The Community Radiative Transfer Model (CRTM)

In memory of Paul van Delst

CRTM Core team:

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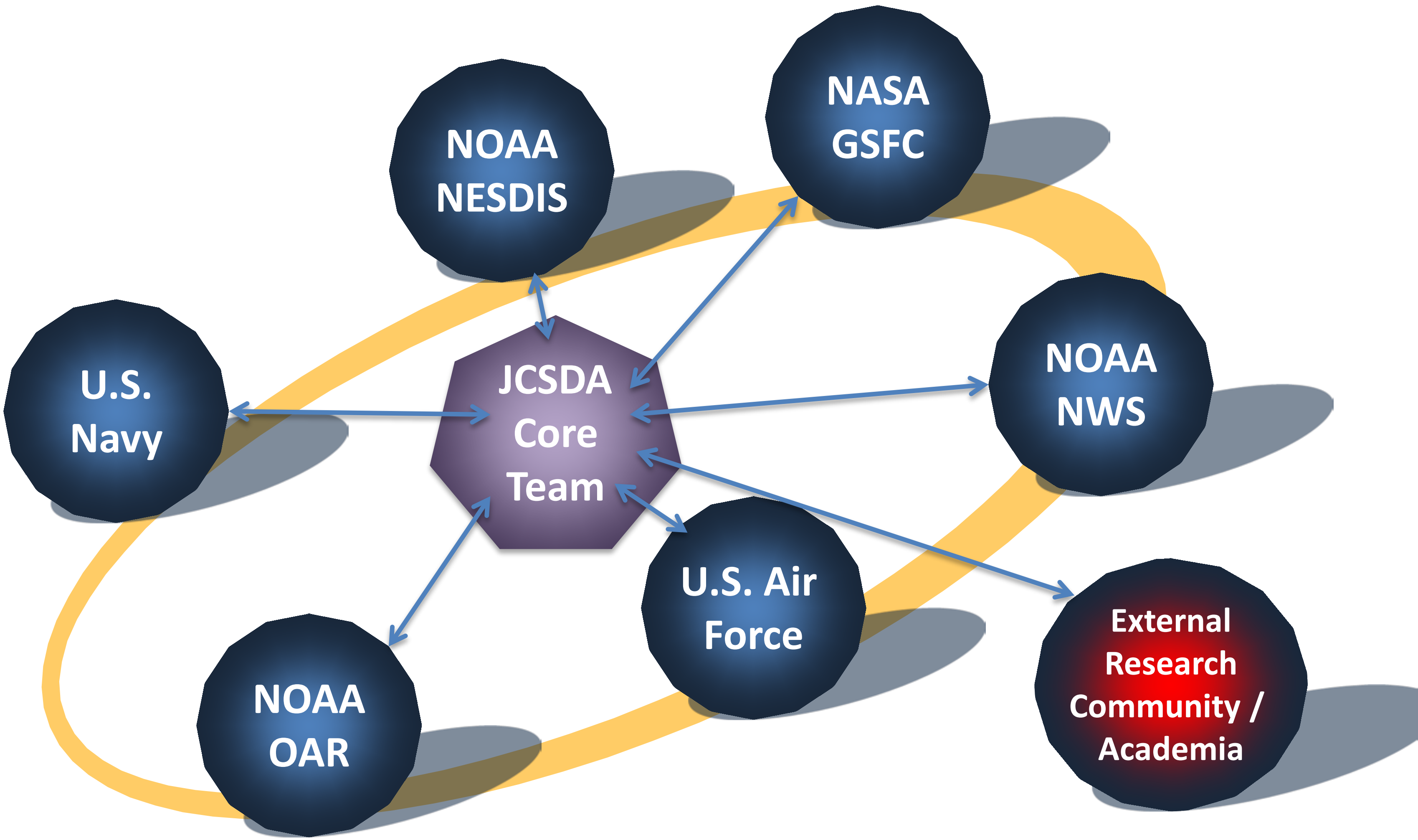
Thomas Auligné (Director, JCSDA)

With essential contributions from: Quanhua Liu, Emily Liu, Andrew Collard, Fuqing Zhang, Ping Yang, Kwo-Sen Kuo, Tom Greenwald, Jim Rosinski, *and many others.*

JCSDA Structure (2017)



CRTM Current Status

- https://svnemc.ncep.noaa.gov/trac/crtm/
- Current Operational Version is 2.2.3
- Version 2.3.0 (released on 11/28/2017)
  - v2.3.0 will likely be the last semimajor (2.x) release
  - Version Format: [major.semimajor.minor]
  - minor releases will occur as needed
- v3.0.0 will be the next major release (Late 2018 est.)
- Documentation updates will occur in parallel with release development
  - Use of community focused development tools (e.g., Atlassian: JIRA, BitBucket, Confluence, etc.) to enable ease of collaboration and version control.

