Data Assimilation and the use of Satellite Observations

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National Centers for Environmental Prediction
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Presentation to Satellite Science Week
March 21, 2013

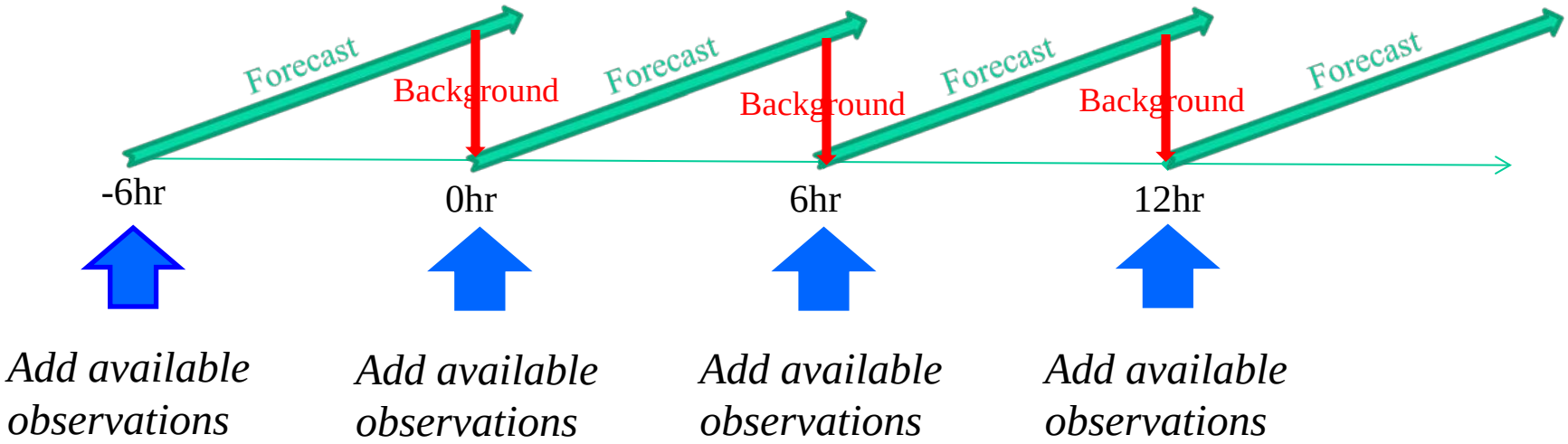
"Where America's Climate, Weather, Ocean and Space Weather Services Begin"

NOAA Operational Data Assimilation Strategy

- Integrated approach
  - Need to use wide variety of observation and analyze all scales results in a unified data assimilation system – Grid-point Statistical Interpolation (GSI) system
  - Complete modeling, data assimilation, data handling, etc. system necessary.
- Make best use of observing system
  - Retrieval or other operations on observations tend to obfuscate instrument characteristics and errors
- Community approach
  - GSI: coordinated development through DTC, NESDIS, NOAA/ESRL, NOAA/EMC, NASA, U. of OK, etc.
  - Requires flexibility with disciplined code management and lots of documentation

Data Assimilation Basics

- **Combines information from previous observations through a short forecast with a new set of observations**



- **Background carries forward information from previous observations**
  - **Background similar overall accuracy as observations – but very different error structures**
- **Improved model = improved analysis and forecast**
- **Only data available in time can be used**

Analysis problem (simplified)

$$J = J_b + J_o$$

$$J = (x-x_b)^T B_x^{-1}(x-x_b) + (K(x)-O)^T (E+F)^{-1}(K(x)-O)$$

J = Fit to background + Fit to observations
x = Analysis
x_b = Background
B_x = Background error covariance
K = Forward model (nonlinear)
O = Observations
$E+F = R$ = Instrument error + Representativeness error

Data Assimilation Basics (Cont.)

- **K(forward model)**
  - **Transformation from analysis to observations**
  - **Includes interpolation – integration of Radiative Transfer – Forecast model (4D-Var) – etc.**

- **E (Instrument error) and F (Representativeness) matrix gives weighting of observations**

- **B (background error covariance matrix) determines scales and structures data is projected into:**
  - **Changes in model variables are related through physics (e.g. temperature and pressure**
  - **Use of ensembles in definition of B (May 22, 2012 implementation)**

