Localized enhancements of total electron content in Southern Hemisphere

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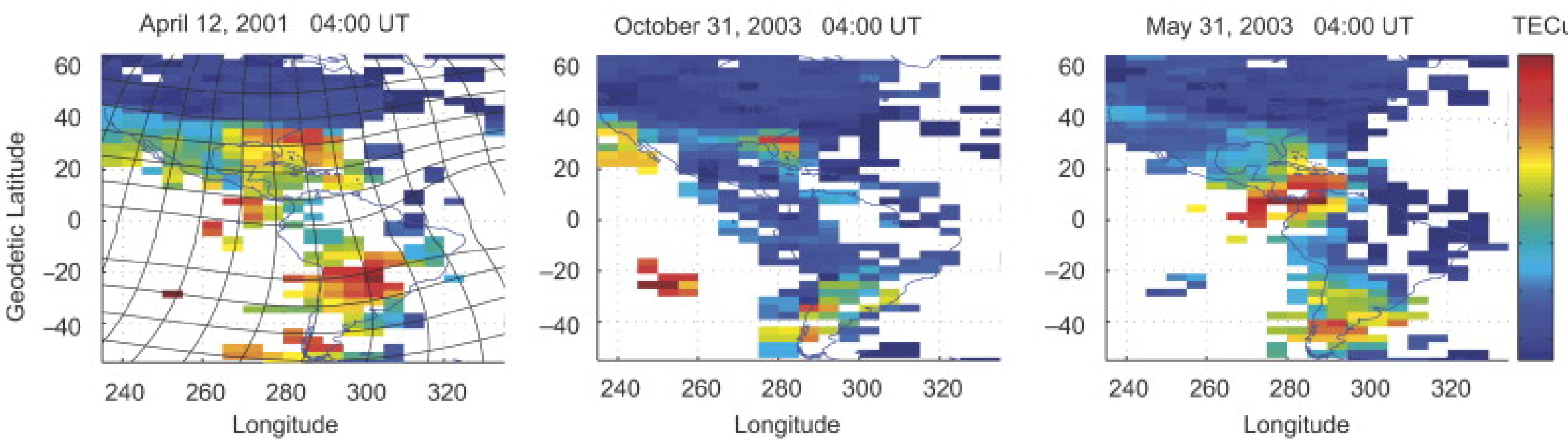
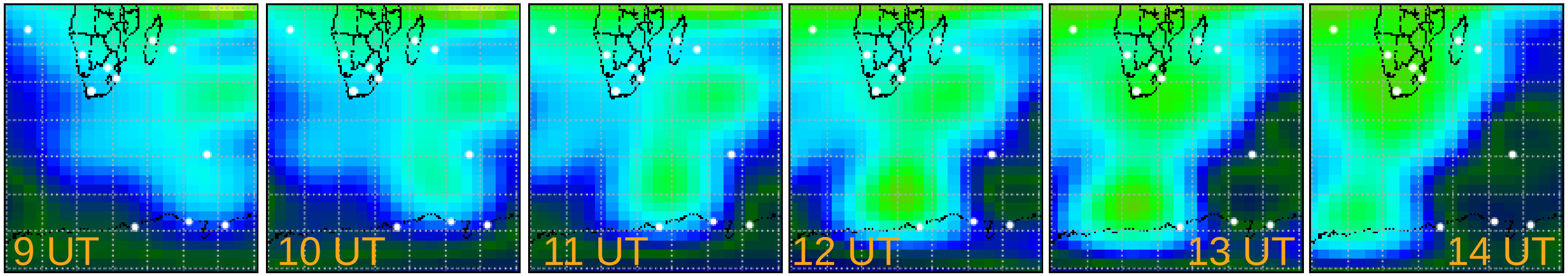
Localized TEC enhancements (LTE)

The most typical irregularities in the distribution of the electron concentration are produced during geomagnetic storms. Foster and Coster[1] investigated storm-enhanced densities (SEDs) and showed that it is possible to detect SEDs which could be observed as localized total electron content (TEC) enhancements (LTE) in TEC maps during severe and extreme storms. They also showed that LTEs can be detected in the night-side ionosphere at the middle latitudes of both hemispheres during a storm recovery phase in magneto-conjugated regions.



[1]J.C. Foster, A.J. Coster / Journal of Atmospheric and Solar-Terrestrial Physics 69 (2007) 1241–1252. doi:10.1016/j.jastp.2006.09.0120

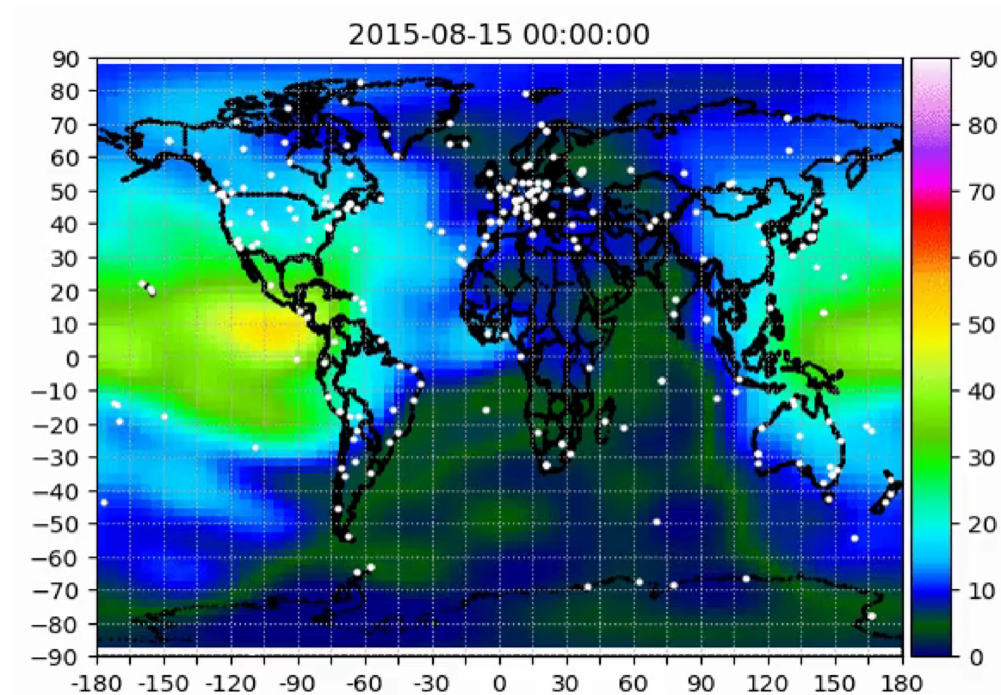
LTE in Southern Hemisphere



Investigating response to coronal mass ejection it was found dayside LTE[1]. Localized enhancement is clearly observed in CODG global ionospheric maps (GIMs) at dayside in Southern hemisphere. It lasts for several hours and is localized in subsolar region (follows the Sun).

Presence of LTE was confirmed by TEC measurements from COSMIC satellite and GNSS-network SANSA .

This LTE was assumed to be connected with disturbed conditions of near-Earth space including magnetic storms caused by negative orientation of IMF z-component (Bz)



[1]Edemskiy, I., Lastovicka, J., Buresova, D., Habarulema, J. B., and Nepomnyashchikh, I. Annales Geophysicae. (2018), 36, 71–79, https://doi.org/10.5194/angeo-36-71-2018

