PITHIA-NRF and T-FORS Training School

Ionospheric prediction for storm effects – who to discover relevant data collections in the PITHIA-NRF e-science center

Anna Belehaki, PITHIA-NRF project coordinator
Research Director, NOA

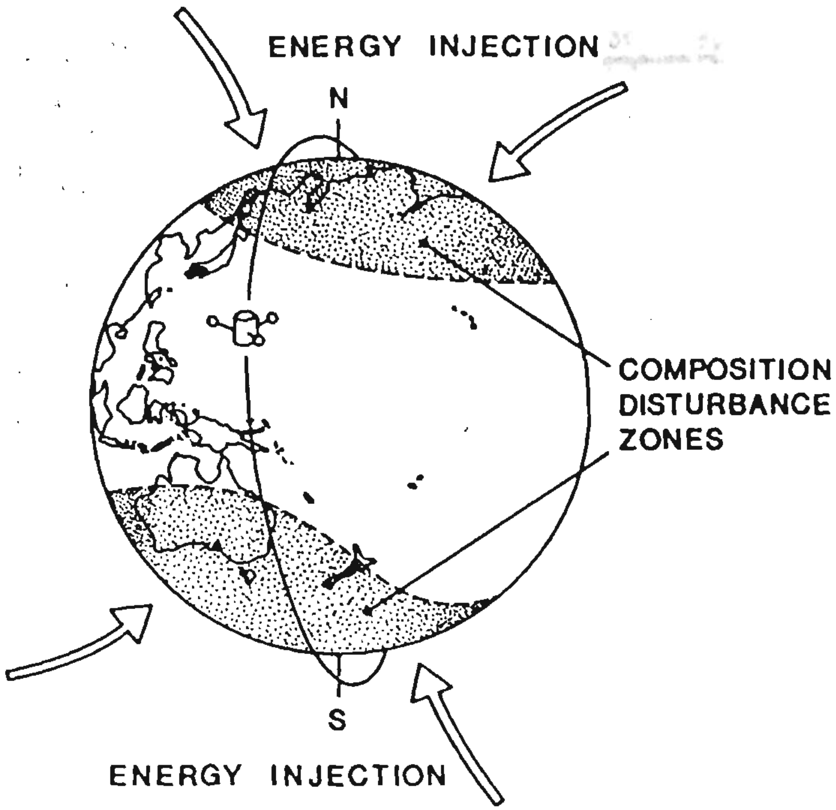
Outline

- The Prölss Ionospheric Storm Model
- Ionospheric Storm Models
  - IRI model – global climatological model
  - SWIF model – regional storm time model
- Travelling Ionospheric Disturbances Detectors
  - TechTIDE detection methodologies
- How to discover data collection in PITHIA-NRF eScience Centre

Ionospheric Storms Phenomenological Model (Prölss)

The enhanced Joule heating is globally the most important factor producing the thermospheric storm.

Ionosphere-Thermosphere coupling: The resulting slow ionization loss by recombination, i.e. neutral atmosphere processes including dynamics, have sufficient time available to affect the ionized component substantially.

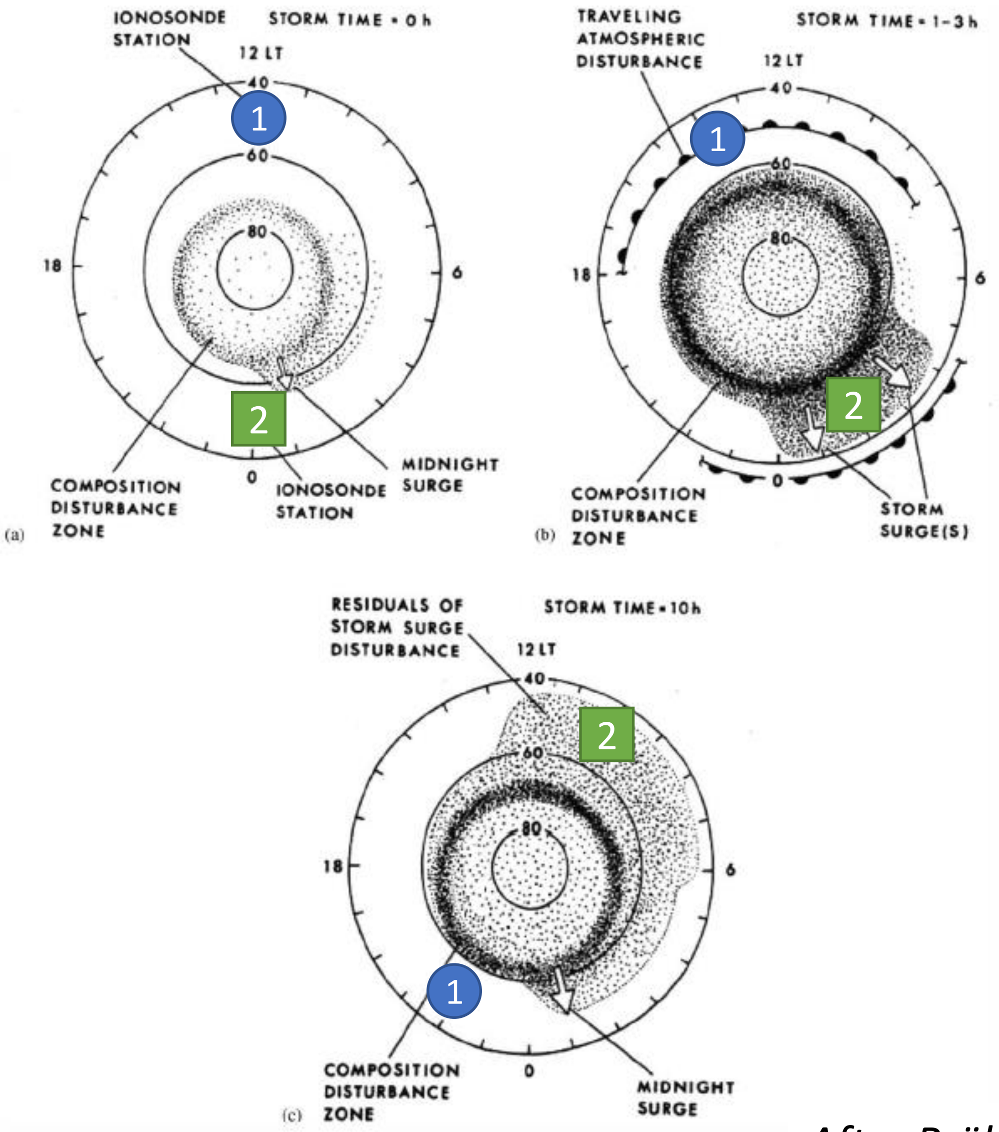


Prölss, 1995
Handbook of Atmospheric Electrodynamics

Prölss phenomenological model: local-time dependent scenario

The station [1] located in the afternoon sector during the expansion phase does not experience the negative phase of the ionospheric storm.

The station [2] located in the early morning sector observes well the ionospheric storm. During strong and long storms, the negative phase reaches lower latitudes, lasts longer and may "occupy" the whole midlatitude area.

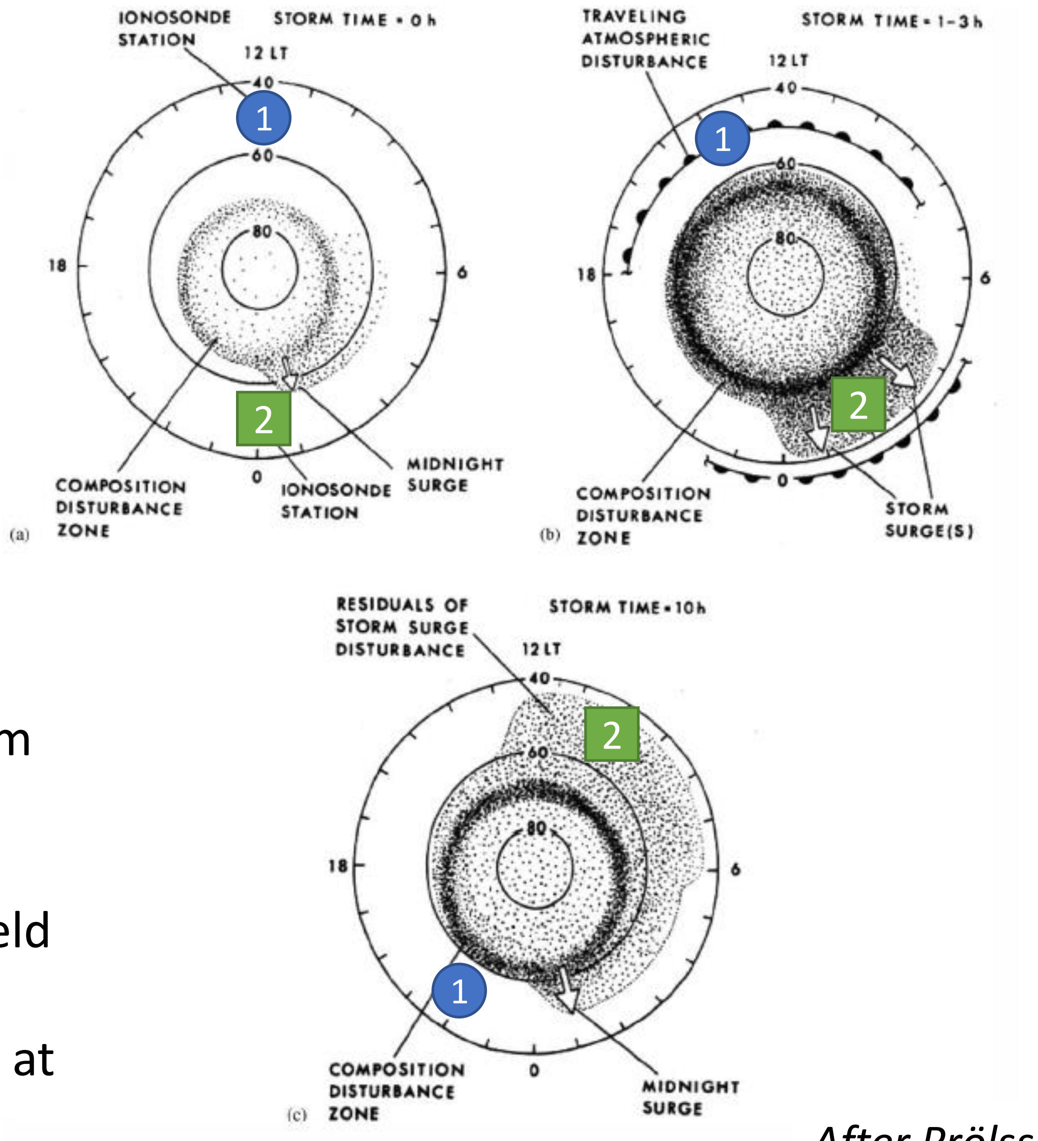


After Prölss, 1996

Prölss phenomenological model:
positive and negative storm effects

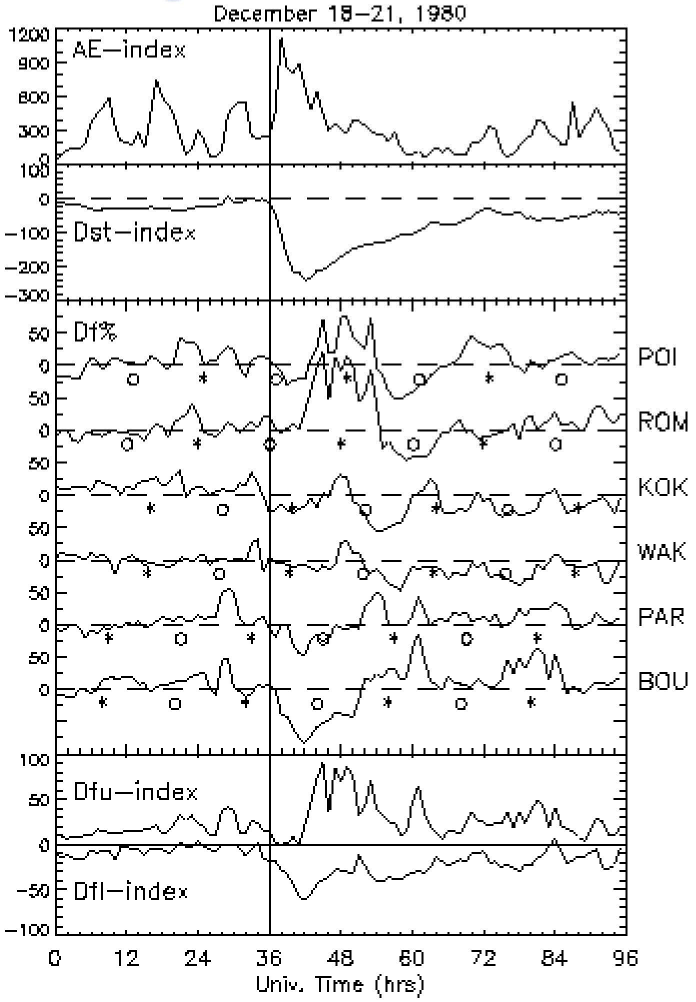
<u>Negative storm effects</u>: The negative phase is predominantly an ionospheric response to the thermospheric disturbance, to a change of composition due to heating of the thermosphere.

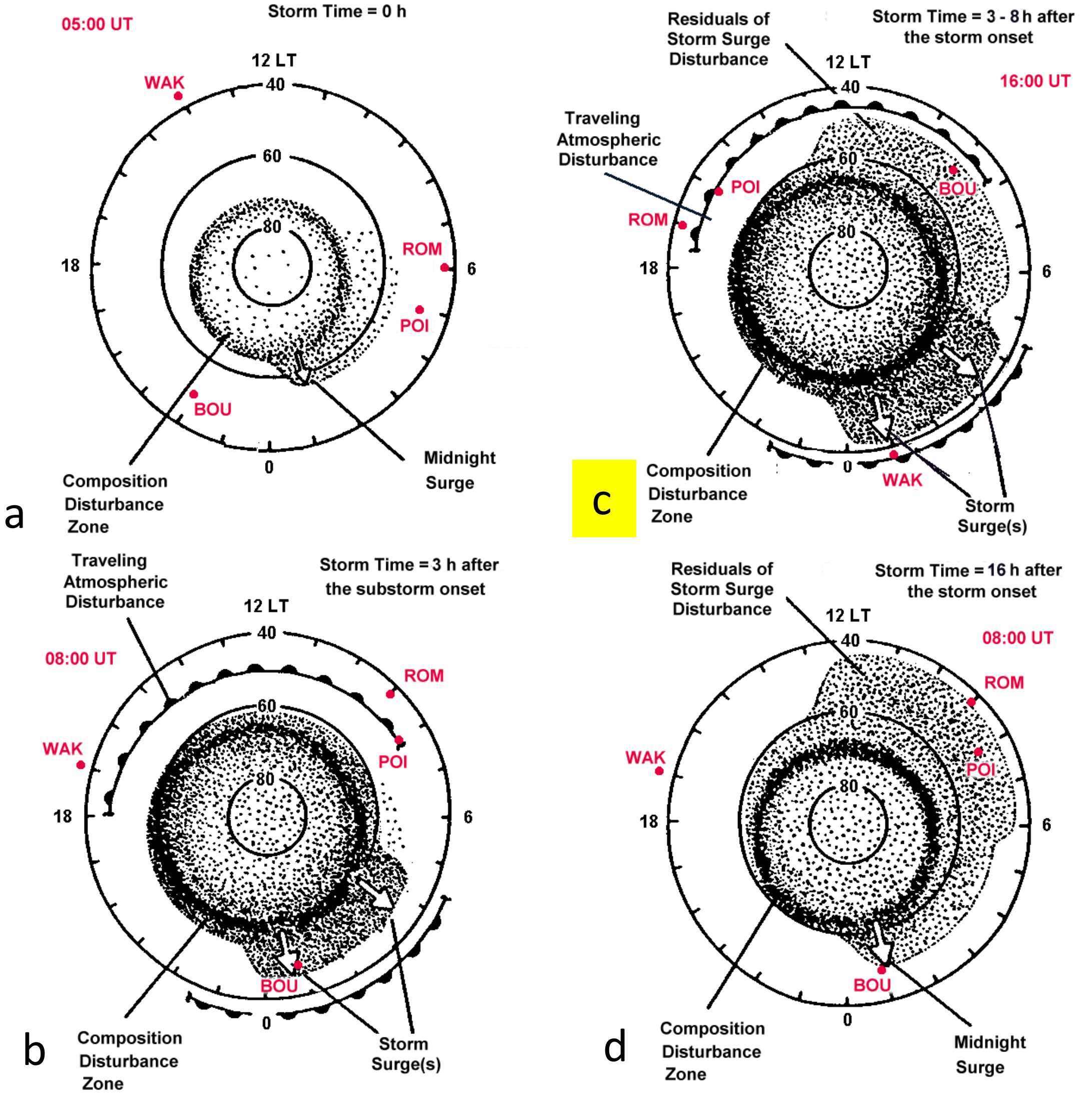
<u>Positive storm effects</u>: During the day Travelling Atmospheric Disturbances (TADs) propagate from auroral zone to lower latitudes. This disturbance propagates with storm-induced meridional wind pushing ionization upward along geomagnetic field lines. It results to an increase of hmF2 and an increase of NmF2 due to lower electron loss rate at higher altitudes. At night lack of ionization production diminishes their formation.



After Prölss, 1996

Capturing night-time positive storm effects





A possible explanation for their generation may be consistent with the point of Fuller-Rowell et al. (1994) suggesting that if a positive phase is driven by winds before dusk it will rotate into the night side.

After Tsagouri and Belehaki, GRL 2000

In Summary, according to the Prölss theory:

Energy injection in the polar cap region causes triggers several physical effects in the ionosphere:

- Ionization enhancement (positive storm effect)
- Ionization depletion (negative storm effect)

→ Relevant models: IRI, SWIF

- Travelling Atmospheric Disturbances (TADs), waves in the thermosphere which are often associated with Travelling Ionospheric Disturbances (TIDs)

→ Relevant models: TechTIDE suite of models

International Reference Ionosphere - IRI

IRI is an international project jointly sponsored by COSPAR and URSI to develop an improved reference model for the most important plasma parameters in the Earth's Ionosphere

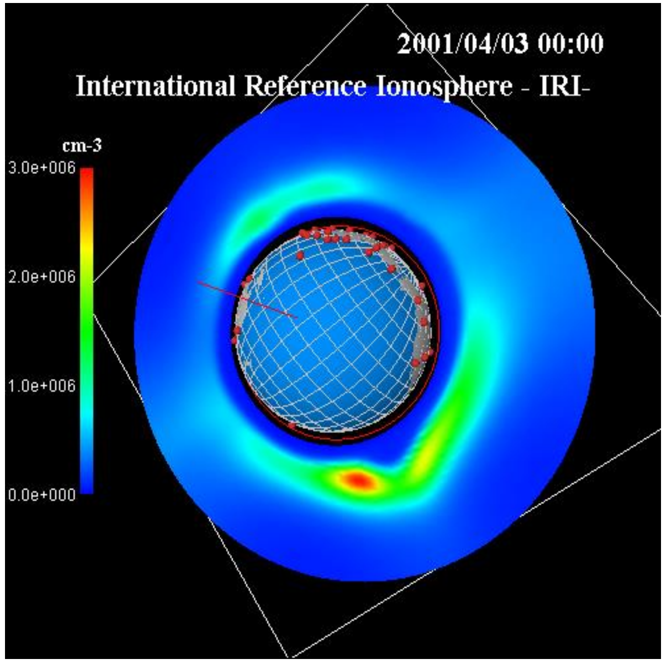
https://irimodel.org/

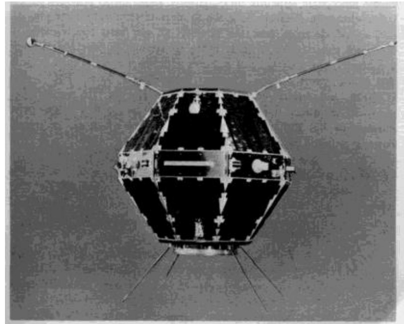
Online computation and plotting at CCMC (HELP): IRI-2020, IRI-2016, IRI-2012, IRI-2007

IRI is an empirical (data-based) model representing the primary ionospheric parameters based on the long data record that exists from ground and space observations of the ionosphere.

