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PROGRESS REPORT
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VISSR Atmospheric Sounder (VAS)
Development and Performance Evaluation

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for

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Goddard Space Flight Center
Greenbelt, MD

I. General

On May 26, 1981, P. Menzel and W. Smith travelled to Greenbelt, MD to participate in a discussion of VAS data distribution. UW/NESS emphasis was placed on data distribution in near real time to the operational branches of the weather services (NSSFC in Kansas City and NMC in Washington, D.C.) where operational evaluation of VAS data products should begin as soon as possible. Mechanisms for the data transfer (remote McIDAS user terminals, phone line data transfers, magnetic tapes) were identified and funding for these activities was discussed.

On July 20, 1981, P. Menzel travelled to Wallops Island, VA for a site visitiation and to give a talk on the early scientific results from the VAS.

II. Data Processing

From June through September of 1981, following the May 22, 1981 launch of GOES-5, the best and most complete VAS data has been gathered. During the routine reception in the latter half of July, the volume of data per day was very large (imaging dwell sound every 30 minutes) and thus the thrust of the efforts at UW during this period was focussed on improving the timeliness of the meteorological data made available from the VAS radiometric measurements. More recently, in September, data gathering over hurricanes was emphasized.

On June 9 the first VAS images were received from GOES-5; a few calibration and navigation problems had to be resolved before the first retrievals were generated. June 22 yielded the first useable VAS dwell sounding. The first good relatively long sounding sequence (1200-1800 GMT) was received on July 1; temporal changes were readily demonstrated with this data. After the engineering checkout was satisfactorily completed, a simple processor data load schedule for the normal operation was agreed upon by UW, NESS, and GSFC. Daily 1200 to 2100 GMT reception started in mid July. It was found that full retrievals take an hour or more and use supporting data; with new data being received possibly every 15 or 30 minutes, the need for quick access was recognized. An existing scheme, previously tested on NOAA-6 data, (see: Smith and Zhou "Rapid Extraction of Layer Relative Humidity, Geopotential Thickness, and Atmospheric Stability from Satellite Sounding Radiometric Data", submitted to Applied Optics) was applied to the VAS observations. The resulting fields, including an approximation to the Total-Totals stability index, can be obtained and displayed in only 10 to 15 minutes with these fast retrievals.

The fast retrieval method was tried in a nowcasting exercise coordinated with the SFSS in Kansas City; preliminary work on a few test days to evaluate the VAS usefulness in application to severe weather problems has begun. July 20 data has been investigated, both with full retrievals every 3 hours and fast retrievals each hour; the VAS results appear very useful as part of the information base necessary to correctly forecast the severe activity near St. Louis that day (see the attached paper). July 13, 16, and 22 are other days being investigated.

Since the beginning of September, GOES-5 has been operating with the VAS hurricane schedule whenever hurricanes are present in the tropics. This schedule cancels every sixth operational VISSR image to enable a VAS dwell sounding. It is the goal of this activity to monitor hurricane development and progress by analyzing convergence/divergence, vertical instability, vertical wind shear, moisture convergence, steering currents and other important aspects of hurricanes. Three-hourly sounding extending 1500 km north-south are frequent enough to cover significant developments. So far, data from Emily, Gert, Harvey, Irene, and Jose have been gathered.

Harvey was observed in real time at UW thorugh the eyes of the VAS and TIROS sounding instruments. The microwave sounding data from TIROS enabled, for the first time, the intensity of a hurricane to be monitored from space quasi-continuously. The magnitude of the maximum temperature and the areal coverage of the warm upper tropospheric vortex at the eye of the storm were observed through Harveys life cycle. There was near perfect correlation between the curl of upper tropospheric temperature observed by the microwave sounding unit and the minimum surface pressure and maximum winds observed by aircraft reconnaisance.

III. VAS Algorithm Development

The availability of a number of superior dwell sound data sets, in particular during July 1981 with GOES 5, has facilitated experiments in the extraction of meteorological data. The most noteworthy finding is the high sensitivity of the retrieval algorithms to surface effects. A general cold bias (reported previously) persists in the window channels reading to low level temperatures which are too warm and too moist in an absolute sense. The errors introduced in the retrieved atmospheric profiles are almost unnoticeable for moderate skin temperatures and low terrain, but they are highly amplified by hot skin temperatures and high terrain. Beginning in October the computation of skin temperature will be done with an empirical regression relationship derived from VAS measurements and surface ship reports. This method will replace the previous regression relationship based on simulated radiances. The cause of the cold bias remains unexplained.

Software was prepared to permit an operator to arbitrarily change estimates of surface skin temperature or terrain height in order to learn more about the sensitivity of the retrieval algorithm. From this we learned that the 100 km resolution of our topography is inadequate for accurate retrievals over rugged terrain. Provisions are being made to introduce much higher horizontal resolution.

As indicated earlier, full scale processing of DS mode data was found to be a time consuming process and several steps were taken to ease the burden on both machine and operator. For complete temperature/moisture retrieval the process was semi-automated so that it does not require continual human intervention. In addition algorithms were developed to make limited retrievals for a somewhat more rapid look at the data. The most successful of these is a relative humidity package which produces three layers of relative humidity, two levels of thickness, and an atmospheric stability parameter in approximately 10 minutes. This program can be run in real-time hourly VAS DS mode whereas the full retrieval program cannot.

The capability of the VAS system to delineate the temporal variation of moisture exceeds our expectations. Continued development in exploiting this capacity should lead to a major improvement in the short-term forecast of severe weather. Typically, the high accuracy is in terms of relative rather than absolute moisture, but the relative accuracy holds temporally as well as spatially so that it is possible to monitor increase (or decrease) in the total moisture as well as any meandering from one time period to the next. It should be stressed again, however, that the accuracy of quantitative estimates depends strongly on the proper determination of the surface temperature.

Two cases of DS retrievals for April 1980 over the eastern Pacific (GOES-4) were given to NMC for evaluation in a forecast impact study. Early returns suggest that an improved forecast resulted, but the NMC has not yet come forth with a definitive statement.

IV. VAS Instrument Support

A post launch spin budget was evaluated from the engineering checkout data of June 9,1981. The autocovariance of the noise agreed very well with prelaunch estimates as did the spin budget. Table I shows the prelaunch and postlaunch comparisons. Only the results of the lower large detectors are shown; the upper large detectors exhibited similar behavior. Analysis of July 14,1981 space view yielded identical results; the spin budget appeared to be stable through the summer months. Analysis of the small detector noise characteristics was not completed due to problems at the ground station during engineering checkout.

