15th Russian-Chinese Workshop on Space Weather
September 9–13, 2024, Irkutsk, Russia

STUDY OF IONOSPHERIC IRREGULARITIES BASED ON HF RADAR NETWORK DATA

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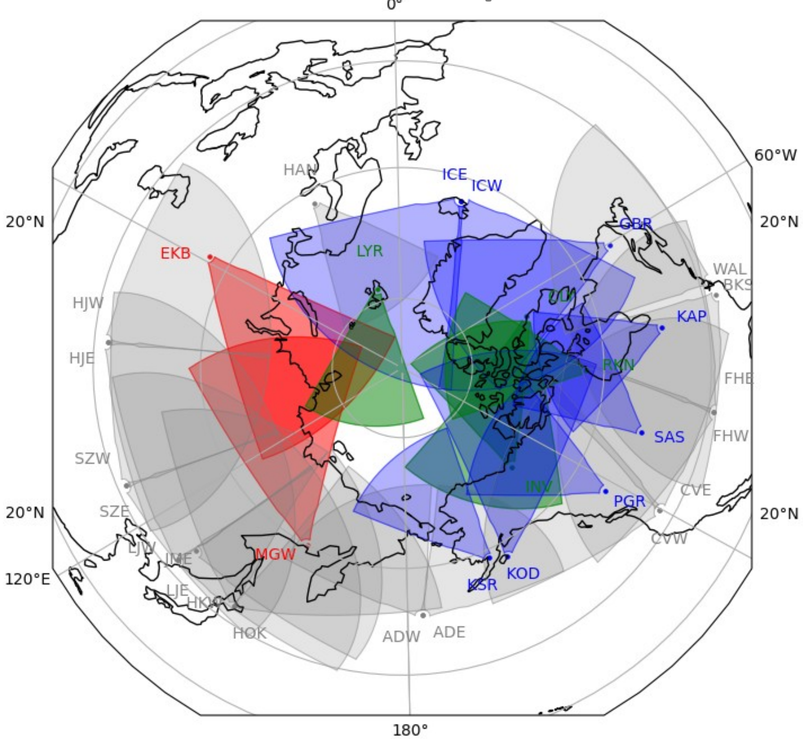
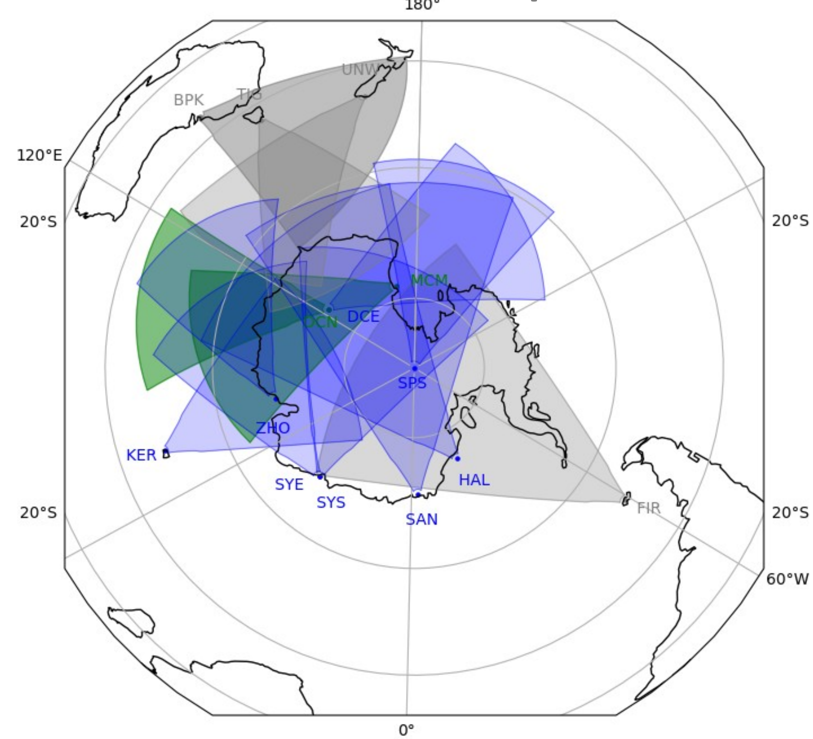
Northern hemisphere



Southern hemisphere



OUTLINE

INTRODUCTION

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    1.2. Statistical study of MSTID’s parameters
    1.3. Comparison with neutral wind model (HWM14)
2. Field-aligned irregularities (FAI). GDI growth rate
    2.1. FAI observation during St.Patrick superstorm (March 17-18, 2015). Comparison with GSMTIP
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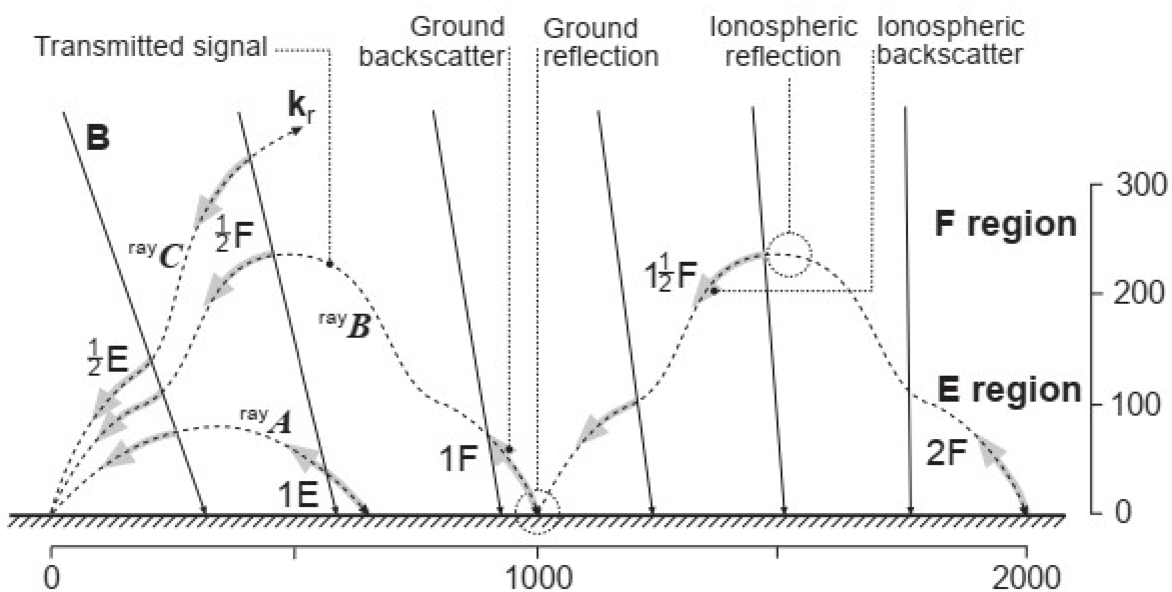
    2.3. Comparison with empirical ionosphere models

CONCLUSIONS and FINAL REMARKS

HF WAVES PROPAGATION MODES (3-30 MHZ)



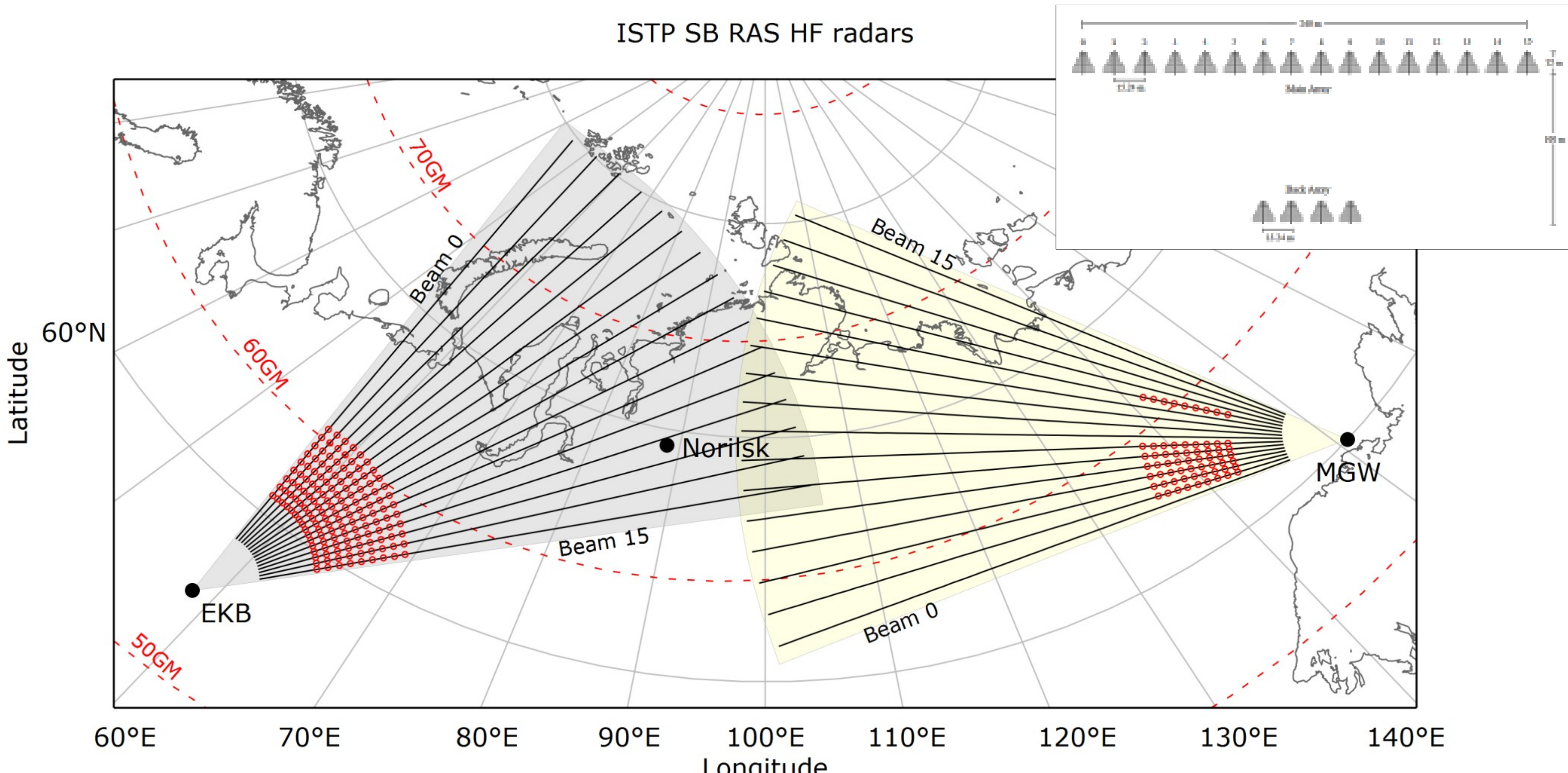
INTRODUCTION

Russian HF radars

Operational frequency: 8-20 MHz
Number of beams: 16
Beam width: ~3.5°
Beam separation angle: 3.24°
Field-of-view: ~52°

Range gate: 15/45 км
Stereo mode – 2 channels

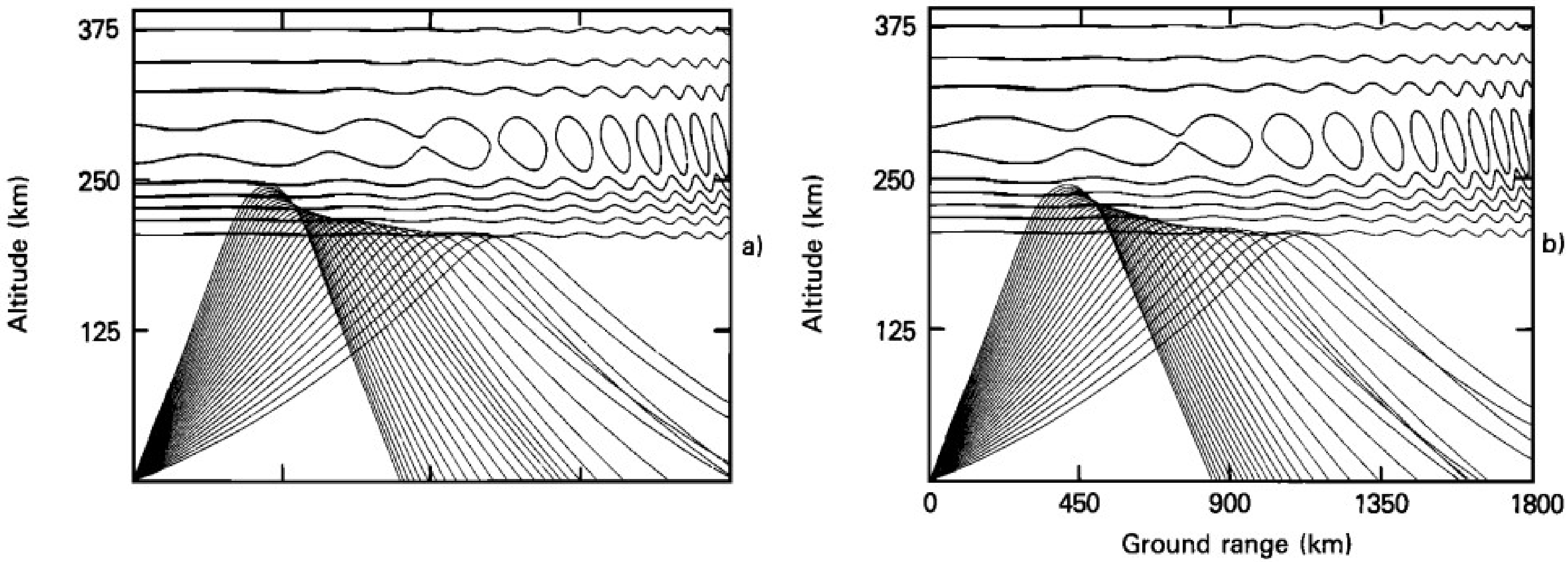
First light dates
EKB: December 2012
MGW: October 2020



