The JCSDA Community Radiative Transfer Model (CRTM)

The Community Radiative Transfer Model

Core Team:

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In-Kind Contributors*:*
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Other Collaborators:
Sarah Lu, Mariusz Pagowski, Barbara Scherllin-Pirscher, Aaron Naeger, Zhenglong Li

What is the CRTM?

CRTM is the “Community Radiative Transfer Model”

Goal: Fast and accurate community radiative transfer model to enable assimilation of satellite radiances under all weather conditions

Type: 1-D, plane-parallel, multi-stream matrix operator method, advanced method of moments solver, with specular and non-specular surface reflections.

Has aerosol (GO-CART), cloud (2 species), precipitation (4 species); with unpolarized scattering and absorption. Computes gaseous absorption/emission for 6 gaseous species (ODPS).

History: Originally developed (as CRTM) around 2004 by Paul van Delst, Yong Han, Fuzhong Weng, Quanhua Liu, Thomas J. Kleespies, Larry M. McMillin, and many others. CRTM Combines many previously developed models into a community framework, and supports forward, tangent linear, adjoint, and k-matrix modeling of emitted/reflected radiances, with code legacy going back to the mid 1970s (e.g., OPTRAN: McMillin).

CRTM Philosophy

Science

- State-of-the Art (speed vs. accuracy)
- Physical consistency across components
- Full consideration of instrument characteristics (e.g., SRF, geometry, orbit, Cal/Val, etc.)
- Requirements driven development

Code

- Clean, generic interfaces
- Consistent self-describing code and variable names
- Internal documentation for each module / subroutine
- Modular and Object-Oriented
- Optimized for memory and HPC requirements
- Hand-crafted TL / AD

Project management

CRTM Overview

CRTM1: CRTM management, release, and support

The first task is an umbrella for all **management, external coordination/collaboration, release support, and oversight of the CRTM team activities** -- covering all versions of CRTM. This specifically includes user-support, documentation, education, and outreach elements.

CRTM Overview

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CRTM2: Computational and technical development

The second task is primarily a **software engineering-driven task** aimed specifically at improving the computational aspects of CRTM.

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CRTM2: Computational and technical development

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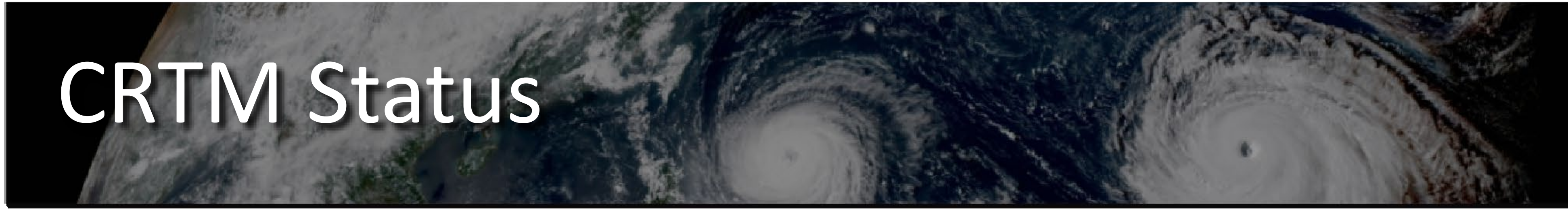
CRTM 3: Improved physical representation for aerosols, clouds, precipitation, and surface

The third and final task aims at **scientific development and testing**. CRTM users require fast computations of radiances with the highest degree of accuracy and sensitivity possible, while still maintaining the operational computational resource requirements.



CRTM Status

1. **CRTM version 2.3.1 final release (minor bug fixes, some coefficient files)**
   Status: significant delays
   Progress: no update, assumed 95% completion
2. **CRTM version 2.1, 2.2, and 2.3 updated documentation**
   Status: minor delays, lack of available effort
   Progress: issue tracking and commit history is being used to augment existing documentation.
3. **CRTM version 3.0 alpha testing.**
   Status: minor delays, possible risks
   Progress:
   i. Q. Liu performing internal tests and assessments. No code received from Q. Liu to CRTM team yet.
4. **CRTM version 3.0 beta initial release**
   Status: on track
   Progress:
   i. Initial work on polarized surface properties (M. Chen),
   ii. polarized aerosol and cloud properties (P. Stegmann).
   iii. Assessing SOI solver for polarized RT.

CRTM 2.3.0 Status

Released November, 2017

1. All-Sky radiance simulation undercloud_fraction condition.
2. Use of all-sky transmittances in FASTEM-X reflection correction.
3. Improve surface reflectance for Microwave under scattering conditions.
4. Add ATMS SeaIce emissivity module.
5. Fixed the simulation near 3.9 micron by adding solar contribution in ADA_Module.
6. Updates of CRTM Coefficients for ABI_GOES-R, AHI_Himawari-8.
7. Updates of CRTM antenna correction coefficients for MHS_N19/Metop-a.
8. Update AIRS coefficients for including NLTE correction.
9. Add new coefficients for: CrIS-fsrB1/B2/B3_NPP, CrIS*_N20, CrIS-fsr431_npp/n20, AHI_Himawari-9, ABI_G16, VIIRS-JPSS1, ATMS_N20, ATMS_N20-SRF, COWVR, tropics_designed_v1.