The electronic calibration waveform was analyzed; all eight successive calibration ramps were observed. The average ramp slope was found to be .309 volt/msec (within 1 % of the specified value) and the average plateau was determined to be 4.44 volts (within 2% of the specified value). As with VAS-D the observed noise level for band 8 is noticeably lower than the other bands, while for band 9 it is noticeably higher.

The VAS-E radiances were compared to the LFM analysis of radiosonde data over a period covering several months. Table II shows the comparison. Data for the window bands is not presented because no reliable surface analysis was available. The relative errors are around 1.0°C except for the noisy bands 1,2,9 and 11 and are within the expected accuracy of the comparison. The large negative bias of 3°C observed for VAS-D in bands 2 though 4 is reduced considerably for VAS-E: also the relative errors for VAS-E are noticeably smaller than those of VAS-D in a similar analysis. Intercomparison with TIROS soundings are still underway. Comparisons of VAS retirevals with the NOAA/ERL ground based microwave profiles are also being made.

Table I

Inflight Spin Budget of VAS-E Large Detectors

Band	σ(erg/etc)		Spin Budget*	
	Inflight	Prelaunch	Inflight	Prelaunch
1L	2.86	3.00	1	2
2L	1.55	1.52	7	7
3L	1.19	1.11	4	4
4L	1.07	.99	3	3
5L	.90	.84	3	2
6L	.023	.025	6	7
7L	.73	.70	2	2
8L	.06	.10	1	1
9L	.72	.68	4	4
10L	.15	.15	1	1
11L	.024	.026	6	8
12L	.007	.008	1	1
			39	42

*for sounding in 30 x 30 km area, except 150 x 150 km area for band 1.

Table II

VAS-E Radiances (brightness temperatures)
Compared to Radiances (brightness temperatures)
Determined from LFM Analysis of Radiosonde Data

Band	$B^{-1}(R_{LFM}) - B^{-1}(R_{VAS})$	
	abs (°C)	rel(°C)
1	- .5	2.8
2	- 1.6	1.4
3	- 1.7	1.0
4	- 1.6	.9
5	.0	.6
6	- 2.9	.7
7	-	-
8	-	-
9	- .0	1.5
10	- 1.4	.7
11	- 5.2	2.6
12	-	-

V. Numerical Model Studies

Regarding the ANMRC limited-area model on NCAR's CRAY-1 computer, the main landmark during the past three months or so has been three comparative experiments in the 10 - 11 April 1979 case study, indicating a beneficial impact of TIROS-N temperature (thickness) data from the three orbits available near 21Z 10 April over the U.S. mainland and eastern Pacific.

In late May 1981, a cleaned-up control experiment had been performed, integrated over 12 hr from 12Z on 10 April to 00Z on 11 April. The initial state was an interpolated 12Z LFM analysis, without modification by the FIB (Field Information Blending) analysis scheme of ANMRC. The control run and the comparative experiments each used 5-min time steps, turned on the broad-scale (non-convective) precipitation option, and handled the horizontal gradients of geopotential and pressure (in the momentum equations) with an improved numerical scheme that helps preserve accuracy and reduce noise over steep topography.

Each comparative data-impact experiment was initialized by putting the post-processed 9-hr (21Z 10 April) control forecast, interpolated from the model's sigma levels to standard pressure levels, through the FIB analysis and then integrating out 6 hr further to 03Z 11 April. Each run blended the MSLP (mean sea level pressure) field by feeding in station observations that had been interpolated on McIDAS to each sub-satellite point, to help suppress imbalances in the mass field. The experiments differed in satellite temperature coverage -- full coverage in the first 9 - 15 hr run, no coverage in the second, and partial coverage of roughly one-sixth in the third. Microfilmed displays of selected fields (MSLP, 850-mb dewpoint and dew point depression, 500-mb height and wind speed, 250-mb height and windspeed, 1000-500 mb thickness, and vertical velocity on mid-level sigma surfaces) have indicated that inclusion of full satellite temperature data yielded significantly better 00Z results than the

9-15 hr run with no TIROS-N temperatures, and that putting only the sub-satellite MSLP data through FIB did not explain much of the improvement. The full-data experiment gave a much better central pressure (MSLP) for the Colorado low (1 mb too high) than did the no-data run (5 mb too low), using the interpolated 00Z LFM analysis as verification. Fields were much smoother, especially upper-air heights and wind speeds, and gravity-inertia oscillations of surface pressure were far smaller (typical amplitudes ~1 mb with full satellite data,~3 mb with no satellite data, over selected grid points in Colorado, well within the topographically toughest part of the model area). Vertical motion fields over Texas and Oklahoma were considerably more consistent with observed data, most notably radar displays and surface rainfall fields, with satellite data than without; around 00Z, mid-tropospheric upward motion was largest close to Wichita Falls, site of the day's most destructive tornado near that time, even though each 9-15 hr run started with no vertical motion since the FIB analysis winds were non-divergent, derived from a streamfunction. The full-coverage run also showed north-northeastward movement of the ascent core, and development of a secondary ascent core upstream of it, during 00-03Z, in reasonably good agreement with observations, even though the modeled Colorado low filled excessively during that time. Both the 12-hr control run and the 9-15 hr run with full TIROS-N coverage, especially the latter, gave better forecasts for the low center position and Texas dryline configuration at 00Z than had the 12-hr LFM forecast for 00Z; the LFM model had moved the low and dryline much too rapidly eastward, and had produced a much more diffuse dryline than the ANMRC model, possibly due in part to coarser horizontal resolution (LFM 190.5 km, ANMRC 67.6 km). Partial coverage model results are still under study as of this writing.

Chapter 3.4

NOWCASTING APPLICATIONS OF GEOSTATIONARY SATELLITE ATMOSPHERIC SOUNDING DATA

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1. INTRODUCTION

On September 9, 1980 the first VAS was launched into geostationary orbit aboard the GOES-4 satellite. VAS is a second order acronym standing for VISSR (Visible and infrared spin scan radiometer) Atmospheric Sounder. VAS in orbit initiated a new era during which the space and time distribution of the temperature and moisture of the atmosphere will be observed with unprecedented detail. On May 22, 1981, a second VAS was orbited aboard the GOES 5.

