Community Radiative Transfer Model: Status and Development

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People

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  - NRL; Ben Ruston and Nancy Baker
  - NCAR; Zhiquan Liu

Outline

- Current Status
  - Preamble
  - Components
- Development
  - Transmittance models
  - Emissivity models
  - Radiative Transfer schemes
  - Visible channels

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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 (delayed?).
  - 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.

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Current Status – Atmospheric Optics

- Atmospheric Optics
  - Gaseous Absorption
  - Clouds

- Gaseous absorption in the CRTM is computed using the "compact" OPTRAN algorithm. Vertical profiles of absorption coefficient are predicted from a set of polynomial basis functions.
- Water vapour, ozone, and "dry" gas absorption.
- Water vapour continuum is poorly handled.
- Training uses 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

Extra Layering.

- OPTRAN operates in absorber, rather than pressure, level space.
- For "dry gas" absorbers, pressure is used as proxy absorber amount.
- Thus, unlike water vapour and ozone absorbers, the start of the dry gas absorber space is always at the defined TOA pressure: 0.005hPa.
- CRTM treats the atmosphere from the bottom of the first user input level to TOA as a single (potentially thick) layer.
- Top layer temperature Jacobians can be very large.

Current Status – Atmospheric Optics

- Atmospheric Optics
  - Gaseous Absorption
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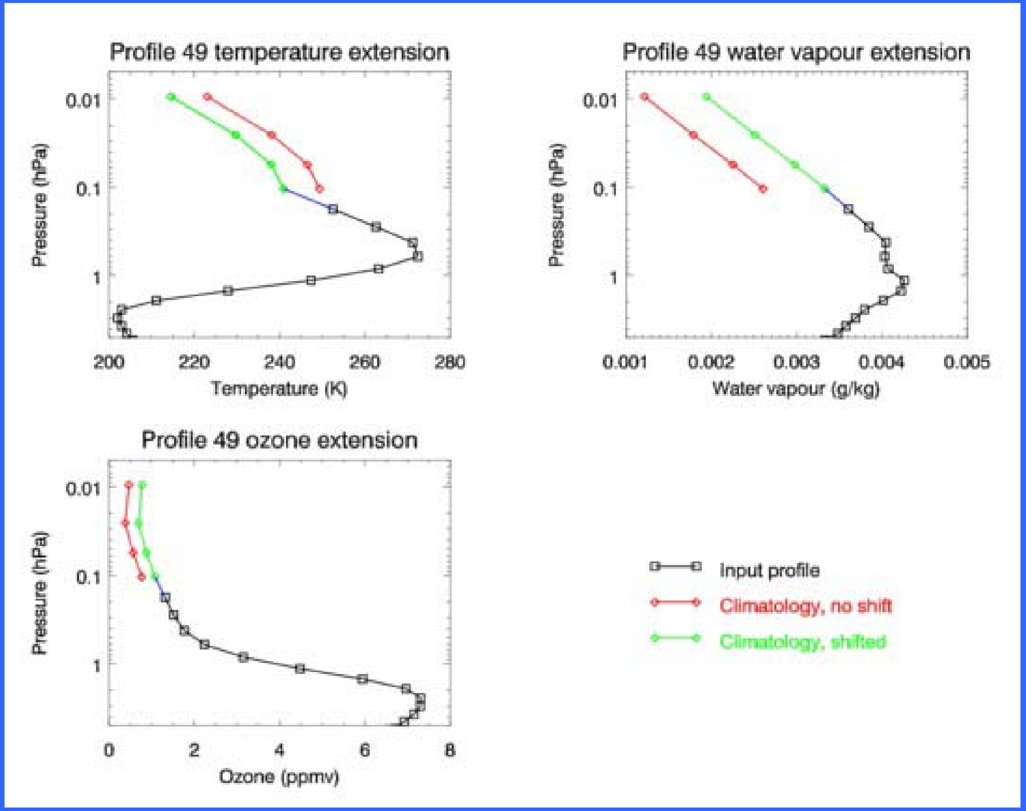
Extra Layering.

- Supplement the user input profile with climatological profile data up to the CRTM TOA.
- Profile is blended via a simple shift to minimise discontinuities.

