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Technique for Estimating Precipitation Areas from Satellite Imagery

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INTRODUCTION

Neil (1984), suggested a scheme for estimating rain areas based on satellite imagery. This technique was predicated upon the continuity equation, and involved the measurement of the change in area of cloud tops over time. It was noted that experimentation must be carried out in order to determine the values of the semi-empirical constants in the governing equation.

This technical note will discuss the data collecting procedure, as well as analysis techniques utilized in this investigation. Also, some experimental results obtained through analysis of case studies will be shown.

THE DATA

It was decided that a one-hour time span would be the optimum interval to use in measuring the change in area of cloud tops. This was because the short time interval gives a more timely and less smoothed measurement than would be obtained over longer periods of time. However, experimentation with longer time intervals will be carried out during the winter of 84/85.

GOES-West IR images taken one hour apart were archived in digital form on magnetic tape for each of the cases studied. Sectors used were either 2000 x 2000 km or 3000 x 3000 km (at subpoint), since these adequately covered the weather systems while enabling the retention of as much detail as possible. Fifteen cases were analyzed, and these constituted the dependent sample in this study. The cases were taken from a number of weather systems which crossed the B.C. coast during the fall and winter of 1983-1984.

Hourly precipitation amounts at coastal weather stations (for the hour spanned by the GOES-W images) was estimated using synoptic reports and hourly aviation reports. Values from data collection platforms (DCP's) and climatological stations were also used.

TOVS (Tiros Operational Vertical Sounder) data appeared to give consistent and reliable values of precipitable water content over the area of interest. Although the sounder does not yield measurements through thick (i.e. precipitating) cloud, values immediately to the warm side of the cloud band can be considered representative. Isolines of precipitable water content were drawn around the cloud areas, thus facilitating the analysis.

In general, it was found that no single threshold temperature value could be selected which would work in all cases. Rather, the threshold value giving the best results was one near the middle of the strongest gradient in pixel values (figure 1). In particular, it was found that a threshold value near the coldest tops should not be chosen, as these areas were not representative of the cloud system as a whole. In one case, the area of the coldest tops was definitely seen to be decreasing, while the cloud system as a whole was expanding. Another guideline can be followed; be sure to include within the threshold area clouds from which precipitation is being reported by ground stations. However, the effect of the thermal wind must be considered when doing this.

Table 1 shows a summary of the data collection from the fifteen cases that have been studied so far.

ANALYSIS

The degree of the polynomial which "best fit" the observational data turned out to be degree 1. Therefore, the prediction equation from Neil (1984) becomes:

$$P = a_0 + a_1 \, m \Delta \ln (rN)$$

where P is the amount of precipitation expected during a time period
a_0 and a_1 are empirical constants:
m is the precipitable water content
r is the resolution factor
N is the number of pixels represented on the satellite image that are colder than a predetermined threshold value

The experimental data together with this curve of best fit is depicted graphically in figure 2.

It can be seen from the graph that the line fits the data reasonably well, with a coefficient of determination of .73 and a standard error of the estimate of .36 mm. This implies that 73% of the variation in the dependent sample was explained by the change in cloud area together with precipitable water values. Although the sample size was too small to yield statistically significant statistics for standard error, the value of .36 does suggest that the equation could predict hourly precipitation amounts to within approximately 15% of their actual value, 68% of the time. It is clear from figure 2 that a more precise definition of the nature of the curve of best fit must await further data and analysis, particularly in the region where $m \Delta \ln (rN)$ values lie between six and fifteen.

APPLICATION

At this stage of development, all that will be required of this technique is for it to classify cloud systems into categories, as shown in table 2. Typical precipitation patterns under clouds in each category and for five different types of synoptic situations are shown in figure 3. Areas of occasional or patchy convective precipitation are enclosed in dashed lines and stippled, while probable areas of widespread continuous precipitation are enclosed within solid lines and shaded. Scalloped lines represent selected threshold temperatures defining the cloud top area. The five different types of synoptic situations are explained in table 3. These patterns are based on models illustrated by Weldon (1979) and also from patterns observed during the case studies and in day-to-day forecast operations.

