

# Continuous Changes in the Thermosphere and Ionosphere over the 20<sup>th</sup> and 21<sup>st</sup> Centuries as Simulated by the Whole Atmosphere Community Climate Model - eXtended (WACCM-X)



Contact email: joemci@ucar.edu

Joe McInerney and Liying Qian

National Center for Atmospheric Research High Altitude Observatory

## Summary

- First continuous 20<sup>th</sup> century model simulations and 21<sup>st</sup> century projection simulation of the upper atmosphere
- Simulations show very close correspondence of greenhouse gas changes and upper atmosphere changes throughout the 20<sup>th</sup> and 21<sup>st</sup> centuries
- This correspondence is more convincing and less complex than the correspondence of greenhouse gases and surface temperature

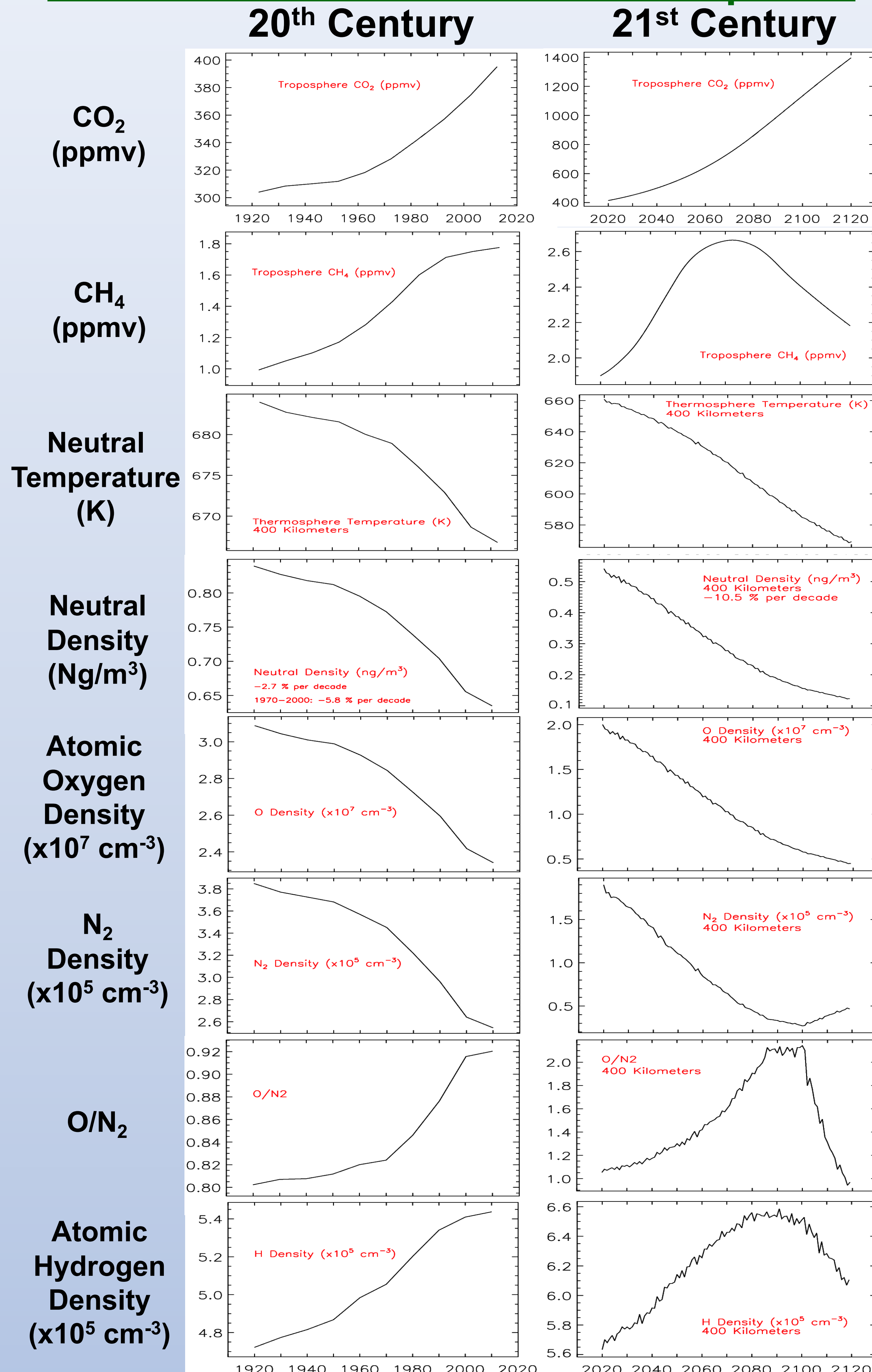
## WACCM-X Model

- Comprehensive self-consistent numerical global climate model of the Earth's atmosphere - vertical range from the surface to the upper thermosphere at 1/4 scale height, part of CESM
- Full thermosphere and ionosphere with electrodynamics
- See Liu et al., 2018 for more details

