Full disk Himawari-8 image adapted from
JMA Dr. Koji Yamashita's presentation

Synthetic Satellite Imagery from CWA WRF forecasts and Its Potential Utility

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with special thanks to 陳登舜、沈彥志、王文隆技士

Synthetic satellite imagery

- Simulated/synthetic satellite imagery is “generated by passing output from an NWP model through a forward radiative transfer model capable of computing realistic radiances for different spectral bands”

Synthetic Satellite Imagery for Real-Time High-Resolution Model Evaluation

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(Manuscript received 18 October 2011, in final form 16 December 2011)

ABSTRACT

Output from a real-time high-resolution numerical model is used to generate synthetic infrared satellite imagery. It is shown that this imagery helps to characterize model-simulated large-scale precursors to the formation of deep-convective storms as well as the subsequent development of storm systems. A strategy for using this imagery in the forecasting of severe convective weather is presented. This strategy involves comparing model-simulated precursors to their observed counterparts to help anticipate model errors in the timing and location of storm formation, while using the simulated storm evolution as guidance.

Bikos et al. (2012, WAF)

- An integrated view (2D image) of the 3D atmosphere that includes ***clouds***
- Identification of features that are important to thunderstorm development in a manner consistent with actual satellite imagery, making diagnosis more intuitive and efficient
- Provides means for comparing model output with real satellite imagery at high temporal intervals before convective initiation

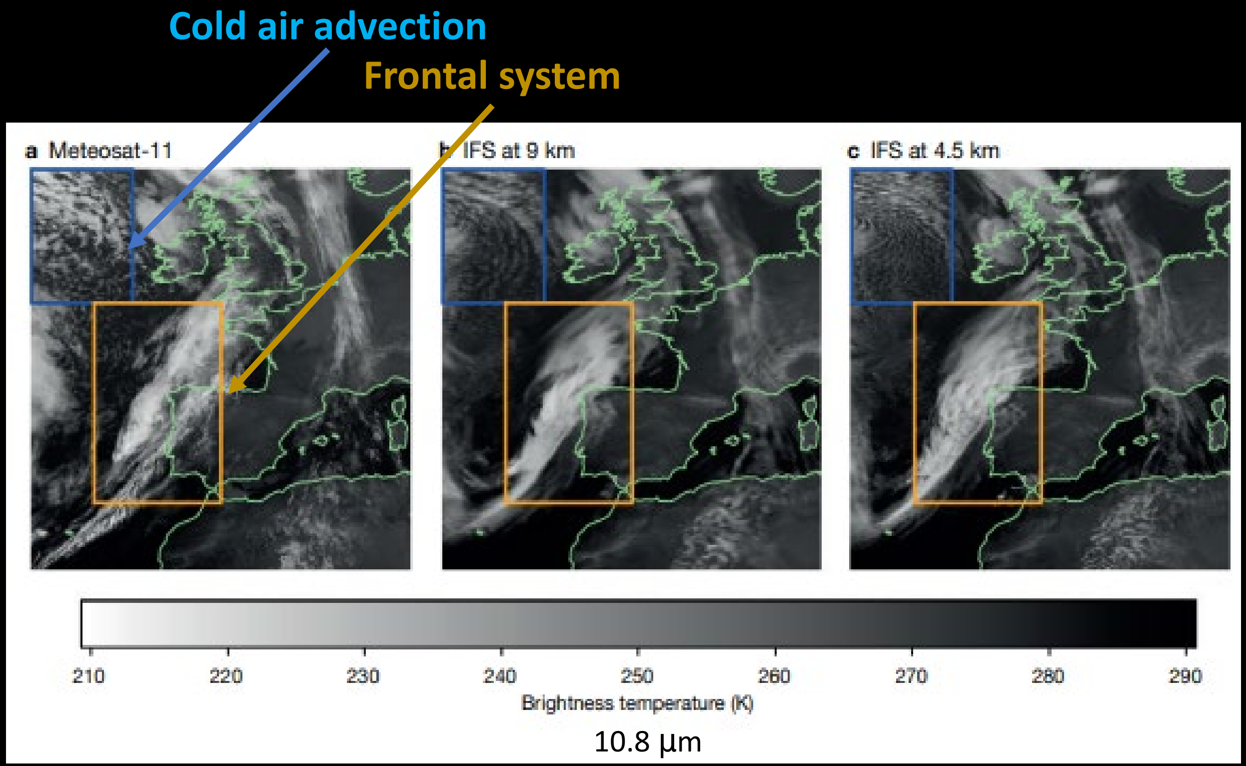
Benefits of synthetic satellite imagery

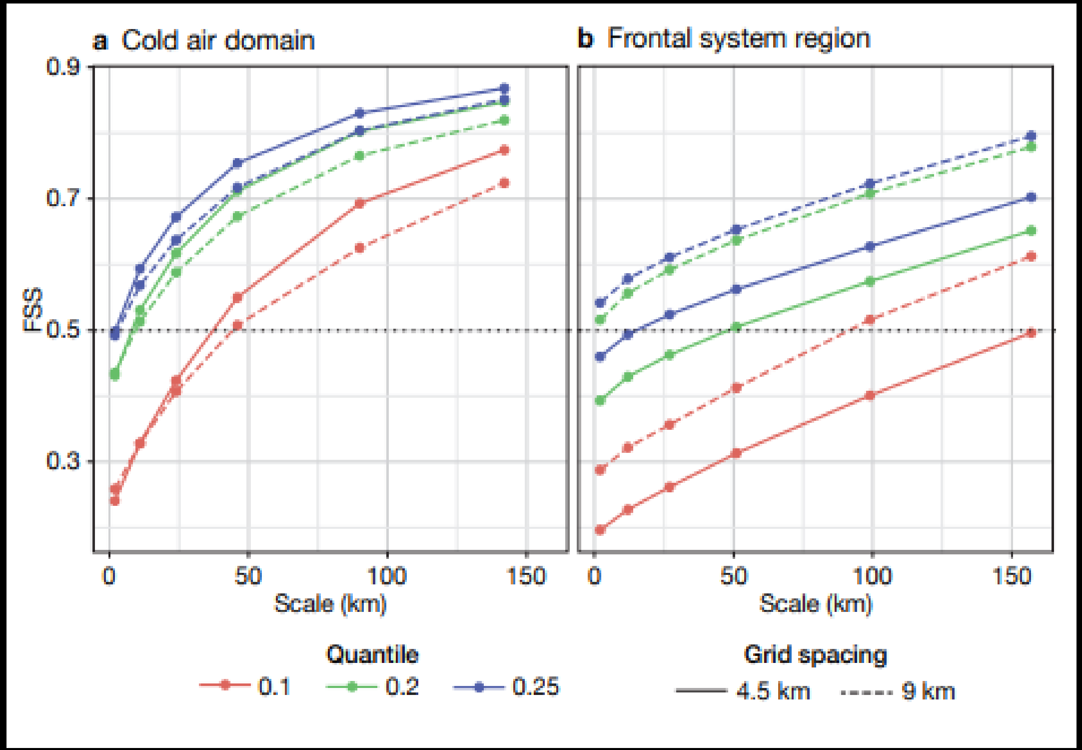
- From a ***forecaster's*** perspective:
  1. The ability to view model-forecast clouds in terms of how it would look from the real satellite images; forecasters trained to evaluate satellite imagery can apply same techniques to the model forecast imagery
  2. Monitor trends in the real satellite imagery during the day to assess how much confidence one should have in the model forecasted weather events

- From a ***NWP developer's*** perspective:
  1. Improving forecast via data assimilation
     - The ability to simulate satellite images is the first step towards assimilation of satellite radiances into a NWP model
  2. Useful in revealing model skill (e.g., microphysics processes)
  3. Useful in identifying model errors (both NWP model and the RTM)

Useful in revealing model skills

- Evaluate model skills in predicting cloud systems by comparing with *real* satellite image

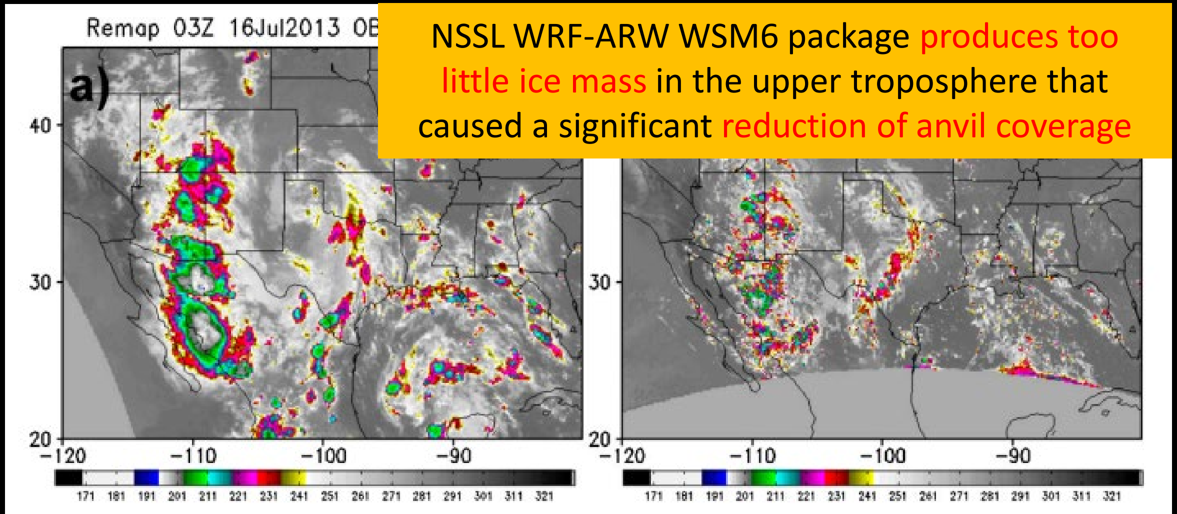




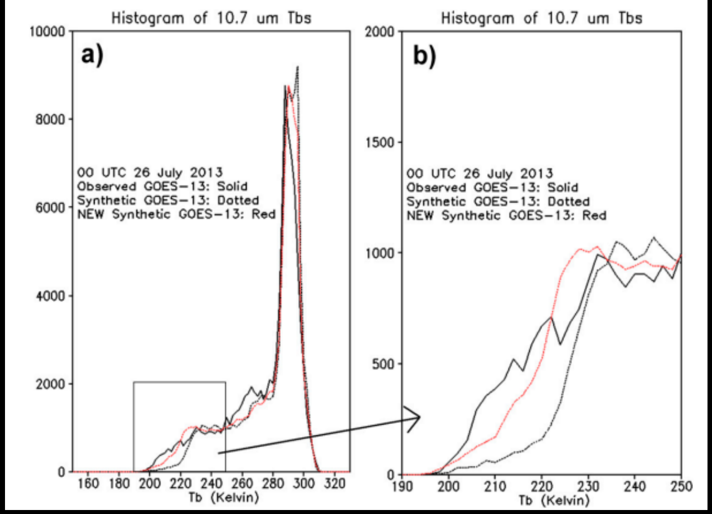
https://www.ecmwf.int/en/elibrary/81337-scale-dependent-verification-precipitation-and-cloudiness-ecmwf

Useful in identifying model errors

- Model errors in microphysics processes (e.g., Grasso et al. 2014)



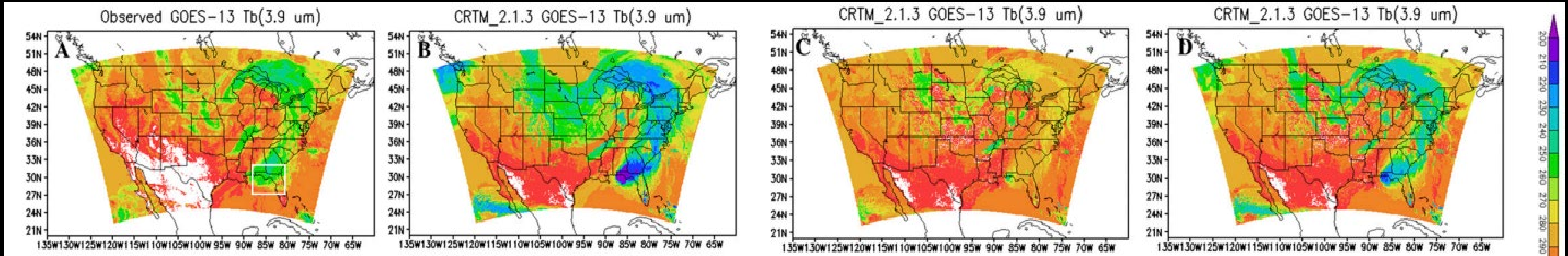
NSSL WRF-ARW WSM6 package produces too little ice mass in the upper troposphere that caused a significant reduction of anvil coverage



It is hypothesized that conversion rates from cloud to graupel & from ice to snow were too excessive, causing lack of ice in simulated anvil.

