The Weather Research and Forecasting Model Based 4-dimensional Variational Data Assimilation System [WRF-(4D)Var]

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Outline

1. WRF-(4D)Var project
2. WRF-(4D)Var formulation
3. Current status
4. Near future plan

WRF-(4D)Var project

Supported by AFWA

Schedule

- FY04: prepare. (wrf model, simplified model, testing TAF on wrf subroutines.)
- FY05: construct. [4D-Var framework, basic (dry) wrf TL and AD components, initial experiments.] – stage I and stage II.
- FY06: refine. (more physics, parallel code, extensive testing.) – stage III and stage IV.

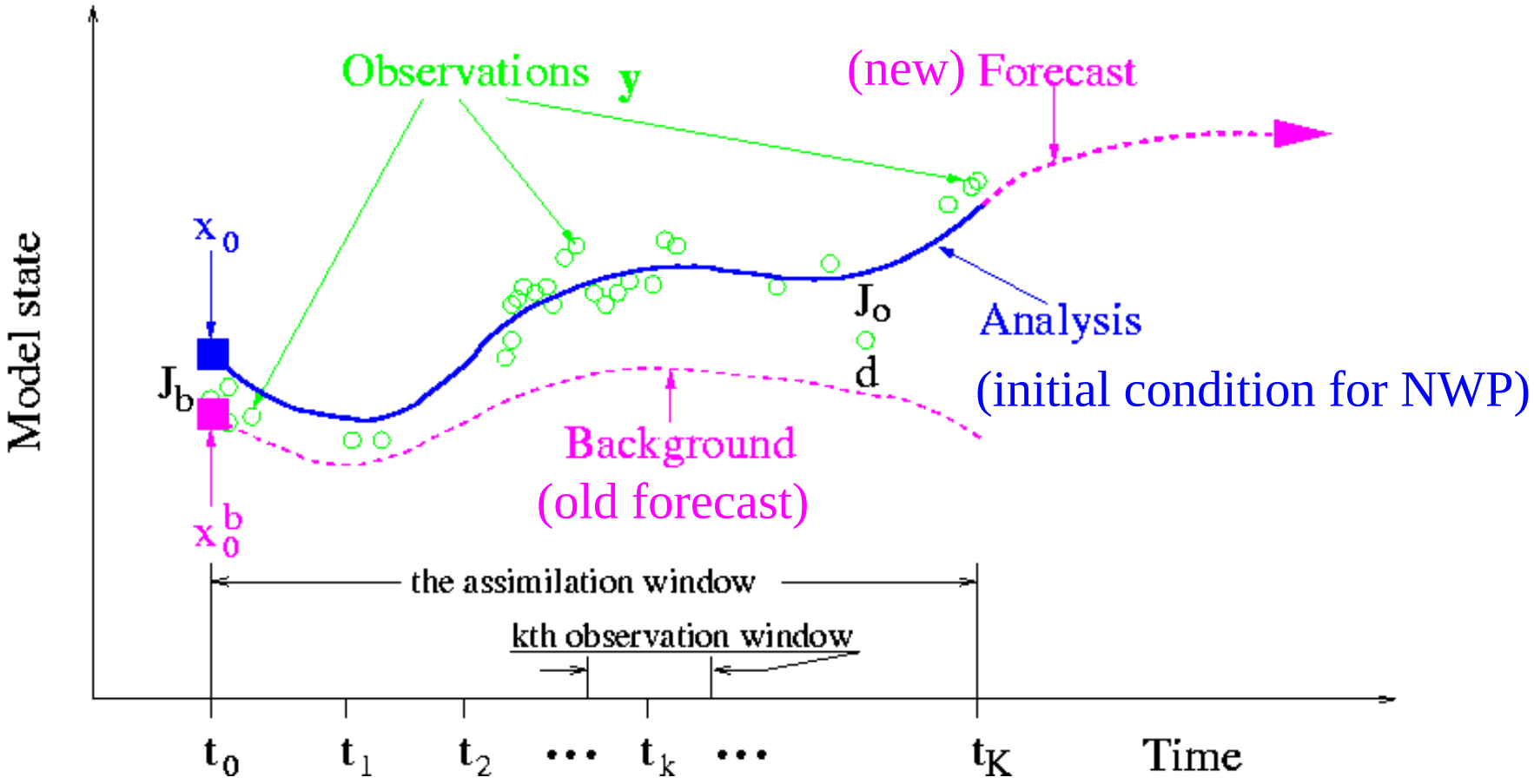
Why 4D-Var?