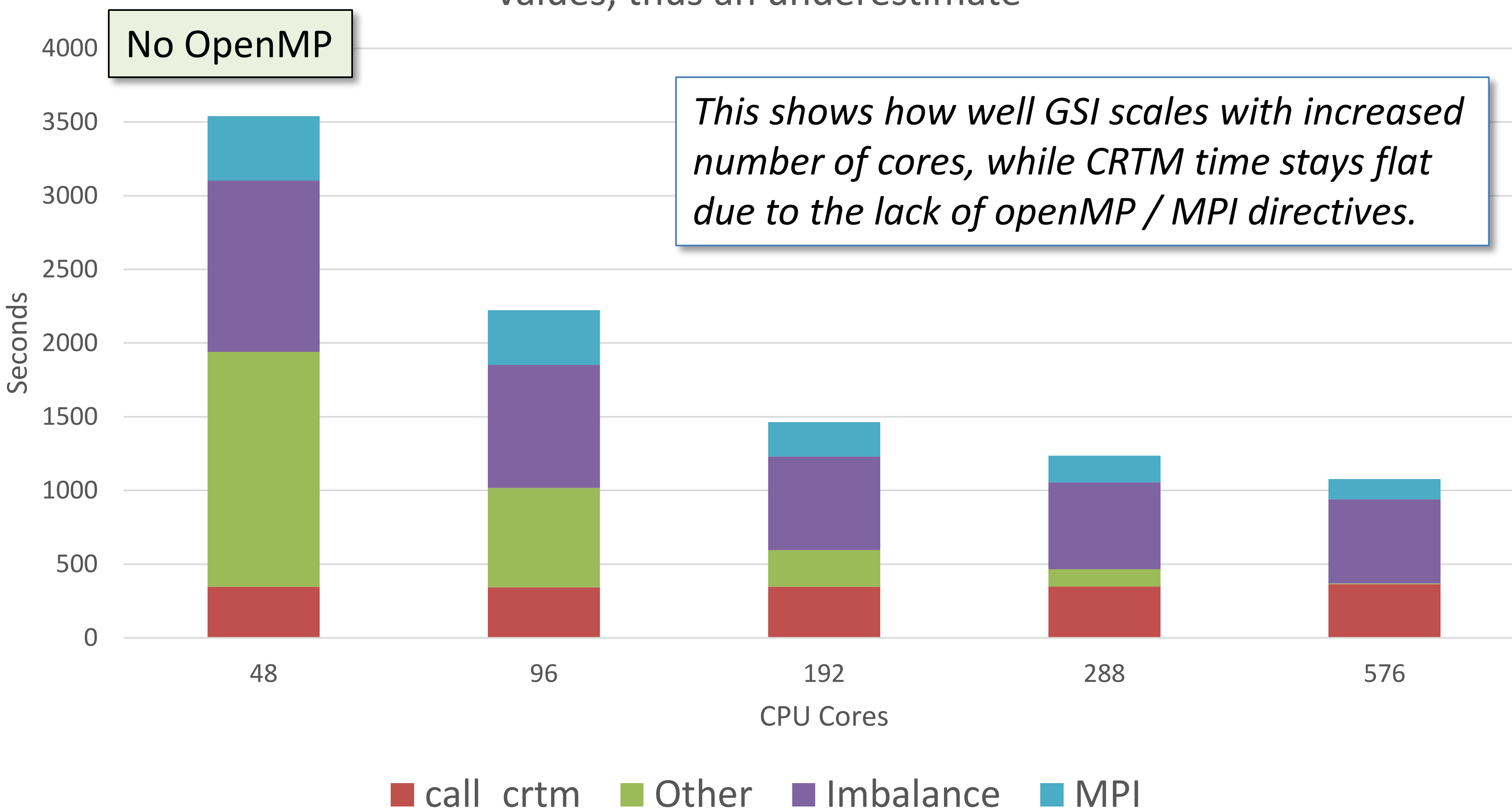
CRTM REL-2.3.0 New features

- **Scientific changes**
  1. All-Sky radiance simulation under various cloud_fraction conditions.
  2. Use of all-sky transmittances in FASTEM-X reflection correction.
  3. Improve surface reflectance in radiative transfer calculation for Microwave under scattering conditions.
  4. Add ATMS SeaIce emissivity module.
  5. Fix 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 support the new compiler with class function, such as ifort version (14.0+, 15.0+, 16.0+), gfortran version (gcc 4.8.5, 4.9, 5.4, 6.4, 7.2), pgi/17.3, ftn/2.3.0.

Optimization (J. Rosinksi) [1/2]

T670 DA time: 48 MPI, various thread counts (1,2,4,6,12) node counts=(2,4,8,12,24) Note: “Other” is a residual calculation from max values, thus an underestimate



Rosinski & Etherton (ESRL)

Optimization (J. Rosinksi) [2/2]

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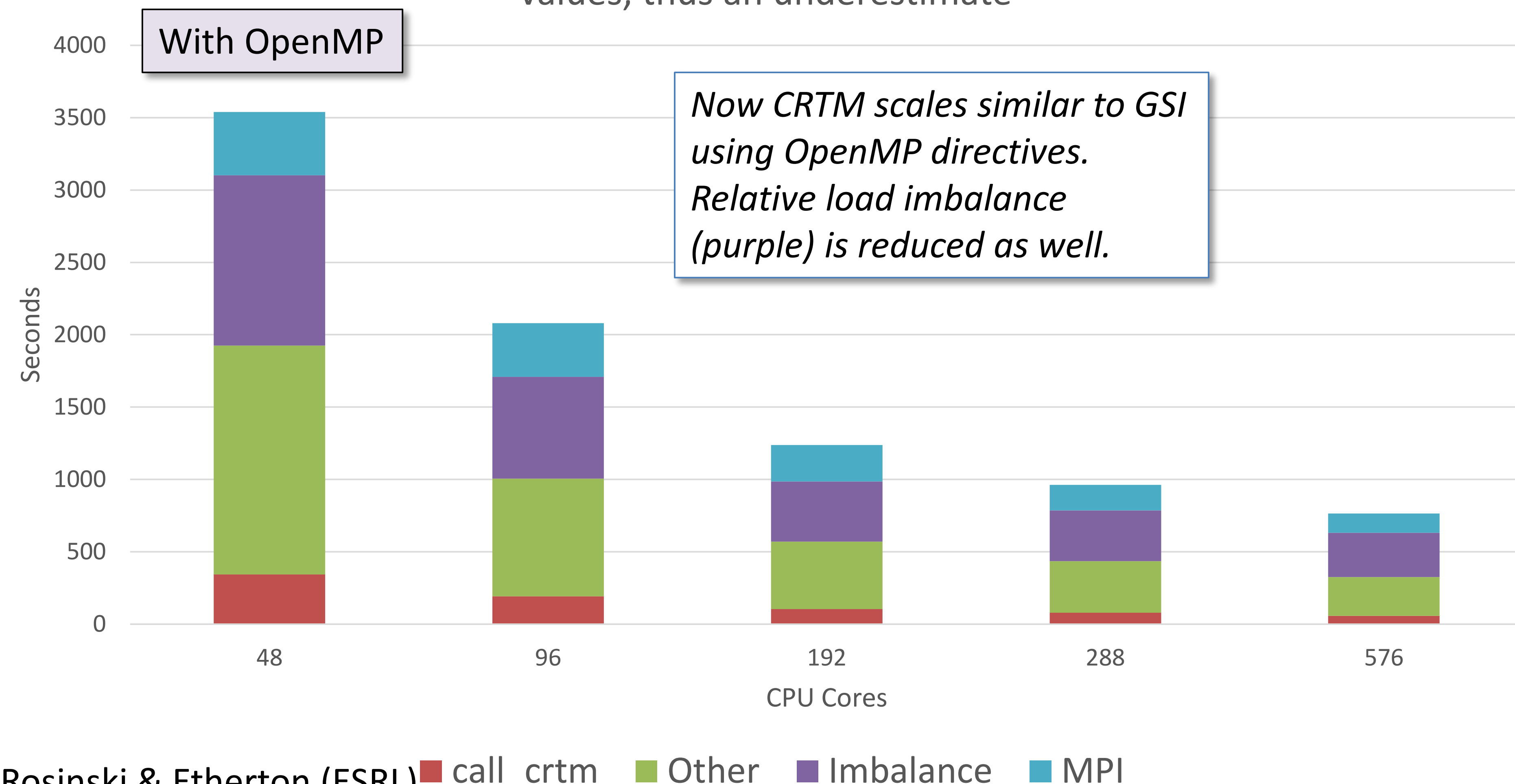


