# Generation of Simulated GIFTS Datasets

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# Purpose

- Prior to GIFTS launch, a GIFTS-specific forward model and retrieval algorithms must be developed
- Because there is no existing geosynchronous instrument with sufficient spectral resolution, GIFTS data must currently be simulated with sophisticated mesoscale numerical models
- GIFTS forward radiative transfer model and retrieval methods are evaluated by comparing retrieved temperature, water vapor, and winds with simulated atmospheric state

# Procedure

1. Produce a highly realistic simulated atmospheric state using a mesoscale numerical model (MM5)
2. Write atmospheric state variables to GIFTS forward model binary ingest format
3. Generate high spectral resolution infrared spectra via forward model calculations performed on simulated temperature, moisture, and condensate fields
4. Retrieve temperature, water vapor and winds from top of atmosphere radiances and compare with original simulated atmosphere to assess retrieval accuracy

# Procedure

1. Produce a highly realistic simulated atmospheric state using a mesoscale numerical model (MM5)
2. Diagnose mean particle size of each MM5 microphysical constituent in each grid box for use in cloudy radiative transfer
3. Write atmospheric state variables to GIFTS forward model binary ingest format
4. Generate high spectral resolution infrared spectra via forward model calculations performed on simulated temperature, moisture, and condensate fields
5. Retrieve temperature, water vapor and winds from top of atmosphere radiances and compare with original simulated atmosphere to assess retrieval accuracy

# Cases

1. IHOP 2002 Convective Initiation: 12 June 2002
   - 2 x 3 GIFTS cubes aerial coverage
   - Highly complex wind and moisture fields
   - Predominantly cloud-free domain before initiation of strong late-day convection
2. Pacific THORPEX 2003 Jet Streak: 12 March 2003
   - 3 x 3 GIFTS cubes aerial coverage
   - Jet streak over central Pacific Ocean
   - Strong vertical wind shear, mix of clouds and clear air

# IHOP 2002 CI Case: Overview and Objectives

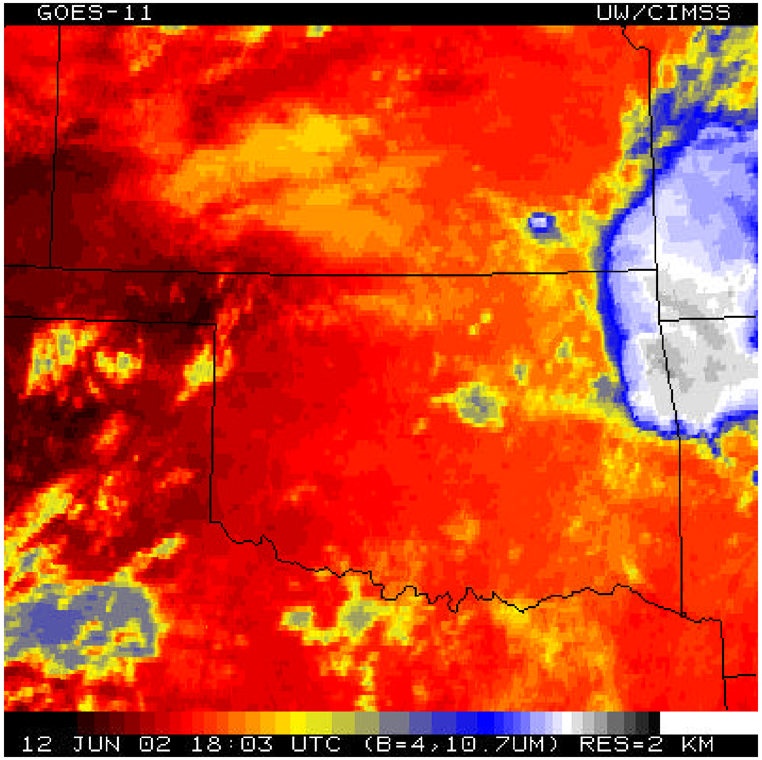
**Overview:**

- Environment mostly clear preceding convection
- Very complex low-level moisture structures and wind fields
- Convection initiated in the presence of strong convergence along a fine-scale low-level water vapor gradient

**Objectives:**

- Demonstrate GIFTS potential to observe moisture convergence prior to convective initiation
- Demonstrate GIFTS usefulness for observation of fine-scale rapidly-evolving water vapor structures
- Develop GIFTS-based analysis techniques for CI applications

GOES-11 10.7 micron imagery: 1803-2355 UTC 12 June 2002

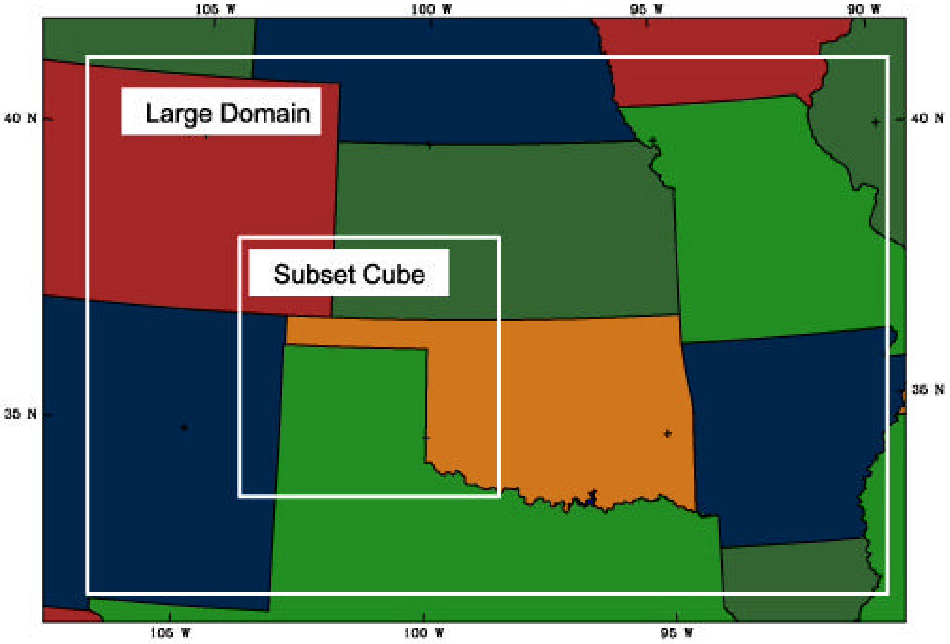


# MM5 Configuration

Simulated atmospheric fields generated using the 5th generation Penn State/NCAR Mesoscale Modeling system (MM5) initialized from 10 km RUC analyses

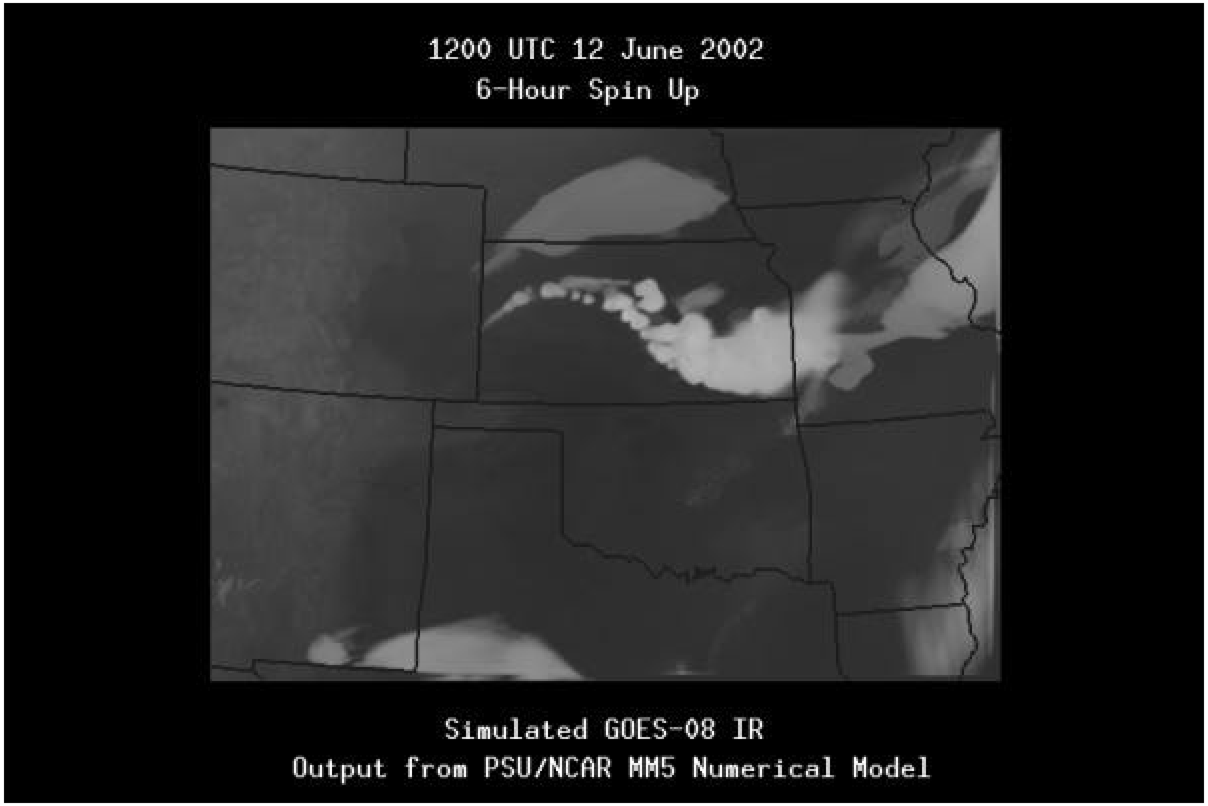
## Configuration details:

- 4 km grid spacing, 60 vertical levels
- Initialized 0600 UTC, 24-hour duration
- Goddard microphysics
- MRF boundary layer
- No cumulus parameterization
- RRTM radiation
- OSU-Land surface model
- Nudged toward RUC analyses during 6-hour spin-up period



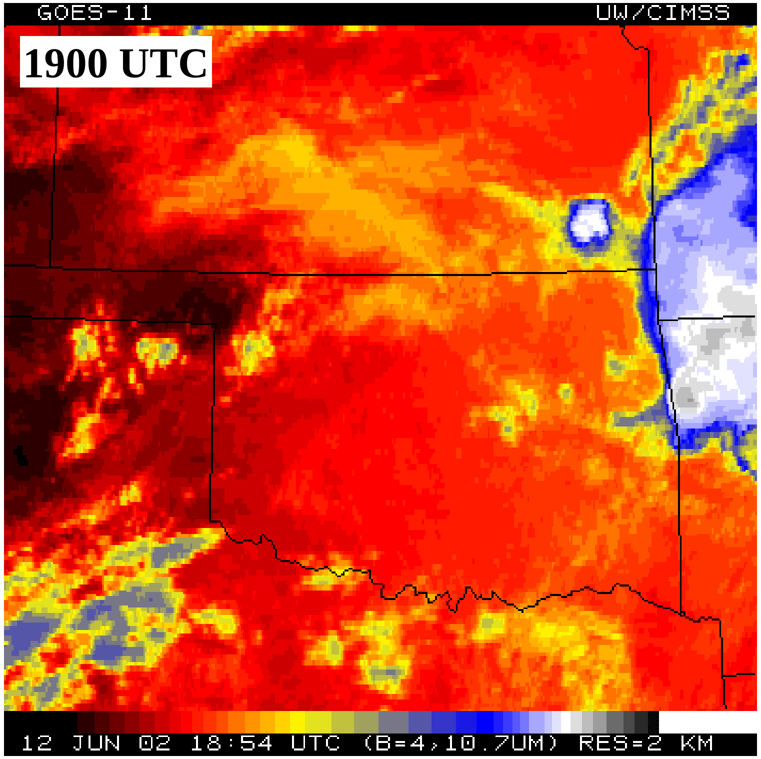
# Simulation Results

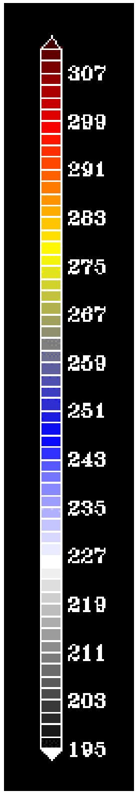
Simulated GOES-11 imagery for the full simulation domain



