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Estimation of relative humidity profiles from INSAT cloud data

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सार — संख्यात्मक मौसम प्रागुक्ति निदर्श के उपयोगी वर्षा पूर्वानुमान प्राप्त करने के लिए उपयुक्त आर्द्रता प्रोफाइलस् की आवश्यकता है। इस संदर्भ में, उपग्रह मेघ आंकड़ों का प्रयोग करते हुए महासागर के क्षेत्रों पर नमी प्रोफाइलस् का विषयपरक आकलन महत्वपूर्ण हो जाता है। इस उद्देश्य के लिए, उपग्रह से उपलब्ध भिन्नात्मक मेघमय आकड़ों को मेघों की विभिन्न वर्गों में वर्गीकृत किया गया जो कि कुल मेघ राशि और जिस स्तर तक मेघ आए, उस पर निर्भर करता है। पोर्टब्लेयर (11·6° उ०, 92.7° पू०) और मिनिकॉय (8.3° उ०, 72.9° पू०) के तापमान आंकड़ों का प्रयोग करते हुए वास्तविक सापेक्षिक आर्द्रता प्रोफाइलस् प्राप्त किए गए। प्रस्तुत मेघ वर्गीकरण के लिए उर्ध्वाधर में आर्द्रता वितरण के प्रतिनिधित्व करने के कारण अत्याधिक बार-बार होने वाली सापेक्षिक आर्द्रता प्रोफाइलस् का चयन किया गया। आरंभिक परिणाम यह सूचित करते हैं कि ये बनावटी सापेक्षिक आर्द्रता प्रोफाइलस् हिन्द महासागर पर उर्ध्वाधर में नमी वितरण पर उपयोगी सूचना प्रदान कर सकते हैं।

ABSTRACT. Accurate humidity profiles are needed for obtaining useful rainfall forecasts from numerical weather prediction models. In this context objective estimation of moisture profiles over ocean areas using satellite cloud data becomes important. For this purpose the fractional cloudiness data available from INSAT has been classified into different cloud categories depending on the total cloud amount and the levels at which the clouds have been present. Actual relative humidity profiles have been obtained using TEMP data of Port Blair (11.6°N, 92.7°E) and Minicoy (8.3°N, 72.9°E). Most frequently occurring relative humidity profile has been selected as being representative of humidity distribution in the vertical for a given cloud category. The preliminary results reported here show that these bogus relative humidity profiles could provide useful information on moisture distribution in the vertical over the Indian Ocean.

Key words — Relative humidity profiles, long wave radiation, NWP, equivalent black body temperature (EBBT).

1. Introduction

Accurate humidity profiles are needed for obtaining useful rainfall forecasts from numerial weather prediction models. In this context objective estimation of moisture profiles on operational basis at main synoptic hours (0000 and 1200 UTC) using cloud data available from geostationary satellites becomes important.

Radiosonde observations are presently the only reliable source of information on the availability of moisture in the upper atmosphere. Though the radiosonde netwerk is adequate to provide humidity analysis over continental India, only a few observations are available from the Bay of Bengal [Port Blair (11.6°N, 92.7°E] and Arabian Sea [Minicoy (8.3°N, 72.9°E) and Amini Divi (11.1°N, 72.7°E)].

Retrieval method of water vapour profiles using radiance measured by the satellites in the water vapour channels (6.7 μm, 7.3 μm and 8.3 μm) have been attempted by Smith and Howell (1971), Hayden *et al.* (1981) and Lipton *et al.* (1986) etc. This method has been found to provide satisfactory humidity profiles under cloud free conditions as compared to that under cloudy regions. The reason being the dependence of the outgoing long wave radiation on the presence of various types of clouds and their amounts in the vertical.

The relationship between surface synoptic observations and co-located TEMP data has been used to obtain humidity at standard pressure levels (850 hPa, 700 hPa, 500 hPa and 400 hPa) by Chisholm *et al.* (1968).

Cloud imageries obtained from meteorological satellites have also been used to estimate indirectly the water vapour fields (Thompson and West 1967, Smigielski and Mase 1970, Walcott and Warner 1981, Mills 1983 etc.). Walcott and Warner (1981) used the information of the present weather conditions assuming 100% relative humidity from surface to the cloud top level if precipitation is reported in the present weather. If present weather is not raining relative humidity is assumed to be 100% only at the cloud top level. The levels below the cloud base are under saturation.