A 50 % reduction in psaci (snow accretes ice to form snow) conversion

- CRTM errors (e.g., Grasso et al. 2018)



~ 30 K Tb discrepancy between observed & CRTM simulations is evident in RAMS, NSSL-WRF, CAPS-WRF, and HWRF (all diff MP schemes)

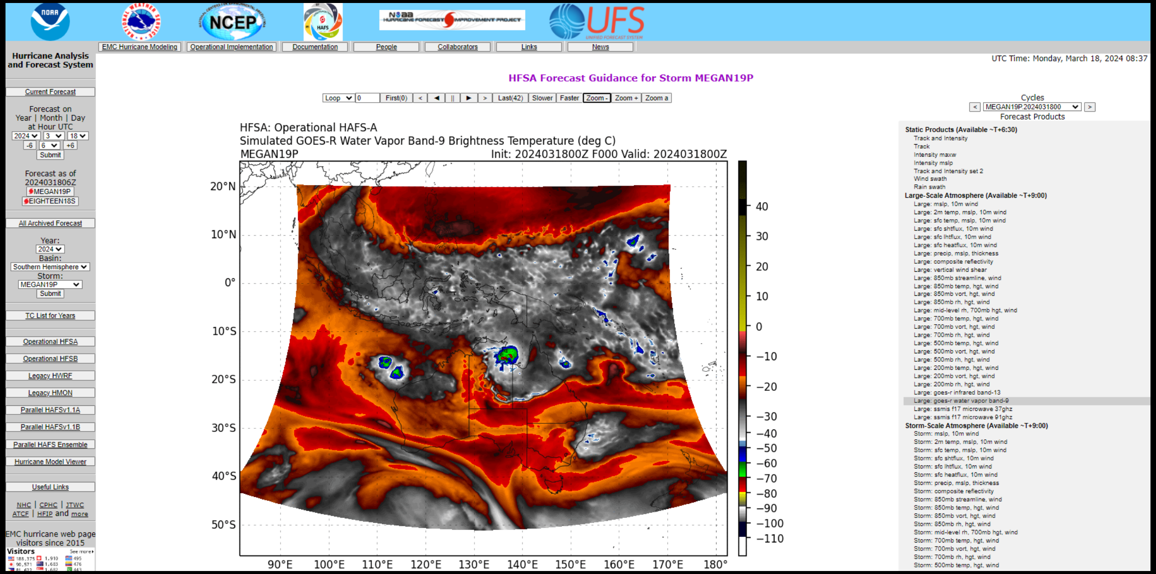
A CRTM error that neglects solar reflection was fixed (since v2.3)

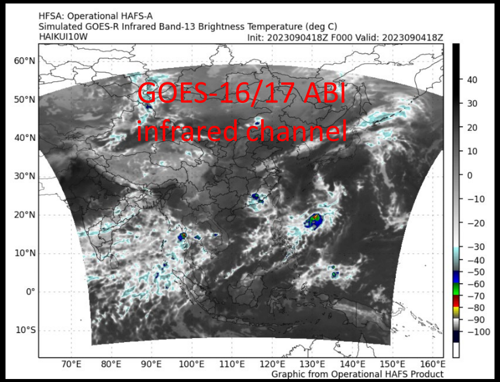
Ice optical property look-up-table (LUT) in CRTM was updated

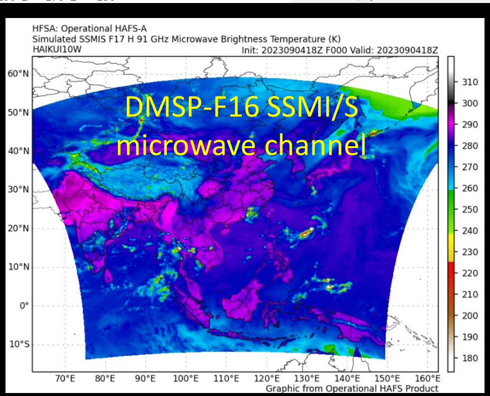
Synthetic satellite imagery in NWP centers

NCEP EMC

https://www.emc.ncep.noaa.gov/hurricane/HFSA/tcall.php

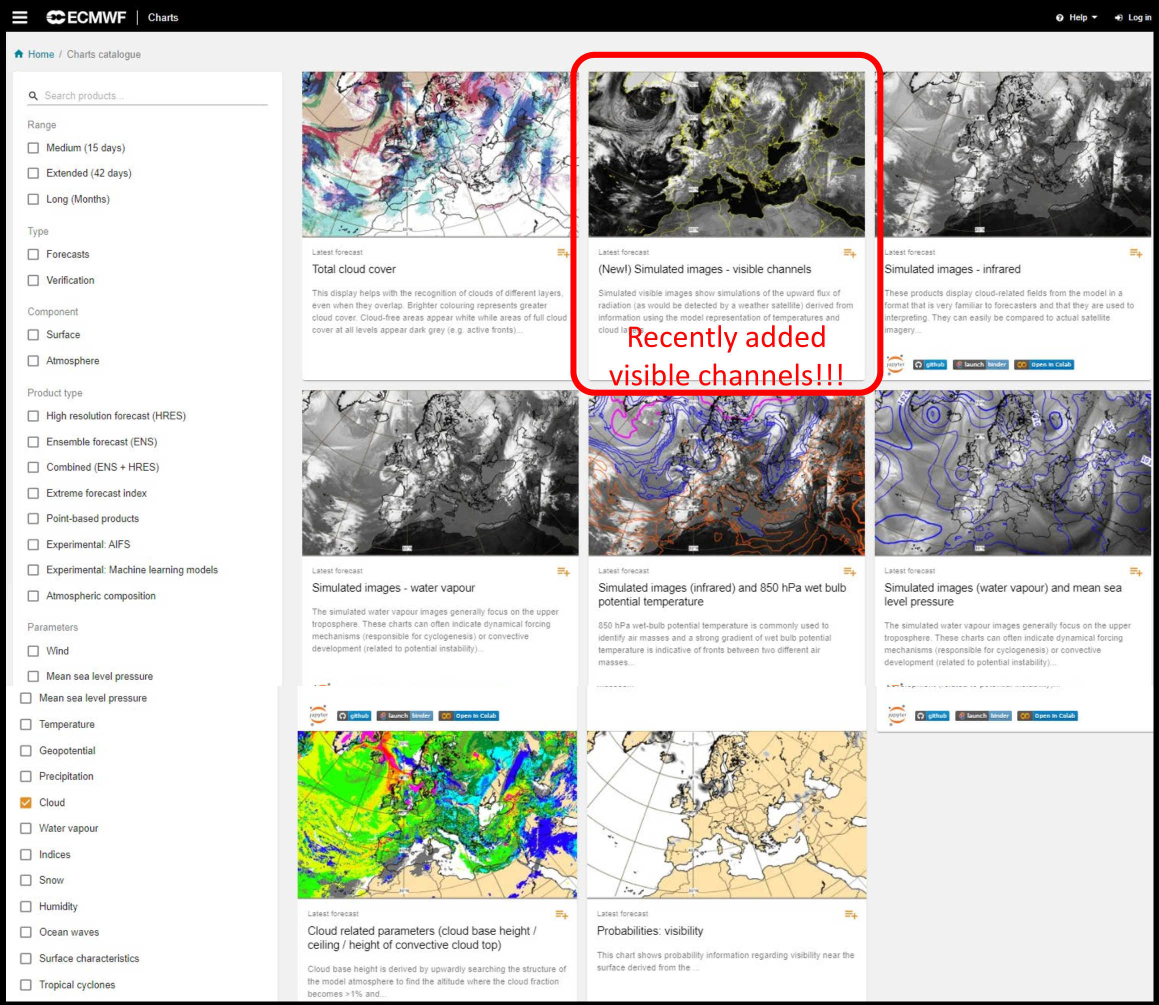






ECMWF

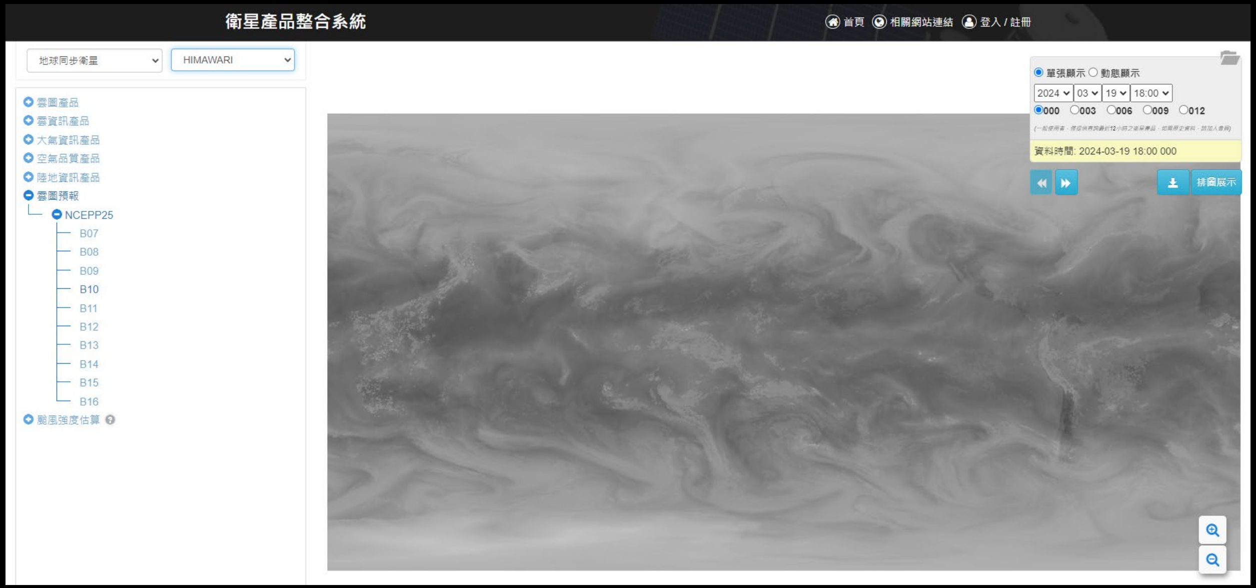
https://confluence.ecmwf.int/display/FCST/Simulated+satellite+data