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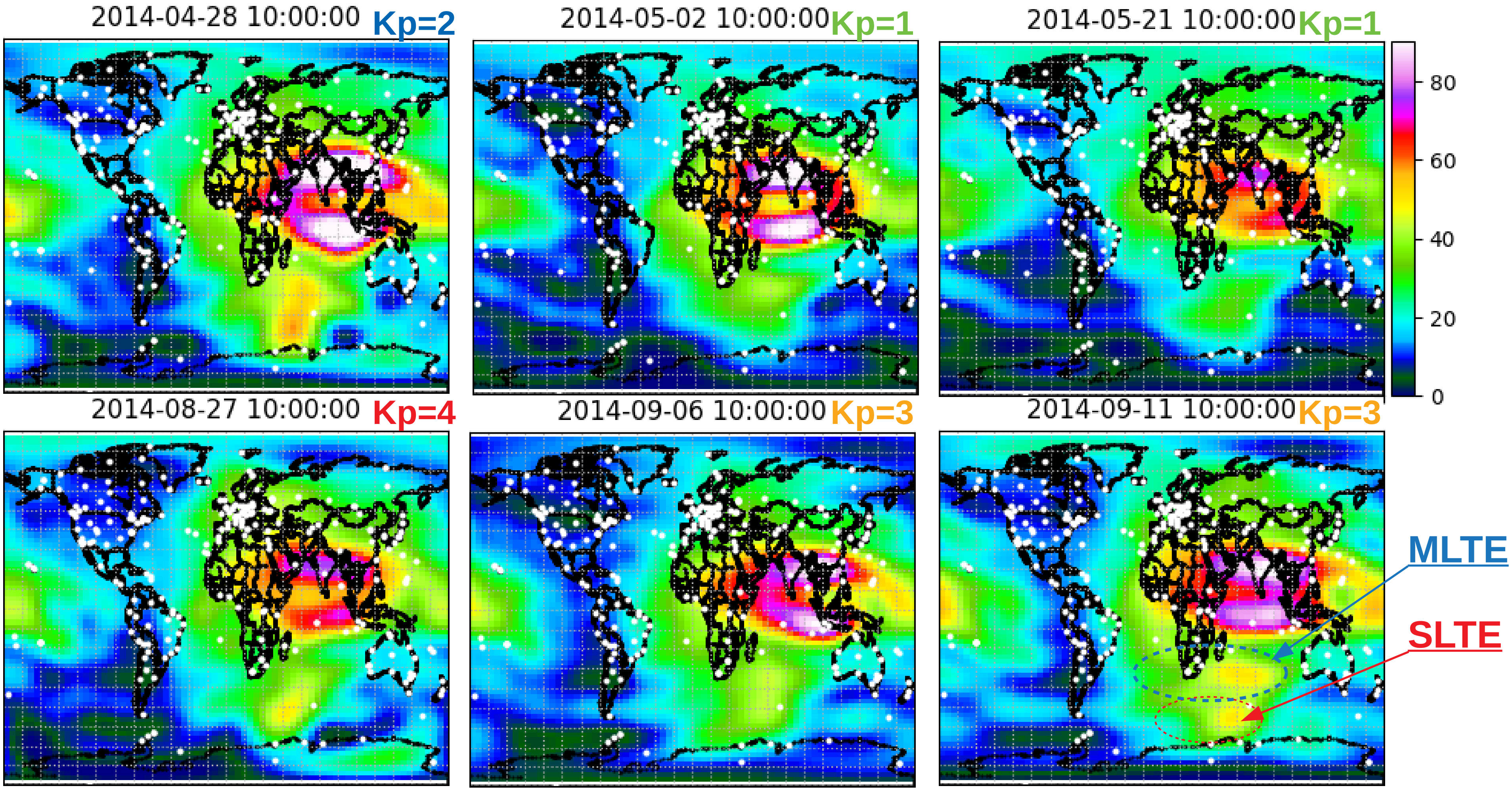
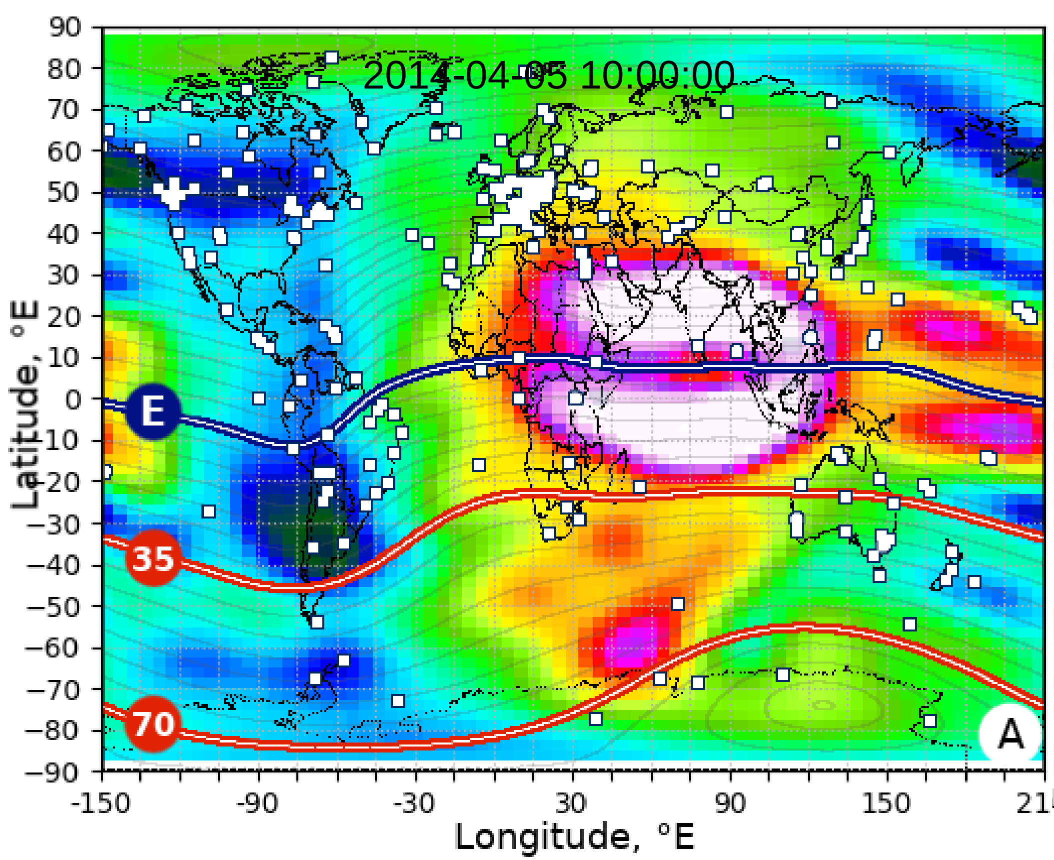
Investigating such localized formations we found that LTEs manifest themselves in Southern Hemisphere at periods of both geomagnetically disturbed and quiet conditions. It is possible to observe LTE even at a quiet day (Kp ~ 1) with no apparent connection between intensity of LTE and geomagnetic state. SH LTEs usually do not have any accompanying enhancement in Northern Hemisphere.

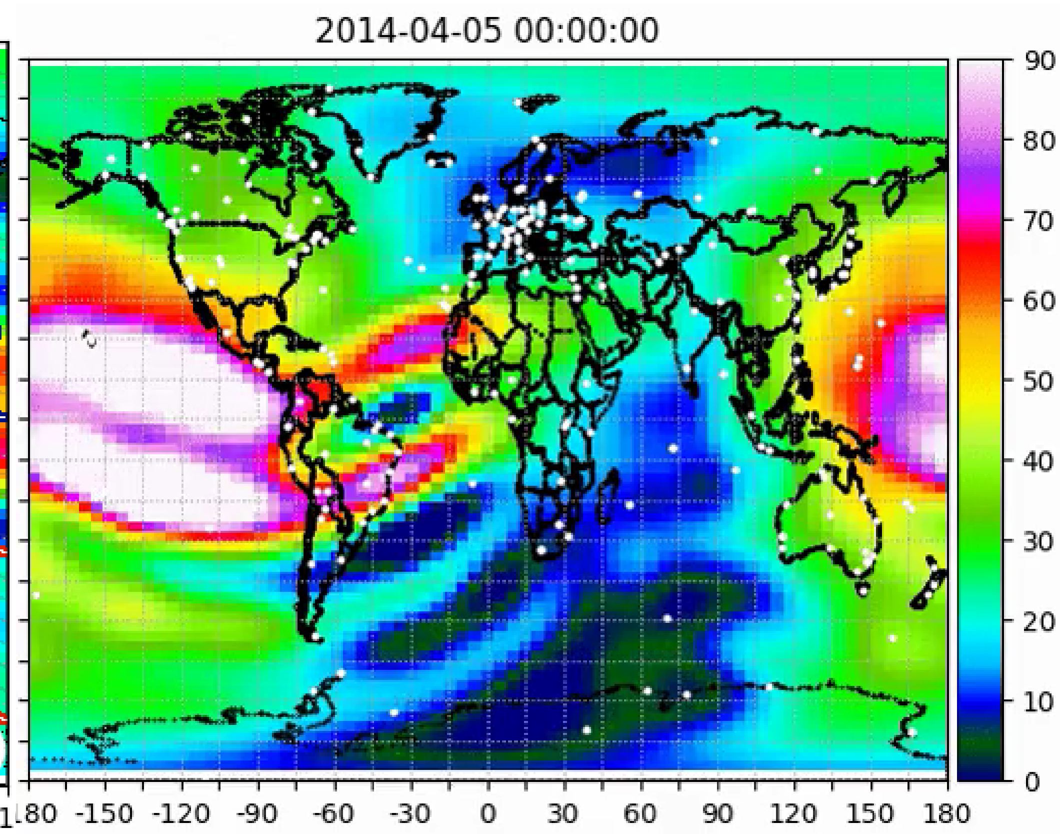
In some cases it is possible to distinguish two parts of LTE: midlattitudinal (**MLTE**) and subpolar (**SLTE**)

*The maps are for 10 UT



Both MLTE and SLTE were observed in LTE of 5 April 2014. During its development, the LTE change its latitudinal position within 30-80°S, corresponding to range of geomagnetic parallels from 35 to 70°S (red lines). The LTE exists for the entire day and changes its intensity unevenly. The less intense MLTE part persists longer and has a lower magnitude than a brighter SLTE. Both parts are confined to their own ranges of geo-magnetic latitudes: 30–50°S for the MLTE, and 50–65°S for the SLTE. During the whole period shown, their positions remain approximately in the subsolar area (local noon)