At numerical prediction division of Japan Meteorological Agency, GMS cloud data, co-located TEMP observations and surface synoptic data have been used for estimation of humidity profiles (Baba 1987). The

TABLE 1

Cloud categories (1a.....15t) based on cloud amount in 2.5° Lat.×2.5° Long. box and presence of cloudiness taken in combination at various levels

Total cloud amount (%)	Cloudiness at 850 hPa only	Cloudiness at 850 and 700 hPa only: 50% or more of the total cloudiness at 850 hPa	Cloudiness at 850 and 700 hPa only: 50% or more of the total cloudiness at 700 hPa	Cloudiness at 700 hPa only	Cloudiness at 700 and 500 hPa only: 50% or more of the total cloudiness at 700 hPa	Cloudiness at 700 and 500 hPa only: 50% or more of the total cloudiness at 500 hPa
100	1a	2a	2f	3a	4a	4f
80-99	1b	2b	2g	3b	4b	4g
50-80	1c	2c	2h	3c	4c	4h
10-50	1d	2d	2i	3d	4d	4i
1-10	1e	2e	2j	3e	4e	4j

Total cloud amount (%)	Maximum cloudiness at 700 hPa and 50% or more of the total cloudiness between 700 & 500 hPa levels	Maximum cloudiness at 400 hPa and 50% or more of the total cloudiness between 500 & 400 hPa levels	50% or more of the total cloudiness at 500 hPa level
Cloudiness at 700, 500 and 400 hPa only			
100	5a	5f	5k
80-99	5b	5g	5l
50-80	5c	5h	5m
10-50	5d	5i	5n
1-10	5e	5j	5o

Total cloud amount (%)	Maximum cloudiness at 700 hPa and 50% or more of the total cloudiness between 500 & 700 hPa levels	Maximum cloudiness at 500 hPa and 50% or more of the total cloudiness between 500 & 700 hPa levels	Maximum cloudiness at 500/400 hPa and 50% or more of the total cloudiness between 500 & 400 hPa levels	Maximum cloudiness at 400/300 hPa and 50% or more of the total cloudiness between 400 & 300 hPa levels
Cloudiness at 700, 500, 400 and 300 hPa				
100	6a	6f	6k	6p
80-99	6b	6g	6l	6q
50-80	6c	6h	6m	6r
10-50	6d	6i	6n	6s
1-10	6e	6j	6o	6t

Total cloud amount (%)	Maximum cloudiness at level (hPa): 700	500	300	500	400	300	50% or more of the total cloudiness at level (hPa): 500	400
100	7a	7f	7k	8a	8f	8k	9a	9f
80-99	7b	7g	7l	8b	8g	8l	9b	9g
50-80	7c	7h	7m	8c	8h	8m	9c	9h
10-50	7d	7i	7n	8d	8i	8n	9d	9i
1-10	7e	7j	7o	8e	8j	8o	9e	9j

Total cloud amount (%)	Cloudiness at 400 hPa only	Cloudiness at 400 & 300 hPa only: 50% or more of the total cloudiness at 400 hPa level	Cloudiness at 400 & 300 hPa only: 50% or more of the total cloudiness at 300 hPa level	Cloudiness at 300 hPa only
Cloudiness at 400 and 300 hPa only				
100	10a	11a	11f	12a
80-99	10b	11b	11g	12b
50-80	10c	11c	11h	12c
10-50	10d	11d	11i	12d
1-10	10e	11e	11j	12e

Total cloud amount (%)	Max. cloudiness at level (hPa): 850	700	500
Cloudiness at 850, 700 and 500 hPa			
100	13a	13f	13k
80-99	13b	13g	13l
50-80	13c	13h	13m
10-50	13d	13i	13n
1-10	13e	13j	13o

Total cloud amount (%)	Max. cloudiness at 850/700 hPa & 50% or more cloudiness between 850 & 700 hPa	Max. cloudiness at 700/500 hPa & 50% or more cloudiness between 700 & 500 hPa	Max. cloudiness at 500/400 hPa & 50% or more cloudiness between 500 & 400 hPa
Cloudiness at 850, 700, 500 and 400 hPa			
100	14a	14f	14k
80-99	14b	14g	14l
50-80	14c	14h	14m
10-50	14d	14i	14n
1-10	14e	14j	14o

