Progress report and planned activities

THORPEX working group on Data Assimilation and Observing Strategies *initially*

Pierre Gauthier	(UQAM, Canada,Co-chair)
Florence Rabier	(Météo-France and CNRS, France, Co-chair)
Carla Cardinali	(ECMWF, Int)
Ron Gelaro	(GMAO, USA)
Ko Koizumi	(JMA, Japan)
Rolf Langland	(NRL, USA)
Andrew Lorenc	(Met Office, UK)
Peter Steinle	(CAWCR, Australia)
Michael Tsyrulnikov	(HRCR, Russia)
+ Thomas Hamill	(NOAA, USA)

Merge with OS

- **Work already covered through OPAG-IOS, rest of work would not constitute a WG. Best to combine, go to DAOS (Obs systems). J. Purdom (OPAG-IOS chair as rapporteur), C. Velden, R. Saunders, T. Keenan (radar), one in situ data. No work on innovative obs, should be done somewhere else.One co-chair from OS group (R. Saunders subject to approval of M-O and THORPEX) and F. Rabier steps down.**

- **Rewrite Strategy.**

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Data Assimilation and Observing Systems **mission**

The DAOS WG ensures that THORPEX contributes to the optimisation of the use of the current WMO Global Observing System.

It contributes to the development of a well-founded strategy for the evolution of the GOS to support NWP (primarily 1-14 days).

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Data Assimilation and Observing Systems WG strategy

It addresses issues in DA and improved understanding of the sources and growth of errors in analyses and forecasts

It promotes research activities that lead to a better use of observations and the understanding of their value

It provides input and guidance for THORPEX regional campaigns for the deployment of observations to achieve their objectives

This will be done in collaboration with the CBS OPAG-IOS

WMO OMM

Outline

- General progress
- AMMA
- Intercomparison experiment and T-PARC
- Plans for the new WG

Report on work performed

- **Impact of observations**
  - Guidance for observation campaigns and the configuration of the Global Observing system
  - Assessment of the value of targeted observations
    - papers by Cardinali, Kelly and Buizza
  - Evaluation of observation impact with different systems
    - A-TreC, Papers by Petersen, Fourrié, Langland..
    - AMMA
    - IPY
    - Proposed intercomparison experiment in the context of T-PARC
- **Improving the use of satellite data**
  - Use of sensitivity information to do adaptive data selection (papers by Dando et al, QJ)
- **Interest group for data assimilation** daos-ig@lists.cmc.ec.gc.ca
- **Promote activities**
  - Various conferences (AMS/EUMETSAT, EMS….)
  - Paper published in NPG in January 2008.

AMMA

A few results obtained in the AMMA-THORPEX WG

In particular , re-analysis at ECMWF

- *Period:* 1 May – 30 September 2006
- *Resolution:* T511 (~40 km), L91
- *Extra data used:* sonde profiles of wind, temperature and humidity extracted from the AMMA database
- *IFS cycle with improved physics:* CY32r3 (Bechtold et al., ECMWF Newsletter No. 114, Winter 2007/08, pp. 29-38)
- *AMMA radiosonde humidity bias correction* (Agustí-Panareda et al. 2008, submitted to Q.J.R.Meteorol.Soc)

And some data impact experiments performed at Meteo-France

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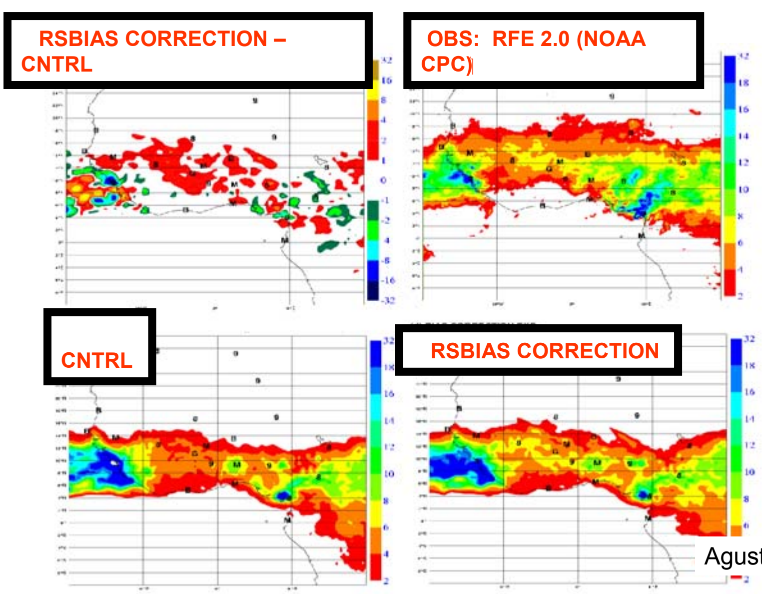
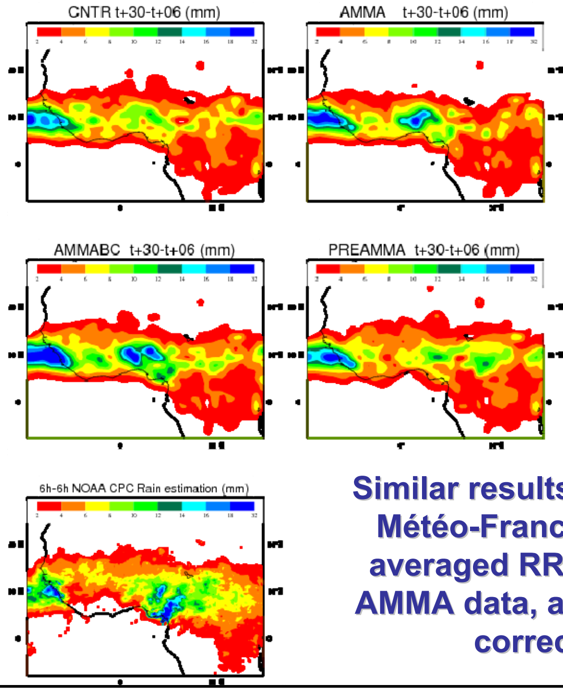
Impact of radiosonde bias correction: RESULTS

