A new short-term forecasting model for the total electron content storm time disturbances

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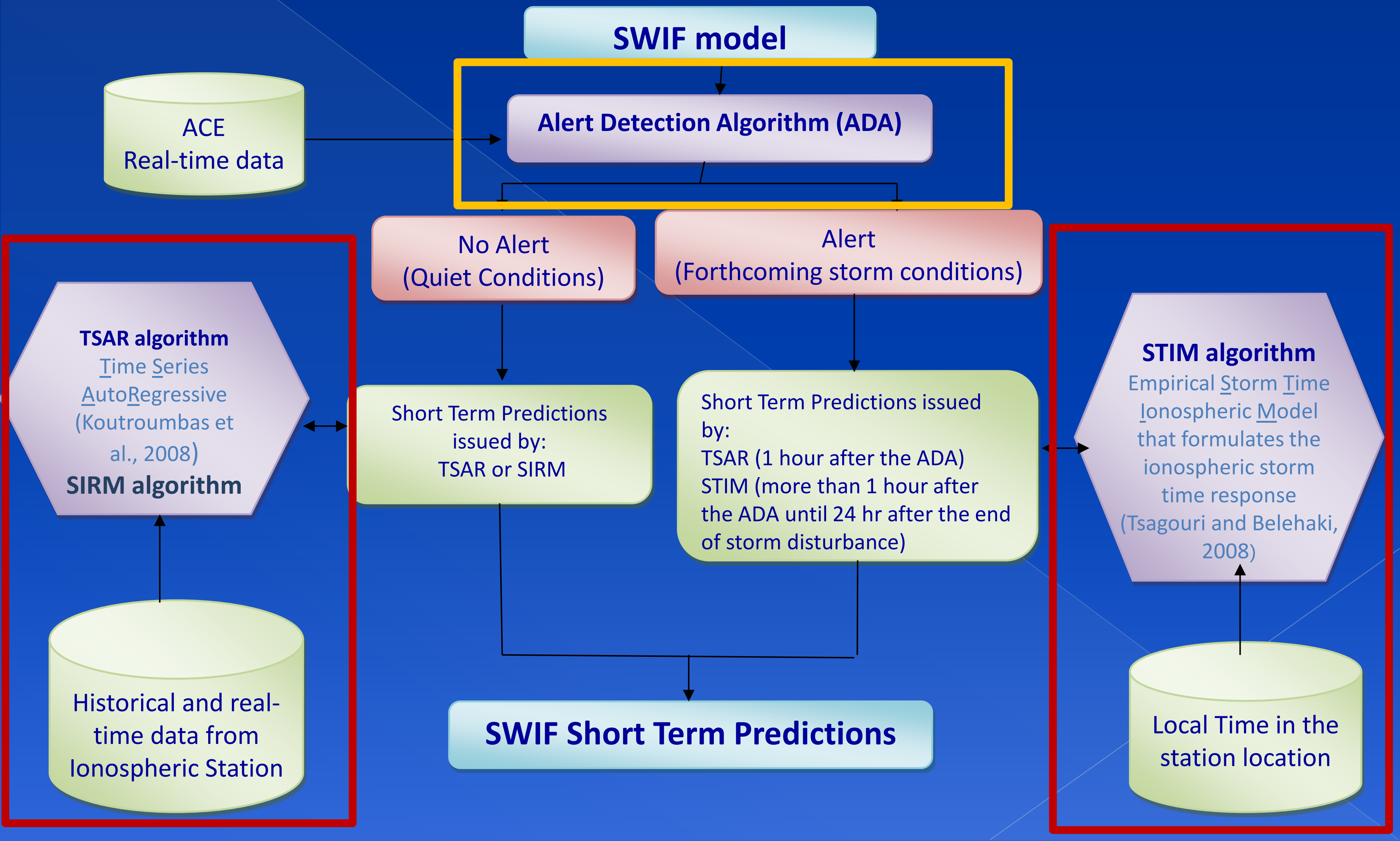
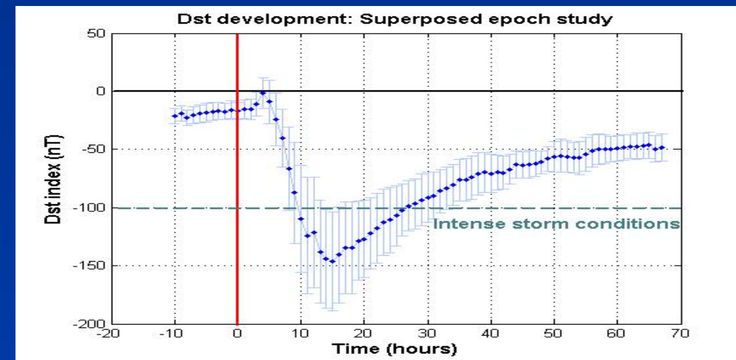
The Solar Wind driven autoregression model for Ionospheric short term Forecast (SWIF) - Middle and high latitudes

(Tsagouri et al., 2009; Tsagouri & Belehaki, 2008)



The Solar Wind driven autoregression model for Ionospheric short term Forecast (SWIF) – Storm conditions
(Tsagouri et al., 2009; Tsagouri & Belehaki, 2008)