In this release, there is a new feature for the simulation of all-sky (cloudy) radiance, which utilizes Fortran class function, and now CRTM will be supported by advanced compilers with class function, such as ifort 14.0+, 15.0+, 16.0+, 18.0+, gfortran (gcc 4.8.5, 5.4, 6.4, 7.2, 8.2), pgi/15.1, 16.5, 17.3, 18.5, ftn/2.3.0.

CRTM 2.3.1-beta Status

December 28, 2018:

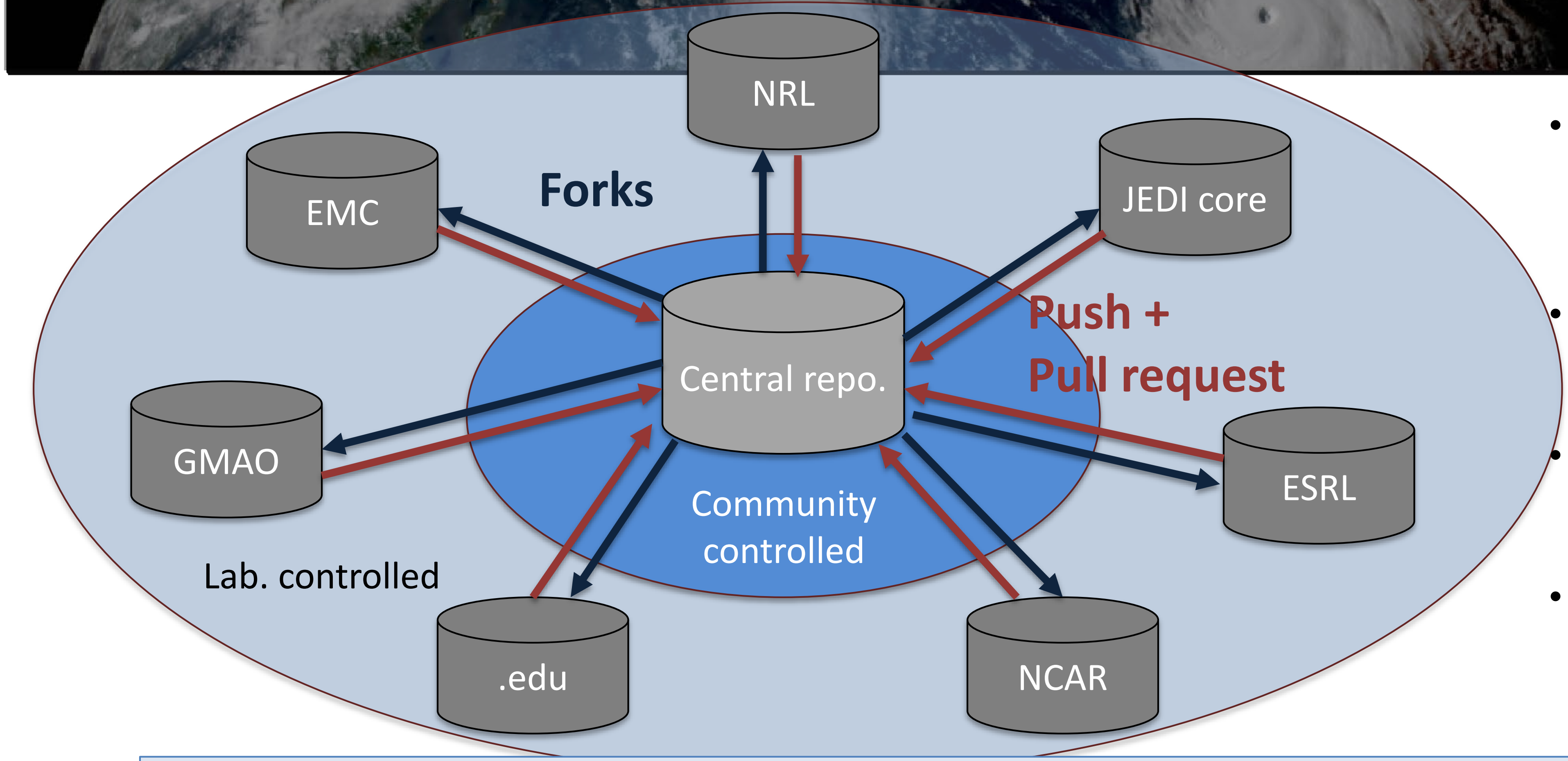
* New/Updated Coefficients:

1. Earth Observing Nanosatellite-Microwave: eon_mw.v1
2. Sentinel-3A Sea and Land Surface Temperature Radiometer: slstr_sentinel3a
3. Meteosat-11 SEVIRI: seviri_m11
4. New coefficient for ABI_G17, and updated IDs from ABI_GR to ABI_G16
5. New coefficients for Metop-C sensors: AVHRR3_Metop-C, IASI(b1,b2,b3)_Metop-C, IASI300_Metop-C, IASI316_Metop-C, IASI616_Metop-C
6. L-Band sensors at 1.413 GHz: SMAP and SMOS (V, H, 3rd, 4th Stokes)
7. Tempest-D_cubesat: 5 microwave bands at 87, 164, 173, 178, and 181 GHz
8. Updated for a shifted WV band SRF of MI-L_COMS.v2

