Causes of long-term change in the upper atmosphere

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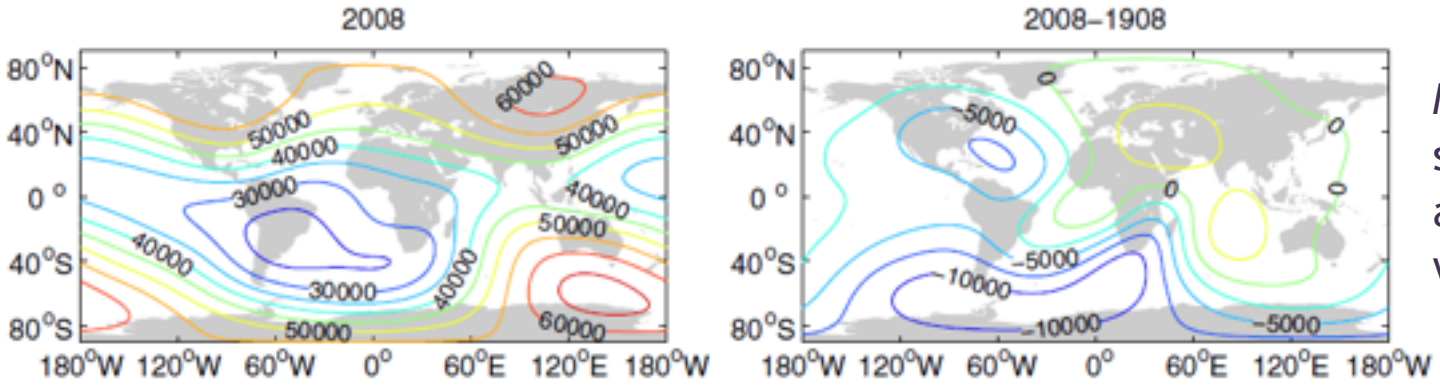
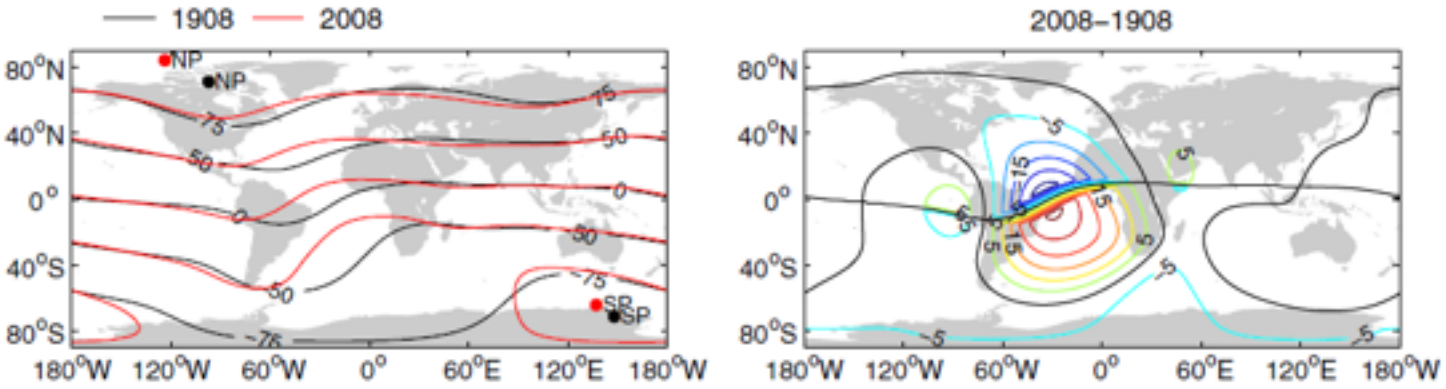
IGRF magnetic field changes 1908-2008



Magnetic field strength in 2008 and difference with 1908 (nT)



