Community Radiative Transfer Model: Status and Development

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Joint Center for Satellite Data Assimilation

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People

- JCSDA Team
  - Quanhua Liu
  - Yong Chen
  - David Groff
  - Banghua Yan
  - Fuzhong Weng
  - Ron Vogel
- Invaluable feedback from
  - NRL; Ben Ruston and Nancy Baker
  - NCAR; Zhiquan Liu

Outline

- Current Status
  - Preamble
  - Components

- Development
  - Transmittance models
  - Emissivity models
  - Radiative Transfer schemes

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Current Status – Preamble

- Current CRTM release is v1.1 (Feb.29, 2008)

- Source code and coefficient tarballs availble at:

  `ftp://ftp.emc.ncep.noaa.gov/jcsda/CRTM`

- Mailing list can be subscribed to at:

  `https://lstsrv.ncep.noaa.gov/mailman/listinfo`

  and click on the

  `NCEP.List.EMC.JCSDA_CRTM`

  link.

- Next scheduled release is v1.2 for Jul.01, 2008.
  - Will also include web page.
  - "Public" repository may also be accessible.

Current Status – Components

- Four models
  - FWD, TL, AD, and K-Matrix
- Atmospheric Optics
  - Gaseous Absorption
  - Clouds
  - Aerosols
- Surface Optics
  - Infrared Land, Ocean, Snow, and Ice emissivity models
  - Microwave Land, Ocean, Snow, and Ice emissivity models.
- Radiative Transfer
  - Clear: view angle emission model
  - Scattering: Advanced Doubling-Adding (ADA) algorithm.

Current Status – Atmospheric Optics

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Current Status – Atmospheric Optics

- Atmospheric Optics
  - Gaseous Absorption
  - Clouds
  - Aerosols

- Gaseous absorption in the CRTM is computed using the compactOPTRAN algorithm.
- Water vapour, ozone, and “dry” gas absorption. Water vapour vapour continuum is poorly handled.
- Vertical profiles of absorption coefficient are predicted from a set from a set of polynomial basis functions.
- Trained from LBLRTM v9.4 (IR) and Liebe89/93 (MW) line-by-line transmittances. Rosenkranz (MW) option.
- HITRAN2000 + AER updates
- UMBC48 dependent profile set.

Current Status – Atmospheric Optics

- Atmospheric Optics
  - Gaseous Absorption
  - Clouds
  - Aerosols

- Six cloud types
  - Water, rain, snow, ice, graupel, and hail.
- Cloud optical properties are interpolated from LUTs as functions functions of frequency, effective radius, temperature (liquid), and (liquid), and density (solid).
- Currently assume spherical particles.
- Need to supplement LUT data to increase data range (no extrapolation is performed) and density (to minimise interpolation interpolation artifacts).

Current Status – Atmospheric Optics

- Atmospheric Optics
  - Gaseous Absorption
  - Clouds
  - Aerosols

- Eight aerosol types
  - Dust, sea salt (SSAM, SSCM), wet and dry organic carbon, carbon, wet and dry black carbon, sulfate.
- Aerosol optical properties are interpolated from LUTs as functions of frequency and effective radius.
- Currently assume spherical particles.
- Need to correct some LUT anomalies (repeated radii, partially partially discretised data)

Current Status – Surface Optics

- Four models
  - FWD, TL, AD, and K-Matrix
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  - Clouds
  - Aerosols
- Surface Optics
  - Infrared Land, Ocean, Snow, and Ice emissivity models
  - Microwave Land, Ocean, Snow, and Ice emissivity models.
- Radiative Transfer
  - Clear: view angle emission model
  - Scattering: Advanced Doubling-Adding (ADA) algorithm.

Current Status – Surface Optics

- Surface Optics
  - Infrared Land, Ocean, Snow, and Ice emissivity models
  - Microwave Land, Ocean, Snow, and Ice emissivity models.

- No operational changes.
- **Ocean**: Emissivity LUT based on Wu-Smith model (ensemble mean of 1-*r*) generated at high resolution. Emissivity interpolated interpolated as a function of view angle, wind speed, and frequency.
- **Land, Snow, and Ice**: Emissivity database LUT. Measurement database is for various land, snow and ice surface types. 24 surface types in total (NPOESS Net Heat Flux ATBD, 2001).

Current Status – Surface Optics

- Surface Optics
  - Infrared Land, Ocean, Snow, and Ice emissivity models
  - Microwave Land, Ocean, Snow, and Ice emissivity models.

- **Ocean**: FASTEM-1. NESDIS model is an option.
- **Land**: Physical model when $f<80$GHz, $\varepsilon=0.95$ for $f\geq 80$GHz.
- **Snow**: Empirical models for AMSU, MHS, AMSR-E, MSU, and SSM/I. Physical model for other sensors when $f<80$GHz, $\varepsilon=0.9$ for $f\geq 80$GHz.
- **Ice**: Empirical models for AMSU, MHS, AMSR-E, MSU, and SSM/I.$\varepsilon=0.92$ for other sensors.
- Operational change: Additional of MHS model.

Current Status – Radiative Transfer

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  - Infrared Land, Ocean, Snow, and Ice emissivity models
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Current Status – Radiative Transfer

- Radiative Transfer
  - Clear: view angle emission model
  - Scattering: Advanced Doubling-Adding (ADA) algorithm.

- Downwelling radiation computed at diffuse angle for Lambertian surface (IR sensors) or at the satellite zenith angle for specular surface (MW sensors).
- Surface reflected solar radiation is included.
- Cloud and aerosol pure absorptions are accounted for.

Current Status – Radiative Transfer

- Radiative Transfer
  - Clear: view angle emission model
  - Scattering: Advanced Doubling-Adding (ADA) algorithm.

