American Meteorological Society 92nd Annual Meeting, January 2012, New Orleans, USA.

Seeder-feeder enhanced rainfall over the mountains of North Wales

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Abstract

North Wales is an area of glaciated mountains with deep valleys descending westwards to the Irish Sea coast. The region experiences high annual rainfall, principally from mid latitude cyclones, and as a consequence supports areas of temperate rain forest and upland peat blanket bog of international ecological importance. A number of small towns lie within the region and are frequently at risk from flooding through saturation excess overland flow into rivers.

A study of rainfall patterns across one of the major catchments of North Wales was carried out between 2002 and 2006 as part of a larger PhD hydrology study. An array of twenty-two data logging rain gauges was installed at locations from valley floors to mountain summits, augmented by three data logging weather stations at valley locations to provide humidity, wind speed and wind direction data.

Observed rainfall patterns differed with the direction of approach of frontal systems, with two patterns dominating: 1) Rainfall maxima along mountain summit ridges when mid-altitude air flows were sub-parallel to mountain orientation, 2) Rainfall maxima inland of mountains, on lower ground at the heads of valleys, when mid altitude air flows were cross-cutting to mountain ridges. The patterns of rainfall recorded in the field were closely replicated by computer models using MM5 and WRF software with a 1km grid spacing.

It is concluded that rainfall type 1 along mountain ridges is generated by a simple orographic uplift process, whilst rainfall type 2 results from seeder-feeder enhancement. Type 2 rainfall is dependant on high velocity moist airflows within the deep valleys which are forced to rise at steep glaciated valley heads. The extents of rainfall enhancement at particular locations during storm events have been estimated.

Ongoing work is using geometrical filtering within a digital terrain model of the wider region of North Wales, to identify areas of likely seeder-feeder rainfall enhancement for frontal systems with different approach vectors. Data is being compared initially to WRF models of storm events, and will subsequently be supported by field rainfall recording on a high resolution grid.

Transcript of presentation

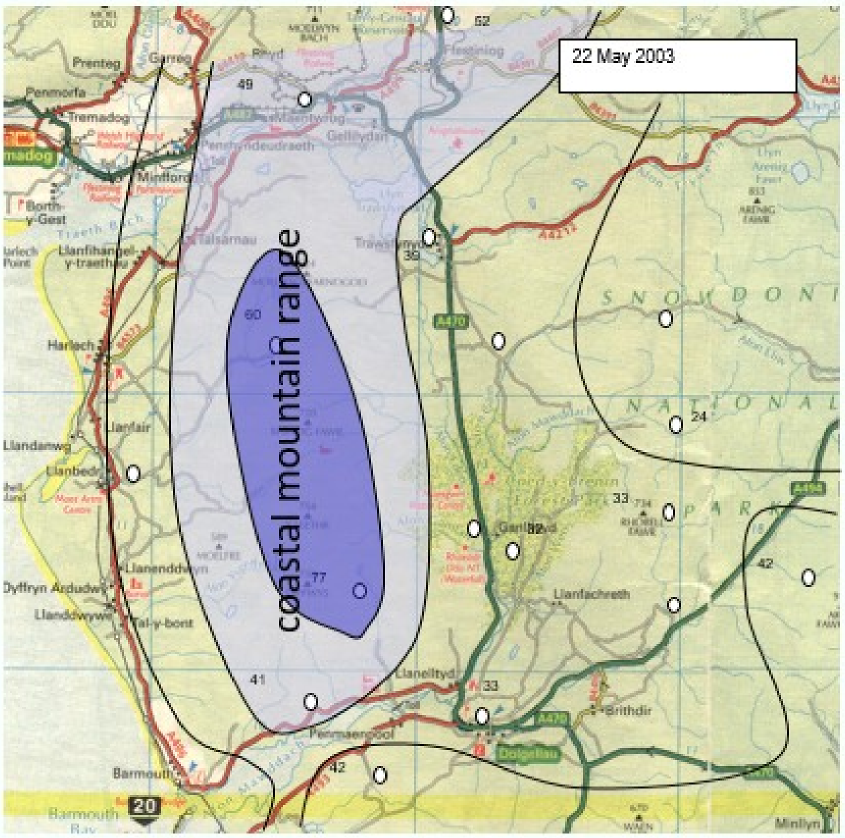
This presentation discusses an aspect of a hydrology project carried out in the Mawddach river catchment of North Wales (Hall, 2008).

Wales lies on the western margins of Europe so is in the track of mid latitude cyclones from the Atlantic. The land rises steeply to about 1000m from the shoreline so there is substantial rainfall from the stratiform cloud systems of frontal rainfall.

A total of 26 data-logging rain gauges were established in the study area, which has an extent of about 30km in width and 30km in length. This produced a sufficiently dense network to record the detailed precipitation patterns of individual storm events .

