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Microwave Integrated Retrieval "System" (MIRS)

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Office of Research Applications
NOAA/NESDIS

The 14th International TOVS Study Conference, Beijing, China
May 25-31, 2005

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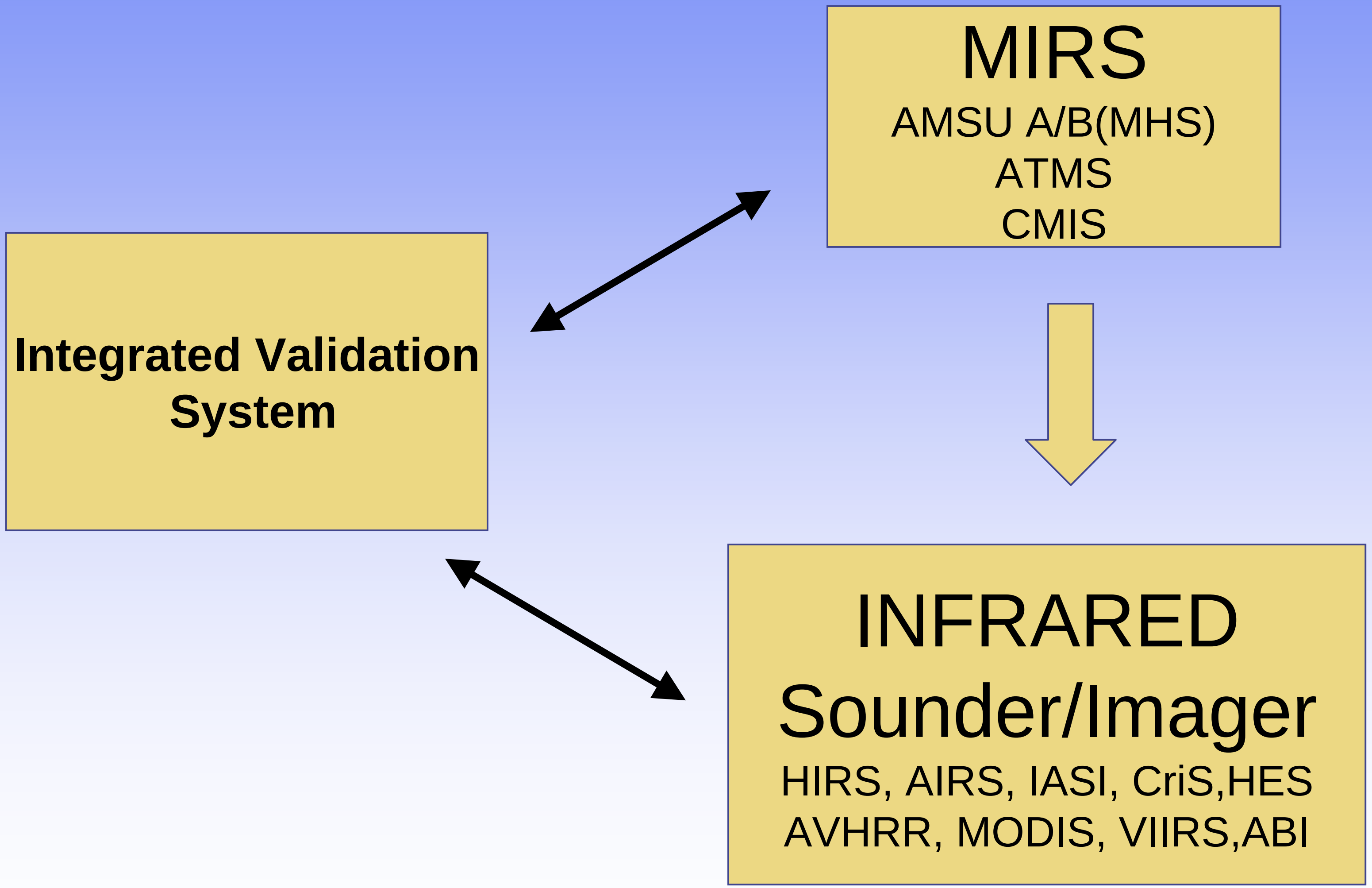
NESDIS Plan on ATOVS System



NESDIS ATOVS Plan

- 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 fovs improved temperature and moisture profiles (for temperature improvement is in lower troposphere)

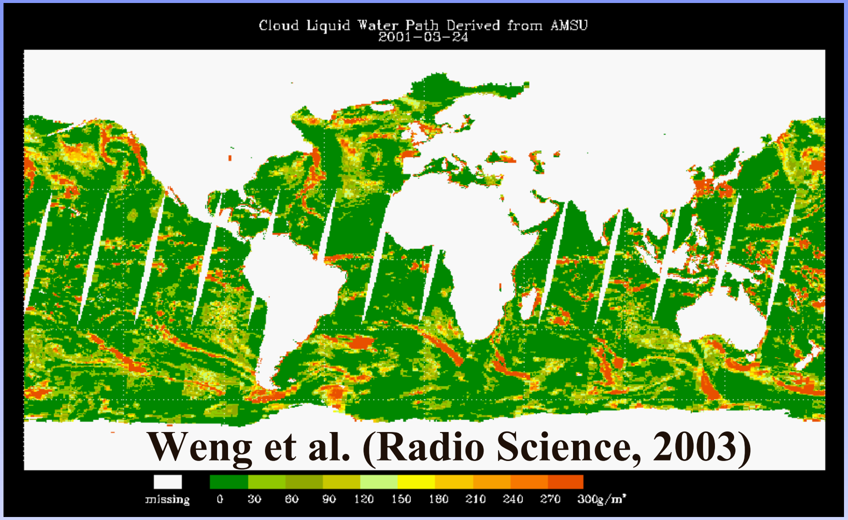
AIRS, CrIS, and IASI

- 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)

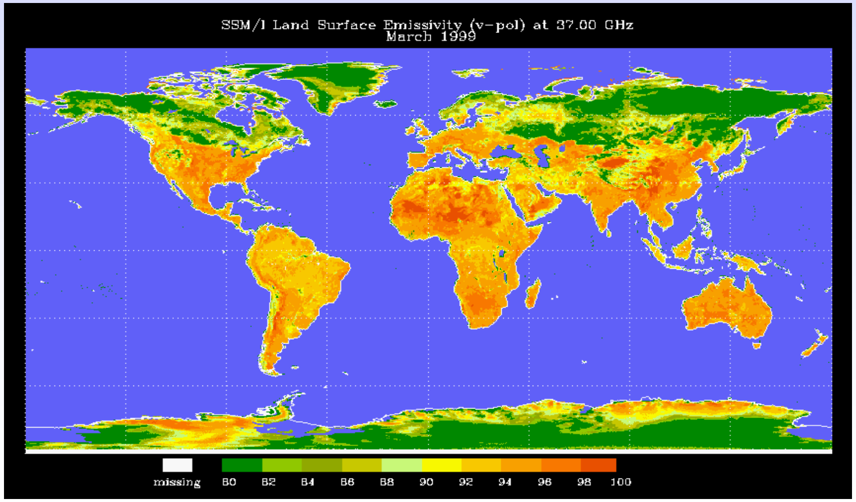
MIRS Objectives

- Enhance Microwave Surface and Precipitation Products System (MSPPS) Performance
- Provide front-end retrievals for the robust first guess to infrared sounding system (HIRS, hyperspectral)
- Profile temperature, water vapor and cloud water from microwave instrument under all weather conditions
- Improve profiling lower troposphere by using more "surface viewing" channels in retrieval algorithm
- Integrate the state-of-the-art radiative transfer model components from JCSDA into MIRS
- Prepare for future microwave sounding system (e.g. ATMS, CMIS, SSMIS, Geo-MW)

AMSU Cloud Liquid Water Path (3/24, 2001)



Microwave surface Emissivity at 37 GHz



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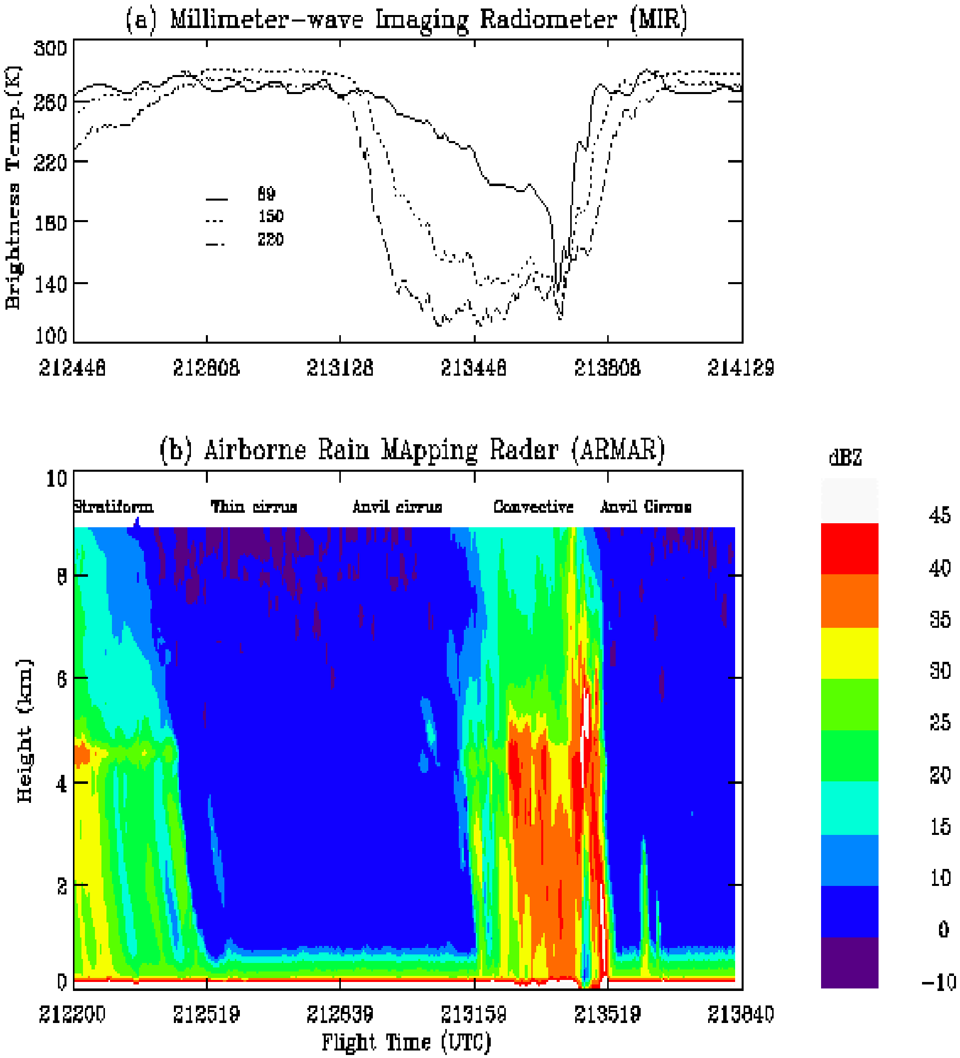
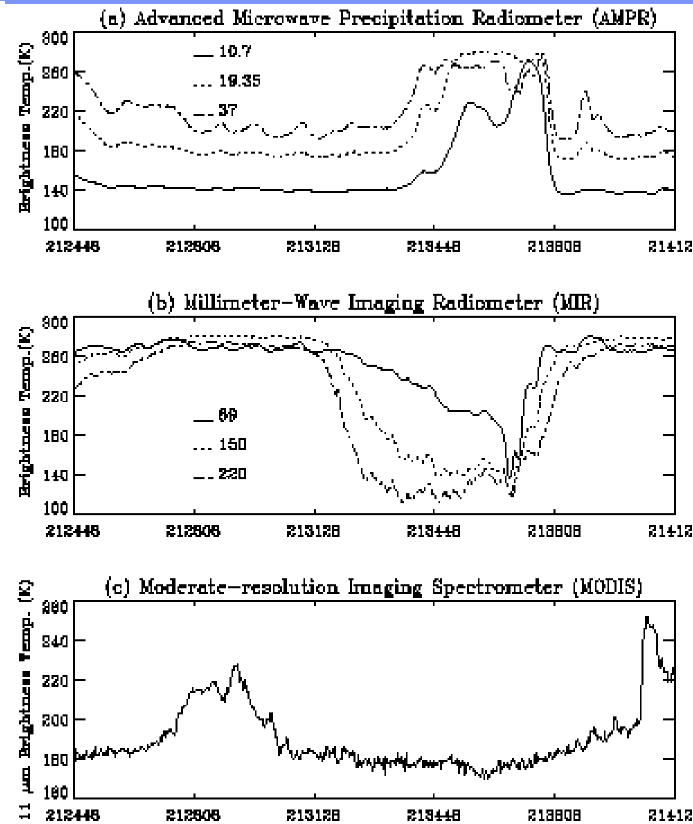
Microwave Products from NPOESS CMIS

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

The highlighted are operational EDRS derived from POES AMSU

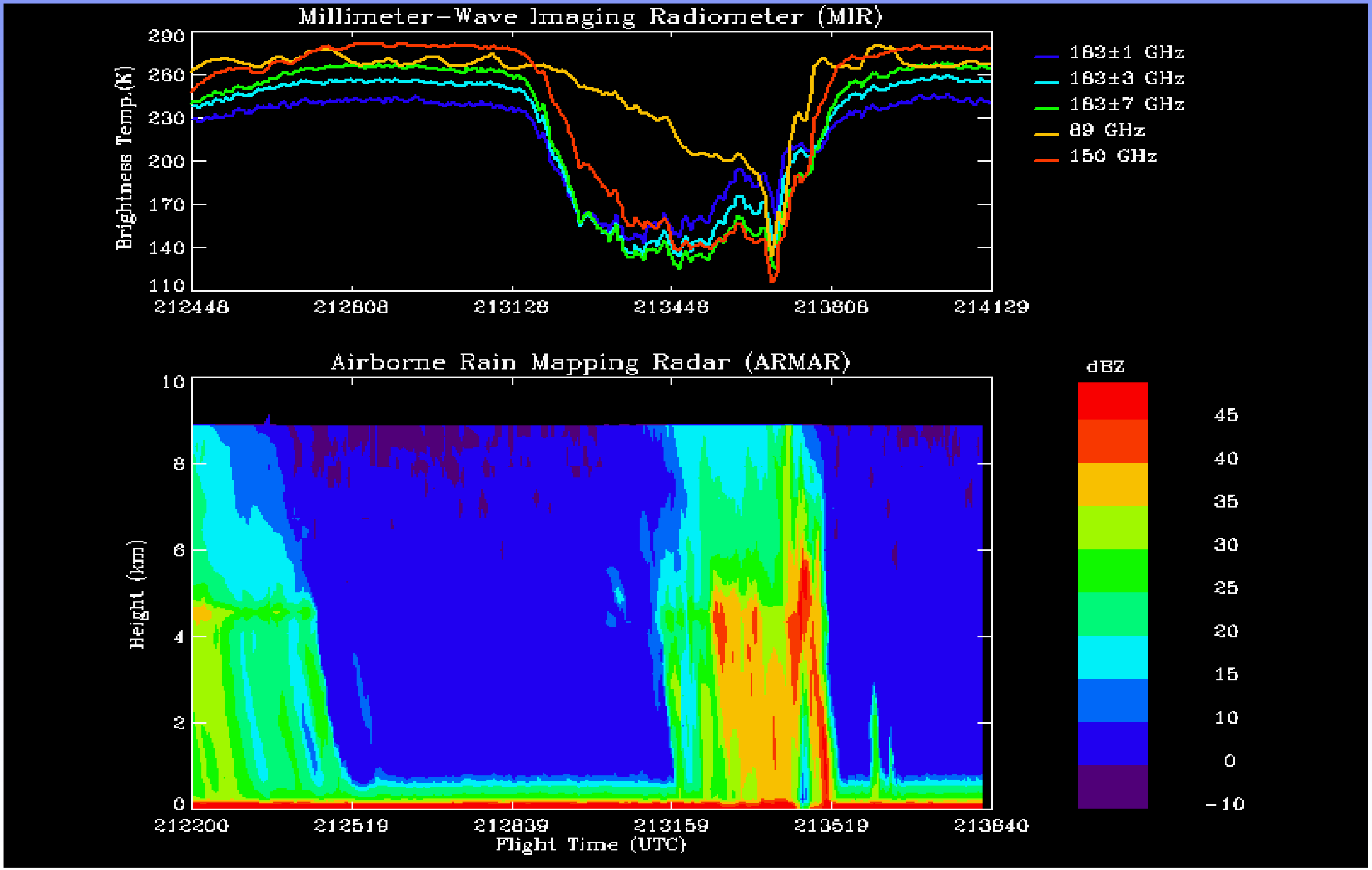
ER-2/DC-8 Measurements during TOGA/CORE (1/2)



