An Analysis of Weather Patterns Along the Lower Hudson Valley- February 15-24, 1996

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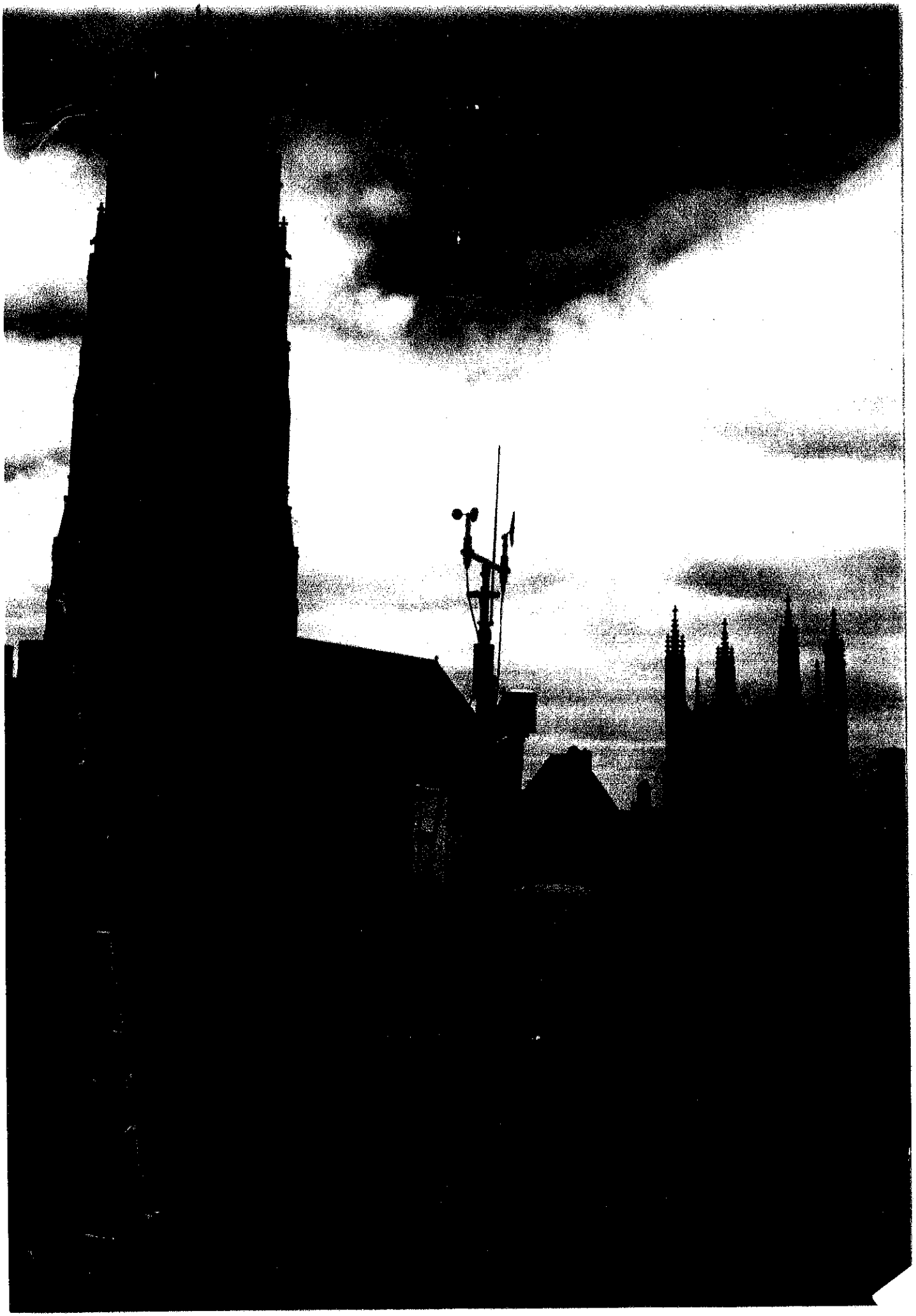

ABSTRACT:

An analysis of the weather patterns in the lower Hudson Valley was done based on the compiled data from four weather stations: the Barnard weather station in Upper Manhattan; the Lamont Doherty Earth Observatory weather station in Palisades, N.Y. ; and the Ridgetop and Openlow weather stations in Black Rock Forest of Cornwall, N.Y. In addition, chlorofluorocarbon (CFC) data from the Lamont Doherty Earth Observatory were incorporated into the study.

By studying temperature, relative humidity, solar radiation, barometric pressure, rain, wind speed and wind direction, normal and anomalous weather conditions were identified. The data, due to its complexity, could not be interpreted via one basic approach. Certain trends in the behavior of solar radiation, temperature and relative humidity were determined based on relationships between recorded local data. However, wind speed, wind direction, precipitation, pressure, as well as other data dealing with temperature and relative humidity, were analyzed utilizing regional weather data.

This study helps explain local weather conditions and will ultimately help in understanding the transport of pollutants, i.e. CFCs, in the lower Hudson Valley.

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INTRODUCTION:

Weather, the instantaneous state of the atmosphere and its short term temporal evolution, is a global phenomenon which affects our entire earth. The Middle-East concerns itself with the next rainfall, Southeast Asia worries about its next harvest, the Africans await the next installment of the drought in the Sahel, and the South Americans dread the next appearance of El-Niño. The importance of weather in molding the climate of our earth has only been recently realized and has resulted in the undertaking of large-scale climate projects, such as the Vostok ice core. In addition to looking at past climates through the ice core analysis, collection of present day weather conditions via a dense, well maintained network of weather stations is necessary. A network of weather stations can help define local scale phenomena and thereby aid in the study of basic weather processes on a larger scale. A small-scale analysis of weather patterns along the lower Hudson Valley in New York, demonstrates the value of this approach.

This study uses data from four weather stations located along the north-south transect of the Hudson Valley and its outcropping valleys. These stations include one at Barnard College, one at Lamont Doherty Earth Observatory, and two at Black Rock Forest (fig 1). The parameters recorded were temperature, solar radiation, relative humidity, precipitation, pressure, wind direction and wind speed. Atmospheric CFC concentrations at Lamont were also incorporated into the study.

Analysis can be complicated by the quality of the data collected. Use of inaccurate and unreliable weather sensors as well as problems associated with programming and the

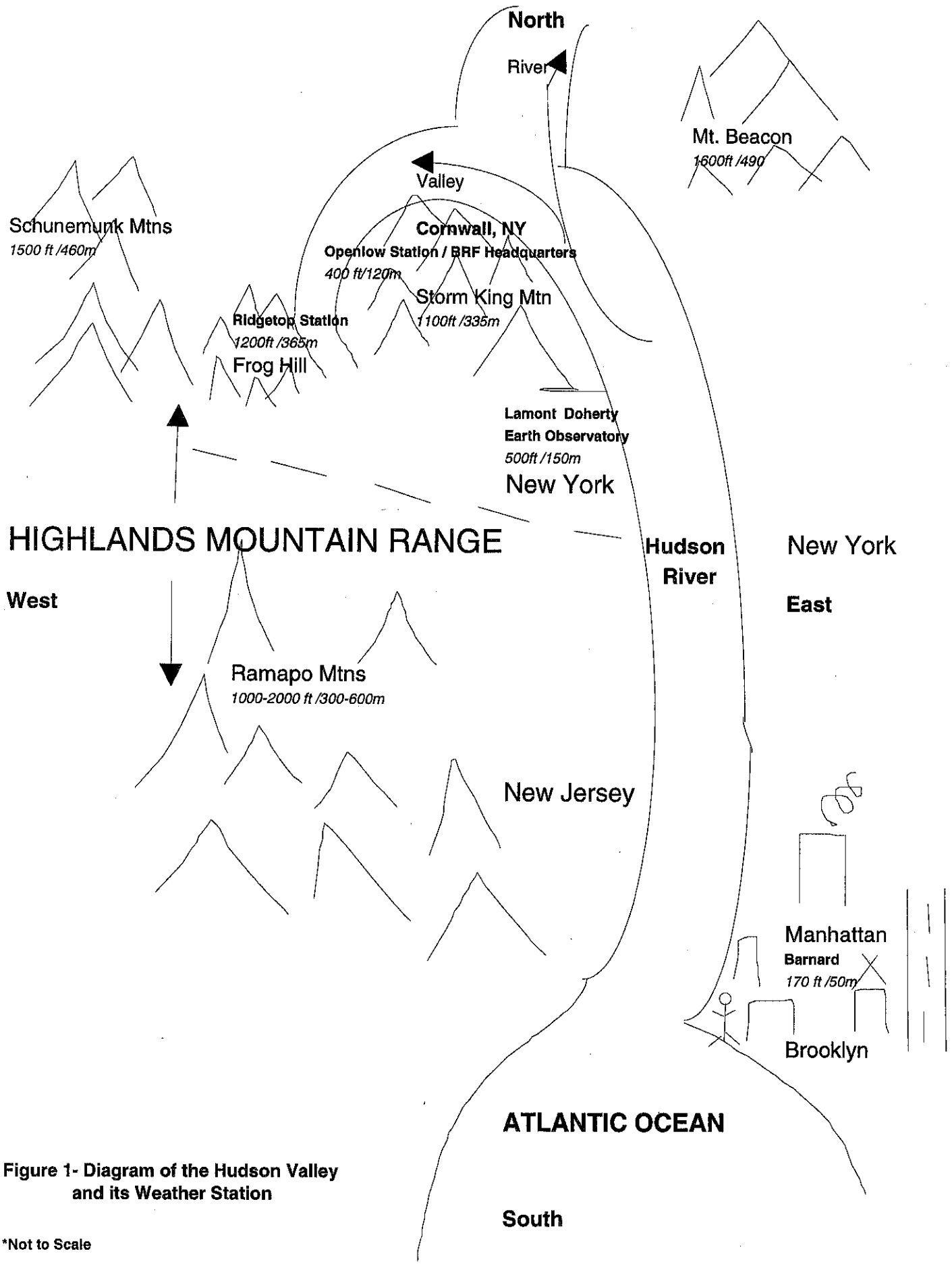


Figure 1- Diagram of the Hudson Valley and its Weather Station

*Not to Scale

compatibility of data, can create many information gaps. Many meteorological phenomena can be analyzed, providing there is proper compensation for these problems.

Throughout the ten-day period of analysis, certain winter weather patterns were determined. These patterns resulted from geographical and topographical effects on weather parameters such as temperature, solar radiation, relative humidity, winds and precipitation. The study also demonstrates time lags between variables.

Aside from the purely local phenomena which were studied, regional weather effects on small-scale phenomena were also incorporated into the study. This is a necessary component in determining a complete weather analysis. Once weather patterns in a certain area are understood, other studies can be initiated.

Atmospheric pollutants are becoming quite common in the global race towards industrialization. Considering the harmful effects of many of these pollutants, their confinement and transport in our atmosphere are important. The study of weather via winds, precipitation and relative humidity can help determine pollutant transport, in our case, the transport of chlorofluorocarbons. Use of such information will be useful in determining more ideal locations for future manufacturing plants.

Chlorofluorocarbons:

CFCs were invented in the late 1920's and early 1930's. At that time, they were considered a safe alternative to the original refrigerant pollutants of sulfur dioxide and ammonia. Many factors deemed CFCs a better choice. They are low in toxicity, non-flammable, non-

corrosive, non-reactive with other chemical species and have a desirable thermal conductivity and boiling point. CFCs were produced in large quantities and distributed globally. It became the material of choice in air conditioners, refrigerators, as solvents for the cleaning of electrical parts and as an ingredient for the production of plastic foam and propellants. Not until 1974 were any deleterious effects publicly recognized. The depletion of stratospheric ozone was understood then to be caused by chlorine containing species. Because of their inert characteristics, CFCs make their way unchanged into the stratosphere where they are finally degraded by bombardment with intense ultraviolet radiation. This process frees the chlorine radicals, which ultimately destroy ozone.

The Montreal Protocol was signed in 1987 and amended in 1990 and 1992. This resulted in condemning the CFCs as an environmental hazard and demanding that it be phased out by the year 2000. Hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) are used as replacements, but are costly and pose other environmental hazards such as an increased potential for global warming. However, because of their chemical composition, i.e. hydrogen atoms, HCFCs are degraded in the troposphere. As a result, the chlorine radical is not freed in the stratosphere to further exacerbate the ozone hole (Ciesin, 1994 and Greenpeace, 1994).

Ideal Site for a Weather Station:

Accuracy of a weather observatory pivots on the physical and topographic site chosen. Typically, an open space of 300-400 square feet is ideal. This area should be devoid of buildings, trees or concrete bordering. In addition, the instrumentation should be mounted on level ground.

When instruments are mounted on a steep slope or sheltered hollow, air drainage occurs which does not give an accurate or representative account of the regional weather, although it provides information on the local environment. Buildings and trees pose a problem for different reasons. Both can create obstructions in gathering accurate precipitation and wind measurements, whereas buildings also affect temperature measurements by storing and releasing heat (Hayne, 1950).

Weather Sensors:

Temperature:

Temperature is widely measured by thermometers, either liquid-in-glass or electrical. The former is made up of a glass bulb attached to a 25cm sealed, graduated glass tube. A small opening termed a bore, extends from the bulb to the end of the tube. Housed within the bulb is mercury or red-colored alcohol. This fluid expands as temperature increases and contracts with a decrease in temperature. In addition, there are special types of thermometers that can measure both the maximum and minimum temperatures. Liquid-in-glass thermometers are widely used because they are easy to read and inexpensive to construct.

The electrical resistance thermometer detects the resistance of a platinum or nickel wire; resistance increases as a function of temperature. An electrical meter measures the resistance and is then calibrated to represent air temperature. Another type of electrical thermometer is a thermistor which is made out of a ceramic material. As its resistance increases, its temperature decreases. Thermistors are widely used in radiosondes (airborne weather monitoring units),

mainly due to their low maintenance requirements. For these same reasons, Barnard and Black Rock Forest use thermistors at their stations. Thermocouples are another kind of electrical thermometer which measures the electrical current formed as a result of the difference between the junction of two dissimilar metals.

Radiometers also measure temperature, by measuring emitted infrared radiation. Thermographs are the fourth type of temperature sensor. Thermographs function based on a bimetallic thermometer. This consists of welded iron and brass. Based on different thermal expansion parameters, the strip bends which is amplified through a system of levers to a pointer on a calibrated scale. These however, are less accurate and need to be corrected periodically.

Radiation shields and instrument shelters are necessary components used with temperature sensors. The instruments are sensitive and need to be protected from rain, snow and the sun's direct rays. The popular units for measuring temperature are degrees Fahrenheit and degrees Celsius (Ahrens, 1994).

Precipitation:

Measuring rain is relatively simple. There are three types of rain gauges: the standard rain gauge, the tipping bucket rain gauge and the weighing-type rain gauge. The standard rain gauge consists of a funnel-shaped collector attached to a measuring tube surrounded by an overflow cylinder. The measuring tube's limit is 5cm or 2 inches. Excess rainfall overflows into an outer cylinder where it is protected from evaporation. Once the gauge is emptied, the overflow is poured in and measured.

The tipping-bucket rain gauge, used at Barnard, Black Rock Forest and Lamont, also consists of a funnel, which leads to two connecting metal collectors. When the rain comes in, the buckets tip whenever one hundredth of an inch is exceeded. As one bucket tips, the second bucket takes its place to catch the next one hundredth of an inch. With each tip of the bucket, an electric contact is made which registers a mark on a remote recording chart.

For remote sensing, the weighing-type rain gauge is used. The rain is caught by a cylinder and accumulates in a bucket which is on a weighing table. The weight is converted to inches or millimeters of rainfall. This information can then be transmitted via special electronic equipment to satellites or land-based stations (Ahrens, 1994). Once transmitted, the bucket empties by an automated mechanism.

Relative Humidity:

Relative humidity is the measure of the air's total capacity for water vapor. It is the actual vapor pressure (mb) divided by the saturation vapor pressure (mb), expressed in a percent (0-100%).

The amount of water vapor required to reach saturation differs in every situation. The relative humidity of a certain air mass depends on the air's temperature at that time, and its resulting pressure. An increase in temperature means that the air can hold more water vapor than it could previously, hence a decrease in relative humidity is expected. The opposite holds true for a decrease in temperature.

Relative humidity is most commonly measured by hygrometers, specifically a

psychrometer. It functions based on the concept of a temperature difference between the wet-bulb temperature and the dry-bulb temperature. The wet-bulb temperature is the lowest temperature that can be obtained by evaporating water into the air, and the dry-bulb temperature is the current air temperature. If there is a large wet-bulb depression, it means that a great deal of water vapor can evaporate into the air and the relative humidity must be low. If the depression is small, the relative humidity is high. As long as the wet-bulb is above freezing temperatures, this form of measurement is reasonably accurate. The hair hygrometer, electrical hygrometer and infrared hygrometer are other types of sensors used, although less frequently (Ahrens, 1994 and Haynes, 1950). The Barnard and Black Rock Forest weather stations measure humidity via a capacitive sensor. Two electrically charged plates will exhibit an increase in capacity when there is an increase in relative humidity.

Pressure:

Pressure is the measure of the weight of air exerted upon the earth's surface. The greater the elevation is, the lower the pressure, and the lower the elevation is, the higher the pressure. This occurs because as one climbs away from the earth's surface, there are fewer molecules of air above and therefore, less pressure is exerted downward at that point. Aside from elevation differences, pressure is also affected by temperature differences. The lower the air temperature, the lower the pressure will be and vice versa.

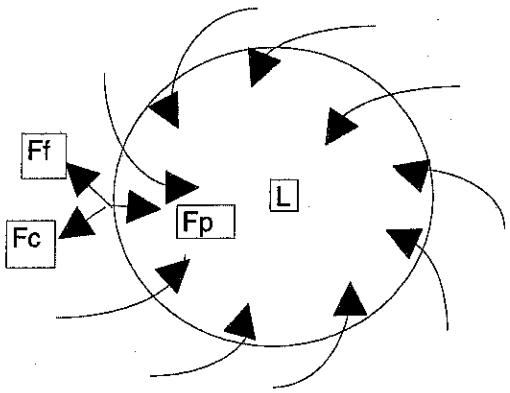
In terms of meteorology, high and low pressure systems play a large role. There is an excess of solar radiation at the equator and a deficit at the poles . Atmospheric circulation is

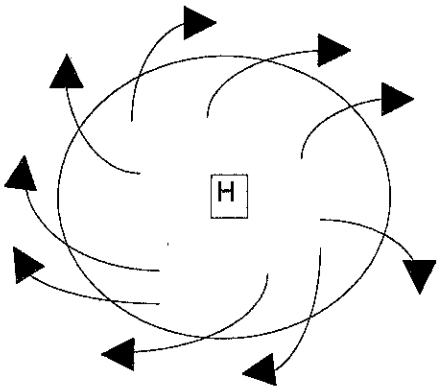
required to transport heat from high latitudes to low latitudes. Heat created due to high solar radiation at the equator creates high and low pressure systems which circulate due to the pressure gradient and the Coriolis force. All of these factors working together create weather.

The pressure gradient force causes air to move from regions of high pressure to regions of low pressure . This air moves clockwise for a high pressure system and counterclockwise for a low pressure system in the Northern Hemisphere and the opposite in the Southern Hemisphere. This occurs because of the earth's rotation which creates an apparent force - the Coriolis force. At the surface of the earth, friction comes into the picture, slowing down the winds, thus weakening the Coriolis force. Considering that the pressure gradient force is always directed toward the low pressure system from the high pressure system, the Coriolis force can no longer offset the pressure-gradient force. As a result, air tends to spiral inward toward the center of the low pressure system and outward from the center of the high pressure system. As the air from the Low converges, it rises adiabatically and cools (fig 2). As height increases, atmospheric temperature decreases at a rate called the lapse rate. Sunlight warms the earth's surface, which in turn, warms the air above it. This lapse rate differs based on whether the air is saturated or not. The dry adiabatic lapse rate is approximately 10C/1000m and the wet adiabatic lapse rate is approximately 6.5C/1000m. These values fluctuate day to day and season to season.

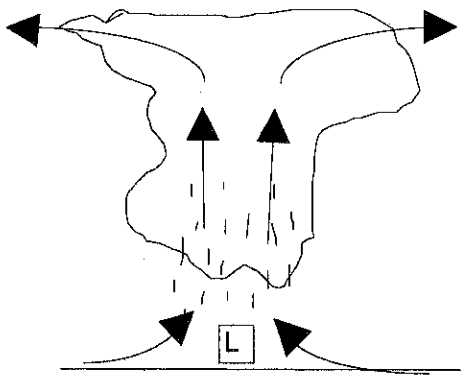
When the air cools, there is an increase in relative humidity which results in overcast skies and poor weather. In contrast, air in high pressure systems diverge away from the center, causing air from above to sink and adiabatically warm, reducing its relative humidity, leading to fair weather (fig 2) (Del-Genio, 1995).

Pressure change is measured by barometers. A bar is a unit of pressure, that describes a





Fp = Pressure-Gradient Force
Ff = Force of Friction
Fc = Coriolis Force



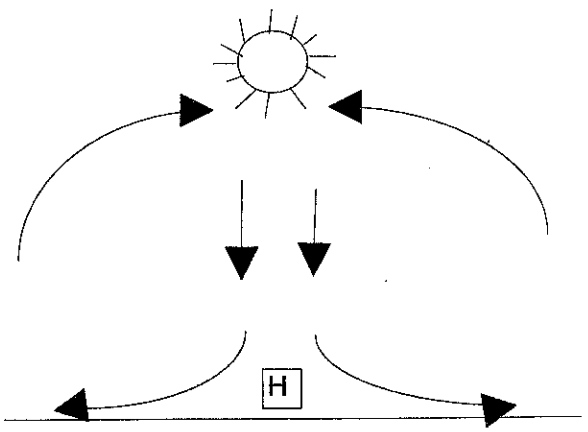


Figure 2- Effects of High and Low Pressure systems

(Re-illustrated from Tony Del-Genio's Class Notes, 1995)

force over a unit of area. Because the unit is so large, pressure is more commonly measured in millibars. The average pressure at sea-level is 1013mb. Another measure unit is 'pascal'. "A pascal is the force of 1 newton acting on a surface area of 1 square meter" (Ahrens, 1994). There are 100 pascals in a millibar, hence 1 kilopascal in 10 millibars. Normal operating ranges for pressure are 600-1060mb.

There are two common types of barometers - the mercury barometer and the aneroid barometer. The mercury barometer, invented by Toricelli in 1643, consists of a glass tube sealed on one end and immersed in a dish with mercury at the other end. With a vacuum existing in the tube, the mercury rises to a height where it balances the weight of the air over the dish.

The second type of barometer contains a flexible metal box called an aneroid cell. This type does not contain any fluid. Before the cell is sealed, air is removed so that even a slight change in atmospheric pressure can be detected by contraction or expansion of the cell. There are two types of aneroid barometers, altimeters that are calibrated to indicate altitude, and barographs. In order to be able to compare pressures from different stations at different altitudes, altitude corrections must be made. Generally, 10 millibars are subtracted per 100 meters in altitude. Another method utilizes the barometric pressure equation ($P_o = P\exp(h/8434m)$). However, neither is a perfect solution considering that atmospheric pressure in cold air decreases at a faster rate with height than it would with warm air. (Ahrens, 1994). None of our station's pressure sensors are corrected for altitude differences.

The pressure sensors at Barnard's and Black Rock Forest's weather stations, like the relative humidity sensor, measure via a capacitive sensor. A vacuum exists between the two electrically charged plates. The higher the pressure, the greater is the expansion between the

plates and vice versa. The Lamont pressure is measured by a Sentra barometer. This is an electrical barometer. The advantage to using an electrical barometer is that the recorded values can be directly connected to a computer.

Wind Speed and Direction:

Wind speed and direction depends largely on thermal gradients that create the low and high pressure systems. Wind is responsible for transport of moisture, heat, dust, insects, pollen etc. As height increases so does wind velocity because the frictional drag on the air parcel is reduced. As a result, surface winds are normally fastest during the afternoon. As the Earth's surface heats up, the atmosphere is destabilized and the vertical mixing of the air links the surface winds with those above which tend to be much faster. At night convection is reduced, resulting in a more stable atmosphere (Ahrens, 1994).

Prevailing winds are those that dominate the wind direction within a given time period. Wind gusts are the peak wind speed noted during a recorded interval. Wind direction is the direction from which the winds blow. A wind rose is the percentage of time that wind blows from different directions.

Wind direction is most commonly measured by a wind vane. A wind vane is the oldest and simplest method for detecting wind direction. It consists of an arrow with a tail that circulates around a vertical post whose nose always faces the direction from which the wind comes. The wind vane's counterpart in terms of observing wind speed , is the cup anemometer. This consists of three or more hemispherical cups mounted on a vertical shaft. Its rotation is

caused by the wind, hence it is directly proportional to the wind speed. The wind vane and anemometer detect wind direction and speed at the Barnard and Lamont stations.

An aerovane is another type of wind sensor that detects both wind direction and wind speed. It consists of a three-bladed propeller atop the nose of a streamlined body with a vertical fin. The two latter characteristics keep the propellers directed toward the approaching winds. This more advanced unit is used at the Black Rock Forest weather stations. Wind direction is measured in degrees ranging from 0 to 360, both of which represent true north. Wind direction is measured in units of meters per second, miles per hour or kilometers per hour.

When measuring wind data, it is extremely important that the wind instruments be at least 10 meters above the surface (although this is rarely the case) to be above the region where wind is influenced by the earth's surface. Wind speed increases rapidly with height. In addition, the sensors should be situated well above the roofs of buildings and the tree canopy so it can come into contact with freely flowing air. Otherwise, erratic wind tendencies will be observed (Ahrens, 1994).

Solar Radiation:

Solar radiation is the amount of incoming radiation emitted by the sun. This value is measured by a pyranometer, which detects the sun's rays with a silicon photovoltaic sensor. Both Barnard and Black Rock Forest measure the sun's incoming rays via a pyranometer. These values are calibrated for the daylight spectrum of 400-1000nm. This instrument is capable of transferring the sun's energy directly into electricity. Daily values and hourly values are most

commonly measured in megajoules per meter squared and watts per meters squared respectively.

METHODS:

Barnard's Weather Station:

Barnard's weather station is located at Barnard College in the Morningside Heights area of Manhattan, on the corner of 120th street and Broadway. This area of Manhattan is situated near sea level, in the Hudson Valley. The station is located 160 meters (530 ft) away from the Hudson River and approximately 20 kilometers away from the coast of the Atlantic Ocean.

The Barnard Weather Station was erected and commenced operation at the beginning of the Fall semester of 1995. Its construction took place under the auspices of Barnard's Environmental Science Department, and under the authority of Jennifer Phillips, an agronomist at the Goddard Institute for Space Studies. The system was purchased from Campbell Scientific Inc. It is situated on the roof of Milbank Hall, which is approximately 50 to 60 feet above street level and 50m (170ft) above sea level (120th street is 110 ft above sea level). The system takes up an area of approximately 25 square feet (fig 3).

The system consists of instrumentation for temperature, relative humidity, solar radiation, rain, pressure, wind speed and direction, as well as the 21X Micrologger, which serves as the computer for the network. All the wiring from the sensors is connected to the datalogger, which has been programmed to record measurements from each sensor. Data stored in the storage module is downloaded weekly via asynchronous short range modems to a computer in the

Barnard's Weather Station

Figure 3 - Barnard's Weather Station

*Before the installment of the Wind Vane. Refer to Figure 27 for visual of the station with the wind vane.

Environmental Science Department in room 329b. As of now, these modems only serve as a direct link between the datalogger and the computer. Their main objective is to aid in the clarity of the transmission. An additional A/B switch must be installed in order for any other computer to have direct access to the data.

The data is retrieved from the datalogger via software designed for the Campbell Scientific Instrumentation (graphterm) and must be imported into a spreadsheet program. Once in a spreadsheet program, basic relationships between variables as well as stations can be determined.

*For details about Barnard's datalogger and programming, refer to Appendix I.

Black Rock Forest's Weather Stations:

Black Rock Forest is situated in Cornwall, NY southwest of Storm King Mountain. It presently has two weather stations which were installed in the late summer/early fall of 1995. In August the Openlow station was set up at an elevation of 140 meters (400 ft) above sea level. It is located approximately 40 ft from the Black Rock Forest headquarters. The second station termed the Ridgetop, was set up in September at an elevation of 365 meters (1200 ft) above sea level. The Openlow station lies along a valley which extends off of the Hudson valley, while the Ridgetop station is located atop of the Highlands (Figures 4a and 4c).

Both stations' equipment were acquired from Campbell Scientific and essentially follow the same program format as that at Barnard. However, Black Rock Forest's datalogger

lacks the 16 character keyboard. It has a Micrologger CR-10 as opposed to the CR-21X that is used at Barnard (fig 4b). The Openlow station is downloaded manually through a storage module. The Ridgetop station downloads via radio telemetry.

*For a brief synopsis describing the Black Rock Forest stations inception and parameters, refer to Appendix II.

Lamont Doherty Earth Observatory (LDEO) Weather Station:

The LDEO weather station is the oldest of the four stations, yet due to lack of funds, it is the least well maintained and the hardest to access. This weather station is located at approximately 150 meters (500 ft) above sea level, on a seismic observation tower (Figure 5a). It was installed in 1993, but has been neglected for the past two years. As a result, many of the sensors are not in working order. The wind sensors and the rain gauge are presently operating. The wind data was not easily accessible until quite recently. The data were not being stored and its short range memory was continually being over-written. The system was changed at the beginning of March 1996, and is now saving the data at hourly intervals. The sensors were acquired from Sensors Institute Co. Although the measuring instruments are the same as those at the other three stations, these sensors come pre-programmed (fig 5b) (Appendix IV).

*For a brief description of the station, its parameters and their limitations, refer to Appendix III.

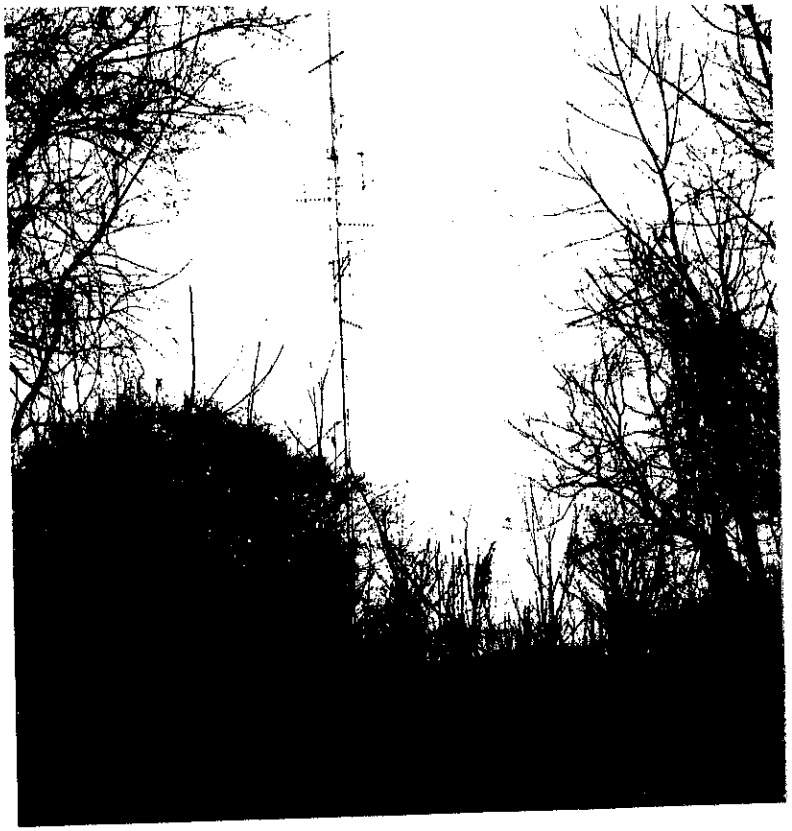


Figure 5a - Lamont's Wind Sensors on the Antenna Tower above the Seismic Observatory

Figure 5b - The Pre-Programmed Devices inside the Observatory

Lamont Doherty Earth Observatory CFC and Pressure Measurements:

Atmospheric CFCs at Lamont are being measured by a graduate student in Geochemistry. A tube is inserted out the window of the SF6 lab in the Geochemistry building. The tube extends to an area just outside the building. Inside the lab, the tube is connected to an automated inlet system (which I and another intern built this past summer and started to run). The inlet system is connected to the gas chromatograph which measures the concentration of CFCs against a standard. This system is automated and is programmed to sample every 8 minutes. The instrument also records atmospheric pressure.

RESULTS AND DISCUSSION:

Data Analysis:

Meteorological data for February 15-24, 1996, was obtained from each of the four weather stations. The parameters recorded at Barnard and Black Rock Forest (Ridgetop and Openlow stations) are temperature, solar radiation, relative humidity, precipitation, pressure, wind speed and wind direction. Lamont's data are recorded for pressure, wind speed and wind direction, as well as atmospheric CFC concentrations. However, some of the data sets from the various stations do not cover the entire ten-day period. Although only a group of ten days have been studied, they are assumed to be representative of winter month weather phenomena existing in the Hudson Valley.

The recorded data was studied by interpreting visual graphics. Microsoft Excel, a spreadsheet program, was utilized to produce time series and scatter plots. The x-axis of the time series graphs represents time, which is generally denoted by hours as opposed to date. The black dot on the x-axis denotes midnight.

Data Quality:

There are three basic problems when analyzing data from many different sources. The first is the accuracy of each stations output. The second is having data for the same parameters covering the same time sequence, and the third is being able to reduce the data to a common denominator so they can be mutually analyzed. Problems such as calibration errors, shutdown of

instruments, faulty sensor programming, lack of compatible sensors and storage capabilities, all serve to hinder analysis.

Pressure Sensors and their Recorded Data:

The Ridgetop station records the lowest pressure values, ranging from 965-990 mb, followed by Lamont whose pressure measurements range from 985-1015 mb. Barnard station's pressure is slightly higher than Lamont's ranging from 990-1020 mb. The Openlow station exhibits the highest pressure measurements ranging from 1000-1028 mb (fig 6). Since pressure decreases with elevation, it's odd that the Openlow station exhibits the highest pressure measurements. One would expect its pressure values to fall between those recorded at the Ridgetop and Lamont stations because of the elevation differences.

To check the consistency between the various pressure gauges, the recorded pressures from each weather station were corrected for elevation. This was done to determine if the Openlow or any other station, exhibits a calibration error. The barometric pressure equation, $Po=P \times \exp(h/8434m)$ was used. P, is the recorded pressure and Po is the observed surface pressure which is on the average 1013 mb. H, is the elevation of the station. H equals 365m, 120m, 130m and 50m for the Ridgetop, Openlow, Lamont and Barnard stations. (Although the LDEO weather station is at a height of approximately 150m, 130m is used because the pressure at Lamont is recorded at a separate location, in the Geochemistry building.) To determine which station displays a calibration error, Po is the unknown.

Figure 6 - February 15-24 (21 for LDEO) - Barometric Pressure for Barnard, Lamont Doherty Earth Observatory and Black Rock Forest (Ridgetop and Openlow)

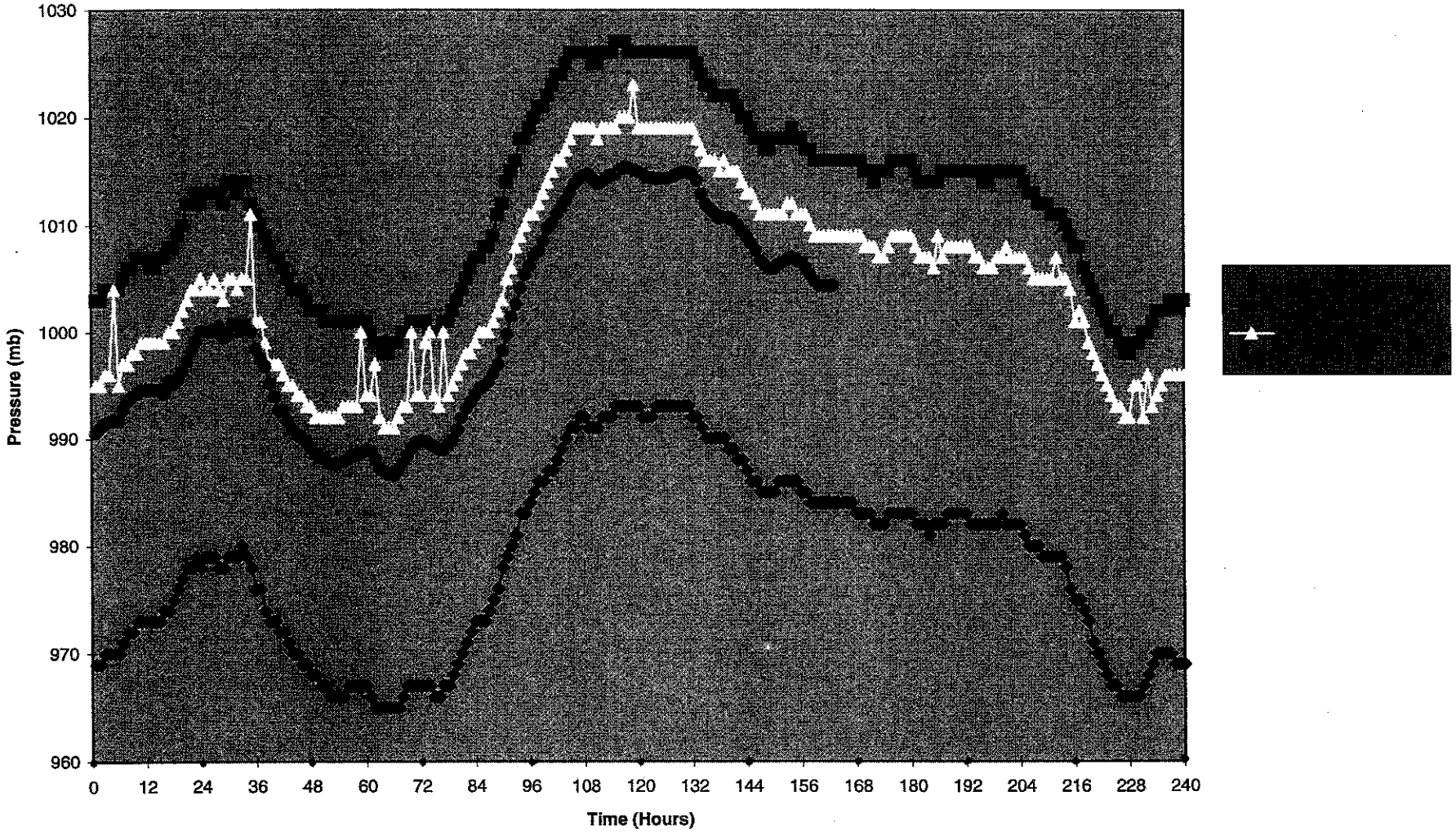


Figure 7 shows the hourly pressure fluctuations. As can be seen, none of the pressure curves overlap. To determine which gauge, if any, reflects standard atmospheric pressure, averages of the new Po values for each station were calculated. The Ridgetop, Openlow and Lamont stations all exceed the average standard surface pressure of 1013mb. The Po values are 1022, 1027 and 1016mb for the Ridgetop, Openlow and Lamont stations. Conversely, Barnard's corrected pressure value is lower, at 1011mb. Although none of these values equal 1013mb, it is hard to determine which pressure gauge, if any, are recording the data incorrectly. The Po value of 1027mb for the Openlow station, deviates the most from the average. This substantiates our previous assumption that a calibration error exists at the Openlow station. However, all the other stations still deviate from the average surface pressure, although by a smaller amount. In order to perform a thorough check on calibration, a longer time series, perhaps a year, is necessary.