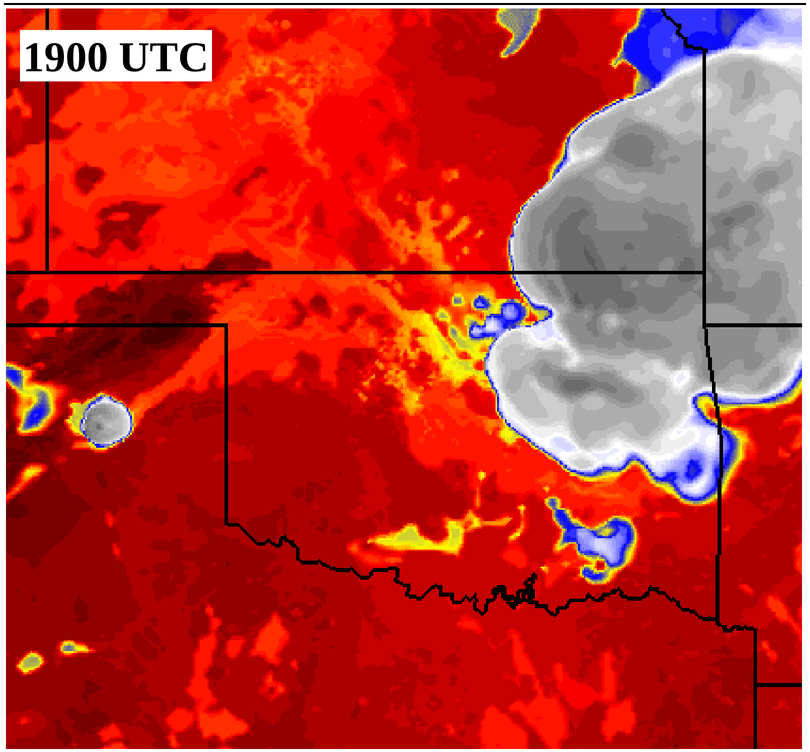
# Simulation Results

Observed GOES-11 imagery



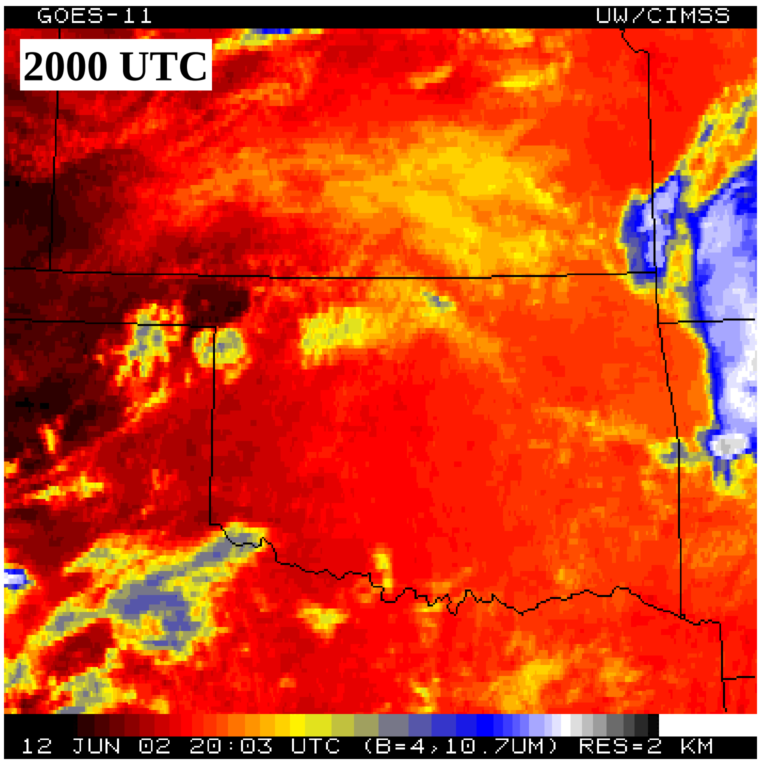



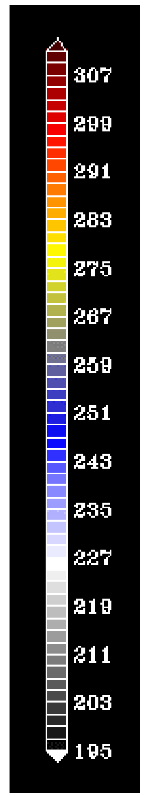

Simulated GOES-11 imagery



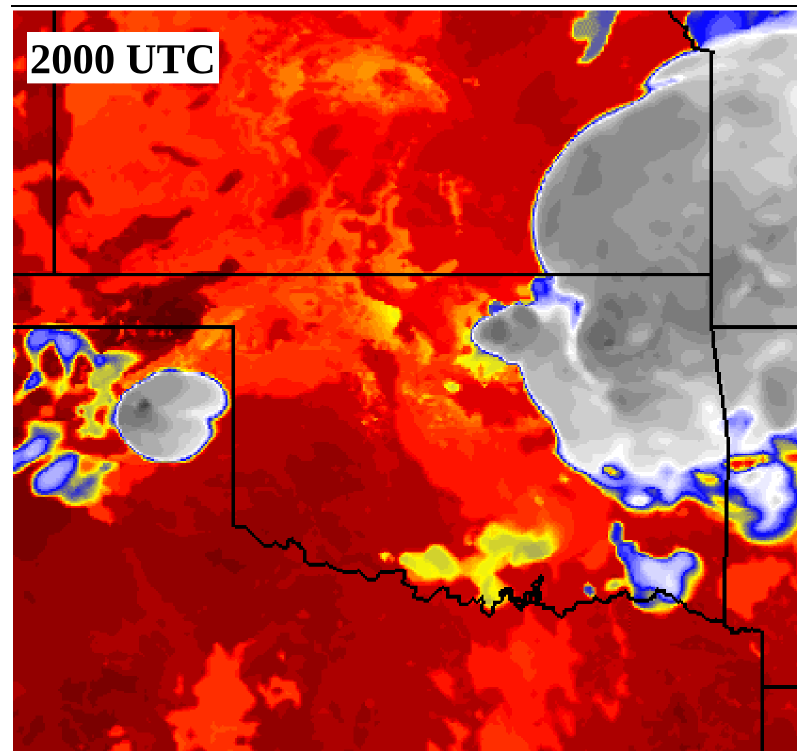
# Simulation Results

Observed GOES-11 imagery



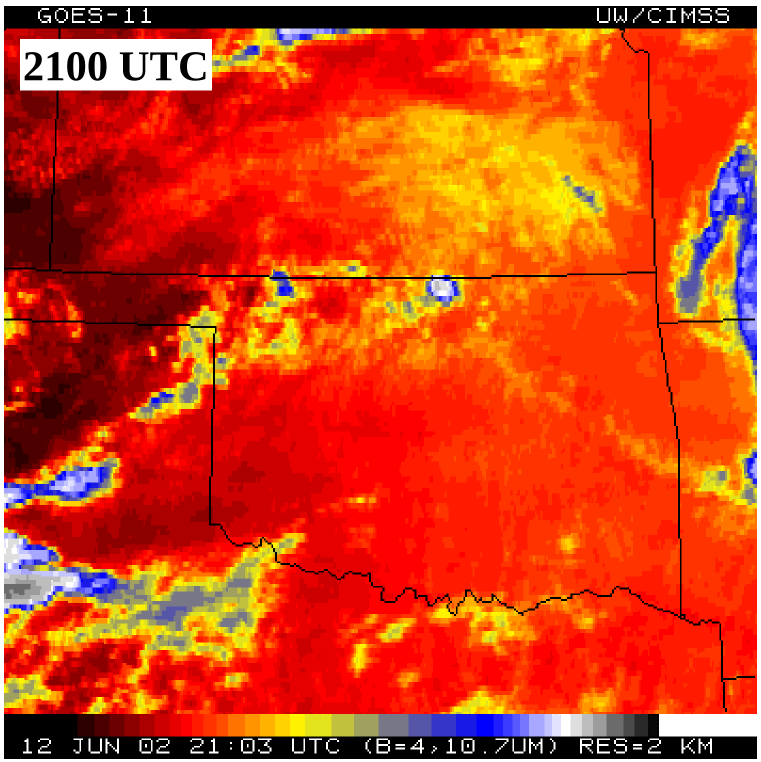



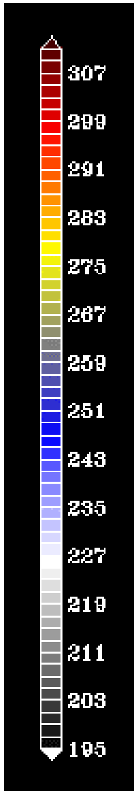

Simulated GOES-11 imagery



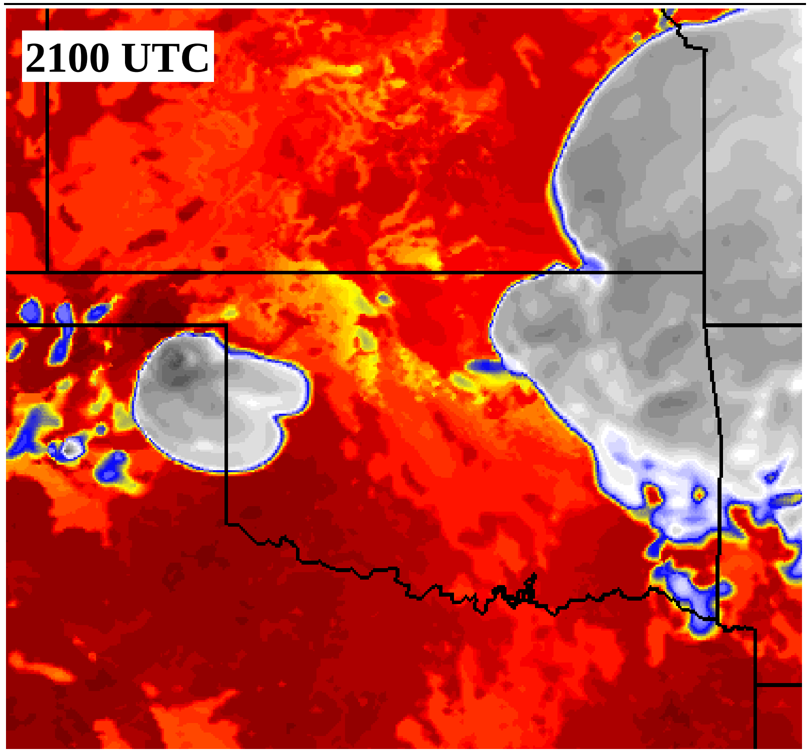
# Simulation Results

Observed GOES-11 imagery




Simulated GOES-11 imagery



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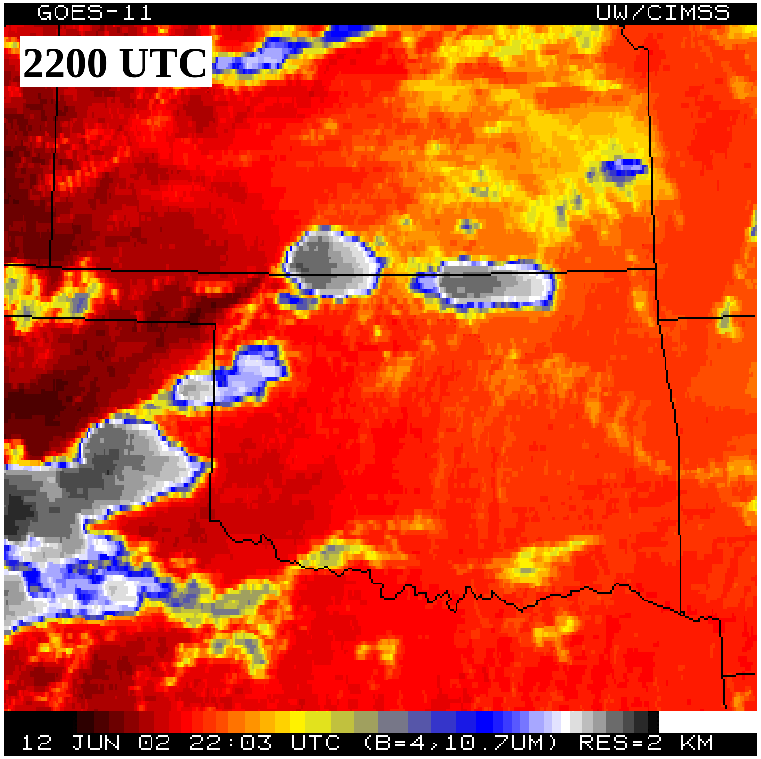
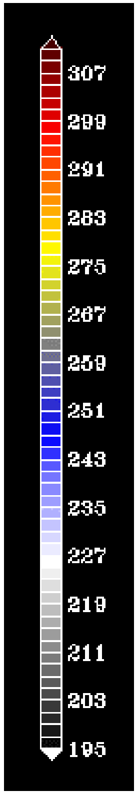
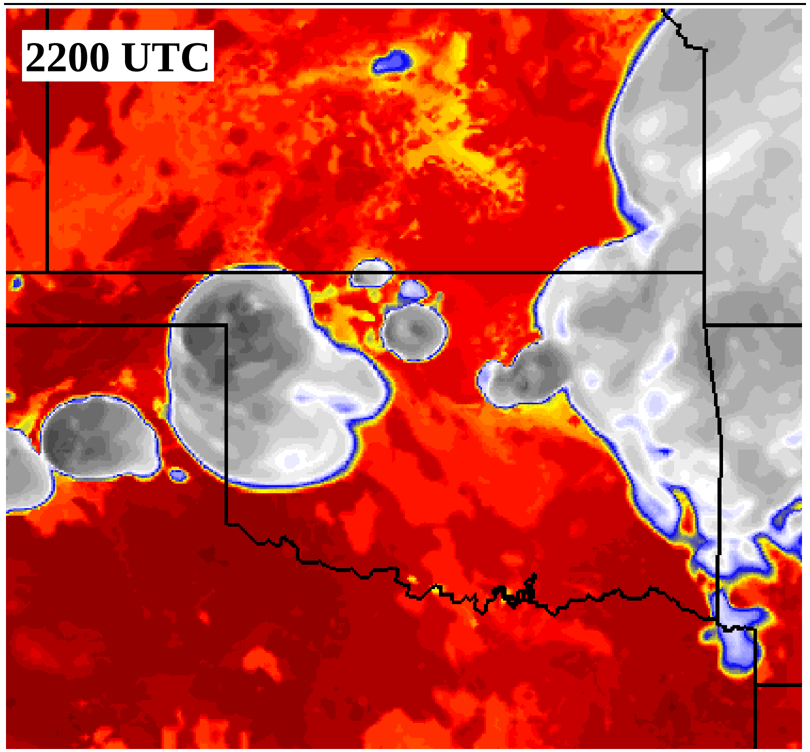
Observed GOES-11 imagery



