



U.S. AIR FORCE



## 2.04

# The Community Radiative Transfer Model

### CRTM Team:

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Cheng Dang (UCAR/JCSDA)

*Jim Rosinski, Yingtao Ma, Ming Chen, Isaac Moradi, Haixia Liu, Nick Nalli, Cory Martin, Daniel Abdi, Tom Greenwald, Emily Liu, Barbara Scherllin-Pirscher, Quanhua "Mark" Liu, Sarah Lu, Ping Yang, Will McCarty, Bryan Karpowicz, Yanqiu Zhu, and many others.*



# CRTM Vision

## CRTM is a Community Model

- Open Source and Open Access
- Version Control (git) and code review
- Distributed Collaboration (GitHub, Zenhub, Google)
  - <https://github.com/JCSDA/crtm>
- Modern Fortran (2003+)
- *Public Domain License (CC0)*

## Education and Outreach

- CRTM User/Developer Workshop(s)
- JCSDA Summer Colloquium
- Code Sprints
- Seminars / Colloquia
- JCSDA.org website

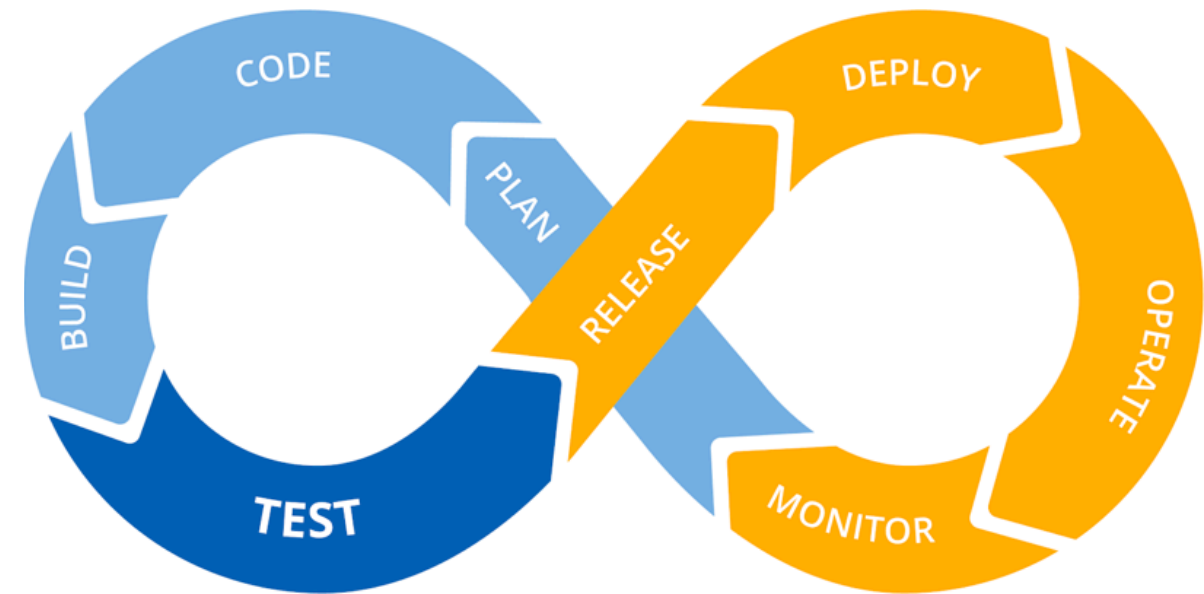


# Project Organization

**CRTM1: Software Management and Workflow**

**CRTM2: Model and Application Development**

**CRTM3: Science Development and Application Outcomes**



# CRTM1: Software Management and Workflow

## CRTM Task 1 Activities

Bi-weekly technical **meetings**, quarterly reviews, 1-on-1 discussions. Meeting minutes posted internally.

**Robust Data management** implementation for **netCDF** and legacy binary files

**Workflow for automated regular builds** out of development branches per application

**CI/CD pipeline** for automated testing

**Code reviews and User support** issues tracked through Github

Publicly accessible (web/repository) **documentation, training tools, online / self-guided tutorials**

**Code Sprint 1: CRTM v3.0 development**

**Code Sprint 2: SimObs Application development**

**Release: CRTM v3.0 code** + associated files

**Release: SimObs v1.0 code** + associated files

**Release: CRTM Trans. Coef. Package v1.0 code** + associated files

**Release: CRTM-AI utilities** + associated files

# Expanded Presence on JCSDA website with regular updates



<https://www.jcsda.org/jcsda-project-community-radiative-transfer-model>

[USER GUIDE](#)   [REPOSITORY](#)   [PYCRTM](#)

**CRTM SUPPORT:**

[SUPPORT FORUM](#)

[CRTM TUTORIAL](#)

**CRTM CONTACT:**

**BENJAMIN T. JOHNSON**

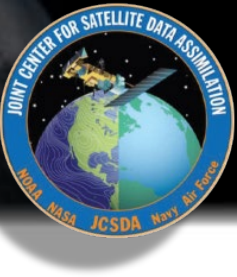
## ADDITIONAL CRTM SUPPORT

Developer updates will be shared via a CRTM Google group. To be added to this group, please contact a member of the core CRTM team.

Additional user support for the CRTM project is provided via a user support Google group. In order to join the CRTM Support Group please log into the Google Groups web application with your required Google account. Search for the keyword 'CRTM' and look for the 'CRTM-Support' group. Click on the icon on the right hand side of the list to request joining the group.

Updated links on CRTM project website, including pyCRTM repo, release information, support forum, and current tutorial repo.

# CRTM v2.4.0



## CRTM v2.4.0

<https://github.com/JCSDA/crtm>

- **Released October 28, 2020**
- **New Features:**
  1. Support for netCDF4 file format reading: CloudCoeff.nc4 and AerosolCoeff.nc4
  2. OpenMP optimization (vs. profiles)
  3. Experimental Cloud Coefficient tables (see `fix/CloudCoeff`) in binary and netcdf4 formats
  4. Added 81 regression and 4 unit tests, see `README.md`.
  5. Updated: CMAQ-based (v4.x) Aerosols and Radiance/AOD simulation
  6. Improved loop-level performance: 4 to 5 times native improvement by optimizing loops.
- Multiple bugfixes vs. v2.3.x (see release notes)
- **Multiple new sensors added:**
  - EON MW, Sentinel3a SLSTR, Meteosat-11 Seviri. GOES-17 ABI 81K fix, Metop-C: AVHRR, IASI, SMAP/SMOS, TEMPEST-D, MI-LCOMS.v2, JPSS-2 VIIRS, GEOKOMPSAT-2a AMI, Metop-SG-A1 MWS, FY4a-GIIRS



# CRTM v2.4.1



CRTM v2.4.1 (under development, expected July 2021)

<https://github.com/JCSDA/crtm>

- **New features + bugfixes vs. v2.4.0:**

- openMP extended, now supports both channel and profile loops (D. Abdi)
- Fix: Snow cover emissivity when bad/missing observation data present (M. Chen)
- Updates to compiler-specific configuration files
- Updated support for Aerosol Coefficient files: CMAQ, GOCART, NAAPS (C. Dang)
- Implemented two new aerosol coefficient look-up tables based on GOCART-GEOS5 and NAAPS aerosol specifications (*New aerosol species: nitrate and smoke*) (C. Dang)
- Binary files / netCDF files hosted via git-LFS, gzipped for storage / speed.
- Test codes updated to reflect/test new coefficient files

- **Sensors added:**

- Corrections to internal sensor naming issues of abi\_g17-81K
- IASI-NG (testing), TROPICS\_sv1\_srf\_v1, OMS GEMS-1/2 (in progress)
- v2 ACCoeff and SpcCoeff for Metop-C / AMSU-A / MHS
- ATMS-NG (in progress)
- GOES-T ABI (testing/STAR)

