T-FORS

Travelling Ionospheric Disturbances Forecasting System

WP3: MSTIDs climatology and probabilistic forecasting

M. Sivakandan

Leibniz Institute of Atmospheric Physics (IAP) at the University of Rostock

Germany.

&

WP3 team members

LEIBNIZ INSTITUTE OF ATMOSPHERIC PHYSICS IAP

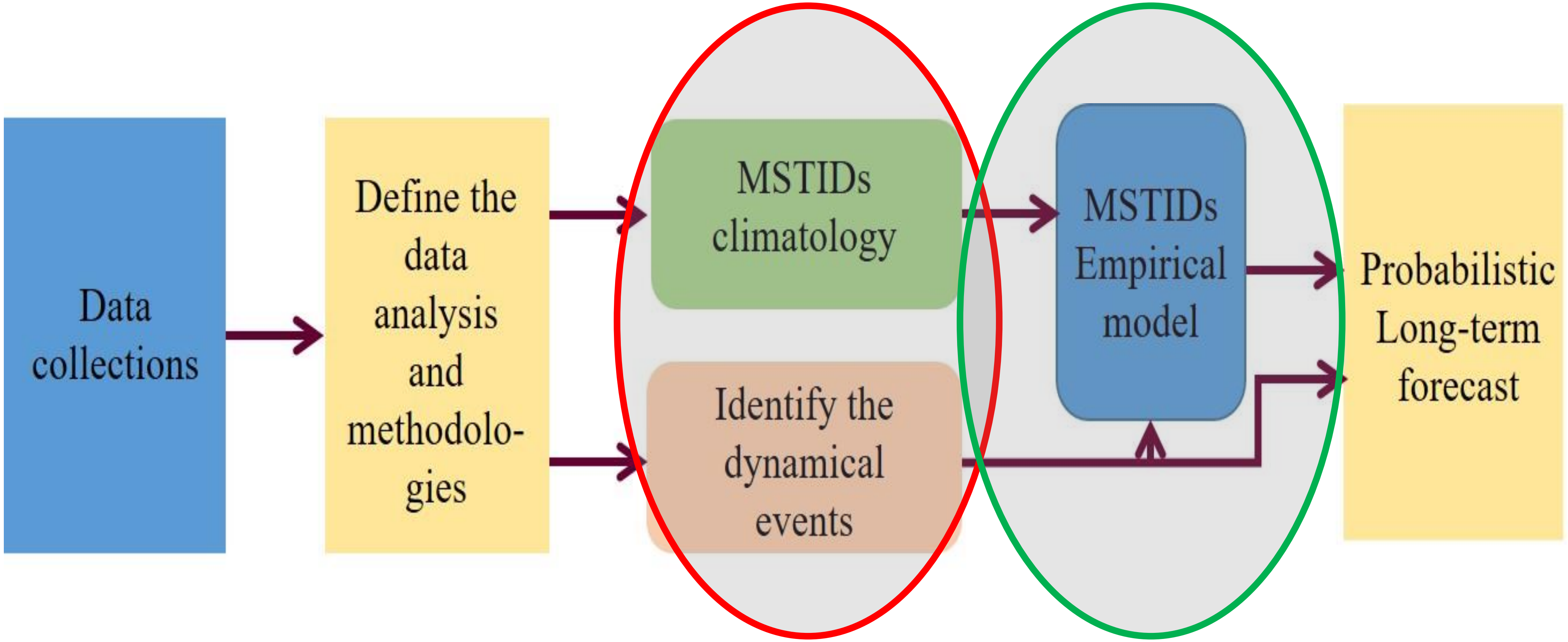
T-FORS: innovation day, 23 November 2023

T-FORS

Objectives

- ➢ Develop new methodologies and statistical models
- ➢ Provide the probabilistic forecast of MSTIDs
- ➢ Issue alerts for extreme MSTIDs
- ➢ An inventory of potential indicators of MSTIDs

General approach



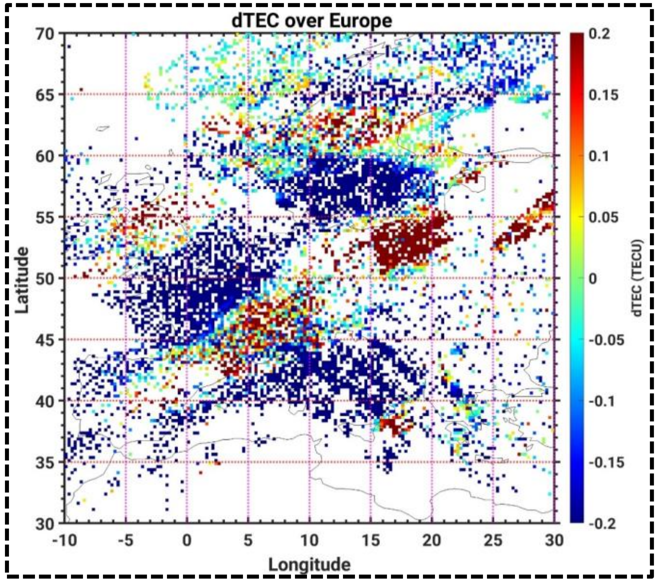
Schematic diagram for the general approach to implement our plans