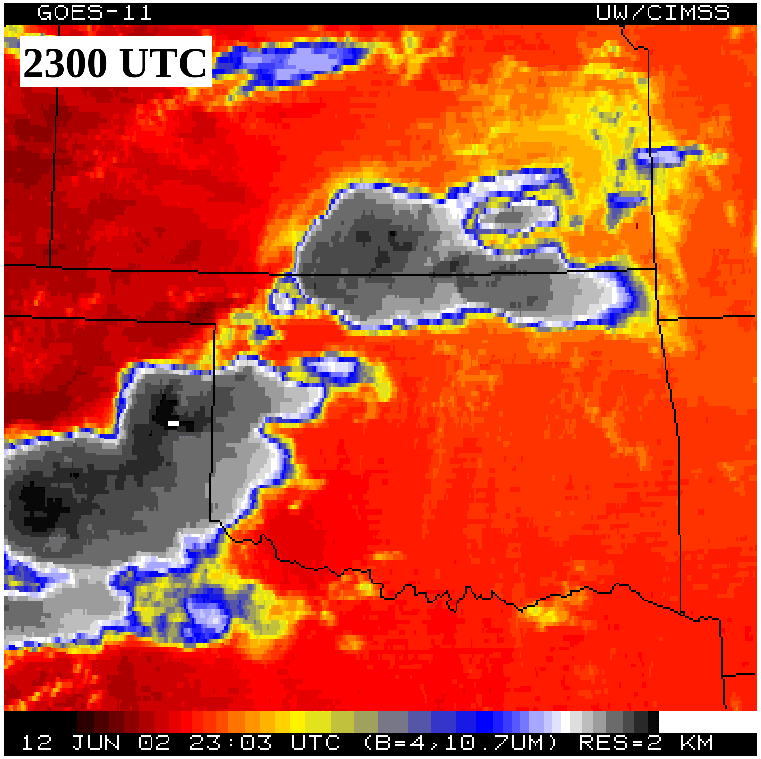

Simulated GOES-11 imagery

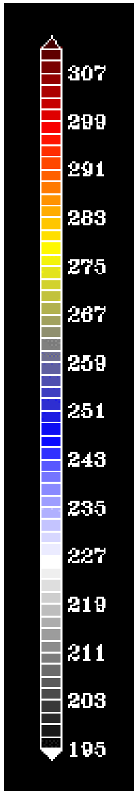


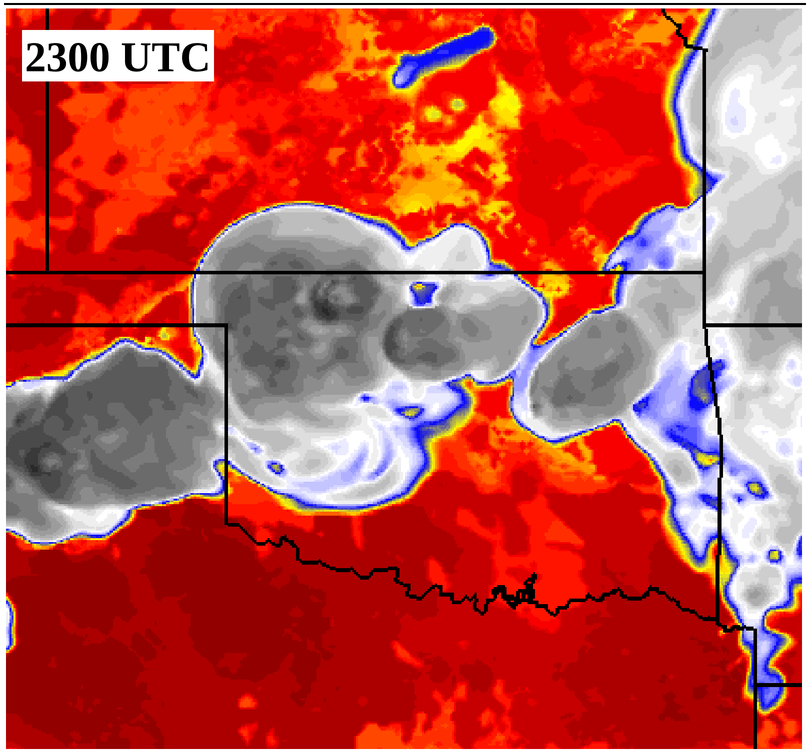
# Simulation Results

Observed GOES-11 imagery

Simulated GOES-11 imagery



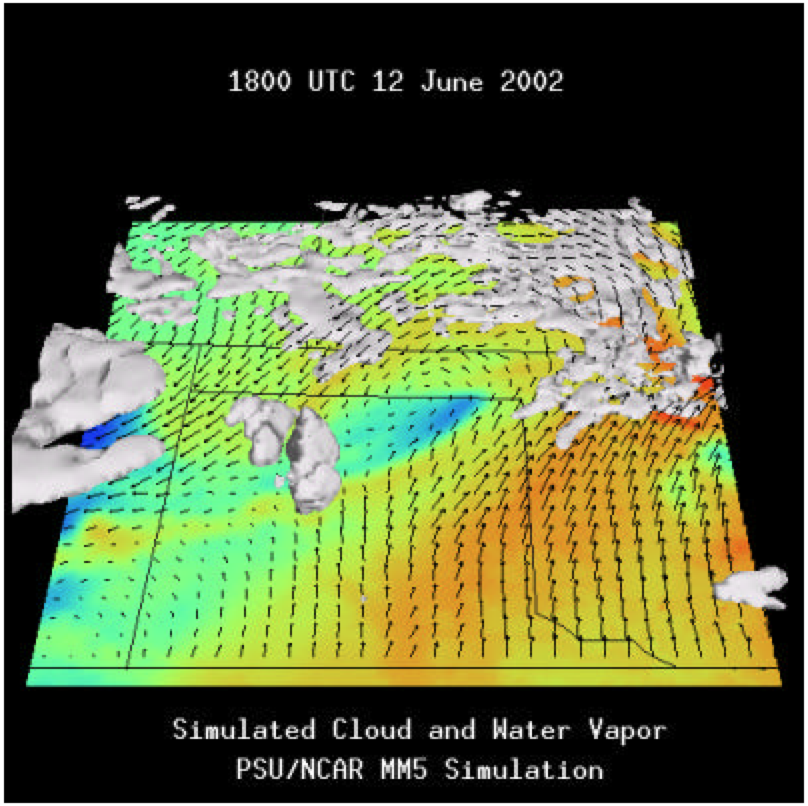



# Simulation Results

## Cloud and water vapor features

- Color-shaded plot depicts 2-meter mixing ratio
- White iso-surfaces encompass cloud boundaries
- Wind vectors valid at 1.5 km height



# THORPEX 2003 Jet Streak Case: Overview and Objectives

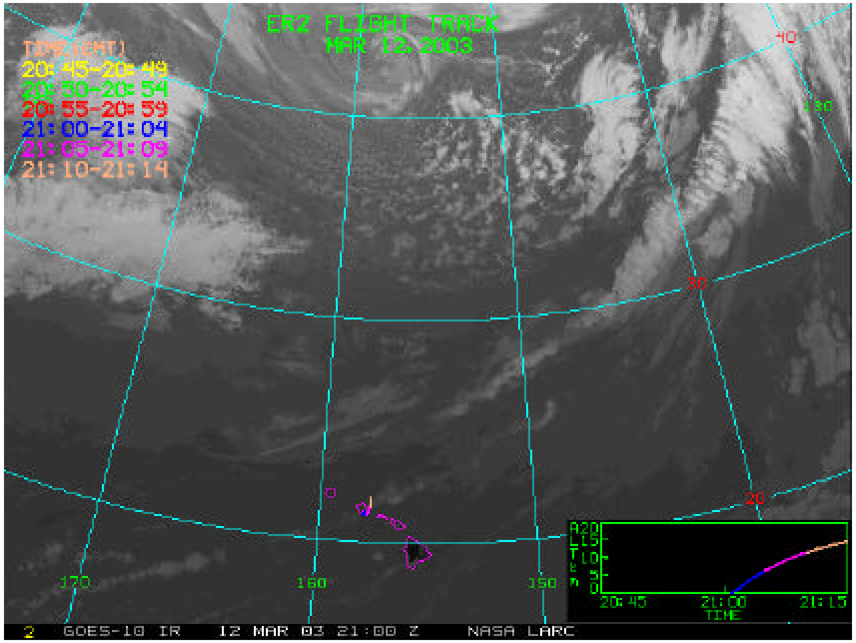
**Overview:**

- Mix of clear, low, and high cloud
- Significant jet streak with winds in excess of 180 knots
- Domain coverage includes Aqua overpass, ER-2 flight, G4 dropsondes
- Extensive observations were taken as part of THORPEX, GWINDEX, and NOAA NCEP Winter Storms Research Program

**Objectives:**

- Demonstrate GIFTS capabilities with respect to winds over the ocean
- Compare simulated GIFTS water-vapor winds with winds derived from GOES rapid-scan WIND EXperiment

GOES-09 10.7 micron imagery: 2100 UTC 12 March 2003 – 0400 UTC 13 March 2003

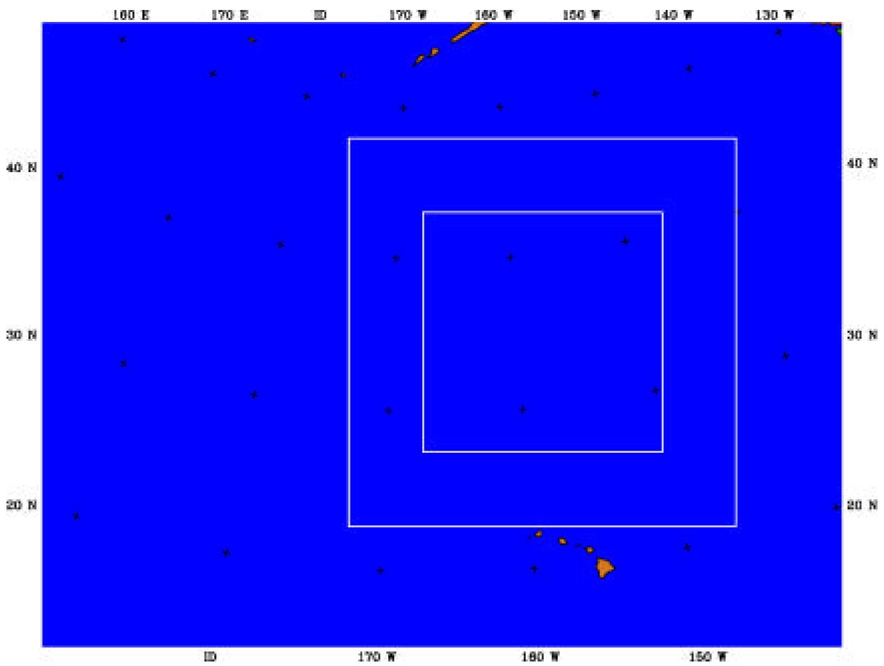


# MM5 Configuration

Simulated atmospheric fields generated using the 5th generation Penn State/NCAR Mesoscale Modeling system (MM5) initialized from 1-degree AVN analyses

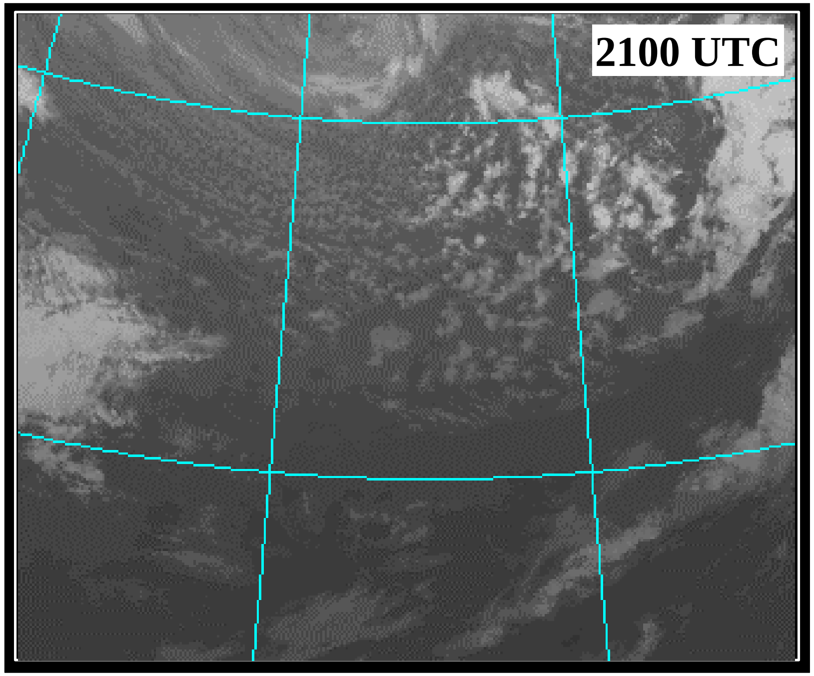
## Configuration details:

- 36/12/4 km grid spacing, 50 vertical levels
- Initialized 1200 UTC 11 March, 48-hour duration with 33-hour spinup
- Goddard microphysics
- MRF boundary layer
- Grell cumulus on 36 km and 12 km domains, no cumulus parameterization on 4 km domain
- RRTM/Dudhia radiation
- No land-surface model

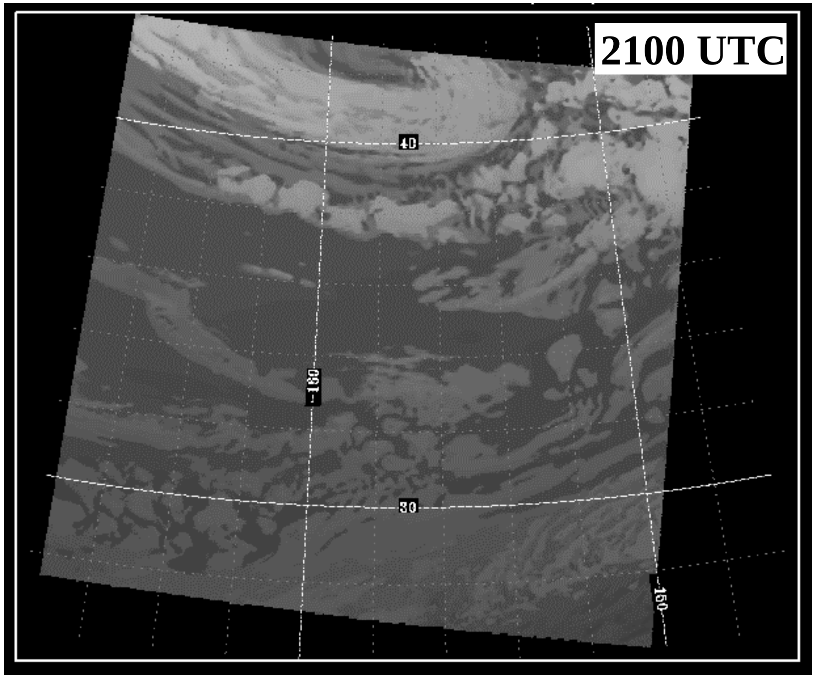


# Simulation Results

Observed GOES-09 imagery




Simulated GOES-09 imagery



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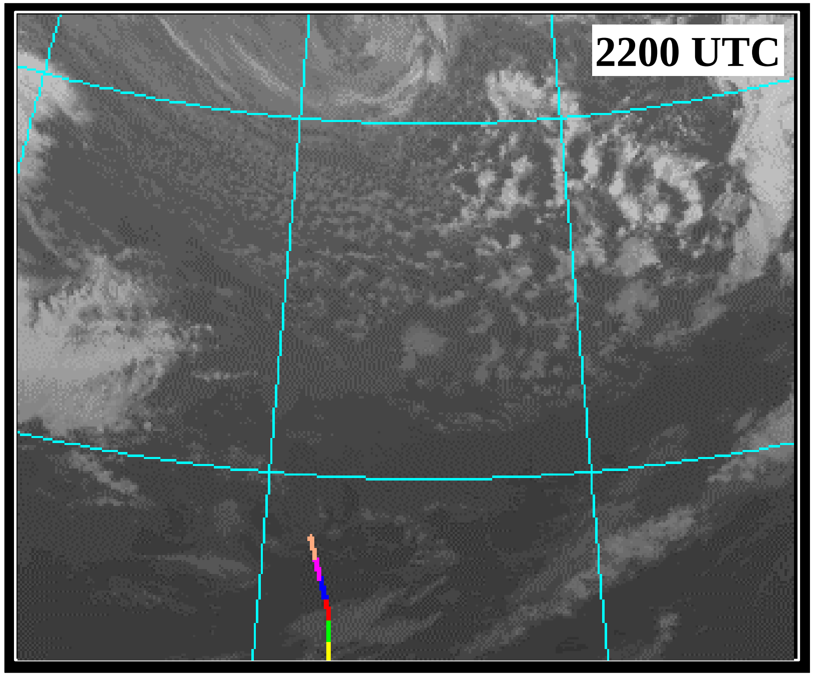
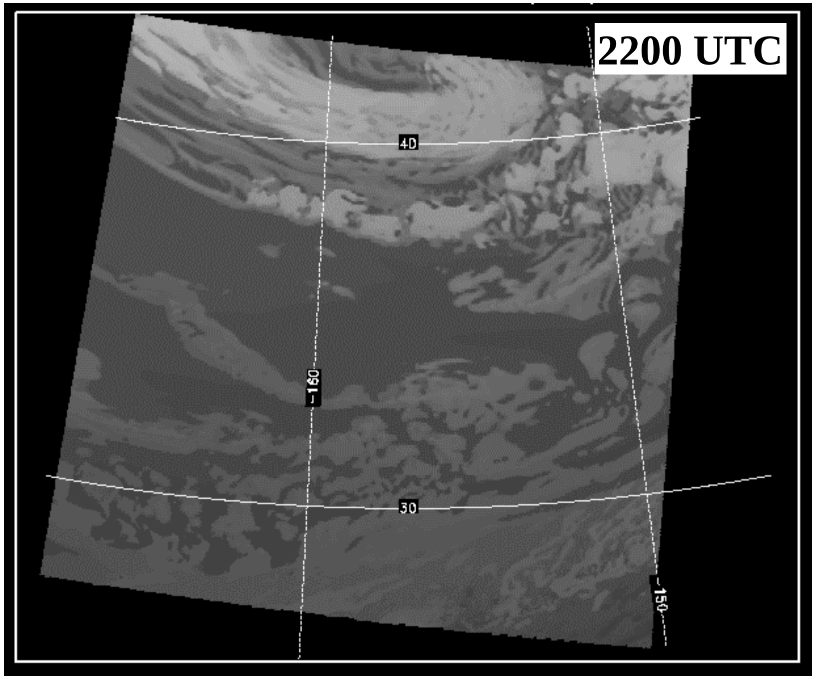
Observed GOES-09 imagery




