# Solar/IR Forward Modeling in Direct Cloud-Affected Radiance Assimilation: Status and Prospects

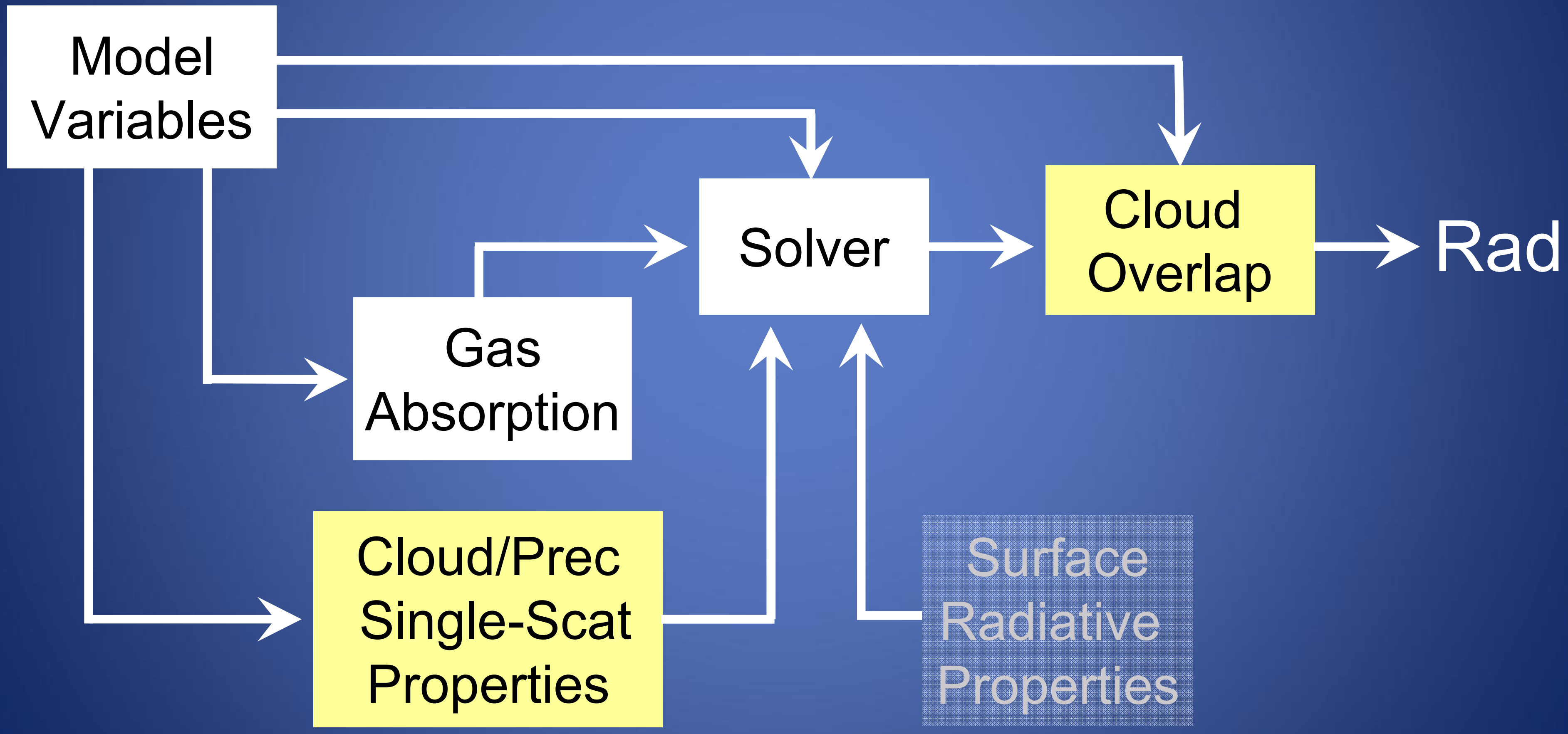
Tom Greenwald
*CIMSS, University of Wisconsin*

With contributions from Yong-Keun Lee and Justin Sieglaff

# Content

- Observational operator
- Current IR (3.7-15 μm) forward model systems
  - Ice cloud single-scattering property errors
- Current solar (0.45-4.0 μm) forward model systems
- Status
- Recommendations