Global Data Assimilation System Upgrade

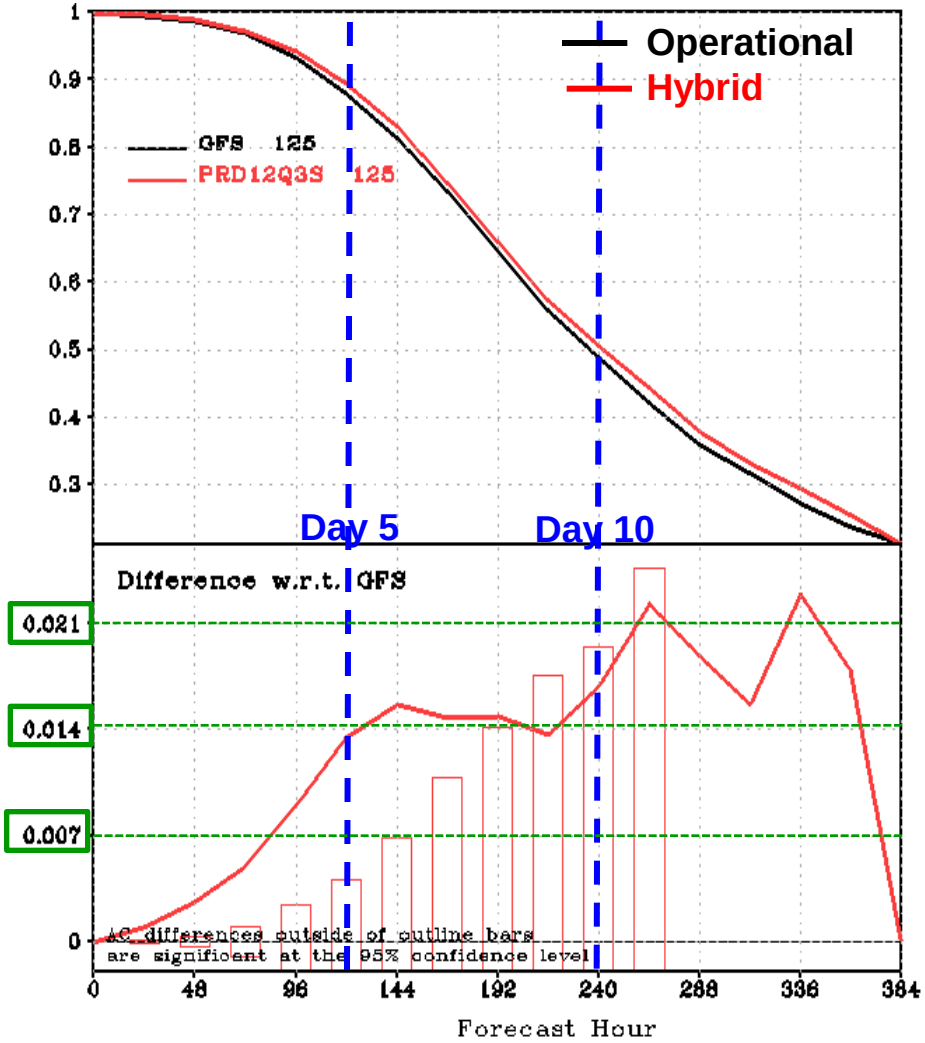
Implemented 22 May 2012

- **Hybrid system**
  - Most of the impact comes from this change
  - Uses ensemble forecasts to help define background error
- **NPP (ATMS) assimilated**
  - Quick use of data after launch
- **Use of GPSRO Bending Angle rather than refractivity**
  - Allows use of more data (especially higher in atmos.)
  - Small positive impacts
- **Post changes**
  - Additional fields requested by forecasters (80m variables)
- **Satellite radiance monitoring code**
  - Allows quicker awareness of problems (run every cycle)
  - Monitoring software can automatically detect many problems
- **Partnership between research and operations**
- **Being tested (with good results) in NAM and HWRF**

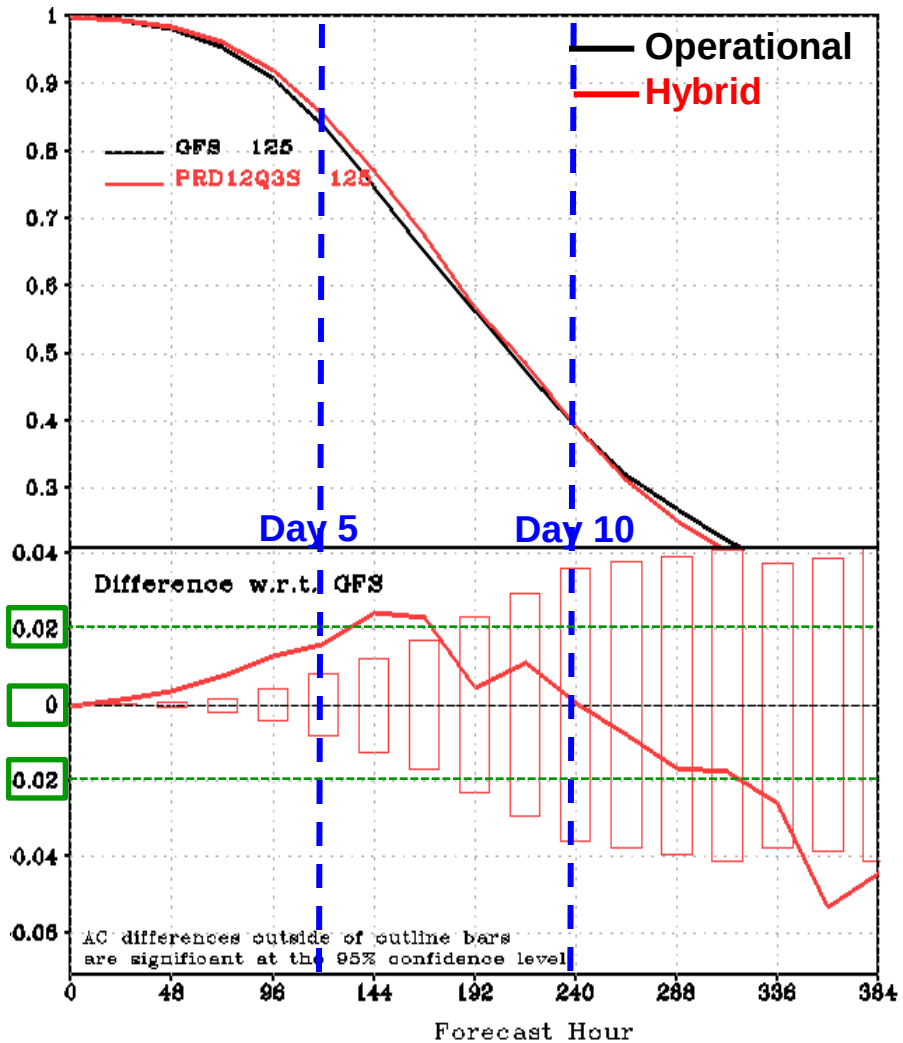
500 hPa Anomaly Correlation for Hybrid GDAS Parallel