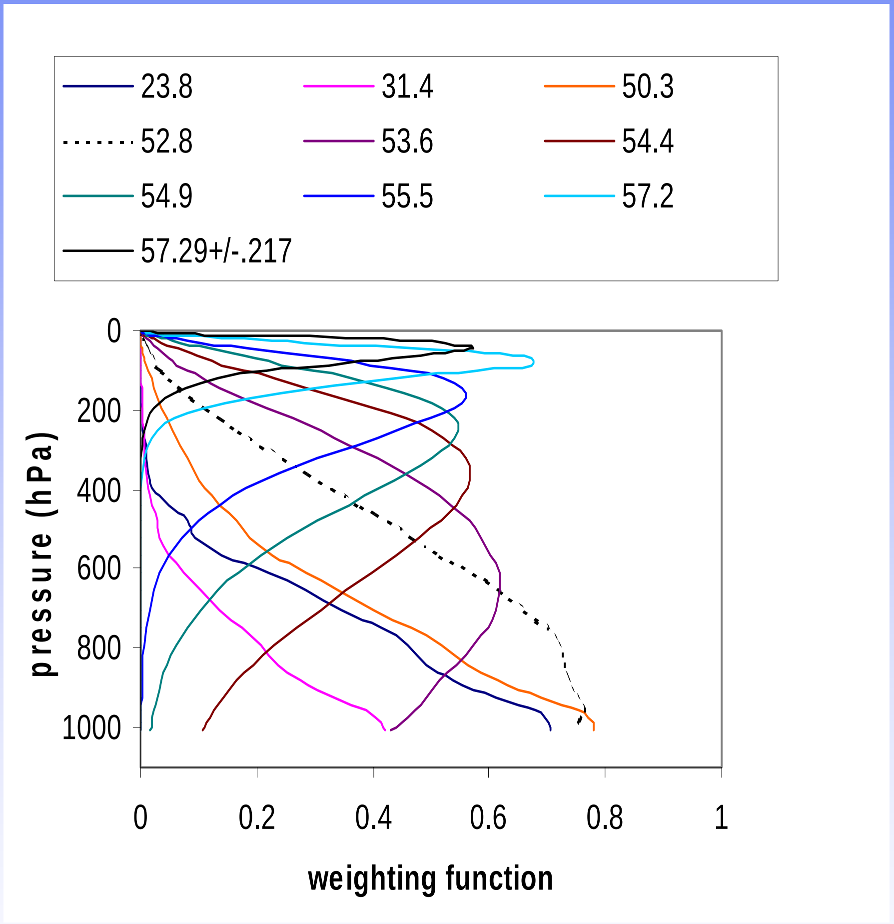


Weng and Grody (2000, JAS)

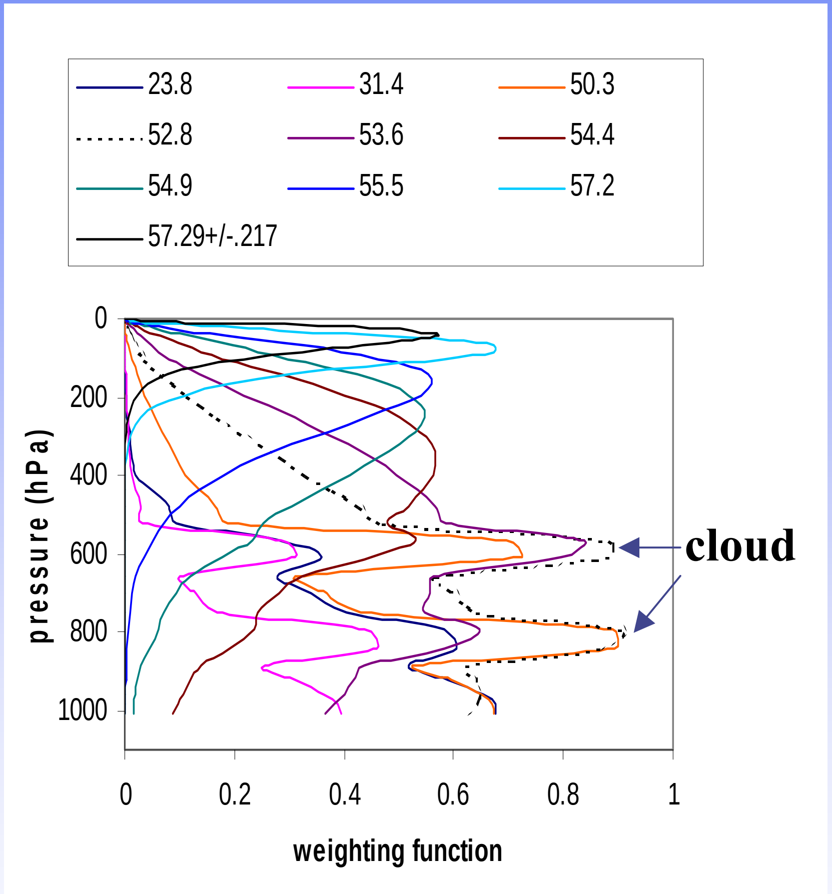
ER-2/DC-8 Measurements during TOGA/CORE (2/2)



Clouds Modify AMSU Weighting Function



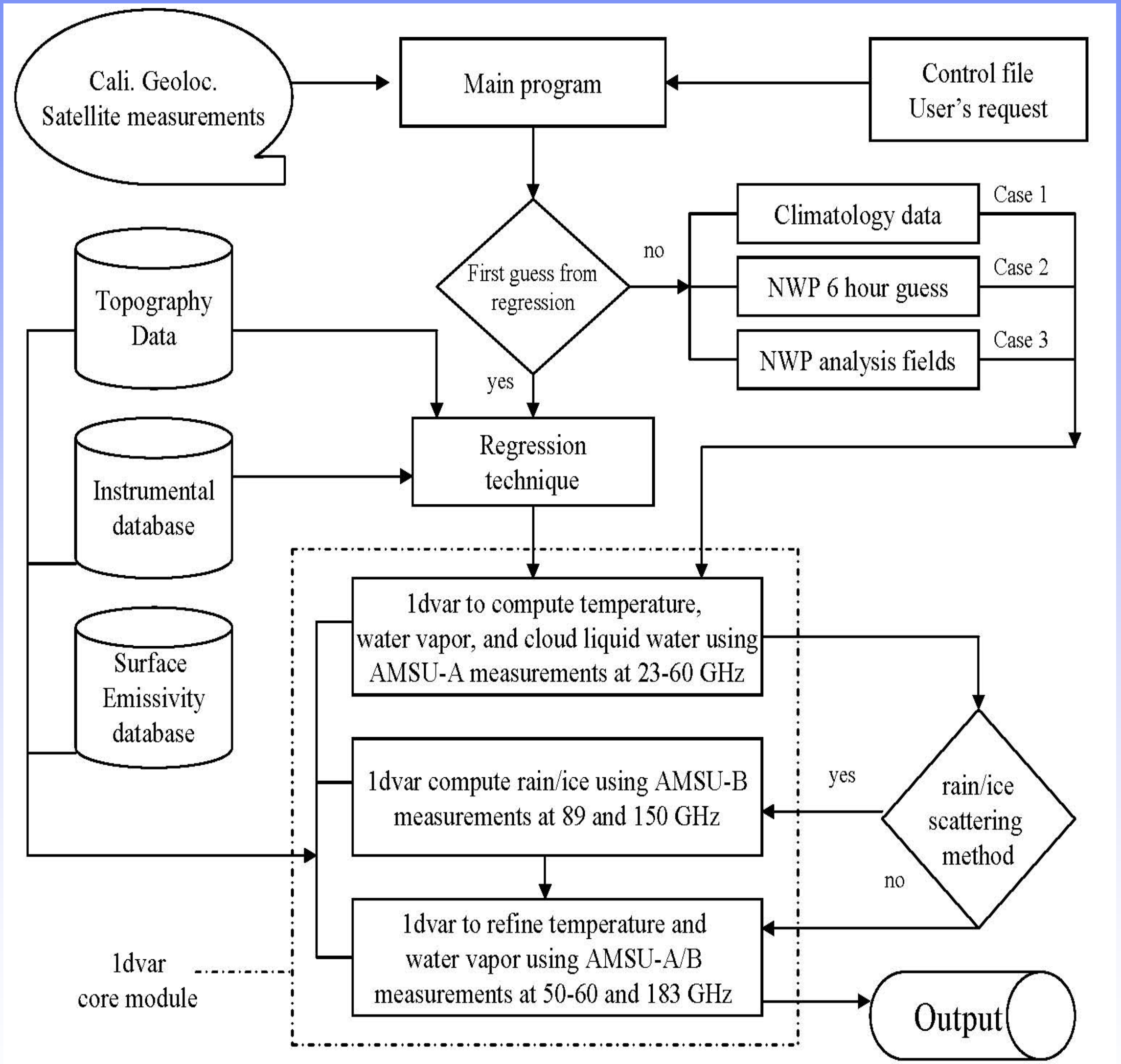
Clear condition



Include two separated cloud layers at 610 and 840 hPa with 0.5 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



Liu and Weng (2005, IEEE)

Algorithm Theoretical Basis (1/9)

Cost Function:

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

where

$\mathbf{x}_\mathbf{b}$ 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

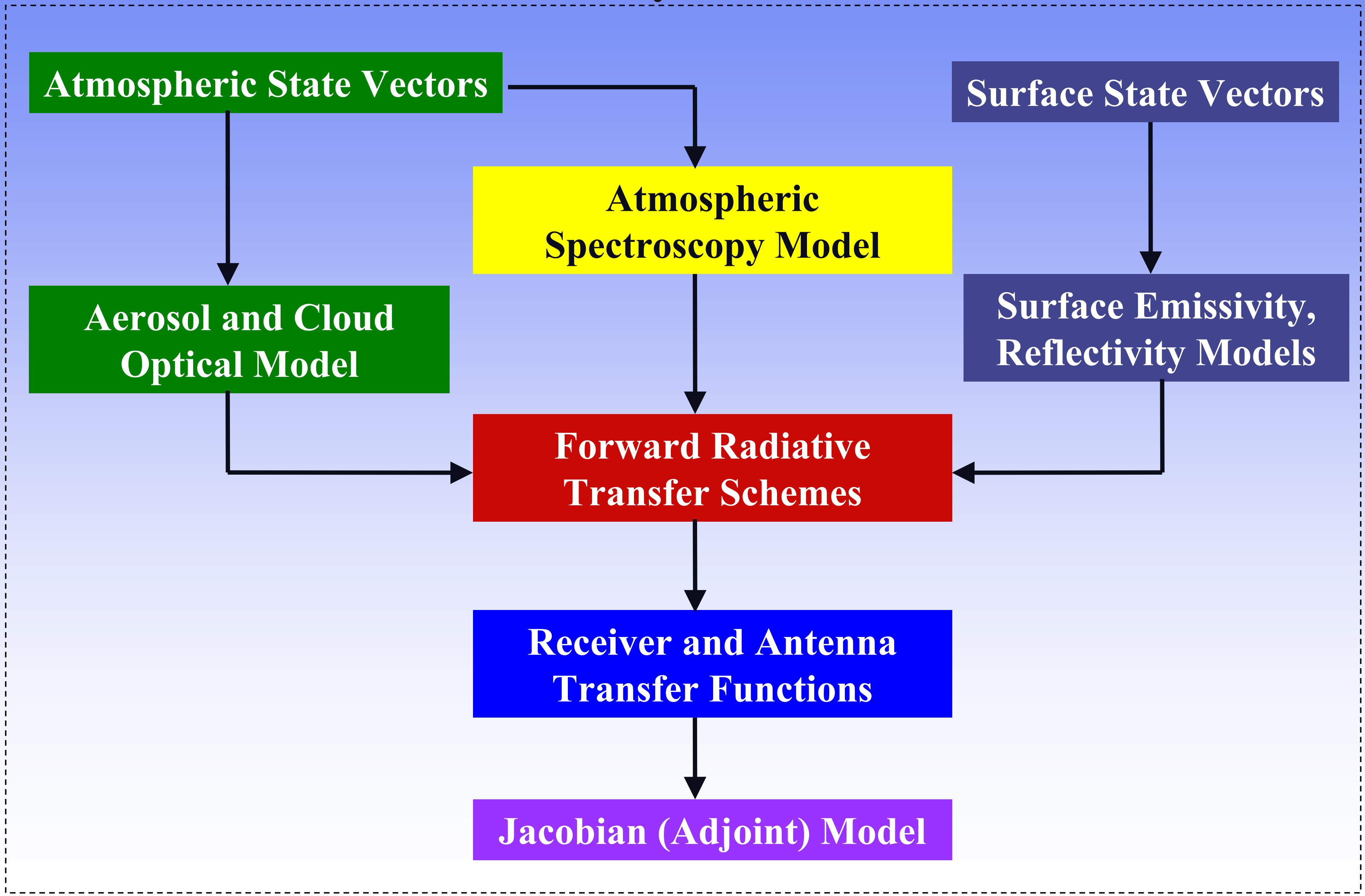
$\mathbf{F}$ is the radiative transfer model error matrix

Algorithm Theoretical Basis (2/9)

- 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:

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

$$\mathbf{s}_l(\tau) = \delta_{m0}[B(\tau_{l-1})\boldsymbol{\Xi} + \frac{B(\tau_l) - B(\tau_{l-1})}{\tau_l - \tau_{l-1}}(\mathbf{A}_l^{-1}\boldsymbol{\Xi} + (\tau - \tau_{l-1})\boldsymbol{\Xi})]$$

$$+ \mu_0[\mu_0\mathbf{A}_l + \mathbf{E}]^{-1}\frac{\varpi F_0}{\pi}\exp(-\tau/\mu_0)\boldsymbol{\Psi}$$

Jacobians Including Scattering:

$$\frac{\partial \mathbf{I}_1(\mu)}{\partial x_l} = \sum_{k=l}^{L}\sum_{j=-4N}^{4N}\mathbf{K}_k(\mu, j)\{\frac{\partial(\mathbf{s}_k(\tau) - \mathbf{s}_{k-1}(\tau))}{\partial x_l}\Big|_{\tau=\tau_{l-1}}\}_j + \delta_{1l}\frac{\partial \mathbf{s}_1(\mu)}{\partial x_l}$$

$$- \sum_{j=-4N}^{4N}\mathbf{K}_l(\mu, j)\{\frac{\partial}{\partial x_l}\exp[\mathbf{A}_l(\tau - \tau_{l-1})]\Big|_{\tau=\tau_l}\mathbf{c}_l\}_j$$

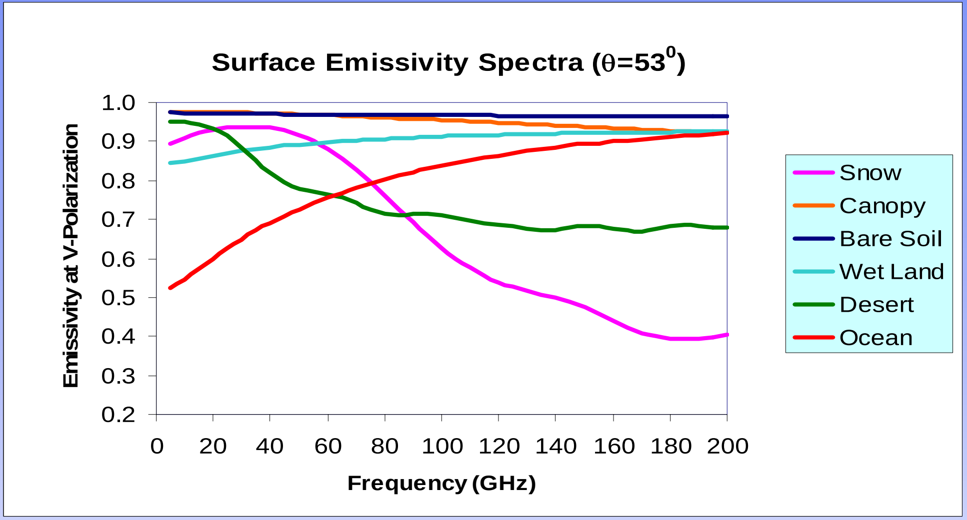
(Weng and Liu, JAS, 2003)

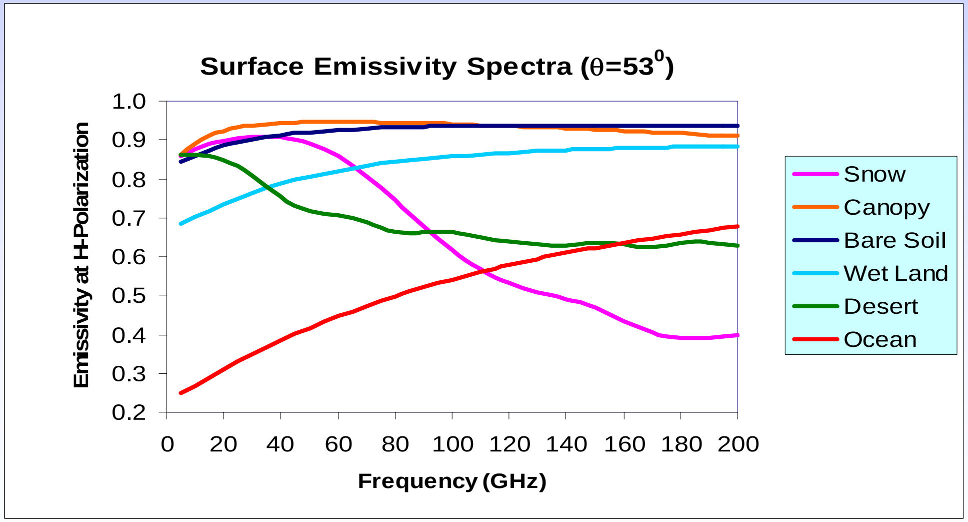
Algorithm Theoretical Basis (6/9)

