NESDIS Contributions to Joint Center for Satellite Data Assimilation

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Acknowledgements

Radiative Transfer: Fuzhong Weng,Yong Han, Mark Liu, Yong Chen, Banghua Yan, Tom Kleespies – Radiative transfer scheme, emissivity, precip/cloud/aerosol, field of effects

Impacts Study: Jim Jung, Lidia Cucurull, Li Bi, Banghua Yan, Shobha Kondrgunta – AIRS, IASI, Windsat, ASCAT, COSMIC, SSMIS, GOES AOD

Data Handling: Walter Wolf, Tom King, Greg Krasowski, Ninghai Sun – Data BUFRing on AIRS, IASI, CRIS, OMI, GOME2, Windsat, SSMIS

Advanced Data Assimilation: Min-jeong Kim, Sid Boukabara, Jerry Zhan – TL/Adjoint Moisture Physics, MIRS/1DVAR, Soil moisture EnKF

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NESDIS Focus

1. Community Radiative Transfer Model (CRTM)
2. Data Assimilation Experiments and Impact Studies
3. Techniques to Improve Uses of Satellite Data
4. New Satellite Data for NWP Community
5. Exploratory Studies for Future Instrumentation

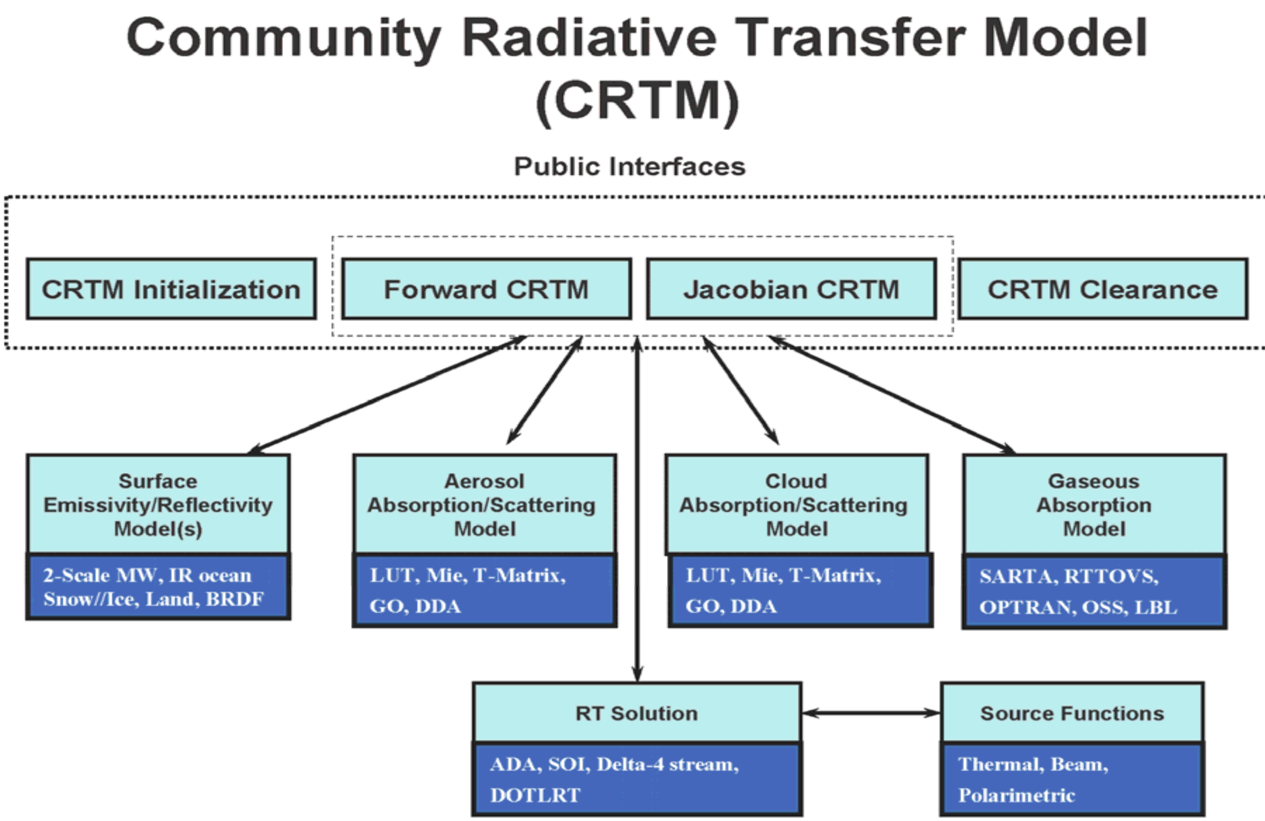
1. Community Radiative Transfer Model (CRTM)

- **New & Fast Radiative Transfer Schemes**
  - Advanced Doubling & Adding (ADA)
  - Successive Optimal Interpolation (SOI)
- **Transmittance Algorithms**
  - Optical Transmitance (OPTRAN)
  - Optical Depth at Pressure level System (ODPS)
- **New & Improved Spectroscopy and Atmospheric Scattering & Absorption**
  - Zeeman splitting effects
  - SSU absorption coefficients including CO2 cell leaking
  - Aerosol, cloud and precipitation scattering
- **Surface Emissivity/Reflectivity Models**
  - MW emissivity models & data base
  - IR land emissivity model and data base
  - Bidirectional reflectivity models in visible wavelengths

Community Radiative Transfer Model

Support over 100 Sensors

- GOES-R ABI
- Metop IASI/HIRS/AVHRR/AMSU/MI
- TIROS-N to NOAA-18 AVHRR
- TIROS-N to NOAA-18 HIRS
- GOES-8 to 13 Imager channels
- GOES-8 to 13 sounder channel 08
- Terra/Aqua MODIS Channel 1-10
- METEOSAT-SG1 SEVIRI
- Aqua AIRS
- Aqua AMSR-E
- Aqua AMSU-A
- Aqua HSB
- NOAA-15 to 18 AMSU-A
- NOAA-15 to 17 AMSU-B
- NOAA-18 MHS
- TIROS-N to NOAA-14 MSU
- DMSP F13 to15 SSM/I
- DMSP F13,15 SSM/T1
- DMSP F14,15 SSM/T2
- Coriolis Windsat
- TiROS-NOAA-14 SSU
- DMSP F16, F17, F18
- FY3 MWTS, MWHS, IRAS, MWRI



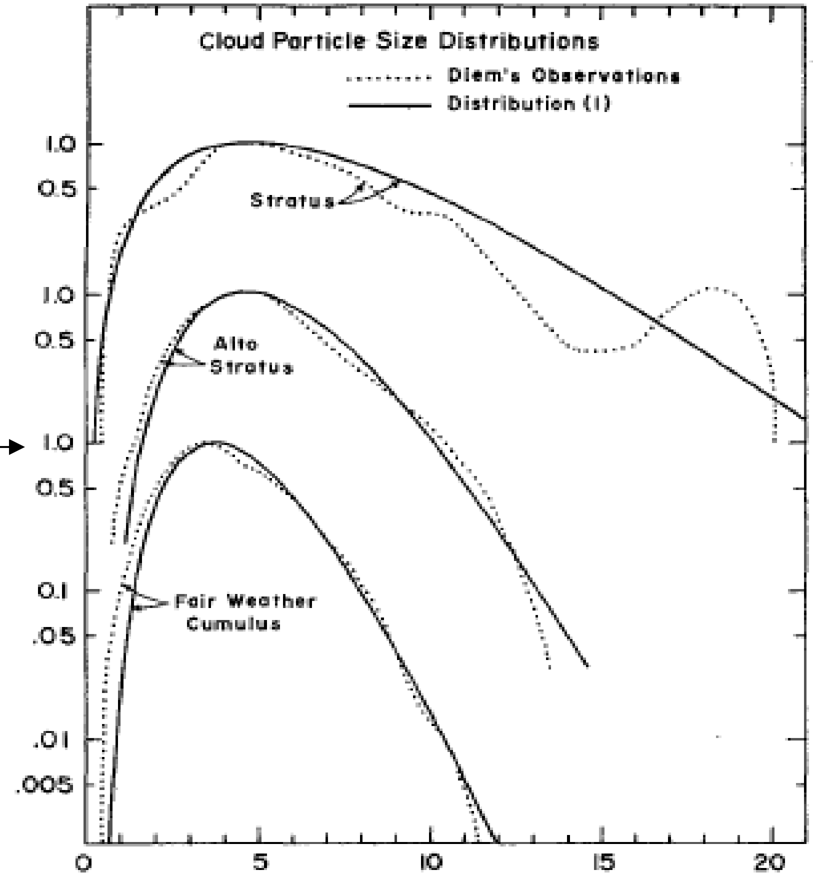
CRTM Team includes core and extended members from all JCSDA partners, universities and other research organizations. STAR/EMC has been leading the developments of CRTM framework and radiative transfer modules, supporting the transition of new science and software into operation