# Components of an observational operator



# Current operational systems at IR wavelengths

- Gas absorption
  - CompactOPTRAN & ODPS (CRTM V2.0)
  - RTTOV V9.1
  - Model comparison study (Saunders et al. 2007): Agreement to within 0.02 K of LBL; 0.2 K when compared to AIRS
- Solvers
  - One calculation per instrument band
  - RTTOV V9.1: "Scaling approximation" (2-stream); errors < 0.5-1 K (RTIASA, Matricardi 2005)
  - CRTM V2.0: Rigorous solvers (MOM – Liu & Ruprecht 1996, ADA – Liu & Weng 2006); errors < 0.1 K (4-stream); no comparison studies for speed vs. accuracy

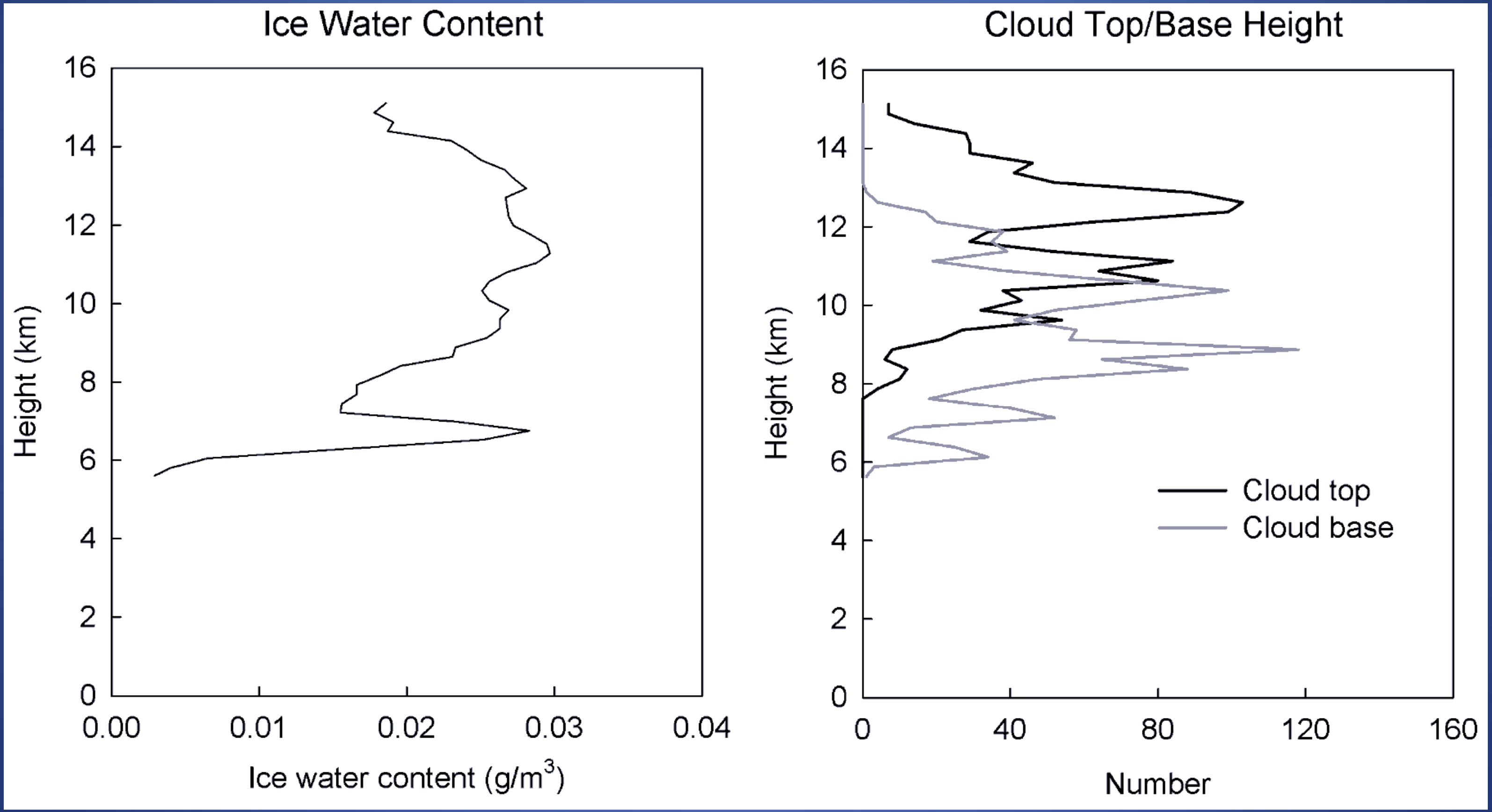
# Current operational systems at IR wavelengths