* Integrated Bug fixes:

1. Bug in CRTM_CloudCover_Define.f90, fixing “Intent(in)” to “Intent(inout)” error for using gfortran compiler.
2. Bug in CRTM_CloudCover_Define.f90, when using the “Maximum-Random” scheme to calculate Total Cloud Cover.
3. Bug in ATMS_SnowEM_module, commented out uninitialized (also unused) variables and calculations.
4. Fix a CRTM_AtmOptics_type uninitialized error in CRTM_AtmOptics_Define.f90.
5. Update the libsrc/make.dependencies file for using make -j option.
6. Fix a bug in Common_RTSolution.f90, for calculating surface emissivity Jacobian.

JCSDA:: Revolution in Ecosystem and Working Practices

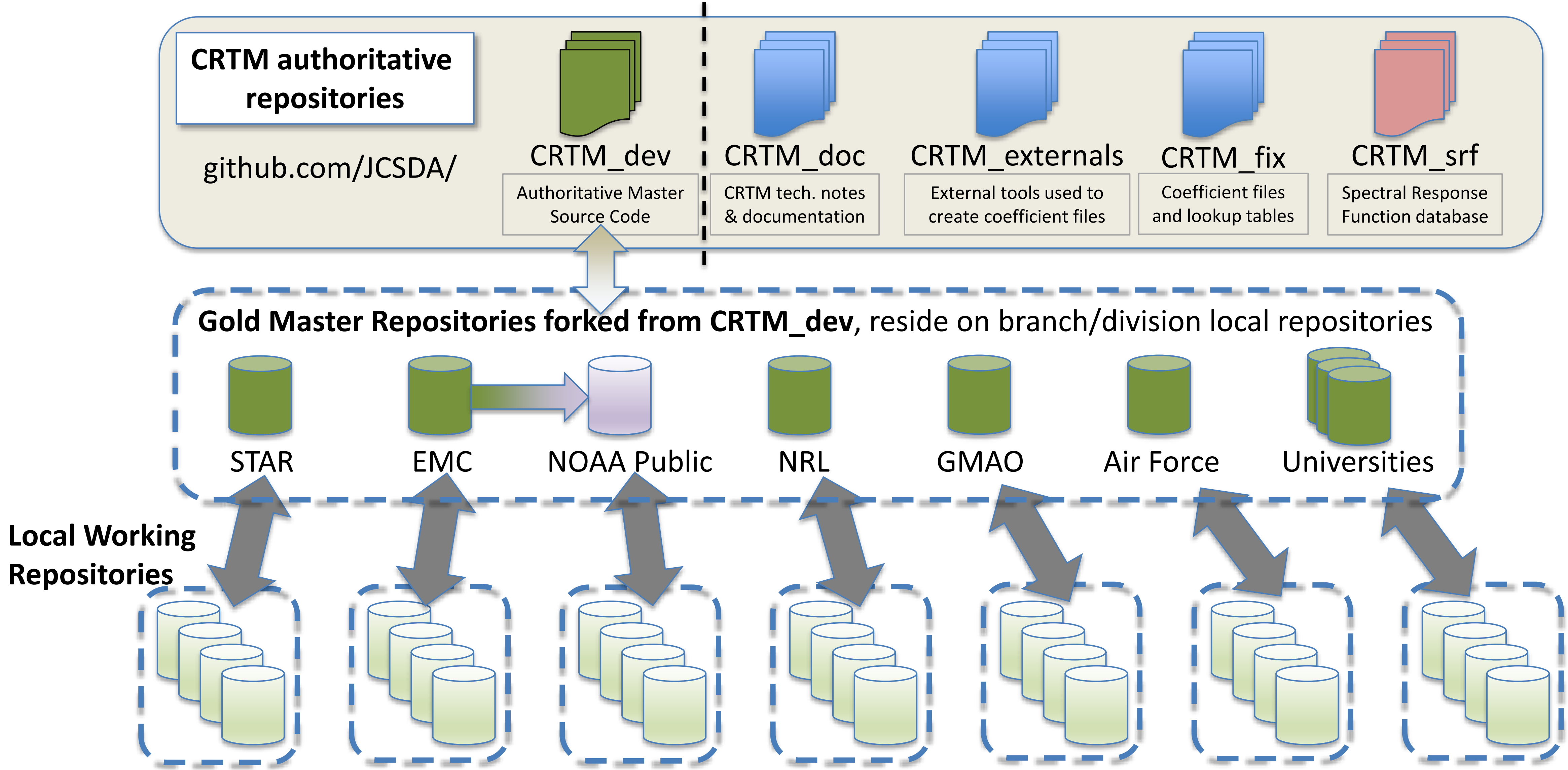


- Strong community engagement @coding level (not ‘working groups’)
- Transparent and inclusive process
- Continuous online discussions + testing
- Fast-paced code development + reviews

