WGNE and Data Assimilation

Jean-Noël Thépaut

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ECMWF

WGNE ToRs

- Advise the JSC and CAS on progress in atmospheric modelling.
- Review the development of atmospheric models for use in weather prediction and climate studies on all scales, including the diagnosis of shortcomings.
- Propose numerical experiments aiming to refine numerical techniques and the formulation of atmospheric physics processes, boundary layer processes and land surface processes in models.
- Design and promote co-ordinated experiments for:
  - validating model results against observed atmospheric properties and variations;
  - exploring the intrinsic and forced variability and predictability of the general circulation of the atmosphere on short to extended ranges;
  - assessing the intrinsic and forced variability of the atmosphere on climate time-scales.
- Promote the development of data assimilation methods for application to numerical weather and climate predictions, and for the estimation of derived climatological quantities.
- Promote the development of new methods for numerical weather prediction and climate simulation.
- Maintain scientific liaison with other WCRP and CAS groups as appropriate.
- Promote the timely exchange of information, data and new knowledge on atmospheric modelling through publications, workshops and meetings.

Introduction (I)

- **WGNE has in its remits to support:**
  - **Atmospheric modeling**
  - **Data assimilation developments**
- **At the last WGNE session (WGNE-27 – Boulder Oct. 2011):**
  - **Joint session with WGCM to explore areas of collaboration and expertise**
  - **Trends indicate progress in seamless prediction strategies**
    - **Same models for NWP and climate**
    - **Trans-AMIP intitiatives**
    - **Systematic errors**
- **WGNE initiatives are directly relevant for WDAC and WMAC**

Introduction (II)

- Data assimilation combines models and observations and provides:
  - Verification facility
  - Essential tool for reanalysis and climate monitoring
  - Consistent framework for observation impact
  - Know-how on quality control, obs error characterisation, etc.
- This presentation is a (incomplete) digest of major events over the last year or so:
  - THORPEX DAOS (Exeter, June 2011), ECMWF annual seminar (September 2011), WMO data impact workshop (May 2012)
  - *WCRP reanalysis conference (May 2012) (→ see M. Bosilovich)*
- We will concentrate on:
  - Progress in data assimilation methods
  - Observation Usage and Impact

- Data assimilation methods
- Observation related aspects
- Real data assimilation systems
- Efficient use of computer architectures

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Historical Background:

What has been important for getting the best NWP forecast? *(over last 3 decades)*

NWP systems are improving by 1 day of predictive skill per decade. This has been due to:

1. ***Model improvements, especially resolution.***

2. ***Careful use of forecast & observations, allowing for their information content and errors.*** *Achieved by variational assimilation e.g. of satellite radiances. (Simmons & Hollingsworth 2002)*