Simulated GOES-09 imagery



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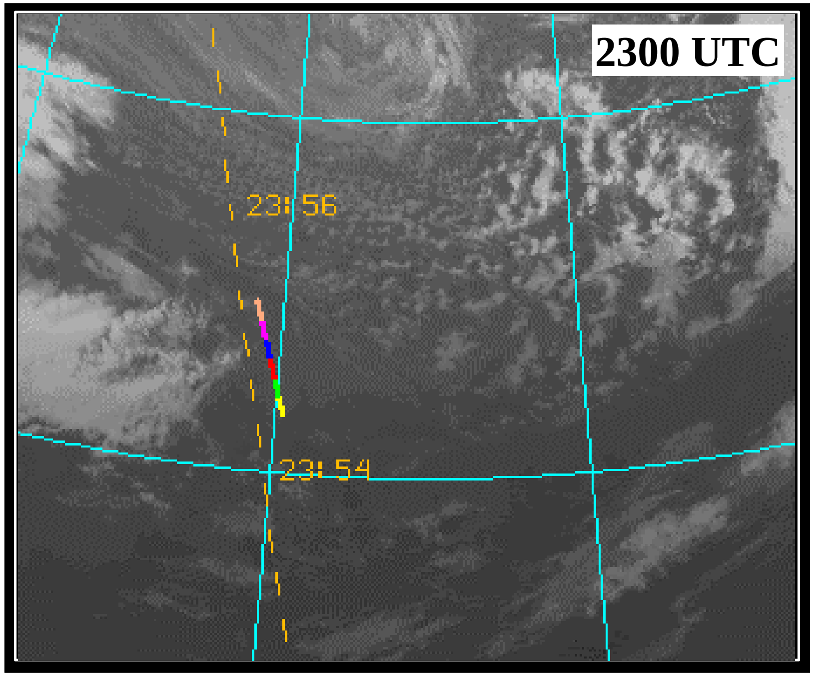
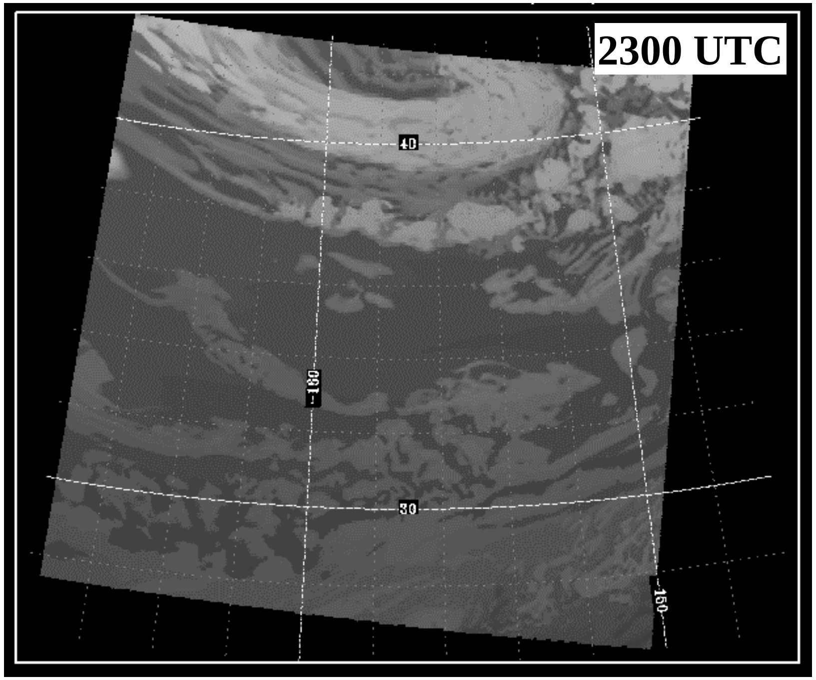



Simulated GOES-09 imagery



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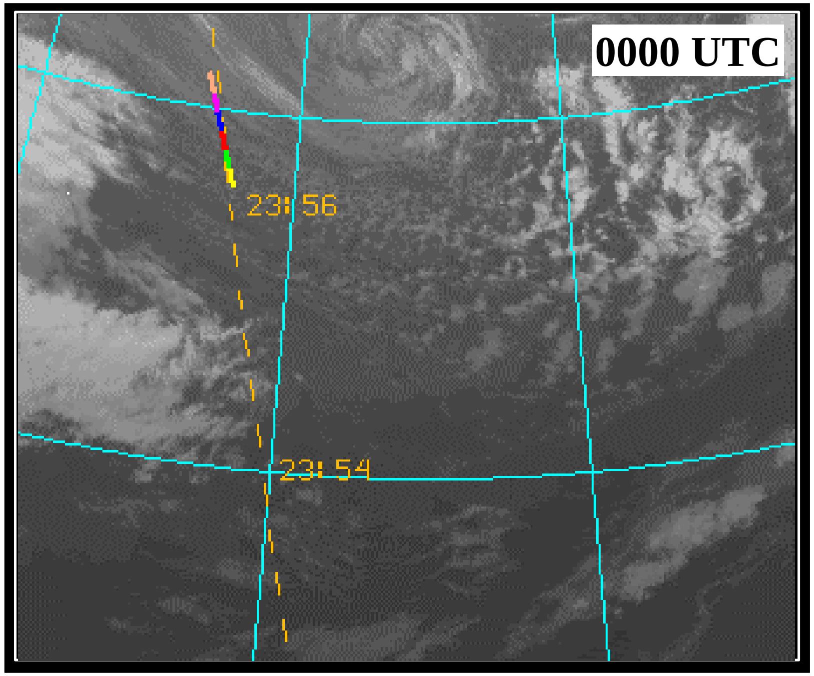
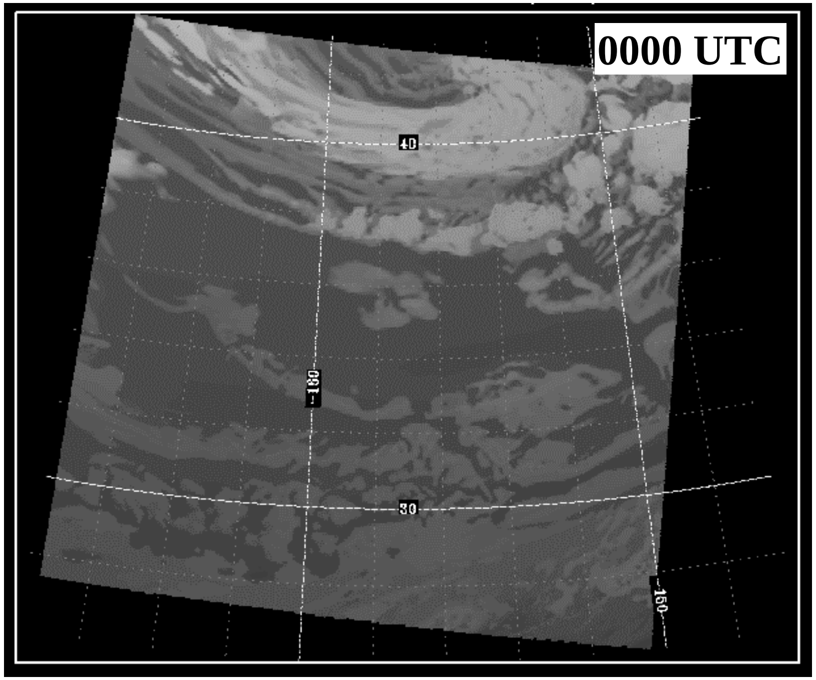



Simulated GOES-09 imagery



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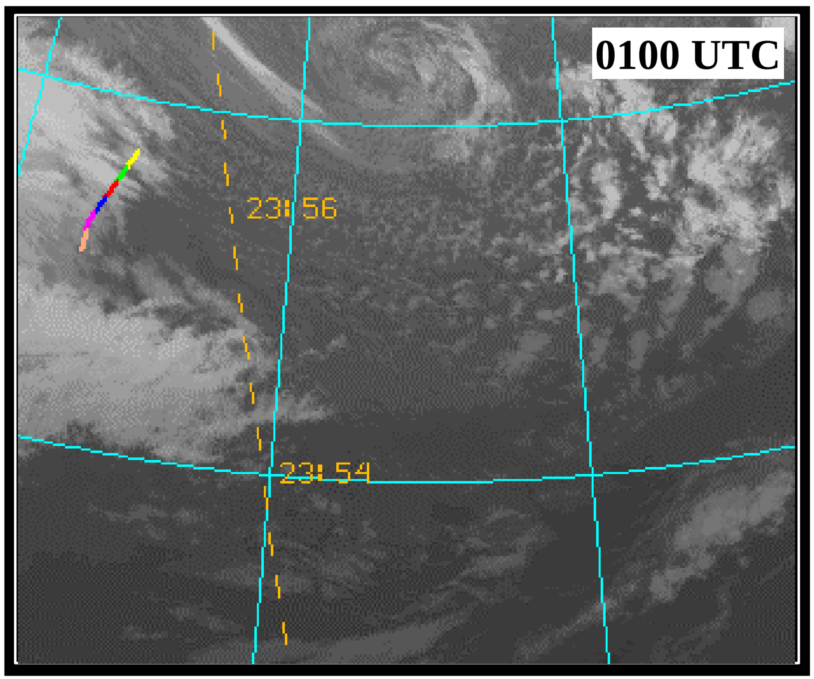
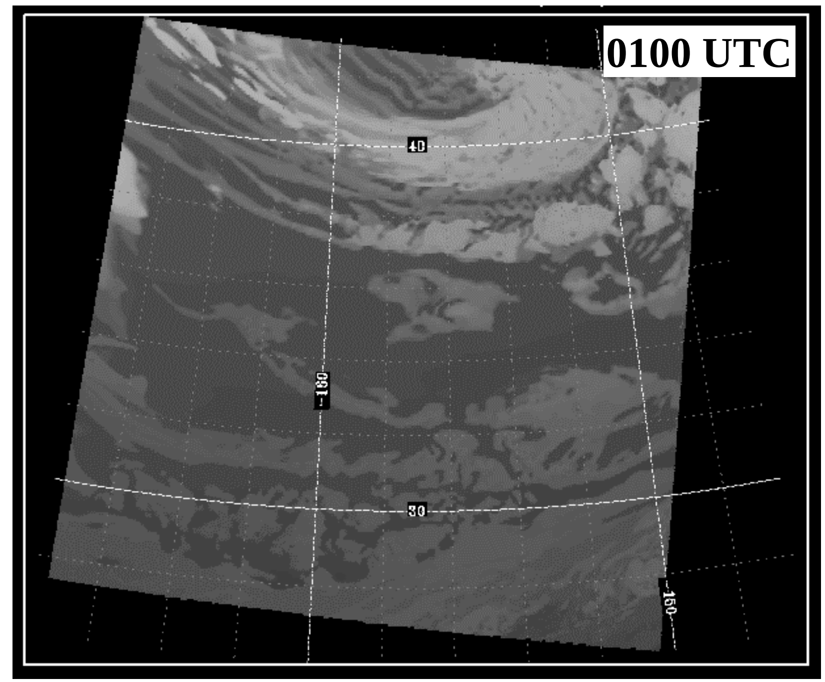
Observed GOES-09 imagery

Simulated GOES-09 imagery



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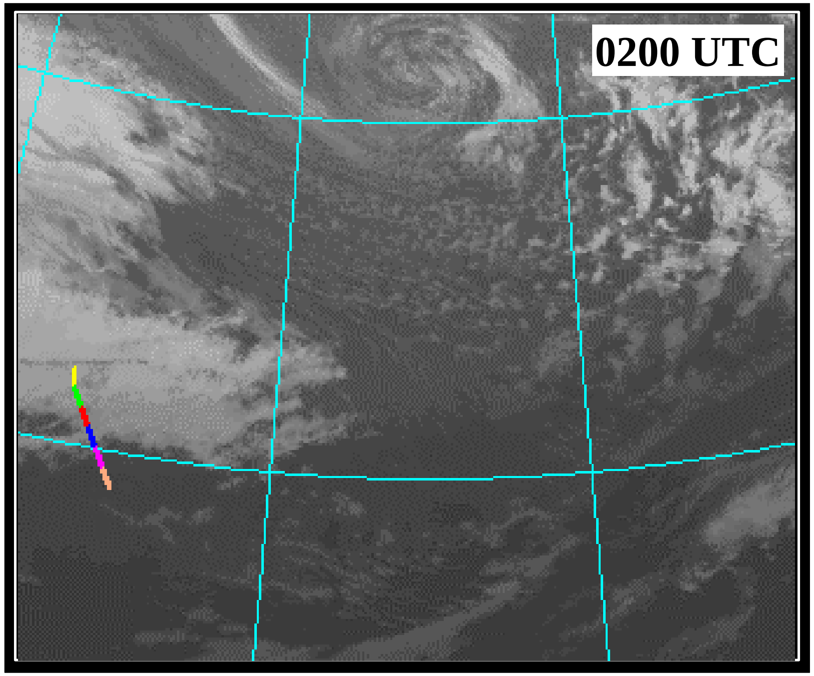
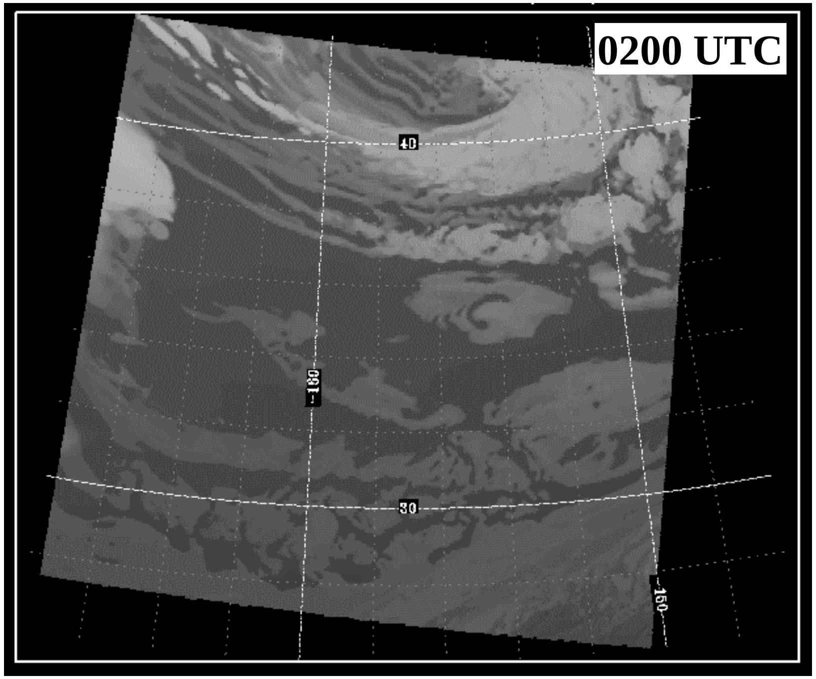
Observed GOES-09 imagery

