The impact of increasing numbers of radio occultation observations on specification and forecasting of the ionosphere and thermosphere

Nick Pedatella[1,2]

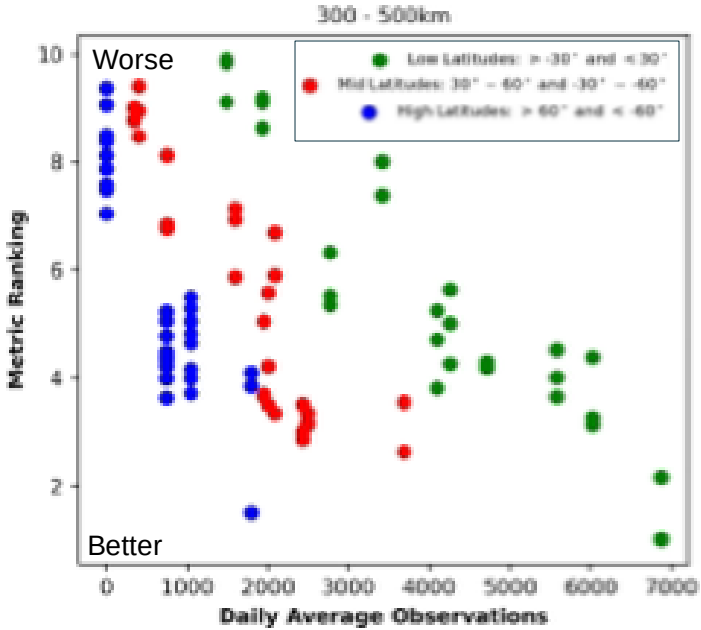
[1]High Altitude Observatory, NSF National Center for Atmospheric Research
[2]COSMIC Program, University Corporation for Atmospheric Research

IROWG-10
17 September 2024

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Objective: Investigate the impact of increasing the number of RO observations on the specification and forecasting of the ionosphere and thermosphere

- Few studies have investigated the potential impact of assimilating large numbers of RO observations in the upper atmosphere.
- Prior studies have looked at assimilating a relatively moderate number (< 10,000) of RO observations.
- In the present study we make use of the ROMEX observation locations to investigate the impact of assimilating large numbers (~30,000) of RO electron density profiles in a whole atmosphere model (WACCMX+DART).

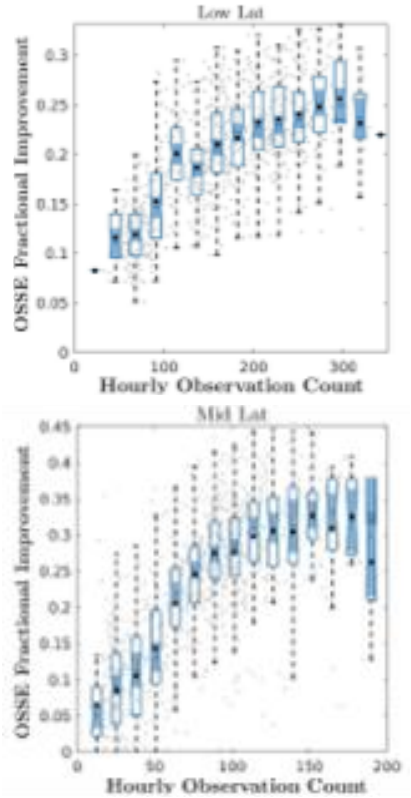


WACCMX: Whole Atmosphere Community Climate Model with thermosphere-ionosphere eXtension
DART: Data Assimilation Research Testbed

(Dietrich et al., 2024)

Objective: Investigate the impact of increasing the number of RO observations on the specification and forecasting of the ionosphere and thermosphere

- Few studies have investigated the potential impact of assimilating large numbers of RO observations in the upper atmosphere.
- Prior studies have looked at assimilating a relatively moderate number (< 10,000) of RO observations.
- In the present study we make use of the ROMEX observation locations to investigate the impact of assimilating large numbers (~30,000) of RO electron density profiles in a whole atmosphere model (WACCMX+DART).

