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Note

Some satellite-derived cloud statistics for the New Zealand region

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Abstract Low-resolution images obtained from the NOAA orbiting satellites were analysed to obtain joint albedo-temperature distributions for six specific geographical areas in the New Zealand region. The distributions were coherently averaged to suppress transient structures and enhance quasi-persistent features. There is strong evidence for the success of the method in identifying orographic cloud that is characteristic of any given area, and in evaluating the synoptic scale effects of a large island complex on ocean cloud cover.

Keywords cloud distributions; cloud albedo; orographic cloud; cloud mapping

INTRODUCTION

There is little literature in the international journals describing the observation of New Zealand clouds from the meteorological satellites. Bradley et al. (1987c) have described a limited number of case studies in which they analysed some typical cloud formations to be found in the New Zealand region. Part of their study involved an examination of the two-dimensional (albedo-temperature brightness) histograms associated with specific cloud types, and they were able to confirm the findings of, for example, Reynolds & Vonder Haar (1977), Platt et al. (1980), and Phulpin et al. (1983) that such histograms are a valid tool for the identification of the major cloud formations. The success of the method rests on the fact that relationships exist between albedo, visible and infrared optical depth, and infrared emittance (Platt & Stephens 1980; Platt 1983). Figure 1 shows versions of the identification scheme according to Platt & Stephens (1980), Fusco et al. (1980), and Bradley et al. (1987c). Platt & Stephens also pointed out that the degree of localisation of peaks occurring on such diagrams can provide additional information on the spatial uniformity of some clouds. The purpose of this paper is to perform a preliminary investigation of the use of spatially coherent averaging, to study the major areas of the New Zealand region over a period of time, using visible and infrared low-resolution images obtained from the NOAA polar-orbiting satellites. The averaging process causes spectral features not associated with specific locations to appear as a background noise, whilst orographically related clouds which persist or frequently appear in a given area will generate the appropriate peaks from which they can be identified. The method is evaluated on a limited sample rather than attempting to provide a climatology of New Zealand clouds.

RAW DATA AND THE ANALYSIS PROCEDURE

Tapes of the NOAA satellite low-resolution image transmissions were obtained by the procedure described by Bradley et al. (1987a). The principal area of analysis is selected by a

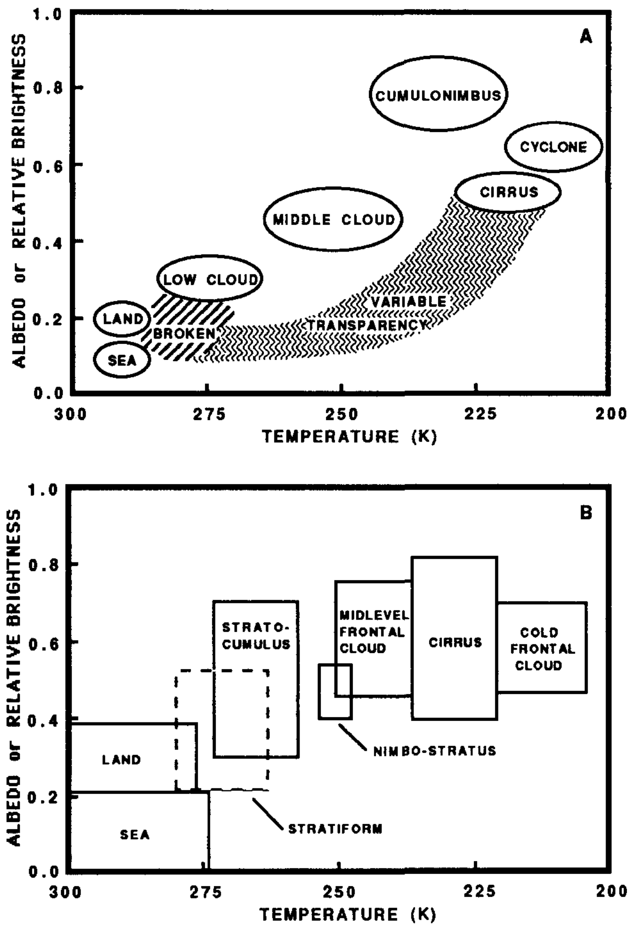

Fig. 1 A, Schematic for cloud identification used by Fusco et al. (1980) and Platt & Stephens (1980). B, Schematic for cloud identification used by Bradley et al. (1987c) for the analysis of New Zealand clouds.