The VAS is capable of achieving multi-spectral imagery of atmospheric temperature and water vapor evolution over short time intervals (~15 minutes) and achieving quantitative vertical sounding of the atmosphere with high spatial (~75 km) and temporal (~1 hour) resolution. Most important for nowcasting applications, the multi-spectral imagery and vertical sounding data can be received, processed, and made available to weather forecasters in real-time.

The successful performance of VAS has already been demonstrated. Significant temporal and spatial variations of atmospheric temperature and moisture can be observed and retrieved with the anticipated accuracy of 1°C and 10%, respectively. As with other polar orbiting satellite (TOVS-TIROS Operational Vertical Sounder) soundings, the vertical resolution of the profiles is limited to several kilometers (Smith, et al, 1979). In this chapter we present a case study demonstrating the utility of this new geostationary satellite sounding capability for nowcasting, especially for the short term prediction of intense local weather.

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2. THE VISSR ATMOSPHERIC SOUNDER (VAS)

The VISSR Atmospheric Sounder (VAS) carried on the GOES is the result of a proposal by Suomi, et al, (1971) to sound the atmosphere from a geostationary spacecraft so as to observe the variations of atmospheric water vapor and temperature distribution. It senses thermal radiation emission from atmospheric water vapor and carbon dioxide at various atmospheric depths as well as from the surface of the earth and clouds. The VAS is a radiometer possessing eight visible channel detectors and six thermal detectors that sense infrared radiation in 12 spectral bands: seven bands for sensing the temperature profile from the ground to the 50 mb level, three bands for sensing the water vapor concentration of the low, middle, and upper troposphere, and two bands for sensing the temperature of the surface of the earth and clouds. A filter wheel in front of the detector package is used to achieve the spectral selection. The central wavelengths of the spectral bands lie between 3.9 and 15 μm. Housed in the GOES satellite, VAS spins in a west to east direction at 100 rpm and achieves spatial coverage at resolutions of 1 km in the visible and 7 or 14 km in the infrared (depending upon the detector employed) by stepping a scan mirror in a north to south direction (or vice versa).

Designed for multipurpose applications, the VAS can be operated in two different modes: 1) a Multi-Spectral Imaging (MSI) mode, and 2) a Dwell Sounding (DS) mode. Within each mode of operation there is a wide range of options regarding spatial resolution, spectral channels, spatial coverage, and the time frequency of observation. The mode of operation is programmed into an onboard processor from the ground through 39 processor parameters.

The DS mode of operation permits multiple samples of the upwelling radiance from a given earth swath in a given spectral band to be sensed by leaving the filter position and mirror position fixed during multiple spins of the spacecraft.

The DS mode of operation was designed to achieve the improved signal-to-noise ratios required to interpret the spectral radiance measurements in terms of vertical temperature and moisture structure. Spatial averaging of several 14 km resolution observations may be employed to improve further the sounding radiance signal-to-noise ratio. Details of the VAS inflight performance are provided by Menzel (1981).

The MSI mode of operation is intended to achieve relatively frequent (e.g., half hourly) full earth disc imagery of the atmospheric water vapor, temperature, and cloud distribution as well as variations in the surface skin temperature of the earth. In order to achieve full disc coverage at half hourly intervals two modes of operation are possible: (a) four spectral channels can be observed (the visible at 1 km resolution, the 11 μm window at 7 km resolution, and two others at 14 km resolution) or (b) five spectral channesl can be observed (the visible at 1 km resolution and any four infrared spectral channels at 14 km resolution).

For nowcasting applications a third mode of operation of the VAS has been programmed; the Dwell Imaging (DI) mode. The DI mode enables measurements in the tropospheric temperature and moisture sounding channels to be achieved over the North American region (20°to 55°N) every half hour. As will be shown later, the spectral coverage and accuracy of the data achieved in the DI mode is suitable for obtaining accurate quantitative measurements of lower and upper tropospheric relative humidity and geopotential thickness as well as atmospheric thermodynamic stability.

The VAS is capable of vertically sounding the atmosphere from a geostationary altitude of 36000 km with the same accuracy as that achieved by infrared sounders on polar orbiting spacecraft at an altitude of 1000 km. Initial results of the VAS vertical sounding capability have already been presented by Smith et al (1981) and Smith and Woolf (1981). The novel capability of the VAS is its ability to sense the temporal variations in atmospheric temperature and moisture as well as the small scale horizontal features.

Algorithms for deriving relative humidity and geopotential thickness have been developed (Smith and Zhou, 1981) to operate in real-time on the University of Wisconsin McIDAS (Man-computer Interactive Data Access System) which ingests VAS data in real-time. Also calculated in real-time is the atmospheric stability defined in terms of the Total-Totals index: $TT = 2(T_{85} - T_{50}) - D_{85}$, where $(T_{85} - T_{50})$ is the difference between the temperatures at the 850 mb and 500 mb levels and D_{85} is the 850 mb level dewpoint depression. From VAS, the Total-Totals is estimated from the lower tropospheric relative humidity and the 850-500 and 500-200 mb layer thickness calculated from the radiance observations. In general, each parameter is derived from an ensemble of twenty-five contiguous spatial samples (a 5 X 5 spatial matrix) of data providing a linear resolution of 75 km. To ensure freedom from cloud contamination, objective cloud checking and editing of the data is performed in the automated processing prior to the spatial averaging and calculation of meteorological parameters. After completion of the automated processing, a meteorologist at a McIDAS terminal rapidly inspects the results and subjectively eliminates any remaining erroneous data through cursor selection. For forecast applications, contour analyses of the results are then displayed over the imagery of preselected VAS channels.

3. A CASE STUDY SHOWING THE MESOSCALE MEASUREMENT CAPABILITIES OF VAS

Vas data obtained on 20 July, 1981 demonstrate the VAS nowcasting capabilities. Although half-hourly results were achieved, they are too numerous to present here; instead, three hourly results are presented. The overall synoptic situation is shown in Fig. 1; full disk (MSI) 11 μm window and 6.7 μm H_2O images were obtained on July 20 midday (1730 GMT).

The 11 μm image shows that the U. S. is largely free of clouds except near the U. S. - Canadian border where a cold front persists. However, in the upper tropospheric moisture image, a narrow band of moist air (delineated by the low radiance white areas of the image) stretches from the Great Lakes into the southwestern U. S.

Figure 2 shows contours of derived upper tropospheric relative humidity superimposed over the VAS 6.7 μm brightness temperature images. In this case the narrow band of moist upper tropospheric air stretching across northern Missouri is the southern boundary of an upper tropospheric jet core (Fig. 6). The southeastward propagation of this moist band and associated jet core is seen. The bright cloud seen along the Illinois - Missouri border in the 21 GMT water vapor image corresponds to a very intense convective storm which developed between 18 and 21 GMT and was responsible for severe hail, thunderstorms, and several tornadoes in the St. Louis, Missouri region.

