ITWG
NWP Working Group

Online Summer Interim Meeting

10th July 2024

Agenda

1. Welcome and Agree Agenda
    - Minutes, outcomes
2. Guest speakers: Overview of recent updates in Radiative Transfer modelling
    - RTTOV – James
    - CRTM – Ben
    - ARMS - Fuzhong
3. Review Actions from **ITSC-24**
4. Interaction with DBnet Coordination Group
5. Short introduction to Arctic Weather Satellite
6. Discussion on MTG-IRS preparation
7. **AOB**: Email list updates, …

N.B. any additions following the meeting are in blue

Guest Speakers – Recent updates to Radiative Transfer Models

- RTTOV – James Hocking
- CRTM – Ben Johnson
- ARMS – Fuzhong Weng

Thanks to our speakers. See slides from these talks at end of this slide pack

Action Status from ITSC-24

<u>Action DA/NWP 24-1</u> on Bill Campbell: To circulate information about the COWVR instrument and RFI detection principle to the WG.

- Information from Steve *Swadley & Bill Campbell including WMO meeting - done circulated*.
- Reminder : Email announcement by Steve English 2.7.24: in-person meeting on RFI
  - October 14-18, Bariloche, Argentina (incuding EO, meteorology, spectrum management)
  - Abstracts due by 14 July 2024 (RFI 2024 (rfi-conference.org)) get in touch with Steve English if pushed for time for submission

<u>ACTION DA/NWP 24-2</u> <u>on Brett Candy</u>: Report to WG members on any useful discussion that

took place on use of microwave data over sea ice, snow or land at EPS-Sterna workshop in

April 2023.

- Focus of workshop was orbit impact. Contacted MAG to find out if any studies have been commissioned Update from the MAG: nothing specific planned, focus is on quality of data and the new 325 GHz channels. But there is an initiative at ECMWF on sea-ice & plans to evaluate data over land / sea-ice at Norway, SMHI
- n.b. Polar Workshop in 2021: Workshop on the optimal use of operational satellite microwave products | EUMETSAT

Action Status from ITSC-24

<u>ACTION DA/NWP 24-3</u> on WG co-chairs: Contact Steve English to obtain more information on his proposal for snow and/or sea ice emissivity ISSI project and circulate to Working Group members.

- Update. Project has been successful – post meeting details from M. Sandells:

The goals of the ISSI team are:

1. Quantify uncertainties due to snow and ice properties in existing microwave emission and backscatter models across the frequency range useful for NWP.

2. Assess the information content of frequencies and sensor types used in combination to improve estimates of geophysical parameters.

3. Develop a fast model across the frequency range and identify a pathway for inclusion in NWP systems.

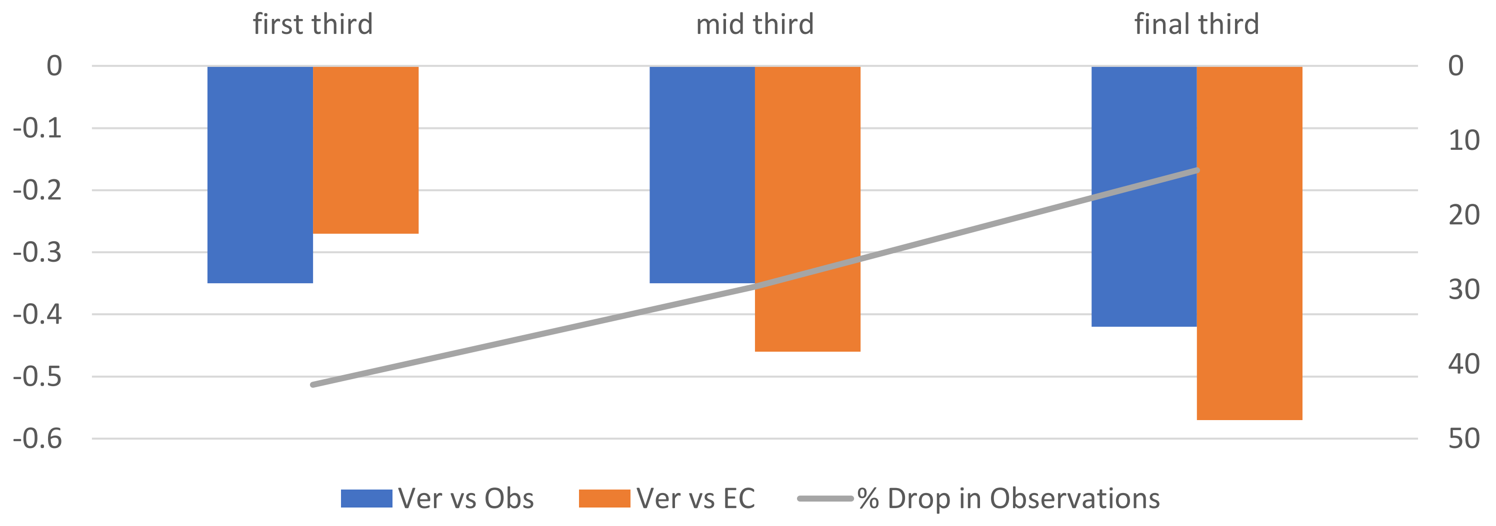
Team leaders are : Mel Sandells (Northumbria University) and Christian Matzler (University of Bern),

<u>Action DA/NWP 24-4</u> <u>on WG co-chairs</u>: Organise a task team to perform experiments to establish the impact of data latency (esp. DBNet data) in both global and local assimilation systems.

Suggest we set up a meeting on this. Now we are 1 year away from next conference. Those interested to <u>let co-chairs know</u> and we will set up a meeting to devise suitable experiments that several centres can carry out

Example below shows impact of removing data

- Removed Sounder data (IASI, ATOVS, ATMS) from each third of the DA window
- %Reduction shows the percentage of obs removed in the main forecast runs



Drop in obcounts ~50% ~35% ~15%

Action DA/NWP 24-4 on WG co-chairs - continued: Organise a task team to perform experiments to establish the impact of data latency (esp. DBNet data) in both global and local assimilation systems. - continues

Examples of data latency impact at 8th WMO meeting on observation impacts:
- https://community.wmo.int/en/meetings/8th-wmo-impact-workshop-home

see 5.10 Peter Lean et al: How Observation Timeliness affects the impact of an observing system
&
5.22 Srinivas Desamsetti et al : Impact of assimilating Indian DB radiances at NCMRWF.

Action Status from ITSC-24

Action DA/NWP 24-5 on Fiona Smith: Check with Tim Hultberg & Dave Tobin regarding what feedback has been received on hybrid PC-scores and report to CGMS.

- Action- 24-5 Fiona – passed to CGMS

- Update received from Dave Tobin regarding hybrid PCs for CrIS:
  - Hybrid PC approach has been implemented for CrIS (following closely the EUMETSAT approach for IASI)
    - PC part provides 64* compression
    - Rapid Event Detection (RED) portion of it provides a convenient way to see unusual events;
    - Approach: 150 global PCs are complemented by 10 local PCs
  - Details & data: GES DISC (nasa.gov)
  - Data processed for CrIS on NOAA-20/JPSS-1 , ~6 years available
  - For more information contact Dave Tobin, Joe Taylor, see also: https://imagine.eumetsat.int/smartViews/view?view=EMSC

Action Status from ITSC-24

Action DA/NWP 24-6 on WG Members: Share impact assessment results for FY-3E with the working group, NOAA and CMA as soon as possible in particular to provide evidence for support of the early morning orbit

- e.g. through links to publications. E.g. ECMWF fellowship report (Steele et al., 2023) https://www.ecmwf.int/en/elibrary/81525-assimilating-fy-3e-mwhs-2-obs-and-assessing-all-sky-humidity-sounder-thinning
- More input needed/welcome

Action 24-8 on WG co chairs Website unused pages "refresh"

- Ongoing – with help from Leanne we are learning to use Wordpress – bear with us!

Action 24-9 Lam validation meeting

Ideal here was to share useful experience (diagnostics/verification types) on how we measure radiance impact in LAMs.

- After discussion with several WG members it has been decided to organise an online meeting along the same lines as the Bias correction meeting several years ago. Planning meeting in August.

Plus….CGMS document on microwave impact. (in association with other WGs). Input from ITWG was put together with input from IPWG and other CGMS Working Groups to provide overall assessment of impact of passive MW as part of hybrid architecture. Analysis welcomed - but as importantly, the process used to collect the input was recognised as a "good thing", and will be reactivated in response to issues identified by CGMS WGIII Gap Analysis activities

Action Status from ITSC-24

Action 24-10 Update "improve" NWP survey

- **More details on NWP systems. This now has its own sheet (global, then conv/regional)**

Table 2: NWP Systems

Global Model Configuration information								
DA			Model Resolution, Levels, Forecast Length			Coupling		
DA System	Window Length (hours)	Data Cutoff (hour:minutes) [N1]	Deterministic	Ensemble	Thinning	Ocean/Sea-ice	Land	Atmospheric Chemistry
4D-EnVAR-IAU + LETKF			15 km L84 (10d)	39 km L84 (20m) (16d)	150km			
4D-VAR/EDA			TCo1279 L137 (10d)	T_CO 639 up to 15d, T_CO 319 d16-45, L91, 51m	variable (mostly 110-140km in 1/2 hour slots)			
Hybrid 4D-VAR + ET			T681 L60 (10d)	T359 L60, 20m, 16d	140km			
EnVAR + LETKF			global/EU two-way nesting: 13/6.5 km L120/L74 (7d)	global/EU: 26/13 km, 40m, 7d	160km			
Hybrid 4D-VAR + En-4DEnVa	6	(main runs) 2:40	10 km L70 (6d)	20 km L70, 44m*, 7d *forecasts run for 12 members	ATOVS 100km, ATMS, AIRS, CrIS 125km(ExTr)/154km(Tr) IASI 80km(ExTr)/154km(Tr)	Ocean DA & model	land surface model with land DA (snow, soilmoisture, soil temp)	No coupling: daily aerosol and ozone climatology
Hybrid 4D-VAR + LETKF	6		TQ959 L128 (11d)	TQ479 L128 (51m) (18d)	AMSU-A, ATMS 250km, MHS 180km, IASI, CrIS 200 km			

Action Status from ITSC-24

<u>Action 24-10 Update "improve" NWP survey - more</u>

- Channel usage is inconsistent across instrument types. Suggest we unify

e.g. Hyper IR columns land, sea

GeoIR columns & MW land/sea, sea/low topog , land

Propose for GeoIR and MW

We have following:

Sea, land, sea-ice, special QC - using notes.

e.g.

AMSU-A													
Satellite									Channels				
N15	N16	N17	N18	N19	AQ	MA	MB	MC	sea	land	sea-ice	special QC	N
X				X			X	X	7-14		5-14		
X			X	X			X	X	4-14	4-14	8-14	rain: 9-14 (land,sea) [T1] cloudy: 6-14 (land) [T2,T3] high orography: 8-14	

- **Also yearly update / remove decommissioned satellites / instruments? (n.b.** this approach was agreed at the online and we will provide a snap shot before each conference)

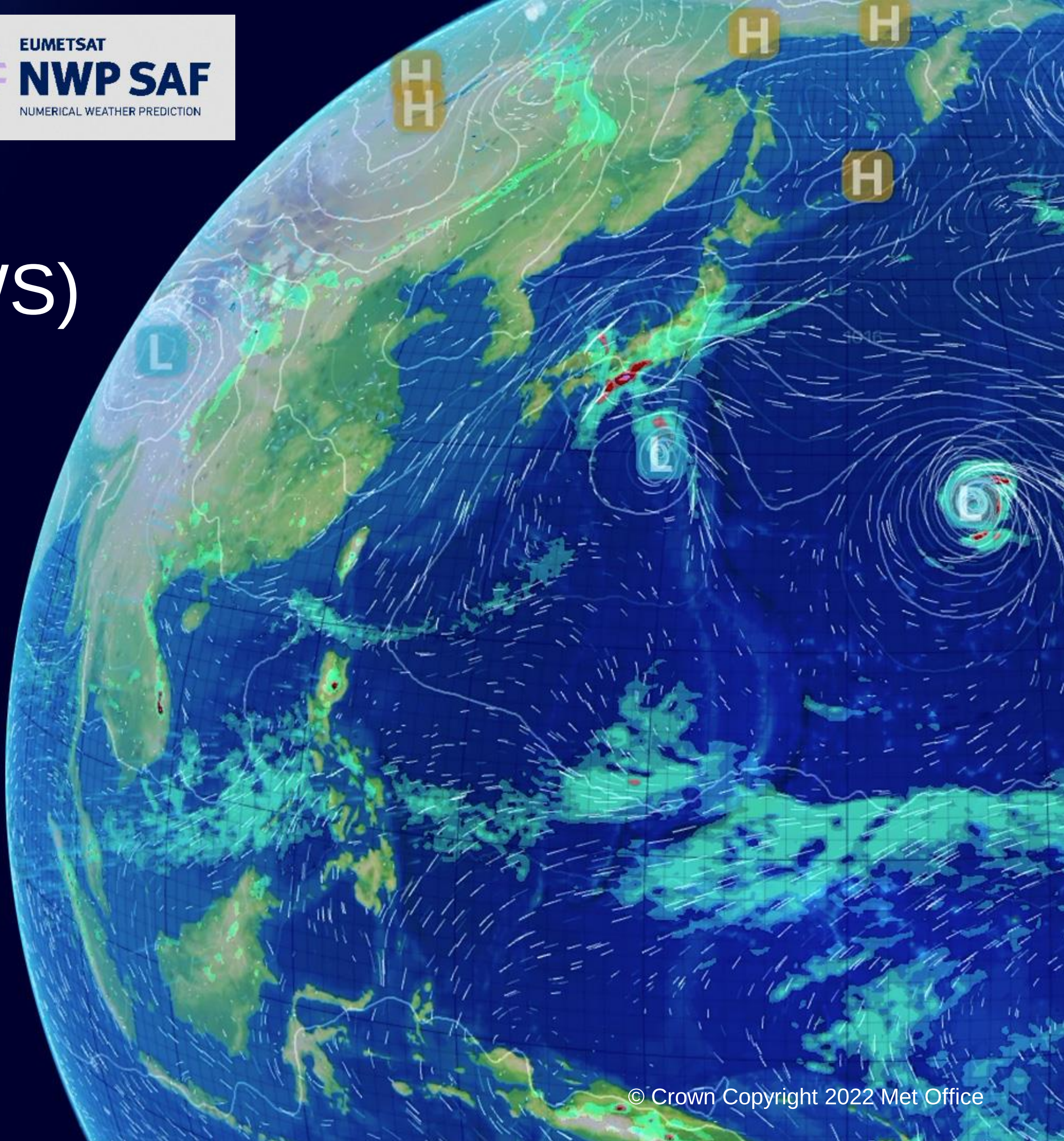
Interaction with DBnet Coordination Group

- Invited to meetings with DBNet coordination group
- Topics:
  - Status of DBNet network and available information:
    - DBNet station overview on WMO page – DBNet network status and plans: Data Access and Use | World Meteorological Organization (wmo.int)
    - DBNet station monitoring / NWP-SAF: DBNet | NWP SAF (eumetsat.int)

- Discussion of NWP requirements, several questions circulated to NWp group and feedback obtained transfered to DBNet coordinators
- Strong interest of DBNet group in any impact experiments with DBNet data to provide suport for the effort

Met Office

EUMETSAT NWP SAF NUMERICAL WEATHER PREDICTION



Arctic Weather Satellite (AWS) update

Nigel Atkinson

ITWG PSWG inter-sessional meeting

11 July 2024

AWS launch

- AWS launch scheduled late July 2024 on Transporter 11 rideshare mission, by SpaceX, at Vandenberg

AWS instrument

- 19 microwave channels in the following bands:
  - 50-57 GHz (8 channels)
  - 89 GHz
  - 165.5 GHz
  - 176.3-182.3 GHz (5 channels)
  - 325.15 (4 channels)
- Footprint 10 to 40km depending on frequency
- https://www.esa.int/Applications/Observing_the_Earth/Meteorological_missions/Arctic_Weather_Satellite/The_instrument

AWS commissioning

After launch, ESA will carry out commissioning activities before turning on the payload:

- LEOP phase: 1 hour to reach 510km, then 1.5h to reach 590km.
- Initial checks. Two weeks
- Orbit adjustment:
  - Eccentricity adjustment (to make the orbit circular) starts 20 days after launch and will take 16 days
  - Altitude needs raising to 595.5km. 8.5 days
  - Inclination needs adjusting, to maintain the correct LTAN. Will take 4 weeks
- So don’t expect any payload data until Sept 2024.

Direct broadcast

- L-band: 1.707GHz, bandwidth 3.4MHz, polarisation RHCP, modulation QPSK, Total signal encoded rate: 3570kbps
- The Space to Ground Interface Document is available. We were hoping it would be on a public web site, but this hasn’t happened yet.
- ESA have procured a DB processor for public use:
  - NWP SAF will host it on their web site (alongside deliverables such as AAPP, RTTOV)
  - Two versions: source code and executables
    - The source code needs compiling (may not be straightforward). You will need the ESA EOCFI library.
    - Executables built on **Ubuntu**
  - It should be possible to put the executables version inside a container (Apptainer, Docker or Podman) – for users who don’t have Ubuntu. But not for day-1.
  - Best endeavours. Remember, this is a demonstrator mission!

Dissemination in Europe

- Dissemination of AWS L1b netCDF data in Europe has been requested by several EUMETSAT member states (as a third party data service)
- EUMETSAT is looking into possibility of dissemination via EUMETCast

- Official information on this is expected very soon

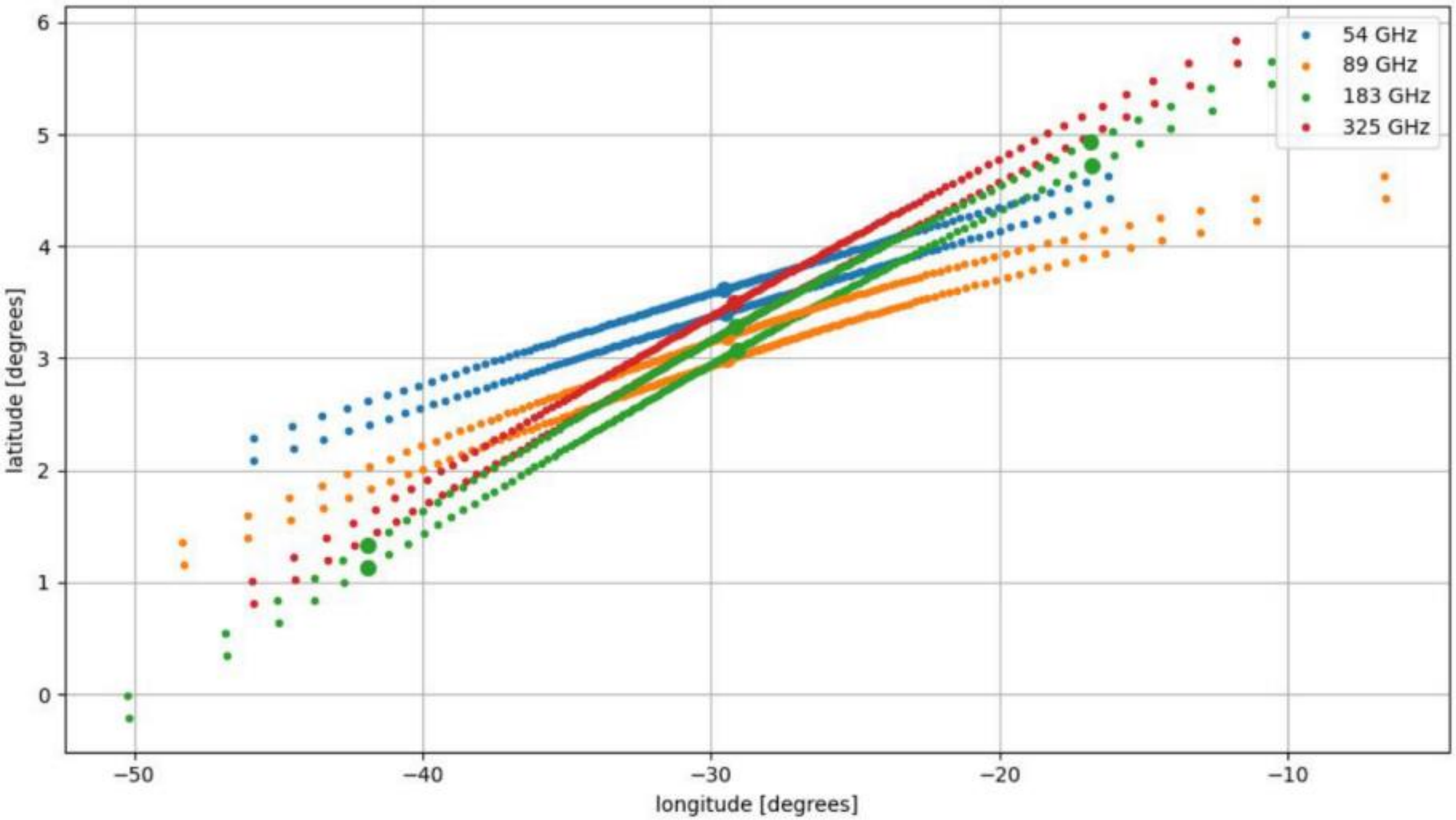
- This could provide an additional data access possibility for users in Europe

AAPP processor

- The ESA package will deliver level 1B – the four feedhorns point in different directions. A global level 1B product is also expected to be available.
- An AAPP module will be released (part of AAPP v8.14?) to map them to a common grid. (ESA also plan to release software to do this)
- The AAPP module will also offer BUFR encoding, using the TROPICS BUFR template – to allow NWP evaluation.
- The AAPP module should be released in August 2024, before payload turn-on

AWS scan pattern

AWS has no quasi-optics – hence the need for re-mapping of the 4 feedhorns



AWS evaluation

- Several centres are planning to evaluate the data (Sweden, Norway, Meteo-France, ECMWF, Met Office)
- Anybody with suitable DB system is welcome to try to receive and process the data, and provide feedback
- The performance of AWS will inform EUMETSAT's decisions in whether or not to go ahead with *EPS-Sterna* – constellation of 6 satellites in 3 orbit planes, from 2029. The radiometer would be the same as AWS

AOB – MTGIRS data volumes

One IASI delivers 120 spectra in 8 seconds = 54000 per hour

Two IASI delivers = 108000 per hour

One IRS = 280x160x160 = 7168000 per hour = factor 66 more than 2 IASIs at full resolution

N.B. Spectra will be disseminated in Near Real Time via Principal Component Scores.

(conversion to radiances via IRSPP etc)

Several centres have already considered thinning options , (rather than super obbing)and we now have an

ACTION for next meeting, make sure there is a MTG-IRS discussion at next ITSC as this will be just prior to launch.

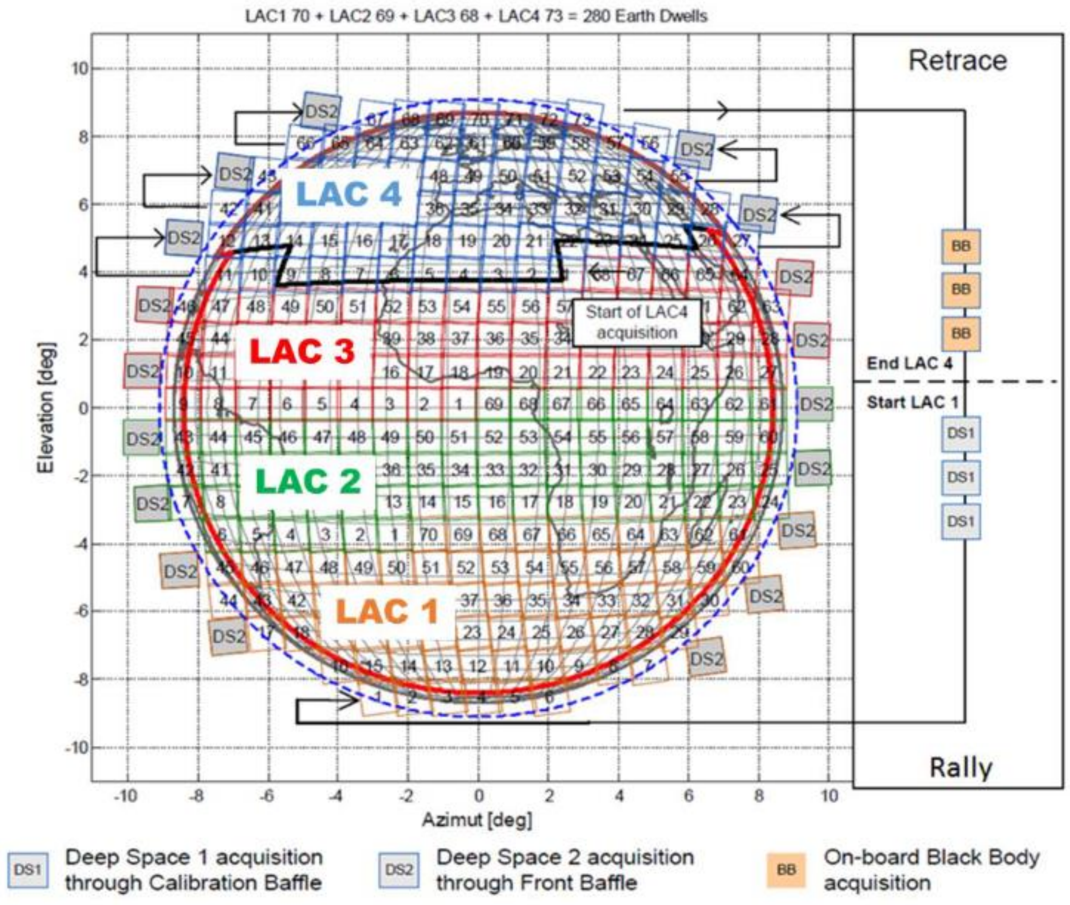


Figure 1: IRS dwell coverage (EUMETSAT figure)

AOB – email list

- Let co –chairs know if your email changes. Also, if you are new and want to be on the mailing list .

- This group is to share information relevant to members of the International TOVS Working Group "DA/NWP Working Group",
  - including working group actions and reports,
  - instrument quality discussions and informal data outage alert information.

- This group is only visible to members of the group itself.

- And finally…from Simon Elliott: to flag up no new data on GTS after the end of this year. Important to note warning. Simon is keen to know when centres start taking data off WIS 2.0.

Thank you!

Plus: Keep an eye out for an invitation to

- LAMs/convective scale validation meeting – Autumn 2024
- DBNet, impact of data latency meeting ?

RT presentations Follow

RTTOV v14 overview

RTSP Working Group, June 2024

RTTOV development team: Florian Baur[4], Mary Borderies[3], Brett Candy[1], Philippe Chambon[3], Alan Geer[2], James Hocking[1], Christina Köpken-Watts[4], Jean-Marie Lalande[3], Cristina Lupu[2], Marco Matricardi[2], Sonia Péré[3], David Rundle[1], Leonhard Scheck[4], Olaf Stiller[4], Christina Stumpf[4], Emma Turner[2], Jerome Vidôt[3]

Met Office[1], ECMWF[2], Météo-France[3], DWD[4]

Met Office

Profile representation

RTTOV v14 profile modified so that NWP model fields map more directly onto the profile variables.

Eliminates inconsistencies related to scattering inputs (especially in VIS/IR where there was a vertical stagger between T/q and cloud/aerosol inputs).

Surface implicitly lies on bottom pressure half-level

=> *users cannot simulate profiles on fixed pressure levels*

Met Office

Unification of RTTOV and RTTOV-SCATT

RTTOV-SCATT capabilities implemented behind RTTOV interface:

- existing hydrometeor optical properties
- delta-Eddington solver
- two-column cloud overlap options
- radar solver

Enables sharing of scientific and technical capabilities across the spectrum and provides greater spectral consistency in scattering simulations.

Met Office

Unification of RTTOV and RTTOV-SCATT

- delta-Eddington solver available in IR (aerosol/hydro) and MW (hydro)
- DOM solver available across whole spectrum *(MW subject to validation)*
- all cloud overlap schemes available for all solvers
- unified file format and data structures for aerosol and hydrometeor optical properties across the spectrum
- input files contain optical properties for arbitrary collections of particle types*
- explicit optical property inputs available for all solvers, across spectrum

**v14.0 optical properties will be the same as in v13 i.e. different in UV/VIS/IR vs MW, but these updates make possible spectrally consistent properties in future versions*

Met Office

Further scattering updates

- Radar simulations simultaneously with passive radiances.
- Emissivity retrieval outputs generalised to clear-sky and all cloud overlap schemes.
- Tang *et al* modification for Chou-scaling fast IR scattering parameterisation.
- Consistent unit conversions for hydrometeor concentrations in UV/VIS/IR and MW.
- Allow separate units selection for aerosols and hydrometeors.

MFASIS-NN

- Fast neural-network-based hydrometeor scattering solver for VIS/NIR channels.
- DWD (Leonhard Scheck, Florian Baur, Christina Stumpf, Olaf Stiller) have improved MFASIS-NN for v14.
- Additional column-integrated water vapour input variable to improve accuracy in weakly-WV-affected channels (e.g. 1.6 microns).
- Optimisation to improve performance especially on vector machines.

Met Office

PC-RTTOV

- Marco Matricardi has trained new PC-RTTOV coefficients for IASI, IASI-NG, and MTG-IRS.
- New files support all trace gases except SO_2, NLTE, aerosol (OPAC), and hydrometeor simulations.
- Surface emissivity from IREMIS and CAMEL v3 climatology atlas.

Met Office

Surface variables in RTTOV v14

- Input/output emissivity, reflectance, and related variables gathered into a single data structure/argument.
- Give users full control over diffuse reflectance (same as emissivity and BRDF).
- Enable capability for heterogeneous surfaces:
    - multiple surfaces may be defined, each with a unique set of near-surface, skin, and emissivity/reflectance properties, and associated fractional coverage
    - properties are combined before the RTE is solved.

Met Office

Other updates

- IR emissivity and BRDF atlases optionally return data from a nearby land point within specified radius if there are no emissivity data at given location (based on code supplied by Robin Faulwetter, DWD).
- Support for CAMEL v3 IR emissivity atlases (with thanks to Eva Borbas, University of Wisconsin).
- Improved consistency between UV/VIS sea BRDF and diffuse reflectance.
- New *rttov_diagnostic_output* structure/argument for geometric heights and effective hydro fraction.
- Optional output of overcast BTs.
- Optional output of VIS/NIR Jacobians in terms of reflectance.

Met Office

Other updates

- Improvements to user-level and internal routines for checking inputs, and improved flagging of inputs outside parameterisation limits.
- Zeeman coefficients in v13 predictor *rtcoef* files (Emma Turner).
- Large coefficient files and atlases in netCDF instead of HDF5 format (HDF5 no longer supported).
- *rttov_error_report* subroutine now in a module which prevents missing interface includes (caused problems for some users)
- New subroutine to map WMO satellite IDs onto RTTOV platform/satellite couplets.

