Overview of NESDIS/STAR Satellite Data Assimilation Activities

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NOAA/NESDIS/STAR

Image: MODIS Land Group, NASA GSFC March 2000

Center for Satellite Applications and Research (STAR) Review
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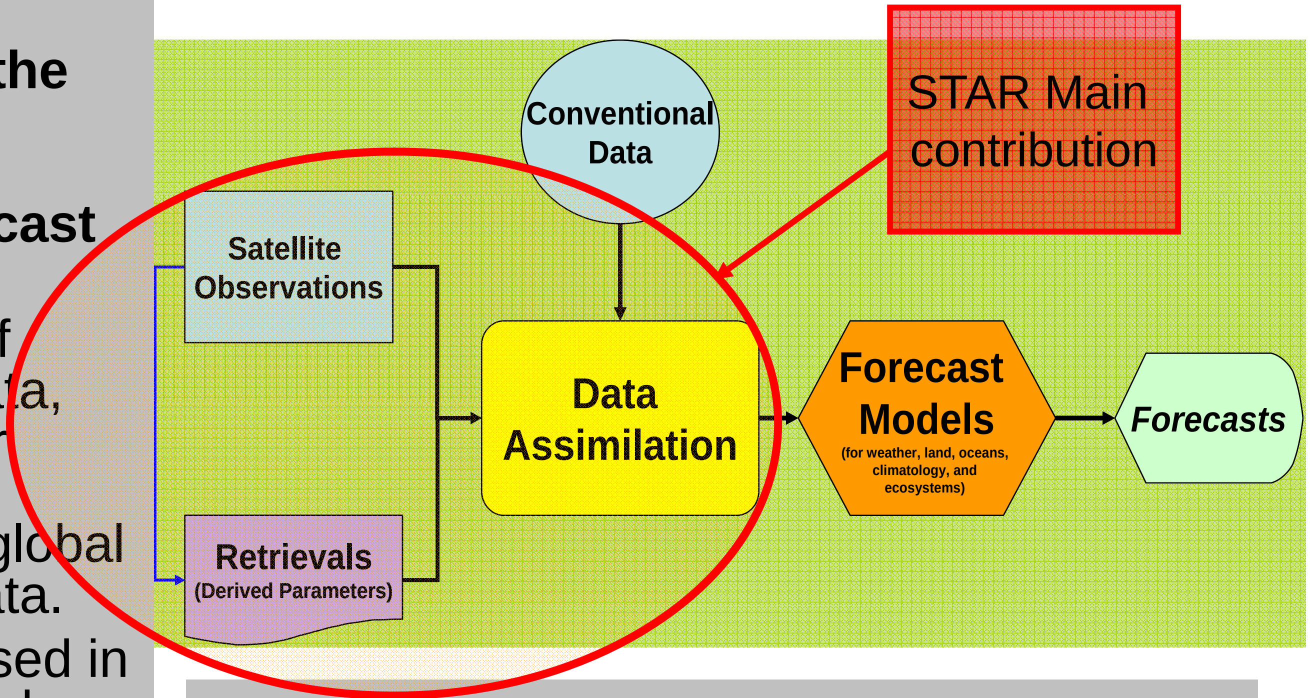
Data Assimilation Overview

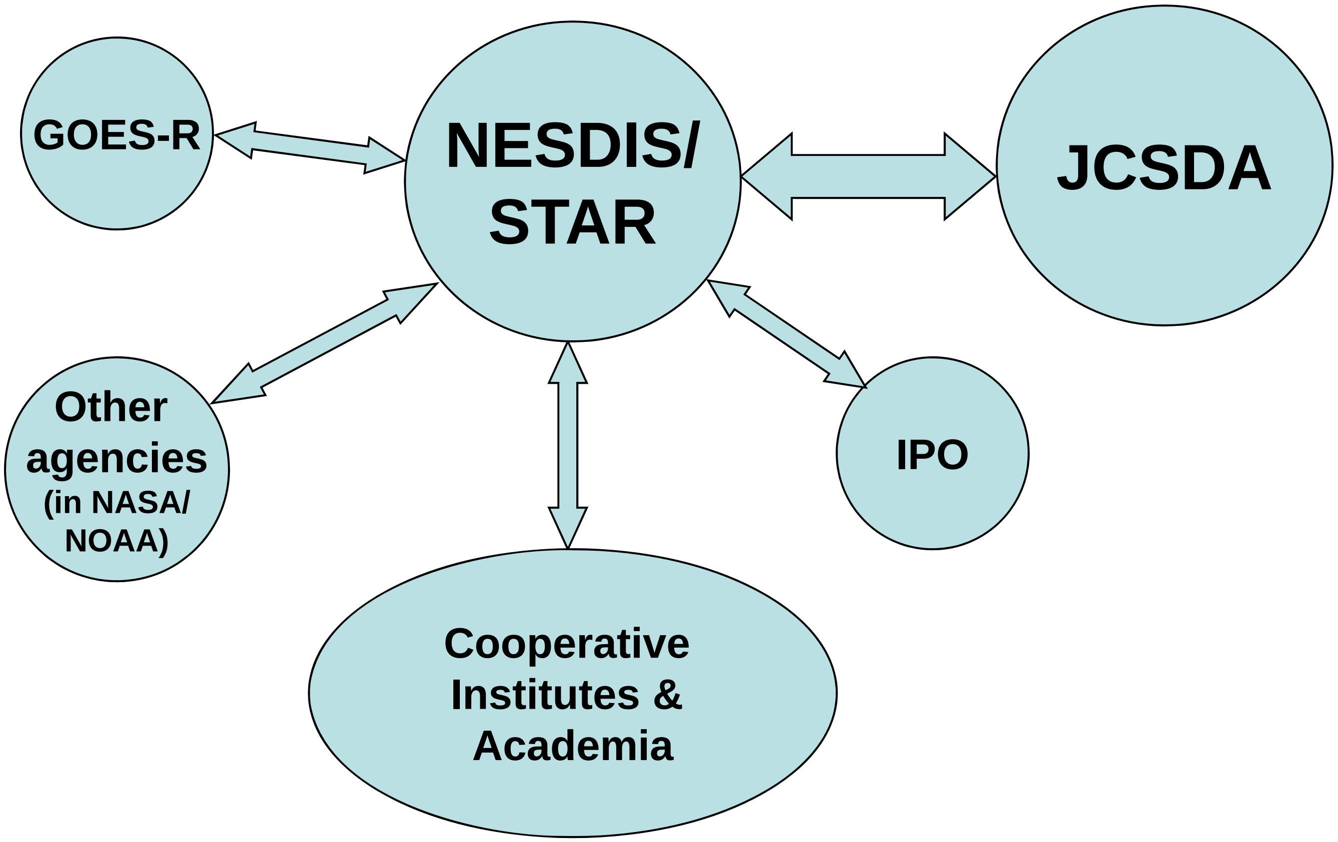
- **Data assimilation is the mortar that binds environment observations to forecast models**
- DA optimizes usage of satellite data, radar data, radiosondes and other conventional data to produce a consistent global field of geophysical data.
- These analyses are used in forecast models to produce next cycle forecasts.
- These analyses (or re-analyses) are also used for climate applications
- DA is done either at global scales or at more regional scales (mesoscale events)



