Clouds and precipitation data in the Joint Center for Satellite Data Assimilation

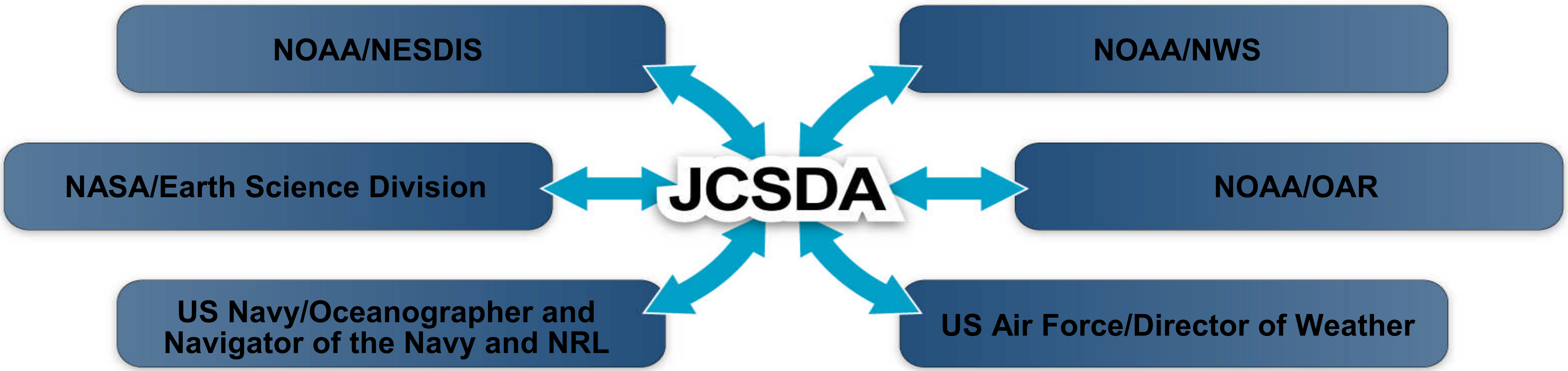
Lars Peter Riishojgaard, JCSDA

Input from Sid Boukabara, Steve Lord, Michele Rienecker, John Zapotocny, John Eylander, Simon Chang, Fuzhong Weng, Quanhua Liu, Jim Jung, Min-Jeong Kim, Xiang-Yu Wang, Tom Auligne, Emily Liu, Gary Gustafson,…

Overview

- Introduction to JCSDA
- Clouds and precipitation-related assimilation efforts in the Joint Center
- Summary

JCSDA Partners, Vision, Mission



Vision:

An interagency partnership working to become a world leader in applying satellite data and research to operational goals in environmental analysis and prediction

Mission:

…to accelerate and improve the quantitative use of research and operational satellite data in weather, ocean, climate and environmental analysis and prediction models.

JCSDA Science Priorities

Overarching goal: Help the operational services improve the quality of their prediction products via improved and accelerated use of satellite data and related research

- Radiative Transfer Modeling (CRTM)
- Preparation for assimilation of data from new instruments
- **Clouds and precipitation**
- Assimilation of land surface observations
- Assimilation of ocean surface observations
- Atmospheric composition; chemistry and aerosol

Driving the activities of the Joint Center since 2001, approved by the Science Steering Committee

JCSDA Mode of operation

- Directed research
  - Carried out by the partners
  - Mixture of new and leveraged funding
  - JCSDA plays a coordinating role
- External research
  - Grants awarded following proposals submitted to Federal Funding Opportunity, administered by NOAA on behalf of all JCSDA partners
    - Option for contracts will be added for FY2011 with help from NASA
  - Open to the broader research community
  - Funding awarded competitively, peer review process
- Visiting Scientist program

JCSDA accomplishments

- Common assimilation infrastructure (EMC, GMAO, AFWA)
- Community radiative transfer model (all partners)
- Common NOAA/NASA land data assimilation system (EMC, GSFC, AFWA)
- Numerous new satellite data assimilated operationally, e.g. MODIS (winds and AOD), AIRS and IASI hyperspectral IR radiances, GPSRO sensors (COSMIC, GRAS, GRACE), SSMI/S, Windsat, Jason-2,…
- Advanced sensors tested for operational readiness, e.g. ASCAT, MLS, SEVIRI (radiances),…
- Ongoing methodology improvement for sensors already assimilated, e.g. AIRS, GPSRO, SSMI/S,…
- Improved physically based SST analysis
- Adjoint sensitivity diagnostics
- Emerging OSSE capability in support of COSMIC-2, JPSS, GOES-R, Decadal Survey and other missions

Clouds and precipitation in JCSDA

- Why are we interested in this?
  - Often, information about clouds and precipitation is what NWP end users need the most
    - Not areas where NWP systems shine
  - Difficult, and strongly non-linear modeling/physical parameterizations
  - Most (if not all) types of satellite data are affected by one or the other

Clouds and precipitation related assimilation efforts in JCSDA

- **EMC (Kim, Jung)**
- **STAR (Boukabara, Kim, Liu, Weng)**
- **GMAO (Liu, McCarty)**
- **AFWA (Eylander, Huang, Auligne, Gustafson)**
- **NRL/Monterey (Baker et al.)**
- OAR (Benjamin et al.)

