



# **Microwave Integrated Retrieval “System” (MIRS)**

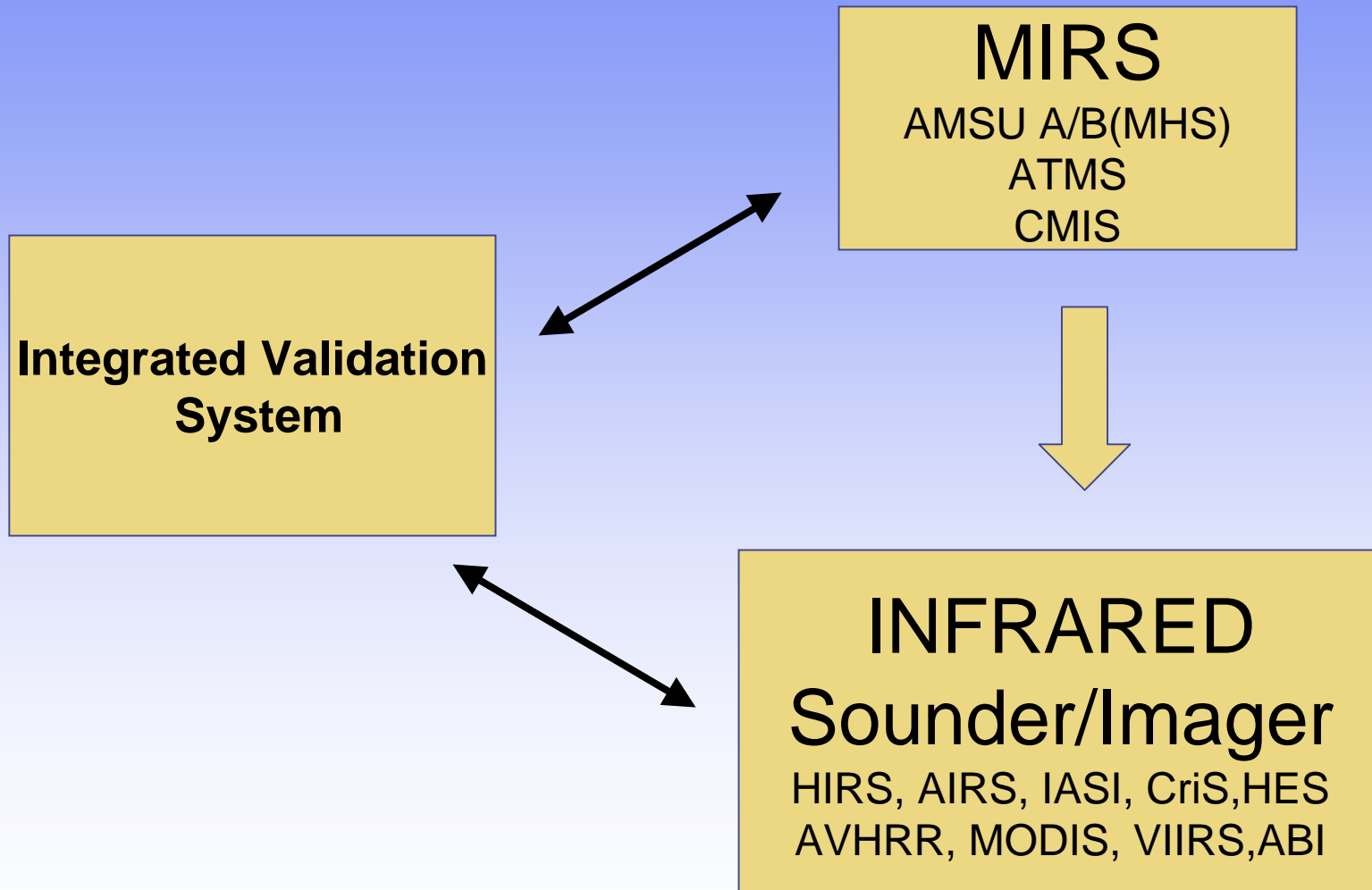
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Ralph Ferraro and Tony Reale**

**Office of Research Applications  
NOAA/NESDIS**

**The 14<sup>th</sup> International TOVS Study Conference, Beijing, China  
May 25-31, 2005**



# NESDIS Plan on ATOVS System





# NESDIS ATOVS Plan

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- Use MIRS as front end
- MIRS provides microwave-only retrieval, and will become an operational product
- MIRS microwave retrieval is first guess for HIRS. HIRS processing software call a function which returns the required microwave information from the MIRS.
- HIRS information is used to derive clouds, OLR, ozone and for clear fogs improved temperature and moisture profiles (for temperature improvement is in lower troposphere)



# AIRS, CrIS, and IASI

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- Continue development of a single software processing system for all three instrument.
- The processing system incorporates microwave information from AMSU and ATMS and imager information from MODIS, VIIRS and AVHRR.
- Use of MIRS is desirable as front-end. (Microwave algorithms are embedded within AIRS processing system, - so software modules from MIRS will need to be embedded)





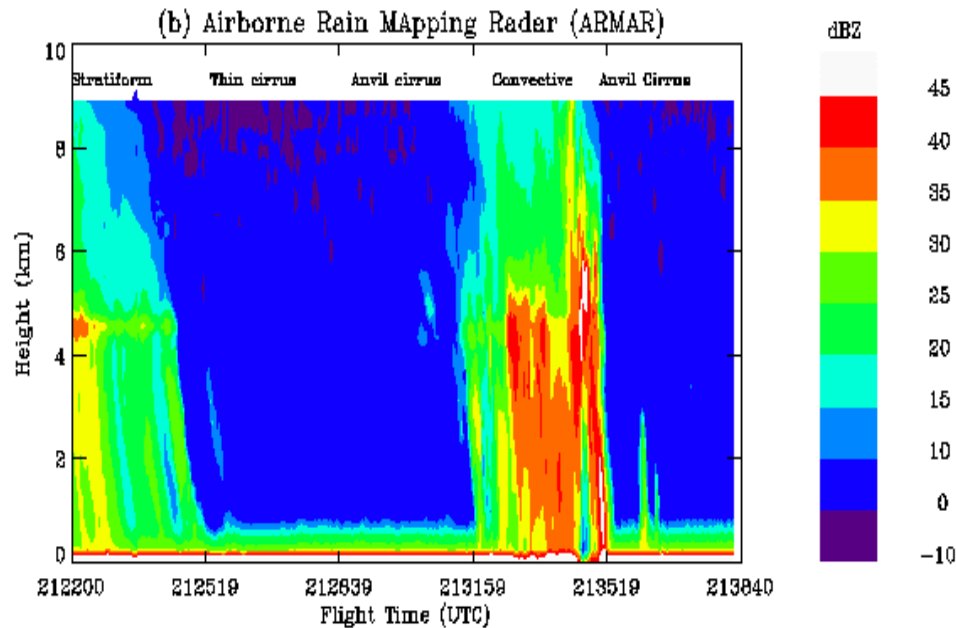
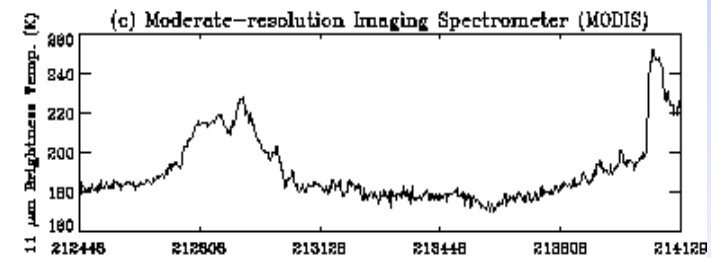
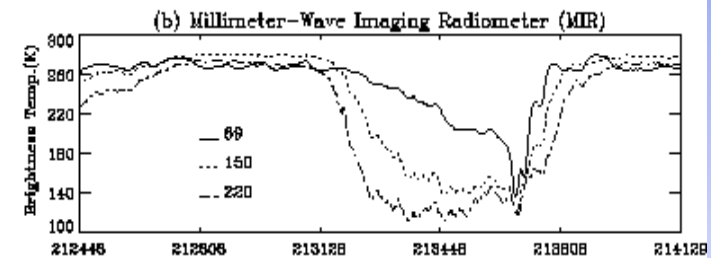
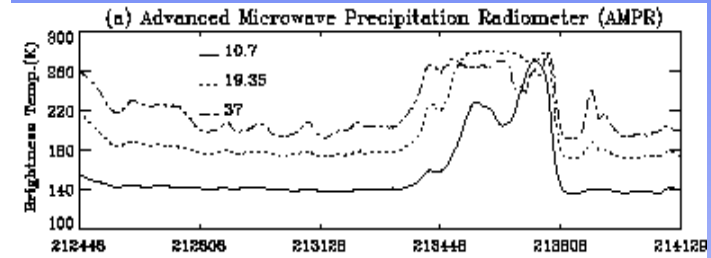
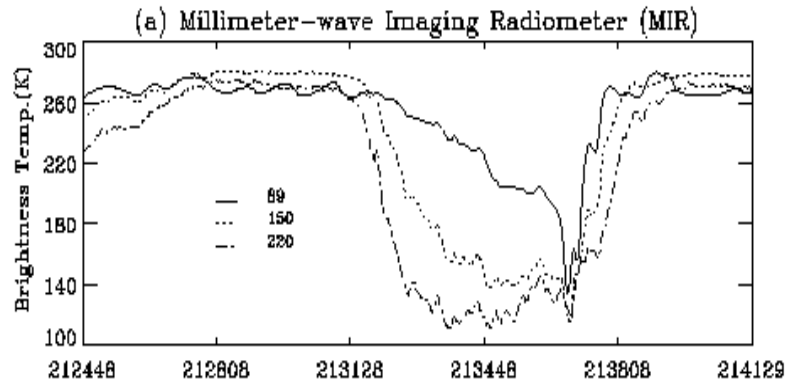
# Microwave Products from NPOESS CMIS

EDR Title	Category
<i>Atmospheric Vertical Moisture Profile (surf to 600mb)</i>	<i>IA</i>
Sea Surface Winds (Speed)	IA
Soil Moisture	IA
<i>Atmospheric Vertical Moisture Profile (600 to 100mb)</i>	<i>IIA</i>
<i>Atmospheric Vertical Temperature Profile</i>	<i>IIA</i>
<i>Cloud Ice Water Path</i>	<i>IIA</i>
<i>Cloud Liquid Water</i>	<i>IIA</i>
Ice Surface Temperature	IIB
<i>Land Surface Temperature</i>	<i>IIB</i>
<i>Precipitation</i>	<i>IIA</i>
<i>Precipitable Water</i>	<i>IIA</i>
Sea Ice Age and Sea Ice Edge Motion	IIB
Sea Surface Temperature	IIA
Sea Surface Winds (Direction)	IIA
<i>Total Water Content</i>	<i>IIA</i>
Cloud Base Height	IIIB
Fresh Water Ice	IIIB
Imagery	IIIB
Pressure Profile	IIIB
<i>Snow Cover / Depth</i>	<i>III B/A</i>
Surface Wind Stress	IIIB
Vegetation / Surface Type	IIIB

*The highlighted are  
operational EDRS  
derived from POES AMSU*



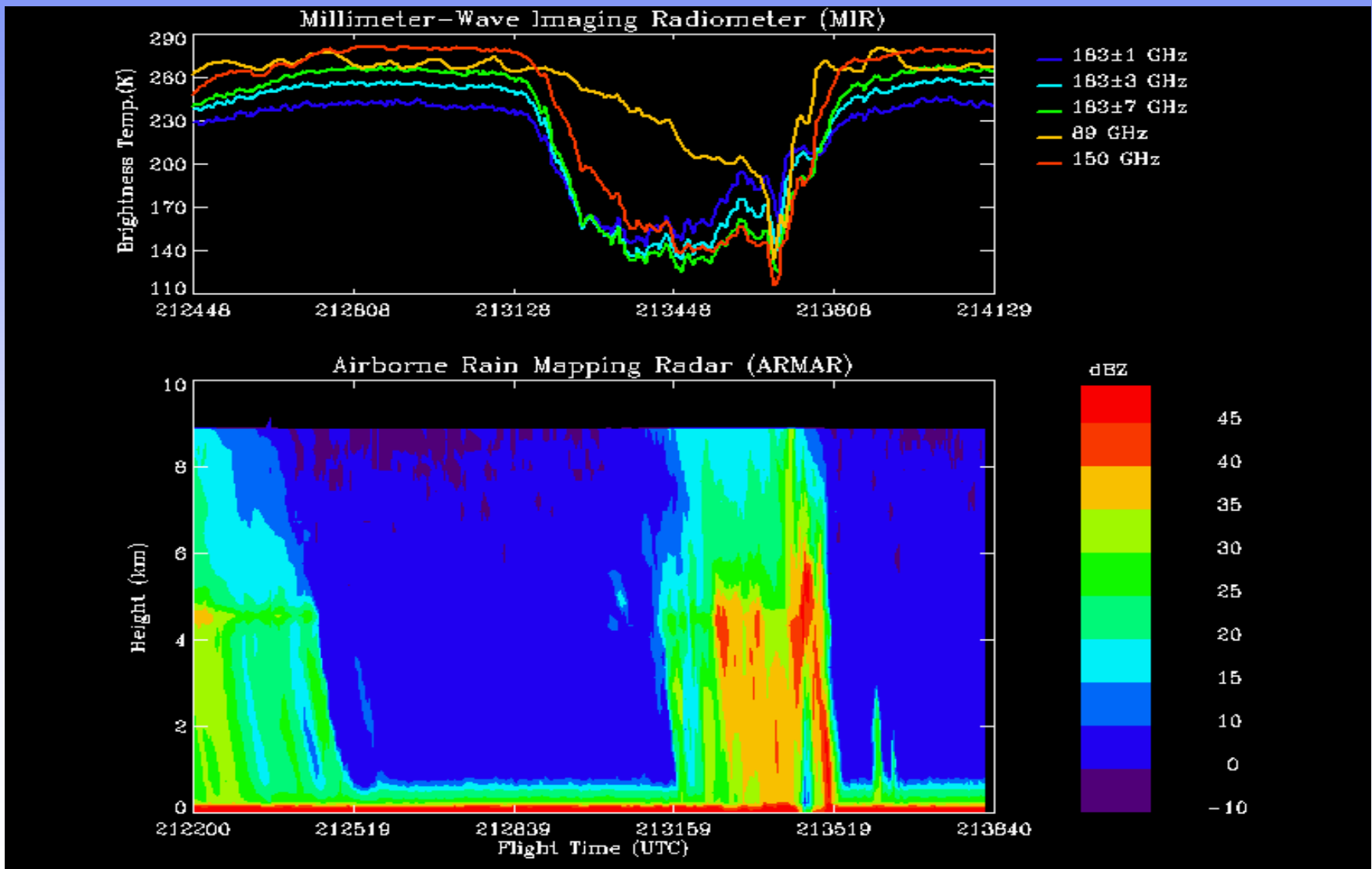
# ER-2/DC-8 Measurements during TOGA/CORE (1/2)



Weng and Grody (2000, JAS)



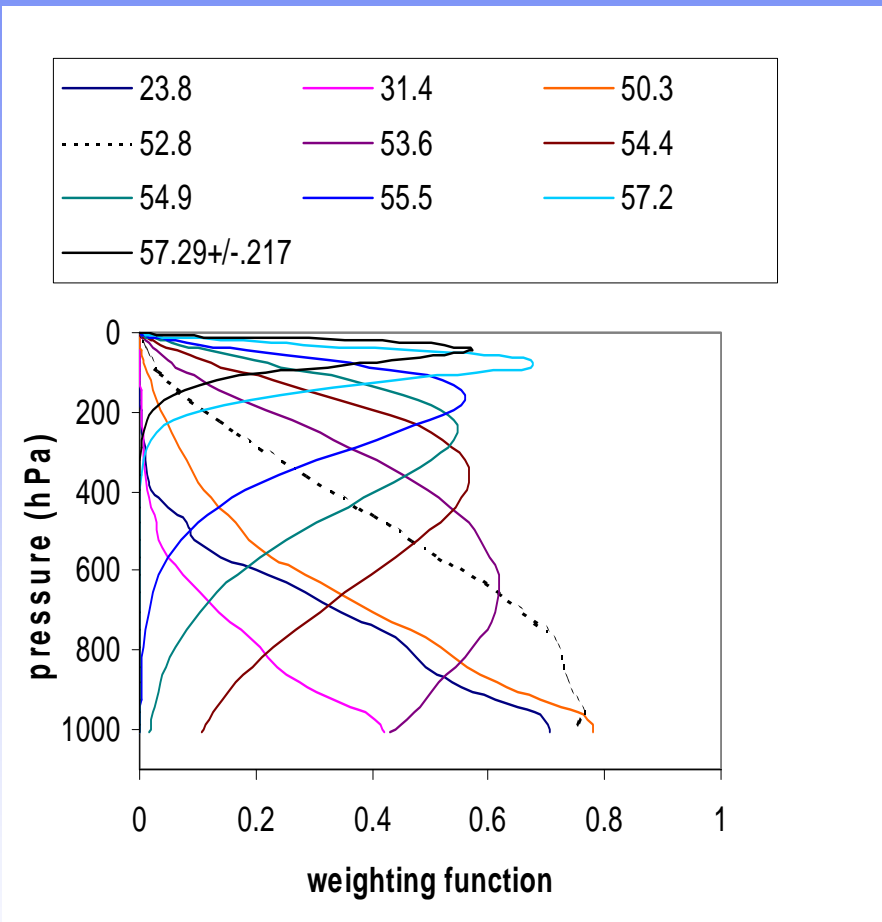
# ER-2/DC-8 Measurements during TOGA/CORE (2/2)



