EARTH AND PLANETARY ATMOSPHERIC CIRCULATIONS

VIEWED FROM SPACE

EDUCATIONAL MODULES

FOR THE

ATMOSPHERIC SCIENCES

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I. INTRODUCTION

This educational module, entitled "Earth and Planetary Atmospheric Circulations Viewed from Space," is designed for use in an introductory meteorology course. The objectives of the module are to: 1) introduce students to temporal and spatial scales of atmospheric phenomena using geosynchronous satellite imagery, 2) provide a perspective from space of the organization and evolution of weather systems and, 3) compare and contrast the atmospheric circulations of several planets in the solar system. The sequences of satellite imagery are intended to aid in the understanding of the atmospheric structure of the earth and other planets and to provide examples of the variety of spatial scales in their circulations.

The videocassette in this module is designed to be viewed and discussed during one class period. During its development at the University of Wisconsin-Madison, the module has been utilized in introductory meteorology courses for non-majors and in courses for undergraduate meteorology majors. Since the module contents are of interest to a broad audience, a number of possibilities exist for its utilization. In large groups (25 or more) several monitors should be arranged such that all viewers are able to see the detail in the images. To stimulate individual participation and to provide a more thorough investigation, the module may be shown and discussed in small groups. Student use of the more detailed synoptic descriptions included in this manual, in conjunction with the videocassette imagery, furthers investigations of greater depth and complexity. Additionally, individual student or class projects could be initiated from these cases.

II. DESCRIPTION OF THE MODULE CONTENTS

This module provides a brief investigation into a number of interesting and unusual atmospheric phenomena. Featured is a 28 minute videocassette showing satellite images displayed on the Man-computer Interactive Data Access System (McIDAS) at the University of Wisconsin-Madison. An audio track provides a basic discussion and interpretation of the imagery. Notes for student use in conjunction with the videocassette outline the sequence of images and provide a brief description of the features displayed. In addition to the videocassette and student accompaniment guide, this manual contains: 1) a brief description of the module contents, 2) a more detailed description of the atmospheric events displayed on the videocassette and, 3) a questionnaire through which students evaluate the educational value of the module and offer suggestions for its improvement.

III. VIDEOCASSETTE DISCUSSION

The utilization of videocomputers to display atmospheric circulation and processes adds an important visual dimension into atmospheric science education. At an introductory level this visual impact provides students with the insight needed for a comprehensive overview of the atmosphere.

The atmospheric events displayed in the videocassettes were chosen to provide a broad range of topics for discussion. The sequences portray spatial scale sizes ranging from the general circulation of a planet (thousands of kilometers) to regional cloud patterns (tens of kilometers). The following is a list of the videocassette contents.

1)	Full Earth Disk	November 1980
2)	Squall Line Development	May 1978
3)	Snowstorm (East Coast)	February 1980
4)	Snowstorm (Midwest)	April 1980
5)	Hurricane Allen	August 1980
6)	Cumulus Development/Ocean Seabreeze	March 1976
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12)	Earth Images (GOES-E)	November 1980
13)	Jupiter Images (Voyager I)	February 1979
14)	Saturn Images (Voyager II)	July 1981

IV. SYNOPTIC DESCRIPTIONS

1) Full Earth Disk November 1980

This sequence of visible and infrared images was obtained from the GOES-East geosynchronous satellite located 36,000 km above the equator at 75° west longitude. Map boundaries outline the North and South American continents and the western edge of Europe. Fig. 1 provides a simple schematic of the general circulation of the troposphere.

Visible imagery indicates the presence of extratropical cyclones over the North Atlantic Ocean, northwestern United States (Northern Hemisphere) and off the west coast of Chile (Southern Hemisphere). The semi-continuous line of

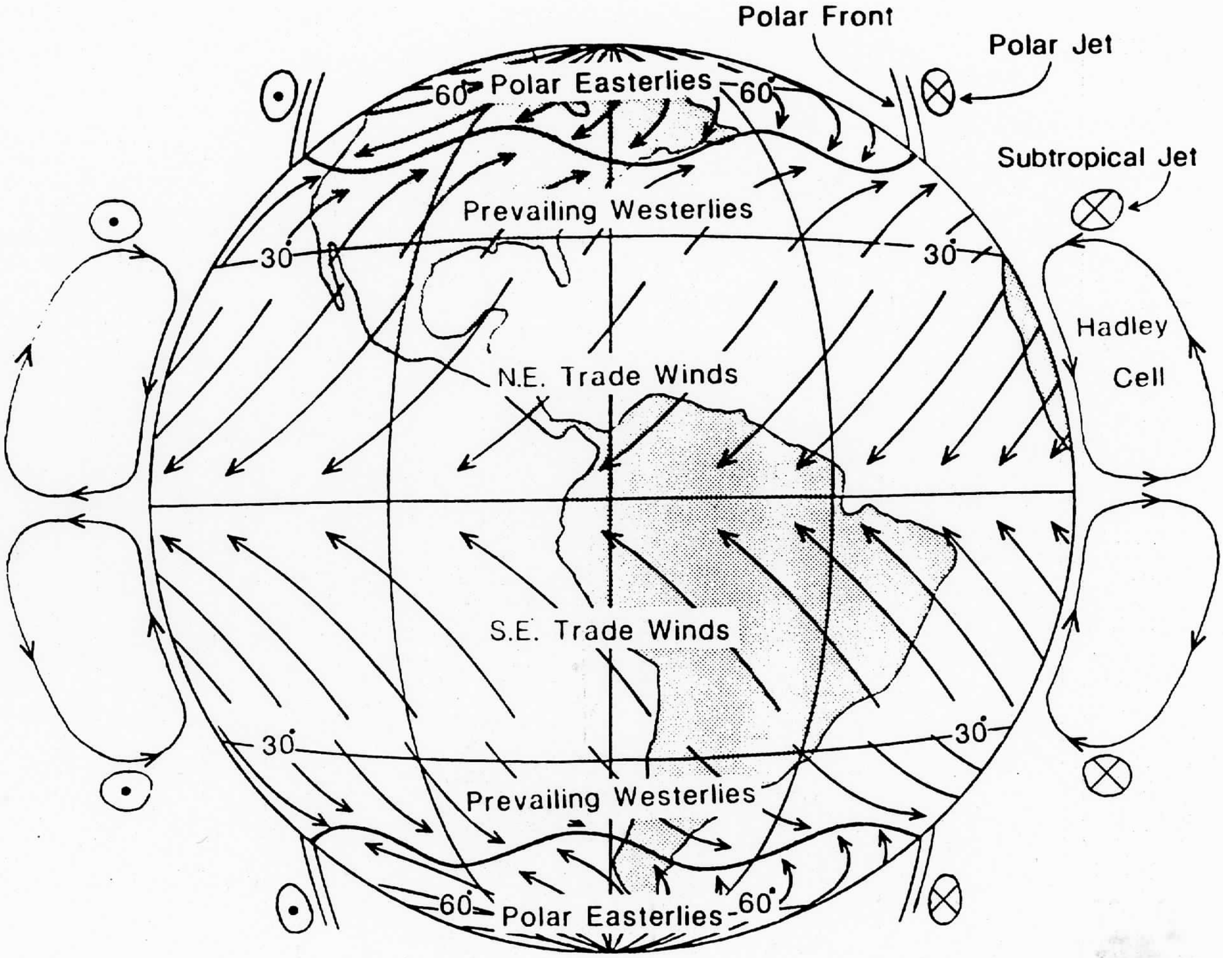

Figure 1. Graphic representation of the general circulation of the atmosphere. Mean position and direction of jet streams are indicated by circled X (into page) and circled dot (out of page).

convective clouds in the tropics, extending from the Atlantic Ocean across South America to the Pacific Ocean, indicates the position of the intertropical convergence zone (ITCZ). Combined use of the visible and infrared imagery aids in determining the relative height of these cloud formations and provides insight into their type and characteristics.