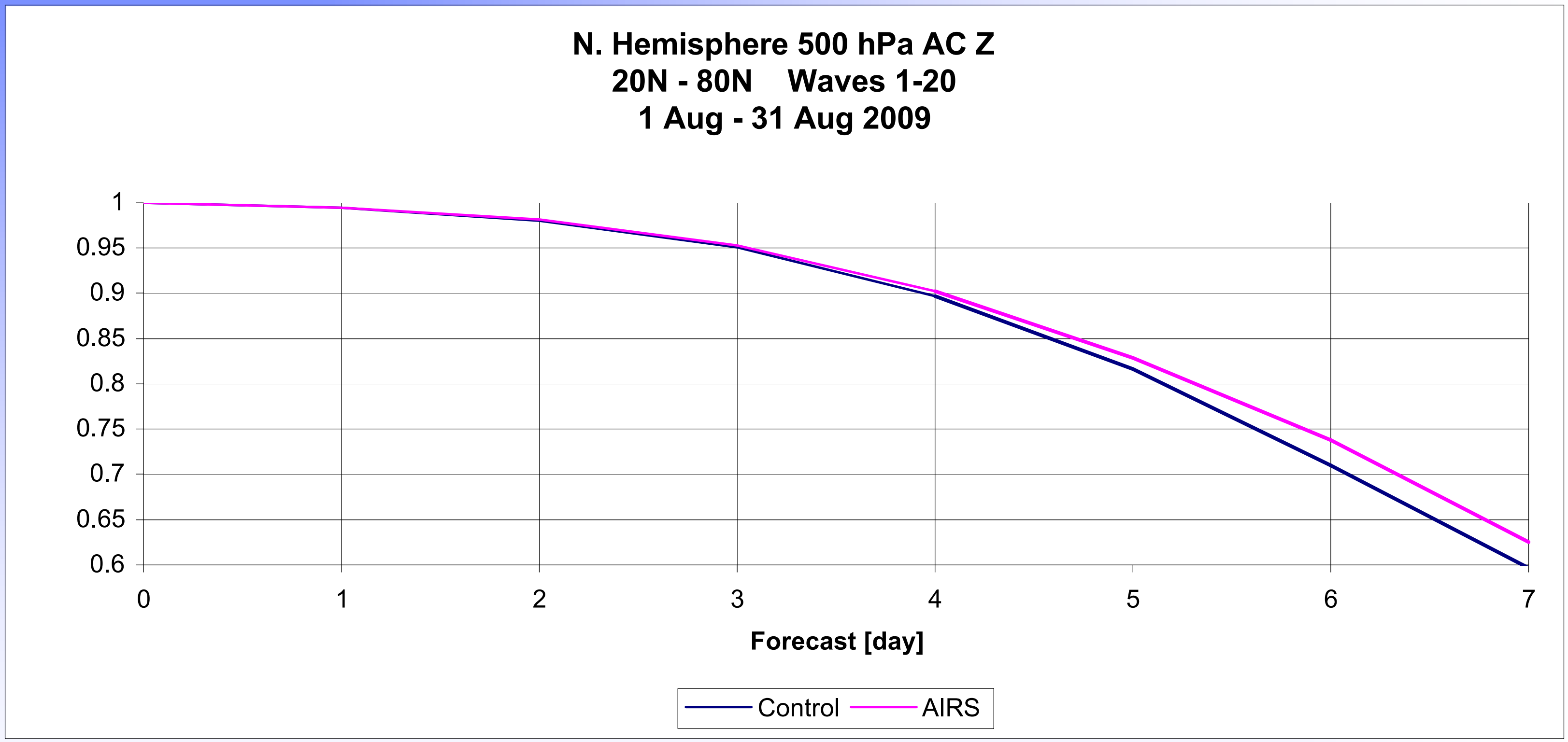
- AER
- CIMSS
- NCAR

AIRS Data Assimilation using cloudy fields of view with NCEP/EMC's GFS

- Motivated primarily by drive toward better data coverage, including areas of potential meteorological significance
- Assimilate radiances from cloudy FOVs preferably with single level cloud.
- (Follow-on to 2007 experiments by Le Marshall and Jung)
- Initially use radiances where cloud coverage and uniformity of FOVs allow accurate estimation of radiances from clear portion
- Compare impact on forecast skill of NCEP GFS with that of clear radiances from identical channel set (~140 channels)
- Compare impact of expanded (~220) set of cloud-cleared channels with that of basic clear set

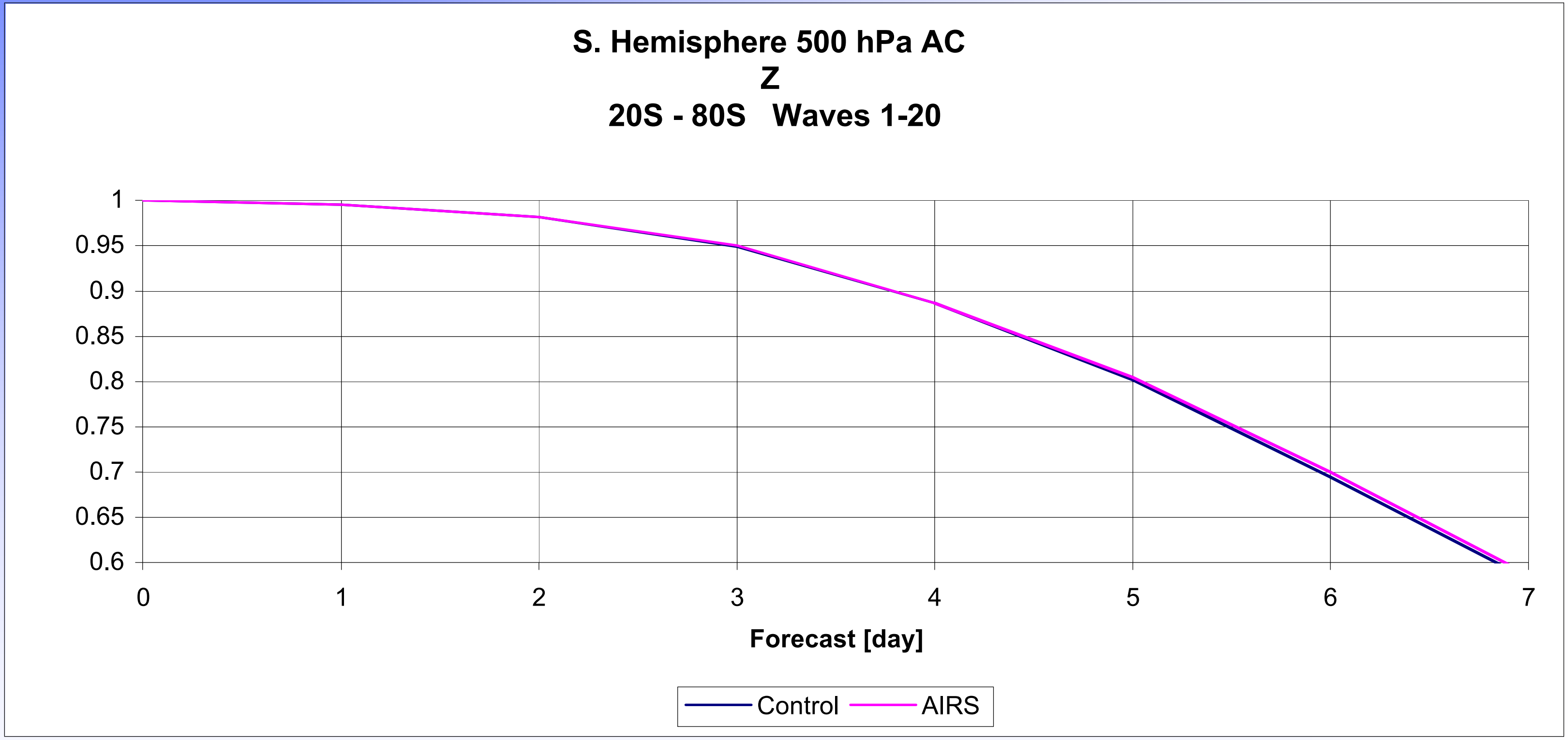
Susskind, J., C.D. Barnet and J.M. Blaisdell 2003. Retrieval of atmospheric and surface parameters from AIRS/AMSU/HSB data in the presence of clouds. IEEE Trans. Geosci. Remote Sens., 41, 390-409.