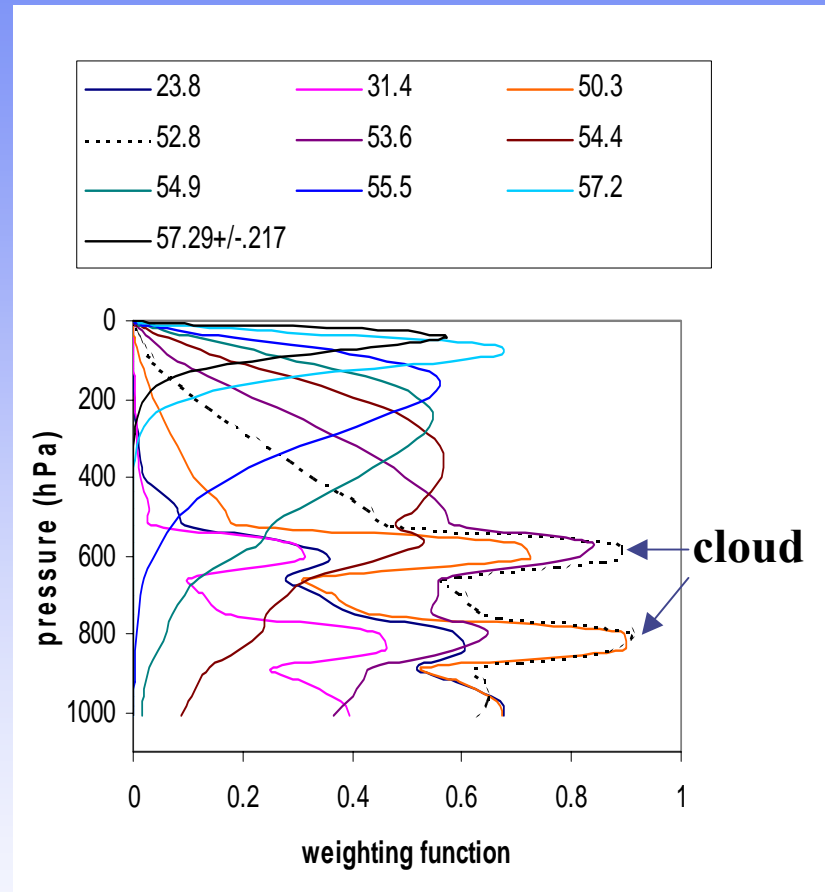




# Clouds Modify AMSU Weighting Function



Clear condition

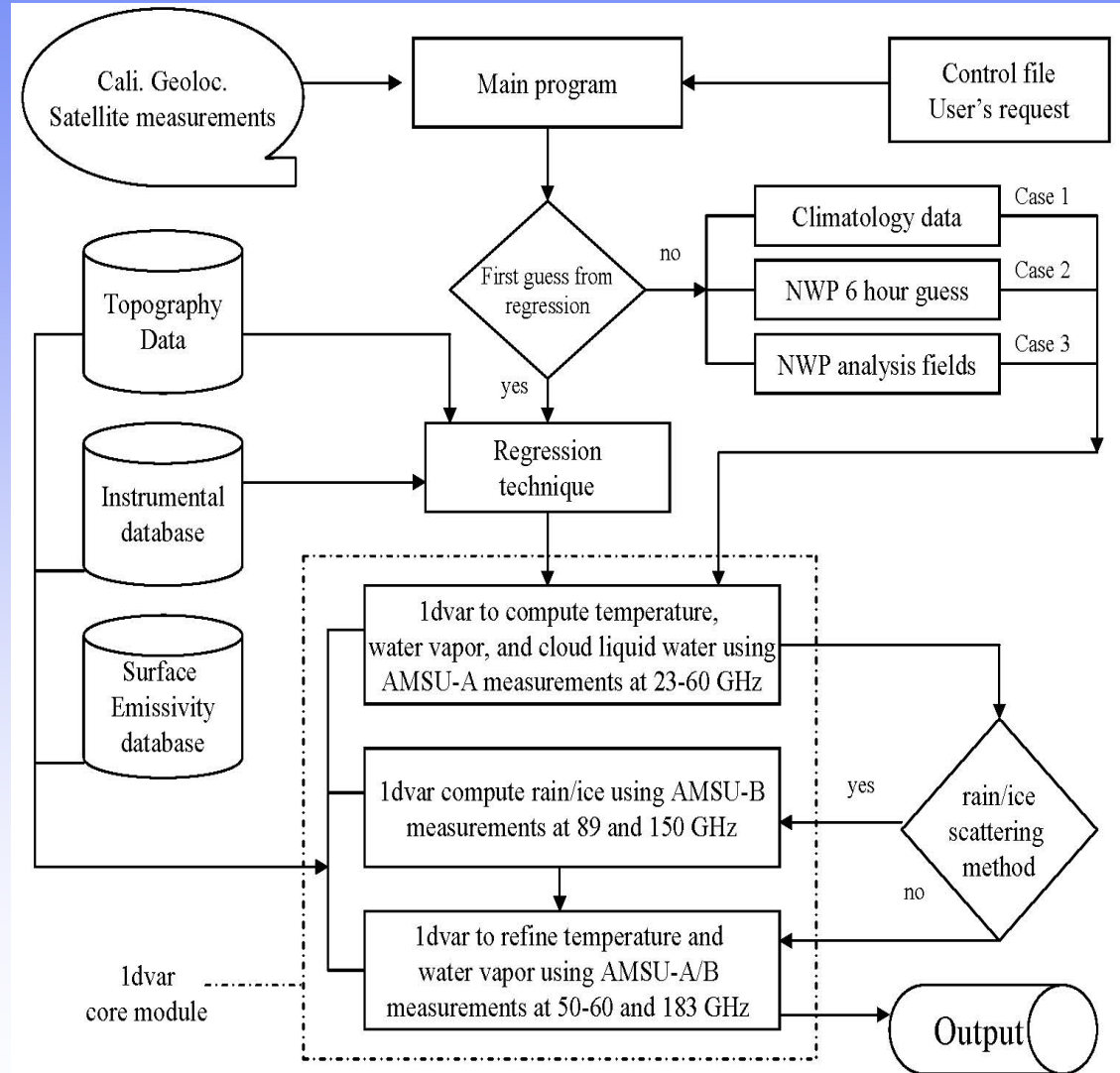


Include two separated cloud layers at 610 and 840 hPa with  $0.5 \text{ g m}^{-3}$  liquid water.



# Microwave Integrated Retrieval System Flowchart

- Fast scattering/polarimetric radiative transfer model/Jacobian for all atmospheric conditions
- Surface emissivity/reflectivity models (soil, vegetation, snow/sea ice, water)
- Fast variational minimization algorithm
- NWP forecast outputs, climatology, regressions as first guess
- Temperature, water vapor and cloud and rain water profiles
- Flexible channel selection/sensor geometry and noise





# Algorithm Theoretical Basis (1/9)

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Cost Function:

$$J = \frac{1}{2} (\mathbf{x} - \mathbf{x}^b)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}^b) + \frac{1}{2} [\mathbf{I}(\mathbf{x}) - \mathbf{I}^o]^T (\mathbf{E} + \mathbf{F})^{-1} [\mathbf{I}(\mathbf{x}) - \mathbf{I}^o]$$

where

$\mathbf{x}_b$  is background vector

$\mathbf{x}$  is state vector to be retrieved

$\mathbf{I}$  is the radiance vector

$\mathbf{B}$  is the error covariance matrix of background

$\mathbf{E}$  is the observation error covariance matrix

$\mathbf{F}$  is the radiative transfer model error matrix



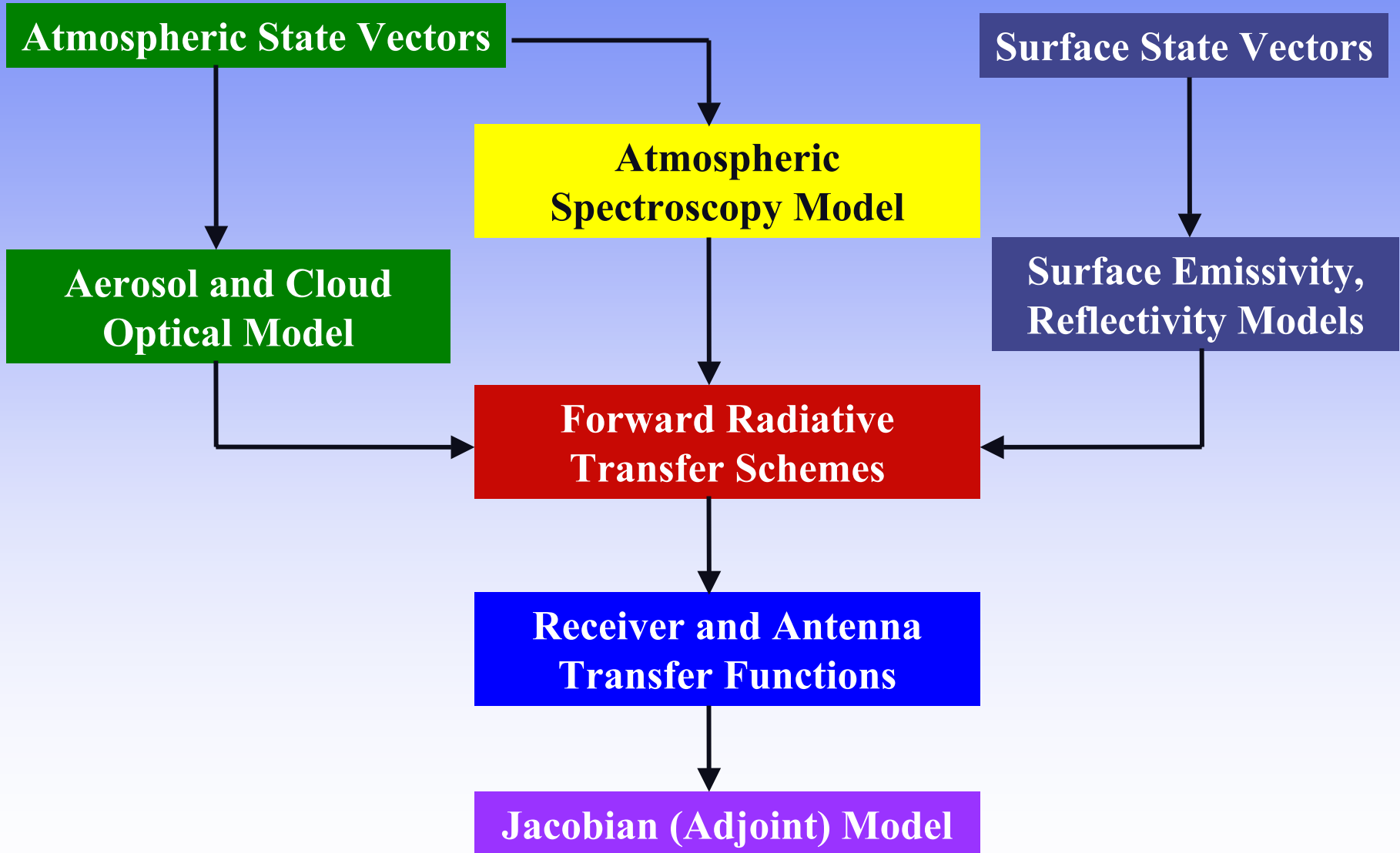
## Algorithm Theoretical Basis (2/9)

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- Retrievals are made at vertical pressure levels (0.1 to surface, maximum levels of 42)
- Surface pressure from GDAS 6-hour forecasts
- Background state variables from climatology which is latitude-dependent
- First guess is from regression (could be the same as background)
- No background information needed for cloud water
- Bias correction for forward models, residuals will be observational error covariance

# Algorithm Theoretical Basis (3/9)

## JCSDA Community Radiative Transfer Model





# Algorithm Theoretical Basis (4/9)

## Radiative Transfer Model:

$$\mu \frac{d\mathbf{I}(\tau, \Omega)}{d\tau} = -\mathbf{I}(\tau, \Omega) + \frac{\omega}{4\pi} \int_0^{4\pi} \mathbf{M}(\tau, \Omega, \Omega') \mathbf{I}(\tau, \Omega') d\Omega' + (1 - \omega) \mathbf{B} + \frac{\omega F_0}{4\pi} \exp(-\tau / \mu_0) \mathbf{S}$$

- Radiative transfer scheme including four Stokes components is based on VDISORT (Weng, JQRST, 1992)
- Accuracies on various transfer problems including molecular scattering, L13 aerosols and microwave polarimetry are discussed (Schulz et al., JQSRT, 1999, Weng, J. Elec&Appl., 2002 )
- Jacobians including cloud liquid and ice water are derived using VDISORT solutions (Weng and Liu, JAS, 2003)
- Surface emissivity and bi-directional reflectivity models are integrated (Weng et al., JGR, 2001)



# Algorithm Theoretical Basis (5/9)

## Vector DIScrete Ordinate Radiative (VDISORT) Solution:

$$\mathbf{I}_l(\tau) = \exp[\mathbf{A}_l(\tau - \tau_{l-1})] \mathbf{c}_l + \mathbf{s}_l(\tau)$$

$$\begin{aligned} \mathbf{s}_l(\tau) = & \delta_{m0} [B(\tau_{l-1}) \mathbf{\Xi} + \frac{B(\tau_l) - B(\tau_{l-1})}{\tau_l - \tau_{l-1}} (\mathbf{A}_l^{-1} \mathbf{\Xi} + (\tau - \tau_{l-1}) \mathbf{\Xi})] \\ & + \mu_0 [\mu_0 \mathbf{A}_l + \mathbf{E}]^{-1} \frac{\varpi F_0}{\pi} \exp(-\tau / \mu_0) \mathbf{\Psi} \end{aligned}$$

## Jacobians Including Scattering:

$$\begin{aligned} \frac{\partial \mathbf{I}_l(\mu)}{\partial x_l} = & \sum_{k=l}^L \sum_{j=-4N}^{4N} \mathbf{K}_k(\mu, j) \left\{ \frac{\partial (\mathbf{s}_k(\tau) - \mathbf{s}_{k-1}(\tau))}{\partial x_l} \Big|_{\tau=\tau_{l-1}} \right\}_j + \delta_{1l} \frac{\partial \mathbf{s}_1(\mu)}{\partial x_l} \\ - & \sum_{j=-4N}^{4N} \mathbf{K}_l(\mu, j) \left\{ \frac{\partial}{\partial x_l} \exp[\mathbf{A}_l(\tau - \tau_{l-1})] \Big|_{\tau=\tau_l} \mathbf{c}_l \right\}_j \end{aligned}$$

(Weng and Liu, JAS, 2003)