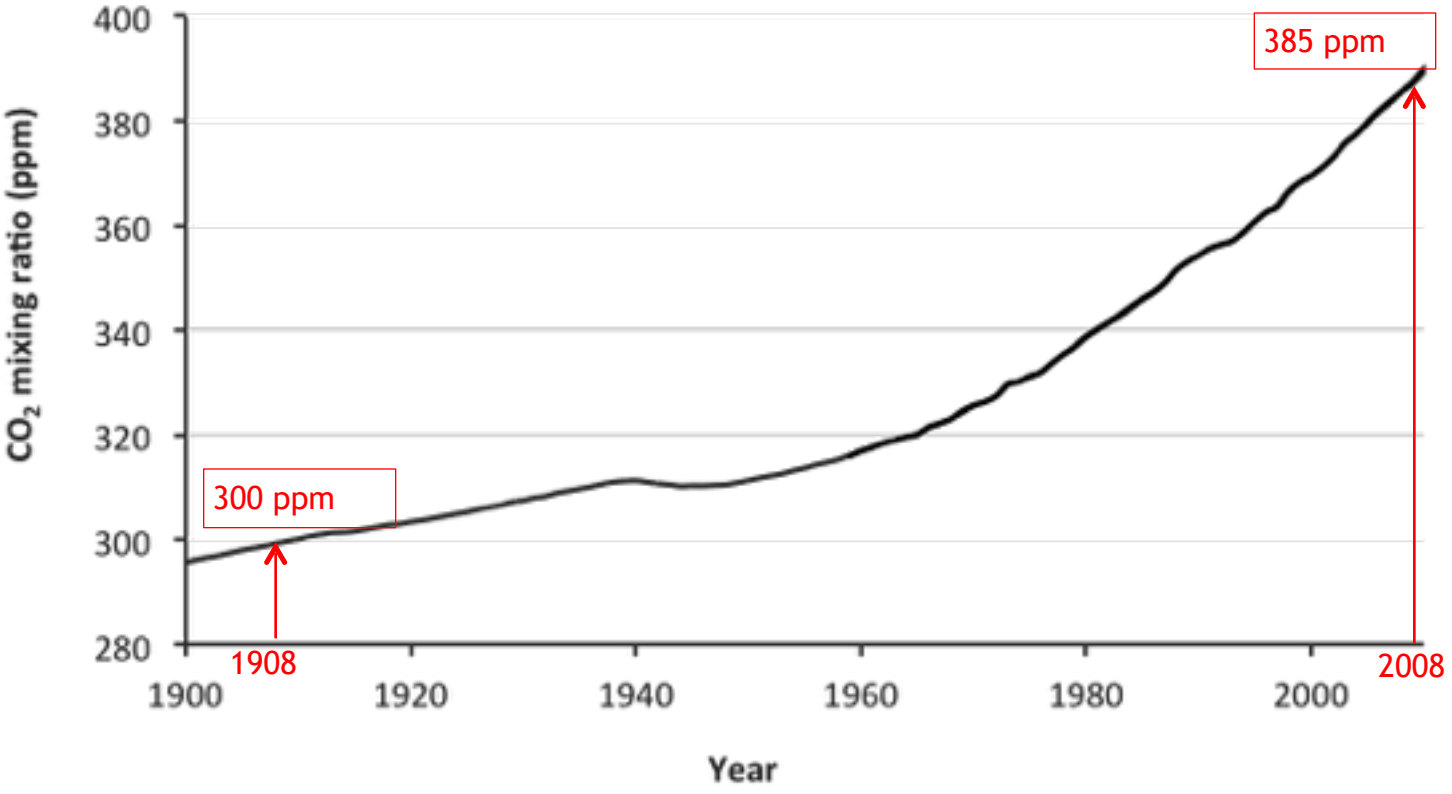
Inclination angle contours of 1908 and 2008 and differences in magnitude of inclination (°)

- Expansion and intensification of the South Atlantic Anomaly region of low magnetic field strength
- Northward and westward movement of magnetic field structures
- Strongest inclination angle changes in Atlantic region (~100°W-50°E; ~60°S-40°N)

IGRF = International Geomagnetic Reference Field

Cnossen and Richmond (JGR, 2013)

