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TEC and Space Weather

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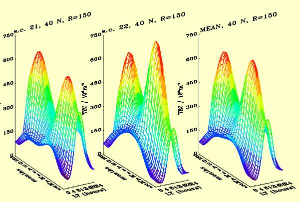
Abstract

Electron content (TEC) is a very important descriptive quantity for the ionosphere of the Earth. Some of its spatial and temporal fluctuations are strongly related to Space Weather. TEC is gained by means of "propagation effects" which are observed on received radio signals which are transmitted from artificial satellites. TEC data have been collected in Europe systematically and on a longterm basis since 1965. The data are used to investigate "geophysical events", e.g., the Space Weather related storm effects. They are also used to formulate empirical models which describe the large scale and longterm behaviour of average TEC data, usually of monthly medians.
We show examples for "instantaneous" TEC data, for a monthly median TEC model and for TEC maps produced on a regular basis for application purposes.

European TEC model, adopted by COST 251 (right hand display; it is the mean of the models for solar cycle 21 [left] and solar cycle 22 [middle])



(Ionospheric) Electron Content (TEC)

The most important property of an ionosphere is the existence of free electrons. They are responsible for the "propagation effects" we observe when radio waves penetrate into the ionosphere or when such waves cross through the ionosphere. The number of free electrons per volume is the most important descriptive quantity in ionospheric physics and in various practical applications of radio wave propagation. The longest standing experience with ionospheric data is related to the maximum of electron number density N_m encountered between the ground and the interplanetary space. N_m is proportional to the square of the "critical frequency" of the ionosphere, f_c:

$N_m = f_c^2 / 80.6$ if N_m is measured in electrons per square meter and f_c in Hz.

The (vertical) Electron Content (TEC) describes the overall ionization of the ionosphere. It is the number of electrons found in a column with a cross section of 1 square meter.

Nearly all artificial satellites use radio waves to communicate with ground stations. Their radio signals have to penetrate (a part of) the ionosphere. The radio waves emitted from artificial satellites suffer "ionospheric propagation effects". In first order approximation these are proportional to "slant electron content" (the number of free electrons in a tube of constant cross section thought to surround the propagation path). By projection it can be converted into vertical content (TEC).

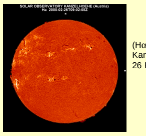
Electron content depends on geographic latitude, longitude and time. As for the ionosphere in general we distinguish between three latitudinal regions:

- High latitudes,
- Mid latitudes and
- Low latitudes.

The configuration of the geomagnetic field is used to distinguish between these regions: the centre of "low latitudes" is the "dip equator", whereas the "invariant magnetic coordinates" or "dipole coordinates" are used to separate mid from high latitudes.

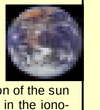
The spatial scales range from "large" (> 1000 km) to "small" (< 1 km). The large scale to medium scale TEC "structures" give the "background" which is often used to characterise the status of the ionosphere by means of empirical "models" with resolutions of a few degrees in latitude and longitude. Superimposed on the "background" are smaller scale structures. A persistent oneis the main "trough" of the F region which is found regularly in winter and equinox nights in geomagnetic latitudes between about 55° and 70°. Other structures are transient or have a wavelike character. In the polar cap TEC "patches" follow the "convection", polewards of the "trough" we often find TEC enhancements ("blobs") and nearly everywhere we find Travelling Ionospheric Disturbances (TIDs) which are composed of wavelike disturbances with horizontal scales from tens to several hundreds of km. TIDs are thought to be the signatures of atmospheric gravity waves (AGWs).

Space Weather



(Hα image of the sun from Solar Observatory Kanzelhoehe / IGAM / University of Graz, 26 Feb. 2000, 09:02:08 UT)

Solar-Terrestrial Relations:
via the Solar Wind
via eUV and X radiation

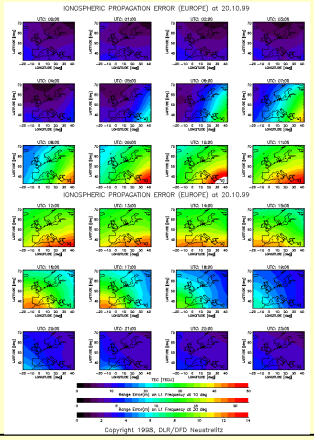


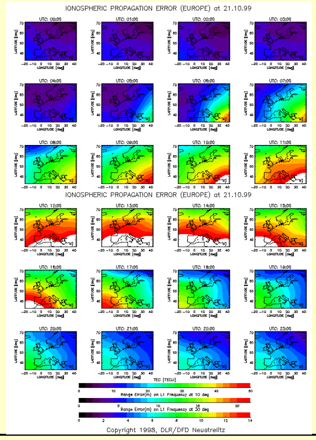
The Solar Wind influences our environment by interaction with the magnetic field of the Earth.This interaction is responsible for the magnetosphere, the magnetopause, the bow shock in front of the magnetopause, etc.

The extreme UltraViolet and the X ray radiation of the sun is responsible for the thermal plasma we find in the ionosphere and in the magnetosphere.

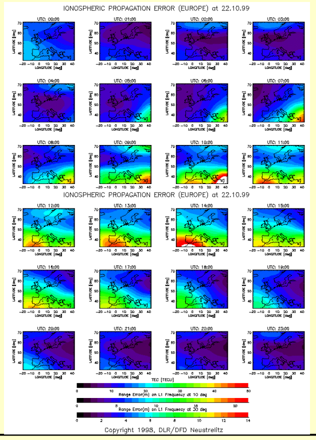
Solar Wind and eUV/X radiation depend strongly on the level of solar activity. The short term variations are responsible for the Space Weather fluctuations of Upper Atmosphere Properties ("satellite environment"). Our magnetic field and various dynamical processes play their role in coupling Space Weather to the middle atmosphere, the lower atmosphere and to the ground (Space Weather influence on the biosphere). The most spectacular Space Weather event is the Major Magnetic Storm with aurora, disruption of radio links and influence on technical installations.

