



## WRF Four-Dimensional Data Assimilation (FDDA)

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## FDDA

ARW only

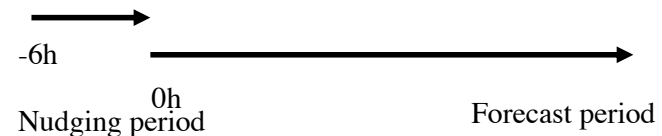
- Method of nudging model towards observations or analysis
- May be used for
  - Dynamical initialization (pre-forecast period)
  - Creating 4D meteorological datasets (e.g. for air quality model)
  - Boundary conditions (outer domain nudged towards analysis)

## 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

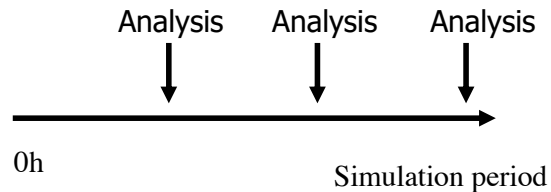
## Dynamic Initialization

- 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



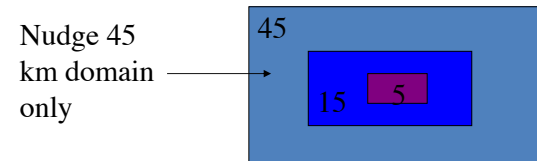
## Four-Dimensional Met Analysis

- 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



## 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

*From MM5: Stauffer and Seaman (1990 MWR, 1994 JAM)*

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

In WRF  $p^*$  is  $\mu v$  and  $\alpha$  is  $u, v, T$  or  $q$

$F$  includes all the regular WRF terms

## 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)
- $\epsilon$  is a horizontal weight for obs density (not implemented)

## 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
  - 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, 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)

## 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 (grid\_fdda=2)

- Spectral nudging does 3d nudging of only selected larger scales
  - Allows model small scales to evolve with no nudging
- This may be useful for controlling longer wave phases for long analysis-driven simulations (e.g. months to years)
  - 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 (and optionally q since V4.0)
  - Can nudge in all levels or use ramp above a specified model level (if\_zfac\_ph, k\_zfac\_ph, dk\_zfac\_ph, etc.)

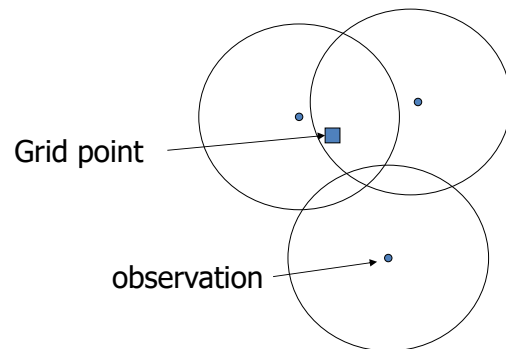
## Obs Nudging (obs\_nudge\_opt=1)

- 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



Note: errors at obs sites are weighted by distance for nudging

## Obs Nudging

$$w_{xy} = \frac{R^2 - D^2}{R^2 + D^2} \quad 0 \leq D \leq R$$

$$w_{xy} = 0 \quad D > R,$$

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

## Obs Nudging

$$w_t = 1 \quad |t - t_0| < \tau/2$$
$$w_t = \frac{\tau - |t - t_0|}{\tau/2} \quad \tau/2 \leq |t - t_0| \leq \tau$$

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

## Obs Nudging

- $w_\sigma$  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

## 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.

## 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

End