Met Office

Interface changes

Changes in the user interface to improve clarity, consistency, and generality:

- options structure reorganised
- numerous variables, types, subroutines renamed
- unused variables removed
- interfaces to various subroutines updated to be consistent in argument order

These changes are fully described in a separate document to be included in RTTOV v14 package.

Met Office

Wrapper updates

- *pyrttov* and C++ wrapper fully up to date with v14 developments.
- Add interface to *rttov_aer_clim_prof* subroutine.
- Enable return of explicit optical property Jacobians.
- Updates to enable users to compute full radar Jacobian matrix.
- In C++: rename *Options/Profile/Atlas* classes and associated source files with *Rttov/rttov_* prefix.
- In C++: various technical improvements to the code (refactoring, tidying, private copy/assignment constructors).

Met Office

GUI updates

- GUI updates by Sonia Péré
- The GUI is now a pure Python application that calls RTTOV via *pyrttov*.

  => Allows for GUI updates to be decoupled (to some extent) from RTTOV release cycle and reduces code complexity.
- Updated for new RTTOV features, including support for MW scattering.
- PC-RTTOV no longer supported as *pyrttov* does not yet allow PC-RTTOV simulations

Met Office

Summary

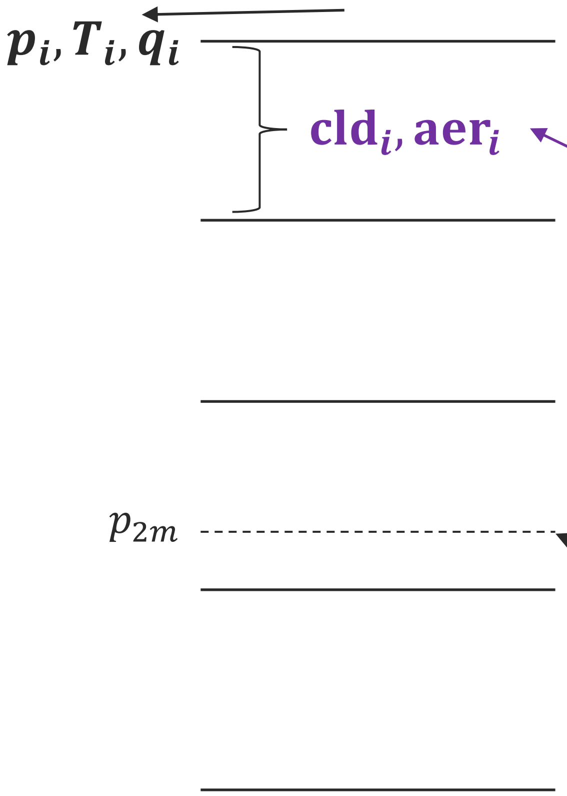
- RTTOV v14 due for release by end of this year.
- Significant update with many new/enhanced capabilities.
- Technical improvements including improved interfaces.

Thanks for listening!

Met Office

RTTOV v13 input profile

point values on pressure levels

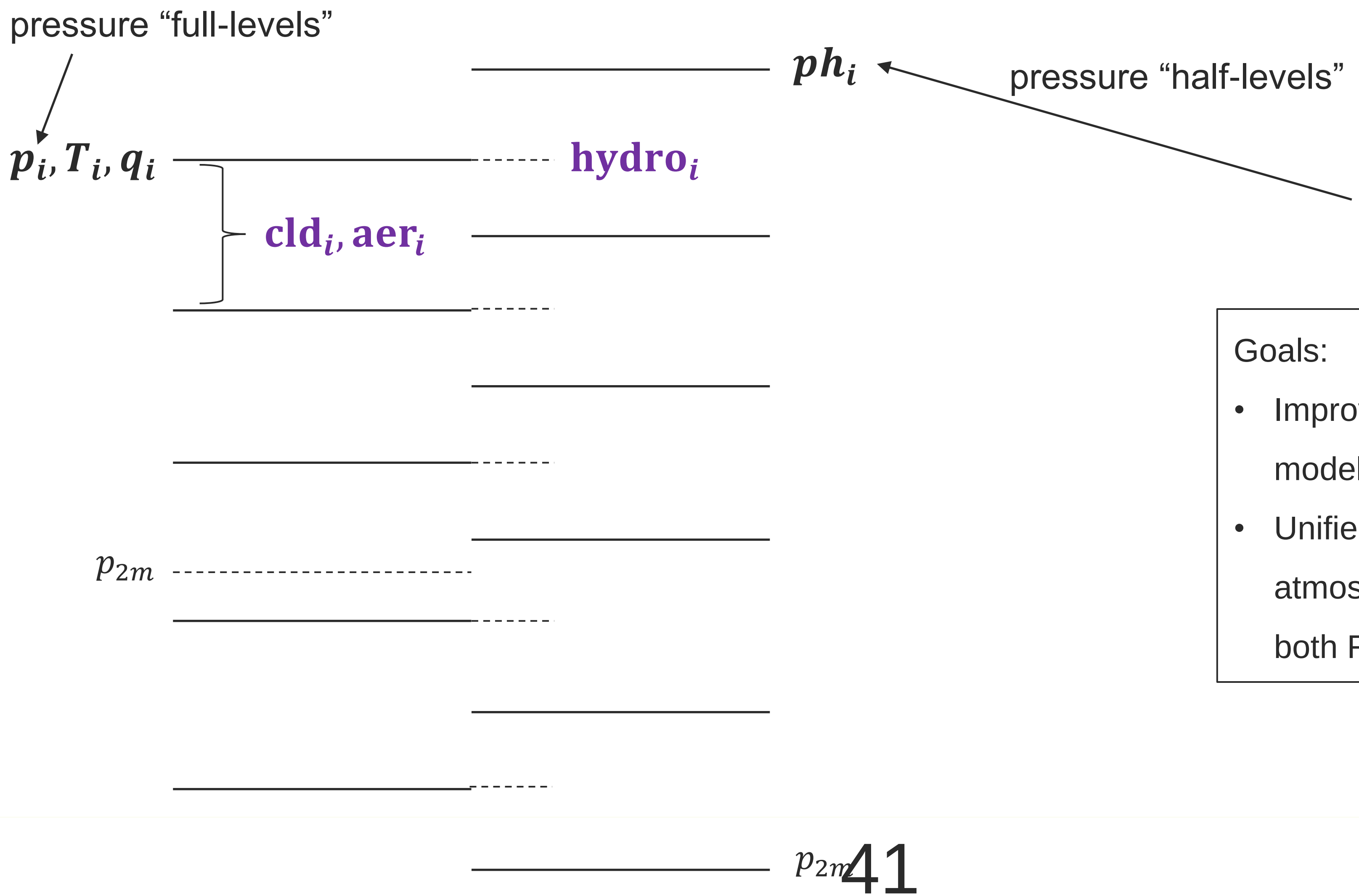


layer-average values

Systematic biases: cloud/aerosol shifted w.r.t. temperature and water vapour

flexible surface, arbitrary location
BUT adds complexity, impact on performance, and for NWP it is better to input profiles on native NWP model vertical grid anyway

RTTOV v13 / RTTOV-SCATT

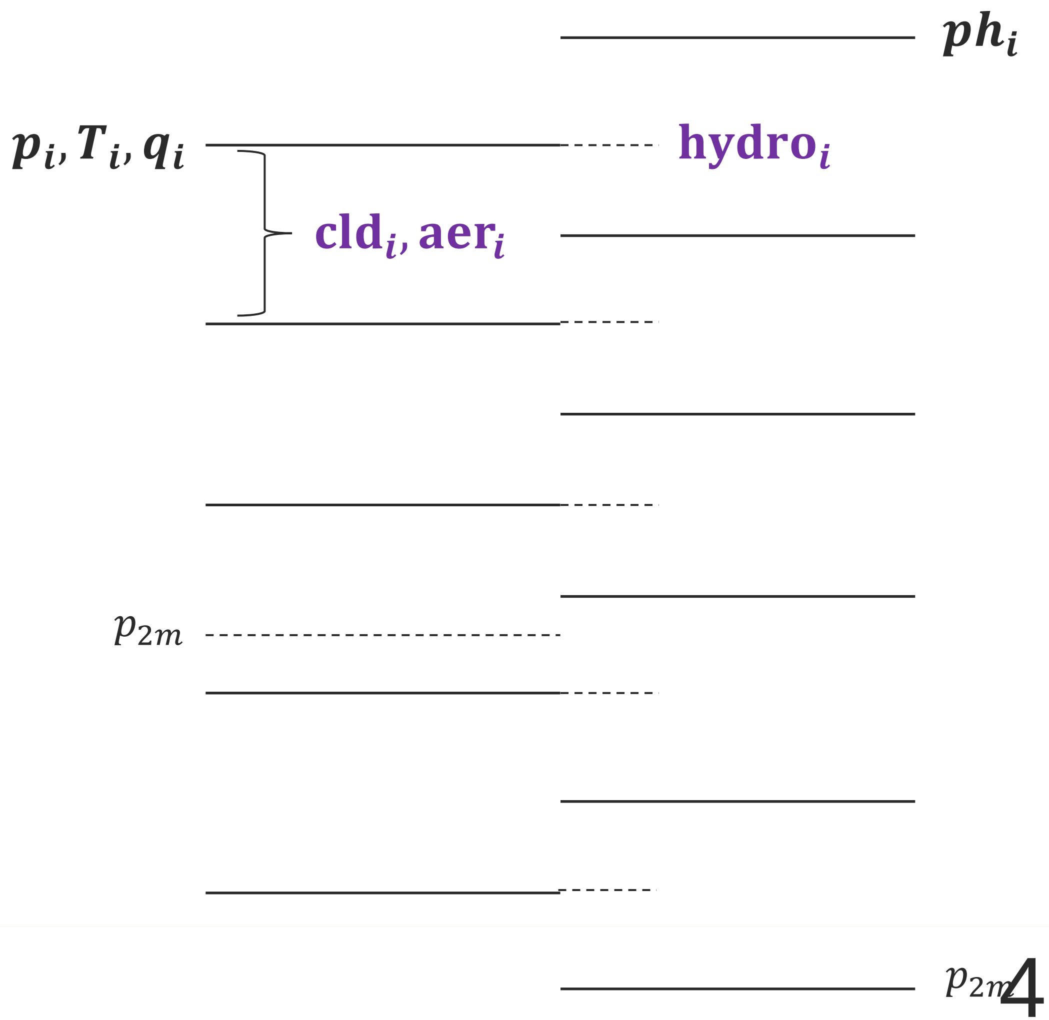


Goals:

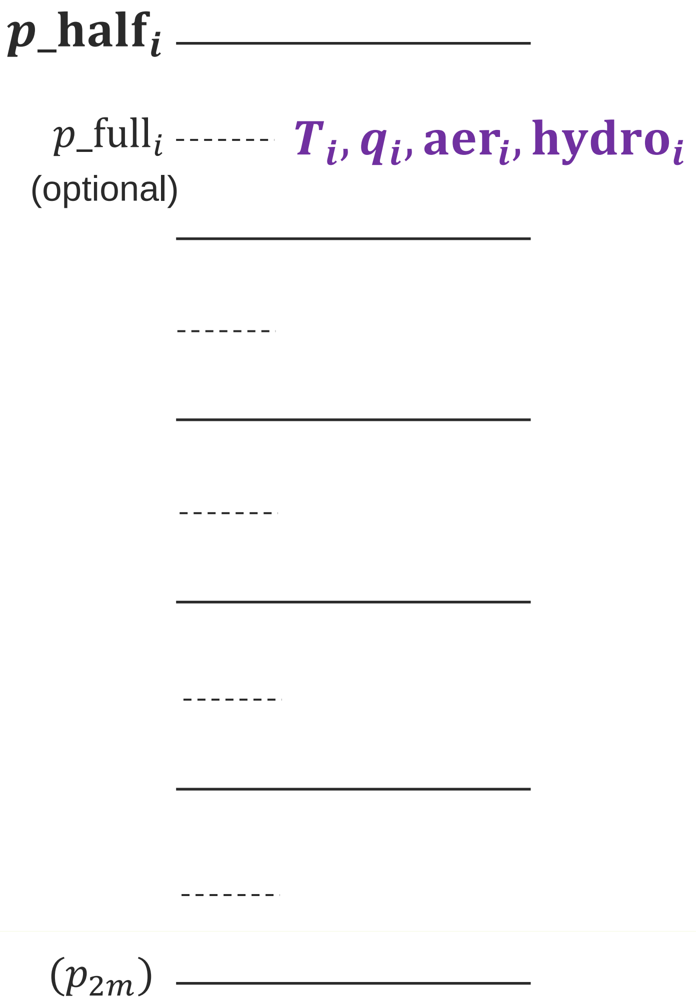
- Improve consistency with NWP model field representation.
- Unified representation of atmospheric profile applicable to both RTTOV and RTTOV-SCATT.

Met Office

RTTOV v13 / RTTOV-SCATT



RTTOV v14



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Capabilities removed

- Solar single-scattering solver.
- MFASIS-LUT.
- FASTEM-1/2/3/4 and TESSEM2 MW sea surface emissivity models.
- JONSWAP sea BRDF model option.
- HTFRTC.
- Redundant/deprecated options: *grid_box_avg_cloud, dtau_test, reg_limit_extrap, spacetop.*

The JCSDA Community Radiative Transfer Model

Benjamin T. Johnson (Project Lead, UCAR/JCSDA)

Cheng Dang (UCAR/JCSDA)
Ming Chen (STAR)
Yingtao Ma (STAR)
Pan Liang (AER)
Quanhua Liu (STAR)

Andrew Tangborn (EMC)
Isaac Moradi (GMAO)
Patrick Stegmann
Bryan Karpowicz (GMAO)
Nick Nalli (now at NRO)

Aerosol Model Collaborators:
Jerome Barré, Virginie Buchard, Peter Colarco, Arlindo da Silva *(NASA*
Peng Xian, Jeff Reid *(NRL)*
James Hocking *(Met Office)*
Shih-Wei Wei, Cheng-Hsuan (Sarah) Lu *(JCSDA/UCAR, University at Albany, SUNY)*

Additional contributions from Greg Thompson, Soyoung Ha, Fabio Diniz, Francois Hebert, Hamideh Ibrahami

ITWG NWP WG July 10, 2024

CRTM enables use of satellite observations

- Satellites are Costly
  - Design, Construction, Launch, Operations, De-orbit
  - Short lifetimes (< 10 years)
  - GOES-T: $11.7B
  - JPSS: $6.8B (J2 - J4)
- Most observation data goes unused in NWP
  - What we do use provides up to 20% of short-range forecast skill improvements (e.g., Geer et al., 2017)
  - Typically up to 80% of available mid-tropospheric observations in cloud-affected scenes are discarded (Geer et al., 2018)

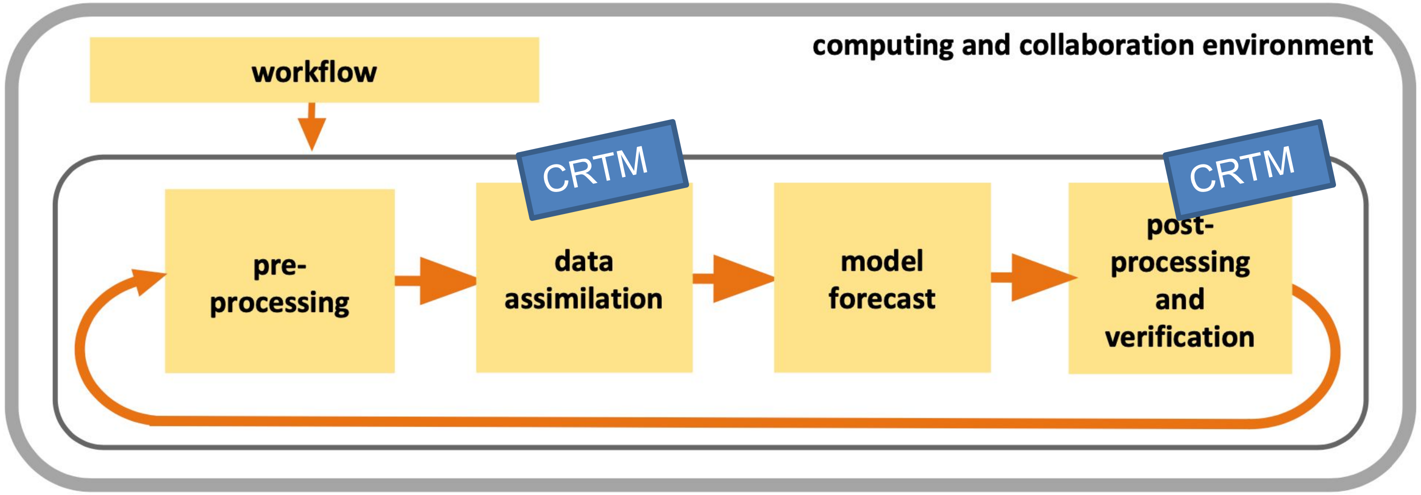
Sources (from left to right): alexyz3d, ABCDstock, 3dsculptor, Framestock, Paul Fleet/stock.adobe.com.

CRTM: the critical enabling component

- Enables DA in US systems
  - UFS, GFS, RRFS, UPP, etc.
  - JEDI/UFO, MPAS-JEDI, WRF-DA, etc.
  - GEOS, MERRA
  - Navy / Air Force

UFS
UNIFIED FORECAST SYSTEM

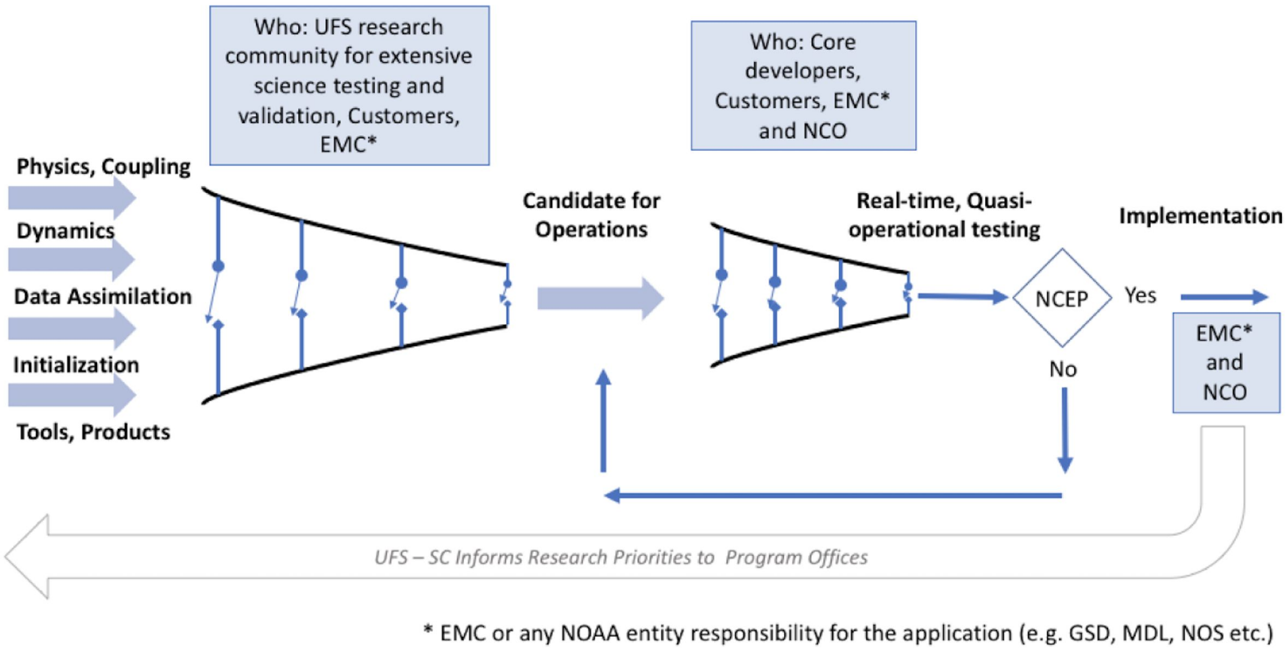
Parts of a UFS Application



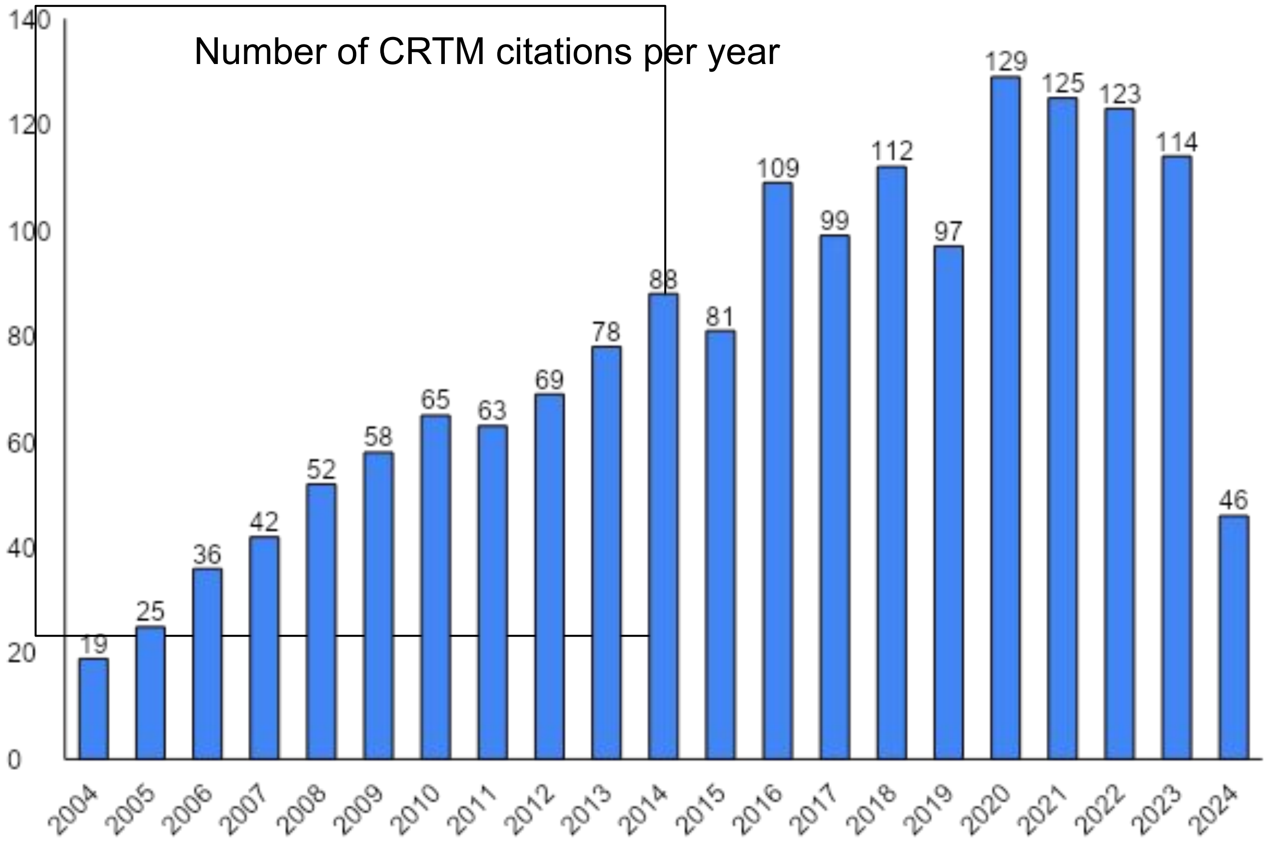
Pre-processing and data assimilation	• Stages inputs, performs observation processing, and prepares an analysis
Model forecast	• Integrates the model or ensemble of models forward
Post-processing and verification	• Assesses skill and diagnoses deficiencies in the model by comparing to observations
Workflow	• Executes a specified sequence of jobs
Computing and collaboration environment	• May be different for research (experiment focus) and operations (forecast focus) • Provides actual or virtualized hardware, databases, and support

CRTM: A Research to Operations (R2O) Pipeline

- Rapid Transition of Research to Operations
  - Modern/Agile Software Development
  - Modern Repository management: GitHub / Zenhub
  - Community Driven development
  - Interdependent project coordination
  - Deep engagement in key scientific communities
  - Public Domain license
- Full cooperation with operational centers
- Direct collaboration with satellite sensor science teams / data product teams (public / private)



CRTM's Role in The Science Community



CRTM Provides the critical link between satellite radiances and physical properties of the atmosphere:

Satellite Data Assimilation -> Analysis, Forecasting
Calibration / Validation
Satellite Simulations
Reanalysis
Real-time Weather Analysis / Support
Satellite Sensor Health Monitoring
Field Experiment Support
Education and Outreach

Representation at WIGOS, GCOS, CGMS, GEWEX, ITWG/ITSC, ICWG, IPWG, LSWG, IWSSM

CRTM

key technical capabilities

Support for Polarized **UV, VIS/near-IR, IR, sub-MM, MW** – future: far IR.

Instrument specific (center frequency, bandwidth, side bands, viewing geometry, polarization basis, spectral response)

Clouds: multi-species / habits supporting clouds / precipitation from VIS -> MW, microphysics-model specific LUTs (Thompson, GFDL, WSM-6)

Aerosols (salt, dust, smoke, black carbon, volcanic ash, etc.)

Gaseous species available in CRTM: H_2O, CO_2, O_3, N_2O, CO, CH_4, O_2, NO, SO_2, NO_2, HNO_3, N_2, OCS, and CFCs – *many others available from LBLRTM, not yet used in CRTM.*

Surface properties: land (soil moisture, vegetated), ocean (wind, foam,), sea-ice, snow cover (land, sea-ice, depth) --- primarily tested in IR/MW.

Active sensor development: space-based radar / lidar (backscat, extinct.)

Non-LTE (daytime) and Zeeman effects; Aircraft-based simulation

CRTM v3.1

https://github.com/JCSDA/CRTMv3

Status: **v3.1.0** released as release/skylab-v8 (**SIMOBS-78**)

v3.1.0-alpha / skylab-v7 released December 21, 2023

New Since v3.0.x

- Active Radar Support: Support for GPM DPR and CloudSat CPR radar reflectivity, and path integrated attenuation. (SIMOBS-62, SIMOBS-63, **SIMOBS-66**, SIMOBS-67)
- Enhanced netCDF4 support: test reference files now output in netCDF (SIMOBS-33, SIMOBS-67.1)
- Cmake support for build/compile (no ecbuild requirement) (SIMOBS-60, SIMOBS-63)
  - (Note: may be some remaining integration issues with GSI / JEDI, will be resolved in v3.1.1, use v3.1.0-skylabv7 tag instead for JEDI)
- Visible radiance reflectance output (Experimental) (OBSPROC-76, OBSPROC-100, PR #99)

Additional Features:

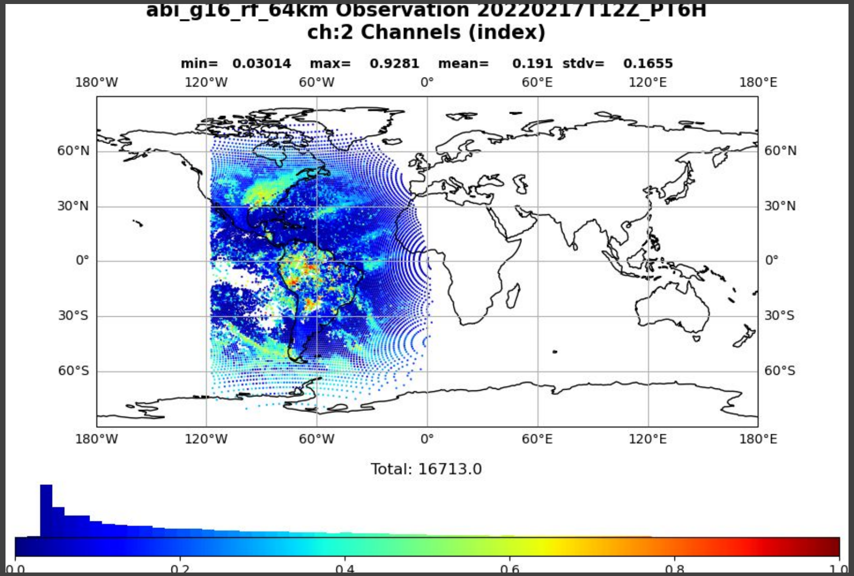
- Crtmv3 active sensor by @imoradi in #73
- Fixing the quiet option inside src/CRTM_LifeCycle.f90 by @fabiolrdiniz in #79
- Feature/cd rt sout net cdf by @chengdang in #66
- Quiet linker output when linking test execs by @fmahebert in #88
- Feature/active sensor by @imoradi in #74
- Merging Active Sensor and DDA Cloud Coefficients into V3 by @imoradi in #39
- updated internal versioning to be v3.1.0 in preparation for release. by @BenjaminTJohnson in #92
- Add quiet print for CRTM Init by @chengdang in #93
- Feature/cd rts netcdf io by @chengdang in #83
- Feature/btj convert v3 to cmake by @BenjaminTJohnson in #90
- Revert "Feature/btj convert v3 to cmake" by @BenjaminTJohnson in #103
- replace ecbuild with CMake in CRTM by @BenjaminTJohnson in #104