Total cloud amount (%)	Max. cloudiness at 850/700 hPa & 50% or more cloudiness between 850 & 700 hPa	Max. cloudiness at 700/500 hPa & 50% or more cloudiness between 700 & 500 hPa	Max. cloudiness at 500/400 hPa & 50% or more cloudiness between 500 & 400 hPa	Max. cloudiness at 400/300 hPa & 50% or more cloudiness between 400 & 300 hPa
Cloudiness at 850, 700, 500, 400 and 300 hPa				
100	15a	15f	15k	15p
80-99	15b	15g	15l	15q
50-80	15c	15h	15m	15r
10-50	15d	15i	15n	15s
1-10	15e	15j	15o	15t

impact of the satellite cloud moisture data on numerical weather prediction were investigated using 12-level fine-mesh limited area model. It was found that the forecasts improved. In particular the rainfall forecast greatly improved for the first 12 hours, the predicted precipitation were much closer to the observations. During the second and third 12-hour periods, though the predicted heavy rainfall amount was less than the observed one, its geographical location was well predicted.

In India Meteorological Department, work has been initiated for objective estimation of humidity profiles using INSAT cloud data. Preliminary results are described below. The relative humidity profiles obtained from INSAT cloud data are climatological in nature and do not provide as much details as the retrieval profiles. However, these bogus relative humidity profiles are able to provide humidity data over the Indian Ocean at main synoptic hours (0000 and 1200 UTC). The usefulness of similar bogus profiles obtained from GMS cloud data has been demonstrated by Baba (1987).

2. Data and methodology

The INSAT cloud data for the period July to September 1987 were used in obtaining the profiles. The area considered is 35°N to 5°N and 65° E to 100° E and the area is further subdivided in smaller areas of 2.5° Lat./Long. which are called boxes hereafter. They are serially numbered starting from the first row. In each box the fractional area covered by a specified cloud top temperature (known as fractional cloud cover) is calculated and this parameter is used for the calibration with the actual relative humidity observations from the radiosonde observations of Minicoy and Port Blair. The method of calculation of the fractional cloud cover is described as below.

Step (*a*) — Infrared (IR) data for each day is considered. The mean temperatures of different pressure levels (1000 hPa, 850 hPa, 700 hPa, 500 hPa, 400 hPa and 300 hPa) are taken as the threshold temperatures. With these temperatures a histogram of six classes is defined in each box.

Step (*b*) — The gray shade value of each pixel (picture element) in a box is read and is converted to its equivalent black body temperature (EBBT) by means of a look-up table. Normally several hundred pixels lie in a box. Since the satellite is 3-axis stabilised, it is presumed that the pixel position is constant in a box. After calculating the EBBT for each pixel, it is assigned one of the classes of the histogram. After the image is scanned, we have frequencies of pixels in each class of the histogram for each box. Then the fractional cloud cover is calculated by :

$$\frac{\text{No. of pixels with specified cloud top temperature}}{\text{Total No. of pixels in each box}}$$

Step (*c*) — This exercise is presently carried out daily for 0000 and 1200 UTC imagery corresponding to the radiosonde ascent throughout the southwest monsoon season.

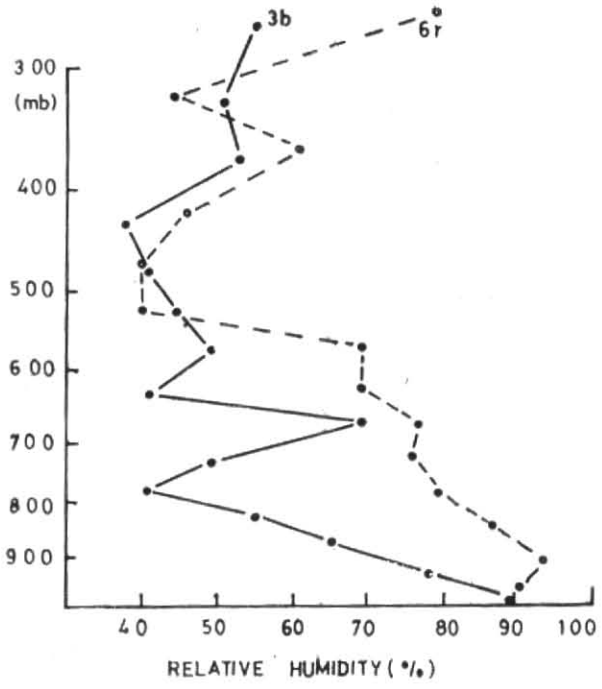

Fig. 1. Estimated related humidity profiles for cloud categories 3b and 6*r*.