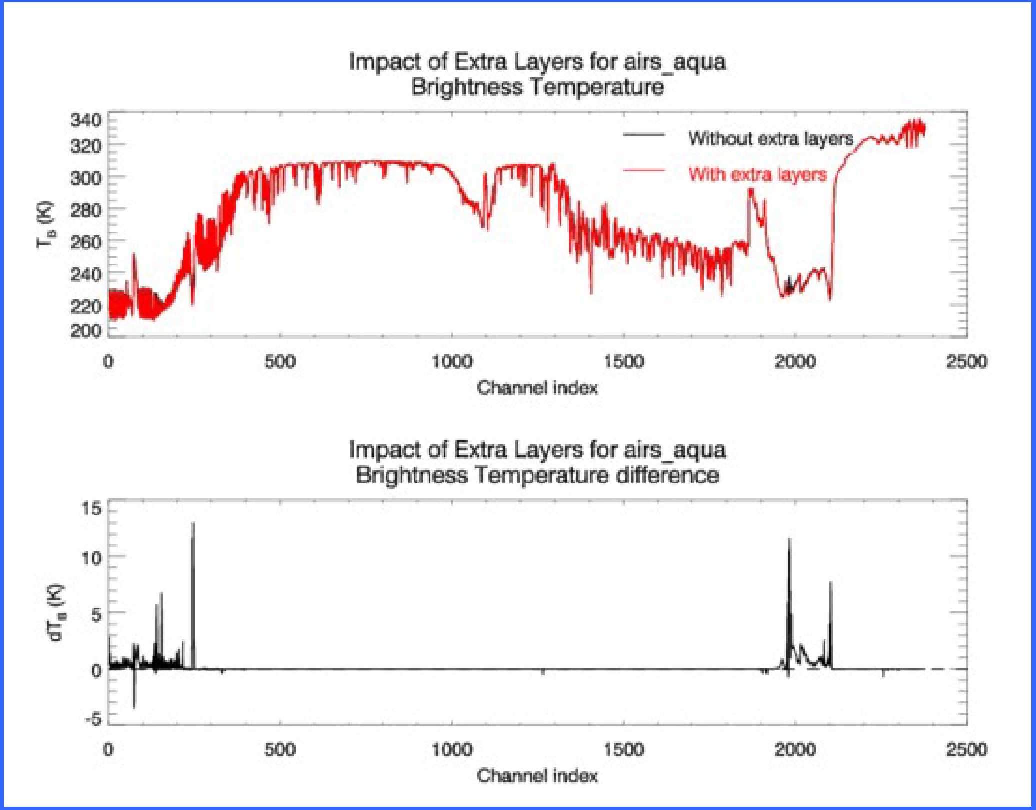


Current Status – Atmospheric Optics

- Atmospheric Optics
  - Gaseous Absorption
  - Clouds

Extra Layering.

- AIRS forward model impact for a single profile.
- Impact in upper level channels can be 10's of degrees.

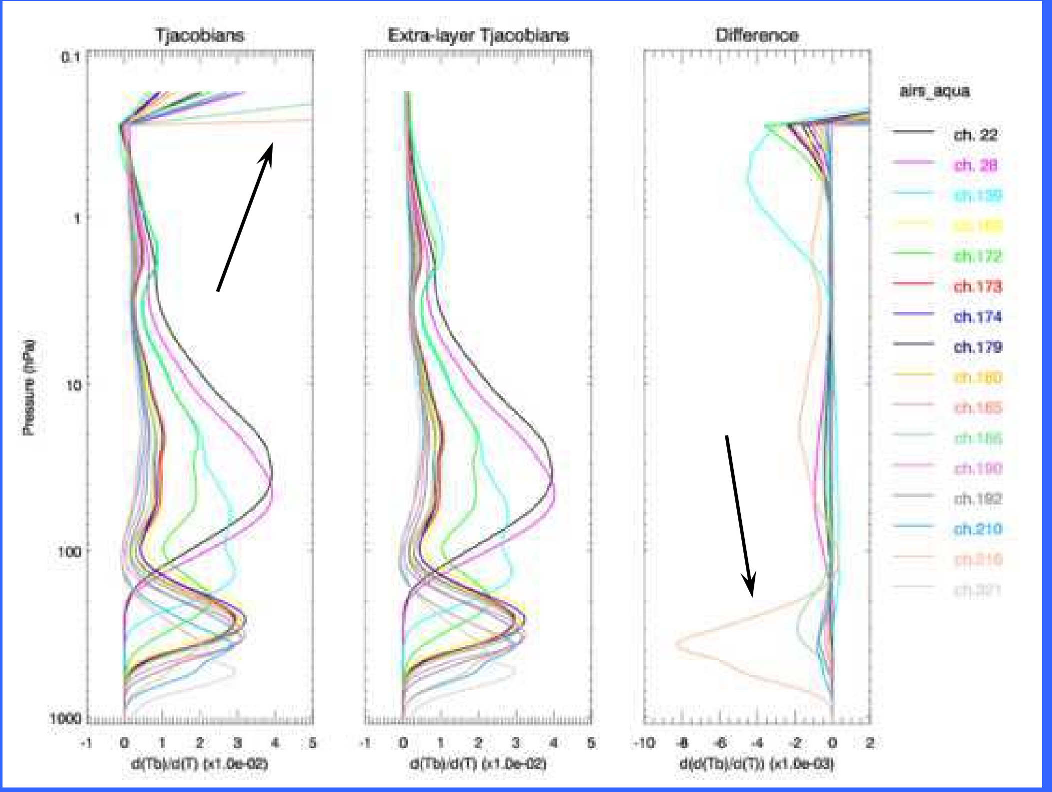


Current Status – Atmospheric Optics

- Atmospheric Optics
  - Gaseous Absorption
  - Clouds

Extra Layering.

- AIRS K-matrix model impact for selected channels for a single profile.
- Note impacts at lower levels. These channels are the ones with the largest upper level excursions.



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 of frequency, effective radius, temperature (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 artifacts).

