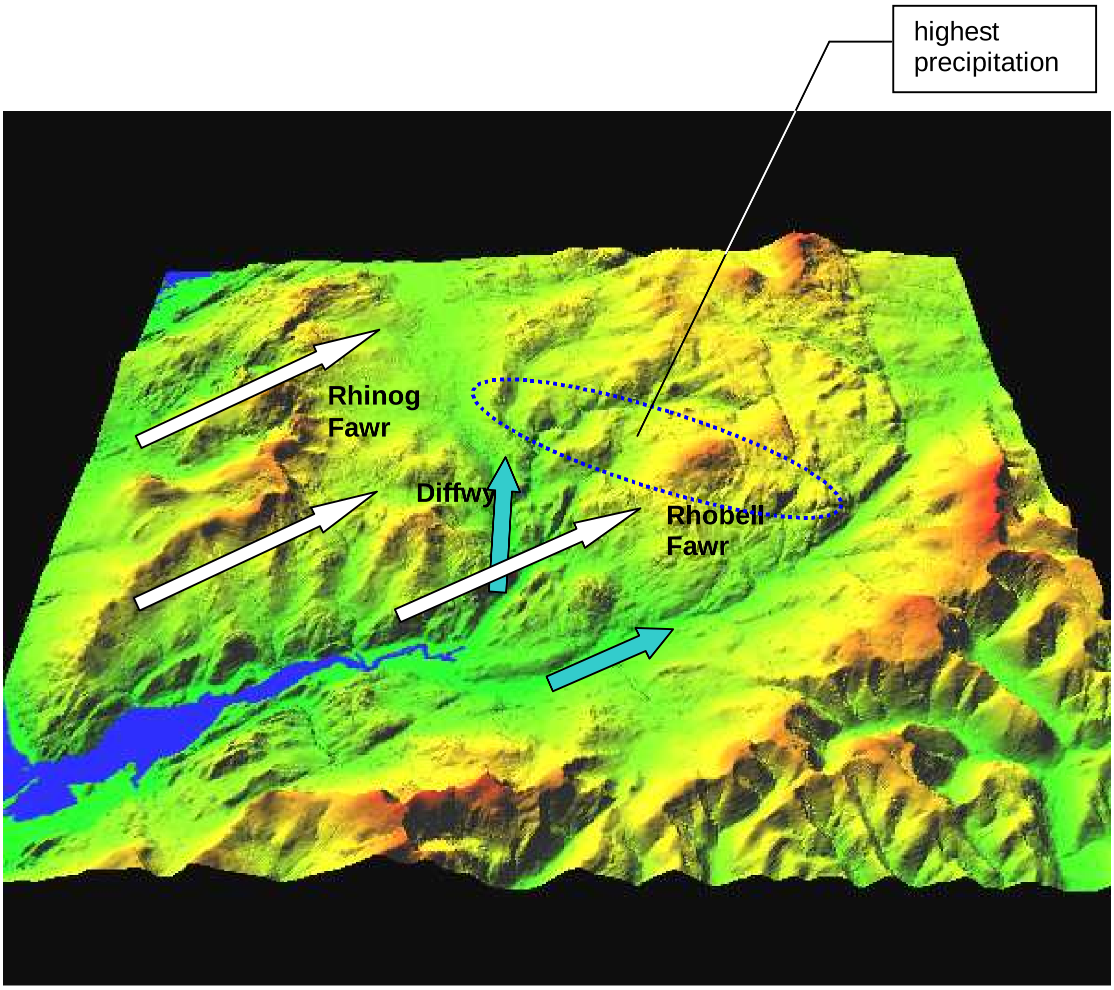

Figure 2.39: Airflow directions across the Mawddach catchment, 8 November 2002. Key to arrows: white: middle atmospheric level, blue: valley airflows.

Rainfall distribution Type A2

Type A2 is a variant on type A1 where rainfall distribution now shows two maxima, one in the area of the Trawsfynydd plateau and the other in the area of Pared yr Ychain in the Aran mountains. Isohyets show a band of high rainfall oriented NW – SE connecting the two zones of rainfall maxima.

A typical storm event of type A2 occurred on **29 December 2002**. Isohyet patterns are shown in fig.2.40.

Synoptic charts for 28-30 December 2002 are given in fig.2.41. During this period there is a slowly moving low A tracking eastwards in the mid Altantic. A depression associated with this low is partly occluded, with surface warm and cold fronts present beyond point C. An older partly-occluded depression at B is tracking eastwards from Scotland to Scandinavia.

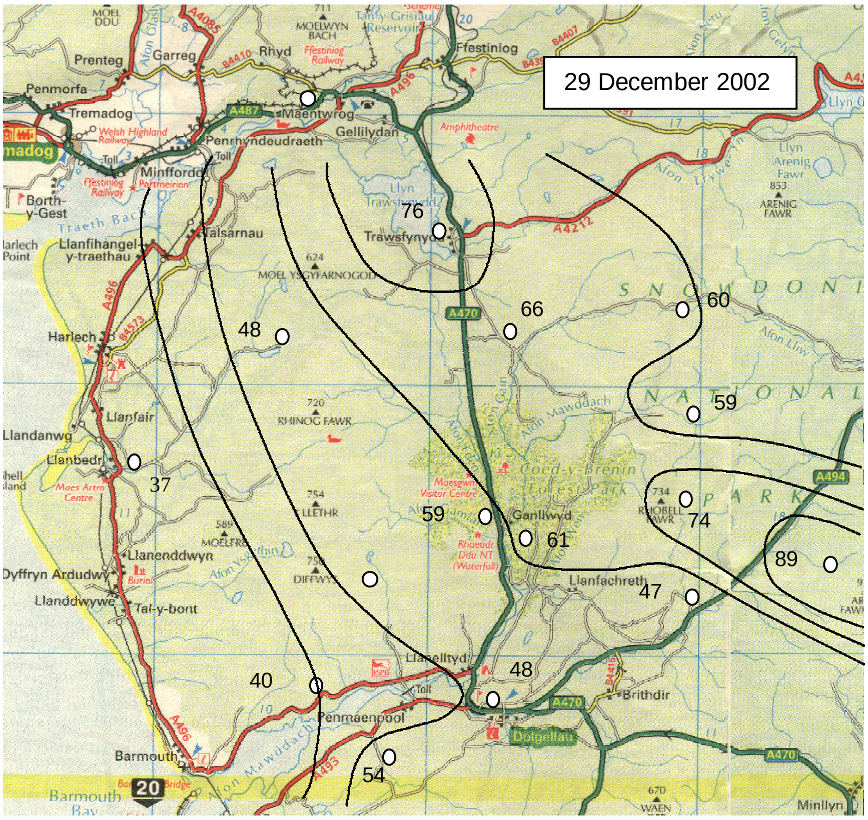

Figure 2.40: Type A2 rainfall distribution pattern. Isohyets show total storm rainfall, 29 December 2002