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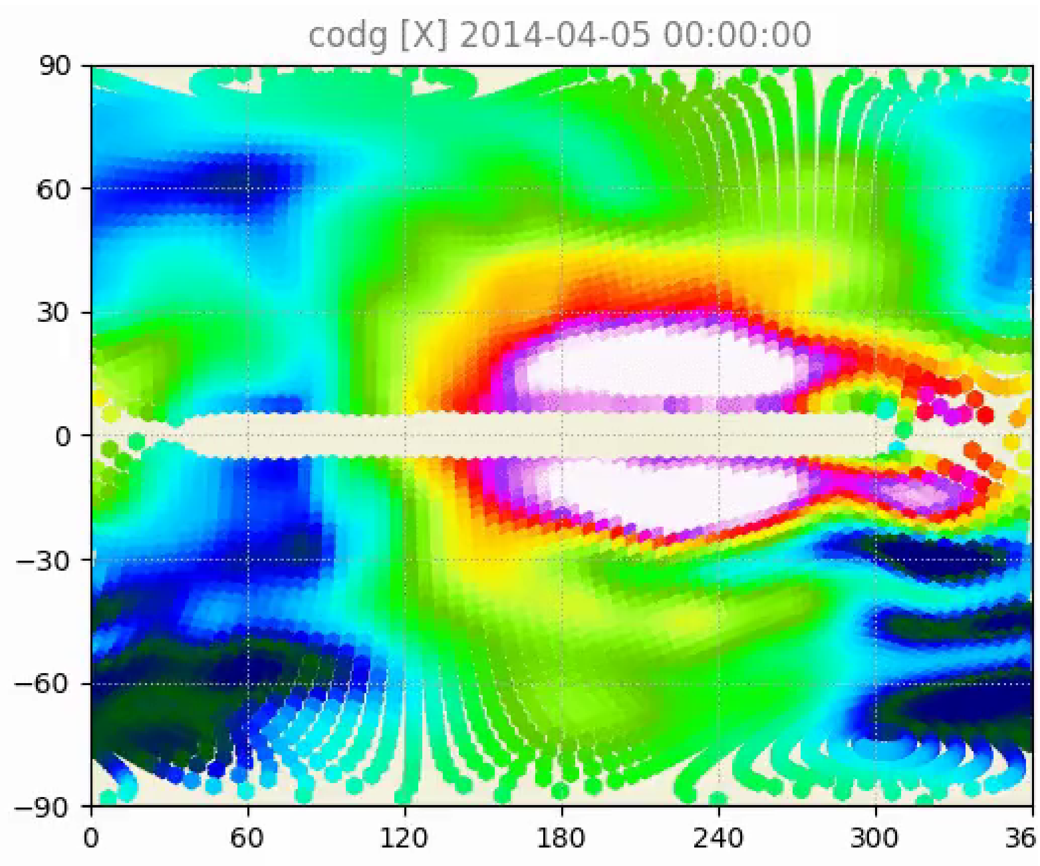
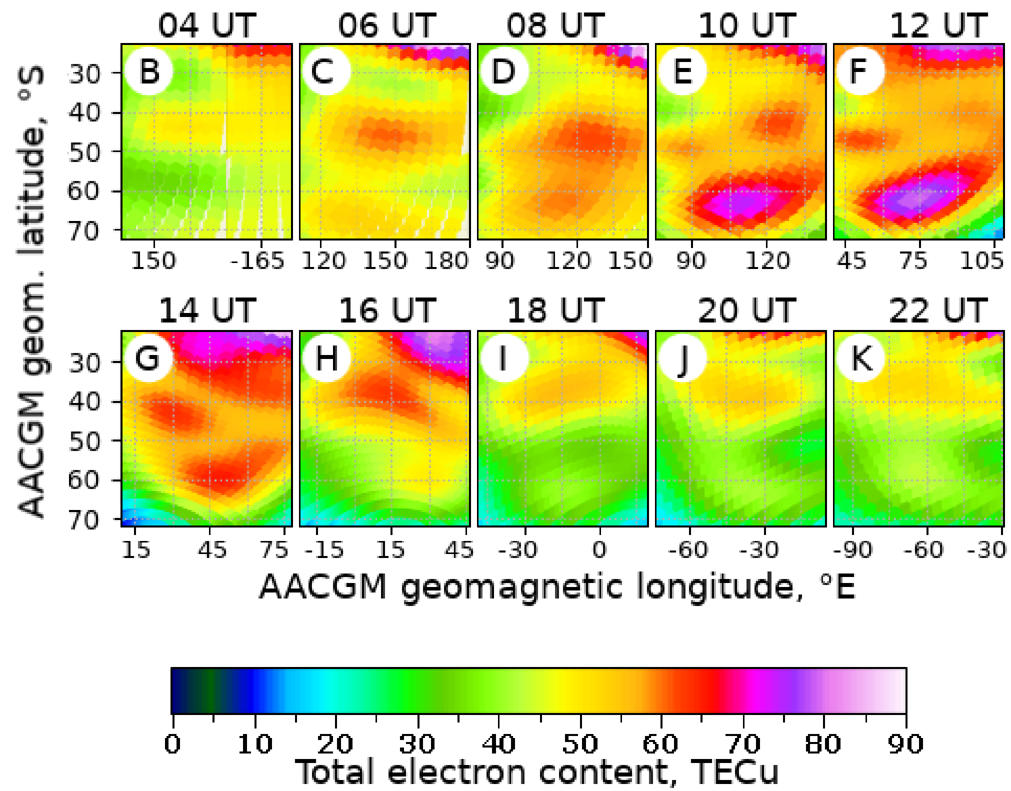
TEC distribution in geomagnetic coordinates





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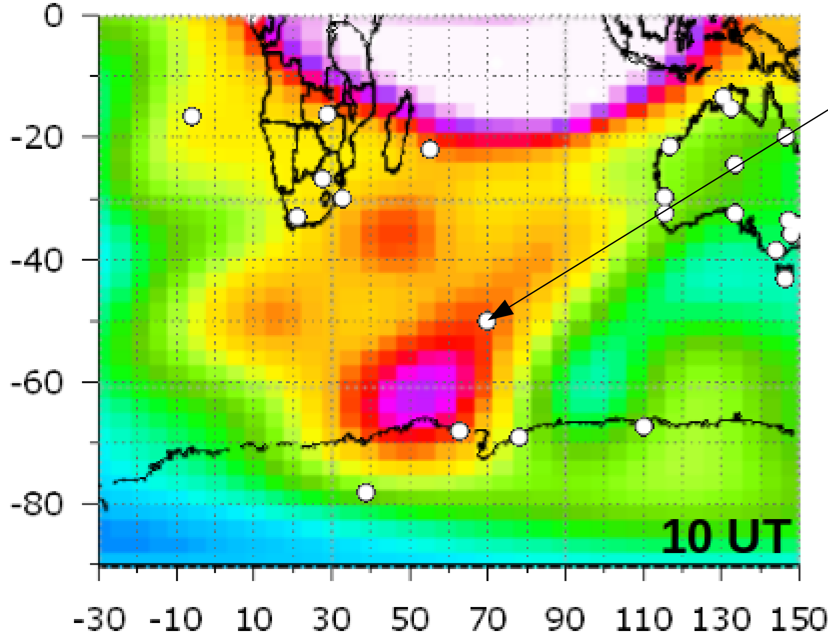
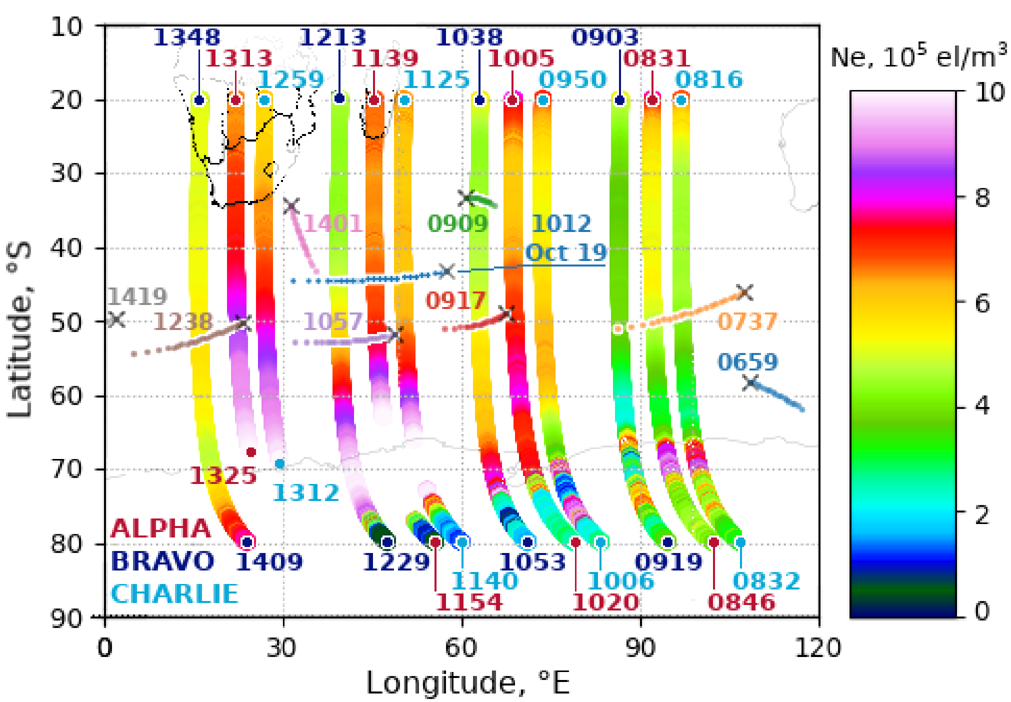
Both MLTE and SLTE are confined to their own ranges of geo-magnetic latitudes during the development of the enhancement: 30–50°S for the MLTE, and 50–65°S for the SLTE.

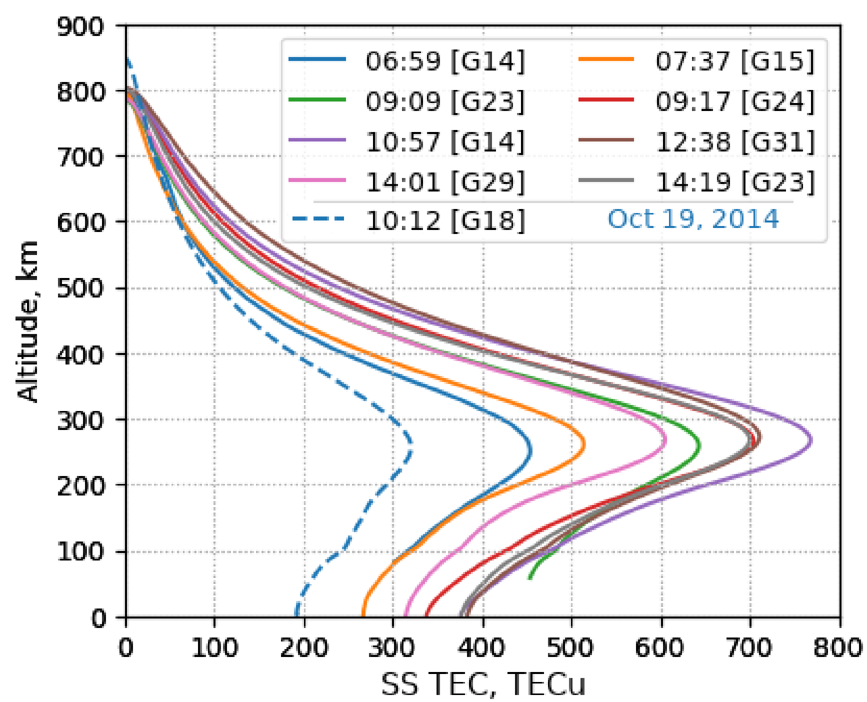
*Geographic coordinates recalculated in geomagnetic ones (AACGM) for altitude of 100 km

Satellite measurements



Despite there is **<u>only one GNSS station</u>** in Indian Ocean, the observed LTE seems to be reflected in GIM properly (not an artifact): in-situ measurements of Ne by SWARM and radio-occultation satellite-to-satellite TEC values from COSMIC confirm presence of the localized enhancement. There were no SS TEC profiles exactly for the region of SLTE (most of them are between MLTE ans SLTE), but it is clear that TEC values are high (compare them with profile of non-LTE day 19 October 2014)

