Status of WRF 4D-Var

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1. Introduction

The 4D-Var component of the expanded 3/4D-Var system (known as WRF-Var, Barker *et al.* 2005), hereafter referred to as WRF 4D-Var, has undergone extensive development since 2004. It uses the WRF model and 3D-Var as its basic components (Huang *et al.* 2005).

The 4D-Var prototype was built in 2005 and has under continuous refinement since then. Many single observation experiments have been carried out to validate the correctness of the 4D-Var formulation. A series of real data experiments have been conducted to assess the performance of the 4D-Var capability (Huang *et al.* 2006). Another year of fast development of 4D-Var has led to the completion of a basic system, which will be described in section 3.

2. The basic system

The WRF 4D-Var prototype was built in 2005. It has been under continuous refinement since then (Huang *et al*. 2006). Collaborative efforts during the last year results in a basic system of WRF-Var (4D, version 2.2). It has the following features:

1) It runs as a combination of WRF (the released version 2.2), WRF+ (the WRF tangent linear model and adjoint model) and WRF-Var (the release version 2.1 with 4D-Var extensions) executables,
2) It uses system calls to invoke the three executables,
3) It uses disk I/O to handle the communication among WRF, WRF+ and VAR,
4) It can run on a single processor as well as multi-processors,
5) It has a penalty term, Jc, to control noise during the minimization, and
6) It includes a simple vertical diffusion with surface friction scheme and a large-scale condensation scheme in addition to the full dynamics in WRF+.

The parallel multiple program multiple data (MPMD) system architecture of WRF 4D-Var has demonstrated encouraging performance and made cycling data assimilation experiments possible.

Figure 2 shows a typical real-case example of the cost functions (J_o , J_b and J_c) evolving as functions of minimization simulations (iterations). For this particular case WRF 4D-Var reaches the minimum, defined as the gradient norm reduces to 1% of its original value, in about 40 iterations.

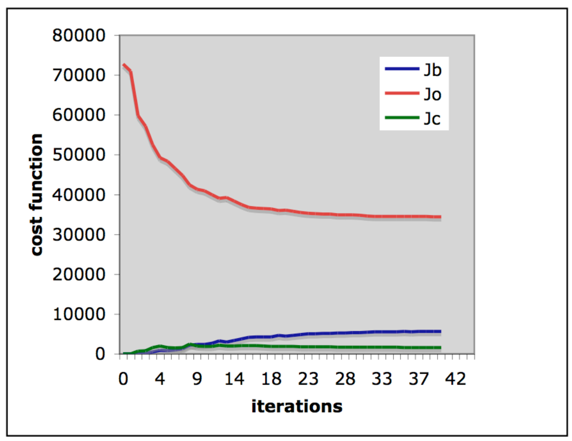

Fig. 1. The cost functions (J_b, J_o and J_c) as functions of minimization simulations (iterations).

3. Cycling experiments

A 4.5-day period from 12 UTC 4 May to 00 UTC 9 May 2006 was chosen for assessing the impact of data assimilation using 3D-Var and 4D-Var in cycling mode on the forecast. During this time

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period, a cyclone moved from the west sea cross the Korean peninsula and caused heavy precipitations.

In these experiments, the model domain is the same as that of the current Korea Meteorological Administration (KMA) regional numerical prediction system, but the horizontal resolution is reduced to 30 km with 60x54x31 grid points. The analysis is done every 6-h followed by a 24-h forecast over this 4.5-day period. In cycling mode, the analysis uses the 6-h forecast from the previous analysis as the background, except at the very beginning of the experiment when the initial model states are obtained by interpolating the 30-km operational model fields.

Two sets of experiments are run over the 4.5-day period:

3DVAR: 3D-Var is used with the interpolated model state as the background. Observations collected from -3h to +3h around the analysis time are assimilated; an example of the numbers of different observations is given in Table 3.

4DVAR: 4D-Var is used. The interpolated model state valid at 6 h before the analysis time is used to make a 3-h forecast. This 3-h forecast is then used as the background for 4D-Var analysis. Observations collected from -3h to +3h around the analysis time are split to hourly time slots. The observations used in one 4DVAR analysis are given in Table 4. Due to the data thinning strategy, 4DVAR uses significantly more SYNOP and METAR observations. There was a small error in the 4DVAR experiment, which excludes all SATOB observations. After 4DVAR analysis valid at -3h, another 3-h forecast is run to advance the model state to the analysis time. The model lateral and lower boundaries are updated at -3h and at the analysis time.

The performance of 4DVAR is evaluated using 3DVAR as a reference. As this is a major precipitation case, the precipitation forecast is verified.

Precipitation skill scores are calculated and averaged over 7 days at 73 observation points in South Korea. The scores are defined as following:

Hit (H) event forecast to occur AND did occur
Miss (M) event forecast not to occur BUT did occur
False_alarm (F) event forecast to occur BUT did not
Critical Success Index (CSI) = H / (H + M + F)

The precipitation scores, CSI of 0.1mm, 5mm, 15mm and 25mm are showed in Fig. 2. The Precipitation forecasts in the 4DVAR experiments over the 4.5-day period are significantly better than the 3DVAR experiments.

Table 1 Number of Observations used by 3D-Var on 2006050412.

