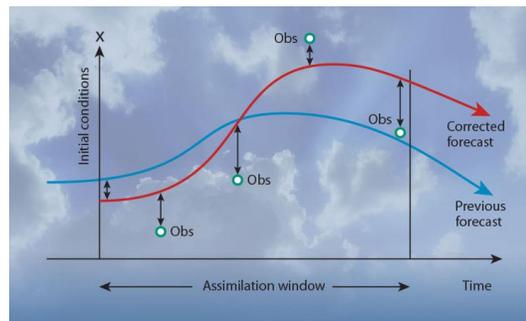


20 years of 4D-Var, the decision making process

Friday, 26th January 2018



The key players for the decision making

- David Burridge (HR, D)
- André Lebeau† (D)
- Jean Pailleux (Prévi-Dev, DAS, Gmap)
- Jean-François Geleynt† (CRMD, Gmap)
- Frédéric Delsol (Met-ops, CNRM)
- Michel Jarraud (Prévi, HO)
- Olivier Talagrand (SAC)
- Michel Rochas (CNRM, Arpege)



An internship at Prévi-dev -1

- Olivier Talagrand and Paul Betout in charge of DA cursus at ENM.
- Would you have an internship ? We had but we no longer propose it, since we think it is not feasible
- In March 1983 a meeting in LMD's library with Olivier, Jean, Claude Lemarechal (INRIA), Yves Durand...
- Direct model, adjoint back in time, minimization, slow manifold... I was quite puzzled

An internship at Prédi-dev - 2

- With Olivier we choose to work with the barotropic vorticity equation in order to circumvent the gravity wave issue
- Lacking some maths basic's, I followed Jacques-Louis Lions lessons at Collège de France
- Lots of exchanges with Olivier, Jean and Yves
- With Olivier we derived a continuous formulation of the adjoint equations and an implementation relying on a property of the spectral operators free of aliasing
- Lots of exchange with Claude Lemarechal on the minimization methods and the gradient quality – necessity of a bug-free adjoint code

An internship at Prévi-dev - 2

- Use of real observations: the continuous formalism no longer applies to the observation operator (terminology introduced by Jean). Some adjoint routines related to the grid point computations coded line per line.
- June 1984 first results: an Aleutian depression reconstructed in a data void area.
- Defence for the engineering degree in June 1984. A question from Bernard Legras: how long can you extend the assimilation window in the case of a chaotic dynamical system
- Final results produced during summer 1984, presented at ECMWF in June 1985 and published in Talagrand & Courtier and Courtier & Talagrand, 1987.

Two years at Prévi-dev: Sept. 1984 – Aug. 1986

- A feasibility issue: the control of the gravity waves
- This had been a long standing NWP issue solved in the late 70's by e.g Machenhauer, Daley, Temperton...
- With Olivier we decided to reproduce the baropic vorticity equation results but with a shallow-water equations
- One result: the addition of a term measuring the distance to the slow manifold allows to control the gravity waves (benefited from numerous discussions with Robert Vautard)
- Two issues: background term (lot of ideas from Grace Whaba)
- Preliminary results presented at ECMWF, june 85, published in Tellus 1990

- Where we were:
 - 4D-Var worked with the barotropic vorticity equation and the shallow-water equations
 - Control of the gravity waves solved for the 2-D problem
- Some issues of utmost importance:
 - The cost issue → nothing to propose
 - Non differentiability of physics → ideas along regularisation
- In ECMWF operations, one problem with the use of satellite data:
 - they had a negative impact in the Northern hemisphere
- The latter was the chance for 4D-Var. Jean, head of the ECMWF data assimilation section, was convinced that 4D-Var was the solution

- I joined ECMWF in Adrian's model section and I was to help Jean-Michel Hoyer with the LAM. Adrian allowed me in parallel to implement the variable mesh (idea which Jean-François brought to my attention in June 1986) in the spectral shallow-water model I brought with me.
- Olivier came to ECMWF in order to finalize the barotropic papers and we had numerous discussions on the way to follow for the primitive equations. The main conclusions at the time were:
 - Necessity to recode the ECMWF model in order to separate data fluxes from computations (first I began coding the adjoint of the ops model)
 - Coding of the adjoint, subroutine by subroutine and line by line while trajectory management at high level
 - Model, data assimilation, but also singular vectors computation (inspired by Robert Vautard)
 - Variable mesh