In the tropics, upper level cirrus clouds, associated with daytime convection over South America, trace the circulation of an upper tropospheric anticyclone. Surface heating in the Chilean desert is indicated by a darkening (warming) of the infrared imagery. The pattern of mid latitude westerly winds and subtropical surface easterlies (trade winds) exemplifies a portion of the large scale circulation in the western hemisphere. Note that in some tropical areas westerly winds aloft overlay the surface easterlies. The northeastward movement of the cloud mass off the southwest coast of Mexico suggests an interaction between the tropics and mid latitudes. Also in this region significant cross equatorial flow toward the northern and southern hemispheres can be inferred from cloud motions.

2) Squall Line Development May 1978

This sequence of images portrays a case of rapid cyclogenesis and intense squall line development that occurred on 12-13 May, 1978 over the Central Plains. The first image shows a disorganized cloud mass in the Northern Plains. During the afternoon and evening hours of 12 May the cyclone deepened from 1003 to 992 mb. An intense squall line developed from Illinois to eastern Texas, with cumulonimbus cloud tops extending vertically to more than 60,000 feet. Numerous severe weather events, including 25 confirmed tornadoes, were reported.

The cloud pattern associated with the Midwest cyclone development attains a classic comma shape in the late afternoon of 12 May. The squall line rapidly develops towards the southwest as the diurnal heating at the surface reaches a maximum. Thin lines of towering cumulus are visible on the southern edge of the squall line prior to thunderstorm development. The large scale clearing behind the squall line is due to subsidence associated with the advection of cold air from the northwest.

Of additional interest is the determination of relative cloud heights using the visible and infrared imagery. Low clouds and fog in the Mississippi River Valley on the morning of the 12th are distinguishable in the visible imagery, but are difficult to see in the infrared. High clouds associated with the squall line and the northern portion of the cyclone are the coldest (brightest) regions of the infrared imagery. Enhanced infrared imagery uses color coding to depict the infrared (equivalent blackbody) temperatures (warmest: black through blue, green, red to white: coldest). This allows subtle grey scale differences of the infrared brightness to be more easily distinguished, especially in thunderstorms containing a wide range of cloud heights.

The close up (high resolution) visible imagery contains regions of intense thunderstorm activity. Wave patterns are evident in the clouds preceeding the squall line. Shadows cast by cumulonimbus cloud turrets can be located in the late afternoon images. These turrets possess the highest vertical extent due to intense upward vertical motion. Within both of these regions there were numerous reports of severe weather.

3) Snowstorm (East Coast) February 1980

This mid latitude cyclone, which occurred on 6-7 February 1980, is an excellent example of East Coast cyclogenesis. The cyclone produced heavy snow in southeast Virginia and northeast North Carolina with accumulations of 12.4 inches in Norfolk, VA and 20 inches at Elizabeth City, NC.

A large amplitude 500 mb wave pattern was present over the United States on 6 February, with a closed circulation low over the Ohio River Valley. The contrast of cold, continental polar air along the east coast and warm, moist maritime tropical air over the Gulf Stream, in conjunction with the presence of an upper tropospheric jet streak moving around the base of the upper air trough, were associated with the onset of cyclogenesis. The surface low, located off the Georgia coast at 7:00 a.m. EST 6 February, moved up the Atlantic seaboard during the next 24 hours, while its central pressure decreased 29 mb to 986 mb (Fig. 2).

The sequence of visible images can be used to distinguish cloud covered regions from snow cover. An expansive area of clouds is associated with the developing cyclone. The cyclonic circulation about the center of the low can be distinguished as it moves toward the northeast along the Atlantic seaboard. Note that the cloud pattern also attains a comma shape with the cyclone's maturation. The textured appearance of the clouds moving over the Mid Atlantic States is an indication of convective activity, capable of producing heavier precipitation.

Infrared imagery indicates a large area of high clouds to the north of the surface low, as well as the convective regions along the coastline. South of the cyclone high clouds move rapidly eastward. These cirrus clouds indicate the presence of a strong subtropical jet stream.

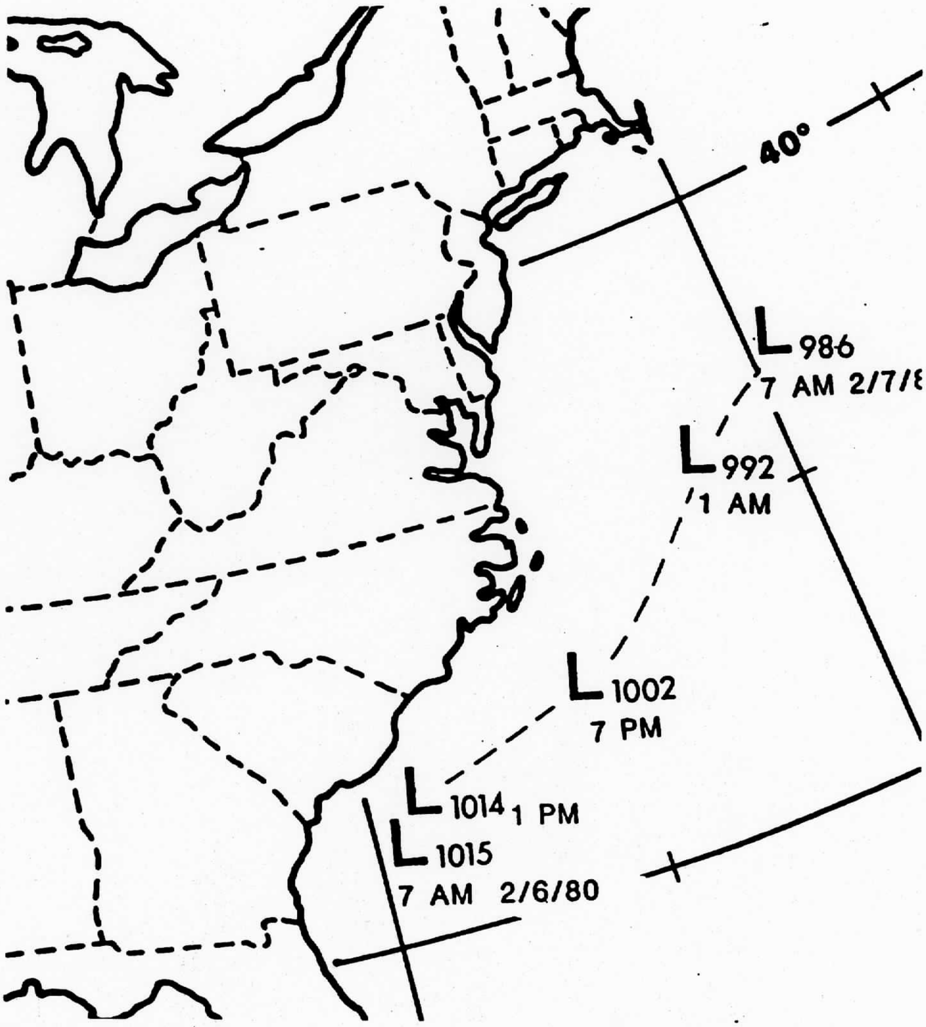

Figure 2. Location and central surface pressure of oceanic extra-tropical cyclone from 7:00 AM EST 6 February to 7:00 AM EST 7 February 1980.