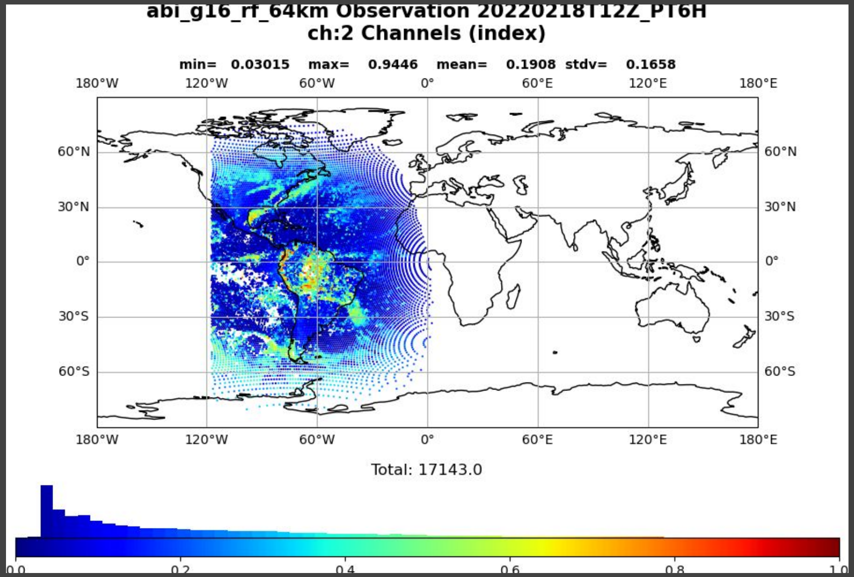
Aerosol Schemes Overview

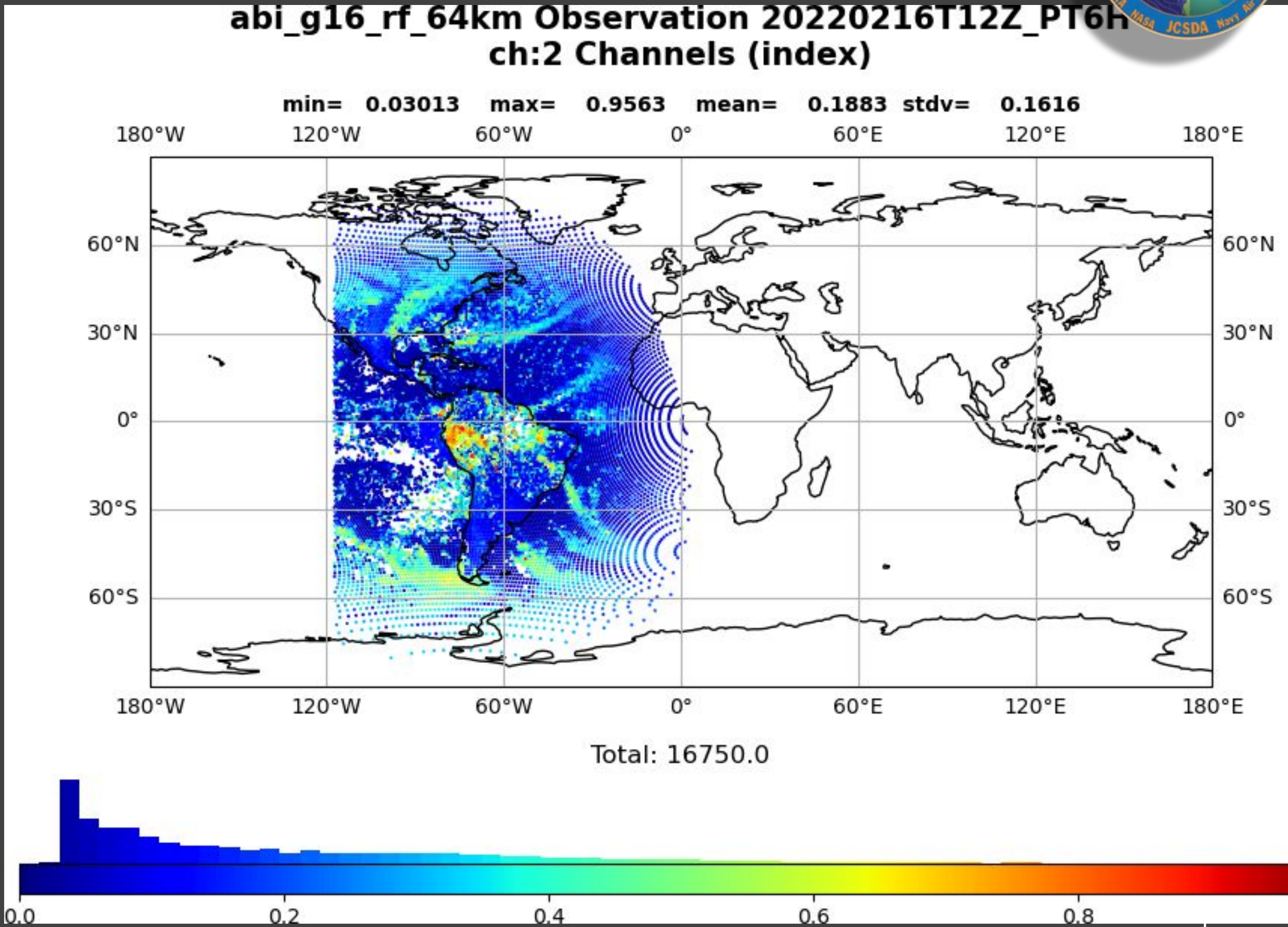
The CRTM team has improved the user interface
by incorporating various aerosol parameters widely used in aerosol modeling over the past few years

CRTM Version	Aerosol model	Aerosol species	Aerosol properties	References
All versions	CRTM (Default)	dust, sea salt, organic carbon, black carbon, sulfate	**effective radius**, **hygroscopicity (implicit)**	Chin et al., 2002; Han, 2006
v2.4 – v3.1 NetCDF	CMAQ	dust, sea salt, water-soluble, soot, sulfate, water, insoluble, dust-like	effective radius, hygroscopicity (implicit), **radius standard deviation**	Binkowski and Roselle, 2003; Liu and Lu 2016
v2.4.1 – v3.1	GOCART -GEOS5	dust, sea salt, organic carbon, black carbon, sulfate, nitrate	effective radius, **hygroscopicity**	Colarco et al., 2010
v2.4.1 – v3.1	NAAPS	Bulk aerosol properties: dust, sea salt, smoke, anthropogenic and biogenic fine particles	hygroscopicity	Lynch et al., 2016
v2.4.1 – v3.1	RTTOV-OPAC RTTOV-CAMS (Internal)	dust, sea salt, organic carbon, black carbon, sulfate, nitrate CAMS: aerosol climatology developed by Copernicus Atmosphere Monitoring Service	effective radius, hygroscopicity	RTTOV v13, https://nwp-saf.eumetsat.int/site/software/rttov/rttov-v13/

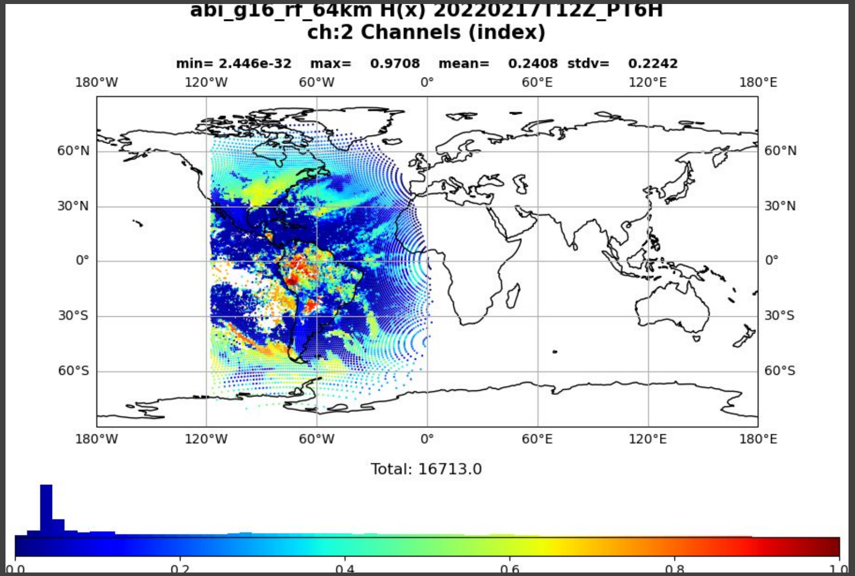
ABI Channel 2 Observed reflectance

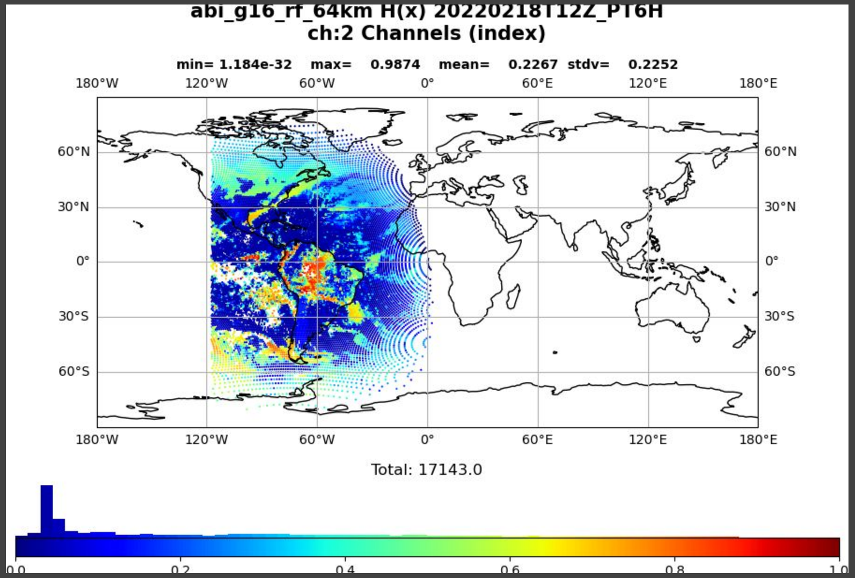


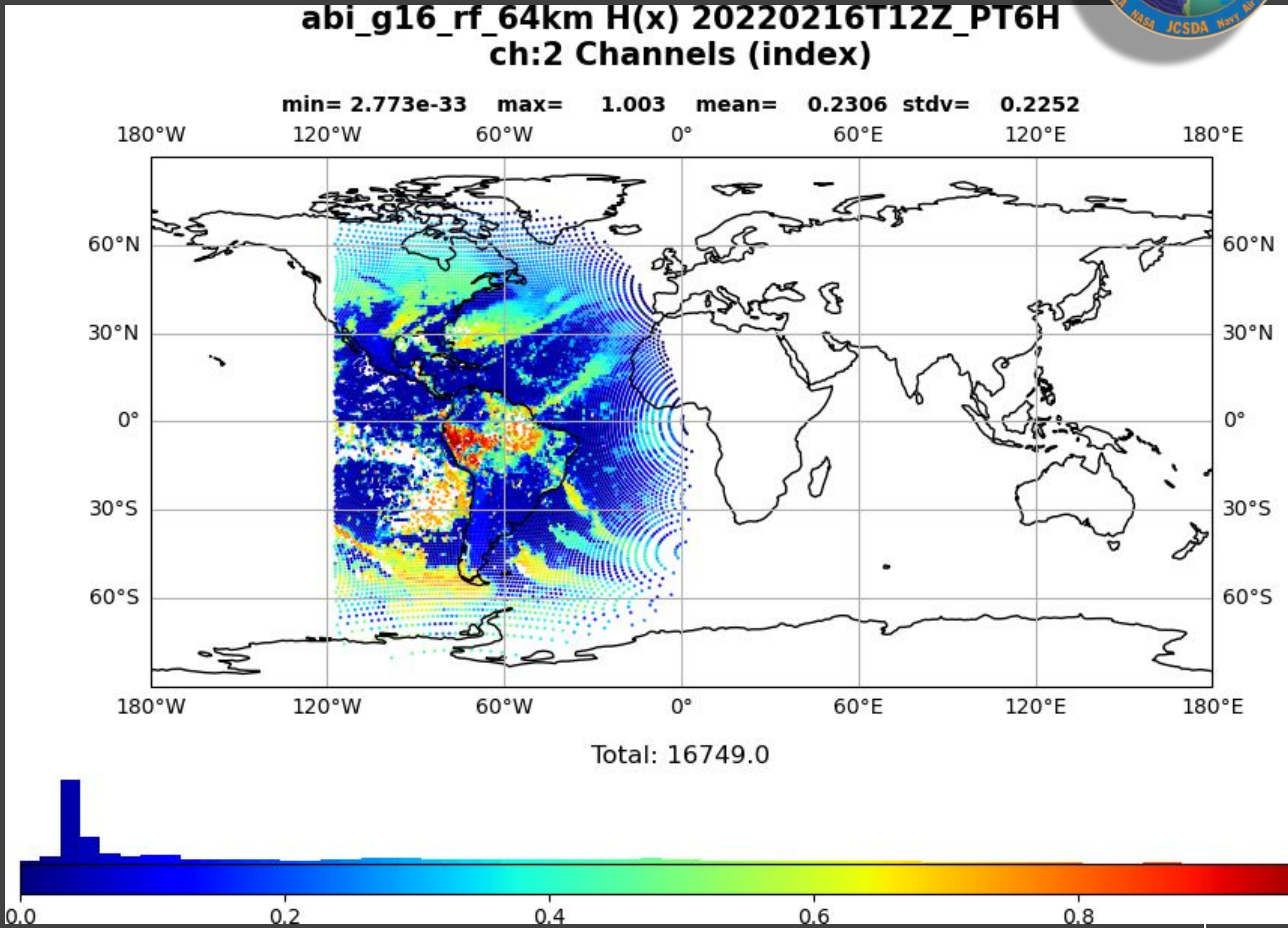




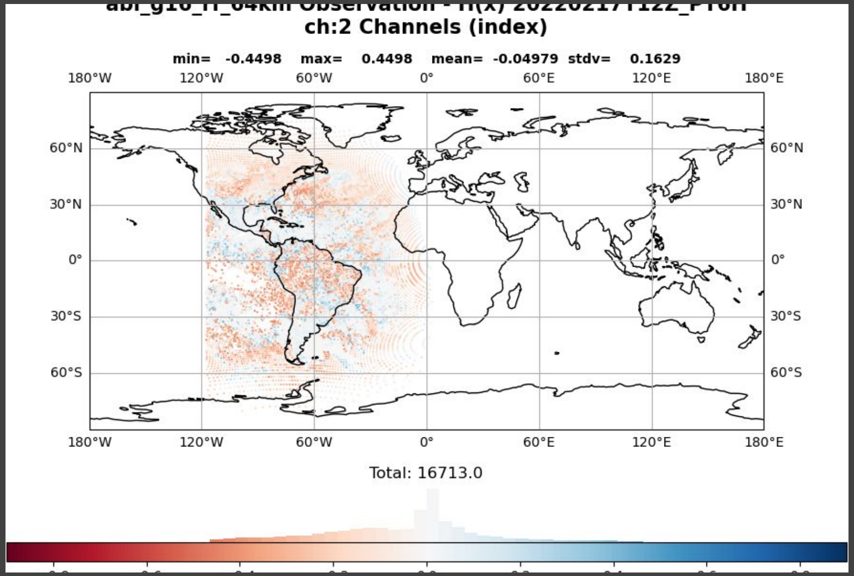
ABI Channel 2 Simulated reflectance

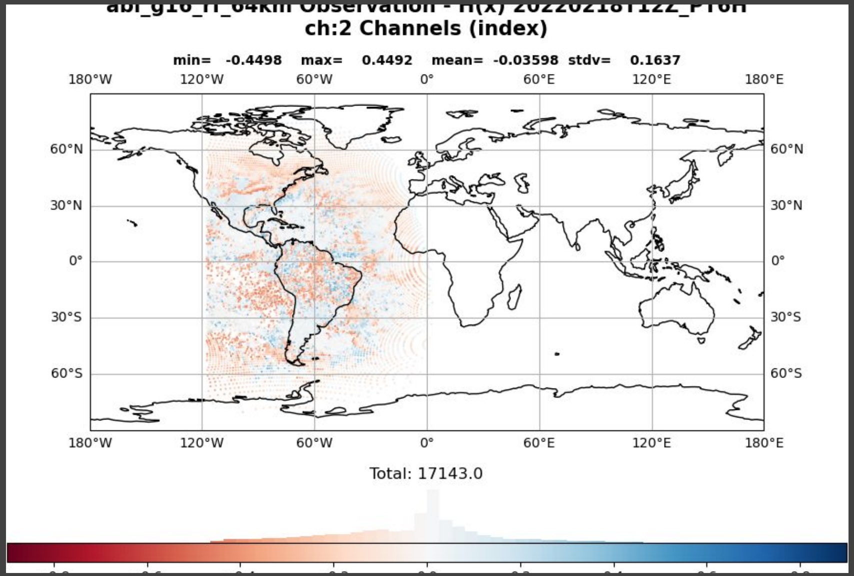


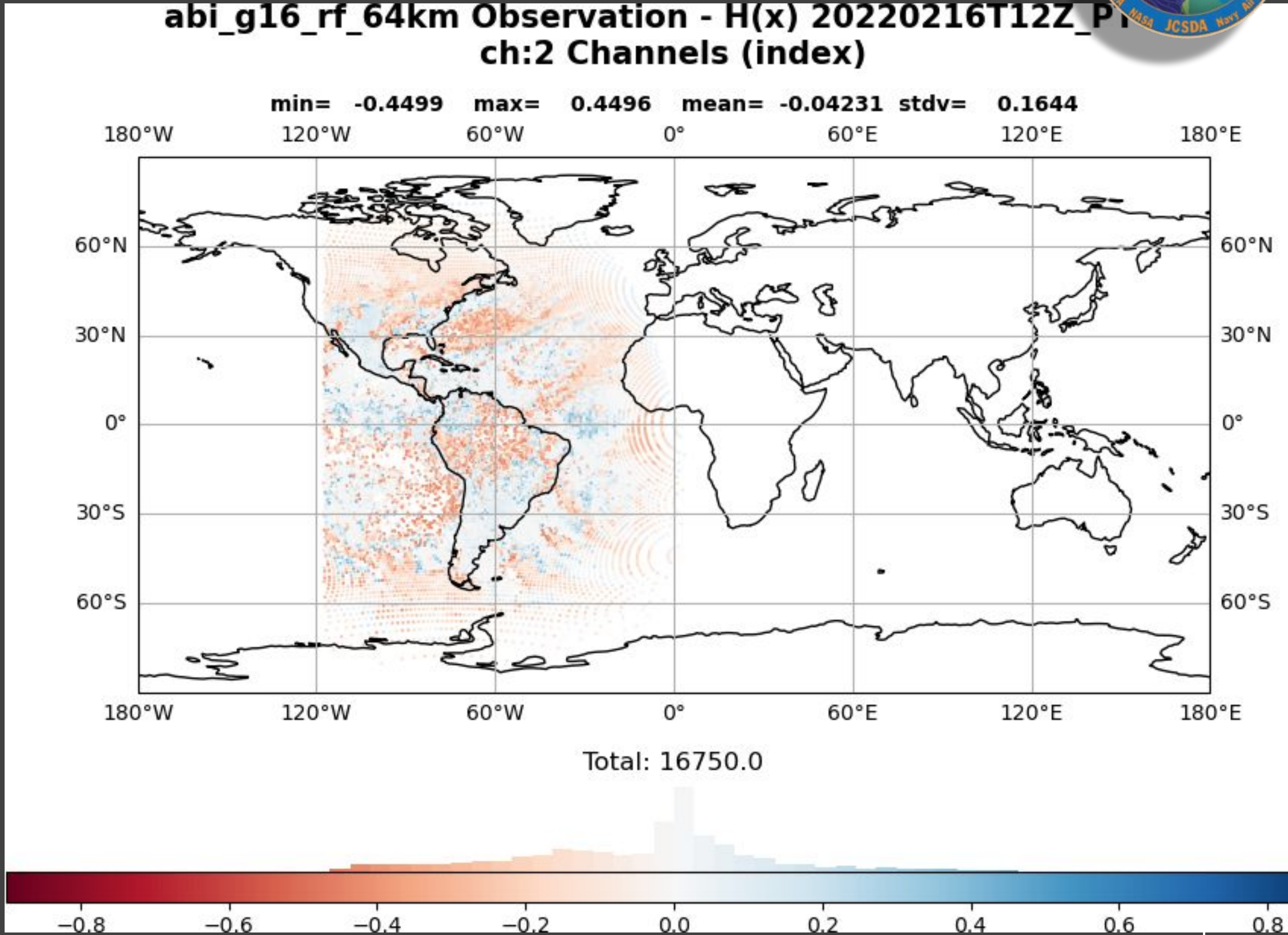




ABI Channel 2 Observed – Simulated (O-B) Reflectance



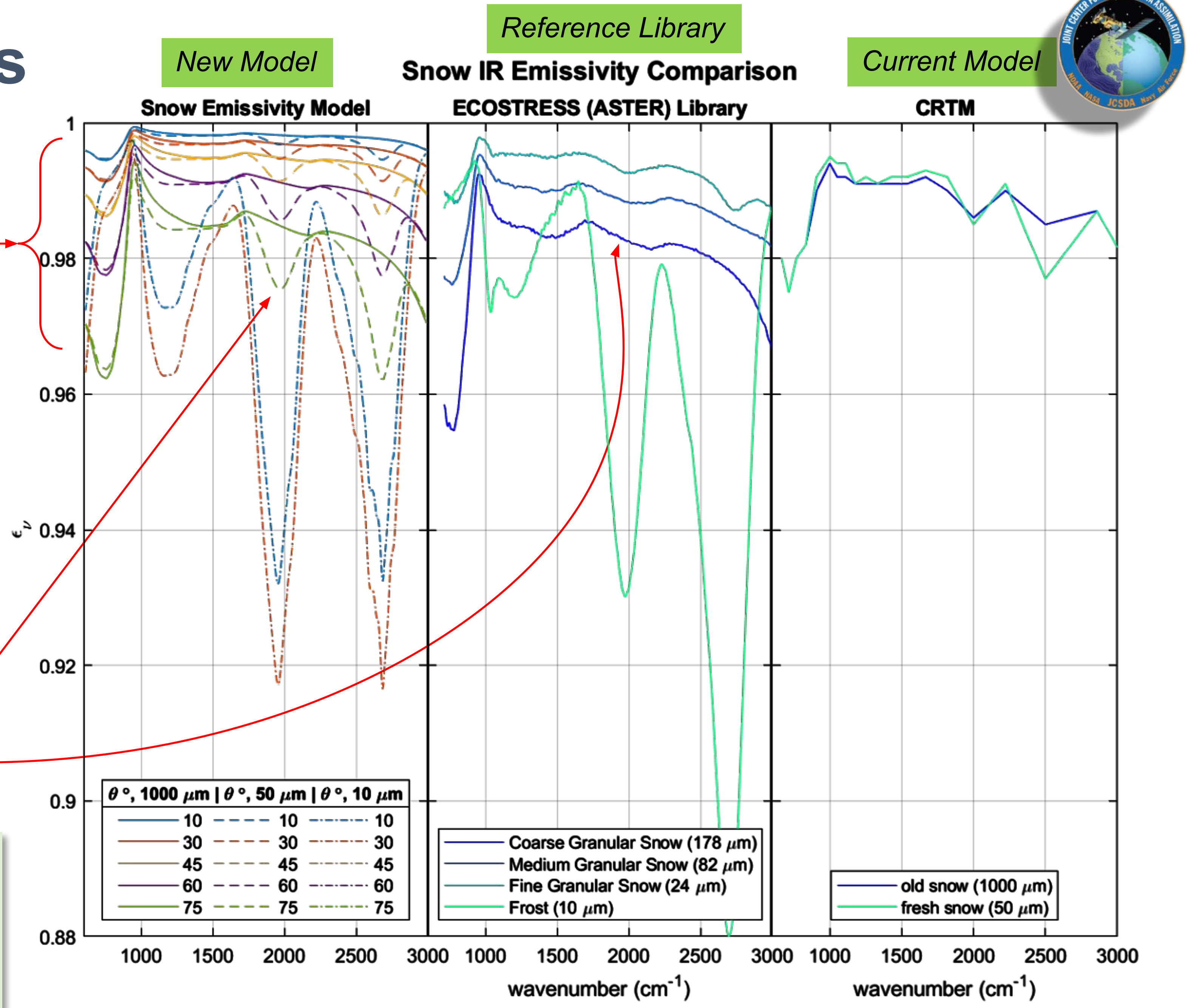




Snow Covered Surfaces Infrared (Nalli)

- **Simplified model (v1.0)**
  - Quasi-infinite optical depth assumption
  - *Warren & Brandt* (2008) optical constants for ice
- Significant **zenith angle dependence** as expected
- However, significant **differences** were seen in the spectral dependence on **particle size** from those

This preliminary model (v1.0) is an implementation
of the Wiscombe & Warren (1980).
A new hybrid model (v1.1) is an extension to the WW80 model that will be an

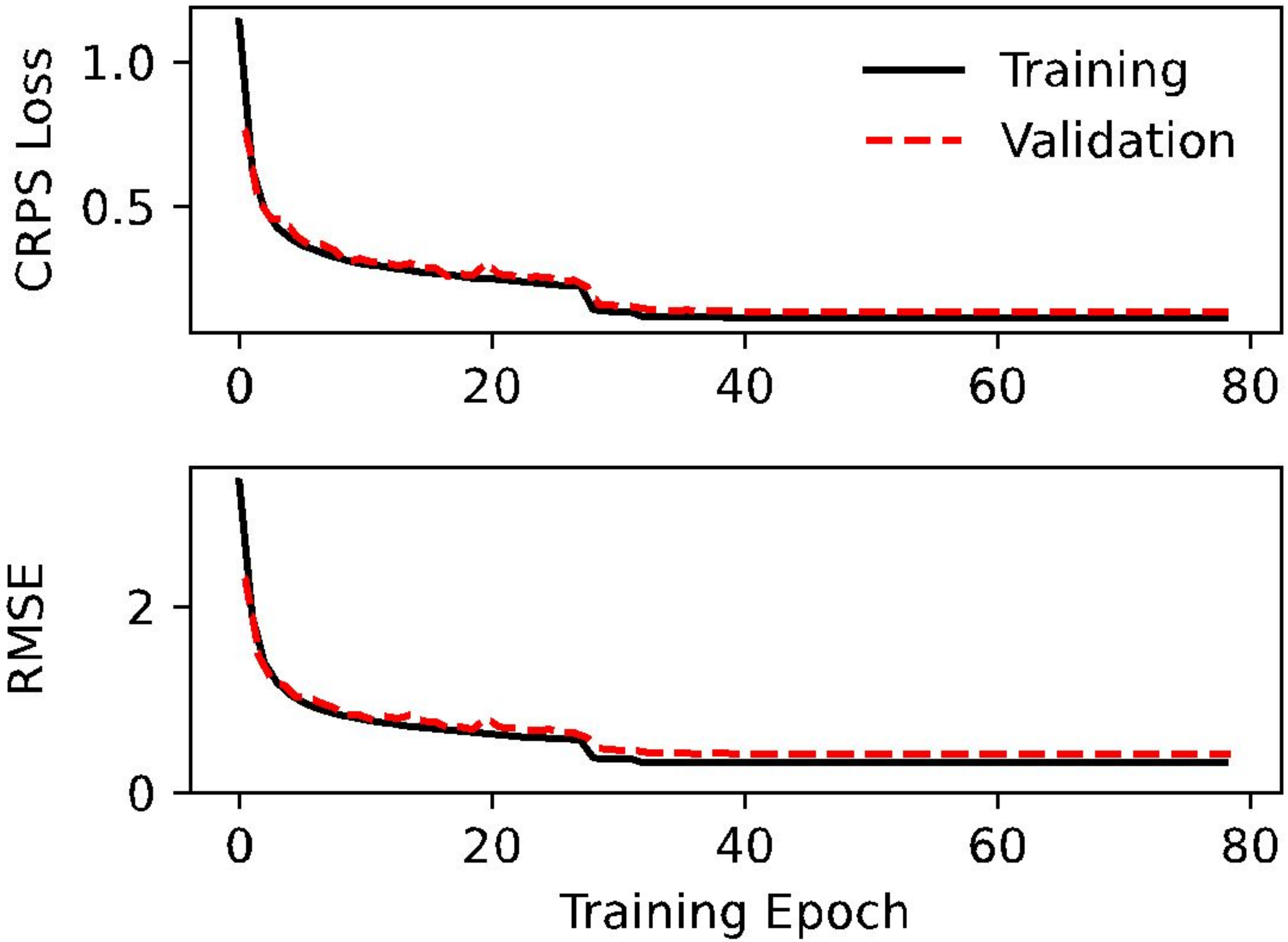


CRTM-AI (Lucas Howard, CU / Greg Thompson, JCSDA)

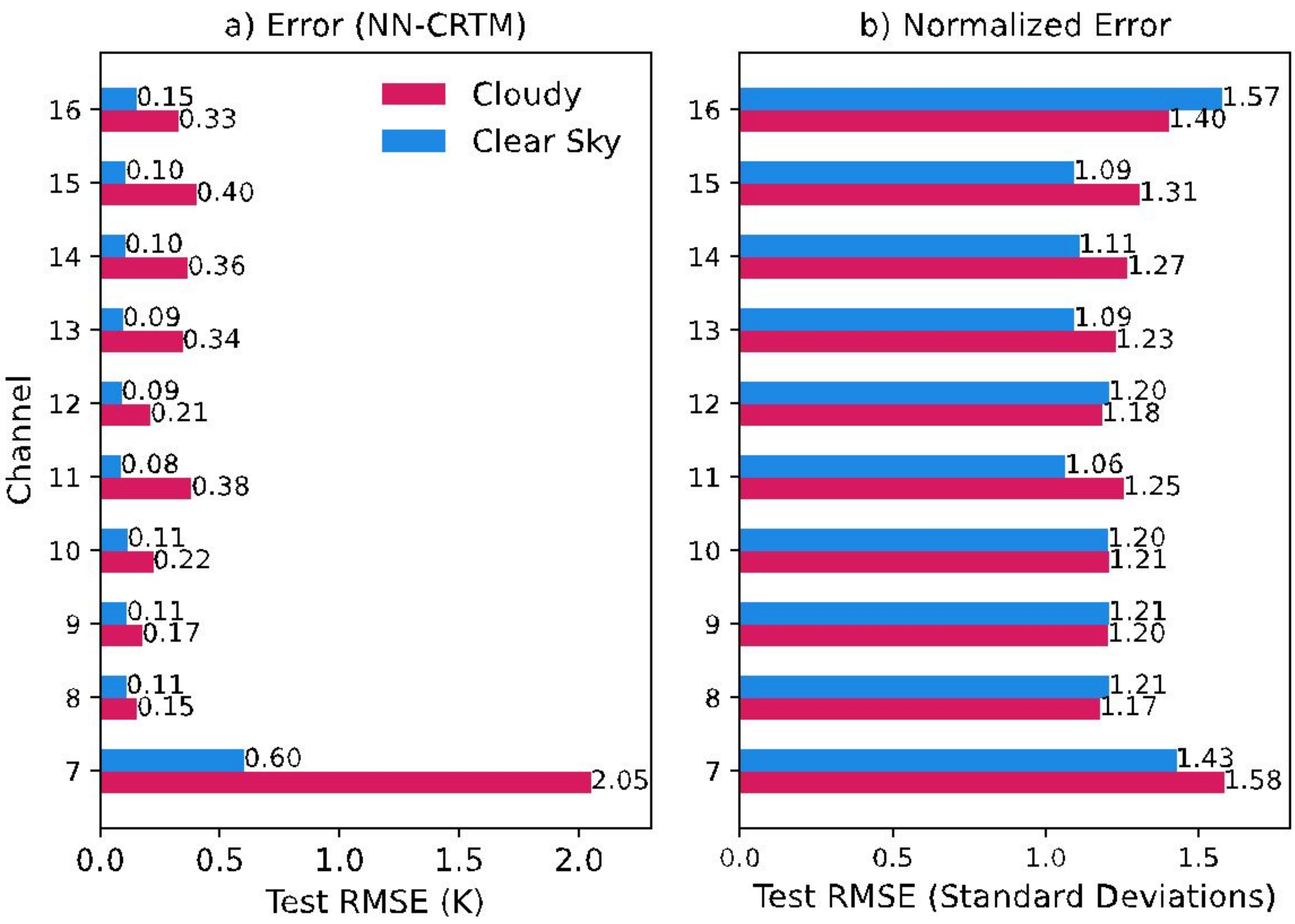
- 3 hidden layers x 512 nodes per layer
  - Some tuning to arrive at this architecture using earlier datasets
  - ~1.1 million trainable parameters
- Input:
  - All CRTM profile, surface, and meta input variables
- Output:
  - Predicted CRTM ABI brightness temperature for channels 7-16
  - Predicted error (NN-CRTM) standard deviation by channel
- Cost function (to be minimized):
  - Continuous rank probability score (CRPS), penalizes inaccuracy and imprecision