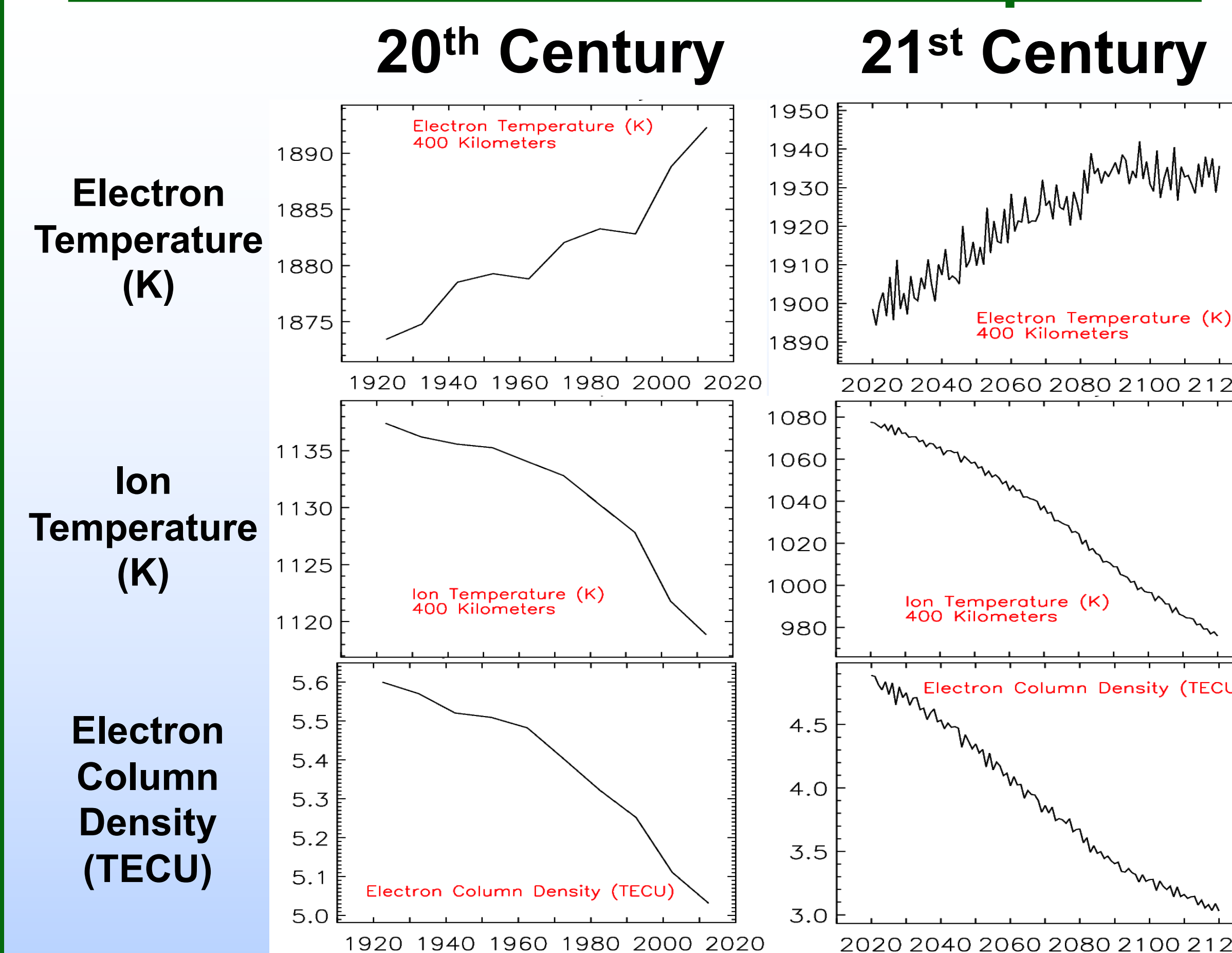
## WACCM-X Simulations

- Nine sets of five year free running time slice simulations each decade from the 1920s and 2010s
- Single SSP 5-8.5 "business as usual" projection simulation from 2020 to 2120
- All simulations impose fixed solar minimum and geomagnetically quiet conditions, fixed year 2000 geomagnetic field for 2020-2120 projection
- Monthly mean output averaged annually and globally