4) Snowstorm (Midwest) April 1980

This loop depicts an occluded mid latitude cyclone over the central United States on 14-15 April 1980. The cyclone developed in the Gulf of Mexico on 13 April and over the next 24 hours moved north to a position over Illinois. Although the cyclone's movement is relatively slow, the cyclonic circulation is still strong.

The structure of this cyclone is an excellent example of the occluded stage. The tongue of dry air and the comma shape cloud pattern have lost their identities within the circulation about the cyclone. Infrared and enhanced infrared imagery shows the coldest cloud tops, associated with cirrus clouds, are located in a band to the north and west of the circulation center. South and east of this cirrus belt the medium grey area is associated with bands of convective snowfall. Two to four inches of snow accumulated across Wisconsin, Iowa and northeastern Missouri. Further south, rain in excess of one inch occurred over much of the region extending from the lower Mississippi River Valley eastward to the Appalachian Mountains.

On the following day the cyclone began to move to the northeast and skies over the Midwest cleared. The sequence of visible imagery shows the band of snow in the upper midwest melting rapidly during the afternoon of 14 April, as temperatures reach into the 40's (°F).

5) Hurricane Allen August 1980

This sequence of images shows the movement of Hurricane Allen through the Carribean and Gulf of Mexico (Fig. 3). Allen began as a disturbance in the tropical Atlantic during the last days of July, 1980. The hurricane crossed over the Windward Islands on 4 August with a central pressure of 950 mb. Moving westward over the next six days, Allen passed to the south of Hispanola

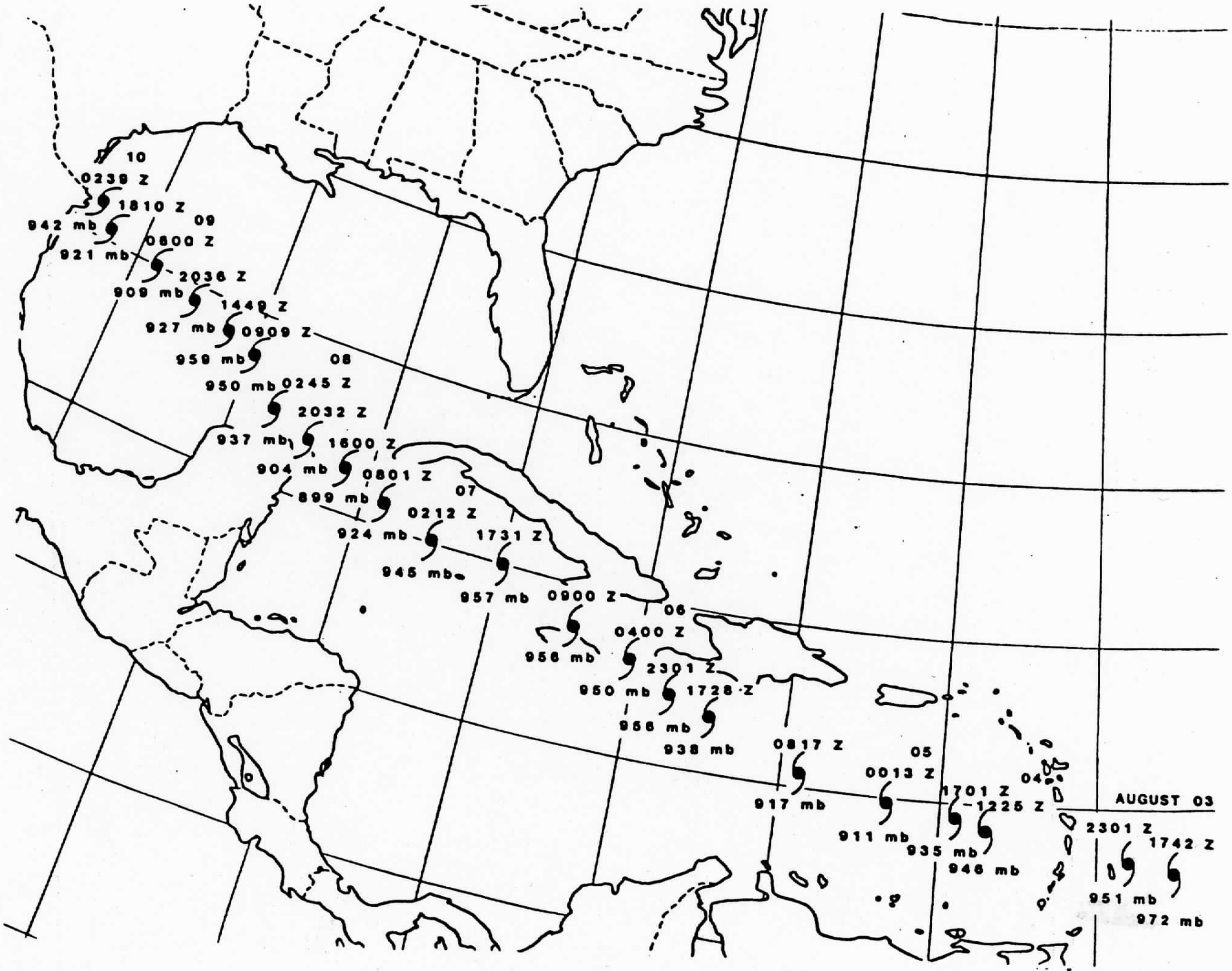

Figure 3. Location and central surface pressure of Hurricane Allen from 3-10 August 1980.

and Cuba. The hurricane's course subsequently curved to the northwest, passing just to the north of the Yucatan Peninsula of Mexico. The hurricane then entered the Gulf of Mexico and eventually made landfall near Corpus Christi, Texas on 10 August. A central pressure of 899 mb was recorded by Air Force reconnaissance at noon EDT 7 August as Allen passed between the western tip of Cuba and the Yucatan Peninsula. This was the second lowest pressure ever recorded in an Atlantic hurricane (an unnamed hurricane that struck the Florida Keys in 1935 had a central pressure of 892 mb).

A number of interesting comparisons can be made between tropical and mid latitude cyclones. In spatial extent the average hurricane is about an order of magnitude smaller in size than a mature mid latitude storm (100 km vs. 1000 km). A mid latitude cyclone typically becomes cold core during maturation with cyclonic circulation present at all levels, while a tropical cyclone is warm core, with cyclonic circulation near the surface and anticyclonic flow further aloft. Mid latitude cyclones derive their kinetic energy from the internal and potential energy associated with large horizontal temperature contrasts, while the kinetic energy of a tropical cyclone is gained through the release of latent heat during heavy rainfall.

