SSMIS Upper Atmosphere Radiance Assimilation: Preprocessing Requirements and Preliminary Results

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Objectives

Assess the value of the SSMIS Upper Atmosphere Sounding (UAS) radiance observations in support of the ongoing development of the Navy's high-altitude global model (NOGAPS-ALPHA*). The model includes the atmosphere from the ground to the lower thermosphere (~130 km), integrating state-of-the-art developments in high-altitude weather and climate monitoring. The development also requires extending the NRL's 4D-VAR data assimilation system (NAVDAS-AR*) to 100 km by modifying the background error structure functions (correlations) and error variances.

NOGAPS: Navy Operational Global Atmospheric Prediction System
NOGAPS-ALPHA: NOGAPS Advanced Level Physics, High Altitude
NAVDAS: NRL Atmospheric Variational Data Assimilation System (3DVAR)
NAVDAS-AR: NRL Atmospheric Variational Data Assimilation System (4DVAR)

NOGAPS-ALPHA backgrounds utilized NAVDAS to assimilate temperature retrievals from NASA's SABER and MLS research instruments between 32 and 0.01 hPa.

Data Assimilation Basics

In an operational NWP model, **data assimilation** is used to incorporate real-world observations. The goal of data assimilation is to give the best estimate (**analysis**) of atmospheric state for the NWP initial conditions by combining forecast model fields (**background**) and **observations**.

We minimize a penalty function:

$$J(x)=\left(y-\mathcal{H}(x)\right)^T R^{-1}\left(y-\mathcal{H}(x)\right)+\left(x-x_b\right)^T P_b^{-1}\left(x-x_b\right)$$

(forward operator; analysis variables; background; observations; observation error covariance; background error covariance)

This is an optimal estimation problem constrained by the error covariance matrices of the background and the observations. The solution is:

$$\vec{x}_a-\vec{x}_b=\mathbf{P_b H}^T\left(\mathbf{H P_b H}^T+\mathbf{R}\right)^{-1}\left(\vec{y}-\mathcal{H}(\vec{x})\right)$$

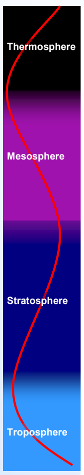
(correction; Jacobian; innovation)

Upper Atmosphere Sounding Instruments

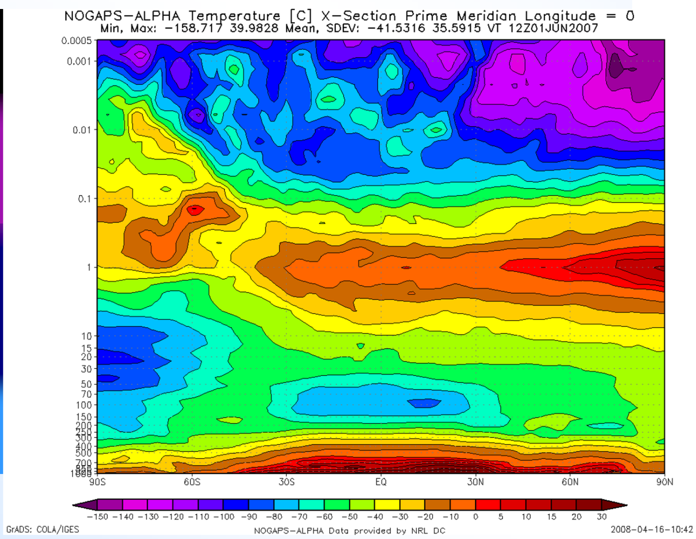
- Temperature sounding data used operationally at NWP centers include both microwave (AMSU) and infrared sounders (HIRS, AIRS, and IASI). These are effective up to about 1 mb (40 km). The recently launched EUMETSAT METOP satellite has AMSU, HIRS and IASI (infrared) sensors.

Other satellite instruments that measure the temperature of the stratosphere and mesosphere include:

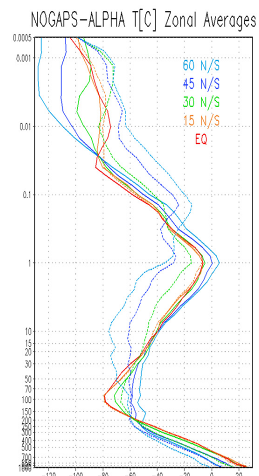
- DMSP SSMIS includes Upper Air Sounding (UAS) channels in the 60 GHz oxygen absorption band which extend the range of downward-viewing microwave radiometers to around 85 km altitude. SSMIS is an operational sensor and data are available in real-time.
- NASA's IR and microwave limb sounders, SABER and MLS, sample the atmosphere from about 10 km to 100 km with high vertical resolution (but poorer horizontal resolution). SABER and MLS are research sensors and data are not available in real-time for operational NWP applications



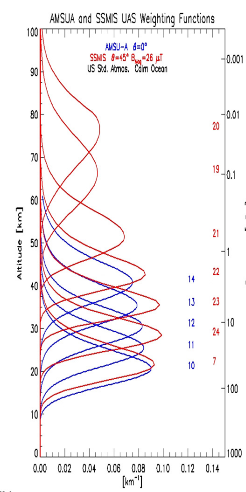
Typical Temperature profile of the atmosphere.