Phased array antenna

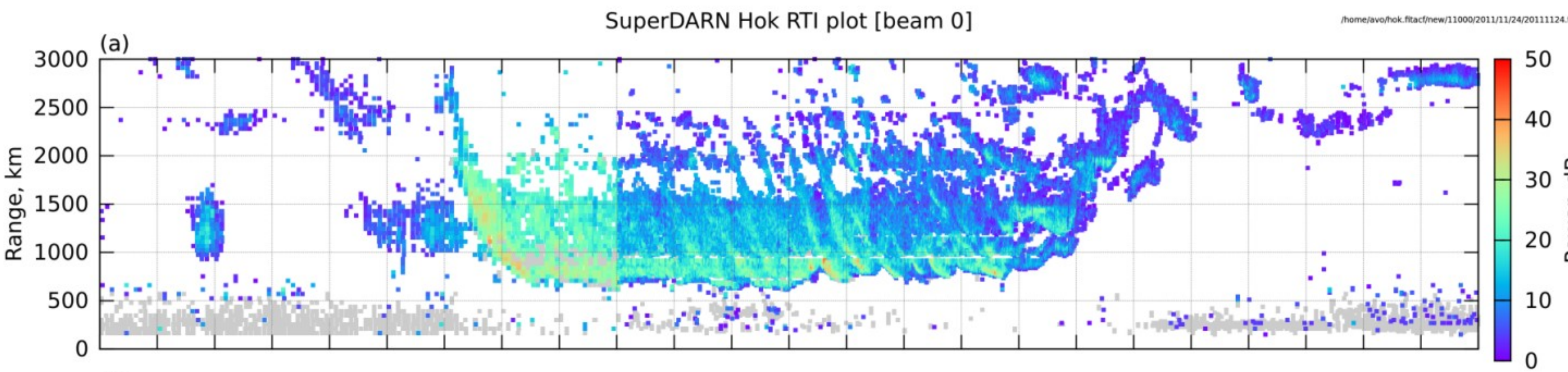
1. Medium scale traveling ionospheric disturbances (MSTIDs)

Simulation example



Samson et al. (1990)

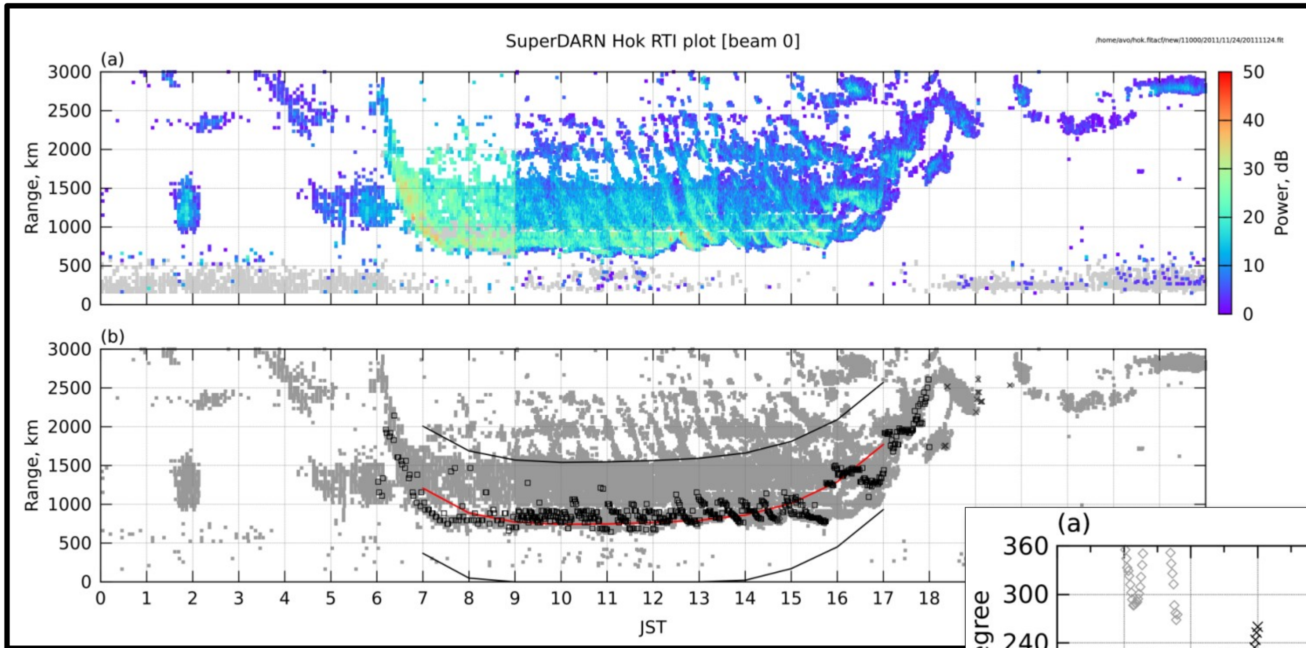
Observation

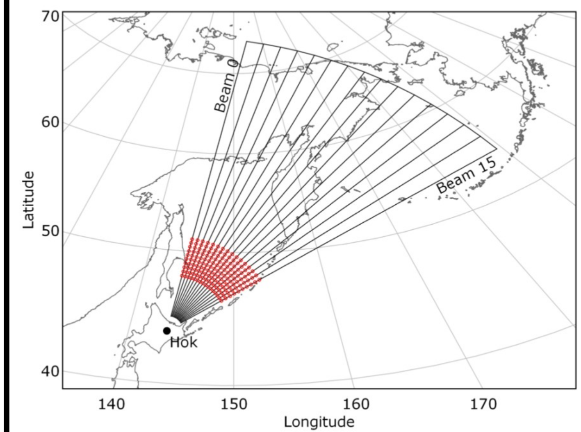


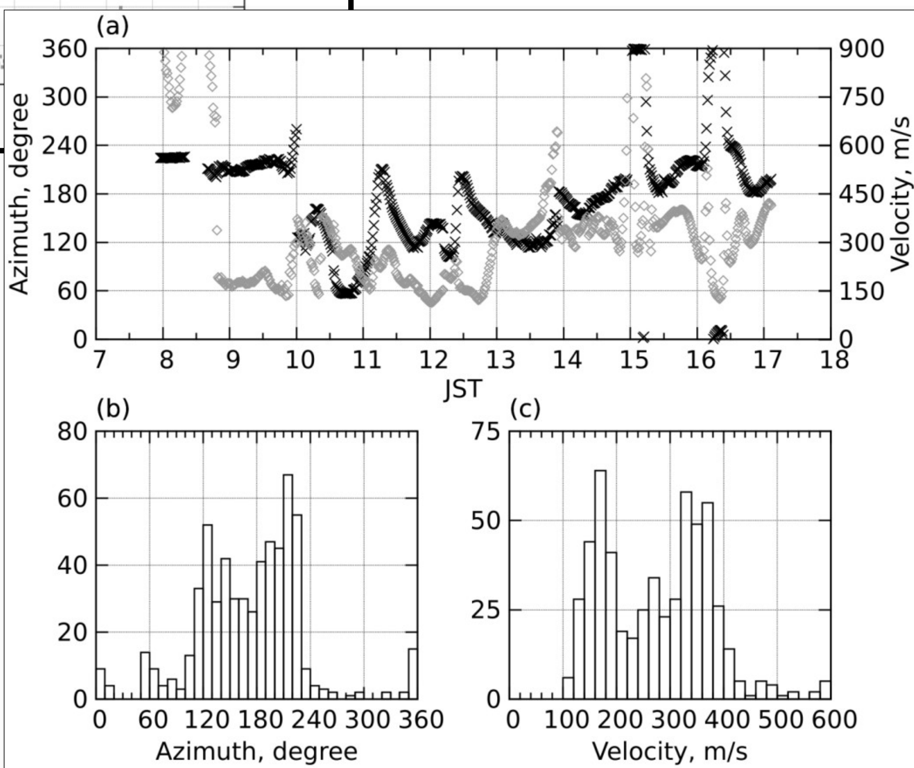
Oinats et al. (2015)

1.1. TID's parameters determination technique

Oinats et al. (2015)



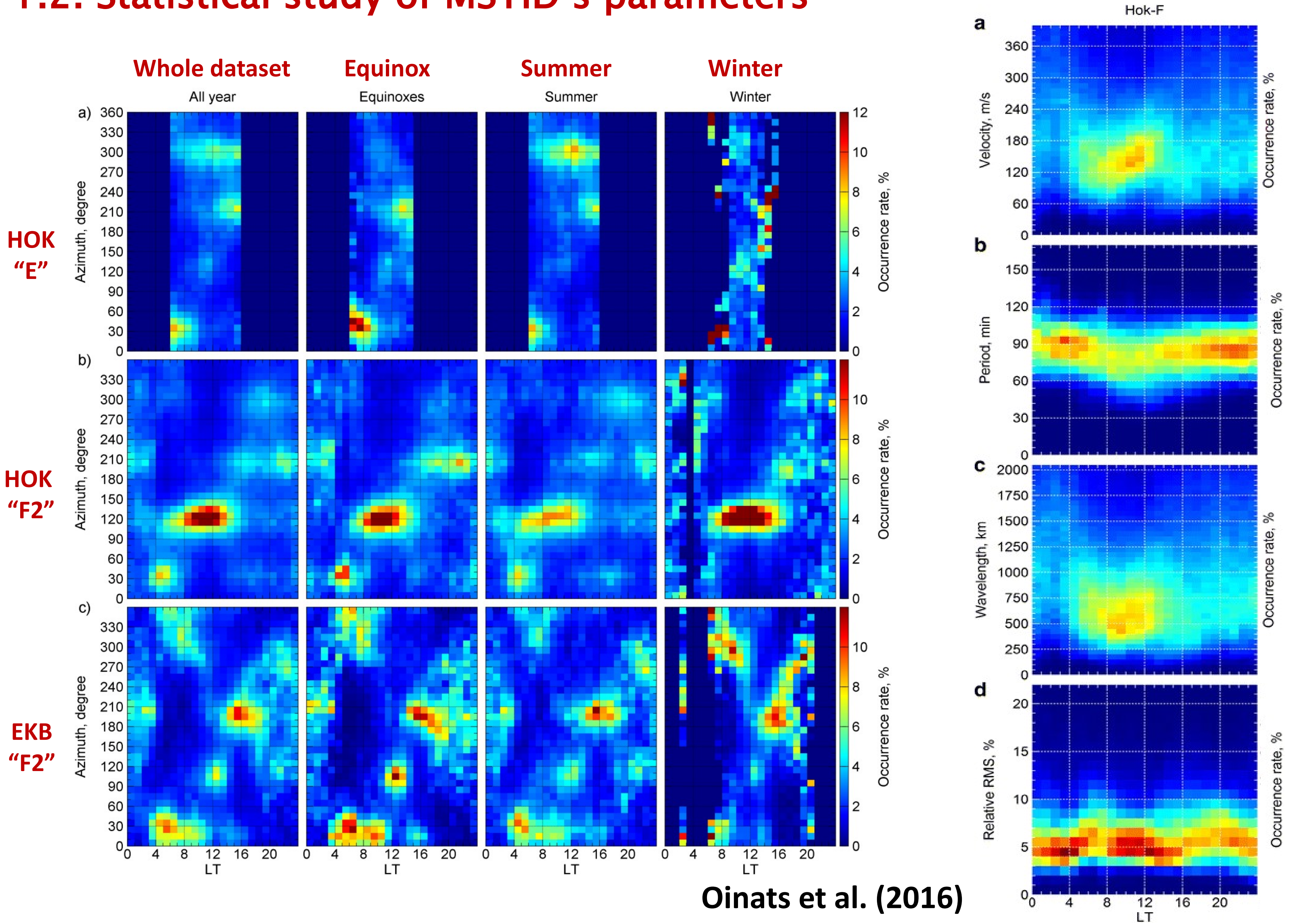




Hokkaido RTI obtained on the beam #0 in November 24, 2011. Red line on the bottom panel is a simulated diurnal variation of minimal range. Black lines is a corresponding "mask" for correct minimal range variations extraction.