3. ***Advanced assimilation using forecast model: 4D-Var***

4. ***Better observations.***

Andrew Lorenc

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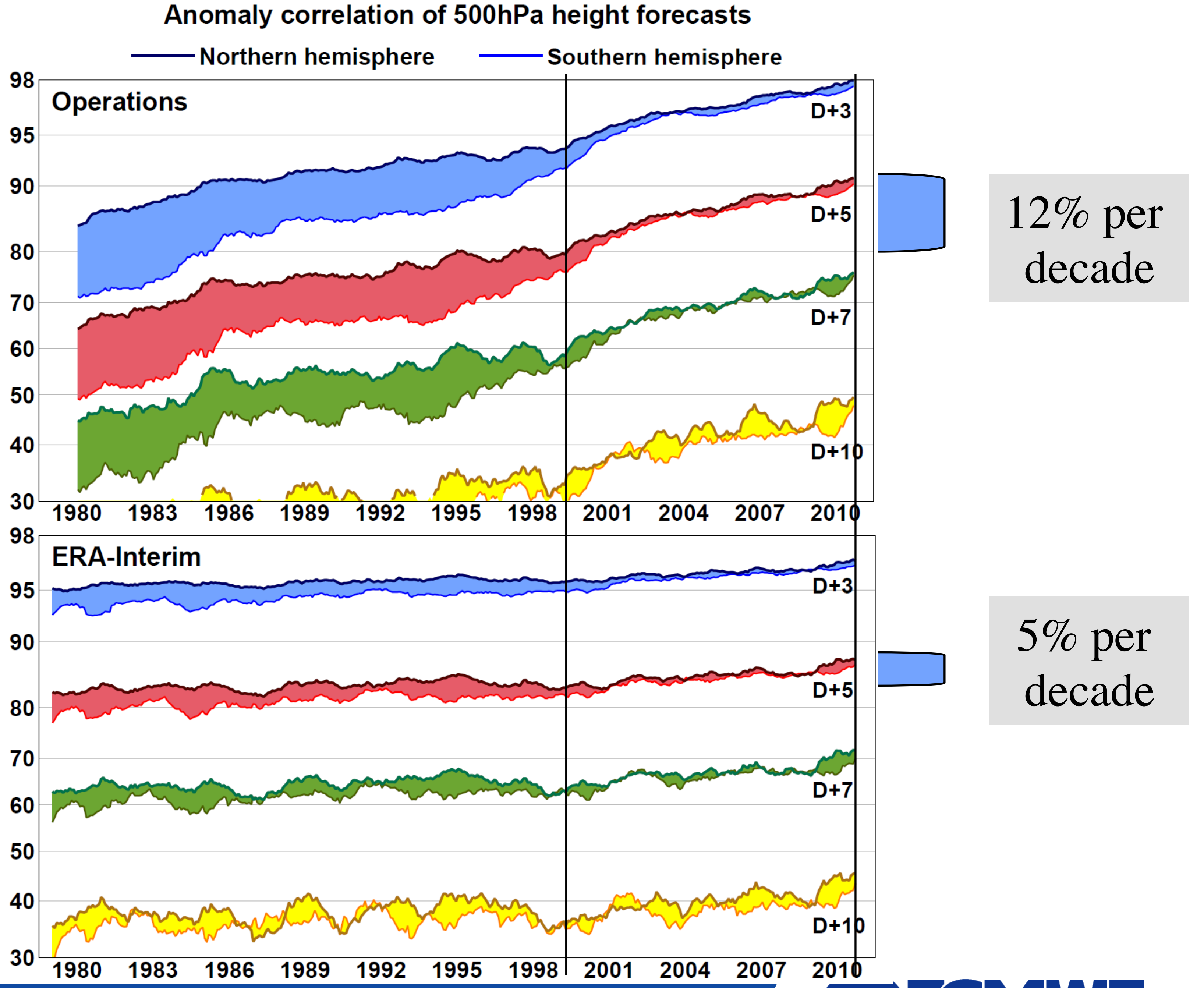
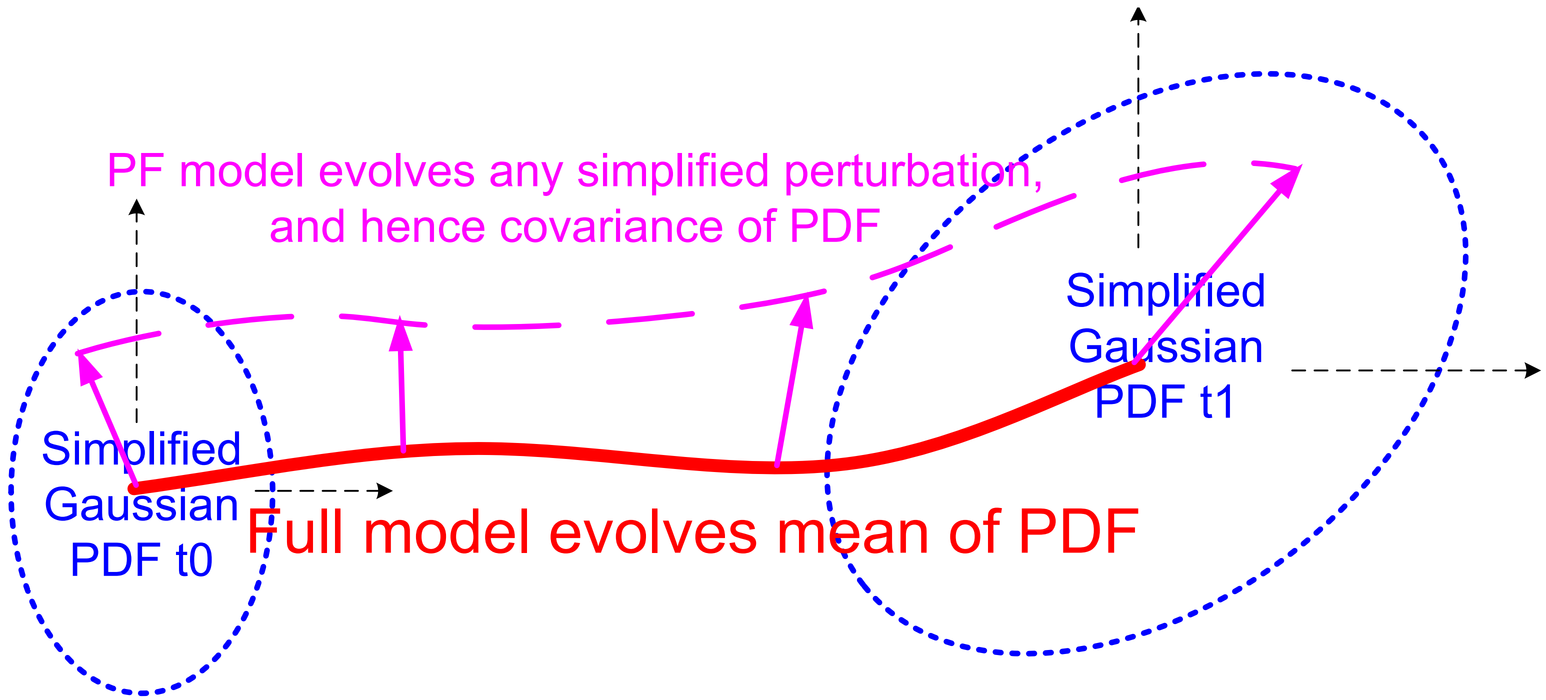


Anomaly correlation of 500hPa height forecasts
Northern hemisphere
Southern hemisphere
Operations
ERA-Interim
D+3
D+5
D+7
D+10
98
95
90
80
70
60
50
40
30
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
12% per decade
5% per decade

Statistical, incremental 4D-Var



optionally augmented by a model error correction term.