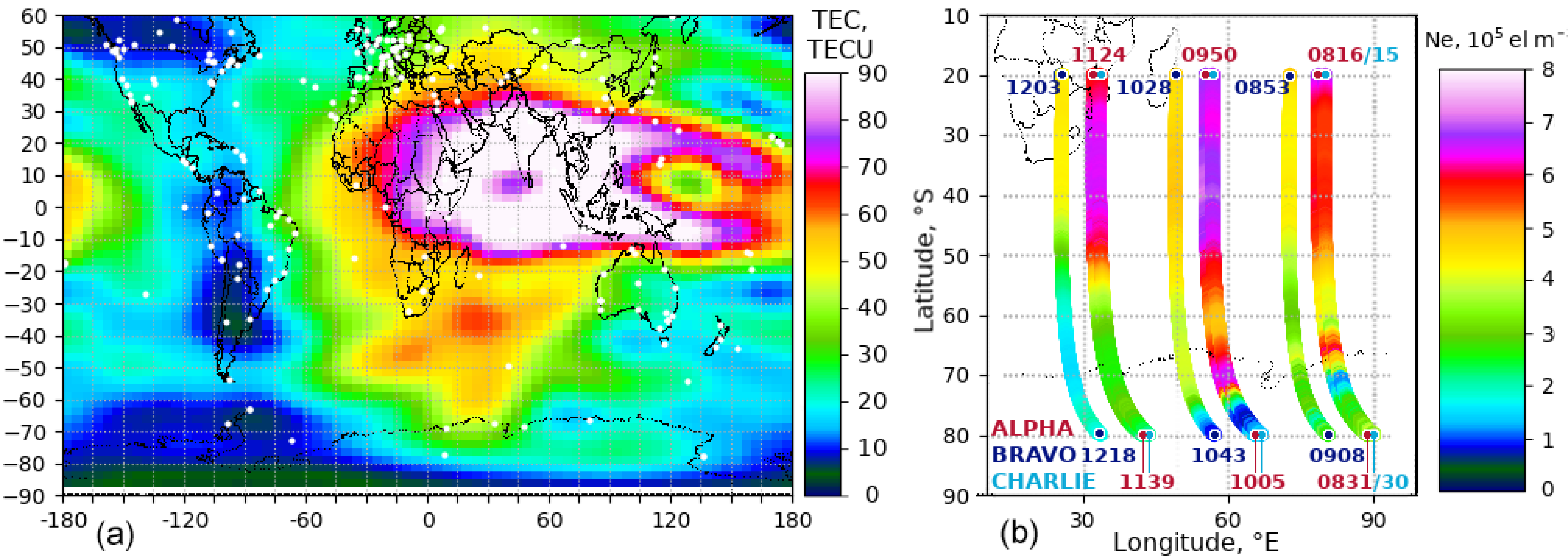




Satellite measurements

Due to orbital motion of satellites not all the LTEs are possible to confirm by Ne measurements. In cases of direct intersection of LTE region by satellites it is quite clear that GIMs represent spatial distribution of TEC properly.

Here SWARM data for 18.04.14 clearly confirm presence of MLTE. Moreover, this, combined with the data shown in previous slide, makes a strong case for the fact that LTEs of both types (MLTE and SLTE) are predominantly located in the F2 region.

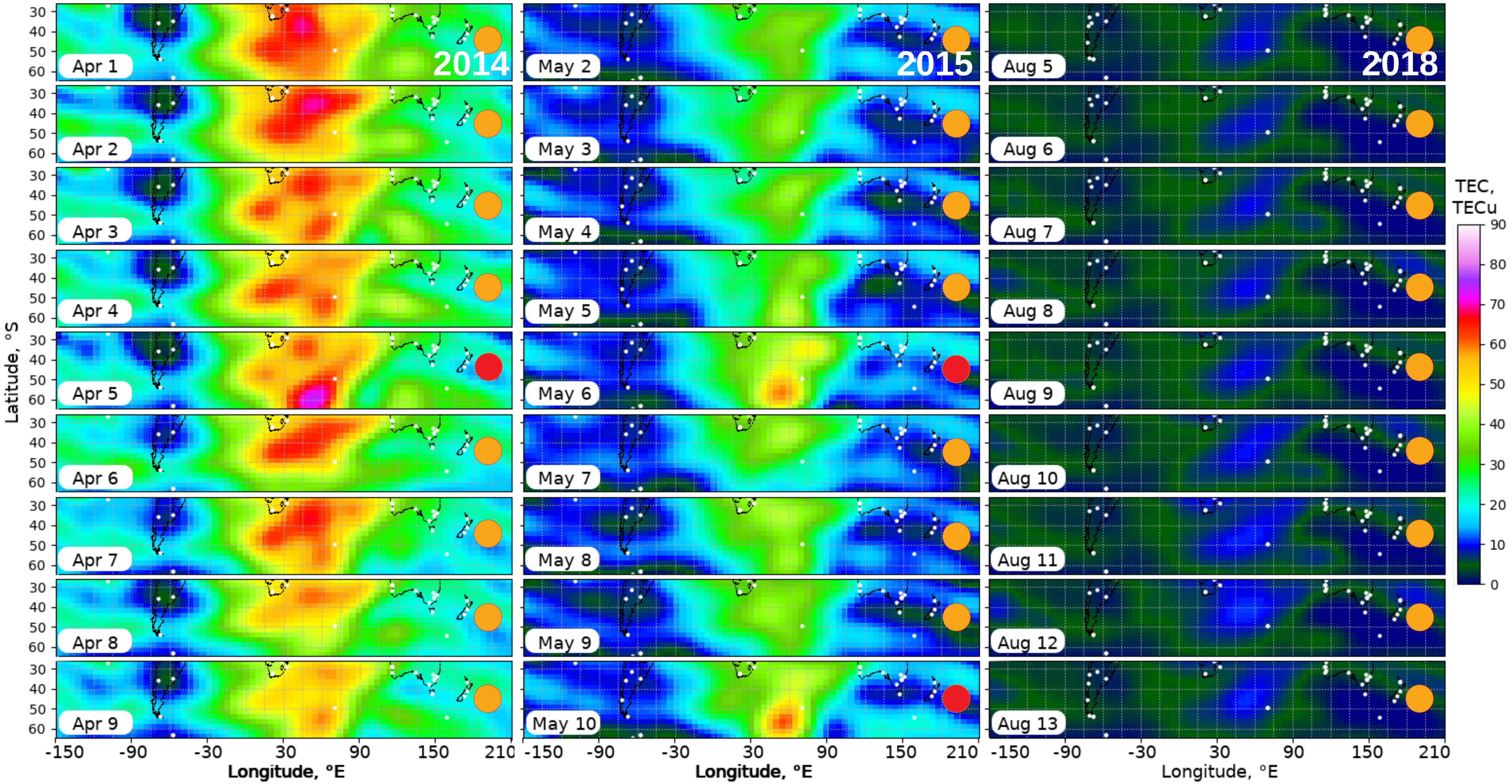


Assuming that distribution of TEC is properly represented by CODE GIMs we analyzed maps for years of different solar activity: 2014(high), 2015 (medium) and 2018 (low). It turned out that LTE is a quite frequent phenomenon. Moreover, it is possible to observe series of LTE.

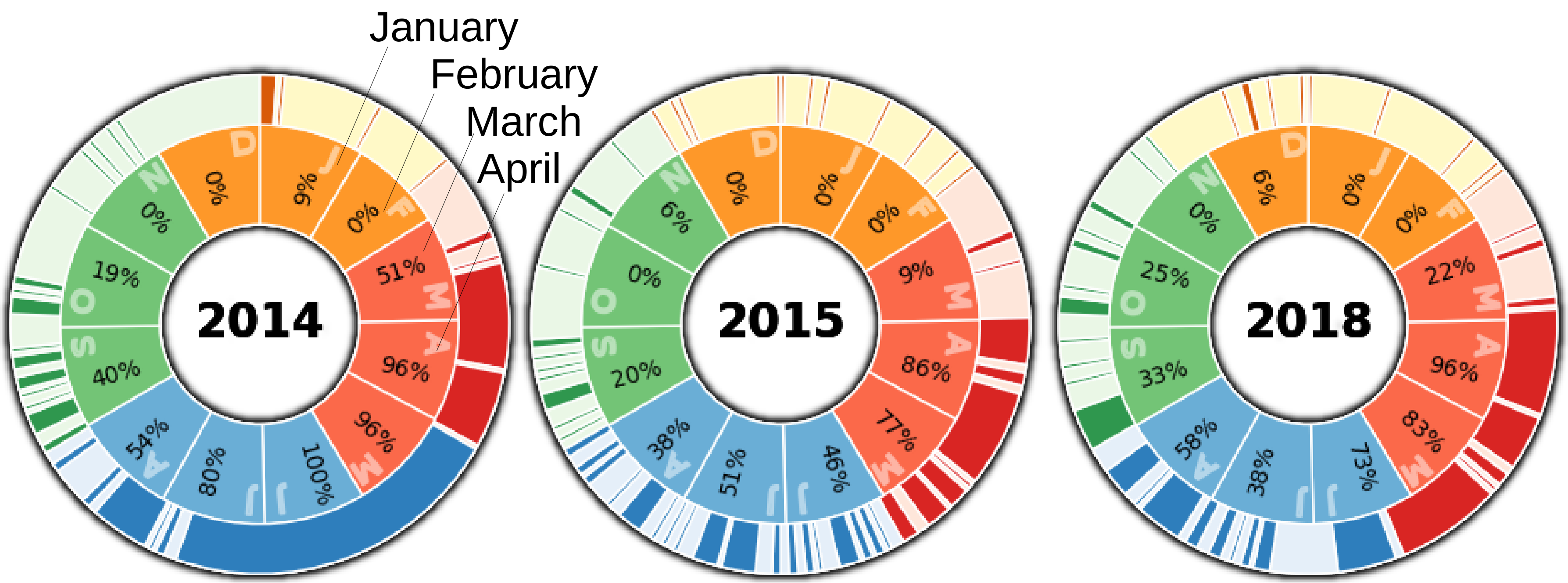
LTE series

LTEs can be observed in serial consequently for a several days. The intensity and shape of the LTEs presented vary from day to day, but at the same universal time, all of the LTEs occupy the same region. The intensities of the MLTE and SLTE varied independently with no clear dependence on space weather.

