Recent Developments in Data Assimilation

Tom Hamill & Jean-Noël Thépaut

WGNE-29

10-13 March 2014

- DAOS Activities
- WGNE Centres contributions

Activities of the WMO/THORPEX Data Assimilation and Observing Systems Group

Tom Hamill

NOAA ESRL, Physical Sciences Division

Boulder, Colorado USA

tom.hamill@noaa.gov

+1 (303) 497-3060

Outline

- Programmatic matters (DAOS membership, charter, DA nomenclature)
- Observing system update
- Highlights of DA symposium
- Supplemental material: review of science findings from 2013 WMO Data Assimilation Symposium

DAOS proposed new terms of reference
(for impending move from THORPEX to WWRP)

"Provide guidance to the WWRP on international efforts to optimise the use of the current WMO Global Observing System (GOS) and to advise on the strategy for its evolution. It will also provide guidance on which data assimilation methods may provide the highest-quality analysis products possible from the GOS. Through these activities, the DAOS-WG will facilitate the development of advanced numerical weather prediction (NWP) capabilities, especially to improve high-impact weather forecasts. DAOS will be primarily concerned with data assimilation and observing system issues from the convective scale to planetary scales and for forecasts with time ranges of hours to weeks.

To achieve its mission, the DAOS WG, in collaboration with the *CBS ET-EGOS,* will:

- Provide community consensus guidance on data assimilation issues, including the development of advanced methods for data assimilation.
- Promote research activities that will lead to a better use of existing observations and that will objectively quantify the impact of current and future observations for NWP.
- Assist WWRP projects and other WMO working groups in achieving their scientific objectives by providing expert advice on the use of observations and data assimilation techniques.
- To organize and provide the scientific steering committee for the WMO Data Assimilation Symposium, which is to be held approximately every 4 years."

We encourage your feedback on this.

Current DAOS members

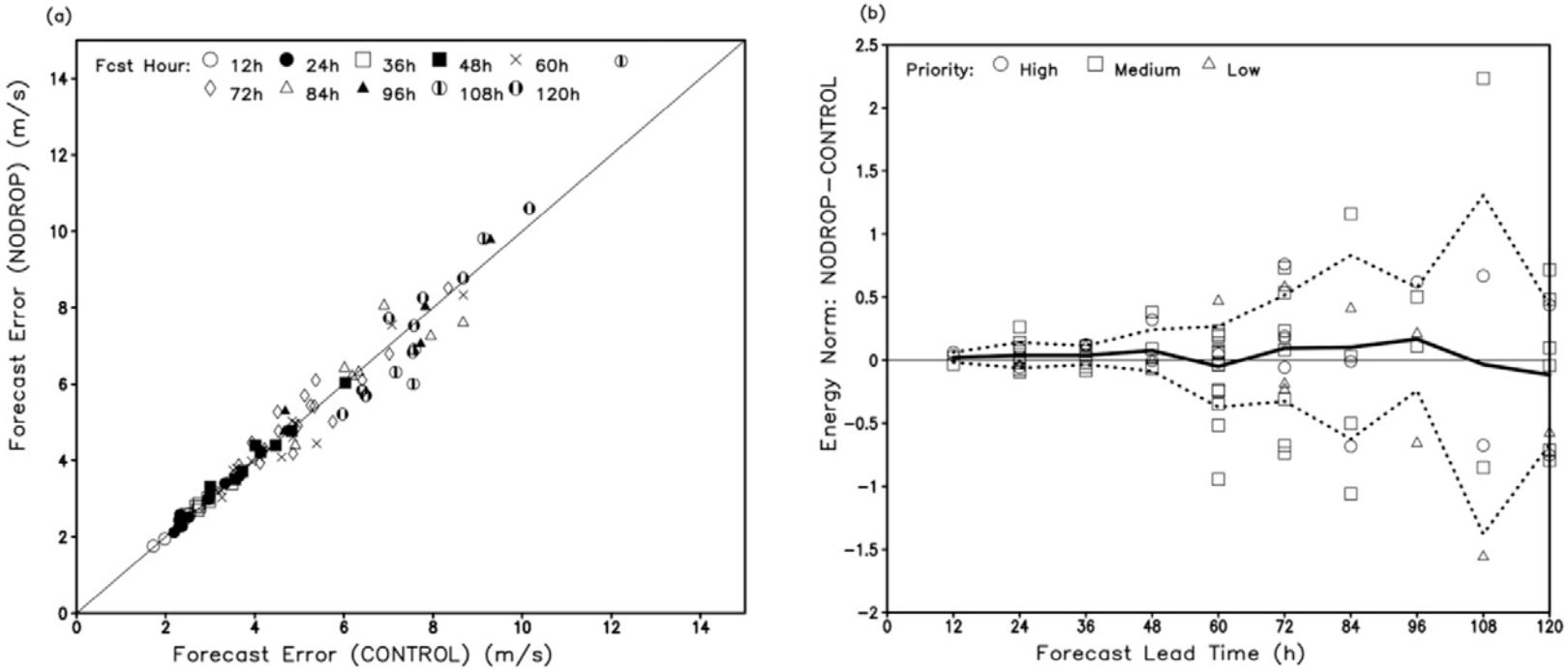
- **Roger Saunders**, UK Met Office: co-chair, observing systems (will leave in 1-2 yrs)
- **Tom Hamill**, NOAA ESRL: co-chair, ensemble-based assimilation methods
- **Sharanya Majumdar**, U. Miami: tropical cyclones, targeting methods
- **Daryl Kleist**, NOAA/NCEP and U Maryland: assimilation methods
- **Bin Wang**, Tsinghua University: assimilation methods, targeted observations
- **Andrew Lorenc**, UK Met Office: assimilation methods
- **Ron Gelaro**, NASA GMAO: Observation impact, OSSEs, adjoint tools.
- **Chris Velden**, U. Wisconsin: Cloud-drift winds and observation impact.
- **Michael Tsyrulnikov**, Roshydromet: assimilation methods
- **Carla Cardinali**, ECMWF: Observation impact, data thinning, assimilation methods.
- **Stefan Klink**, DWD: In-situ observations, radar data assimilation.
- **Tom Keenan**, Bureau of Meteorology, Australia:
- **Rolf Langland**, US Navy: observation impact, analysis uncertainty.
- **Mark Buehner**, Env. Canada: assimilation methods, cryospheric assimilation.
- **Nadia Fourrie**, Meteo France (NEW!): remote sensing, IR sounders over land
- **Saroja Polavarapu**, Env. Canada and U Toronto (NEW!): middle-atmosphere, chemistry DA

Standardized data assimilation terminology

- **Problem**: many different data assimilation approaches being developed that combine aspects of EnKFs and/or 4D-Var, but no standard terminology.
  - Kayo Ide et al.'s previous article (*J Met. Soc. Japan*) clarifying assimilation terminology 17 years ago was immensely helpful to community.
- Andrew Lorenc has circulated a proposal for terminology to be applied to various new assimilation methods (part of WGNE Blue Book)
  - http://tinyurl.com/assim-nomenclature

Recent group activities: targeting

- Observing system experiment of 2011 Winter Storms Reconnaissance using ECMWF system: minimal impact.
  - for more, see Hamill et al., 2013, http://journals.ametsoc.org/doi/pdf/10.1175/MWR-D-12-00309.1



NOAA's WSR cancelled in 2014

Consistency in radar data format

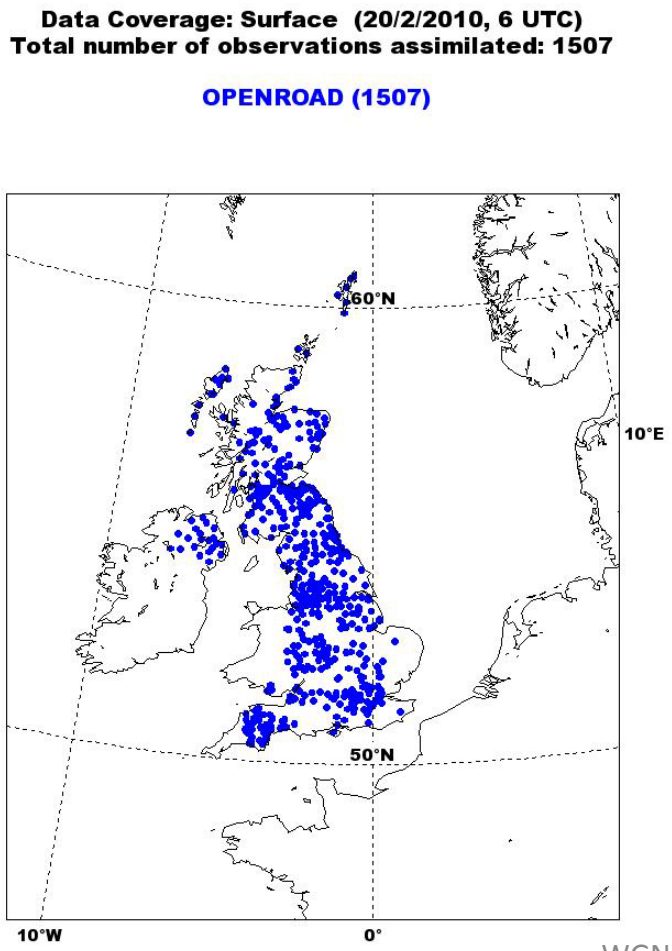
- DAOS facilitated a workshop at the Met Office in Exeter from the 24-26 April 2013 on this topic.
- Data models are most advanced in Europe and the USA. The data exchange formats being used vary widely and include: BUFR, GRIB, TITAN, HDF5, netCDF, etc.
- The Workshop determined that
  - The best approach is to use ODIM (OPERA) as a basis for finalising a model for international exchange.
  - A BUFR template for radar data exchange should be finalised.
  - The use of more modern alternative formats such as HDF5 should be investigated.
- WMO/CBS taking this forward now.

