WRF-Var

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WRF-Var: WRF Variational data assimilation

Acknowledge:
NCAR/ESSL/MMM/DAG, NCAR/RAL/JNT/DATC,
AFWA, USWRP, NSF-OPP, NASA, AirDat,
KMA, CWB, CAA, BMB, EUMETSAT
ARW = Advanced Research WRF (NCAR) Core
NMM = Nonhydrostatic Mesoscale Model (NCEP) Core
WRF-Var (WRFDA) Data Assimilation Overview

- **Goal:** Community WRF DA system for
  - regional/global,
  - research/operations, and
  - deterministic/probabilistic applications.
- **Techniques:**
  - 3D-Var
  - 4D-Var (regional)
  - Ensemble DA,
  - Hybrid Variational/Ensemble DA.
- **Model:** WRF (ARW, NMM, Global)
- **Support:**
  - NCAR/ESSL/MMM/DAG
  - NCAR/RAL/JNT/DATC
- **Observations:** Conv.+Sat.+Radar
The WRF-Var Program

- NCAR staff: 15FTE
- Non-NCAR collaborators: ~10FTE.
- Community users: ~30 (more in 6000 general WRF downloads?).
The first WRF-Var tutorial

- July 21-22, 2008
- 9 hours lectures and 4 hours hands on
- 53+ participants, US and international

WRF-Var tutorial agenda
http://www.mmm.ucar.edu/events/tutorial_708/agenda/agenda.php

WRF-Var tutorial presentations
http://www.mmm.ucar.edu/wrf/users/tutorial/tutorial_presentation.htm

WRF-Var online tutorial and user guide

Next: 2/2-4/2009
WRF-Var Observations

- **In-Situ:**
  - Surface (SYNOP, METAR, SHIP, BUOY).
  - Upper air (TEMP, PIBAL, AIREP, ACARS).

- **Remotely sensed retrievals:**
  - Atmospheric Motion Vectors (geo/polar).
  - Ground-based GPS Total Precipitable Water.
  - SSM/I oceanic surface wind speed and TPW.
  - Scatterometer oceanic surface winds.
  - Wind Profiler.
  - Radar radial velocities and reflectivities.
  - Satellite temperature/humidities.
  - GPS refractivity (e.g. COSMIC).

- **Radiative Transfer:**
  - RTTOVS (EUMETSAT).
  - CRTM (JCSDA).

**KMA Pre-operational Verification:**

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<th>6</th>
<th>9</th>
<th>12</th>
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<td>1.25</td>
<td>1.50</td>
<td>1.75</td>
</tr>
</tbody>
</table>

Threshold = 5.0mm

2004082600 ~ 2004092812

(with/without radar)
**WRF 4D-Var Summary**

- 4D-Var included within WRF-Var.
- Linear/adjoint models based on WRF-ARW.
- Status:
  - Parallel code, JcDFI, limited physics.
  - Current focus: PBL/microphysics, optimization.
- Advantages of 4D-Var
  - Flow-dependent response to obs
  - Better treatment of cloud/precip obs
  - Forecast model as a constraint
  - Obs at obs-times
WRF-Var and NMM (Pattanayak and Rizvi)
Analysis increments

Difference of 00 hours forecast from NMM at Sigma level=25
Global WRF-Var
(Rizvi and Duda)

Analysis increments
Adjoint sensitivity (Thomas Auligne)

**Observation** (y)

WRF-VAR Data Assimilation

Analysis (x_a)

WRF-ARW Forecast Model

Forecast (x_f)

Define Forecast Accuracy

Forecast Accuracy (F)

- **Observation Impact**
  \[ \langle y - H(x_b) \rangle \left( \frac{\partial F}{\partial y} \right) \]

- **Adjoint of WRF-VAR Data Assimilation**

- **Analysis Sensitivity**
  \[ \left( \frac{\partial F}{\partial x_a} \right) \]

- **Adjoint of WRF-ARW Forecast TL Model (WRF+)**

- **Gradient of F**
  \[ \left( \frac{\partial F}{\partial x_f} \right) \]

- **Define Forecast Accuracy**

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- **Gradient of F**
  \[ \left( \frac{\partial F}{\partial x_f} \right) \]

- **Define Forecast Accuracy**
Adjoint of WRF-VAR DA: Observation Impact
Future Plans

General Goals:
- Unified, multi-technique WRF DA system.
- Retain flexibility for research, multi-applications.
- Leverage international WRF community efforts.