CO_2 changes 1908-2008

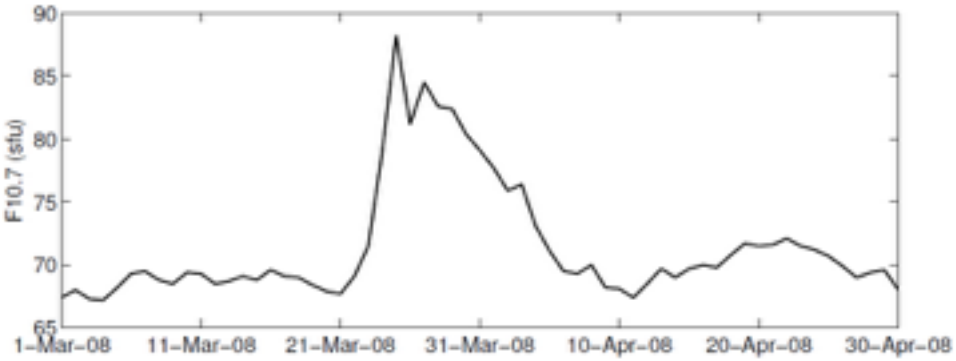


- 85 ppm increase in CO_2 concentration from 1908 to 2008
- CO_2 cools the middle and upper atmosphere

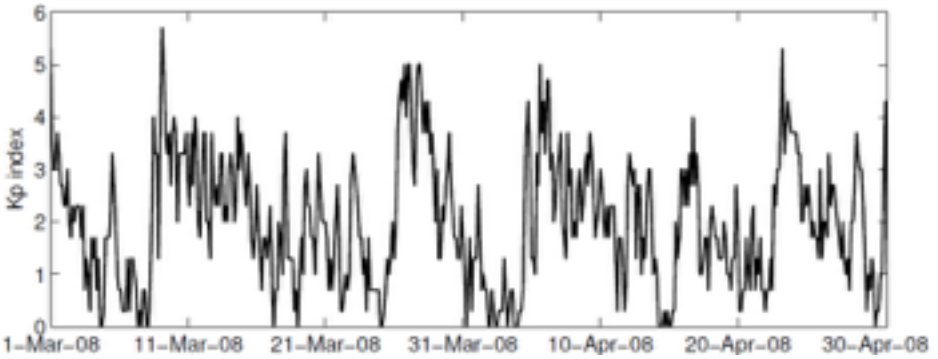
TIE-GCM simulation and analysis setup

- TIE-GCM = Thermosphere-Ionosphere-Electrodynamics General Circulation Model
- Four cases:
  - IGRF of 2008, CO_2 of 2008
  - IGRF of 2008, CO_2 of 1908
  - IGRF of 1908, CO_2 of 2008
  - IGRF of 1908, CO_2 of 1908
- Each run 61 days long
- 1 March-1 May (~equinox)
- Observed solar and geomagnetic activity of 2008
- Test significance of differences against day-to-day variability with *t*-test

