24-B: Validation of Stratopause retrievals from Spire Radio Occultation Data

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Abstract:

The stratopause sets the upper boundary to the stratospheric layer. It is reached by rocket sondes that show an upper stratospheric cooling *[Ramaswamy, 2001]*. Satellites, like the Microwave Limb Sounder (MLS) *[France et al. 2012]* and the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) *[Remsberg et al., 2003]*, estimate the cooling trend at ~0.3-1 K/decade cooling *[Zhao et al., 2021]*. Understanding the mechanisms behind this trend and its latitudinal and longitudinal asymmetries requires understanding upper stratospheric processes and to achieve this, dense coverage is a necessity. Rocket sondes are few and very localized in time and geographically. SABER and MLS improve this coverage with a vertical resolution ~2 km near the stratopause and GNSS RO could add to their coverage. Additionally, given the high vertical resolution of RO and their ability to track the tropopause, RO might be used to track the thickness of the stratosphere with high vertical resolution. But GNSS RO measure refractivities, i.e. atmospheric density profiles in the stratosphere. Even if they have a denser coverage and finer vertical resolution than SABER and MLS, RO temperatures above 30 km - 40 km, have not been a target for temperature retrievals by GNSS RO data centers. Moreover, initializing the GNSS RO abel integral above the stratopause has been shown to improve the retrieval accuracy *[Schröder et al., 2004]*.

We describe a technique to identify the stratopause height from Spire RO data. We test an approach to calculate stratopause altitudes starting from each RO profile refractivity independently from ancillary data or climatologies. We discuss the magnitude of the spread of values in stratopause heights and temperatures as well as the results of comparisons with coincident SABER and MSL profiles. The difference in spatio-temporal sampling is also presented.

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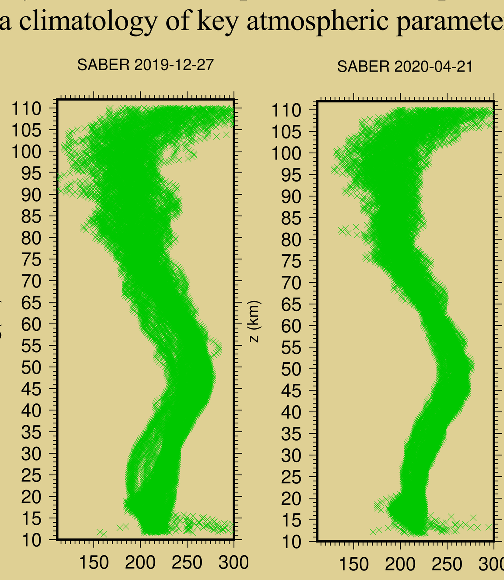
SABER

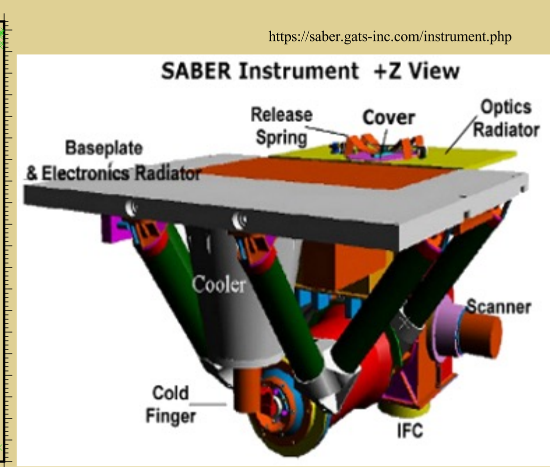
Launched December 2001

1. "The Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument is one of four instruments on NASA's TIMED (Thermosphere Ionosphere Mesosphere Energetics Dynamics) satellite."
2. Science goal: "To explore the mesosphere and lower thermosphere globally and achieve a major improvement in our understanding of the fundamental processes governing the energetics, chemistry, dynamics, and transport of the atmospheric region extending from 60 km to 180 km."
3. "Develop a climatology of key atmospheric parameters in the TIMED core region from 60 to 130 km."

