An evaluation of GNSS-RO data from NOAA Commercial Radio Occultation Purchase using the NRL global NWP system

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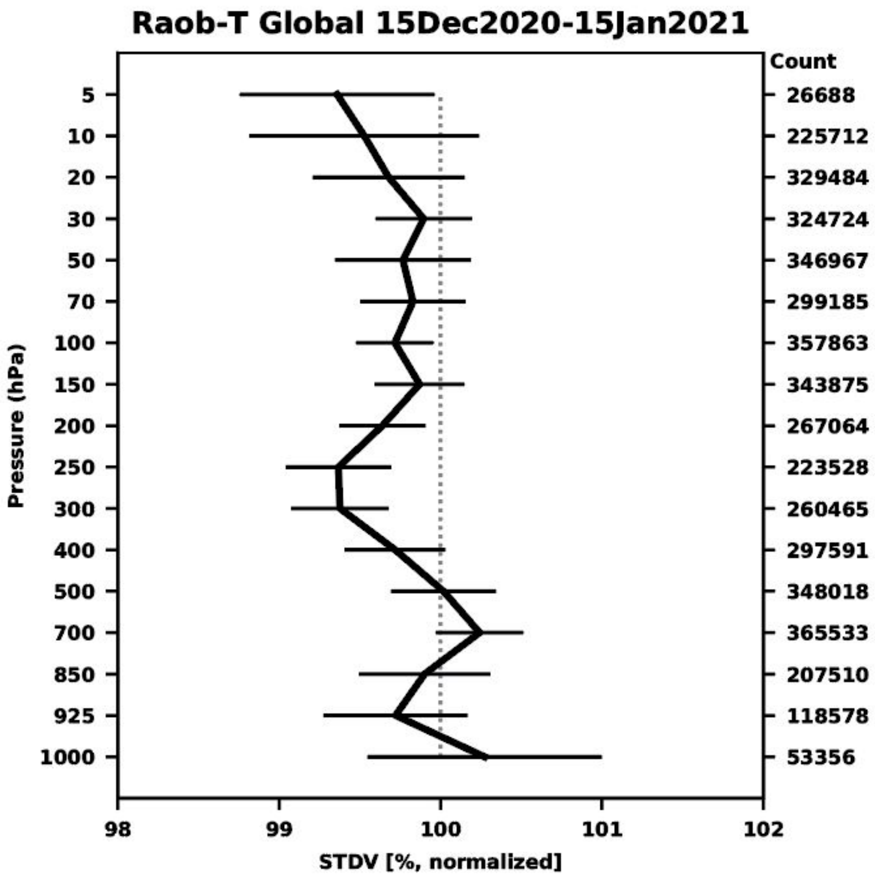
Outline

BLUF: Global Evaluation Using 1 Month of Data

- Datasets used; level-1b from two vendors
- Experiment setup including NWP model and data assimilation system
- Results:
  - Traditional forecast metrics
  - Fit-to-observations (*fit-to-raob shown on right*)
  - Observation fit to background statistics



Primary Tools

NAVGEM - NAVy Global Environmental Model

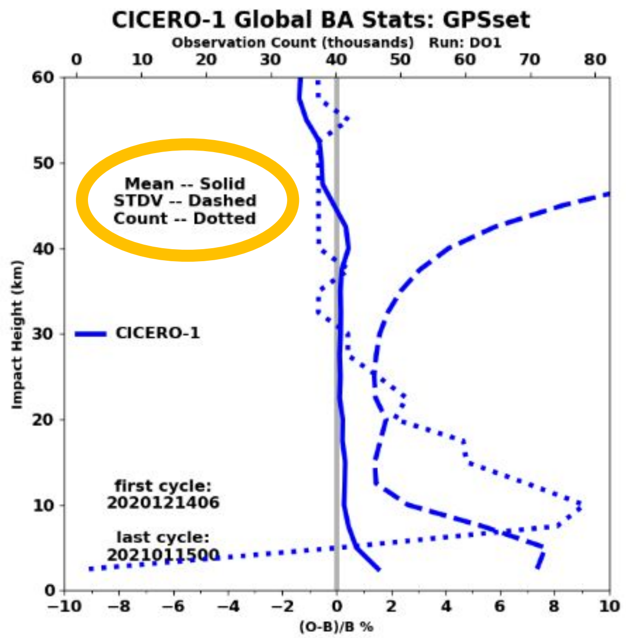
ROPP – Radio Occultation Pre-Processing Package (EUMETSAT ROM-SAF)

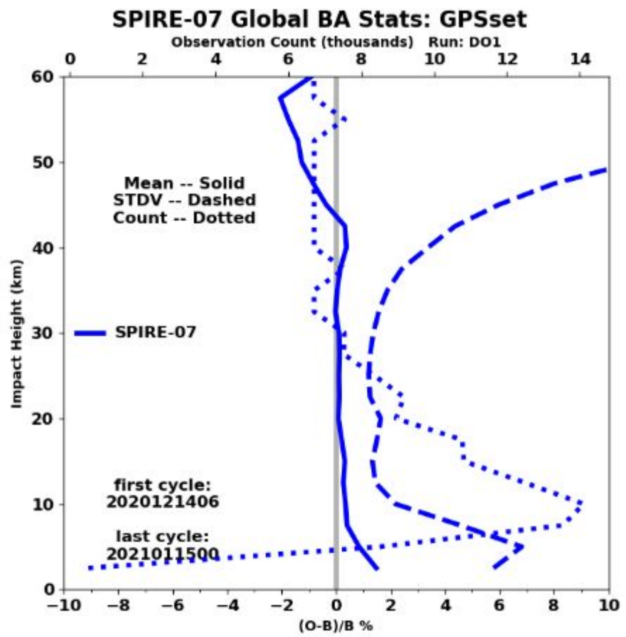
NOAA DO1 DataSets

- NOAA provided real time access to U.S. centers to evaluate data
  - Delivery Order 1 (DO1)‡ contained two vendor
    - GeoOptics (2 receivers)
      - 15Dec2020-14Jan2021
    - Spire* (17 receivers)
      - 16Dec2020-15Jan2021

