MPMD implementation of pre-operational 4D-Var on IBM P690

Simon Pellerin
Michel Valin
Pierre Gauthier
Monique Tanguay
Stéphane Laroche
Josée Morneau
Pierre Koclas
Meteorological Service of Canada

Outline

- 4D-Var Configurations
- Extension of 3D-Var to 4D-Var
  - Coupling strategy
  - Use of a coupling library
  - Re-mapping of resources: Wait I/O & soft_barrier
  - Pros and cons of the approach
- Performances : Current & future implementations
- Operational requirements & double cut-off outer-loop

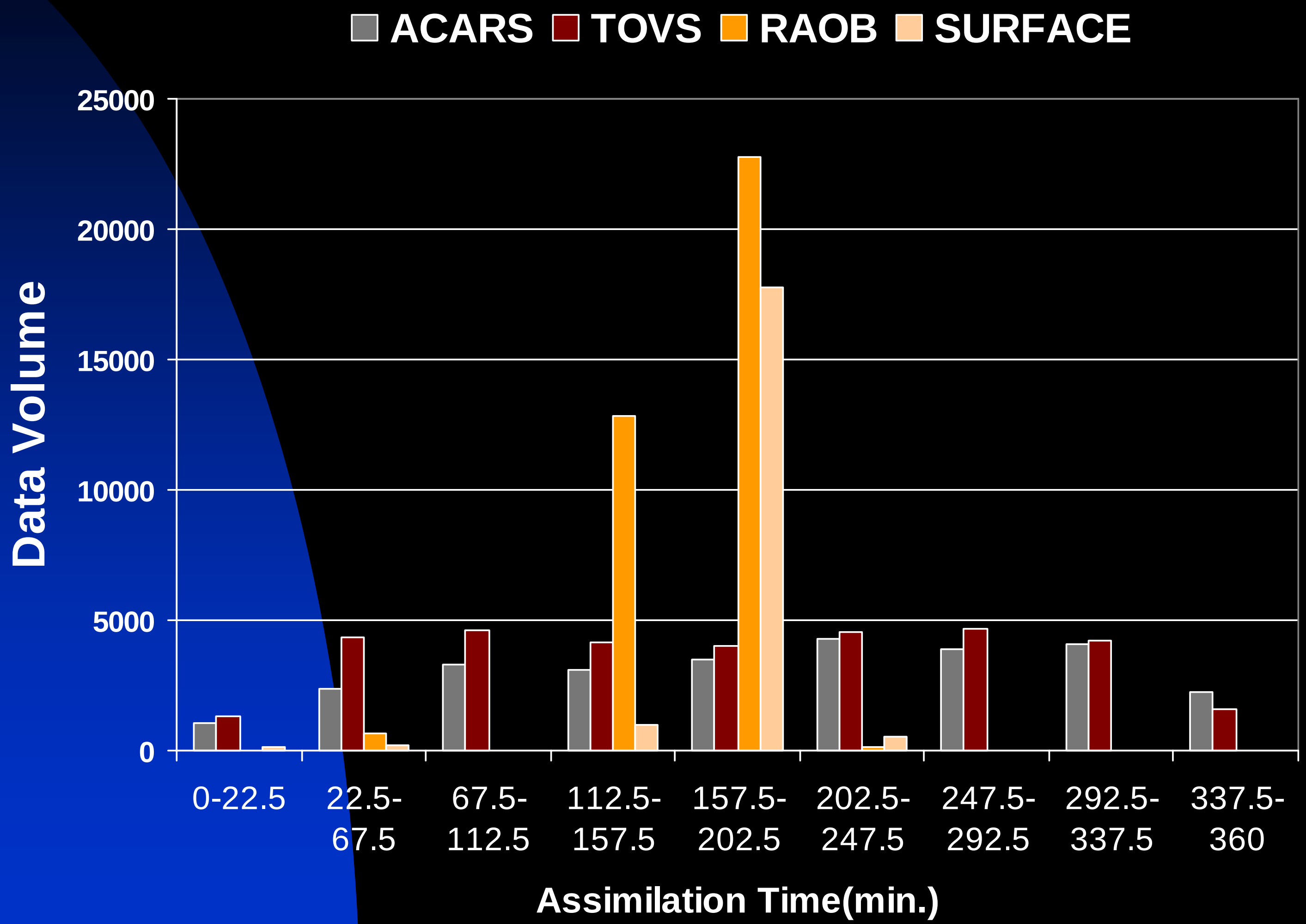
4D-Var configuration

- Non-Linear Model : Computation of Innovations
  - Global Environmental Model (GEM)
  - Uniform lat-lon grid of .9º, 401x200 pts (~100 km)
  - 28 eta vertical levels
  - 45 min. time step
  - Kuo convection scheme
  - Sundqvist stratiform scheme
  - Force-restore surface module
- 3D-Var : Minimisation, Cost function and its gradient
  - 28 η levels, Incremental formulation at T108, Gaussian 240x120 (170 km)
  - Background errors statistics from 24-48 method
  - Observations quality control: BG check & QC-VAR
  - Uses OpenMP
- Tangent-linear and Adjoint model
  - Uses OpenMP / MPI
  - 28 η levels, 240x120, 45 min. time step
  - 1st Inner loop
    - 40 iterations
    - Simplified physics: vertical diffusion scheme
  - 2nd inner loop
    - 30 iterations
    - Simplified physics: Vertical diffusion, Large scale condensation, convection scheme

4D-Var assimilated observations

TYPE	FORMAT / INSTRUMENT	PLATFORM	VARIABLES
Upper-air soundings	▪ radiosonde ▪ pilot ▪ dropsonde ▪ profiler	▪ land stations ▪ ships ▪ aircraft (dropsonde)	▪ temperature ▪ moisture ▪ winds ▪ sfc pressure
Surface observations	▪ synoptic	▪ land stations ▪ ships ▪ fixed buoys ▪ drifting buoys	▪ temperature ▪ moisture ▪ sfc pressure ▪ winds (marine)
Satellite	▪ NOAA ATOVS amsu-a & amsu-b	▪ circumpolar (NOAA series) (Aqua, amsu-a)	▪ radiance
	▪ GOES imager	▪ geostationary (GOES-W) (GOES-E)	▪ radiance
	▪ AMVs (IR, WV, VI channels)	▪ geostationary (GOES-E/W/P, METEOSAT-5/7) (circumpolar, Terra & Aqua)	▪ derived winds
Aircrafts	▪ BUFR / AMDAR ▪ AIREP / ADS	▪ Aircrafts (single level & profiles)	▪ temperature ▪ winds