Much of the data required in utilizing this technique is available through the Pacific Weather Centre satellite facility. The precipitable water content needs to be input into the system by the meteorologist. The meteorologist also must use a degree of subjective judgement in determining what areas beneath a cloud are experiencing precipitation, based on the diagrams in figure 3.

CONCLUSION

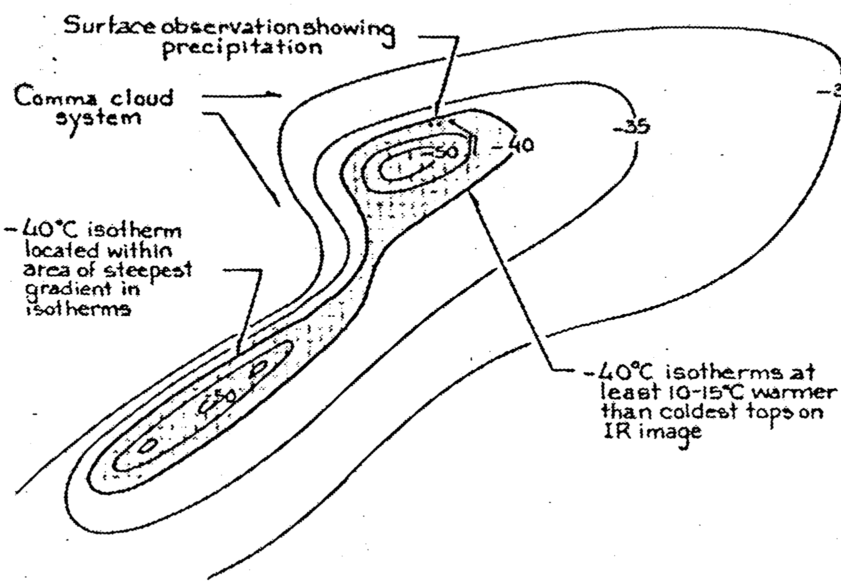
The technique described in this note for defining precipitation areas from satellite imagery utilizes a man/machine mix which can be expected to be quite efficient in an operational setting. It appears that the technique should be applicable in all synoptic situations, and that the input of precipitable water content will account for seasonal and airmass variability. Convective precipitation embedded within synoptic scale systems can best be assessed subjectively by the meteorologist.

This scheme will be tested on a research basis over the next year at the Pacific Weather Centre. It is hoped that combined visible and IR data will be used to see if more accurate results can be obtained. If the technique performs satisfactorily, computer programs will be developed to streamline the procedure and it will be implemented operationally at the Weather Centre.

REFERENCES

1. Neil, Laurie K., 1984: Estimating Precipitation Areas from Satellite Image Data, Pacific Region Technical Note 84-01.

2. Weldon, R. "Cloud Patterns and the Upper Air Wind Field", Part IV of in-house publication of the Applications Laboratory, NESS/NOAA, page 42.



Choosing a threshold temperature for measuring the change in area of clouds on GOES IR imagery.

Figure 1

Case #	P	m	Δ ln(rN)	m Δ ln(rN)
1	.99	15	.290	4.343
2	.46	13	.019	.248
3	3.03	18	.861	15.500
4	1.74	13	.134	1.744
5	.87	15	.050	.747
6	.39	8	.064	.510
7	1.04	12	.045	.542
8	1.04	11	.072	.787
9	.94	13	.012	.151
10	1.73	12	.336	4.031
11	.61	12	.248	2.974
12	.60	10	.043	.432
13	.75	11	.116	1.280
14	.59	11	.078	.853
15	.85	10	.213	2.127