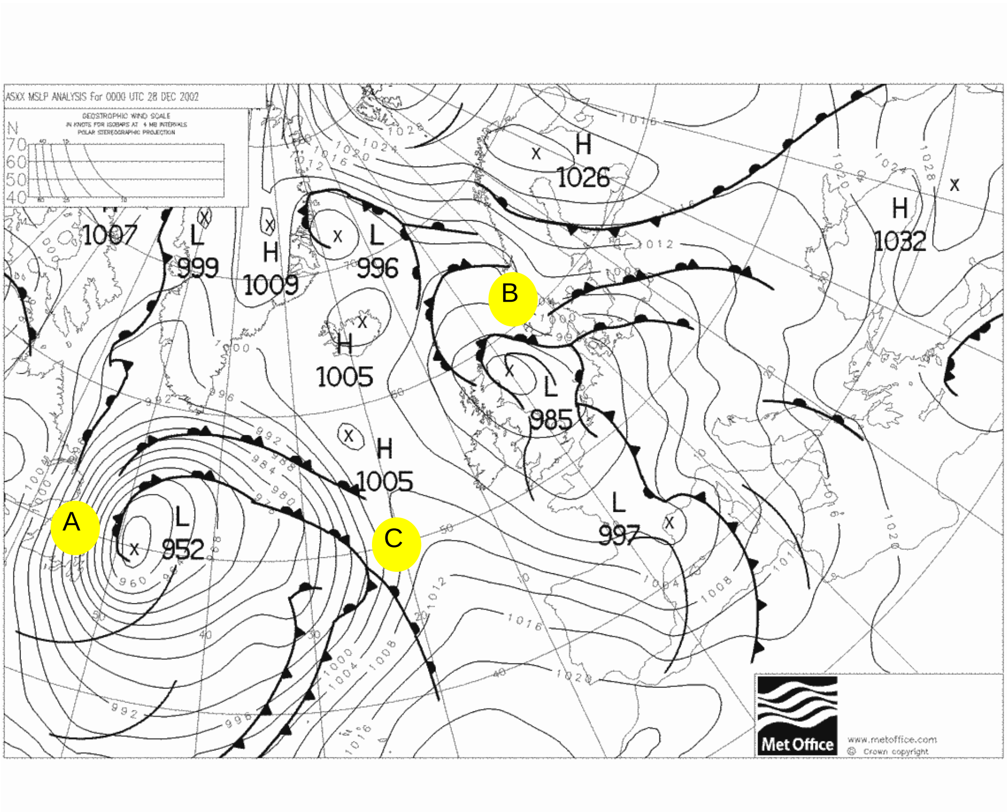

Figure 2.41(a). Synoptic chart, 0:00h 28 December 2002

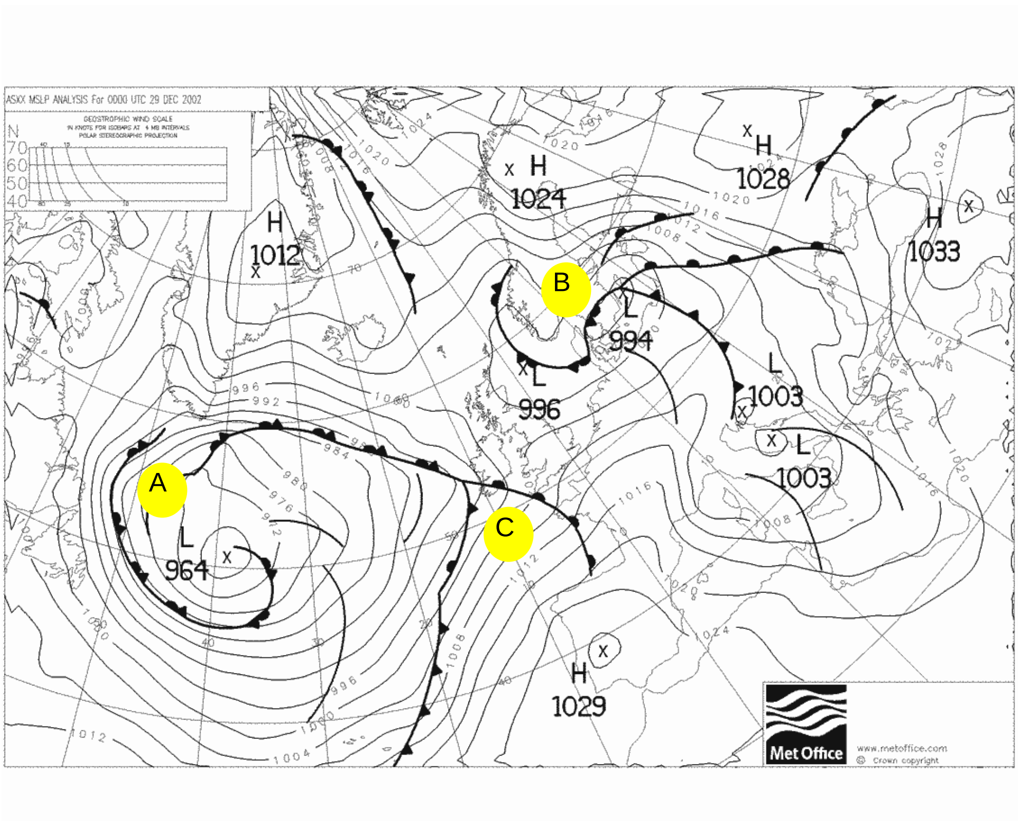

Figure 2.41(b). Synoptic chart, 0:00h 29 December 2002

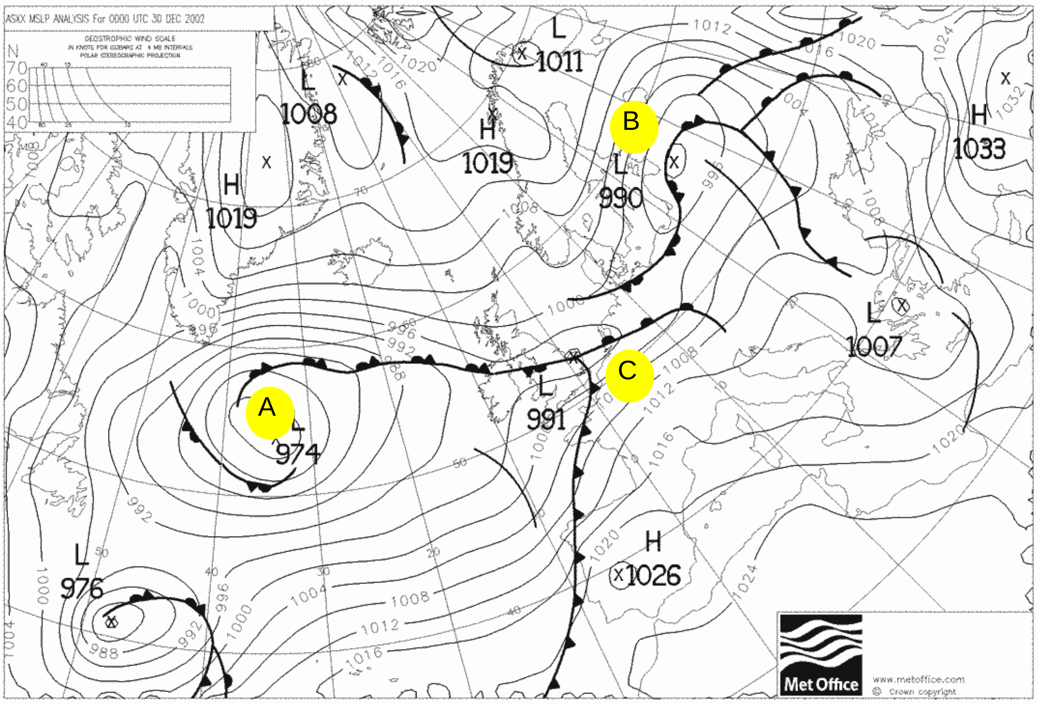

Figure 2.41(c). Synoptic chart, 0:00h 30 December 2002

Regional charts for the period 10:00h to 16:00h on 29 December are given in fig.2.42. The warm front close to point C crosses the Mawddach catchment at 12:00h with a NW-SE orientation. Within the warm sector, winds are from the south-west. The cold front is slow moving and crosses the Mawddach catchment during the evening of 29 December.

Rainfall totals for 29 December are given in fig.2.38. Substantial rainfall occurs around mid-day, below and behind the warm front where a warm air conveyor is ascending towards the NE. Rainfall continues through the afternoon, up to the time that the cold front passes.

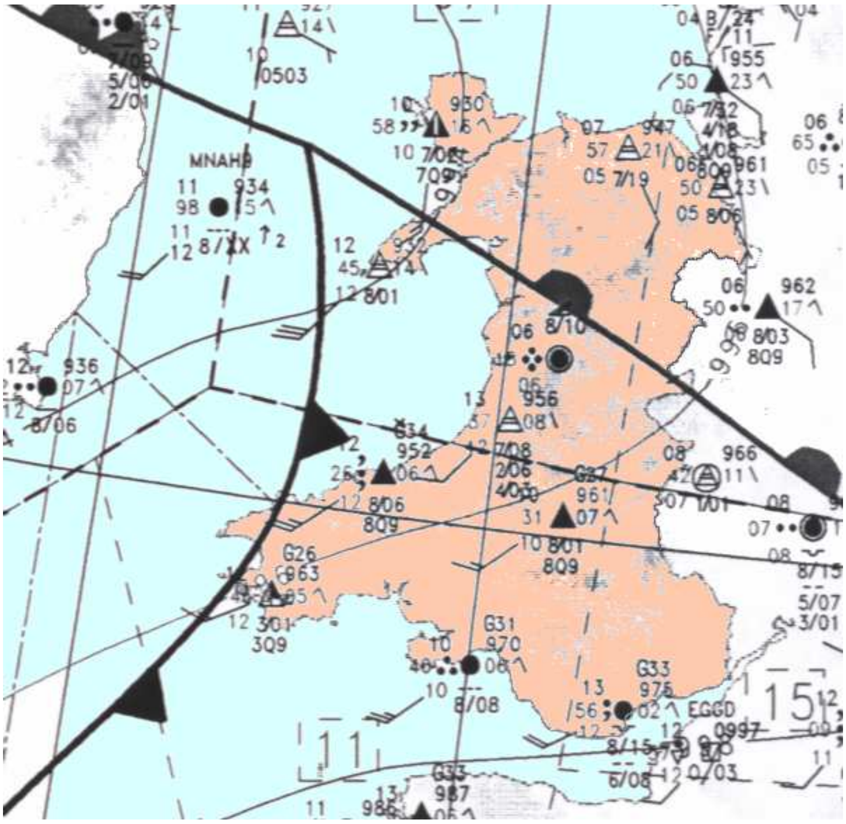

Figure 2.42(a). Regional meteorological chart: 12:00h 29 December 2002

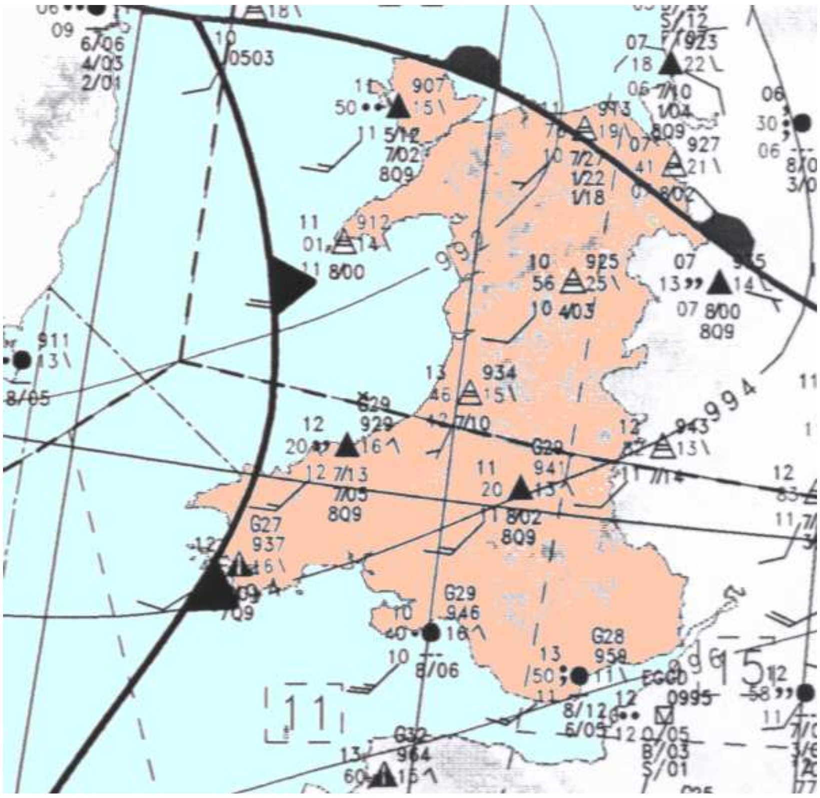

Figure 2.42(b). Regional meteorological chart: 16:00h 29 December 2002

The orientation of winds on 29 December is illustrated in fig.2.43. It is conjectured that the mid altitude warm airmass in the conveyor ascends over Rhinog Fawrand Aran Fawddwy, initiating precipitation above these mountains. Low level airflows follow the deep Mawddach and Wnion valleys and are forced to rise at the valley heads, leading to saturation and condensation. Rainfall enhancement by the seeder-feeder mechanism occurs where rain drops descend through this saturated valley air, concentrating the maximum rainfall in the areas of Trawsfynydd and Pared yr Ychain.

