

The MUSTARD project: Development of a long-term upper-stratospheric and mesospheric temperature record from limb sounding radiometers and occultation instruments

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Workshop of the SPARC Temperature Trends Activity

9 – 10 April 2015

Victoria, BC

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- I won't presume to preach to this crowd about the importance of middle atmospheric temperature.
 - Impacts of greenhouse gasses
 - Impacts of ozone loss and recovery
 - Paucity of observations compared to lower in the atmosphere
 - Needs for process studies in addition to climate studies (SSWs, PMCs)
 - Verification of models and DAS
- We particularly want to bring the UARS MLS temperature record to the table
 - Reprocess the record with modern algorithms/compute power
 - Combine with other similar (high vertical resolution, global) records
- This talk is in anticipation of these climate data records rather than a presentation of them.



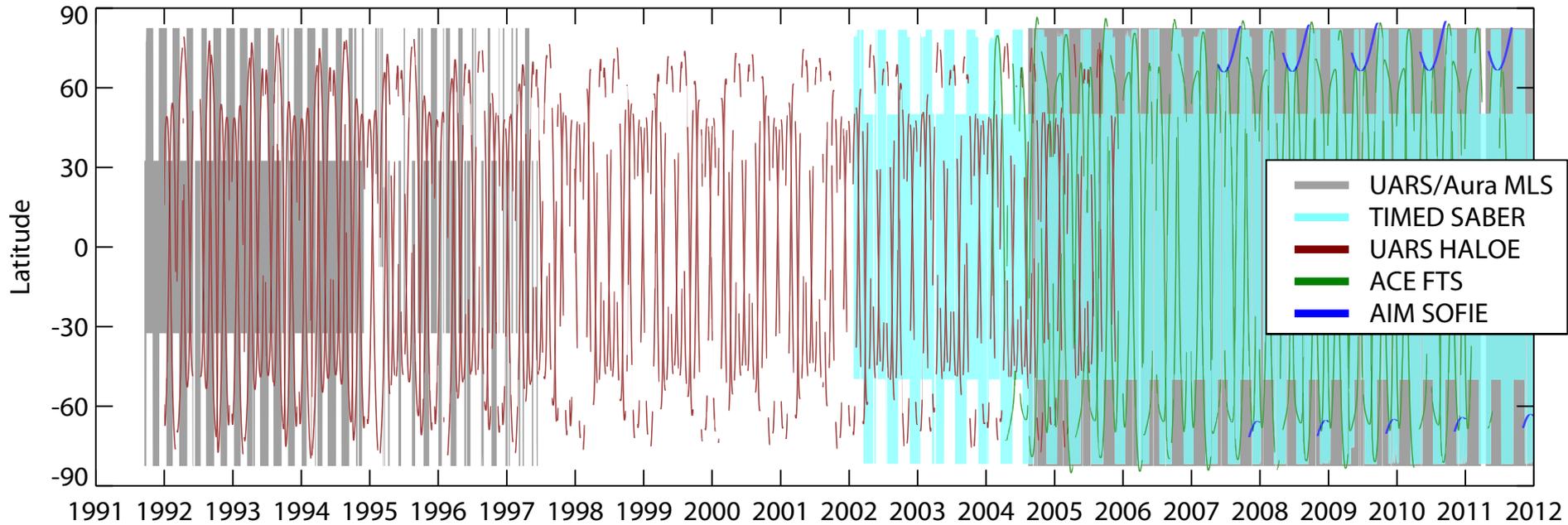
Mesospheric and Upper Stratospheric Temperature and Related Datasets