Current satellite status

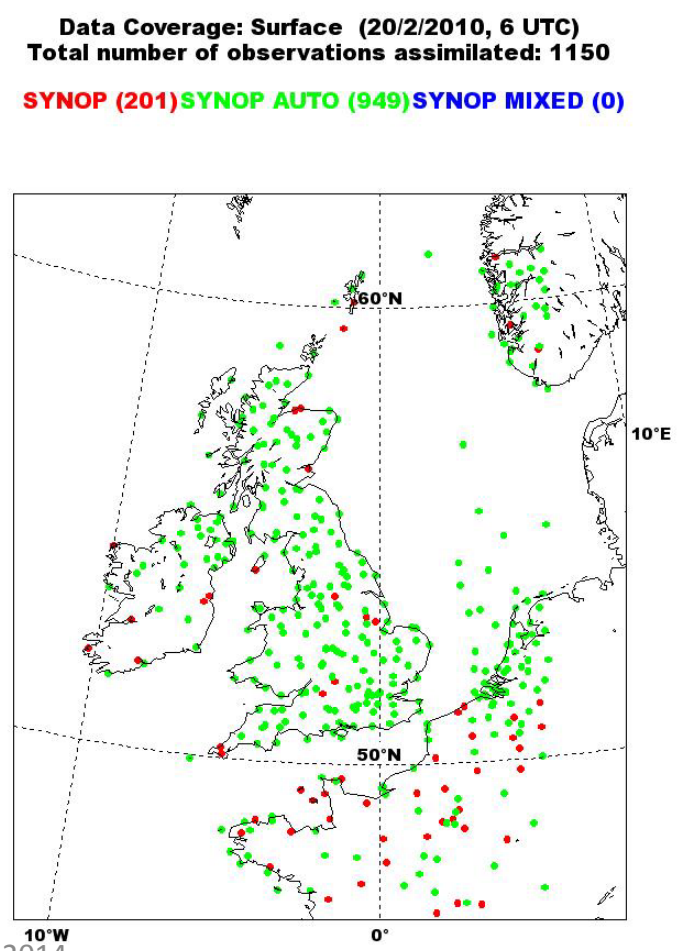
- Operational geostationary satellites
  - USA: GOES-13 (East), -15 (West), ~~-12 (S. America);~~
  - EUMETSAT: METEOSAT-10 (0 Deg.) & -7 (Indian Ocean);
  - India/ISRO: Kalpana & INSAT-3A
  - CMA:FY-2E & F; KMA:COMS; Russia:ELECTRO-L; JMA:MTSAT-2
- Operational Polar Satellites
  - Suomi-NPP data used operationally in NWP centres (ATMS, CrIS radiances) with good impacts.
  - METOP-A&B IASI, AMSU-A/MHS on METOP-B assimilated *in addition to METOP-A*
  - Japanese GCOM-W1 AMSR-2 proving a good replacement for AMSR-E (SST, precip,…).
  - Chinese FY-3C polar orbiter now launched. New MW channels at 118GHz.

Met Office: Roadside sensor network
T, RH at screen level now assimilated

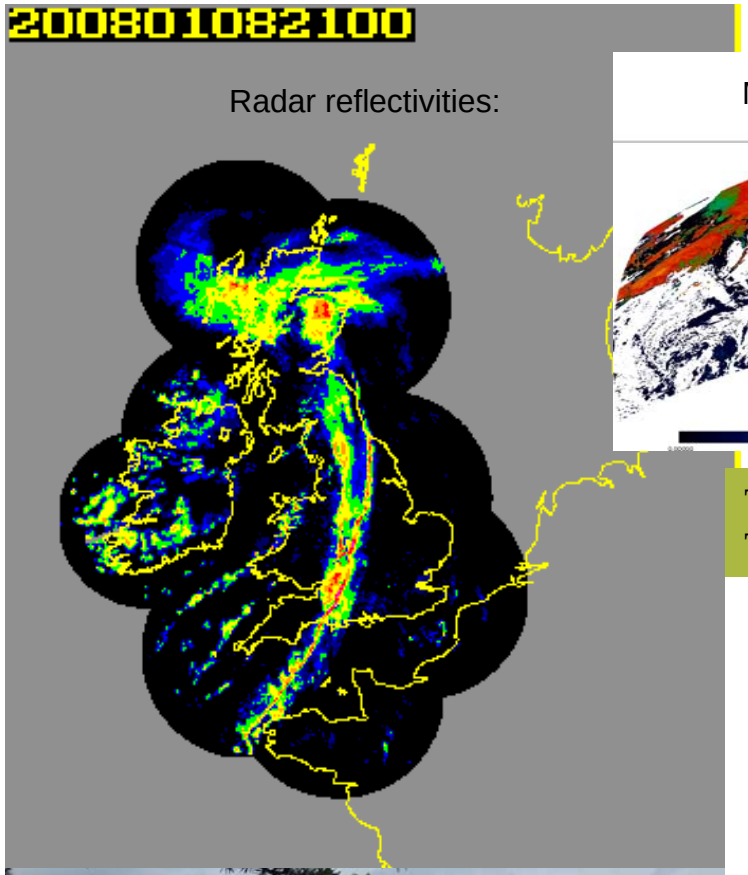
OpenRoad – full network

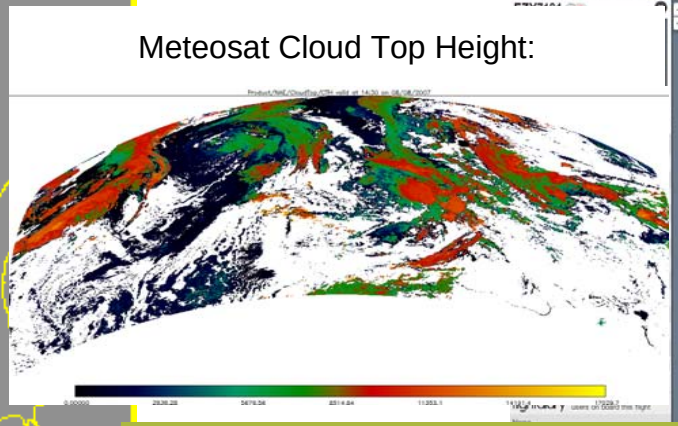


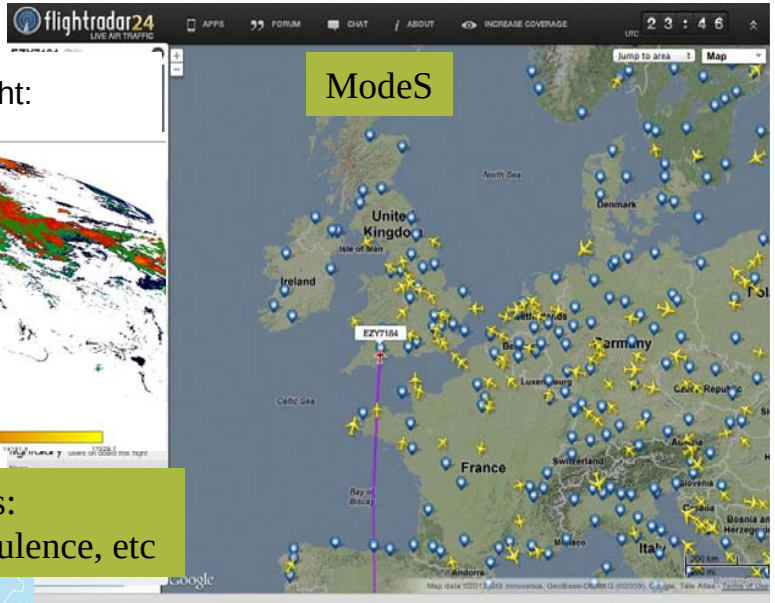
SYNOPS



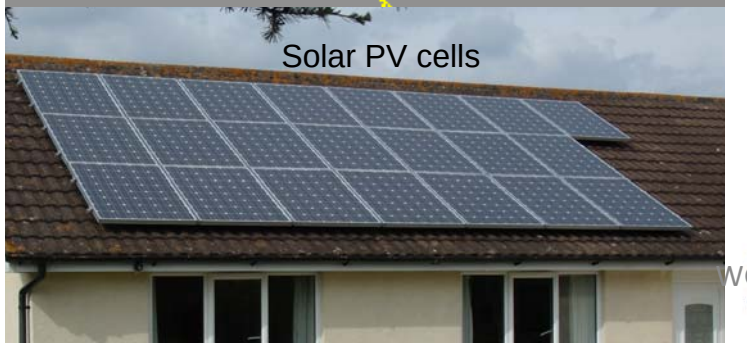
Novel observations for convective-sale DA

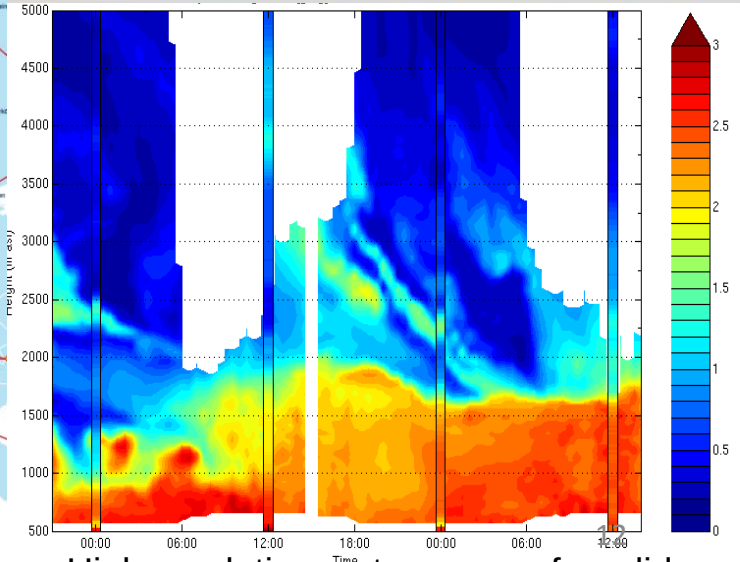






TAMDAR Observations:
T, wind, RH, icing, turbulence, etc





High resolution water vapour from lidar:

