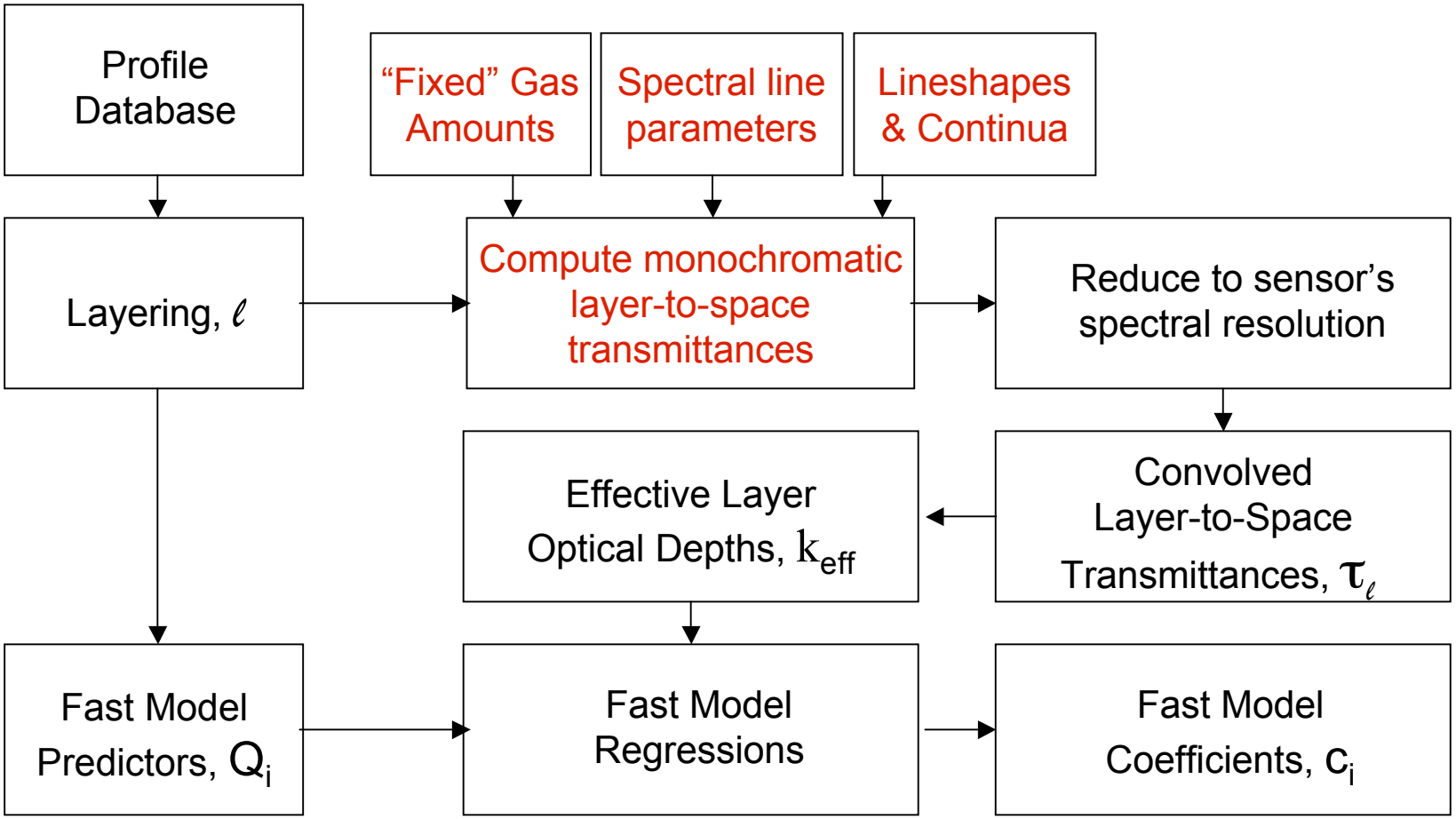
Clear Sky Radiative Transfer Forward Model Development Overview

- Line-by-line modeling (Tobin)
- Fast Model (Moy)