Example of 2 days with 192 SABER profiles of Kinetic Temperature.



https://saber.gats-inc.com/instrument.php



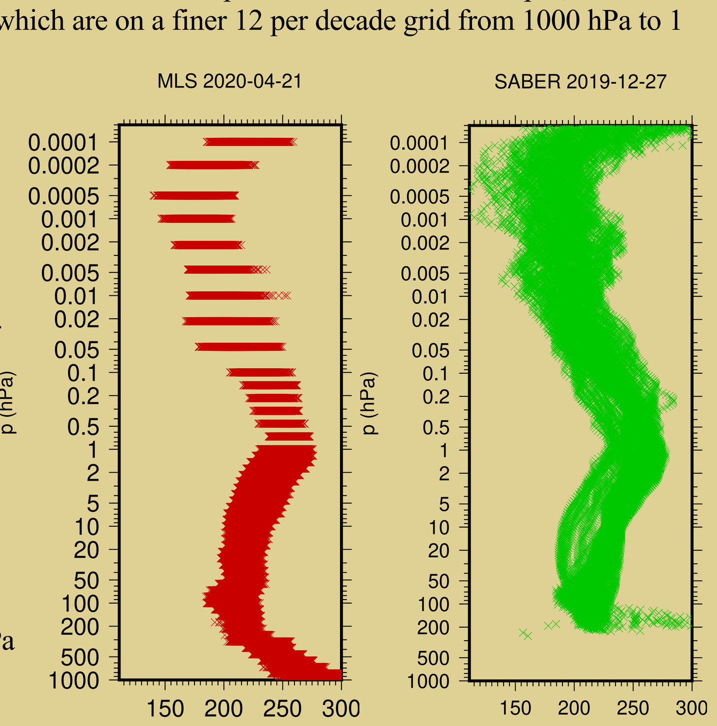
Microwave Limb Sounder (MLS):

Launched July 2004

1. Version 5.0 data: Provides vertical profiles of the abundance of BrO, CH3Cl, CH3CN, CH3OH, ClO, CO, H2O, HCl, HCN, HNO3, HO2, HOCl, N2O, O3, and OH and SO2, along with temperature, geopotential height, relative humidity (deduced from the H2O and temperature data), cloud ice water content and cloud ice water path, all described as functions of pressure.
2. Output on a grid that has a vertical spacing of six surfaces per decade change in pressure (~2.5 km), thinning out to three surfaces per decade above 0.1 hPa. Exceptions to this are water vapor, temperature, ozone and relative humidity which are on a finer 12 per decade grid from 1000 hPa to 1 hPa.

Temperatures
1. MLS v5.0x temperature has ~ −1 K bias with respect to correlative measurements in the troposphere and stratosphere, with 2–3 K peak-to-peak additional systematic vertical structure.

2. Vertical resolution is
 3–4 km from 261 hPa to 10 hPa
 7–8 km at 1–0.1 hPa
 11 km at 0.01 hPa
 12 km at 0.0001–0.0002 hPa.
Along track resolution is
 ~165 km from 261 hPa to 0.1 hPa
 280 km at 0.001 hPa and
 316 km at 0.00046 hPa.



Comparison 3495 MLS profiles to SABER in pressure coordinates

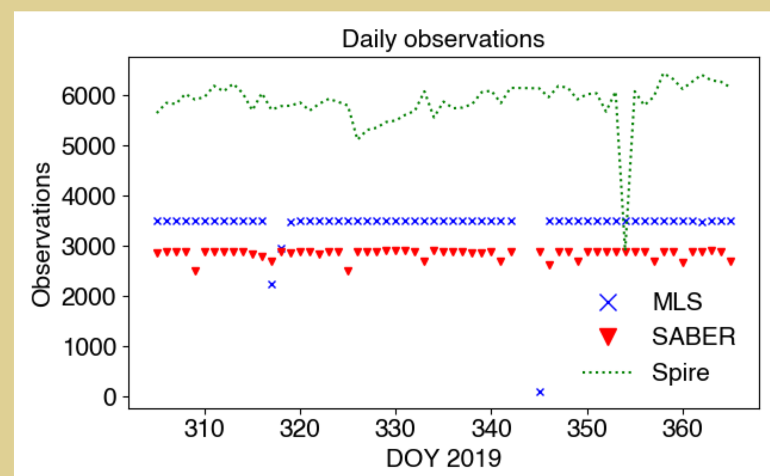
References:
Lievesay et al. https://mls.jpl.nasa.gov/data/v5-0_data_quality_document.pdf