The core model describes monthly averages in the altitude range 50-1500 km:

+ Electron density
+ Electron temperature
+ Ion composition (O+, O2+, NO+, N+, He+, H+)
+ Ion temperature
+ Ion drift (currently only equatorial vertical F-region drift)
+ spread-F occurrence probability (currently limited to South-American sector)





ISIS 1 (RCA Ltd. photo)

Data Sources

Instrument	*Platform*	*Used for*	*Comments*
Ionosondes	Worldwide Network	N_e from E to F2	Fifties to now
Incoherent Scatter Radar	Jicamarca, Arecibo, St. Santin, MillstoneH., Malvern	N_e profile (E- valley) T_e, T_i	Few radars, many parameters
Topside Sounder	Alouette 1, 2 ISIS 1, 2	N_e topside profile	newer data from Ohzora, ISS-b, IK-19
Insitu Aeros-A,-B	AE-C,-D,-E profile,T_e,T_i, IK-24, DE-2	N_e topside DMSP, OGO ion comp.	many more: Hinotori
Rocket	data compilations	N_e D-region, Ion comp.	sparse data set

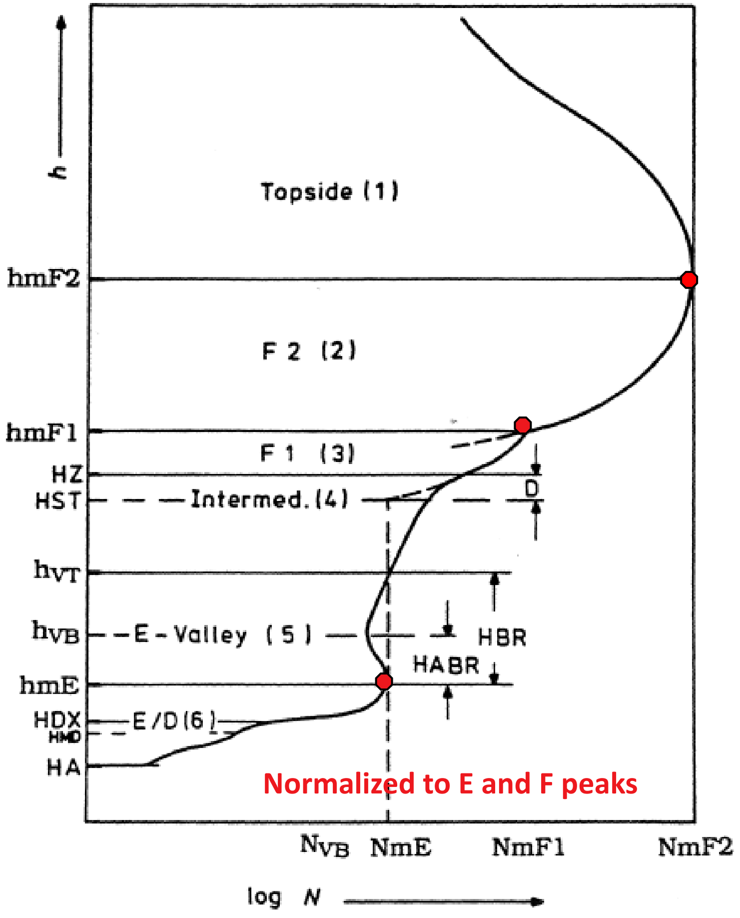
Build-up of IRI electron density profile

Mathematical functions:

Global Variations:
Spherical harmonics,
special functions

Time Variations:
Fourier,
simple sin/cos,
step-functions

Height Variations:
Epstein functions



Global models for
foF2/NmF2, foF1/NmF1, foE/NmE
hmF2/M(3000)F2, hmF1 , hmE

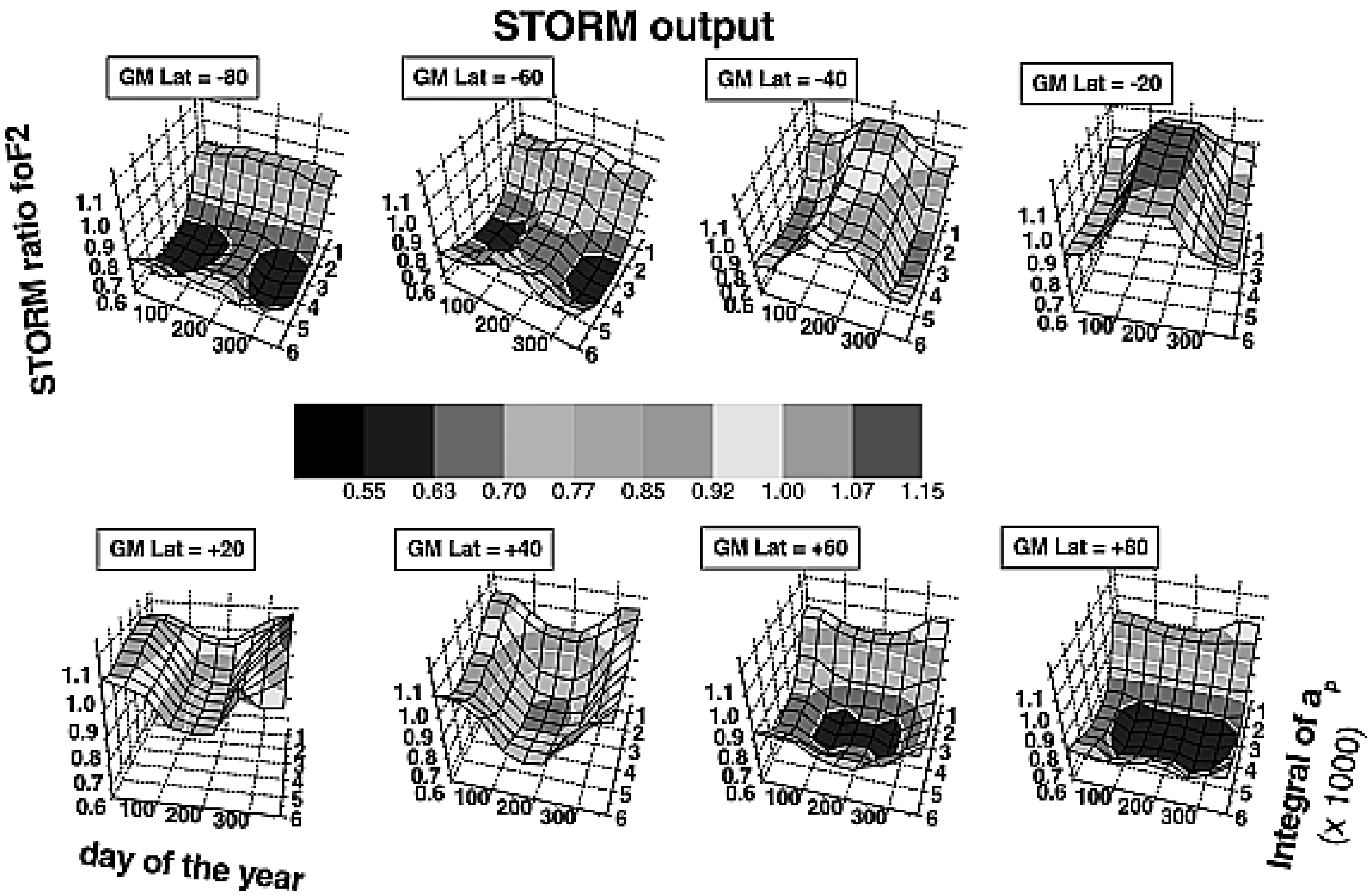
Additional IRI capabilities

Developments in the IRI have the goal to move **from the climatological** representation provided by the standard IRI model **to a description of real-time or past-time ionospheric weather conditions** based on:

- the integration of the Empirical Ionospheric Storm-Time Correction Model
- the ingestion of real-time measurements - IRI-based Real-Time Assimilative Mapping IRTAM

Empirical Ionospheric Storm-Time Correction Model
by E. A. Araujo-Pradere, T. J. Fuller-Rowell, and M. V. Codrescu (Radio Science, 2002)
Integrated in the International Reference Ionosphere in an effort to include a dependence on geomagnetic activity within this climatological model.

A new index was developed to characterize the intensity of the storm by integrating the previous 33 hours of ap, weighted by a filter. The output of the model provides a simple correction to the quiet time F-region peak critical frequency due to the storm.



Input: 36 hour filtered ap (based on ap, global ionospheric foF2, Many years of storm-time intervals)

Output: Ionospheric foF2 correction

Lead time: depends on ap lead time

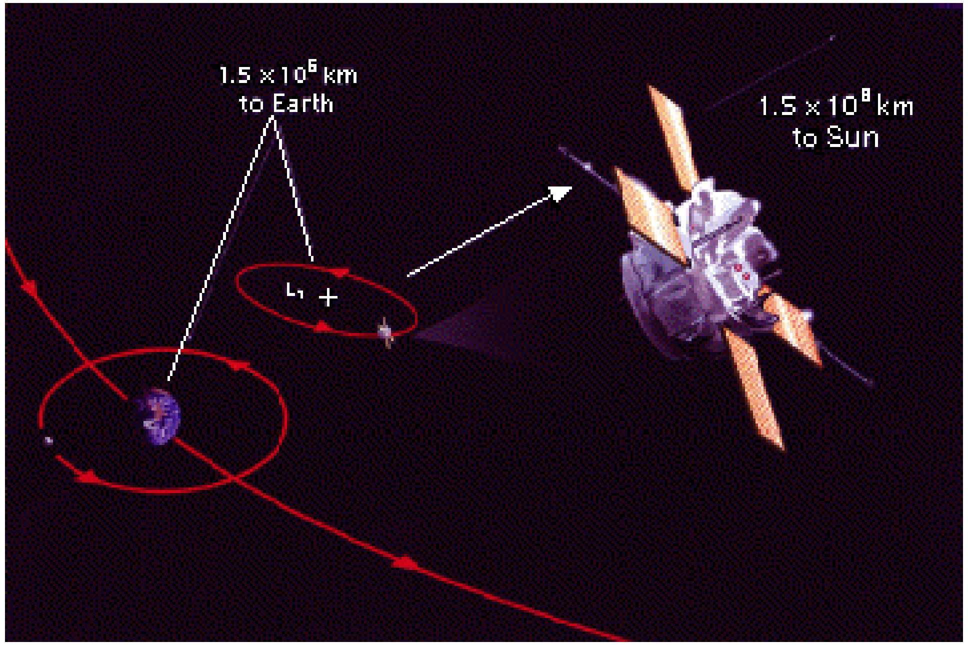
The model validation study indicates that a significant improvement is provided in equinox and summer, but in winter no quantitative improvement can be demonstrated.

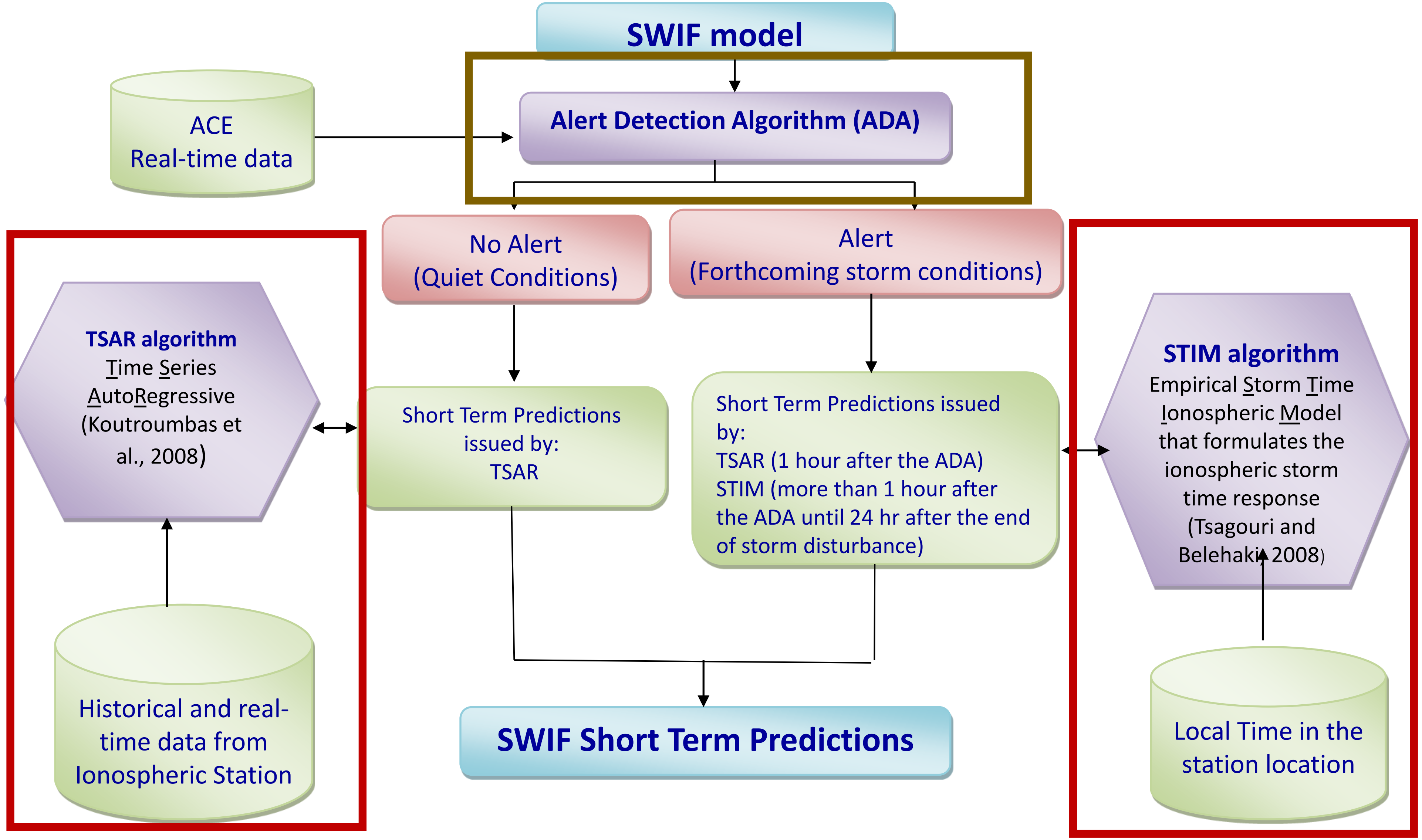
Solar wind – driven Ionospheric Forecasts: the SWIF model

The concept:

Use as “driver” the solar wind magnetic field at L1 contributing to the forecast of the high latitude Joule heating at least <u>one hour in advance</u>.

By orbiting the L1 point, ACE/DSCOVR satellites will stay in a relatively constant position with respect to the Earth as the Earth revolves around the sun.




SWIF model
ACE
Real-time data
Alert Detection Algorithm (ADA)
No Alert
(Quiet Conditions)
Alert
(Forthcoming storm conditions)
TSAR algorithm
Time Series
AutoRegressive
(Koutroumbas et al., 2008)
Short Term Predictions issued by:
TSAR
Short Term Predictions issued by:
TSAR (1 hour after the ADA)
STIM (more than 1 hour after the ADA until 24 hr after the end of storm disturbance)
STIM algorithm
Empirical Storm Time Ionospheric Model that formulates the ionospheric storm time response
(Tsagouri and Belehaki, 2008)
Historical and real-time data from Ionospheric Station
SWIF Short Term Predictions
Local Time in the station location

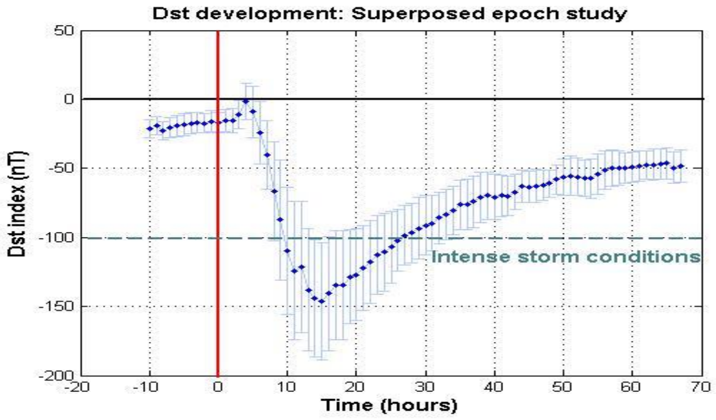
SWIF model – Alert detection criteria

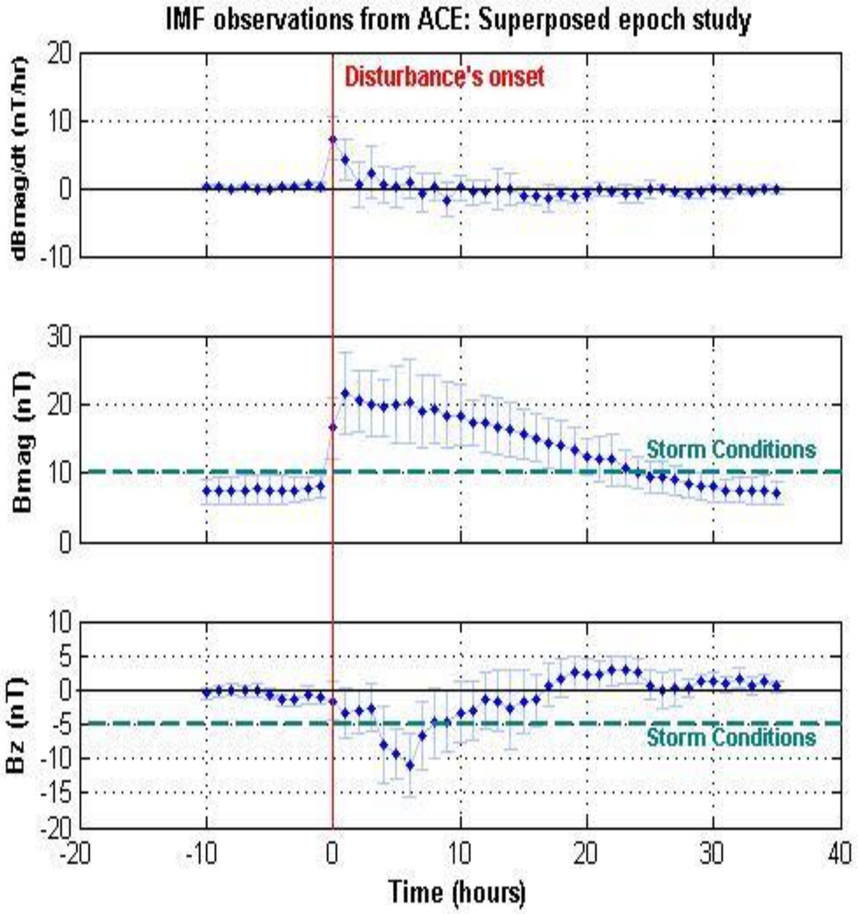
The criteria were determined through empirical tests (superimposed epoch analysis) and literature investigation. In principle, they are set up to predict the ionospheric storm time response during intense storm events (min Dst < -100nT)

(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 13nT.