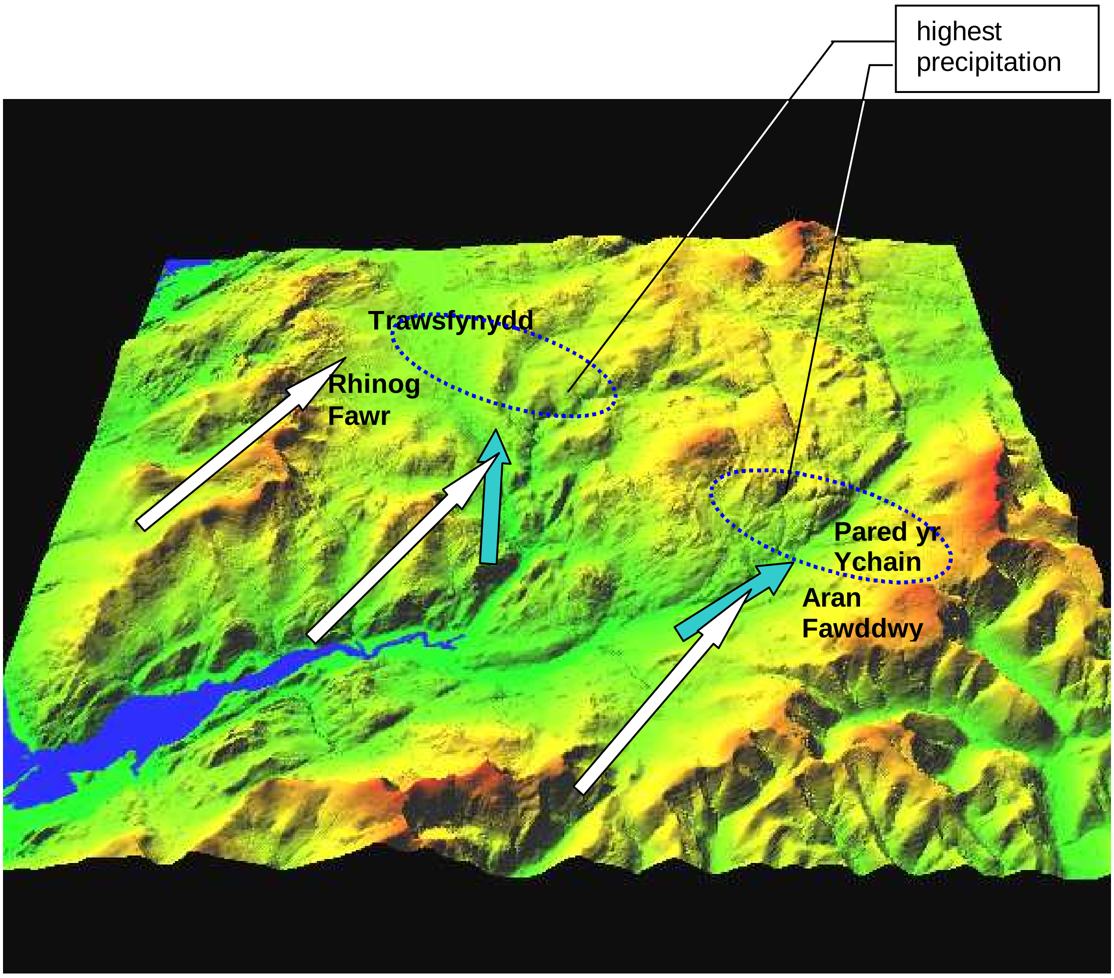

Figure 2.43: Airflow directions across the Mawddach catchment, 29 December 2002. Key to arrows: white: middle atmospheric level, blue: valley airflows.

Rainfall distribution Type B

Rainfall is concentrated in a band following the axis of the Rhinog mountains from the Mawddach estuary in the south to the Vale of Ffestiniog in the north. Rainfall declines inland.

A typical storm event of type B occurred on **22 May 2003**. Isohyet patterns are shown in fig.2.44.

Synoptic charts for 22-23 May 2003 are given in fig.2.45. At this time, a low pressure centre at A is occluding in the area of Greenland. To the east, a low pressure centre B is tracking in from the mid-Atlantic towards the north of Scotland. Associate with centre B is a complex front separating cold Polar air to the north from the warm Tropical airmass to the south. The front shows oscillation, with warm air pushing northwards in some sectors and cold air pushing southwards in others. During 22 May this front sweeps southwards across Wales.

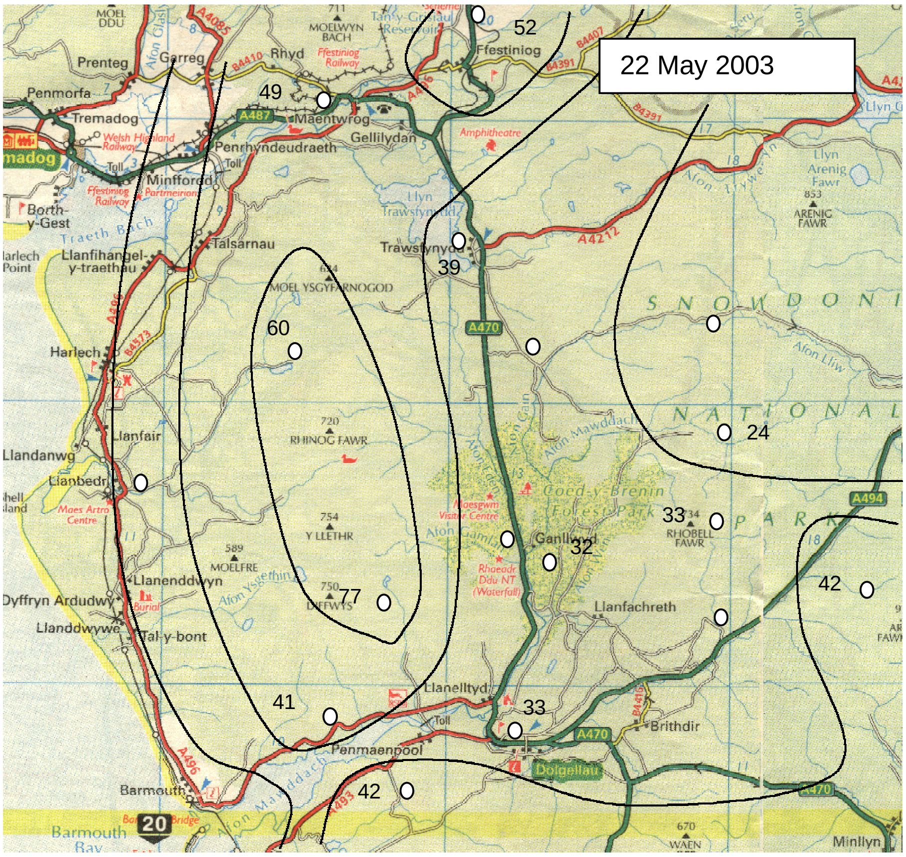

Figure 2.44: Type B rainfall distribution pattern. Isohyets show total storm rainfall, 22 May 2003

