Impact of outer loop for WRF data assimilation system (WRFDA)

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ABSTRACT

In variational data analysis, via outer loop it is possible to include the non-linearities in the observation operators. Thus it is very beneficial for assimilating observations such as wind speed, radar radial velocity etc. With outer loop, it is also possible to control the influence of various types of data representing different scales of analysis by utilizing them in certain order of the outer loop. In this paper we show how an inner loop linear solution can be augmented by an outer loop iteration procedure that introduces non-linear effects in the form of a first-order Taylor series expansion. The non-linear problem is then solved iteratively as a sequence of linear problems. Result shows that by running more than one analysis outer loops, the assimilation system is able to utilize more observations. It is also extracting more information, especially from observations like GPS refractivity, total precipitable water etc., which are non-linearly related with the analysis control variables. Finally, the outer loop is visualized as a tool to extract information more efficiently from observations representing small scales features by designing a suitable strategy to assimilate various types of observations with different analysis outer loops.

INTRODUCTION:

Current WRF variational data assimilation (WRF-Var) basically minimizes the following cost function (Barker et al. 2003).

$$J(x)=.5[(x-x_b)^T B^{-1}(x-x_b) + (y_o - y)^T O^{-1} (y_o - y)] \quad (1)$$

Where,

x - analysis state vector,

x_b - Background vector,

y_o - observation vector,

B - background error covariance matrix,

O - Observation and $y = Hx$,

H is the operator transforming the grid-point field to the observation locations. In terms of control analysis variable v, defined as,

$$(x - x_b) = U v, \quad (2)$$

where, $B=UU^T$. The cost function J(v), can be written as

$$J(v)=.5[v^T v + (y_{o'} - \mathbf{H}Uv)^T O^{-1}(y_{o'} - \mathbf{H}Uv)]$$

Where, $y_{o'} = y_o - H(x_b)$, is the innovation vector and **H** is the tangent linear operator corresponding to H-operator, used in the calculation of $y_{o'}$. Following the standard procedure for solving the minimization problem, the first derivative $\partial J/\partial v$ is equated to zero, leads to the following analysis equation.

$$[I+U^T\mathbf{H}^T O^{-1}\mathbf{H}U]v = U^T\mathbf{H}^T O^{-1} y_o,$$

or,

$$Zv = Q \qquad (2)$$

Where, Thus it is very beneficial for assimilating observations such as wind speed, radar radial velocity etc. With outer loop, it is also possible to control the influence of various types of data representing different scales of analysis by utilizing them in certain order of the outer loop.

$Z = [I + U^T\mathbf{H}^T O^{-1}\mathbf{H}U]$ and

$Q = U^T\mathbf{H}^T O^{-1} y_o,$

Thus, we see that the 3DVAR cost function minimization problem has finally converged to solving a set of non-linear equations for the control variable v. Since the degree of freedom for the control is very large, direct solution is absolutely prohibitive. Solution to analysis equation is approximated in a sequence by employing a double iteration technique as follows.

Set $x = x_b$, so that $v = 0$
Start of outer iteration
    $x = x_b + U v$
  Start of inner iteration
    a) Compute Q,
    b) Solve $Z\,\delta = Q$ for δ,
      (using standard CG method)
    c) Update $v = v + \delta$
    End of inner loop
  End of outer loop

Thus we see that in variational data analysis, via outer loop it is possible to include the non-linearities in the observation operators. Following Veerse & Thepaut (1998) and Courtier et. al (1994), the concept of outer loop has been implemented in WRF-Var. In this study in response to outer loop, various aspects like, data rejections, impact of special observations which are non-linearly related with observation operators, fit of observations with analysis and short range forecast, impact on minimization procedure etc. will be examined.

RESULTS:

We show results of the outer loop strategy, where the first loop, the “linear” solution, is modified in the second outer loop by both a Taylor series term in the calculation of the observation innovations, and a linearized form of the background model that is linearized about an analysis ‘trajectory’ from the solution of the first loop. We also show results of how the outer loop strategy allows better assimilation of various types of observations. By increasing the outer loop iterations, more observations are getting assimilated into WRF-Var.

WRF-Var was run in 6-houlry cyling (cold start) mode for the period 15th August to 15th September, 2008 for T8-domian. The results clearly show that by employing two outer loops the data rejections are very less. Fig, 1 (a)-(c) illustrates GPS refractivity, sound & synop data rejections with single (outer_01) and two outer (outer_02) analysis loops. Here it may be noted that data counts are not the data observations location points but consists of all types of observations. For muti-level observations, like from "sound" etc., it also includes all the levels. Thus it is clearly seen that with two outer loops WRF-Var is able to assimilate almost all the observations quality controlled by observations pre-processor ("obsproc"). Impact of outer loop on minimization was examined by monitoring the reduction of cost & gradient function. In general, towards the beginning of the second outer loop both cost & gradient function jumps up. This rise is mainly contributed by additional observations getting into the assimilation, which were rejected in the first outer iterations. It is also contributed by the non-linearities in some of the observation operators. Fig. 2 displays typical behavior of cost & gradient functions for the two outer loops.

