WRF Four-Dimensional Data Assimilation (FDDA)

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Method

- Model is run with extra nudging terms for horizontal winds, temperature and water vapor
- In analysis nudging, these terms nudge point-by-point to a 3d space- and time-interpolated analysis field
- In obs-nudging, points near observations are nudged based on model error at obs site
- The nudging is a relaxation term with a user-defined time scale around an hour or more
- Nudging will work with nesting and restarts

Dynamic Initialization

- Model domains are nudged towards analysis in a pre-forecast period of 6-12 hours
- This has benefit of smooth start up at forecast time zero

FDDA

- Method of nudging model towards observations or analysis
- May be used for
  - Dynamical initialization (pre-forecast period)
  - Creating 4D meteorological datasets (e.g. for air quality model)
  - Boundary conditions (outer domain nudged towards analysis)
Four-Dimensional Met Analysis

- Produces analyses between normal analysis times
- High-resolution balanced and mass-continuity winds can be output to drive off-line air quality models

[FDDA Diagram]

Boundary Conditions

- Nudge an outer domain towards analysis through forecast
- This has benefit of providing smoother boundary conditions to domain of interest than if 15 km domain is the outer domain with interpolated-analysis boundary conditions

FDDA Methods

- Two Methods
  - Grid or analysis nudging (suitable for coarse resolution)
  - Observation or station nudging (suitable for fine-scale or asynoptic obs)
- Nudging can be applied to winds, temperature, and water vapor

Note: nudging terms are fake sources, so avoid FDDA use in dynamics or budget studies

Analysis Nudging (grid_fdda=1)

- Each grid-point is nudged towards a value that is time-interpolated from analyses

\[
\frac{\partial \mathbf{p^*}}{\partial t} = F(\mathbf{\alpha, x, t}) + G_{\mathbf{c}} \cdot W_{\mathbf{c}} \cdot \epsilon_{\mathbf{c}}(\mathbf{x}) \cdot \mathbf{p^*}(\hat{\mathbf{\alpha}} - \mathbf{\alpha})
\]

In WRF p* is \( \mu, v, T \) or \( q \), and \( F \) includes all the regular WRF terms
Analysis Nudging

\[ \frac{\partial p^* \alpha}{\partial t} = F(\alpha, x, t) + G_{\alpha} \cdot W_{\alpha} \cdot e_{\alpha}(x) \cdot p^*(\hat{\alpha}_0 - \alpha) \]

- G is nudging inverse time scale
- W is vertical weight (upper air and surface)
- e is a horizontal weight for obs density (not implemented yet)

Analysis-Nudging namelist options

Can choose
- Frequency of nudging calculations (fgdt in minutes)
- Nudging time scale for each variable (guv, gt, gq in inverse seconds)
- Which variables not to nudge in the PBL (if_no_pbl_nudging_uv, etc.)
- Model level for each variable below which nudging is turned off (if_zfac_uv, k_zfac_uv, etc.)
- Ramping period over which nudging is turned off gradually (if_ramping, dt_ramp_min)

Analysis Nudging

- 3d analysis nudging uses the WRF input fields at multiple times that are put in wrffdda_d01 file by program real when run with grid_fdda=1
  - With low time-resolution analyses, it is recommended not to use 3d grid-nudging in the boundary layer, especially for temperature
- Surface (2d) analysis nudging available in Version 3.1
  - Nudges surface and boundary layer only

Surface Analysis Nudging

- 2d (surface) nudging (grid_fdda=1 and grid_sfdda=1) for surface analyses
  - wrfsfdda_d01 file created by obsgrid.exe
  - Weights given by guv_sfc, gt_sfc, and gq_sfc
  - Note: grid_fdda=1 must be used to activate this. If upper-air nudging not wanted, set upper weights guv, gt, gq =0.
- In Version 3.8 we have FASDAS (grid_sfdda=2)
  - Flux-Adjusted Surface Data Assimilation System
  - This is a special option to also nudge the soil state
    - Only works with YSU PBL and Noah LSM
**Spectral Nudging**

- In Version 3.1 added spectral nudging (grid_fdda=2) to do 3d nudging of only selected larger scales
- This may be useful for controlling longer wave phases for long simulations. Compensates for error due to low-frequency narrow lateral boundaries
  - Top wavenumber nudged is selected in namelist (xwavenum, ywavenum, e.g. =3)
    - Typically choose so that (domain size)/(wavenumber)=~1000 km in each direction
  - Nudges u, v, theta, geopotential (not q)
  - Can nudge in all levels or use ramp above a specified model level (if_zfac_ph, k_zfac_ph, dk_zfac_ph, etc.)

**Obs Nudging (obs_nudge_opt=1)**

- Each grid point is nudged using a weighted average of differences from observations within a radius of influence and time window

\[
\frac{\partial p^*}{\partial t} = F(\alpha, x, t) + G\cdot p^* \sum_{i=1}^{N} \left( \frac{W_i^2(x, t) \cdot \gamma_i \cdot (\alpha_i - \alpha)}{\sum_{i=1}^{N} W_i(x, t)} \right)
\]

\[
W(x, t) = w_{xy} \cdot w_{\sigma} \cdot w_{t}
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\]

**Obs Nudging**

\[
w_{xy} = \frac{R^2 - D^2}{R^2 + D^2}
\]

\[
0 \leq D \leq R
\]

\[
w_{xy} = 0
\]

\[
D > R
\]

- R is radius of influence
- D is distance from ob modified by elevation difference
**Obs Nudging**

\[
\begin{align*}
\omega_t &= 1 & |t - t_0| < \tau/2 \\
\omega_t &= \frac{\tau - |t - t_0|}{\tau/2} & \tau/2 \leq |t - t_0| \leq \tau
\end{align*}
\]

- \( t \) is the specified time window for the obs
- This is a function that ramps up and down

**Obs-Nudging namelist options**

Can choose
- Frequency of nudging calculations (iobs_ionf)
- Nudging time scale for each variable (obs_coef_wind, etc.)
- Horizontal and vertical radius of influence (obs_rinxy, obs_rinsig)
- Time window (obs_twindo)
- Ramping period over which nudging is turned off gradually (obs_idynin, obs_dtramp)

**Vertical weighting functions**

- Added flexibility options for advanced usage of obs-nudging with surface observations (switches in run/README.namelist, e.g. obsnudgezfullr1_uv, etc.)
  - These allow specifying how variables are nudged in a profile with their full weight and/or ramp down function relative to the surface or PBL top in different regimes (stable or unstable).
  - Defaults are set to reasonable values, so these can be left out of namelist unless needed.

- \( w_z \) is the vertical weighting – usually the vertical influence is set small (0.005 eta-difference) so that data is only assimilated on its own eta level
- obs input file is a special ascii file (OBS_DOMAIN101) with obs sorted in chronological order
  - each record is the obs \((u, v, T, Q)\) at a given model position and time
  - Utility programs exist to convert data to this format from other common formats
  - In V3.1 obsgrid.exe can create this file from standard observations that are in little_r format
FDDA Summary

- FDDA grid nudging is suitable for coarser grid sizes where analysis can be better than model-produced fields.
- Obs nudging can be used to assimilate asynoptic or high-frequency observations.
- Grid and obs nudging can be combined.
- FDDA has fake sources and sinks and so should not be used on the domain of interest and in the time period of interest for scientific studies and simulations.