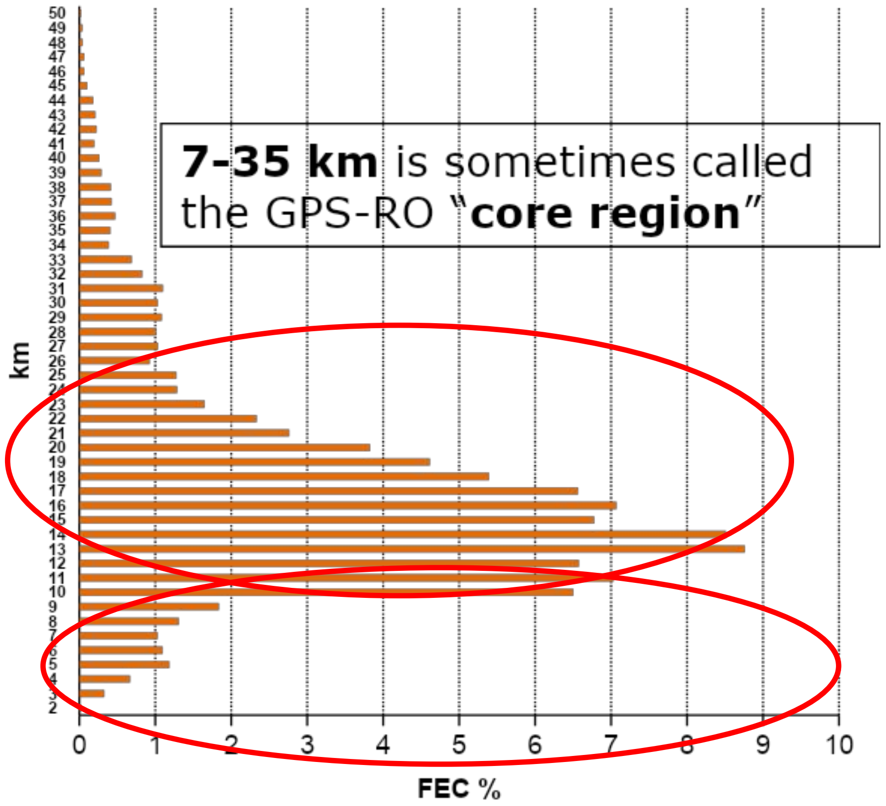
National Environmental Satellite,
Data, and Information Service

Lessons Learned from the Preparation and Evaluation of Multiple GNSS RO Data for the ROMEX from NOAA/STAR

1. NOAA/NESDIS/STAR, 2. Cooperative Institute for Satellite Earth System Studies (CISESS), ESSIC, University of Maryland

Shu-peng.ho@noaa.gov

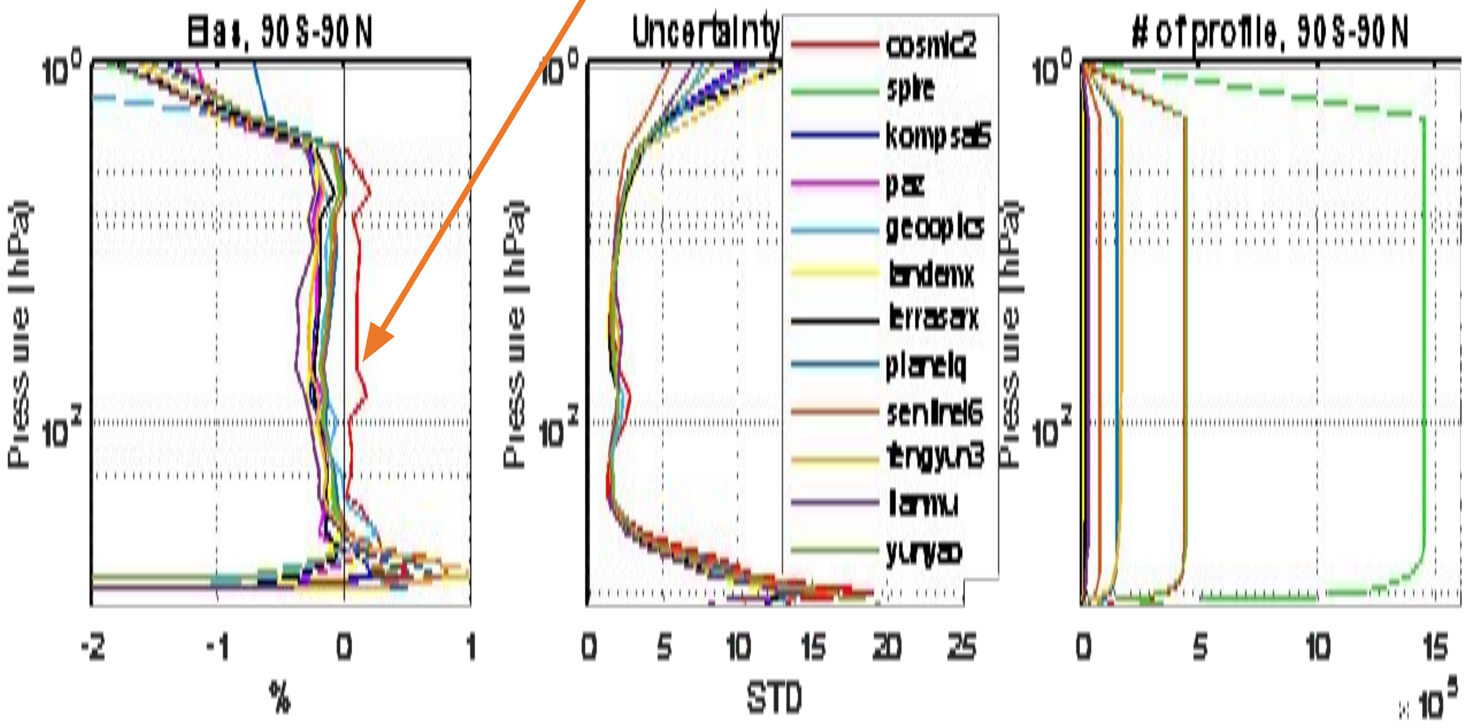
Heights where GNSS-RO is reducing the 24hr forecast errors



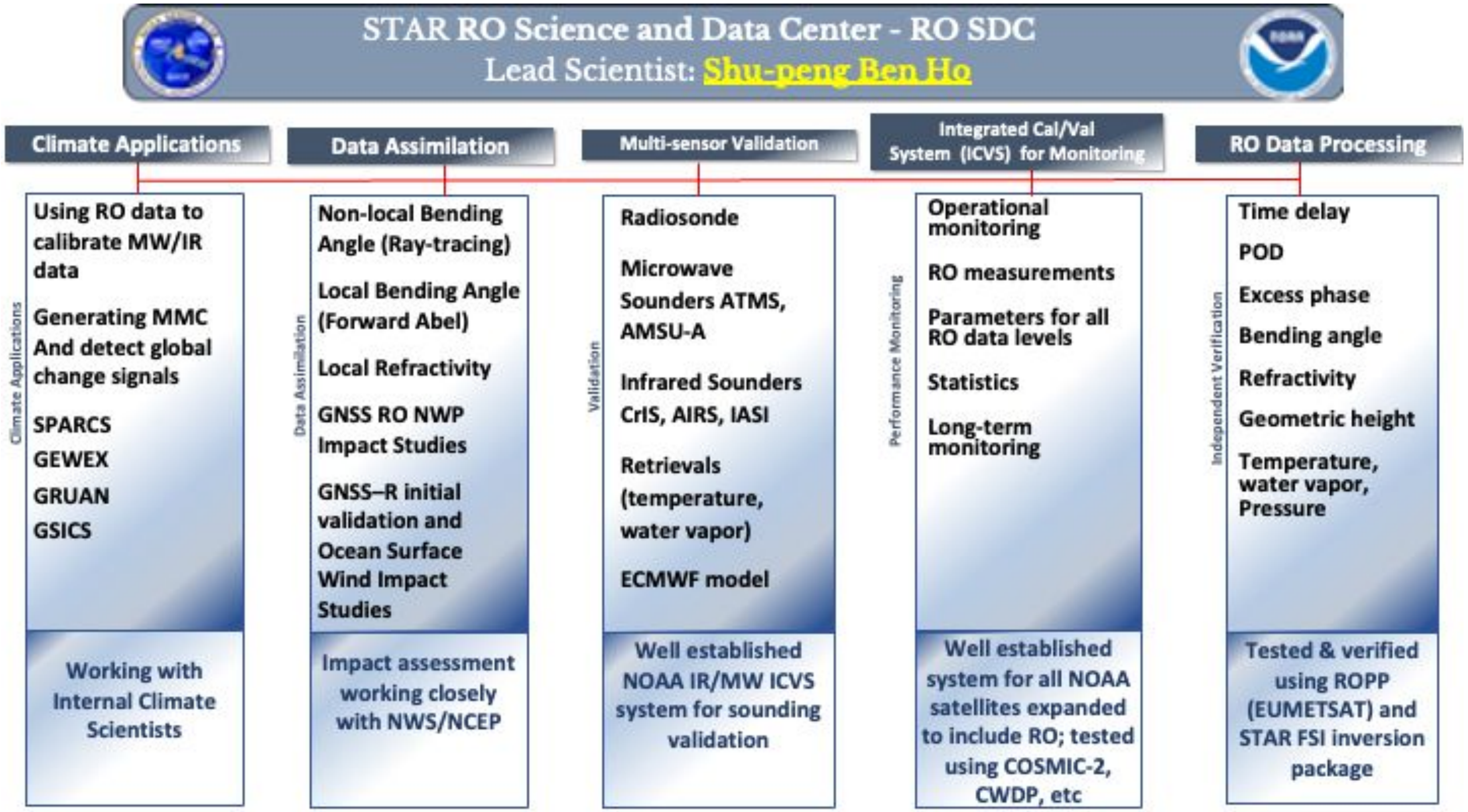
Florian Harnisch, Sean Healy, Peter Bauer, Steve English, Nick Yen, 2013