Met Office obs impact in global assimilation

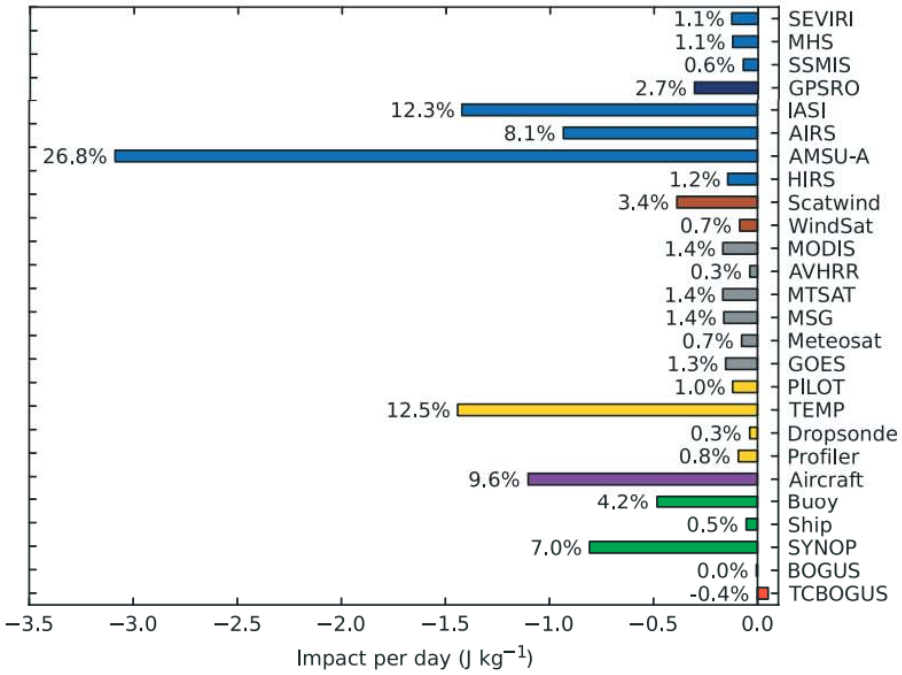


Figure 9. 24 h observation impact per day by observation type for the period shown in Figure 8. Colours/shading represent higher-level observation groups: satellite radiances and GPSRO (blue/navy in the online article); scatterometer winds (brown in the online article); AMVs (grey in the online article); sondes and wind profilers (yellow in the online article); aircraft (purple in the online article); surface observations (green in the online article) and synthetic observations (red in the online article). Percentage values give the fraction of the total impact. This figure is available in colour online at wileyonlinelibrary.com/journal/qj

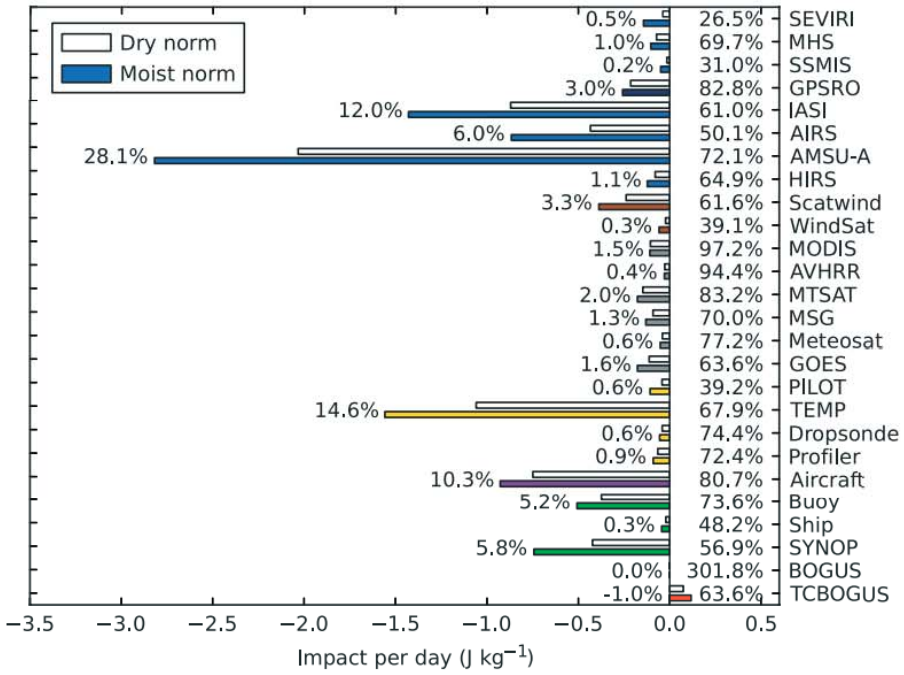
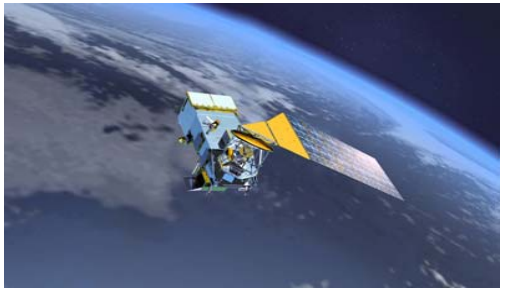


Figure 10. 24 h observation impact per day using moist and dry energy norms (shaded and unshaded respectively, with colours as in Figure 9) for the subperiod 0000 UTC, 27 August–0000 UTC, 30 August 2010. The percentage values to the left of the bars give the fraction of the total impact for the dry norm; the percentage values to the right give the dry impact as a fraction of the moist. This figure is available in colour online at wileyonlinelibrary.com/journal/qj

Lorenc and Marriott, *QJRMS*, Jan 2014, DOI: 10.1002/qj.2122 ; supportive of previous results by Gelaro et al. 2010 MWR and Cardinali (2009 QJ, DOI: 10.1002/qj.366)

Key messages on observational systems



- Operational satellite data contributions to the GOS by nations increasing (e.g. FY-3, Oceansat-2), to hopefully mitigate against future gaps

- Research satellites/instruments can be valuable as operational data providers, but can fail suddenly without backups (e.g. ENVISAT, AMSR-E are recent examples)

- Contribution of satellite data to the GOS is dominant impact in many advanced DA systems

- Assimilation of novel observations in convective scale models is challenging, but progressing.

- Research underway to extend/improve use of satellite data (cloudy radiances, use principal components, more data over land etc.).

http://das6.cscamm.umd.edu/ October, 2013

Sixth Symposium on Data Assimilation

WMO

Home > Sixth Symposium on Data Assimilation

UNIVERSITY OF MARYLAND

Sixth Symposium on Data Assimilation

About | Program | Sponsors | Hotels | Travel | Organizers

Link to presentations and posters

Thanks to everyone for making the symposium a huge success!

Foreword and Symposium Summary
The symposium foreword and meeting summary can be Downloaded Here (PDF)

Location:
University of Maryland, Riggs Alumni Center, http://www.riggs.umd.edu/
College Park, MD, USA

Presentations:
Presentations have been uploaded. Please click on the Program tab for links, instructions, and further information.

Special Collection:
Please remember to select the 6th DA Symposium Special Collection when submitting your article to the AMS journals for your contribution to be included.

Symposium Goals:
(1) Assess recent progress in atmospheric, oceanographic, and hydrologic data assimilation, in both research and operational environments
(2) Reach common understanding of the main challenges and opportunities that lie ahead in data assimilation

Important Dates:
10 May 2013: Abstracts Due
08 July 2013: Abstract Notifications Sent
08 July 2013: Draft Agenda
September 2013: Last Days for Hotel Bookings
30 September 2013: Registration closed
02 October 2013: Final Program
07-11 October 2013:Symposium

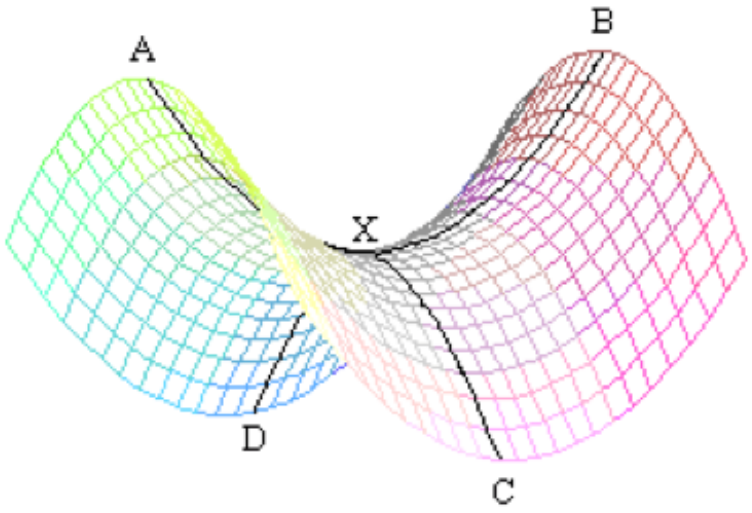
Contact:
For more information please email daryl.kleist @ gmail.com.

Venue switched at last moment from NCEP to University of Maryland to accommodate US government shutdown (special thanks to Daryl Kleist, Kayo Ide, and UMD). Many US government employees and invited speakers could not attend. Nonetheless, many hundreds of international visitors did. Next symposium ~ 2017. Venue not yet identified, but Brazil a strong possibility.