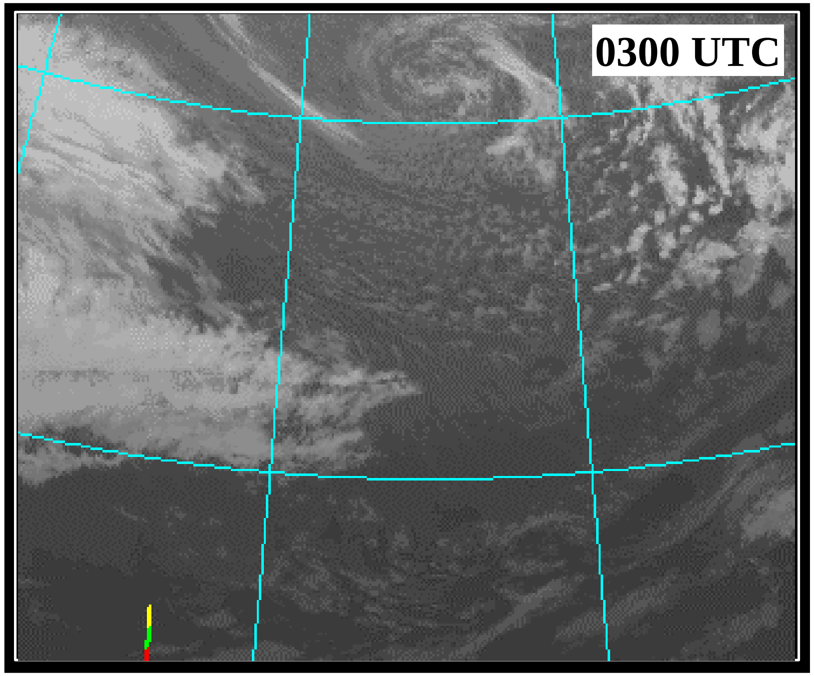



Simulated GOES-09 imagery

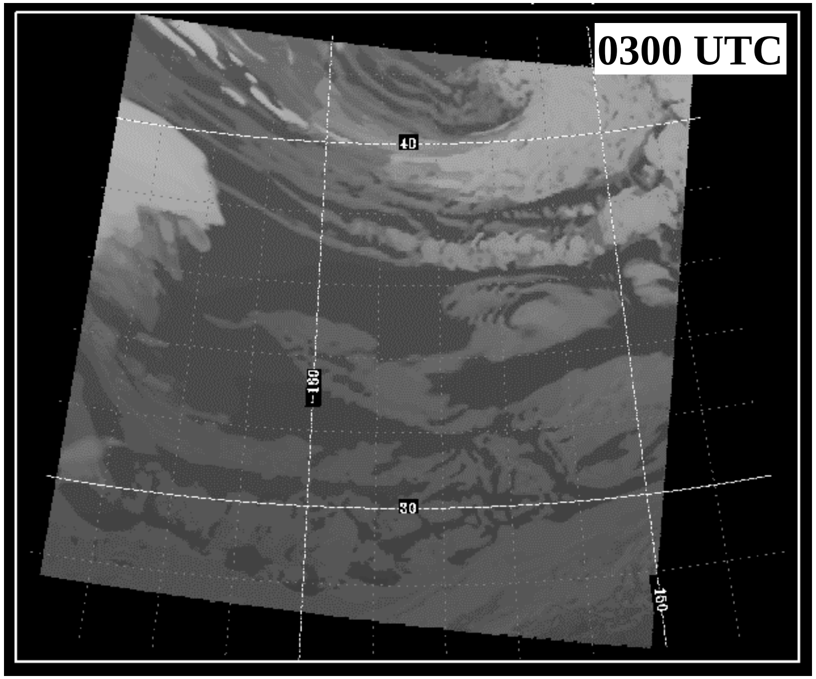


# Simulation Results

Observed GOES-09 imagery




Simulated GOES-09 imagery



# Future Work

- Finalize Pacific THORPEX simulation and compare with GWINDEX data
- Investigate transition to WRF as a replacement for MM5 at smaller spatial scales
- As computing power grows, generate much finer-resolution datasets (grid spacing < 4 km), as well as much larger spatial coverage (4 x 4 and higher)

# Computing cloudy radiances

- A method for rapidly computing cloudy radiances has been provided (Yang, 2003).
- **`gifstfrte`** has been modified to accommodate this method.
- Accuracy of the updated model is being assessed through comparisons with LBLRTM/DISORT (Dave Turner, LBLDIS*).
- Methods and findings are presented here.

*modified for more layers and higher spectral resolution

# Data inputs: prior release

- Surface conditions
- Profiles
  - T, q, O3
- Ice and liquid water paths

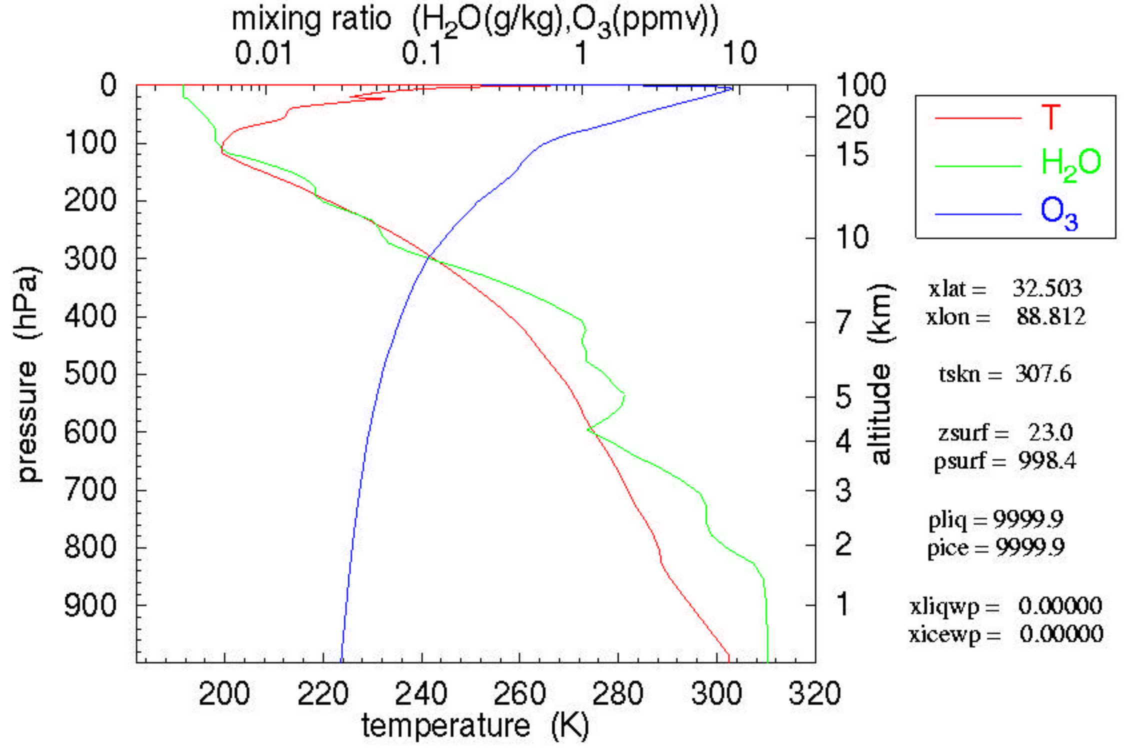
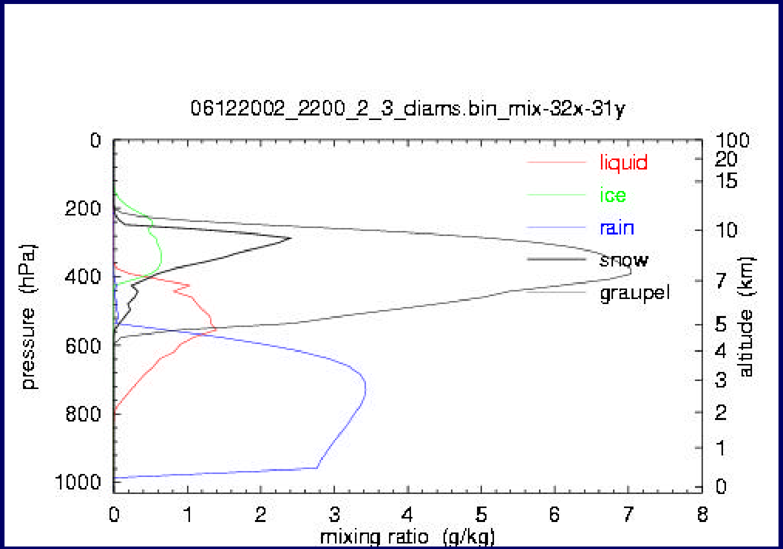
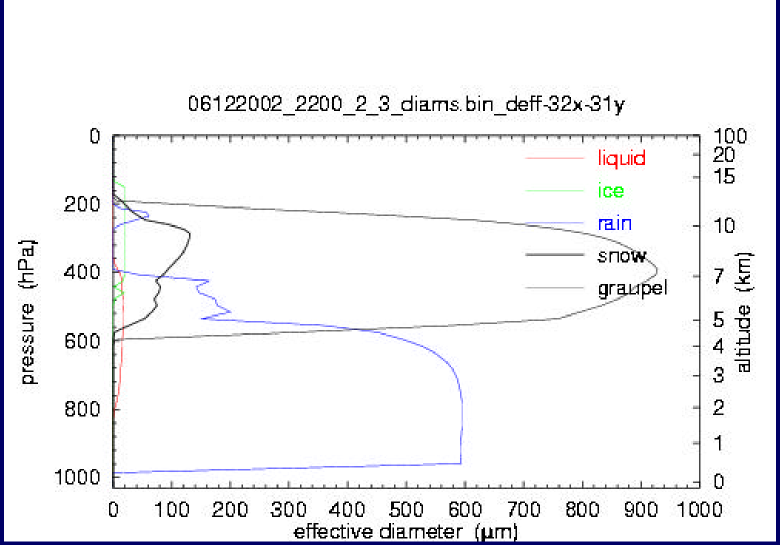



Figure 10: Example atmospheric profile. The nine non-profile quantities are listed to the right of the plotted profile data. In this example the pressure levels of water and ice condensate, `pliq` and `pice` respectively, have been assigned flag values. Liquid water and ice water paths, `xliqwp` and `xicewp` respectively, are zero — i.e. this is a "clear" atmospheric profile.

# Additional data inputs

- Condensate profiles
  - Deff
  - Mixing ratio




- Previously
  - $Deff(liq) = 2\ LWP^{1/3}$
  - $Deff(ice) = 24\ IWP^{1/3}$

# Ensemble Deff

In the delivered cloud model, water clouds are assumed to contain spherical droplets with a size distribution based on Deirmendjian's modified gamma distribution [3]. The effective size of water cloud droplets, $D_w$, is [10],

$$D_w = \frac{\int_0^\infty n(D)\, D^3\, dD}{\int_0^\infty n(D)\, D^2\, dD} \quad , \tag{3}$$

where $n(D)$ is the number density in the diameter range $D$ to $D + dD$. For an external mixture of "liquid" and "rain",

$$D_w = \frac{\int_0^\infty [n_{rain}(D) + n_{liquid}(D)]\, D^3\, dD}{\int_0^\infty [n_{rain}(D) + n_{liquid}(D)]\, D^2\, dD} \quad . \tag{4}$$

Presently the mixing ratio, $M$, and the effective diameter, $D$, are available to `gifsftre` from the `MM5` condensate profiles. The effective diameter of a mixture of "liquid" and "rain" is computed as,

$$D_w = \frac{M_{rain} + M_{liquid}}{M_{rain}/D_{rain} + M_{liquid}/D_{liquid}} \quad , \tag{5}$$

where $M$ and $D$ are interpolated to pressure `pliq`. $M$, the mass of condensate per unit mass of dry air, has replaced the condensate volume in the numerator of Eqn. (4) since $M \propto$ condensate volume for air masses at the same atmospheric pressure.

