Assessing the skill of AIRS to derive upper troposphere humidity by comparison with in-situ measurements

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ABSTRACT Understanding upper troposphere humidity (UTH) is important in the context of radiative forcing and climate. We present a detailed statistical comparison of upper troposphere water vapor retrieval profiles derived from the Atmospheric Infrared Sounder (AIRS) and in-situ measurements. The in-situ measurements are based on a recently compiled database of "best estimate" atmospheric state profiles, obtained from a careful selection of RS-90 radiosondes at Department of Energy Atmospheric Radiation Measurement (ARM) sites, during AIRS overpasses. The aim of this research is to improve the skill and accuracy of the retrieval algorithms in order to understand and quantify the biases between AIRS and RS-90 radiosondes.

Upper troposphere studies have been receiving growing attention due to the open controversy about the overall positive or negative water vapor feedback to increasing surface temperature, resulting from enhanced anthropogenic emissions of carbon dioxide. In fact, current general circulation models predict that roughly two thirds of the total water vapor feedback originates from the upper troposphere. Indeed, the outgoing longwave radiation (OLR) is highly sensitive to changes in this region of the atmosphere from which much of the OLR escapes and where, due to the low temperature, the climatological humidity is relatively low.

Extended observations of upper troposphere humidity have been made possible by satellite sounders that have the ability to characterize water vapor distributions on a global scale. Since September 2002, the Atmospheric InfraRed Sounder (AIRS) onboard the Earth Observing System Aqua satellite, has allowed the retrieval of water vapor and temperature soundings for weather and climate studies. The pre-launch accuracy requirement for water vapor retrievals was 20% with the goal of 10% in 2 km layer thickness below 100 mbar, a goal that hasn't been reached yet.

An exhaustive validation of UT water vapor retrievals is in progress and is based on a comparison study with a sample of in situ measurements carefully selected very close in time and space with the satellite overpass, in order to reduce uncertainties coming from the spatial and temporal variability of the atmosphere over the satellite sensor footprint. In this work, we describe the results of a validation study of AIRS water vapor retrievals against a specific database of "best estimates" of the atmospheric state at the Aqua overpass. This validation has brought to major improvements of the retrieval algorithm.

INSTRUMENTATION & DATA

Launched into orbit on May the 4th 2002 onboard EOS Aqua platform, AIRS is a medium resolution infrared grating spectro-radiomater. A diffraction grating system disperses the incoming infrared radiation into 17 arrays of linear detectors comprising 2378 spectral channels covering the IR spectrum from 650 to 2675 cm^{-1}. The spectral resolution is about 0.5 cm^{-1} for longwave radiation and decreases to about 2 cm^{-1} for shortwave radiation. A microwave sounder, the Advance Microwave Sounding Unit (AMSU), also accompanies AIRS. AMSU is a 15-channel temperature sounder which utilizes the 55 GHz oxygen absorption band. The AIRS field of view is 1.1 degree wide, with a nominal footprint diameter of 13.5 km. The AMSU field of view is 3.3 degree wide, with a nadir spatial resolution of 50 km and overlaps with a 3 x 3 array of AIRS field of views. Exploiting the high spectral resolution and combining the use of the AMSU instrument for microwave and infrared radiance measurements in cloudy conditions, AIRS was designed to provide retrievals of temperature and water vapour with high vertical resolution (1-2 km from the surface through the upper troposphere and lower stratosphere)

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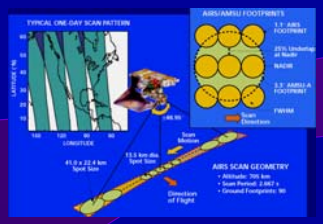

AIRS technical characteristics

Aqua launching from Vandenberg Air Force Base
www.jpl.nasa.gov

The best estimate validation dataset is the result of a collaborative effort between the AIRS Science Team, the NASA Earth Observatory System project and the Department of Energy Atmospheric Radiation Measurement (DOE ARM) program. It consists of an ensemble of temperature and water vapour profiles created from RS-90 radiosondes launched at the approximate Aqua overpass times at three ARM sites: the Tropical Western pacific (TWP, 166.9E, 0.5S) site on the equatorial island of Nauru, the Southern great Plains (SGP, 97.5W, 36.6N) site in North central Oklahoma, and the North Slope of Alaska (NSA, 156.6W, 71.3N) near Barrow, Alaska. These sites have been chosen to represent three of Earth's primary climate regimes. For the purpose of this study, we temporarily referred to the SGP site only. Further studies in the near future will extend our research to the complete set of acquired data. Due primarily to sensor calibration uncertainties, the absolute uncertainties in the mean biases for the SGP ensemble is estimated to be ~0.2 K below 100 mbar for temperature, and ~3% below 500mbar and ~10% from 500 to 100 mbar for water vapor.

The uniqueness of this database rests in a series of adjustments made to improve the accuracy of the measurement of the atmospheric state, particularly when dealing with the temporal and spatial variability of the data. By considering the differences between each pair of profiles launched ~60 minutes apart at the SGP site, we find that the water vapor RMS percent differences show a temporal variability ranging from 10% to 25% for both daily and nighttime cases, and differences between local ARM site profiles and those adjusted to account for the spatial variability inside the AMSU footprint, range from ~10% to 20%.

For the purpose of the present study, we further restricted our database to a subset of ARM SGP launches selected in a time range of 1 hour from the overpass time and falling in a spatial range of 50 km from AIRS FOV. We further restricted our selection by imposing a 30% cloudiness threshold, with the aim of extending our study to the full dataset in the near future. Following these requirements, the final version of the best estimates subset for the retrieval optimization analysis described in this study consists of a sample of 61 selected cases. Out of these 61 cases, only 41 cases will finally pass the quality flag restrictions of the retrieval routine.