- A strict multiple scattering method for any discrete-ordinate angles (i.e. streams).
- Sensor zenith angle is included as an additional stream.
- Layer transmission and reflection matrices are calculated using a doubling method; layer source function is a linear analytic expression of the transmission and reflection matrices. A stack technique is used for integrating layers and surface.
- Surface reflection matrix is used.

Outline

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- Development
  - Transmittance models
  - Emissivity models
  - Radiative Transfer schemes

Development – Transmittance Models Models

- SSU model
  - Developed for NCEP reanalysis

- Model that accounts for Zeeman-splitting.
  - Earth rotation Doppler shift
  - Channel polarisation

- New CRTM transmittance module
  - Multiple algorithm
  - Addition of trace gases.

- Line-by-line model updates
  - Improvement in microwave continuum.
  - Recomputation of infrared transmittances.

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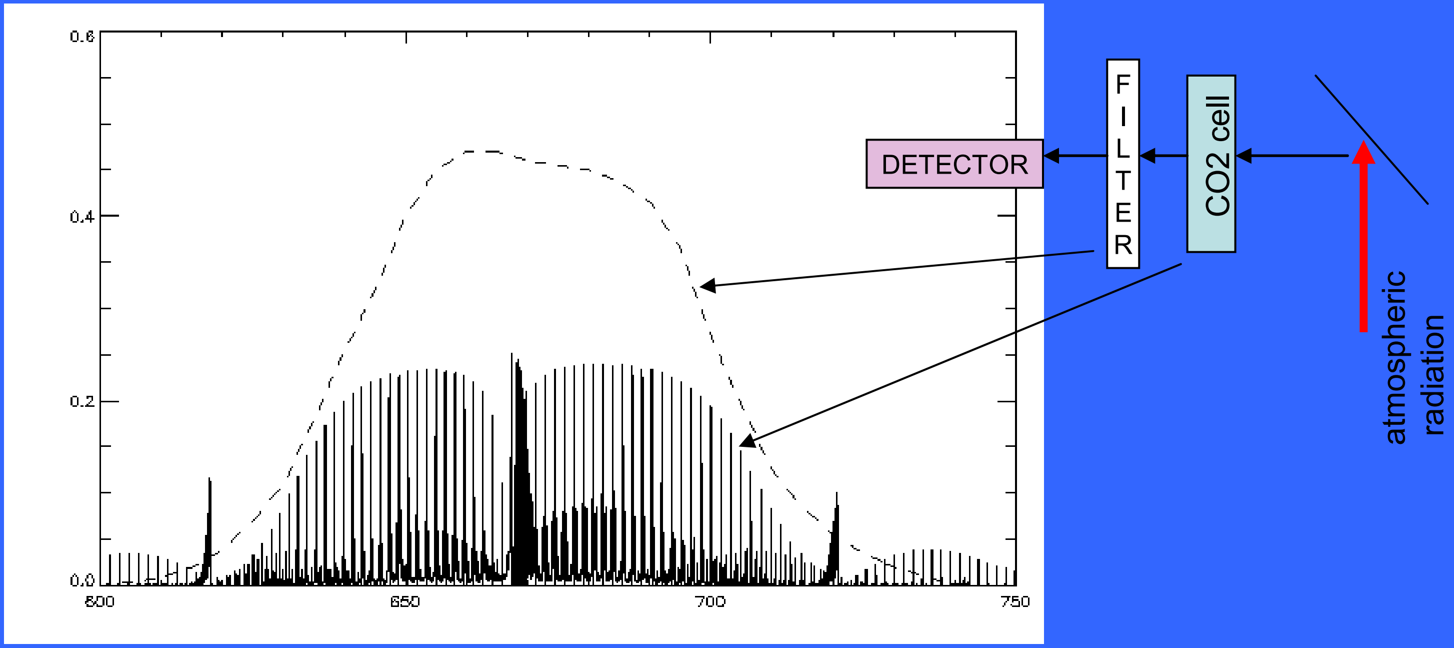
Development – Transmittance Models Models

- SSU model
  - Developed for NCEP reanalysis

- SSU SRFs are the product of traditional broadband and the CO_2 cell absorption response.



Development – Transmittance Models Models

- SSU model
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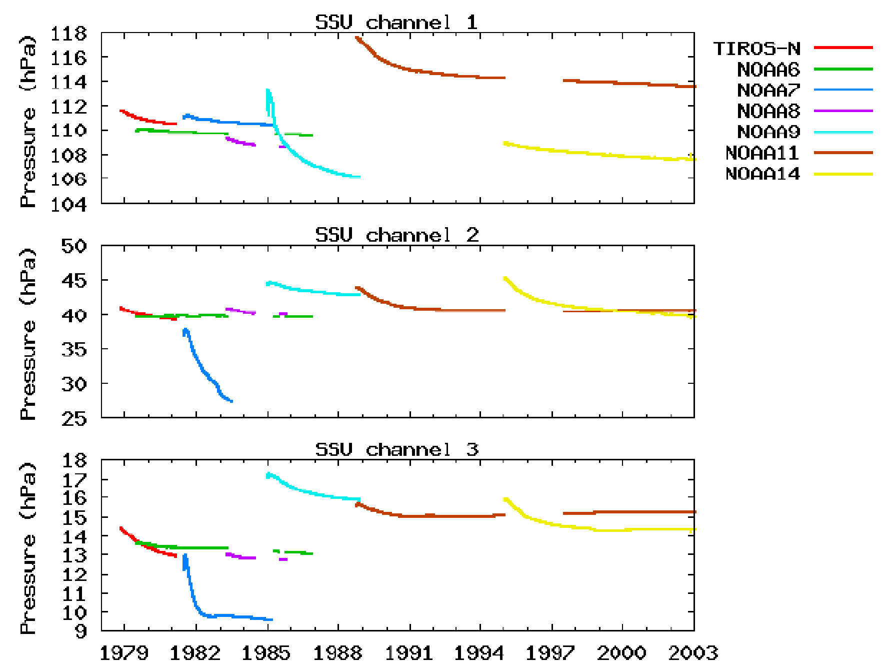
- CO_2 leakage in cell pressure modulator causes SRF variation.