# How are clouds simulated ?

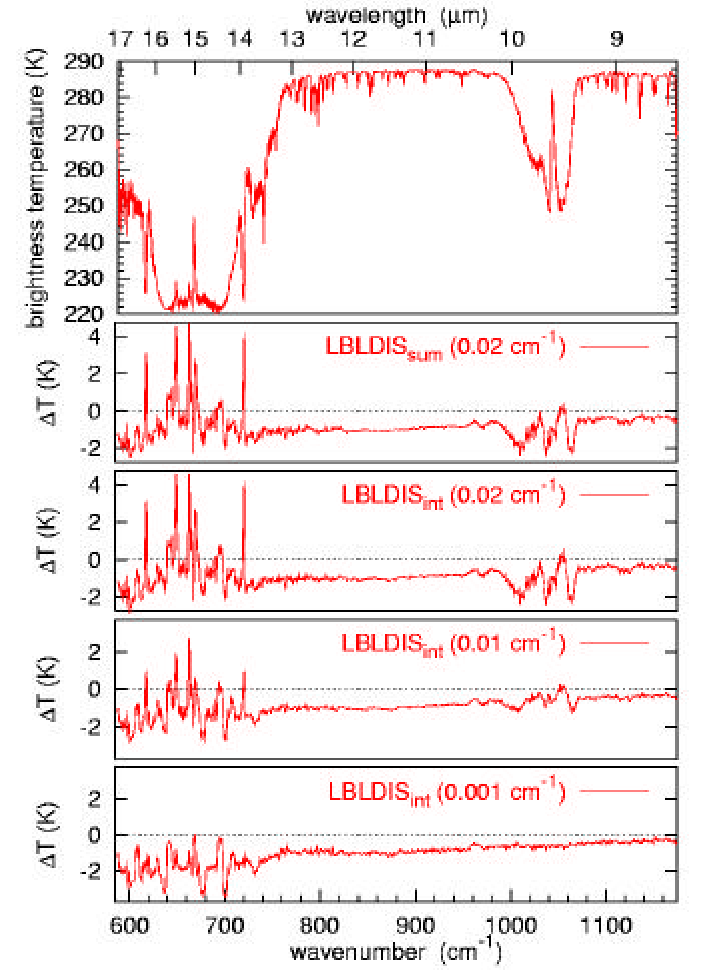
- A single cloud layer (either ice or liquid) is inserted at a pressure level specified in the input profile.
- Spectral transmittance and reflectance for ice and liquid clouds interpolated from multi-dimensional LUT.
  - Wavenumber (500 – 2500 1/cm)
  - observation zenith angle (0 – 80 deg)
  - $D_{eff}$ (ICE: 10 – 157 um, LIQUID: 2 – 100 um)
  - OD(vis) (ICE: 0.04 - 100, LIQUID 0.06 – 150)

# What is “TRUTH” ?

- The output of LBLDIS !
  - gas layer optical depths from LBLRTM v6.01
  - layers populated with particulate optical depths, assymetry parameters and single scattering albedos.
  - DISORT invoked to compute multiple scattered TOA radiances.
  - Radiances spectrally reduced to GIFTS channels and converted to brightness temperature.

# Split atmosphere to increase "TRUTH" accuracy

Figure 22: LBLRTM vs DISORT for clear US 1976 standard atmosphere. The upper pane shows the top-of-atmosphere brightness temperature computed by LBLRTM and spectrally reduced to GIFTS LW channels. The panes beneath this show the brightness temperature difference arrived at by subtracting the upper pane result from LBLDIS computations for the same clear atmosphere.




- Need only execute DISORT to cloud top.
- Separately compute monochromatic radiances and transmittances above cloud top with LBLRTM.
- Interpolate DISORT output to LBLRTM TOA output resolution and compute "pseudo" monochromatic TOA radiances.
- Spectrally reduce to GIFTS channels.

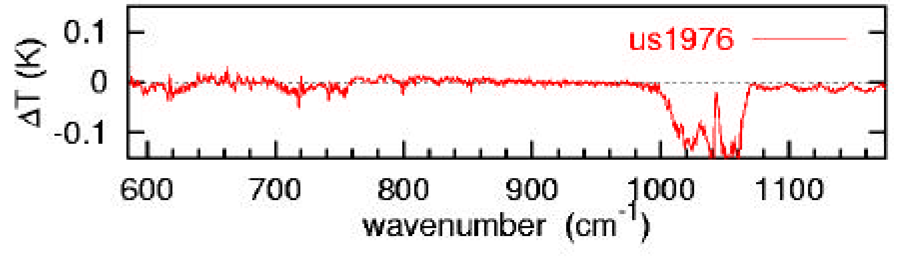
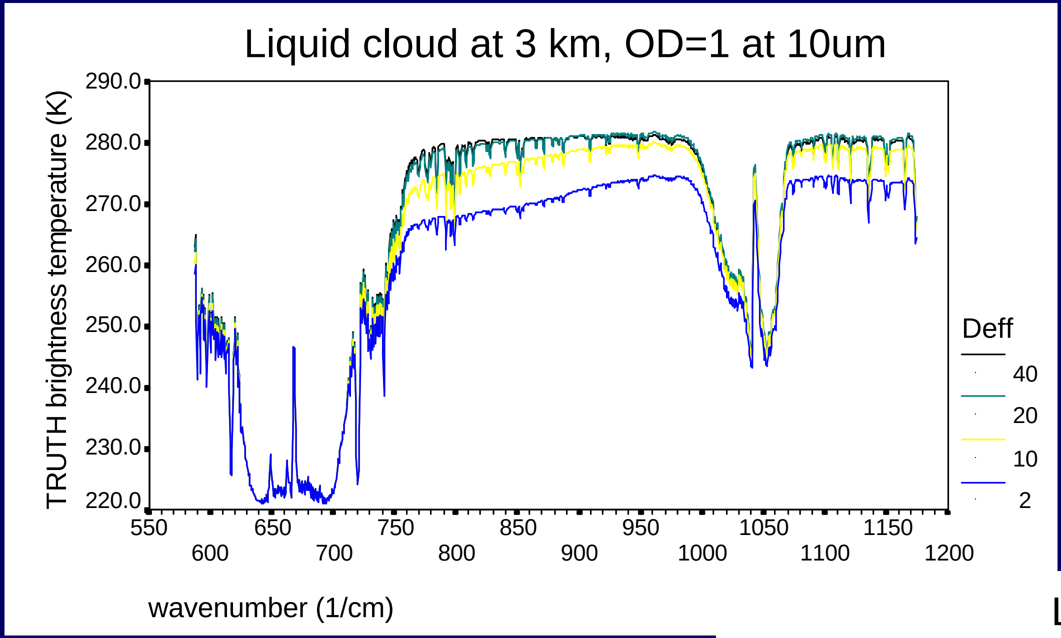



Figure 23: LW brightness temperature differences between DISORT and LBLRTM.

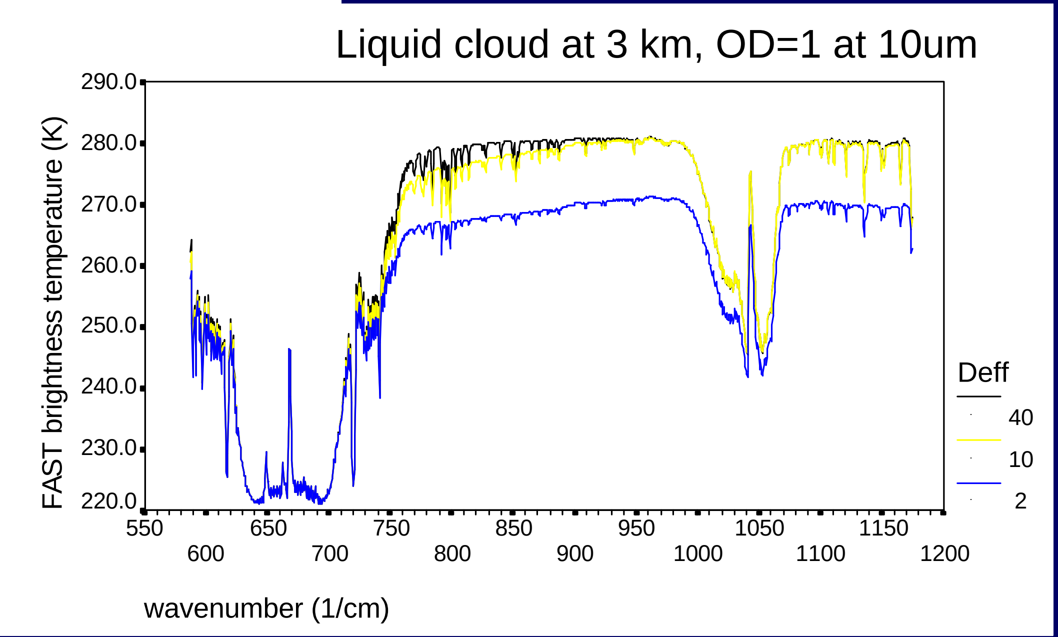
# Simulations performed

- Nadir view, OD = 0, 0.1, 0.5, 1, 2, 3, 5 @ 10 um
- Liquid clouds (Mie spheres, gamma dist.)
  - 1, 2, 3 km cloud top altitude
  - 2, 10, 20, 40 um $D_{eff}$
- Ice clouds (Hexagonal ice crystals, gamma dist.)
  - 5, 10, 15 km cloud top altitude
  - 10, 20, 40, 100 um $D_{eff}$
- LABELS
  - "FAST"
    - new method of estimating $D_{eff}$
    - new cloud property database
  - "TRUTH"
    - LBLRTM/DISORT

# LW band

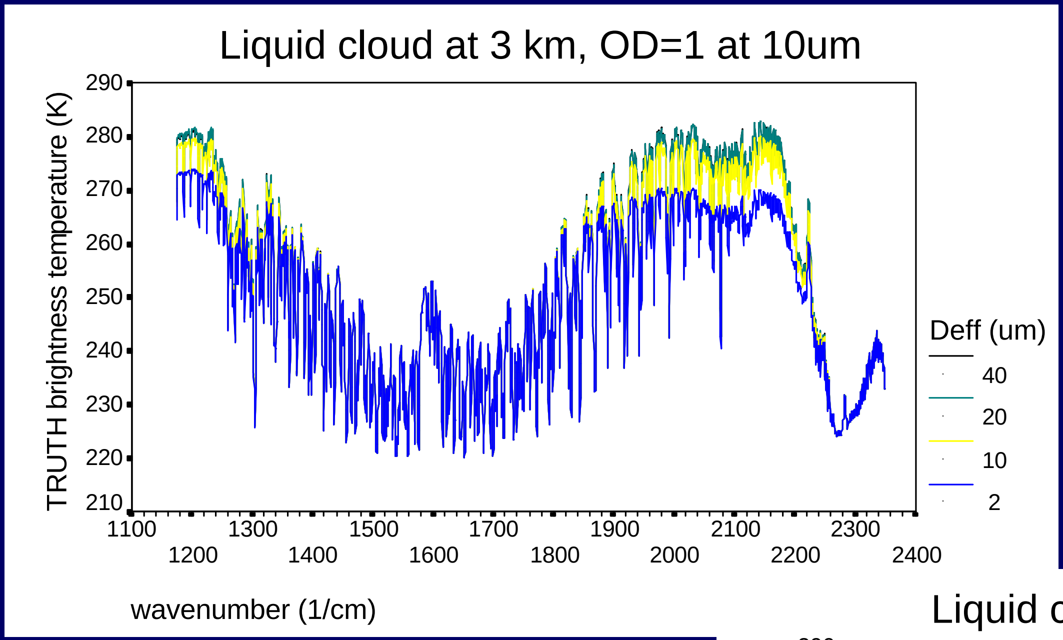


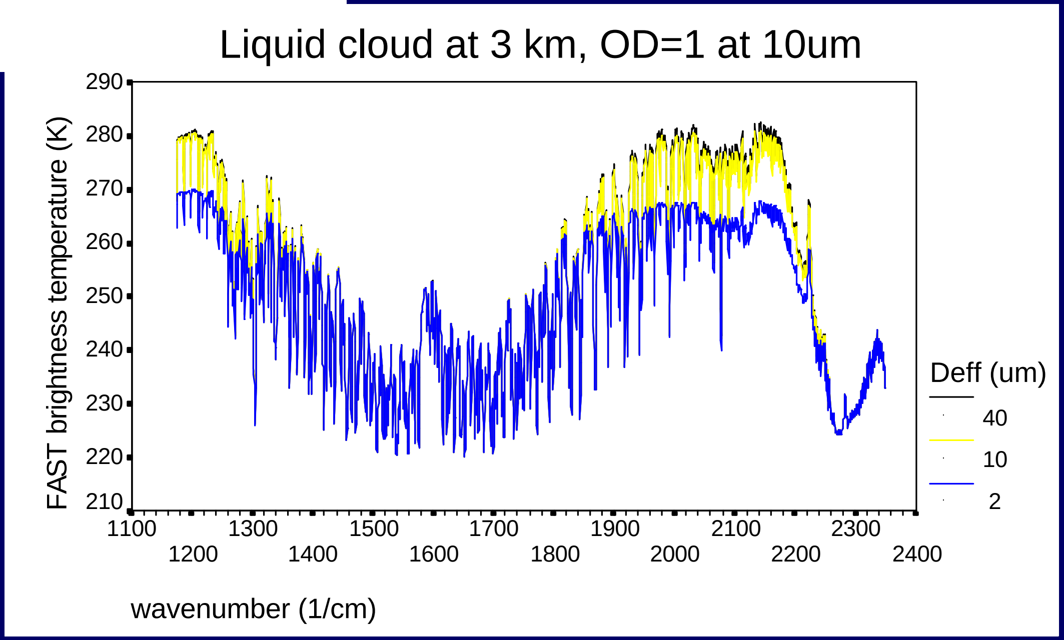
Liquid cloud at 3 km, OD=1 at 10um
TRUTH brightness temperature (K)
290.0
280.0
270.0
260.0
250.0
240.0
230.0
220.0
550
650
750
850
950
1050
1150
600
700
800
900
1000
1100
1200
wavenumber (1/cm)
Deff
40
20
10
2

