Downscaling GPM-like satellite precipitation information by WRF ensemble data assimilation system

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Goals

- Develop an ensemble based data assimilation system for assimilation and downscaling of precipitation information from the GPM-like observations (e.g., TMI, AMSR-E, MHS, AMSU-B radiances)
- Focus on high-frequency channels (e.g., clouds)
- Incorporate the following state-of-the art components:
  ✧ Weather Research and Forecasting (WRF) model with NASA cloud-microphysical scheme
  ✧ NCEP GSI forward observation operators for conventional and cloud cleared satellite observations NASA SDSU forward operator for precipitation sensitive satellite radiances
  ✧ CSU Maximum Likelihood Ensemble Filter (MLEF) data assimilation method as a framework for addressing non-linear and discontinuous data assimilation problems (Zupanski et al. 2008)
  ✧ Goddard Satellite Data Simulator Unit (SDSU) as radiative transfer models in radiance observation operator
- Assimilate conventional and satellite observations to produce accurate high-resolution precipitation analyses and short term forecasts, with uncertainties assigned to them
- Use this system as a prototype for producing the Level-4 regional high-resolution precipitation analyses and short term forecasts
- Explore applications of the precipitation analyses and forecasts for improving hydrological forecasts

Data Assimilation Method
Maximum Likelihood Ensemble Filter (MLEF)

(Zupanski 2005; Zupanski and Zupanski 2006; Zupanski et al. 2008)

$$J = \frac{1}{2}(\boldsymbol{x}-\boldsymbol{x}_b)^T \boldsymbol{P}_f^{-1}(\boldsymbol{x}-\boldsymbol{x}_b) + \frac{1}{2}\{H[M(\boldsymbol{x})]-\boldsymbol{y}_{obs}\}^T \boldsymbol{R}^{-1}\{H[M(\boldsymbol{x})]-\boldsymbol{y}_{obs}\} = min$$

$\boldsymbol{x}-\boldsymbol{x}_b = \boldsymbol{P}_f^{1/2}(\boldsymbol{I}+\boldsymbol{C})^{-1/2}\zeta$ - Control variable transformation (preconditioning)

$\boldsymbol{C} = \boldsymbol{Z}^T\boldsymbol{Z}$ - ***C*** is information matrix in ensemble subspace (of dim $Nens \times Nens$)

$z^i = R^{-1/2}H[M(x+p_f^i)] - R^{-1/2}H[M(x)]$ - z^i are columns of ***Z***

$p_f^i = M(x+p_a^i) - M(x)$ - $\boldsymbol{p}_f^i$ and $\boldsymbol{p}_a^i$ are columns of $\boldsymbol{P}_f$ (forecast error cov) and $\boldsymbol{P}_a$ (analysis error cov)

$\boldsymbol{y}_{obs}$ - Observations vector of dim $Nobs$

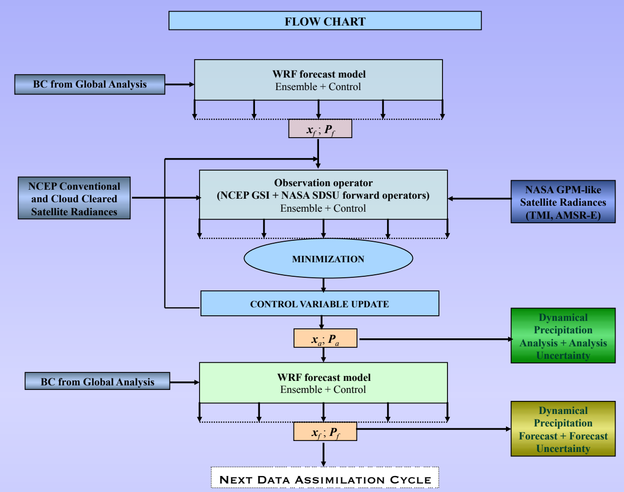
$\boldsymbol{x}$ - Model state vector of dim $Nstate >> Nens$

