Evolution and Status of the Stand-Alone Radiative Transfer Algorithm (SARTA)

AIRS Science Team Meeting

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Outline of talk

- Historical Context
- Design Features
- Strengths
- Limitations
- Applications examples
- Current Needs, Future Developments

Motivation

- Produce Level 1b AIRS,CrIS, IASI and CHIRP radiances for trending and retrievals.
- Goals
  - Radiometric stability, inter-sensor bias, intra-sampling bias and trending analysis.
  - Working in radiance space is in principle very simple and quick. Allows frequent re-processing.
- What's Hard:
  - Dealing with clouds
  - AIRS radiometric stability estimates (ie. how good?)

Historical Context

- The SARTA was developed on 1990s computer systems - light load and memory requirements.
- Origninaly developed as part of AIRS level 2 retrieval suite.
- First supplied to AIRS project with separate coefficient sets for different instrument focal plane and filter temperatures.
- Since 2016 SARTA was delivered for the AIRS.L1C channel SRF specification.
- Used for AIRS validation and more recently for CrIS and IASI validation.
- In the past couple of years has been adapted for use with CHIRP.

Attributes: Strengths

- Implicitly high speed computation (even more on modern systems).
- SARTA is available for clear-sky and all-sky (scattering) computations.
- Flexible channel selection, multi-sensor compatible, relatively quick development/update turn-around.
- The scattering version uses a fast 2-slab model for clouds and aerosols (S. De Souza-Machado).
- Model includes H_2O, CO_2, O_3, N_2O, CO, CH_4, HNO_3, HDO, SO_2, NH_3, nonLTE (4.3 um), Surface emissivity and albedo, scattering from water, ice, aerosols, smoke. Other absorbers could be added.
- Accuracy well quantified.

Attributes: Dependencies

- Fast coefficients are derived using Optical Depths calculated using kCARTA - the pseudo-line by line RTA (S. De Souza-Machado)
- The atmospheric layering is currently defined as the 101 AIRS levels set, using Klayers algorithm.
- The atmospheric layering can be changed (see later).
- The data format for file I/O uses the HDF4 specification (original to AIRS project) (see later).
- The spectral line shapes use the HITRAN databases, cross-sections and various dust and aerosol models.
- Code is written in FORTRAN (this is NOT a limitation!).
- Radiometric accuracy may be improved with tuning in some regions.

Attributes: Limitiations

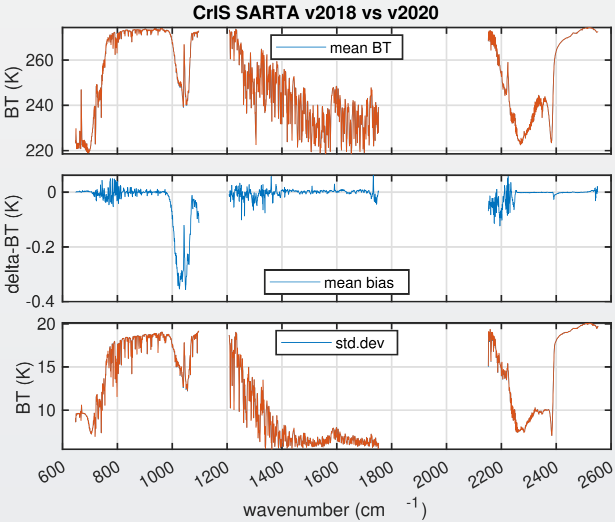
- Finite diff Jacs - until now !
- Currently uses AIRS levels - may be too fat for UTLS and narrow ILS - can be changed via klayers.
- Currently complex library of functions required for fast coefficient regression.
- HDF4 dependency.

Most Recent Updates

- HITRAN 2020 spectroscopy (data available early 2022).
- HDO included in MW and SW bands.
- New nonLTE model being tested.
- Long term trend bias accuracy for green-house gases; CO_2, CH_4, N_2O has been verified.