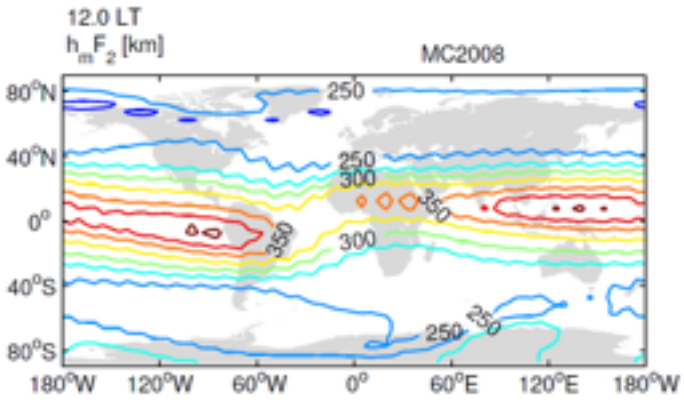
solar activity

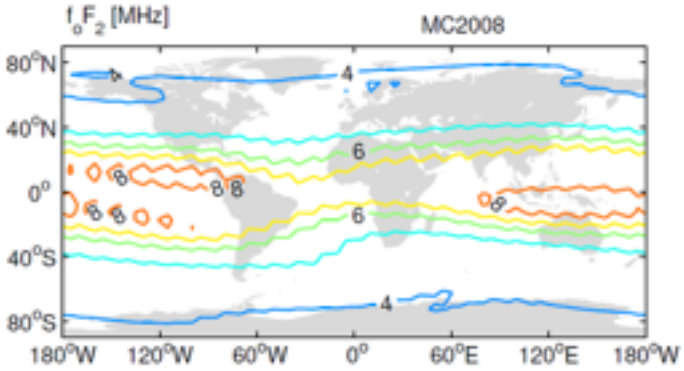


geomagnetic activity

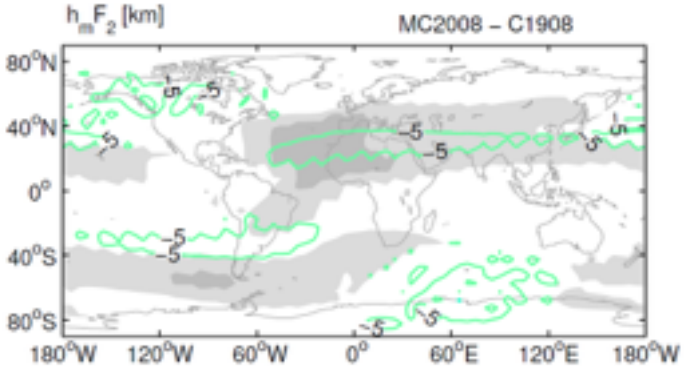


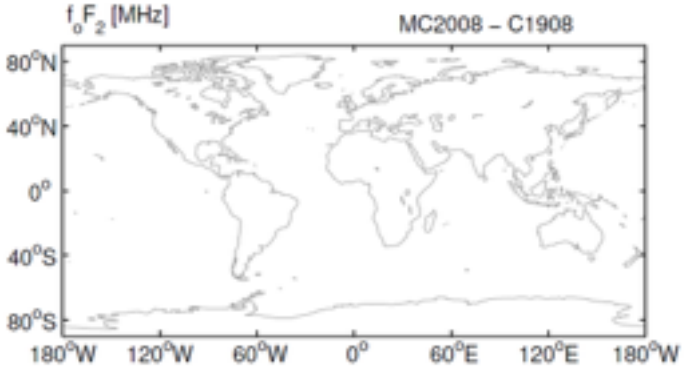
Magnetic field vs. CO_2 effects: h_mF_2 and f_oF_2 at 12 LT





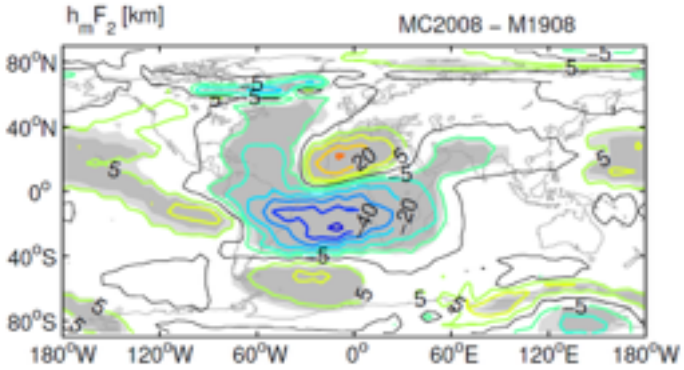
2008
control case

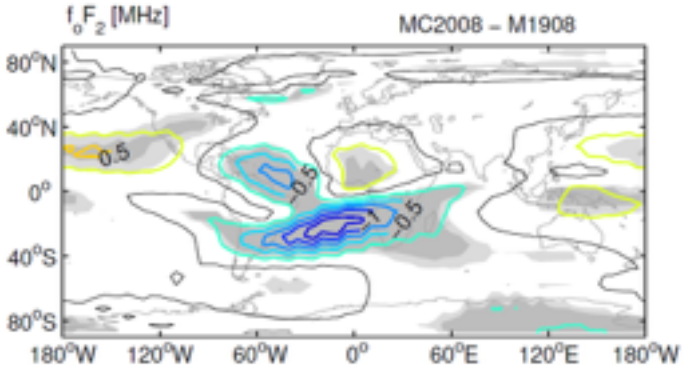




CO_2 effect

(2008-1908)