Determined diurnal dependencies of azimuth and apparent horizontal velocity and corresponding distributions

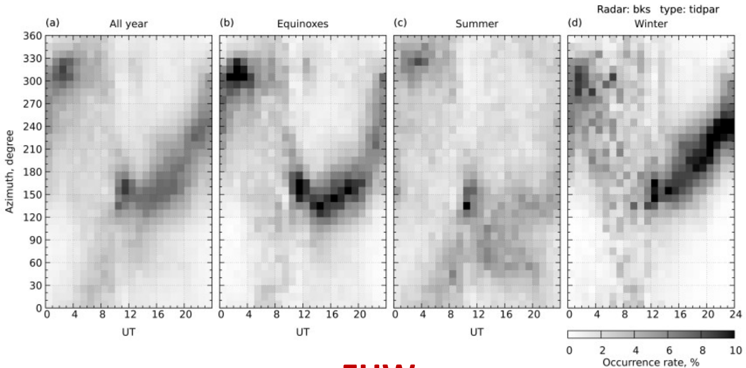
1.2. Statistical study of MSTID's parameters



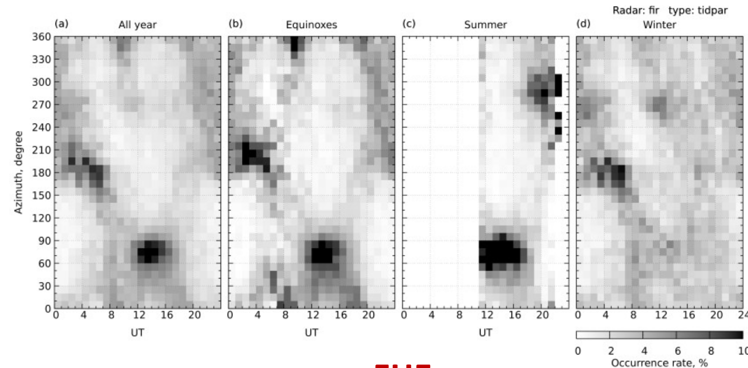
Oinats et al. (2016)

1.2. Statistical study of MSTID's parameters

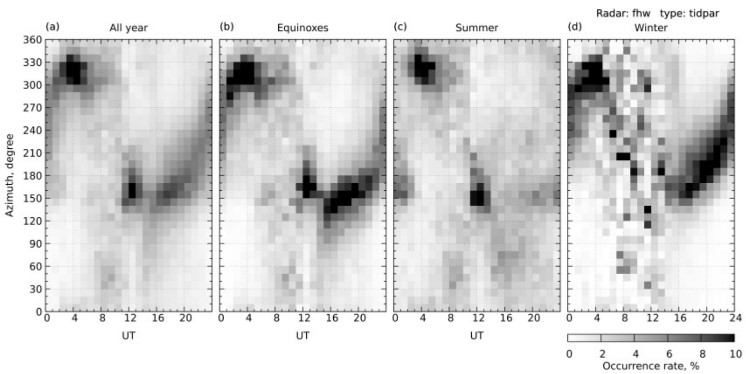
BKS



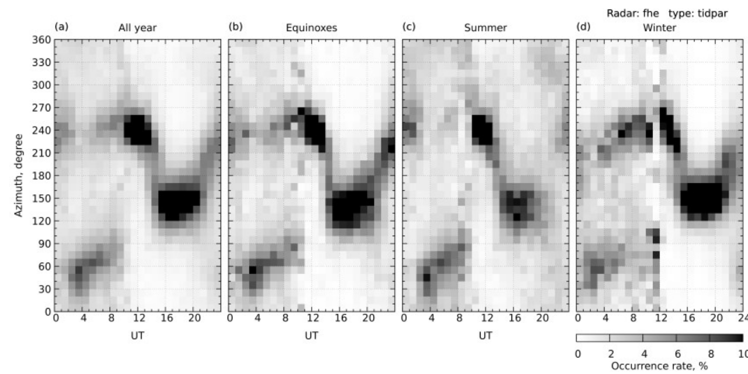
FIR



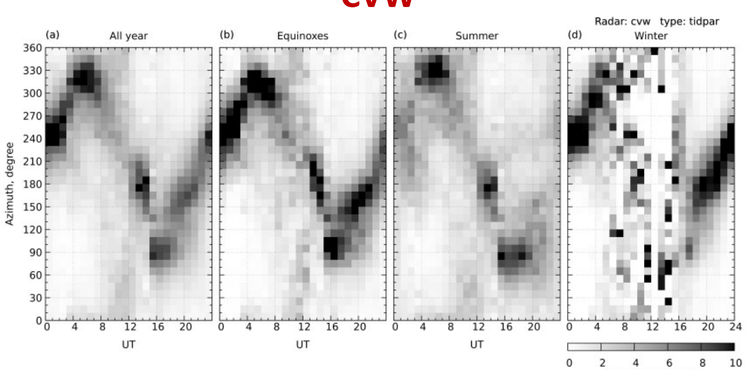
FHW



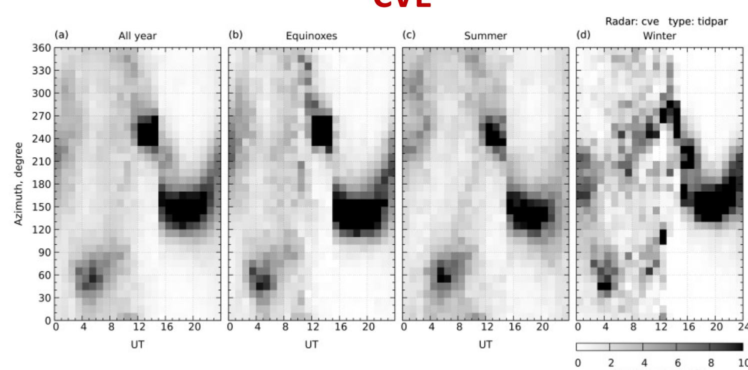
FHE



CVW



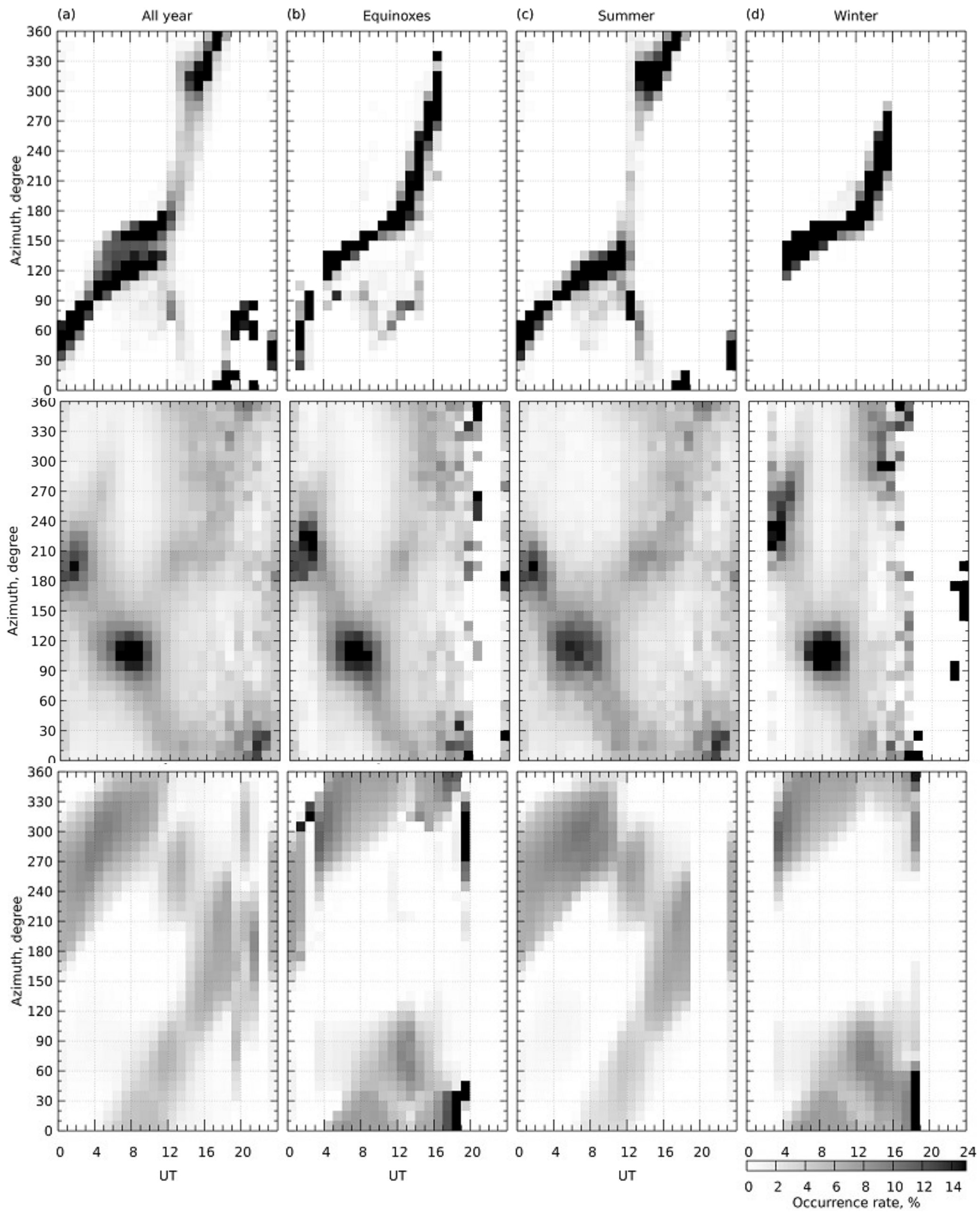
CVE



***preliminary results**

1.3. Comparison with neutral wind models

EKB
(2013 - 2021)



"Allowed" azimuths (HWM14)

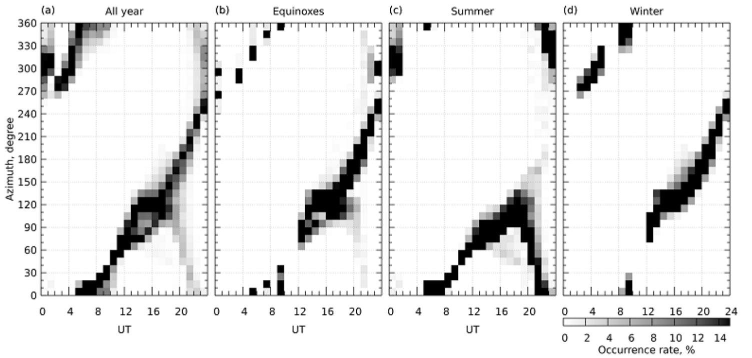
Observed MSTID azimuths

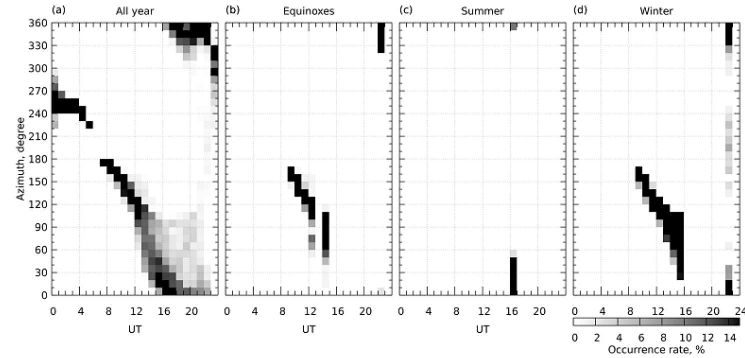
"Restricted" azimuths (HWM14)

1.3. Comparison with neutral wind models

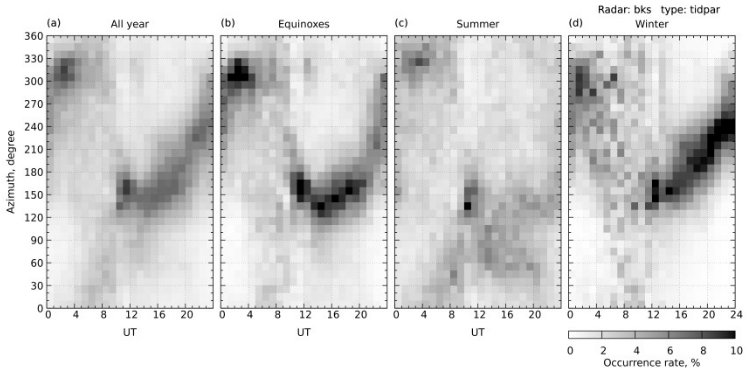
BKS (2010-2011 and 2013-2014)

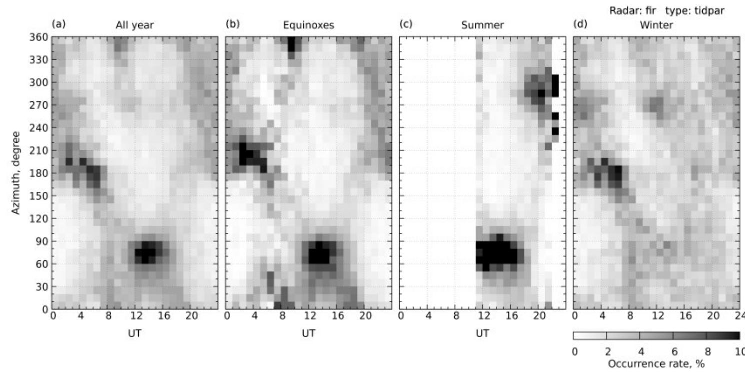
FIR (February 2010 – October 2011)



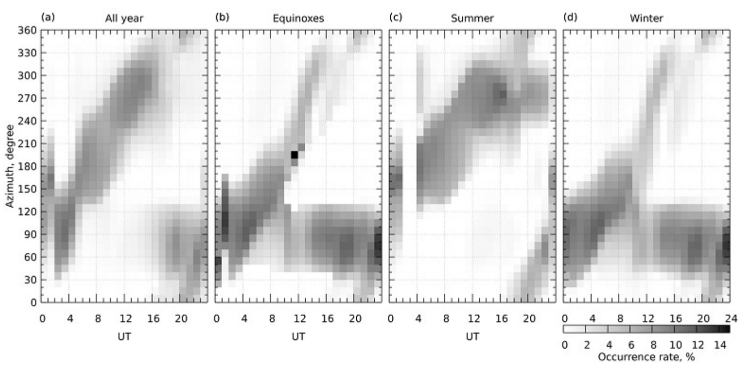


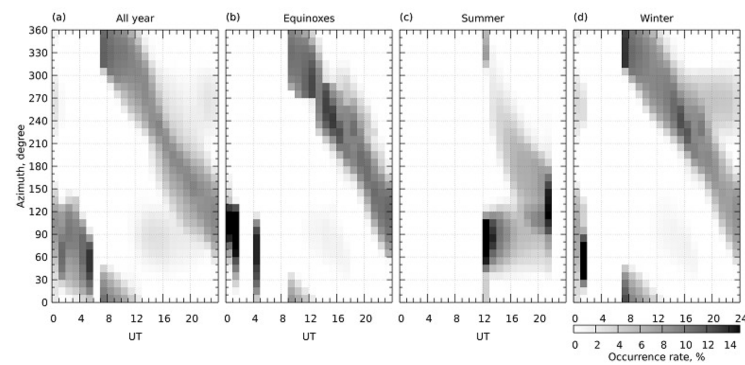
“Allowed” azimuths (HWM14)





