The Matlab codes, IONEXmanager, TECmapperGreenland, and TECmapperGlobal, prepare and plot hourly TEC maps for either the Greenland region or the whole world. The data files, RIM130010.INX and CODG0010.13I, cover a period of 24 hours. They contain ground-based GNSS observations of ionosphere delays for a range of stations in Greenland and the globe, respectively, transformed into TEC measurements.

1. **Describe in general the Matlab code.**

The IONEX data format is somewhat similar to the well-known RINEX data format, the IONEX file contains vertical ionospheric total electron content (VTEC) values for a set of specific geographic coordinates. The coordinates form a grid. The angle between the grid points are typically 1 to 5 degrees. The IONEX files also contain RMS values for each grid point. This particular data set was processed by the Bernese software, employing precise point positioning (PPP) processing and spherical harmonics solutions.

There are two extents in this assignment: Global and Greenland. The global data was processed by the University of Bern, the Greenland data was processed here at DTU Space. The numbers of GNSS ground stations and individual satellites are also recorded in the IONEX file additionally to the station differential code bias (DCB) values. By using all these data in an IONEX file it is possible to map the ionosphere in 2D or 3D. These particular files contain 2D, single-layer data only. Therefore I will generate 2D VTEC maps using the values in the files.

The provided Matlab code loads the IONEX file's content into Matlab variables and then organizes them in order to allow for easy mapping of the data.

CODG0010.13I contains the global grid of VTEC values.

RIM130010.INX contains the data for the Greenland sector.

IONEXmanager.m this script will read the IONEx file, the user has to manually set the file name and the map extent.

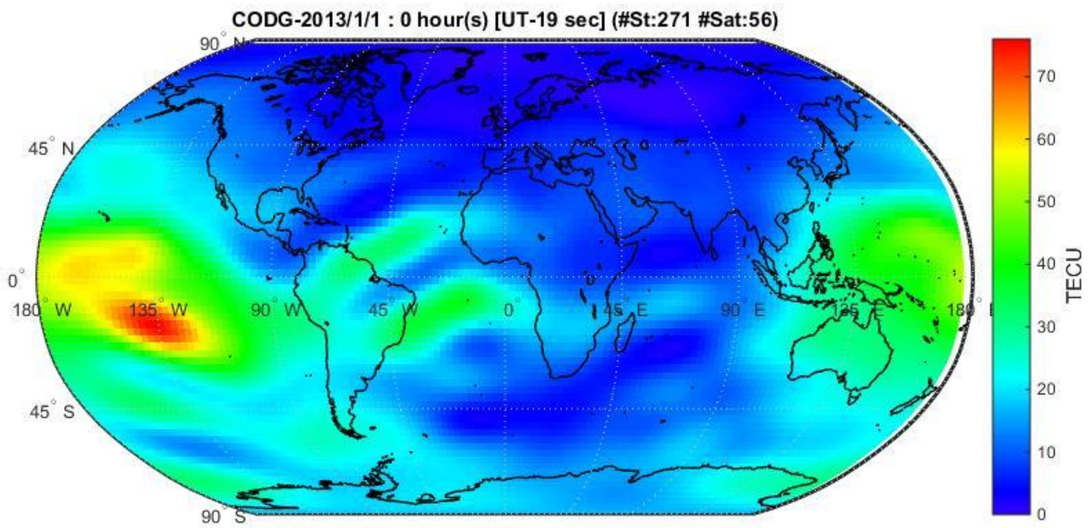
CalcNumOfHeaderLines.m, **CalcNumOfLines.m**, **ReadingHeader.m** these three small scripts calculate variable from the IONEX file that are needed in order to automatically read the data regardless of the extent, file size and header size. These will return the required variables to the main script.

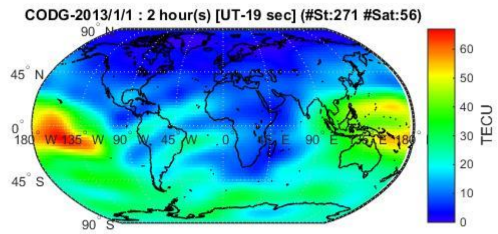
TECmapperGlobal.m once the *IONEXmanager* script has read the data into Matlab, this mapping script can plot it in 2D in the case of global extent.