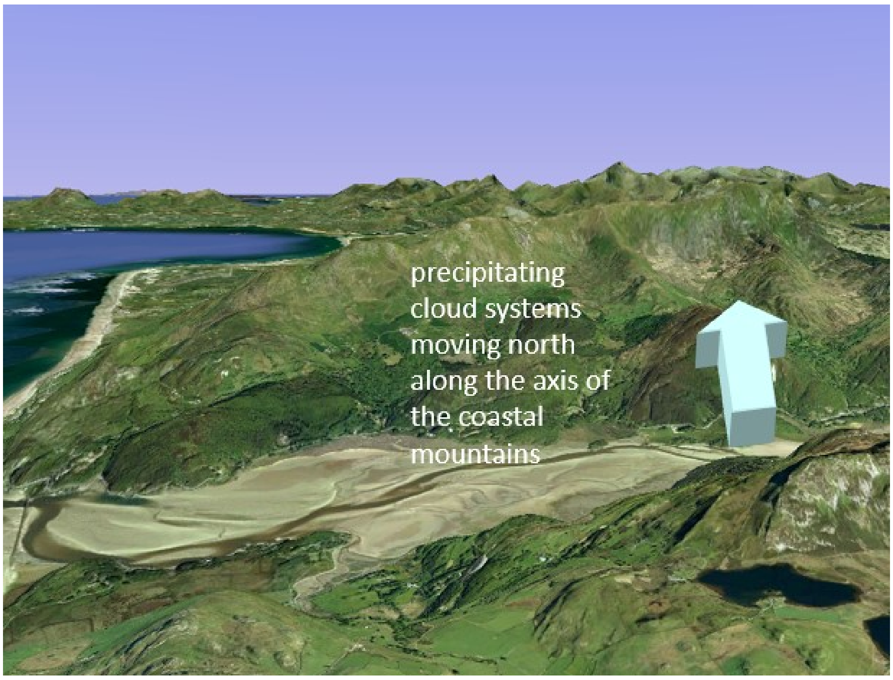
Rainfall patterns were studied over four years, and fitted into two distinct groups which have been designated as ***type A*** and ***type B***.

Type B is less common. It is the most straightforward, and can be explained as simple orographic rainfall over that coastal mountain range.

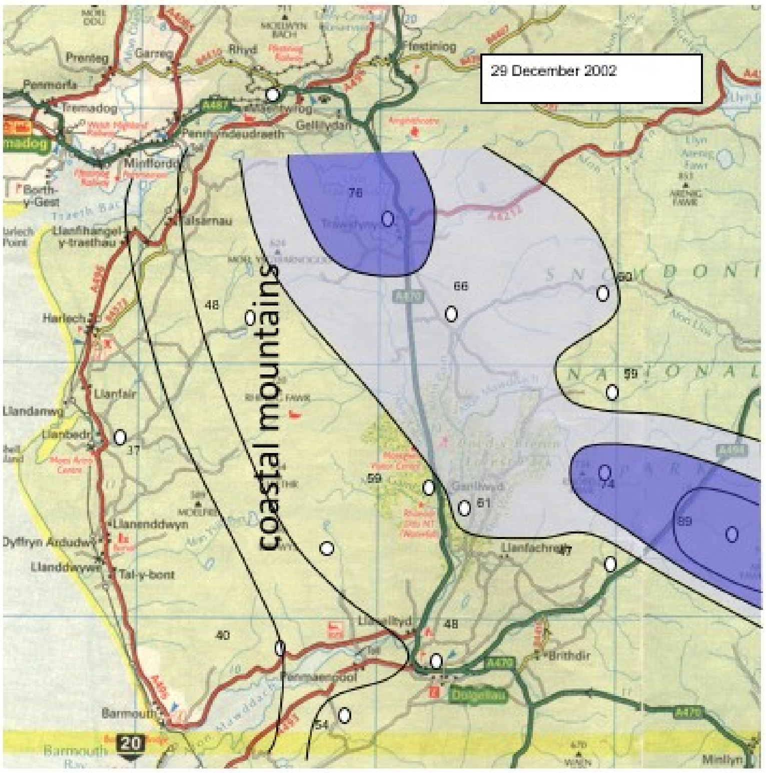


Type B rainfall distribution pattern. Isohyets show total storm rainfall, 22 May 2003

Type B rainfall is always associated with precipitating air flows moving from the south along the axis of the mountain ridge.



The type A rainfall is quite different, and perhaps more interesting. This is associated with south-westerly air flows, and precipitation appears in a diagonal band across the area, with two maxima occurring inland from the coastal mountains at the heads of deep valleys.



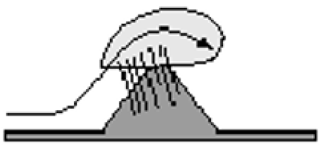
Type A rainfall distribution pattern. Isohyets show total storm rainfall, 29 December 2002

It seemed likely that this type A precipitation pattern is due to a seeder-feeder mechanism. The approach of a warm front is shown in the figure below. An upper layer of cirrus cloud occurs at high altitude. Below this, in a middle layer, is stratiform frontal cloud producing precipitation. At low level we see orographic cumulus, produced as the airflow is forced upwards over the mountains.

A seeder-feeder mechanism suggests that rainfall generated in a mid-level *seeder* cloud falls through a lower level *feeder* cloud, picking up additional moisture which would not otherwise have been precipitated.

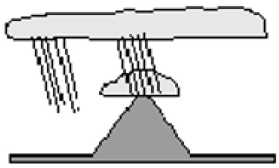
photograph: John Mason

Orographic rainfall occurs close to the mountain summit or slightly upwind from the summit. Seeder feeder rainfall is expected to occur at the summit or slightly downwind due to advection. However neither of these patterns correspond with the *type A* rainfall in the study area, where maximum rainfall zones occur in valleys at a substantial distance from mountain ridges.