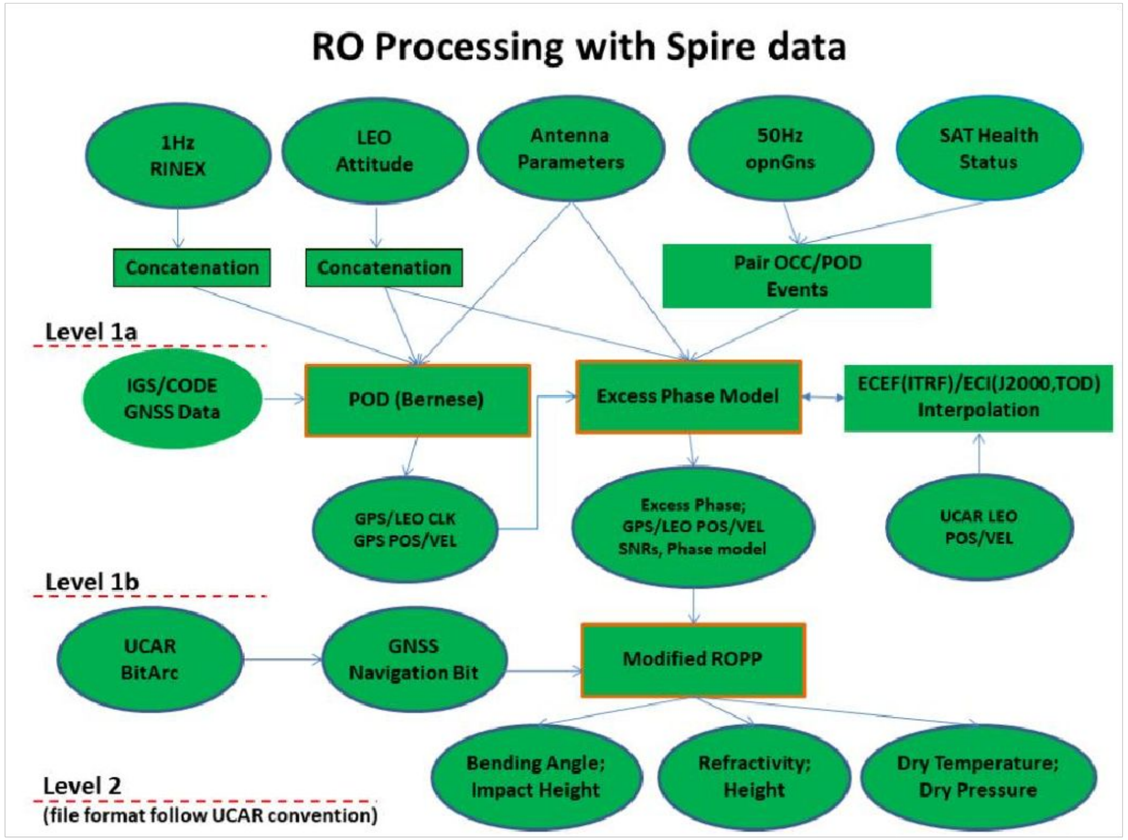
ROMEX biases vs ERA5

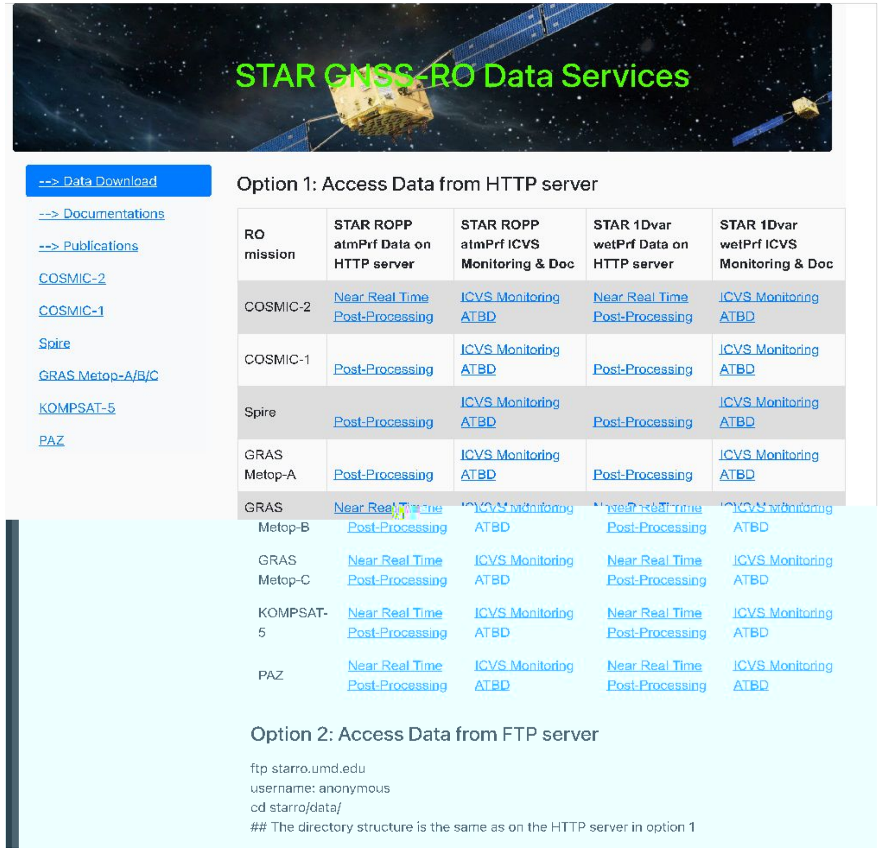
UCAR COSMIC-2 (45N-45S)



My results shows negative biases of ~-0.1 to -0.4 from about 4 km up to 35 km for all ROMEX missions except C2, which shows a positive bias of about 0.05 to 0.10 %. So C2 appears to have a positive bias compared
to the other missions by about 0.3%
(Heights are approximate)


STAR RO Science and Data Center - RO SDC
Lead Scientist: Shu-peng Ben Ho
Climate Applications
Data Assimilation
Multi-sensor Validation
Integrated Cal/Val System (ICVS) for Monitoring
RO Data Processing
Climate Applications
Using RO data to calibrate MW/IR data
Generating MMC And detect global change signals
SPARCS
GEWEX
GRUAN
GSICS
Working with Internal Climate Scientists
Data Assimilation
Non-local Bending Angle (Ray-tracing)
Local Bending Angle (Forward Abel)
Local Refractivity
GNSS RO NWP Impact Studies
GNSS–R initial validation and Ocean Surface Wind Impact Studies
Impact assessment working closely with NWS/NCEP
Validation
Radiosonde
Microwave Sounders ATMS, AMSU-A
Infrared Sounders CrIS, AIRS, IASI
Retrievals (temperature, water vapor)
ECMWF model
Well established NOAA IR/MW ICVS system for sounding validation
Performance Monitoring
Operational monitoring
RO measurements
Parameters for all RO data levels
Statistics
Long-term monitoring
Well established system for all NOAA satellites expanded to include RO; tested using COSMIC-2, CWDP, etc
Independent Verification
Time delay
POD
Excess phase
Bending angle
Refractivity
Geometric height
Temperature, water vapor, Pressure
Tested & verified using ROPP (EUMETSAT) and STAR FSI inversion package





STAR GNSS-RO Data Services

--> Data Download
--> Documentations
--> Publications
COSMIC-2
COSMIC-1
Spire
GRAS Metop-A/B/C
KOMPSAT-5
PAZ

Option 1: Access Data from HTTP server

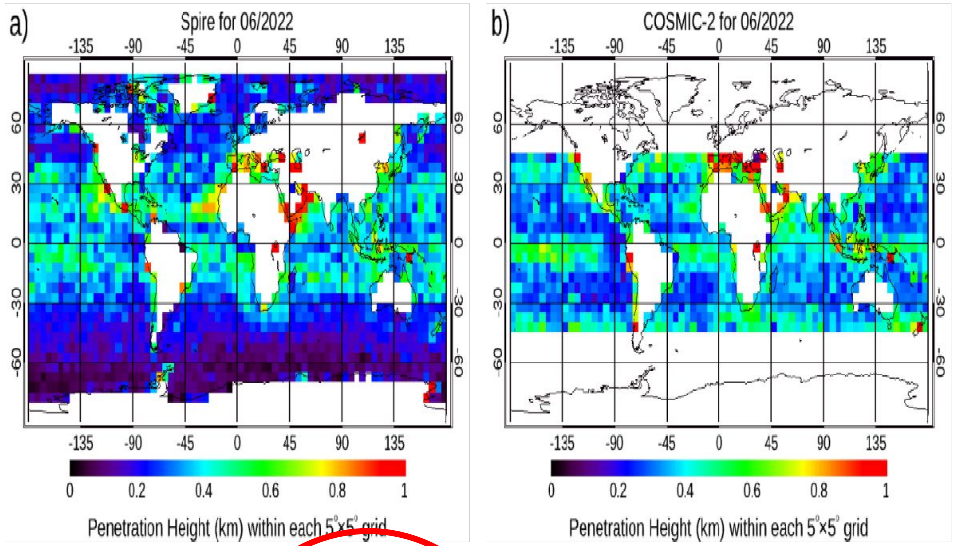
RO mission	STAR ROPP atmPrf Data on HTTP server	STAR ROPP atmPrf ICVS Monitoring & Doc	STAR 1Dvar wetPrf Data on HTTP server	STAR 1Dvar wetPrf ICVS Monitoring & Doc
COSMIC-2	Near Real Time Post-Processing	ICVS Monitoring ATBD	Near Real Time Post-Processing	ICVS Monitoring ATBD
COSMIC-1	Post-Processing	ICVS Monitoring ATBD	Post-Processing	ICVS Monitoring ATBD
Spire	Post-Processing	ICVS Monitoring ATBD	Post-Processing	ICVS Monitoring ATBD
GRAS Metop-A	Post-Processing	ICVS Monitoring ATBD	Post-Processing	ICVS Monitoring ATBD
GRAS Metop-B	Near Real Time Post-Processing	ICVS Monitoring ATBD	Near Real Time Post-Processing	ICVS Monitoring ATBD
GRAS Metop-C	Near Real Time Post-Processing	ICVS Monitoring ATBD	Near Real Time Post-Processing	ICVS Monitoring ATBD
KOMPSAT-5	Near Real Time Post-Processing	ICVS Monitoring ATBD	Near Real Time Post-Processing	ICVS Monitoring ATBD
PAZ	Near Real Time Post-Processing	ICVS Monitoring ATBD	Near Real Time Post-Processing	ICVS Monitoring ATBD