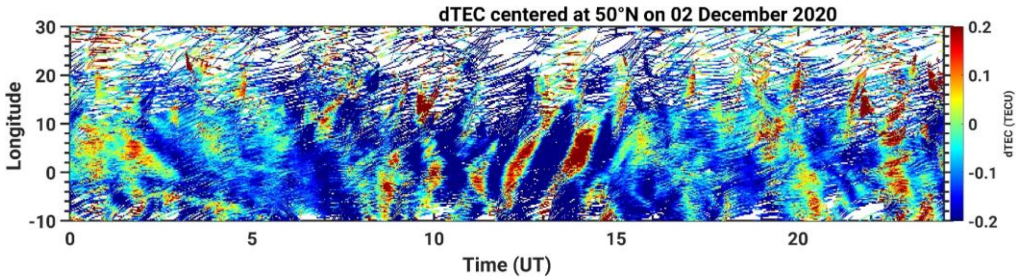
MSTIDs climatology: GNSS-TEC

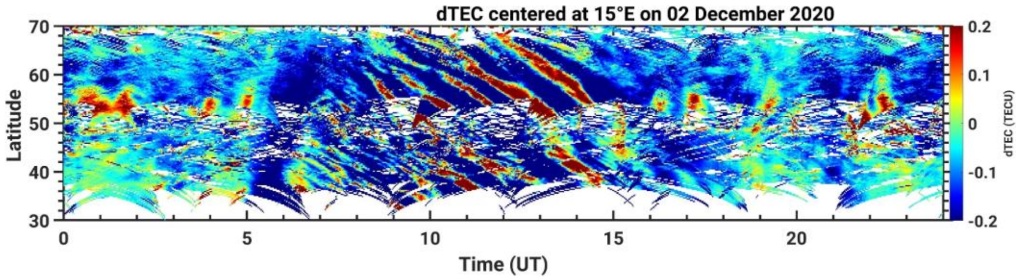
- ✓ To obtain perturbation component of TEC, which could be caused by MSTIDs, 1-hour running average of TEC was subtracted from the original TEC time series for each pair of satellites and receivers, and converted the slant to vertical TEC.

- ✓ Temporal resolution is 30 seconds, and the spatial resolution is 0.25×0.25 latitude and longitude.

02 December 2020 at 13:00 UT







- ✓ Keogram analysis is used to identify the propagation direction, wavelength and phase speed of the MSTIDs