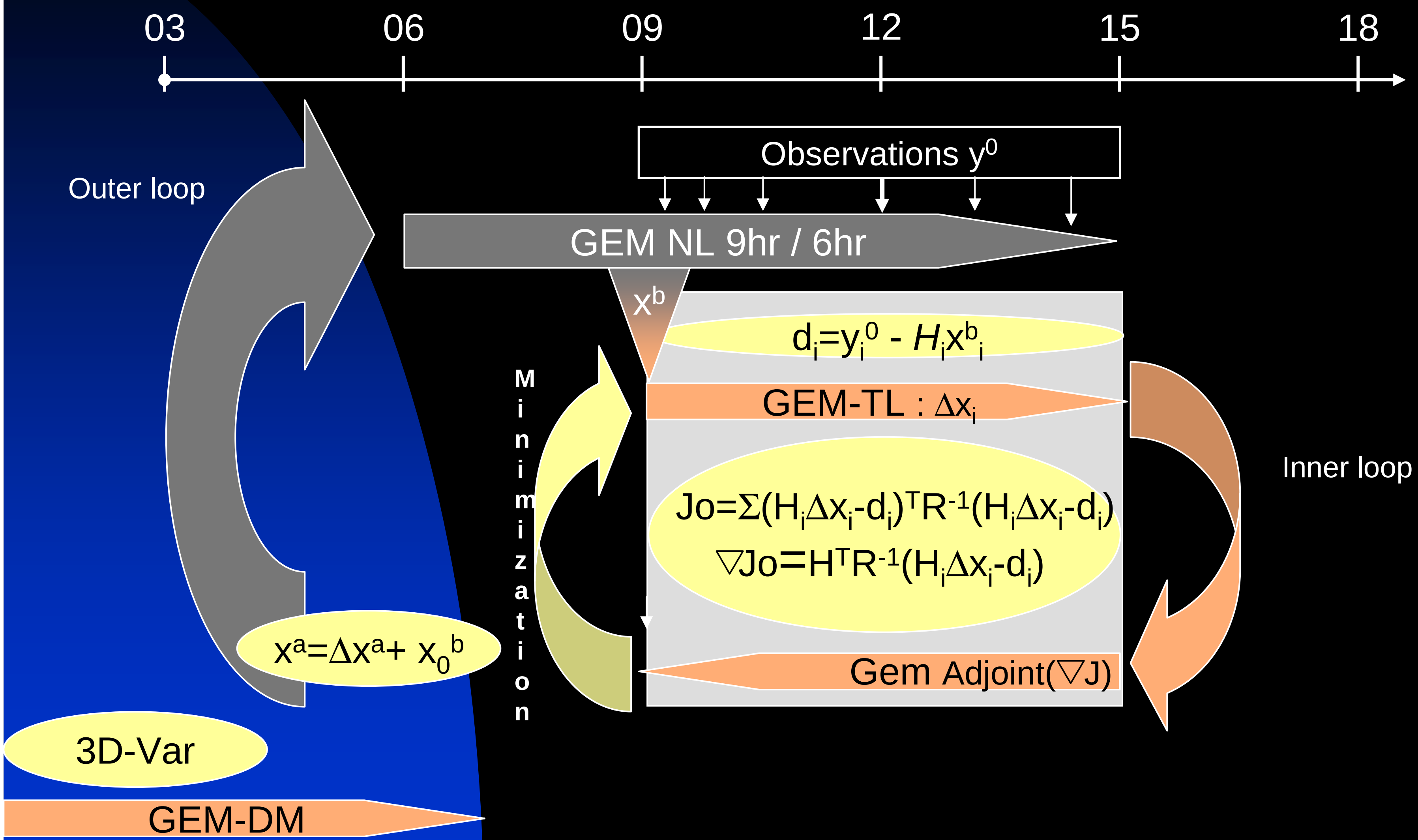
Time distribution of observations 6 hour window



Impact of 4D Thinning

Type	Received	3D	4D	Diff.
ACARS	34166	3809	12067	+217%
AMDAR	5412	919	2381	+159%
AIREP	808	222	590	+166%
ADS	150	49	129	+163%
SATWINDS	165305	5740	15209	+165%
AMSUA	170500	5262	6676	+27%
AMSUB	1516049	4232	4965	+17%

Incremental 4D-Var Cycle



Extension of 3D-Var to 4D-Var

General coupling strategy

- 3D-Var and TLM-ADJ (GEM) are launched as two independent applications
- 3D-Var
  - Controls the whole minimization process
    - Estimation of the cost function
    - Estimation of the gradient of the cost function
    - Minimization
- GEM
  - In 4D-Var execution mode, GEM responds to requests from 3D-Var
    - Nonlinear model integrations
    - Tangent-linear model integrations (TLM)
    - Backward integrations of the adjoint (ADJ) model
- Coupling of these two modules is insured by an external coupler that manages the computer resources

3D-Var Pseudo-code: J_o estimation

… minimization return with a new model state (iterate)

Call SPGD ! Spectral ➔ grid point : $\delta \mathbf{X} = \left(\delta \mathbf{u}^T \quad \delta \mathbf{v}^T \quad \delta \mathbf{T}^T \quad \delta \ln q^T \quad \delta p_s^T \right)^T$

if (4DVar)

Call PutDx ! GEM-DM request: Integration of TLM
! Return: profiles of the model state
! localized to obs.