- **What sensors are included?**
  - **Polar-orbiting, geostationary, and low inclination orbits (e.g. Jason)**
  - **All spectral regions (MY, IR, NIR, etc)**
  - **Broadband and hyper-spectral sensors**
  - **US, current and future sensors; EU and other international sensors**

NESDIS/STAR
Data Assimilation Activities

Data Assimilation efforts at STAR are multi-faceted:
- **Direct efforts by STAR scientists (CRTM, DA of GPS, SSMIS, etc)**
- **STAR contributions to JCSDA funding leading to DA activities (FFO, JSDI)**
- **Close collaboration between STAR scientists and scientists from other agencies, CIs, Academia, etc)**



STAR Major Accomplishments in Data Assimilation

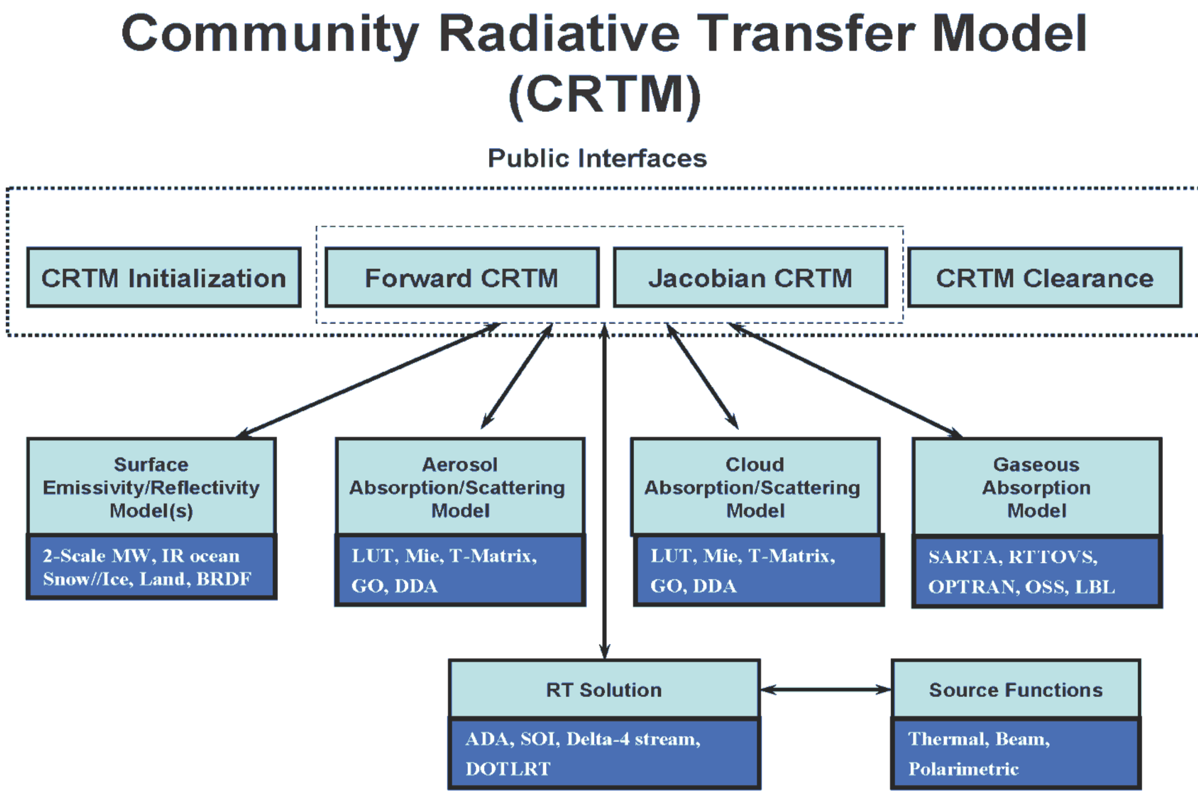
- **STAR has achieved or directly contributed to these major achievements:**
  - Radiative Transfer Modeling: CRTM & Surface Emissivity modeling
  - Data assimilation of new sensors (AIRS, IASI, SSMIS, METOP-A, COSMIC)
  - Implementation of Cloudy Radiance assimilation
  - Data Impact Experiments: OSSE & OSE
  - Improvement in the assimilation of existing sensors (ex: new QC approach for Metop-A and POES data assimilation).
  - Development of an all-weather 1-Dimensional Variational System