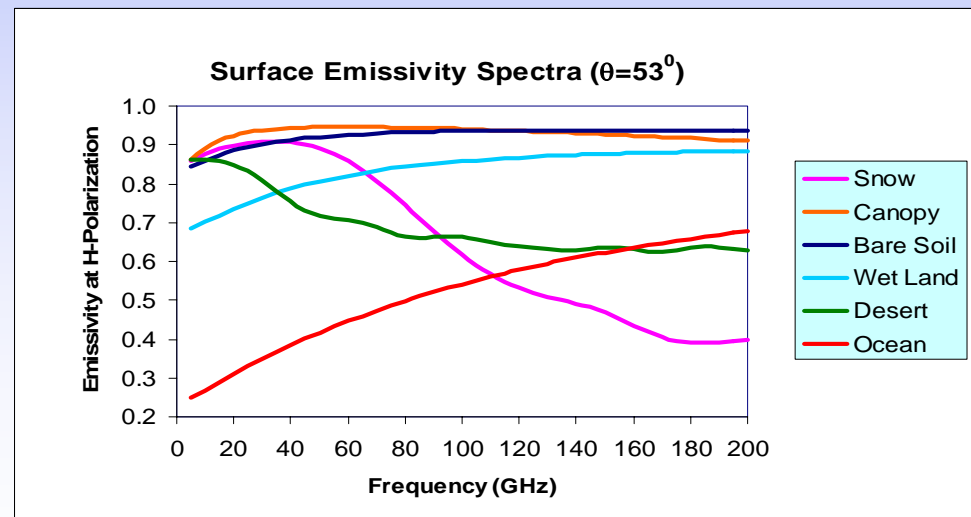
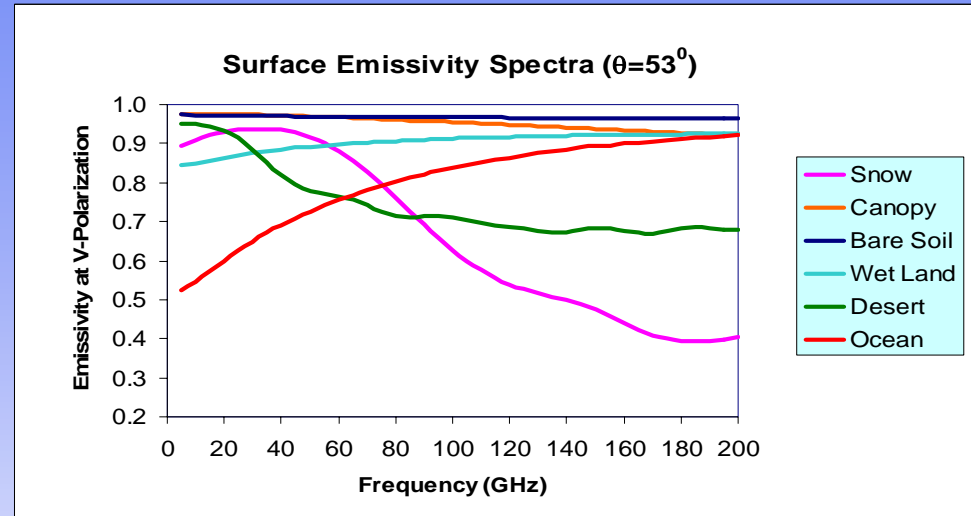


# Algorithm Theoretical Basis (6/9)

## Emissivity Model:

- **Open water** – two-scale roughness theory
- **Sea ice** – Coherent reflection
- **Canopy** – Four layer clustering scattering
- **Bare soil** – Coherent reflection and surface roughness
- **Snow/desert** – Random media

Weng et al (2001, JGR)

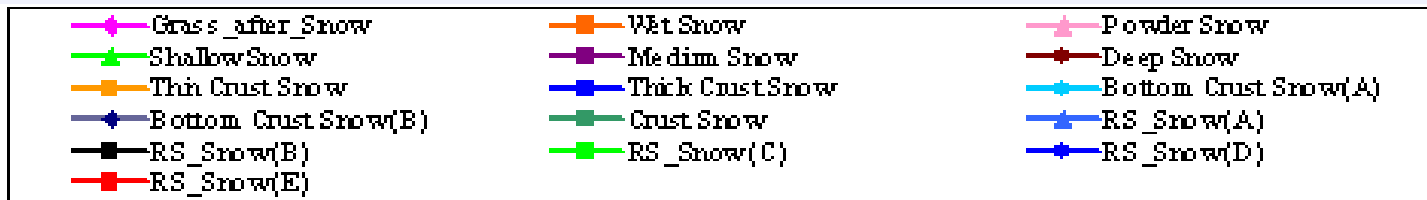
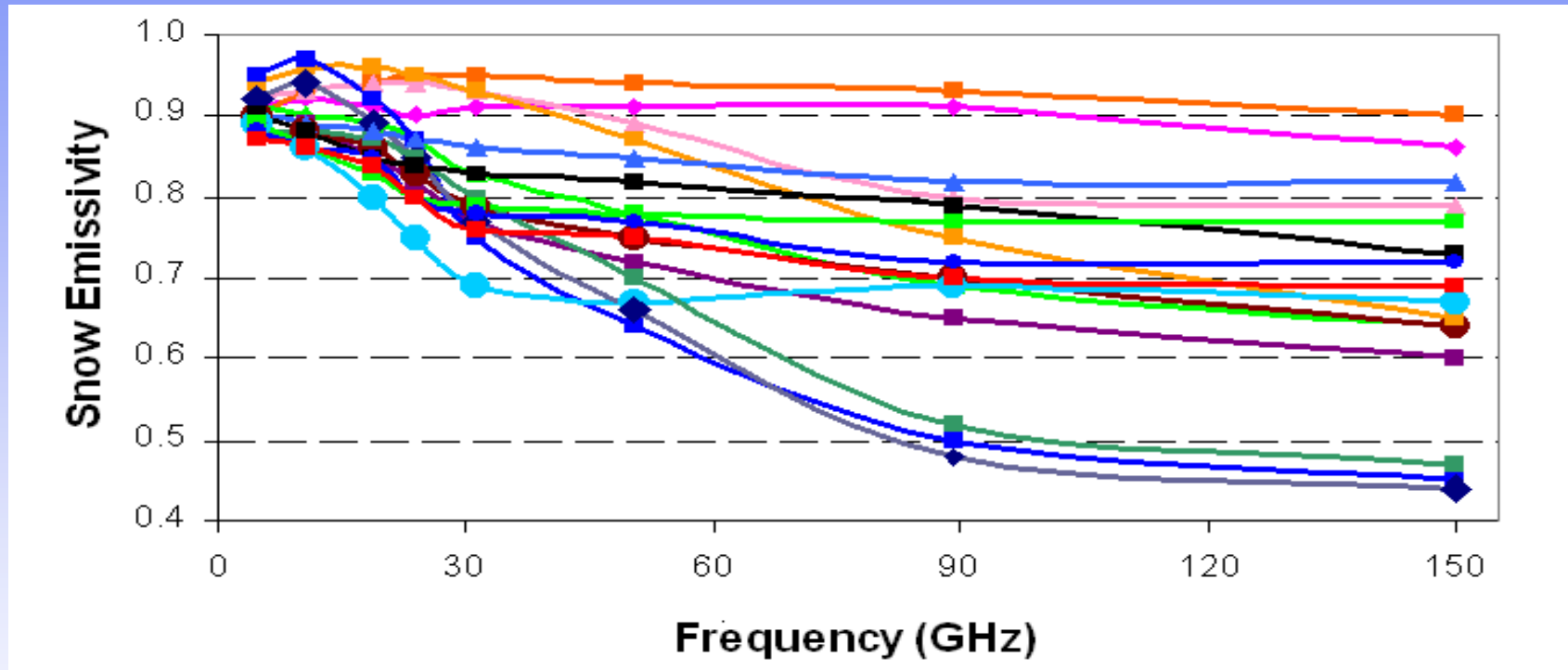






# Algorithm Theoretical Basis (7/9)

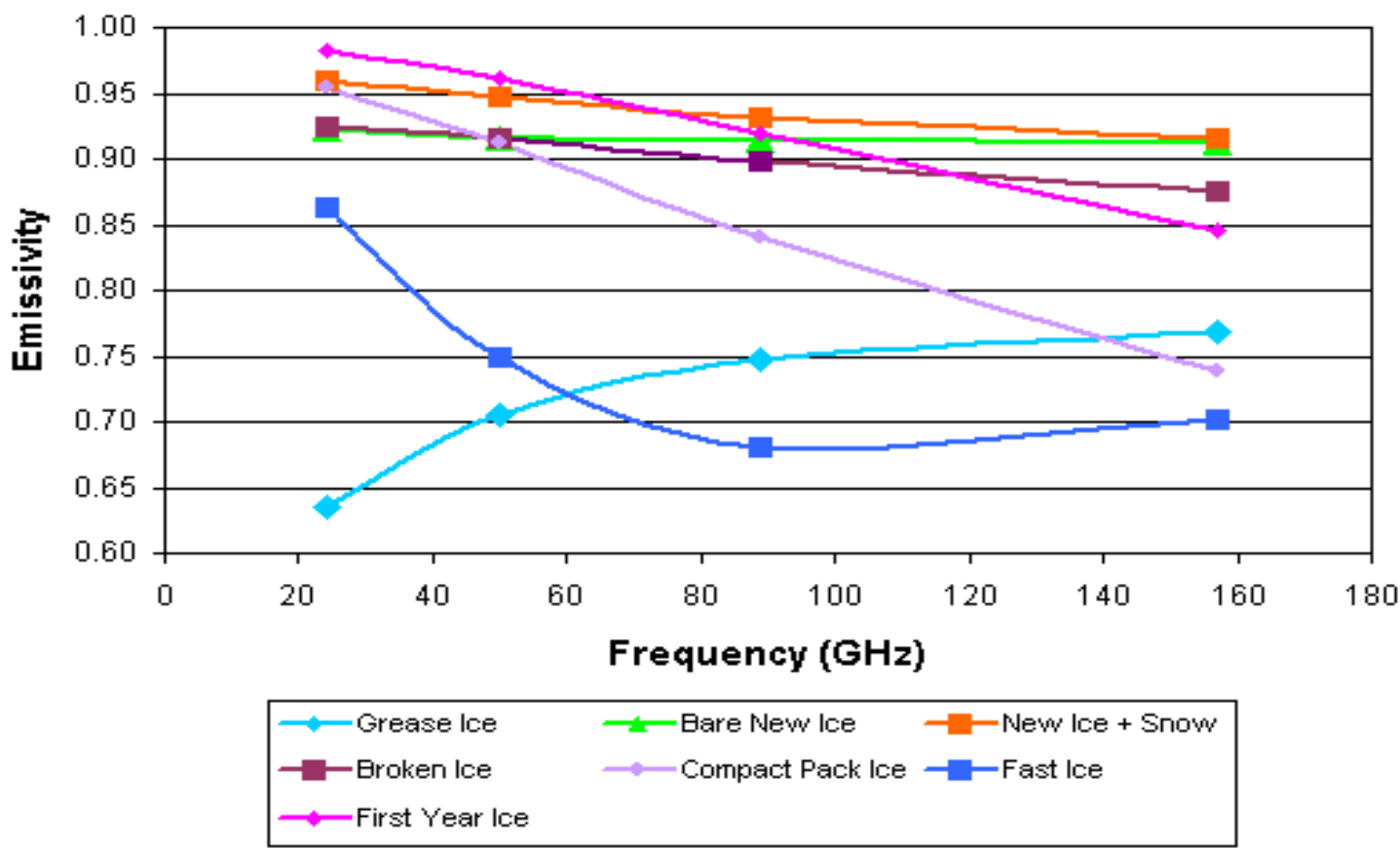
## Snow Emissivity:





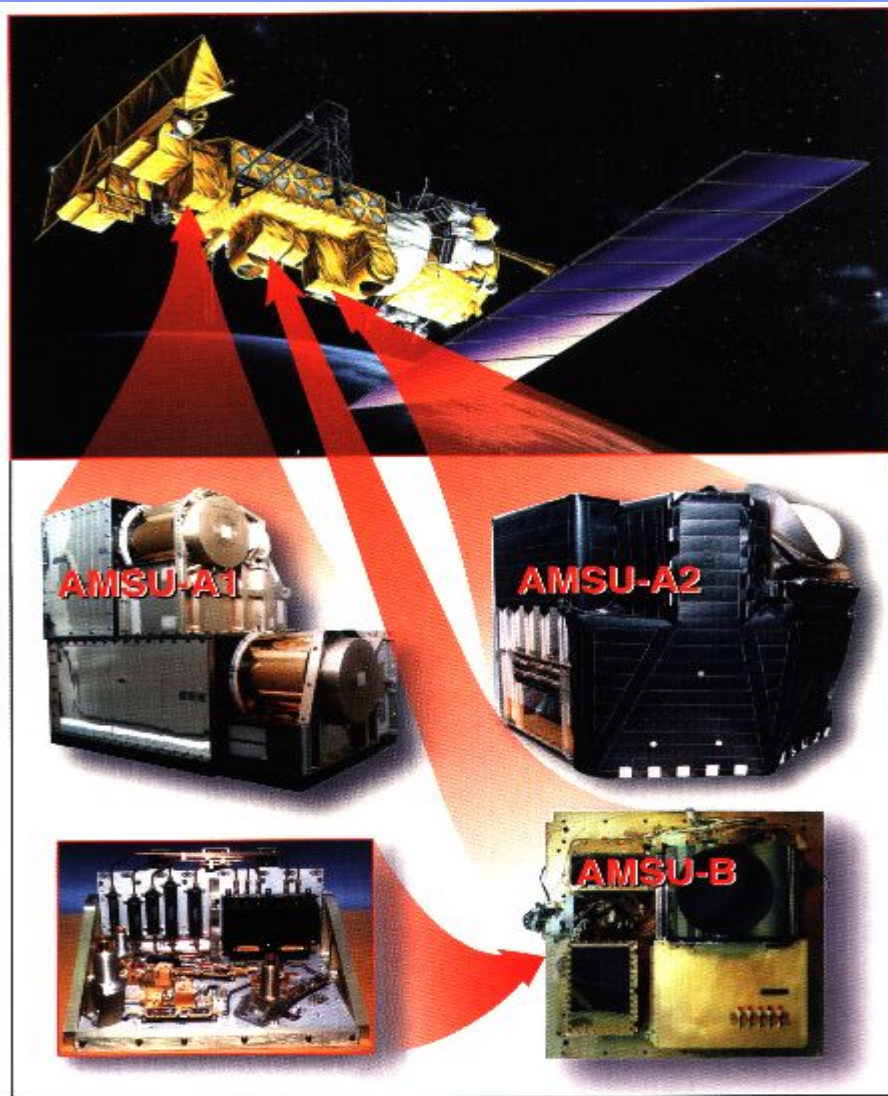
# Algorithm Theoretical Basis (8/9)

## Sea Ice Emissivity Spectra





# Advanced Microwave Sounding Unit

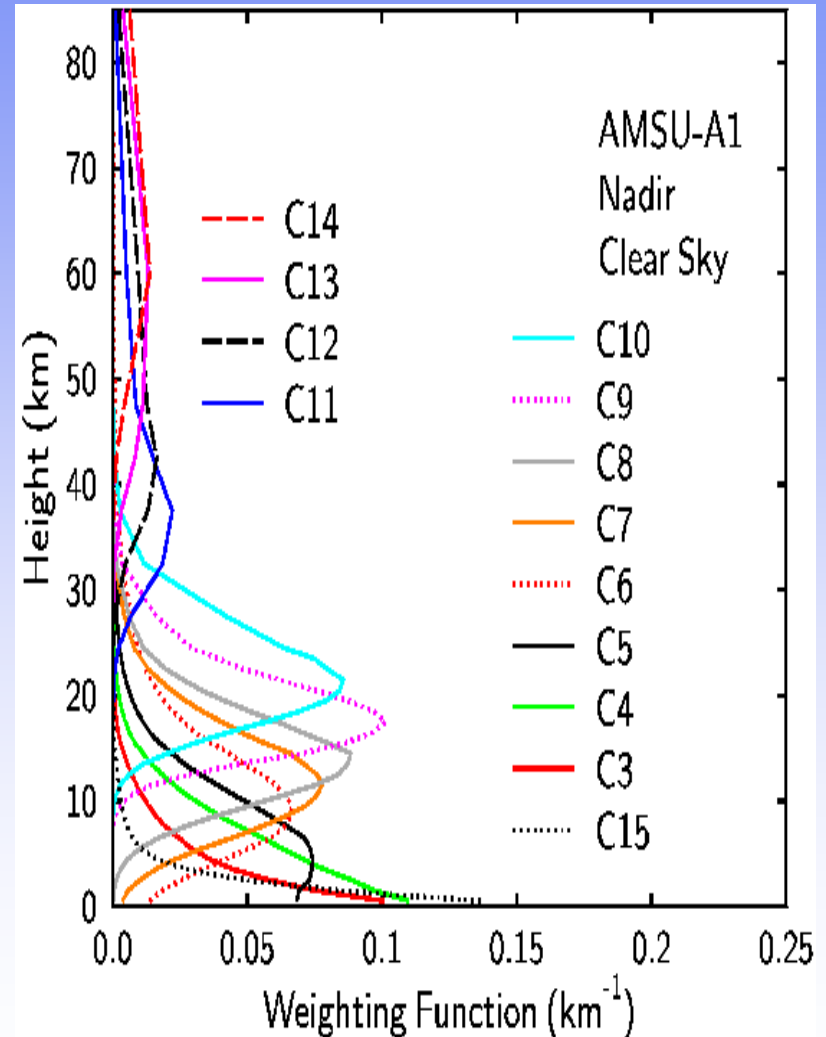


- Flown on NOAA-15 (May 1998), NOAA-16 (Sept. 2000) and NOAA-17 (June 2002) satellites
- Contains 20 channels:
  - AMSU-A
    - 15 channels
    - 23 – 89 GHz
  - AMSU-B
    - 5 channels
    - 89 – 183 GHz
- 4-hour temporal sampling:
  - 130, 730, 1030, 1330, 1930, 2230 LST