Synthetic satellite imagery in NWP centers

CWA

https://satimage.cwb.gov.tw/SPD/?menu_index=0

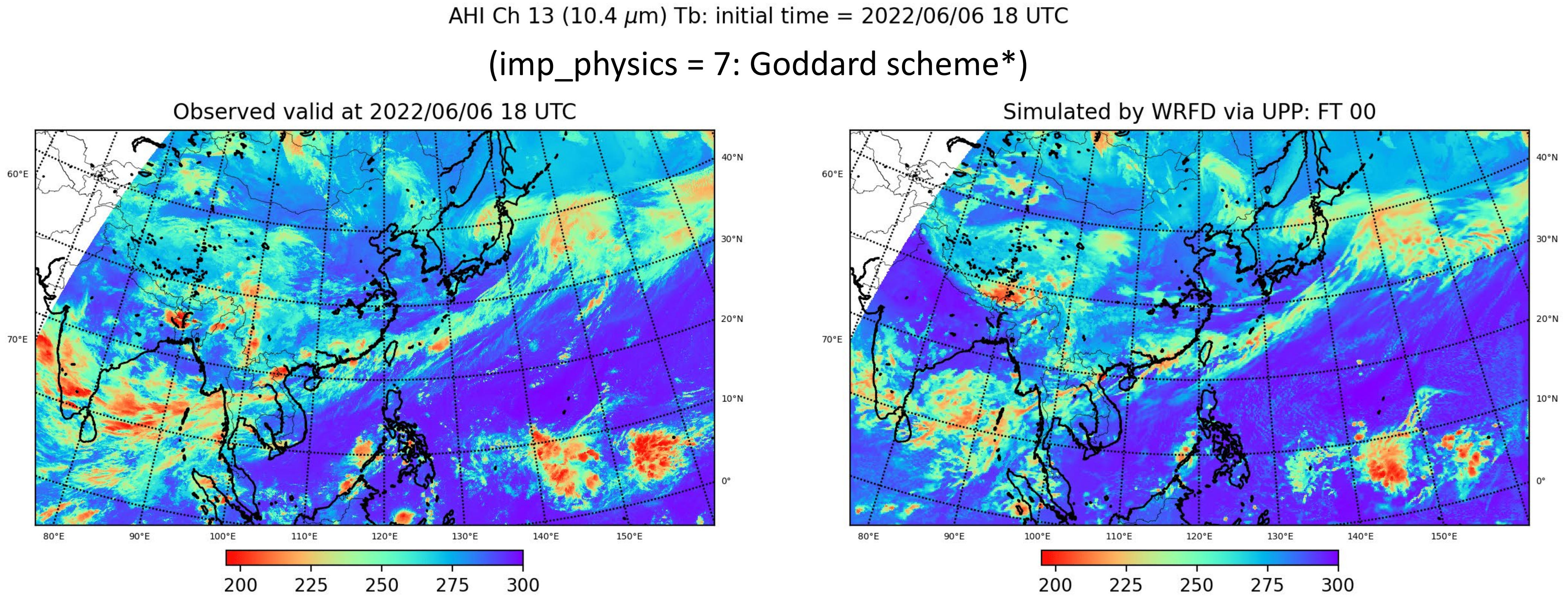


- These are Himawari 8/9 AHI synthetic satellite images from NCEP 0.25 product created using the JCSDA **Community Radiative Transfer Model (CRTM)**
- An experimental set of products made by the CWA satellite data processing division.

With **CWA WRF**, we can generate synthetic satellite imagery in **higher spatiotemporal intervals** as well as **ensemble** of synthetic satellite images!

- We use the **NCEP Unified Post-Process (UPP)** package, which incorporates the CRTM as the satellite simulator.
- We generate synthetic satellite images for CWAWRF via UPP with modifications made to ensure compatibility and consistency.

Synthetic AHI images from WRFD (d01)

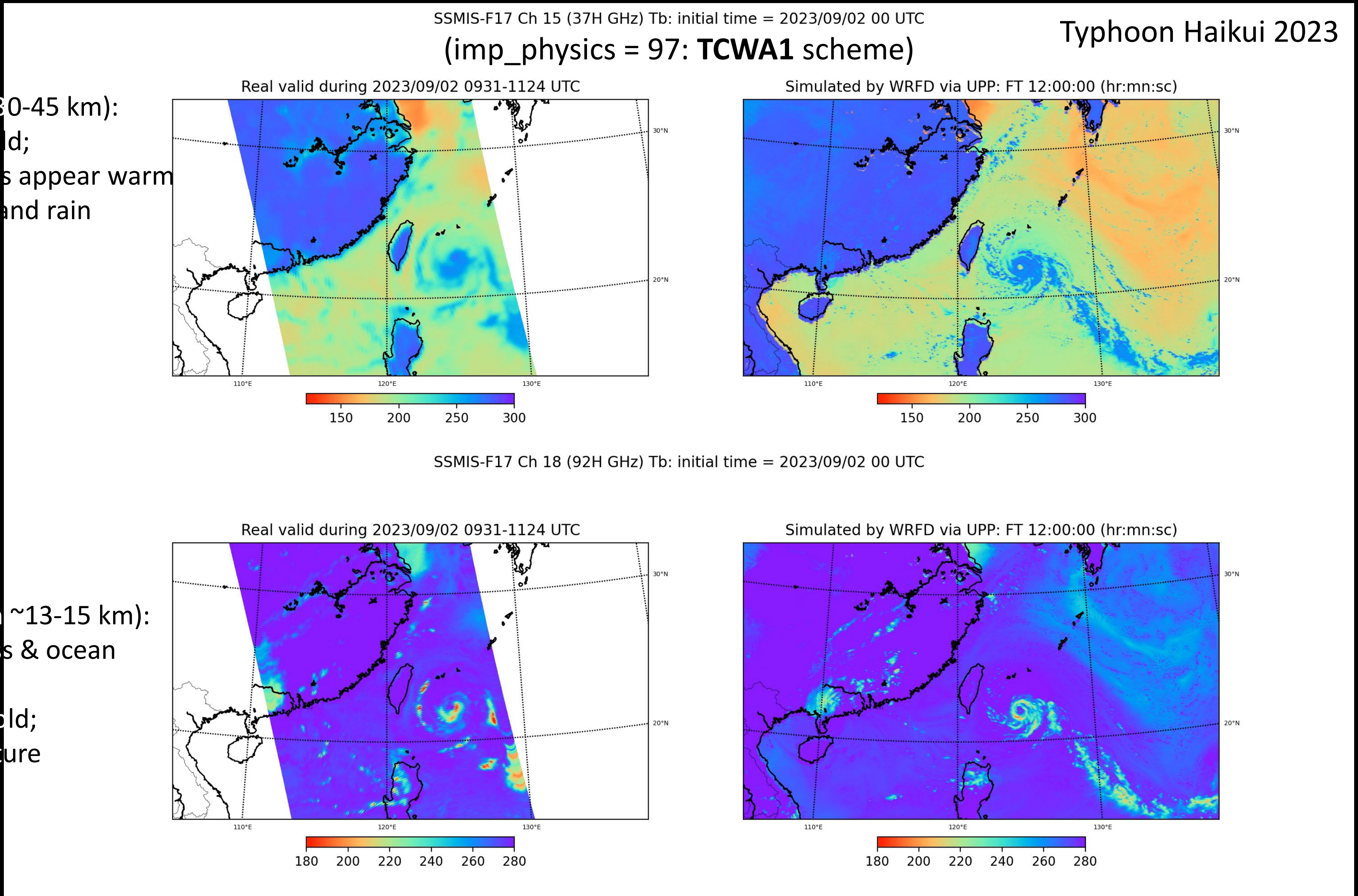


"Satellite data are most valuable when they are ***animated*** *and* ***enhanced with a color table*** *(Suchman et al. 1981)"*

Synthetic SSMI/S images from WRFD (d02)

At ***37*** GHz (spatial resolution ~ 30-45 km):

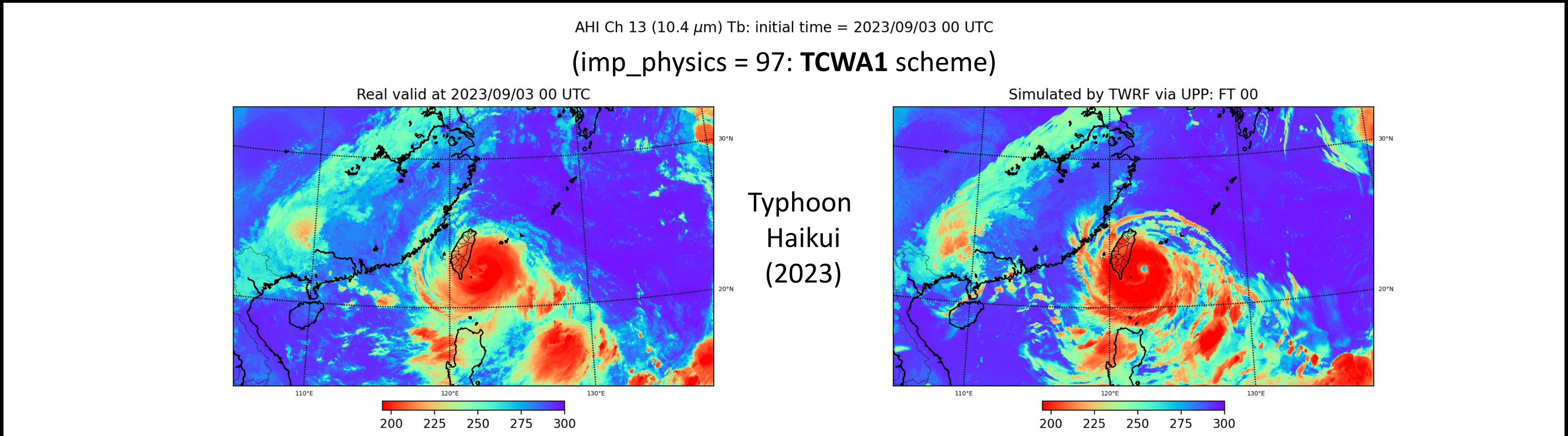
- Ocean appears relatively cold;
- Liquid & precipitating clouds appear warm
- Highlights low-level clouds and rain



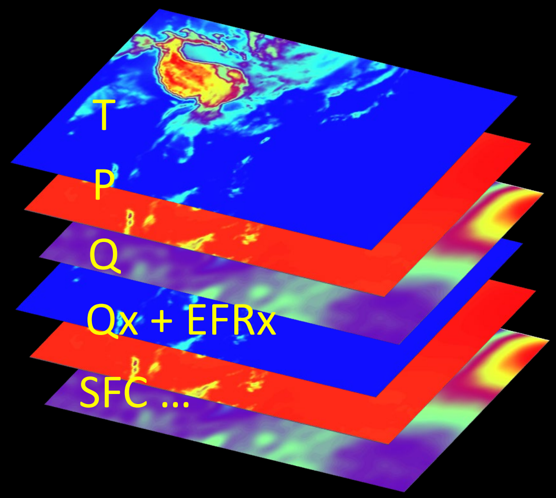
At ***85-91*** GHz (spatial resolution ~13-15 km):

- Liquid clouds, moist air mass & ocean appears relatively warm;
- Deep convection appears cold;
- Reveal internal storm structure

Synthetic AHI images from TWRF (d02)



Remap for image comparison



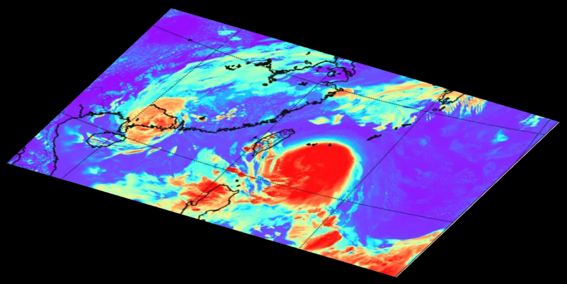
WRF output

↓

UPP (via CRTM)

