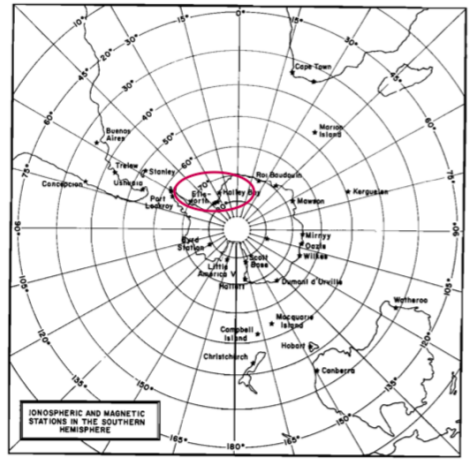
Changes in the Earth‘s Magnetic Field and the Impact on the Spatial Pattern of the Ionospheric Weddell Sea Anomaly

PM3, CBK

Motivation - Weddell Sea Anomaly

- Initially: the WSA is summer phenomenon which extends from the Falkland Islands to the southern shore of the Weddell Sea. Characterized by an unusual diurnal variation in concentration of electron density, with maximum occurring around local midnight (not local noon).
- **Why it is called the Weddell Sea Anomaly, when noticeable part of the anomaly is located in the Bellingshausen Sea region?** (*Webb and Essex, 2003* - postulate to change name of the phenomenon)



Images: 1. (Pendorf, 1978) 2. http://cism.hao.ucar.edu/

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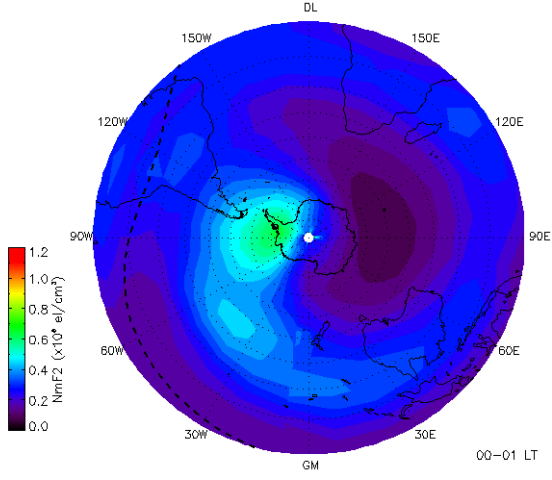
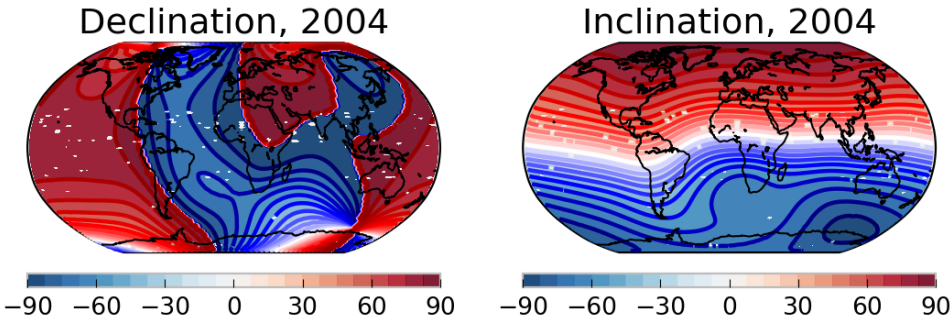


Images: 1. (Pendorf, 1978) 2. http://cism.hao.ucar.edu/

Motivation

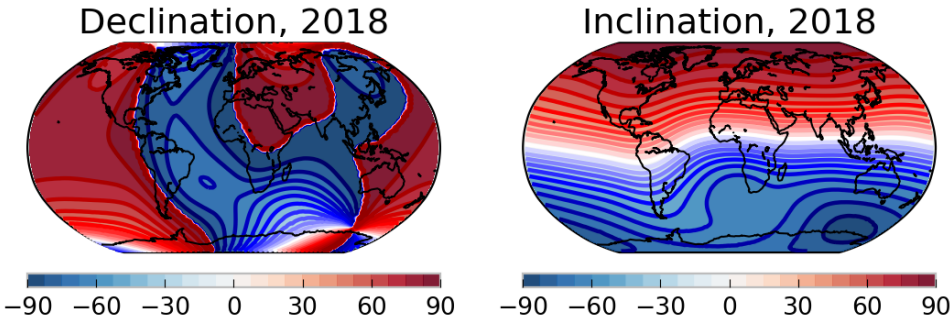
- Are we able to capture migration of certain ionospheric structures with data (from Swarm and CHAMP), not only models?
- What are the effects of changes in the Earth‘s magnetic field on ionospheric structures?
- Do long-term changes in the Earth‘s magnetic field have an impact on the morphology of the WSA?