ζ - Control vector in ensemble space of dim $Nens$

$\boldsymbol{x}_n = M_{n,n-1}(\boldsymbol{x}_{n-1})$ - Dynamical forecast model

$y_n = H_n(\boldsymbol{x}_n)$ - Observation operator

System Design



Case Study

✧ **Hurricane Irene** was formed over the Atlantic on August 20, 2011. While it reached Category 3, with winds over 115 mph on August 24, it was a Category 1 hurricane with winds over 85 mph at landfall on August 27. Although not a very strong hurricane at landfall, it covered a wide area causing an extensive damage due to excessive rainfall and flooding

✧ Assimilation of high-frequency MHS radiances (level 1b) at 89,157,183 GHz over land and ocean

✧ Assimilation of high-frequency AMSR-E radiances (level 1b) at 10.7, 18.7, 23.8, 36.5 GHz (H,V) over ocean and 89GHz (H,V) over land

✧ Assimilation of NOAA operational observations

✧ Data assimilation interval is 3 hours (18UTC 26 AUG2011 - 03UTC 29 AUG2011)

✧ Ensemble size is 32 members

✧ Non-hydrostatic WRF model with nests (9 km and 3 km)

✧ Control variable includes: u, v, t', ph', q, qcloud, qrain, qsnow, qice, qgraupel

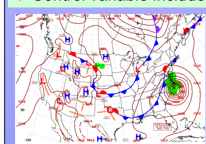


Figure 1. Hurricane Irene: Surface weather map at landfall on 12UTC 27 AUG 2011, near Cape Lookout, North Carolina. The hurricane strength was Category 1, with winds at 85 mph.

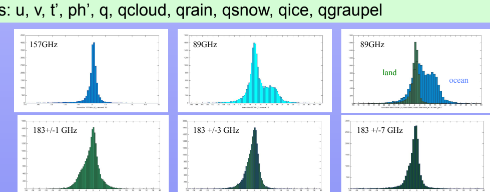


Figure 2. Distribution of radiance departure (MHS). Although departures group near zero, thus no bias, there is a noticeable skewness in the histograms. This illustrates a challenge the bias correction algorithm must resolve. It is also interesting to note the differences for 89 GHz over ocean and over land, another illustration of the complexity of radiance bias correction problem.

Results

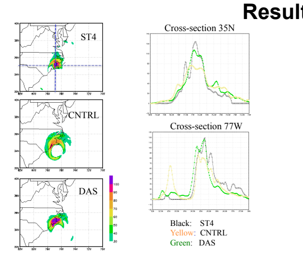


Figure 3. Surface precipitation (mm) accumulated between 09UTC to 12UTC 27 AUG 2011, from forecasts issued at 06UTC 27 AUG 2011 after the first assimilation of MHS radiances, valid 12UTC 27 AUG 2011. Left column: horizontal map, Right column: vertical cross-section. Assimilation of MHS radiances has positive impact on both the the spatial coverage and intensity of precipitation.

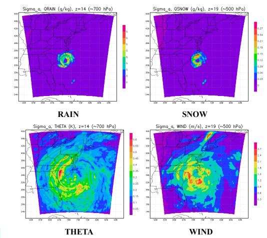


Figure 4. Background error standard deviations for cloud rain, cloud snow, wind and potential temperature, valid 06UTC 27 AUG 2011. Note local character of uncertainty associated with cloud variables, and wide spread uncertainty of dynamical variables.

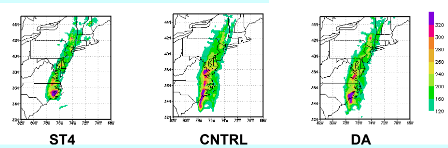


Figure 5. 48-hour accumulated surface rainfall (mm) from 00UTC 27 AUG 2011 to 00UTC 29 AUG 2011: Observed (ST4), no assimilation (CNTRL), and with assimilation (DAS). One can note the improved estimates from DAS, in particular in the areas with the maximum precipitation amounts.

Conclusions

❑ Data assimilation system has been successfully tested in several intensive precipitation events
❑ The system is capable of assimilating precipitation sensitive GPM-like radiances
❑ The system produces dynamically balanced (in balance with wind and other dynamical variables) precipitation analysis.

Future Work

❑ Include assimilation of AMSU-B high frequency channels
❑ Develop radiance observation operator for GPM instruments with realistic scan configurations
❑ Develop capability of precipitation radar observations
❑ Produce Level 4 GPM precipitation analysis at cloud-resolving scales

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