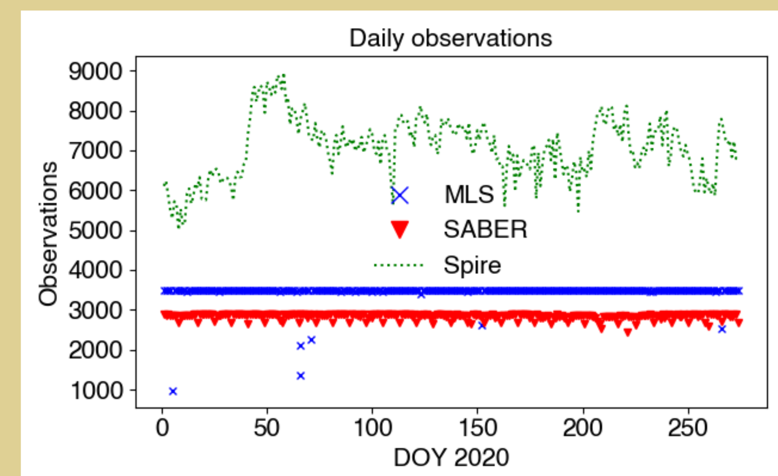
Spire:

Available under the Commercial SmallSat Data Acquisition program starting from Nov 2019

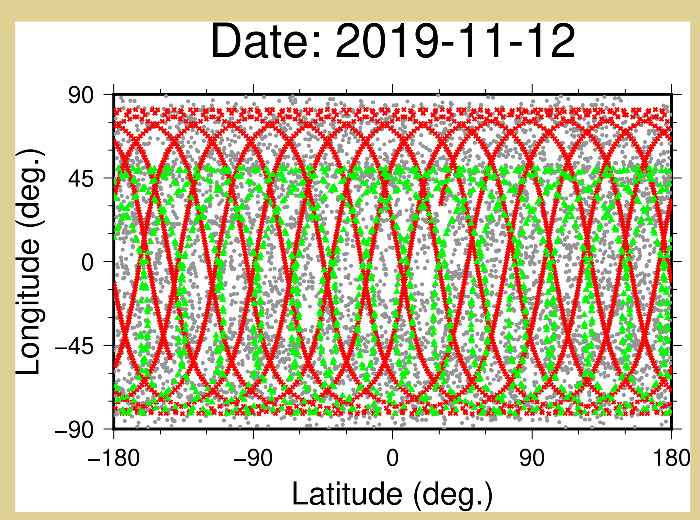
Spire is a constellation of 3U satellites collecting thousands of radio occultation profiles daily.

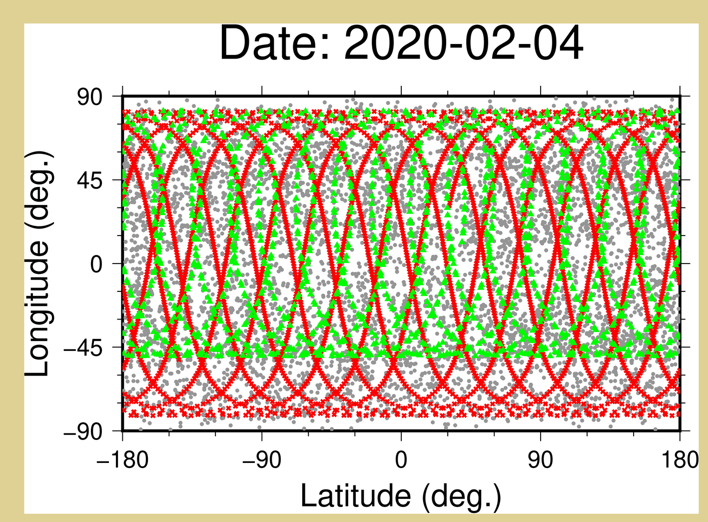
•The data presented here stem from NASA's Commercial Satellite Data (CSDA) server
• On a first step, the CSDA L2 temperature data were used. They have been extracted after optimizing the raw bending angles when they separate above a threshold from a reference model.