8 Jan to 15 May 2012 (00Z cycles only)

Northern Hemisphere



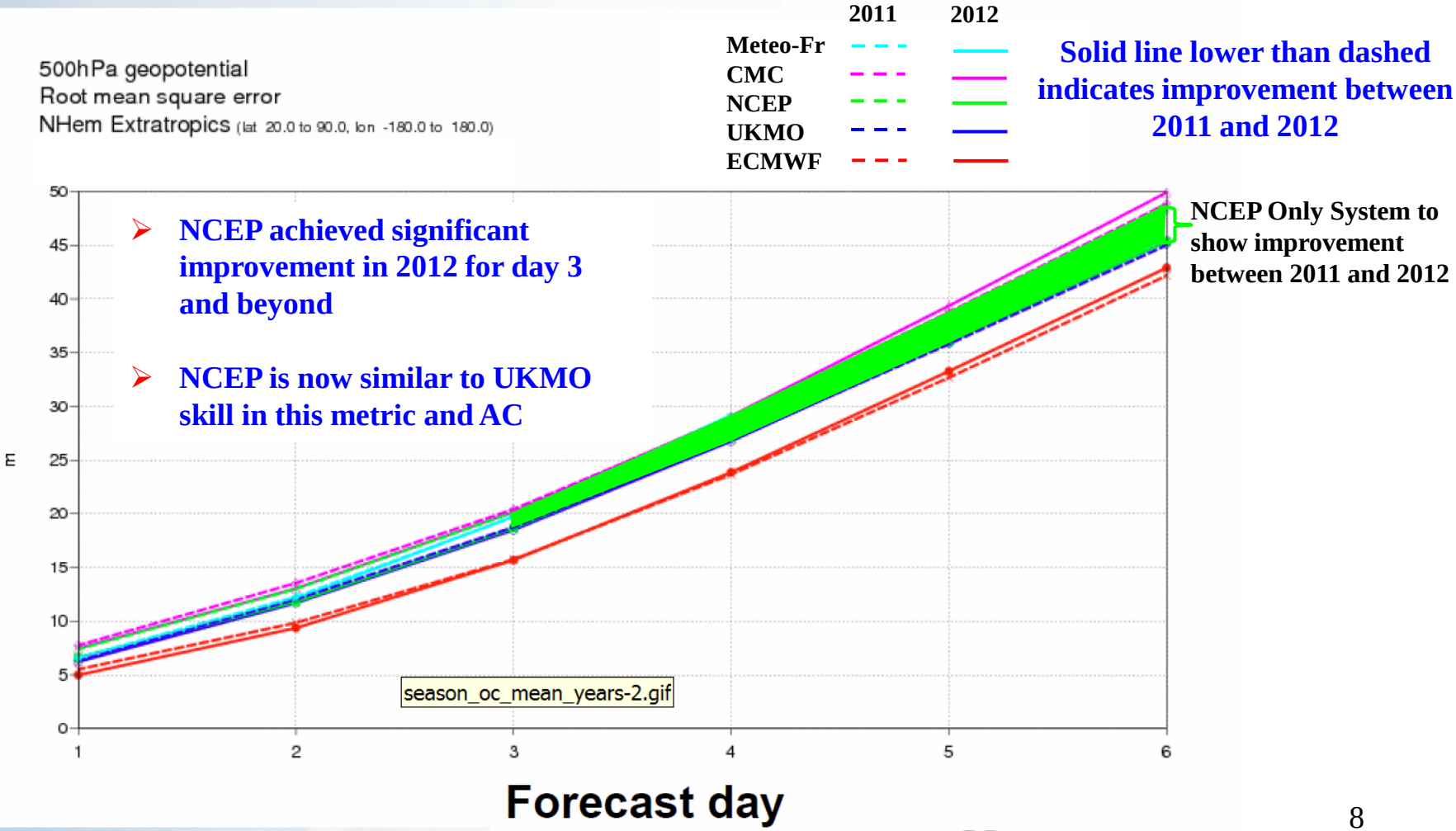
Southern Hemisphere



NCEP Closing the International Gap

June, July, August 500hPa Geopotential RMSE

Comparison with other forecasting centres

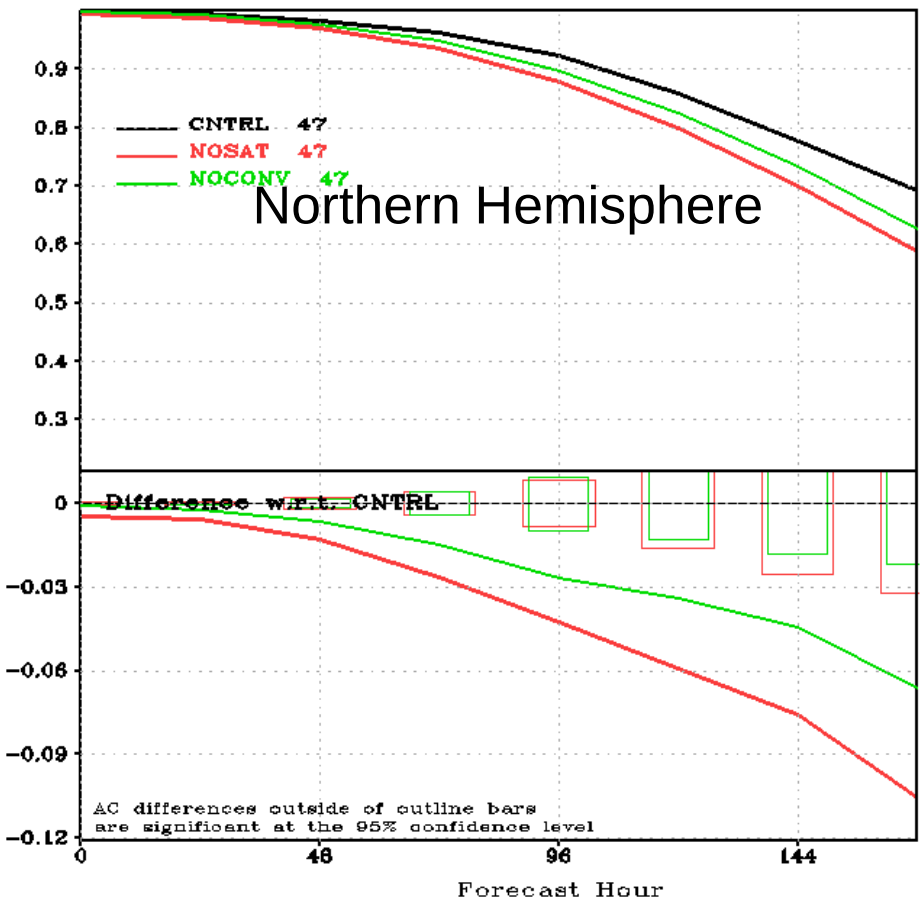


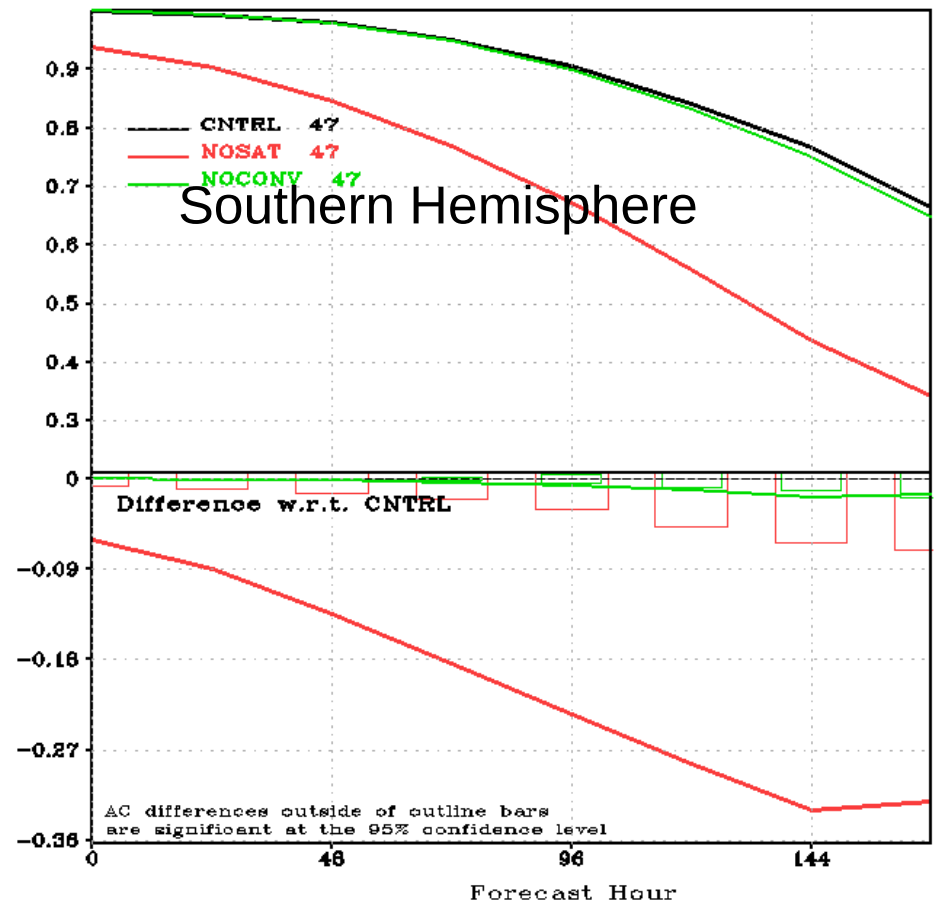
Use of Satellite Data

- Historically, usefulness of data is driven by data assimilation system developments
- Many ongoing satellite data assimilation projects
- Two examples:
  - Clear Imager data from GOES-R
  - Use of cloudy radiance data