Rosinski & Etherton (ESRL)

Solvers (T. Greenwald / R. Bennartz) [1/2]

Ultrafast Solvers for Enhanced CRTM Performance in Cloudy Atmospheres

Tom Greenwald (University of Wisconsin-Madison)
Ralf Bennartz (Vanderbilt University)

- Overview:
  - Exploit analytic 2/4-stream solvers to optimize the CRTM in calculating all-sky (including aerosols) microwave and IR radiances
  - Demonstrate impact of these improvements in the GOES-5 DAS and GDAS

Solvers (T. Greenwald / R. Bennartz) [2/2]

- **Progress**:
  - Created new CRTM solver modules
    - EDD: Delta-Eddington (Bauer et al. 2005)
    - P2S: Polarized (I,Q) 2-stream (Liu and Weng 2002)
  - Modified CRTM code to allow use of these new solvers
  - Successfully built the CRTM Library with the new modifications
  - Testing of the solvers is in progress

Community Hydrometeor Model (CHYM)

Community Hydrometeor Model (CHYM) (V 0.3)

GFS or User Particle Size Distribution (PSD)

CHYM Inputs:
Per Hydrometeor Category:
PSD-Layer Inputs (below)
Output Type (binary, netcdf),
Output filename

Interface Layer In CRTM at CRTM_CloudCoeff.f90

Single Particle Database Layer

Physical Description:
Shape, Mass (radius), Maximum Dimension, Bulk Density, Orientation, Melt Frac., Temperature, Frequency, Dielectric Const.

Scattering / Extinction Computation Outputs:
Scattering, Extinction, Asymmetry Parameter, Backscattering, and Scat. Phase Function

PSD-Integrated Database Layer

Physical Description:
Hydrometeor Category, Effective Radius, Orientation, Temperature, Humidity, Frequency, and Mass-Dimension params.

Integrated Scattering and Extinction Computation Outputs:
Scattering, Extinction, Asymmetry Parameter, Backscattering, and Full Phase Function (for each category)

CHYM Outputs:
Per Hydrometeor Category:
Scattering, Extinction,
Asymmetry, Backscattering*,
Legendre Coeff. of Phase Func.

Processed by CRTM as standard CloudCoeff

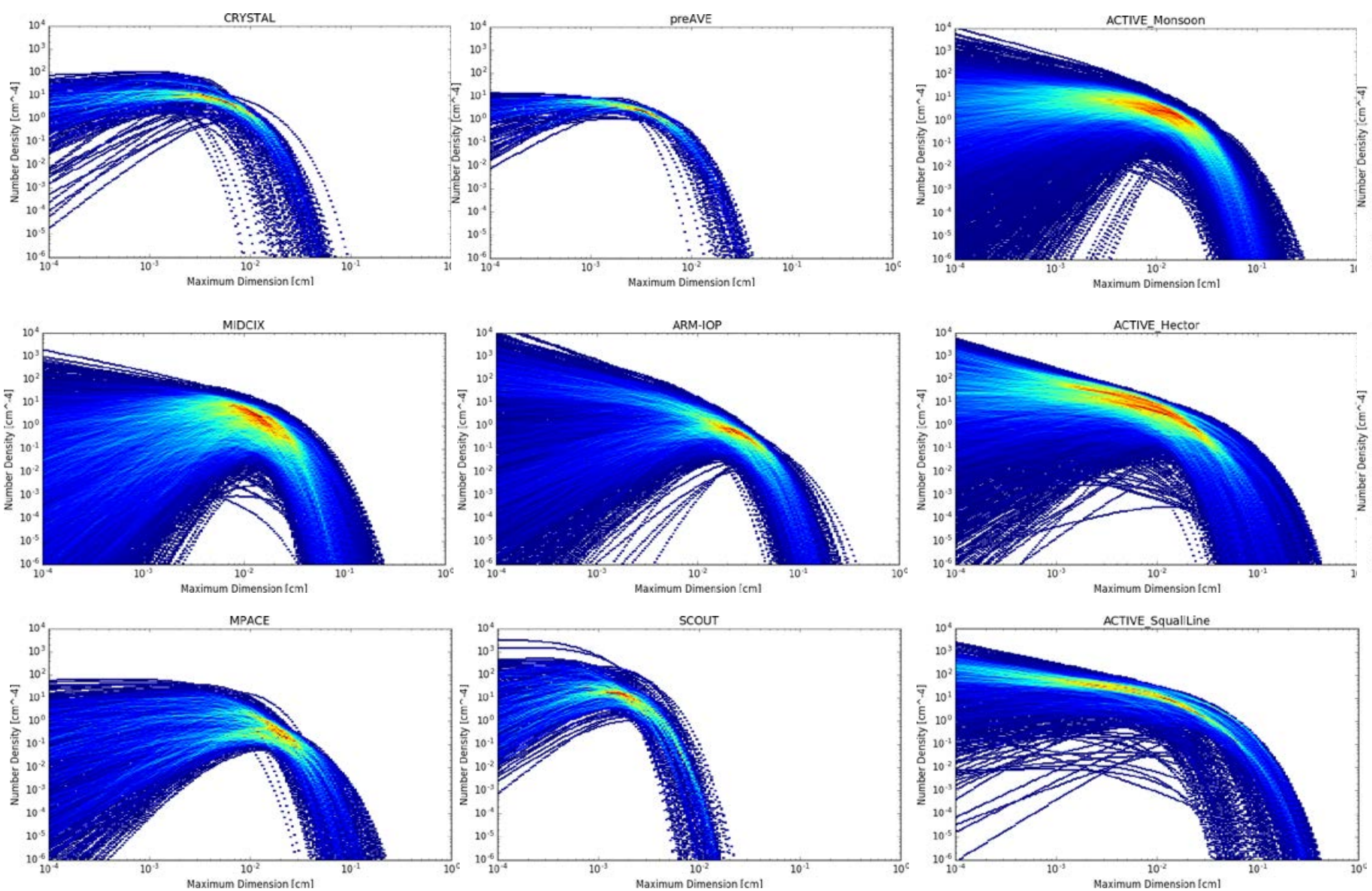
B. Johnson (JCSDA / UCAR)