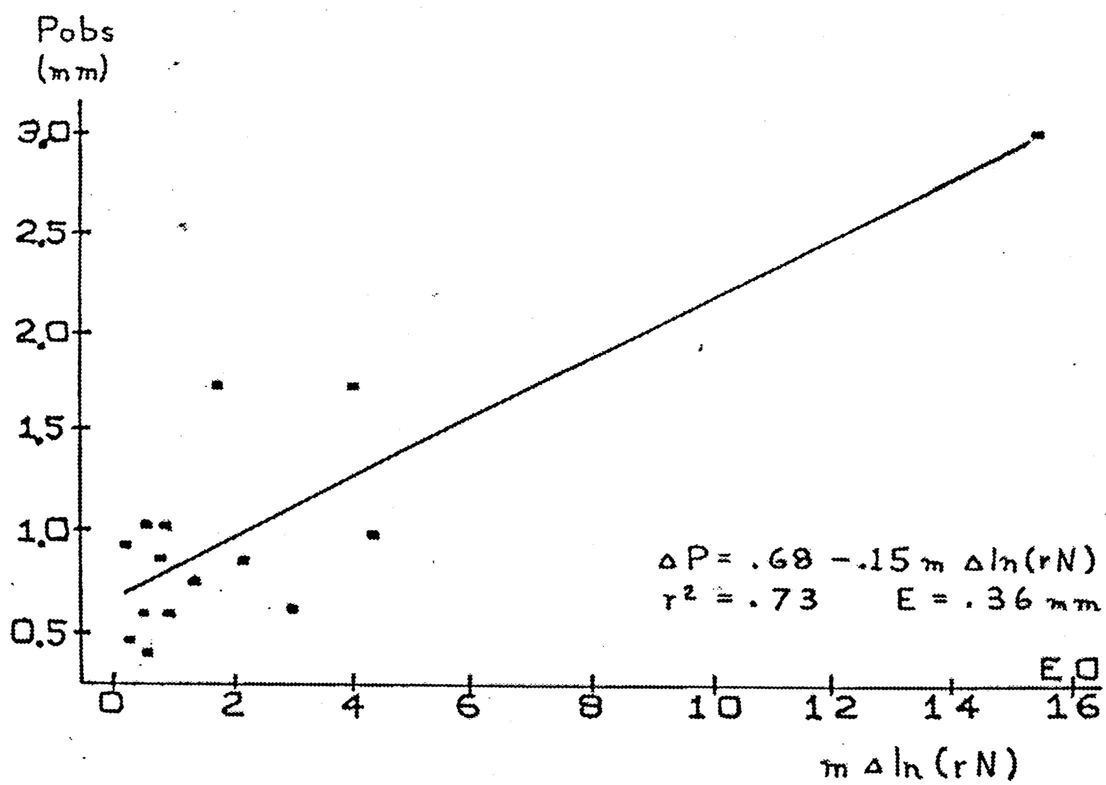
Table 1

Summary of results from case studies constituting the dependent sample.

Category #	P range (mm)	Precipitation Characteristics
1	0 to .24	No organized area of precipitation. Patchy convective precipitation is likely.
2	.24 to 1.5	Organized area(s) of continuous precipitation within the cloud band are probable.
3	1.5	Widespread continuous precipitation under cloud shield, except under high/thin clouds ahead of a system. Areas of moderate and heavy precipitation may exist.

Classification categories for cloud systems based on result of prediction equation. For details of precipitating areas, see figure 3.

Table 2



Observed precipitation vs m Δln (rN)

Figure 2

Cloud System Classification

Synoptic systems are classified into one of the following five types (refer to figure 3).

A) Associated with upper level wind maximum on the back side of a trough.

B) Associated with upper level wind maximum on the front side of a trough.

C) Negatively tilted systems.

D) Systems embedded in baroclinic zone cloudiness.

