



Ionospheric storm alerts by the European Ionosonde Service (EIS): an overview of capabilities



Tsagouri I. and A. Belehaki

National Observatory of Athens

*Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing
Greece*



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EIS ionospheric storm alerts are based on the SWIF model - Middle and high latitudes

(Tsagouri & Belehaki, 2022; Tsagouri et al., 2018; Tsagouri & Belehaki, 2015; Tsagouri et al., 2009; Tsagouri & Belehaki, 2008)

- 2008:** STIM's original concept (empirical formulation of the foF2 storm time variations, middle latitudes, based on solar wind input from L1 point)
- 2009:** SWIF's development and implementation in the DIAS system at NOA (foF2 forecasting products and services for the European middle latitudes) - **Operational**
- 2013:** SWIF's upgrade to include forecasts for high latitudes (foF2) and implementation in European Ionosonde Service (EIS) of the I-ESC within ESA SSA SWE Service Network - **Operational**
- 2018:** SWIF's upgrade to include TEC forecasts – **Not operational yet**
- 2021:** SWIF's upgrade to Real Time Solar Wind (mainly DSCOVR) input



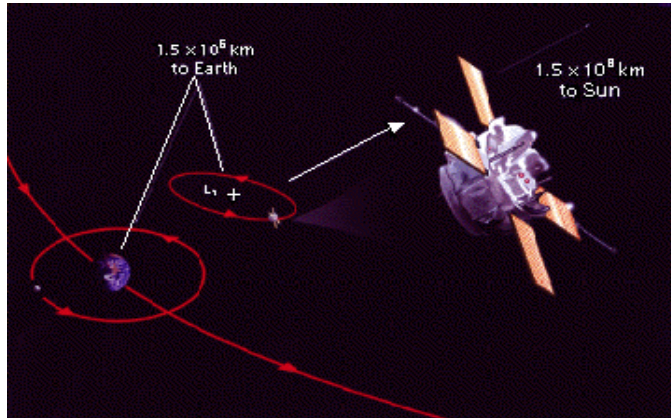
<http://dias.space.noa.gr>

<http://swe.ssa.esa.int/>



European Ionosonde Service (EIS)
ESA SSA Space Weather Service Network

SWIF's Alert: background concept



The idea:

Use of IMF (Interplanetary Magnetic Field) parameters at L1 as proxies of ionospheric activity level

Rate of the solar wind energy input into the magnetosphere (i.e., the energy coupling function between the solar wind and the magnetosphere) (Perreault and Akasofu, 1978):

$$\varepsilon = V B^2 \sin^4(\theta/2) l_0^2,$$

where l_0 is $7 R_E$, B is the magnitude of the IMF, and θ is the IMF clock angle defined as

$$\theta = \tan^{-1}(|By/Bz|) \quad \text{for } Bz > 0$$

$$\theta = 180^\circ - \tan^{-1}(|By/Bz|) \quad \text{for } Bz < 0.$$

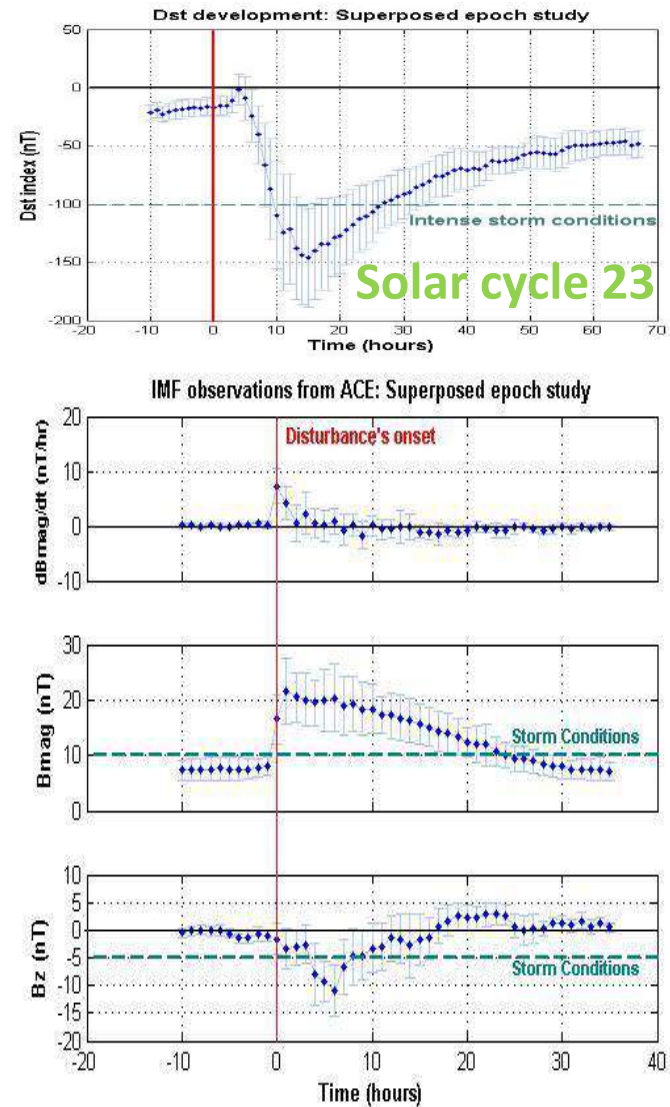
SWIF's Alert Detection Algorithm: Determination of the storm onset