NH skill score, August 2009, clear vs. cloudy, 140 channels

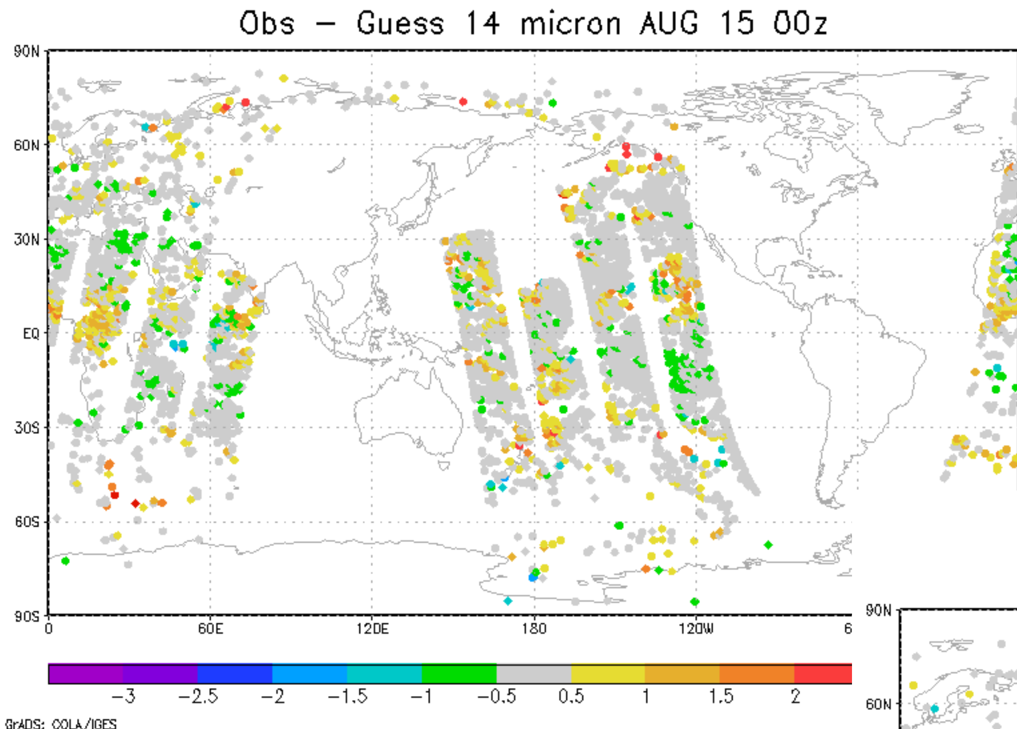


Slide by Jim Jung

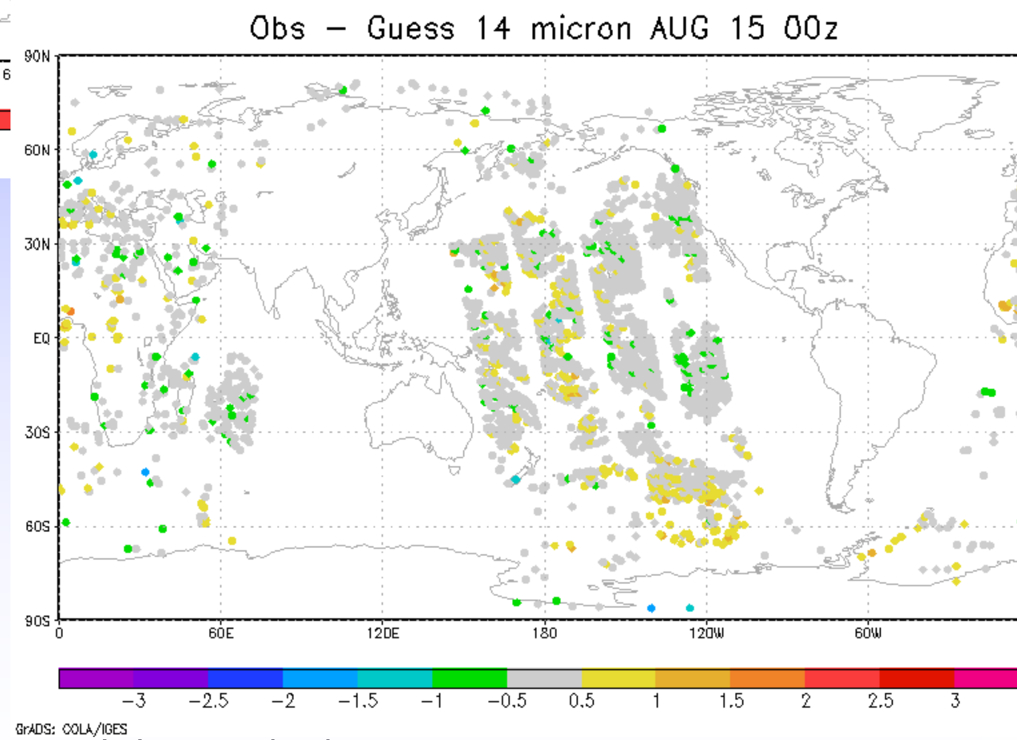
SH skill score, August 2009, clear vs. cloudy, 140 channels



Slide by Jim Jung



Sample data coverage, cloud-cleared radiances



Sample data coverage, clear radiances

Current Setup for TMI Retrieved Rainrate Assimiation in Operational GSI

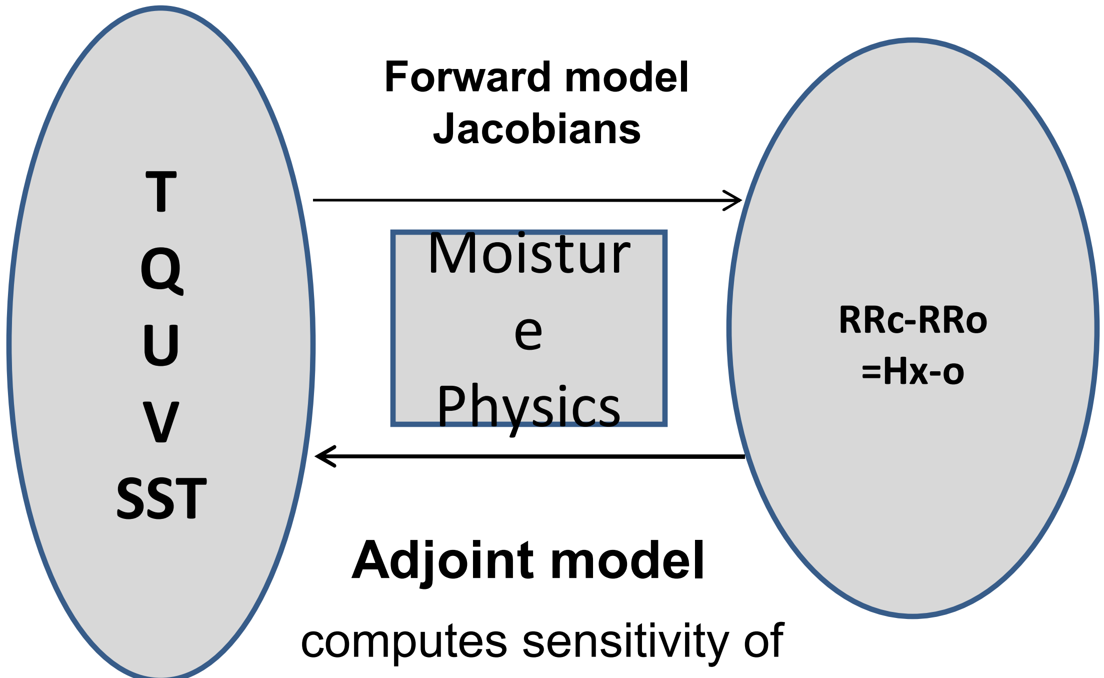
- TMI "SURFACE" rainrates are currently being assimilated in GDAS.
- Data resolution : 1°×1°

- Observation error = 0.137+0.118*log (1+RR) : ocean
  0.3148+0.1781*log(1+RR) : land

- Observation errors are inflated depending on
  (1) surface type
  (2) magnitude of adjoint sensitivities,
  (3) smoothness of adjoint sensitivity profile,
  (4) difference between analysis time and overpass time, etc ..

