Research Experience for Teachers at NRAO-Green Bank : Predicting Good Observing Periods for High Frequency Radio Astronomy

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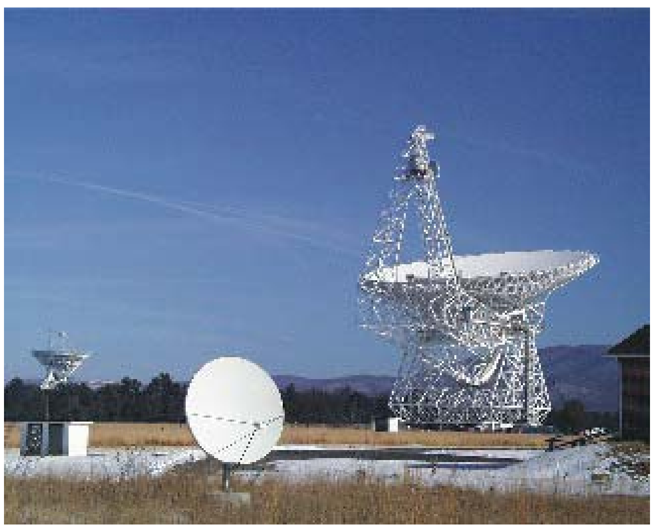
High frequency observations with the NRAO Green Bank Telescope are affected by atmospheric conditions. Water vapor and the atmospheric stability influence radio waves by increasing the opacity of the atmosphere and degrading the quality of the "seeing." Although Green Bank is located in a temperate climate, preliminary studies using data from an 86 GHz tipping radiometer and a 12 GHz phase monitoring interferometer suggest that about 30% of the time (~100 days/year) conditions will be excellent for observations at 100 GHz.

This project attempts to determine in detail what atmospheric conditions produce simultaneously optimal seeing and opacity. We examined fifty-one periods of good observing that occurred over a period of 100 days. The analysis looks for patterns between twenty-five different weather parameters, drawn from a combination of surface, satellite, and vertical atmospheric measurements. Our preliminary results indicate that conditions of good opacity and good seeing do occur simultaneously and we can frequently predict good observing conditions from a combination of temperature, wind direction, pressure, and water vapor.

From this research, two high school projects were developed for students taking an introductory one semester astronomy course. In the first, students use data from the Observatory and four surrounding weather stations, as well as geographical and climatic information of the area, to create and test an interpolated vertical profile of the atmosphere over Green Bank. In the second, students analyze weather parameters on a set of poor observing days and compare their results with those of the good-weather study described above.



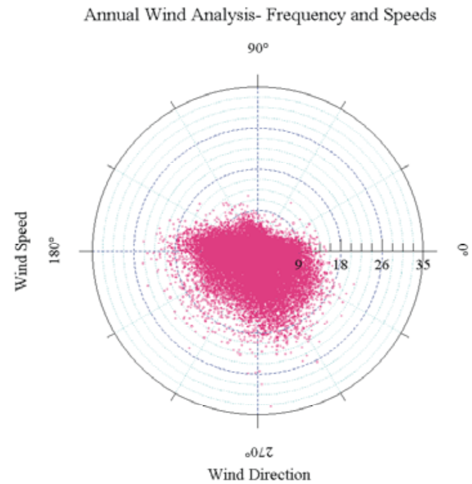
One Element of the12 GHz Interferometer (foreground) with GBT and 140' telescopes in the background.

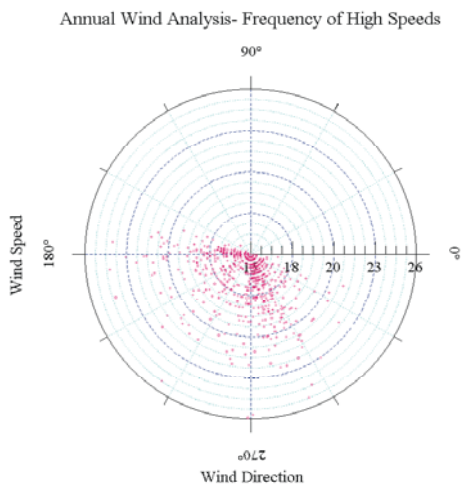
Procedure

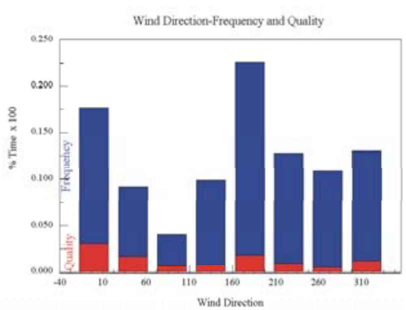
We collected and reduced data from the observatory's 86-GHz tipping radiometer and 100-m baseline, 12 GHz phase-monitoring interferometer (Radford, Reiland, and Shillue 1996, PASP 108, 441), along with the corresponding surface weather data. The data spanned 100 days between March and June 2000.