WRF-Var Development (MMM Division):
- 4D-Var (additional physics, optimization).
- Sensitivities tools (adjoint, ensemble, etc.).
- EnKF within WRF-Var -> WRFDA.
- Instrument-specific radiance QC, bias correction, etc.

Data Assimilation Testbed Center (DATC):
- Technique inter-comparison: 3/4D-Var, EnKF, Hybrid
- Obs. impact: AIRS, TMI, SSMI/S, METOP.
- New Regional testbeds: US, India, Arctic, Tropics.

Applications:
- Hurricanes/Typhoons
- OSEs and OSSEs
- Reanalysis (Arctic System Reanalysis)
Assimilation methods  (for WRF-Chem?)

• Empirical methods
  – Successive Correction Method (SCM)
  – Nudging
  – Physical Initialisation (PI), Latent Heat Nudging (LHN)

• Statistical methods
  – Optimal Interpolation (OI)
  – 3-Dimensional VARiational data assimilation (3DVAR)
  – 4-Dimensional VARiational data assimilation (4DVAR)

• Advanced methods
  – Extended Kalman Filter (EKF)
  – Ensemble Kalman Filter (EnFK)
Sequential data assimilation

The Extended Kalman Filter:

For the analysis step $i$:

$$K_i = P_i^f H_i^T (H_i P_i^f H_i^T + R)^{-1}$$

$$x_i^a = x_i^f + K_i [y^o - H(x_i^f)]$$

$$P_i^a = (I - K_i H_i) P_i^f$$

For the forecast step, from $i$ to $i+1$:

$$x_{i+1}^f = M(x_i^a)$$

$$P_{i+1}^f = M_i P_i^a M_i^T + Q_i$$
3D-Var (4D-Var replace $H$ by $HM$)

$$J = \frac{1}{2}(x - x^b)^T B^{-1} (x - x^b) + \frac{1}{2}(y - H(x))^T R^{-1} (y - H(x))$$

The incremental formulation (in the general form, $x^g \neq x^b$!)

$$J = \frac{1}{2}(x - x^g + x^g - x^b)^T B^{-1} (x - x^g + x^g - x^b) + \frac{1}{2}(y - H(x^g) + H(x^g) - H(x))^T R^{-1} (y - H(x^g) + H(x^g) - H(x))$$

$\delta x = x - x^g$

$\mathbf{d} = y - H(x^g)$

$H(x) - H(x^g) = H\delta x$

$$J = \frac{1}{2}(\delta x + x^g - x^b)^T B^{-1} (\delta x + x^g - x^b) + \frac{1}{2}(\mathbf{d} - H\delta x)^T R^{-1} (\mathbf{d} - H\delta x)$$

The first outer-loop: $x^g = x^b$

$$J = \frac{1}{2}\delta x^T B^{-1} \delta x + \frac{1}{2}(\mathbf{d} - H\delta x)^T R^{-1} (\mathbf{d} - H\delta x)$$

Outer-loop:

$\mathbf{d}$ (and QC, etc) … nonlinear!

Inner-loop: minimization

update $x^g$
**Issues on data assimilation**

- Observations $y^o$  
  (Also for WRF-Chem!)
- Observation operator $H$
- Observation errors $R$
- Background $x^b$
- Size of $B$: statistical model and tuning
- $M$ and $M^T$: development and validity
- Minimization algorithm (Quasi-Newton; Conjugate Gradient; ...)
- Model errors $Q$
- Size of $P^f$ and $P^a$: simplifications