TABLE 2

Cloud Category	No. of observations of INSAT fractional cloudiness and co-located TEMP data	Cloud Category	No. of observations of INSAT fractional cloudiness and co-located TEMP data
2d	2	6p	2
2f	1	6q	6
2g	2	6r	8
3a	8	6s	3
3b	12	7b	2
3d	1	7c	1
4b	5	7i	2
4c	4	7m	2
4d	1	8b	1
4j	1	8c	2
5a	1	8g	7
5b	7	8h	5
5c	4	8i	7
5g	1	8l	2
5h	1	8m	3
5m	2	8n	2
6a	3	9b	2
6b	3	9c	1
6c	4	9h	1
6d	2	11i	4
6f	1	11j	2
6h	2	12c	1
6l	1	12d	1
6m	4	12e	1

TABLE 3

Tentative relative humidity profiles

S. No.	Profile No.	Relative humidity (%) at level (hPa)														
		1000	950	900	850	800	750	700	650	600	550	500	450	400	350	300
1	2a	67	77	73	43	21	15									
2	2f	82	89	91	84	73	36	48	23	18	18	16	18	23	39	
3	2g	77	82	90	56	33	23	18	33							
4	3a	71	78	83	88	89	85	93	67	36	27					
5	3b	87	92	83	70	71	47	27	70	59	49	37	42	70	61	
6	4b	87	91	88	79	85	58	34	27	25	26	25	30	27	26	
7	4c	84	88	84	78	82	51	40	44	38	20	23	22	20		
8	4d	88	76	74	74	63	56	51	46	51	46	29	22	24		
9	4j	65	81	73	57	62	68	10	21	10	17	23	31	22		
10	5a	73	68	66	65	71	71	60	18	13	14	18	40	40	30	
11	5b	88	84	79	82	78	78	75	70	63	27					
12	5c	81	83	84	82	76	79	80	73	68	43	29	27	45		
13	5g	76	80	79	58	20	15	10	10	10	26	61	45	23		
14	6a	72	83	85	57	39	25	25	33	46	44					
15	6b	87	79	71	44	26	13	32	40	19	15	15	21	23	37	40
16	6c	84	80	70	55	49	43	70	60	49	46	44	34	43	56	50
17	6d	92	80	63	55	57	57	45	35	40	34	29	27	22	22	
18	6h	78	81	76	77	75	74	75	72	75	69	57	50	40	28	38
19	6l	74	84	78	73	57	27	16	20	21	22	22	31	43	61	45
20	6m	75	87	86	77	70	70	68	69	63	51	60	68	75	63	58
21	6p	79	81	70	73	74	68	40	26	19	18	16	23	25	30	32
22	6q	75	89	76	78	80	50	58	65	43	38	24	31	53	65	68
23	6r	91	92	95	90	81	77	78	70	70	41	42	47	62	46	85
24	6s	85	94	83	88	91	89	94	83	67	67	71	63	56	60	75
25	7b	87	91	98	91	54	37	44	29	23	26	28	33			
26	7i	85	79	71	66	69	60	58	56	44	53	26	33	38	44	
27	7m	84	88	81	73	60	46	48	51	12						
28	8b	84	95	92	76	66	52	42	40	28	37	39				
29	8c	90	95	93	94	89	86	73	63	55	46	63	75	77	67	56
30	8g	84	95	84	75	69	61	44	42	48	35	31	74	57	58	55
31	8h	83	94	85	78	80	71	66	61	49	42	31	43	58	53	65
32	8i	83	84	78	70	65	74	75	71	63	69	78	74	64	53	63
33	8l	74	80	80	82	45	24	19	10	17	17	15	12	23	38	45
34	8m	88	89	86	82	71	65	67	58	14	24	53	50			
35	8n	80	82	67	43	30	21	20	25	25	16	25	35	40	40	40
36	9c	74	78	82	95	72	47	37	32	47	33	21	25	30		
37	12i	84	89	86	84	72	62	36	33	57	69	81	80	62	44	53
38	12j	95	85	78	72	71	73	67	74	73	74	67	76	63	39	40
39	13c	75	78	81	83	55	53	38	33	21	26	30	53	63	65	64
40	13d	87	86	77	72	79	86	83	64	71	78	83	70	75	75	50
41	13e	97	83	75	63	56	62	75	73	70	70	69	71	60	43	32