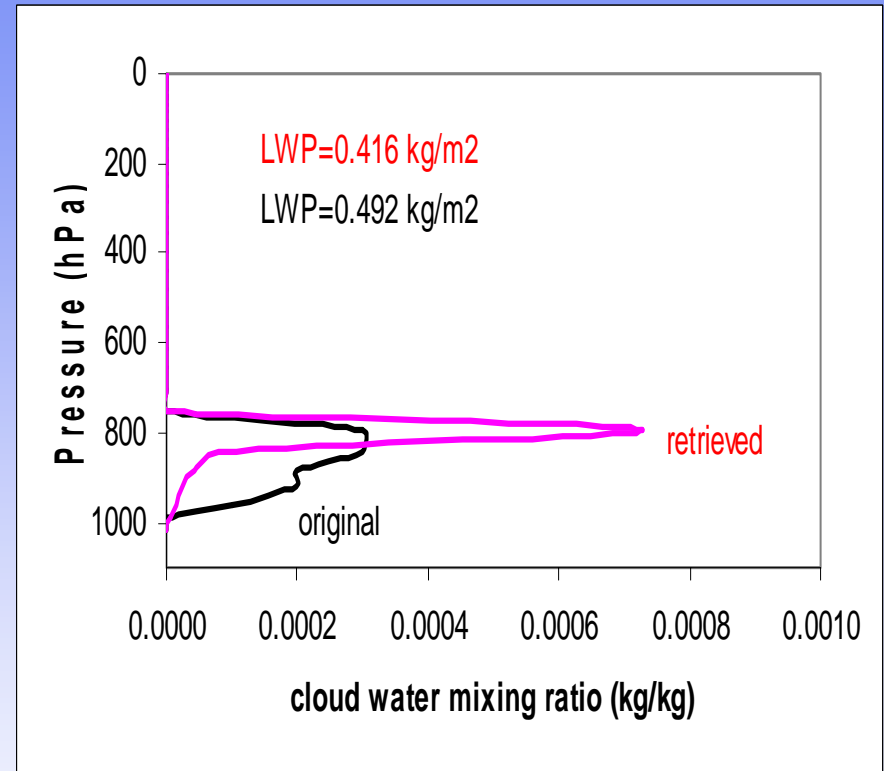
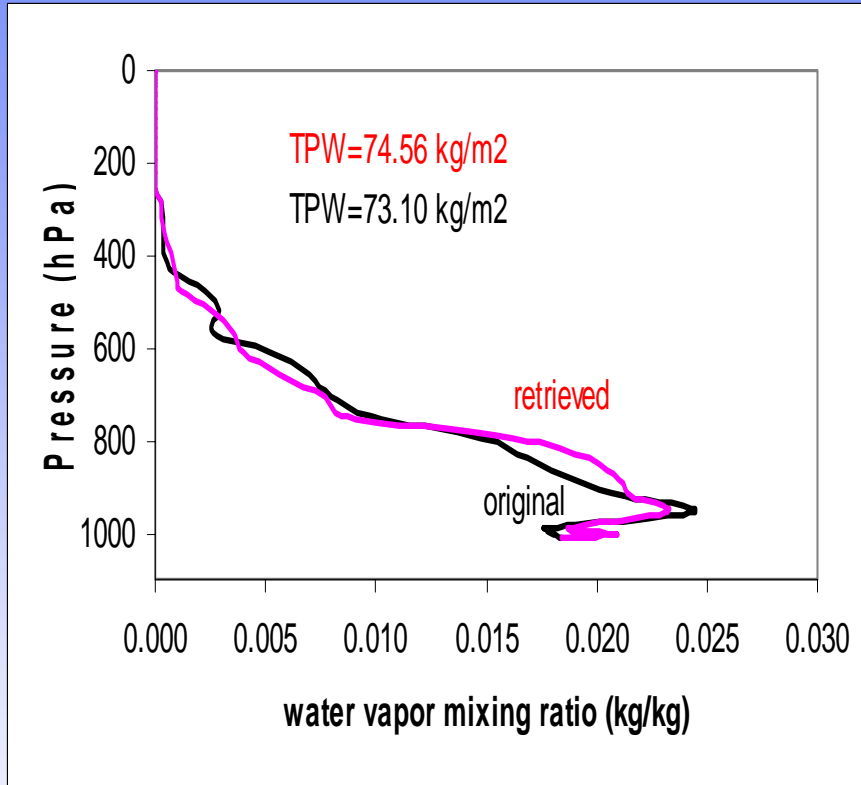
# Advanced Microwave Sounding Unit

- AMSU measurement at each sounding channel responds primarily to emitted radiation within a layer, indicated by its weighting function
- The vertical resolution of sounding is dependent on the number of independent channel measurements
- Lower tropospheric channels are also affected by the surface radiation which is highly variable over land





# Water Vapor and Cloud Water Profiles



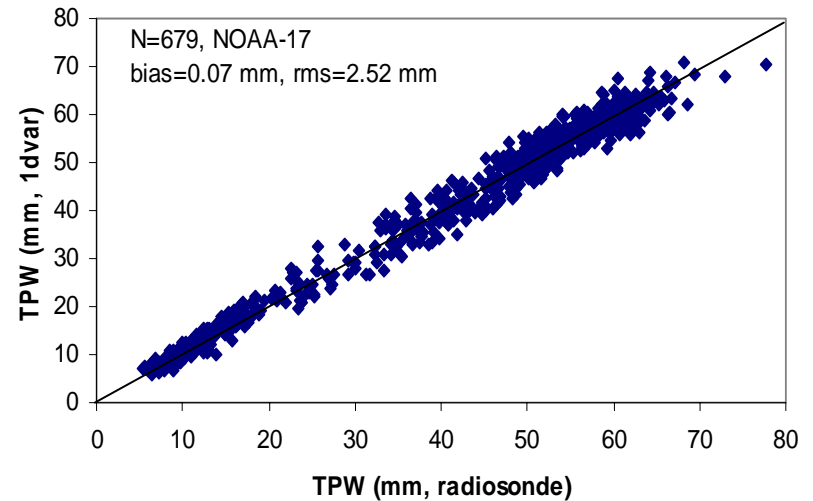
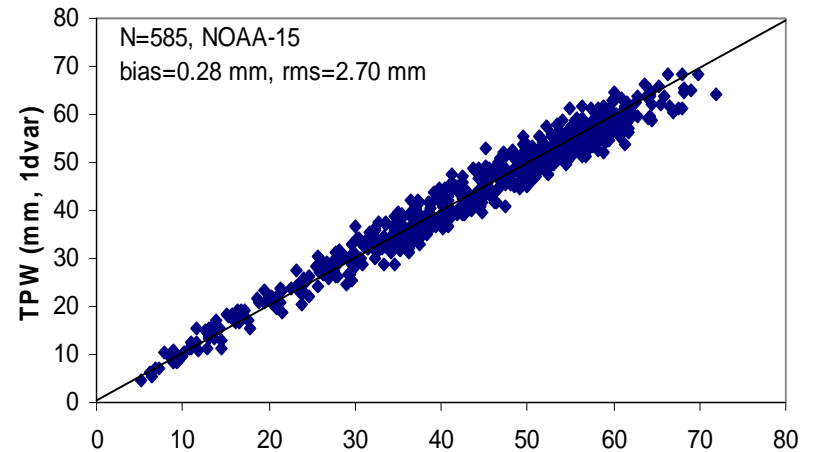
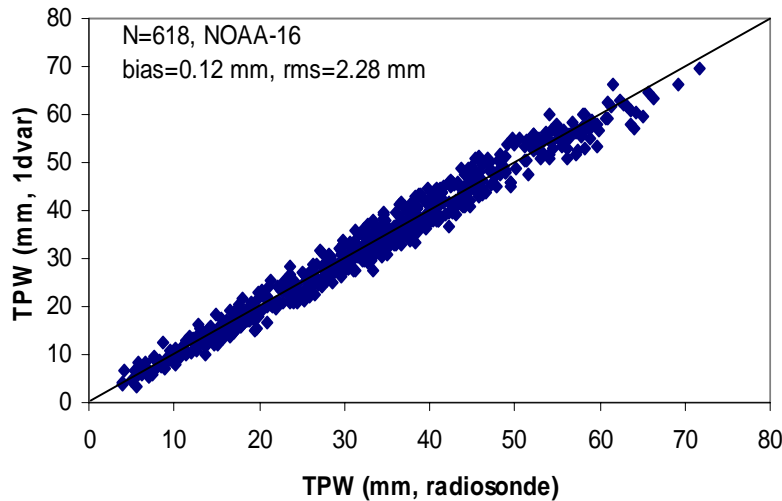
Standard atmosphere and cloudy layers between 800 and 950 hPa

Retrievals is based on simulated AMSU brightness temperatures at nadir



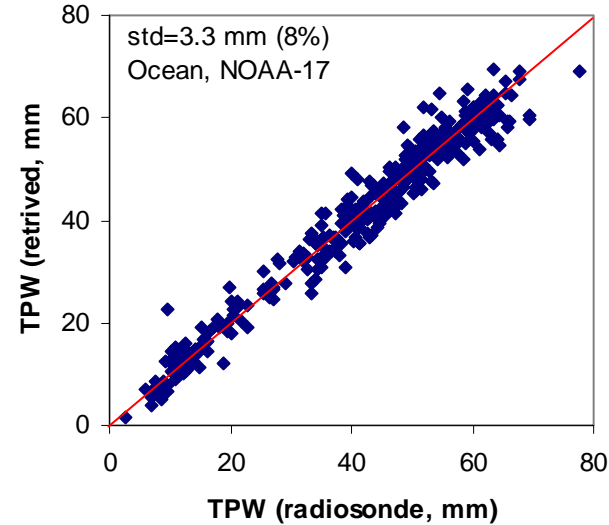
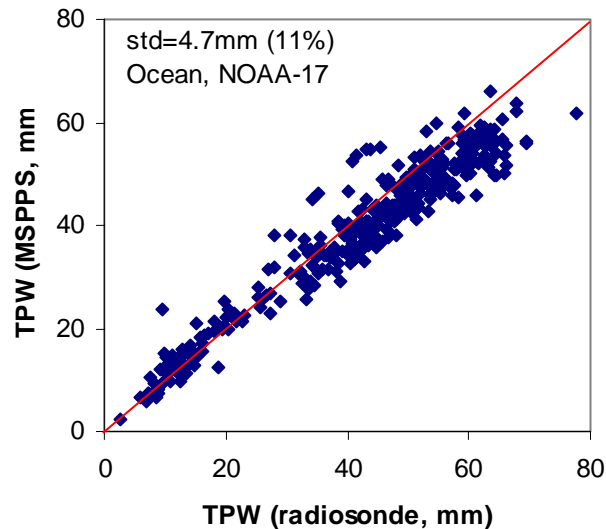
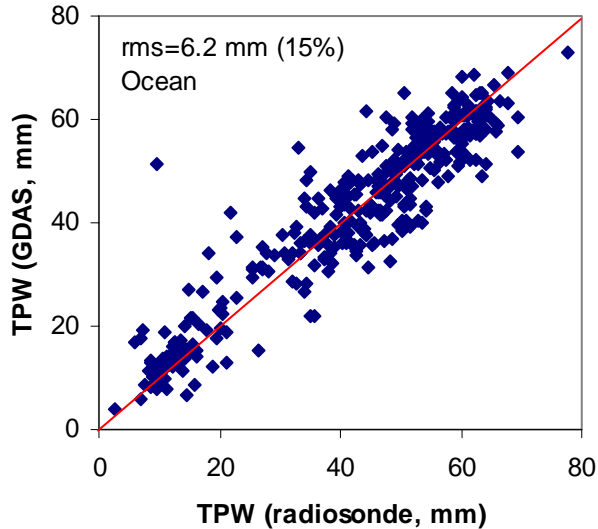
# Vertically Integrated Water Vapor

Match-up TPW from radiosondes  
and AMSU retrieval in 2002.





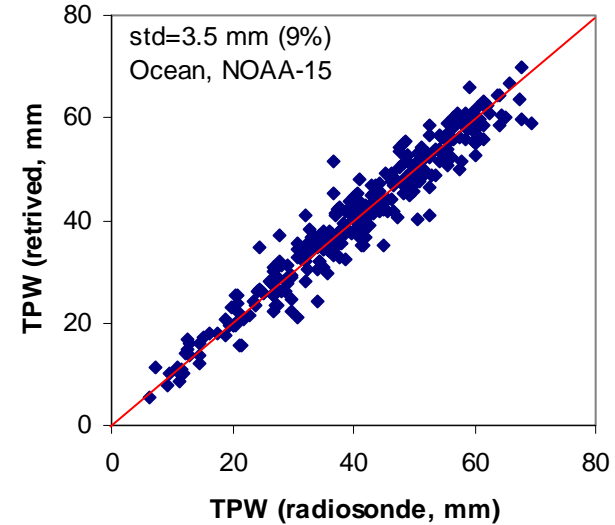
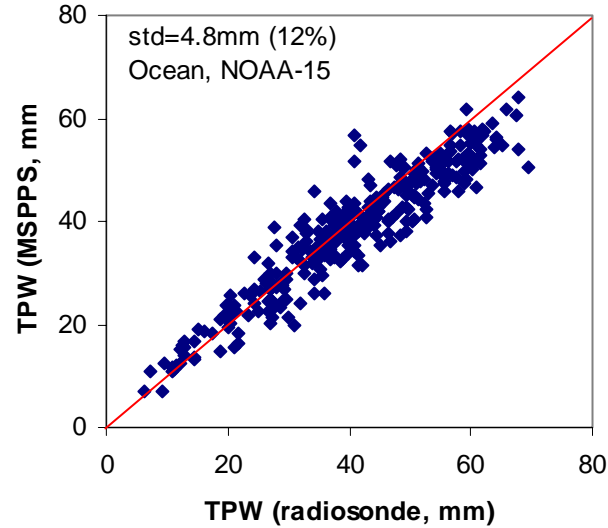
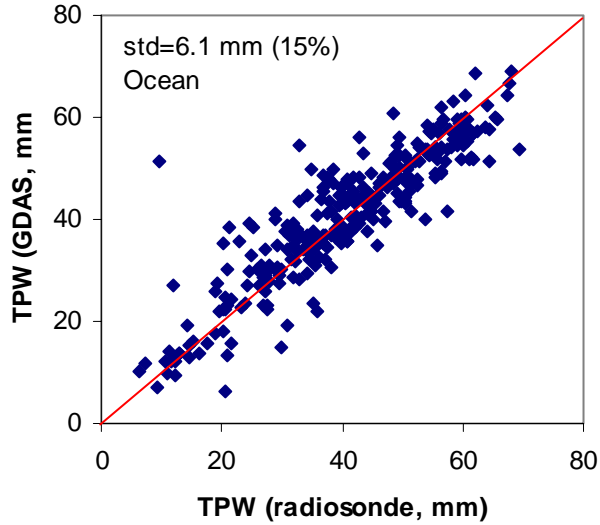
# TPW Validation (NOAA-17)



**In comparison to radiosonde measurements, MSPPS TPW product gives accuracy better than GDAS but is slightly biased. MIRS TPW is the best (no priori information).**



# TPW Validation (NOAA-15)





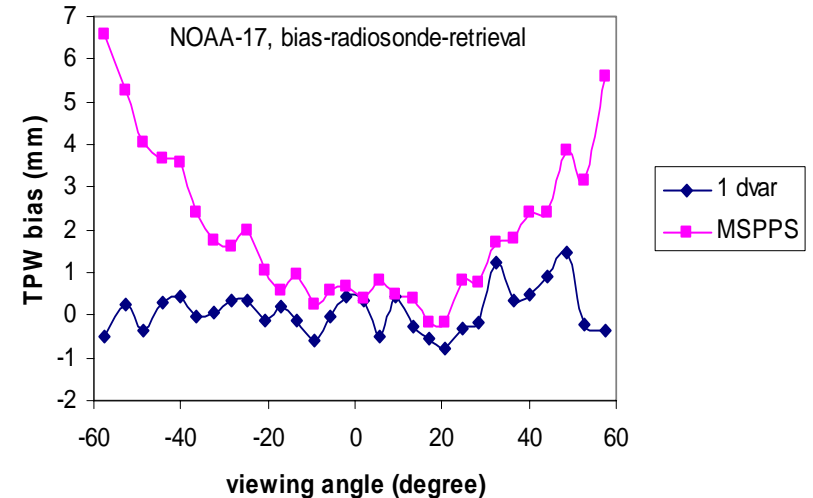
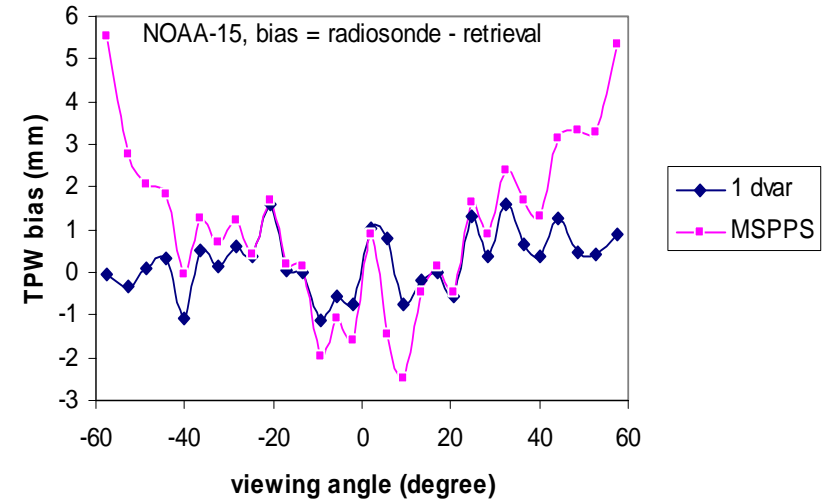
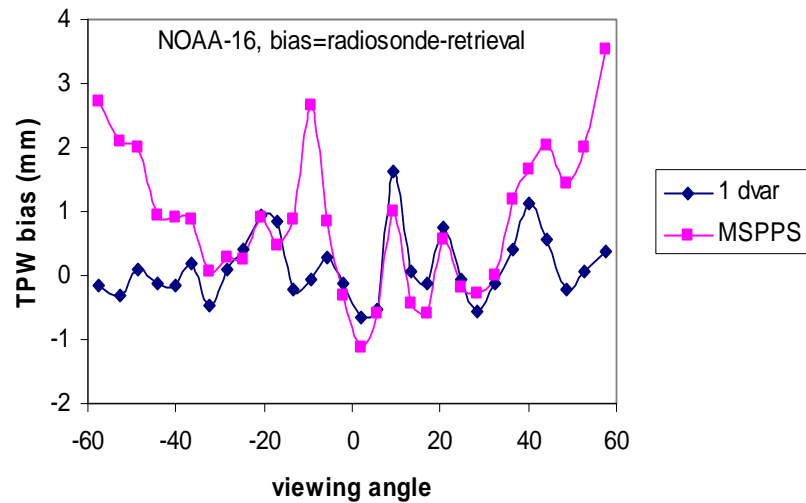


# Retrieval Bias vs. Viewing Angles

Match-up TPW from radiosondes  
and AMSU retrieval in 2002.