foF2 critical frequency



Alert Detection Algorithm

Quantitative criteria to

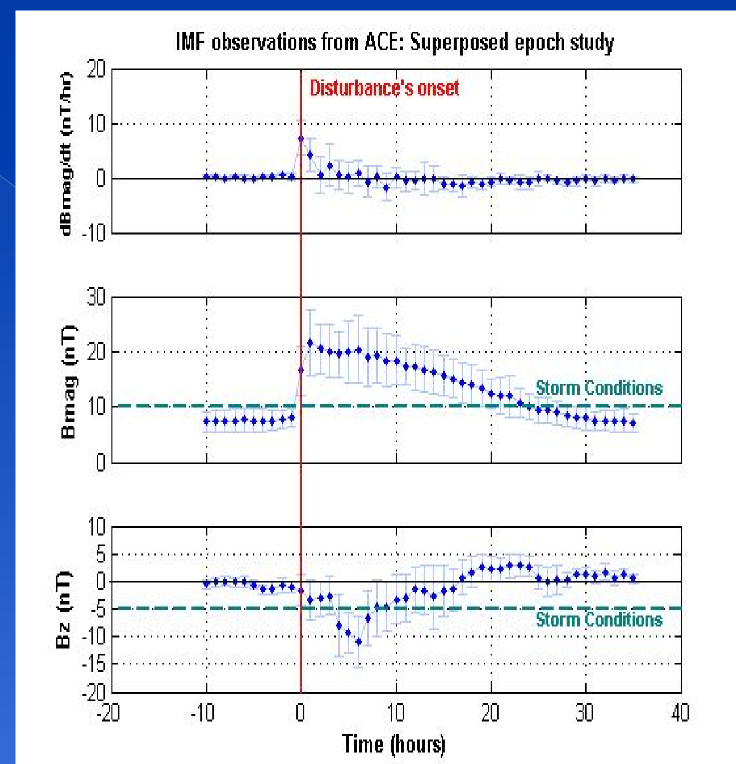
IMF-B (Total magnitude and rate of change)

IMF-Bz component

(i) The IMF–B should record either a rapid increase denoted by time derivative values greater than 3.8 nT/h or absolute values greater than 13 nT.

(ii) The IMF–Bz component should be southward directed either simultaneously or a few hours later. Intense storm conditions (Bz<-10 nT for at least 3h)

(e.g. Gonzalez and Tsurutani, 1987; Tsurutani and Gonzalez, 1995)

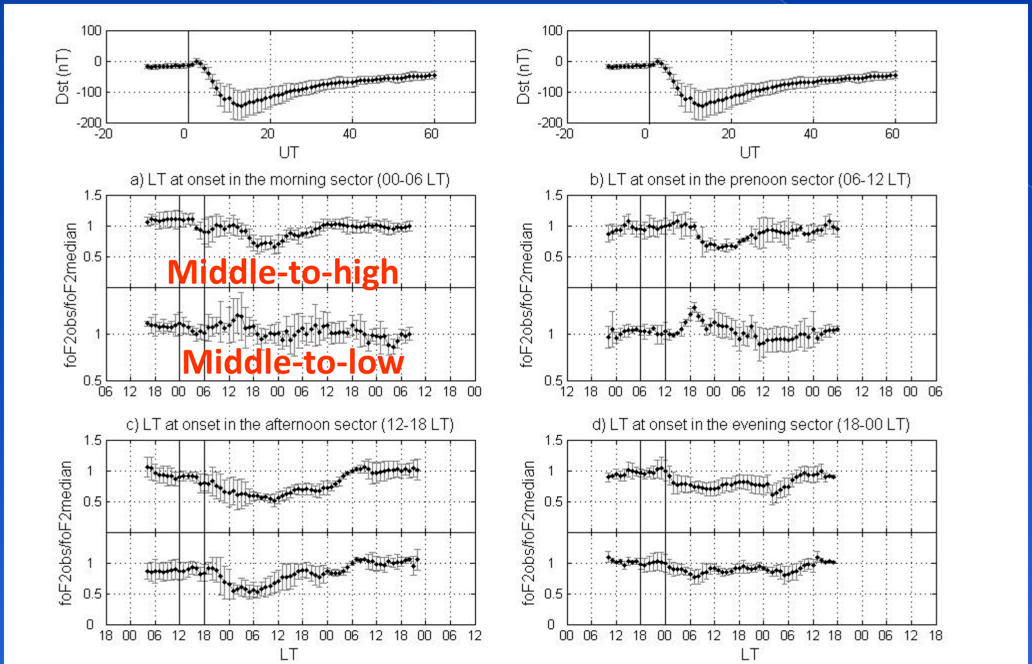


The Solar Wind driven autoregression model for Ionospheric short term Forecast (SWIF) – Storm conditions
(Tsagouri et al., 2009; Tsagouri & Belehaki, 2008)

STIM’s formulation of the ionospheric storm time response: empirical expressions to provide a correction factor to the reference variation based on the latitude of the observation point and its local time at the storm onset at L1 point:

- **Two latitudinal zones** for middle and high latitudes (greater or less than 45°)
- **Four local time sectors**:
  Morning (00 – 06 LT); Prenoon (06 – 12 LT); Afternoon (12 – 18 LT); Evening (18 – 00 LT)

foF2 critical frequency



Middle to High latitudes: negative storm effects (ionization decrease) due to neutral composition changes

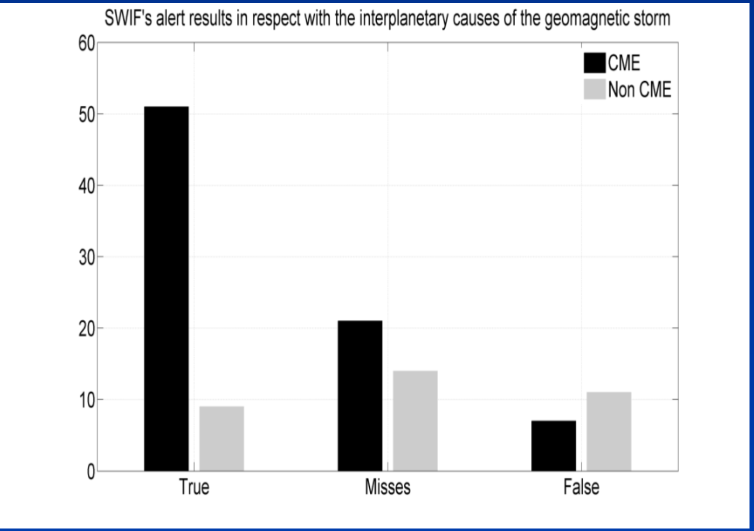
Middle to Low latitudes:
negative storm effects due to neutral composition changes in the night-side hemisphere and positive storm effects (ionization increase) during daytime due to travelling ionospheric disturbances and global wind circulation.