Radiative Transfer Modeling: Community Radiative Transfer Model (CRTM)

CRTM is an essential element in the data assimilation system, linking the geophysical state vector to the radiances that are assimilated. It also provides the Jacobians.

Support over 100 Sensors

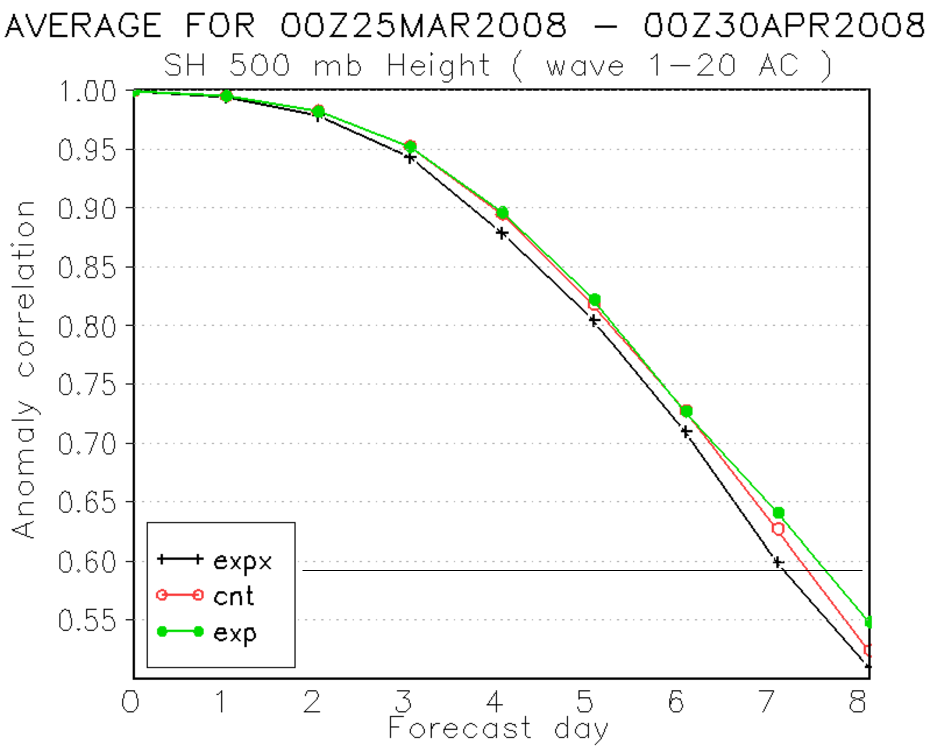
- **GOES-R ABI**
- **Metop IASI/HIRS/AVHRR/AMSU/MHS**
- **TIROS-N to NOAA-18 AVHRR**
- **TIROS-N to NOAA-18 HIRS**
- **GOES-8 to 13 Imager channels**
- **GOES-8 to 13 sounder channel 08-13**
- **Terra/Aqua MODIS Channel 1-10**
- **METEOSAT-SG1 SEVIRI**
- **Aqua AIRS**
- **Aqua AMSR-E**
- **Aqua AMSU-A**
- **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**
- **DMSP F16-20 SSMIS**
- **NPP ATMS/CrIS**
- **Coriolis Windsat**
- **TiROS-NOAA-14 SSU**



CRTM was initially proposed to support primarily the assimilation of satellite radiance data into global/regional forecast systems. Its applications have expanded to include the generation of high quality proxy data for algorithms testing, development and integration in support of US satellite program developments (GOES-R, NPP, NPOESS). Its applications also include usage in operational retrieval Algorithms, in simulation over nature runs for observation system simulation experiments (OSSE), in cal/val activities, re-analyses, etc.

Recent impact with COSMIC

- AC scores (the higher the better) as a function of the forecast day for the 500 mb gph in Southern Hemisphere
- 40-day experiments:
  - **expx (NO COSMIC)**
  - **cnt (old RO assimilation code - with COSMIC)**
  - **exp (updated RO assimilation code - with COSMIC)**