Updates 1: HITRAN 2020 vs 2016

- Most significant change in 1050 cm-1 O3 band.



Updates 2: HDO

- HDO lines have been modelled for all sensors in the MW and SW bands.
- Some validation has been successfully performed using ORACLES field data.

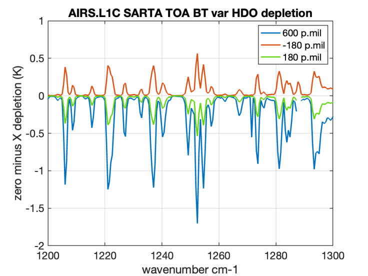


Figure 1: Simulated TOA BT changes due to varying HDO depletion, MW band.

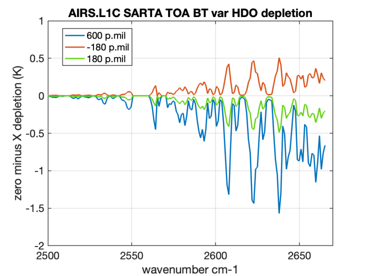
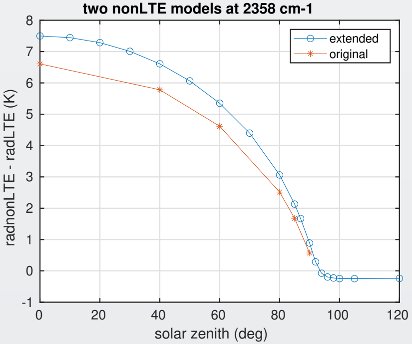


Figure 2: Simulated TOA BT changes due to varying HDO depletion, SW band

Updates 3: nonLTE

- New vibrational temperatures in the 4.3 um CO2 band have been received from Peurtas et al Instituto Astrophysica de Andalucia (Sp.) that extend the range through sunset.
- The new (extended) nonLTE model includes 19 solar zenith angles instead of 6 previously increasing the atmospheric profile training set to 5586 from 1764.



Updates 3: nonLTE (2)

- Fast coefficients using the original predictor set and several other predictors have been trialed.
- To-date there is little difference in the performance of the simulations.

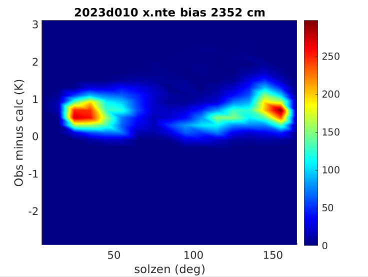


Figure 3: BT Bias vs solzen for a day of AIRS random obs at 2352 cm-1 (Untuned)

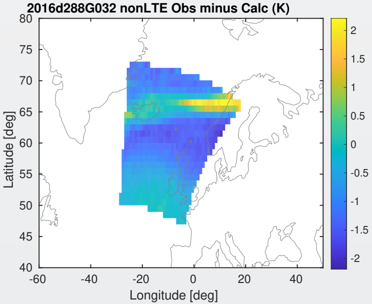


Figure 4: Auroral Emission event, Bias BT at 2352 cm-1.

Updates 4: Analytic Jacobians

- Sergio has developed a method to compute Jacobians analytically using derivatives of the predictors, currently in experimetnal phase.
- Results compare well with kCARTA based Jacobians.
- SARTA analytic Jacs are 60 x faster to compute than kCARTA Jacs.

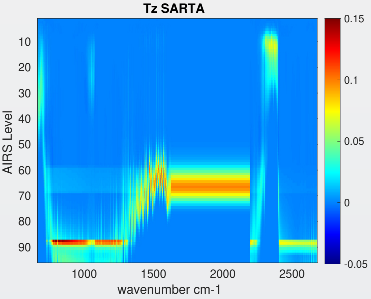


Figure 5: T(z) Jacobian from SARTA analytic.