Expected effect



- Due to geomagnetic secular variation, particular features like the dip equator, the South Atlantic Anomaly, the Sq and equatorial electrojet current systems slowly evolve in time (times scales of decades)

Expected effect



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Expected effect - II

WSA is in close proximity to the SAA, similar consequences related to changes in the main field may be observed

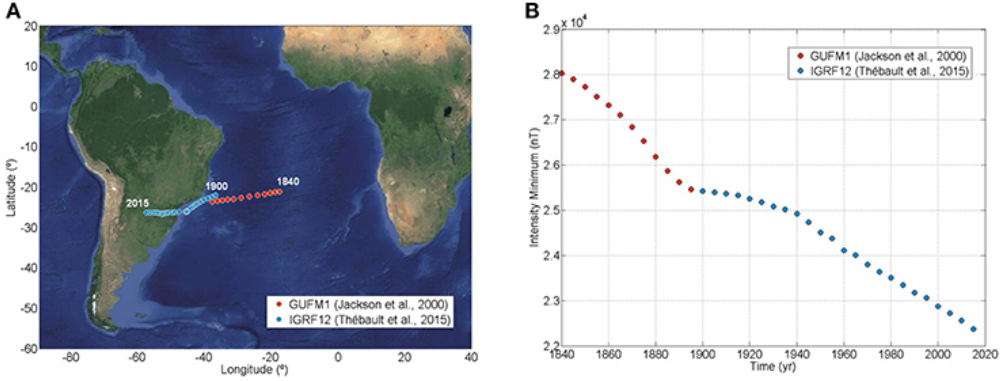
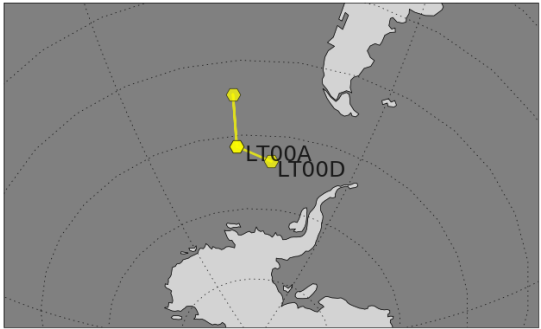


image source: *The South Atlantic Anomaly: The Key for a Possible Geomagnetic Reversal*, F. Javier Pavon-Carrasco, and Angelo De Santis

Key finding:

For every LT bin, maximum of I_{NDD} in the WSA region derived from Swarm is shifted westwards when compared with CHAMP



Identification of the WSA

Normalised density difference index - I_{NDD}

$$I_{NDD}(\lambda,\theta) = \frac{N_e^{night}(\lambda,\theta,@LT) - N_e^{day}(\lambda,\theta,@LT+12h)}{N_e^{night}(\lambda,\theta,@LT) + N_e^{day}(\lambda,\theta,@LT+12h)}.$$

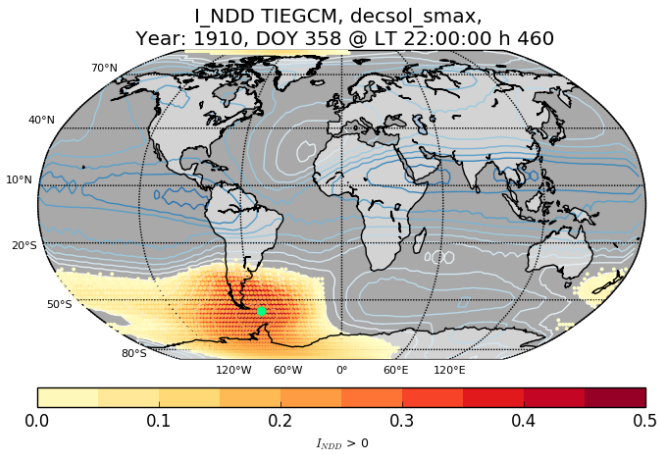
- I_{NDD} index which estimates the values of normalised electron density difference
- relies on separation between measurements taken on ascending and descending passes (12-hour difference needed to capture diurnal variations)
- I_{NDD} varies in the range [-1:1];
- LT-frame representation, for WSA LT: (22:00-02:00)
- in the first approach $I_{NDD} > 0$ indicates regions with anomalous characteristics.

TIEGCM Synthetic index I_{NDD}

- TIEGCM - Thermosphere-Ionosphere-Electrodynamics General Circulation Model - developed by NCAR. TIEGCM is a time-dependent, three dimensional model that solves the fully coupled, nonlinear, hydrodynamic, thermodynamics, and continuity equations of the neutral gas self-consistently with the ion continuity, momentum, and energy equations
- Realistic magnetic field implemented (IGRF-12)
- **Goal: Use Stand-alone runs to reconstruct "historical index" with fixed configuration representing solar and geomagnetic conditions.** In such way the main effect of the role of magnetic field in formation of the WSA is captured
- For a fixed LT frame - certain ionospheric features (expressed by ionosphere fields such as N_e, hmF2, TEC...) remain at specific locations. Intensity of observed features may vary with season and solar activity - On a time scales of couple of years remain unchanged, but... we may expect changes on scales of decades.

Synthetic index and the impact of the magnetic field - December solstice

- For a given LT we track max. of the anomaly ($I_{NDD} > 0$) in the 3^{rd} quadrant (WS hemisphere)



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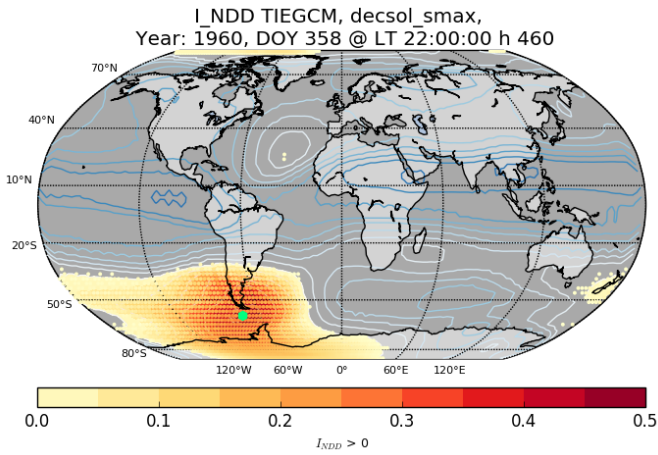