Geographic coverage:

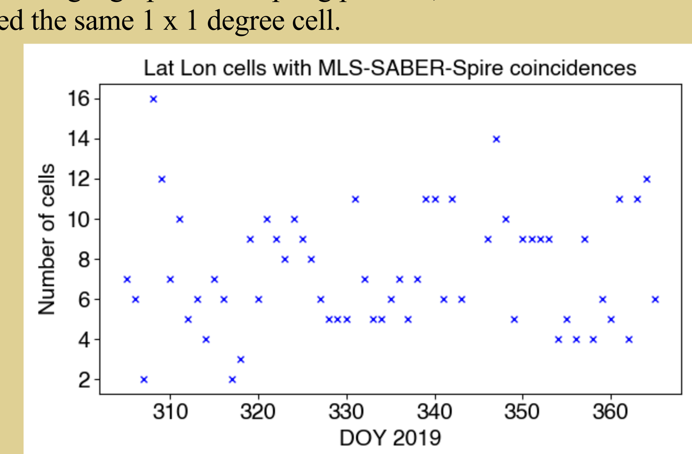


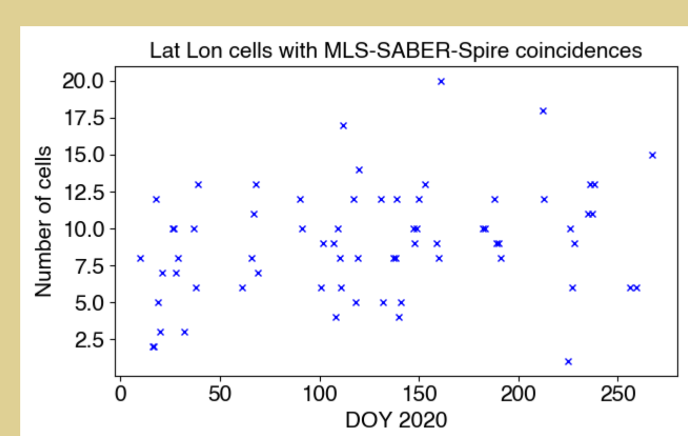


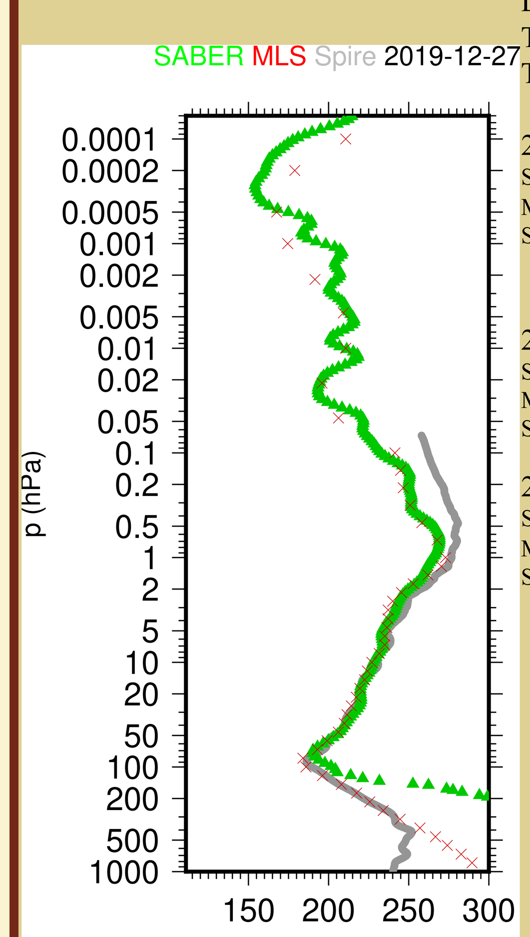
Two days where there were coincidences within a 1 x 1 lon-lat box, 15 and 17 minutes for all three instruments. *Spire* (grey) has a much denser geographic coverage than SABER (green symbols) and MLS (red).