Option 2: Access Data from FTP server

ftp starro.umd.edu
username: anonymous
cd starro/data/
The directory structure is the same as on the HTTP server in option 1

The global mean of the lowest penetration height in June 2022 binned into 5°× 5° grid

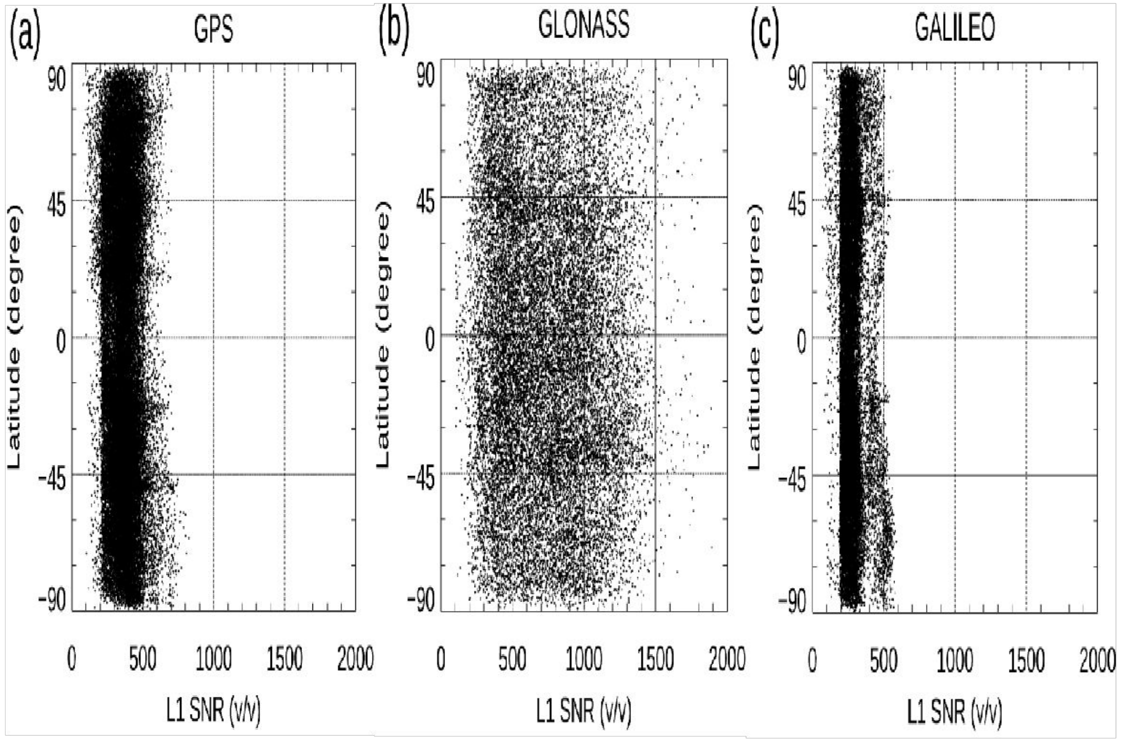
Penetration Height



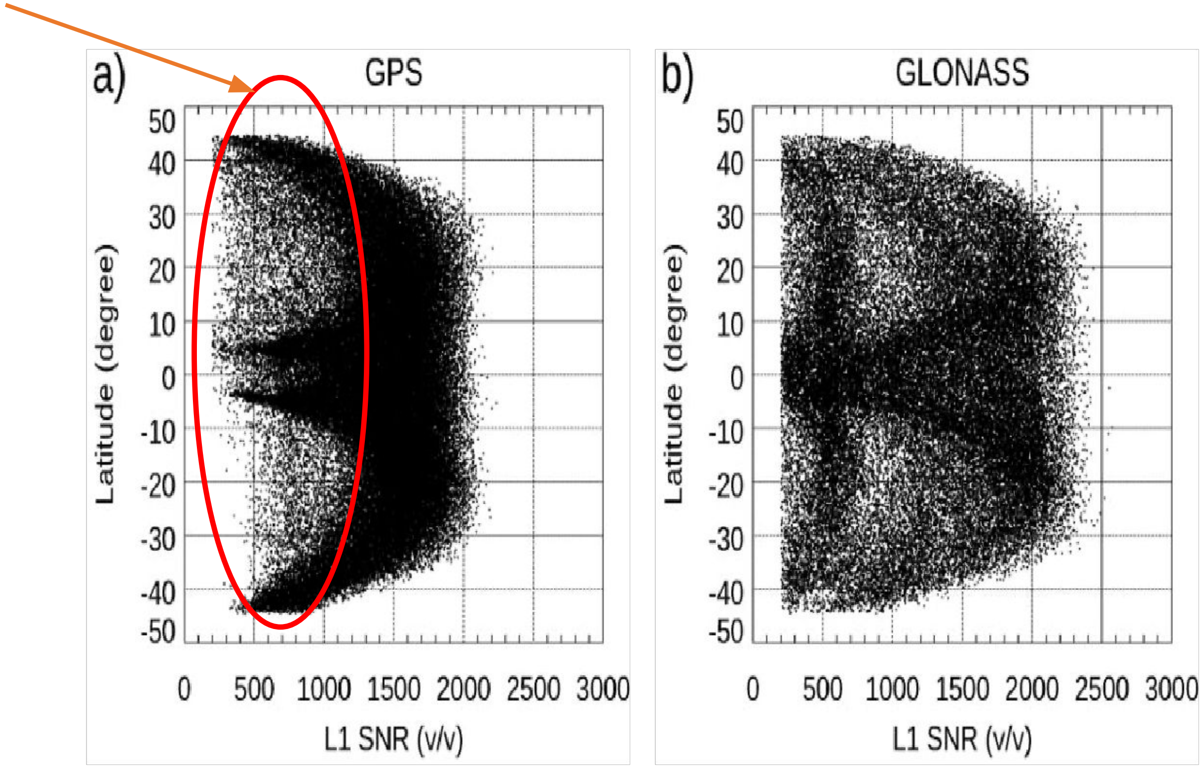
	10°N-10°S	30°N-10°N	10°S-30°S	45°N-30°N	30°S-45°S	60°N-45°N	45°N-60°S	90°N-60°N	60°S-90°S
COSMIC-2	0.85	0.90	0.75	1.35	1.10				
Spire	0.90	0.90	0.75	0.80	0.55	0.45	0.25	0.45	0.20
KOMPSAT-5	1.85	1.50	1.15	0.40	0.95	0.35	0.40	0.25	0.20
PAZ	2.65	1.85	2.05	0.90	1.30	0.45	0.45	0.35	0.35

The lowest penetration height of 80% of the total data for different RO missions at different latitudinal zones.

We usually use the SNR to indicate the strength of RO signals in penetrating the lower troposphere (Ho et al., 2023). The lowest penetration height of RO tracking is usually related to the data's SNR and the atmosphere's dryness. However, because the high SNR signals still cannot resolve the combination of i) complexity of water vapor along the track, ii) the turbulence effects, iii) the instrument effect (see Ao et al., 2022), we did not see high SNR RO data improv i) retrieval accuracy, and ii) retrieval uncertainty in the lower troposphere (Ho et al., 2022, 2023).