Satellite imagery of Hurricane Allen depicts the low level cyclonic and upper level anticyclonic circulations. An extremely distinct, cloud free eye is evident in the images when the hurricane is near Hispanola and over the Yucatan Channel (high resolution imagery). The strength of Hurricane Allen increases as it moves over the warm ocean expanses, but diminishes as the storm encounters drier air from nearby land masses. This behavior is strikingly evident when Allen is located north of the Yucatan Peninsula. Enhanced infrared imagery shows dry air being drawn into the circulation from the land mass and the ensuing disorganization of the storm. In the last images Allen becomes almost stationary off the southern Texas coast. The weakening of the storm circulation before moving onshore saved the southeast Texas coastal region from massive destruction.

6) Cumulus Convection/Seabreeze March 1976

Within the smaller spatial scales, daytime heating from solar radiation causes a diurnal cycle in convective cloud development. An expansive anti-cyclone off the east coast of the United States on 27 March 1976 creates fair weather conditions for the southeast. Moisture is plentiful in the lower troposphere due to flow off the ocean. A surface trough of low pressure stretches from the upper Great Lakes southward to Texas. The incoming solar radiation heats the Earth's surface causing warm, moist air parcels to ascend, cool adiabatically, and condense to form cumulus clouds. By late afternoon some cumulus clouds develop into thundershowers over the southern states.

Along the east coast of Florida the thermal contrast of the land and water combines with the synoptic scale easterly flow to produce a line of cumulus clouds parallel to the coastline. Moist air moving from the ocean over the land is warmed in the surface layers. Again, the upward vertical motion results in adiabatic cooling and the formation of cumulus clouds. At higher levels the return flow from land to sea would result in subsidence over the ocean, completing the direct thermal circulation characteristic of a sea-breeze. These two features are examples of the heating due to absorption of solar radiation causing convection within an unstable atmosphere.

7) Tornado Producing Thunderstorm April 1979

Severe thunderstorms lashed north central Texas and southern Oklahoma during the late afternoon of 10 April 1979. A line of thunderstorms formed between a dry line and warm front and moved northeastward into Oklahoma. Near 6:00 p.m. CST a large, violent tornado moved through Wichita Falls, TX, cutting a broad swath of destruction through the city.

On 10 April a very large amplitude 500 mb trough was located over the western United States, with a strong upper tropospheric jet streak moving through the base of the trough to a position in western Texas. A stationary surface low pressure center (987 mb) was located in northern Colorado, with a cold front trailing southwestward into old Mexico (Fig. 4). Southeasterly flow off the Gulf of Mexico transported low level moisture into the Southern Plains, while dry southwesterly flow in the mid troposphere combined to render the atmosphere convectively unstable. The thunderstorms developed within the region of strongest low level winds (a low level jet) in northwestern Texas and moved rapidly to the northeast.

Satellite imagery indicates the dramatic thunderstorm development on the afternoon of 10 April. Several distinct convective cells are evident in the imagery, with a large area of cirrus outflow moving downstream. Late in the afternoon the severe thunderstorm which strikes Wichita Falls develops to the southeast of the main line and propagates to the northeast. A large cloud of dust, visible in west Texas behind the thunderstorm line, is transported by strong, dry winds in the lower troposphere.

A special research network of observing stations and systems called SESAME (Severe Environmental Storms And Mesoscale Experiment) was in operation

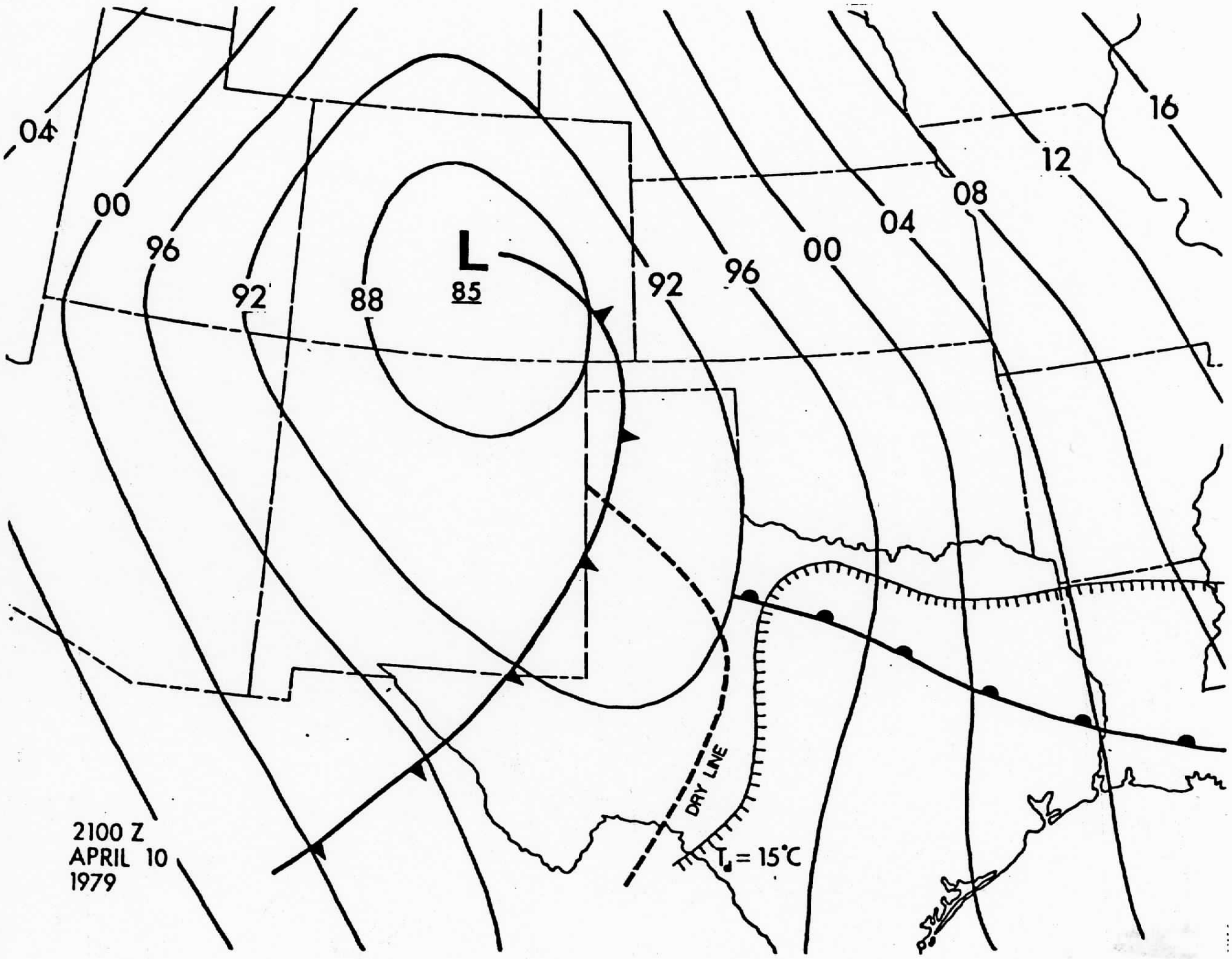

Figure 4. Surface analysis from 3:00 PM CST 10 April 1979, including fronts, pressure (mb), 15°C or greater dewpoints (areas within hatched line) and location of surface moisture gradient (dashed line).

this day. As part of the experiment the GOES-East satellite scanned the mid-section of the United States every three minutes instead of scanning the full earth disk at 30 minute intervals. This provided a more desirable time resolution for the study of severe convective storms. The black spot in the high resolution imagery moving toward Wichita Falls (cross) may be a shadow cast on a lower cloud layer by a large overshooting cumulonimbus top. The shadow grows in size as the sun angle gets smaller. Near sunset the shadow moves to a location near Wichita Falls, TX.