# CRTM v3.0 Goals and Work Plans

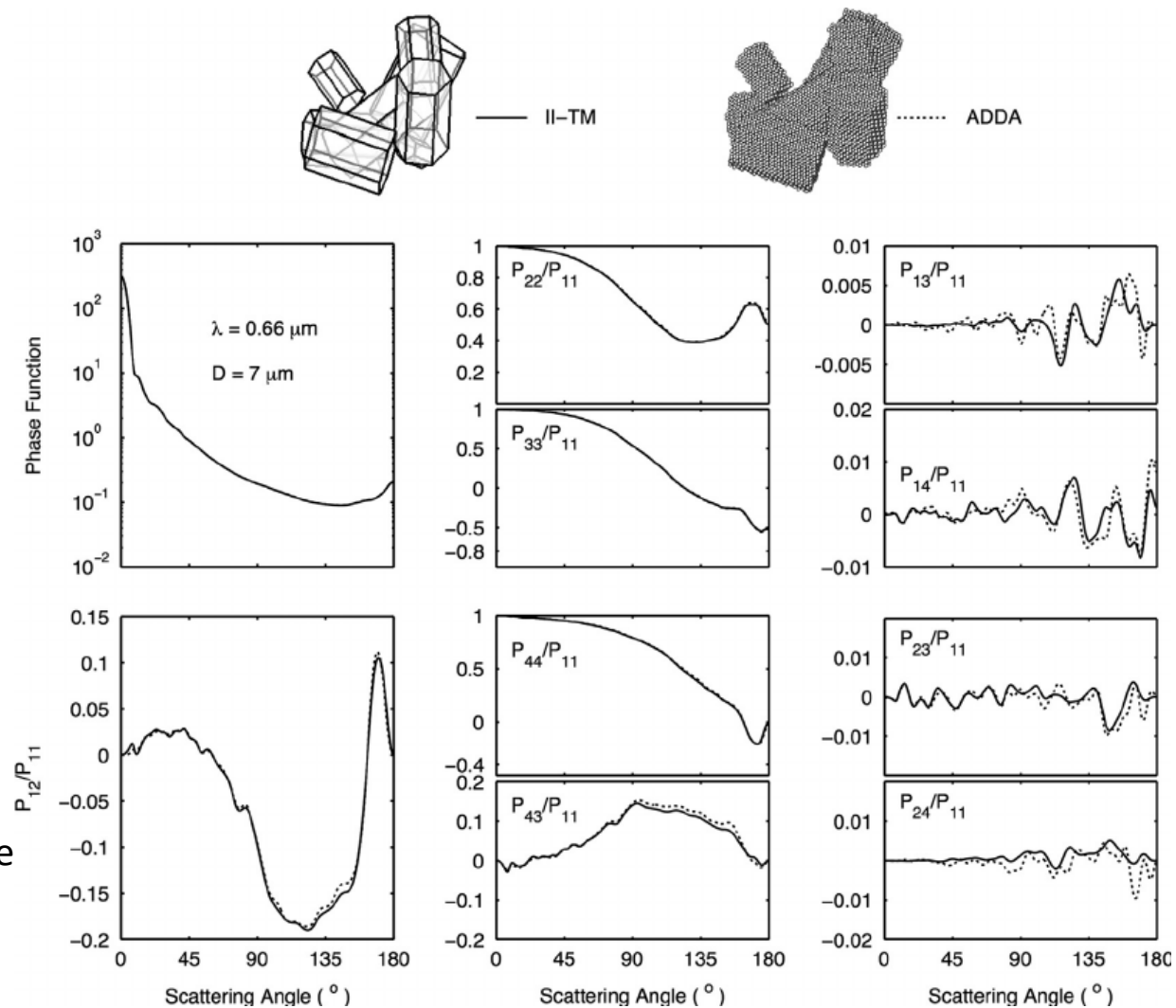
- **Cloudy Radiance** (B. Johnson)
  - ■ Backscattering coefficients for CRTM active sensor capability (Moradi, Johnson, Stegmann)
  - ■ Produce (Polarized) CRTM Scattering Coefficients from BHMIE and T-Matrix spheroids in binary and NetCDF
  - ■ Start systematic investigation of “optimal” single-scattering properties for CRTM applications
  - ■ Update of CHYM for microphysical consistency with NWP (B. Johnson, G. Thompson, Y. Lu, E. Clothiaux)
- **Surface** (M. Chen, Y. Zhu)
  - ■ Test CRTM-CSEM in GFS/GSI, focusing on the comparisons among model options.
  - ■ Analyze and document the tests of CRTM-CSEM in GFS/GSI.
  - ■ Initial implementation of MW ocean surface BRDF model.
  - ■ Ocean Surface Emissivity improvements IR (IRSSE, N. Nalli)
- **Full Polarization Solver Capability** (Q. Liu, T. Greenwald, B. Johnson, C. Cao)
  - ■ UV capable solver + polarization support under evaluation (CRTM v3.0-beta)
- **SW / IR improvements in CRTM**
  - ■ Cloud, surface, and aerosol impacts on visible channels (C. Dang)
- **Aerosols update** (Johnson, Stegmann, S. Lu, M. Pagowski, B. Scherllin-Pirscher, others).
  - ■ Improved aerosol indices of refraction (via D. Turner, J. Gasteiger, C. Dang)
  - ■ Update of CRTM using initial CMAQ specifications (C. Dang, Y. Ma)
  - ■ Improve Lidar backscattering and attenuation calculations (Pagowski, Scherllin-Pirscher)



# CRTM v3.0 Beta Focus

## Cloud-impacted radiance and physical model simulation improvements (UV, VIS, IR, MW)

- Community Hydrometeor Model (CHYM)
  - Development continuing, and creating new polarized MW, IR, and VIS integrated cloud and aerosol scattering tables that are more closely linked with model assumed microphysical properties.
  - netCDF transition and conversion.
  - Updating Space-based radar support with linear polarization capabilities
- Coefficient tool development e.g.:
  - [https://github.com/PStegmann/INSPECT\\_CloudCoeff](https://github.com/PStegmann/INSPECT_CloudCoeff)
  - [https://github.com/JCSDA/CRTM\\_coef](https://github.com/JCSDA/CRTM_coef)
- Community Surface Emissivity Model (Ming Chen)
  - Extension of CSEM capabilities to support fully polarized surface BRDFs for ocean and land



# AOP 2021 CRTM2: Model and Application Development



## CRTM Task 2 Activities

CRTM v3.0 Code with **expanded openMP directives**

CRTM v3.0 Code with **optimized structure for vectorization** and minimal I/O overhead (potential GPU port)

Code that fully supports **netCDF4 for all input files** (CRTM + Applications)

