Assimilation of cloud/precipitation data at regional scales

Thomas Auligné
National Center for Atmospheric Research
auligne@ucar.edu

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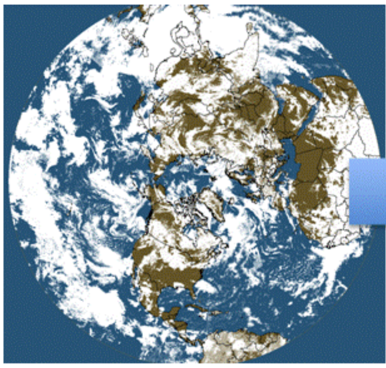
Introduction

- **The Model**
  - Weather Research and Forecasting (WRF) community model.
  - Advanced Research WRF (ARW) non-hydrostatic dynamical core
- **The Data Assimilation (DA)**
  - Data Assimilation Research Testbed (DART): EnKF
  - WRF Data Assimilation (WRFDA): 3DVar, FGAT, 4DVar
  - Gridpoint Statistical Interpolation (GSI): 3DVar, 4DVar under development
- **The Operational Applications**
  - Air Force Weather Agency (AFWA)
  - NOAA ("Rapid Refresh")

Introduction

World-
Wide
Merged
Cloud
Analysis



AFWA Coupled Analysis and Prediction System (ACAPS)

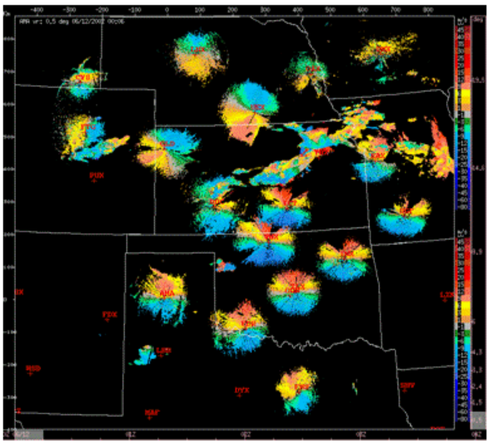
SCOPE: *Develop an analysis and prediction system of 3D cloud properties combined with the dynamical variables.*

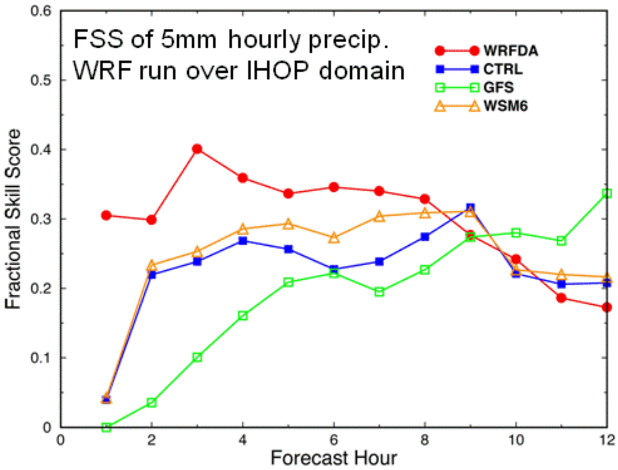
WRFDA 3DVAR and radar radial velocity

IHOP one-week retrospective study

CTRL	Initialization by NCEP ETA analysis
GFS	Initialization by NCEP GFS analysis
WRFDA	WRF 3DVAR radar radial velocity
WSM	CTRL with different microphysics