Cloud Particle Size Distribution in CRTM

Gamma size distribution for small particle size:

$$f(r) = \frac{\Gamma(v)}{r_n}(r/r_n)^{v-1} e^{-r/r_n}$$

For rain drops, snow, graupel/hail, Marshall-Palmer size distribution is used



Significance: CRTM including aerosol, clouds and precipitation enables cloudy radiance data assimilation in NWP and supports many other satellite remote sensing applications.

CRTM Ready for NOAA-N’ and DMSP-18 Sensors

- The Community Radiative Transfer Model (CRTM) is ready for the following new satellite sensors:

  AVHRR/3 on NOAA-19

  HIRS/4 on NOAA-19

  AMSUA on NOAA-19

  MHS on NOAA-19

  SSMIS on DMSP-17

  SSMIS on DMSP-18

- Coefficients (SpcCoeff and TauCoeff) for these sensors used in CRTM are now available.

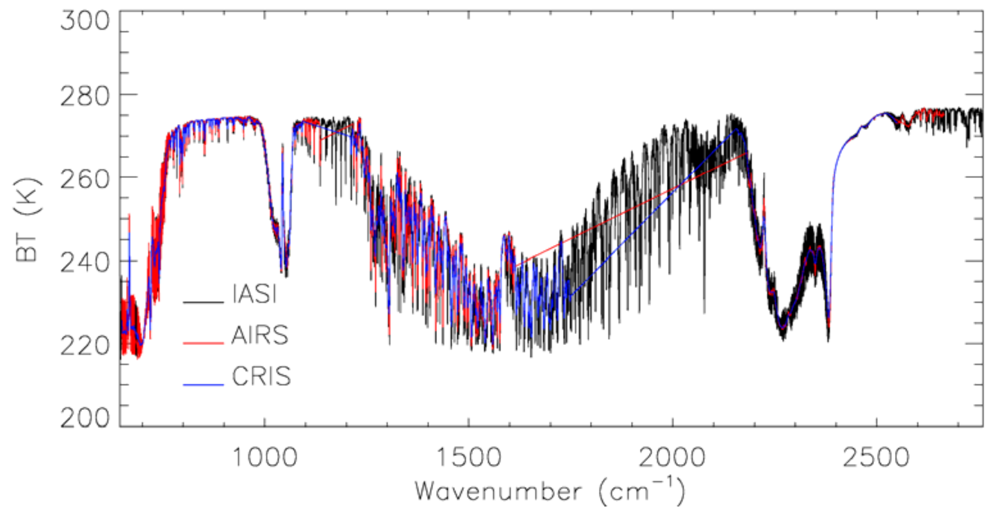


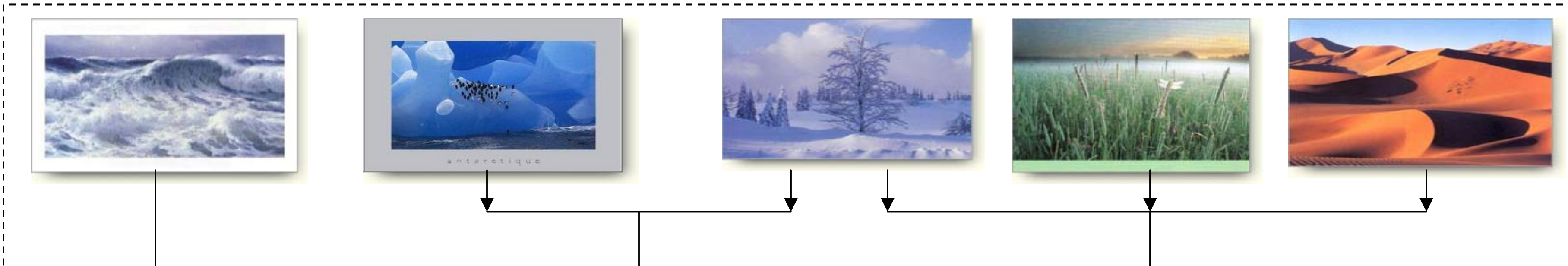
Figure Caption: CRTM simulated brightness temperature (BT) spectrum for hyper-spectral infrared sensor IASI (black line), AIRS (red line), and CrIS (blue line).

Significance: CRTM team is getting ready for NPP/NPOESS CrIS/ATMS

Slide Courtesy of Y. Chen, Y. Han, P. van Delst, and F. Weng

Surface Emissivity Models in CRTM

Ocean **Sea Ice** **Snow** **Canopy (bare soil)** **Desert**



Microwave land emissivity model (Weng et al., 2001)

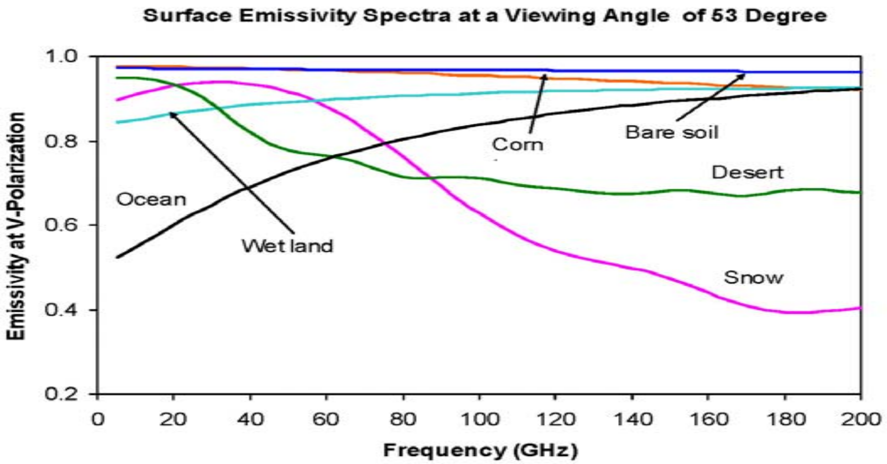
NPOESS Infrared emissivity data base

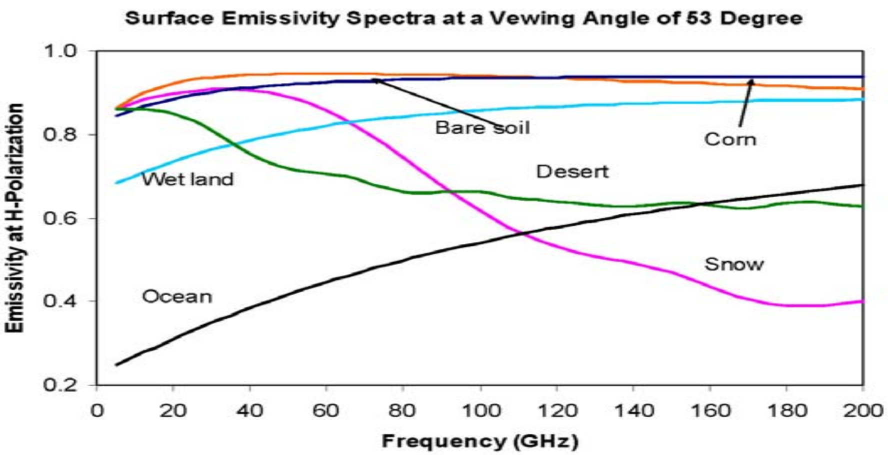
Empirical snow and sea ice microwave emissivity data base (Yan and Weng, 2003; 2008)