From Dr. Shinya Kobayashi, ECMWF

Development – Transmittance Models Models

- SSU model
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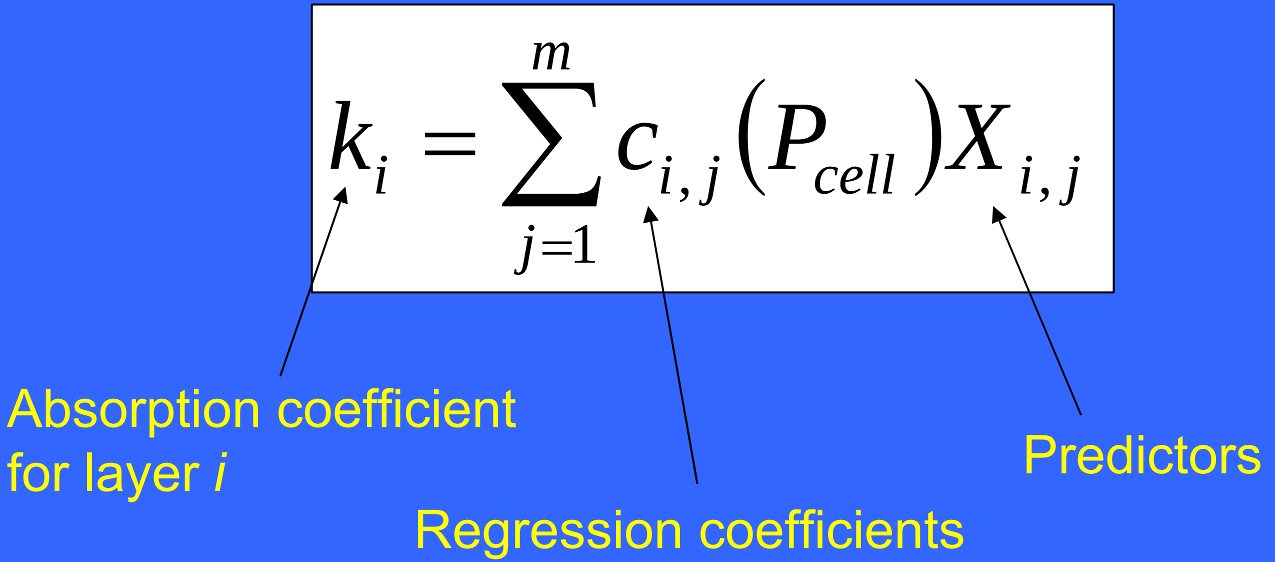
- The transmittance model is compactOPTRAN
- The regression coefficients coefficients are stored as a function of CO_2 cell pressure,



$$k_i = \sum_{j=1}^{m} c_{i,j}(P_{cell})X_{i,j}$$

Absorption coefficient
for layer *i*

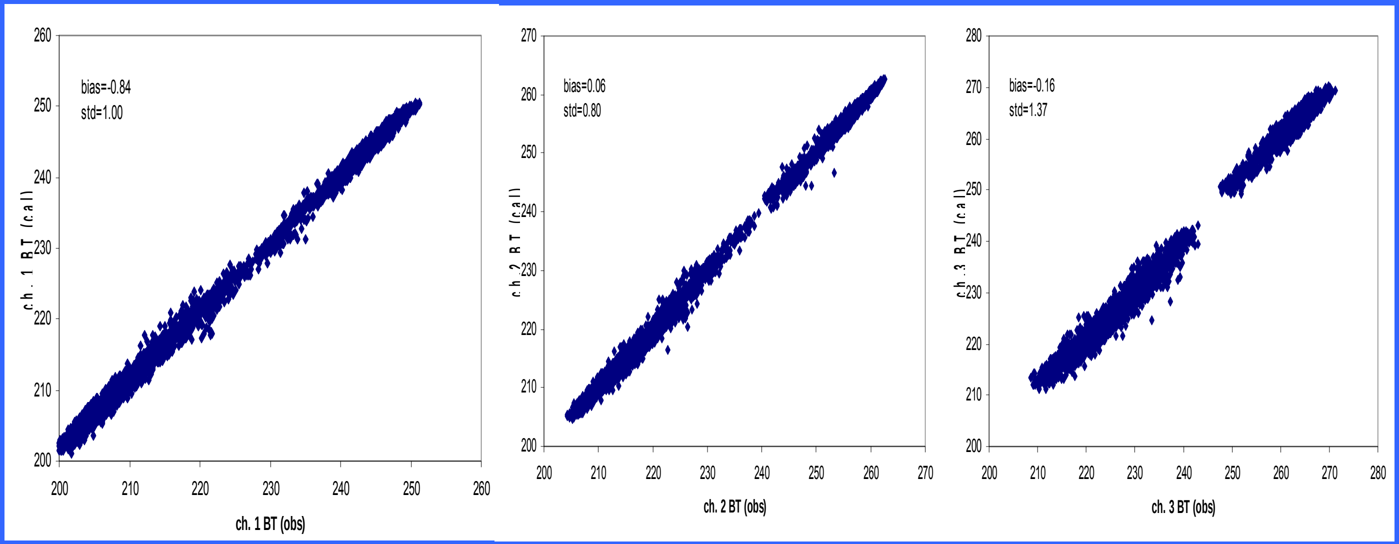
Regression coefficients

Predictors

Development – Transmittance Models Models

- SSU model
  - Developed for NCEP reanalysis

- Validation using Microwave Limb Sounding Product.
- SSU and MLS data in 11/2004 for all match-up points,



Development – Transmittance Models Models

- SSU model
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Development – Transmittance Models Models

- Model that accounts for Zeeman-splitting.
  - Earth rotation Doppler shift
  - Channel polarisation