Importance of Satellite Data

No Satellite / No Conventional Data

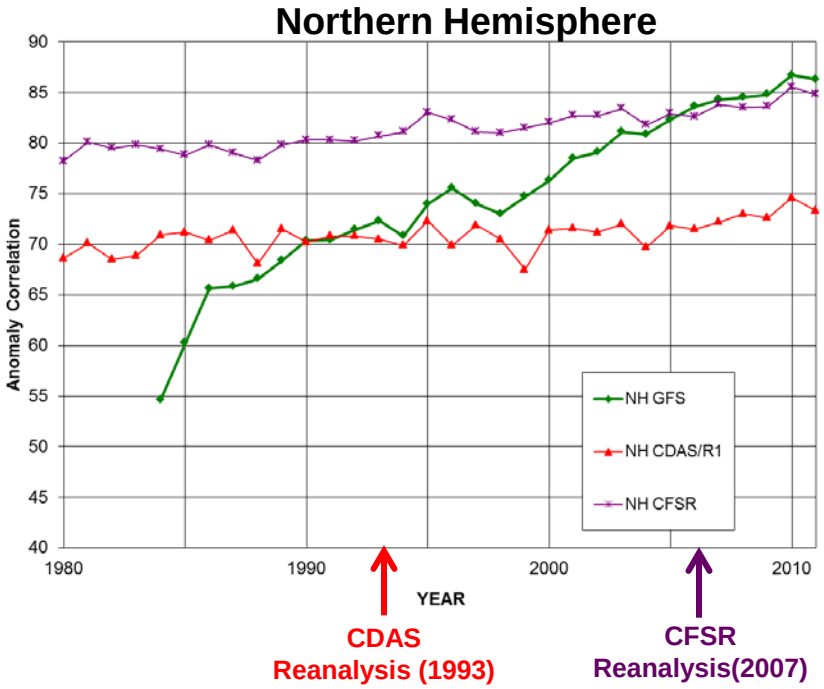


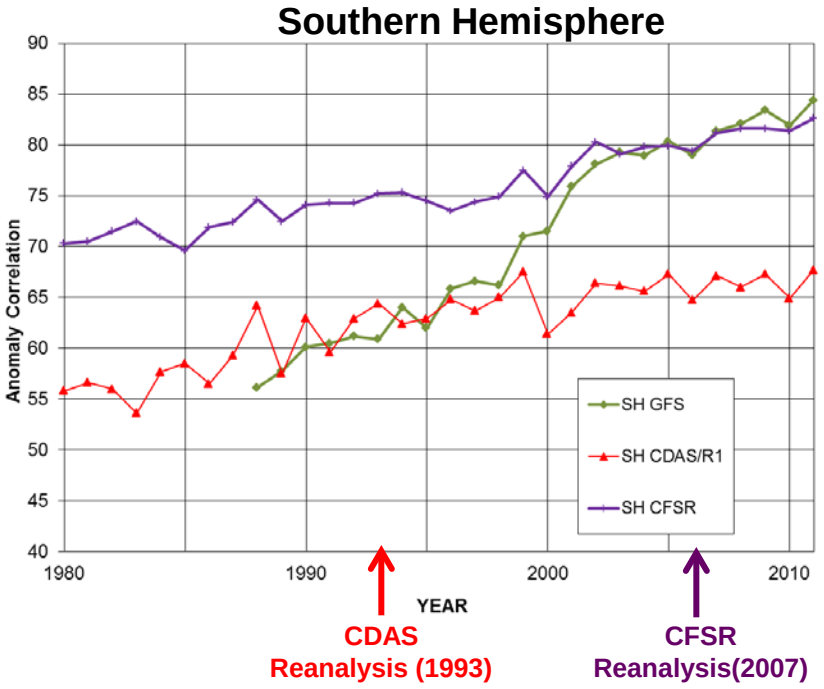


500 hPa Anomaly Correlations
15 Aug – 30 Sep 2010

Historical Global Numerical Guidance Improvement

500hPa Day-5 Anomaly Correlation
Reanalyses and Operational Guidance
1980 to 2011 Annual Average



