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Cover picture from a colour transparency by Susan Postle
Cumulus over Krakatau, 1987

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RECURRENCE PROBABILITY – A DIFFERENT APPROACH

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LOCAL meteorologists often develop subjective impressions of repetitive local weather behaviour which can – when used judiciously – provide valuable, supplementary input to the daily forecast. Before leaning too heavily on such perceptions, though, it is always advisable to bolster these subjective impressions with statistical 'fact'. Such confirmatory studies not only lend weight to perceived tendencies, but might also provide additional insight into atmospheric phenomena. However, statistical testing must be applied with caution. Too cursory a study might produce misleading results, particularly were it to cause us to override an experience-based forecast rule erroneously. The following case-in-point is offered as an example of how easily one can be misled.

SEVERE WEATHER STATISTICS

A popular perception among meteorologists responsible for forecasting weather in north-east Colorado and south-east Wyoming (Fig. 1) is that severe weather is very frequent during the first three weeks of June, that it then diminishes for several weeks, and

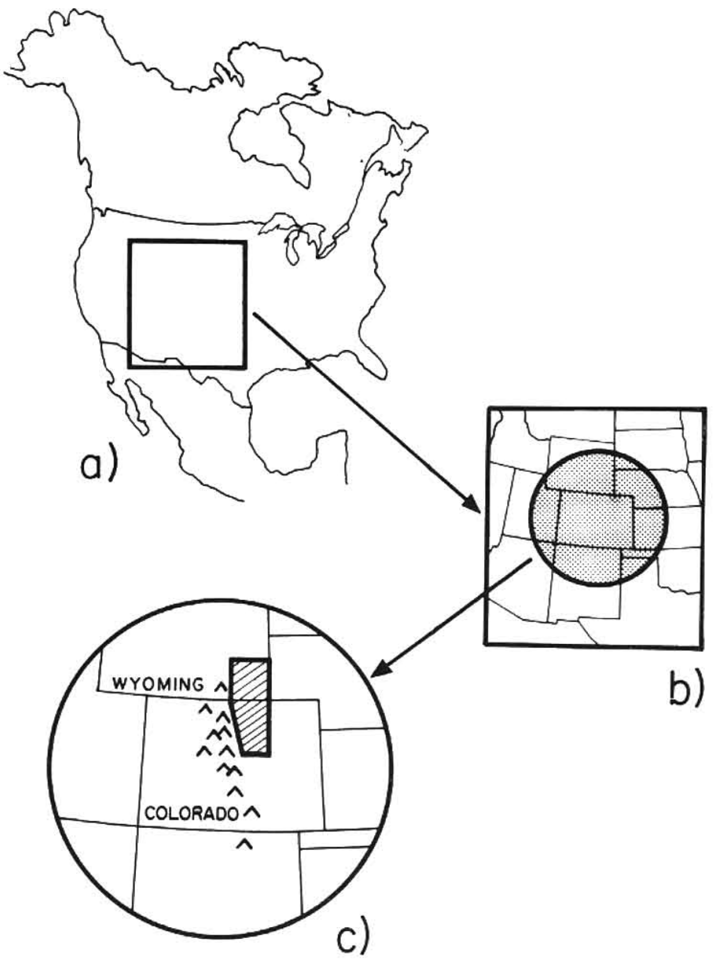

Fig. 1 Map sequence illustrating the location of the Front Range Corridor: (a) shows North America and the USA, (b) excerpts a large portion of the western USA, and (c) focuses on the region discussed in this article. More formally the region includes the area from 39.5°N to 42.5°N, and from 104°W, westward to the eastern foothills of the Rocky Mountains. A few severe reports that occurred slightly east of longitude 104°W in Colorado were allowed into the dataset. These were allowed when it was suspected that a storm, which produced severe weather to the east of the 104°W line, had been strong enough to have earlier produced severe weather in the deserted country further west.

that this lull is usually followed by a period in late July and early August during which one can again expect severe weather to occur, almost without exception. To check this hypothesis, a dataset was compiled of all reported occurrences of severe weather within a portion of the 'Front Range Corridor' (Fig. 1) for the period 1959–88. For the purposes of this study, severe weather was defined as hail with diameter greater than or equal to 0.75 inches (1.9 cm) and/or tornadoes*.

