MODIFICATIONS TO NCEP DATA

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Background

Earth-GRAM 2010 uses climatological means and standard deviations derived from a National Centers for Environmental Prediction (NCEP) global Reanalysis database, characteristics of which are discussed in the following section. As part of validation studies conducted for Earth-GRAM 2010, NCEP hourly and daily averages of surface winds and temperatures were compared with comparable statistics from more directly-observed surface winds and temperatures. During these studies, it was found that NCEP average surface winds and temperatures did not have nearly as large magnitude of variation with hour-of-day as did observed surface winds and temperatures. Consequently a more detailed study of surface and near-surface NCEP and observed winds and temperatures was undertaken.

The purpose of this write-up is twofold:

(1) To describe details of averaging and interpolation processes used for surface and near-surface NCEP winds and temperatures
(2) To describe development of and results from a methodology to adjust NCEP surface and near-surface winds and temperatures, in order to better replicate characteristics of observations, especially their diurnal variation.

Comparison of NCEP Climatology with Range Reference Atmospheres and Buoy Data

Characteristics of NCEP Data

Details of the NCEP Reanalysis database are given in documentation file README4.txt, distributed with Earth-GRAM 2010. More information about the Reanalysis project and data are available from several sources, including Kalnay et al. (1996).

As provided with GRAM, NCEP data consist of means and standard deviations (at a global latitude-longitude resolution of $2.5° \times 2.5°$) for four hours of the day (00, 06, 12, and 18 UTC), as well as for all four times-of-day combined, at the surface and at each of 17 pressure levels. Averages and standard deviations are by month, over a period-of-record from 1990 through 2008. Details are described more fully in the Appendix for how averages and standard deviations are computed from original NCEP data, available every six hours. For simplicity, also as described in the Appendix, period-of-record average, monthly-average hourly mean values are here referred to as "hourly averages", while period-of-record average, monthly-average means for all hours of the day are referred to simply as "monthly averages" or as "daily averages" (especially when being contrasted with hourly averages).

NCEP Reanalysis Data and General Circulation Model Variables

Grid-based General Circulation Models (GCMs) use numerical techniques to solve the transport equations for atmospheric momentum and energy, by computing time changes of fluxes of energy and momentum into and out of the model grid "boxes". For representing model variables, most modern GCMs use an Arakawa "C-grid" (Arakawa and Lamb, 1977), as illustrated in Figure 1. Latitude-longitude grid boxes are indexed by i (longitude) and j (latitude). Horizontal velocity components, u(i,j) and v(i,j) have a half-grid latitude-longitude offset from locations of temperature, T(i,j), or other scalar variables. This scheme simplifies model calculations of fluxes into and out of each grid box. For example, as illustrated in Figure 1, eastward wind u(i,j) is used to compute fluxes into the westward end of box i,j, while u(i+1,j) is used to compute fluxes out the eastward end of box i,j. Similarly, northward wind component v(i,j) [at different latitude-longitude than u(i,j)] is used to compute fluxes into the southward end of box i,j, and v(i,j+1) is used to compute fluxes out of the northward end of this box. Vertical ends of GCM grid boxes are usually defined at pressure levels (or "sigma" levels, where sigma = pressure divided by surface pressure). Vertical winds, w(i,j), used to compute upward and downward fluxes into and out of tops and bottoms of the Arakawa grid are not illustrated in Figure 1. Vertical wind components are also offset from the scalar variables, being evaluated at the midpoints between tops and bottoms of the grid boxes, but at the same latitude-longitude as the scalar quantities.

Unlike Arakawa-grid variables, NCEP Reanalysis data are taken to be "point variables" that are all co-located at a given latitude-longitude and pressure level. However, like GCM variables, NCEP data have been "optimized" to best represent energy and momentum flux into and out of the 2.5° NCEP grid boxes. This means that (especially for "surface" data) NCEP quantities may not correspond with locally-measured data at sites that happen to be located at an NCEP grid point. NCEP surface data are of special interest, because at the literal topographic surface of a land-surface point, vertical wind is zero (due to the solid nature of the land surface), and horizontal wind components are zero (by the "no-slip" boundary condition). In GCMs, vertical fluxes of heat and momentum through the bottom of a surface grid box are calculated by atmospheric boundary layer sub-models. However, these fluxes depend on near-surface temperature and wind. For example, under neutral stability, surface shear stress (momentum flux into the surface) is proportional to the square of wind speed at 10 m altitude (by a factor depending on surface roughness). In NCEP data processing, skin temperature is determined diagnostically as the temperature required to balance heat fluxes at the surface, and temperature at 2 m is interpolated between skin temperature and the bottom sigma-layer.

There are actually two different types of "surface" data in the NCEP Reanalysis climatology: (1) values on the 0.995 sigma level (pressure = 0.995 times surface pressure) at 2.5° lat-lon resolution grid points, and (2) temperature at 2-meters above the surface and winds at 10-meters above the surface, evaluated on a 192 × 94 "T62" Gaussian grid (Kanamitsu et al., 2002). For simplicity of the interpolation schemes that it employs, Earth-GRAM 2010 uses "surface" variables from the 2.5° NCEP grid at the 0.995 sigma level.

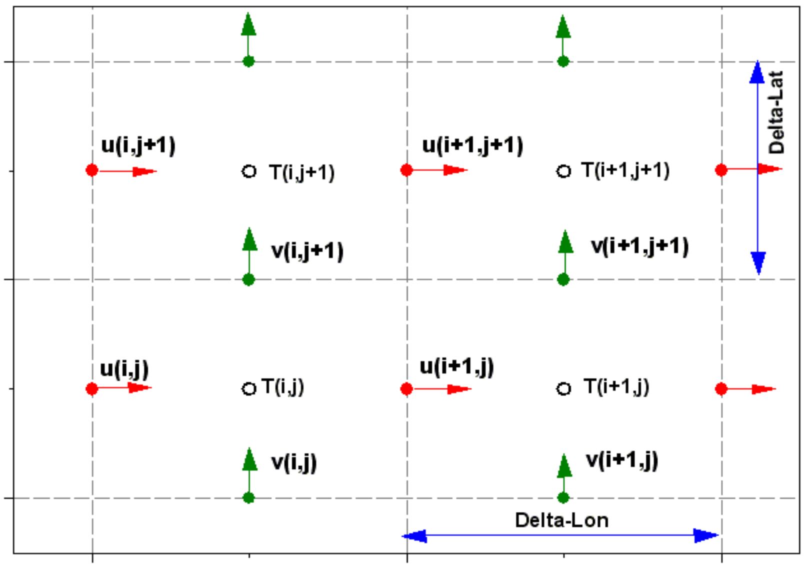

Figure 1- Schematic of lat-lon gridded variables from an Arakawa C-grid.

Representation of Surface Altitude in Earth-GRAM 2010

Figures 2 and 3 show that surface topographic altitude can be quite variable, even at high spatial resolution. With its 2.5° global grid resolution, NCEP data provide only a crude approximation to the true variability of surface topography. As a means of providing somewhat better resolution, while still maintaining manageable data file sizes, a 1°-by-1° surface topography data set (Gates and Nelson 1975) is employed in Earth-GRAM 2010. Surface altitudes from NCEP, treated as "point values" at the same lat-lon grid points as the NCEP data, are derived for GRAM (by hydrostatics, using surface pressure information) from NCEP geopotential altitude values at near-surface pressure levels. Topographic altitudes from Gates and Nelson, are treated as "point values" at the center of integer-valued, 1°-by-1° grid boxes.

Figure 4 provides an example (at longitude 120°W) of NCEP "surface" (pressure level 1) altitude at 2.5° grid resolution (dashed line), and GRAM topography at 1° resolution (solid line, interpolated between values at 119.5°W and 120.5°W). This figure also gives results of GRAM height-latitude interpolation of NCEP January average temperature, between NCEP grid points at 35.0°N and 37.5°N, along 120°W. Numbered dots at the left and right of this figure indicate altitudes for pressure levels 0 through 4 from the GRAM NCEP daily- average data. Sea level (pressure level 0) values are derived from hydrostatic extrapolation of near-surface NCEP data. Note that, as illustrated in Figure 4, the NCEP database provides globally-complete values at all pressures, such as level 2 (1000 mb), even when these levels are below the local NCEP "surface" altitude. Also note that, since the 1°-resolution topography data are treated as "point values" at the center of integer-valued, 1°-by-1° grid boxes, data values in Figure 4 are at 35.5°, 36.5°, and 37.5°, with linearly-interpolated topography between these points.

