The development of Lamb weather types: from subjective analysis of weather charts to objective approaches using reanalyses

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Introduction

We provide a brief review of the history of daily weather-type analyses for the British Isles. This review is necessarily focused on the pioneering work of Hubert Lamb and points to later and continuing work that he fostered in this area. Hubert Lamb's first mention of weather types in the context of the British Isles can be found in Lamb (1950). In this extensive paper, he reviews various schemes used to characterise atmospheric circulation dating back to the nineteenth century, including that from Germany, which became the pan-European scheme we know today as Grosswetterlagen (GWL, Hess and Brezowsky, 1969). Lamb lays out the basic classification of his subsequent weather-type catalogue that built on the earlier work of Levick (1949; 1950) for the years from 1898 to 1947 across the British Isles, and discusses the annual and seasonal frequency of the types, spells and singularities of the weather throughout the year. The study of singularities (the occurrence of similar weather patterns at the same time each year) arose out of research that was intended to assist in long-range forecasting studies (see background to weather typing in Kelly *et al.*, 1997). However, work on singularities has fallen out of favour in recent years.

During the 1960s, Lamb (1972a) produced the final version of his British Isles weather-type catalogue beginning in the year 1861 (henceforth referred to as Lamb weather types, LWTs). He kept this catalogue up to date until his death in 1997. Lamb (1991) additionally classified a number of earlier short-period intervals, including the time of the Spanish Armada in 1588 and the latest was in the 1850s, periods for which he had helped derive weather charts. Along with John Kington, Lamb also classified all days during 1781–1786 for which daily weather charts had been produced by Kington (1988). Lamb (1972a) has been cited 454 times according to Google Scholar (checked 2 October 2013). This is about three to four times less than his later books (e.g. Lamb, 1972b; 1977). In these later books, the LWT scheme was generally referred to in the form of a diagram showing the annual count of westerly days from 1861 to the present, emphasising, at the time of writing, the reduction in this count since the 1920s.

Objective classification schemes

An objective approach to classifying the daily atmospheric circulation according to the Lamb weather-typing scheme was developed by Jenkinson and Collison (1977). The objective scheme uses a single grid-point mean-sea-level-pressure analysis for a fixed observation time (at 0000 UTC or 1200 UTC) each day, while the original Lamb (1972a) concept was based on the diurnal sequence of weather, and so made use of charts: for the previous, current and subsequent day, and also the steering of depressions (making use of upper air charts after they became available from the 1940s). The objective and the original subjective Lamb schemes have been compared by Jones *et al.* (1993).

An updated objective series has recently been produced using reanalysis data (Jones *et al.*, 2013). These provide a convenient and simple way to update the catalogue regularly. For the period 1871–1947, the twentieth century reanalysis (20CR) developed by Compo *et al.* (2011) is used and the National Centers for Environmental Prediction (NCEP) Reanalysis by Kalnay *et al.* (1996) is used for 1948 to the present. Jones *et al.* (2013) showed that the time for which the observation chart was produced was important (a point briefly alluded to by Lamb, 1972a) and they derive a more consistent analysis by always using the 1200 UTC chart, centring this version on the civil day. The series from 1871 to the present day is used in this short paper, together with the original catalogue developed by Lamb (1972a) and the first objective analysis (Jones *et al.*, 1993). The objective scheme developed by Jenkinson and Collison (1977) uses three measures of the circulation derived from the gridded sea-level-pressure field across the British Isles (see figure A1 in Jones *et al.*, 2013, for their derivation): the strength (*F*), vorticity (*Z* – i.e. shear and curvature) and direction (*D*) of the large-scale geostrophic flow.

Changes in weather-type frequency

Lamb (1972a) simplified the 27 possible LWTs into seven principal types (anticyclonic, cyclonic, northerly, easterly, southerly, westerly and northwesterly: A, C, N, E, S, W and NW, respectively) and produced seasonal and annual counts of these (one of which is the well-used westerly day count, Lamb, 1972b). In producing this, hybrid types (e.g. AS and CNE) count one-half to both A and S and one-third to each of C, N and E, respectively. Lamb (1972a) argued that NW days are distinct from both W and N and not a hybrid of the two cardinal directions. Figure 1 shows annual time series of the three major types (A, C and W) for the updated version (Jones *et al.*, 2013), and smoothed series of the original objective version (Jones *et al.*, 1993) and the original Lamb (1972a) subjective version (updated to the end of 1996).