T-FORS Identification of MSTD propagation direction

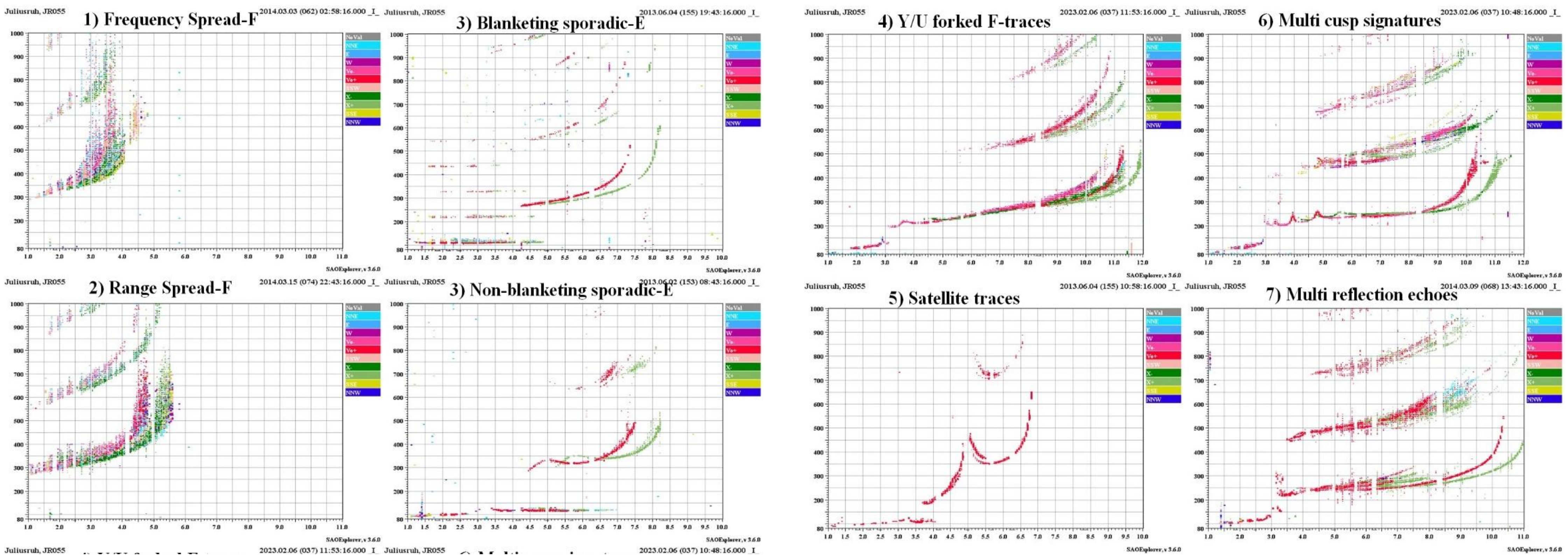
Label	Direction	Characteristics of phase front in EW and NS keogram
1	North	EWK-aligned; NSK-progression towards north
2	East	EWK-progression towards east; NSK-aligned
3	South	EWK-aligned; NSK-progression towards south
4	West	EWK-progression towards west; NSK-aligned
5	Northeast	EWK-progression towards east; NSK-progression towards north
6	Southeast	EWK-progression towards east; NSK-progression towards south
7	Southwest	EWK-progression towards west; NSK-progression towards south
8	Northwest	EWK-progression towards west; NSK-progression towards north

We analyzed three years (2014, 2016, 2020) of data for the four seasons i.e. two equinoxes (March and September) and two solstices (June and December)

MSTIDs climatology: Ionosonde

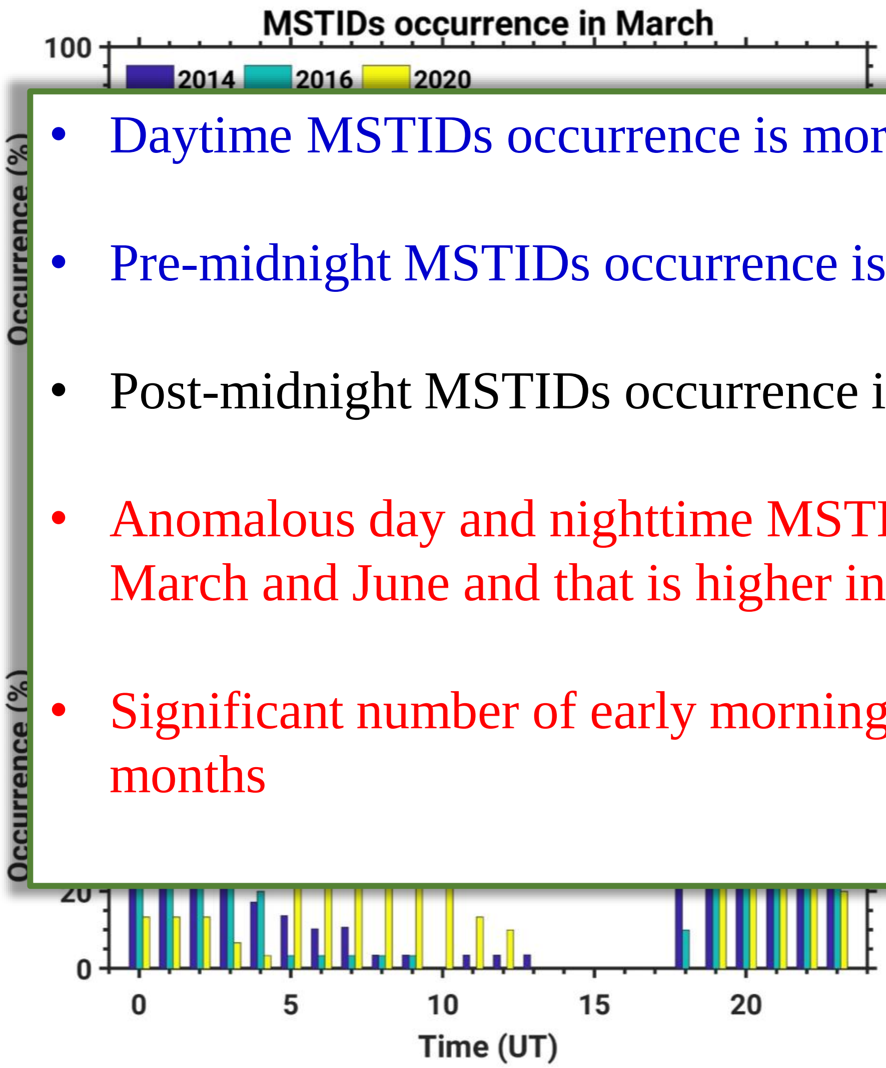
URSI-code	Name	Latitude	Longitude	Ionosonde type
JR055	Juliusruh	54.60	13.40	DPS-4D
FF051	Fairford	51.70	358.50	DPS-4D
RL052	Chilton	51.50	359.40	DPS-1
DB049	Dourbes	50.10	4.60	DPS-4D
PQ052	Pruhonice	50.00	14.60	DPS-4D
SO148	Sopron	47.63	16.72	DPS-4D
RO041	Rome	41.90	12.50	DPS-4
EB040	Roquetes	40.80	0.50	DPS-4D
VT139	San Vito	40.60	17.80	DPS-4D
AT138	Athens	38.00	23.50	DPS-4D
EA036	El Arenosillo	37.10	353.30	DPS-4D
NI135	Nicosia	35.03	33.16	DPS-4D