Ionospheric response to the storm events: consistent with Prölls phenomenological scenario [Prölls (1993)]

Analysis of the TEC storm-time response with respect to the SWIF's concept

List of storm events

Time interval	Min Dst (nT)
5-8 August 2011	-115
26-27 September 2011	-118
24-27 October 2011	-147
8-11 March 2012	-131
23-26 April 2012	-108
14-18 July 2012	-127
16-20 March 2013	-132
16-21 March 2015	-223
21-25 June 2015	-204
19-22 December 2015	-155



- Intense storm events (Dst ≤ -100 nT) that occurred in the present solar cycle 24
- CME-driven events http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm (Richardson and Cane, 2010).

Validation results show that the majority of **hits or true alerts** are received under the occurrence of storms related with **interplanetary CME** signatures - usually intense storms. **False alarms** tend to be related with **non-CME structures**, while such structures are related also with a significant number of **misses -** usually storms of moderate intensity (Tsagouri and Belehaki, 2015).

Analysis of the TEC storm-time response with respect to the SWIF's concept

List of stations

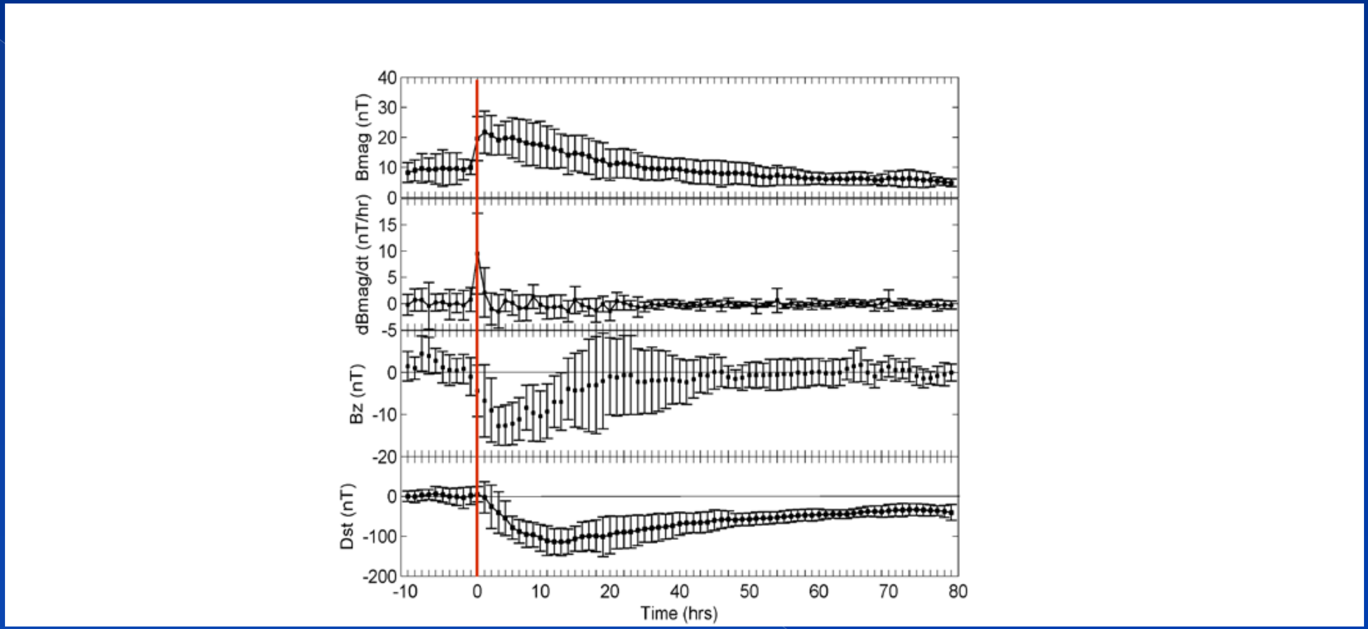
Ionospheric Station	Geographic longitude (°E)	Geographic latitude (°N)	GPS Station	Geographic longitude (°E)	Geographic latitude (°N)
Chilton	359.4	51.5	HERT	0.334	50.867
Dourbes	4.6	50.1	DOUR	4.595	50.095
Juliusruh	13.4	54.6	SASS	13.643	54.514
Pruhonice	14.6	50.0	GOPE	14.786	49.914
Ebre	0.5	40.8	EBRE	0.492	40.821
Rome	12.5	41.9	M0SE	12.493	41.893
San Vito	17.8	40.6	USAL	18.110	40.330
Athens	23.5	38.0	NOA1	23.864	38.047

- **foF2 records of hourly resolution obtained by ground-based Digisondes in Europe**. The data were retrieved from the Global Ionosphere Radio Observatory (GIRO - http://giro.uml.edu/) and they mainly come as the result of automatically scaled ionograms

- **GPS-derived TEC estimates, also of hourly resolution based on data from GPS receivers located close to the Digisondes.** At each station, vertical TEC (vTEC) values are calculated from data extracted from Receiver Independent Exchange Format (RINEX) files with 30 s sampling, using the single station solution proposed by Ciraolo (2005) and Ciraolo et al. (2007).

- The ionospheric disturbances are determined through the comparison between observed and monthly median values that are obtained from actual observations recorded within each calendar month. The monthly medians were estimated for each hour/month/year.

