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Geodetic sensitivity to surface meteorological data: 24-h and 6-h observing sessions

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Abstract Tests have been performed to assess the utility of surface meteorological measurements for improved geodetic performance. Three types of a priori met data are considered: a default global, seasonal model; local met measurements collected at a subset of the test network; output values from a NOAA Forecast Systems Lab assimilation model. A variety of configurations for handling tropospheric parameters in the geodetic solutions is also considered. We find no geodetic advantage in using the measured met data under any test scenario. Differences among the three types of a priori information are generally insignificant, although biases can be introduced when some troposphere parameters are not adjusted. Even when using only a relatively small network (<100 km) the differences remain minor. When observing sessions are reduced from 24 h to 6 h the increased error due to measurement noise obscures all other effects except for the shortest baselines where some advantage may be achieved by not adjusting troposphere parameters for very close station pairs.

Background

Tropospheric delays

In using any radiometric system, such as GPS, to determine terrestrial positions, it is necessary to account for the propagation delay of the neutral atmosphere (mainly the troposphere) if accuracies better than a few meters are needed. The zenith delay at sea level due to the hydrostatic ("dry") component of the troposphere is about 2.3 m. By definition, this contribution can be determined from local surface measurements of barometric pressure to millimeter accuracy, limited by the measured refractivity constants for dry air. The standard model of Saastamoinen (1972) is normally used to compute dry delays given surface pressure data. At a given altitude, the relationship between pressure and dry delay is linear; at sea level, a 1 mbar pressure change corresponds to a delay change of about 2.3 mm. In the absence of local pressure data, global models for the dry delay can be reasonably accurate given latitude, ellipsoid height, and day of year; pressure varies over a range of up to about ±5%, leading to comparable errors in the modeled dry delay.

The non-hydrostatic ("wet") delay is much more spatially and temporally variable. For this reason, models for the zenith wet delay (ZWD), even given highly accurate surface met data, are notoriously unreliable. At sea level in temperate and tropical latitudes, the ZWD can reach ~35 cm in summertime (i.e., ~15% of the dry delay). In wintertime, the ZWD outside the tropics can sometimes approach 0, especially at higher latitudes.

If uncalibrated, unmodeled, or inaccurately calibrated, tropospheric delays will induce an error in geodetic height measurements of a similar or larger magnitude. The height measurement error will be magnified due to the effect of increasing atmospheric depth at low elevation angles, depending on the minimum elevation data used in the determination. Figure 1 illustrates the position error variations due to a range of hypothetical errors in the assumed barometric pressure, for three different elevation angle cutoffs. The nominal pressure is 1,000 mbar in this example using two nearby stations. When a pressure error is introduced at one end, the apparent height is changed by about −6.7 mm/mbar for a 15° elevation cutoff, −4.2 mm/mbar for 30°, and −3.15 mm for 45°. The horizontal position is affected by only a few millimeter.

To achieve sub-meter geodetic accuracies, it is therefore necessary to account for the tropospheric delays. As described above, the accuracy of a priori tropospheric corrections is usually limited by the wet component, the ZWD, which means that the accuracy varies with the local climate and season. Existing models can give a priori total tropospheric corrections with statistical errors less than 10 cm averaged over the globe (see below). However, errors in particular areas can be larger, especially in very humid regions, and during any given period they are typically more systematic than random.

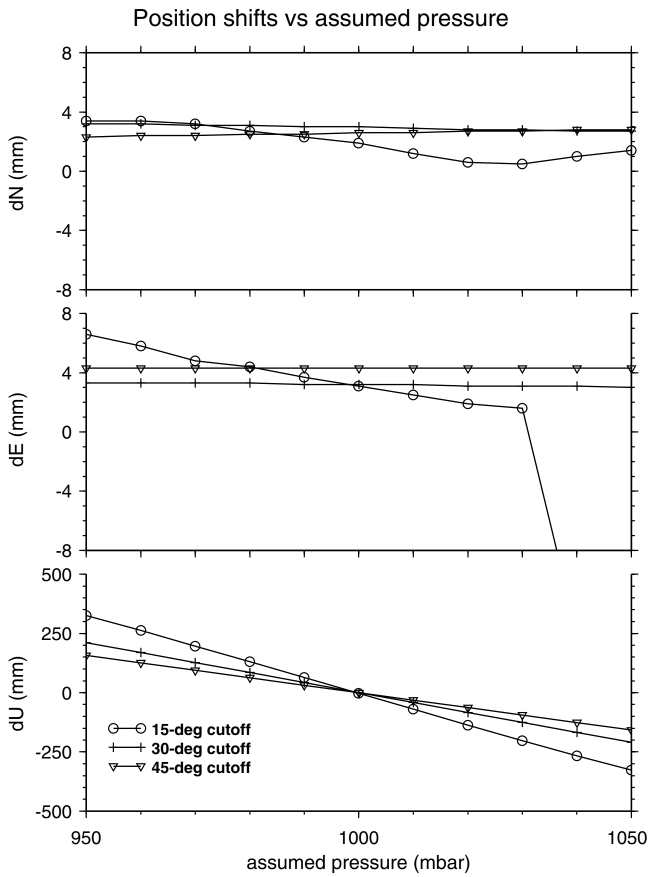

Fig. 1 Position shifts caused by various barometric pressure errors. USNO is the reference station with a local pressure of 1,000 and USN1, separated by 176 m, is the remote station with varying assumed pressures. The a priori tropospheric model, which accounts for height differences (see text), is otherwise used with no troposphere parameters adjusted. The position adjustments are relative to the a priori coordinates. Data for 6 July 2003 have been used. Note the much larger vertical scale for the Up component in the *bottom panel*