Spring 1987

- Dave, on Jean and Adrian's advice decided to launch the project. This decision relied at the time on very few results, none published yet!
- Two scientists allocated: Mats and I, one third of the model section resources!
- One intuition, compatibility of the model architecture with largely // computers

- As such, the project was not allocated enough resources. Therefore I tried to embark Météo-France.
- I spent a couple of days in Paris to convince Michel and Jean-François with for the variable mesh one Haurwitz wave result with me!
- Frédéric was already convinced after the numerous discussions we had at coffee break during fall 86. André Lebeau was also convinced, I had the chance to have a thorough discussion with him at an ECMWF council.
- I was then invited at Météo-France at a workshop for the definition of the Arpege project and it started... first cooperation meeting 12th October 1988

Summer 1987 - 1988

- 18 months of coding with Mats and iterations with Jean-François for the set of equations, constants...

Summer 1989 – 3/1992

- The project at risk, several feasibility studies:
 - Thepaut and Moll, 1990: TOVS inversion and information content
 - Thépaut and Courtier, 1991: 3D primitive equations model
 - Gauthier, Courtier and Moll, 1992: Kalman filter and Lidar wind
 - Rabier and Courtier, 1992: 4D-Var in the presence of baroclinic instability
 - Rabier, Courtier and Talagrand, 1992: sensitivity analysis
 - Rabier, Courtier, Pailleux, Talagrand, Vasiljevic, 1993: comparison 4D-Var / 3D-Var
- All results very promising, but... cost issue remains

- « *We thank J.Derber who hosted us [Jean-Noël and I] in 1990 at the National meteorological Center. It was during a discussion with him that he expressed the idea of working in terms of increments to avoid developing the adjoint of the physics. After some time, this eventually became section 3.* » [of 4D-Var using an incremental approach, Courtier, Thépaut and Hollingsworth, 1994]
- The paper was submitted in July 1993 and presented at the 1993 SAC session (tech Mem 194): the major remaining feasibility issue was behind us.

Satellite data

- Meanwhile and following results obtained at UKMO, the use of satellite data followed the variational approach and one year after the withdrawal of TOVS data in the northern hemisphere, they were back in use at ECMWF in 1992. Eyre, Kelly, McNally, Andersson, 1992 TechMem 187
- Work was ongoing for implementing 3D and 4D-Var and initially, the plan was to implement B, capitalizing on the HL and LH 86 results, thus transferring the operational OI structure functions in the 3D-Var environment
- No real positive impact – internal ECMWF crisis for all of us
- An afternoon meeting : John, Graeme, Eric, Tony, Florence, Per myself, analysing the results: the problem was with the non separability of the structure functions
- Florence implemented the « NMC » method which led to operational implementation of 3D-Var in January 1996 (the three collective 3D-Var papers Courtier et al, Rabier et al, Andersson et al, 1998)

- François, John and Mike revised the J_b term (TechMem 238, 1997) and Adrian and Florence suppressed large scale initialisation of increments, Jean-François Mahfouf and Florence implemented a simplified physics direct and adjoint
- November 1997 4D-Var operational implementation, on the Fujitsu VPP700 which arrived in September 1996:

Tech Mem 240:

F. Rabier; J.F. Mahfouf; M. Fisher; H. Järvinen; A. Simmons; E. Andersson; F. Bouttier; P. Courtier; M. Hamrud; J. Haseler; A. Hollingsworth; L. Isaksen; E. Klinker; S. Saarinen; C. Temperton; J.J. Thepaut; P. Undén; D. Vasiljevic

Recent experimentation on 4D-Var and first results from a Simplified Kalman Filter
October 1997

the three papers Rabier et al, Mahfouf et al and Pesonen et al Tech Mem 272, 273 and 274.

- The 1997 decision was risky and ten years later led to a major success. At the time of the decision:
 - 4D-Var was not proved to be feasible,
 - and to perform the necessary research, it was necessary to develop 4D-Var
 - Necessary collaborative work to gather the resources
 - Variable mesh model with SL at the heart of MF project, feasibility not demonstrated with a PE model before Florence's thesis

Many thanks to the brave guys who took this decision