- Community repositories on github.com/JCSDA + flexible build system + ‘graduate student test’
- Improved collaborative environment (Zenhub issue tracking, Sphinx/ReadTheDocs/Doxygen, Singularity containers)
- Enforce software quality (correctness, coding norms, efficiency)
- Initial work toward continuous integration

CRTM Umbrella Repository Strategy

(Goal: complete consistency and interoperability with UFS strategy)



CRTM authoritative repositories

github.com/JCSDA/

CRTM_dev
Authoritative Master Source Code

CRTM_doc
CRTM tech. notes & documentation

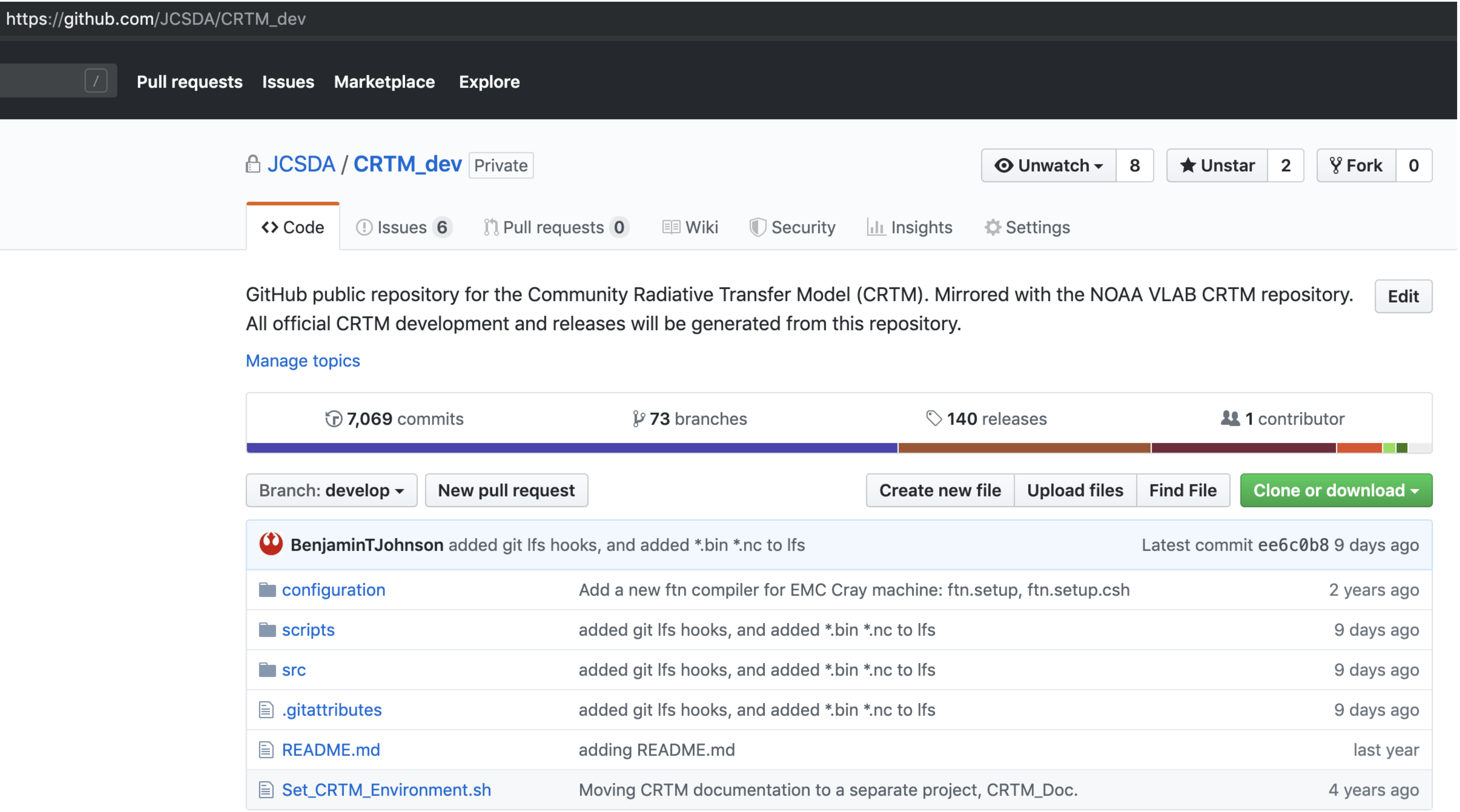
CRTM_externals
External tools used to create coefficient files

CRTM_fix
Coefficient files and lookup tables

CRTM_srf
Spectral Response Function database

Gold Master Repositories forked from CRTM_dev, reside on branch/division local repositories