Forward and Adjoint Models for Moisture Physics

$$\frac{\partial \mathbf{J}}{\partial \mathbf{x}} = \mathbf{B}^{-1}\mathbf{x} + \mathbf{H}^{\mathrm{T}}\mathbf{O}^{-1}(\mathbf{Hx} - \mathbf{o})$$



computes sensitivity of analysis variables to surface rainrate changes

$$\frac{\partial\ RR}{\partial\ T},\ \frac{\partial\ RR}{\partial\ q},\ \frac{\partial\ RR}{\partial\ CW},\ \cdots$$

Slide by Min-Jeong Kim

Assimilation of TMI Retrieved Rainrates

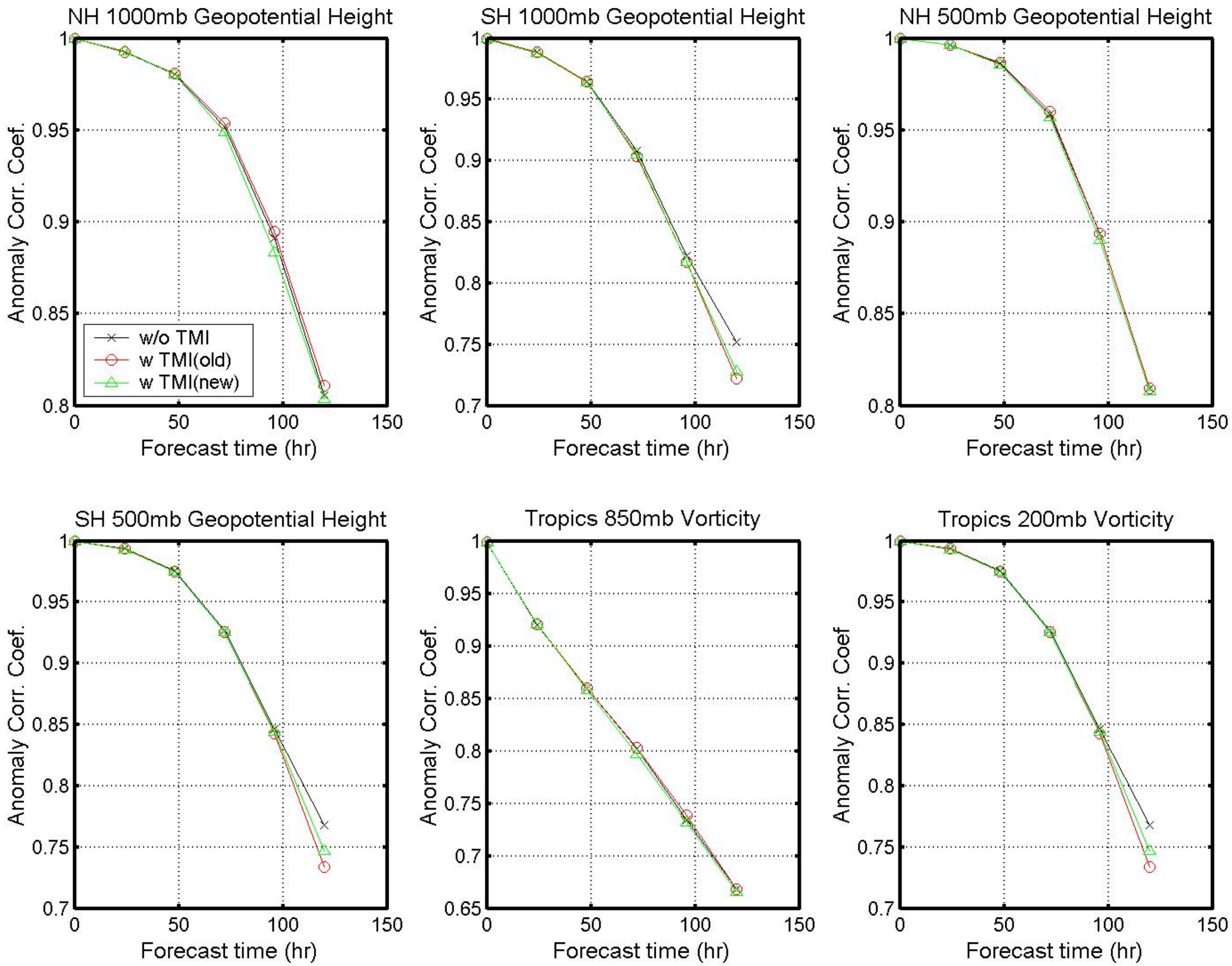
- From the first trial, I found 90% of TMI rainrate observations are not being assimilated with old or new moisture models.

- In addition to the QC criteria, the major reason is that the sensitivities of T, Q, and CW come out to be zero for most of cases. That is, even though the observation is "rainy", if the first guess field doesn't generate rain, the TMI observations are tossed.

Currently in operation

	Obs (rainy)	Obs (not rainy)
First guess (rainy)	O	X
First guess (not rainy)	X	X

Experiments for TMI Rainrate Assimilation



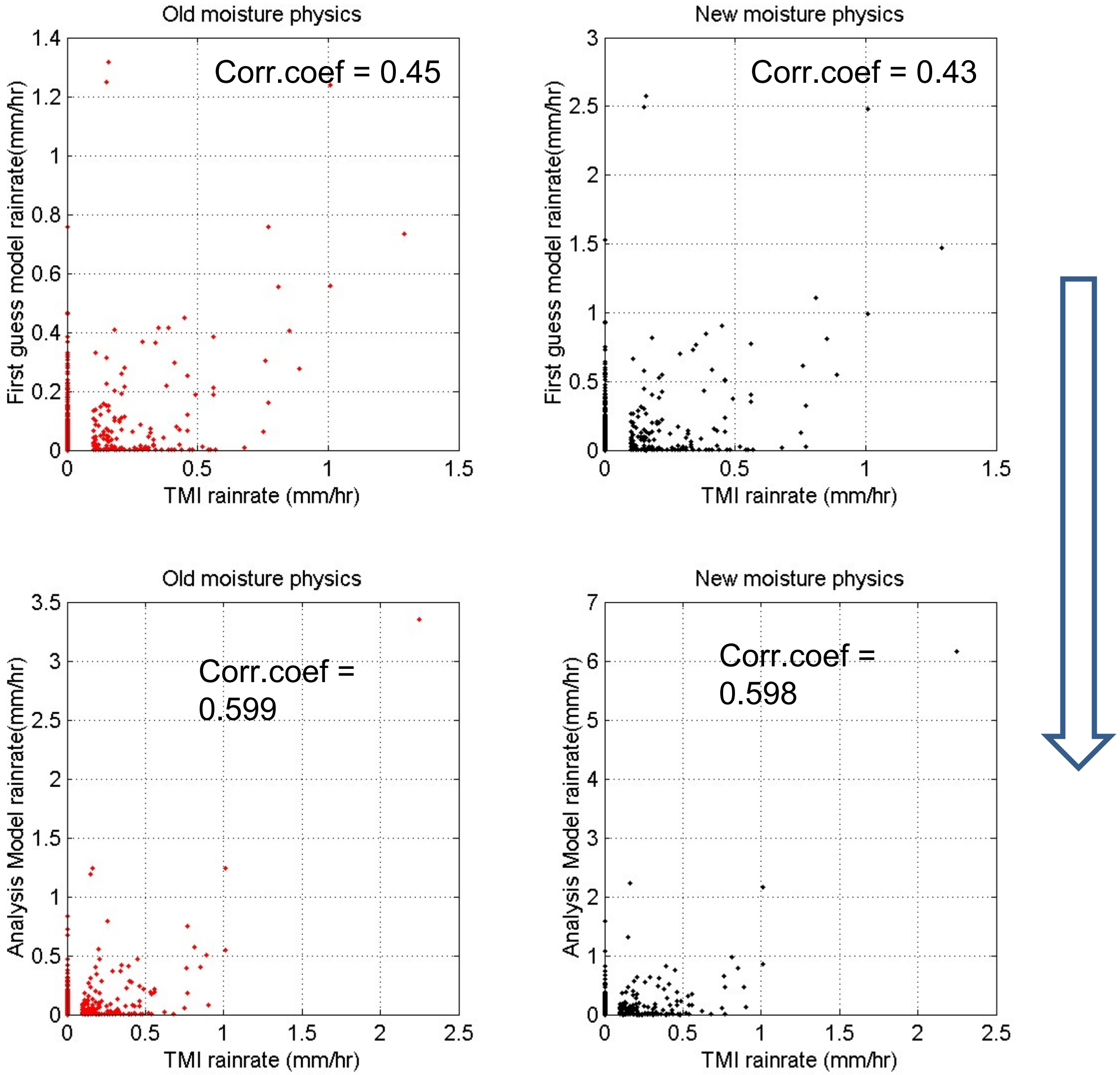
Impact study results show that TMI surface rain rates do not make significant impacts on the current GDAS analysis.