‡*Data were provided by NOAA's Commercial Data Program under its first operational weather data contract for commercial radio occultation data.*

- Product
  - Level 2 bending angle product in BUFR





*Spire grouping	FM#	Orbit
Spire 04	99-102	LTAN 09:30
Spire 05	103-108	LTAN 15:05
Spire 06	115, 117, 119	37
Spire 07	116, 118, 120, 122, 124, 125	LDTN 10:30

Experiment Set-Up and Modeling System

- Two experiments, one including the data from DO1 the other excluding the data
  - Strategy coordinated with team at NOAA*

**Thanks to Kristen Bathmann, Daryl Kleist, François Vandenberghe, Will McCarty and others*

- NWP model:
  - Navy Global Environmental Model (NAVGEM) this is the operational model run at Fleet Numerical Meteorology and Oceanography Center (FNMOC)
  - Degraded horizontal resolution t425l60 (~30km); operational resolution t681l60 (~20km)
- Data Assimilation System
  - Naval Research Laboratory Atmospheric Variational Data Assimilation System-Accelerated Representer (NAVDAS-AR)
  - Hybrid 4D-Var system run in operational style configuration
    - Single outer loop
    - 80 member ensemble for hybrid component of background error
- ROPP v9
  - Forward operator developed under the EUMETSAT Radio Occultation Meteorology - Satellite Application Facility (ROM-SAF)

NRL GNSS-RO Observation Error Model

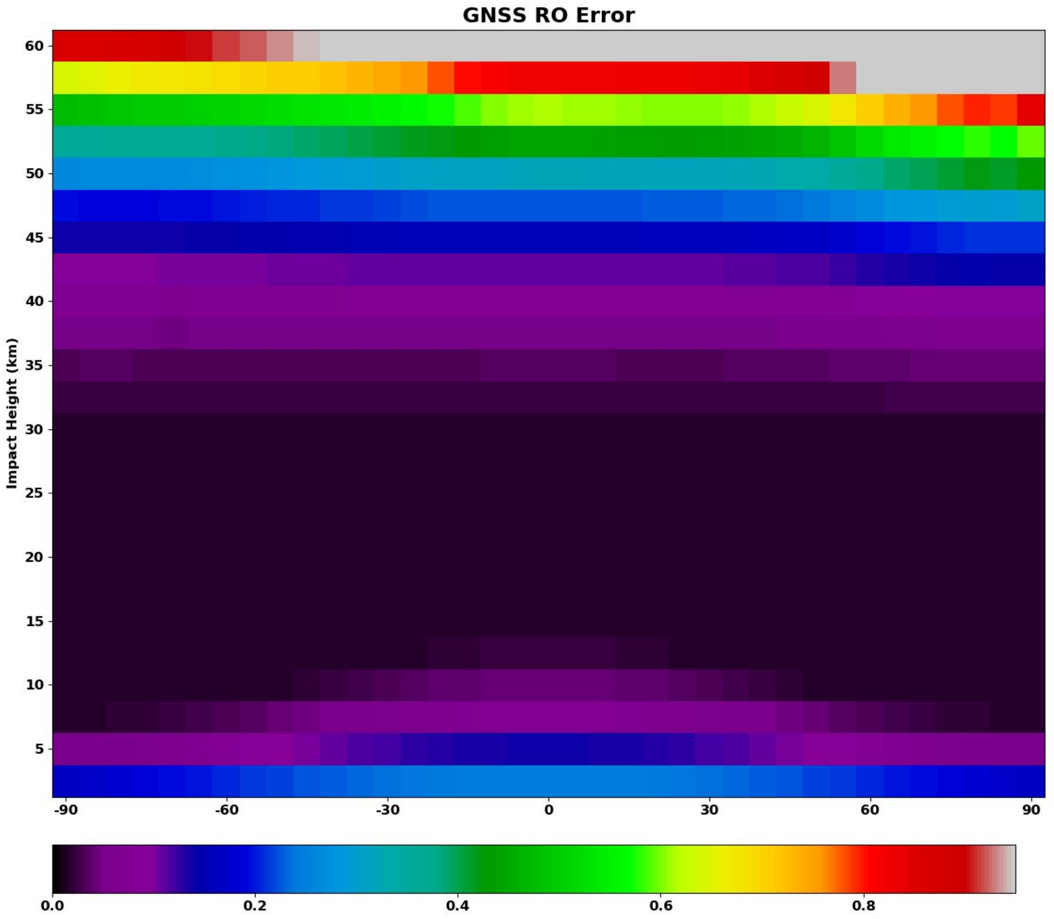
- NRL bending angle error model
  - Empirically developed based on GNSS-RO fit to background statistics
  - Same for all sensors
- At zero impact height maximum uncertainty percentage of 25% at the equator, damped by cosine of the latitude, falling to 16.5% at the Poles

$$Maximum\ error\ at\ zero\ impact\ height = 0.25 * (0.66 + \frac{\cos(lat)}{3})$$

