Exploring the Utility of CRTM in Assimilating Clear and Cloudy Radiances for Forecast Model Initialization

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Introduction

The validation of radiative transfer model capabilities is the foundation for research in cloudy satellite radiance data assimilation. In this study, the Community Radiative Transfer Model (CRTM) version 2.0.2 forward model (forward/ observation operator) and K-Matrix model are evaluated in the infrared range of the Geostationary Operational Environmental Satellite (GOES) Imager. Since our previous study shows the simulated brightness temperature is very sensitive to the surface condition, land surface type is considered for the forward model checkouts. In addition, high and low solar altitudes are assumed allowing for the solar zenith angle effect in the near infrared region. For the K-Matrix checkouts, input data includes Hurricane Katrina moving toward the gulf. As a matter of convenience, the whole domain is assumed to be over water and no cloud coverage.

Case 1.
Forward Model Checkout

- Okla. and the extended area
- Weather Research and Forecasting (WRF) Model
- 249 x 249 x 35 grids
- Over land
- 4 hydrometeor types
- No aerosols
- High solar alt : 12 LST (noon)
- Low solar alt : 18 LST (6pm)
- Output: Brightness Temp.
- Observation: GOES-8 Imager

Input Data

Convective clouds during IHOP campaign – 2002/06/13 00 UTC

Component	Degree
Sensor Zenith Angle	30.0
Sensor Scan Angle	26.4
Latitude	35.2
Longitude	-97.4
Source Zenith Angle	13.6 (@ 12 LST) 71.1 (@ 18 LST)

Index	USGS Code	CRTM Category
1	Urban and Built-Up Land	URBAN_CONCRETE
2	Dryland Cropland and Pasture	TILLED_SOIL
3	Irrigated Cropland and Pasture	IRRIGATED_LOW_VEGETATION
4	Mixed Dryland/Irrigated Cropland and Pasture	TILLED_SOIL
5	Cropland/Grassland Mosaic	TILLED_SOIL
6	Cropland/Woodland Mosaic	TILLED_SOIL
7	Grassland	MEADOW_GRASS
8	Shrubland	SCRUB
9	Mixed Shrubland/Grassland	GRASS_SCRUB
10	Savanna	BROADLEAF_BRUSH
11	Deciduous Broadleaf Forest	BROADLEAF_FOREST
12	Deciduous Needleleaf Forest	BROADLEAF_PINE_FOREST
13	Evergreen Broadleaf Forest	BROADLEAF_PINE_FOREST
14	Evergreen Needleleaf Forest	PINE_FOREST
15	Mixed Forest	BROADLEAF_PINE_FOREST
16	Water Bodies	INVALID_LAND
17	Herbaceous Wetland	WET_SOIL
18	Wooded Wetland	WET_SOIL
19	Barren or Sparsely Vegetated	COMPACTED_SOIL
20	Herbaceous Tundra	TUNDRA
21	Wooded Tundra	TUNDRA
22	Mixed Tundra	TUNDRA
23	Bare Ground Tundra	TUNDRA
24	Snow or Ice	INVALID_LAND

