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Some aspects of Indian northeast monsoon as derived from TOVS data

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सार - टायरस ऑपरेशनल वर्टिकल साउंडर (टी.ओ.वी.एस.) एक प्रचलित उपग्रह साउंडिंग प्रणाली है। इस शोध-पत्र में प्रादेशिक मौसम केन्द्र, चेन्नई स्थित उपग्रह भू-केन्द्र से प्राप्त तीन वर्षों के टी.ओ.वी.एस. आँकड़ों की सहायता से भारत की उत्तरी पूर्वी मानसून की कुछ विशेषताओं का अध्ययन किया गया है। तमिलनाडु के तटीय और अंदरूनी भागों एवं महासागरीय क्षेत्रों की उत्तरी पूर्वी मानसून वर्षा ऋतु की विभिन्न अवस्थाओं के टी.ओ.वी.एस. आधारित बहिर्गामी दीर्घ तरंग विकिरण (ओ.एल.आर.) और वर्षणीय जल वाष्प (पी.डब्ल्यू.वी.) के अक्षांशीय और देशांतरीय प्रोफाइल तैयार किए गए है। ये उत्तरी पूर्वी मानसून ऋतु की स्थानिक वर्षा की ज्ञात विशेषताओं के अनुरूप पाए गए हैं। विभिन्न क्षेत्रों की उत्तरी-पूर्वी मानसून वर्षा की विभिन्न अवस्थाओं से प्राप्त हुए औसत उर्ध्वधर तापमान प्रोफाइल से यह ज्ञात होता है कि शुष्क मौसम की तुलना में सक्रिय उत्तरी - पूर्वी मानसून वर्षा ऋतु के समय निम्नतम स्तर और ऊपरी क्षोभमंडल कुछ उष्ण और मध्य क्षोभमंडल कुछ ठंडा रहता है। ओ.एल.आर. और पी.डब्ल्यू.वी. में दैनिक परिवर्तन का तथा परम्परागत उपरि वायु के आँकड़ों एवं उपग्रह के आँकड़ों की टी.ओ.वी.एस. से प्राप्त आँकड़ों के साथ तुलनीयता के विषय में संक्षेप में अध्ययन किया गया है।

ABSTRACT. The Tiros Operational Vertical Sounder (TOVS) is a popular satellite sounding system. In this paper certain features of Indian northeast monsoon have been studied with the help of three years of TOVS data received through the satellite ground station located at the Regional Meteorological Centre, Chennai. The TOVS based latitudinal and longitudinal profiles of Outgoing Longwave Radiation (OLR) and Precipitable Water Vapour (PWV) were derived for various phases of northeast monsoon activity, over coastal and interior Tamilnadu and oceanic regions. These were consistent with the known spatial rainfall characteristics of northeast monsoon. The average vertical temperature profiles derived for the various phases of northeast monsoon for the different regions revealed that the lowest layer and upper troposphere are warmer and mid troposphere colder during active northeast monsoon compared to dry phase. The diurnal variation of OLR and PWV and the comparability of TOVS derived data with conventional upper air data and INSAT data have been briefly discussed.

Key words – TOVS, NOAA satellite, Northeast monsoon, Precipitable water vapour, Outgoing longwave radiation, Satellite sounding.

1. Introduction

Satellite data availability for various meteorological applications has increased considerably as weather satellites provide wealth of meteorological information over data sparse and oceanic areas. Satellites are capable of providing data with improved radiometric, temporal and spatial resolutions compared to conventional methods of obtaining data.

Conventional radiosonde soundings, available on a limited scale over the globe, provide upper air data which serve as crucial input in several present day weather applications such as forecasts through global models, climatic forecasts etc. Obtaining radiosonde data over the vast oceanic area in the same scale as that of the land is almost impossible. Even over land there are areas with vast upper air data gaps. Upper air soundings through weather satellites provide vital data in the data-sparse regions besides augmenting the conventional upper air data over the land. The Tiros Operational Vertical Sounder (TOVS) system is a popular satellite sounding system which was first operationalised in 1978 and has since been continuously improved upon (Asnani, 1993). The TOVS instrumental package consists of three units *viz.* 20 channel high resolution infrared radiation sounder (HIRS), 4 channel microwave sounding unit (MSU) and 3 channel stratospheric sounding unit (SSU). The sounding details retrieval procedure are described in Smith *et al.* (1979); Smith & Schreiner (1985); Hayden *et al*. (1979) and Khanna and Kelkar(1993). The TOVS system provides upper air sounding over a finer grid of approximately 80×80 km.