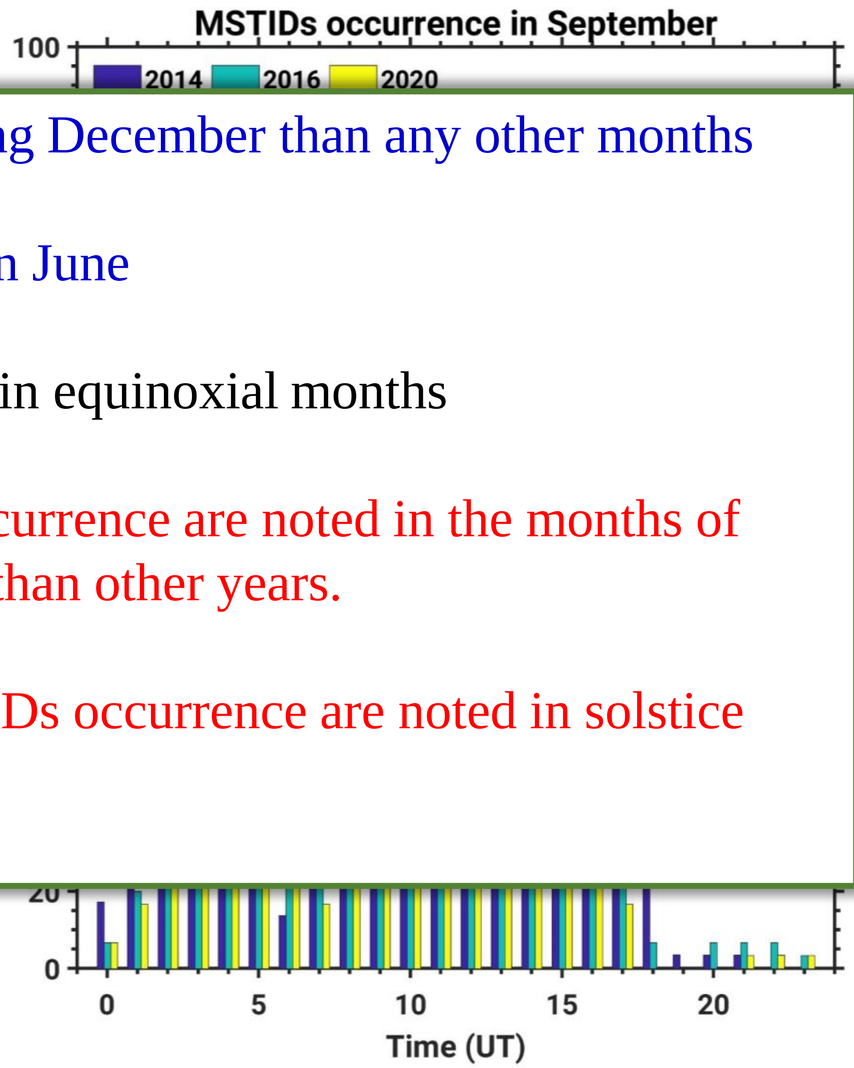
Data analysis and methodologies: Ionosonde



- We analyzed three years (2014, 2016, 2020) of data for the four seasons i.e. two equinoxes (March and September) and two solstices (June and December)
- Only hourly ionograms are considered for the analysis: 24*365=8760 ionograms per station