Coincidences:

Given the geographical sampling patterns, from Dec 2019-Oct 2020, there was a limited number of cases where all three instruments visited the same 1 x 1 degree cell.





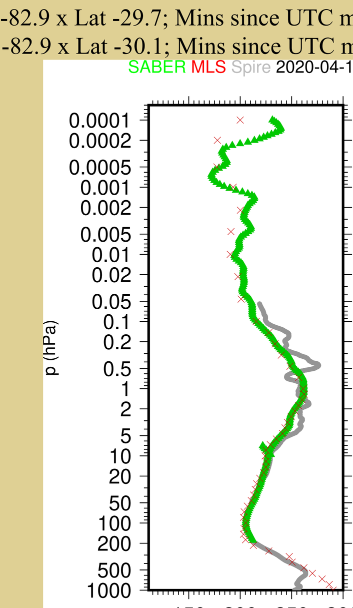


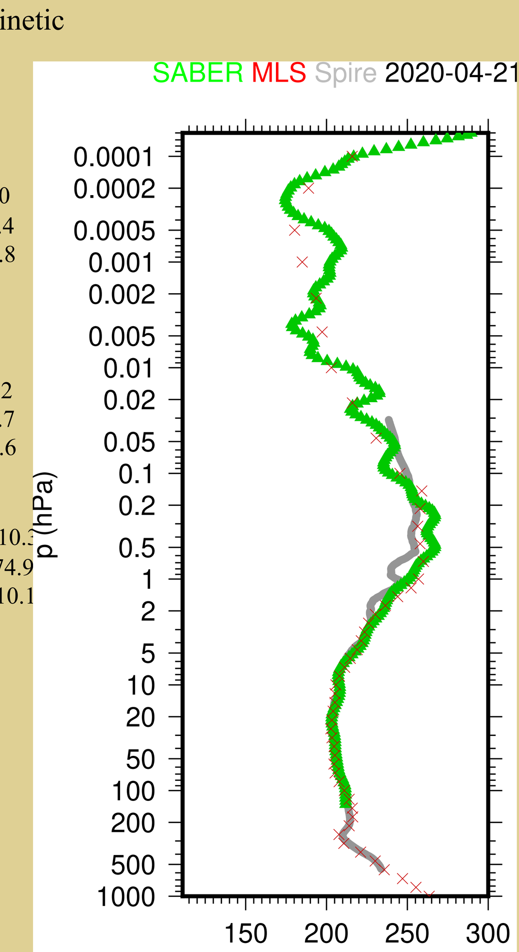
Dry temperature retrievals (Spire) compared to Kinetic Temperature (SABER, green symbols) and MLS Temperature (red symbols)

2019-12-27 within 16 minutes (Equatorial)
SABER Lon 197.1 x Lat -6.9; mins since UTC midnight 766.0
MLS Lon -163.1 x Lat -7.4; mins since UTC midnight 752.4
Spire Lon -162.7 x Lat -7.5; mins since UTC midnight 768.8

2020-04-21 within 17 minutes (Polar)
SABER Lon 80.1 x Lat -80.9; Mins since UTC midnight 734.2
MLS Lon 79.2 x Lat -80.6; Mins since UTC midnight 751.7
Spire Lon 79.6 x Lat -80.5; Mins since UTC midnight 750.6