- Use observations over a time interval, which suits most asynoptic data.
- Use a forecast model as a constraint, which ensures the dynamic balance of the analysis.
- Implicitly use flow-dependent background errors, which ensures the analysis quality for fast developing weather systems.

Variational methods

$$J = \frac{1}{2}\left\{\left(\mathbf{x}-\mathbf{x}_0^b\right)^T \mathbf{B}^{-1}\left(\mathbf{x}-\mathbf{x}_0^b\right) + \left[H(M(\mathbf{x}))-\mathbf{y}\right]^T \mathbf{R}^{-1}\left[H(M(\mathbf{x}))-\mathbf{y}\right]\right\}$$

$\delta\mathbf{x}$



Algorithms

4DVAR:

$$J' = \mathbf{B}^{-1}\delta\mathbf{x} + \mathbf{M}^{T}\mathbf{H}^{T}\mathbf{R}^{-1}\mathbf{H}\mathbf{M}\delta\mathbf{x} + \mathbf{M}^{T}\mathbf{H}^{T}\mathbf{R}^{-1}\{H[M(\mathbf{x})] - \mathbf{y}\}$$

3DVAR: $M = \mathbf{M} = \mathbf{M}^{T} = \mathbf{I}$

$$J' = \mathbf{B}^{-1}\delta\mathbf{x} + \mathbf{H}^{T}\mathbf{R}^{-1}\mathbf{H}\delta\mathbf{x} + \mathbf{H}^{T}\mathbf{R}^{-1}[H(\mathbf{x}) - \mathbf{y}]$$

FGAT: $\mathbf{M} = \mathbf{M}^{T} = \mathbf{I}$, but $M \neq \mathbf{I}$

$$J' = \mathbf{B}^{-1}\delta\mathbf{x} + \mathbf{H}^{T}\mathbf{R}^{-1}\mathbf{H}\delta\mathbf{x} + \mathbf{H}^{T}\mathbf{R}^{-1}\{H[M(\mathbf{x})] - \mathbf{y}\}$$

Important issues

- *H* observation operator, including the tangent linear operator **H** and the adjoint operator $\mathbf{H}^{\mathbf{T}}$.
- *M* forecast model, including the tangent linear model **M** and adjoint model $\mathbf{M}^{\mathbf{T}}$.
- **B** background error covariance (N∗N matrix ~10^{14}).
- **R** observation error covariance which includes the representative error (K*K matrix 10^{12}).

WRF-(4D)Var

- *H*, **H** and $\mathbf{H}^{\mathbf{T}}$: WRF-3DVar (with modifications)
- **R**: WRF-3DVar
- **B**: WRF-3DVar

- *M*: WRF model
- **M** and $\mathbf{M}^{\mathbf{T}}$:

- WRF-4DVar framework

Black – WRF-3DVar
Green – modification required
Blue – existing (for 4DVar)
Red – new development

WRF-(4D)Var formulation

Outer-loop:

$$J'_{\chi^n} = \chi^n + \sum_{i=1}^{n-1}\chi^i + \mathbf{U}^{-T}\mathbf{S}_{V\text{-}W}{}^{T}\sum_{k=1}^{K}\mathbf{M}_k{}^{T}\mathbf{S}_{W\text{-}V}{}^{T}\mathbf{H}_k{}^{T}\mathbf{R}^{-1}[\mathbf{H}_k\mathbf{S}_{W\text{-}V}\mathbf{M}_k\mathbf{S}_{V\text{-}W}\mathbf{U}^{-1}\chi^n + H_k(M_k(\mathbf{x}^{n-1})) - \mathbf{y}_k]$$