An objective of the VAS real-time parameter extraction software is to provide an early delineation of atmospheric stability conditions antecedent to intense convective storm development. For this purpose a Total-Totals stability index is estimated as described previously. On this day, the atmosphere was moderately unstable over the entire midwestern U. S. yet intense localized convection was not observed during the morning hours. In order to delineate regions of expected intense afternoon convection, three hourly variations of stability (Total-Totals) were computed and displayed over the current infrared window cloud imagery on an hourly basis. Figure 3a shows the result for 18 GMT. The most notable feature is the narrow zone of decreasing stability (positive three hour tendency of Total-Totals) stretching from Oklahoma across Missouri and southern Illinois into western Indiana. Also shown on Fig. 3a are the surface reports of thunderstorms which occurred between 21 and 23 GMT. Good correspondence is seen between the past three hour tendency toward instability and the thunderstorm activity 3 to 5 hours into the future.

Figure 3b shows the one hour change in the Total-Totals between 17 GMT and 18 GMT. The greatest 1 hour decrease of atmospheric stability is along the northern Missouri-central Illinois border where the tornado producing storm developed during the subsequent three hour period (see Fig. 2d). The stability variation shown was the largest one hour variation over the entire period studied, 12-21 GMT.

Finally, a few detailed sounding results are presented for the Missouri region. The soundings were retrieved from VAS DS data with high spatial resolution (~75 km) using the interactive processing algorithms described by Smith and Woolf (1981). In Fig. 4 radiosonde observations of 700 mb temperature and 700 mb temperatures retrieved from GOES-5 VAS Dwell Sounding radiance data are presented for a region surrounding the state of Missouri on 20 July, 1981. Figure 5 shows a similar comparison for the 300 mb dewpoint temperature. As can be seen from the 12 GMT observations, the VAS, while being consistent with the available radiosondes delineates important small scale features which cannot be resolved by the widely spaced radiosondes. This is particularly obvious in the case of moisture (Fig. 5) where the horizontal gradients of dewpoint temperature are as great as 10°C over a distance of less than 100 km. The temporal variations of the atmospheric temperature and moisture over the Missouri region are well observed by the three hourly interval VAS observations presented in Figs. 2 and 5. Furthermore, in this case, the twelve hour interval radiosonde data provide little evidence of the diurnal variability. For example, in the case of the 700 mb temperature, the VAS observes a diurnal warming of the lower troposphere with a tongue of warm air protruding in time from Oklahoma across southern Missouri and northern Arkansas with maximum temperatures being observed around 18 GMT in this region. The diurnal variation of upper tropospheric moisture may be seen in Fig. 5; a narrow intense moist tongue (high dewpoint temperature) across northwestern Missouri steadily propagates southeastward with time. The dewpoint temperature profile results achieved with the interactive profile retrieval algorithm are consistent with the layer relative humidities achieved automatically in real-time (Fig. 2). It is noteworthy that over central Missouri, where the intense convective storm developed, the VAS observed a very sharp horizontal gradient of upper tropospheric moisture just prior to and during the storm genesis between 18 GMT and 21 GMT. Here again the inadequacy of the radiosonde network for delineating important spatial and temporal features is obvious. The VAS Dwell Sounding data provides, for the first time, the atmospheric temperature and moisture observations needed for the timely initialization of a mesoscale numerical model for predicting localized weather.

Figure 6 shows streamlines and isotachs of 300 mb gradient winds derived from the VAS temperature profile data. There is agreement (not shown) between the VAS 12 GMT gradient winds and the few radiosonde observations in this region. As can be seen there is a moderately intense subtropical jet streak which propagates east southeastward with time. Note that at 18 GMT the exit region of the jet is over the area where the severe convective storm developed. As shown by Uccellini and Kocin (1981), the mass adjustments and isallobaric forcing of a low level jet produced under the exit region of an upper tropospheric jet streak can lead to rapid development of a convectively unstable air mass within a 3 to 6 hour time period.

Figure 7 shows the three hour change of total precipitable water prior to the severe convective storm development. A local maximum exists over the location of storm prior to its development. It is apparent from Figs. 3b and 7 that the convergence of lower tropospheric water vapor is a major mechanism for the thermodynamic destabilization of the atmosphere leading to severe convection between 18 and 21 GMT along the Missouri-Illinois border.

4. CONCLUSION

The VAS geostationary satellite sounder offers exciting new opportunities for real-time monitoring of atmospheric processes and for providing on a timely basis the vertical sounding data at space resolution required for initializing mesoscale weather prediction models. Results from this case study and others not reported here indicate that VAS can detect several hours in advance, the temperature, moisture, and jet streak conditions forcing severe convective development. Unfortunately, in order to achieve the Dwell Imaging or Dwell Sounding multi-spectral data, the VAS cannot at the same time achieve full disk cloud imagery with the half hour frequency as has been the past operational practice. Consequently, a new geostationary satellite operating scenario is required. A program is being initiated by NESS to steadily integrate new VAS capabilities into daily operational practice. This will provide meteorologists with much more information about the varying state of the atmosphere than is provided by half-hourly imagery of the earth's cloud cover.

ACKNOWLEDGEMENTS

Thanks are extended to Messrs. G. S. Wade and A. J. Schreiner for their continual support in processing the VAS data. Appreciation for software assistance is extended to H. M. Woolf and C. M. Hayden of NOAA/NESS. Ms. Susan Francis and Ms. Vong Pui-sui assisted in the preparation of the manuscript.