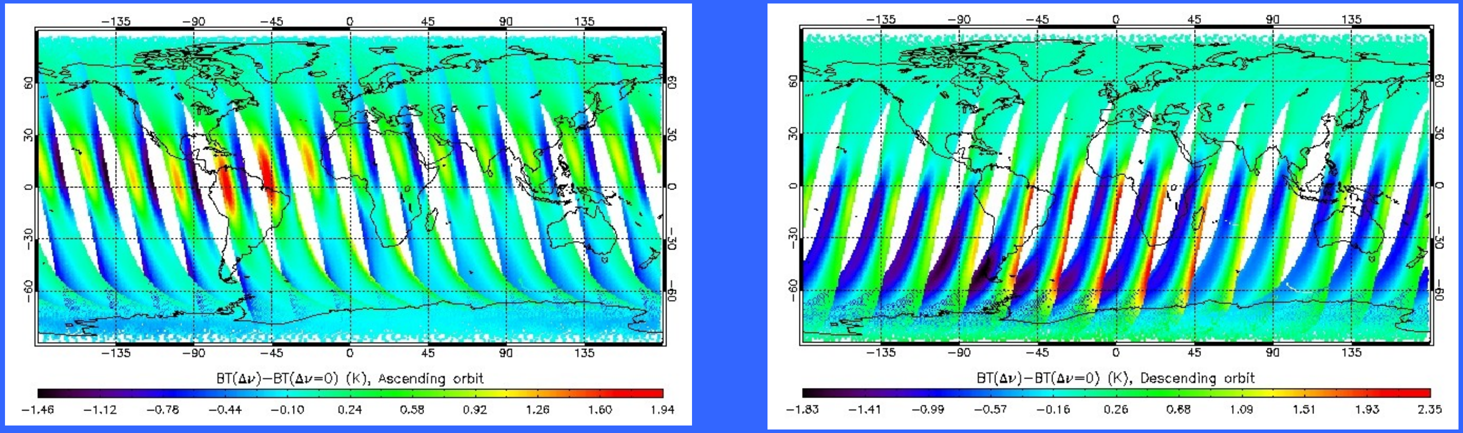
- See poster A08: “*Radiative Transfer Modeling for SSMIS Upper-air Sounding Channels: Doppler-shift Effect due to Earth’s Rotation*” by Y.Han.

- See poster A09: “*A Fast Radiative Transfer Model for AMSU-A Channel 14 with the Inclusion of Zeeman-splitting Effect*” by Y.Han.

Development – Transmittance Models Models

- Model that accounts for Zeeman-splitting.
    - Earth rotation Doppler shift
    - Channel polarisation

- Earth rotation Doppler shift (up to 75kHz) has significant impact (up to 2K) on SSMIS channels 19-21.



Simulated brightness temperature differences for SSMIS ch.20 with and without the inclusion of the Doppler shift effect

Development – Transmittance Models Models

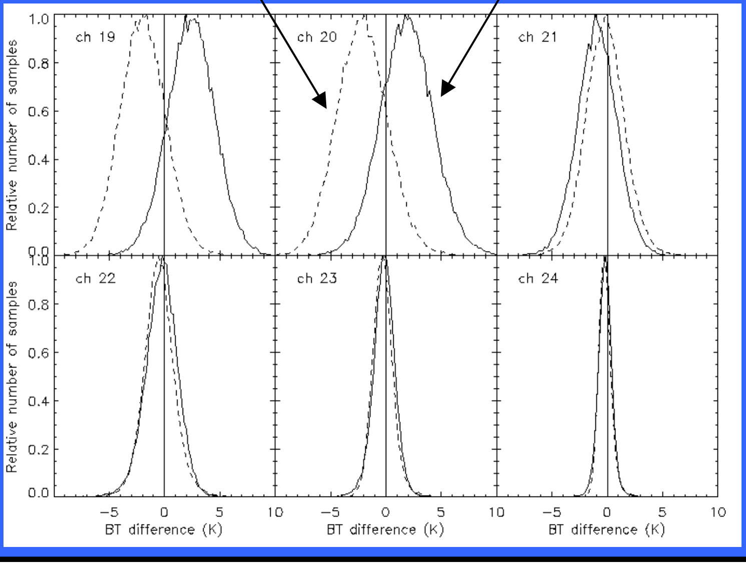
- Model that accounts for Zeeman-splitting.
  - Earth rotation Doppler shift
  - Channel polarisation

- Receivers of the UAS channels are confirmed to be right circularly polarised; knowing the correct polarisation is important in the presence of the Doppler shift

Histogram of the measured BT difference between the east- and west-most pixels of the scans. Pattern matches that from RCP receivers

Descending, cos(θ_B) ≈ 0.6

Ascending, cos(θ_B) ≈ -0.6



Development – Transmittance Models Models

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Development – Transmittance Models Models

- New CRTM transmittance module
  - Multiple algorithm
  - Addition of trace gases.

- Current transmittance algorithm: CompactOPTRAN
  Advantages: Smooth Jacobian profiles; Small memory footprint.
  Disadvantages: Poor accuracy in some channels; Predictand is ln(*k**) and *k** can be negative; Polynomial evaluation is computationally expensive.

- Adapt CRTM to accept multiple algorithms for transmittance calculations; OPTRAN, RTTOV, SARTA.

Development – Transmittance Models Models

- New CRTM transmittance module
  - Multiple algorithm
  - Addition of trace gases.

- Current algorithm can still only handle H_2O and O_3.
- Add CO_2, CO, CH_4, and N_2O as variable gases.
- Possibly others. E.g. SO_2 and CFCs.

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- Line-by-line model updates
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Development – Transmittance Models Models

- Line-by-line model updates
  - Improvement in microwave continuum.
  - Recomputation of infrared transmittances.

- AER, Inc. is working on improving the microwave continuum in their MonoRTM model. Currently, the CRTM is trained using Liebe model; switch to MonoRTM when work completed.