- The uncertainty percentage falls linearly with impact height to 1.5 % at a “minimum error height”. The height of the minimum varies from 12 km at the equator decreasing by cosine of latitude to 5333.33km at the Poles

$$Minimum\ error\ height = 8666.66 + 3333.33 * \cos(2 * lat)$$

- The minimum uncertainty value of 1.5% of the observation is used vertically upwards until this drops below a threshold of 6 microradians



Note the alternate error model:
Bowler NE. GNSS-RO observation uncertainties in the Met Office NWP system. *Q J R Meteorol Soc*. 2020;146:2274–2296. https://doi.org/10.1002/qj.3791

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Traditional Forecast Scores

Standard FNMOC scorecard

Neutral impact (Score +0)

Scorecard by Weight for DO1 vs CTL 2020121500-2021011500

TOTAL SCORE: 0

Show 100 entries Filter:

Reference	Level	Region	Lead time	Variable	Level type	Metric	Weight	Score
Fixed Buoy	None	Northern Hemisphere	96	Wind Speed	surface	Mean Error	2	0
Fixed Buoy	None	Tropics	96	Wind Speed	surface	Mean Error	2	0
Radiosondes	100.0	Global	96	Geopotential Height	pressure	RMS Error	1	0
Radiosondes	250.0	Global	96	Air Temperature	pressure	RMS Error	1	0
Radiosondes	250.0	Global	96	Wind	pressure	Vector RMS Error	1	0
Radiosondes	500.0	Global	96	Geopotential Height	pressure	RMS Error	1	0
Radiosondes	850.0	Global	96	Air Temperature	pressure	RMS Error	1	0
Radiosondes	850.0	Global	96	Wind	pressure	Vector RMS Error	1	0
Self Analysis	200.0	Southern Hemisphere	96	Wind	pressure	Vector RMS Error	1	0
Self Analysis	200.0	Tropics	96	Wind	pressure	Vector RMS Error	1	0
Self Analysis	200.0	Northern Hemisphere	96	Wind	pressure	Vector RMS Error	1	0
Self Analysis	500.0	Northern Hemisphere	120	Geopotential Height	pressure	Anomaly Correlation	2	0
Self Analysis	500.0	Southern Hemisphere	120	Geopotential Height	pressure	Anomaly Correlation	1	0
Self Analysis	500.0	Northern Hemisphere	120	Geopotential Height	pressure	RMS Error	2	0
Self Analysis	500.0	Southern Hemisphere	120	Geopotential Height	pressure	RMS Error	1	0
Self Analysis	850.0	Northern Hemisphere	96	Wind	pressure	Vector RMS Error	1	0
Self Analysis	850.0	Southern Hemisphere	96	Wind	pressure	Vector RMS Error	1	0
Self Analysis	850.0	Tropics	96	Wind	pressure	Vector RMS Error	2	0
Self Analysis	1000.0	Northern Hemisphere	120	Geopotential Height	pressure	Anomaly Correlation	1	0
Self Analysis	1000.0	Southern Hemisphere	120	Geopotential Height	pressure	Anomaly Correlation	1	0

Showing 1 to 20 of 20 entries

Stratospheric scorecard

Neutral impact (Score -1)

Scorecard by Weight for DO1 vs CTL 2020121500-2021011500

TOTAL SCORE: -1

Show 100 entries Filter: Self

Reference	Level	Region	Lead time	Variable	Level type	Metric	Weight	Score
Self Analysis	10.0	Southern Hemisphere	72	Geopotential Height	pressure	RMS Error	1	-1
Self Analysis	10.0	Northern Hemisphere	72	Air Temperature	pressure	RMS Error	1	0
Self Analysis	10.0	Southern Hemisphere	72	Air Temperature	pressure	RMS Error	1	0
Self Analysis	10.0	Northern Hemisphere	72	Geopotential Height	pressure	RMS Error	2	0
Self Analysis	10.0	Tropics	72	Wind	pressure	Vector RMS Error	1	0
Self Analysis	10.0	Northern Hemisphere	72	Wind	pressure	Vector RMS Error	1	0
Self Analysis	10.0	Southern Hemisphere	72	Wind	pressure	Vector RMS Error	1	0
Self Analysis	50.0	Northern Hemisphere	72	Air Temperature	pressure	RMS Error	1	0
Self Analysis	50.0	Southern Hemisphere	72	Air Temperature	pressure	RMS Error	1	0
Self Analysis	50.0	Southern Hemisphere	72	Wind	pressure	Vector RMS Error	1	0
Self Analysis	50.0	Tropics	72	Wind	pressure	Vector RMS Error	1	0
Self Analysis	100.0	Northern Hemisphere	72	Air Temperature	pressure	RMS Error	1	0
Self Analysis	100.0	Southern Hemisphere	72	Geopotential Height	pressure	RMS Error	1	0
Self Analysis	100.0	Southern Hemisphere	72	Air Temperature	pressure	RMS Error	1	0
Self Analysis	100.0	Northern Hemisphere	72	Geopotential Height	pressure	RMS Error	2	0
Self Analysis	100.0	Southern Hemisphere	72	Wind	pressure	Vector RMS Error	1	0
Self Analysis	100.0	Tropics	72	Wind	pressure	Vector RMS Error	1	0
Self Analysis	200.0	Northern Hemisphere	72	Air Temperature	pressure	RMS Error	1	0
Self Analysis	200.0	Northern Hemisphere	72	Geopotential Height	pressure	RMS Error	2	0
Self Analysis	200.0	Southern Hemisphere	72	Air Temperature	pressure	RMS Error	1	0
Self Analysis	200.0	Southern Hemisphere	72	Geopotential Height	pressure	RMS Error	1	0
Self Analysis	200.0	Northern Hemisphere	72	Wind	pressure	Vector RMS Error	1	0
Self Analysis	200.0	Northern Hemisphere	72	Wind	pressure	Vector RMS Error	1	0
Self Analysis	200.0	Northern Hemisphere	96	Wind	pressure	Vector RMS Error	1	0
Self Analysis	200.0	Southern Hemisphere	96	Wind	pressure	Vector RMS Error	1	0
Self Analysis	200.0	Tropics	72	Wind	pressure	Vector RMS Error	1	0

