RTA Updates and Applications : kCARTA, SARTA and Single Footprint Retrievals

Sergio DeSouza-Machado, Larrabee Strow, Chris Hepplewhite

August 27, 2018

Department of Physics, JCET
University of Maryland Baltimore County (UMBC)

Overview

- Generally spectroscopy is the main contributor to RTA error
- UMBC is unique in that we can mix/match UMBC-LBL with LBLRTM
- Some real advancements in lineshapes now taking place, compared to last 10 years
- We are working to get these into SARTA quickly, are interacting with HITRAN (Harvard-Smithsonian), AER (LBLRTM), and CNRS (Hartmann) to ingest latest algorithms.
- More SARTA parametrization work necessary:
  - Improve fitting (neural net, etc), using thousands of training profiles
  - Can now provide error covariance matrix for SARTA parametrization errors
  - *Want to greatly simplify fitting code and SARTA for ease of use by others in the future.* This is a big job, but we want to get there.

RTA development at UMBC

kCARTA: *kCompressed Atmospheric Radiative Transfer Algorithm*

- Two versions: Matlab, f90
- Based on ~1 Gbyte compressed look-up tables
- 45 seconds for full radiance spectrum
- 0.0025 cm^{-1} spectral resolution, averaged from 0.0005 cm^{-1} data grid

SARTA: *Stand Alone Rapid Transmittance Algorithm*

- Used by NOAA NUCAPS and NASA EOS-AIRS
- Regressions over kCARTA generated optical depths
- 0.03 seconds for 2255 channels
- Training sets: UMBC profiles (49), TIGR (about 2000), ECMWF (25000)

SARTA Scattering: TwoSlab cloud representation for single footprint retrievals and for validation under partly cloudy scenes.

Code Base

UMBC Line-by-Line RTA: Voigt-VanHuber lineshape, cross-section gases, UMBC CO2 line mixing, Hartman line mixing; switches for HITRAN 1996-2016, GEISA 2015,MT-CKD continuum, ...

AER LBLRTM: Latest versions (12.4,12.8) have CO_2/CH_4 line mixing, plus MT-CKD continuum

kCARTA: Built (look-up tables) from *both* LBL's listed above! kCARTA allows us to use 100's to 1000's of fitting profiles Includes scattering if desired.

SARTA: Fast RTA model using in NUCAPS. Built from kCARTA. Includes 2-slab cirrus/water/aerosol scattering. (Cris NSR, CrIS FSR, AIRS, IASI)

Single Footprint Retrievals

- Used to test SARTA performance
- Allows radiosonde inter-comparisons under some cloud cover
- Examine single footprint fitting residuals to uncover issues

kCARTA

KCARTA Details

- Uses various HITRAN databases and water continuum models
- In addition to IR Sounder Spectral region we have 15-605 cm^{-1}, 2830-44000 cm^{-1} capability
- Clear/cloudy sky calculation includes fast analytic jacobians
- Background thermal done at each layer/wavenumber point with variable diffusivity angle
- Fluxes/heating rates can be computed

kCARTA Development: Continual!

(blue = under development)

Have continually updated kCARTA with each HITRAN release

- Past: 1996,2000,2004,2008,2012 .. now have 2016
- Recent addition: GEISA 2015 (European “HITRAN”)

H_2O: "without basement" plus continuum (MT-CKD 2.5, 3.2)

- kCARTA has HDO; will break out HDO scaling for future SARTAs

CO_2: UMBC line mixing based on 1998 data/HITRAN

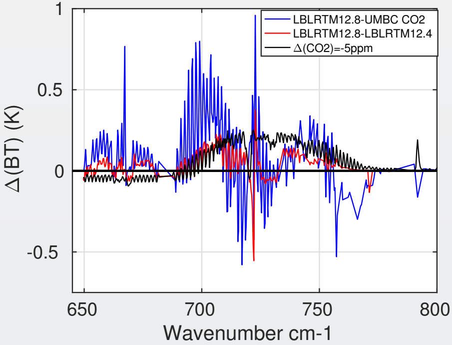
- Can use LBLRTM CO_2 line mixing, v12.4, 12.8, (from Hartmann)
- HITRAN now provides line mixing package from Hartmann, we found problems that HITRAN is fixing. Hopefully soon!
- non-LTE fitting : Updated for HITRAN 2016
- 4.3 μm collision induced absorption: CO_2:N_2, and now CO_2:H_2O Hartmann