CHYM Approach

- (1) **Development of the microphysical parameters of clouds and precipitation** (Lead: Emily Liu)
  - – Relate to the current and planned GFS microphysical assumptions.
  - – converting mixing ratios into particle size distributions (PSD) and habit distributions, consistent with the microphysics schemes
- (2) **Creating the PSD-integrated scattering properties** (Lead: Ben Johnson).
  - – Extend and replace current CloudCoeff.bin lookup table, consistency with above microphysics

Cloud Microphysical Modeling [2/3]

Observed Ice Particle Size Distribution



PSDs plotted using data downloaded from Brian Baum's website:
http://www.ssec.wisc.edu/ice_models/microphysical_data.htm

Cloud Microphysical Modeling [2/3]

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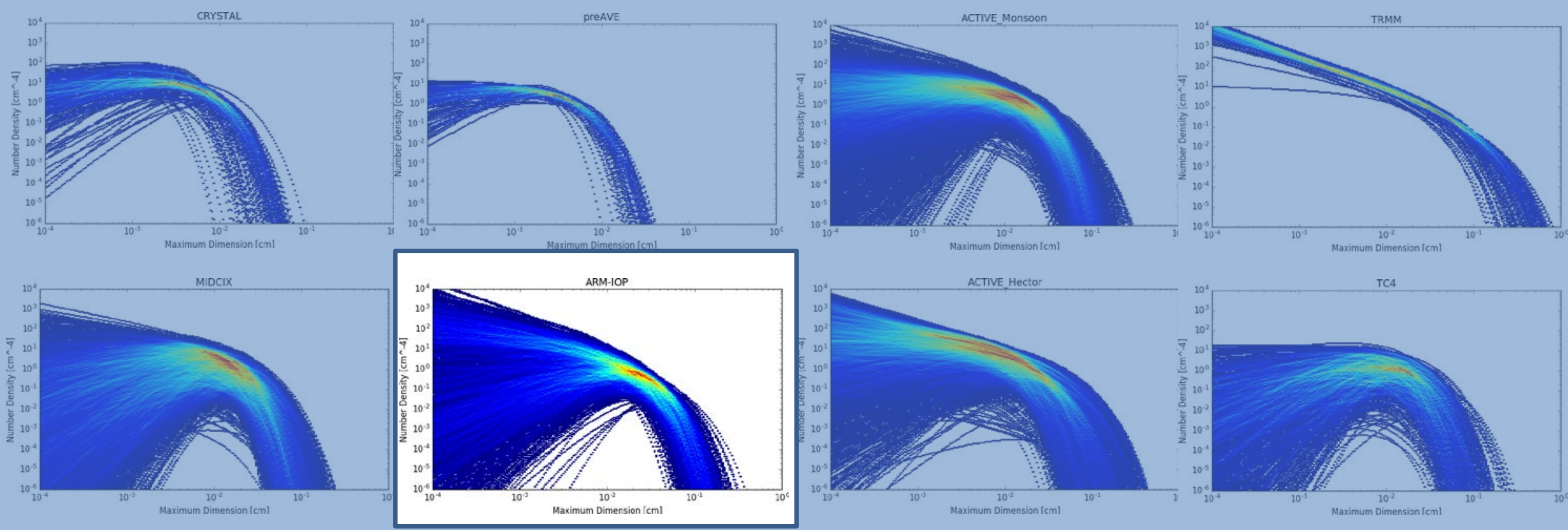

