Simulated trends in ionosphere-thermosphere climate due to predicted main magnetic field changes from 2015 to 2065

Ingrid Cnossen[1]

Astrid Maute[2]

[1]NERC Independent Research Fellow (NE/R015651/1), British Antarctic Survey
[2]National Center for Atmospheric Research

Why do we care about high-altitude climate?

- Managing space debris
  - Satellites operate in the upper atmosphere (~90-500 km)
  - Population of space debris is growing – collisional hazard
  - Satellite orbit and space debris lifetime depend on upper atmosphere density
- Remote sensing signals can be distorted by the ionosphere
  - Stability of long-term measurements can be affected by long-term ionospheric changes
- Connections to lower atmosphere climate change


BBC Sign in News Sport Weather Shop Earth Travel More

NEWS

Home Video World UK Business Tech Science Magazine Entertainment & Arts Health World Ne

Science & Environment

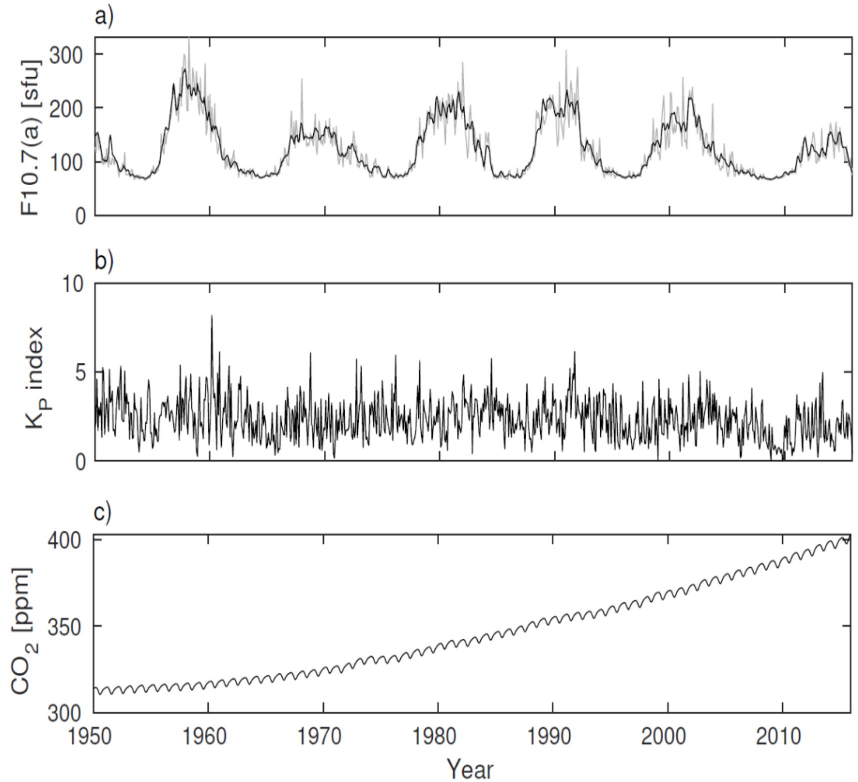
Trouble in orbit: the growing problem of space junk

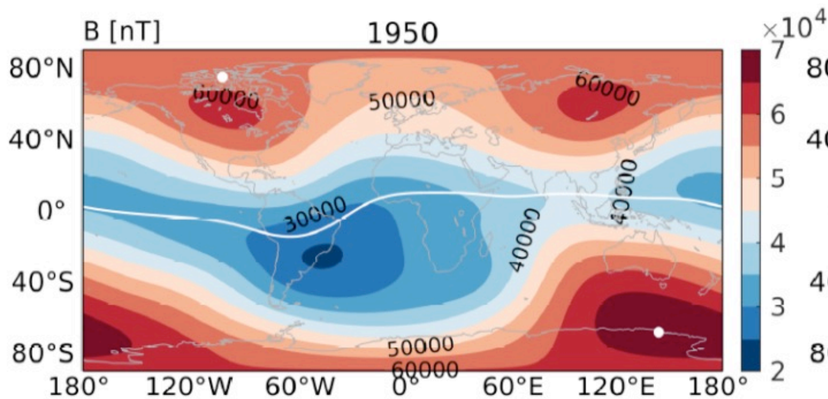
By Dr Hugh Lewis
University of Southampton