Data assimilation symposium themes

- **Global and Regional Atmospheric Data Assimilation** (e.g. troposphere, stratosphere, high-impact weather, reanalysis)
- **Convective Scale Data Assimilation** (e.g. to initialize high resolution NWP, nowcasting, severe local storms)
- **Atmospheric Constituent Data Assimilation** (e.g. stratospheric and tropospheric composition, aerosols, air quality, reanalysis)
- **Coupled Data Assimilation** (e.g. atmosphere/land, atmosphere/ocean, ocean/wave, land/ocean/sea-ice, carbon cycle, reanalysis, initializing seasonal to decadal predictions)
- **Global and Regional Ocean Data Assimilation** (e.g. coastal, reanalysis, operational oceanography, salinity, ocean chlorophyll, biogeochemical)
- **Assimilation of Observations for the Land Surface** (e.g. novel variables such as soil moisture, skin temperature)
- **Assimilation of Satellite, In Situ and Radar Observations** (e.g. new observation operators, bias correction, observation error specification, adaptive thinning and targeting methodology, use in cloudy and precipitating areas)
- **Methodology** (e.g. variational, EnKF, hybrid methods, estimating error covariances, techniques for highly non-gaussian systems, long window/weak constraint, new methods for optimizing reanalyses, variational/ensemble parameter estimation, improving scalability, other advanced techniques)
- **Diagnostic Tools** (e.g. adjoint and ensemble sensitivity, study of analysis increments for model evaluation, observation impact studies, OSSEs, climate applications)

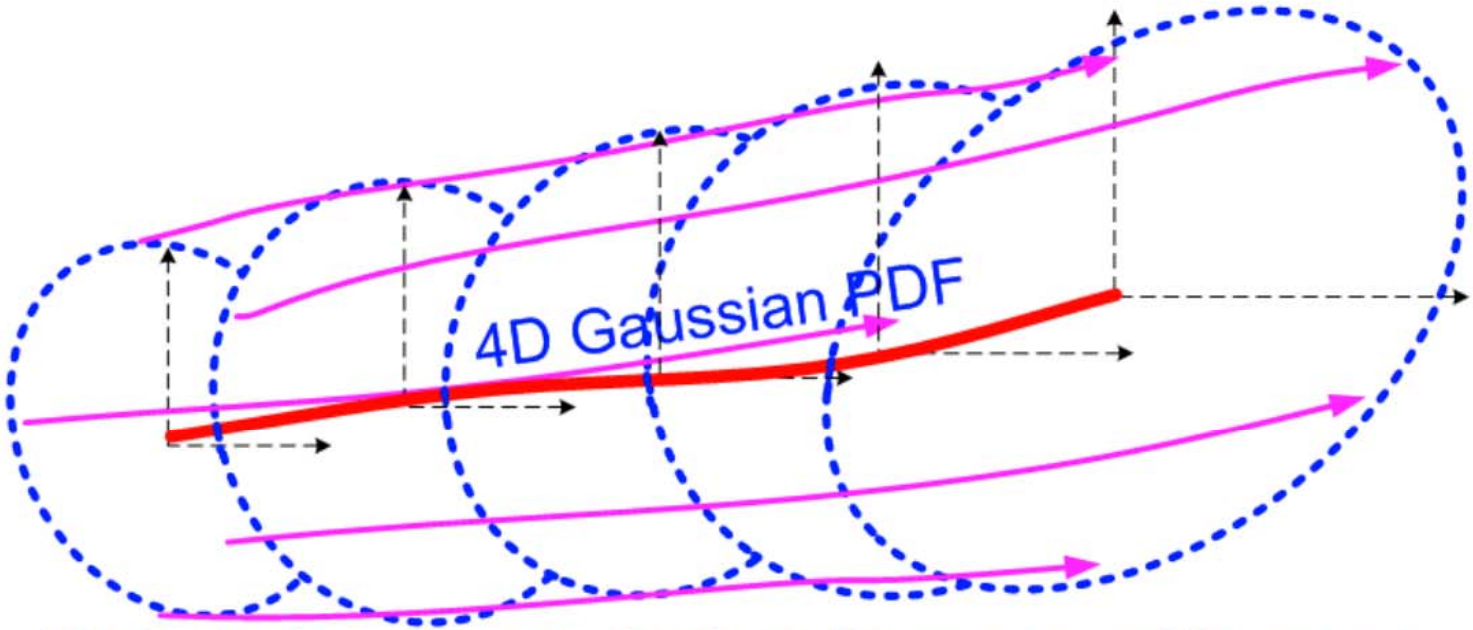
Advanced methodologies



Lagrangian: $\mathcal{L}(\delta\mathbf{x}, \delta\mathbf{p}, \delta\mathbf{w}, \lambda, \mu)$

ECMWF working on "saddle-point" formulation of 4D-Var based on the Lagrangian dual 4D-PSAS (physical-space assimilation system) that allows minimization to be broken up in time for efficiency on massively parallel computers. See http://tinyurl.com/saddlepoint-4DVar

Incremental 4D-Ensemble-Var



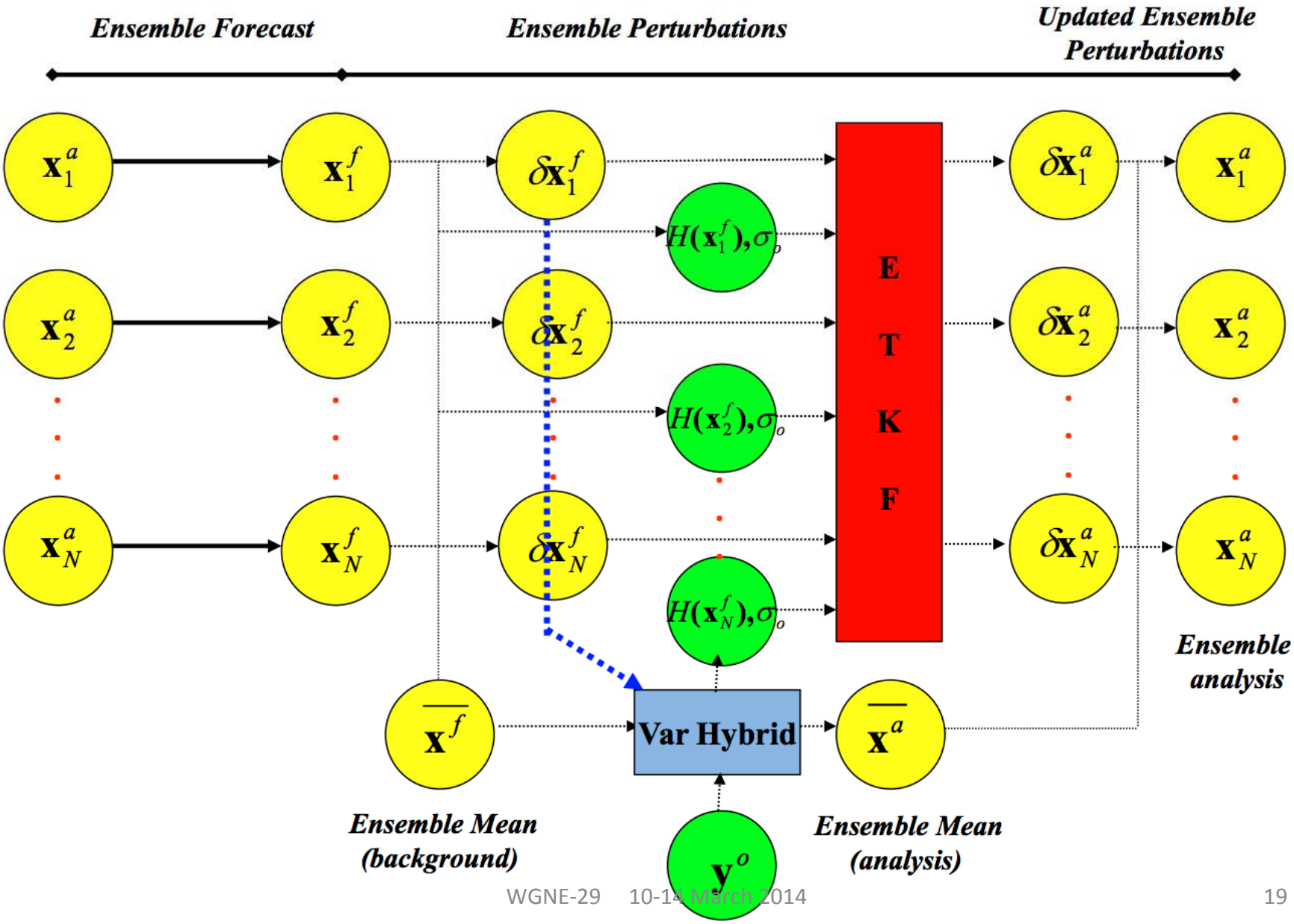
Trajectories of perturbations from ensemble mean

Full model evolves mean of PDF

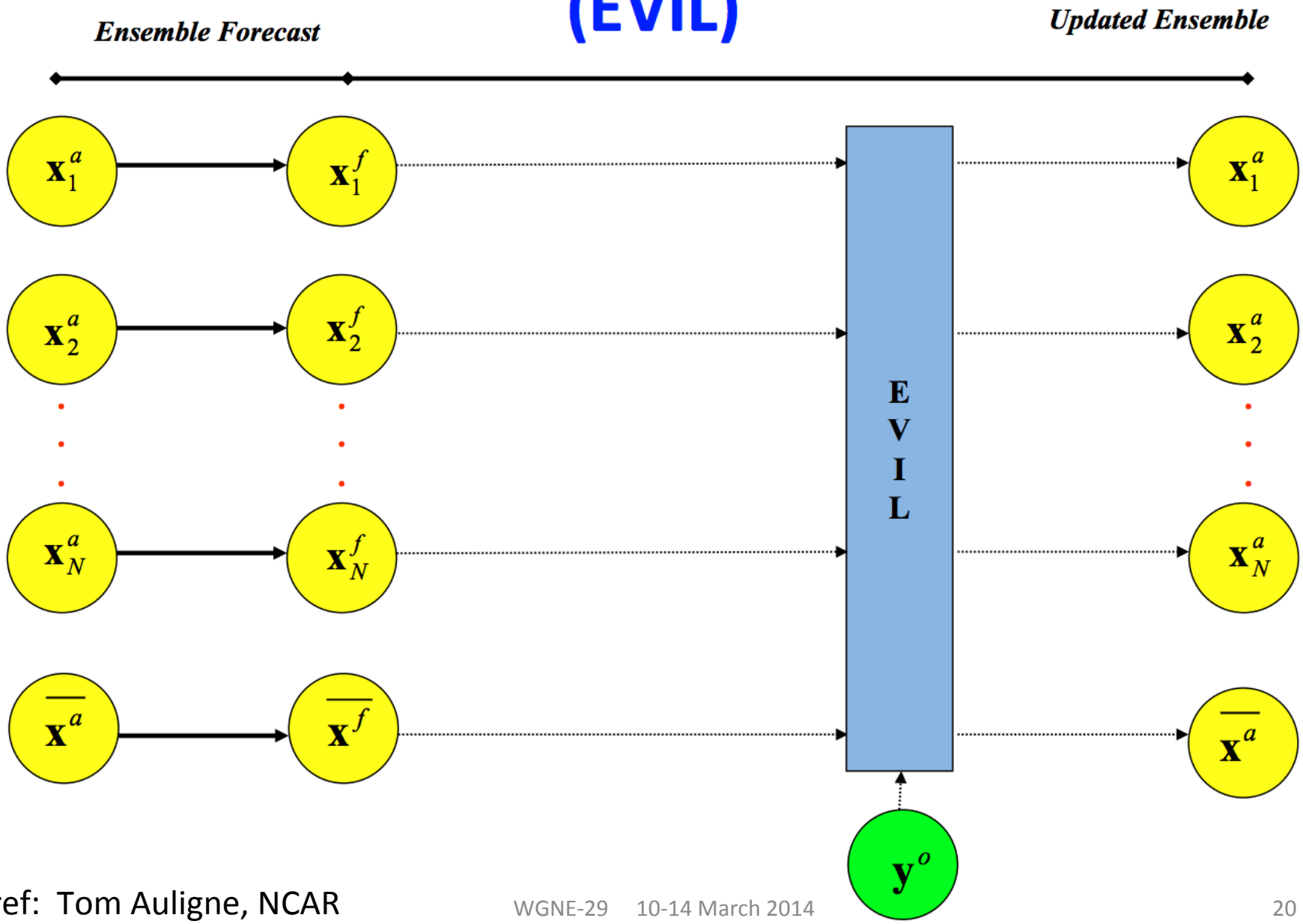
Localised trajectories define 4D PDF of possible increments