Current Status – Atmospheric Optics

- Atmospheric Optics
  - Gaseous Absorption
  - Clouds
  - Aerosols

- Eight aerosol types
  - Dust, sea salt (SSAM, SSCM), wet and dry organic 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 discretised data)

Current Status – Surface Optics

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

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

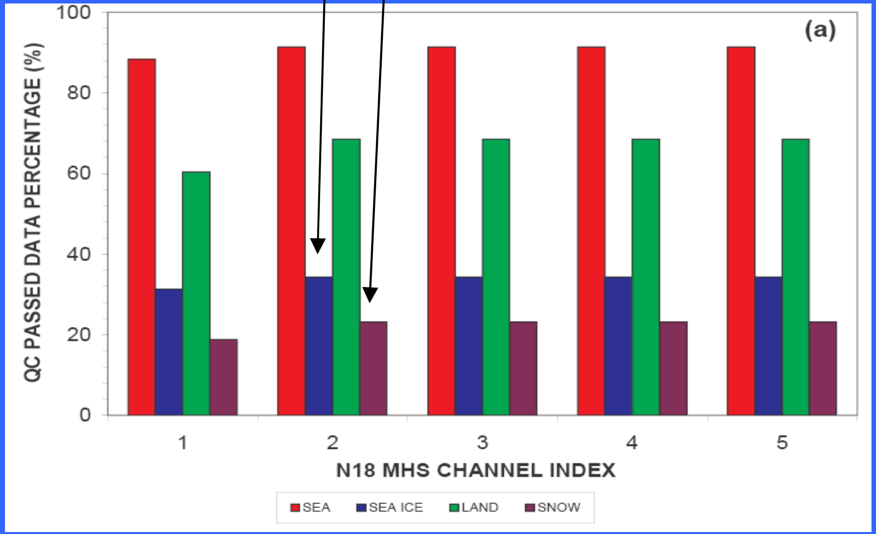
Current Status – Surface Optics

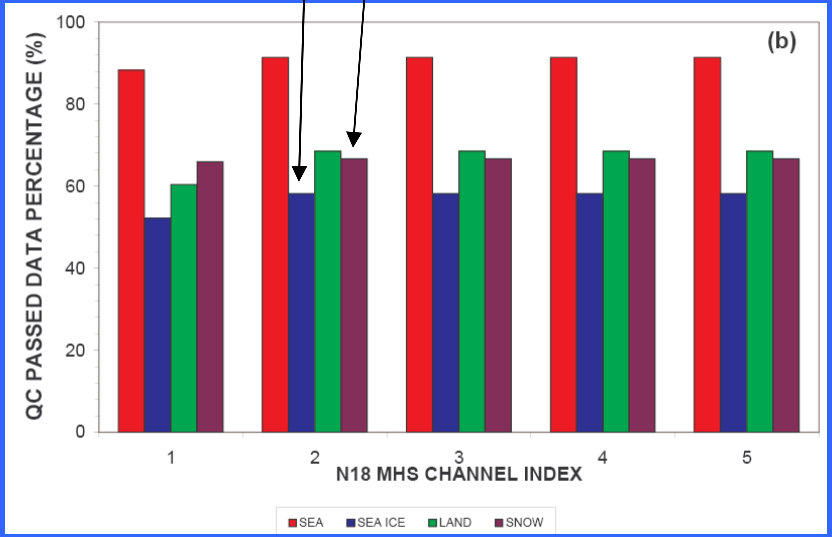
- Surface Optics
  - Infrared Land, Ocean, Snow, and Ice emissivity models
  - Microwave Land, Ocean, Snow, and Ice emissivity models.

• Assimilation impact of new MHS Snow and Sea Ice emissivity models.

Old Model
low snow and sea ice data usage

New Model
increased snow and sea ice data usage





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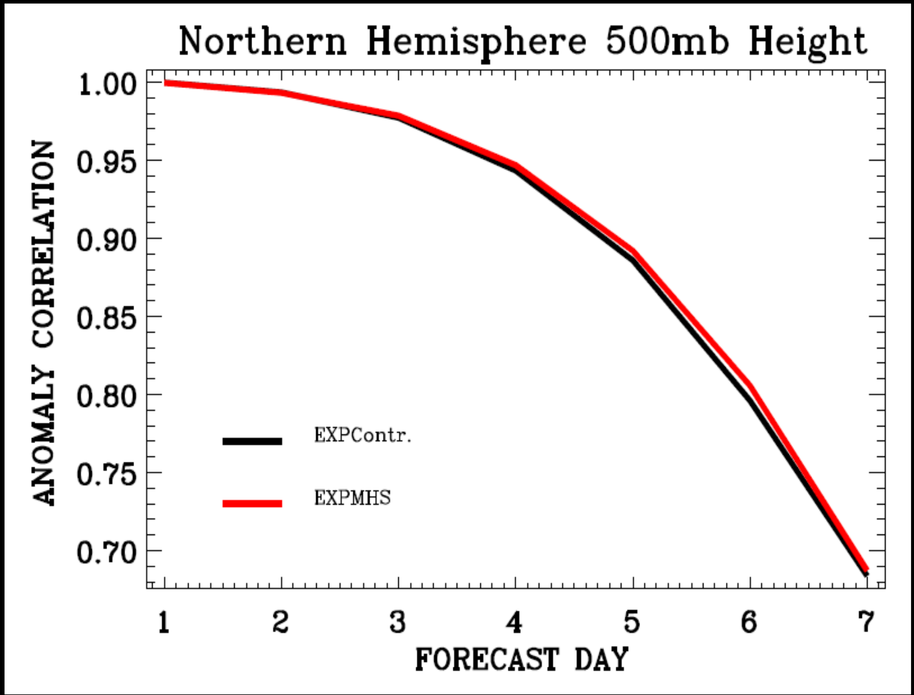