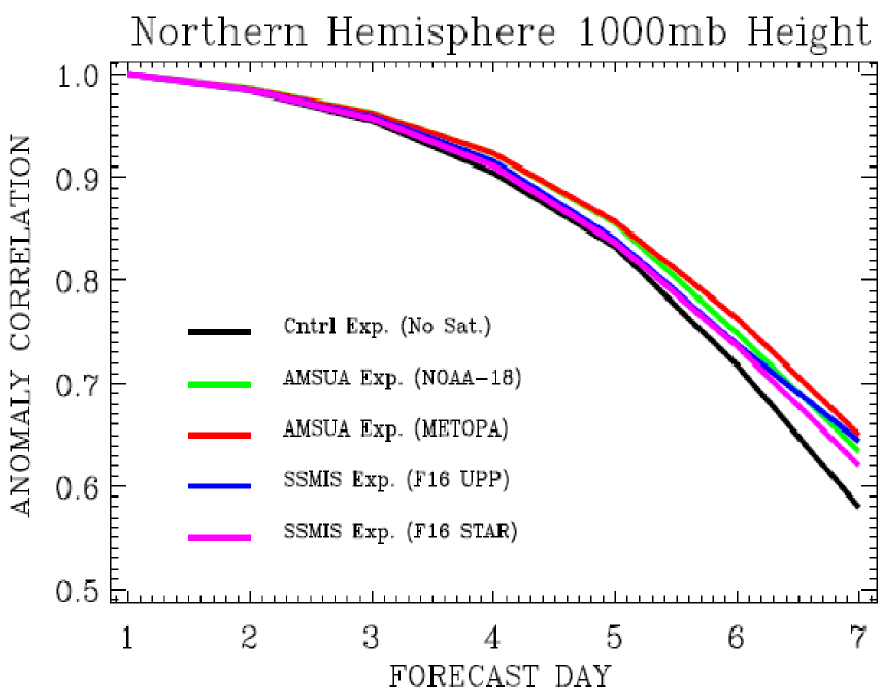
COSMIC provides 8 hours of gain in model forecast skill starting at day 4 !!!

Courtesy L. Cucurull, NOAA(IPA)

Assimilation of New Sensors (Case of SSMI/S)

– **STAR played a direct and critical role in the implementation of the SSMIS radiance assimilation within NCEP's Operational GSI/GFS**

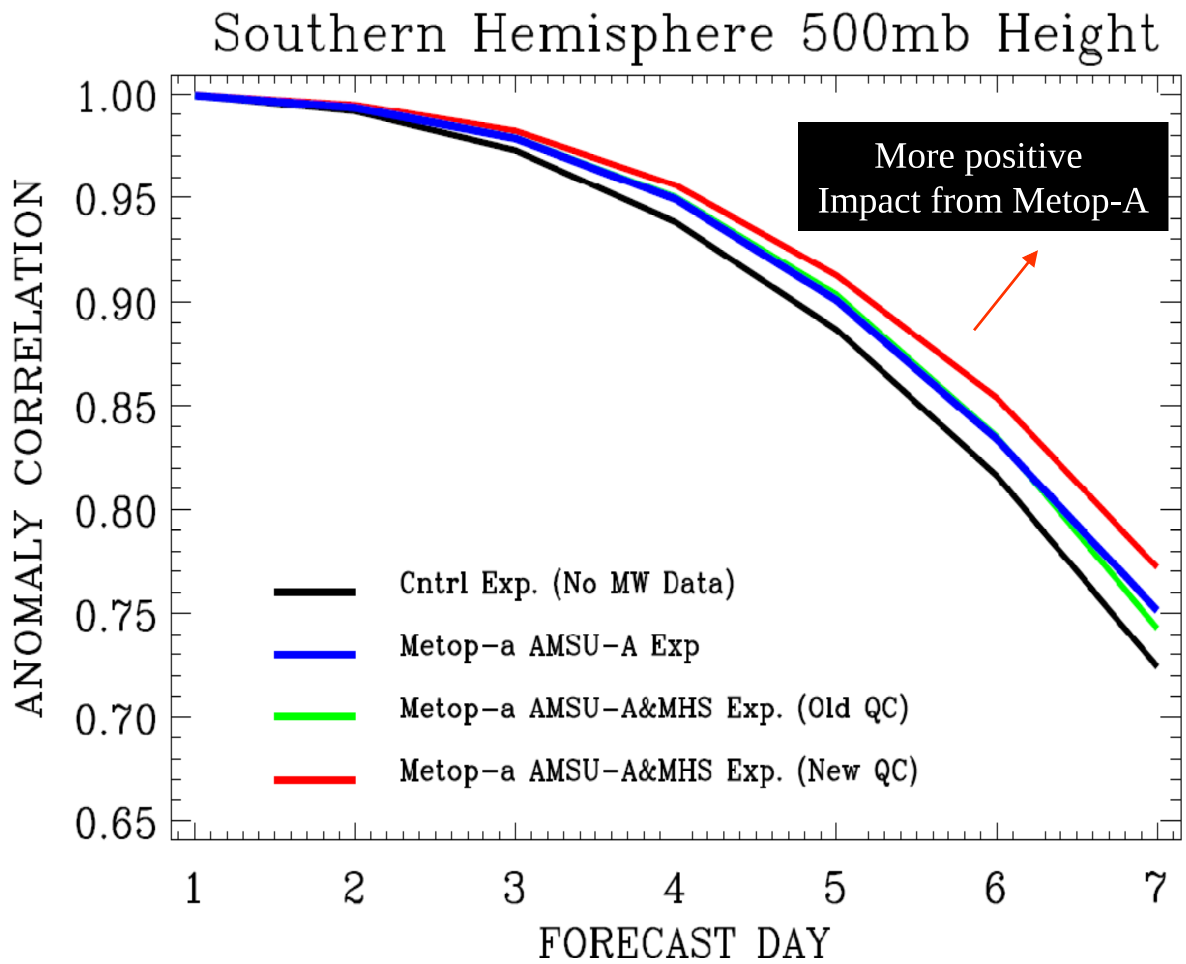
–**Continuous improvement of the SSMIS assimilation led to an impact of similar magnitude than that of AMSU-A from NOAA-18**



Results showing improved impact from SSMIS after calibration correction (similar impact to AMSU). A reliable calibration plays a critical role for producing more positive impact on NWP!

