Some Recent Papers on Anomalous Seeing

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The question has been raised as to whether the atmosphere will allow the GBT to point to an accuracy of 1 arcsec, even if the structure can be calibrated to that accuracy, in view of the report of anomalously poor image stability at centimeter and millimeter wavelengths (Altenhoff et.al., A&A, 184, 381, 1987). At the recent URSI/IAU symposium on Astronomical Seeing there were two more papers on the subject, copies of which are now in the NRAO libraries. These papers are:

Measurements of Daytime Atmospheric "Seeing" on Mauna Kea made with the JCMT, by S. Church and R. Hills

Anomalous Refraction at Radio Wavelengths, by D. Downes and W. J. Altenhoff.

I will summarize these papers in this note, and draw some conclusions about this effect in the context of the GBT. In trying to understand the literature on optical seeing, I benefited from a discussion with Buddy Martin (Steward Observatory), for which I am most grateful.

The two papers agree quite well on the nature of the phenomenon. In each case, at millimeter wavelengths, the position of a radio source appears to wander by typically 5 arcsec in timescales of a few seconds to a few tens of seconds. The motions are about equal in azimuth and in elevation. The JCMT shows the effect is of equal magnitude at 2 mm and at 0.8 mm, while the MPI work shows the effect is similar at 3 mm and 13 mm.

The Church and Hills paper says that the effect is observed on most afternoons. It often begins in the morning, and ceases towards sunset. They suggest it may be associated with the rise of the inversion layer each day, and note that the mountain top need not be clouded in . The effect is probably stronger in the summer than in the winter. From an analysis of the power density spectrum of the image motion they deduce that the effect could arise in a water vapor cloud of horizontal scale of order 100 m and a fluctuation in water vapor of a few tenths of a millimeter.

The Downes and Altenhoff paper concurs that the events are more typical of the afternoon, and occur less frequently in the winter. The earlier paper states that the effect has never been seen if the ambient temperature is less than -10 C. They also see very occasional large events, where the image shift can be 30-40 arcsec for as long as 30 seconds. It is not clear how these large events are related to the more common 5 arcsec event, that is, are they just the "tail" of some distribution, or are they a different effect.

Downes and Altenhoff give a nice summary of what is now understood, and what additional work needs to be done. Their model also envisions water vapor clouds of size about 100 m, and a variation in the electrical path of order 0.5 mm, corresponding to a difference in water vapor of 0.1 mm, in excellent agreement with Church and Hills. It is important to emphasize that Downes and Altenhoff present strong evidence that the effect is present at 1.3 cm with the 100 m dish. What is completely absent from the paper is any estimate about the frequency of occurrence at Effelsberg, although anomalous refraction is obviously a real headache for them at Pico Veleta.

My conclusions from these papers are:

1. It seems probable that Green Bank will experience anomalous refraction, since Effelsberg does. If it were only the mountain peaks where the effect is seen, it might be possible to write it off as a feature of an isolated mountain peak. But that seems not to be the case.

2. If Green Bank does experience anomalous refraction, it will severely limit the high frequency performance of the GBT. In essence, for observations requiring integrations much longer than the time scale of the anomalous refraction, the radio "seeing disk" may be of order 5 arcsec, making precise measurements of intensity and size impossible, because it does not now appear to be possible to calibrate out the effect.

3. I think it is very likely that there will be no anomalous refraction effects during observations on winter nights in Green Bank. Therefore I recommend that we continue to specify a high pointing accuracy for the GBT.

4. There is no information in these papers which relates to the question of variation of anomalous refraction effects with location at a given site. It is my guess that the effect will not vary much from place to place within the Observatory site, but that is really just a guess.

5. Green Bank can not be tested at optical wavelengths, since the refraction appears to arise in water vapor, and the refractive index is much smaller at optical wavelengths. The only hope would be if there is a coupling between the water vapor fluctuations and those of the dry air, an effect that has been observed over oceans (c.f. Friehe et al. 1975, JOSA, 65, 1502). In the traditional optical seeing literature the variations in image position arising from fluctuations in water vapor are always ignored.

6. The 225 GHz radiometers now being used in site testing for the MMA should be able to see the clouds which produce the anomalous refraction events. If such a cloud increases the water vapor in the path by 0.1 mm, the 225 GHz opacity in the path should increase by about 0.0055, resulting in an increase in the observed sky temperature of about 1.5 K. The theoretical sensitivity of the 225 GHz system is 0.13 K for an integration time of 4 seconds, so that the typical events should be seen with a signal-to-noise of 10. One of the radiometers has recently been installed at the CSO on Mauna Kea, and we should soon be able to make a direct comparison between the observed brightness fluctuations and the seeing fluctuations at either the CSO or the JCMT.

7. An attempt could be made to observe the effect directly using the 140 ft at 22 GHz. A source would be tracked at the half-power point, and any fluctuation in amplitude would be interpreted in terms of relative motion between the telescope and source. The biggest uncertainty about this approach is the tracking accuracy of the telescope. I have not been able to find a good value for this quantity, and indeed it may not be known. It is possible that the telescope does not track well enough to study the 5 arcsec events, but it surely could see the 30-40 arcsec events found occasionally at Effelsberg.