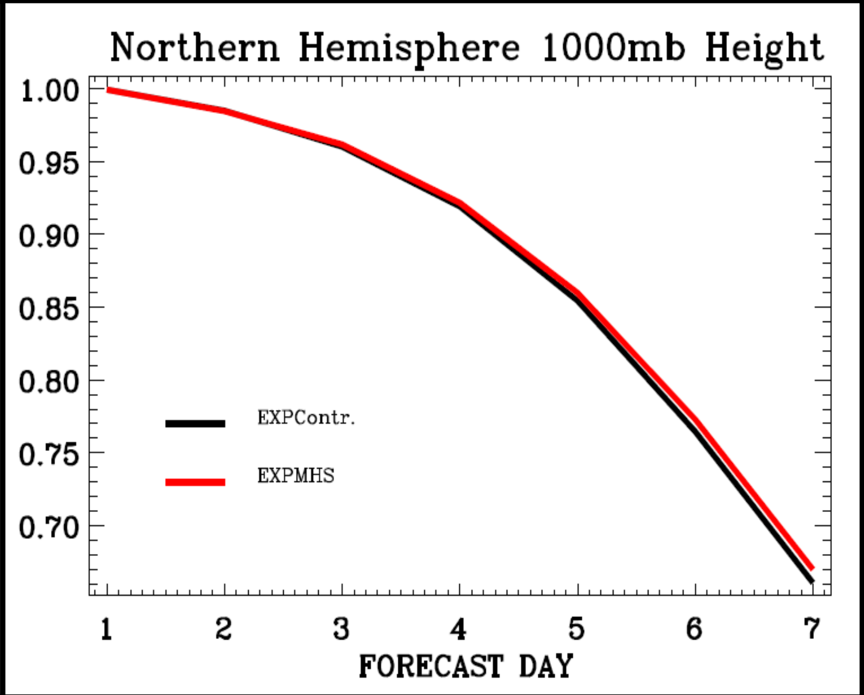

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Current Status – Radiative Transfer

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  - 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.

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Development – Transmittance Models

- SSU model
  - Developed for NCEP reanalysis
- Model that accounts for Zeeman-splitting.
  - Fast Zeeman RT model for AMSU-A channel 14
  - Earth rotation Doppler shift effect and channel polarization in SSMIS
- 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

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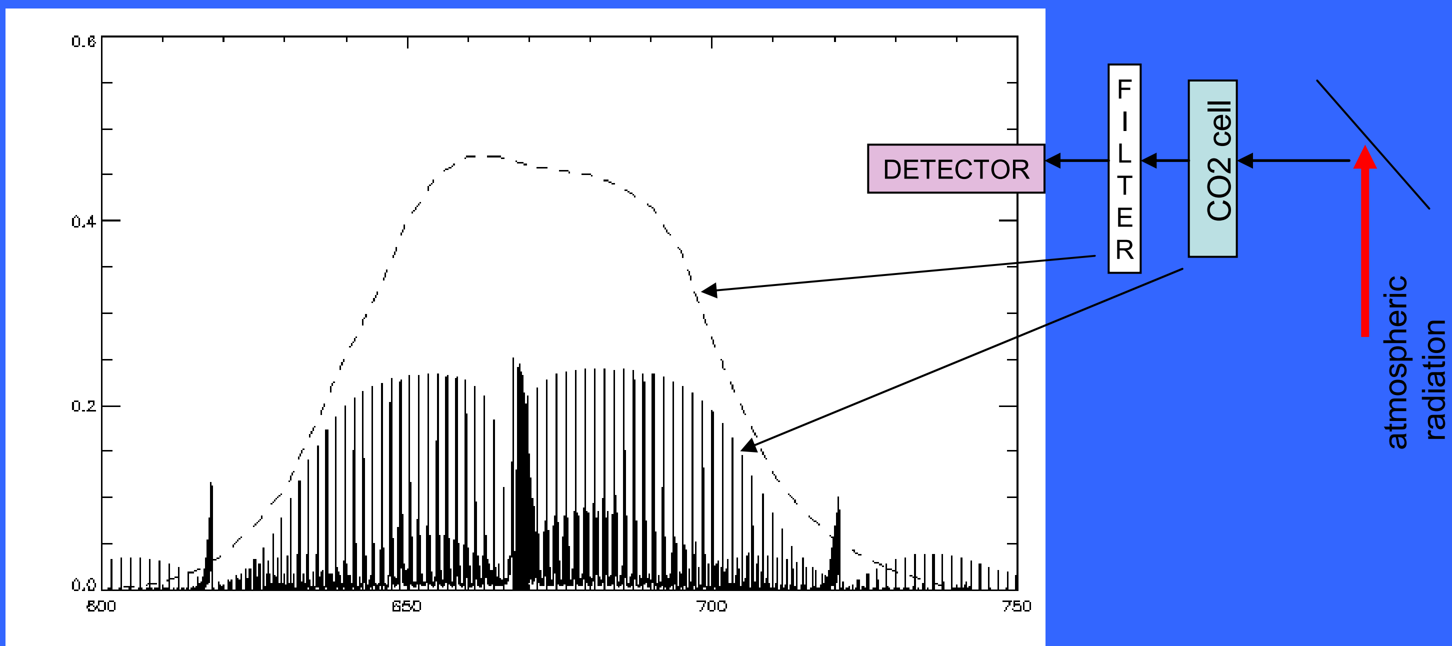
  - Developed for NCEP reanalysis