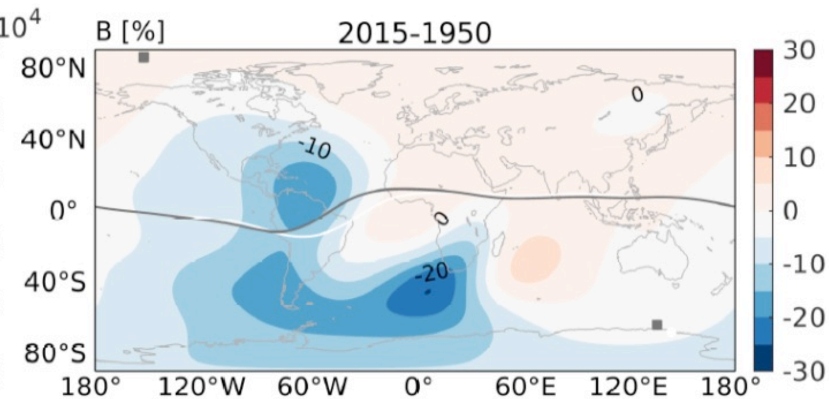
5 August 2015 | Science & Environment

Drivers of upper atmosphere climate change

- Solar and geomagnetic activity variations
- Increase in CO_2 concentration
  - Cools upper atmosphere
  - Thermal contraction
  - Indirect changes via altered lower boundary forcing?
- Magnetic field changes
  - Important for ionosphere
  - Regionally varying

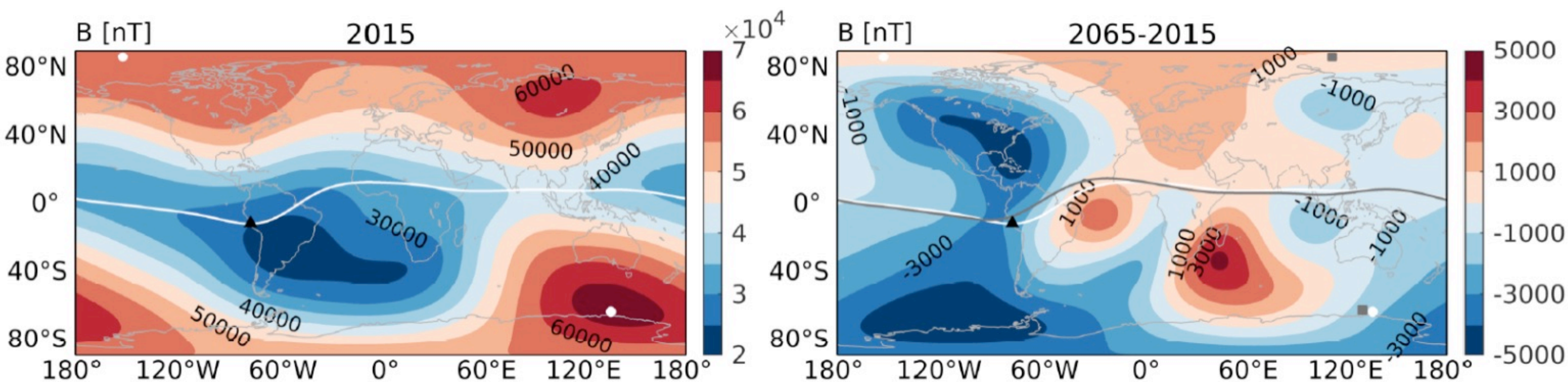






Geomagnetic field changes and effects

- Decreasing main field strength
  - Causes increase in ionospheric conductivity
- Changes in field orientation
  - Causes changes in plasma transport processes, electron density
- Change in position of magnetic pole / auroral oval
  - Causes change in geographic distribution of high-latitude current systems, Joule heating
- Change in position of magnetic equator
  - Causes changes in low-latitude current systems, electron density



From Cnossen & Maute (2020), based on prediction by Aubert (2015)