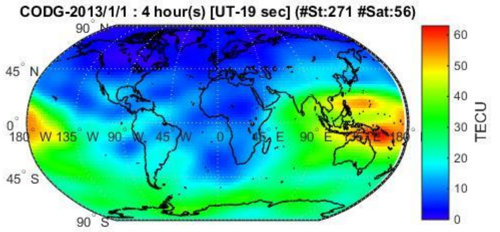
TECmapperGreenland.m once the *IONEXmanager* script has read the data into Matlab, this mapping script can plot it in 2D in the case of Greenland.

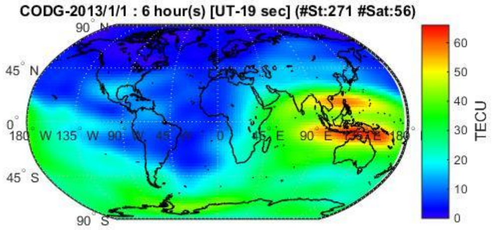
2. **Run the codes and plot the TEC maps for the Greenland sector and the world. Start by running IONEXmanager. Then run the TEC-mapper for the region in question.**

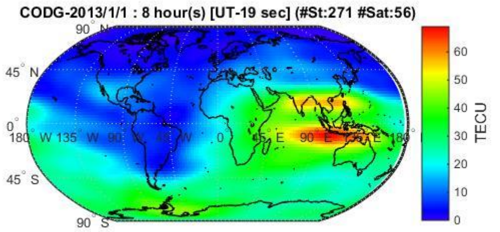
Plotting the global VTEC maps, time between "snapshots" is 2 hours:

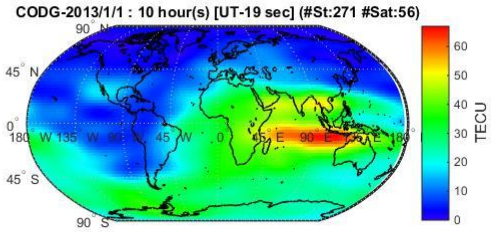


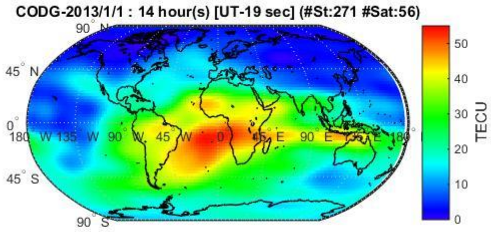


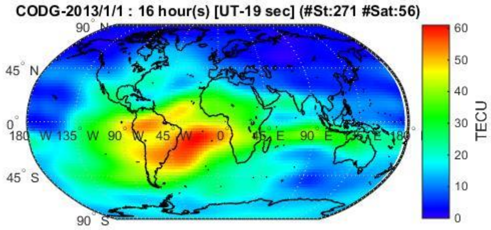

CODG-2013/1/1 : 4 hour(s) [UT-19 sec] (#St:271 #Sat:56)
TECU
0
10
20
30
40
50
60

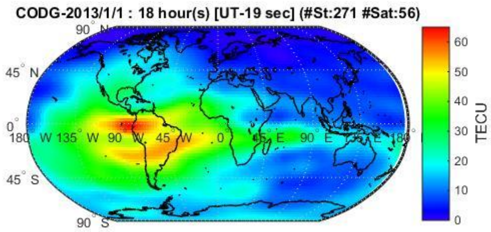

CODG-2013/1/1 : 6 hour(s) [UT-19 sec] (#St:271 #Sat:56)
TECU
0
10
20
30
40
50
60

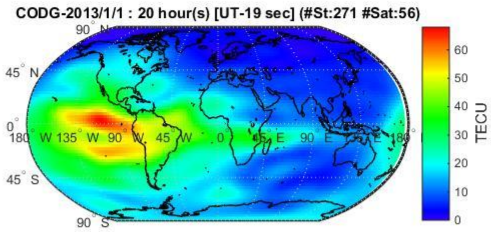

CODG-2013/1/1 : 8 hour(s) [UT-19 sec] (#St:271 #Sat:56)
TECU
0
10
20
30
40
50
60


CODG-2013/1/1 : 10 hour(s) [UT-19 sec] (#St:271 #Sat:56)
TECU
0
10
20
30
40
50
60