MURI Fast Model Production Flowchart:



$$k_{eff,\ell} = -\ln(\tau_\ell / \tau_{\ell-1}) = \sum_i c_i Q_i$$

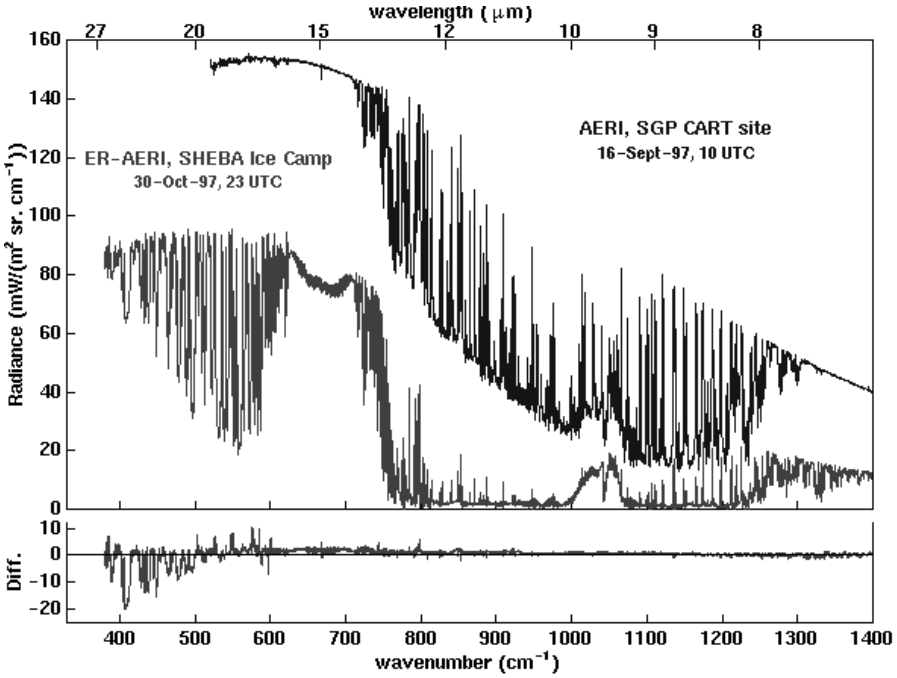
Overview of clear sky line-by-line forward model development over the last ~3 years

- Scope:
  - Temperature and Water Vapor
  - LBLRTM and kCARTA
  - Crosses various projects
- Outline:
  - AERI / LBLRTM QME
  - MT_CKD H_2O Continuum Model
  - CO_2 lineshape representations
  - AIRS
  - Summary and Remaining Issues