E) "Cold" Systems:
   i) PVALS
   ii) Spiral Bands

Table 3

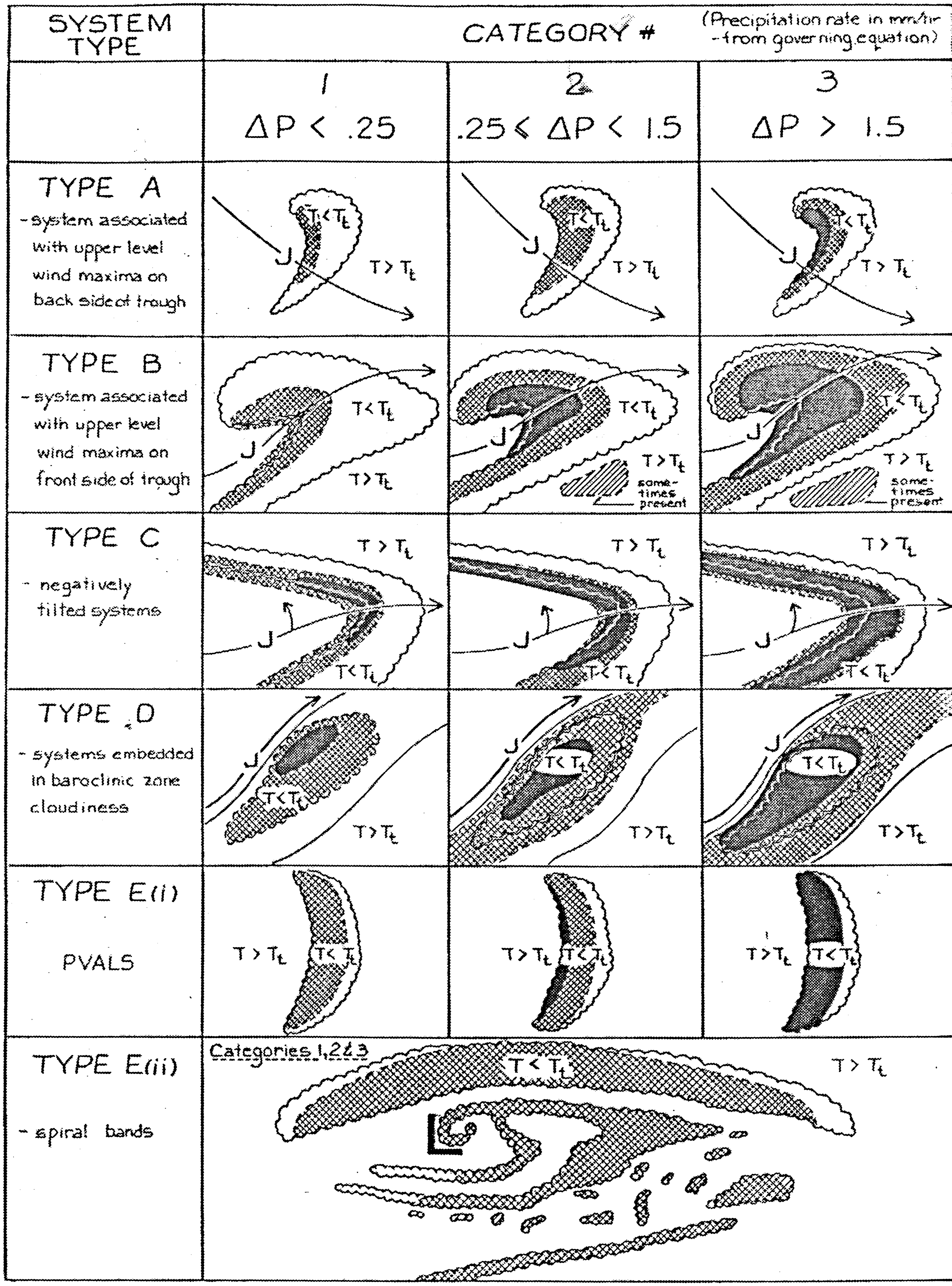

SYSTEM TYPE
CATEGORY #
(Precipitation rate in mm/hr - from governing equation)
1
ΔP < .25
2
.25 ≤ ΔP < 1.5
3
ΔP > 1.5
TYPE A
- system associated with upper level wind maxima on back side of trough
T < Tt
T > Tt
J
TYPE B
- system associated with upper level wind maxima on front side of trough
T < Tt
T > Tt
J
some-times present
TYPE C
- negatively tilted systems
T > Tt
T < Tt
J
TYPE D
- systems embedded in baroclinic zone cloudiness
J
T < Tt
T > Tt
TYPE E(i)
PVALS
T > Tt
T < Tt
TYPE E(ii)
- spiral bands
Categories 1, 2 & 3
T < Tt
T > Tt
L

FIGURE 3.