Observed MSTID azimuths





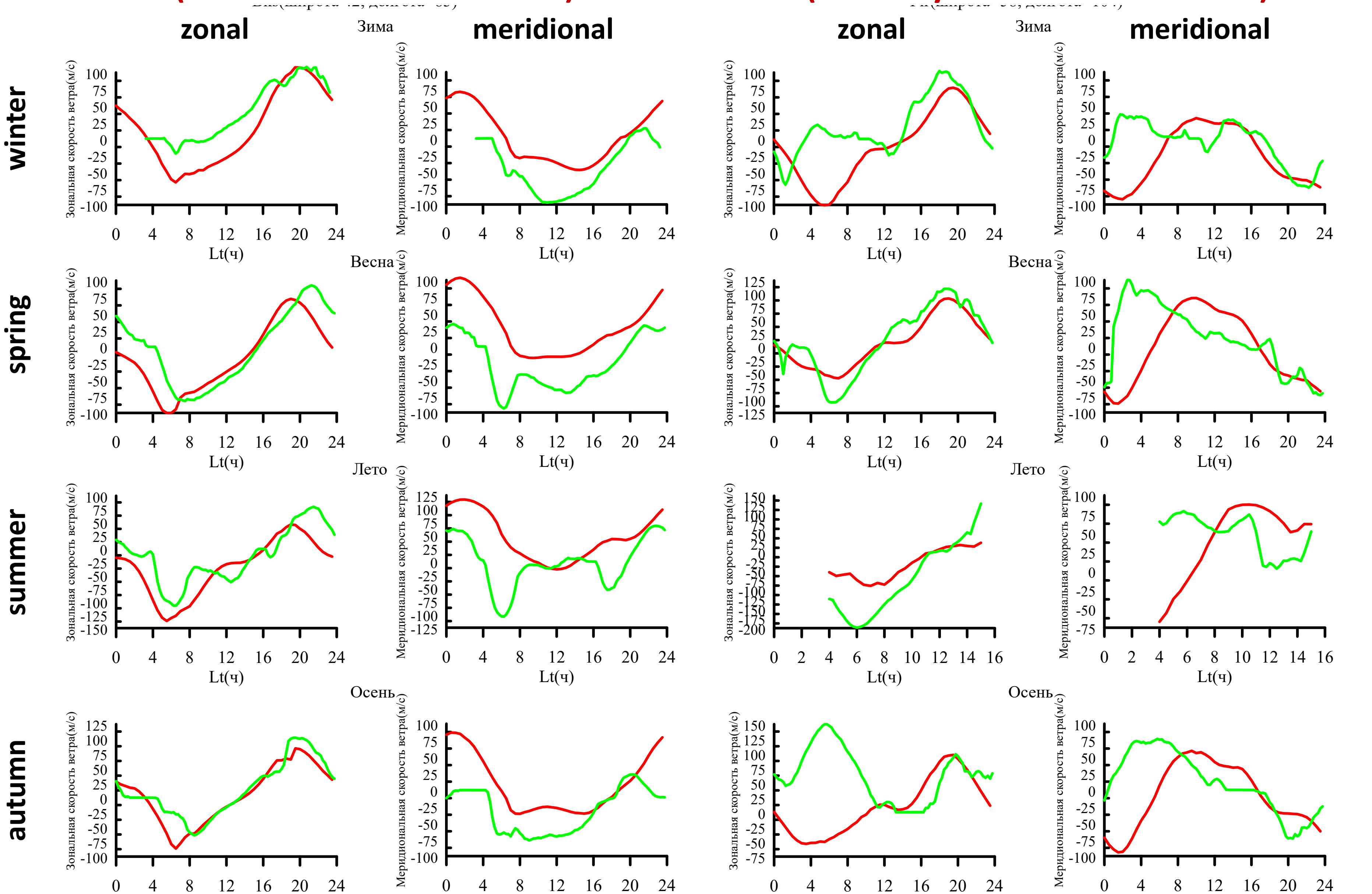
“Restricted” azimuths (HWM14)

1.3. Comparison with neutral wind models

GREEN – calculated
RED – HWM14

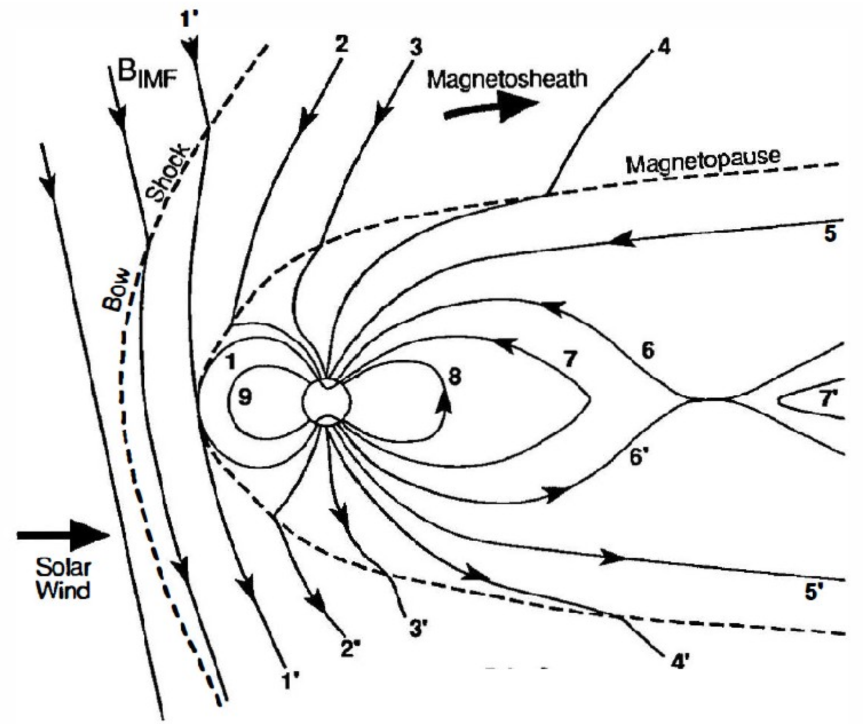
BKS (2010-2011 and 2013-2014)

FIR (February 2010 – October 2011)

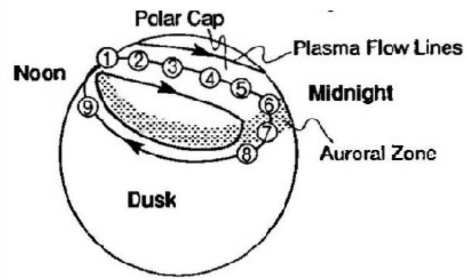


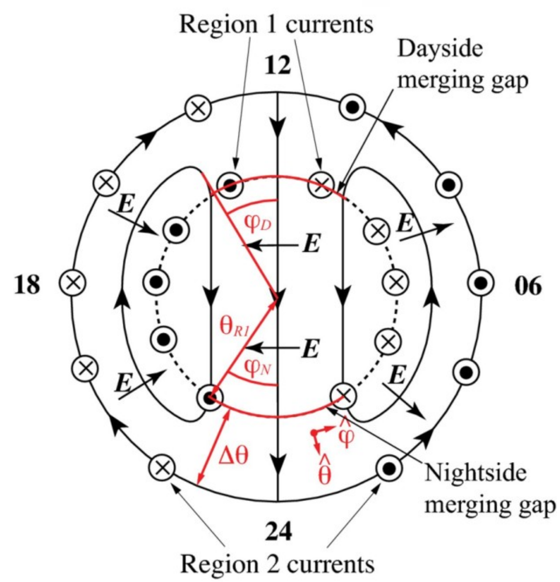
Please, see Tolstikov et al., 2022 in “Solar-Terrestrial Physics” for details

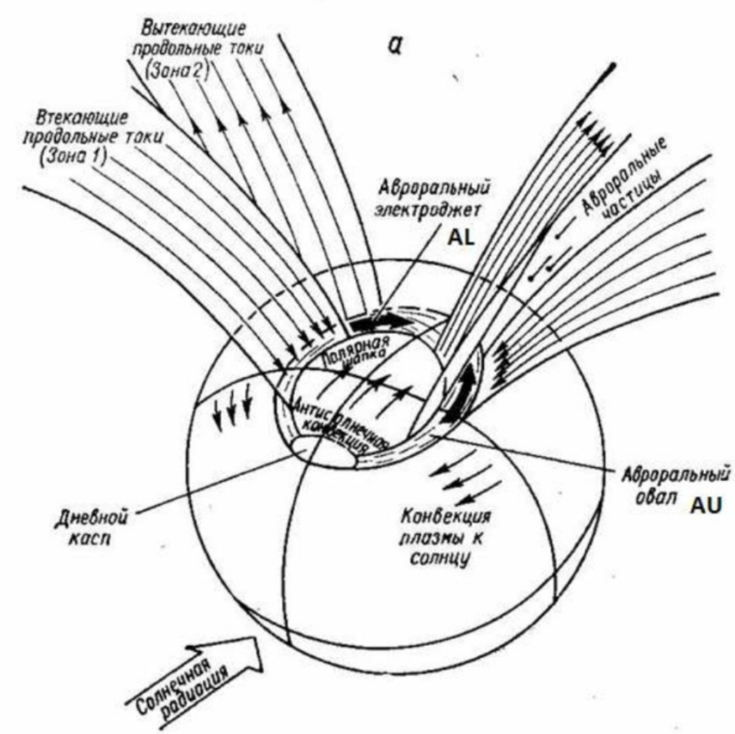
2. Field-aligned irregularities (FAI). GDI growth rate



(Dungey, 1961)

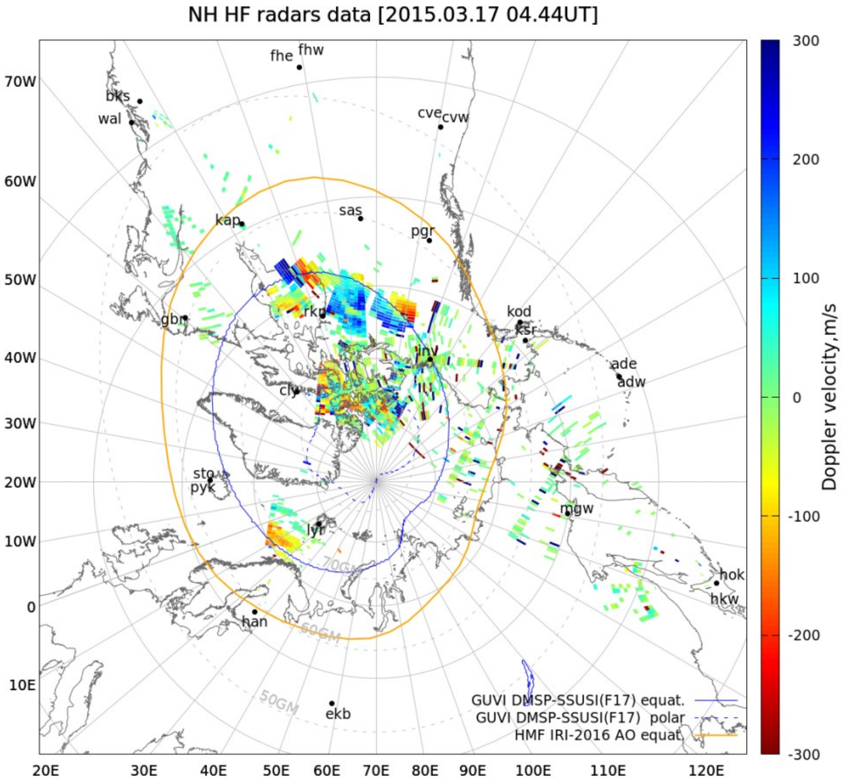


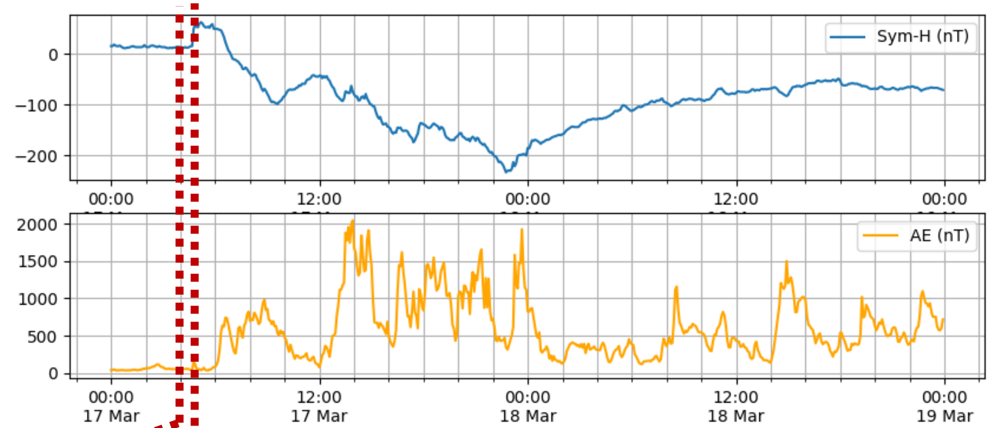




2. Field-aligned irregularities (FAI). GDI growth rate

04:44UT 17.05.2015





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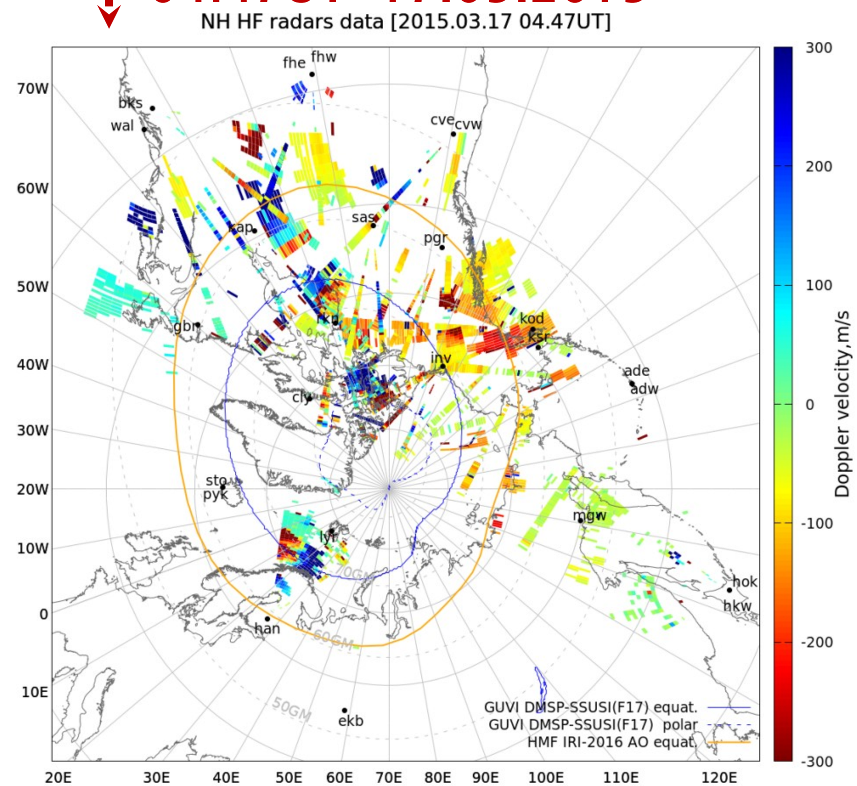