- MUSTARD is a JPL-led, MEaSUREs-funded project to produce a long-term observational record of US/M temperature and GPH.
 - Three Limb Emission Radiometers:
 - [UARS MLS](#) (1992–1997), [Aura MLS](#) (2004–present) and [TIMED SABER](#) (2002–present)
 - provide near-global, daily, day & night, along-orbit coverage -->daily/monthly maps
 - good vertical resolution in the middle atmosphere compared to nadir sounders
 - Three Solar Occultation instruments:
 - [UARS HALOE](#) (1992–2005), [ACE-FTS](#) (2004–present), [AIM SOFIE](#) (2007–present)
 - provides excellent precision and vertical resolution
 - sparse latitudinal and temporal coverage is limited to one sunrise and sunset per orbit
 - US/M temperature data sets are generally high-quality and well-characterized
 - HALOE operational period overlaps that of all three emission radiometers, providing a potential transfer standard
 - Odin SMR, UARS ISAMS and ground-based lidar provide correlative data
 - SSU, SSMIS are not included (they lack definitive temperature products)

- Nathaniel J. Livesey (PI), Michael J. Schwartz (Co-I), William G. Read (Co-I)
 - MLS Science Team members at JPL
- Gloria L. Manney (Co-I) Northwest Research Assoc./NMT & MLS Science Team
 - Derived meteorological fields lead
- Ruth Lieberman (CO-I) GATS inc.
 - Spectral decomposition and synoptic mapping lead
- John Anderson, (Co-I) Hampton University
- Collaborators
 - James M. Russell (Hampton University) AIM and SABER PI
 - Kaley A. Walker, (University of Toronto) ACE-FTS deputy PI
 - I. Stuart McDermid, (JPL) Ground-based LIDAR correlative data
 - Karl Hoppel (Naval Research Laboratory)

- New UARS MLS and Aura MLS Level-2 temperature (profiles at measurement locations)
 - Definitive UARS MLS US/M temperature, properly accounting for Zeeman splitting of lines by the geomagnetic field, leveraging Aura MLS operational code
 - “Independent” Aura MLS US/M temperature using trendless, climatological a priori
- Use spectral analysis of the radiometer data (accounting for longitude/time precession of zonal observations using the Salby method)
 - characterize diurnal-scale zonal variability (tides, multiday zonal waves)
 - Use resulting Fourier components to produce synoptic (at a single time) daily maps and facilitate comparison of data sets with different spatial and temporal sampling
- Produce daily and monthly maps and zonal means from the three radiometer data sets and monthly zonal means from the three occultation data sets
- Identify biases between instruments, using Fourier components to reconstruct radiometer observations at correlative observation times/locations and using HALOE observations (which overlap the three radiometers) as a transfer standard
- Produce bias-corrected versions of all six temperature records
- Produce derived fields including GPH, winds, PV, static stability, stratopause height.