Dataset Summary

- 30 days of GOES-17 and GOES-16 scans
  - 6-hr, 64 km resolution
  - Geovals from GFS
  - Bias correction removed for all channels
- Train/Validate/Test split:
  - 151/19/19 scans randomly chosen
  - 3.4E6/4.3E5/4.3E5 data points



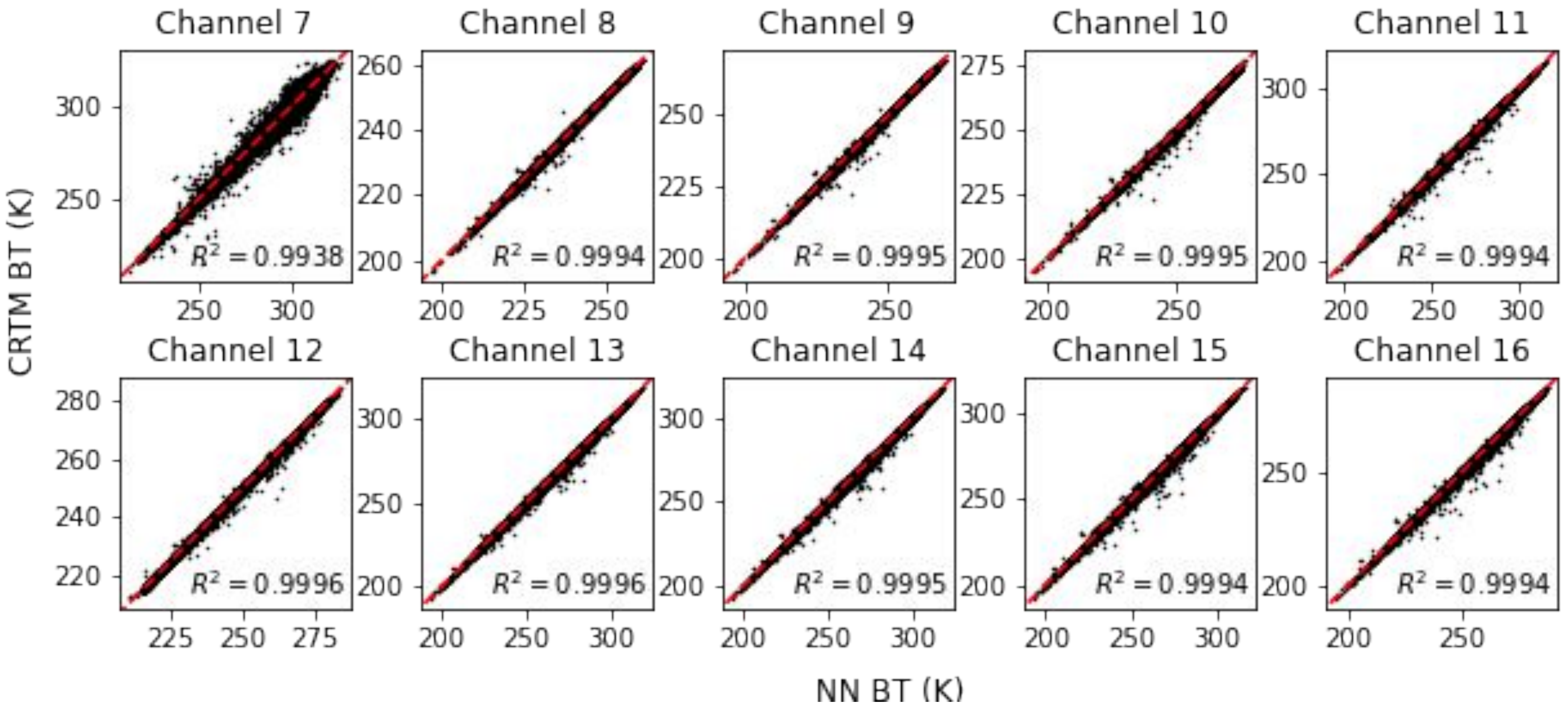
CRTM AI training data and plots courtesy of Lucas Howard, CU-Boulder



CRTM AI training data and plots courtesy of Lucas Howard, CU-Boulder

Normalized error=(NN-CRTM)/predicted error

NN/CRTM Correlation (512 Nodes)



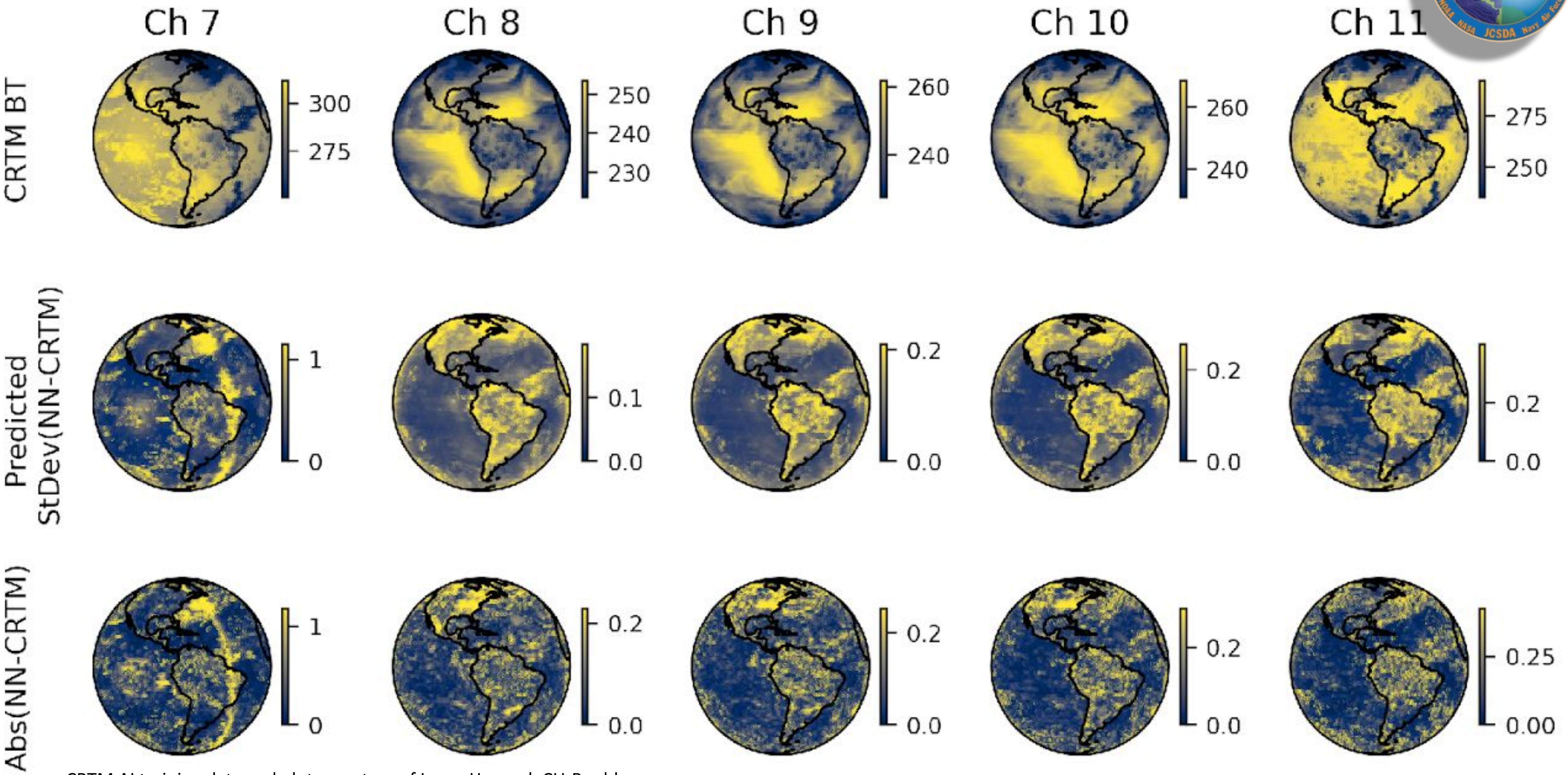
CRTM AI training data and plots courtesy of Lucas Howard, CU-Boulder

Channel	Mean (NN-CRTM) (K)	StDev(NN-CRTM) (K)
7	-0.023	1.8
8	0.018	0.14
9	0.018	0.16
10	0.000059	0.20
11	0.0020	0.34
12	0.0016	0.19
13	0.0012	0.31
14	0.0022	0.33
15	0.0034	0.36
16	0.013	0.30

Evaluated on test data withheld from training

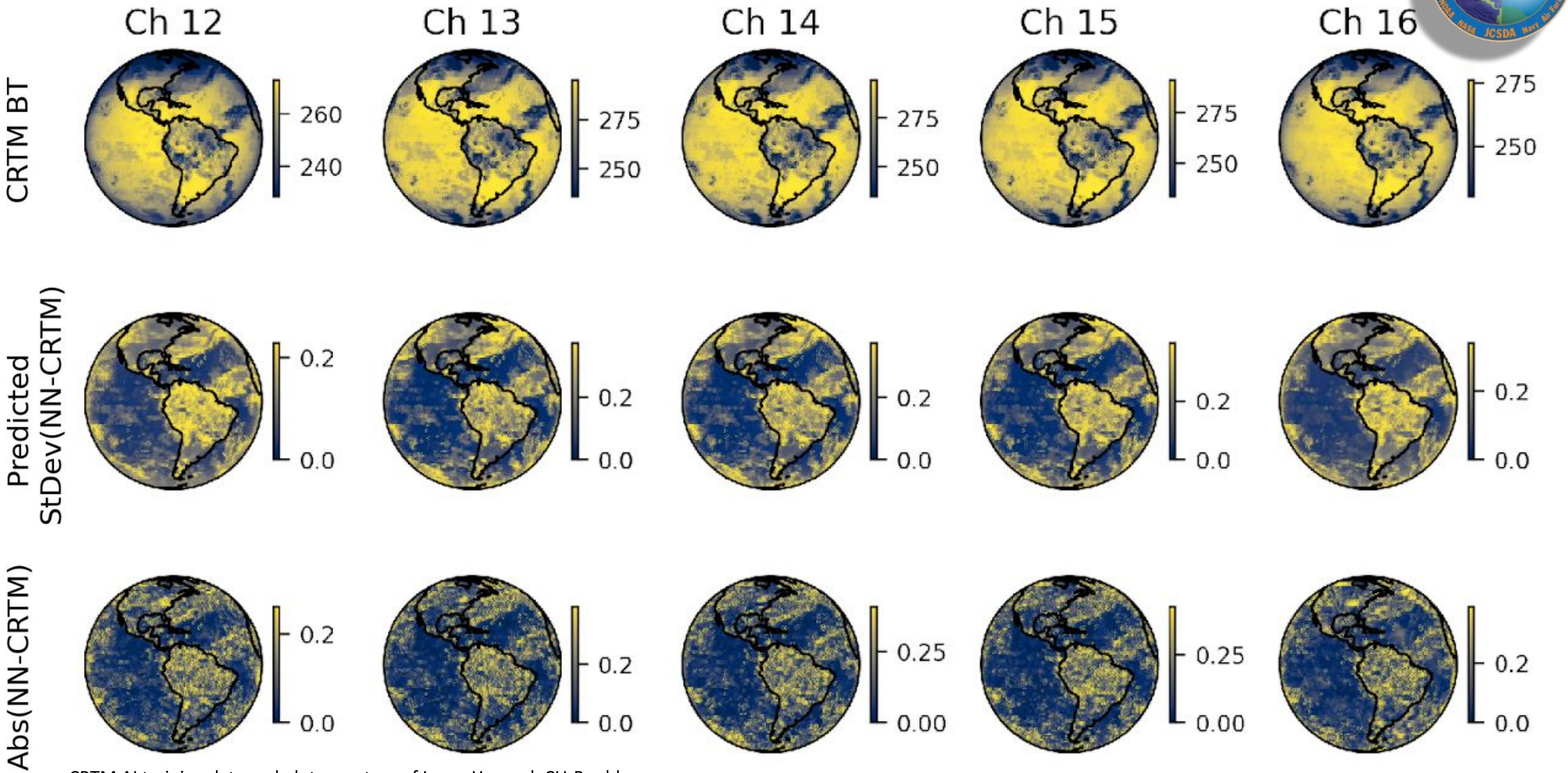
CRTM AI training data and plots courtesy of Lucas Howard, CU-Boulder

Figure 4a



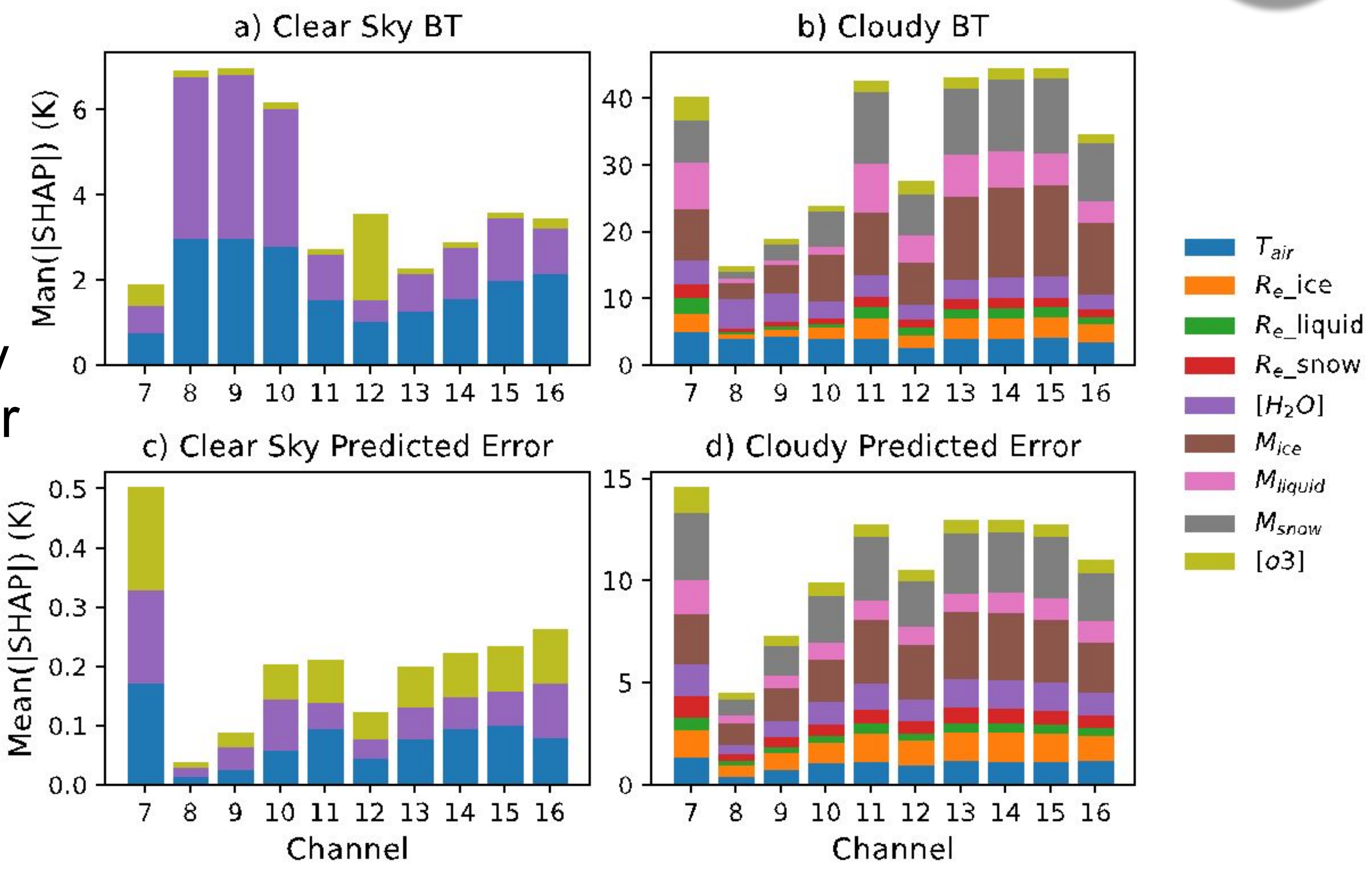
CRTM AI training data and plots courtesy of Lucas Howard, CU-Boulder

Figure 4b



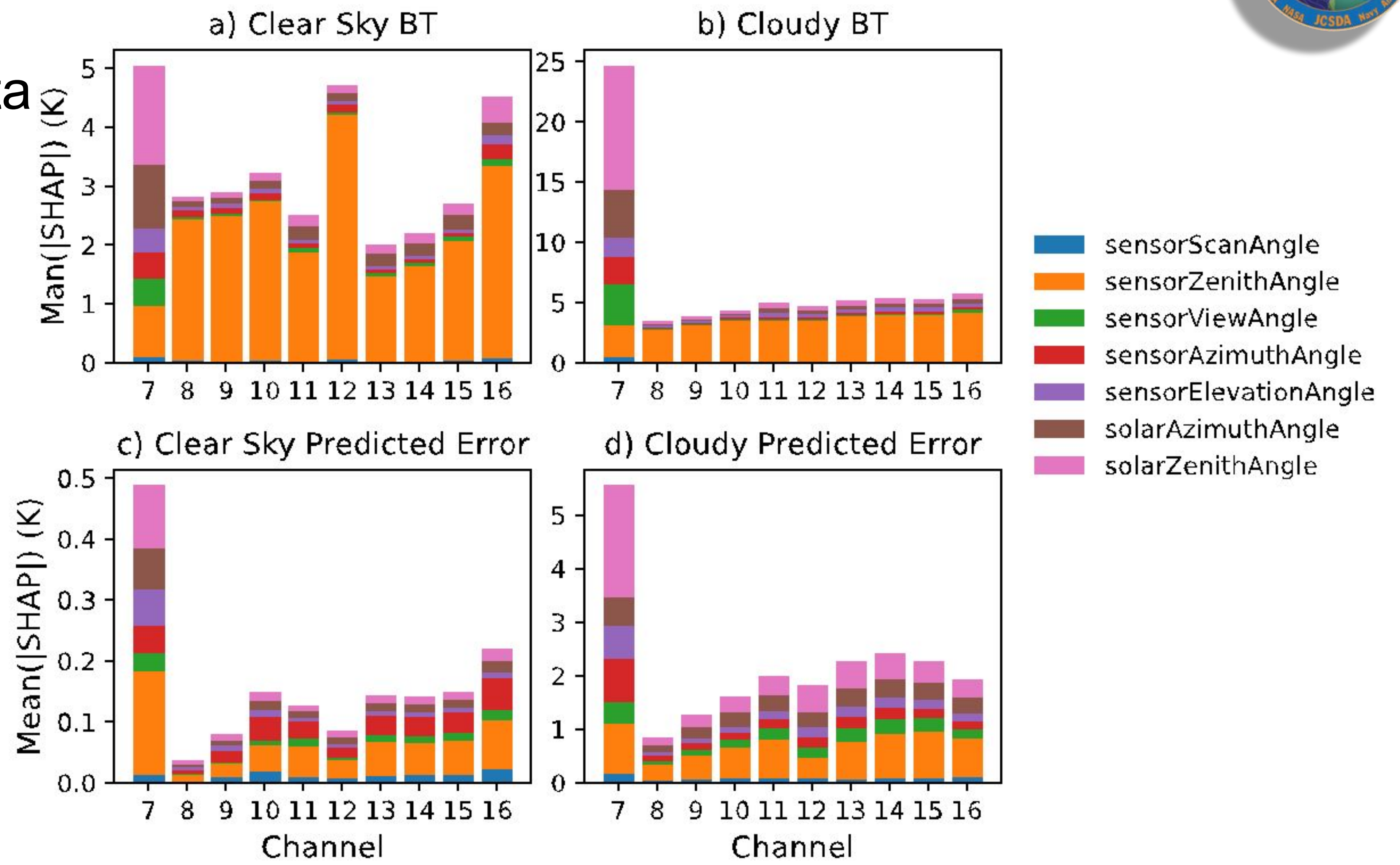
CRTM AI training data and plots courtesy of Lucas Howard, CU-Boulder

- Impact of all atmospheric variables on all channels
- Summed vertically and averaged over samples



CRTM AI training data and plots courtesy of Lucas Howard,

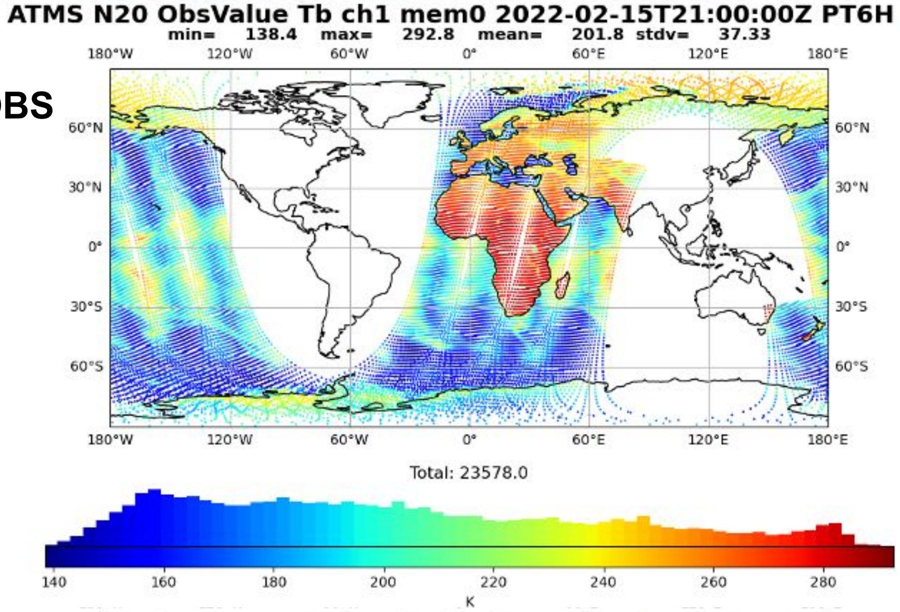
- Impact of all meta variables on all channels



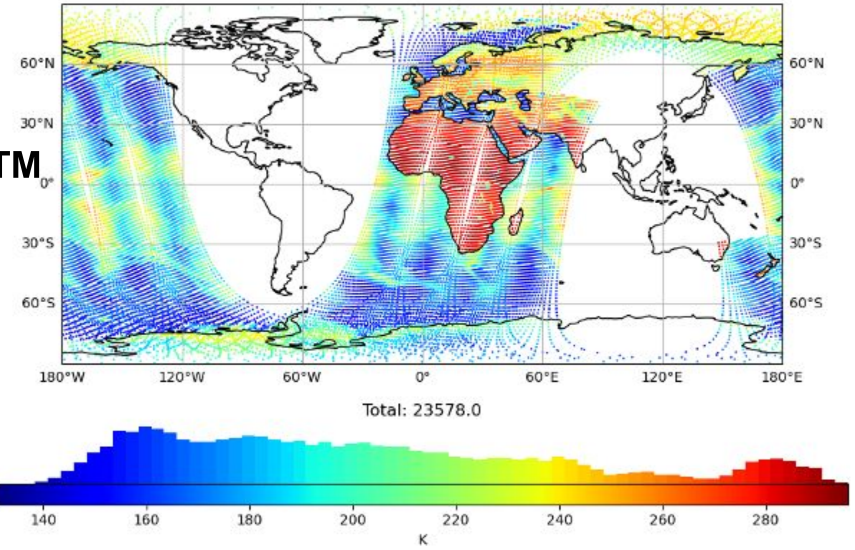
CRTM AI training data and plots courtesy of Lucas Howard,