Mean total daily PPN FC (T+42-T+18) [mm/day] **1 to 31 Aug 2006, 12 UTC**



Agusti-Panareda et al



CNTR: data available on GTS

AMMA: additional RS profiles

AMMABC: with ECMWF special bias correction

PreAMMA: with a 2005 RS network

Similar results obtained at Météo-France: monthly averaged RR better with AMMA data, and with bias correction

Faccani et al

Summary of AMMA results

- **Humidity bias correction over AMMA region is beneficial**
- **Significant impact of additional AMMA RS data on the analysis and on RR**
- **Using more satellite data over land also has a large impact in the Tropics**
- **More results to come in a special issue Weather and Forecasting**

THORPEX

Intercomparison of sensitivity to observations in the context of the THORPEX Pacific-Asia regional campaign (T-PARC)

Contributions from Carla Cardinali (ECMWF), Ron Gelaro (GMAO),
Rolf Langland (NRL), Pat Harr (NPS),
Florence Rabier and Gérald Desroziers (Météo-France)
Stéphane Laroche and Simon Pellerin (Environment Canada)

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The observation impact intercomparison experiment

- **Baseline experiment**
  - Common set of observations assimilated by all centres
  - Assimilation and model configurations
  - Metrics to measure the impact of observations
- **Selection of period**
  - Winter phase of T-PARC: December 2008 to February 2009
  - Period selected: January 2007
    - observations available were closer to what would be available during T-PARC

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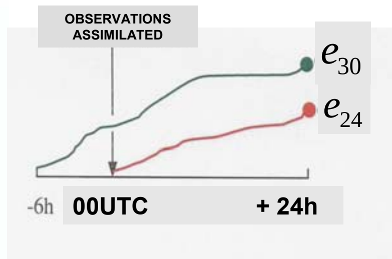
Observation Impact Methodology

(Langland and Baker, 2004)



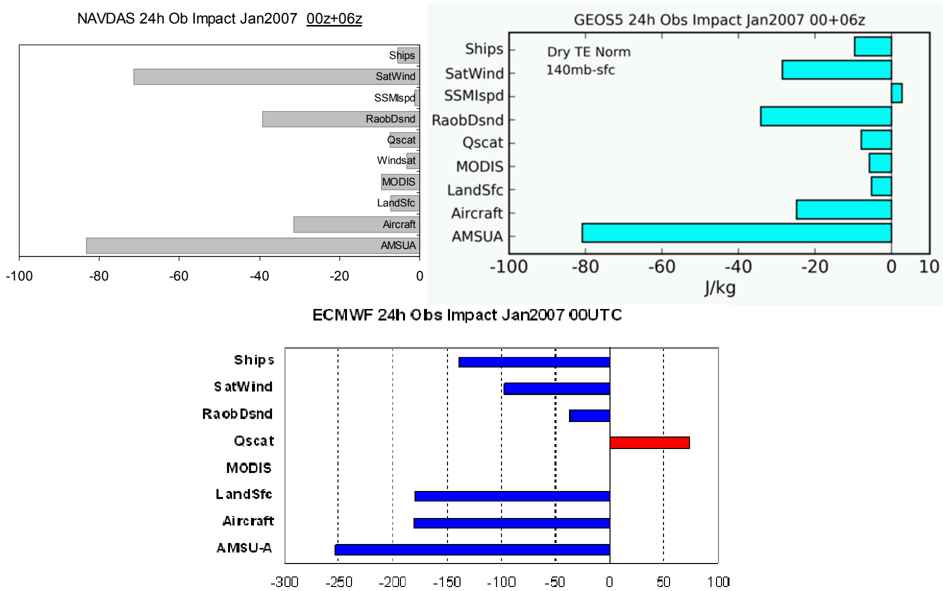
Observations move the model state from the "**background**" trajectory to the new "**analysis**" trajectory

The difference in forecast error norms, $e_{24} - e_{30}$, is due to the combined impact of all observations assimilated at 00UTC

Sensitivity with respect to analysis

- **Configuration of the measure of forecast error**
  - Departure with respect to a verifying analysis (each centre uses its own)
  - Dry adjoint model
  - 24h (third order) sensitivity gradient (LB04), dry forecast error norm, from surface to 150hPa
- **Forecast Sensitivity to Observation**
  - impact at 0,6,12,18 (3D-Var or 4D-Var 6h) or 00, 12 (4D-Var 12 h)

Total observation impact at 00 UTC



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DAOS plans

As presented to the THORPEX Executive Committee

25 September 2008

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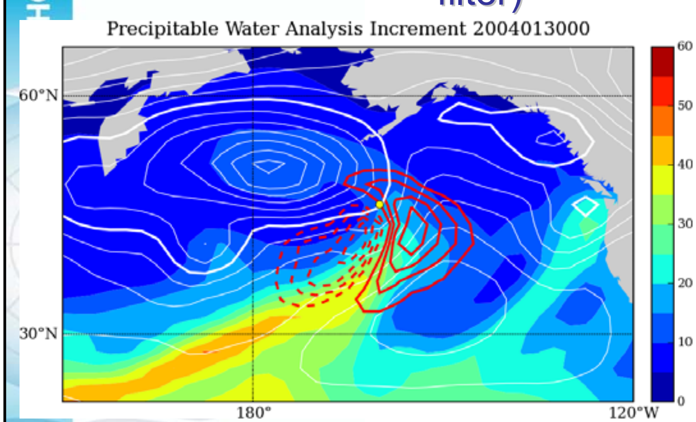
Value of targeted data (1)