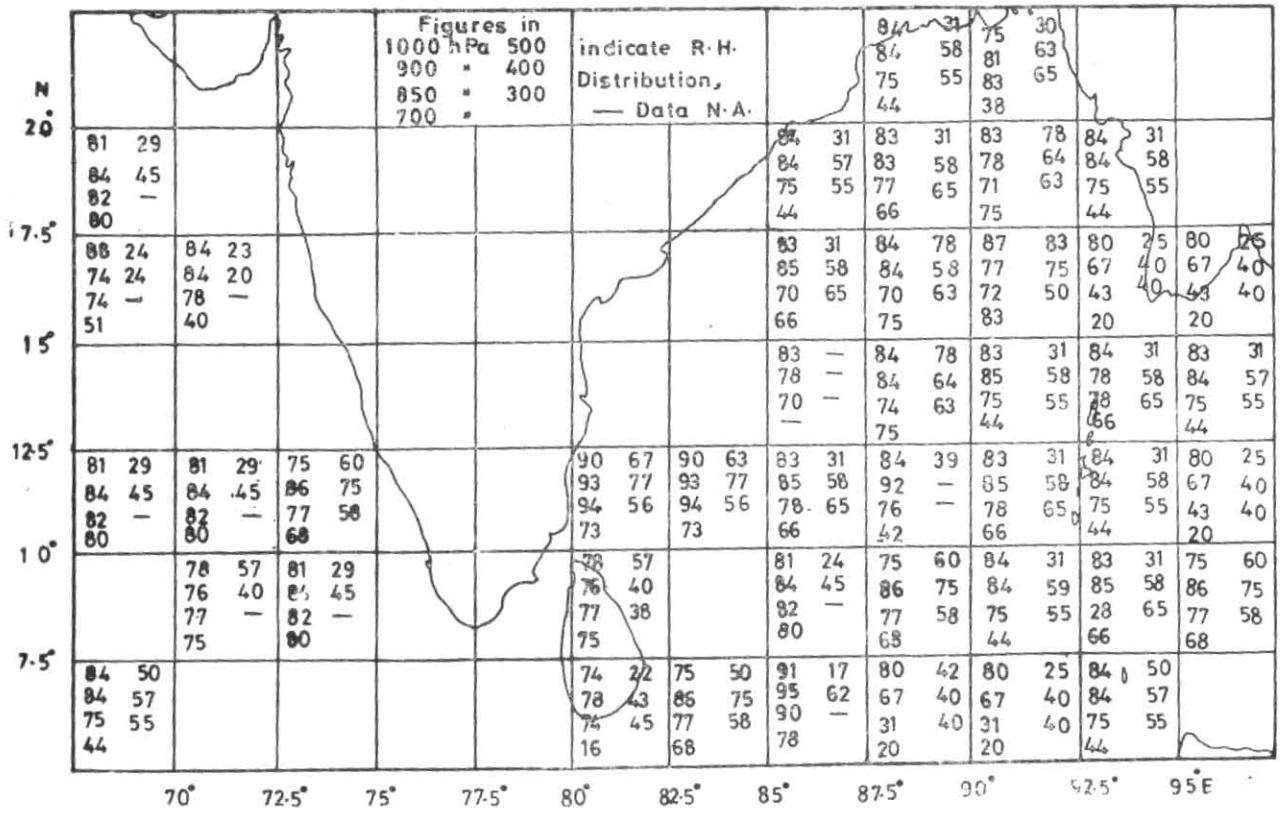

Fig. 2. Relative humidity distribution at 1000, 900, 850, 700, 500, 400 and 300 hPa at 0000 UTC on 13 August 1987

2.1. *Synop observations*

Synop observations of cloud and present weather may offer some clues, qualitatively, about the moisture conditions in the vertical. Incorporation of the parameters of synop observations containing information about the moisture, *i.e.*, total amount of all low clouds (Nh), height of the base of the lowest cloud seen (h) and present weather (ww), whenever available may, therefore, improve the estimation of humidity profiles. When the present weather is precipitating, it is estimated to be moist from the cloud top to the surface. If no precipitation is observed and there are no low clouds, it is estimated to be dry in low levels, even if there are high level clouds.

Following Baba (1987) the total cloud amount in every 2.5° Lat. × 2.5° Long. box has been divided into 6 classes, *viz.*, 0%, 1-10%, 10-50%, 50-80%, 80-99% and 100%. Depending on the total cloud amount and the levels at which the clouds have been present, cloudiness has been classified into different categories as shown in Table 1. For each cloud category the corresponding TEMP data has been used to obtain relative humidity upto 300 hPa at every 50 hPa interval beginning from 1000 hPa. Relative humidity is generally not available at 350 and 300 hPa. However, wherever available relative humidity at these levels have also been included. Out of a number of relative humidity profiles available for a given cloud category, the most frequently occurring profile has been selected as the representative profile for that category of clouds.