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

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

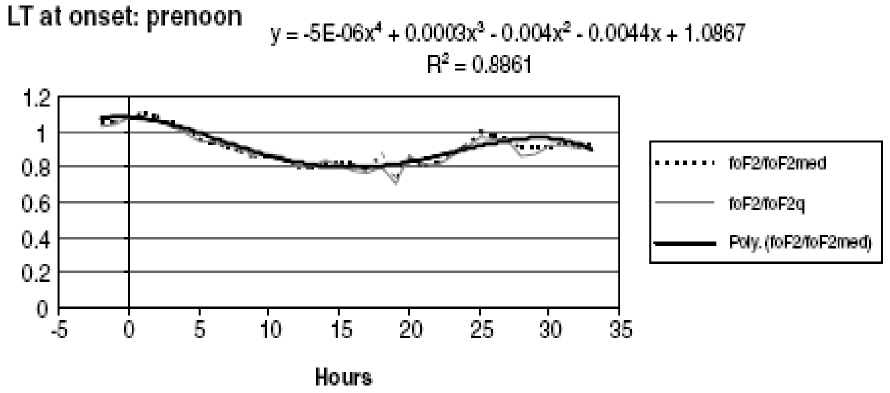


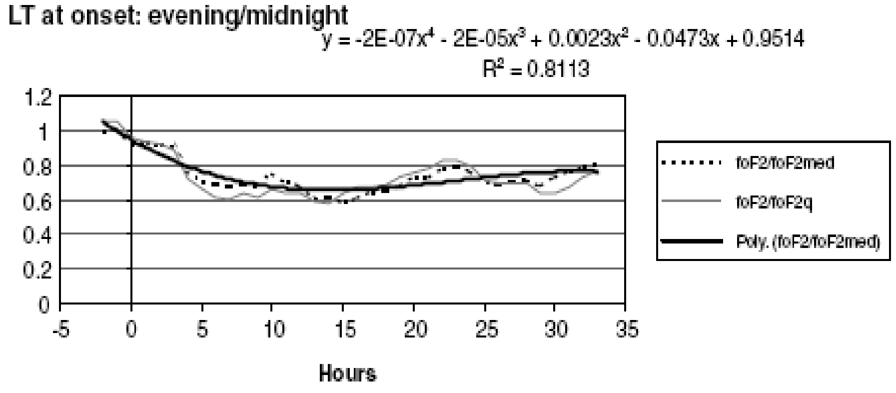


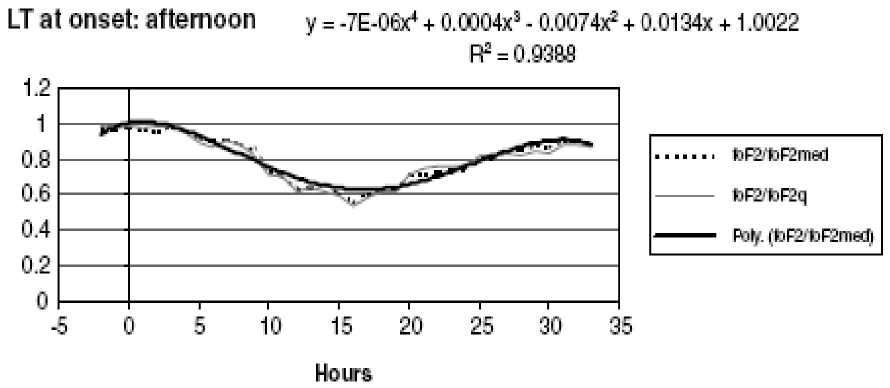
SWIF model – Formulation of storm time ionospheric response

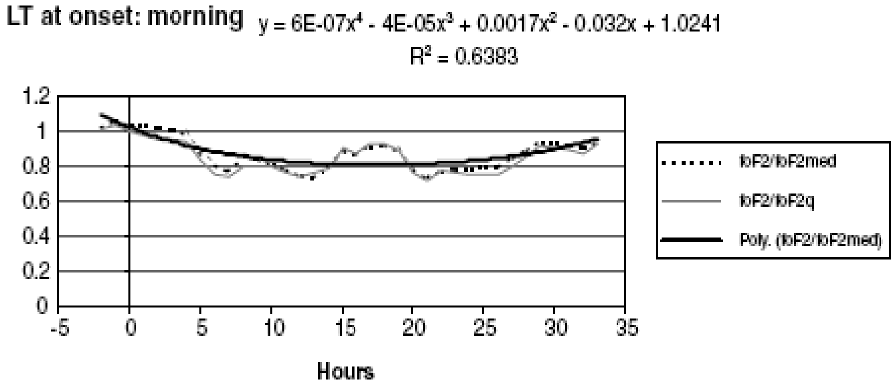
The STIM formulation of based on empirical expressions to provide a correction factor to the reference variation based on the latitude of the observation point and its local time at the storm onset at L1 point:

- Two latitudinal zones (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)

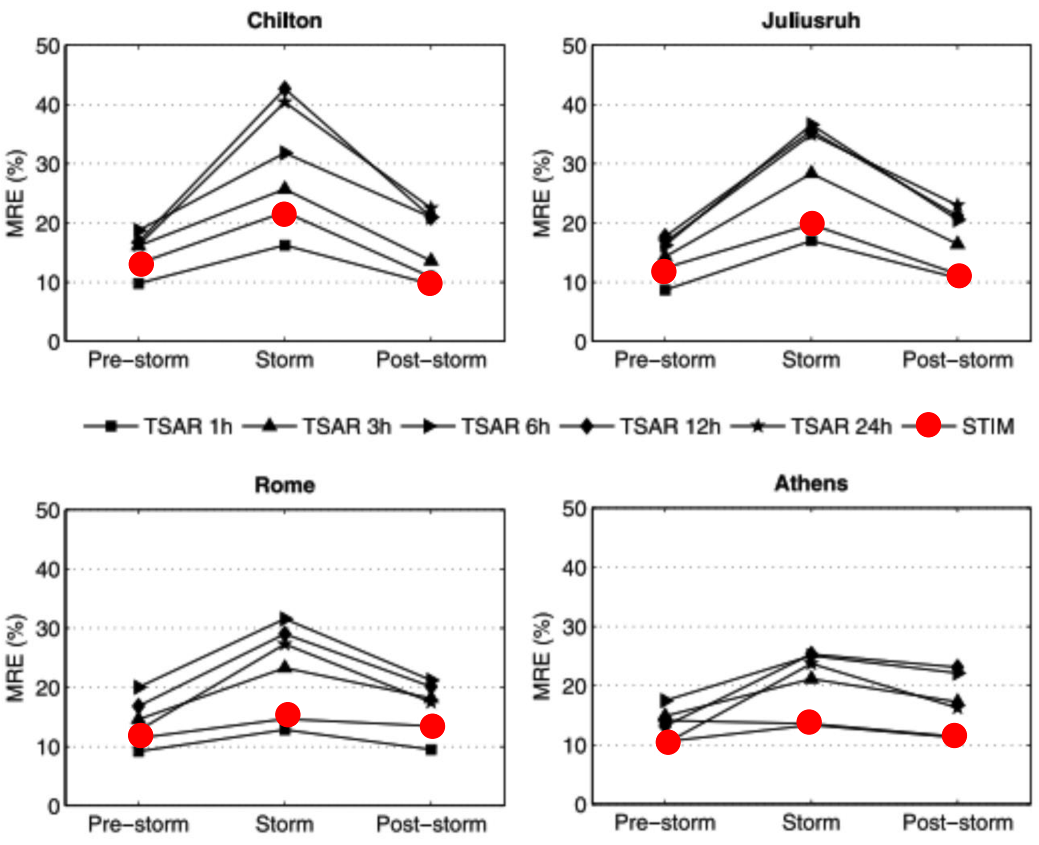








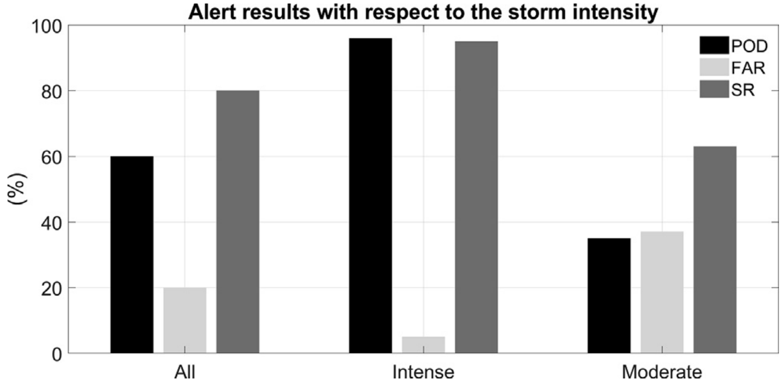
SWIF model – Verification



The mean absolute relative error (MRE) of TSAR's and STIM's predictions from actual observations in respect to the storm development for each ionospheric station. The results are obtained over 12 storms occurred from 1998 to 2005.

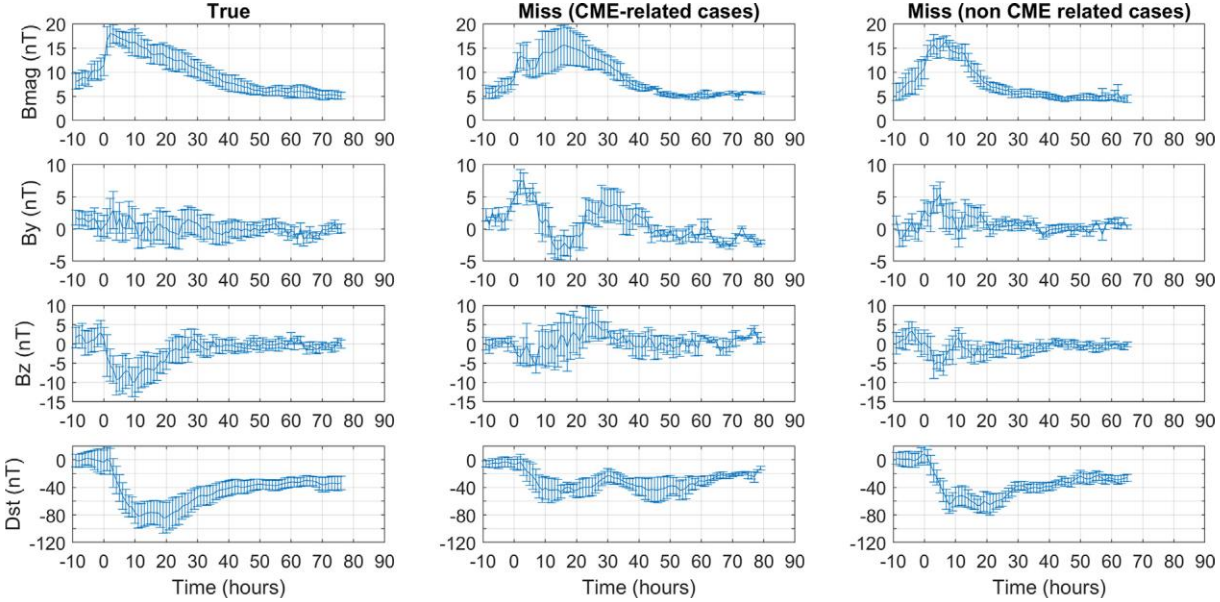
(Tsagouri, Koutroumbas and Belehaki, Radio Science doi:10.1029/2008RS004112, 2009)

Evaluation of SWIF performance



Considering the Akasofu epsilon parameter, the possible effect of the By-IMF component is considered for future upgrade of the SWIF Alert criteria

$$\varepsilon(\mathrm{erg/s}) = vB^2 \sin^4\left(\frac{\theta}{2}\right) l_0^2$$



(i) Probability of Detection (POD) as T/(T + M)
(ii) False Alarm Rate (FAR) as F/(T + F)
(iii) Success Ratio (SR) as T/(T + F)
T: True alerts – F: False alarms – M: Misses

The SWIF's alert efficiency for 43 storms occurred in SC 23 and SC 24. The prediction efficiency is higher for intense storms, but significantly poorer for storms of moderate intensity. For moderate storm events, POD is reduced up to more than 50%.

- High forecasting ability for intense storms usually driven by coronal mass ejections
- Limited forecasting ability mainly for storms not related to coronal mass ejections which are usually of moderate intensity.

Tsagouri and Belehaki, ASR, 2022, https://doi.org/10.1016/j.asr.2022.06.047

Some examples on the performance of ionospheric prediction models during storms

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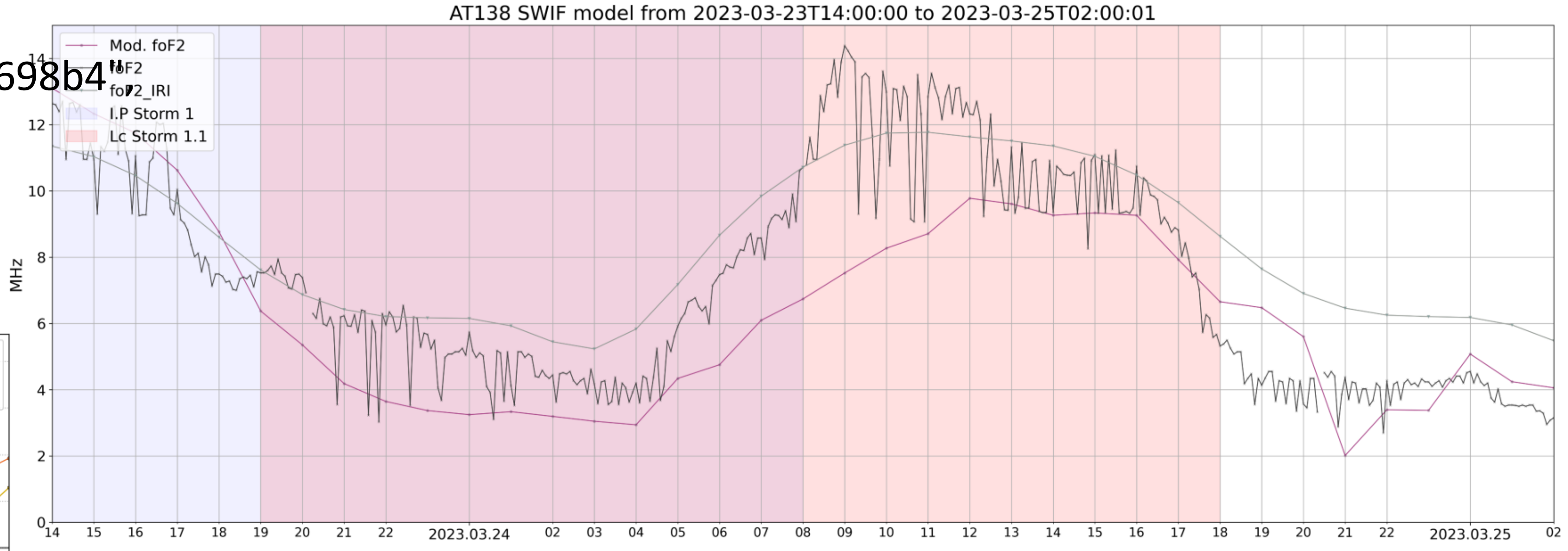
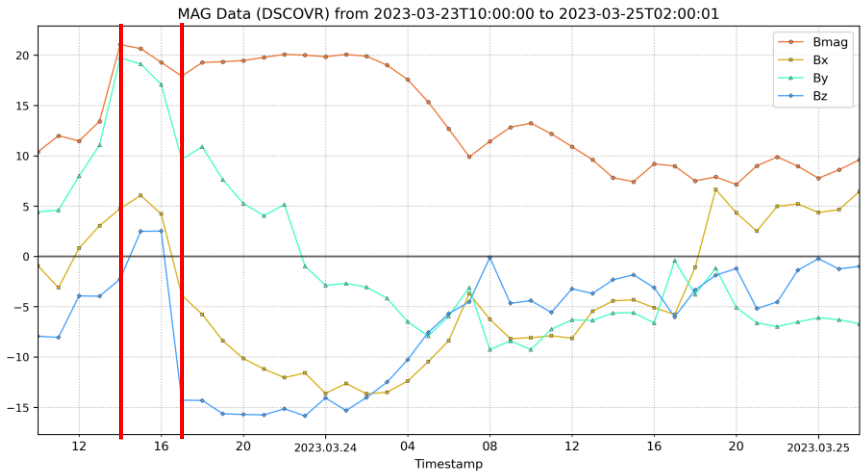
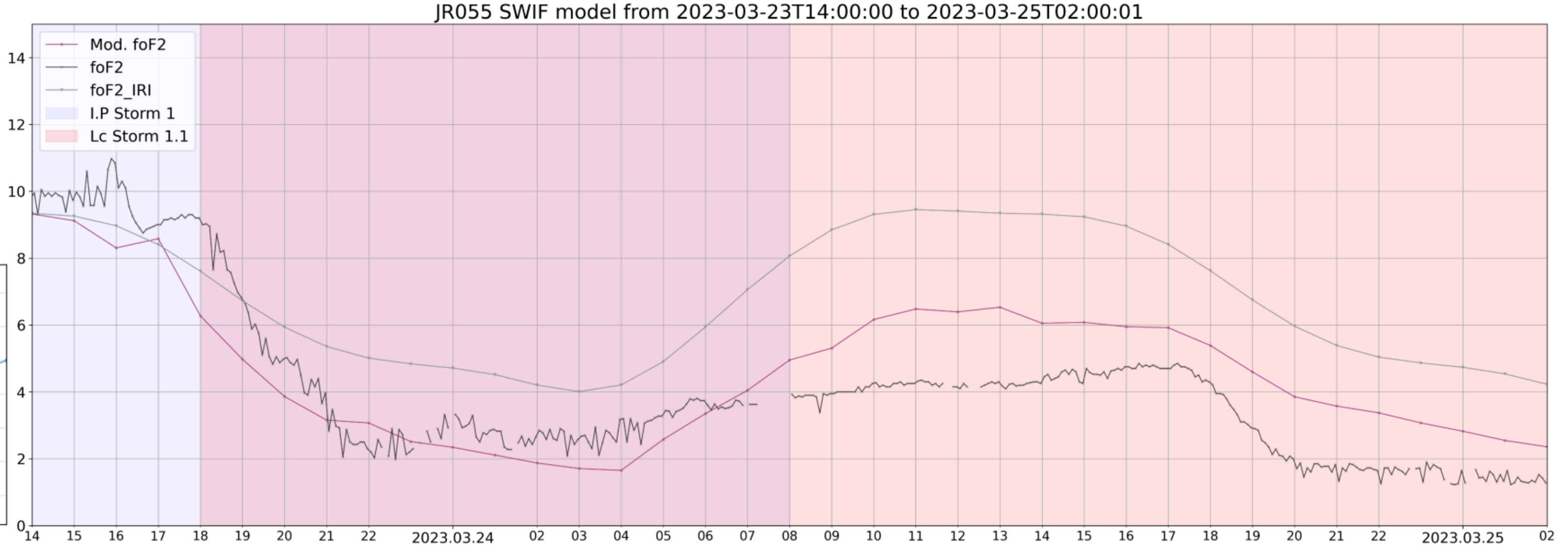
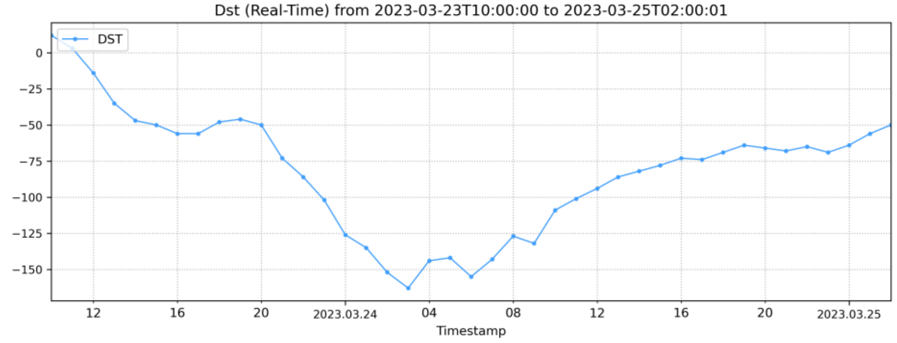
"status": "closed"