In addition to the calibration errors, choppy anomalies are seen in the Barnard pressure data. These fluctuations are due to a missing valve on the bottom of the pressure sensor. As the winds become very strong, it hits this area of the sensor which causes a rapid fluctuation to occur.

Aside from operational errors exhibited by the pressure sensors, problems also exist in reading the stored data. From our reading of the pressure graph for all four stations (fig 6), it appears that a pressure system passes through every 2 days. It was originally thought that high pressure systems existed in the Hudson Valley on February 15-16 (hours 0-48) and on February 19-20 (hours96-144), with low pressure systems existing otherwise. However, by utilizing regional weather maps it was apparent that the pressure systems over this designated time period

Figure 7 - February 15-24 (21 for LDEO)- Barometric Pressure Corrected for Altitude- Barnard, Lamont Doherty Earth Observatory and Black Rock Forest (Ridgetop and Openlow)

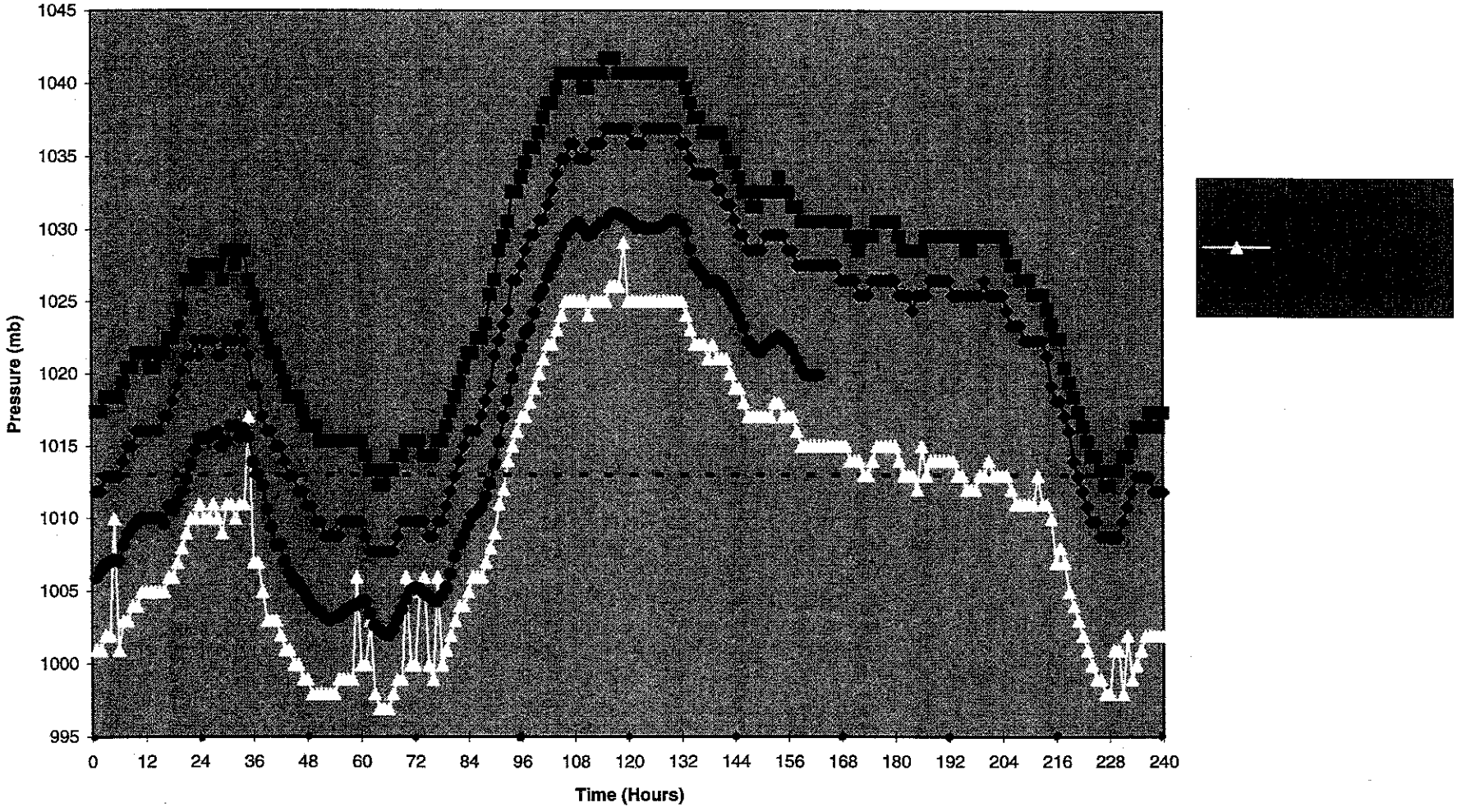
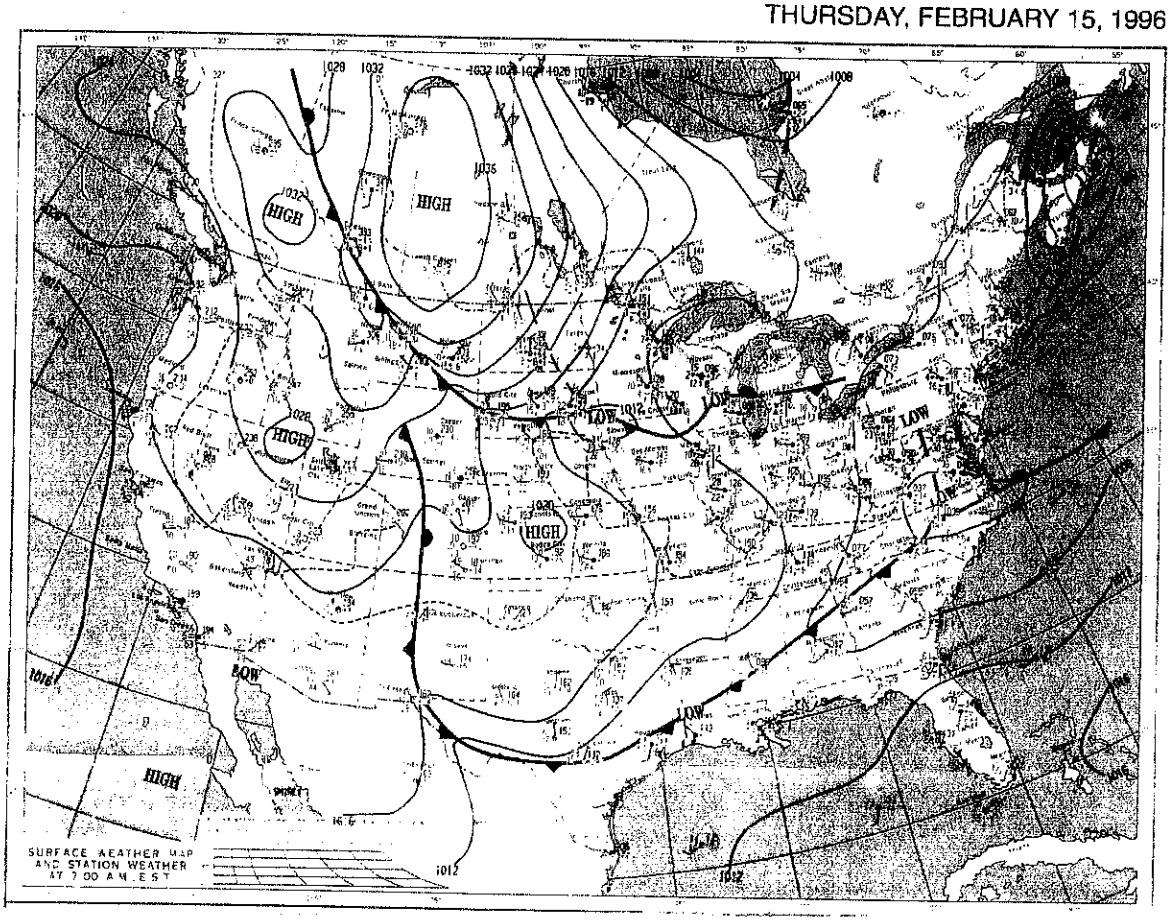


Figure 8 - Daily Weather Map - United States - February 15 and 16, 1996

THURSDAY, FEBRUARY 15, 1996



FRIDAY, FEBRUARY 16, 1996

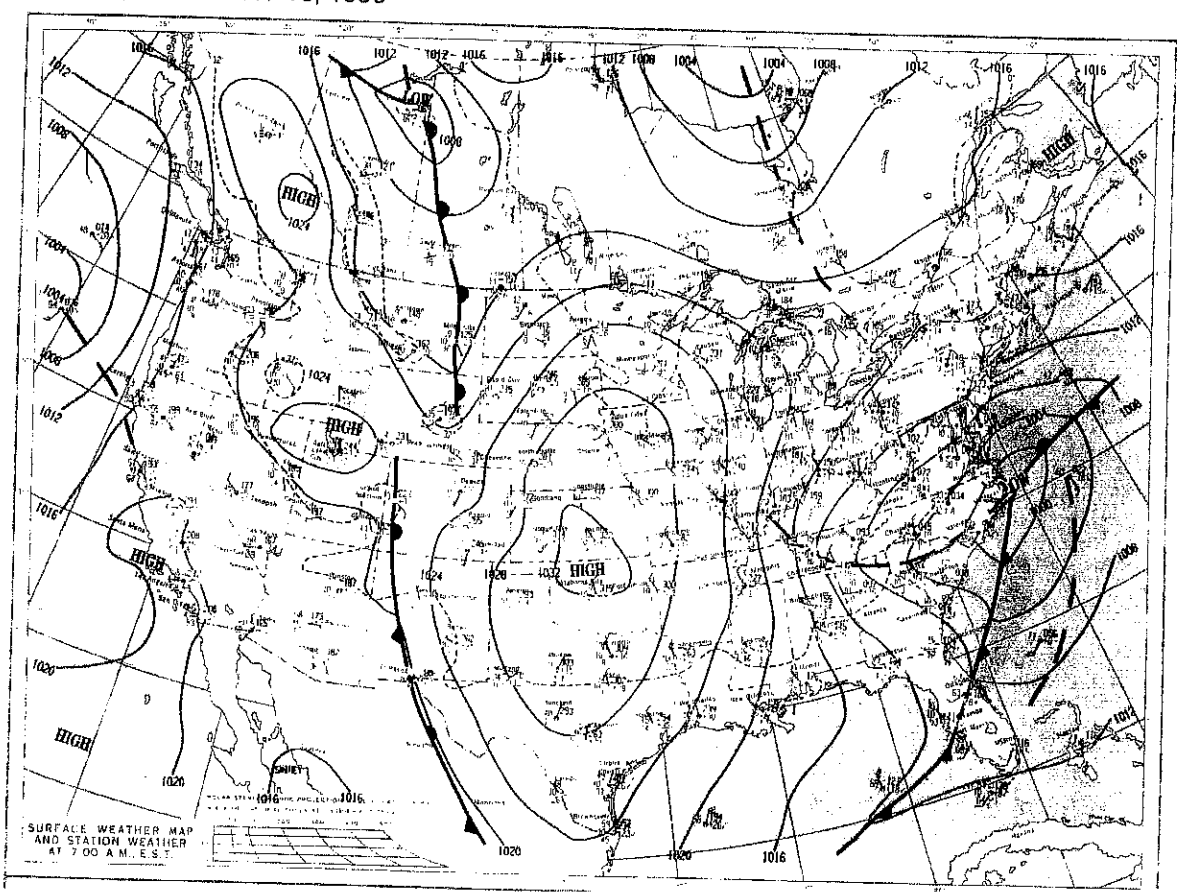
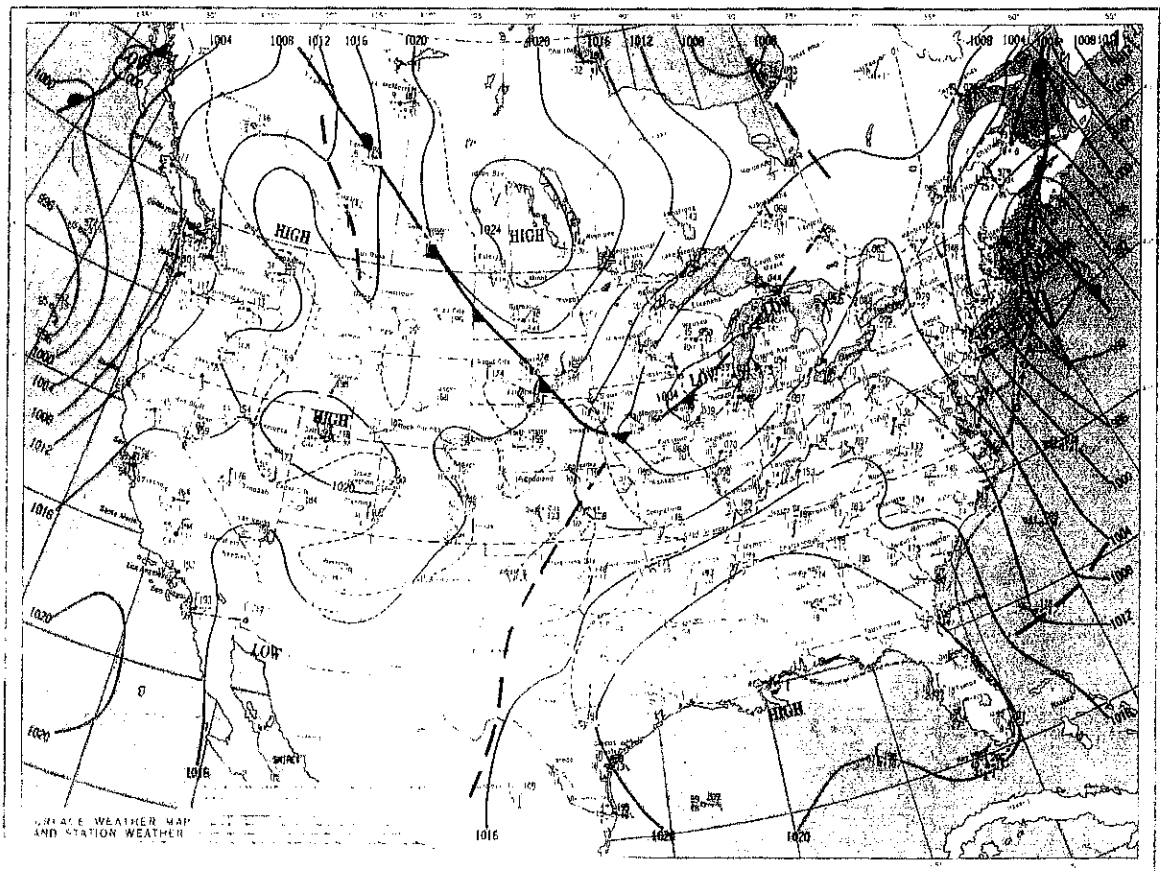


Figure 9 - Daily Weather Map - United States - February 17 and 18, 1996

SATURDAY, FEBRUARY 17, 1996



SUNDAY, FEBRUARY 18, 1996

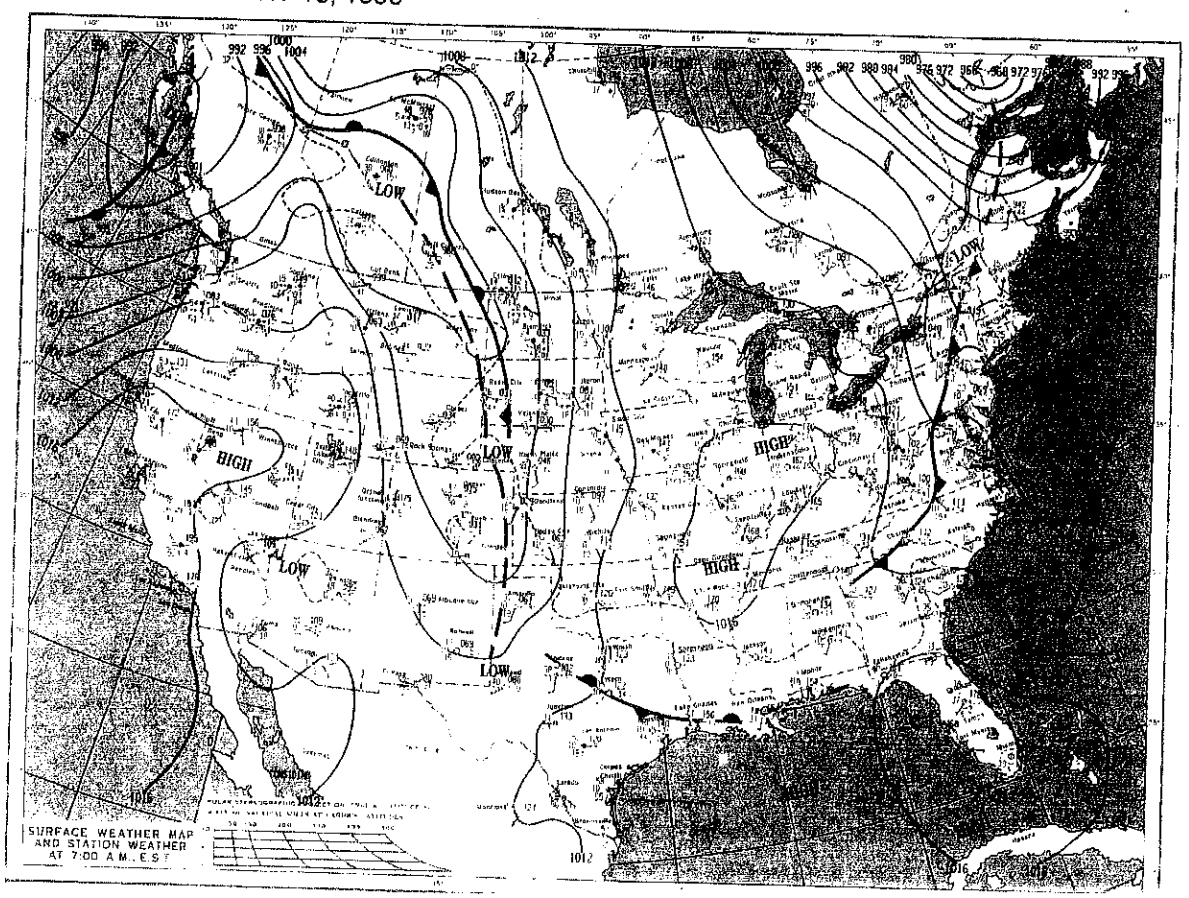
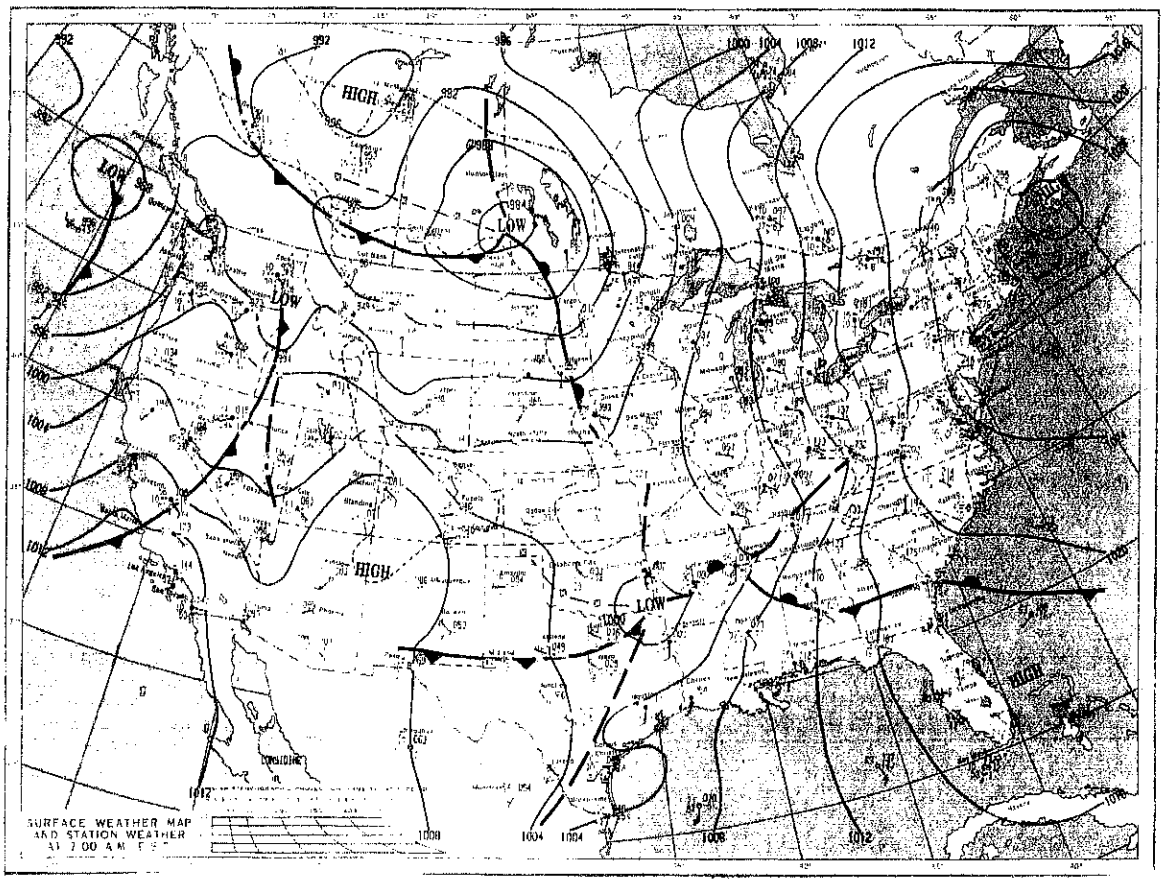


Figure 10 - Daily Weather Map - United States - February 19 and 20, 1996

MONDAY, FEBRUARY 19, 1996



TUESDAY, FEBRUARY 20, 1996

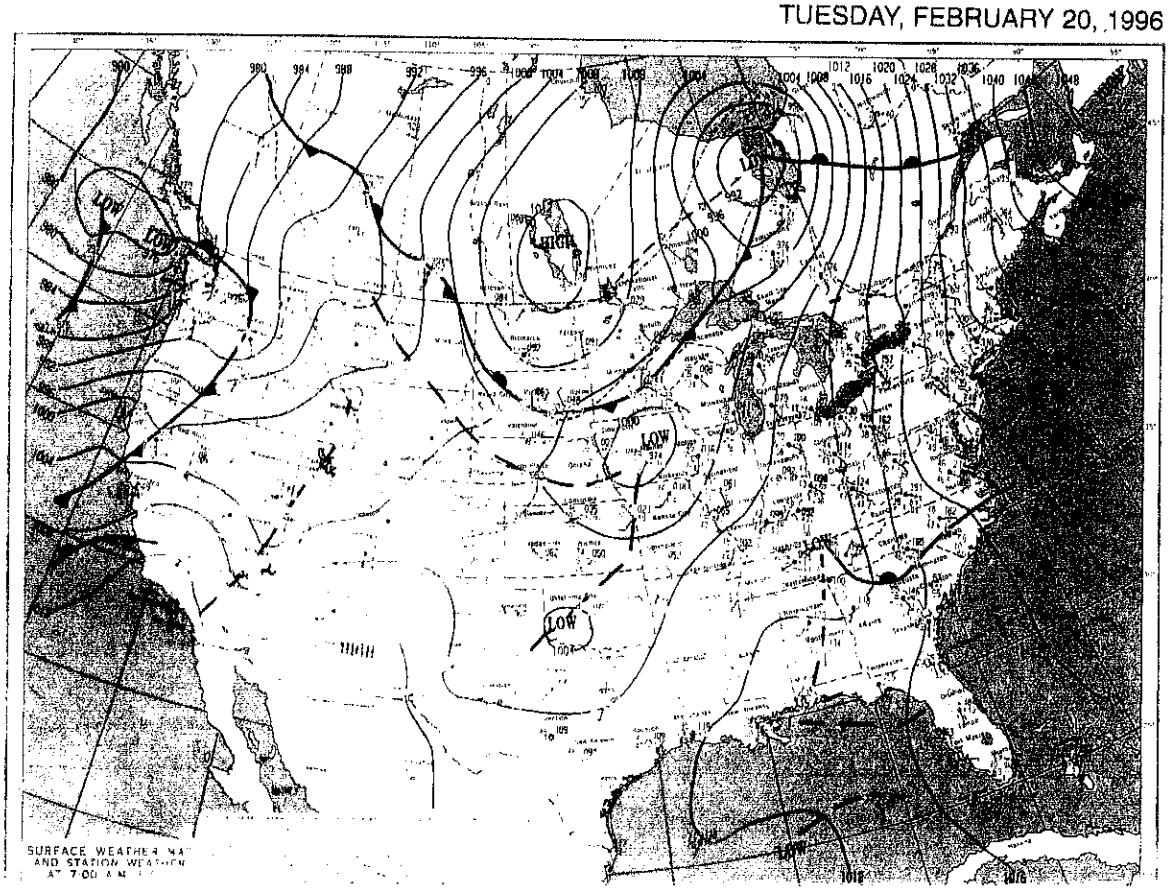
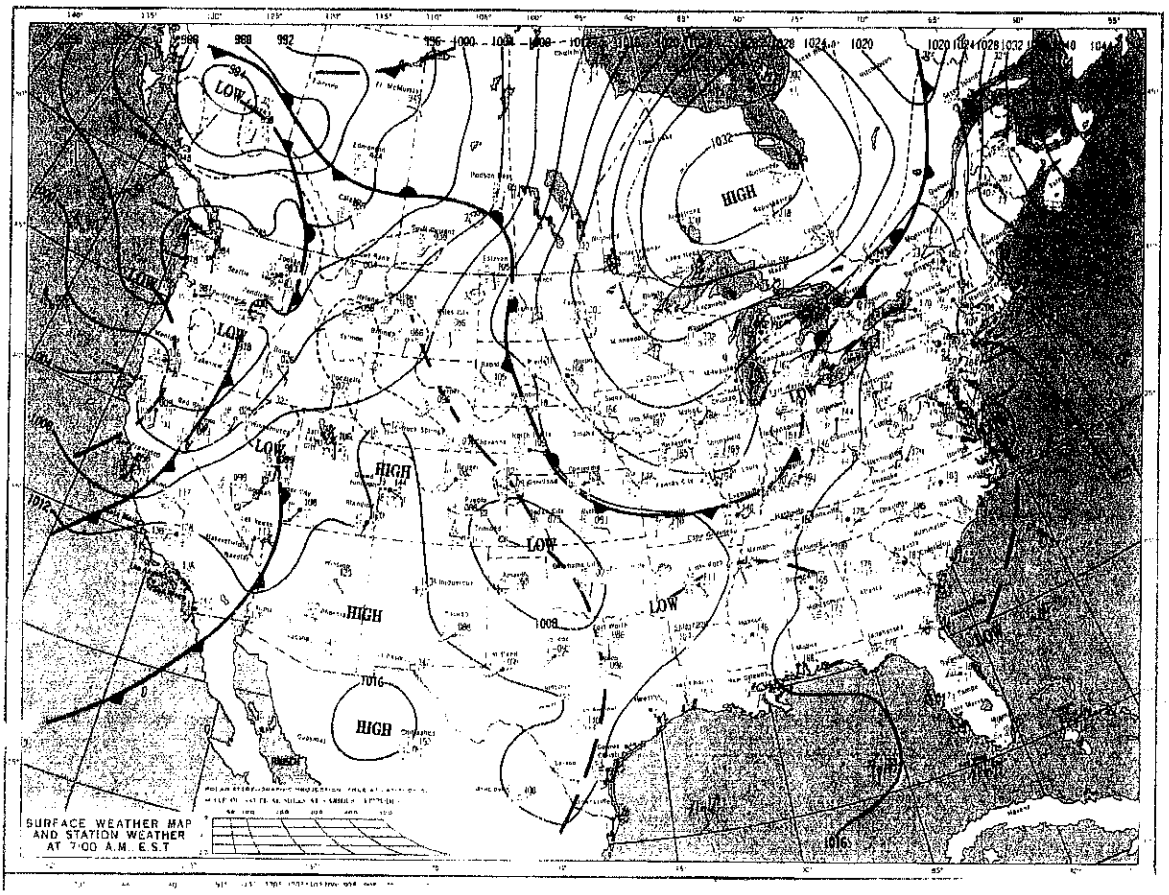


Figure 11 - Daily Weather Map - United States - February 21 and 22, 1996

WEDNESDAY, FEBRUARY 21, 1996



THURSDAY, FEBRUARY 22, 1996

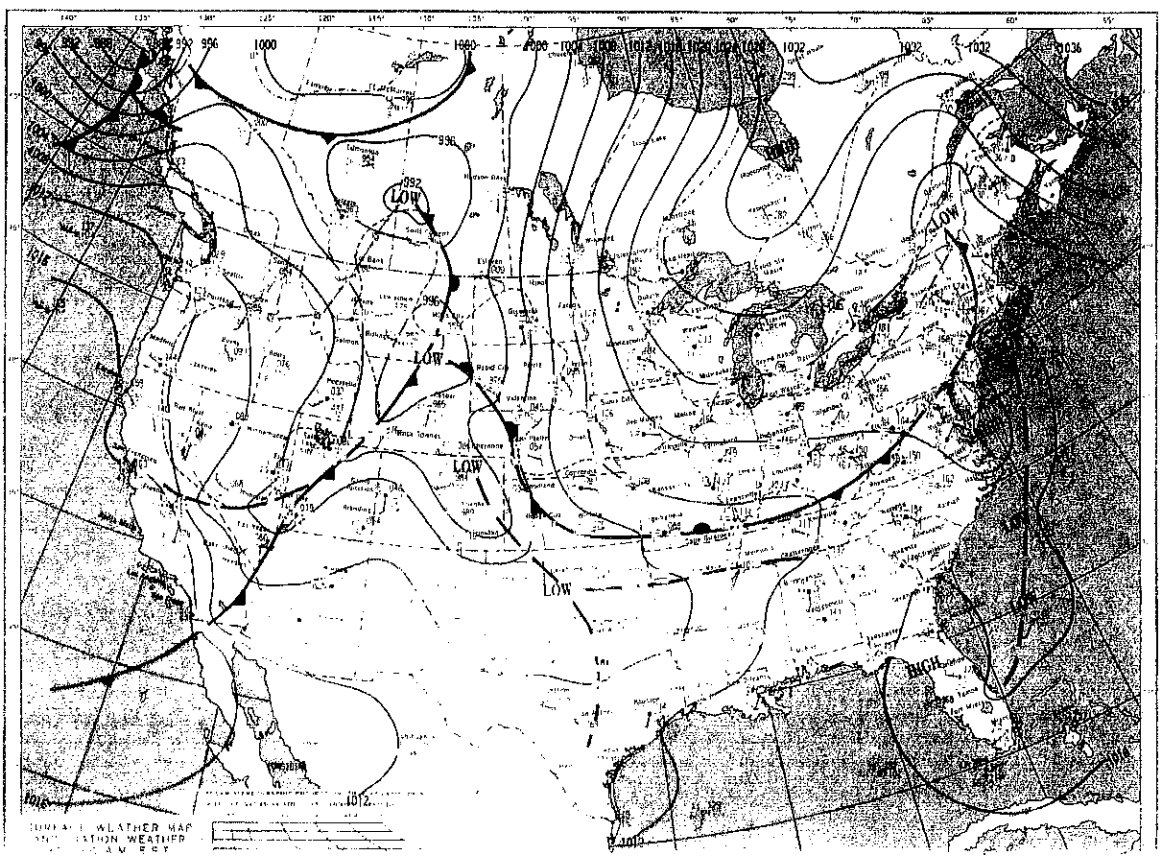
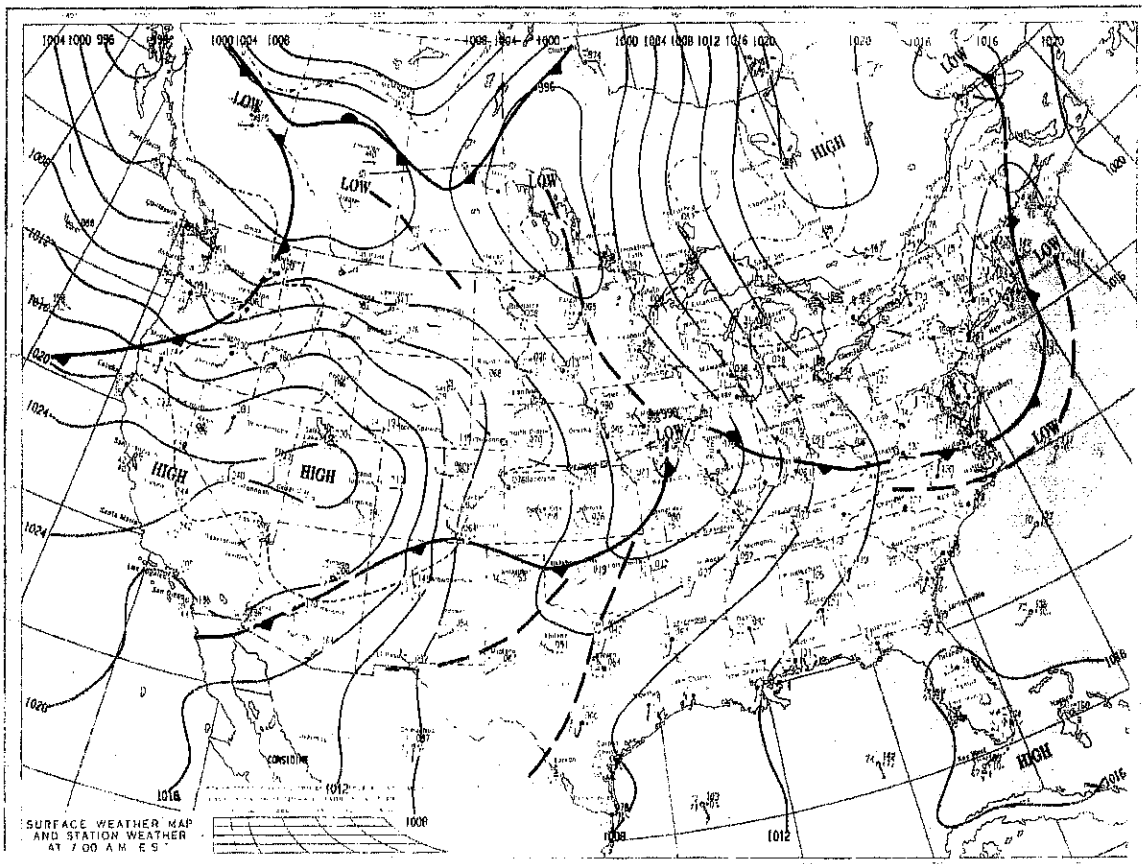