Sudden storm commencement (SSC) effects during St. Patrick's day superstorm

2. Field–aligned irregularities (FAI). GDI growth rate

Gradient-drift instability (GDI) growth rate in the ionospheric F region **[Makarevich, 2014]**

$$\gamma^F \cong \frac{\mathbf{k}\cdot\hat{\mathbf{b}}\times\mathbf{G}}{1+\psi}\frac{1}{k^2}\frac{\mathbf{k}\cdot\mathbf{E}_0}{B} = \frac{GV_E}{1+\psi}\left(\hat{\mathbf{k}}\cdot\hat{\mathbf{b}}\times\hat{\mathbf{g}}\right)\left(\hat{\mathbf{k}}\cdot\hat{\mathbf{e}}\right)$$

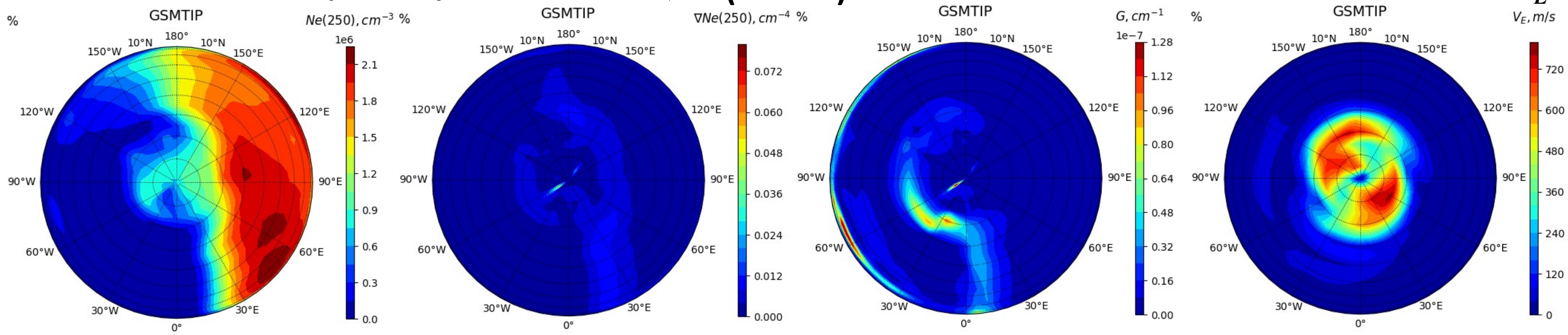
$$\gamma^F = -\frac{GV_E}{1+\psi}\cos\alpha\cos(\alpha-\beta)$$

The angles give orientation of GDI wave vector and electric field in the XY plane when use a coordinate system with axes directed along the electron density gradient vector (Oy) and magnetic field (Oz)

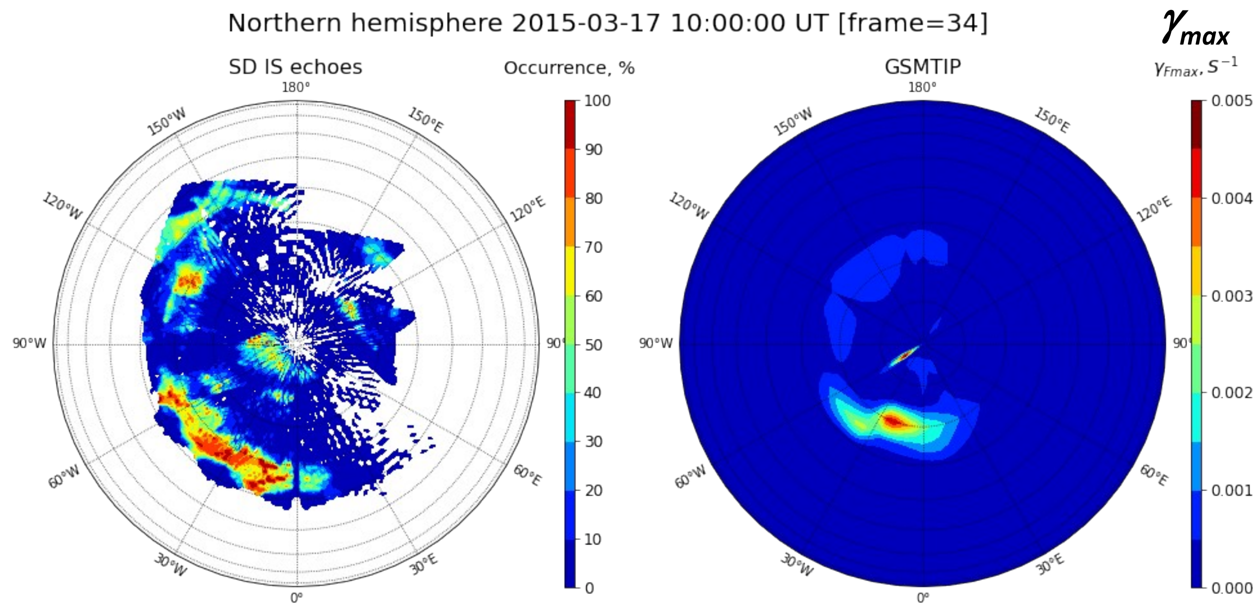
$$\gamma^F_{\max} = -GV_E$$

2.1. FAI observation during St.Patrick superstorm (March 17-18, 2015). Comparison with GSMTIP

Ne(250km) **∇Ne(250km)** **G** V_E



Please, see details about GSMTIP in [Korenkov et al., 1998; Klimenko et al., 2019]