Tropospheric parameters

For the highest geodetic accuracy, the sensitivity of the GPS observations to tropospheric delays can be used to advantage by including additional "nuisance" parameters to account for this effect. Height performance at the centimeter level can be achieved with 24-h integrations and the zenith total troposphere delay (ZTD) can be determined with few-millimeter accuracy. In following this approach, potentially large (10 cm level) systematic errors are eliminated in favor of a modest increase in the formal errors due to nonnegligible correlations between the geodetic and tropospheric parameters. To more appreciate this latter point, note that the sensitivity of the GPS observation equation to a local height error is equal to $\sin(e)$, where e is the local elevation angle of a particular satellite. The corresponding sensitivity to an error in ZTD is equal to the atmospheric depth, or approximately proportional to $1/\sin(e)$. [At elevation angles below about 20°, deviations from $1/\sin(e)$ become significant, depending on local climate and season, and azimuthal nonuniformities can also be important.]

At high elevations, $1/\sin(e)$ is very close to $2 - \sin(e)$, which is perfectly correlated with the height partial. This means that the height and ZTD parameters are highly correlated if data are not available over a wide range of elevation angles. The elevation dependence of the relationships is illustrated in Fig. 2. It is evident that collecting data in the lower half of the local sky is essential if one is to decorrelate height and ZTD parameters. An elevation cutoff of 15° or lower is used in most high-accuracy geodetic analyses. For data below 15°, tropospheric gradient parameters are also routinely included to account for azimuthal variations, mostly in the wet delay. In practice, the simple $1/\sin(e)$ "mapping function" is not used. Instead, more accurate forms, such as NMF by Niell (1996), are popular.

If for any reason low-elevation data cannot be used, then one must consider the trade between potential systematic troposphere errors when no nuisance parameters are adjusted versus the dilution of precision caused by adding extra highly correlated parameters. If the observational limitations are severe, realistic a priori constraints can be applied to the ZTD parameters to overcome near-singularity when this is a problem.

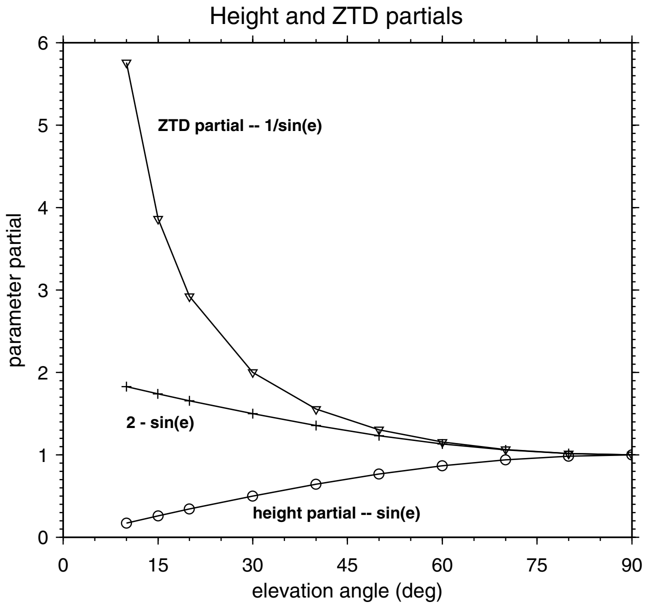

Fig. 2 Height and ZTD partials plotted as a function of elevation angle. The function 2 – sin(*e*) closely approximates the ZTD partial at high elevation angles and is perfectly correlated with the height partial

Small networks

Even when low-elevation data are available, it is not feasible to freely estimate ZTD parameters when the station separations are small because the local elevation angles will be nearly identical, causing the ZTD estimates among different stations to be nearly indeterminate. For plane waves (i.e., infinitely distant source), the difference in elevation angles as a function of baseline length B is $\arccos[1\text{–}0.5^*(B/\mathrm{Re})^2]$, where Re is the radius of the Earth (6,378.145 km). (For sources at a finite distance, geometric parallax will increase the angular difference, but this effect is most pronounced for the long baselines where the elevation angles already differ.) If $B << \mathrm{Re}$, the difference in elevation angles is approximately $(0.00898°)^*(B/\mathrm{km})$. Stations must be separated by more than 111 km in order to have elevation angles different by more than 1°. In order for such a small angular difference to permit separation of ZTD and height parameters at both ends of the baseline, it is all the more vital to include low-elevation data (see Fig. 2). Nonetheless, the estimates will remain highly correlated if separations greater than several hundred kilometer are not used. The situation is complicated by the realization that multipath errors are normally largest near the horizon, which may introduce a greater sensitivity to both systematic and random errors from that source.