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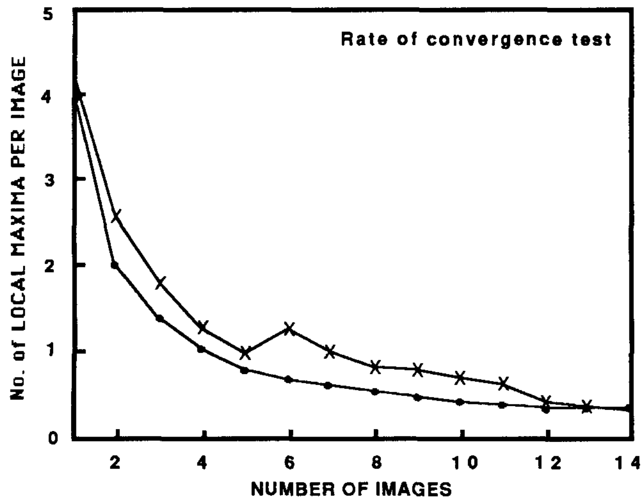

Fig. 2 Convergence of number of maxima on joint distributions as the number of images is increased. The curve for four maxima per image is shown for comparison.

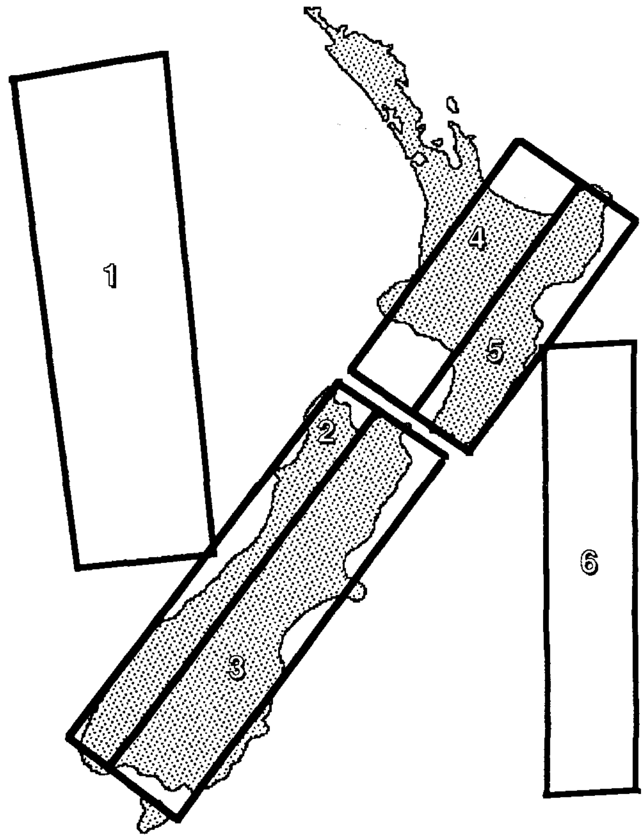

Fig. 3 The six New Zealand regions analysed by coherent averaging of joint temperature-brightness distributions.

process which automatically inverts south–north satellite passes, and files are standardised to a region enclosing New Zealand. By this means, parameters to reference each pixel geographically are incorporated into file processing. The digitised visible and infrared levels are converted into values of temperatures and relative brightness, with corrections made for sun angle and viewing angle (see, e.g., Bradley et al. 1987b). The error in the estimation of temperature is ±5 K, made up of a ±2 K error from the radiometer (Schwalb 1982) and other errors due to quantisation and linear interpolation. The error in the geographic location of the image files is minimised by comparing the output image with a standard overlay of New Zealand. Parameters are then altered manually to obtain a best fit, enabling locations to be determined to within two pixels, or 8 km. In this investigation, images were processed by the above means covering the months of August and November 1984. The images were all collected at about 1600 NZST. The low-resolution imagery is appropriate to this study because the objective is to remove small-scale fluctuations via the averaging process.

Synchronous averaging means that, at each geographical location, a number N pixel values from N images are averaged. Variance reduction in averaged values will be by a factor of N, assuming Poisson statistics. As N is increased the mean cloud features for a location should emerge. Tests were first conducted to establish how large N need be to adequately characterise cloud in a region. The basis for this was to count local maxima in joint albedo-temperature distributions. Each such maximum, if persistent, is associated with a particular surface or cloud type. For low N the number of maxima might be expected to fluctuate as N is increased by adding another image, but as N becomes larger the number of maxima should converge. Figure 2 shows the number of maxima per region versus N so as to emphasise the convergence toward four maxima. On this basis we have chosen to analyse 14 images. To preclude the appearance of many statistically insignificant local maxima, a peak was identified whenever a pixel value exceeded the mean of the 7×7 pixel array surrounding the peak.