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

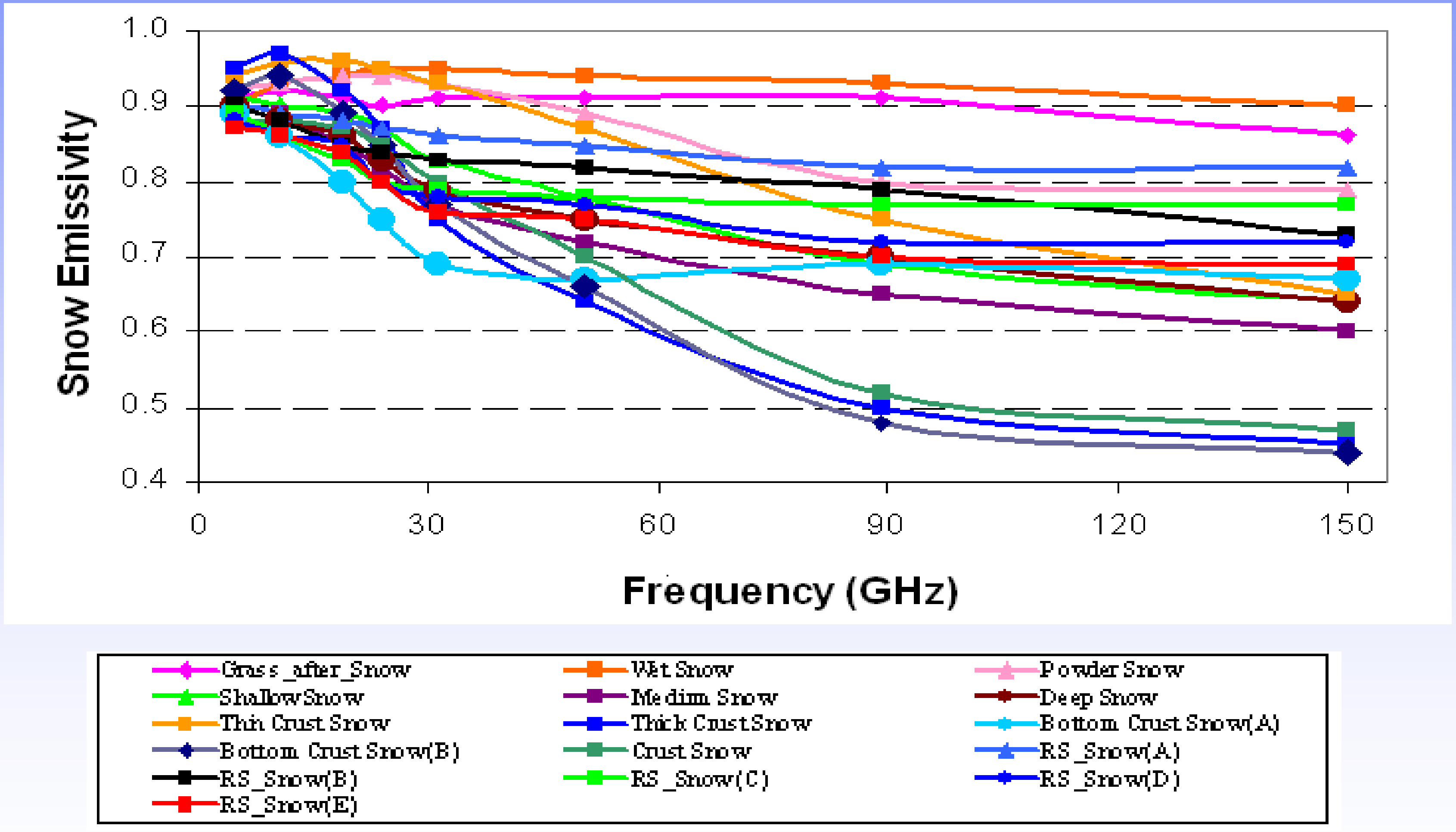
Weng et al (2001, JGR)



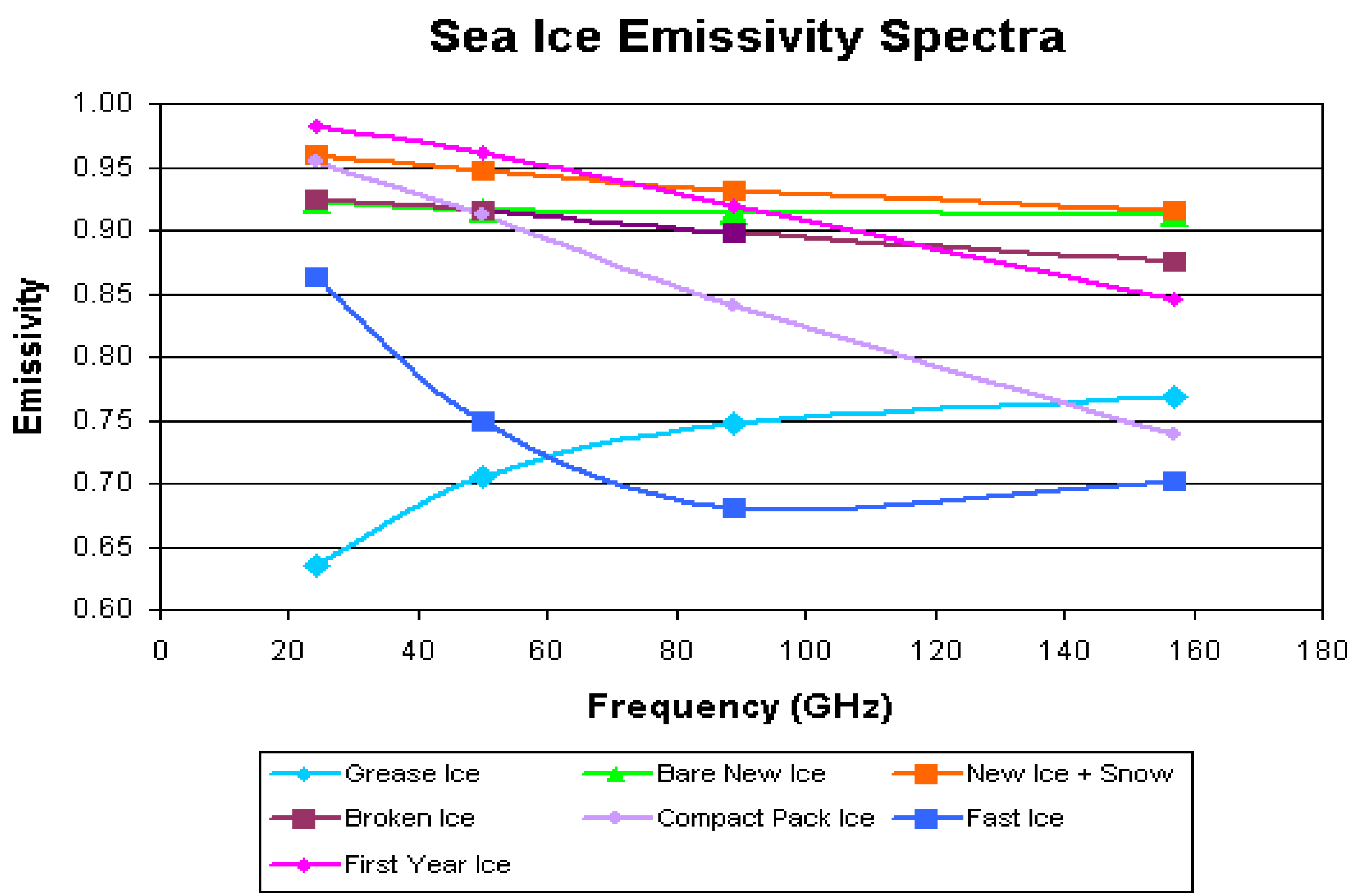


Algorithm Theoretical Basis (7/9)

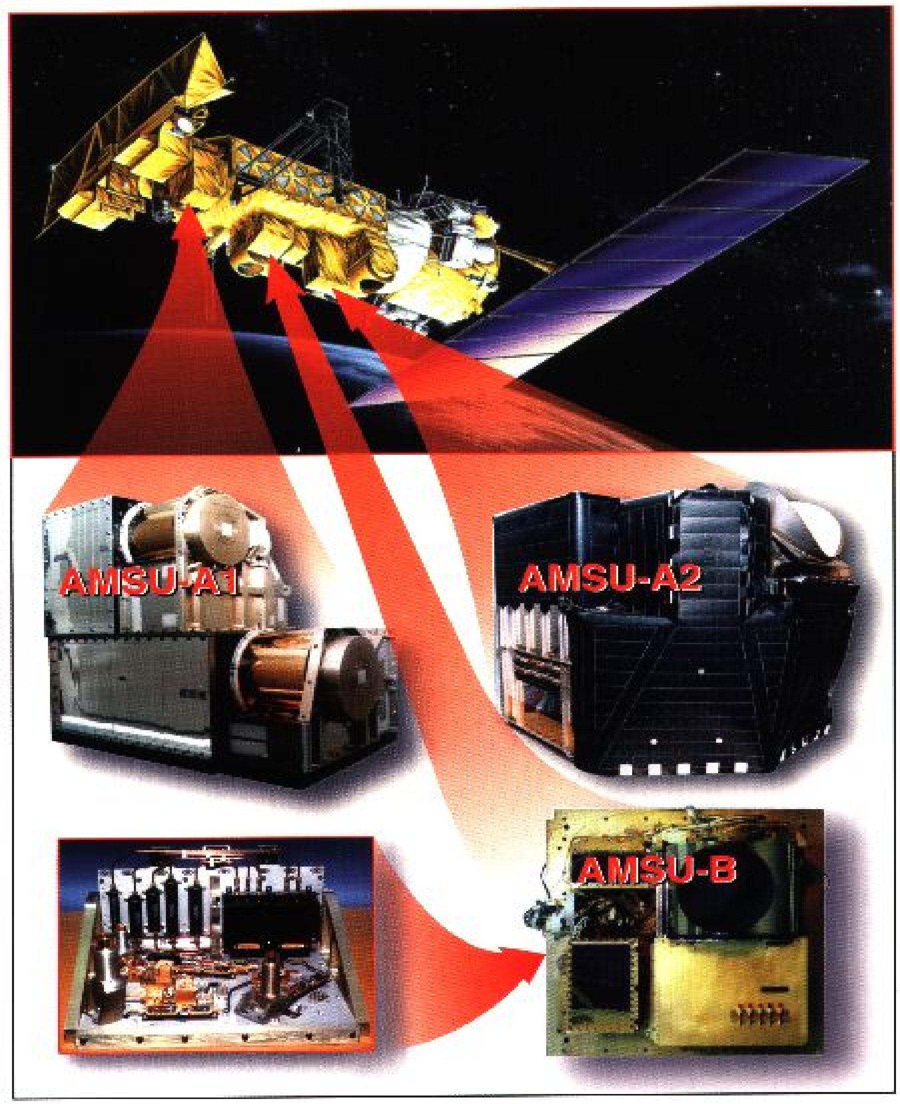
Snow Emissivity:



Algorithm Theoretical Basis (8/9)



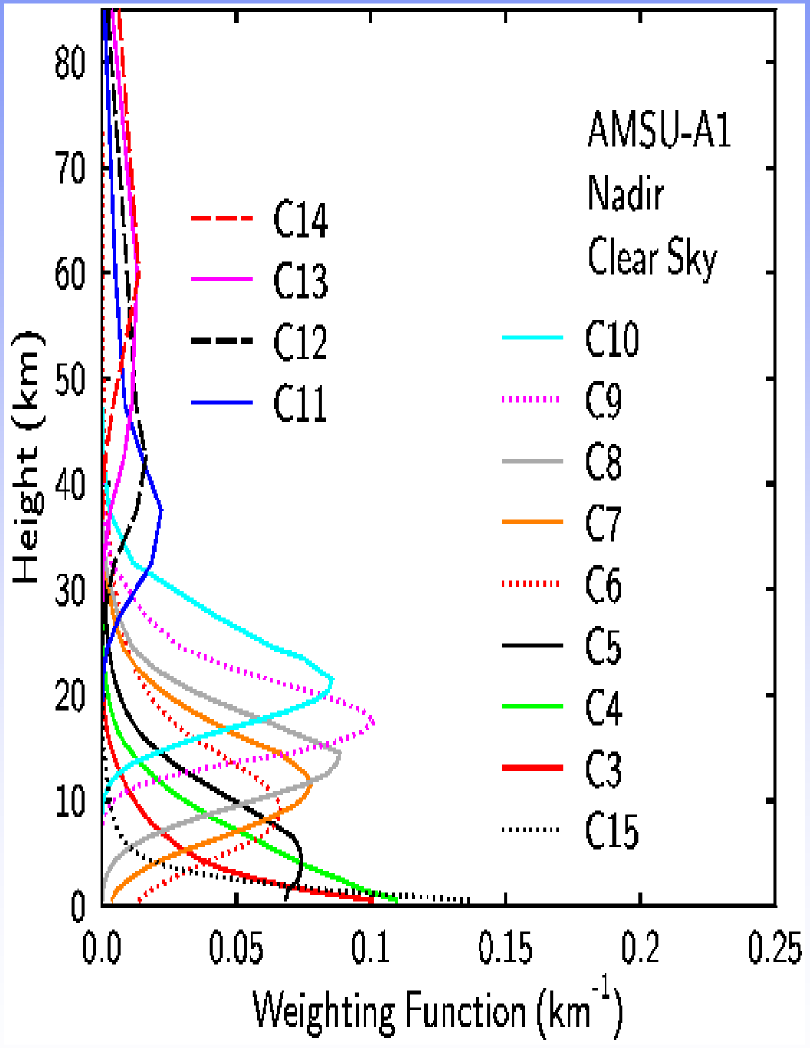
Advanced Microwave Sounding Unit



- 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



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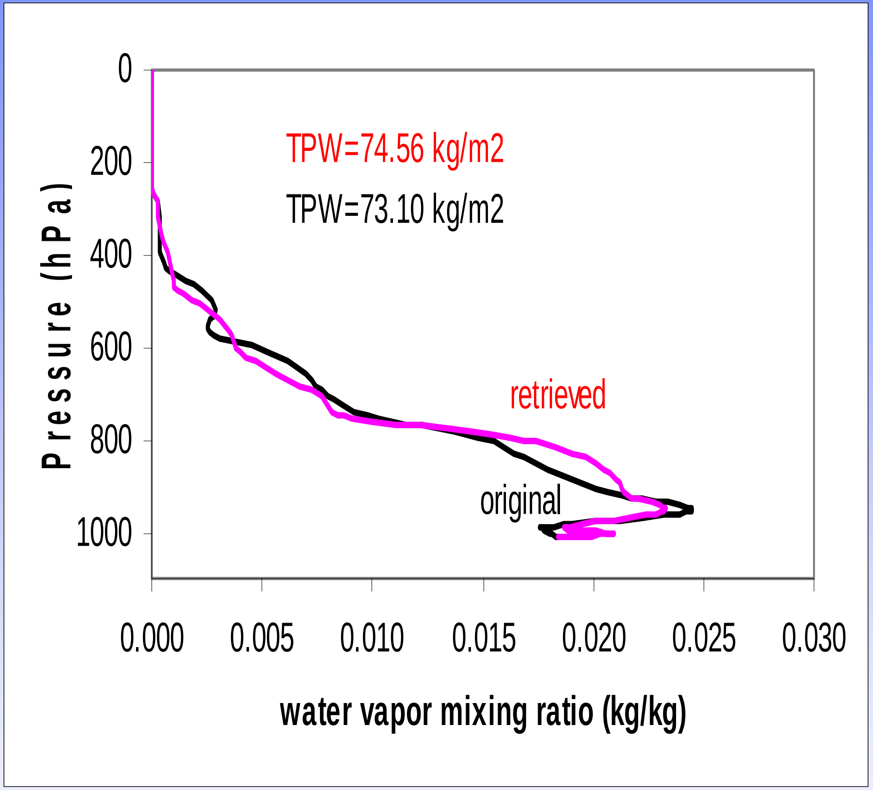
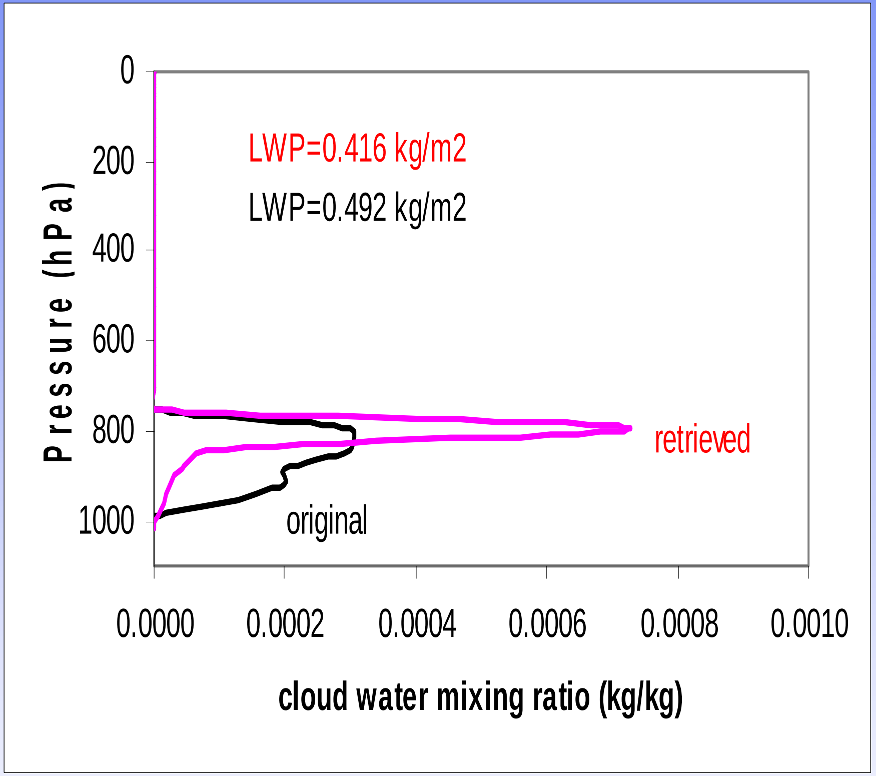
Water Vapor and Cloud Water Profiles