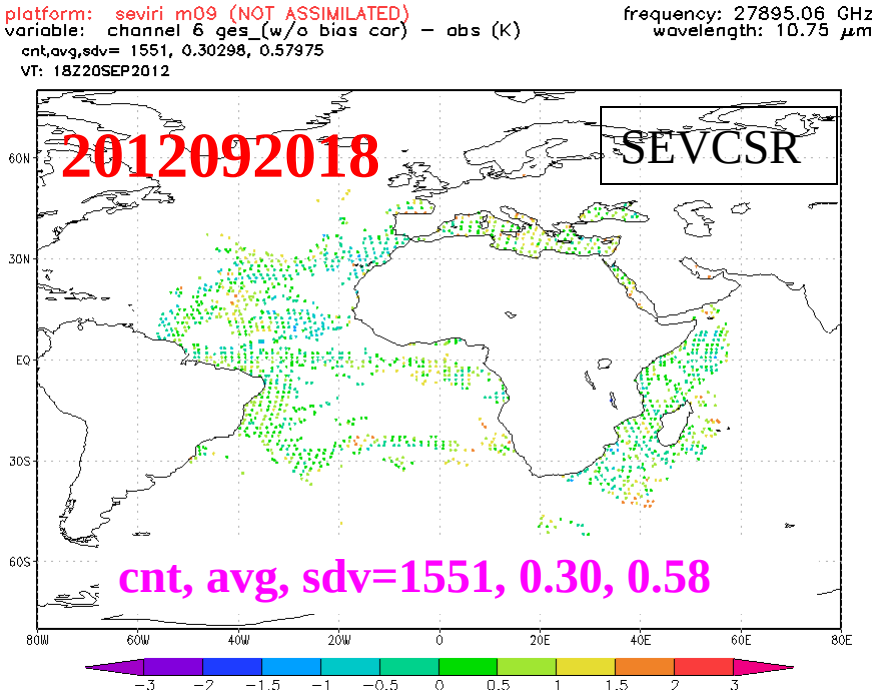


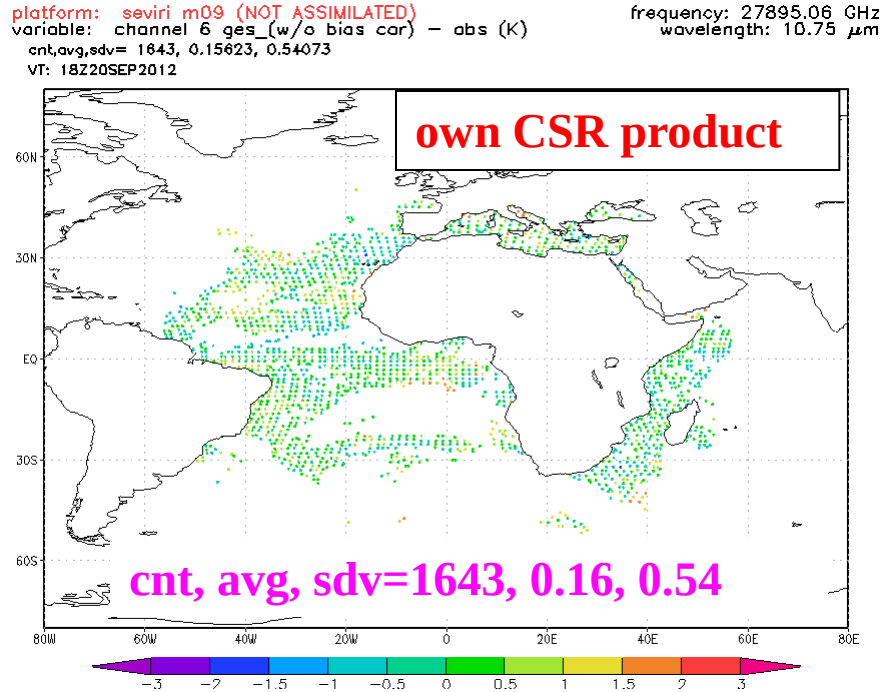
- **Enhancements in the modeling, data assimilation and ability to use observations has driven much of the increase in forecast skill over the last 30 years.**

Clear Imager data from GOES-R

H. Liu, A. Collard

- Using SEVIRI as proxy data
- Use of EUMETSAT area average clear radiances in global operational system
- Preparation for use of individual GOES-R pixals
  - Requires development of cloud detection
  - Comparison after area averaging to EUMETSAT
  - Use of radiances above clouds?


platform: seviri m09 (NOT ASSIMILATED)
variable: channel 6 ges_(w/o bias cor) – obs (K)
cnt,avg,sdv= 1551, 0.30298, 0.57975
VT: 18Z20SEP2012
frequency: 27895.06 GHz
wavelength: 10.75 μm
2012092018
SEVCSR
cnt, avg, sdv=1551, 0.30, 0.58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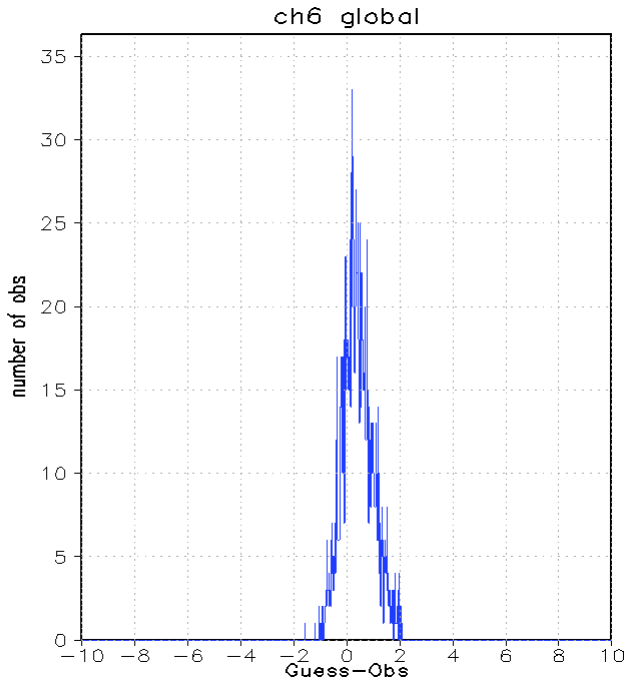
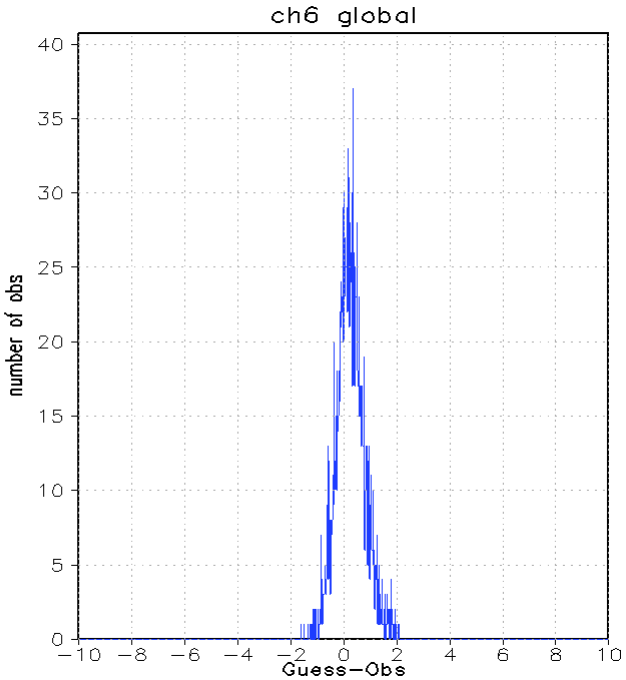
variable: channel 6 ges_(w/o bias cor) – obs (K)
cnt,avg,sdv= 1643, 0.15623, 0.54073
VT: 18Z20SEP2012
frequency: 27895.06 GHz
wavelength: 10.75 μm
own CSR product
cnt, avg, sdv=1643, 0.16, 0.54


