Warning and Mitigation Technologies for Travelling Ionospheric Disturbances Effects

TechTIDE

User Manual
TEC Gradient Map

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Document Information

Title: TEC Gradient User Manual
Date of Publication: 20 December 2018
Author(s):   Claudia Borries
Work Package no.:   2
Work Package title: TID Identification Methodologies
Work Package leader: OE
Dissemination level: Public, Open Access, distributed under the terms of Creative
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1   Some information about the TEC Gradient method

Changes of the Total Electron Content (TEC) with horizontal distance are called TEC gradients. They are related to inhomogeneities in the thermosphere composition, plasma drifts and neutral drag. They are frequently observed in the equatorial region due to Rayleigh-Taylor instabilities and during geomagnetic storm conditions in high latitudes potentially caused by thermosphere heating in the Auroral region.

In TechTIDE, TEC gradients have been studied in correlation with Large Scale Travelling Ionospheric Disturbances (LSTIDs). The TEC gradients have the potential to be an early indicator for the generation of LSTIDs in high latitudes.

The IMPC TEC maps are available on the IMPC Portal http://impc.dlr.de and can be downloaded in JSON format.

2   Installation of the code

The following steps should be executed for installing the code:

1. This code requires a Matlab environment and a valid Matlab license

2. This code is designed to work under both, Windows and Linux platforms.

3. Create a folder where the code will be installed (hereafter, "main folder").

4. De-compress the downloaded zip file in the main folder.

5. Install Matlab json_parser

    a. Download https://github.com/christianpanton/matlab-json/tree/master/bin

    b. And put it into a new folder 'json_parser'

    c. Run "make" within MATLAB to build the MEX functions.

3   Contents of the compressed file

The zip file contains the files listed in Table 3-1.

Table 3-1: List of files to run the HF interferometry method with a short description

File	Folder	Type	Short description
User manual	Main folder	PDF	This file contains all necessary information for running the TEC Gradient code
generate_TECGradientMap_TechTIDE.m	Main folder	Matlab Code	Main file for near real-time process. Bash file that download data, create folders and call the programs.
distGC.m	Tools	Matlab Code	Subfunction used to calculate

File	Folder	Type	Short description
			a distance on a great circle.
Example_TECmap.json	Main folder	Input data file	Input data: IMPC TEC map in the JSON format

The Matlab file *generate_TECGradientMap_TechTIDE.m* is the main executable to run the TEC gradient calculation. Files highlighted in light orange in Table 1 can be modified by the users to adapt to their needs.

4 Compilation of the code

The Matlab code does not need compilation. Just the json_parser must be compiled as described in Sec. 2.

5 Executing the code

5.1 Start command

The main program that controls the whole method is a Matlab file. This program reads the input data and writes the result files.

The Matlab environment must be started for running the code. The program is called with the following command

```
generate_TECGradientMap_TechTIDE(filename,outputTYPE,outputDIR)
```

5.2 Input Parameters

Filename

The parameter 'filename' is the only mandatory parameter, which is a string, indicating the filename and location of the input file. The required format and description of the input file is presented in Sec. 6. The program tests the existence of the input file and ends with an error if the input file does not exist.

An example of a successful run of the program with input parameter filename is presented below

```
>> generate_TECGradientMap_TechTIDE('Example_TECmap.json')
Output: TECGradientMap_2018-10-09T14-15-00.png
>> |
```

An example of a program run with a non-existing filename is presented below

```
>> generate_TECGradientMap_TechTIDE('Example_TECmap2.json')
ERROR: The input filename does not exist!
>>
```

outputTYPE

The parameter 'outputTYPE' is an optional parameter which is a string, specifying whether the output shall be a data file or an image. The program allows the two options 'file' and 'image'. If the user enters another string, the program will end with an error message.