Simple orographic rainfall:

Rain maxima upwind of summit ridge

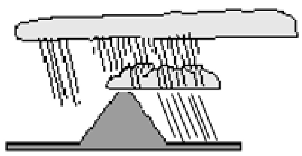


Seeder – feeder mechanism:

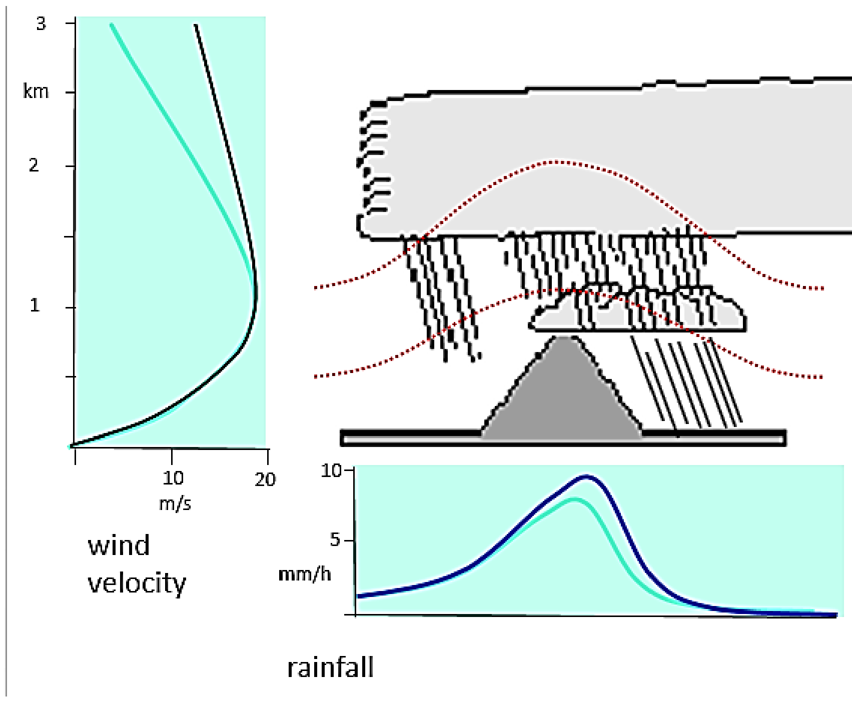
Rain maxima at or downwind of summit ridge

Observed rainfall in the study region:

Rain maxima well inland of summit ridge



Rainfall processes in the area were investigated theoretically using a two-dimensional finite difference model by Robichaud and Austin (1988). This model simulates an upper layer of stratiform airflow and a lower layer in which the orographic cloud can develop. Cloud and rain water mass are conserved. Modelling used a sinusoidal ground profile to represent a mountain mass. Satisfactory results were obtained for rainfall around the mountain ridge, with the maximum increasing and moving to the lee of the mountain as the simulated wind speed at higher levels was increased.

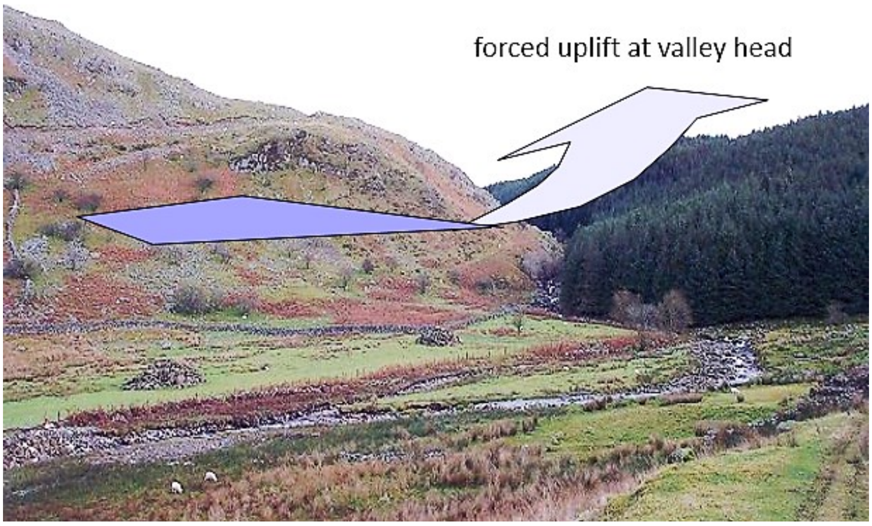


However, the simple hill model was unable to replicate the observed situation in the Mawddach study area where rainfall maxima occur at a considerable distance from mountain ridges.

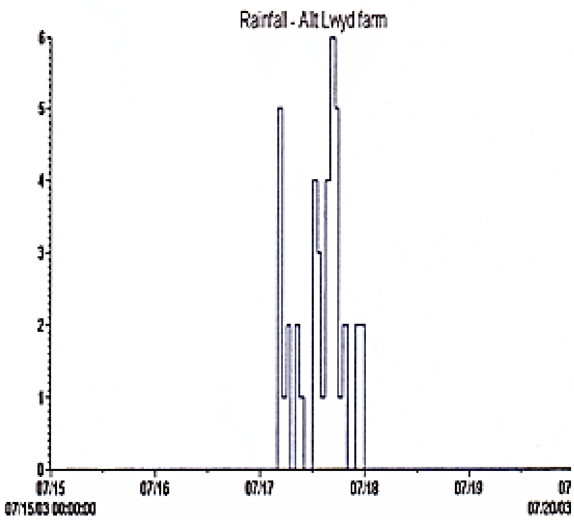
Work by Lin (2007) in the Alps in Europe identifies low level valley air flows that are forced upwards towards the mountain fronts. As valley air rises, it interacts with middle level cloud over the mountain summits and that can form very heavy rainfall.