Slide by Min-Jeong Kim

Experiments for TMI Rainrate Assimilation

1st outer loop

After finishing 2nd outer loop



Model surface rain rates changing in the right direction

MiRS Mathematical Concept

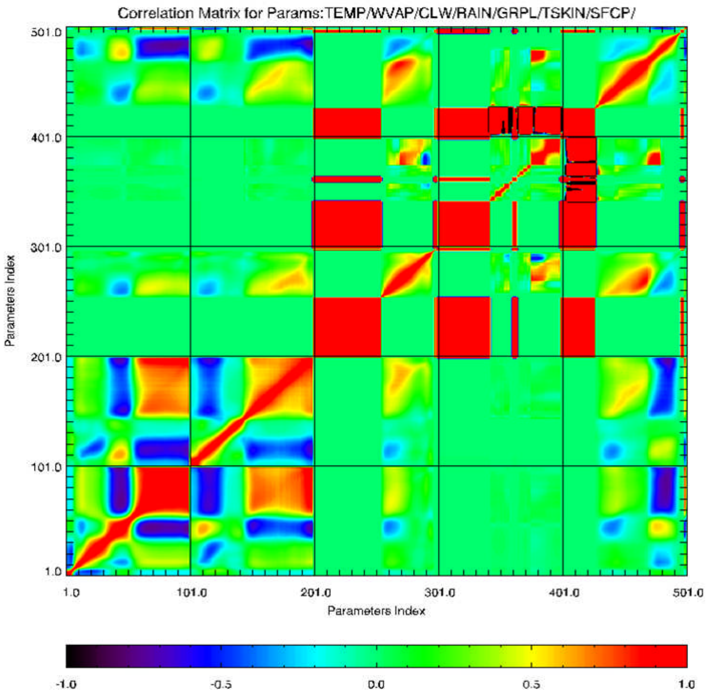
Boukabara et al.

- **A 1DVAR System (MiRS) has been developed by NOAA/NESDIS that has the following characteristics:**
  - Minimizes a Cost Function similar to NWP:

$$J(X)=\left[\frac{1}{2}(X-X_0)^T\times B^{-1}\times(X-X_0)\right]+\left[\frac{1}{2}(Y^m-Y(X))^T\times E^{-1}\times(Y^m-Y(X))\right]$$

  - Uses CRTM as a forward Model for TB and Jacobians (all-weather conditions)
  - Handles cloud/rain/ice- impacted radiances by including them in the state vector (cloud, rain and ice profiles are control variables)
  - No use of a cloud-resolving model
  - Handles emissivity dynamically (all-surfaces applications)
  - The Rainfall Rate is a by-product of the hydrometeors retrieved by the 1DVAR
  - Runs operationally for Metop-A, NOAA-18,19 and DMSP F16/F18

Correlation Matrix used in MiRS



Features:
- Applicability over all surfaces
- Rainfall rate is a by-product of the hydrometeors

Is the retrieval stable?
- EOF decomposition for all profiles (T, Q, C, R, I) and emissivity vector.

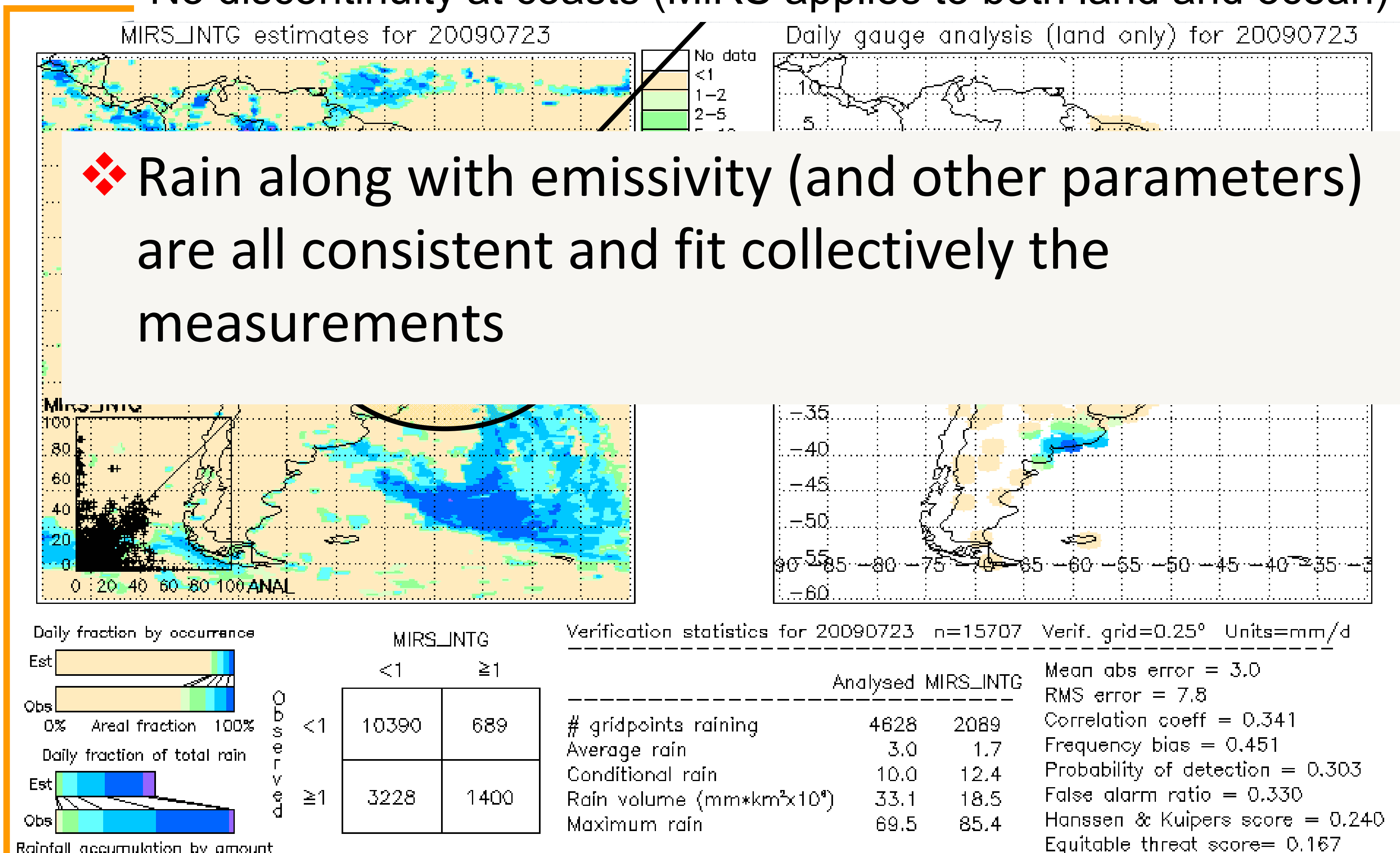
Is the solution physically consistent? (between T, Q, C, R and I)
-Cov Matrix constraint
-Physical Retrieval & RT constraints
-Convergence (fitting Ym)
-Jacobians to determine signals

Assessment of the Cloudy/Rainy Radiance Handling:

Added Value of Emissivity Handling:

Same RR algorithm Over Both Ocean and Land

No discontinuity at coasts (MiRS applies to both land and ocean)



- Rain along with emissivity (and other parameters) are all consistent and fit collectively the measurements

r

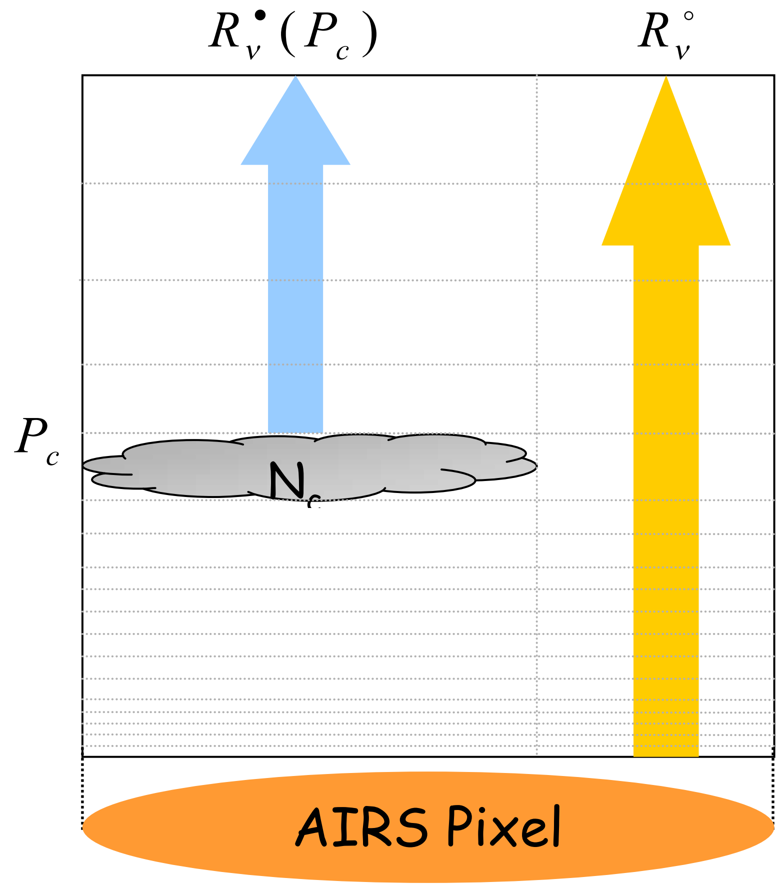
Image taken from IPWG web site: credit to Danie

Goals

- Use Lidar and Radar measurements as guidance for comparing cloud top heights (CTHs) retrieved from IR instruments using various cloud detection schemes
- Study the potential for using cloud parameters retrieved from the cloud detection scheme as first-guess cloud parameters for assimilating cloudy radiances in the variational analysis system.

Cloud Detection in GSI

- Minimum residual method (Eyre and Menzel 1989, JAM)
- Assumptions:
  - One single layer of cloud with emissivity equal to one
  - Clouds has the same temperature as the layer they are in
- Additional constraints:
  - $0 \le N_c \le 1$
  - Pc > pressure at the tropopause
- Given the N_c and P_c, all channels which would produce a change in the brightness temperature greater than a threshold are eliminated

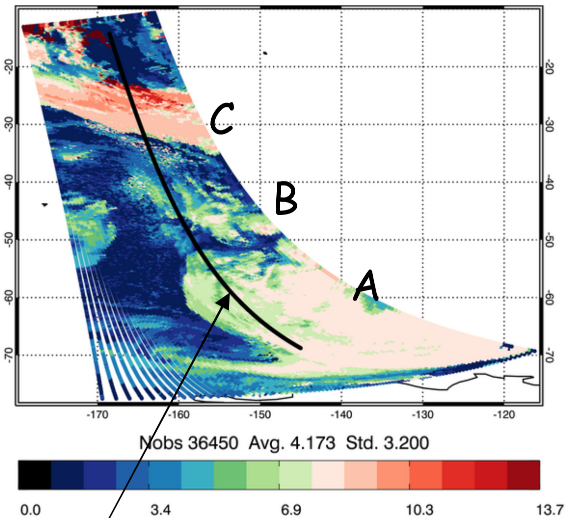


$$J(N_c, P_c) = \sum_v \left(\frac{R_v^{cld} - R_v^{obs}}{\sigma_v} \right)^2$$

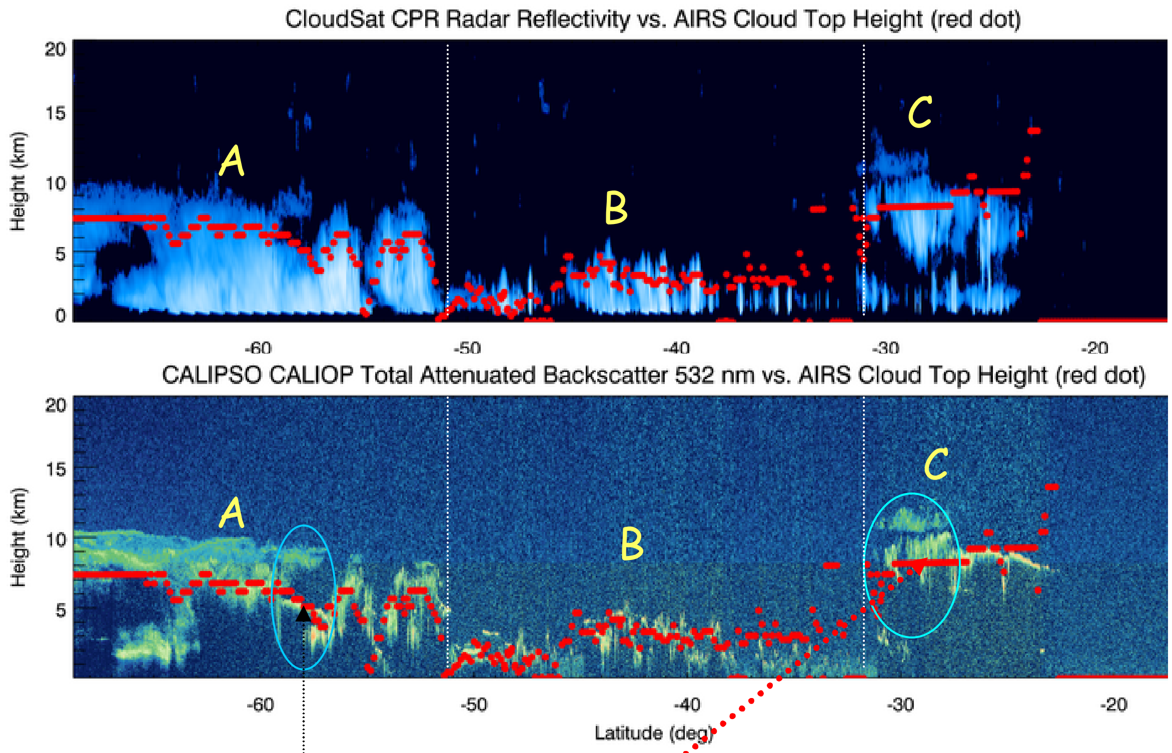
$$R_v^{cld}(N_c, P_c) = (1 - N_c) R_v^{\circ} + N_c R_v^{\bullet}(P_c)$$

CloudSat and CALIPSO are being used to evaluate and improve the NCEP/GMAO GSI cloud detection algorithm for AIRS