Storm onset time based on quantitative criteria applied to

IMF-B (Total magnitude and rate of change)
IMF-Bz component

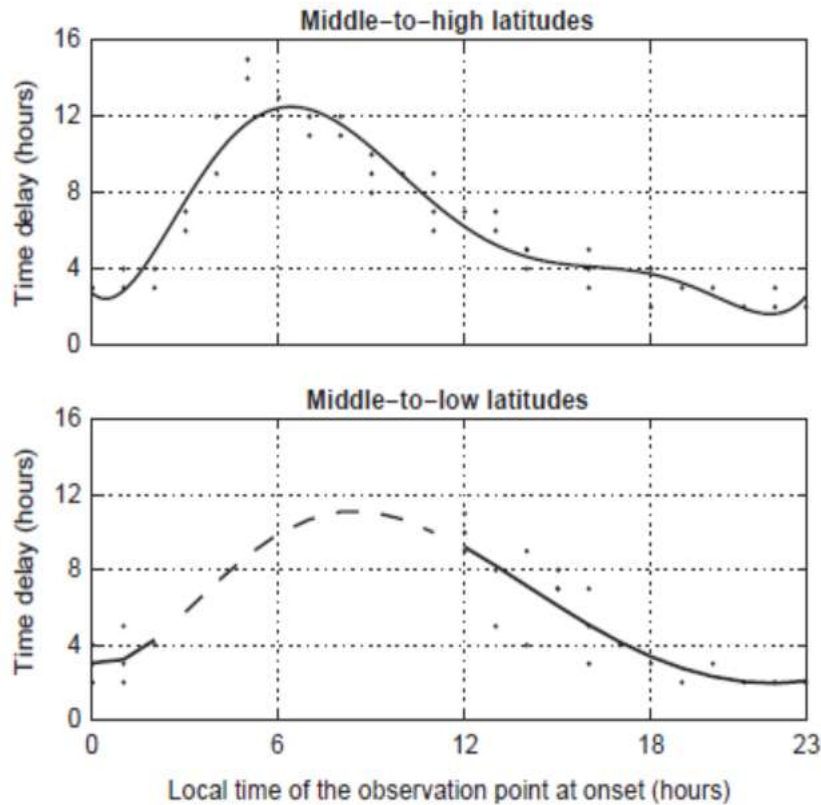
- (i) The IMF-B should record either a rapid increase denoted by time derivative values greater than 3.8 nT/h or absolute values greater than 13 nT.
- (ii) The IMF-Bz component should be southward directed either simultaneously or a few hours later. Intense storm conditions ($B_z < -10$ nT for at least 3h)

Tsagouri & Belehaki, 2008



SWIF's Alert Detection Algorithm:

Ionospheric storm onset



Tsagouri & Belehaki, 2008

i. Negative storm effects (ionization decreases)

The time delay in ionospheric negative storm onset with respect to the IMF storm onset ranges from about 3 to 13 hrs and it depends on the latitude and the LT of the observation point at the storm onset.

Negative storm effects are not anticipated by SWIF during daytime hours at middle-to-low latitudes.

ii. Positive storm effects (ionization increases): The time delay in ionospheric positive phase onset is about 2-3 hours.