Local Working Repositories

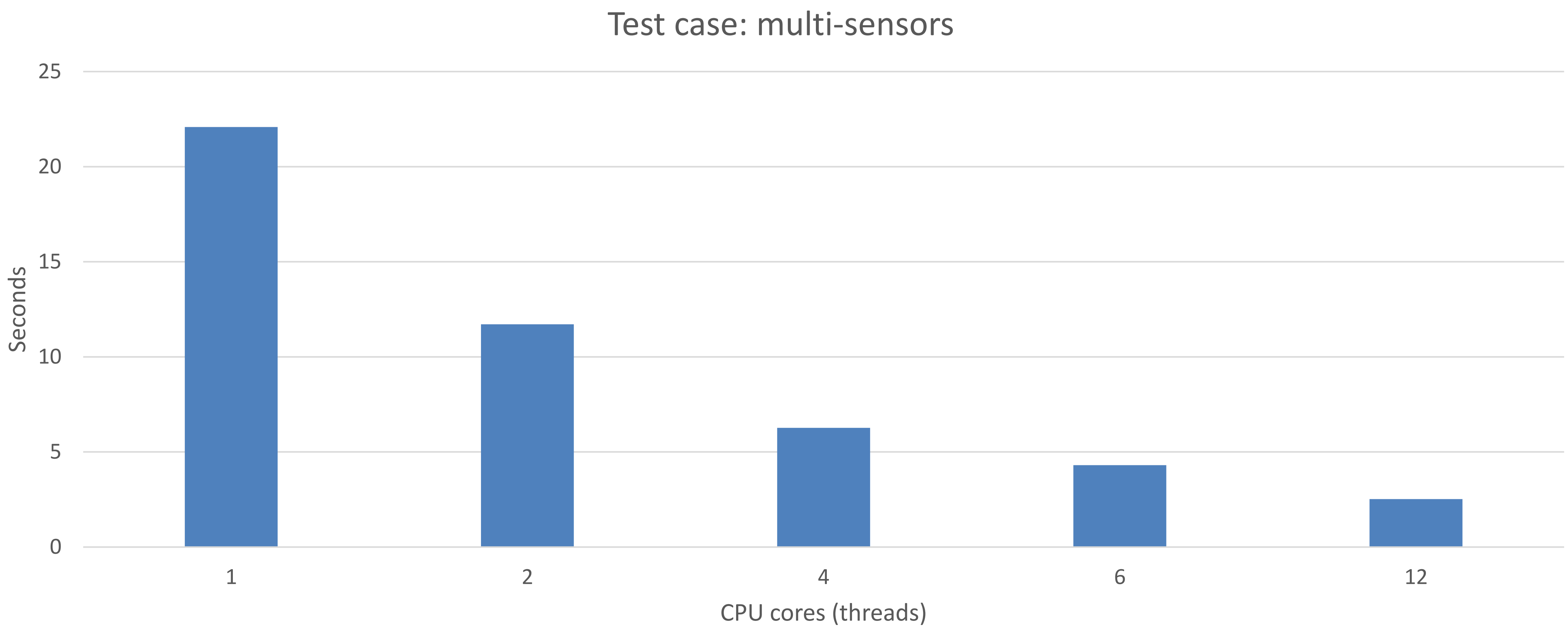


GitHub public repository for the Community Radiative Transfer Model (CRTM). Mirrored with the NOAA VLAB CRTM repository. All official CRTM development and releases will be generated from this repository.

BenjaminTJohnson added git lfs hooks, and added *.bin *.nc to lfs — Latest commit ee6c0b8 9 days ago

configuration	Add a new ftn compiler for EMC Cray machine: ftn.setup, ftn.setup.csh	2 years ago
scripts	added git lfs hooks, and added *.bin *.nc to lfs	9 days ago
src	added git lfs hooks, and added *.bin *.nc to lfs	9 days ago
.gitattributes	added git lfs hooks, and added *.bin *.nc to lfs	9 days ago
README.md	adding README.md	last year
Set_CRTM_Environment.sh	Moving CRTM documentation to a separate project, CRTM_Doc.	4 years ago

CRTM_Forward OpenMP Scaling on a single (12-core) socket of NOAA machine theia



Current work: Improve loop-level performance

- Original code from ODPS_AtmAbsorption.f90:

```
DO k = n_Layers, 1, -1
  DO j = 1, n_orders
    Predictor_AD%Ap(k, j) = Predictor_AD%Ap(k, j) + coeff(j)*b_AD(k,i)
  END DO
  b_AD(k,i) = ZERO
END DO
```

- Modified code (note swapping of j,k loops):

```
DO j = 1, n_orders
  DO k = 1, n_Layers
    Predictor_AD%Ap(k, j) = Predictor_AD%Ap(k, j) + coeff(j)*b_AD(k,i)
  END DO
END DO
b_AD(1:n_Layers,i) = ZERO
```

Polarized RT toward CRTM 3.0 (Greenwald)

(1)Optimize the multi-stream solvers (MOM, SOI, and SOS) at microwave and infrared wavelengths

(2)Integrate a fast analytic solver, the delta-Eddington approximation, into the CRTM.

(1)Integrate a fast SOS solver into the CRTM.