- **Value of extra-tropical targeted data has been found to be positive but small, on average**
  - Observations taken in sensitive areas have more value than observations deployed randomly
  - Past experiments do not provide evidence of big impact obtained from just a few observations (when averaged over a large sample of cases)
  - There are limitations due to the current assimilation methodologies (not yet fully flow-dependent)
  - Sensitive areas characterization does not appear to be the first order problem

- **Additional observations for tropical cyclones have proven to be useful.**

Example of flow-dependent background-error covariances (here, from an ensemble Kalman filter)



Single-observation example from data assimilation test using EnKF and NCEP GFS. EnKF ensemble mean background, PRMSL contoured in white. PWAT background in colors. Obs at yellow dot is 1 hPa smaller than background. Red contours = moisture analysis increment (solid +, dashed -)

• EnKF make flow-dependent corrections to moisture field with non-moisture obs.
• In USA, NCEP's operational GSI (3D-Var) can only increment moisture with moisture (or moisture channel) obs.

Tom Hamill

Value of targeted data (2)

- **Recommendations**
  - Observation campaigns should be designed with science plans that take into consideration assimilation issues
    - Expensive observation campaigns should not be justified based on current targeting strategies alone.
  - Decision to undertake observation campaigns would benefit from preproject evaluation of expected value (e.g., using OSSEs or OSEs)

Value of targeted data (3)

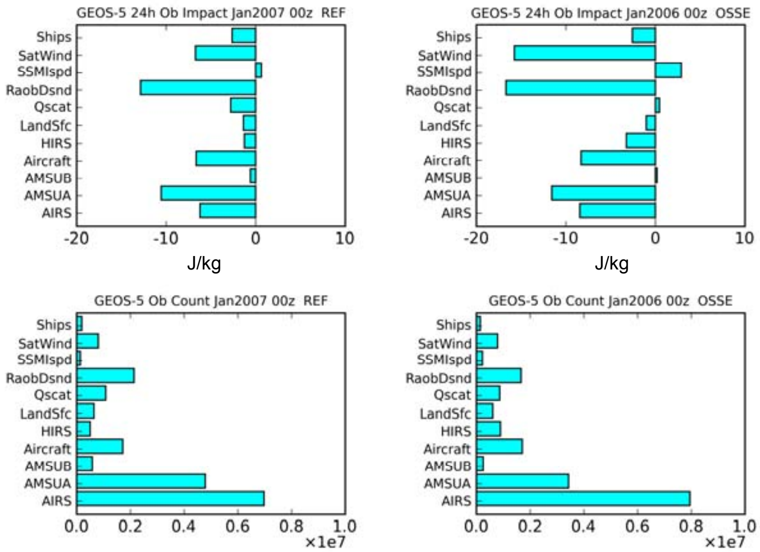
Recommendations

- **Additional benefit may be obtained from :**
  - Optimisation of existing operational resources
  - Regional (vs highly localised) and systematic targeting during low predictability flow regimes on a continuous basis (periods of days to weeks)
  - Adaptive processing and data selection of satellite data
- **OSSEs would be useful to evaluate the impact of instruments and targeting strategies**
  - Collaborative effort on OSSEs based on nature run from ECMWF
  - Calibration with respect to the impact of synthetic data
    - Using OI adjoint based methods, synthetic data show a similar quantitative impact to real observations
  - NASA will try this out to evaluate a space-based Doppler wind lidar instrument (similar to ADM)
  - Evaluation of the anticipated impact of future instruments need to be made in the context of the future observing network and future modeling and assimilation systems

OSSE calibration for Jan 2006 vs. Jan 2007 reference **First Results**

Impact of **various observing systems** on GEOS-5 24h forecast error

REAL OBS **OSSE**



impact

count

Value of targeted data (4)

- **Targeting for longer range forecasts**
  - NRL intends to investigate this topic
  - Which flow regimes show lower predictability and what impact additional data may have.
    - Cardinali et al. (2007) and Langland et al. (2008) have presented results on that. Can we make this distinction?
  - Issues for targeting at shorter range remain and should be addressed before getting into longer range forecasts
  - Evidence shows that removing or adding data does not lead to significant impact in the longer range
    - Experiments from Kelly et al. (2007) show that removing data from the North Pacific does not have any impact on Europe at day-6

Impact of denying observations over the Pacific on forecasts of increasing length in 3D-VAR

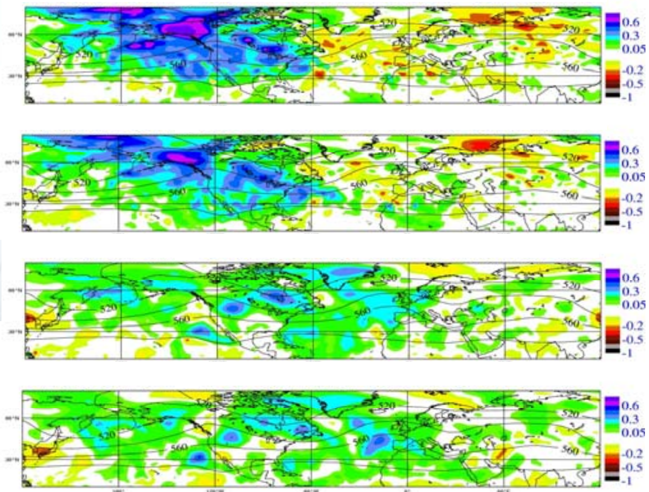
RMSE Denial – RMSE Control 500 hPa Height 00UTC Dec 2003-Feb 2004

Day 1

Day 2

Day 5

Day 6



Kelly et al. 2007, *QJRMS*

…signal becomes global and diffused in the medium range

Impact of denying observations over the Pacific on forecasts of increasing length in 4D-VAR

