US Total Electron Content (US-TEC) Text Files Explanation

All Files:

The header text lines begin with either a colon (:) or a pound sign (#). The header contains metadata on product name, creation time, units, source, missing data, end of record identifier, time range, and cadence. The product filename includes the begin date/time (UTC) of each product run in the format of yyyyMMddhhmm_filename.txt. Where yyyy = 4-digit year, MM = 2-digit month, dd = 2-digit day, hh = 2-digit hour, and mm = 2-digit minute. The product run interval is 15 minutes and is indicated by the Time Range field in the header.

Note: The data files cover regions outside of the CONUS where no real-time data is available. Values outside the CONUS have larger uncertainty and should be treated with caution.
Note also that the product has not been operating in real-time through many extreme storm events so the TEC estimates should again be treated with caution.

Vertical and Slant TEC:

yyyyMMddhhmm_ustec.txt contains the vertical and slant TEC. The number in the first row, first column indicates the number of GPS stations used in the calculation of this file. The first row, from second column to the last column, contains the longitude locations. The first column, from the second row to the row just before the row starting with 999xx, contains the latitude locations. The latitude and longitude values should be divided by 10 to obtain the correct values. The latitude and longitude values are written without decimals to minimize the file size. Latitude and longitude are in degrees x 10. The latitude column and longitude row are the left and top borders for a matrix containing the vertical TEC values, which are in TECU (10^16 electrons/m^2) x 10. An example of this matrix is given below.

The first value in the table after the header text provides the number of stations used in this assimilation cycle. In the example, the number of GPS stations used in this assimilation cycle is 81, the top-left number in the file. The latitude ranges from 10.0 to 16.0 degrees longitude where all positive values are in the northern hemisphere. The longitude ranges from -150.0 to -146.0 degrees, where all negative values are in the western hemisphere. The vertical TEC is found in the first array before the first line beginning with 999xx. Therefore, the TEC value at 13.0 degrees latitude and -147.0 degrees longitude is 47.0 TECU, or the TEC at 15.0 degrees latitude and -150 degrees longitude is 46.7 TECU. In this particular array, all values are in the northern and western hemispheres.

```
Vertical and Slant Path Total Electron Content
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   81 -1500 -1490 -1480 -1470 -1460
  100   479   478   478   478   479
  110   482   481   480   480   480
  120   480   478   477   477   477
  130   473   471   469   470   471
  140   468   466   463   464   464
  150   467   465   462   461   460
  160   471   468   465   463   460
99901 -1500 -1490 -1480 -1470 -1460
  100     0     0     0     0     0
  110     0     0     0     0     0
  120     0     0     0     0     0
  130   698   699   700   701   703
  140   728   728   728   730   731
  150   754   754   753   755   757
  160   779   778   777   779   780
99921 -1500 -1490 -1480 -1470 -1460
  100  1215  1192  1169  1145  1121
  110  1188  1165  1142  1118  1093
  120  1159  1136  1113  1089  1065
  130  1128  1106  1083  1060  1036
  140  1090  1068  1046  1024  1001
  150  1047  1027  1007   985   964
  160  1002   983   963   943   922
```

The slant TEC arrays follow the first array containing the vertical TEC. These arrays begin with a number in the form 999xx, where the xx is the space vehicle number (SVN). Again, the slant TEC values are bordered by the latitude as the first column and longitude as the first row, matching the vertical TEC spacing. The value within the array are the TEC along the line of site from the latitude and longitude position indicated and the satellite with the SVN number xx. In the example above, two GPS satellites are viewed, 01 and 22, indicated by the values, 99901 and 99922. The TEC, from SVN 01 and the position 16.0 degrees latitude and -14.6 degrees longitude, is 78.0 TECU, or the TEC, from SVN 22 and the position 10.0 degree latitude and -15.0 degrees longitude, is 121.5 TECU. If a 0 is indicated, then the satellite is not in view. For example, the above array indicates that satellite 01 is only in view between 13.0 and 16.0 degrees latitude, and satellite 22 is in view for all locations

TEC uncertainty:

yyyyMMddhhmm_ERR.txt contains the expected error in the vertical TEC. These errors are obtained from the Kalman filter's estimate of the state error. The number in the first row, first column indicates the number of GPS stations used in the calculation of this file. The first row, from second column to the last column, contains the longitude locations. The first column, from the second row to the last row, contains the latitude locations. The latitude and longitude values should be divided by 10 to obtain the correct values. The latitude and longitude values are written without decimals to minimize the file size. Latitude and longitude are in degrees x 10. The latitude column and longitude row are the left and top borders for a matrix containing the expected vertical TEC values, which are in TECU (10^16 electrons/m^2) x 10. An example of this matrix is given below.