Showing 1 to 26 of 26 entries (filtered from 40 total entries)

Traditional forecast metrics are not greatly affected by this type of experiment

adding a relatively small dataset on top of a full system

A stratospheric scorecard was constructed to contain metrics more directly related to the GNSS-RO observations

Fit to Observations

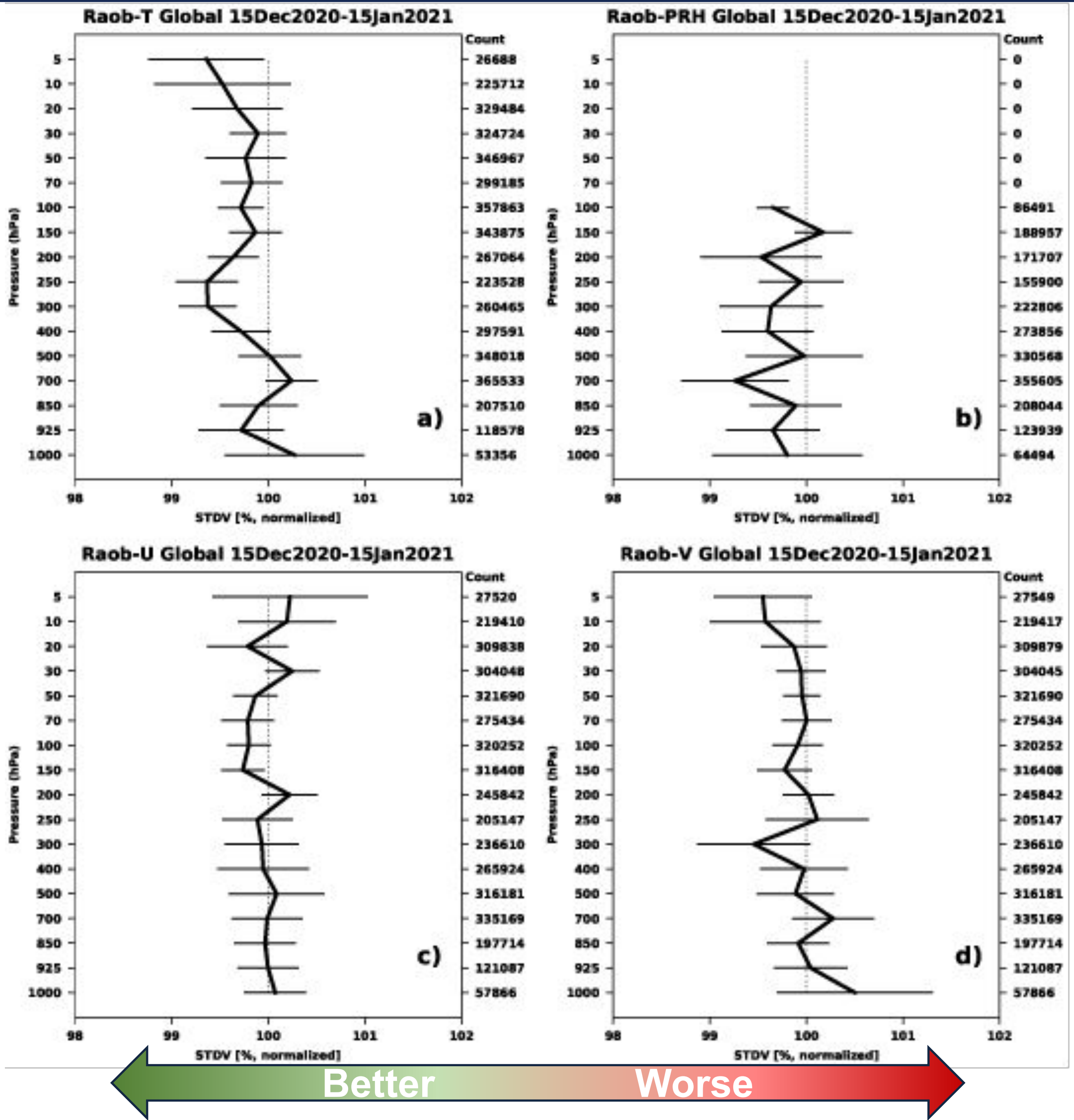
Fit to Radiosonde

Change in the RMS of the fits to radiosondes between the experiment (DO1) and control

A time series of these differences are used to generate the 95% confidence intervals

Strongest response was seen in the temperature field between 300 – 200 hPa

Very little response in the other fields, positive response in pseudo RH (PRH) at 700 hPa encouraging but unexplained