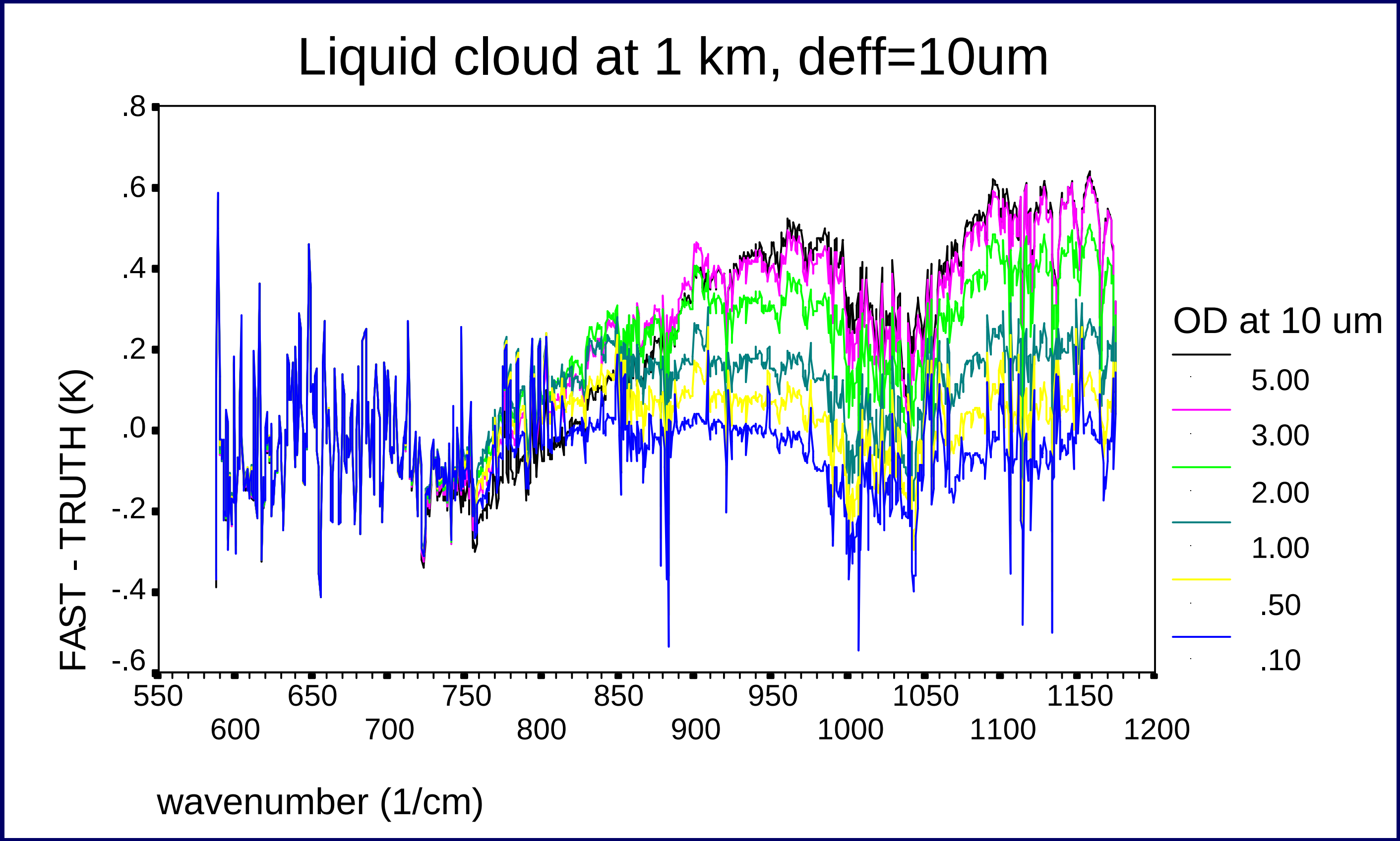
Liquid cloud at 3 km, OD=1 at 10um
FAST brightness temperature (K)
290.0
280.0
270.0
260.0
250.0
240.0
230.0
220.0
550
650
750
850
950
1050
1150
600
700
800
900
1000
1100
1200
wavenumber (1/cm)
Deff
40
10
2

# SMW band

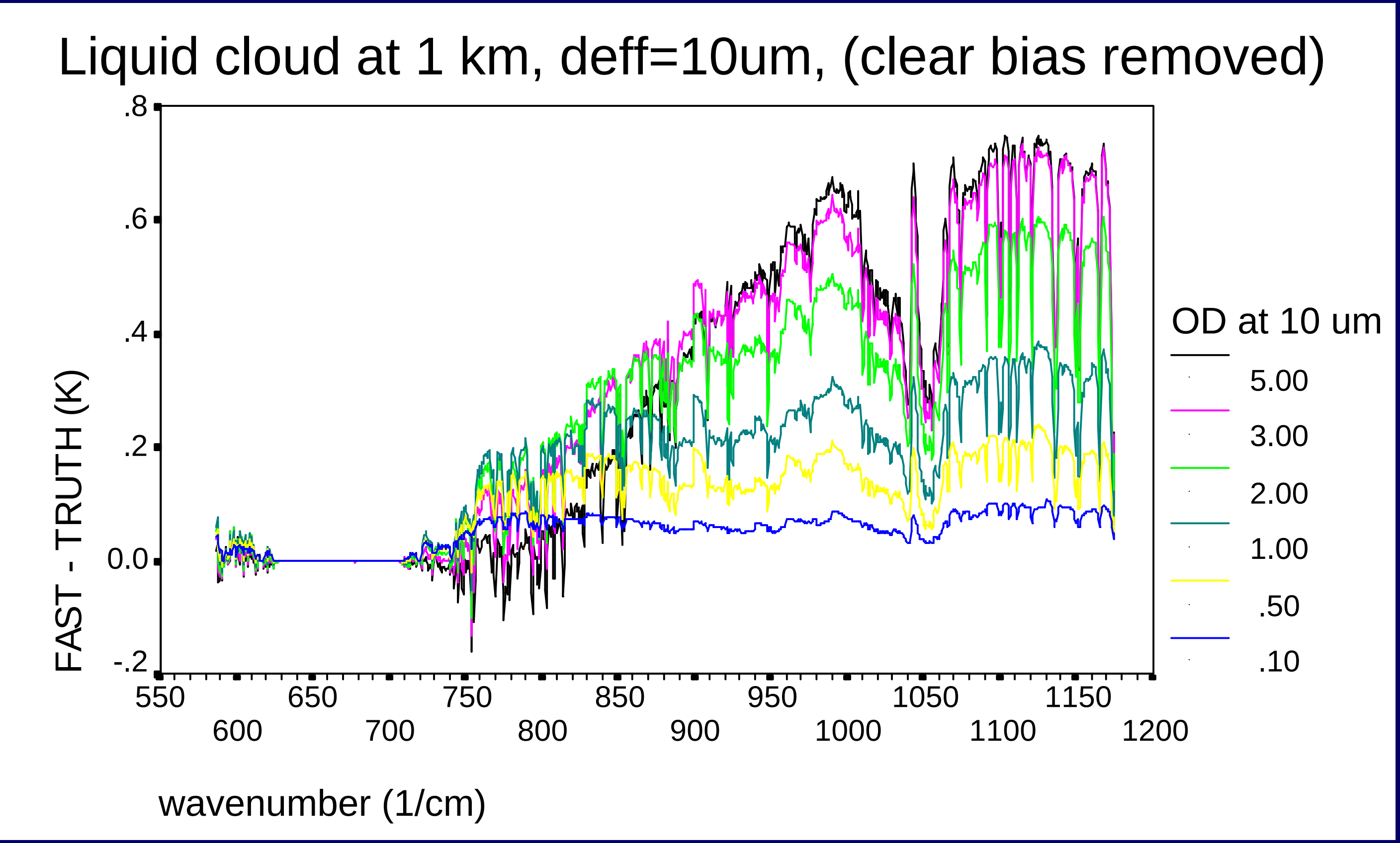

Liquid cloud at 3 km, OD=1 at 10um
TRUTH brightness temperature (K)
290
280
270
260
250
240
230
220
210
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
wavenumber (1/cm)
Deff (um)
40
20
10
2


Liquid cloud at 3 km, OD=1 at 10um
FAST brightness temperature (K)
290
280
270
260
250
240
230
220
210
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
wavenumber (1/cm)
Deff (um)
40
10
2

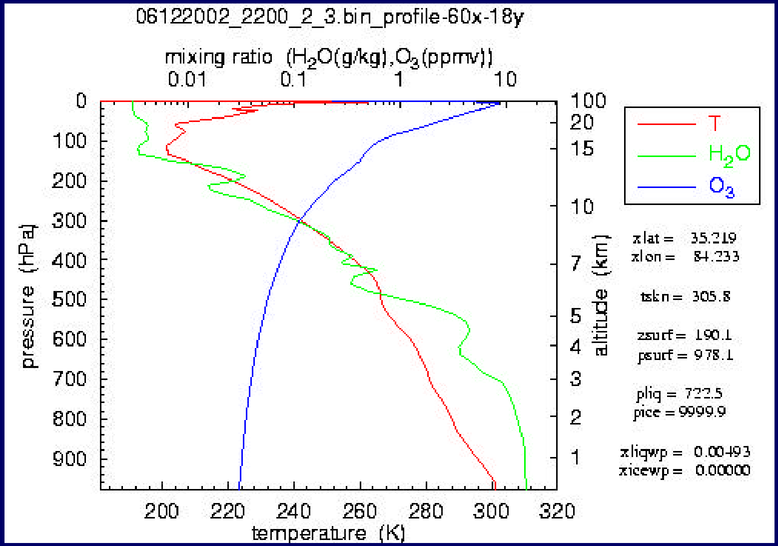
# LW band difference spectra



# LW band difference spectra

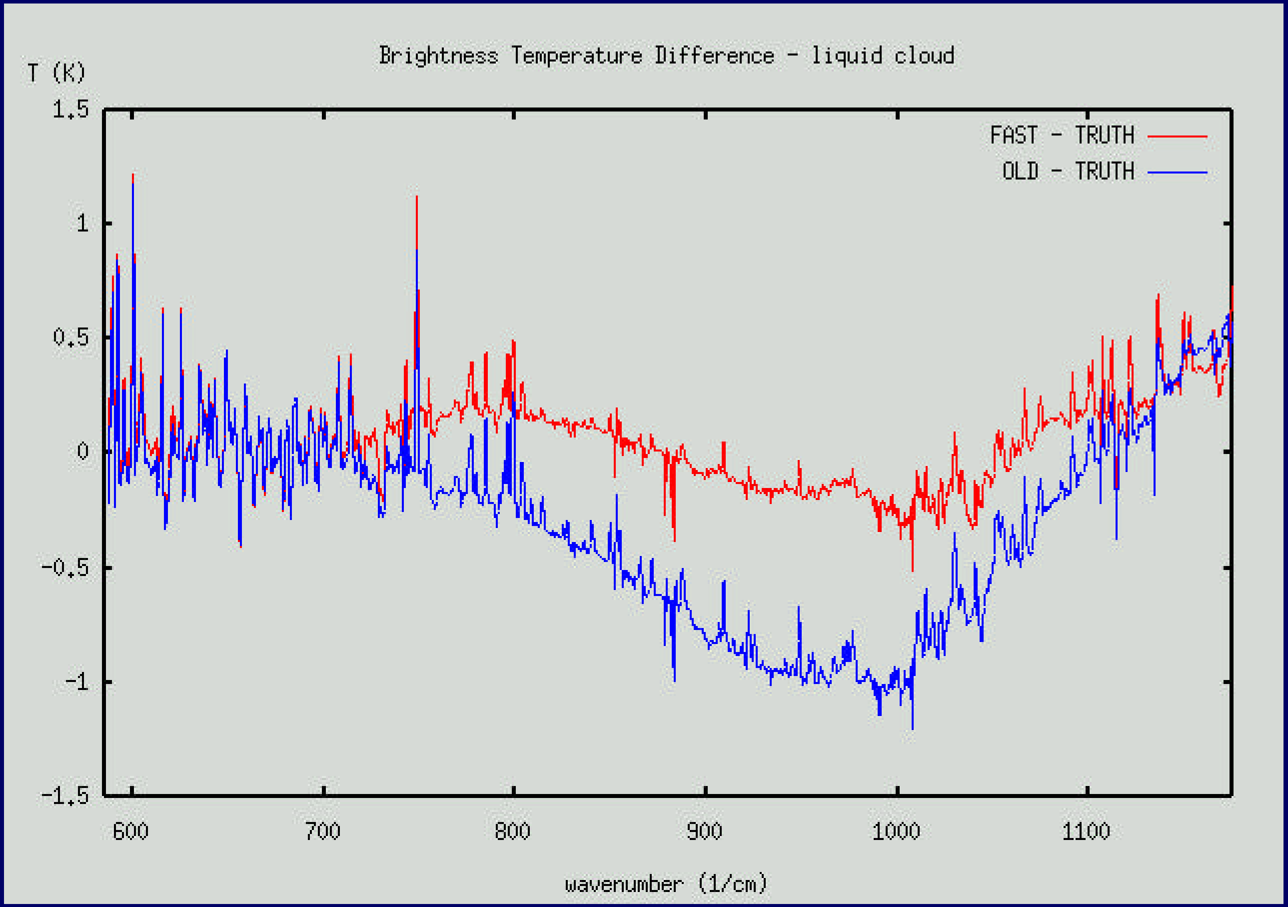


# A realistic profile comparison




```
Header line
000.0
550.0 2400.0 0.01
1
7
0 1.2 1.0 1000. 0.040
0 1.5 1.5 1000. 0.348
0 1.8 1.0 1000. 0.012
0 2.0 1.0 1000. 0.001
0 2.3 1.7 1000. 0.352
0 2.6 2.7 1000. 2.724
0 2.8 1.7 1000. 0.398
/abyss/Users/jimd/real_cloud_experiment_v6.01/liq/surf_to_cloud
3
/home/jimd/LBLDIS/single_scat_properties/ssp_db.mie_wat.gamma_sigma_0p100
/home/jimd/LBLDIS/single_scat_properties/ssp_db.mie_ice.gamma_sigma_0p100
/home/jimd/LBLDIS/single_scat_properties/ssp_db.hex_ice.gamma.0p100
305.8
2
100 1
3000 1
```

# LW spectra comparison



# `giftsfrte` status and future

- An improved  method for rapidly computing cloudy radiances has been added to the GIFTS top-of-atmosphere radiance model.
- Comparisons with a more rigorous model show some increased accuracy - but a cloudy profile test set is needed to quantify the improvement.
- Future considerations to increase model fidelity:
  - Surface spectral emissivity
  - Aerosols
  - Multi-layer / mixed phase clouds

# Modeling Capabilities

- We have the capability to produce detailed simulations of the variables that will influence GIFTS data.
- MURI research primarily uses TOA radiances (the first two steps)

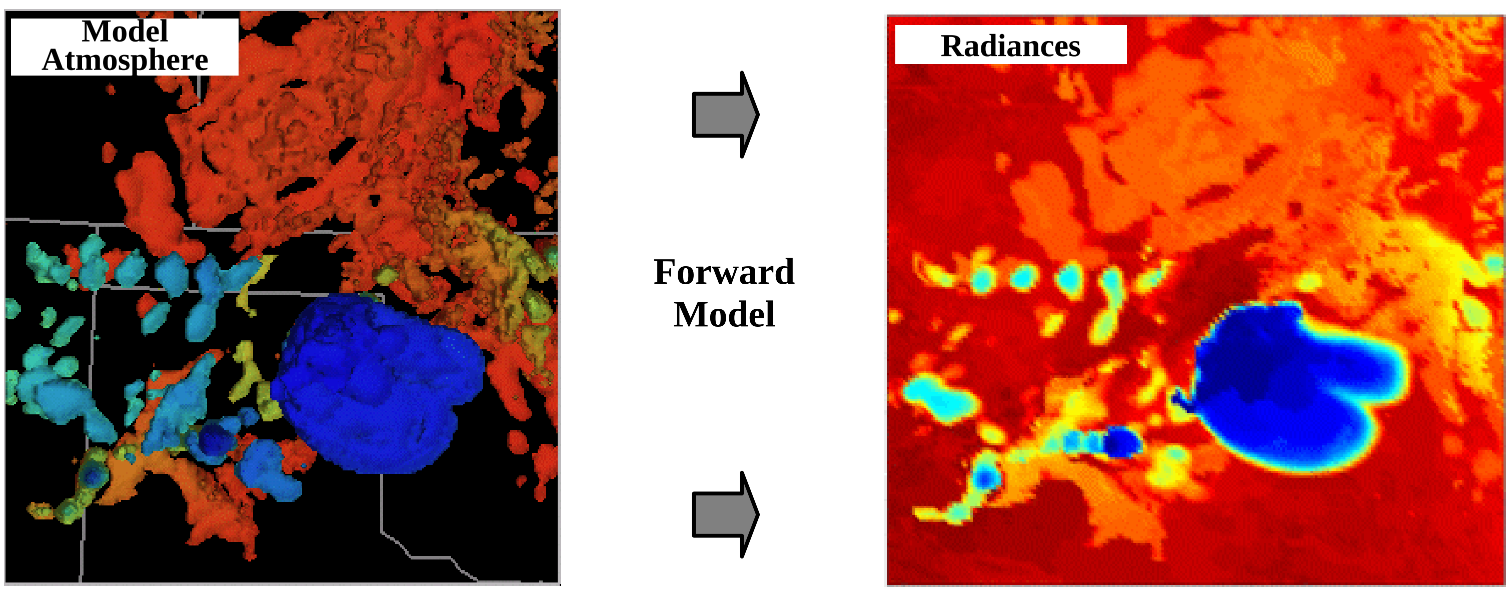
| Modeling step | Product |
|---|---|
| MM5 model | Atmospheric state profiles |
| GIFTS fast model | TOA radiances |
| Optics Model | Interferogram signal |
| Detector Model | Calibrated GIFTS spectra |

# Goals of simulated data for MURI

- Provide spectra and images for retrievals
  - Profiles
  - Clouds
  - Winds
- Capture representative examples of realistic TOA radiances.