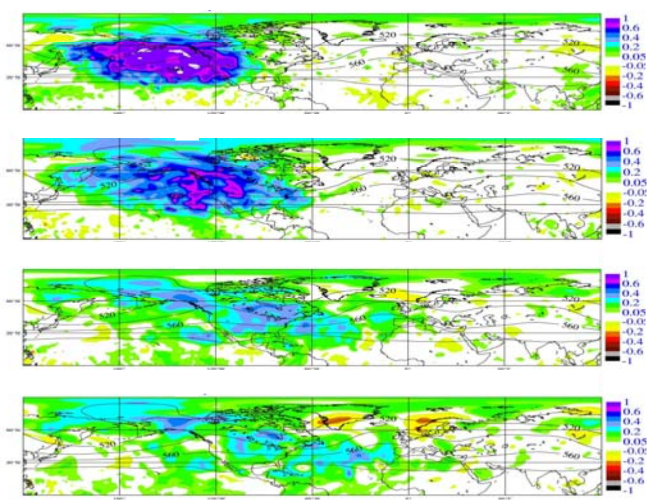
RMSE Denial – RMSE Control 500 hPa Height 00UTC Dec 2003-Feb 2004

Day 1

Day 2

Day 5

Day 6



Kelly et al. 2007, *QJRMS*

…medium range signal is even weaker in 4D-VAR (but less diffused)

THORPEX

Recommendations and Comments on Winter T-PARC

Predictability and Dynamical Processes THORPEX Working Group
&
Data Assimilation/Observations THORPEX Working Group

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Recommendations / Comments (W T-PARC)

1) **To facilitate the intercomparison of the results of the impact of targeted observations, it would be useful to have results from Winter Storm Reconnaissance 2001-2008 summarised as a review paper with the same metrics used in other studies.**
   – It would also provide sense of the change in impact as obs density has increased, data assimilation/modeling techniques have improved.

2) **Hypotheses such as "the source of forecast errors could be a lack of amplitude in the forecasts of upper-tropospheric ridging in cyclone warm sector" could be tested – can obs from W T-PARC be deployed to test this sort of hypothesis?**

3) **Potential to use additional obs to investigate bias corrections of satellite radiances and their use in cloudy regions. Number from W T-PARC may be insufficient for this, but this is to be considered for future field campaigns.**

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Recommendations / Suggestions in W T-PARC

(4) Russian raob network in W T-PARC : do parallel tests of operational DA systems with/without this network to determine whether to sustain in future years.

- This can also be explored/compared with observation impact evaluation such as forecast sensitivity to observations.

(5) Rapid-scan on MTSAT-2 from Japan unlikely to be available for W T-PARC, as it is only pre-operational now. Explore GOES rapid-scan as part of W T-PARC planning

(6) Explore the use of Australian BOM & CIMSS AMVs as a resource for W T-PARC

Field experiments: T-PARC

- W T-PARC: extend the observation impact intercomparison.
  - Understanding of differences/validation/evaluation with general study; look at sensitivity patterns + obs errors + B characteristics.
  - Use additional obs during T-PARC and look at individual cases/data. Verification and metrics to be agreed on.
- W T-PARC: NRL, Env Canada, GMAO will evaluate the impact of observations
- S T-PARC: CAWCR and NRL have expressed an interest in performing re-analysis and evaluation of obs (OSEs and Sensitivity at NRL). M. Weissmann at ECMWF, GMAO and EC will test the impact of wind lidar.

Field experiments: AMMA

Observations have proven to be useful to diagnose model and assimilation performance and improve their quality (physical processes, background errors).

Recommendation: These data are used operationally by NWP centres and it is very important to keep in situ data to help improve forecasting systems.

A few centres will continue to look at impact of radiosonde data over Africa (forecast sensitivity to obs mainly). To support the African regional plan, evaluate the impact of AMDAR data.

IPY

- A few of the projects of the THORPEX-IPY cluster focus on improving the use of satellite data over the poles.
- Coordinate the work on satellite data assimilation over these regions
- Investigate the impact, in polar and other regions

General statement about targeting

- There are still several lines of useful research (as already mentioned)
- But experiments so far have failed to show consistent dramatic impact.
- Targeting is unlikely to show enough benefit to justify a programme as large as THORPEX.
- Targeting should instead be viewed as one way of optimising the deployment of resources which were already justified.

Data assimilation at higher resolution

- Global data assimilation is required to provide accurate boundary conditions
- Currently, downscaling from 4D-Var analysis yields better results than a mesoscale assimilation with a 3D-Var
- EnKF is also actively explored for this topic
- What is really necessary for mesoscale DA?

Model error and weak-constraint 4D-Var

- Model error may be able to be assessed with ensembles. Exchange ideas and results on the subject with current EPS.
- TIGGE may be a resource for future studies (may need to be extended like for TIGGE-LAM)
- Initial results in weak-constraint 4D-Var indicate that the bias component of model error is critical.

ISSUES for GMPP

- Evolution of water in all phases in the first 6 hours of the forecast particularly in the tropics in the troposphere.

- Evolution of temperature and ozone in the stratosphere in the first 24 hrs

- Representation of near surface variables and their linkage to the surface

Radiosonde RH Bias correction

- Well-documented dry bias for Vaisala sonde types *(e.g. Wang et al., 2002, Nuret et al., 2008).*
- **Motivation:** In West Africa many radiosondes are located within a region of strong low-level moisture gradient and there is lack of ppn in the short-range forecast over Sahel.
- Can be used in data impact studies of enhanced AMMA radiosonde network, AMMA reanalysis experiment and water budget studies within the AMMA project.
- Based on the ECMWF operational RS bias correction implemented in CY32r3.
- Main differences between AMMA and OPER. RS RH bias correction:
  - ✓ Takes into account the dependence of bias on the observed RH values, which is very important in the Sahel because of its pronounced seasonal cycle.