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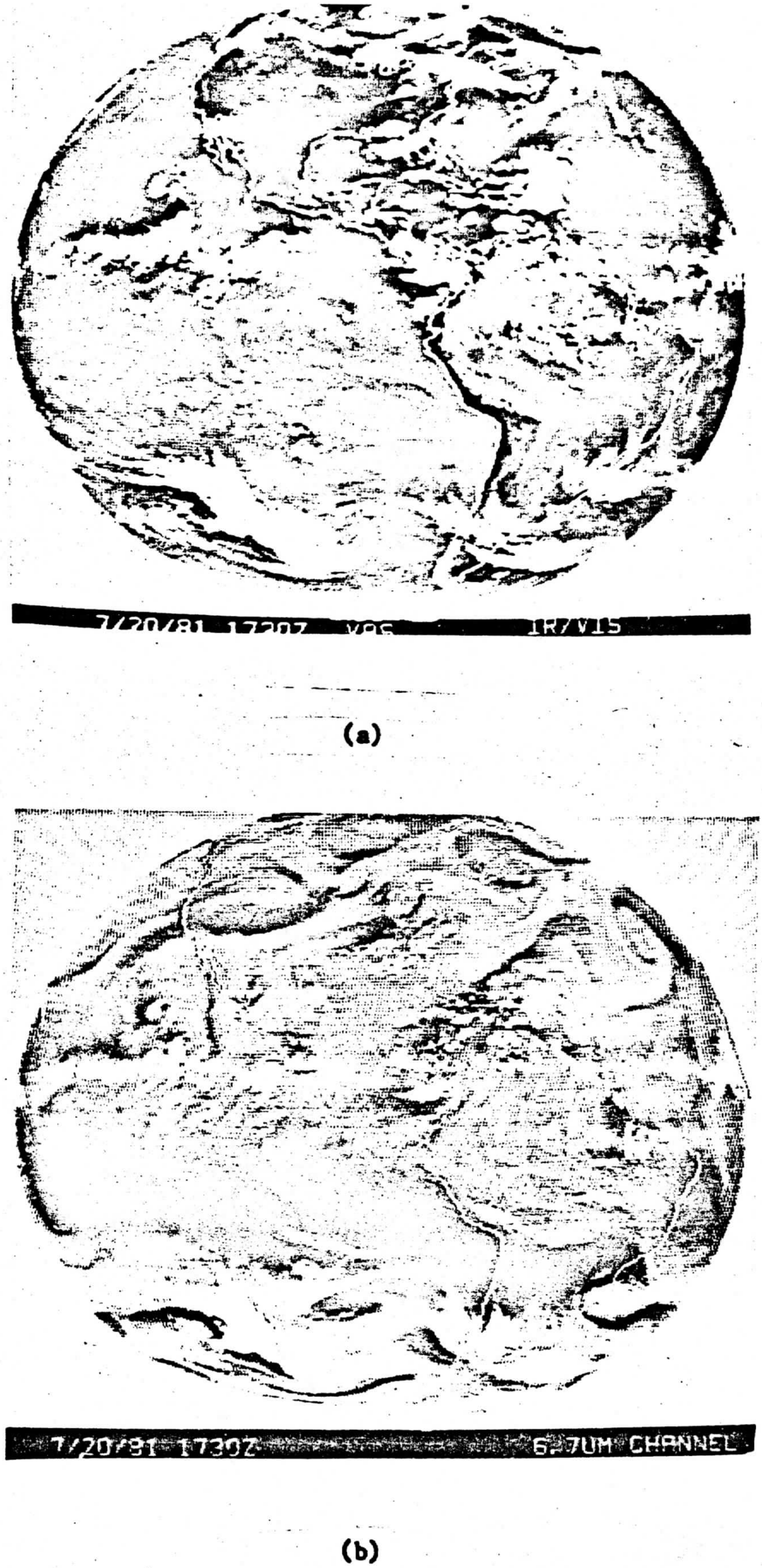
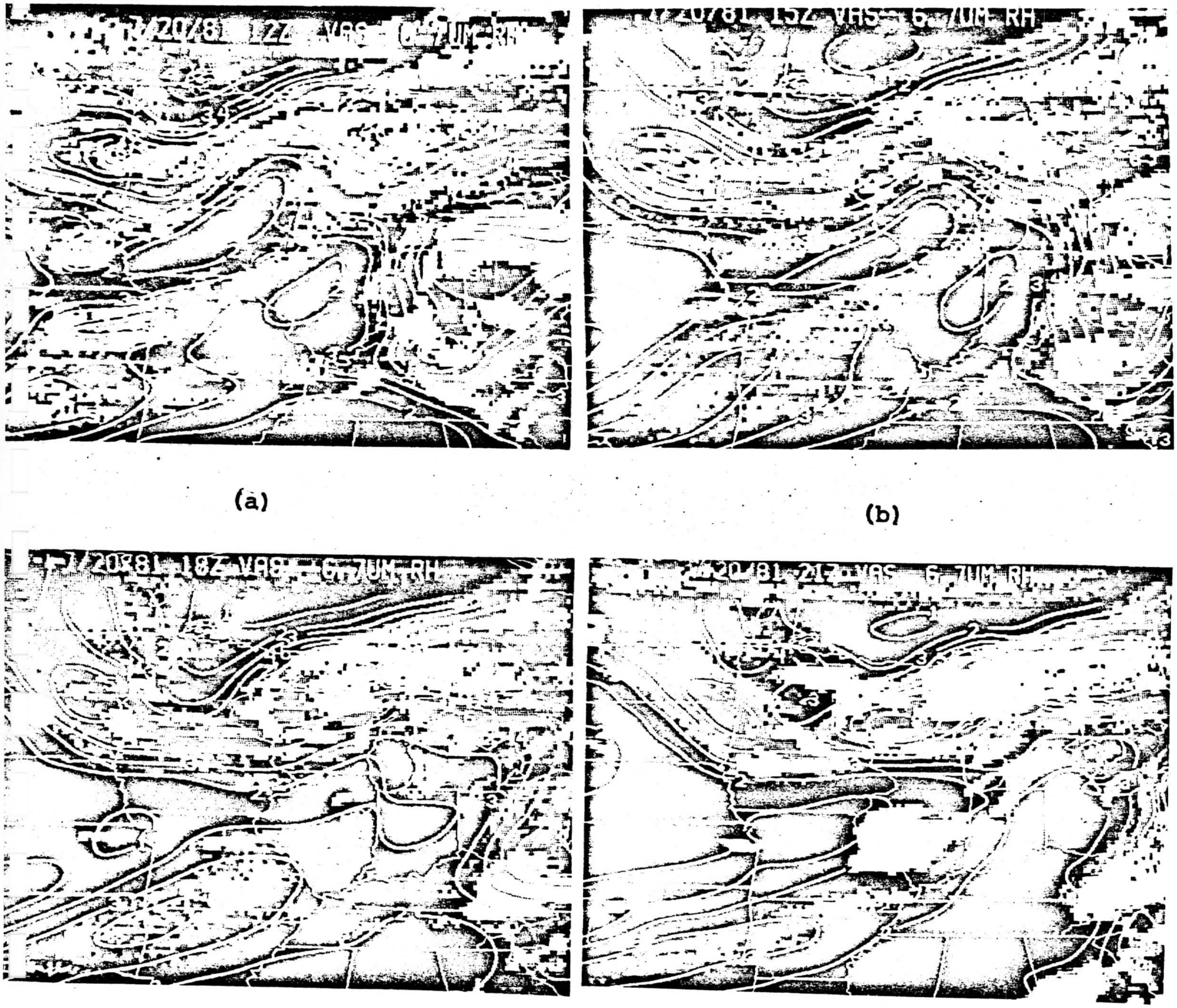


Fig. 1: Full disk images obtained on 20 July, 1981 between 1730 and 1800 GMT: (a) 11 μm window and (b) 6.7 μm H_2O.