Availability of fractional cloudiness data and colocated TEMP data for various cloud categories is shown in Table 2. A total of 41 relative humidity profiles have been obtained (Table 3). Relative humidity values not shown at some of the levels in Table 3 indicate non-availability of dew point depression at those levels. Out of the small sample of data used here, the maximum number of observations were available for cloud categories 3*b* and 6*r*. Fig. 1 shows the relative humidity profiles for these two cloud categories. The data has been plotted at every 50 hPa interval from 1000 hPa to 300 hPa on T-ϕ grams.

As an illustration of the availability of relative humidity data using these profiles, relative humidity values for 0000 UTC for a randomly selected date, *i.e.*, 13 August 1987 is shown in Fig. 2. Fig. 3 shows the corresponding IR picture of INSAT covering the Arabian Sea and the Bay of Bengal.

3. Comparison of estimated and actual profiles

In order to know about the usefulness of the inferred profiles, relative humidity profiles were printed for the period 22 to 28 July 1989 using the software developed for the purpose and they were compared with the actual relative humidity profiles obtained from the radiosonde data of two island stations, *i.e.*, Port Blair (Table 4) and Minicoy (Table 5). The software reads fractional cloudiness data and searches for the cloud category (Table 1) for every box. If the cloud data in a box corresponds to one of the cloud categories of Table 1 and