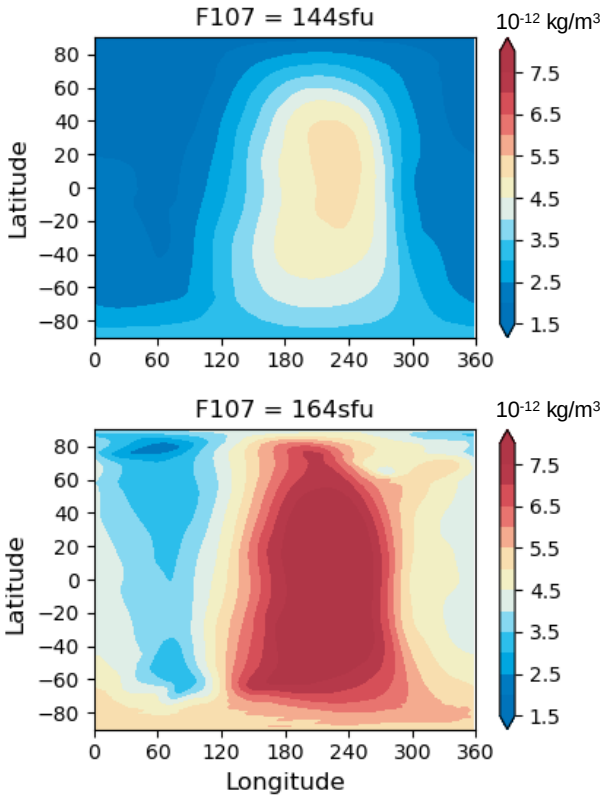


WACCMX: Whole Atmosphere Community Climate Model with thermosphere-ionosphere eXtension
DART: Data Assimilation Research Testbed

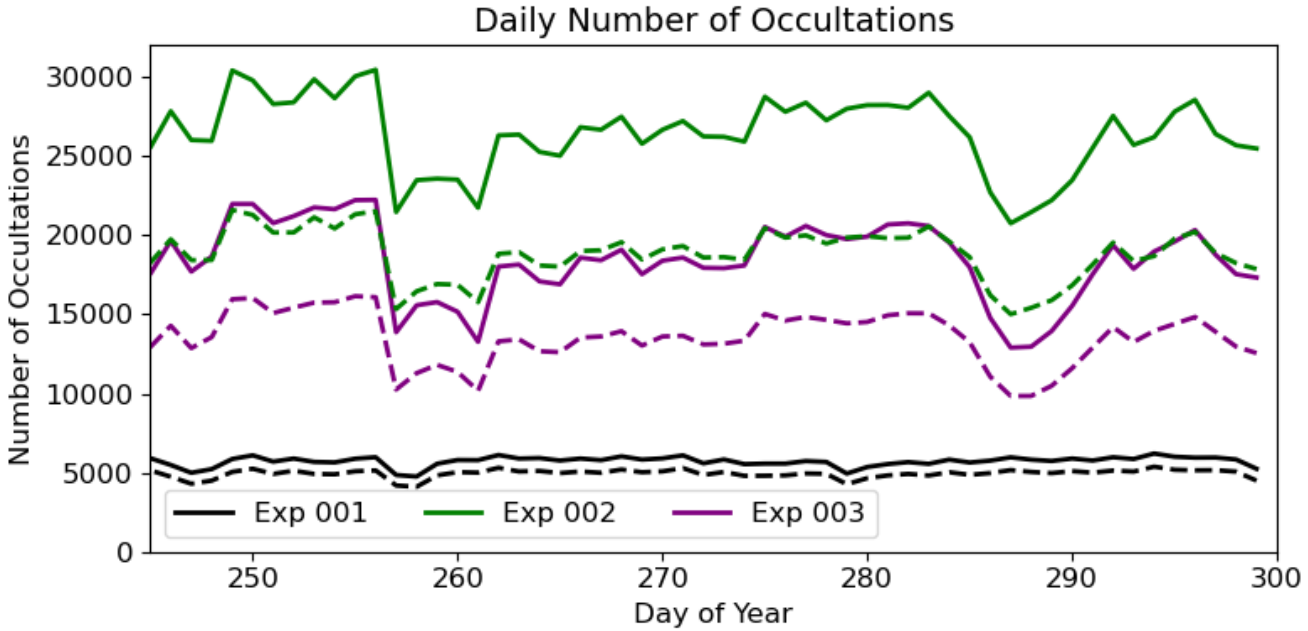
(Dietrich et al., 2024)

WACCMX+DART Observing System Simulation Experiments (OSSEs)

- Nature run uses a F10.7 solar flux value of 164 sfu and Kp value of 4.
- Data assimilation experiments use a mean F10.7 of 144 sfu and Kp of 0.33. This results in a **biased ionosphere-thermosphere relative to the nature run**.
- Perform four data assimilation experiments based on assimilating RO observations from different constellations
  - Assume ionosphere profiles occur at the same location and time as neutral atmosphere profiles from ROMEX observations.
  - Add observation error from Abel retrieval errors
- OSSEs provide insight into **the impact of increasing numbers of ionospheric RO observations impact the specification and forecasting of the ionosphere-thermosphere.**