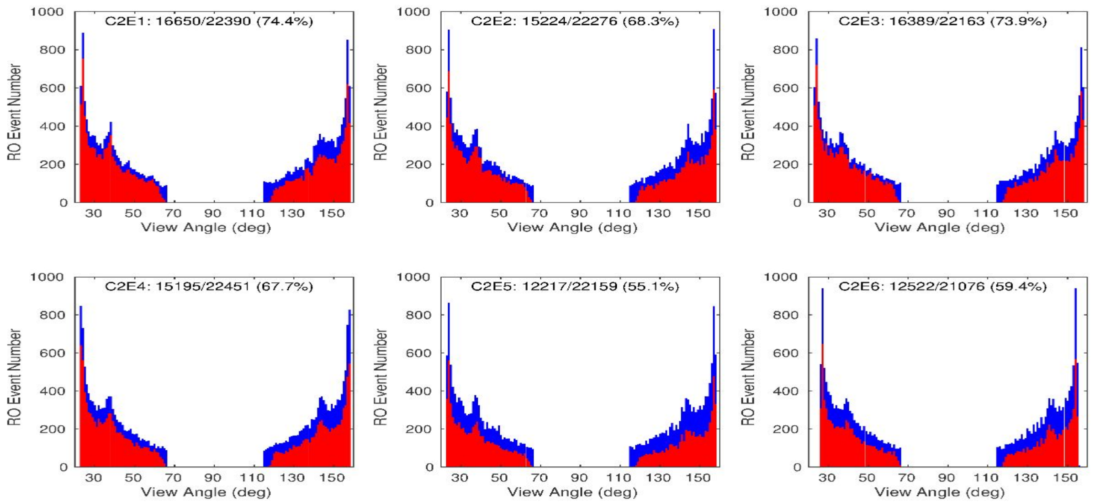
Latitudinal distribution for Spire L1 SNR for a) GPS, b) GLONASS, and c) GALILEO



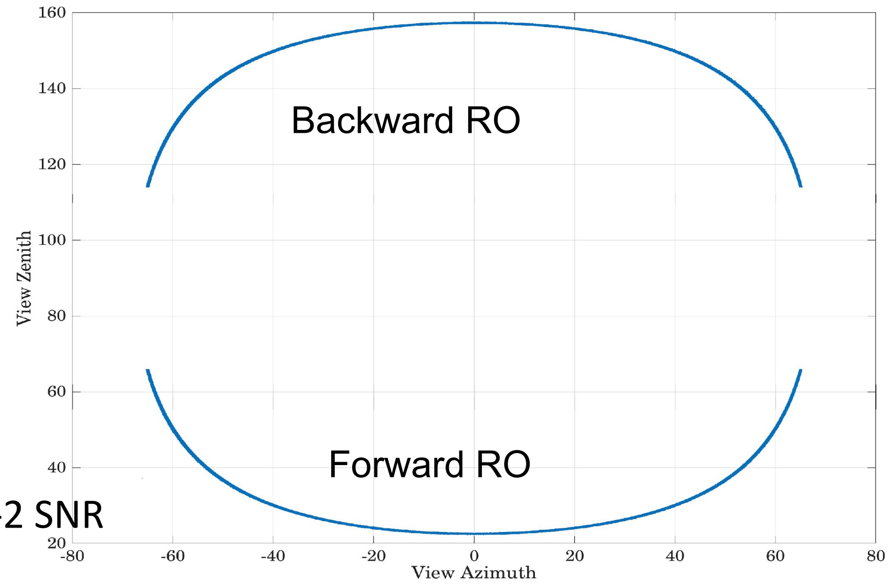
Latitudinal distribution for COSMIC-2 L1 SNR from February 15 to March 15, 2022, for a) GPS and b) GLONASS.

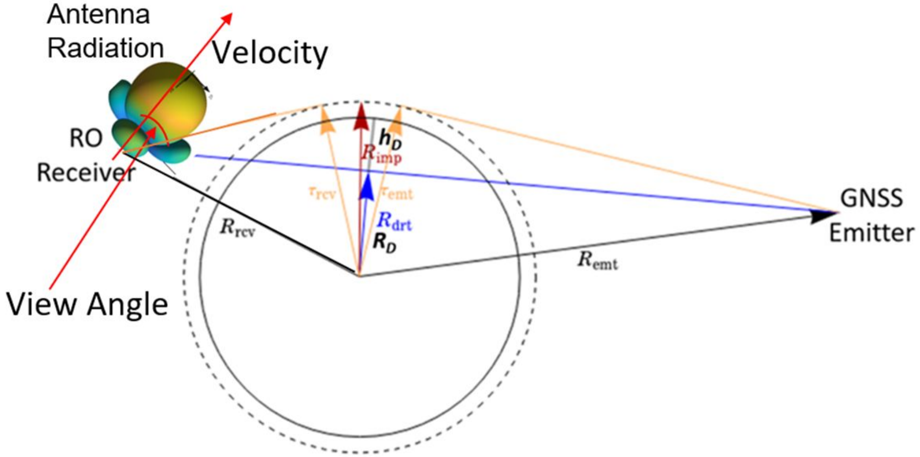
Ho, S.-p.; Zhou, X.; Shao, X.; Chen, Y.; Jing, X.; Miller, W. Using the Commercial GNSS RO Spire Data in the Neutral Atmosphere for Climate and Weather Prediction Studies. *RemoteSens.* ,*15*,4836. https:// doi.org/10.3390/rs15194836

COSMIC-2



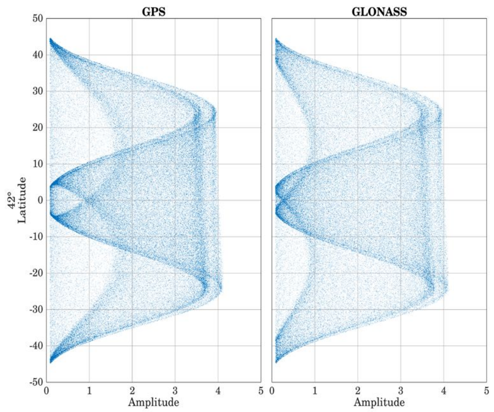
Relationship between View Zenith and View Azimuth Angle for RO Limb Sounding

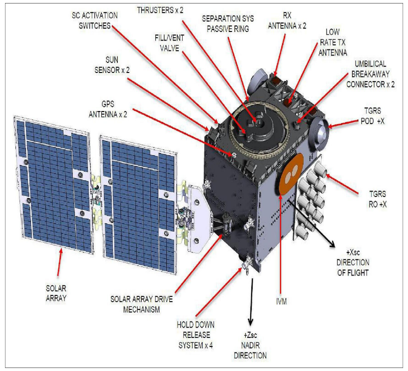


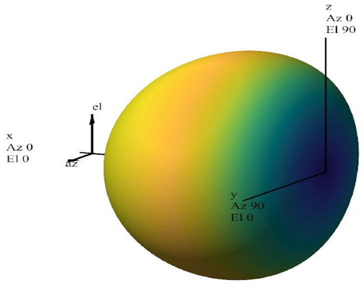


Simulated Distribution of COSMIC-2 SNR

(3x4 Phase Array Antenna)