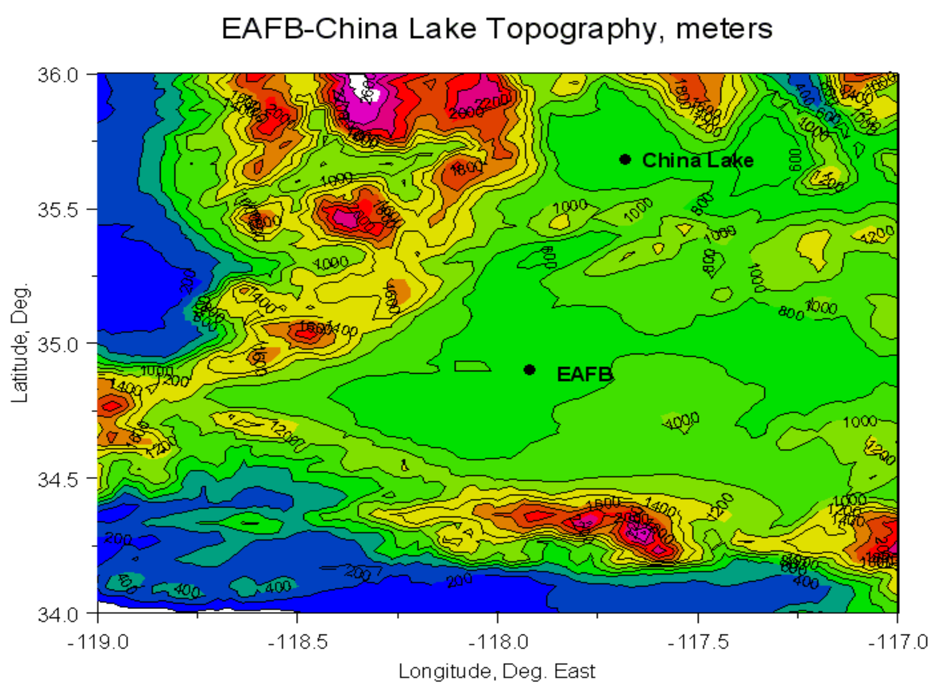

Figure 2 – Topographic surface altitude above mean sea-level, versus longitude and geodetic latitude (at 0.033° resolution) near Edwards Air Force Base (EAFB) and China Lake., CA

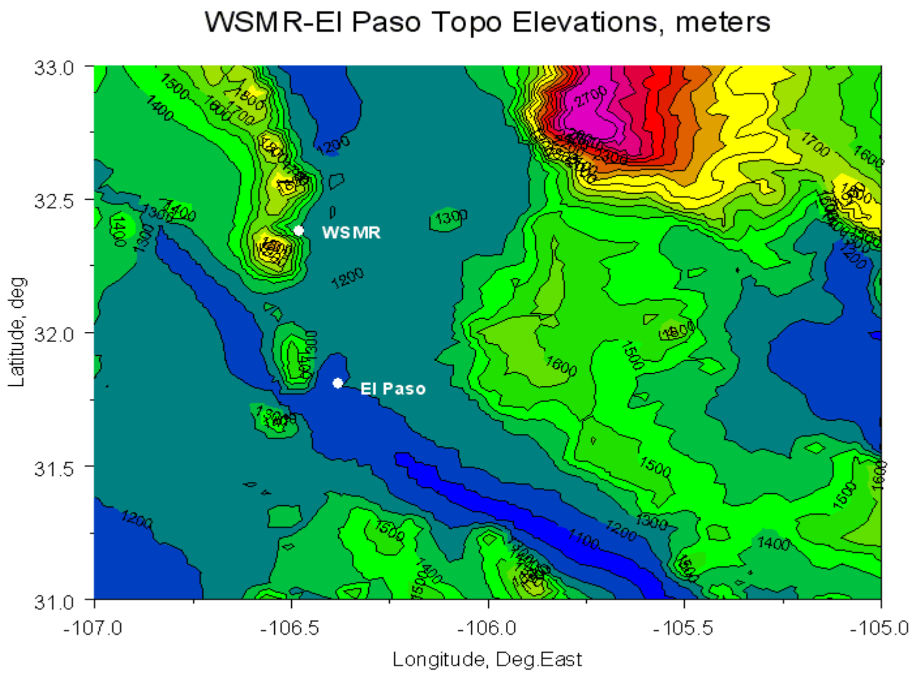

Figure 3 – As in Figure 2, near White Sands Missile Range (WSMR) and El Paso (Santa Teresa), TX.

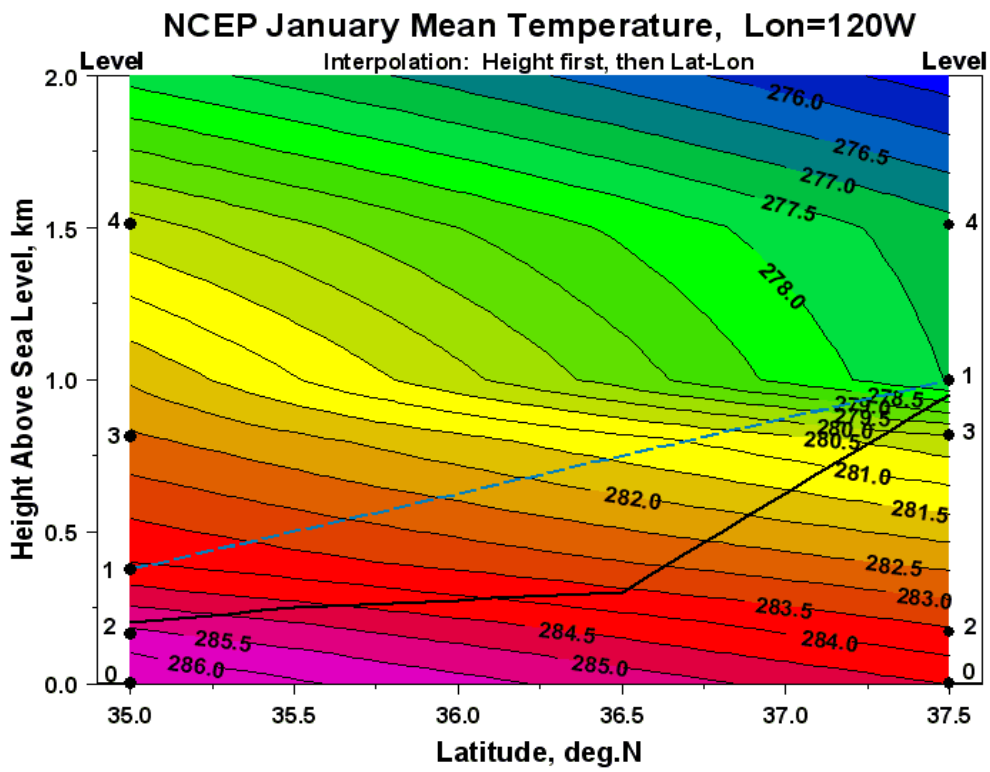

Figure 4 – NCEP "surface" (pressure level 1) at 2.5° grid resolution (dashed line), interpolated GRAM topography at 1° resolution (solid line), and interpolation of NCEP January average temperature.

In order to more quantitatively illustrate how NCEP data (especially surface values) are used in the height-lat-lon interpolation process, Table 1 gives values of NCEP January daily-average temperature at the grid locations on the left and right of Figure 4, as a function of pressure level or altitude (numbered dots on the left and right of Figure 4). Level 0 in Table 1 is (extrapolated) sea-level, and level 1 is NCEP "surface" level. GRAM-interpolated temperature values are shown as contours in Figure 4. This interpolation is done first on altitude (by vertical interpolation between values in a given column of Table 1), and then on latitude-longitude (e.g. between values at 35.0°N and 37.5°N, in this example).

Table 1 - NCEP values of pressure, geopotential altitude, and January monthly-average temperature for grid points at the left and right of Figure 4 (at Longitude 120°W). Level 0 is (extrapolated) sea-level, and level 1 is NCEP "surface" level.

	Latitude = 35.0°N			Latitude = 37.5°N		
Pressure Level	Pressure (mb)	Altitude (m)	Temperature (K)	Pressure (mb)	Altitude (m)	Temperature (K)
0	1019.58	0	286.5	1020.83	0	284.5
1	974.75	375	284.1	904.25	997	277.5
2	1000	162	285.7	1000	170	283.6
3	925	812	282.6	925	816	280.1
4	850	1511	280.2	850	1507	277.2

NCEP versus Range Reference Atmospheres (Daily Data)

For 21 selected locations (mostly NASA or Air Force test ranges), Earth-GRAM 2010 provides an alternate to NCEP climatology, in the form of Range Reference Atmosphere (RRA) profiles. These data contain only monthly-average "daily" averages and standard deviations (i.e. no information from individual hours of the day, as with NCEP). The RRA data are described in detail in file README5.txt, distributed with Earth-GRAM 2010.

Temperature and wind speed data from NCEP daily averages for various months were compared with monthly-average profiles from 17 of the RRA sites. Excluded from this analysis were four "island" RRA sites (Ascension, Barking Sands, Kwajalein, and Taguac), because of possible cross-contamination between water-surface and land-surface characteristics.

Figure 5 gives a scatter plot of January average RRA wind speed, from the 17 sites examined, versus January average NCEP wind speed, evaluated (by interpolation) at each RRA site location. This graph shows wind speeds from the RRA site surface to 16 km altitude. Figure 6 presents a similar plot for January average temperature. These two graphs show that there is no significant bias error between NCEP and RRA values for either temperature or wind speed.