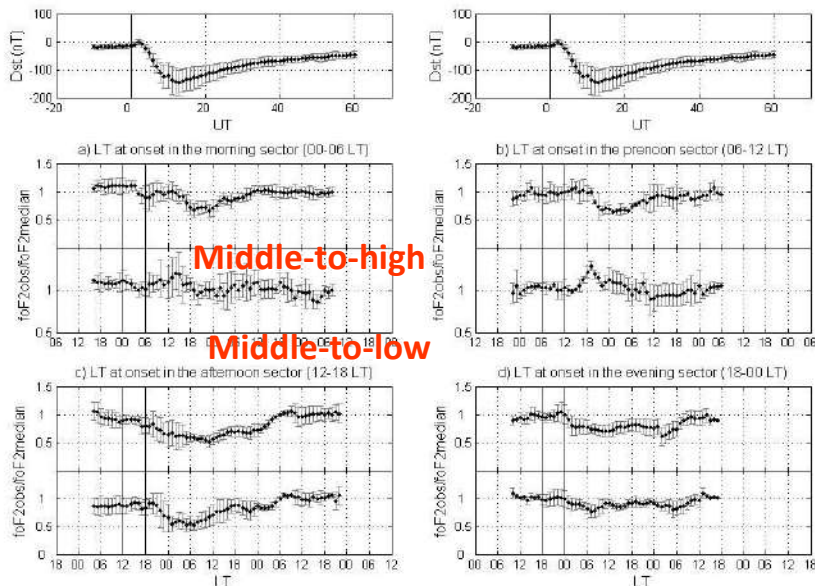
Ionospheric response

STIM's formulation of the ionospheric storm time response: empirical expressions (different for foF2 and TEC) 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-to-low and middle-to-high latitudes (less or greater than 45° , respectively)
- **Four local time sectors**:

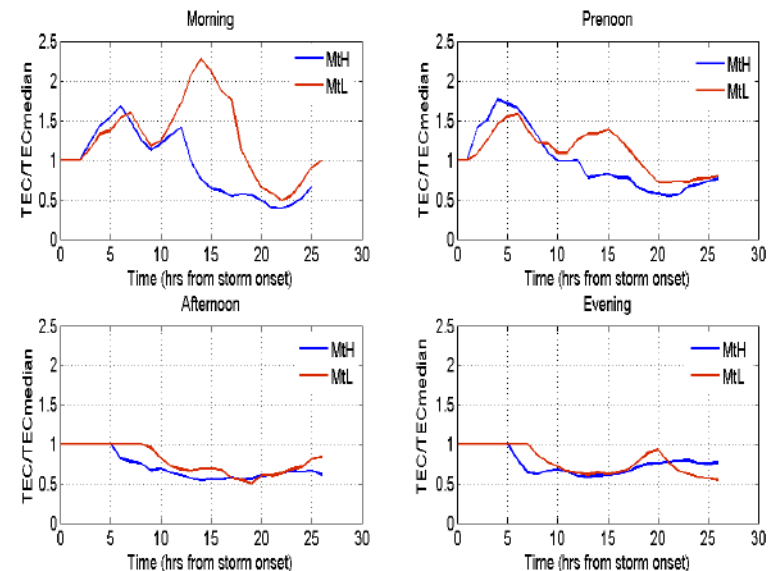
Morning (00 – 06 LT); Prenoon (06 – 12 LT); Afternoon (12 – 18 LT); Evening (18 – 00 LT)

foF2 critical frequency



Tsagouri & Belehaki, 2008

Total Electron Content (TEC)