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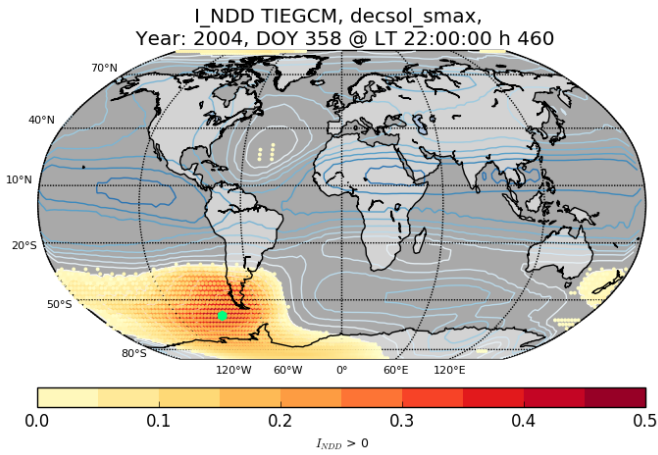

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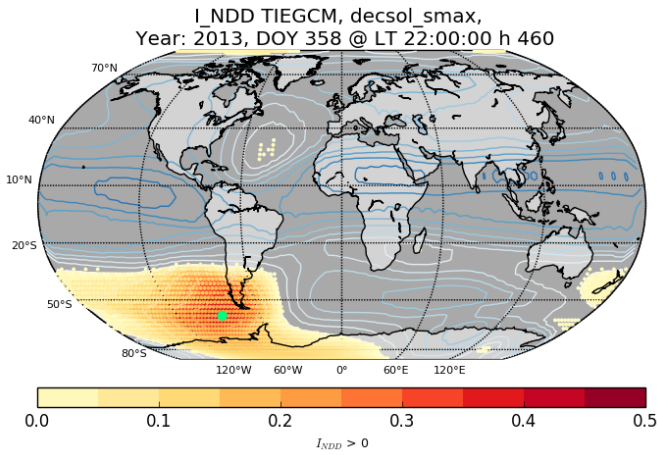
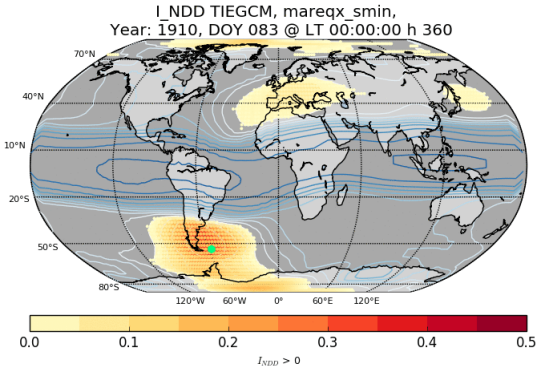
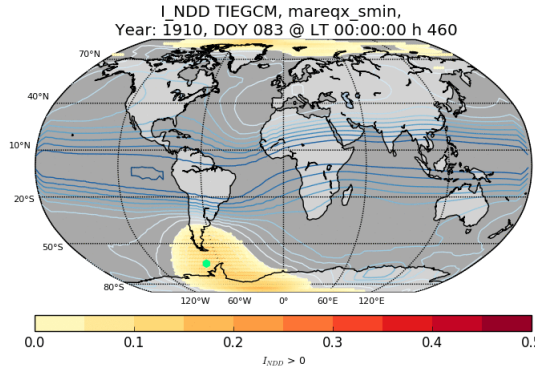
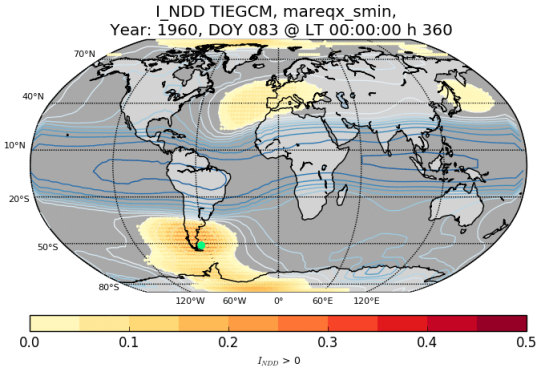


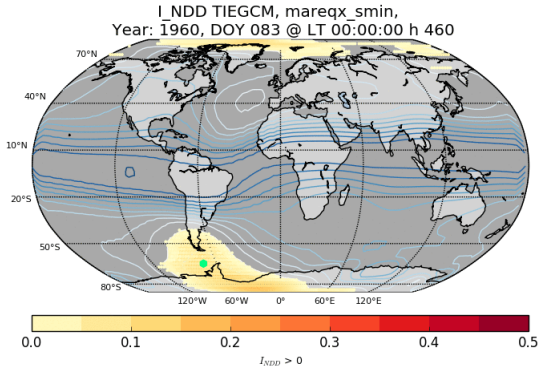
TIEGCM results - I_{NDD}@(360 km & 460 km) - March equinox (1910)