A modified analysis strategy commonly used for small networks is to include a priori constraints on the relative ZTD parameters among stations, rather than allow them all to be freely adjusted. The variations of most atmospheric variables obey a characteristic power-law behavior for a Kolmogorov turbulent cascade. On the shortest scales, smaller than the scale height of the troposphere, fully developed 3D turbulence is expected and the power-law exponent for variance is 5/3. At larger scales, 2D turbulence prevails and the exponent is 2/3, up to the largest continental weather systems beyond which there is no further increase in variability. In the case of water vapor distributions, which usually dominate ZTD variability, the transition from 5/3 to 2/3 power-law exponent is thought to be roughly 1–2 km. Treuhaft and Lanyi (1987) provide a quantitative statistical form for the spatial domain (or equivalent temporal domain, related by the wind speed aloft) correlations of troposphere variations, which has been widely applied in radio astronomy, radio interferometry, GPS, and InSAR analyses.

Expressed equivalently as standard deviation (or RMS), the variation of ZWD scales as distance to the 5/6 power up to about 1–2 km, then transitions to 1/3 power for longer separations up to continental distances. The amplitude of the RMS variations ranges over a factor of 4 or so, depending on location, season, and atmospheric conditions, but is around 1 mm for 1 km separations (Wright 1996). When applied as an a priori constraint on the ZTD parameter adjustments, the geodetic results are usually not highly sensitive to the specific values chosen for the correlation scaling (provided it is not too tight) because the GPS observations themselves contain some relevant information.

Data selection

Core network

The core test network used here consists of USNO (Washington, DC, USA), USN1 (Washington, DC,USA), GODE (Greenbelt, MD, USA), USNA (Annapolis, MD, USA), SOL1 (Solomons Island, MD, USA), and HNPT (Cambridge, MD, USA). Baseline distances from USNO are 0.176, 23.677, 51.370, 85.330, and 89.223 km, respectively. These are all stations in the International GPS Service (IGS) and National Geodetic Survey (NGS) CORS networks, except USN1. USNO and GODE are generally included in the weekly IGS combined products; USNA, HNPT, and SOL1 are often included too. The IGS products provide useful ground truth station coordinates and ZTD values. Surface met data are available for USNO, USN1 (same as USNO), and SOL1.

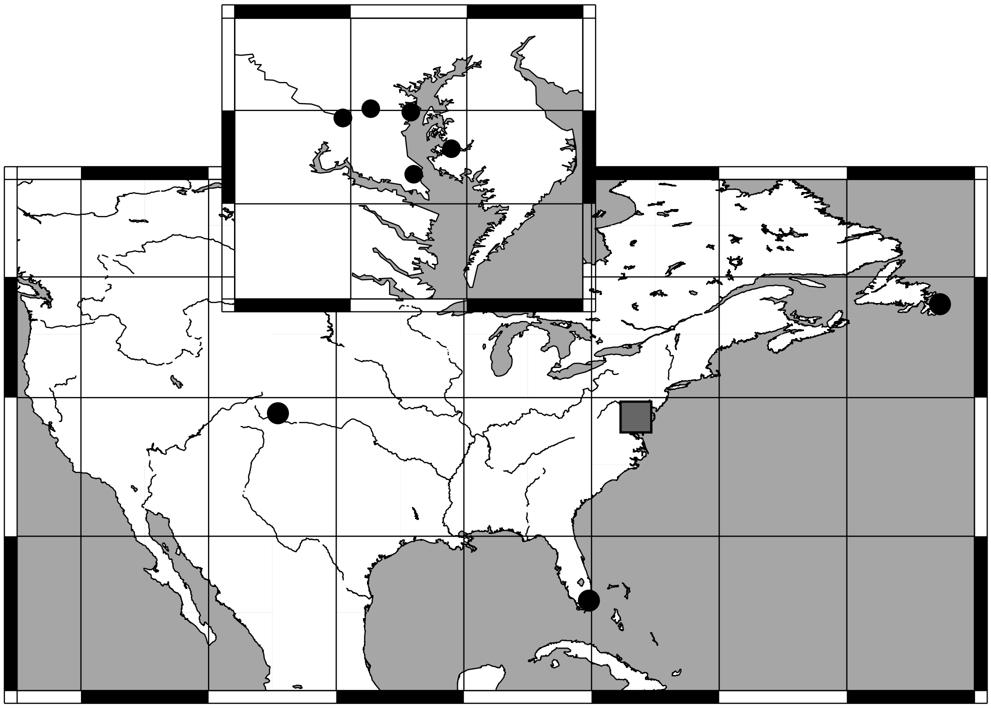

Fig. 3 This map of North America shows the locations of the far stations as *large black dots* in the main panel. The core network is marked by the *square*, which is expanded in the smaller *inset* map. USNO (and USN1) is the westernmost point in the core network

Far stations

To test the effect of adding distant stations to stabilize the ZTD parameter estimates of the small network, we will also consider the IGS stations at AOML (Miami, FL, USA), STJO (St John's, Newfoundland, Canada), and AMC2 (Colorado Springs, CO, USA). These stations form a large triangle surrounding the core net, with sides about 4,000 km long. Distances from USNO are 1487.154, 2179.167, and 2360.920 km, respectively. Surface met data are available from AOML and STJO. All three are usually included in the IGS combined products. Figure 3 shows the locations of the core and far station networks.