Call GetProf ! 3D-Var releases resources and waits
! for profiled model state
! Read the profiles

else

Call Bilin ! 3D-Var Localizes model state to obs.

end if

Call Obs_oper ! Bring profiled model state into observation
! Space (without time consideration)

Call R^{-1} ! Compute normalized departures

3D-Var Pseudo-code : grad(J_o) estimation

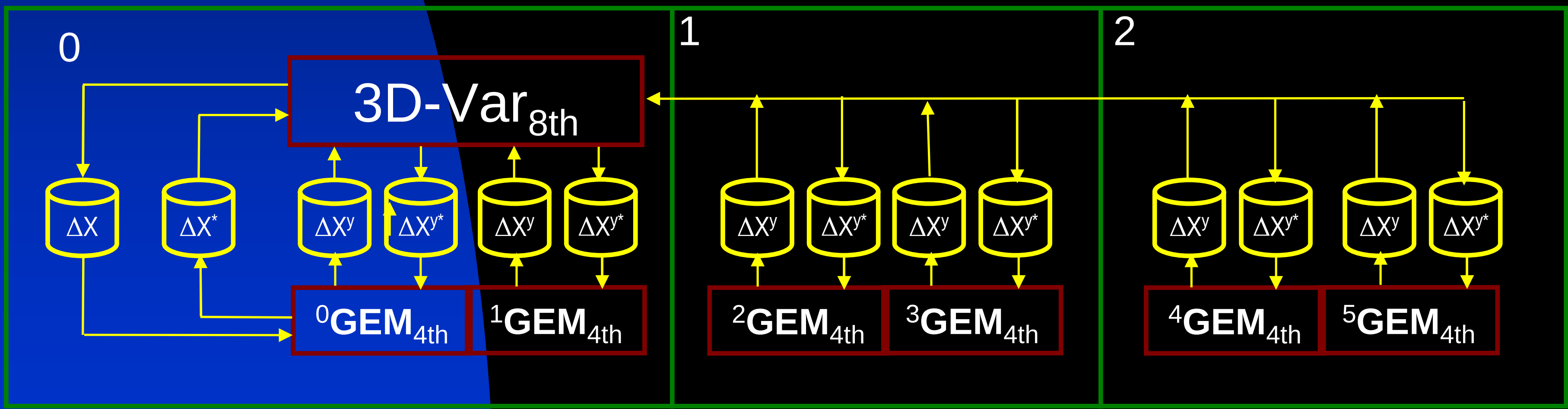
```
Call Obs_oper_ad          ! Contribution of normalized departures to
                          ! to gradient
                          ! Returns adjoint profiles
if (4DVar)
    Call PutProf      ! GEM-DM request: adjoint
                      ! (backward) integration
                      ! Reads in adjoint profiles
                      ! Return: gradient (grid points) to 3D-Var
    Call GetDx        ! 3D-Var releases resources and waits for
                      ! grad(Jo)
else
    Call Bilin_ad     ! 3D-Var brings the adjoint profiles to grid
                      ! point grad(Jo)
end if
Call SPGD_ad          ! Grid point ➔ Spectral

… Gives Jo and grad(Jo) to the minimizer
```

Pseudo-code GEMDM

```
Event_Loop: do while(nstatus.eq.0)
   Call V4d_GetEvent(nevent,nstatus)
   Select Case (Nevent)
   Case(TLM_Event)
        CALL V4D_GETDX(NSTATUS)
        call gem_ctrl_tl()
        CALL V4D_PUTPROF(NSTATUS)
   Case(Adj_Event)
        CALL V4D_GETPROF(NSTATUS)
        call gem_ctrl_ad()
        call v4d_putdx(nstatus)
   Case (Nonlinear_Event)
        call v4d_getdx(nstatus)
        call gem_ctrl()
        CALL V4D_PUTPROF(NSTATUS)
   Case (End_Event)
        NSTATUS = -99
   End Select
End Do Event_Loop
```

Current implementation : Release of resources on I/O wait

```
Imaxthr = omp_get_max_threads      ! Remember the number of threads
Ier = omp_set_num_threads(1)       ! Set the number of thread to 1
Open : do
     If ( file_is_there) exit open      ! Check for the existence of the file
     Ier = micro_sleep(sleeptime)       ! Base on 'select' unix command: execution
                                        ! thread identify as a comm. I/O wait
Enddo open
Unit_num=Open(prof_file,'FTN+SEQ+UNF+OLD')      ! Open the file
Ier = omp_set_num_threads(imaxthr)              ! Re-set the number of
     threads
```

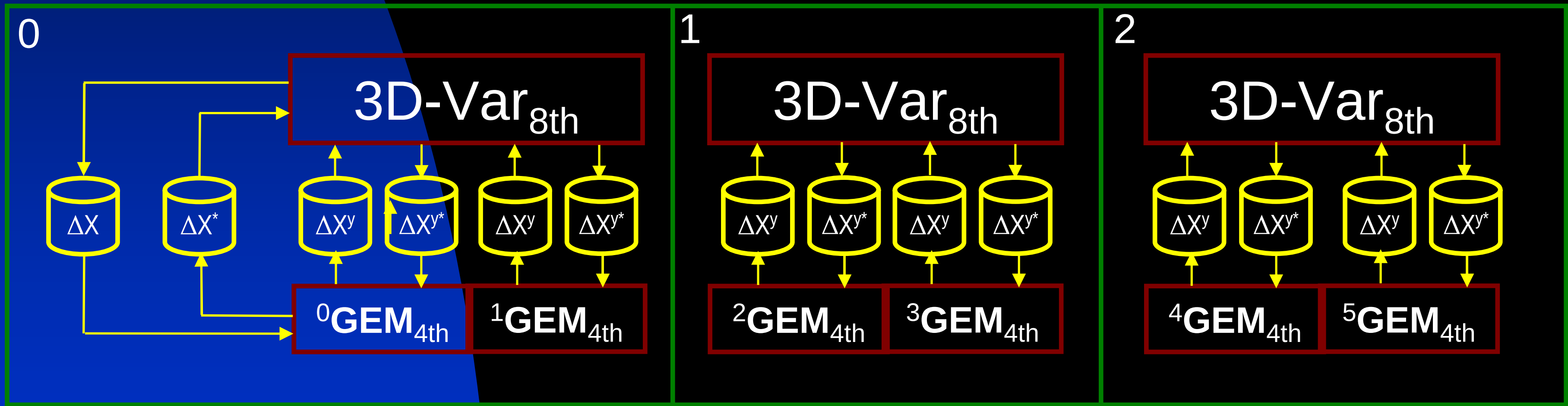


Future implementation : Release of resources on soft_barrier

Imaxthr = omp_get_max_threads
Ier = omp_set_num_threads(1)
Wait for TCP IP token from upstream task (except task 0)
Send TCP IP token to downstream task (except task 5)
Wait for TCP IP token from downstream task (except task 5)
Send TCP IP token upstream (except task 0)
Ier = omp_set_num_threads(imaxthr)
MPI_BARRIER