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



Development – Transmittance Models

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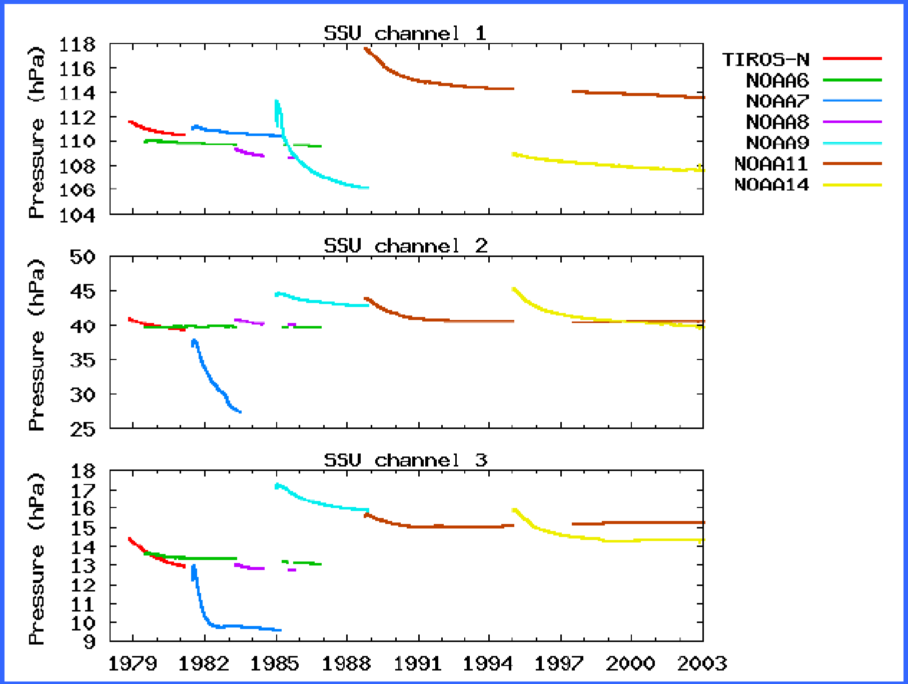
• CO_2 leakage in cell pressure modulator causes SRF variation.



From Dr. Shinya Kobayashi, ECMWF

Development – Transmittance 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*

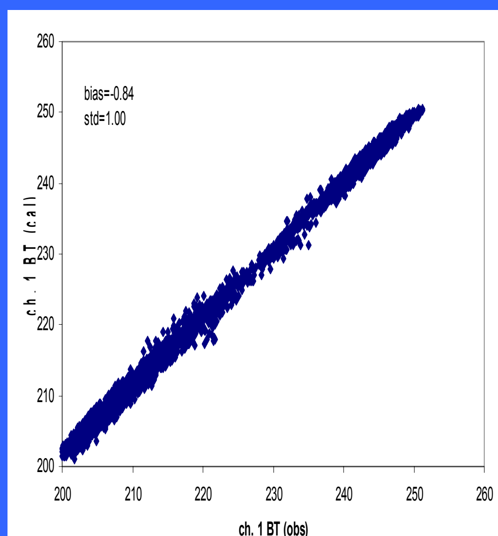
Regression coefficients

Predictors

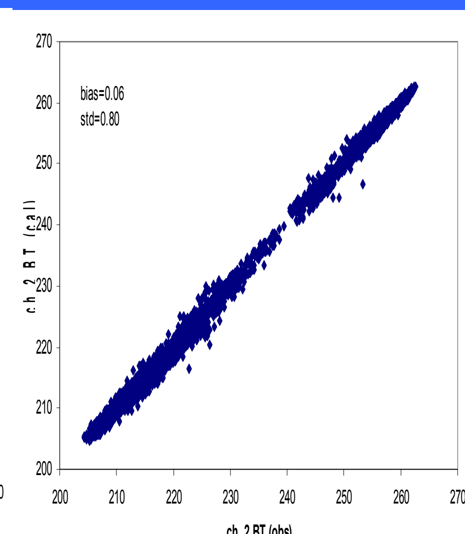
Development – Transmittance Models

- SSU model
  - Developed for NCEP reanalysis

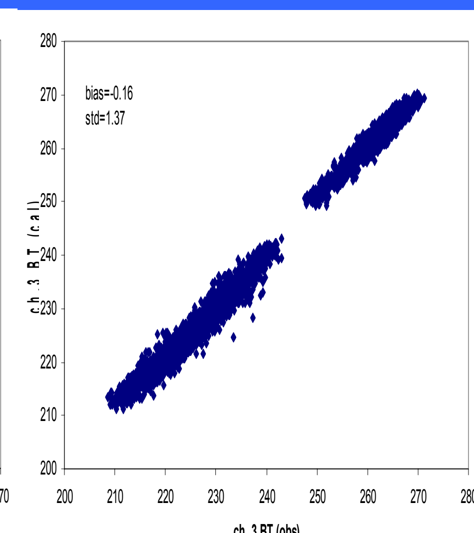
- Validation using Microwave Limb Sounding Product.
- SSU and MLS data in 11/2004 for all match-up points,



Ch.1



Ch.2



Ch.3

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Development – Transmittance Models

- Model that accounts for Zeeman-splitting.
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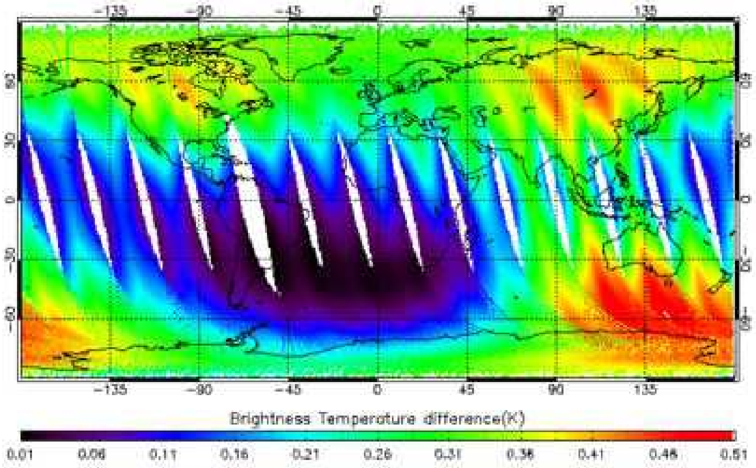
- Zeeman splitting can have an effect of up to 0.5 K on AMSU-A channel 14.
- The radiation is polarized.
- A fast model is developed to take the effect and polarization into account.
- Software has also been developed to compute the parameters needed for the model from the 1B data stream.