DEFINITION OF THE REGIONS ANALYSED

As a first approximation, New Zealand is modelled as a ridge starting at the bottom of the Southern Alps and stretching northeast to the East Cape of the North Island. As the predominant wind over New Zealand is from the southwest, it was expected that orographically modified cloud would be apparent over this ridge, and this was often identified by visual inspection of the images. Figure 3 shows the six regions to be compared, and Table 1 defines their salient features in terms of the ridge model. All of the regions are rectangular but are not of equal size, thus the number of data points for each area is different. From the joint histograms obtained for each region, some intercomparison of land and sea, west and east, and north and south can be made.

RESULTS

Region 1. Tasman Sea

The joint histogram for an area of the Tasman Sea immediately to the west of New Zealand is shown in Fig. 4A. This and other joint histograms presented below have been normalised with respect to the number of data points, and contour intervals are the same for each, enabling qualitative estimates of the relative height and sharpness of peaks to be made. Region 1 is the largest region analysed and generated a strong peak (of height 15) at a temperature of 284 K and brightness 0.08. The peak is thus defined as (284 K, 0.08, 15). The temperature and brightness values are typical of a sea surface. The above-mentioned peak is located on a ridge of ranging temperature values, but similar brightness, due to general cooling away from the Equator. This explanation is consistent with an observed general brightening of the infrared image (not shown). The seasonal variation between August and November also contributed to the formation of the ridge structure. Two considerably smaller peaks at (286 K, 0.11, 10) and (286 K, 0.15, 11) may be interpreted as caused by stratocumulus clouds, the narrowness of the peaks being indicative of a homogeneous cloud layer.

Region 2. West Coast, South Island

The region is mountainous and receives considerable orographically enhanced rainfall. The joint histogram (Fig. 4B) shows a sea-surface peak at (284 K, 0.08, 8) on a broad temperature ridge structure similar to that in Fig. 4A. The land surface has contributed a minor peak and surrounding cluster at (286 K, 0.19, 3). The significant cloud type of the region appears at (278 K, 0.11, 5) and is representative of stratocumulus which forms over the Southern Alps. The ridge extending to colder temperatures has probably been caused by a higher orographic cloud formation of a similar thickness to the lower cloud.

Region 3. East Coast, South Island

This region is mostly characterised by coastal plain, but includes some sea and mountainous regions. In Fig. 4C the major maximum is a peak at (283 K, 0.08, 10), representing sea-surface radiance. The peak is more localised than for Regions 1 and 2 because the sea surface extends over a relatively small latitude range. No land peak is present, being obscured by the relatively warm bright cloud. A peak at (276 K, 0.10, 9) characterises stratocumulus cloud which, together with cloud corresponding to the secondary peak at (272 K, 0.10, 4), may be orographic clouds generated to the lee side of the Southern Alps.

Region 4. Central Plateau, North Island

The region also encompasses two regions of sea, one at the northeastern end and one at the southwestern end. Correspondingly, Fig. 4D shows a major sea-surface ridge from 284 K to 289 K at a brightness level of 0.08 and a height of over 20. A land cluster may be seen at 293 K over a range of brightness levels corresponding to a range of vegetative cover in the region. Three significant cloud types can be identified as the peaks (282 K, 0.12, 13), (278 K, 0.10, 9), and (278 K, 0.13, 12). Compared to the sea-surface maxima, these peaks are small, but probably represent orographic cloud over the region. It is likely, given the time of day, that the brighter, colder tail of the plot represents land-based cumulus. The spread of the distribution indicates fractured cloud types.

Table 1 Salient features of the New Zealand regions analysed for persistent cloud cover.

Area	Area position			No. of data points
1	Sea	West	North	12800
2	Land	West	South	3600
3	Land	East	South	6000
4	Land	West	North	3500
5	Land	East	North	2900
6	Sea	East	South	6000

Region 5. East Coast, North Island

Characteristic land and sea peaks occur at (295 K, 0.3, 4) and (284 K, 0.08, 9), respectively (Fig. 4E). However, the most significant features are a ridge at (279 K, 0.13, 11), and a peak at (270 K 0.15, 10), the ridge being associated with orographic cloud generated by the eastern mountain chain. The temperature spread suggests that clouds of different heights were formed. The peak at (273 K, 0.1, 5) may have been caused either by snow on the ranges, or by the high transient cloud content that was not successfully filtered out.