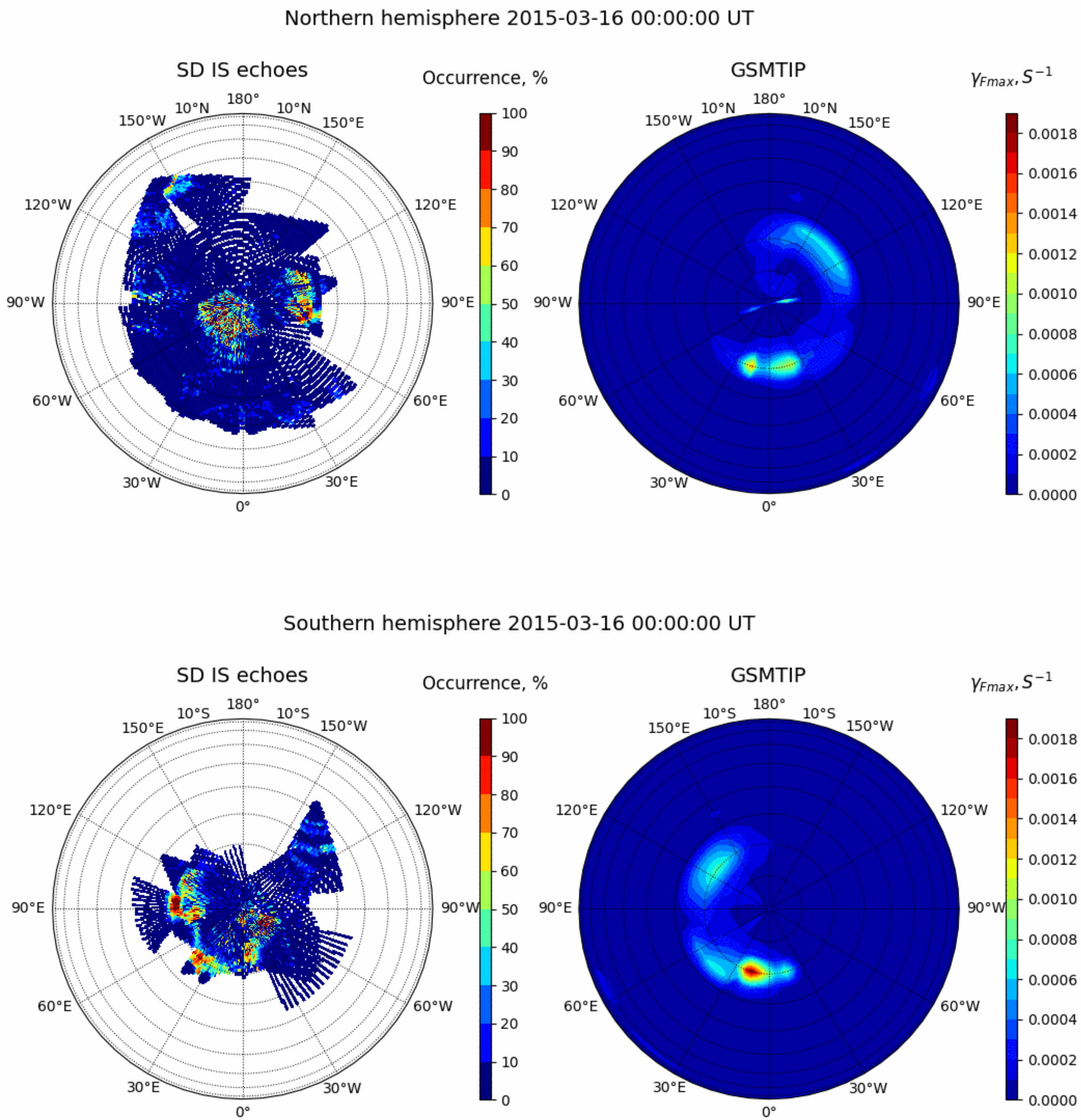


Oinats et al., «PROGNOZ-2024» conference
May 27-31, 2024, IZMIRAN, Moscow

2.1. FAI observation during St.Patrick superstorm (March 17-18, 2015). Comparison with GSMTIP

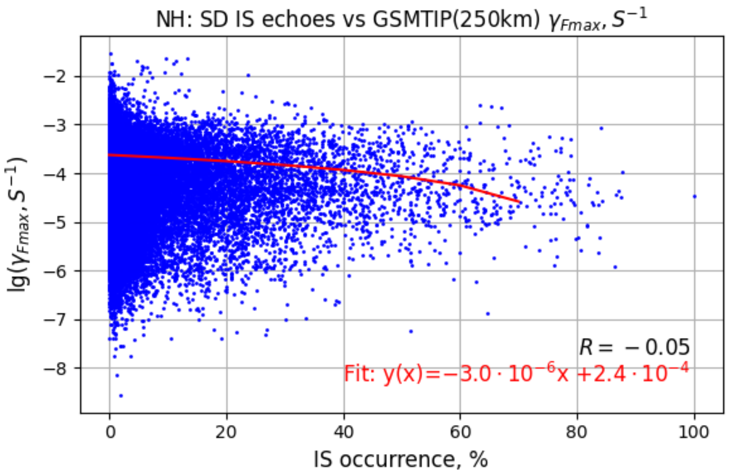
NH

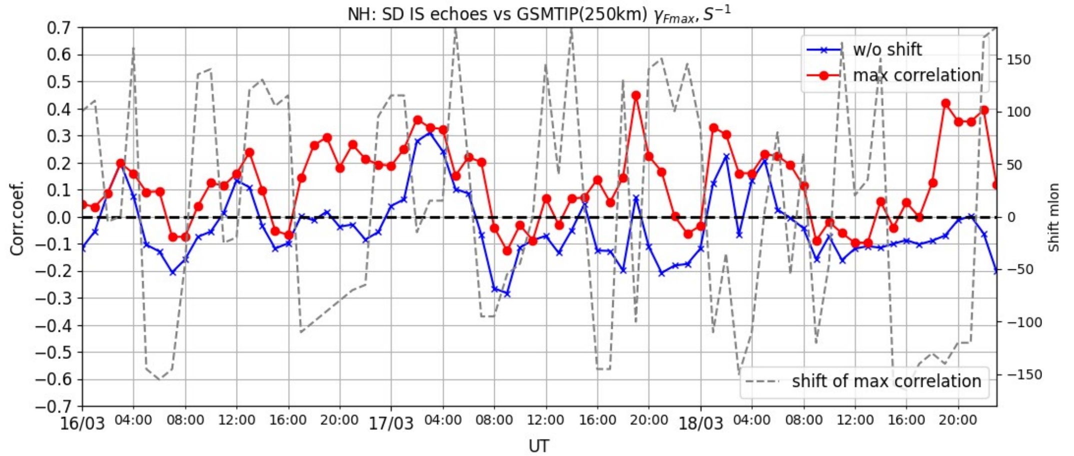
SH

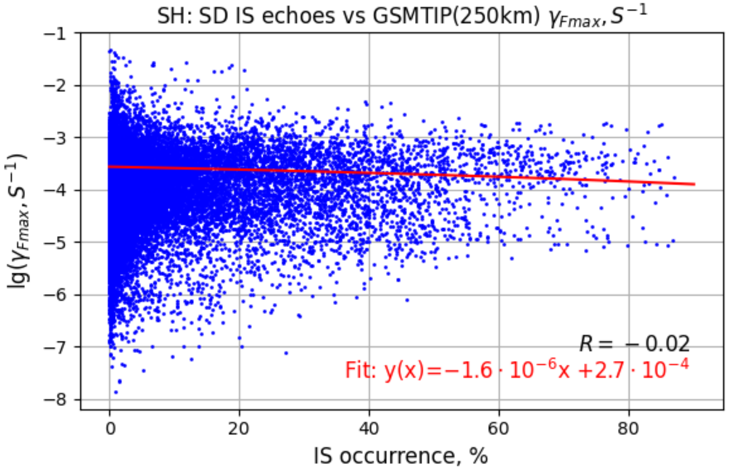


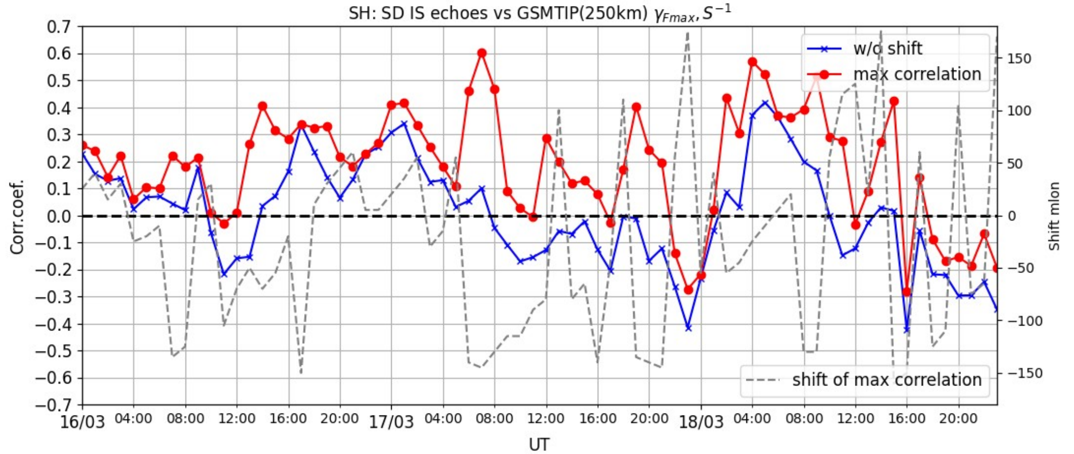
2.1. FAI observation during St.Patrick superstorm (March 17-18, 2015). Comparison with GSMTIP

GSMTIP – regression and correlation





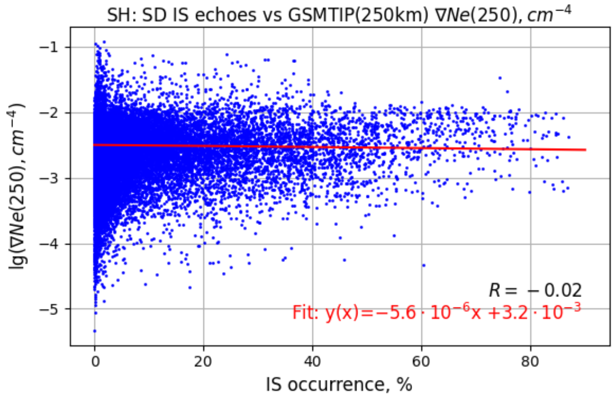


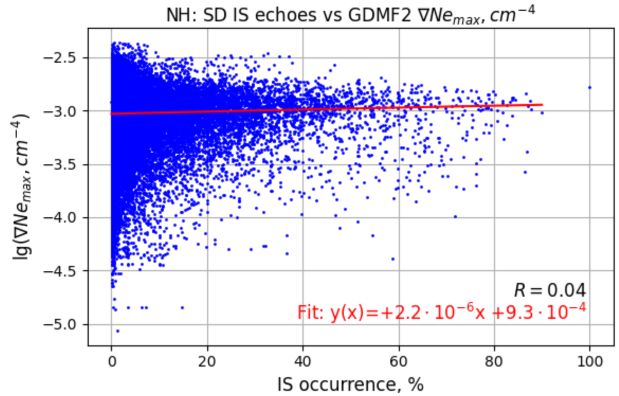


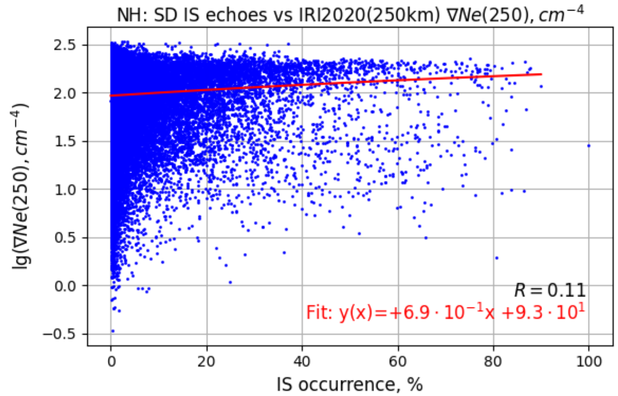
2.1. FAI observation during St.Patrick superstorm (March 17–18, 2015). Comparison with GSMTIP

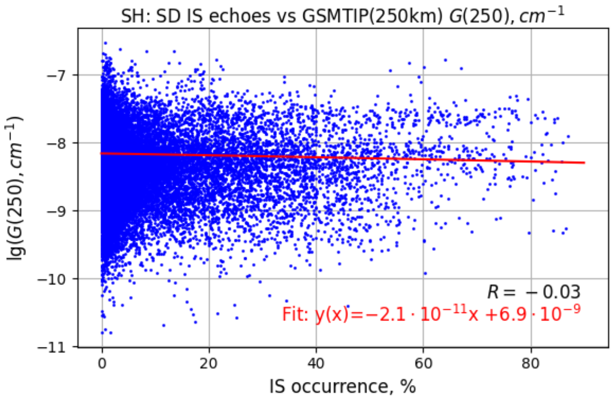
GSMTIP, GDMF2, IRI2020 – regression and correlation

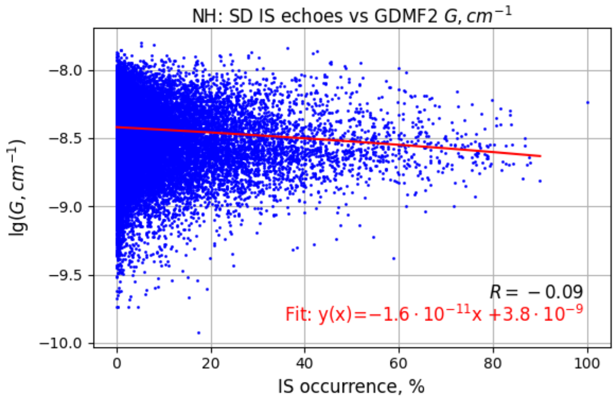
GSMTIP	GDMF2 [Shubin & Deminov, 2019]	IRI2020 [Bilitza et al., 2022]

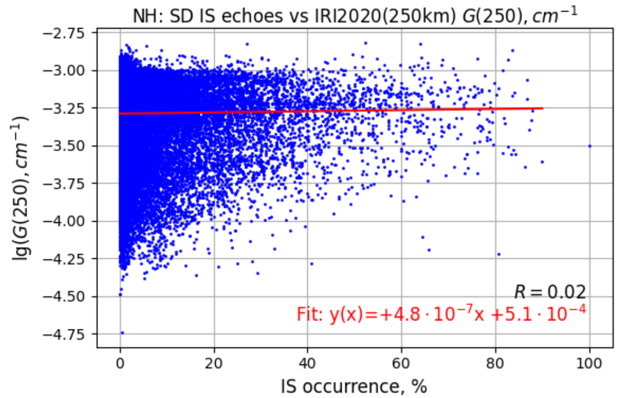








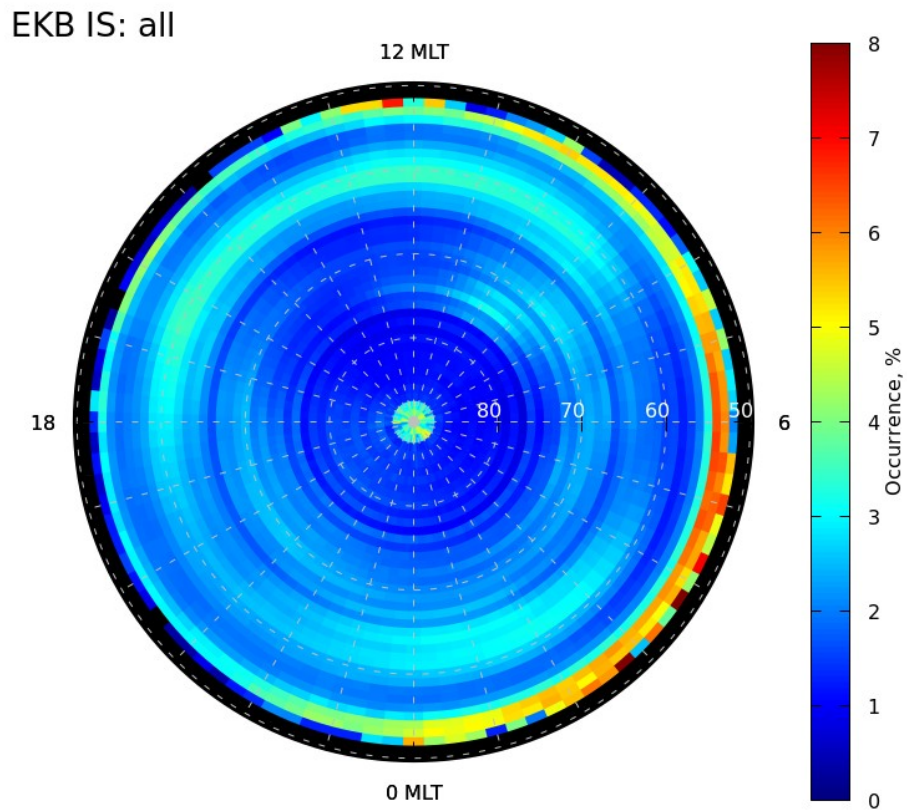


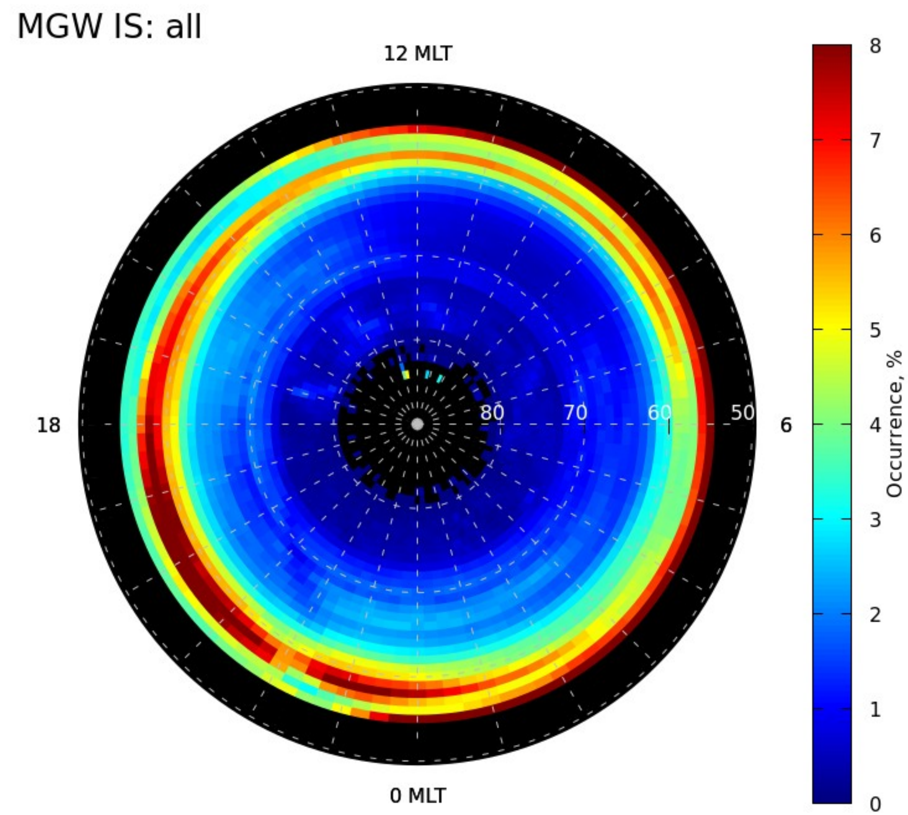


2.1. FAI observation during St.Patrick superstorm (March 17–18, 2015). Comparison with GSMTIP

Dataset	Ne_{max}	∇Ne	G	γ_{max}
	GSMTIP			
NH	-0.09	-0.07	-0.04	-0.05
SH	0.07	-0.05	-0.05	-0.02
	GDMF2			
NH	0.12	0.04	-0.09	
SH	-0.07	-0.05	0.03	
	IRI2020			
NH	0.12	0.05	-0.07	
SH	-0.02	-0.04	-0.06	