CODG-2013/1/1 : 14 hour(s) [UT-19 sec] (#St:271 #Sat:56)
90° N
45° N
0°
45° S
90° S
180° W 135° W 90° W 45° W 0° 45° E 90° E 135° E 180°
TECU
0
10
20
30
40
50


CODG-2013/1/1 : 16 hour(s) [UT-19 sec] (#St:271 #Sat:56)
90° N
45° N
0°
45° S
90° S
180° W 135° W 90° W 45° W 0° 45° E 90° E 135° E 180°
TECU
0
10
20
30
40
50
60


CODG-2013/1/1 : 18 hour(s) [UT-19 sec] (#St:271 #Sat:56)
90° N
45° N
0°
45° S
90° S
180° W 135° W 90° W 45° W 0° 45° E 90° E 135° E 180°
TECU
0
10
20
30
40
50
60


CODG-2013/1/1 : 20 hour(s) [UT-19 sec] (#St:271 #Sat:56)
90° N
45° N
0°
45° S
90° S
180° W 135° W 90° W 45° W 0° 45° E 90° E 135° E 180°
TECU
0
10
20
30
40
50
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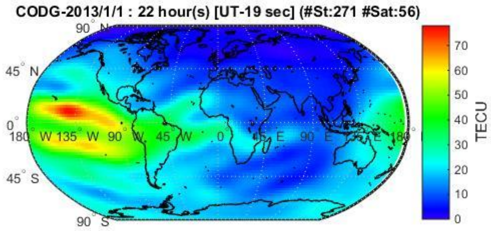
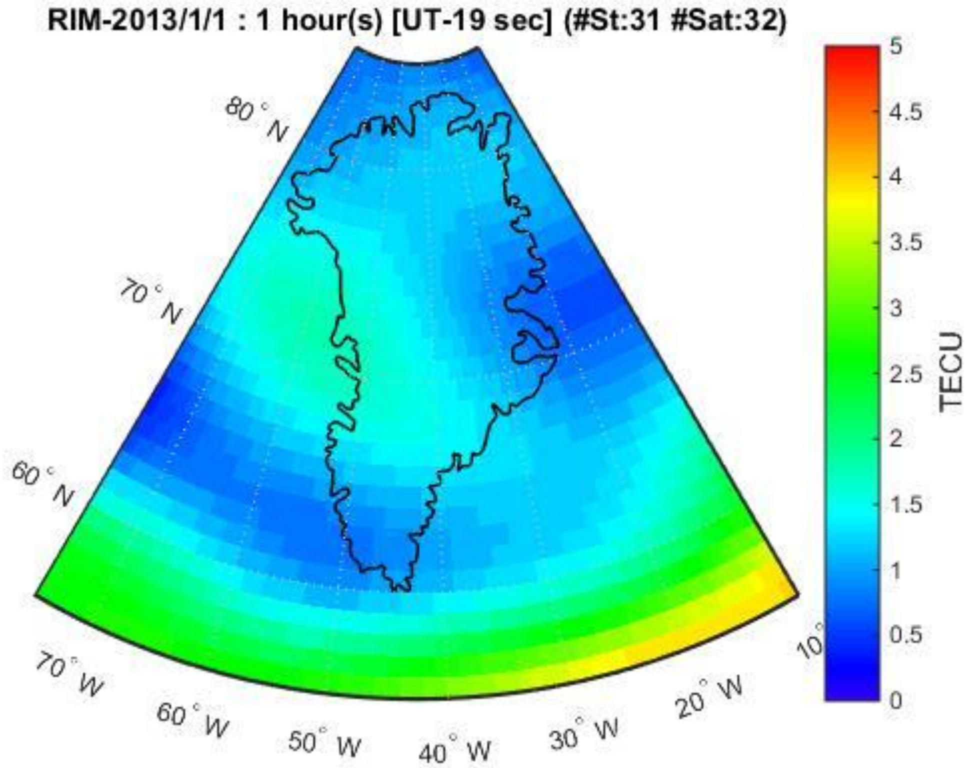
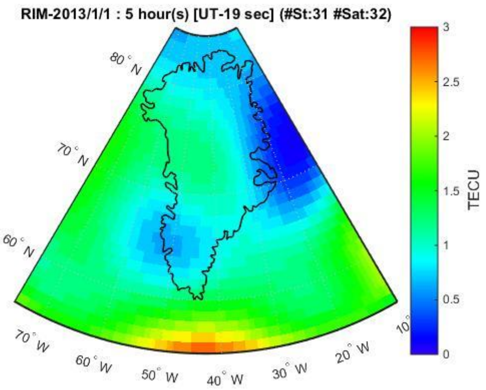