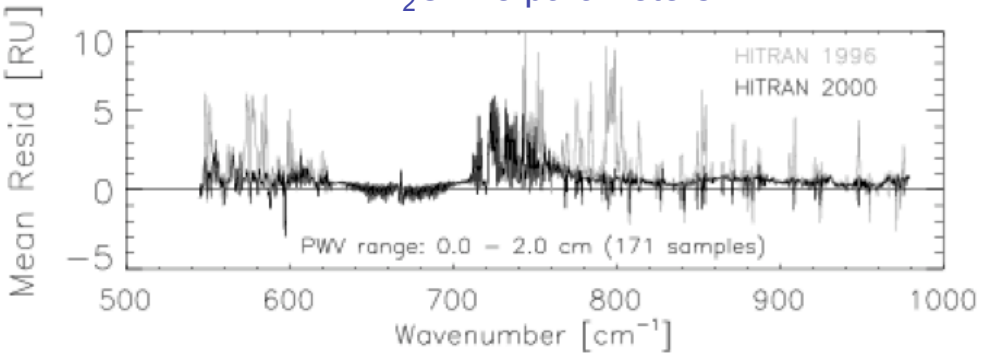
The ARM AERI / LBLRTM QME

- Comparisons of observed and calculated clear sky downwelling radiance spectra at the surface
- Forward model development/validation
  - 10 μm and 3-4 μm self-broadened water vapor continuum
  - 16-25 μm foreign broadened water vapor continuum
  - Longwave H_2O line parameters
  - 15 μm CO_2 lineshape
- Refs:
  - Turner et al., The AERI LBLRTM QME: A closure experiment for downwelling high spectral resolution infrared radiance, *J. Atmos. Sci.*, **61**, 2657-75, 2004.
  - Tobin et al. Downwelling spectral radiance observations at the SHEBA ice station: water vapor continuum measurements from 17 to 26 μm, *J. Geophys. Res.,* **104**, 2081-92, 1999.
  - Clough et al., Radiation Models for ARM: Updates and Validations, In *Thirteenth ARM Program Science Team Meeting*, Ed. by D. Carrothers, U.S. Department of Energy, Richland, WA. 2003.