The principal difference between the subjective and the objective approaches is that the objective annual westerly day count does not show a reduction since the 1920s, whereas this reduction is apparent (and indeed emphasised) in many Lamb publications (e.g. 1972b). The original Lamb (1972a) subjective scheme produces similar numbers of westerly days to the objective schemes after the mid-1970s. Commenting on the difference, Kelly *et al.* (1997) say:

> *The use of surface charts (alone) introduces a bias in that days on which the steering of synoptic systems, determined*

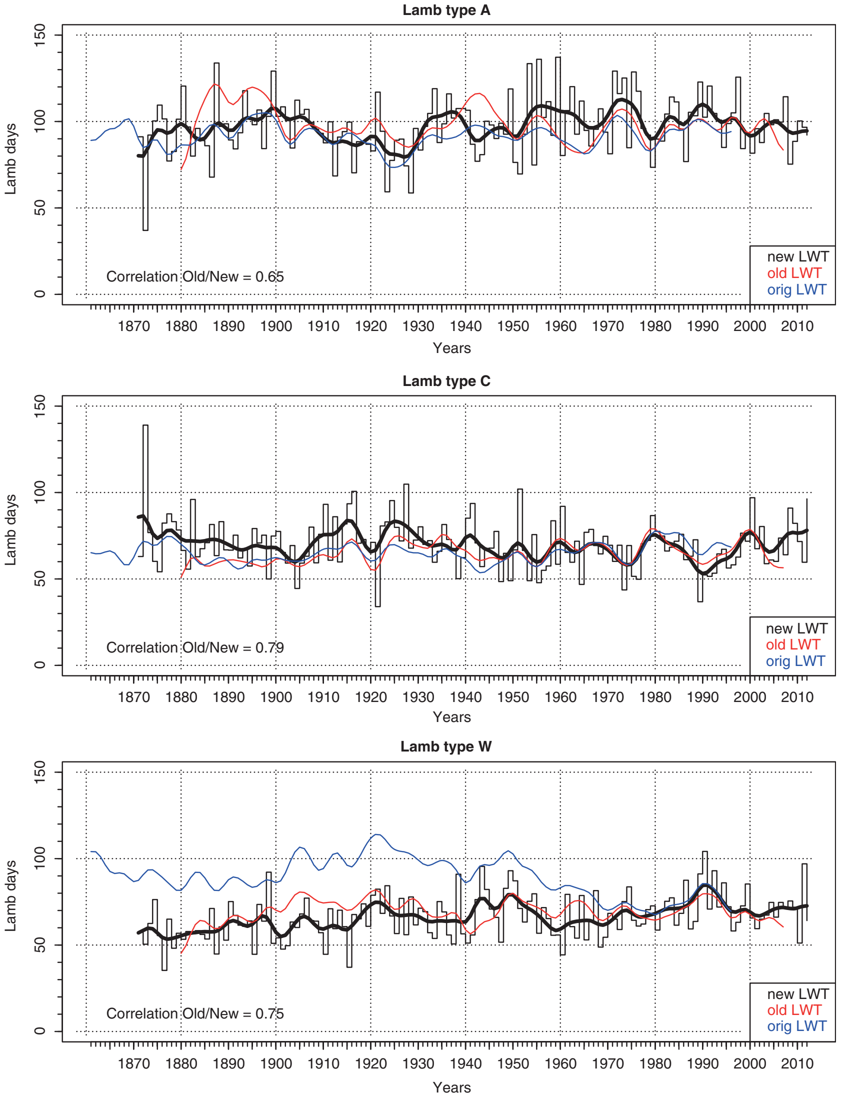

Figure 1. Annual counts (for 1871–2012) of the three most frequent LWTs (A, anticyclonic; C, cyclonic and W, westerly) with the histogram showing the annual totals from the latest objective version (Jones et al., 2013). Smoothed lines are 10-year Gaussian filtered versions of the latest objective LWT (black), the old objective version (Jones et al., 1993; red) and the original Lamb (1972a) subjective version (blue).

Table 1

Correlations between seasonal counts of the seven principal Lamb (objective) weather types and England and Wales seasonal precipitation totals (HadEWP) and Central England seasonal average temperatures (CET) for the period 1871–2011.