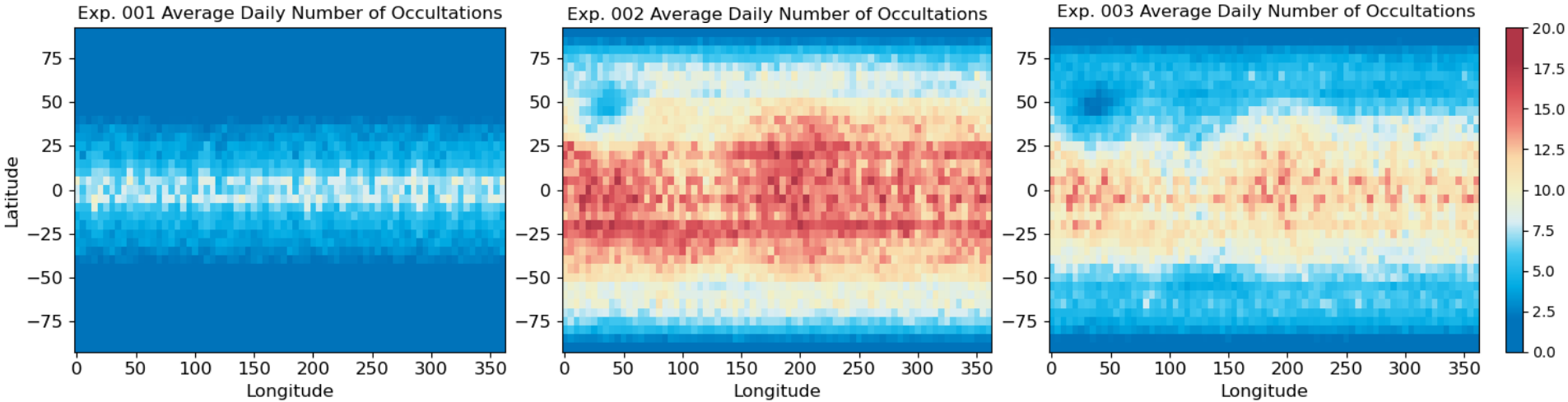
Daily number of RO observations varies from ~6,000 occultations per day to nearly 30,000 occultations per day



Exp 001: COSMIC-2
Exp 002: All ROMEX
Exp 003: COSMIC-2, Spire, Yunyao
Control: No RO observations

Solid: global
Dashed: low latitudes (< 20°)

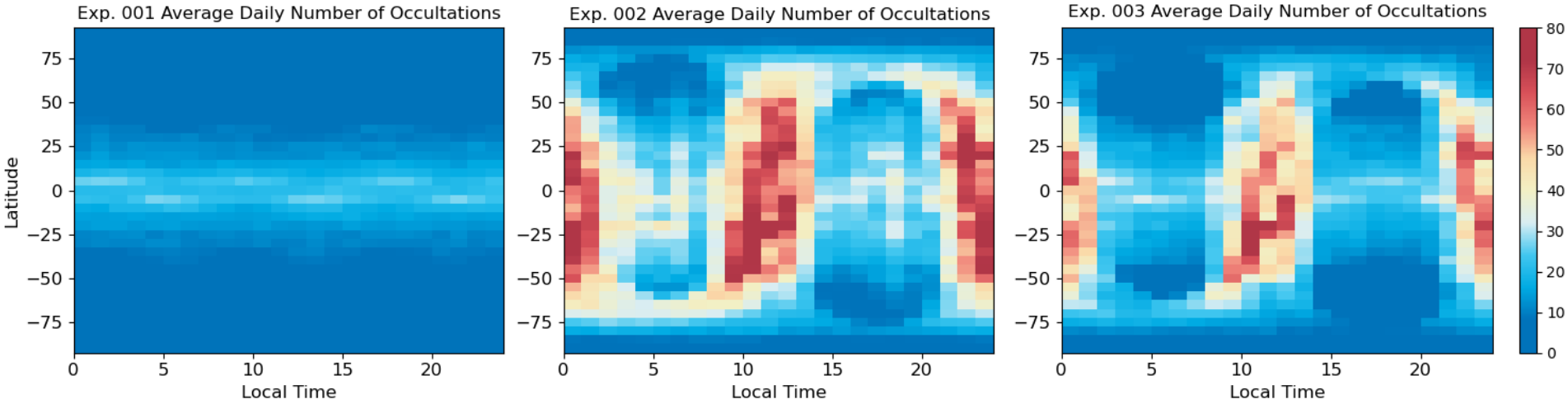
Geographic distribution of RO observations