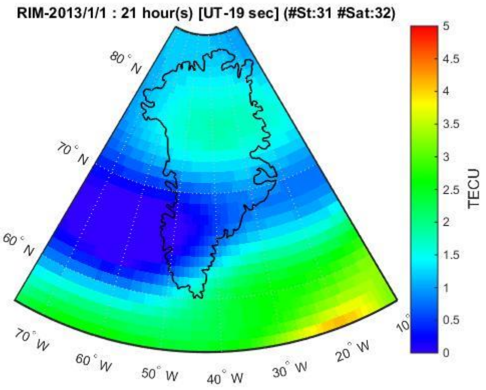
The global data is for January 1, 2013 (near solar maximum). 271 ground GNSS stations and 56 satellites were used (GPS + GLONASS).

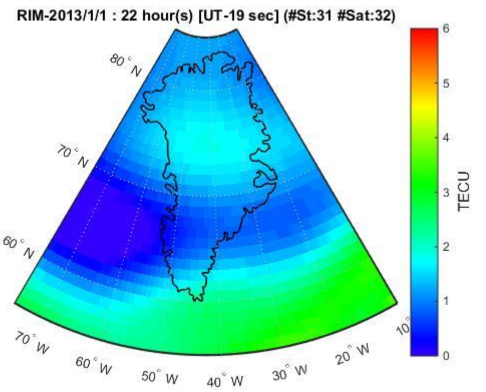
The Greenlandic IONEX contains data for each hour of this day.

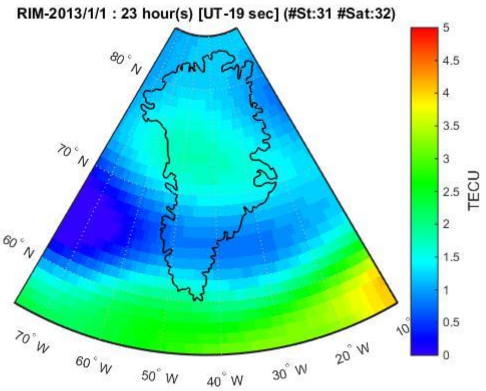


Here there are only GPS stations and 31 ground stations. Local features are clearly visible and rotating around the magnetic pole.


RIM-2013/1/1 : 5 hour(s) [UT-19 sec] (#St:31 #Sat:32)
TECU


RIM-2013/1/1 : 21 hour(s) [UT-19 sec] (#St:31 #Sat:32)
TECU


RIM-2013/1/1 : 22 hour(s) [UT-19 sec] (#St:31 #Sat:32)
TECU


RIM-2013/1/1 : 23 hour(s) [UT-19 sec] (#St:31 #Sat:32)
TECU

Night time and daytime are clearly different. The daytime ionization and night time depletion due to recombination are evidently visible.