References:

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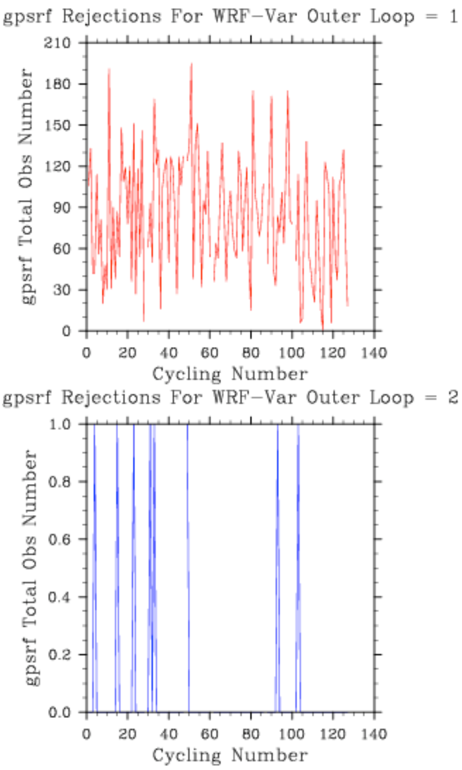
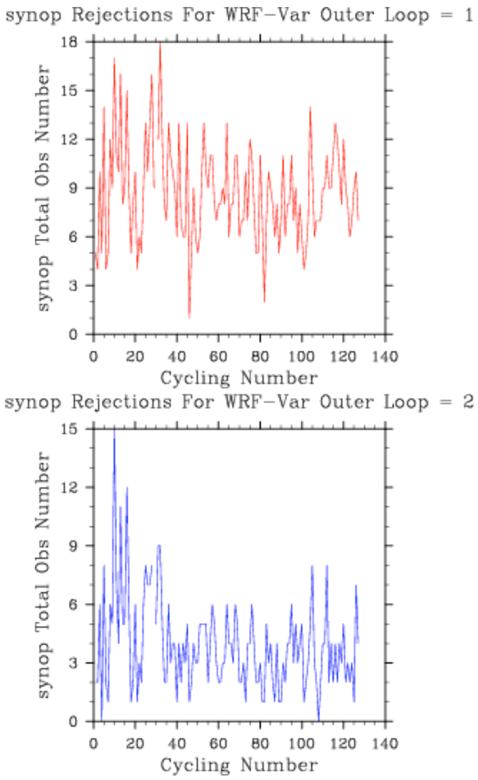
(a)



(b)



(c)

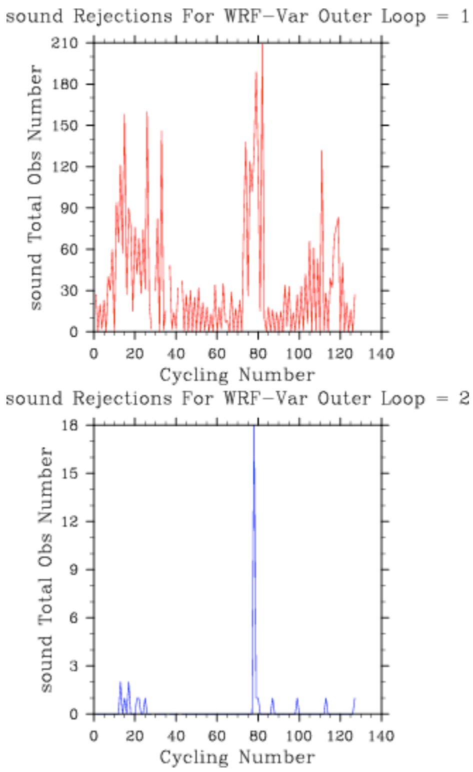


Figure 1. WRF-Var outer loop data rejection [(a) gpsref, (b) sound and (c) synop] in T8-domin for 6-hourly cycling

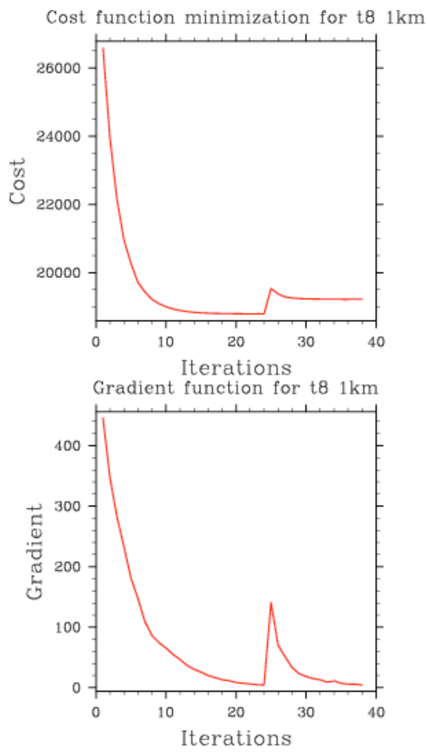


Fig2: WRF-Var Cost and gradient Date: 2007081712