- Recompute the infrared transmittances using latest version of LBLRTM (also from AER, Inc.)

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Development – Emissivity Models

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  - Land emissivity
  - Ocean Emissivity

- Microwave Emissivity
  - Empirical models for MHS and SSMIS.
  - Low-frequency ocean emissivity model.
  - Multilayer soil and vegetation land emissivity model.
  - Improvement of physical snow emissivity model.

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Development – Emissivity Models

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  - Ocean Emissivity

- **Land emissivity**
- Improvements are being made to the IR land surface emissivity LUT. Evaluation of current and new LUT that matches the NCEP GFS surface types

- **Ocean emissivity**
- Improving interpolation of emissivity LUT to use new averaged quadratic interpolation module for continuous derivatives.
- Adding temperature dependence to LUT data.

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Development – Emissivity Models

- Microwave Emissivity
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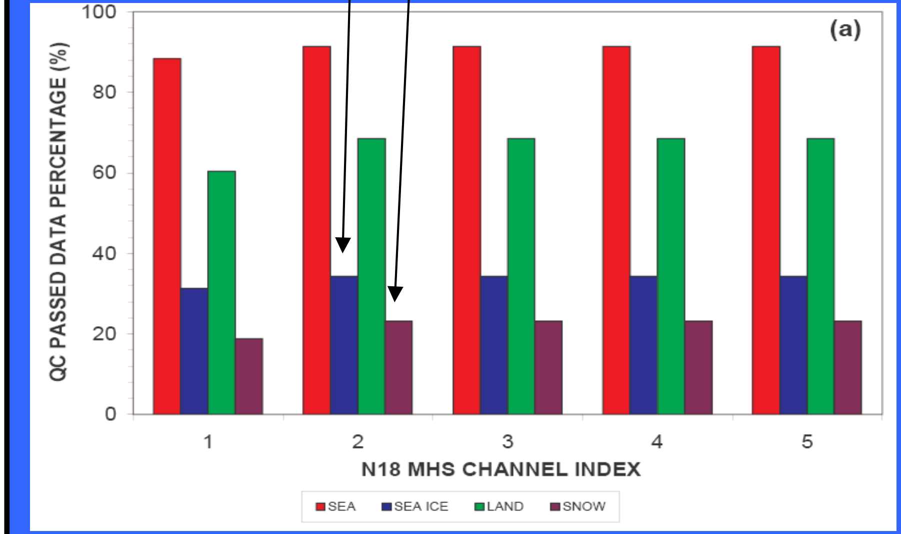
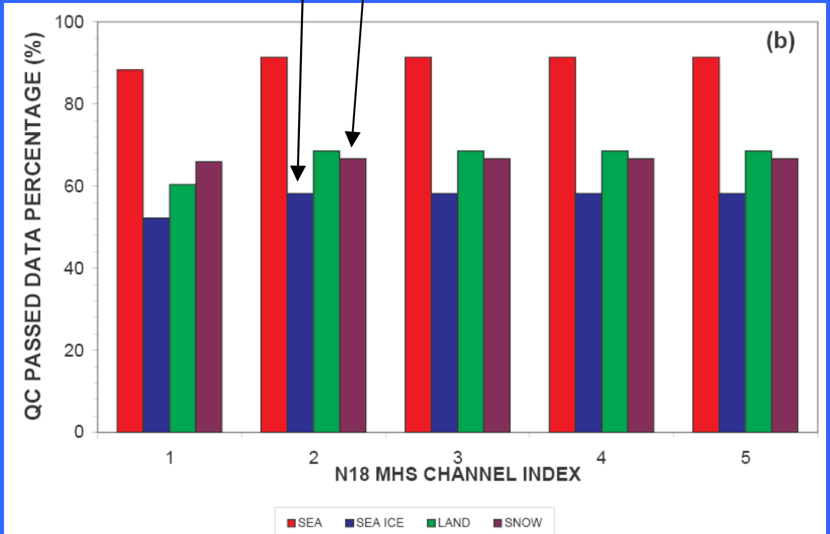
- Assimilation impact of new MHS Snow and Sea Ice emissivity model.

Old Model
low snow and sea ice data usage

New Model
increased snow and sea ice data usage





Development – Emissivity Models

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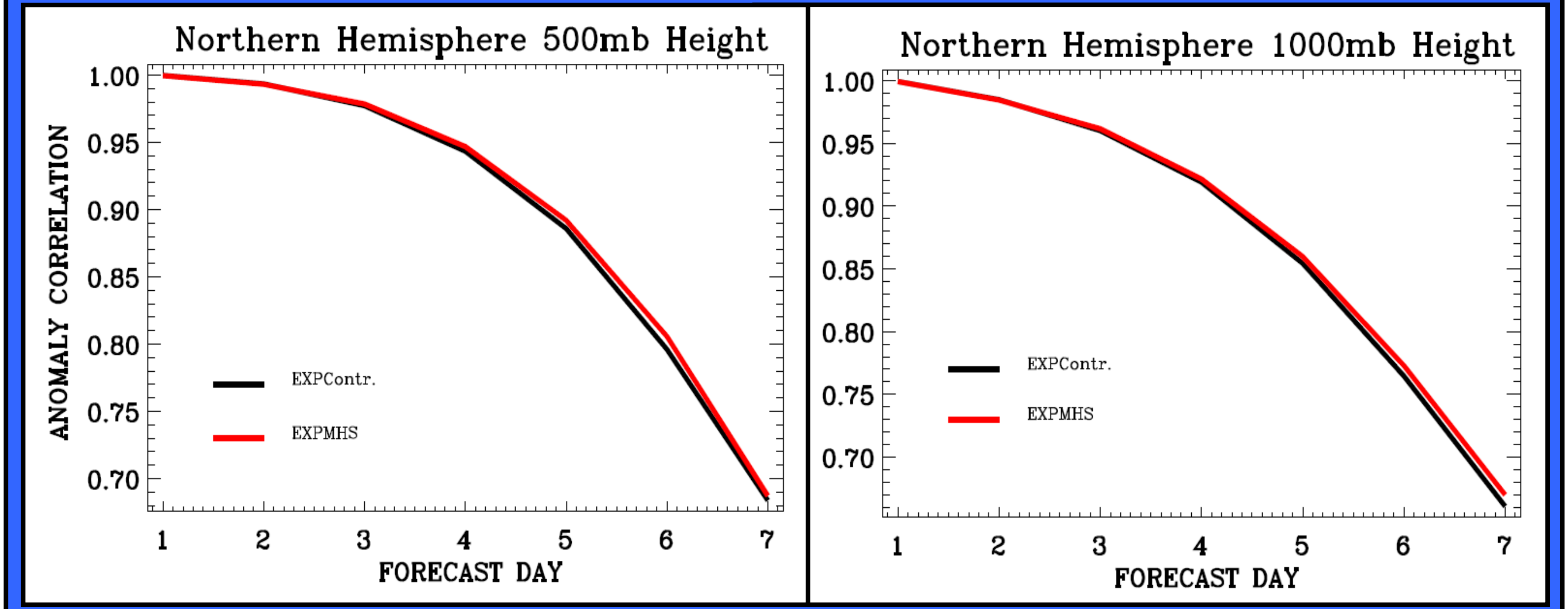