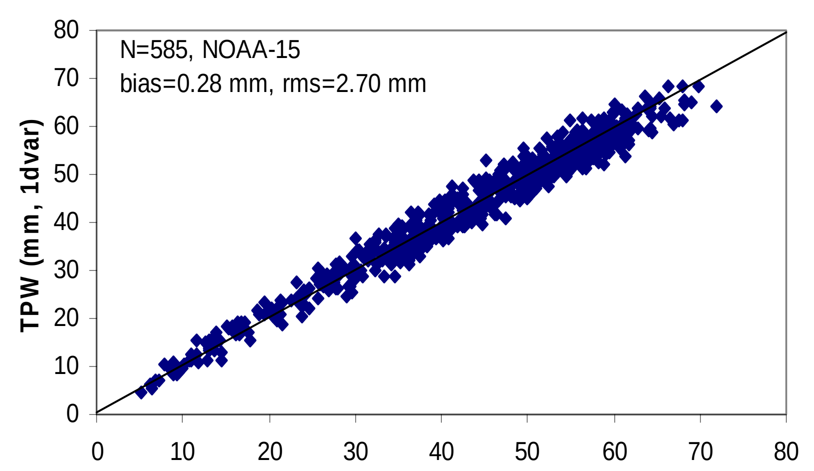


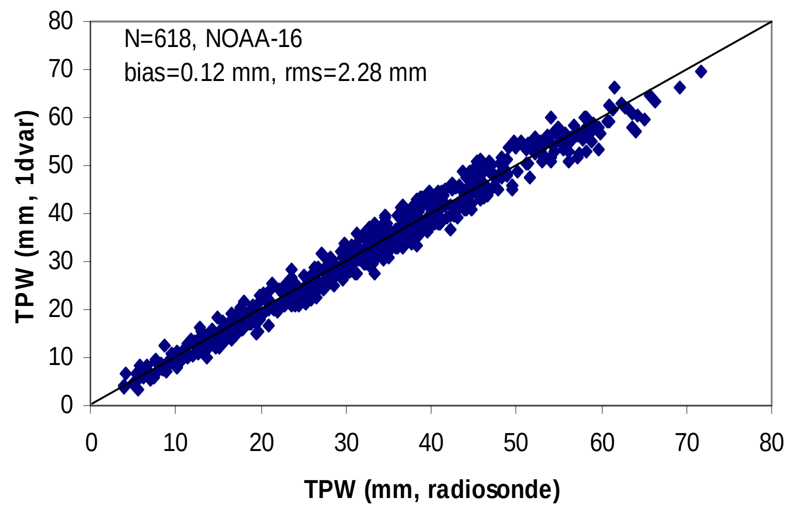
Standard atmosphere and cloudy layers between 800 and 950 hPa

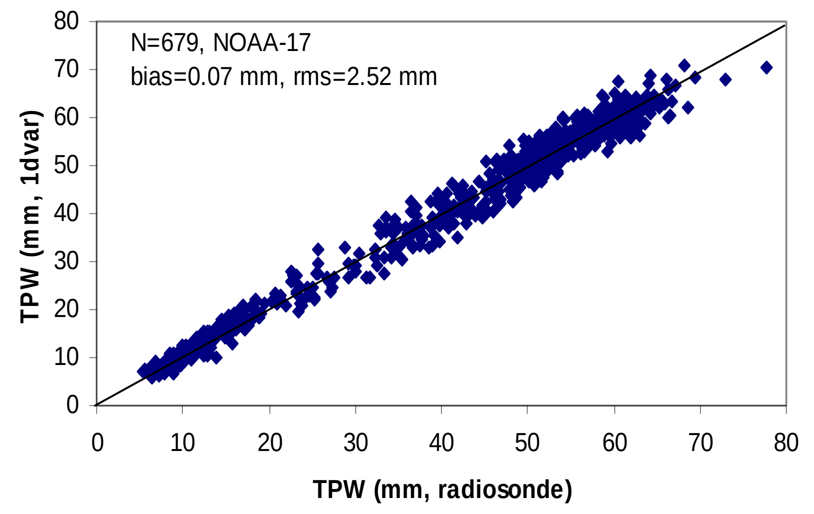
Retrievals is based on simulated AMSU brightness temperatures at nadir

Vertically Integrated Water Vapor

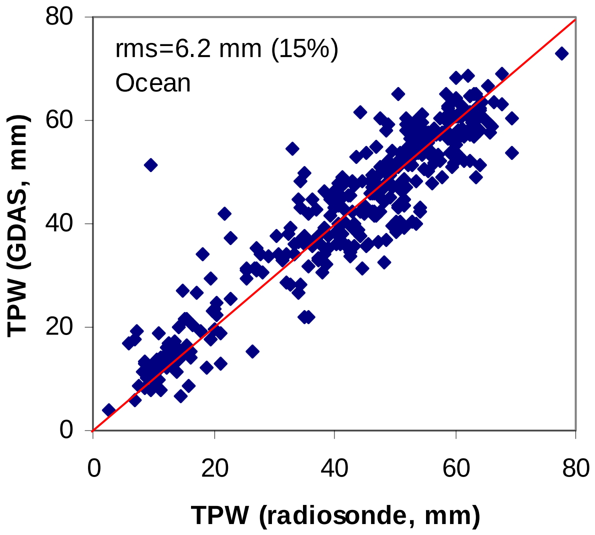
Match-up TPW from radiosondes and AMSU retrieval in 2002.

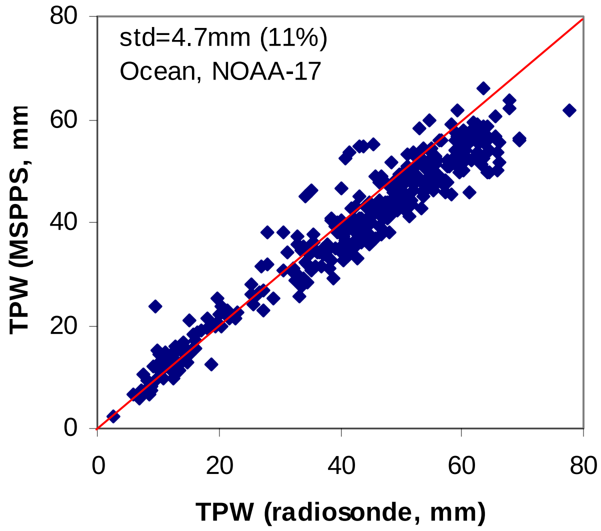


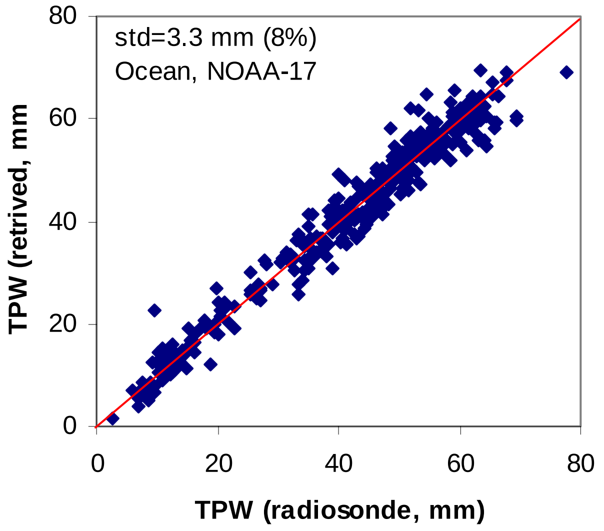




TPW Validation (NOAA-17)

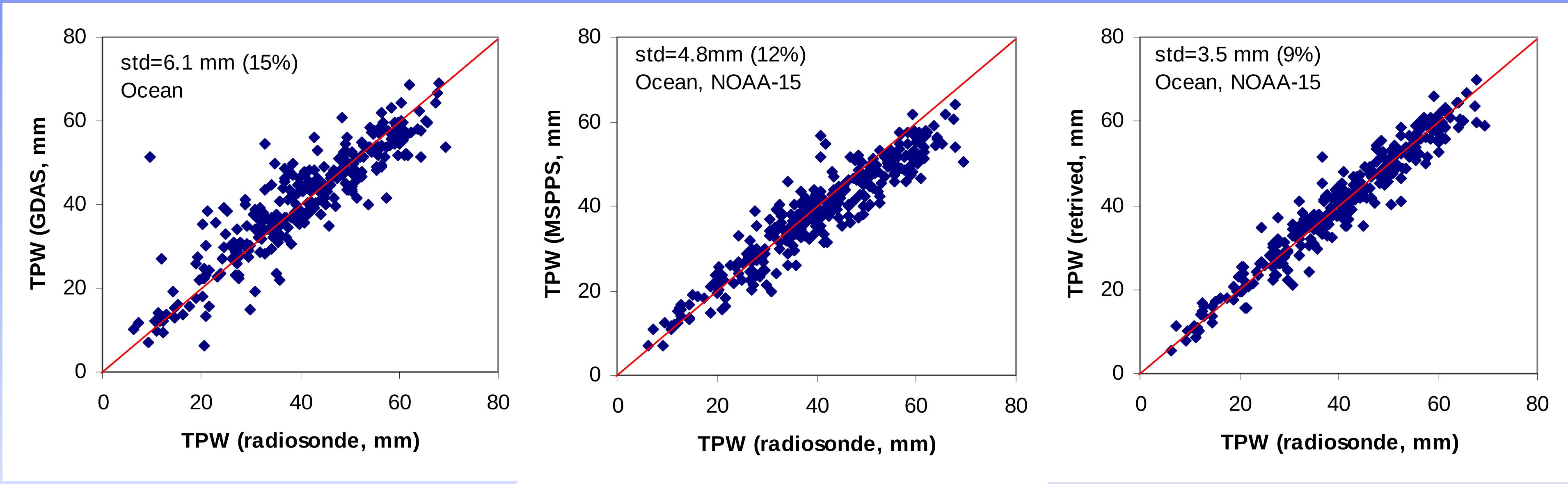






In comparison to radiosonde measurements, MSPPS TPW product gives accuracy better than GDAS but is slightly biased. MIRS TPW is the best (no priori information).

TPW Validation (NOAA-15)

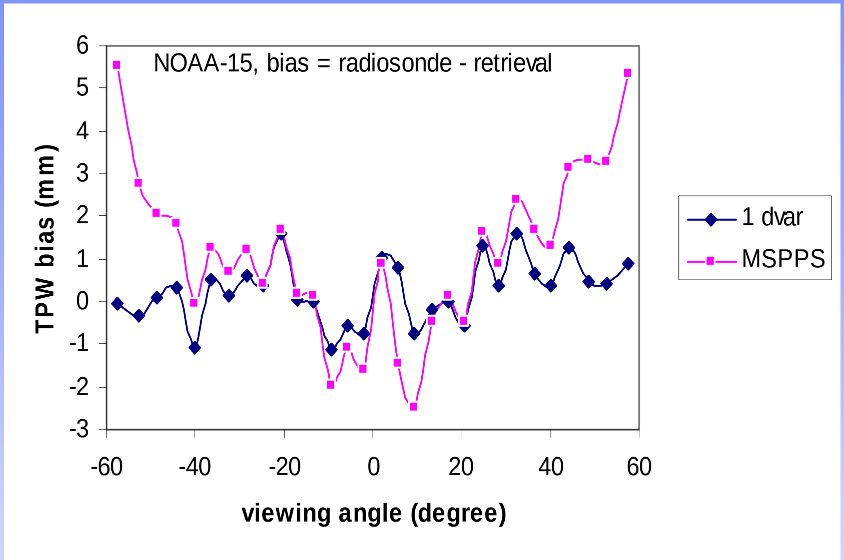


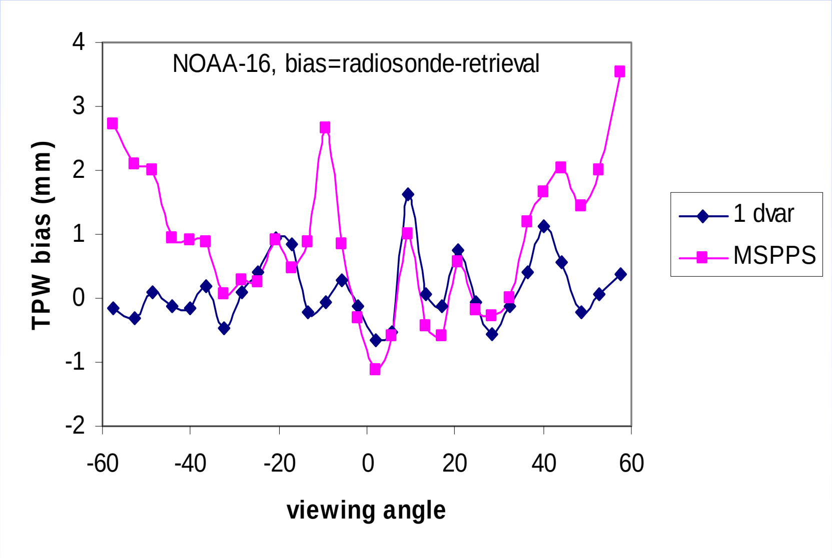
Retrieval Bias vs. Viewing Angles

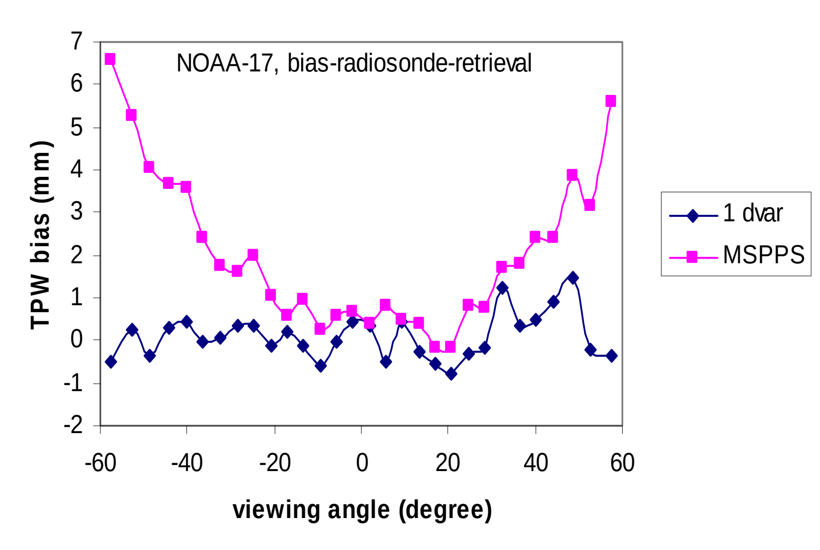
Match-up TPW from radiosondes and AMSU retrieval in 2002.

Bias variation to viewing angles.