TABLE 1

Northeast monsoon activity over Tamilnadu, October-December, 1996-98

Year	Date of onset	Date of withdrawal	Type of activity No. of days of			Oct-Dec rainfall of Tamilnadu as % anomaly
			A	W	PW	
1996	8 Oct	20 Dec	34	25	12	20
1997	13 Oct	22 Dec	67	-	9	70
1998	2 Nov	18 Dec	23	7	13	30

A – Active, W – Weak, PW – Post withdrawal

NOAA satellites are orbiting at an altitude of about 850 km. TOVS retrieval gives temperature, dew-point temperature, geopotential height at standard pressure levels and outgoing longwave radiation (OLR), precipitable water vapour (PWV) from surface to 300 hPa, ozone and stability index at the point of vertical sounding.

In this paper we have utilised the TOVS derived upper air sounding data available from NOAA-12 satellite to study certain features of Indian northeast monsoon. The OLR, PWV and the vertical temperature profiles for the southern Indian region and adjacent Bay of Bengal (BOB) have been made use of in the study.

2. HRPT direct readout ground station facility at Madras

A direct readout HRPT ground station to track and process data from NOAA - 12 and 14 satellites was installed at Regional Meteorological Centre, Madras, hitherto called Chennai (13.07° N, 80.25° E) in August 1995. The state of art system, its capabilities and some of the limitations have been described in Gupta *et al.* (1996). International TOVS Processing Package (ITPP) version 4.0 of the University of Wisconsin, Madison on one step physical retrieval scheme has been used at HRPT station, Chennai to derive TOVS products. Since MSU undergoes calibration in every scan and microwave radiation is almost unaffected by the cloud contaminations, the MSU channels data are considered as a sensitive indicator of the atmospheric cooling and heating processes (Kidder and Vonder Harr, 1995). Regression estimates obtained from HIRS channels at stratospheric level and MSU channels have been used as first guess profile to retrieve atmospheric temperature at various levels. Validation of TOVS products derived from NOAA - 12 was carried out as routine from October 1996 to December 1998 by HRPT station Chennai with co-located RS/RW stations in the southern peninsular India as these satellite passes normally coincide with conventional radiosonde ascents taken at 0000 and 1200 UTC. Early results have been presented in Gupta *et al.* (1996). Validation indicates that reasonably good agreement exists in regard to temperature between 850 and 200 hPa with root mean squared biases of less than 2.5° C and geopotential heights less than 80 gpm. The difference between TOVS and radiosonde may be due to the fact that the sounding techniques are different and both retrievals are compared even when they are upto 75 km apart and three hours of sounding time difference. However, Rao *et al.* (1990) opine that estimates of OLR and PWV agree well with observations and can be used as input to climatological models.

3. Northeast monsoon over southern Indian peninsula

The Indian northeast (NE) monsoon is a smaller scale monsoon that affects southern parts of Indian peninsula during October-December. Its activity is well defined in Tamilnadu especially over coastal regions. India Meteorological Department (1973) provides a detailed description of this monsoon. Raj (1996) has studied some of the thermodynamical aspects such as variation of PWV, upper air temperature, moisture flux during different phases of NE monsoon activity such as active, weak and post withdrawal phase etc. This study was based on conventional upper air soundings of Chennai located in Coastal Tamilnadu (CTN). Variation of such thermodynamic parameters over BOB and over Interior Tamilnadu (ITN) in association with NE monsoon activity is a problem that holds considerable interest but could not be studied so far due to non-availability of upper air soundings in such areas. However with the availability of TOVS data, over ITN and Bay of Bengal it has now become possible to attempt such a study.