Radial velocity 2002061200 UTC

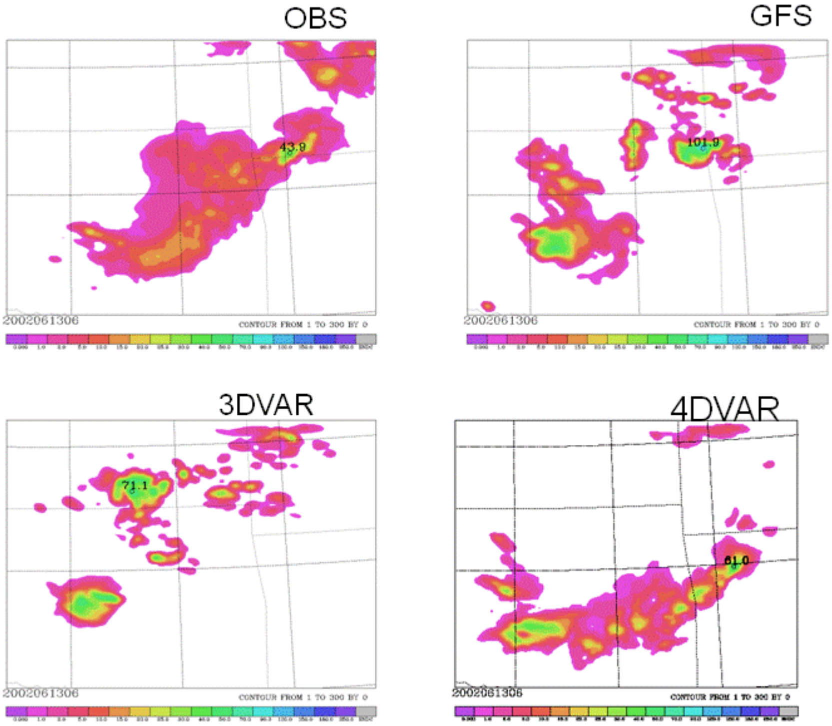




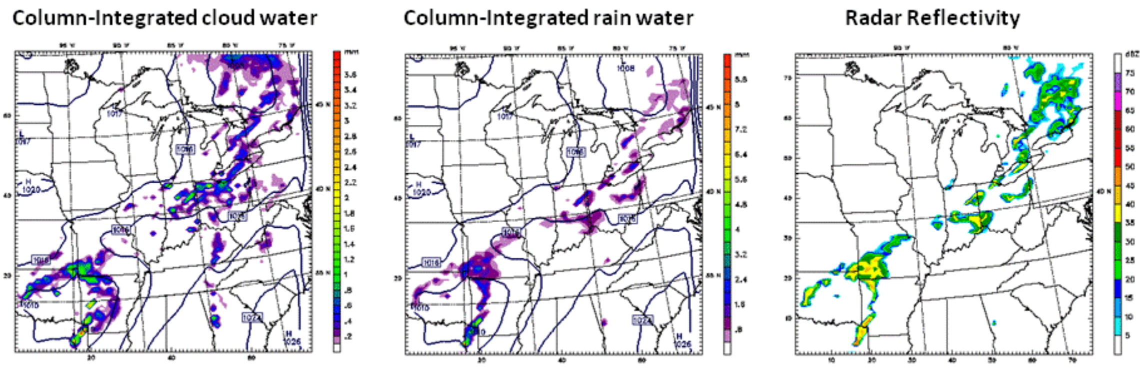
- Radar data assimilation improves the precipitation forecast up to 8 hours
- Forecast is more sensitive WRT initial conditions than physics (microphysics is most sensitive among all physics tested)

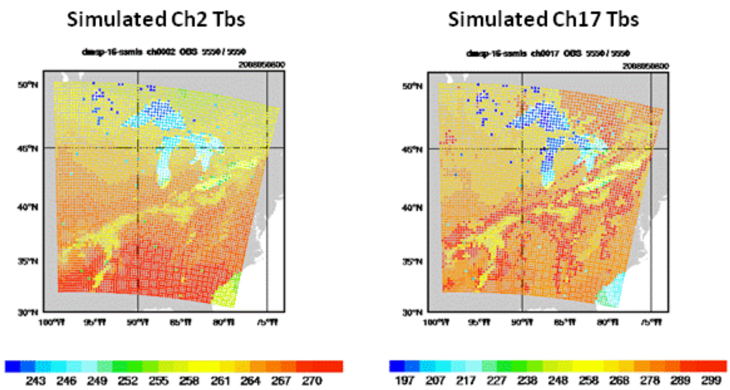
(Jenny Sun)