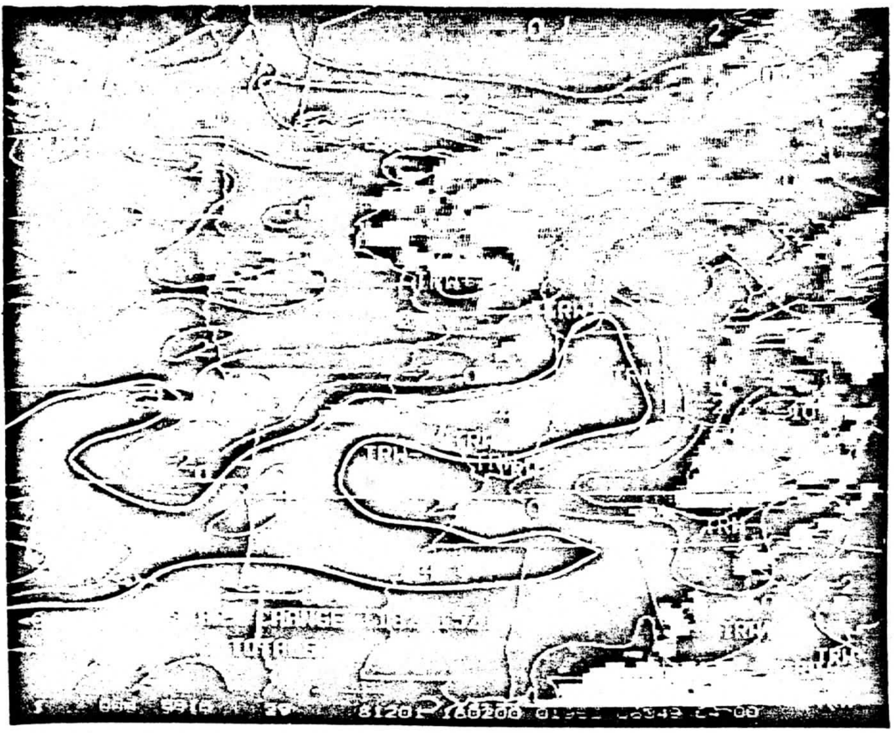
(a)

(b)

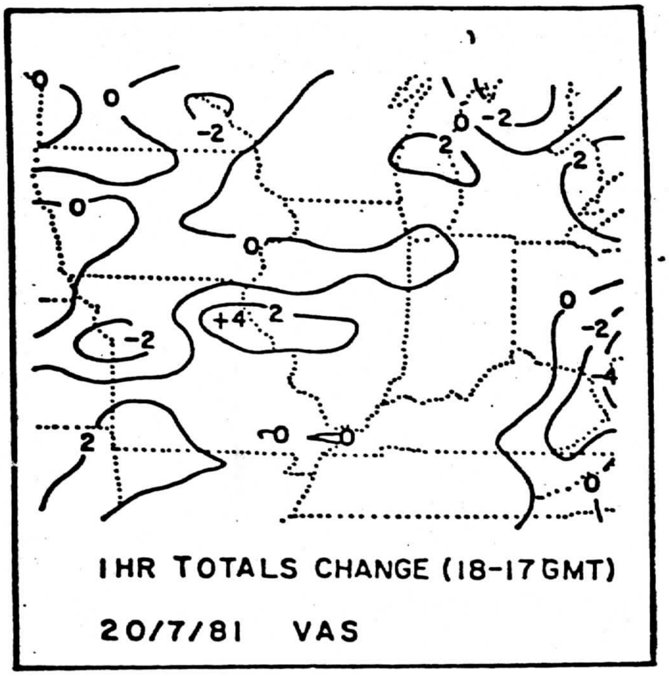
(c)

(d)

Fig. 2: Upper tropospheric relative humidity (%/10) over the VAS image of 6.7μm atmospheric water vapor radiance emission; (a) 12 GMT (b) 15 GMT (c) 18 GMT and (d) 21 GMT on 20 July, 1981.



(a)



(b)

Fig. 3 : (a) 3-hour variation of VAS derived Total-Totals (°C) between 15-18 GMT superimposed over the 18 GMT VAS 11μm image of cloudiness. The symbols of Thunderstorms (TRW) which were observed between 20 and 23 GMT are also shown, (b) 1-hour (17-18 GMT) variation of Total-Totals (°C) showing that the maximum one hour variation (4°C) observed by VAS on 20 July, 1981 occurred at the location of and just prior to the development of a severe convective storm.