4. Data and analysis

4.1. The data pertaining to northeast monsoon for the year 1996 to 1998 were extracted from publications of India Meteorological Department such as Indian/Madras Daily weather reports and the weather charts available at Regional Meteorological Centre, Chennai. The following details were obtained:

(*i*) Days of active northeast monsoon conditions when realised rainfall is atleast 1.5 times than normal,

(*ii*) Days of weak northeast monsoon which are generally dry spells juxtaposed between two wet spells and

(*iii*) Days of post northeast monsoon withdrawal phase when there is generally continuous dry

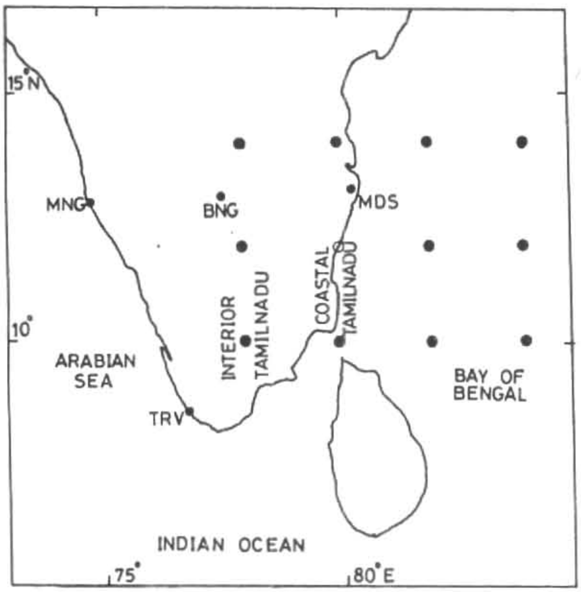
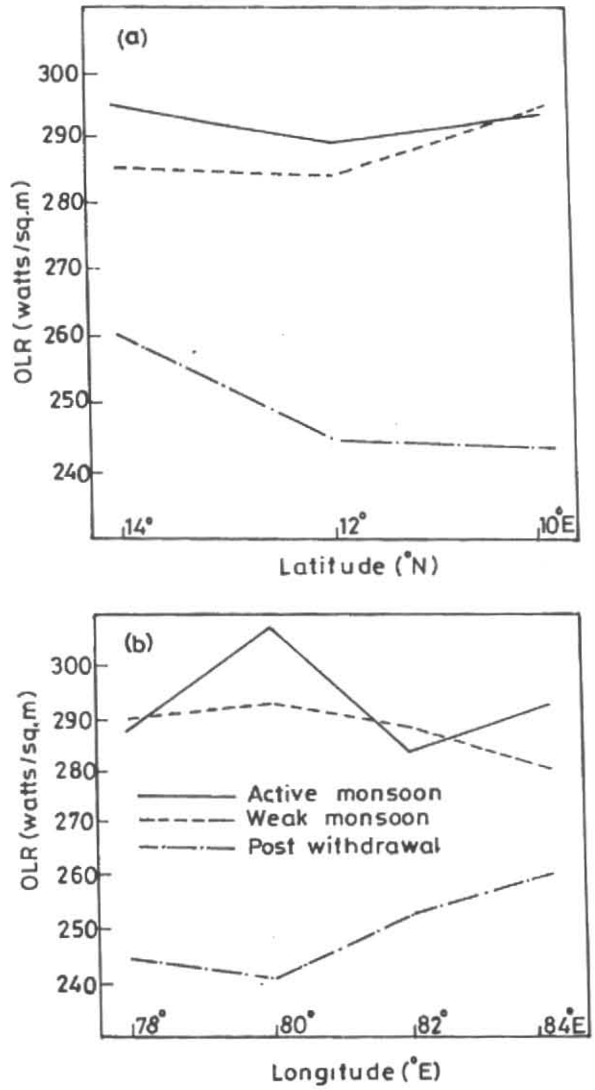


Fig. 1. Geographical locations of grid points, coastal and interior Tamil Nadu and Bay of Bengal

weather. Table 1 presents the rough dates of onset and withdrawal of northeast monsoon over Tamilnadu besides the number of days corresponding to the different types of northeast monsoon activity and also the overall rainfall realised during October-December.

4.2. TOVS derived OLR and PWV for all the NOAA-12 satellite passes over the domain equator to 26° N and 60° to 100° E for the period October to December, 1996-98 have been considered. As there are innumerable soundings over this domain, averaging of such soundings within 75 km radius from the satellite observed location grid points between 10° and 14° N and 78° and 84° E has been done for each sounding to mask the noise in the soundings. Fig.1 presents the grid point locations and also the geographical areas of CTN and ITN.