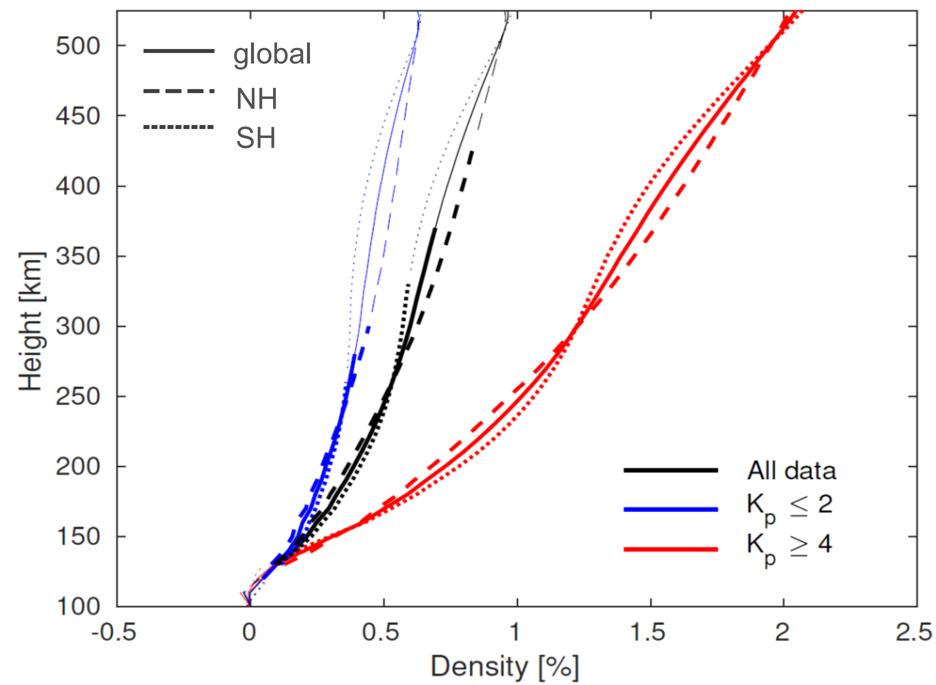
Methodology

- Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM)
- 2.5°x2.5° grid, ¼ scale height
- Two full-year simulations with magnetic field of 2015 (mf2015) and 2065 (mf2065)
- Includes effects of the magnetic field on conductivity and electrodynamics, and changes in mapping from magnetic to geographic coordinates
- Observed solar and geomagnetic forcing for 2015 used for both
  - High-latitude forcing is fixed in magnetic coordinates – only mapping effects included
- Hourly data
- Analyze average differences

Joule heating power and neutral density

- Small increase in neutral density
- Largest and most significant for high geomagnetic activity
- Probably due to increase in Joule heating – expected for reduced main field strength
- Larger effect in SH due to larger decrease in main field strength

Neutral density difference (mf2065-mf2015)

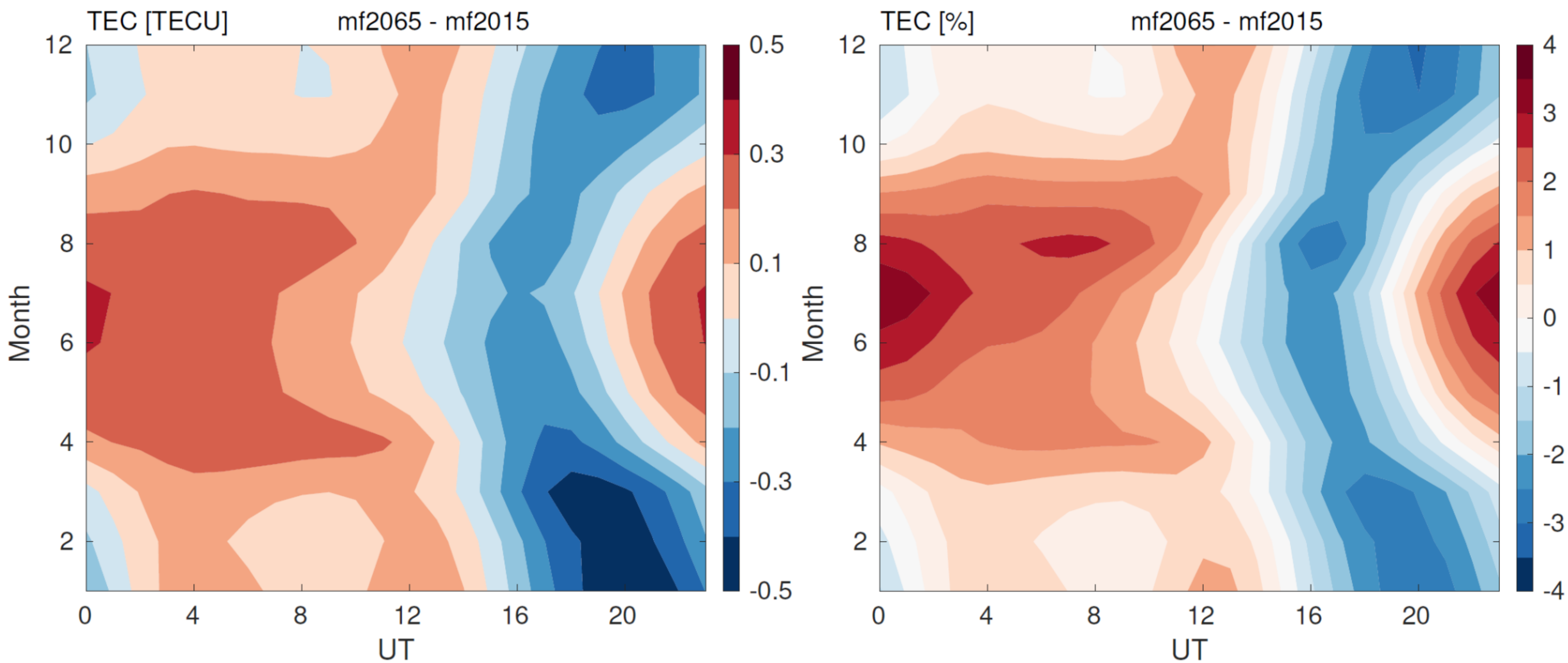


Joule heating power (GW)