Region 6. East Coast, Pacific Ocean

The joint histogram shown in Fig. 4F possesses a strong sea-surface ridge from 284 K to 289 K at a brightness level of 0.08 and a height of over 20. The temperature spread is almost certainly caused by the sea-surface temperature gradients over the region. The presence of extensive cloud cover is marked by the peak at (273 K, 0.13, 17) and corresponds to higher cloud than that detected elsewhere. The wide spread of values around this peak, including the many local maxima at lower brightness levels, implies greater cloud variability in this region.

Comparison between regions

Three distinct groupings emerge from the above. Region 1 is characterised by sea surface and warmer, brighter cloud than appears in the other regions. This is consistent with the region extending further north and not being subject to any orographic influence. Regions 2 and 3 only differ in the land peaks: both show a high orographic cloud signature and a lower stratocumulus peak. Regions 4, 5 and 6 form the third grouping, having a well-defined sea peak and low-brightness cloud over an extended temperature range. Region 6 cloud is clearly dominated by airmasses flowing off the North Island. There are also neligible differences between central and east North Island regions. The land does appear to have influenced cloud cover, however, since there are substantial differences between this group and Region 1 (significantly more high cloud). Note also the relative frequency of colder cloud in Regions 4, 5 and 6 compared to Regions 2 and 3. The orographic cloud of the latter grouping is more localised and transient.

DISCUSSION

The joint distributions for the chosen regions are generally different from each other. Where clouds have been indentified the brightness levels measured have been low. This may be due to a systematic but untraced error in calibration, to the strongly maritime aerosol in which cloud is growing, to partially filled pixels, or because enhanced low-level orographic cloud is not generally associated with high brightness levels. Given that the sea-surface brightness levels measured are of an acceptable value, the first explanation is the least likely. Furthermore, partial filling of pixels would broaden the range of brightness levels rather than lower maximum values.

A comparison of land/sea contrasts supports the thesis that spatially coherent averaging can be used to identify orographic cloud characteristic of a region. All areas contained a certain amount of sea surface, so that all of the joint histograms show strong maxima in the vicinity of (283–289 K, 0.08), the temperature differences being largely a function of latitude.