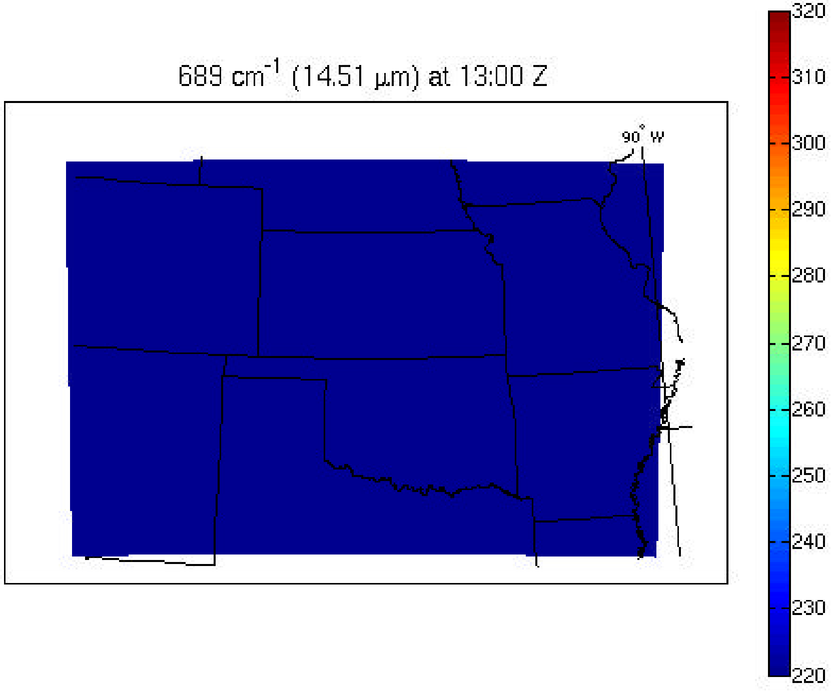
# GIFTS Simulated TOA Radiances

- Using GIFTS forward radiative transfer model to produce top of atmosphere radiances from simulated atmospheric fields



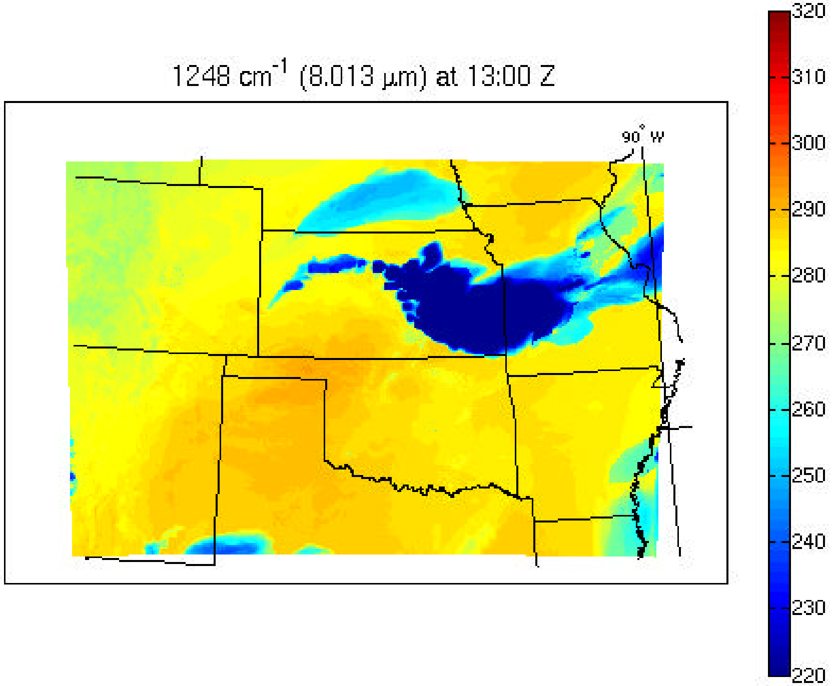
# Wavenumber Animation

- The advantage of GIFTS
- IHOP 2 by 3, 4 km dataset at ~5 1/cm resolution.
- June 12th, 13:00 UTC
- Single time step = 1.2 GB of TOA radiance data.



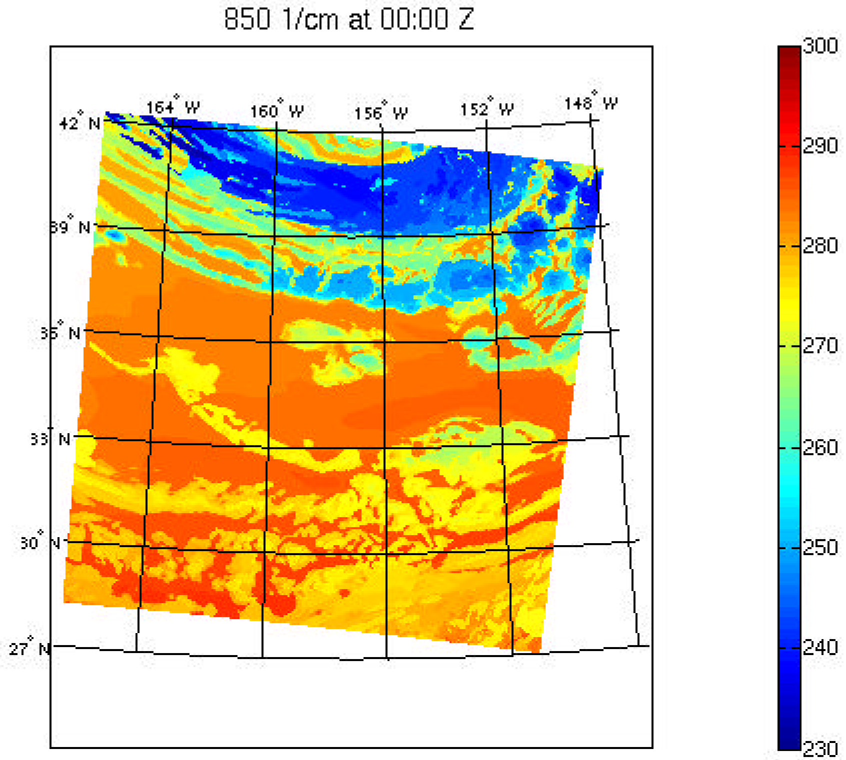
# SMW Wavenumber Animation

- IHOP 2 by 3, 4 km dataset at ~5 1/cm resolution.
- June 12th, 13:00 UTC

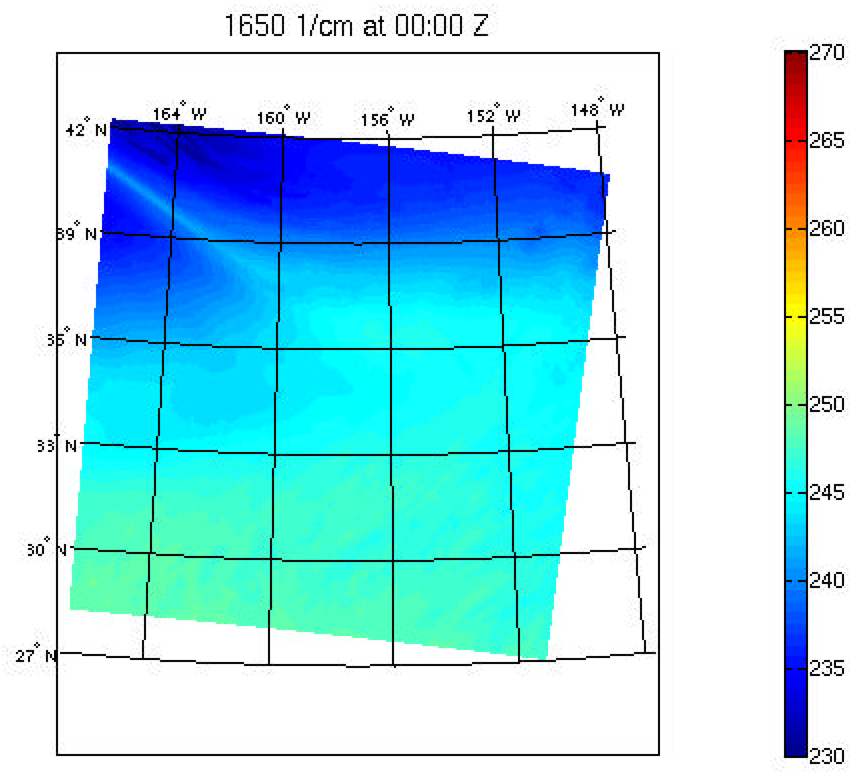


# Thorpex Time Animations

- Final choice of MM5 run?
- 7 time steps
- 3 by 3 array of cubes.
- 850 1/cm (window region)

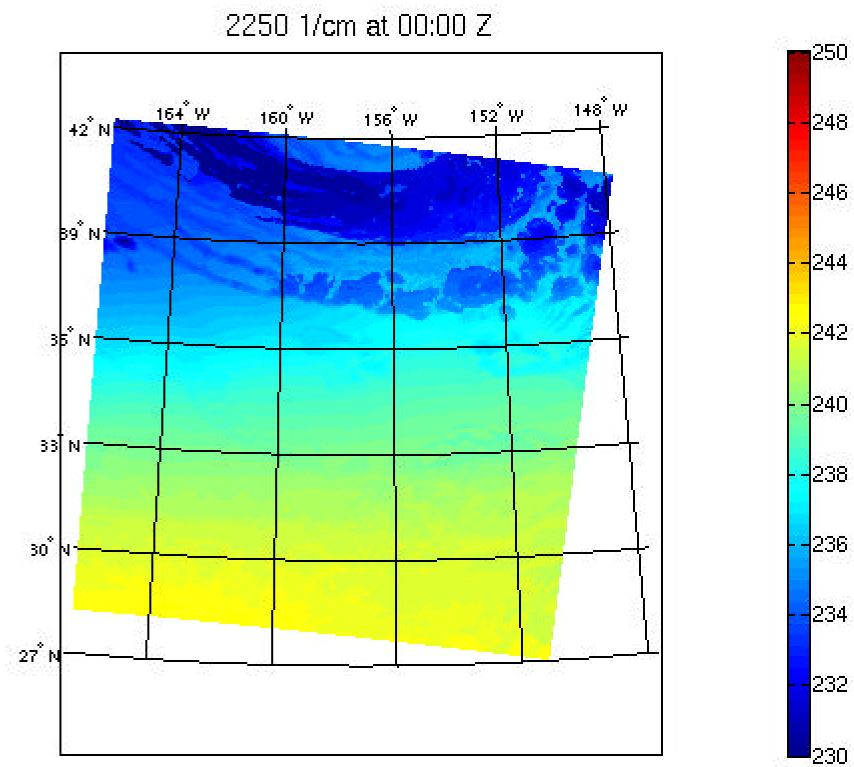


# 1650 wavenumber



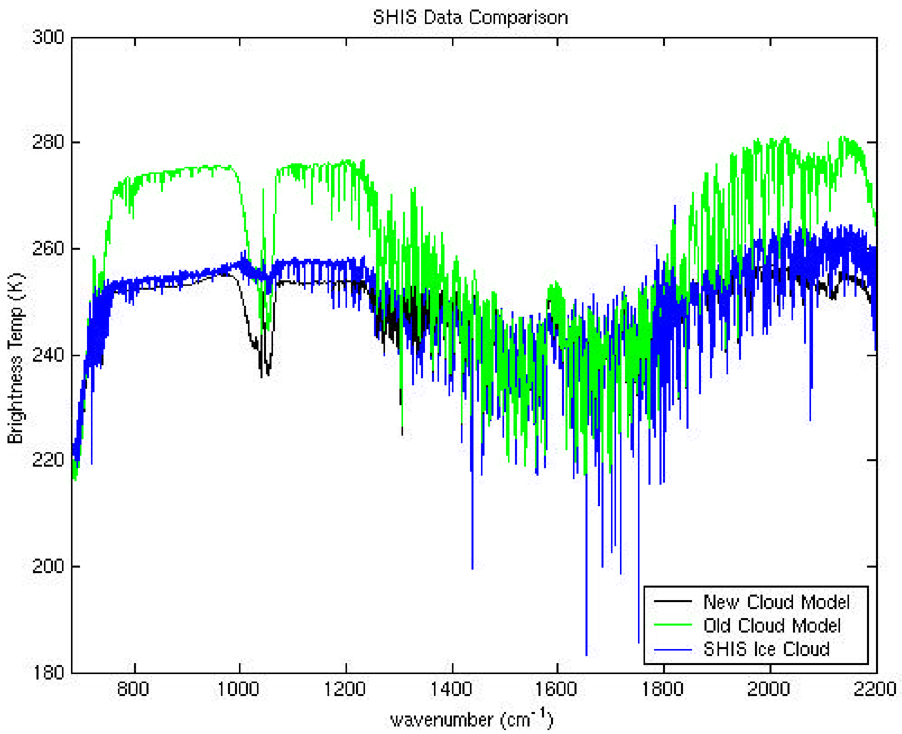
# THORPEX SMW sample

- Same region
- 7 time steps
- 2250 1/cm



# Fast Model Testing

- Checking simulated data with line by line and DISORT
- Drawing a bridge between the simulated data and the field experiment data.
  - Compare THORPEX results to aircraft and GWINDEX data




- Checking broad features of the spectra
  - Scanning HIS: similar type of interferometer. Participated in both IHOP and THORPEX
  - Giftsfrte output from a thick ice cloud in the IHOP simulation
  - S-HIS data is an average of an area of cirrus coverage (significant lidar attenuation and cold window temps)

# Questions?