- Cloud overlap
  - Overcast conditions (McNally 2009)
  - Random overlap (Pavelin et al. 2008)
  - Maximum-random overlap: "Stream" method for RTIASI; (Matricardi 2005)
  - For broadband LW fluxes, maximum-random overlap scheme does not perform significantly better than either random or random-overcast schemes despite having 2.5x the computational cost (Stephens et al. 2004)
- Cloud/precipitation single-scattering properties
  - RTTOV V9.1: Water clouds (Lorenz-Mie LUTs); Ice: RO hexagonal column or RO aggregates (Baran & Francis 2004)
  - CRTM V2.0.1: Water clouds (Lorenz-Mie LUTs); Ice categories: ice, graupel, hail, snow (Baum et al. 2005)
    - V1.1 evaluated by Chen et al. (2008); AVHRR band 4 (10.8 $\mu$m); ice clouds: bias of 2.2 K; SD of 6 K
  - New evaluation of cirrus properties using CloudSat data

# Evaluation of cirrus IR single-scattering properties

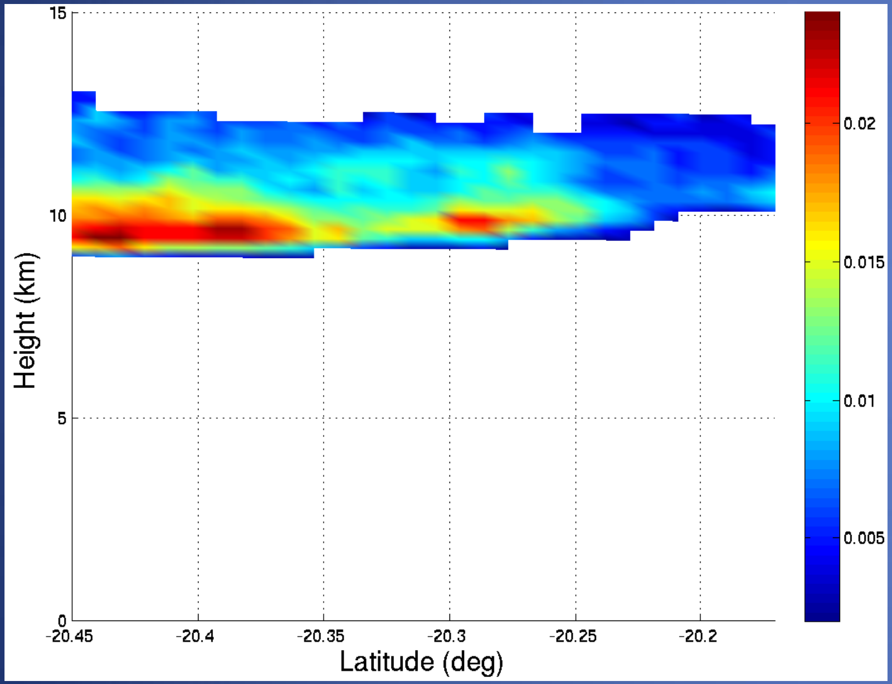
- Cirrus properties
  - CRTM V2.0 (“ice” category: mixed habits)
  - RTTOV V9.1 (RO hexagonal columns)
- Data
  - Collocated CloudSat IWC profiles (2B-CWC-RO) and 1-km MODIS band 31 (11 $\mu$m) measurements and cloud products (obtained from A-Train Data Depot for July 2007)
  - Atmospheric profiles: ECMWF analyses (CloudSat 2B-GEOPROF products)
- Methods
  - Limit to relatively optically thin ($\tau < 5$) single-layer cirrus (1206 profiles)
  - MODIS cloud products used to specify ice particle size (constant with height)
  - CRTM framework (same solver and gas absorption model)