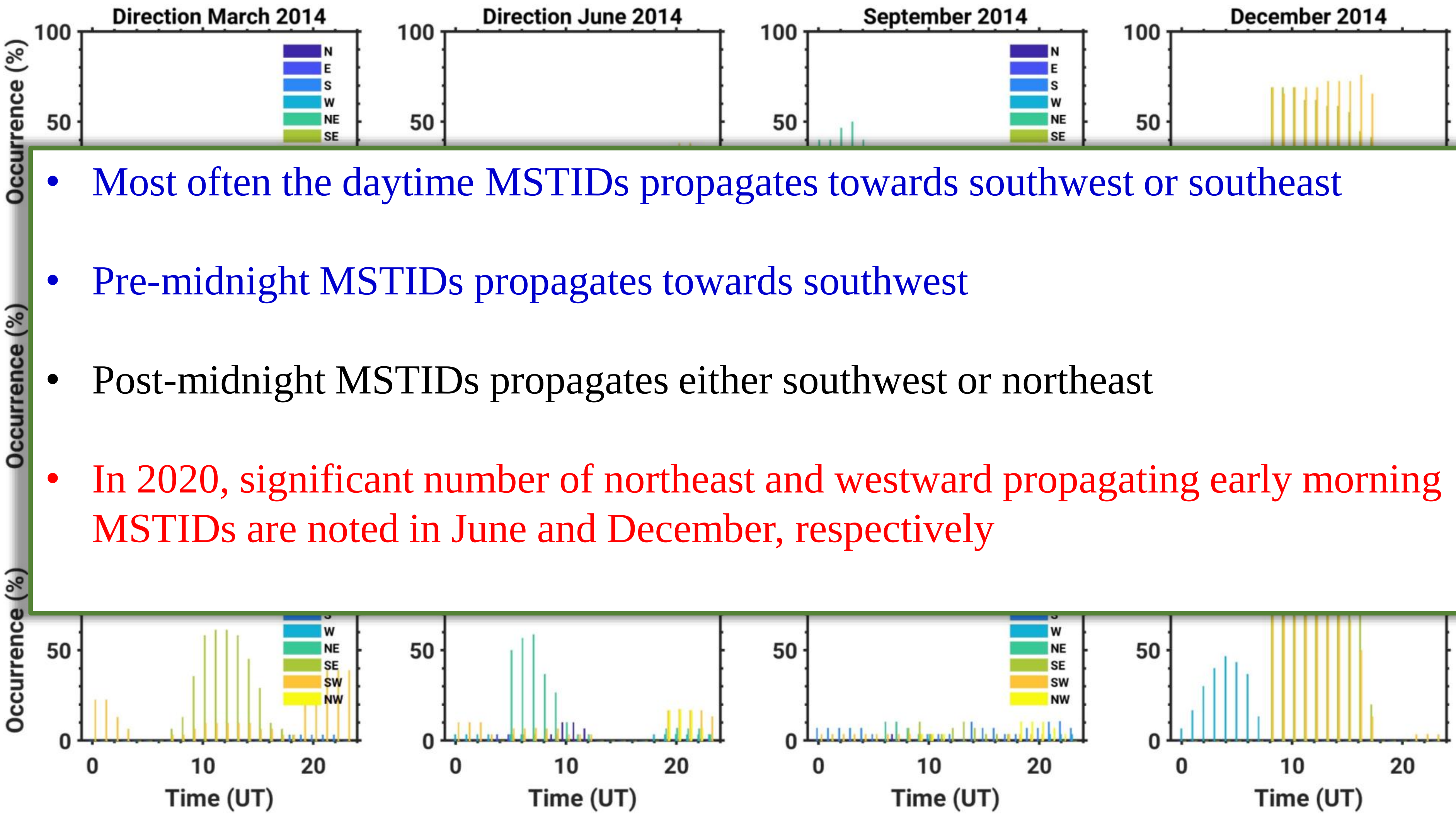
dTEC: Seasonal and diurnal variation of MSTIDs occurrence