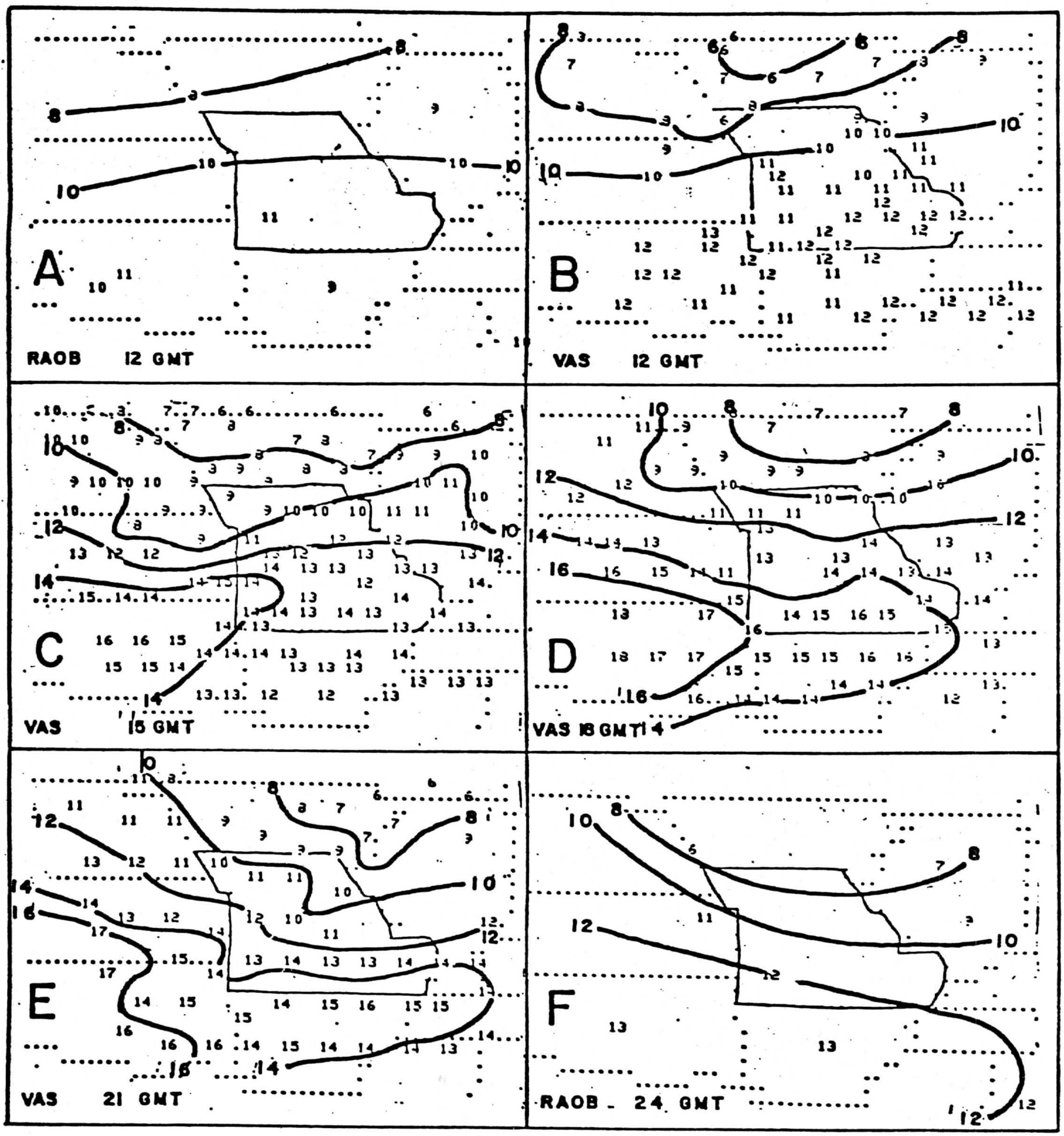


Fig. 4: Radiosonde and VAS observations of 700mb temperature (°C) on 20 July, 1981.