**Generic, modular/OO code interfaces** for each input data type

**Code for SIMOBS** application, supports CRTM1.10

**Python Code/Utilities** in support of CRTM3.9 - CRTM3.11

**Code/Utilities in support of CRTM transmittance** coefficient generation

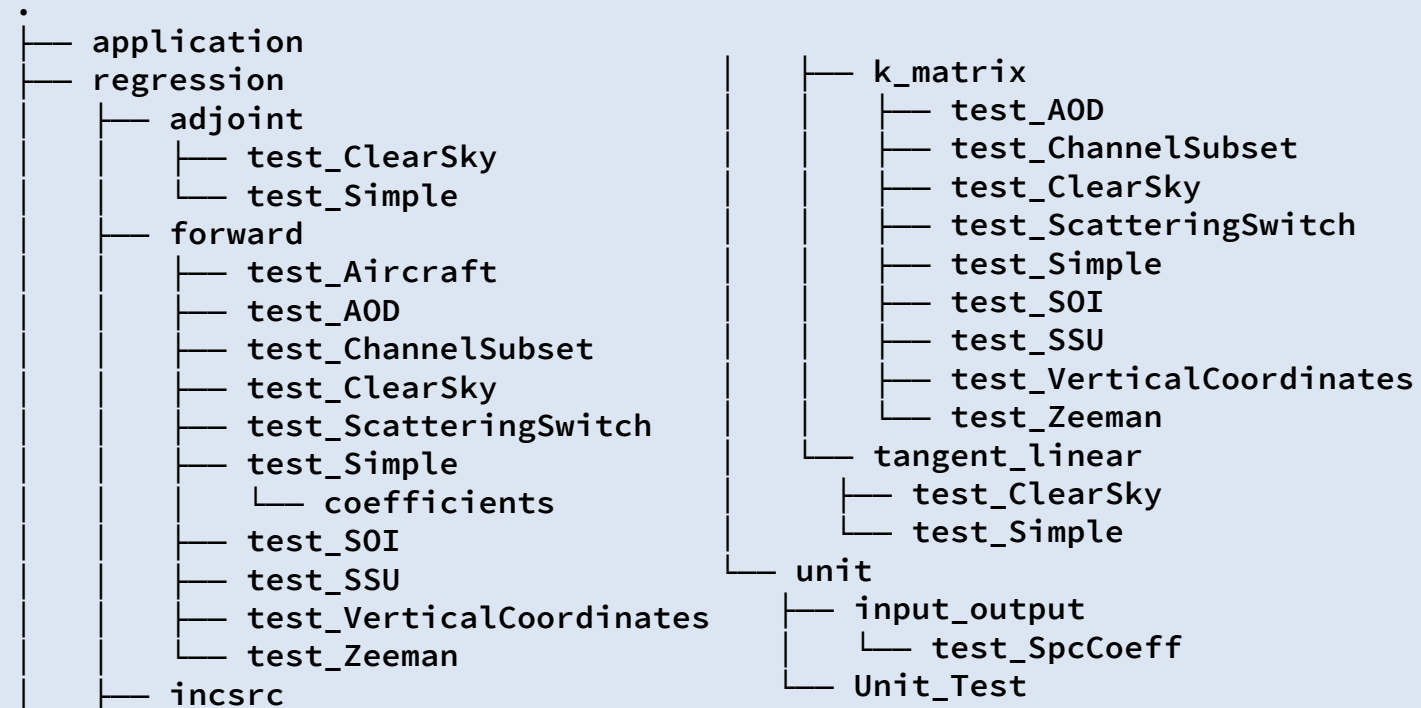
# Testing Framework

## Levels of Testing



```
Start 1: get_crtm_coeffs
1/92 Test #1: get_crtm_coeffs ... Passed 39.84 sec
Start 2: test_check_crtm
2/92 Test #2: test_check_crtm ... Passed 3.30 sec
Start 3: test_check_crtm_random
3/92 Test #3: test_random ... Passed 25.27 sec
Start 4: Unit_TL_TEST
4/92 Test #4: Unit_TL_TEST ... Passed 0.10 sec
Start 5: Unit_test_spc_io
5/92 Test #5: Unit_test_spc_io ... Passed 0.09 sec
<...>
Start 91: test_tangent_linear_ClearSky_v.abi_gr
91/92 Test #91: test_tangent_linear_ClearSky_v.abi_gr
... Passed 0.18 sec
Start 92: test_tangent_linear_ClearSky_modis_aqua
92/92 Test #92: test_tangent_linear_ClearSky_modis_aqua
... Passed 0.10 sec

0 tests failed out of 92
```





# AOP 2021 CRTM3a: Science Development

## CRTM Task 3 Activities

**Non-spherical particle properties database for aerosols and clouds**

**Expanded aerosol coefficients:** radius, species

**UV/Visible/NearIR radiative transfer model improvements** for surface properties

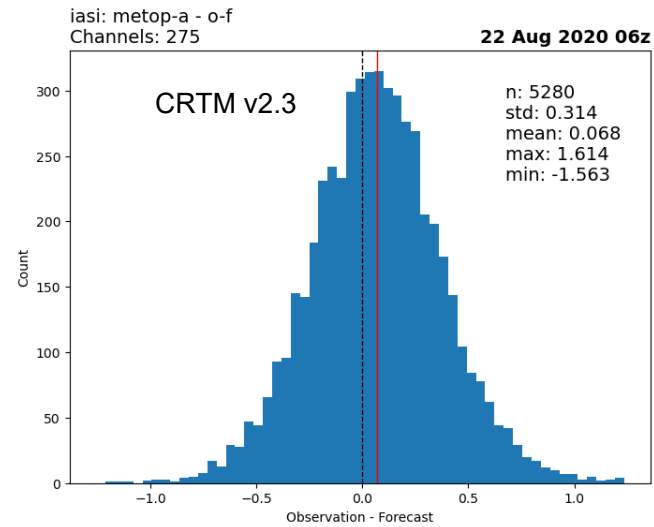
**Zeeman** code updates

Non-local thermodynamic equilibrium (**NLTE**) updates across instruments

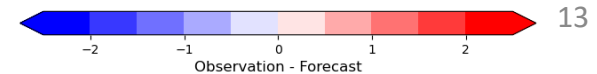
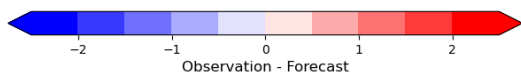
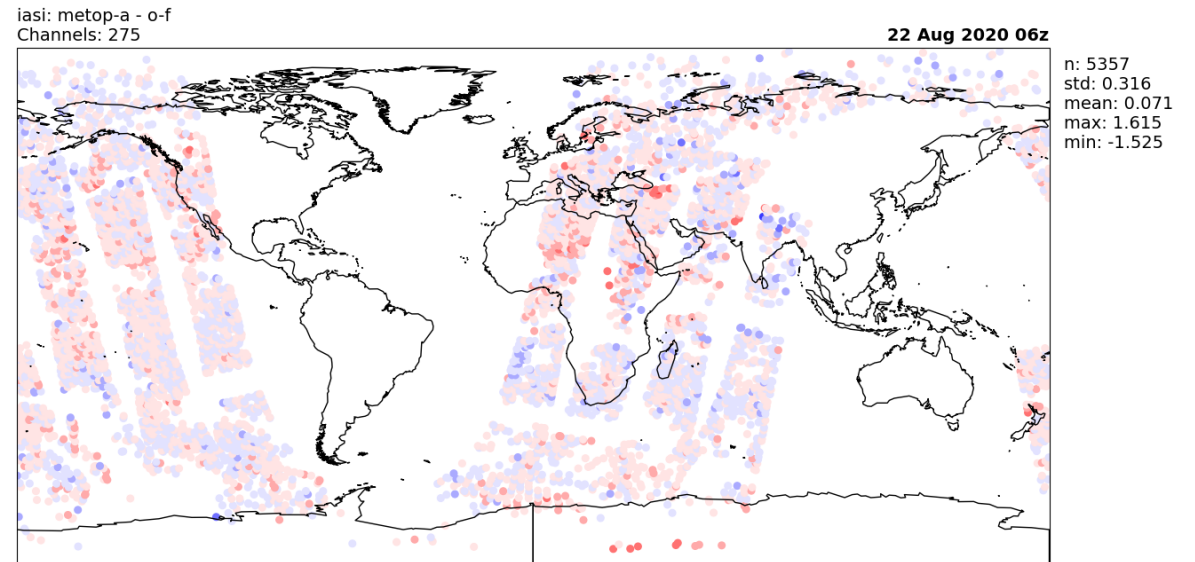
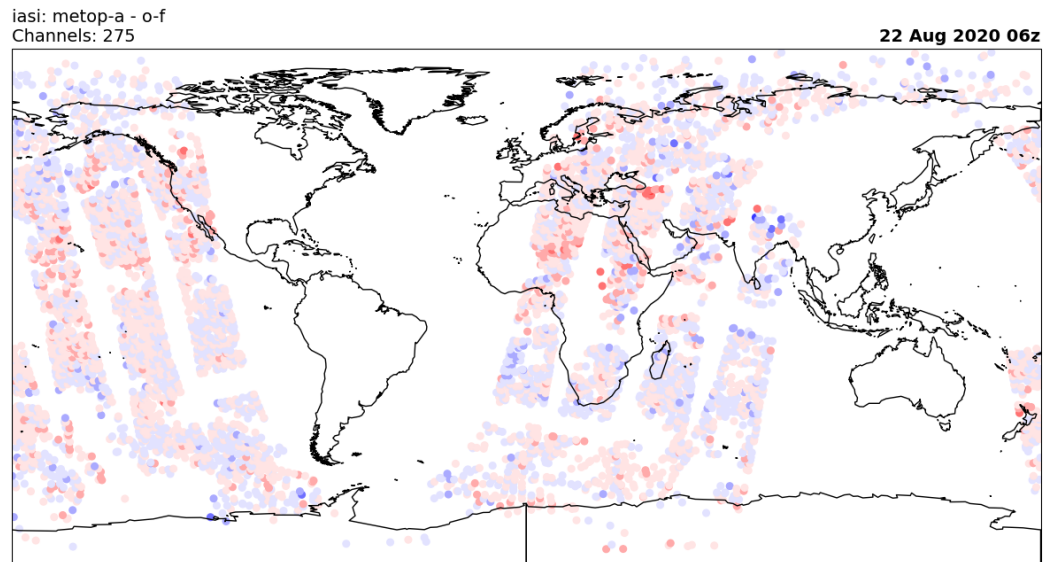
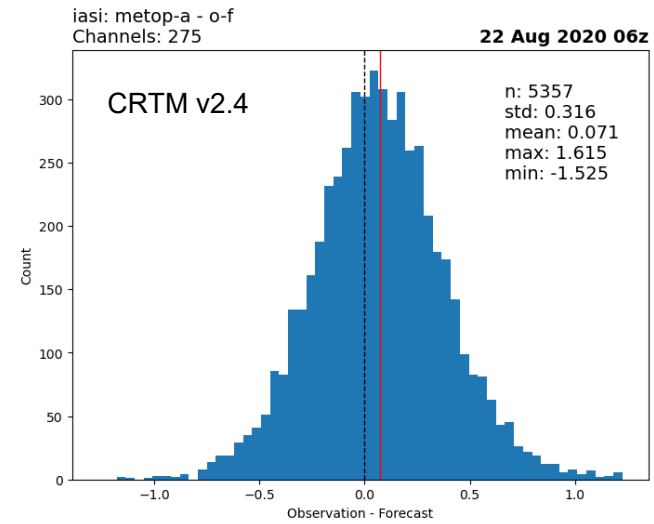
**CSEM expansion to support polarized BRDFs** across all surfaces & spectral bands