		Season			
	Weather type	*December–February*	*March–May*	*June–August*	*September–November*
HadEWP	A	**−0.75**	**−0.68**	**−0.74**	**−0.65**
	C	**0.68**	**0.68**	**0.76**	**0.77**
	N	−0.06	0.09	0.12	0.05
	E	−0.01	0.06	**0.18**	0.08
	S	**0.28**	0.11	0.08	−0.08
	W	−0.02	−0.06	−0.07	−0.06
	NW	−0.04	0.11	−0.01	0.03
CET	A	**−0.19**	**0.25**	**0.51**	−0.05
	C	−0.08	**−0.35**	**−0.47**	−0.04
	N	**−0.42**	**−0.49**	**−0.25**	**−0.62**
	E	**−0.65**	**−0.37**	0.02	**−0.32**
	S	0.13	**0.21**	**0.20**	**0.40**
	W	**0.66**	**0.43**	−0.14	**0.33**
	NW	0.12	0.04	**−0.17**	−0.12

Correlations in bold face are significant at the 95% level.

A, anticyclonic; C, cyclonic; N, northerly; E, easterly; S, southerly; W, westerly; NW, northwesterly.

> *by the flow at height in the atmosphere is, say, westerly, will tend towards south-westerly flow at the surface.*

Upper-air charts would not have been available to Lamb (1972a) before the late-1940s, so this may be a factor, but the convergence of the schemes occurs much later. It would be possible to use various NCEP Reanalysis products to address this issue, possibly using the pattern-correlation training scheme developed by James (2007) for the GWL, but using Lamb (1972a) instead. Lamb foresaw that it would be possible to use computers for this type of approach (see Lamb, 1972a, p. 20). Another possible reason for the difference is the change in charts used between 1966 and 1967, which involves a switch from midday to midnight charts (see discussion in Jones *et al.*, 2013, but this should only affect the old LWT series) or possibly a change in the number of charts available to Lamb (1972a, and in his subsequent subjective updating) each day. Lamb (1972a) stated that four charts per day were being used during the early 1970s and the chart series from 1899 to 1961 is based on two charts per day, but it is unclear when in the 1960s the change occurred. In summary, the precise reasons for the differences in the trends of the westerly day counts between the original LWT and the objective types remain uncertain.

More complex reduction schemes have been developed, such as the Progressive, Southerly, Cyclonic and Meridional (PSCM indices; Murray and Lewis, 1966; Murray and Benwell, 1970) and the PC-based approaches of Jones and Kelly (1982) and Briffa *et al.* (1990). Inherent in all these combinations of types is that the original 27 LWTs are not independent of each other, and a few combinations can be shown to represent most of the variability in the dataset. Later in this paper we assess this using the values of the three basic parameters (*F*, *Z* and *D*) used in the objective derivation of the LWTs.

Relationships with temperature and precipitation

A principal reason for the enduring interest in weather types is the way in which they convincingly portray the strong association with other aspects of the weather, especially temperature and precipitation. Table 1 shows seasonal correlations between counts of Lamb's seven basic types (using the latest objective version from Jones *et al.*, 2013) and Central England Temperatures (CET; Parker *et al.*, 1992) and England and Wales Precipitation (EWP; Alexander and Jones, 2001) totals for the period 1871–2011. For the EWP, the positive correlations with cyclonic and inverse correlations with anticyclonic days are as expected, with little seasonal variation. For the CET, there are