Bias variation to viewing angles.

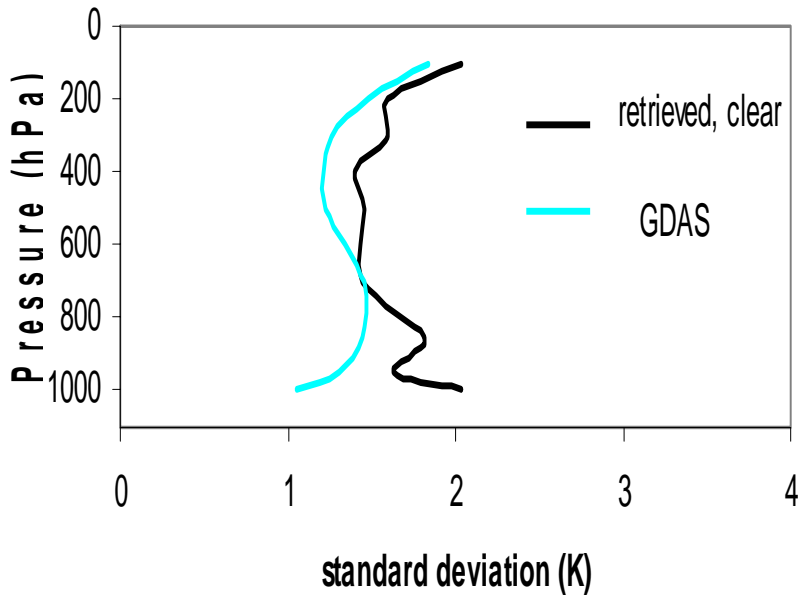
Bias = radiosonde – AMSU



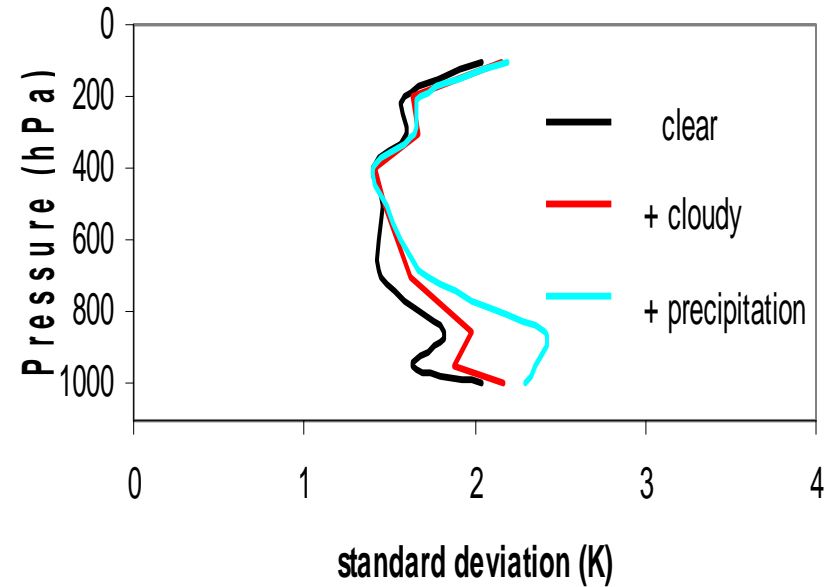


# Temperature Validation (NOAA-17)

Comparison of temperature to radiosondes  
ocean, NOAA-17



retrieved vs radiosondes temperature  
ocean, NOAA-17

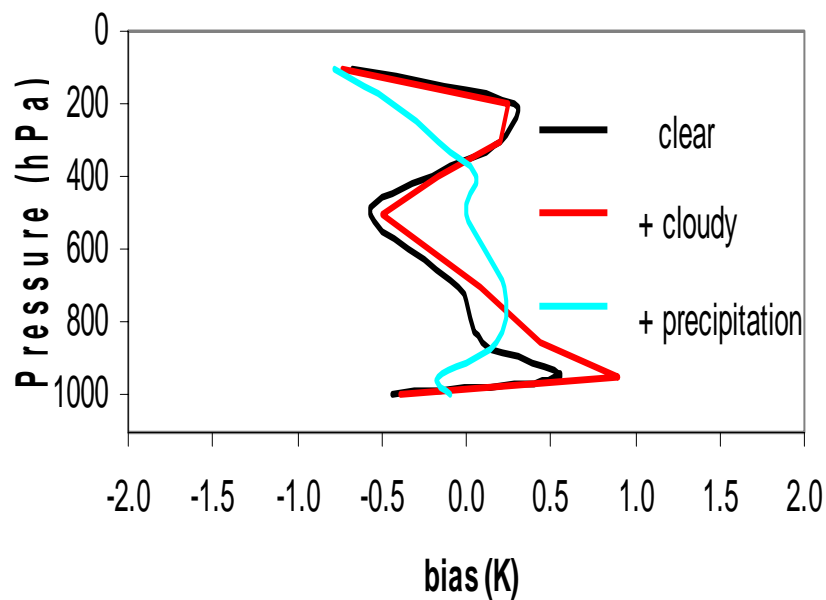


**GDAS (1 x 1 deg) and radiosondes agree well. Clouds degrade the retrieval accuracy slightly. Clear samples = 357, clear+cloud samples = 501, clear+cloud+precipitation=552**

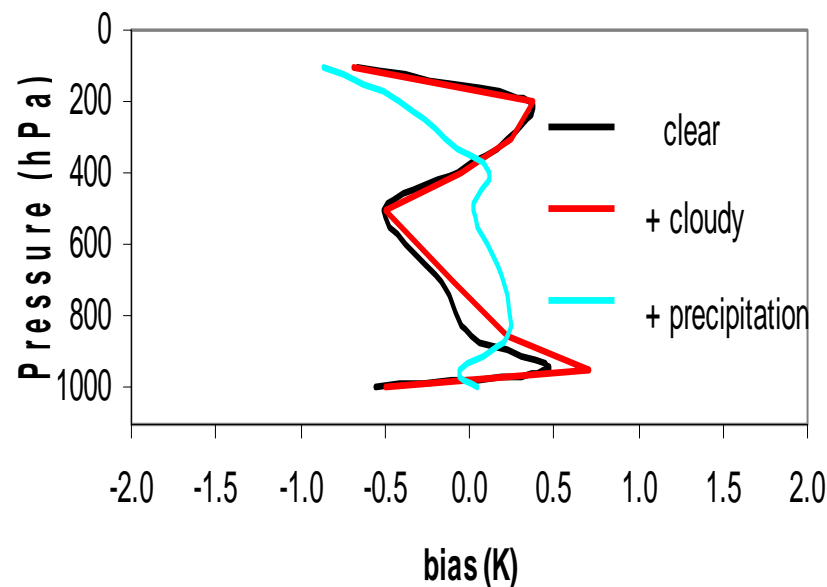


# Temperature Validation (NOAA-17)

retrieved vs radiosondes temperature  
ocean, NOAA-17



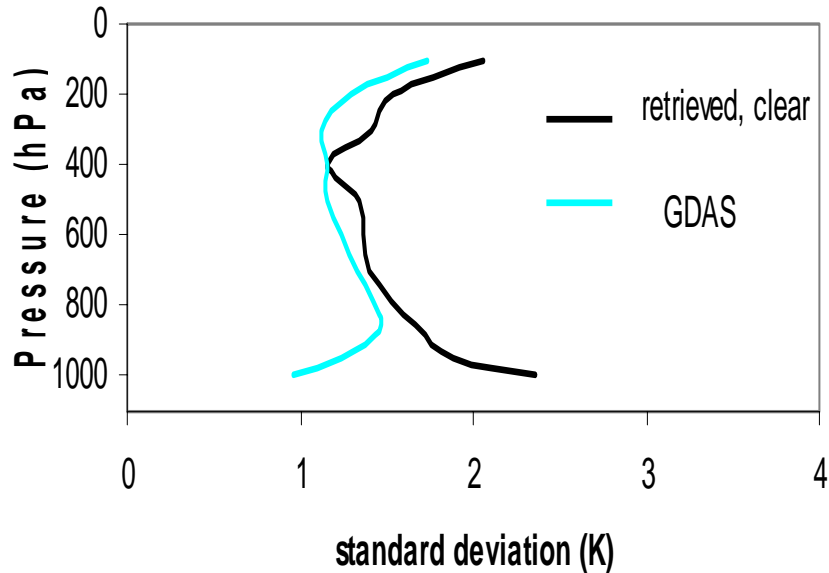
retrieved vs radiosondes temperature  
ocean, NOAA-15



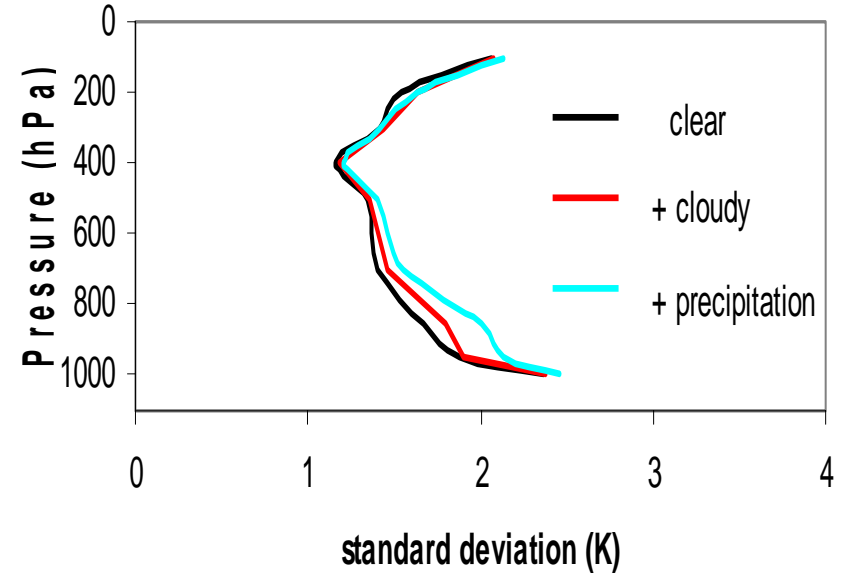


# Temperature Validation (NOAA-15)

Comparison of temperature to radiosondes  
ocean, NOAA-15



retrieved vs radiosondes temperature  
ocean, NOAA-15

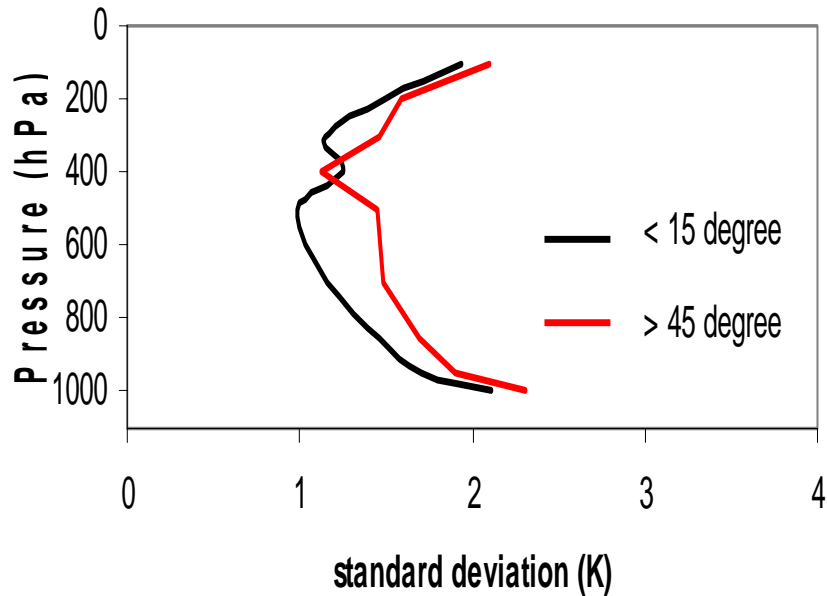


**GDAS (1 x 1 deg) and radiosondes agree well. Clouds degrade the retrieval accuracy slightly. Clear samples = 278, clear+cloud samples = 386, clear+cloud+precipitation=416**

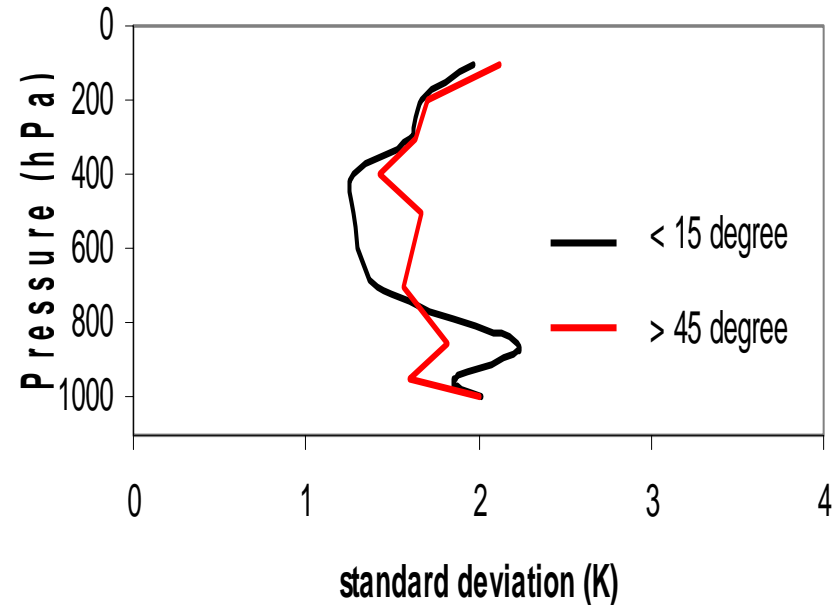


# Temperature Accuracy (Nadir vs. off-Nadir)

Comparison of temperature to radiosonde ocean, NOAA-15



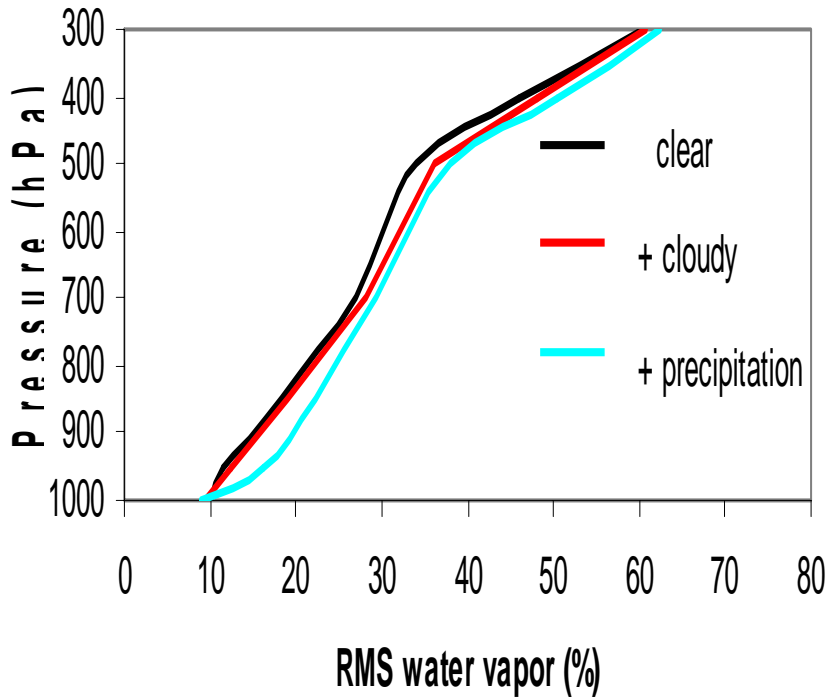
Comparison of temperature to radiosonde ocean, NOAA-17



