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Precision of Meterological Measurements

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The meteorlogical instruments are used for the following purposes: 1). The windspeed may be consulted for considerations of safety of personell or of equipment. 2). Windspeed and direction may be used in an antenna pointing model. I know of at least one case in which this has been attempted, I do not know with what success. 3). Surface pressure and partial pressure of water vapor are used to calculate the surface index of refraction, which is used a) for calculation of the first (cotan elevation) term of refraction, b) estimation (with a plausible guess at elevation distribution of water vapor) of the second (cubed) term of refraction, c) for the VLA, estimation of the additional phase path due to unequal elevations of the antennas, d) for the VLA, estimation of the phase path correction due to the differing zenith angle of the source as viewed from the various antennas, and e) for VLBI, estimation of the total atmospheric contribution to phase path. Each of these purposes has associated with it a required accuracy of the instrument.

For safety considerations, "Engineering accuracy" is required. I suggest that 10% accuracy in windspeed is appropriate.

Using wind instruments in a pointing model is probably limited by extremely complicated interactions between the wind gust spectrum and the normal modes of the antenna, the servo spectral response, and the wind instrument spectral response. I again suggest that 10% is sufficient and appropriate accuracy in speed, and 10 degrees in direction. The apparent factor of two difference in these specifications (10 degrees is 20% of a radian, not 10%) is due to the fact that forces are proportional to square of windspeed.

The index of refraction at an absolute temperature T, in degrees Kelvin is

N = 7.76E-5 * (P + 4810 W/T)/T

where P is the dry air surface pressure in millibars, and W is the partial pressure of water vapor. To a sufficient approximation, the steam equation is

W = exp(17.27 D/(237.3 + D) + 1.81)

where D is the dew/frost point, in degrees Celsius.
The first refraction term is

cot (elevation) * (N-1)

in radians. The second, also in radians, is

cot(elevation)**3 * (N-1) * H/a

Where H is the scale height of the atmosphere (or the component thereof of interest) and a is the radius of the earth.

Since dewpoint is much harder to measure than the other quantities, I suggest that the uncertainties introduced by pressure and temperature measurements be substantially smaller than those introduced by measurement of dewpoint. This criterion seems to be met with an accuracy of plus or minus 5 mB in pressure, plus or minus 1 C in air temperature.

In the practical cases, the uncertainty in the first term of refractivity seems to be more important than that of the cubed term.

The table below illustrates the required accuracies over the likely range of dew/frost points. The first column contains the dew/frost point, the second the partial pressure of water vapor, the third the dewpoint accuracy required for a VLA antenna to point with an error of no more than 0.1 beam at its highest frequency (that is, 12"), at the elevation limit (eight degrees). The fourth column gives the equivalent number for the VLBA antenna, given that the highest frequency is a factor of two higher than for the VLA and the elevation limit is two degrees rather than eight. The fifth and sixth columns give the lowest elevation at which the telescopes will point adequately if the dewpoint is known to one degree accuracy, for the VLA and VLBA respectively.

D	W	D Accur, VLA	D Accur, VLBA	Emin, VLA	Emin, VLBA
-30	0.5	-	6	8	2
-25	0.8	-	4	8	2
-20	1.2	-	2.5	8	2
-15	1.9	-	1.8	8	2
-10	2.9	-	1.2	8	2
-5	4.2	6	0.8	8	2.6
0	6.1	4	0.5	8	3.7
5	8.7	3	No Way	8	5.5
10	12	2	"	8	7.5
15	17	1.5	"	8	10
20	23	1.0	"	8	14
25	32	0.8	"	9	18

For estimating the plane term refraction due to different elevations, we note that the total relief of the VLA is only plus or minus 25m (or 83ns) from the midplane. Other effects limit VLA accuracy to about 2ps. In order that uncertainty in this term not exceed this, the refractivity must be known to .000024*cos(elev), or .0000033 at the elevation limit. The required accuracy of dew point is shown in the third column of the table below, or, correspondingly, the lowest elevation of satisfactory astrometric performance with a one degree uncertainty in dewpoint in the fourth column.

In the estimation of the differential phase path due to the different zenith angles at the different antennas, we note that, first, the effect goes as csc(elevation)*cotan(elevation), and second, that if the dewpoint accuracy is better than about 1.5 degrees, the estimation of the effect is dominated by the uncertainty in the height distribution of the water vapor. The Fifth and sixth columns of the table below show the required accuracies (or rather, those worse than 1.5 degree) and the minimum astrometric elevation due to this effect).

Similar arguments may be advanced for the required accuracy for estimating the total atmospheric delay for VLBI purposes. That is to say, if the accuracy of the dewpoint is known to about 1.5 degree, the uncertainty in the water vapor scale height dominates the uncertainty in the phase corrections. The last column merely illustrates the problem by giving the elevation at which the a priori atmospheric delay exceeds 30 ps, given a 1.5 degree accuracy measurement of the dewpoint. Some serious astrometry can be done with a 30ps atmospheric uncertainty, although the best work requires an order of magnitude better.

D	W	D Accur	Emin	D Accur	Emin	E(30ps)
-30	0.5	-	8	-	8	3
-25	0.8	-	8	-	8	5
-20	1.2	9	8	5	8	7
-15	1.9	6	8	3	8	11
-10	2.9	4	8	1.9	8	17
-5	4.2	2.5	8	1.3	8	25
0	6.1	1.7	8	0.9	10	38
5	8.7	1.2	8	0.6	12	60
10	12	0.9	9	No Way	14	zenith
15	17	0.6	13	"	17	"
20	23	No Way	17	"	20	"
25	32	"	23	"	23	"

The overall conclusion to be gained from the above tables is, I think, that for VLA purposes a dewpoint accuracy of about 1.5 degrees is needed for dew/frost points above about -10 C (Which on a hot, very dry summer day implies a dewpoint depression of about 40 C). For VLBA purposes, the 1.5 degree accuracy continues to be useful down to -30 C dewpoint, with a maximum useful dewpoint depression of about 50 C. Although accuracies better than 1.5 C are modestly useful for antenna pointing purposes, they are critical only for the rather limited purpose of pointing the VLBA antenna at elevations near its elevation limit at frequencies of the order of 15 GHz.

A particular conclusion is that the shenanigans of the General Eastern dewpoint instruments at about -2 C dewpoints are only modestly worse than the limits in the first table above, and, while painful for observations at low elevations and the highest frequencies, do not seriously damage observations at 6cm or longer wavelengths, except for the most careful 6cm astrometric observations. Shorter wavelength observations at elevations greater than about 20 degrees are also undamaged. These exceptions cover the greatest bulk of VLA observations.