General approach for non symmetric Threads/Task

LL Request	2	2	2	2
TLM-ADJ	4	4	0	0
3D-Var	0	0	0	8



Token exchange on soft_barrier

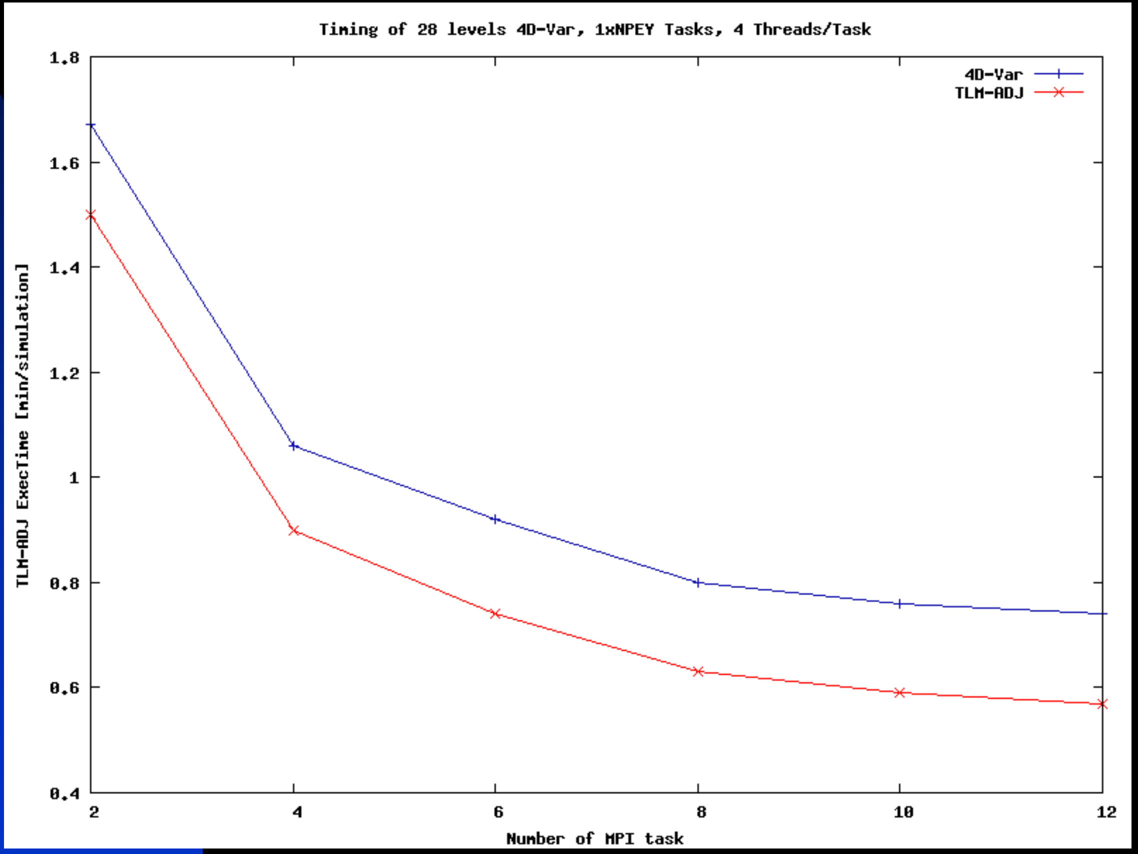
Adventages of the approach

- Independent development of 3D-Var and GEM
  - Addition of new data types in 3D-Var readily available in 4D-Var
  - Refinements of background-error covariances in 3D-Var
  - 3D-Var LA & LAM ➔4D-Var LA
  - 3D-Var Strato & GEM Strato (0.1 hPa) ➔ 4D-Var strato (chemical-dynamical DAS)
  - Computation of Singular vectors
- 3D-Var implemented as a collection of basic transformations
  - 3D-PSAS (early 2004) ➔4D-PSAS
  - When coupled with TLM-Adjoint ➔ sensitivity estimation in observation space