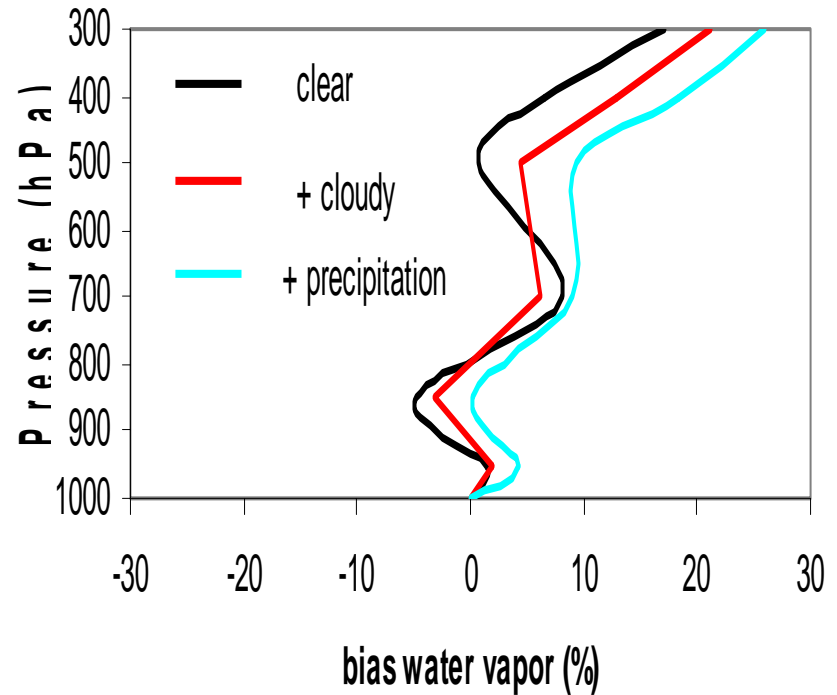


# Validation for Water Vapor Profile

retrieved vs radiosondes water vapor profile  
ocean, NOAA-17



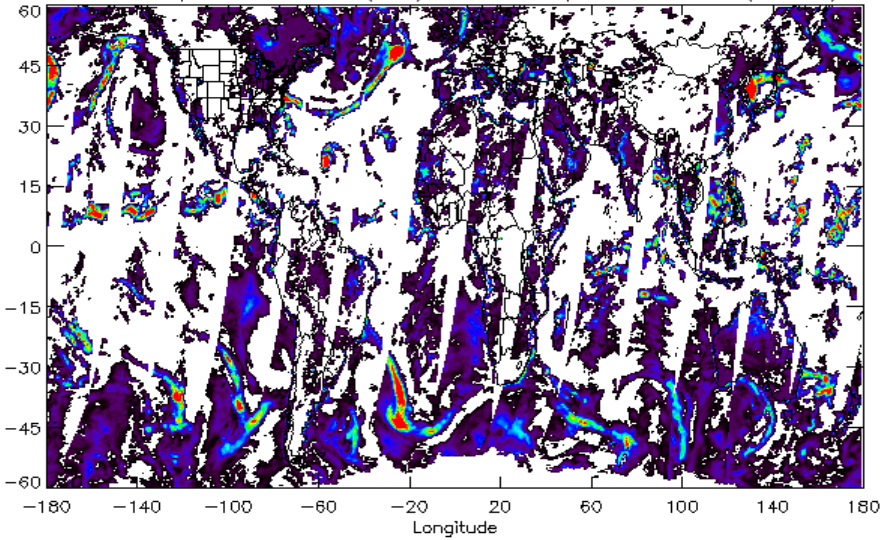
retrieved vs radiosondes water vapor profile  
ocean, NOAA-17



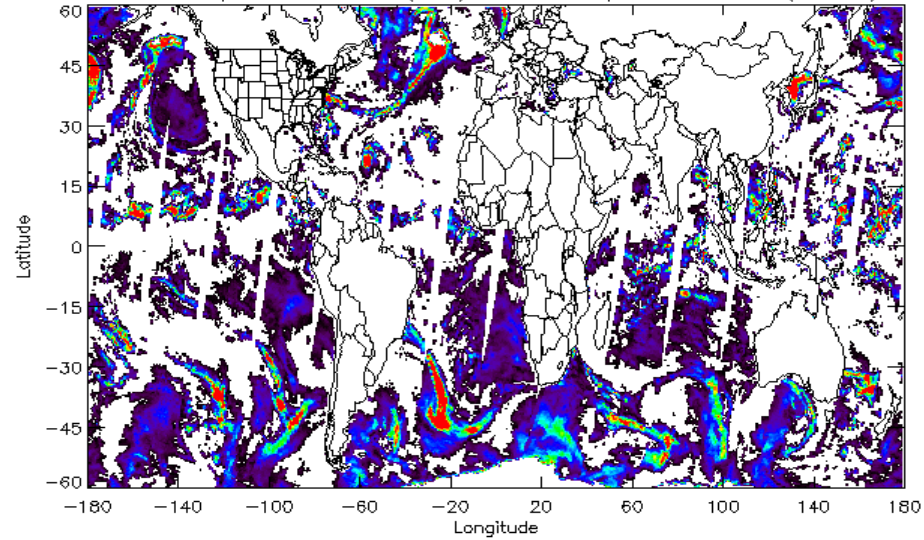


# Cloud Liquid Water (MIRS vs. MSPPS)

Cloud Liquid Water Path (mm) on 12th September, 2003 (1D\_var)

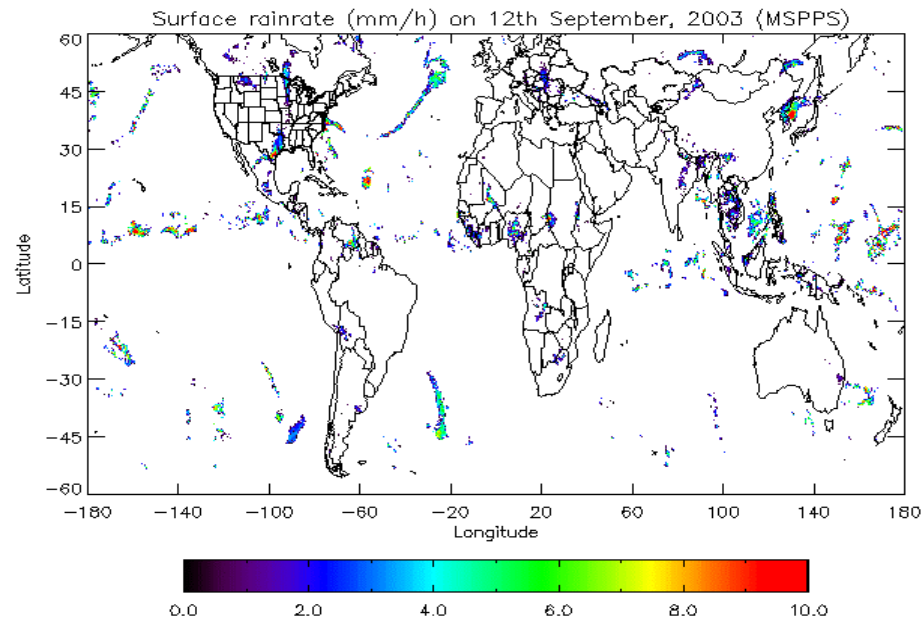
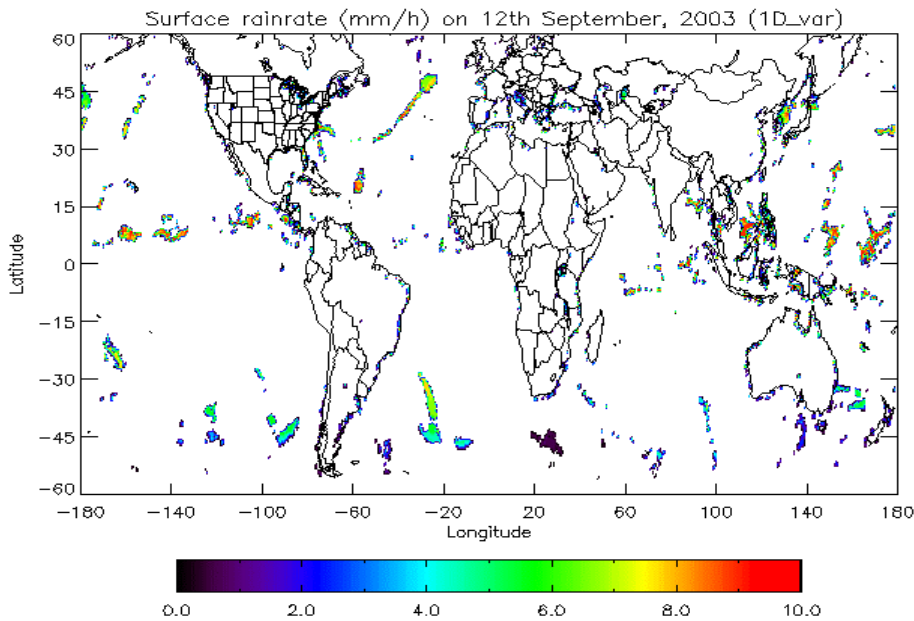


Cloud Liquid Water Path (mm) on 12th September, 2003 (MSPPS)





# Precipitation (MIRS vs. MSPPS)

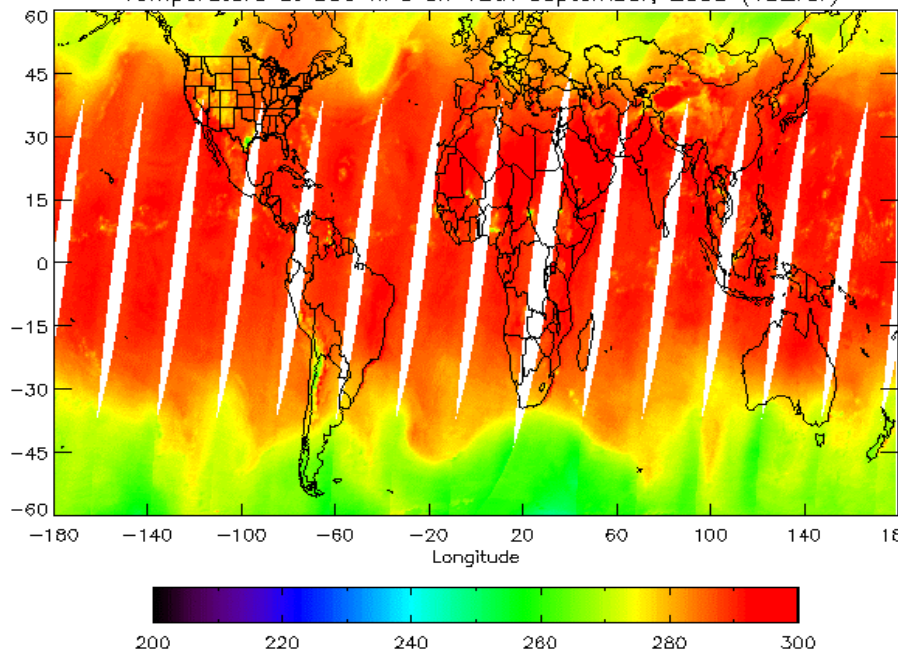




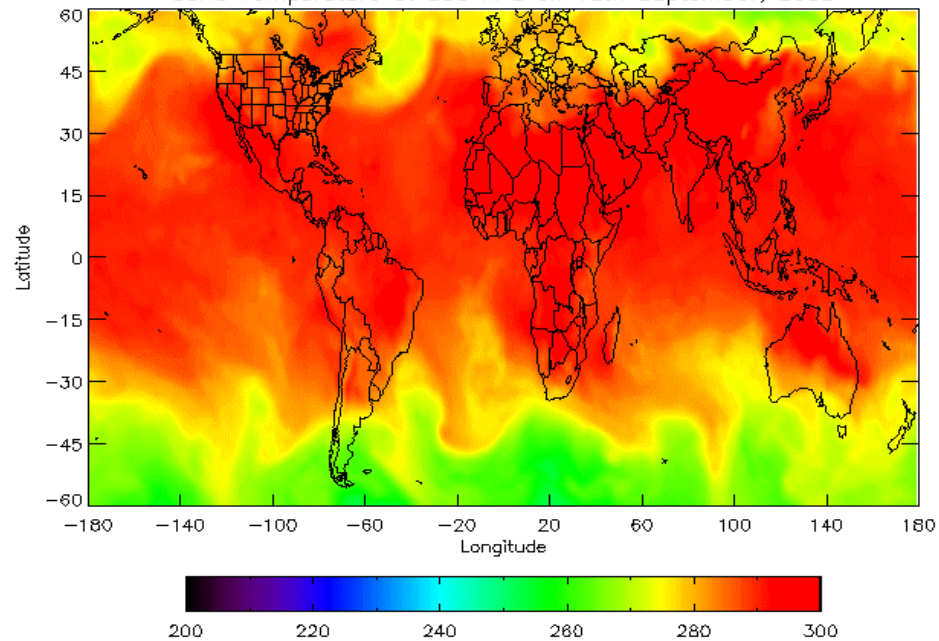


# Temperature at 850 hPa (MIRS vs. GDAS)

Temperature at 850 hPa on 12th September, 2003 (1D\_var)



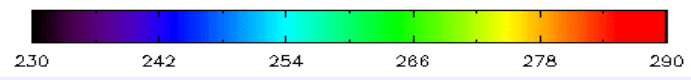
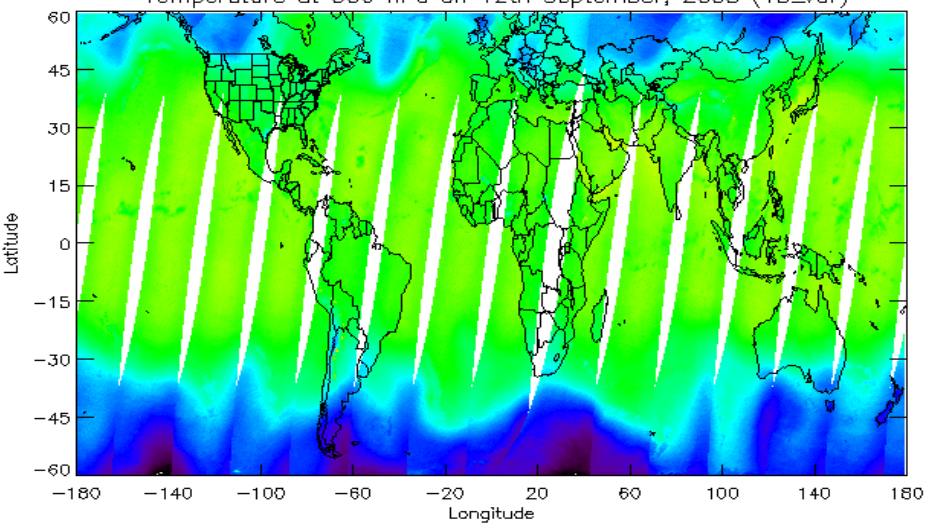
GDAS Temperature at 850 hPa on 12th September, 2003



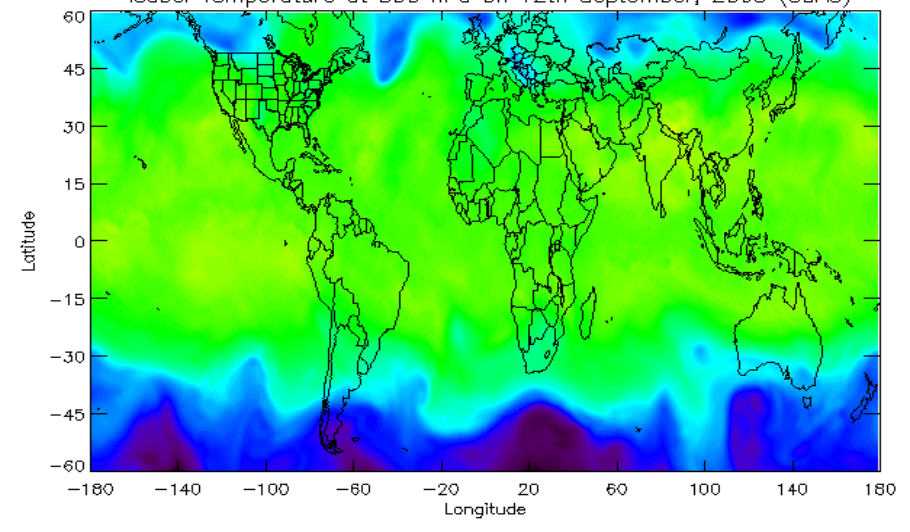


# Temperature at 500 hpa (MIRS vs. GDAS)

Temperature at 500 hPa on 12th September, 2003 (1D\_var)