Improvement in Data Assimilation of Existing Sensors

Newly developed QC Procedure leads to improved impact of METOP-A MHS Data on Forecast Skills



Positive impact of Metop-A AMSU and MHS measurements on the global forecast skill. The newly implemented quality control leads to an improved impact. MHS impact used to be negligible when using the old version of QC. Courtesy Weng, 2010.

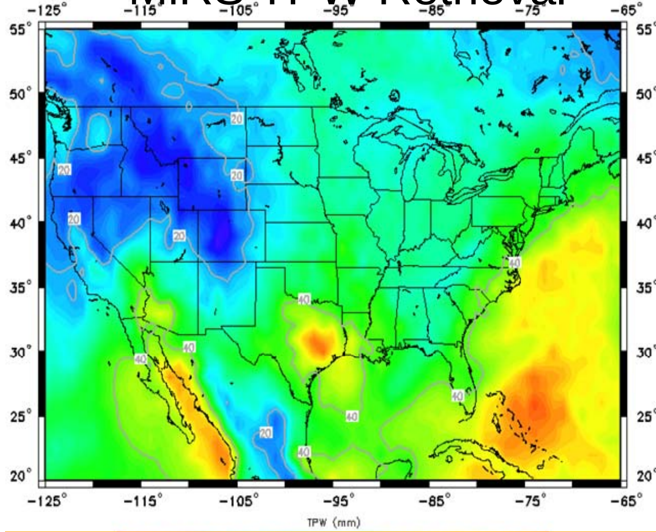
An All-Weather, All-Surfaces 1D-Variational Retrieval System

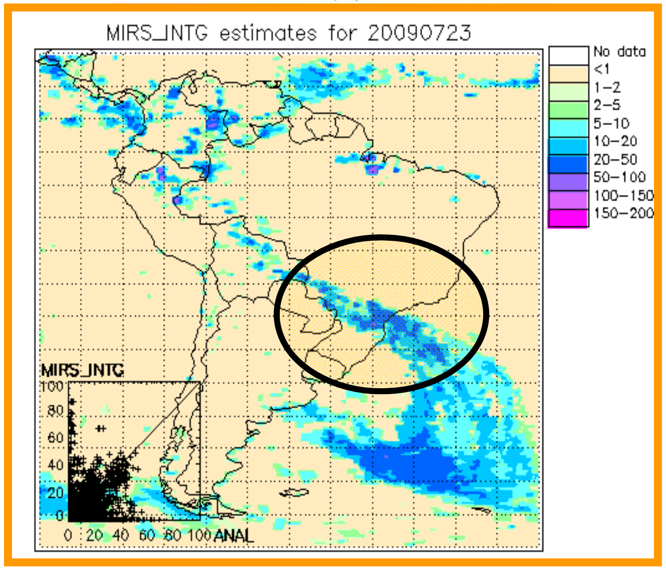
- **A 1DVAR System has been developed by STAR that has the following characteristics:**
  - Minimizes a Cost Fct similar to NWP:

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

  - Uses CRTM as a forward Model for TB and Jacobians (all-weather conditions)
  - Handles emissivity dynamically (all-surfaces applications)
  - Runs operationally for Metop-A, NOAA-18,19 and DMSP F16/F18
- **The MIRS package is readily available to all JCSDA partners.**