Figure 2 shows a plot of the number of occurrences of severe weather on each day for the 30-year period. As one might expect, there is a great deal of fluctuation on a day-to-day basis, and general tendencies are difficult to see. Figure 3 presents the same data, with daily fluctuations smoothed, using a 3-point running mean. This presentation makes it easier to identify significant patterns.

The results of this simple analysis do show a higher frequency of severe weather during the first three weeks of June consistent with the perception of local forecasters. On 13 June, for example, severe weather has been reported ten times during the past 30 years within this

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*In the USA, the National Weather Service (NWS) defines a severe thunderstorm as one which produces 0.75-inch hail, one or more tornadoes, *and/or* winds of speed ⩾ 50 knots. Flash floods are not included in the NWS definition of severe weather. Even though high winds *are* part of this official definition, their reporting is often much more haphazard, and therefore less reliable, than tornadoes or hail. Thus, neither high winds nor flooding were included in this study.

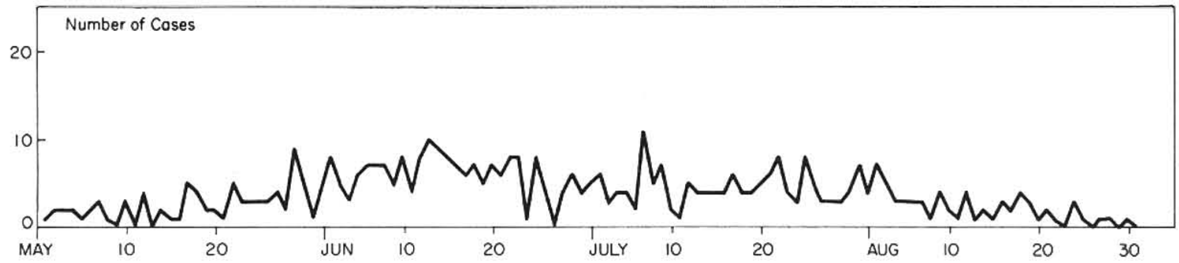

Fig. 2 Number of days on which severe weather was reported within the Front Range Corridor (see Fig. 1) during the period 1959–88. Plot shows the count of the number of times a particular day reported severe weather during the 30-year period.

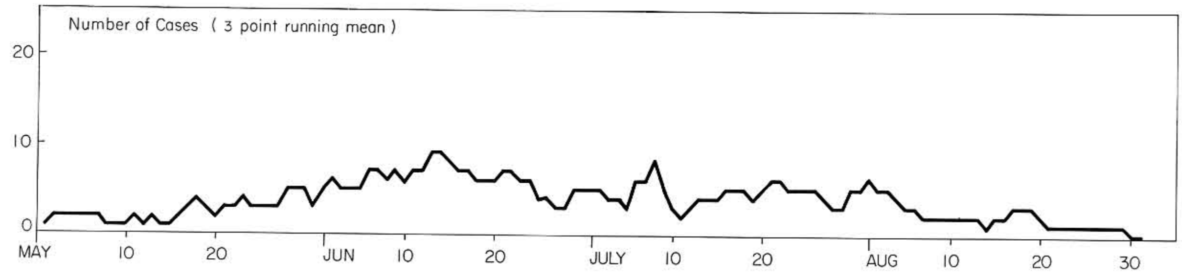

Fig. 3 Same as Fig. 2 except that data points are smoothed using a 3-point running mean

relatively small region – a remarkably high frequency for an individual day. This June maximum is readily explained by the fact that severe convection in mid-latitides is most normally associated with strong synoptic forcing. According to Doswell (1980), Colorado and Wyoming are no exceptions. In late May and early June the jet stream and associated storm track are still far enough south to affect these regions, while heating (and therefore potential instability) is on the rise. Thus, this late-spring, severe weather maximum is not surprising.