ch6 global
number of obs
Guess–Obs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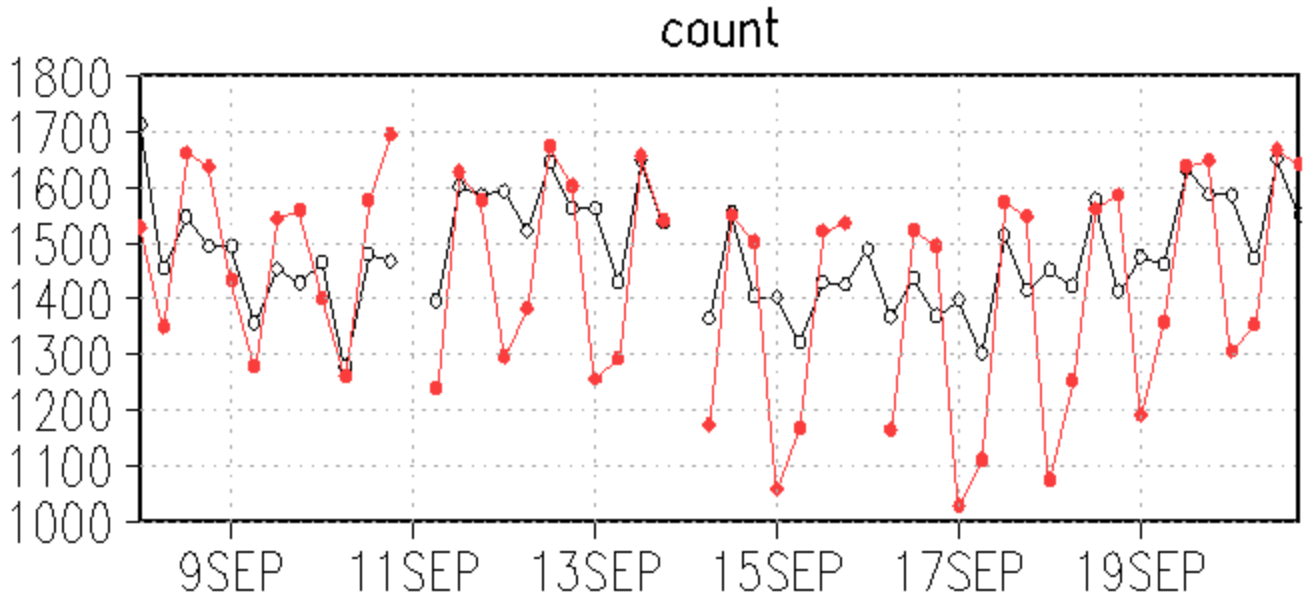
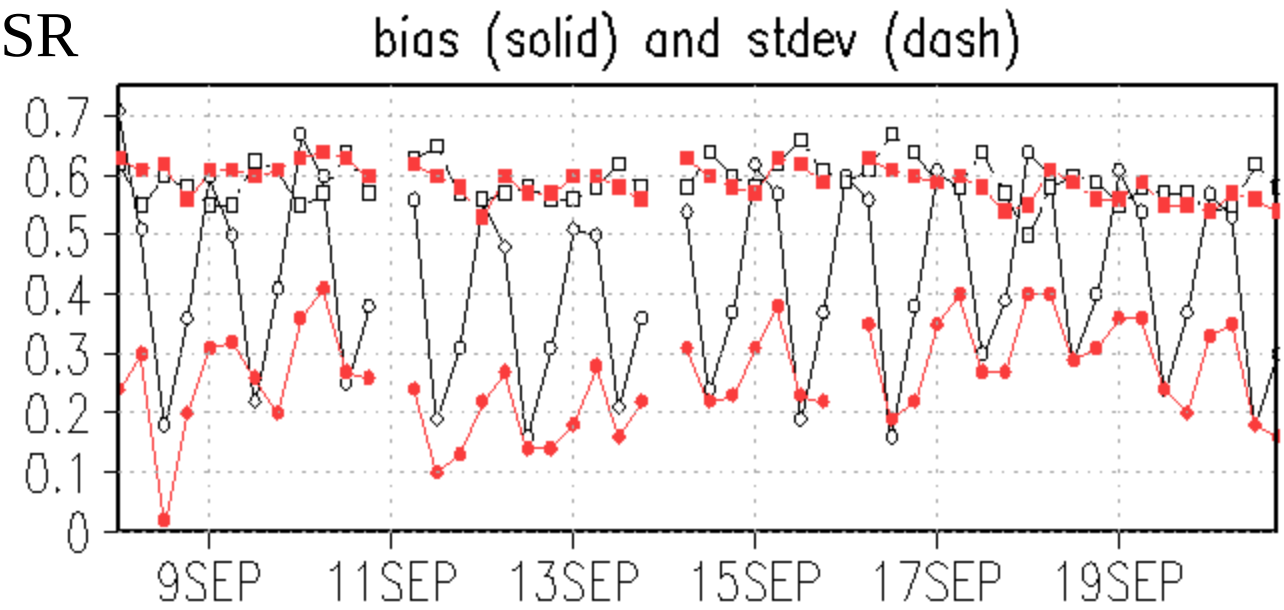


Red: own CSR product

Black: SEVCSR



Cloudy Radiance Assimilation

Min-Jeong Kim, Emily Liu, Yanqiu Zhu, Will McCarty (GMAO)

- Large numbers of radiances contain cloud (and precipitation) signal.
- If cloudy radiances can be properly used, potential for significant improvement in forecasts of temperature, wind, moisture and cloud fields.
- Initially addressing simpler problem with microwave and non-precipitating clouds
- Starting work with IR clouds (with GOES-R funding)
  - Xiaoyan Zhang + collaborators
- Considerable progress has already been made using AMSU-A data

Necessary Modifications To Use Cloudy Radiances

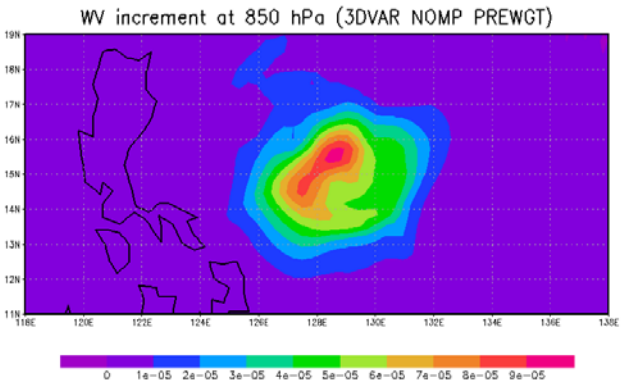
- Simulate cloudy radiances (CRTM)
- Define control variable(s) for clouds
- Define background error for control variable(s)
  – hybrid
- Define quality control (currently only doing nonscattering clouds)
- Define observation errors
- Develop forward model for cloud physics
  – Tangent Linear
  – Adjoint (for gradient)