innovation

wrf_nl

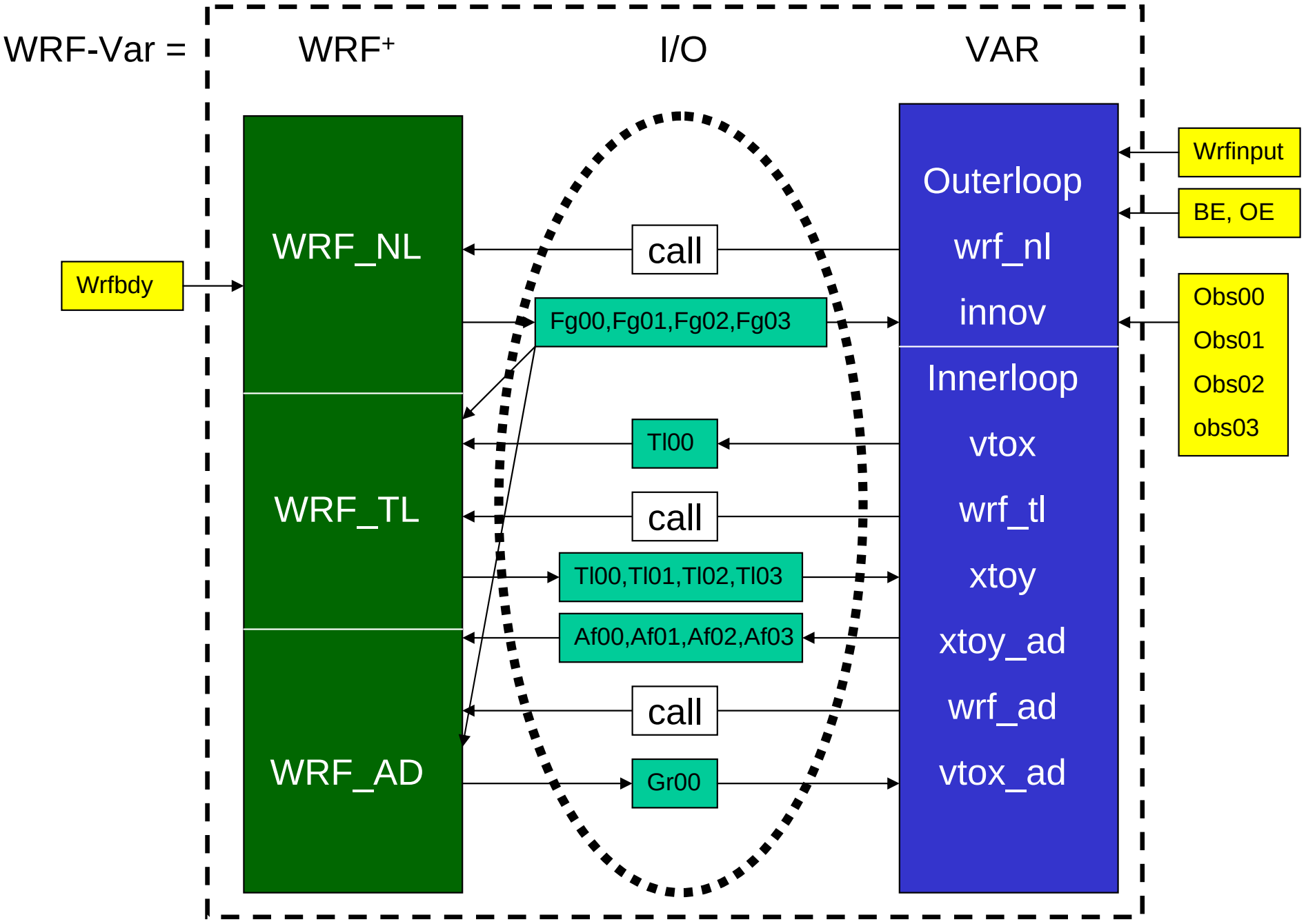
Inner-loop:

Vtox
Xatowrftl
Wrf_tl
Wrftltoxa
Xtoy
Jo_grad_y
Xtoy_ad
Wrftltoxa_ad
Wrf_ad
Xatowrftl_ad
Vtox_ad

