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Use of satellite observed cloud patterns for the analysis of 500-mb level in tropics

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ABSTRACT. This paper illustrates the use of a quasi objective scheme suggested by Nagle *et al.* (1970), to utilize satellite observed cloud patterns for the analysis of 500 mb height field in the areas of sparse network in the tropics.

The scheme based on, only satellite pictures, provides a very useful first guess field for the machine analysis and excellent guide, especially over areas of scanty data, for the conventional analyst.

The basic limitations of the scheme for its use over the tropics and future studies required for its best exploitation have also been briefly discussed.

1. Introduction

Analysis over tropical areas suffers from a lack of data. Analysis over the Indian region are extremely difficult and subjective because of scant or lack of observations from the Arabian Sea, Bay of Bengal and Middle East countries. Satellite cloud data provide a potential means for solving this dilemma. Interesting studies have been made relating cloud patterns with important synoptic features such as troughs, ridges, fronts and jet streams etc (Widger 1964, Oliver and Bittner 1969). These studies, although very useful for delineating the synoptic features at surface and 500-mb levels, do not offer a direct means for deriving quantitative information for any level.

The earlier studies carried out by Bristor and Ruzeki (1960), McClain *et al.* (1965) and Hayden and Wiin-Nielsen (1968) made use of relationships between cloud patterns and vertical motion at 500 mb as expressed in the vorticity advection term of the quasi-geostrophic 'Omega equation', to modify the 500 mb analysis of height or stream function field.

The basic limitation of the above technique, as mentioned by the authors themselves as well as pointed out by Nagle (1970) is the following —

The Laplacian of height field is modified to bring the pattern of the vorticity advection in correspondence with the cloud patterns. The height field is then retrieved by operating upon the Laplacian field with relaxation techniques. Thus, the effects on the final height field are not known until it is retrieved by relaxation. If total vorticity is not conserved in the re-analysis regions, the process may also tend to bring out changes in the analysis which conflict with the conventional observations.

Nagle *et al.* (1966, 1968, 1970) have proposed a new approach for using the satellite observed cloud patterns in the analysis of 500 mb height field over the Northern Hemisphere. The technique is now used operationally at the National Meteorological Center (NMC) to modify the 500 mb height analysis over Pacific and Atlantic oceanic areas.

This paper presents the results of Nagle's technique when applied for the tropical areas of India for a winter case.

2. Basic concept of Nagle's scheme

2.1. Nagle *et al.* (1966) have shown that certain characteristic features of the cloud patterns are related to the 500 mb relative vorticity field and, further, that short wave length component of the height field closely approximates the field of the relative vorticity (Holl 1963). The above relationship permits the manual modification of the short wave component field based on the empirical relation between the satellite observed cloud patterns and short wave length component field. The final

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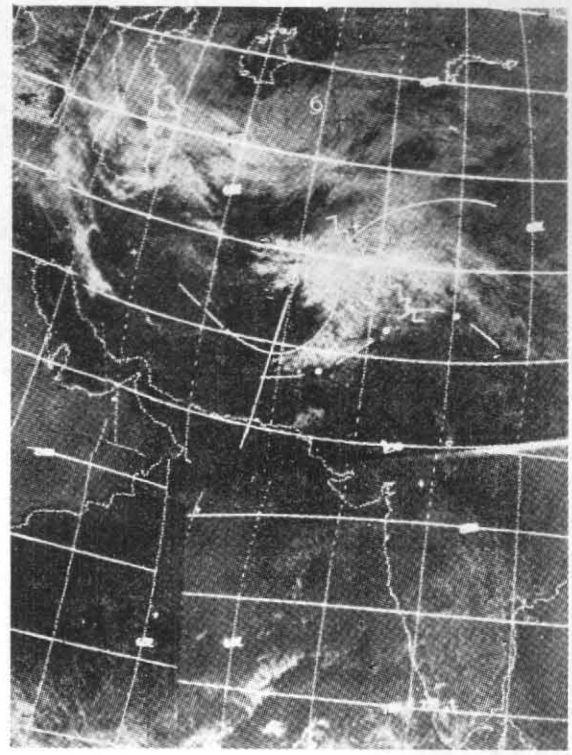