GSI retrieved cloud top height (CTH) from AIRS



CloudSat/CALIPSO track

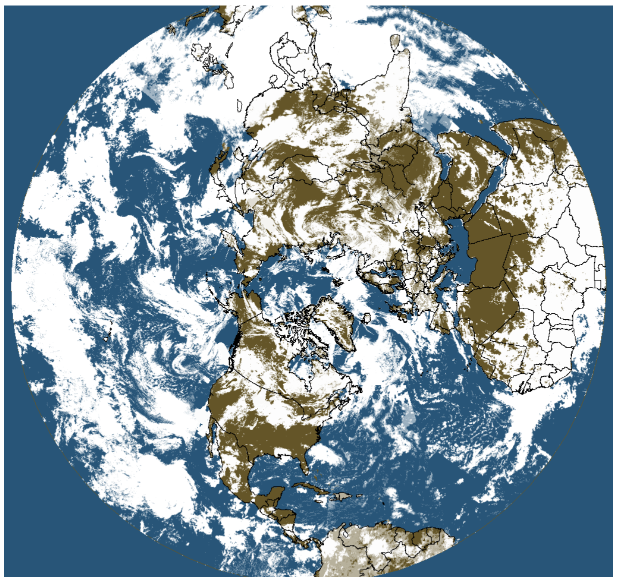


- Due to large differences in footprint size between AIRS and CPR/CALIOP, the CTH validation is done only in regions A and C where the clouds are more uniform.
- In general, GSI-retrieved CTHs from AIRS are underestimated for optically thick clouds.
- Difficulties are seen in retrieving CTH in multi-layer clouds.

Emily Liu, GMAO

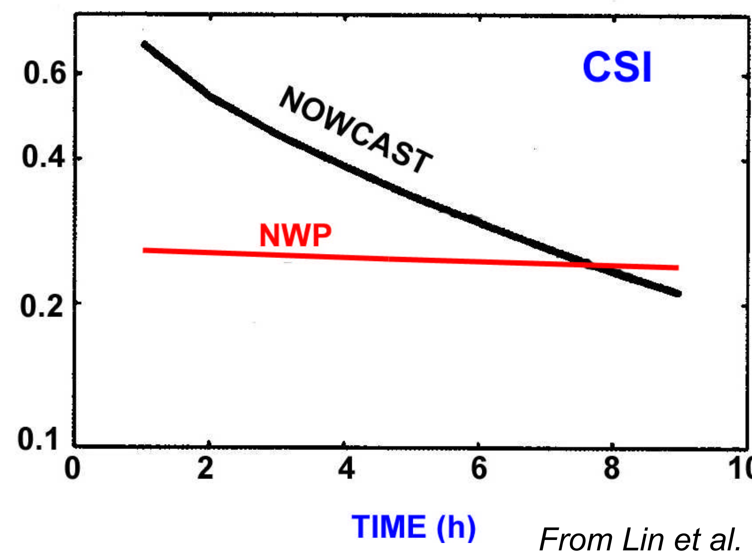
AFWA Coupled Analysis and Prediction System (ACAPS)

World-
Wide
Merged
Cloud
Analysis



(AFWA current operational system)

0.1 mm hourly precipitation skill scores over 21 days

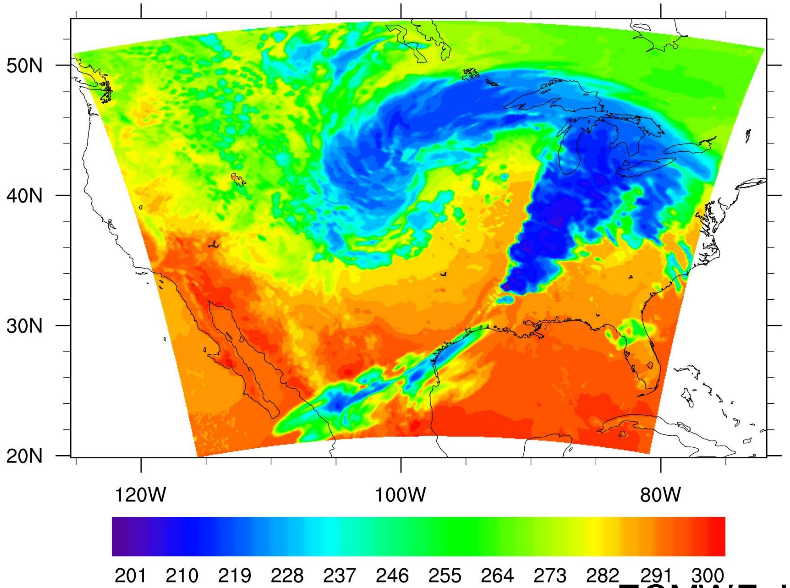


From Lin et al. (2005)

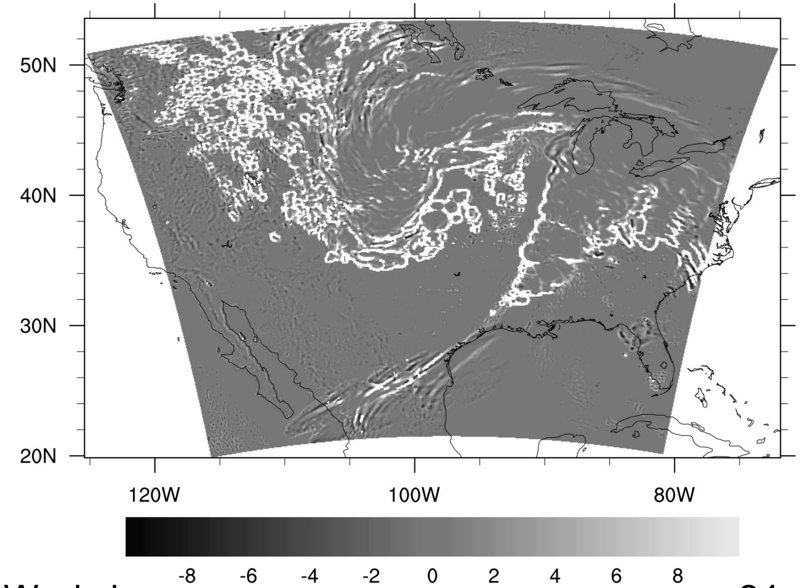
SCOPE: *Develop an analysis and prediction system of 3D cloud properties combined with the dynamical variables.*

Highlights from ACAPS 2009

- International Workshop on Cloud Analysis in Boulder, CO
- Simple (warm-rain) microphysics in WRF TL/AD model
- Wavelet formulation for Background Error Covariances
- 1DVar and 3DVar simulated satellite cloudy/rainy (IR and MW) radiances DA experiments



Simulated AIRS window channel



Simulated representativeness error

Atmospheric and Environmental Research, Inc.