The values of OLR and PWV were obtained for the above grid points for each day of 1 October-31 December for the three year period 1986-98 for the satellite passes close to 0000 and 1200 UTC as explained earlier. The mean values of OLR and PWV were averaged over all the days of (*i*) active (*ii*) weak and (*iii*) post withdrawal NE monsoon days and further averaged over longitudes and latitutes and also over the two time slots 0000 and 1200 UTC to obtain a smoother profile. The longitudinal and latitudinal variation of OLR and PWV for various type of monsoon activity are depicted in Figs. 2 and 3 respectively.

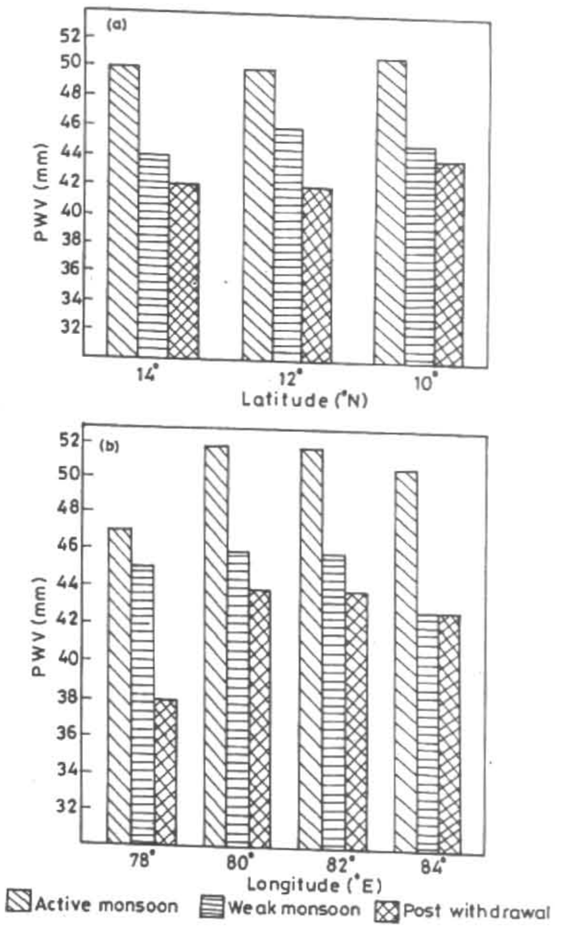


Figs. 2(a&b). (a) Latitudinal and (b) longitudinal variation of outgoing longwave radiation (OLR) during northeast monsoon season

5. Results and discussions

5.1. *OLR*

Fig. 2 describes the variation of OLR during different phases of NE monsoon. By and large we can take the longitudinal belt of 80° E spanning the latitude 10-14° N as representing CTN (Fig.1) which normally receives the maximum amount of northeast monsoon rainfall. During active northeast monsoon conditions, in the belts of 10-14° N and 78-80° E, the OLR decreases towards



Figs. 3(a&b). (a) Latitudinal and (b) longitudinal variation of precipitable water vapour (PWV) of the atmosphere during northeast monsoon season

lower latitudes clearly indicating that more cloudiness and precipitation are obtained at lower latitudes than higher latitudes. This pattern is consistent with the realised values of normal rainfall for October – December obtained over CTN. For, Vedaranyam (close to 10° N) receives 103 cm whereas Nellore located slightly north of 14° N receives only 67 cm. However during weak northeast monsoon the distribution is almost reversed with more clouding in the higher latitudes and less clouding in lower latitudes.

During active northeast monsoon OLR is lowest at 80° E (CTN) and increases eastwards and westwards, which again is consistent with the well known distribution of northeast monsoon rains which are heavier in CTN and decrease inland. It is clearly revealed from the OLR distribution that the cloudiness and precipitation decreases as one moves from CTN towards Bay of Bengal, eastwards. Frictional convergence which is arguably one of the causative factors behind the occurrence of high amount of rainfall over the coast, perhaps explains

TABLE 2

Mean diurnal variation of PWV (mm) and OLR (Watts/m²) (0000 – 1200 UTC data)

	Active	Weak	Post Withdrawal
PWV	4	2	6
OLR	22	28	49

TABLE 3

Diurnal variation of mean clouding over coastal and interior Tamilnadu (October-December, Surface Data)

Region	Coastal Tamilnadu		Interior Tamilnadu	
Time(UTC)	I	II	I	II
0300	5.3	2.8	4.9	2.3
1200	5.3	2.7	5.5	3.0

I – All types of clouds, II – Low cloud (octas)

the decrease of rainfall from coast to ocean during active northeast monsoon conditions.