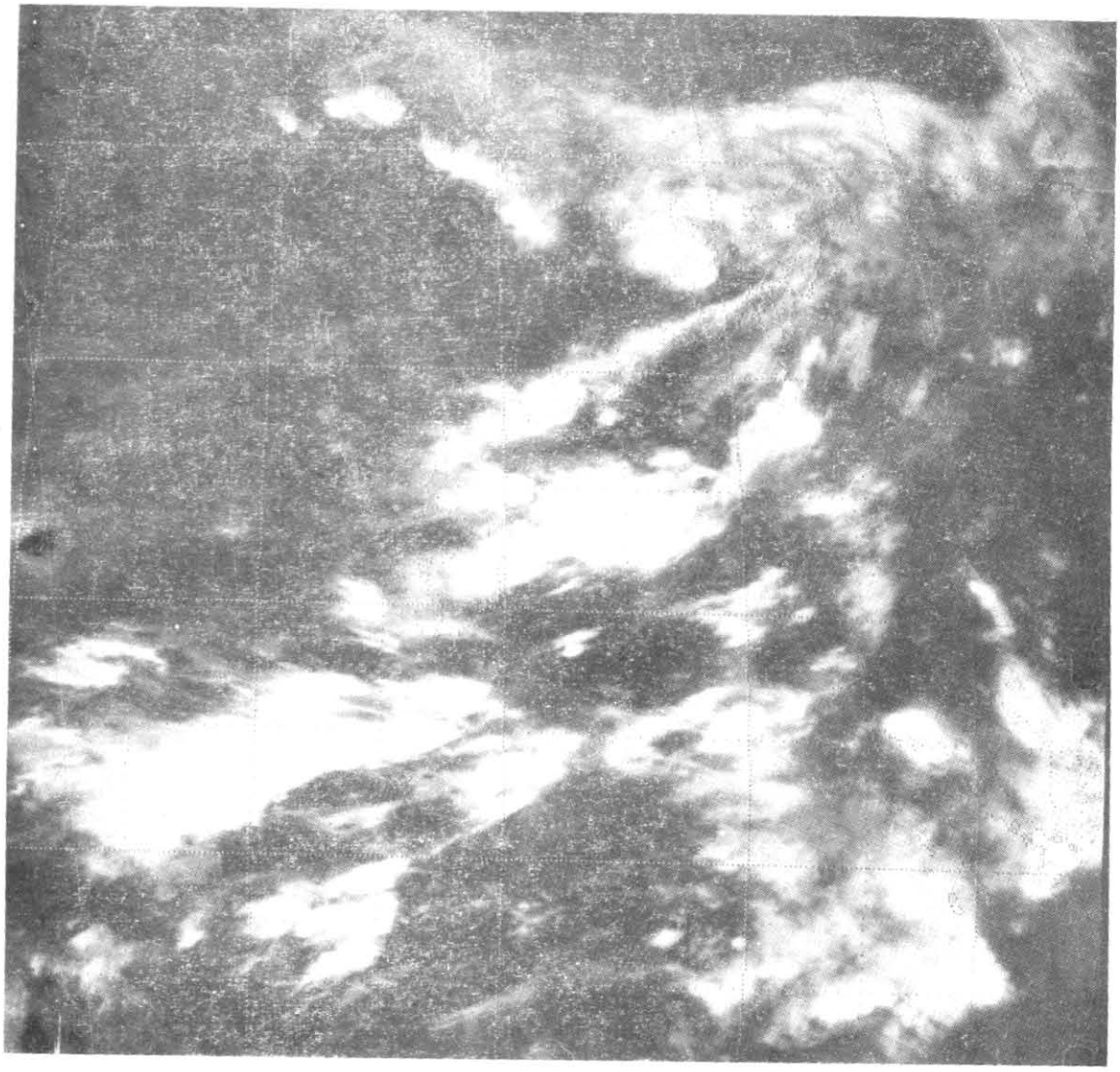

Fig. 3. INSAT-1B infrared cloud picture of 0000 UTC of 13 August 1987

if a relative humidity profile (Table 3) is available for that cloud category, the profile is printed. Otherwise the fractional cloudiness data together with the co-ordinates of the central point of the box is printed. The purpose of getting the cloud data printed is to incorporate modifications in assigning cloud categories so as to accomodate maximum possible combinations of cloud distribution at various levels. An examination of the profiles printed for the period 22 to 28 July 1989 shows that on an average relative humidity profiles were printed for about 90 per cent of the boxes. This may be considered encouraging so far as categorization of cloud data is concerned. The accuracy of the estimated profiles is discussed below.

An examination of the estimated and actual profiles for the boxes containing Port Blair and Minicoy shows that the inferred profiles compare well with the observed profiles from 1000 hPa to about 600 hPa. Considerable differences in some cases are seen in upper levels. In upper levels high relative humidities are observed on some days both in estimated as well as observed profiles. The observed errors may considerably reduce if more data is used and such a study is in progress.

There is a large variation in the cloud system distribution over the Indian Ocean during the SW monsoon season (Prasad *et al.* 1983). In the west Arabian Sea and over the south Indian Ocean south of the southern hemispheric equatorial trough there is inhibited development of convective clouds. We need to analyse INSAT cloud data and available co-located TEMP data from these regions also.

TABLE 4

Estimated and actual relative humidity profiles for the period 22-28 July 1989

Station : Port Blair

Level (hPa)	Relative humidity (%) with date/time (UTC)																			
	22/00		22/12		23/12		24/12		25/00		26/00		26/12		27/00		28/00		28/12	
	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.
300	44	60	44	46	53				53	50			45	63		50			44	
350	39	37	39	33	44				44	33	53	28	38	50		30			39	
400	63	73	63	29	62				62	27	64	25	23	50	45	19			63	47
450	76	80	76	40	80		50		80	36	74	64	20	44	27	17	50		76	42
500	67	73	67	64	81	19	53	25	81	40	78	28	15	50	29	13	53		67	36
550	74	75	74	75	69	43	24	60	59	77	69	15	17	88	43	16	24		74	13
600	73	57	73	67	57	36	14	72	57	78	63	63	17	84	68	36	14		73	18
650	74	79	74	54	33	50	58	73	33	76	71	65	10	83	73	31	58		74	38
700	67	78	67	50	36	59	67	71	36	75	75	62	19	73	80	27	67	10	67	75
750	73	86	73	71	62	63	65	67	62	75	74	64	25	87	79	49	65	14	73	67
800	71	85	71	75	72	71	71	75	72	78	65	71	45	94	76	77	71	20	71	58
850	72	83	72	89	84	76	82	88	84	78	70	75	82	89	83	79	82	56	72	87
900	75	88	78	84	86	77	86	84	86	89	78	75	80	88	84	80	86	93	78	89
950	85	89	85	73	89	77	89	84	89	90	84	80	80	80	83	80	89	83	85	81
1000	95	93	95	76	84	77	88	83	84	87	83	83	74	80	81	87	86	88	95	77