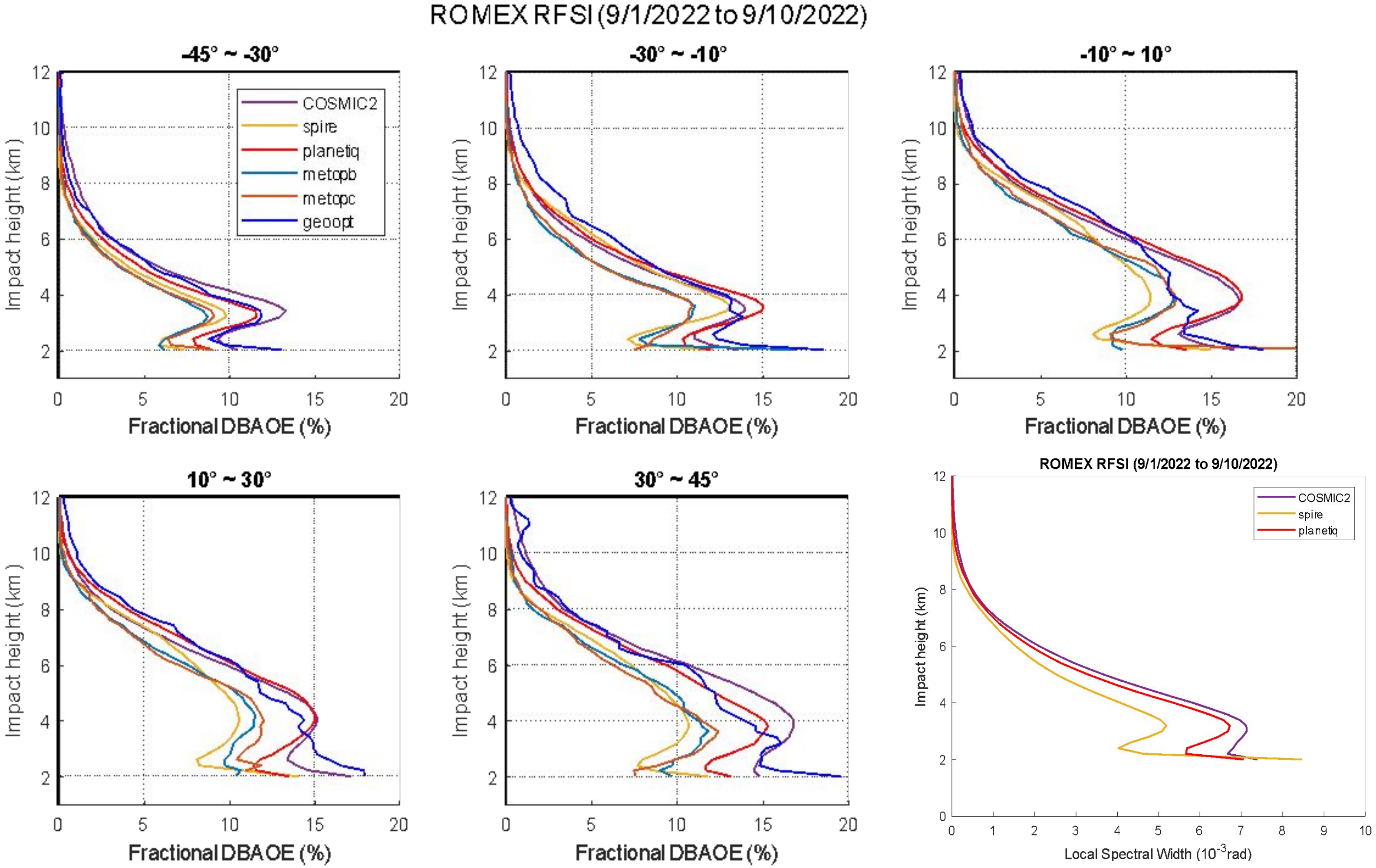




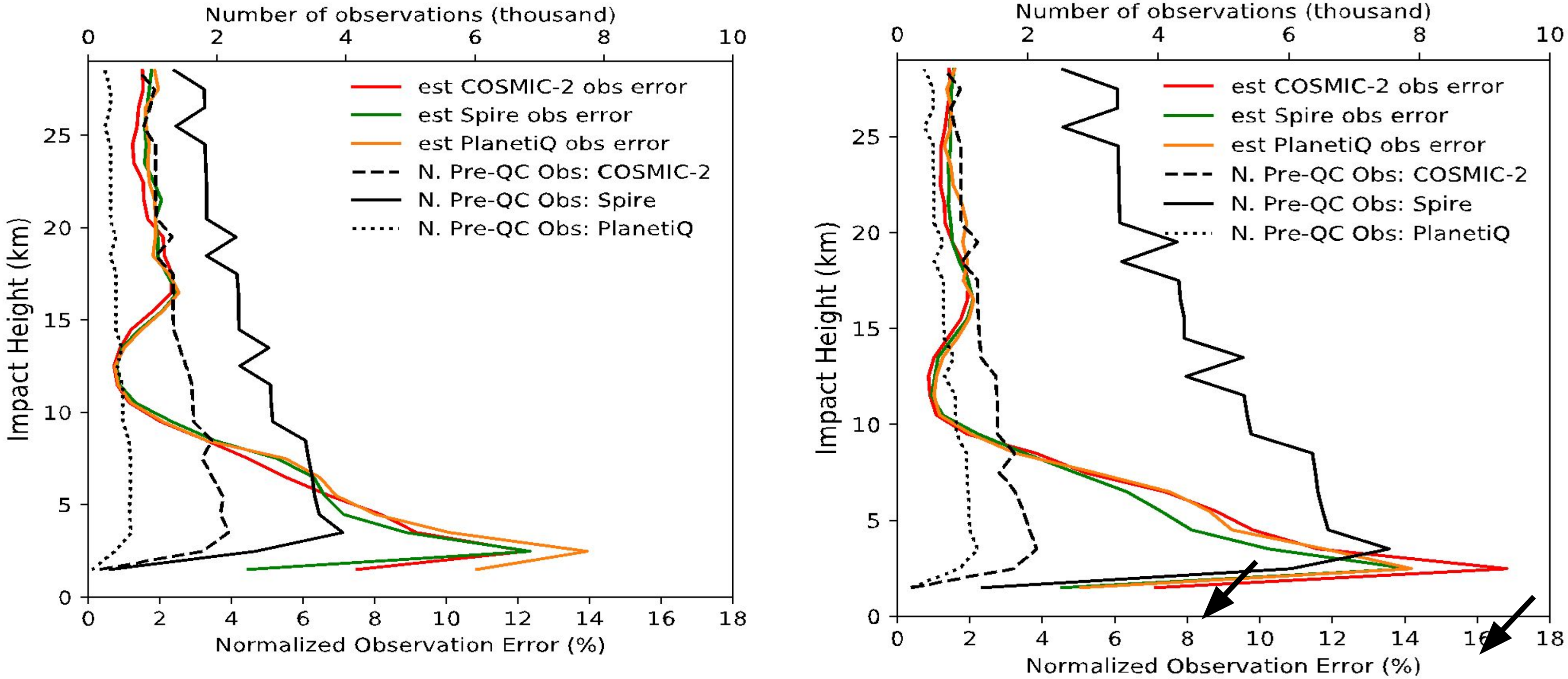


See Tom Liu's poster: A Completed Simulation Tool to Explore the Optimal Configuration for the NOAA's Future GNSS RO Architecture Missions

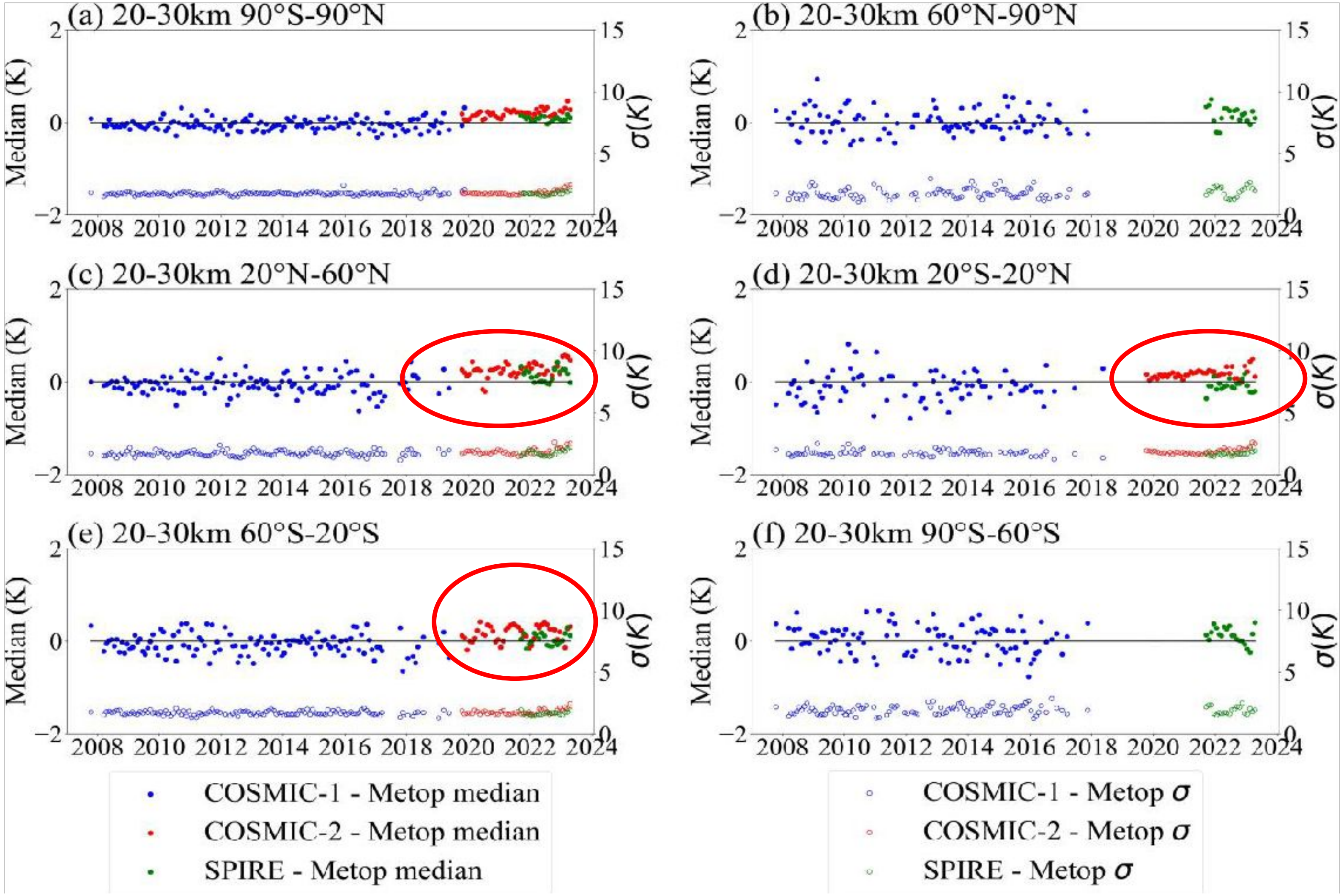
DBAOE latitudinal distribution

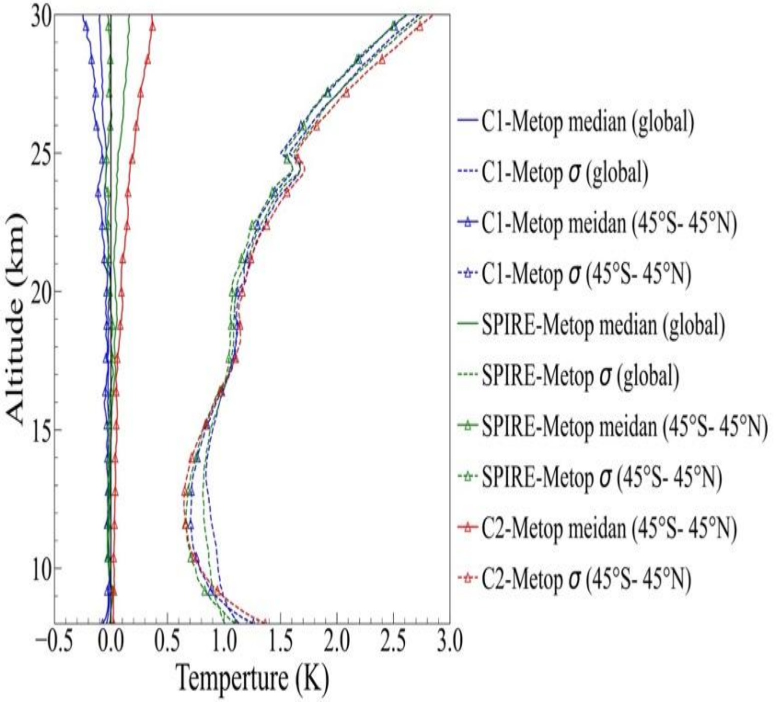


Diagnosed Observation Errors



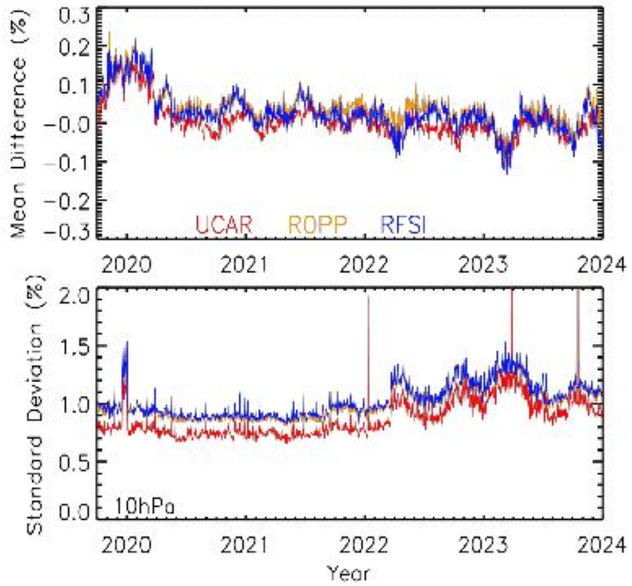
- Use Desroziers et al. (2005): $\widetilde{\sigma_i^o}^2 = \frac{(\boldsymbol{d}_b^o)_i^T(\boldsymbol{d}_a^o)_i}{p_i} = \sum_{j=1}^{p_i}(y_j^o - y_j^b)(y_j^o - y_j^a)/p_i$