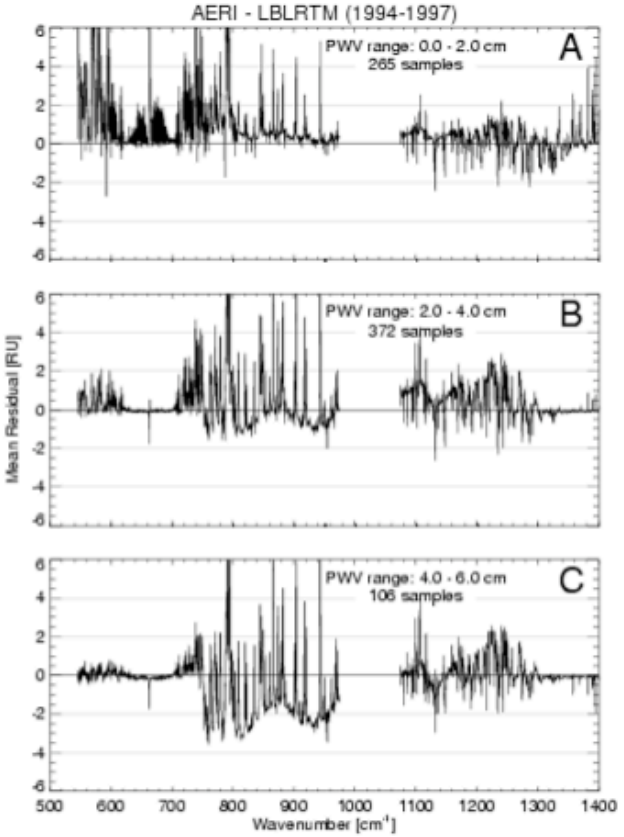
Far-IR water vapor continuum

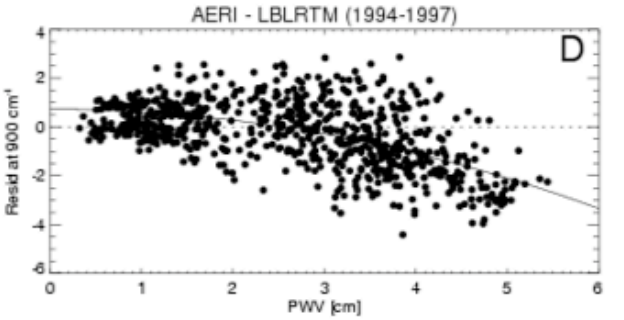


H_2O line parameters



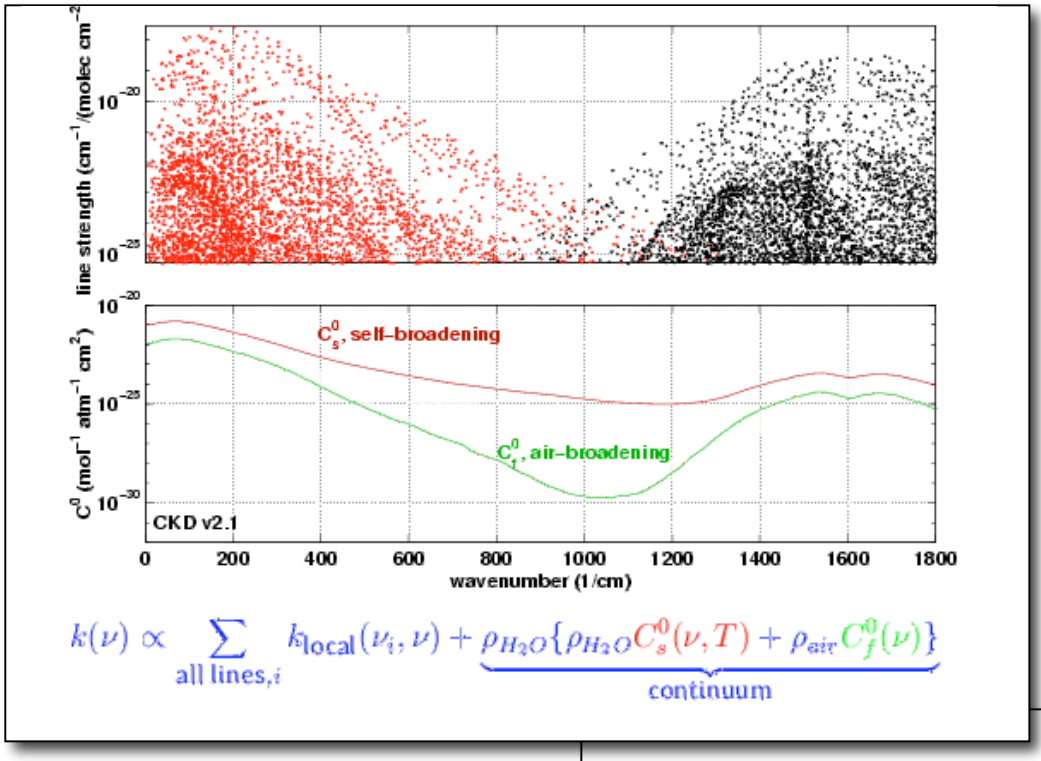
Longwave window region residuals versus total column water vapor

