SOME RELATIONSHIPS BETWEEN SYNOPTIC VARIABLES AND SATELLITE RADIATION DATA [1]

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ABSTRACT

Various synoptic variables are related to satellite radiation data. It is shown that: (1) Vertical motion is related jointly to window radiation and water vapor radiation. (2) Surface relative humidity can be estimated from window radiation and cloud brightness. (3) Ceilings can be estimated from window radiation and cloud brightness.

1. INTRODUCTION

One of the major purposes of the meteorological satellite program is to make available information, in regions of sparse conventional data, which can be used for weather-map analysis and forecasting.

Objective forecasts begin from analyzed fields of mass, motion, and temperature. Satellite pictures, on the other hand, mainly give information about clouds which cannot be utilized directly in analysis. Of course, a good deal of progress has been made in using cloud pictures to infer the positions of jet streams and circulation centers and this has been incorporated subjectively into otherwise objectively analyzed charts.

So far, little synoptic use has been made of the radiation received by several of the satellites. Jensen et al. [1] devised regression techniques for the estimation of isobaric heights from window radiation, and Shenk [2] related window radiation, corrected for surface temperatures, to vertical motion. This paper extends Shenk's work to the simultaneous application of radiation in several wavelength channels to the estimation of a number of synoptic variables.

2. SATELLITE RADIATION AND VERTICAL MOTION

Almost all recent synoptic work with infrared TIROS radiation has concentrated on the analysis of channel-2 radiation intensities, which essentially give the energy in the 8–12-μ window. It has been frequently demonstrated that these energies are related to the temperature of the radiating surface—the ground in the absence of clouds, or essentially the cloud tops. The actual energy received at the satellite is usually less than that expected from blackbody calculations because of the small absorption of water vapor and ozone in the window, and possibly radiation by particulates.

Nevertheless, it is clear that a low value of window radiation indicates continuous high clouds, unless the ground is cold. Broken high clouds would lead to somewhat higher channel-2 energies.

In order to remove the ambiguity between low ground temperatures and high clouds, Shenk [2] introduced a quantity DV which measured the difference between the actual window radiation received at the satellite and that radiation which would have been received if the sky had been clear. This quantity essentially measures the product of lapse rate and cloud height in regions of overcast; in partially cloudy areas the values of DV are somewhat less. Shenk showed a fair correlation between large-scale vertical motion and DV obtained from TIROS II in the eastern United States in November and December.

Oceanic areas are particularly suitable for this type of study since most areas of scarce observations are oceanic, and since the surface temperature required to estimate DV can be obtained with sufficient accuracy from climatic atlases of the sea.

Instead of Shenk's DV, we shall here use ΔT, defined as the actual (or climatological, in case of oceans) surface temperature minus the equivalent blackbody temperature corresponding to the energy received by a satellite in the window channel. This quantity is usually between 10° C. and 20° C. even in clear areas, since the actual surface temperature generally exceeds the equivalent channel-2 temperature. With thick or high clouds, ΔT may exceed 70° C. Although it might have been better in principle to utilize equivalent clear-sky window temperatures rather than actual surface temperatures, the distribution of ΔT is not significantly affected by this change, and the simpler definition is therefore preferable.

Channel-2 TIROS IV. radiation data (8–12μ) were

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sampled every 5° longitude and latitude from composite radiation charts supplied by the National Environmental Satellite Center. The radiation data were converted to temperatures according to the TIROS IV User's Manual [4]. These composite charts had been prepared previously for a different purpose at the Satellite Center from Final Meteorological Radiation tapes compiled by NASA. The Atlantic data were supplied on the NWP grid, and a correction for degradation was applied. All meteorological data were interpolated for the mean time of the composite radiation data. Five orbital passes each were utilized for April 13, May 12, and May 15; six for May 14; one for May 26, and three for May 27, 1962. From these passes five composite maps were constructed.

Surface temperatures needed for the computation of ΔT were taken from the monthly average sea-surface temperatures contained in Hydrographic Office Publication 225 [5]. Ten-day average temperature maps were also obtained from the Navy Oceanographic Office in Washington, but judged to be unsatisfactory because of the often unjustified analysis of small-scale features in the temperature field. In any case, the variance of sea-surface temperatures is negligible compared to the variance of ΔT, so that average temperatures are quite adequate. This is particularly important since it makes possible estimates of ΔT in regions of no meteorological observations.