On the other hand, the perceived secondary maximum, which we expected to find in late July and early August, was not found. In fact, these data actually indicate a small minimum near the end of July, apparently disproving a portion of the perceived pattern regarding seasonal distribution of severe weather.

Despite these results, the perception was so strong concerning the existence of a secondary maximum that we decided to evaluate more carefully what it was about that period that had left such a strong impression. In the end, we decided to try a totally different method of analysing the same data.

RECURRENCE PROBABILITY

After considerable thought, we began to recognise that it was not a large number of severe weather events each year that had captured our attention. Rather, our perception seemed to relate to the consistency, regularity, and reliability of severe weather during this secondary maximum. What had really caught our attention was that during nearly every year at least one major severe weather event took place sometime during that late-July/early-August period. Thus, we restructured our analysis to look more carefully at the regularity of severe weather, instead of just the total frequency. We organised the severe weather data into two-week periods at five-day intervals, beginning 1 May. We then counted the number of years in which severe weather occurred at least once during each two-week period. Thus, overall severe weather frequency did not have to be *high* in order for a two-week period to qualify; there simply had to be at least one severe weather day.

Figure 4 shows the two-week periods plotted as overlapping bar graphs at five-day intervals. For the readers' convenience, the value for each two-week period is plotted as a point at the centre of each period. Notice that in this presentation – where we are looking at the recurrence frequency instead of the total number of severe weather occurrences – not

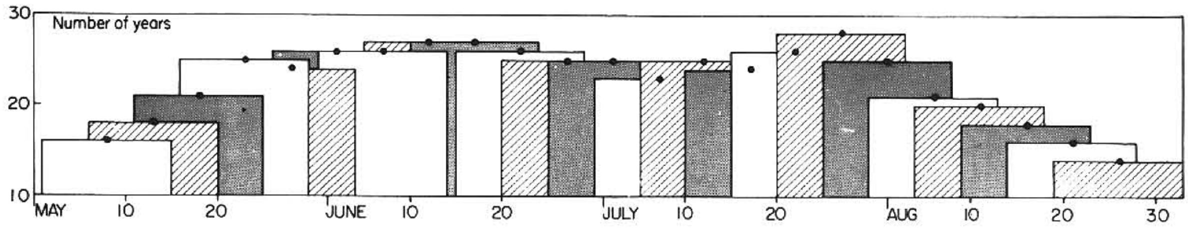

Fig. 4 Overlapping bar graph representing the number of years (for the period 1958–88) during which severe weather occurred at least once during various two-week periods. The two-week periods are shown at five-day intervals.

only does the severe period in early June once again show itself clearly, but also now we see the secondary maximum. In fact, notice that in terms of *recurrence,* the secondary maximum is actually slightly higher in amplitude.

The statistics associated with the secondary maximum are very interesting. A total of 28 out of the 30 years studied experienced severe weather in the Front Range Corridor on at least one day (actual average was three) during the two-week period. In terms of year-to-year regularity, no other time of year has had a greater recurrence frequency for severe weather.

It is also interesting that many of the most notable Front Range Corridor severe events have occurred during this period. This also affects our perception. For example, very large and damaging hailstorms in Fort Collins, Colorado, struck on 22 July 1973, 30 July 1979 (where one of the two confirmed US hail-related deaths of this century was reported) and 2 August 1986. In Cheyenne, Wyoming, there have been many incidents, including the severe flood and hailstorm of 1 August 1985 in which 12 people lost their lives, 70 were injured, and damage to homes, cars and business was estimated at approximately $65 million. Although flash floods are not included in these severe weather statistics, the infamous Big Thompson Canyon flash flood also occurred during this period – on 31 July 1976. This event killed 139 people.