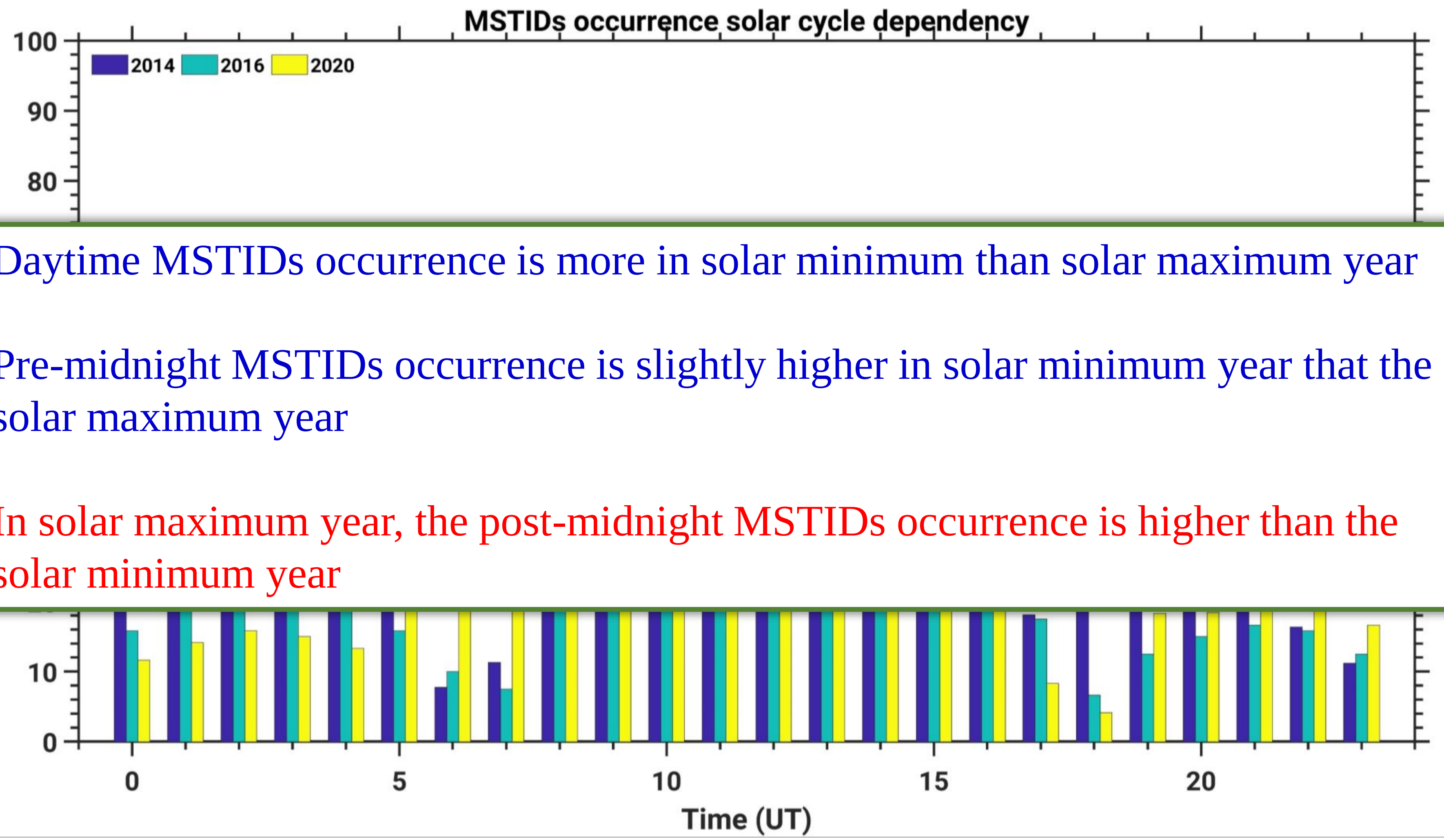
- Daytime MSTIDs occurrence is more during December than any other months
- Pre-midnight MSTIDs occurrence is high in June
- Post-midnight MSTIDs occurrence is high in equinoxial months
- Anomalous day and nighttime MSTIDs occurrence are noted in the months of March and June and that is higher in 2020 than other years.
- Significant number of early morning MSTIDs occurrence are noted in solstice months