	mf2015			mf2065 - mf2015		
	NH	SH	global	NH	SH	global
all	5.4	5.2	10.7	0.0 (0.0%)	**0.3 (6.2%)**	**0.3 (3.3%)**
$K_p \geq 4$	12.8	12.7	25.5	0.2 (1.3%)	**0.9 (7.4%)**	1.1 (4.4%)
$K_p \leq 2$	3.6	3.3	6.8	0.0 (0.0%)	**0.2 (5.2%)**	**0.2 (2.5%)**

Cnossen & Maute (2020)

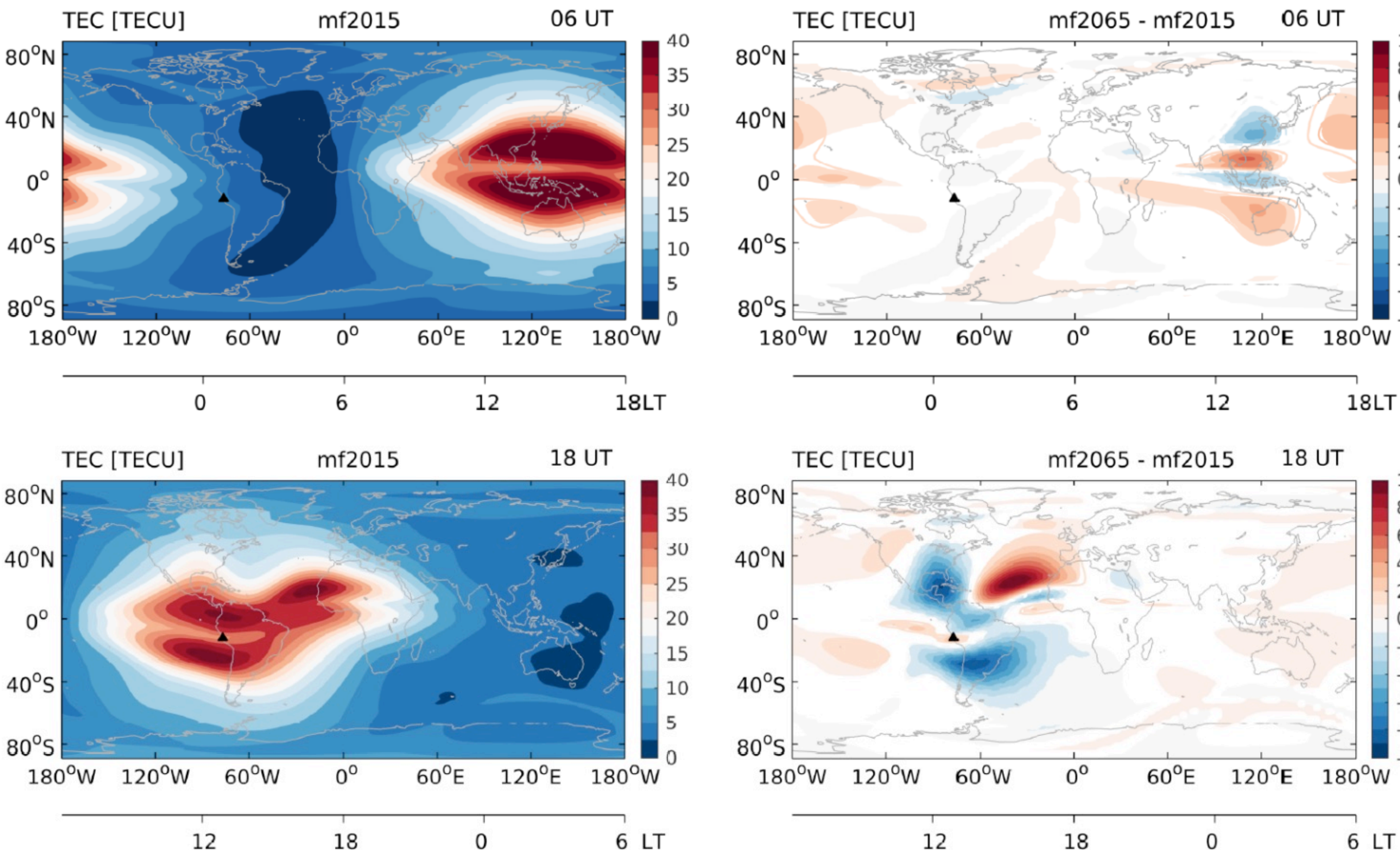
Global mean total electron content (TEC)