Official reports of severe weather can provide insight into the movement of storms and the type of damage that is associated with them. The following is a reprint from Storm Data, April, 1979 (U.S. Department of Commerce).

> The tornado began beneath the southwest flank of thunderstorm #3 about 3 miles east-northeast of Holliday in Archer County. Witnesses say that several distinct small vortices were visible during the formative stage of the tornado as it moved along the Fort Worth and Denver Railroad into Wichita County. Two oil-storage tanks were blown away and several homes were unroofed near Farm Road 2650 as the tornado approached Wichita Falls. Six cross country steel transmission towers were destroyed just east of 2650. About the time the tornado entered town, it changed in appearance, becoming one large black cloud of condensation and debris. The tornado was about 0.5 miles wide when it struck Memorial Stadium snapping the light standards and causing heavy damage to the field house. McNeil Jr. High School was next in the path of the tornado and the school was severely damaged. The western portion of the school building was crushed by the intense winds.
>
> The tornado then moved east-northeast into the Western Hills neighborhood, south of Southwest Parkway. Several apartment complexes and many homes were destroyed, with several of the first deaths occurring in this area. The tornado expanded in size as it crossed Southwest

Parkway, throwing automobiles about and leveling a number of businesses including a bank and fire station. The twister was almost 1 mile wide when it entered the Faith Village neighborhood on the north side of the east-west oriented Southwest Parkway. Most of the homes in Faith Village were demolished. Ben Milam Elementary School was heavily damaged as the cafeteria-auditorium was completely destroyed and exterior classrooms were pummeled by flying debris. The inner hallways would have been the only relatively safe shelter in the building. Surprisingly, very few fatalities occurred in Faith Village. Most people heeded the warnings and took shelter inside interior, small rooms in their homes. Most of the destroyed homes had some of these interior walls still standing after the tornado.

Moving out of Faith Village, the tornado flattened several businesses, including a restaurant on Kemp Boulevard. Three people were killed in the restaurant. A number of people were killed or injured in the parking lot of Sikes Center Mall, also on Kemp Boulevard. Some of these people attempted to run to their cars from the mall. Inside the mall, portions of the Penny's store collapsed while other stores sustained light to moderate damage. No one was killed and only several major injuries occurred among about one thousand shoppers who were in the mall. The mall was on the north side of the tornado path and appeared to escape the most violent winds. Near the center of the tornado and about 0.5 miles south of the mall, a church was demolished with one person killed inside of the building.

The tornado then crossed a short span of open fields before moving into the Colonial Park area. More widespread home destruction occurred in Colonial Park and several more apartment complexes were demolished. Heaviest damage in the apartments was to the second story of the two story buildings.

The tornado then swept through the Southmoor area, destroying homes and a shopping center. After crossing Highway 281, the twister struck the Sun Valley neighborhood and destroyed additional homes, apartments, and businesses on the south side of Highway 287. A large number of cars were smashed and some people were killed along 287. Some of these people had stopped their cars under an overpass on the highway, seeking shelter from the storm. The tornado leveled a mobile home park on the north side of 287, but residents had evacuated that area and no fatalities occurred in the park. The tornado then destroyed several industrial plants before moving into Clay County just south of Highway 79.

The tornado was up to 1.5 miles wide as it passed through 8 miles of resident area in Wichita Falls. The intense damage averaged between 0.25 and 0.5 miles in width. Forty-two people were killed outright by the storm and 5 others died of heart attacks. Further statistics reveal that 25 of the deaths were auto-related. Sixteen of these 25 were people who entered their cars trying to evade the tornado. Eleven of these 16 people left homes that were not even damaged. Eight persons were killed outside, 4 were killed in homes or apartments, and 4 other died in public buildings.

Seventeen hundred injuries were reported in Wichita Falls. Total damage in Wichita Falls was estimated at 400 million dollars. Three thousand and ninety-five homes were destroyed and 600 were damaged. One thousand and sixty two apartment units and condominiums were demolished and 130 damaged. In addition, 93 mobile homes were devastated. It is estimated that 5000 families consisting of almost 20,000 people were left homeless in Wichita Falls.

The most damaging single tornado in history continued into Clay County, resulting in no deaths but 40 additional injuries. About 15 million dollars damage occurred as the tornado destroyed homes to the immediate south of Highway 79, from Wichita Falls into the Dean and Petrolia areas. The tornado exited Texas about 4 miles east of Byers, uprooting over 300 trees along the Red River. Dissipation of the tornado occurred northwest of Waurika, Oklahoma, bringing the path length to 36 miles in Texas and 11 miles in Oklahoma. Minor wind damage and hail to 2 inches in diameter occurred north of the tornado track in Wichita Falls, in conjunction with thunderstorm #3. Also, tornado survivors said that some golf ball size hail fell just prior to and immediately after the tornado.

There is no doubt that hundreds of lives were saved by the news media and siren warnings. Amateur radio storm spotters turned in the first report of the storm, which allowed 5 to 10 minutes of valuable warning time. This followed an earlier warning at 5:08 p.m. due to the Rocky Point tornado. Undoubtedly, this earlier warning and the afternoon Vernon tornado had primed the Wichita Falls populace to the threat of additional tornado activity.

8) Symmetric Cloud Pattern in the Gulf of Mexico February 1980

Following a major winter storm on 10 February 1980, cold, dry Canadian air swept rapidly southward through most of the United States east of the Rocky Mountains. As this cold dry air moved over the Gulf of Mexico, clouds formed in rows or streets parallel to the lower tropospheric winds.

When continental polar or arctic air masses move over warm expanses of water the static stability of the lower troposphere is reduced through sensible heat transfer from the warm water to the relatively colder air. Warm, moist air now lies below cold, dry air contributing to a partial overturning of the lower troposphere. As parcels of warm, moist air rise and cool adiabatically, condensation occurs, forming low clouds. Rising motion in one area is compensated by subsidence in other areas leading to a partial overcast. Frequently this phenomena is accompanied by strong winds which result in the formation of cloud lines oriented parallel to the flow in the lower atmosphere. These cloud lines are frequently called cloud streets (Schaefer and Day, 1981, Haugen, 1973, Storer, 1972).

