NASA CR-
147743

TECHNICAL MEMORANDUM

WATER VAPOR AS AN ATMOSPHERIC ATTENUATOR TO THE SATELLITE-OBSERVED SPECTRAL RADIANCE

Job Order 92-105

Prepared By

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Contract NAS 9-12200

For

HEALTH APPLICATIONS GROUP
LIFE SCIENCES DIRECTORATE

National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER
Houston, Texas

April 1976

LEC-8478

TECHNICAL REPORT INDEX/ABSTRACT
(See instructions on reverse side.)

1. TITLE AND SUBTITLE OF DOCUMENT TECHNICAL MEMORANDUM WATER VAPOR AS AN ATMOSPHERIC ATTENUATOR TO THE SATELLITE-OBSERVED SPECTRAL RADIANCE	2. JSC NO. JSC- 11163
3. CONTRACTOR/ORGANIZATION NAME Lockheed Electronics Co., Inc.	4. CONTRACT OR GRANT NO. NAS 9-12200
5. CONTRACTOR/ORIGINATOR DOCUMENT NO. LEC-8478	6. PUBLICATION DATE (THIS ISSUE) April 1976
7. SECURITY CLASSIFICATION Unclassified	8. OPR (OFFICE OF PRIMARY RESPONSIBILITY) C. M. Barnes
9. LIMITATIONS GOVERNMENT HAS UNLIMITED RIGHTS [X] YES [ ] NO IF NO, STATE LIMITATIONS AND AUTHORITY N/A	10. AUTHOR(S) W. V. Abeele
11. DOCUMENT CONTRACT REFERENCES	12. HARDWARE CONFIGURATION
WORK BREAKDOWN STRUCTURE NO. N/A	SYSTEM N/A
CONTRACT EXHIBIT NO. N/A	SUBSYSTEM N/A
DRL NO. AND REVISION N/A	MAJOR EQUIPMENT GROUP N/A
DRL LINE ITEM NO. N/A	

13. ABSTRACT

This document summarizes the importance of precipitable water as an atmospheric attenuator to the satellite-observed spectral radiance.

14. SUBJECT TERMS

Water Vapor
Meteorological Satellite
NOAA-4 Satellite

Contract NAS 9-12200
Job Order 92-105
JSC-11163

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INTRODUCTION

The ability to gather meteorological information has expanded greatly with the advance of satellites. Instrumentation advances have made monitoring of total water vapor content in the atmosphere possible. Water vapor and other atmospheric constituents such as ozone and carbon dioxide will attenuate the emitted radiation before it reaches the satellite sensor system. Correction for these atmospheric attenuations is a major problem in measuring temperatures by way of remote sensing. The progress made in instrumentation is unable to counterbalance the difficulties encountered in obtaining vapor data with sensors and the large amounts of computer time required. Consequently, a way had to be devised to integrate some parameter related to the assumed water vapor content of the atmosphere.

In order to do this, an investigation of the assumptions involved in the attempt to relate radiometric temperatures to daily mean air temperatures (DMAT) is necessary. The first assumption is that the instantaneous radiometric surface measurement is representative of the air temperature above it. The second is that a maximum of two daily estimates of air temperature will be representative of the DMAT. The third is that the attenuation due to several atmospheric constituents will be a constant, regardless of the concentration of these constituents or the nadir angle.

As weak as these assumptions may seem to be, they provided usable data for the estimation of the DMAT, using the radiometric temperature above the stations at satellite passage as an independent variable and the recorded ground truth temperature at the stations as the dependent variable in a regression analysis. As a result, DMAT estimates could be calculated for the entire scanned region.

In July 1975, regression studies performed at the Johnson Space Center showed that the inclusion of altitude as a variable improved the standard error of estimate considerably. Further improvements were suspected if a way could be found to include moisture as a variable instead of a constant correction, since water vapor is the common atmospheric constituent whose concentration is most subject to variation. Of course, extremely critical is the fact that water vapor is opaque to infrared radiation, the "atmospheric window" cancelling this effect only partially.