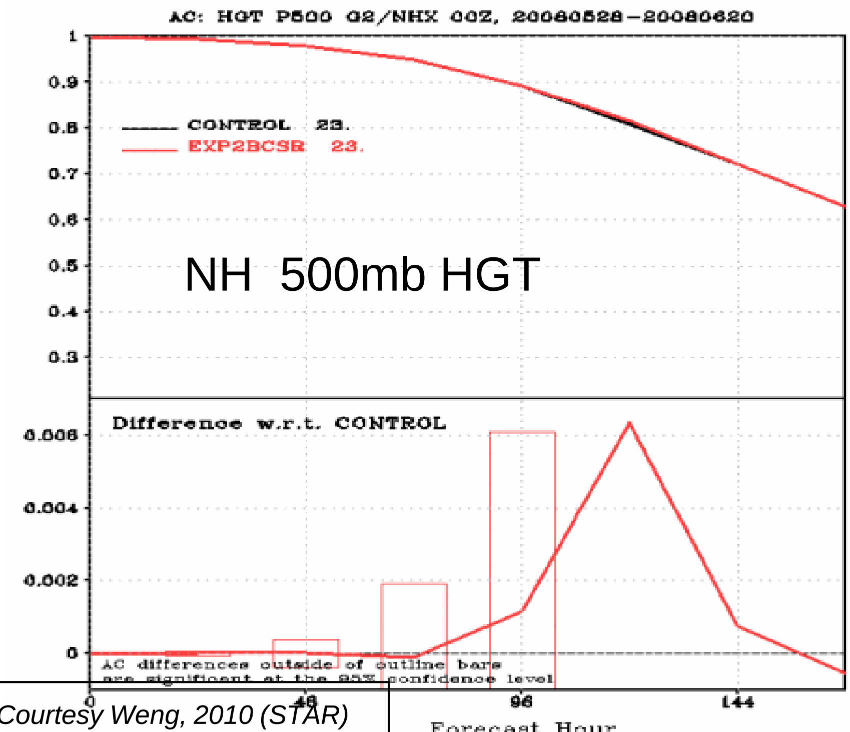
MiRS TPW Retrieval

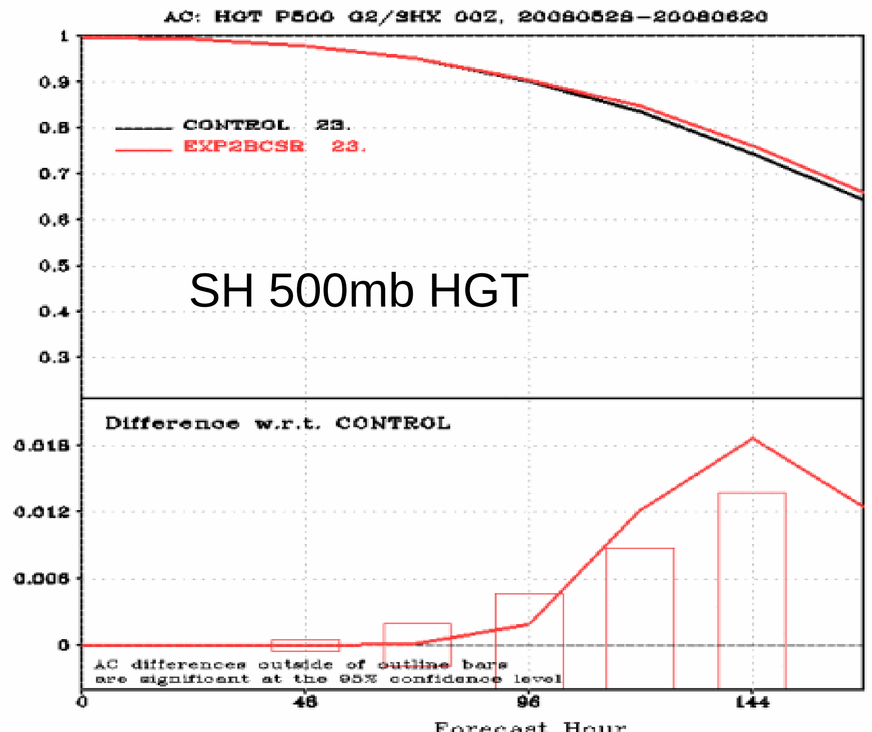




Assimilation of New Sensors (SEVIRI H2O & CO2 Channel Data)

- GSI version with T382 resolution
- Control run: conventional data + all current sensors (e.g. AMSU-A/B, HIRS, AIRS, SSMI, MHS, GOES sounder)
- Exp1 run: control run + SEVIRI 8 IR bands
- Exp2 run: control run + SEVIRI 2 WV bands and CO2 band.



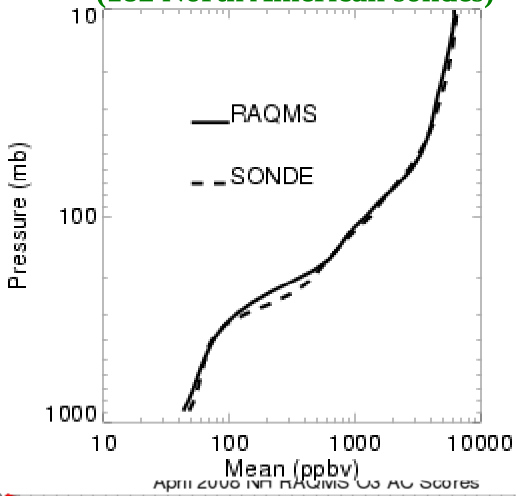


Courtesy Weng, 2010 (STAR)

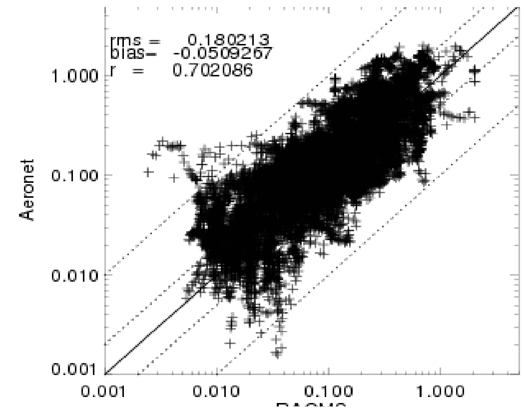
Some positive impacts are found, especially in Northern Hemisphere when SEVIRI H2O and CO2 channels are assimilated in GFS.