Andrew Lorenc

Hybrid Var/EnKF - best of both worlds?

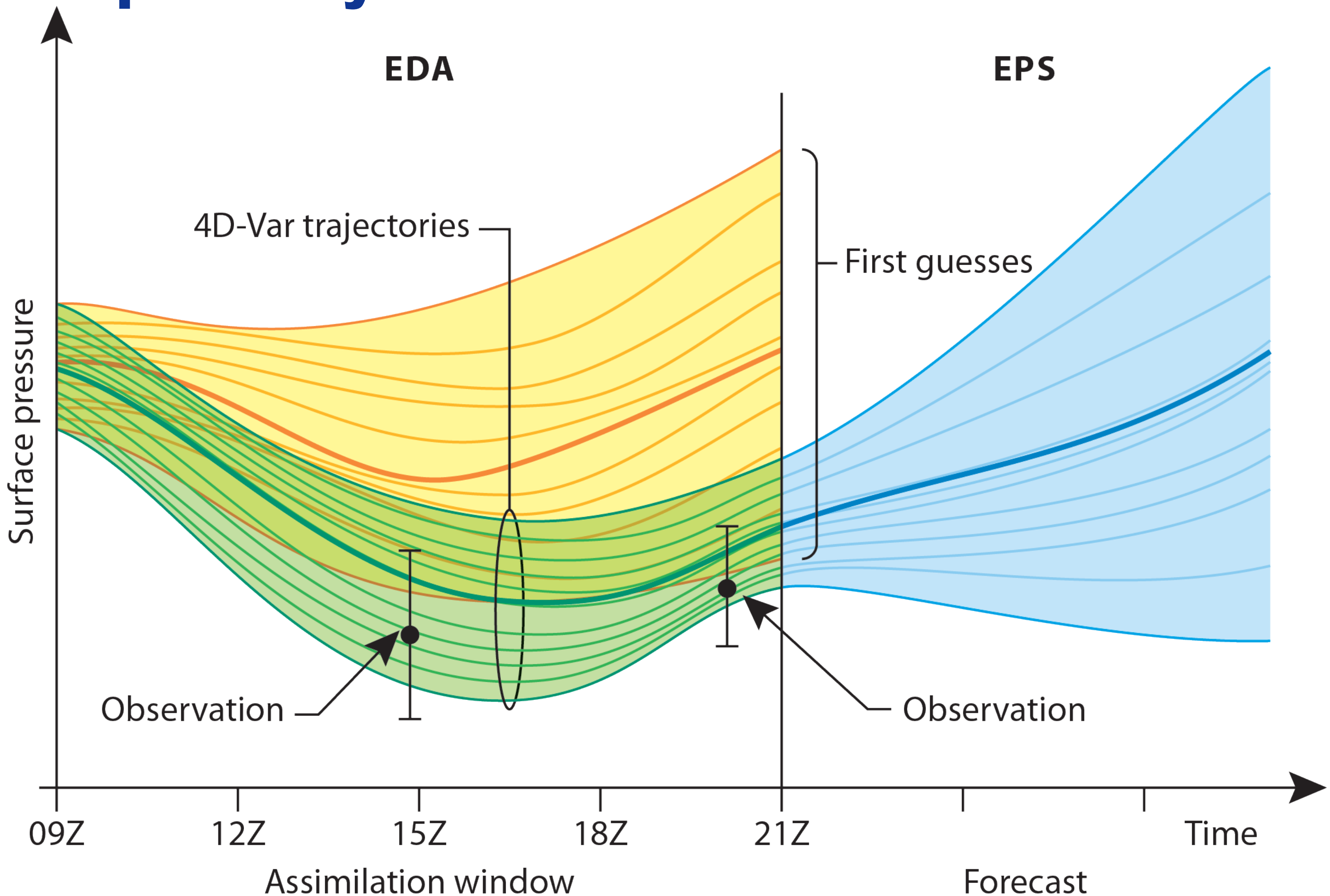
Features from EnKF	Features from VAR
Extra flow-dependence in $\mathbf{P}^b$	Localization done correctly (in model space)
More flexible treatment of model error (can be treated in ensemble)	Reduction in sampling error in time-lagged covariances (full rank evolution of $\mathbf{P}^b$ in assimilation window in 4DVar).
Automatic initialization of ensemble forecasts, propagation of covariance info from one cycle to the next.	Ease of adding extra constraints to cost function

--: covariance inflation,
covariance localization

--: scalability,
static B, maintenance cost

Jeff Whitaker

Example of Hybrid: Ensemble of data assimilation



- 10 members of 2 inner-loop 4D-Var's at T95/159 L91, T399 outer lops
- Perturbations from observations, SST, SPPT; noise filtering, scaling