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

Variational/Ensemble Hybrid DA

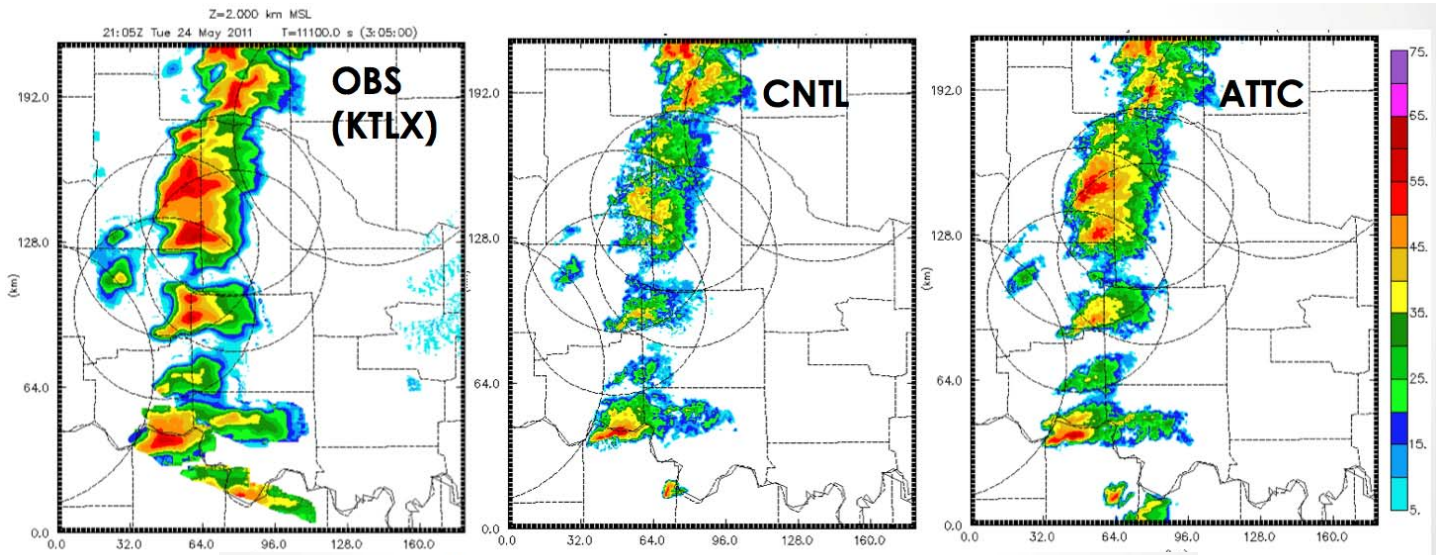


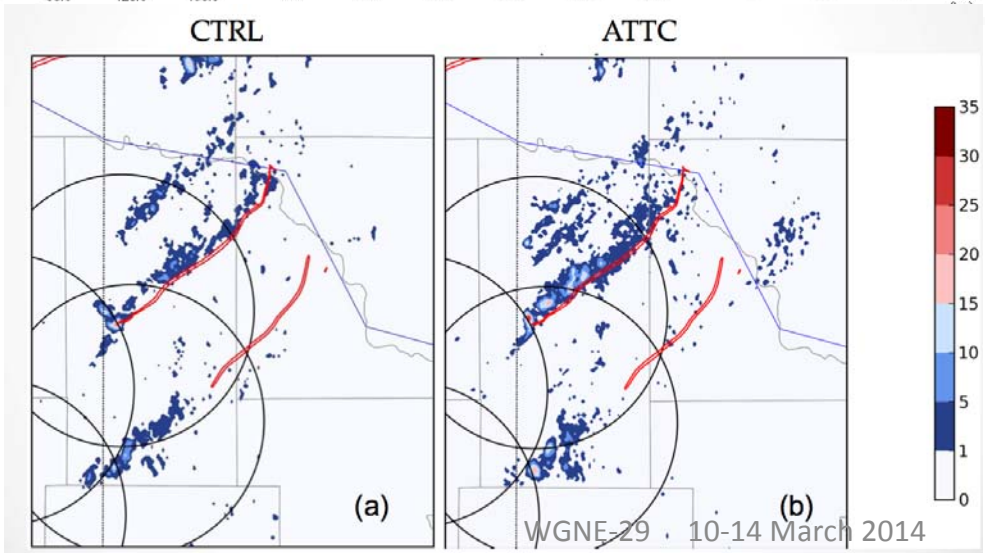
Ensemble Variational Integrated Lanczos (EVIL)



ref: Tom Auligne, NCAR

Radar data assimilation and severe local storms



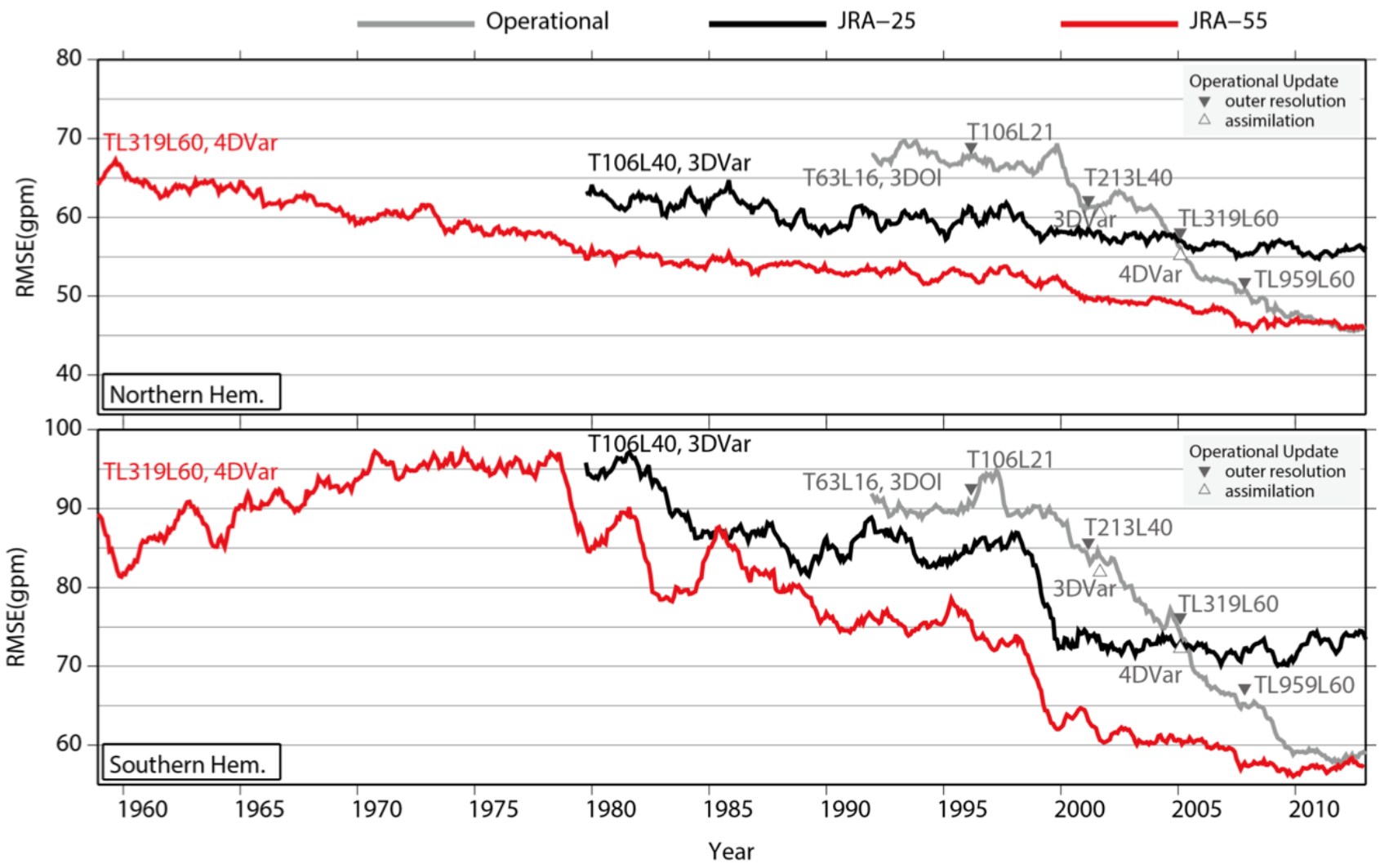


EnKF assimilation of X-band radar data (Cheng and Xue, talk 13.2 at symposium)

improved ensemble forecasts of low-level rotation. Red are observed tornado tracks.