External methods for **Validation**

# CRTM v2.4.0 Testing / Evaluation (H. Liu)



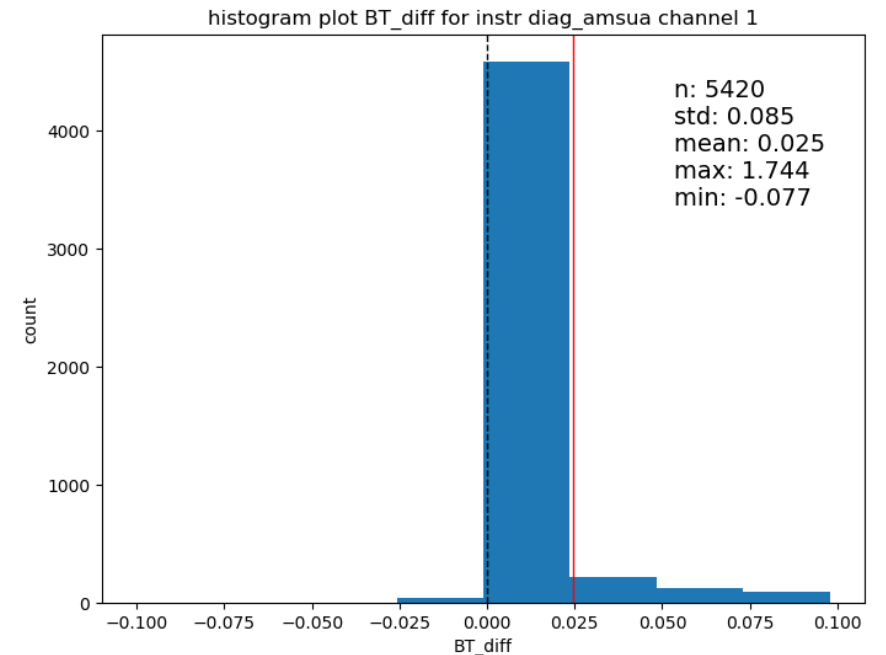
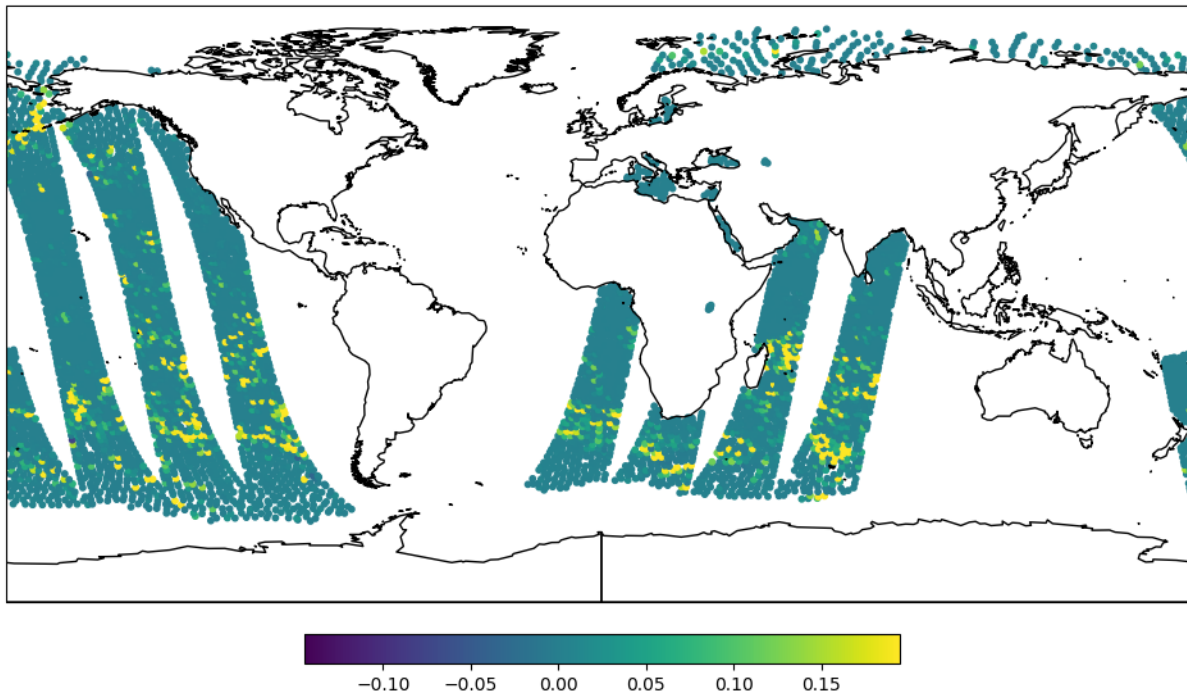
**IASI**  
**Nobs:**  
**5280 v2.3.0**  
**5357 v2.4.0**



# CRTM v2.4.0 Testing / Evaluation (H. Liu, M. Chen)

AMSU-A BT simulations show differences over sea (all-sky simulation), no differences over land, ice, snow, or mixed (clear-sky simulation).