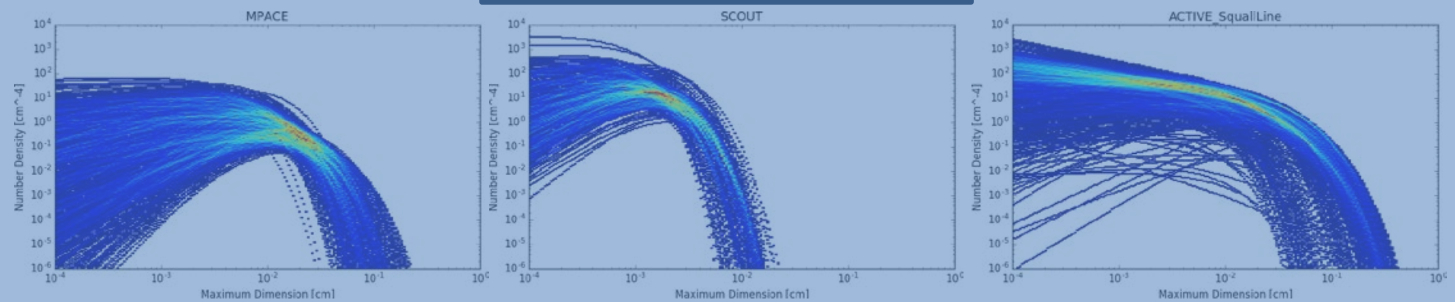

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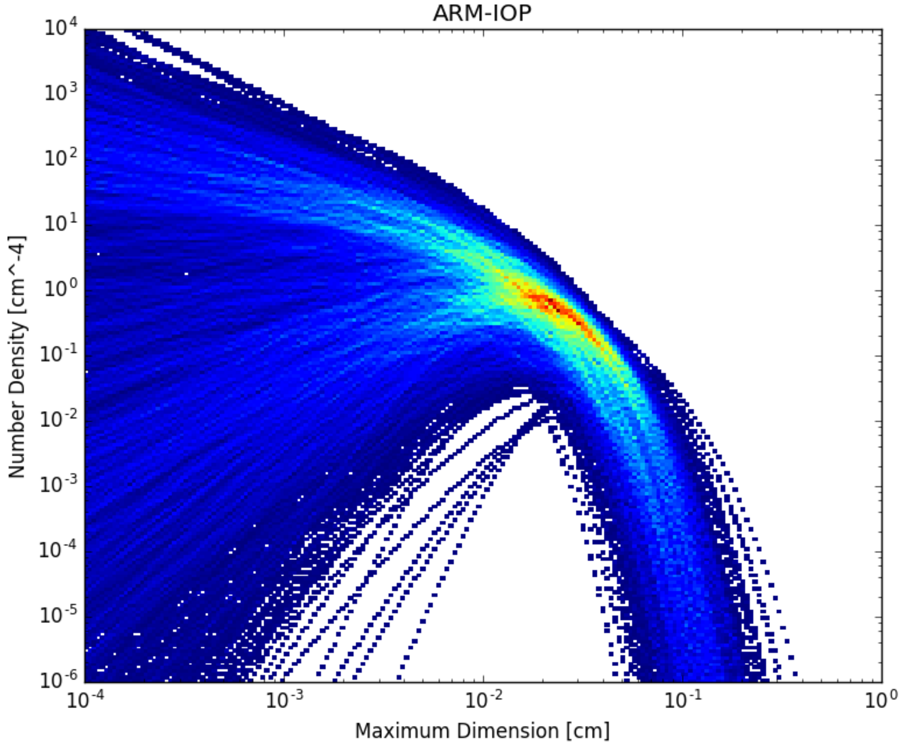
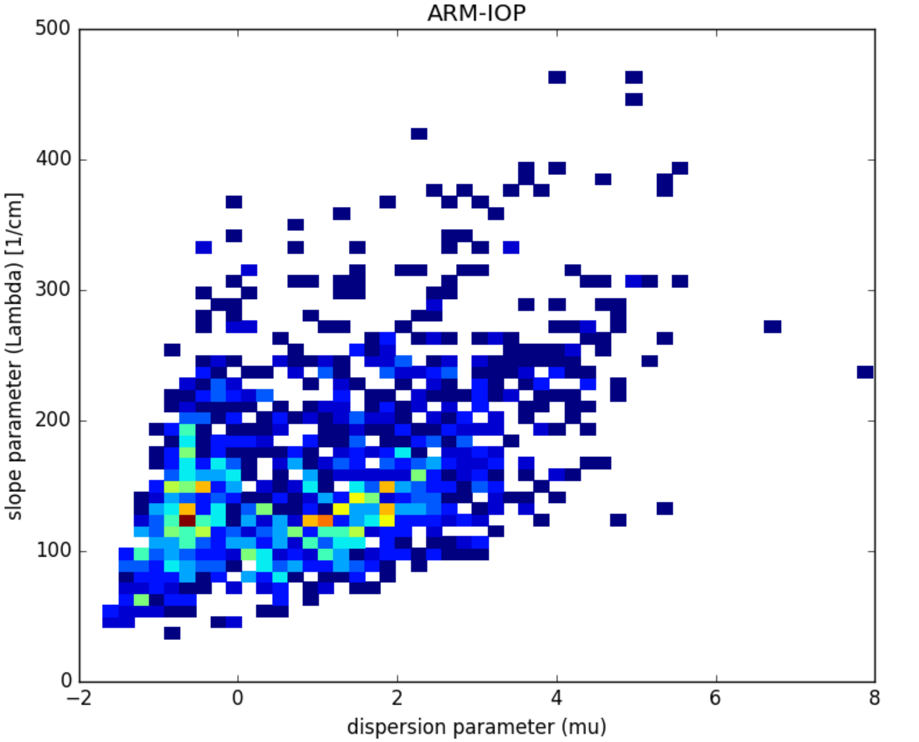
Cloud Microphysical Modeling [3/3]