Temporal and Latitudinal Coverage of Observations

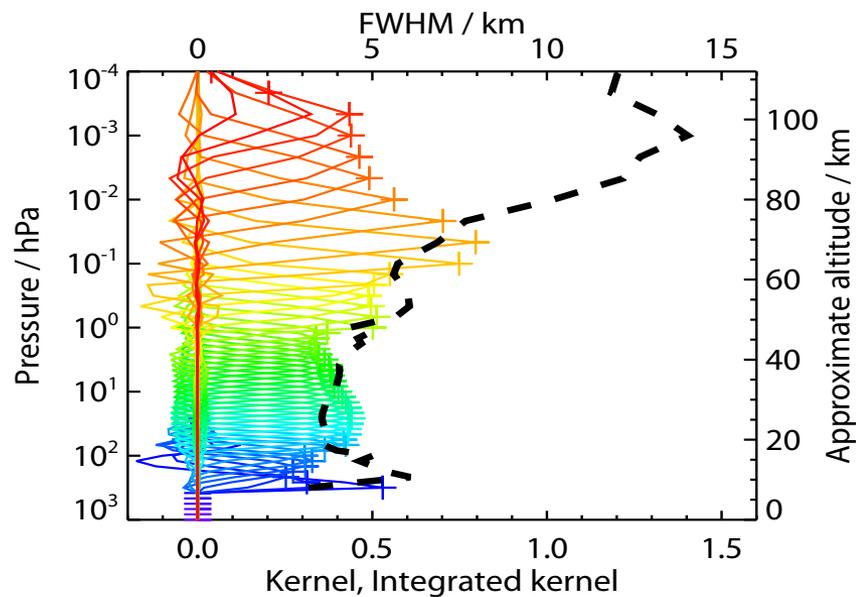
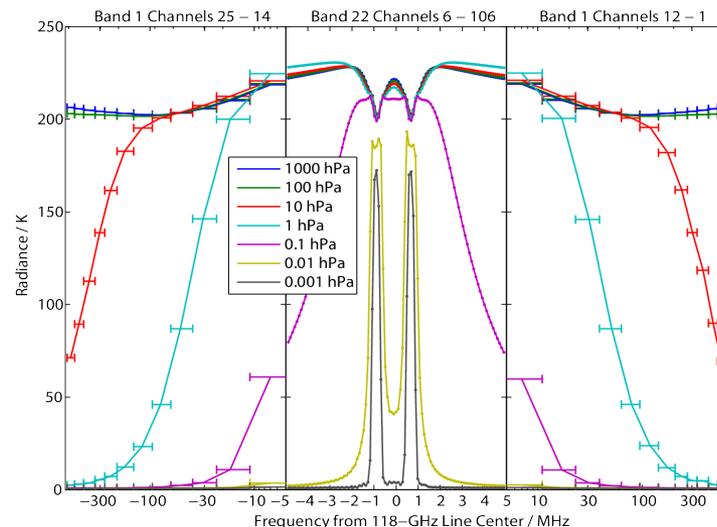


- ◆ Emission Radiometers: provide daily, near-global coverage
 - ◆ UARS, TIMED observe high latitudes in only one hemisphere at a time, yawing ~monthly
 - ◆ Aura is sun synchronous while UARS and TIMED observation times precess
- ◆ Solar occultation instruments:
 - ◆ HALOE and ACE-FTS sunrises and sunsets move through latitudes (~monthly)
 - ◆ AIM SOFIE observes only high latitudes.