Development – Emissivity Models

- Microwave Emissivity
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  - Low-frequency ocean emissivity model.
  - Multilayer soil and vegetation land emissivity model.
  - Improvement of physical snow emissivity model.

- Implementation of Masahiro Kazumori's (JCSDA Visiting Scientist from JMA) low-frequency (<20GHz) ocean surface emissivity model.
- Refactored Guillou and Ellison ocean permittivity models.
- Implemented new interpolation module for the ocean surface height variance LUT. Data is interpolated as a function of frequency and wind speed.

- FASTEM-3 will also be implemented in calling code for f>20GHz. Use new Guillou and Ellison modules?

Development – Emissivity Models

- Microwave Emissivity
  - Empirical models for MHS and SSMIS.
  - Low-frequency ocean emissivity model.
  - Multilayer soil and vegetation land emissivity model.
  - Improvement of physical snow emissivity model.

- **Multilayer model:**
- See poster A01: "*Radiative Transfer in Vertically Stratified Soil and Vegetation Boundary*" by F.Weng.

- **Physical snow model**
- Improving the computation of the optical properties of snow for higher frequencies.
- Addition of extra layers

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Development – Radiative Transfer

- Algorithms for scattering radiative transfer
  - ADA speedup
  - Fast 2- and 4-stream models
  - SOI integration

- Other
  - Comparisons between CRTM and Xu Liu's PCRTM.
  - Implementation of CRTM in WRF-Var for cloudy radiance assimilation. assimilation.
  - Optical parameters for clouds and aerosols.
  - Field-of-view considerations.

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- It was found that the IBM Fortran95 intrinsic matrix multiplication function was extremely slow.
  - Added faster matrix multiplication functions.
  - Used library calls (e.g. ESSL, MASS libraries)
- Computational efficiency is memory-usage sensitive.
  - Refactored modules that retain the forward calculations.

- Changes save about 30% CPU time. Still not enough for cloudy radiance assimilation.

Development – Radiative Transfer

- Algorithms for scattering radiative transfer
  - ADA speedup
  - Fast 2- and 4-stream models
  - SOI integration

- Work is continuing on the development of fast 2- and 4-stream + observation angle algorithms.
- The 4-stream + observation angle method is generally accurate for microwave and infrared simulations.
- Requires a better treatment of cloud and aerosol phase functions.
- The new 2- and 4-stream + observation algorithms use the same adding code as the ADA, but a fast transmittance, reflectance, and source function calculation in each layer is performed using a matrix operator method.

Development – Radiative Transfer

- Algorithms for scattering radiative transfer
  - ADA speedup
  - Fast 2- and 4-stream models
  - SOI integration

- Yoshihiko Tahara visited from JMA in February to begin the integration of the SOI algorithm (from UWisc) in the CRTM.
- Main problem encountered is the unavailability of level temperatures (GSI only provides layer temperatures.)
- Different methods for layer→level conversion impact speed and accuracy.
- Need to remove use of public module variables in SOI modules for thread safety.