Basic performance of the data assimilation system

Japanese reanalysis; see Kobayashi, talk 6.4



Time series for the RMS errors of 5-day forecasts of geopotential height (gpm) at 500hPa verified against its own analysis

Conclusions

- Soliciting feedback on terms of reference with move of DAOS from THORPEX to WWRP.
- Observations:
  - Increasing use of satellite data from emerging nations (China, India) in operational centres
  - Moves to make all rain radar data consistent
  - Use of new observations for convective scale DA
  - Reducing emphasis on aircraft targeted observations for mid-latitude storms
- Data assimilation
  - Note on DA terminology published in WGNE blue book
  - More developments of hybrid methods than on the traditional 4D-variational methodology
  - EnKF actively explored for convective scale models
- Data assimilation symposium a success, with many young scientists from several continents.
- Next DAOS WG meeting in Montreal, Aug 2014 (prior to WWRP Open Science Conf.)

Supplementary material

- The following slides are condensed notes from the various sessions at the 2013 WMO Data Assimilation Symposium.
- Information on reprocessing of GOES AMVs for reanalysis.

Assimilation methodology

- Operational system development focused on advanced methods that work efficiently on massively parallel computers
- Particularly active areas: weak-constraint 4D-Var, 4D-Ensemble-Var, and Ensemble Kalman Filters (EnKF).
- No consensus yet, but more development of hybrid methods than on the traditional 4D-variational methodology.
- Particle-filter approaches of interest but have not been demonstrated to be practical in high-dimensional systems.

Assimilation of atmospheric constituents

- Growing area of activity, with several atmospheric models incorporating chemical and aerosol capabilities.
- Assimilation of aerosol optical depth products (at 0.55µm wavelength) using MODIS measurements is now operational at several NWP centres.
- Assimilation of satellite ozone concentration measurements in atmospheric models continues to be an area of research.
- Concern over the lack of continuity of limb sounders for stratospheric composition measurements in the future.

Atmospheric data assimilation

- Fewer talks comparing EnKF with 4D-Var, more on investigating which hybridization of ensemble and variational methods worked best.
- ECMWF is exploring long-window, weak-constraint “saddle-point” 4D-Var which may address scalability issues.
- Environment Canada is retiring 4D-Var in favour of a 4D-En-Var system.
- EnKF actively explored for convective scale models.

Reanalyses

- Continuing efforts at several centres in maintaining and improving atmospheric and ocean reanalyses, many applying EnKF techniques that produce ensembles of analyses.
- Reanalyses are increasingly important for climate services and for reforecast initialization (to support statistical post-processing)
- Heavily used reanalysis data sets:
  - Japanese 55-year reanalysis completed.
  - US/NOAA EnKF-based 20th-Century reanalysis (actually from 1850 onward) is now available; uses only surface pressure observations.
  - ECMWF has continued running "ERA-Interim," with future reanalyses planned.
  - NOAA's Climate Forecast System Reanalysis (79-current)
  - US NASA/GMAO "MERRA" (79-current); MERRA2 planned; MERRA special collection in *J. Climate*.
- There are also several regional reanalyses activities underway.
- GOES AMVs have been reprocessed to support future reanalyses; see slides at end of this deck for details.

Convective-scale assimilation

- Methods that realistically leverage non-Gaussian background-error statistics are of particular interest due to more rapid onset of nonlinear processes at the smaller scales.
- Dealing with displacement errors especially important for smaller-scale features. Techniques to deal with this, e.g., "field alignment" may be especially helpful at convective scales.
- Initialization procedures that ameliorate the "spin-up" problem are of particular interest to convective scales and the short-term forecast problem.
- Balance constraints (hydrostatic or geostrophic) may be inappropriate to include in the construction of the background-error covariance at convective scales.
- Interest in assimilation of many new novel observation types (e.g. radar reflectivity) in rapid update mode (sub-hourly).
- Multi-scale data assimilation and verification: leveraging hi-res local observation while still providing high-quality global analyses.

Ocean data assimilation

- Challenges:
  - comparative paucity of data relative to atmosphere
  - very slow-timescale dynamics (El Nino- Southern Oscillation) as well as much faster dynamics (eddies along boundary currents).
- Several ocean reanalyses are now being produced or developed.
  - weakly coupled (background ocean and atmospheric states from a coupled model, with separate ocean and atmospheric analyses)
  - strongly coupled (joint state estimations, with cross-covariances accounted for).

Land-surface data assimilation

- Several new satellite missions dedicated to land surface measurements have been launched and are providing useful measurements, and more are planned.
- Soil moisture analyses now commonly use satellite data and/or in situ SYNOP observations of screen-level parameters. This improves the representation of near-surface temperatures.
- Measurements of fractional snow cover and in-situ snow depth are also being assimilated in many operational centres.
- Skin temperature from satellite measurements over land is a more challenging variable to assimilate, but efforts are now underway at several centres to achieve this.
- Coupled land-atmosphere assimilation methods are being investigated (see next slide).

Coupled data assimilation

- Increasing trend towards assimilation of observations in coupled systems.
  - Many talks and posters at the symposium demonstrated weakly coupled models and assimilation systems and their benefits.
- Strong coupling (e.g. simultaneous cycled assimilation and forecasting of ozone concentrations and the upper stratospheric temperatures) is more challenging and not always beneficial in current systems.
  - The applicability and accuracy of the estimates of cross-covariances between the atmosphere and land/ocean for coupled data assimilation is an area of active investigation.

Assimilation of satellite, in-situ, and radar observations

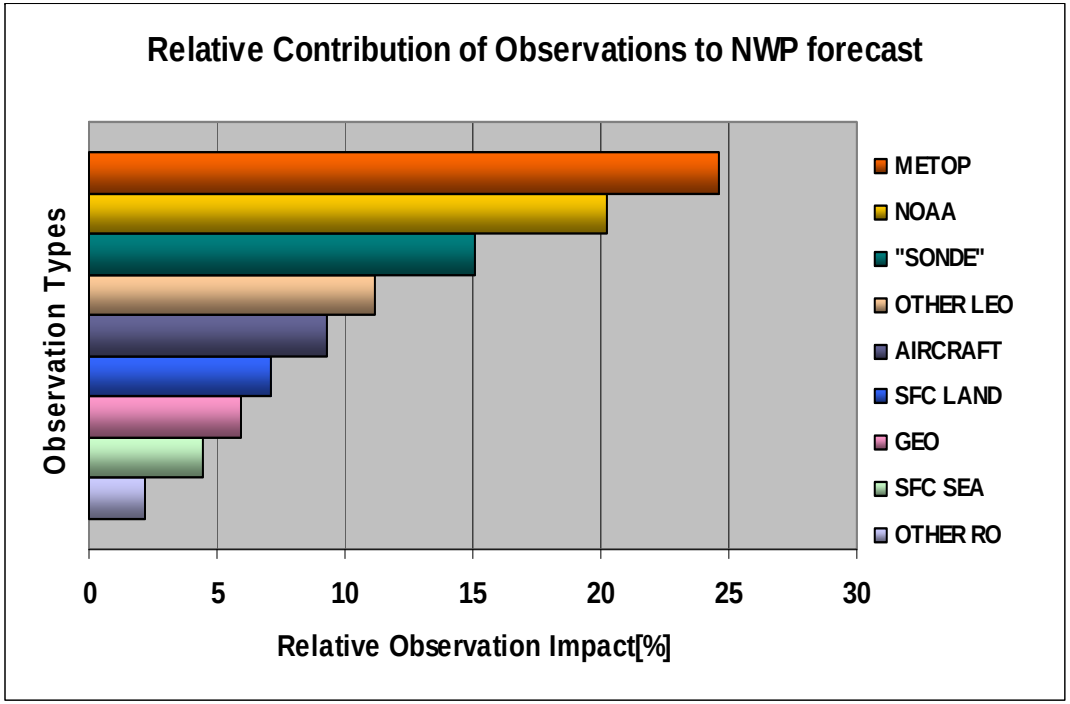
- Radar reflectivity assimilation showing benefit in local models using EnKFs.
- The use of improved satellite-derived Atmospheric Motion Vectors is increasing resulting in higher impacts at some centres.
- Exploiting the data from the advanced infrared sounders is becoming more sophisticated. It is important to allow for the cross-correlation between channels, especially for low-noise instruments such as the new high-resolution infrared sounder, CrIS, on the Suomi-NPP satellite.

Data assimilation diagnostics

- Traditional Observing System Experiment (OSE) where data are denied or added to a baseline system continues to have merit and are baseline for other techniques.
- Forecast sensitivity to observations (FSO) tools are providing useful information for the short-range impacts.
- Observing System Simulation Experiments (OSSEs) : same pro's and con's as ever.
  - Optimistic estimates of observation impact, especially with nature runs that are similar to forecast model used in the assimilation.
  - Necessity to assimilate the *full suite* that are assimilated operationally in order to get realistic quantitative estimates.
  - Still, about the only tool around for evaluating potential new observing systems.
  - OSSEs provide a useful cost/benefit analysis prior to fielding new multi-billion dollar satellites.
  - Room for international collaboration on OSSEs
- New objective data assimilation diagnostics
  - for tuning observation errors and spatial/inter-channel correlations.
  - for tuning covariance localization and optimal/adaptive ensemble inflation for EnKFs.