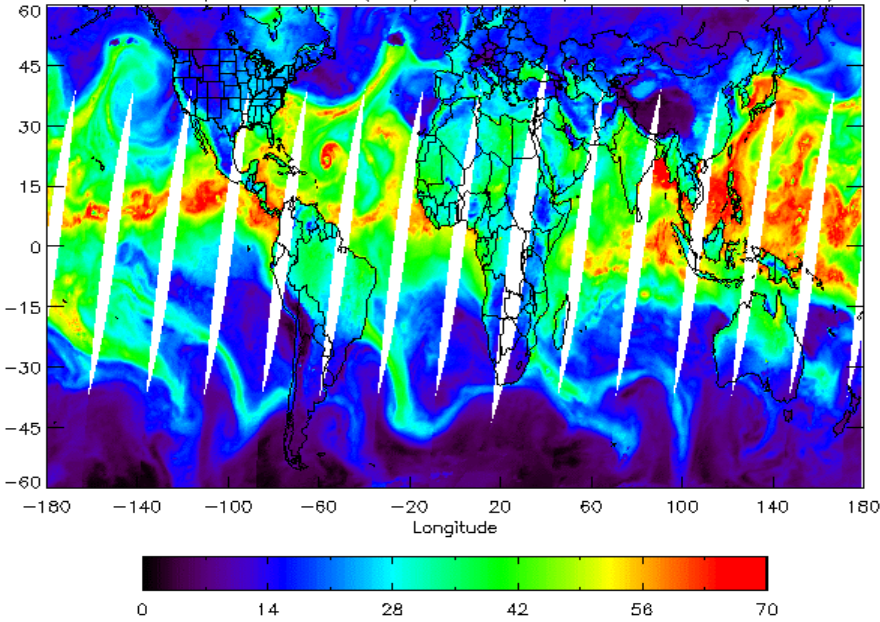
Isabel Temperature at 500 hPa on 12th September, 2003 (GDAS)



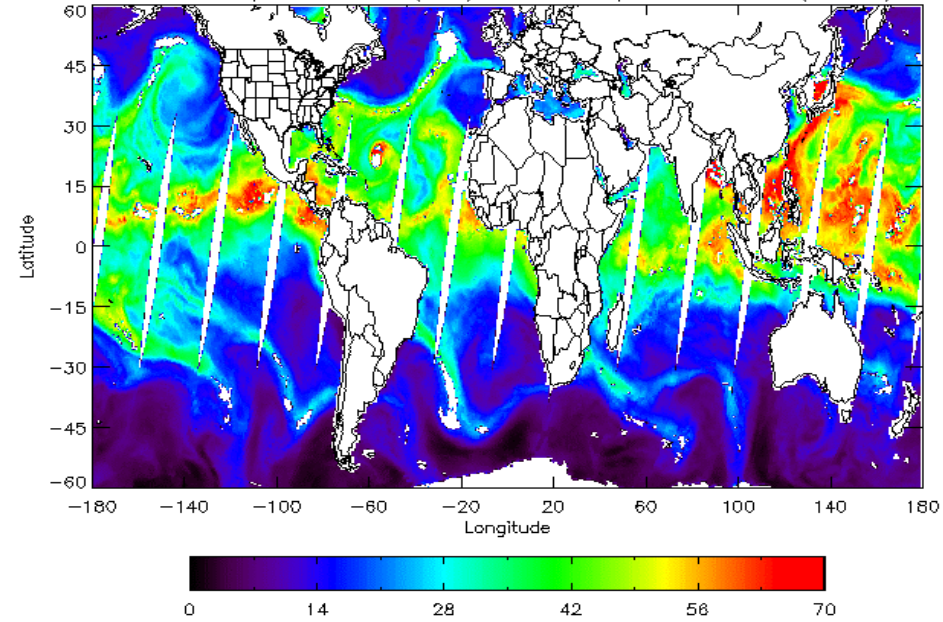


# Total Precipitable Water (MIRS vs. MSPPS)

Total Precipitable Water (mm) on 12th September, 2003 (1D\_var)

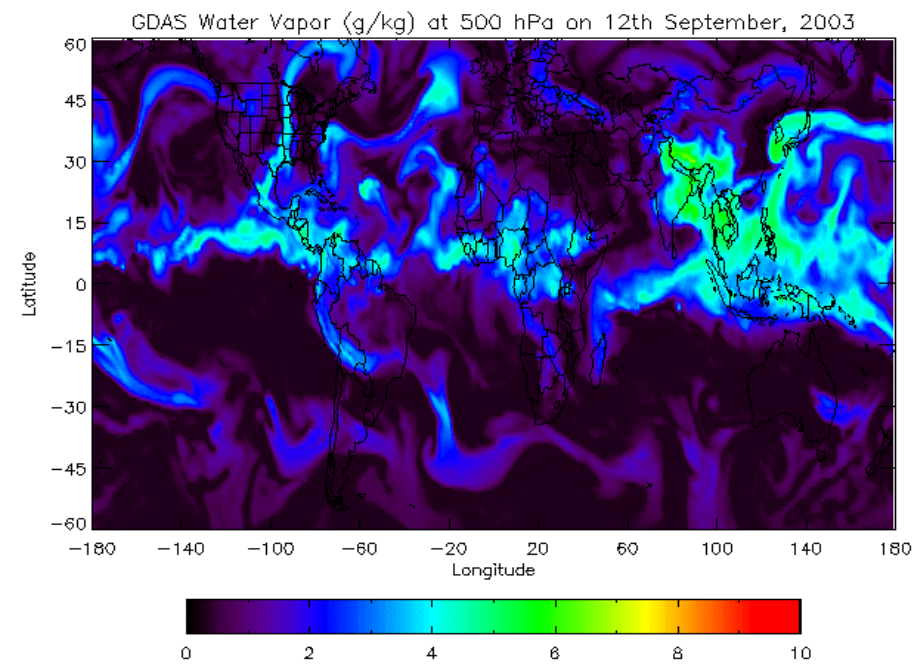
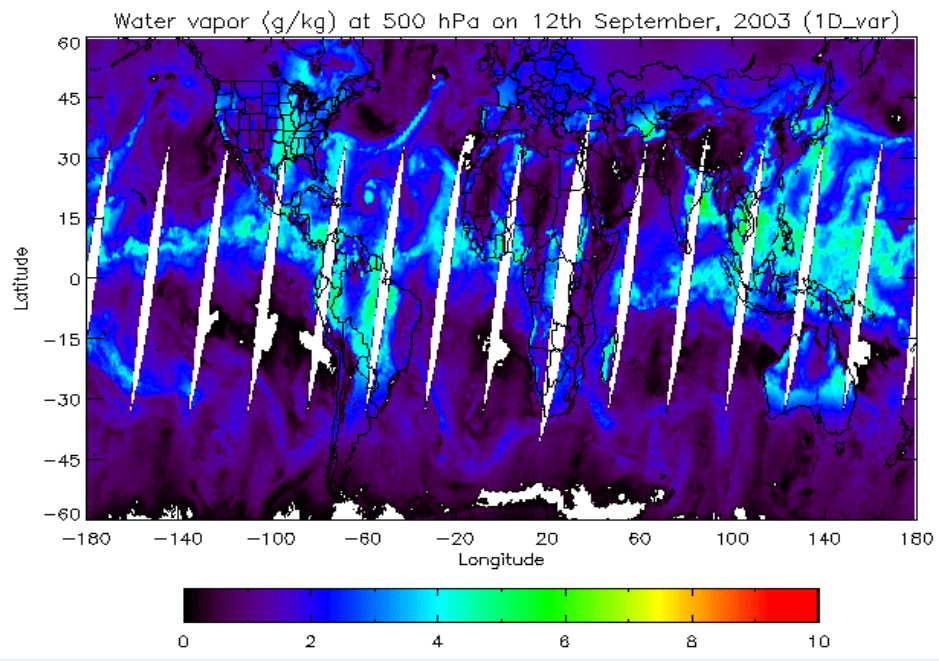


Total Precipitable Water (mm) on 12th September, 2003 (MSPPS)





# Water Vapor at 500 hPa (MIRS vs. GDAS)

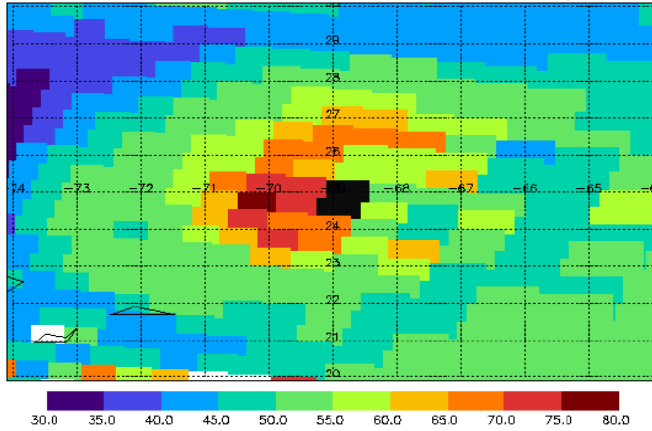




# Water Vapor, Cloud Water and Rain Rate

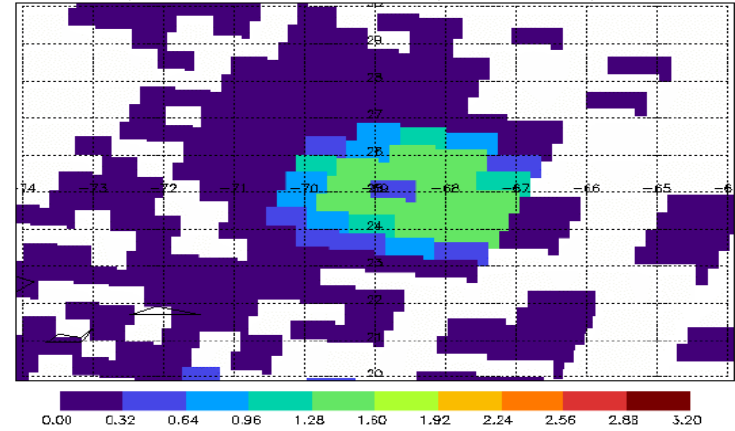
## TPW

TPW for Isabel on 15th September, 2003 (N16, 1dvar)



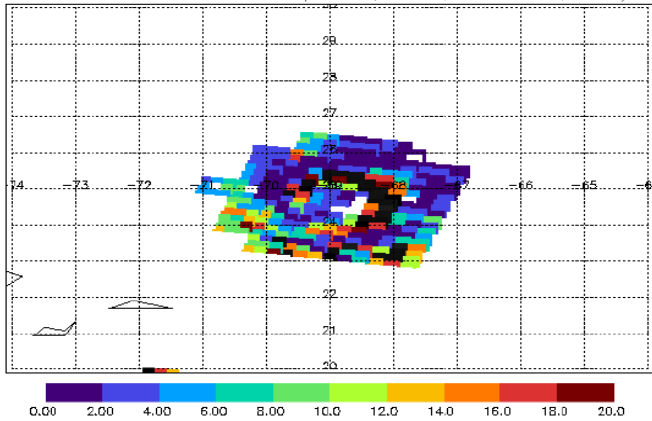
## CLW

Cloud liquid water for Isabel on 15th September, 2003 (N16, 1dvar)



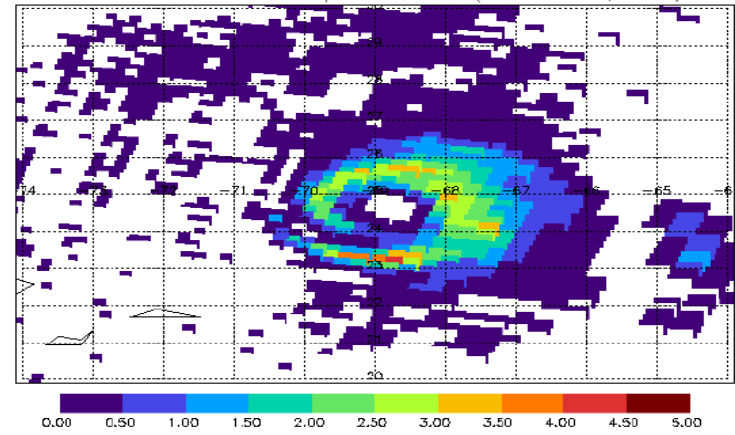
## Rain Rate

Rainrate for Isabel on 15th September, 2003 (N16 AMSU-B, 1dvar)



## IWP

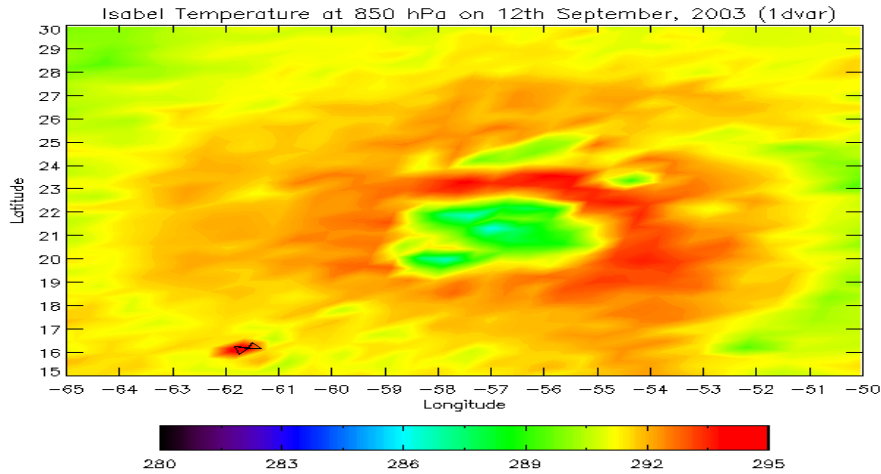
IWP for Isabel on 15th September, 2003 (N16 AMSU-B, 1dvar)