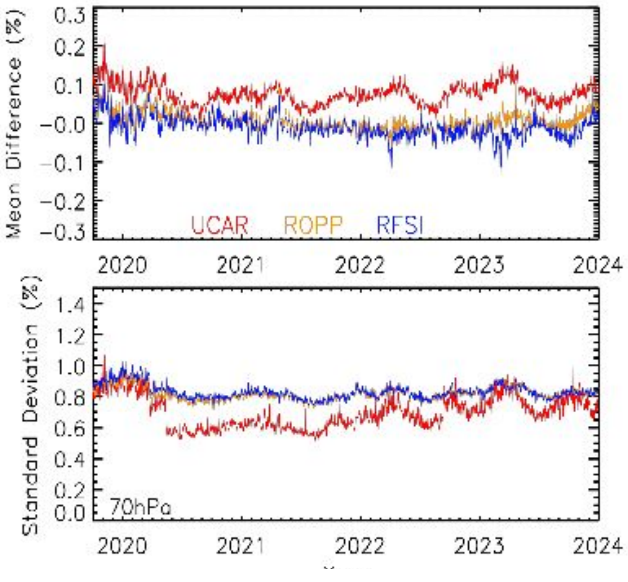


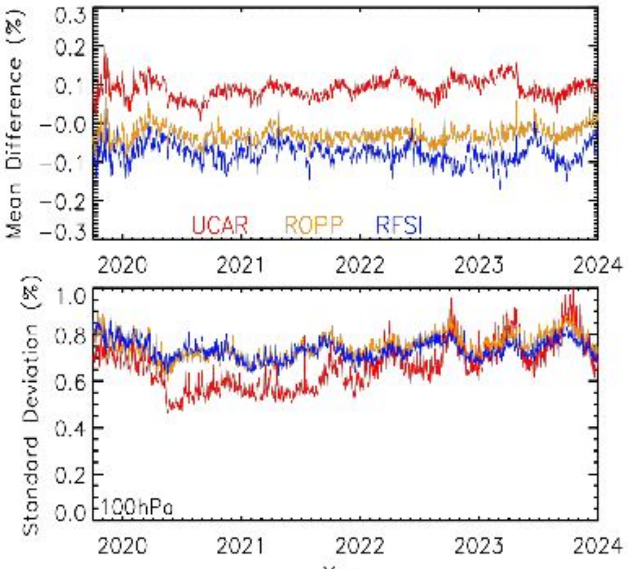


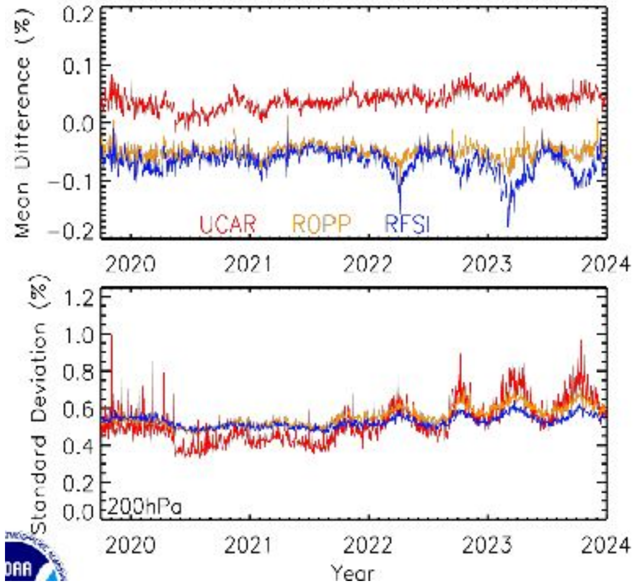
Jun Zhou et al., 2024 (JGR)

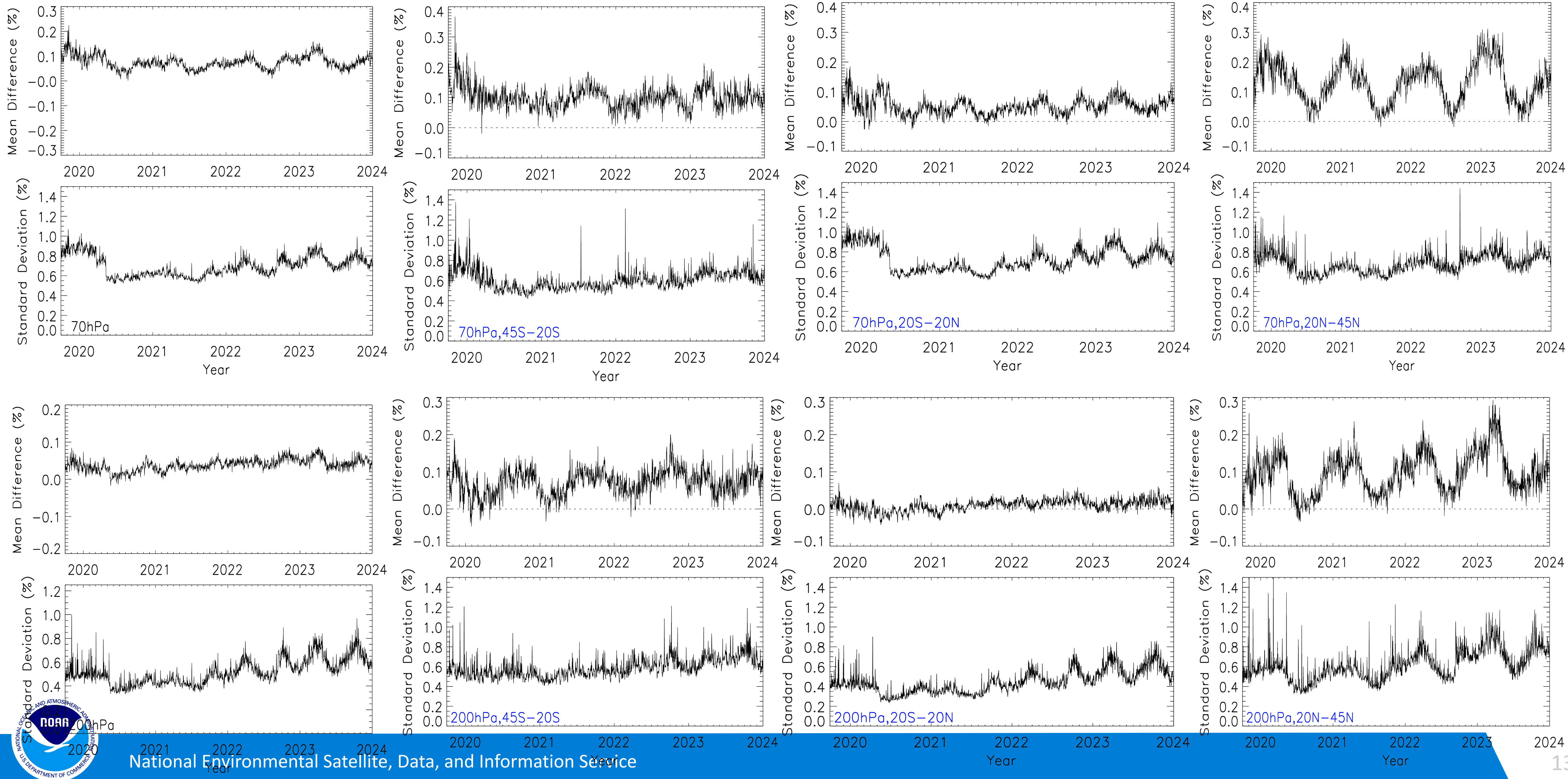
COSMIC-2 Time Series Refractivity Compared to ERA-5