Further, we will try to analyze cases of intense SLTE and all the others LTE separately



Detection rate over seasons

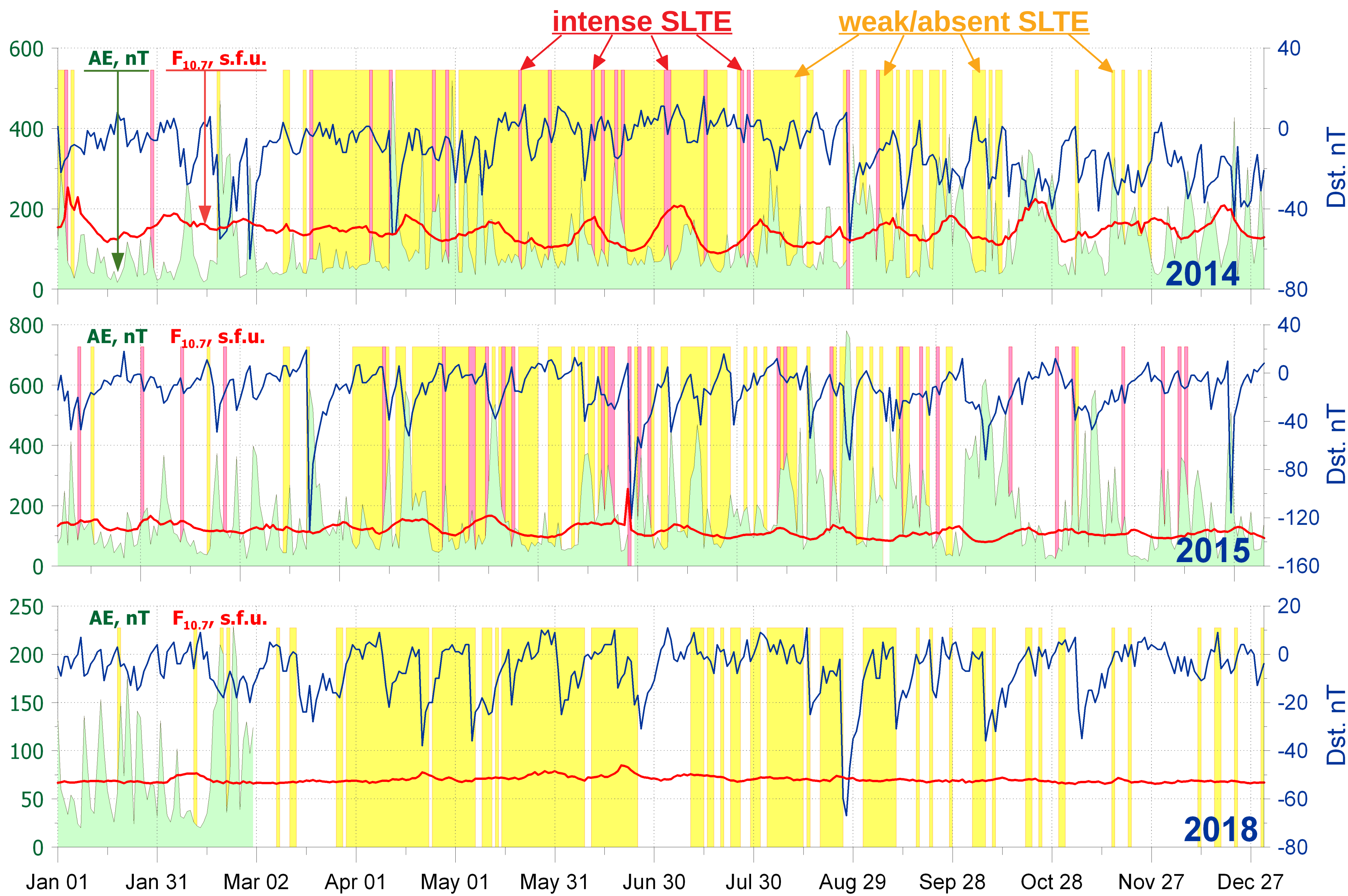


LTEs are most often detected in autumn and at the beginning of winter (March to June–July). The absolute maximum of LTE series occurrence is observed in the autumn–winter period, and the longest series occur between April and June.

The most interesting series here lasted 80 days (May – July, 2014) or 120 day (excluding several short gaps between series); thus, the entire period from late March to July of 2014 should probably be considered one long series. Such a long sequence occupying one-third of a year definitely points to a regular process. For the other years, the same season contains majority of the LTE series, although they are separated by more frequent and wider gaps. It is interesting to see that we detect more series during a year of low solar activity (2018) than during a moderately active one (2015).

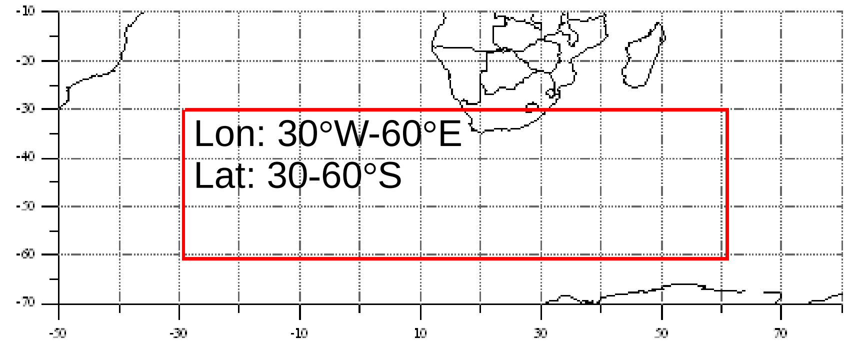
We tried to analyze occurrence rate of LTE in dependence on space weather (next slide)