BT Simulation diff v230-v240

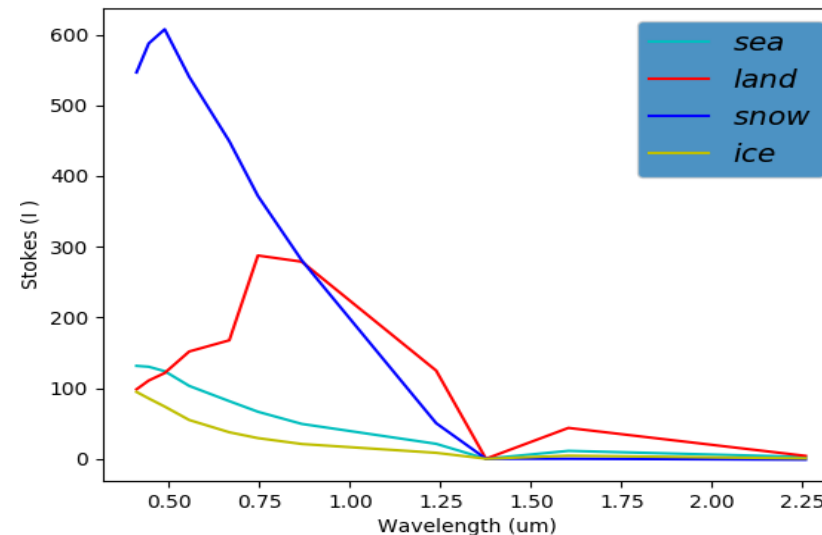
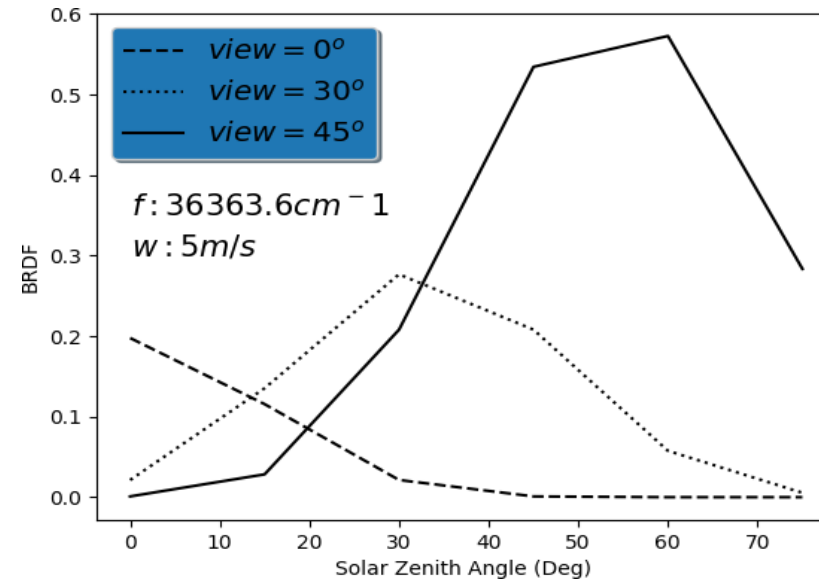




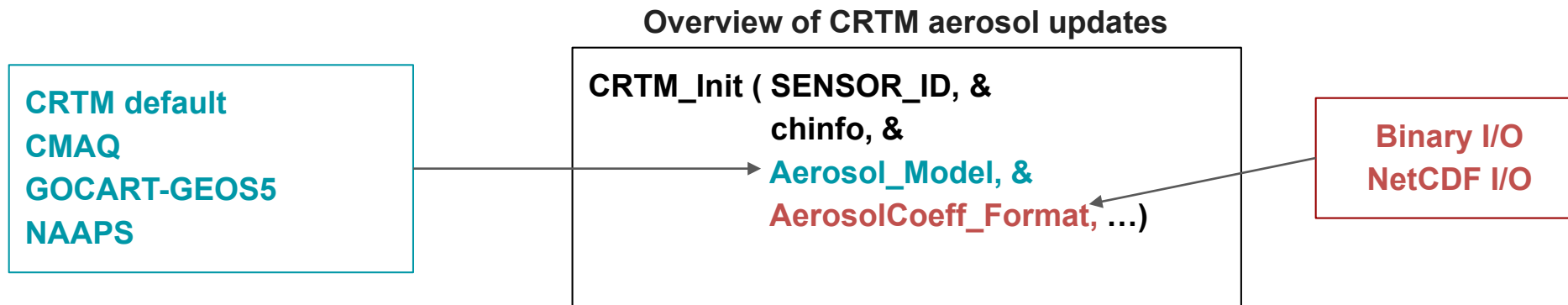
# Community Surface Emissivity Model (M. Chen)

## Updates on CSEM Development and Improvement

- The Visible-UV ocean surface BRDF model from Mark Liu's CRTM 3.0beta package has been implemented into CSEM to support the CRTM 3.0 beta release. This model is similar to the IR ocean surface BRDF model, but with the extended water refractive index from 2.9um to 0.27um.
- A new Visible-UV surface reflectivity model was developed by using the NPOESS type-based spectral LUT to replace the constant value in the CRTM 3.0beta.
- The updated IR ocean surface emissivity LUTs from Nick Nalli have been implemented into CSEM. The CSEM package with these LUTs was delivered and is currently used to address the bias zonal dependency in GSI.
- The ATMS snow emissivity model has been improved to handle the invalid model inputs.

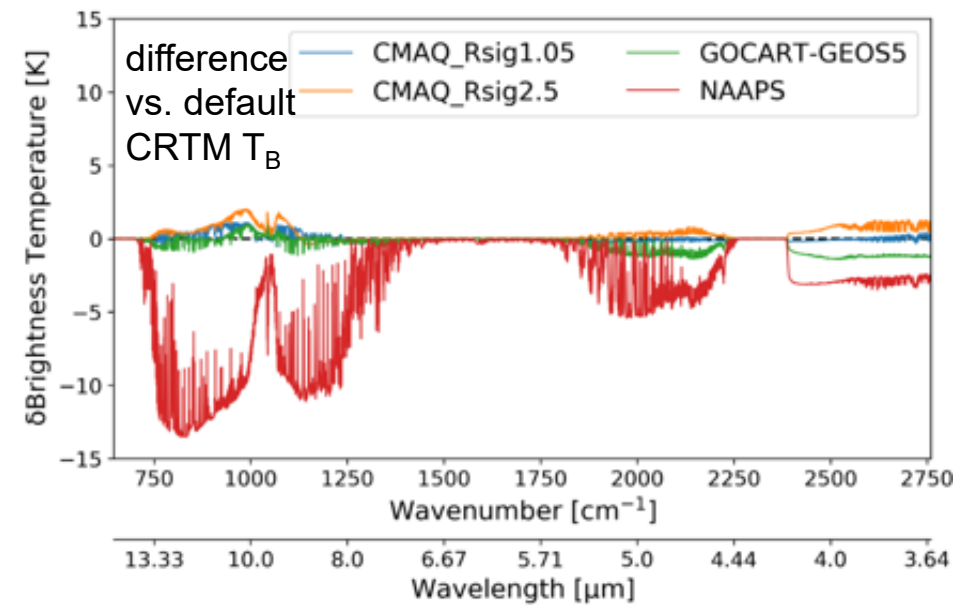
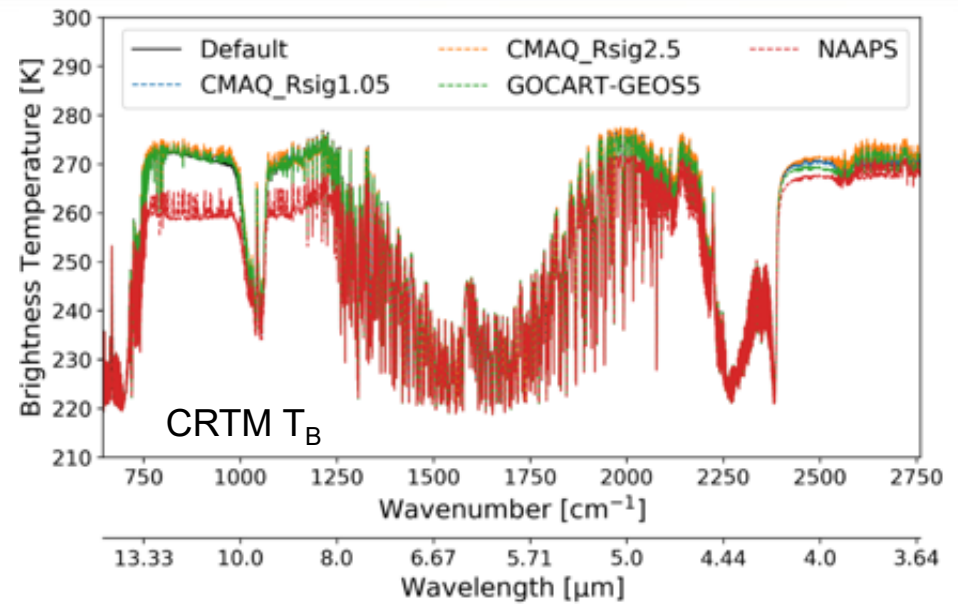
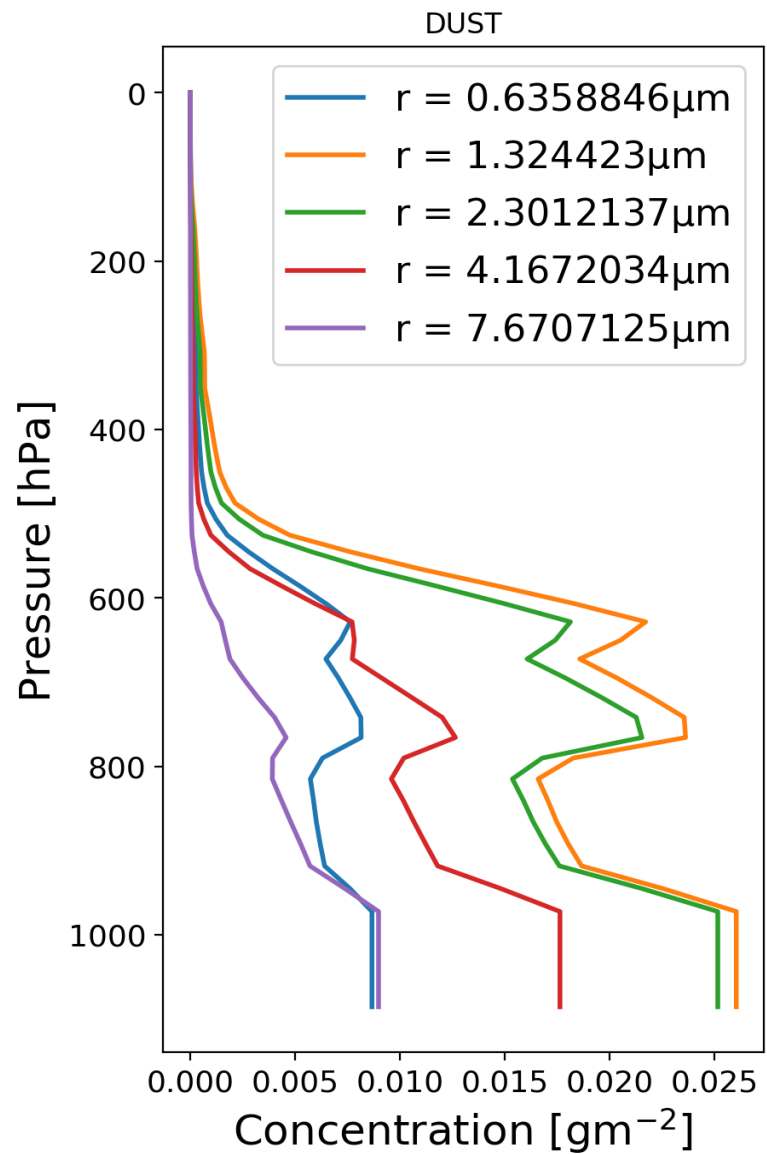