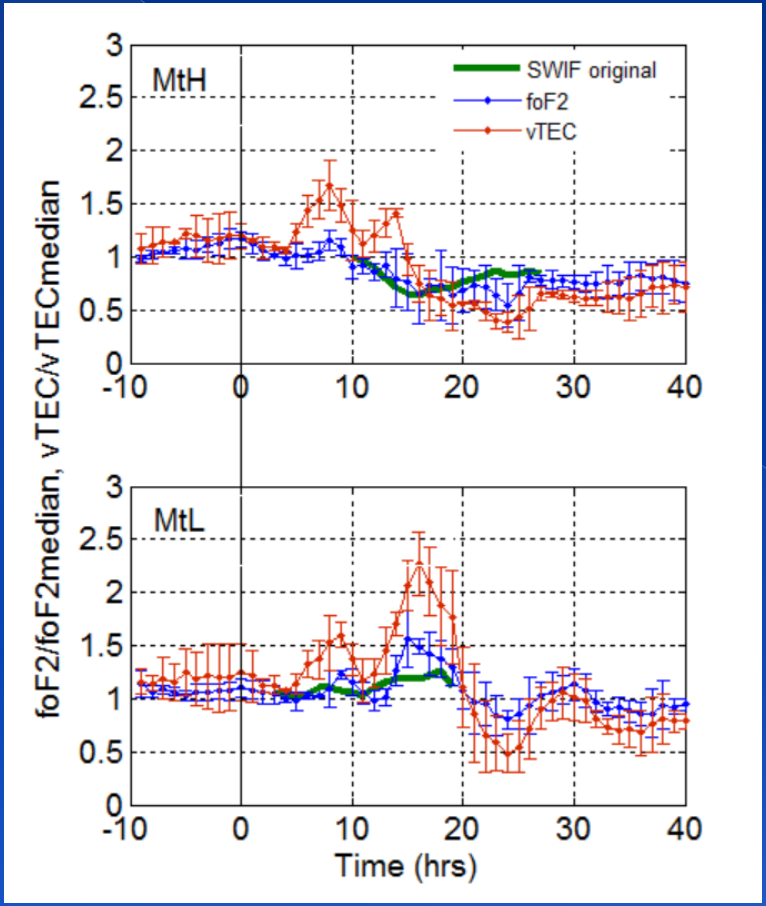
Analysis of the interplanetary conditions

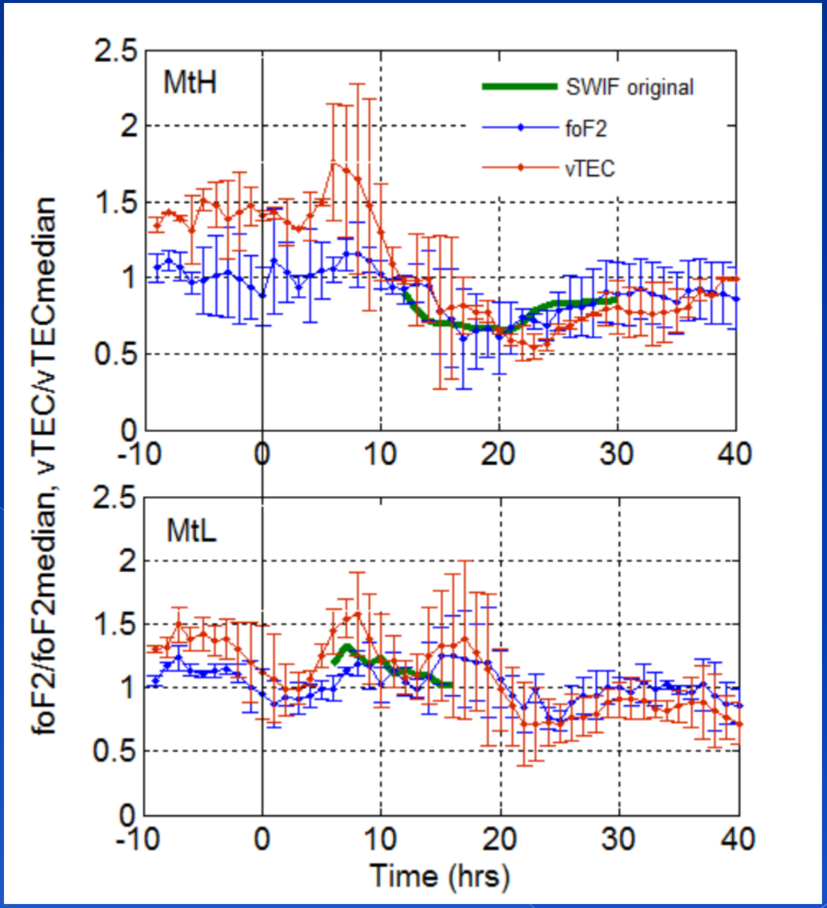


The results of superposed epoch analysis applied to the IMF total magnitude (Bmag), its rate of change (dBmag/dt) and the Bz-component. The Dst index is also included to verify geomagnetic storm conditions. The vertical red line indicates the storm onset time (0 hrs).

The results demonstrate that the SWIF's criteria are fully applicable also in the analyzed set of events: IMF–B derivative values greater than 3.8 nT/h or absolute values greater than 13nT; IMF–Bz component southward directed and Bz<-10nT for at least 3h.