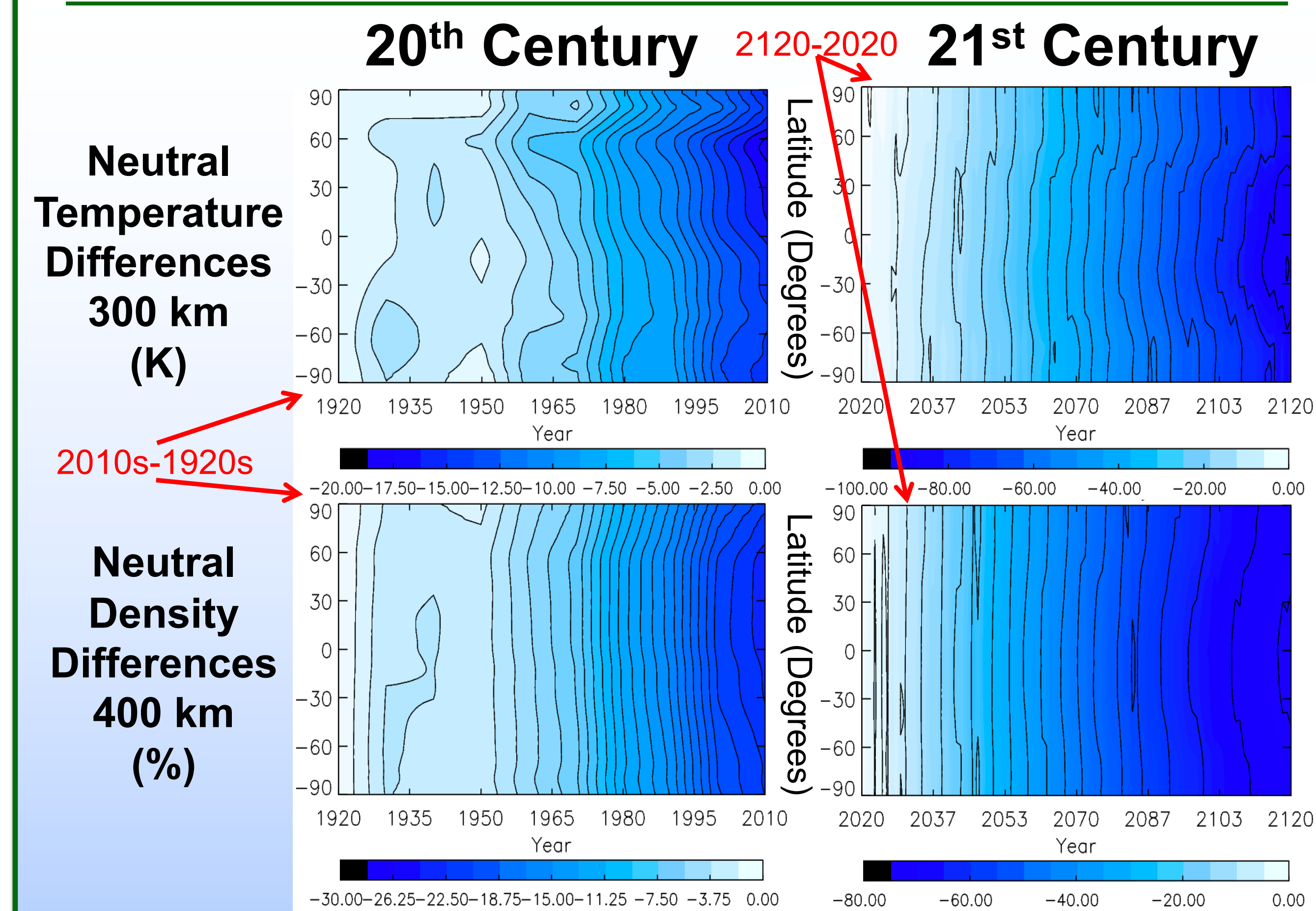
## 400 km Time Series - Thermosphere



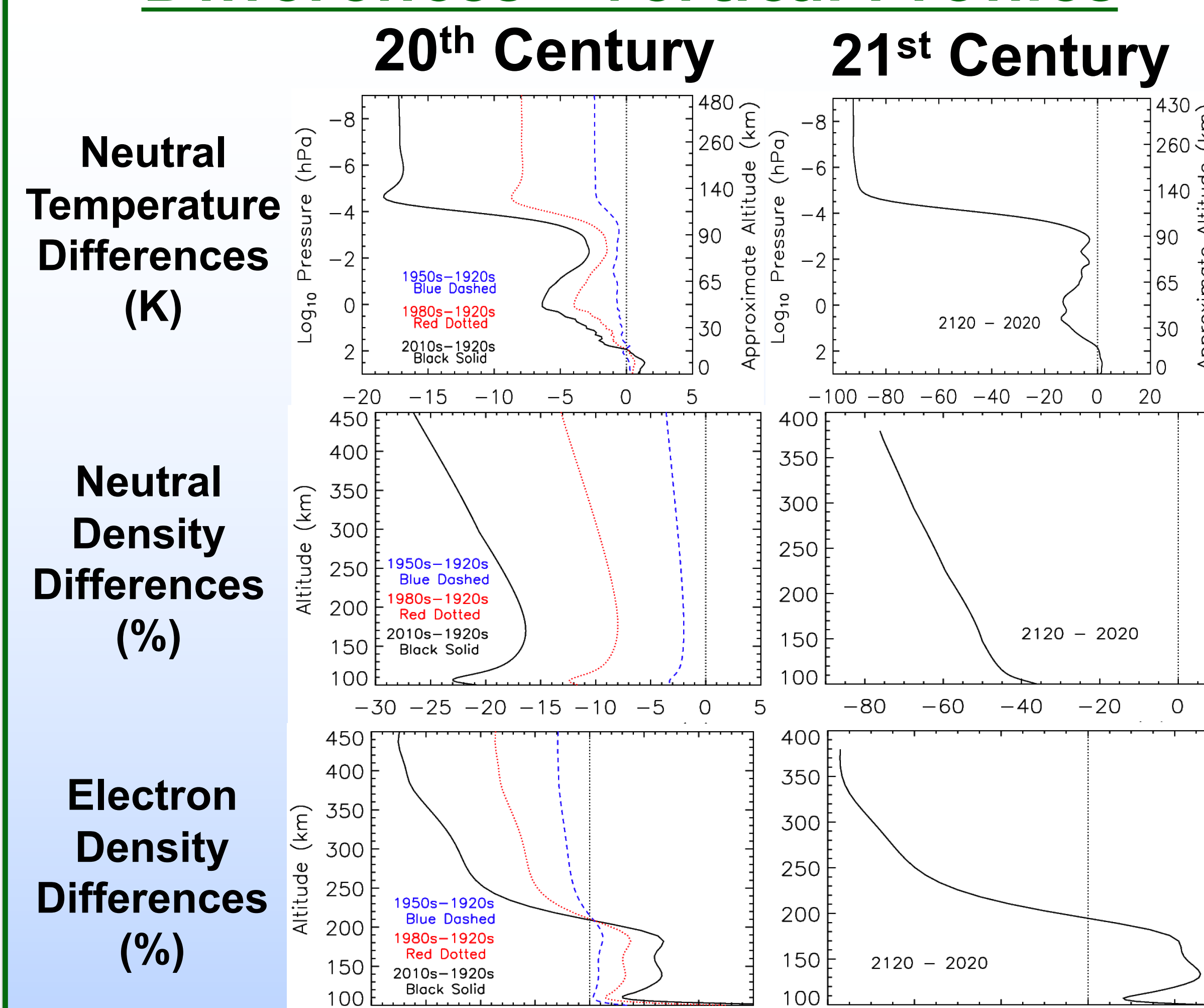
## 400 km Time Series - Ionosphere



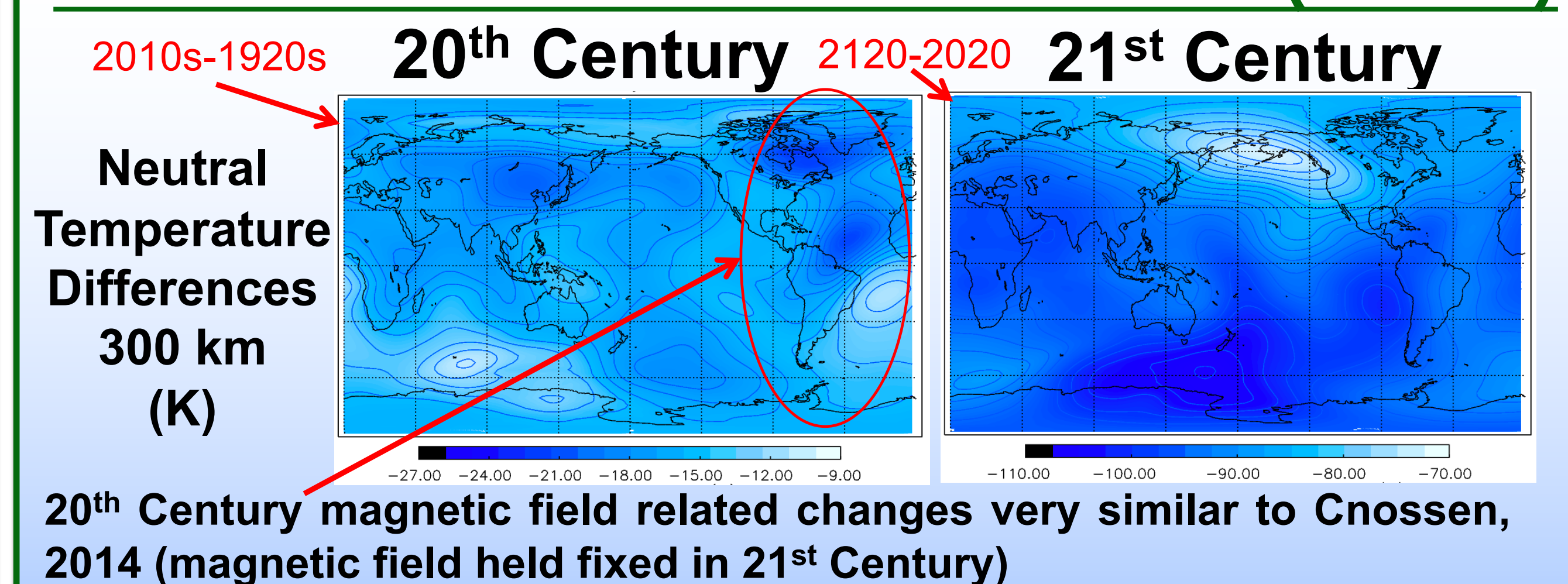
## March Differences - Latitude vs Time



## Differences - Vertical Profiles



## March Differences - Lat vs Lon (0-360)



## References

McInerney, J. M., Qian, L., Liu, H.-L., and Solomon, S. C. (in prep). Changes in the Thermosphere and Ionosphere from the Early Twentieth Century to the Early Twenty-First Century Simulated by the Whole Atmosphere Community Climate Model - eXtended

Liu, H.-L., Bardeen, C. G., Foster, B. T., Lauritzen, P., Liu, J., Lu, G., ... Wang, W. (2018). Development and validation of the whole atmosphere community climate model with thermosphere and ionosphere extension (WACCM-X v. 2.0). *Journal of Advances in Modeling Earth Systems*, 10. <https://doi.org/10.1002/2017MS001232>.

Cnossen, Ingrid (2014), The importance of geomagnetic field changes versus rising CO<sub>2</sub> levels for long-term change in the upper atmosphere. *J. Space Weather Space Clim.*, 4(2014)A18. <https://doi.org/10.1051/swsc/2014016>.