↓

Synthetic Tb image on WRF grid



Remap* to WRF grid for quantitative comparison

visual comparison

AHI HSD dataset

HS_H08_20220606_*00_*_FLDK*.bz2

↓

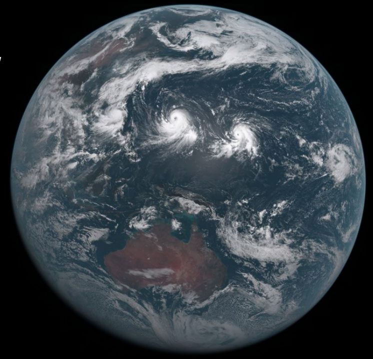
Himawari HSD reader

https://github.com/simonrp84/Himawari_HSD_Reader

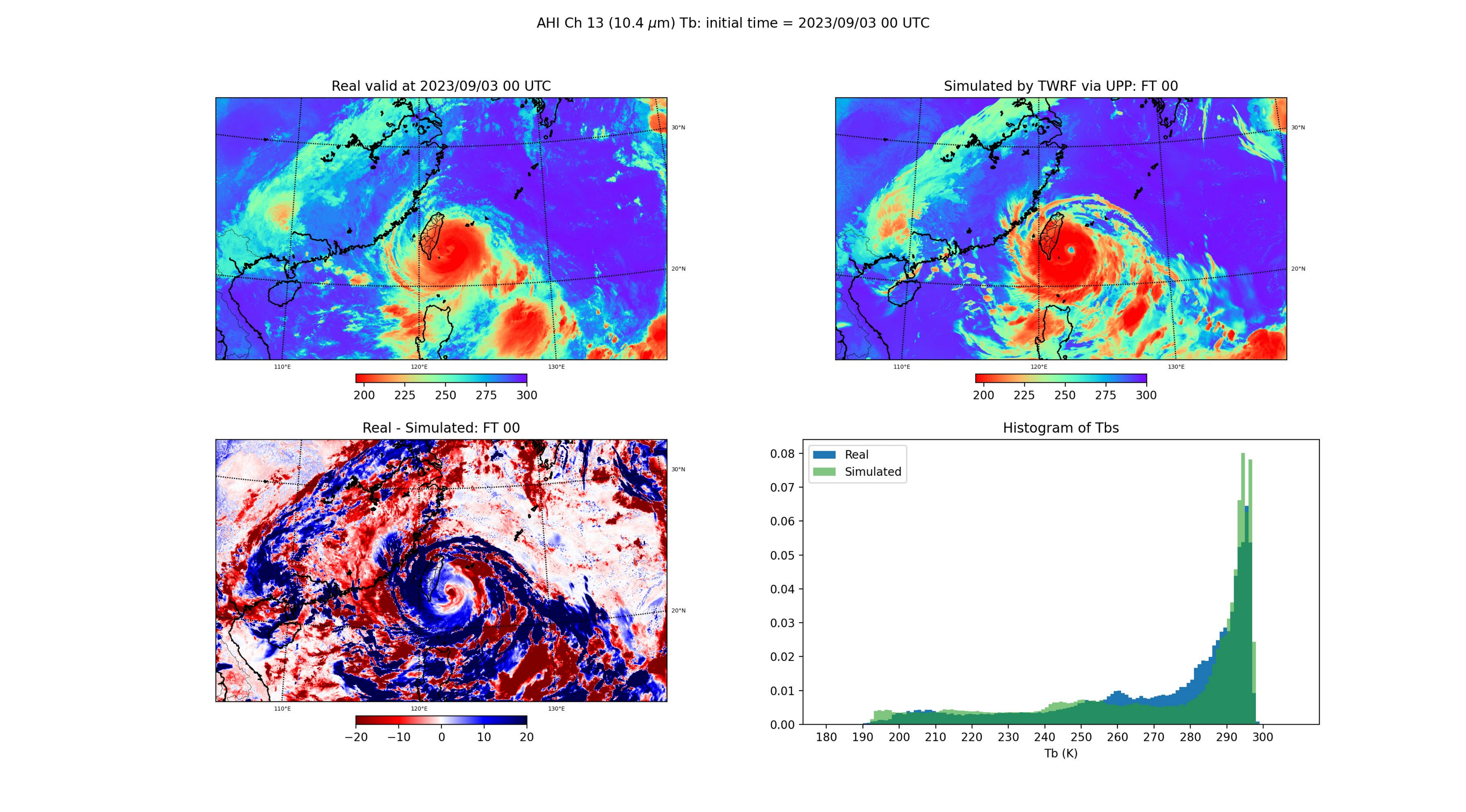
gather all 10 segments, and geo-registered

↓

Real Tb image on native AHI grid



Synthetic AHI images from TWRF (d02)



Summary of CWA WRF synthetic sat image

- Synthetic Himawari-8/9 AHI IR (band 7-16) and SSMI/S MW satellite images can now be generated from the CWA WRF output via the use of UPP.
  - It is currently being implemented to be part of the operational production line of WRFD, providing CWA forecasters with high spatiotemporal resolution of synthetic satellite images to aid their forecast.

- Simple side-by-side visual comparisons suggest that the CWA WRF synthetic satellite images are qualitatively comparable to the real images.

- It is straightforward to extend to other OP systems
  - M06 (TGFS-driven WRFD), WEPS, or AI-driven DWP (if hydrometeors are output variables).
  - Some modifications to the UPP code are required to address the microphysics consistency.

- Now that CWA WRF is successfully interfaced with UPP, we are taking advantages of the available features in UPP to generate products such as 10 m gust potential, surface visibility, etc that are of great interests to CWA forecasters.

Computing time & cost

Tested Case	Domain size (x, y, z)	Forecast length (h)	Output frequency	Total # of processed wrfout files	# of CPU used	Process Time
WRFD	D1: 662 x 386 x 52	72	6-hourly	13	64	~ 10 min
	D2: 1161 x 676 x 52	72	6-hourly	13	64	~ 35 min
TWRF	D2: 1161 x 676 x 52	48	6-hourly	9	64	~ 45 min*
RWRF	451 x 451 x 52	12	1-hourly	13	64	~ 14 min
	451 x 451 x 52	12	1-hourly	13	108	~ 9 min

* Includes 4 channels from SSMI/S (37 H/V GHz and 92 H/V GHz) in addition to 10 AHI channels

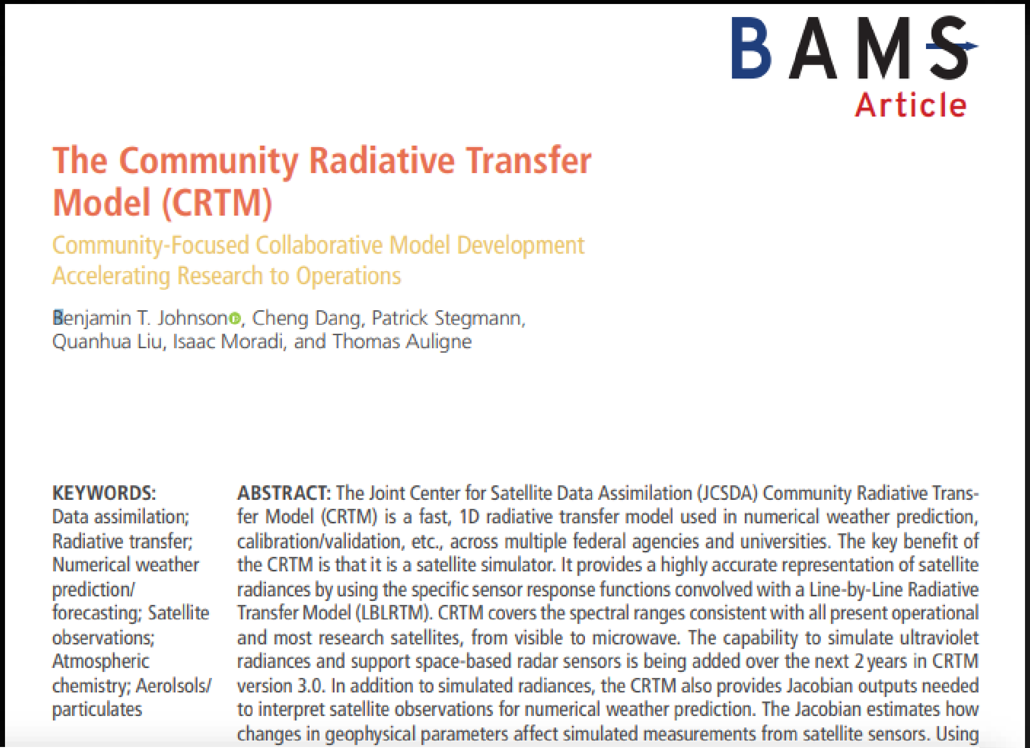
Backup slides

Radiative Transfer Models

- **Community Radiative Transfer Model (CRTM):**
  - Widely used by US operational entities & research community
  - Website: https://www.jcsda.org/jcsda-project-community-radiative-transfer-model
  - Developed and maintained by the JCSDA
  - Designed to be a *library* to link to from other models
  - A fast ***1-D*** RTM using sensor response functions convolved with a ling-by-line RTM
  - CRTM up to v2.4.0 (Oct, 2020) via GitHub (https://github.com/JCSDA/crtm/wiki)
  - CRTM v3 onward for JEDI (latest is v3.1.0): https://github.com/JCSDA/CRTMv3/releases

- **Radiative Transfer for TIROS Operational Vertical Sounder (RTTOV):**
  - Used mostly by the European agencies (e.g., ECMWF, UKMO) and Japanese operational and research entities
  - Website: https://nwp-saf.eumetsat.int/site/software/rttov/
  - Developed and maintained by EUMETSAT-funded NWP SAF
  - Latest public release: v13.2 (Dec, 2022)

- **Advanced Radiative transfer Modeling System (ARMS):** CMA
- **Optimal Spectral Sampling (OSS), Rapid Radiative Transfer Model (RRTM):** AER
- **Atmospheric Radiative Transfer Simulator (ARTS):** U Hamburg & Chalmers U
- **Spherical Discrete Harmonics Ordinate Method (SHDOM):** CU Boulder
- **Simulated Weather Imagery (SWIm; visible-wavelength):** CSU/CIRA/NRL/NOAA GSL
- **… and many more**


BAMS Article

The Community Radiative Transfer Model (CRTM)

Community-Focused Collaborative Model Development Accelerating Research to Operations

Benjamin T. Johnson, Cheng Dang, Patrick Stegmann, Quanhua Liu, Isaac Moradi, and Thomas Auligne

KEYWORDS: Data assimilation; Radiative transfer; Numerical weather prediction/forecasting; Satellite observations; Atmospheric chemistry; Aerolsols/particulates

ABSTRACT: The Joint Center for Satellite Data Assimilation (JCSDA) Community Radiative Transfer Model (CRTM) is a fast, 1D radiative transfer model used in numerical weather prediction, calibration/validation, etc., across multiple federal agencies and universities. The key benefit of the CRTM is that it is a satellite simulator. It provides a highly accurate representation of satellite radiances by using the specific sensor response functions convolved with a Line-by-Line Radiative Transfer Model (LBLRTM). CRTM covers the spectral ranges consistent with all present operational and most research satellites, from visible to microwave. The capability to simulate ultraviolet radiances and support space-based radar sensors is being added over the next 2 years in CRTM version 3.0. In addition to simulated radiances, the CRTM also provides Jacobian outputs needed to interpret satellite observations for numerical weather prediction. The Jacobian estimates how changes in geophysical parameters affect simulated measurements from satellite sensors. Using