Moving onto Ensemble-3DVAR Hybrid GSI System Single Obs (AMSU-A Channel 2) Tests

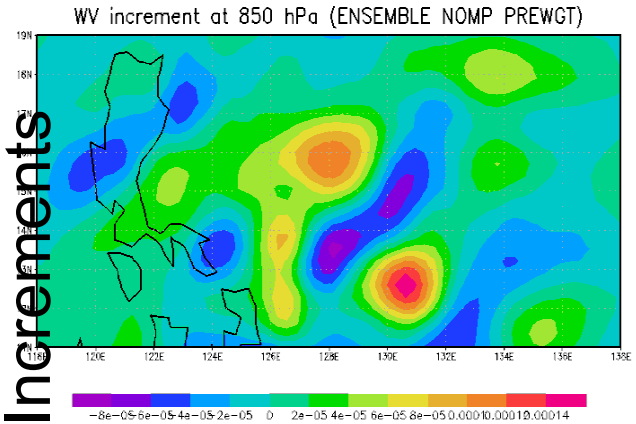
Water Vapor Increments

850 hPa Increments

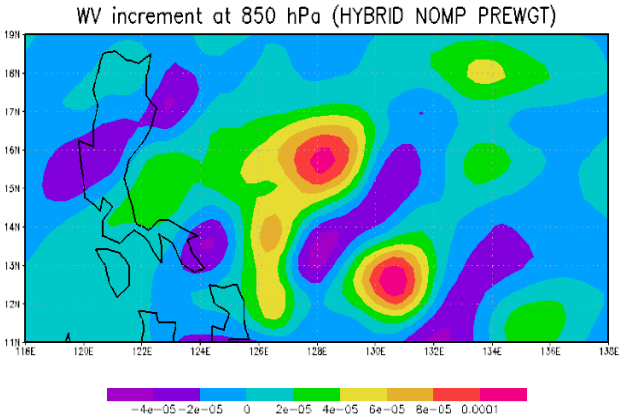
3DVAR

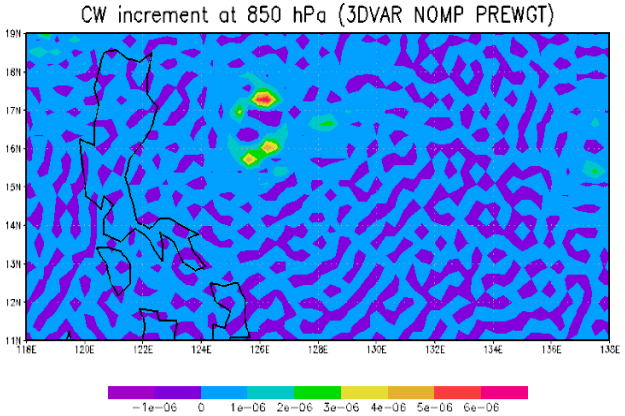


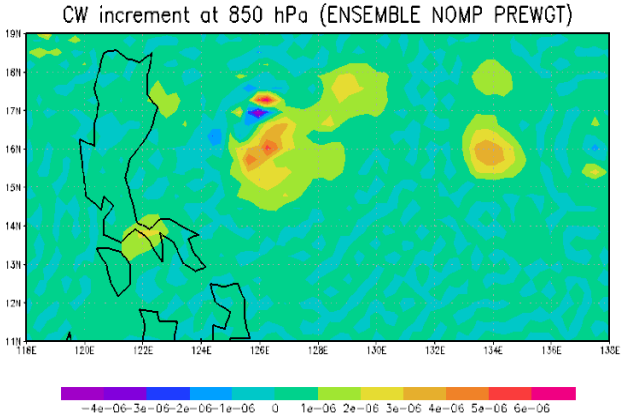
Ensemble

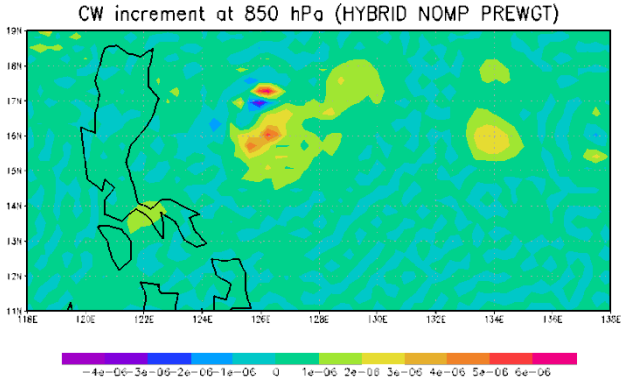


Hybrid





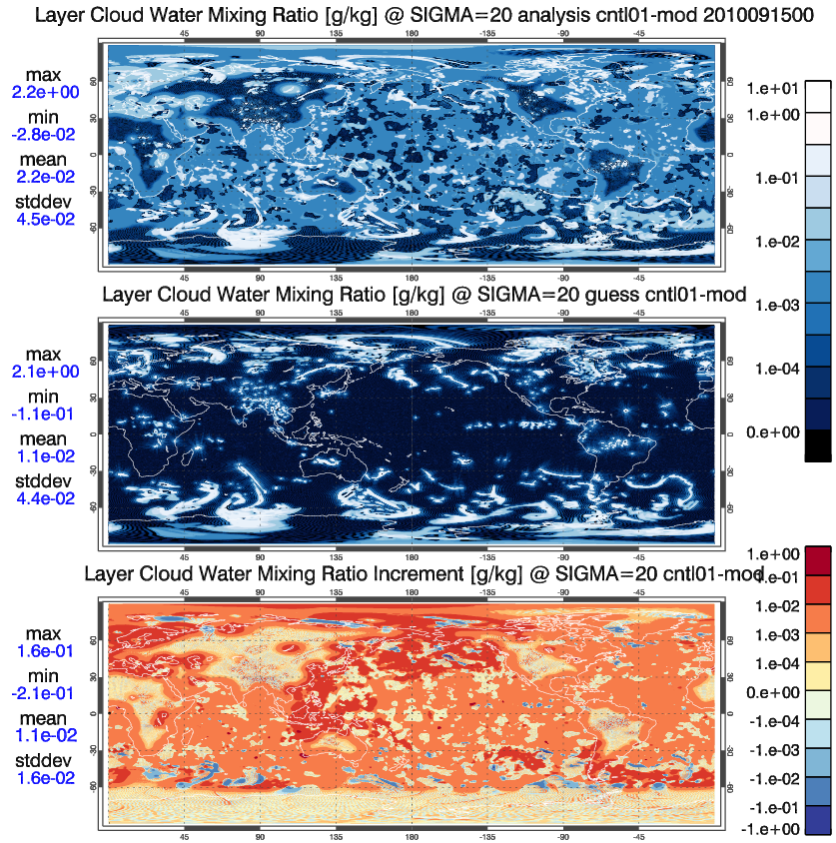




Cloud Water Increments

Testing Impact of Different Control Variables on Cloud Analysis

CW as control variable

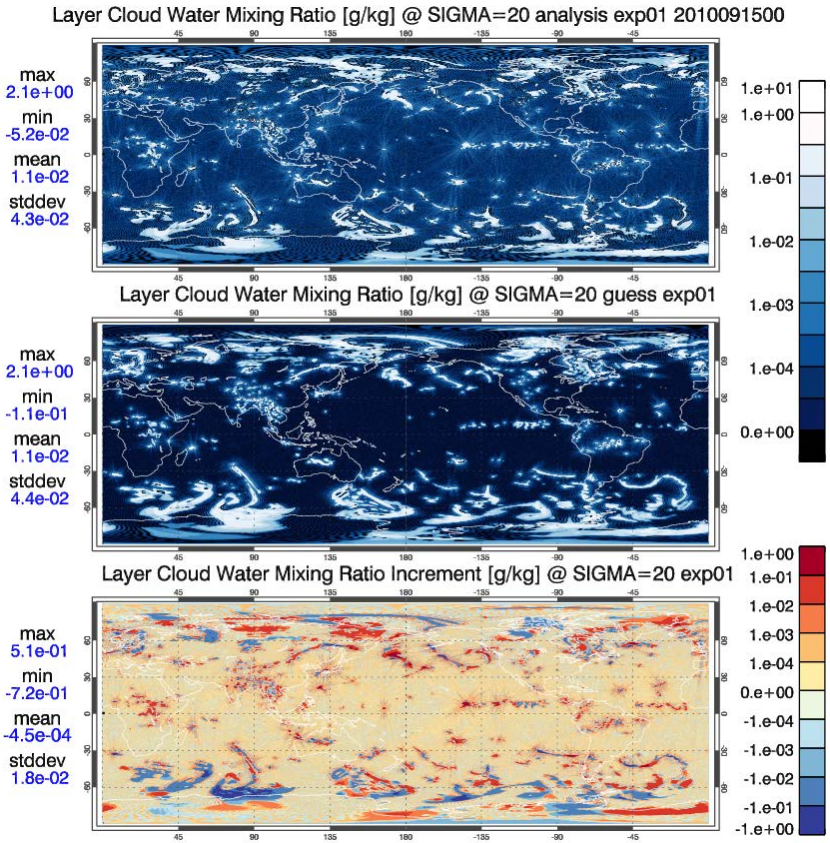


ANL

BKG

INC

Normalized RH total as control variable

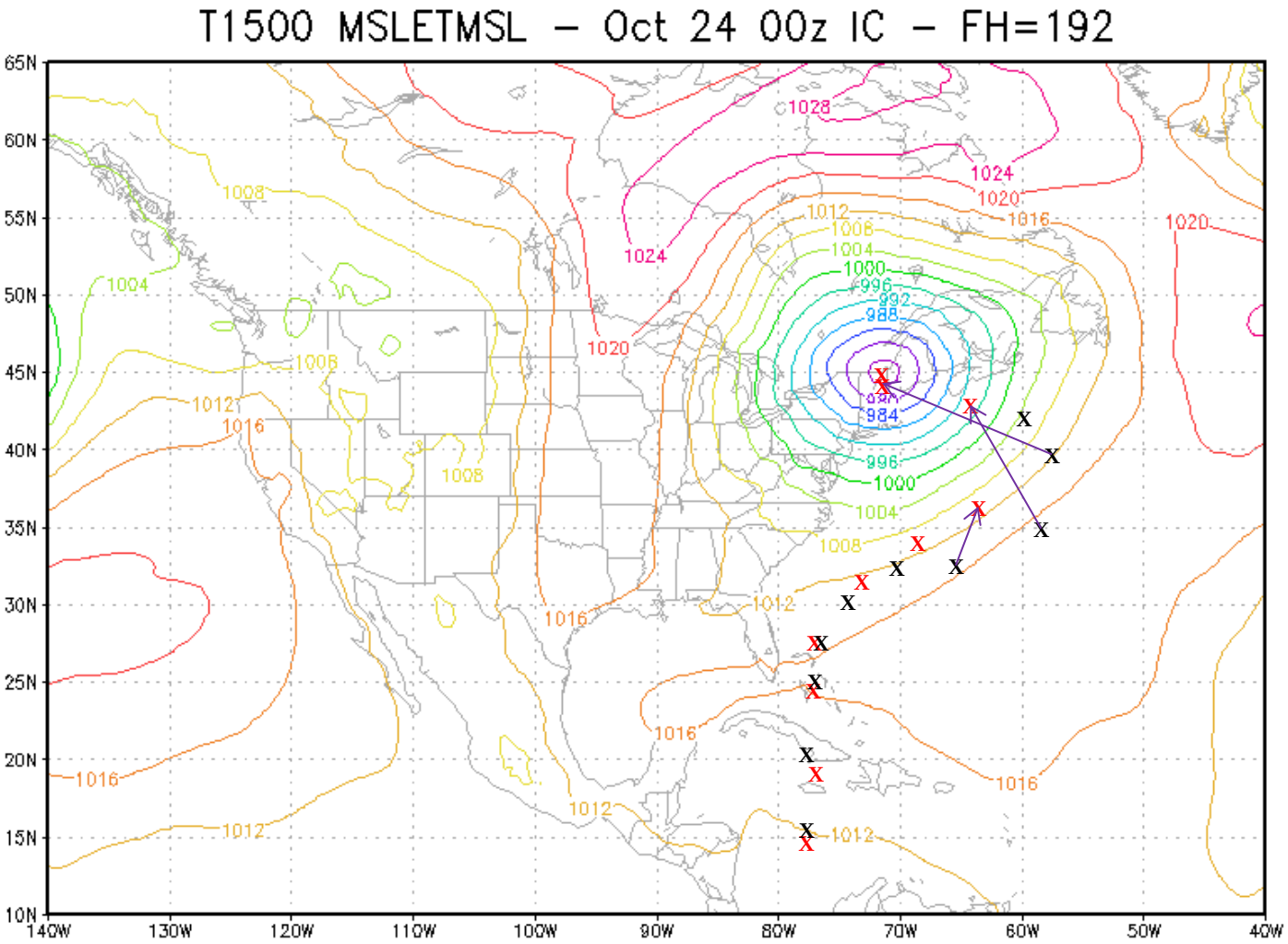


Generate excessive clouds in the analysis
May lead to degradation in the subsequent forecast

Generate reasonable cloud analysis and increments

GDAS/GFS & GEFS Into 2015

System	Current	Q2FY14	Q1FY15
GDAS	3D En-VAR Dual Res Hybrid	3D En-VAR Dual Res Hybrid	4D En-VAR Dual Res Hybrid
	80 Members @ T254 (55 km)	80 Members @ T574 SL (35 km)	80 Members @ T574 SL(35 km)
	Analysis @ T574 (27 km)	Analysis @ T1148 SL(16 km)	Analysis @ T1148 SL(16 km)
	64 Vertical Levels	64 Vertical Levels	128 Vertical Levels
		Additional Obs. and Hurricane relocation	Cloudy Radiances, Additional Obs., Improved QC and ob. errors