In each of the three satellite images from 4:00 p.m. CST 11 February 1980 the progressively higher resolution makes smaller scale features associated with the cold air outbreak more visible. Clouds have not formed over the immediate offshore area, since in this area the atmosphere has not been sufficiently heated for destabilization to occur. Further offshore, the sensible heat transfer from the warm ocean to the colder atmosphere has occurred over a longer period of time, thereby causing destabilization and cloud formation.

9) Smoke Plume April 1980

This sequence of high resolution (1 km) imagery displays the beginning of a forest fire in northwestern Wisconsin and the downstream dispersion of its plume. During the early morning of 22 April 1980 the weak cold front passing through Wisconsin caused low level winds to shift from the southwest to the northwest. The imagery shows the smoke plume embedded in northwesterly flow. The curling of the plume as it is carried downstream may be due to periods of very intense fire activity which caused portions of the plume to rise to greater heights and encounter winds from a different direction. Synoptic charts indicated backing winds in the vertical in the vicinity of the fire, which would lead to a more easterly plume track for those portions of the plume which reach greater heights. The fact that shadows are cast by the more northerly curls in the plume seems to confirm the relative height difference.

10) Volcanic Eruption-Mt. St. Helens May 1980

In the early morning hours (8:38 PDT) of 18 May 1980, Mt. St. Helens erupted with an explosive and spectacular fury that devastated a large area in Oregon's Cascade Mountains and spread ash over the immediate region downwind.

Within minutes a cloud of debris and hot gases reached 50,000 feet into the atmosphere. Westerly winds aloft (Fig. 5) carried the debris cloud eastward over Washington, Idaho and Montana, with the areal coverage estimated to be over 40,000 sq. km. by 10:45 PDT (Edman and Selin, 1981). Surface visibilities of less than a mile were reported by stations over much of eastern Washington and northern Idaho.

The four kilometer resolution infrared imagery clearly shows the spatial and temporal extent of the eruption. Within hours the eruption plume covers portions of eastern Washington and Idaho in ashed darkness. A weak upper air trough entering the west coast at this time is associated with southwesterly flow in the mid troposphere, while a weak ridge of high pressure extends over the northern intermountain region. The plume curves anticyclonically as it crosses the ridge axis during its progression downstream.

High resolution imagery between 8:15 and 9:45 a.m. PDT captures the awesome power of the eruption. The shape of the debris cloud is remarkably similar to the anvil of a large thunderstorm. A band of cirrus clouds, created by a shock (gravity) wave, moves outward from the volcano's perimeter. Early morning shadows cast on the earth's surface by the ash cloud are also apparent in the imagery.

A VIEW OF THE PLANETS

11) Venus, viewed from the Mariner spacecraft — February 1974

These images of the cloud top circulation of Venus were taken by the Mariner spacecraft as it moved past the planet Venus in February, 1974. In order to produce a sequence of images depicting cloud motions, the motion of the satellite must be eliminated through remapping. Image brightness must

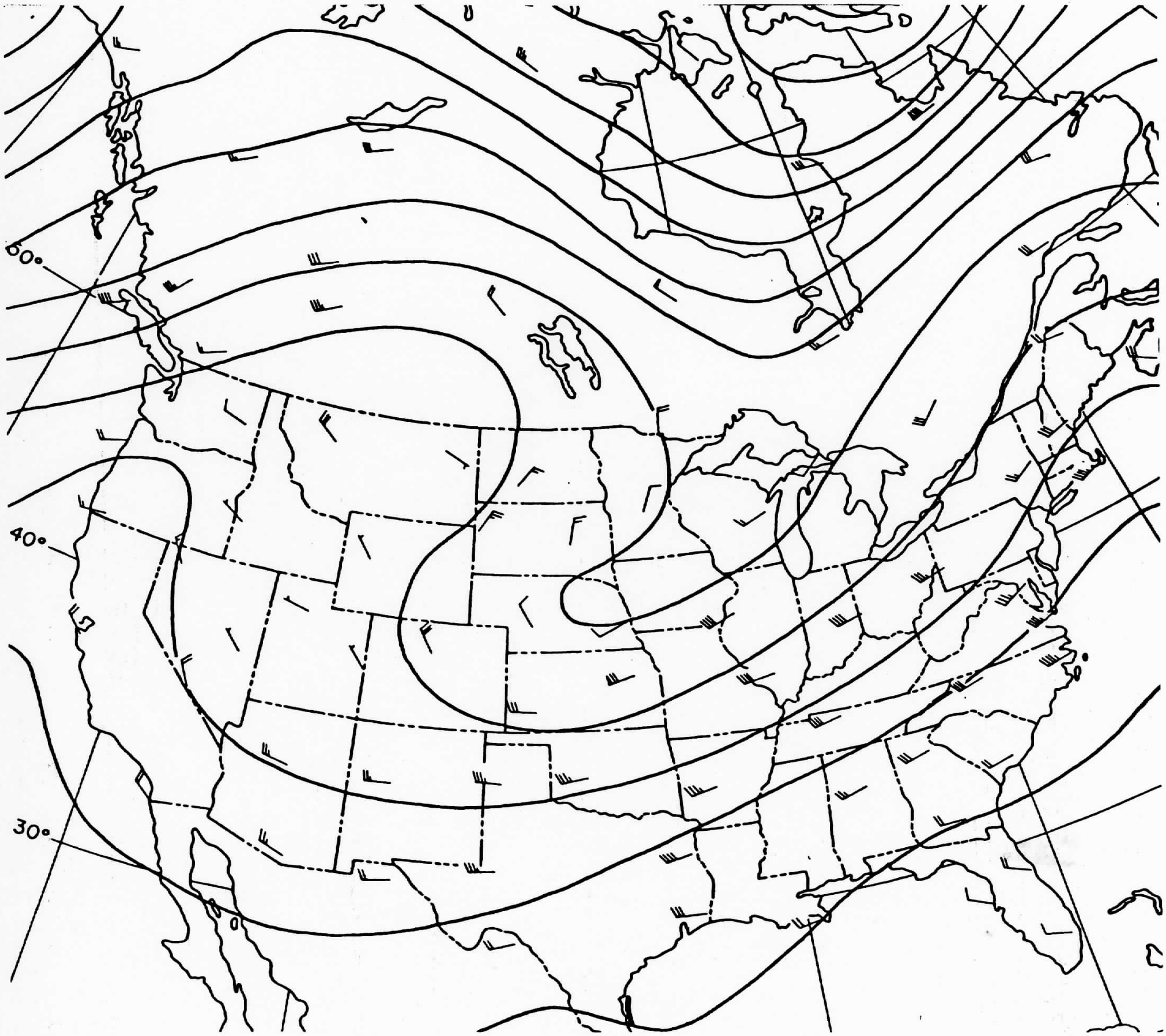

Figure 5. Relative 500 mb geopotential height distribution and winds (kts) for 1200 GMT (5:00 AM PDT) 18 May 1980 (from daily weather map series, U.S. Department of Commerce).

also be normalized for changes in the viewing angle. Through extensive effort a sequence of images is created which appears to be from a point above the same longitude of the planet. Once the sequence of images is constructed, cloud motions can be traced to provide insight into the circulation of the planet's atmosphere.