CH_4: Our LBL code defaults to Voigt lineshape

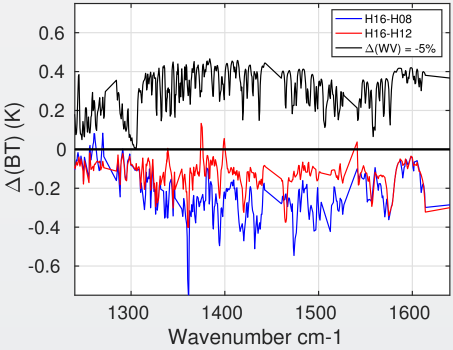
- LBLRTM has CH_4 line mixing, now used in SARTA

Comparing CO_2 line mixing, H_2O databases

CO_2 15μm



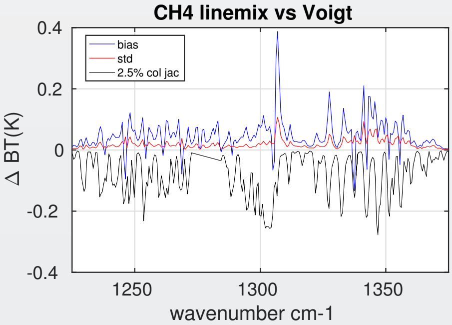
H_2O 6.7μm



Assessing CH_4 line mixing, HITRAN 2016 vs GEISA 2015

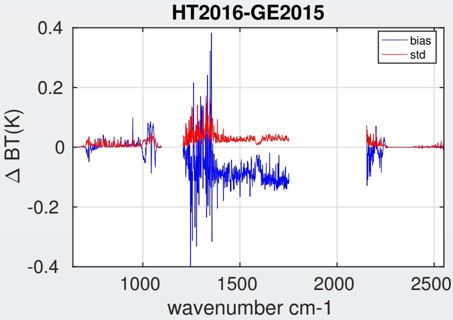
CH_4 line mixing

LBLRTM has CH_4 line mixing (H2012), we do not (H2016)



HITRAN-16 vs GEISA-15

Not all xsec gases that I use are in GEISA (will soon be fixed)



SARTA

Fast Radiative Transfer (SARTA)

- Validated against kCARTA LBL and statistical analysis of large test data sets.
- Allows computation of SARTA error covariance matrix (for parmeterization errors)
- Clear/cloudy RT calcs using eg sonde (clear) or NWP model fields (cloudy)
- Many minor gases included
- Emissivity and reflectance
  - Ocean emissivity by Masuda (wind speed dependance)
  - Land emiss by U. Wisc or NASA Langley
  - Daytime over ocean bi-directional reflectance (Nalli et. al.)

Latest CrIS FSR SARTA

Already delivered

- HITRAN 2012 (molecular and xsec gases)
- MT-CKD 2.5
- LBLRTM v12.4 : CO_2 and CH_4 line mixing

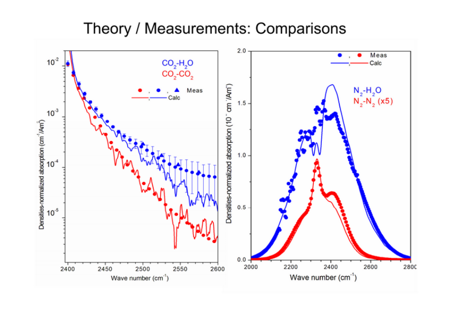
Future plans (roughly ordered by increasing complexity)

- NH_3 + MT-CKD3.2 + HITRAN2016
- HDO (column mult wrt H_2O is easy; 100 layer more involved)
- Updated CO_2 line mixing (depends on kCARTA tests)
- 4.3 um bandhead CO_2/H_2O and CO_2/N_2 CIA (depends on kCARTA tests)
- Move from linear regression to Gaussian Kernel Regression?
    - LLS is straighforward but can be inaccurate "outside training"
    - GKR is more accurate esp "outside training" regime; very promising but much more complex
- New parameterization with simplified algorithm (longer term)

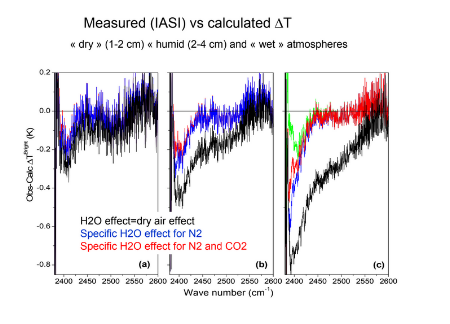
New Spectroscopy For LBL (J.M. Hartmann/H. Tran)

Recent work by J.M. Hartmann/H. Tran and others (HITRAN 2018 Conference) indicate that N_2-H_2O and CO_2-H_2O collisions are important for the 4.3 μm band head! Significant effort to incorporate into LBL and separate from existing H_2O continuum.