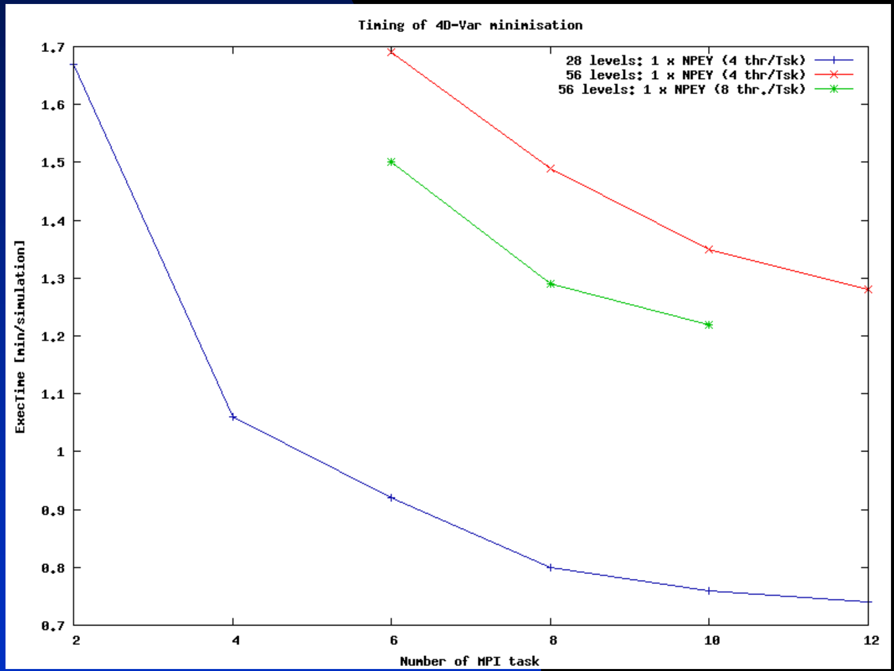
Drawbacks of the approach

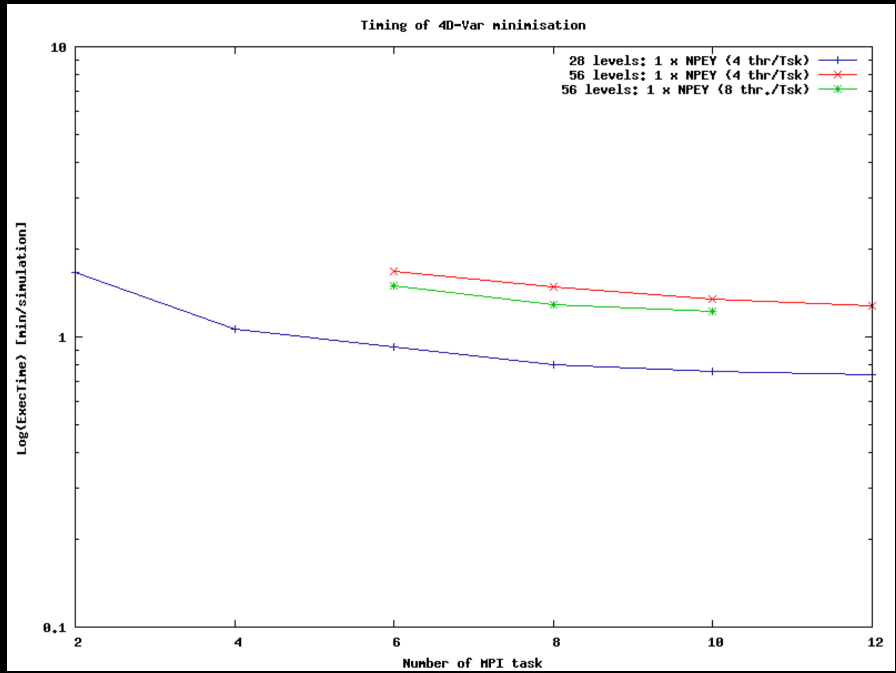
- Mapping of resources more complex
- Independent launching procedures harder to maintain
- Configurations of units highly fragmented