Fig. 1

Composite could pictures as observed by ESSA 9 on 24 January 1970 (approximate time of observation 10 O'clock local time)

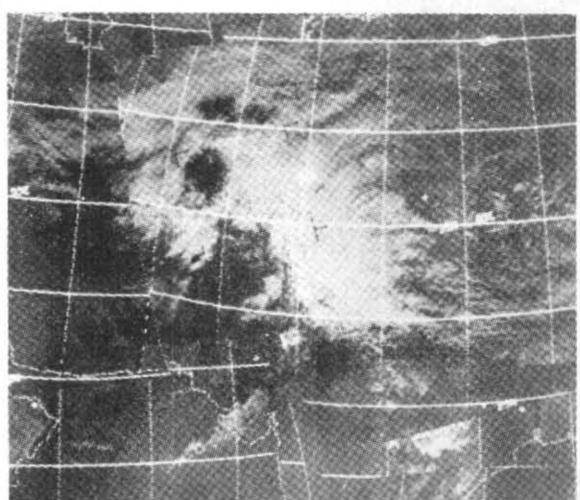

Fig. 2

Composite cloud pictures as observed by ESSA 9 on 25 January 1970 (approximate time of observation 10 O'clock local time) height field is obtained by adding the short wave length component field to the heavily smoothed 12-hr forecast, 500 mb height field (smoothing is to suppress the less conservative short waves from the 12-hr forecast).

2.2. *Principle of smoothing and short wave length field*

The long wave length component field is derived from the 12-hr forecast height field by a process of smoothing. This process is basically similar to one described by Fjortoft (1952). It essentially reduces the amplitude of a specified wave length component of the field to a desired percentage of its initial value.

Further, the smoothing operator is linear; therefore, various components can be added or subtracted linearly.

The smoothing as defined by Holl (1963) may be written in the form —

$$Z_{LW} = Z_o + C \int_o^{\alpha} \nabla^2 Z \, d\alpha = Z_o - Z_{SW} \quad (1)$$

where, Z_{LW} defines the long wave length field, Z_0 the original field, Z_{SW} is the short wave length component, C is a constant and α is a parameter representing the degree of smoothing. In this scheme, α is set equal to 5, which reduces the amplitude of a wave length of 7 grid lengths (1 grid length = 381 km at 60°N) to 5 per cent of its initial value and hardly affects the longer wave length field of 23 grid length or more (it retains more than 96 per cent of its original amplitude).

Further it may be shown from (1) that —

$$Z_{SW} = -C \int_o^{\alpha} \nabla^2 Z \, d\alpha \quad (2)$$

or by mean value theorem for integrals —

$$Z_{SW} = -C \alpha \nabla^2 Z(\alpha^*) \quad (3)$$

where, $Z(\alpha^*)$ represents the partially smoothed field at some degree of smoothing α^* between 0 and α. Now noting that relative geostrophic vorticity ξ is expressed by —

$$\xi = g/f \, \nabla^2 Z_o \quad (4)$$

and by comparing (3) and (4) it is seen that the relative vorticity and short wave length component of Z field should look similar (but having opposite sign), since these depend on the latitude and equivalence of $\nabla^2 Z(\alpha^*)$ and $\nabla^2 Z_o$. In particular, the similarity should be more prominent where the fields have either extreme or zero values.

Based on detailed studies of data over the Atlantic Ocean, Nagle *et al.* (1970), specified relationships between the 500 mb relative vorticity field and identifiable cloud patterns. These relationships are provided in Section 2.3.

Although we realize for the tropical areas these may differ, as a first step, however, we propose to use exactly the same criteria as outlined below, for the Indian area. These may be modified when sufficient experience is gained.