CHYM Status

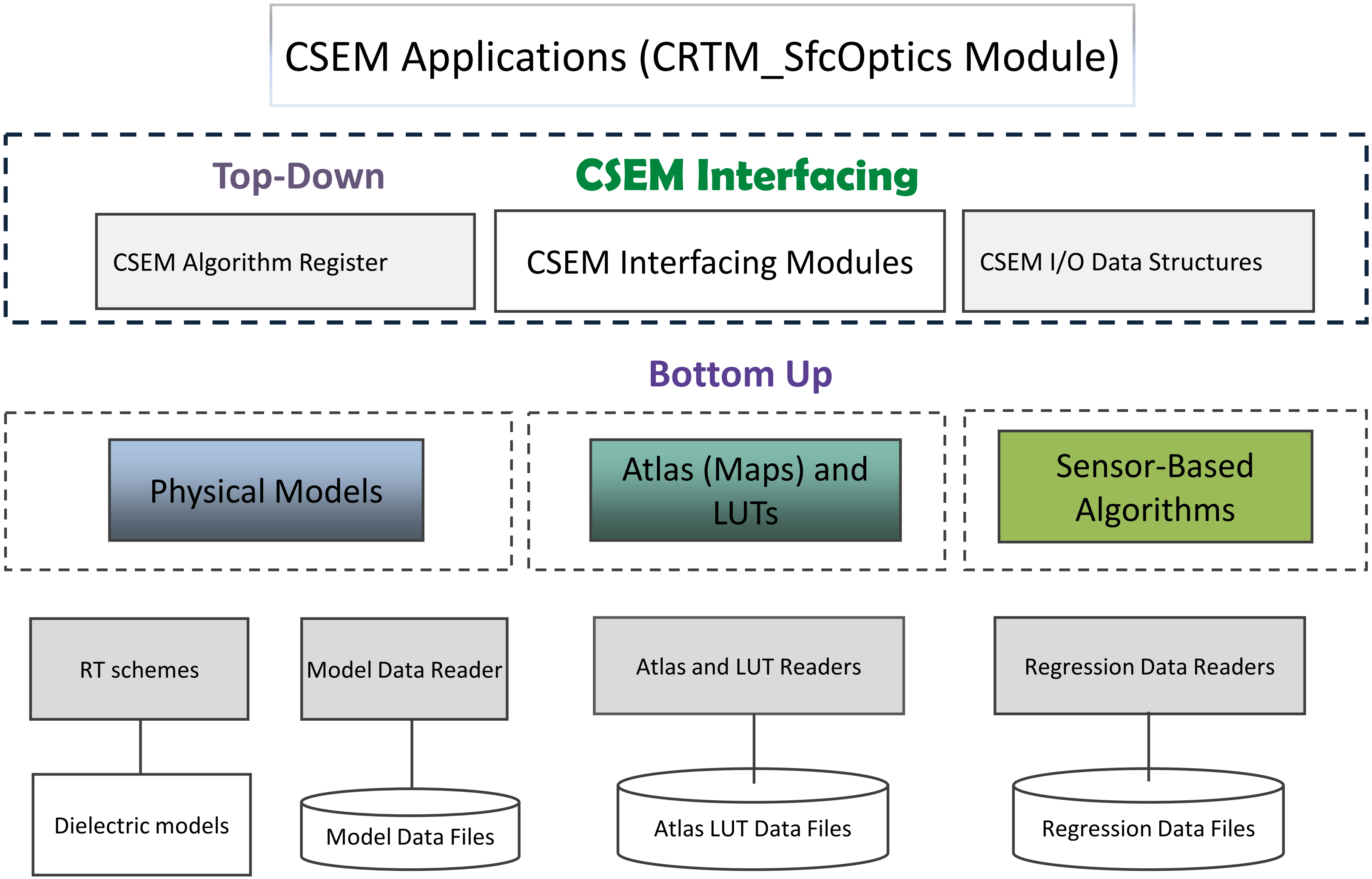
- **Current Status**:
  - Cloud physical data has been collected (from B. Baum's work)
  - Single-particle scattering database from P. Yang's group (Jiachen Deng, Patrick Stegmann) available
  - Stand-alone code to create new CRTM scattering tables (with and without backscattering) is working (non-automated)
  - **Given a PSD, mass-diameter relationship, temperature, and habit distribution, we can now construct updated scattering tables.**
- **Next Steps**:
  - Construct scattering tables for the regimes presented here
  - Stand-alone testing within CRTM
  - Preliminary GSI testing (single-cycle)
  - Preliminary GFS testing (without automatic table selection) Targeting ITSC-21 conference at end of November.
  - Implement method to communicate GFS microphysics to CRTM to enable automatic table selection. Targeting CRTM v 3.0.0 release.

CSEM New Components

- New ocean surface MW FASTEM version with enhanced performance in frequency bands lower than 19GHz and zenith angles larger than 60 degrees. **The forward and tangent-linear modules have been implemented. Coding of the adjoint module is on the way. The calibration of the new FASTEM model was performed with several in-situ data sets.**
- Ocean surface MW BRDF model for coupling with the upper-level CRTM multi-stream cloudy scattering scheme. **Coding of the forward BRDF module is on the way.**