Difference between RT models with and without the inclusion of the Zeeman effect

Development – Transmittance Models

- Model that accounts for Zeeman-splitting.
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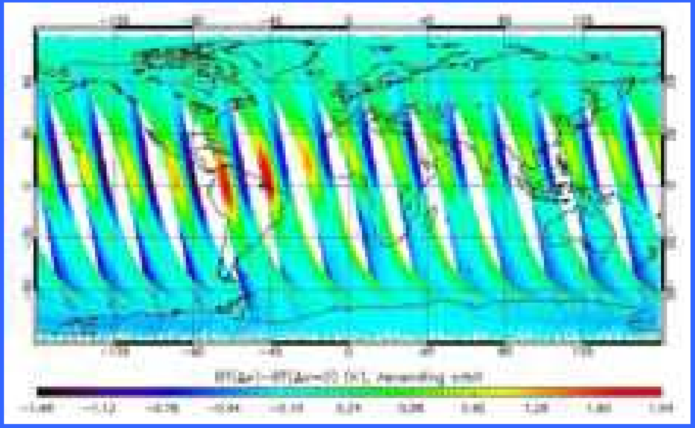
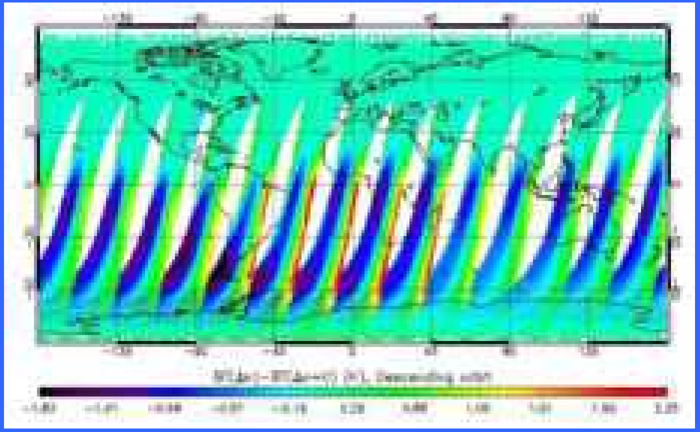
  - Earth rotation Doppler shift effect and channel polarization in SSMIS

- 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

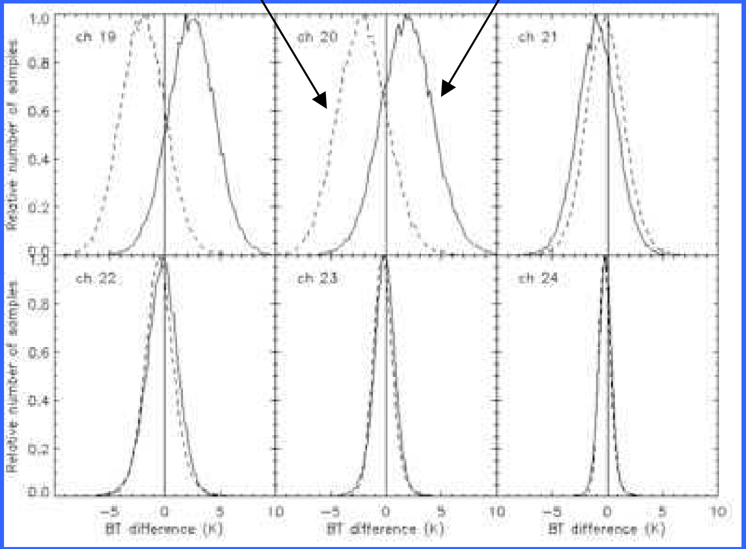
- Model that accounts for Zeeman-splitting.
  - Fast Zeeman RT model for AMSU-A channel 14
  - Earth rotation Doppler shift effect and channel polarization in SSMIS

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

Descending, $\cos(\theta_B) \approx 0.6$

Ascending, $\cos(\theta_B) \approx -0.6$

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



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Development – Transmittance 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.

- Also allows CRTM to use instrument- and channel-specific transmittance algorithms; e.g. SSU, Zeeman.