Most meteorological data were obtained from the National Environmental Satellite Center in Suitland with the help of Mary Ann Ruzecki. In particular, vertical velocities computed at 600 mb. were supplied for 5°×5° gridpoints. These vertical velocities had been computed by solving the diagnostic (omega) equation. Also available were the height field at 0000 GMT and 1200 GMT at 500 mb. and geostrophic vorticity and vorticity advection computed from the height fields at NMC. Maps were drawn from all these variables and it was quite clear that the longitudes of centers of ΔT, vertical motion ω, and vorticity advection $\mathbf{V}\cdot\nabla\zeta$ agreed well, with considerable differences in the shapes of the detailed patterns. As was expected, maximum upward motion and maximum ΔT generally occurred a quarter wavelength east of 500-mb. troughs. In general, both vorticity advection and ΔT patterns had many small-scale features which did not appear on the vertical velocity charts.

In order to provide fields of ΔT, ω, and $\mathbf{V}\cdot\nabla\zeta$ of comparable scale, two different space averages were tried for ΔT and $\mathbf{V}\cdot\nabla\zeta$; 3-point zonal unweighted moving averages from observations every 5° longitude; and 9-point averages of the values at the intersections of 5° latitude and longitude lines. There was no significant difference between the results obtained by the two techniques.

At latitude 40° and farther north, clear relations emerge. It is, of course, well known that vorticity advection and vertical motion are closely related to each other at 500 mb. in mid-latitudes, so much so that vorticity advection has been useful in qualitative predictions of precipitation. Table 1 summarizes the correlations between ΔT, $\mathbf{V}\cdot\nabla\zeta$ and ω over the Atlantic, for all five periods.

TABLE 1.—*Correlations between ΔT and ω, $\mathbf{V}\cdot\nabla\zeta$*

	Latitude				
	30°	35°	40°	45°	50°
	Atlantic Area				
ω and ΔT	0.07	−0.34	−0.55	−0.64	−0.54
$\mathbf{V}\cdot\nabla\zeta$ and ΔT	.23	−.07	−.44	−.58	−.23
No. of Observations	71	68	65	56	56
	Pacific Area				
ω and ΔT	−0.30	−0.30	−0.24	−0.12	−0.40
No. of Observations	86	89	90	89	86

The correlations of ΔT with ω are consistently larger numerically than those with $\mathbf{V}\cdot\nabla\zeta$, which is not surprising since vertical motion produces clouds and ω is only imperfectly related to $\mathbf{V}\cdot\nabla\zeta$.

Table 1 also shows correlations between ω and ΔT over the Pacific. Although they are of the correct sign, they are very low, particularly in middle latitudes where the Atlantic study indicates high values. It is quite unlikely that this result reflects real differences in the relationships over the two oceans, or that it is a statistical accident. Rather, the explanation is probably found in the lack of accuracy of the ω-field, because of sparse data in the Pacific. This suspicion is fully confirmed by conversations with personnel of the National Meteorological Center.

Channel 1 on TIROS II, III, and IV measured radiation from the atmosphere in a band centered at 6.5μ, where water vapor is extremely absorbent. Therefore, if the upper troposphere is relatively humid, the satellite sees the temperature at the top of the troposphere, which is low; if the middle troposphere is dry, the satellite sees farther down into a warmer region. Therefore, large water-vapor-channel temperatures indicate middle troposphere dryness, and vice versa. Of course, in the presence of high clouds, channel 1—as channel 2—senses the cloud-top temperature. Therefore, one would expect that channel 1 and 2 temperatures are well correlated with each other.

In previous studies of the relations between window radiation and vertical motion, it was noted that in clear air (as indicated by the window temperatures), subsidence was indicated; but the strength of the subsidence was not related to the window temperatures. It might be suggested that, on the average, rapid subsidence dries out the air more than slow subsidence. Therefore, tropospheric humidity, as indicated by channel 1, should be usable to infer the strength of subsidence.