Examples of successful runs of the program with input parameters filename, outputTYPE:

```
>> generate_TECGradientMap_TechTIDE('Example_TECmap.json','image')
Output: TECGradientMap_2018-10-09T14-15-00.png
>> generate_TECGradientMap_TechTIDE('Example_TECmap.json','file')
Output: TECGradientMap_2018-10-09T14-15-00.json
>>
```

An example of a program-run with a wrong indication of the outputTYPE:

```
>> generate_TECGradientMap_TechTIDE('Example_TECmap.json','files')
Please use correct outputTYPE (file or image)
>>
```

If outputTYPE is not specified, the program automatically generates image files.

outputDIR

The parameter 'outputDIR' is an optional parameter which is a string, specifying the directory, where the output file shall be stored. The program tests the existence of the output directory and ends with an error if it does not exist.

Examples of successful program-runs with input parameters filename, outputTYPE and outputDIR:

```
>> generate_TECGradientMap_TechTIDE('Example_TECmap.json','image','graphiken')
Output: graphiken\TECGradientMap_2018-10-09T14-15-00.png
>> generate_TECGradientMap_TechTIDE('Example_TECmap.json','file','data')
Output: data\TECGradientMap_2018-10-09T14-15-00.json
>>
```

An example of a program run with a non-existing output directory is presented below

```
>> generate_TECGradientMap_TechTIDE('Example_TECmap.json','file','dataaa')
ERROR: The ouput directory does not exist!
>>
```

6 Description of the input files

The Ionosphere Monitoring and Prediction Center (IMPC), which is operated by DLR, provides European TEC maps. These TEC maps provide information about vertical TEC (VTEC) at a shell-height of 400 km. The spatial resolution of these TEC maps is 1°x1° in latitude and longitude. The product will be validated in a cross validation campaign within the ESA activity in the SSA Programme.

Input GPS data is acquired from different providers in real-time via the German Federal Agency for Cartography and Geodesy (BKG) in Frankfurt. This data is pre-processed in order to derive calibrated slant TEC (STEC) and to update the coefficients of the Neustrelitz Total

Electron Content Model (NTCM) serving as ionospheric background. Subsequently the calibrated STEC measurements are assimilated into NTCM, cf. [Jakowski et al., 2011]. Every 15 minutes a VTEC matrix with an ionospheric grid point spacing of 1° latitude x 1° longitude is generated and stored in JSON format. The usage of this product intends to help to improve the accuracy during GNSS positioning. The quality of the TEC map for Europe depends on the errors of the GNSS measurements. These errors are monitored through the production pipeline and displayed in a TEC error map. This TEC error map is provided separately as quality information along with the product.

The TEC is provided in TEC units (1 TECU = 10^{16} electrons per square meter). More product information is listed below.

Table 6-1 Specifications of IMPC TEC maps for Europe.

Specification	Description
External parties	German Federal Agency for Cartography and Geodesy, data providers below
Data providers	EUREF, ASI, IGS
Input data	GPS dual-frequency measurements
Input sampling rates	1s
Reliability of data source	Data is pre-processed by DLR including e.g. cycle slip detection
Region of sensors	Europe
Single-layer shell height	400 km
Spatial resolution	1° Latitude x 1° Longitude
Boundaries of grid	30°N – 72°N, 30°W – 50°E
Temporal resolution	15 min

Specification	Description
Time information	UTC Time
Timeliness	5 min
Reference coordinate system	ECEF coordinate system with WGS84 reference ellipsoid
Algorithms	24 hours weighted least-squares estimate of DCBs, background model coefficients; 5 min updates of DCBs and background model coefficients in linear recursive filter; previous estimates serve as background for the assimilation of estimated calibrated STEC into the update background model by means of a successive correction method.

Table 6-2: Data file description of IMPC TEC map Europe.

Item	Description
Naming Convention	*Current:* DLR_GNSS_GCG_L4_VTEC-NTCM-SCM_NC_EUROPE_YYYY-MM-DDTHH-MM-SS_YYYY-MM-DDTHH-MM-SS_DOY_X Description: DLRNZ: Owner of product DLR and processing facility Neustrelitz (NZ) GNSS: GNSS Receiver GCG: Ground-based calibration of GNSS biases R: Regular (continuous) measurements 2: Product level "value added" TCAV: TEC absolute vertical NC: Nowcast EU: Coverage over European Region M05: Files are produced each 5 minutes (available as DLR employee) D: Output type data YYYY: Year DOY: Day of year HH: Hours