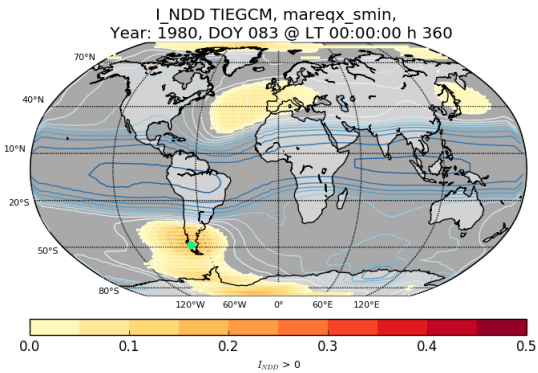


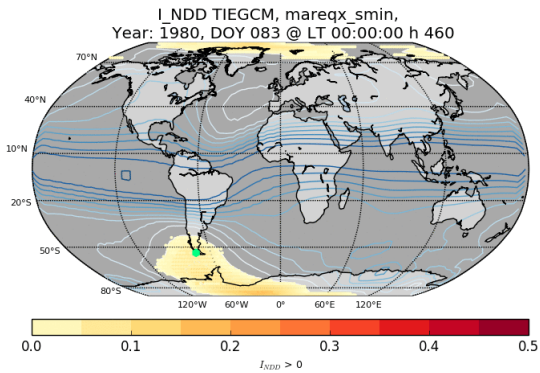
TIEGCM results - I_{NDD}@(360 km & 460 km) - March equinox (1960)





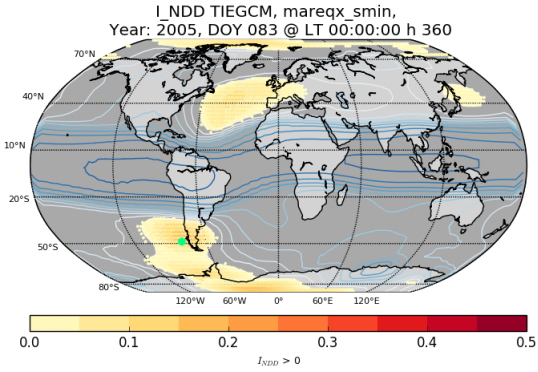
TIEGCM results - I_{NDD}@(360 km & 460 km) - March equinox (1980)

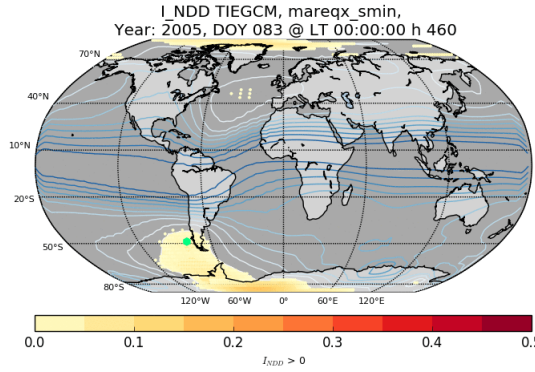




No signatures of northern NPDEs at higher altitude

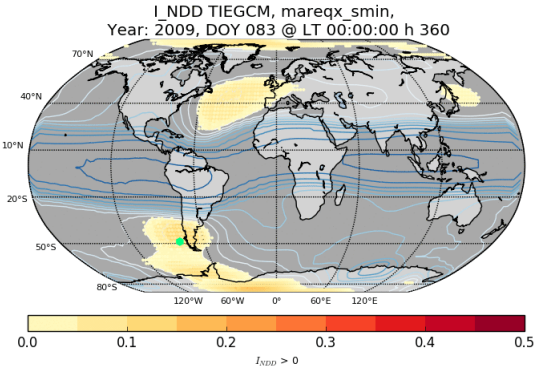
TIEGCM results - I_{NDD}@(360 km & 460 km) - March equinox (2005)

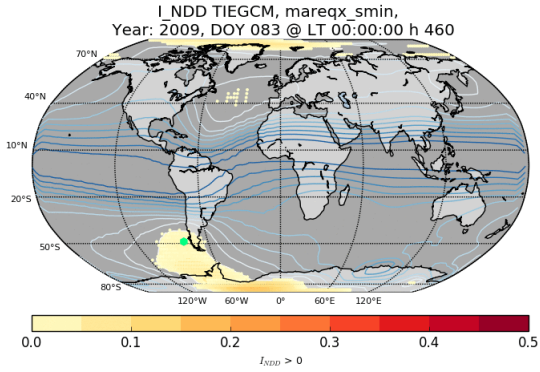




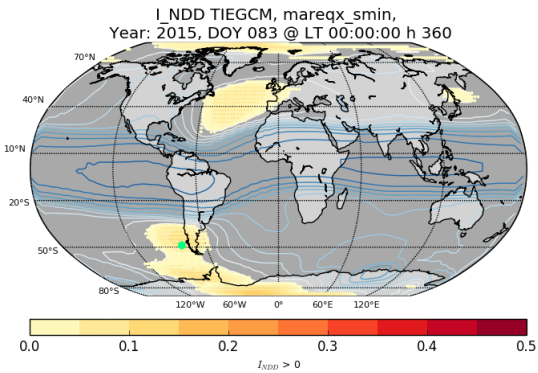
First evidences of NPDEs in the Atlantic sector at the altitude of 460 km