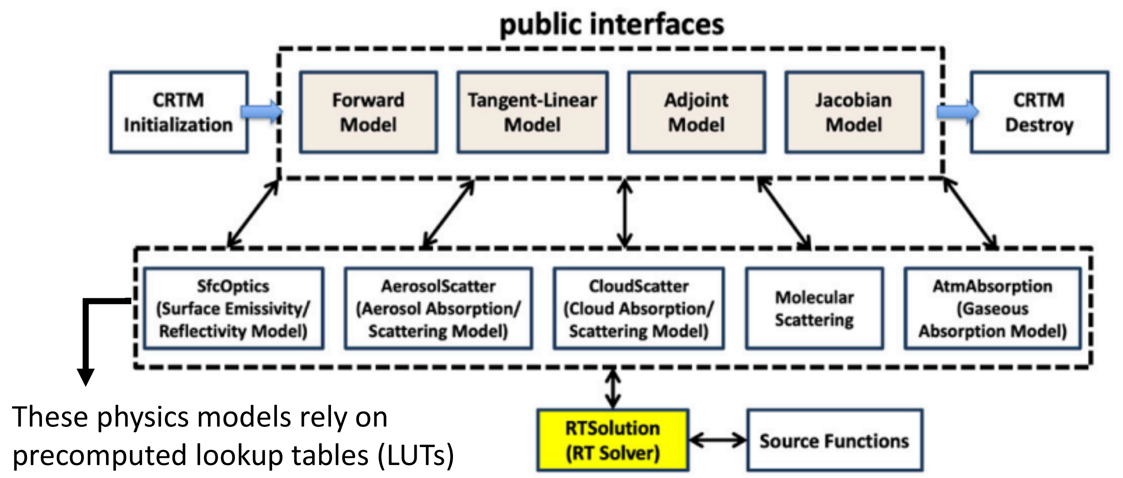
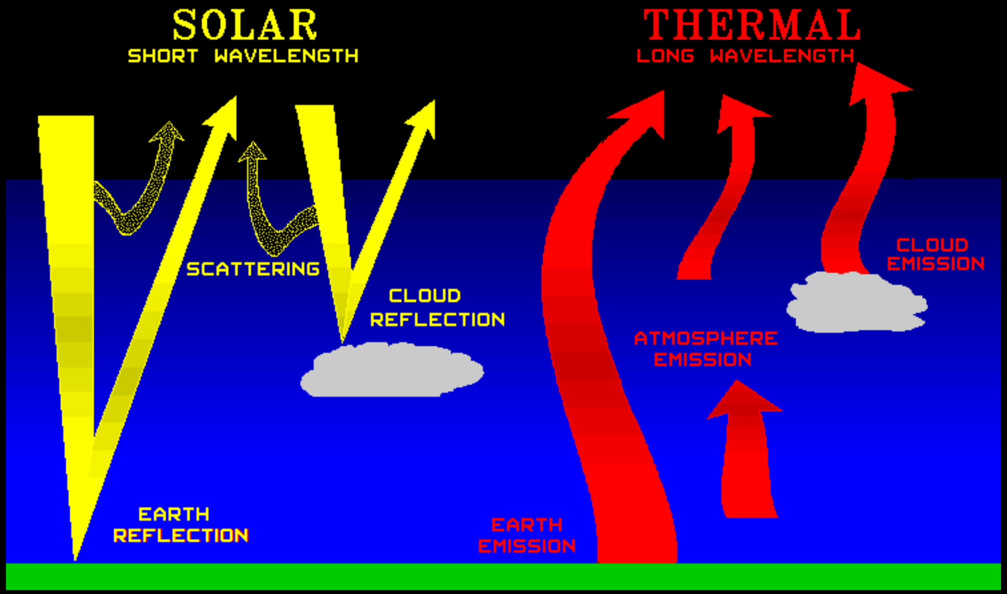
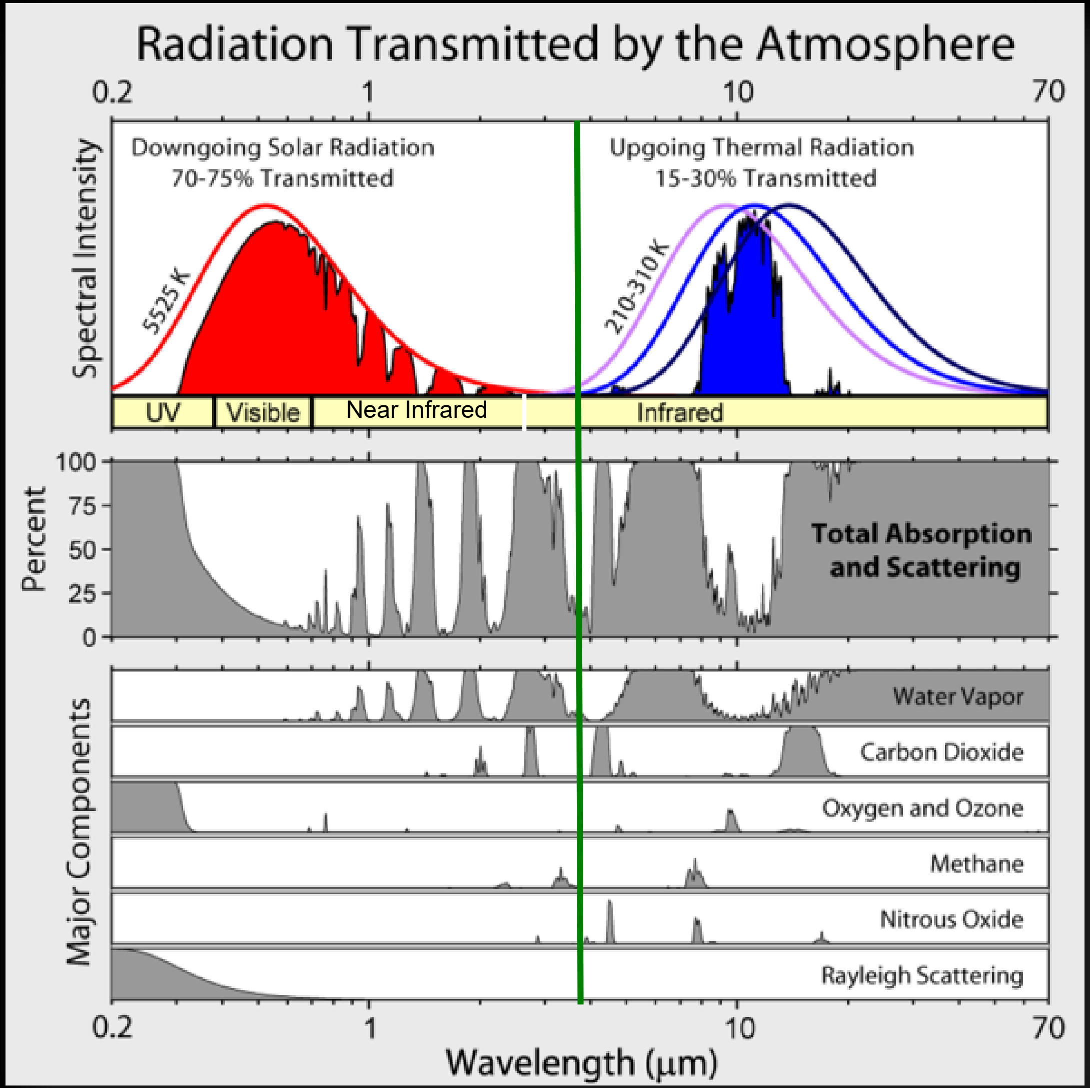


Fig. 1. CRTM public interfaces.

Some basics of Radiative Transfer



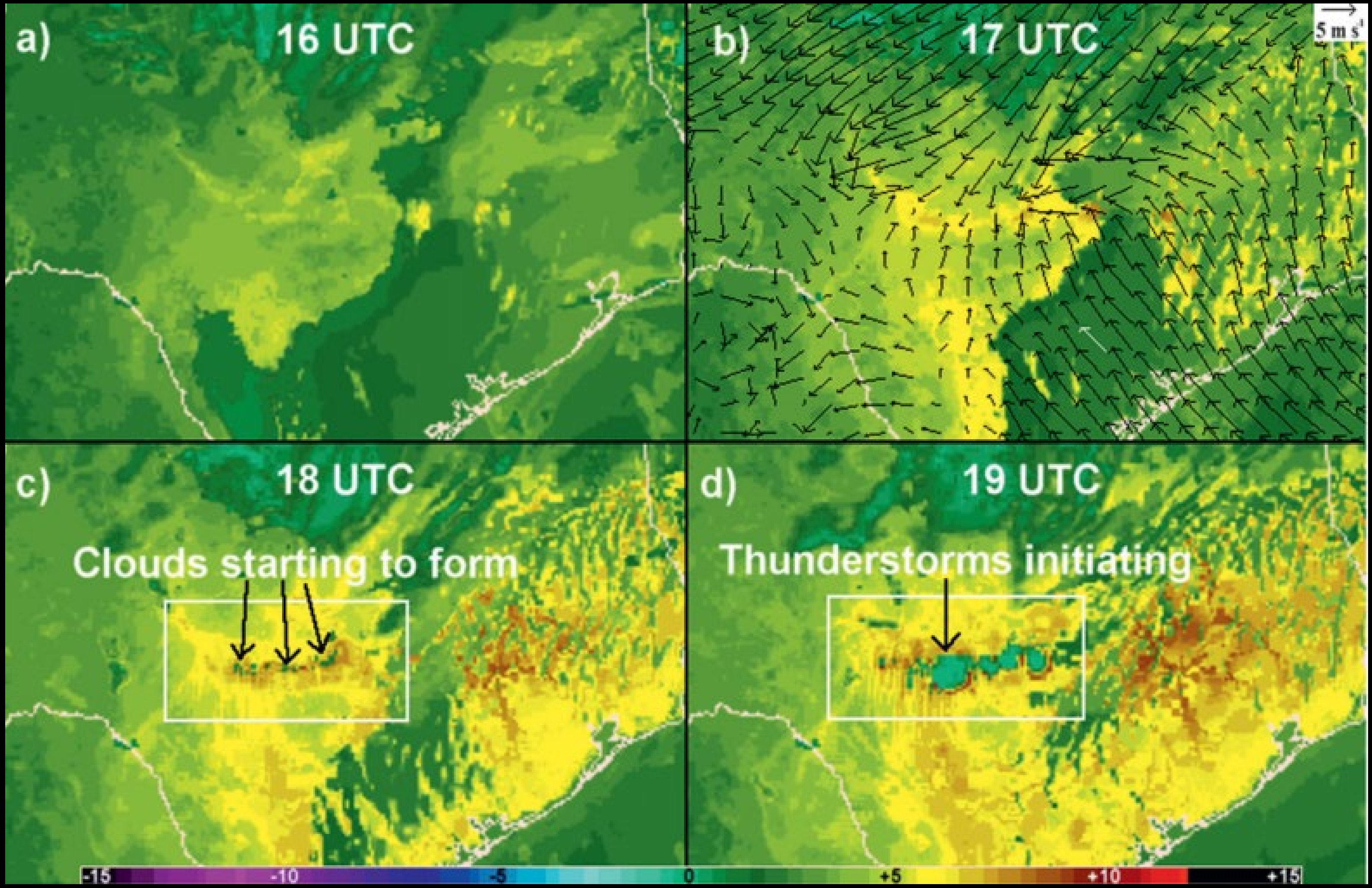


- Radiance to reflectance (percentage; 0-1)
  - Solar/reflective bands (only available at daytime)
  - visible & near-IR (absorption)
- Radiance to brightness temperature (Kelvin)
  - Thermal/emissive bands (day/night)
  - infrared
  - Bands near 3.9 μm are unique because they sense both **earth emitted radiation** and significant **reflected solar radiation** during the day

fcster can apply same techniques to sim. images

Synthetic 10.35 – 12.3 µm channel difference from the NSSL WRF initialized at 0000 UTC 20 April 2011

(same in N-AWIPS)



10.35 – 12.3 µm brightness temperature differences.

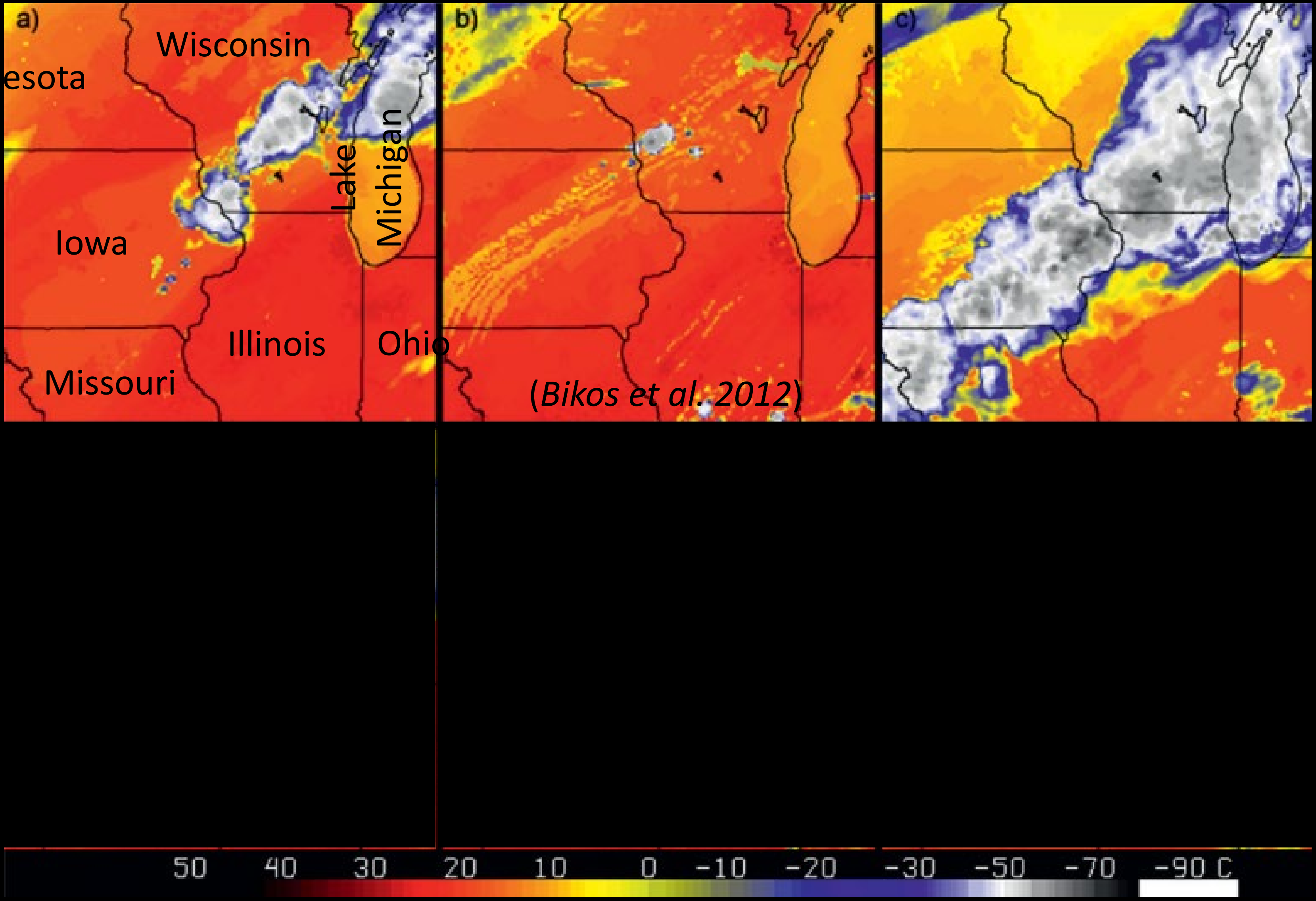
Deepening water vapor associated with low-level convergence will then appear as local maxima increasing with time.