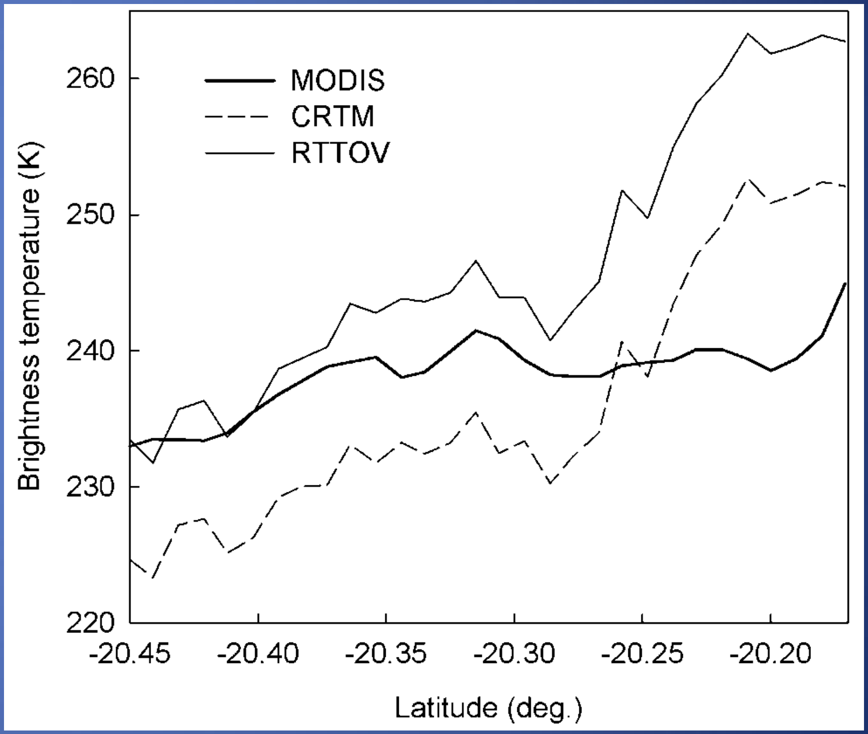
# Cirrus characteristics



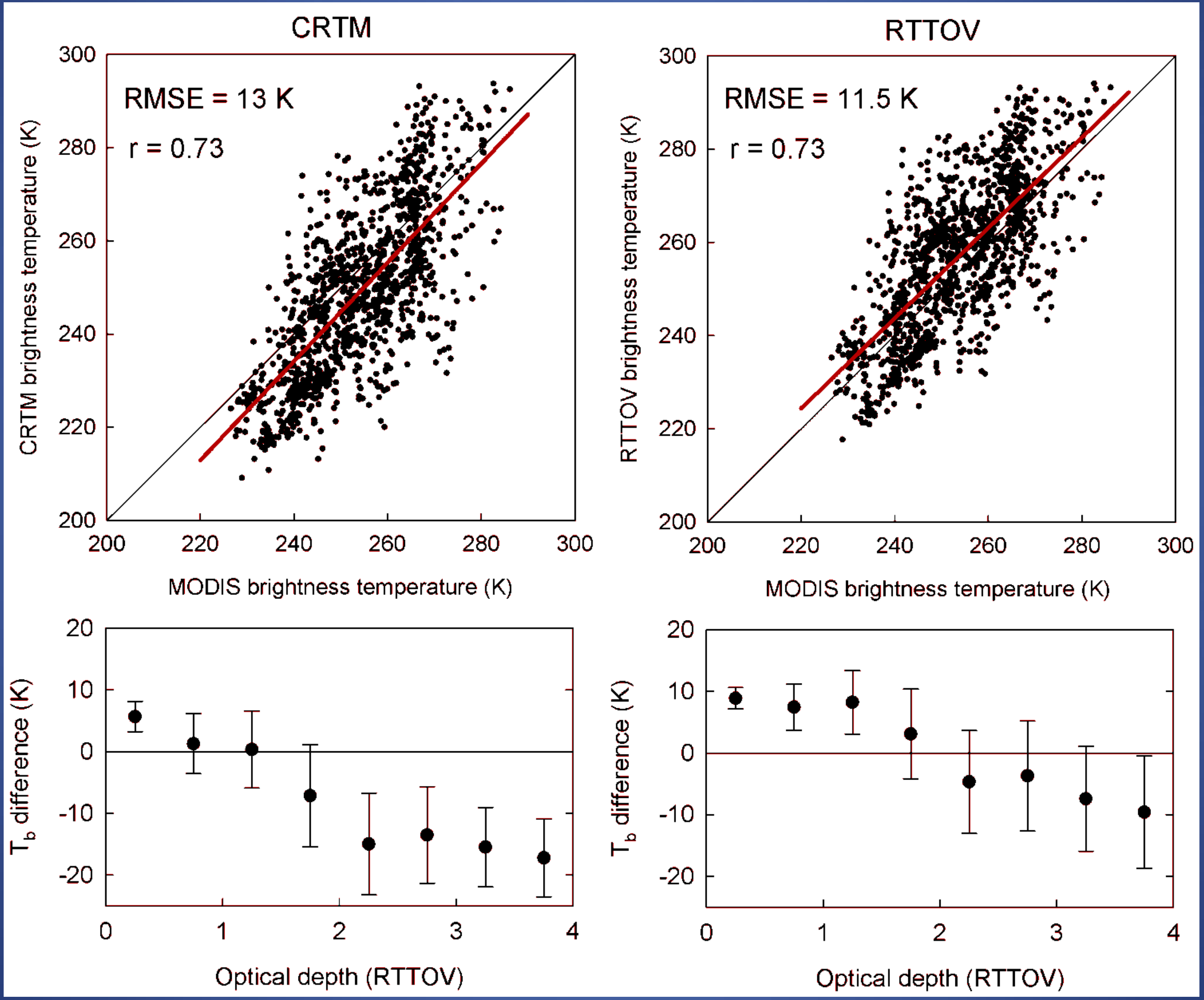
# Case study

CPR Ice Water Content (g/m$^3$)



# Overall results



# Current systems at solar wavelengths

- Gas absorption
  - ODPS & CompactOPTRAN (CRTM); errors unknown
  - OTRAN (e.g., Greenwald et al. 2002; Vukicevic et al. 2004)
- Solvers
  - One calculation per instrument band (e.g., Greenwald et al. 2002)
  - MOM, ADA (CRTM): (Liu and Ruprecht 1996; Liu and Weng 2006)
  - SHDOM (Greenwald et al. 2002; Evans 2007)
  - SOI (Heidinger et al. 2006)
- Cloud overlap
  - Studied in context of broadband albedo but not narrow-band radiance
- Cloud/precipitation single-scattering properties
  - MADT (Greenwald et al. 2002; 2004); errors uncertain for ice
  - Mixed habit ice (Baum et al. 2005); errors uncertain

# Status

- Gas absorption component has acceptable accuracy (at least in IR)
- Several fast solvers exist but only approximate solution methods are used in current assimilation of cloud-affected IR radiances
- Various strategies used to account for cloud overlap in IR but systematic studies of overlap assumptions are lacking
- IR SS properties for thin cirrus are in general agreement with MODIS measurements for RTTOV but 5-10 K biases remain for CRTM at larger optical depths
- Direct assimilation of solar measurements not currently done operationally
  - Solvers too slow (more streams needed + azimuthal terms)
  - Highly dependent on particle shape, orientation and roughness
  - 3D effects dominate at smaller scales

# Recommendations

- Possible ways to use cloud-affected solar measurements in operations:
  - Relax solver errors (reduce streams, etc.)
  - Restrict to nadir measurements (azimuthal terms go away)
  - Use neural networks to compute radiances (NSSL-WRF)
  - Make use of particle absorption bands (1.6, 2.2, 3.9 μm)
- Infrared issues:
  - Encourage use of rigorous solvers
  - Comparison study needed to test speed/accuracy of solvers
  - Hyperspectral applications (PCA approach - Liu et al. 2006)
- Solar and IR issues:
  - Need further validation of forward model components, especially cloud single-scattering properties (IR & solar simultaneously), and systematic testing of cloud overlap schemes (e.g., Stephens et al. 2004)
  - Explore multiple spectral calc per band (e.g., OSS, k-distribution)
  - Better use of existing solvers: Find ways of setting optimal number of streams automatically and selecting optimum solver

# Simulated GOES visible imagery

Based on cloud-resolving (2-km) WRF model simulation (1024 x 1280 grid points)