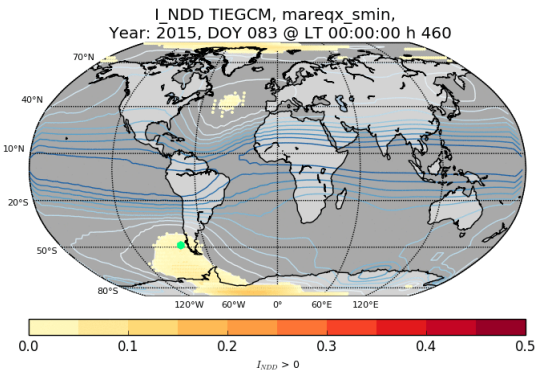
TIEGCM results - I_{NDD}@(360 km & 460 km) - March equinox (2009)





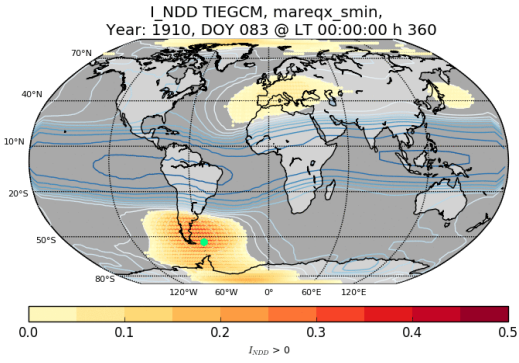
TIEGCM results - I_{NDD}@(360 km & 460 km) - March equinox (2015)

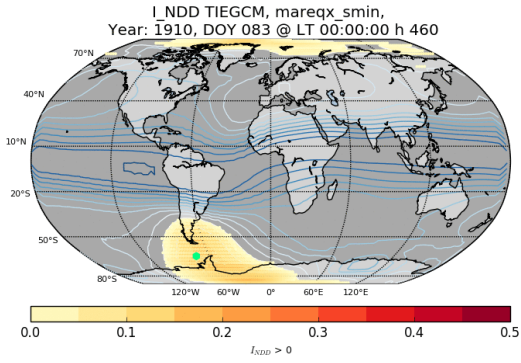




NPDEs in the Atlantic sector are getting stronger

TIEGCM results - I_{NDD}@(360 km & 460 km) - March equinox (Animation)

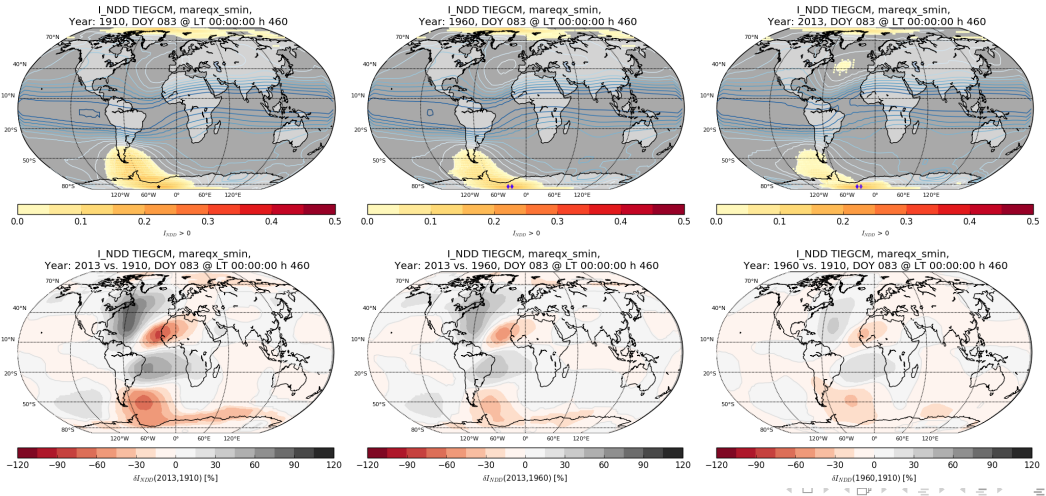




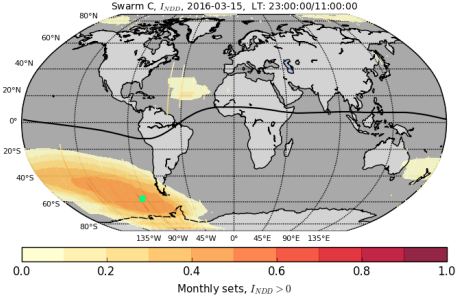
TIEGCM suggests that for fixed solar conditions, and varying configuration of the main magnetic field maximum of I_{NDD} in the WSA region gradually shift in the direction of the Pacific Ocean

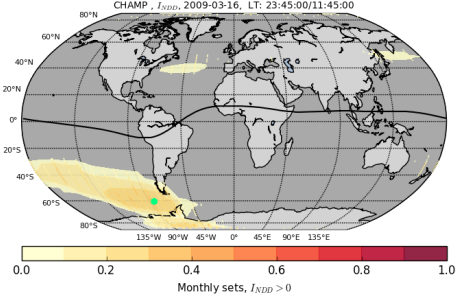
Magnetic field secular variations and the WSA - theoretical analysis

- Based on model simulation there is constant decrease of I_{NDD} in the region of the Weddell Sea, and increase in the Bellingshausen Sea