Fit to Observations

Fit to Microwave Radiances

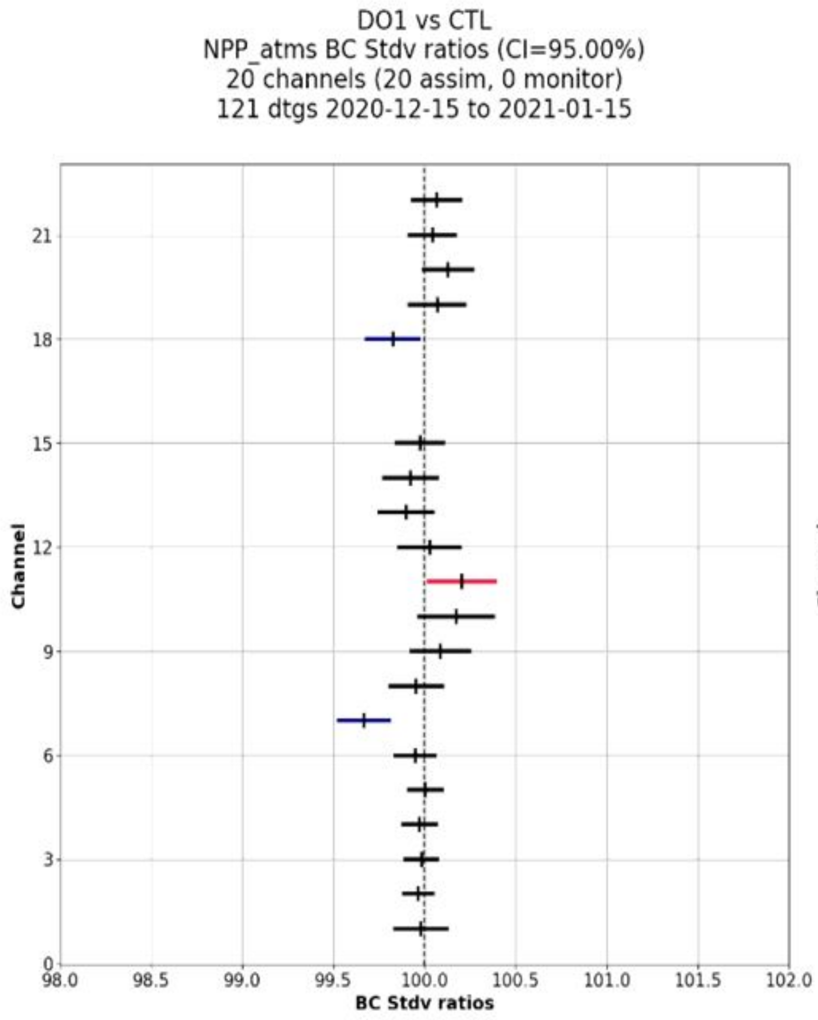
Change in RMS of the fits to ATMS* between DO1 and control

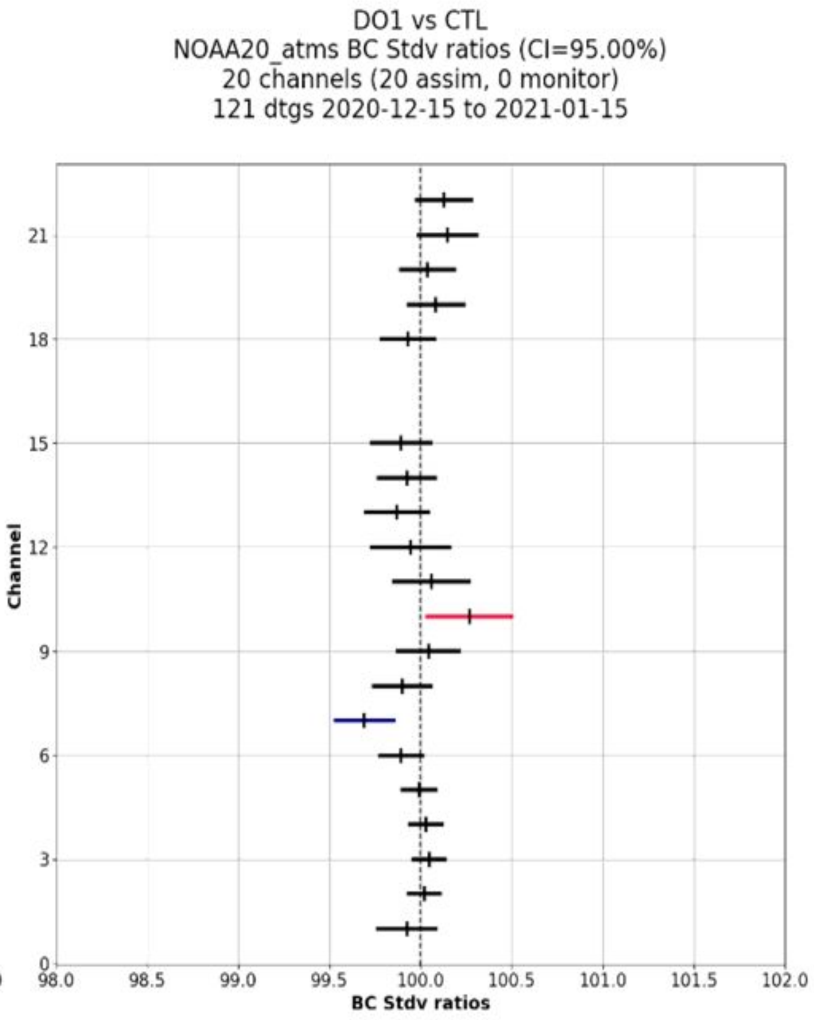
**Advanced Technology Microwave Sounder*

