1. FY08 –FY10 GOES-R3 Project Title

- Title: **Data Assimilation: Extracting Maximum Information from the GOES-R Data**
- Project Type: GOES Utilization
- Status: Final Year
- Duration: 3 years
- Leads:
  - » M. Zupanski, CIRA
  - » D. Zupanski, (formerly CIRA)
- Other Participants:
  - » M. DeMaria, STAR/RAMMB
  - » L. Grasso, CIRA
  - » R. Brummer, CIRA
  - » D. Lindsey, STAR/RAMMB
  - » M. Sengupta, NREL
  - » I. Jankov, CIRA

2. Project Summary

1) Prepare algorithms to maximize the use of information from the GOES-R observations
   - Use NCEP operational codes (WRF model, GSI forward operator, CRTM radiative transfer), and the CIRA/CSU hybrid ensemble-variational data assimilation system (Maximum Likelihood Ensemble Filter - MLEF)
   - Expected result: Have available the algorithms for maximizing the information from the GOES-R ABI observations

2) Evaluate the use of information from the GOES-R observations
   - Focus on improving severe weather forecasts and on quantifying the forecast uncertainty
   - Expected result: By extracting maximum information from the GOES-R data we expect to significantly improve the use of the GOES-R ABI observations

3) Preparation for the GOES-R launch:
   - Translate GOES-R data assimilation (DA) development into NOAA operational environment, with clear path to potential operational application. Achieved through the use of NCEP operational codes and alignment with NCEP advanced data assimilation plans.

3. Motivation/Justification

1) Support NOAA Mission Goals: Climate, Weather and Water
   - Use NCEP computer and operational codes to provide smooth transition to potential operational applications

2) Improved use of future GOES-R ABI observations
   - Flow-dependent and dynamically balanced uncertainty using a hybrid ensemble-variational data assimilation (DA) system developed at CIRA/CSU
   - Develop and test the ability of advanced data assimilation to extract maximum information from the GOES-R observations
   - Quantify improvements by introducing and evaluating advanced information measures
   - Evaluate the impact of GOES-R observations on improving cloud microphysics, achieved by extending standard DA control variables to include microphysical variables

4. Major Milestones and Accomplishments (FY08-09)

- **FY08 (accomplished):**
  - » **Goal 1**: Develop algorithms for assimilation of band-averaged AIRS and/or MSG radiances similar to GOES-R ABI radiances

    - Developed basic data assimilation algorithm that employs WRF, MLEF, CRTM

  - » **Goal 2:** Employ other observations available at the NCEP operational data assimilation systems to be able to assess the impact of the AIRS data in the presence of other data.

    - NCEP observations included via the forward GSI component

- **FY09 (accomplished):**
  - » **Goal 1**: Evaluate information measures of satellite observations similar to GOES-R ABI data (e.g., band-averaged AIRS and/or MSG radiances)

    - DA algorithm was updated and real MSG radiances have been assimilated

  - » **Goal 2**: Evaluate the algorithm's ability to extract maximum information from the data through the use of various information measures

    - Two common types of information measures have been considered (*i*) Degrees of Freedom for Signal (DFS) and (*ii*) E-dimension

4. Major Milestones and Accomplishments (FY10)

- **Goal 1**: Summarize results by quantifying the potential impact of the GOES-R ABI data on the forecast improvements

  - Information measures, such as DFS and E-dimension, are useful diagnostic tools that clearly indicate the areas with high impact of GOES-R observations (as well as the areas with low observation impact).

  - Ensemble DA with WRF model and assimilating GOES-R (synthetic and proxy) shows that DA does maximize the impact of observations, as suggested by theory.

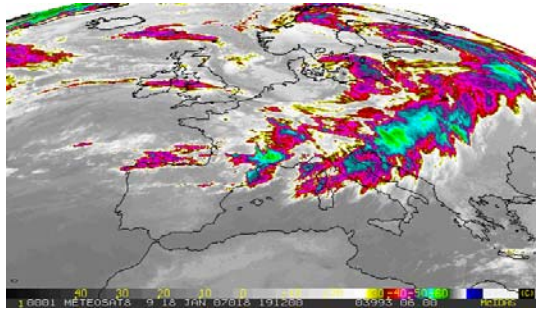
  - It is possible to improve analysis and forecast by adjusting cloud microphysical control variables, very encouraging for future use of GOES-R observations. However, this requires the use of a hybrid DA or other advanced DA system that can produce dynamically balanced increments all model variables (including microphysics).