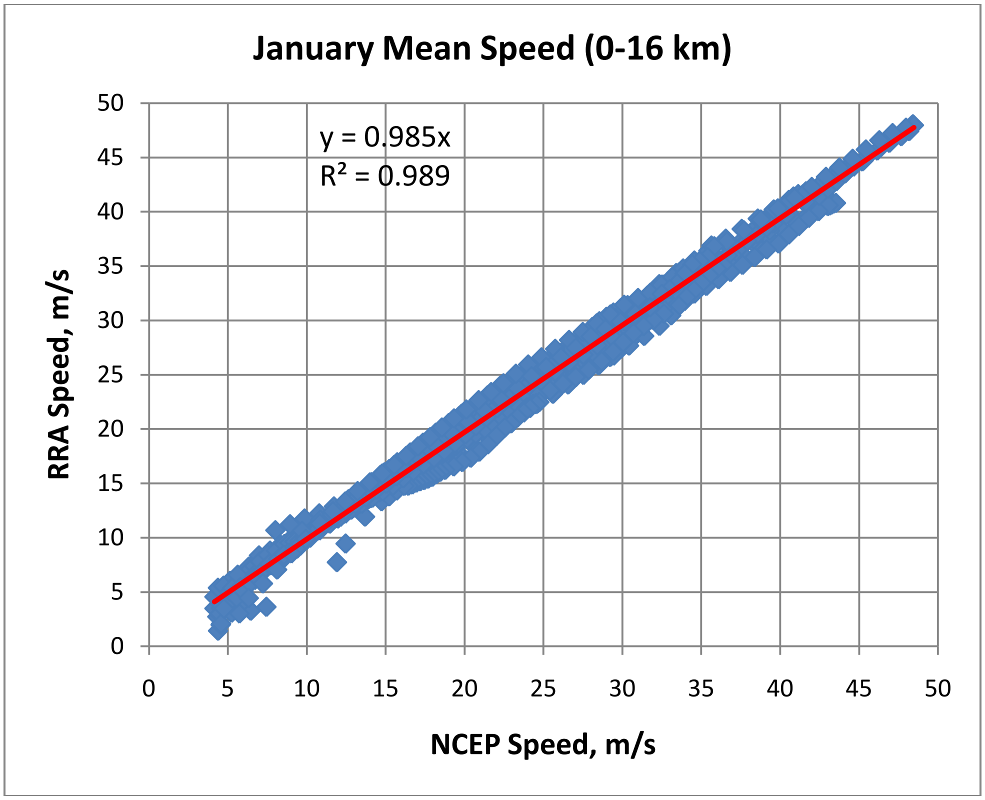

Figure 5 – January mean wind speed (at altitudes from the surface to 16 km) from 17 RRA sites, versus comparable NCEP wind speeds, evaluated by interpolation to the RRA site locations and altitudes.

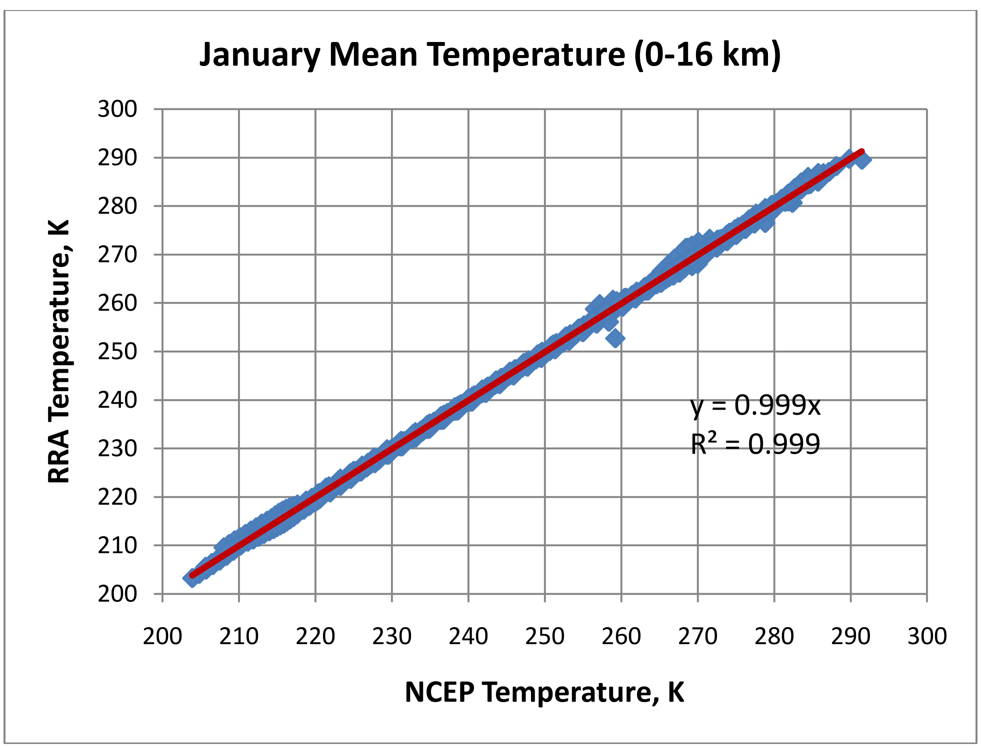

Figure 6 – As in Figure 5 for January average temperatures

Surface altitude at a given RRA site is the altitude (above mean sea level) of the actual local topographic surface. As shown by Figures 2 through 4, this may differ significantly from the 1°-by-1° topographic surface altitude in the GRAM database. For this reason, a more detailed comparison was made between monthly-average, near-surface RRA values of wind speed and temperature and monthly-average GRAM values interpolated to RRA surface altitude from the NCEP data. Ratios of RRA to NCEP monthly surface wind speed values were averaged over several months examined, and the results for average wind speed ratio are plotted in Figure 7. This figure indicates a significant tendency of the NCEP surface winds to overestimate the true (RRA) surface winds. The red trend line in this figure is given by

$$\text{RRA surface wind} = (0.634 + 0.205 \times \text{RRA site elevation}) \times \text{NCEP surface wind} \quad . \tag{1}$$

For consistency between means and standard deviations of the wind components [$\langle u \rangle$, $\sigma(u)$, $\langle v \rangle$, and $\sigma(v)$] and the mean and standard deviation for wind speed [$\langle S \rangle$ and $\sigma(S)$], the factor given by the term in parentheses in equation (1) must be applied to all of these statistics. Angle brackets around a quantity x ($\langle x \rangle$) are used to indicate the average of x, while $\sigma(x)$ indicates the standard deviation of x about its average value. That a common factor on all the wind statistics preserves consistency is easily seen from the fact that a given wind speed value S is related to wind components u and v by

$$S^2 = u^2 + v^2 \quad , \tag{2}$$

and taking an average of equation (2) leads to the result

$$\langle S \rangle^2 + \sigma(S)^2 = \langle u \rangle^2 + \sigma(u)^2 + \langle v \rangle^2 + \sigma(v)^2 \tag{3}$$

[compare Appendix equation (A7)]. Any common factor applied to all the means and standard deviations in equation (3) leaves this equation unchanged.

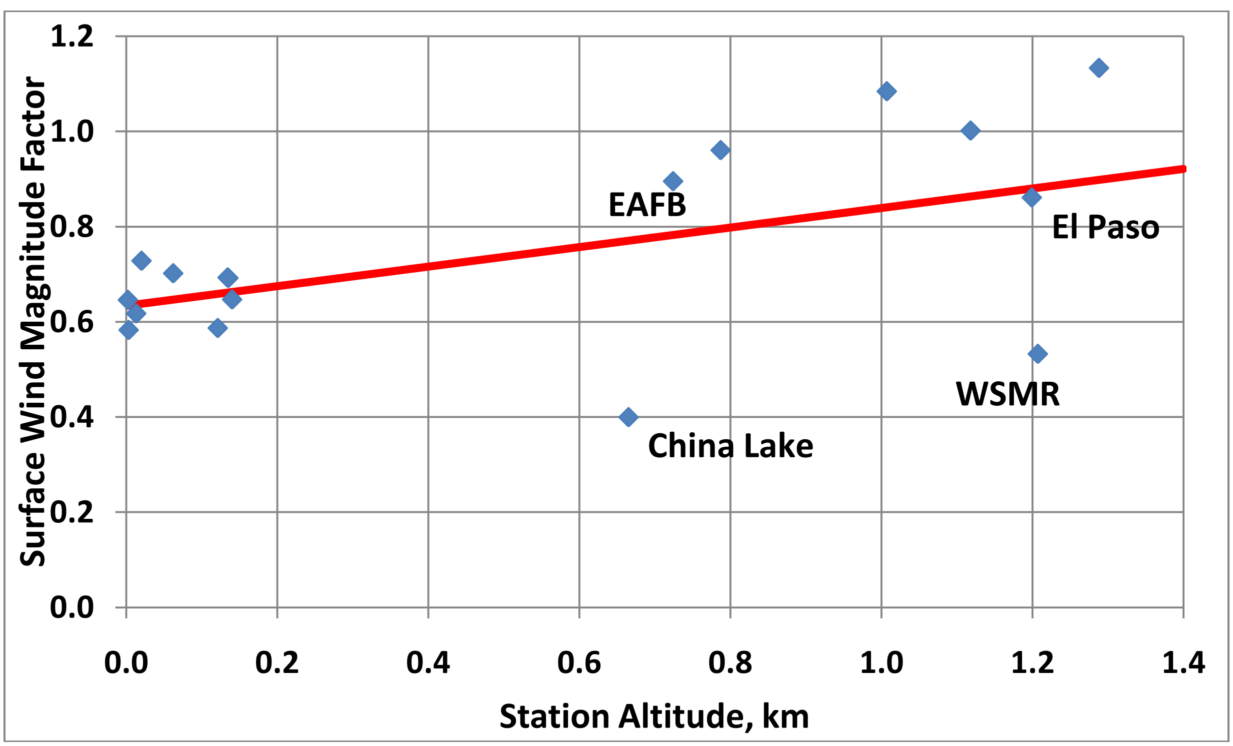

Figure 7 – Average ratio of RRA surface wind speed to NCEP wind speed evaluated at the RRA surface altitude. Red trend line is given by equation (1).