Hourly precipitation at 0600 UTC 13 June



Simulated SSMIS radiances





Model = "truth" for SSMI/S radiance simulation

Only liquid hydrometeors considered

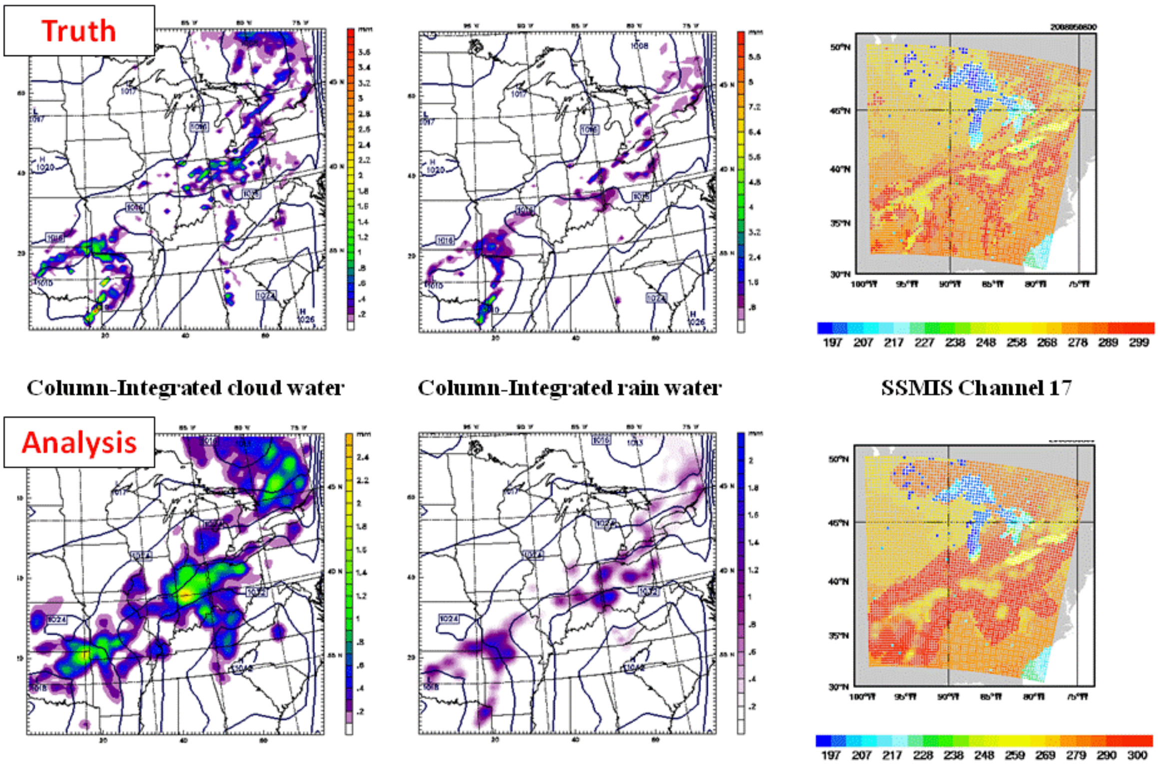
Simulated SSMIS radiances (ch 1~6, 8~18) at each grid-point using CRTM

(Zhiquan Liu)

Assimilation of simulated SSMIS radiances in WRF 3DVAR

- Use total water $\mathbf{Q_t=Q_{wv}+Q_{clw}+Q_{rain}}$ as a control variable (instead of individual hydrometeors)
- Use a warm-rain microphysics scheme's TL&AD for partitioning Q_t increment into Q_{wv}, Q_{clw} & Q_{rain}. (Xiao et al., 2007)
- CRTM as cloudy radiance observation operator
- Minimization starts from a cloud-free background, this scenario can be realistic for less accurate cloud/precip. forecast in the real world
- Perfect background for other variables (T,Q etc.)
- Perfect observations (no noise added to the simulated Tbs)
- 2 outer-loops

Simulated SSMIS radiances

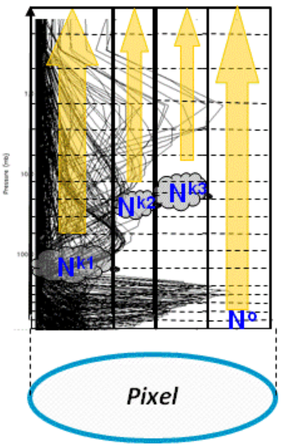


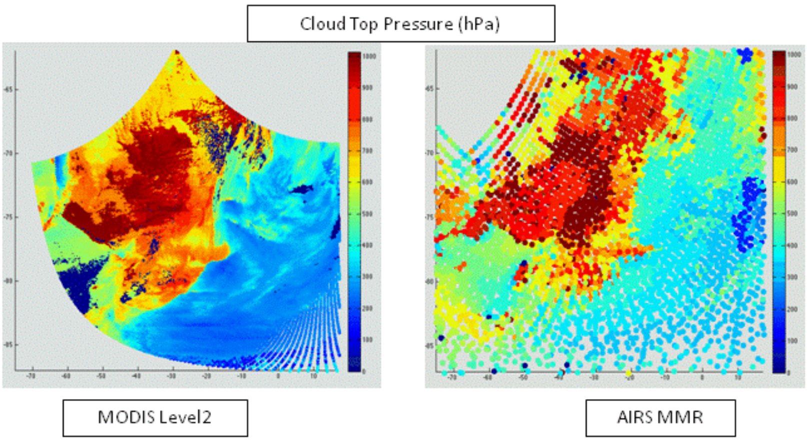
Infrared Cloudy Radiances

$$R_\nu^{Cld} = N^0 R_\nu^0 + \sum_{k=1}^{n} N^k R_\nu^{\bullet k}$$

Cloud fractions N^k are ajusted variationally to fit observations:

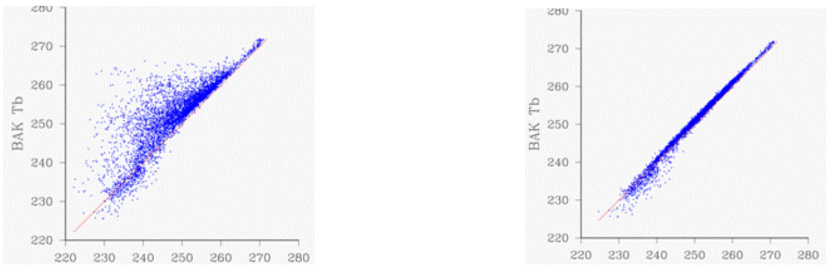
$$J(N) = \frac{1}{2}\sum_\nu \left(\frac{R_\nu^{Cld} - R_\nu^{Obs}}{R_\nu^{\circ}} \right)^2 \quad \text{with} \quad \begin{cases} 0 \le N^k \le 1, \forall k \in [0, n] \\ N^\circ + \sum_{k=1}^{n} N^k = 1 \end{cases}$$

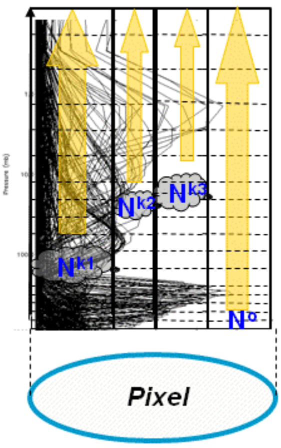




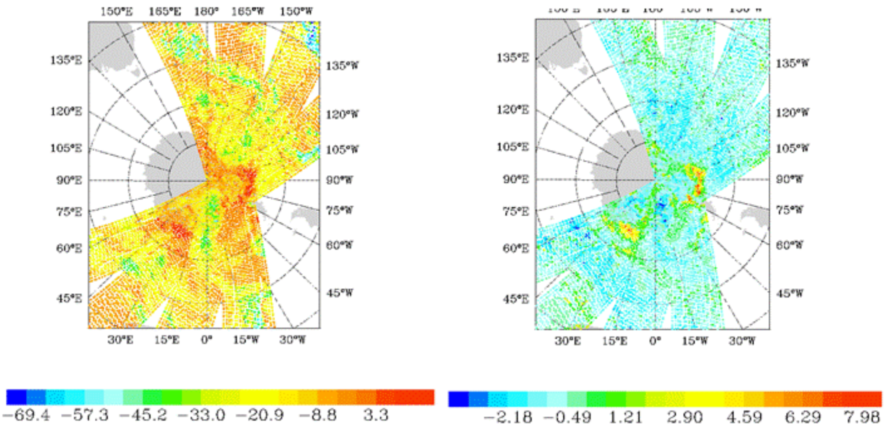
IR Cloudy Radiances

(linear obs operator)