During weak/dry northeast monsoon however OLR is highest at 80° E (CTN) and decreases an either side. This suggests that during such periods the interior and ocean are more cloudy than CTN. Climatologically convection is more likely in interior parts of the peninsula than over east coast of India, due to the existence of conditions favourable for convective development and so this feature is also readily comprehended.

5.2. *PWV*

Fig. 3 describes the variation of precipitable water vapour during different phases on NE monsoon. The lower values of PWV over ITN compared to CTN during 'active' phase is consistent with the profile of OLR obtained in this study and also the normal rainfall pattern realised. During 'weak' phase, the PWV shows almost identical values over CTN and ITN. The low value of PWV over ITN in the post withdrawal phase which occurs in December is mainly due to prevalent low temperatures over ITN and also the possible intrusion of northern continental airmass into the interior parts during winter.

5.3. *Diurnal variation*

The diurnal variation of PWV and OLR from the data of 0000 and 1200 UTC (0530 and 1730 hrs IST) has been studied despite the limitations imposed by different equatorial time crossing of the polar orbiting satellites and the minor variation in the observation times from day to day and also the over all inadequacy of only two observational hours to study the same. Table 2 presents

TABLE 4

Temperature (°C) difference at various levels between different phases of northeast monsoon over CTN , ITN and Bay of Bengal (BOB)

Region	Pressure (hPa) 1000	850	700	500	300	200	150	100
				(Active – Weak) phase				
CTN	0.6	0.8	-0.6	-1.6	-2.2	-0.4	0.7	1.0
ITN	-	0.0	-0.5	-1.6	-2.0	-0.2	1.0	1.2
BOB	0.7	0.7	-0.6	-1.4	-1.4	-0.0	1.0	1.3
				(Active – Post withdrawal) phase				
CTN	0.9	1.6	-0.6	-1.7	-1.8	0.0	1.1	1.9
ITN	-	1.9	-0.5	-1.1	-0.9	0.4	1.0	1.6
BOB	1.2	2.2	-0.1	-1.1	-1.0	0.5	1.5	2.3

CTN – Coastal Tamilnadu, ITN Interior Tamilnadu

the mean diurnal variation of PWV and OLR for the three phases of monsoon. The PWV at morning is only 2-6 mm higher than that of the evening and the diurnal variation does not appear significant. The lower OLR at 1200 UTC compared to 0000 UTC by as much as 22-49 W/m^2 suggests more clouding in the evening than in the morning. To examine this further we present in Table 3 the normal amount of clouding over CTN and ITN at 0300 & 1200 UTC (0830 & 1730 hr IST) for the period October to December (India Meteorological Department, 1974). Though there is hardly any difference in clouding for CTN between the two hours of observation, in respect of ITN the clouding at 1730 hr IST of 5.5 octas (all types) is more by 0.6 octa compared to 0830 hr IST. At 1730 hr IST, the amount of low clouds at 3.0 octas is more by 0.7 octa or 30% higher than the cloud during 0830 hr IST. Kelkar *et al.* (1993) showed that the diurnal variation of OLR based on INSAT data was characterised by lower OLR over the oceanic region at 1200 UTC than that at 0000 UTC. Thus it appears that despite the preference for early morning rain during northeast monsoon, clouding is slightly more in the evening than in the morning as evidenced by the NOAA OLR data and amply supported by the conventional surface data. It is noteworthy to observe that diurnal variation is minimal during active phase and increases for weak/post withdrawal phase.