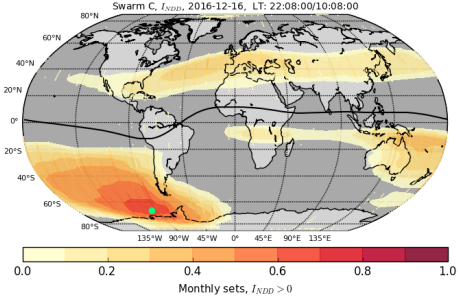


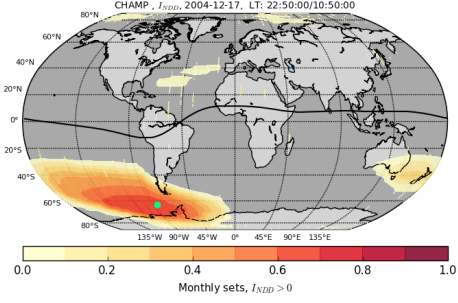
Results: Position of the WSA maximum - Champ vs. Swarm (I)

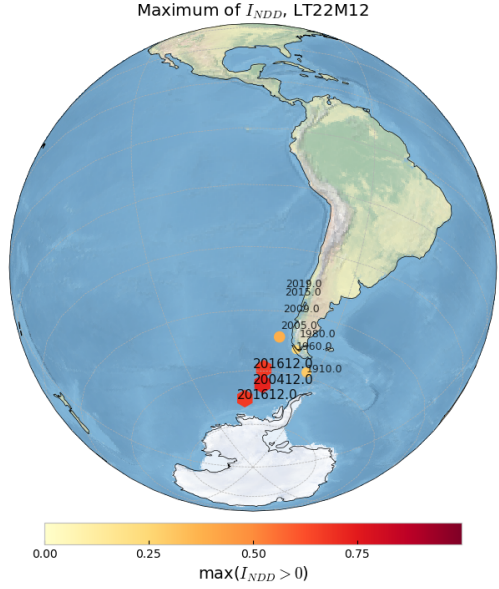




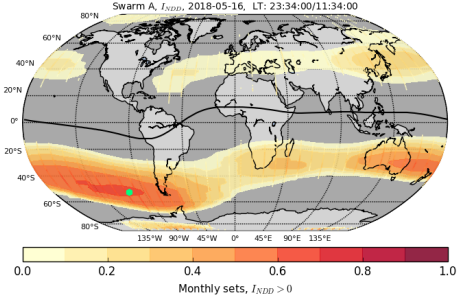
Results: Position of the WSA maximum - Champ vs. Swarm (II)

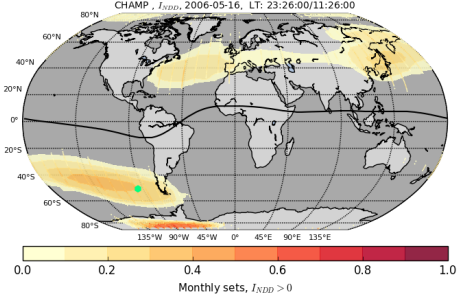


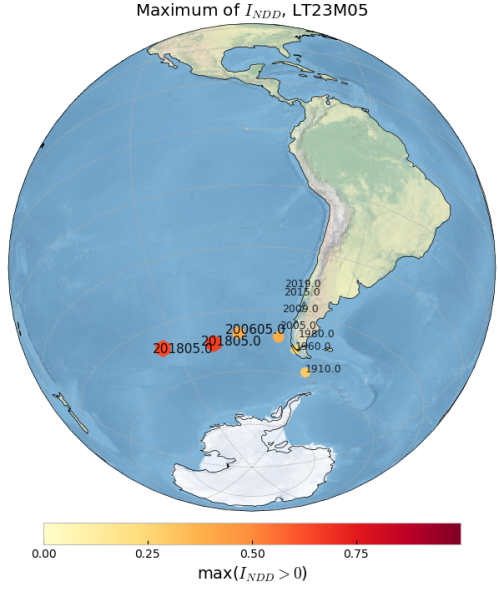




Results: Position of the WSA maximum - Champ vs. Swarm (III)

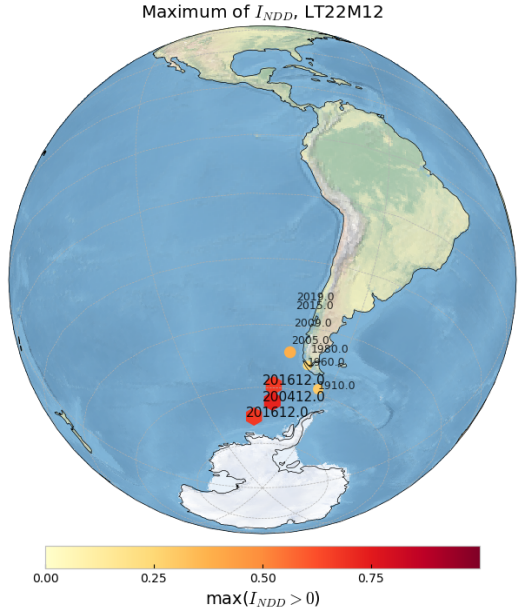






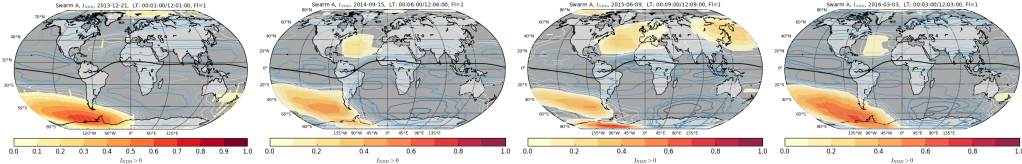
Tracking maximum of the WSA - Champ vs. Swarm