- Global mean TEC changes depend on UT and season, varying from -4% to +3% or -0.5 to +0.3 TECU
- Due to spatial and local time variations

Cnossen & Maute (2020)

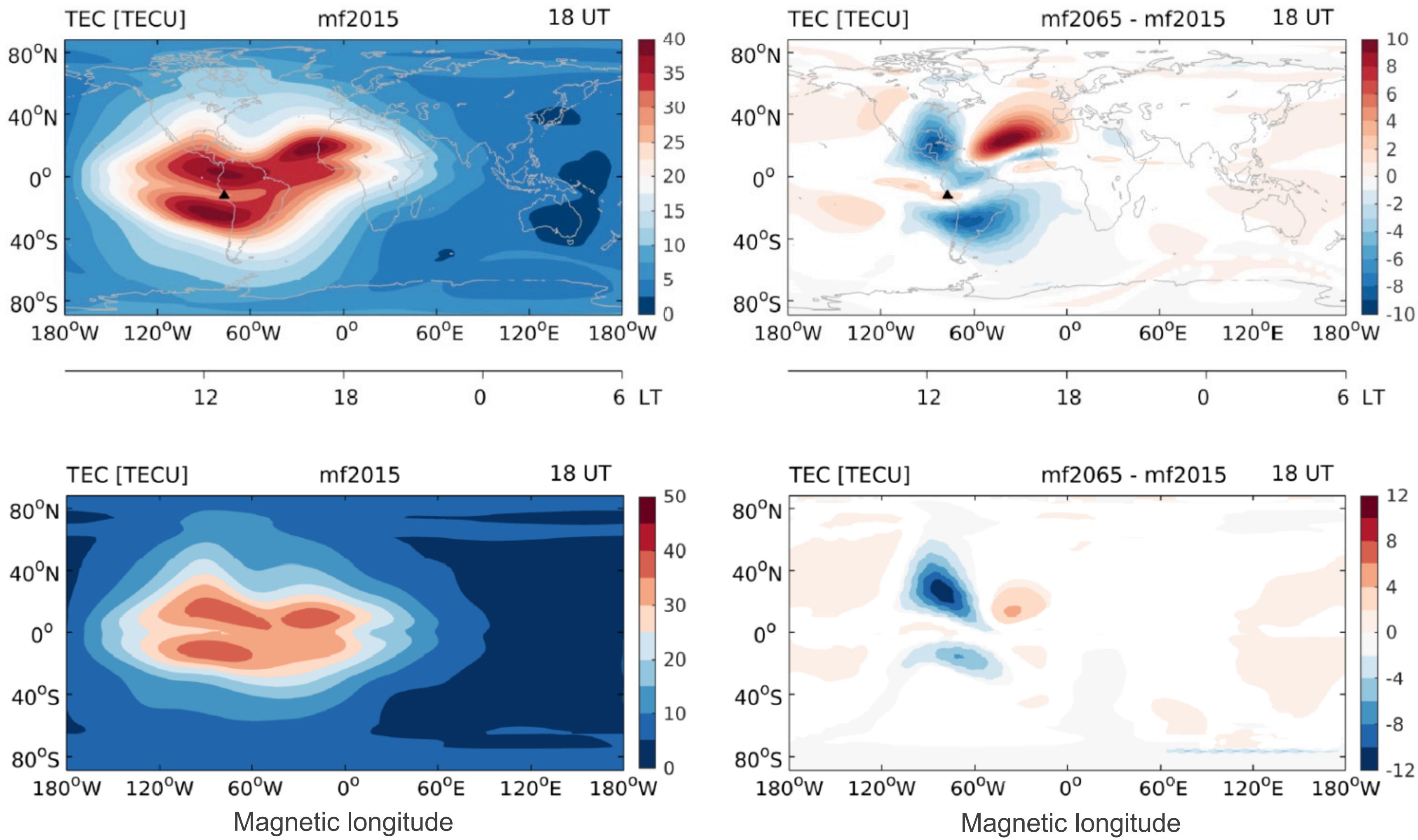
Total electron content (TEC) – spatial variations



- Largest changes occur in South Atlantic Anomaly region during daytime

Cnossen & Maute (2020)