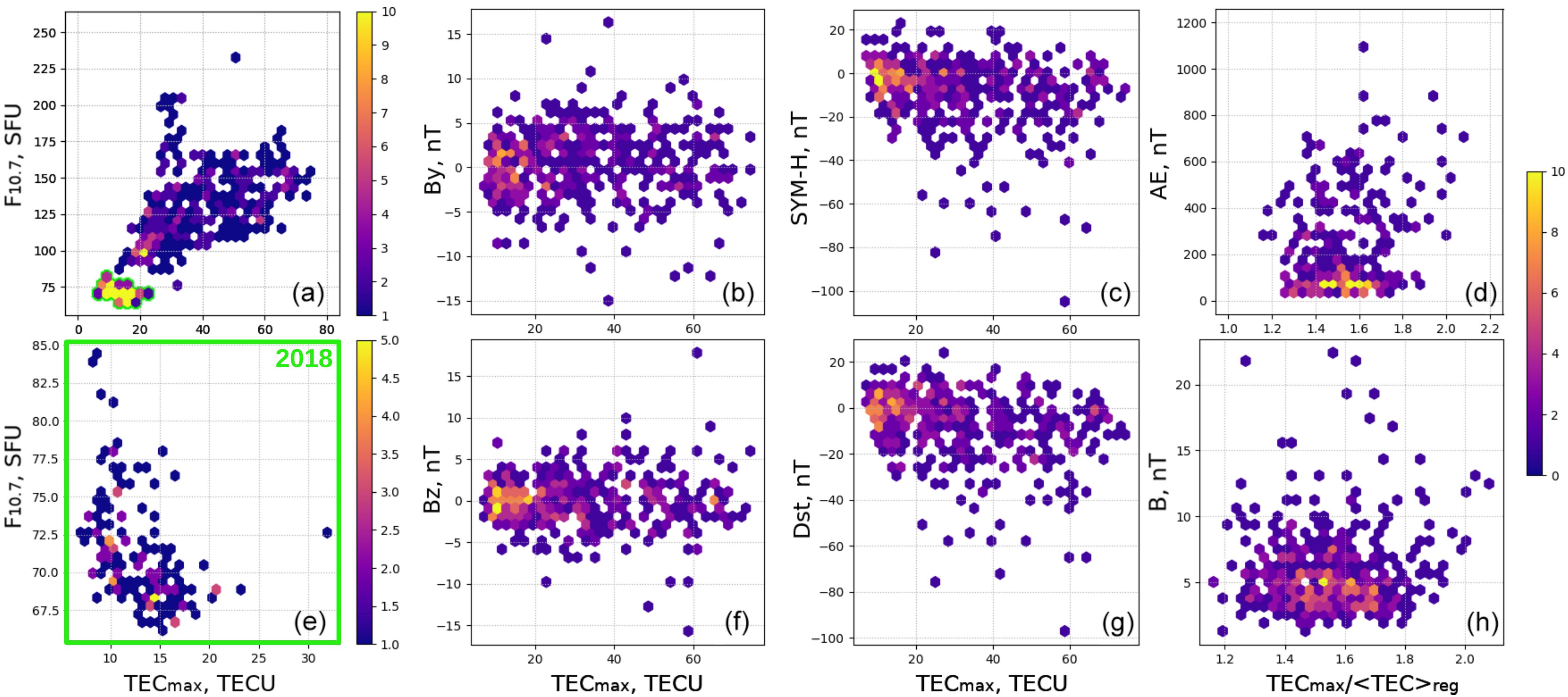
Annual occurrence of LTE



Occurrence vs space weather

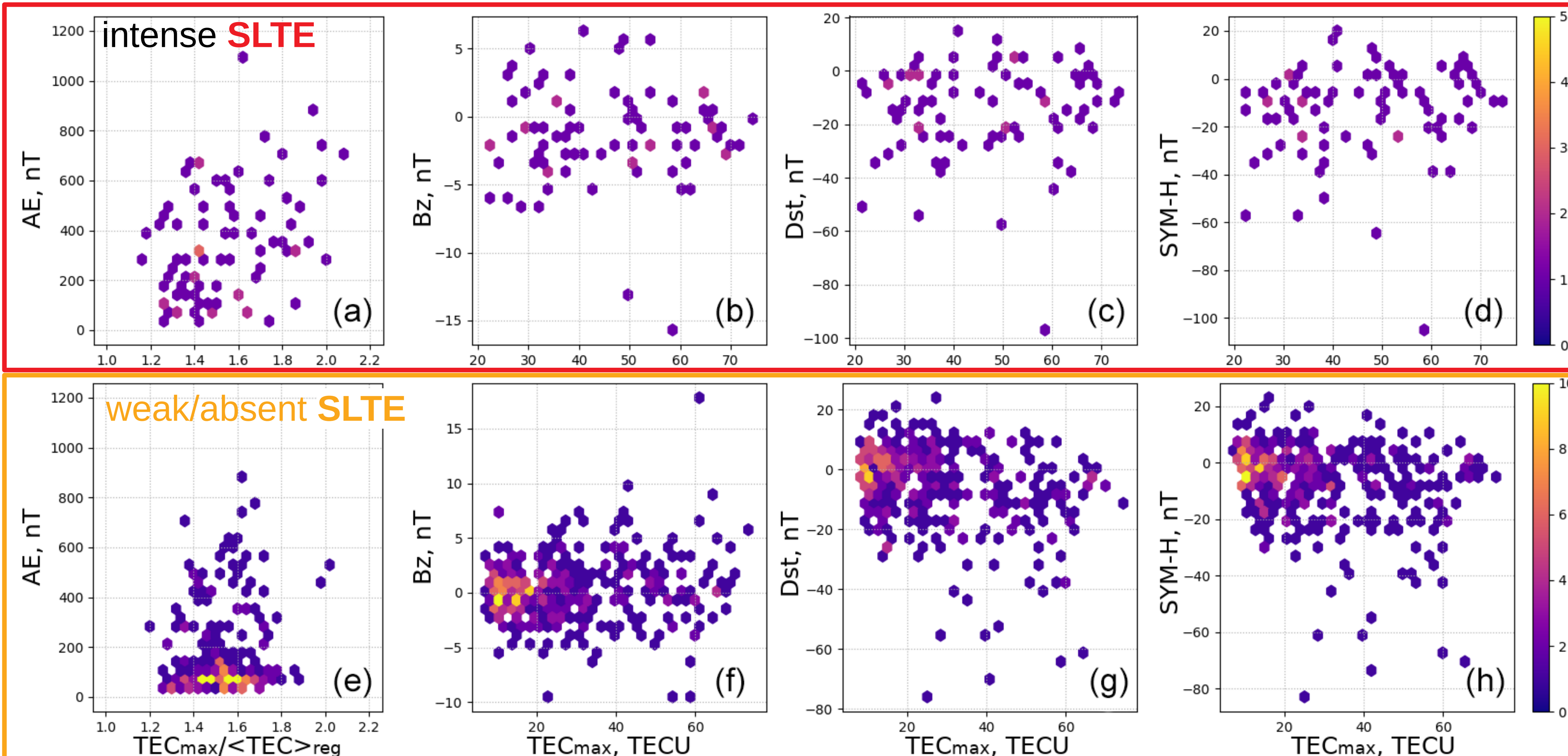
Investigating dependence of LTE occurrence we analyzed distributions of maximal TEC (TECmax) values in the given region versus main parameters of near space. The distributions presented did not reveal any pronounced dependence (except TECmax vs $F_{10.7}$)





Occurrence vs space weather

Most of the intense SLTEs were detected at disturbed conditions (Dst<0, SYM-H<0, high AE) This means that bright SLTEs are often observed during magnetic storms and can be connected with SEDs. Although part of them is observed with positive Dst, SYM-H, Bz and low AE values and obviously should not be connected with geomagnetic disturbances.



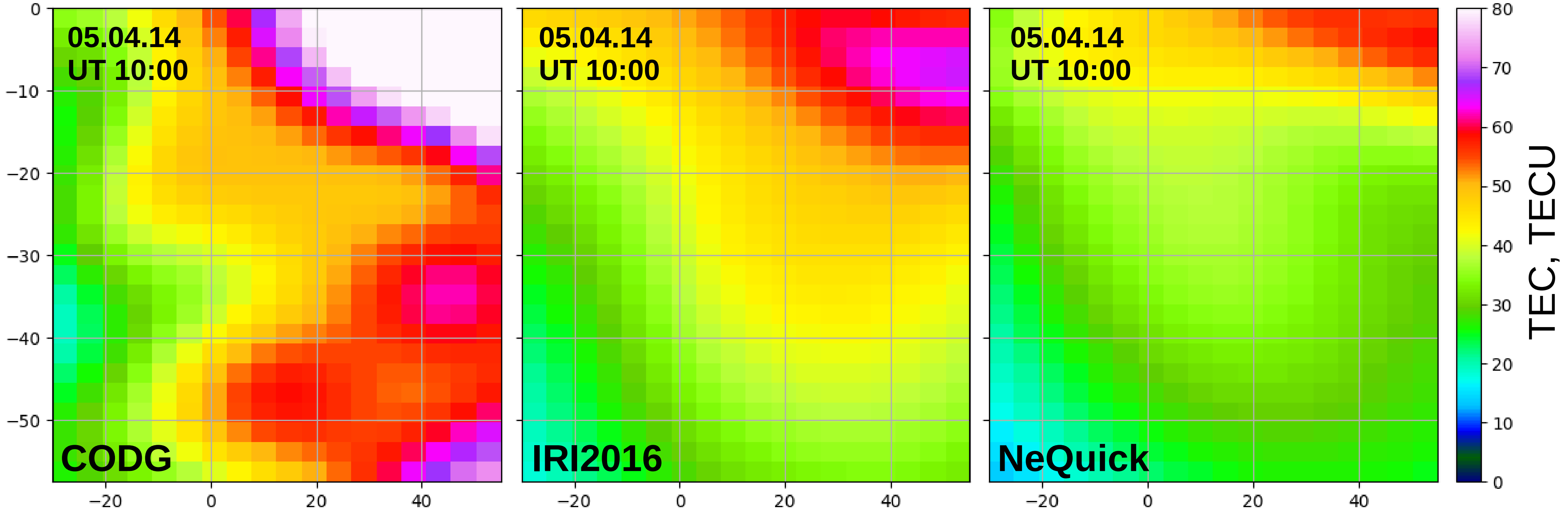
Distributions are for days with intense **SLTE** (a-d) and with weak or absent **SLTE** (e-h)

Simulations of TEC distribution in SH

The data presented lead us to the opinion that, although observed LTEs are supposed to be an ionospheric disturbance, LTEs are most likely a feature of the SH ionosphere. However, there is lack of papers describing the phenomenon.

Lee et al.[1] showed the presence of enhanced electron concentration formation over the western part of the Indian Ocean using measurements from GRACE and CHAMP satellites, and concluded that 2001 and 2007 IRI models did not predict the observed enhancement at all.

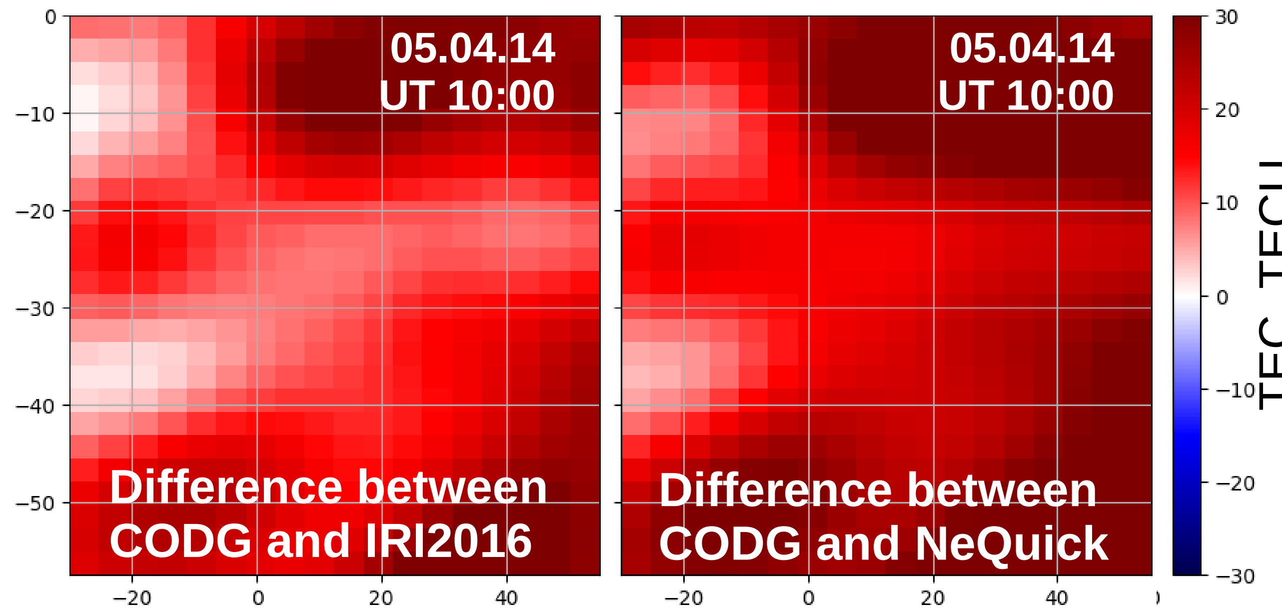
We compared TEC distributions from widely used IRI2016 and NeQuick models with GIM and found that they hardly predict LTEs in the investigated region (30°W-60°E, 30-60°S)