FASTEM microwave emissivity model from (English and Hewison, 1998)
NESDIS IR emissivity model (Wu and Smith, 1991; van Delst et al., 200x)

Microwave Emissivity Spectra Produced from CRTM

- **Open water** – two-scale roughness theory
- **Canopy** –Geometric optical scattering
- **Bare soil** – Coherent reflection and surface roughness
- **Snow/desert** – Dense medium scattering





Microwave emissivity spectra is simulated qualitatively consistent with satellite and ground-based retrievals. Deserts is treated as scattering in order to produce observed characteristics from satellite

2. Data Assimilation Experiments and Impact Studies

- Assimilation of IASI data in GFS produces positive impacts
- Windsat data improve GFS surface and lower tropospheric wind
- SSMIS data produce small to neutral impacts
- Uses of COSMIC data in GFS produce positive impacts
- Assimilation of ASCAT data results in impacts on lower level winds
- Utilization of GOES aerosol products in WRF-CMAQ

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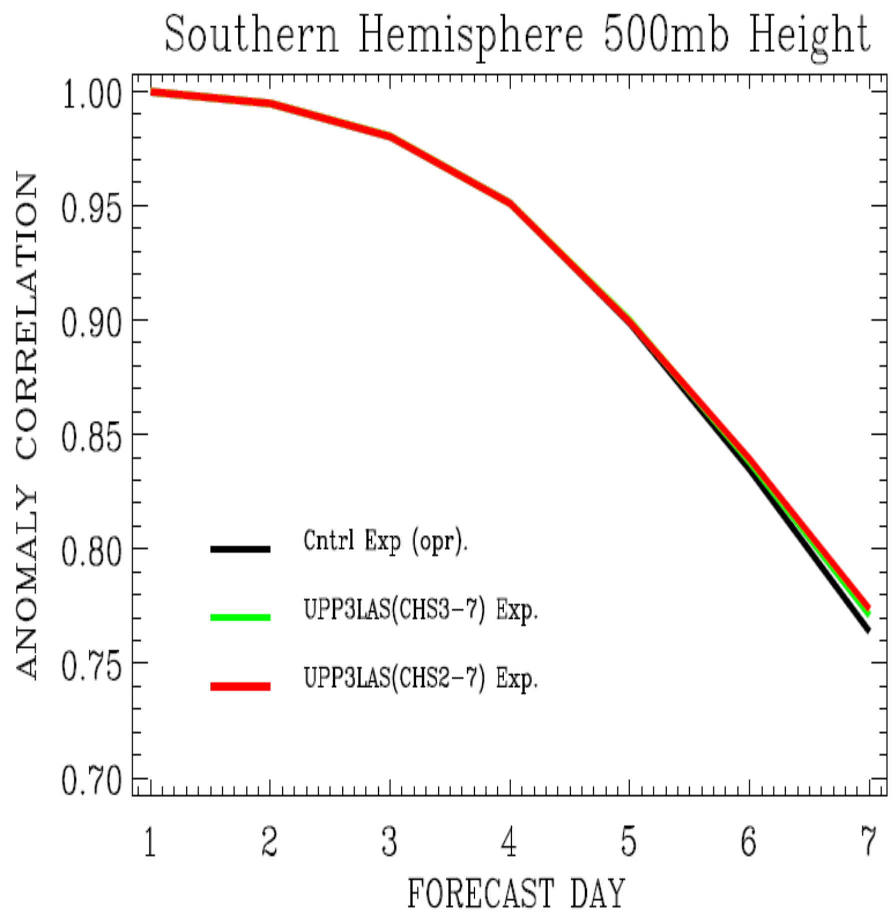
Impact of SSMIS Lower Atmospheric Sounding Channels

- GSI 3D-Var: T382L64
- Assimilation Period: Aug. 1 – Sept. 30, 2008
- Forecast: 168 hour
- Only microwave clear radiance data over ocean used
- Existing GSI bias correction scheme
- New scan dependent bias correction



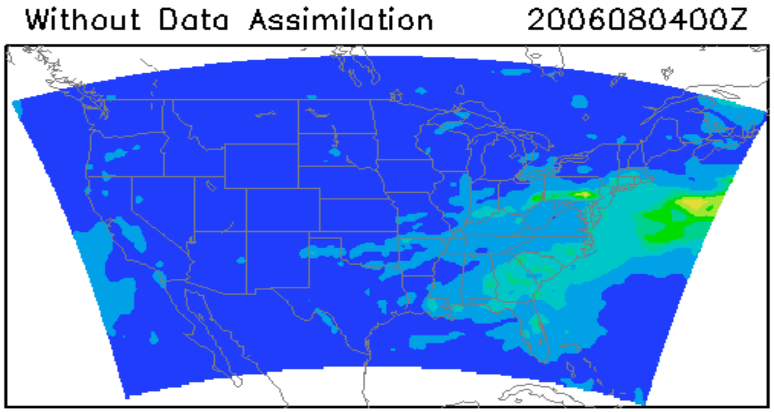
F16 SSMIS data distributed from NRL/MetOffice Unified Preproccessor produce positive impacts in GFS but there remain some regional dependent biases which may limit its full capability

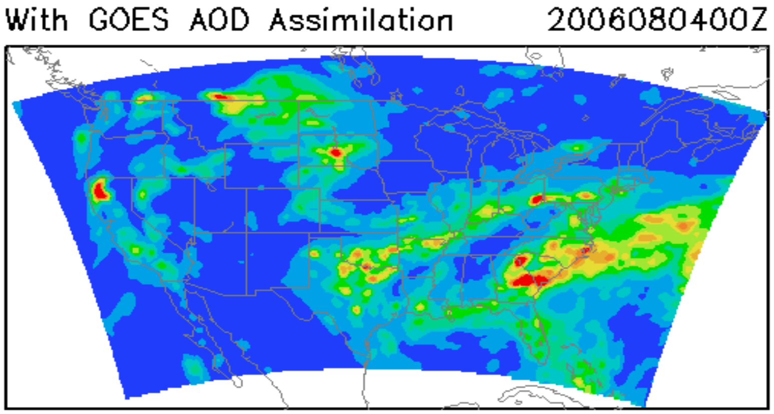
Assimilation of GOES AOD in WRF/CMAQ

- **STAR is funded by NWS to work on developments of GOES AOD products for improving air quality forecasts**

- **Hourly GOES Aerosol Optical Depth (AOD) is assimilated in a NOAA-EPA Weather and Research (WRF)/Community Multiscale Air Quality (CMAQ) model**

- **Major difference from uses of GOES AOD is the spatial coverage over an east coast pollution episode**