In the example, the number of GPS stations used in this assimilation cycle is 78, the top-left number in the file. The latitude ranges from 21.0 to 25.5 degrees longitude where all positive values are in the northern hemisphere. The longitude ranges from -160.0 to -144.0 degrees, where all negative values are in the western hemisphere. Therefore, the estimated error in the TEC value at 22.5 degrees latitude and -156.0 degrees longitude is 4.5 TECU, or the estimated error in the TEC at 25.5 degrees latitude and -144.0 degrees longitude is 5.5 TECU. In this particular array, all values are in the northern and western hemispheres.

```
Vertical and Slant Path Total Electron Content
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   78 -1600 -1560 -1520 -1480 -1440
  210    43    42    41    40    39
  225    47    45    44    43    38
  240    52    51    49    46    42
  255    65    63    58    57    55
```

Recent Trend

yyyyMMddhhmm_DIF.txt contains the deviation of the vertical TEC from the average of the most recent 10 previous days where a US-TEC solution was obtained. US-TEC tries to obtain the most recent 10 days. If data is not available, US-TEC searches for a set of 10 days within the most recent 20 days. If 10 days of US-TEC output are not available within the last 20 days, then this file is not displayed.

The number in the first row, first column indicates the average number of GPS stations over the previous 10 days used in the calculation of this file. The first row, from second column to the last column, contains the longitude locations. The first column, from the second row to the last row, contains the latitude locations. The latitude and longitude values should be divided by 10 to obtain the correct values. The latitude and longitude values are written without decimals to minimize the file size. Latitude and longitude are in degrees x 10. The latitude column and longitude row are the left and top borders for a matrix containing the deviation in TEC from the previous 10-day average, which are in TECU (10^16 electrons/m^2) x 10. An example of this matrix is given below.

In the example, the number of average GPS stations over the 10 days used in the calculation of the file is 83, the top-left number in the file. The latitude ranges from 25.0 to 31.0 degrees longitude where all positive values are in the northern hemisphere. The longitude ranges from -160.0 to -144.0 degrees, where all negative values are in the western hemisphere. Therefore, the deviation from the 10-day average in the TEC value at 26.5 degrees latitude and -156.0 degrees longitude is 1.2 TECU, or the estimated error in the TEC at 31.0 degrees latitude and -144.0 degrees longitude is -0.5 TECU. In this particular array, all values are in the northern and western hemispheres.