In Figure 7, the wind speed factor for China Lake is seen to be significantly lower than the factor for nearby Edwards Air Force Base (EAFB). This might be due to the fact that China Lake could be significantly more affected by local topography than EAFB (see Figure 2). It is also likely that the NCEP period-of-record (1990-2008) yields significantly different results than the China Lake RRA period-of-record (1948-2000). Some instrumental problems are known to exist in pre-1990 data, which may adversely influence the China Lake RRA data. A similar situation exists for the different results between nearby sites El Paso and White Sands Missile Range (WSMR) in Figure 7. WSMR RRA has a period-of-record 1949-1993. Figure 3 also shows that WSMR may be more affected by local topography than nearby El Paso.

Figure 8 shows results from a comparable study of RRA surface temperature at the 17 land-surface RRA sites, versus surface temperature interpolated from NCEP data to RRA surface altitude. This figure indicates that, unlike wind speed results in Figure 7, there is no significant bias between surface RRA temperature and NCEP surface temperature (the ratio RRA/NCEP is uniformly close to 1.0). It should be noted, however, that China Lake is also a significant "outlier" in Figure 8, with a much lower temperature ratio than that for nearby EAFB.

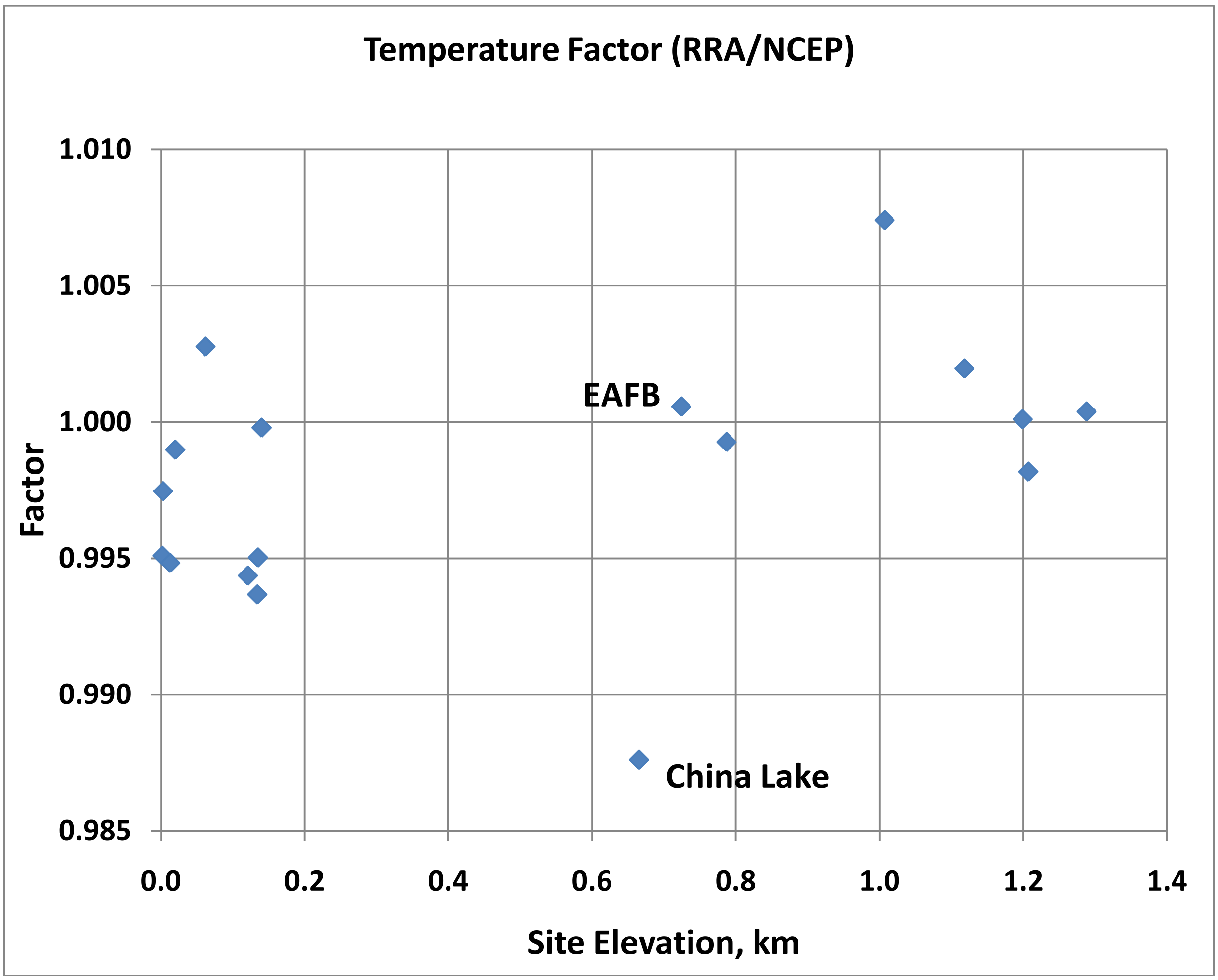

Figure 8 – Average ratio of RRA surface temperature to NCEP temperature evaluated at the RRA surface altitude.

NCEP versus Buoy Data (Daily and Diurnal)

To assess NCEP data at water-surface locations, a data set was examined from 14 Tropical Atmosphere Ocean (TAO) buoy sites and 9 National Data Buoy Center (NDBC) sites. The TAO array (McPhaden et al., 1988) covers a region of the Pacific Ocean between latitudes 8°S and 8°N and between longitudes 135°E and 95°W. Buoy sites selected from the NDBC array (Gilhousen, 1987) were off both the East coast and West coast of the United States.

Figures 9 and 10 show results from 276 values (23 buoy sites times 12 months) of monthly average buoy data versus monthly average NCEP data for both surface wind speed and surface air temperature. Both of these graphs show very little systematic bias error between NCEP data and buoy observations (slopes very near 1.0 in both graphs).

Ocean water surfaces have very large heat capacity and therefore are expected to have very little thermal response of monthly-average hourly temperature to diurnal variations in solar heating. For the 23 buoy sites examined, this was found to be the case, with variability in monthly-average hourly-mean temperature being no more than a fraction of a degree. Diurnal variation in monthly average hourly-mean wind speed was also found to be small, about ±0.3 m/s for the TAO sites and about ±0.7 m/s for the NDBC locations.

On the basis of these results, no need for NCEP adjustment is perceived to be required for either daily-averages or hourly-averages for either wind speed or air temperature at water-surface NCEP grid locations.