Skylab 4.0, CRTM v2.4 ATMS N20 Ch1

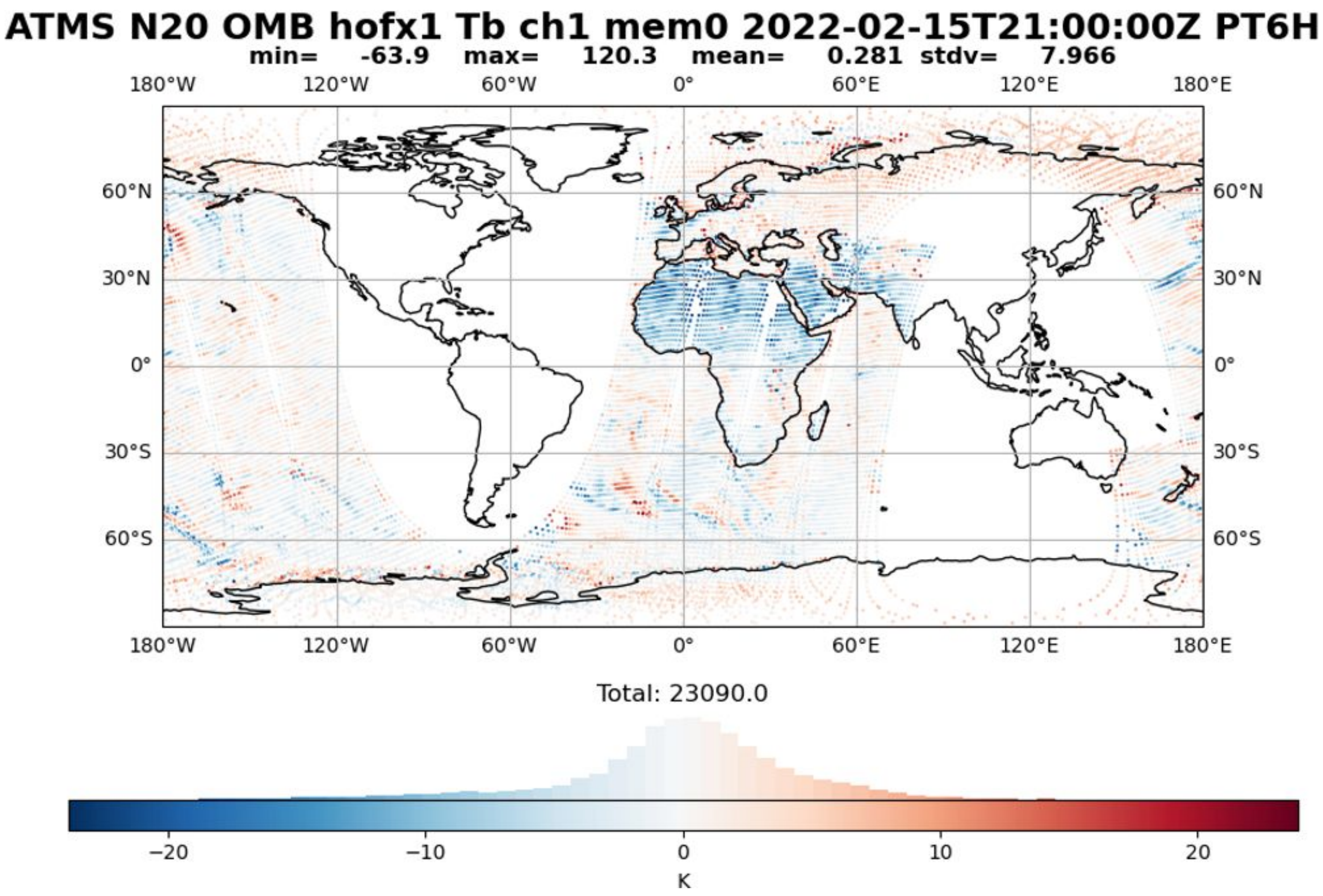
OBS



SIM CRTM

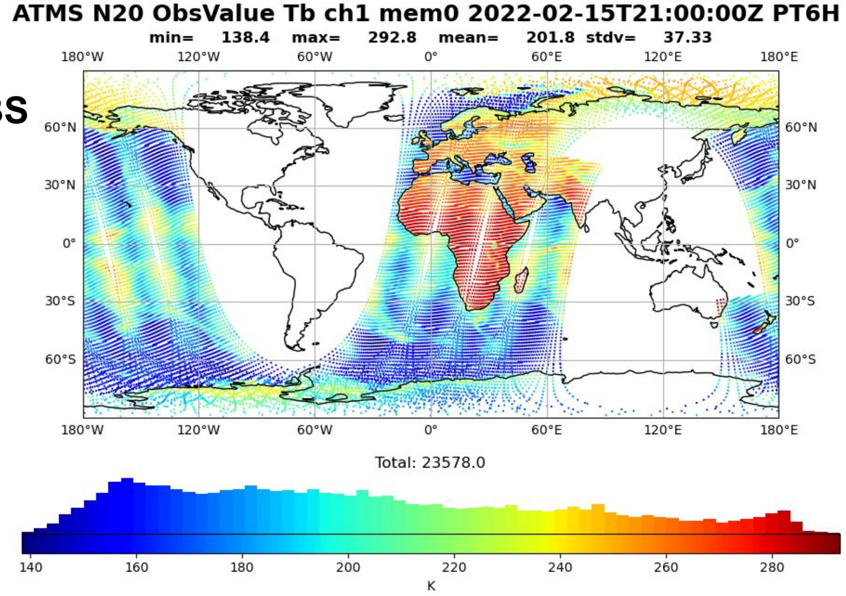


OBS – CRTM

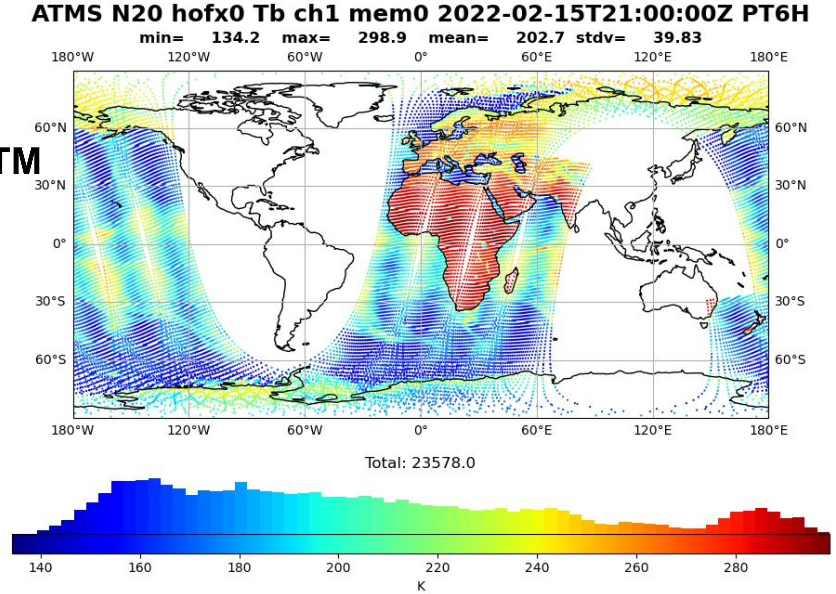


Skylab 6.0, CRTM v3.0 ATMS N20 Ch1

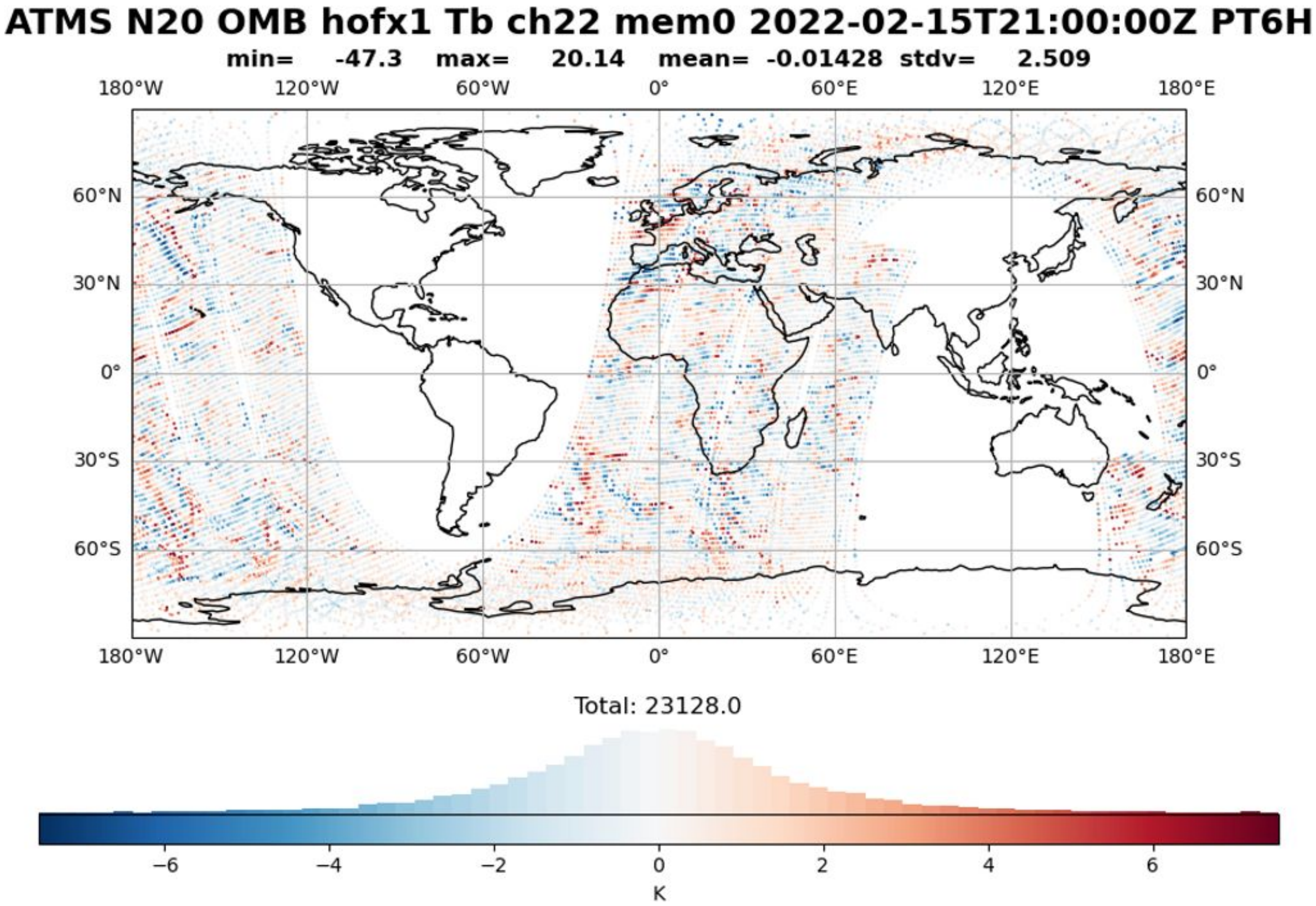
OBS



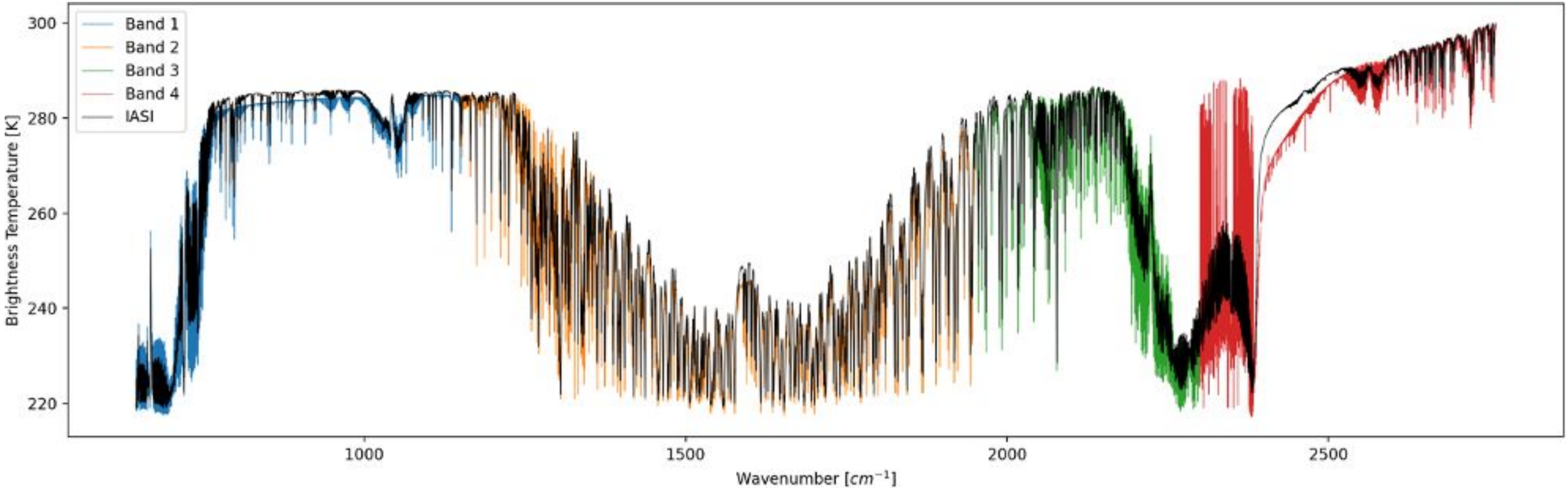
SIM CRTM



OBS – CRTM



Coefficient Generation: IASI-NG example



Future

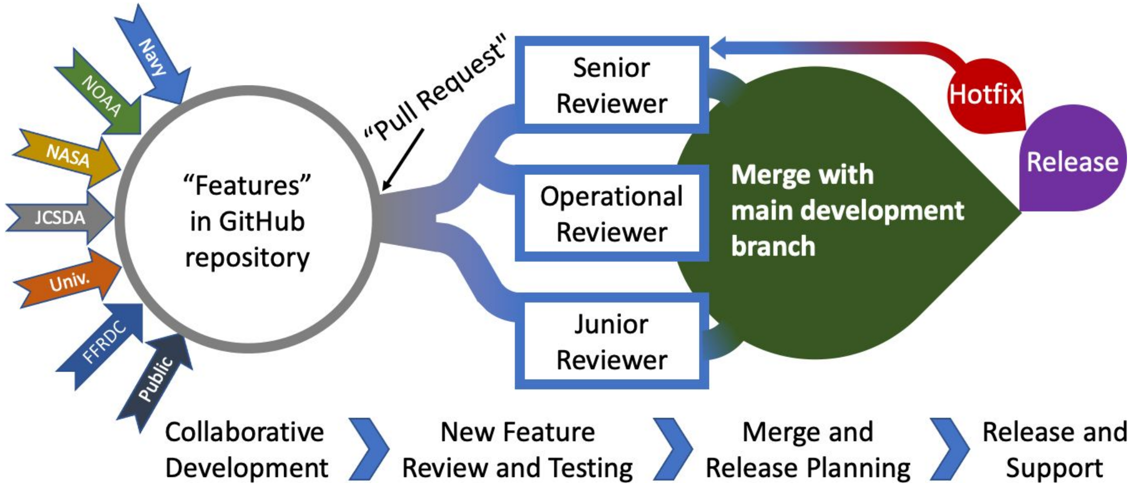
- PCRTM (X. Liu) implementation in CRTM enable PC-score based forward operator
  - Hyperspectral support
- Updates to all surface emissivity models
  - PARMIO -> fast model
  - CAMEL v3 emissivity
  - surface reflectance databases in support of UV/VIS
  - full BRDF support where available
  - updated snow emissivity (N. Nalli)
- Improvements to interface enable generic optical properties inputs
- AI/ML: continue to develop and test for transparent operational implementation
- Linear polarization, multi-angle, multiple scattering extensions to existing active radar
- Active Lidar

Thank you!

Sign up for our mailing list!
JCSDA: https://www.jcsda.org/

Code access

- Skylab releases: https://www.jcsda.org/jediskylab
- CRTM repository: https://github.com/JCSDA/CRTMv3



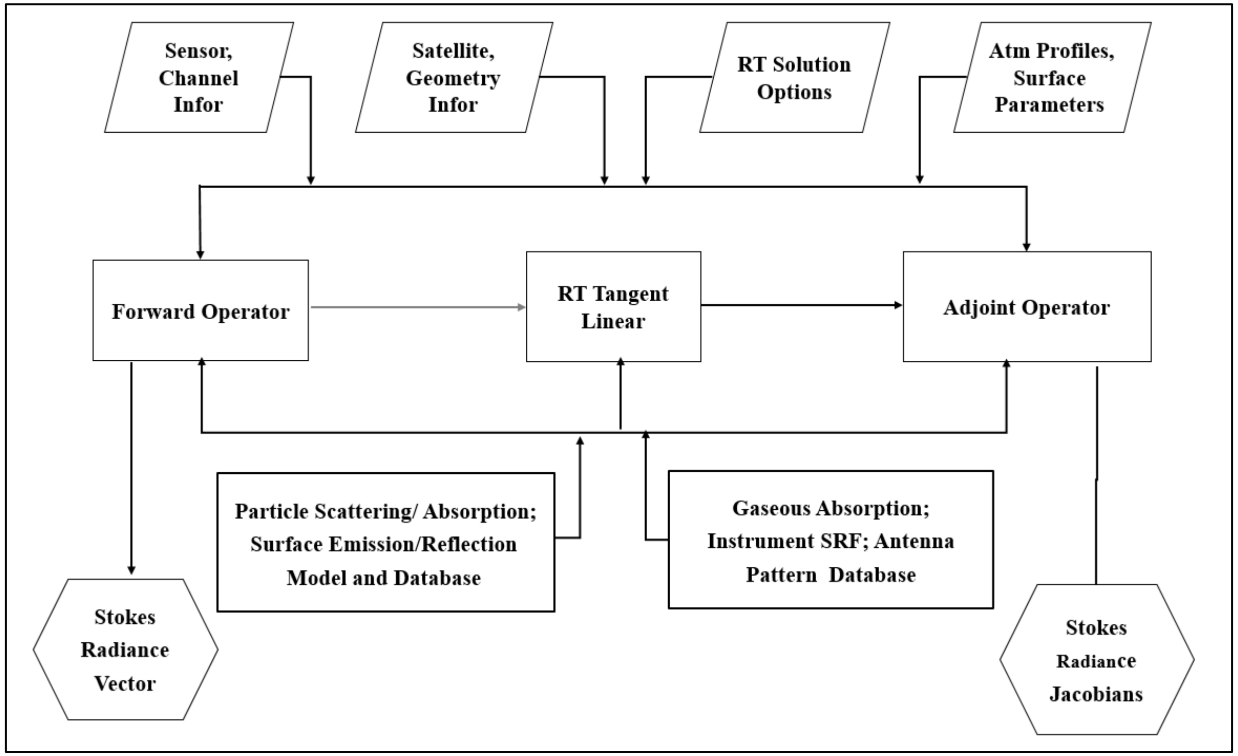
Update on Advanced Radiative Transfer Modeling System (ARMS)

CMA Earth System Modeling and Prediction Centre

ITSC NWP Working Group Summer Meeting, July 10, 2024

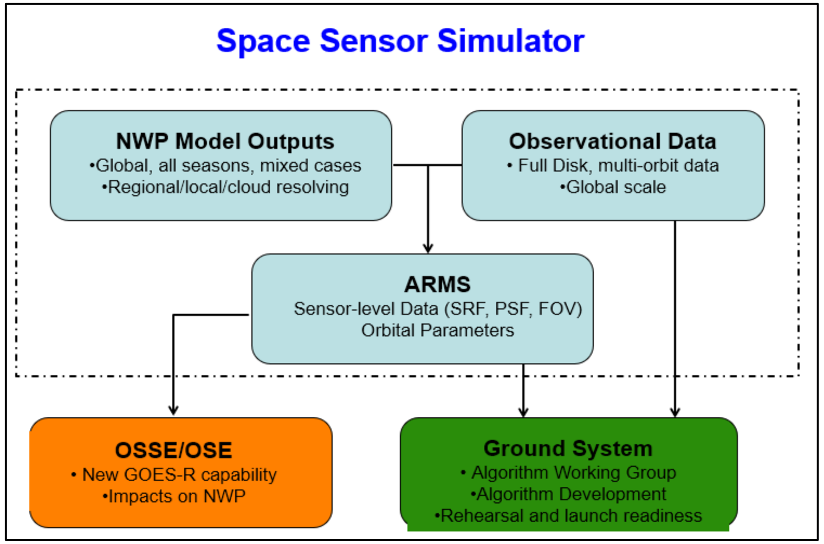
ARMS Version 1.2

- **Atmospheric gaseous absorption**
  - Band absorption coeff trained by LBL spectroscopy data with sensor response functions
  - Variable gases (e.g. H2O, CO2, O3, SO2) .
  - Zeeman splitting effects near 60 GHz
- **Cloud/precipitation scattering and emission**
  - Fast LUT optical models at all phases including non-spherical ice particles
  - Gamma size distributions
- **Aerosol scattering and emission**
  - Types: dust, sea salt, organic/black carbon
  - Lognormal distributions
- **Surface emissivity/reflectivity**
  - Two-scale ocean emissivity model （FASTEM）
  - Geometrical optics for infrared ocean emissivity
  - Land microwave emissivity model
  - Land infrared emissivity data bases
- **Radiative transfer schemes**
  - Vector Discrete Ordinate Radiative Transfer (VDISORT)
  - Polarization Two-Stream Approximation (P2S)
  - Advanced Doubling and Adding (ADA)

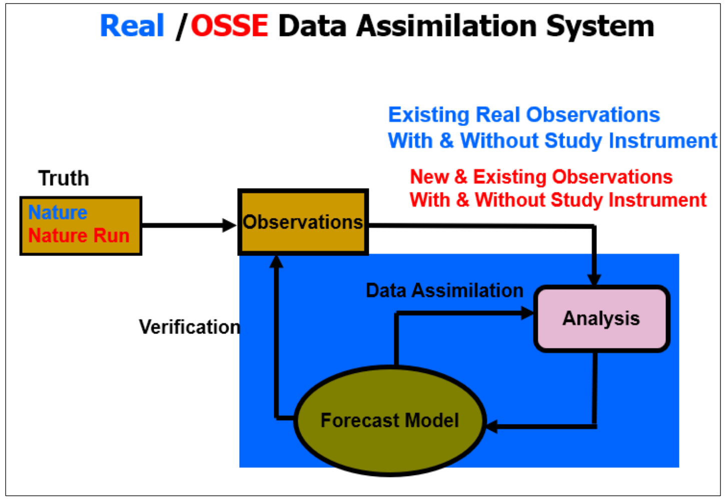


Weng, F., X. Yu, Y. Duan, J. Yang, and J. Wang, 2020: Advanced Radiative Transfer Modeling System (ARMS): A new-generation satellite observation operator developed for numerical weather prediction and remote sensing applications. Adv. Atmos. Sci., 37(2), https://doi.org/10.1007/s00376-019-9170-2

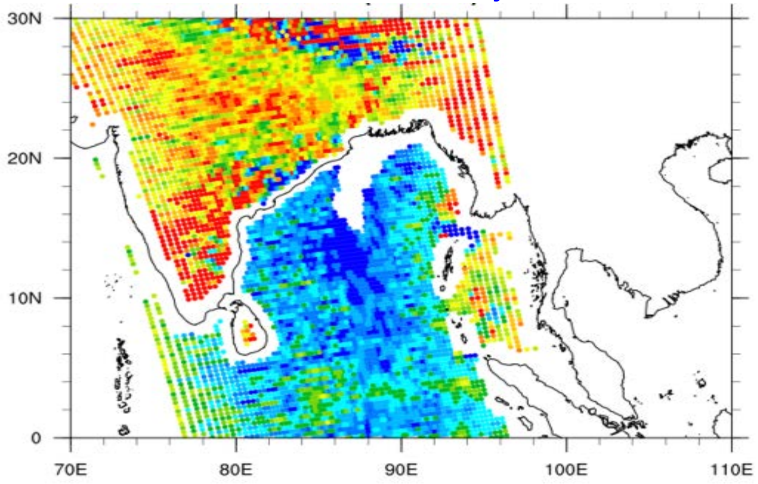
ARMS Major Applications in CMA

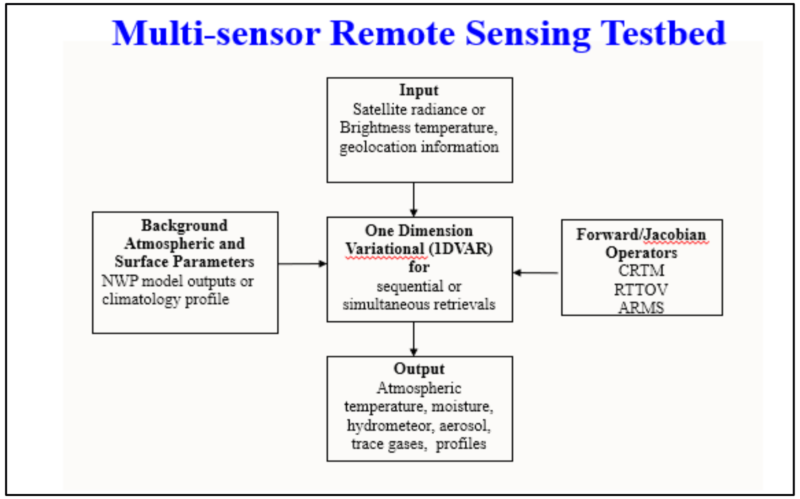


- Space Sensor Simulation
- Instrument Calibration
- Remote Sensing Algorithm
- Product Validation
- Data Assimilation

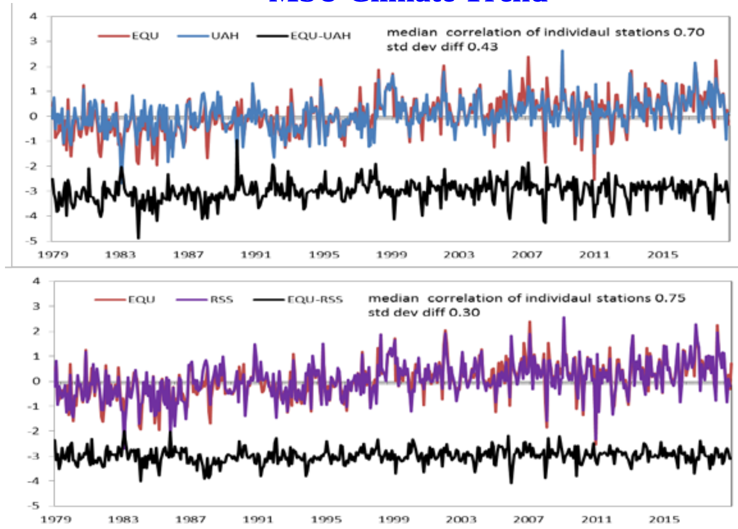


MWTS Anomaly

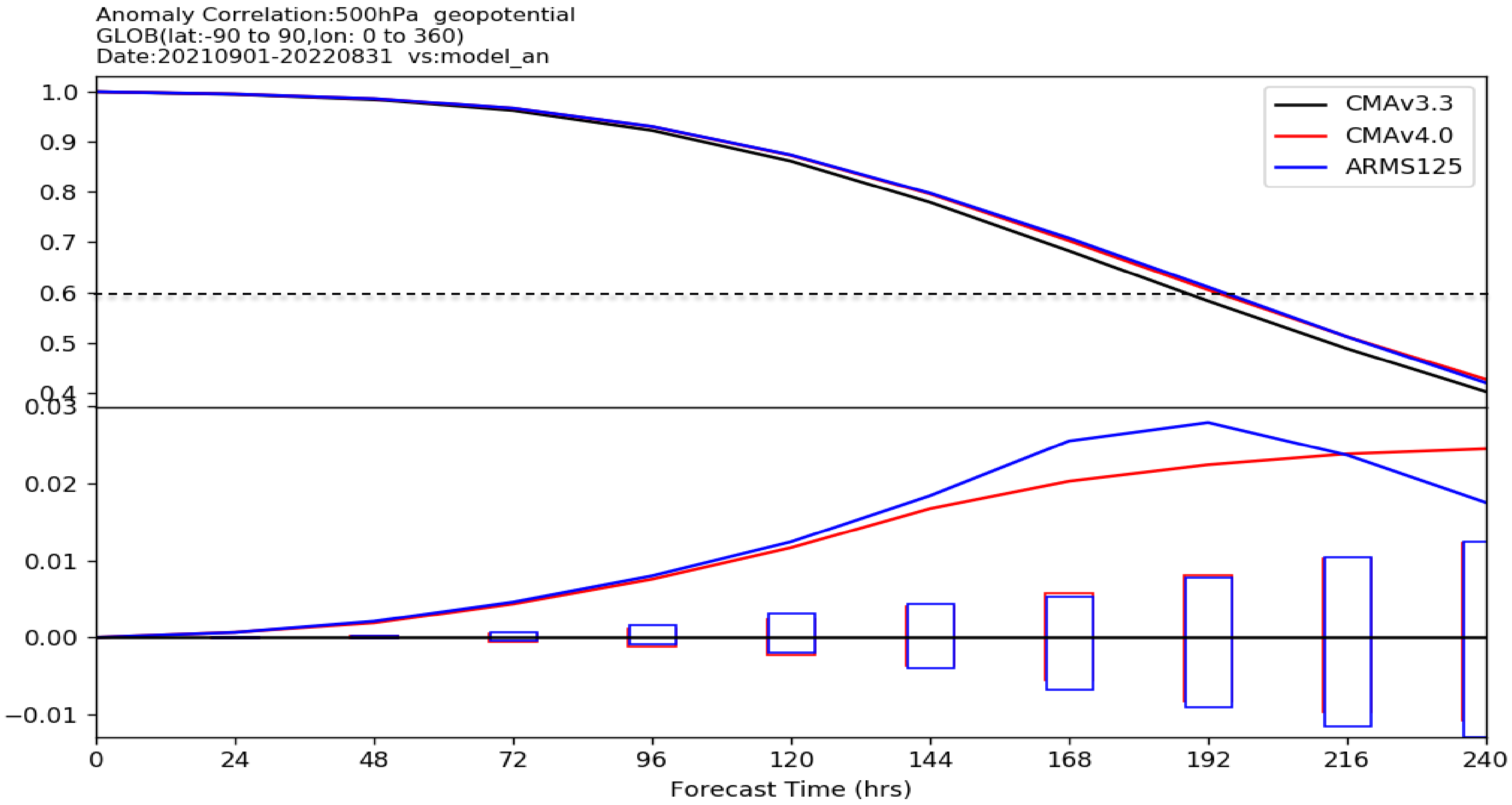




MSU Climate Trend



Evaluation of ARMS Performance in CMA-GFS



Comparing with CMA GFS V3.3 (25km resolution), uses of ARMS in CMA GFS4.0 results in significant increases in 500 hPa ACC. ARMS performance is better than RTTOV upper to 8 days of forecasts

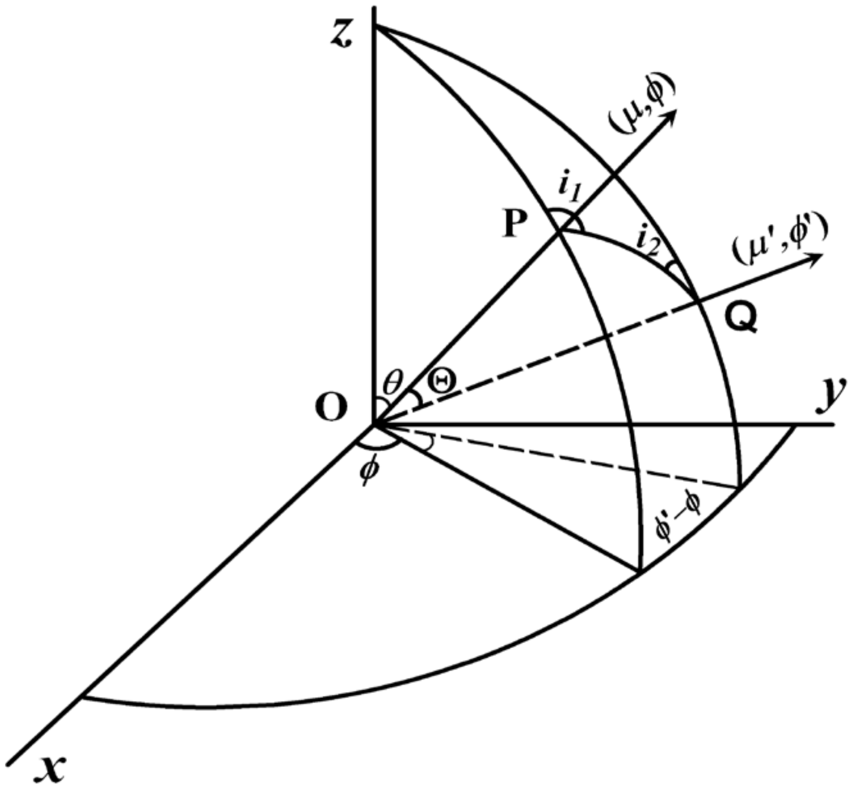
Major Updates of ARMS 1.5

- **Gaseous Absorption**
  - ✓ **SO2 in training infrared hyperspectral transmittance**
  - ✓ **User selections of simulating apodized and un-apodized radiances**
  - ✓ **New NLTE models for early morning satellite**
  - ✓ **SRF-based atmospheric transmittance models for MW sounders (TU1.R9.3, Hu et al; TUPA.90, Han et al.)**
  - ✓ **O3 and N2 for microwave transmittance training**
- **Microwave Land Emissivity**
  - **New permittivity models for microwave land emissivity models**
  - **1DVAR FY-3D MWRI emissivity data base (TUPA.PA.87, Tan et al.)**
- **Non-spherical particle scattering LUT using DDA**
- **ARMS Capabilities for Ground-Based Microwave Radiometer (TUPA.91, Shi etal)**
- **A Vector Radiative Transfer Solver**
  - **Advanced Vector Discrete Ordinate Radiative Transfer （VDISORT） Scheme**
  - **Passive and Active Scattering and Emission Model over Ocean (FR3.R11, Wen etal)**

Vector Radiative Transfer Equation

$$\mu \frac{d\boldsymbol{I}(\tau,\mu,\phi)}{d\tau} = \boldsymbol{I}(\tau,\mu,\phi) - \frac{\omega(\tau)}{4\pi}\int_0^{2\pi} d\phi' \int_{-1}^{1} \boldsymbol{M}(\tau,\mu,\phi;\mu',\phi')\boldsymbol{I}(\tau,\mu',\phi')d\mu' - \boldsymbol{Q}(\tau,\mu,\phi)$$

$$\boldsymbol{Q}(\tau,\mu,\phi) = \frac{\omega(\tau)}{4\pi}\boldsymbol{M}(\tau,\mu,\phi;-\mu_0,\phi_0)\boldsymbol{S}_b \exp(-\tau/\mu_0) + (1-\omega(\tau))\boldsymbol{S}_t(\tau)$$



where $\left(I_l, I_r, I_u, I_v\right)^T$

$$\mathbf{M} = \mathbf{L}(\pi - i_2)\mathbf{S}(\Theta)\mathbf{L}(-i_1)$$

$$\mathbf{S} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

For spherical particle:

$$\mathbf{S} = \begin{bmatrix} S_{11} & 0 & 0 & 0 \\ 0 & S_{22} & 0 & 0 \\ 0 & 0 & S_{33} & S_{34} \\ 0 & 0 & -S_{34} & S_{33} \end{bmatrix}$$

Assumption on Phase Matrix Properties

$$\boldsymbol{I}(\tau,\mu,\phi)=\sum_{m=0}^{2N-1}\left\{\boldsymbol{I}_m^c(\tau,\mu)\cos m(\phi_0-\phi)+\boldsymbol{I}_m^s(\tau,\mu)\sin m(\phi_0-\phi)\right\}$$

$$\boldsymbol{M}(\tau,\mu,\phi;\mu',\phi')=\sum_{m=0}^{2N-1}\left\{\boldsymbol{M}_m^c(\tau,\mu,\mu')\cos m(\phi'-\phi)+\boldsymbol{M}_m^s(\tau,\mu,\mu')\sin m(\phi'-\phi)\right\}$$

with Mie Scattering:

$$\boldsymbol{M}_m^c(\tau,\mu,\mu')=\begin{pmatrix}\boldsymbol{M}_{m,11}^c & \boldsymbol{0}_{2*2}\\ \boldsymbol{0}_{2*2} & \boldsymbol{M}_{m,22}^c\end{pmatrix},\quad \boldsymbol{M}_m^s(\tau,\mu,\mu')=\begin{pmatrix}\boldsymbol{0}_{2*2} & \boldsymbol{M}_{m,12}^s\\ \boldsymbol{M}_{m,21}^s & \boldsymbol{0}_{2*2}\end{pmatrix}$$

This approach is also applicable for randomly oriented non-spherical scattering!