Total electron content (TEC) – spatial variations



- TEC response is partly a mapping effect

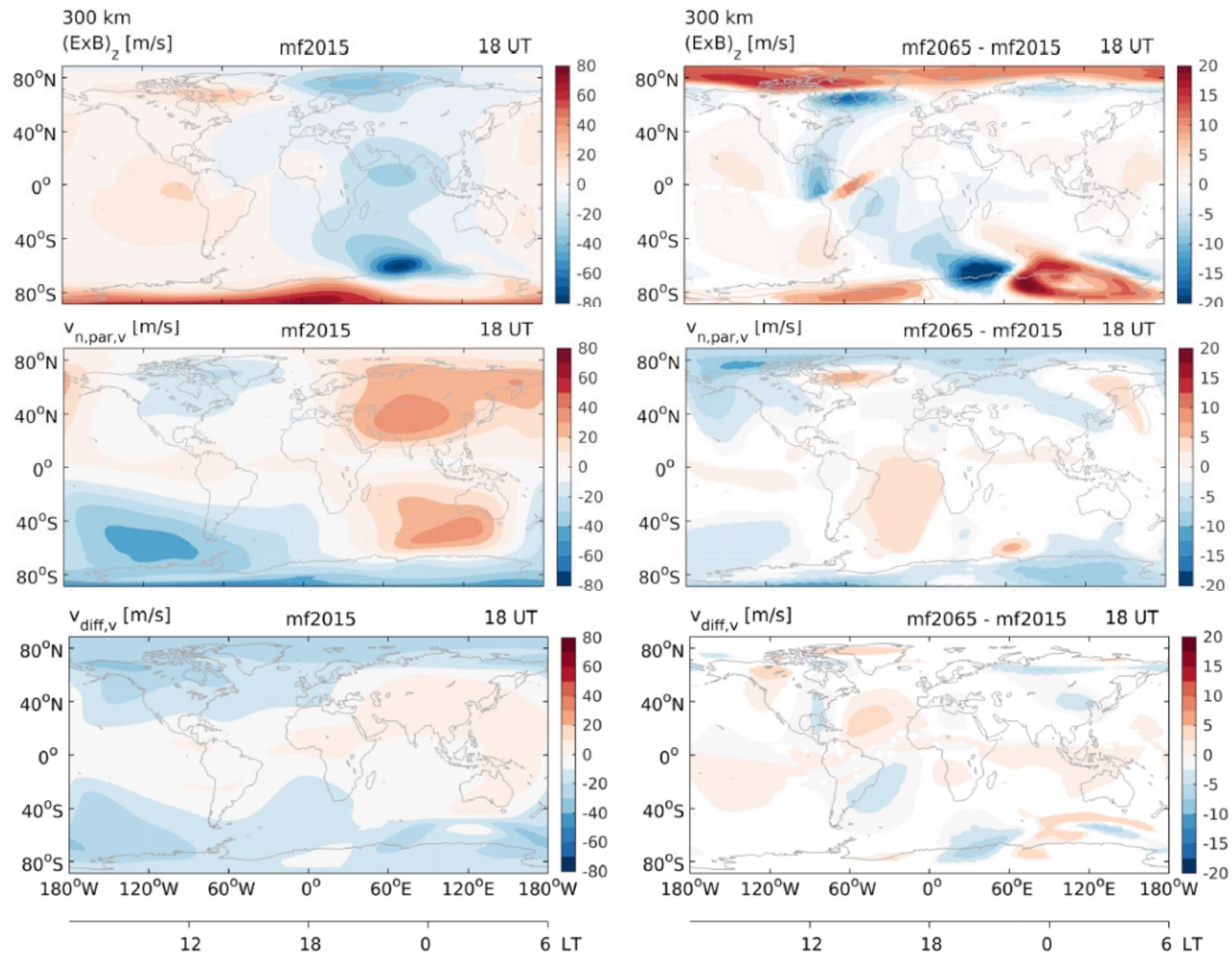
Cnossen & Maute (2020)

Cause of TEC response: vertical transport terms

Vertical
ExB drift

Vertical
movement due to
horizontal winds
pushing plasma
up/down magnetic
field lines

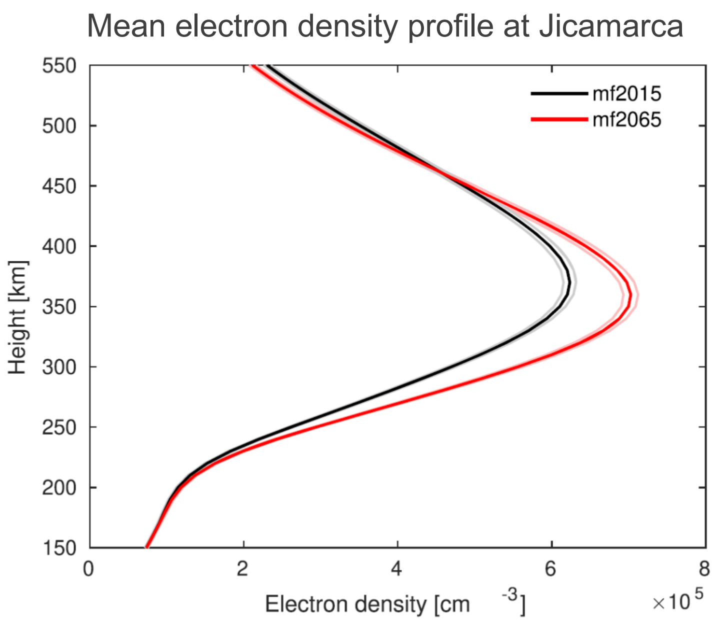
Vertical
component of
diffusion along the
magnetic field