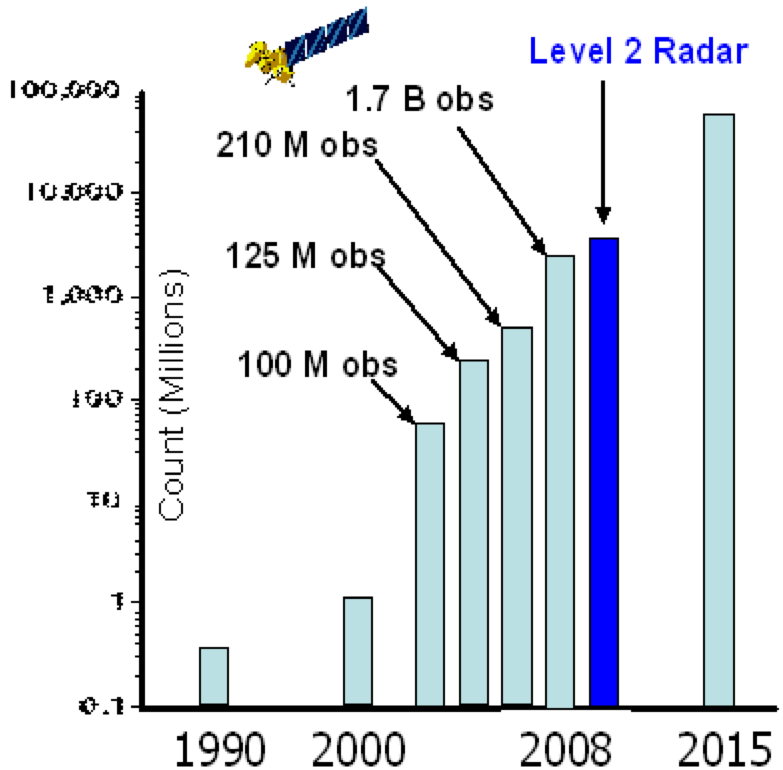




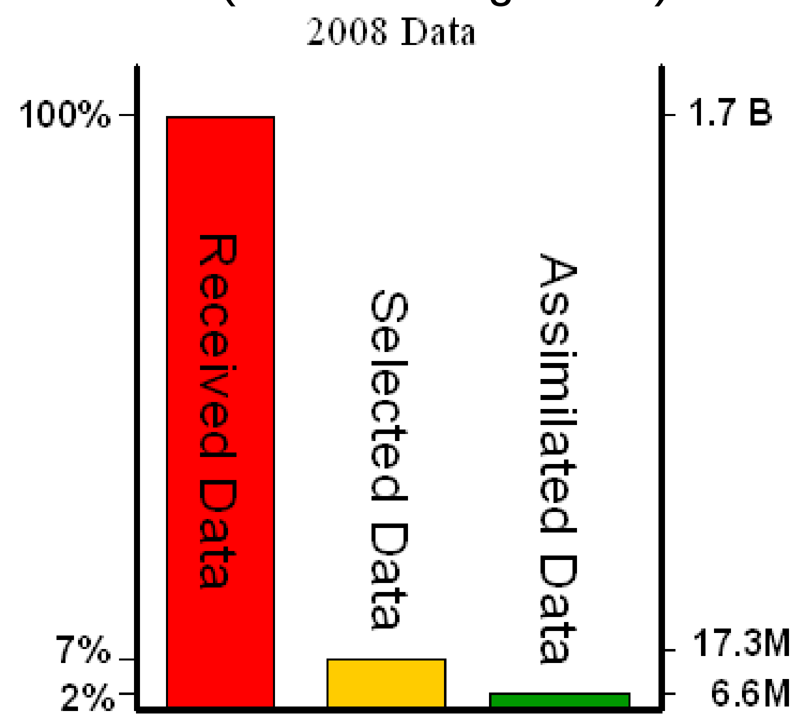
Uses of GOES AOD products account for missing sources and sinks in the model via aerosol data assimilation and help improve particulate pollution predictions. NWS is mandated to deploy nationwide PM2.5 forecasts early next decade.

Challenges in Uses of Satellite Data in NWP
Data Volume and Lower Percentage

Daily Satellite & Radar Observation Receipt Counts



Daily Percentage of Data Ingested into Models (Not Counting Radar)



Received = All observations received operationally from providers
Selected = Observations selected as suitable for use
Assimilated = Observations actually used by models

From received data to selected, some data thinning and quality control result in major data reduction to the model. From selected to assimilated, the reduction is due mostly to inability of handling clouds, uses of surface sensitive channels, etc.

3. Improve Uses of Satellite Data in NWP

- **Improve Surface Emissivity Models**
  - Snow and sea ice emissivity data base
  - Multilayer snow emissivity model
  - 20 years of MW emissivity data base
  - Hyperspectral IR emissivity data base

- **Uses of Cloudy Radiances**
  - Improve bias corrections using more predictors (e.g. cloud liquid water and ice water path) from satellite retrievals
  - Include cloud and moisture physics in minimization processes
  - Use more channels with extended control (state) variables including hydrometeor parameters
  - Test infrared cloud-cleared radiances in NWP
  - Produce improved radiances after satellite intercalibration

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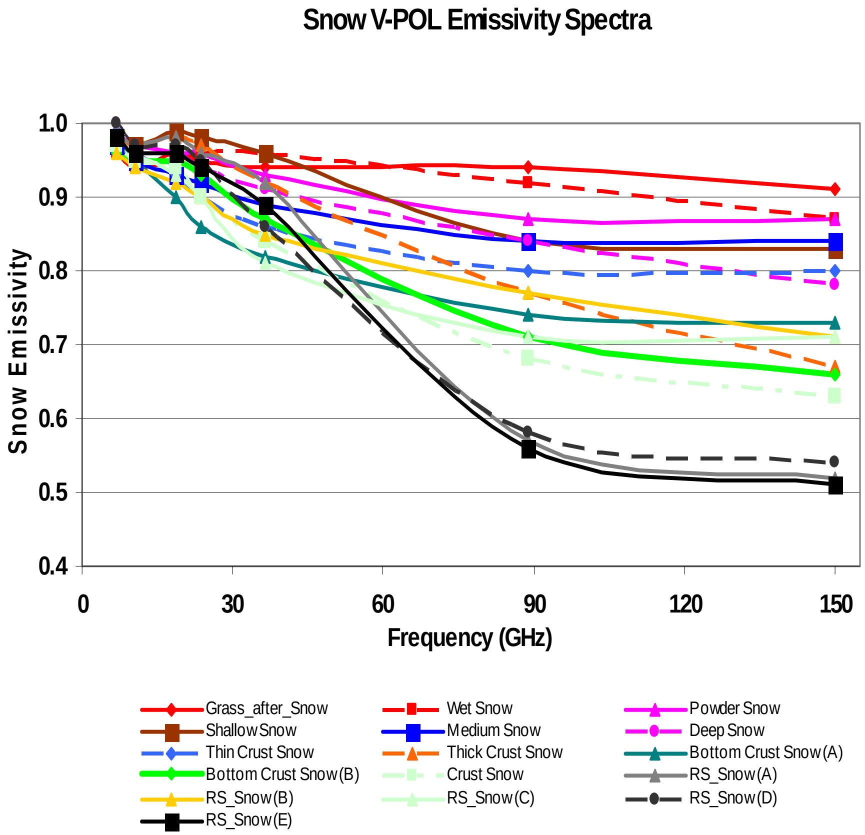
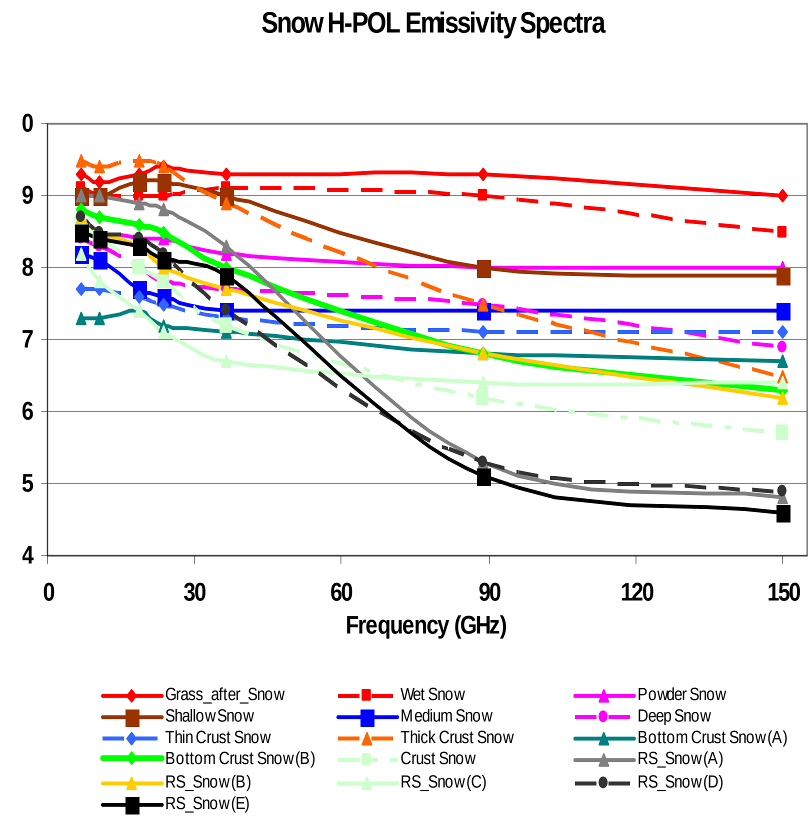
Snow Microwave Emissivity Spectra Data Base