Meteorological data

Stations and days with local met data are indicated in Table 1. (USN1 uses the same met data as USNO.) In addition, the core network falls near the middle of the Forecast Systems Lab (FSL) real-time Northeast test grid. (For further information see IGS Mail#4509 at the IGS website igscb.jpl.nasa.gov.) The grids are updated hourly and provide zenith hydrostatic (dry), wet, and total delays given station latitude, longitude, and ellipsoidal height.

Test period

A few-days period during the summertime is best because that is when the ZTD and ZWD values are largest and most variable. Checking for a period with complete RINEX and met data for all the test stations, preferably also with IGS combined station coordinates and ZTD values for all or most stations, GPS week 1229 is promising (see Table 1). Only doy 212 is missing some data (for AOML). Data yields from the old AOA TurboRogue (TR) receivers are not as high as from newer receiver types but should still be usable. Days 208–211 (27–30 July 2003) have been used in the following tests.

Analysis procedures

PAGES a priori configuration

The GPS analysis package developed at NGS, PAGES, has been used for all tests. (For further information, see the NOAA analysis summary at igscb.jpl.nasa.gov.) In the following solutions, the GPS orbits have been fixed to the IGS Final sp3 values. The a priori coordinates for all available stations, in Table 2, are from the IGS network combination for week 1229. The a priori coordinates of USNO are very tightly constrained (effectively not adjusted) to the IGS values in order to use it as a fixed reference for all the network solutions, which consist of the baselines radiating from USNO to the other stations. In these tests, an elevation cutoff of 15° is applied for all stations. Carrier phase ambiguity parameters have been fixed as much as possible in all solutions independently.

Table 1 Availability of test data for GPS week 1229 (27 July–2 August 2003)

Site	rcvr	Usable number of complete observations as reported by teqc						
		208	209	210	211	212	213	214
AMC2	Z12T	20,934 (t)	21,627 (t)	21,626 (t)	21,672 (t)	21,675 (t)	21,203 (t)	21,604 (t)
AOML	TR-08	18,501 (mt)	19,230 (mt)	19,346 (mt)	18,748 (mt)	118 (m)	19,260 (mt)	18,385 (mt)
GODE	ACT-8	21,784 (t)	21,798 (t)	21,681 (t)	21,801 (t)	21,805 (t)	21,695 (t)	21,753 (t)
HNPT	TR-08	18,151	18,205	18,325	18,361	18,332	18,249	18,178
SOL1	TR-12	20,625 (m)	20,224 (m)	19,462 (m)	18,554 (m)	20,693 (m)	19,885 (m)	20,651 (m)
STJO	ACT12	22,673 (mt)	22,433 (mt)	22,579 (mt)	22,649 (mt)	22,618 (mt)	21,539 (mt)	22,568 (mt)
USN1	Z12T	19,742 (m)	19,570 (m)	19,632 (m)	19,558 (m)	19,541 (m)	19,240 (m)	19,731 (m)
USNA	TR-08	19,426	19,594	19,191	19,890	19,470	19,247	19,456
USNO	Z12T	21,320 (mt)	21,271 (mt)	21,228 (mt)	20,892 (mt)	21,292 (mt)	20,430 (mt)	21,314 (mt)

m has met data, *t* has IGS ZTD troposphere file

Table 2 IGS station coordinates for GPS week 1229 (27 July–2 August 2003)

Site	ACs[a]	IGS combined geocentric station coordinates			Epoch
		X (m)	*Y* (m)	*Z* (m)	YYYY:DOY:secnd
AMC2	CGJS	-1,248,596.1818 0.0015	-4,819,428.2232 0.0035	3,976,505.9901 0.0028	2003:212:21592
AOML	CGJ	982,296.7327 0.0024	-5,664,607.2328 0.0073	2,752,614.4864 0.0040	2003:211:43195
GODE	CEGS	1,130,773.7639 0.0019	-4,831,253.5822 0.0040	3,994,200.4142 0.0032	2003:212:21592
HNPT	G	1,196,626.3535 0.0046	-4,846,358.4944 0.0122	3,956,723.0951 0.0098	2003:211:43200
SOL1	G	1,173,608.7562 0.0041	-4,871,160.8486 0.0116	3,933,263.0990 0.0088	2003:211:43200
STJO	CMGJS	2,612,631.1150 0.0018	-3,426,807.0416 0.0021	4,686,757.8565 0.0025	2003:212:08634
USN1	–	....	....	....	....
USNA	G	1,160,668.8333 0.0037	-4,826,883.3477 0.0098	3,990,863.0681 0.0076	2003:211:43200
USNO	CMES	1,112,189.7887 0.0018	-4,842,955.0399 0.0040	3,985,352.2550 0.0032	2003:212:21592