Development – Transmittance 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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Development – Transmittance 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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- Infrared Emissivity
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  - Ocean Emissivity

- Microwave Emissivity
  - Empirical models for 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

- Infrared Emissivity
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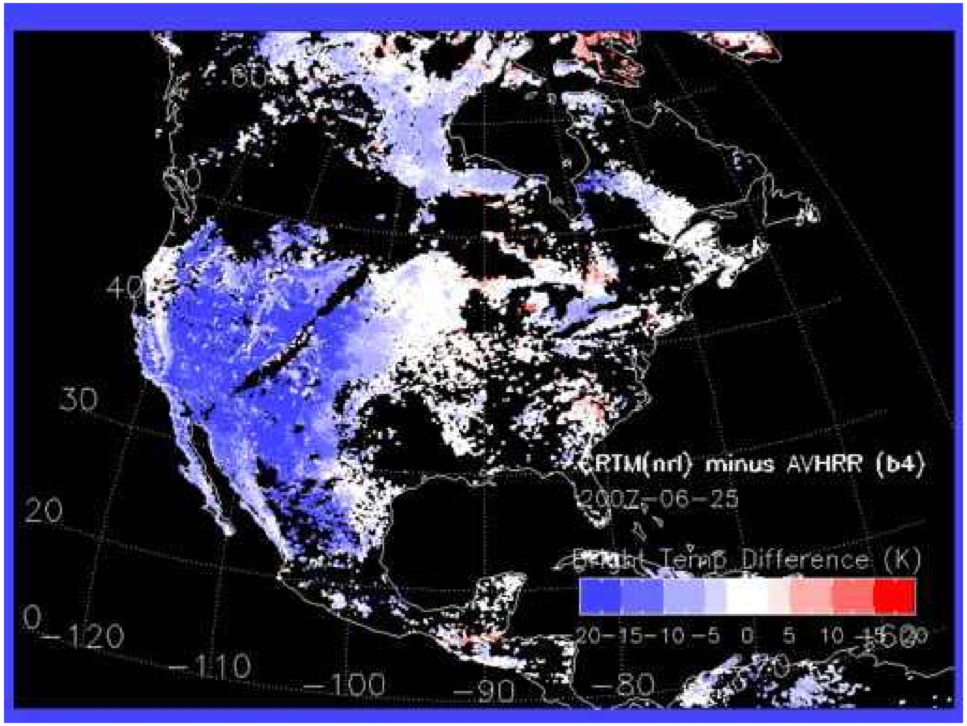
- Evaluation of NRL emissivity model in CRTM:
  - CRTM compared to AVHRR
  - CRTM run with current internal emissivity and new NRL emissivity
  - Resulting high bias (15K) is due to biased surface temperature input to CRTM.
- Effort underway to establish surface emissivity testbed with accurate surface temperature measurements.
- New reflectance spectra for matching CRTM with GFS/GDAS land classes using new NCEP classification.



CRTM with NRL emissivity minus AVHRR Tb (band 4)

Development – Emissivity Models

- Infrared Emissivity
  - Land emissivity
  - Ocean Emissivity

- Improving interpolation of emissivity LUT data (Wu-Smith model) to use new averaged quadratic interpolation module for continuous derivatives.
- Adding temperature dependence to LUT data.

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

Multilayer model:

- A radiative transfer model is being developed for vertically stratified soil and vegetation.

Physical snow model

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

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

- Optical properties for clouds and aerosols.

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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
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- 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
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- 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.

Development – Radiative Transfer

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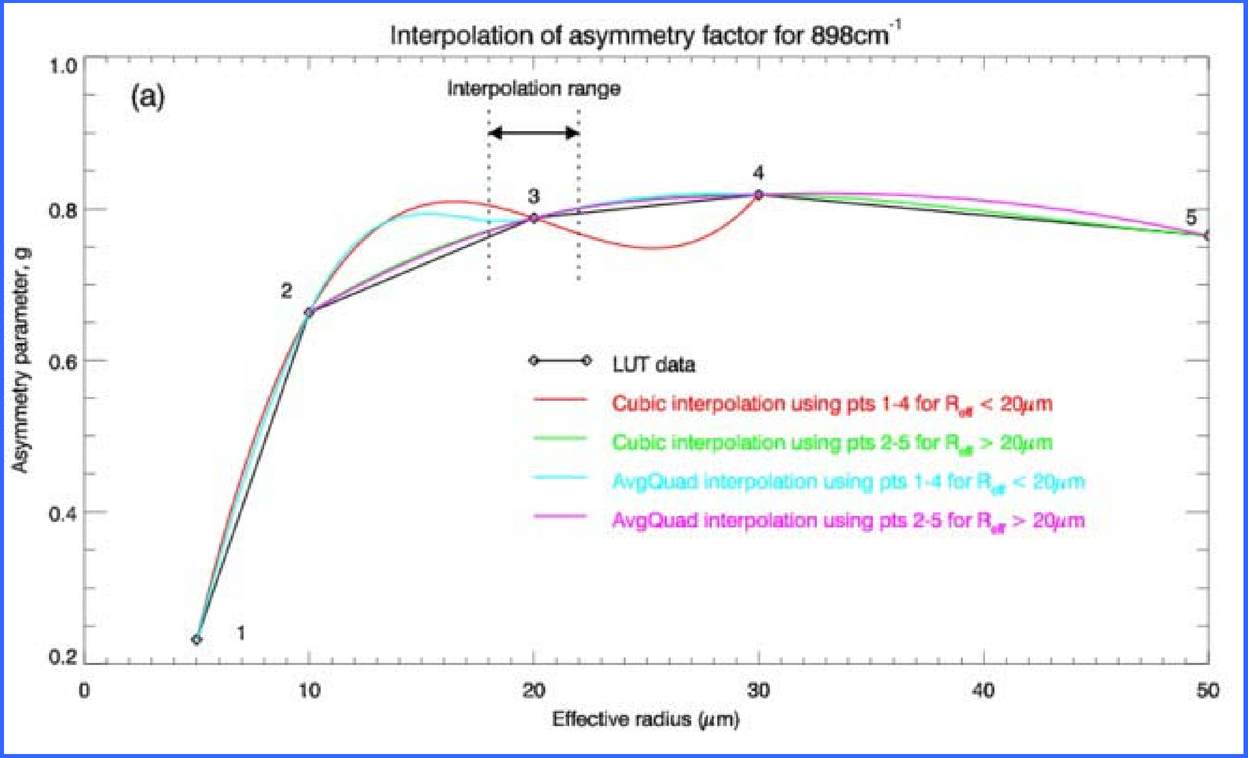
- Optical properties for clouds and aerosols.