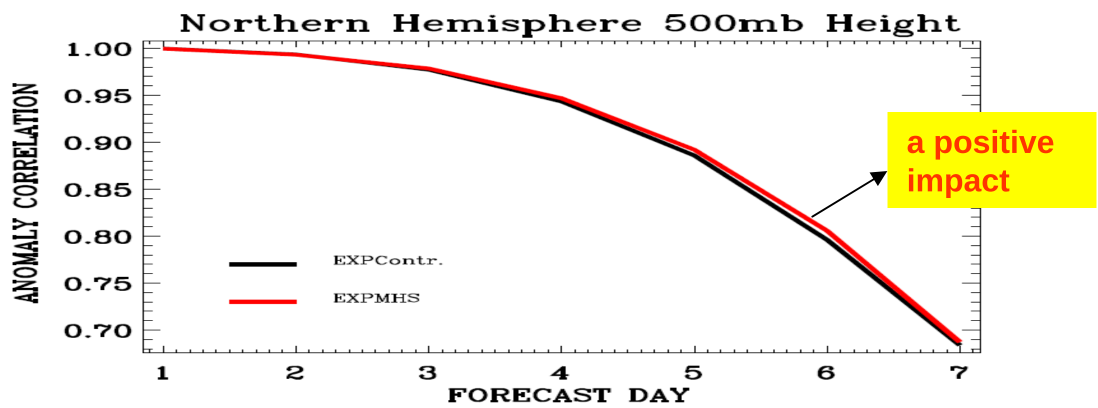


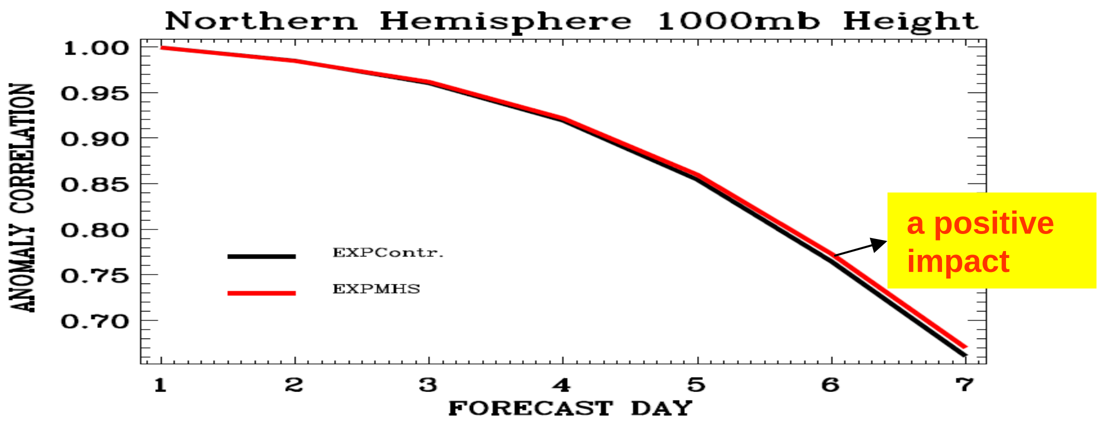


This global snow emissivity data base is generated from the ground-based retrieval (Matzler, 1991) and satellite AMSU and SSMIS data

Impacts of Snow & Sea Ice Emissivity Model on SSMIS/MHS Assimilation

- •Uses of new snow and sea ice emissivity
- •About 60% SSMIS data passed quality control due to improved SSMIS snow and sea ice emissivity information
- •20% SSMIS data passed quality control in NCEP/GSI using the old emissivity model





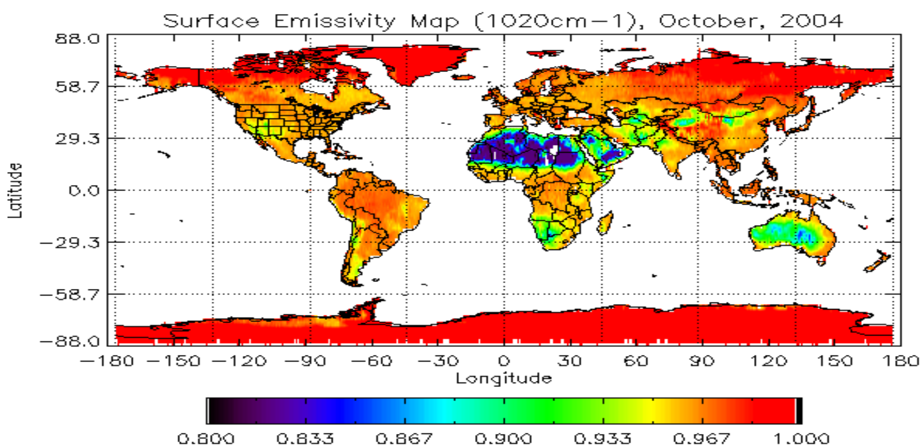
Impacts of snow emissivity models and data base on GFS medium-range forecast is positive for both hemispheres

Hyperspectral Emissivity Data Base

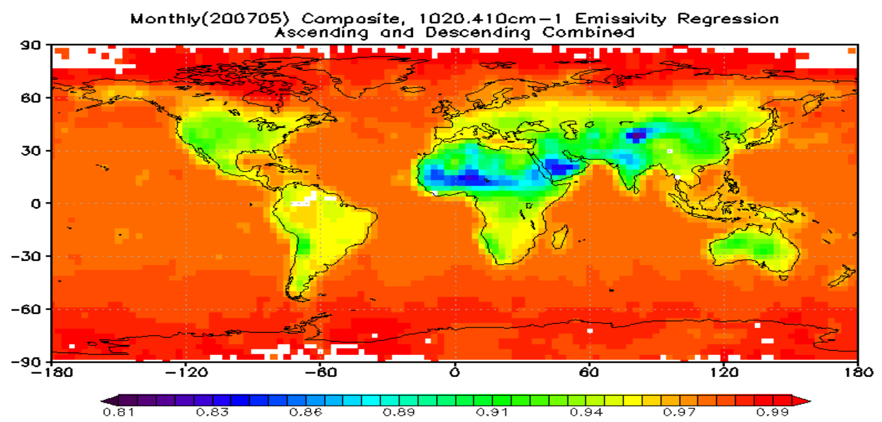
- AIRS and IASI 39 hinge point emissivity data are retrieved in AIRS/IASI systems
- Two LSE data sets agree well within 1% for most areas
- Differences exist over coastal areas and desert region where the large variations of emissivity occur
- The IASI and AIRS systems will be enhanced to cover the entire 2-15 micron emissivity with dynamic updated information from pentad to monthly scale

Infrared emissivity data sets will result in improved uses of surface sensitive sounding channels from hyperspectral instruments