Old Vector Discrete-Ordinate Radiative Transfer (VDISORT) Scheme

$$\mu\frac{d}{d\tau}\begin{pmatrix} \boldsymbol{I}^{c}_{m,lr}(\tau,\mu_s) \\ \boldsymbol{I}^{c}_{m,uv}(\tau,\mu_s) \\ \boldsymbol{I}^{s}_{m,lr}(\tau,\mu_s) \\ \boldsymbol{I}^{s}_{m,uv}(\tau,\mu_s) \end{pmatrix} = \begin{pmatrix} \boldsymbol{I}^{c}_{m,lr}(\tau,\mu_s) \\ \boldsymbol{I}^{c}_{m,uv}(\tau,\mu_s) \\ \boldsymbol{I}^{s}_{m,lr}(\tau,\mu_s) \\ \boldsymbol{I}^{s}_{m,uv}(\tau,\mu_s) \end{pmatrix} - \begin{pmatrix} \boldsymbol{Q}^{c}_{m,lr}(\tau,\mu_s) \\ \boldsymbol{Q}^{c}_{m,uv}(\tau,\mu_s) \\ \boldsymbol{Q}^{s}_{m,lr}(\tau,\mu_s) \\ \boldsymbol{Q}^{s}_{m,uv}(\tau,\mu_s) \end{pmatrix} -$$

$$\sum_{j=-(N+1),\, j\neq 0}^{N+1}\left\{\begin{pmatrix} c_1\boldsymbol{M}^{c}_{m,11}(\tau,\mu_s,\mu_j) & c_1\boldsymbol{M}^{c}_{m,12}(\tau,\mu_s,\mu_j) & -c_2\boldsymbol{M}^{s}_{m,11}(\tau,\mu_s,\mu_j) & -c_2\boldsymbol{M}^{s}_{m,12}(\tau,\mu_s,\mu_j) \\ c_1\boldsymbol{M}^{c}_{m,21}(\tau,\mu_s,\mu_j) & c_1\boldsymbol{M}^{c}_{m,22}(\tau,\mu_s,\mu_j) & -c_2\boldsymbol{M}^{s}_{m,21}(\tau,\mu_s,\mu_j) & -c_2\boldsymbol{M}^{s}_{m,22}(\tau,\mu_s,\mu_j) \\ c_2\boldsymbol{M}^{s}_{m,11}(\tau,\mu_s,\mu_j) & c_2\boldsymbol{M}^{s}_{m,12}(\tau,\mu_s,\mu_j) & c_2\boldsymbol{M}^{c}_{m,11}(\tau,\mu_s,\mu_j) & c_2\boldsymbol{M}^{c}_{m,12}(\tau,\mu_s,\mu_j) \\ c_2\boldsymbol{M}^{s}_{m,21}(\tau,\mu_s,\mu_j) & c_2\boldsymbol{M}^{s}_{m,22}(\tau,\mu_s,\mu_j) & c_2\boldsymbol{M}^{c}_{m,21}(\tau,\mu_s,\mu_j) & c_2\boldsymbol{M}^{c}_{m,22}(\tau,\mu_s,\mu_j) \end{pmatrix}\begin{pmatrix} \boldsymbol{I}^{c}_{m,lr}(\tau,\mu_j) \\ \boldsymbol{I}^{c}_{m,uv}(\tau,\mu_j) \\ \boldsymbol{I}^{s}_{m,lr}(\tau,\mu_j) \\ \boldsymbol{I}^{s}_{m,uv}(\tau,\mu_j) \end{pmatrix}\right\}$$

$$c_1 = \frac{\omega(\tau)}{4}w_j\left(1+\delta_{0m}\right); \quad c_2 = \frac{\omega(\tau)}{4}w_j\left(1-\delta_{0m}\right); \quad s = -(N+1),\cdots,(N+1)\ \textit{and}\ s\neq 0$$

$$\boldsymbol{i}_m(\tau,\mu_s) = \begin{pmatrix} \boldsymbol{I}^{c}_{m,lr}(\tau,\mu_s) \\ \boldsymbol{I}^{c}_{m,uv}(\tau,\mu_s) \\ \boldsymbol{I}^{s}_{m,lr}(\tau,\mu_s) \\ \boldsymbol{I}^{s}_{m,uv}(\tau,\mu_s) \end{pmatrix}; \quad \boldsymbol{q}_m(\tau,\mu_s) = -\begin{pmatrix} \boldsymbol{Q}^{c}_{m,lr}(\tau,\mu_s) \\ \boldsymbol{Q}^{c}_{m,uv}(\tau,\mu_s) \\ \boldsymbol{Q}^{s}_{m,lr}(\tau,\mu_s) \\ \boldsymbol{Q}^{s}_{m,uv}(\tau,\mu_s) \end{pmatrix}$$

Weng, F., 1992: A multi-layer discrete-ordinate method for vector radiative transfer in vertically-inhomogeneous; emitting and scattering atmosphere, Part I: Theory, *J. Quant. Spectrosc. Radiat. Trans.*, **47**, 19-33

VDISORT theory was developed in 1990s and has been widely used in community. However, it has some limitation for non-specular surface reflection and non-spherical ice cloud scattering etc.

New Vector Discrete-Ordinate Radiative Transfer (VDISORT) Scheme

$$\mu\frac{d}{d\tau}\begin{pmatrix} \mathbf{I}^c_{m,lr}(\tau,\mu_s) \\ \mathbf{I}^c_{m,uv}(\tau,\mu_s) \\ \mathbf{I}^s_{m,lr}(\tau,\mu_s) \\ \mathbf{I}^s_{m,uv}(\tau,\mu_s) \end{pmatrix} = \begin{pmatrix} \mathbf{I}^c_{m,lr}(\tau,\mu_s) \\ \mathbf{I}^c_{m,uv}(\tau,\mu_s) \\ \mathbf{I}^s_{m,lr}(\tau,\mu_s) \\ \mathbf{I}^s_{m,uv}(\tau,\mu_s) \end{pmatrix} - \begin{pmatrix} \mathbf{Q}^c_{m,lr}(\tau,\mu_s) \\ \mathbf{Q}^c_{m,uv}(\tau,\mu_s) \\ \mathbf{Q}^s_{m,lr}(\tau,\mu_s) \\ \mathbf{Q}^s_{m,uv}(\tau,\mu_s) \end{pmatrix} -$$

$$\sum_{j=-(N+1),\, j\neq 0}^{N+1}\left\{\begin{pmatrix} c_1\mathbf{M}^c_{m,11}(\tau,\mu_s,\mu_j) & c_1\mathbf{M}^c_{m,12}(\tau,\mu_s,\mu_j) & -c_2\mathbf{M}^s_{m,11}(\tau,\mu_s,\mu_j) & -c_2\mathbf{M}^s_{m,12}(\tau,\mu_s,\mu_j) \\ c_1\mathbf{M}^c_{m,21}(\tau,\mu_s,\mu_j) & c_1\mathbf{M}^c_{m,22}(\tau,\mu_s,\mu_j) & -c_2\mathbf{M}^s_{m,21}(\tau,\mu_s,\mu_j) & -c_2\mathbf{M}^s_{m,22}(\tau,\mu_s,\mu_j) \\ c_2\mathbf{M}^s_{m,11}(\tau,\mu_s,\mu_j) & c_2\mathbf{M}^s_{m,12}(\tau,\mu_s,\mu_j) & c_2\mathbf{M}^c_{m,11}(\tau,\mu_s,\mu_j) & c_2\mathbf{M}^c_{m,12}(\tau,\mu_s,\mu_j) \\ c_2\mathbf{M}^s_{m,21}(\tau,\mu_s,\mu_j) & c_2\mathbf{M}^s_{m,22}(\tau,\mu_s,\mu_j) & c_2\mathbf{M}^c_{m,21}(\tau,\mu_s,\mu_j) & c_2\mathbf{M}^c_{m,22}(\tau,\mu_s,\mu_j) \end{pmatrix}\begin{pmatrix} \mathbf{I}^c_{m,lr}(\tau,\mu_j) \\ \mathbf{I}^c_{m,uv}(\tau,\mu_j) \\ \mathbf{I}^s_{m,lr}(\tau,\mu_j) \\ \mathbf{I}^s_{m,uv}(\tau,\mu_j) \end{pmatrix}\right\}$$

$$c_1 = \frac{\omega(\tau)}{4}w_j(1+\delta_{0m}); \quad c_2 = \frac{\omega(\tau)}{4}w_j(1-\delta_{0m}); \quad s=-(N+1),\cdots,(N+1) \text{ and } s\neq 0$$

$$\mathbf{i}_m(\tau,\mu_s) = \begin{pmatrix} \mathbf{I}^c_{m,lr}(\tau,\mu_s) \\ \mathbf{I}^c_{m,uv}(\tau,\mu_s) \\ \mathbf{I}^s_{m,lr}(\tau,\mu_s) \\ \mathbf{I}^s_{m,uv}(\tau,\mu_s) \end{pmatrix}; \quad \mathbf{q}_m(\tau,\mu_s) = -\begin{pmatrix} \mathbf{Q}^c_{m,lr}(\tau,\mu_s) \\ \mathbf{Q}^c_{m,uv}(\tau,\mu_s) \\ \mathbf{Q}^s_{m,lr}(\tau,\mu_s) \\ \mathbf{Q}^s_{m,uv}(\tau,\mu_s) \end{pmatrix}$$

Zhu, Z., F. Weng, and Y. Han, 2024: Vector radiative transfer in a vertically inhomogeneous scattering and emitting atmosphere. Part I: A new discrete ordinate method. *J. Meteor. Res.*, **38**(2), 209–224, doi: 10.1007/s13351-024-3076-3.

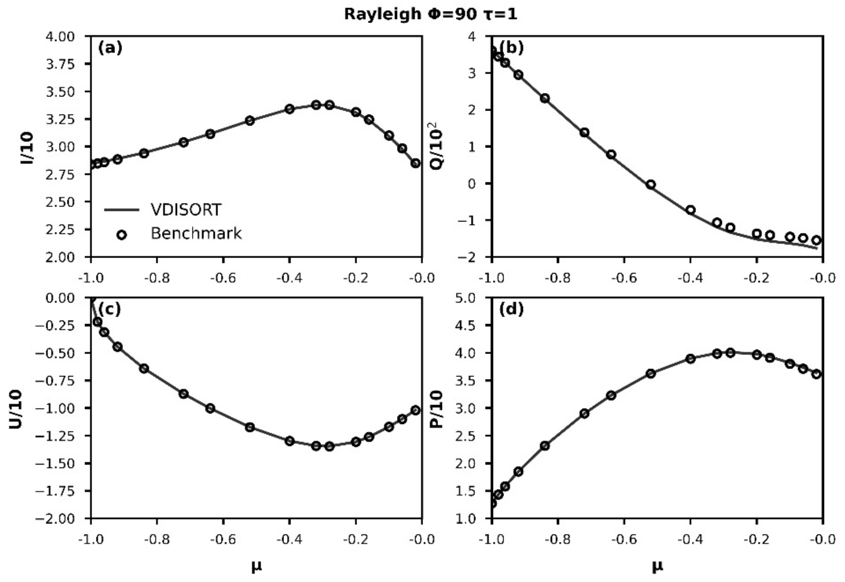
ARMS 2.0 will be based on new VDISORT theory and can be applied for both non-specular surface reflection and non-spherical ice cloud scattering

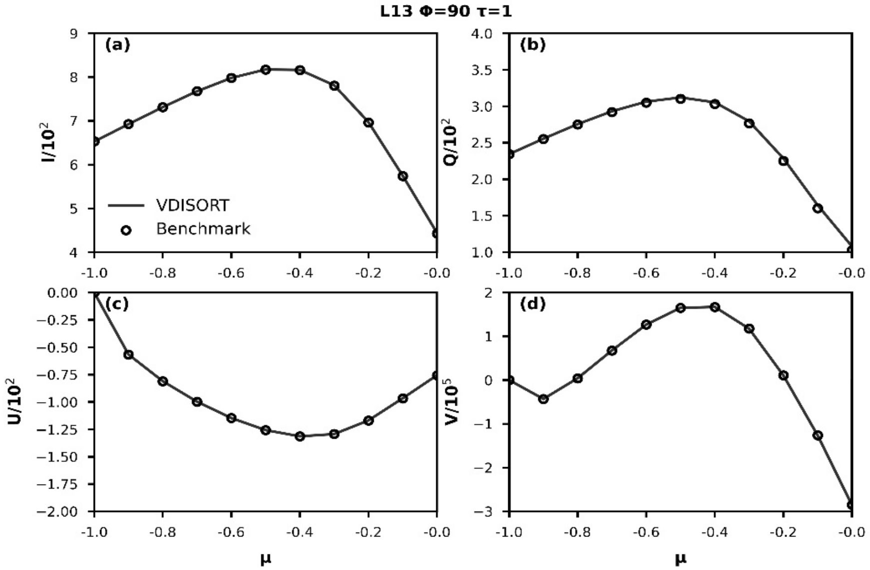
VDISORT Benchmark Test

Benchmark Definition:

- **Rayleigh scattering**
- **L13 scattering**
- **Sun glint effects**

Simulation of Rayleigh and L13 case with new VDISORT shows a good agreement to the decimal place of 4th place.





VDISORT Lower Boundary Scheme

$$I(\tau_L,\mu_s,\varphi_s) = \boldsymbol{E}\boldsymbol{S}_t + \frac{1}{\pi}\int_0^{2\pi} d\phi' \int_0^1 \mu \boldsymbol{R}(\mu_s,\varphi_s,-\mu',\phi') \boldsymbol{I}(\tau_L,-\mu',\phi') d\mu' + \frac{\mu_0 \boldsymbol{R}(\mu_s,\varphi_s,-\mu_0,\phi_0)}{\pi} \boldsymbol{S}_b \exp\left(-\frac{\tau_L}{|\mu_0|}\right)$$

Surface Thermal Emission — Reflected Atmospheric Emission+Scattering — Reflected Solar Source

where emissivity vector (***E***) and BRDF (***R***) are related to each other; $\boldsymbol{S_t}$ and $\boldsymbol{S_b}$ are thermal Stokes vector and solar Stokes vector respectively

$$\boldsymbol{R}(\mu_s,\varphi_s,\mu_i,\varphi_i) = \begin{bmatrix} R_{11} & R_{12} & 0 & 0 \\ R_{21} & R_{22} & 0 & 0 \\ 0 & 0 & R_{33} & R_{34} \\ 0 & 0 & R_{43} & R_{44} \end{bmatrix} \longrightarrow \boldsymbol{R}(\mu_s,\varphi_s,\mu_i,\varphi_i) = \begin{bmatrix} R_{11} & R_{12} & R_{13} & R_{14} \\ R_{21} & R_{22} & R_{23} & R_{24} \\ R_{31} & R_{32} & R_{33} & R_{34} \\ R_{41} & R_{42} & R_{43} & R_{44} \end{bmatrix}$$

Liu, Q. , F. Weng and S. English, 2011: An Improved Fast Microwave Water Emissivity model: *IEEE Trans. Geosci. Remote Sens.*, 1238-1250, DOI: 10.1109/ TGRS.2010.2064779.

He, L. and F. Weng, 2023:Improved Microwave Emissivity and Reflectivity Model derived from Two-scale Roughness Theory, *Adv Atmos. Sci.,40,1923-1938*

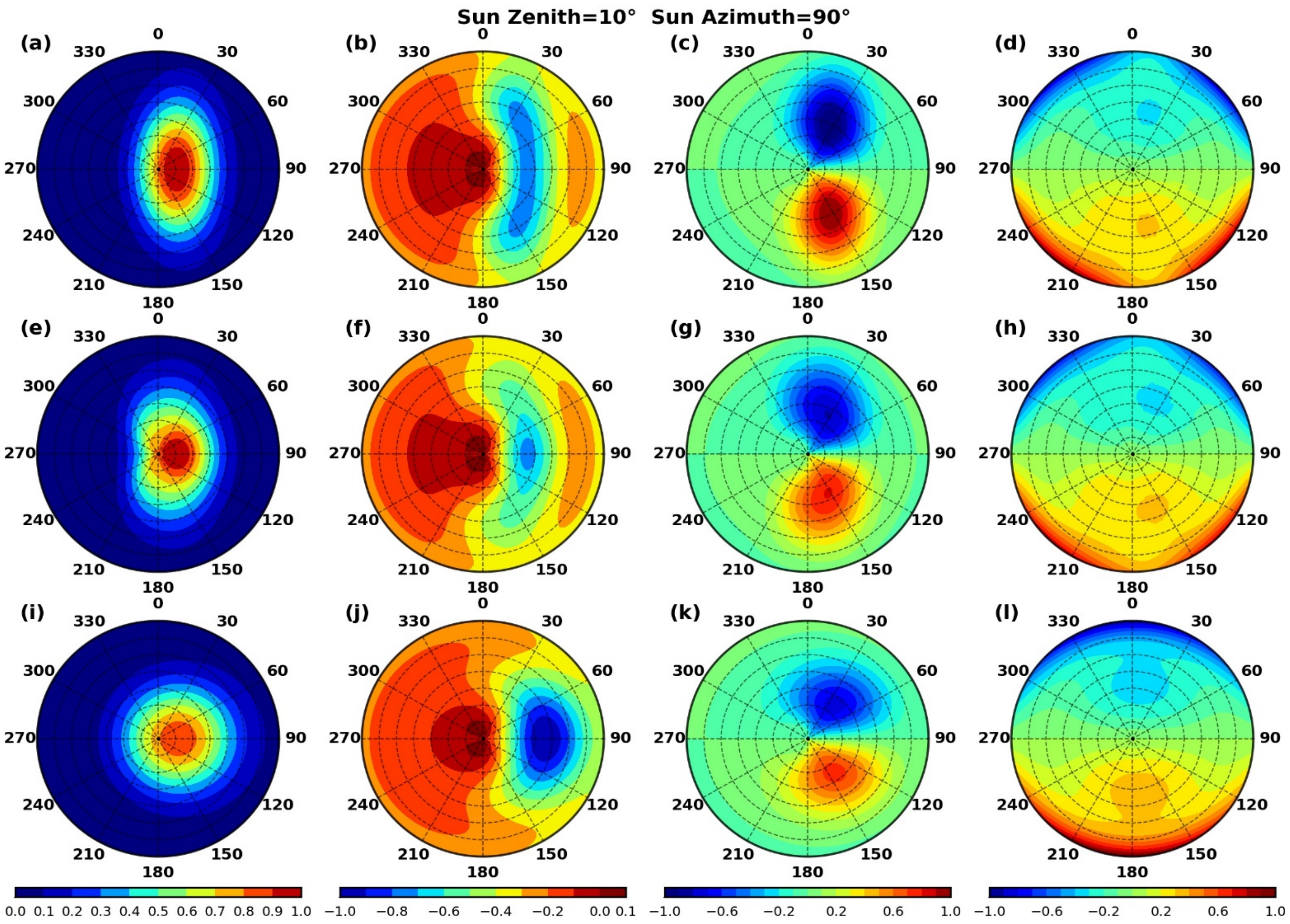
$$\boldsymbol{R}(\mu_s,\varphi_s,\mu_i,\varphi_i) = \sum_{m=0}^{\infty}\left\{\boldsymbol{R}_m^c(\mu_s,\mu_i,\varphi_s) cosm(\varphi_i-\varphi_s) + \boldsymbol{R}_m^s(\mu_s,\mu_i,\varphi_s) sinm(\varphi_i-\varphi_s)\right\}$$

IQUV Simulations from VDISORT

Up-/Cross-wind Slope Ratio = 0.6

Up-/Cross-wind Slope Ratio = 0.6, Neglect sinusoidal harmonics

Up-/Cross-wind Slope Ratio=1.0

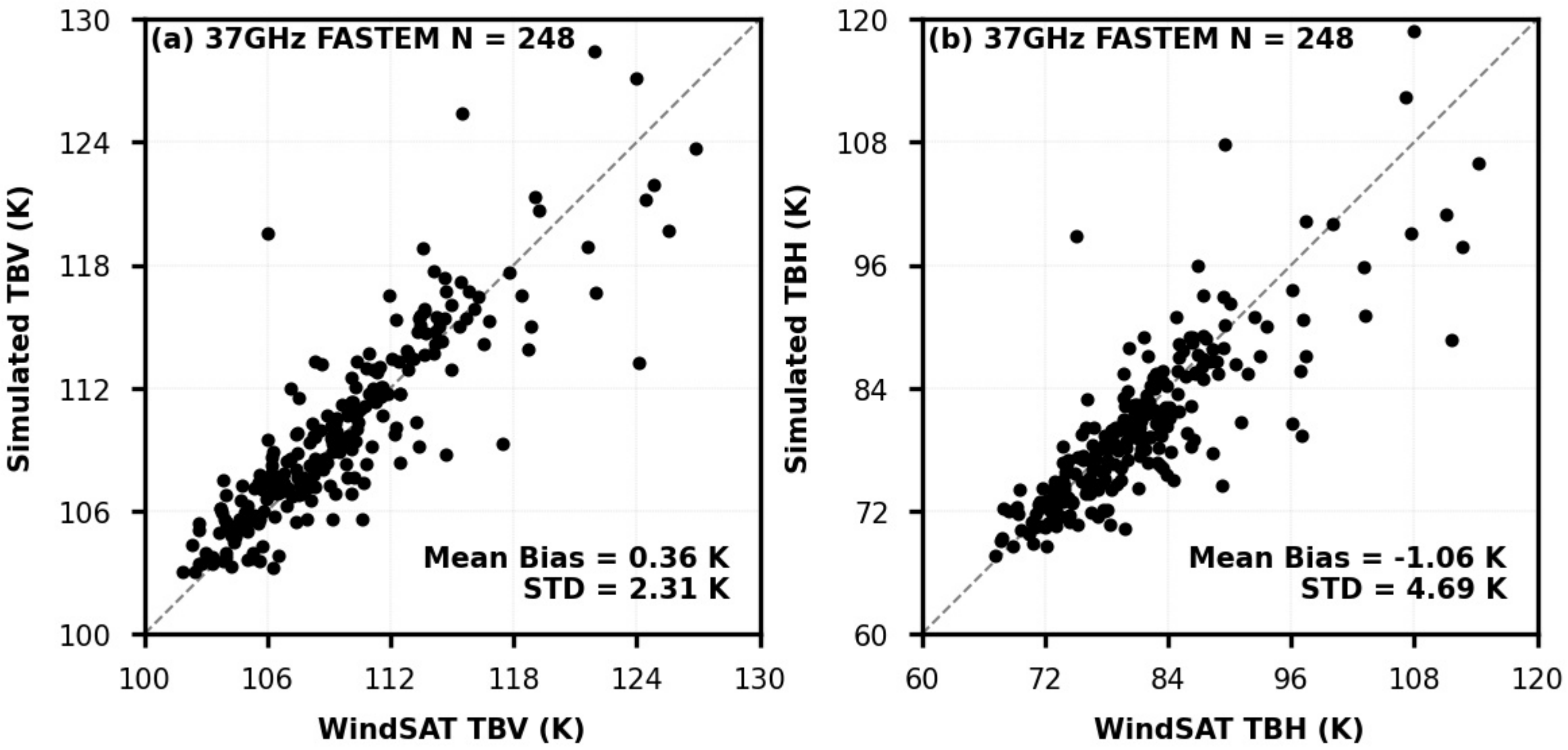


NewVDISORT Scheme

Old VDISORT Scheme

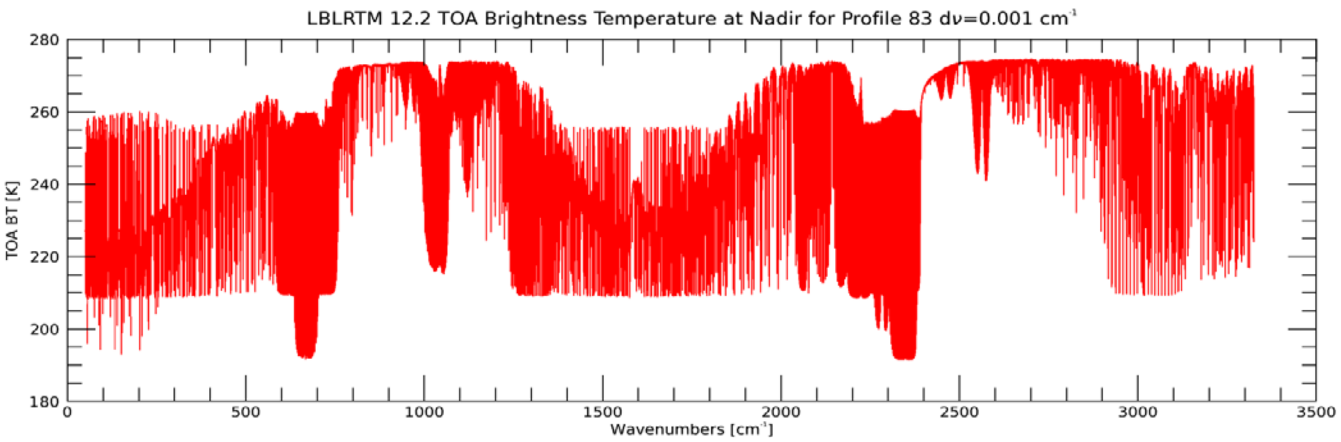
Clockwise azimuthal direction: 0-360° ; zenith direction of 10 degree increment from 10° to 70°

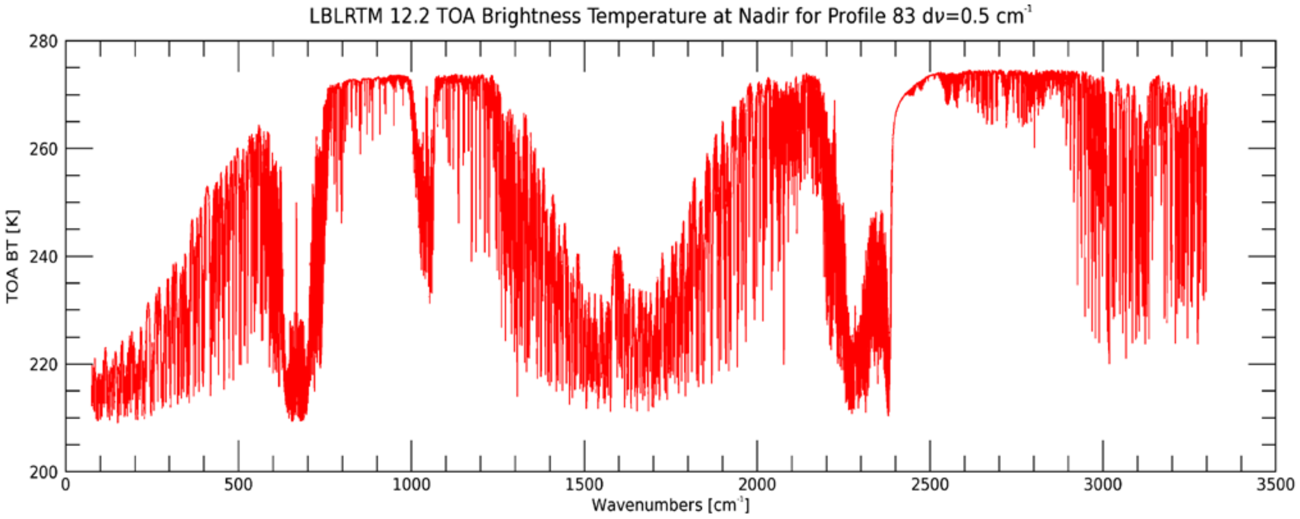
VDISORT Simulations vs. WindSAT Observations



NRL Windsat data are collocated with ERA5 data (Temperature, humidity, hydrometeor profiles, surface temperature, surface wind. Shown are the all sky vertically (left) and horizontally (right) brightness temperatures at 37 GHz simulated with VDISORT. The surface emissivity model is based on FASTEM-6

Infrared Line by Line Spectroscopy Data Base

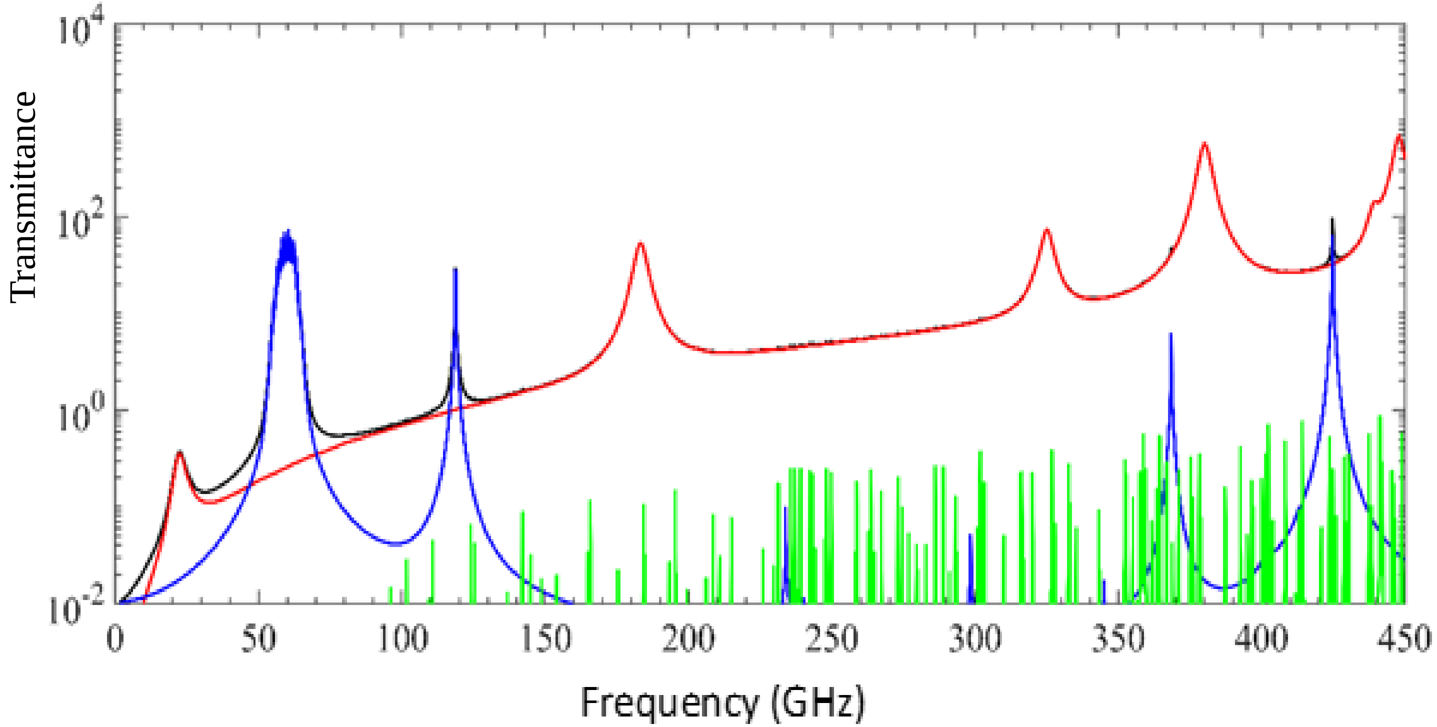




Gordon et al., 2020; JQSRT:
"The HITRAN2020 molecular spectroscopic database"

- The state-of-the art molecular spectroscopic parameters;
- It was established in the early 1970s and updated periodically and is widely used to simulate the transmission and emission of light in gaseous media;
- Major components: the line-by-line spectroscopic parameters required for high-resolution radiative-transfer codes;
- Experimental infrared absorption cross-sections (for molecules where it is not yet feasible for representation in a line-by-line form);
- Collision-induced absorption data,.