TABLE 5

Estimated and actual relative humidity profiles for the period 22-28 July 1989

Station : Minicoy

Level (hPa)	Relative humidity (%) with date/time (UTC)																	
	22/00		22/12		23/00		23/12		24/12				25/00					
	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.			Est.	Act.				
300		58	44	36	55		45	31					44					
350		50	39	39	58	47	61	32					39					
400		33	63	24	57	31	43	24					63					
450	50	22	76	20	74	27	31	20					76					
500	53	32	67	17	31	51	22	17	25	19			67	19				
550	24	43	74	14	35	28	22	43	26	33			74	33				
600	14	18	73	35	48	51	21	87	25	49			73	49				
650	58	35	74	74	42	64	20	73	27	52			74	52				
700	67	65	67	76	44	80	16	46	34	71			67	71				
750	65	70	73	76	61	79	27	55	58	56			73	56				
800	71	64	71	76	69	87	57	69	85	63			71	63				
850	82	68	72	76	75	81	73	83	79	67			72	67				
900	86	81	78	65	84	83	78	96	88	84			78	84				
950	89	96	85	65	95	83	84	92	91	93			85	93				
1000	88	85	95	81	84	87	74	81	87	84			95	84				

TABLE 5 (*contd.*)

Level (hPa)	Relative humidity (%) with date/time (UTC) 26/00 Est.	26/00 Act.	26/12 Est.	26/12 Act.	27/00 Est.	27/00 Act.	27/12 Est.	27/12 Act.	28/00 Est.	28/00 Act.	28/12 Est.	28/12 Act.
300	65	32	65	50	44	75	63	54		50		
350	53	39	53	63	39	78	53	36		50		
400	58	53	58	80	63	87	64	43		50		35
450	43	57	43	90	76	95	74	60	50	25		20
500	31	69	31	86	67	100	78	79	53	42	27	43
550	42	72	42	92	74	97	69	39	24	48	63	60
600	49	73	49	86	73	98	63	69	14	19	70	56
650	61	72	61	92	74	93	71	60	58	85	75	67
700	66	71	66	83	67	96	75	52	67	93	78	73
750	71	71	71	91	73	96	74	78	65	90	78	79
800	80	72	80	86	71	96	65	78	71	88	82	81
850	78	72	78	87	72	95	70	78	82	87	79	83
900	85	78	85	90	78	94	78	74	86	84	84	81
950	94	81	94	90	85	95		75	89	82	87	78
1000	83	80	83	91	95	95	83	88	88	85	88	71

4. Conclusions

The profiles, though tentative in nature, demonstrate the usefulness of the INSAT cloud data in obtaining relative humidity profiles. The profiles are climatological in nature and do not provide finer details of moisture distribution in the vertical as provided by retrieval profiles. However, when improved upon by making use of more data these bogus profiles may enable us to provide better humidity analysis over the Indian Ocean region.

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References

Baba, Atsushi, 1987, 'Improvement of the estimation method of moisture data from satellite cloud soundings', JMA/NPD Tech. Rep. No. 16, pp. 54.

Chisholm, D.A., Ball, J.T., Veigas, K.W. and Luty, P.U., 1968, 'The diagnosis of upper level humidity', *J. appl. Met.*, **7**, pp. 613-619.

Hayden, C.M., Smith, W.L. and Wolf, H.M., 1981, 'Determination of moisture from NOAA polar orbiting satellite sounding radiations', *J. appl. Met.*, **20**, pp. 450-466.

Lipton, A.E., Higgler, D.W. and Haar, T.H.V., 1986, 'Water vapour vertical profile structures retrieved from satellite data via: classification and discrimination', *Mon. Weath. Rev.*, **114**, pp. 1103-1111.

Mills, G.A., 1983, The sensitivity of numerical prognosis to moisture detail in the initial state, *Aust. Met. Mag.*, **31**, pp. 111-119.

Prasad, O., Mishra, D.K., and Jain, R.K., 1983, 'Satellite observed cloud distribution over Indian Ocean during southwest monsoon season', *Mausam*, **34**, pp. 449-454.

Smigielski, F.J. and Mase, L.M., 1970, Estimating mean relative humidity from the surface to 500 mb by use of satellite pictures, ESSA—Tech. Memo. NESCTM, **23**, 12 pp.

Smith, W.L. and Howell, H.B., 1971, 'Vertical distributions of atmospheric water vapour from satellite infrared spectrometer measurements', *J. appl. Met.*, **10**, pp. 1026-1034.

Thompson, A. and West, P.W., 1967, 'Use of satellite cloud pictures to estimate average relative humidity below 500 mb with application to Gulf of Mexico area', *Mon. Weath. Rev.* **95**, pp. 791-798.

Walcott, S.W. and Warner, T.T., 1981, 'A moisture analysis procedure utilizing surface and satellite data', *Mon. Weath. Rev.*, **109**, pp. 1989-1998.