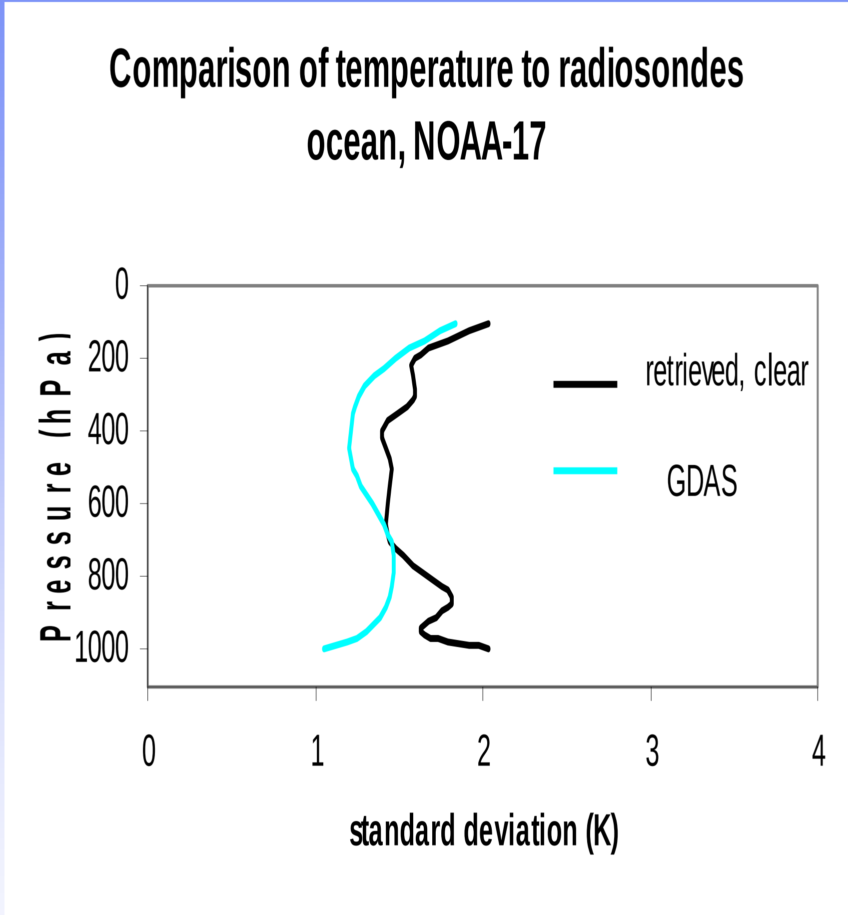
Bias = radiosonde – AMSU

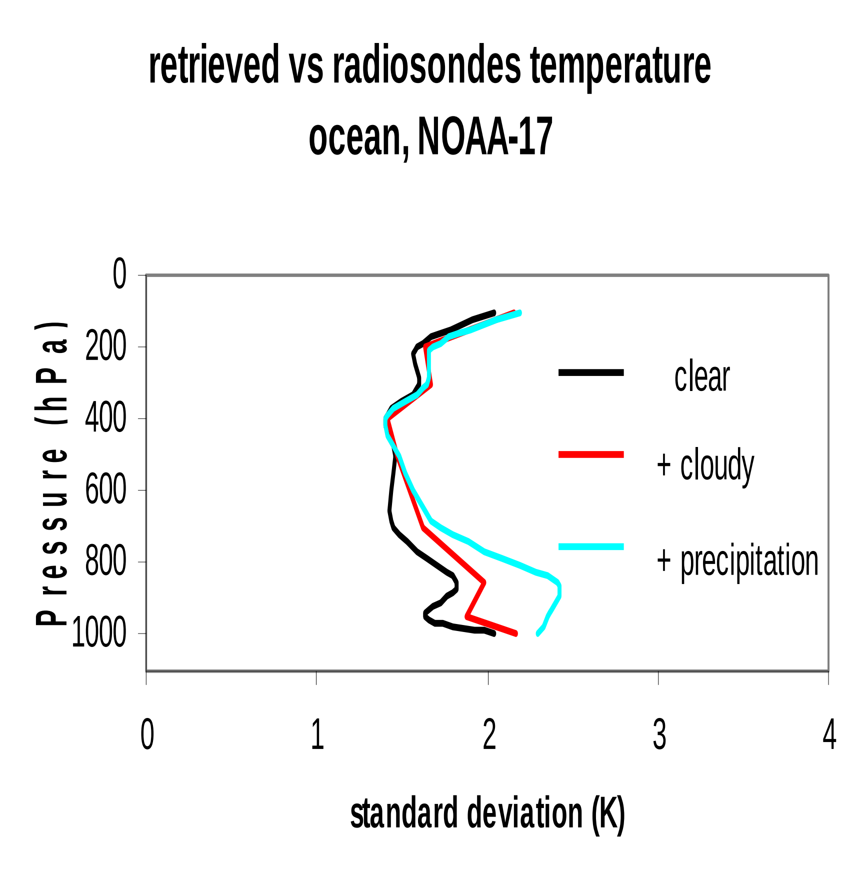






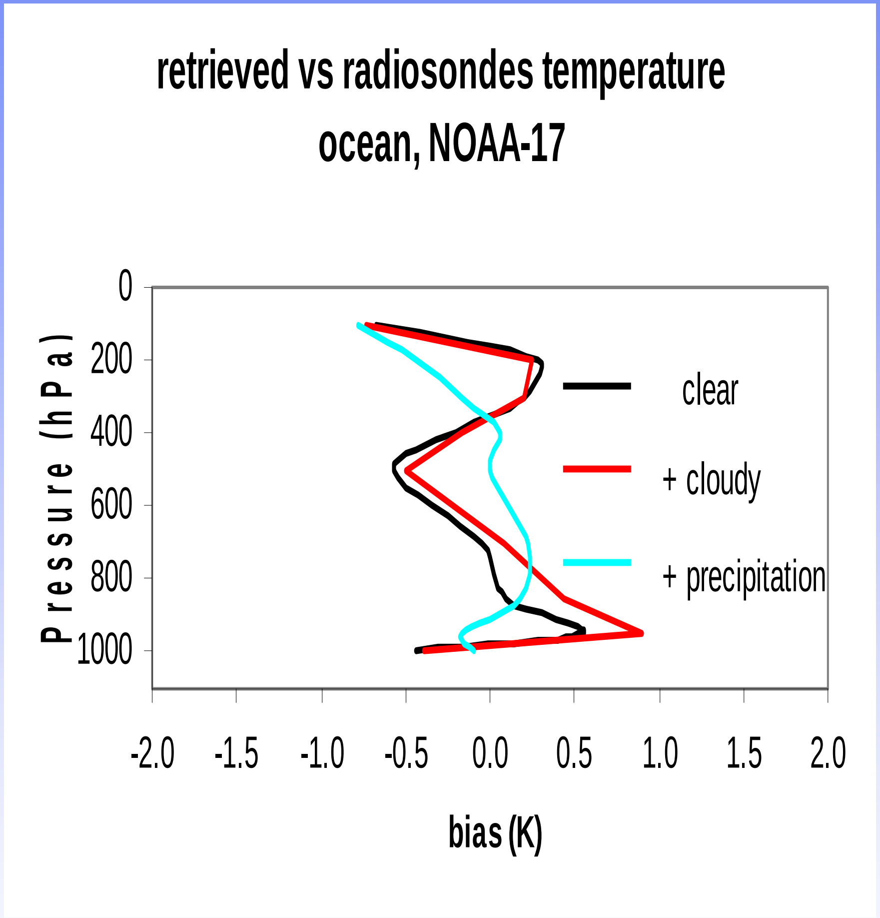
Temperature Validation (NOAA-17)

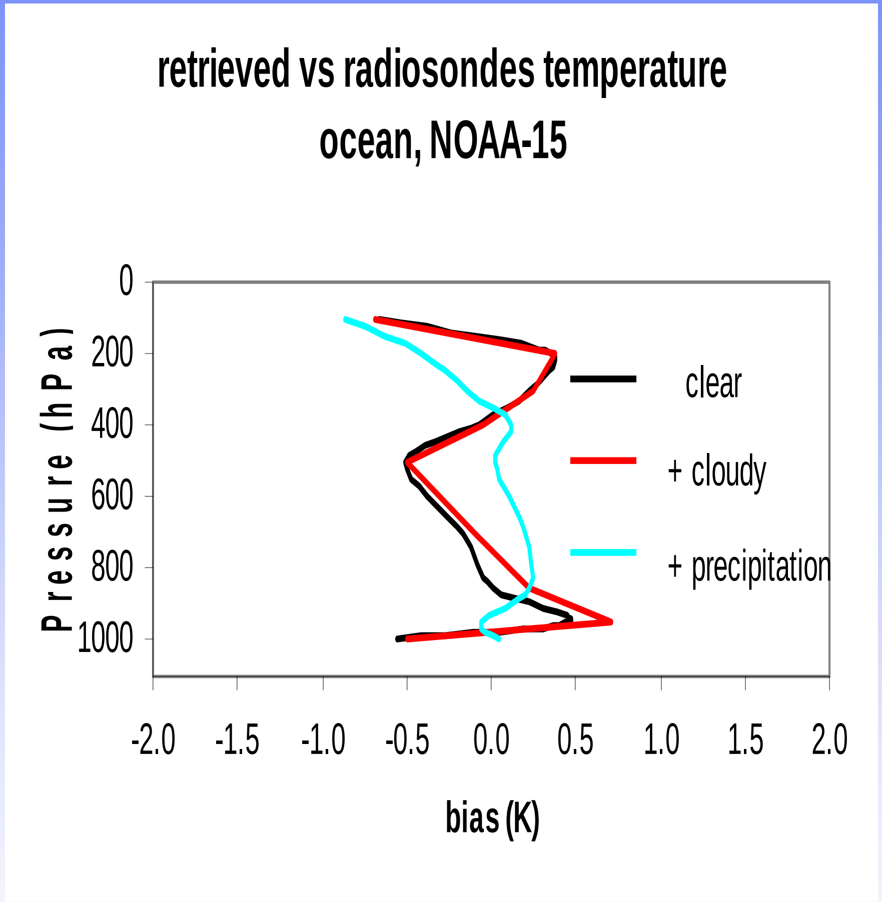




GDAS (1 x 1 deg) and radiosondes agree well. Clouds degrade the retrieval accuracy slightly. Clear samples = 357, clear+cloud samples = 501, clear+cloud+precipitation=552

Temperature Validation (NOAA-17)





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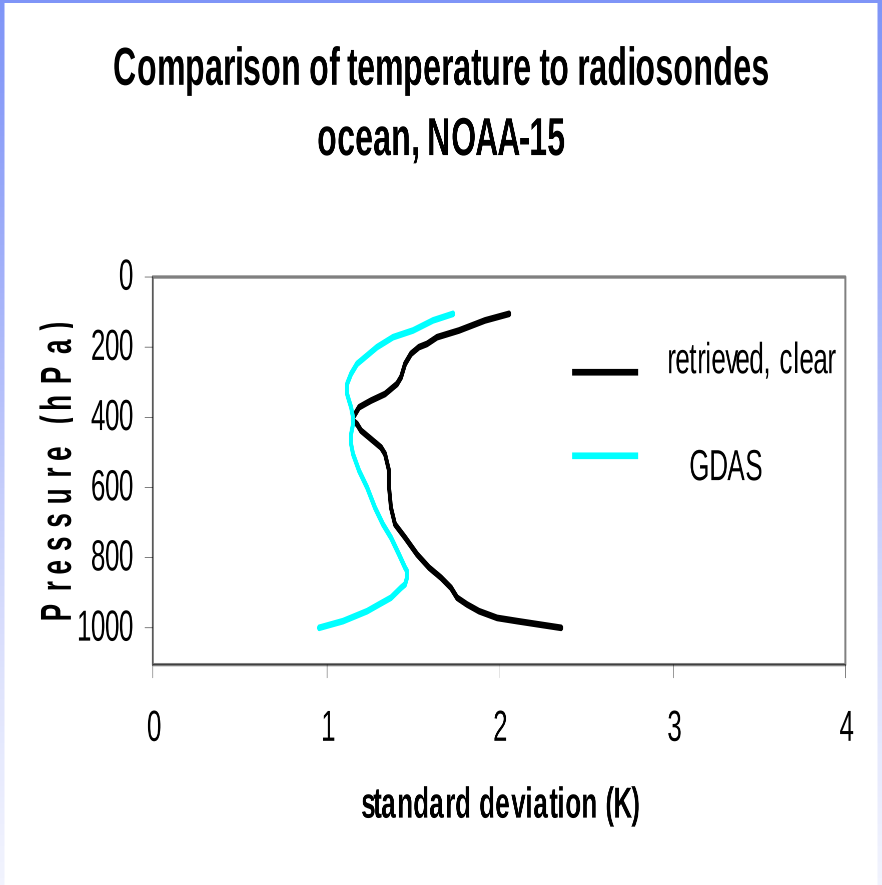
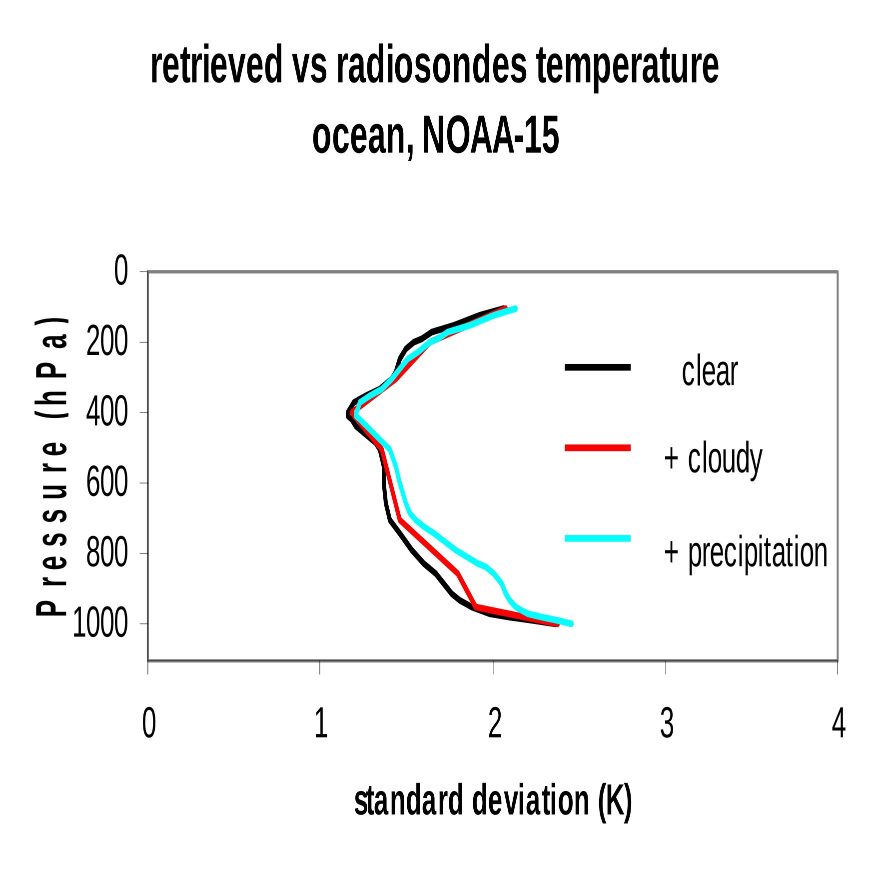
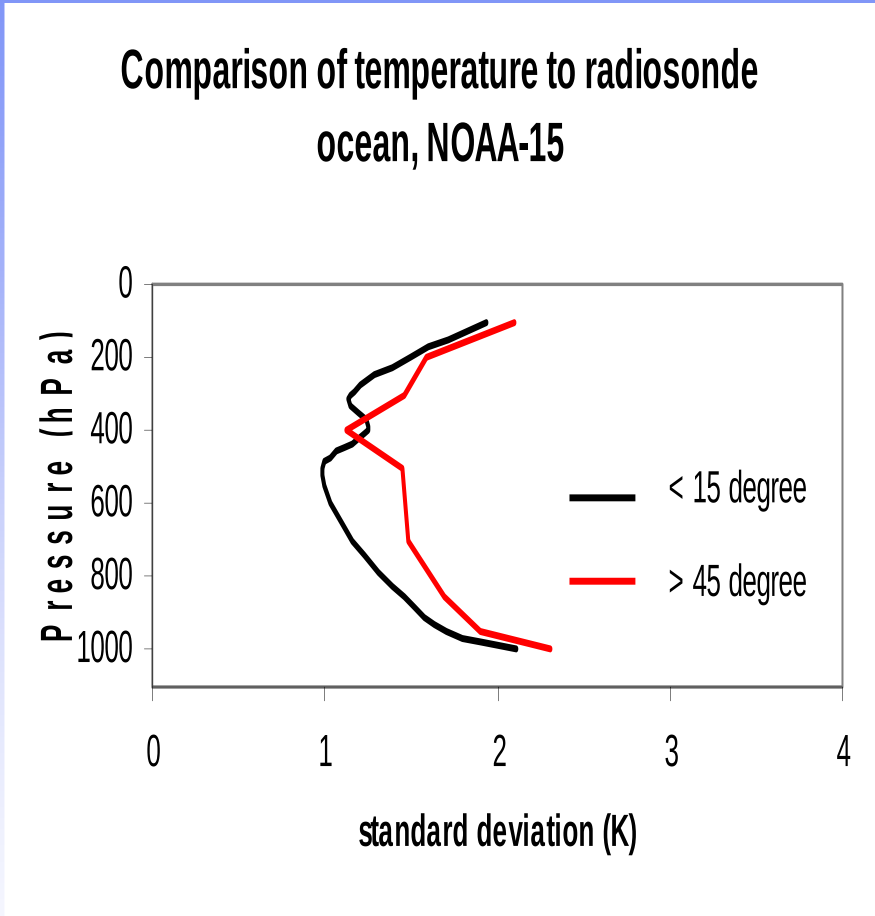
Temperature Validation (NOAA-15)

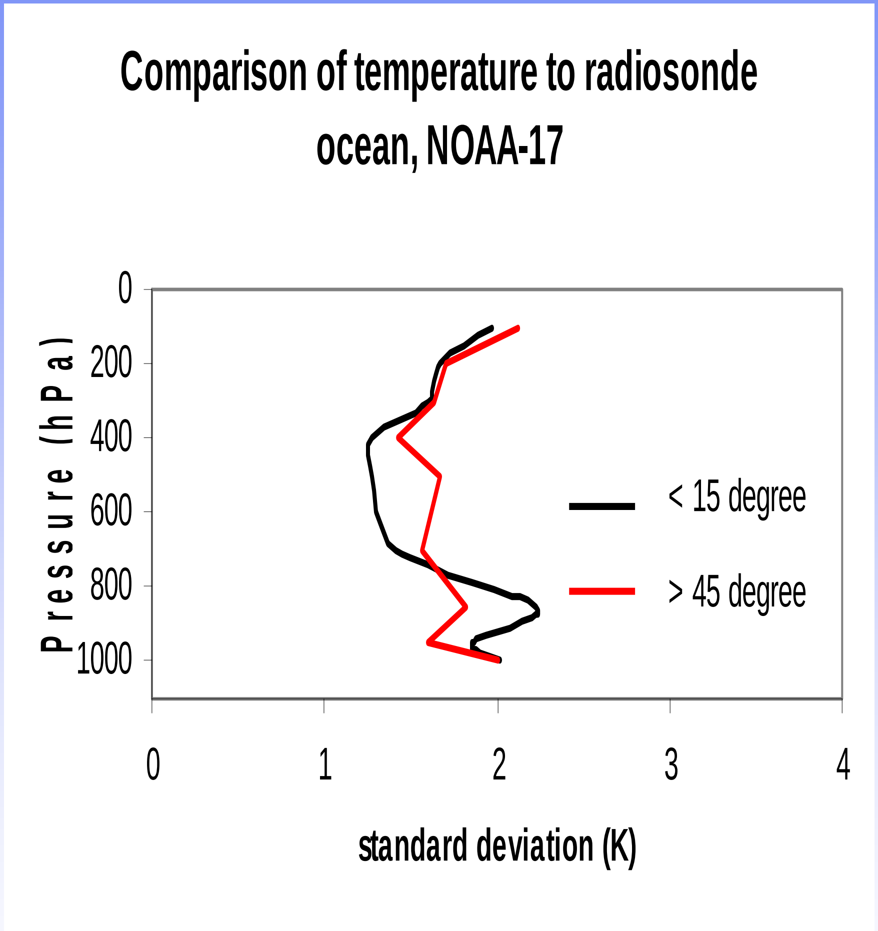




GDAS (1 x 1 deg) and radiosondes agree well. Clouds degrade the retrieval accuracy slightly. Clear samples = 278, clear+cloud samples = 386, clear+cloud+precipitation=416