Scalability – exploiting massively parallel computers

- 4D-Var as usually implemented requires *sequential* running of a reduced resolution linear PF model and its adjoint. It will be difficult to exploit computers with more (but not faster) processors to make 4D−Var run as fast at higher resolution.
- Improved current 4D-Var algorithms *postpone* the problem a few years, but it will probably return, hitting 4D-Var before the high-resolution forecast models.
- *4DCV 4D-Var can be parallelised* over each CV segment, but is difficult to precondition well.
- Ensemble DA methods run a similar number of model integrations in *parallel*. It is attractive to replace the iterated running of the PF model by precalculated ensemble trajectories: *4D−Ensemble-Var*. Other advantages of VAR can be retained.

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Incremental 4D-Ensemble-Var

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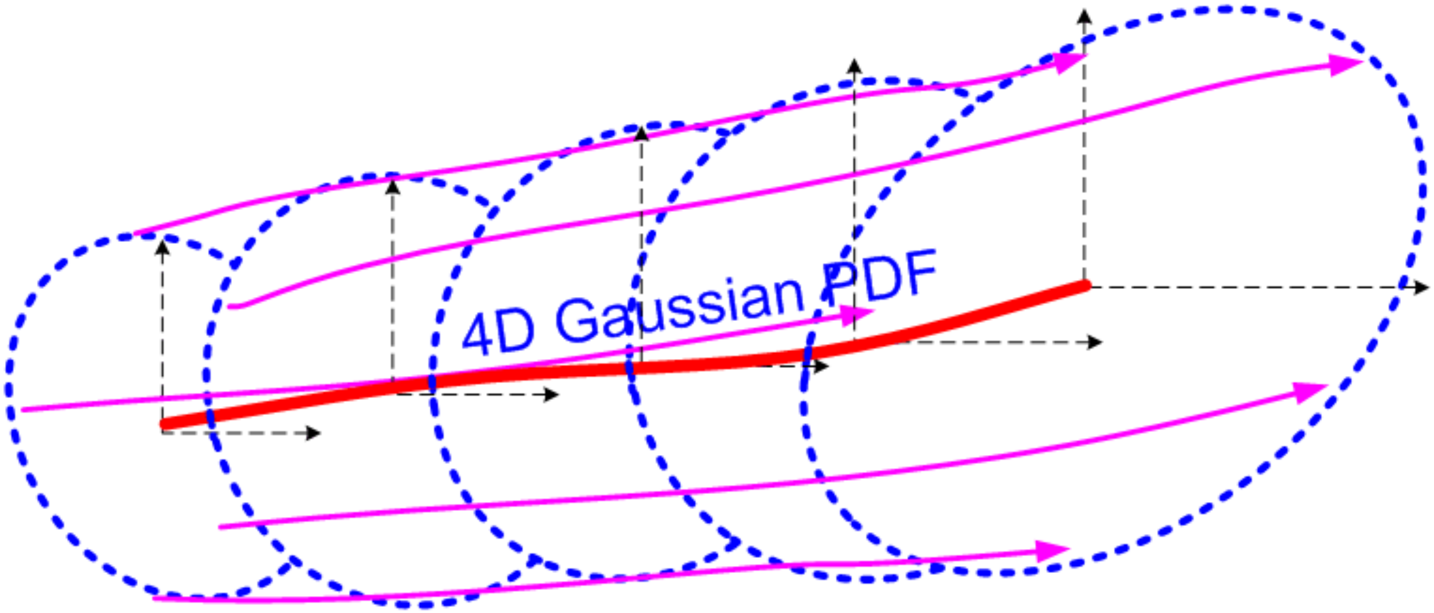