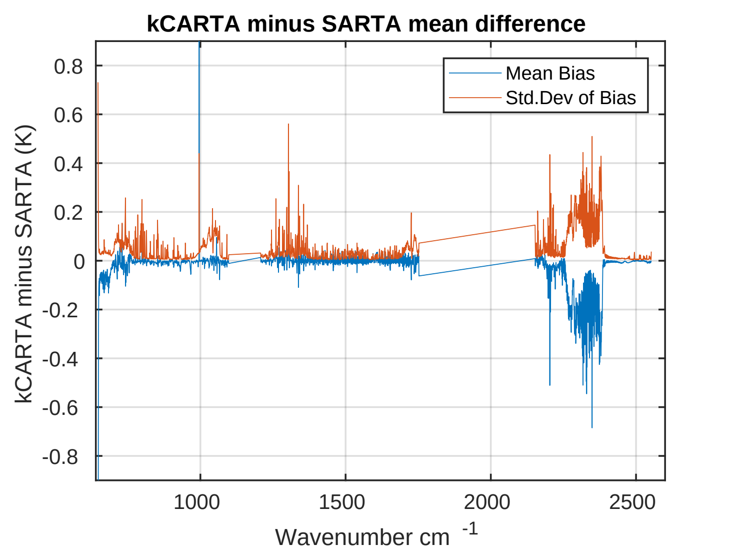
Lab Spectra



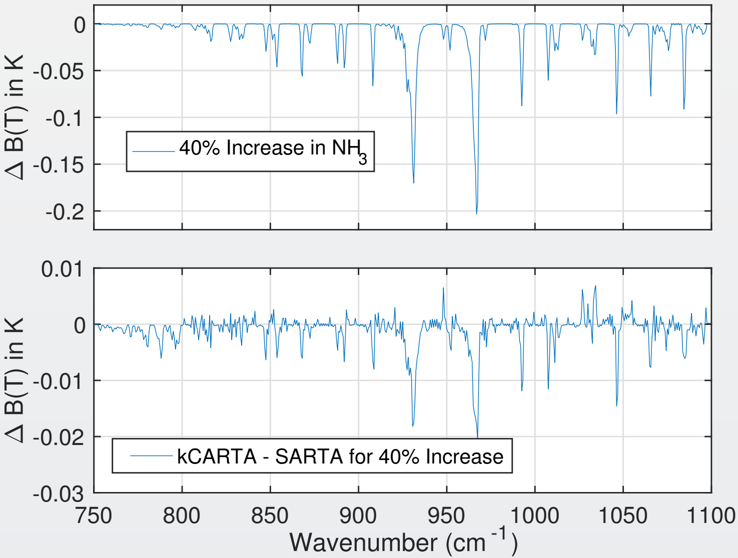
IASI Biases



SARTA vs kCARTA comparison (49 regr profiles)



NH_3: SARTA vs KCARTA



Small, mostly systematic errors (4% error for 40% variation in NH_3).

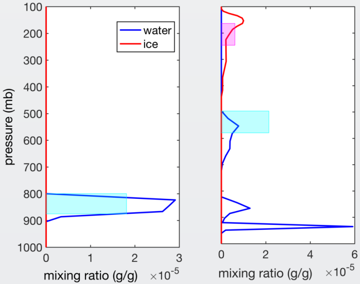
Retrievals

Single Footprint Retrievals

- Cloud Representation : NWP multilayer cloud converted to Two Slab Clouds (ice/water)
  - OEM methodology, so DOF is a natural diagnostic
  - smoothing by combination of Tikonov matrices, $\sigma(i)^2 e^{-((i-j)/h)^2}$, climatology
  - State vector : Surf temp, 100 layer T(z),H_2O (z),O3(z),ice and water clouds
  - 100 layer retrieval takes $\leq$ 2 seconds per single FOV

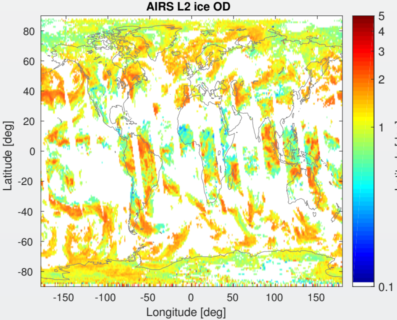
Single Footprint Retrievals, DeSouza-Machado *et. al.*, *Atmos. Meas. Tech.*, 2018