Venus is covered by a thick layer of clouds from 45-60 km above the surface. Its atmosphere is 96% carbon dioxide (CO_2), with small amounts of nitrogen (N_2) and water vapor (H_2O) present (see Table 1). The concentration of CO_2 produces a 'greenhouse' effect, which has raised the surface temperature above 450°C. Atmospheric pressure at the surface is ninety times that of earth.

Venus has a period of rotation of 243 days. Dynamically this implies the Coriolis force is small. Since little solar radiation reaches the surface, equator to pole Hadley cells exist within the Venusian cloud layer (45-60 km above the surface). At the top of the cloud layer a rapidly moving and, as yet, unexplained east to west circulation is present. Additionally, the axial tilt of Venus is very small, implying little variation in incoming solar radiation over a period of planetary revolution about the Sun (i.e., no seasons).

The sequence of images depicts the circulation at the top of the cloud layer which encompasses Venus. Cloud motions indicate wind speeds of 100 m s^{-1} over much of the planet. This superrotation of clouds overwhelms the Hadley circulation at the highest cloud level, giving rise to a vortex at each pole. The vortices are areas of stratospheric mass convergence and subsidence. A 'Y' shaped cloud feature moves east to west in the equatorial circulation. Later imagery from the Pioneer missions (1978, 1979) indicates this feature moves around the planet in a four day period. Detailed study of Venusian cloud imagery reveals convective cells present in the equatorial regions. However, much of the detail needed to understand these features remains for future planetary space missions.

12) Earth, viewed from the GOES-East satellite November 1980

The sequence of full disk images of the Earth's circulation is compared with the circulation of neighboring planets. In contrast to the other planets investigated, the Earth's atmosphere is only partially cloud covered, allowing a view of the surface. A large scale circulation feature of the Earth's atmosphere apparent in the imagery is westerly flow throughout the troposphere in the middle latitudes, with smaller scale cyclonic and anticyclonic vorticies embedded in the flow. Lower tropospheric easterly flow dominates the lower latitudes. Cross equatorial flow is present along the equator in association with a semi-continuous line of convection, the intertropical convergence zone (ITCZ) to the north. Over the oceans in the subtropical latitudes the skies tend to be cloud free, due to large scale subsidence. The convergence zone near the equator and the cloud free areas near 30° latitude in both hemispheres depict a direct thermal Hadley circulation at low latitudes in both hemispheres. The upper atmospheric anticyclone over South America is produced by surface heating, low level convergence, rising motion and upper level divergence.

13) Jupiter, viewed from the Voyager I spacecraft February 1979

These images portray the planetary circulation observed by the Voyager I spacecraft during its approach of Jupiter in February, 1979. The images are spaced approximately 10 hours apart, the period of rotation of Jupiter.

Cloud motions indicate the presence of numerous circulation belts of different cloud color, wind direction and wind speed within the Jovian upper atmosphere. The various cloud colors represent different cloud heights; red being the highest, while white, brown and blue clouds represent progressively lower cloud tops. It has been suggested that phosphorous creates the red color in some clouds. The white clouds are known to be composed of ammonia (NH_3), ammonium hydrosulfide (NH_4HS) and ice (H_2O). The speed of cloud motions vary from 130 m s^{-1} near the equator to near zero at the poles. Clouds moving in opposite directions in adjacent belts indicate the strong horizontal wind shear within which organized vorticies form.

The largest of the organized vorticies on Jupiter is the Great Red Spot. This storm rotates counterclockwise between a westward moving current to the north and an eastward moving current to the south. The storm has a diameter of 25,000 km, which makes it visible by telescope from the earth. In fact, the Great Red Spot has been observed for over 300 years. The white ovals are smaller eddies within Jovian shear zones. A number of these white colored storms enter the circulation of the Great Red Spot in the sequence of iamgery, some being absorbed, others being torn apart.

14) Saturn, viewed from the Voyager II spacecraft July 1981

These images were collected over a period of fourteen days by the Voyager II spacecraft during its approach to Saturn. The relative size of the planet increases in the field of view as the spacecraft approaches Saturn. Similar to Jupiter, this planet exhibits numerous different colored cloud bands, with great variation in the wind speed and direction of flow.

Cloud motions on Saturn are significantly faster than on Jupiter. Equatorial easterlies reach speeds of almost 500 m s^{-1}. The easterly winds diminish and turn westward near 40° latitude in each hemisphere, but eastward moving cloud belts again reach speeds over 100 m s^{-1} in higher latitudes. Saturn's cloud belt colors are not as pronounced as those of Jupiter. Strong horizontal wind shears again produce oval shaped vorticies, but the poorer resolution of this sequence makes their location difficult to ascertain. Thus, the cloud top circulations of Saturn and Jupiter are very similar in structure, although Saturn's circulation is more intense and somewhat less belted.

TABLE 1

	VENUS	EARTH	JUPITER	SATURN
Distance from Sun (Earth=1=1.5×10^8 km)	.75	1.0	5.0	10.0
Diameter (Earth=1=12,756 km)	.95	1.0	11.2	9.5
Mass (Earth=1=6.0×10^{24} kg)	.80	1.0	318.0	95.0
Period of Rotation (Earth=1=23 hr. 56 min.)	243. (retrograde)	1.0	.41 (9.9 hours)	.43 (10.5 hours)
Period of revolution (Earth=1=365.3 days)	.61	1.0	11.9	29.5
Important Atmospheric Gasses	CO_2, H_2Ov, N_2	N_2, O_2, H_2O, CO_2	H_2, He, CH_4, NH_3	H_2, He, CH_4, NH_3

V. MODULE EVALUATION

The utilization of videocomputer technology in educational modules provides an innovative resource capable of enhancing classroom instruction. An important step in the development of these modules is feedback from instructors and students to evaluate the impact of this educational resource to facilitate improvements in module content and quality. Students are requested to evaluate this module using copies of the enclosed questionnaire. The instructor is requested to enclose a summary of how the module was utilized, the student's impression of its effects upon the course work and suggestions for improvement. Input from previous module utilization within the Department of Meteorology at the University of Wisconsin-Madison has led to revisions in the videocassette.

VI. STUDENT EVALUATION FOR EARTH AND PLANETARY ATMOSPHERIC CIRCULATIONS VIEWED FROM SPACE

This evaluation is intended to judge the effectiveness of the videotape as a teaching tool in meteorology. Your answers will help to improve the quality of tapes such as this. Please write a short response in the space provided below. Thank you.

1) Is the overall pace of the tape

Fast _____

All right _____

Slow _____

2) Was the visual quality of the tape acceptable (were you able to distinguish important features)?

Good _____

All right _____

Needs improvement _____ (please state where)

3) Did these images help you to understand atmospheric processes more fully?

If yes, how?

4) Are there other atmospheric features or phenomena you would like to see on this tape?

5) Were there any images that you feel did not contribute or did not present the material well? Explain.

6) Was the audio track (if used) of value to your understanding of the tape contents?

Yes _____

Somewhat _____

No _____

7) Do you think this tape has been an eduation aid to the material presented in this class? Why?

8) Any additional comments?