Exp 001: All observations concentrated at low latitudes
Exp 002 & 003: Global coverage with greater number of observations at low-latitudes

Number of obs. per 5° x 5° bin

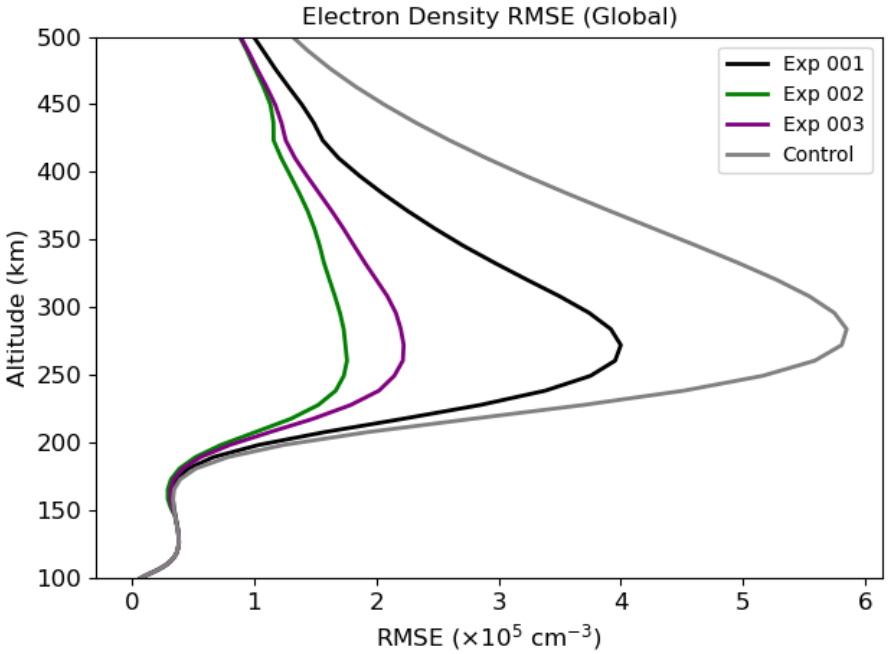
Local time distribution of RO observations

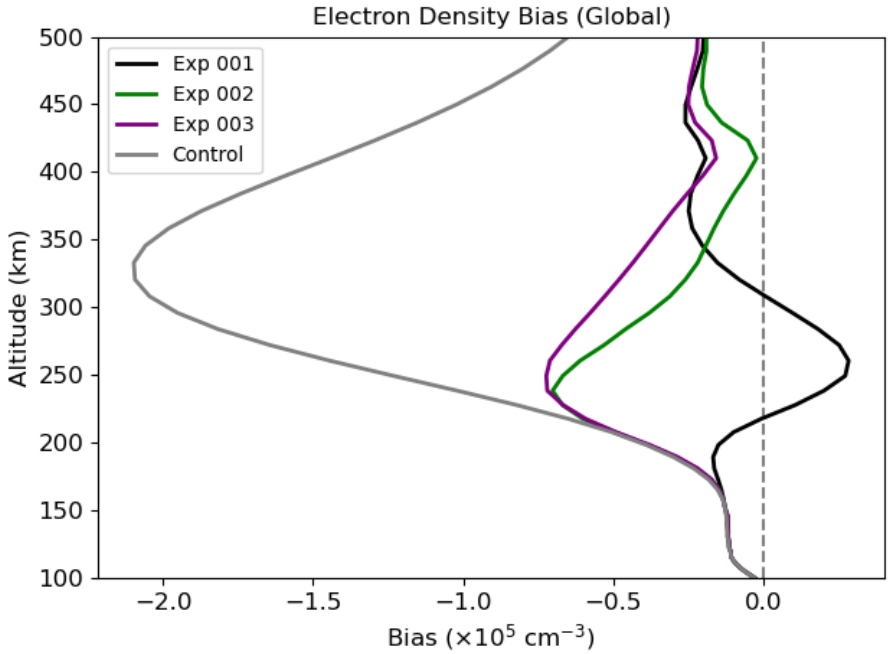


Exp 001: Coverage across all local times
Exp 002 & 003: Local time of observations concentrated around noon and midnight.