Time series of differences are used to generate the 95% confidence intervals

Strongest response in channel 07 which is sensitive to temperature between approximately 300 – 200 hPa

Very little response in other channels





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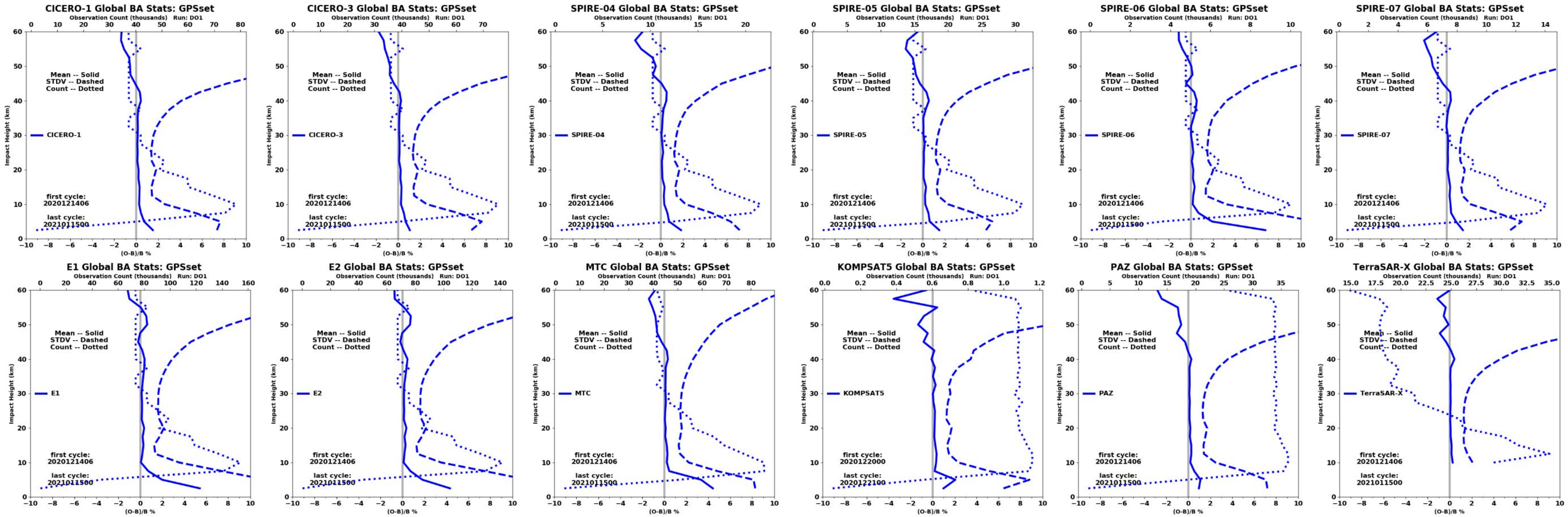
Statistics on the GNSS-RO fit to background

GPS setting occultations

Setting occultations show better background fit, and greater penetration depths

This was most obvious in the standard deviations of the innovation (observation – background)

GeoOptics receivers do not and can not provide rising occultations



Statistics on the GNSS-RO fit to background

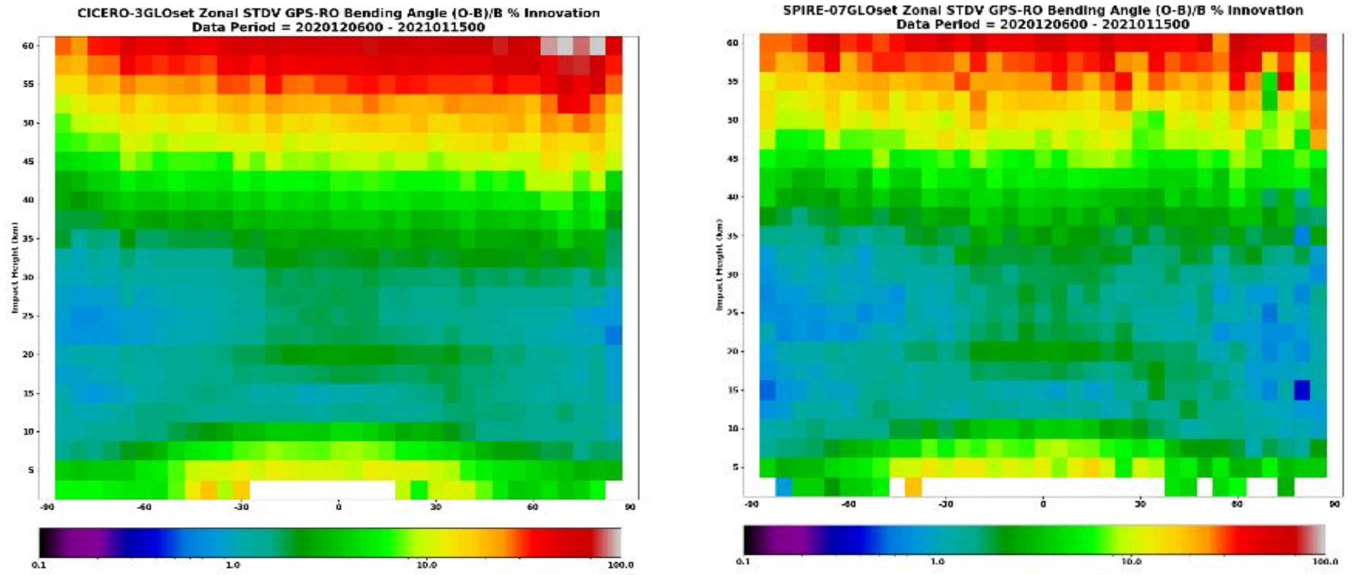
GLONASS/GPS setting occultations

The differences between which **transmitter was tracked** is subtle and most pronounced above 50km