RAQMS OSE Studies: Impact Assessment of MODIS & OMI

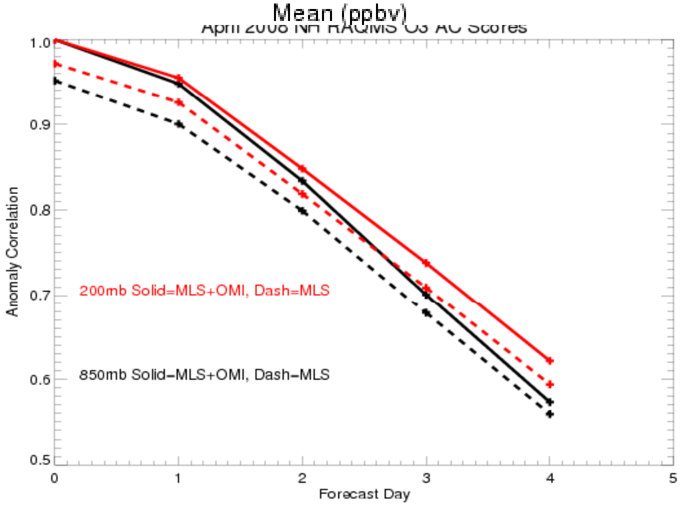
April 2008 RAQMS vs ARCIONS ozonesonde (182 North American sondes)



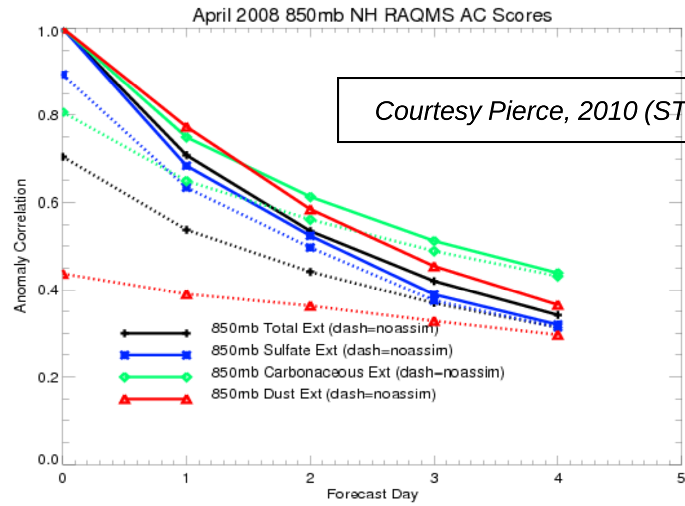
April 2008 RAQMS vs Aeronet AOD 153 Global Aeronet sites



April 2008 O3 and Aerosol Optical Depth Validation



Northern Hemisphere Anomaly Correlation (AC) scores



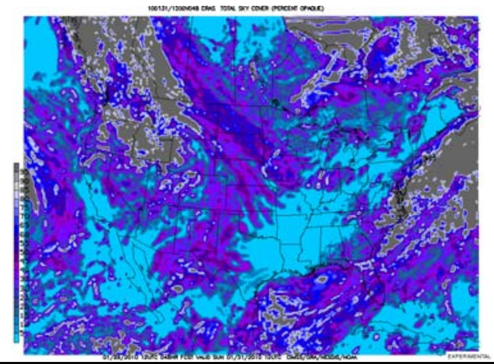
Courtesy Pierce, 2010 (STAR)

- •**Assimilation of MLS & OMI ozone retrievals extends skill (AC>0.6) to 3-4 days for 200mb, 850mb ozone forecasts**
- •**Assimilation of MODIS AOD retrievals extends useful skill past 2 days for Smoke and Dust forecasts at 850mb**

CIMSS Regional Assimilation System

The Advanced Satellite Products Branch (ASPB) has teamed with scientists at the Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin, to develop the CIMSS Regional Assimilation System (CRAS). It's purpose is to evaluate the impact of space-based observations on mesoscale numerical weather prediction accuracy.

CRAS is a regional mesoscale numerical prediction model. It is unique in that, since 1996, it's development was guided by validating forecasts against information extracted from the GOES imager and sounder.



48-hour forecast sky cover (0-100%) from CRAS is currently being evaluated at NWS Forecast Offices.

CRAS History (2004 to present)

Domain	Active	Grid(km)	BCs	Hrs	Sat	Observations	Research-> Ops	Notes
North America*	Y	45	GFS	84	GOES	PW3/Cld/wind	GOES PW in Eta	First forecast IR imagery (1996)
Central US (nest)	Y	15	CRAS	36	GOES	PW3/Cld		Severe weather forecasting
Pacific NW (nest)	Y	15	CRAS	12	GOES	PW3/Cld		Cloud forecast for solar power
Eastern Pacific	Y	48	GFS	72	GOES-11	PW3/Cld	Forecast IR/WV	Evaluation by Pacific Region
					AVHRR	Cld		
South America	N	48	GFS	72	GOES-10	PW3/Cld		Evaluate goes-10 soundings
CONUS (nest)	Y	20	CRAS	48	GOES	PW3/Cld	GOES Cld in RUC	GOES sounder assimilation test
South Pole	Y	48	GFS	72	MODIS	TPW/Cld	Forecast IR/WV	Supporting Govt/private sector
Alaska*	Y	45	GFS	84	MODIS	TPW/Cld	Forecast IR/WV	Evaluation by Alaska Region
					AVHRR	Cld		
					GOES-11	PW3/Cld		
N Hemisphere	Y	90	GFS	168	None	GFS Grids		CRAS model evaluation
DBCRAS (portable)	Y	48	GFS	72	MODIS	TPW/Cld	Local MODIS-IMAPP	Used in 14 countries