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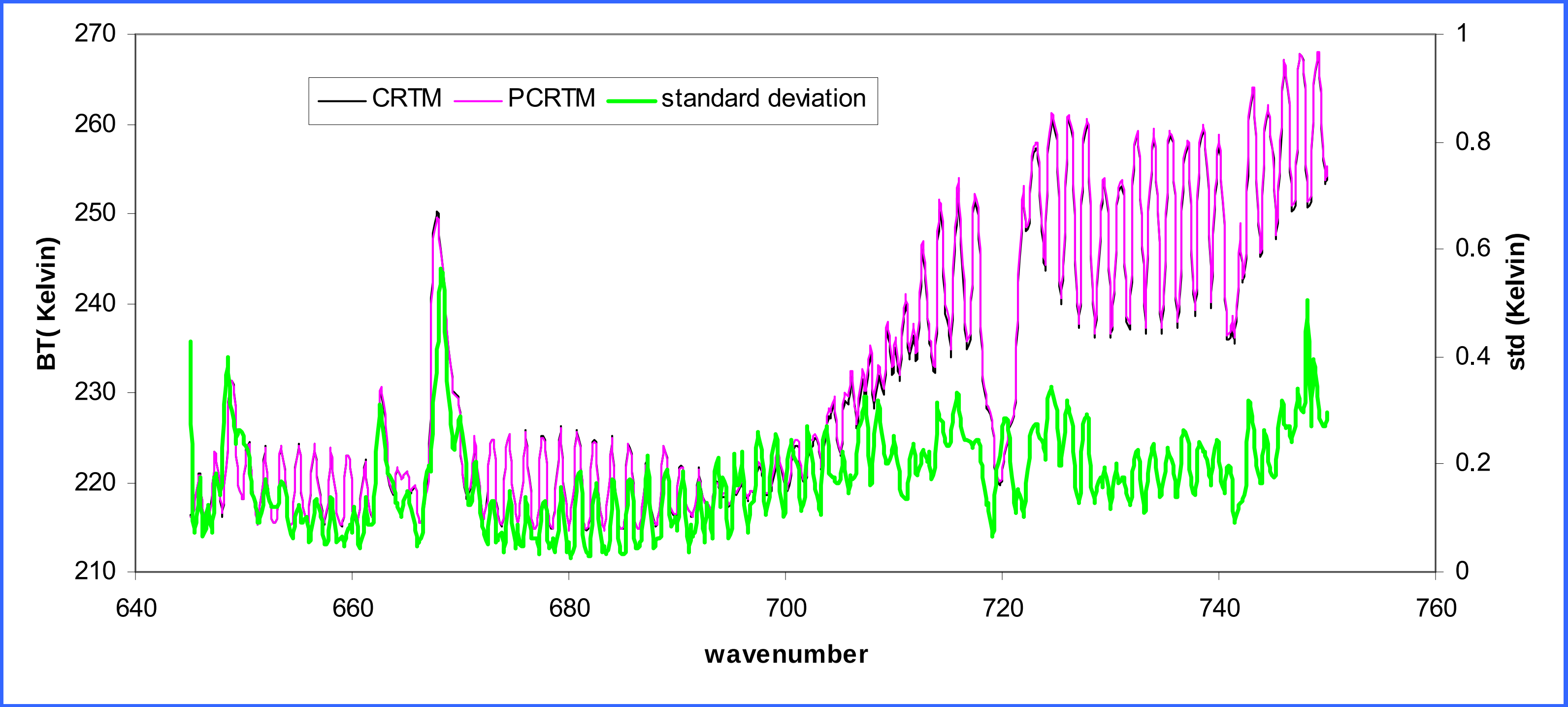
- Forward spectral domain for IASI



Development – Radiative Transfer

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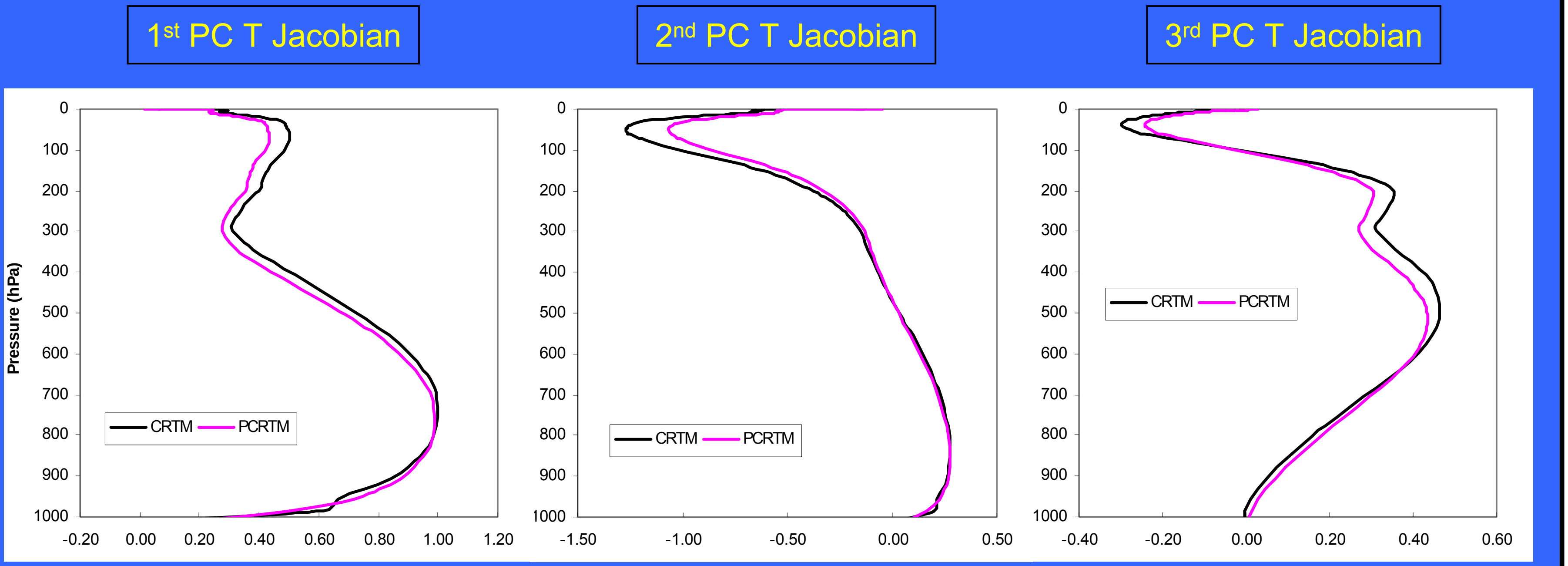
- PC-score domain for T Jacobians