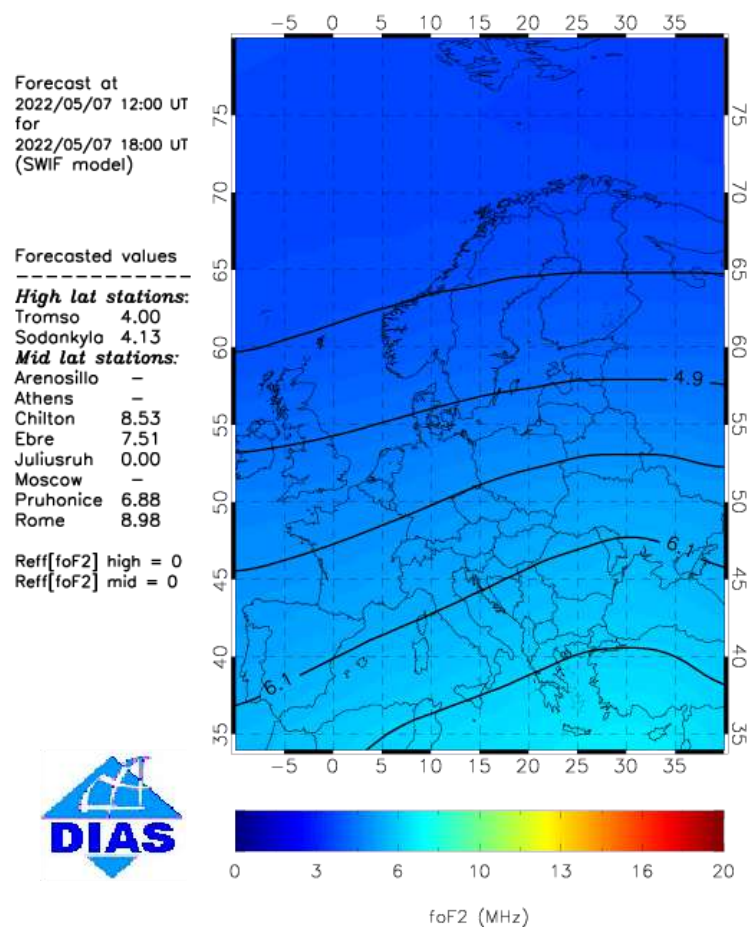
Tsagouri et al., 2018

Products presently available through the implementation of the SWIF model:

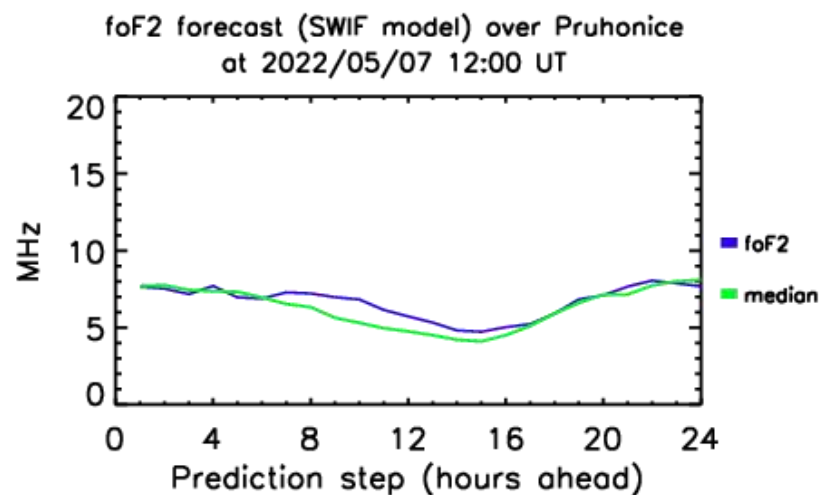
DIAS system: <http://dias.space.noa.gr>

ESA /SSA / SWE/ EIS: <http://swe.ssa.esa.int/web/guest/dias-federated>

Forecasting maps for foF2 over Europe up to 24 hrs ahead



Single-site forecasts of foF2 over DIAS locations up to 24 hrs ahead



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Alerts and warnings for upcoming storm-time disturbances

1iEIS Product I.118: Alerts for ionospheric disturbances in the European sector (based on the Alert Algorithm of the SWIF model)

EIS Ionospheric Storm Alert for Europe powered by the DIAS backend

Issue Time: 2022-02-03 03:00 UT

Updated on: N/A

foF2 storm time disturbances are expected over Europe from 03-02-2022 to 04-02-2022