Figure 12 - Daily Weather Map - United States - February 23 and 24, 1996

FRIDAY, FEBRUARY 23, 1996



SATURDAY, FEBRUARY 24, 1996

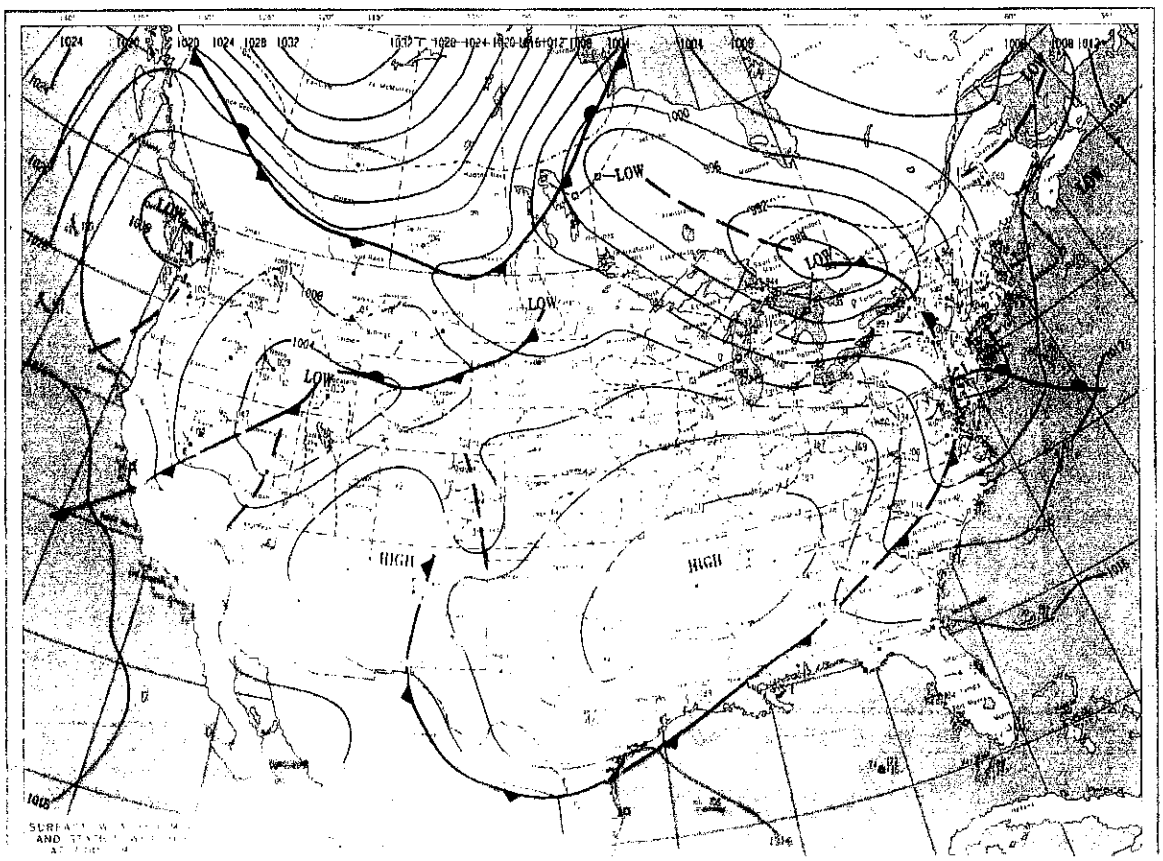
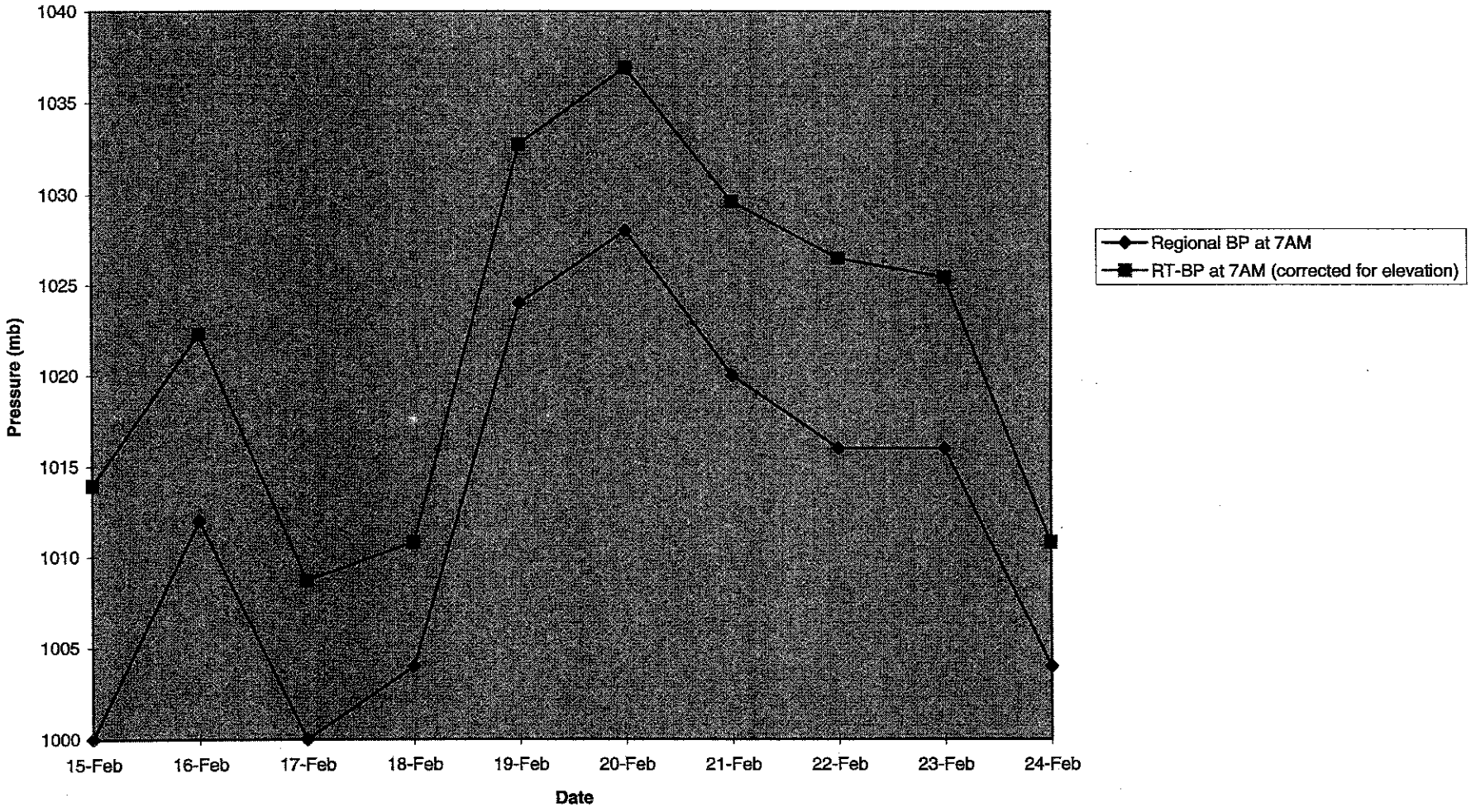


Figure 13 - February 15-24, 1996- Barometric Pressure at 7AM for Regional Weather and Ridgetop Station (corrected for elevation)



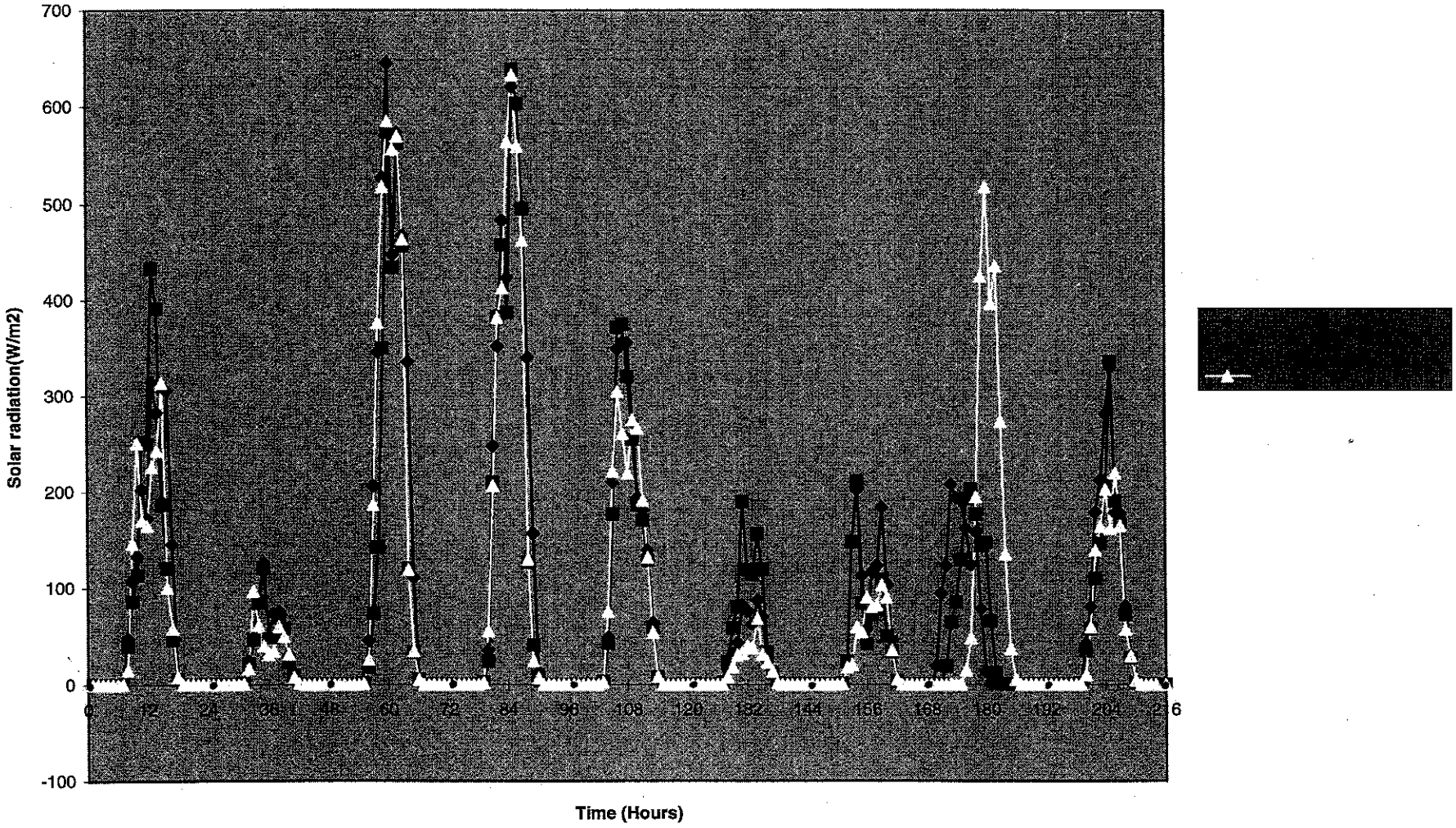
calibration error. Assuming that the Weather Bureau's values are recorded by efficient pressure gauges, it is apparent that a calibration error exists at the Ridgetop station. A difference of approximately 10mb exists between the Ridgetop and Weather Bureau values. Perhaps one could also say that the readings at the Ridgetop station are not 100% accurate because the difference between recorded values at the Ridgetop and by the Weather Bureau is not a constant. The values fluctuate between 8 and 12mb.

The Solar Radiation Sensor:

The pyranometers at both of the Black Rock Forest stations seem to have malfunctioned at a certain point. Solar radiation as seen in figure 14, is clearly defined by diurnal variations. For all three stations, the peaks occur slightly before (1hr), or at noon. At nighttime, the values remain at zero. Nighttime, defined by the lack of solar radiation, ranges from approximately 6PM-7AM for each location. The only exception is February 22 (Hours 168-192), when the Ridgetop station and Openlow station experience the onset of solar radiation at 2AM and 4AM respectively. The Barnard cycle begins as usual at 7AM. It is an impossibility for the Openlow and Ridgetop station to have detected the sun's energy at these early winter hours in the Northern Hemisphere. As a result, this oddity is attributed to an instrument failure.

In addition to a faulty mechanism, snowfall can affect the accuracy of the recorded solar radiation data. During a snow event, the flat horizontal surface of the pyranometer (refer to Appendix I figure D-2 for a visual) becomes covered with snow making it difficult for the sensor to detect the full extent of the sun's energy. On February 16, 1996, New York City, as well as
(hours 24-48)

Figure 14 - February 15-23, 1996- SOLAR RADIATION for Barnard and Black Rock Forest (Ridgetop and Openlow)



a large part of the Hudson Valley, experienced approximately 10 inches of snow (McFadden, 1996). The highest solar radiation value recorded at the three stations barely reaches 100 W/m2. Even on cloudy days (days that exhibit two peaks in solar radiation) , solar radiation values rarely exhibit such low values (fig 13).

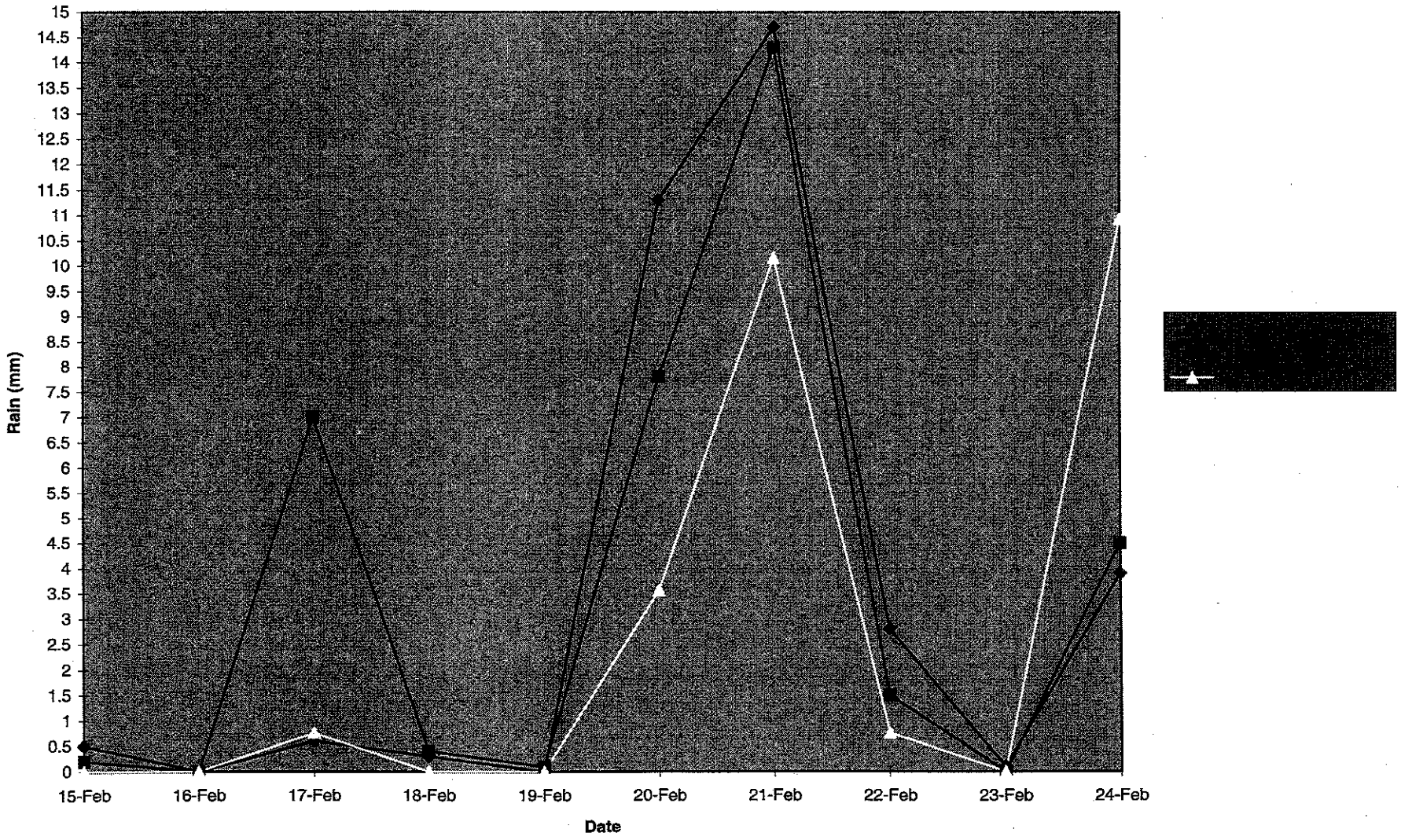
In addition to instrumentation errors, Black Rock Forest is missing the last day of solar radiation data. The received data ends on February 23, as opposed to the other weather parameters which end on the 24th.

Rain Gauge Sensor:

Snowfall also has an effect on the recorded precipitation measurements at Barnard, the Openlow and the Ridgetop stations. Rain, as stated previously, is measured via a tipping-bucket rain gauge. However, during a snowfall event, the snow accumulates in the funnel collector and remains there until temperatures rise, subsequently melting the snow. As a result, the tipping bucket mechanism is temporarily put on hold until the snow is converted into water. Once warmer temperatures melt the snow, the amount of rain will be recorded, although inaccurately. The rain gauge will record rain on the days of melting, as opposed to on the days of the snowfall itself. In addition, the amount of snow in the funnel is not representative of the entire amount of snowfall, because once the funnel is filled the remaining snow no longer has a surface area on which to accumulate.

This can be seen by figure 15 which shows the total rain for February 15-24, 1996 at both Barnard and Black Rock Forest. The snowstorm on February 16th is not apparent by the recorded

Figure 15 - February 15-24, 1996- TOTAL RAIN for Barnard and Black Rock Forest (Ridgetop and Openlow)



data. The snow measurement taken at Central Park was 9.9" (254 mm) (Mcfadden, 1996), while the Barnard, Ridgetop and Openlow stations total rain values equal zero. In addition, only light showers occurred on February 20th (Weather Report, 1996), yet between 3.5 and 12.5mm of rain were detected. These high values must be due to snow melt (warmer temperatures-fig 51) .

Rain gauges also pose a problem in recording normal rain events. Depending on the winds and the location of the sensor, rain could at times, hit the side of the collector resulting in an incorrect recorded precipitation value.

CFC data:

The CFC data from Lamont is also incomplete. The CFC data exists from February 15-20th and 21st for CFC-12 and CFC-11 concentrations. These were the only days that had overlapping data with the four weather station's data sets (which range from February 15-24, 1996). Prior CFC measurements existed, but prior weather data from Black Rock Forest and Lamont were inaccessible at the time of the analysis.

In addition to the lack of compatible data, calibration problems also exist. As seen by figures 16 and 17, CFC-11 ranges from 330-350 ppt and CFC-12 ranges from 650-750 ppt. However, on February 17th (hours 48-72) at about 9AM both the CFC 11 and 12 measurements plummet to concentrations of 220 and 350 ppt, respectively. This could be due to two reasons. February 17th was a Saturday and perhaps local manufacturing plants were closed, giving the CFCs a chance to disperse. Unfortunately, no research has yet been done on the

Figure 16 - February 15-21, 1996- CFC-11 Concentrations at Lamont

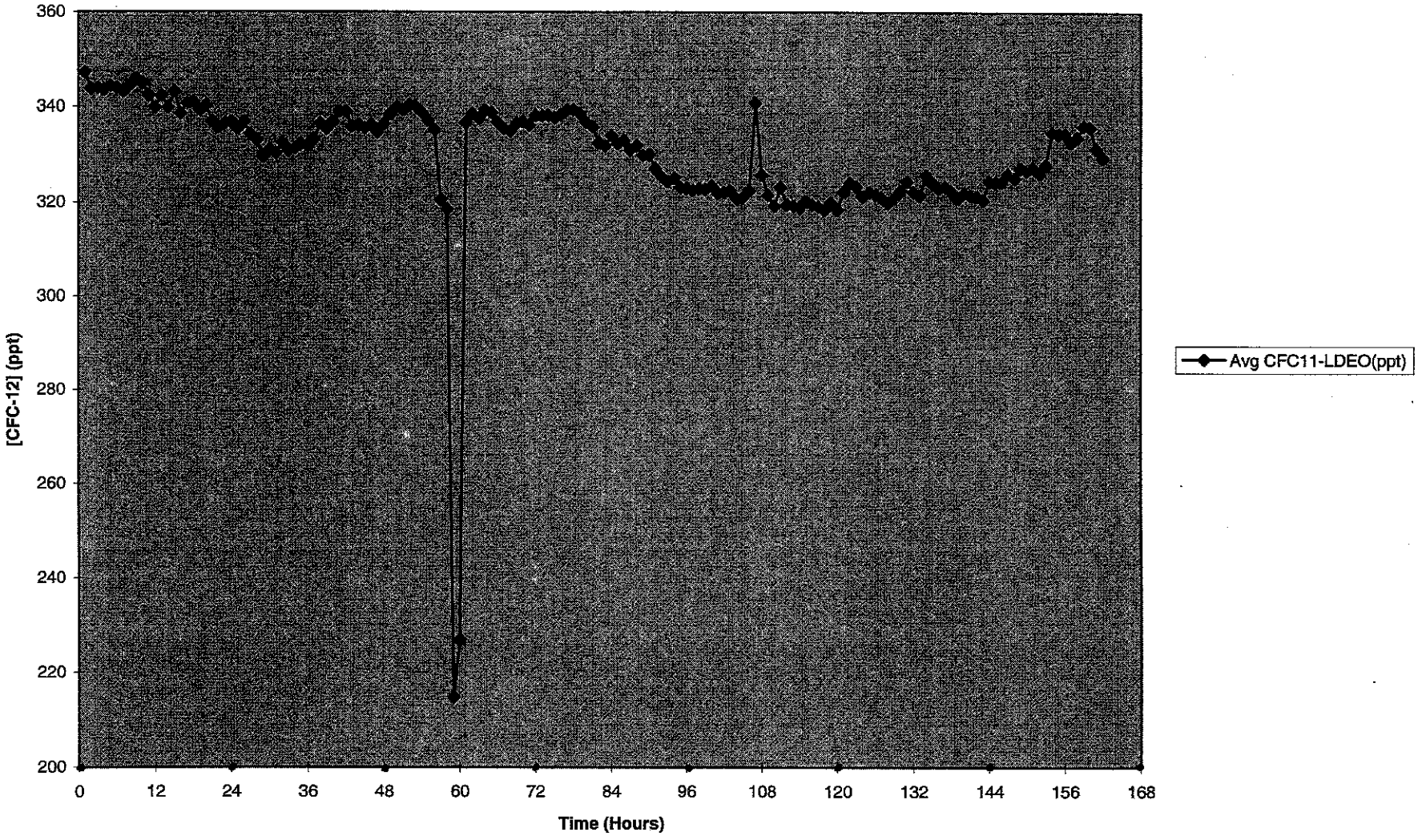
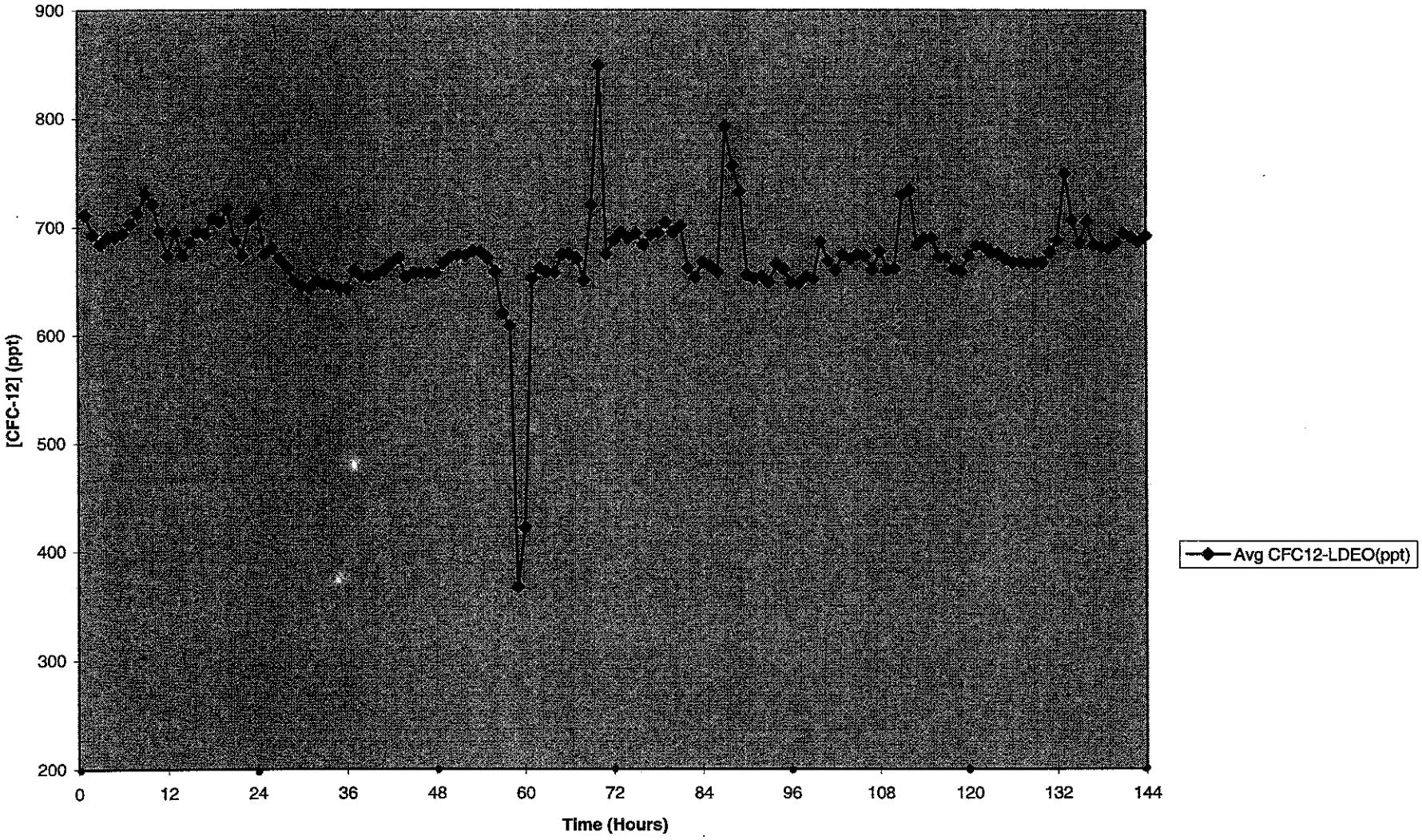


Figure 17 - February 15-20, CFC-12 Concentrations at Lamont



existence of such plants in the area as well as ones further away. In addition, it seems highly unlikely that such a drastic change in concentrations would occur over such a short time period. Considering that nothing out of the ordinary occurred on this day, one is skeptical about the instruments accuracy.

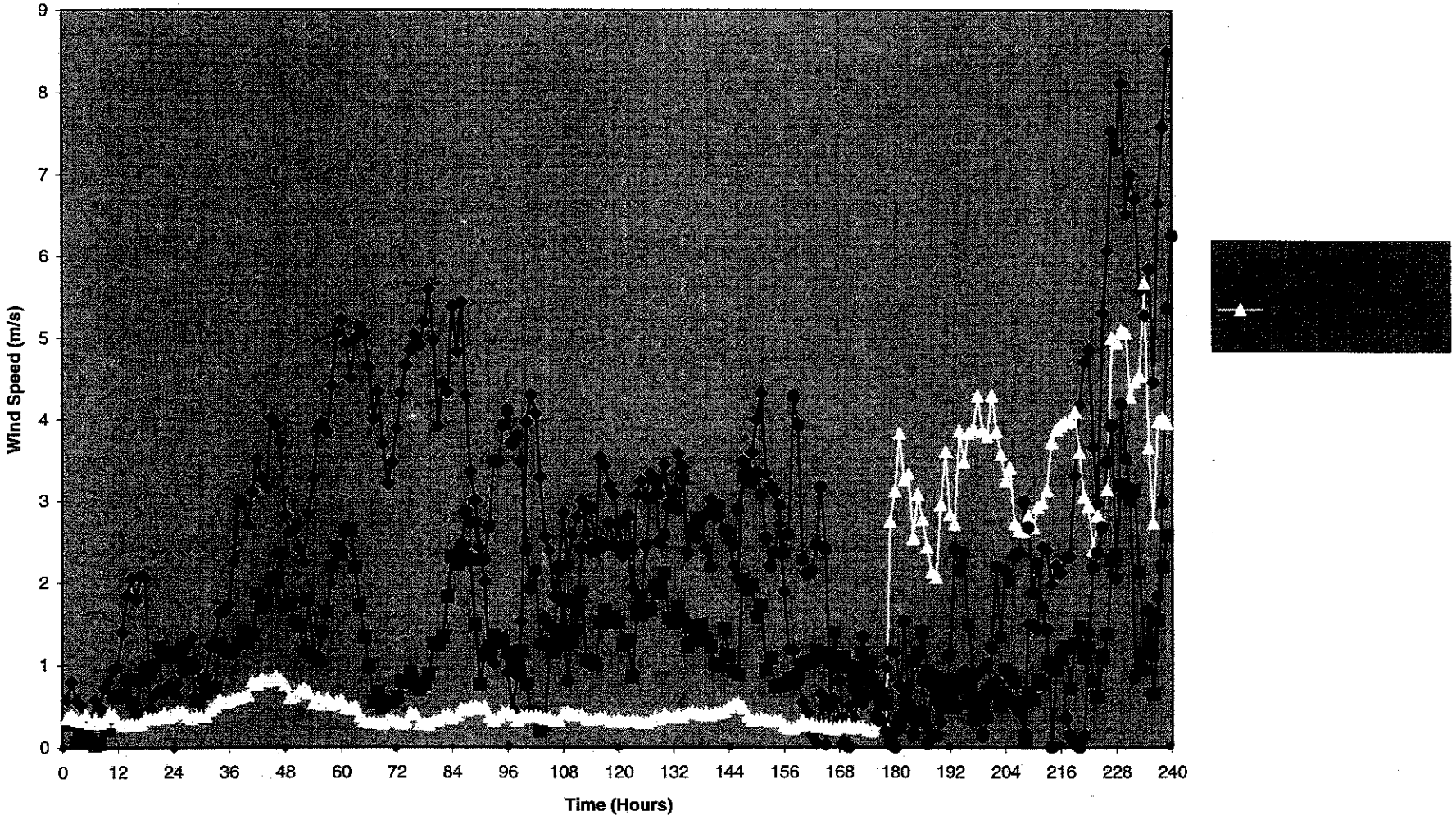
When running an air sample through such a device, one should run a standard through prior to each sample. This is a necessary component by which to determine the accuracy of one's measurements. The inlet source/gas chromatograph system is capable of drifting, thereby producing faulty data. A standard serves to realign the drift. Unfortunately, these CFC measurements were done without continuous standardization.

Barnard's Wind Sensors:

Barnard's weather station is the newest addition among the four weather stations. Unfortunately, at the time of its inception, a wind vane was not deemed necessary. This oversight was recognized, and a wind vane was installed in mid-February 1996. However, there were programming complications with the wind vane sensor, and no wind direction data were recorded during the desired time frame (February 15-24).

Although an anemometer and wind vane normally come as a unit, Barnard did have an anemometer installed separately in September 1995. As can be seen by figure 18, Barnard station's wind speed data of February 15-21 shows no high frequency fluctuations. This can be attributed to a mistake made in the program. An effort was made to rectify the error. However, the wind speed section of the program was reprogrammed incorrectly a number of times. One

Figure 18 - February 15-24, 1996- WIND SPEED for Barnard, Lamont and Black Rock Forest (Ridgetop and Openlow)



could therefore, not make an intelligent decision as to how to correct any of the variables. Therefore, this data could not be used.

Expected and Observed Time Lags Between Weather Variables:

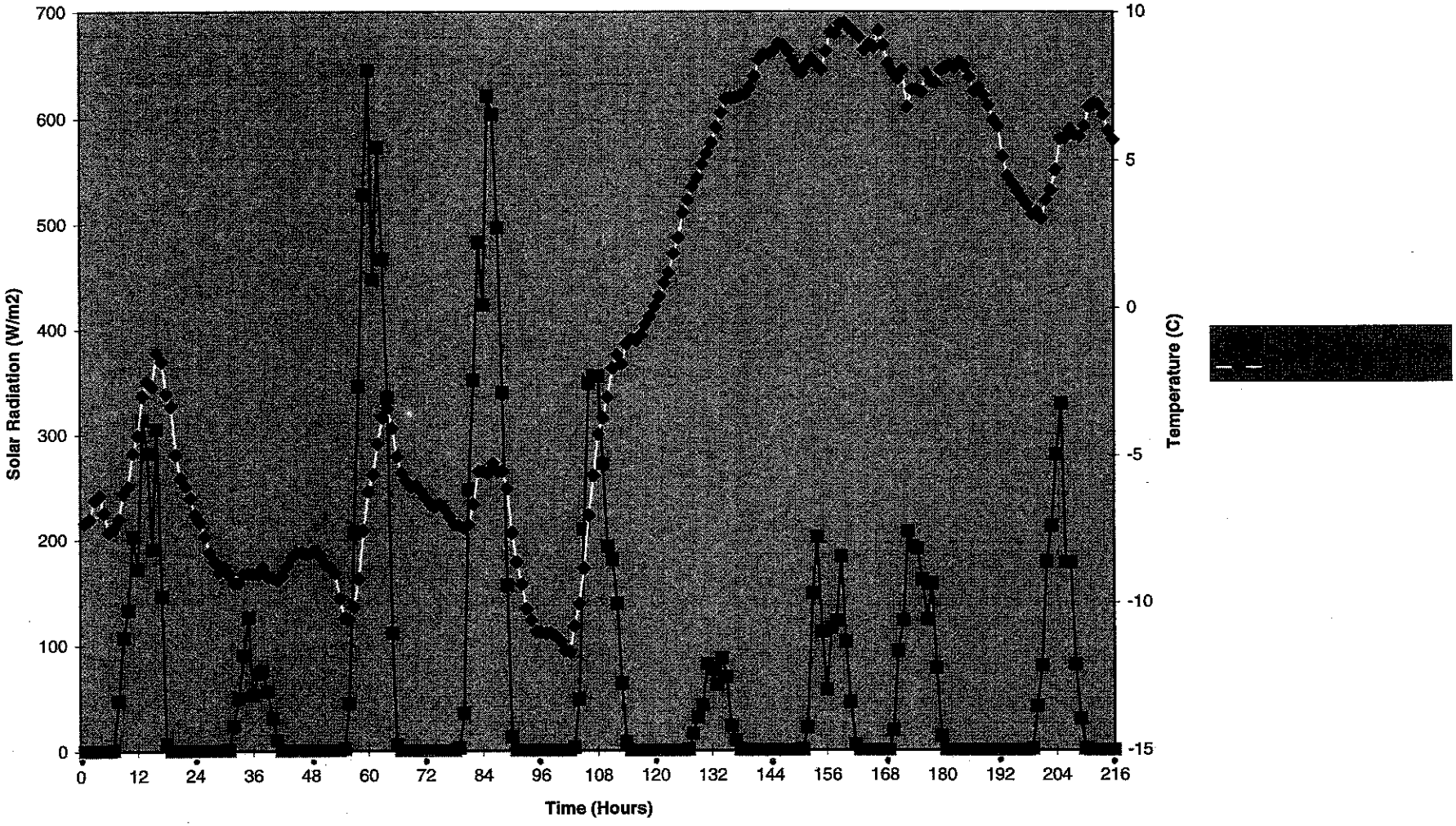
Time lags between variables at the same station, as well as between two parameters at separate stations, are important points to note when analyzing weather data. On the whole, a lag exists between peak solar radiation and temperature and wind speed. In addition, it is possible to detect time lags between stations based on variables like temperature and wind speed.

Solar Radiation and Temperature:

In all three locations (Barnard, Ridgetop and Openlow), the warmest part of the day is usually in the afternoon. This occurs primarily because this is the time when the sun's energy is the most intense. Temperature peaks about 2-3 hours following peak solar radiation. This phenomenon is illustrated by the Ridgetop station in figure 19 (for plots at the Barnard and Openlow station, refer to Appendix V). A lag exists because surfaces slowly heat up by absorbing radiation and converting it into sensible heat. This heat is then slowly lost to the air. Even following peak solar radiation, temperatures can remain high because of continued heat release from the surface.

It is interesting to compare the solar radiation values recorded at the Ridgetop and Openlow station. Because of the Ridgetop's elevation, one would expect it to have the

Figure 19 - February 15-23, 1996- TEMPERATURE and SOLAR RADIATION for RIDGETOP station at Black Rock Forest



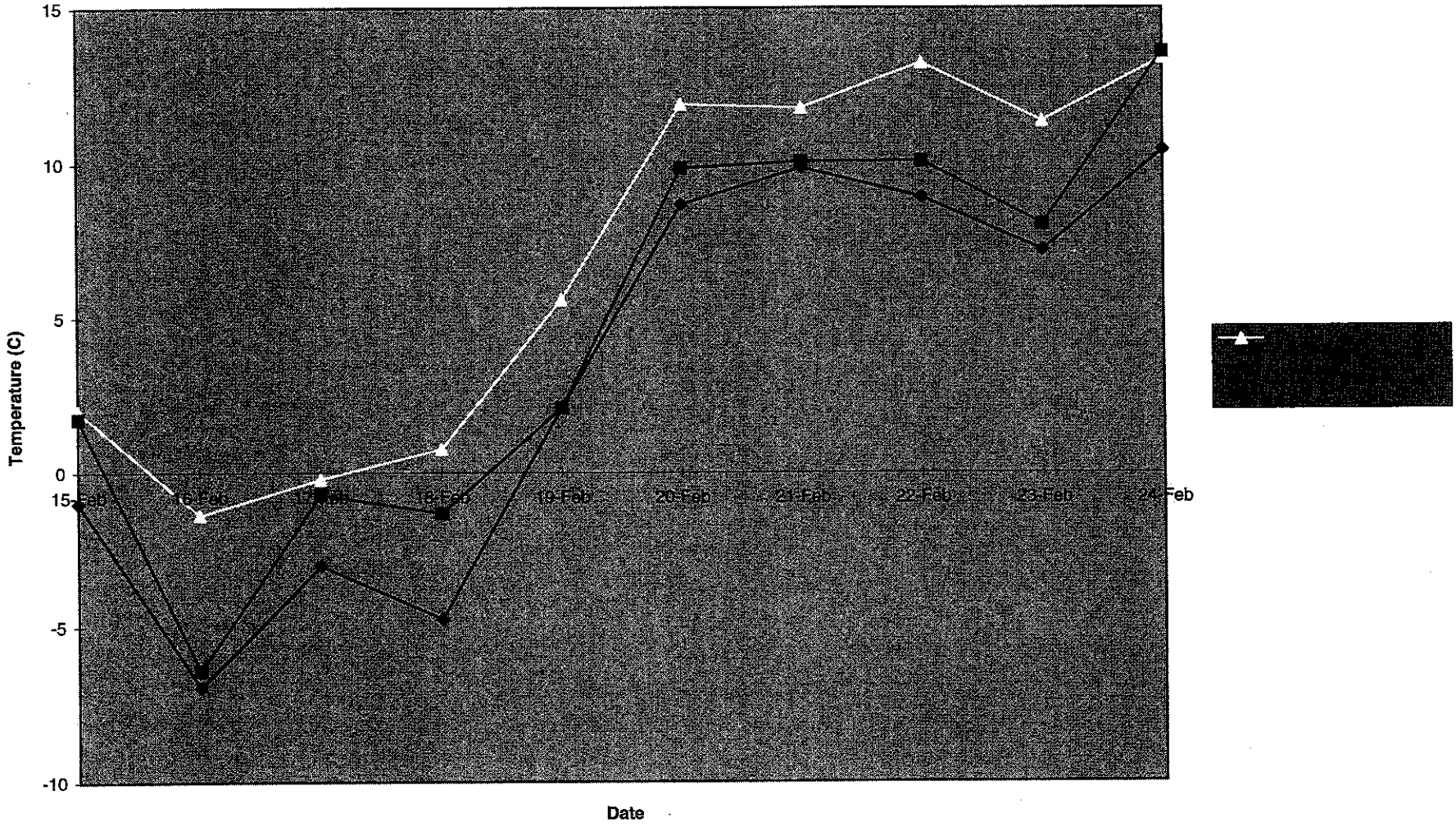
highest solar radiation values. The higher in elevation, the less obstruction there is of the sun's direct rays. Although the Openlow station is in a valley below the mountain tops, it still experiences high solar radiation values. A lag would be expected, with the Ridgetop receiving the sun's rays earlier than the rays received at the Openlow station. However, no lag is seen (fig 14). Perhaps the Openlow station's location in the lowland of the valley is expansive enough so that the sun's energy is not significantly intercepted. More importantly however, because the sun rises in the east, the rays will reach the western mountain top (Ridgetop) and its preceding expansive valley (where the Openlow station is located), at approximately the same time. For the same reason, no lag is discernible as the sun starts to set in the west.