The cause of the late season severe weather maximum has not been studied in detail. Some of the factors normally present in severe weather (*e.g.* strong frontal boundaries, airmass differences, strong vorticity advection, etc.) are not normally present in late July and August in Colorado. Instead this maximum seems to be closely related to the period of northernmost penetration of the South-west Monsoon (Hales 1974) which brings moist, subtropical air into the southern Rocky Mountains each summer. In combination with the local convective instability (which occurs almost daily throughout the summer in and near the Rocky Mountains), this extra moisture source may be all that is needed to trigger severe weather late in the season. One indication that this moist, south-westerly flow might play a rôle in forcing this secondary maximum is found in some of the results of satellite climatology studies done at Colorado State University (*e.g.* Klitch *et al.* 1983; Weaver *et al.* 1987; Weaver and Segal 1988).

As an example, consider Figs. 5 and 6. Both are portrayals of cloud frequencies that occurred during the summer of 1985. They were produced from digital GOES satellite imagery. The frequency composites were made by: (1) identifying cloudy elements on individual pictures (refer to Weaver *et al.* 1987), (2) constructing new images in which cloudy elements were turned pure white and all others pure black, and (3) summing the resulting altered imagery in various ways – *e.g.* into various time intervals, synoptic categories, etc. For the data shown, Fig. 5 represents a composite of 'monsoon days' for July and August 1985, while Fig. 6 includes only 'non-monsoon days' for the same two months. (For this study, 'monsoon days' were defined as those having south-westerly flow over the region at 700mbar and/or 500mbar, with a relative humidity of at least 70 per cent.)

Notice how much more cloudy the Front Range Corridor appears on monsoon days (Fig. 5), as compared with non-monsoon days (Fig. 6). These composites were originally constructed to look at rainfall statistics. It was found that 'monsoon moisture' was the probable source for more that 80 per cent of the rainfall measured during our period of study and for the area considered. It is interesting that when we sorted the severe weather