We first determined good periods for high frequency observing by finding when the RMS phase from the interferometer was 300 microns or less and when the atmospheric opacity as measured by the tipper was less than 0.1. We then made attempts to compare about 50 such periods with site weather data and archived weather-service products. The types of data used were:

- Surface weather from the NRAO weather station: air and dewpoint temperatures, wind speed and direction, pressure, and relative humidity.
- Surface maps and radar analysis: nearby fronts and pressure centers and their position relative to Green Bank, precipitation and pressure tendencies.
- Upper air (300mb) maps: location of jet stream, troughs and ridges relative to the observatory, wind speeds and directions.
- 850mb maps: direction of steering winds, cold or warm advection
- Water vapor imagery: relative amounts.
- Clear Air Turbulence maps: To examine how steady the atmosphere is with respect to different vertical layers.
- Skew-T diagrams and GOES soundings: precipitable water, K index, height of the tropopause, inversions (locations), wind shears (types and locations).







Effects of Climate and Topography: The ridge (Little Mountain) to the west of the observatory appears to have little negative influence on stability but the ridge seems to deflect the direction of the prevailing surface winds. Although winds at the 850mb level are from the west or southwest 55% of the time the observed surface winds are from these directions only 25% of the time. North and south surface winds predominate for 40% of the time, even though they account for only 13% of the winds aloft. There is not a direct correlation between the orientation of the valley and the preferred surface wind direction. Nor is the phase stability better for winds from these orientations.

In the warm months on fair weather days there is a noticeable valley breeze/mountain breeze effect. Although convection may contribute to the degradation of observing conditions in the warm months, the primary contributing factor is the increased potential for water vapor due to high temperatures. Radiation fog is frequent, indicating a pattern of light winds, humid air near the ground and drier air aloft. This fog may become a concern at times when the top surface extends over the telescope's dish, since a very active convective interface exists at this boundary.

Analysis of Weather on Good Observing Days : There are a large number of days when opacities are good but phase measurements are not, and vice versa. There is no simple way to predict the optimal days from a single indicator, such as surface weather, mesoscale products, or vertical atmospheric profiles.

Generally, good conditions often occur when the air is stable and dry. In particular:

- N, NW and NE surface winds produce the most favorable conditions about 20% of the time. Winds from the SE through W are usually not favorable. West winds appear to be the worst, providing good conditions less than 5% of the time.
- Winds from the NW often indicate the presence of a high pressure center with cold and dry air moving into the area. NW winds are also present after the passage of a cold front.
- Cold air advection along troughs is another good scenario, particularly in the winter if the ground is snow-covered thereby slowing down the sensible heating of the air.
- Cold-type occlusions or stationary fronts, even if associated with light precipitation, can also dictate good conditions especially if there is strong divergence aloft.
- Our finding that optimal conditions are sometimes associated with light precipitation needs to be further investigated. This precipitation may be in the form of snow only, and good seeing may not coincide with liquid water precipitation.
- The data do not support the assumption that all high pressure days bring about good conditions. Cold core pressure systems tend to be more favorable. Cold core lows can bring about good conditions even when overhead. Warm core highs or a ridge aloft may not create good conditions probably because these systems can support considerable amounts of precipitable water.
- In the upper atmosphere, meridional flow patterns dictate good observing when troughs set up to the west. This probably results from the southward movement of cold polar air masses that accompany this weather pattern. Particularly good forecasting scenarios would be an omega block system with troughs oriented in a favorable position for a number of consecutive days.

The preferred orientation of the jet stream does not correlate with good observing condition -- good days are seen with the jet stream to the north, south, overhead, or even experiencing "split flow", where it is positioned simultaneously north and south of the observatory.

Summary: From this preliminary work, it seems likely that there will emerge a set of weather variables which will be key indicators of good high frequency observing and that these may be used to predict good observing conditions 48 hours in advance with a high reliability. The most likely combination of factors will be precipitable water, upper level wind analysis, and dewpoint temperatures and tendencies. Skew T diagrams or GOES soundings may prove exceptionally useful as they allow for a study of the vertical atmospheric profile below the tropopause, and can reveal trends aloft.

Katie analyzes 300mb and 850mb upper air maps for the class research project.

Tom and Isaac discuss their research project with meteorologist Bryan Tilley at the National Weather Service office in White Lake.