The a priori coordinates for USN1 were generated as the weighted mean of the results from local solutions of the USNO–USN1 baseline using data from 27 July to 2 August while holding the coordinates of USNO fixed to the IGS values

[a]contributing IGS Analysis Centers: *C* COD, *M* EMR, *E* ESA, *G* GFZ, *J* JPL, *N* NGS, *S* SIO

Table 3 ZWD residuals from NGS Rapid solutions for 30 July–10 August 2003

DOY	211	212	213	214	215	216
wtd mean (cm)	2.47	3.39	4.69	4.94	4.37	3.76
std dev (cm)	4.70	4.76	5.98	6.38	5.92	5.83
wtd RMS (cm)	5.31	5.84	7.60	8.06	7.35	6.93
# ZWD estimates	780	780	780	767	779	780
DOY	**217**	**218**	**219**	**220**	**221**	**222**
wtd mean (cm)	4.43	4.47	3.59	4.03	3.33	3.72
std dev (cm)	6.02	5.80	4.97	5.36	5.97	6.36
wtd RMS (cm)	7.47	7.32	6.13	6.70	6.84	7.37
# ZWD estimates	780	780	780	779	780	780

These results use the PAGES default troposphere model with synthetic met data for 60 globally distributed stations

PAGES default ZTD modeling

The a priori ZTD values in PAGES are computed from the Saastamoinen (1972) model for dry and wet zenith delays using synthetic met data from a global climate model by T. Herring (private communication) which depends on station latitude, ellipsoidal height, and day-of-year. The zenith delays are mapped to elevation with the NMF dry and wet mapping functions (Niell, 1996) and ZWD residuals are adjusted in 2-h piecewise linear, continuous segments. Measured met data are not normally used, but if they are available (as in some of the tests below) they are converted to zenith delays and mapped to elevation using the same models.

To get a sense of the accuracy of the PAGES a priori ZTD model, Table 3 tabulates the ZWD residuals from 12 days of NGS Rapid solutions for the period from 30 July through 10 August 2003. A global tracking network is used consisting of 60 stations each day. The global mean, standard deviation, and root-mean-square (RMS) statistics have been computed for each day using the formal ZWD errors for weighting. First, it can be seen that the mean global ZWD residual is biased, up to about 5 cm. Inspection of the geographic distribution of the residuals suggests that the net bias is caused by the subset of stations in very humid temperate and tropical zones with residuals of 10–20 cm. East coast US stations are among those with large biased residuals; typically ALGO, GODE, GUAM, NTUS, TIXI, TSKB, WES2, and WUHN are most biased. During this period the Antarctica sites are all negatively biased, but by smaller amounts. The standard deviations about the mean residuals are only modestly larger than the biases. In all cases, the global weighted RMS residuals are below about 8 cm. As noted above, however, the residuals at individual stations can be biased by more than double this global RMS. Nonetheless, these results give a good idea of suitable error bounds on the PAGES default ZTD models.

A notable feature of the default PAGES troposphere modeling is the height-dependence of the a priori ZTD values. Consider, for example, two stations horizontally close but with ellipsoidal height differences of 100 m, the lower being at sea level. The PAGES model accounts for the effect of the height difference so that the lower station is assigned about 3 cm more ZTD than the higher point. Were this not done, the 3 cm ZTD difference would bias the relative height estimates by a similar or larger amount (see Figure 1) in any GPS solution that did not adjust ZTD parameters due to their proximity.

Test solution configurations

Table 4 lists the various analysis test configurations studied. Initially, all configurations were evaluated for 4 days of GPS week 1229 (27–30 July) using 24-h data sets. This provides the highest geodetic accuracy and sensitivity to detect whether differences related to the handling of ZTD a priories and parameters are significant. To examine the effect of shorter sessions appropriate to typical GPS field surveys, the same tests were then repeated for the same period using four 6-h data sets for each day.

Results

24-h sessions

Evaluation of the results must consider both systematic errors compared to the ground truth IGS combined

Table 4 Configuration of test solutions

Soln#	Network	A priori tropos	ZTD parameters
Cd1	Core	Default	None
Cd2	Core	Default	Fix USNO and USN1; adj others
Cd3	Core	Default	Adj all
Cg1	Core	FSL grid + default	None
Cg2	Core	FSL grid + default	Fix USNO and USN1; adj others
Cg3	Core	FSL grid + default	Adj all
Cm1	Core	Met + default	None (all in FSL grid)
Cm2	Core	Met + default	Fix USNO and USN1; adj others
Cm3	Core	Met + default	Adj all
Fd1	Core + far	Default	None core; adj all far
Fd2	Core + far	Default	Fix USNO and USN1; adj others
Fd3	Core + far	Default	Adj all
Fg1	Core + far	FSL grid + default	None core (in FSL grid); adj far
Fg2	Core + far	FSL grid + default	Fix USNO and USN1; adj others
Fg3	Core + far	FSL grid + default	Adj all
Fm1	Core + far	Met + default	None core; adj all far
Fm2	Core + far	Met + default	Fix USNO and USN1; adj others
Fm3	Core + far	Met + default	Adj all