An investigation was carried out at the head of the Mawddach study catchment, where narrow steep sided valleys end abruptly at the high plateau of the Waen y Griafolen peat blanket bog.

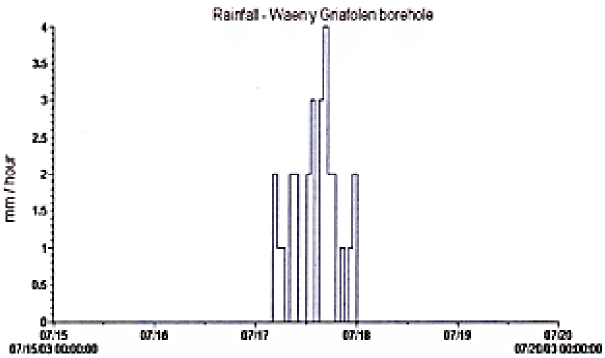
As the air flow is channelled along the valley, it is forced to rise at the steep valley head.



Rain gauges were established on the plateau and within the valley. Observations during approximately 30 storms demonstrated that the rainfall was always heavier at the valley head than on the plateau.

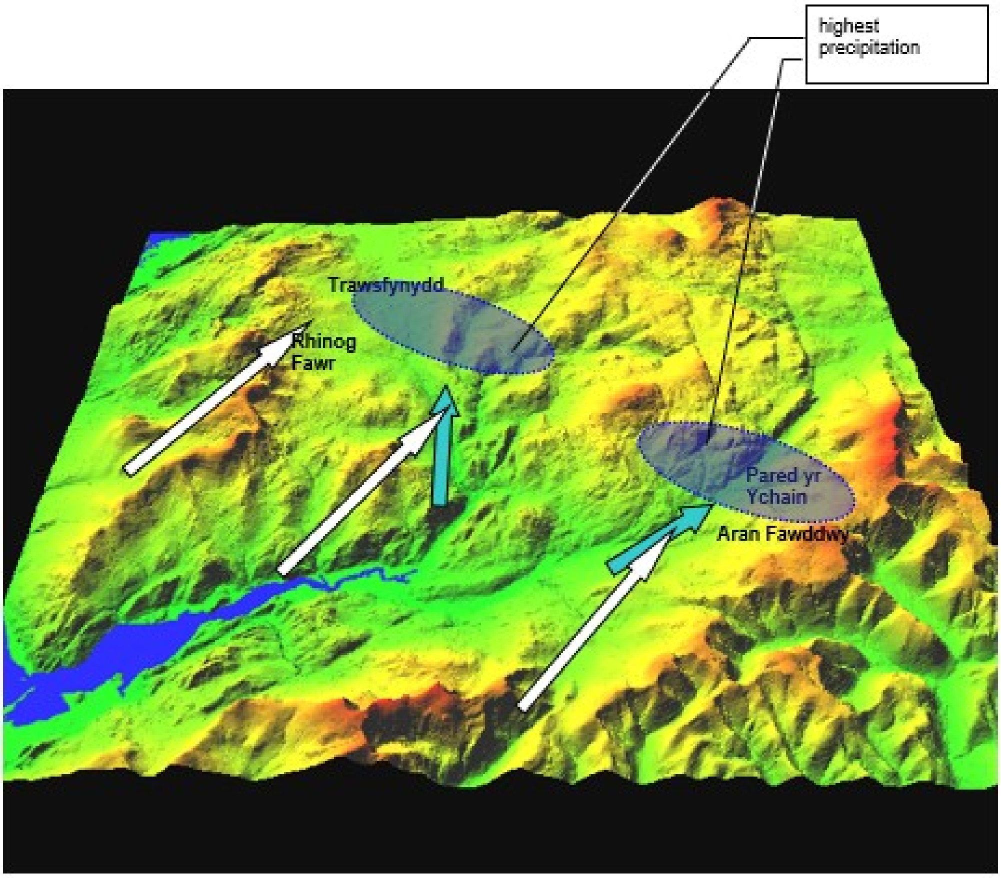


valley head



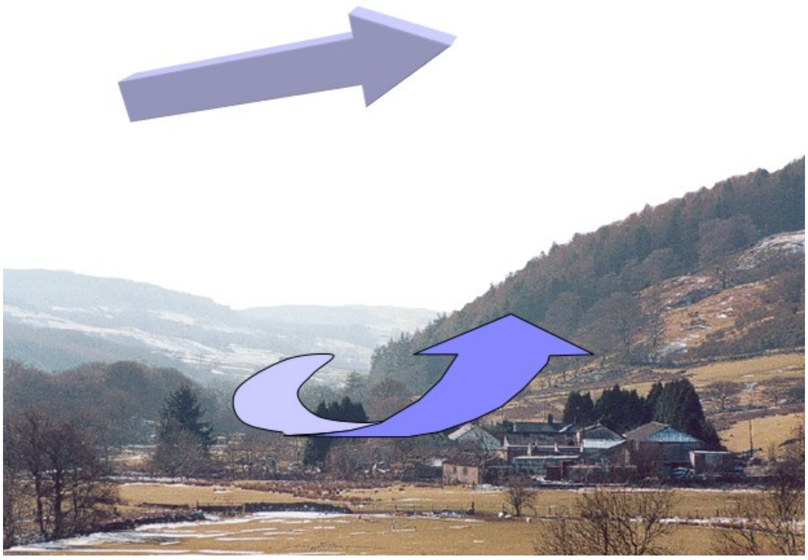
plateau