Table 2 gives the result of a study of the interrelationship between vertical motion at 700 mb. (computed by the adiabatic method), channel 1 temperature, and ΔT for March 31–April 3, 1962 in the eastern two-thirds of the United States. Four orbital passes, one for each day, were utilized in this study. Only passes within 2 hours of the midpoints of the 12-hr. average vertical velocity periods were used.

TABLE 2.—ΔT, *channel-1 temperature and vertical motion. Number in center gives mean vertical velocity; upper right, number in each box; lower right, mean deviation*

Channel-1 Temperature (°K.)	ΔT, °K. ≤14	15–24	25–34	35–44	≥45
≥241	N=21 −2.2 E=1.0	N=6 −2.5 E=0.8	N=2 −1.1 E=0.2	N=3 −0.2 E=1.8	
232–240	N=27 −1.4 E=0.7	N=27 −1.1 E=0.9	N=8 −1.3 E=0.5	N=1 −0.9 E=0	
224–231	N=14 −1.3 E=.08	N=28 −0.6 E=1.3	N=18 −0.4 E=1.4	N=6 0.0 E=1.5	
216–223	N=7 0.3 E=.06	N=22 −0.3 E=0.6	N=12 0.9 E=1.2	N=6 0.6 E=1.2	N=4 1.1 E=0.7
≤215		N=1 0.4 E=0	N=5 −1.1 E=1.5	N=3 0.0 E=2.0	N=7 1.5 E=0.7

Table 2 shows that, particularly for small ΔT (few or no clouds), the mean vertical velocity given in each box depends strongly on the water-vapor-channel temperature. The scatter in each box is shown by the mean deviation. It is quite considerable, so that estimates of vertical motion based on satellite data alone are not very accurate; the standard error comes out 1.4 cm./sec. for this sample. The large scatter is not surprising for several reasons. First, there are uncertainties in the vertical velocities; second, clouds can be advected in horizontally moving air; and third, even weak subsidence can dry out air if continued for a sufficiently long period.

3. SATELLITE RADIATION AND RELATIVE HUMIDITY

A low window-radiation amount indicates that there are high cloud tops. The clouds could be cirrus or cumulonimbus. But if, at the same time, the cloud is bright, it is likely to be thick. Hence, if the window channel gives low values and the brightness is large (large values in channel 5) the clouds are likely to be cumulonimbus or many layers of stratified cloud. In either case, precipitation probability is high and ceilings are low.

Timchalk and Hubert [3] have shown that low ceilings go with high surface relative humidity and vice versa. Therefore, relative humidities at the ground should be related to channel 2 and 5 radiation amounts.

Table 3 shows the relation between surface relative humidity, window temperatures, and cloud brightness. In each box, determined by channel-2 and 5 temperatures, is given the average relative humidity, the number of observations on which it is based, and the average deviation for six passes of the March–April 1962 period. The over-all variation is from an average of 39 percent for low or no clouds and low surface brightness (probably mostly clear skies) to 81 percent for cold cloud tops and bright clouds. The relative humidities are about equally dependent on both predictors; given one predictor, considerable variation in relative humidity is experienced as the other predictor varies.

TABLE 3.—*Surface relative humidity as function of channel-2 temperature* T_2 *and cloud brightness* B *in watts* m.$^{-2}$ *Number in center gives mean relative humidity; upper right, number in each box; lower right, mean deviation.*

B \ T_2°K.	≥260	259–250	249–240	≤239
≤20	N=255 39% E=10	N=82 48% E=13	N=16 53% E=12	N=5 62% E=14
21–25	N=21 55% E=18	N=54 54% E=16	N=25 63% E=16	N=13 61% E=20
26–30	N=12 57% E=18	N=26 59% E=18	N=28 67% E=21	N=15 72% E=15
≥31	N=13 68% E=19	N=35 69% E=22	N=28 81% E=13	N=27 81% E=13

TABLE 4.—*Probability of ceiling ≤2000 ft. as function of channel-2 temperature* T_2 *and cloud brightness* B *in watts* m.$^{-2}$, *based on passes 707, 708, 722, 750, 764, and 778*