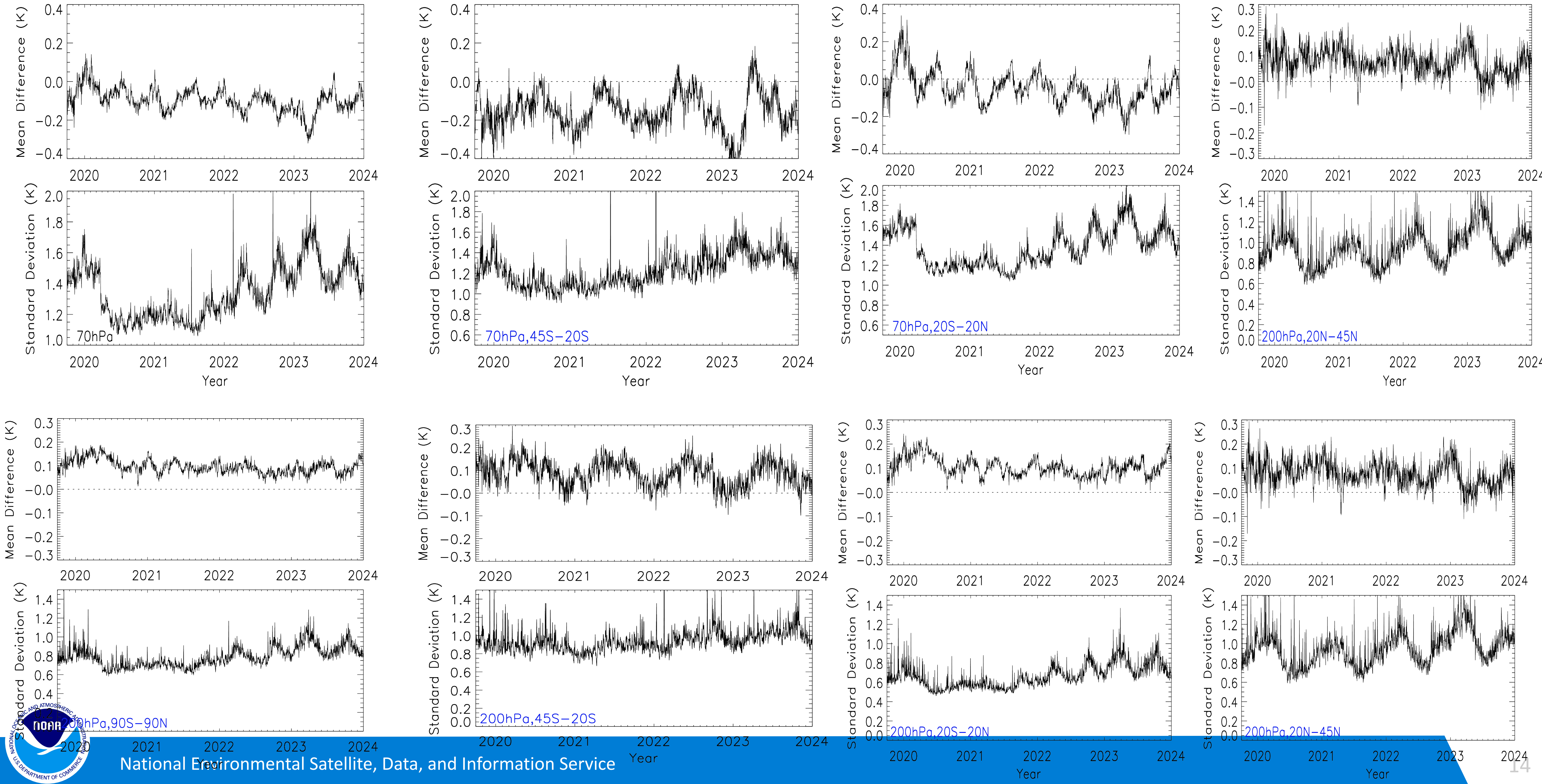


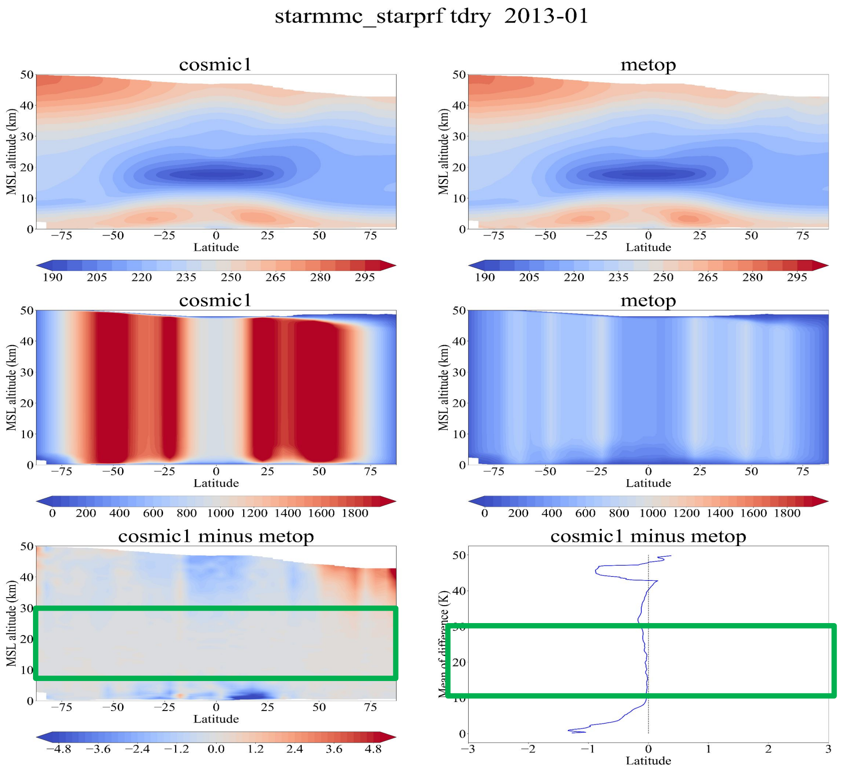




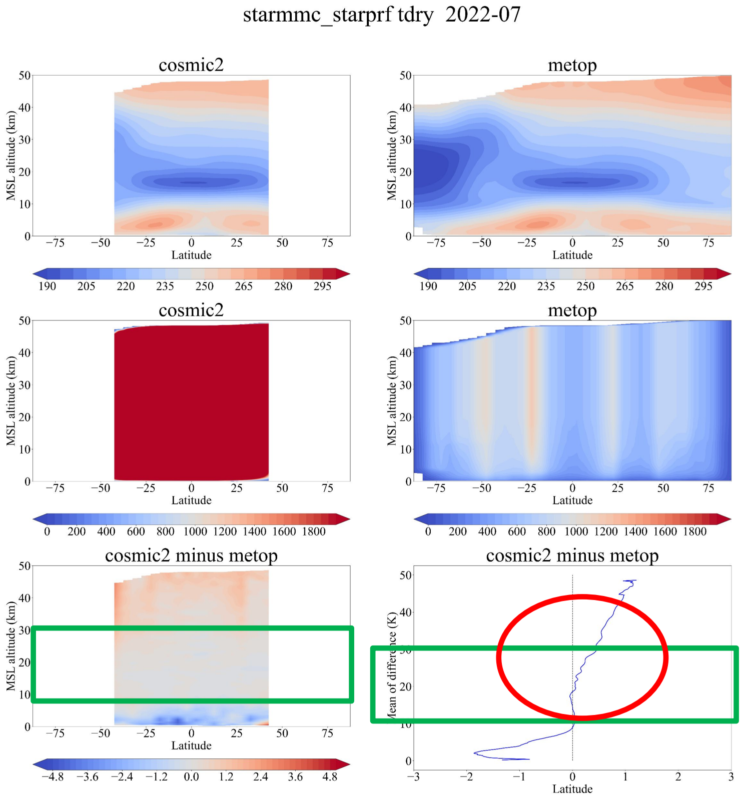



Mean Difference (%)
Standard Deviation (%)
Year
70hPa
70hPa,45S−20S
70hPa,20S−20N
70hPa,20N−45N
200hPa,45S−20S
200hPa,20S−20N
200hPa,20N−45N


Mean Difference (K)
Standard Deviation (K)
Year
70hPa
70hPa,45S−20S
70hPa,20S−20N
200hPa,20N−45N
200hPa,90S−90N
200hPa,45S−20S
200hPa,20S−20N
200hPa,20N−45N



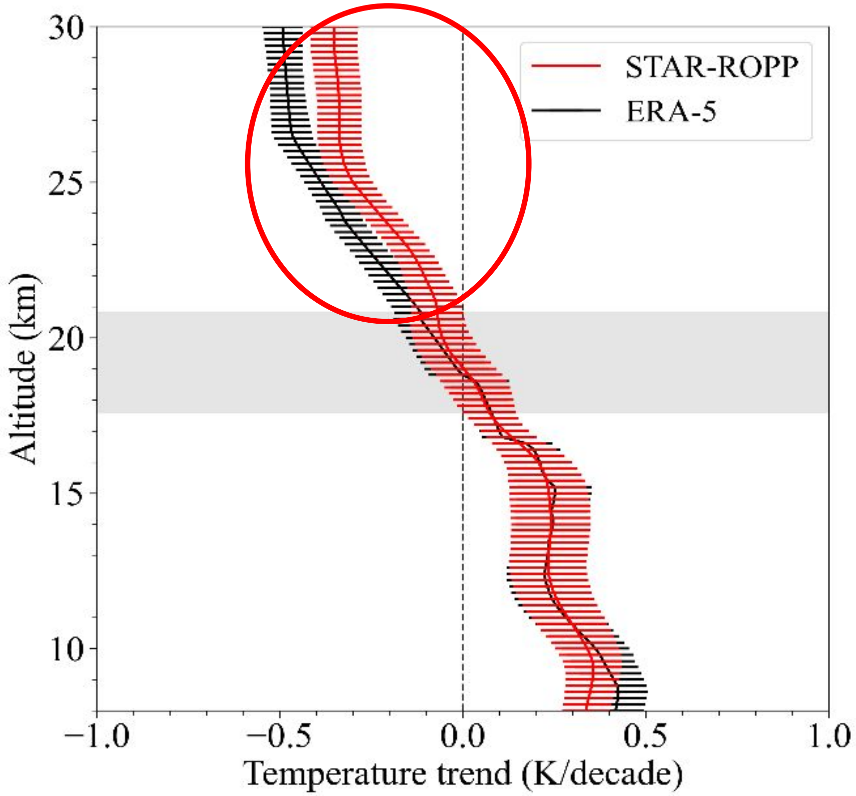
Range of the difference between 8-30 km: -0.13 ~ -0.01 K