Considering now the regional model, two areas of heavy rainfall persistently occur at the heads of major valleys. It is suggested that airflow is funnelled into those valleys, forced to rise, then interact with the middle level stratiform air flow to produce enhanced rainfall.

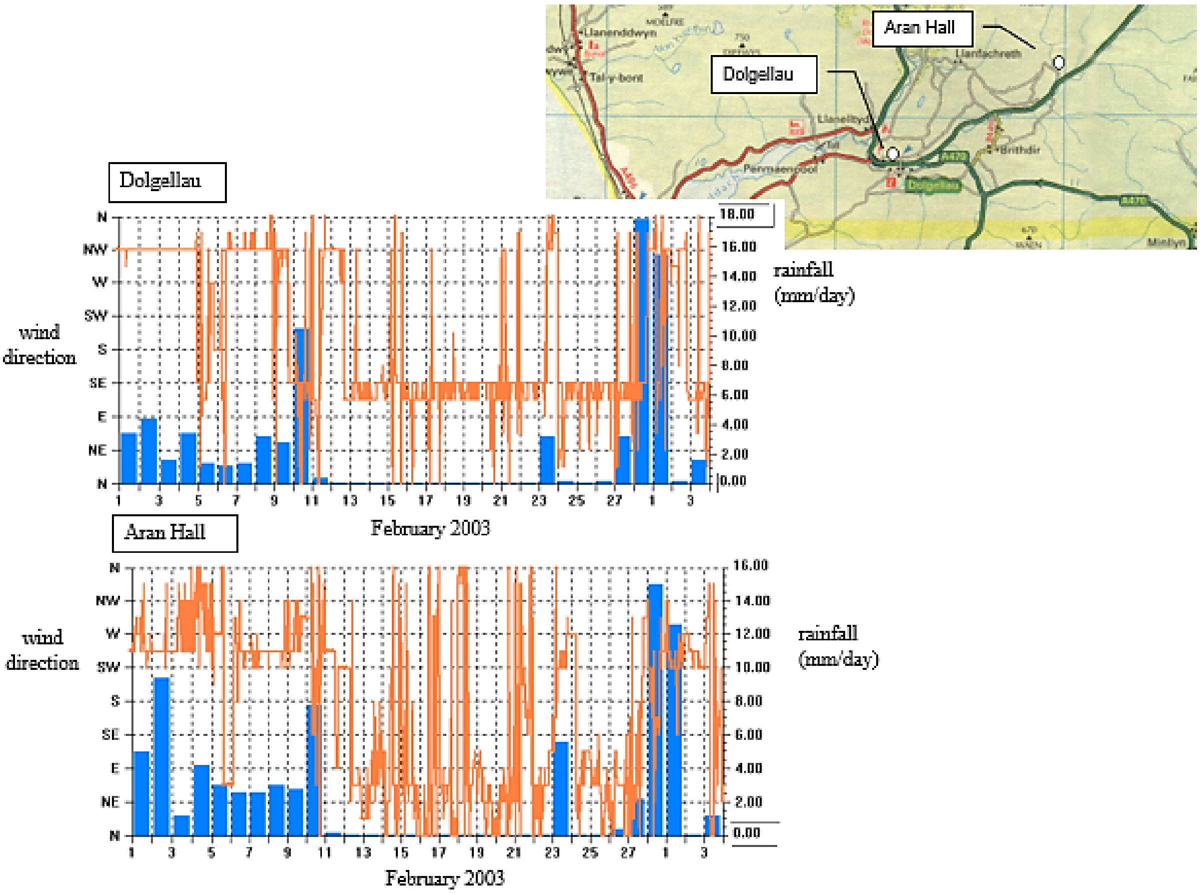


Airflow directions across the Mawddach catchment, 29 December 2002.
Key to arrows: white: middle atmospheric level, blue: valley airflows.

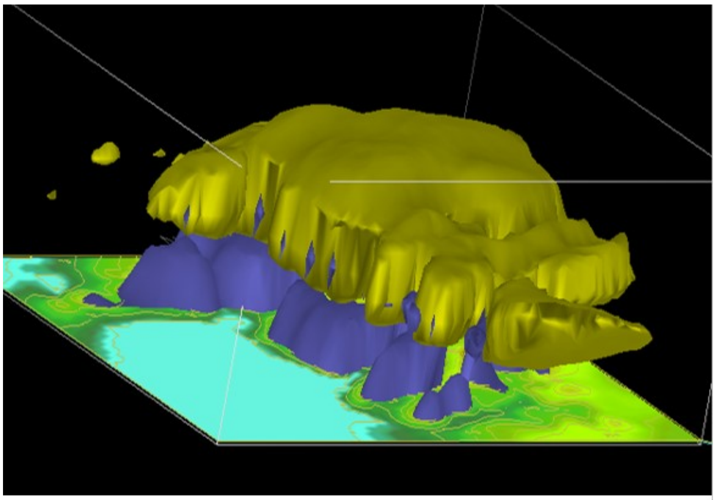
The easterly zone of maximum rainfall occurs around the village of Rhydymain where airflow travelling inland along the valley would be forced to rise rapidly.



