Improved Initialization and Prediction of Clouds in Numerical Weather Prediction

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Acknowledgments: Gael Descombes, Francois Vandenberghe, Dongmei Xu, Thomas Nehrkorn, Brian Woods, Yann Michel, Greg Thompson.
Initialization of clouds in NWP models

Non-linear model & radiative transfer
Underdetermined problem
Complex balance
Significant model errors

Challenging NWP initialization
Our approach to initializing clouds

- **WRF** (Weather Research and Forecasting) regional, non-hydrostatic model
- All-sky satellite radiances
- Expansion of analysis control variable
  - Total water + linearized physics
  - Microphysical parameters
- Hybrid data assimilation (variational/ensemble)
**NEW ALGORITHM:**
update ensemble perturbations within variational analysis

\[
J(v, v) = J_o + \frac{1}{2} v^T v + \frac{1}{2} v^T v
\]

\[
x = c x_c + e x_e \quad \text{with} \quad x_c = B^{1/2} v
\]

\[
x_e = (P_f \circ C)^{1/2} v
\]

where \((z_k, k)\) are Ritz pairs from Lanczos algorithm (Gratton et al., 2011)
Control Variable Transform

- **Multivariate covariances** for $qc$, $qr$, $qi$, $qsn$
- **Binning** using dynamical cloud mask
- **Vertical and Horizontal** autocorrelations (Recursive Filters)
- **3D Variance**
Displacement Pre-Processing
Poster Nehrkorn (H-p22)

Forecast Calibration & Alignment (Grassotti et al. 1999)

OSSE: Hurricane Katrina
Synthetic observations
(Total Column Precipitable Water)

Balanced displacement
(Nehrkorn et al. 2013)
Processing All-Sky Satellite data

- **IR and MW radiance:** AIRS, IASI, CrIS, AMSU-A/B, MHS
- **VarBC:** Variational Bias Correction
- **Revisited QC and thinning:** to conserve cloudy information
- **Huber Norm:** robust definition of observation error
- **Land Surface:** $T_{\text{skin}}$, $\varepsilon_s$ introduced as sink variable
- **Field of View:** advanced interpolation scheme
- **CRTM Jacobians:** rescaled base state (floor and ceiling values for cloud parameters)
- **Middle Loop:** Multiple re-linearizations
Update of $q_{\text{cloud}}$, $q_{\text{ice}}$ in WRF

AIRS Window Channel #787
Experimental Demonstration

CONUS 15km, 20012/06/03 (12UTC)
WRF-ARW model, Thompson microphysics
First Guess = Mean of 50-member ensemble
from EnKF experiment (courtesy Romine)
No displacement pre-processing
CTRL = no DA

- 3DVAR  Multivariate B matrix (5 middle-loops)
- EVIL   3D-Hybrid-EnVar (5 middle-loops)
$q_{\text{ice}}$ (level 20)

$3DVAR$

$EVIL$

$q_{\text{cloud}}$ (level 10)
Multi-scale verification

goes-13-imager, tb_obs, chan 5, 2012060313

0.5°

0.25°

0.12°

1°

2°

3°
Multi-scale verification

Analysis

Forecast

CTRL
3DVAR
EVIL

GOES-Imager (channel 5)
Conclusion

- Expansion of analysis vector for clouds
- Multivariate, flow-dependent background errors
- Displacement pre-processing
- Updated processing of all-sky satellite observations
- Sustained impact in short-term forecast
- More work required…