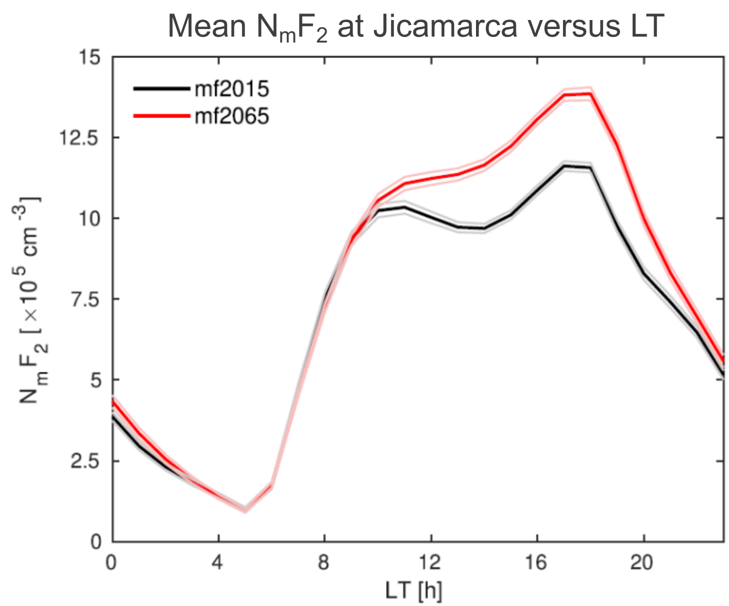


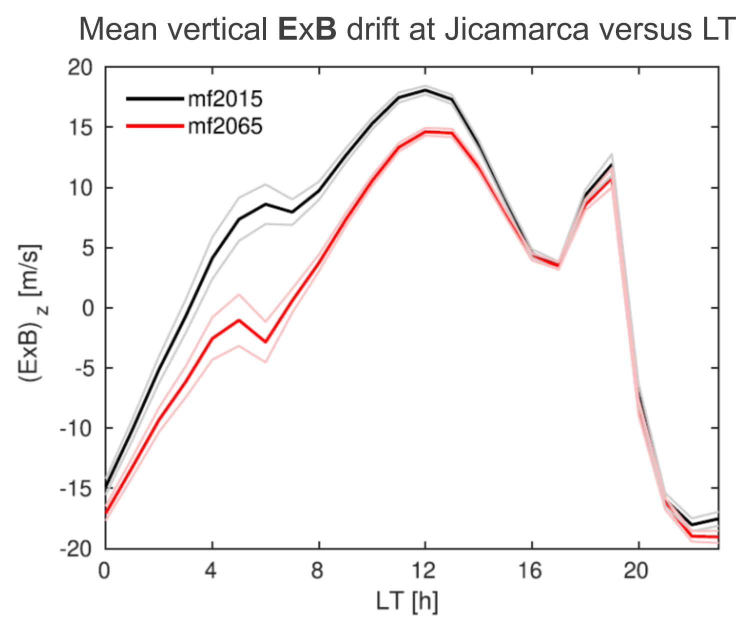
- Changes in vertical **ExB** drift are the most important driver of the TEC response

Cnossen & Maute (2020)