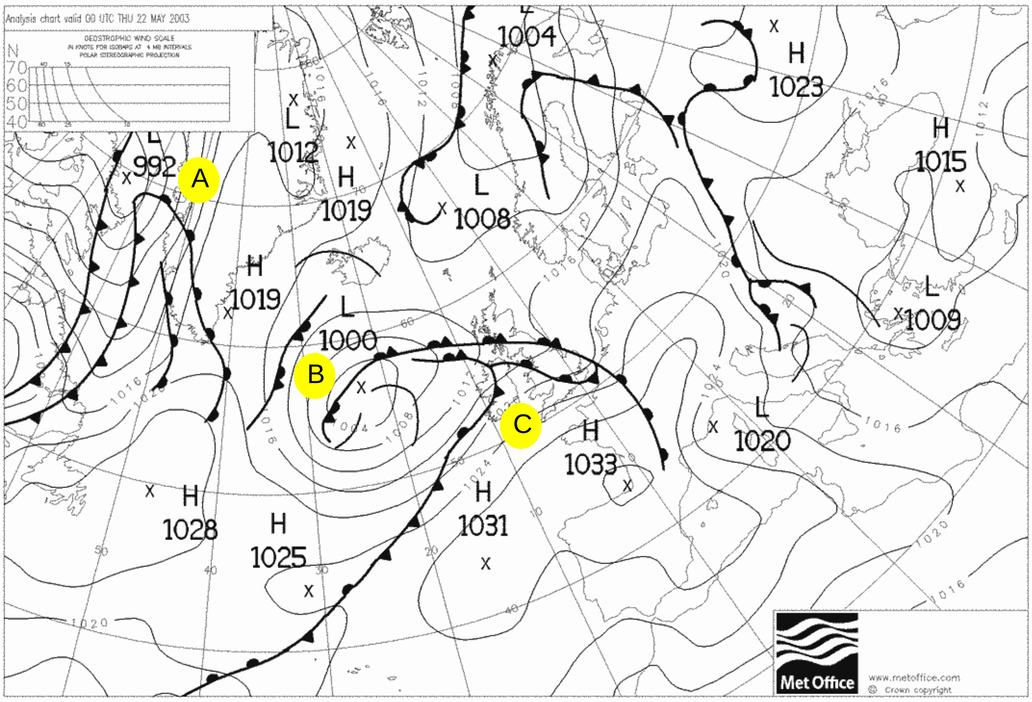

Figure 2.45(a). Synoptic chart, 00:00h 22 May 2003

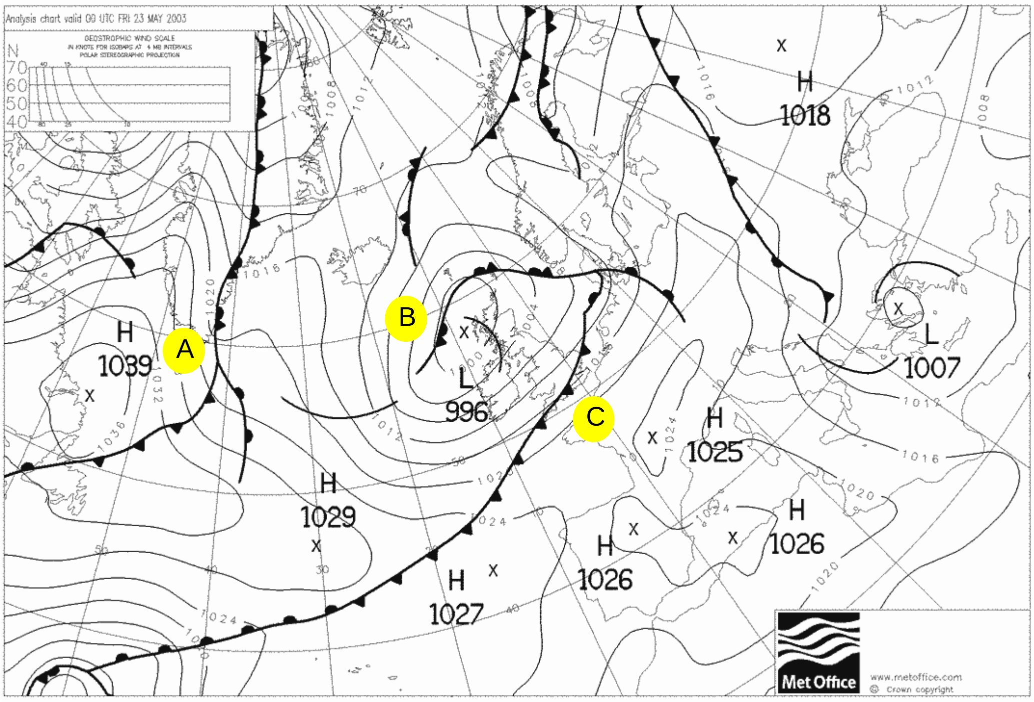

Figure 2.45(b). Synoptic chart, 00:00h 23 May 2003

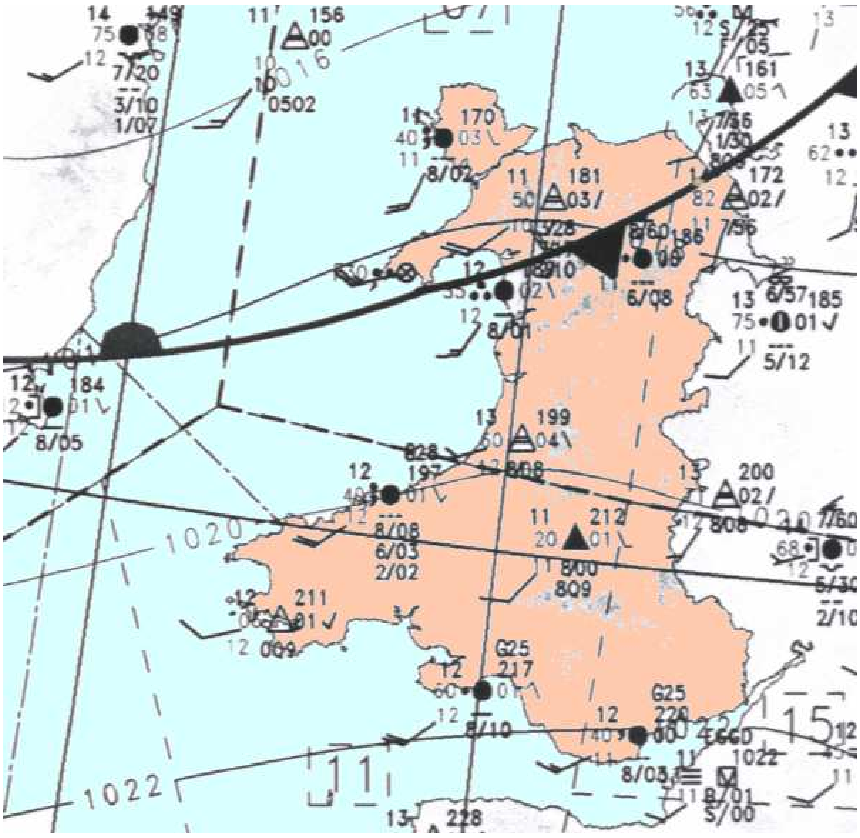

Figure 2.46(a). Regional meteorological chart: 07:00h 22 May 2003

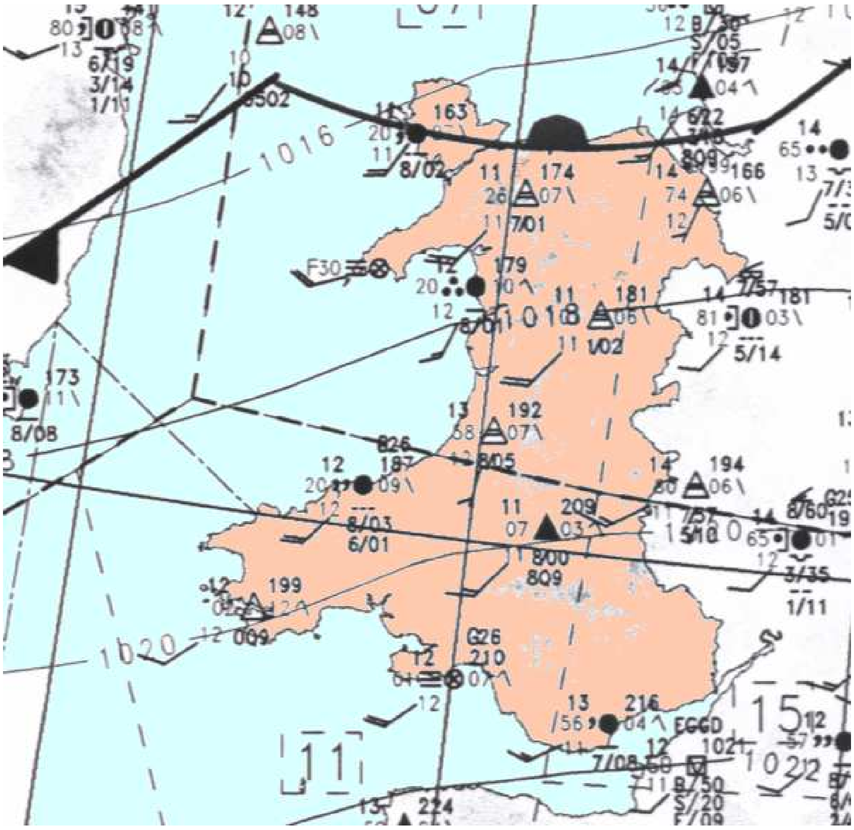

Figure 2.46(b). Regional meteorological chart: 10:00h 22 May 2003

The motion of the oscillating front is seen more clearly in the regional chart, fig.2.46. The front line is moving southwards across the Mawddach catchment at 07:00h, but pushes northwards again to reach Anglesey by late morning. Warm air is being drawn northwards towards the low pressure centre in a conveyor ascending above the surface front.

The orientation of winds on 22 May is illustrated in fig.2.47. It is conjectured that winds from the south-south-west encounter the mountain masses of the Rhinogs and Arans, and forced ascent causes precipitation. Rainfall is largely concentrated along the north-south axis of the Rhinogs, with a subsidiary maximum in the area of Pared yr Ychain to the north of the Aran ridge. Type B precipitation patterns are purely orographic, with no appreciable valley air interraction affecting rainfall intensity.

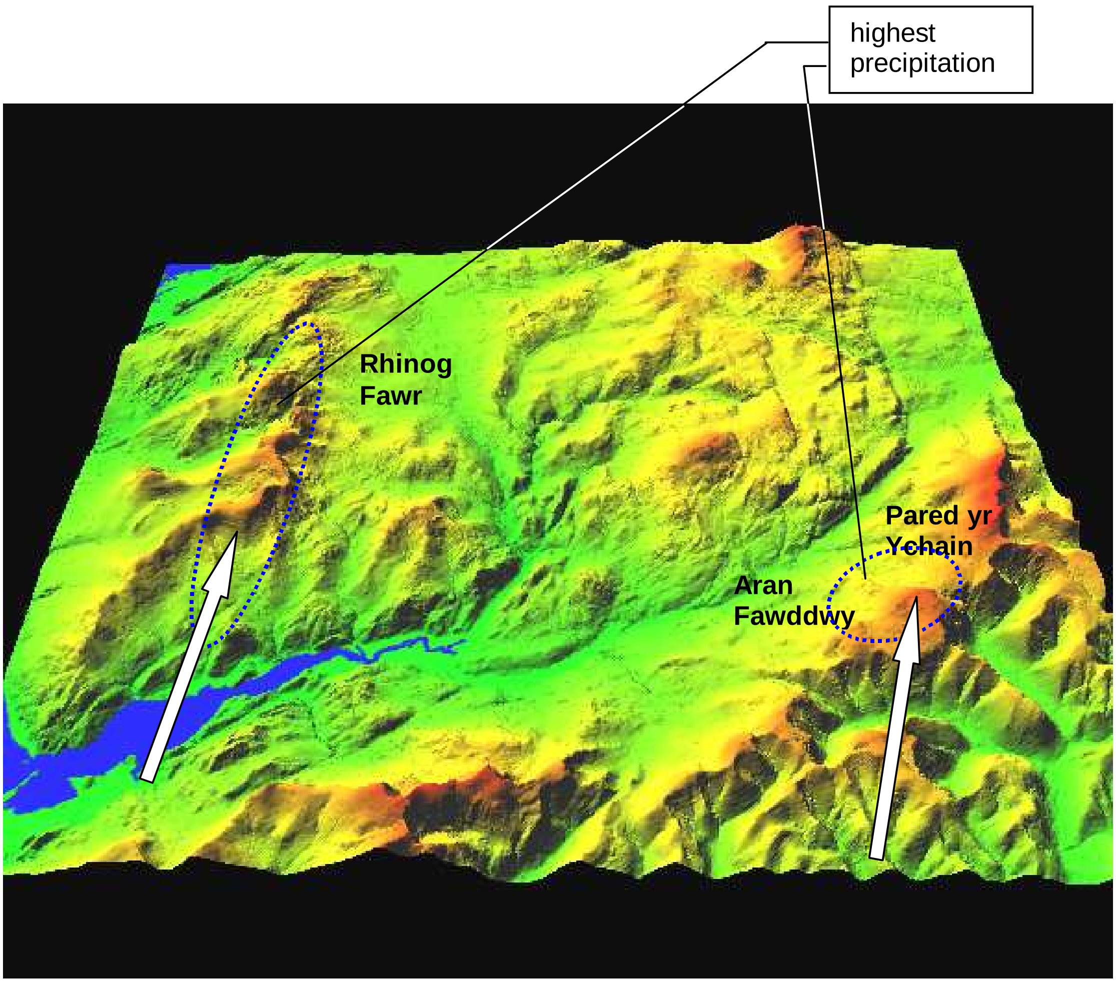

Figure 2.47: Airflow directions across the Mawddach catchment, 22 May 2003

The extended rainfall period of 2-4 February 2004

During the first week of February 2004, the Mawddach catchment experienced flooding of exceptional severity, with farmland around the head of the Mawddach estuary submerged for several days and road communication disrupted (fig.2.49). The flooding was the result of a prolonged period of heavy rainfall, during which large areas of the catchment became saturated and runoff progressively increased. Flooding during this period was widespread throughout Snowdonia:

> *"The early part of February 2004 brought heavy rainfall to North Wales. The effect of this, falling on already sodden ground, led to very serious flooding particularly in the Conwy Valley around Llanrwst. The Conwy Valley railway line suffered very badly with serious damage to the line between Tal y Cafn and Betws y Coed. Repairs to the line were extensive and it was not reopened until 22nd May 2004."* (Sallery, 2005)

Figure 2.48: Flood damage to the Conwy Valley railway line near Betws y Coed 4 February 2004. photo: Dave Sallery

The February 2004 flood event has been analysed by Sibley (2005). It will be used as a test case in the evaluation of hydrological models for the Mawddach catchment.

Figure 2.49: Flooding around Llanelltyd at the head of the Mawddach estuary, 4 February 2004

The origins of the flood event can be ascribed to a period of nearly a week in which the jet stream remained stable above the British Isles (fig.2.50). During this time a series of depressions formed in the mid-Atlantic and tracked north eastwards below the jet stream, carrying a sequence of fronts across North Wales.

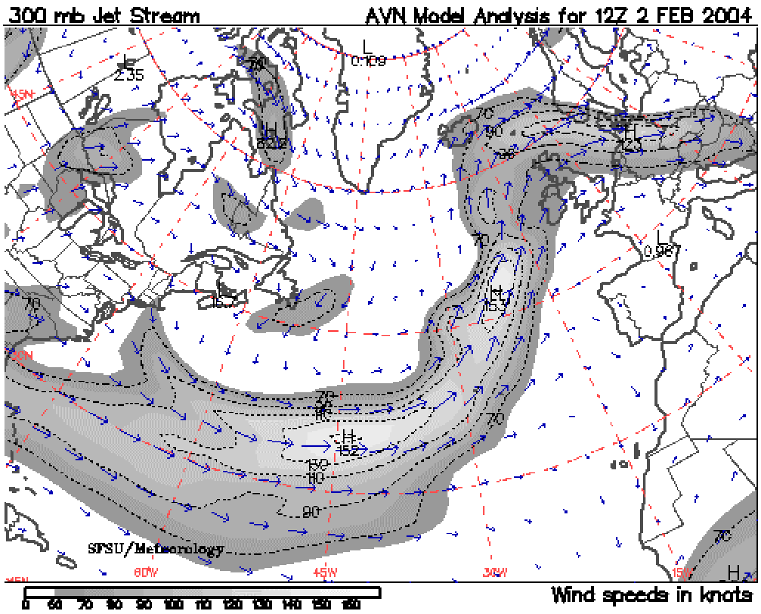

Figure 2.50(a).
Jet stream map for 12:00h, 2 February 2004

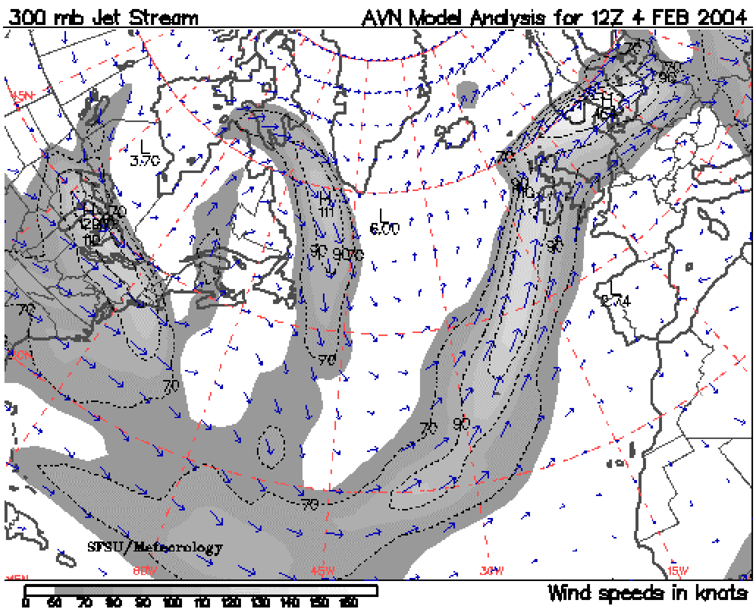

Figure 2.50(b).
Jet stream map for 12:00h, 4 February 2004

Synoptic charts for the period 00:00h 3 February to 00:00h 5 February are given in fig.2.51. Fast moving low D clears Britain during 2 February, with a cold front associated with low C moving north-westwards across Wales during that day. On 3 February this front pushes slowly southwards to cross Wales for a second time.

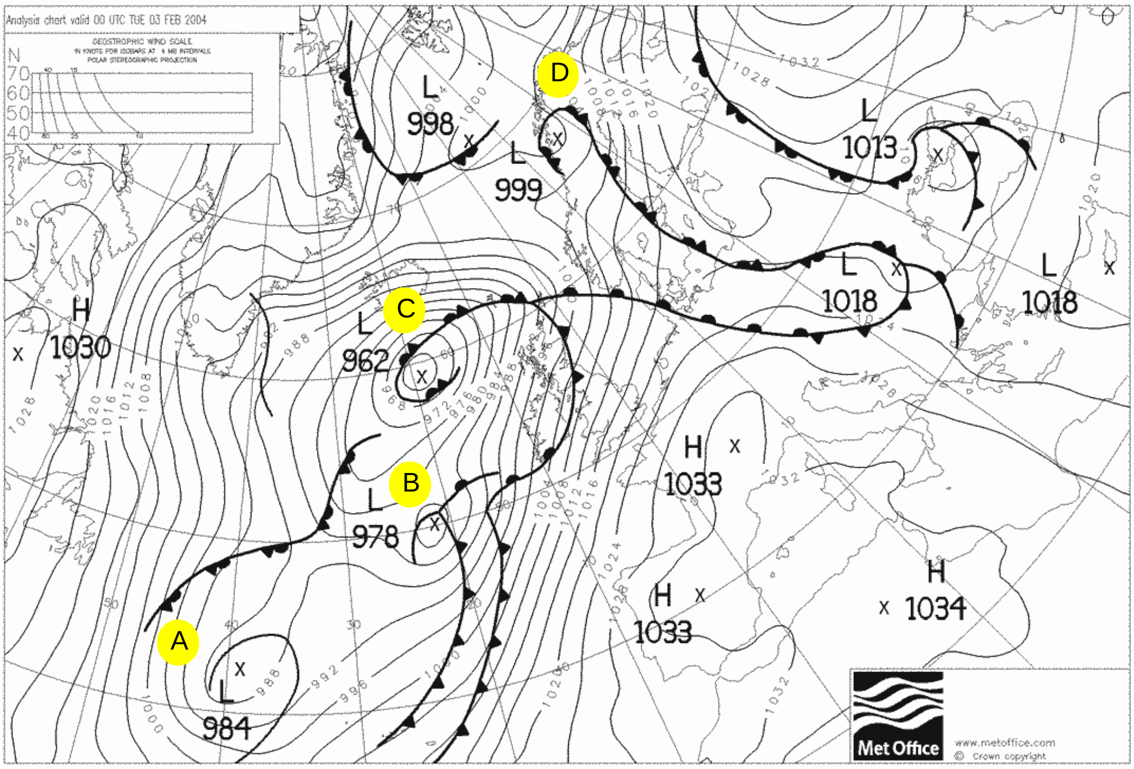

Figure 2.51(a). Synoptic chart for 00:00h, 3 February 2004

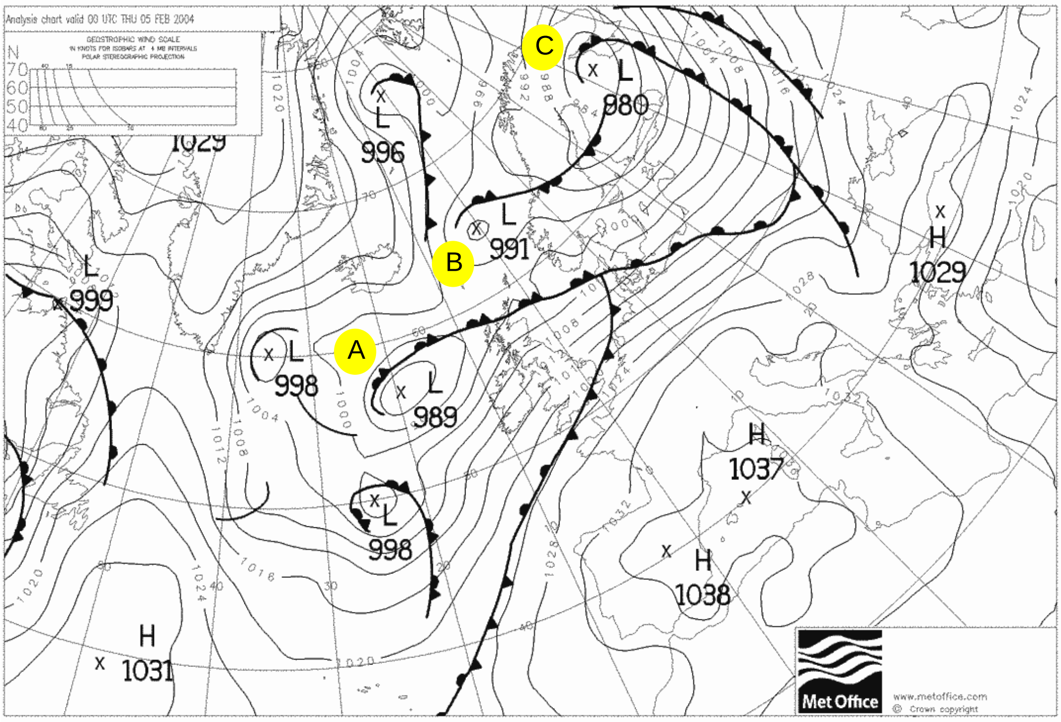

Figure 2.51(b). Synoptic chart for 00:00h, 5 February 2004

Frontal system C at 00:00h on 3 February and frontal system A at 00:00h on 5 February both show the characteristics of the Shapiro-Keyser cyclone model. The warm and cold fronts are near-perpendicular, and extensions of the warm fronts curve around seclusions (see fig.2.14).