Evaluation of Radiative Transfer Models with Clouds, Aumann *et. al.*, *J. Geophys. Res*,2018

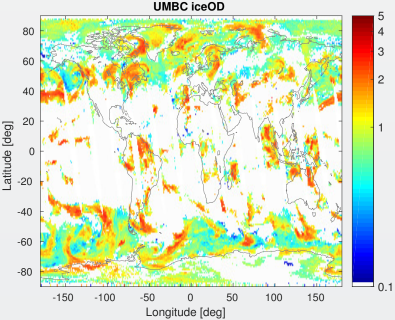


Ice Cloud ODs 2011/03/11 day

AIRS L2



UMBC

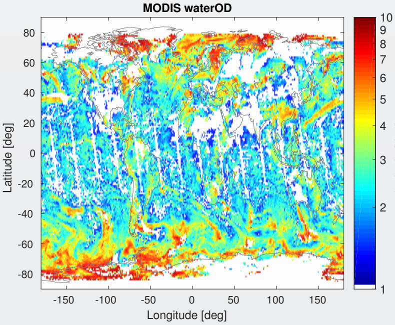


Have looked at cldforcing, and the differences in cloud OD (UMBC vs L2) are typically in regions of "low" forcing, need to investigate further

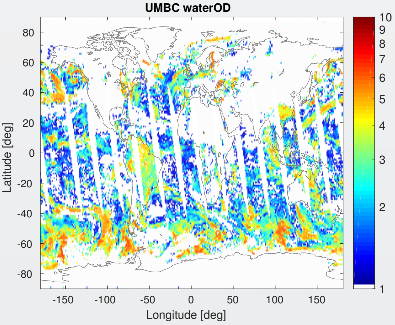
Water Cloud ODs 2011/03/11 day

(different sensor/wavelengths used in retrieval, so expect different magnitude ODs ... but patterns are similar)

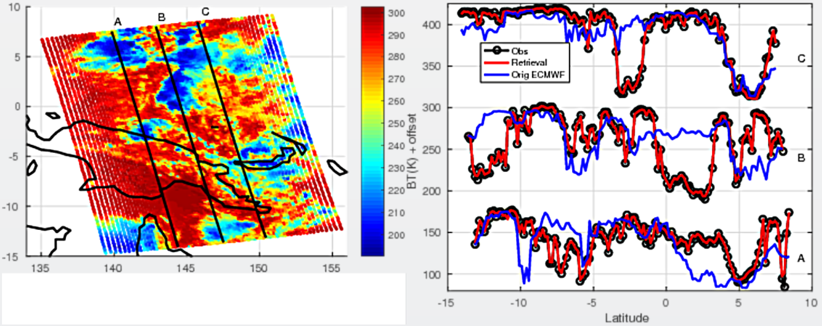
MODIS L3



UMBC



2011/03/11 g039 : DCC over TWP

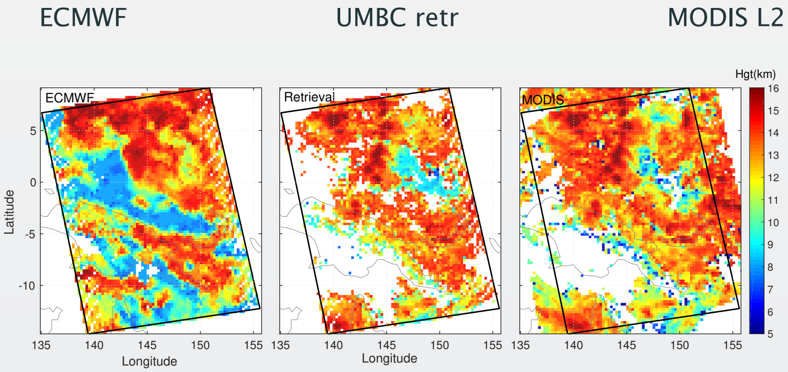


BT 1231 cm^{-1} observations and calculations, in Kelvin.

Left panel : AIRS observations for Granule 039 on March 11, 2011. The lines are at three different AIRS scan angles.

Right panel : BT1231 Observations (black) compared to calculations using the original ECMWF model fields (blue) and with the mitigated/retrieved cloud fields (red).