4. Major Milestones and Accomplishments (FY10)

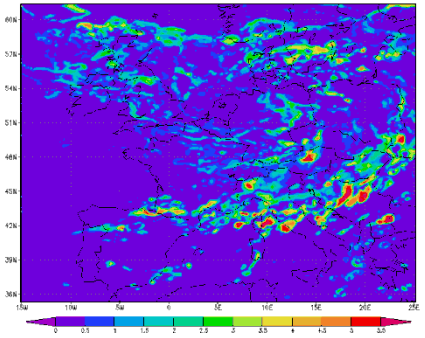
Flow-dependent information measures

Results shown for Kyrill, a strong extratropical storm over Europe in Jan 2007

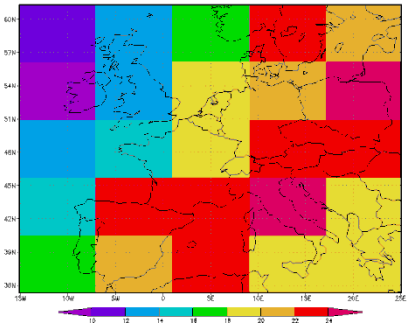
METEOSAT Imagery valid at 19:12 UTC 18 Jan 2007



Cloud ice analysis uncertainty



Degrees of Freedom for Signal (DFS)



For 10.35 μm, valid 1900 UTC 18 Jan 2007)

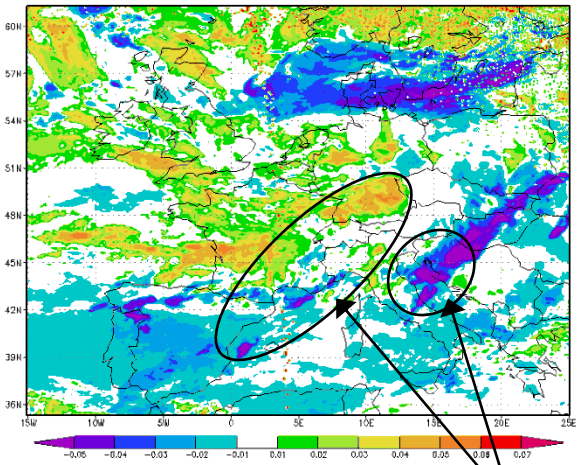
- Highest information content in the area of the storm (where it is needed) indicating a maximization of the information from GOES-R observations.

- There is a large sensitivity of cloud ice to GOES-R observations (an outcome of the enhanced DA capability to adjust microphysical control variables)

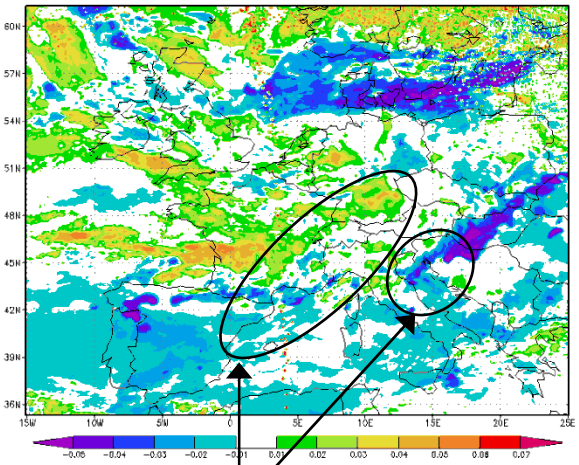
4. Major Milestones and Accomplishments (FY10)

Assimilation of MSG 10.80 μm radiance observations
(Kyrill, valid 1900 UTC 18 Jan 2007)