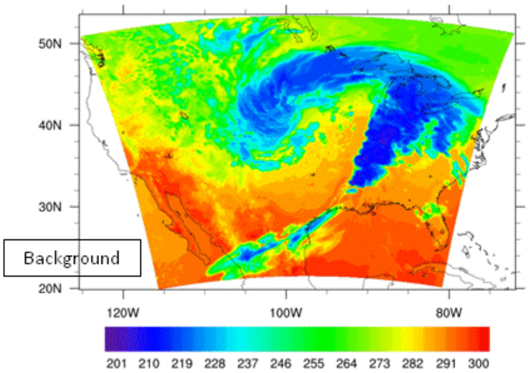


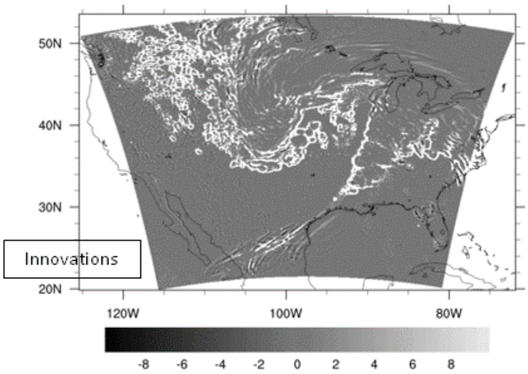


$R_\nu^{Obs} - R_\nu^{\circ}$ $\quad$ $R_\nu^{Obs} - R_\nu^{Cld}$



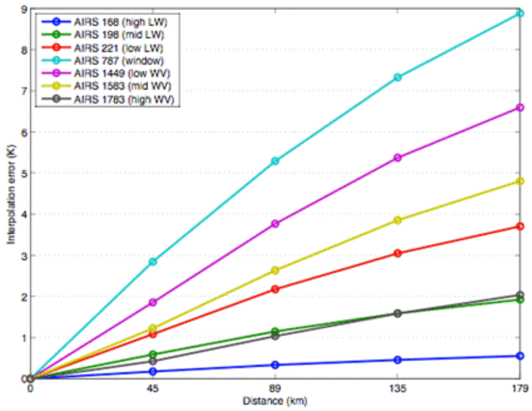
Representativeness Error





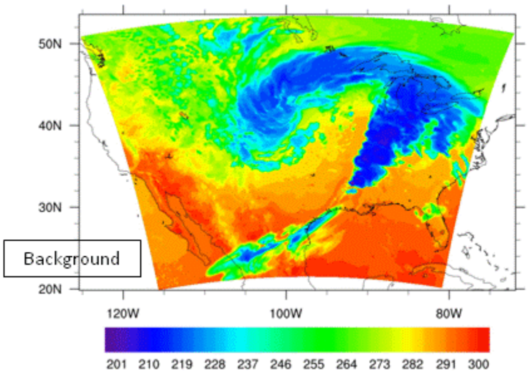
Simulated mismatch in resolution:

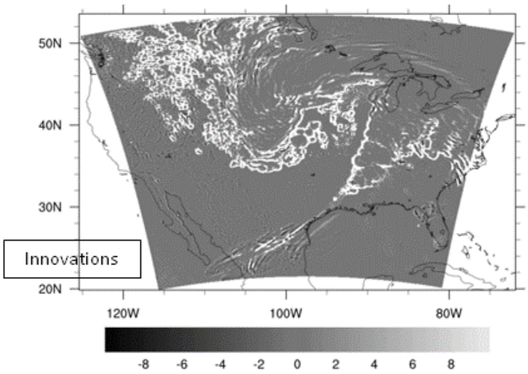
- Perfect observations (high resolution)
- Perfect Background (lower resolution)



11

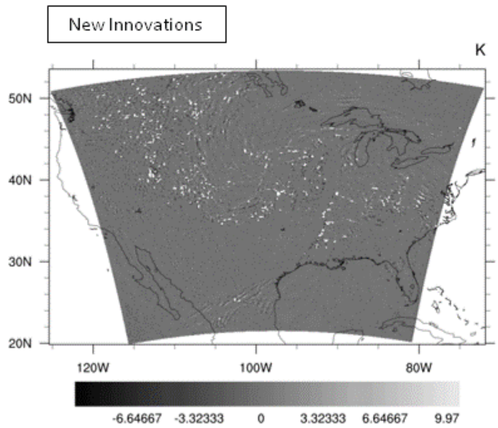
Representativeness Error



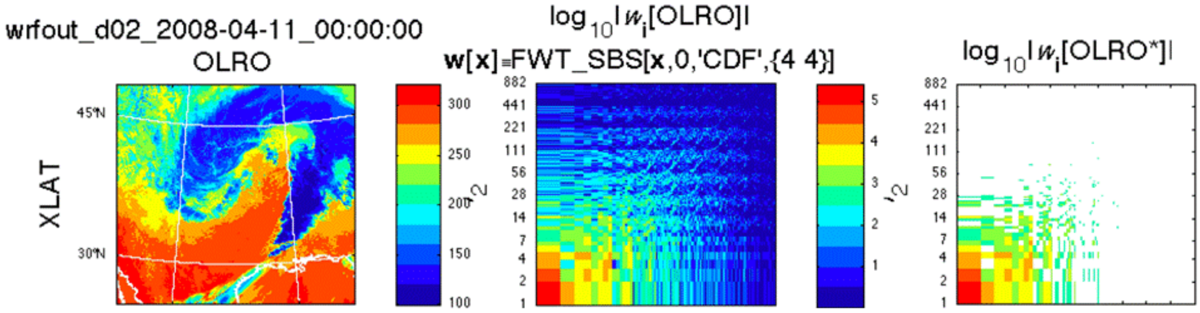


New interpolation scheme:

1. Automatic detection of sharp gradients
2. New "proximity" for interpolation



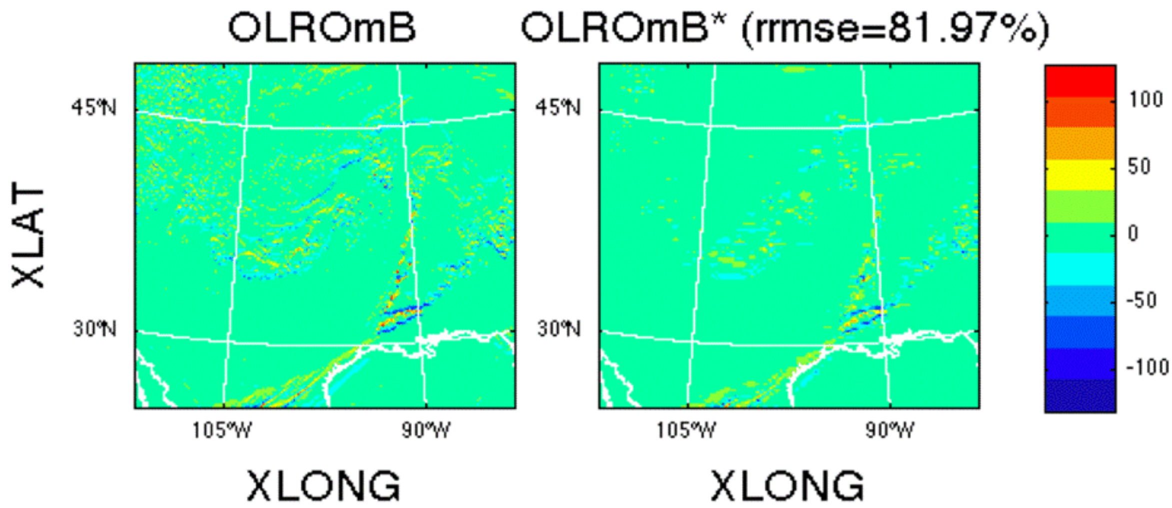
Biorthogonal wavelet transform can *isolate* observation-background differences scale-by-scale while preserving physical-space localization



By sorting and comparing $|w_i|$ for obs. $\mathbf{y}_o$ & background $\mathbf{y}_b$ we can isolate a multi-scale subset $\boldsymbol{i} \in \mathbb{I}$ (right) from which *equivalent* representations $\mathbf{y}_o^*$ and $\mathbf{y}_b^*$ of $\mathbf{y}_o$ and $\mathbf{y}_b$ can be reconstructed…

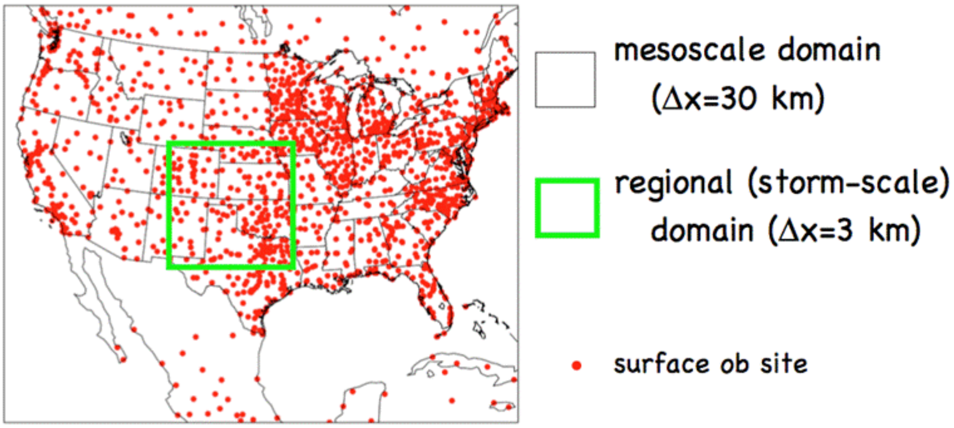
(Aimé Fournier)

Reduction in representativeness error within observation-background differences



The raw $\mathbf{y}_o - \mathbf{y}_b$ (left) includes errors due to $\mathbf{y}_o$ and $\mathbf{y}_b$ coming from completely different representations, that (hypothetically) have been *reconciled* by the foregoing wavelet-coefficient selection procedure.