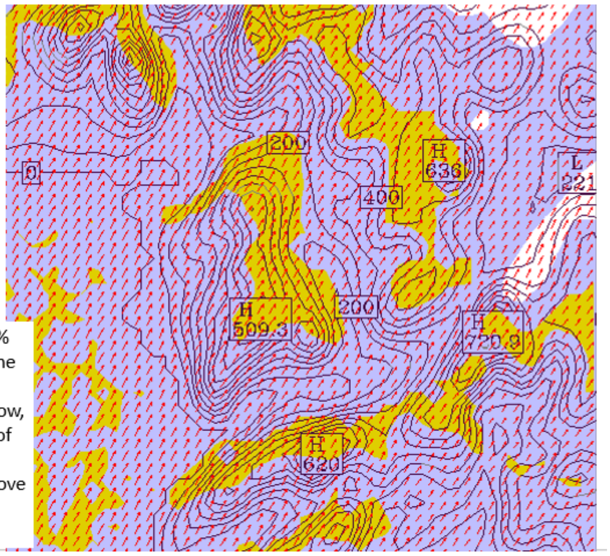
To investigate a link between rainfall and valley airflow, two weather stations were within valleys at Dolgellau and Aran Hall. Both are points where constrictions in the valley cross profile would cause upwards deflection of valley air flows. A close correlation was found between heavy rainfall and periods when airflows were following the axes of the valleys – from the NW in the case of Dolgellau, and from the WSW in the case of Aran Hall. Little or no rainfall occurred when the airflow was directed across the valley axes, from either the north or south.



An MM5 meteorological model was in use for the Mawddach catchment, nested down to a 1km grid for the inner domain. The model produced satisfactory plots of stratiform cloud during the passage of frontal systems, and gave convincing predictions of areas of middle level saturation around mountain ranges to produce seeder rainfall.

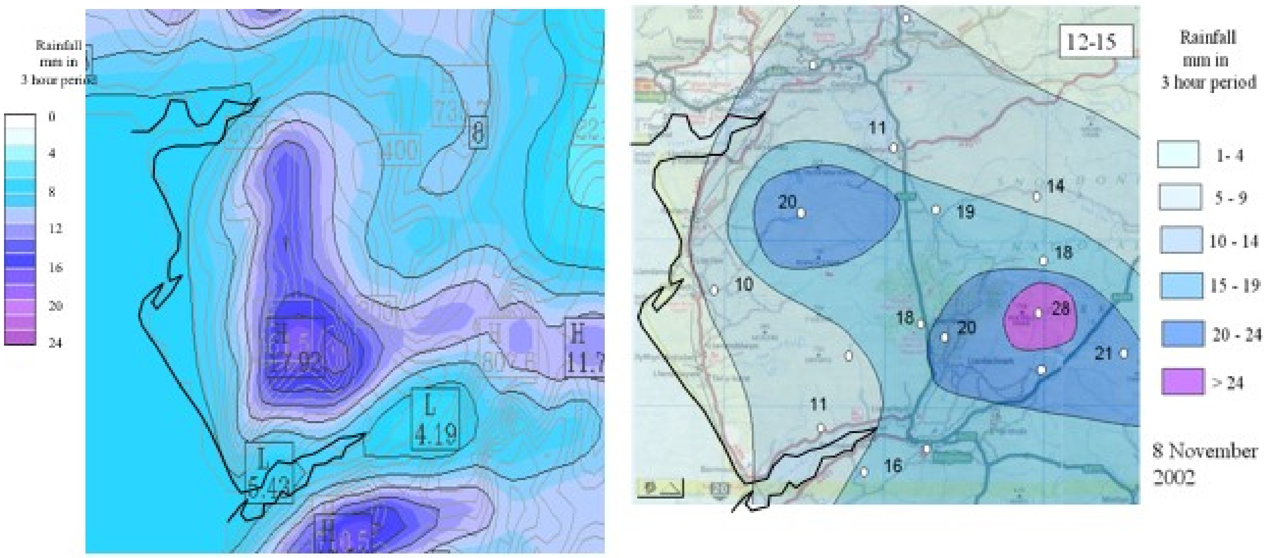


Isosurfaces for cloud mixing ratio >0.4 (yellow) and precipitation mixing ratio >0.4 (blue)



Zones of 100% humidity at the 900mb level, shown in yellow, occur inland of the coastal range and above the inland range.

Rainfall predictions by MM5 were compared with actual rain gauge readings for about 30 storm events. The pattern of type A rainfall was only reproduced approximately. A diagonal band of rainfall across the area is seen, but the maxima are not accurately represented in magnitude or position. It appears that some parameters are not being modelled adequately by MM5.