Trajectories of perturbations from ensemble mean

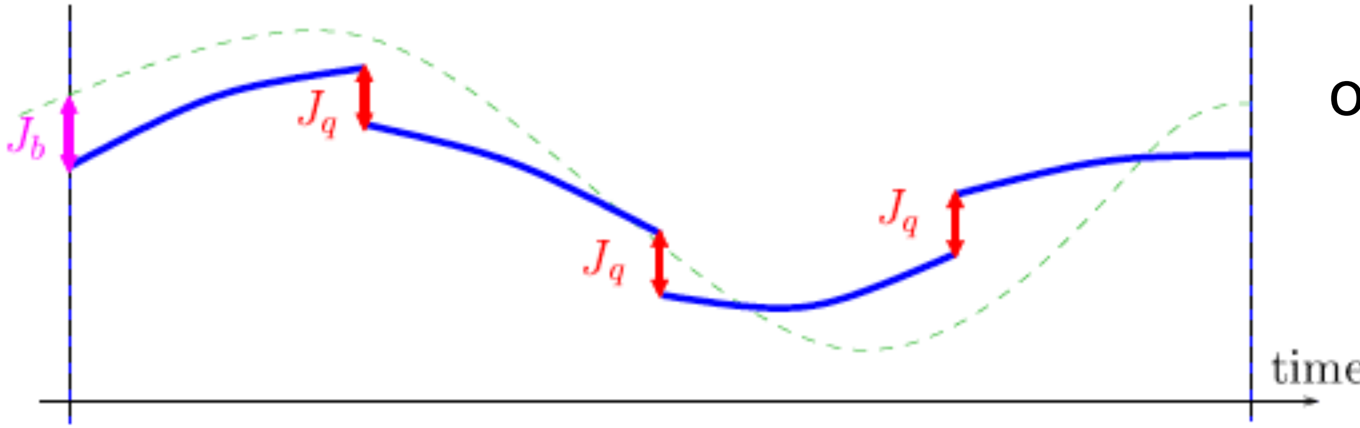
Full model evolves mean of PDF

Localised trajectories define 4D PDF of possible increments

4D analysis is a (localised) linear combination of nonlinear trajectories. It is not itself a trajectory.

Long window weak constraint 4D-Var

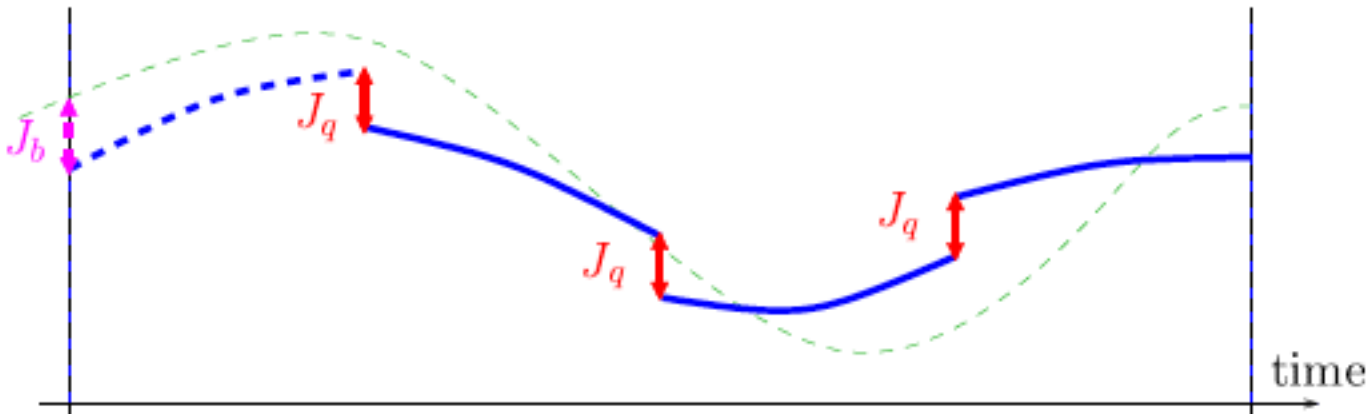
Suppose we extend the window by a few hours:



Parallelisation over sub-windows

We expect very little change in the the analysis for the first sub-window:

Mike Fisher



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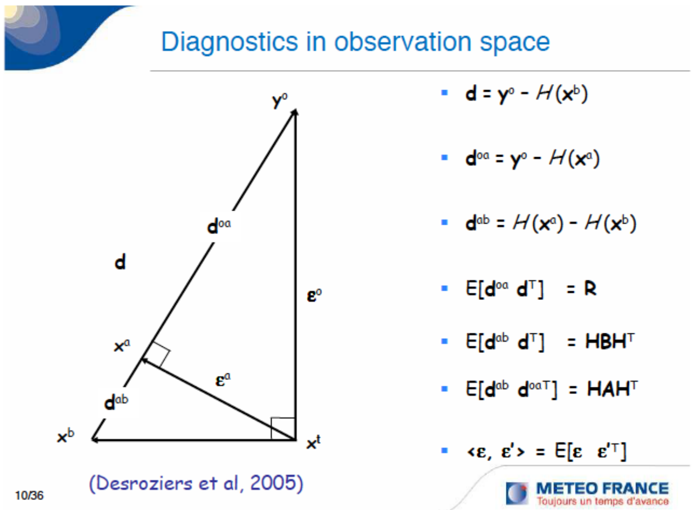
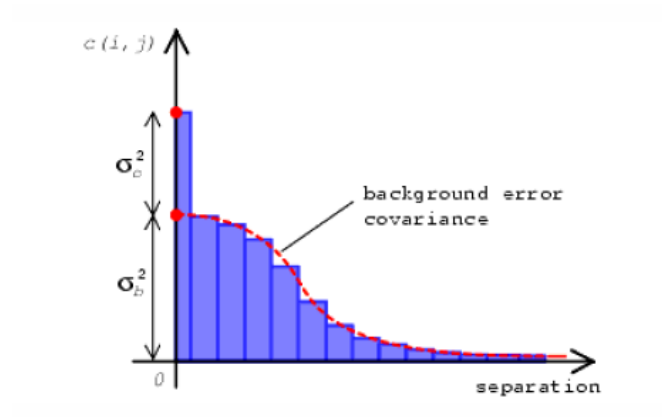
Other active areas in DA