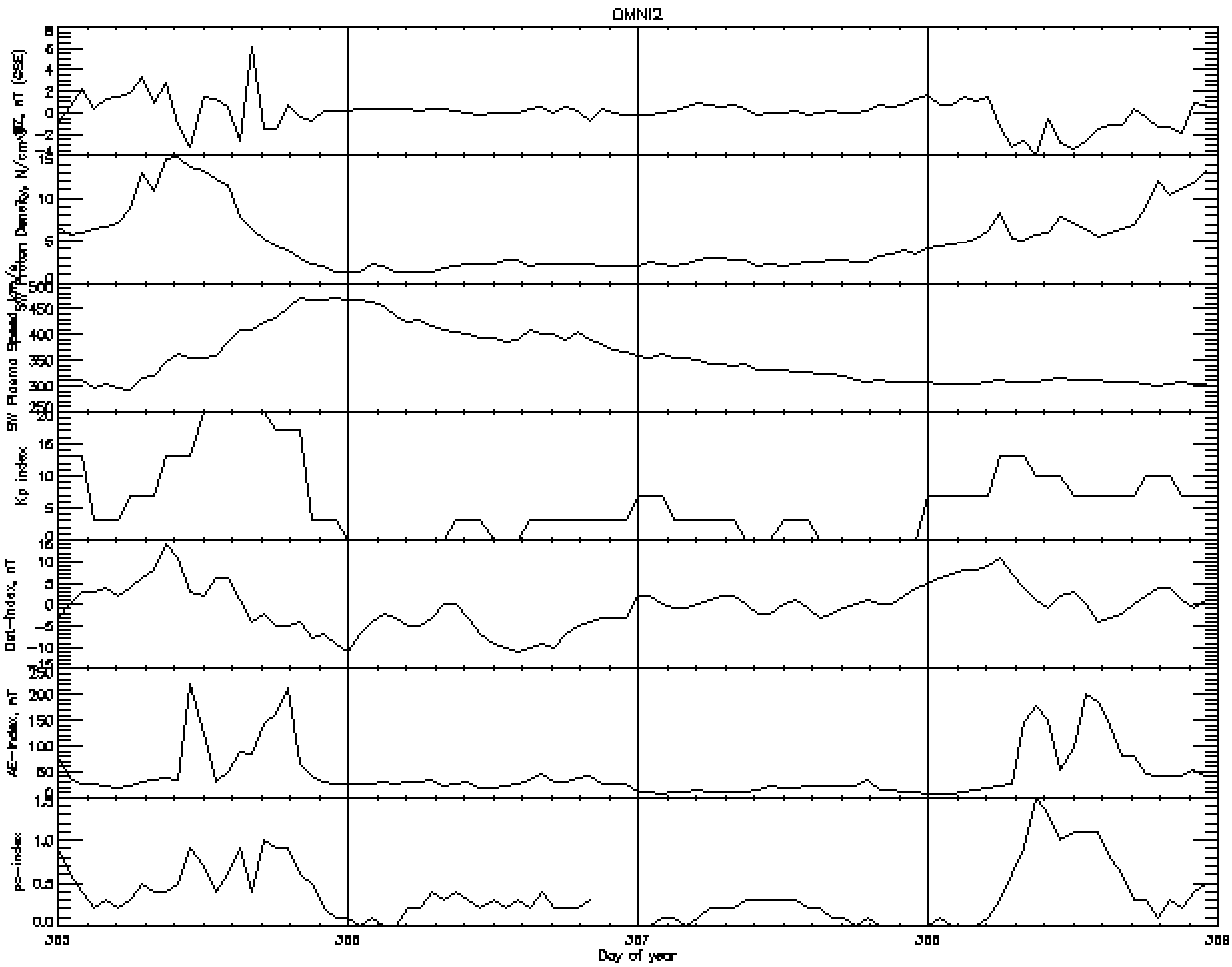
3. **Explain the TEC maps and compare them with solar wind driving forces (or indices) for changes in the auroral and the equatorial region.**