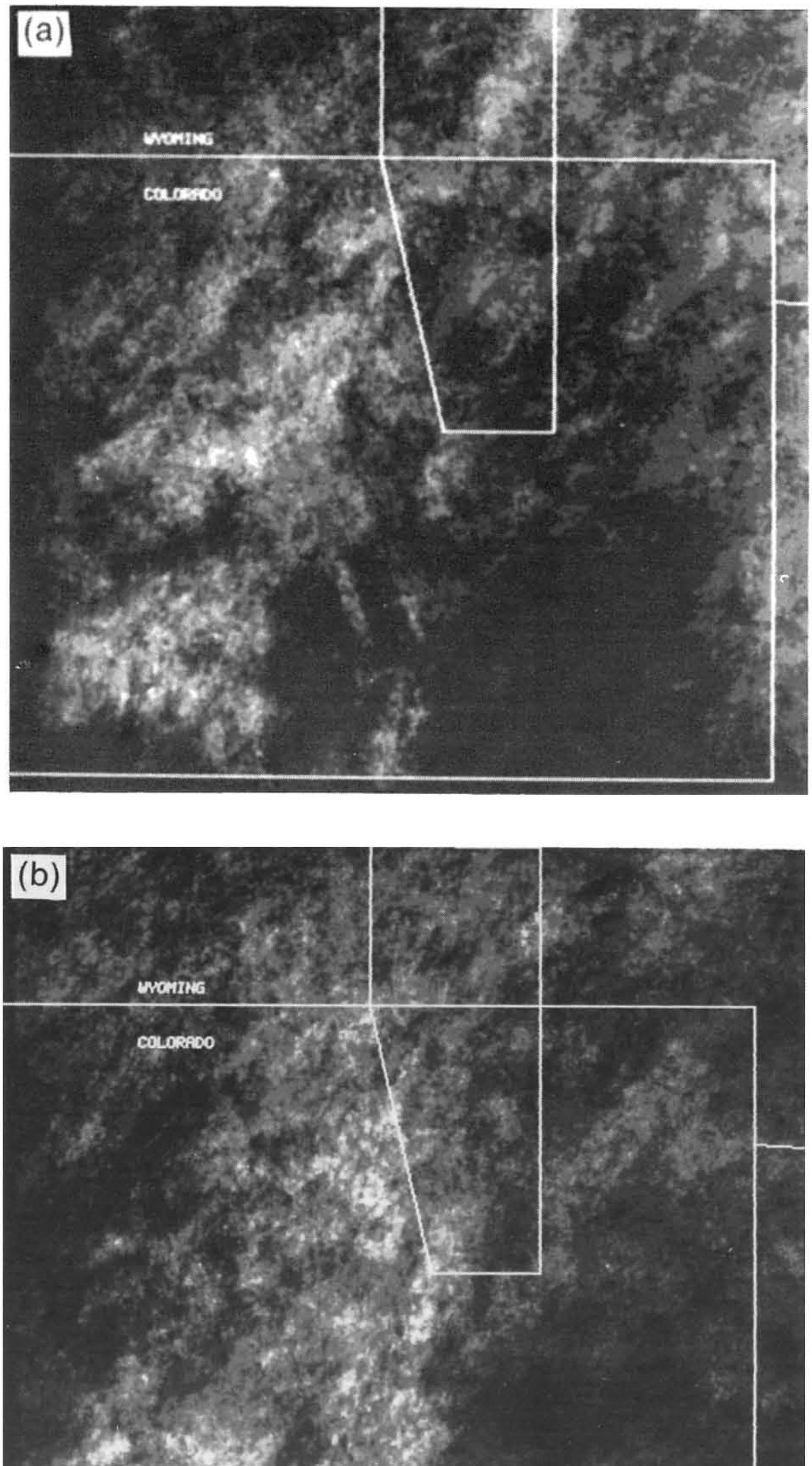

Fig. 5 Frequency of cloudiness over Colorado for the period 10 July to 23 August 1985. Brightness is directly proportional to cloud frequency and ranges from 0 to 80 per cent. Imagery was produced as described in text. Days selected for this composite were so-called moist, late summer 'monsoon days'. (a) Frequency data for 1700 GMT, *and (b) imagery taken at 2100* GMT.