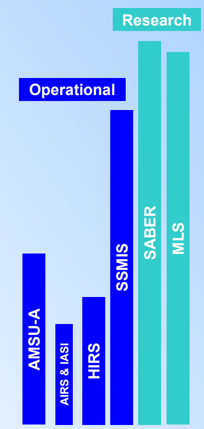
NOGAPS-Alpha L61 X-Section



NOGAPS-ALPHA Zonal Averaged Temperature Profiles



Weighting functions of highest-peaking channels on AMSU-A and SSMIS instruments



Approximate altitude range of some satellite temperature-sounding instruments

Upper Atmosphere RTMs

Data assimilation requires both the forward RTM and its adjoint (Jacobian).

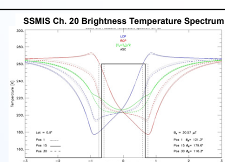
Forward RTM computes brightness temperatures from the model background model fields and geomagnetic field parameters with respect to the SSMIS viewing angle.

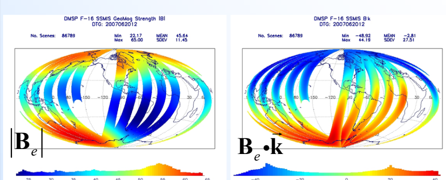
The Jacobian maps differences between the observed and background brightness temperatures (i.e., innovation) back to changes in the background temperature profiles (i.e., the correction).

Operational data assimilation requires a fast and accurate RTM and adjoint -- 6 hours of satellite radiances in under 5 minutes

The fully polarized NRL line-by-line model is computationally intensive. Plans are to use the Community Radiative Transfer Model including the Zeeman parameterization (CRTM-Z), developed by the Joint Center for Satellite Data Assimilation (JCSDA).

SSMIS channel 20 T_B spectrum under weak geomagnetic conditions in an ascending node for various polarizations and scan positions. Dashed vertical lines represents an 80 kHz uncertainty in the center frequency stability, which also represents the equatorial maximum magnitude of the Earth rotation Doppler shift.

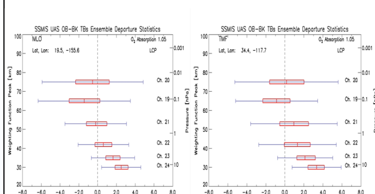




Geomagnetic field $\mathbf{B}_e$ (left) and $\mathbf{B}_e \cdot \mathbf{k}$ (right) for SSMIS observation locations.

SSMIS T_B Calibration vs. LBL RTM and Lidar

- Compared T_B from line-by-line (LBL) RTM using coincident Lidar profiles from Table Mountain, CA and Mauna Loa, HI, merged with (ECMWF and COSPAR) for all scenes within spatial and temporal matchup criteria (150 km and ±1.5 h)
- SSMIS Observed $|\mathbf{B}_e|$, $\mathbf{B}_e \cdot \mathbf{k}$ and θ_B used for each scene in RTM
- Compare to observed SSMIS TBs (SDR)
- SSMIS Observations Agreed within Calibration Uncertainties



Boxes show the median and interquartile range (IQR). Whiskers show range of data out to 1.5 times the IQR range.

SSMIS UAS Preprocessing and RTM Comparisons (LBL vs. CRTM-Z)