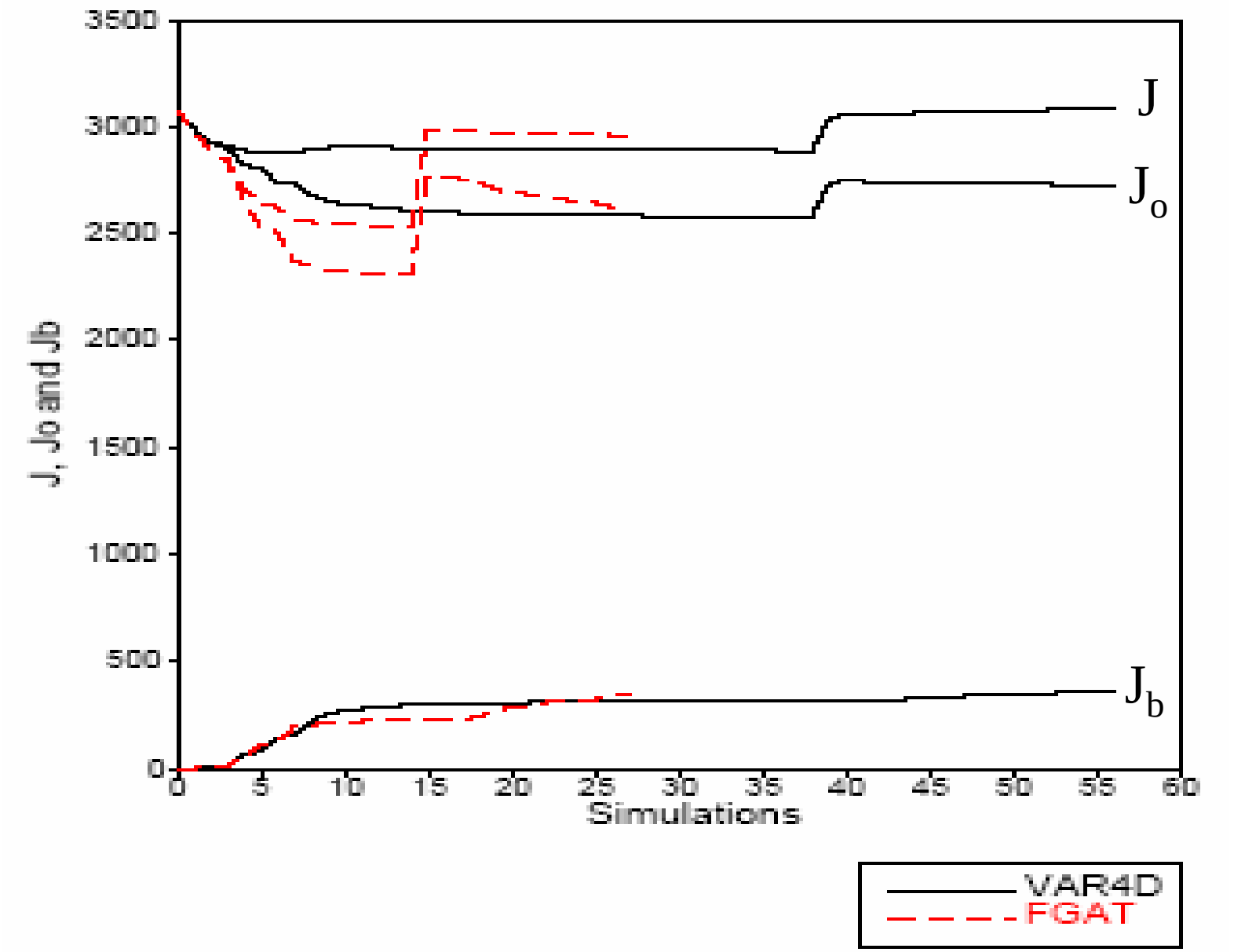
Stage I. Prepare VAR (start from WRF-3DVar) - finished.

Subroutine	Comments	Current status
innovation	Break H to H_k	Ready due to FGAT
wrf_nl	Exists	Start with a system call
vtox	The same as in 3DVAR	Ready
wrf_tl	New development	Start with I
xtoy	Break $\mathbf{H}$ to $\mathbf{H_k}$	Done
Jo_grad_y	Can be applied for all obs win	Ready
xtoy_ad	Break $\mathbf{H^T}$ to $\mathbf{H^T_k}$	Done
wrf_ad	New development	Start with I
vtox_ad	The same as in 3DVAR	Ready