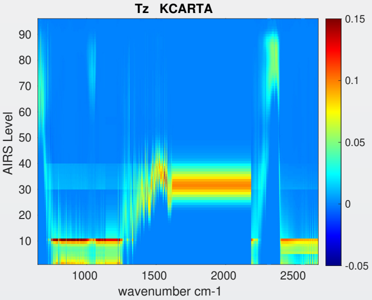


Figure 6: T(z) Jacobian from kCARTA.

Updates 5: GHG stability (1 of 2)

- Atmospheric state now includes the long-term values of CO2, CH4 and N2O, the former two as function of latitude, longitude and altitude, from ESRL.
- Obs:Calc biases for selected channels for the 20+ year AIRS mission have been evaluated. (CO and HNO3 are in development).

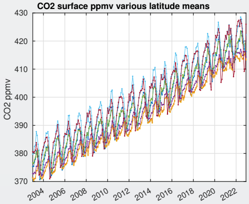


Figure 7: CO2 values for selected locations.

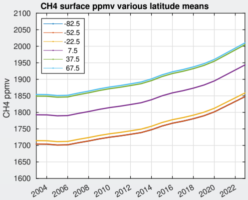


Figure 8: CH4 values for selected locations

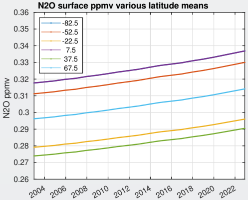


Figure 9: N2O values for selected locations

- Obs:Calc Biases are the averages of the first day of each month global random FOVs matched to NWP and ESRL.

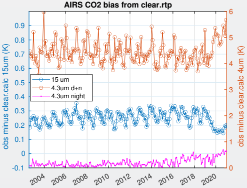


Figure 10: CO2 bias of observed and simulated radiance.

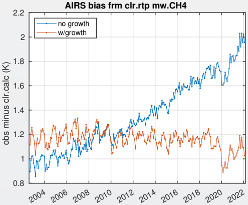


Figure 11: CH4 bias of observed and simulated radiance.

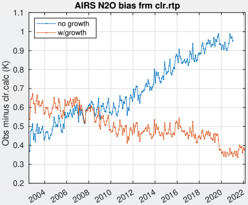


Figure 12: N2O bias of observed and simulated radiance.

Beneficial Future Changes

- Make independent (agnostic) of file format types (HDF4, H5, netCDF).
- Simplify packaging and coefficient management.
- Extend/update training set, add machine learning if demonstrably beneficial.
- Adapt to the cloud and complete open-source migration (documentation).
- Re-package code with Julia or Python wrappers for wider community use.
- Include as part of CHIRP processing suite (cloud).

Future 1: File format, Language and packaging

- Currently there are 15 separate coefficient tables with many different predictors some predictors are common amongst some sets.
- Coefficients are stored as fortran binary files.
- Atmospheric state variables are supplied to SARTA as HDF-4 format files.
- Core routines are FORTRAN, with MATLAB wrappers, linked to HDF4 libraries.
- Unification and simplification for easier access to general users.

Future 2: Adapt to the cloud

- Application to studies based in the *cloud*, esp where hyperspectral sensor data are cloud accessible, requires SARTA and dependencies portable.
- AWS (Amazon Cloud) does permit use of MATLAB licence for open-source use SARTA wrappers need to be repackaged to Julia or Python for example.
- Opensource use in general requires simplification and documentation, test and examples.

Conclusions

- Continue validation studies, include tuning where beneficial, possible refinement of modelling in UTLS.
- SARTA remains a core component of research at UMBC/GESTAR-2 having been extended to simulation of radiances for several hyperspectral infrared sensors.
- SARTA radiometric accuracy continues to meet the needs for long term stabilty and climate studies.
- SARTA is particularly useful because of the speed of computation, together with parallization supports analysis of multi-decade, global sets of complete sensor spectra.
- Adapting SARTA to a complete opensource for use in the cloud should provide easy access to wide range of users.