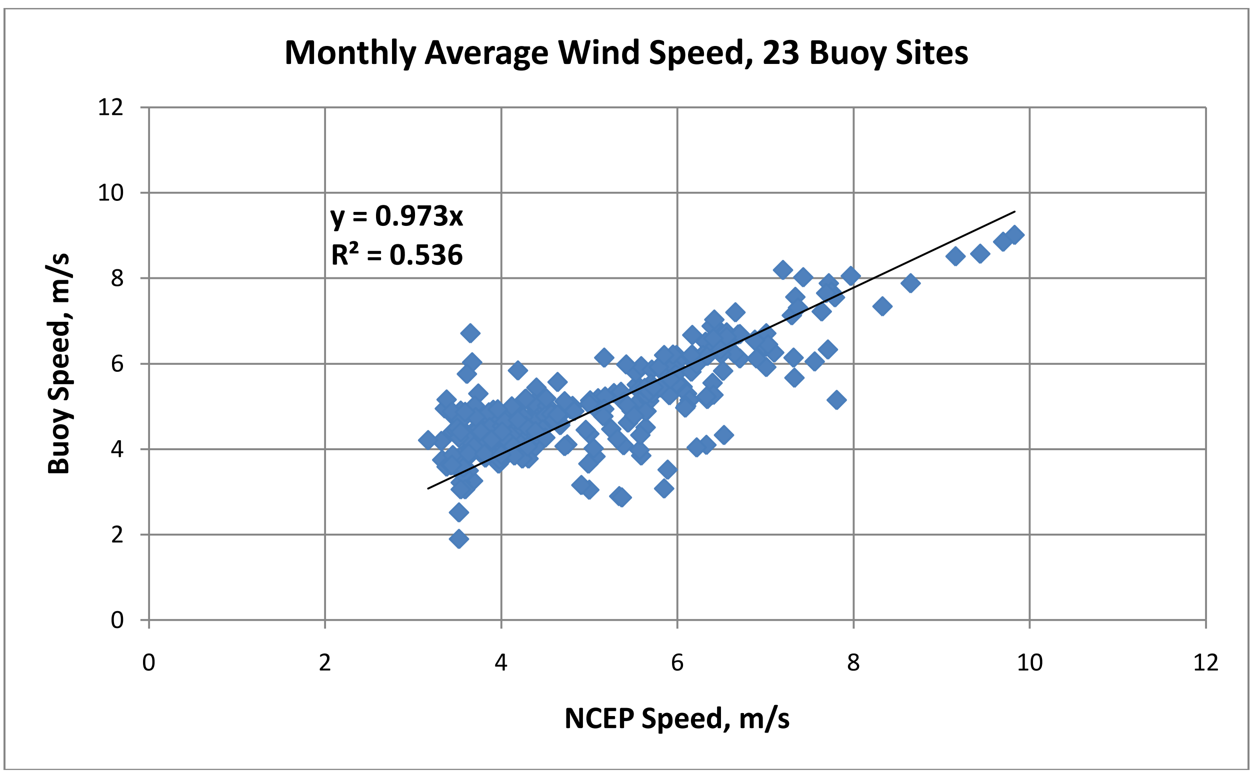

Figure 9 - Monthly average buoy wind speed versus monthly average NCEP wind speed from 23 buoy locations.

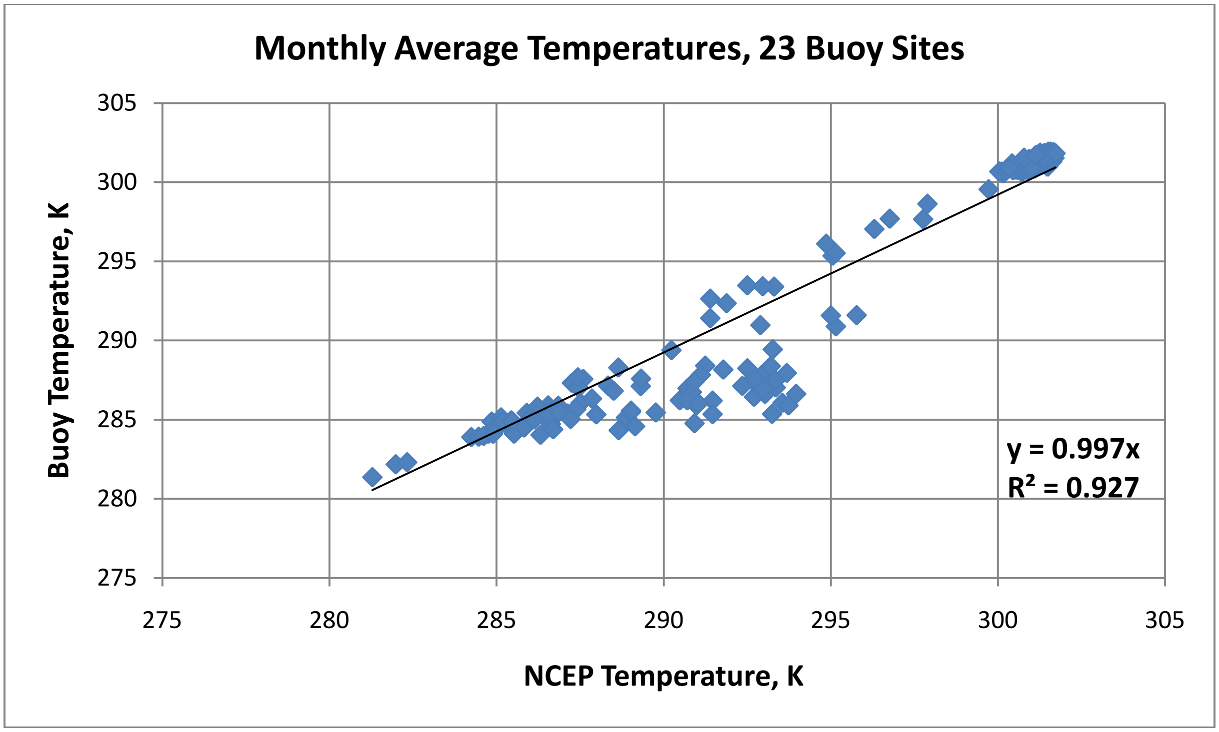

Figure 10 – As in Figure 9, for monthly average temperature.

Land-Surface Diurnal Data

Since the land-surface Range Reference Atmosphere (RRA) data examined earlier did not include diurnal variations of hourly-mean wind speed or temperature, these factors for near-surface data had to be examined by using specially-collected data. To this end, multi-year period-of-record, hourly wind and temperature data were assembled from Cape Canaveral, Edwards Air Force Base (EAFB), and White Sands Missile Range (WSMR). Two data sets were used from Cape Canaveral – one from a small tower at the Shuttle Landing Facility (SLF) site, and one from the 54-foot (16.5 m) height on Kennedy Space Center Tower 313.

From each of these four data sets, and for each month, ratios of period-of-record average monthly-average hourly-mean values and daily-mean values were evaluated. Ratios of hourly-average to daily-average, by local hour of the day, were averaged across the data sets to produce a "Universal Diurnal Factor" (UDF) curve. Standard deviations about the UDF averages give a sense of the variability of UDF values among the four data sets and 12 months examined. UDF data values for wind speed are shown in Figure 11, and for temperature are given in Figure 12. Red lines in these figures show least squares fits to these UDF data points, with both diurnal and semi-diurnal harmonics represented in the UDF analytical curves. The UDF curve for wind speed, $UDF_S(H)$, is given by

$$UDF_S(H) = 1.0 + 0.3525217 \bullet \mathrm{Cos}((\pi H/12) - 3.727402) + 0.0944736 \bullet \mathrm{Cos}((\pi H/6) - 0.593014) \quad , \qquad (4)$$

while UDF_T (H), for temperature, is given by

$$UDF_T(H) = 1.0 + 0.0174553 \bullet \mathrm{Cos}((\pi H/12) - 3.714795) + 0.0040833 \bullet \mathrm{Cos}((\pi H/6) - 0.204262) \quad , \qquad (5)$$

where H is local time, in hours (determined strictly from local longitude, not from local civil time zone). By definition, the leading term in both UDF equations is 1.0, since averaging over all hours should leave the daily average unchanged.

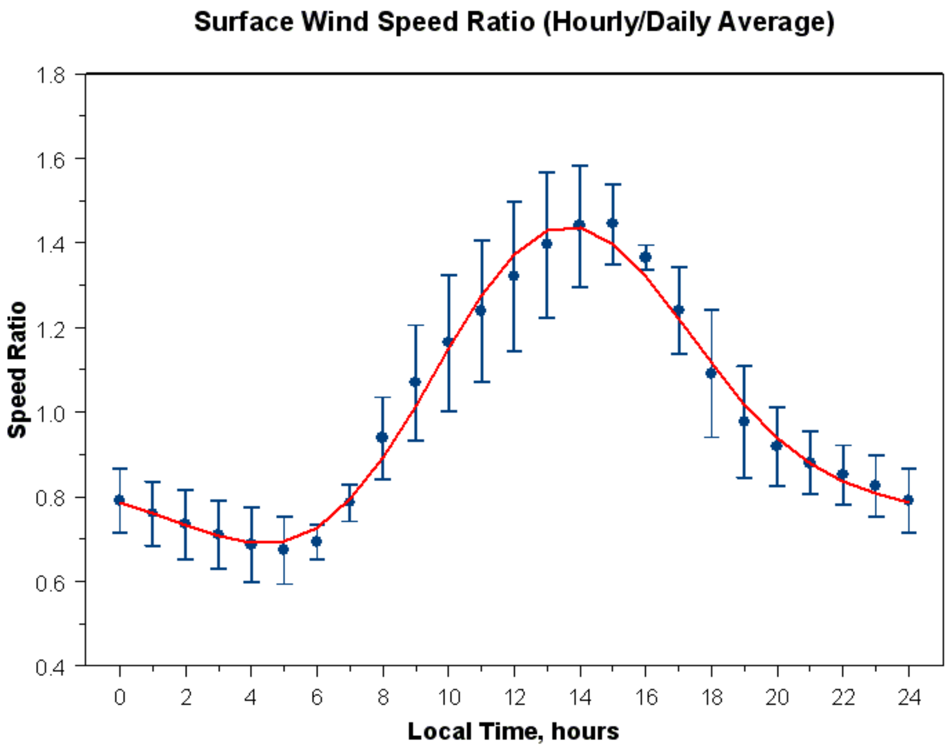

Figure 11 – Multi-site average of ratio of hourly-average wind speed to daily-average wind speed (Universal Diurnal Factor for wind speed). Red line fit to the data is given in equation (4).