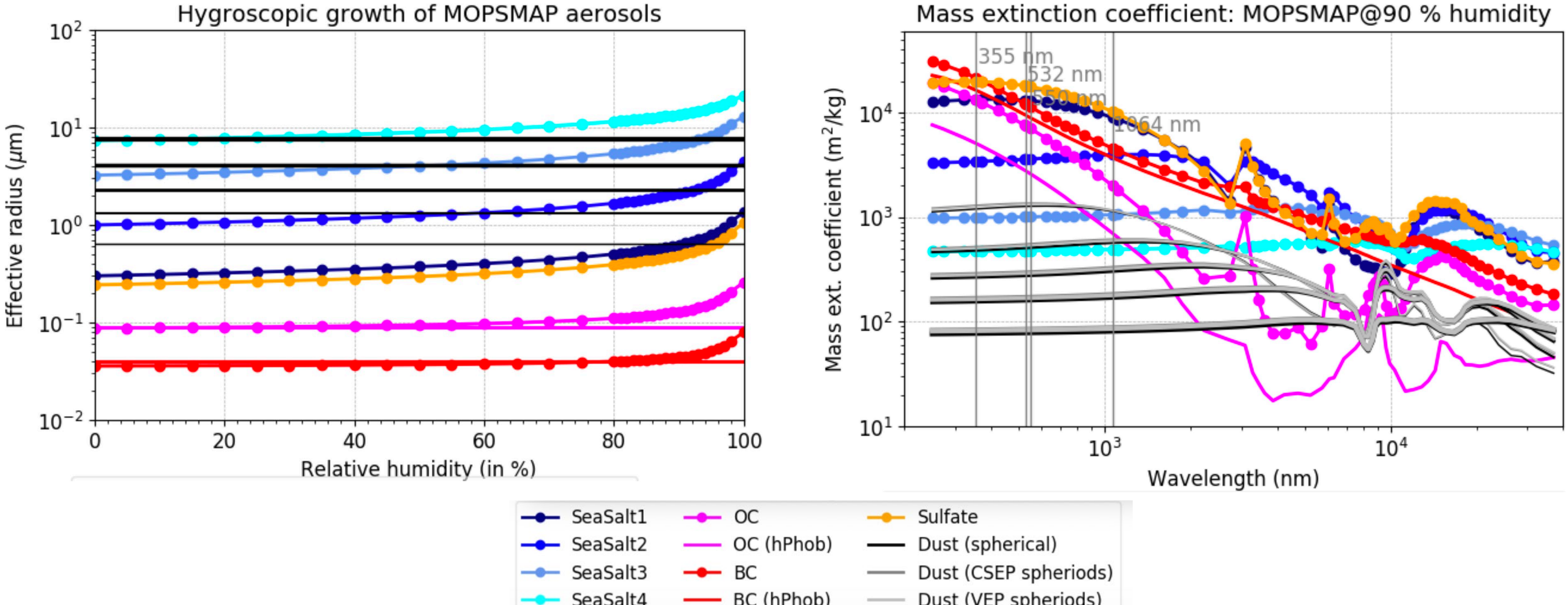
(2)Develop a vector version of the SOI solver and related code for the polarization phase matrix.

	No Atmosphere				Absorbing Atmosphere $(\tau=1)$	
	RT3		Vector SOI		Vector SOI	
Zenith Angle	I (K)	Q (K)	I (K)	Q (K)	I (K)	Q (K)
84.5°	127.13	102.88	127.13	102.88	282.42	0.00
73.6°	169.19	107.04	169.19	107.04	291.82	0.09
62.7°	169.81	76.63	169.81	76.63	293.01	0.99
51.8°	167.63	49.82	167.62	49.82	290.68	1.99
40.9°	166.27	29.64	166.27	29.64	287.06	2.13
30.0°	165.68	15.37	165.68	15.37	283.58	1.54
19.2°	165.50	6.09	165.50	6.09	253.51	0.74

Vector SOI model is in agreement with Evans and Stephens (1991) polarized adding-doubling model (RT3) at 85 GHz for no atmosphere (a test of the polarized ocean surface) and shows expected depolarization of the polarized surface for an absorbing-only atmosphere