- **Diagnostics for specifying observation error covariances in the assimilation**

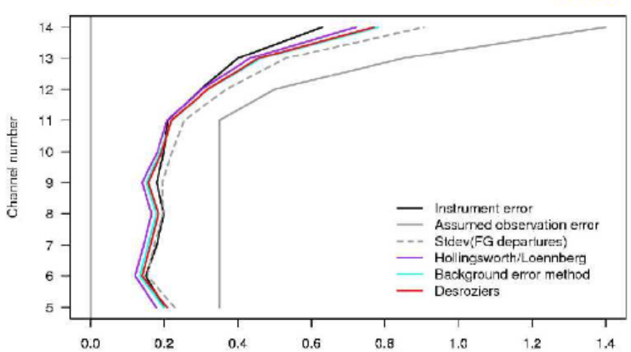
Gerald Desroziers

  - **Desroziers, Lonnberg & Hollingsworth, etc.**
  - **Effort in all centres to better characterize structure and amplitude**

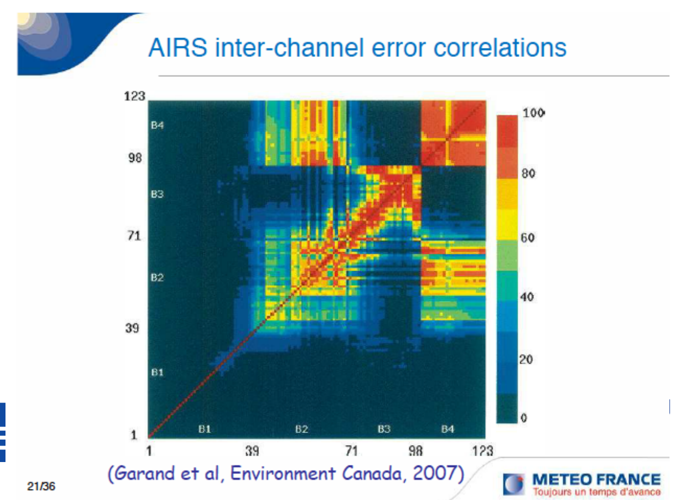




N-18 AMSU-A: Estimated observation errors (σ_O)

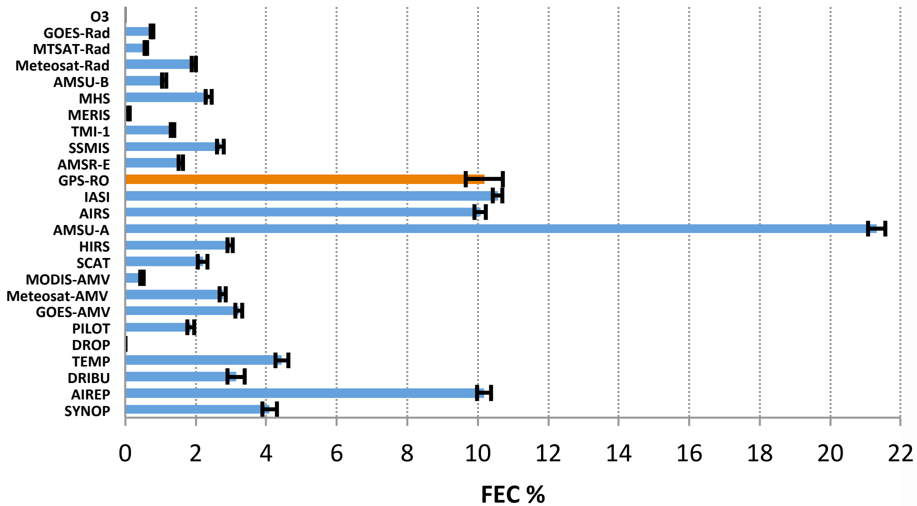


(Bormann et al, ECMWF, 2010)



Other active areas in DA

- **Enhanced diagnostics of assimilation and forecast performance (obs, R, B)**



Carla Cardinali

- **The invisible world: pre- and post- processing in Data Assimilation**

Transforming the raw data
- Transforming into a different space
- Averaging the data
- Filtering the observations

Comparing model and observations
- Monitoring and choice of observations
- Bias correction
- Removing wrong data

Thinning the data
- Reducing data quantity and error correlation
- Choosing the most relevant local data
- Selective thinning depending on the flow