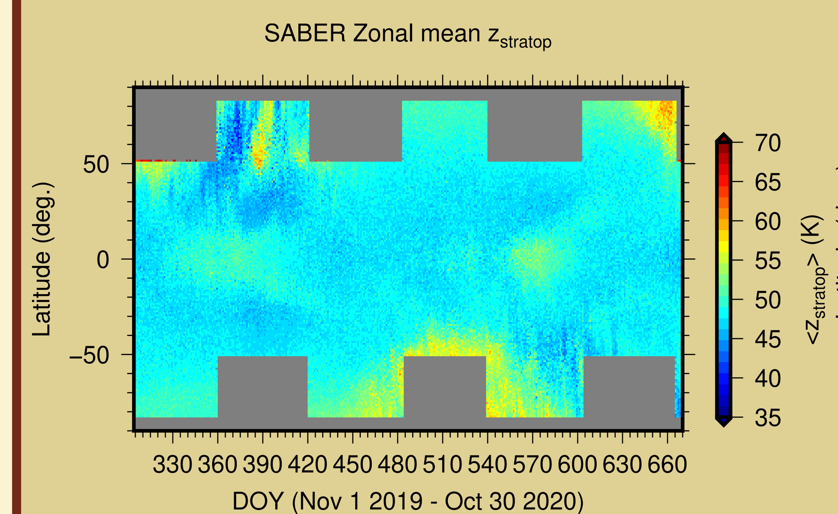
2020-04-19 within 35minutes (Low latitude -30)
SABER Lon -82.6 x Lat -30.0; Mins since UTC midnight 1210.
MLS Lon -82.9 x Lat -29.7; Mins since UTC midnight 1174.9
Spire Lon -82.9 x Lat -30.1; Mins since UTC midnight 1210.1

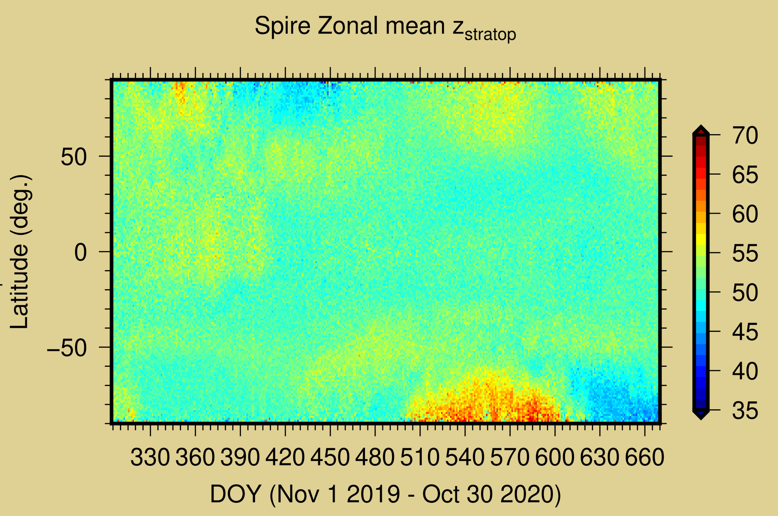




SABER & Spire stratopause heights:

Criterion
The stratopause was chosen as the warmest altitude between 20 km and 70 km on both data sets.