Item	Description
	MM: Minutes
	SS: Seconds
	X: File type (D: data file, M: meta data file, I: Image file)
	Both time stamps describe the time period for which data has been used to generate the product. The first timestamp represents the start time and the second the end time.
Location under federated products pages	https://esc-sso.dlr.de/Total_Electron_Content/TEC_Near_Real-Time/Europe-beta
File format	JSON

The JSON data file is rather big to show. Therefore, we present just the first lines in the following image.

```
{
        "metadata":{
                "filename":"DLR_GNSS_GCG_L4_VTEC-NTCM-SCM_NC_EUROPE_2018-10-02T13-40-30_2018-10-02T13-45-00_275_D.json",
                "details":{
                        "spatial_coverage":{
                                "coordinate_system":"ECEF",
                                "min_lat":30,
                                "reference_system":"EPSG:4326",
                                "max_lon":50,
                                "delta_lat":1,
                                "max_lat":72,
                                "delta_lon":1,
                                "min_lon":-30,
                                "unit":"degrees"
                        },
                        "naming_convention":"DLR_GNSS_GCG_L4_VTEC-NTCM-SCM_NC_EUROPE_2018-10-02T13-40-30_2018-10-02T13-45-00_275_D.json",
                        "data_description":[
                                {
                                        "datasets":[
                                                {
                                                        "attributes":[
                                                                {
                                                                        "name":"index",
                                                                        "unit":"n/a",
                                                                        "description":"index"
                                                                },
                                                                {
                                                                        "name":"rcv",
                                                                        "unit":"n/a",
                                                                        "description":"receiver name"
                                                                },
                                                                {
                                                                        .. .. .. ..
```

Figure 1: Excerpt from the data file.

7 Description of the output files

7.1 Data file

The data file generated by the program is in the json format. It contains the essential meta data information as well as the data set.

The data is stored in the variables

- TEC_grad_lat: latitudinal TEC gradient

- TEC_grad_lon: longitudinal TEC gradient

- TEC_grad_tot: absolute TEC gradient

- latitude

- longitude

```
{ "metadata": { "description": "Changes of the Total Electron Content (TEC) with
horizontal distance. TEC gradients are calculated from TEC maps.",
"temporal_coverage": { "start_time": "2018-10-09T14:10:30", "end_time":
"2018-10-09T14:15:00" }, "data_name": "European Total Electron Content (TEC)
Gradients", "data_unit": "mm\/km", "created": "2019-01-09T21:40:13" }, "data": {
"TEC_grad_lat": [ [ 0, 0.13238014039123533, 0.079140301320847886,
0.0071945728473535257, -0.083457045029257951, -0.18274215032268953, -
0.27914942647717261, -0.36692321521484061, -0.42879654170205334, -
0.46476940593880051, -0.47196397878614893, -0.45469700395250862, -
0.42160196885470236, -0.3755567026316608, -0.32807252183915253, -
0.27771051190770601, -0.23310416025413355, -0.19137563773950717, -
0.15684168807222659, -0.12662448211335611, -0.10504076357130829, -
0.087773788737668029, -0.073384643042968642, -0.066190070195617665, -
0.060434411917738427, -0.057556582778800082, -0.057556582778797521, -
0.057556582778800082, -0.057556582778797521, -0.060434411917738427, -
0.058995497348269255, -0.058995497348269255, -0.054678753639859183, -
0.048923095361977392, -0.03885069337569063, -0.025900462250457865, -
0.0057556582778817977, 0.01582806026417111, 0.044606351653567321,
0.074823557612440361, 0.11079642184918755, 0.14101362780805549, 0.16691409005851843
, 0.17986432118374612, 0.17986432118374612, 0.16547517548904417,
0.14101362780805804, 0.10935750727971837, 0.077701386751378707,
0.048923095361977392, 0.024461547680988696, 0.0071945728473509687, -
0.0043167437084100698, -0.011511316555758483, -0.010072401986291869, -
0.0057556582778792416, 0.0057556582778792416, 0.020144803972581178,
0.037411778806218904, 0.060434411917738427, 0.083457045029257951,
```