Temperature Accuracy (Nadir vs. off-Nadir)





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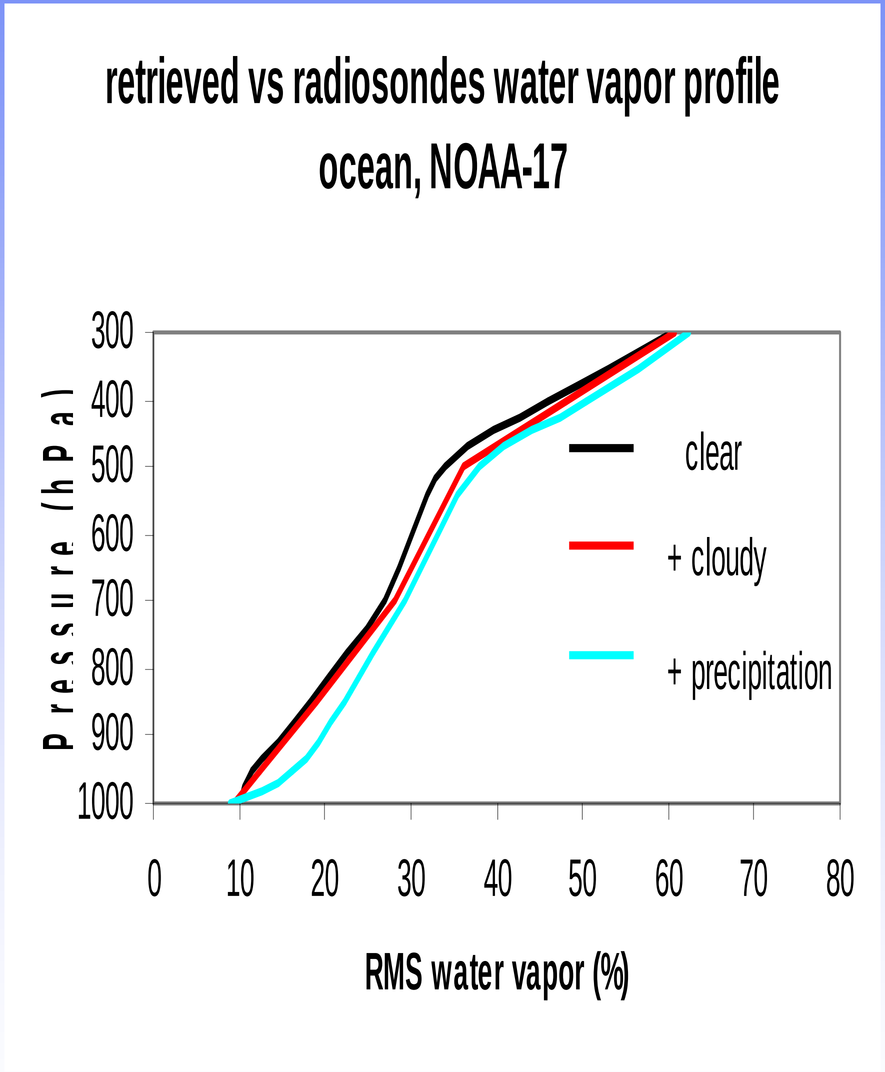
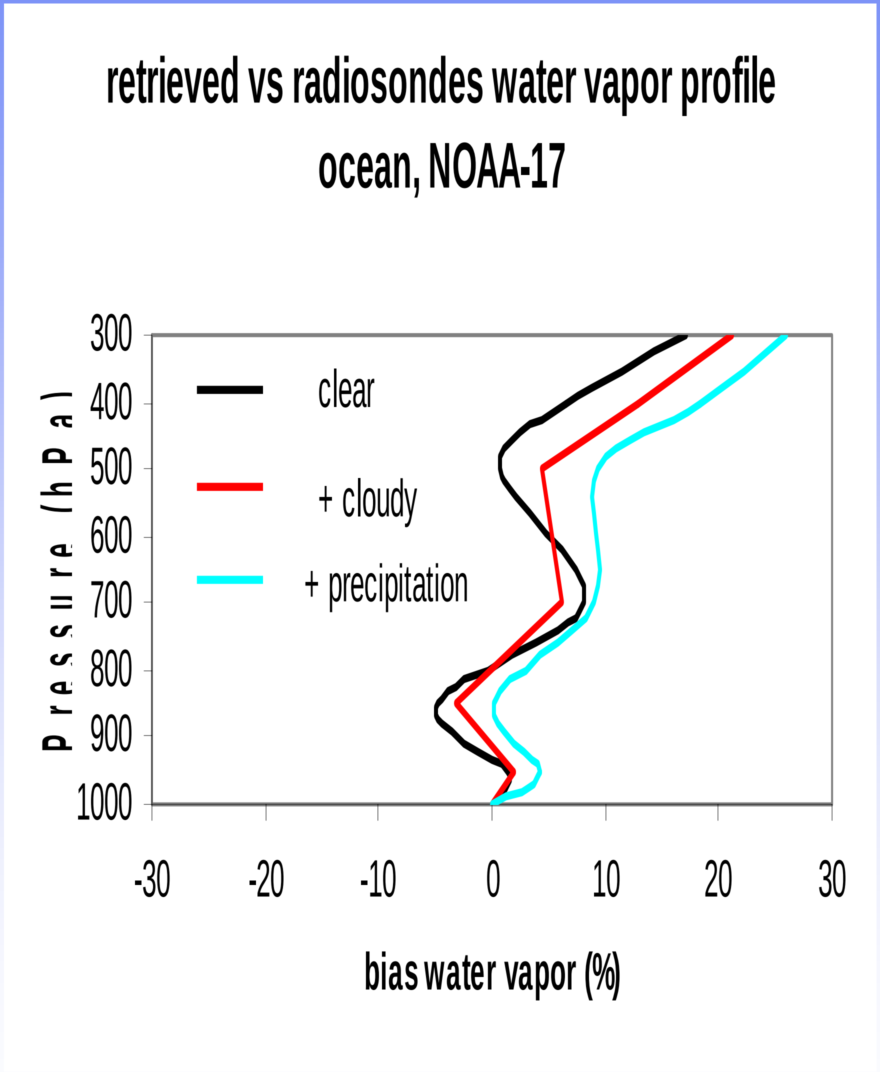
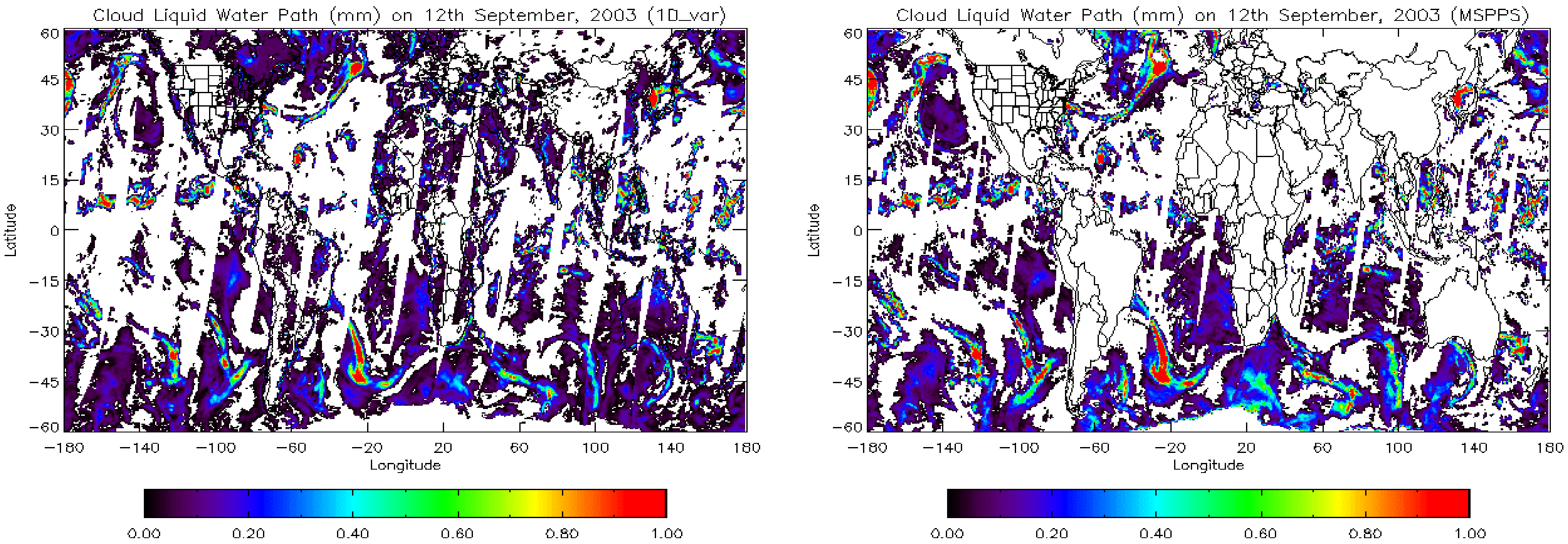
Validation for Water Vapor Profile

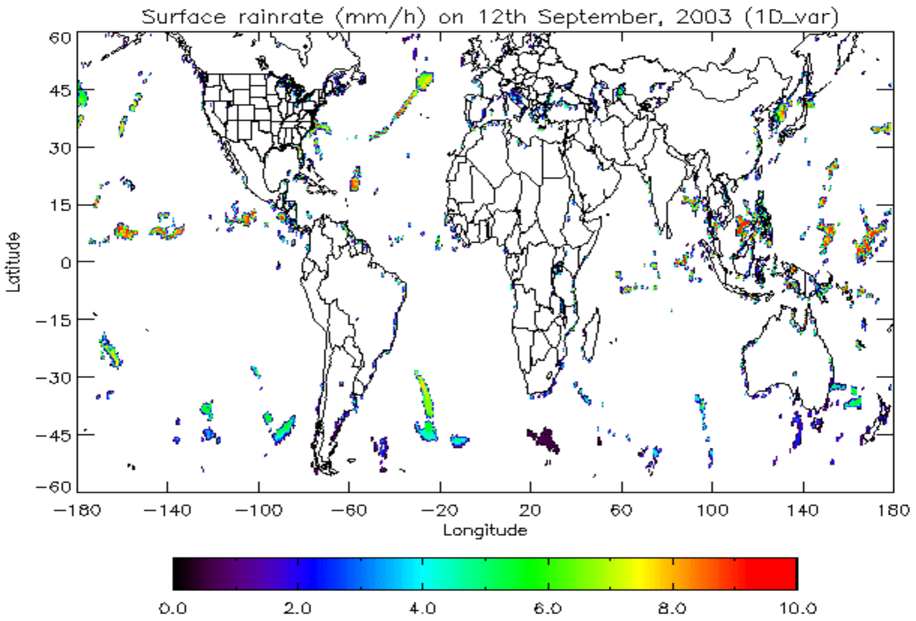


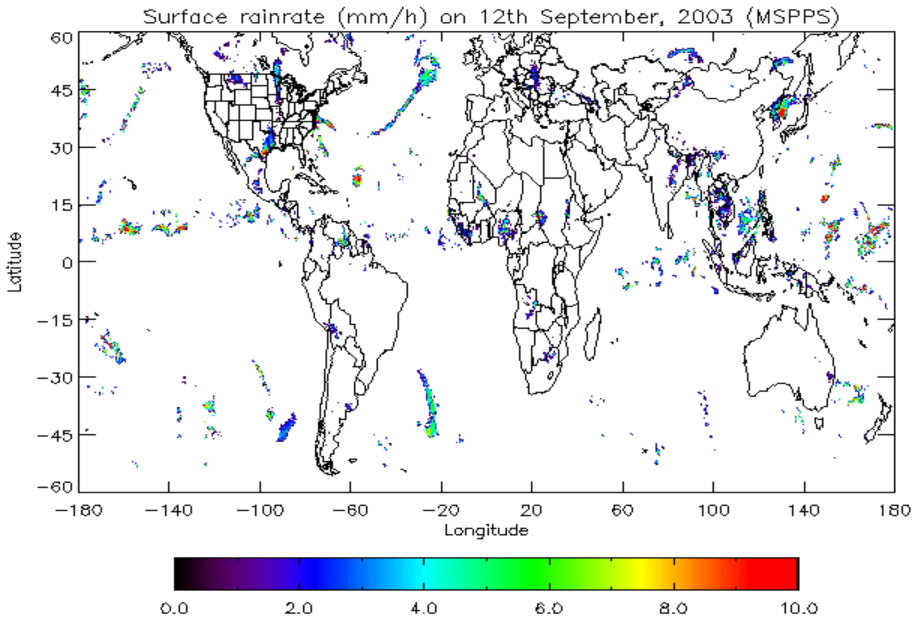


Cloud Liquid Water (MIRS vs. MSPPS)

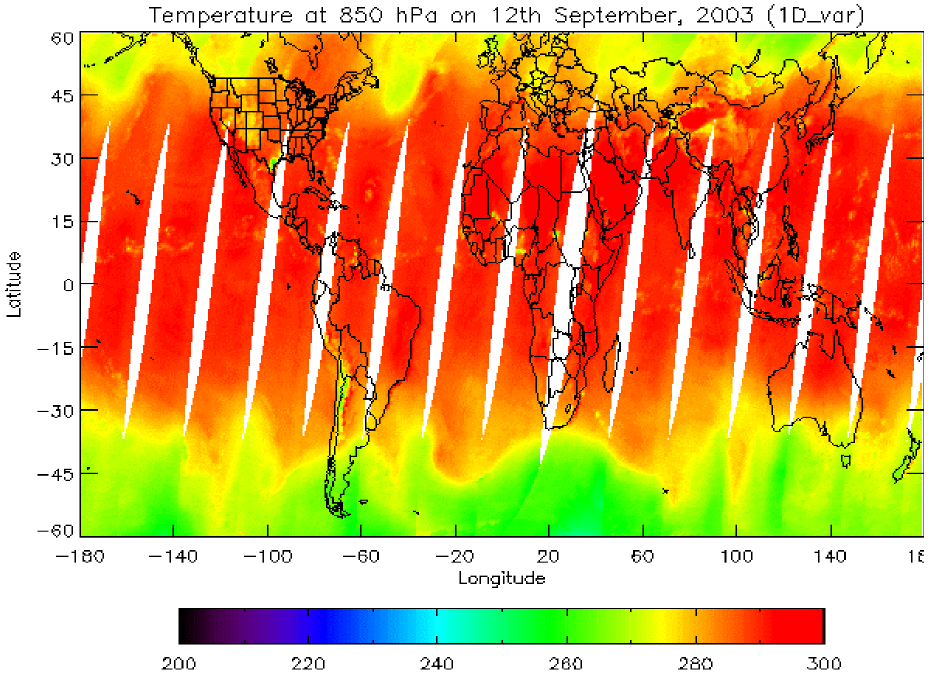


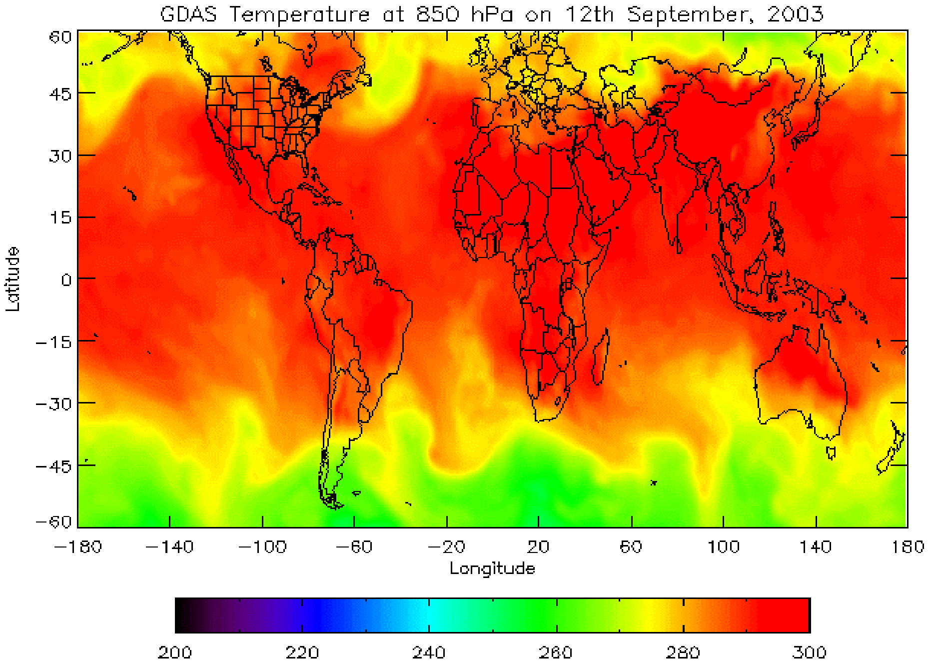
Precipitation (MIRS vs. MSPPS)