Rainfall during the period 2-4 February predominantly followed patterns A1 and A2, with an axis of high rainfall intensity crossing the Mawddach catchment from north-west to south-east (fig.2.52).

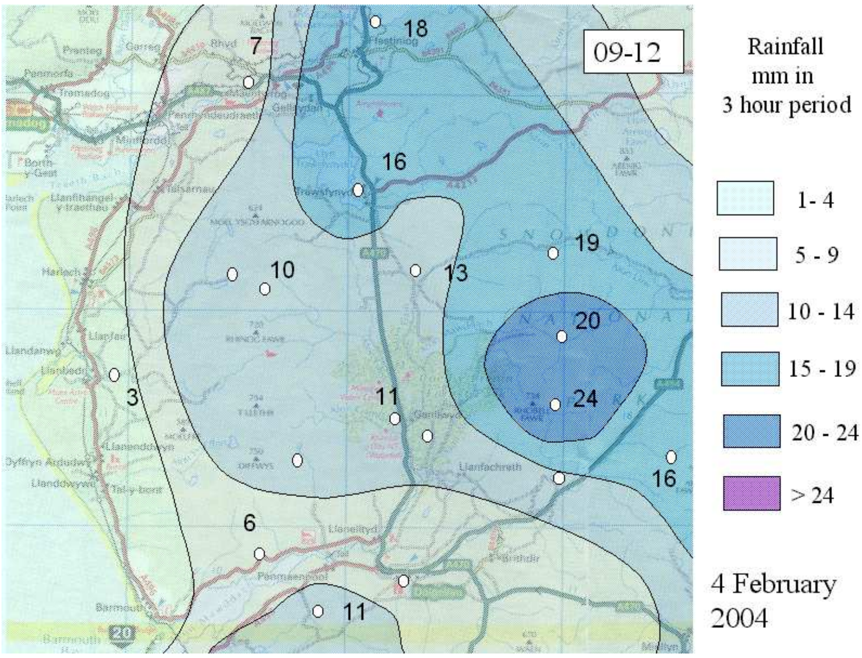

Figure 2.52. Typical rainfall pattern during the 2-4 February 2004 rainfall event: 3 hour rainfall total(mm) for the period 09:00h to 12:00h, 4 February.

A feature of the storm event is the extreme enhancement of rainfall totals inland, in comparison to coastal locations. This feature was also observed further north in Snowdonia, and is illustrated by Sibley (2005) in rainfall graphs contrasting the inland site of Capel Curig with the coastal site of Aberdaron (fig.2.53). Sibley suggests mechanisms for the rainfall enhancement:

Uplift of warm moist air occurred in a conveyor ahead of the cold front along the west coast of Wales. Cloud associated with the conveyor is seen in the satellite photograph for 13:40h, 4 February 2004 (fig.2.54).

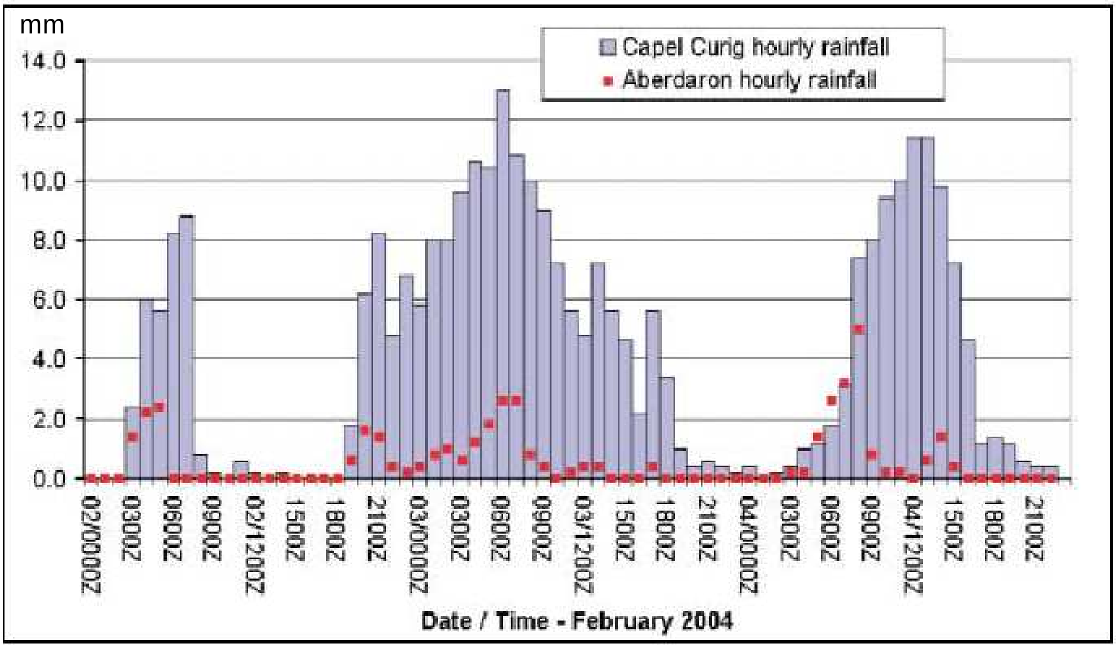

Figure 2.53. Comparison of rainfall at inland (Capel Curig) and coastal (Aberdaron) sites during the 2-4 February 2004 storm event. Reproduced from Sibley(2005)

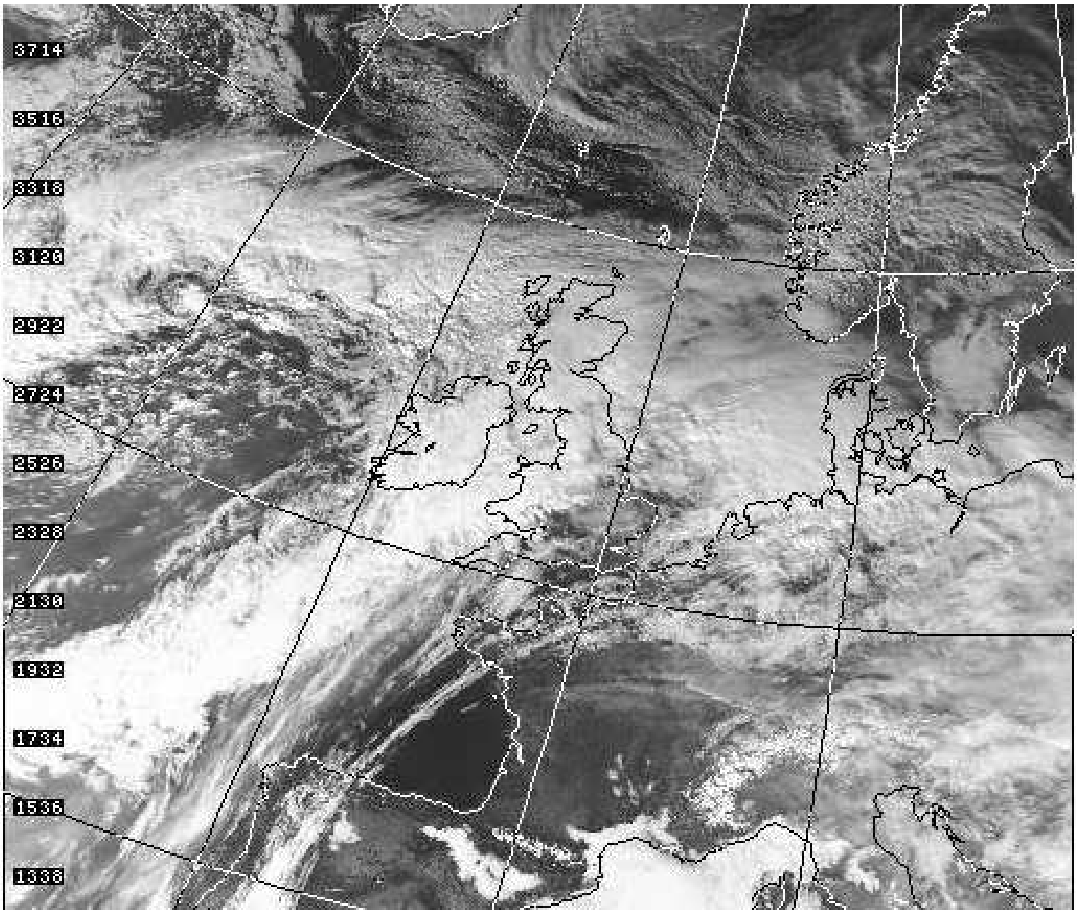

Figure 2.54. Satellite image (visible range), 13:40h on 4 February 2004.
Dundee satellite receiving station

Air within the warm sector was unseasonally warm, with a wet bulb potential temperature of 12^0-14^0C. This allowed the air mass to carry an unusually large amount of moisture, and provided thermal instability which assisted ascent within the conveyor.

The seeder-feeder mechanism of rainfall enhancement is considered by Sibley (2005) to have produced approximately 6-7mm h^{-1} additional rainfall over the mountains of Snowdonia at the peak of the February 2004 storm event, in comparison to the coastal area. This is consistent with evidence from the Mawddach catchment. Hill et al. (1981), in a study of rainfall in South Wales, have calculated that 80% of rainfall enhancement occurs in the lowest 1.5km of the troposphere, as rain from the upper cloud layer falls through orographic cloud covering hills and mountains.