dTEC: Seasonal and diurnal variation of MSTIDs propagation direction



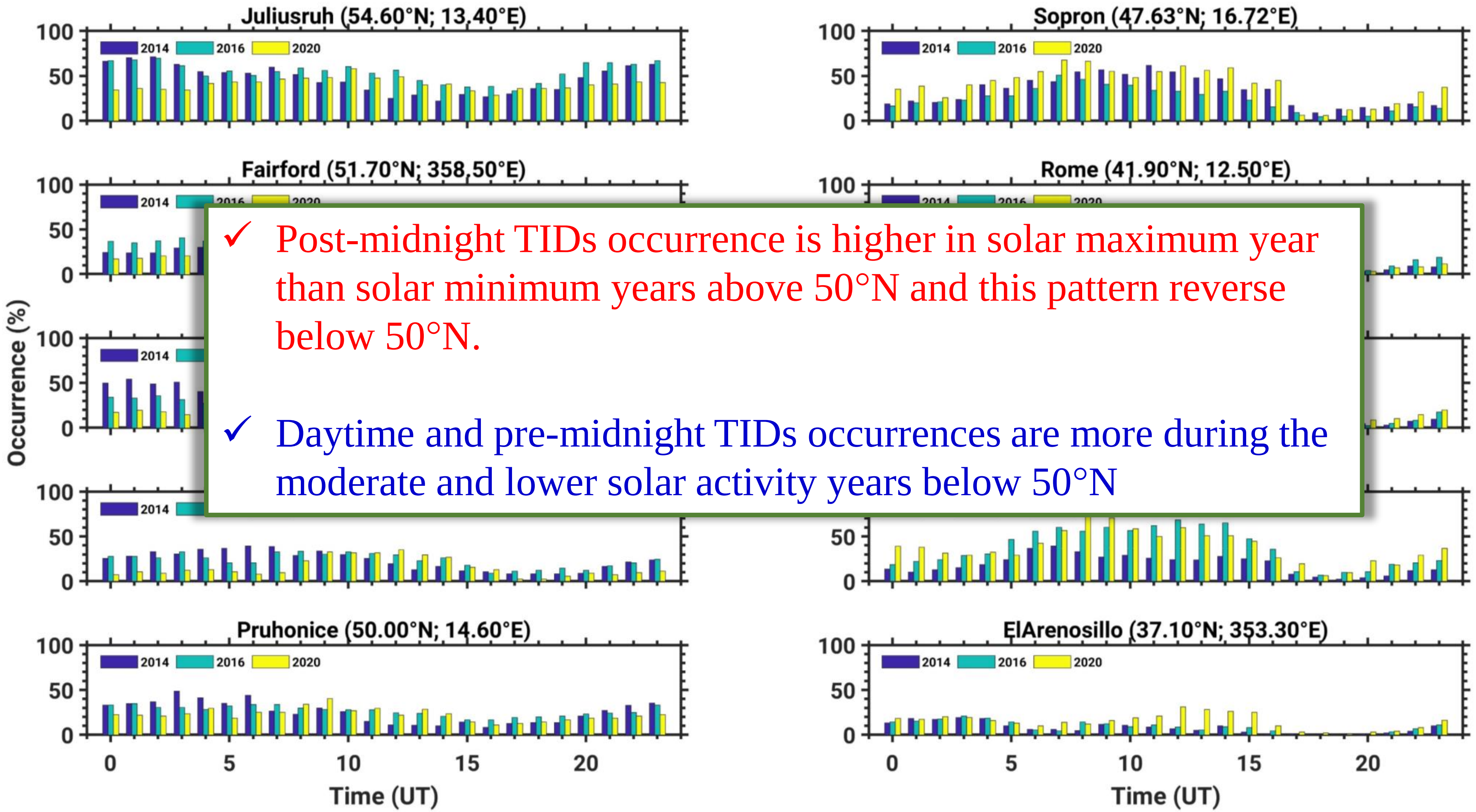
- Most often the daytime MSTIDs propagates towards southwest or southeast
- Pre-midnight MSTIDs propagates towards southwest
- Post-midnight MSTIDs propagates either southwest or northeast
- In 2020, significant number of northeast and westward propagating early morning MSTIDs are noted in June and December, respectively

dTEC: Solar dependency of MSTIDs occurrence



- ✓ Daytime MSTIDs occurrence is more in solar minimum than solar maximum year
- ✓ Pre-midnight MSTIDs occurrence is slightly higher in solar minimum year that the solar maximum year
- ✓ In solar maximum year, the post-midnight MSTIDs occurrence is higher than the solar minimum year

Ionosonde: Solar and latitudinal dependency of TIDs occurrence



- ✓ Post-midnight TIDs occurrence is higher in solar maximum year than solar minimum years above 50°N and this pattern reverse below 50°N.