Start: 23 March 2023









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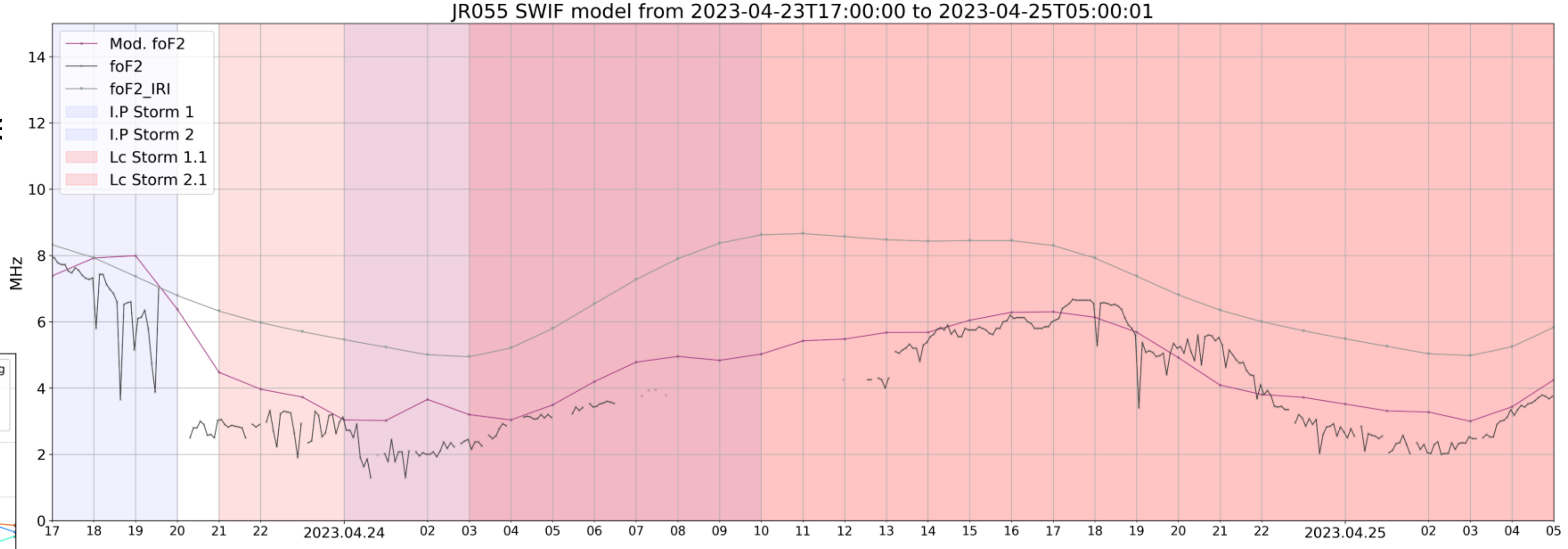
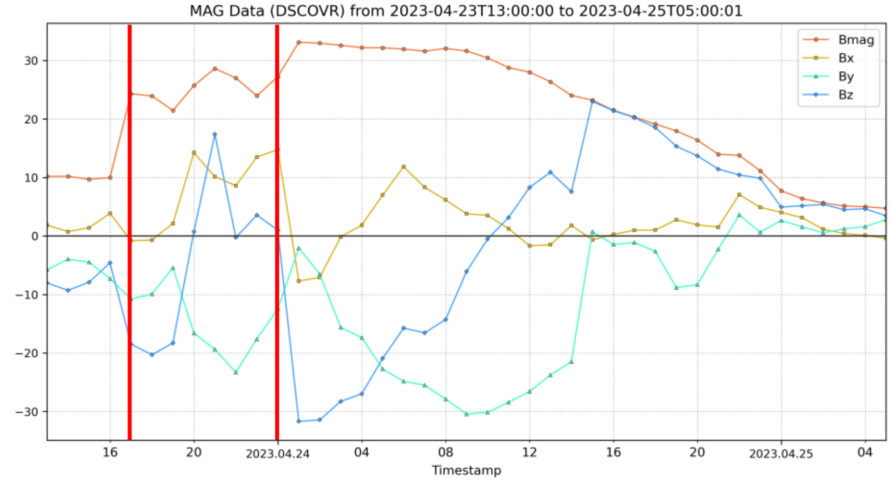
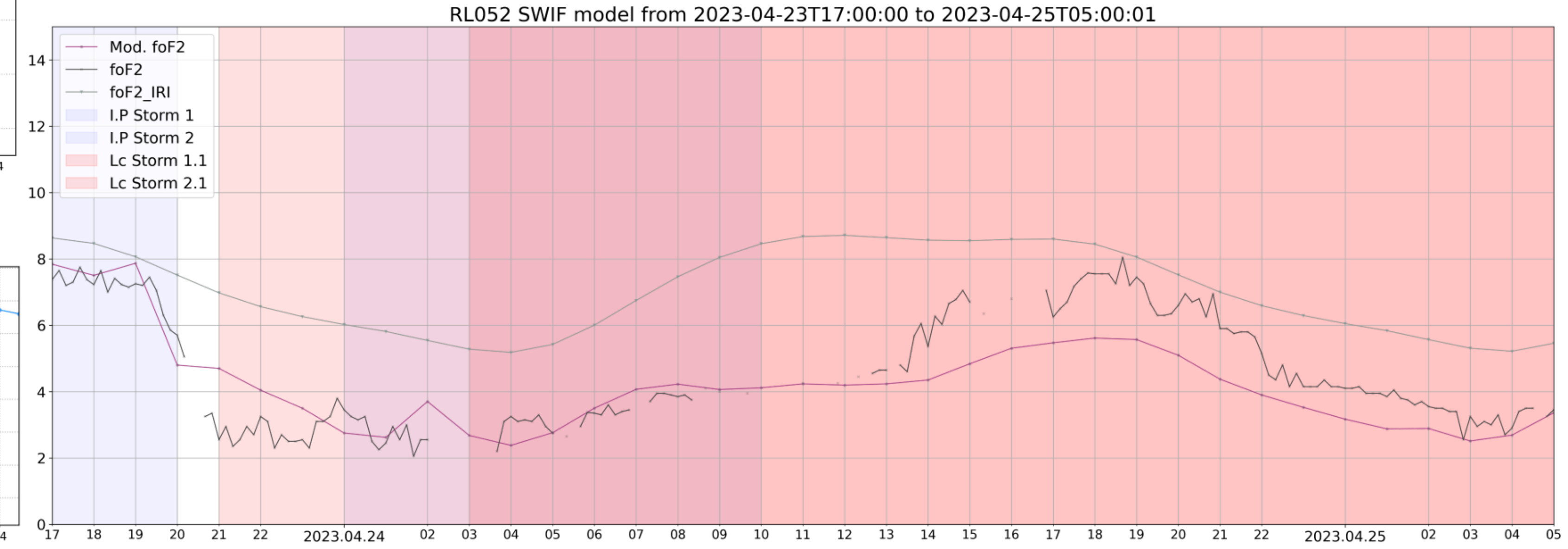
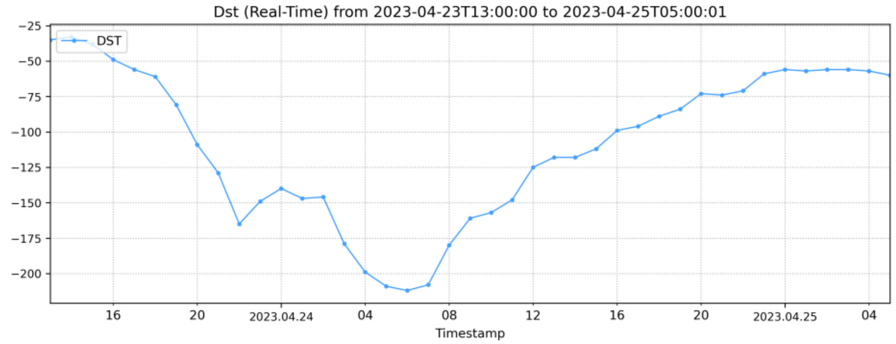
Start: 23 April 2023



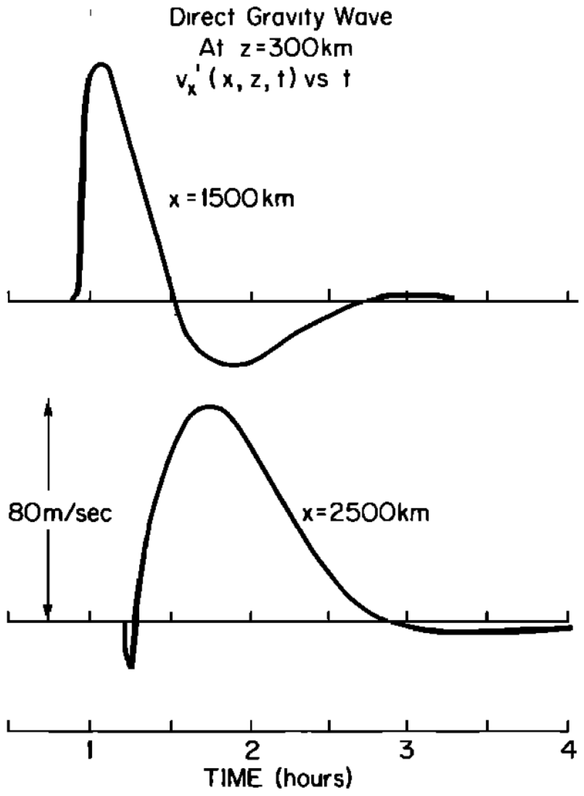




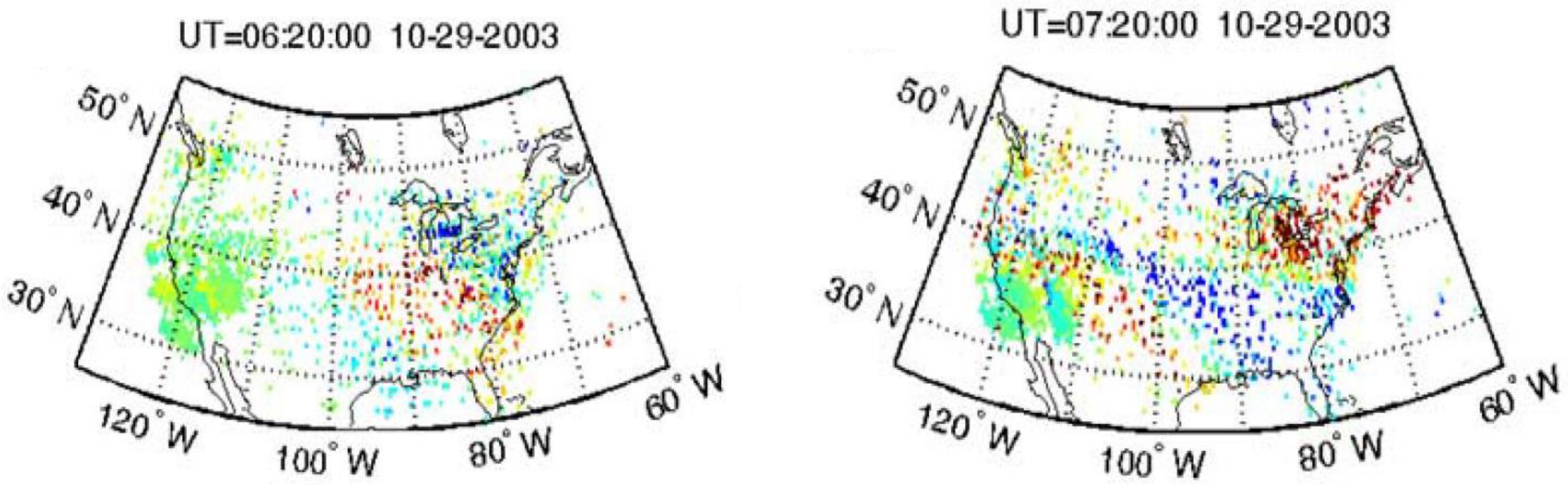


Travelling Ionospheric Disturbances

Francis' theoretical development shows that the average fluctuations of the auroral electrojet are sufficient to generate freely propagating neutral waves which should be detectable at large distances as Travelling Ionospheric Disturbances.

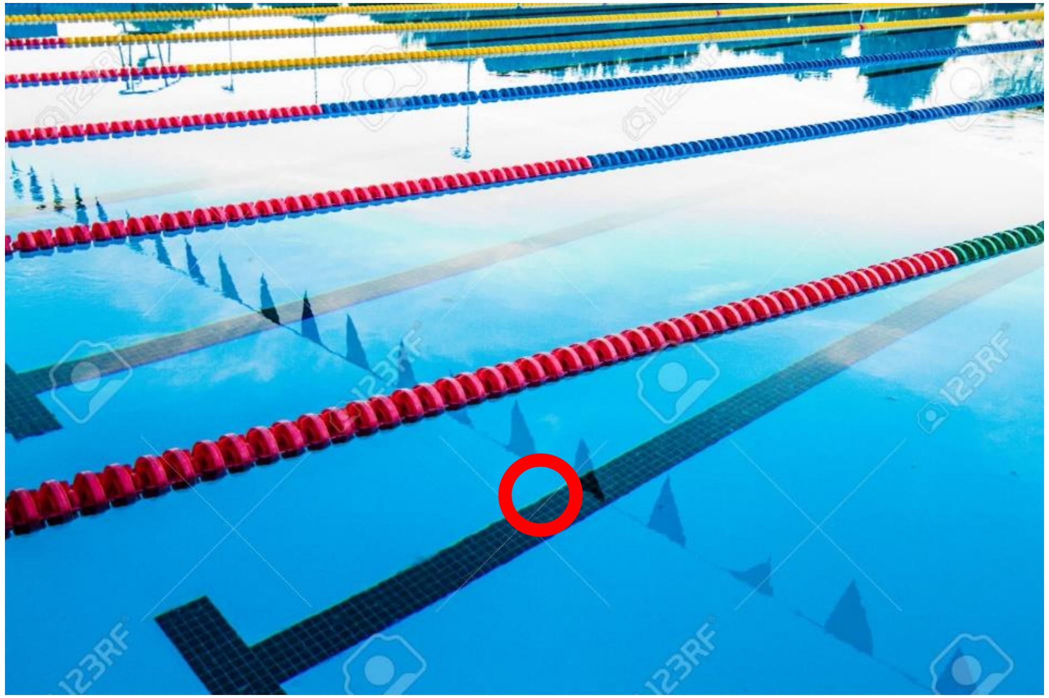


Hunsucker, 1982

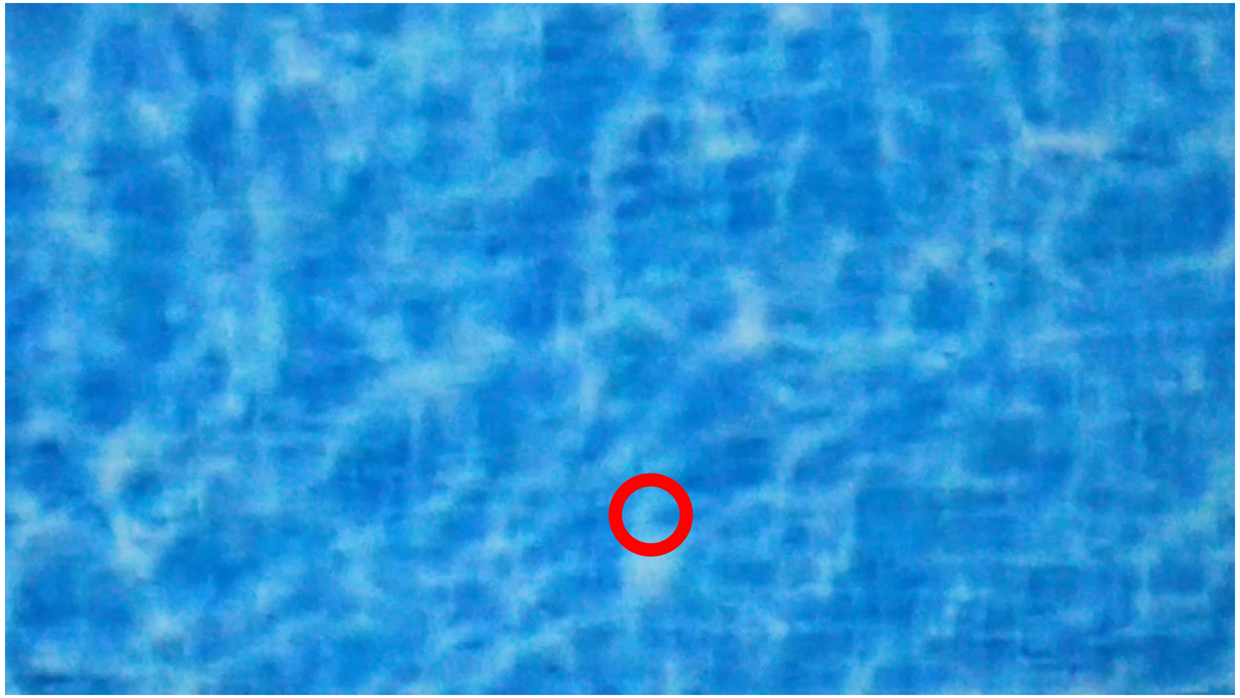


Ding et al., 2007

Travelling Ionospheric Disturbances (TIDs)