Agusti-Panareda et al

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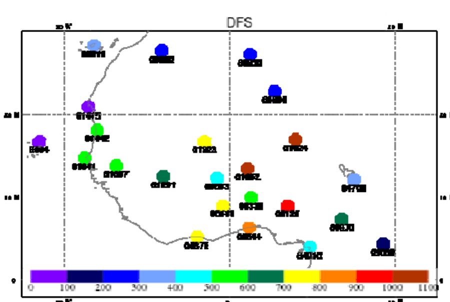
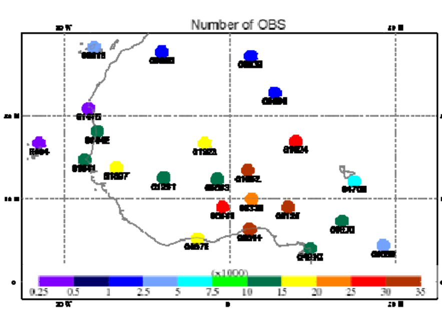


More influence



DFS= degrees of freedom for signal

DFS =Tr ($\delta H(x_a)/\delta y$)

Calculated for each station, averaged 1-15 August 2006

Large impact of additional AMMA data

Faccani et al

THORPEX

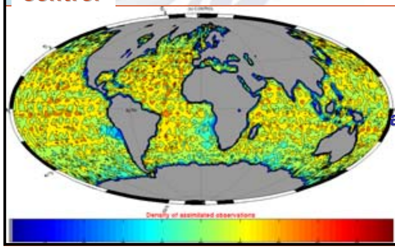
Impact of assimilating low-level humidity observations over land on the African Monsoon during AMMA

Karbou et al

Assimilation of MW observations over land

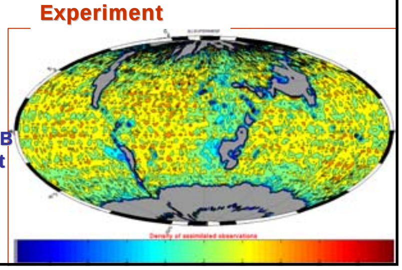
- New methods for estimating the land surface emissivity (Karbou et al. 2006) operational at Météo-France since July 2008.
- First trials: assimilate low-level humidity observations from AMSU-B over land (still rejected)

Control



Density of assimilated AMSU-B Ch5 during August 2006

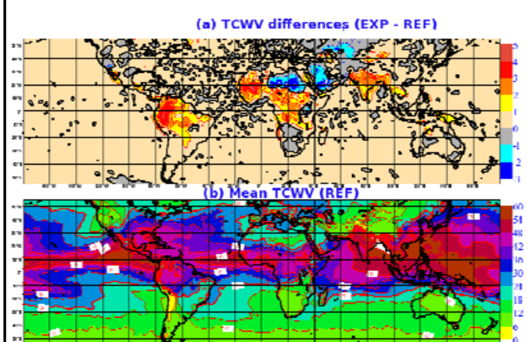
Experiment



Impact of assimilating low-level humidity observations over land on the African Monsoon during AMMA

Impact on analyses and forecasts

- Improvement of the fit to humidity observations (HIRS, SSM/I)
- Objective scores% radiosondes: significantly positive
- Large impact on the analyses of humidity, temperature, wind (surface to 500 hPa) over tropics implying big changes in the Monsoon flux



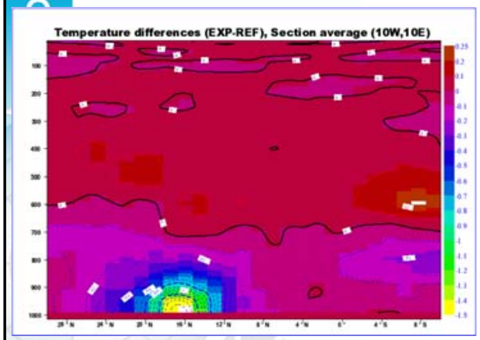
Moistening of the Atmo. In EXP

Drying of the atmos. In EXP

From 01/08/2006 to 14/09/2006

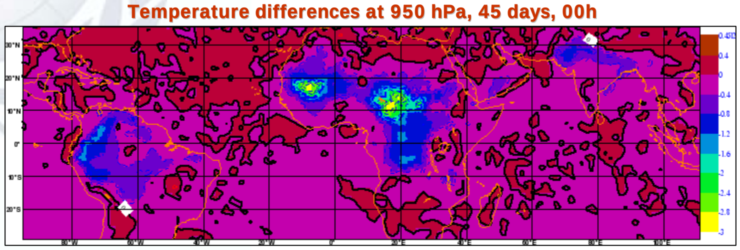
Karbou et al

Impact of assimilating low-level humidity observations over land on the African Monsoon during AMMA



45 days, 00h

Temperature differences at 950 hPa, 45 days, 00h



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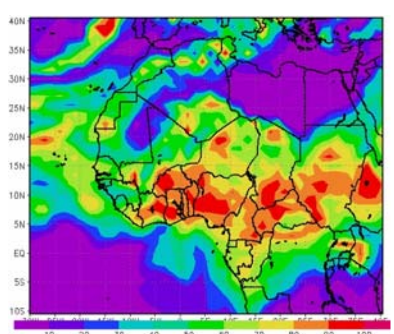
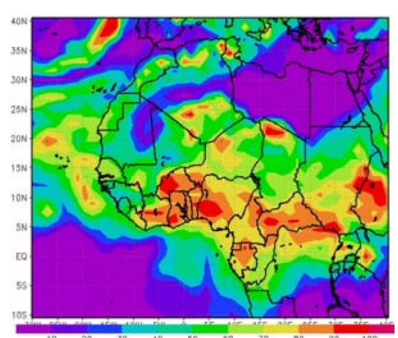
Case studies evaluated locally