Gravity mountain waves, unconstrained upwards, can produce the uplift required for seeder cloud formation (see figs 2.25-2.27). A strong low level jet at an altitude of approximately 1.5km was identified by Sibley (2005) in the tephigram of a balloon ascent from Aberporth at 06:00h on 3 February. This south westerly jet, reaching 80 knots, would carry seeder drops well inland below the warm air conveyor and orographic clouds of the coastal mountains.

July 2001 exceptional rainfall event

Effects of the storm of 3 July 2001 over the Mawddach catchment are described in Chapter 1. This was the most destructive storm in living memory. Flood waters destroyed or seriously damaged bridges built before the 19th century, so this storm may represent more that a 200-years maximal event. The 3 July 2001 storm occurred within a violent squall line. The pattern of the storm was unique, and did not conform to the normal Type A or B patterns of frontal rainfall in the catchment.

Features of the storm are recorded in the photographs of figs 2.55-2.56, with roll clouds developed ahead of the storm front, and intense convective activity producing great vertical development of thunder clouds. At the height of the storm, electrical activity was intense, with lightening strikes occurring with a frequency greater than one per minute.

Figure 2.57 shows the synoptic situation under which the squall line developed. A cold front associated with low A separated cold Polar air from very warm and convectively unstable air within the warm sector. Uplift began well ahead of the cold front, in association with an upper trough of low pressure air which promoted convective activity. It is conjectured that upper air was being removed along this north-south line by high level cyclonic circulation. The trough position is shown in the regional charts of fig.2.59, advancing slowly inland during the evening of 3 July.

Rainfall maps for the 3 July storm have been constructed from limited data (fig.2.60). The 1-hour readings from a ring of five raingauge sites around the periphery of the Mawddach catchment have been augmented by a hypothetical modelled raingauge for Oernant, approximately 5km to the ESE of Trawsfynydd, where field evidence suggests that the storm reached its maximum intensity. Derivation of the modelled data will be discussed in section 2.4. The rainfall maps suggest a very narrow band of high intensity rainfall crossed the catchment in the period between 18:00h and 20:00h, accounting for the majority of the storm damage through rapid infiltration-excess runoff directly into watercourses.

Figure 2.55: July 3 storm over the Mawddach catchment, showing roll or shelf cloud ahead of the main body of the storm (photo: John Mason)

Figure 2.56: Cloud base of the July 3 storm over the Mawddach catchment (photo: John Mason)

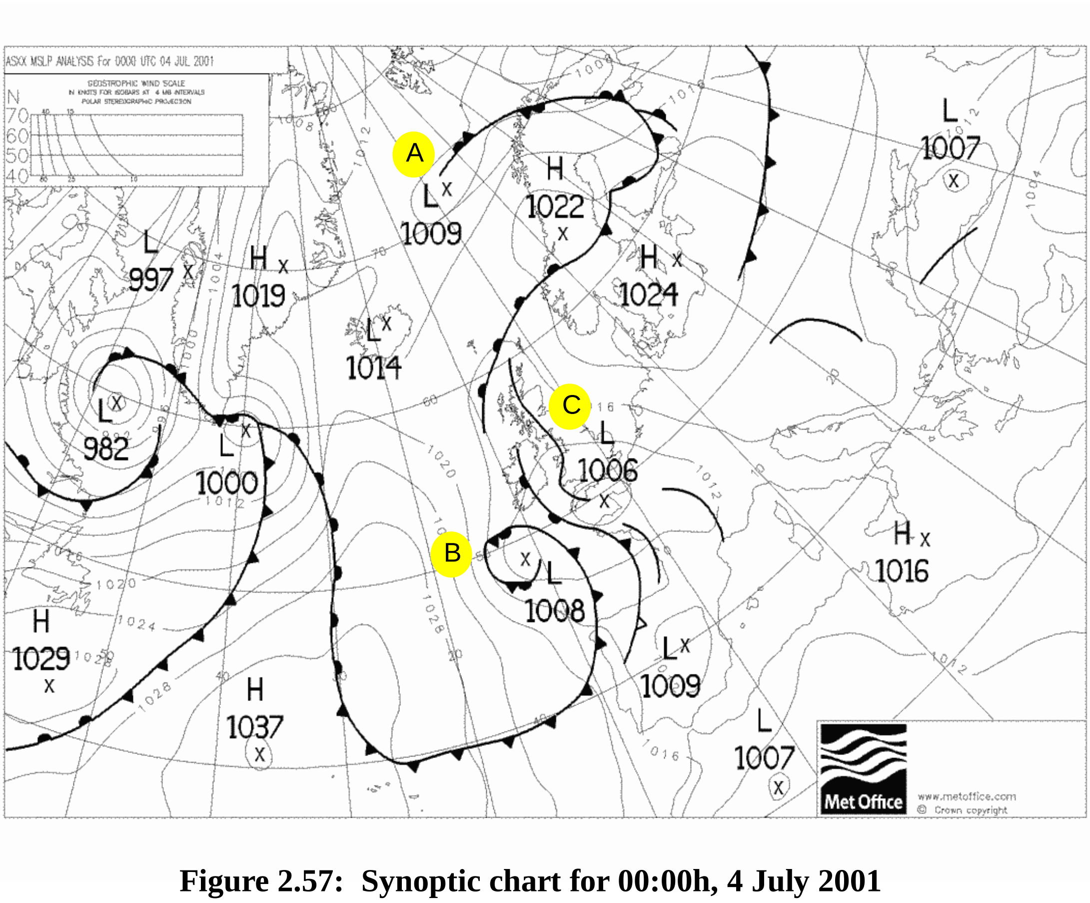

Figure 2.57: Synoptic chart for 00:00h, 4 July 2001

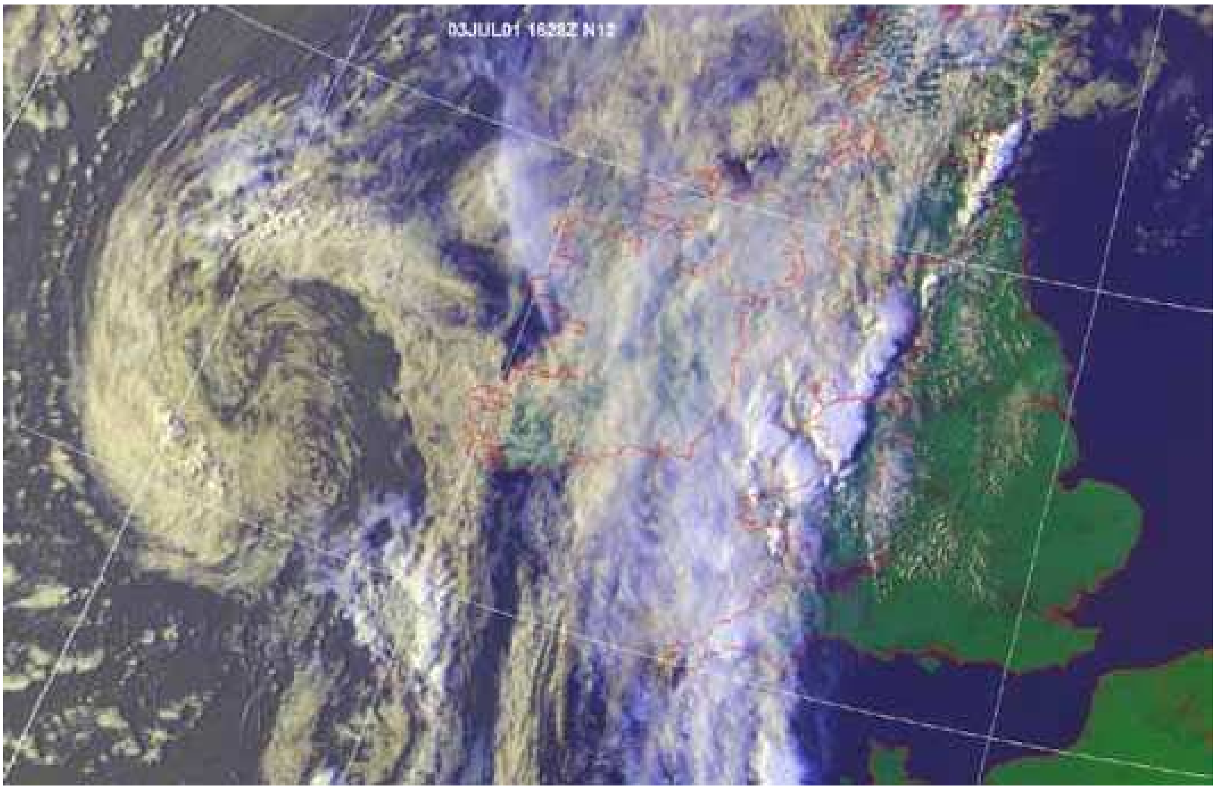

Figure 2.58: Visible satellite image, 16:30h 3 July 2001 (courtesy of Bernard Burton**)**