Observation impacts in Met Office global NWP

Metop:	AMSU-A, MHS, HIRS, IASI, ASCAT, GRAS
NOAA:	AMSU-A: N-15, N-18, N-19 MHS: N-18 HIRS: N-17, N-19 AVHRR AMVs: N-15, N-16, N-17, N-18, N-19
Other LEO:	EOS-Aqua AIRS, MODIS AMVs EOS-Terra MODIS AMVs DMSP F-16 SSMIS ERS-2 AMI; Coriolis WINDSAT
GEO:	GOES AMVs; MTSAT AMVs; Meteosat AMVs, CLRs
Other RO:	CHAMP, GRACE
Aircraft:	AMDAR, AIREP
"SONDE":	PILOT, TEMP, Wind profiler, DROPSONDE
Surface land:	SYNOP, BOGUS
Surface sea:	BUOY, SHIP, TCBOGUS



Lorenc and Marriott, QJRMS, Jan 2014
DOI: 10.1002/qj.2122

Centres Contributions

BoM

Data assimilation in ACCESS

Recent and Current:

- APS2 upgrade: assimilation of new satellite instruments: CrIS/ATMS, SSMIS (F17, F18), OSCAT, WindSAT, MTSAT imager
- Adjoint-based forecast sensitivity to observations (FSO):
  - as guidance for selecting additional satellite instrument channels to assimilate (e.g. IASI moisture-sensitive channels)
  - as guidance for Bureau observation network assessment and planning
- Improved observation monitoring
- Total satellite observation impact demonstration (withholding all satellite observations degrades forecast skill in S Hemisphere by 3 ½ days, versus only ½ day in N Hemisphere).
- Impact of adding SSMIS microwave radiance data to ACCESS-TC forecasts (Currently, rainfall forecasts improve but track

Soon

- Impact of high frequency (10 min) AMVs.
- Assimilation of Cloud Top Pressure/Temperature from Geostationary imagers, particularly in high-res systems

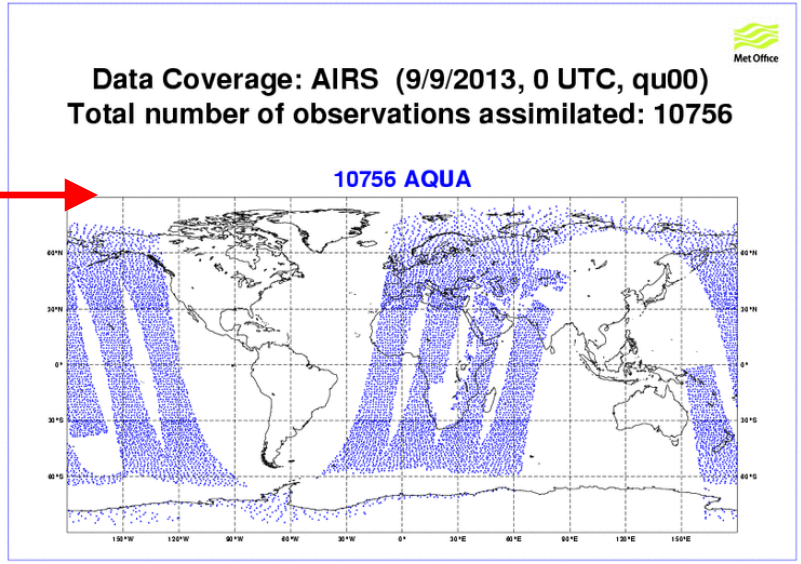
Future

- Assimilation of ground based GPS data
- Assimilation of cloud affected radiances
- Assessing the effect of diurnal SST variation on radiance data pre-processing
- Hybrid Ensemble 4dVAR assimilation

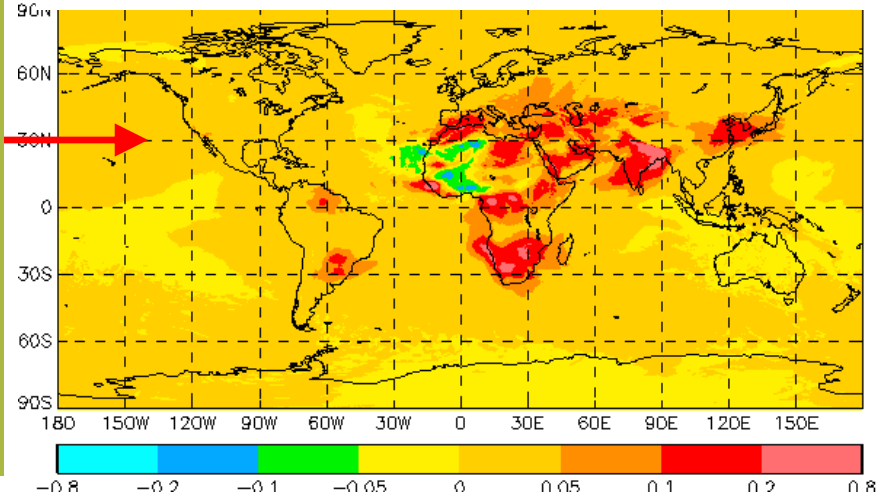
The Met Office

Global DA/SA and Ensembles: Recent Highlights (2012-2013)

- Significant increase (>50%) in satellite observations assimilated.
- Implemented adjoint sensitivity tool to assess detailed observation impact.
- Increased global (MOGREPS-G) ensemble size to 44 members for hybrid 4DVAR.
- Upgraded MOGREPS-G resolution from 60km to ~33km.
- Implemented dust (AOD) assimilation in hybrid 4DVAR.
- Implemented Extended Kalman Filter DA scheme for global land-surface model.

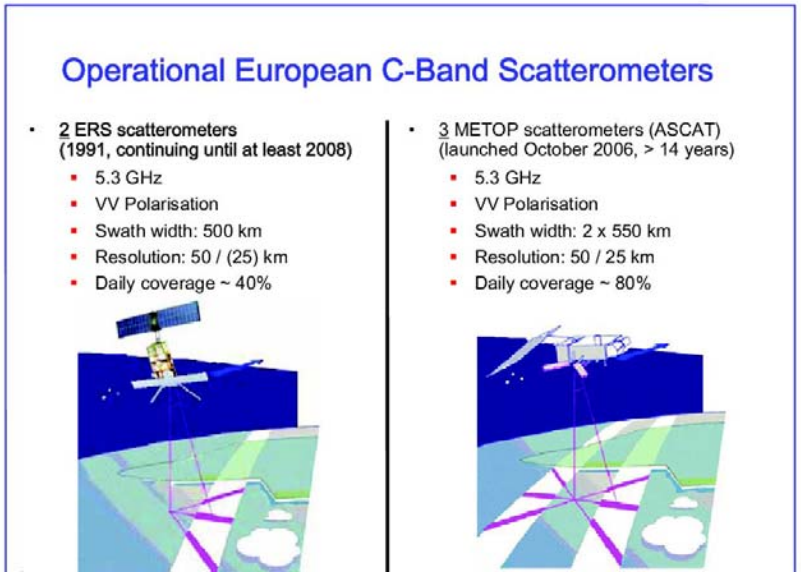


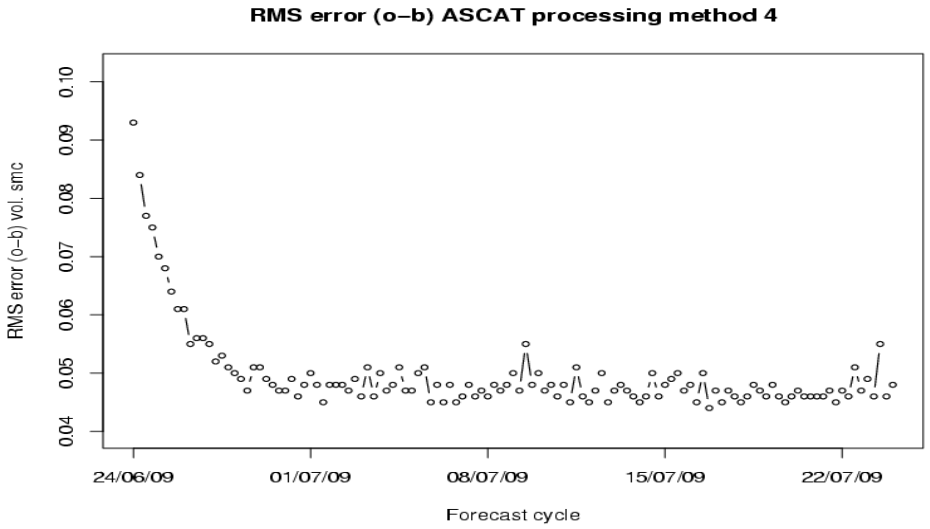
Mineral Dust Difference (DA-NoDA)



Land Surface DA

Dharssi, Candy





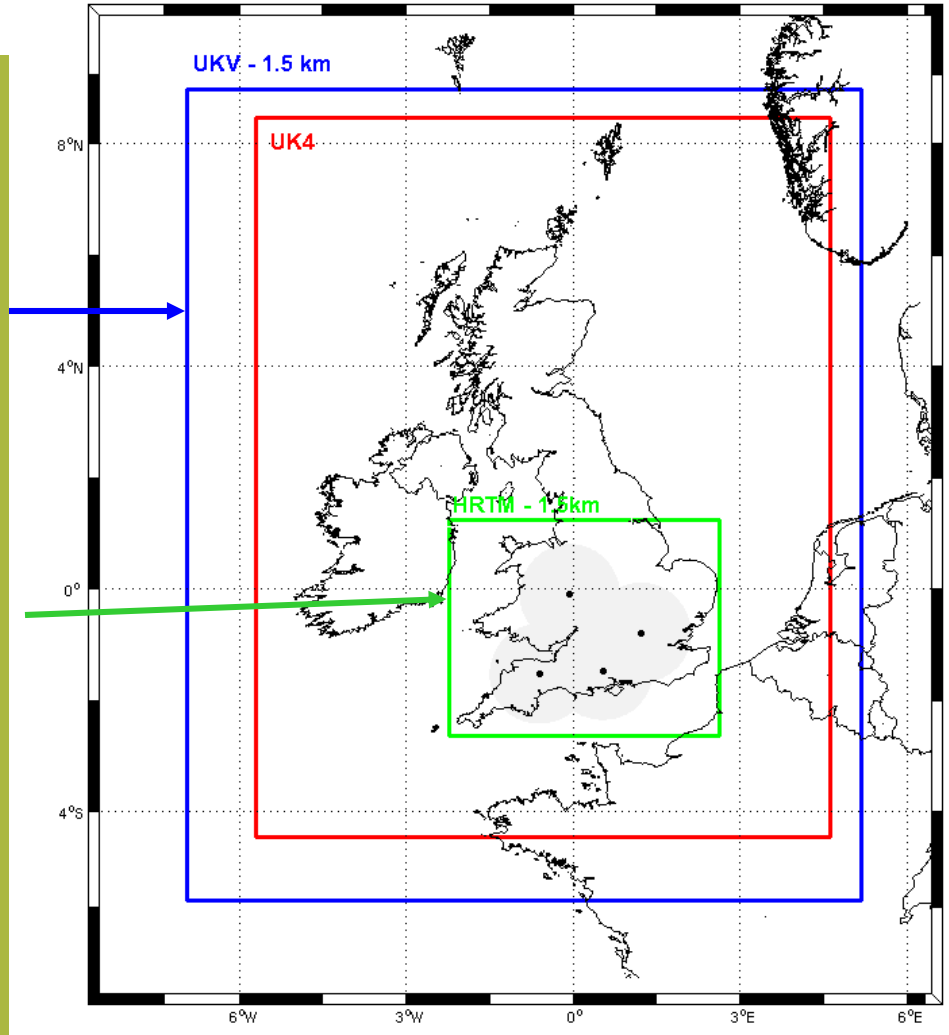
- ASCAT soil wetness assimilation implemented.
- Simple/cheap method to assimilate measurements of ASCAT soil wetness:
  - Nudge level 1 soil moisture. Surface T etc corrected through 4D-Var.
- Initial trials indicates ASCAT soil wetness assimilation improves forecasts of screen temperature and humidity in tropics (neutral in Europe so far).