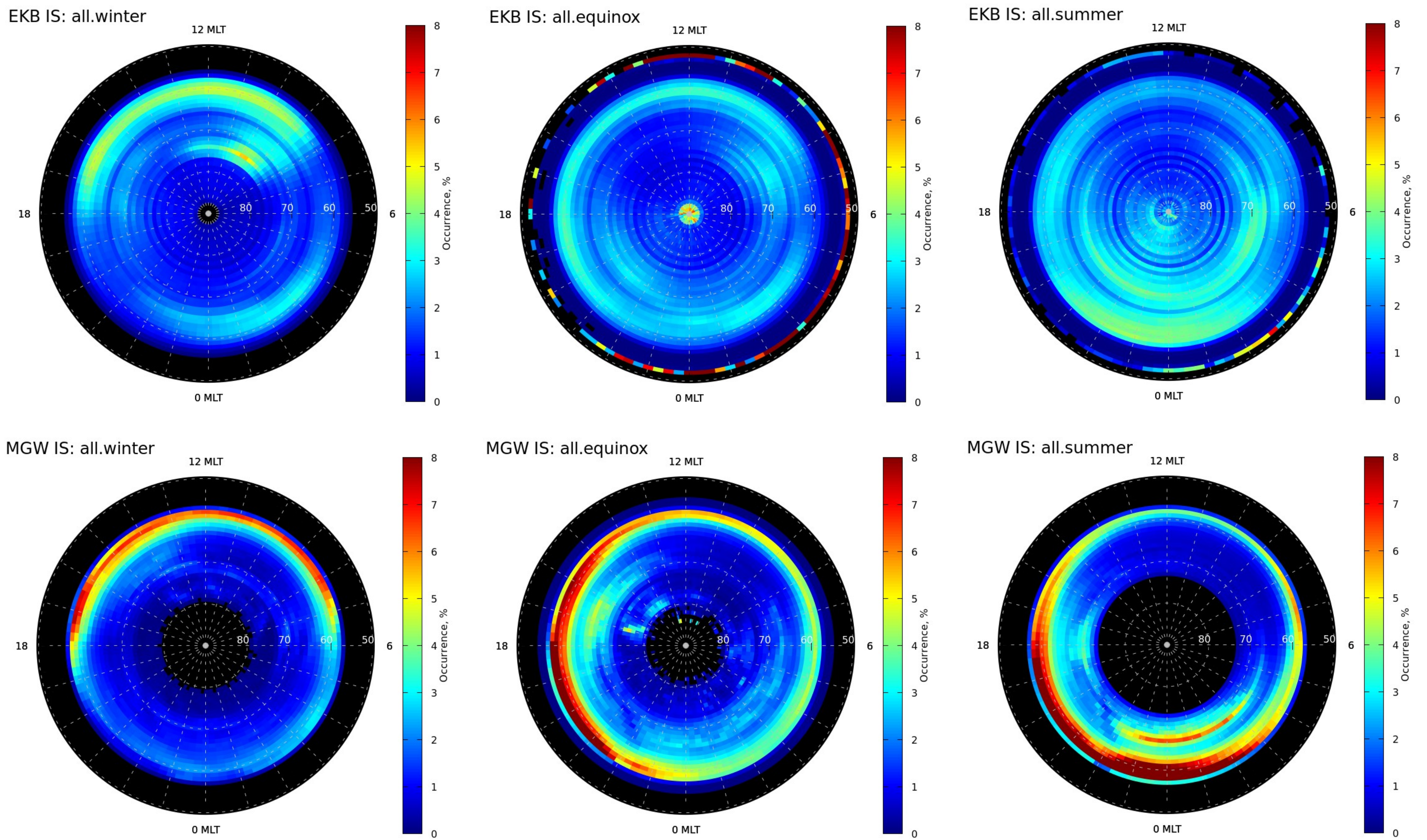
2.2. Statistical study of FAI occurrence observed by EKB and MGW radars





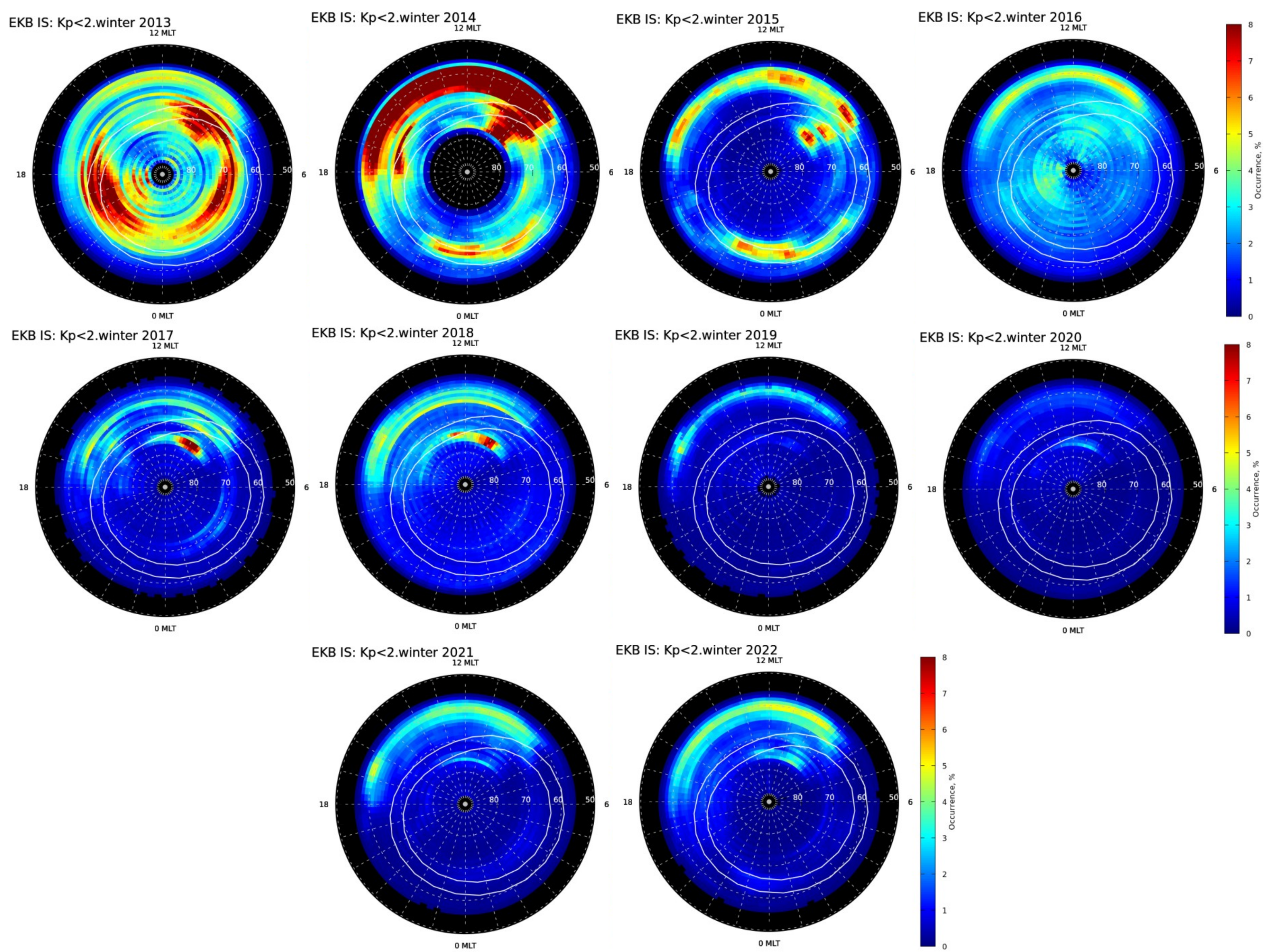
2.2. Statistical study of FAI occurrence observed by EKB and MGW radars

Seasonal dependence



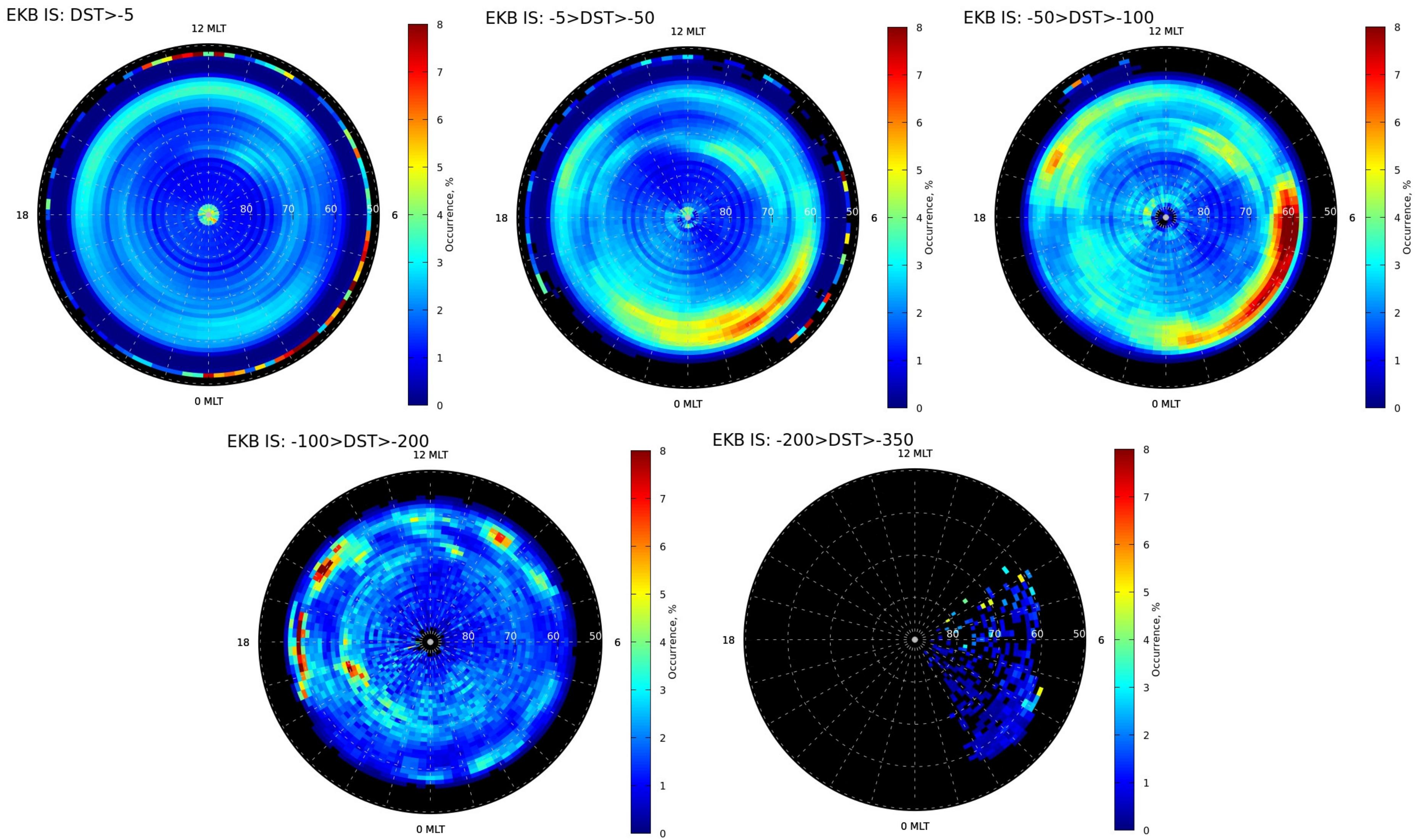
2.2. Statistical study of FAI occurrence observed by EKB and MGW radars