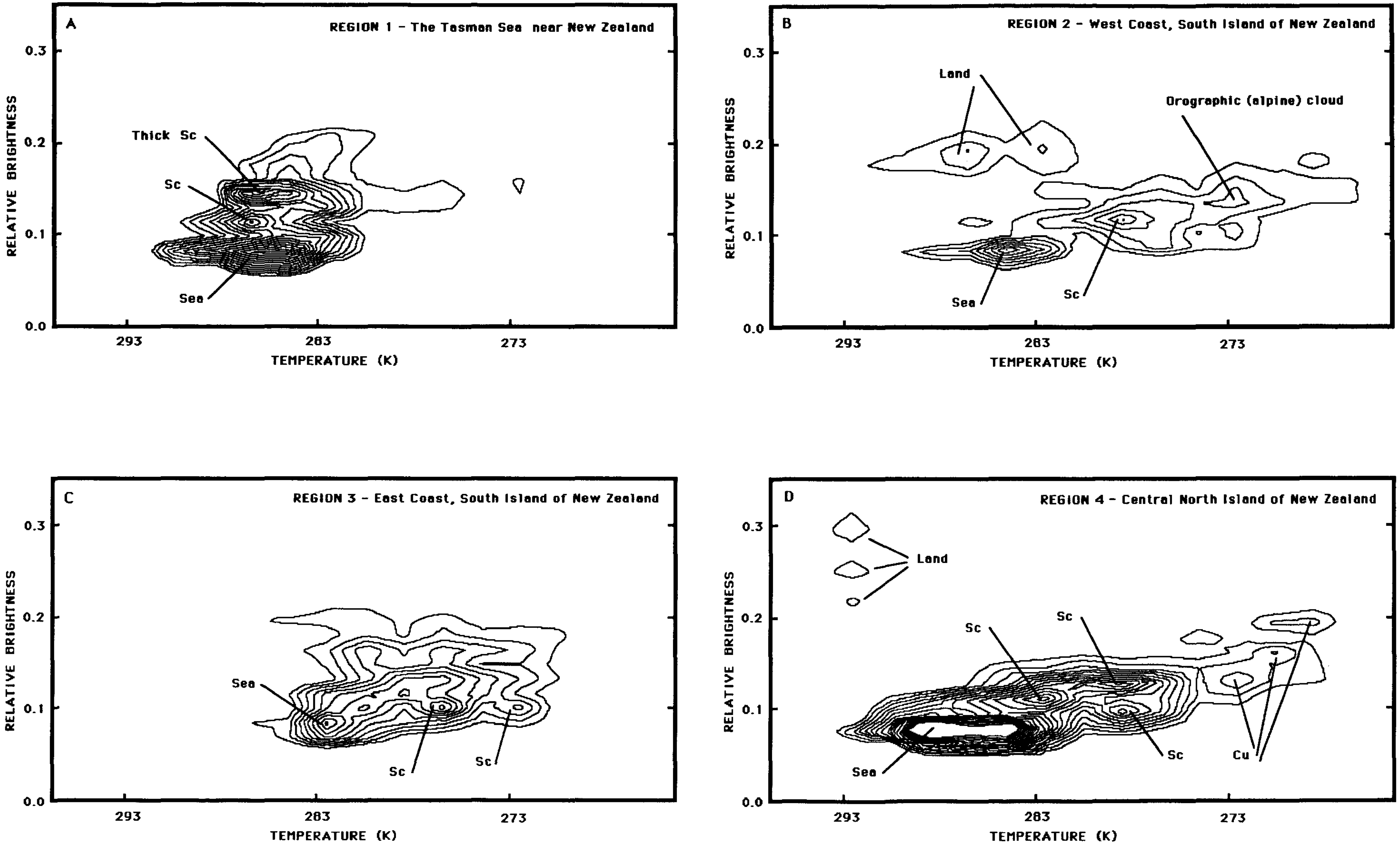

Fig. 4A–F Joint histograms of visible brightness and infrared brightness temperatures for the six regions. Data are generated by the spatially coherent averaging of 14 APT images from the NOAA polar-orbiting satellites during August and November of 1984.

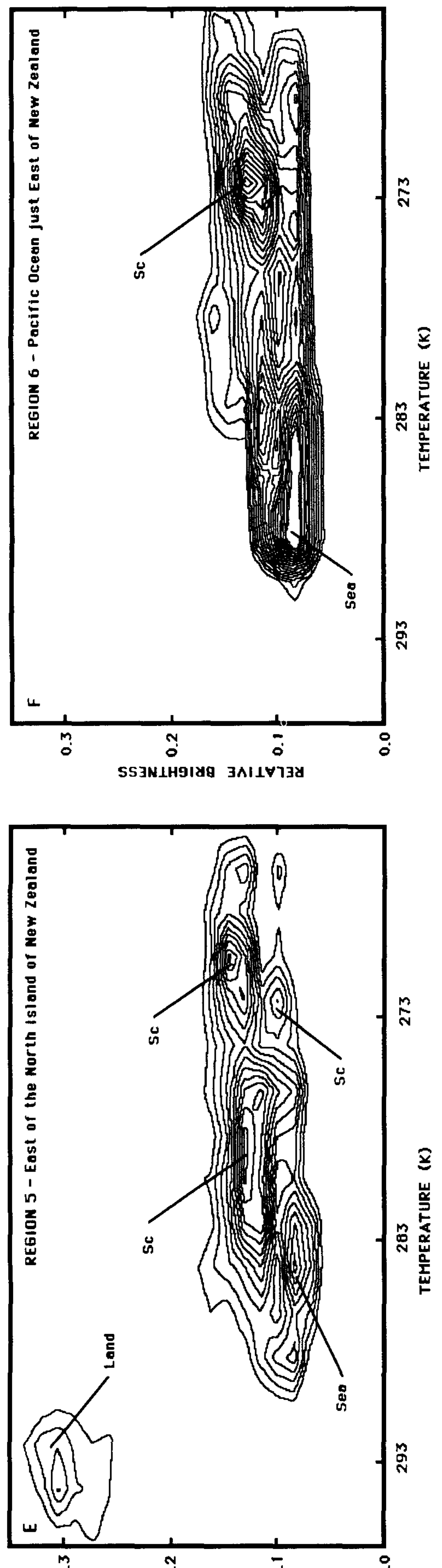

Fig. 4A–F *(continued)*.