Quiet pool



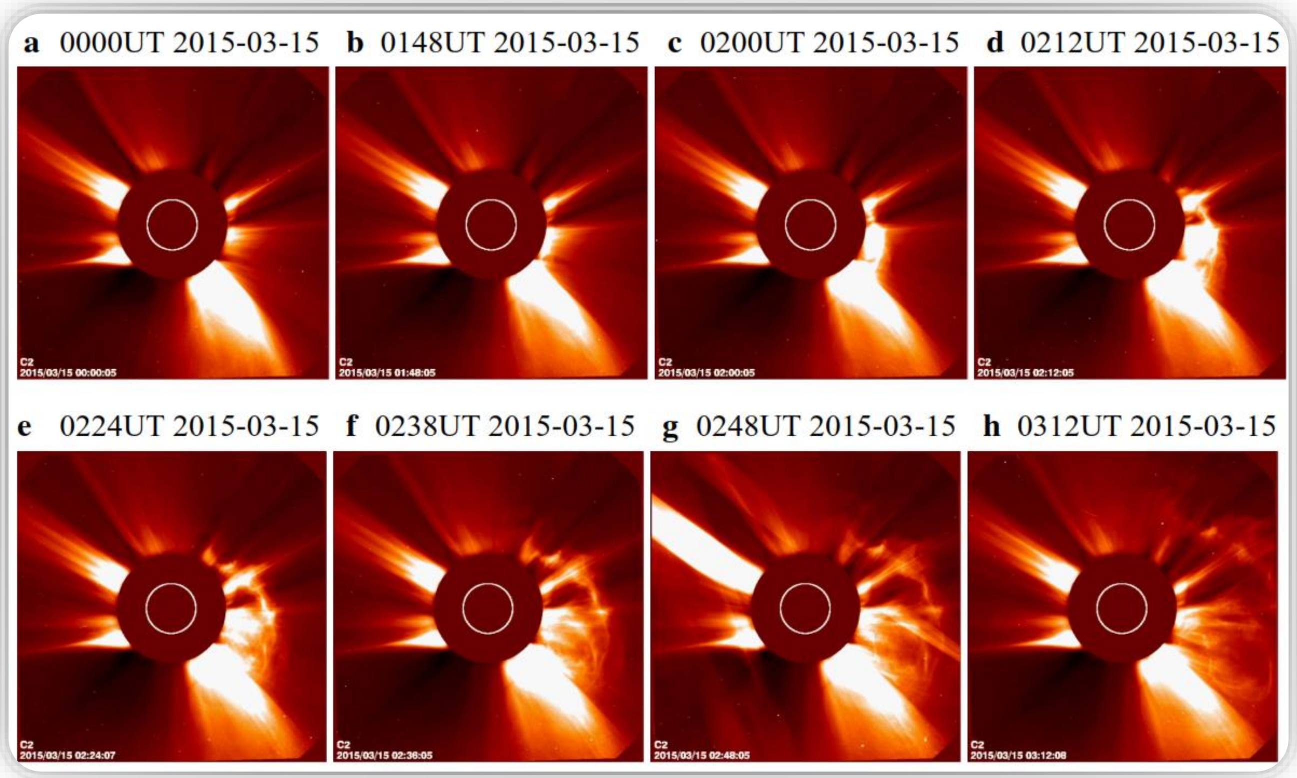
“Irregularities” in the pool (artist’s interpretation)

Courtesy: David Altadill, Ebro Observatory

What happened on 17 March 2015?

This is the St Patrick storm 2015, the first super-geomagnetic storm of the 24^{th} solar cycle.

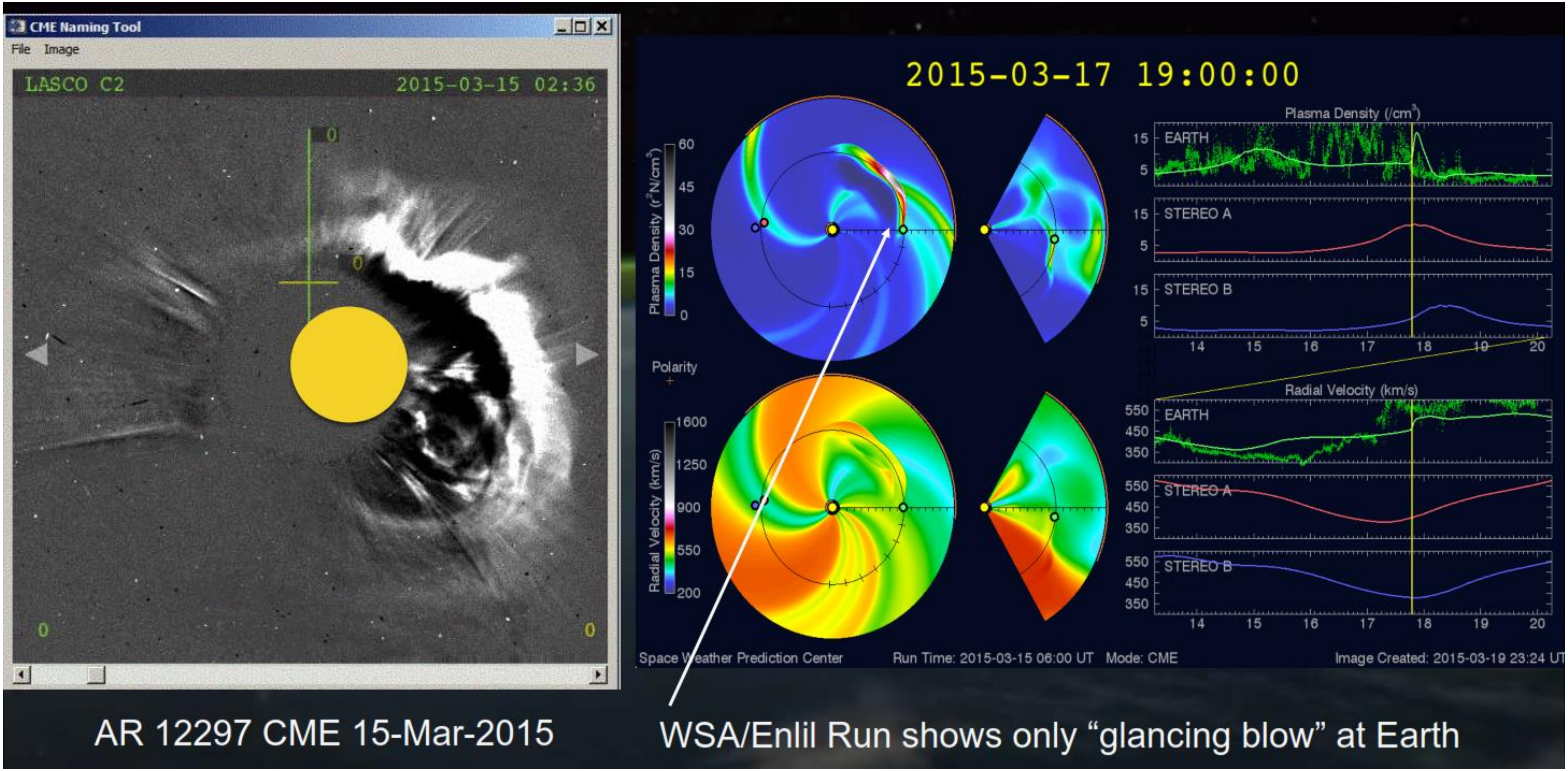
A CME observed by LASCO on 15 March 2015.



Coronal images recorded by SOHO/LASCO C2 during 00:00–03:12 UT

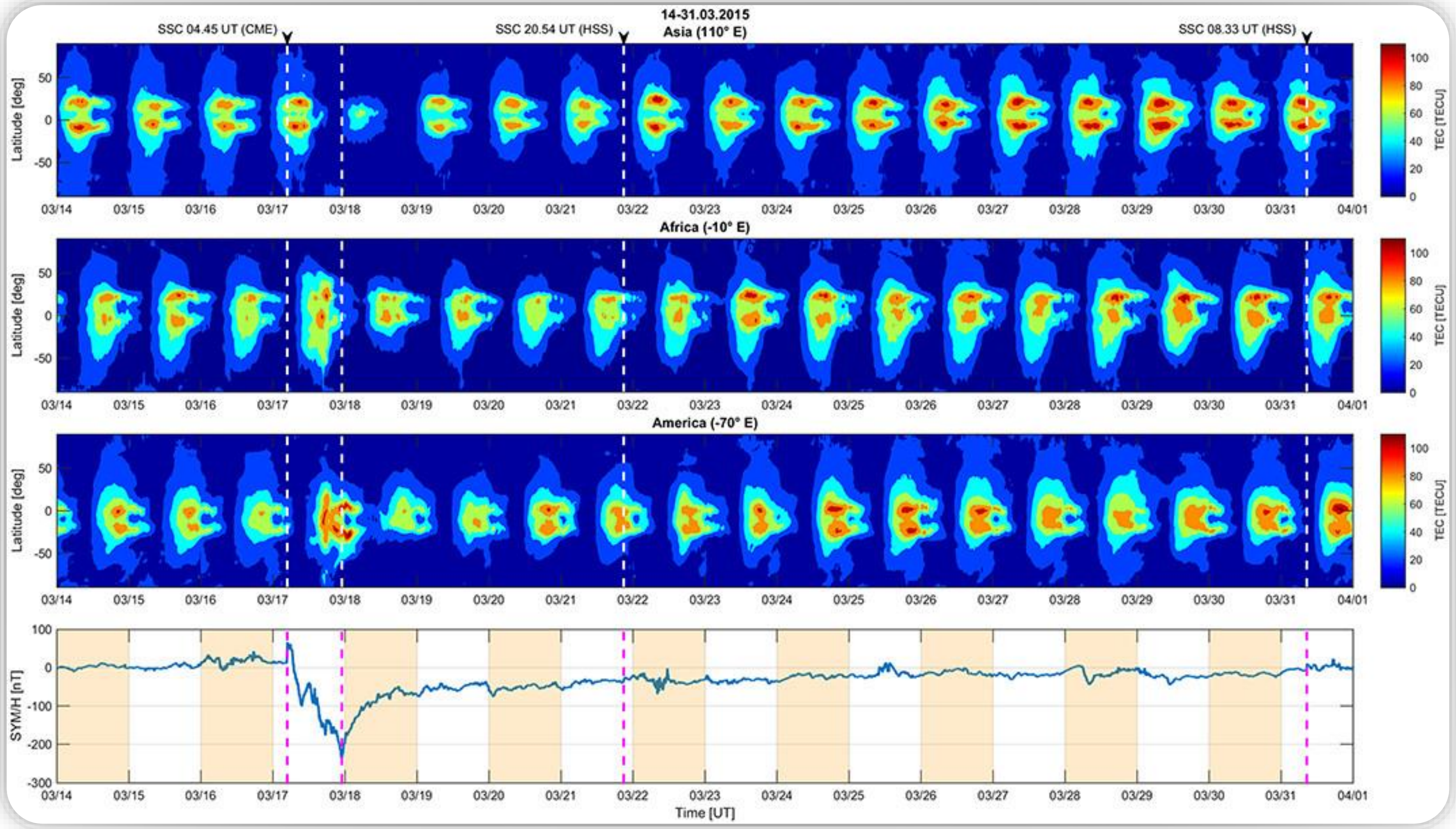
Wu et al., 2016

The CME propagated in the interplanetary medium reached the Earth 2 days after its ejection



NOAA, National Weather Services

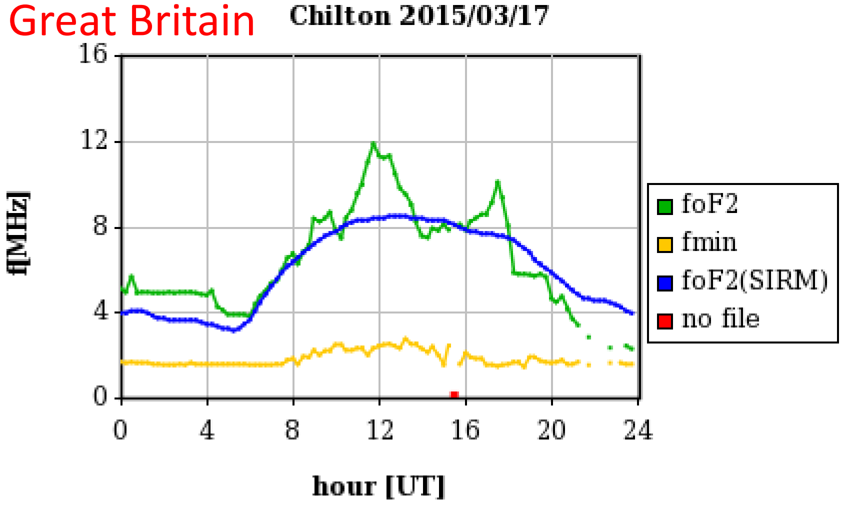
The CME produced a deformation of the Earth magnetosphere with impact in the geomagnetic field and the ionosphere



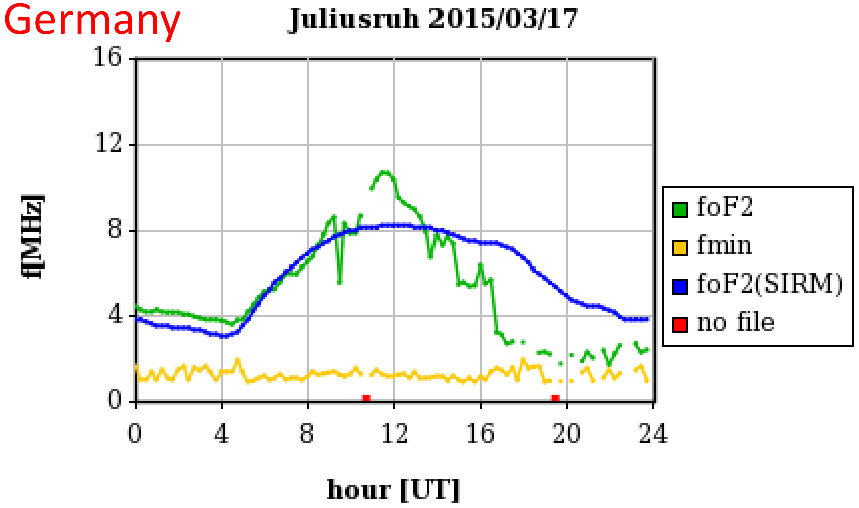
Borries et al., 2016

The large scale effects in the ionosphere – ionization enhancement and depletion depending on the location

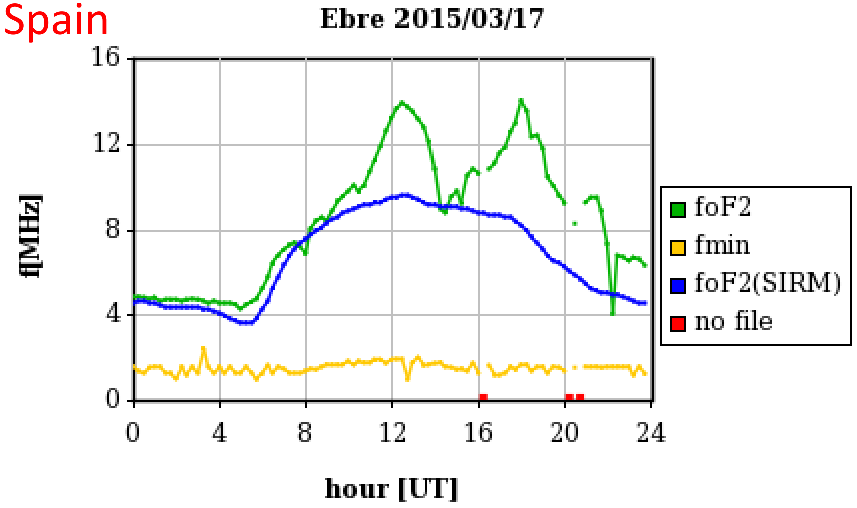
Great Britain



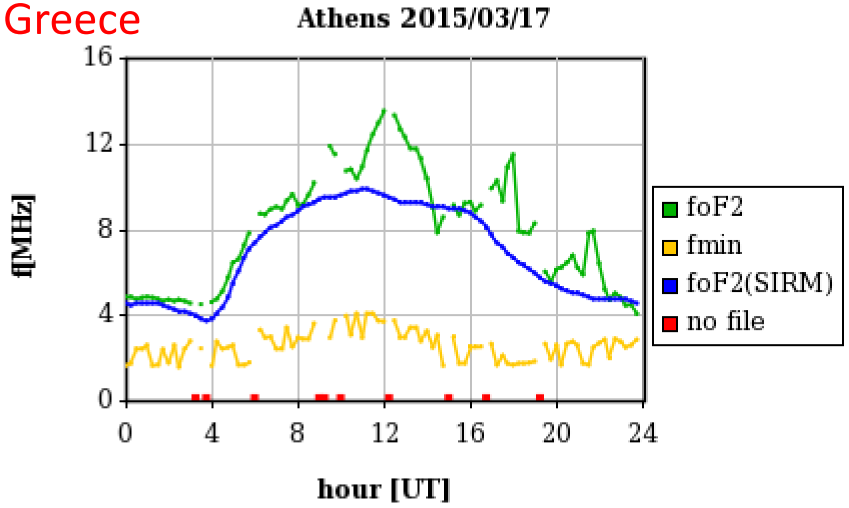
Germany



Spain

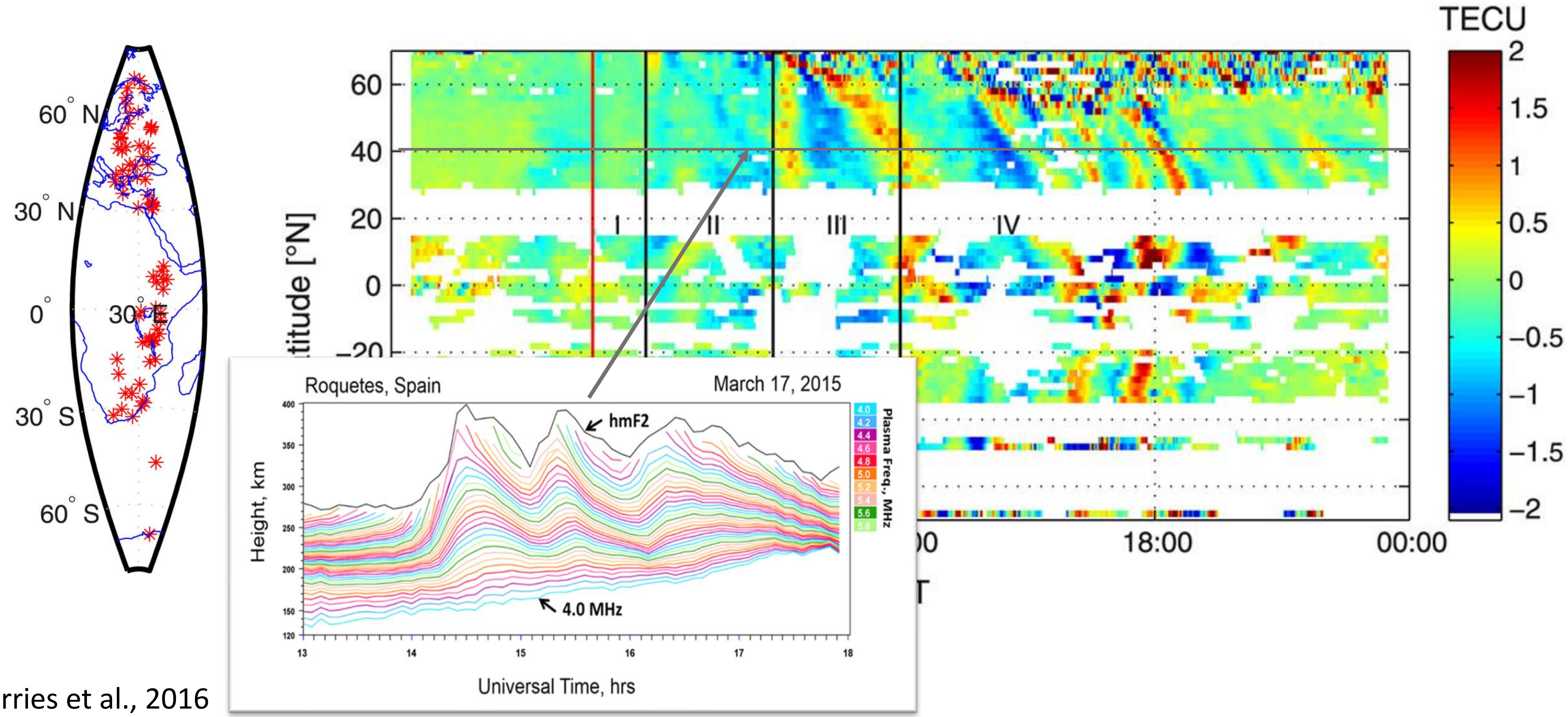


Greece



DIAS products

Detection of aurora generated Travelling Ionospheric Disturbances



Borries et al., 2016

Methodologies for Large Scale Travelling Ionospheric Disturbances detection:

TechTIDE portal http://tech-tide.eu/

also through the PITHIA-NRF e-science center

TechTIDE

HOME | API | INDIV SENSORS | INDICATORS | DRIVERS | ACTIVITY | ABOUT

TID - Activity Reports

Warning and Mitigation Technologies for Travelling Ionospheric Disturbances Effects — TechTIDE

Most recent conditions: Conditions tend to be median @ 2024-02-05T19:30:00 UTC

View TID Activity | Reference Date: 2024-02-05T20:27:00 UTC

LSTID Detection	Date	Critical Characteristic	Current value of critical characteristics	Activity level	ACVICO
AATR	2024-02-05T20:20:00	AATR at polar, high, medium and low latitudes	0.101	LOW	
GNSS TEC Gradient	2024-02-05T20:15:30	TEC gradient amplitude in high latitudes	1.468	MEDIUM	
HF Interferometry (HF-INT)	2024-02-05T20:20:00	Spectral Energy Contribution	0.1	LOW	
$LSTID_{idx}$	2024-02-05T19:55:00	Relative Std Dev of Ne	0	LOW	
HF TID	2024-02-05T20:27:00	Amplitude (in situ)	18.4	STRONG	

LS TID Detection products with good time coverage in TechTIDE database

- **HF Interferometry:** The disturbance potentially associated to TID in the last 6-h interval can be related to the de-trended ionospheric characteristics after removing the main daily harmonics. The dominant period of oscillation and amplitude of the LSTID are obtained by spectral analysis.
- **GNSS TEC gradient:** The method calculates temporal and spatial TEC gradients based on TEC maps. TEC gradients are not a direct signature of TIDs. Instead, TEC gradients are considered to be precursors of LSTID activity. Significant TEC gradients at high latitudes are indicative of strong ionosphere-thermosphere perturbations, which are in turn considered to be sources of LSTIDs.

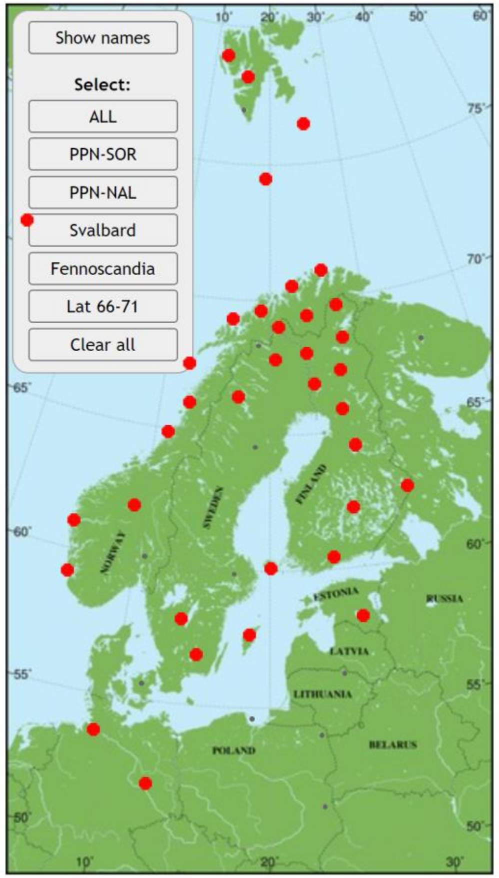
LSTIDs occurrence chain of events: an example

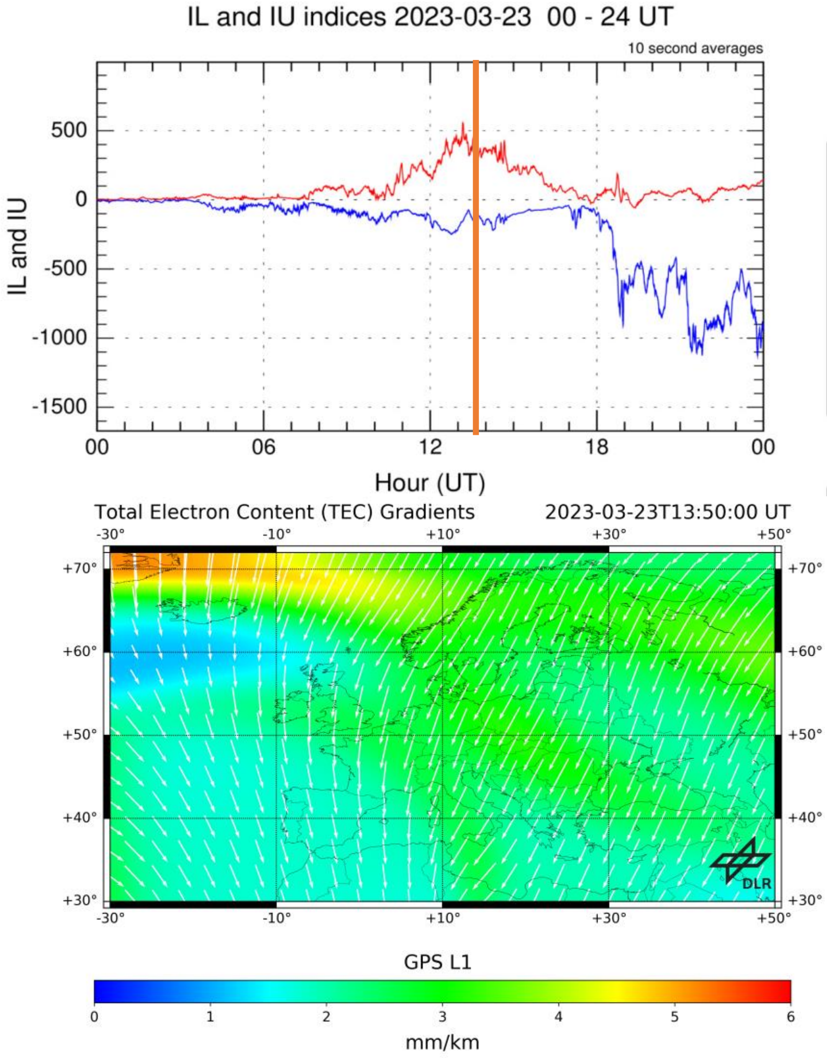
Energy injection @ high latitude inducing Joule heating

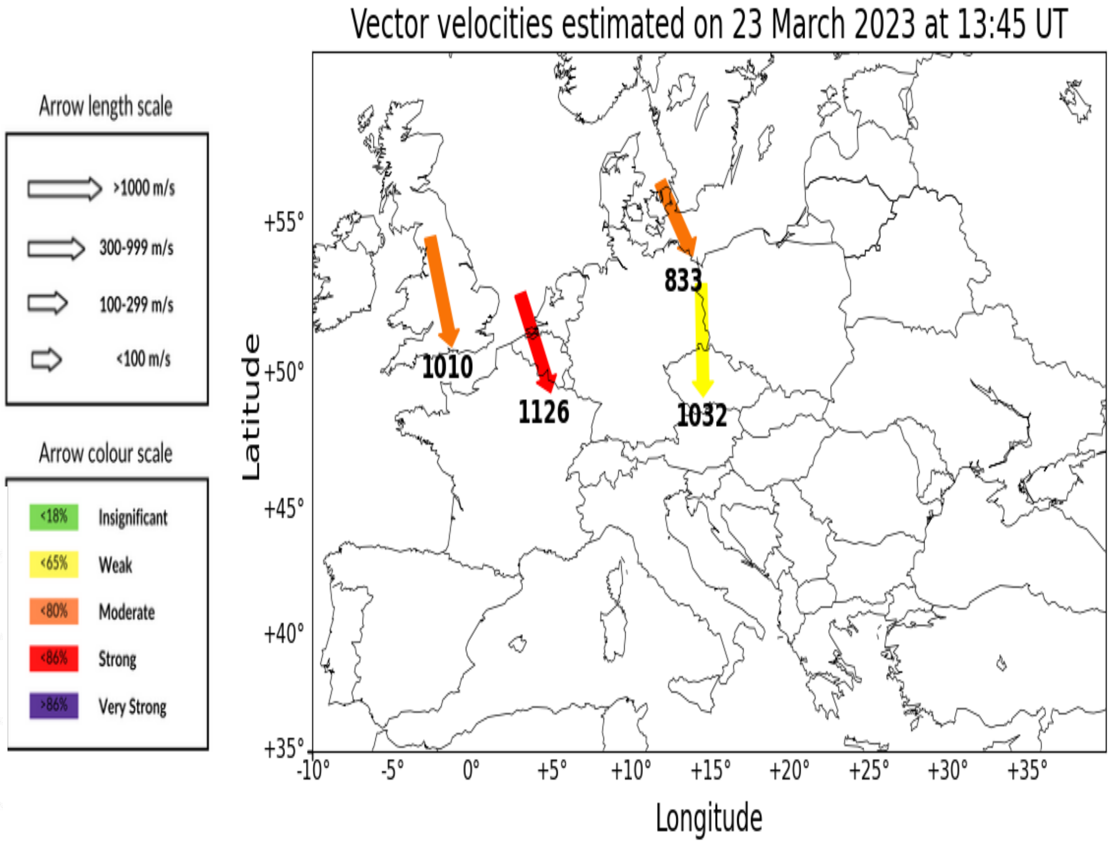
Geomagnetic field disturbances detected along a meridional chain of magnetometer @ ground

Equatorward Propagation of LSTIDs from auroral latitudes

Detection of LSTIDs by HF Interferometry applied over Digisonde characteristics

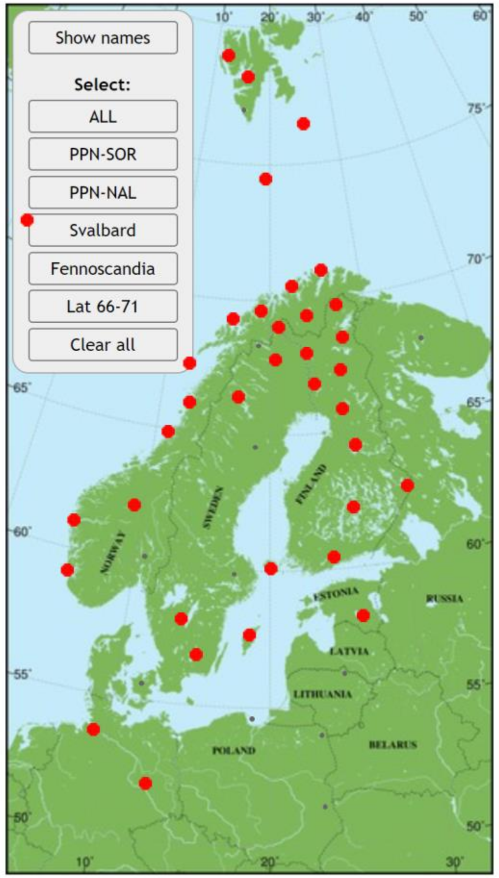


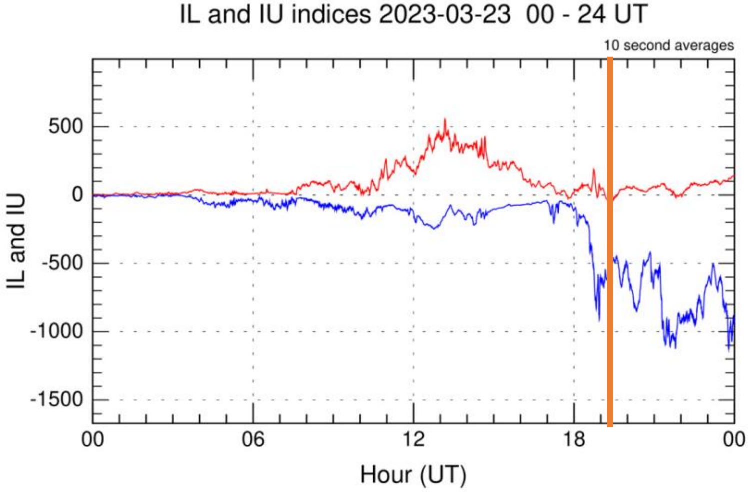


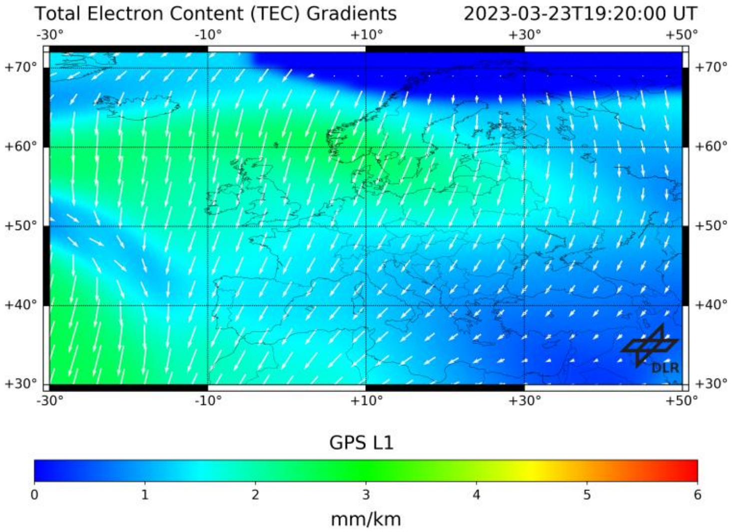


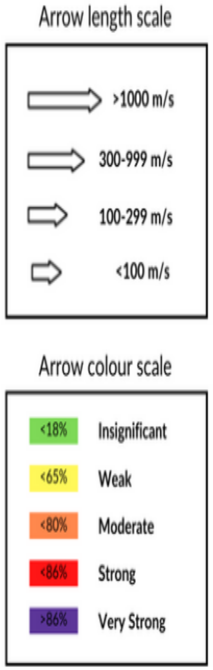
LSTIDs occurrence chain of events: an example

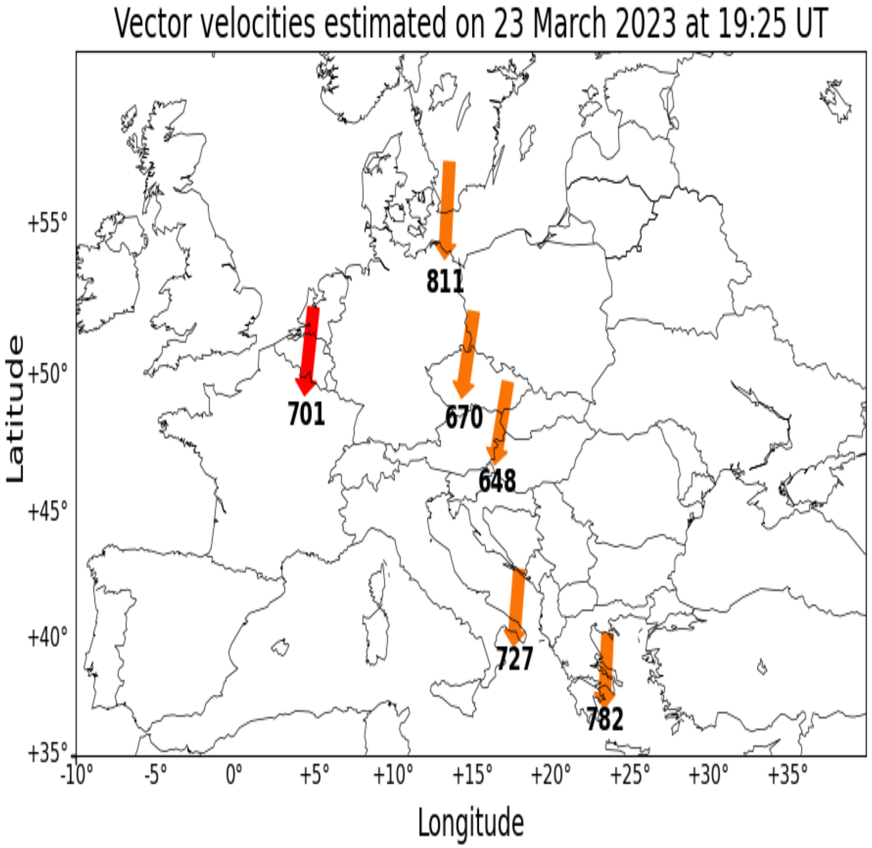
1. Energy injection @ high latitude inducing Joule heating
2. Geomagnetic field disturbances detected along a meridional chain of magnetometer @ ground
3. Equatorward Propagation of LSTIDs from auroral latitudes
4. Detection of LSTIDs by HF Interferometry applied over Digisonde characteristics