The AIRS Product Retrieval Software (APS) has been designed to derive several geophysical parameters including temperature and water vapour profiles, IR and microwave surface emissivity, total ozone and cloud parameters.

This module solves for the solution of the radiative transfer equation :

$$\Delta X_L = S^{-1}_{n,L} \cdot \Delta R_n$$

ΔX_L: Perturbation to the first guess geophysical state (L=100 levels)

$S^{-1}_{n,L}$: "Sensitivity" matrix inverse

ΔR_n: Observed minus calculated radiance for each channel n

OPTIMIZATION (1) :

A new selection of 59 channels chosen through a careful revision of noise values, transmittance properties and altitude sensitivity

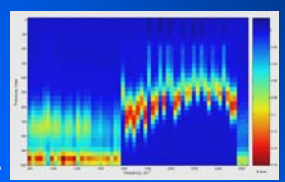

Fig.1 Water vapor sensitivity functions for the new water vapor channel list

OPTIMIZATION (2) :

The adjustment to the parameters is found by performing a singular value decomposition of the *weighted sensitivity matrix* at step *s* and iteration *i* :

$$\Delta X_L^{s,i} = U_k^{s,i} \cdot \frac{1}{\lambda_k^{s,i}} \cdot \left(U_k^{s,i}\right)^T \cdot \left(S_k^{s,i}\right)^T \cdot \left(W_{n,n}^{s,i}\right) \cdot \Delta R_n^{s,i-1}$$

$U_k^{s,i}$: Diagonalization matrix

$W_{n,n}^{s,i}$: Weighting matrix

The information content of the weighted sensitivity matrix is defined by choosing a critical eigenvalue, "λ_c" and discarding all the lower eigenvalues. This is equivalent to define a maximum value of allowed change in the parameter, ΔX_{max}. The optimum value was confirmed to be the same as the currently used in AIRS retrieval code, equal to *1*.

OPTIMIZATION (3) :

The physical retrieval is a least squares minimization between observed and calculated radiances, performed by varying the water vapor geophysical state, using the geophysical perturbation parameter ΔX_L and an associated *perturbation function, F*. For water vapor profiles, the perturbation function is given by a trapezoid with dimensionless maximum height equal to 1 and adjustable base width.

The optimum configuration found in this study, is made of 10 perturbation functions, with trapezoids heights all equal to 10% and basis limited by the following pressure levels: 0.01mbar, 170mbar, 272mbar, 314mbar, 343mbar, 407mbar, 515mbar, 617mbar, 706mbar, 852mbar, 1100mbar

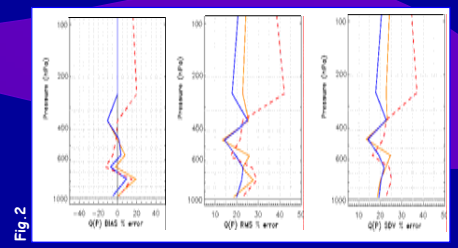

Fig. 2

Biases (left), RMS (middle) and standard deviation (right) percentage differences between the average radiosonde water vapor profile and three different average water vapor (Q(P)) retrievals: AIRS first guess (red dashed curve), original version 4.0 physical retrieval, updated version physical retrieval.

DISCUSSION:

Improvement of ~5% and ~10% in the BIAS profile at ~600mbar and ~800mbar

Improvement of ~5% in the RMS above 300mbar and at ~600 and ~800 mbar

Improvement of ~5% in the SDV above 300mbar and at ~600mbar

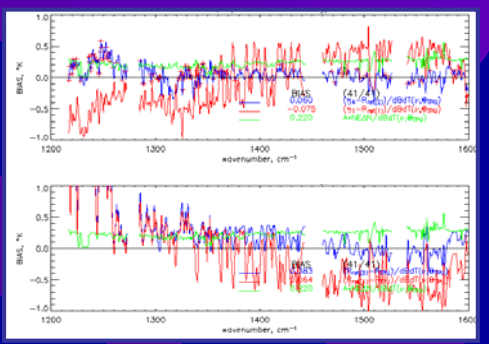

Fig.3

TOP - Red curve: cloud-cleared observed radiances ("η_1") minus the calculated radiances ("$R_{RET(1)}$") from the first guess. Blue curve: cloud-cleared observed radiances ("η_1") minus the calculated radiances ("$R_{RET(2)}$") from the physical retrieval. The cross symbols indicate the channels used in the retrieval. Both curves are converted to brightness temperature (dB/dT ^-1 factor). Green curve: estimate uncertainty in the observed minus computed effective brightness temperature.

BOTTOM – Red curve: calculated radiances from the first guess ("$R_{RET(1)}$") minus calculated radiance ("R_{TRU}") from the truth. Blue curve: calculated radiances from the physical retrieval ("$R_{RET(2)}$") minus calculated radiances ("R_{TRU}") from the truth. Both curves are converted to brightness temperature (dB/dT ^-1 factor). Green curve: estimate uncertainty in the observed minus computed effective brightness temperature. The average value is also reported for each curve.

WHAT'S NEXT?

Extension of the validation to the entire database

Further channel selection study to improve the retrieval performance, particularly in the UT region and the radiance bias comparison

Optimization study of a fourth parameter, the channel weighting term, entering in the expression of the error covariance matrix.