Number of obs. per 5° x 1hr bin

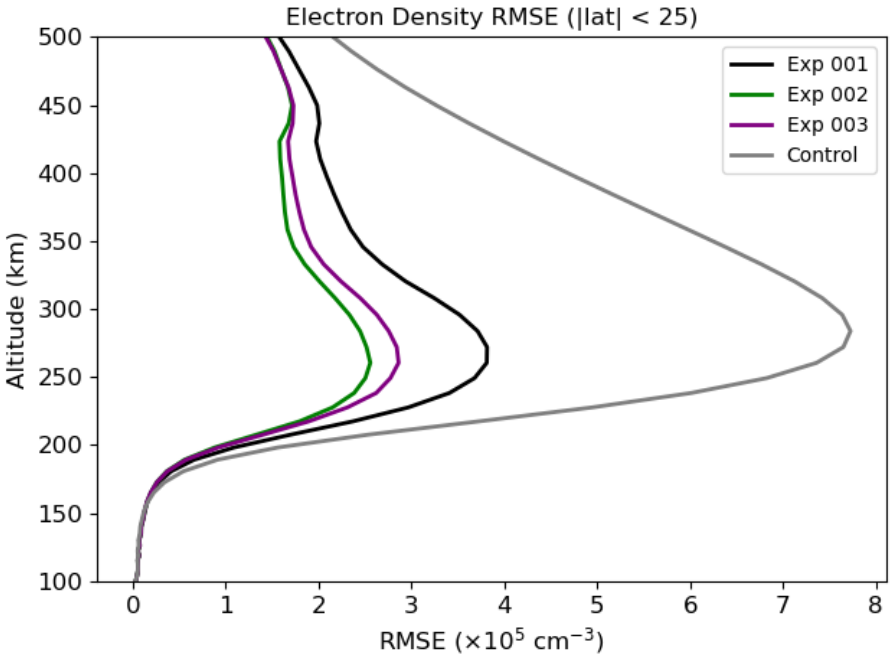
Global RMSE and bias of electron density are reduced with the increasing number of RO observations