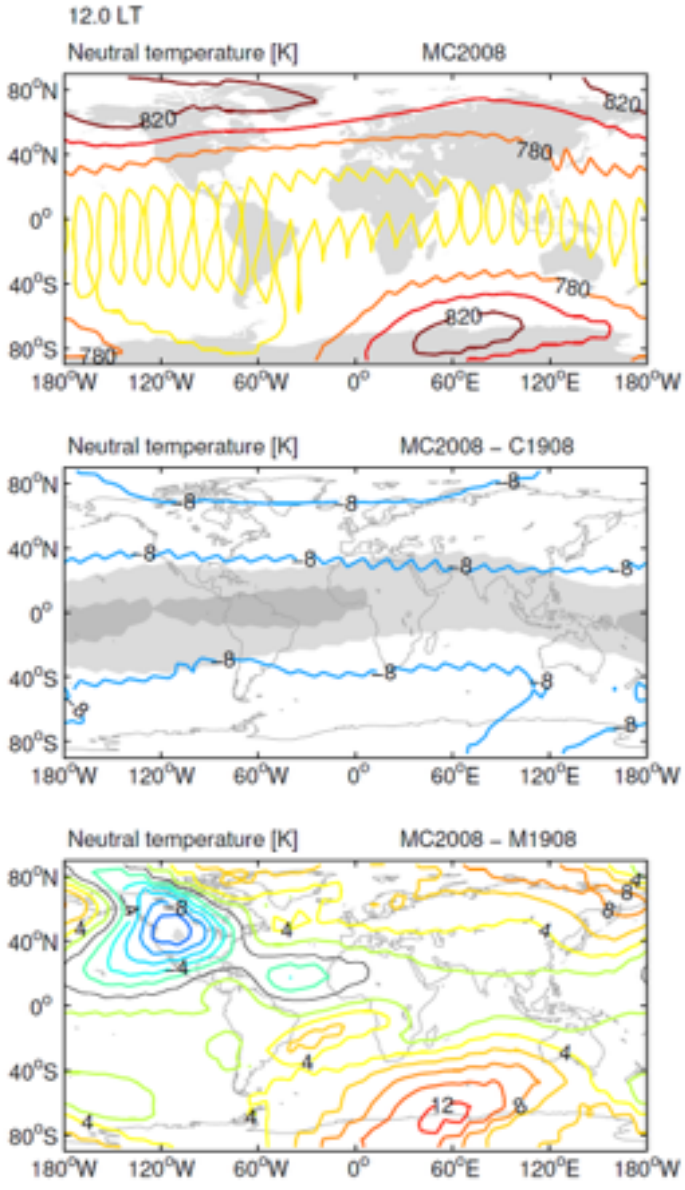




Magnetic field
effect
(2008-1908)

Cnossen (J. Space Weather Space Climate, 2014)

Magnetic field vs. CO_2 effects: neutral temperature @ 300 km, 12 LT

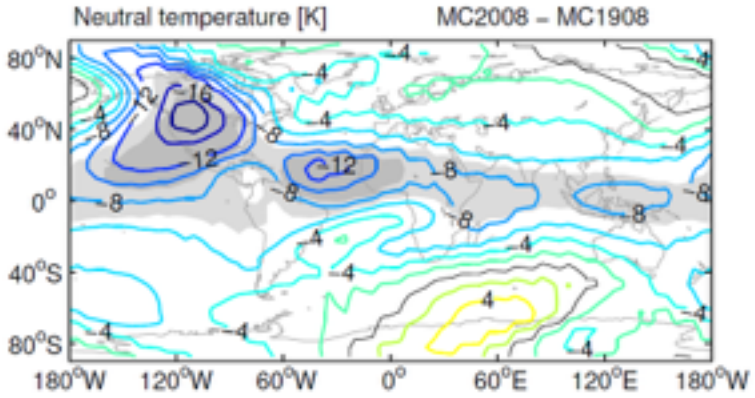


- The increase in CO_2 concentration is more important for long-term changes in neutral temperature in the thermosphere than magnetic field changes
- But changes in the magnetic field do influence the total effect of the two processes combined

CO_2 effect

Magnetic field effect

Combined CO_2 and magnetic field effect



Cnossen (J. Space Weather Space Climate, 2014)

Conclusions and final remarks

- Both enhanced CO_2 levels and changes in the Earth's magnetic field contribute to long-term change in the upper atmosphere
- Geomagnetic field changes are more important for hmF2 and foF2
- CO_2 and magnetic field effects combined still do not fully explain observed long-term trends of T
- Other factors may also be important, e.g., long-term changes in tides from the lower/middle atmosphere

Question: By what mechanisms do geomagnetic-field changes affect the thermospheric temperature, and how do these mechanisms modulate CO_2 effects?

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