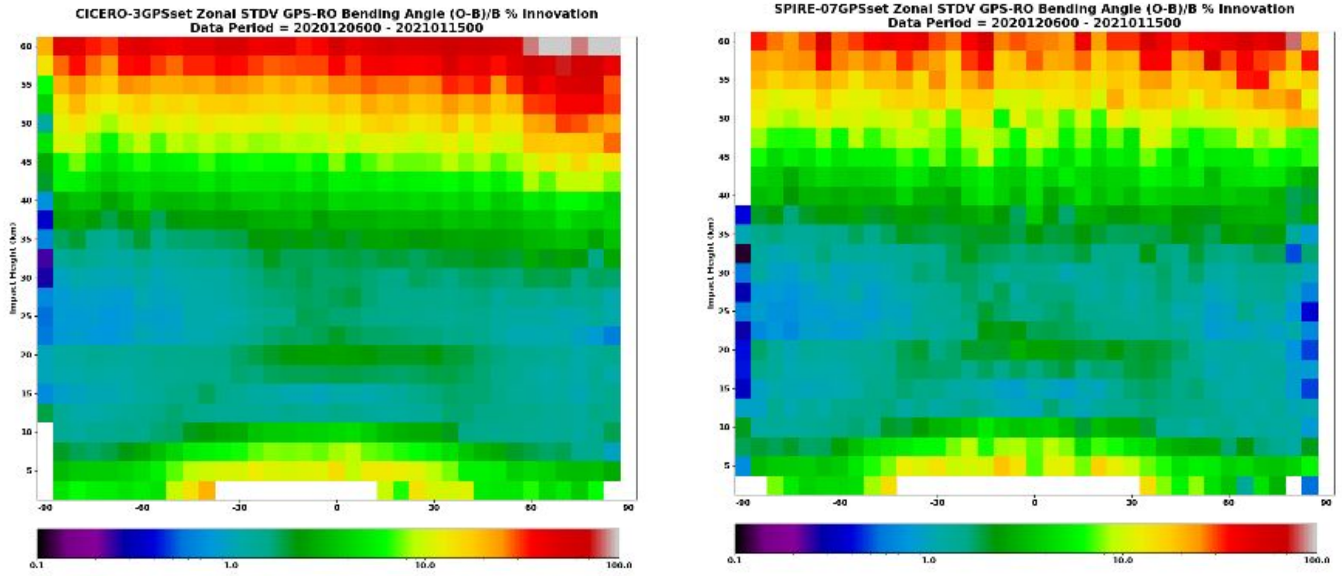
At present only the GeoOptics, Spire and COSMIC-2 data provide occultations tracked by GPS and GLONASS

Further augmentation of the tracked transmitter should be monitored closely for variations in the quality of the fits