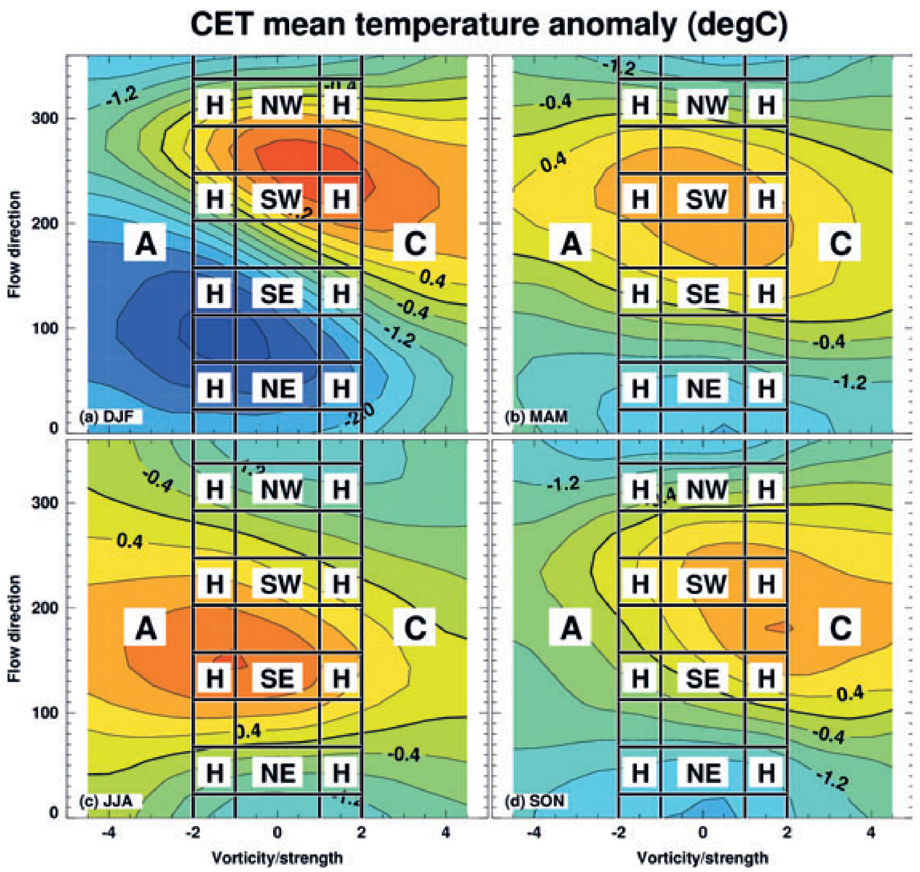

Figure 2. Mean CET anomaly (degC) as a function of flow direction (y-axis in degrees) and the ratio of flow vorticity to strength (x-axis), calculated by assigning each day to one of 10 flow-direction classes and to one of 10 vorticity/strength classes (100 bivariate classes overall) and averaging the observed CET anomalies from all days assigned to each class. The colour-shaded contours have an interval of 0.4°C, from blue (negative anomalies) to red (positive anomalies) and the zero anomaly contour is the thicker line between pale and lime green. The grid of black lines represents the objective LWT definition scheme of Jenkinson and Collison (1977), with anticyclonic (A) and cyclonic (C) types separated by hybrid (H) and pure direction types (NW, SW, SE and NE shown; intervening W, S, E, N omitted for clarity). Unclassified (U) LWT days are not associated with a particular location on these axes and thus cannot be depicted here. Results are shown separately for each season, based on data for 1871–2012: (a) winter (DJF); (b) spring (MAM); (c) summer (JJA); and (d) autumn (SON).

marked seasonal variations, with correlations often opposite in sign in summer compared with winter. Only northerly and southerly days display associations of consistent signs for all seasons, and correlations are always stronger for northerly counts.

For many applications, such as statistical downscaling used to provide climate change information at fine spatial and/or temporal scales (e.g. Wilby and Dawson, 2013), the relationship between synoptic atmospheric circulation and local weather must be understood at a daily time-scale. The association between individual LWTs and the expected daily mean-temperature anomaly or the probability of a wet day at a particular location has been reported previously (e.g. Conway *et al.*, 1996), but here we illustrate the advantage of using continuous measures of atmospheric circulation rather than discrete weather-type classifications.