Surface Condition
- Land Coverage
- Surface Type
- Temperature

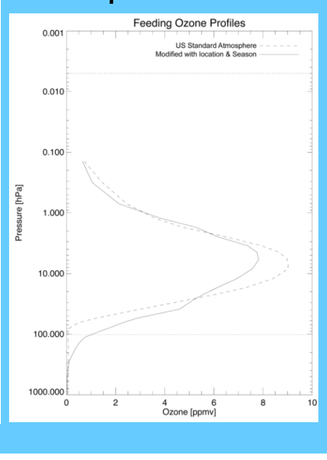
Climatology
US Standard Atmosphere

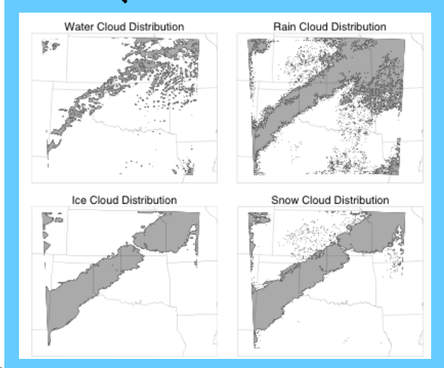
Temperature Profile

Absorber Profile
- Water Vapor
- Ozone

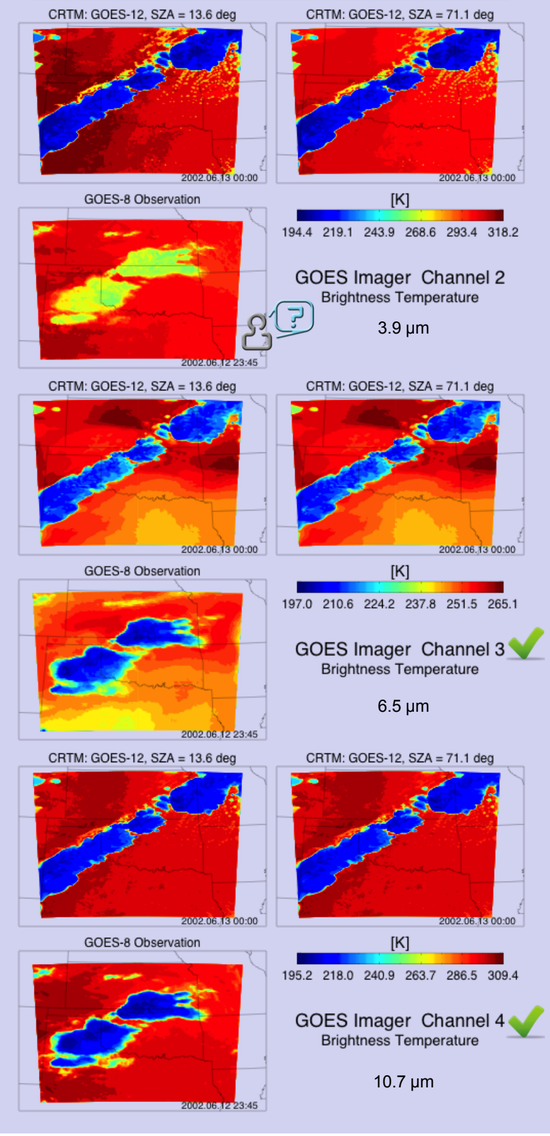
Cloud data
- Hydrometeors
- Water Content

Geometry data
- Lon & Lat
- Sensor Scan/Zenith Angle
- Source Zenith Angle
- Year, Month & Day





Simulations vs. Observations



Case 2.
K-Matrix Model Checkout

The CRTM K-Matrix results are compared to the simulated radiance (R) variations with respect to perturbations of a state variable (i.e. surface temperature, atmospheric temperature/specific humidity/ ozone amount) as approximate Jacobian values.

- The Gulf of Mexico and the extended area
- Local Analysis and Prediction System (LAPS)
- 257 x 257 x 56 grids
- Over water
- No clouds/precipitations
- No aerosols
- Output: Radiances

Forward Model

$$\mathbf{R} = \mathbf{F}\left(\mathbf{T},\ \mathbf{q},\ \mathbf{O_3},\ T_{sfc}\right)$$

Focusing on temperature at one pressure level…

$$\Rightarrow \mathbf{R} = \mathbf{F}\left(\mathbf{T}\right)$$

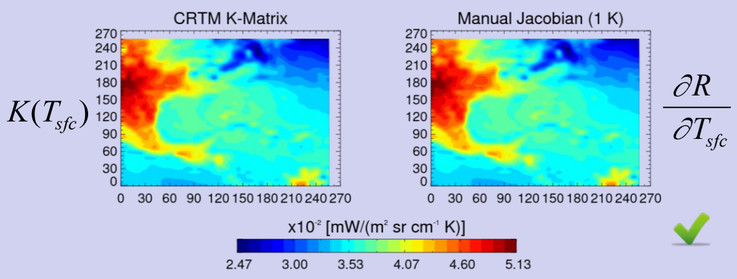
K-matrix Model

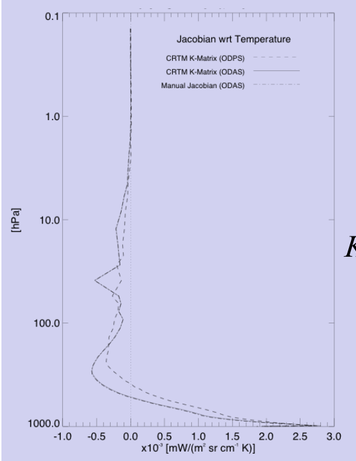
$$\frac{\partial \mathbf{R}}{\partial \mathbf{T}} = \mathbf{K}\left(\mathbf{T},\ \mathbf{q},\ \mathbf{O_3},\ T_{sfc}\right) \Rightarrow \frac{\partial \mathbf{R}}{\partial \mathbf{T}} = \mathbf{K}\left(\mathbf{T}\right)$$

Approx. Jacobian Derived with Forward Model

$$\frac{\partial R}{\partial T} \approx \frac{R\left(T+\Delta T\right)-\left(T-\Delta T\right)}{2\Delta T}$$