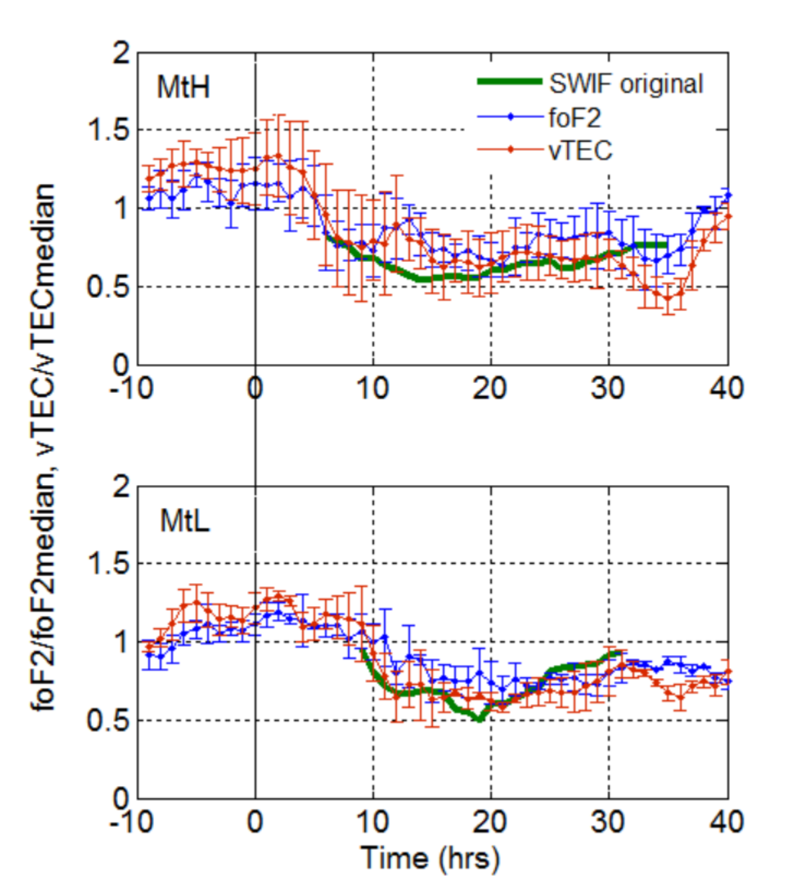
Analysis of the vTEC storm time response wrt the local time at storm onset

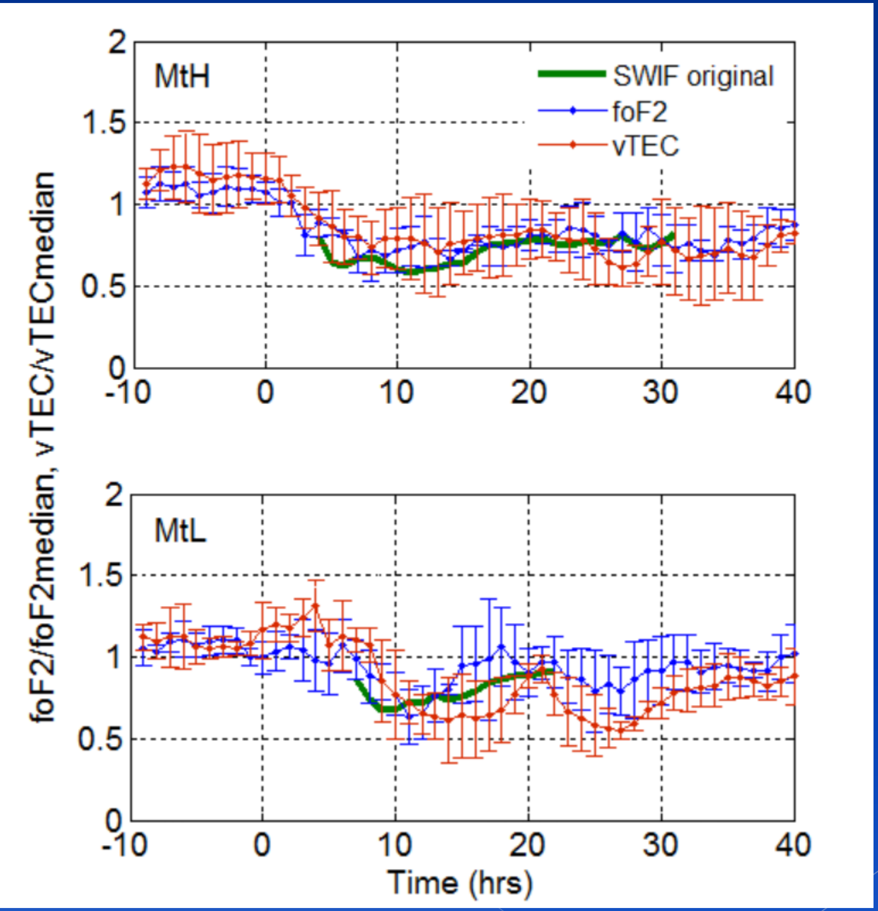




Superposed epoch analysis results of the vTEC and foF2 storm time response when the observation point is located in the **morning** (left) and **prenoon** (right) LT sector at storm onset, for MtH (top panel) and MtL (bottom panel) locations. The empirical formulation that the original SWIF's expressions can provide is also included (green line). Error bars represent standard deviations. The vertical black line at 0 hrs indicates the storm onset time.

Analysis of the TEC storm time response wrt the local time at storm onset





Superposed epoch analysis results of the vTEC and foF2 storm time response when the observation point is located in the **afternoon** (left) and **evening** (right) LT sector at storm onset, for MtH (top panel) and MtL (bottom panel) locations. The empirical formulation that the original SWIF's expressions can provide is also included (green line). Error bars represent standard deviations. The vertical black line at 0 hrs indicates the storm onset time.

Findings:

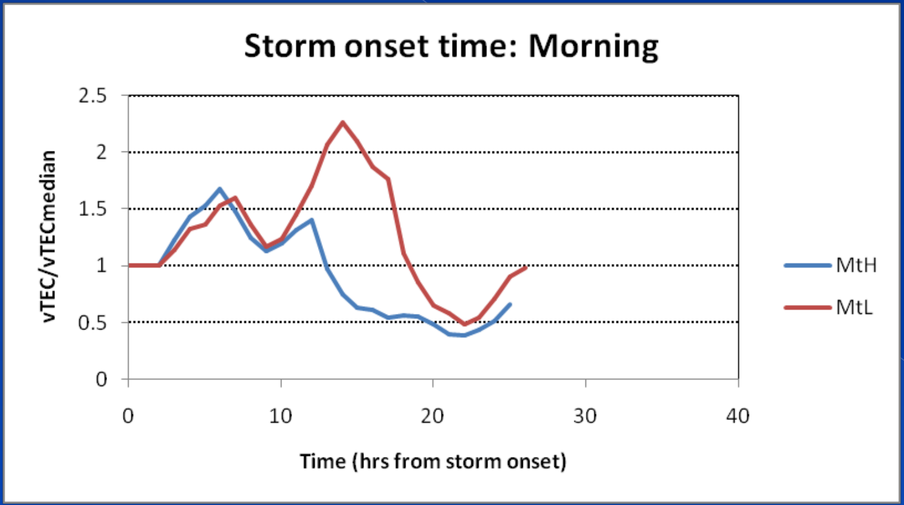
1. The ionospheric storm-time response starts almost simultaneously in foF2 and vTEC parameters. This indicates that **one may count on the SWIF's original settings for the determination of the ionospheric storm onset in vTEC response.**