Ice CldTop Heights

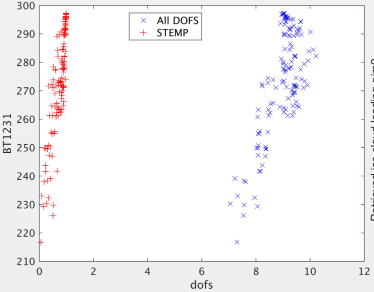


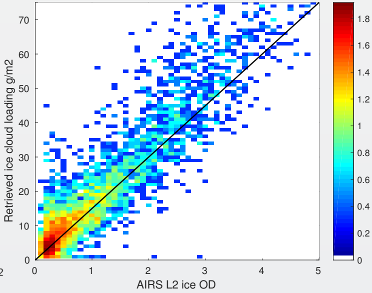
Ice clouds with OD ≤ 0.5 have been removed from plots
Note similarity to BT1231 obs (high clouds = cold obs)

DOFS and ice OD comparisons

DOFS

Ice OD





DOF scale with obs BT 1231 : Red crosses for stemp (between 0 and 1), blue crosses : all DOF (between 6 and 14)

Ice OD : UMBC cloud loading vs AIRS L2 : colorbar is log10(number of points)

Lindenberg, Germany GRUAN sondes
52.21N, 14.12 E, 98 m asl

- 3200 sonde launches over a few years, ($\sim$ 220 each month)
- Select AIRS ovepasses within $\pm$ 1 hour and 100 km of sonde launch, gives 80-100 "nearest" AIRS obs per sonde
- Match AIRS observations to ERA thermodynamic/cloud profiles (252455 "nearest" AIRS obs)
- Compare retrievals to sonde, sonde*AK and ERA
- Look at results as function of DOF

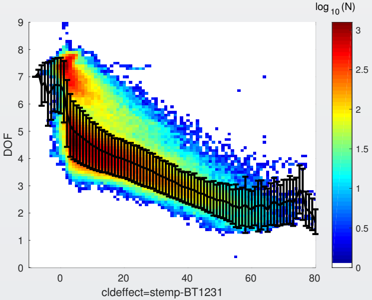
Wide variety of atmospheric conditions

- Surf temp varies from from 275 K (winter) to 295 K (summer); col water from 8 to 26 mm
- Clouds varied from none to DCC : Mean cloud forcing each month (Surftemp-BT1231 obs) = 15 K

Sonde-UMBC Retrieval

Divide the retrievals in quantiles of DOF, look at 4 quantile ranges

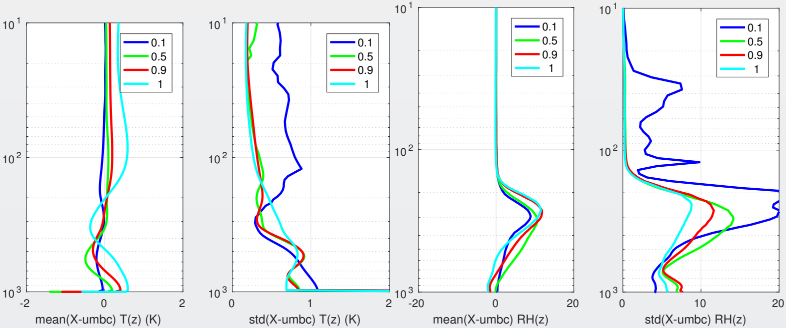
Cloud condition	Quantile range	DOF range	CldEffect(K) (rough)	Number AIRS obs
Very Thick cloud	0.0-0.1	0.00-3.12	> 50	2769
Thick cloud	0.1-0.5	3.12-4.29	20-50	43699
Medium Cloud	0.5-0.9	4.29-6.84	2-20	84579
Thin/no cloud	0.9-1.0	6.38-8.65	< 2	24742



Sonde-UMBC Retrieval

Divide the retrievals in quantiles of DOF, look at 4 quantile ranges
As expected biggest problems when clouds are thickest (low DOF);
otherwise <sonde-retrieval> is typically within 1 K, 20% RH

T(z) RH(z)



Conclusions

- We have been concentrating on spectroscopy and line-by-line improvements
- CO_2 lineshape changes are particularly important because they are *not* static but depend on the H_2O burden.
- We have shown (Lindeberg) that HITRAN 2016 H_2O is slightly better than HITRAN 2012 (not discussed)
- Improvement to kCARTA can be migrated to SARTA quickly (with current parameterization)
- Single Footprint Retrievals are very promising and allow vastly improved validation of SARTA to sondes, reanalysis, etc.
- Next delivery : HITRAN16, updated CO_2 line-mix, NH_3, HDO