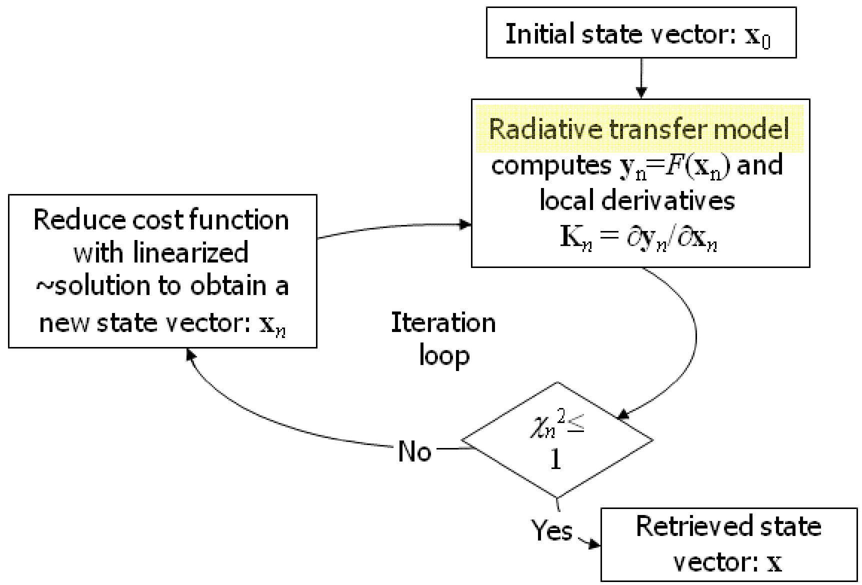
Application of 1DVAR methodology to retrieval of cirrus cloud properties

- **Variational technique adapted to retrieval of cloud properties from infrared MODIS imager data**
- **Oriented toward global, real-time production of cloud products and data assimilation**
- **Variational framework ensures radiometric consistency between retrieved cloud properties**
  - **Facilitates conversion between retrieved microphysical properties and optical properties**
- **1DVAR Framework compatible with transition to four-dimensional assimilation systems**
  - **Either as a pre-processor or toward inclusion of cloud properties among the assimilation control variables**

- **Optimal match of radiances to cloud properties achieved by minimizing cost function**

$$J(\mathbf{x}) = \underbrace{\left(\mathbf{y}^m - \mathbf{y}(x)\right)^T \mathbf{S}_y^{-1} \left(\mathbf{y}^m - \mathbf{y}(x)\right)}_{\text{Match of result to the radiance measurements}} + \underbrace{\left(\mathbf{x} - \mathbf{x}_0\right)^T \mathbf{S}_x^{-1} \left(\mathbf{x} - \mathbf{x}_0\right)}_{\text{Consistency of result with “background” information}}$$

- **Uses Newton iterative method**

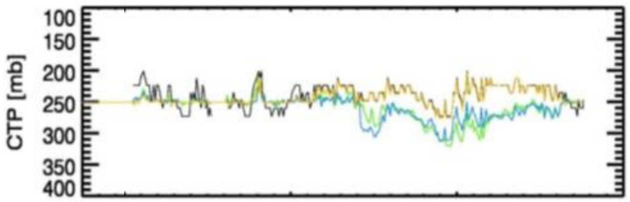


aer Atmospheric and Environmental Research, Inc.

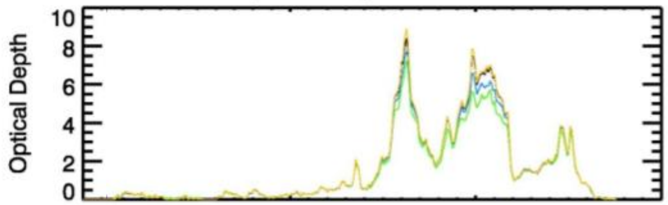
1DVAR summary

- **Initial comparisons with CALIPSO encouraging**

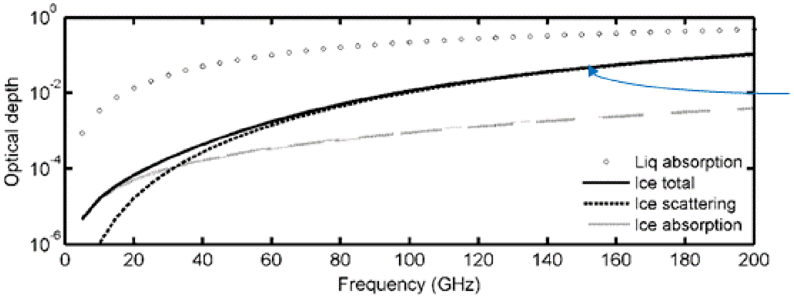
Cloud altitude



Cloud optical depth



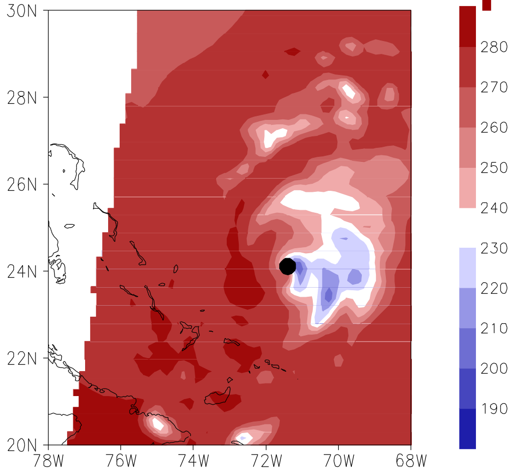
- **Future work: combined microwave/IR retrievals**
  - **Information is complementary**
  - **Microwave ability to detect liquid clouds under ice clouds**
  - **Most ice clouds are largely transparent in the microwave**



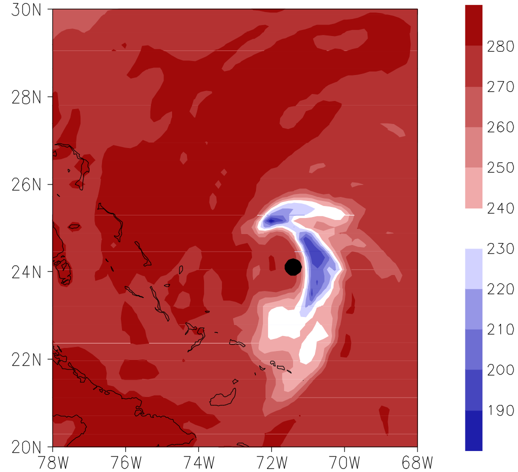
Ice optical depth ~1 order of magnitude less than liquid at 150 GHz, ~2 at 50 GHz

200 g/m² liquid and 100 g/m² ice cloud (spheres D_{me} 100 μm)

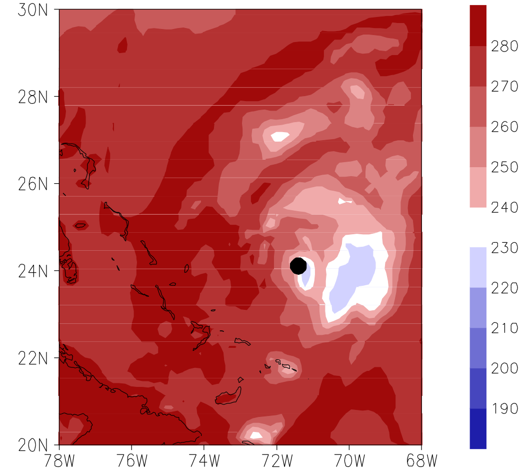
Assimilation of Precipitation Affected Microwave (SSM/I) Radiances with Improved COAMPS® Adjoint Model



<u>Observed</u> SSM/I 85V
Brightness Temperature (K)
12:00 UTC August 23 1998



Brightness Temperature (K)
from Background
RMSE = 11.4 K



Brightness Temperature (K)
from Analysis
RMSE = 5.1 K

1. The brightness temperature from analysis after SSM/I assimilation is much closer to the observations than the background field. RMS error reduced by >50%.
2. The improved COAMPS® adjoint model has been incorporated into COAMPS® 4DVAR for assimilation of storm-related observations from conventional & non-conventional sensors.

Slide by C.Amerault

Summary

- Clouds and precipitation important to NWP
  - Important to end users
  - Modeling and prediction arguably among the most difficult problems in atmospheric science
  - Affects nearly all satellite observations, either as signal or as noise
- JCSDA and its partners has efforts going on in several different directions
- We look forward to the guidance provided by this Workshop