Community Active Sensor Model :: Lidar

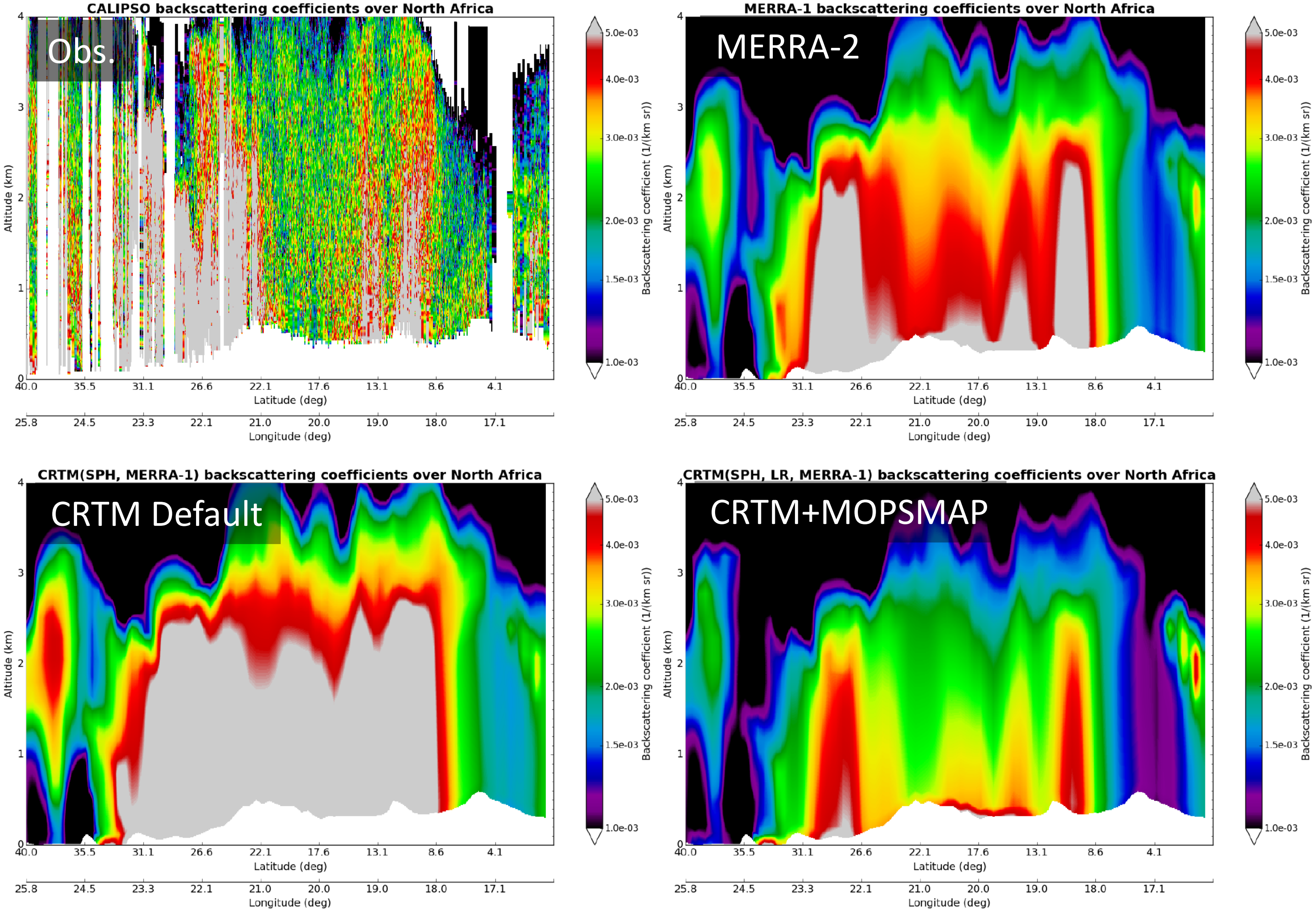
- Updated Aerosol Tables for MOPSMAP aerosol scattering coefficients (Courtesy of J. Gasteiger, U. Vienna) in support of CASM LIDAR.



Community Active Sensor Model :: Lidar

Dust Backscattering (532 nm) Coefficients

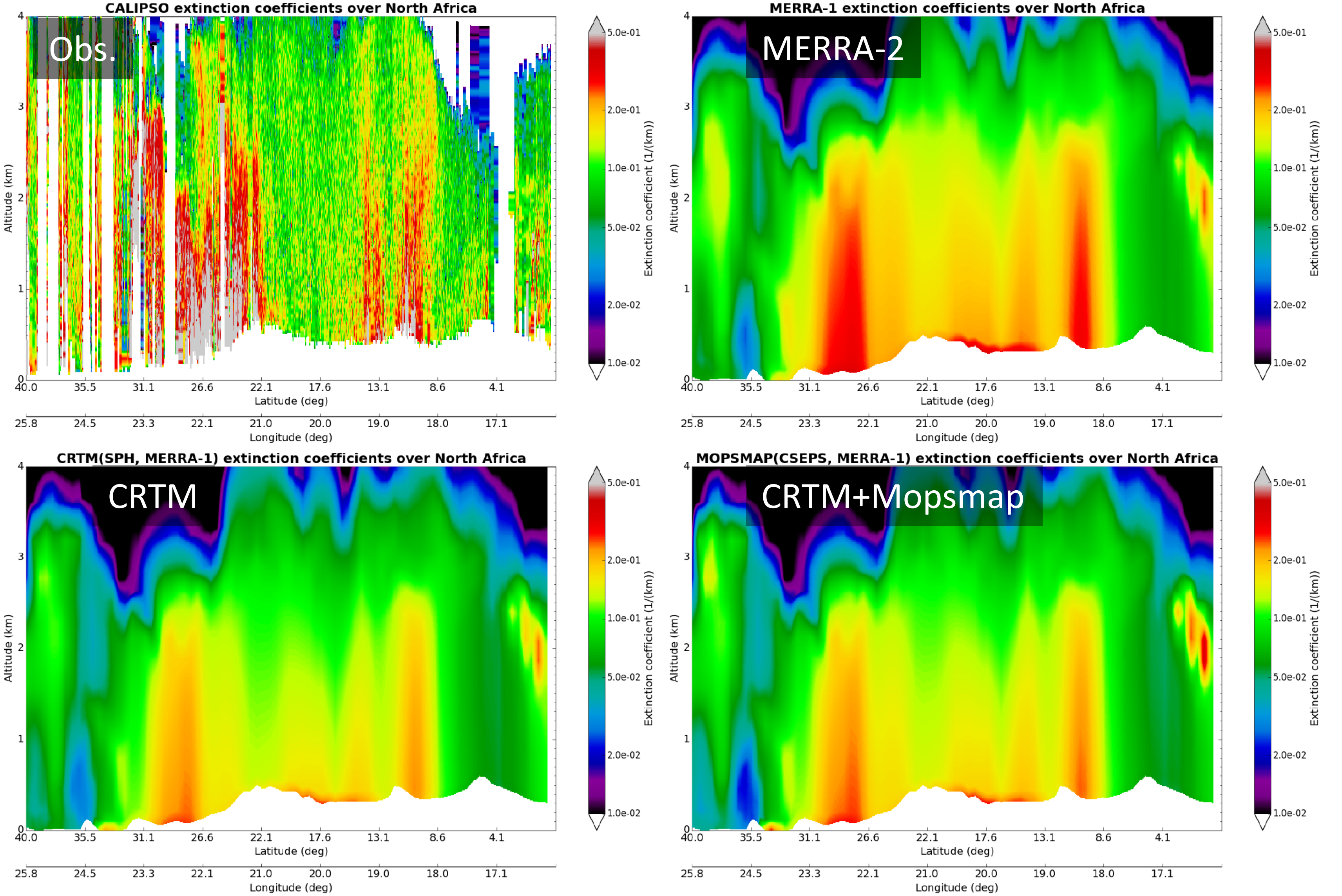
- Barbara Scherllin-Pirscher (U. Graz), Ben Johnson (JCSDA), Mariusz Pagowski (ESRL), Josef Gasteiger (U. Vienna), Patrick Stegmann (JCSDA)
- Goal: Produce an aerosol-sensitive LIDAR forward operator for use in DA, initially focusing on CALIOP
- Output: Aerosol specific AOD and LIDAR backscattering coefficient.
- CRTM backscattering compared to MERRA has similar variability, but consistently too large.