Could be useful in forecasting cloud and convection formation locations.

Influence forecaster confidence in modeled event

NSSL 4-km WRF-ARW synthetic images

0900 LT June 8, 2011 | 1500 LT June 8, 2011 | 2000 LS June 8, 2011



Morning thunderstorm was depicted well (a vs. d), which increased forecaster's confidence that thunderstorms would redevelop later in the day despite the extensive morning cloud cover.

The need of microphysics-consistent cloud and precipitation single-scattering property LUTs

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2017JD026494

Key Points:
- The CRTM is modified to use microwave scattering look-up tables made consistent with cloud/precipitation properties of microphysics schemes
- The CRTM as-released, using effective radius to specify cloud particle sizes, produces higher brightness temperatures than the modified CRTM
- Brightness temperatures are sensitive to the assumed bulk density of graupel and ice cloud particle sizes produced by microphysics schemes

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Citation:
Sieron, S. B., E. E. Clothiaux, F. Zhang, Y. Lu, and J. A. Otkin (2017), Comparison of using distribution-specific versus effective radius methods for hydrometeor single-scattering properties for all-sky microwave satellite radiance simulations with different microphysics parameterization schemes, *J. Geophys. Res. Atmos.*, 122, 7027–7046, doi:10.1002/2017JD026494.

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Comparison of using distribution-specific versus effective radius methods for hydrometeor single-scattering properties for all-sky microwave satellite radiance simulations with different microphysics parameterization schemes

Scott B. Sieron[1], Eugene E. Clothiaux[1], Fuqing Zhang[1], Yinghui Lu[1], and Jason A. Otkin[2]

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Abstract The Community Radiative Transfer Model (CRTM) presently uses one look-up table (LUT) of cloud and precipitation single-scattering properties at microwave frequencies, with which any particle size distribution may interface via effective radius. This may produce scattering properties insufficiently representative of the model output if the microphysics parameterization scheme particle size distribution mismatches that assumed in constructing the LUT, such as one being exponential and the other monodisperse, or assuming different particle bulk densities. The CRTM also assigns a 5 μm effective radius to all nonprecipitating clouds, an additional inconsistency. Brightness temperatures are calculated from 3 h convection-permitting simulations of Hurricane Karl (2010) by the Weather Research and Forecasting model; each simulation uses one of three different microphysics schemes. For each microphysics scheme, a consistent cloud scattering LUT is constructed; the use of these LUTs produces differences in brightness temperature fields that would be better for analyzing and constraining microphysics schemes than using the CRTM LUT as-released. Other LUTs are constructed which contain one of the known microphysics inconsistencies with the CRTM LUT as-released, such as the bulk density of graupel, but are otherwise microphysics-consistent; differences in brightness temperature to using an entirely microphysics-consistent LUT further indicate the significance of that inconsistency. The CRTM LUT as-released produces higher brightness temperature than using microphysics-consistent LUTs. None of the LUTs can produce brightness temperatures that can match well to observations at all frequencies, which is likely due in part to the use of spherical particle scattering.

Key single-scattering properties include extinction efficiency, single scattering albedo, asymmetry factor and phase function, etc which represents the extinction, absorption, and scattering abilities of particles respectively.

- In “old” CRTM, a single (PSD) scattering look-up-table (LUT) approach that parameterizes the PSD to scattering properties via effective radius (R_{eff}) per hydrometeor species was used:
  - LUTs for liquid species are ***func (freq, R_{eff}, T)*** and LUT for precipitation species are ***func (freq, effR, phase or particle bulk density)***
  - They are used to calculate the values of single-scattering properties under a particular PSD of the specified bulk density.
- But, CRTM did not specify (in literature & source code) what PSDs were used nor did it specifies how the R_{eff} relates to these PSDs… which scattering regime? Geometric/nonselective, Rayleigh, or Mie scattering.
- If the PSD by a microphysics scheme do not match those used in constructing the CRTM scattering LUT (the so-called inconsistency), then the CRTM would incorrectly express the scattering properties of the clouds and precipitation.
- Baran et al. (2014, 2016) showed improved modeled short/longwave fluxes by directly coupling PSDs to scattering properties instead of parameterizing the relationship via R_{eff}.

The need of microphysics-consistent cloud and precipitation single-scattering property LUTs

CRTM (as-released): *R_{eff}* parameterized scattering properties

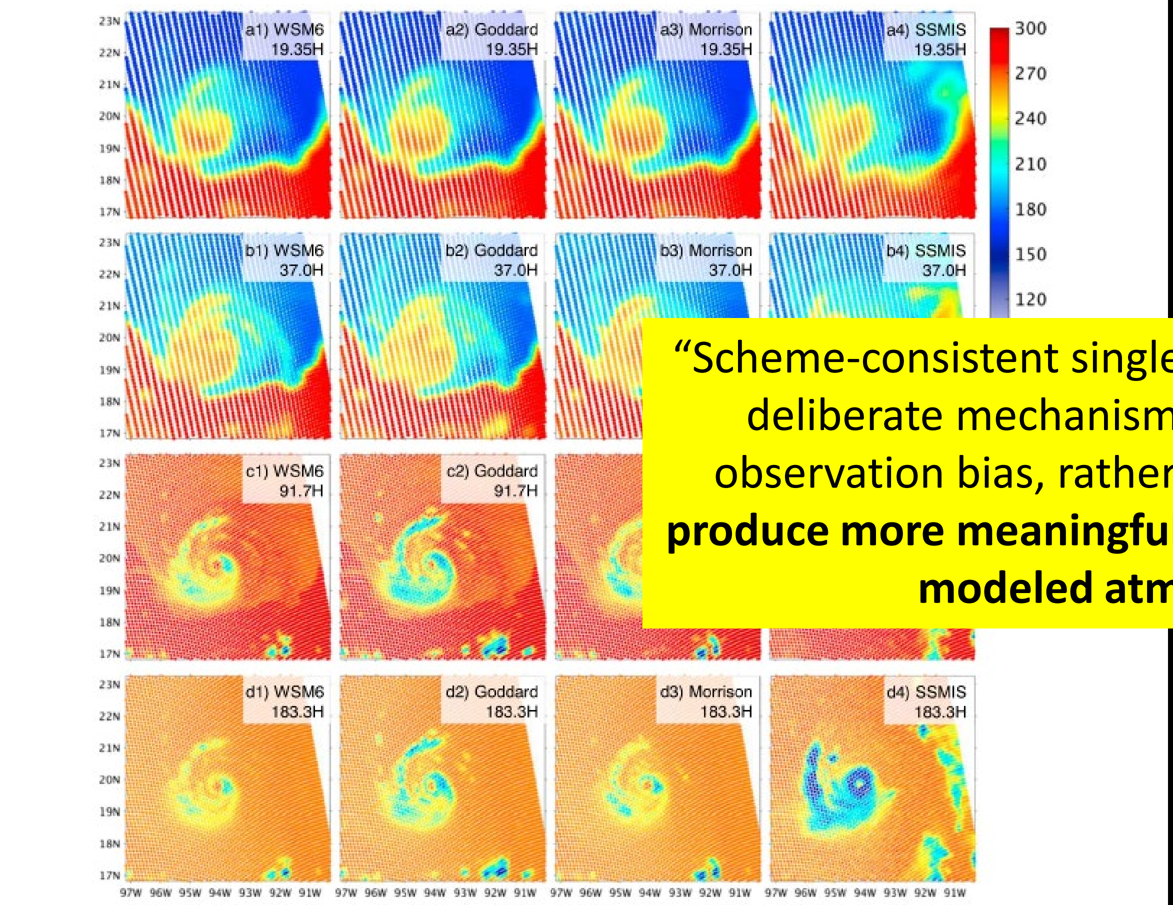


Figure 4. Same as Figure 3 but using CRTM as-released. Values of effective radius for all species but liquid and ice cloud are the ratio of third and second moments of the particle size distribution specified for each species by the respective microphysics scheme (CRTM-RE).

Modified CRTM using distribution-specific scattering properties

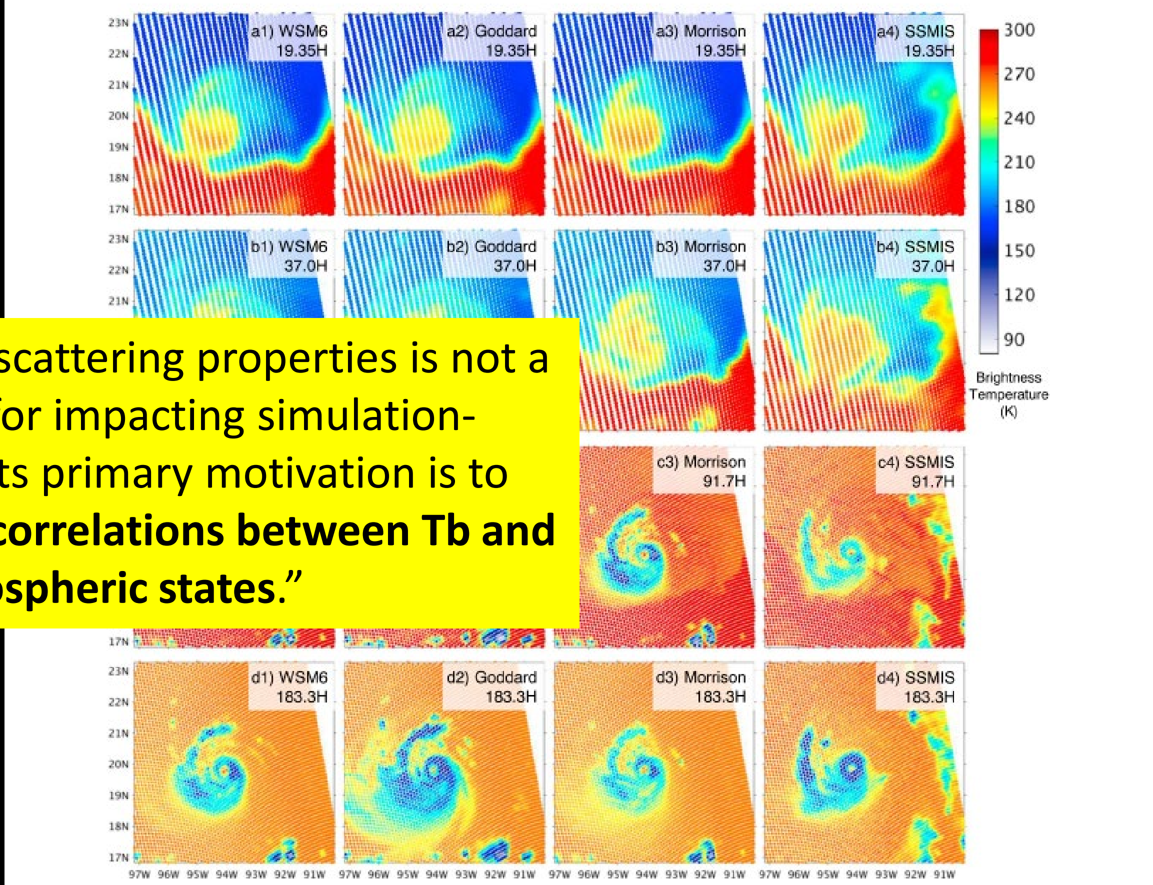


Figure 3. (columns 1–3) Outputs of CRTM-DS (microphysics-consistent hydrometeor scattering properties) from WRF simulations and (column 4) SSMIS observations of Hurricane Karl valid at 0000 UTC and 0117 UTC, respectively, on 17 September. The microphysics schemes used in the WRF simulations are (1) WSM6, (2) Goddard, and (3) Morrison.