Ming Chen, ESSIC/UMD

CRTM-CSEM Interfacing Implementation



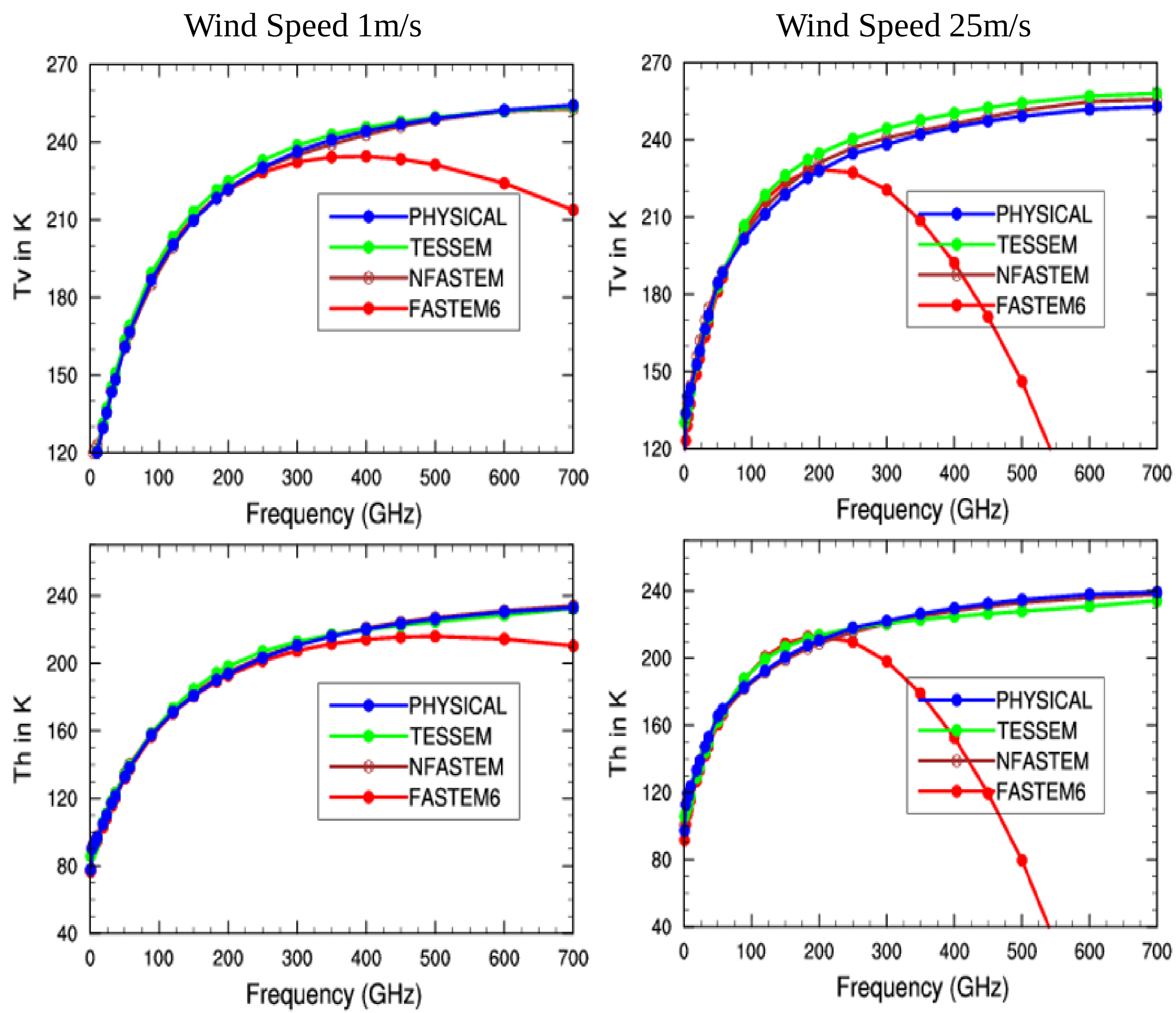
Ming Chen, ESSIC/UMD

Comparison of MW Ocean Model (theta=30º)

The original two-scale physical model is applicable to a much wider frequency range, but the current FASTEM 6 is limited to 200GHz.

A new FASTEM version (NFASTEM) has been developed to cover L-band to submillimeter channels.

It agrees very well with FASTEM 6 at channels lower than 200GHz, as well as with TESSEM at channels over 200GHz.