WRF ensemble

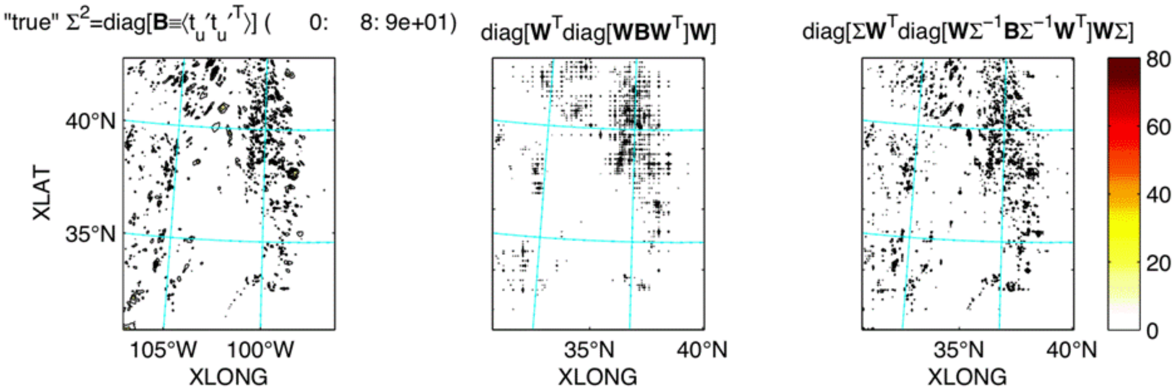


- 30-km ensembles are initialized at 1200 UTC on the day of interest.
  - Multi-physics ensemble
    - PBL (3 schemes), cumulus (3 schemes), shortwave radiation (2 schemes)
  - Ensemble mean and boundary conditions from 1200 UTC NAM
  - Spatial perturbations from an ensemble Kalman filter applied to observations (sounding, surface, aircraft) during the previous 2.5 days
    - Perturbations are mesoscale and flow dependent.
    - Grid-scale dynamics and parameterization diversity increase ensemble spread.
    - Observations decrease ensemble spread.
- Each 30-km ensemble member provides initial and boundary conditions for a 3-km ensemble member.

(David Dowell)

Wavelet representation of Background Error Covariance Matrix

Background covariance can be *efficiently* modeled by assuming diagonality of the wavelet-coefficient covariance matrix (Fisher & Andersson, Deckmyn & Berre).



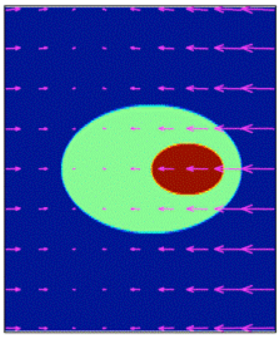
•The normalization with $\boldsymbol{\Sigma}^2 = \text{diag}\,\mathbf{B}$ (left) yields a model with *fewer* artifacts (right) than does $\boldsymbol{\Sigma} = \mathbf{I}$ (center) (as found by D&B earlier).

• In these plots $\mathbf{x}$ is unbalanced temperature anomaly in a 30-member ensemble computed by Dowell with horizontal resolution $N = 450 \times 350$.

(Aimé Fournier)