Aura MLS Temperature Level-2 Reprocessing



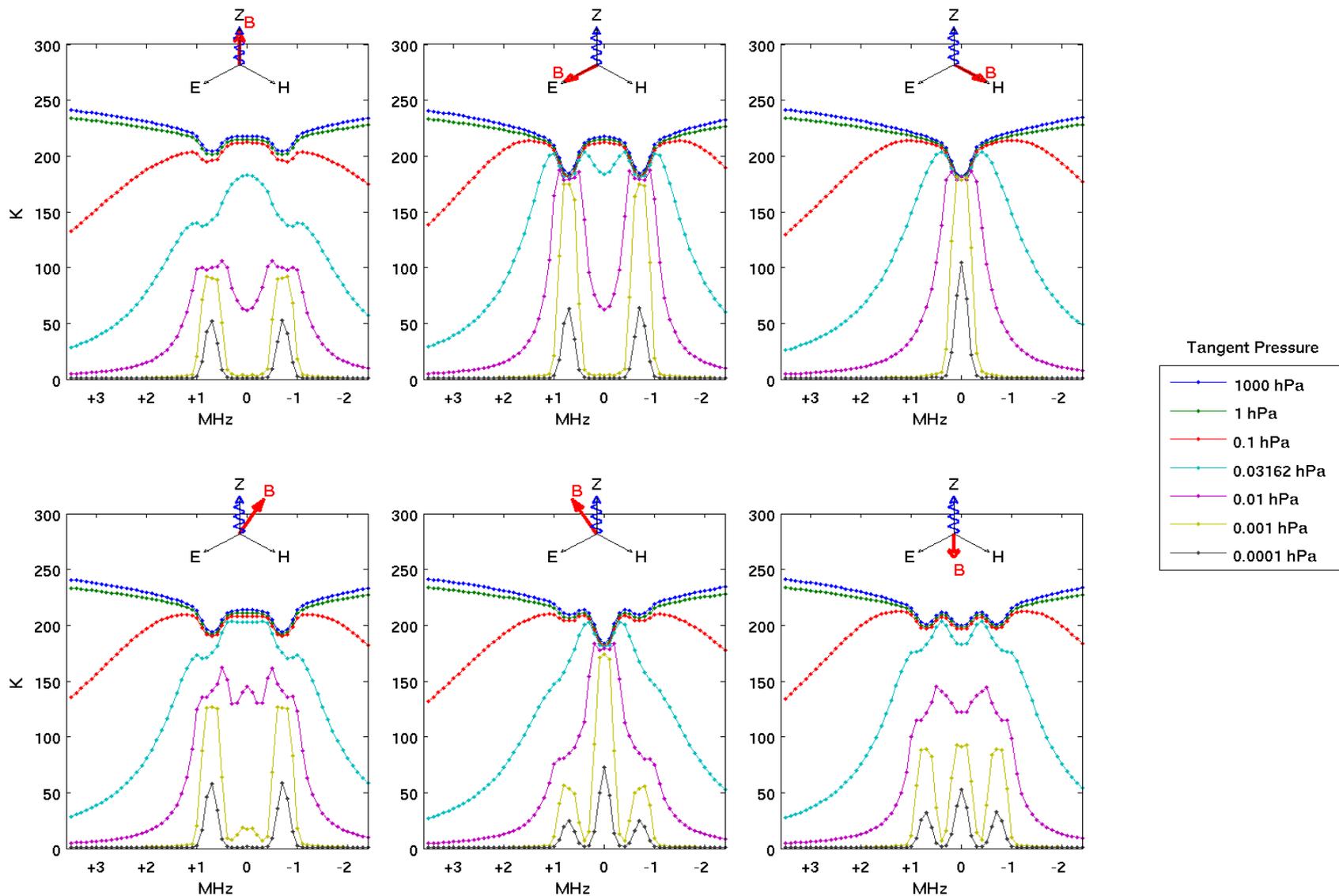
- Refinements to Aura MLS retrieval algorithms for MUSTARD reprocessing include:
 - ✧ Use of a trendless temperature *a priori* rather than GEOS-5
 - ✧ Better assumed O₂ mixing ratio
 - ✧ Improved assumed geomagnetic model
 - ✧ Extended forward-model 2D representation in the direction of the spacecraft to better account for saturated line centers
 - ✧ Adjustment smoothing parameters
 - ✧ Attempt to improve internal consistency of saturated and hydrostatic temperatures
 - ✧ Vertical resolution will likely be similar to that of operational Aura MLS retrievals.



Geomagnetic Field Orientation Dependence of Zeeman-Split O₂ Line Limb Radiances (118-GHz)