Solar activity dependence

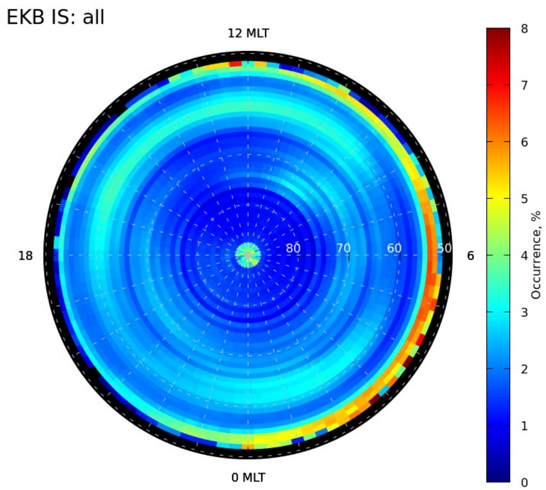


2.2. Statistical study of FAI occurrence observed by EKB and MGW radars

Geomagnetic activity dependence

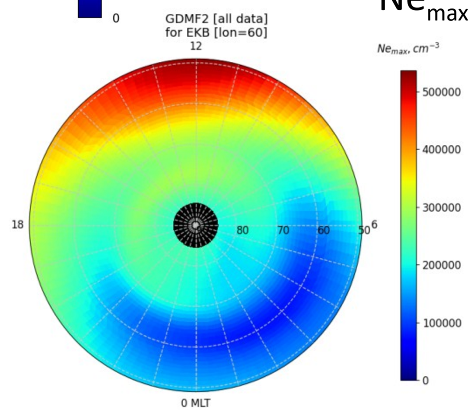


2.3. Comparison with empirical ionosphere models

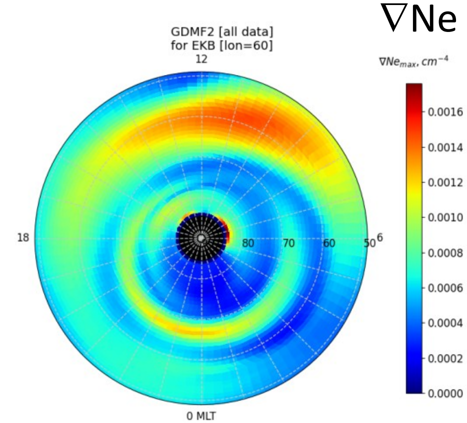


GDMF2

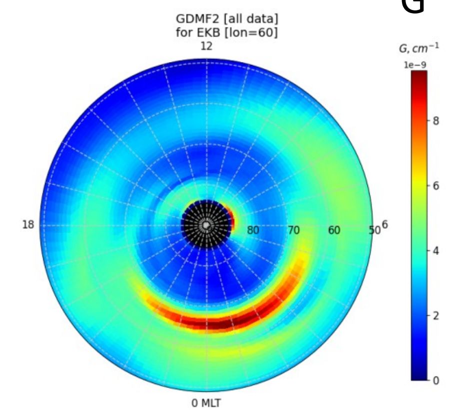
Ne_{max}

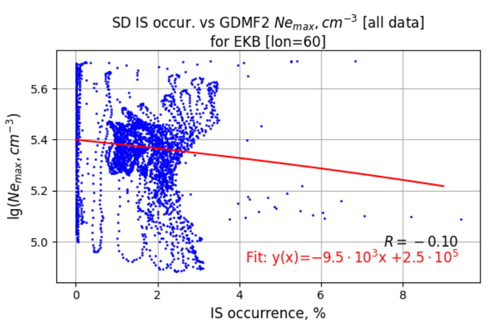


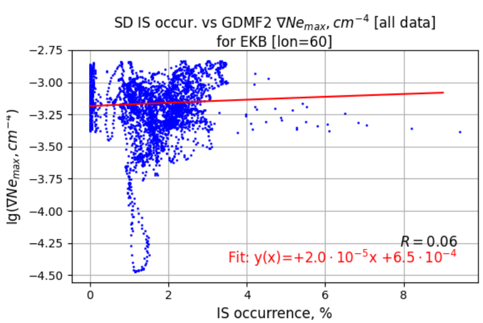
∇Ne

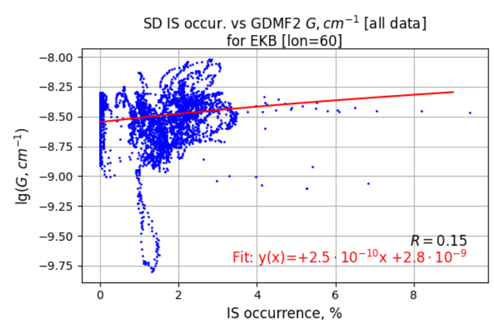


G

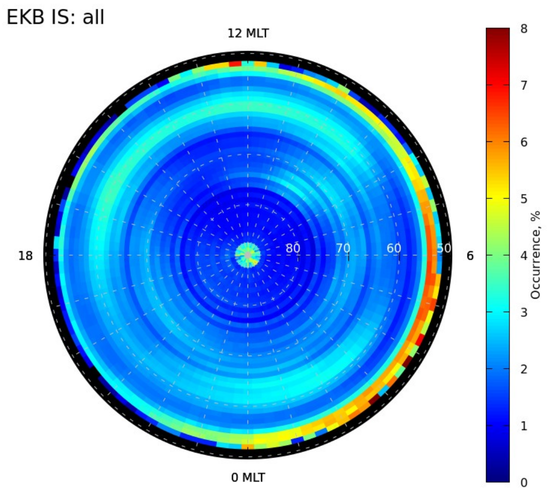






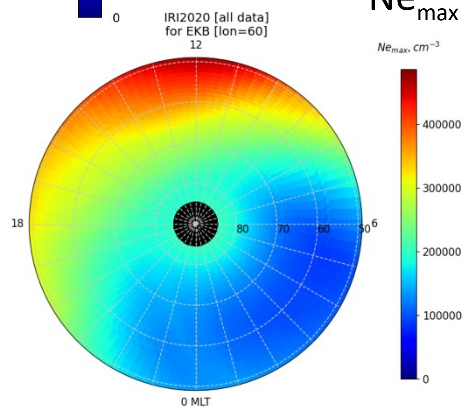


2.3. Comparison with empirical ionosphere models

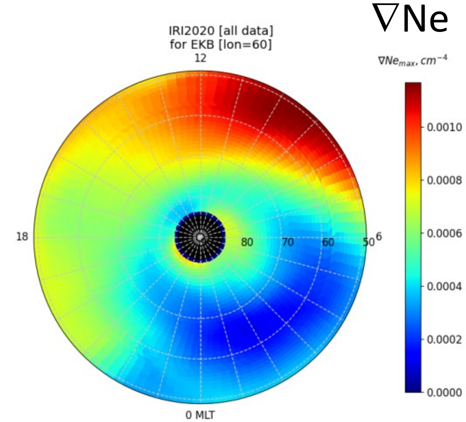


IRI2020

Ne_{max}



∇Ne



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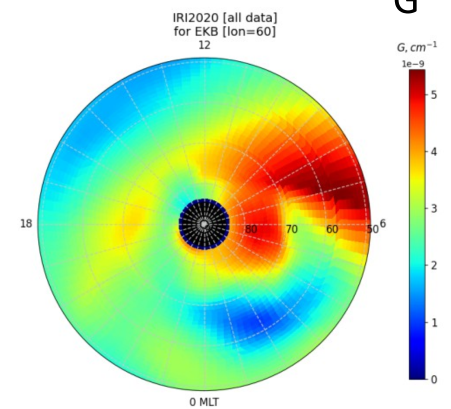
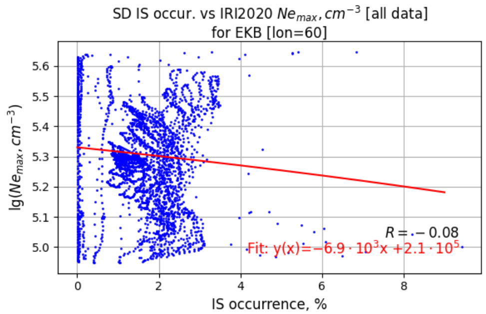
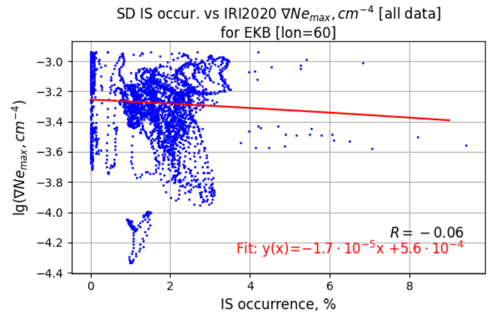
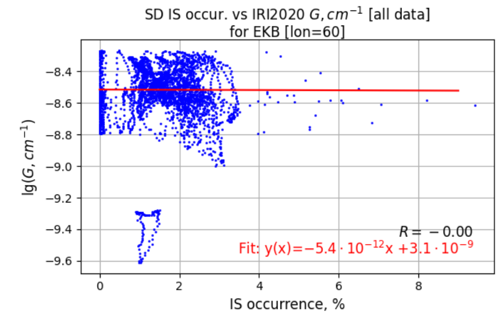








2.3. Comparison with empirical ionosphere models

Dataset	GDMF2			IRI2020		
	Ne_{max}	∇Ne	G	Ne_{max}	∇Ne	G
All data	-0.1/-0.07*	0.06/**0.38***	0.15/0.4*	-0.08/0.1*	-0.06/0.07*	0.0/-0.24*
Winter	0.32/0.35*	0.49/**0.52***	0.21/0.17*	0.36/0.45*	0.43/0.42*	0.22/0.12*
Summer	-0.41/0.15*	-0.11/**0.49***	0.06/0.56*	-0.38/0.1*	-0.21/0.41*	-0.04/0.44*
Equinox	-0.04/-0.01*	0.04/**0.39***	0.09/0.32*	-0.03/0.12*	-0.05/0.04*	-0.04/-0.13*
Kp<2	-0.36/0.02*	0.08/**0.36***	-0.02/0.35*	0.05/0.12*	0.09/0.09*	0.06/-0.21*
2<=Kp<3	0.08/-0.08*	0.08/0.38*	0.22/**0.42***	-0.07/0.09*	-0.07/0.03*	-0.06/-0.3*
Kp>=3	-0.12/-0.09*	-0.06/**0.29***	0.21/0.27*	-0.25/0.1*	-0.25/0.05*	-0.13/-0.2*
2013	0.04	0.09	-0.02	-0.04	0.07	0.25
2014	0.51	0.59	0.07	0.55	0.59	0.34
2015	0.18	0.38	0.39	0.18	0.23	0.2
2016	0.34	0.15	**-0.36**	0.27	0.36	0.34
2017	0.30	0.23	-0.14	0.26	0.40	0.31
2018	0.31	0.24	-0.1	0.35	0.37	0.09
2019	0.48	0.38	-0.1	0.52	0.43	-0.03
2020	0.54	0.37	-0.17	0.52	0.46	-0.04
2021	0.55	0.58	-0.07	0.62	0.63	0.13
2022	0.55	0.66	0.07	0.59	**0.69**	0.37

***EKB/MGW**

CONCLUSIONS and FINAL REMARKS

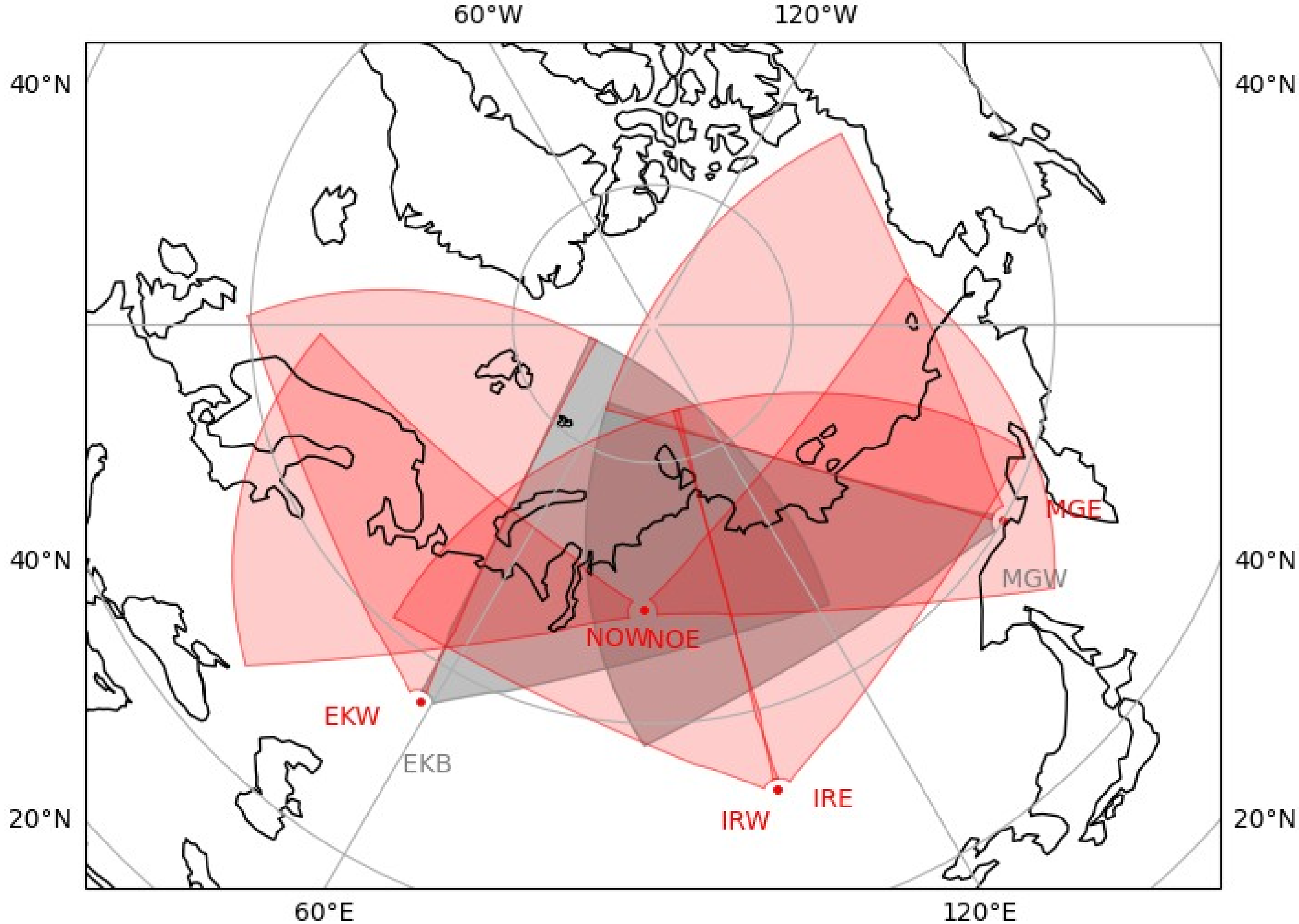
HF radars are very effective tool for monitoring ionospheric dynamics in a wide spatial regions including polar, auroral, sub-auroral, and mid-latitudes.

Statistical dependencies of the main parameters of MSTIDs on the time of day, season of the year, levels of solar and geomagnetic activity, location of HF radars, and the state of the neutral atmosphere are revealed. Properties of most of the MSTIDs are in good agreement with the hypothesis of IGW filtration by neutral wind. This allowed us to develop and test a method for estimating the horizontal neutral wind velocity vector based on statistical distributions of MSTIDs azimuths and velocities.

First principle and empirical ionosphere models allows for a satisfactory prediction of FAI generation regions of, both during individual events and for the purpose of interpreting statistically observed patterns. Monitoring of radio aurora in quiet and disturbed conditions is useful for validating the models of large-scale ionospheric formations, such as the MIT, auroral oval, SAPS, SAID, etc. Location and dynamics of the aspect scattering regions are directly related to the radial current systems of the magnetosphere (FAC), and, at the same time, there are features of their manifestation associated with the conditions of radio wave propagation in the absorbing medium.

CONCLUSIONS and FINAL REMARKS

RUSSIAN "SEKIRA" HF RADAR NETWORK (NATIONAL HELIOGEOPHYSICAL COMPLEX OF RAS)



OPERATING **PLANNING**

THANK YOU FOR ATTENTION!

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