"Scheme-consistent single-scattering properties is not a deliberate mechanism for impacting simulation-observation bias, rather its primary motivation is to **produce more meaningful correlations between Tb and modeled atmospheric states**."

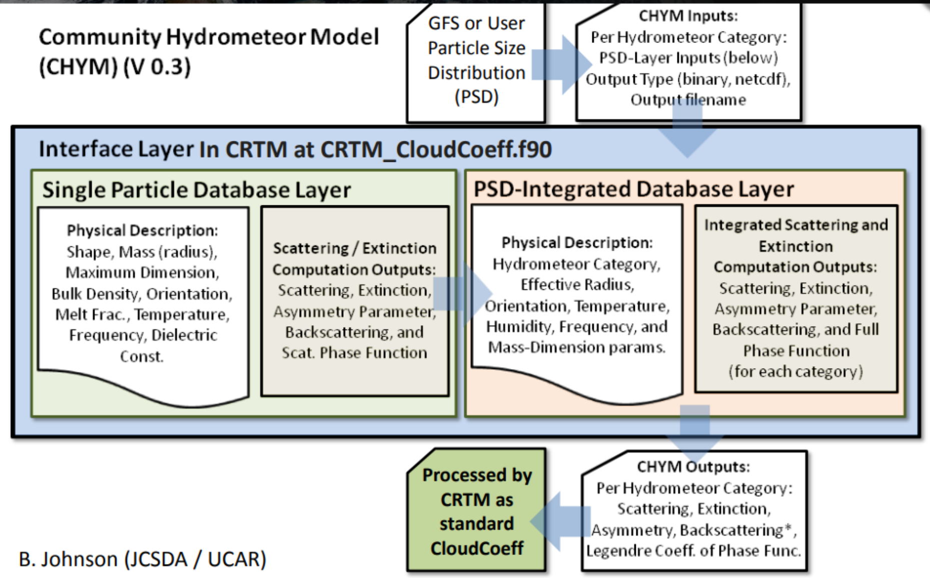
CRTM RELEASE 2.4.0 KEY FEATURES

CRTM release 2.4.0 contains a host of new features, while still supporting all prior satellite systems:

- Backwards interface compatibility with CRTM v2.3.0 (current operational version).
- Support for upcoming and updated sensors: Earth Observing Nanosatellite-Microwave, Sentinel-3A Sea and Land Surface Temperature (SLSTR), Meteosat-11 SEVIRI, GOES 17 ABI, Metop-C AVHRR and IASI, Soil Moisture Anisotropy Probe (SMAP), Soil Moisture Ocean Salinity (SMOS), Temporal Experiment for Storms and Tropical Systems - Demonstration (TEMPEST-D), MI-L COMS, FY4-GIIRS, TROPICS, and many more under development.
- Expanded scattering tables for more physically realistic cloud and precipitation simulations. Additional optional aerosol species from the CMAQ model. Enhanced physical consistency between CRTM and model microphysics (i.e., GFDL, Thompson, and WSM6).
- (User Option) Multi-threaded parallelization using OpenMP directives: enables improved wall-clock performance. Improved loop-level performance with code

Daryl Kleist (NOAA) sort of mentioned this when he visited last year

Community Hydrometeor Model (CHYM)



B. Johnson (JCSDA / UCAR)

- (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
- (3) New: Addition of Aerosols to CHYM (similar to Clouds/ Precip. in structure)

CRTM 1: CRTM REL-3.0.0 Plans

- **Physical properties / ongoing work toward version 3.0**
  - **Aerosols**: Develop new scattering tables to conform with updated aerosol properties (PSD, index of refraction, etc.) in coordination with the "A-Team". Determine whether CMAQ adequately covers NAAPS species; NRL + others will provide an intercomparison of AOD/aerosol speciation operators from GoCart, NAAPS, CMAQ and NGAC.
  - **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.
  - **Shortwave / IR improvements:** New Hire via Hurricane Supplemental Funding
  - **Active Sensor support:** Lidar and Radar operators are under development, and are expected to be available in V3.0
- **CRTM 3.0 alpha release Q4FY18.**
  - Targeting core functionality (polarization and optimization)

https://cpaess.ucar.edu/sites/default/files/meetings/2019/documents/Johnson.pdf

https://www.jcsda.org/news-blog/2020/8/28/version-30-of-jcsdas-community-radiative-transfer-model-crtm

CRTM v3

https://github.com/JCSDA/CRTMv3/releases

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BenjaminTJohnson

v3.1.0-skylabv8

262599d

Compare

CRTM v3.1.0 release for JEDI/Skylab v8

What's Changed

- 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
- merging release/REL-3.1.0 back into develop by @BenjaminTJohnson in #106
- Add aerosol bypass in CRTM by @chengdang in #115
- Add reflectance output (feature/crtm_add_reflectance_output) by @BenjaminTJohnson in #99
- Comment out alert messages with Invalid WMO Satellite Id by @chengdang in #118
- Ensuring that surface: reflectivity, direct_reflectivity, and emissivity are bounded from [0:1], inclusive. by @BenjaminTJohnson in #123
- Revert "Ensuring that surface: reflectivity, direct_reflectivity, and emissivity are bounded from [0:1], inclusive." by @BenjaminTJohnson in #126

See Moradi et al. (2022)

DDA stands for Discrete Dipole Approximation; it is a technique for simulating the optical/scattering properties of non-spherical hydrometeors in the microwave region

JGR Atmospheres

RESEARCH ARTICLE

10.1029/2022JD036957

Implementation of a Discrete Dipole Approximation Scattering Database Into Community Radiative Transfer Model

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Key Points:

- The cloud scattering lookup tables of Community Radiative Transfer Model (CRTM) discussed and documented
- A new scattering database generated using the Discrete Dipole Approximation (DDA) implemented into CRTM
- The scattering parameters computed using the DDA technique perform considerably better than Mie coefficients for microwave frequencies

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Author Contributions:

Conceptualization: Isaac Moradi
Data curation: Isaac Moradi
Formal analysis: Isaac Moradi

Abstract The Community Radiative Transfer Model (CRTM) is a fast model that requires bulk optical properties of hydrometeors in the form of lookup tables to simulate all-sky satellite radiances. Current cloud scattering lookup tables of CRTM were generated using the Mie-Lorenz theory thus assuming spherical shapes for all frozen habits, while actual clouds contain frozen hydrometeors with different shapes. The Discrete Dipole Approximation (DDA) technique is an effective technique for simulating the optical properties of non-spherical hydrometeors in the microwave region. This paper discusses the implementation and validation of a comprehensive DDA cloud scattering database into CRTM for the microwave frequencies. The original DDA database assumes total random orientation in the calculation of single scattering properties. The mass scattering parameters required by CRTM were then computed from single scattering properties and water content dependent particle size distributions. The new lookup tables eliminate the requirement for providing the effective radius as input to CRTM by using the cloud water content for the mass dimension. A collocated dataset of short-term forecasts from Integrated Forecast System of the European Center for Medium-Range Weather Forecasts and satellite microwave data was used for the evaluation of results. The results overall showed that the DDA lookup tables, in comparison with the Mie tables, greatly reduce the differences among simulated and observed values. The Mie lookup tables especially introduce excessive scattering for the channels operating below 90 GHz and low scattering for the channels above 90 GHz.

Cloud coefficients for parametrizations

CRTM

fedecutraro — Aug 2023

Hi,
I've recently compiled version 3 of CRTM and I wanted to use the cloud coefficient developed for WSM6 parametrization but I receive the following error when using the IR channels of GOES16-ABI

forrtl: severe (408): fort: (3): Subscript #1 of the array FREQUENCY_IR has value -2 which is less than the lower bound of 1

BenjaminTJohnson — Aug 2023

The microphysics changes are only relevant to microwave, no infrared for these tables. I realize that's a limitation, but that's what we received from our partner.

Please feel free to reach out to me directly (bjohns@ucar.edu) with any additional questions.

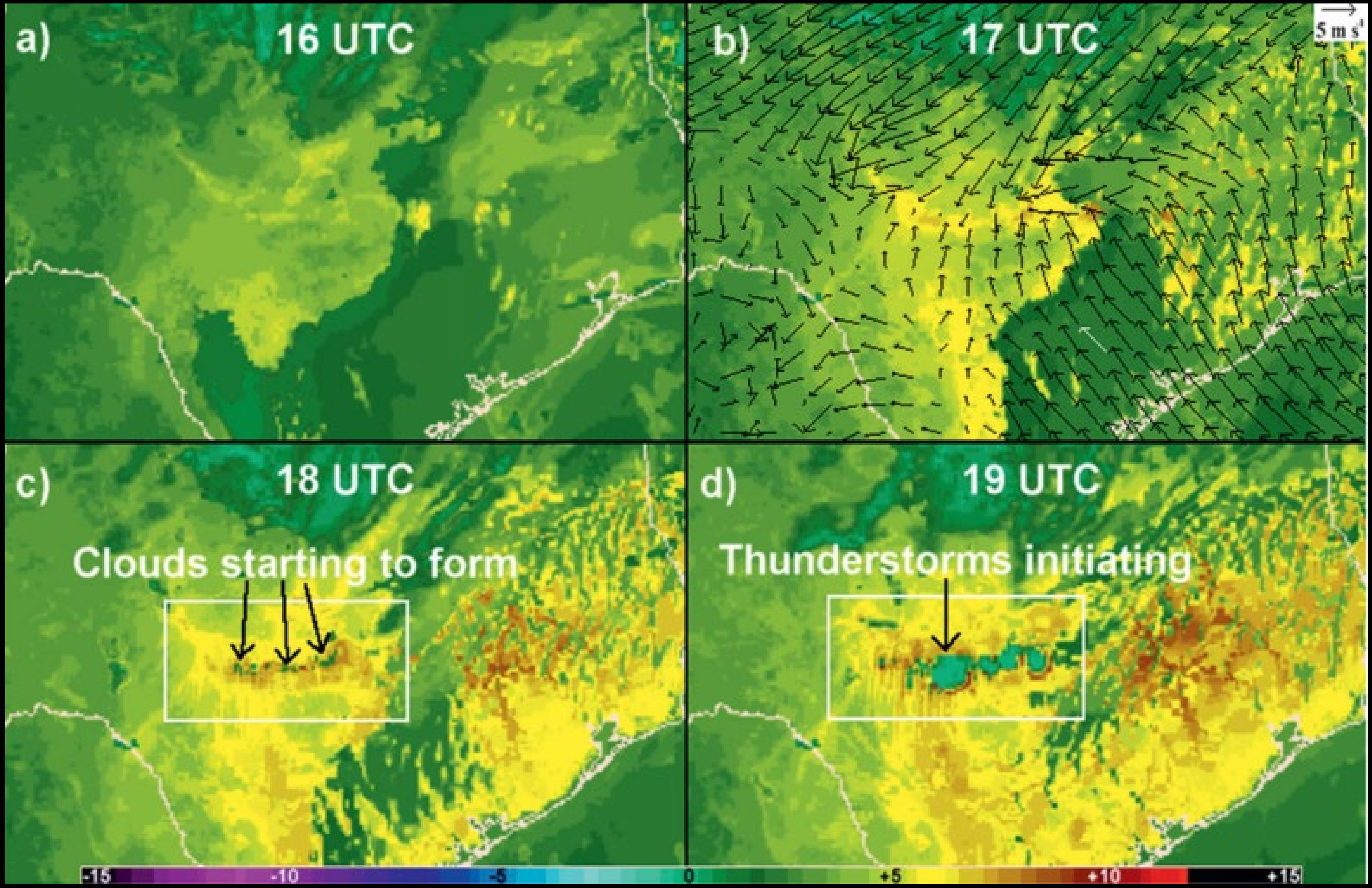
https://forums.jcsda.org/t/cloud-coefficients-for-parametrizations/495

fcster can apply same techniques to sim. images

Synthetic
10.35 – 12.3 µm
channel difference
from the NSSL WRF
initialized at 0000
UTC 20 April 2011

(same in N-AWIPS)

(*Bikos et al. 2012*)



Areas of deeper water vapor will have more positive 10.35 – 12.3 µm brightness temperature differences.