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Vertical and Slant Path Total Electron Content
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   83 -1600 -1560 -1520 -1480 -1440
  250    11     9    10     9     7
  265     9    12     4     2     2
  280     8     3     0    -2     0
  295     5    10    -3    -5    -2
  310    11    -2    -5    -7    -5
```

Stations Used

yyyyMMddhhmm_stations.txt contains a list of the station used in the US-TEC calculation for this given time frame. The station can be identified through the web site, https://geodesy.noaa.gov/CORS/.

Data from each station listed was used in the calculations for the time-corresponding USTEC maps and data files.

Daily Empirical Ortho-Normal Functions (EOFs)

yyyyMMdd_EOF.txt contains the empirical orthonormal functions (EOFs). The 1st row of data in yyyyMMdd_EOF.txt lists 4 numbers describing the elements for the array immediately below this row. The 4 numbers in this 1st row, in order from left to right, are:

Na =number of altitude ticks (one tick for each row)

Ne = number of EOFs (one EOF for each column, 1st EOF in column 1,

2nd EOF in column 2, etc), (also, number of columns = Ne).

h = starting altitude from the center of the earth (km) in first row

Dh = spacing (km) of altitude ticks

Array size in yyyyMMdd_EOF.txt = Na X Ne

Examples: if Na=10, Ne=3, h=6550.0, Dh=25.0

The array size in yyyyMMdd_EOF.txt would be 10 x 3

The element in row 1, column 1: 6550 km alt., 1st EOF

The element in row 2, column 1: 6575 km alt., 1st EOF

The element in row 1, column 2: 6550 km alt., 2nd EOF

The element in row 6, column 2: 6675 km alt., 2nd EOF

The element in row 10, column 3: 6775 km alt., 3rd EOF

End of Examples.

Coefficients

yyyyMMddhhmm_COE.txt contains the Coefficients for the empirical orthonormal functions (EOFs) in yyyyMMdd_EOF.txt. The 1st row of data in yyyyMMddhhmm_COE.txt lists 6 numbers describing the elements for the array immediately below this row. The 6 numbers in this 1st row, in order from left to right, are:

Lat.Ticks = number of latitude ticks (one tick for each row)

Lon.Ticks = number of longitude ticks (one tick for each column)

StartLat = value (degrees) of the first latitude tick in the upper left corner

StartLon = value (degrees) of the first longitude tick in the upper left corner

LatSpacing = spacing (degrees) of the latitude ticks

LonSpacing = spacing (degrees) of the longitude ticks

Array size in yyyyMMddhhmm_COE.txt = (Ne * N) x M

where Ne = number of EOFs (Ne found in yyyyMMdd_EOF.txt). The 1st NxM array is the factor for the 1st EOF (column 1 of yyyyMMdd_EOF.txt), the 2nd NxM array is the factor for the 2nd EOF (column 2 of yyyyMMdd_EOF.txt), etc.

Examples: if N=3, M=5, No=40.0, Mo=-90.0, Ns=10.0, Ms=2.5, columns in EOF file = 3

The array size in yyyyMMddhhmm_COE.txt would be (3*3) x 5 = 9 x 5

The element in row 1, column 1: 40 deg. lat., -90 deg. long., factor for 1st EOF

The element in row 2, column 1: 50 deg. lat., -90 deg. long., factor for 1st EOF

The element in row 1, column 2: 40 deg. lat., -87.5 deg. long., factor for 1st EOF

The element in row 3, column 5: 60 deg. lat., -80 deg. long., factor for 1st EOF

The element in row 4, column 1: 40 deg. lat., -90 deg. long., factor for 2nd EOF

The element in row 5, column 3: 50 deg. lat., -85 deg. long., factor for 2nd EOF

The element in row 7, column 1: 40 deg. lat., -90 deg. long., factor for 3rd EOF

The element in row 9, column 4: 60 deg. lat., -82.5 deg. long., factor for 3rd EOF

Using Daily Empirical Ortho-Normal Functions (EOFs) and Coefficients

Electron Density

To solve for the Electron Density (Ne) at a given latitude (lat), longitude (long), and altitude (alt):

EOF denotes values from yyyyMMdd_EOF.txt.

COE denotes values from yyyyMMddhhmm_COE.txt.

Ne(lat,long,alt)=COE(lat,long,EOF(column1))*EOF(column1,alt) +COE(lat,long,EOF(column2))*EOF(column2,alt)+... ...+COE(lat,long,EOF(columnN))*EOF(columnN,alt)

Where N is the number of EOFs, and Ne(lat.long,alt) is the electron density for an individual bin at (lat,long,alt) in units of 10^{11} electrons/m^3 .

Ne calculation example using the above examples: (3 EOFs):

To find the Ne at 60 deg. lat., -80 deg. long., and 6675 km alt:

Ne(60,-80,6675)=COE(row3,column5)*EOF(row6,column1) +COE(row6,column5)*EOF(row6,column2) +COE(row9,column5)*EOF(row6,column3)*

Vertical and Slant Total Electron Content

To calculate the "Vertical" Total Electron Content (TEC) at a given latitude and longitude, or the line-of-sight Electron Content along a given "Slant" direction :

EOF denotes values from yyyyMMdd_EOF.txt.

COE denotes values from yyyyMMddhhmm_COE.txt.

For "vertical" TEC, first evaluate Ne as outlined above at a given latitude (lat), longitude (long), and altitude (alt):

Ne(lat,long,alt)=COE(lat,long,EOF(column1))*EOF(column1,alt)
+COE(lat,long,EOF(column2))*EOF(column2,alt)+...
...+COE(lat,long,EOF(columnN))*EOF(columnN,alt)

where N is the number of EOFs and Ne(lat,long,alt) is the electron density for an individual bin at (lat,long,alt) in units of 10^{11} electrons/m^3.

With a bin size of 25 km, the electron content in each bin is given by: Ne(lat.long,alt) * 2.5x104 electrons/m^2

Secondly, by summing over all altitudes bins at a given latitude and longitude provides the total vertical TEC in units of electrons/m^2. This number will correspond to the vertical TEC in yyyyMMddhhmm_ustec.txt, which is in TEC units (TECU), where 1 TECU = 10^{16} electrons/m^2.

For "slant" TEC:

To obtain the slant TEC in yyyyMMddhhmm_ustec.txt, the geometry of the bin and raypath between satellite and receiver must be considered. The TEC for the slant, slantTEC, will increase proportionally to the distance traveled through the bin as compared to the vertical TEC value and distance, i.e. slantTEC(lat,long,alt) = TEC(lat,long,alt) *dh/Dh, where dh = distance traveled by slant raypath through a bin, Dh thick, centered at (lat,long,alt).

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