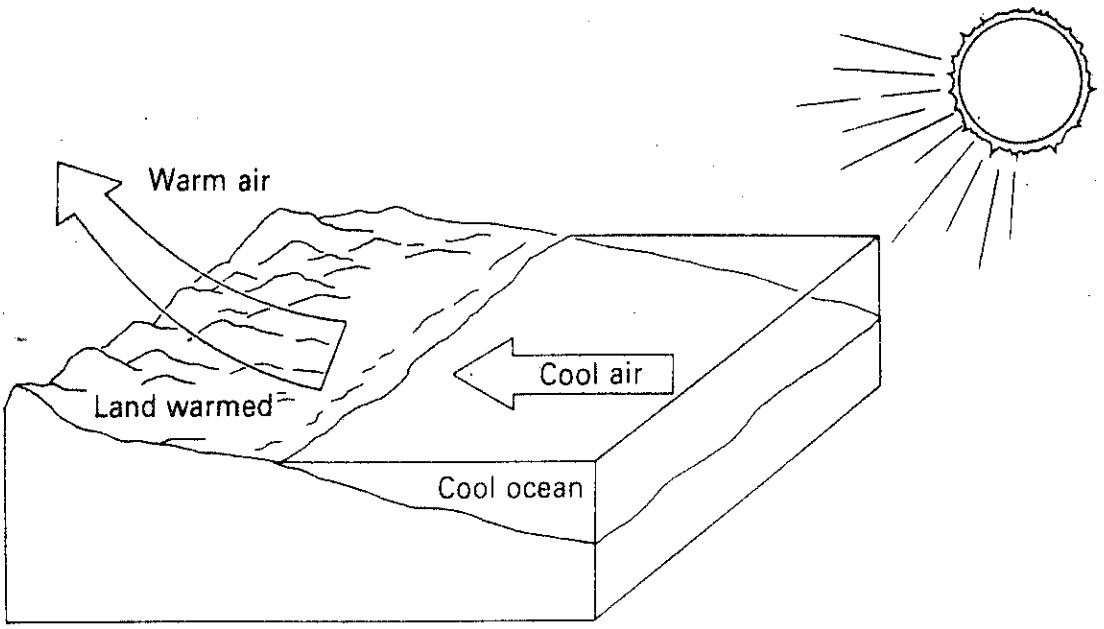
Temperature and Wind Speed:

Another lag between stations was expected but not found. There are times that the warm temperatures noted at the Openlow station are very similar to those recorded at Barnard (fig 20). This occurs on February 15, 17 and 24. This was originally thought to occur due to the combination of valley/mountain winds and the land/sea breezes. Coastal winds are formed due to the uneven heating rates of land and water. As the sun heats the earth's surface, the land heats up more quickly than the water which produces a temperature and pressure gradient. This results in the sea breeze which blows sea air (high pressure overhead) towards the land (low pressure overhead) bringing with it cooler air. At night the reverse occurs where the cooler air from the land blows out to sea termed the land breeze (fig 21).

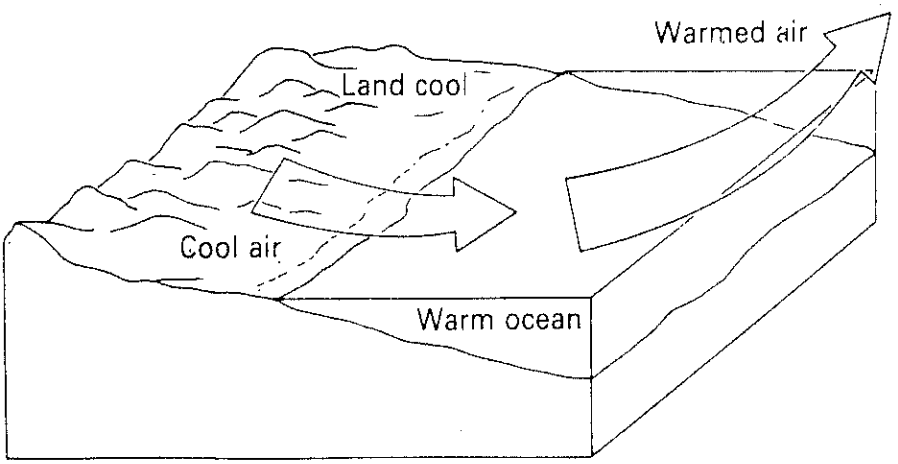
The valley/mountain winds are also created by the uneven solar heating of the earth's

Figure 20 - February 15-24, 1996- MAXIMUM TEMPERATURES for Barnard and Black Rock Forest (Ridgetop and Openlow)





(a) Sea breeze

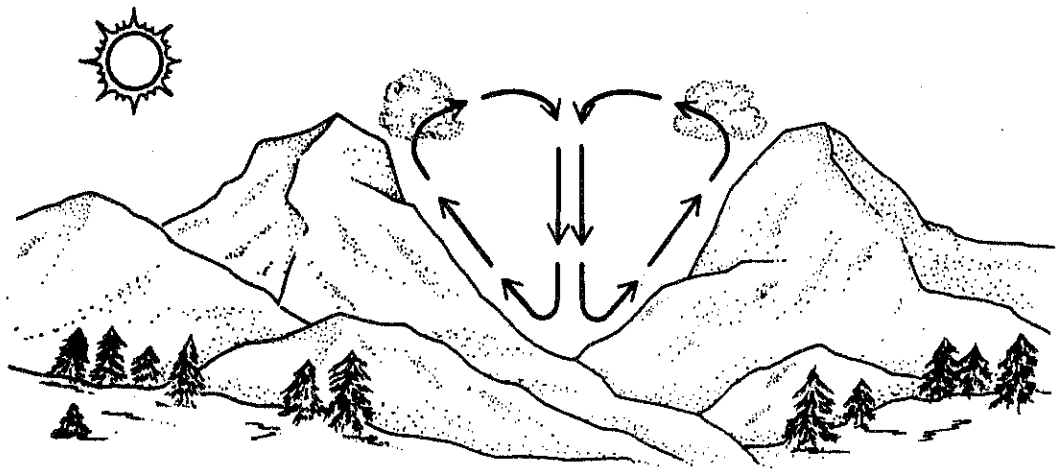


(b) Land breeze

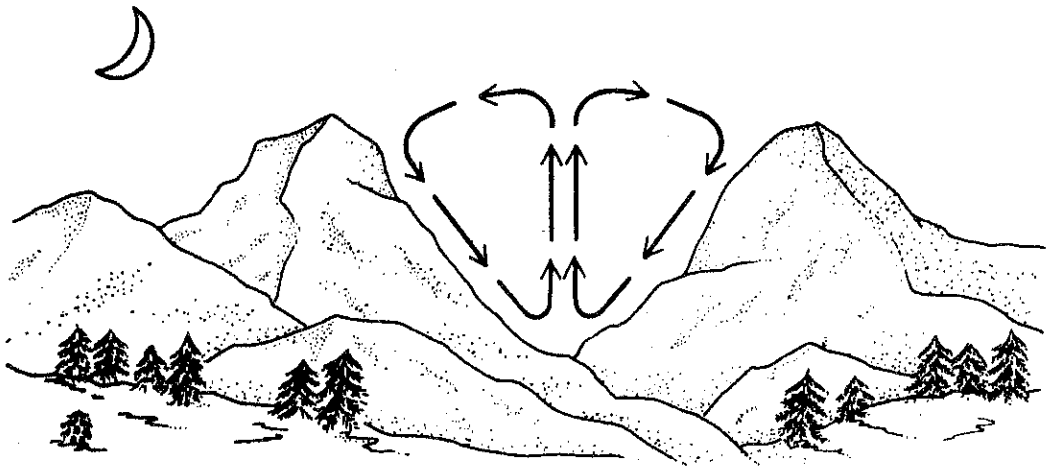
Figure 21 - The Land/Sea Breezes

(Gross and Gross, 1996)

surface which actually intensify the land/sea breeze (fig 22). As the sun heats the earth's surface, the warmer air rises up the valley walls causing a valley breeze. During the night the cool air of the mountain slopes glides down the valley walls creating the mountain breeze. Resulting from these added winds, warm city air could be funneled up the valley and rise up the valley wall to the Openlow monitoring station (fig 23) (Ahrens, 1994). If this were the case, there should exist some time lag between the temperature peaks at Barnard and the Openlow station. However, no real time lag is discernible (fig 24). Barnard may exhibit high enough wind speeds, that the distance between its station and the Openlow's could be covered in less than an hour or two. Unfortunately, no applicable wind speed data for Barnard exists for February 15-21 due to its programming error. However, wind speed data exists for the last three days of the time sequence. On the 24th, Barnard exhibits its highest recorded wind speed at 6m/s. Just as an example, one could use this value to get a basic understanding for the possibility of transported air masses from Barnard to the Openlow station. 6m/s is equal to approximately 13 miles per hour. Even if one wants to assume a value of 10m/s on the grounds that Barnard can't represent the city's true wind speed (blockage due to neighboring buildings), it still only equals 22 miles per hour. Considering the 60 mile (100km) trek that the winds must follow to reach the Openlow station from Barnard, this explanation as to why warm temperatures were recorded at the Openlow station is incorrect. It is possible that a warm air mass is transported from a place further up in the valley, i.e. Lamont. However, temperature data is not currently recorded at Lamont to determine this possibility. Although this is the likely explanation, another suggestion is that the warm air can originally be attributed to high solar radiation values followed up by the land/sea breezes and mountain/valley winds bringing in warmer air from the south.



Valley breeze

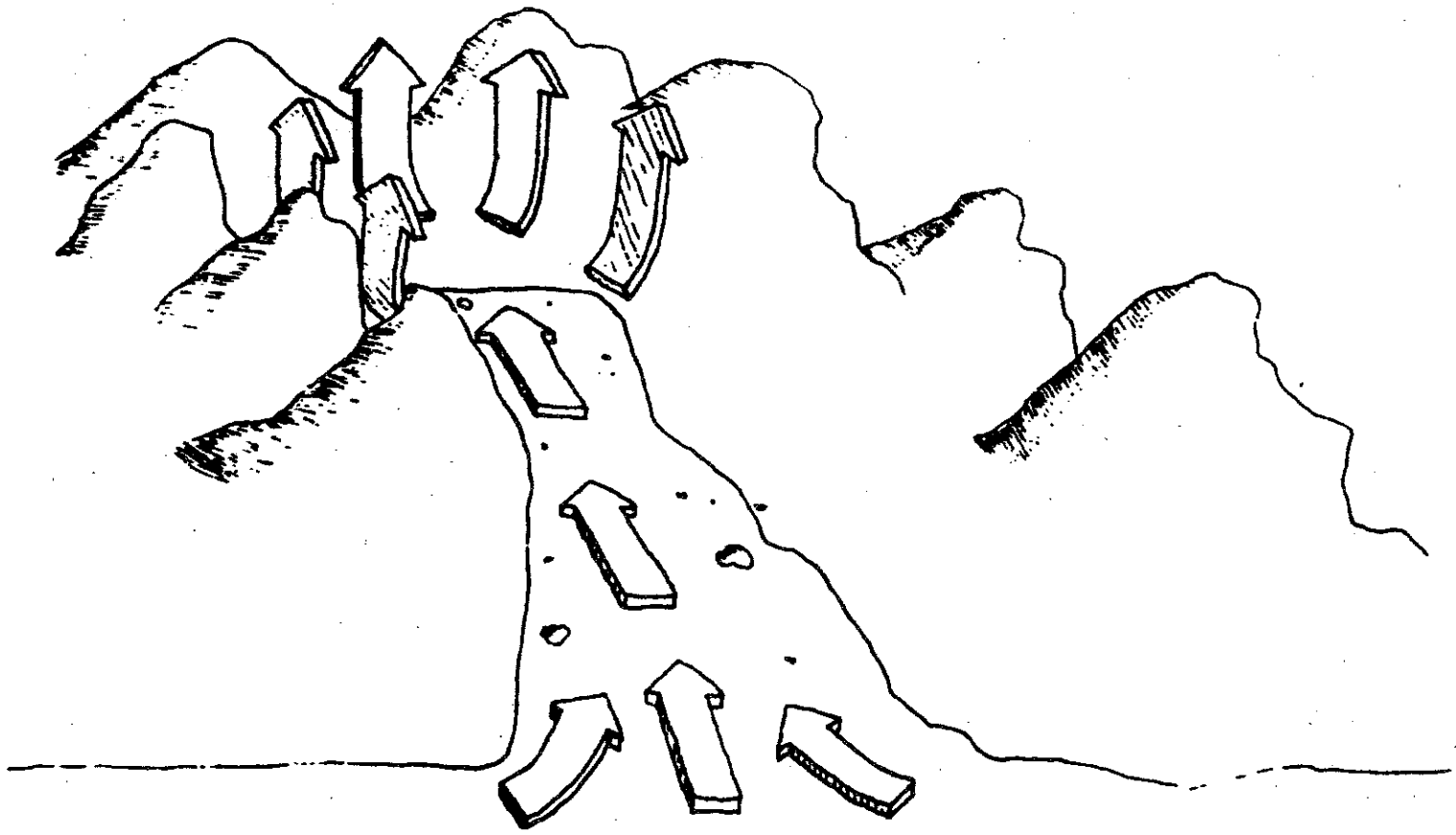


Mountain breeze

A schematic representation of valley and mountain breeze circulation. (*Fig. 12.13/Book page 330)*

Figure 22 - The Mountain/Valley Winds

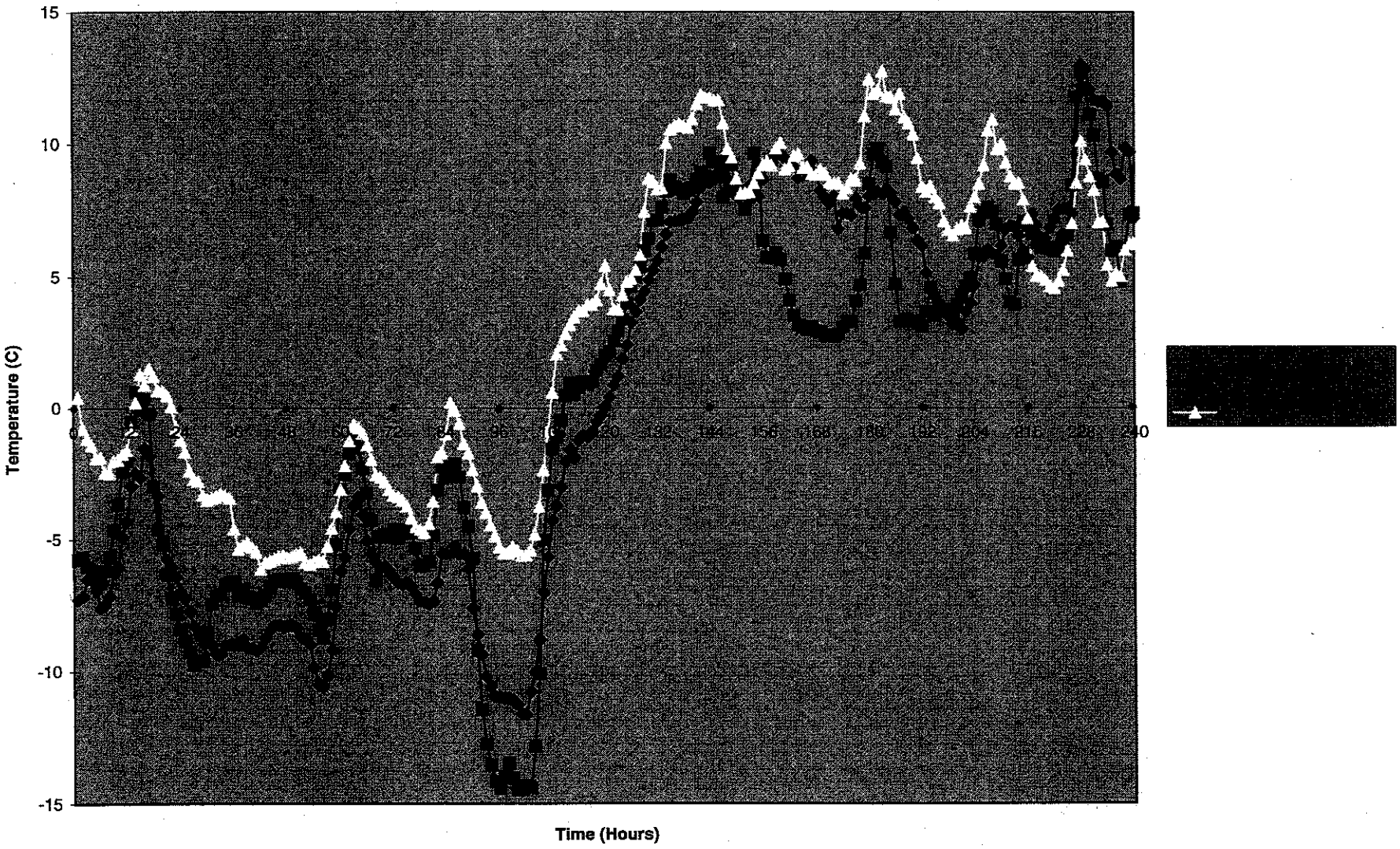
(Morgan and Morgan, 1991)



Valley winds. Like the sea breeze, a valley wind is created by uneven solar heating of the Earth's surface. In response to heating by the sun, air rises along the sides of the valley, drawing air up the valley. Under nighttime conditions, cold air may drain down the valley in response to rapid cooling along the hillsides.

Figure 23 - A Combination of the Land/Sea Breezes and the Mountain/Valley (Hemmond and Fechner, 1994)

Figure 24 - February 15-24, 1996- TEMPERATURE for Barnard and Black Rock Forest (Ridgetop and Openlow)



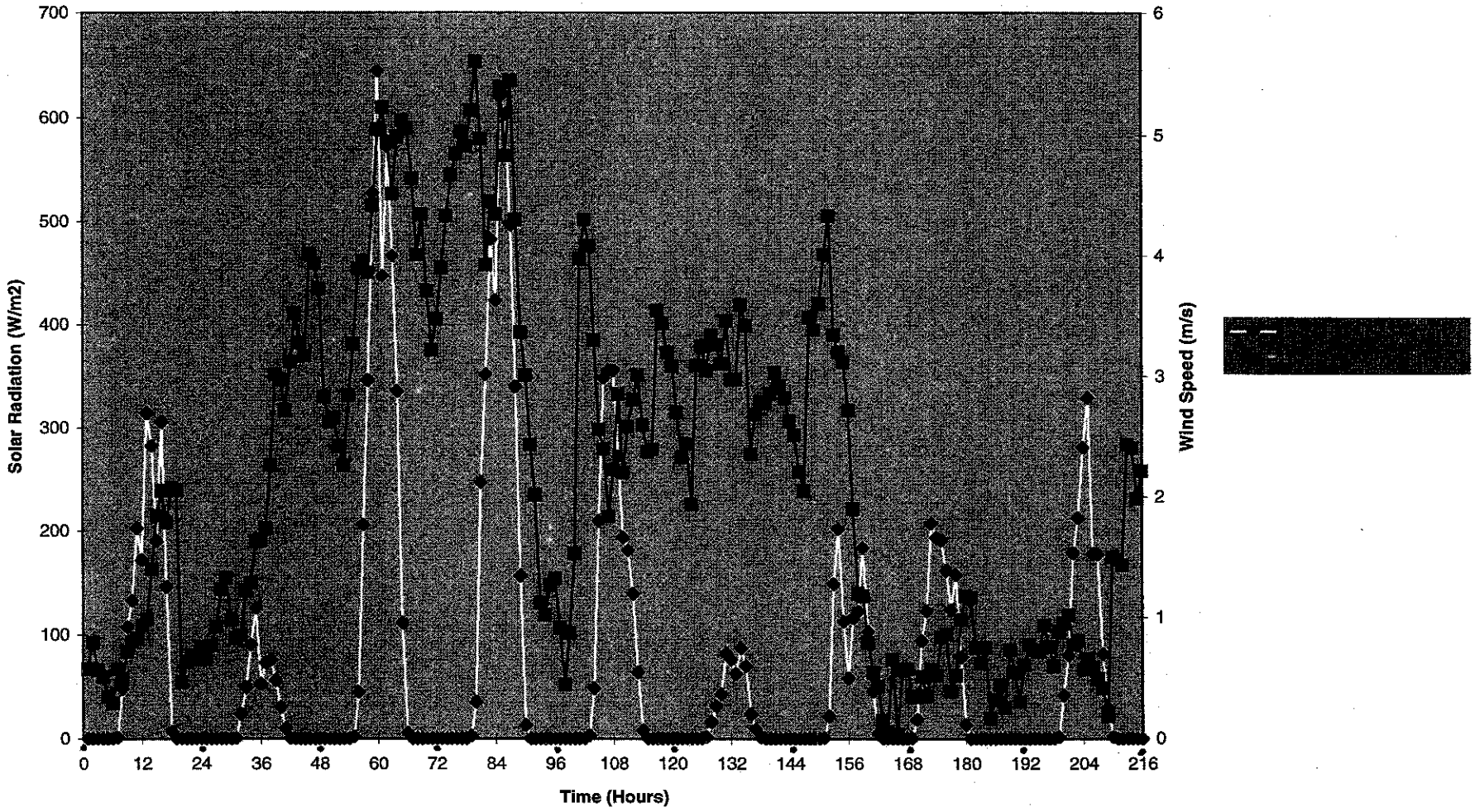
Wind speed is a function of solar radiation. All three locations experience their fastest wind speeds during the daylight hours. The Ridgetop station exhibits its wind speed peaks between noon and 2PM. The Openlow station experiences its peaks in the early afternoon hours (approximately 2PM) approximately 2 hours following peak solar radiation (fig 25).

Because temperature contrasts between land and water are much smaller during the night, the land breezes tend to be weaker, therefore slower. As a result, the Openlow station experiences slower winds in the nighttime hours. The Ridgetop also experiences faster winds in the afternoon hours as opposed to the night. Vertical mixing occurs due to thermal turbulence as the earth's surface is heated. This links the surface air with the faster moving air above and creates faster moving surface air. At night convection is at a minimum and therefore, the surface air moves on its own at a slower pace and is less affected by the faster wind flow above (Ahrens, 1994).

Geographical and Topographical Effects on Weather Data:

When compiling weather data from different stations, it is necessary to incorporate the station's geographical location into the study. Geography and elevation play an important role in a weather station's measurements. Although two stations may be in the same region, or along the same valley, differences are observed in their data collection. Factors such as proximity to bodies of water, rural-versus-urban locations, as well as topographic differences, contribute to variations in small-scale weather phenomena. Although the data from the four weather stations at Barnard, Lamont and Black Rock Forest, contribute to define the basic weather patterns exhibited along the lower Hudson Valley, dramatic differences in recorded values are noted.

Figure 25 - February 15-23, 1996- SOLAR RADIATION and WIND SPEED for RIDGETOP station at Black Rock Forest



These differences in data are observed primarily in the stations' recorded temperature, solar radiation, relative humidity, wind direction and wind speed data.

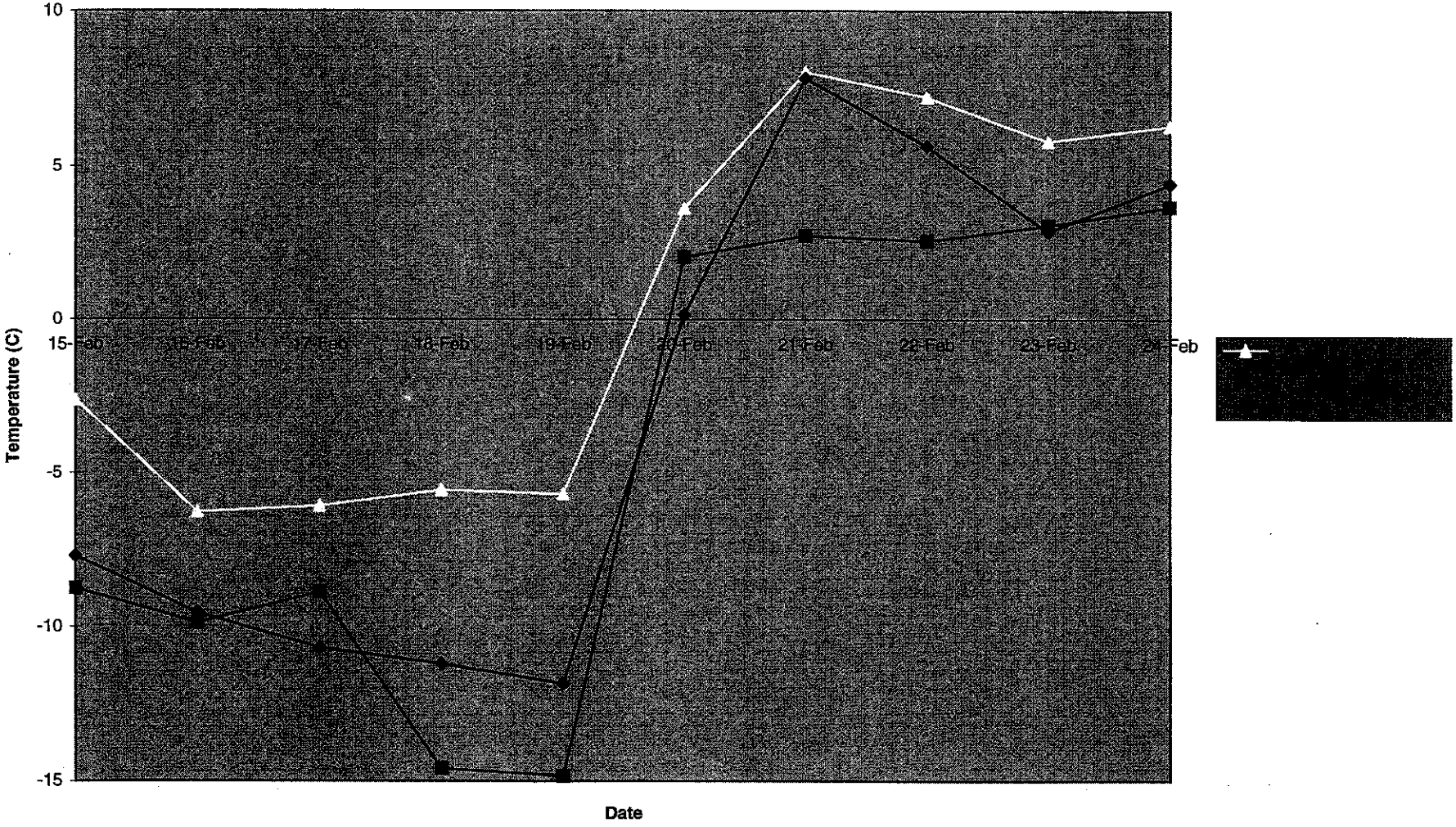
Temperature:

During the winter months, Barnard exhibits the highest temperature values among the three stations. Black Rock Forest's Ridgetop station records the lowest temperatures, whereas the Openlow station at Black Rock Forest displays intermediate values (fig 24). (The average temperature values covering this period are 0.2C for the Ridgetop station, 0.2C for the Openlow station, and 3.1C for Barnard.) Although this is the overall pattern, there are times when the Openlow station exhibits the coldest temperatures. Figure 26 displays the average minimum temperatures at Barnard, the Ridgetop, and Openlow stations.

Barnard's weather station produces the warmest temperature values among the three stations. Located in New York City, this station is influenced by the "urban heat island" effect. In addition, the station's proximity to the Hudson River as well as to the Atlantic Ocean, aids in keeping the temperatures relatively warm.

The urban heat island occurs in cities producing, on average, temperatures a few degrees warmer than those experienced in the surrounding suburbs and countryside. The urban heat island is primarily caused by waste heat, the city's physical makeup, and its limited latent heat flux. Cities produce and release large quantities of heat energy. This heat energy is a combination of major and minor influences such as commercial and residential buildings (furnaces, air conditioners), automobiles, industry and even people. In addition, due to industrial and urban

Figure 26 - February 15-24, 1996- MINIMUM TEMPERATURES for Barnard and Black Rock Forest (Ridgetop and Openlow)



developments, cities exist as large conductors of heat. Asphalt, concrete and brick buildings absorb the heat from the incoming daily solar radiation and release it into the nighttime air. Although the heat is released at night, the tall buildings and skyscrapers serve as an enclosure, further limiting the heat loss. Aside from the buildings and pavements conductivity properties, urban developments have curbed the existence of vegetated areas and areas of exposed soil. Soil and vegetation play an extremely important role in the atmosphere. They offset the sun's rays by causing evaporation to occur, thereby keeping the temperatures constant. In urban areas where there exists a lack of vegetation, sensible heat flux works through conduction and dry convective turbulence warming the near-surface air. Aside from causing the temperatures to be warmer, most of the rain in cities is lost to water runoff and sewers which creates drier surface air in urban areas.

In addition, Barnard's observed temperatures will be very high due to its location on the roof of Milbank Hall. The temperature sensors not only detect the absorbed and emitted solar energy conducted through the building, yet they also exhibit temperature values influenced by additional heat exhaust produced by the building itself (fig 27).

In addition to the urban heat island, the Barnard weather station experiences even warmer temperatures then would be expected due to its proximity to the Hudson River and the Atlantic Ocean. Sea water (saline) can not become colder than -1.8C. Considering that the data under analysis is from the winter months, it would seem that the water's temperature affects its coast's surface temperature by increasing its values slightly.

Water has a higher heat capacity than land. This means that water heats and cools more slowly than land. As a result, areas near large bodies of water tend to remain warmer in winter

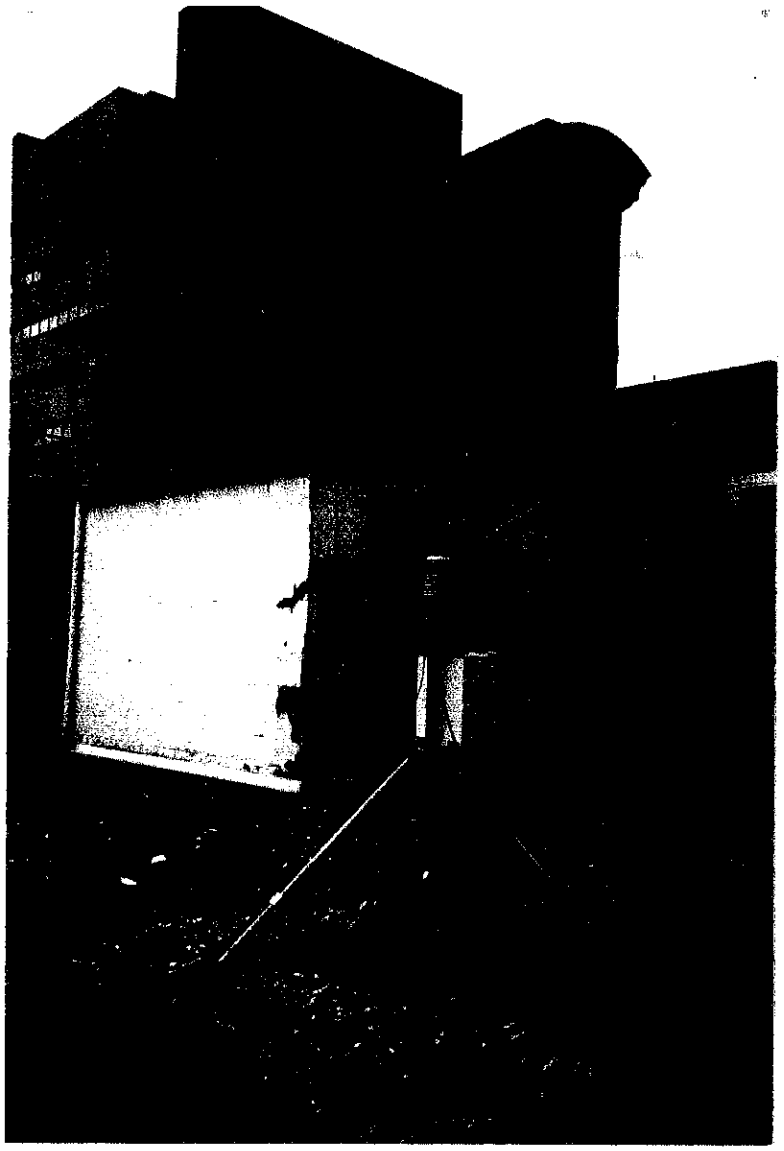


Figure 27 - Barnard's Weather Station on the Roof of Milbank Hall

and cooler in summer than nearby inland regions.

The Ridgetop station exhibits the coldest temperatures because it's situated at 365m (1200 ft). This is the highest elevation of the three stations. As stated previously, atmospheric temperature decreases with elevation at a rate called the lapse rate. The Openlow station is at a lower elevation of 120m (400ft). Therefore, based on the lapse rate concept, it would only make sense for the Openlow's temperature values to be warmer than those at the Ridgetop. They both represent the same geographic region and differ only in elevation. The temperature values at the Openlow station should be colder than those at Barnard, both due to its higher elevation and inland, rural region.

Topographical differences, as opposed to differences in elevation, could explain why the temperatures exhibited at the Openlow station are at times the coldest temperatures recorded among the three stations. At night there is radiational cooling of the surface. This results in air subsiding from the Ridgetop into the valley. As air subsides, it adiabatically warms. This air becomes compressed vertically by the weight of the atmosphere. An inversion occurs because the upper part of the atmosphere sinks farther than does the lower part of the atmosphere (Ahrens, 1994). Therefore, the air mass on the Ridgetop exhibits warmer values than does the Openlow situated on the valley wall. This explanation fits in well with the data. At all times that the Openlow station records the coldest temperatures during the nighttime hours (fig 24).

The Adiabatic Lapse Rate:

The Ridgetop and Openlow stations represent the same geographic area; they only differ

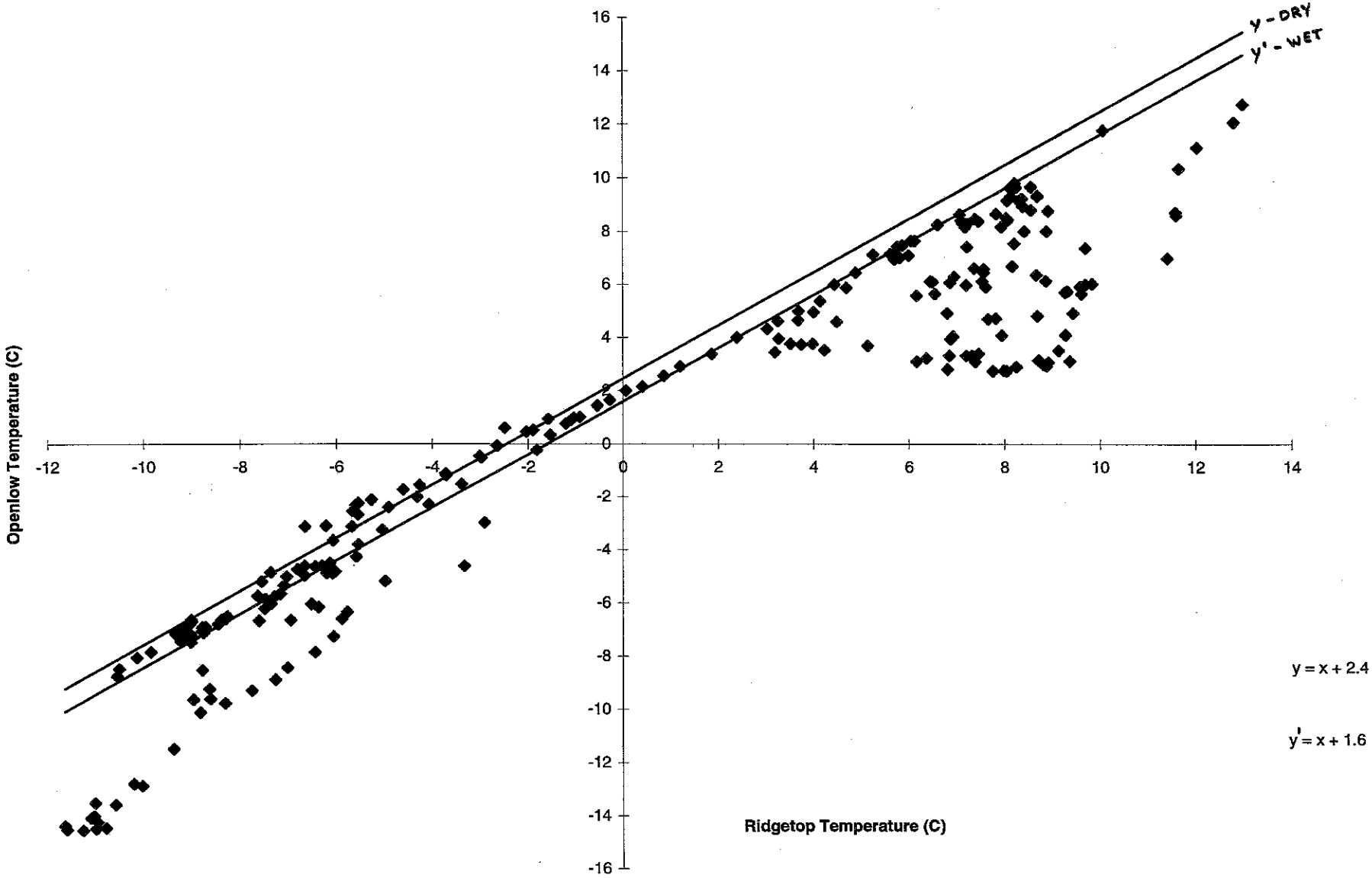
in elevation. Using our knowledge of the adiabatic lapse rate, it is interesting to determine whether the temperature values recorded at both stations follow its predicted lapse rate. Figure 28 is an x-y scatter plot for the temperatures recorded at the Ridgetop and Openlow stations for February 15-24, 1996. This plot shows the experimental and predicted relationship between the Ridgetop and Openlow temperatures based on both the dry and wet adiabatic lapse rates. Under dry conditions, the Ridgetop station should be 2.45C colder (10C/1000m=2.45C/(365-120m)). Under wet conditions, the Ridgetop station should be 1.60C colder (6.5C/1000m=1.60/(365-120)) than the Openlow station.