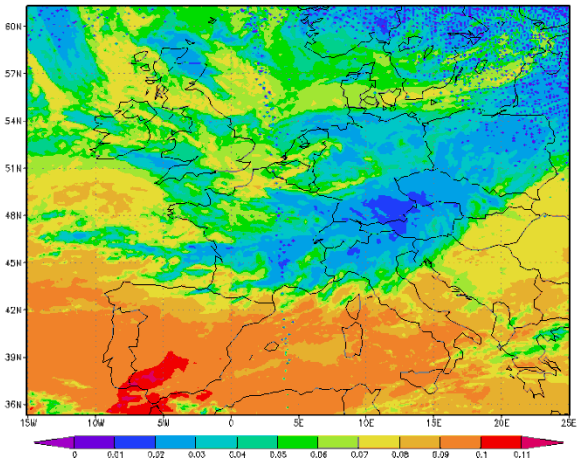
Diff: FG-OBS



Diff: ANL-OBS



OBS (Radiance field)



Improved fit to observations due to data assimilation.

- DA reduces guess forecast error in the area of the storm
- Due to flow-dependent cross-correlations, DA is capable of "moving" forecasted clouds to the observed location

4. Major Milestones and Accomplishments (FY10)

- **Goal 2**: Submit publications to refereed journals
  (2 published, 1 in press, 1 in preparation)

Zupanski, D., 2009: Information measures in ensemble data assimilation. Chapter in the book titled "*Data Assimilation for Atmospheric, Oceanic, and Hydrologic Applications*", S. K. Park and L. Xu, Eds., Springer-Verlag, Berlin, 85-95, 475 pp.

Zupanski, M., 2009: Theoretical and practical issues of ensemble data assimilation in weather and climate. Chapter in the book titled "*Data Assimilation for Atmospheric, Oceanic, and Hydrologic Applications*", S. K. Park and L. Xu, Eds, Springer-Verlag, Berlin, 67-84, 475 pp.

Zupanski, D., **M. Zupanski**, **L. Grasso**, **R. Brummer**, I. Jankov, **D. Lindsey**, M. Sengupta and **M**. **DeMaria**, 2010: Assimilating synthetic GOES-R radiances in cloudy conditions using an ensemble-based method. *Int. J. of Remote Sensing.*, In press.

Zupanski, M., **D. Zupanski**, **L. Grasso**, **R. Brummer**, **D. Lindsey**, and **M**. **DeMaria**, 2010: Impact of cloudy satellite radiance observations in quasi-operational environment using an ensemble data assimilation method. *Int. J. of Remote Sensing.*, to be submitted.

4. Major Milestones and Accomplishments (FY10)

- **Goal 3**: Finalize algorithms for the GOES-R team and, if applicable, for the NOAA/NCEP operations

  - Ensemble DA system employing NCEP operational model and observations is being implemented on the NOAA R&D computer, and will be used for evaluation of the assimilation of GOES-R ABI observations in quasi-operational environment.

  - Availability of the system on the NOAA computer, coupled with synergy with this and other NOAA projects, will provide the mechanism for transferring results of this research (whole algorithm or its components) into potential NOAA operations

5. Unexpected Results

- Assimilation of synthetic and proxy (MSG SEVIRI) GOES-R ABI data shows a similar impact. This suggests that synthetic data experiments are beneficial and reliable tool for investigating the impact of future satellite instruments.

- This also suggests that a non-identical twin experiment setup (i.e., using different models to create synthetic observations and for assimilation) can simulate model errors, thus provide a realistic environment for testing future satellite data.

6. Additional Activities Leveraged

GOES-R data assimilation research creates a synergy with related projects:

- NOAA Hurricane Forecasting Improvement Program (HFIP)
- NOAA NESDIS Utility of GOES-R for Hurricane Assimilation and Prediction
- NASA Global Precipitation Mission (GPM)
- NSF Collaboration in Mathematical Geosciences.

A common scientific theme is the assimilation of all-sky satellite radiances and its impact on the analysis and forecast of clouds and precipitation.

7. Recommendations for follow on research

- Perform a thorough assessment of assimilation of GOES-R observations in NOAA operational environment
- Focus on high-impact weather of relevance to NOAA
- Include nonlinear radiance bias correction
- Relate NASA GPM, JCSDA and GOES-R development