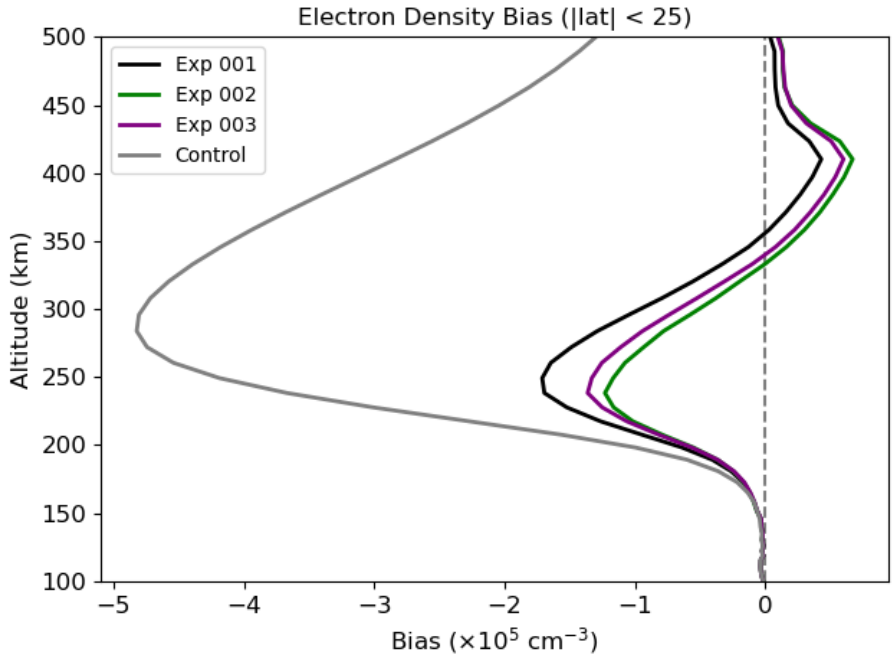




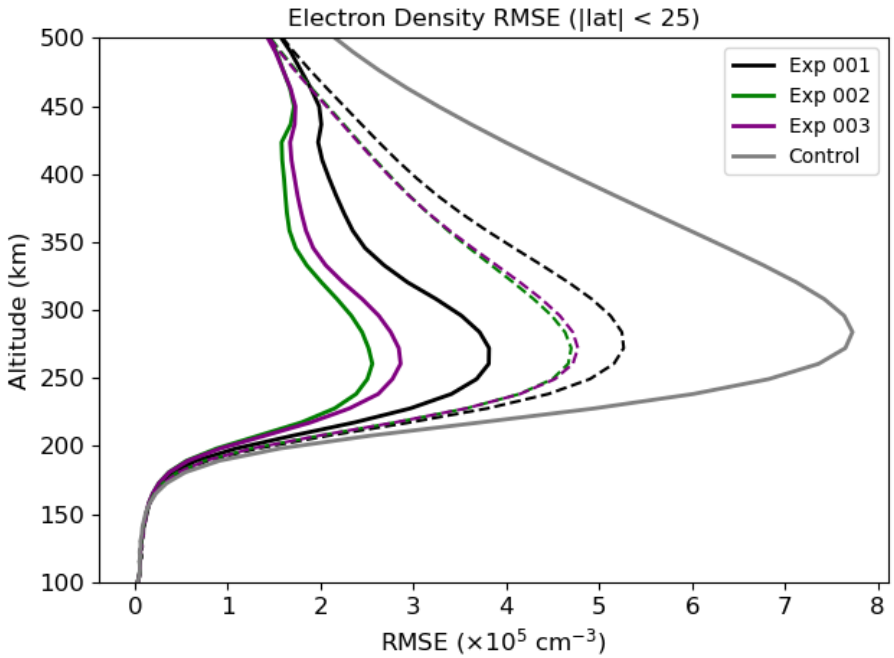
Going from ~20,000 occultations/day (Exp 003) to almost 30,000 occultations/day (Exp 002) leads to an additional ~8% reduction in global electron density errors at ~300 km.

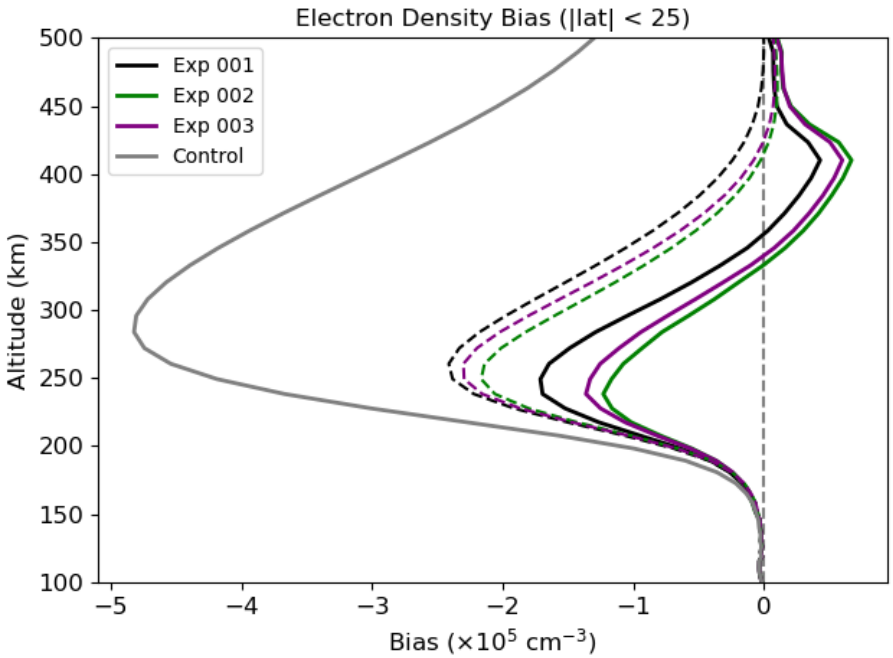
The reduction in errors at low latitudes (< 25°) are smaller, but increasing the number of observations does lead to an error reduction





Impact of increasing number of RO observations is also evident in the short term (1h) forecast errors