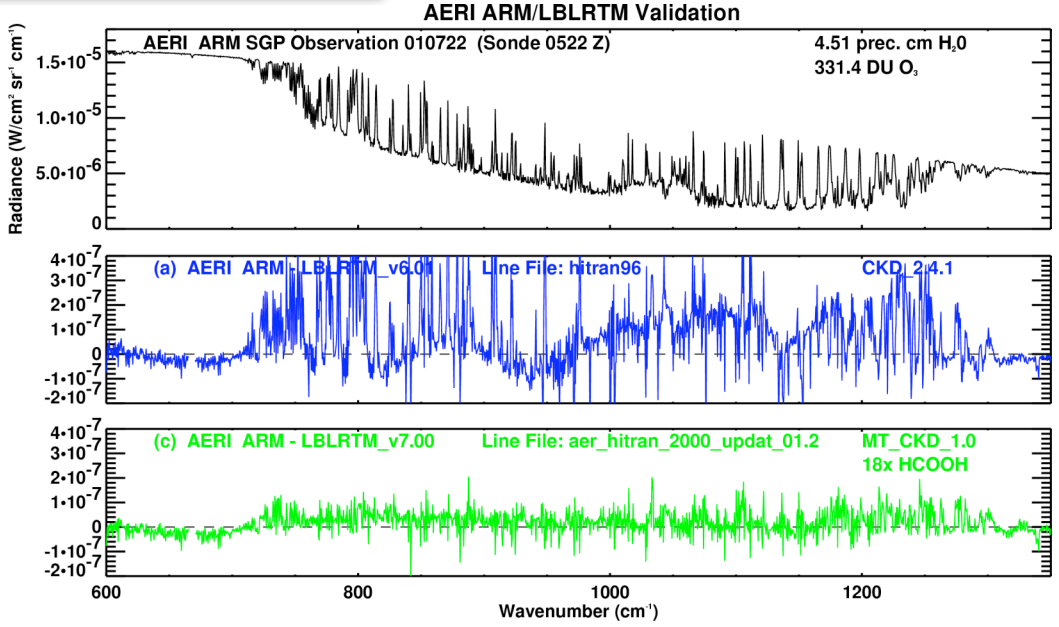




MT_CKD Water Vapor Continuum Model

- Semi-empirical representation of non-Lorentzian H_2O absorption/emission
- Re-formulation of the original CKD water vapor continuum model
  - Tied to an underlying H_2O lineshape model
  - Fit to various laboratory and atmospheric observations. E.g.:
    - C_s^0 and C_f^0 from AERI/LBLRTM
    - High altitude aircraft (e.g. HIS) C_f^0
    - Laboratory measurements
- Refs:
  - Mlawer, E.J., D. C. Tobin, and S. A. Clough, A New Water Vapor Continuum Model: MT_CKD_1.0, In *Proceedings of the Thirteenth Atmospheric Radiation Measurement (ARM) Program Science Team Meeting CONF-2003*, Ed. by D. Carrothers, U.S. Department of Energy, Richland, WA.
  - Clough et al., Atmospheric radiative transfer modeling: a summary of the AER codes, Short Communication, *J. Quant. Spectrosc. Radiat. Transfer*, ***91***, 233-244, 2005.

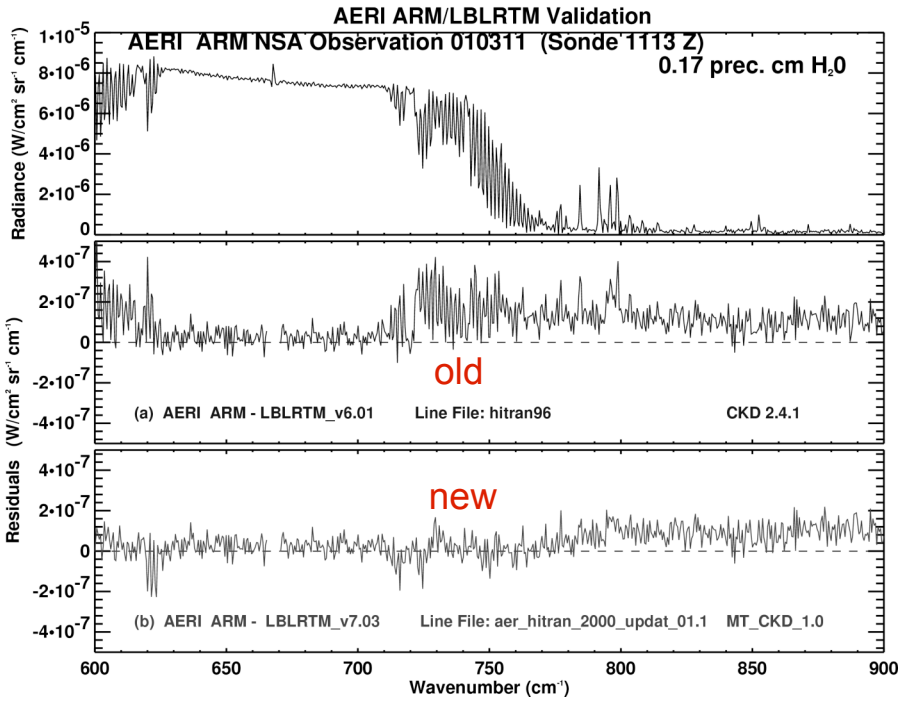

line strength (cm^{-1}/(molec cm^{-2}))
10^{-20}
10^{-25}
C^0 (mol^{-1} atm^{-1} cm^2)
10^{-20}
10^{-25}
10^{-30}
C_s^0, self-broadening
C_f^0, air-broadening
CKD v2.1
0
200
400
600
800
1000
1200
1400
1600
1800
wavenumber (1/cm)
$k(\nu) \propto \sum_{\text{all lines},i} k_{\text{local}}(\nu_i, \nu) + \underbrace{\rho_{H_2O}\{\rho_{H_2O} C_s^0(\nu, T) + \rho_{air} C_f^0(\nu)\}}_{\text{continuum}}$