AIRS



IASI



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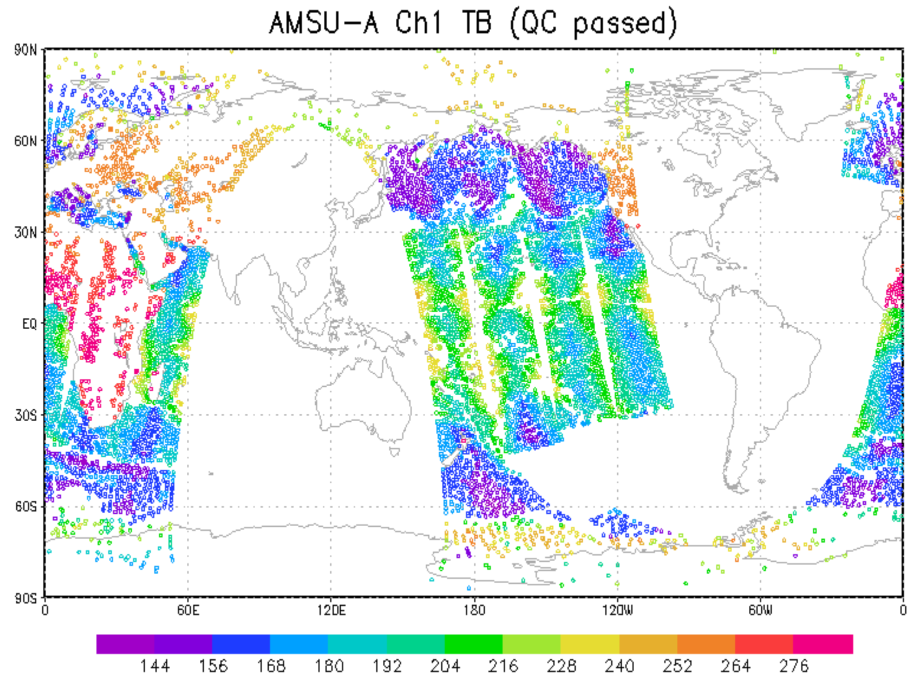
Current Approach in Handling Cloudy and Rain-Affected Radiances

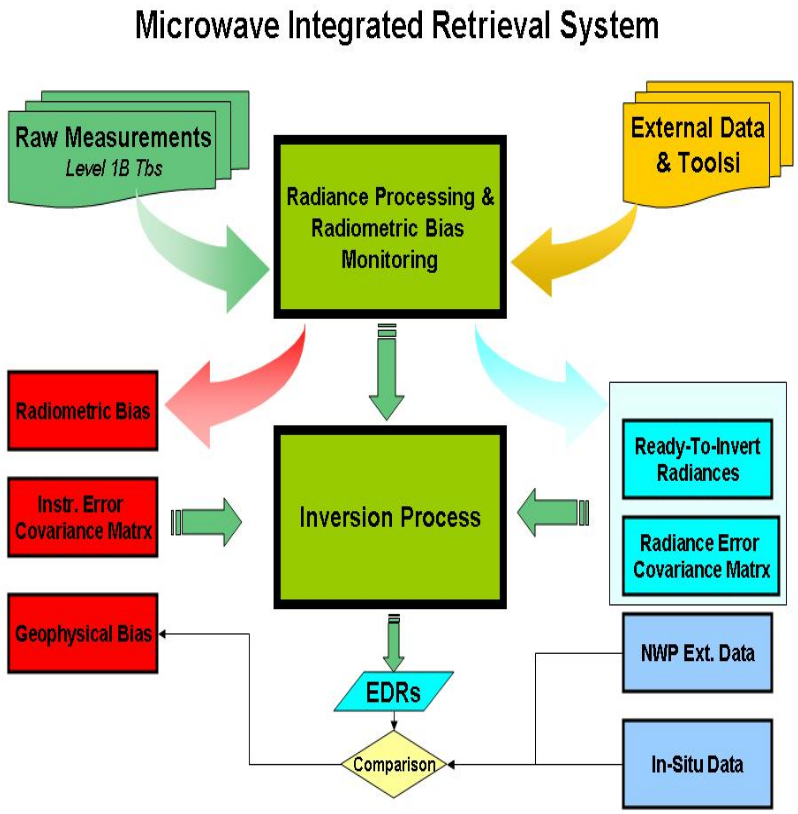
- Radiances in cloudy areas (rainy pixels rejected) are handled as clear pixels in forward calculation
- Radiance biases due to clouds are corrected through bias correction algorithms
- Bias correction in cloudy conditions uses retrieved cloud liquid water and ice water



Data over thick cloudy area are screened out but those over thin cloudy area have been assimilated without including cloudy radiance computation

New Approach in Handling Cloud Radiances

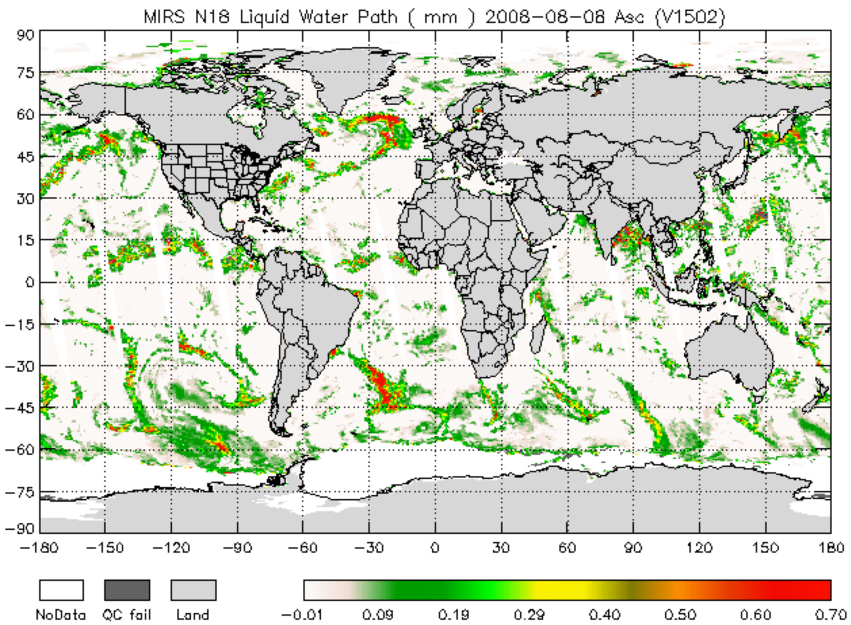
- **Test of ECMWF approach using GFS cloud microphysics in TL/AD**
  - LWP is first retrieved from cloud algorithms (Weng and Grody, 1994) and used to check if radiances are clear or cloudy/rainy. Clear pixels directly go to 3/4dvar
  - For cloudy/rainy pixels, it goes to 1dvar for refinement in LWP, TPW, and other parameters which are further assimilated in 3dvar
  - Impacts of TPW on other analysis fields (Q and Wind) are done through cloud and moisture physics in 3/4dvar systems
- **Test of Metoffice approach**
  - Atmospheric parameters under cloudy and precipitating conditions are retrieved from 1dvar and the 1dvar convergence flag is used to control the radiances into 3/4dvar, also rain and non-rain pixels
  - 3/4dvar process include several key hydrometeor parameters (no precipitation) and TL/AD from cloud and moisture physics.