Microwave Line by Line Spectroscopy Data Base



Clough et al., *JQSRT, 2005:*
"Atmospheric radiative transfer modeling: a summary of the AER codes"

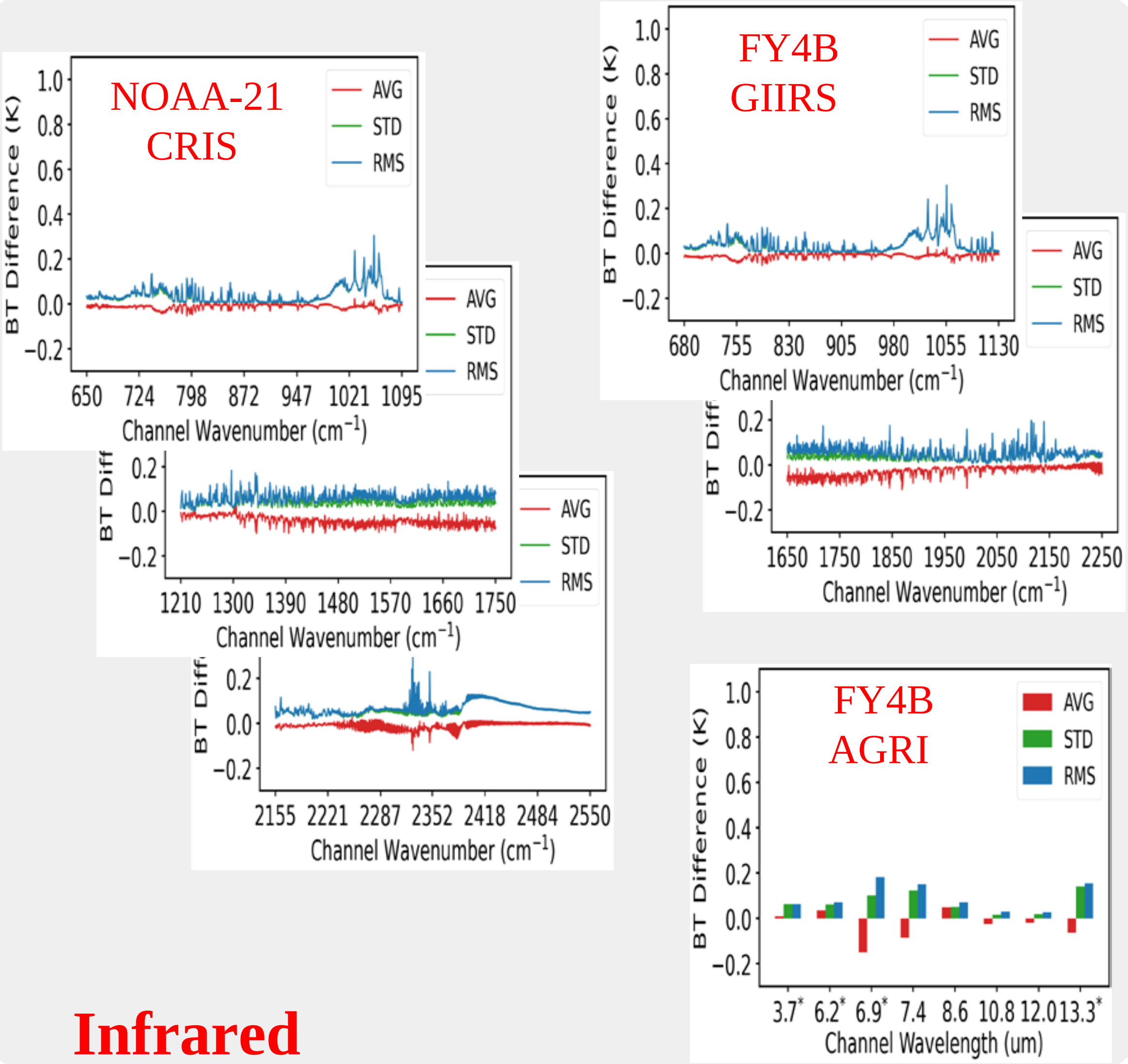
Atmospheric transmittance as a function of frequency in microwave region.
The black, blue, red and green curve represents the contribution of total, oxygen, water vapor and ozone to the optical depth

ARMS Supported Instruments

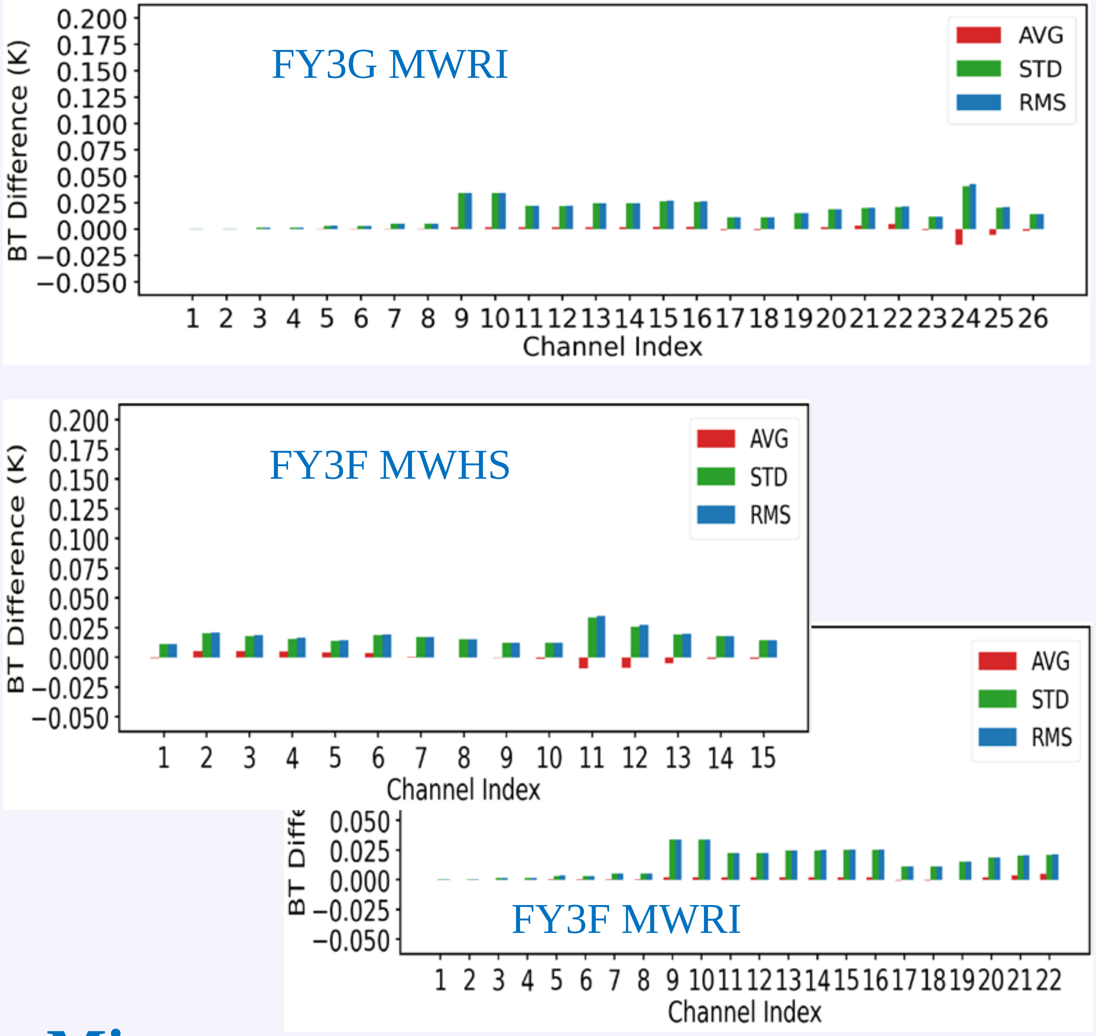
- FY-3A MWTS
- FY-3A MWHS
- FY-3B MWTS
- FY-3B MWHS
- FY-3C/D MWTS-2
- FY-3C/D/E/F-MWHS-2
- FY-3 B/C/D/F/G MWRI
- FY-3 B/C VIRR
- FY-3C MERSI
- FY-3C IRAS
- FY-3D MERSI-2
- FY-3D/E/F HIRAS
- FY-4A/B GIIRS
- FY-4A/B AGRI
- FY-4M GeoMW
- FY-3E/F MWTS-3

- NOAA 15 to 19 AMSU-A
- NOAA 18-19 MHS
- NOAA 18-19 HIRS
- NOAA 15-19 AVHRR
- SNPP/NOAA-20/NOAA-21 ATMS
- SNPP/NOAA-20/NOAA/21 CrIS
- SNPP/NOAA-20/21 VIIRS
- METOP-A to C IASI
- METOP-A to C IASI
- METOP-A to C AMSU-A
- METOP-A to C AVHRR
- JAXA AMSR2
- NASA GMI
- EOS Aqua AIRS
- EOS Terra/Aqua MODIS

ARMS Supported FengYun Instruments



Infrared

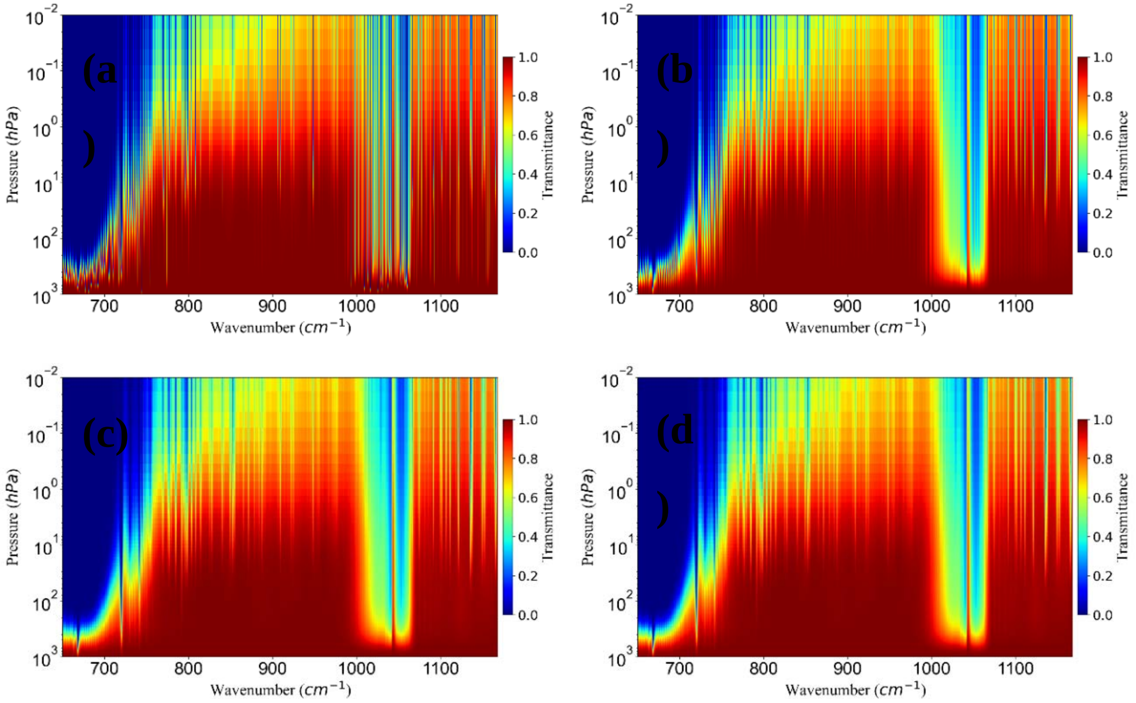


Microwave

Apodized and Unapodized Transmittance and Spectral Brightness Temperature Difference

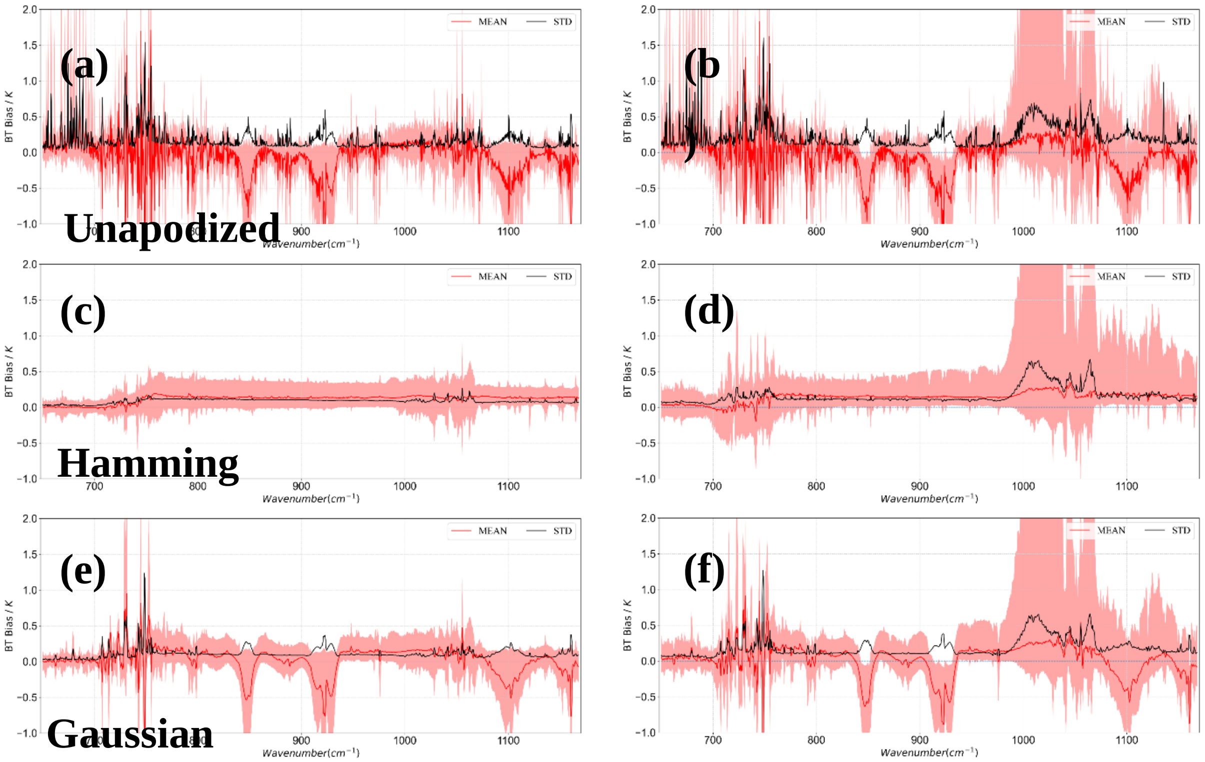
Transmittance

LBLRTM 0.001cm^{-1} | Unapodized 0.625cm^{-1}



Hamming | Gaussian

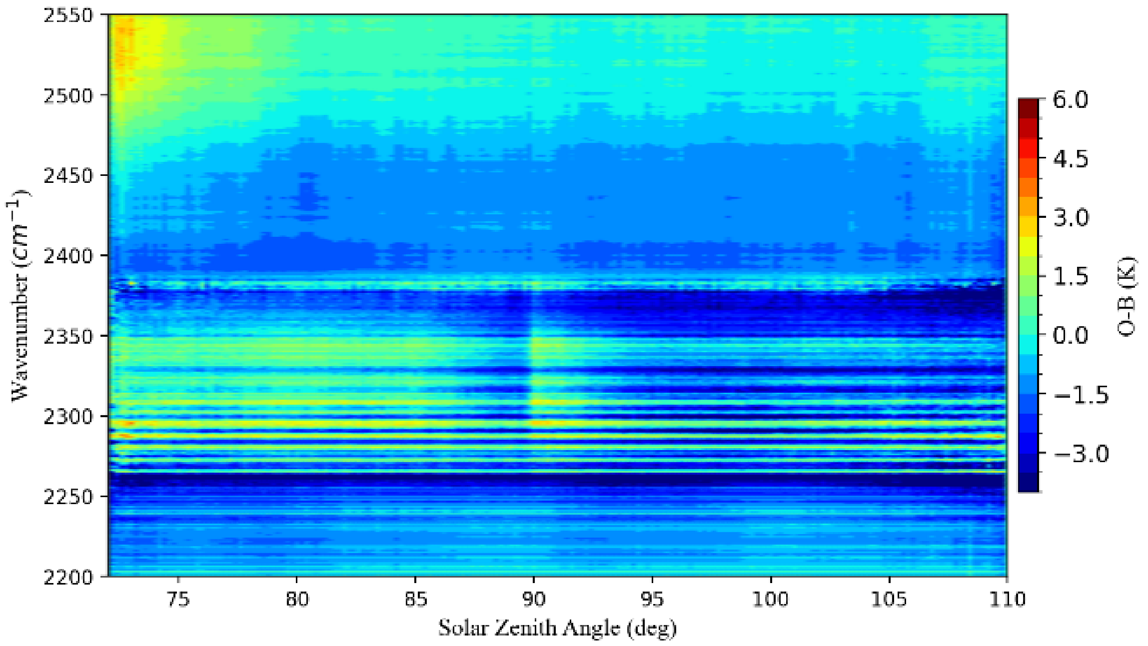
Brightness Temperature



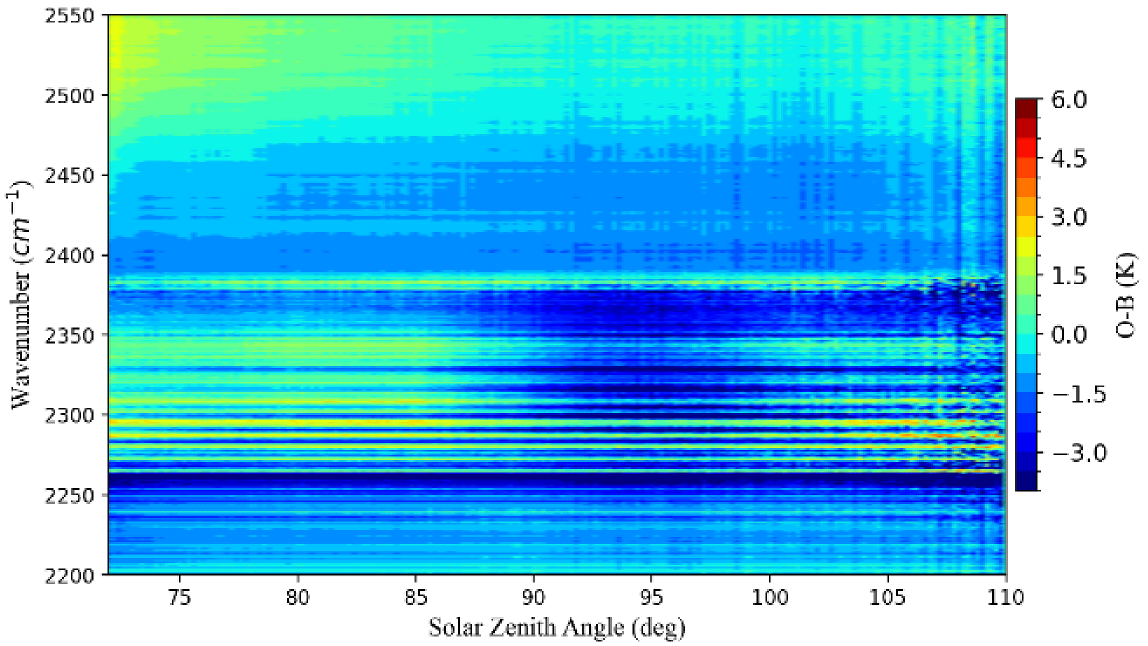
ECMWF83 | UMBC48

Extending NLTE Model for Early Morning Satellites

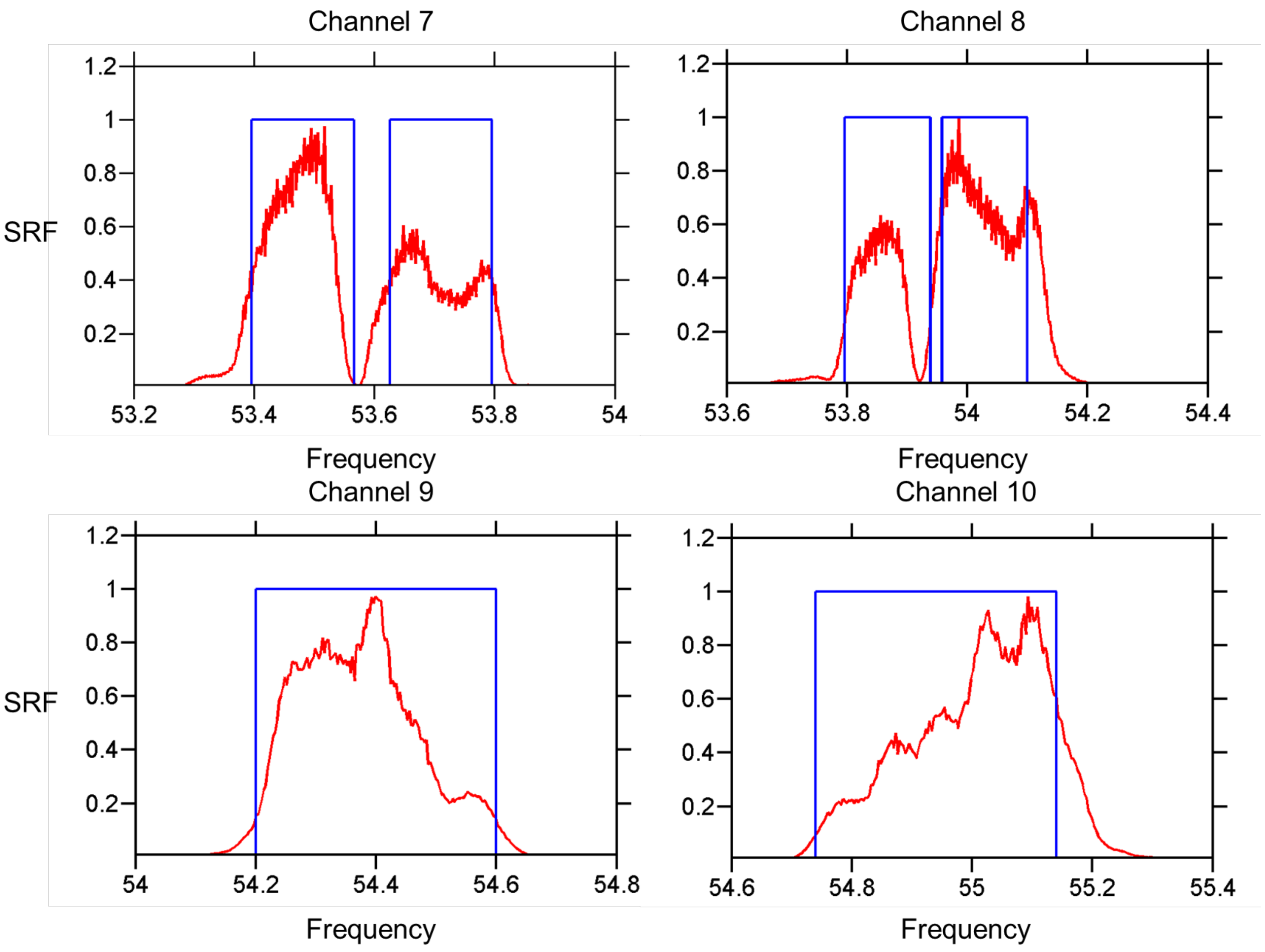
NLTE

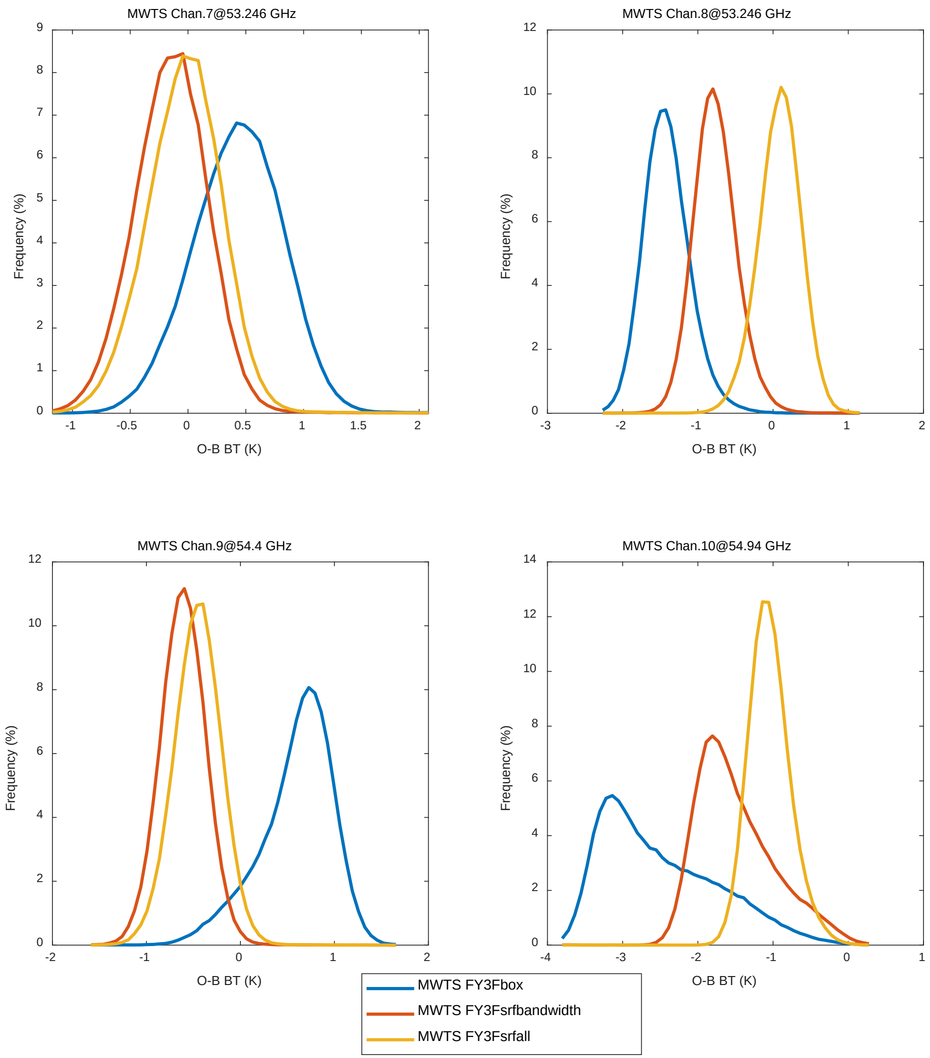


newNLTE



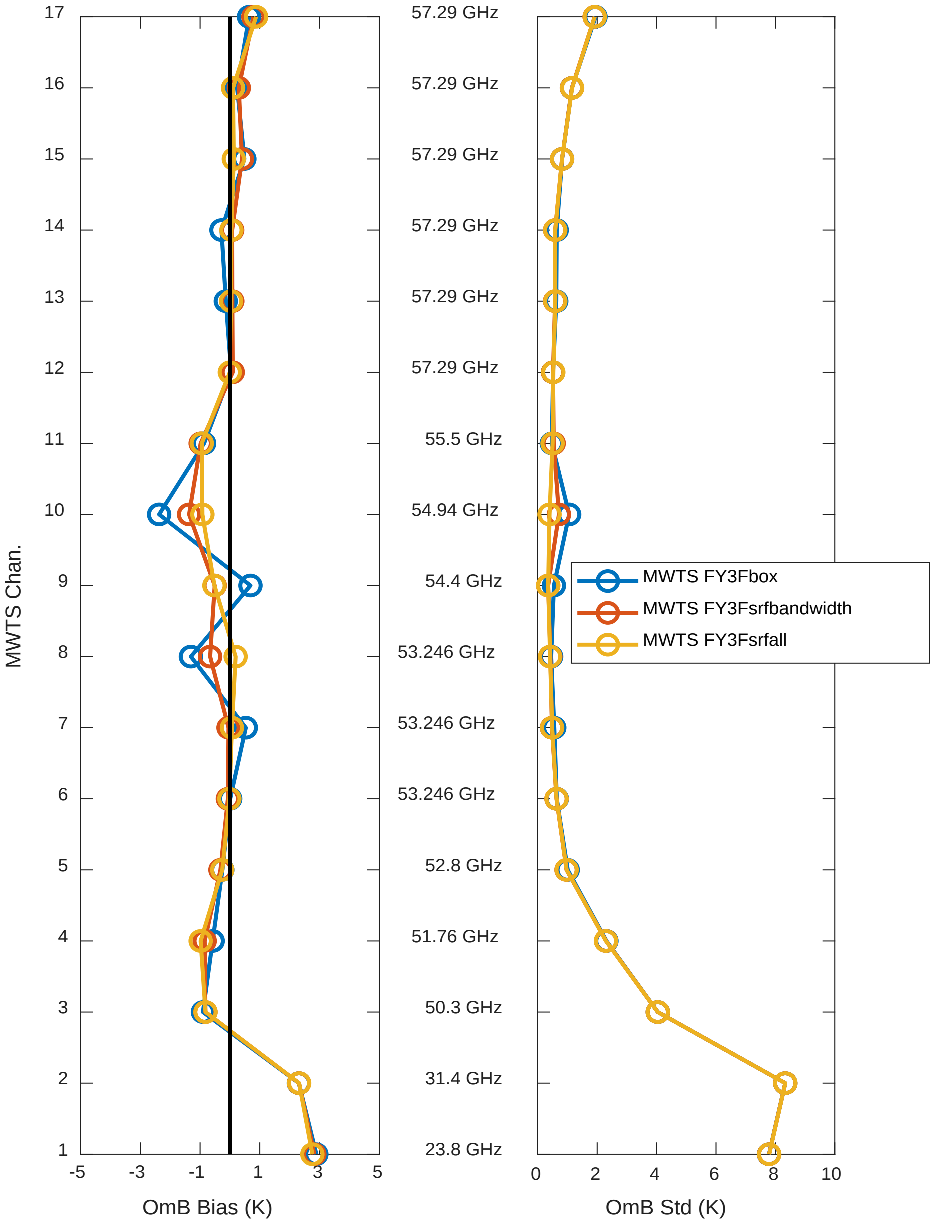
Assessments of FY-3F MWTS using ARMS (Boxcar vs SRF)





Simulations of Ch8 & Ch10 improve a lot after considering real SRF.

Assessments of FY-3F MWTS using ARMS (Boxcar vs SRF)



- FY-3F MWTS Ch7-10 are sensitive to the shape of SRF
- Using SRF without bandwidth could significantly improve the simulation results of CH7-10.