Performances : pre-operational Global 28 levels

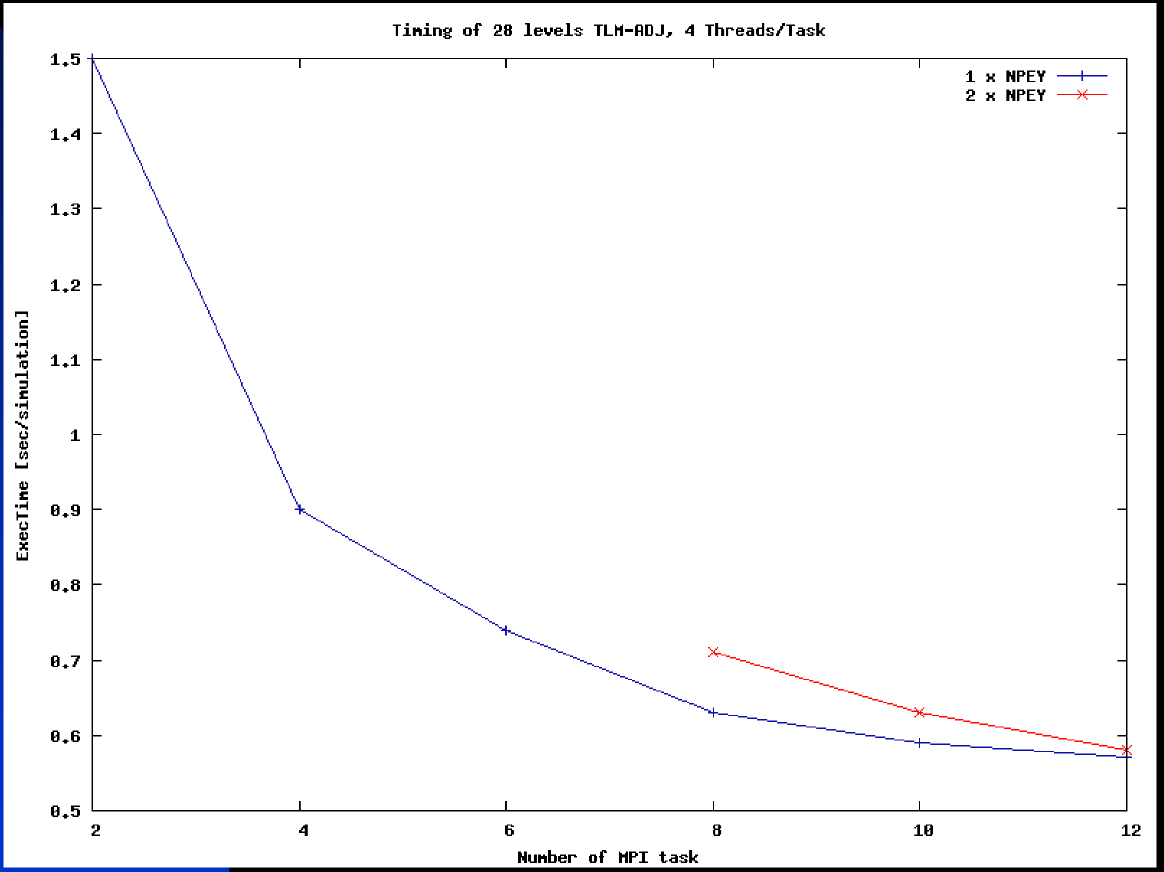


Performances
Development phase meso-Global 56 levels

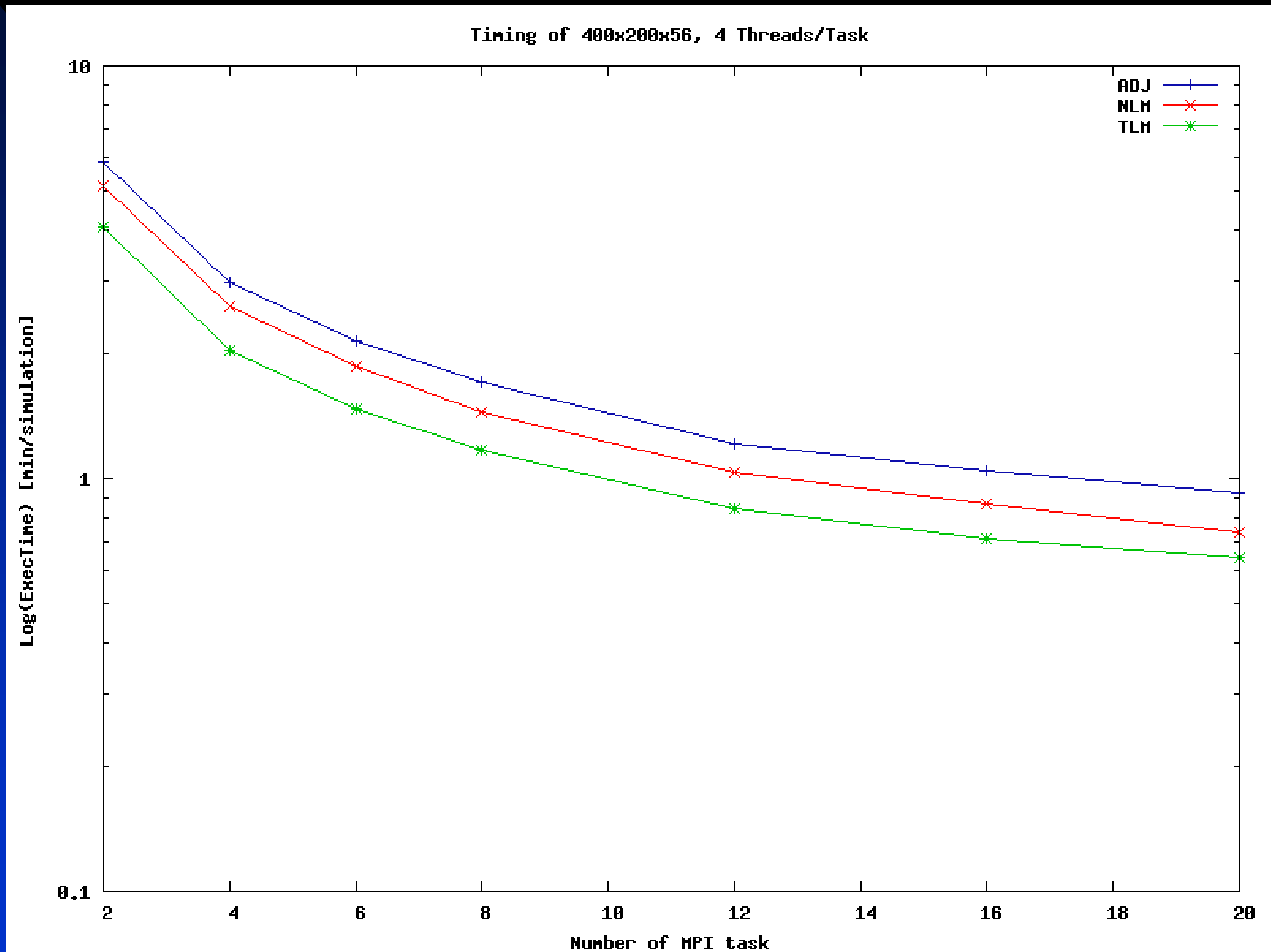




X decomposition of TLM-ADJ



TLM-ADJ-NLM Exec Time 400x200L56



Solutions to reach future Operational requirements

- Increase TLM adjoint performances
  - Avoid global collect with polar decomposition
  - Increase OpenMP gain
  - Work on the numeric of the TLM-ADJ
- Refinement of outer-loop strategy
  - More continuous introduction of observations
  - Change of horizontal and/or vertical resolution : multi-incremental approach

Operational timings

Execution times (minutes)