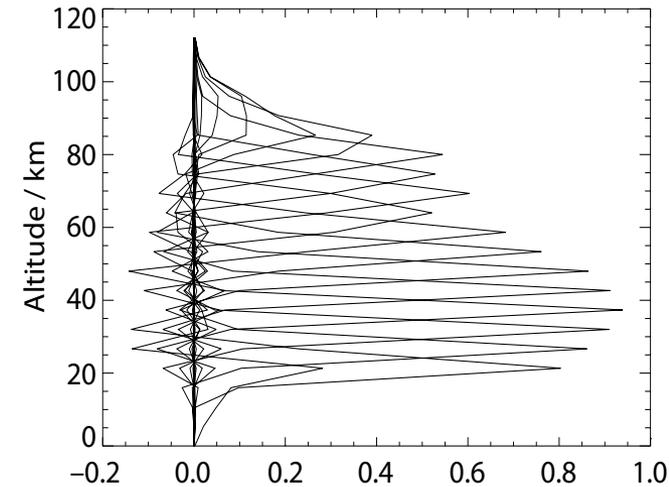
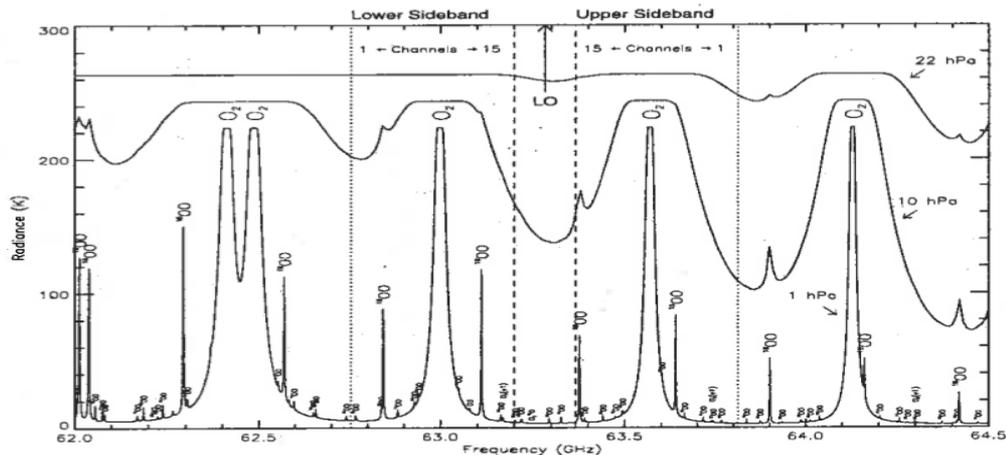
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UARS MLS Level-2 Reprocessing



- UARS MLS observes two O₂ lines near 63 GHz in the 50–70 GHz band of O₂ spin-rotational lines.
- Coupling with the geomagnetic field breaks these two lines into 198 components (the 118-GHz line used by Aura MLS has 3)
- Mesospheric radiances depend significantly upon field strength and orientation, even though Zeeman components are not resolved by the 2-MHz wide UARS center filterbank channels.
- A fraction of our current computational resources is sufficient to reprocess UARS MLS level 2 with the “Aura” algorithm, including line-by-line, polarized radiative transfer with derivatives.
- UARS views perpendicular to the satellite path, so no 2D retrieval, but magnetic field gradients along the line of sight will be modeled.

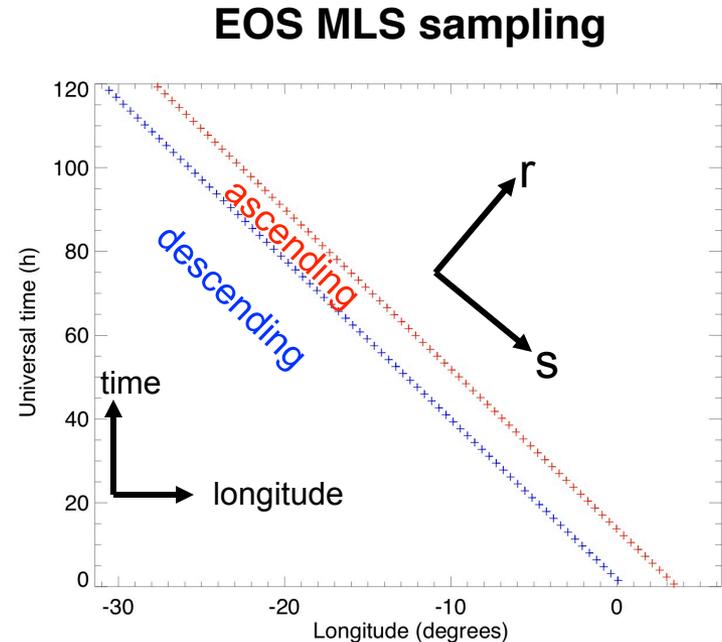


- UARS MLS 63 GHz FOV is ~2x broader than that for the Aura MLS 118 GHz observations
- We may choose to tune the retrieval to improve UARS vertical resolution at the expense of precision