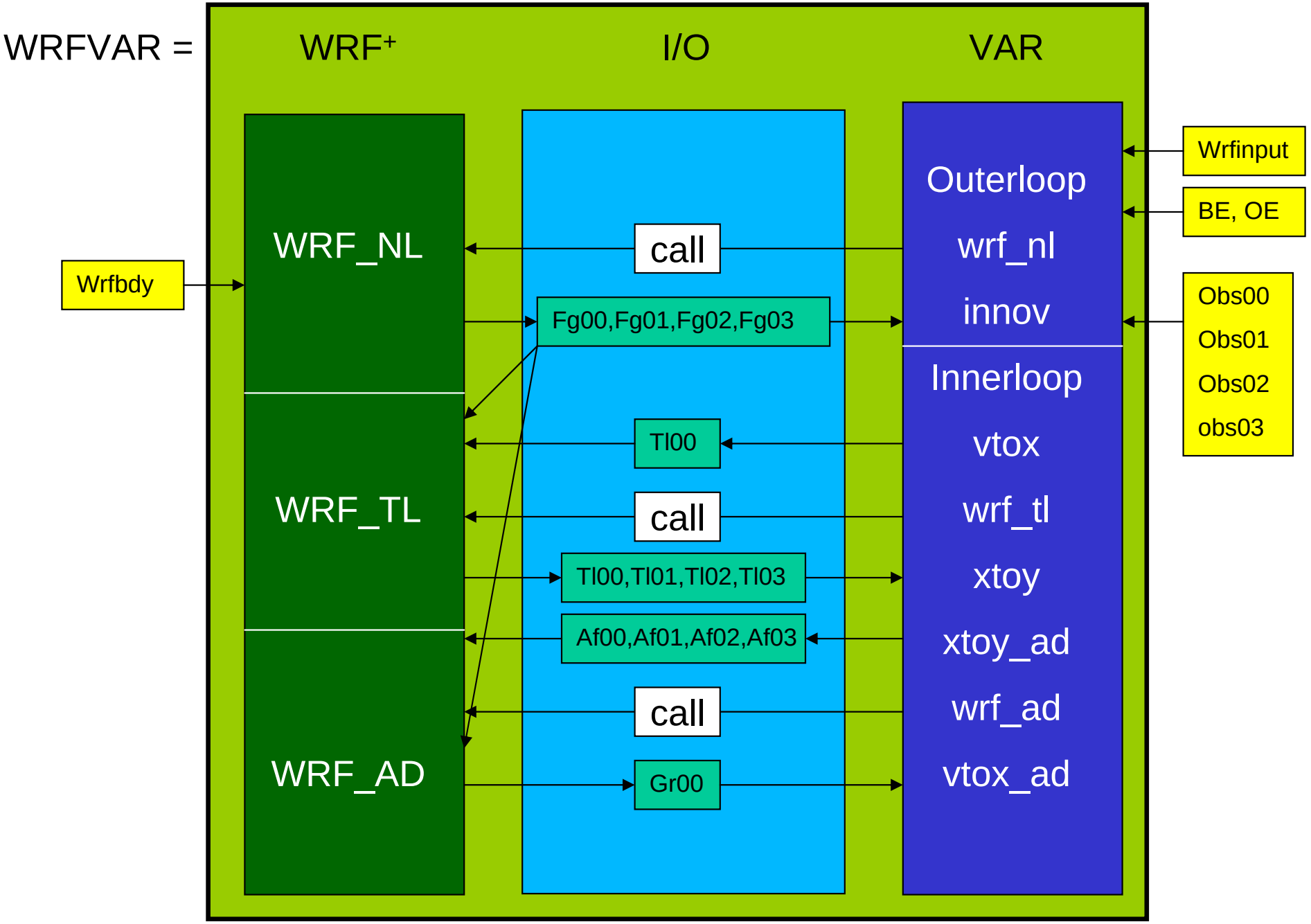
Stage II. Use separate executables, communicate through I/O



The very first WRF-4DVar run



Stage III. Integrate WRF-4DVar (FY2006)



Stage IV. Improve the performance (FY2006)

- Multi-resolution
- MPP
- More physics
- Data assimilation experiments

Summary

1. WRF-(4D)Var project: 2004-2006.
2. WRF-(4D)Var formulation:
   - Based on the existing WRF 3D-Var and WRF model
   - Multi-incremental
   - Simplified tangent linear and adjoint models
3. Current status of WRF-(4D)Var:
   - Necessary modifications to WRF-3DVar have been completed.
   - WRF-(4D)Var framework has been done.
   - The prototype has been put together and “can run”.
4. Near future plan
   - Evaluate the performance through single observation experiments and case studies
   - Prepare for the Stage III (I/O to memory) and Stage IV (more physics, MPP, etc) work.