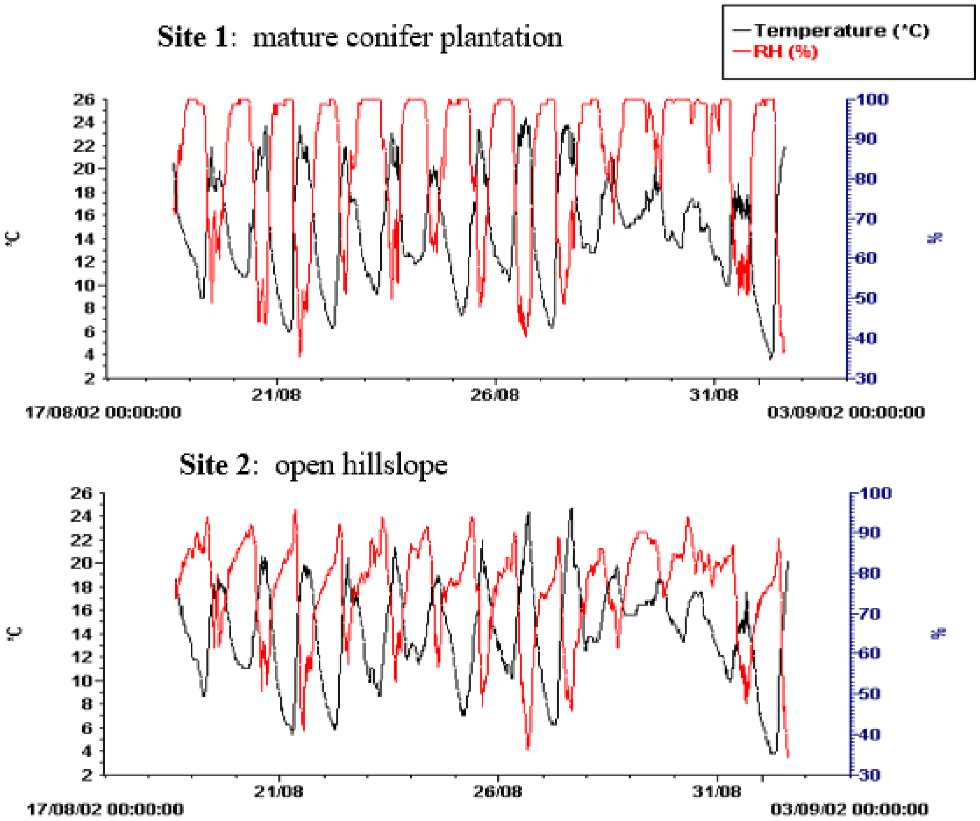


MM5 3-hour rainfall simulations (left) and 3-hour raingauge totals (right):
12:00h – 15:00h, 8 November 2002

Rainfall enhancement at the valley heads may be due to more than simple topography. Field observations during rainfall events suggest that vegetation, particularly forest, is influencing rainfall in the area. During wet and windy days, condensing air is often present in areas of forest and is advected out of stands of trees at the valley head.

condensing airflows advected from the forest at the heads of valleys

The coastal area of west Wales is classified as temperate rain forest, with thick moss growth in both the natural broadleaf woodlands and mature conifer plantations. A microclimate is maintained in the forest with relative humidity remaining at virtually 100% for long periods, whilst humidity fluctuates considerably on unforested hillsides nearby.



A model can be developed with condensing air advecting out of the forest, becoming unstable through warming as it condenses, and rising into the stratiform cloud above the valley head. This process enhances both the quantity of seeder droplets in the air flow, and also the thickness of feeder cloud available to raindrops during descent.

A statistical evaluation was carried out for the MM5 meteorological model, relating rainfall forecasts for the grid of rain gauge sites to actual gauge readings over a series of storm events. Clear differences in forecasting accuracy were found between rainfall patterns.

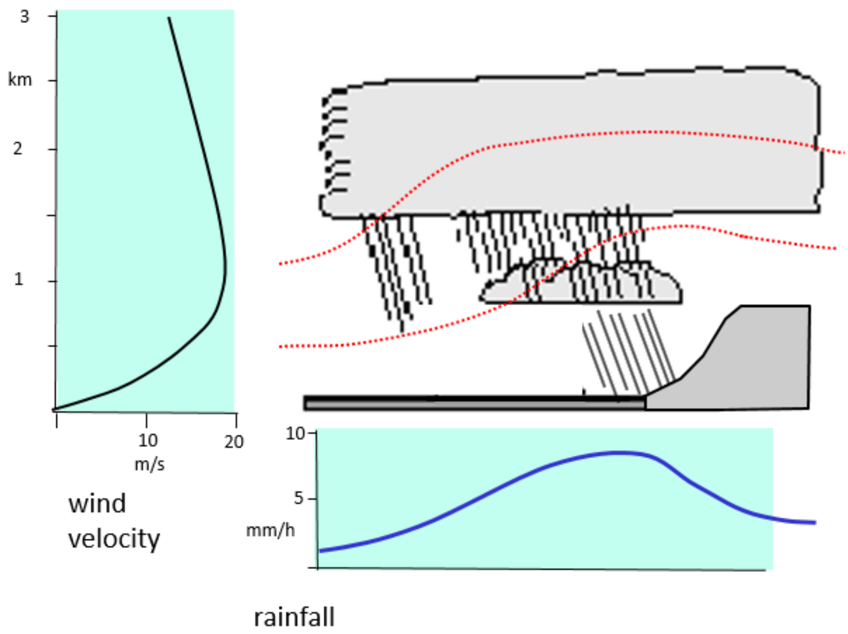
> Absolute deviation for the type A rainfall thought to involve a valley induced seeder-feeder mechanism was around 35%, whilst the type B rainfall thought to be dominantly orographic was around 25%.
>
> Signed deviations were then calculated, allowing overestimates at one gauge site to cancel underestimates at another site. A low value for the signed deviation might suggest a correct but geographically displaced overall rainfall pattern. Type A rainfall gives a signed deviation of around 34%, whilst type B rainfall gives a much smaller signed deviation of around 7%.