Figure 2 shows, separately for each season, the relationship between CET anomalies (from the long-term-mean annual cycle) and two measures of synoptic airflow (the ratio of vorticity (*Z*) to strength (*F*) and the flow direction (*D*)). This combination of predictor variables is convenient because it includes the influence of the most important control on temperature, namely the direction of the synoptic airflow. This allows the circulation to be catalogued using the Jenkinson and Collison (1977) definitions of objective LWTs, because the pure directional, hybrid directional, anticyclonic and cyclonic types are defined according to the ratio of *Z* and *F*. As *Z* and *F* also have the same units (see Jones *et al.*, 2013) their ratio is dimensionless. The negative temperature anomaly association with wintertime flow from the north and east, in contrast to the positive anomaly association with westerly flow, is clear and is apparently well captured by the different directional weather types (Figure 2(a)). However, even when flow vorticity is more than double the magnitude of flow strength, the influence of flow direction remains important. Classifying all these situations as a single weather type (anticyclonic or cyclonic) loses these important distinctions, degrading the capability for predicting the temperature anomaly expected under a given circulation pattern. For winter, temperature anomalies from −3.2 to +0.4 degC that can be distinguished using the airflow indices are instead all classified as a single anticyclonic weather type (for the cyclonic type, the range is −2 to +1.6 degC). The variation in temperature in the other seasons is smaller, but nevertheless the use of single cyclonic or anticyclonic types when vorticity is more than double the flow strength overlooks the influence of flow direction that is still apparent within these weather types (Figure 2(b–d)). A classification based only on flow direction would not be sufficient (see figure 9 of Osborn *et al.*, 1999), given the importance of the strength and curvature of the flow, particularly in winter when cold anomalies are associated with anticyclonic and weak flow conditions.

For precipitation in South East England (Alexander and Jones, 2001), the LWT classification captures most of the important variations (Figure 3). The main gradient from dry to wet across the panels apparent in each season shown in this figure, arises from the control exerted by vorticity and the dominance of frontal rainfall associated with cyclonic conditions. This is well captured by the classification into anticyclonic, hybrid-anticyclonic, directional, hybrid-cyclonic and cyclonic types. There is little dependence of precipitation on flow direction under anticyclonic conditions, but flow direction becomes more important when vorticity is positive. This is partly captured by the directional weather types, but the cyclonic weather type is unable to distinguish the higher precipitation amounts observed when cyclonic flow is associated with an easterly (in summer; Figure 3(c)) or southerly component (in winter, Figure 3(a)).

Given the importance of vorticity for precipitation in southeastern England and of flow strength for precipitation in the northwest of the UK (Osborn *et al.*, 1999), it is also useful to consider the relationship between precipitation and vorticity and strength (rather than using the ratio of vorticity and strength). For South East England (Figure 4), this results in a dry to wet gradient from negative to positive vorticity, with some rotation of the contour lines in summer (Figure 4(c)) and autumn (Figure 4(d)) such that drier conditions are associated with stronger airflow. In contrast, the gradient for precipitation across northern Scotland (Figure 5) is almost perpendicular, with the transition from dry to wet conditions occurring from weak to strong flow across most of the domain. The exception is for flow strengths below 10 units (hPa per 10°