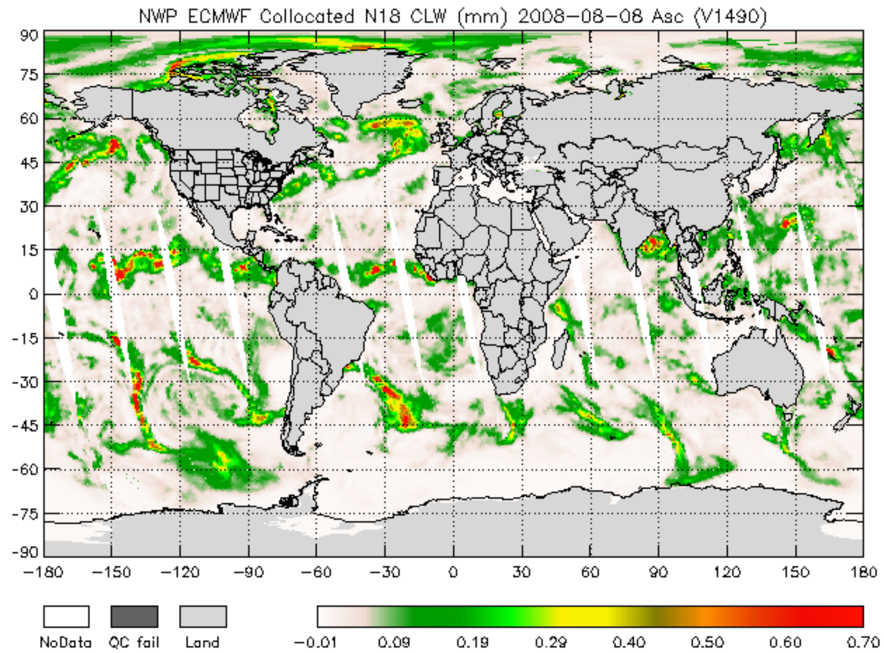
The key component is the 1dvar preprocessor which can be used for quality control and refinements of hydrometeor profiles. MIRS is a stand-alone 1dvar software developed by NESDIS and is made available for NWP users

MIRS/1DVAR Derived Cloud Liquid Water vs. ECMWF Analysis

MIRS LWP



ECMWF



1DVAR derived cloud liquid water from NOAA-18 AMSU displays spatial distribution and agrees well ECMWF, especially for the oceans where clouds are widespread and both satellite and forecast models can resolve the clouds well.

4. Prepare New Datasets for NWP Community

- AIRS/MODIS BUFR data is completed and ready for NWP center tests
- CrIS/ATMS simulated data in BUFR format will be distributed in March – April, 2009
- Conversion of MSG SEVIRI WMO BUFR to NCEP-BUFR is on going
- Conversion of AURA OMI from HDF5 to BUFR data was completed in 2008 and the data is distributed
- METOP-A GOME2 BUFR data is received and tested

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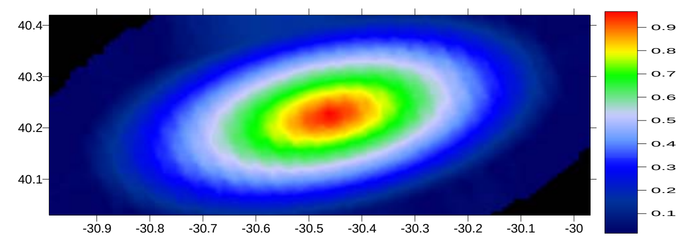
AIRS/MODIS BUFR Data: Spatial and Spectral Collocations

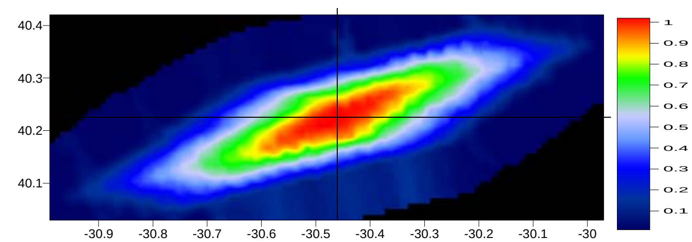
- MODIS Aerosol Optical Depth product from both TERRA and AQUA are being placed into BUFR format for NCEP

- MODIS data has been collocated to the AIRS footprints using both the spectral response and spatial response functions for both instruments

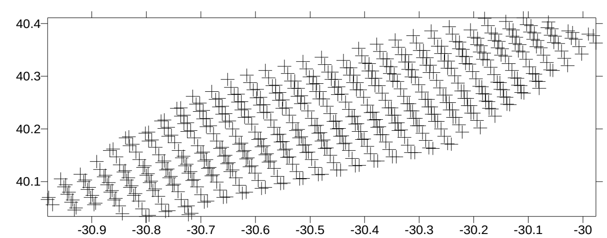
- These collocations have enabled MODIS data to be averaged to the AIRS footprints



Simplized AIRS EFOV SRF .Fp=1



Simulated AIRS EFOV SRF Fp=1



Collocated MODIS observation

Data handling processes require and prepare new knowledge and information for advanced data assimilation research

5. Exploratory Studies of Future Instruments

- NRC Decadal Survey and NASA Missions:
  - NASA Global Precipitation Measurement (**GPM**) Mission
  - NASA Soil Moisture Active and Passive (**SMAP**) Mission
  - NASA Precipitation and All-Weather Temperature and Humidity (**PATH**) Mission
  - NASA Orbiting Carbon Observatory **(OCO)** in A-Train
- GOES-R/NPOESS
  - CRTM for GOES-R Advanced Baseline Imager (ABI)
  - GOES-R Risk Reduction Studies using MSG
  - NPOESS CalVal Studies

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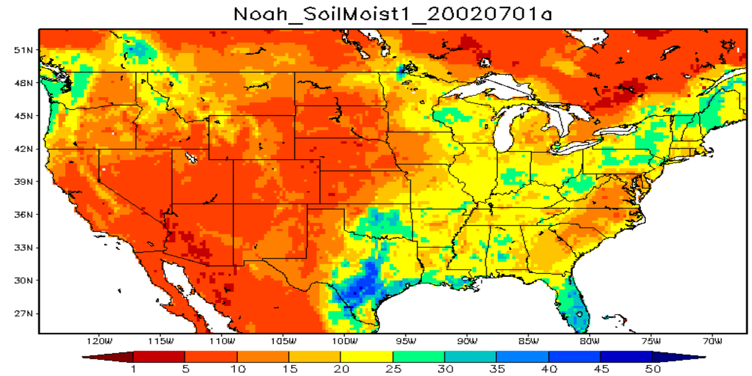
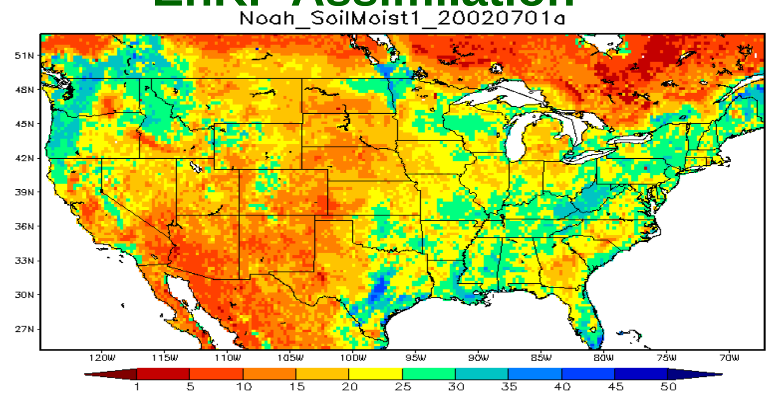
Preparation for NASA SMAP Mission

- *Test the Ensemble Kalman Filter for assimilation of soil moisture products*
- *Development fast multilayer surface emissivity model for L-Band applications*
- Prepare the ground system for receiving and disseminating the data to NWP users

Noah LSM Run



EnKF Assimilation



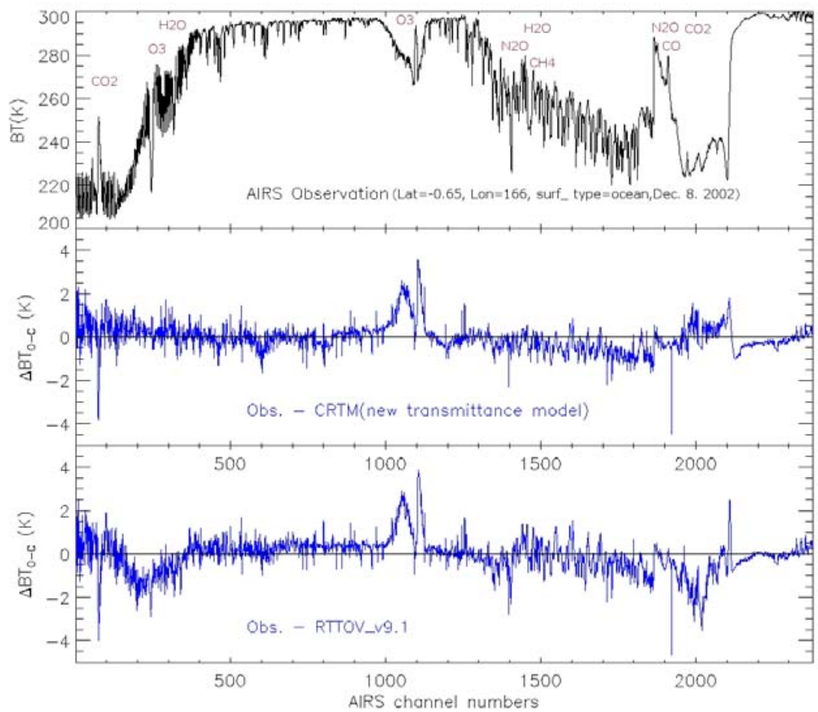
NOAA SMAP transition science team will be established including all the NOAA users and other NWP users (R2O Lead: Dr. Jerry Zhan)