1^{st} PC T Jacobian

2^{nd} PC T Jacobian

3^{rd} PC T Jacobian

Development – Radiative Transfer

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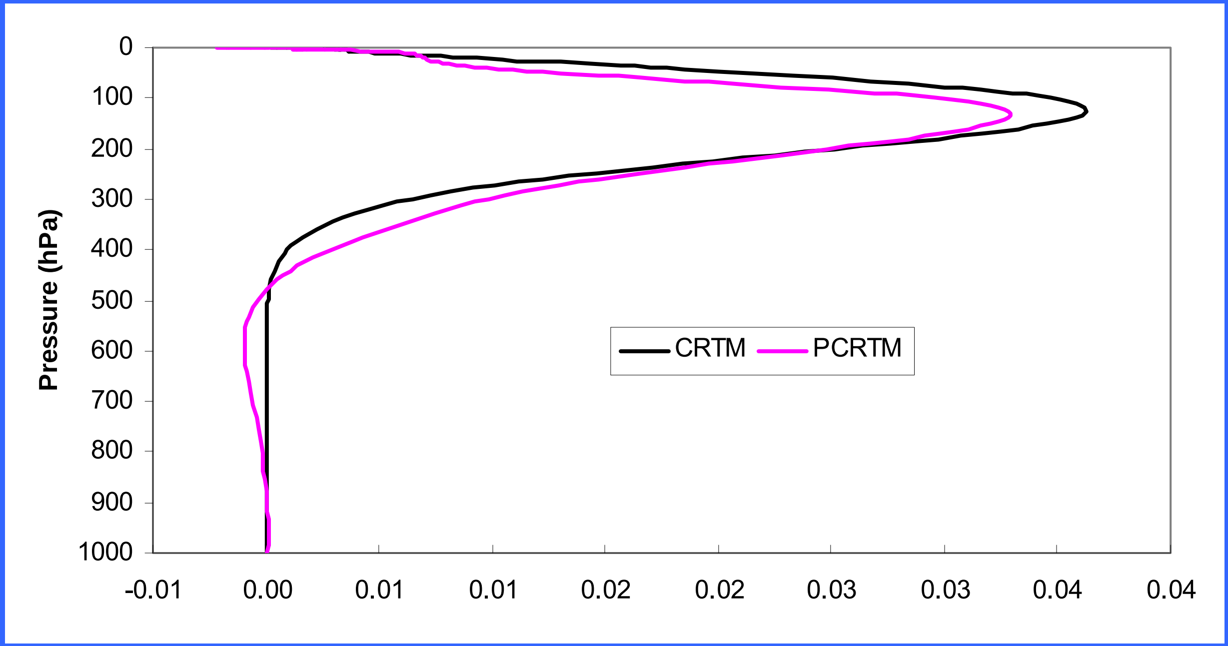
- Atmospheric domain for T Jacobians (IASI 645cm^{-1})



Development – Radiative Transfer

- Other
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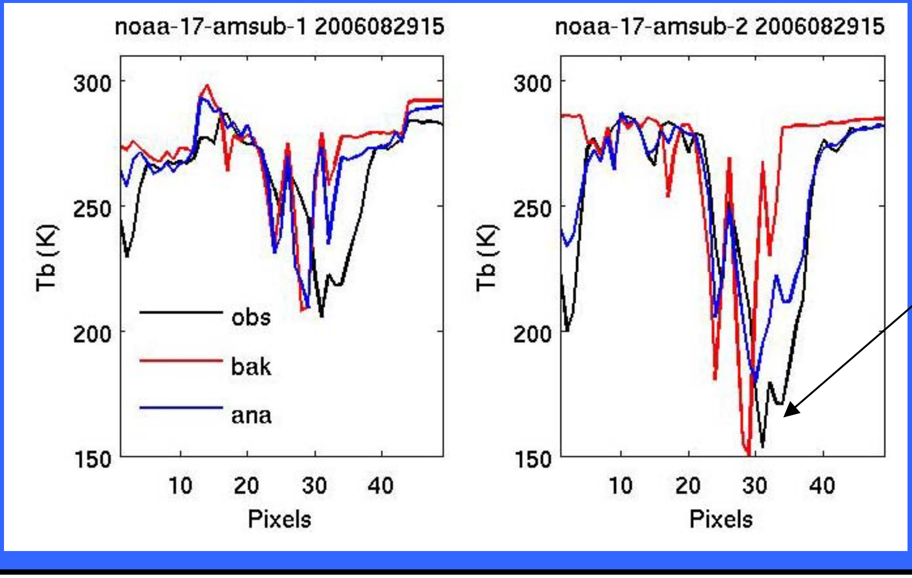
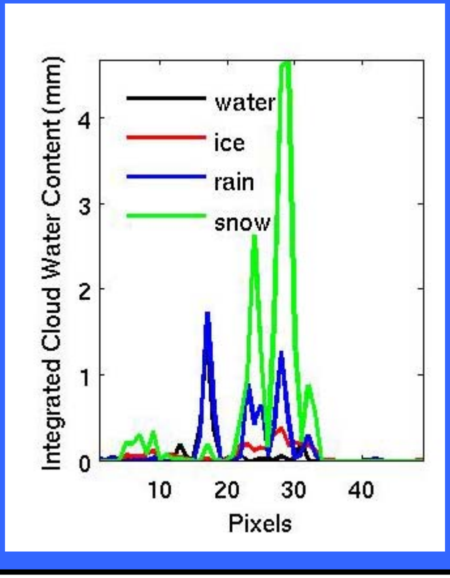
- Work performed by Z.Liu's group at NCAR/AFWA, looking at N17 AMSU-B T_B along CloudSat path; No QC was performed. Ch.1,2 calculations look good despite location mismatches.



Mismatch between observation and background



Development – Radiative Transfer

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assimilation.
  - Optical parameters for clouds and aerosols.
  - Field-of-view considerations.

- **Cloud and Aerosol Optical parameters.**
- LUT data are being improved.
- Interpolation method to keep derivatives continuous.
- Non-spherical particle data added (from Ping Yang at TAMU)
- Refactored modules that retain the forward calculations.

- **Field of View.**
- See presentation (S3): “*Microwave Radiative Transfer at the Sub-Field-of_View Resolution*” by T.Kleepies.

International TOVS Study Conference, 16th, ITSC-16, Angra dos Reis, Brazil, 7-13 May 2008.
Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center,
Cooperative Institute for Meteorological Satellite Studies, 2008.