600hPA relative humidity analysis on 25thJuly 2006 at 1800



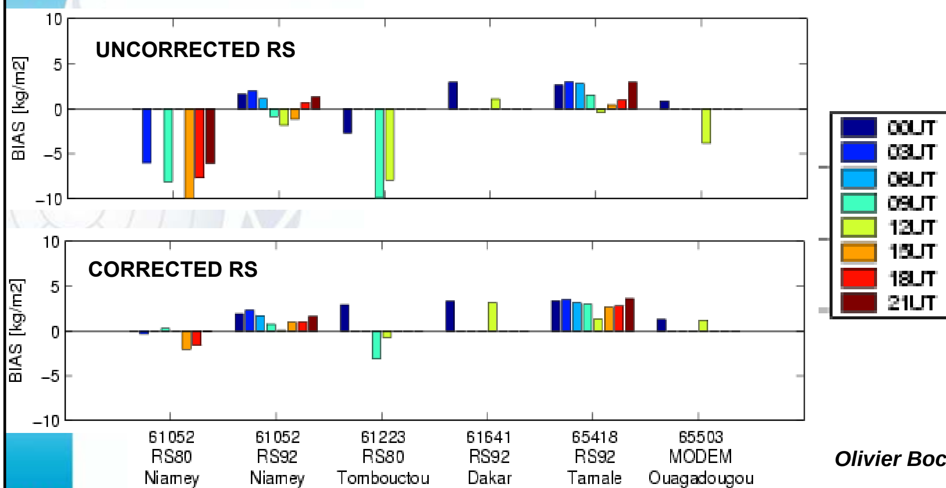
Conventional data + Satellite CSR data



Conventional data only

Mumba et al

Radiosonde (RS) RH Bias correction: RESULTS
Comparison with GPS TCWV
RS-GPS: BIAS



Olivier Bock

Agusti-Panareda et al

Evaluation of the impact of observations

- **Measure of the reduction in forecast error**

$$\Delta e_a^b = J_a(t) - J_b(t)$$
$$= \frac{1}{2}\langle \mathbf{x}_a - \mathbf{x}_t, \mathbf{x}_a - \mathbf{x}_t \rangle_{t=t_0+T} - \frac{1}{2}\langle \mathbf{x}_b - \mathbf{x}_t, \mathbf{x}_b - \mathbf{x}_t \rangle_{t=t_0+T}$$
$$= \frac{1}{2}\left\langle \mathbf{x}_a - \mathbf{x}_b, \frac{\partial J_a}{\partial \mathbf{x}_a} + \frac{\partial J_b}{\partial \mathbf{x}_b} \right\rangle_{t=t_0+T}$$

- **Evaluation at the initial time**

$$\Delta e_a^b = \left\langle \mathbf{y} - \mathbf{H}(\mathbf{x}_b), \mathbf{K}^T \left(\mathbf{L}_a^T \frac{\partial J_a}{\partial \mathbf{x}_a} + \mathbf{L}_b^T \frac{\partial J_b}{\partial \mathbf{x}_b} \right) \right\rangle$$

Observations assimilated by NRL, GMAO and ECMWF

(also at Météo-France and Environment Canada)

- Radiosondes
- Dropsondes
- Land surface stations (all data except winds and humidity)
- Ship surface (winds and p_s)
- Aircraft (all data except humidity)
- AMV from geostationary satellites (no rapid-scan winds)
- MODIS winds
- AMSU-A radiances
- QuikScat

Comparison of the characteristics of the systems

	NRL	GMAO	ECMWF
Analysis	T239L30 3D-Var	0.5ºx0.67ºL72 6-h 3D-Var	T255L60 12-h 4D-Var
Forecasts	T239L30 spectral	0.5ºx0.67º L72 Finite Volume model	T255L60 spectral

Adjoint of Assimilation Equation

Baker and Daley 2000 (QJRMS)

Sensitivity to Observations:

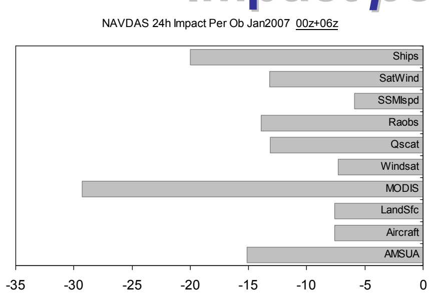
$$\frac{\partial J}{\partial \mathbf{y}} = \underbrace{[\mathbf{HP}_b\mathbf{H}^T + \mathbf{R}]^{-1}\mathbf{HP}_b}_{\mathbf{K}^T} \frac{\partial J}{\partial \mathbf{x}_a}$$

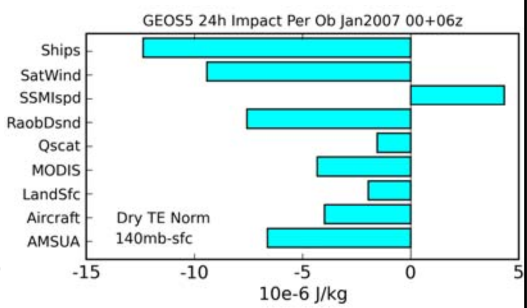
Adjoint of forecast model produces sensitivity to $\mathbf{x}_a$

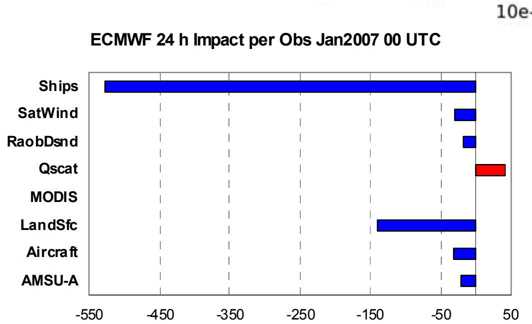
Sensitivity to Background:

$$\frac{\partial J}{\partial \mathbf{x}_b} = \frac{\partial J}{\partial \mathbf{x}_a} - \mathbf{H}^T \frac{\partial J}{\partial \mathbf{y}}$$