EVALUATION OF DAILY MEAN AIR TEMPERATURE (DMAT) ESTIMATES

The parameter, chosen to relate to the assumed water vapor content of the atmosphere, is the pressure of aqueous vapor over water, the temperature of said water being equated with the dew point at the considered station at satellite passage.

Estimates of DMAT, using sets of coefficients derived from multiple linear regression studies are converted from data obtained by the NOAA-4 satellite. Depending upon the amount of cloud-free data gathered during the twice daily satellite passage, three basic methods were used to calculate DMAT—

1) Both Day and Night Radiometric Data Available

$$DMATK = A_0 + A_1 * NK + A_1 * DK + A_3 * AL + A_4 * VP$$

2) Day Radiometric Data Only is Available

$$DMATK = B_0 + B_2 * DK + B_3 * AL + B_4 * VP$$

3) Night Radiometric Data Only is Available

$$DMATK = C_0 + C_1 * NK + C_3 * AL + C_4 * VP$$

where the symbols are defined as follows:

DMATK	—	Daily mean air temperature in degrees Kelvin
DK	—	Day radiometric temperature in degrees Kelvin
NK	—	Night radiometric temperature in degrees Kelvin
AL	—	Altitude in meters
VP	—	Vapor pressure in mmHg
A_i B_i C_i	—	Multiple regression coefficients

ANALYSIS OF MODEL

To test the significance of moisture content of the air column between the observed surface and the sensor at the time of satellite passage, several regression studies were performed using data generated during the month of November 1975. Each of the three methods of calculation described previously were examined both with and without the approximation involving the calculated vapor pressure as a variable.

The regression studies were performed using as the dependent variable data obtained from the control stations shown in Table I. Summaries of these regression studies include the coefficient of determination and the standard error of estimate, and are described in Table II.

Using the regressions obtained with or without vapor pressure as an additional independent variable, an Analysis of Variance was performed to determine the significance of vapor pressure at satellite passage as a regression variable. As a result, vapor pressure at satellite passage was found to be extremely significant. The highest significance occurred when both radiometric measurements were available and the lowest significance was found when night radiometric data only was available.

Obtaining vapor pressure at the time of satellite passage could, however, be impractical in an operational situation. Therefore, another series of regression analysis were performed using monthly average vapor pressure as an independent variable. As can be seen from Table III, this model did not bring about any significant improvement.

An attempt was also made to use the daily average vapor pressure when night radiometric data alone was available. It is not sure yet if this method would be much more practical in an operational situation than the use of the calculated vapor pressures at the time of satellite passage. As can be seen from Table IV, an extremely significant improvement was again obtained. These data were taken during the month of December 1975.

CONCLUSION

Using the three different methods of calculation at satellite passage, the best regression results were obtained when both radiometric passes were available. Average performance in this case was near 1.8°C standard error of estimate. The performance for the night and day radiometric data only was near 2.0° and 3.4°C respectively. The remaining big error for day only data is due to the fast heating of the soil surface on a cloudless morning (time of passage around 10 A.M.).

The standard error of estimate for the night radiometric data, taking the average daily vapor pressure into account, improved in December to 1.7°C. This study demonstrates that a standard error of estimate of less than 2°C is obtainable using radiometric data, altitude and daily average vapor pressure to estimate the daily mean air temperature.

TABLE I.— TEXAS CONTROL STATIONS

Station Name	Altitude	Avg. V. P. (Nov.)
Abilene	543 m	5.8
Waco	153 m	7.3
Midland-Odessa	868 m	5.1
Port Arthur	5 m	10.3
San Angelo	579 m	5.8
Houston	29 m	9.5
Austin	182 m	7.6
El Paso	1192 m	3.7
San Antonio	240 m	7.9
Victoria	32 m	10.3
Del Rio	313 m	6.8
Corpus Christi	12 m	12.3