- A synoptic mapping method developed by Salby (1982) will be applied to MLS and SABER temperature profiles to provide both gridded datasets and spectral coefficients:
 - Satellite measurements are inherently asynoptic (not a single time) and sampling is dependent upon orbital precession and latitudinal distribution.
 - Code developed for SABER will be adapted to UARS and Aura MLS temperature records
 - Ruth Liebermann is leading this effort.
- Diurnal tides will be characterized and filtered from the record to the extent possible:
 - Information available for tide characterization is dependent on details of satellite precession and tidal wavenumbers/directions of propagation
- Fourier components will permit reconstruction of profiles at precise locations and times of correlative data, including the occultation instruments.
- Fourier components will be archived and useful in their their own right for wave studies.
- Daily-gridded and monthly zonal mean temperatures will be produced
- “Monthly” bins will respect orbital precession and yaw cycles, as possible

- Zonal waves evolve in both space and time as they are being sampled.
- “Salby” method rotates the space to do zonal FFT in ‘s’ dimension, combines ascending and descending (‘r’ dimension), then rotates back.
- The wavenumbers and frequencies that can be observed are explicitly determined.
- The westward-propagating diurnal tide (the one that propagates with the sun) is near the Nyquist frequency and is hard to observe.
- We are investigating methods to do a 2D Fourier transform on the combine SABER and MLS data set when both are available.



$$\text{Re } \Psi_m^\sigma \exp[i(m\lambda + \sigma t)]$$

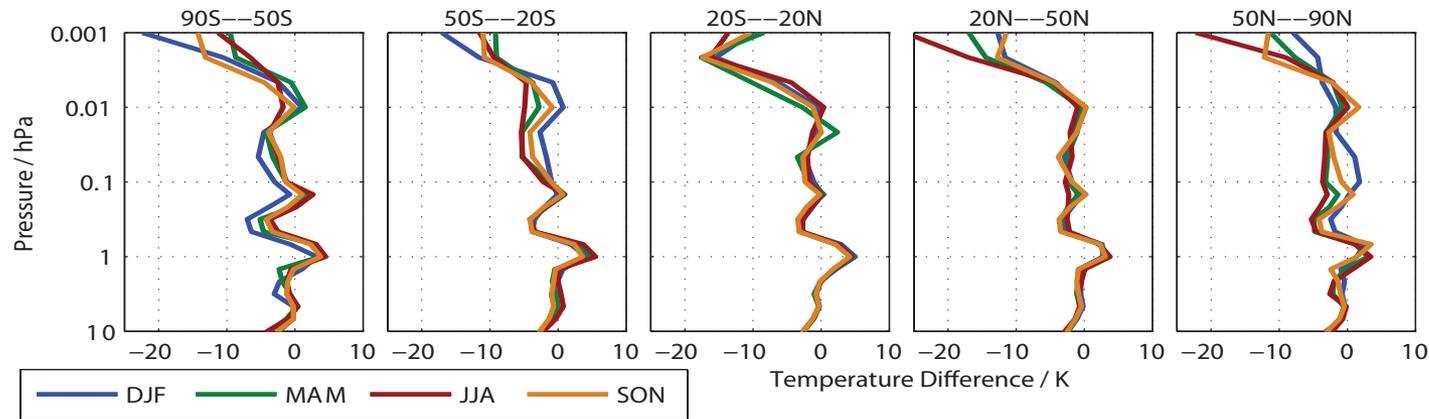


$$\text{Re } \Psi_r^s \exp[i(k_s s + k_r r)]$$

Bias Identification and Merging



- Biases will be identified between Aura MLS T and SABER T degraded to MLS resolution. Previous work suggests systematic biases exist.