* : Concurrent jobs

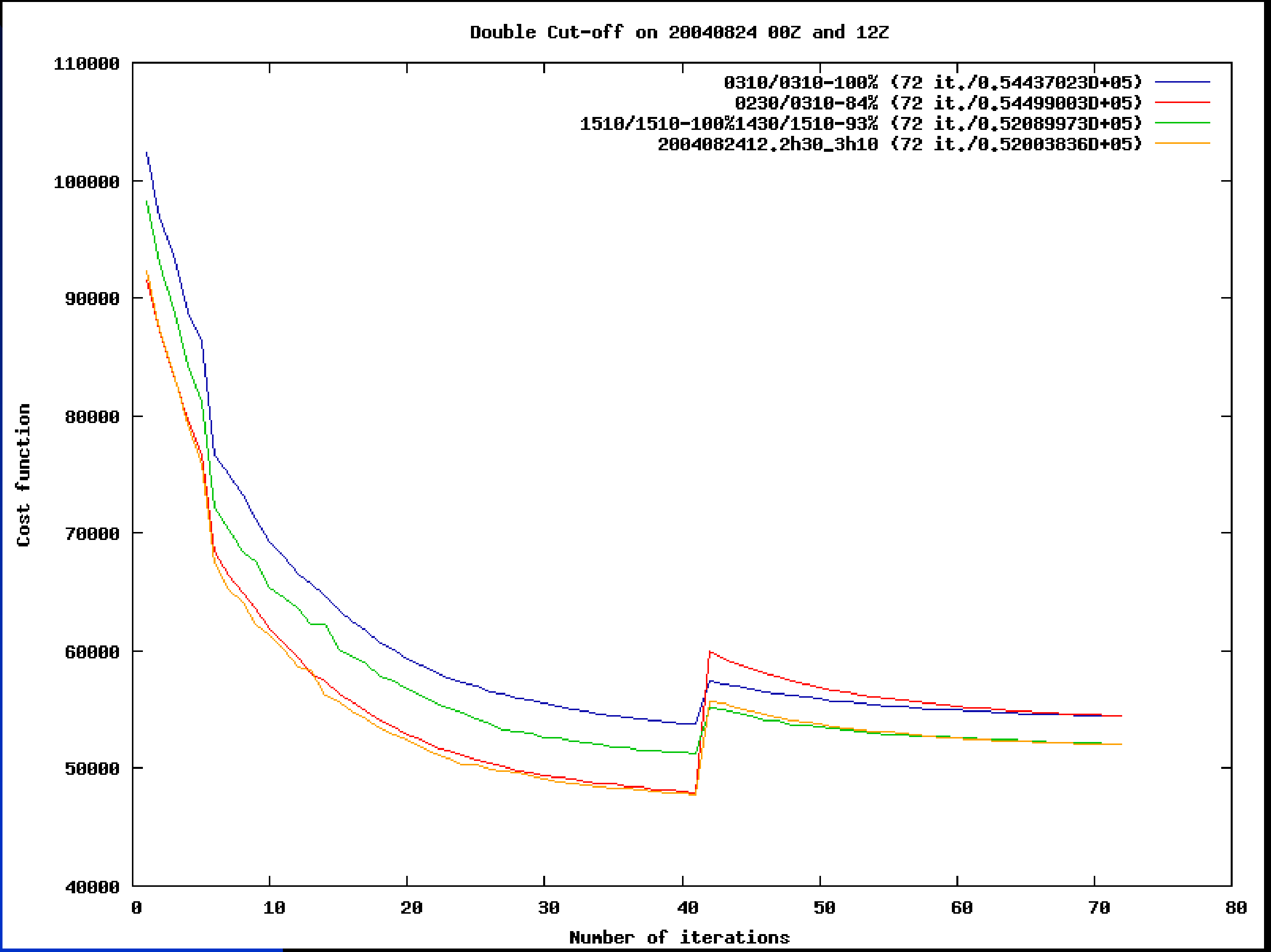
Nbr. O/I Loops	Total time	TLM-ADJ	3D-Var	NLM (6 hrs)	BGCK & Thinning
1 / 40	45	26	7	4*	8
2 / 30	37 (29)	19	6	4	(8)*
Total	82 (74)	45	13	8	16 (8)

Cut-off times & schedules

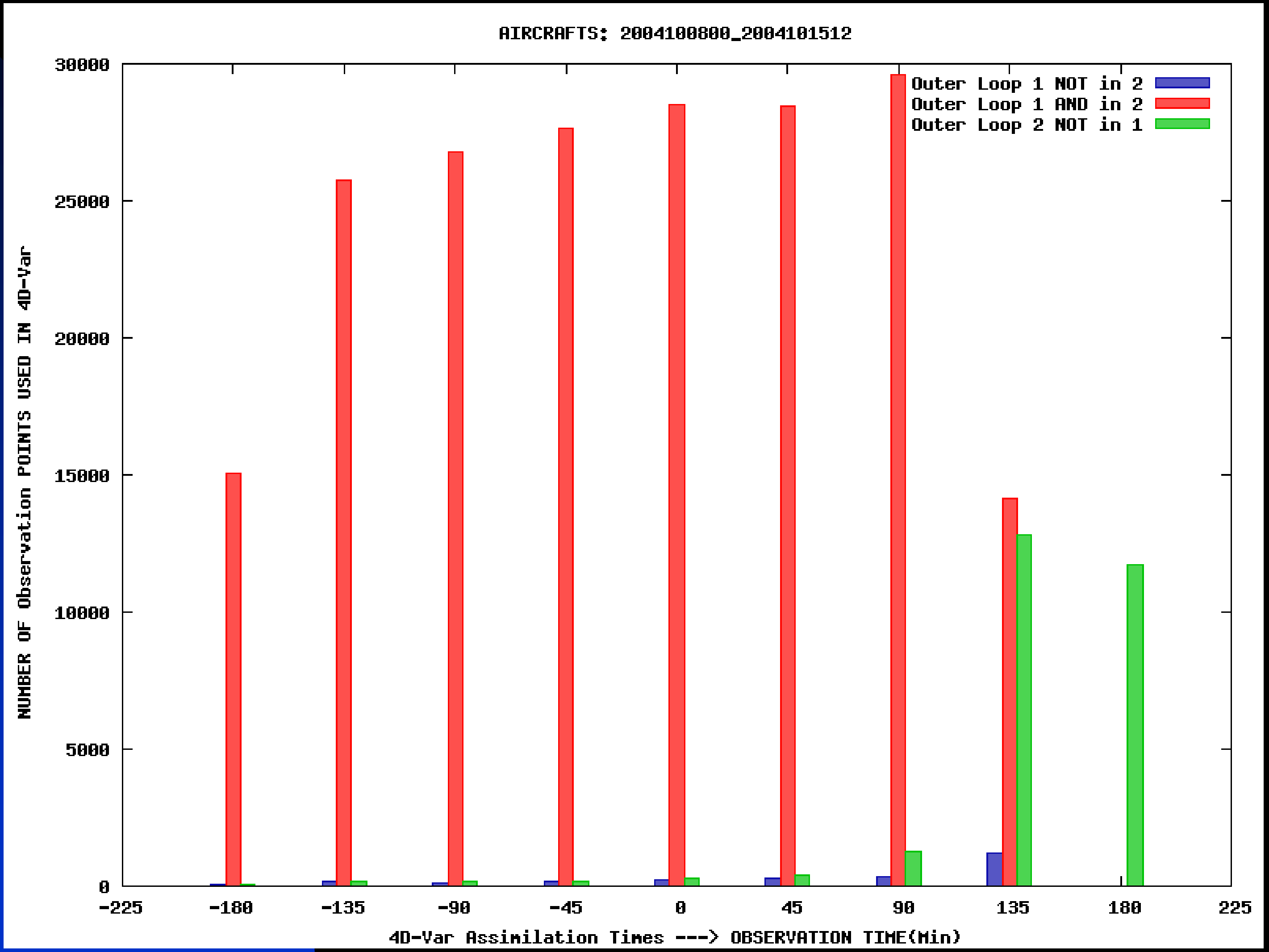
Start Time : End Time (HHMM GMT)