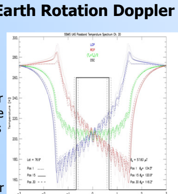
- Global Simulations using NOGAPS-ALPHA and CIRA-86 Climatology
  - NOGAPS-ALPHA extends to 0.0005 hPa (~95 km)
  - CIRA-86 Climatology extends T(p,z) to 100 km
- NRL LBL RTM vs Fast Model with Zeeman Effects Included
  - CRTM-Z compares to LBL within 1.0 K in the mean
  - NRL LBL -- 6 Hours of CPU time per SSMIS rev
  - CRTM-Z -- under 30 seconds per SSMIS rev
- NRL LBL explicitly calculates Zeeman effect on TBs
- CRTM-Z Zeeman effects use regression based predictors:
  - $|\mathbf{B}_e|$, $\mathbf{B}_e \cdot \mathbf{k}$ and $\cos(\theta_B)$
  - Integer powers (-2, -1, 2, 3) of $|\mathbf{B}_e|$, $\mathbf{B}_e \cdot \mathbf{k}$ and $\cos(\theta_B)$
- Global Simulations and Radiance Assimilation of SSMIS UAS data now possible with CRTM-Z
- Software has been developed to compute propagation vector from the TDR file and extract geomagnetic field components from SSMIS data base files (geomag_db)
- Doppler shift due to spacecraft motion is compensated to first order by Local Oscillator tuning in the hardware based upon scan position to within 0.75 to 15 kHz (a small fraction of narrowest UAS sideband, 1.3 MHz)
- Doppler shift due to Earth rotation has a maximum magnitude of ~80 kHz at the equator and is an odd function of the scan position. The sign of the shift also depends upon the orbital mode (ascending/descending)

Zeeman Effect

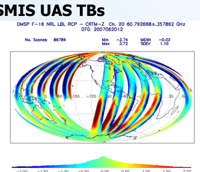
- Interaction of O_2 absorption spectrum with geomagnetic field (B_e) leads to Zeeman splitting of absorption lines.
- Important for upper atmosphere remote sensing (above ~40 km) within the microwave oxygen spectrum
- Leads to a shift in peaks of the weighting functions depending on the strength and orientation of B_e
- Upper atmosphere radiative transfer (RT) calculations require anisotropic polarized radiative transfer to resolve Zeeman splitting due to the interactions of the directional geomagnetic field and the permanent dipole moment of the O_2 molecule.

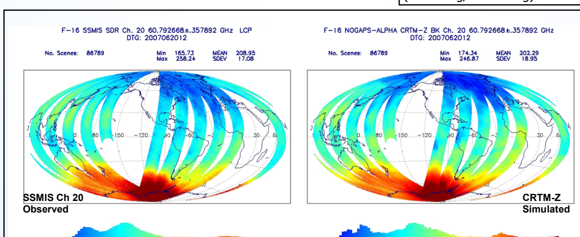
Importance if the Earth Rotation Doppler on Circular Polarized SSMIS UAS TBs

Simulated Brightness Temperature Spectrum for SSMIS Ch 20 for a strong magnetic field case across the channel passband for beam positions 1, 15, and 30 (left, center and right of scan). The slope of the spectrum across passband denotes the greater sensitivity of LCP and RCP to small frequency shifts compared to the $(T_V+T_H)/2$ measurement originally planned for the SSMIS. The dashed line about the passband (black rectangle) represents an uncertainty of 80 KHz about the center frequency.



NRL LBL with Earth Rotation Doppler Shift vs. CRTM-Z without Earth Rotation Doppler Shift for ascending revs of SSMIS Ch 20 over the western pacific. Differences indicate the importance of including both the Earth Rotation Doppler Shift in the RTM calculations and properly parameterizing the Zeeman effects and orientation of the Earth's magnetic field.

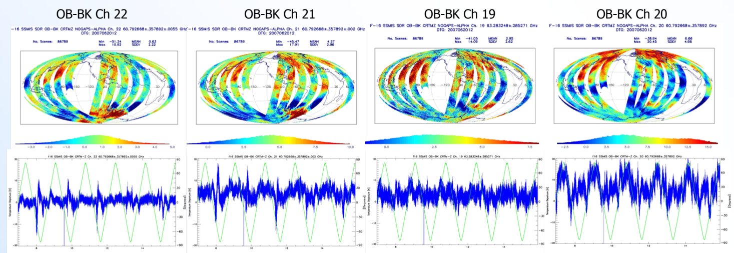




SSMIS UAS Radiance Assimilation Requirements

1) NWP Model T(p) to 100 km
2) Fast Radiative Transfer Model including Zeeman Splitting effects
3) Geomagnetic Field and Orientation with SSMIS Viewing Geometry

Preliminary Results SSMIS UAS Radiance Monitoring



Time Series of UAS OB-BK

Future Work

- Further validation of JCSDA CRTM-Z to determine the importance of including the Earth rotation Doppler effects into RTM
- Develop methodology to assimilate the SSMIS UAS TBs into NOGAPS-ALPHA using CRTM-Z simulations
- Develop and validate NAVDAS-AR assimilation of SSMIS radiances for upper atmospheric analysis and modeling
- Develop and validate NAVDAS-AR assimilation of AIRS, HIRS, and IASI radiances for upper atmospheric analysis and modeling.

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