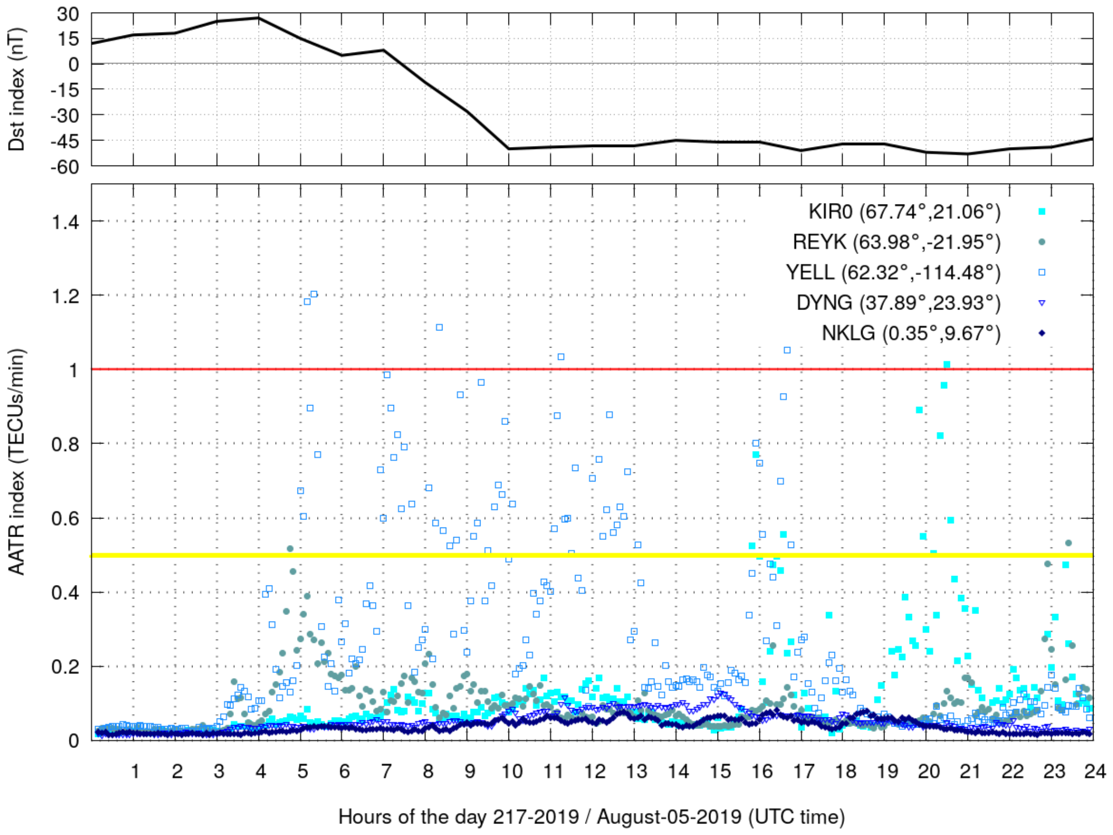






TechTIDE products : indicators

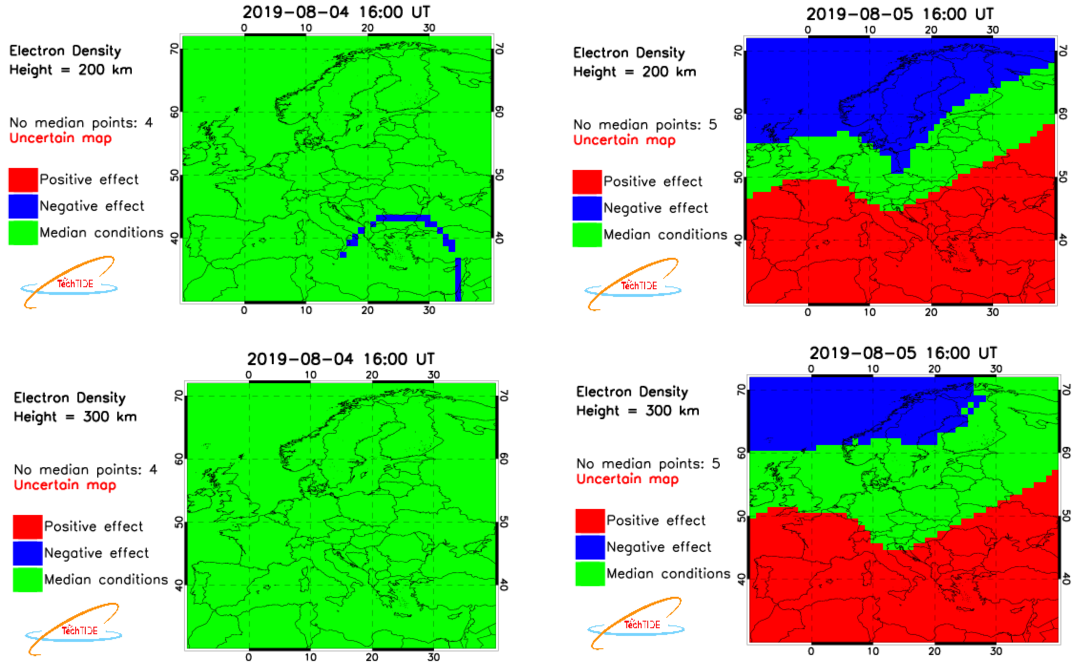
Results for a moderate geomagnetic storm occurred on 5 August 2019

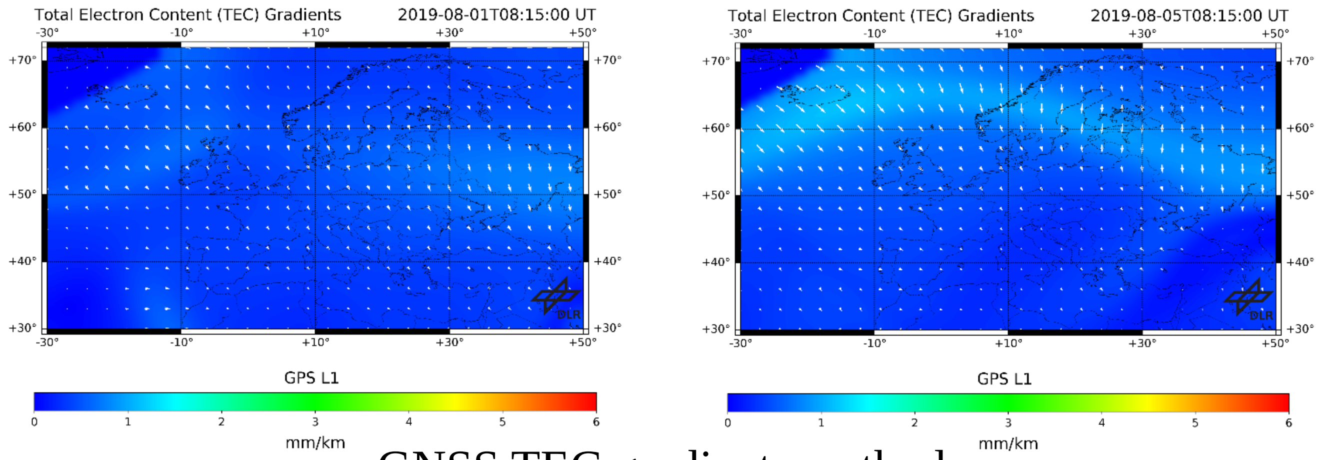


Along the Arc TEC Rate indicator

Pre-storm day

Storm day



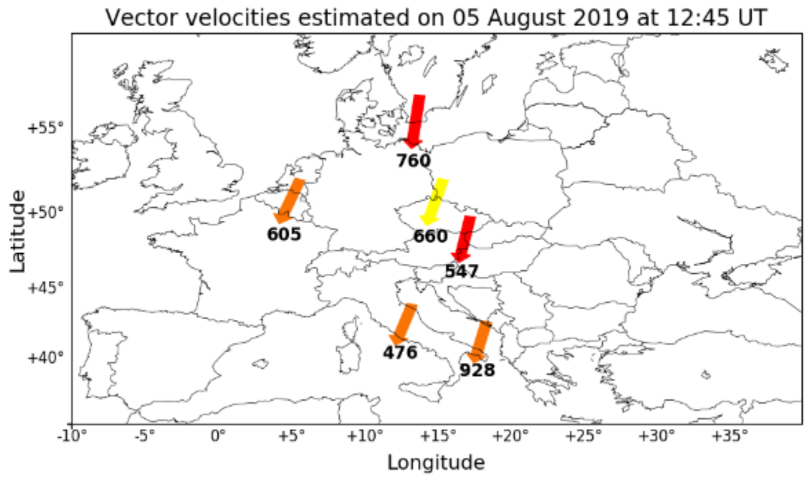


Belehaki et al., 2020, JSWSC

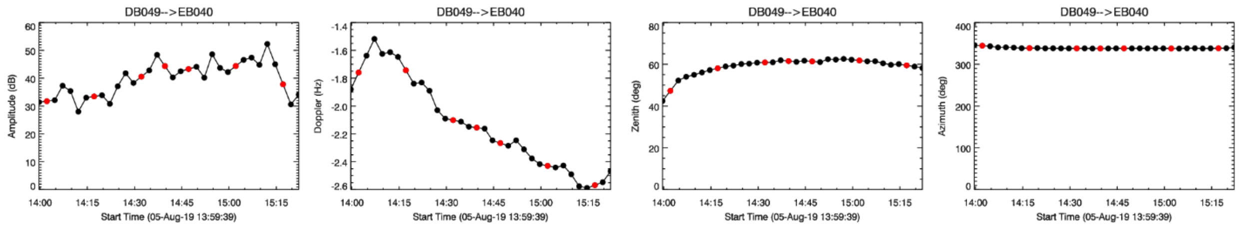
GNSS TEC gradients method

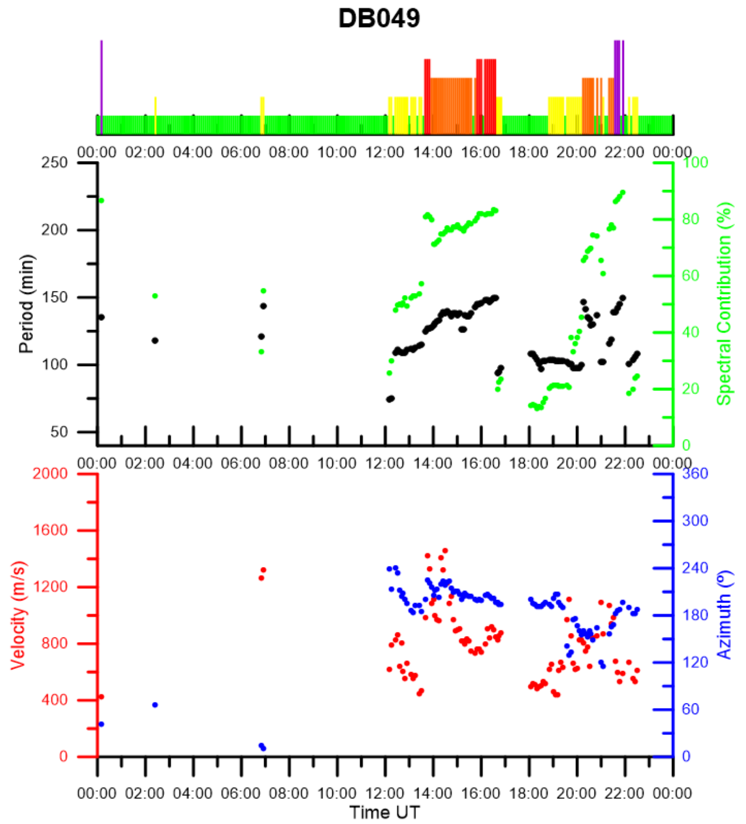
TechTIDE: LSTID identification

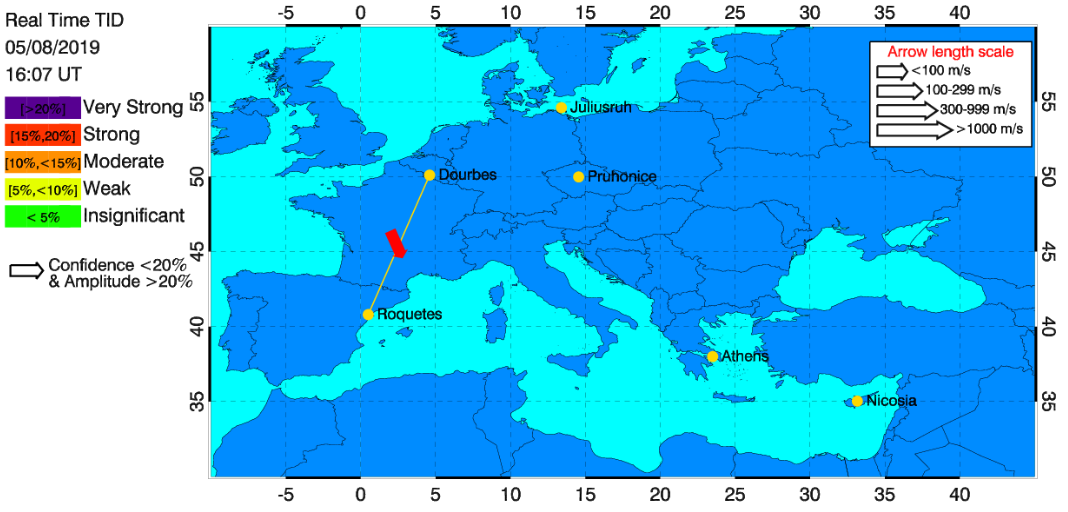
Results for a moderate geomagnetic storm occurred on 5 August 2019



HF Interferometry results over Dourbes







Digisonde-to-Digisonde TID detection method (HF-TID)

How to get access to data and models

- IRI – no input data are required
- SWIF – input data are automatically provided by the backend DataBase
- TechTIDE –input data are automatically provided by the backend Database
- Data for comparison/validation: API ionostream_noa & SWIMAGD_IONO Workflow

IRI: International Reference Ionosphere version 2001

The International Reference Ionosphere (IRI) is an international project sponsored by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI). These organizations formed a Working Group (members list) in the late sixties to produce an empirical standard model of the ionosphere, based on all available data sources (Charter). IRI 2001 is one of the earliest stable releases of the model. Several steadily improved editions of the model have been released since 2001. For given location, time and date, IRI provides monthly averages of the electron density, electron temperature, ion temperature, and ion composition in the ionospheric altitude range.

Identifier Properties

Local ID	DataCollection_IRI-2001
Namespace	pithia
Version	1
Created	Monday 28th Feb. 2022, 01:30:00
Last Modified	Wednesday 22nd Feb. 2023, 10:00:00

Interact

Interaction Method	**Description**	**Data Format**	**Link**
Direct Link to Data Collection	The IRI home page has the list of resources (numerical data, display/plot products, FORTRAN code) and documentation for operating the latest IRI release.	text/html (click the link to show information on this ontology term)	Open Latest IRI Landing Page in new tab
Direct Link to Data Collection	The IRI landing page at CCMC has the list of data resources (numerical, display) for operating several versions of IRI.	text/html (click the link to show information on this ontology term)	Open IRI Landing Page at NASA CCMC in new tab

CCMC Instant Run System

Date Time

11/02/2012 10:00

Coordinate

Coordinate Type

Geographic

Latitude (-90° to 90°)

10

Longitude (0° to 360°)

110

Height (0 to 1000 km)

300

Profile

Profile Type

Height [0 to 1000 km]

Start

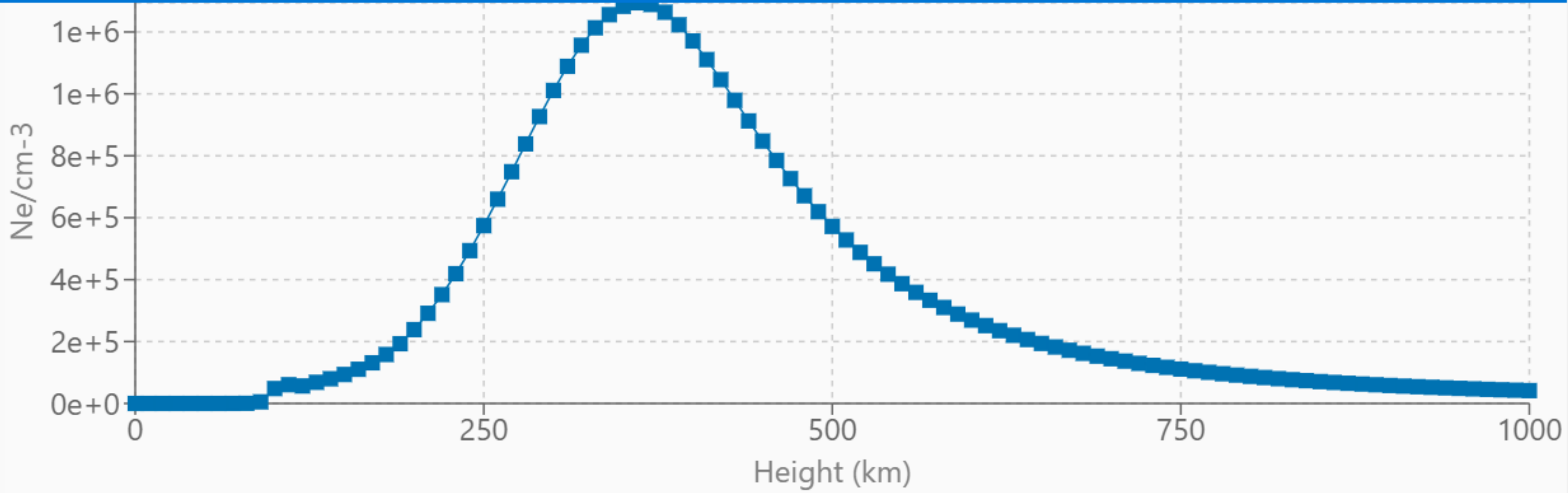
0

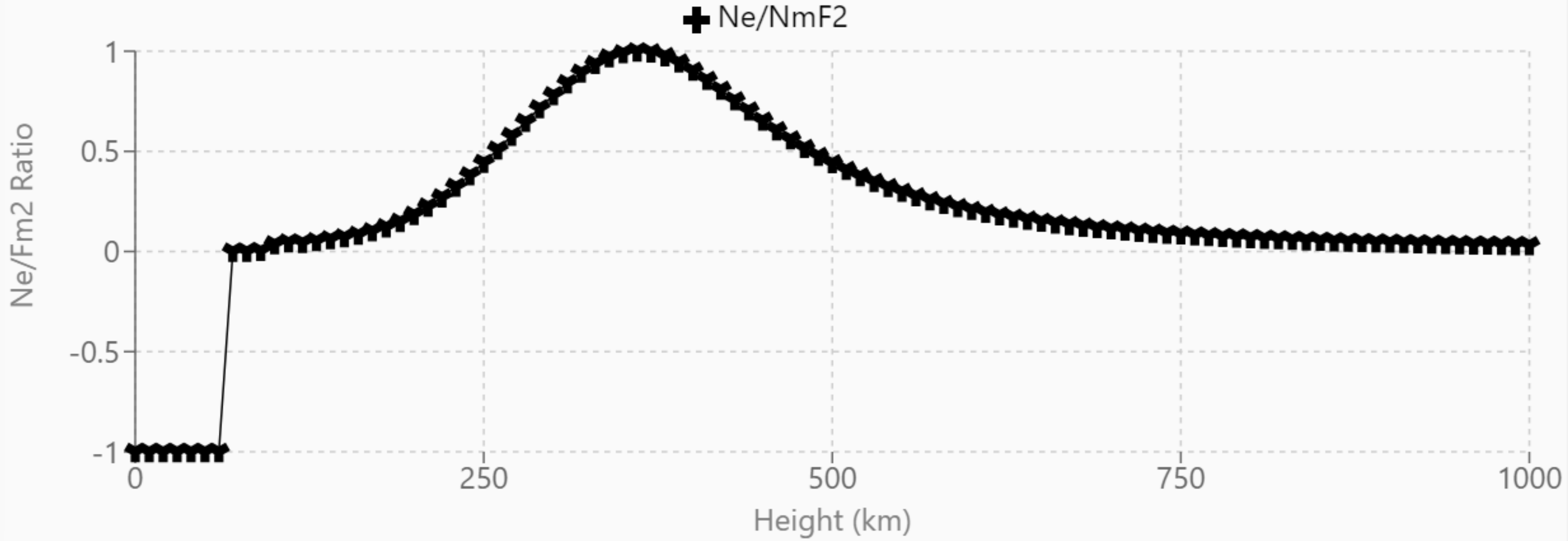
Stop

1000

Step Size

View Raw Output





SWIF Model

The SWIF ionospheric forecasting algorithm provides alerts and warnings for upcoming ionospheric storm disturbances and ionospheric forecasts over Europe. SWIF combines historical and real-time ionospheric observations with solar wind parameters obtained in real time at L1 point through the cooperation of an autoregression forecasting algorithm, namely TSAR that provides real-time ionospheric forecasts up to 24 hours ahead during all possible conditions with an empirical method, namely STIM, that formulates the ionospheric storm-time response triggered by solar wind disturbances.