products (where available) as well as random errors evidenced by the scatter in the results. We first consider the core + far network tests as these are likeliest to give the most accurate (that is, least biased) height and ZTD estimates, though not necessarily the most precise (that is, least scatter). Even though results are included in Fig. 4 for the remote stations (AMC2, AOML, and STJO), they will not be considered diagnostic here because the network design is not optimized for them. The Fd3, Fg3, and Fm3 solutions, wherein zenith delay parameters have been adjusted for all stations, are in good agreement with one another for height and ZTD estimates. The a priori heights are consistent within 2 mm with our estimates for USN1 and GODE, but differ by ~4 mm for USNA, ~15 mm for SOL1, and ~20 mm for HNPT. The reported errors in the a priori IGS coordinates for SOL1 and HNPT are at a similar level, up to about 16 mm.

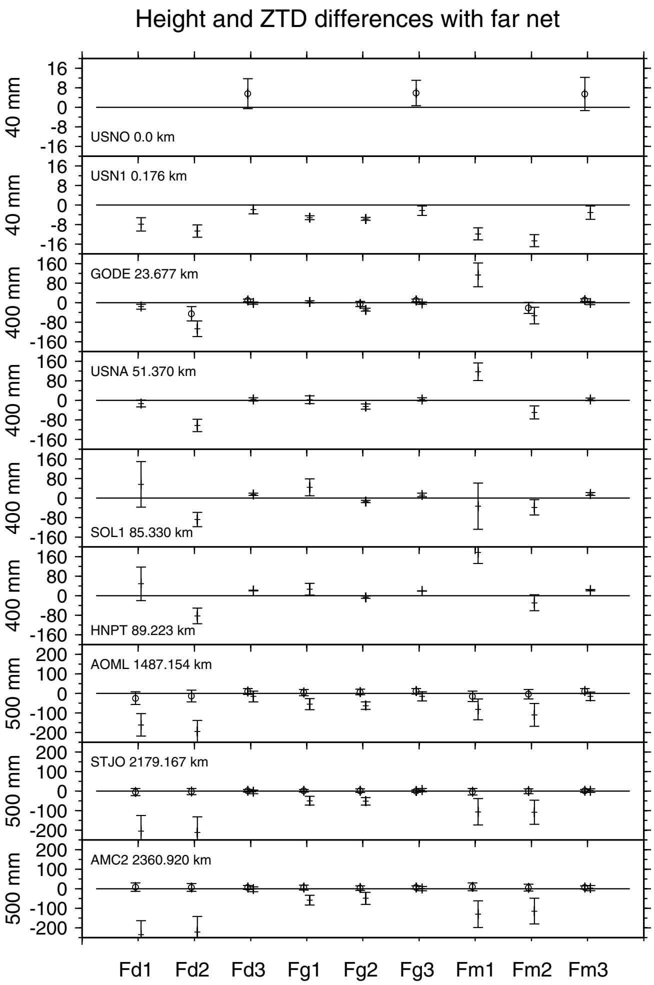

Fig. 4 Height and troposphere results using the core + far networks with 24 h of data. Means and standard deviations of the local heights, indicated by + *symbols*, and ZTD differences, indicated by *circles*, are plotted with respect to the IGS combined results for week 1229. The analysis is for the 4 days 27–30 July 2003. The USNO position is held fixed for all solutions. Statistics are weighted by the formal errors of the parameter estimates. There are no IGS ZTD values for USN1, USNA, SOL1, or HNPT. The full vertical scale for each station panel (in mm) is given on the *left*

By contrast, all the other solutions, wherein tropo parameters for some stations are not adjusted, show much larger height scatter or biases or both. Evidently, the a priori ZTD error at USNO and the other stations where tropo parameters are not adjusted cannot be accommodated elsewhere in the network so the height estimates are degraded. Obviously and not surprisingly, this is not an effective strategy when distant stations are included in the network. Their presence is specifically intended to make all the ZTD parameters as observable as possible. It is probably notable, though, that the FSL grid solutions (Fg1 and Fg2) perform better than the default and met data cases when some tropo parameters are not adjusted. This is a positive indication that the a priori ZTD error at the unadjusted stations is reduced using the FSL grid, but not enough to compete with adjustment of all ZTD parameters.

With respect to the three approaches for a priori tropo information, there seems to be little difference among the Fd3, Fg3, and Fm3 tests. The height scatter is slightly better for Fd3 (default tropo model) at USN1, GODE, and SOL1, while Fm3 (measured met data) is best at USNA and Fg3 (FSL grid) is best at HNPT. These differences are probably not significant, though.