# Updated Aerosol properties (C. Dang)



- Implemented two new aerosol coefficient look-up tables based on GOCART-GEOS5 and NAAPS aerosol specifications (*New aerosol species: nitrate and smoke*).
- Performed more tests on CRTM-AOD simulations with different aerosol schemes.
- Supported CMAQ AOD data assimilation.
- Next: develop aerosol coefficient generation packages.
- Next: evaluate CRTM simulations with different aerosol schemes.

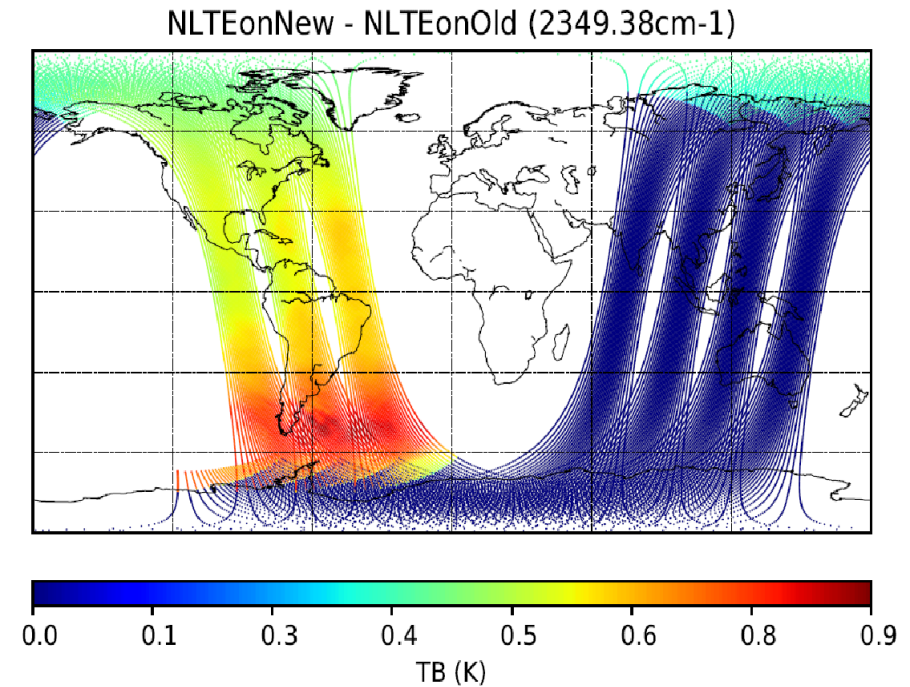
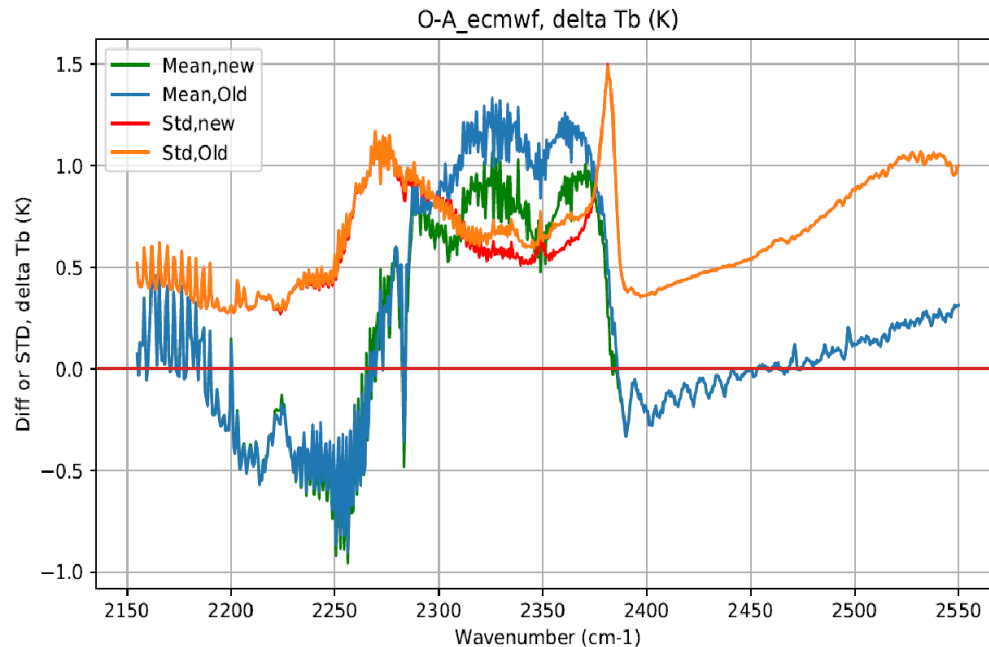
# Updated Aerosol properties (C. Dang)