Total electron content (TEC) can be observed and calculated through different methods, e.g., GPS-derived TEC observed at ground stations or radio occultation (RO). Greenland's GNSS ground-stations present a unique opportunity to observe the high-latitude ionosphere. Due to Greenland's unique location the ground-based GNSS measurements will cover regions representing the polar cap and auroral oval of the ionosphere providing a complete latitudinal profile of the Arctic ionosphere. The geodetic GNSS receivers are capable of tracking several observables, such as code observables (P1 or C1 and P2), phase observables (L1, L2), and carrier-to-noise-density ratios (S1 and S2).

The GPS geometry-free combinations of phase and code (L1, P1) were calculated for each satellite-receiver pair. The code observables can be smoothed using a Hatch-filter approach and corrected for satellite and receiver differential code biases (DCBs). The TEC calculation has included the DCB values. These slant TEC (STEC) measurements exhibit a pronounced elevation angle-dependence. Since at different satellite elevation angles the length of the signal path through the ionosphere increases with lower elevation angles. To account for this effect an elevation-angle-dependent scaling scheme can be applied in addition to a, e.g., 10-degree elevation cut-off angle to minimize the effects of multipath error at low elevation angles. Various 1/cosine-type weighting functions (or mapping functions) are commonly found in the literature.

STEC and VTEC values are typically given in TEC units (TECU). One TECU is defined as 10^{16} electrons in 1 m^2 cross-section column along the signal path. The computed TECU values serve as a basis for the interpolation and two-dimensional (2D) TEC mapping. The data point locations for the interpolation are the geographic coordinates where the signal path pierces the single-layer model thin shell that represents the ionosphere, also known as IPPs. The IPPs form a 2D irregular grid. During high scintillation phases with storm time periods, the number of available IPPs is typically lower due to the increased number of cycle slips, which typically deteriorates data quality. Short satellite arcs are often impacted by carrier-phase cycle slips and depending on the size and location of the phase breaks, often the short arcs need to be discarded by the software. Any VTEC values between ionospheric observations at IPP locations have to be estimated using an interpolation scheme. The 2D TEC map color scales are consistent throughout the assignment to allow comparisons among different figures.

The main driver behind atmospheric ionization is solar EUV radiation. Therefore, in general the dayside ionosphere will exhibit higher TEC values than the night side. We can see that the maximum global ionization happens about 2 hours after local noon and the latitude depends on the inclination of the Earth relative to the Sun. The ionosphere is best described in the context of magnetic coordinates (magnetic latitude and magnetic local time). Although, the figures shown in this assignment are made in geographical coordinate systems.



The figure above shows different (hourly averaged) solar wind (SW) parameters from OMNI (http://omniweb.gsfc.nasa.gov/form/dx1.html) for the days around the TEC map day. We can see that this is a relatively calm period. The Dst doesn't indicate any significant effect on the ring current. AE index is also quite low throughout the day. Therefore this is a calm day globally and even in the auroral zone. The PCN index is again very low all day, therefore I can assume that the polar cap was also in a calm state all day. The Bz was slightly positive.

4. **Compare the large-scale features at high-latitudes in the Greenland sector with models of the auroral region (as the Feldstein model).**

The Feldstein and other models provide description for the auroral oval location and properties. We could expect that the auroral oval would be visible on the TEC maps, but this is generally not the case. In general locating the auroral oval using GNSS observations would be easier if we used phase scintillations or ROTI. To be able to observe the ionization caused by the processes that are responsible for the auroral (e.g. substorms) we would need to set up the experiment in a specific way and filter out other, more intense, effects. The large-scale features at high-latitudes are mainly governed by large-scale plasma convection (tongue of ionization, polar patches etc.), while these are governed by the electric and magnetic fields, and these fields are driven by the interaction between the SW and the geomagnetic field. One of the typical features we could observe at high latitudes is the dayside to night side over-the-pole convection between the electric field cells that are mainly depend on the current direction of the IMF.