For the two core stations with IGS combined ZTD values (USNO and GODE), the PAGES ZTD solutions are biased positive when the tropo parameters are freely adjusted at all stations. The bias is ~6 mm with 6 mm of scatter at USNO and ~10 mm with 5 mm scatter at GODE. In the IGS combination itself, the NGS solution for week 1229 had a bias of 6.0 mm and scatter of 6.6 mm for GODE. So these biases are probably a reflection of the intrinsic PAGES performance more so than the solution strategies used here. Other analyses used in the IGS combination for USNO and GODE have biases between 2.7 mm and −8.2 mm, so the NGS result is not especially unusual (though the NGS scatter is highest). Nevertheless, these small biases should not affect the conclusions based on our comparative tests.

We now compare the results above with those for the core network only (in Fig. 5). The effect of not adjusting any tropo parameters is about the same as with the core + far network and is clearly not an effective strategy regardless of network design. However, adjusting all but the two very close stations (USNO and USN1) seems to give better height performances at most stations than freely adjusting all tropos. The heights of the two stations closest to USNO (USN1 and GODE) do appear biased, however, even though the scatters decrease; the height is especially biased for the Cm2 solution at USN1. There

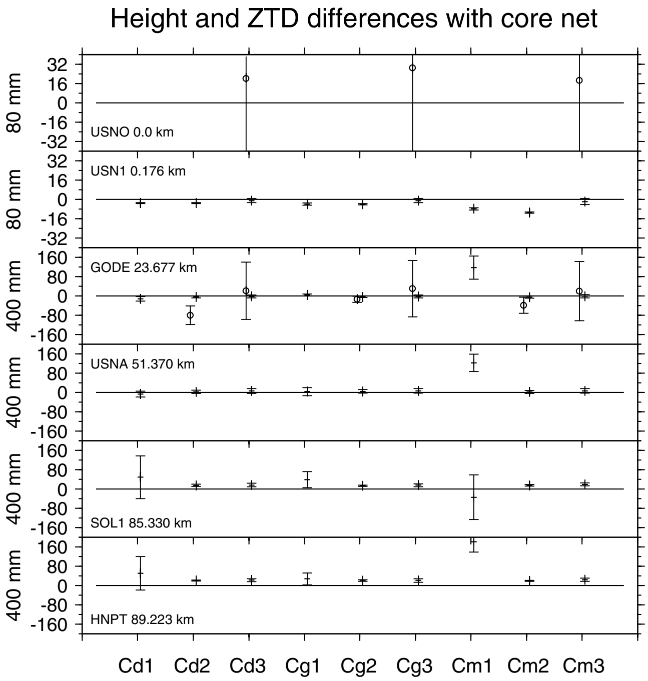

Fig. 5 Same as Fig. 4 except using core network only (with 24 h of data)

are no significant bias errors when all the tropo parameters are adjusted but the scatters are larger than when USNO and USN1 are not adjusted.

As with the core + far network, there is no obvious advantage to any particular a priori tropo model. The differences among them are minor. Clearly, though, the small network alone is not suitable to determine accurate ZTD estimates as shown by the much larger scatter in ZTD values compared to Fig. 4 and the larger differences compared to the IGS. So, when this parameter is of interest, either the network must be expanded or some other method used to improve the ZTD observability.

A further word of caution should be inserted here. Our core network uses stations all at similar ellipsoidal heights and tropospheric conditions. Results could be significantly different were these circumstances not satisfied, such as in very mountainous terrains.

6-h sessions

Some of the tests above using 24 h of data have been repeated for solutions where each day is divided into four 6-h sessions. For the core + far network, the comparisons are for the case with all tropo parameters adjusted (see Fig. 6). For the core-only network, 6-h tests have been made for the cases with all tropos adjusted and with USNO and USN1 tropos held fixed (Fig. 7).