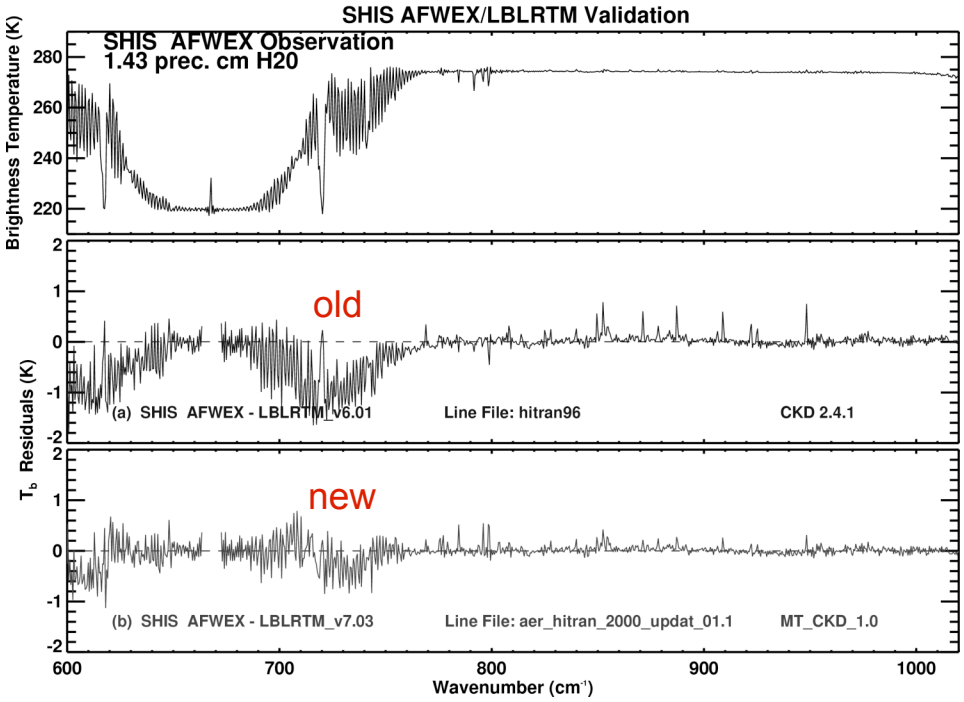

AERI ARM/LBLRTM Validation
AERI ARM SGP Observation 010722 (Sonde 0522 Z)
4.51 prec. cm H_2O
331.4 DU O_3
Radiance (W/cm^2 sr^{-1} cm^{-1})
$1.5 \cdot 10^{-5}$
$1.0 \cdot 10^{-5}$
$5.0 \cdot 10^{-6}$
0
(a) AERI ARM - LBLRTM_v6.01
Line File: hitran96
CKD_2.4.1
$4 \cdot 10^{-7}$
$3 \cdot 10^{-7}$
$2 \cdot 10^{-7}$
$1 \cdot 10^{-7}$
0
$-1 \cdot 10^{-7}$
$-2 \cdot 10^{-7}$
(c) AERI ARM - LBLRTM_v7.00
Line File: aer_hitran_2000_updat_01.2
MT_CKD_1.0
18x HCOOH
600
800
1000
1200
Wavenumber (cm^{-1})

CO_2

- LBLRTM: 15 μm CO_2 lineshape and continuum derived from AERI and Scanning-HIS observations
- kCARTA: line-mixing plus duration-of-collision formulation
- Refs:
  - Strow, L. L., Hannon, S. E., De Souza-Machado and Tobin, D. C., An overview of the AIRS radiative transfer model: IEEE Transactions on Geoscience and Remote Sensing, **41**, 303-313, 2003.
  - Clough et al., Atmospheric radiative transfer modeling: A summary of AER codes." Presented at Fourteenth ARM Science Team Meeting. Albuquerque, NM, 2004.
  - Tjemkes et al., The ISSWG line-by-line inter-comparison experiment: Journal of Quantitative Spectroscopy & Radiative Transfer, **77**, p. 433-453., 2003.