B \ T_2°K.	≥260	259–250	249–240	≤239
≤20	4% N=255	2% N=82	0 N=16	0 N=5
21–25	33% N=21	14% N=54	24% N=25	31% N=13
26–30	17% N=12	23% N=26	43% N=28	33% N=15
≥31	31% N=13	43% N=35	64% N=28	48% N=27

TABLE 5.—*Probability of unlimited ceiling as function of channel-2 temperature* T_2 *and cloud brightness* B *in watts* m.$^{-2}$, *based on same passes as table 4*

B \ T_2°K.	≥260	259–250	249–240	≤239
≤20	69% N=255	44% N=82	31% N=16	40% N=5
21–25	24% N=21	22% N=54	12% N=25	23% N=13
26–30	17% N=12	12% N=26	11% N=28	13% N=15
≥31	23% N=13	11% N=35	4% N=28	0 N=27

4. SATELLITE RADIATION AND CEILING

If clouds are bright and have high (cold) tops, chances are that the ceilings will be low. If the radiation in channel 2 is high, and the brightness is low, it is probable that there are no or few clouds and the ceiling is unlimited. Tables 4 and 5 show the probabilities for ceilings below 2000 ft., and for unlimited ceilings (respectively) as a function of channel-2 radiation amount and cloud brightness for the March–April period in the eastern two-thirds of the United States. Again, the probabilities appear to be related to both variables. However, the dependence on channel-2 temperatures for a given cloud brightness is weak and erratic.

The probability of unlimited ceiling behaves in just the opposite way as the probability of ceilings below 2000 ft. With low cloud-top temperatures and large cloud brightness, there are no unlimited ceilings. In the opposite case of small brightness and large surface temperatures, the probability of unlimited ceiling is 69 percent.

5. SATELLITE RADIATION AND SKY COVER

Both cloud brightness and window temperatures are affected by the fraction of the sky covered; therefore, these two variables can be used as estimators of sky cover. Here, sky cover was obtained from surface observations.

Table 6 gives the relation between the three variables for the March period. In each box, the mean sky cover in tenths is given as a function of cloud brightness (B) and window temperatures (T_2). Again, both predictors clearly contribute to the estimate of sky cover, although there is large scatter in each box.

In particular, low cloud-top temperatures are recorded only when the sky is essentially overcast, so that the brightness does not contribute any information when this is the case; on the other hand, when the window radiation is large (low clouds or no clouds), brightness is clearly related to cloud cover, essentially because it differentiates between no clouds and low clouds.

Of course, radiation data are probably less efficient for the estimation of cloud cover than television pictures. It is only in the absence of television pictures that a table such as table 6 is useful.

6. CONCLUDING REMARKS

This paper has summarized a few, rather incomplete studies of relationships between various synoptic variables and satellite radiation data.

The purpose was to show that radiation in two wavelength bands in combination can be used to advantage in inferring the distribution of certain atmospheric characteristics. The results so far are fragmentary, and no definite statements can be made as to their generality; similar work is recommended for different periods and places.

TABLE 6.—*Mean cloud cover as function of channel-2 temperature T_2 and cloud brightness B in watts m.$^{-2}$. Number in center gives mean cloud coverage in tenths; upper right, number in each box; lower right, mean deviation. Based on same passes as table 4*

B \ T_2°K.	≥260	259–250	249–240	≤239
≤20	N=255 4.8 E=3.6	N=82 6.7 E=2.7	N=16 8.8 E=1.7	N=5 9.8 E=0.3
21–25	N=21 7.3 E=2.9	N=54 7.6 E=2.3	N=25 8.6 E=2.0	N=13 9.1 E=1.5
26–30	N=12 6.5 E=3.0	N=26 8.5 E=1.6	N=28 8.8 E=1.8	N=15 9.1 E=1.5
≥31	N=13 8.5 E=2.6	N=35 8.6 E=2.0	N=28 9.7 E=0.5	N=27 9.8 E=0.4

The paper is not intended to suggest specific applications of satellite radiation data to meterological analysis in regions of sparse data; instead, certain relationships are indicated which may point to methods of developing such techniques in the future.

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