Figure 28 has two trendlines called y and y'. They represent the predicted trendlines for the dry and wet conditions. Their respective equations are y=1x+2.45 and y'=1x+1.60. The slopes should have a 1:1 ratio if the temperature change between the Openlow and Ridgetop stations were solely attributed to the adiabatic lapse rate. In addition, the data points would either fall on or between the trendlines. During the warmer periods, the temperature differences between the two stations conform better to the wet lapse rate, whereas during colder periods, some of the values fall in between the trendlines representing the wet and dry rates. However, as can be seen by the large scatter, factors other than the adiabatic lapse rate must be operative.

Solar Radiation and Relative Humidity:

As stated previously in the "Time Lag" section the Ridgetop and Openlow station experience the highest measurements of solar radiation. These high values are due to higher elevations for both the Ridgetop and Openlow stations. Although the Openlow station is not as

Figure 28 - February 15-24, 1996- TEMPERATURE at the RIDGETOP and OPENLOW stations at Black Rock Forest



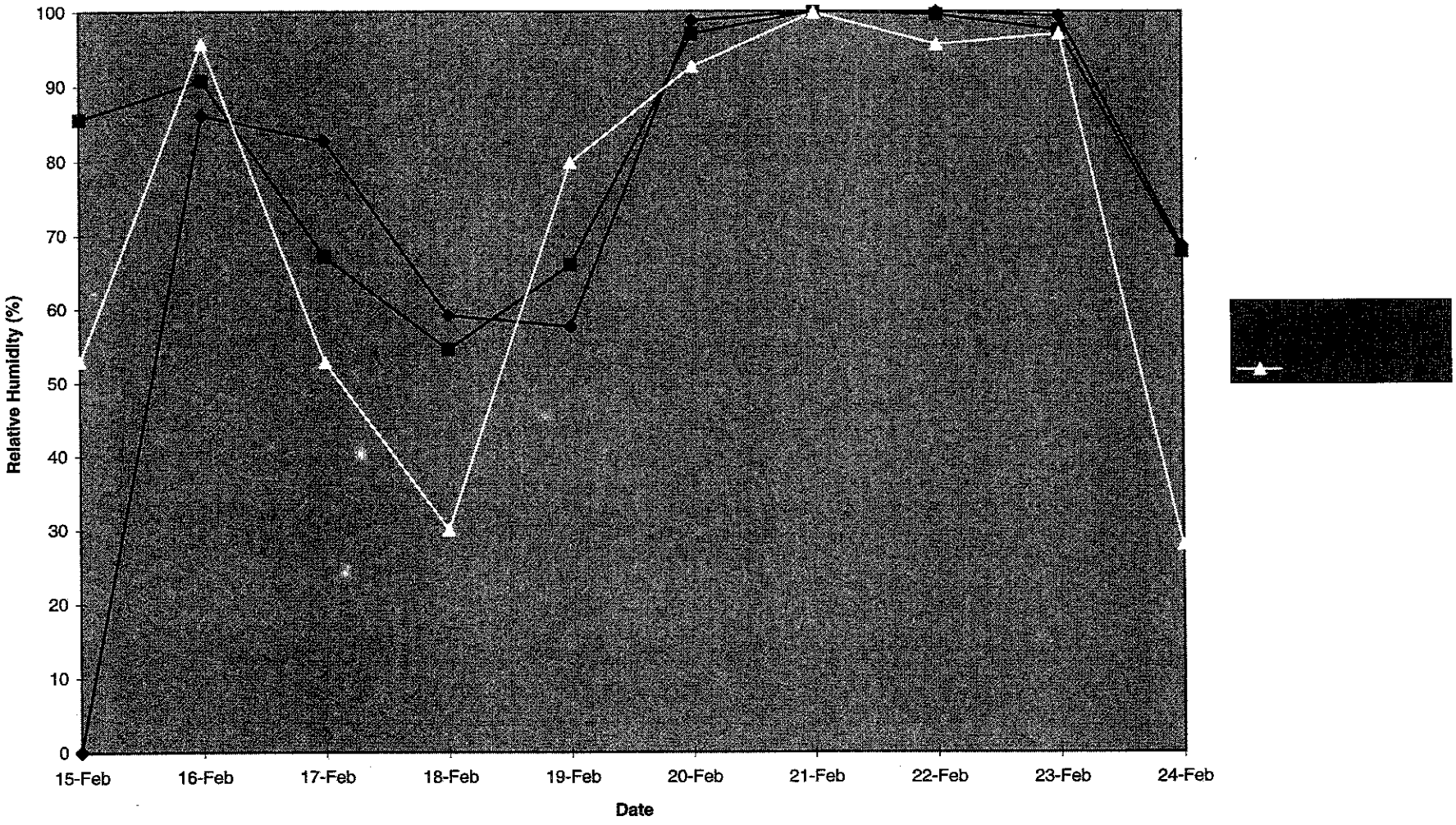
high as is the Ridgetop station, its location in the valley is relatively unobstructed.

The Barnard weather observatory is located on a roof of a city building. Considering its small size as compared to the surrounding buildings, one would expect many of the sun's rays to be intercepted before reaching the pyranometer. However, Barnard's recorded solar radiation values are not that much lower than those recorded at Black Rock Forest. It is possible that the surrounding buildings at Barnard, only block the sun from one angle (perhaps by the Altschul building on campus) (fig 27).

However, it is more probable that the sun's rays are deterred by the urban haze. Cities are prone to accumulation of pollution, since they create a regional thermal circulation where air rises over the city and sinks outside it causing an encapsuled dome scenario (Ahrens,1994) (Del-Genio, 1995). This includes both pollutants and water vapor, which is a greenhouse gas. Water vapor is known for keeping the heat in and the solar radiation out, due to it's greenhouse gas characteristics and reflectivity components. Although overall, Barnard exhibits the lowest amounts of relative humidity, this does not necessarily mean that it houses the least amount of water vapor (fig 29). Being near two major bodies of water, Barnard probably has the highest amount of water vapor among the three stations (even though it's in the urban heat island). The percentage of relative humidity acts as a function of temperature; the warmer the air mass, the more water vapor it can hold due to it's higher saturation value. Considering Barnard's on the average 3C warmer temperature values than the Ridgetop and Openlow stations, it is quite likely that the city contains the highest values for absolute humidity.

High relative humidity values at Barnard, causing an increase in urban haze, is further substantiated by the effects of wind speed. At times of high wind speeds, the water vapor

Figure 29 - February 15-24, 1996- Average daily RELATIVE HUMIDITY for Barnard and Black Rock Forest (Ridgetop and Openlow)



becomes dispersed and there is an increase in solar radiation (figures 30 and 31). (The Ridgetop station is used to show wind speed effects on relative humidity and solar radiation since practically no correct wind speed data exists for Barnard.)

The Ridgetop and Openlow stations exhibit the highest values for relative humidity (fig 29). This follows the concept that cooler air is capable of holding less water vapor than warmer air. The coldest recorded air temperatures occur at the Ridgetop and sometimes at the Openlow stations.

Barnard has low relative humidity values because of its high temperature values (fig 32). If Barnard were not near water sources, one could attribute this to the water runoff and limit of latent heat flux. As described previously about the urban heat island, less water is available to offset the incoming solar rays, resulting in drier near-surface air. This is not such an issue considering Barnard's proximity to water. One would expect high amounts of water vapor resulting from the transport of air coming from the Hudson River and the Atlantic Ocean. Barnard exhibits the warmest temperature values of the three stations, which conceptually goes hand in hand with low relative humidity values. Its warm temperatures explain why the relative humidity values at Barnard are low even though the City holds the highest amount of water vapor (absolute humidity).

Barnard's proximity to two bodies of water is the dominant factor contributing to the air mass value of relative humidity. This is seen by a diurnal variation (fig 33). Overall, during the day, an increase in relative humidity is observed as the sea breeze brings air in from the river to the land. At night, a decrease in percentage humidity should occur, because the land breeze brings air in from the land out to the river. However, there are times when this pattern is not

Figure 30 - February 15-23, 1996- RELATIVE HUMIDITY and SOLAR RADIATION for RIDGETOP station at Black Rock Forest

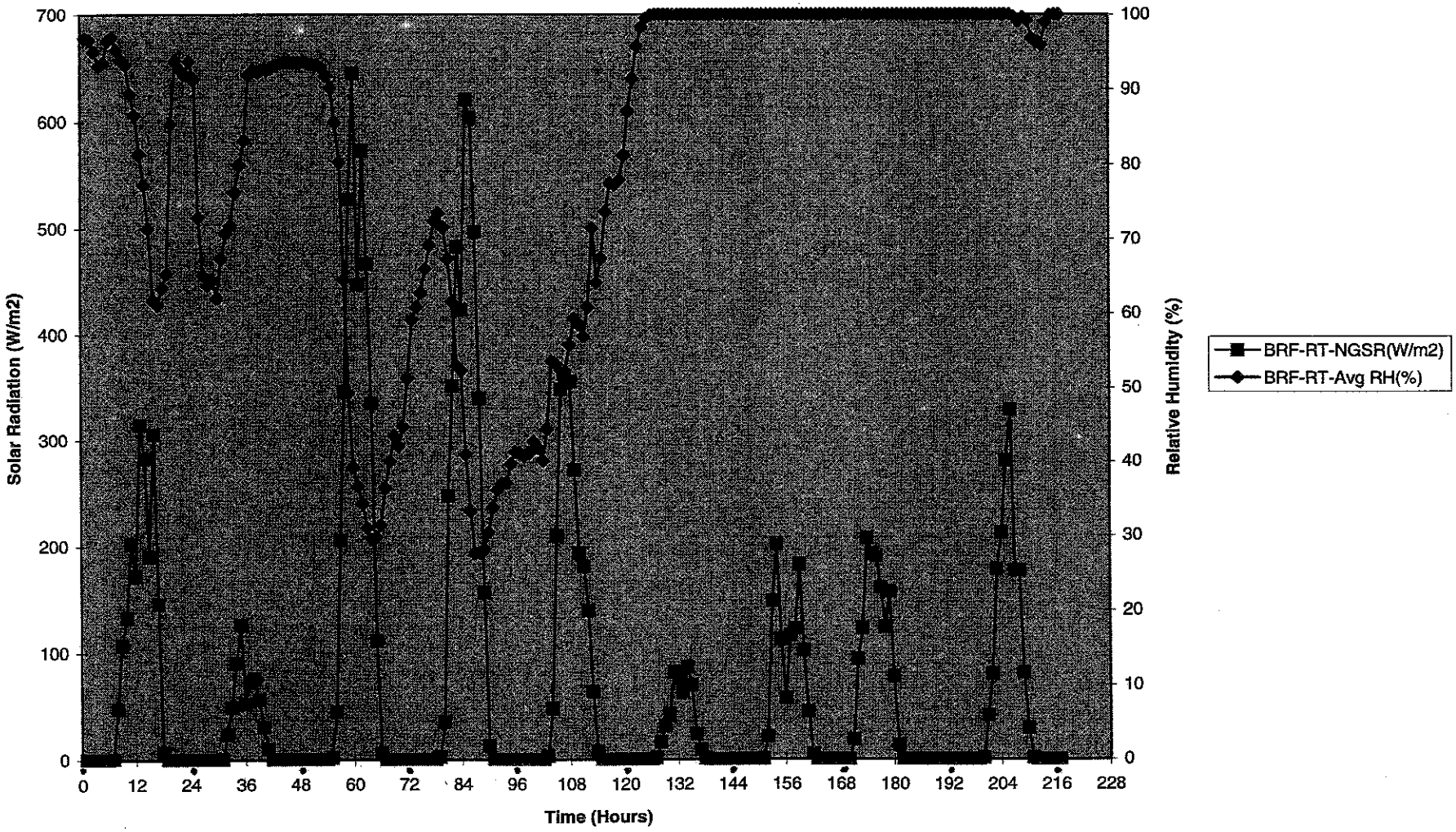


Figure 31 - February 15-24, 1996- WIND SPEED and RELATIVE HUMIDITY for RIDGETOP station at Black Rock Forest

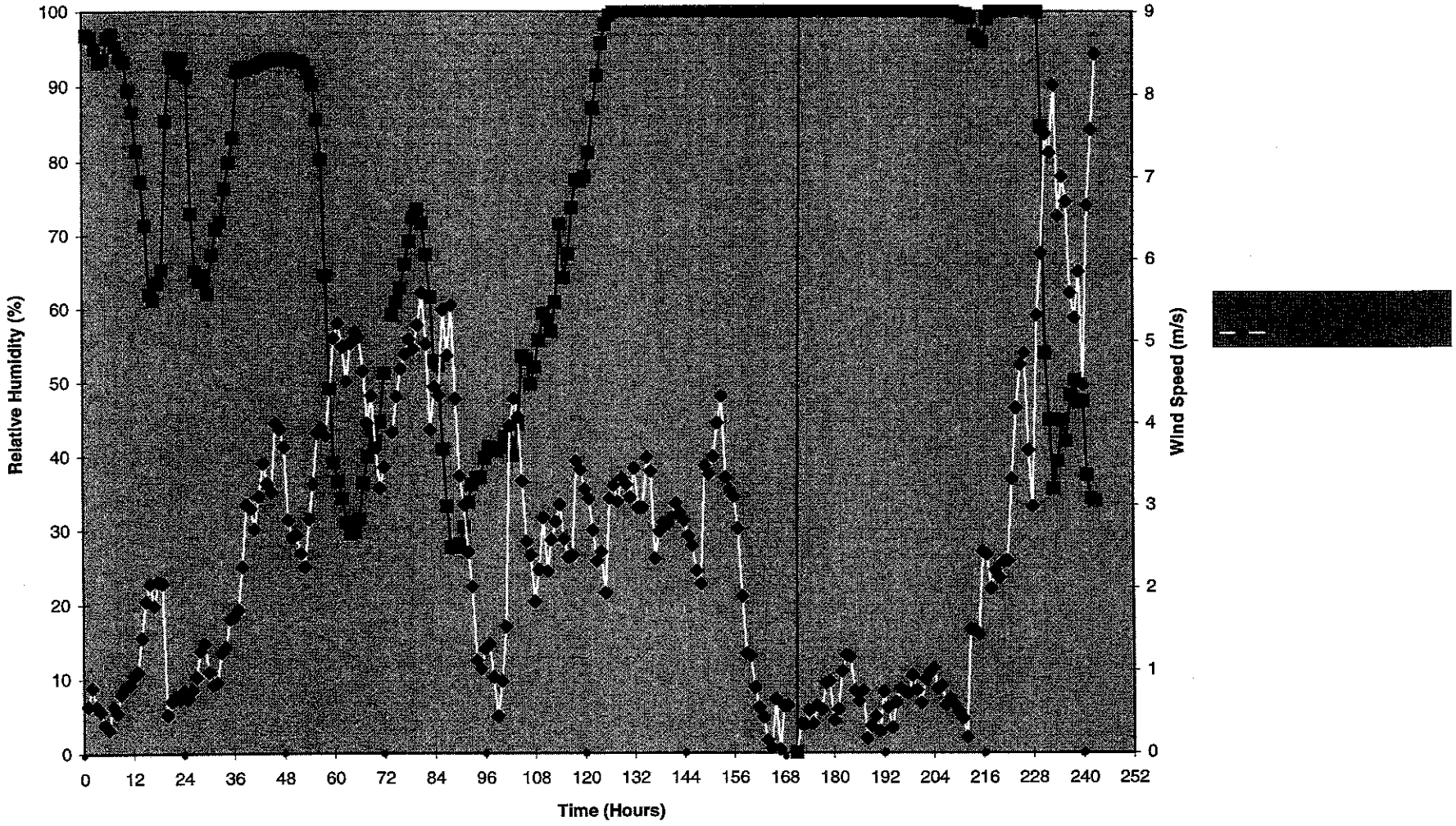


Figure 32 - February 15-24, 1996- TEMPERATURE and RELATIVE HUMIDITY for BARNARD

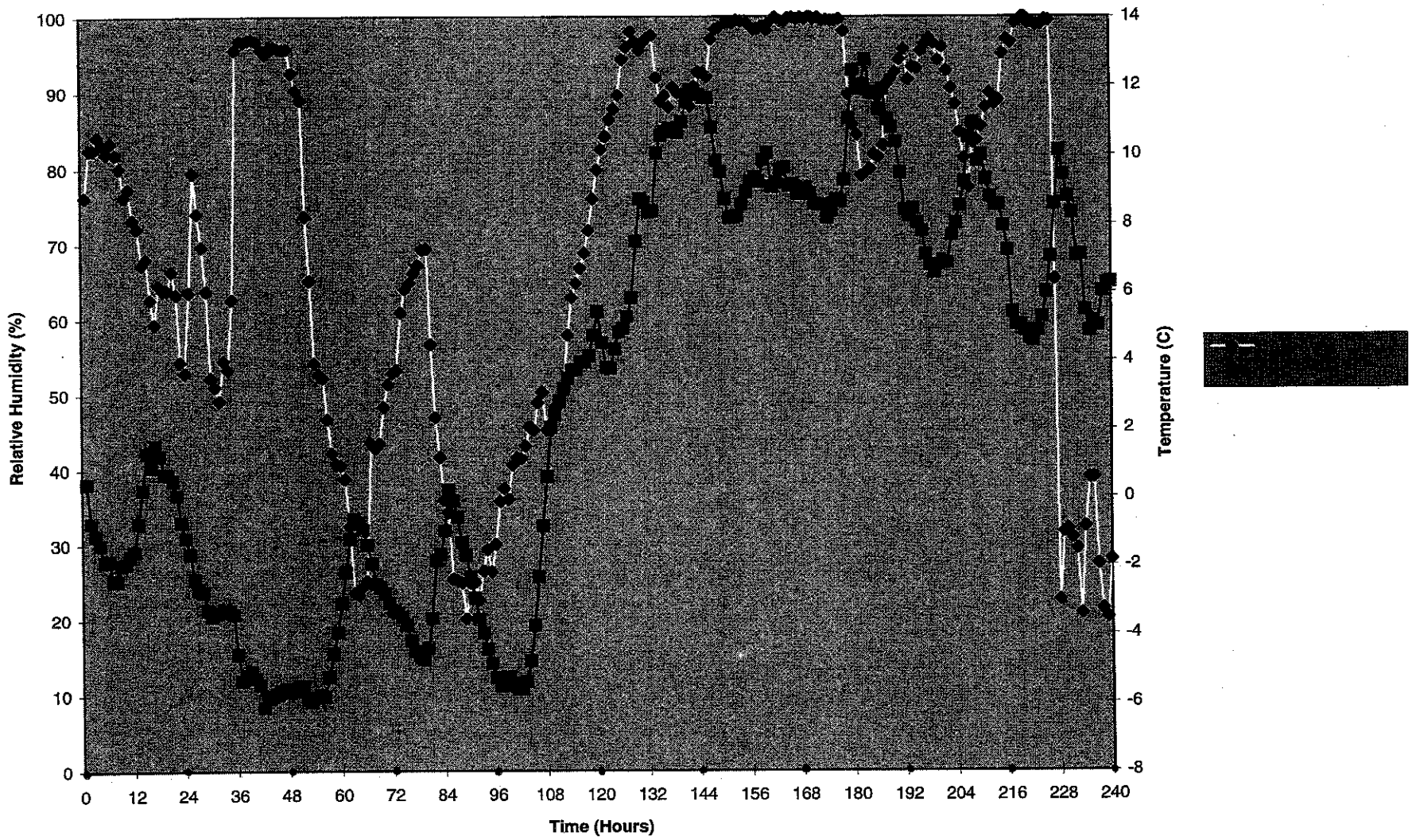
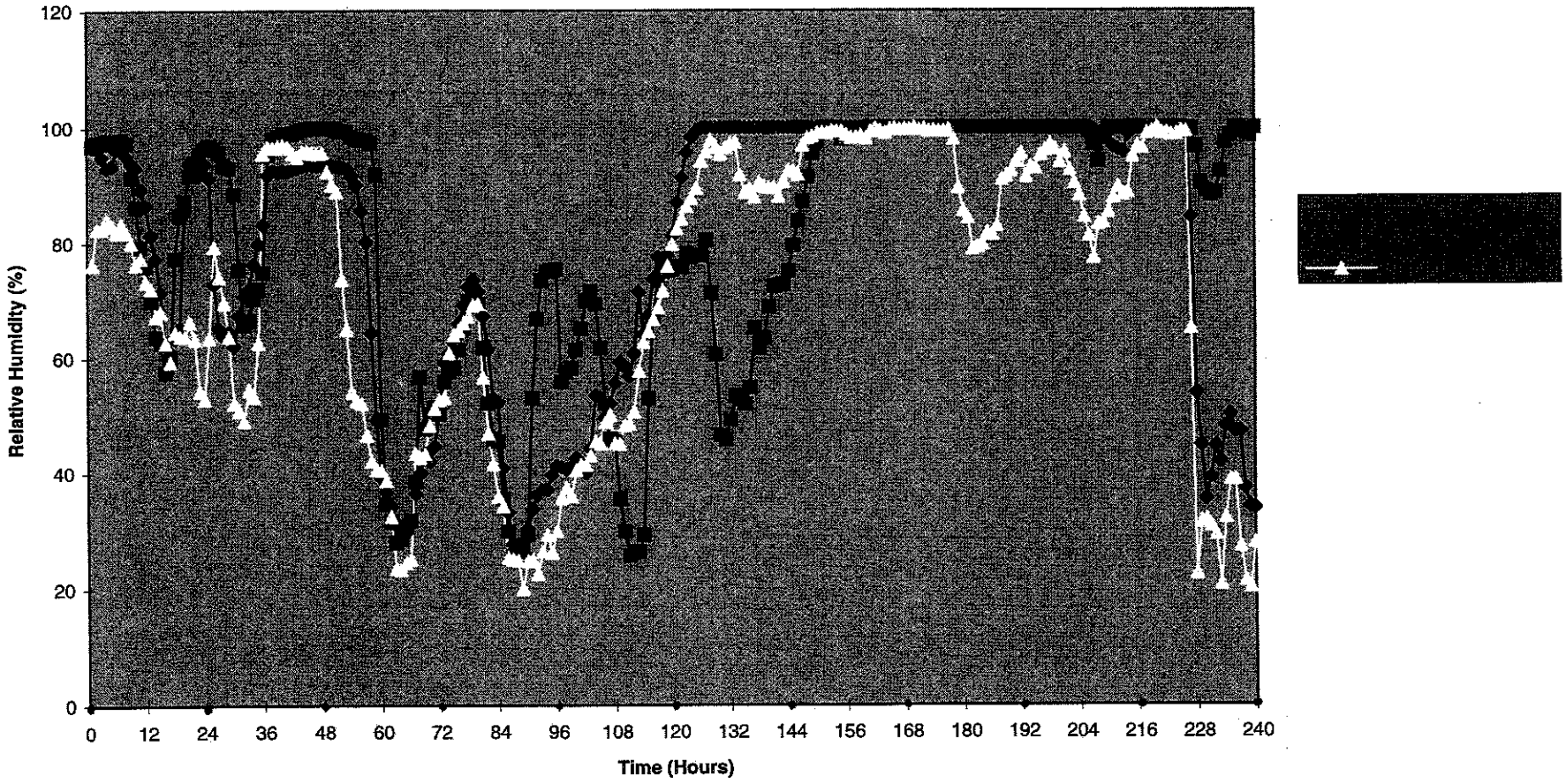


Figure 33 - February 15-24, 1996- RELATIVE HUMIDITY for Barnard and Black Rock Forest (Ridgetop and Openlow)



observed in the data because the cold nighttime temperatures have separate effects on relative humidity that may override the land/sea breeze effect. In addition, maybe the close proximity of Barnard to the waters creates a wetter region regardless of the land/sea breezes. This is true, although not noticed, because of the city's warm temperatures and possible slight offset created by the city's sensible heat flux.

At times, the Openlow station experiences low measurements for relative humidity. On February 19-21 (hours 96-168), the Openlow station does not follow the gradual increase of 20 to 100% exhibited by both the Ridgetop and Barnard stations. On February 19 (hours 96-120) the Openlow exhibits a decrease from 80 to 20% and on February 20 (hours 120-144) it increases to 80%. Openlow's relative humidity values then decreases to 50% before it gradually increases to 100% on February 22 (hours 144-168) when it coincides once again with the other stations (fig 33).

The decrease and pattern shift in relative humidity exhibited by the Openlow station for these three days could be explained by the orographic effect (fig 34). This occurs when air masses are forced to rise over topographic barriers. South of the Openlow station lies the Ramapo mountains, at an elevation of approximately 1100-1200 ft, and Frog Hill (location of Ridgetop station-1200ft). On February 19th (hours 96-120) when the Openlow station exhibits low values for relative humidity the winds are approaching from the south(hours 96-168) (fig 35). As air is forced to rise over the mountains in the south, it's forced up into a cooler region, thus creating higher values of relative humidity. Air approaching the mountains is forced to rise above it, thereby increasing its relative humidity. If the air rises and becomes saturated, its lifting condensation level will be reached, which will cause precipitation and latent heat release. The windward side experiences the rainfall and the leeward side (the Openlow station) will have drier air moving downhill since much of its moisture

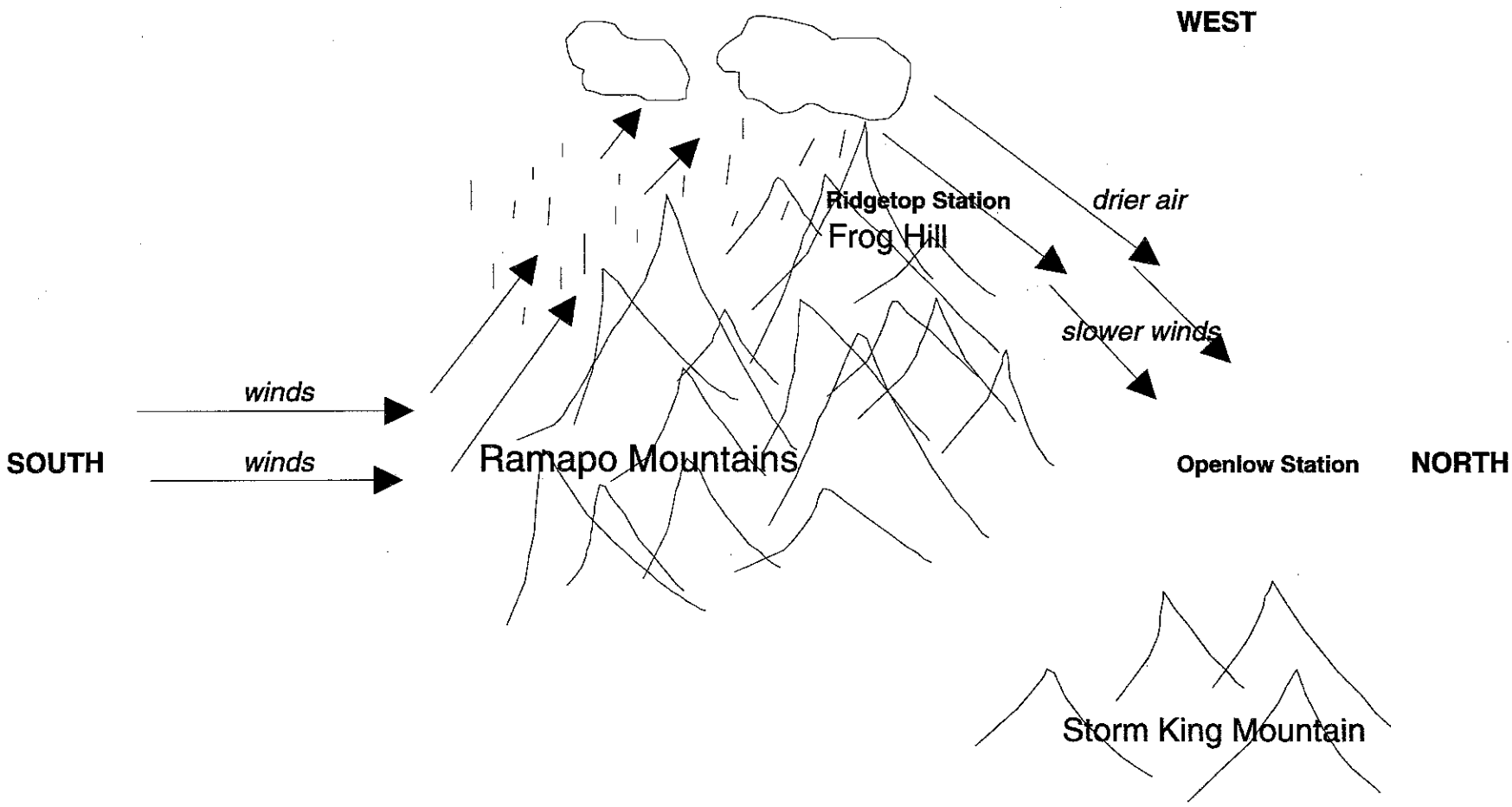
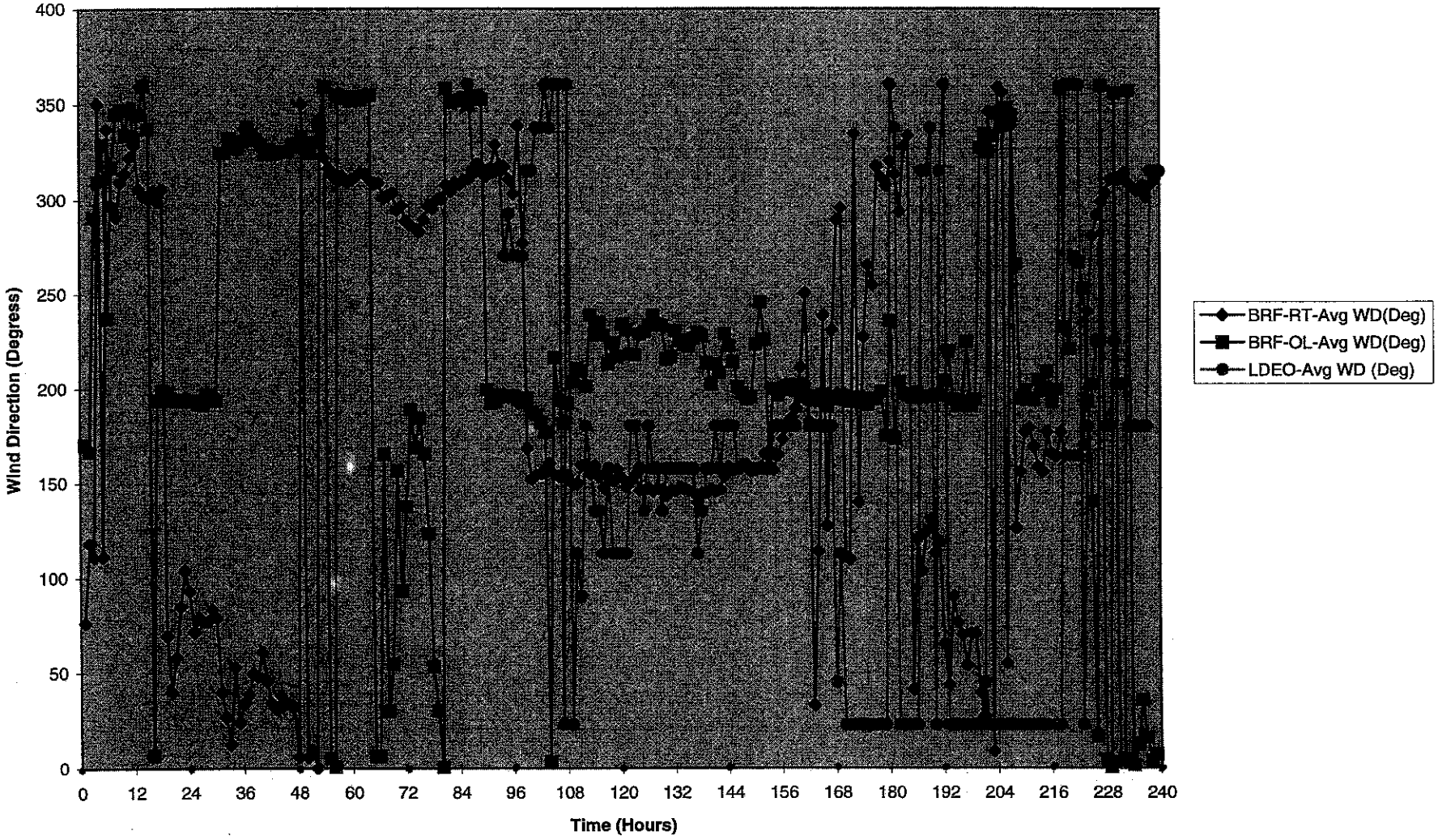


Figure 34 - The Orographic / Topographic Effect

Figure 35 - February 15-24, 1996- WIND DIRECTION for Lamont and Black Rock Forest (Ridgetop and Openlow)



was removed in the form of clouds and precipitation on the windward side (Ahrens, 1994).

Wind Direction:

Wind direction varies throughout the day at both the Ridgetop and Openlow stations (fig 35) The Openlow station exhibits winds primarily along the north-south transect, whereas the wind direction recorded on the Ridgetop station, does not follow such a clear pattern. However, some clusters do appear in the winds coming from the south and from the north and northwest (fig 36). Winds at Lamont approach from both the north and the south. However, the wind direction data are extremely limited and much of the data (February 19-20) were gathered during abnormal conditions when each station recorded winds approaching constantly from the south, with no apparent diurnal cycle.

The nighttime wind direction at the Openlow station comes from the south and during the day, the winds come from the north. The only discernible trend at the Ridgetop station is nighttime winds approaching from the northeast, and daytime winds coming from the northwest. These winds are influenced by the overlying pressure systems. Yet, on February 15 at 0 hours, February 17, at 71 hours, February 22 at 190 hours and February 24 at 230-240 hours, the winds approach from the west. These westerly winds occur in conjunction with approaching Lows (except for February 22nd) (fig 37). At these same times the Openlow station records winds approaching primarily from the south.

Wind direction will vary throughout the day at each of the three locations. Since the Ridgetop is completely exposed on the mountaintop, it will be vulnerable to winds coming from any direction.