Community Active Sensor Model :: Lidar

Dust Extinction (532 nm) Coefficients

- MERRA-2 extinction higher than CRTM default, but using MOPSMAP aerosol tables get us closer.
- Future: update aerosol scattering tables, test for different aerosol



Ongoing tasks toward CRTM 3.0

- **Cloud and Aerosol Lookup Tables** (P. Stegmann, E. Liu, Johnson)
  - Adding backscattering coefficients for CRTM active sensor capability.
  - 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
- **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 (Emily Liu)
  - Continued testing of CSEM in GSI
- **Full Polarization Solver Capability** (T. Greenwald, Q. Liu, B. Johnson, C. Cao)
  - UV capable solver + polarization support under development
  - Need to touch each element of CRTM to support UV capabilities – still establishing scope of effort required.

Ongoing tasks toward CRTM 3.0

- **NLTE corrections** (Z. Li)
- **SW / IR improvements in CRTM** (New Hire)
  - IR Sea surface emissivity improvement (N. Nalli, M. Chen)
  - Aerosol + solar impacted IR
- **Aerosols update** (Johnson, Stegmann, S. Lu, M. Pagowski, B. Scherllin-Pirscher, A. Naeger, NRL, GMAO, others).
  - Update of CHYM to work with aerosol tables (Johnson, Stegmann)
  - Improved aerosol indices of refraction (via D. Turner and J. Gasteiger)
  - Update toward CMAQ specifications (Team)
  - Improve Lidar backscattering and attenuation calculations (Pagowski, Scherllin-Pirscher)
- **Fast coefficient generation** (Johnson, Stegmann, Moradi)
  - Modernized physically-based approach
  - AI / Machine Learning-based approach

Education and Outreach

- **CRTM User / Developer Workshop:**
  - Friday, February 28, 2020
  - Monterey, CA in coordination with JCSDA JEDI Academy IV, Feb 24-27, 2020.
- **Code Sprints**
  - CRTM-COEF :: Transmittance Coefficient Generation Package
    - Jan 20-31, 2020, College Park
  - CRTM-SURF :: Replacement / update of land/ocean surface emissivity
    - March 2020, Boulder
  - CRTM-PYTH :: Python interfaces for stand-alone CRTM and for JEDI/UFO, facilitate RTTOV-CRTM direct intercomparison.
    - Date/Location TBD
- JCSDA Summer Institute :: Date / Location TBD (likely Summer 2020)
- Group training on request
- Seminars / Colloquia

Coordination with other I*WG

- ICWG (Me, Ralf Bennartz, Andy Heidinger, others?)
  - Needs more DA and MW RT attention
- IPWG (Me, Philippe Chambon, Alan Geer, others?)
  - Strong DA presence, need to invite key folks to ITSC.
- ISWG (Ben Ruston)
- IWWG (?)

Questions / Comments?

See Emily Liu and Patrick Stegmann's posters, Ming Chen on CSEM, Zhenglong Li on NLTE, and Nick Nalli's talk on IRSSE.

Please join our new CRTM google groups:

Developer Discussion:
https://groups.google.com/forum/#!forum/crtm-developers

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

New support email:
crtm-support@googlegroups.com

This will post to the support forum, so anything you email will be available to the members of the support group.

Email: Benjamin.T.Johnson@noaa.gov for direct support, questions, and comments