Range of the difference between 8-30 km: -0.07 ~ 0.45 K

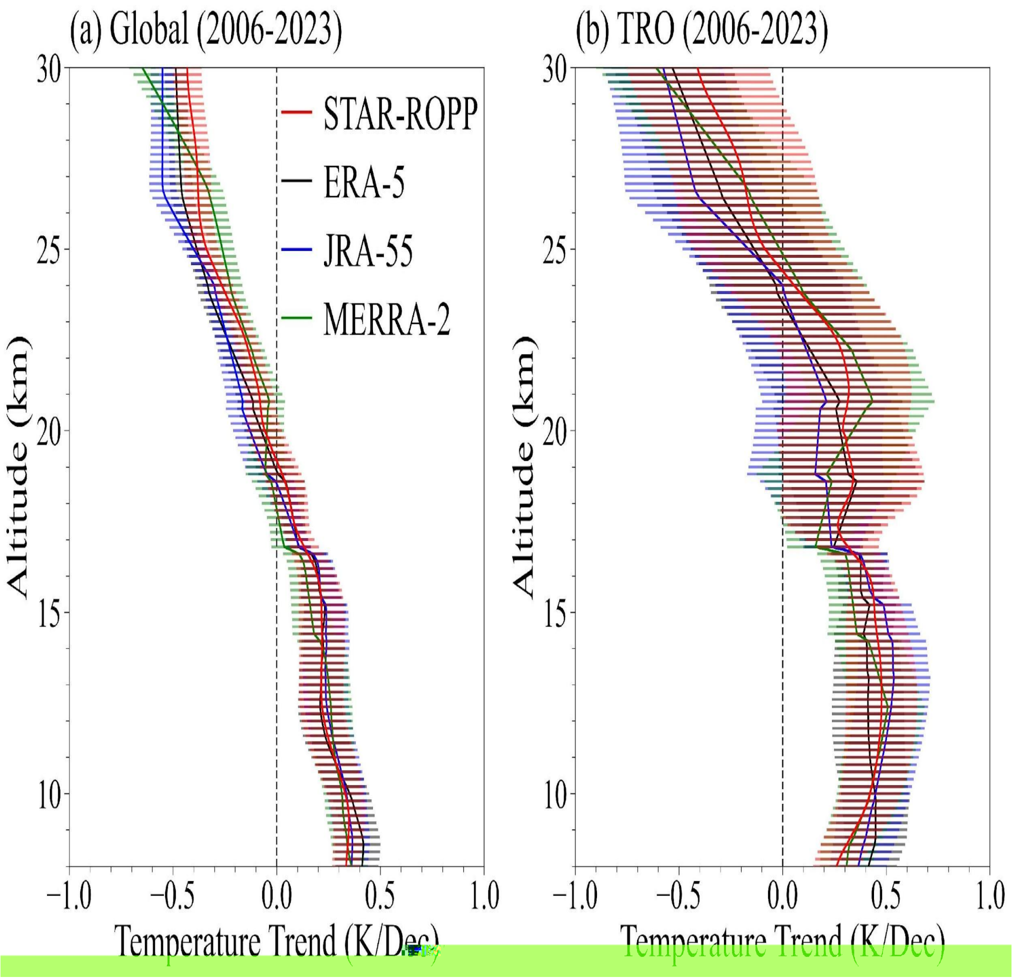
- Bias between C2 and Metop from 20-30 km is much larger than that between C1 and Metop.
- Compared to C1 and Metop in 2013-01, C2 and Metop in 2022-07 have much larger sampling number which should result in less residual sampling error.
- The large bias between C2 and Metop is likely caused by residual ionospheric error.

SPIRE	Sep 2021 to Jul 2023
COSMIC2	Oct 2019 to Jul 2023
COSMIC1	Apr 2006 to Apr 2020
Metop-A	Oct 2007 to Nov 2021
Metop-B	Feb 2013 to Mar 2023
Metop-C	Jul 2019 to Feb 2023



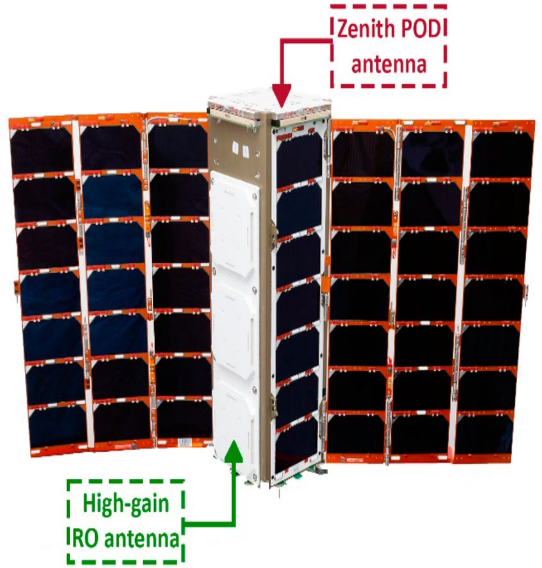
Vertically resolved temperature trends were estimated from STAR-ROPP (red) and ERA-5 (black) data sets. Error bars represent the trend uncertainty at the 95% confidence level. The shaded area denotes the altitude levels where temperature trends are insignificant.

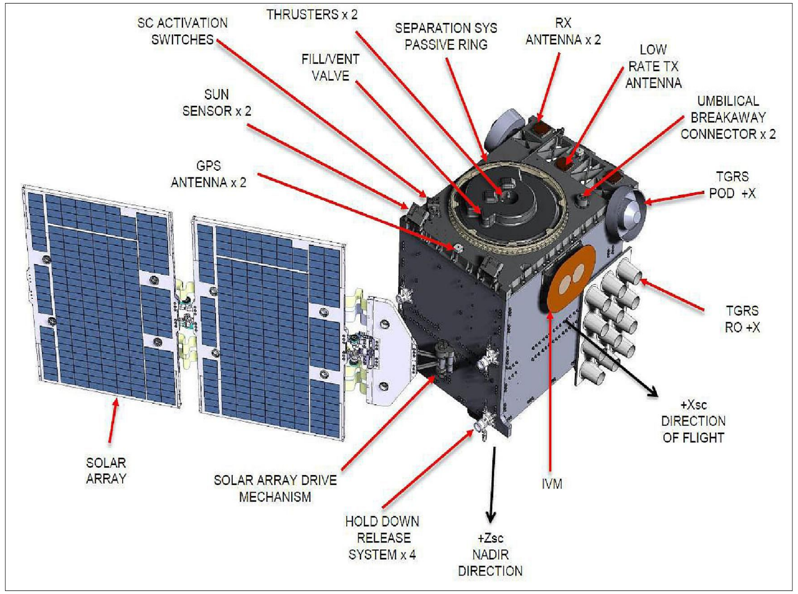
SPIRE	Sep 2021 to Jul 2023
COSMIC1	Apr 2006 to Apr 2020
Metop-A	Oct 2007 to Nov 2021
Metop-B	Feb 2013 to Mar 2023
Metop-C	Jul 2019 to Feb 2023



RO backbone (ROBB) vs. others

- anchor for weather
- anchor for climate
- anchor for space weather





, R. A. Anthes, C. O. Ao, S. Healy, A. Horanyi, D. Hunt, A. J. Mannucci, N. Pedatella, W. J. Randel, A. Simmons, A. Steiner, F. Xie, X. Yue, Z. Zeng, 2019: The COSMIC/FORMOSAT-3 Radio Occultation Mission after 12 years: Accomplishments, Remaining Challenges, and Potential Impacts of COSMIC-2, *Bul. Amer. Meteor. Sci.*, DOI: 10.1175/BAMS-D-18-0290.1

, X. Zhou, X. Shao, Yong Chen, Xin Jing, William Miller, 2023: Using the Commercial GNSS RO Spire Data in the Neutral Atmosphere for Climate and Weather Prediction Studies, *Remote Sensing. 2023, 15(19), 4836*, https://doi.org/10.3390/rs15194836

, Nick Pedatella, Ulrich Foelsche, Sean Healy, Jan-Peter Weiss, Richard Ullman, 2022: Using Radio Occultation Data for Atmospheric Numerical Weather Prediction, Climate Sciences, and Ionospheric Studies and Initial Results from COSMIC-2, Commercial RO Data, and Recent RO Missions, *Bulletin of the American Meteorological Society, 01 Sep 2022*, DOI: 10.1175/BAMS-D-22-0174.1

Ao et al., (2022), Exploitation of New Approaches of Using COSMIC-2 Data in Numerical Weather Prediction in the Moist Troposphere, Final report for CISESS task code: XSXS_COSMIC_19. 2022.

Jun Zhou et al., 2024 (JGR): Construction of Temperature Climate Data Records in the Upper Troposphere and Lower Stratosphere Using Multiple RO Missions from 2006 to 2023 at NESDIS/STAR

Ho, S.-p.; Zhou, X.; Shao, X.; Chen, Y.; Jing, X.; Miller, W. Using the Commercial GNSS RO Spire Data in the Neutral Atmosphere for Climate and Weather Prediction Studies. *RemoteSens.*2023,*15*,4836. https:// doi.org/10.3390/rs15194836