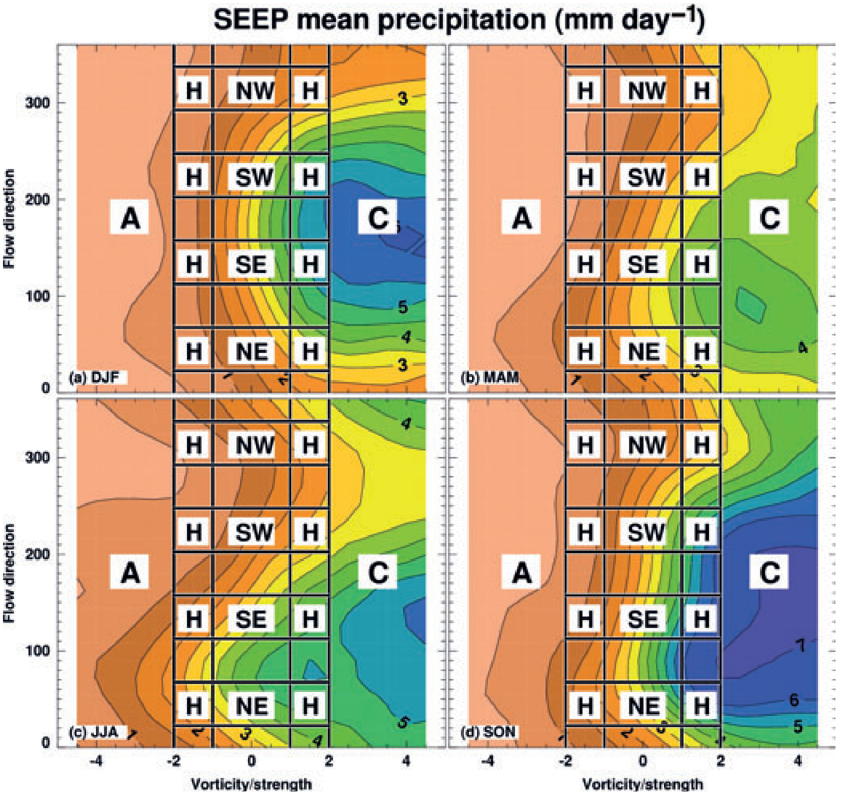

Figure 3. As Figure 2, but for mean precipitation (mm day^{-1}) in South East England. Colour shading runs from beige (<0.5mm day^{-1}) to dark blue (>6 mm day^{-1}) with a contour interval of 0.5mm day^{-1}; thereafter the contour interval is 1mm day^{-1} (i.e. dark purple represents >7mm day^{-1}). Based on daily precipitation data for 1931–2012.

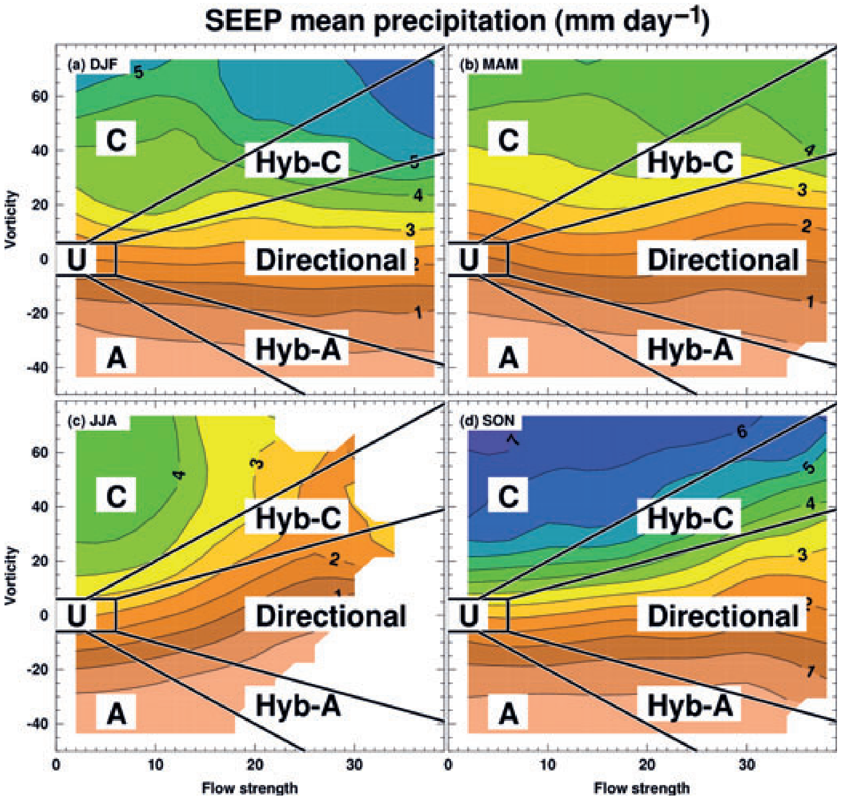

Figure 4. Mean precipitation (mm day^{-1}) for South East England as a function of vorticity (y-axis) and flow strength (x-axis). The grid of black lines represents the objective LWT definition scheme of Jenkinson and Collison (1977) on these axes: anticyclonic (A), unclassified (U) and cyclonic (C). Flow direction is not included in this figure and thus individual pure and hybrid directional types cannot be depicted, although the regions in which these types lie are shown (Directional, Hyb-C and Hyb-A). Classes that are not sampled within the observed record are left white (e.g. high flow strengths in summer).

latitude at 55°N, so approximately 12 knots, see Jones *et al.*, 2013 for definition of the *F* and *Z* units used), where the contour lines become horizontal, indicating more influence of vorticity than when the flow is stronger. The axes used in Figures 4 and 5 depict the main groups of weather types (anticyclonic, hybrid-anticyclonic-directional, directional, etc.) but as flow direction is not considered the directional types cannot be separated. Nevertheless, the limitation of the single anticyclonic and single cyclonic weather types is clear, especially for northern Scotland precipitation where the cyclonic type is unable to distinguish between synoptic situations that on average produce only 2.5mm day^{-1} (F = 3 and Z = 10) and those that produce 11mm day^{-1} (F = 35 and Z = 72) in winter (Figure 5(a)).