Figure 36 - February 15-24, 1996- Wind Direction for Ridgetop and Openlow stations at Black Rock Forest

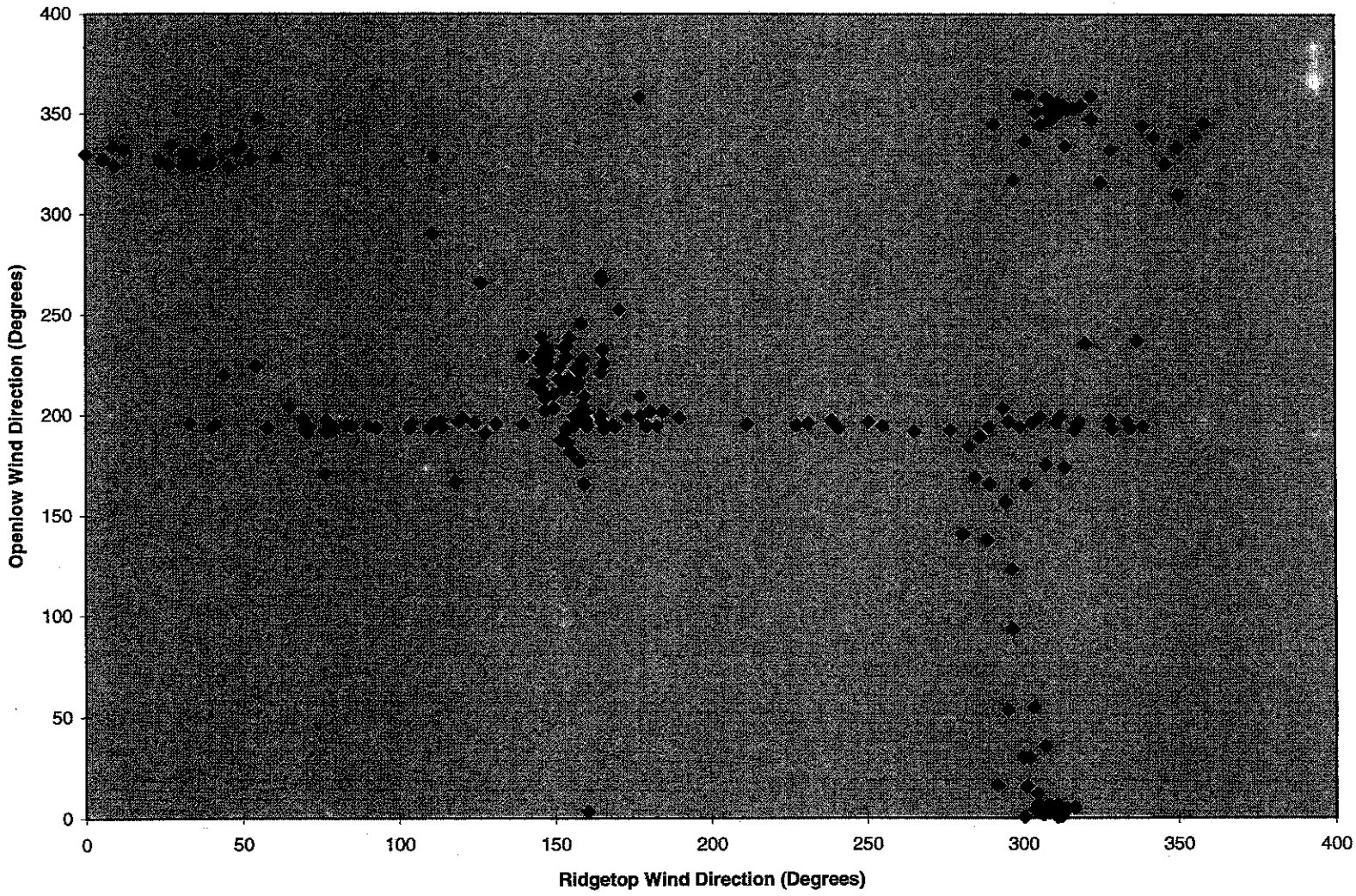
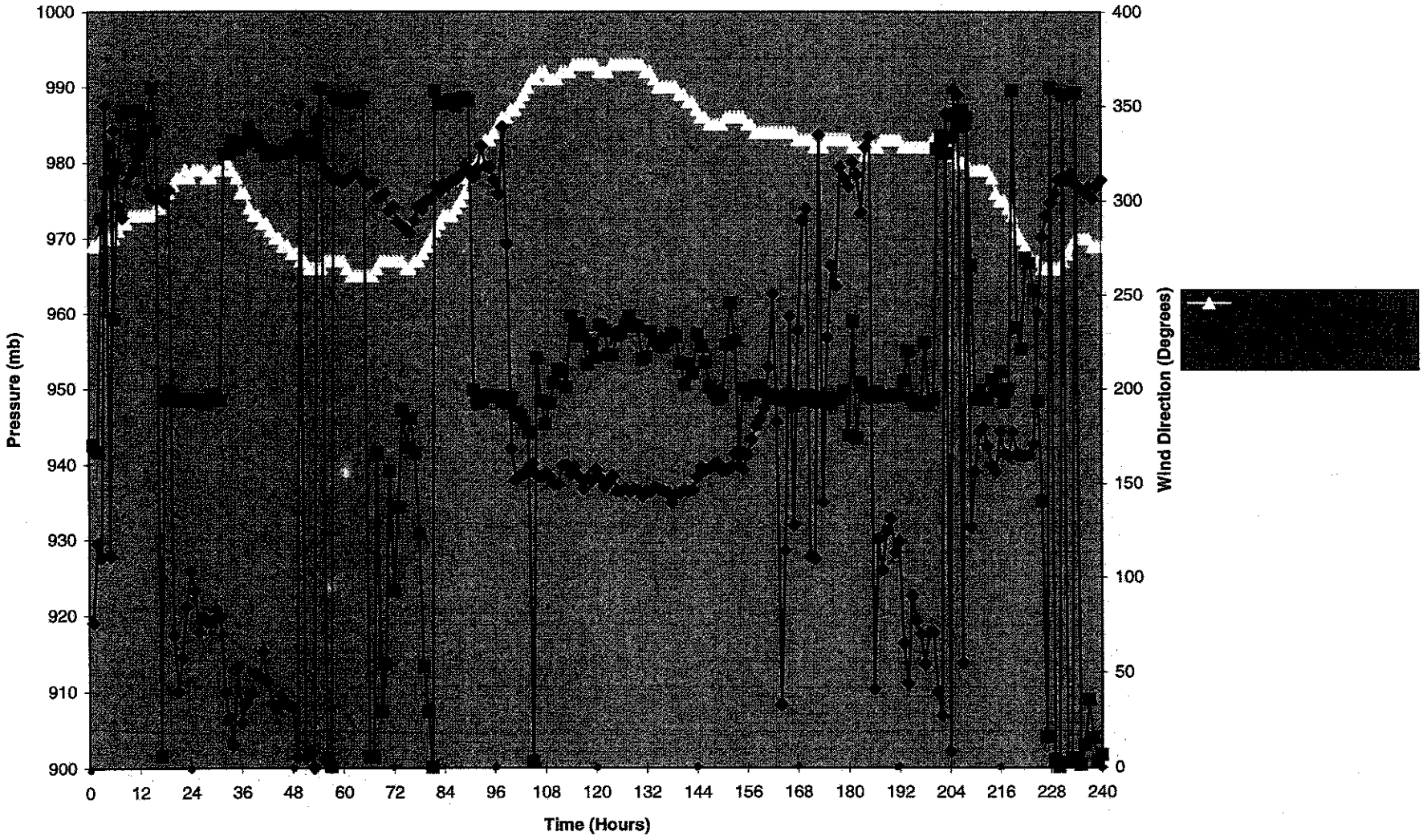


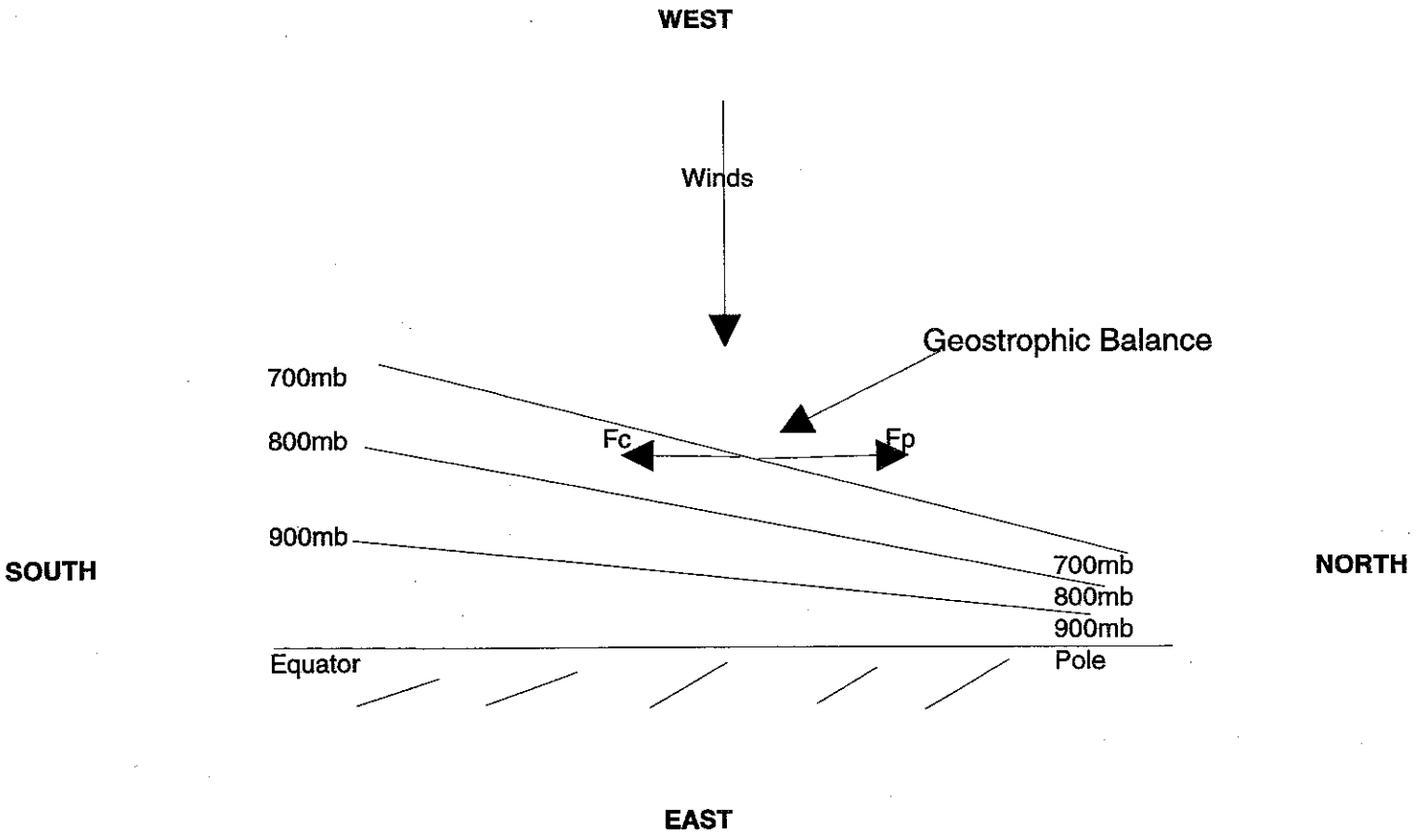
Figure 37 - February 15-24, 1996-BAROMETRIC PRESSURE and WIND DIRECTION for The Openlow and Ridgetop stations



However, it is dominated at times by winds approaching from the west. This is due to the existence of the jet stream. The atmosphere expands as one moves equatorward since warm air is less dense than cold air. As a result, the higher in altitude, the stronger the meridional pressure gradient is. A strong wind blowing from west to east is thus necessary to maintain geostrophic balance (because the Coriolis force veers to the right in the Northern Hemisphere) (fig 38). This strong wind is termed the jet stream and occurs between 35-45 degrees latitude. This is why our weather generally comes from the west (Del Genio, 1995) (fig 39).

The Openlow station is the only weather observatory that is predictable. Its location in a valley, determines its wind patterns. It experiences its daytime winds from the north and its nighttime winds from the south due to the land/sea breezes. Although the bodies of water are to the south of the station, the topography creates the path that the winds will take. These winds will originate from the south but will hook around Storm King Mountain (fig 1) in Cornwall, N.Y. on their way to the Openlow station. Therefore, the winds actually detected by the Openlow station approach from the north. The opposite occurs at night, thereby producing winds originating from the south. These winds are known to be extremely weak thereby explaining the extremely slow winds recorded in the valley (fig 18).

Although the lower valley experiences a snow event on February 16th (hours 24-48) through the early hours of the 17th, north-south winds are still exhibited for the 17th and the 18th (hours48-96). Before the snowfall, on February 15th (hours 0-24), land/sea breezes are responsible for the north-south diurnal variation experienced at the Openlow station. On February 16th the winds dominate from the north as a result of the northeaster responsible for bringing in the winter storm (fig 35) (Mcfadden, 1996).

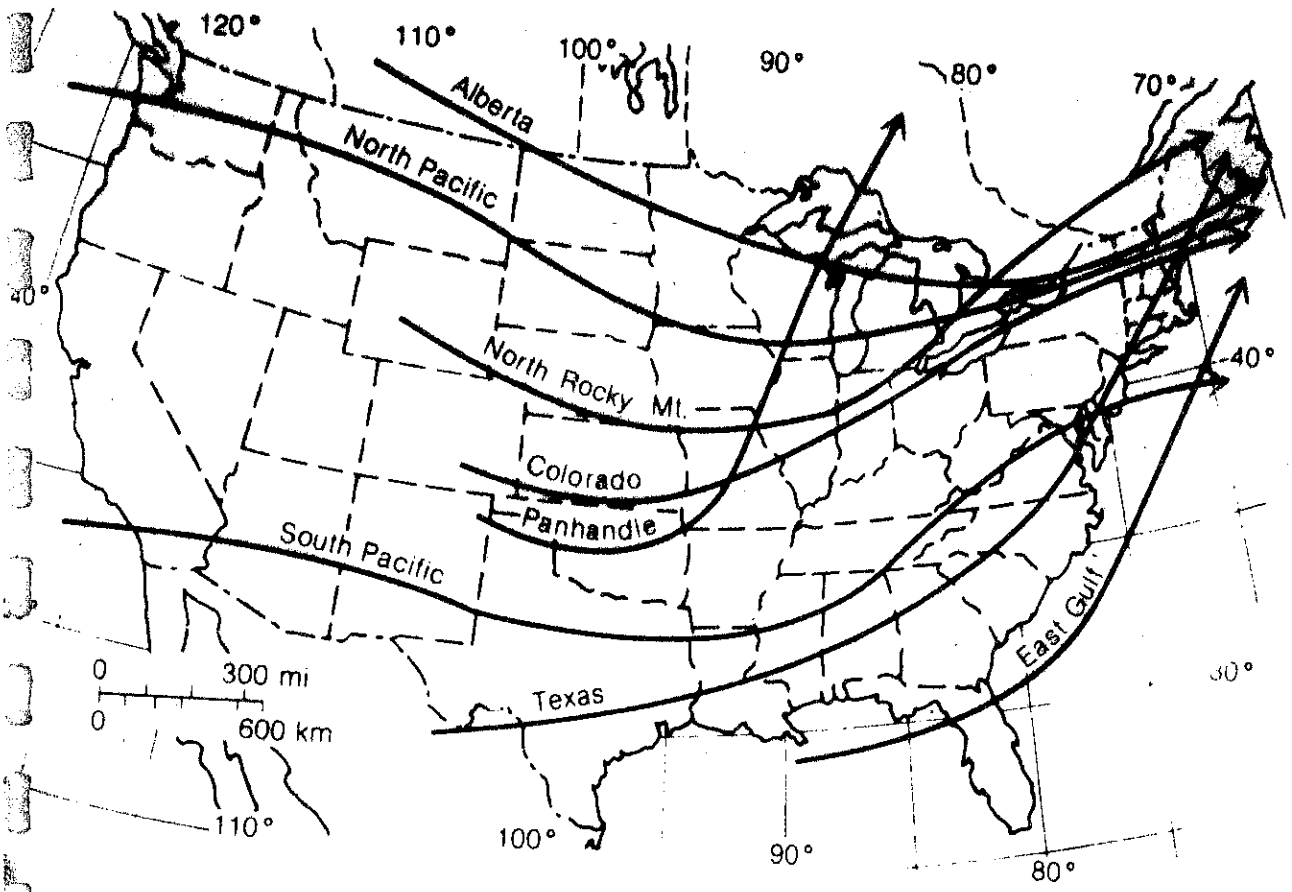


Fp = Pressure Gradient Force
Fc = Coriolis Force
Geostrophic Balance- Fc = Fp

Figure 38 - Diagram Describing the Origin of the Jet Stream

(Re-illustrated from Anthony Del-Genio's Class Notes, 1995)

Figure 39 - Principal storm tracks across North America. *(Fig. 11.12/ Book page 298)*



(Morgan and Morgan, 1991)

One would assume that following a snow event, only a slight temperature and pressure differential, if any, would exist between the land and the water. However, figure 35 shows that the north-south diurnal variation still exists following the snowfall. The possibilty of snow melt is low because the temperature values remain below freezing through the 18th (fig 24). The northerly winds could be a result of the northeaster which is responsible for the winter storm. However, the nighttime southerly winds are still apparent. Perhaps the Openlow did not accumulate a large amount of snow due to the interception of the snowfall by the many surrounding mountain ranges. This could result in a temperature differential between the land surrounding the Openlow station, and the coastal land and water. This new temperature and pressure differential could maintain the north-south wind directions.

The LDEO weather station exhibits winds approaching from the south for February 19-21. On the 22nd and 23rd the winds approach from the north due to the existence of a High to the northwest of NYC. Because of its location in the valley, Lamont's topography makes it conducive to north-south transport of winds resulting from the moving pressure systems. On the 24th, a Low passes through and Lamont exhibits north-south transport due to the land/sea breezes. During the day, the winds approach from the south with nighttime winds coming from the north. Unfortunately, not enough wind data exists for Lamont for the desired time frame. As a result, it is impossible to determine what factors affect wind direction and what is considered the norm.

Wind Speed:

Wind speed increases exponentially with height due to the diminishing effects of friction.

Therefore, the wind at the Ridgetop exhibits the fastest wind speeds (0.5-8.8 m/s) due to its higher elevation (fig 18). One would assume that the winds at Barnard would be quite fast since the strongest thermal and pressure gradients exist at the land-water boundary. This should cause the strongest winds to occur along the coast and diminish inland. However, Barnard is not directly at the boundary, and limitations exist for Barnard's wind data. The buildings block a lot of wind resulting in lower than expected averaged hourly wind speed data (2-6 m/s). However, Barnard might still experience gusts of strong winds.

The Openlow station is relatively unobstructed which probably results in more accurate wind speed data. Its wind speed ranges from 0.5-3 m/s. The Openlow winds seem to be solely determined by the mountain/valley winds and land/sea breezes with some response to low pressure systems to the south of NYC. In the scenario with the Openlow station, its winds are caused by its topography. The land/sea and mountain/valley winds are known to be weak, especially considering the station's 60 mile distance from the river. In addition, when the winds originate from the south (as a result from the Low) they tend to flow into the valley. They start out stronger than the 1m/s that is recorded at the Openlow station. The winds come from the south and hit the mountain range (Ramapo mountain and Frog Hill) in front of the Openlow station, causing a major decrease in wind speed (fig 34). This could explain why the wind speed values for the 22nd and 23rd were so low.

Wind Speed at Lamont, like the Ridgetop station, ranges from 1-4m/s for February 19-21. Although Lamont's anemometer is not as high as is the one at the Ridgetop station (150m vs 365m), its wind speed variables are just as high. This is because Lamont's sensor is located above the tree canopy but more importantly, it's located by a land/sea interface (Hudson River).

Wind speeds at Lamont decreases to 1m/s (along with the Ridgetop and Openlow stations)

on February 22nd through the 23rd. This occurs when a cold front is approaching. On the 24th winds increase at Lamont to values ranging between 4 and 6m/s. A diurnal variation can be observed with stronger wind speeds recorded during the day (sea breeze) and weaker winds settling in at night (land breeze). However, an increase in wind speed is observed at midnight of the 24th, yet it is hard to determine what is occurring because at this point our data ends.

Precipitation:

Precipitation depends on air transport and topography. All three stations exhibit significant amounts of rainfall on February 21st (hours 144-168) (fig 15). The air mass originates from the southwest bringing with it warmer air from the south and moister air from the west (fig 10). On February 17th (hours 48-72), the Openlow station has more than 3mm of rain, with the Ridgetop and Barnard station collecting just under 1mm. The Low on the 17th brings in cool, yet moist air from the northwest. The Openlow experiences the largest amount of rainfall because of its topography. As moist air moves up and down the valley, its pathway is extremely limited and the air is forced to condense. February 21-22 (hours 144-192) and the 24th (hours 216-240) also display an increase in rainfall at all three stations. These are days that experience occluded, warm and cold fronts. Weather that accompanies a cold occluded front is similar to that of a warm front (Ahrens, 1994). A convergence occurs at the front where the less dense warm air slides up the sloping frontal surface of the cold air creating cloud formation (thin cirrus--cirrus--cirrostratus--altostratus--nimbostratus) with a chance of rain. A cold front violently knifes under the leading warm air mass, thereby lifting it up and triggering thick nimbostratus clouds and violent thunderstorms (Del Genio, 1995).

Due to the orographic effect, the Ridgetop station experiences the most rainfall when the air mass approaches from the south. As explained previously, as the warm, moist air approaches from the south, it is forced to rise over a mountain range which includes the Frog Hill mountain. As the air rises and its water content condenses, the Ridgetop experiences rainfall (fig 34).

Regional Weather's Impact on Local Scale Phenomena:

When analyzing wind direction data, it is necessary to incorporate regional weather patterns into the study. Wind direction is promoted by global pressure and thermal gradients. Although one may be interested only in local weather events, certain parameters such as the origin of winds, which can only be studied on a large scale.

Based on the daily weather maps (figures 8-12), it appears that a Low exists from February 15-17, and again on the 24th. One High exists throughout these ten days, ranging from the 18th to the 23rd. On The 18th a cold front approaches, moving in a high pressure system. The 21st exhibits an occluded front, when a cold front catches up to and overtakes a warm front (Ahrens, 1994). This occurs even though New York was previously experiencing a High because a Low was approaching from the south of New York. This Low however, doesn't last. A cold front approaches on the 22nd, pushing the Low to the east. The 23rd records the same High, with a warm front approaching on the 24th.

Based on the concepts of cyclonic and anticyclonic flow for low and high pressure systems (anti-clockwise movement around a Low and clockwise around a High), wind direction and its associated temperatures are largely dependent on the existence of pressure systems. Depending on

the center of the system relative to the weather observatory in question, the wind direction can be adequately justified.

On February 15 (fig 8), the center of the Low is northeast of NYC. This results in winds approaching from the north, bringing with it cooler, drier air (fig 40a). On February 16 (fig 8), the Low is moved further east and its center is south east of NYC. This results in cool and moist winds approaching from the northeast. The Low is located northeast of NYC on the 17th (fig 9), brings air in from the northwest. On the 18th (hours 72-96), the Ridgetop records its winds approaching from the west, because of the approaching cold front from the west (figures 9 and 37). These winds dominate and they are relatively fast due to the knifing pattern of the Highs lifting up the Lows. The cold front brings in the High that exists on the 19th and the 20th (fig 10). Its center is northeast of NYC (fig 40b) bringing in warmer, moister air from the southeast. The winds at the Openlow and Lamont stations come from the south because its valley opening is toward the south. These are the only times that forces other than the land/sea and mountain/valley breezes come into effect at the Openlow station. On the 21st (fig 11), an occluded front occurs, resulting in winds coming from all directions. The Openlow and Lamont stations still have winds coming from the south due to the Low south of NYC. February 22nd (fig 11) has a cold front approaching which is exhibited by winds approaching from the west at the Ridgetop station. The Lamont station records winds approaching from the north because of the cold front approaching from the northwest. The High on the 23rd (fig 12) is centered to the northwest of NYC, bringing with it cool, drier air. At this point, the Openlow station resumes its north-south diurnal variation based on the land/sea and mountain/valley breezes. A warm front approaches on the 24th (fig 12) from the west and the south. Once again the strong winds from the west dominate the Ridgetop station and Lamont resumes what is assumed to be its

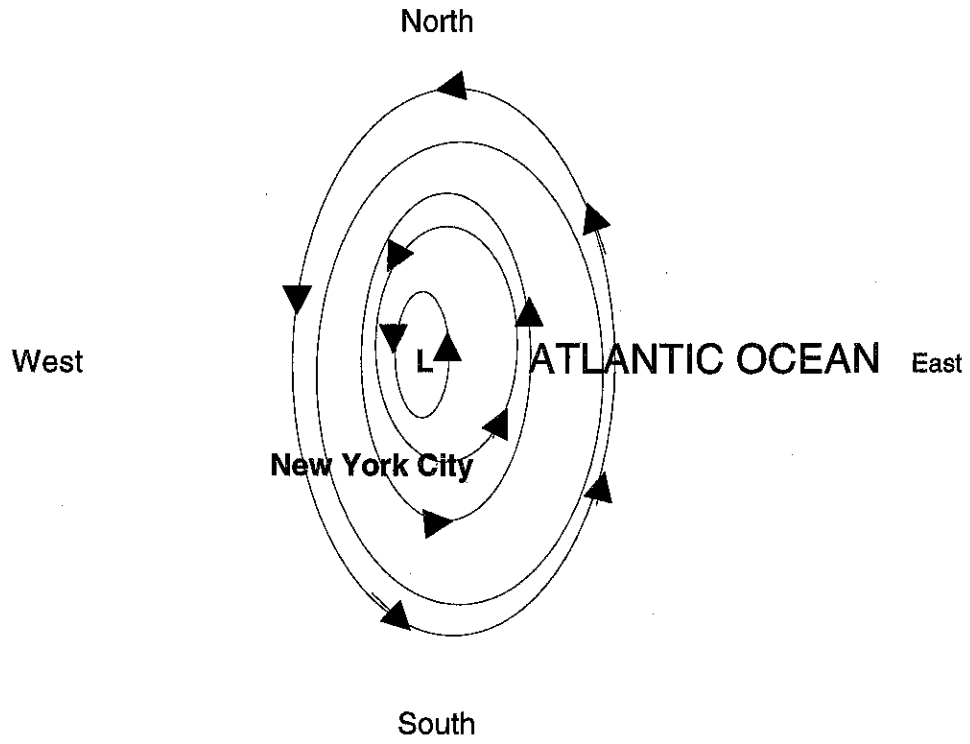


Figure 40a - February 15, 1996 - A Low Northeast of NYC

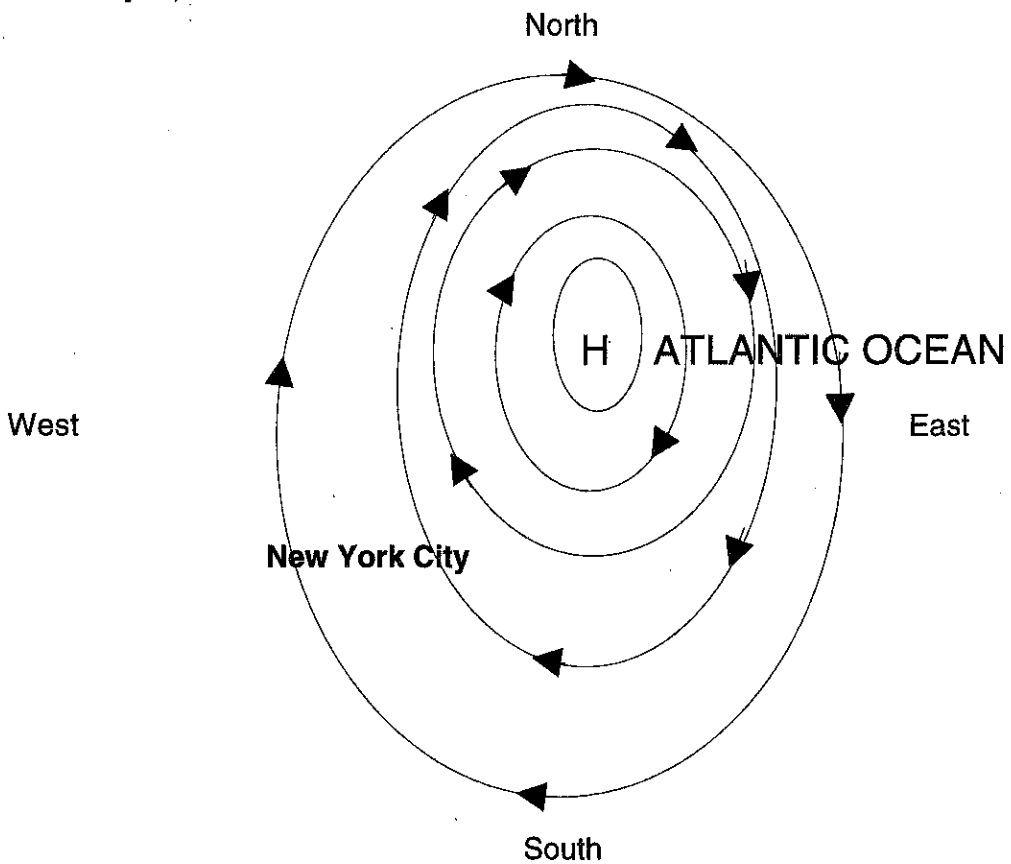


Figure 40b - February 19, 1996 - A High Northeast of NYC

normal north-south diurnal cycle based on the land/sea breezes.

February 19-20 - The Gradual Increase in Temperature:

February 19th through the 20th (hours 96-144) exhibit gradually increasing temperature values with no diurnal variation (fig 24). This anomaly occurs in conjunction with altering wind patterns. The Openlow station usually exhibits winds primarily along the north-south transect, whereas the wind direction recorded on the Ridgetop station experiences sporadic winds with a discernible diurnal trend between the northeast and the northwest.

However, for February 19-20, both stations display daily and nightly winds approaching from the south. Figures 41 and 42 show a strong relationship between winds approaching from the south and an increase in temperature for both the Ridgetop and Openlow stations. Figure 10 shows a cold front that brings in the High that exists on the 19th and 20th. Its center is northeast of NYC (fig 40b) bringing in warmer, moister air from the southeast.

Weather Effects on CFCs:

An accurate account of CFC transport is quite difficult considering that the CFC data ends on the 20th and 21st, whereas the Lamont wind data only begins on the 18th. In addition, no accessible rain or relative humidity data currently exists for Lamont. Although these parameters are covered by the other three weather stations it is necessary to have the Lamont data since that is where the CFC measurements were sampled.

Figure 41 - WIND DIRECTION and TEMPERATURE for OPENLOW station at Black Rock Forest

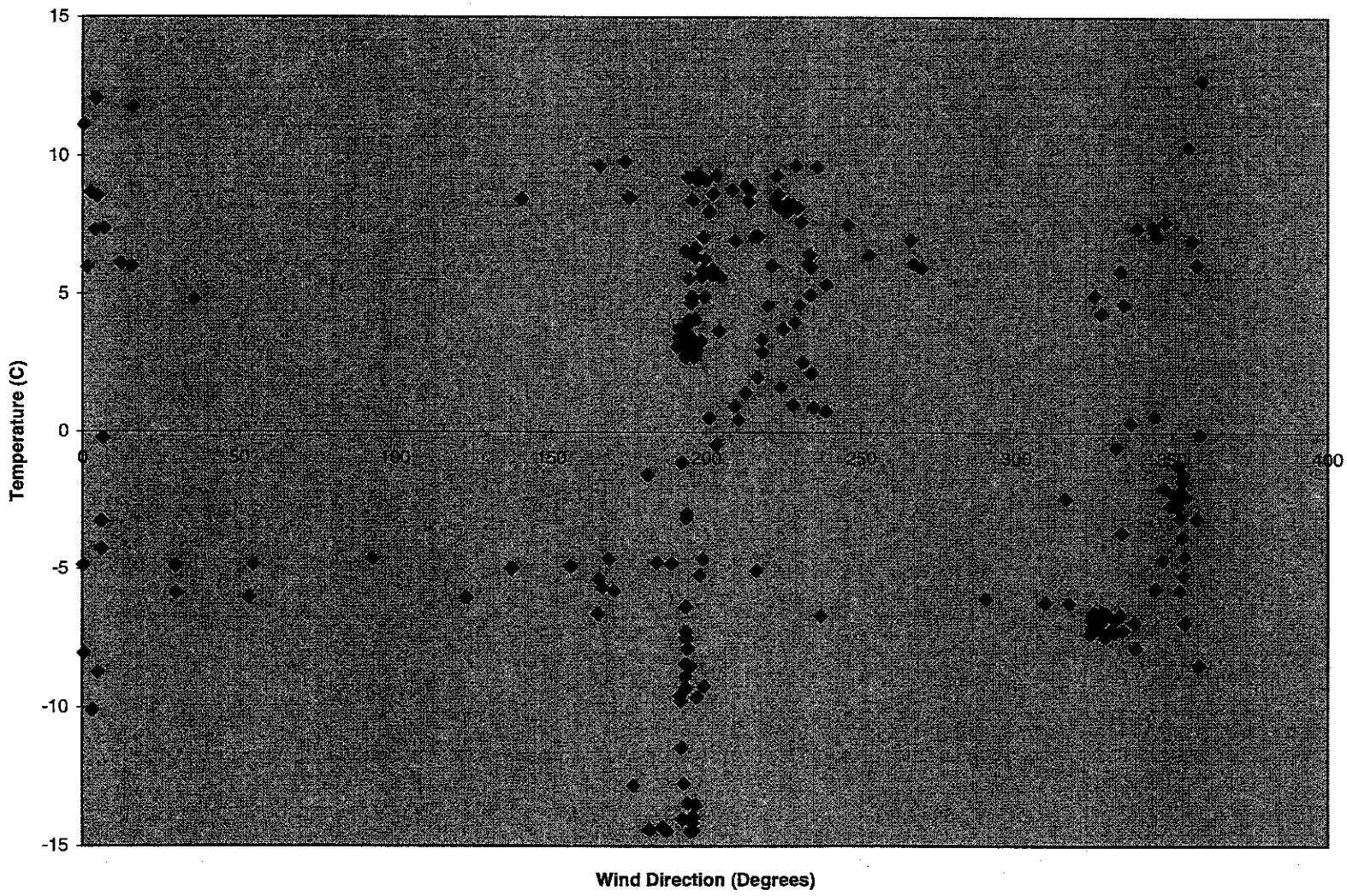
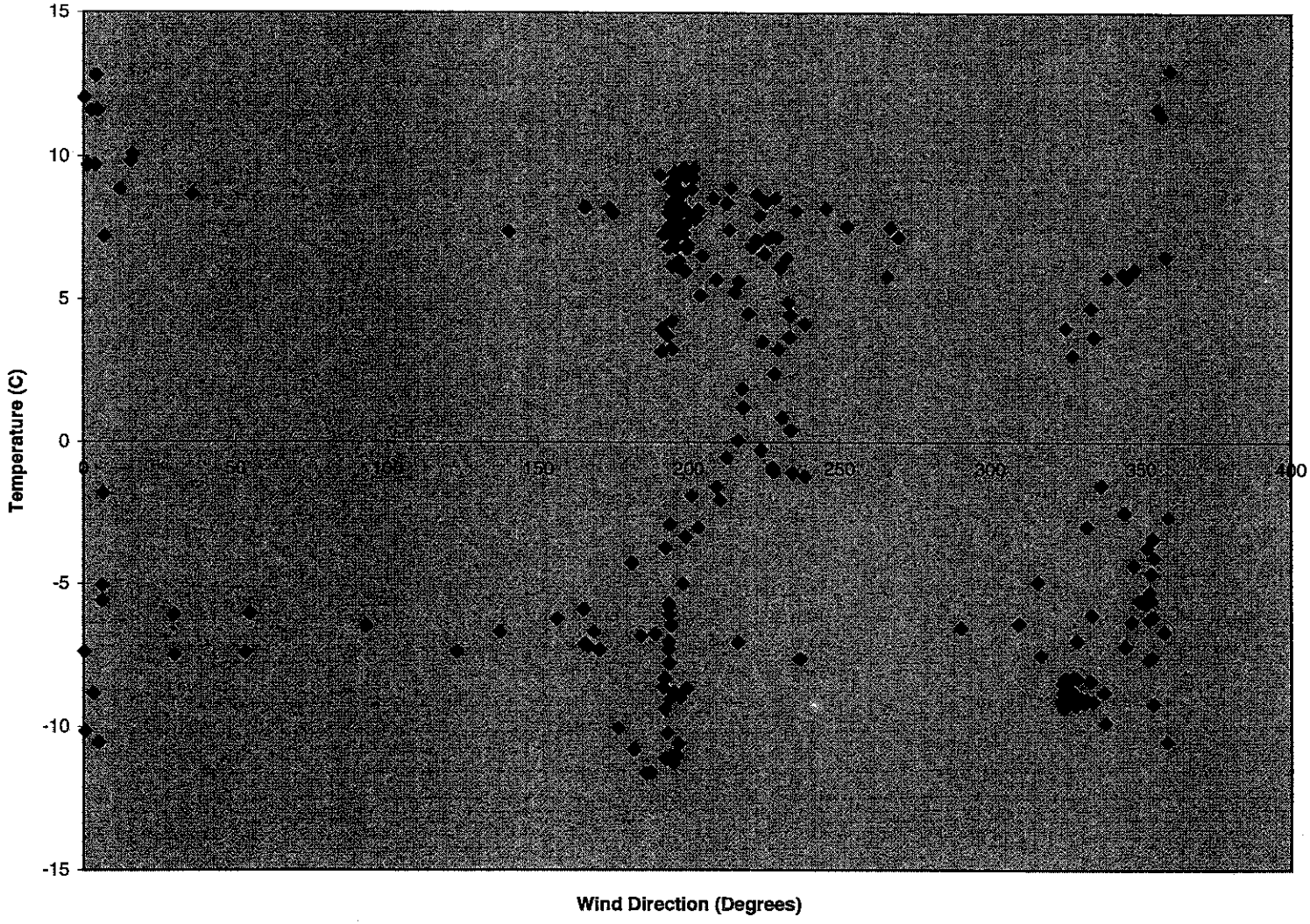


Figure 42 - WIND DIRECTION and TEMPERATURE for RIDGETOP station at Black Rock Forest



CFC-11 remains relatively constant at values of 330-350ppt. The dip on February 17th (hours 58-61) was previously attributed to instrument error. However, an additional peak is observed on February 19th when winds are coming from the northeast at a rate of 2 m/s. This is not enough data to make a hypothesis or conclusion (fig 16).

CFC-12 also experiences a dip on February 17th between the hours of 57-60. However, the CFC concentrations following the plummet, exhibit peaks at mid-day hours. This approximate 24 hour cycle occurs at approximately 70, 90, 115 and 135 hours. These hours relate to 10pm, 6pm,7pm and 3pm. At these times there is no notable trend in wind direction, however, the winds are always low ranging from 2-2.5m/s (figures 43a-b,44a-b).

Another interesting point which gives even less credence to the accuracy of the CFC data is that on February 16, the day of the ten inch snowfall, no variation in CFC concentrations were detected. If the CFC data were recorded accurately, this would mean that all the CFC production that is being recorded were emitted from the Geochemistry building itself. (hours 24-48).