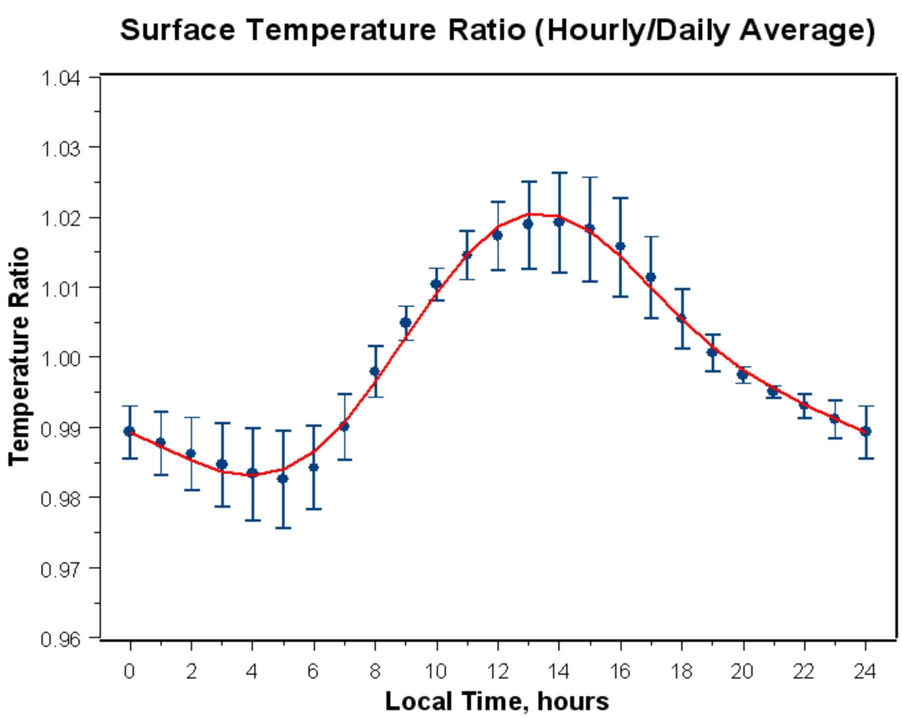

Figure 12 – Multi-site average of ratio of hourly-average temperature to daily-average temperature (Universal Diurnal Factor for temperature). Red line fit to the data is given in equation (5).

Methodology for "Fixing" Near-Surface NCEP Data

Based on study results described in the previous section, the following methodology is used to "fix" near-surface values of hourly-average and daily-average NCEP wind and temperature data. The methodology is applied (as necessary) at each 2.5°-by-2.5° NCEP grid point, for each of the 12 monthly data sets.

(1) The 1°-by-1° global surface-type data set of DeFries and Townshend (1994) is used to determine if the NCEP grid point has a water surface or land surface.
(2) For water-surface grid points, no adjustment is applied to the NCEP data for either wind or temperature.
(3) For land-surface locations, topographic altitude (h) at the NCEP grid point is determined from the 1°-by-1° global topography of Gates and Nelson (1975), and a surface wind adjustment factor, F(h) = 0.634 + 0.205 h, is computed [see factor in equation (1)]. For large h, F(h) is limited to be ≤ 1.
(4) If, for a given NCEP pressure level, the geopotential altitude, z, above the surface, is ≤ 0 then factor F(h) is used as a multiplier on the hourly-averages and standard deviations and daily-averages and standard deviations for wind speed and for both horizontal wind components [c.f. discussion of equation (3) in the previous section].
(5) If z is > 0 and z $\leq$ 500 m, then factor F is linearly interpolated between F=F(h) at z = 0 and F=1.0 (no adjustment) at z = 500 m. The factor F is then used as an adjustment multiplier on all wind statistics, as in step (4).
(6) If z > 500 m, no adjustment is applied to wind statistics.
(7) Based on longitude of the NCEP grid point, and on UTC time for the NCEP hourly-average, local time H is computed. Values of "Universal Diurnal Factors", $UDF_S(H)$, for speed, and $UDF_T(H)$, for temperature, are computed from equations (4) and (5). As for wind adjustment factor F in items (4) through (6), values of UDF are interpolated on height above the surface, z, until UDF=1 (no diurnal adjustment) at z $\geq$ 500 m.
(8) Factor $UDF_T(H)$ is used to adjust hourly average and standard deviation of temperature, as necessary, according to the procedure described in discussion of Figure 13. Atmospheric density and moisture variables are also adjusted to preserve the perfect gas law relation, based on the given hourly-average relative humidity.
(9) Factor $UDF_S(H)$ is also used, as necessary, to adjust hourly-averages and standard deviations of wind speed and both horizontal wind components, by a procedure similar to that described for temperature, in discussion of Figure 13.

Figure 13 illustrates four cases for how $UDF_T(H)$ is used to adjust hourly-average and standard deviation of surface temperature. UDF makes no adjustment in daily-average surface temperature. Note that the amplitude of the UDF variation with hour H is reduced for height above the surface, z, until UDF = 1 (no adjustment is applied) for z $\geq$ 500 m. Temperature adjustment is done according to which of the four cases happens to apply to the hourly-average surface temperature, <T(H)> (at given hour H). Here R(H) is the ratio <T(H)>/<Tday>, where <Tday> is the daily-average surface temperature.

Case 1 - $UDF_T(H) < 1$ and $R(H) > UDF_T(H)$: Adjust hourly-average <T(H)> by a factor of $UDF_T(H)/R(H)$; adjust temperature standard deviation $\sigma(H)$ by the same factor

Case 2 - $UDF_T(H) > 1$ and $R(H) \geq UDF_T(H)$: No adjustment is applied.

Case 3 – $UDF_T(H) > 1$ and $R(H) < UDF_T(H)$: Adjust <T(H)> and $\sigma(H)$ by a factor of $UDF_T(H)/R(H)$.

Case 4 – $UDF_T(H) < 1$ and $R(H) \leq UDF_T(H)$: No adjustment is applied.

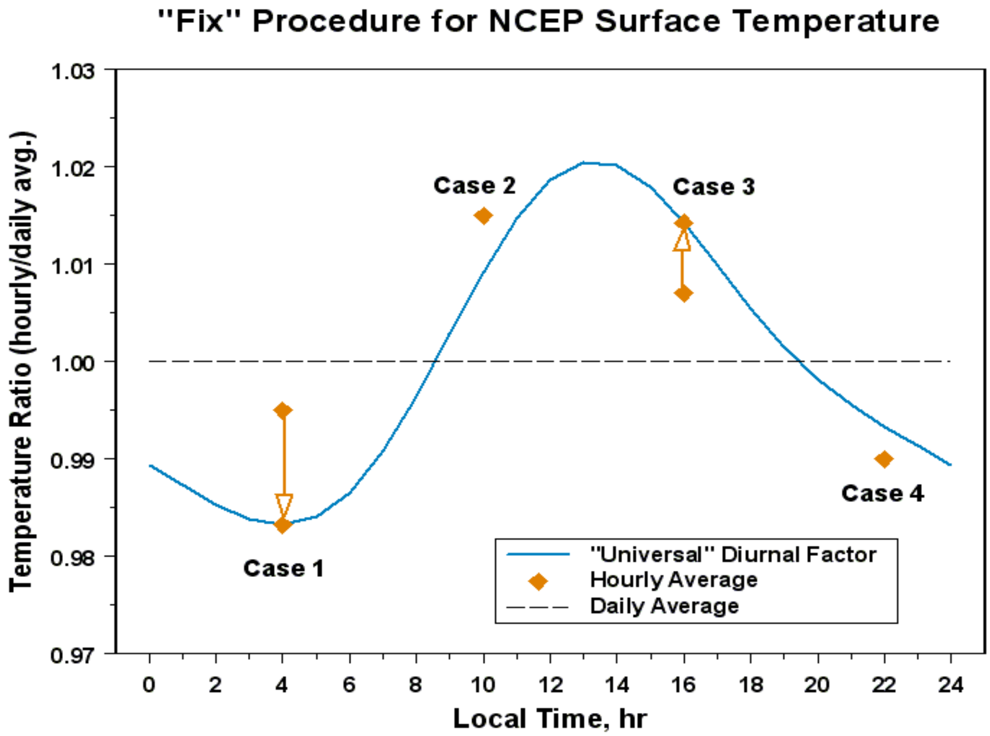

Figure 13 – Schematic of how the "Universal Diurnal Factor" for temperature is used to adjust hourly averages and standard deviations of surface temperature, for each of 4 cases.

In summary: if hourly average NCEP temperature <T(H)> deviates from the daily average by less than the amount expected from $UDF_T(H)$, then <T(H)> is adjusted until the deviation from the daily average is as expected; if <T(H)> deviates from the daily average by more than the amount expected from $UDF_T(H)$, the value of <T(H)> is assumed to be valid, and is left unchanged. To insure consistency with adjusted hourly NCEP values, the daily NCEP average value <Tday> is re-computed from the adjusted hourly values, after the hourly adjustment has been completed.