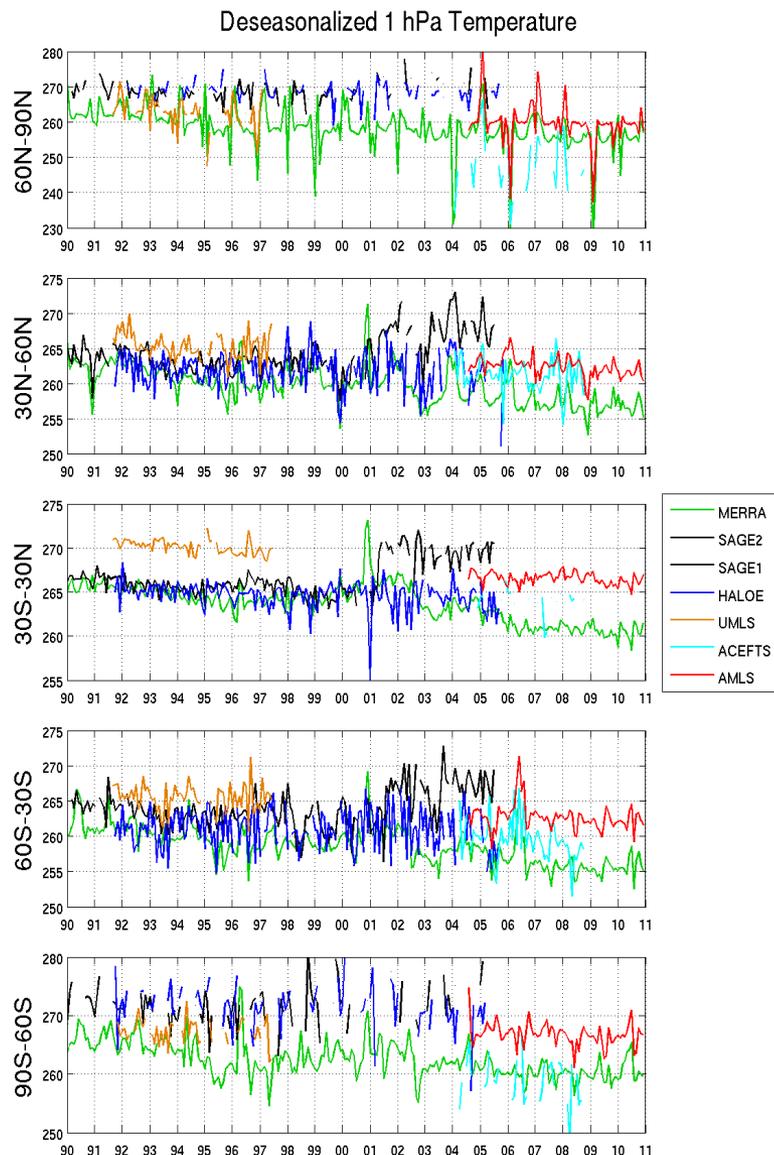
- Aura MLS/SABER T and UARS MLS T will be tied together by adjusting both to be consistent with HALOE T.
- Biases between this combined dataset and the occultation sounders, ACE-FTS and AIM SOFIE will be quantified and the occultation records will be adjusted to bring them into agreement with the HALOE/MLS/SABER unified record.
- Ground-based lidar, UARS ISAMS and Odin SMR will provide additional independent validation.
- Experience from GOZCARDS (previous MEASUREs project) will be leveraged.

Bias Correction and Merging

Example from GOZCARDS



- Examples of zonal-mean, 1-hPa deseasonalized temperature records from GOZCARDS show the kind of persistent biases that exist between instruments' temperature.
- Differences in sampling, particularly in diurnal temporal sampling of mesospheric tides and gravity waves, will make simple bias correction difficult at higher altitudes.
- We plan to avoid use of tide models,(e.g. GSWM) as they could bias subsequent model comparisons, but “Salby” methods of identifying waves are limited by twice-daily sampling.
- Lidar and occultation-instrument comparisons will be compared with “reconstructed” observations using Salby-derived Fourier coefficients.



Schedule of Activities (Five-Year Plan)



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- Software adaptation and tuning (years 1–2)
 - Currently underway
- MLS reprocessing and MLS+SABER Level 3 generation (year 3)
- Bias correction and derived products (years 3–4)
- Final validation, documentation, deliveries and close out (year 5)