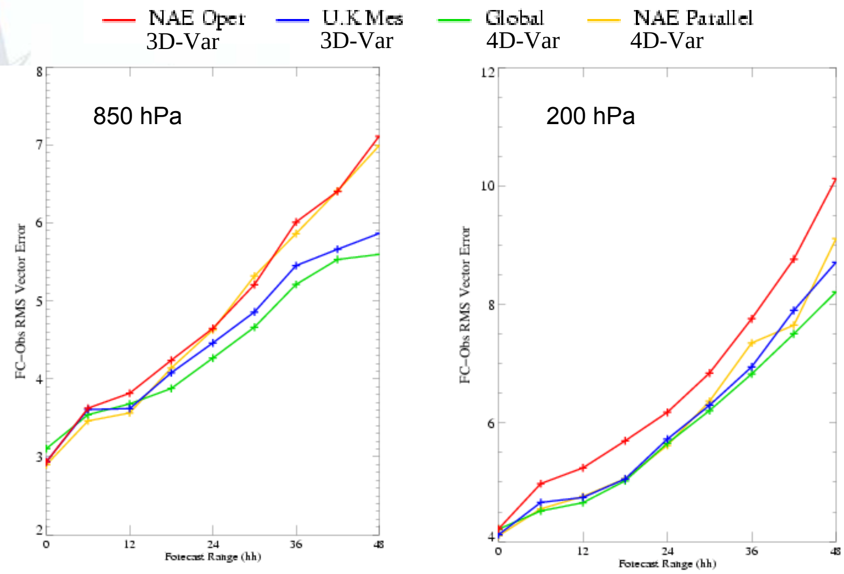
Impact *per* observation







RMS forecast errors v UK radiosondes winds 26/2/2006 to 15/3/2006



Potential benefits of mesoscale DA/NWP

- **Higher resolution gives better picture of high-impact weather**
- **Higher resolution allows better assimilation and forecast of observed detail**
- **Can afford timely forecast using more recent observations.**
- **Limited area allows use of a tailored DA & NWP system.**

But there are caveats: boundary conditions, lack of connection with larger scales…

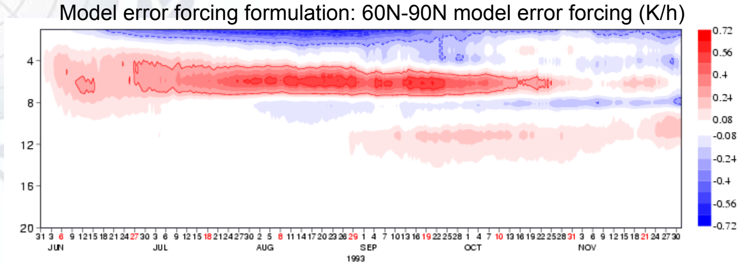
Weak-constraint vs strong constraint 4D-Var experiments:

1 year parallel run started from June 1993:

- **ERA interim strong constraint 4D-Var**
- **W.C. 4D-Var with model error forcing formulation, Q confined to stratosphere and alphaq=0.3**

Upper atmosphere 6 months temperature model error time evolution

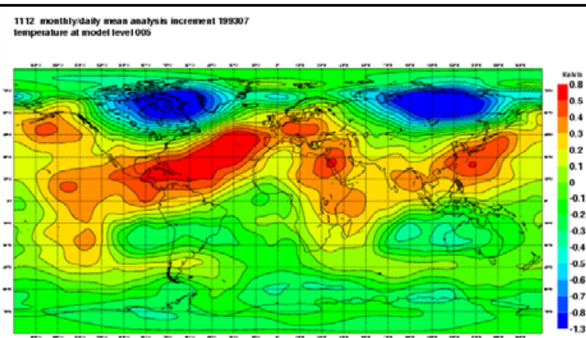
Model error forcing formulation: 60N-90N model error forcing (K/h)



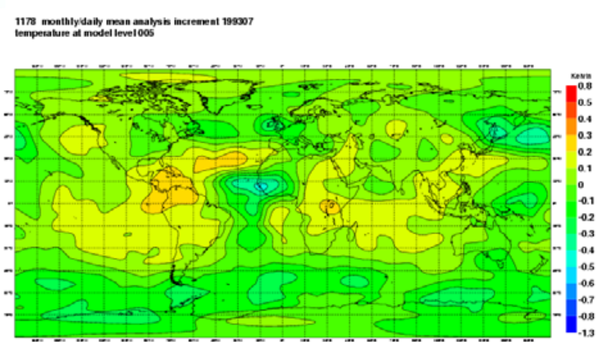
Lindskog et al, 2008

Model level 5 (~1.5hPa) Monthly mean temperature analysis increments for July 1993

