WRF Lightning Data Assimilation

A Summary of Changes to WRF

2 June 2014

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I. Introduction

This document exists to fully describe the changes made to WRF in order to assimilate lightning as in my MS Thesis. The work is a modification of the observation nudging technique described in *Stauffer, D. R. and N. L. Seaman, 1994 Stauffer & Seaman, 1994* and implemented in WRF by *Liu, Y., A. Bourgeois, T. Warner, S. Swerdlin, and J. Hacker, 2005*.

Within the WRF system, only two files are changed: `WRFV3/phys/module_fddaobs_rtfdda.F` and `WRFV3/share/wrf_fddaobs_in.F`. All changes are marked within these scripts by `dixon` or `dixon_v2`. After installing these files, WRF must be recompiled. The python script `generate_obs.py` and functions in `wwlln.py` are used to create the formatted observation files that can be ingested by WRF (in a format known as Little R).

If the contact information above is not current, consult Bob Holzworth or Cliff Mass.

II. Lightning Assimilation Technique

First, WWLLN lightning observations are grouped into 5 minute bins[1]. This technique nudges all grid points within 10 km[2] of a lightning stroke. Only grid points with $p > 200$ hPa are nudged[3]. The rate of nudging at any grid point does not depend on the number of lightning strokes within 10 km during a 5 minute interval. The relaxation time scale is 5 minutes, so the nudging coefficient (`obs_coef_mois` in `namelist.input`) is $\frac{1}{5\,\text{min}} = \frac{1}{300\,\text{sec}} = 3.33 \times 10^{-3}\ \text{s}^{-1}$. The rate of nudging will not depend on the distance of the grid point or timestep from the lightning observation.

There are a number of differences between this technique and the implemented observation nudging code provided with WRF. Changes to the WRF code required to realize this lightning data assimilation technique are listed in **Section III** by subroutine.

[1] This is long enough so that nudging is persistant in set locations, but short enough to follow the motion of the storms.

[2] WWLLN location errors fall within 10 km, and this is large enough to affect multiple gridpoints without going too far beyond convective scale

[3] This is a crude threshold for the troposphere.

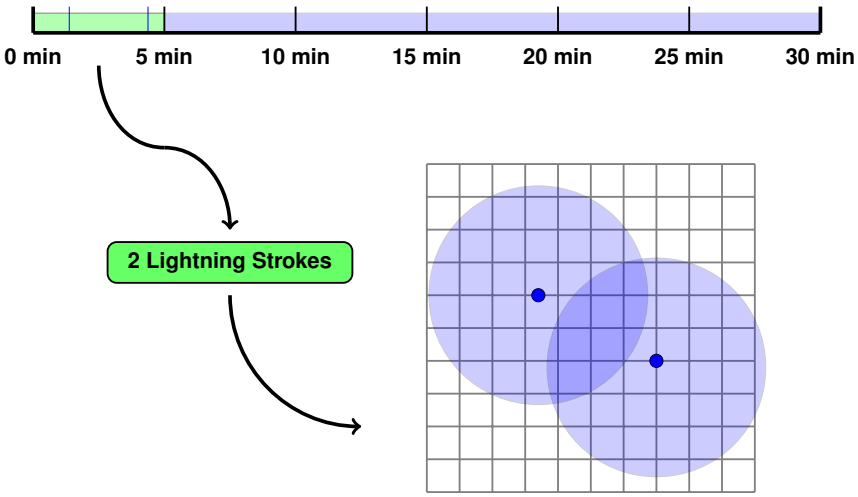

Figure 1: A visualization of the lightning nudging process. On top, a timeline during the assimilation phase of the simulation which is divided into 5 minute bins. The green highlighting indicates the temporal bin of interest, in which blue vertical lines indicate the temporal location of lightning strikes within the model domain in that bin. On bottom, an example of how the lightning strikes in a temporal bin are used to determine which grid points to nudge on the model domain, when the model integration is within the green highlighted temporal bin. The gray grid indicates the model domain, while blue dots indicate lightning strikes. Nudging will be enabled at all grid points within the light blue circles as long as $p > 200$ hPa.

III. WRF Subroutines & Changes

`fddaobs_init`

- Purpose: Perform initialization of `fddaobs` processing. Of particular concern are the parameters set in this subroutine.
- Location: `WRFV3/phys/module_fddaobs_rtfdda.F`
- Changes:
  - Changed `fdob%rinfmx` from `2.0` to `1.0` so that the horizontal radius of influence of an observation does not increase with height up to 500 mb. This parameter existed initially to reduce weird results happening near terrain (*Stauffer & Seaman, 1994*).