Analysis time	Outer loop #1	Outer loop #2	Ndata OL1/OL2	Forecast Model 10-15 days
Double cut-off 00 / 12	+0230 : +0315	+0310 : 0350	85% - 95%	+0350 : +0420
Single cut-off 00/06/12/18	+09/06/08/04	+9:52/6:52/8:52 /4:52	100%	--

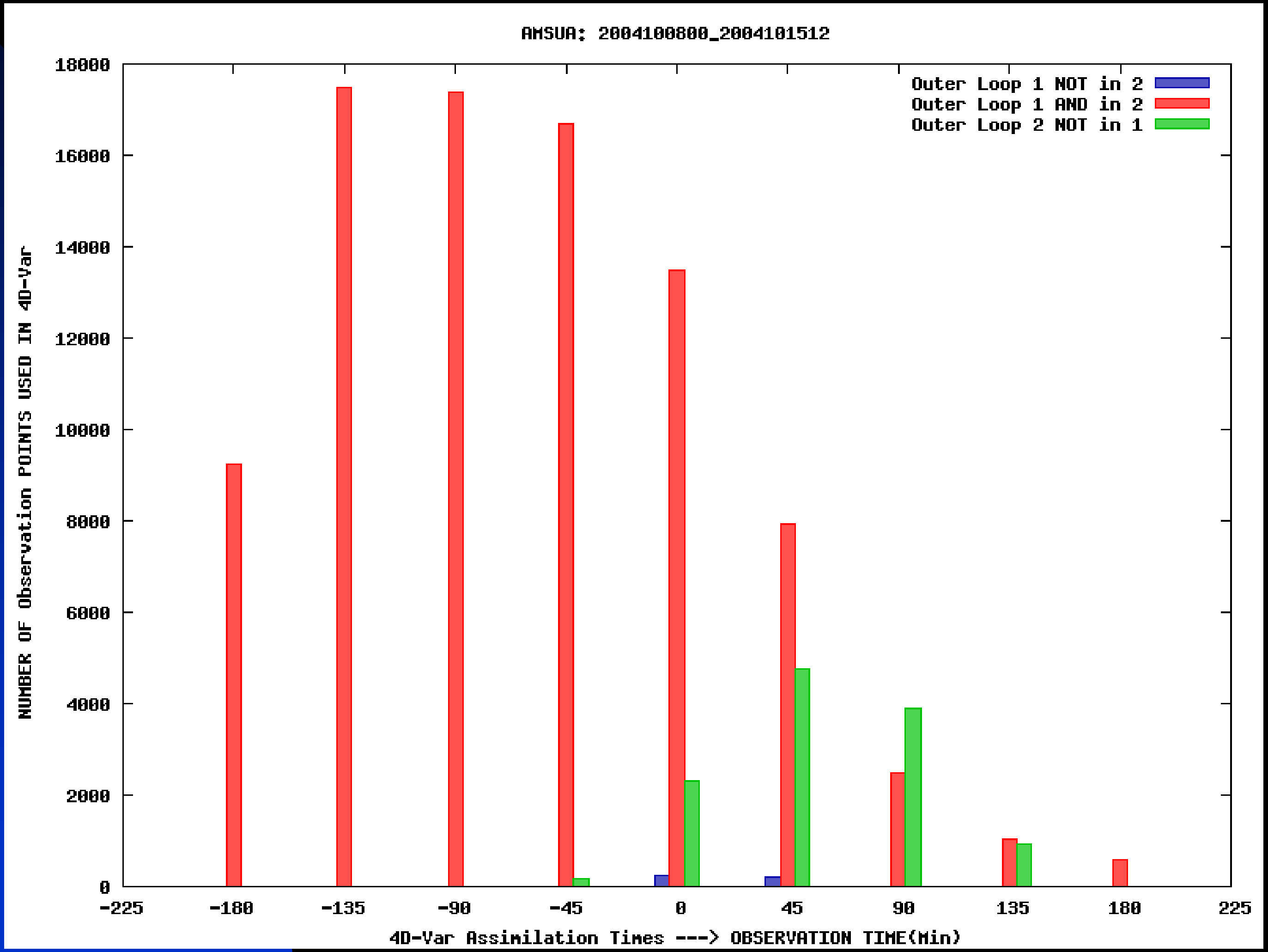
Double cut-off convergence



Double cut-off : aircraft reports



Double cut-off : AMSUA data



Conclusion

- 4D-Var data assimilation system will be operational in early 2005
- It uses a general MPMD coupling strategy
- Flexible and extensible: Independent development of 3D-Var and GEM
- Uses Double Cut-Off outer loop successfully
- Require performance improvement to meet future operational requirement

Extension of 3D-Var to 3D-PSAS

- 3D-Var in its incremental formulation (Courtier et al. 1994)

$$\mathrm{J}(\boldsymbol{\delta}\mathbf{x}) = \frac{1}{2}\delta\mathbf{x}^T\mathbf{B}^{-1}\delta\mathbf{x} + \frac{1}{2}(\mathbf{H}\delta\mathbf{x} - \mathbf{d})^T\mathbf{R}^{-1}(\mathbf{H}\delta\mathbf{x} - \mathbf{d})$$

- 3D-PSAS (Da Silva et al. 1995; Courtier 1997)

$$\mathrm{F}(\mathbf{w}) = \frac{1}{2}\mathbf{w}^T(\mathbf{R} + \mathbf{HBH}^T)\mathbf{w} - \mathbf{w}^T\mathbf{d})$$

Global Environmental Multiscale (GEM) model

- Run in 2 operational configurations
  - Global : lat-lon grid 0.9°
  - Regional : 15km
- Mémoire distribuée
- Global, équations primitives, (Non)/Hydrostatique
- Shéma d’intégration: semi-Lagragien implicite à 2 niveaux de temps
- Différences finies 3D
- Coordonnée verticale hybride
- Traceurs passifs
- Configurations de grilles multiples (tournée/stretching lat-lon)
  - Global à résolution uniforme
  - Variable avec grille-coeur sur la région d’intéret
  - LAM (en construction)
- TLM-Adjoint développé et validé
- Operational configuration
  - Type of forecast operationally