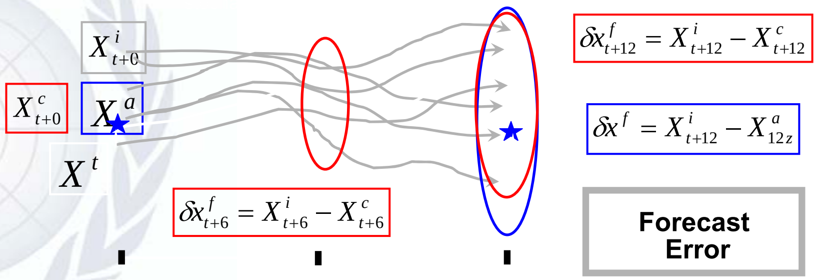
aninc ERA interim



aninc with model error forcing



Perturbation Growth versus Model Error



$X^a \approx X^{truth}$

Perturbation Growth + Tuning = $X^i_{t+12} - \overline{X}_{t+12}$

Perturbation Growth + Model Error = $X^i_{t+12} - X^a_{12z}$

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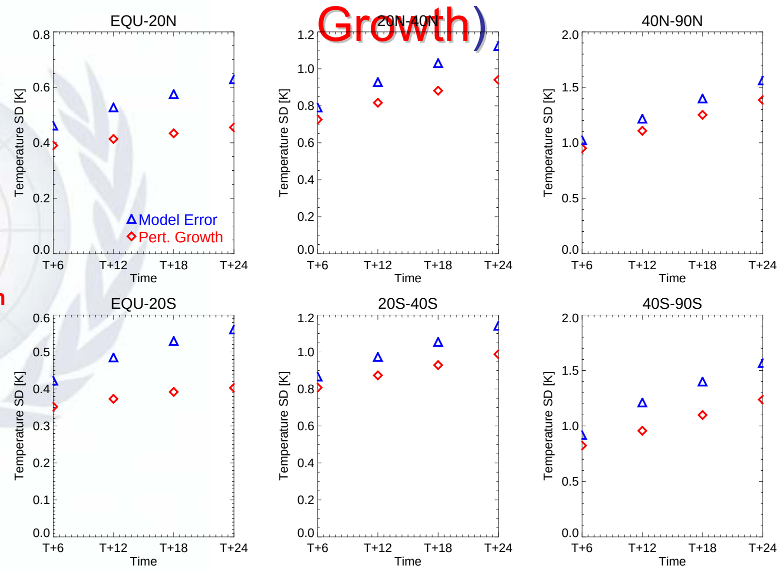
Temperature Error Growth at 500hPa (Model Error vs Pert. Growth)

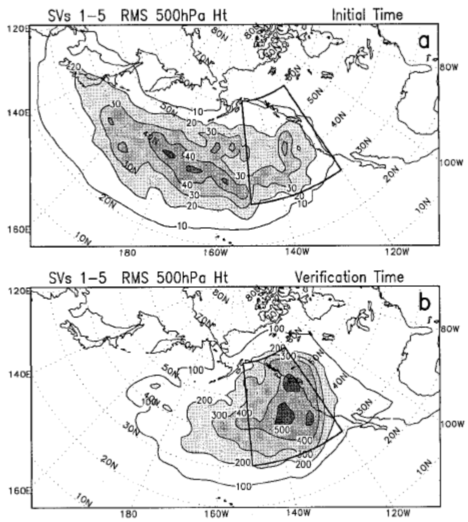
Model Error
Pert. Growth



THORPEX

WMO OMM

SV-sensitivity pattern for 48-h forecasts verifying over western North America during January 1998



t=0 hrs

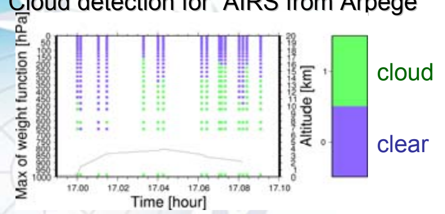
t=48 hrs

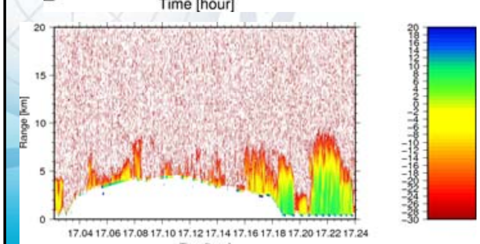
Gelaro et al. 2000, MWR

Cloud Detection (over Antarctica, similar studies over the Arctic)

- AIRS: 10/01/2008

Cloud detection for AIRS from Arpege

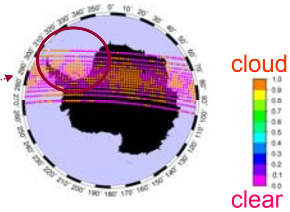




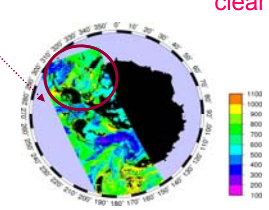
Comparison with reflectivity product from CLOUDSAT

- IASI : 9/01/2008

Example with channel 242 of IASI, with a max of weight. function at 286hPa



Goog detection over the peninsula



Comparison with MODIS product : cloud top Pressure (hPa)

DAOS WG Tasks

- **Provide guidance to the design of field experiments**
  - Observation campaigns should be designed with science plans that take into consideration assimilation issues
  - Decision to undertake observation campaigns would benefit from preproject evaluation of expected value (e.g., using OSSEs or OSEs)
  - Regional (vs highly localised) and systematic targeting during low predictability flow regimes on a continuous basis (periods of days to weeks)
- **Support the use of well-calibrated OSSEs to evaluate the impact of new instruments**
- **Increase/optimise the usage of existing operational in-situ observations**
- **Explore adaptive processing and data selection of satellite data**

DAOS WG Tasks

- **Review the results from Winter Storm Reconnaissance 2001-2008 review paper as a guide for future planning**
- **Support testing of the impact of enhanced Russian raob network on operational DA systems to determine whether to sustain in future years.**
- **W T-PARC: extend the observation impact intercomparison.**
- **W T-PARC: NRL, Env Canada, GMAO will evaluate the impact of observations**
- **S T-PARC: CAWCR and NRL have expressed an interest in performing re-analysis and evaluation of obs (OSEs and Sensitivity at NRL). M. Weissmann at ECMWF, GMAO and EC will test the impact of wind lidar.**

DAOS WG Tasks

- In support of the African regional plan, encourage investigation of the impact of radiosonde and AMDAR data over Africa.
- Coordinate the work on satellite data assimilation over the polar regions and investigate the impact, in polar and other regions

THORPEX

WMO OMM

DAOS WG Tasks

- Exchange ideas and results on the assessment of model error using ensembles.
- Investigate use of flow-dependent structure functions
- Evaluate the downscale impact of global scale improvements on the mesoscale
- Investigate issues on coupled DA and new data sets

THORPEX

WMO OMM