Interact

Interaction Method	Description	Data Format	Link
Direct Link to Data Collection	The EIS provides a browser-based user interface for data browsing and downloading. Three products derive from the SWIF Model: (a) foF2 Forecasts Maps, (b) foF2 Forecasts Plots Over Stations and (c) Ionospheric Alerts.	text/plain (click the link to show information on this ontology term)	Open European Ionosonde Service (EIS) Interface in new tab
Direct Link to Data Collection	The SWIF API provides a browser-based user interface for data browsing and downloading.	text/plain (click the link to show information on this ontology term)	Open SWIF API in new tab

Identifier Properties

Local ID	DataCollection_EIS_SWIF_Model
Namespace	noa
Version	1
Created	Monday 22nd May 2023, 09:55:00
Last Modified	Monday 22nd May 2023, 10:05:00

https://electron.space.noa.gr/swif/api/v2/docs#/idb

Swifdb/forecasts/pager: end point to get forecasted values over Digisonde locations

GET `/swifdb/forecasts/pager` List Forecasts Metadata [Pager]

Retrieve List of Serialized Datasets from Forecast records ingested into SWIFDB.

Parameters

Name	Description
start `string($date-time)` *(query)*	start
end `string($date-time)` *(query)*	end
stations `array` *(query)*	*Available values* : AT138, EB040, JR055, PQ052, RL052, RO041, SO148, TR170, -- AT138 EB040 JR055

Swifdb/solardb/magdata/pager: end point to get DSCOVR magnetic field data

GET `/swifdb/solardb/magdata/pager` List DSCOVR Magdata Metadata [Pager]

Retrieve List of Serialized Datasets from DSCOVR Magdata records ingested into SWIFDB.

Parameters

Name	Description
start **string($date-time)** *(query)*	start
end **string($date-time)** *(query)*	end
page **integer** *(query)* *minimum: 1*	*Default value* : 1 1
size **integer** *(query)* *maximum: 100* *minimum: 1*	*Default value* : 50 50

PITHIA-NRF
e-Science Centre

HOME SEARCH & BROWSE ADMIN Login

Home / Browse Metadata / Data Collection-related Metadata / Projects / TechTIDE

TechTIDE

Warning and Mitigation Technologies for Travelling Ionospheric Disturbances Effects (TechTIDE) is a real-time warning system that provides the results of complementary TID detection methodologies and many potential drivers to help users assess the risks and develop mitigation techniques tailored to their applications. The TechTIDE methodologies are able to detect in real time activity caused by both large-scale and medium-scale TIDs and characterize background conditions and external drivers, as an additional information required by the users to assess the criticality of the ongoing disturbances in real time.

Properties

Property	Value
Short Name	techtide
Abstract	Warning and Mitigation Technologies for Travelling Ionospheric Disturbanc... cts
URL *(from URL (1/2))*	https://techtide-srv-pub.space.noa.gr:8443/api/
URL *(from URL (2/2))*	https://techtide-srv-pub.space.noa.gr/techtide/#/pages/intro

Identifier Properties

Local ID	Project_NOA_TechTIDE
Namespace	noa
Version	1
Created	Saturday 28th Jan. 2023, 17:54:00
Last Modified	Saturday 11th March 2023, 18:46:00

https://techtide-srv-pub.space.noa.gr:8443/api/

GET `/products/hfi/data/meta/` Retrieve archived collection of HFI datasets [FS *gz] from DB metadata slice | Max Allowed Temporal Range 15 days

Parameters Cancel

Name	Description
date_from * required `string($date-time)` *(query)*	Start date for requested product dataset 2023-03-23T13:00:00
date_to * required `string($date-time)` *(query)*	End date for requested product dataset 2023-03-23T14:00:00
station `string` *(query)*	Requested provider code DB049
product * required `string` *(query)*	Requested product(s): hfi, hficond hfi
withmanifest `boolean` *(query)*	Include manifest file true

Execute Clear

Responses

Response content type application/zip

Curl

```
curl -X GET "https://techtide-srv-pub.space.noa.gr:8443/api/products/hfi/data/meta/?date_from=2023-03-23T13%3A00%3A00&date_to=2023-03-23T14%3A00%3A00&station=DB049&product=hfi&withmanifest=true" -H
"accept: application/zip"
```

Request URL

```
https://techtide-srv-pub.space.noa.gr:8443/api/products/hfi/data/meta/?date_from=2023-03-23T13%3A00%3A00&date_to=2023-03-23T14%3A00%3A00&station=DB049&product=hfi&withmanifest=true
```

Server response

Code	Details
200 *Undocumented*	Response body Download file Response headers

```
access-control-allow-origin: *
access-control-expose-headers: Content-Disposition
connection: close
content-disposition: attachment; filename="TechTIDE_HFI_arcv.zip"; size=0
content-type: application/zip
date: Tue, 30 May 2023 15:20:05 GMT
server: gunicorn/20.0.4
transfer-encoding: chunked
```

Responses

Code	Description

C:\Users\abele\Documents\Training School - 1\presentation\HFI_data\TechTIDE_HFI_arcv\TechTIDE_hfi.DB049_HFI.P.EBRO_202303...

File Edit Search View Encoding Language Settings Tools Macro Run Plugins Window ?

TechTIDE_hfi.DB049_HFI.P.EBRO_20230323T130000_20230323T140000


```
[
    {
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        "azi": 155.0,
        "code": "P.EBRO",
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        "date": "2023-03-23 13:00:00",
        "fl": 1.0,
        "iq": 70.0,
        "ir": 66.0,
        "iw": 1.0,
        "lat": 50.1,
        "lng": 4.6,
        "method": "hfi",
        "name": "P.Ebro",
        "nt": 1.0,
        "nw": 2.0,
        "perio": 128.0,
        "power": 46.8,
        "product": "hfi",
        "pubid": "c1669522-c076-4d90-9891-1603b2a42412",
        "qi": 1.0,
        "spcont": 56.0,
        "st": 2.0,
        "station": "DB049",
        "trl": 2.0,
        "vel": 879.0
    },
    {
        "ampli": 0.34,
        "azi": 153.0,
        "code": "P.EBRO",
        "country": "Spain",
        "date": "2023-03-23 13:05:00",
        "fl": 1.0,
        "iq": 70.0,
        "ir": 66.0,
```

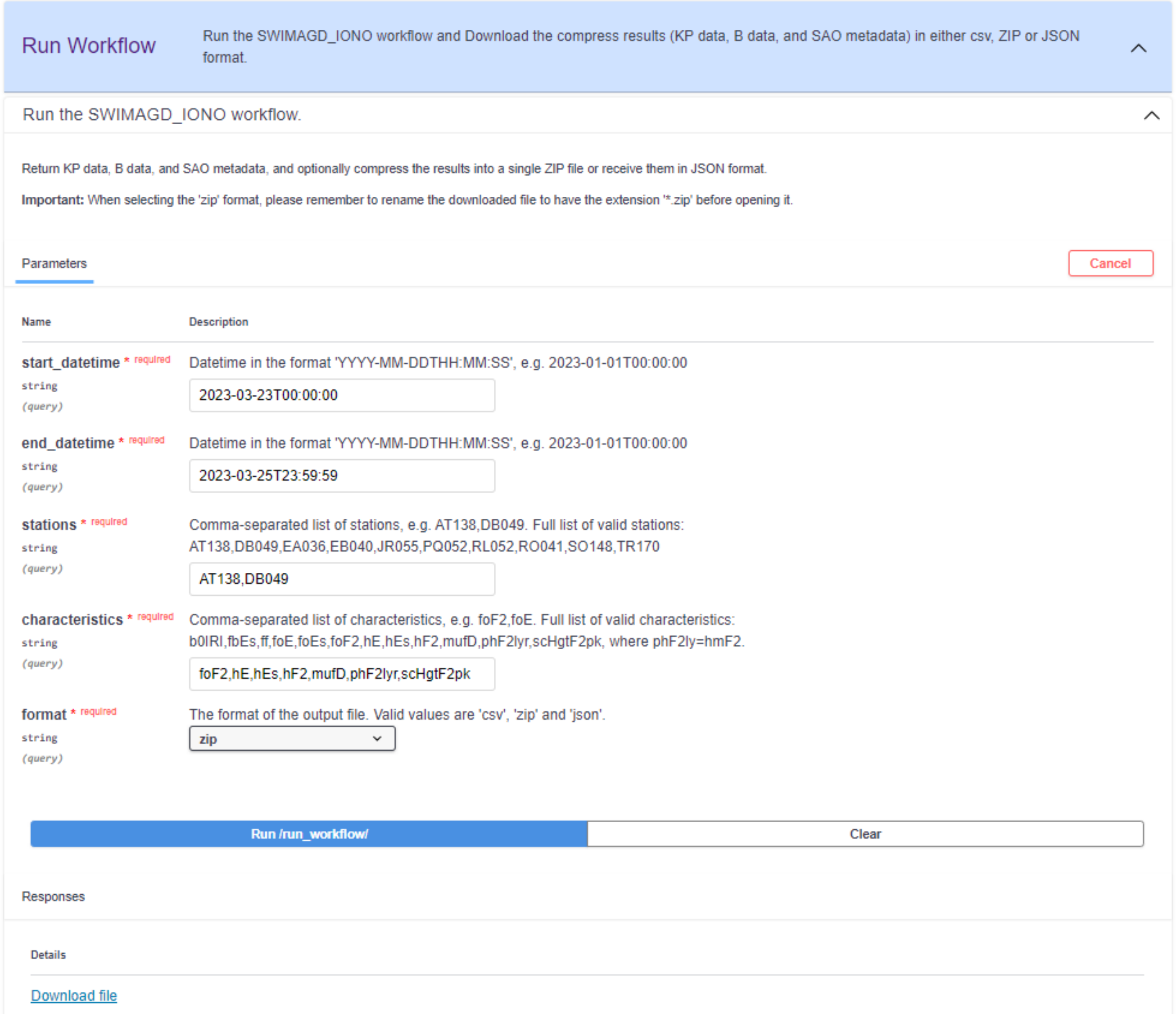
SOLAR WIND MAGNETOSPHERE DRIVEN IONOSPHERIC RESPONSE (SWIMAGD_IONO)

The SWIMAGD_IONO workflow provides:

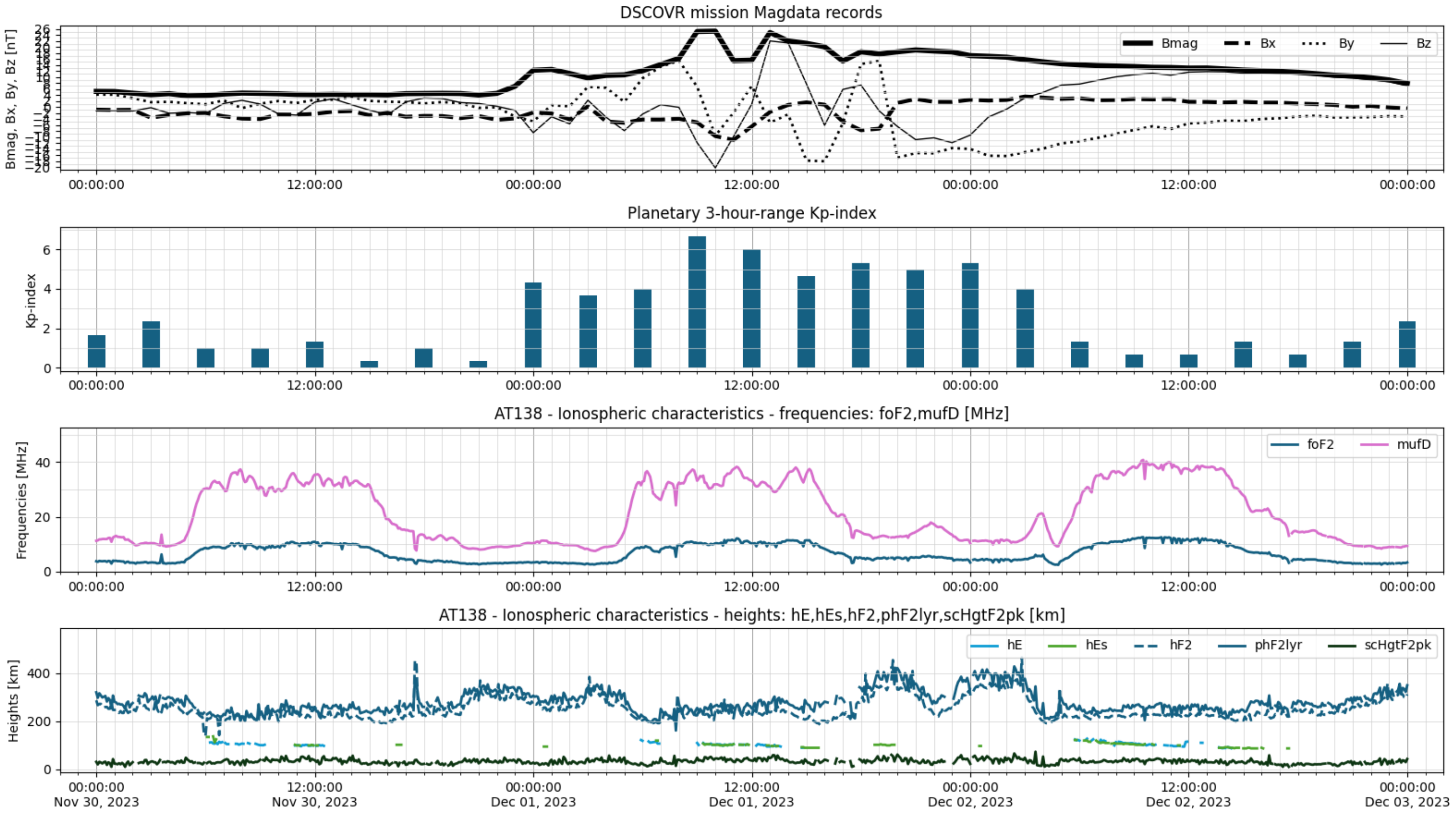
(a) Planetary 3-hour-range (T00:00:00, T03:00:00, …, T21:00:00) Kp-index;

(b) DSCOVR mission Magdata records (Bmag, Bx, By, Bz) as part of the SWIF model Data Collection;

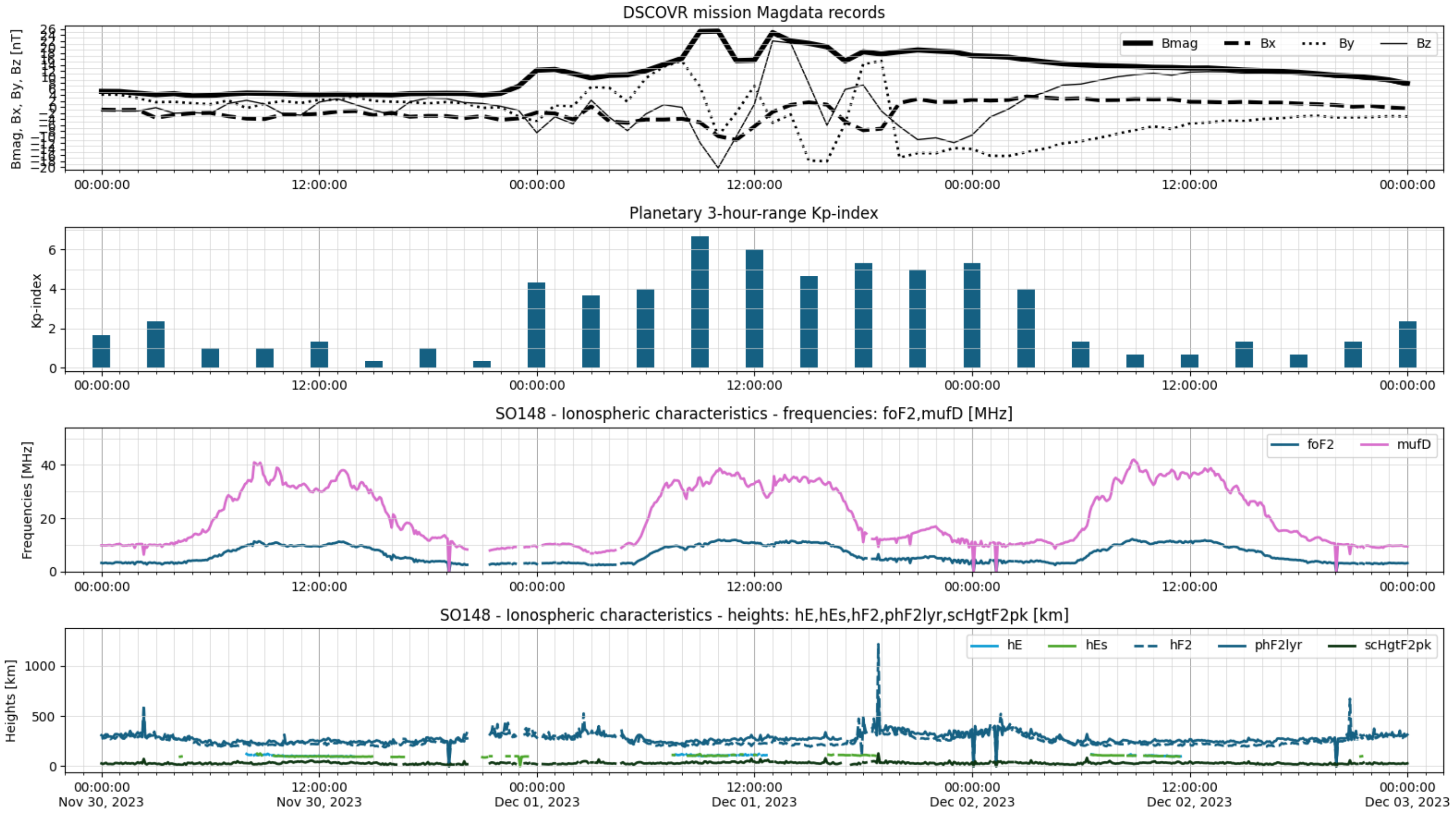
(c) Distinct ionospheric characteristics (SAO records) for 10 European Digisonde stations (AT138, EA036, EB040, DB049, JR055, PQ052, RL052, RO041, SO148, TR170).



Athens Digisonde data, Greece



Sopron Digisonde data, Hungary



Acknowledgements

- To the KULeuven Group
- To PITHIA-NRF Horizon 2020 project
- To T-FORS Horizon Europe project

HORIZON 2020

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Funded by the European Union

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