The cloud cover identified in Region 1 forms a cluster near the sea-surface peak, whereas in Region 6 a ridge is generated towards colder temperatures. The reason for the difference is not certain, though it may be because clouds in Region 6 reflect the nearly synoptic-scale effect of the entire country on an airmass characterised by the clouds identified in Region 1. Nevertheless, Region 1 contains twice as much data as Region 6, so that the former's histograms are statistically more reliable. Three of the four regions containing land showed typical radiance values, and there appears to be significantly more cloud over land than over the sea, as might be expected. Thus orographic cloud features over the land do appear to have been enhanced and selected at the expense of transient clouds. This conclusion is reinforced by the fact that the cloud peaks appearing over the land are of the type associated with orographic effects.

The greater distribution of values of radiance associated with clouds in Region 2 as compared with Region 3 indicates a greater cloud cover over the West Coast of the South Island than over the east. The result is consistent with the supposition that the Southern Alps induce orographic cloud. The cloud cover that does occur in the east may well be secondary orographic cloud caused by the general uplift of westerly airstreams; this would be consistent also with the differences between Regions 1 and 6 discussed above. The east/west difference in cloud cover does not follow this pattern over the North Island land mass owing to the lack of a well-defined topological ridge.

Comparison of the cloud-cover characteristics over the North Island with those for the South Island reveals that the peaks associated with the former are spread out, whereas those of the latter are generally well defined. The interpretation of this difference is that there is a greater variety of permanent cloud types over the North Island. This interpretation is consistent with the presence of a relatively complex topology in that region.

SUMMARY

Analysis of 14 visible and infrared APT images from the NOAA polar-orbiting satellites has shown that the method of spatially coherent averaging can produce useful results despite the resolution of about 4 km. Clear differences between areas with underlying ocean rather than land, and between the east and west, and the North Island and South Island, were apparent. Thus mesoscale and synoptic-scale orographic influences can be assessed. The limited number of images processed in this preliminary investigation did not enable noise due to transient cloud cover to be completely eliminated, or all interpretation to be unambigous, but the potential of the analysis is clear. It would also appear to be feasible to investigate seasonal and longer term climatological correlations between persistent orographic cloud types and rainfall measured at the ground. The analysis of submesoscale features, such as lee-wave cloud systems, is unlikely to be successful using APT data, and recourse to high-resolution AVHRR data is required.

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REFERENCES

Bradley, S. G.; Green, S. G.; Stow, C. D. 1987a: A low-cost satellite image reception and analysis facility. Part I: Objectives, image reception and data management. *Weather 42*: 77–85.

———1987b: A low-cost satellite image reception and analysis facility. Part II: Pre-processing. *Weather 42*: 106–111.

Bradley, S. G.; Green, S. G.; Stow, C. D.; Grainger, R. G. 1987c: A low-cost satellite image reception and analysis facility. Part III: Display and data analysis—a case study. *Weather 42*: 134–143.

Fusco, L.; Lunnon, R; Mason, B; Tomassini, C. 1980: Operational production of sea-surface temperature from METEOSAT image data. *ESA bulletin 21*: 38–43.

Phulpin, T. M.; Derrien, M.; Brard, A. 1983: A two dimensional histogram procedure to analyse cloud cover from NOAA satellite high-resolution imagery. *Journal of climate and applied meteorology 22*: 1332–1345.

Platt, C. M. R. 1983: On the bi-spectral method of cloud parameter determination from satellite VISSR data: separating broken cloud and semi-tranparent cloud. *Journal of climate and applied meteorology 22*: 429–439.

Platt, C. M. R.; Stephens, G. L. 1980: Interpretation of remotely-sensed high-cloud emittance. *Journal of the atmospheric sciences 37*: 2314–2322.

Platt, C. M. R.; Reynolds, D. W.; Abhire, N. L. 1980: Satellite and lidar observations of albedo, emittance and optical depths of cirrus compared to model calculations. *Monthly weather review 108*: 195–204.

Reynolds, D. W.; Vonder Haar, T. H. 1977: A comparison of radar determined cloud height and reflected solar radiance measured from the geosynchronous satellite ATS-3. *Journal of applied meteorology 12*: 1082–1085.

Schwalb, A. 1982: The TIROS-N NOAA A-G satellite series. *NOAA technical memorandum NESS 95*. U.S. Department of Commerce.