GPS derived TEC maps illustrating a strong positive storm effect. The GPS satellites are in heights of about 20000 km. A strong geomagnetic storm had its Sudden Commencement in the morning of the 21th October, 1999. The 20th October was geomagnetically quiet. Around local noon and especially in the afternoon of the the "storm day" the electron content is strongly enhanced ("positive storm effect"). Such storm effects influence important applications, like satellite navigation, positioning, time transfer. In first order approximation the "propagation errors" are proportional to slant electron content for the transmitter to receiver radio links.





GPS derived TEC maps, cont. The 22nd October is still affected by the positive storm effect but to a much
lesser degree than the 21st October.
(The white areas are regions where the storm TEC exceeded the preset scale)



Time dependence of Electron Content (TEC)

In the time domain we have to make a clear distinction between

- Short term variability (time scales < 1 hour)
- Diurnal variation (24 hours and harmonics)
- Seasonal variation (months)
- Solar activity dependence (11 years "cycle" and cycle to cycle differences)
- Long term trends.

It is usual to separate the "regular" behaviour from superposed "fluctuations". Various smoothing procedures can be applied to separate these two parts. For example: the seasonal variation, the solar activity dependence and long term trends are investigated by inspecting monthly medians of electron content.

Except for "small scale TIDs" and "thermospheric modulations" most of the "fluctuations" are "Space Weather" related and can be used as Space Weather Indicators and Tracers.

The strongest TEC related "geophysical events" are Magnetic Storm effects. Especially strong magnetic storms and their ionospheric signatures are part of "Space Weather event chains" which originate in the atmosphere of the sun and end in the biosphere.

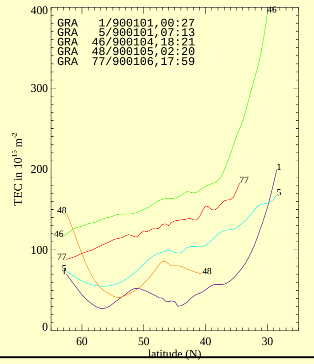
Space Weather Information / Internet addresses:

http://www-ssi.colorado.edu/SWOP
(Space Weather Center, Colorado)
http://sel.noaa.gov/today.html
(today's Space Weather)
http://www.ips.gov.au/asfc/current
(Space Weather Status Panel of the Australian Ionospheric Prediction Service)
http://www.ngdc.noaa.gov/stp/stp.html
(Solar-terrestrial relations at NOAA)
http://www.dxlc.com/solar
(Solar-Terrestrial Activity Report)
http://www.sec.noaa.gov/ises/data.html
(ISES Index to solar data sources)

Ionospheric Products, Europe / Internet addresses:

http://www.rcru.rl.ac.uk/iono/
(forecasts, etc., Rutherford Appleton Laboratory, UK)
http://cost251.ictp.trieste.it/
(COST251 data bank, Abdus Salam ICTP, Trieste, Italy)
ftp://ftp.nz.dlr.de/nav/navigation/TEC/
(ftp server for TEC maps, DLR Neustrelitz)
ftp://haydn.cbk.waw.pl/pub/idce/
(ftp server of the Ionospheric Dispatch Center for Europe, Warsaw, Poland)

Examples for the latitude dependence of TEC gained by means of the Diff. Doppler effect on the 150/400 MHz signals of polar orbiting satellites.
Receiving station Graz (47°N, 15°E).
Winter conditions (January), high solar activity. Date and time (CET=UT+1 hour) of mid points in the insert.
Ionospheric "structures": TEC increase towards Equatorial Anomaly (1, 46); main trough (1, 48). Signatures of Large Scale Travelling Ionospheric Disturbances (LS-TIDs) (especially 77).



Examples for the latitude dependence of TEC gained by means of the Diff. Doppler effect on the 150/400 MHz signals of polar orbiting satellites.
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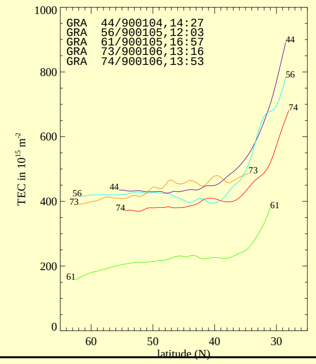
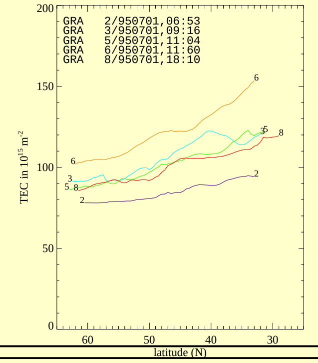
Ionospheric "structures": TEC increase towards Equatorial Anomaly (all except 73). Signatures of Large Scale Travelling Ionospheric Disturbances (LS-TIDs) (especially 56, 73, 74).



Examples for the latitude dependence of TEC gained by means of the Diff. Doppler effect on the 150/400 MHz signals of polar orbiting satellites.
Receiving station Graz (47°N, 15°E).

Summer conditions (July), low solar activity. Date and time (CET=UT+1 hour) of mid points in the insert.
Typical day time mid latitude profiles. Signures of Large Scale Travelling Ionospheric Disturbances (LS-TIDs).



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