GLONASS



GPS



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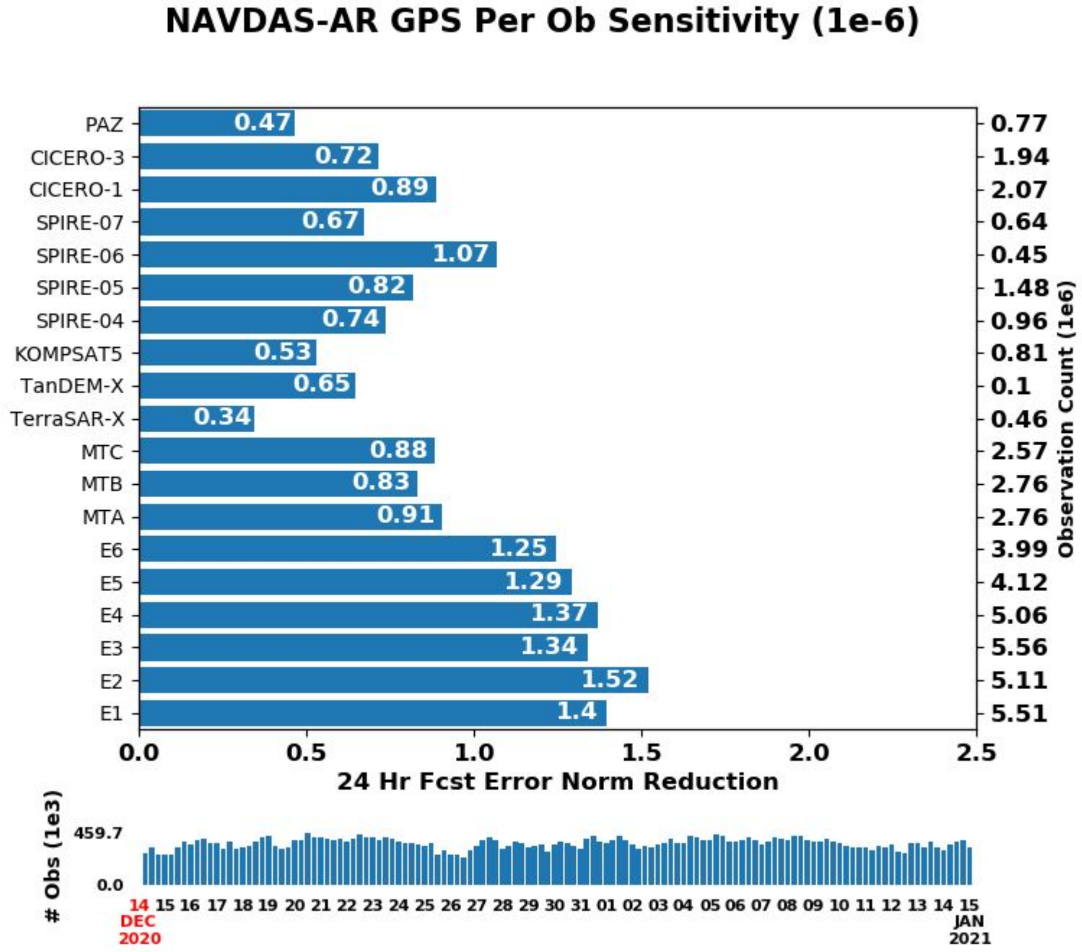
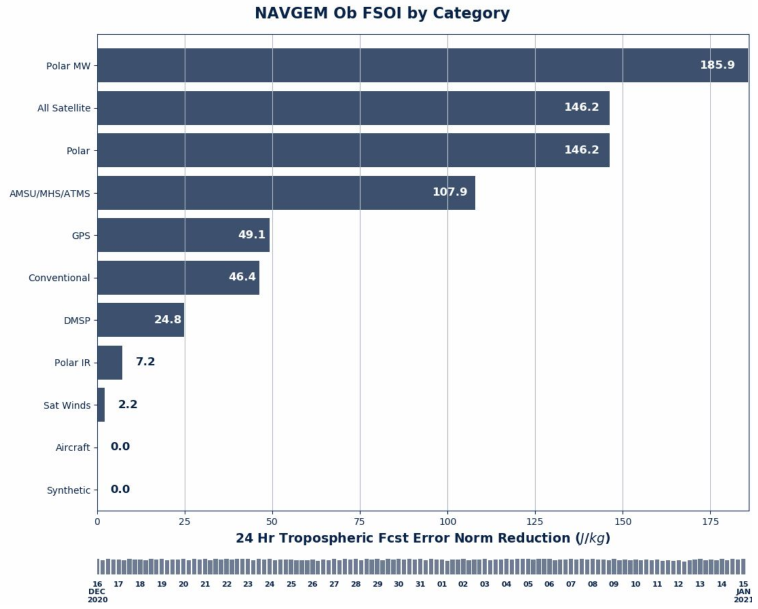
Statistics on the GNSS-RO fit to background

FSOI*

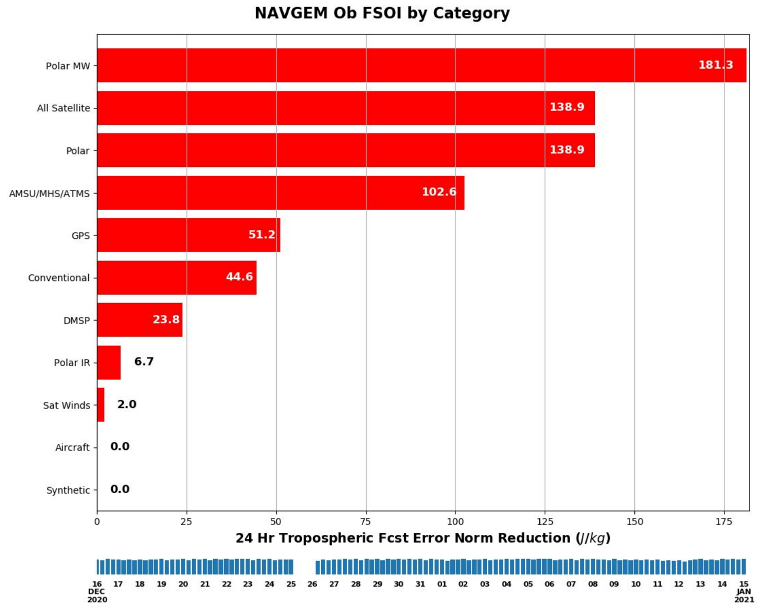
*Forecast Sensitivity to Observation Impact



Control



NOAA DO1



The additional GNSS-RO data increased the overall impact of the data type (GPS in the figures above)

The additional GNSS-RO observation are accompanied by a corresponding reduction of the impact of all other data

The additional GNSS-RO data have not reached saturation

Summary

- NOAA provided data from two vendors for a 1 month evaluation period spanning from Dec2020-Jan2021
  - Traditional forecast metrics showed little impact of the data on top of a full system
  - Fit-to-Observation metrics did show this additional data improved both radiosonde and microwave sounders sensitive to temperature around 300-200 hPa

- Differences in the data quality were small; however:
  - Spire provided both rising and setting occultations
  - GeoOptics provides only setting occultations

- Differences in the fit of the observation are seen between rising and setting (setting better) and which transmitter was tracked (GPS better than GLONASS)

- Observation error could be designed to vary depending on mission, rising versus setting and which transmitter is tracked
  - This has potential to maximize the impact of the GNSS-RO observation suite

Backup

ATMS Weighting Functions

Reiterating:

U.S. Std Atmosphere
Viewing geometry Nadir and Limb