5.4. *Vertical temperature profile during active, weak and post withdrawal phases*

The vertical temperature profile computed for the active, weak and post withdrawal phases for CTN, ITN and BOB provided some interesting patterns. Table 4 presents the difference of temperature at various levels between (*i*) active and weak phases and (*ii*) active and post withdrawal phases. The data is provided from 1000 to 100 hPa except for ITN where it is provided from 850 to 100 hPa. As seen clearly, the differences are all positive upto 850 hPa, negative from 700 to 200 hPa and again positive at 150 – 100 hPa levels. During active northeast monsoon, there is more easterly component and less northerly component in the lower levels whereas during weak northeast monsoon the northerly component predominates (Raj,1996). This pattern is capable of providing warm(cold) air advection in the lowest levels and so slightly warm(cold) temperature anomalies during active(weak / post withdrawal) phase. However in the layer 700-300 hPa the temperature difference is negative. The phenomenon of warmer temperature in lower level and colder temperature in mid troposphere would lead to a higher lapse rate and so would be conducive for an active northeast monsoon. Complement of the above would be favourable for a weak northeast monsoon. Table 5 which presents the vertical gradient of temperature for 1000 - 500 hPa for CTN and BOB and 850 - 500 hPa for ITN for the various phases of northeast monsoon brings out this phenomenon very clearly. The vertical gradients are higher by 2-3° C during active phase compared to weak/ post withdrawal phase. This type of upper air temperature profile for active *vis-a-vis* weak northeast monsoon has been obtained in Raj (1996) also based on 0000 UTC conventional radiosonde data for 10 years of northeast monsoon.

TABLE 5

Vertical temperature gradient (°C) between 1000-500 hPa for CTN and BOB, 850-500 hPa for ITN for various phases of northeast monsoon

Phase region	Active	Weak	Post withdrawal
CTN	33.6	31.3	30.9
ITN	24.5	22.9	22.6
BOB	33.6	31.5	31.7

CTN – Coastal Tamilnadu, ITN – Interior Tamilnadu, BOB – Bay of Bengal

5.5. *Comparison of TOVS data vis-a-vis INSAT and conventional data*

The PWV values obtained through TOVS appear to be substantially higher than the conventional RS/RW data obtained. The mean PWV of Chennai for October, November and December as obtained from the climatological data of India Meteorological Department

(1988) is 44,38 and 32 mm respectively. In Raj (1996) the PWV over Chennai was derived to be 46 mm for active northeast monsoon, 28 mm for weak and 22 mm for post withdrawal. Evidently these figures are lower and more dispersive than those derived from TOVS data. Kelkar *et al.* (1993) reported OLR values of nearly 230 W/m^2 for October and 260 W/m^2 for January over BOB. The TOVS based OLR appears higher than the INSAT derived OLR by nearly 10% of the absolute values. Despite the above discordance in the comparability of absolute values of TOVS data with those derived from other sources, it is evident that results of analysis based on comparison of TOVS derived data through the same type of instrument system would admit reasonable reliability.

6. Summary and conclusions

(*i*) The vertical temperature profiles computed for various phases of northeast monsoon activity revealed that the atmosphere is warmer during active phase upto 850 hPa, cooler in 700-200 hPa and warmer above 150 hPa than weak/post withdrawal phase. Higher lapse rate was obtained during active *vis-a-vis* other phases. These results are consistent with similar results obtained in earlier studies using conventional radiosonde data.

(*ii*) The TOVS derived PWV values are higher than that could be derived from radiosonde data by nearly 10%. Similarly the TOVS OLR values are higher by atleast 10% than the INSAT OLR values. Overall the TOVS derived OLR and PWV profiles have been consistent with the available climatological features of Tamilnadu during northeast monsoon.

(*iii*) During active northeast monsoon OLR was lower over CTN compared to ITN and BOB, which was in conjunction with the higher PWV over CTN. This is consistent with the rainfall distribution over CTN during northeast monsoon season with CTN receiving more rainfall than ITN. The OLR distribution suggests decreasing rainfall and clouding from CTN to BOB.

(*iv*) In the post northeast monsoon phase CTN is less cloudy compared to ITN and adjacent BOB. During post northeast monsoon, PWV over ITN is substantially lower than that of CTN and Bay of Bengal consistent with lower temperature over ITN and probably suggesting spreading of colder continental air mass into ITN.

(*v*) During active northeast monsoon, south CTN is associated with less OLR consistent with its receiving higher rainfall than north CTN.

(*vi*) The OLR values are lower at 1200 UTC compared to 0000 UTC suggesting more clouding in the evening compared to morning hours consistent with the diurnal variation of clouding obtained over Tamilnadu from conventional surface observations.

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