



WRF Four-Dimensional Data Assimilation (FDDA)

Jimmy Dudhia



Developmental Testbed Center



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)

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

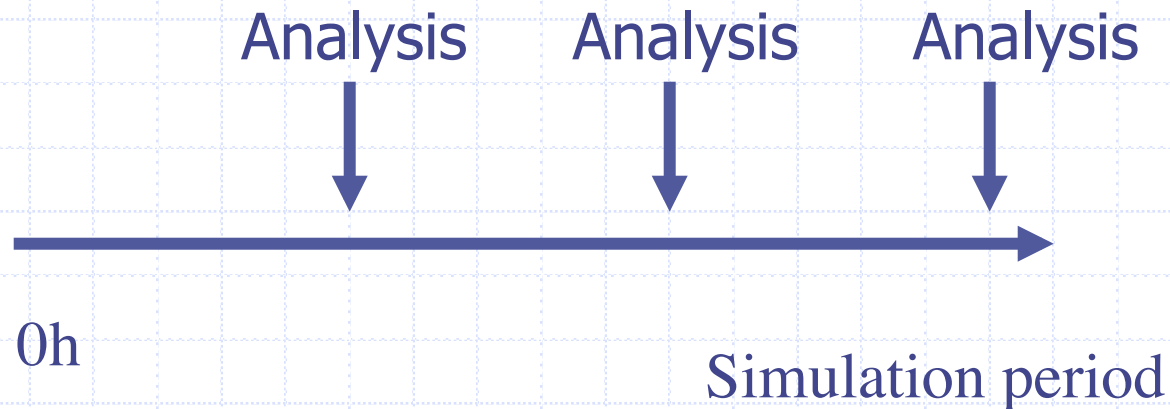
Dynamic Initialization

- ◆ 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



Four-Dimensional Met Analysis

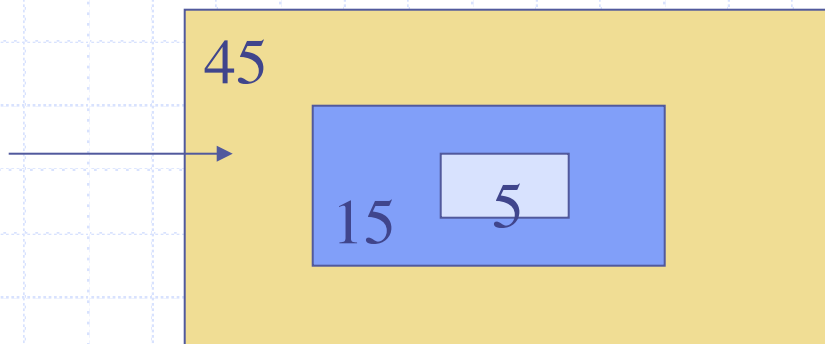
- ◆ Produces analyses between normal analysis times
- ◆ High-resolution balanced and mass-continuity winds can be output to drive off-line air quality models



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

Nudge 45
km domain
only



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

$$\frac{\partial p^* \alpha}{\partial t} = F(\alpha, \mathbf{x}, t) + G_{\alpha} \cdot W_{\alpha} \cdot \epsilon_{\alpha}(\mathbf{x}) \cdot p^*(\hat{\alpha}_0 - \alpha)$$

In WRF p^* is mu

Analysis Nudging

$$\frac{\partial p^* \alpha}{\partial t} = F(\alpha, \mathbf{x}, t) + G_\alpha \cdot W_\alpha \cdot \epsilon_\alpha(\mathbf{x}) \cdot p^*(\hat{\alpha}_0 - \alpha)$$

- ◆ 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

- ◆ 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

Analysis-Nudging namelist options

Can choose

- ◆ Frequency of nudging calculations (fgdt in minutes)
- ◆ Nudging time scale for each variable (guv, gt, gg 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)

Surface Analysis Nudging

- ◆ In Version 3.1 added 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.

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 lateral boundaries.
 - Top wavenumber nudged is selected in namelist (xwavenum, ywavenum, e.g. =3)
 - 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

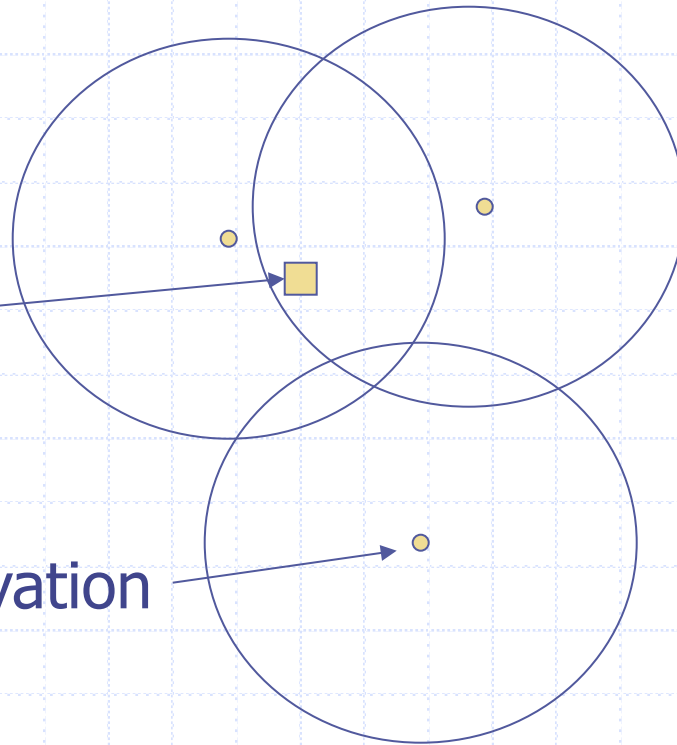
$$\frac{\partial p^* \alpha}{\partial t} = F(\alpha, \mathbf{x}, t) + G_\alpha \cdot p^* \frac{\sum_{i=1}^N W_i^2(\mathbf{x}, t) \cdot \gamma_i \cdot (\alpha_o - \hat{\alpha})_i}{\sum_{i=1}^N W_i(\mathbf{x}, t)}$$

$$W(\mathbf{x}, t) = w_{xy} \cdot w_\sigma \cdot w_t$$

Obs Nudging

Grid point

observation



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

$$w_t = 1$$

$$|t - t_0| < \tau/2$$

$$w_t = \frac{\tau - |t - t_0|}{\tau/2}$$

$$\tau/2 \leq |t - t_0| \leq \tau$$

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

Obs Nudging

- w_s is the vertical weighting – usually the vertical influence is set small (0.005 sigma) so that data is only assimilated on its own sigma 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

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)

New in Version 3.2

- ◆ 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.

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