Electron density changes at Jicamarca



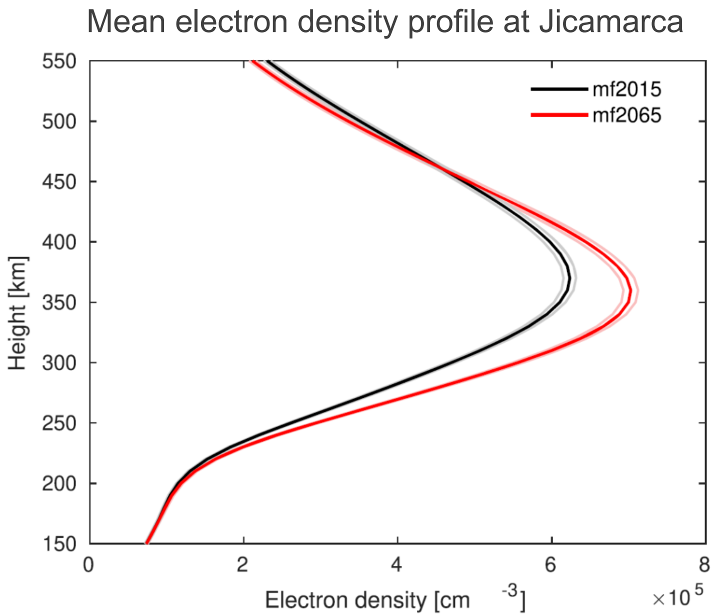


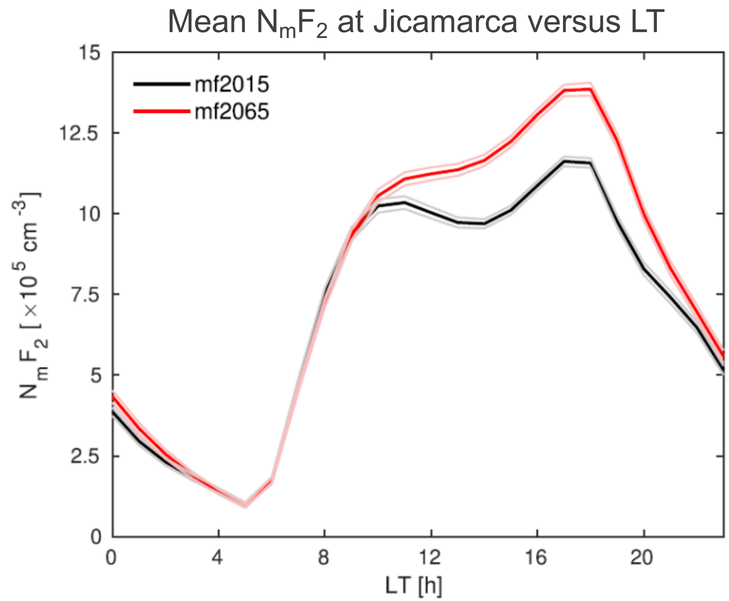


- Increase in daytime peak electron density at Jicamarca
- Appears inconsistent with reduced upward **ExB** drift

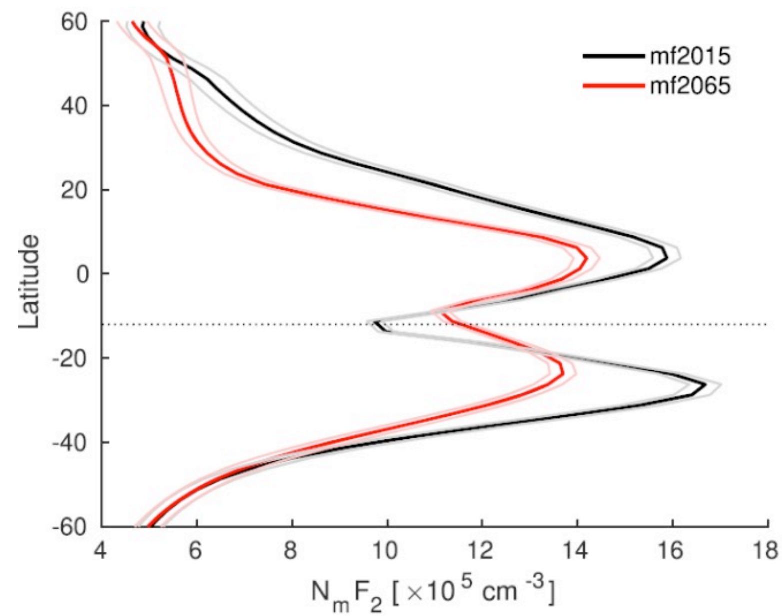
Cnossen & Maute (2020)

Electron density changes at Jicamarca





- Increase in daytime peak electron density at Jicamarca
- Appears inconsistent with reduced upward **ExB** drift
- But makes sense as entire EIA structure weakens!



Cnossen & Maute (2020)

Summary and conclusions

- Predicted main magnetic field changes from 2015 to 2065 cause minor effects on the thermosphere
  - Very small increase (1-2%) in thermosphere density – too small to be reliably detectable; unimportant compared to CO_2 effect on density
  - Due to minor increase (2-4%) in Joule heating, mainly coming from SH
- But they cause substantial effects on the ionosphere
  - Changes in TEC of up to ±10 TECU or ±35% during daytime between ~45°S-45°N, 110-0°W
  - Mainly driven by changes in vertical **E**x**B** drift
  - In the Jicamarca longitude sector reduced **E**x**B** drifts weaken the EIA, causing an increase in the daytime electron density at Jicamarca
- Effects of predicted magnetic field changes on TEC should be observationally detectable and could make a significant contribution to long-term trends in TEC, depending on spatial and temporal averaging

Cnossen, I., and A. Maute (2020), Simulated trends in ionosphere-thermosphere climate due to predicted main magnetic field changes from 2015 to 2065, *J. Geophys. Res. Space Physics, 125*, e2019JA027738, doi: 10.1029/2019JA027738.