* Forecasts transmitted to NWS AWIPS for evaluation

Forecasts available for viewing at http://cimss.ssec.wisc.edu/cras/

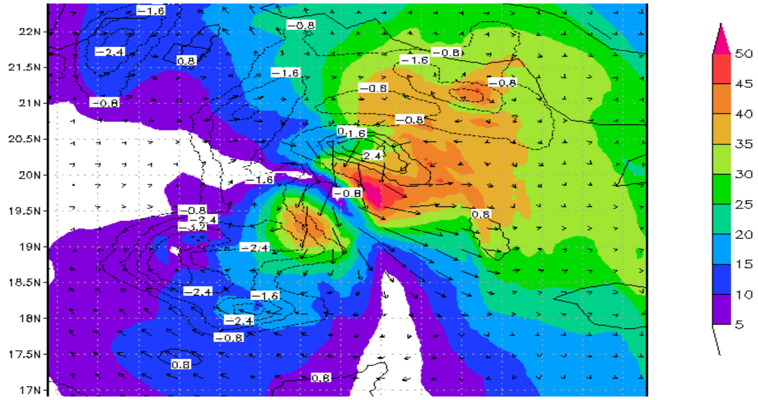
R. Aune, CoRP/ASPB

ENSEMBLE DATA ASSIMILATION AT CIRA

- *Development of ensemble data assimilation system for highly-nonlinear applications*
  (Maximum Likelihood Ensemble Filter - MLEF):
  - Optimal state + Uncertainty
  - Iterative minimization of the cost function + implicit Hessian preconditioning
- *Applications with NOAA operational systems (HWRF, WRF-NMM):*
  - *Hurricane assimilation and prediction (HFIP)*
  - *Maximizing information from satellites (GOES-R Risk Reduction)*

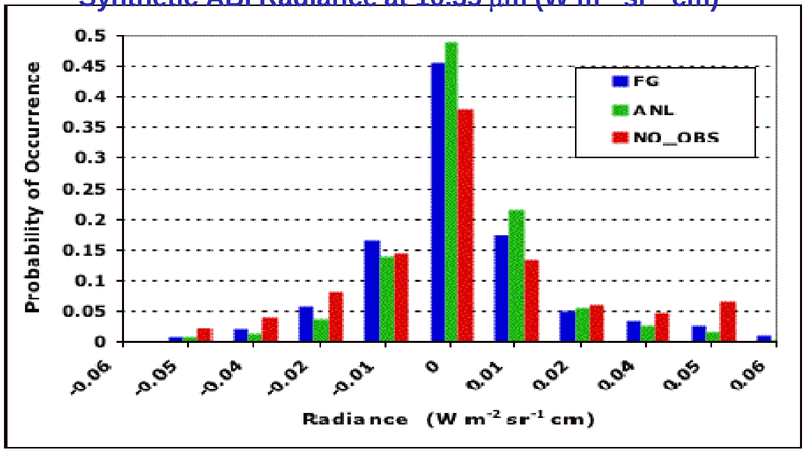
Courtesy Zupanski and DeMaria, 2010 (CIRA/STAR)

Hurricane Gustav (2008):
Analysis correction (analysis minus background) for wind and specific humidity at 850 hPa



Physically consistent adjustments of wind and moisture in a hurricane

Synthetic ABI Radiance at 10.35 μm (W m^{-2} sr^{-1} cm)



Zupanski D., M. Zupanski, L.D. Grasso, R. Brummer, I. Jankov, D. Lindsey, M. Sengupta, and M. DeMaria, 2010: Assimilating synthetic GOES-R radiances in

Cloudy radiance assimilation shows that errors are reduced (e.g., increasing number of zero errors)

MLEF is an ensemble data assimilation system with capability to use NOAA operational framework and assimilate cloudy satellite radiances, with important implications for hurricanes, clouds and precipitation.

OSSEs & OSEs

- STAR contributes to the joint NASA/NOAA OSSE Steering Group which was formed to formalize and accelerate the current collaboration on OSSEs among NASA, NOAA, and OAR

- STAR is also a member of an OSSE testbed effort being seed-funded by USWRP

Ultimately, the goal is to achieve an OSSE capability for both global and regional scales, for all sensors In order to :

- Determine the potential impact of proposed space-based, airborne, and in situ observing systems on analyses and forecasts

-Evaluate trade-offs in observing system design, and

- Assess proposed methodology for assimilating new observations

DA Challenges and Path Forward

- **Science challenges:**
  - o Improve the JCSDA CRTM in all meteorological conditions
  - o Data assimilation of cloudy- and rainy- impacted radiances
  - o Optimization of the data assimilation of NPOESS/JPSS and GOES-R data (unprecedented flow of data)
  - o Four-Dimensional Variational Assimilation Model (4DVAR)
  - o Develop environmental data assimilation for global and regional scale applications (higher resolution)
  - o Coupling of Atmosphere, Ocean and Land data assimilations in an optimal and most effective way to achieve objectives

- **Other Challenges:**
  - o Infrastructure (lack of a IT infrastructure, access to supercomputers, disk space, etc)
  - o Resources (funding not sufficient to cover all sensors and address all science issues)

- **Next steps**
  - Further collaborate with partners (NCEP, OAR, NASA, DoD), to leverage efforts, through the JCSDA
  - Continue to engage external community (Cooperative Institutes, private sector, academia, etc) in DA issues, through JCSDA FFO and JSDI
  - GOES-R data assimilation readiness
  - NPP/NPOESS (or JPSS) data assimilation readiness
  - Work towards establishing an IT infrastructure for data assimilation purposes