Preparation for NASA OCO Mission

- OCO measures reflected lights and analyze the spectrum to determine the (CO2) concentration

- *Explore uses of the CO2 products in 3dvar for eliminating regional and temporal biases in infrared sounding radiances.*

- *OCO potentially also provides surface pressure estimates*

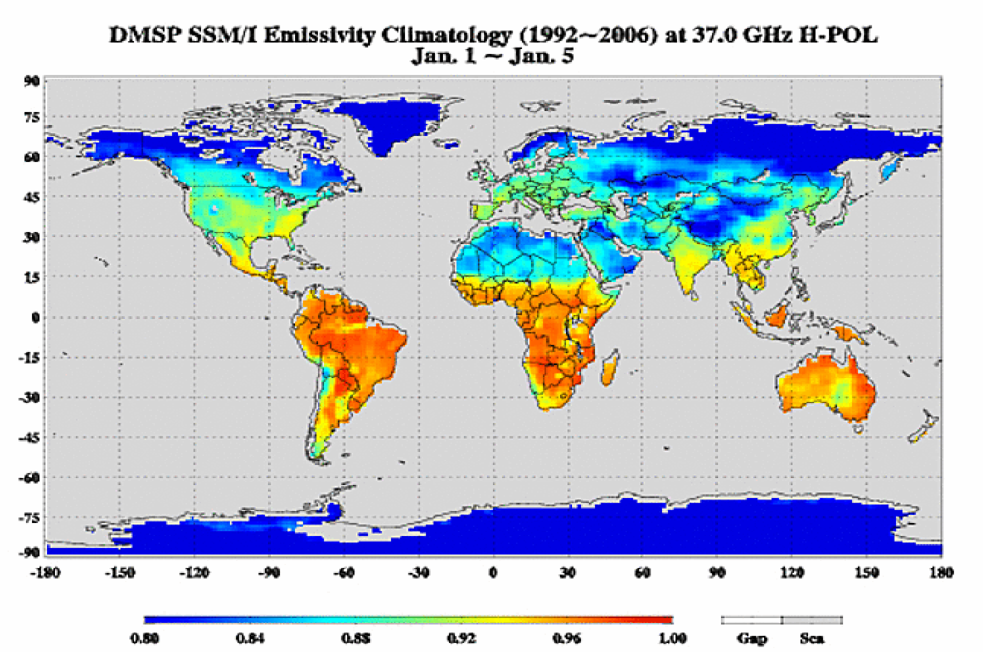


CRTM is now including variable trace gases (CO, CO2, CH4, etc) and allows uses of CO2 products

NOAA OCO transition science team will be established, including all the NOAA users and other NWP users (R2O Lead: Dr. Chris Barnet)

Preparation for NASA GPM Mission

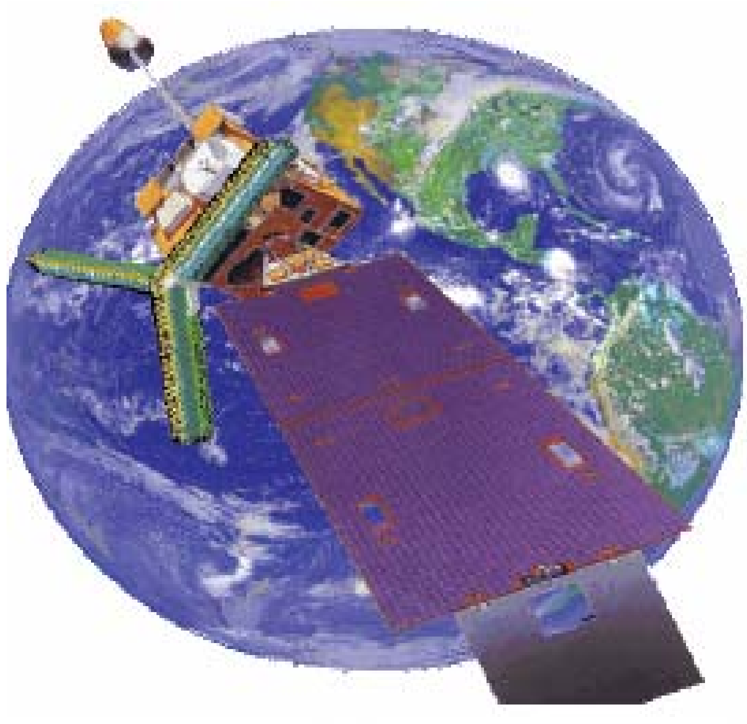
- *Uses of GPM Microwave Imager (GMI) cloudy and rain-affected radiances*
- Microwave emissivity data base and models for improving GPM land precipitation retrieval
- Prepare the ground system for receiving and disseminating the data to NWP users



NOAA GPM transition science team has been established including all the NOAA users and other NWP users (R2O Lead: Ralph Ferraro)

Preparation for NASA PATH Mission

- *GeoSTAR (*Synthetic Aperture Antenna) *microwave radiance simulations* for OSSE
- MIRS 1dvar retrievals using JPL aircraft observations in hurricane conditions (high spatial/temporal information). Understanding of requirements in spatial resolution for resolving hurricane warm core structure
- GeoSTAR calibration algorithms and intercalibration



NOAA PATH transition science team will be established including all the NOAA users and other NWP users (R2O Lead: Dr. Fuzhong Weng)

Summary and Conclusions

- NESDIS/STAR provides critical supports for CRTM science developments
- Currently, CRTM has been used by JCSDA partners: NCEP, NRL, GMAO, NCAR/AFWA, and GOES-R Program.
- It will supports many future instruments in NRC decadal survey missions
- Validation of CRTM under cloudy conditions has begun and shows very promising aspects in cloudy radiance assimilations in terms of reduced biases and RMS
- Impacts of MW land emissivity model and data set alone on global 6-7 forecasts are positive.
- 1dvar system including cloudy and rain-affected radiances are developed and used in NESDIS operation for sounding products and also requested by several NWP centers for quality control or preprocessor.

Future Plan

- **CRTM improvements in**
  - Spatial inhomogeneity from atmosphere and surface
  - Spectroscopy improvements for training the fast models
  - Multilayer microwave emissivity models for new missions (SMAP, SMOS, Aquarius, FY3, GCOM-W)
  - Hyperspectral infrared emissivity data base

- **Improvements in data handling techniques**
  - NPP/NPOESS advanced BUFR data (e.g. CrIS/VIIRS)
  - METOP IASI/AVHRR
  - Cloud-cleared IR radiances

- **More data assimilation experiments**
  - Demonstration of N Prime, DMSP F18
  - Uses of AMSU-A and SSM/I cloudy radiances
  - Assimilation tests using hyperspectral infrared retrievals

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Selected Publications

1. Errico, M., G. Ohring, P. Bauer, B. Ferrier, J. Mahfouf, J. Turk, and F. Weng, 2007, Assimilation of Satellite Cloud and Precipitation Observations in Numerical Weather Prediction Models: *J. Atmos. Sci.*,**64**, 3737 – 3741.IEEE Special volume on surface remote sensing and property modeling
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