Figure 2: Exerpt of an example file generated by the program

7.2 Image

The image, which is generated by the program contains two panels. The upper panel shows the original TEC map, while the lower panel shows the TEC gradients. The absolute TEC gradients are indicated with colors for each grid cell. At each grid point the direction of the TEC gradient is indicated with arrows. The length of the of the arrow is proportional to the value of the absolute TEC gradient.
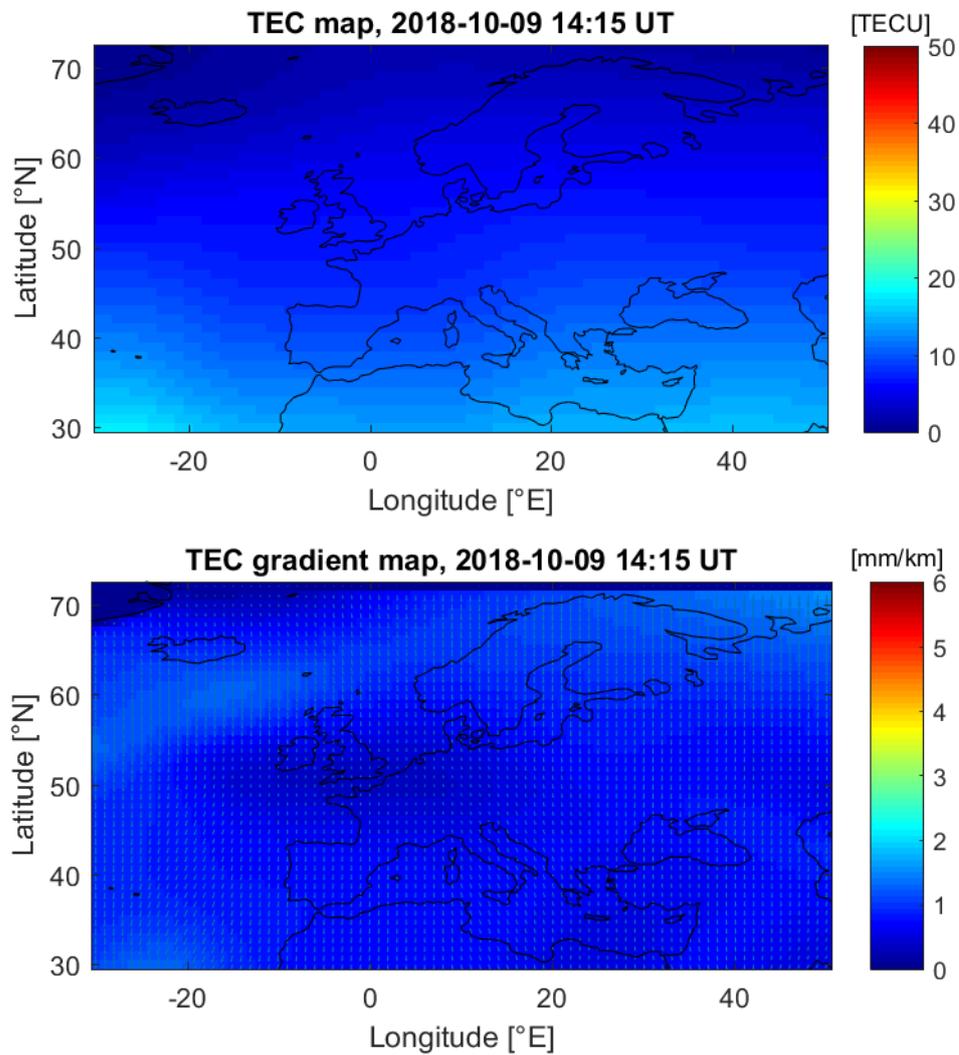
Figure 3: Example image generated by the program

8 References

[Jakowski et al., 2011] Jakowski, N., C. Mayer, M. M. Hoque, and V. Wilken (2011), Total electron content models and their use in ionosphere monitoring, *Radio Sci.*, 46, RS0D18, doi:10.1029/2010RS004620.