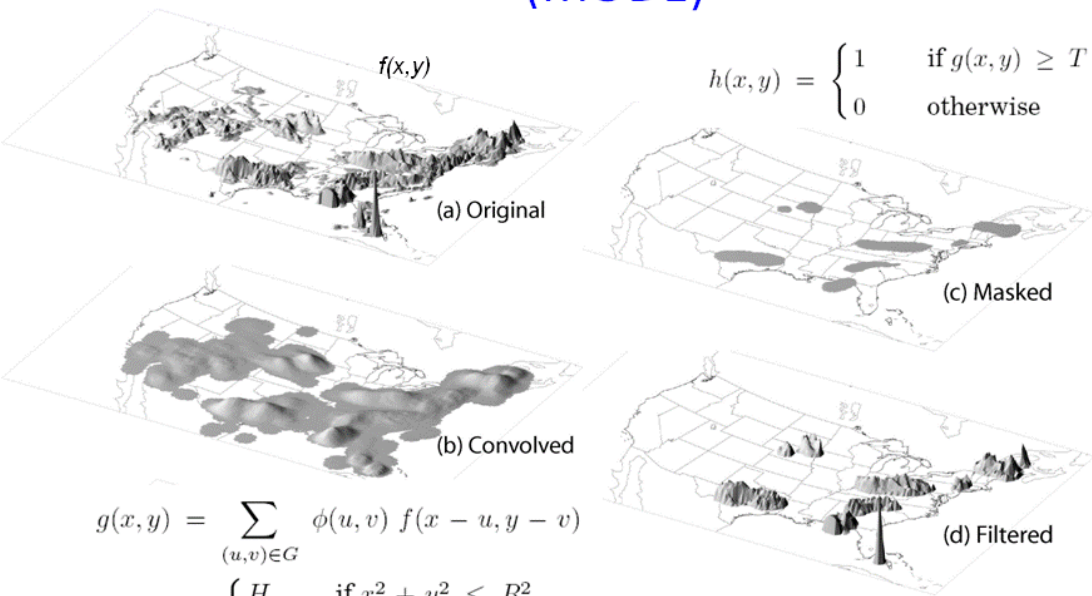
Diagnostic Verification Methods

1. Object-based
2. Field Deformation
3. Neighborhood (fuzzy)
4. Scale Decomposition
5. Variograms



(Chris Davis - http://www.ral.ucar.edu/projects/icp*)*

Method of Object-based Diagnostic Evaluation (MODE)



$$g(x,y) = \sum_{(u,v)\in G} \phi(u,v)\, f(x-u, y-v)$$

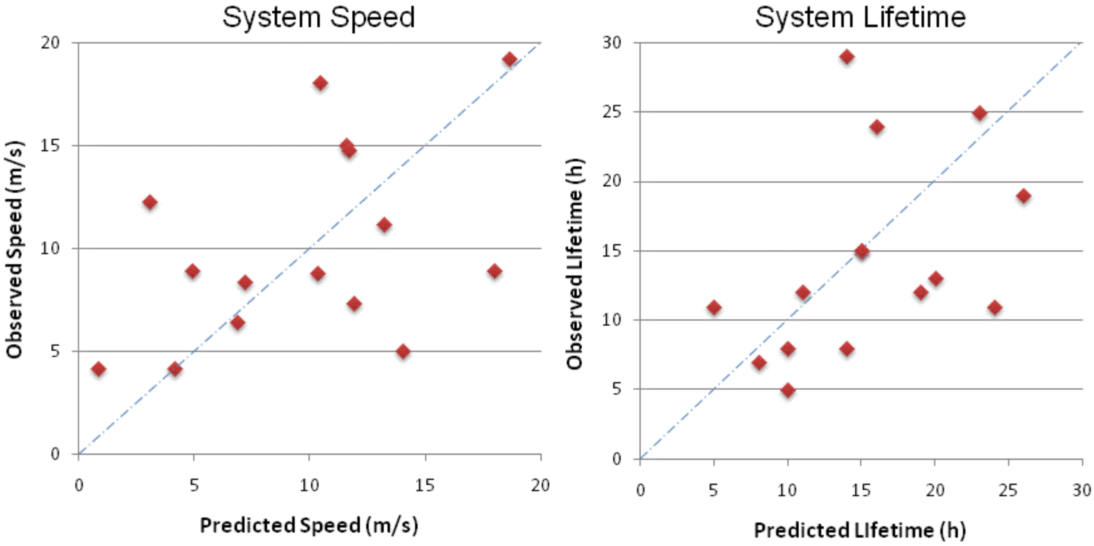
$$\phi(x,y) = \begin{cases} H & \text{if } x^2+y^2 \le R^2 \\ 0 & \text{otherwise} \end{cases}$$

$$\pi R^2 H = 1.$$

$$h(x,y) = \begin{cases} 1 & \text{if } g(x,y) \ge T \\ 0 & \text{otherwise} \end{cases}$$

Restore original field where h(x,y) = 1

Attributes of Rain Systems



No obvious bias
Limited skill

Small high bias in
predicted lifetime

ICP Workshop, August 24-25, 2009 19

Recommendations

- Will traditional DA methods work for clouds? (*e.g.* non-linear, non-Gaussian)
- Focus on model error (*e.g.* microphysics, RTM)
  - info on model deficiencies
  - new DA techniques
- Leverage Ensemble / Variational experience
- Modular codes
  - increase flexibility
  - facilitate collaborations