`in4dob`

- Purpose: This subroutine "reads an observation data file and selects only those values observed at times that fall within a time window (`TWINDO`) centered about the (`TWINDO`) centered about the current forecast time (`XTIME`). The incoming obs files must be in chronological order."
- Location: `WRFV3/share/wrf_fddaobs_in.F`
- Changes:
  - Added `kds, kde` (vertical grid indices) to the end of the subroutine call. This is visible where the subroutine is called from `wrf_fddaobs_in`), where the subroutine arguments are defined, and where the arguments are declared within the subroutine. These values are needed

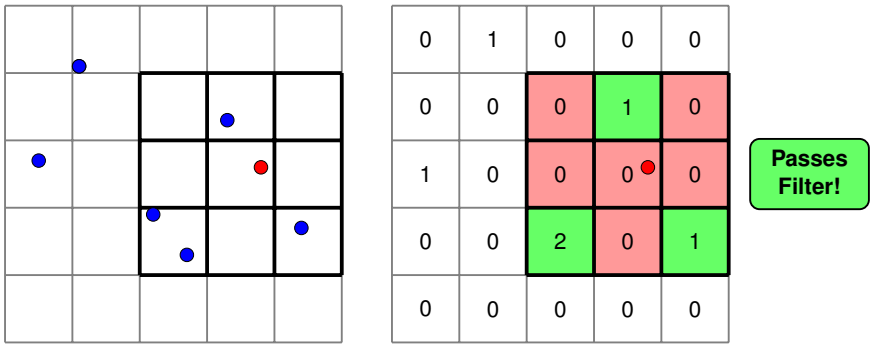

Figure 2: Left: A grid comprised of 0.5° × 0.5° grid boxes and a lightning strike at the location of the red dot. The blue dots represent all lightning strikes that happened in the 60 minutes prior to the red lightning strike. Right: The number of lightning strikes in each 0.5° × 0.5° bin. In this case, the presence of lightning strikes in the boxes outlined with thick black lines signal that the red lightning strike in question will not be removed from the assimilation process.

in order to determine the number of vertical "observations" for a lightning strike (number of vertical levels in the model).

- Added platform identification number for soundings that are described as `WWLLN`. The identification number is `plfo(n)=10.` This allows WRF to identify observations from `WWLLN` soundings and handle them differently than non-WWLLN sources.
- Added a portion to the code to change the number of vertical observations in a sounding to the number of vertical levels in the model when a sounding platform identification number is `plfo(n)=10.` (WWLLN). This is necessary so that subsequent loops go through the number of vertical levels in the model, regardless of how many vertical observations are present in the sounding.
- When looping through the number of vertical levels in the model, if the platform is identified as `plfo(n)=10.` (WWLLN), then the 2 actual sounding lines are read, and all data for observation nudging is voided (set to `-888888`) except for `pressure_data` (set to 50000 Pa plus the vertical level index), `pressure_qc=0.`, `rh_data=100.`, and `rh_qc=0.` so that LATER SUBROUTINES know which vertical level to nudge.
- When looping through the number of vertical levels in the model for this sounding, if the platform is identified as `plfo(n)=10.` (WWLLN), then two operations are performed. First, `varobs(5,n)=varobs(5,n)*1e3-50000` is done to convert the fake pressure to the vertical index. Second, `r_data=100.` is done so that `errob` will recognize this obviously unrealistic water vapor mixing ratio and nudge the model to 100% relative humidity instead.

`errob`

- Purpose: The purpose of this subroutine is to compute the model error at the observation point. Model values at observation points are trilinearly interpolated from adjacent grid points.
- Location: `WRFV3/phys/module_fddaobs_rtfdda.F`
- Changes:

- Added local variable declarations for calculating interpolated temperature and storing other intermediate variables necessary to determine the mixing ratio that corresponds to 100% relative humidity for nudging.
- Added a section to detect `VAROBS(4,N).eq.100` and subsequently handle the WWLLN based observation as desired for the purposes of this section. To be more specific, some local constants are defined, followed by the determination of temperature through bilinear interpolation and computing the pressure by adding the base and perturbation values together. Then the saturation vapor pressure is computed using Tetens formula (*Murray, 1967*), followed by the saturation water vapor mixing ratio. This value is stored back into `VAROBS(4,N)` as the mixing ratio to nudge toward. Finally, the error is computed for all observations where pressure is greater than 200 mb. This check, normally in `in4dob` was bypassed for WWLLN soundings by edits made to that subroutine. It is important to note that the error is only bilinearly interpolated since the "observations" are at vertical grid points (no need to interpolate in the vertical dimension).

`nudob`

- Purpose: The purpose of this subroutine is to compute the new tendency values. Is this done by adding or replacing the old values?
- Location: `WRFV3/phys/module_fddaobs_rtfdda.F`
- Changes:
  - Added a commented-out print check to see how often `nudob` is called.
  - Added a commented-out print message to check if nudging was actually occurring.
  - Added a check to the four possible times that `WT2ERR` is calculated. These checks ensure that in any given timestep, any grid point is nudged no more than once (i.e., multiple lightning strokes within 10 km of a grid point do not increase the rate of nudging).
  - Added a check to remove all horizontal, vertical, and temporal weighting functions so that the rate of nudging did not depend on how close a lightning stroke is (just that it is within 10 km and in the current 5 minute bin; which is handled by another routine).

IV. Patching WRF

The files to overwrite are provided in `wrfedit.tar`. Unpack this and move the appropriate files contained within the directory `wrfedit` to the proper directories in `WRFV3`. See the file called `README` for more information.