Table Table 3 Number of Observations used by 3D

	u	*v*	*T*	*p*	*q*
TEMP	459	464	519	-	385
SYNOP	67	59	73	71	72
SATOB	74	76	-	-	-
PILOT	182	195	-	-	-
METAR	559	551	614	33	36
SHIP	1	1	2	2	1

Table 2 Number of Observations used by 4DVAR on 2006050412.

	u	*v*	*T*	*p*	*q*
TEMP	456	461	519	-	384
SYNOP	253	212	268	191	204
SATOB	-	-	-	-	-
PILOT	185	194	-	-	-
METAR	2636	2402	2957	218	240
SHIP	1	1	2	2	1

4. Conclusions

The current status of the WRF 4D-Var is characterized by the basic system which uses multiple executables, can run on a single processor as well as multiple processors and uses disk I/O to handle the communication among the executables.

Within the WRF-Var framework, 4D-Var can assimilate most observation types as 3D-Var does, and it can assimilate more observations from non-moving platforms, such as SYNOP, than 3D-Var. The results indicate that 4D-Var is working properly and, on the average, outperforms 3D-Var with a similar configuration.

Cycling experiments have just become possible with recent development of the parallel multiple programs multiple data system architecture of WRF 4D-Var. Preliminary results are encouraging and in agreement with those from the cold start experiments. Further experiments and evaluation are on going.

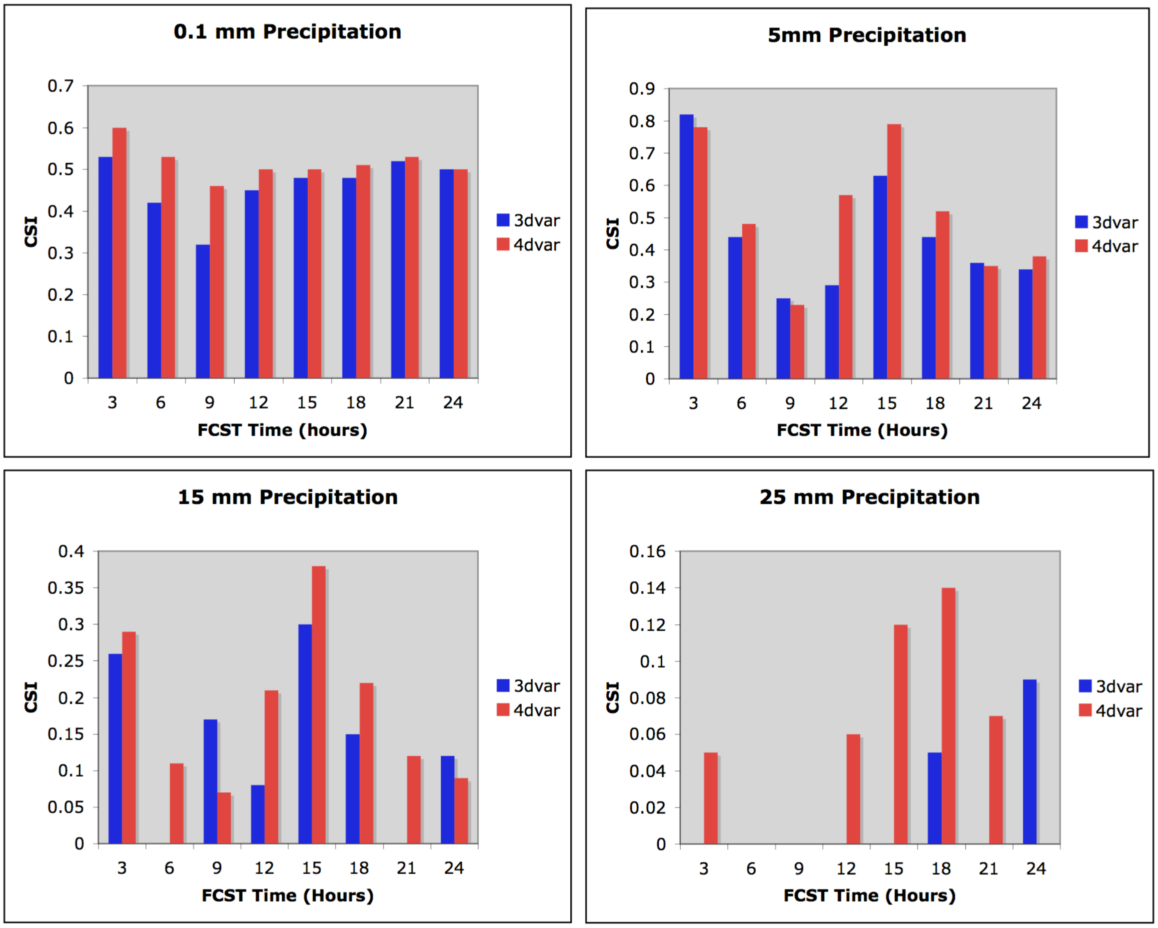

Fig. 7. Precipitation Verification: 0.1mm, 5mm, 15mm, 25 mm Precipitation.

The current WRF 4D-Var has a simple vertical diffusion scheme and a large-scale condensation scheme, in addition to the full WRF dynamics, in the tangent linear and adjoint models. As high impact weather prediction is receiving more and more attention in recent years, further studies will be conducted to assess the impact of 4D-Var on WRF forecasts of severe weathers, such as heavy rainfall events, tropical cyclones, and so on. It is obvious that more physics should be added in the tangent linear and adjoint models of WRF 4D-Var.

There are many tunable parameters in WRF-Var, for example the variances and scale lengths of the background errors. Most of these parameters have been tuned for optimizing the 3D-Var performance. In all the 4D-Var experiments conducted so far, none of these parameters have been touched. Extensive tuning experiments are necessary and planned. Results will be reported in the near future.

References

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