Expected storm effects

Positive: Possible at middle to low latitudes

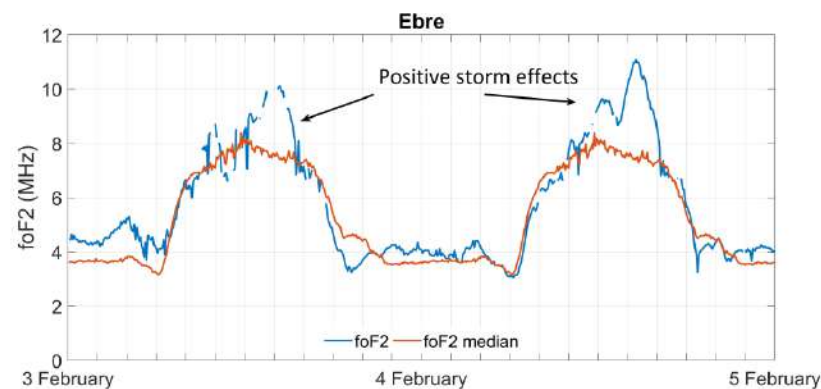
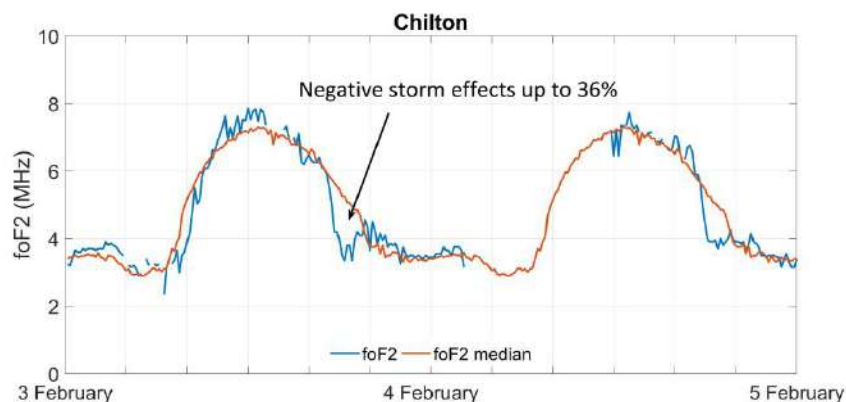
Negative: Possible up to 36% (locally)

National Observatory of Athens

Ionospheric Physics Group, IAASARS

DIAS - European Digital Upper Atmosphere Server

For more information, see <http://dias.space.noa.gr>





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ESC Ionospheric Weather

ESC Geomagnetic Conditions

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Data providers: NOA IAP RAL INGV OE UFA INTA IZMIRAN ROB NOAA

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Current Ionospheric
Conditions

Ionospheric Alerts

foF2 Nowcasting Maps

foF2 Long Term Prediction Maps

foF2 Forecasts

hmF2 Maps

Near Real-time TEC Maps

Monitoring Tool

Quality Indicators

Rules of the Road

The EIS Team

ESA SSA-SWE Portal

Alerts for Ionospheric Disturbances (I.118)

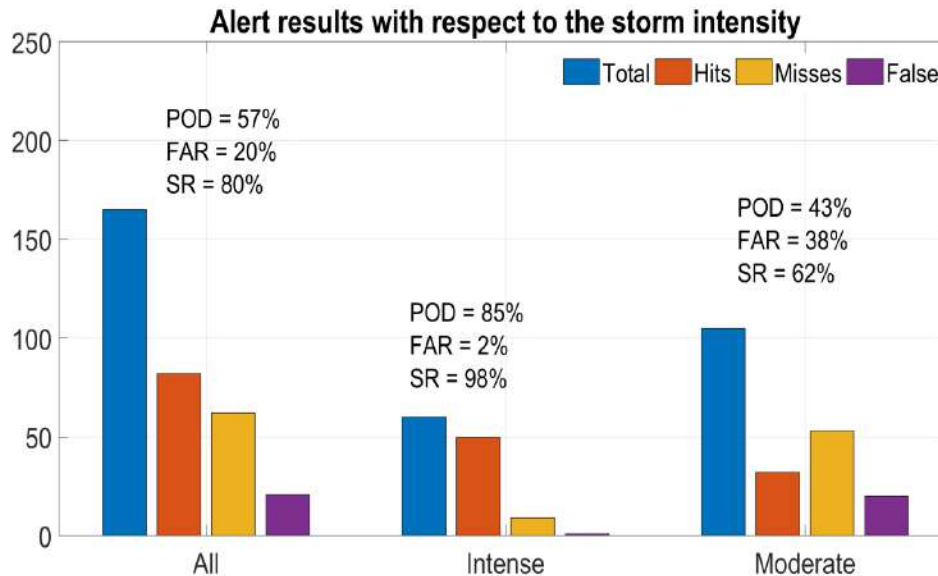
EIS Home / Ionospheric Alerts

- > 2022
- > 2021
- > 2019
- > 2018
- > 2017
- > 2016
- > 2015
- > 2014
- > 2013

Need Help?