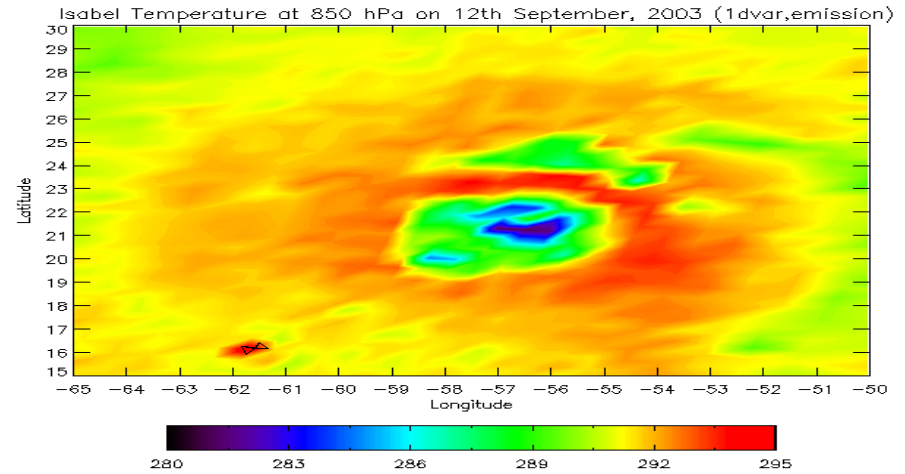


# Impacts of Forward Models

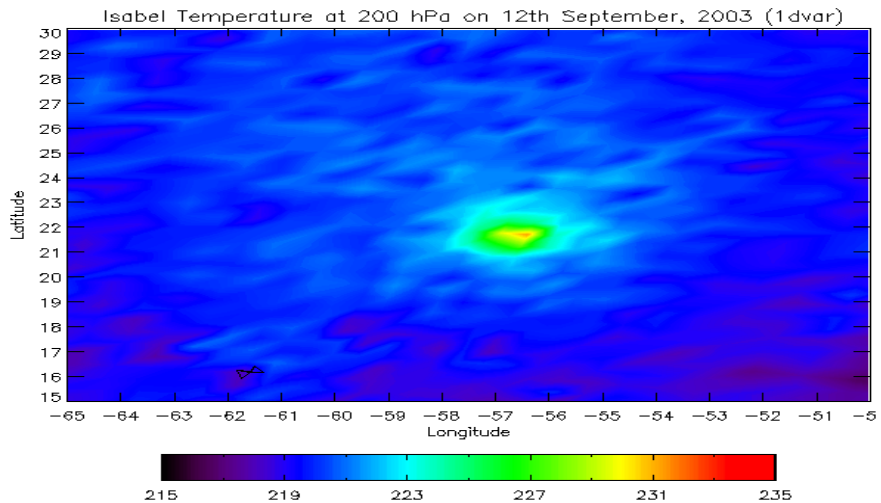
## T(850hPa) – Scattering



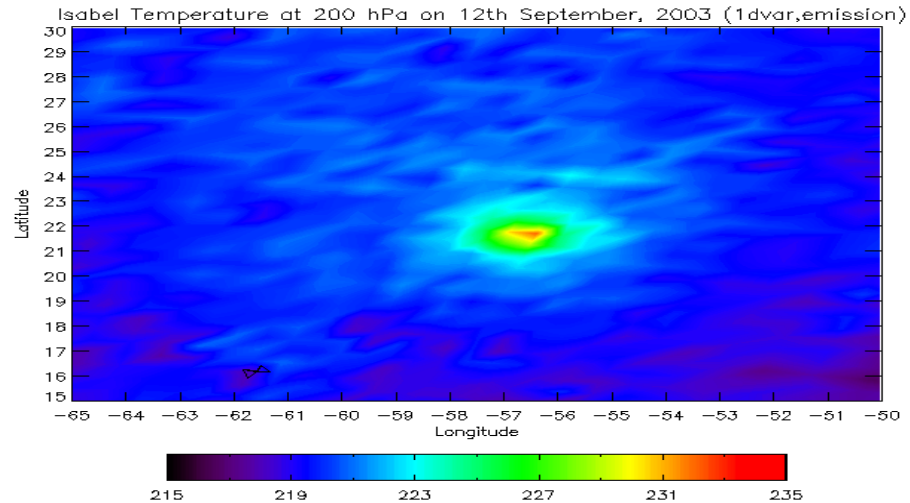
## T(850hPa) – Emission only



## T(200hPa) – Scattering



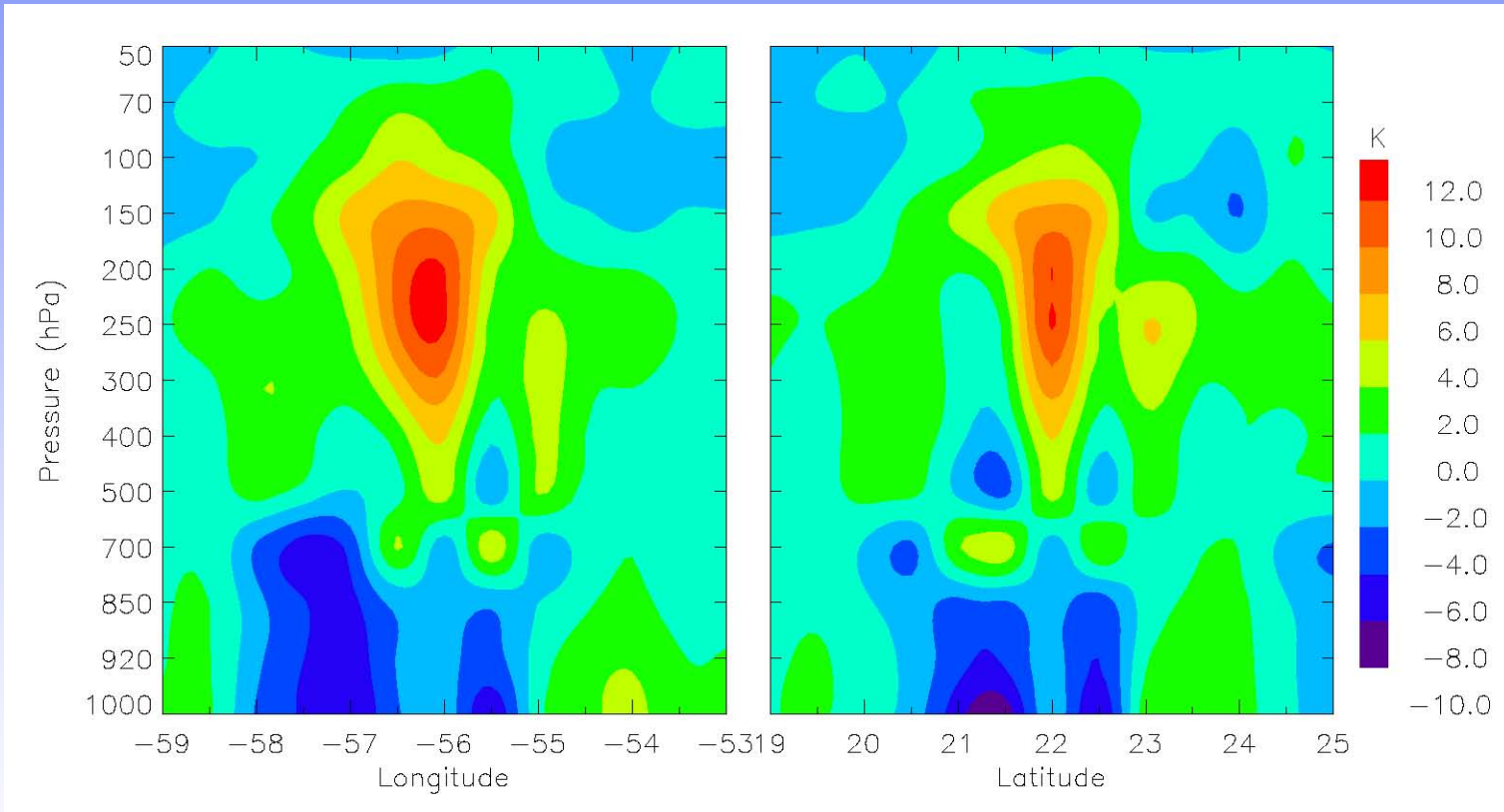
## T(200hPa) – Emission only





# Temperature Anomaly

## With Cloud/Precipitation Scattering



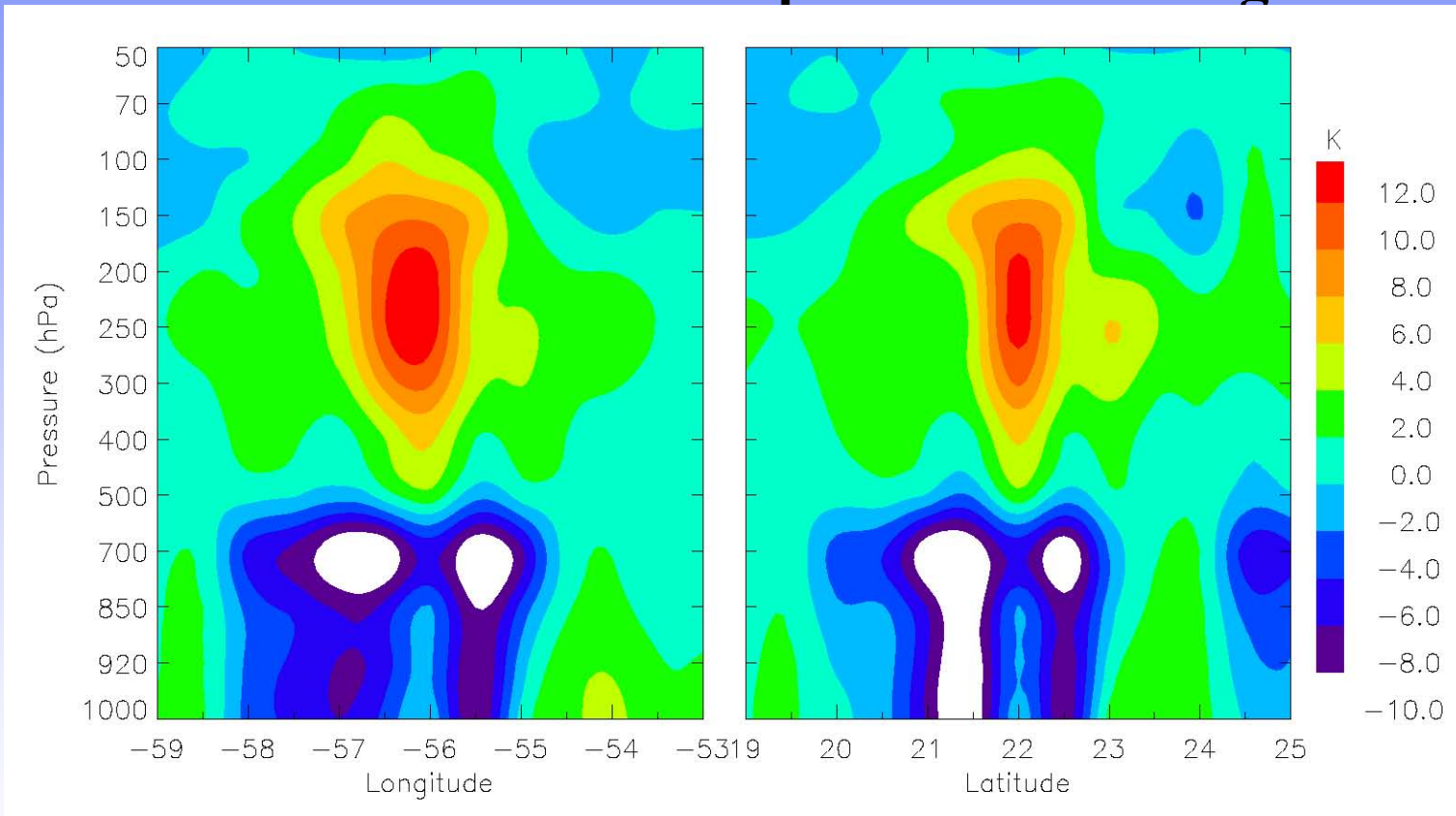
Vertical cross section of temperature anomalies at 06:00 UTC 09/12/2003. Left panel: west-east cross section along 22°N, and right panel: south-north cross section along 56°W for Hurricane Isabel

$$\mu \frac{d\mathbf{I}(\tau, \Omega)}{d\tau} = -\mathbf{I}(\tau, \Omega) + \frac{\omega}{4\pi} \int_0^{4\pi} \mathbf{M}(\tau, \Omega, \Omega') \mathbf{I}(\tau, \Omega') d\Omega' + (1 - \omega) \mathbf{S}_t$$



# Temperature Anomaly

## Without Cloud/Precipitation Scattering



Vertical cross section of temperature anomalies at 06:00 UTC 09/12/2003. Left panel: west-east cross section along 22°N, and right panel: south-north cross section along 56°W for Hurricane Isabel

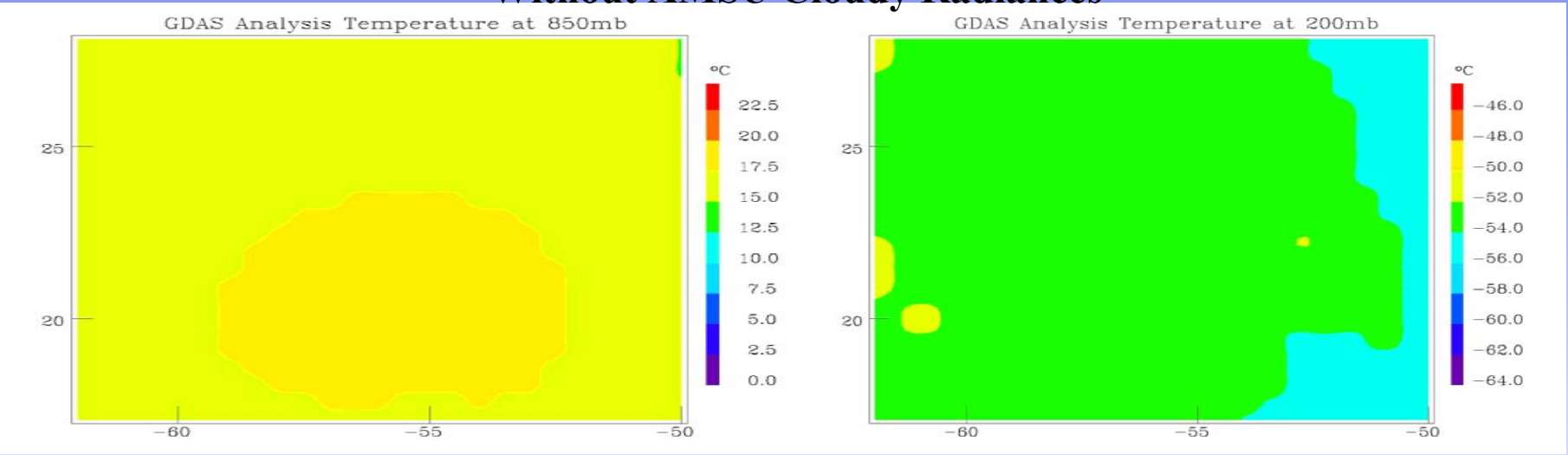
$$\mu \frac{d\mathbf{I}(\tau, \Omega)}{d\tau} = -\mathbf{I}(\tau, \Omega) + (1 - \omega)\mathbf{S}_t$$



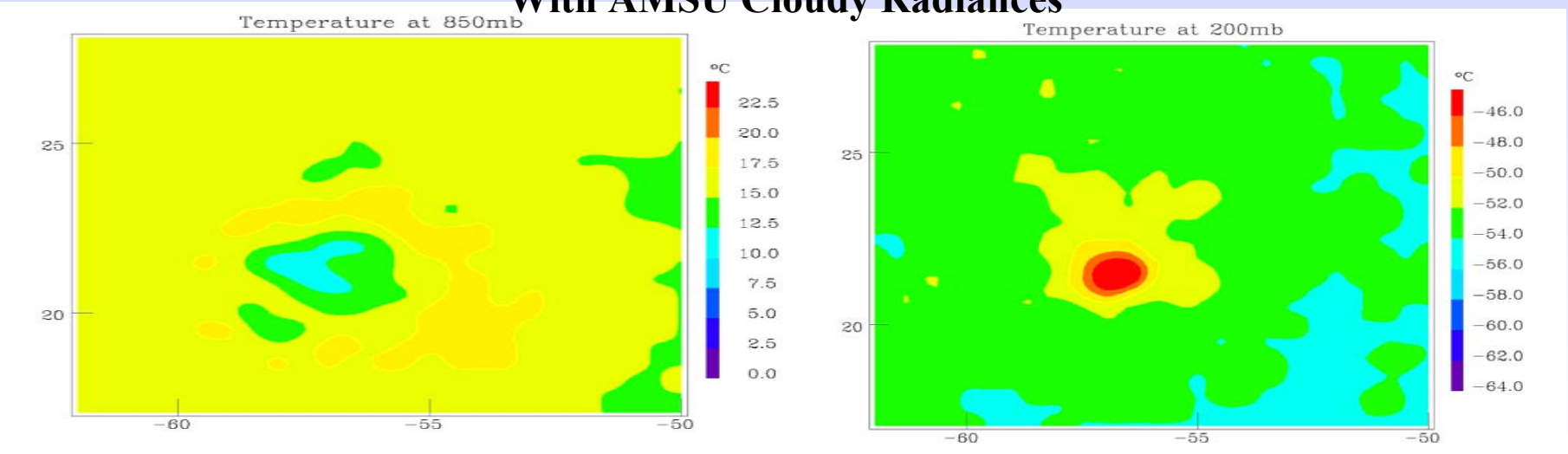


# Improved 3DVAR Analysis with AMSU

## Without AMSU Cloudy Radiances



## With AMSU Cloudy Radiances





# Summary and Conclusions

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- Integrated uses of microwave imager and sounder data can significantly improve temperature profiling in lower troposphere
- Advanced radiative transfer models including cloud/precipitation scattering are vital for improving profiling capability in severe weather conditions such as hurricanes
- MIRS with bias corrections to radiative transfer models produces improved performance from AMSU and makes the retrieval errors less dependent on scan angle
- MIRS retrievals are being validated against variable independent sources. Overall performances are very encouraging. The system is of great potentials for NPOESS ATMS, CMIS applications
- MIRS has a lot of room to improve and incorporate more variables in the processing.



# Open Issues

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- Refine the retrievals for better regional performance (e.g. high terrains, deserts, snow/sea ice cover, coast conditions)
- Bias corrections for water vapor sounding channels are highly required. Alternatively, the retrievals will be also tested with limb-adjusted AMSU measurements
- Investigate non-convergent behaviors over particular regions (scattering RT model vs. abnormal observations) in the last retrieval process when AMSU-B water vapor sounding channels are included
- Test the system for SSMIS applications

International TOVS Study Conference, 14<sup>th</sup>, ITSC-14, Beijing, China, 25-31 May 2005.  
Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center,  
Cooperative Institute for Meteorological Satellite Studies, 2005.