Figure 43a - February 15-20, 1996- WIND DIRECTION for Lamont and Black Rock Forest (Ridgetop and Openlow) and CFC-12 Atmospheric Concentrations at Lamont

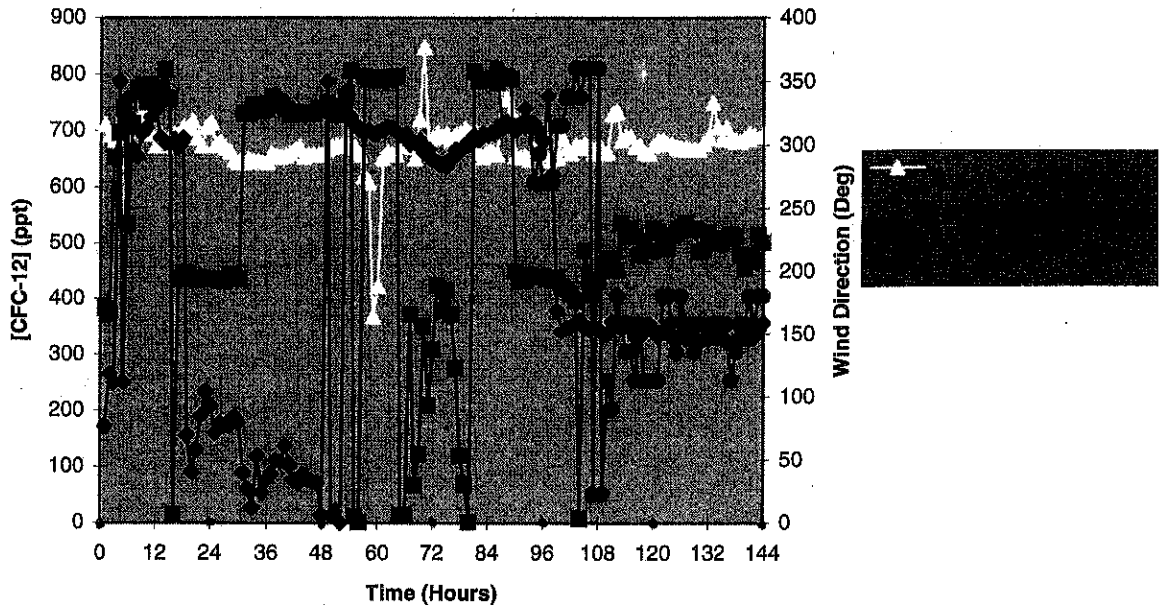


Figure 43b - February 15-20, 1996- WIND DIRECTION for Lamont and Black Rock Forest (Ridgetop and Openlow) and CFC-11 Atmospheric Concentrations at Lamont

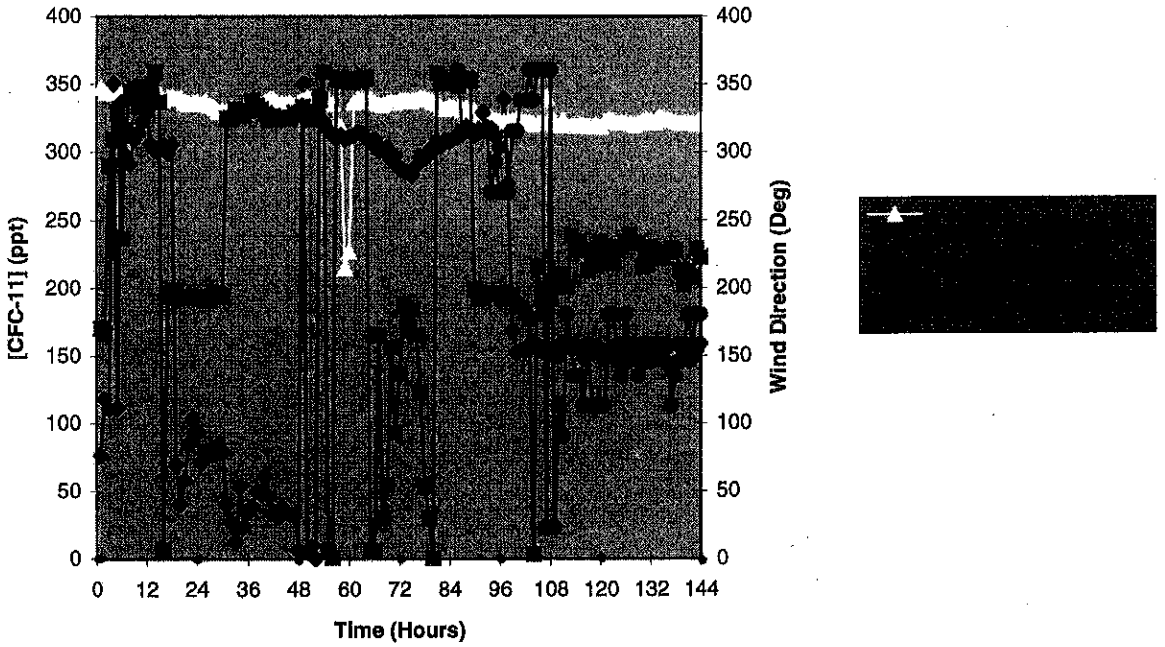


Figure 44a - February 15-20, 1996- WIND SPEED for Lamont, Barnard and Black Rock Forest (Ridgetop and Openlow) and CFC-12 Atmospheric Concentrations at Lamont

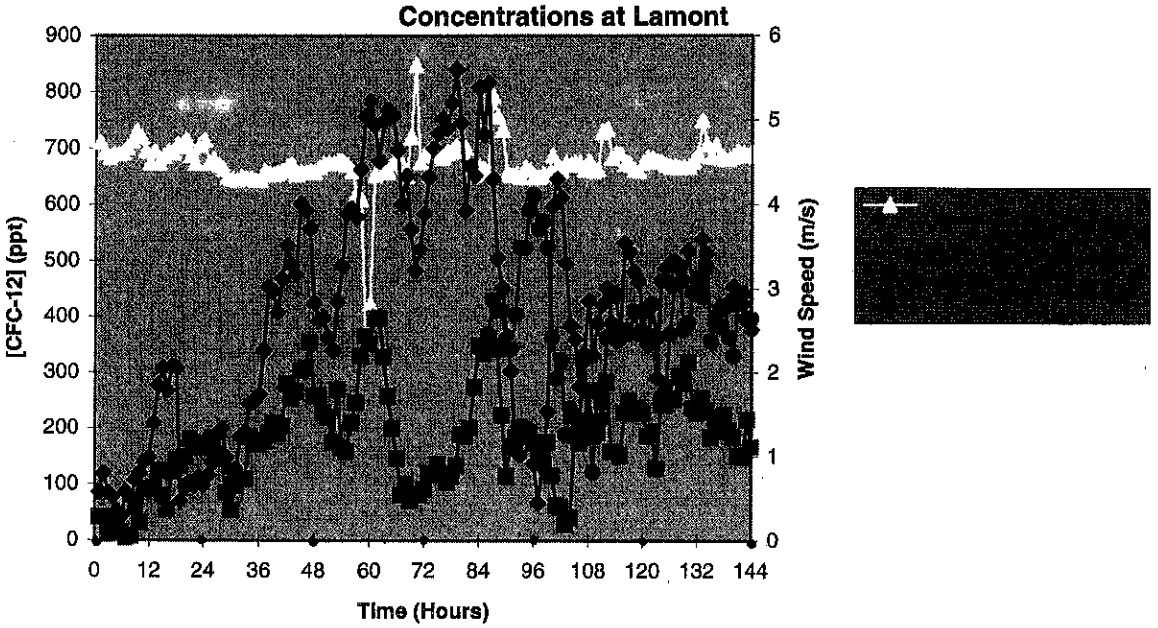
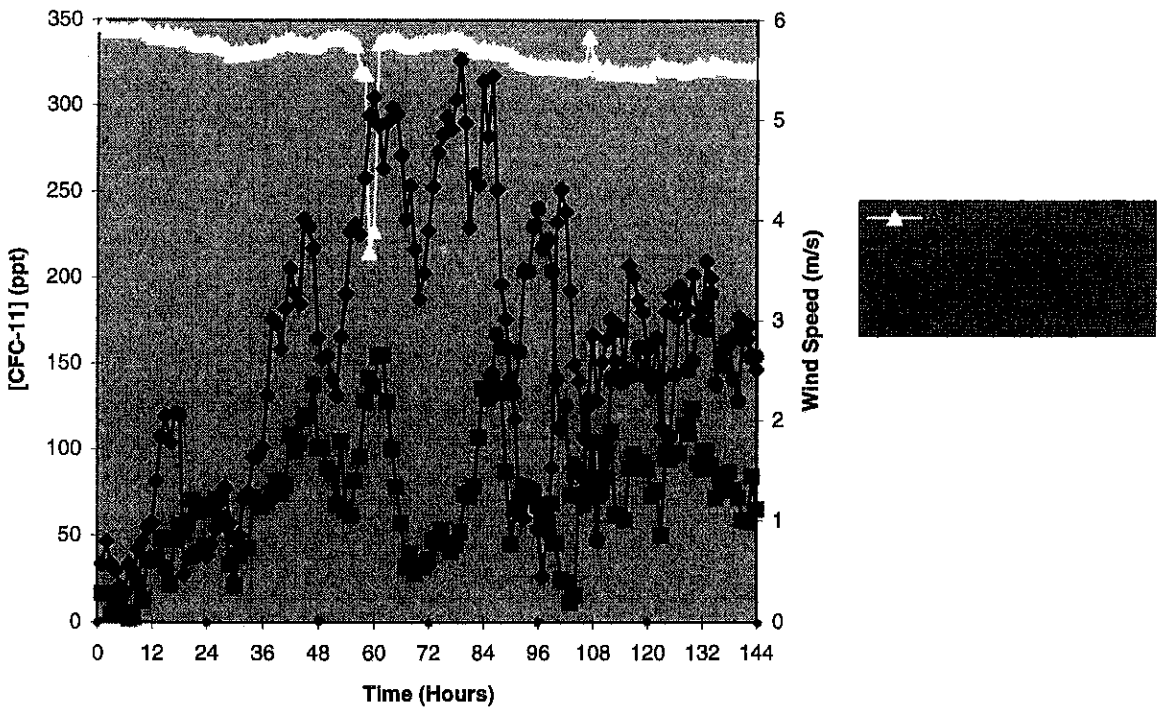


Figure 44b - February 15-20, 1996- WIND SPEED for Lamont, Barnard and Black Rock Forest (Ridgetop and Openlow) and CFC-11 Atmospheric Concentrations at Lamont



CONCLUSION:

Although the four weather stations at Barnard, Lamont and Black Rock Forest were all used to analyze the weather patterns along the lower Hudson Valley, it is still apparently impossible to come to one regionally based analytical conclusion. All of the studied locations demonstrate that geography and elevation play an important role in a weather station's measurements. Although all the weather stations lie either along or nearby the Hudson Valley, their proximity to bodies of water, their rural-versus-urban locations and their topographical differences (mountaintops versus valleys), play a significant role in their individual weather data recordings. The weather events at the various stations are responsive to the same large-scale systems, although deviations in data reflect each station's individual location.

The majority of Barnard's weather hinges on its urban location along a land/sea interface. Although solar radiation strikes the observed areas in the lower Hudson Valley with approximately the same intensity, New York City is on the average 3C warmer than the rural inland regions of the valley. The "urban heat island" effect, not only affects the city's temperature, but it also influences the city's relative humidity values and its ability to trap atmospheric pollutants. Its location along the Hudson River and proximity to the Atlantic Ocean dictates its water vapor content, precipitation events, wind direction and wind speed.

Although all 4 analyzed locations exhibit the same overlying pressure systems, their individual topographies determine how each area will be influenced. The weather observed at the Openlow station, is dictated by its location in a valley. Its winds are funneled up through the valley, bringing with it transported air masses. As a result, the recorded air temperature and

relative humidity measurements at the Openlow station originate in areas to the south of the station. Although precipitation is not transported, water vapor is, and it is forced to condense because of the valley topography.

The weather events at the LDEO weather station still remains a mystery due to the paucity of data. However, it is clear that the winds measured at the station are influenced by its location along the Hudson River. Although the LDEO weather station has a similar elevation to the Openlow station, its wind speeds are much greater. This emphasizes how choice of location, despite relative propinquity, can record quite different data values.

Because of its high elevation, the majority of the wind data for the Ridgetop station are representative of the large-scale weather phenomena. Yet, the height of the station distinguishes itself from the regional weather observations in precipitation, temperature and wind speed.

As is apparent by this study, regional weather gives a basic guideline as to how each individual location will react to large-scale weather patterns. However, to adequately analyze an area's weather events, many different data bases must be incorporated into the study. One universal interpretation will define the range of the possible variables that would be expected in each location, yet for the purpose of further study more specific results are required.

RECOMMENDATIONS:

I recommend a continued analysis of the data collected throughout the Hudson Valley. Although I am confident in my work, a ten-day data collection period presents limitations. Although problems with data quality will always exist, the more data collected, the more accurate the analysis will be. The problem demonstrated with the Barnard wind speed data would not have paralyzed its ability to be analyzed had data been collected over a longer time period.

It would also have been helpful if each station recorded identical parameters. It is unfortunate that the Lamont weather station was unable to collect temperature data. With temperature measurements, we might have been able to explain the uncharacteristically warm air temperatures detected at the Openlow station. It was suggested that the air mass possibly originating at Lamont, traveled up the valley, however, without the necessary temperature measurements, we can only hypothesize.

The most frustrating issue was the lack of Lamont weather and CFC data. One important goal of the study of weather is the ability to analyze pollutant transport. If sufficient CFC data exists along with complimentary weather data - wind speed, wind direction, precipitation and relative humidity - one can study the transport, as well as the source of CFCs. With these five parameters, one can determine whether mixing (caused by high wind speeds), promotes the import of CFCs, or whether CFCs are damped with high humidity values. If CFC levels always increase when winds come from a certain direction, or only when the wind speeds are high, one can ascertain that the CFCs are being imported.

In order to study CFC transport, certain corrections with the CFC collection are

necessary. The sampled air should not come from right outside the laboratory, but should be imported from a distance, away from the influence of the surrounding buildings. Lamont should then incorporate all the necessary parameters into its weather observatory. Once these necessary steps are taken, the CFC data can be adequately interpreted and the question of whether CFCs are locally produced or are transported to Lamont can be approached. Wind speed, wind direction, precipitation and relative humidity can be analyzed together to determine where CFCs are produced, how long the duration of their transport is under different conditions, and what their effects will be on the surrounding areas. All these approaches can help determine why Lamont exhibits high CFC concentrations and how these high concentrations will affect the entire area.

On a more technical note, all of the pressure sensors should have their calibrations checked. They should also be corrected for elevation.

ACKNOWLEDGMENTS:

I would like to thank Miguel Maccio for supplying me with Lamont's wind data and for taking the time to meet with me. Thanks as well to Dave Ho for measuring the CFC and pressure data at Lamont. Bill Schuster as well as Aaron Kimple at Black Rock Forest were extremely helpful in supplying the Ridgetop and Openlow data, and in answering all my questions. Thanks for being so helpful.

I would also like to thank Stephanie Pfirman and Jennifer Phillips for giving me the opportunity to work at the Barnard Weather Station. Although at times I thought it was a curse rather than a blessing, I learned a lot. Thank you. I would like to thank Jennifer who showed me the ropes and was always willing to answer my questions. I would also like to express my thanks to Stephanie for always sharing in my excitement and for helping me get started with the analysis. Thank you for showing me a side of science I've never seen before and for a productive two years.

I would like to express my gratitude to Martin Stute for getting me started at the beginning and saving me from the fall at the end. Thanks also for supplying me with the Lamont CFC and pressure data and for never minding the fact that I was oblivious to the limitation of office hours. I really appreciate it all.

I would like to thank all of you again who put in the time to answer all my questions, of which there were many. Last but not least, thanks to Molly Rivera, my friends and my family who kept me sane throughout.

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Appendix I - Barnard's Datalogger and Programming Information

Datalogger:

The Micrologger 21X is presently being powered by a 12 volt car battery. Previously it was surviving solely on 8 alkaline "D" batteries, but the car battery allows the system to maintain power while changing internal batteries and provides power over longer intervals. There is an additional 12 volt battery back-up in the department, as well as a recharger. Being that this model of the datalogger only has the power switch on the base (as opposed to 21XL which has rechargeable acid cells and a charger input plug), the car battery is the better option. Previously, when the battery required replacement, the whole system shut down and it was necessary to reenter the program back into the datalogger.

Figure A is a reproduction of what the datalogger physically looks like. It consists of analog inputs, excitation outputs, continuous analog outputs, control ports, pulse inputs and the serial I/O. Analog inputs are the upper strip of the wiring panel. The four switched excitation outputs on the lower wiring panel are only active during measurements, and supply programmable excitation voltages for resistive bridge measurements. Next to the switched excitation outputs are the two continuous analog outputs. They send out continuous voltages which could be used with strip charts, X-Y plotters or proportional controllers. The six digital control ports to the right allow for on-off control of external devices and the pulse count inputs measure contact closure, low level AC or high frequency pulse signals. The +12 volt terminal serves as a direct connection to the dataloggers power supply (this terminal and the

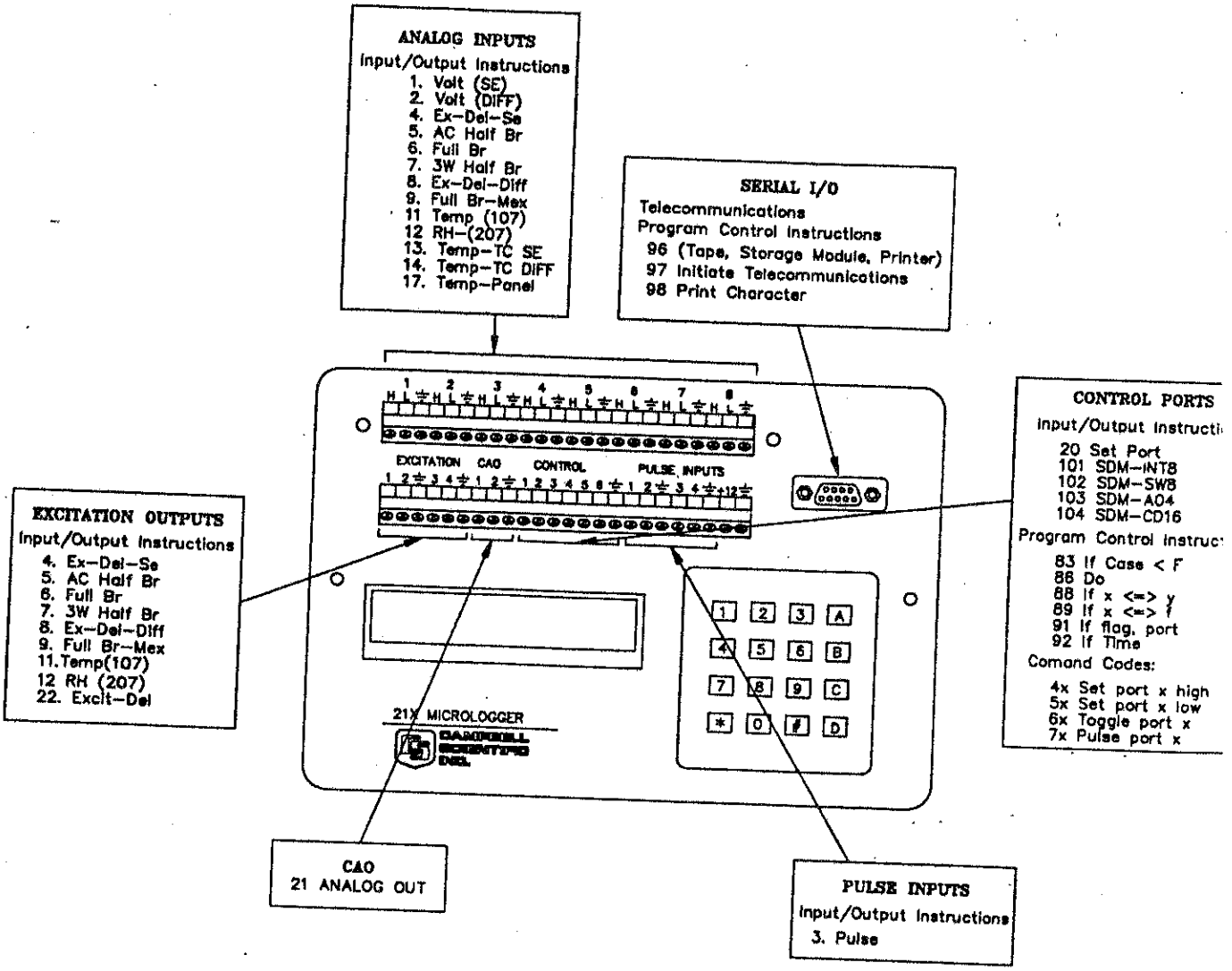


FIGURE A-1. 21X Wiring Panel and Associated Programming Instructions

ground terminals are how the 12 volt battery is connected).

The 21X micrologger also has a 40,960 bytes internal random access memory. It is divided into five parts which include: 1) input storage-which holds the measurements or calculations, 2) intermediate storage-which provides temporary storage for intermediate calculations (can not be accessed by user), 3) final storage-which stores final, processed values for retrieval, 4) system memory-which is used for overhead tasks (can not be accessed by user), 5) program memory-which is available for user programs. This internal memory system goes hand in hand with the instruction types, as can be seen on figure B. The first of the instructions are the input/output instructions. This controls the terminal strip inputs and outputs, which converts the sensor signal to a data value which is then sent to the input storage. The second instructions are the processing instructions. It takes the values in input storage and numerically calculates them. The newly calculated information is then sent back to input storage. The final instructions are output processing. It includes intermediate and final processing. Intermediate processing compiles the data as it comes in, and the final processing occurs only when the output flag is high, meaning that the time parameters for that specific component has been reached. The final values are therefore calculated and are ready for transfer to printer, tape, solid state Storage Module or retrieval via telecommunication links. Figure I is a listing for the internal memory locations, output parameter listings and the wiring diagram showing the connections from the sensors to the datalogger itself.

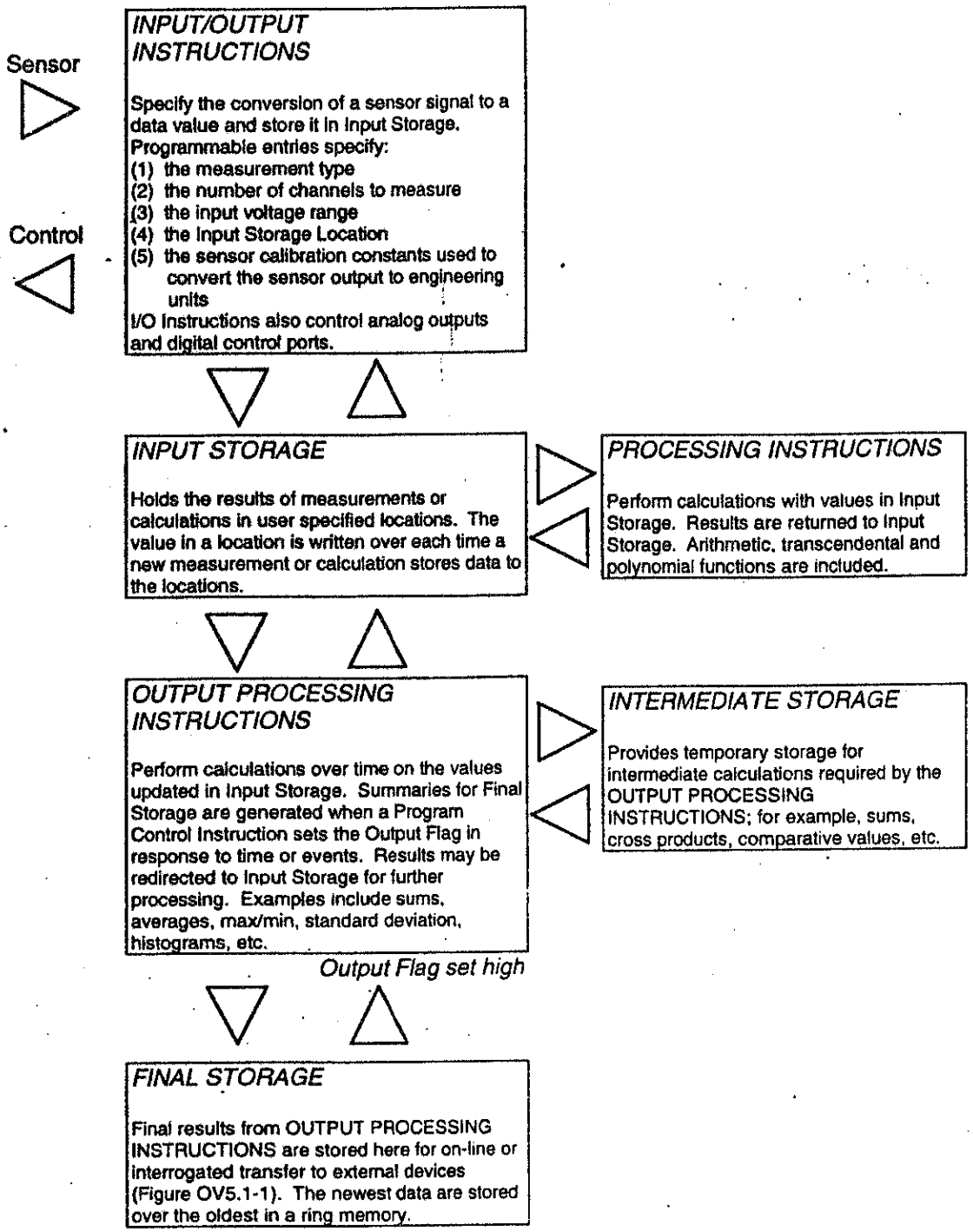


Figure B- **Instruction Types and Storage Areas**

Barnard Weather Station- Figure 1
Details on sensor wiring, datalogger program etc.

Internal Memory Locations

Loc	Data Input
1	Battery Voltage
2	Temperature (C)
3	Relative Humidity (%)
4	Wind Speed (m/s)
6	Solar Radiation (MJ/m2)
7	Rain (mm)
8	Barometric Pressure (mb)
9	Barometric Pressure (kpa)
10	Solar Radiation (W/m2)
11	Wind Direction (Degrees)

Output Parameter Listing:

1440 Minute Output

1	Array ID 222
2	Day of Year
3	Hour Minute
4	Maximum Daily Temperature (C)
5	Minimum Daily Temperature (C)
6	Sample Relative Humidity (%)
7	Total Daily Solar Radiation (Mj/m2)
9	Average Daily Wind Speed (m/s)
10	Wind Direction (Degrees)
11	Total Daily Rain (mm)
12	Sample Barometric Pressure (mb)
13	Battery Voltage

60 Minute Output

1	Array ID 111
2	Day of Year
3	Hour Minute
4	Sample Relative Humidity (%)
5	Total Hourly Solar Radiation (W/m2)
6	Average Hourly Wind Speed (m/s)
7	Wind Direction (Degrees)
8	Total Hourly Rain (mm)
9	Sample Barometric Pressure (mb)

21X Wiring Diagram
Codes: E=excitation, G=ground , P=pulse, C=control

HMP35C Probe (Temperature and Humidity)
Red = +12V
Yellow = E2
Purple = G
Clear = G
Orange = 1H*
Green = 2L*
Black = E3
White = G

*These are single ended measurements, therefore, the first 2 ports are numbered sequentially 1 and 2.

03101 Young Wind Sentry Anemometer
Black = P1
White = G
Clear = G

03301-5 Young Wind Sentry Vane
White = G
Clear = G
Black = E1
Red = 7H(13)

LI200X Solar Sensor
Red = 2H*
Black = 2L*
White = G
Clear =G

*This is a double-ended measurement, therefore, the 3rd and 4th ports are numbered 2Hi and 2Lo.

CS105 Barometric Pressure
Red = +12V
Black = G
Brown = 5H*
Clear = G
Green = C1
White = Not used with 21X

Programming:

In addition to all it's aforementioned components, the datalogger also has a 16 character keyboard which can be used for direct programming, commands and data entry. Aside from entering the program directly onto the datalogger via its keyboard, one may use a PC with the PC208 Datalogger Support Software called EDLOG. This is a prompting editor for writing and documenting programs for Campbell Scientific dataloggers. Table 1 is the actual program that exists currently in the datalogger at the Barnard Weather Station. The previously mentioned processing is dependent on the program.

The programming at the Barnard Weather Station is segmented into daily and hourly data with storage areas of 222 and 111, respectively. This was primarily done to mimic the setup at Black Rock Forest. As a result, the parameters and units used between the two stations are compatible.

At the beginning of the program of Table 1 are the input/output instructions. For example we will look at ID# 02.

02: P11 Temp 107 Probe

01: 1 Rep

02: 1 IN Chan

03: 3 Excite all reps w/EXchan 3

04: 2 Loc :Temp C

```
Program: Barnard - Milbank Weather Station
Flag Usage: 1440 min output
Input Channel Usage: Single-ended 1 thru 5
Excitation Channel Usage: 2, 3
Continuous Analog Output Usage:
Control Port Usage: 1
Pulse Input Channel Usage: 1, 2
Output Array Definitions: Daily


*      1        Table 1 Programs
  01: 10        Sec. Execution Interval

Temperature sensor

Relative Humidity

Anemometer

Solar Radiation (MJ/m2 to be summed by day)

Remove negative values

Rain Gage

Barometer


Here is final processing (daily)
Remember, units here are actually MJ/m2/day

01:  P10       Battery Voltage
  01: 1        Loc [:BattVolt ]

02:  P11       Temp 107 Probe
  01: 1        Rep
  02: 1        IN Chan
  03: 3        Excite all reps w/EXchan 3
  04: 2        Loc [:Temp C   ]
  05: 1        Mult
  06: 0        Offset

03:  P4        Excite,Delay,Volt(SE)
  01: 1        Rep
  02: 5        5000 mV slow Range
  03: 2        IN Chan
  04: 2        Excite all reps w/EXchan 2
  05: 15       Delay (units .01sec)
  06: 5000     mV Excitation
  07: 3        Loc [:RH %     ]
  08: .1       Mult
  09: 0        Offset
```

Table 1

```
04:  P3          Pulse
  01: 1          Rep
  02: 1          Pulse Input Chan
  03: 21         Low level AC; Output Hz.
  04: 4          Loc [:Wspd m/s ]
  05: 0.75       Mult
  06: .2         Offset

05:  P4          Excite,Delay,Volt(SE)
  01: 1          Rep
  02: 5          5000 mV slow Range
  03: 13         IN Chan
  04: 1          Excite all reps w/EXchan 1
  05: 2          Delay (units .01sec)
  06: 2500       mV Excitation
  07: 11         Loc :
  08: 0.071      Mult
  09: 0          Offset

06:  P92         If time is
  01: 0          minutes into a
  02: 60         minute interval
  03: 10         Set high Flag 0 (output)

07:  P2          Volt (DIFF)
  01: 1          Rep
  02: 2          15 mV slow Range
  03: 2          IN Chan
  04: 6          Loc [:kJ/m2     ]
  05: 0.002      Mult
  06: 0          Offset

08:  P2          Volt (DIFF)
  01: 1          Rep
  02: 2          15 mV slow Range
  03: 2          IN Chan
  04: 10         Loc :
  05: 200        Mult
  06: 0          Offset

09:  P89         If X<=>F
  01: 6          X Loc kJ/m2
  02: 4          <
  03: 0          F
  04: 30         Then Do

10:  P30         Z=F
  01: 0          F
  02: 6          Z Loc [:kJ/m2     ]

11:  P95         End
```

Table 1

```
12:  P3          Pulse
  01: 1          Rep
  02: 2          Pulse Input Chan
  03: 2          Switch closure
  04: 7          Loc [:Rain mm  ]
  05: 0.254      Mult
  06: 0.0000     Offset

13:  P92         If time is
  01: 59         minutes into a
  02: 60         minute interval
  03: 41         Set high Port 1

14:  P92         If time is
  01: 0          minutes into a
  02: 60         minute interval
  03: 30         Then Do

15:  P1          Volt (SE)
  01: 1          Rep
  02: 5          5000 mV slow Range
  03: 5          IN Chan
  04: 8          Loc [:Baro kPa ]
  05: 0.184      Mult
  06: 600        Offset

16:  P37         Z=X*F
  01: 8          X Loc Baro kPa
  02: .1         F
  03: 9          Z Loc :

17:  P86         Do
  01: 51         Set low Port 1

18:  P95         End

19:  P92         If time is
  01: 1439       minutes into a
  02: 1440       minute interval
  03: 10         Set high Flag 0 (output)

20:  P80         Set Active Storage Area
  01: 1          Final Storage Area
  02: 222        Array ID or location

21:  P77         Real Time
  01: 110        Day,Hour-Minute

22:  P73         Maximize
  01: 1          Rep
  02: 0          Value only
  03: 2          Loc Temp C
```

```
23:  P74        Minimize
  01: 1         Rep
  02: 0         Value only
  03: 2         Loc Temp C

24:  P70        Sample
  01: 1         Rep
  02: 3         Loc RH %

25:  P72        Totalize
  01: 1         Rep
  02: 6         Loc kJ/m2
Value expressed in MJ/m2

26:  P71        Average
  01: 1         Rep
  02: 4         Loc Wspd m/s

27:  P71        Average
  01: 1         Rep
  02: 11        Loc

28:  P72        Totalize
  01: 1         Rep
  02: 7         Loc Rain mm

29:  P70        Sample
  01: 1         Rep
  02: 8         Loc Baro kPa

30:  P70        Sample
  01: 1         Rep
  02: 1         Loc BattVolt

31:  P96        Serial Output
  01: 30        SM192/SM716/CSM1

32:  P92        If time is
  01: 59        minutes into a
  02: 60        minute interval
  03: 10        Set high Flag 0 (output)

33:  P80        Set Active Storage Area
  01: 00        Final Storage Area
  02: 111       Array ID or location

34:  P77        Real Time
  01: 110       Day,Hour-Minute

35:  P71        Average
  01: 1         Rep
  02: 2         Loc Temp C
```

 Table 1

```
36:  P70        Sample
  01: 1         Rep
  02: 3         Loc RH %

37:  P71        Average
  01: 1         Rep
  02: 10        Loc

38:  P69        Wind Vector
  01: 1         Rep
  02: 0000      Samples per sub-interval
  03: 01        Polar Sensor/(S, D1)
  04: 4         Wind Speed/East Loc Wspd m/s
  05: 11        Wind Direction/North Loc

39:  P72        Totalize
  01: 1         Rep
  02: 7         Loc Rain mm

40:  P70        Sample
  01: 1         Rep
  02: 8         Loc Baro kPa

41:  P          End Table 1


*     2         Table 2 Programs
  01: 0.0000    Sec. Execution Interval

01:  P          End Table 2


*     3         Table 3 Subroutines

01:  P          End Table 3


*     4         Mode 4 Output Options
  01: 00        (Tape OFF) (Printer OFF)
  02: 00        Printer 300 Baud


*     A         Mode 10 Memory Allocation
  01: 28        Input Locations
  02: 100       Intermediate Locations


*     C         Mode 12 Security (OSX-0)
  01: 00        Security Disabled
  02: 0000      Security Code
```

05: 1 Mult

06: 0 Offset

Once instruction P11 is entered EDLOG immediately knows that these are the instructions for the temperature probe. Parameter 01 immediately notifies the program that this is dealing with repetitions. This instruction is used to repeat the instruction on a number of sequential input channel or storage locations. Considering that there is only one thermistor, the measurements will only be done once at its specified time, hence 1 Rep. Parameter 02 specifies in which storage location the first measurement should be directed. Parameter 03 excites and measures the thermistor probe and directs it towards channel 2. Parameter 04 explains in which input storage location to find the reference temperature. Parameters 05 and 06 are the multiplier and offset which convert the measurements to engineering units. By using the equation of y=mx +b, the voltage value is converted to the specified units. When a multiplier of 1 and an offset of 0 are used, as in this case, the thermistor instructions return the measurements in units of Celsius.

An example of the output processing instruction is ID #33:

33: P72 Totalize

01: 1 Rep

02: 7 Loc Rain mm

P72 means that the output is totaled over its specified period, and it is known from before, that

01 refers to the repetition(which in regard to all the instruments at this station, is 1) 02 tells where the internal memory locations are. Therefore, rain is in location 7. The instrument locations for the daily and hourly values are listed in Figure I.

Weather Sensors:

1) Model HMP35C Temperature and Humidity Probe (figure C)- Temperature is measured by a thermistor. Temperature is expressed in degrees Celsius, and the possible measurements at the Barnard station can range from -35'C to +50'C. Its parameters include the maximum and minimum values for its specific time frame.

The relative humidity is measured by a Vaisala capacitive sensor and its measurements range is from 0 to 100%.

2) LI200X Pyranometer(figure D-2)-this measures the total incoming solar radiation that is hitting the earth's surface throughout the day. The measurements are detected with a silicon photovoltaic sensor. This instrument is capable of transferring the suns energy, directly into electricity which enables the pyranometer to be measured directly by the datalogger. This system is calibrated for the daylight spectrum of 400 to 1000 nm. The solar radiation at night could possibly be a negative value due to RF noise. For the daily values, the solar radiation is measured in Megajoules per meter squared. This measurement unit can not be used for the hourly values because it is too large. Therefore, solar radiation for the hourly data is measure in Watts per meter squared (Figure I).

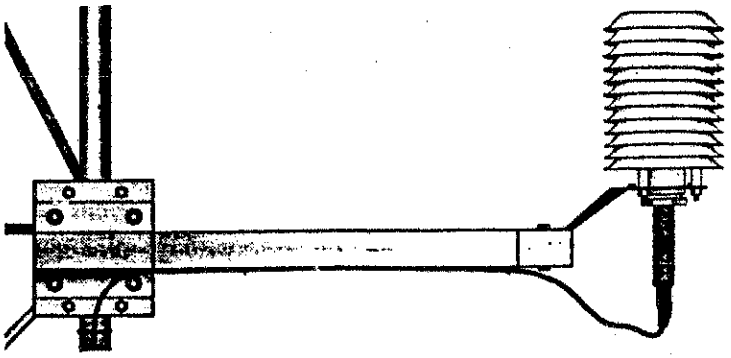
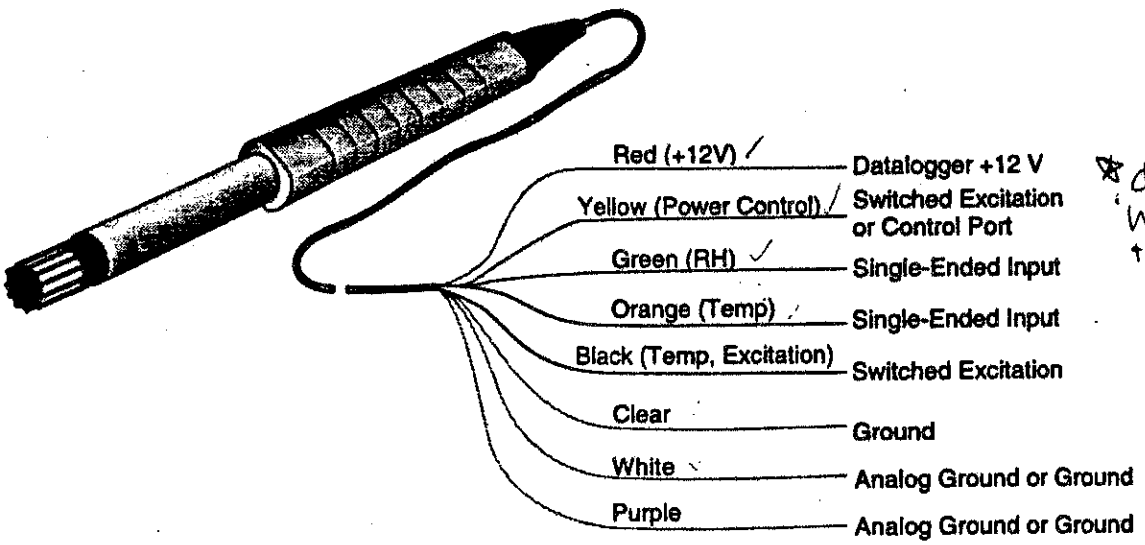


FIGURE 3-2. HMP35C with UT018 Mounting Bracket and Crossarm and UT12VA Radiation Shield Mounted on a UT3/UT930 Tower



* do not hook yello. + black to same po

Figure C-[illegible]. **HMP35C Probe Datalogger Connections**

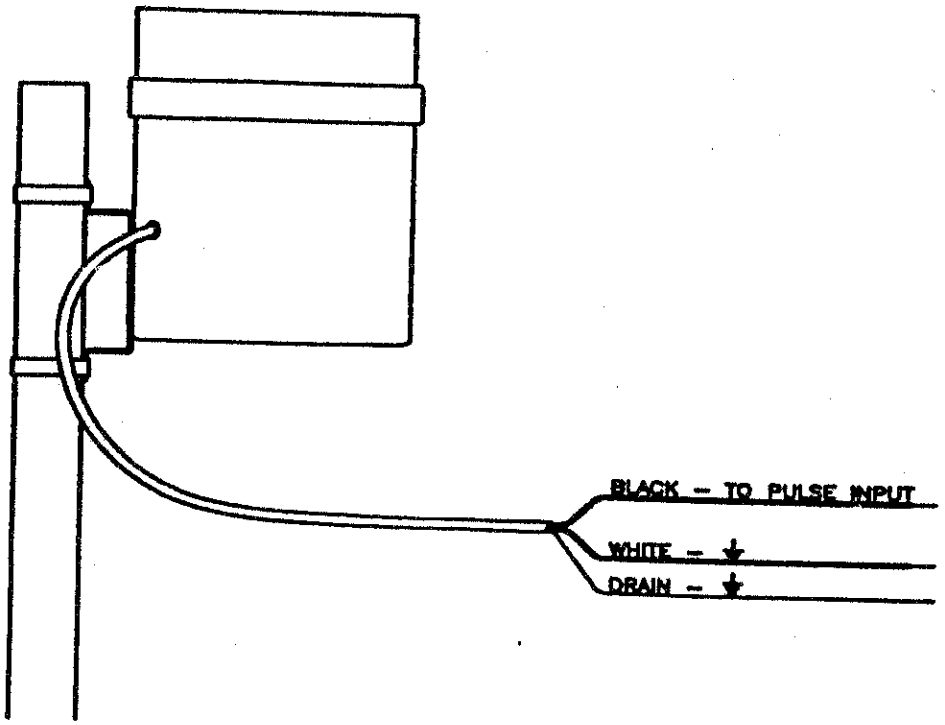


Figure D-1 **TE525 Tipping Bucket Rain Gage**

2

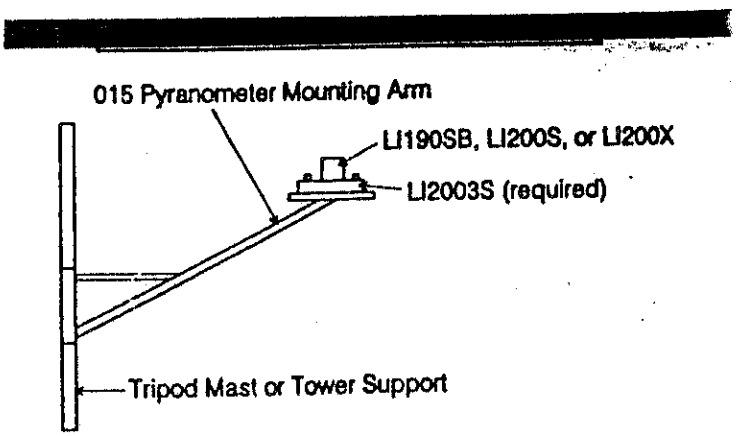


Figure D-2 . **015 Pyranometer Mounting Arm**

3) TE525 Tipping Bucket Rain Gauge (figure D-1)-This system measures the total rainfall for the specified period, by having an output switch closure for each bucket tip of .01 inch of rain fall, which is 0.25 mm. The bucket has the capacity to measure up to 2 inches/50.8 mm per hour. This system is expressed in the metric version of millimeters. It should be mounted in a level spot, at least 30 cm above the ground and away from obstructions and pavement, being that otherwise it could give data unrepresentative of that region. Trees and buildings on the surface of the ground could block the rain from reaching the bucket. In addition, the pavement doesn't absorb the precipitation which would otherwise negate the incoming solar radiation by evaporating, thereby keeping the temperature constant. These are two issues that need to be noticed when dealing with the data from the Barnard weather station.