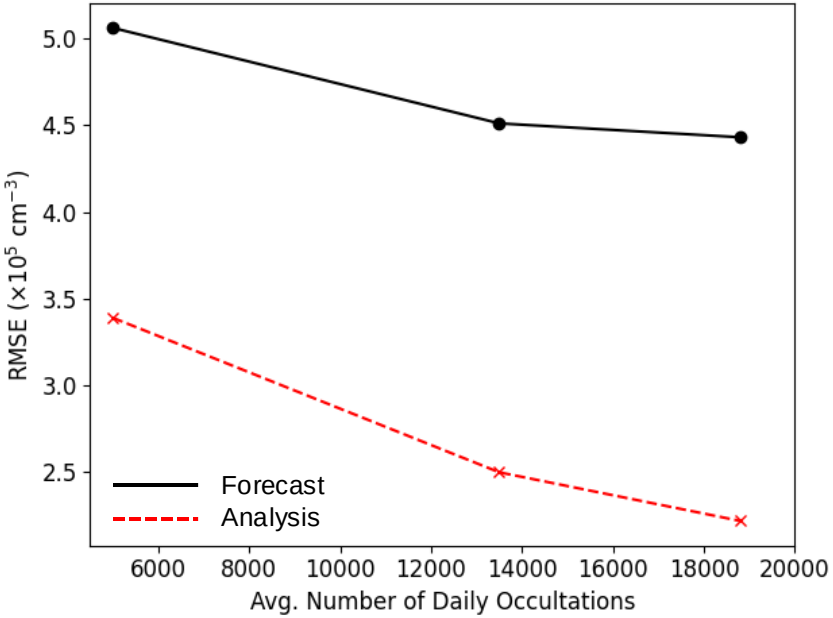
Solid: analysis
Dashed: 1h forecast

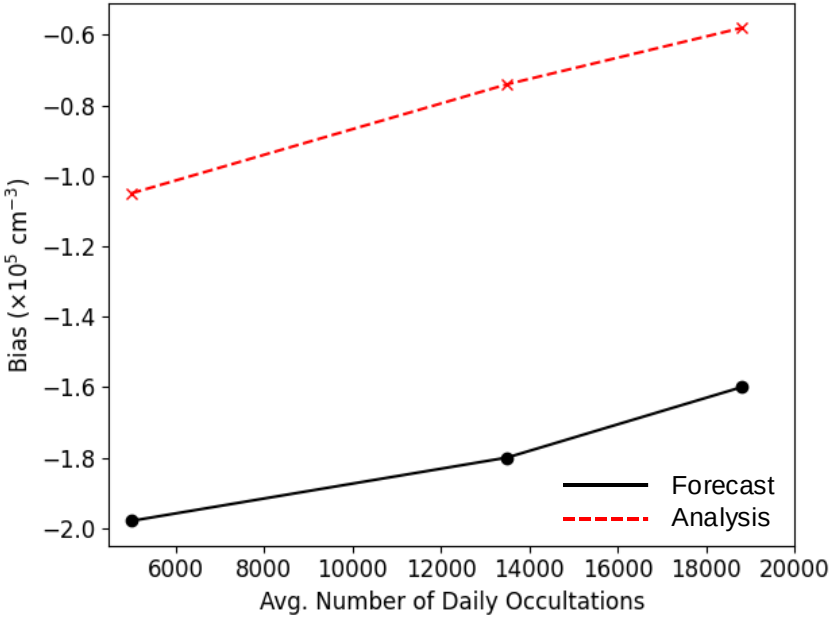
Electron density RMSE and bias at low-latitudes are significantly reduced, with impact extending up to at least ~20,000 occultations/day

Experiment	RMSE (forecast)	RMSE (analysis)	Bias (forecast)	Bias (analysis)
Control	7.60	7.60	-4.80	-4.80
Exp 001	5.06 (-33%)	3.39 (-55%)	-1.98 (-58%)	-1.05 (-78%)
Exp 002	4.43 (-42%)	2.22 (-70%)	-1.60 (-67%)	-0.58 (-88%)
Exp 003	4.51 (-40%)	2.50 (-67%)	-1.80 (-63%)	-0.74 (85%)

Results for 300 km
Units: $x10^5$ cm^{-3}
%: (Exp – Control) / Control

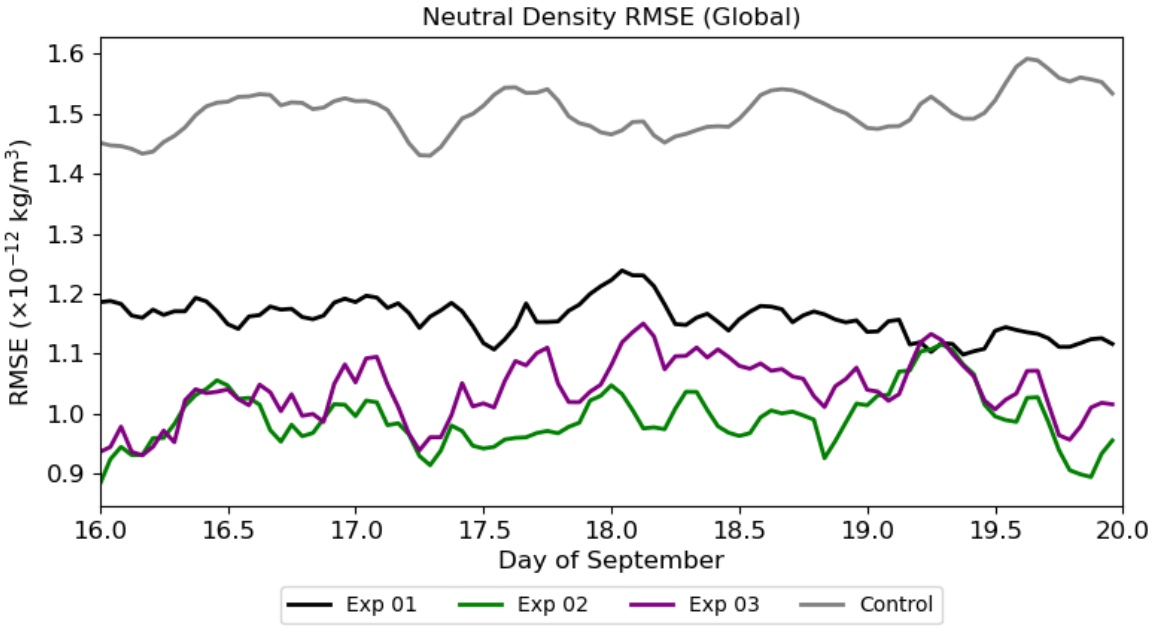
Electron density RMSE and bias at low-latitudes are significantly reduced, with impact extending up to at least ~20,000 occultations/day