2·3. *500 mb relative vorticity field and cloud patterns*

Nagle (1970) has outlined the following correspondence between the 500 mb relative vorticity field and cloud patterns —

(*a*) The boundaries of cellular convective cloud areas and/or the trailing edge of the frontal cloud bands correspond to the zero line in the relative vorticity field,

(*b*) The locations of spiral cloud centres associated with cold core systems correspond to the positive vorticity maxima,

(*c*) The leading edges of frontal cloud bands correspond to the axis of maximum negative vorticity and

(*d*) The points marking the apex of the anticyclonic curvature on the leading edge of the frontal cloud bands correspond to negative vorticity maxima.

These relationships permit a subjective specification of the patterns of short wave length field based on the close scrutiny of cloud patterns. The next step is to specify the magnitude of the negative extremal in the short wave length field and 500 mb heights along the inferred zero relative vorticity field.

2.4. *Fixing the central value of short wave length system*

Nagle *et al.* (1970), derived regression equations between the magnitude of the negative maxima in the short wave length field and parameters derived from both the long wave length and measurements of cloud systems. Two separate regression equations have been derived, one in the case of well organized cloud patterns and another when the cloud patterns are not well organized.

The equation and the method of calculations of the central value are given in Appendix IA and IB.

Because of the additive features of the short and long wave length, the components, it is possible to derive 500 mb heights along the inferred zero relative vorticity time. Where the short wave

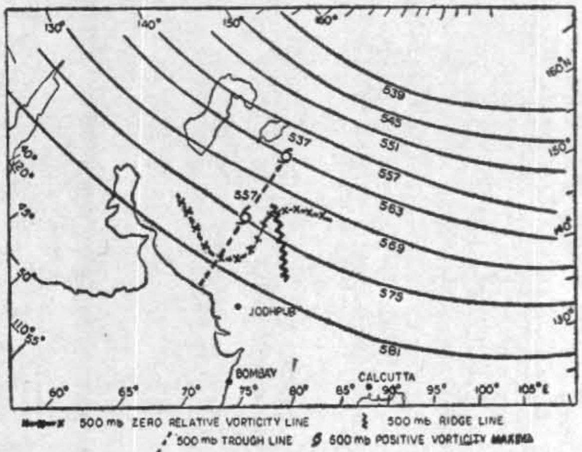

Fig. 3

500 mb long wave length field, 0000 GMT of 24 Jan 1970
(Heights in tens of gpm)

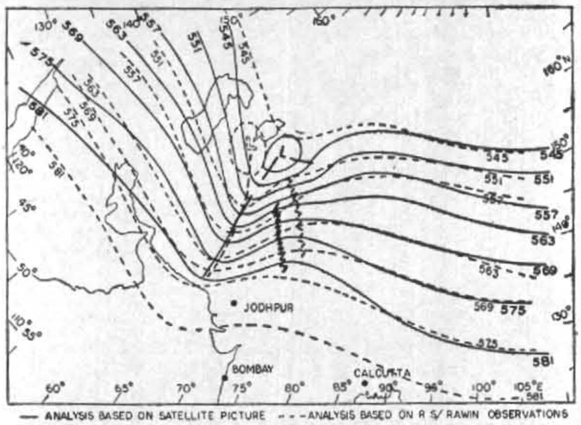

Fig. 4

Final 500 mb height field, 0000 GMT of 24 January 1970
(Heights in tens of gpm)

length field has a zero value, the 500 mb height is the height of the long wave length field.