- Monthly sets, provide limited statistics - couple of cases
- Derive, max. position from medians of 6-day sets, for specified LT bins

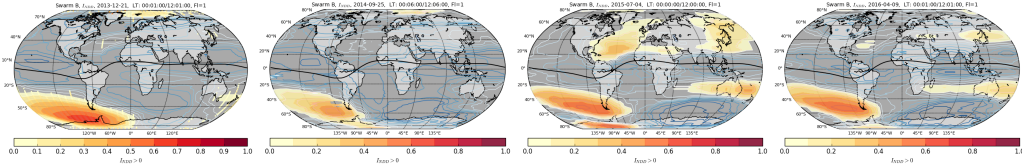


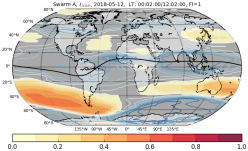
Spatial patterns of I_{NDD} - 00/12 LT - 6-day composites

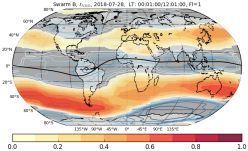
Alpha:

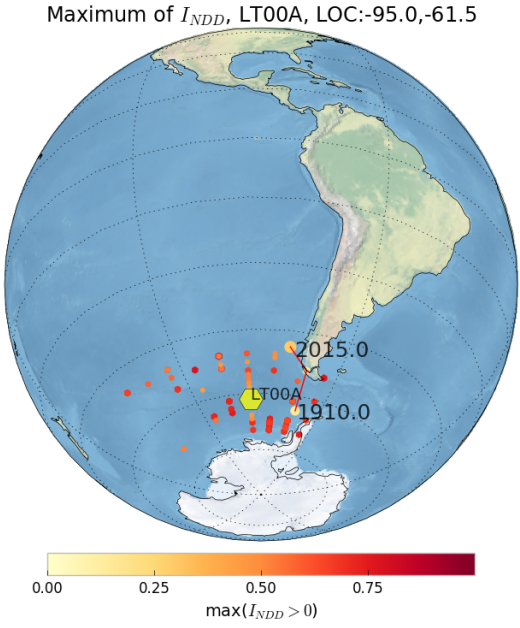


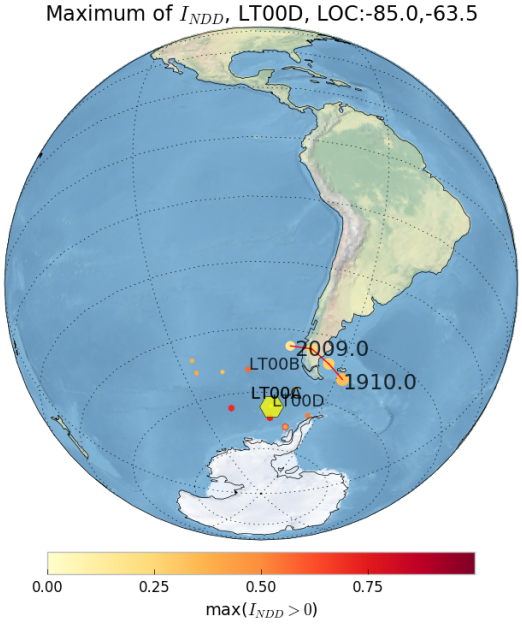
Bravo:



A: (2018-05-12) 

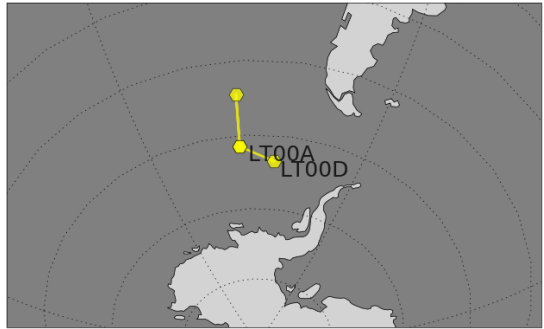
B: (2018-07-28) 


Maximum of I_{NDD}, LT00A, LOC:-95.0,-61.5
2015.0
LT00A
1910.0
0.00
0.25
0.50
0.75
max($I_{NDD} > 0$)

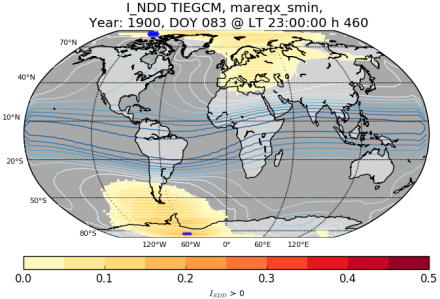

Maximum of I_{NDD}, LT00D, LOC:-85.0,-63.5
2009.0
LT00B
1910.0
LT00C
LT00D
0.00
0.25
0.50
0.75
max($I_{NDD} > 0$)

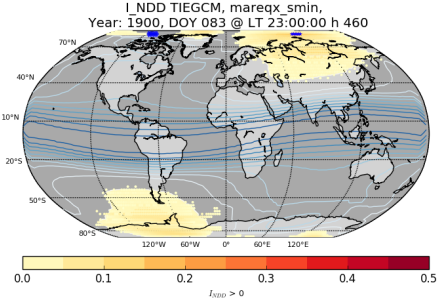
Key finding:

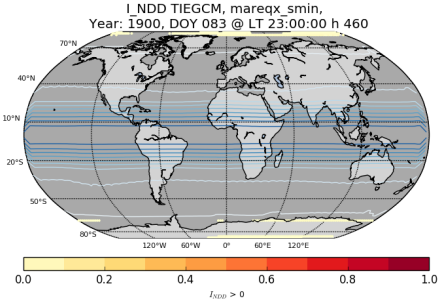
Satellite	LT bin	Long./Lat.
CHAMP	22/10	-90./-60
Swarm A	22/10	-105./-62.5
Swarm B	22/10	-105./63.5
Swarm C	22/10	-105./-62.5
CHAMP	00/12	-85./ -63.5
Swarm A	00/12	-95./-61.5
Swarm B	00/12	-95./-54.5
Swarm C	00/12	-95. /-61.5
CHAMP	02/14	-75./-57.5
Swarm A	02/14	-85./-56.
Swarm B	02/14	-85./ -53.5
Swarm C	02/14	-85/ -56.5

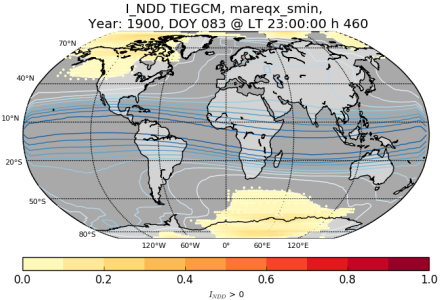


Dipolar components and settings - Interpretation



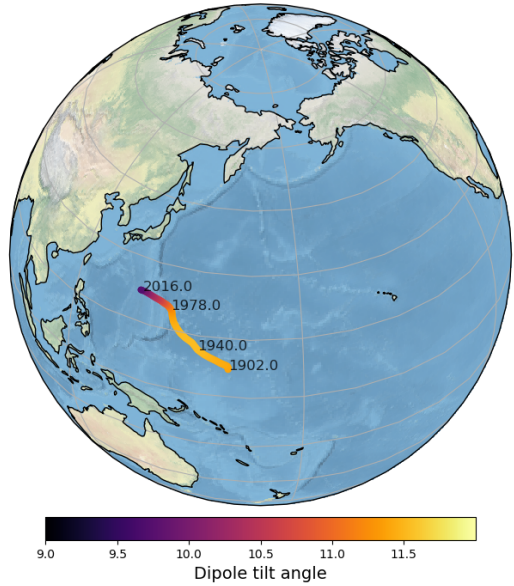






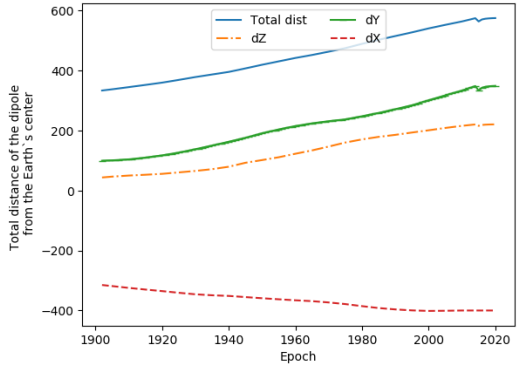
Summary (I)

- Swarm- and CHAMP-derived index I_{NDD} seems to confirm modeled prediction - westward drift of the maximum of the WSA.
- Magnitude of such changes is much smaller, when compared with diurnal, seasonal and solar activity variations - main difficulty in detection
- The influences of the secular changes of the orientation of the geomagnetic field: the variation of the eccentric dipole field center, the movement of the geomagnetic poles, and the variations of I and D, should be reflected in the substantial movement of certain ionospheric features



Summary (II)

- The influences of the secular changes of the orientation of the geomagnetic field: the variation of the eccentric dipole field center, the movement of the geomagnetic poles, and the variations of I and D, should be reflected in the substantial movement of certain ionospheric features (including WSA)
- Configuration in the eccentric dipole representation is as an important indicator of the increasing asymmetry of Earth's field with respect to the Earth's center and the Earth's spin axis.



WSA position: derived from TIEGCM

Year	LT bin	$Max.I_{NDD}$	Long./Lat.	LT bin	$Max.I_{NDD}$	Long./Lat.
Alt: 360 km						
1910,	22:00:00	0.528	-65.0 -38.75	00:00:00	0.337	-57.5 -53.75
1960,	22:00:00	0.477	-72.5 -38.75	00:00:00	0.274	-65.0 -51.25
1980,	22:00:00	0.456	-72.5 -38.75	00:00:00	0.245	-72.5 -48.75
2005,	22:00:00	0.448	-80.0 -41.25	00:00:00	0.189	-80.0 -48.75
2015,	22:00:00	0.442	-80.0 -41.25	00:00:00	0.150	-80.0 -48.75
Alt: 460 km						
1910,	22:00:00	0.443	-65.0 -58.75	00:00:00	0.189	-72.5 -63.75
1960,	22:00:00	0.349	-72.5 -63.75	00:00:00	0.131	-72.5 -63.75
1980,	22:00:00	0.315	-80.0 -53.75	00:00:00	0.123	-72.5 -53.75
2005,	22:00:00	0.277	-80.0 -51.25	00:00:00	0.076	-80.0 -48.75
2015,	22:00:00	0.275	-80.0 -51.25	00:00:00	0.075	-80.0 -48.75

CHAMP ('2004) and Swarm ('2016) - December solstice