exploring wrf-chem/dart as a research-based nwp system with chemistry

ave arellano
univ. of arizona
customizing wrf/dart for chemistry and aerosol apps
How does it work?

1. Use model to advance ensemble (3 members here) to time at which next observation becomes available.

Ensemble state estimate after using previous observation (analysis).

Ensemble state at time of next observation (prior).

\[ x^f_j \]

\[ t_k \]

\[ t_{k+1} \]
2. Get prior ensemble sample of observation, $y = h(x)$, by applying forward operator $h$ to each ensemble member.

\[ y_{m,j}^{f} = h(x_{j}^{f}) \]

$h$ can be a RTM or a retrieval transformation that involves the use of averaging kernels.

from DART tutorial
3. Get observed value and observational error distribution $\sigma_o$ from observing system.
4. Find **increment** for each prior observation ensemble (this is a scalar problem for uncorrelated observation errors).

\[ \Delta y_{m,j} = \left( \sqrt{\sigma_o (\sigma_o + \sigma_m^{-1})} \right) (y_{m,j}^f - \bar{y}_{m}^f) + (\bar{y}_m^a - y_{m,j}^f) \]

**Scalar Update**

\[ \sigma_m^a = \left[ (\sigma_m^f)^{-1} + (\sigma_o)^{-1} \right]^{-1} \]

\[ \bar{y}_m^a = \sigma_m^a \left[ (\sigma_m^f)^{-1} \bar{y}_m^f + (\sigma_o)^{-1} y_o \right] \]

*from DART tutorial*
5. Use ensemble samples of $y$ and each state variable to linearly regress observation increments onto state variable increments.

\[ \Delta x_j = \frac{\text{cov}(x_j^f, y_m^f)}{\text{var}(y_m^f)} \Delta y_{m,j} \]

\[ x_j^a = x_j^f + \Delta x_j \]

from DART tutorial
1. What is the value of MODIS AOD retrievals in improving aerosol ensemble prediction?

Project funded by AFWA
**WRF-Chem/DART Configuration**

- 36km horiz. res across CONUS domain using MOZCART for June 2008 (c/o Gabi Pfister)

- IC/BC perturbations from met initial conditions only

- State vector includes: T2, U10, V10, TH2, Q2, PSFC, PH, MU, T, U, V, W, QVAPOR, QCLOUD, QICE, QRAIN, QSNOW, CO, SO2, SO4, BC1, BC2, OC1, OC2, DUST_1 to DUST_5, SEAS_1 to SEAS_4, TAUAER1 to TAUAER4

- Uses only conventional met obs
\[ \tau_{550} = y_{m,j}^f = h(x_j^f) \]

we take advantage of PNNL’s work on optical depth calculation in wrf-chem
radiosonde temperature

radiosonde horizontal wind

rmse

0 m/s
3 m/s
7 m/s

0 K
1 K
2 K

hPa

0 K
1 K
2 K

hPa

0 m/s
3 m/s
7 m/s

rmse
MODIS AOD Retrievals Used in the Assimilation (June 23-30, 2008)

Used best possible retrievals from collection 051 product
Adjustments mostly over California fires, Mexico border and Colorado. Ensemble spread appears to be low.
Ensemble Mean Surface PM Forecasts Versus US EPA Surface PM Data

Reasonable improvements in PM concentrations

- Pacific: NME: 76% NME: 58%
- Mountain: NME: 74% NME: 44%
- Central: NME: 216% NME: 90%
- Eastern: NME: 91% NME: 32%

FREE_RUNNING

EPA AQS PM (µg/m³)

ASSIM
AOD assimilation largely impacted aerosols in the free troposphere and in regions of convection.
2. how do we best utilize IASI O$_3$ retrievals in improving O$_3$ model prediction?

(on-going work, project funded by NASA - PI G. Pfister)
WRF-Chem/DART Configuration

36km horiz. res across CONUS domain (extending to Hawaii) using MOZCART for June 2008 (c/o Gabi Pfister)

IC/BC perturbations from met/chem initial conditions, emissions, and ‘multi-physics’

state vector includes T2, U10, V10, TH2, Q2, PSFC, PH, MU, T, U, V, W, QVAPOR, QCLOUD, QICE, QRAIN, QSNOW, o3, co, no, no2, hno3, hno4, n2o5, pan, mek, ald, ch3o2, c3h8, c2h6, acet, hcho, c2h4, c3h6, tol, mvk, bigalk, isopr, macr, glyald, c10h16

uses only conventional met obs
Current Challenges

a) large number of obs \( (10^4 / \text{sub-column}) \) leading to increase in assimilation time

from G. Pfister
b) IASI retrievals have correlated errors: cannot assimilate each sub-column or select sub-columns sequentially
summary and future directions

wrf-chem/dart is being developed and implemented to study the value of satellite observations in model predictions (MODIS AOD, IASI O₃)

it serves as nwp with chemistry which has potential utility for studies on met/chem interactions

it is a flexible framework for adding various observation types

future work will involve MOPITT CO and ACOS XCO₂ retrievals