3. Results and discussions

The aim of this preliminary study is to illustrate the use of satellite pictures in the analysis of 500 mb contour patterns. We have, therefore, selected a winter case of January 24, through January 27, 1970. On a critical examination of the cloud pictures, it was found that the clouds were, to some extent, well organized on January 24, whereas the cloud features get difficult to demarcate afterwards. In Figures 1 and 2 we present the composite cloud pictures as observed on the 24th and 25th of January by ESSA 9. In Figure 1, we have also indicated the trough ridge, 500 mb zero relative vorticity line, positive vorticity maxima and axis of maximum anticyclonic shear. These are based on the criteria as laid down in para (2.3). It may be noted that the centres of maximum vorticity is well marked at about 43°N and 64°E and because of good organization of the cloud system, this has been taken as the centre of low pressure area at 500 mb. The second maximum vorticity center at approximately 33°N and 65°E is envisaged to be associated with a centre of maximum vorticity at the apex of the trough. The zero relative vorticity line is coinciding approximately with the boundary of cellular convective clouds to the east of approximately 67°E and to the trailing edge of the frontal cloud band west of 67°E. The other features like trough, ridge and axis of maximum anticyclonic shear have also been marked based on the criteria discussed in (2.3).

Based on the factors as marked in Fig. 1, and using regression equations, we determined the 500 mb height values at the centres. These, when combined with the heights along the zero line as determined from the long wave pattern (Fig. 3) obtained from the 12-hr NMC (National Meteorological Centre) forecast valid for 0000 GMT on January 24, permits an analysis of the final Z field. The final field is presented in Fig. 4. This is the Z field which is based mainly on the satellite pictures and provide very useful 'first-guess' information for the machine analysis or an excellent guide for the conventional analyst.

For comparison purposes we have also superimposed the conventional 500 mb height pattern based on NHAC (New Delhi) analysis. The general pattern seems to be quite comparable. There is difference in absolute height values of the order of 60 gpm and also a shift in centres of low pressure area. The position of trough in both cases seems to be fairly in agreement. The reasons for the above difference in height value and displacement of low pressure system could be the following —

(*a*) The input for the satellite analysis has been the NMC (Washington) long wave length pattern which could be different from the conventional (subjective) analysis based on limited data at NHAC (New Delhi).

(*b*) The regression equation applicable for the Atlantic Ocean may need modification for its application in tropics.

Since the cloud patterns were not well organized on the rest of the days, we have not presented the computations for those days.

4. Limitation of the technique and future outlook for its use in India

From the day to day results of the SINAP programme at the National Environmental Satellite Service, it has been observed that the scheme gives very good results in winter months over oceanic areas but runs into some difficulty during summer when the cloud patterns are not well organised. Since the winter conditions over the Indian area are more similar to the summer conditions over the United States, there seem to be some inherent difficulties. Moreover, this technique has been basically devised to be applied over the oceanic areas. Some modifications might, therefore be necessary to extend it for cloud patterns over land areas.

However, this technique is a very good approach towards the best exploitation of satellite observed cloud pictures to improve the analysis over the oceanic areas and areas of meagre data. The detailed studies are necessary before this technique can be put in operational use over the Indian area.

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APPENDIX I A

Worksheet for computing 500 mb height at spiral cloud centres

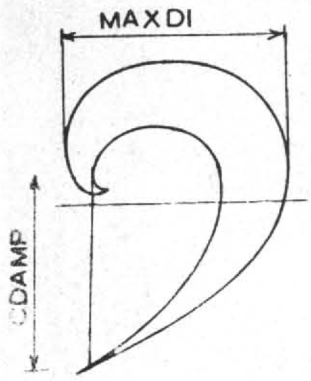
Parameters :

I LAT deg. N

II MAXDI

III CDAMP

IV LASPR→∇^2(long wave field) at the grid point closest to the centre of spiral cloud.



Regression equation —

SDINT = (—1·7×I—10·4×II—1·0×III—2·1×IV+21·4) m

Z_{500} = SDINT+SRVAL

where, SRVAL is the height (metres) in the long wave length field.

APPENDIX I B

Worksheet for computing 500 mb height at spiral cloud centre without measurable cloud parameters

Parameters :

I LAT deg. N

II SRVAL *—5572

III LASPR*

Regression equation —

SDINT=(—1·5×I—0·06×II—3·0×III—20·5) m

Z_{500} = SDINT+SRVAL

* For definition refer appendix IA