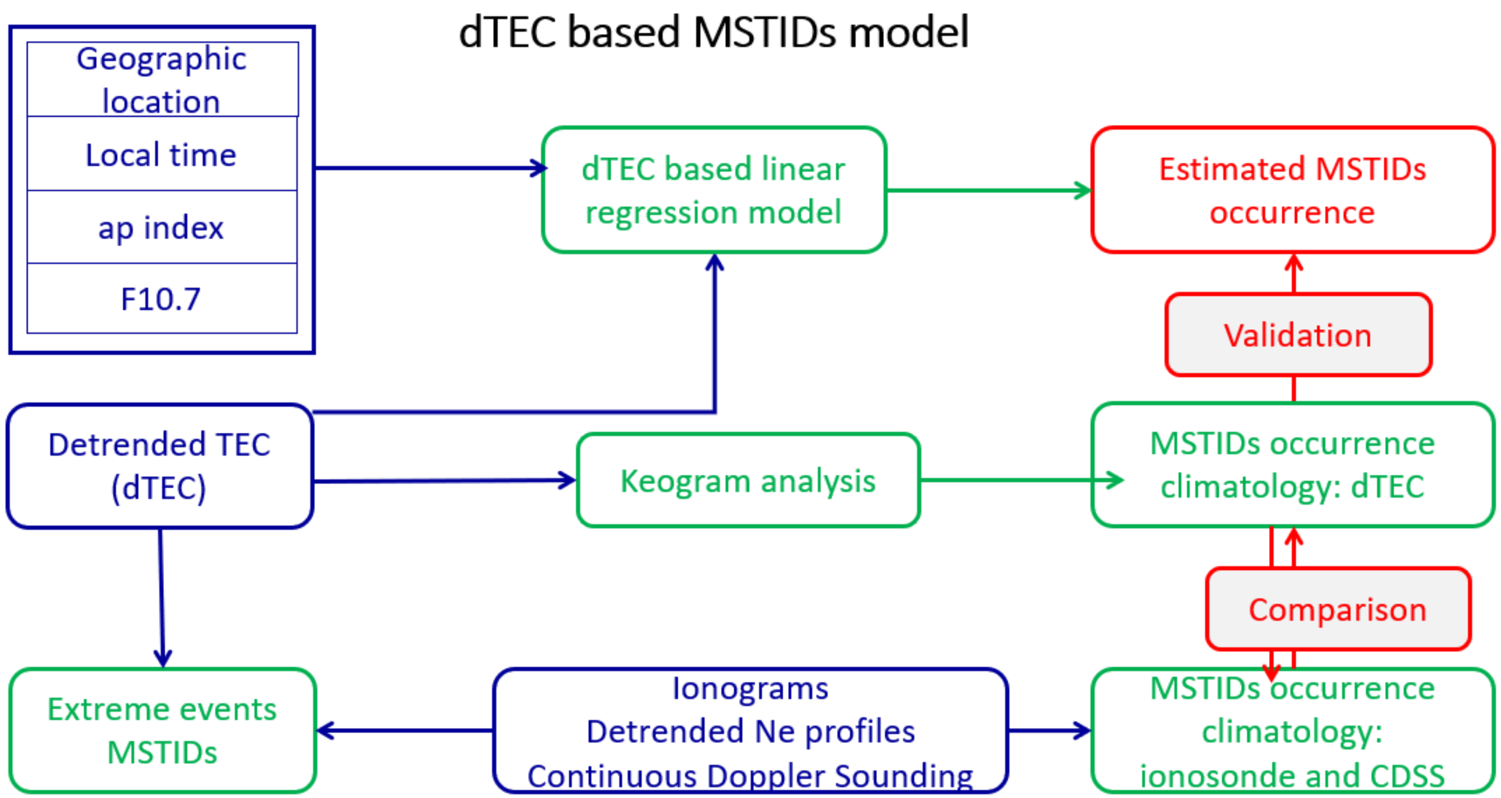
- ✓ Daytime and pre-midnight TIDs occurrences are more during the moderate and lower solar activity years below 50°N

Linear regression model

$$dT = \alpha_0 + \alpha_1 ap + \alpha_2 LT + \alpha_3 SP + \alpha_4 GL \ldots\ldots. (1)$$

$$\alpha_n = \begin{bmatrix} \alpha_0 \\ \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{bmatrix} = (X^T X)^{-1} . X^T Y \ \ldots\ldots\ldots (2)$$

- We are working on the dTEC based linear regression model which will provide the MSTIDs occurrence characteristics.



Summary

➢ New data methodologies are implemented to analysis the GNSS-TEC and ionosonde data sets to explore the MSTIDs climatology over Europe.

- ✓ We found a clear seasonal and solar cycle dependency of the day and nighttime MSTIDs occurrence.
- ✓ Daytime MSTIDs occurrence is more during December than any other months and pre-midnight MSTIDs occurrence is high in June. Surprisingly, post-midnight MSTIDs occurrence is high in equinoxial months.
- ✓ During solar maximum, pre-midnight MSTIDs occurrence is slightly higher than the solar maximum year.
- ✓ In solar maximum year, the post-midnight MSTIDs occurrence is higher than the solar minimum year.
- ✓ In 2020, significant number of northeast and westward propagating early morning MSTIDs are noted in June and December, respectively

Potential services that could be used in a forecasting system, i.e.

- Inventory of potential MSTID indicators (as a precursor)
- Long term forecasting based on the climatological model
- Alerts for extreme events

Thank you for your attention!

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