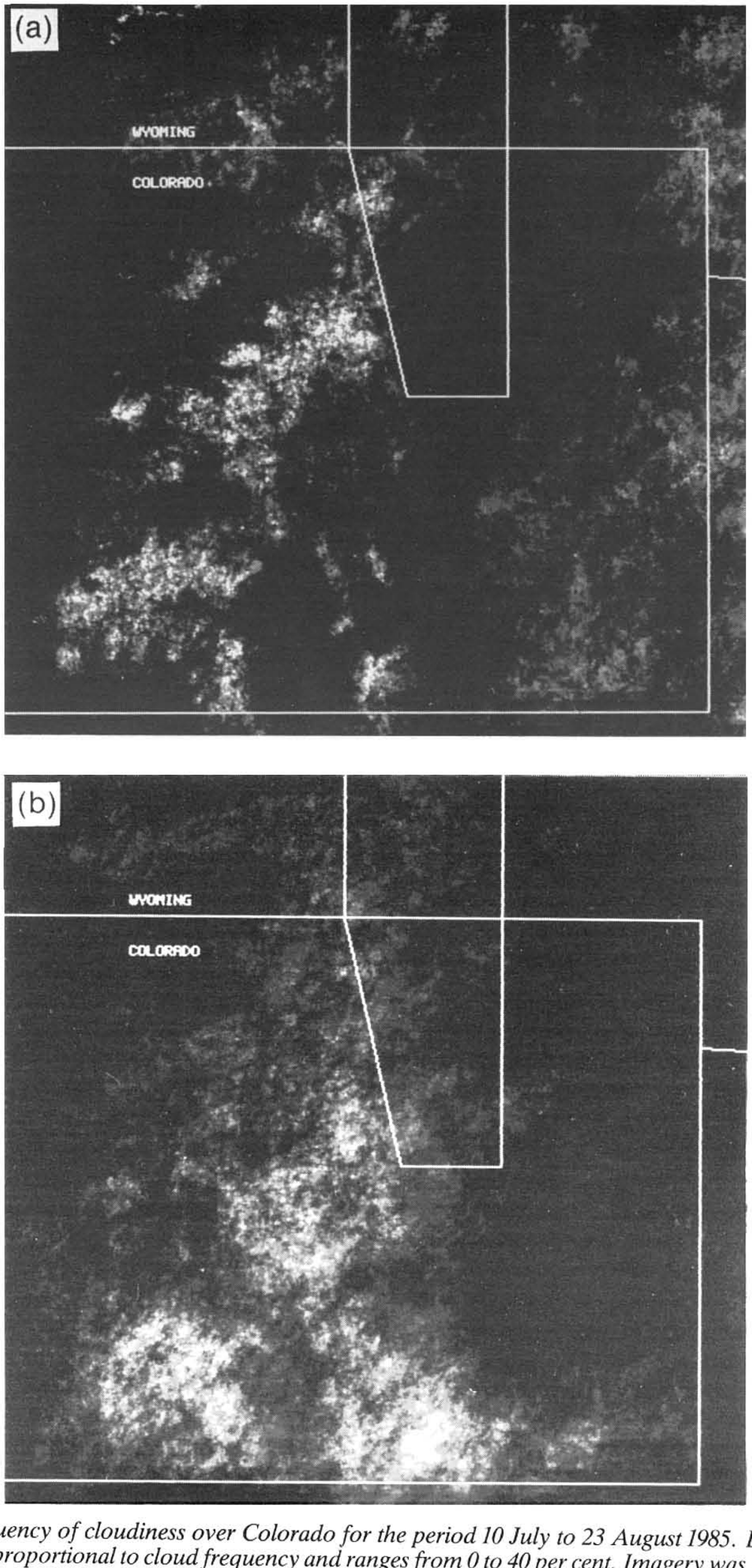

Fig. 6 Frequency of cloudiness over Colorado for the period 10 July to 23 August 1985. Brightness is directly proportional to cloud frequency and ranges from 0 to 40 per cent. Imagery was produced as described in text. Days selected for this composite were days on which the so-called late summer monsoon were not occurring. (a) Frequency data for 1700 GMT, and (b) imagery taken at 2100 GMT.

reports into two sets corresponding to the sets of days comprising Figs. 5 and 6, we found that severe weather occurred on 29.4 per cent of the monsoon days, and only 16.7 per cent of the non-monsoon days. That is, monsoonal flow seemed to produce nearly double the severe days. Of course, we realise that our sample set is much too small for conclusive results, and offer these examples only as indicative.

CONCLUDING REMARKS

Our perceptions of weather and climate help form an experience base from which we can draw as we observe and/or forecast the weather. These perceptions are based on a combination of many factors and can provide an important supplement to the daily forecast. However, these experience-based rules can also be misleading, or even erroneous. As scientists, it is imperative that we objectively evaluate our perceptions, being careful (as we have shown in this note) to define and analyse them appropriately. Then, once we are confident of the reliability of the perceived behaviour, it is incumbent on us to use and share the experience-based knowledge.

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THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

At the end of May, Working Group 1 of the Intergovernmental Panel on Climate Change (IPCC) completed its report on the Scientific Assessment of Climate Change. IPCC was established, under the auspices of the United Nations Environment Programme and the World Meteorological Organization, to survey and assess our knowledge of climate change, its effects and possible responses. Working Group 1 was chaired by Dr J. T. Houghton, Chief Executive of the Meteorological Office, and co-ordinated by Dr G. J. Jenkins, Meteorological Office, and aimed to provide a scientific assessment of:

1. The factors which may affect climate change during the next century, especially those due to human activity.
2. The responses of the atmosphere/ocean/land-ice system.
3. Current capabilities of modelling global and regional climate changes and their predictability.
4. The past climate record and presently observed climate anomalies.

The report has three components: an Executive Summary, reproduced below, a more substantive Policymakers Summary and an 11-chapter Main Report. The latter two are hoped to be published by a major publisher and should be widely available this autumn (at a very reasonable price!).

The other two working groups to IPCC are considering the impacts of climate change on society and the policy options for dealing with climate change; these working groups are chaired in the Soviet Union and the USA respectively.