Although people might take the necessary precautions, the rain gauge is not a great system being that there could be a thunderstorm in the vicinity, but not directly over the rain gauge. In addition, what if the rain comes in on an angle (due to winds) and hits the side of the bucket?

4) CS105 Barometric Pressure Sensor (figure E)-It takes measurements by using a Vaisila Barocap silicon capacitive pressure sensor. Its operating range is from 600 to 1060 mb (60-160 kpa).

This analog barometer is capable of two modes: shutdown and continuous. The one at the Barnard station is configurated for the shutdown mode because the barometer drains the battery. The barometer does not have a jumper, but is turned on and off with a control port. As one can

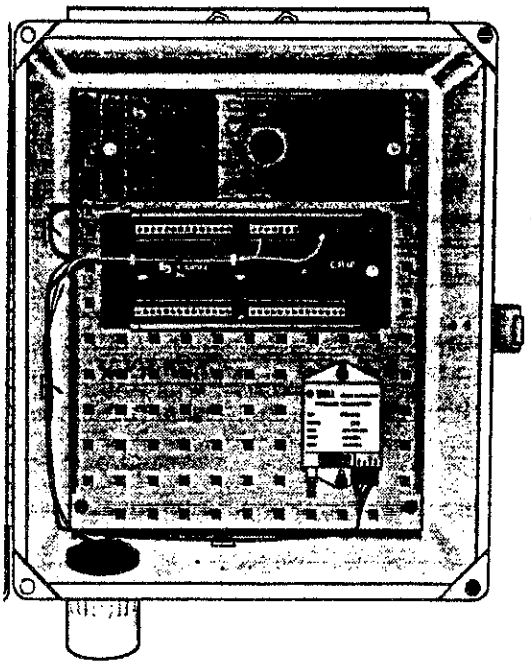
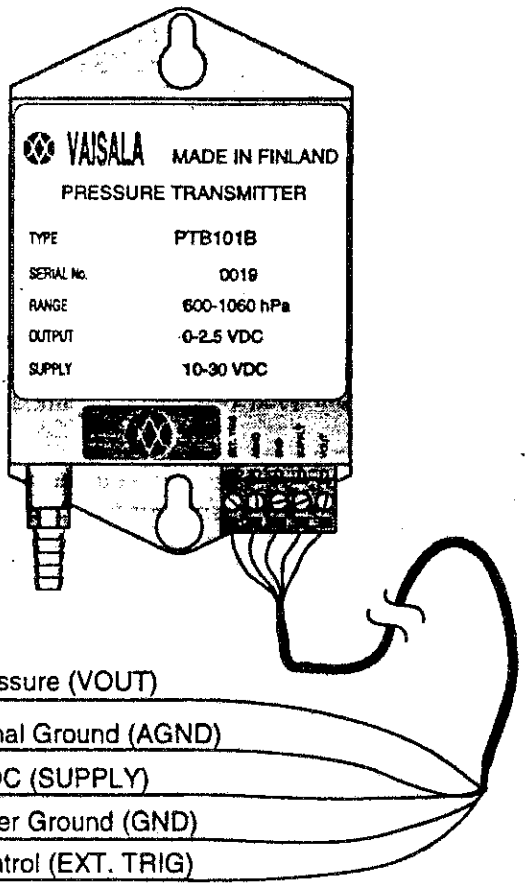


Figure E-**CS105 Mounted on the Backplate of an ENC 12/14 Enclosure.**



CS105 Wiring Diagram

see in ID #10 (Table 1), the CS105 is turned on one minute before the hour (in order to warm up), and on the hour (ID#11), the pressure is recorded and the CS105 is subsequently turned off. This mode is also used because atmospheric pressure changes very little with time.

5) 03101-5 R.M. Young Wind Sentry Anemometer-The horizontal wind speed is measured and its average value is expressed in meters per second. These units were determined by incorporating into the program a .75 multiplier, and 0.2 offset (Table 1, ID #4). The cup wheel (figure F) is small in size, corrosion resistant and made of stainless steel which is lubricated with a wide temperature range, high quality instrument oil. As the cup wheel rotates an AC sine wave voltage is produced, which is directly proportional to wind speed. One rotation represents one full cycle of the sine wave.

6) 03301-5 Young Wind Sentry Vane- The wind vane is mounted on a 10" unthreaded pipe. It is measured by instruction 4 (Excite, Delay and Measure). The wind vane consists of an arrow with a tail that circulates around the vertical pipe (figure G). Its nose always faces the direction from which the winds come. Wind direction is measured in Degrees. 0 and 360 represent true north.

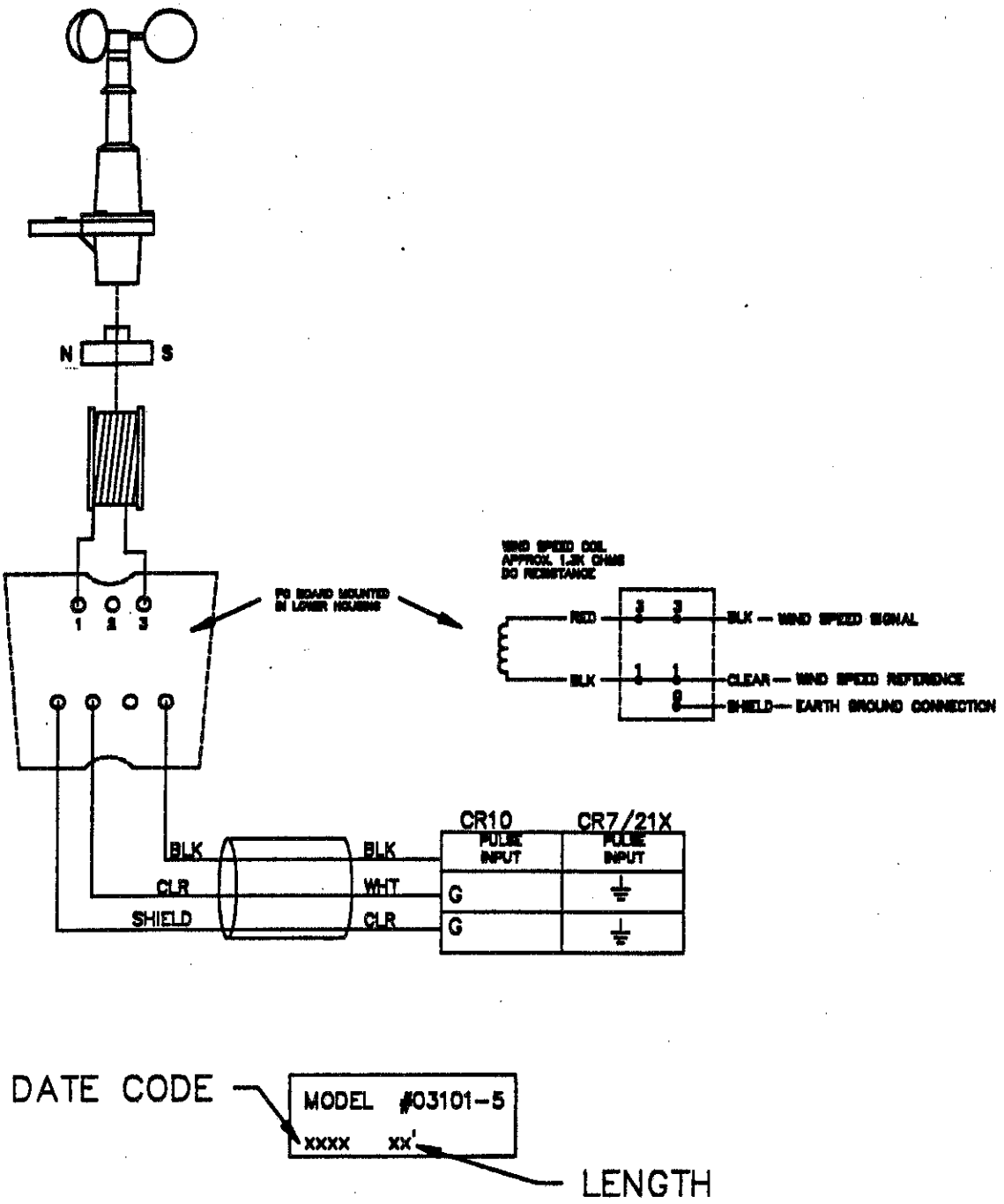


Figure F - **03101-5 Wind Sentry Anemometer**

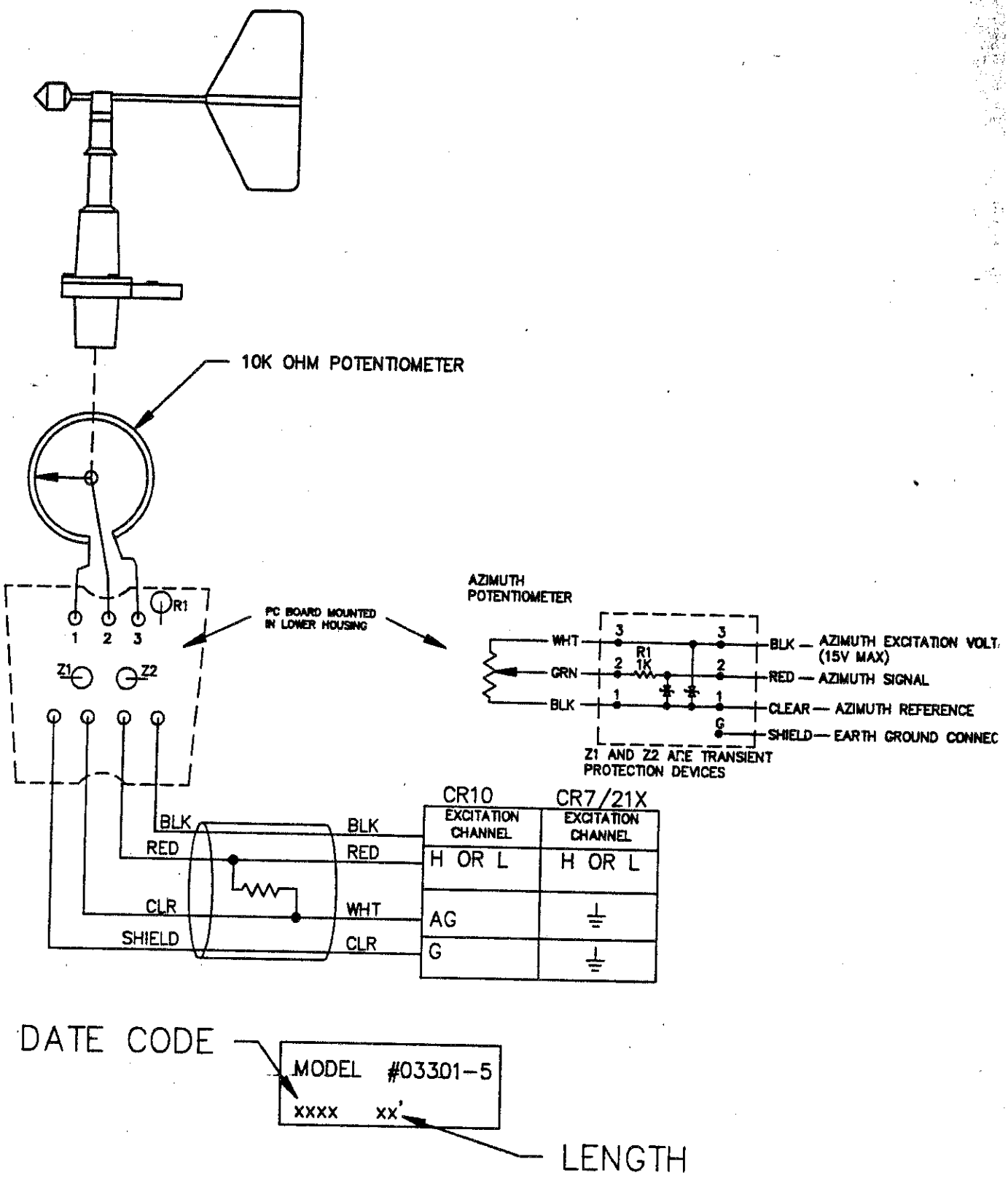


Figure G - 03301-5 Wind Sentry Vane

Appendix II-Compiled by Bill Schuster and Aaron Kimple who run the Ridgetop and Openlow Stations.

Black Rock Forest environmental sensor network

The Virtual Forest Initiative will include a network of eight environmental sensor stations spanning the major terrestrial and aquatic habitats within the forest. All stations will be equipped with an identical sensor/datalogger backbone, but each will also carry additional sensors appropriate for use in the particular habitat surrounding each station. Additional sensor stations will be added to the network as needed.

Terrestrial Stations

Four terrestrial habitats will be monitored. There will be two lowland stations (below 140 m elevation), one located in an open field[1] and the other located beneath the canopy of a representative deciduous forest stand. A third station will be established beneath the canopy of a native conifer stand at an elevation of 275 m. The fourth terrestrial station will be established on an exposed ridgetop near the upper elevation limit of the forest (365 m)[2].

Station #1: Open Lowland Station

Description and Rationale- This station will be located in an open, nearly level area near the forest headquarters at an elevation of 110 m. The rationale for selecting this site is to provide a primary terrestrial station in an open area, comparable to the siting of most existing weather stations. Additional advantages to this location are 1) ease of access for maintenance and demonstrations, 2) the provision of environmental data for the portion of the forest most heavily frequented by consortium visitors, and 3) the provision of data for the lowest elevation in the forest for comparison with conditions at higher elevations.

Environmental variables to be measured include precipitation, air temperature, barometric pressure, solar radiation, relative humidity, wind speed and direction, and soil temperature.

Site selection and preparation will seek compliance with the weather station guidelines established by the United States EPA (1988)[3], and The American Association of State Climatologists (1985)[4]. Consideration will be given to slope, aspect, and obstructions such as buildings and trees to match the guidelines as closely as possible (these may not be primary considerations in the selection and preparation of other sensor stations sites).

Station #1 sensors

Precipitation- Precipitation amount will be measured using a tipping bucket system[5]. Rainfall amount (or equivalent amount of water in hail, fog, snow, etc.) per time interval will be measured in increments of 0.25 mm. The receptacle is mounted at 1.0 m above ground, encircled by an alter type wind shield.

Precipitation will be collected separately for physical and chemical analysis, and the resulting data will be used in ongoing watershed studies. The first component of the system is a manual bulk collector[5], open to both wet and dry precipitation. The collector is manually changed on a weekly basis matching the protocol of stations in the National Acid Deposition Network[7]. The second component is an automated wet/dry deposition collector[6]. Both the bulk and the wet/dry sampling methods are required since the difference between wet and dry precipitation is an important environmental parameter that is currently under investigation at the forest.

Temperature - Air temperature, in degrees celsius, will be continuously recorded at a height of 2.0 m above the ground. The sensor

Station #2: Ridgetop Station

Description and Rationale- This station will be located in a natural opening atop a scrubby, exposed hilltop at an elevation of 365 m. The rationale for selecting this site is to monitor environmental conditions near the upper elevation limit of the forest, in a site where access by personnel and data transmission via radio telemetry are both feasible. These ridgetop locations are of special interest since they support unusual plant communities[18], they experience the full force of storms and great environmental extremes[19], and these conditions can only be studied through *in situ* monitoring.

The sensors will be nearly identical those in the Open Lowland Station at forest headquarters, measuring precipitation, temperature, relative humidity, barometric pressure, soil temperature, air temperature, and wind speed and direction. This station will not be equipped to routinely collect precipitation for analysis.

Station #2 sensors

Precipitation- Precipitation amount will be measured using a tipping bucket system[5]. Rainfall amount (or equivalent amount of water in hail, fog, snow, etc.) per time interval will be measured in increments of 0.25 mm. The receptacle is mounted at 1.0 m above ground, encircled by an

probe[9] will be housed in a twelve-plate radiation shield to mitigate the effects of direct sunlight.

Relative Humidity - Relative humidity, in percent, will be continuously recorded by a probe[9] mounted at 2.0 m above the ground. (Note that dew point will be calculated from temperature and relative humidity data).

Barometric Pressure- Barometric pressure, in millibars, will be continuously recorded by a pressure sensor[10].

Solar Radiation- Solar radiation will be measured by separate sensors designed to measure 1) total solar radiation, and 2) photosynthetically-active radiation (PAR). A pyranometer[11] mounted at 2.75 m will be used to measure the total solar radiation in Einsteins/s/m^2. A Quantum Sensor[12] mounted at 3.0 m will be used to measure the PAR as Photosynthetic Photon Flux Density (PPFD; photons in the 400 to 700 nm waveband/second/m^2).

Wind- Both wind speed and wind direction will be continuously monitored by a directional wind monitor[13] mounted at 3.25 m. Speed will be measured in m/s, and wind direction will be measured in compass degrees (azimuth).

Soil Temperature - Soil temperature, in degrees celsius, will be continuously monitored by a probe[14] buried at 10 cm beneath the ground surface.

Additional System Components- Most of the above sensors will be attached to a 3m tripod-based tower. The rain gage, soil temperature probe, and precipitation sample collectors will be set in the ground adjacent to the tower. A computerized data logger[15] within an enclosure mounted on the tower will record all the vital data. Station records will be transmitted to a base station at regular intervals of about five minutes[16]. Hourly averages, and daily, weekly, monthly, and annual reports will be automatically generated and placed into long term storage files.

The datalogger and sensor components will be powered by a twelve volt rechargeable battery connected to a solar panel[17], also mounted on the tower, providing an inexpensive and relatively efficient energy source.

Appendix III- Compiled by Miguel Maccio at Lamont who is part of the engineering group selected to monitor the weather station.

Lamont-Doherty Earth Observatory

Weather Station.

A PC computer located in the Geoscience building acquires meteorological data from the sensors via modem, it stores the data in a hard disk, plots it and distributes the data to the SUN computer network. The plots consist of hourly values for the last 23 days of wind speed, temperature, humidity and rainfall rate and are displayed on the PC video graphics screen. A more complete data set is available through the SUN network using the command "weather" from any workstation or terminal.

The weather station itself is located in the "seismology data network receiver station" (close to the water tower). The location was chosen to permit optimum meteorological observations (above the tree canopy) and given the availability of power and phone lines.

The sensors are mounted on an antenna tower whose base is 430 ft above sea-level. The anemometer and wind vane are located at the top of that tower, 75 ft over the ground or 504 ft. above sea level. Temperature and humidity sensors are also mounted on that tower at about 30 ft over the ground. The rainfall tipping bucket is located on the roof of the small building adjacent to the tower. The sensors corresponding electronics and modem are located inside that building.

The LDEO station forms part of the Rockland County Climate Network. The center gathers meteorological data from about 26

stations distributed throughout Rockland and Orange County in the State of New York. A meteorological database is being stored at the computer center.

System Specifications:

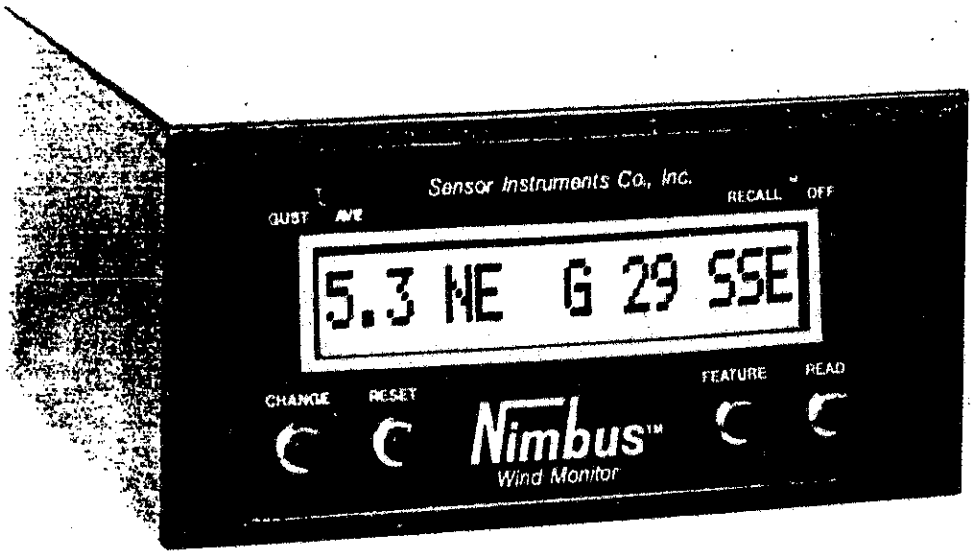
Temperature:
- Resolution: 0.1 F
- Range -40 F to 130 F
- Accuracy: +- 1 F

Precipitation:
- type: tipping bucket rain gauge
- Resolution: 0.01"
- Total Accumulation: 99.99 "
- Max. rate 36 "/hr

Humidity:
- Temperature compensated
- Resolution: 0.5 % RH
- Accuracy: RH(20%- 100%): 2% at 70 F

Wind:
- Range: - 150 MPH
- Resolution: 0.1 below 10 MPH
  1 above 10 MPH
- Accuracy: 1 MPH
- Response Time: 2 sec. (4-10 MPH), 1 sec (> 10 MPH)

Nimbus™ WIND MONITOR



FEATURES

- ☐ **Wind change, speed and direction**
- ☐ **Peak gust and direction**
- ☐ **Five or fifteen minute average speed and prevailing direction**
- ☐ **Ten day memory with hourly average and direction, hourly peak gust and direction**
- ☐ **Wind Rose for all sixteen compass points**
- ☐ **Battery backup for six weeks of full operation**
- ☐ **Durable and handsome solid cherry or oak case**

The Nimbus™ Wind Monitor *records and analyzes wind data* and *aids prediction with a variety of computational and memory features.* It *combines the capabilities of advanced microcomputer technology* with the *established reliability and accuracy* of lexan anemometer cups and reed switch directional vanes. The Monitor uses new electronic adaptive filtering circuits to smooth out low speed fluctuations and yet provide rapid response to gusts and lulls.

Functional Description:

The Wind Monitor displays wind speed in mph and direction is shown in one of sixteen compass points. In normal operation it also shows the average wind speed and prevailing direction for either the last 5 or 15 minute period. It can also show the peak gust and its direction in the last 5 or 15 minute period. Peak gust and its direction are remembered until reset.

The memory feature recalls the average speed and prevailing direction and also the peak gust and its direction for each hourly period for the last ten days.

The Wind Monitor accumulates a wind rose giving the average wind speed for each of the 16 compass points. The rose can be cleared at any time.

The Monitor shows whether the direction is backing, veering or steady, and whether the speed is increasing, decreasing or constant.

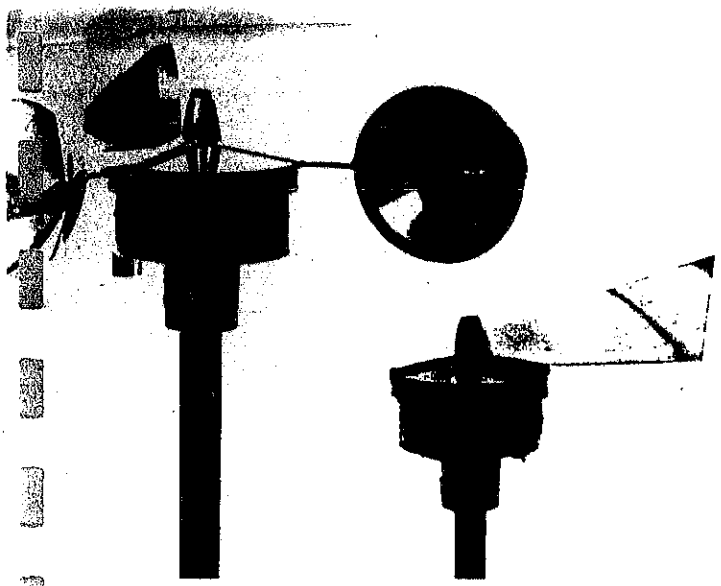
The monitor is powered from a wall transformer with battery back up giving full operation (not just memory).

A computer interface is optionally available.

Sensor

Sensor Instruments Co., Inc.
Instruments for the Environment

41 Terrill Park Drive, Concord, New Hampshire 03301
CALL TOLL FREE 1-800-633-1033
From N.H. call (603) 224-0167



SENSOR KIT

The sensor kit consists of anemometer cups, reed switch directional vane, two stub masts, two clamps, 75′ of pvc jacketed cable, RTV contact sealer, and a roll of tape.

The cups are Maximum type 40. *The low moment of inertia and teflon bearings provide rapid response and long life.* The lexan cups resist icing.

The cable is seven conductor pvc jacket and resists moisture and uv exposure. It is terminated with ring connectors for ease of connection to cups and vane. It connects to the monitor with spade connectors. The wires are cut to the proper length *for error free connection.* The cable may be passed through a hole approximately 5/16″ in diameter.

TECHNICAL SPECIFICATIONS

Speed Range: 0–150 mph

Resolution: Speed: 0.1 below 10 mph
1 above 10 mph
Direction: 1 of 16 points

Accuracy: (4.0–100 mph)
Monitor: 1 mph
Cups: depends primarily on siting

Response Time:
Monitor: 4–10 mph < 2 sec
10–150 mph < 1 sec
Cups: distance constant (63%) 10′

Starting Threshold: < 4.0 mph

Measurement Interval: 1 sec

Averaging: Uses one reading/sec

Averaging time: 5 or 15 min (switch selectable)

Hourly memory averaging: 3600 readings

Wind rose accumulation time: > 1 yr.

Units: mph (optional km/hr, ft/sec, m/sec)

Power Supply: 7.5 Vdc 100 mA from wall transformer (115 Vac 60Hz)

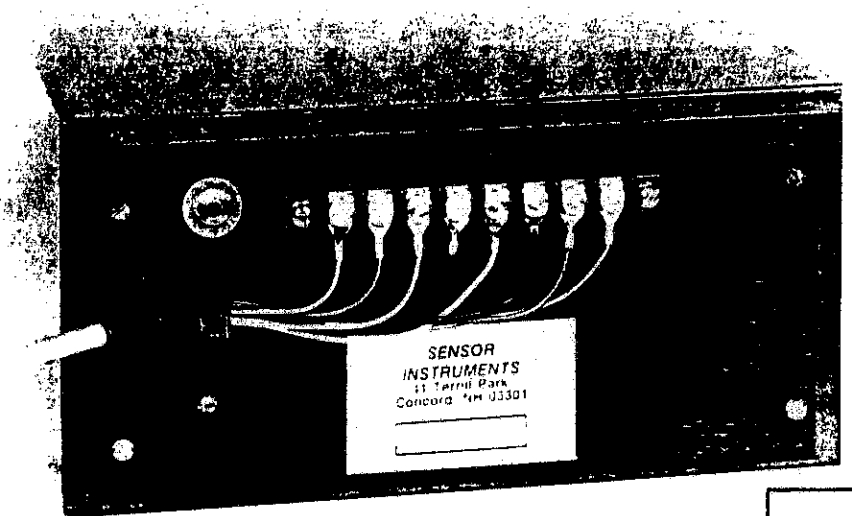
Batteries: 4 alkaline C cells

Battery life: > 1 yr as backup
> 6 wks in full operation

Cable Length: 75′ standard. Longer cable available.

Computer interface (optional): RS232C, 25 pin female D connector

Exterior Dimensions: 7.75″ wide
3.75″ high
6.88″ deep



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WARRANTY

SENSOR INSTRUMENTS, CO., INC., of 41 Terrill Park Drive, Concord, New Hampshire, hereby grants to the purchaser of its NIMBUS™ Wind Monitor a three-year limited warranty against defects in material and workmanship. This warranty does not cover damages due to improper use or caused by unauthorized service. In no event shall Sensor Instruments Co., Inc. be liable for incidental or consequential damages resulting from installation or use of the instrument. Any defective instrument which is returned to Sensor during the warranty period will be repaired or replaced at the option of Sensor, free of charge.

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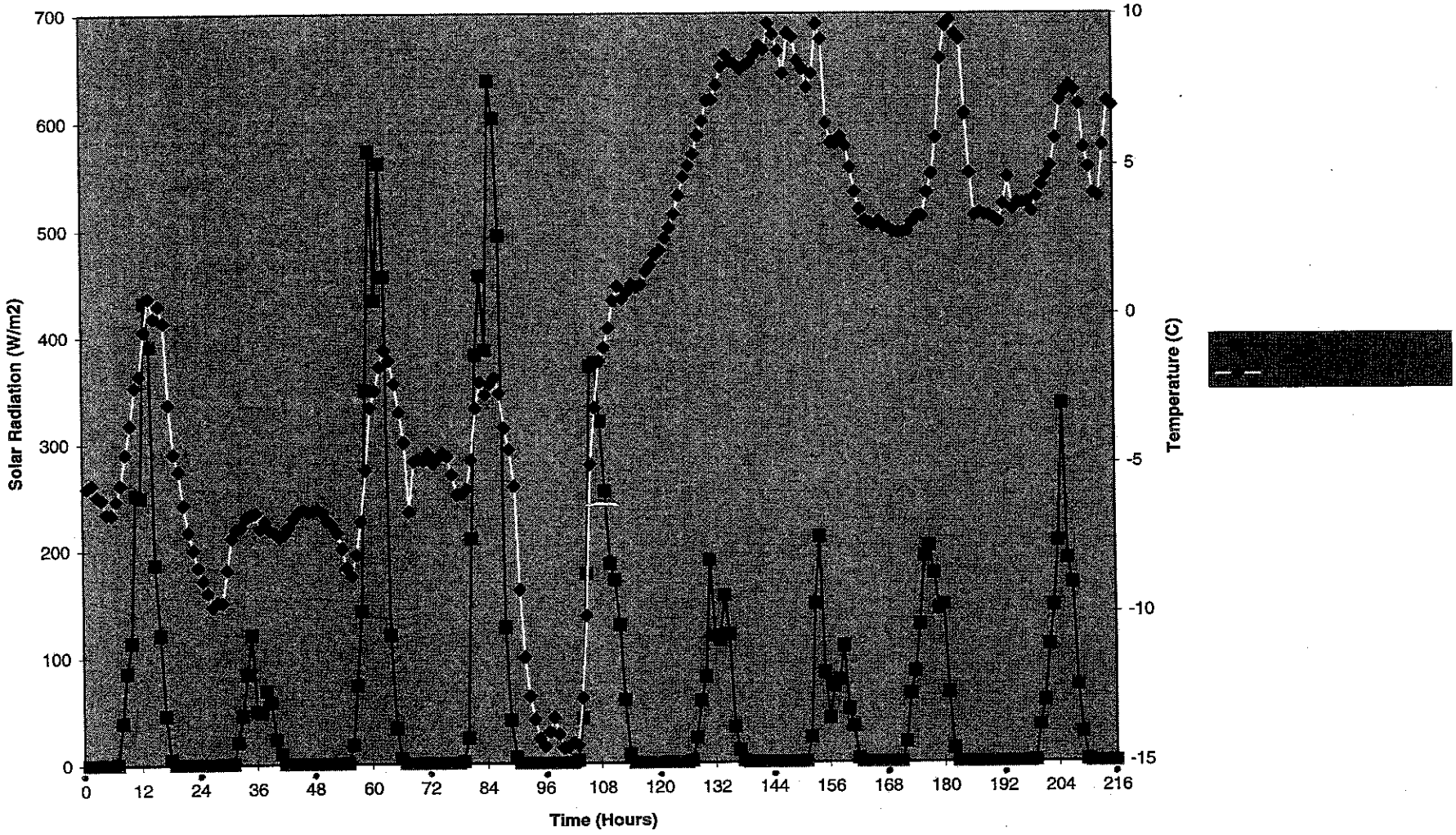
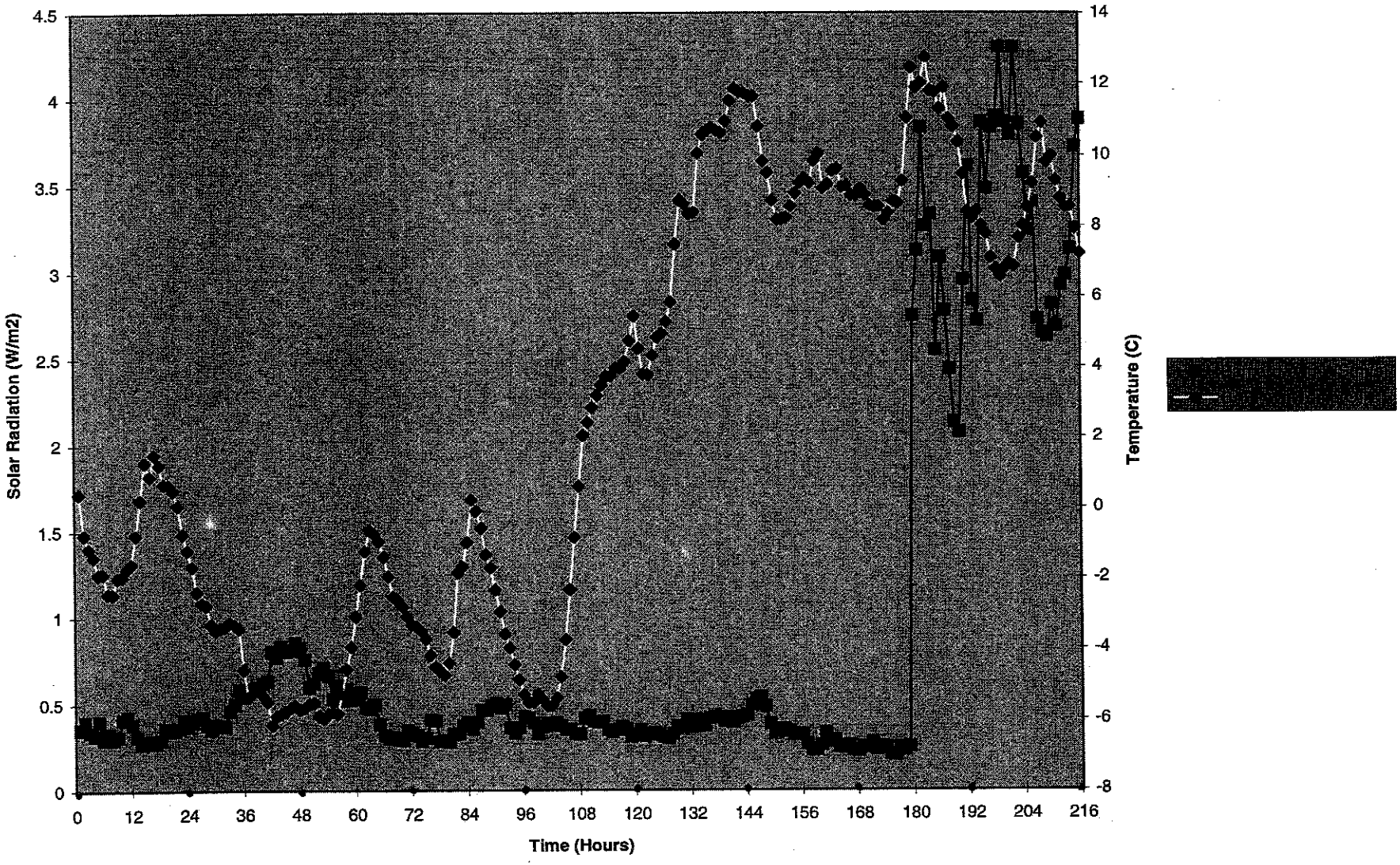
Design and specifications subject to change without notice.

Appendix V-1 - February 15-23, 1996- TEMPERATURE and SOLAR RADIATION for OPENLOW station at Black Rock Forest



Appendix V-2 - February 15-23, 1996- TEMPERATURE and SOLAR RADIATION for BARNARD