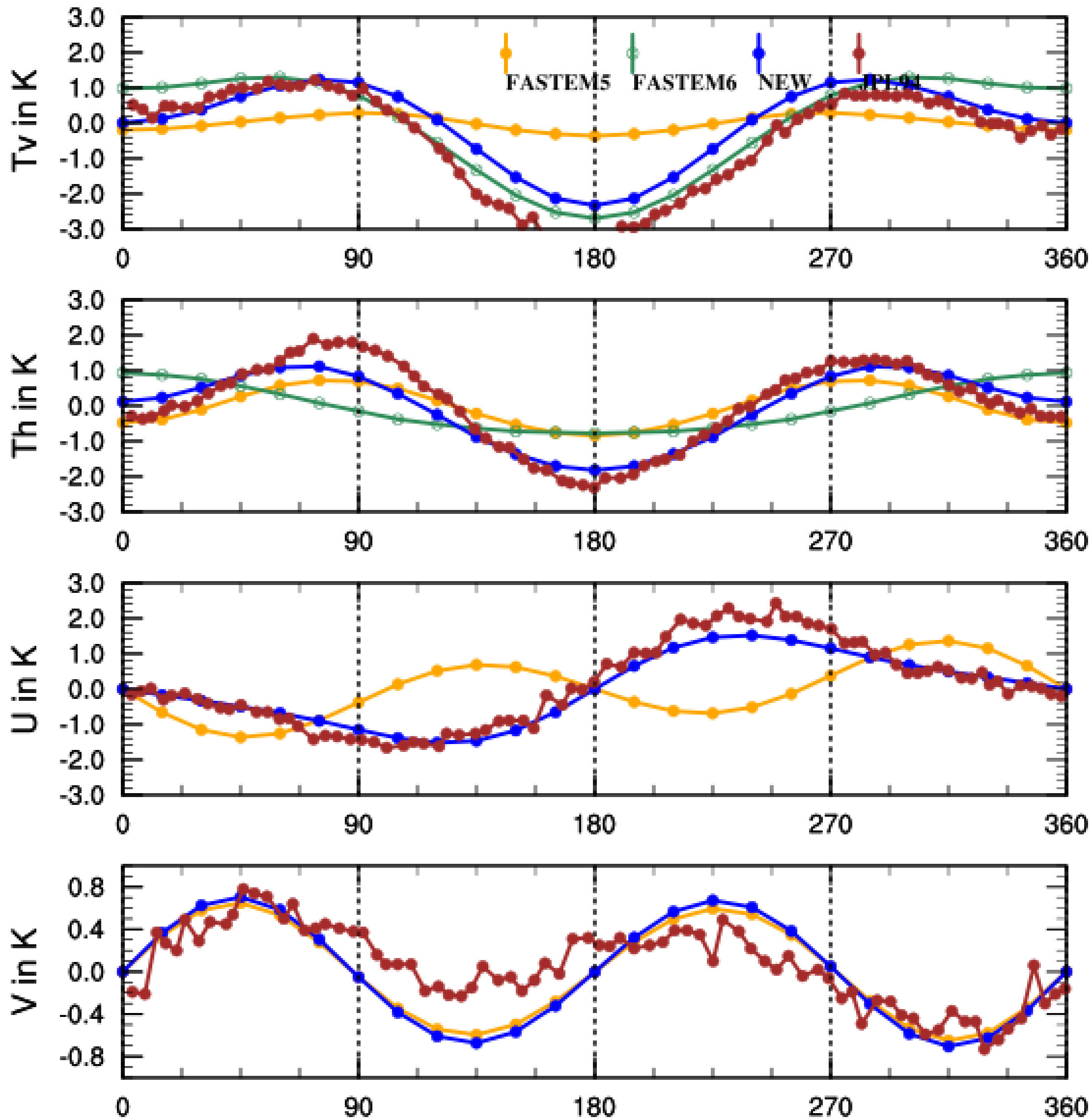


Ming Chen, ESSIC/UMD

Comparison of FASTEM with JPL WINDRAD Observations (theta=65º)

In general, the previous FASTEM versions were developed for zenith/view angles less than 60 degree. FASTEM 6 also turned off the 3rd and 4th Stokes components. TESSEM is similar to FASTEM 6 except for the frequency extension to submillimeter channels.

The NFASTEM provides full-Stokes component calculations. The azimuthal variations in NFASTEM now agree well with the observations (Red) in both magnitude and phase change.



Ming Chen, ESSIC/UMD

Ongoing Work/Future Plans [1/2]

- **CRTM 2.3.0 post-release integration testing**
  - Documentation update
- **Coefficient Generation Toolkit**
- **Optimization Plans** [J. Rosinski / B. Etherton]
  - Thread via OpenMP the loop over observations in GSI routine setuprad.f90
  - Redesign CRTM data structures to enable vectorization of inner loops (vertical dependencies within inner loops prevent this now)
- **Solver Plans** [T. Greenwald/R. Bennartz]
  - Continue testing of the solvers
  - Add scattering indicator routine to the CRTM to help characterize the degree of scattering in a given atmospheric profile
  - Conduct benchmark timing/accuracy tests using NWP model data and determine optimum configuration for solvers

Ongoing Work/Future Plans [2/2]

- **Physical Properties Ongoing Work**
  - **Aerosols**: Develop new scattering tables to conform with updated aerosol properties (PSD, index of refraction, etc.) in coordination with the A-Team. Updated specifications using CMAQ.
  - **CSEM**: Continue the CRTM-CSEM integration efforts so that we may have a working version of the integrated CRTM-CSEM package as soon as possible for demonstration and various testing purposes. The implementation of new CSEM functionality and components will depend on the priority and the requirements of the user community.
  - **Microphysics / CHYM**: Continue expanding microphysics database, and testing newly-created scattering tables in stand-alone CRTM and in GSI/GFS for analysis and forecast impact assessment.
  - **CLBLM**: Transition to STAR
  - **Shortwave / IR improvements**: Seeking new hire for NASA GMAO position to focus on this requirement

Questions / Comments?

- CRTM TRAC page (documentation)
  https://svnemc.ncep.noaa.gov/trac/crtm
- CRTM SVN repository (version control)
  https://svnemc.ncep.noaa.gov/projects/crtm

- CRTM FTP site
  ftp://ftp.emc.ncep.noaa.gov/jcsda/CRTM

- Coming Soon!
  - New community-focused integrated documentation, GIT-based version control, user-support, release / build / testing environment (under development, FY18 target)

CRTM Optimization Status

- Run REL-2.3.0-beta for 100 profiles on Theia machine, and compared with REL-2.2.3.
- For hyperspectral IR sensors, like CrIS, the all sky (Cloud_Fraction) run can save about 10% CPU time than run CRTM twice for Clear and Cloudy conditions.

Timing_test 100 profiles		Clear-Sky		Cloudy		All-Sky: (Clear + Cloudy)	
		Rel-2.2.3	Rel-2.3.0	Rel-2.2.3	Rel-2.3.0	Rel-2.2.3	Rel-2.3.0
ATMS	**Forward**	0.043	0.055	0.325	0.338	N/A	0.383
	Forward + K_Matrix	0.182	0.216	1.065	1.102	N/A	1.303
CrIS399	**Forward**	0.657	0.795	8.275	8.385	N/A	8.906
	Forward + K_Matrix	4.317	4.777	30.182	30.404	N/A	31.415

Cloud Microphysical Modeling [1/3]

Ice Crystal Model

User Input

- Size Distribution $n(D)$
- Characteristic Diameter D_e
- Mass-Dimension Relationship $m(D) = aD^b$
- Ice Water Content $w_x = \rho_a q_x$
- Number Concentration N_t

- Size Distribution
- Habit Distribution
- Convolve each single particle optical property with the size and habit distribution to obtain distribution mean (bulk) ice particle optical property
- Parameterize distribution mean (bulk) ice particle optical properties as a function of characteristic diameter:

$k_{ext}(D_e, \nu)$, $k_{sca}(D_e, \nu)$, ω_o, $g(D_e, \nu)$, $P(\Theta, D_e, \nu)$

- Distribution Mean (Bulk) Ice Particle Optical Properties
- Ice Water Content

Single Ice Crystal Microphysical and Optical Properties Data Base

- Is the output IWC approximately equal to the input ?
- There is no doubt that mixture of habit is more realistic, but are we using the habit distribution which best represents the nature ?
- Should we parameterize the cloud optical properties using the same ice crystal database and model for the radiation model used in GFS for consistency ?

Slides from Emily Liu

Optimization (J. Rosinksi) [1/3]

- Thread loop over channels in CRTM_K_Matrix_module.f90 using OpenMP
  - ~5X speedup using 6 OMP threads
  - ~8X speedup using 12 OMP threads
- Numerous code changes are required to enable OpenMP threading, but no significant structural changes to the code
- However, explicit vectorization of code will require substantial code rewrite.