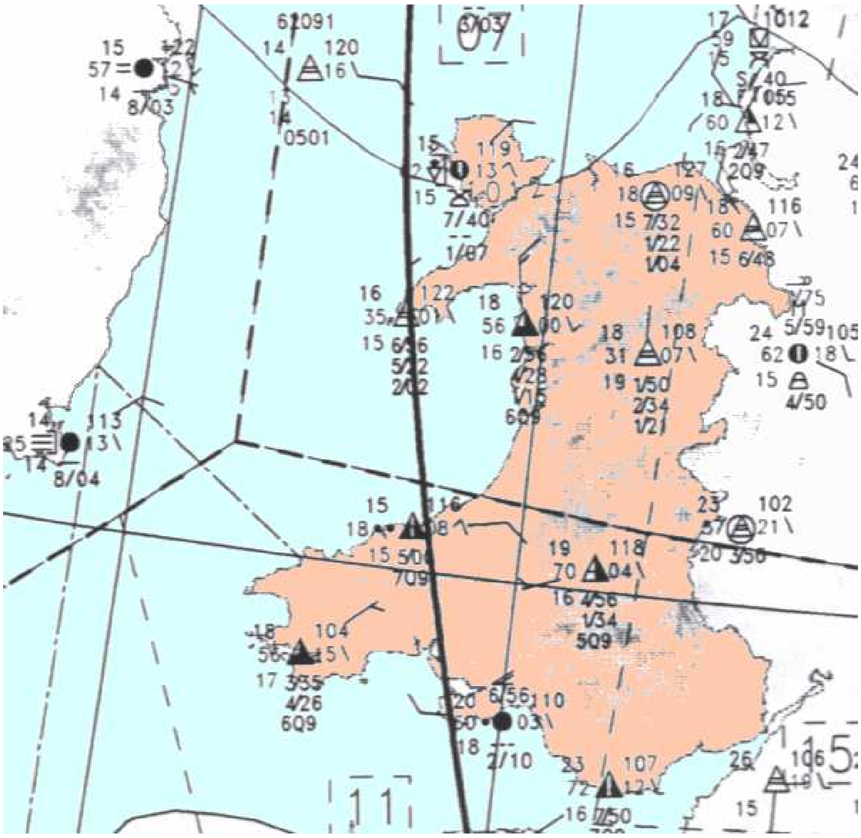

Figure 2.59(a). Regional chart for 19:00h 3 July 2001

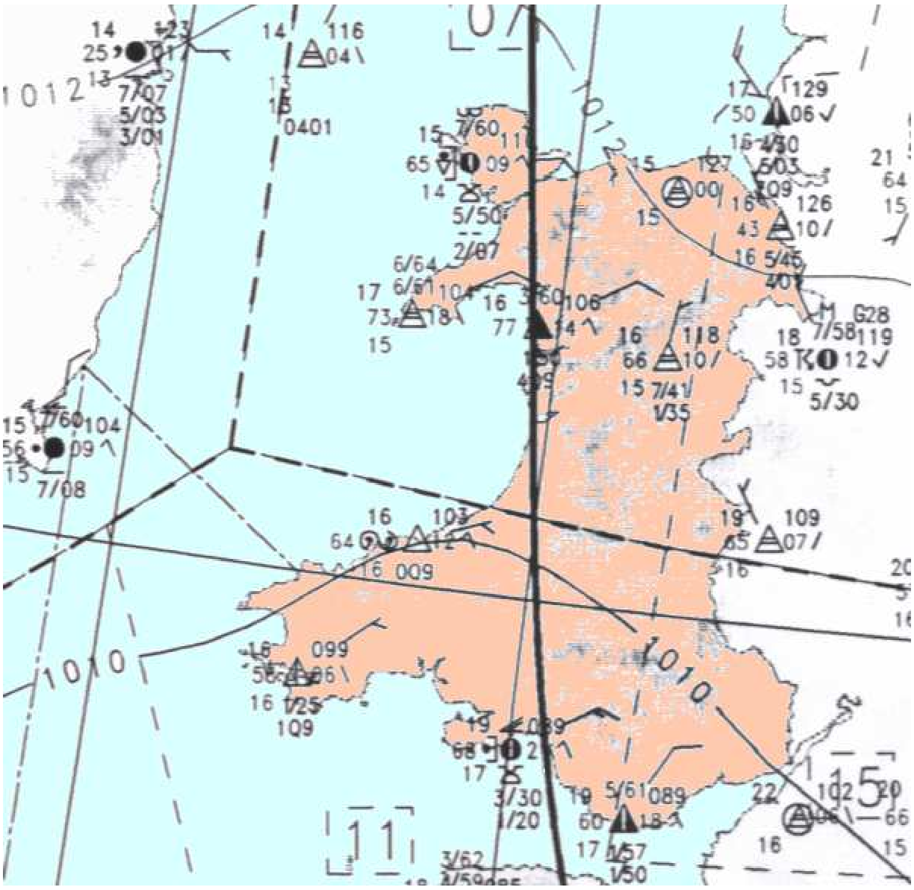

Figure 2.59(b). Regional chart for 22:00h 3 July 2001

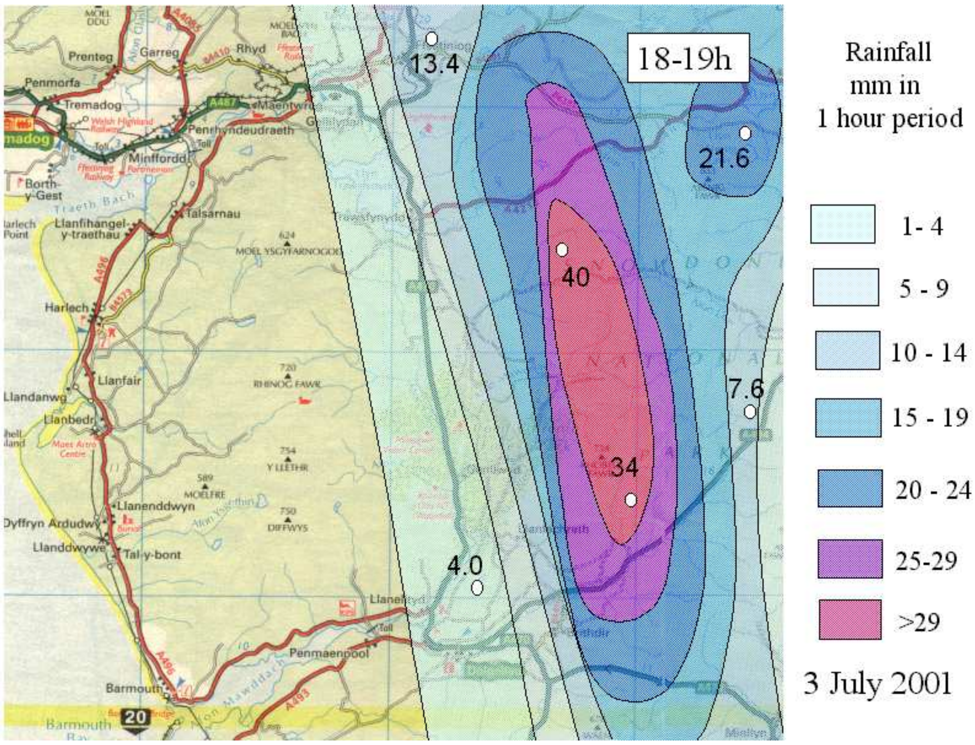

Figure 2.60(a). Rainfall total for the period 18:00h to 19:00h, 3 July 2001.

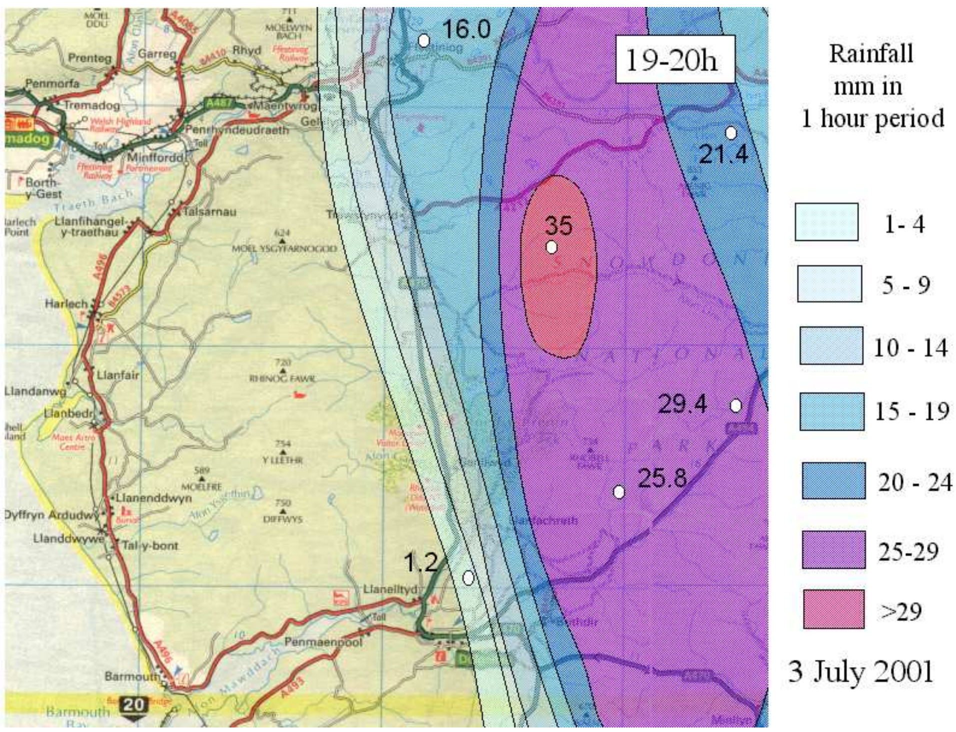

Figure 2.60(b). Rainfall total for the period 19:00h to 20:00h, 3 July 2001.

Summary

- The great majority of storm events in the Mawddach catchment are associated with frontal systems.
- Three distinct rainfall distribution patterns have been identified for storms within the Mawddach catchment, and have been termed Types A1, A2 and B.
- In the Type A1 pattern, a zone of high rainfall crosses the Mawddach catchment on a diagonal axis from Trawsfynydd in the NW to Pared yr Ychain in the SE. A single rainfall maximum occurs in the centre of the catchment, around Coed y Brenin and Rhobell Fawr. This pattern is associated with a dominantly west-south-westerly airflow.
- In the Type A2 variant, rainfall maxima are located at the two ends of the axis of high rainfall from Trawsfynydd to Pared yr Ychain . This pattern is associated with a dominantly south-westerly airflow.
- In the Type B pattern, a zone of high rainfall is oriented north-south along the line of the Rhinog mountain range. This pattern is associated with a dominantly south-south-westerly airflow.
- Dominant wind directions may be linked to the orientation of warm fronts. Type A1 rainfall patterns are typically produced by N-S oriented warm fronts. Type A2 patterns are typically produced by NW-SE oriented warm fronts. Type B patterns are typically produced by W-E oriented warm fronts.
- During an individual rainfall event, the orientation of a front may change as it crosses the Mawddach catchment, leading to a change in rainfall pattern between the early and late stages of the rainfall event.
- Within an individual storm event, total rainfall may differ by a factor of four or more between different locations within the Mawddach catchment. Zones of highest rainfall do not generally correspond with the highest ground.
- The most extreme and destructive storm event experienced in the catchment occurred in association with a low pressure trough in the upper air which promoted uplift of large volumes of air ahead of a cold front, forming a squall line.