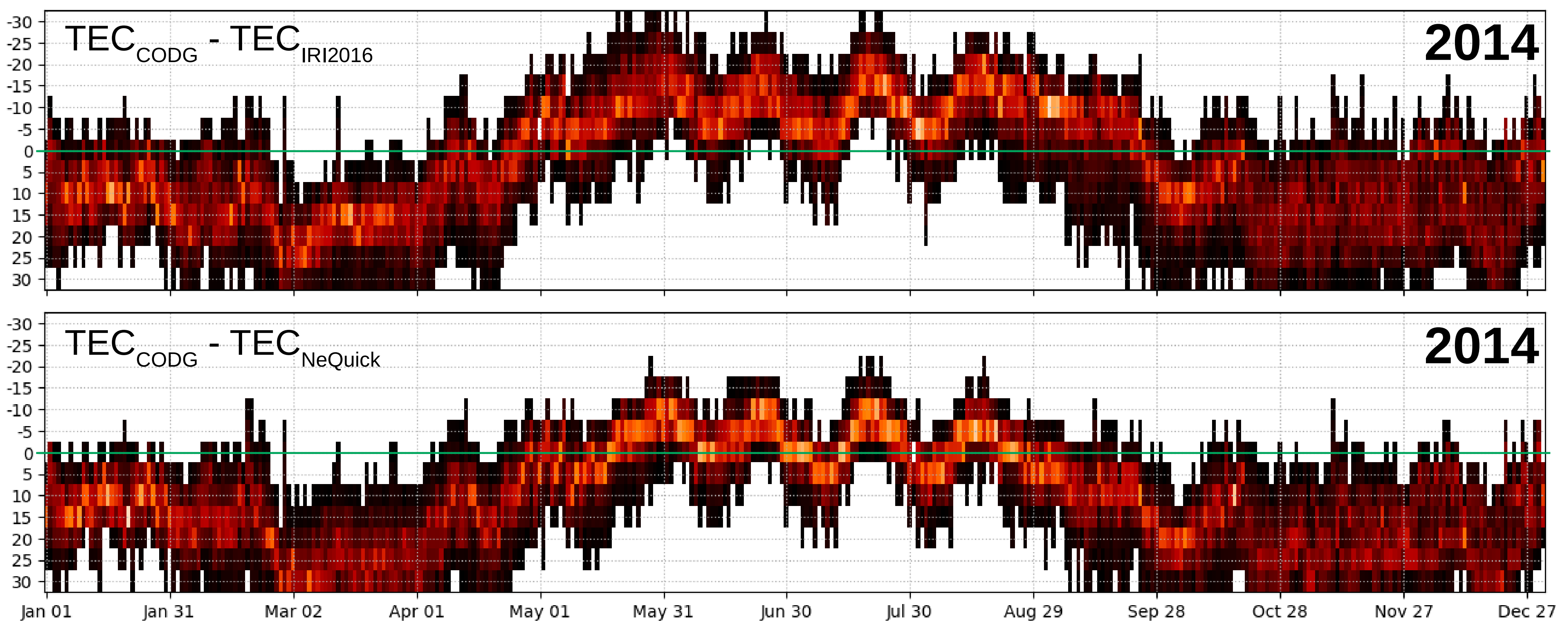


[1] Lee, C. K., Han, S. C., Bilitza, D., and Chung, J.-K.: Validation of international reference ionosphere models using in situ measurements from GRACE K-band ranging system and CHAMP planar Langmuir probe, J. Geodesy, 85, 921–929, https://doi.org/10.1007/s00190-011-0442-6, 2011

Difference between measured and simulated TEC can exceed 30 TECU. We calculated a histogram of values from each differential map and analyzed annual variation of these histograms.

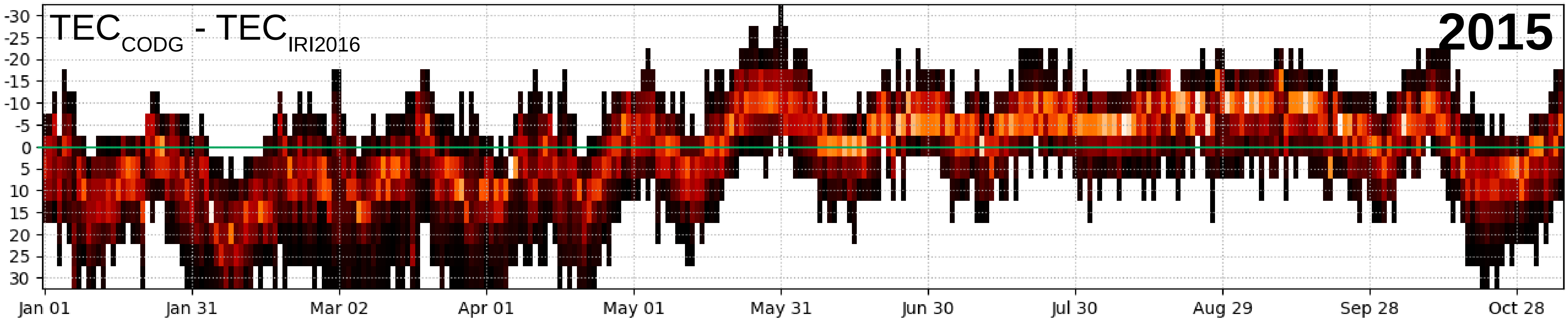
Both the models do not predict TEC properly. They either overestimate or underestimate values depending on season

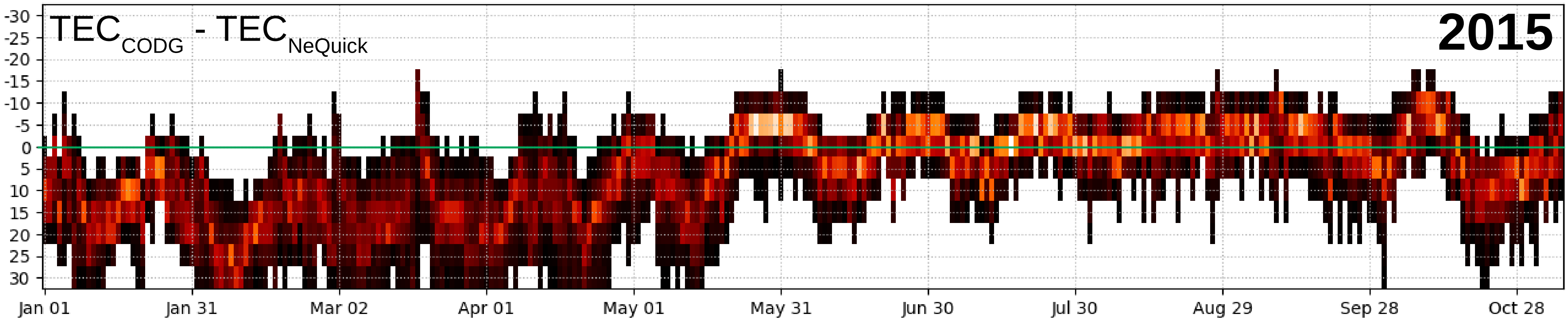




Difference between distributions of measured and simulated TEC in SH

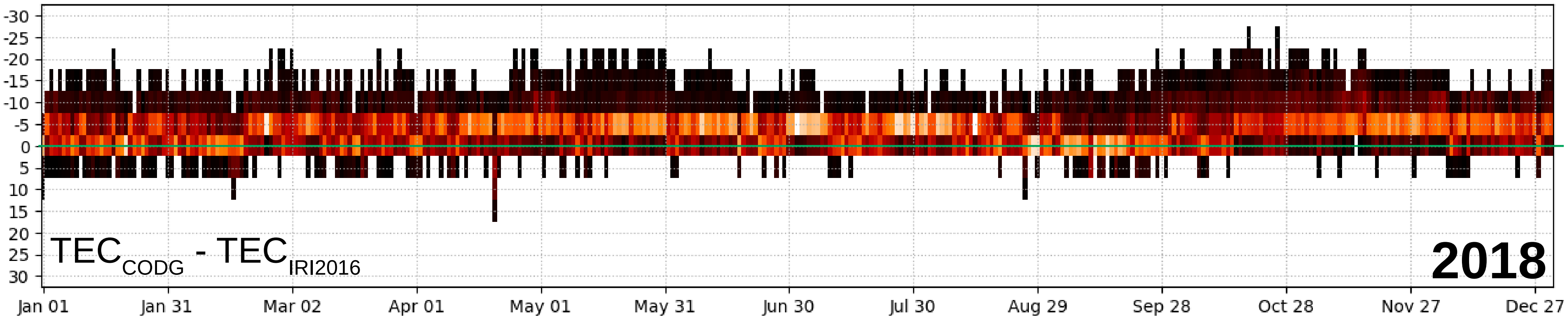
During a year of moderate solar activity (2015) differential maps still demonstrate under- and overestimation of TEC, although in a period of Jun–Sep differences became lower (esp. for NeQuick model). Nevertheless, histograms for most LTE-effective period (March-May) still demonstrate significant underestimation by the models.

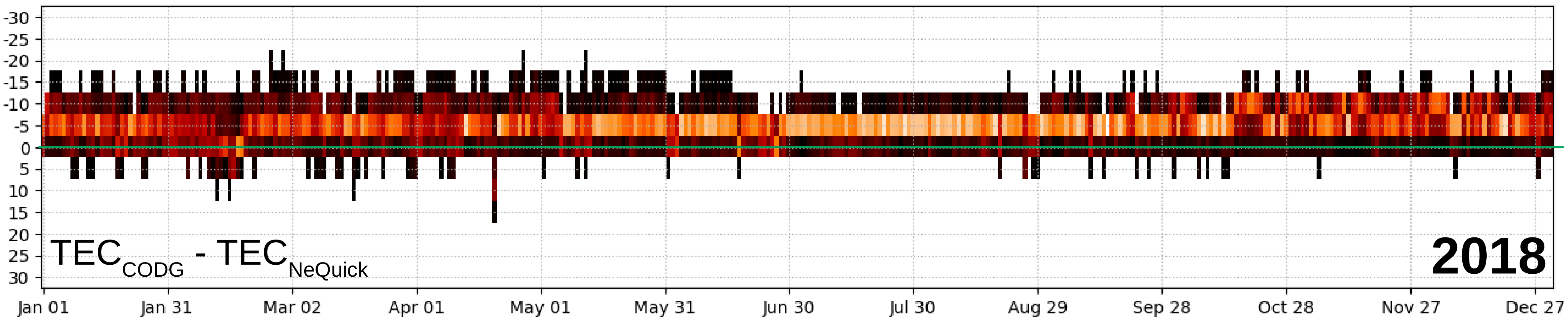




Difference between distributions of measured and simulated TEC in SH

At the year of low activity (2018) both the models overestimate TEC independently on season, although typical difference is about 5 TECU.