Validation tests: ADA's prediction efficiency in terms of the storm intensity (Tzagouri & Belehaki 2015; Tzagouri & Belehaki 2022)

The design of the validation plan follows the guidelines for common validation in the SSA SWE network (ssa-swe-escdef-tn-5401, i2r2, 08/09/2020): Technical Note on Validation of EIS alerts, 2021 (P3-SWE-V)



From Technical Note on Validation of EIS alerts

> 150 storm events (intense or moderate) in SC23, SC24 and SC25

Intense storm events (min Dst < -100 nT) are successfully captured by SWIF's ADA.

Poorer performance is recorded under the occurrence of moderate storm events

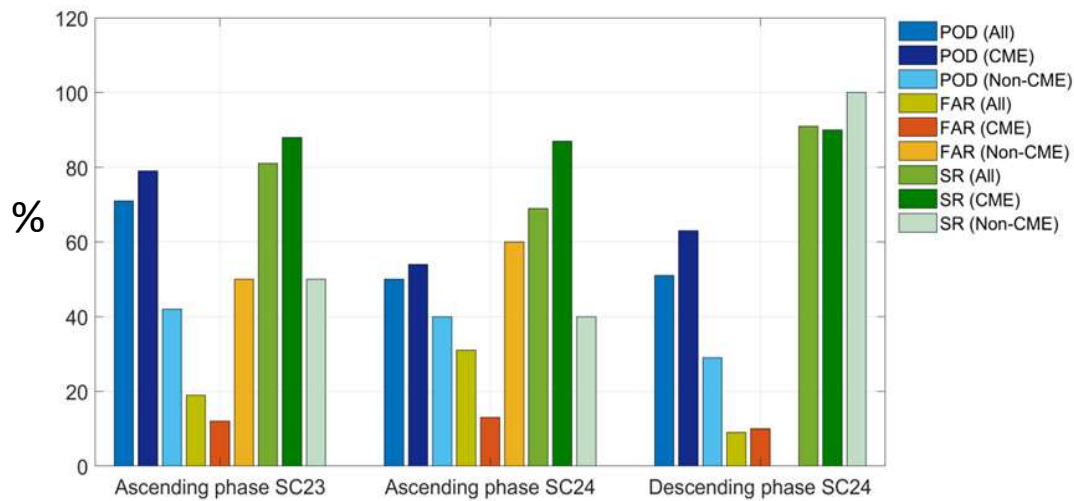
Metrics:

- Probability of Detection: $POD = A / (A + C)$
- False Alarm Rate: $FAR = B / (A + B)$
- Success Ratio: $SR = A / (A+B)$

where: A the number of true alerts or hits (ionospheric storm time disturbances over Europe were forecast and did occur) ; B the number of false alarms (ionospheric storm time disturbances over Europe were forecast but not occurred); and C the number of missed events (ionospheric storm time disturbances were not predicted but did occur).

Validation tests: ADA's prediction efficiency in terms of the interplanetary causes of the storms

(Tsaouri 2011; Tsaouri and Belehaki 2015; Tsaouri and Belehaki 2022)



The results show that the **higher performance** is recorded under the occurrence of storms related with **interplanetary CME** signatures (usually intense storms). **Lower performance** tend to be related with **non-CME structures** (usually storms of moderate intensity).

CME: Storms related to CME-associated solar wind flows (e.g., sheath fields or the ejecta itself) in the near-Earth solar wind

Non CME: storms not related to such structures. The latter may be associated to other sources of disturbances, e.g., Corotating Interaction Regions (CIRs) and pure High Speed Streams (HSSs).

The different cases were distinguished through the examination of the list of ICMEs that is available at <http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm> (Richardson and Cane, 2010).

Future upgrades

- Accommodation of TEC predictions in the alerts formulation. The empirical expressions that quantify the TEC storm-time response have been obtained (Tsagouri et al. 2018)
- Upgrade of SWIF's alert criteria towards the better performance of the model under the occurrence of storms of moderate intensity / not-CME driven storms