# NLTE (Y. Ma)

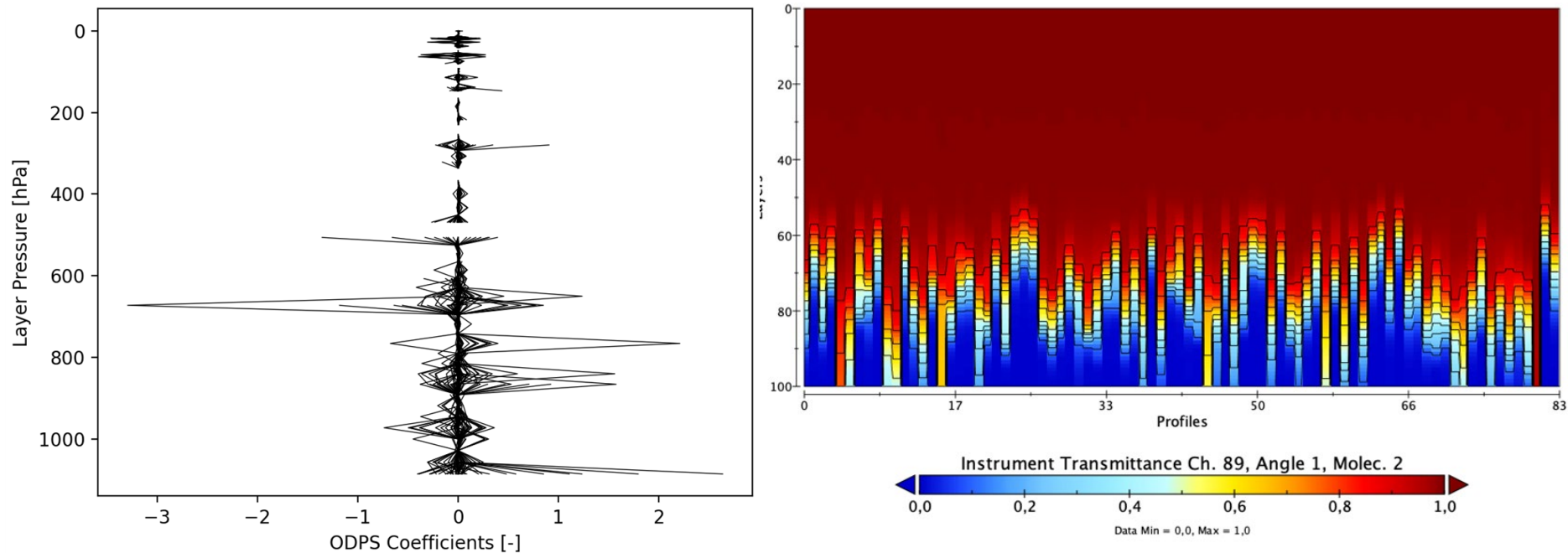
- Updated the Non-LTE correction coefficients for CrIS instruments on NOAA-NPP and NOAA\_N20 based on the newly available vibrational temperature profiles for CO<sub>2</sub> in 4.3 um band from M. López-Puertas et al. (*Milestone# CRTM3.3.3*)
- Worked with Haixia from EMC on assessing the impact of temperature induced SRF change with ABI-G17. (*Milestone# CRTM3.3*)



**Left:** Mean bias and standard deviation of O-A over the mid-latitude ocean after non-LTE correction. **Right:** Spatial distribution of the difference between the old and the new corrections.

# Spectral expansion of CRTM radiance and sensor simulation capabilities (P. Stegmann)

## IASI-NG coefficients created, under evaluation

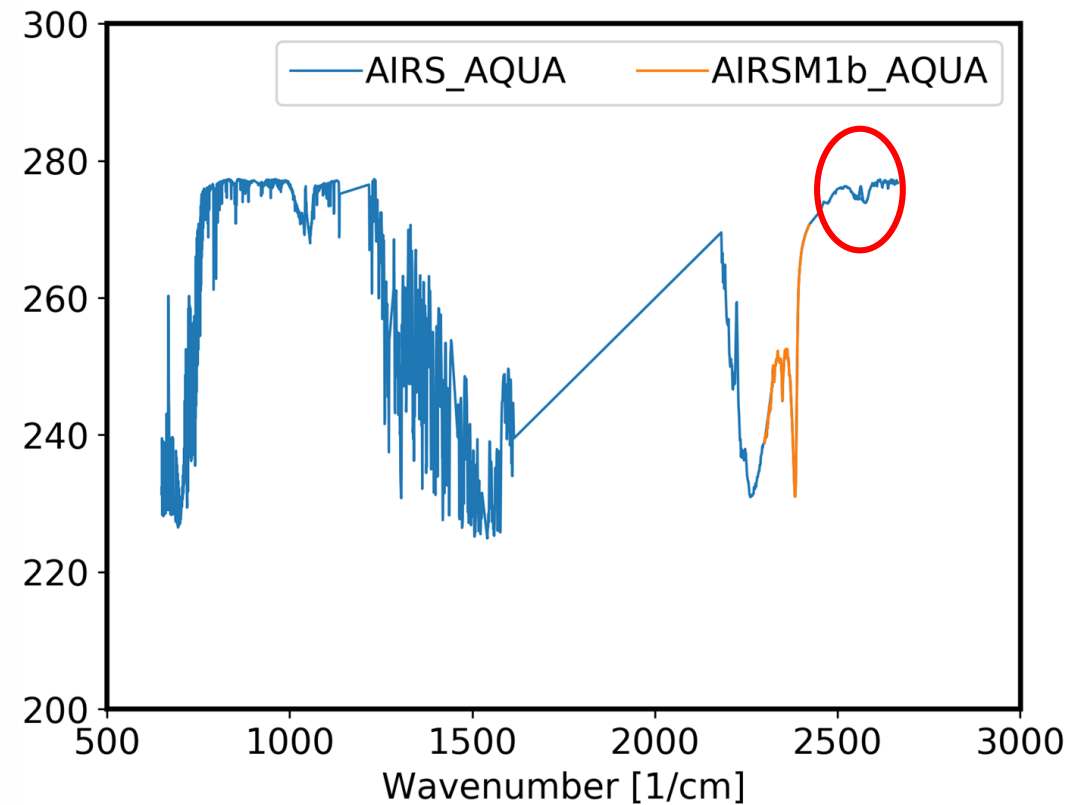
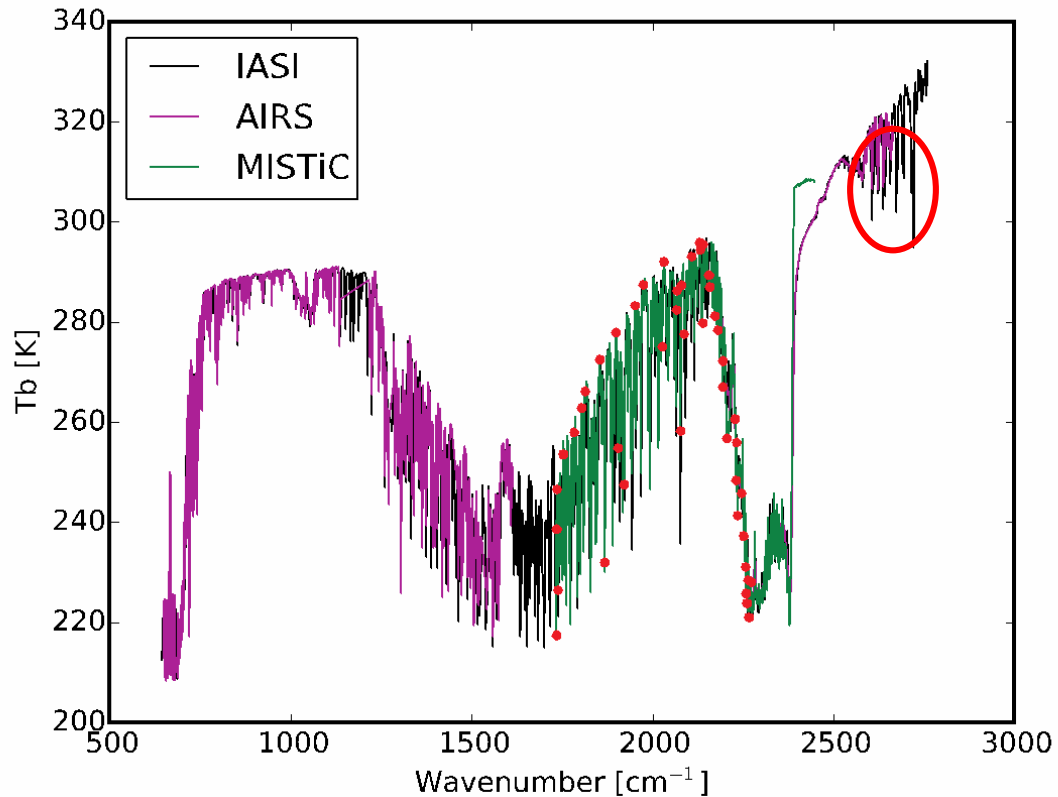