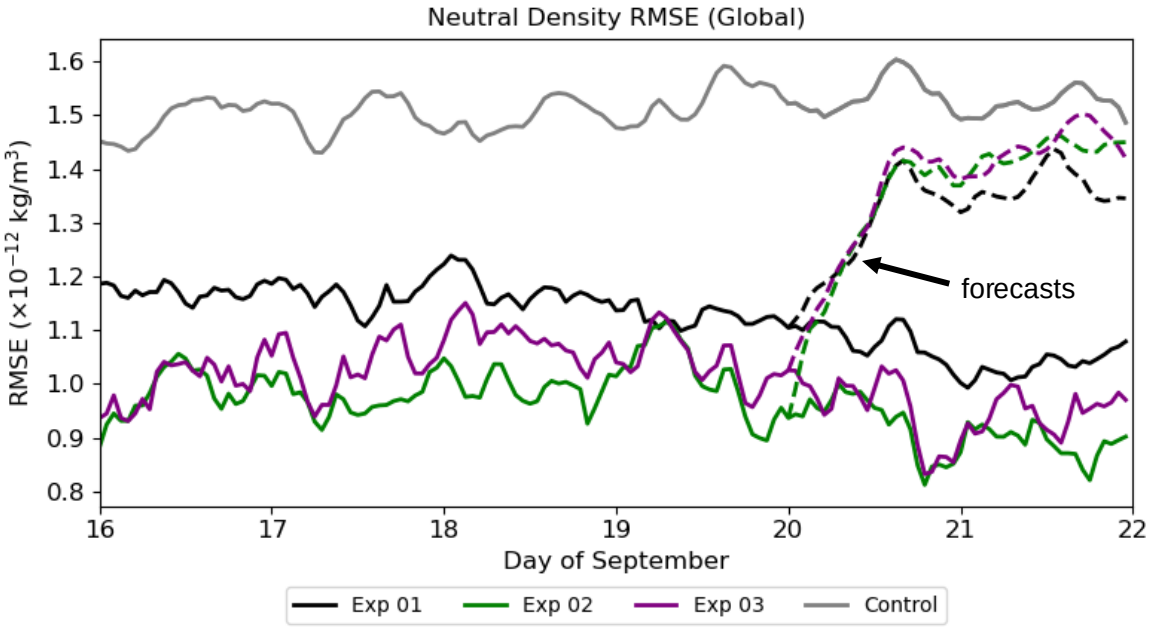
Results for 300 km

Increasing the number of RO observations also has a positive impact on the global mean thermosphere neutral density when assimilated in a coupled ionosphere-thermosphere model



Reduction in global thermosphere neutral density RMSE: 22%, 34%, 31%

Increasing the number of RO observations also has a positive impact on the global mean thermosphere neutral density when assimilated in a coupled ionosphere-thermosphere model



No noticeable impact on global thermosphere density forecasts

Summary and Conclusions

- OSSE results demonstrate that there is an improvement in the specification and short-term forecasting of the ionosphere and thermosphere up to at least ~30,000 occultations per day.

- Current study is partly limited by the OSSE setup and did not consider potential impacts of the observation local time distribution or the impact of the number of ionospheric RO observations on specification and forecasting scintillation.

- A future ROMEX-like campaign with a large number of ionosphere observations would be highly valuable for assessing the impact of real observations on the ionosphere and thermosphere.

Acknowledgements: Funding support from NSF AGS-2054356 and NASA C22K0658. Thanks to ROMEX organizers and data providers.