GFS	T574 (27 km) 0 to 7.5-d	T1500 SL (13 km) 0 to 10 d	T1500 SL (13 km) 0 to 10 d
	T254 (55 km) 7.5 to 16-d	T574 SL (35 km) 10 to 16-d	T574 SL (35 km) 10 to 16-d
	64 Vertical Levels	64 Vertical Levels	128 Vertical Levels
		Semi-Lagrangian – Enhanced physics	Higher top, non-hydrostatic, NEMS, Coupled Ocean
GEFS	T254 (55 km) 0 to 8-d	T574 SL (35 km) 0 to 16-d	T574 (35 km) 0 to 16-d
	T190 (70 km) 8 to 16-d		
	42 Vertical Levels	64 Vertical Levels	128 Vertical Levels
		Semi-Lagrangian Integrated with EnKF used in analysis	Full Stochastic physics


T1500 MSLETMSL – Oct 24 00z IC – FH=192
65N
60N
55N
50N
45N
40N
35N
30N
25N
20N
15N
10N
140W
130W
120W
110W
100W
90W
80W
70W
60W
50W
40W
1028
1024
1020
1016
1012
1008
1004
1000
996
992
988
984

Final comments

- Improved use of satellite data requires enhancements to:
  - Model
    - Resolution
    - Physics
    - Non—hydrostatic, etc.
  - Assimilation techniques
    - Improved forward model(e.g., improved RT)
    - Enhanced data handling (improved delivery)
    - Improved quality control
    - Improved specification of observation and background errors
    - Use of cloudy radiances
    - Use of new data
- Collaboration with external groups to enhance global analysis and prediction system is important to our progress