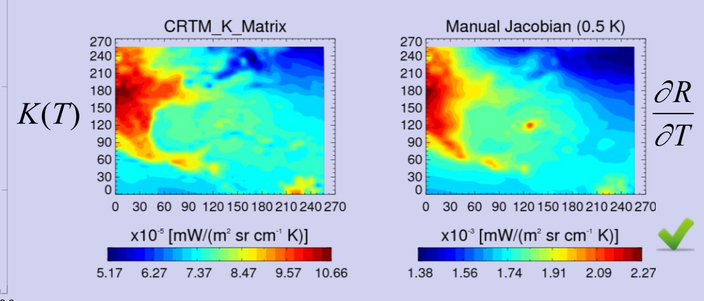
▪ GOES-12 Channel 2 radiance variations with respect to surface temperature perturbations

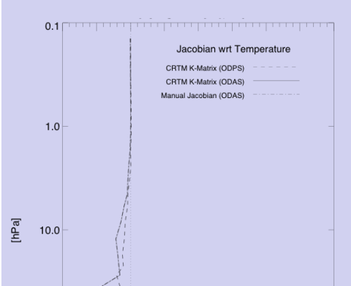




▪ GOES-12 Channel 2 radiance variations with respect to atmospheric temperature perturbations at 1007 hPa

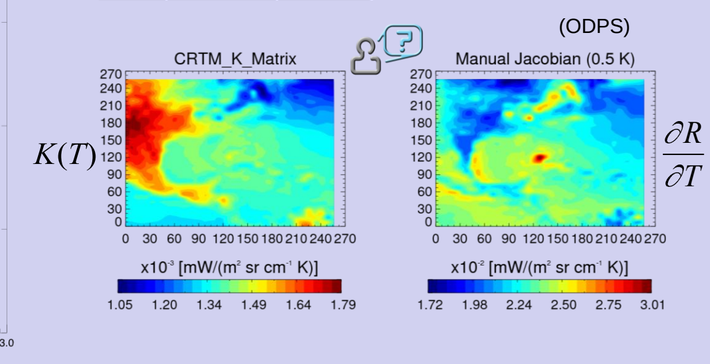
(ODPS)

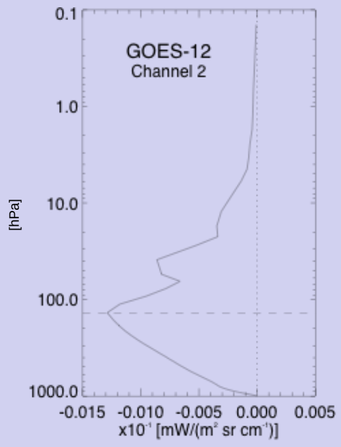




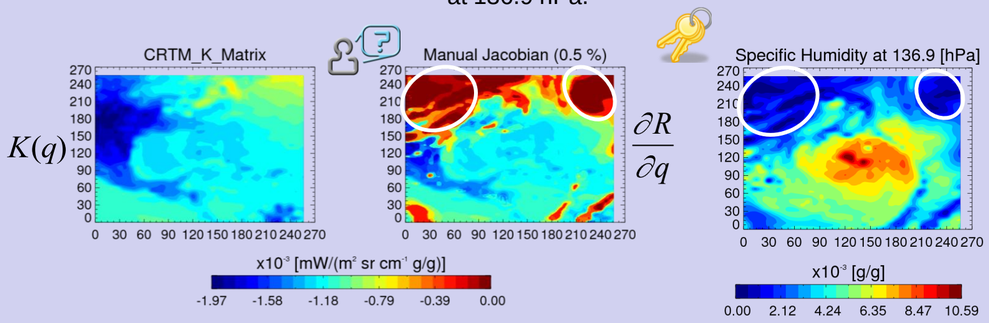
▪ GOES-12 Channel 4 radiance variations with respect to atmospheric temperature perturbations at 1007 hPa

(ODPS)





▪ GOES-12 Channel 2 radiance variations with respect to to specific humidity perturbations at 136.9 hPa.



Transmittance Models:
- ODPS (Optical Depth in Pressure Space) - CompactOPTRAN
- ODAS (Optical Depth in Absorber Space) - RTTOV-type

Summary

- The CRTM forward model is reasonably accurate for radiance simulations, but the simulated cloud top radiances are lower than the observed in near the infrared channel.
- The CRTM K-matrix function performs well for Jacobians with respect to surface temperature perturbations.
- With respect to atmospheric temperature perturbations, the similarity between K-Matrix and approximate Jacobians varies according to channels.
- With respect to moisture perturbations, the two results show similar patterns where specific humidity is larger than a certain threshold value.

Future Work

- Further radiance simulations in the near-infrared channel with variance conditions, such as night time comparisons, different microphysical assumptions.
- Statistical analysis of the K-Matrix and Jacobian results with respect to atmospheric temperature and specific humidity.

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