Development – Radiative Transfer

- Optical properties for clouds and aerosols.

- Implemented new interpolation module to preserve derivatives.
- LUT data needs to be improved.

Cloud LUT data density is too low for small particles



Development – Radiative Transfer

- Optical properties for clouds and aerosols.

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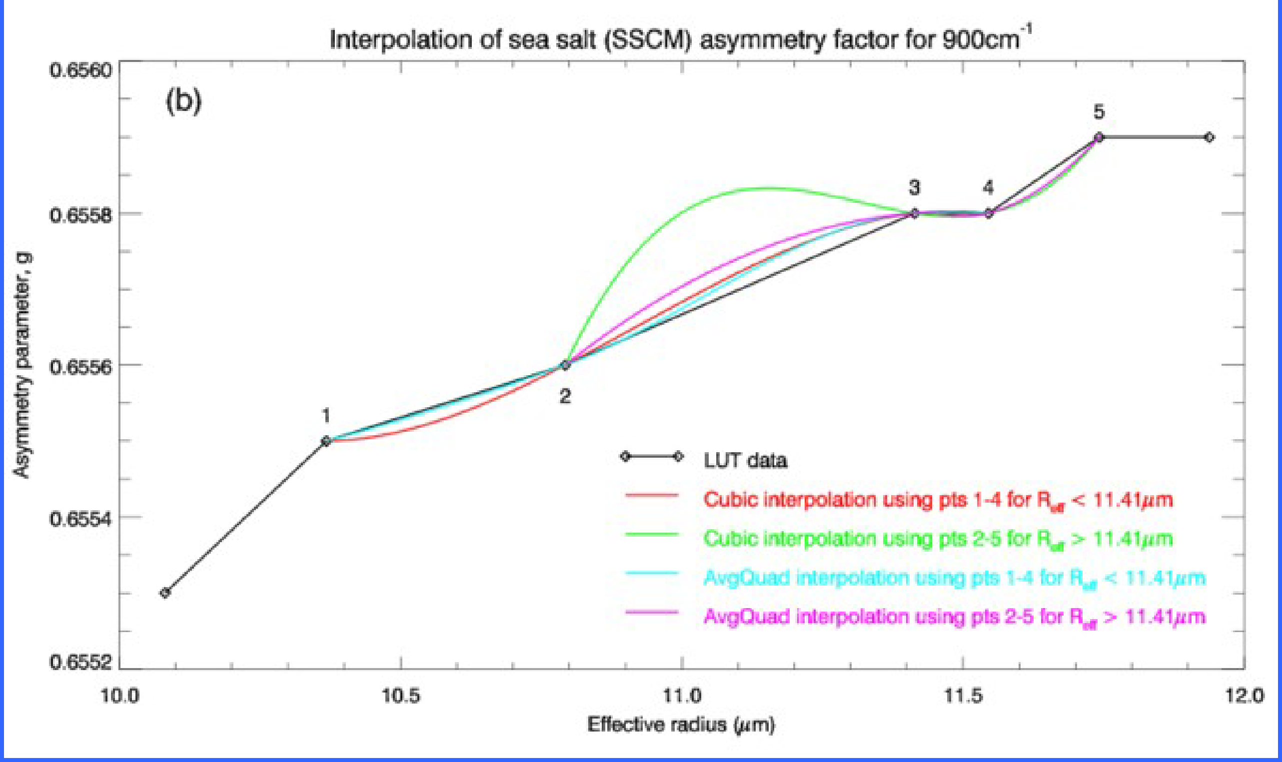
Aerosol LUT data is discret-ised which can cause interp-olation artifacts.



Development – Radiative Transfer

- Optical properties for clouds and aerosols.

- Cloud and Aerosol scatter modules have been refactored to retain the required intermediate forward model interpolation results for tangent-linear and adjoint calculations.
- Current cloud and aerosol LUT data are for spherical particles only.
- Non-spherical particle data for ice cloud and dust aerosol received from Ping Yang (TAMU). These data are being incorporated into the CRTM LUTs.

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Development – Visible Channels

- Derived analytical expressions for the scattering source function.
- Azimuthal dependence of the solar source function taken into account.
- Earth curvature effects at large solar zenith angles taken into account. (Also being applied to “regular” radiative transfer)
- Cloud and aerosol optical property LUTs are being extended into the visible spectral region.

Development Summary

- Good progress made in CRTM development in the last year.
  - Feedback from users proved very helpful.
  - Public code repository should be online sometime in July.
- Modules completed and waiting:
  - SSU and Zeeman models ready to be included when multiple-algorithm transmittance module is completed.
  - SSMIS snow and ice emissivity models ready to be integrated.
- Modules still being developed:
  - Multiple algorithm transmittance model.
  - Trace gas transmittance model.
  - Improved IR and MW surface emissivity models.
  - Improved cloud and aerosol LUT data.
  - Visible models.