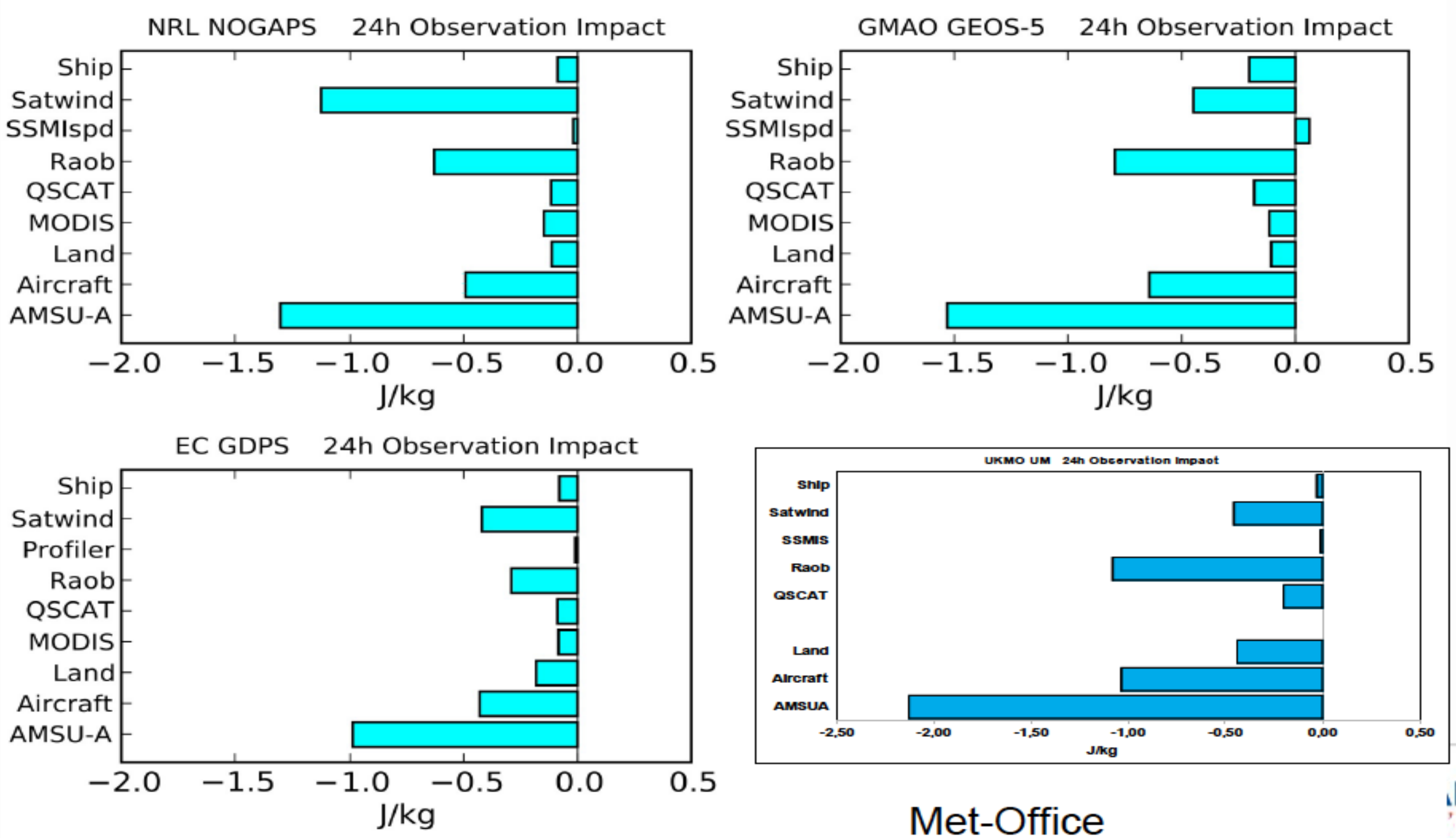
Filtering the analysis
- Initialisation methods
- Influence on the analysis

Florence Rabier

More widespread use of DFS and FSO types of diagnostics to evaluate impact of observations. Complementarity with OSEs

Impact of observation intercomparison: now including the Met-Office

D. Barker, M-O



Met-Office

Other active areas in DA: Ocean Data assimilation

Summary

- Ocean DA is diverse and mature
- Many basic challenges still exist:
  - expansion of control vector (B?)
  - tracer assimilation
  - initialization shock & filtering
  - vertical projection of satellite obs
  - covariance models
  - biogeochemical data assimilation
  - model error
  - internal tides
  - quality control & bias correction
  - air-sea coupling at all scales
- Sub-mesoscale and deep ocean are poorly observed (and poorly constrained)