Simulated values for all the investigated years do not reflect spatial distribution of TEC values shown by GIMs and confirmed by satellites. Most probable both the used models do not take into account some unknown process redistributing plasma.

Conclusion

LTEs in Southern Hemisphere:

- are mostly observed during autumn-winter
- do not demonstrate any clear dependence on SW parameters
- manifest themselves during both high and low solar activity periods
- seem to be a <u>feature</u> of Southern Hemisphere ionosphere dynamics, <u>not a disturbance</u>

Models of ionosphere NeQuick and IRI2016 **<u>do not predict</u>** LTE properly. Moreover difference between measured and simulated TEC in Southern hemisphere can exceed 30 TECU (both positive and negative) at years of moderate and high solar activity

Acknowledgments

The author is grateful to Jan Laštovička for the idea behind this investigation, for fruitful discussions and for corrections to the text. Martin Pačes is acknowledged for his kind help with obtaining SWARM data, and thanks are due to Nikolay Zolotarev for his help with the COSMIC data treatment and Yuri Yasyukevich for simulated data from NeQuick.

I want to thank Maxim Klimenko for his comments and corrections to the paper dedicated to the presented investigation:

Edemskiy, I. K. Localized total electron content enhancements in the Southern Hemisphere, Annales Geophysicae, 38, 2020, 2, 591-601, DOI 10.5194/angeo-38-591-2020

Data availability

The author is grateful to all of the data centers that provided data, including NASA's Crustal Dynamics Data Information System (CDDIS), the CODE scientific group, and the SWARM and COSMIC mission staff.

All the used data and software are freely available via links:

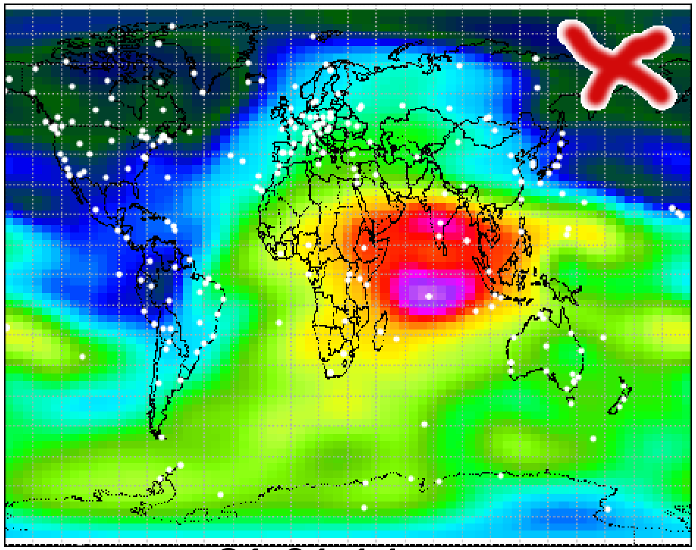
OMNI database: https://omniweb.gsfc.nasa.gov/
Kyoto World Data Ceter: http://wdc.kugi.kyoto-u.ac.jp/dstae/index.html
GIM (CODG and others): ftp://cddis.gsfc.nasa.gov/gps/products/ionex
SWARM data usage service (VirES): https://vires.services/
VirES client on Python: https://github.com/ESA-VirES/VirES-Python-Client
COSMIC data: https://cdaac-www.cosmic.ucar.edu/
AACGM (Python wrapper): https://github.com/aburrell/aacgmv2
GIM treatment module (Python): https://github.com/gnss-lab/ionex

Thank you for your attention!

additional

Criteria for LTE selection

(definition of localized TEC enhancement)



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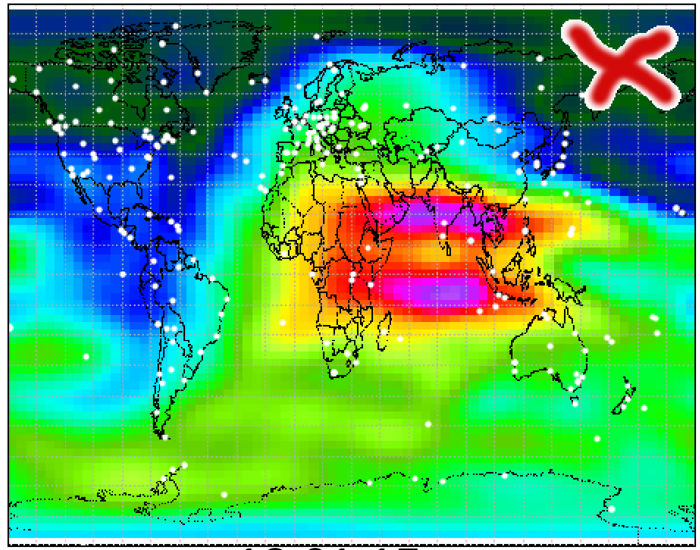

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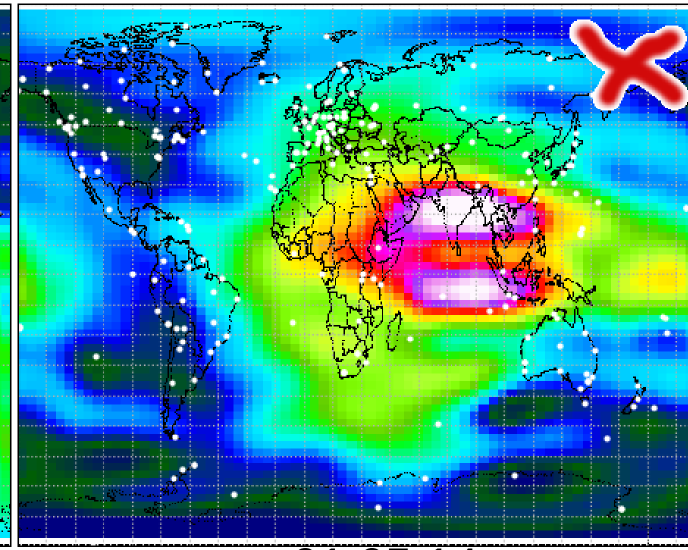

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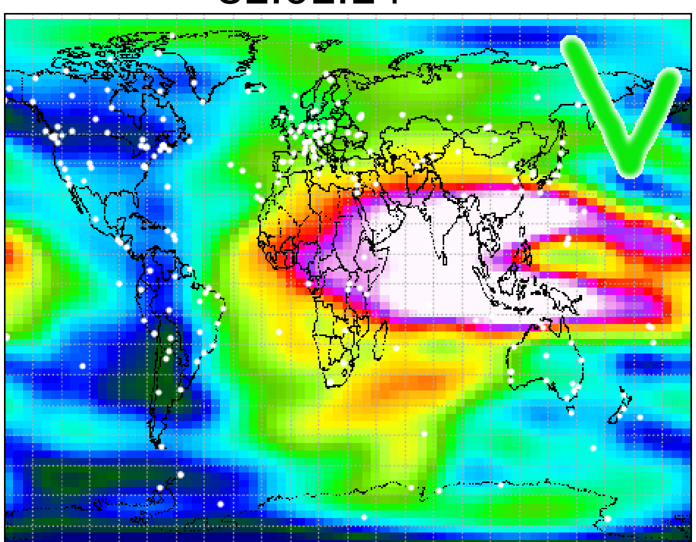

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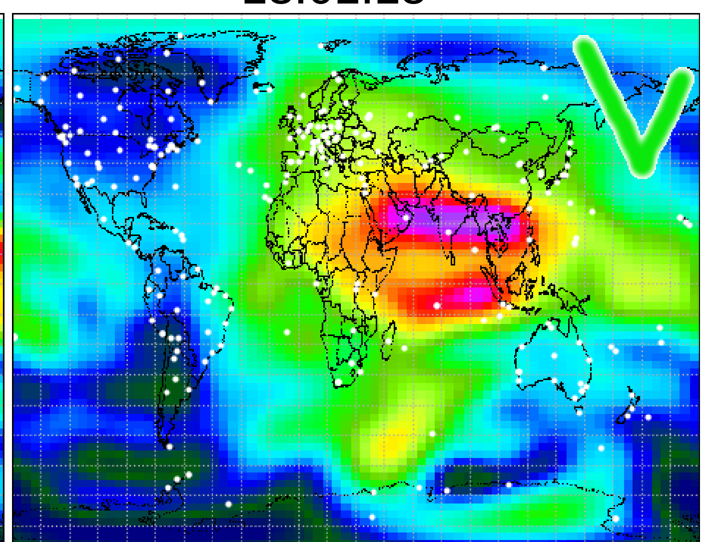

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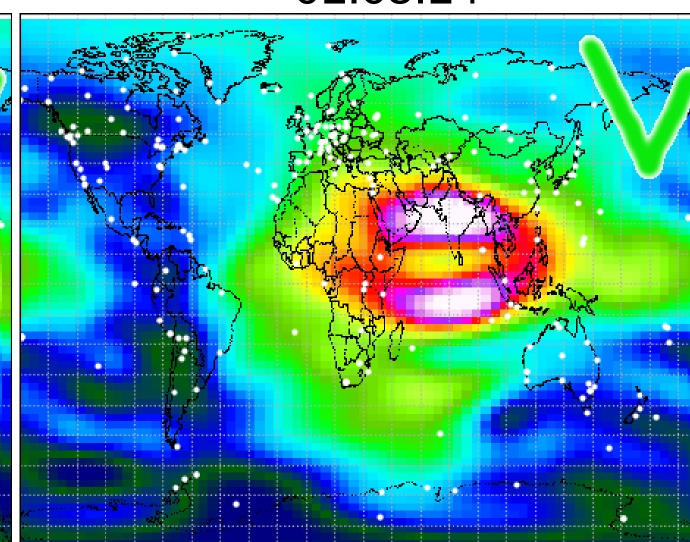

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additional

SWARM data during 05.04.14