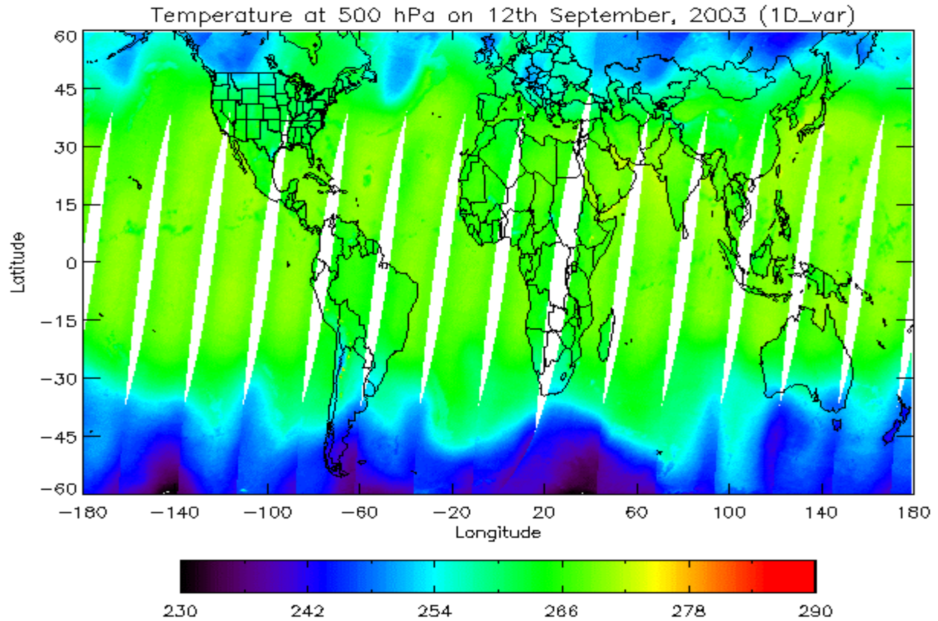


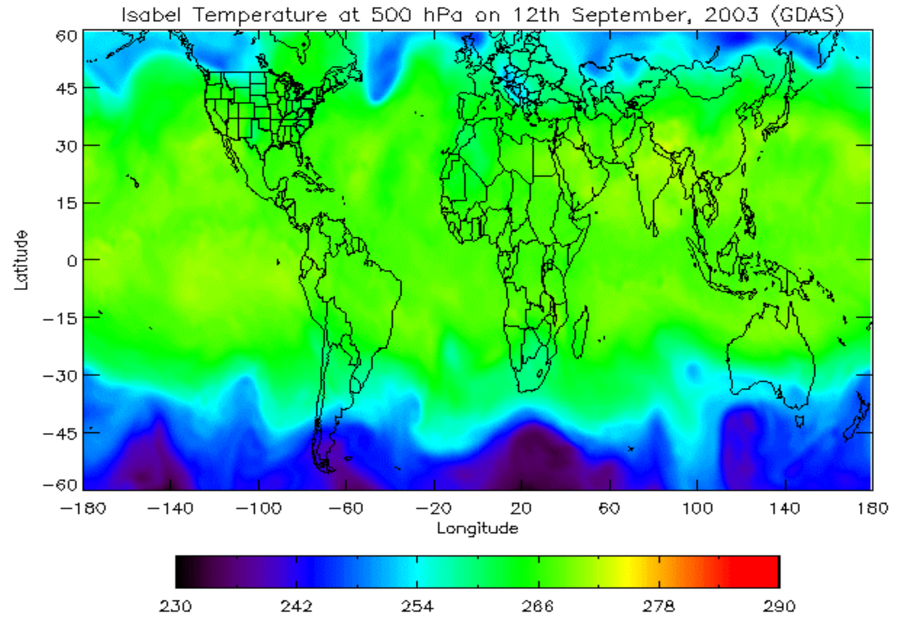
Temperature at 850 hpa (MIRS vs. GDAS)





Temperature at 500 hpa (MIRS vs. GDAS)





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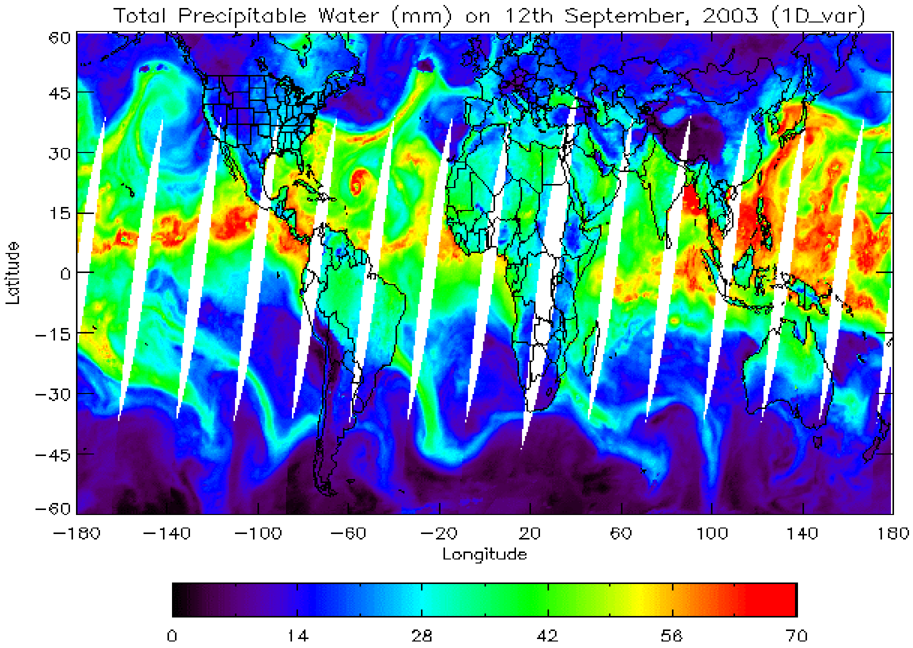
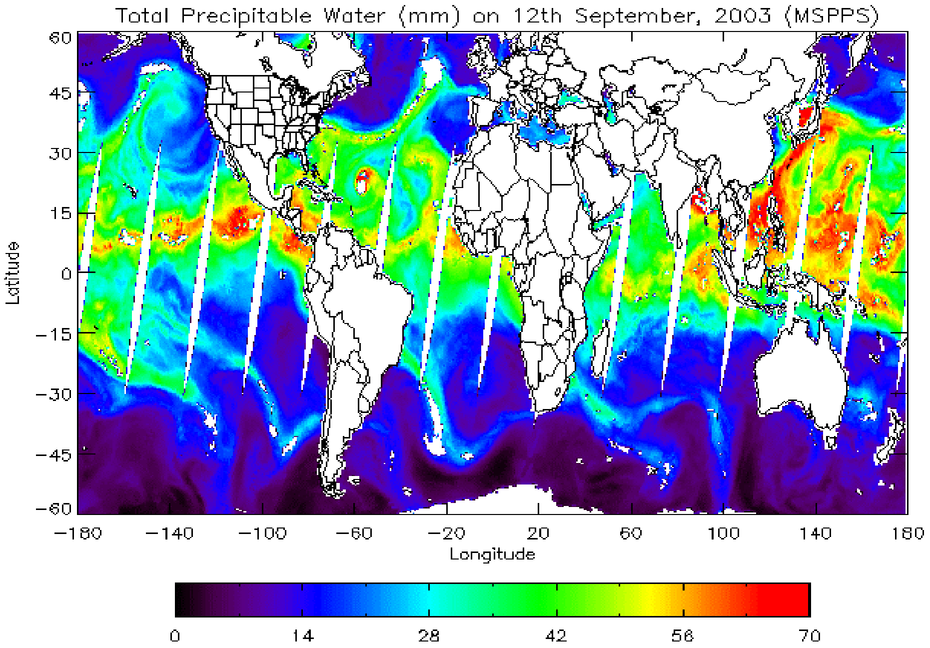
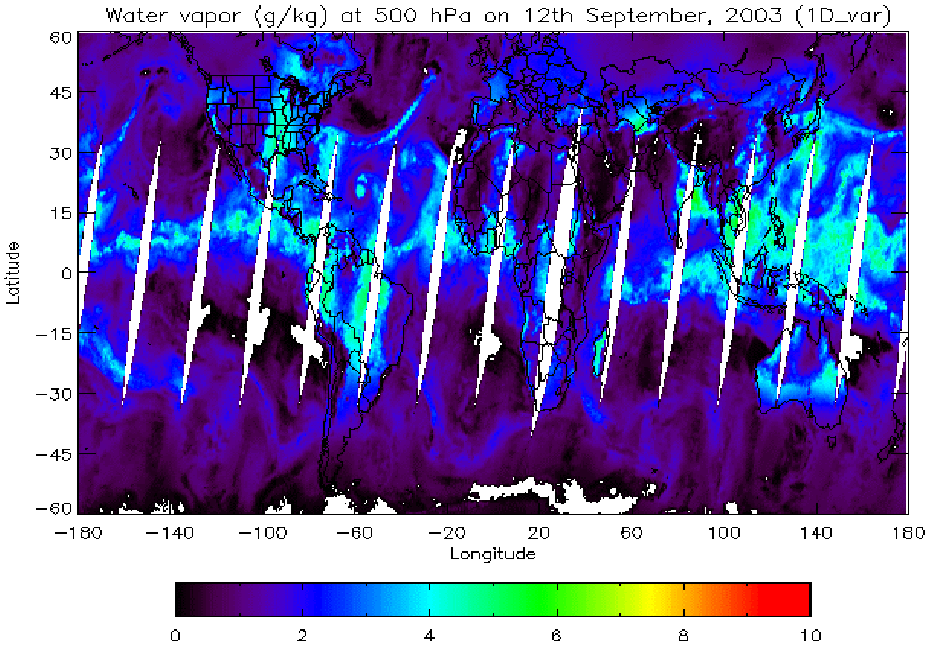
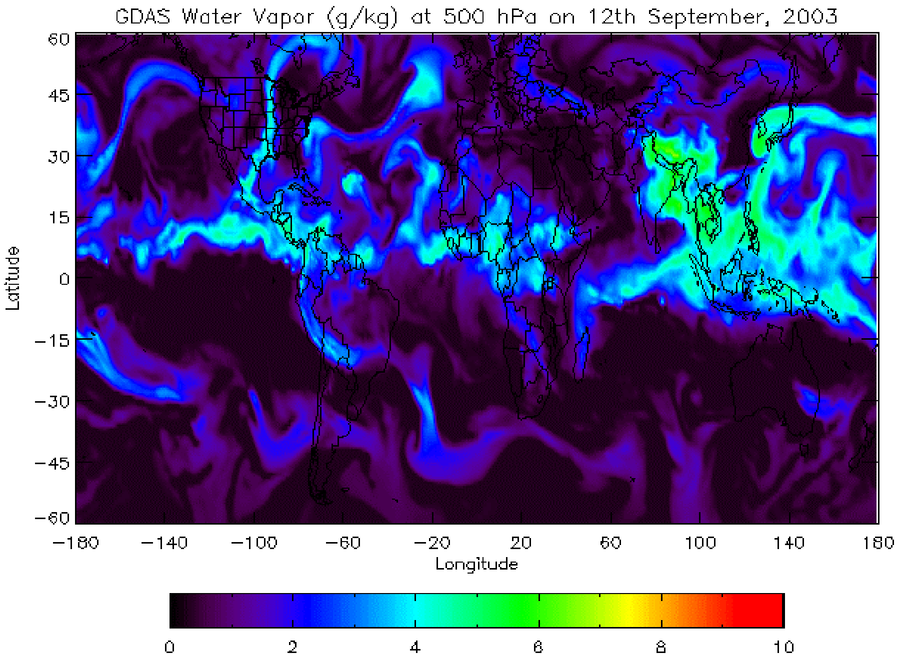
Total Precipitable Water (MIRS vs. MSPPS)





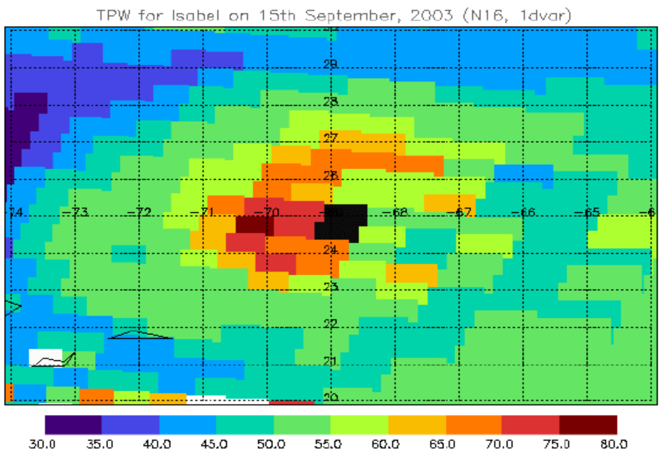
Water Vapor at 500 hPa (MIRS vs. GDAS)



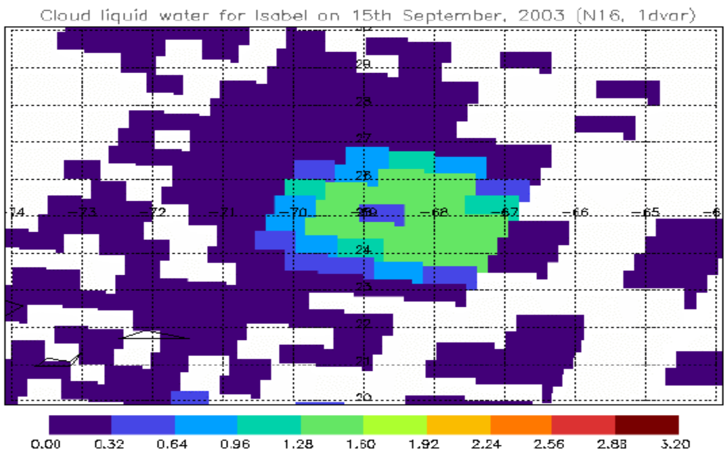


Water Vapor, Cloud Water and Rain Rate

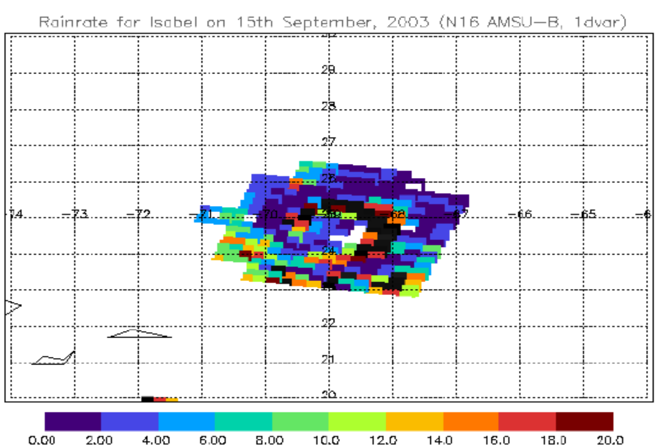
TPW



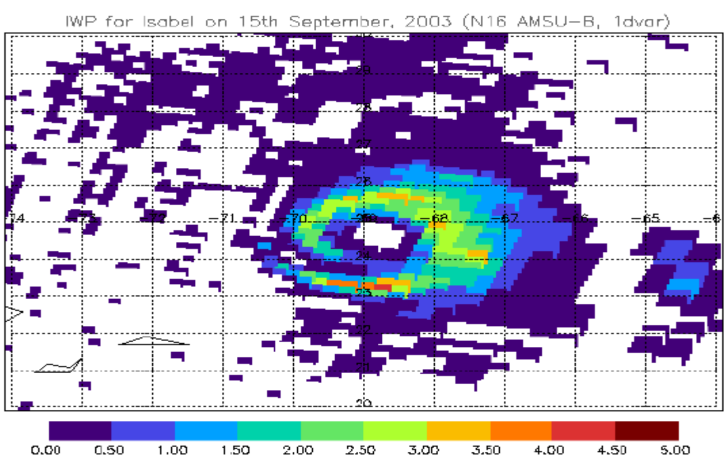
CLW



Rain Rate



IWP



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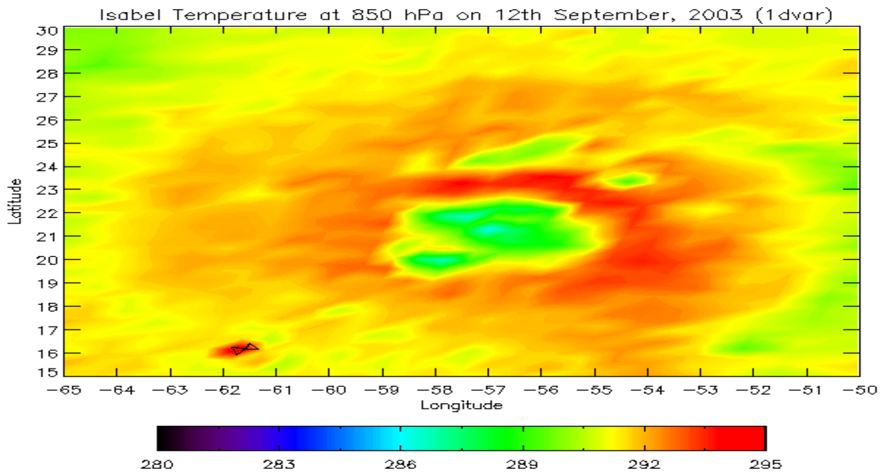
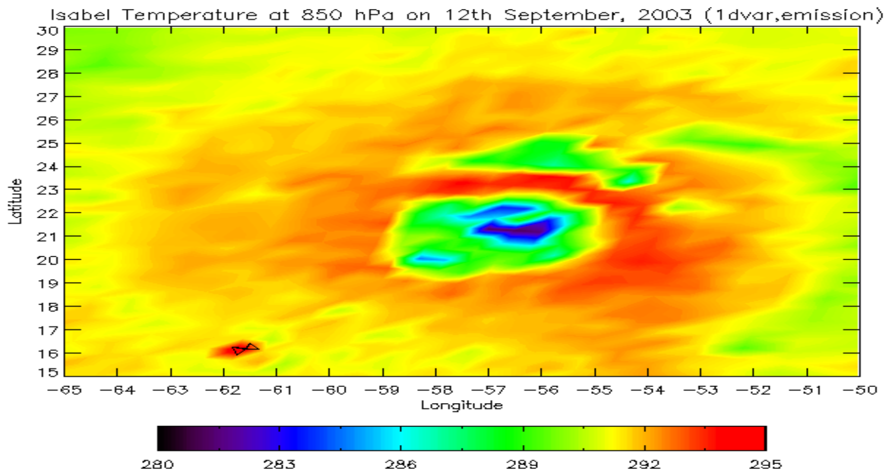
Impacts of Forward Models