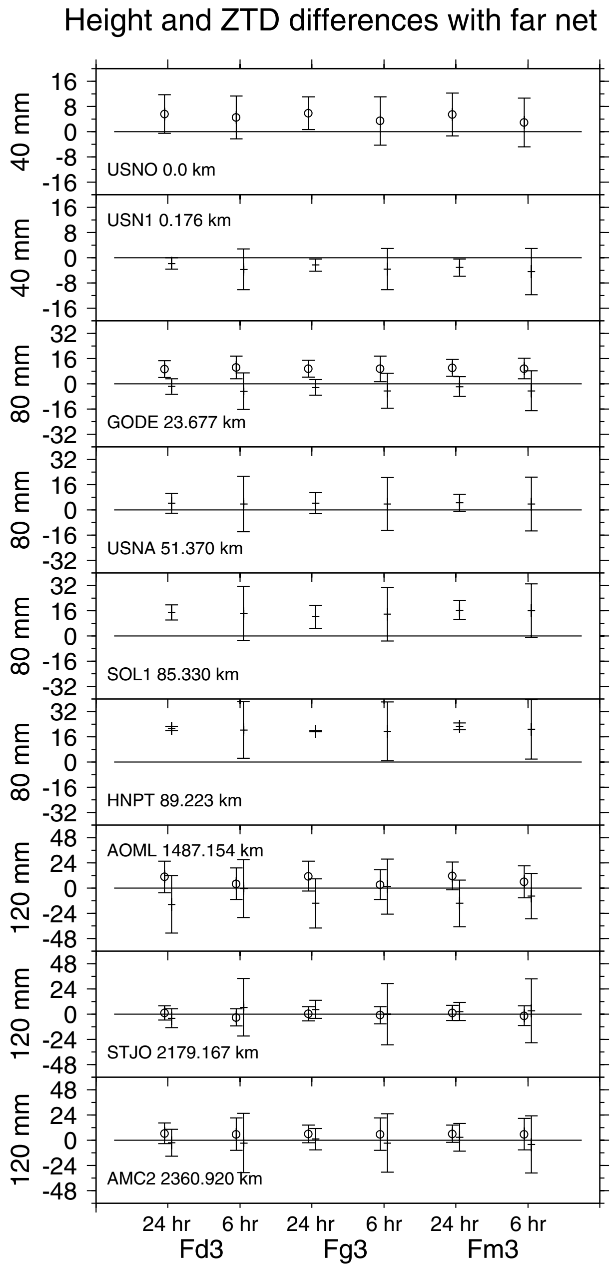

Fig. 6 Height and troposphere results using the core + far networks. Means and standard deviations of the local heights, indicated by + symbols, and ZTD differences, indicated by circles, both with respect to the IGS combined results for week 1229, are compared for 24-h (from Fig. 4) and 6-h sessions. Only scenarios with ZTD parameters adjusted at all stations are shown. The analysis is for the 4 days 27–30 July 2003. Statistics are weighted by the formal errors of the parameter estimates. There are no IGS ZTD values for USN1, USNA, SOL1, or HNPT. The full vertical scale for each station panel (in mm) is given on the *left*

Looking only at the height performances, there is little to distinguishable between the three different a priori tropo procedures for any given network and parameterization choice. As noted already, with 24 h of

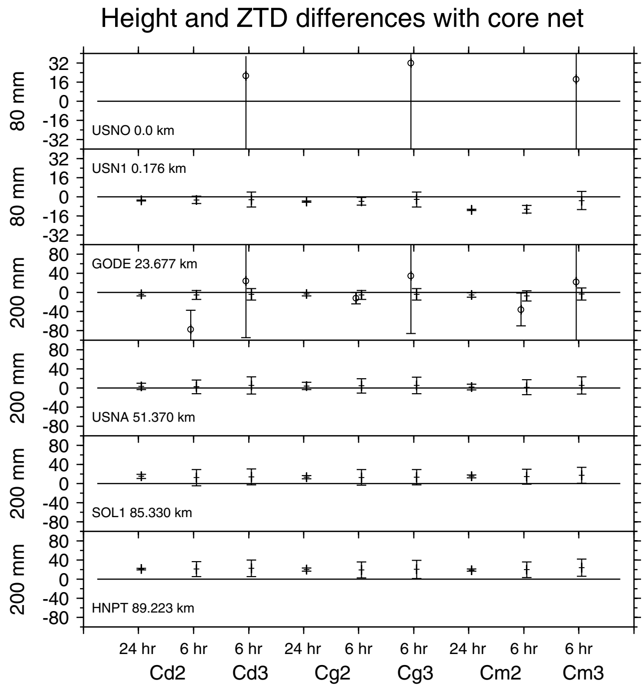

Fig. 7 Similar to Fig. 6 except using only the core network for some of the most promising ZTD parameterization scenarios

data the C-2 strategies (core network holding USNO/USN1 tropos fixed) give smaller scatter than the F-3 schemes (core + far network with all tropos adjusted) for the shortest baselines, especially USNO-USN1 (176 m separation). However, the results are somewhat biased, the more so for the shortest baselines and especially when surface met data are used. That distinction seems to be lost after about 25 km. The same general behavior applies when the session duration is reduced to 6 h except that the C-2 advantage in repeatability extends then to more than 50 km. In this case any biases are obscured by the larger noise scatter.

Theoretically, the measurement accuracy should scale as sqrt($1/T$), where T is the observing span. Our results find increases in scatter that are generally larger than the expected factor of two, sometimes much greater. To some extent this may be a matter of limited statistics, but the clear tendency is for the observed scatter to increase by more than sqrt($1/T$) would imply.

One could consider whether the addition of a priori constraints on the tropo parameters might be useful with the shorter sessions (see Background). This could indeed be beneficial for the very short USNO-USN1 baseline where the 6-h height scatters are considerably larger than any realistic expectation from a stochastic tropo model. The same would probably not be true for any of the longer baselines, though.

Conclusions

To the central question, whether measured surface met data can be used to improve geodetic performance, we find no such utility. In testing this against two other scenarios (using a default climatological model and an atmospheric assimilation model) the geodetic height differences are insignificant when tropospheric differences are adjusted in the data analysis. Even using only a relatively small network (<100 km) the differences remain very minor when tropo parameters are estimated. When some troposphere parameters are suppressed, the height repeatability can sometimes improve but at the expense of possibly biased estimates. This can be particularly true for very short baselines (under 1 km). When the duration of observing sessions is reduced from 24 h to 6 h the increase in error due to measurement noise generally obscures all other effects. Under these conditions, however, there may be some modest advantage in not adjusting tropospheres for very nearby stations, provided that care is taken of possibly larger bias errors.

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