Vertical profile of ODPS coefficients for IASI-NG

Layer-to-space transmittance for Ch 89, IASI-NG  
for each training profile from the ECMWF-83 set

# Spectral expansion of CRTM radiance and sensor simulation capabilities (I. Moradi)

## Generating CRTM Coefficients Hyperspectral Infrared Instruments

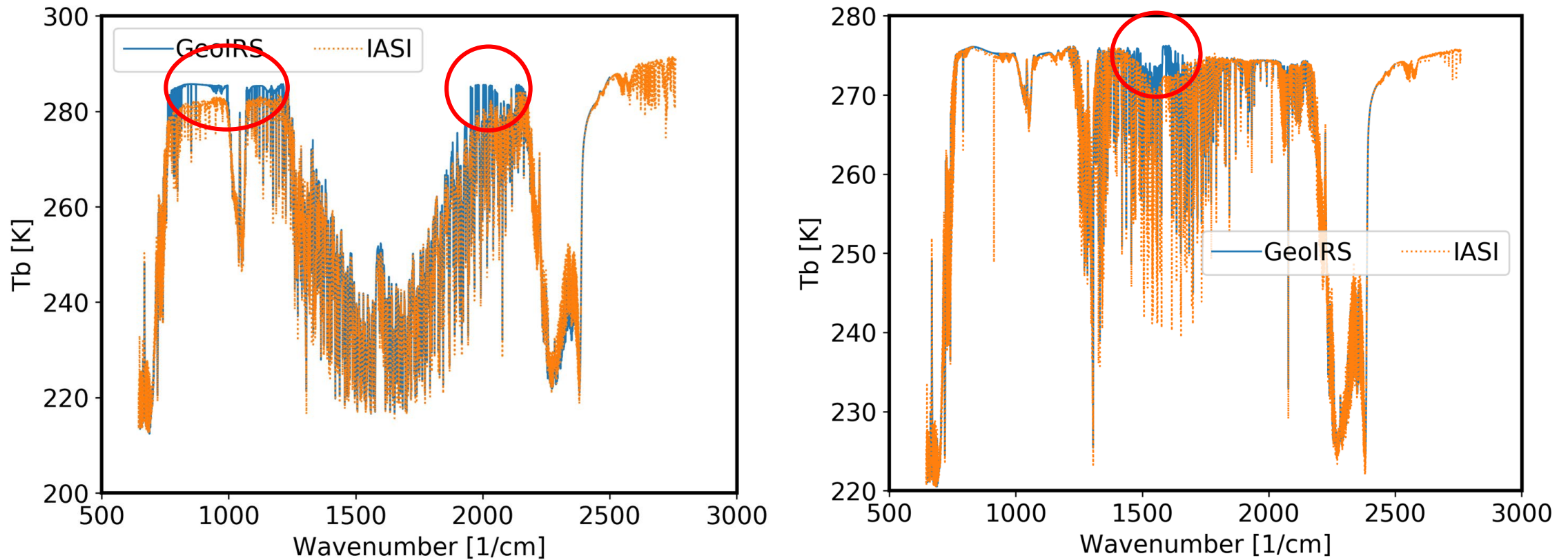


Some discrepancies exist between coefficients generated using available CRTM coefficient generation package and previous operational coefficients. After an extensive evaluation, the problem is caused by some inconsistencies in the bash files that are used to process Tape5 files. Although this issues was solved for 2500 1/cm but later it was found that the problem still exist for the higher frequencies (next slide).



# Spectral expansion of CRTM radiance and sensor simulation capabilities (I. Moradi)

## Generating CRTM Coefficients Hyperspectral Infrared Instruments



The problem seems to depend on the profiles used to run CRTM. The left image was created using Era profiles as input and right image using FASCOD profiles as input. GeoIRS is an instrument similar to MSG IRS and IASI shows the operational coefficients.



# AOP 2021 CRTM: Application Outcomes

## Task

SimObs:  $H(x)$  + Jacobians

SimObs: Statistical Analysis

SimObs: Instrument Analysis / Monitoring

Analyze CRTM v3.0: Cloud/Aerosol Interactions

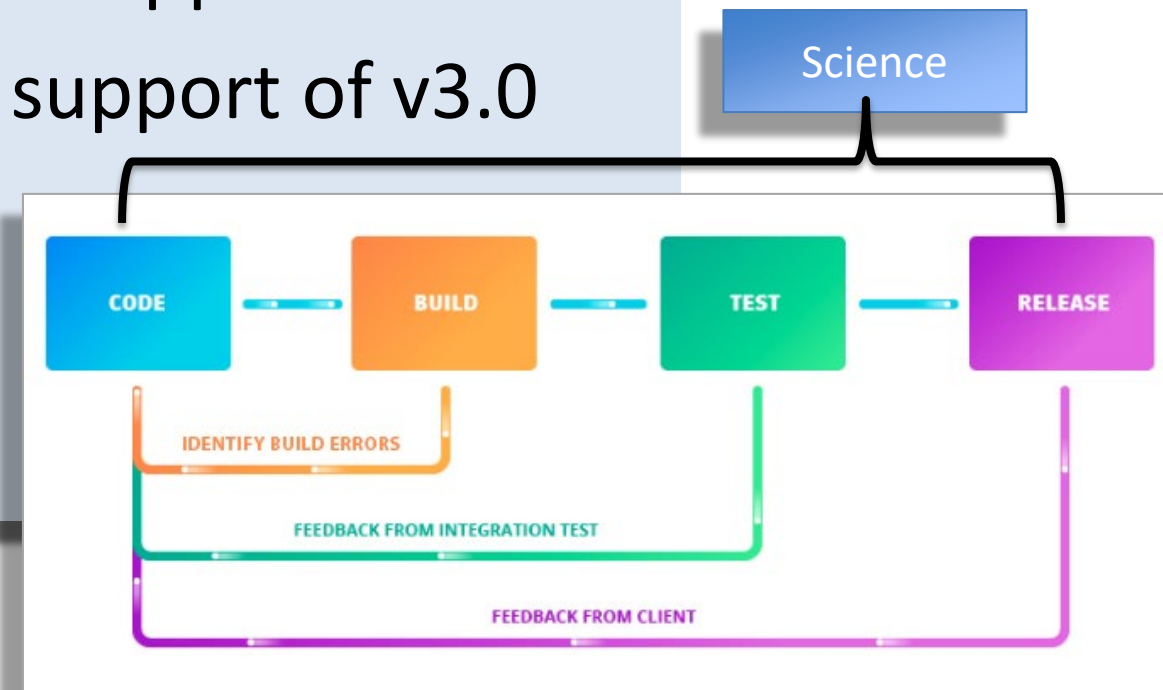
Create CRTM v3.0: Polarization vs. non-Polarized Impact Statistics

Generate CRTM Transmittance Package Coefficients

Evaluate AI-based replacements for regression methods and LUTs.

# AOP 2021 Summary

1. Transmittance Coefficient Package for v2.x and v3.0
2. Cloud / Aerosol Coefficient Package and updated coefficient files for v2.4.x and v3.0
3. Ocean Surface Coefficients (LUTs) in support of v3.0
4. Land Surface Coefficients (LUTs) in support of v3.0
5. CRTM v3.0 release (Code + LUTs)
6. SIMOBS application + Utilities
7. CRTM AI: Transmittance



# Support / Contact



Website: <https://www.jcsda.org/jcsda-project-community-radiative-transfer-model>

Support:

<https://groups.google.com/forum/#!forum/crtm-support>

Support email:

[crtm-support@googlegroups.com](mailto:crtm-support@googlegroups.com)

Email: [Benjamin.T.Johnson@noaa.gov](mailto:Benjamin.T.Johnson@noaa.gov) for direct support, questions, and comments