The Universal Diurnal Factor for wind speed, $UDF_S(H)$, is used in a similar fashion to adjust surface wind statistics. For wind adjustment, R(H) is the ratio <S(H)>/<Sday>, where <S(H)> is hourly-average surface wind speed and <Sday> is daily-average surface wind speed. Once an adjustment factor $UDF_S(H)/R(H)$ (other than 1.0) is determined, this factor is used to multiply both hourly-average speed and standard deviation of speed, and to multiply hourly-averages and standard deviations for both horizontal wind components [c.f. discussion of equation (3)]. UDF makes no adjustment to daily-average wind statistics.

Example Results and Validation

Figures 14-18 compare observed period-of-record average, monthly-average hourly-mean surface wind speed (for simplicity, "hourly-average" wind speed; see the Appendix) at five locations: Edwards Air Force Base (EAFB); Kennedy Space Center (KSC); Huntsville, AL; Yuma, AZ; and White Sands Missile Range (WSMR). Except for WSMR, periods-of-record for the observed data are similar to the period-of-record for NCEP data (1990-2008). For WSMR data, the period-of-record is 1990-1998. Earth-GRAM 2010 output values for hourly-average surface wind speed and standard deviation at the four NCEP UTC times (expressed as local time at each site) are shown by the data points and "error bars", connected by a dashed line. For the GRAM output, near-surface NCEP data were employed, after having been "fixed" by the procedure discussed in the previous section. For comparison, original NCEP data values are also shown.

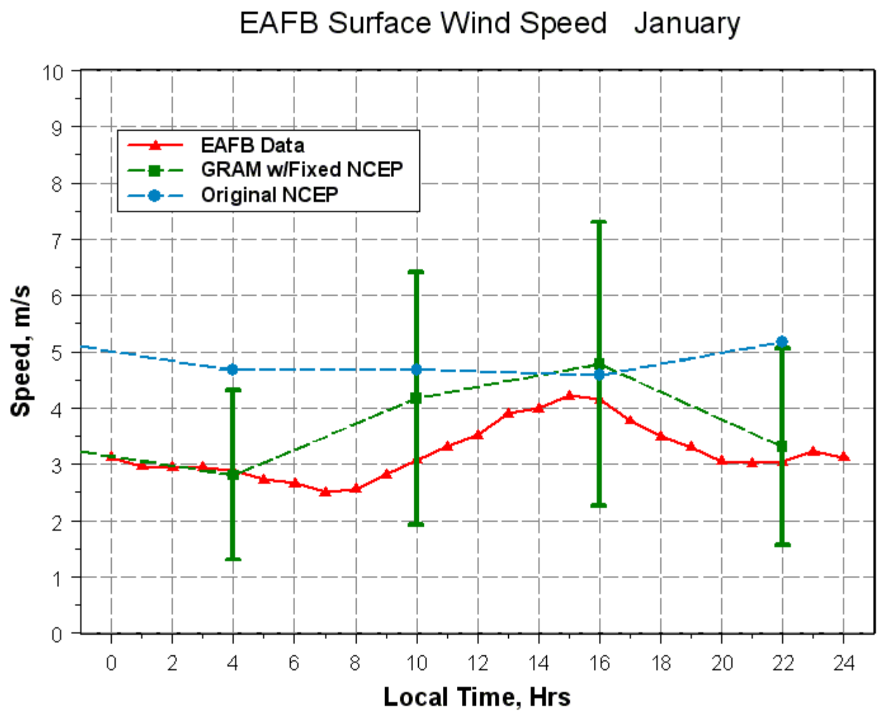

Figure 14 – Observed diurnal variation of January hourly-average surface wind at EAFB, compared with GRAM-calculated January hourly-average and standard deviation of surface wind speed, at the four available times-of-day. NCEP near-surface data "fixed" by the process described in the previous section, were used for the GRAM calculations (dashed line and 1-sigma "error bars"), while original NCEP data are shown as dashed line and solid dots.

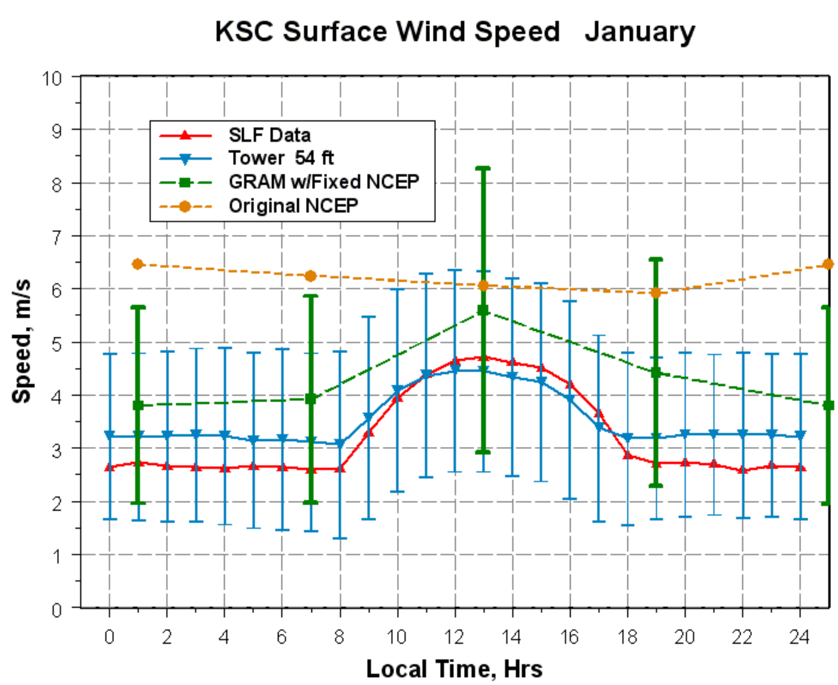

Figure 15 – As in Figure 14 for Kennedy Space Center. Observed data are shown from both Tower 313 and the Shuttle Landing Facility (SLF) .

Figures 14, 16, and 17 show good agreement between measured and modeled ("fixed") data both for daily-average wind speed [as adjusted by the factor given in equation (1)] and for diurnal variation of the hourly-average wind speed [as adjusted by $UDF_S(H)$, given in equation (4)].

In Figure 15, "fixed" NCEP surface winds have about the right amplitude of diurnal variation, but the NCEP daily-average wind speed is still somewhat larger than observed. This results from the fact that one of the four NCEP grid point locations surrounding KSC is a water-surface site (in the Atlantic Ocean). NCEP winds at this grid location are not adjusted downward, as are the winds at the other three (land-surface) NCEP grid locations surrounding KSC. Even after GRAM does horizontal interpolation to the lat-lon of KSC, GRAM output winds at KSC are still "contaminated" somewhat by this nearby water-surface grid point.

Figure 18 also shows that "fixed" NCEP model winds at WSMR agree well with observed magnitude of diurnal variation, but the model value for daily-average wind speed is significantly higher than observed. This is because the model adjustment factor given in equation (1) and shown in Figure 7, significantly overestimates winds for WSMR (see WSMR data point in Figure 7). At the nearby El Paso site (see Figure 3), there is much better agreement between January daily-average values from observations and "fixed" NCEP data. El Paso January daily-average wind speed, from the observed hourly data, is 3.9 m/s; For January El Paso RRA data, it is 3.5 m/s; and for "fixed" NCEP data, it is 4.4 m/s.

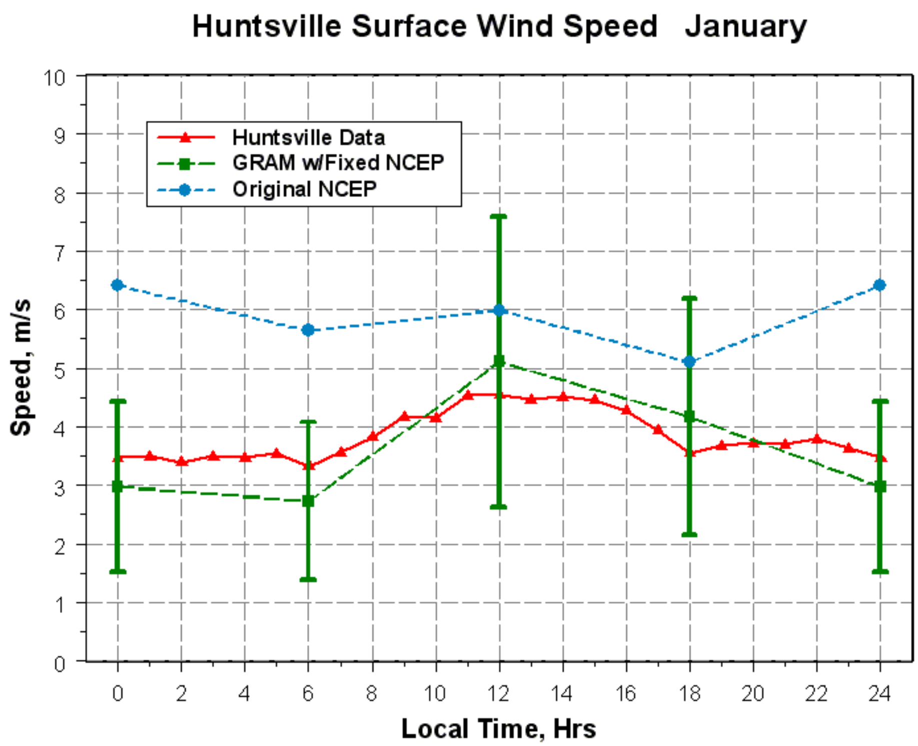

Figure 16 – As in Figure 14, for observed and GRAM-modeled winds for Huntsville, AL International Airport.