Andy Moore

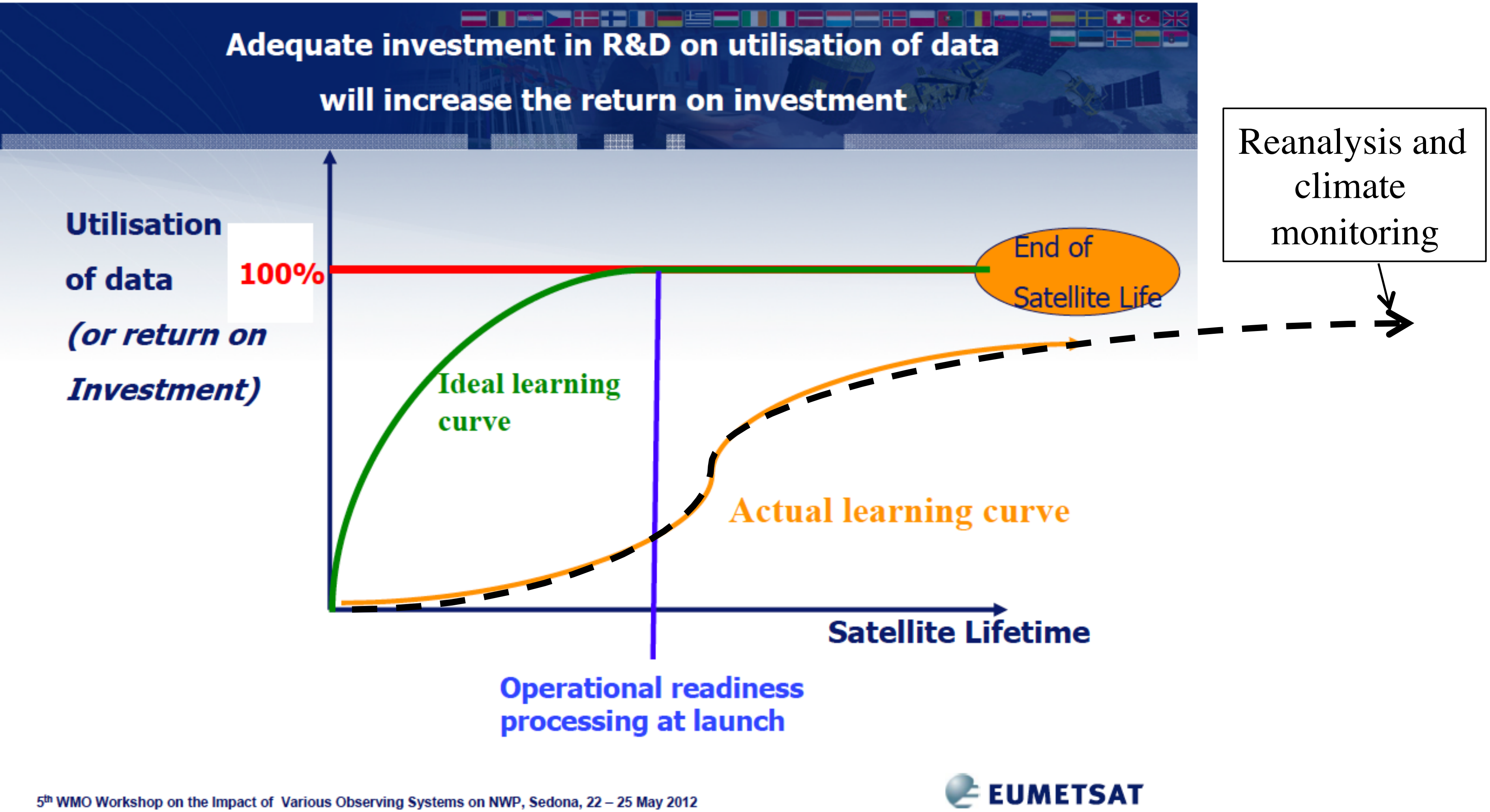
Other active areas in DA

- **Regional aspects**
  - High resolution data assimilation, hydrometeors
- **Challenge of satellite data assimilation**
  - Over land/sea-ice, use of PCs from hyper-spectral instruments, etc.
- **Assimilation of the hydrological cycle**
  - e.g. coupling with land surface assimilation
- **Ocean/atmosphere coupled data assimilation**
  - Systematic errors, time scales, etc.
- **Nonlinear data assimilation**
  - Particle filters, etc.
- **Reanalysis**
  - Requires specific DA formulation, not necessarily recycled from NWP
    - Longer window, highly time varying forecast error covariances, coupling

Conclusions and Suggestions (see also beginning)

- Impact studies (data denial or forecast error contributions) are a good tool to demonstrate the robustness of the GOS and to provide guidance on priorities for improved use of current data and of future missions
- WMO could enhance processes that:
  - maintain an up-to-date knowledge on impact of satellite data on NWP including guidance on interpretation (update cycle of this is tbd)
  - provide guidance for development work toward improved use of current data (that could also help to leverage dedicated funding)
  - provide guidance on future satellite missions (that does exist to large extent and is agreed => vision for the global GOS)
- *Longer term future:* WMO could trigger a concerted effort in support of the planning and coordination of a future space-based GOS from the very beginning

Johannes Schmetz



Johannes Schmetz

Conclusions

- **WGNE initiatives are relevant to WDAC and WMAC**
  - **Synergy or overlap? (something to watch out..)**
- **DA has an integrating role in providing consistent and qc-ed datasets for climate monitoring and therefore climate research (→ reanalysis)**
- **DA provides unique tools to assess gaps in the G(C)OS**
  - **How to assess observation impact for climate applications?**
  - **OSSEs in reanalysis mode?**
- **Progress in DA techniques will allow to address new challenges (→ coupled modeling and assimilation)**
- **We have to make sure that DA developments for reanalyses are properly coordinated and promoted across WWRP and WCRP**
  - **Reanalysis purely piggybacking on NWP DA is probably and obsolete hypothesis**
  - **Can WDAC/WGNE help ensuring this coordination?**