Conclusions and future of weather and circulation types

In this article we have discussed the history of Lamb weather types in the context of the British Isles. Even though they were originally developed for this region, the objective nature of the Jenkinson and Collison (1977) scheme and the availability of the NCEP Reanalyses, means that they can be applied in many other parts of the world. Applications outside the British Isles have been rare, although Goodess and Jones (2002) have used the LWT approach for Iberia.

We have also shown the greater potential of the continuous measures of the objective approach compared with the original 27 basic types. This illustration with large-scale temperature and regional precipitation could be extended in the regional context of the British Isles to include more regional weather types along the lines suggested by Mayes (1991; 1994). With the greater resolution of the upcoming ERA-20C Reanalyses in 2014 it should be possible to apply the typing approach to subregions of the UK, potentially enhancing the links to regional precipitation and temperature series representing equivalent-sized regions. As discussed in Jones *et al.* (2013), the LWT approach could be used in regions beyond the British Isles, but only where the NCEP Reanalyses are consistently reliable. Additionally, circulation-based links can also be assessed in Regional Climate Model simulations providing validation of the small-scale processes incorporated (see e.g. Turnpenny *et al.*, 2002). Both of these areas are important avenues for further research in synoptic climatology.

Acknowledgements

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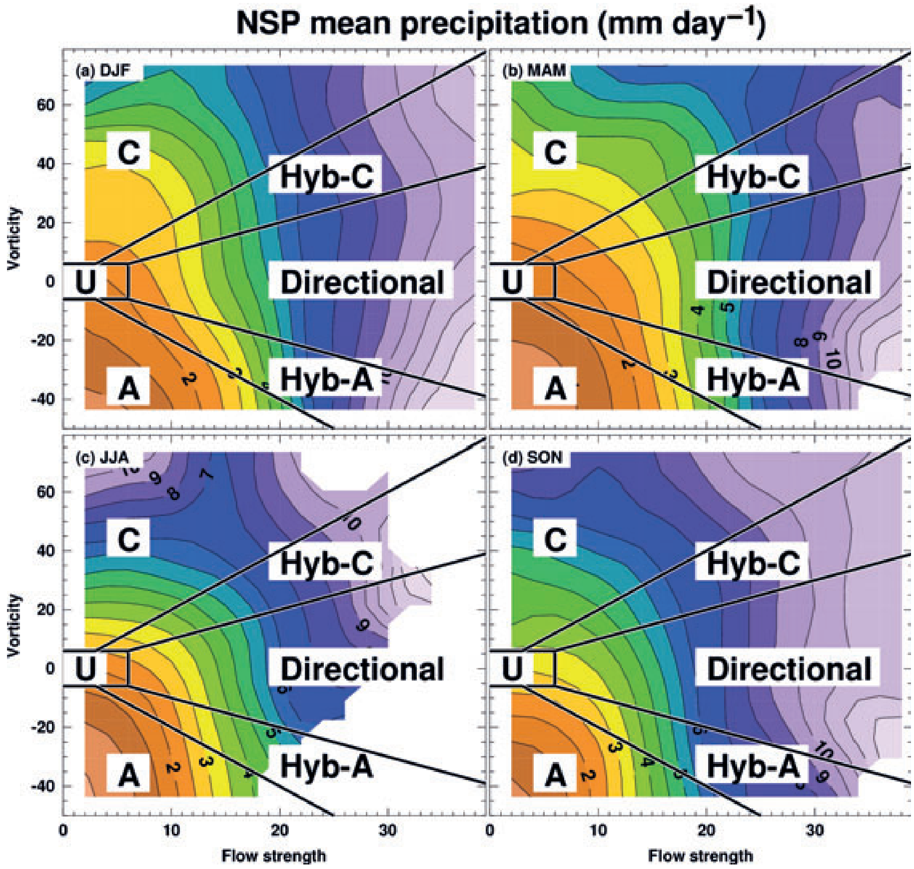

Figure 5. As Figure 4, but showing mean precipitation (mm day^{-1}) in northern Scotland based on data for the period 1931–2012. See Figure 3 for a description of the correspondence between the colours and scale, noting that the contour interval is 1mm day^{-1} above 6mm day^{-1} (dark blue).

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