LBLRTM: 15μm CO_2 changes

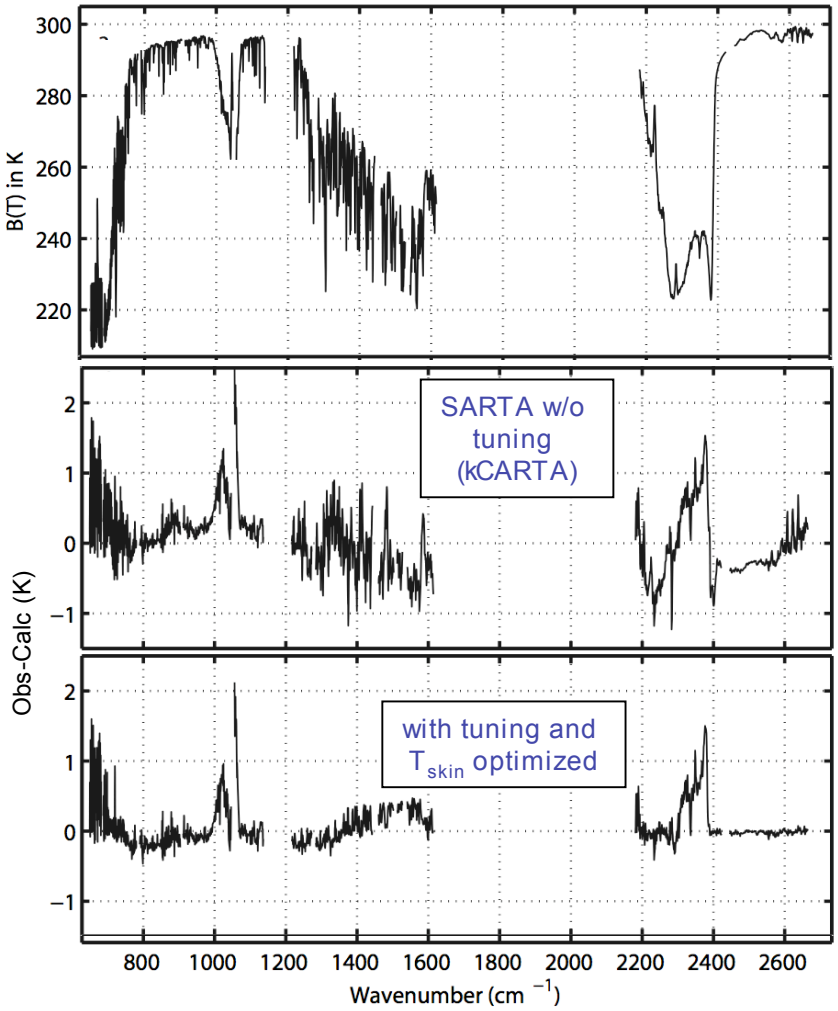


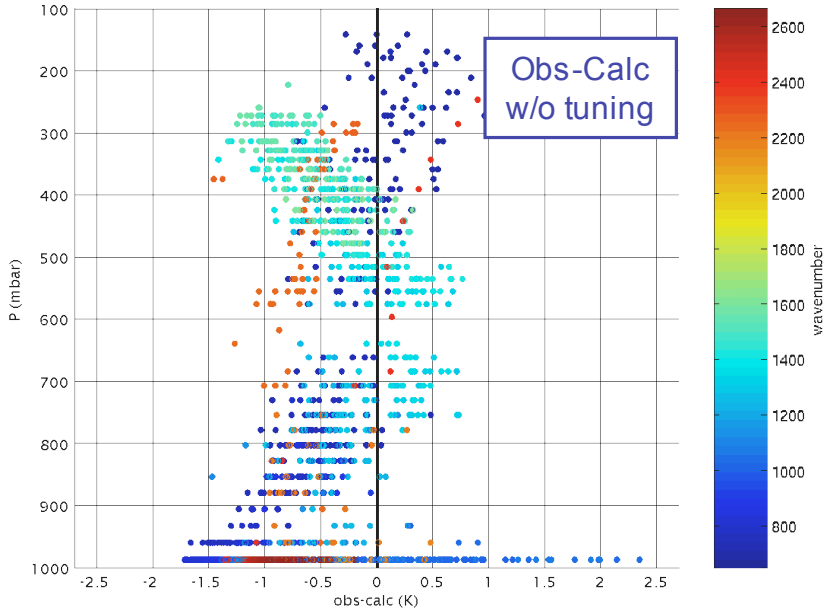


Atmospheric Infrared Sounder (AIRS) on EOS Aqua

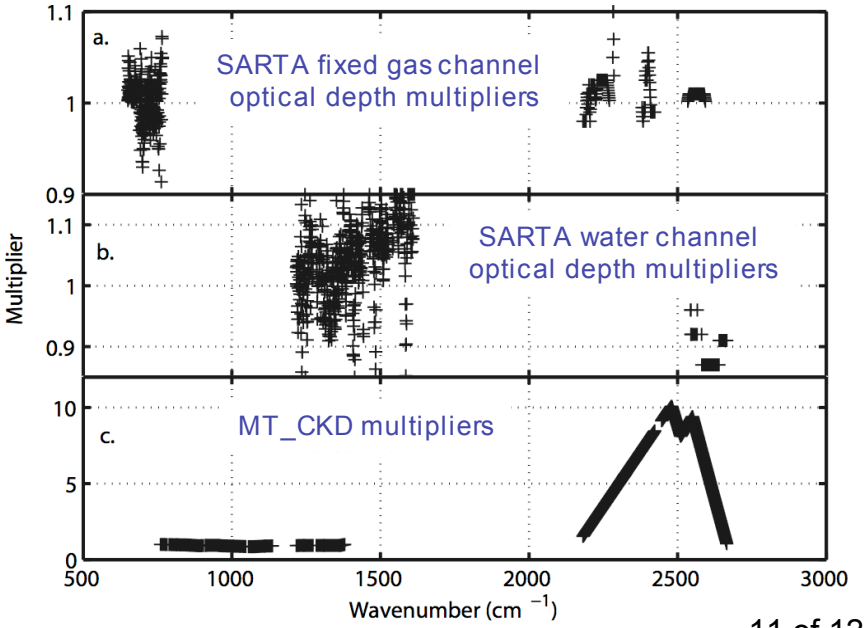
- Global clear sky ensembles for forward model assessment.
- ARM site atmospheric state best estimates
- Empirical channel transmittance tuning applied to AIRS RTA not yet reflected in line-by-line codes.
- Refs:
  - Tobin et al., ARM site atmospheric state best estimates for AIRS temperature and water vapor retrieval validation, *J. Geophys. Res.*, submitted, 2005.
  - Strow, L. L., S. E. Hannon, S. DeSouza Machado, and D. C. Tobin, Validation of the AIRS RTA, JGR special issue on AIRS Validation, *J. Geophys. Res.*, submitted, 2005.
  - Tobin, D. C., H. E. Revercomb, R.O. Knuteson, W. F. Feltz, B. Lesht, T. Cress, L. Strow, and S. E. Hannon. 2004. "ARM site atmospheric state best estimates for AIRS forward model and retrieval validation." AGU 2004 Fall Meeting. San Francisco, California.
  - Shephard, et al., Validation of the Forward Model with interferometric measurements for passive remote sensing, ASSFTS 12th Workshop, Quebec City, 2005.

Mean Obs-Calcs for clear sky ocean ensemble





Changes to kCARTA and AIRS Fast Model (SARTA) ala Strow et al.



Summary and Remaining Issues

- Major progress in line-by-line model development and validation in the past ~3 years. Clear sky TOA obs-calcs generally less than 1 K.
- LBLRTM and kCARTA approaches and end-results are converging, although some significant differences (CO_2) remain.
- Now looking for spectral and species consistency on the order of tenths of K. Uncertainties in the forward model components as well as the radiance observations and atmospheric profiles on this order must be considered.
- The quantitative impact of remaining forward model biases on retrieval bias is now being investigated.
- Specific remaining issues:
  - Translate empirical tuning performed to SARTA back into line-by-line codes
  - Upper level water vapor truth and near wing H_2O lineshape
  - CO_2 and N_2O lineshapes. Spectral consistency in approach and results.
  - Non-LTE