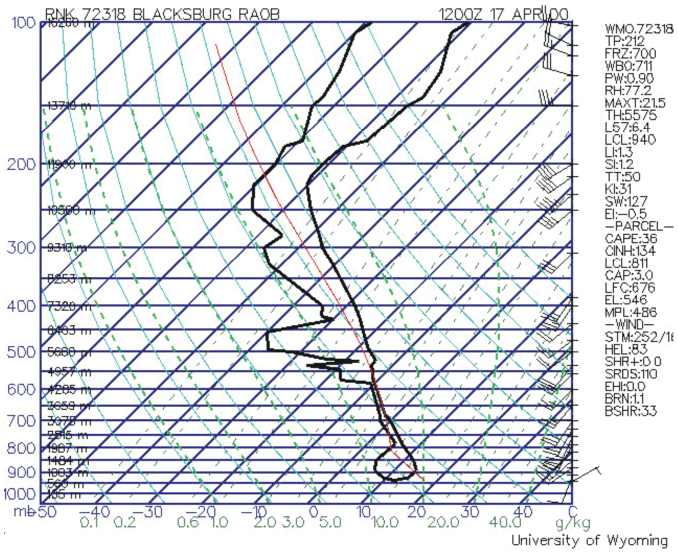
Student Investigations - Classroom

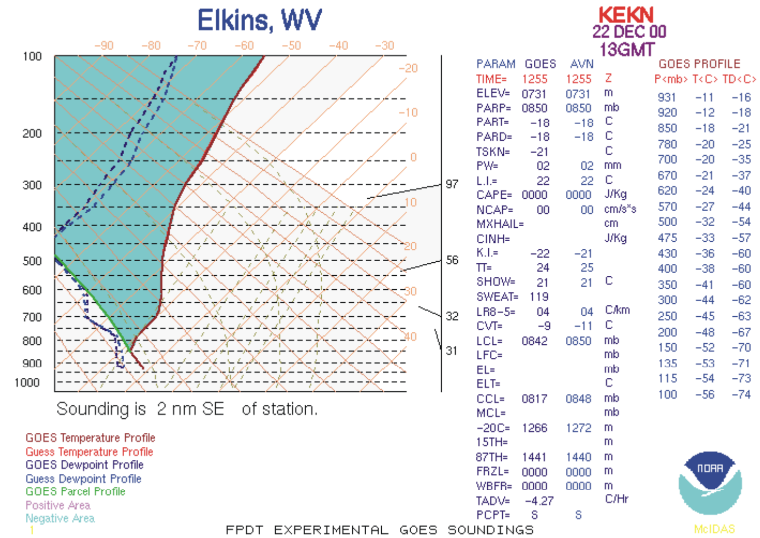
Twenty students in a 10-12th grade, one-semester elective Astronomy class are analyzing 27 periods of poor observing conditions for any evident patterns. The periods occurred from March-June 2000, the same time span as was analyzed for good observing conditions.

The poor observing conditions are defined as when opacities and radio seeing are at least twice as bad as marginally acceptable conditions (the opacity greater than 0.2 and RMS phase higher than 600 microns.) In addition, the time periods are all 4 hours or longer.

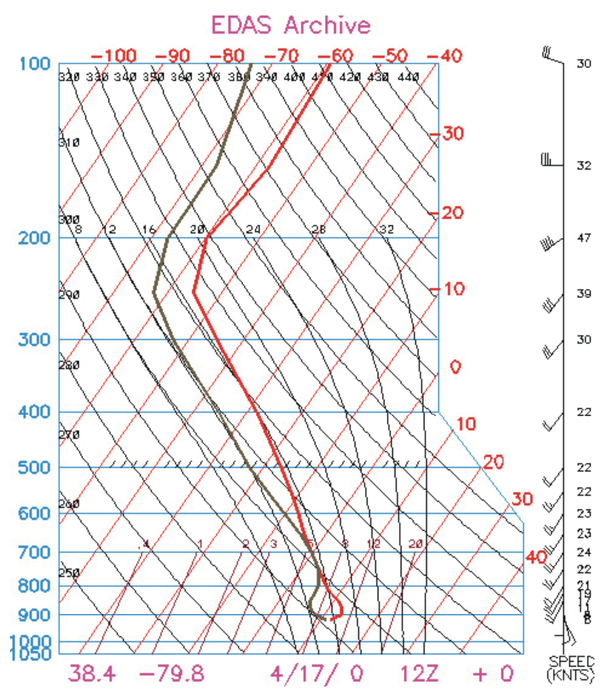
Students are collecting data for these types of analysis:

- Surface weather from the NRAO weather station: air and dewpoint temperatures, wind speed and direction, pressure, relative humidity.
- Surface map and radar analysis: nearby fronts and pressure centers and their position relative to Green Bank, precipitation.
- Upper air (300mb) maps: location of jet stream, troughs, and ridges relative to the observatory.
- 850mb maps: direction of steering winds, cold or warm advection.
- Water vapor imagery: relative amounts.
- Skew-T diagrams and GOES soundings: precipitable water, K index, height of the tropopause, inversions (locations), wind shears (types and locations).





Sample data. The closest NWS raw insonde data to Green Bank (above); closest experimental GOES sounding (above-right); and READY simulated vertical profile over Green Bank, WV (below).



Student Investigations - Small Group Research Team

Three students are working on a special year-long project to attempt to create a simulated profile of the vertical atmospheric conditions over Green Bank by using existing weather products from the surrounding region. The observatory has no way of directly measuring on-site vertical conditions. But, if there is a way to construct a vertical profile then one might be able to analyze unseen conditions and tendencies such as movement and stability of the air aloft and changing amounts of water vapor in air layers above the boundary layer (i.e., the layer closest to the ground).

The project attempts to do the following:

- Develop baseline data for seasonal changes in surface weather at the observatory.
- Compare these data with regional ground stations to see how they match or how they might be inferred by interpolation.
- Devise a way to interpolate vertical soundings so as to create a simulated vertical profile over the observatory.
- Analyze three-dimensional maps of the area to see if the general flow of winds over the mountain ridges and along the valley floor can be modeled at the location of the GBT.