Experimentation was then carried out using neural network software, to determine whether improvements could be made to rainfall predictions during the course of a storm event. Readings from each gauge site for the first 3 hours of rainfall were input to the neural network model, as training data to determine the weighting parameters for linear and log-sigmoid transfer functions. MM5 rainfall predictions for each subsequent 3 hour interval during the storm event were then processed through the neural network, and the revised predictions compared to actual recorded rainfall.

It was found that a significant improvement was obtained for type A storm events, reducing the signed deviation from 34% to around 19%. No improvement was achieved for type B events, with the signed deviation remaining at around 7%.

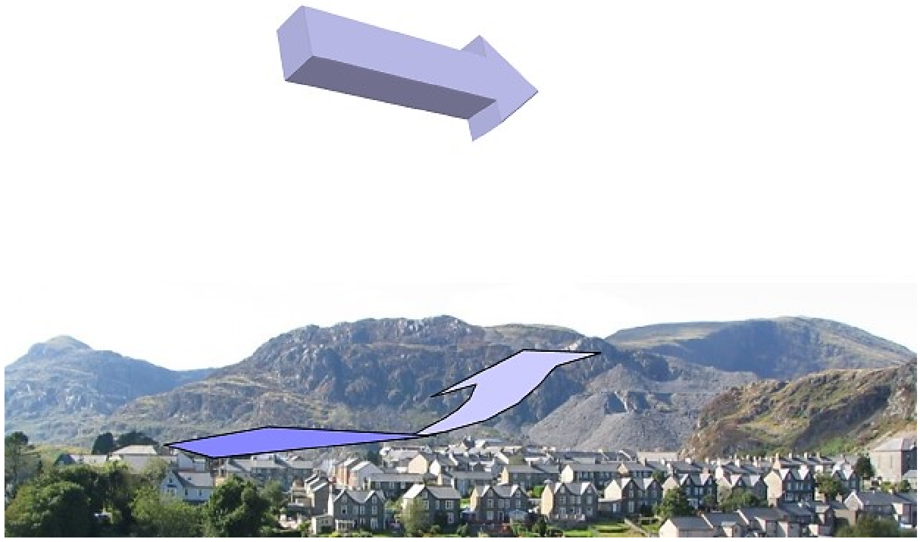
The conclusion is that the MM5 model is predicting orographic rainfall over a mountain ridge quite accurately, especially in terms of total rainfall for the area. Inaccuracies exist, however, for valley induced seeder-feeder rainfall, both in terms of location and quantity. Tests with a neural network suggest that a systematic error is present which might be addressed by a modification to the model. It may be possible to identify steep valley head slopes from the digital elevation model, and simulate enhanced seeder-feeder rainfall at these locations. The necessity to retrain the neural network for each individual storm event indicates that a time-dependent parameter is present. It is suggested that this is the angle of approach of the mid-level weather system in relation to the orientation of the low level air flow along the valley axis.

A revised Robichaud model was configured to simulate a steep valley head. This was found to produce rainfall predictions which were qualitatively and quantitatively plausible.



As a further example from North Wales we might consider rainfall in Blaenau Ffestiniog, which is well known as being one of the wettest towns in Wales.

The town is located around the steep heads of several valleys, at a point where air flow from the coast along the vale of Ffestiniog is forced to rise rapidly at the mountain front. This again represents a suitable topographic configuration for generating enhanced seeder-feeder rainfall.



In a presentation during this conference by Shrestha, Toma and Webster (2012), storm rainfall in Pakistan was discussed. It was suggested that valley airflows pick up moisture from vegetation and are then being forced up at the Himalayan mountain front, interacting with mid-level cloud to form huge amounts of rain. This represents a similar situation to rainfall along the west coast of Wales, but on an enormously greater scale. Seeder-feeder rainfall induced by valley topography may be more important and more widespread worldwide than seeder-feeder rainfall induced by hill summit processes.

References

Hall, G. (2008). An Integrated Meteorological /Hydrological Model for the Mawddach Catchment, North Wales. Ph.D. thesis, Bangor University. Available on-line at: www.grahamhall.org/mawddach

Lin, Yuh-Lang. Mesoscale dynamics. Cambridge University Press, 2007.

Robichaud, A. J., & Austin, G. L. (1988). On the modelling of warm orographic rain by the seeder-feeder mechanism. Quarterly Journal of the Royal Meteorological Society, 114(482), 967-988.

Shrestha, K., Toma, V. E. and Webster, P. J. (2012). Modeling the Major Pakistan Floods of 2010: A Coupled Atmospheric-Hydrologic Forecasting Scheme for the Indus Valley. American Meteorological Society 92nd Annual Meeting, January 2012.