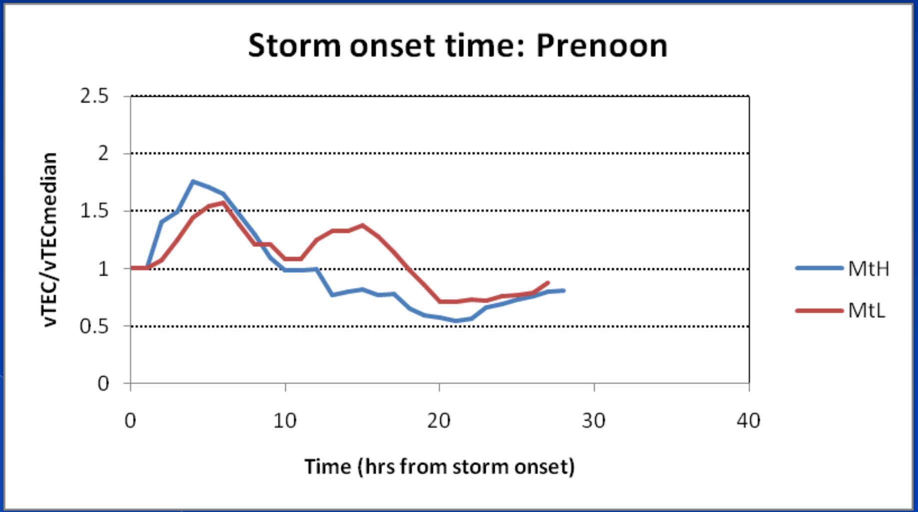
1. **LT dependence:** the vTEC response tends to follow qualitatively the trends present in the foF2 pattern, with positive storm effects to predominate in the daytime response of both parameters and negative storm effects to characterize the nighttime response in all cases. However, there are noticeable differences in the quantitative characteristics of the disturbances in each case. **The most important one applies in the intensity of positive storm effects that appears significantly greater in the vTEC case. It is also interesting to note that positive storm effects at higher latitudes in the morning sector are present only in terms of vTEC.**
2. SWIF's prediction efficiency: the model in its original version is able to reproduce satisfactorily well the intensity and the duration of the foF2 disturbances. However, with respect to vTEC, it fails to reproduce key features of the storm time response: the significant negative response that follows the positive phase in the morning sector, a secondary peak of ionization depletion appeared in the evening sector, positive storm effects in the morning and prenoon sectors, **indicating that some adjustments should be anticipated in the SWIF’s empirical formulation for the prediction of vTEC.**

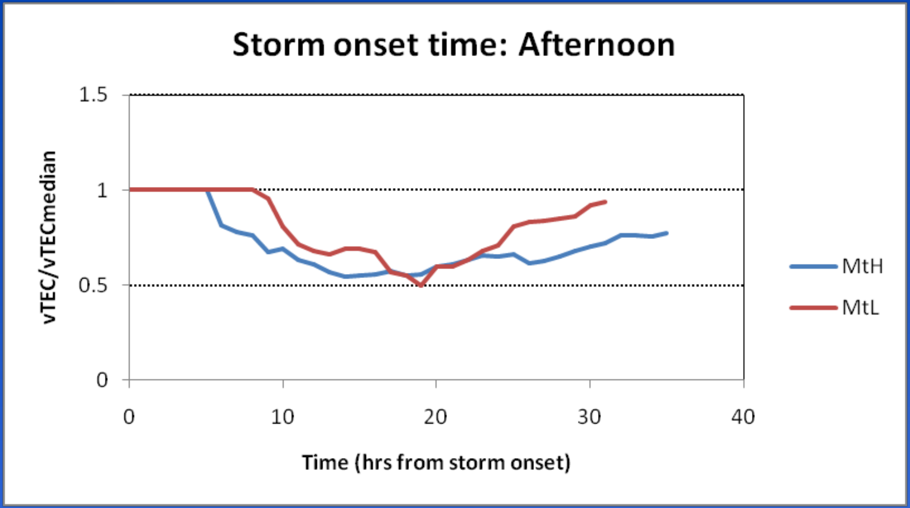
SWIF's formulation for the vTEC forecast

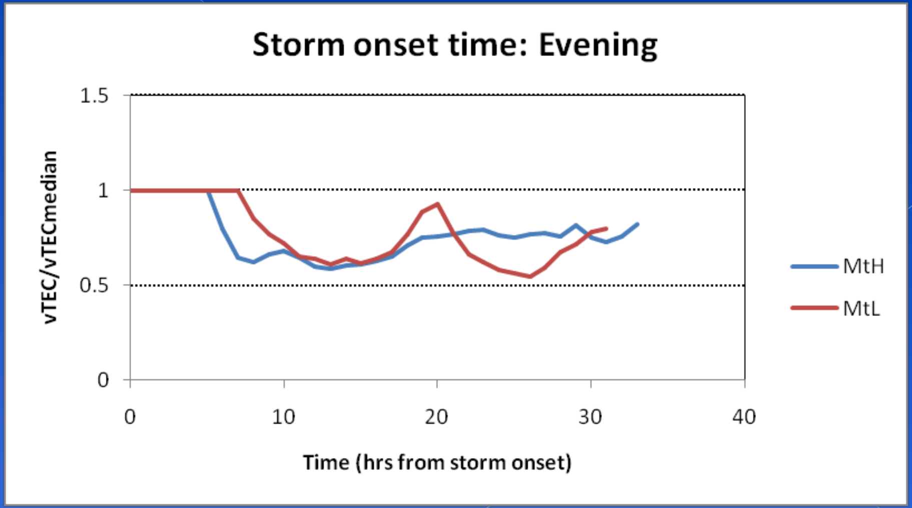
1. Determination of the storm onset time: as in the original version