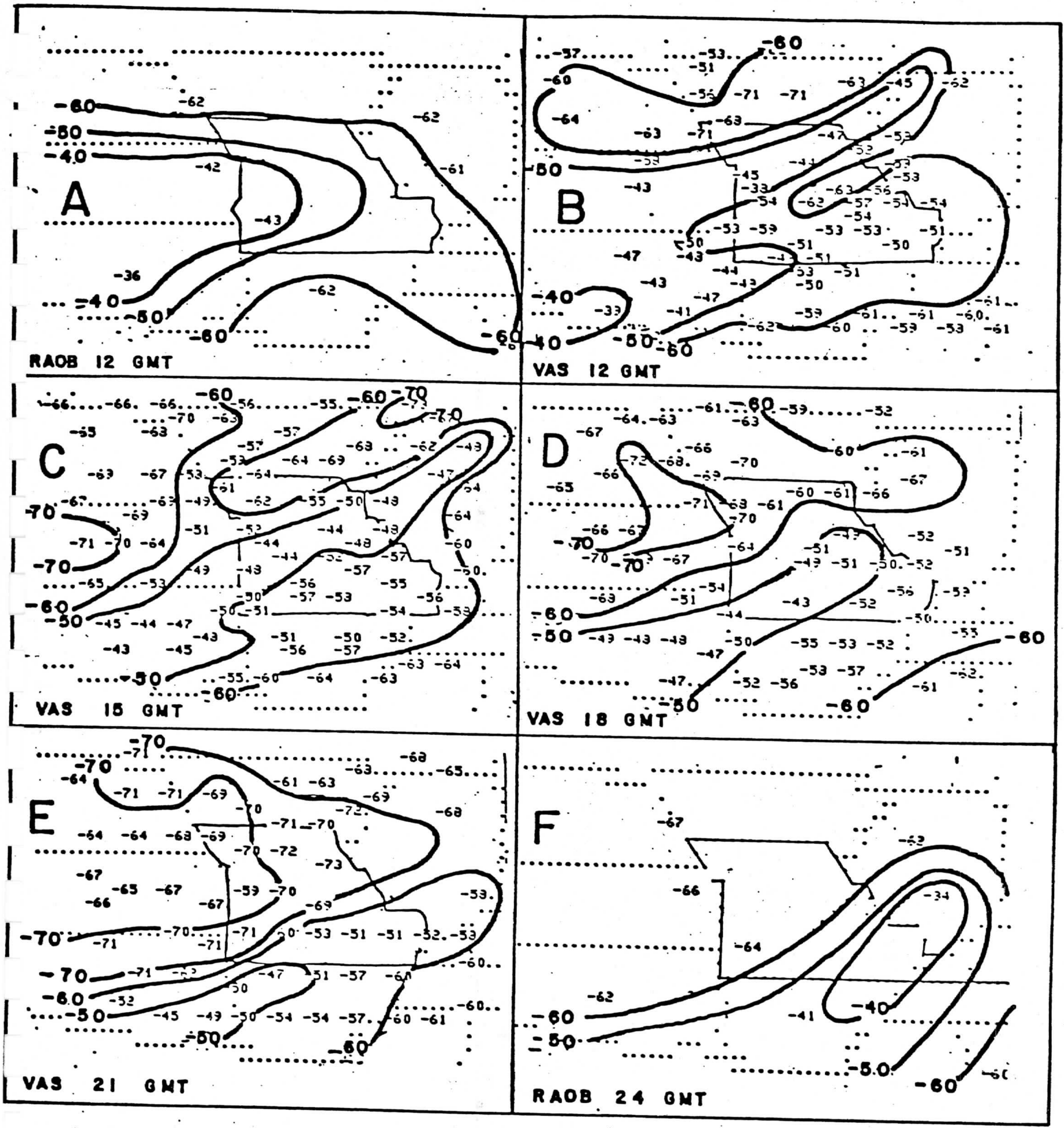
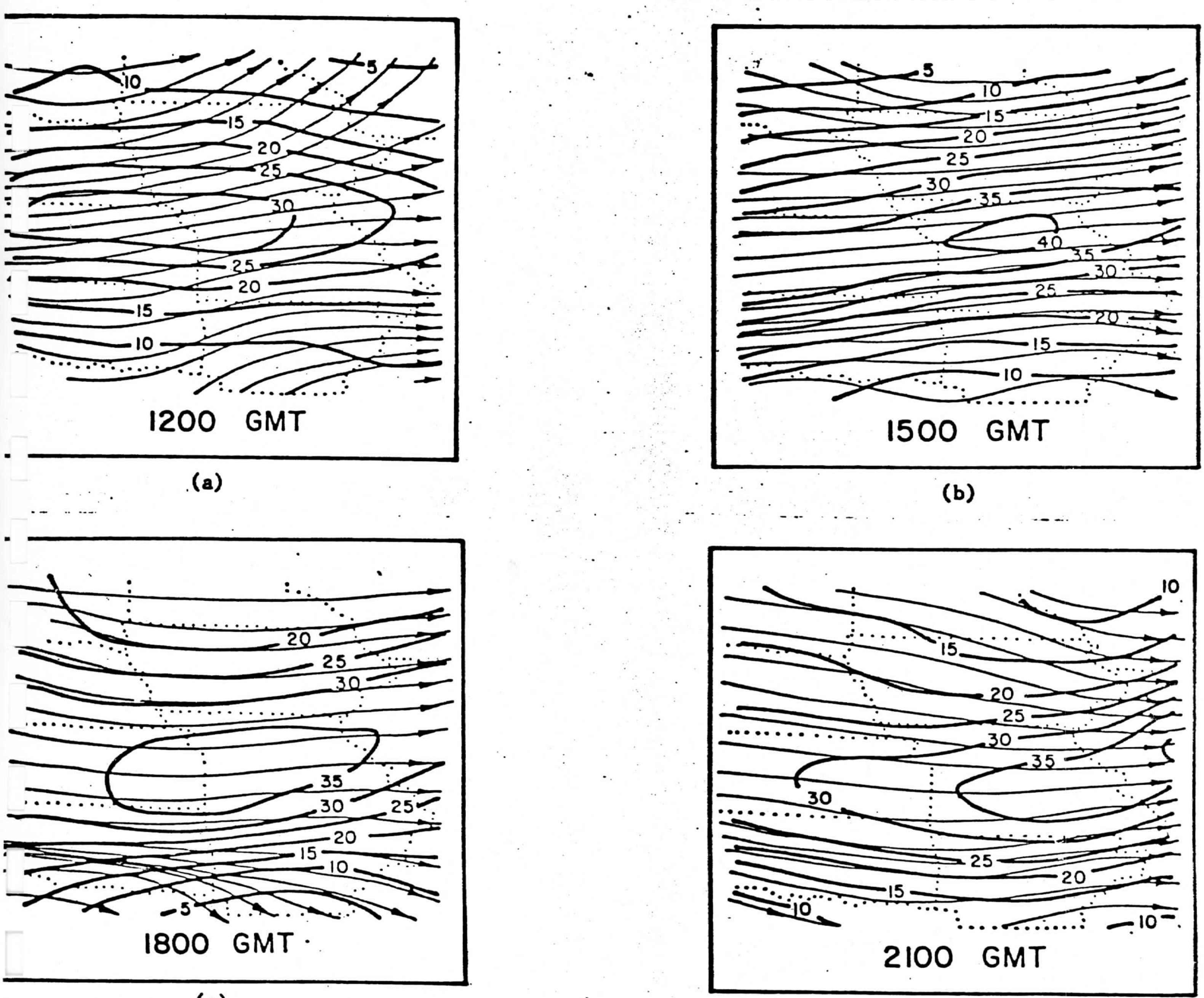


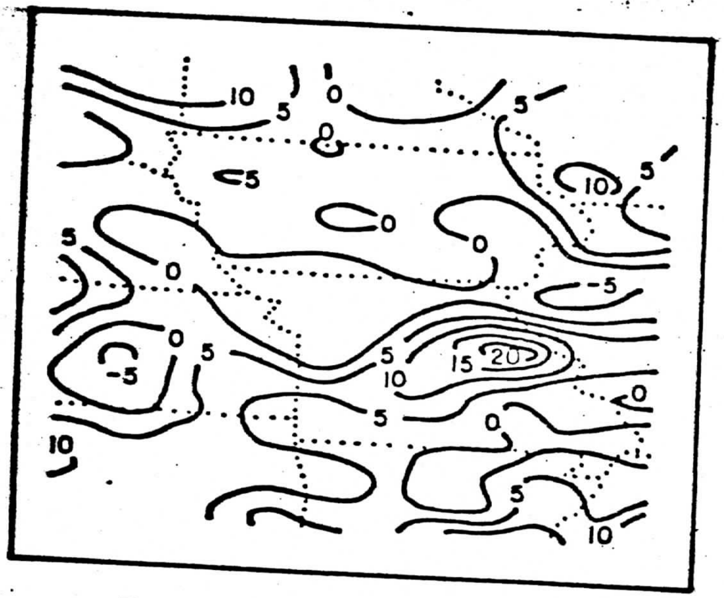
Fig. 5: Radiosonde and VAS observations of 300mb dewpoint temperature (°C) on 20 July, 1981.



(a) (b)

(c) (d)

Fig. 6: Streamlines and isotachs (meters/seconds) of 300mb gradient wind calculated from VAS temperature soundings: (a) 12 GMT, (c) 18 GMT, and (d) 21 GMT on 20 July, 1981.



Three hour change of precipitable water vapor (millimeters) between 15 and 18 GMT on 2 July, 1981.

SPACE SCIENCE AND ENGINEERING CENTER

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Madison, Wisconsin 53706
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October 12, 1981

Ms. Vanessa Scott
Code 269, Bldg. 16
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

Dear Ms. Scott:

In accordance with Article III of Contract NAS5-21965, I am submitting the required Progress Report for activities through September 1981.

If you have any questions or desire further information, please contact me at (608)262-6361.

Sincerely,

Paul Menzel

Paul Menzel
Program Manager

WPL:sf

Enclosure

cc: H. Montgomery, (10 copies)