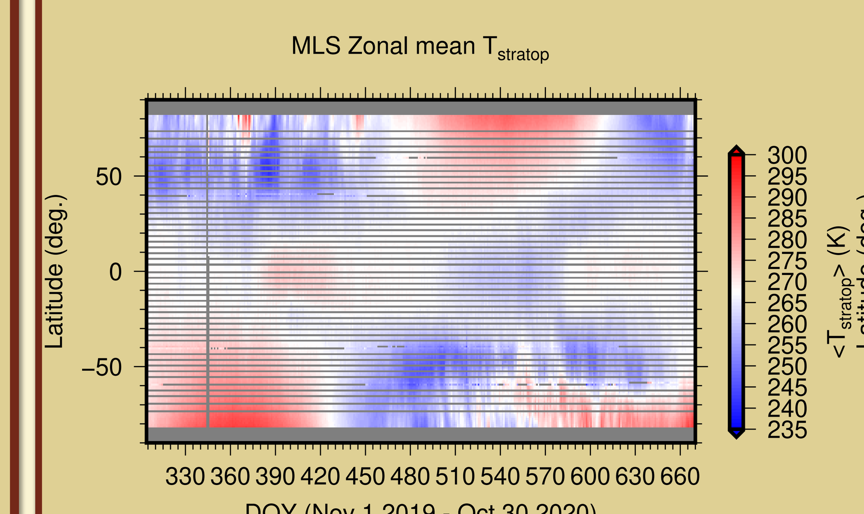


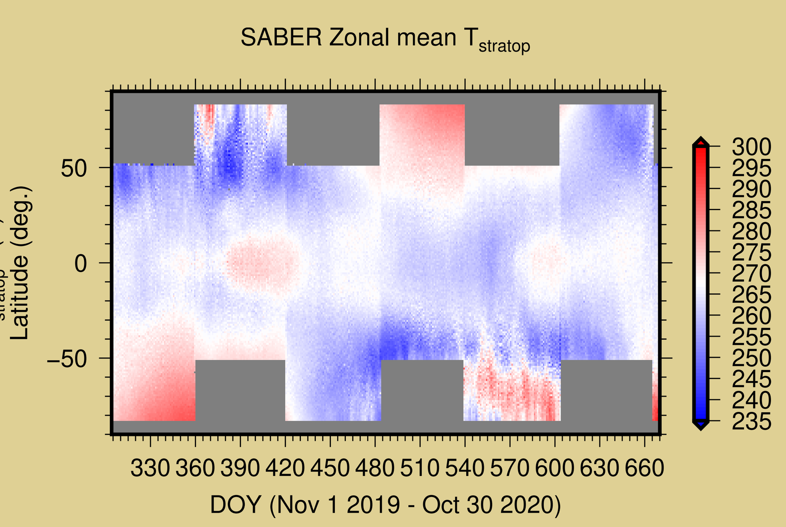


Differences
Coverage: SABER orbital changes shift coverage between 50N-80S and 50S-80N depending on the season. Spire does not.
Results: SABER shows a wider range of stratopause heights that tend to be lower than with Spire.
The seasonal variability in stratopause altitudes has some coincidences, but clear differences.

Stratopause Temperatures MLS vs. SABER:

Temperatures from SPIRE are not reliable yet at these altitudes and were not included in this part of the comparisons.





MLS and SABER show very similar temperature patters at the stratopause
There appears to be a propagating warm wave from the Summer Southern pole to the Northern Summer pole that is not visible from North to South.
Theres is a propagation from the equator to the Southern polar latitudes starting near DOY 420.
This warm pattern coincides with a slightly higher stratopause height.

Raw vs. optimized bending angle:

There is work for improvement to get stratopause temperatures in Spire data.
The current optimized bending angles do not miss the structure, but may be prone to introduced a priori climatologies.
Next step Is to explore the raw angle without optimization.

Summary

- <u>**Spire data have a dense coverage**</u>: denser in space and time than SABER or MLS.
- <u>**Comparisons to MLS are only possible in Pressure coordinates**</u>:
 This requires finding methods that enable better retrievals at altitudes above the stratopause.
- <u>**Comparisons to SABER are possible in height coordinates**</u>
- <u>**Spire stratopause altitudes are typically higher than on Spire**</u>:
 Altitudes are the better magnitude to validate against SABER, better than temperatures that are more sensitive to initialization biases.
 Spire estimates the altitude of the warmest point between 20 km and 70 km to be slightly higher than SABER. At the same time, its range of altitudes is narrower than for SABER.
 Individual profiles have to be analyzed separately to understand why SABER stratopause altitudes can be wo much higher. Wave activity that is smoothed out in Spire optimized retrievals is one possible factor, but there may be other.

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