2. Formulation of the vTEC response as below:





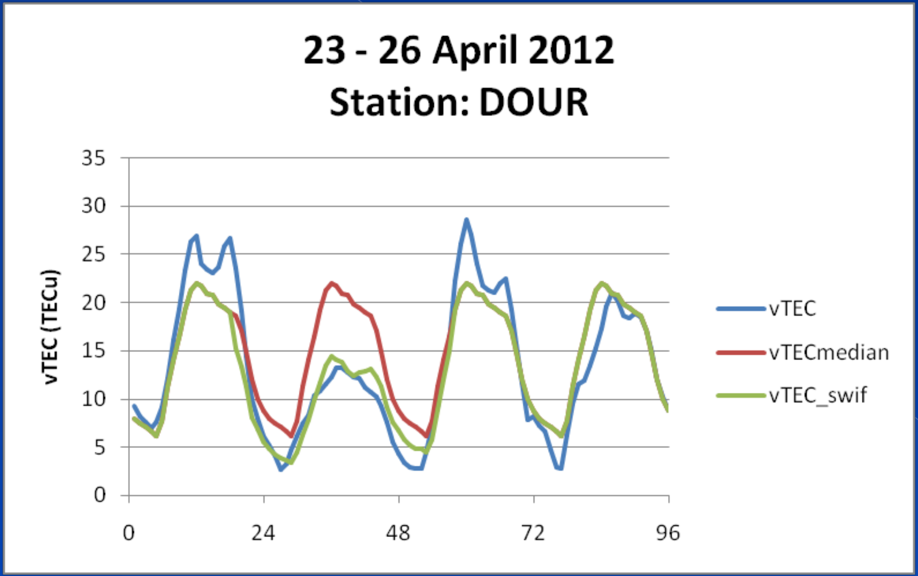


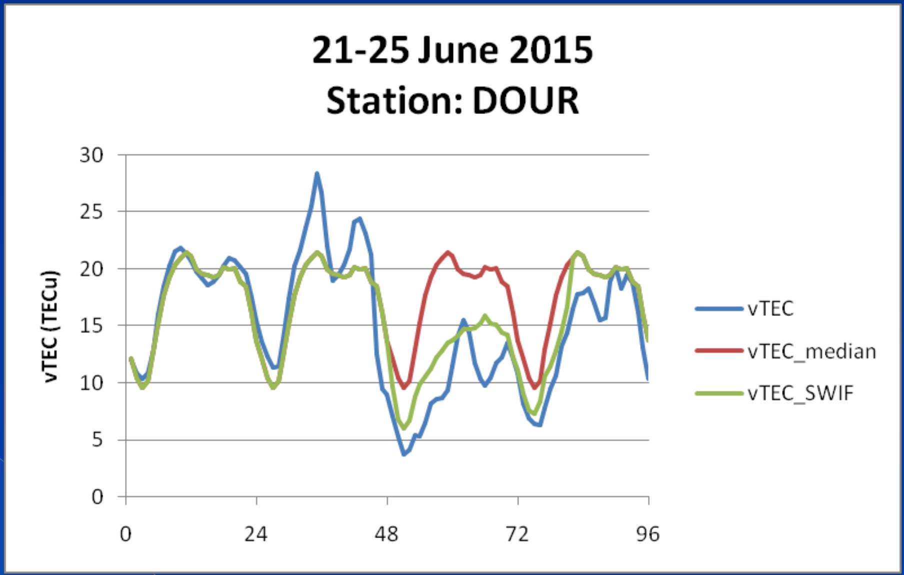


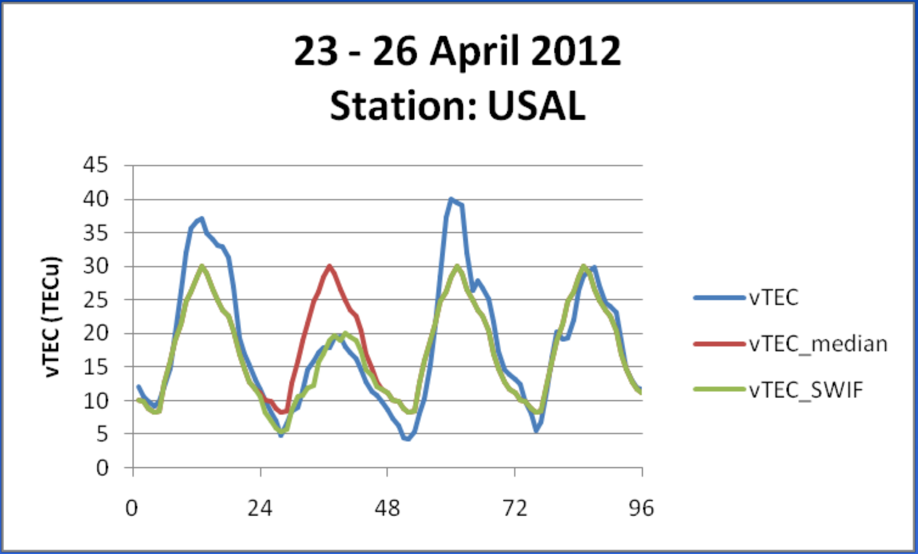
Model validation: preliminary results

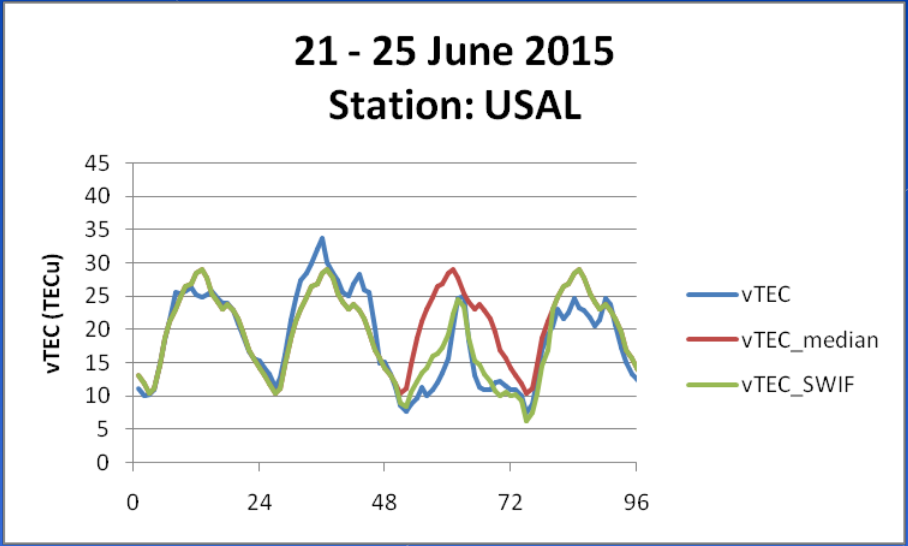
Storm onset time:
23/4/2015, 14:00 UT

Storm onset times:
22/06/2015 18:00 UT
22/06/2015 23:00 UT
23/06/2015 04:00 UT

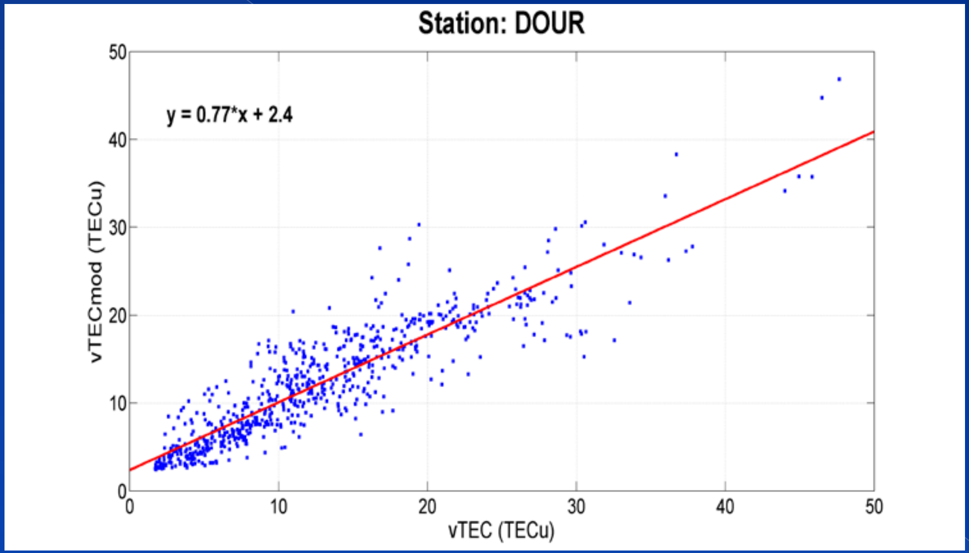


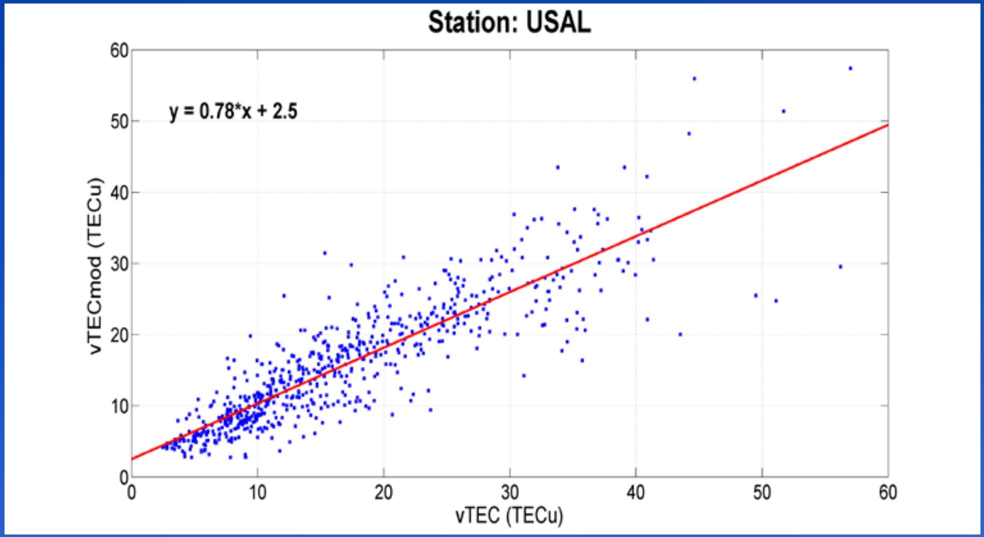






vTEC forecasts: Statistical results





	DOUR	USAL
ME (TECu)	0.5	1.0
MAE (TECu)	2.4	3.2
MRE (%)	4.0	-1.3
RMSE (TECu)	3.5	4.8

ME: *Mean Error*

MAE: *Mean Absolute Error*

MRE: *Mean Relative Error (wrt to the observed value)*

RMSE: *Root Mean Square Error*

Conclusive remarks

This investigation provides promising results regarding the forecasting of the storm time response of vTEC parameter (at least for middle latitudes) several hours in advance within an operational environment, based on the online analysis of the solar wind conditions.

The operational implementation of the SWIF model can be considered as a solid basis for further improvements in forecasting TEC storm time disturbances.

Challenge: Real time availability of the TEC estimates and determination of the TEC background level: results obtained by single station solutions may be more representative, but they are not available in real time. In contrary, results available in real time come with significant discrepancies depended on their calculation method and further analysis is required to effectively respond to the needs.