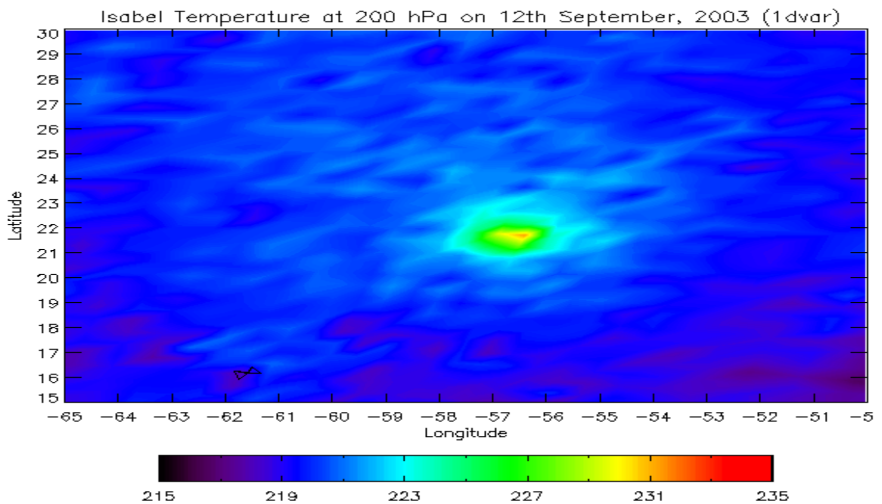
T(850hPa) – Scattering



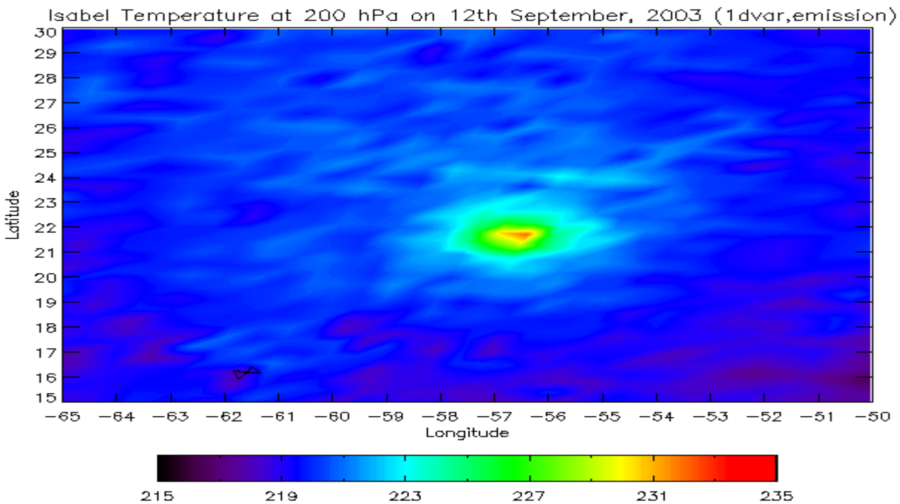
T(850hPa) – Emission only



T(200hPa) – Scattering

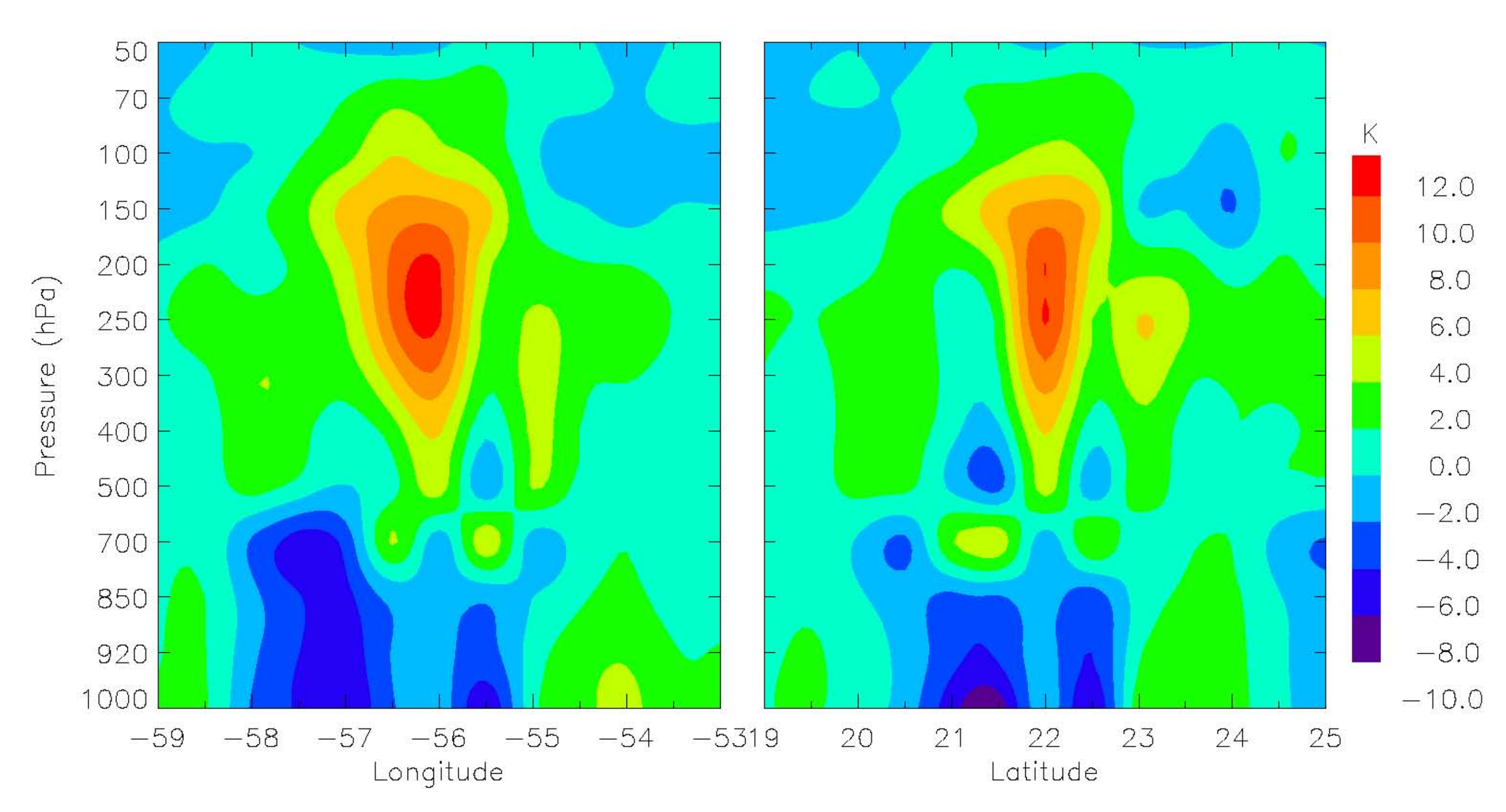


T(200hPa) – Emission only



Temperature Anomaly

With Cloud/Precipitation Scattering

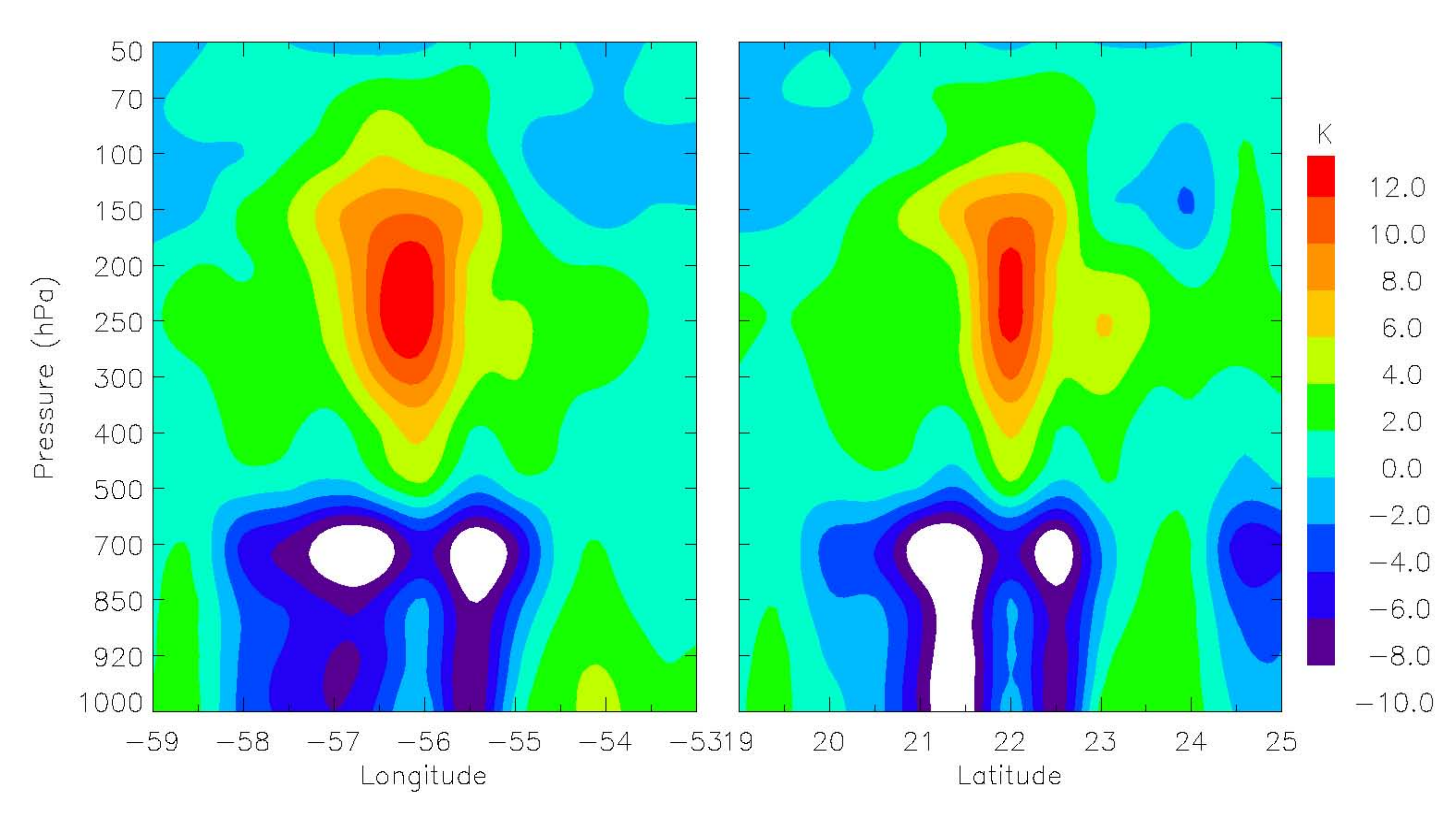


Vertical cross section of temperature anomalies at 06:00 UTC 09/12/2003. Left panel: west-east cross section along 22°N, and right panel: south-north cross section along 56°W for Hurricane Isabel

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

Temperature Anomaly

Without Cloud/Precipitation Scattering



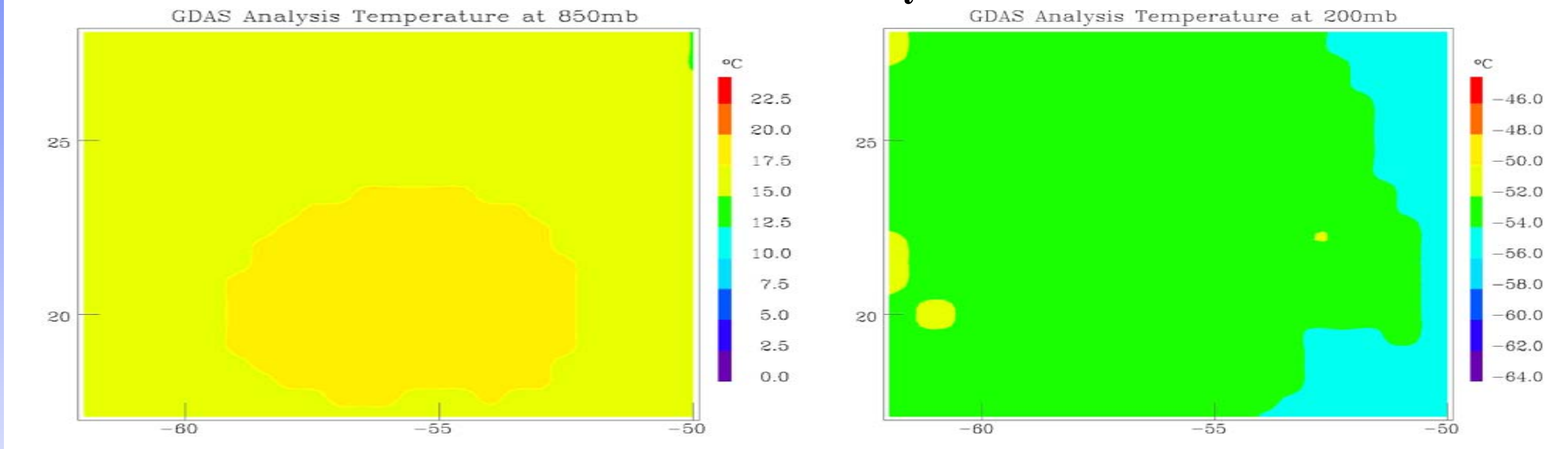
Vertical cross section of temperature anomalies at 06:00 UTC 09/12/2003. Left panel: west-east cross section along 22°N, and right panel: south-north cross section along 56°W for Hurricane Isabel

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

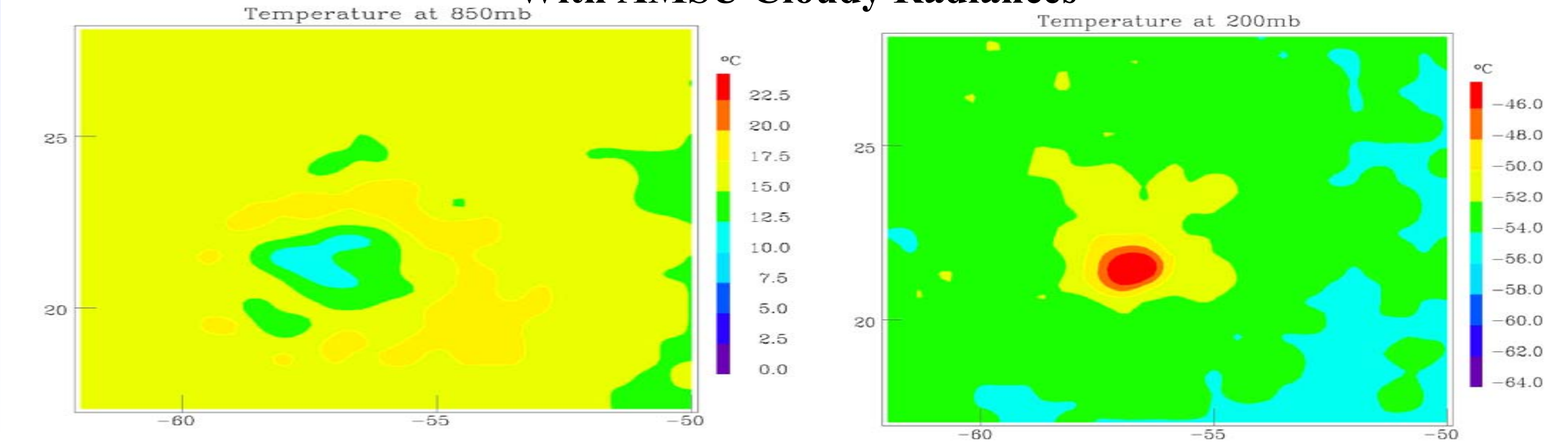
Improved 3DVAR Analysis with AMSU

National Environmental Satellite, Data, and Information Service

Without AMSU Cloudy Radiances



With AMSU Cloudy Radiances



Summary and Conclusions

- 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

- 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