	Chan	box	srfbandwidth	srfall
bias	7	0.532	-0.049	0.066
	8	-1.308	-0.664	0.191
	9	0.688	-0.511	-0.52
	10	-2.371	-1.368	-0.923
std	7	0.557	0.479	0.485
	8	0.452	0.425	0.417
	9	0.545	0.352	0.352
	10	1.058	0.713	0.397

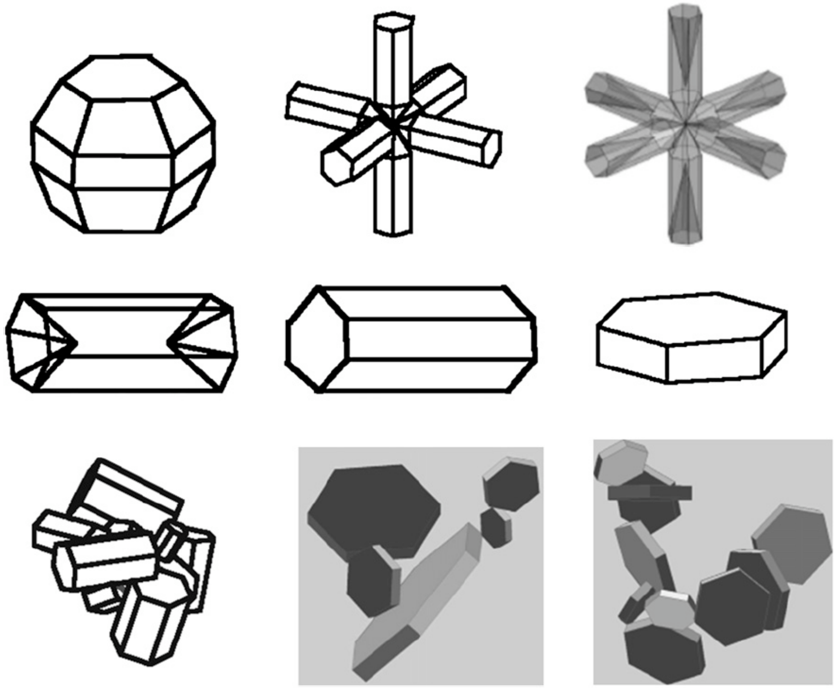
The bias and std of FY-3F MWTS improve a lot compared with FY-3E MWTS, and is comparable with ATMS.

Cloud Optical Property Library Used in ARMS

Ice particle single-scattering property database

Spectrally Consistent Scattering, Absorption, and Polarization Properties of Atmospheric Ice Crystals at Wavelengths from 0.2 to 100 μm

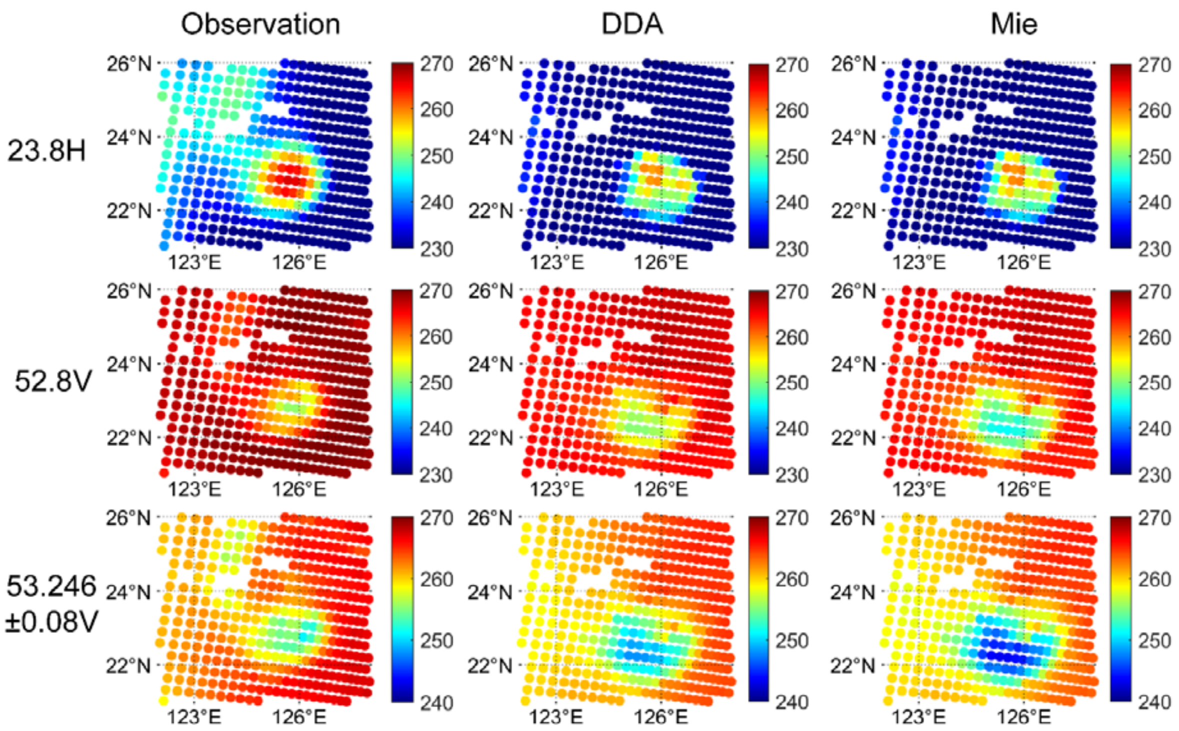
PING YANG,* LEI BI,* BRYAN A. BAUM,+ KUO-NAN LIOU,# GEORGE W. KATTAWAR,@ MICHAEL I. MISHCHENKO,& AND BENJAMIN COLE*

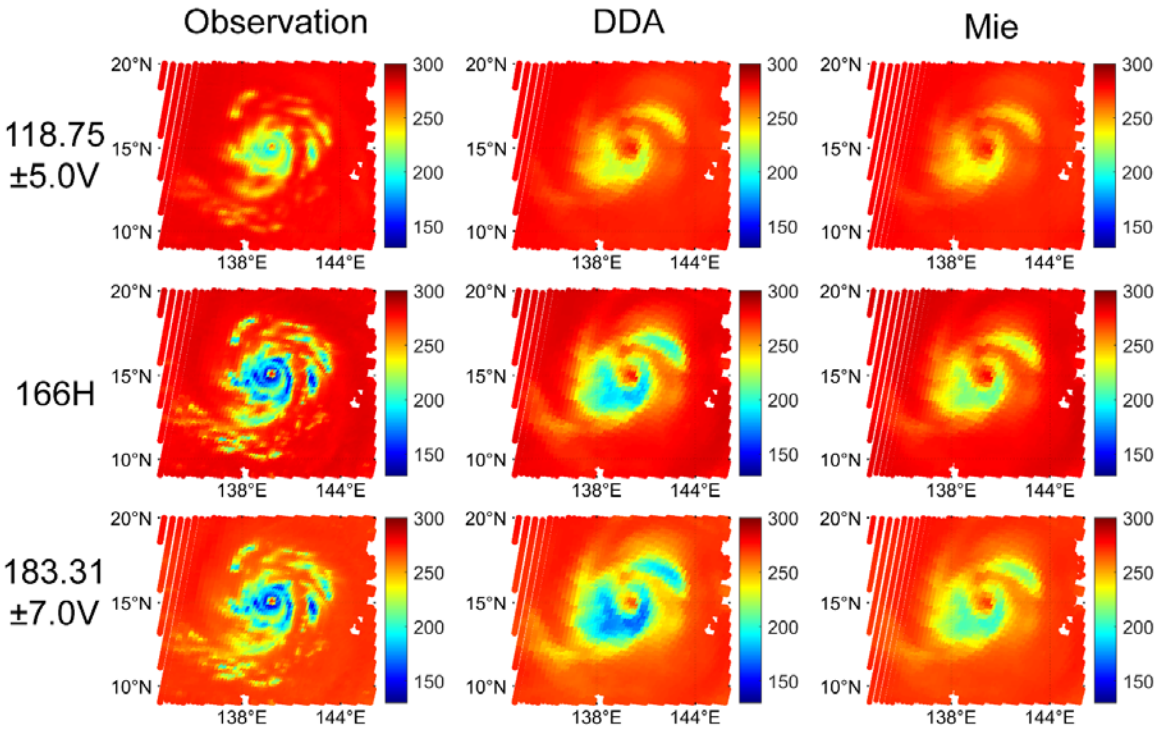


Bi et al., 2014; Yang et al., 1996

- Developed with the most accurate and state-of-the-art light scattering computation methods
- Wide coverage of the spectrum from 0.2 to 100 um;
- Wide particle size range (maximum dimension) from 2~10^4 um;
- Complete scattering phase matrix with polarization
- Three degrees of ice surface roughness: Completely smooth, moderately rough, reverely rough;
- Extended to the microwave spectrum; temperature dependence considered;

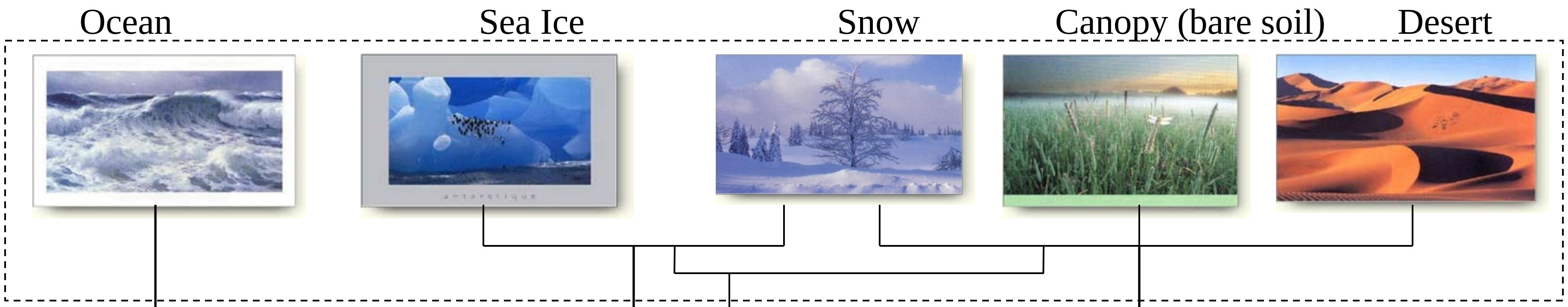
Simulations between Spherical and non-spherical Particle Scattering





- The spherical assumption of ice cloud particles will generate excessive scattering at low frequencies and insufficient scattering at high frequencies.
- The simulation results of non-spherical scattering based on DDA are closer to observations.

ARMS Surface Emissivity and BRDF Models



Microwave land emissivity model (Weng et al, 2001)
Vegetation model (Chen and Weng, 2014)
Surface roughness (Chen and Weng, 2015)
Updated soil permittivity (Liu et al., 2023)

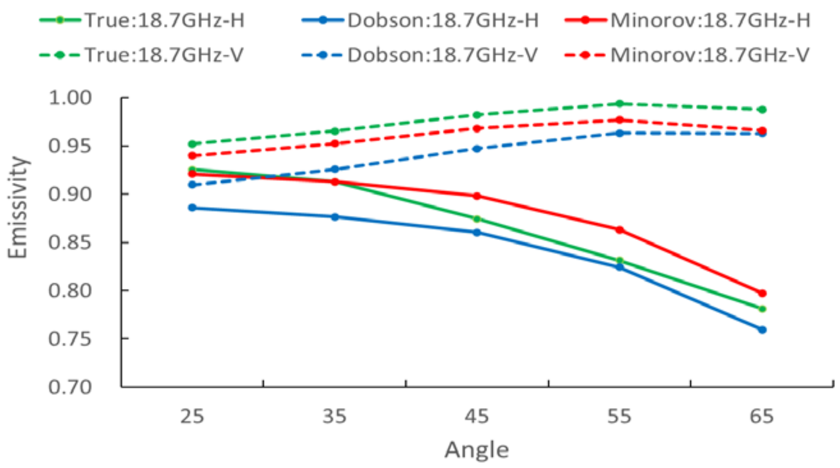
NPOESS infrared emissivity database
CAMEL database

Empirical snow and sea ice microwave emissivity algorithm (Yan and Weng, 2003; 2008)

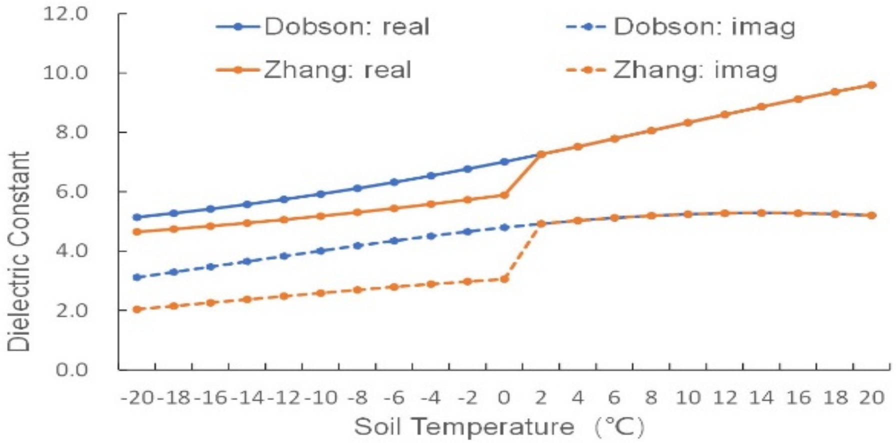
pBRDF for visible and near-IR sensors (Zhu and Weng, 2024)
pBRDF for microwave passive and active sensors (He and Weng, 2023)
FASTEM microwave emissivity model (Liu et al., 2010)
IR emissivity model (Wu and Smith, 1991; van Delst et al., 2001; Nalli et al., 2008)

Microwave Land Emissivity Model Updates

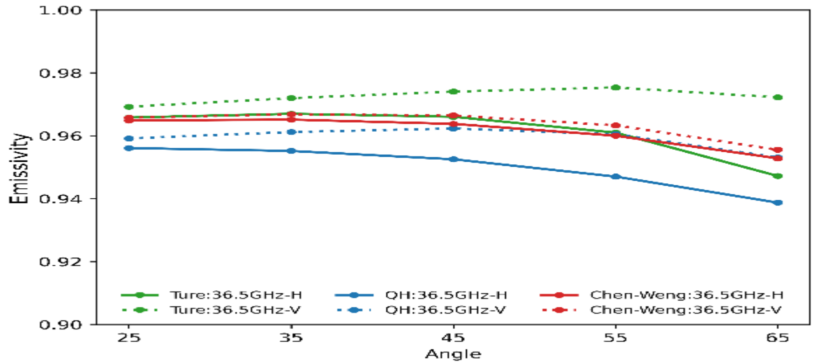
（1）Minorov room temperature soil dielectric constant model（Minorov et al，2009）



（2）A new frozen soil dielectric constant model (Zhang et al, 2010)



（3）Chen-Weng rough surface reflectance model (Chen and Weng，2016)

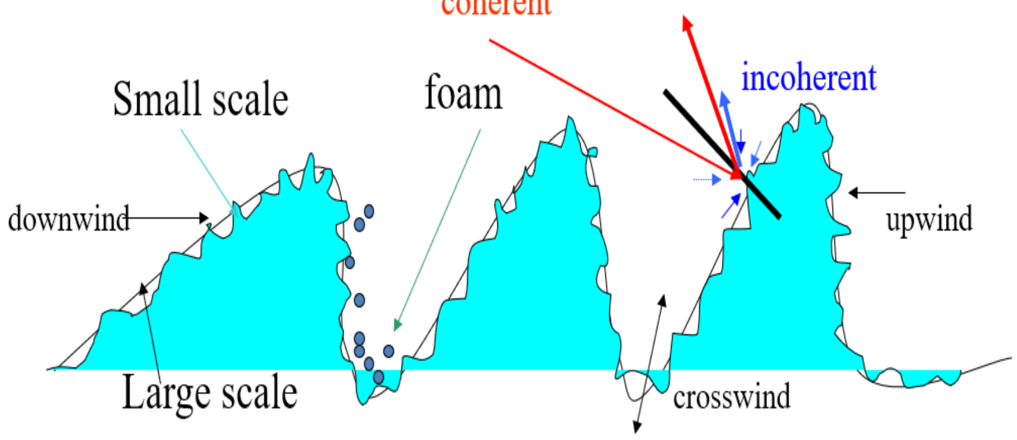


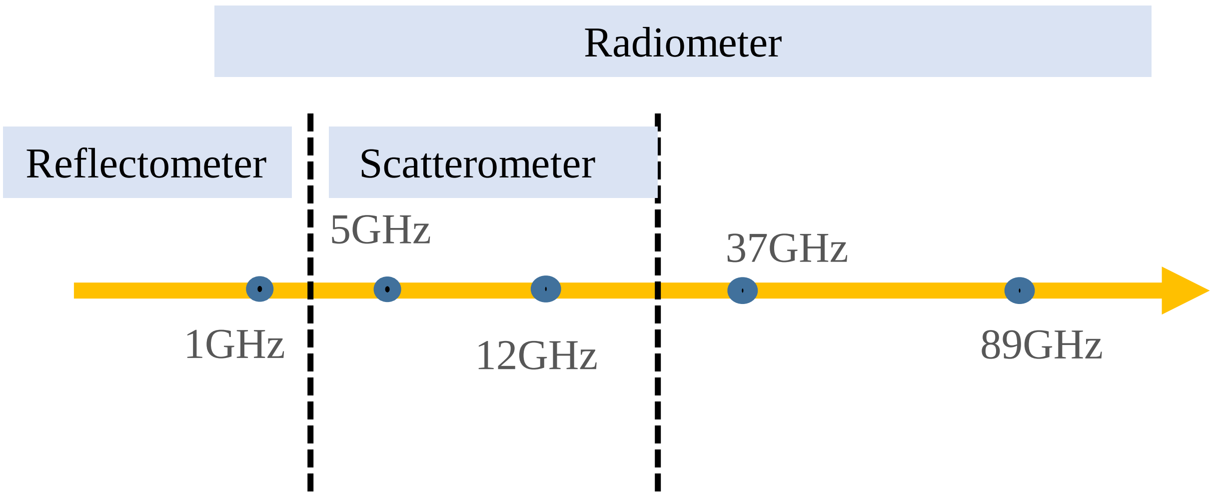
（4）Optimize emissivity simulation scheme

For bare soil surface, the Qp model (Shi et al, 2015) is introduced and for vegetation areas, the Chen-Weng model is used.

Passive and Active Scattering and Emission Model for Oceans

Two-Scale Model (TSM)

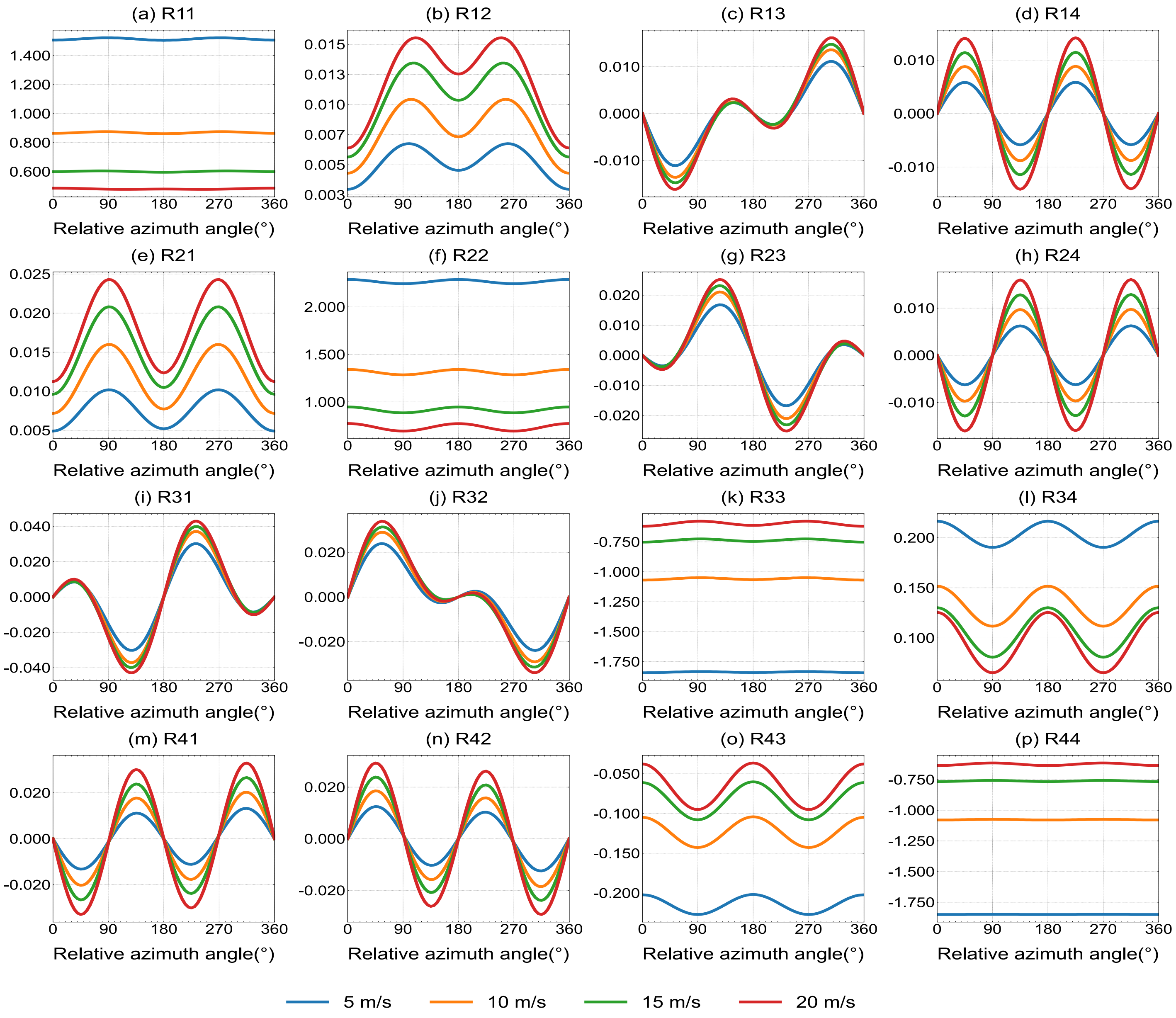




,

- Large scale roughness is generated gravity wave and small scale roughness is related capillary waves
- Coherent and non-coherent reflection and scattering from both scales
- Coherent term is derived from geometric optics
- Non-coherent is derived from small perturbation model (SPM)
- TSM is valid for small to medium incidence angles and moderate wind speed

pBRDF (R) Matrix Derived from Ocean Two-Scale Roughness



For a specific geometry

$$\theta_i = \theta_s, \varphi_i = \varphi_s$$

Frequency = 37GHz
Zenith angle = 45°
SST = 285K
SSS = 35‰

1. pBDRF elements can have a unit of inverse solid angle (sr^{-1})
2. Thus, the magnitudes can be greater than 1
3. As wind speed increases, the harmonic amplitudes of some elements increases significantly

ARMS Microwave Land Surface Emissivity Database

Basic Info

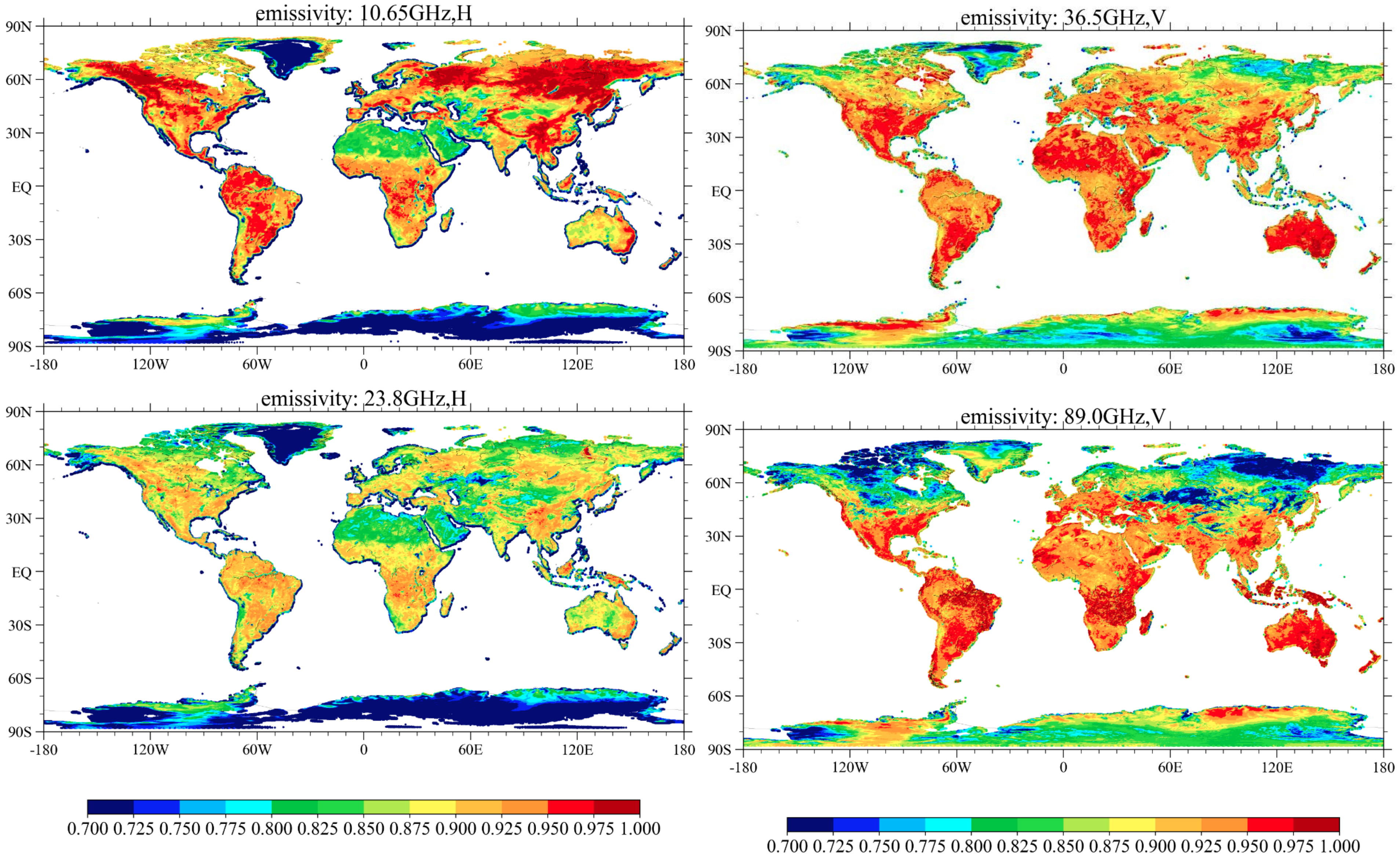
Global microwave land surface emissivity

Frequency

- 10.65 GHz
- 18.7 GHz
- 23.8 GHz
- 36.5 GHz
- 89 GHz

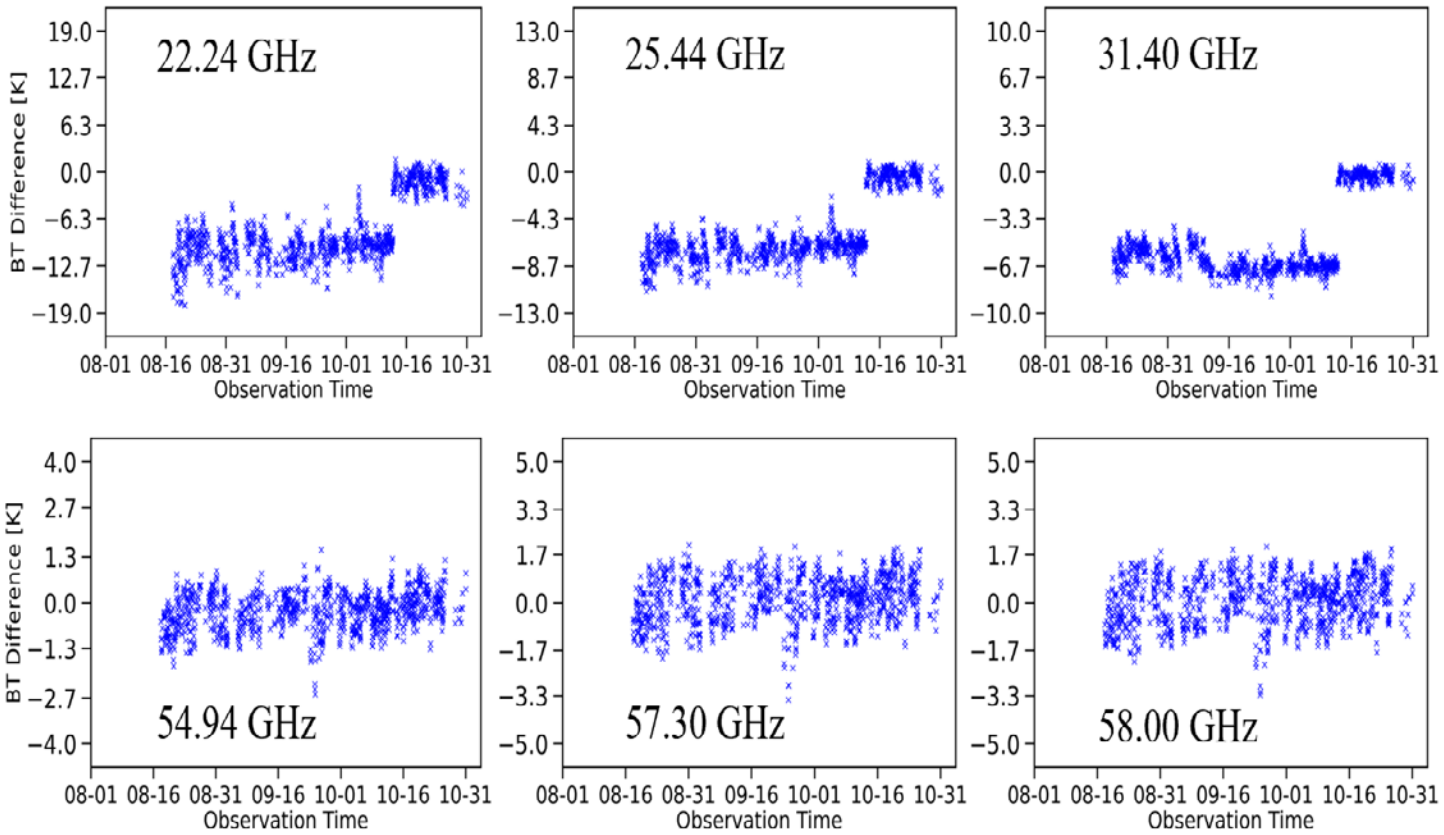
Resolution

- Spatial:0.25×0.25
- In tenday, 3×12 files, 2022-2023



ARMS-Ground-based (gb) MW Radiometer

- In past few years, China has installed more than one hundred ground-based microwave radiometers
- Currently, due to the lack of precise RT model, it is difficult to diagnose the observation quality of these instruments
- Use of these data in remote sensing and NWP models is a daunting task



O-B at Karamay, China (84.5° E, 45.4° N), August – October， 2023.

Distribution of ground-based microwave radiometers in China

Summary and Conclusions

- Fast and accurate radiative transfer models are required for sensor simulation, instrument calibration and product validation, and data assimilation.

- ARMS1.2 has been operationally used in CMA-GFS since May 26, 2023.

- ARMS1.2 is also supporting the assimilation of satellite data in regional NWP models as well as emerging commercial small satellites

- ARMS1.5 version will have more fundamental scientific advancements in radiative transfer theory, surface optics for passive and active instruments,

- ARMS2.0 will support the coupled data assimilation required in the earth system prediction models and support the instruments in the NWP reanalysis system

- ARMS2.0 will also support uses of ground-based microwave radiometer measurements