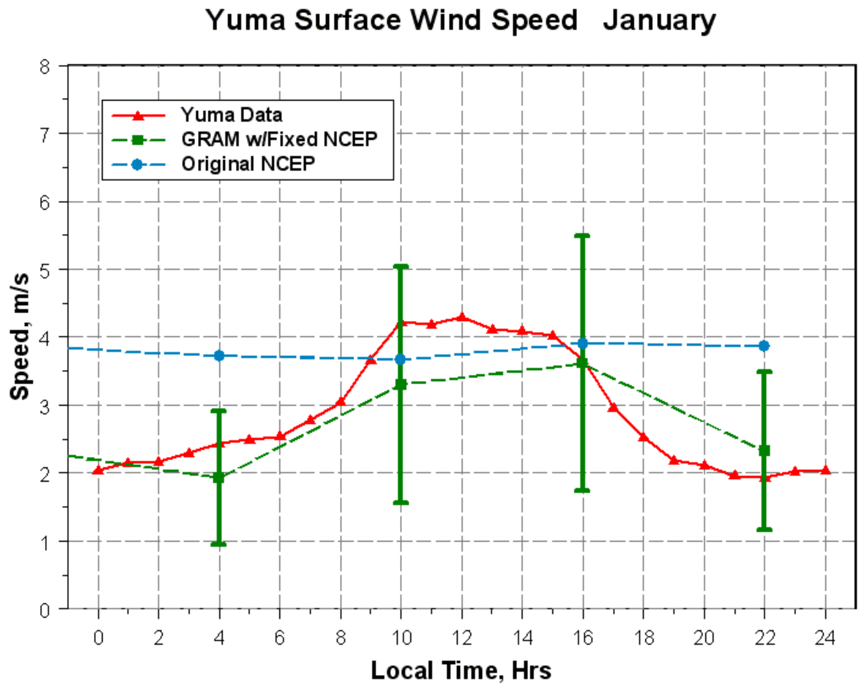

Figure 17 – As in Figure 14, for observed and GRAM-modeled winds for Yuma Proving Ground, AZ.

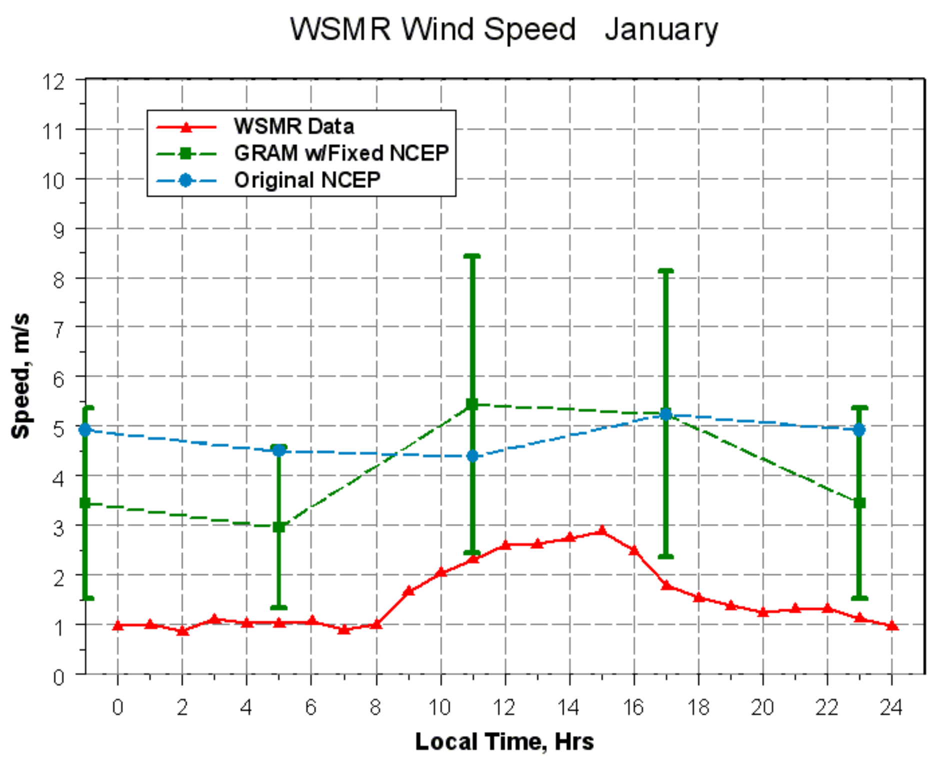

Figure 18 – As in Figure 14, for observed and GRAM-modeled winds for White Sands Missile Range.

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Appendix – Averaging Procedure Methodology and Nomenclature

NCEP data are available globally (at a latitude-longitude resolution of $2.5° \times 2.5°$) every six hours (00, 06, 12, and 18 UTC), at the surface and at each of 17 pressure levels. For details, see file README4.txt, distributed with Earth-GRAM 2010. NCEP values over a period-of-record consisting of years 1980 through 2008 were used to compute averages and standard deviations, by month, at each grid location and pressure level, for each time-of-day. Averages and standard deviations were also computed for all data, regardless of time-of-day. Details of the procedures for computing these averages and standard deviations are given in the following. As a specific example, the procedure applied to temperature is described. Similar averaging procedures were applied to all variables (wind components, wind speed, density, etc.).

Let T(y,m,d,h) be NCEP temperature at a given latitude-longitude grid point and pressure level, for year=y, month=m, day=d, and hour=h (with h=00, 06, 12,or 18). Period-of-record years y range from y1=1980 through y2=2008. Period-of-record monthly-mean hourly-average temperature, Tav(m,h), is computed from

$$\mathrm{Tav}(m,h) = \sum_{y=y1}^{y2} \sum_{d=1}^{n} T(y,m,d,h) \ / \ N \qquad \text{(A1)}$$

where n is the number of days in month m, and N is the total number of data values in the summation. If there are no missing data, then N = (1 + y2 – y1) • n. For simplicity, Tav(m,h) is here referred to as the “hourly-average temperature for month m and hour h”, or more simply as the “hourly-average” temperature.

Period-of-record monthly-average temperature, Tav(m), for month m and all data (all available hours of day), is given by

y2 n 18

$$Tav(m) = \sum_{y=y1} \sum_{d=1} \sum_{h=0} T(y,m,d,h) \ / \ (4\ N) \quad . \qquad (A2)$$

A “daily mean” temperature, Tday(y,m,d), for each year, month, and day could be computed from the four available hours of the given day by

$$Tday(y,m,d) = \sum_{h=0}^{18} T(y,m,d,h) \ / \ 4 \quad . \qquad (A3)$$

Thus, equation (A2) can equally be expressed as

$$Tav(m) = \sum_{y=y1}^{y2} \sum_{d=1}^{n} Tday(y,m,d) \ / \ N \quad . \qquad (A4)$$

Therefore, Tav(m), is the equivalent of the period-of-record monthly-average daily-mean temperature for month m. For simplicity, Tav(m) is here referred to as the “daily-average temperature for month m”, or more simply as the “monthly-average” temperature or the “daily-average” temperature (especially when contrasting it with the “hourly-average” temperature).

Standard deviation of any quantity, such as temperature, is the root-mean-square deviation of the individual values about the mean value. Therefore, the temperature standard deviation, Tsd(m,h), for month m and hour h is given by

$$Tsd(m,h) = \left[\sum_{y=y1}^{y2} \sum_{d=1}^{n} [\ T(y,m,d,h) - Tav(m,h)\ ]^2 \ / \ N \ \right]^{1/2} \quad , \qquad (A5)$$

and temperature standard deviation, Tsd(m), for month m and all hours-of-day, is given by

$$Tsd(m) = \left[\sum_{y=y1}^{y2} \sum_{d=1}^{n} \sum_{h=0}^{18} [\ T(y,m,d,h) - Tav(m)\ ]^2 \ / \ (4\ N) \ \right]^{1/2} \quad . \qquad (A6)$$

In practice, standard deviations are computed from the square root of the variance, and the mathematical identity is used that the variance of T is the mean-square T minus the square of the mean of T, that is

$$Tsd = [\ \Sigma\ T^2 / N - (\ \Sigma\ T / N\ )^2\ ]^{1/2} \quad . \qquad (A7)$$

This approach allows averages and standard deviations to be computed from running sums of values and sums of squares of values (Σ T and Σ T^2), rather than first having to compute averages, then to re-compute root-mean-square deviations from the averages, as expressed in equations (A5) and (A6).