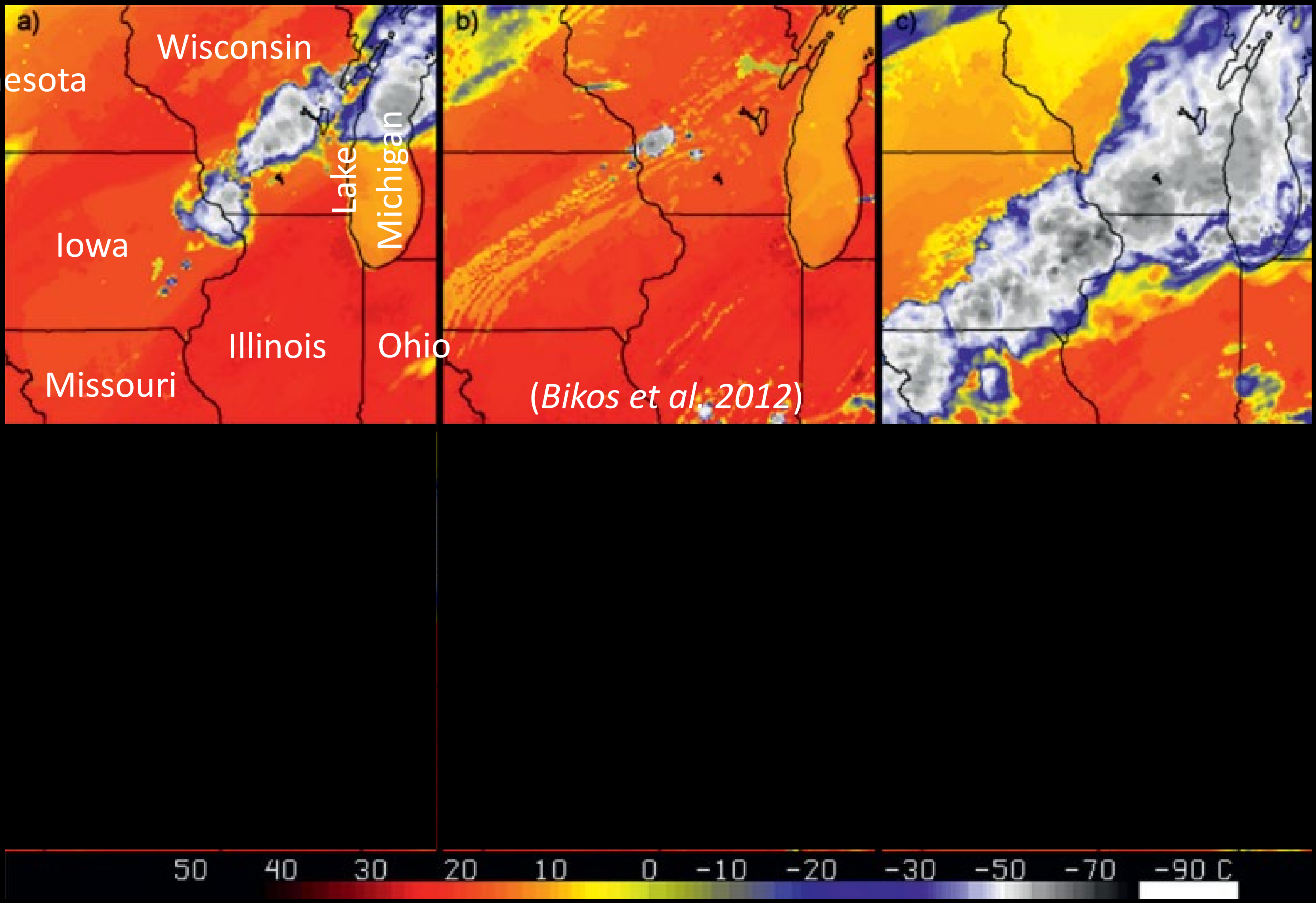
Deepening water vapor associated with low-level convergence will then appear as local maxima increasing with time.

Could be useful in forecasting cloud and convection formation locations.

Influence forecaster confidence in modeled event

NSSL 4-km WRF-ARW synthetic images

0900 LT June 8, 2011 | 1500 LT June 8, 2011 | 2000 LS June 8, 2011



Morning thunderstorm was depicted well (a vs. d), which increased forecaster's confidence that thunderstorms would redevelop later in the day despite the extensive morning cloud cover.

atmosphere

```
atmosphere(1)%n_layers = lm
atmosphere(1)%absorber_id(1) = H2O_ID
atmosphere(1)%absorber_id(2) = O3_ID
atmosphere(1)%absorber_units(1) = MASS_MIXING_RATIO_UNITS
atmosphere(1)%absorber_units(2) = VOLUME_MIXING_RATIO_UNITS
atmosphere(1)%level_pressure(0) = TOA_PRESSURE

atmosphere(1)%cloud_fraction(k) = min(max(cfr(i,j,k),0.),1.)
atmosphere(1)%level_pressure(k) = pint(i,j,k+1)/r100
atmosphere(1)%pressure(k)       = pmid(i,j,k)/r100
atmosphere(1)%temperature(k)    = t(i,j,k)
atmosphere(1)%absorber(k,1)  = max(0.  & ,q(i,j,k)*h1000/(h1-q(i,j,k))) ! use mixing ratio
atmosphere(1)%absorber(k,2)  = max(ozsmall,o3(i,j,k)*constoz)
```

!! Depending on the **microphysics** option: **code modifications needed** !!!

```
atmosphere(1)%cloud(1)%n_layers = lm
atmosphere(1)%cloud(1)%Type = WATER_CLOUD
atmosphere(1)%cloud(2)%n_layers = lm
atmosphere(1)%cloud(2)%Type = ICE_CLOUD
atmosphere(1)%cloud(3)%n_layers = lm
atmosphere(1)%cloud(3)%Type = RAIN_CLOUD
atmosphere(1)%cloud(4)%n_layers = lm
atmosphere(1)%cloud(4)%Type = SNOW_CLOUD
atmosphere(1)%cloud(5)%n_layers = lm
atmosphere(1)%cloud(5)%Type = GRAUPEL_CLOUD
```

Effective radius is conceptualized as the “mean radius for scattering”

```
! 03/15/2024 TCW: add features specific to CWA WRFD: following module_ra_goddard.F in WRFV3.8.1
        else if (imp_physics==7) then
          atmosphere(1)%cloud(1)%water_content(k)=max(0.,qqw(i,j,k)*dpovg) ! water
          atmosphere(1)%cloud(2)%water_content(k)=max(0.,qqi(i,j,k)*dpovg) ! ice
          atmosphere(1)%cloud(3)%water_content(k)=max(0.,qqr(i,j,k)*dpovg) ! rain
          atmosphere(1)%cloud(4)%water_content(k)=max(0.,qqs(i,j,k)*dpovg) ! snow
          atmosphere(1)%cloud(5)%water_content(k)=max(0.,qqg(i,j,k)*dpovg) ! graupel
          atmosphere(1)%cloud(1)%effective_radius(k)=10. ! water
          atmosphere(1)%cloud(2)%effective_radius(k)=min(125.,max(25.,125.+(t(i,j,k)-243.16)*5.)) ! ice
          atmosphere(1)%cloud(3)%effective_radius(k)=0. ! rain
          if ( qqi(i,j,k) > 0 ) then
            atmosphere(1)%cloud(4)%effective_radius(k)=min(125.,max(25.,125.+(t(i,j,k)-243.16)*5.)) ! ice + snow
          else
            atmosphere(1)%cloud(4)%effective_radius(k)=125. ! snow
          endif
          atmosphere(1)%cloud(5)%effective_radius(k)=0. ! graupel
! 03/15/2024 TCW: add features specific to CWA WRFD: following module_ra_goddard.F in WRFV3.8.1
```

surface

```
surface(1)%sensordata%n_channels = channelinfo(sensorindex)%n_channels
surface(1)%sensordata%sensor_id  = channelinfo(sensorindex)%sensor_id
surface(1)%sensordata%WMO_sensor_id = channelinfo(sensorindex)%WMO_sensor_id
surface(1)%sensordata%WMO_Satellite_id = channelinfo(sensorindex)%WMO_Satellite_id
surface(1)%sensordata%sensor_channel = channelinfo(sensorindex)%sensor_channel

surface(1)%land_type = model_to_crtm(itype)
if(gridtype=='B' .or. gridtype=='E')then
   surface(1)%wind_speed       = sqrt(u10h(i,j)*u10h(i,j)   &
                                 +v10h(i,j)*v10h(i,j))
else
   surface(1)%wind_speed       = sqrt(u10(i,j)*u10(i,j)   &
                                 +v10(i,j)*v10(i,j))
end if
surface(1)%water_coverage       = sfcpct(1)
surface(1)%land_coverage        = sfcpct(2)
surface(1)%ice_coverage         = sfcpct(3)
surface(1)%snow_coverage        = sfcpct(4)

surface(1)%land_temperature      = tsfc
surface(1)%snow_temperature      = min(tsfc,280._r_kind)
surface(1)%water_temperature     = max(tsfc,270._r_kind)
surface(1)%ice_temperature       = min(tsfc,280._r_kind)
if(smstot(i,j)/=spval)then
   surface(1)%soil_moisture_content = smstot(i,j)/10. !convert to cgs !???
else
   surface(1)%soil_moisture_content = 0.05 ! default crtm value
end if
surface(1)%vegetation_fraction   = vegcover
!      surface(1)%vegetation_fraction   = vegfrc(i,j)
surface(1)%soil_temperature      = 283.
!      surface(1)%soil_temperature      = stc(i,j,1)
surface(1)%snow_depth            = snodepth ! in mm
```

geometryinfo

```
geometryinfo(1)%sensor_zenith_angle=sat_zenith
geometryinfo(1)%sensor_scan_angle=sat_zenith

!only call crtm if we have right satellite zenith angle
IF(geometryinfo(1)%sensor_zenith_angle <= MAX_SENSOR_SCAN_ANGLE &
   .and. geometryinfo(1)%sensor_zenith_angle >= 0.0_r_kind)THEN
    geometryinfo(1)%source_zenith_angle = acos(czen(i,j))*rtd ! solar zenith angle
    geometryinfo(1)%sensor_scan_angle   = 0. ! scan angle, assuming nadir
```

channelinfo

```
allocate( channelinfo(n_sensors))
error_status = crtm_init(sensorlist_local,channelinfo, Process_ID=0,Output_Process_ID=0 )

 if (channelinfo(j)%sensor_id == isis_local ) then
     sensorindex = j
     exit sensor_search
endif

if(isis=='abi_g16')channelinfo(sensorindex)%WMO_Satellite_Id=270
if(isis=='abi_g16')channelinfo(sensorindex)%WMO_Sensor_Id=617
```

rtsolution

```
allocate(rtsolution  (channelinfo(sensorindex)%n_channels,1))

do n=1,channelinfo(sensorindex)%n_channels
     tb(i,j,n)=rtsolution(n,1)%brightness_temperature
end do
```