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VIDEOCASSETTE ACCOMPANIMENT GUIDE

TO

EARTH AND PLANETARY ATMOSPHERIC CIRCULATIONS

VIEWED FROM SPACE

Space Science and Engineering Center
University of Wisconsin-Madison
1225 West Dayton Street
Madison, Wisconsin 53706

EARTH AND PLANETARY ATMOSPHERIC CIRCULATIONS
VIEWED FROM SPACE

Sequence	Time	Tape Counter
1) Full Earth Disk	0:50	023
2) Squall Line Development	4:32	118
3) Snowstorm (East Coast)	8:23	202
4) Snowstorm (Midwest)	10:07	235
5) Hurricane Allen	10:59	252
6) Cumulus Development/Ocean Seabreeze	15:07	326
7) Tornado Producing Thunderstorm	15:44	336
8) Symmetric Cloud Pattern in the Gulf of Mexico	17:24	364
9) Smoke Plume	18:27	381
10) Volcanic Eruption (Mt. St. Helens)	19:26	396
11) Venus Images (Mariner)	22:49	447
12) Earth Images (GOES-E)	23:43	460
13) Jupiter Images (Voyager I)	24:38	474
14) Saturn Images (Voyager II)	26:35	501

This guide provides a brief description of the images shown on the videocassette. A more detailed account of these events is available in the manual.

1) Full Earth Disk 20 Nov 1980

visible: 8:00 a.m. to 11:00 p.m. CST

infrared: 8:00 a.m. to 11:00 p.m. CST

image interval: 1 hour

Extratropical cyclones are located over the North Atlantic, northwestern United States and off the west coast of Chile. The intertropical convergence zone (ITCZ) can be distinguished by the semi-continuous line of convective clouds near the equator. In South America, daytime surface heating leads to rising motion, condensation and divergence aloft. The latter is exemplified by the anticyclonic cloud motions.

2) Squall Line 12 May 1978

infrared: 8:00 a.m. to 11:00 p.m. CDT (int: 1 hr.)

visible: 8:00 a.m. to 7:00 p.m. CDT (int: 1/2 hr.)

A rapidly intensifying low pressure center moves across Iowa. Along the cold front a line of very intense thunderstorms develops during the afternoon. Over 20 tornadoes, 100 mph winds and 2" hail are associated with the thunderstorms.

3) Snowstorm (East Coast) 6 Feb 1980

visible: 8:30 a.m. to 3:30 p.m. EST (int: 1 hr.)

infrared: 8:30 a.m. to 3:30 p.m. EST (int: 1 hr.)

A cyclone rapidly develops off the Atlantic seaboard bringing heavy rains and locally heavy snowfall to the east coast. The storm moves northeastward along the coast resulting in strong onshore winds. Snow cover can be differentiated from clouds using the sequence of visible imagery.

4) Snowstorm (Midwest) 14 Apr 1980

infrared: 10:00 a.m. to 5:00 p.m. CST (int: 1/2 hr)

This cyclone is in the occluded stage of its life cycle. The cyclone center, located over Illinois, moves slowly northward, while clouds rotate cyclonically around it. Cirrus clouds to the west and north of the center are associated with the brightest (coldest) part of the imagery. Locally heavy snowfall over portions of Wisconsin, Iowa and Missouri produced 2-4" of snow. Visible imagery from the next day shows the rapid melting of the snow.

5) Hurricane Allen Aug 1980

most imagery has 1/2 hr. interval

This sequence of images shows Hurricane Allen at several locations during its path through the Carribean and Gulf of Mexico. The hurricane achieves a classic shape and eye structure as it deepens to 899 mb, the second lowest pressure ever recorded in an Atlantic hurricane. Cloud motions portray the low level cyclonic and upper level anticyclonic circulations associated with warm core cyclones.

6) Cumulus cloud development 21 March 1977

visible: Noon to 3:00 p.m. EST (int: 1/2 hr.)

An anticyclone off the east coast is producing fair weather for the southeastern states. By late morning radiational heating of the earth's surface causes cumulus clouds to develop. Later in the day some of the cumulus develop into thunderstorms.

Along the northeast coast of Florida low level onshore flow and heating of the land surface leads to rising motion, condensation and cumulus cloud formation. The inland penetration of the seabreeze is delineated by a line of convective clouds parallel to the coastline.

7) Tornado producing thunderstorm 10 Apr 1979

visible imagery: 9:30 a.m. to 5:00 p.m. CST (int: 1/2 hr.)

visible imagery at 3 min. interval: 5:30 to 6:24 p.m.

The first sequence of images shows several thunderstorms developing in west Texas, moving to the northeast. Severe weather was associated with several of these thunderstorms. Late in the afternoon a very strong thunderstorm moves over Wichita Falls, TX (cross), spawning a violent tornado which causes tremendous destruction and the loss of over 40 lives.

8) Parallel rows of clouds in the Gulf of Mexico 11 Feb 1980

visible imagery: 4:00 p.m. CST

These three images show an outbreak of cold, dry air over the warm moist water of the Gulf of Mexico. The thermodynamic contrast of the air and water causes a sensible heat exchange, leading to the destabilization of the lower troposphere. Rising air parcels in one area are compensated by subsidence in other areas, creating a partly cloudy sky. Strong low level winds cause the clouds to line up in streets parallel to the direction of wind flow.

9) Smoke plume from a forest fire 22 Apr 1980

visible: noon to 6:00 p.m. CST (int: 1/2 hr.)

A forest fire near Spooner, WI creates a smoke plume which spreads downwind. Northwest winds at low levels behind a weak cold front carry the plume southeastward. However, backing winds in the mid troposphere cause the plume to move in a more easterly direction as it rises to higher altitudes, giving the plume a curling appearance.

10) Volcanic eruption 18 May 1980

infrared imagery: 7:45 a.m. to 4:15 p.m. PDT (int: 1/2 hr.)

High res. vis. imagery: 8:15 a.m. to 9:45 a.m. (int: 1/2 hr.)

The first eruption of Mt. St. Helens produces a large debris cloud which reaches the tropopause. Westerly winds in the mid and upper troposphere carry the volcanic debris eastward over Idaho and Montana.

11) Venus imagery Feb 1974

These images, obtained from the Mariner spacecraft flyby in 1974, show the stratospheric circulation of the planet. A large bright vortex is located above the south pole. Brighter areas near the equator suggest convection. The "Y" shaped feature moving westward near the equator is propagating at speeds in excess of 100 ms^{-1}.

12) Earth imagery Nov 1980

Satellite imagery of earth indicates a partially cloud covered planet. Cyclonic vorticies move eastward in the mid latitudes, while low level easterly winds are present near the equator. Convection over the South American continent is indicated by the formation of cumulus clouds and anticyclonic flow aloft.

13) Jupiter imagery Feb 1979

Images from the Voyager I flyby of Jupiter show stratospheric cloud belts of varying width and color moving in opposite directions, and indicate the presence of many different circulation regimes. The wind shear between the belts creates intense vorticies. The largest of these vorticies, shown in the close up sequence, is the Great Red Spot.

14) Saturn imagery July 1981

The images from the Voyager II flyby of Saturn show circulation belts in the stratosphere similar to Jupiter's, but with less intense coloring. The lower resolution of these images does not distinguish the vortices along band edges as clearly as on Jupiter. An apparent spin of the ring system is evident from the movement of spokes or dark areas in the rings.