TABLE II.— INCLUSION OF VAPOR PRESSURE IN MULTIPLE LINEAR REGRESSION ANALYSIS; ANALYSIS OF VARIANCE BASED ON INCLUSION OF INSTANTANEOUS VAPOR PRESSURE

A) When night radiometric data is available

	DF	SS	MS	F
Due to regression (max. model)	3	1074.36		
Due to regression (normal model)	2	1040.01		
Difference	1	34.35	34.35	8.42**
Deviation from regression (max.)	81	330.29	4.08	
Deviation from regression (normal)	82	364.64		
Total	84	1404.65		

Coefficient of determination:

$R^2 = 0.76$ (when V.P. is one of the independent variables)

Standard error of estimate:

$S = 2.02$

**Very significant

B) When day radiometric data is available

	DF	SS	MS	F
Due to regression (max. model)	3	1225.15		
Due to regression (normal model)	2	1025.96		
Difference	1	199.19	199.19	17.6***
Deviation from regression (max.)	24	271.61	11.32	
Deviation from regression (normal)	25	470.79		
Total	27	1496.76		

Coefficient of determination:

$R^2 = 0.82$ (when V.P. is one of the independent variables)

Standard error of estimate:

$S = 3.36$

***Extremely significant

TABLE II.— INCLUSION OF VAPOR PRESSURE IN MULTIPLE LINEAR REGRESSION ANALYSIS; ANALYSIS OF VARIANCE BASED ON INCLUSION OF INSTANTANEOUS VAPOR PRESSURE (Cont.)

C) When both are available

	DF	SS	MS	F
Due to regression (max. model)	4	1727.27		
Due to regression (normal model)	3	1641.60		
Difference	1	85.67	85.67	26.75***
Deviation from regression (max.)	42	134.51	3.20	
Deviation from regression (normal)	43	220.18		
Total	46	1861.78		

Coefficient of determination:

$R^2 = 0.93$ (when V.P. is one of the independent variables)

Standard error of estimate:

$S = 1.79$

***Extremely significant

TABLE III.— INCLUSION OF AVERAGE MONTHLY VAPOR PRESSURE IN MULTIPLE LINEAR REGRESSION ANALYSIS; ANALYSIS OF VARIANCE BASED ON INCLUSION OF AVERAGE MONTHLY VAPOR PRESSURE

	DF	SS	MS	F
A) When night radiometric data is available				
	DF	SS	MS	F
Due to regression (max. model)	3	1040.06		
Due to regression (normal model)	2	1040.01		
Difference	1	0.05	0.05	0.003A
Deviation from regression (max.)	81	364.59	15.19	
Deviation from regression (normal)	82	364.64		
Total	84	1404.65		
B) When day radiometric data is available				
	DF	SS	MS	F
Due to regression (max. model)	3	1077.37		
Due to regression (normal model)	2	1025.96		
Difference	1	51.41	51.41	2.94A
Deviation from regression (max.)	24	419.38	17.47	
Deviation from regression (normal)	25	470.79		
Total	27	1496.76		
C) When both are available				
	DF	SS	MS	F
Due to regression (max. model)	4	1642.17		
Due to regression (normal model)	3	1641.60		
Difference	1	0.57	0.57	0.11A
Deviation from regression (max.)	42	219.61	5.23	
Deviation from regression (normal)	43	220.18		
Total	46	1861.78		

Anot significant

TABLE IV.— ANALYSIS OF VARIANCE BASED ON INCLUSION OF DAILY AVERAGE VAPOR PRESSURE IN MULTIPLE LINEAR REGRESSION ANALYSIS

	DF	SS	MS	F
Due to regression (max. model)	3	1767.11		
Due to regression (normal model)	2	1657.65		
Difference	1	109.46	109.46	37.52***
Deviation from regression (max.)	50	145.87	2.92	
Deviation from regression (normal)	51	255.33		
Total	53	1912.98		

Coefficient of determination

$R^2 = 0.92$

Standard error of estimate

$S = 1.71$

***Extremely significant

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