Global DA and Ensembles: Summary of Plans (2014-2016)

- Implement new covariance model in hybrid 4DVAR.
- Upgrade 4DVAR inner-loop resolution from 60km to 40km.
- Upgrade MOGREPS-G: ~200 ensemble members for hybrid 4DVAR, 33 to 20-25km resolution and range from 3 to 7 days.
- Develop EnKF algorithm for land-surface model.
- Test 4DEnVar algorithm as alternative to hybrid 4D-Var.
- Test En4DEnVar as alternative to ETKF.
- Retire obsolete (60km resolution) MOGREPS-15

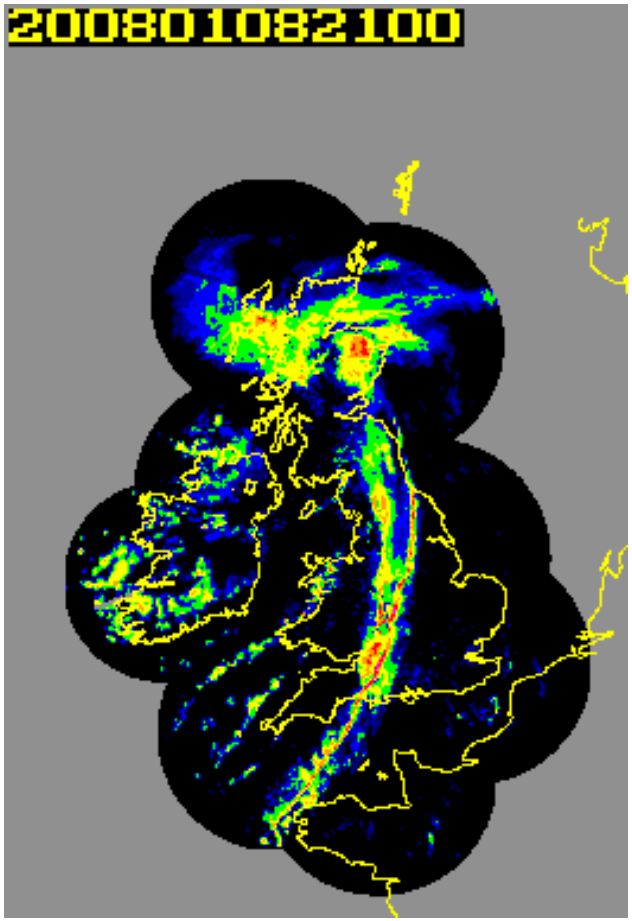
Convective-Scale DA and Ensembles: Recent Highlights (2012-2013)

- Performed detailed observation-impact assessment for UKV DA (3hourly 3DVAR)
- Introduced direct assimilation of satellite/surface cloud obs.
- Ran hourly-cycling convective-scale 4DVAR in Nowcasting Demonstration Project (NDP) for London 2012 Olympics and following winter.
- Also for L2012, implemented 12 member, 2.2km MOGREPS-UK convective-scale ensemble.



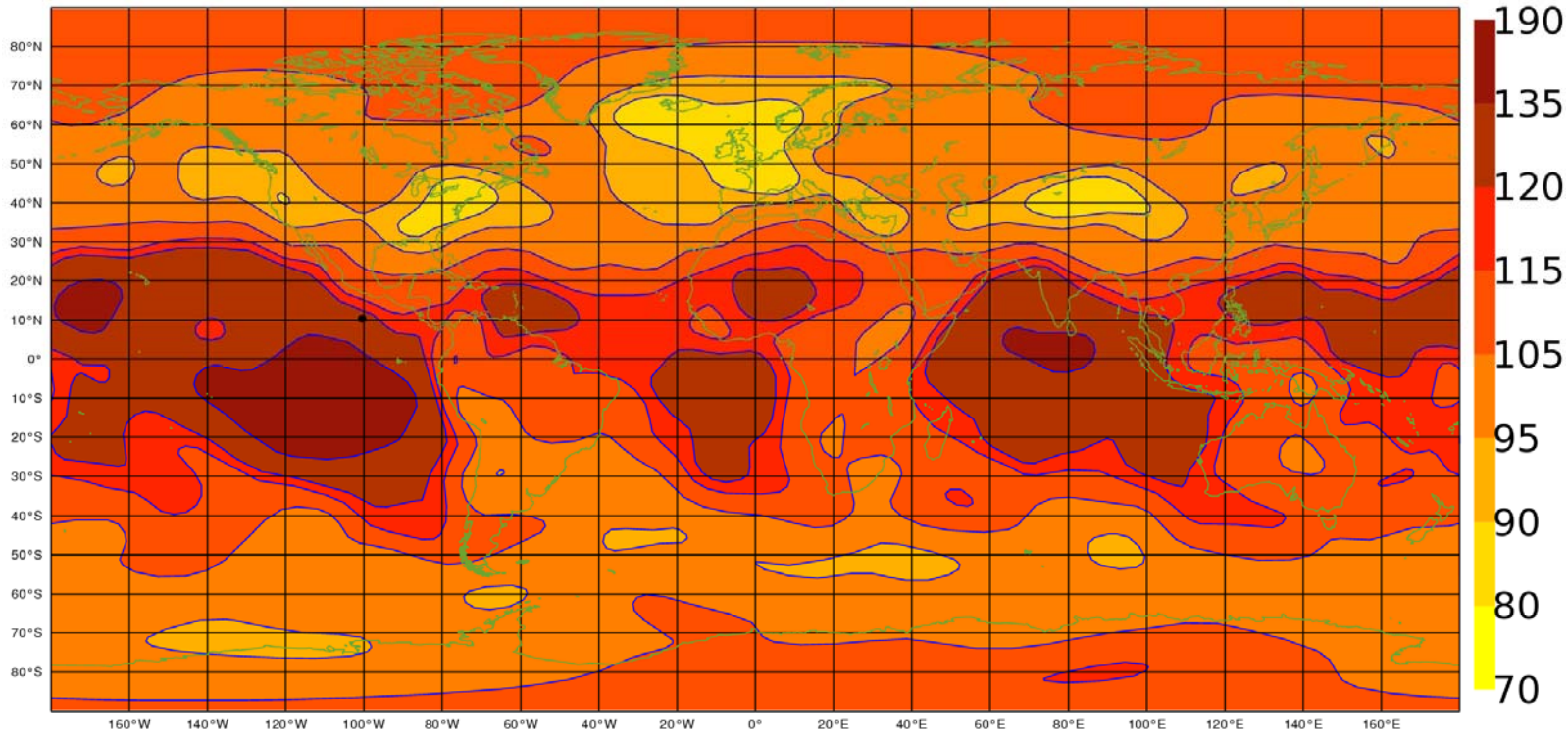
Convective-Scale DA and Ensembles: Summary Of Plans (2014-2016)

- Further improvements to covariances (e.g. 3D adaptivity to improve Sc/fog analysis).
- Implement UK-wide hourly-cycling 4DVAR.
- Test/implement 4DVAR reflectivity assimilation.
- Develop high-resolution land EKF scheme.
- Centre MOGREPS-UK on UKV DA analysis (using global perturbations).
- Increase ensemble size for MOGREPS-UK
- Initial experiments with convective-scale EnDA (hybrid 4DVAR?).



Météo-France

Wavelets in Arpège Bg Err Cov Matrix: horizontal lengthscales for wind at 500 hPa



Horizontal length scale (in km), for wind at 500 hPa:

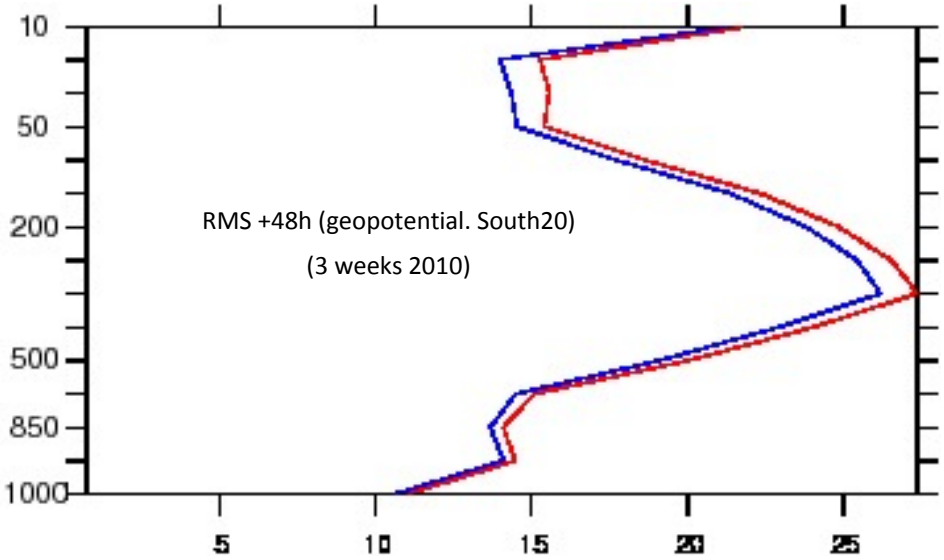
mean on 4 days : 6 members x 4 networks x 4 days = 96 realizations

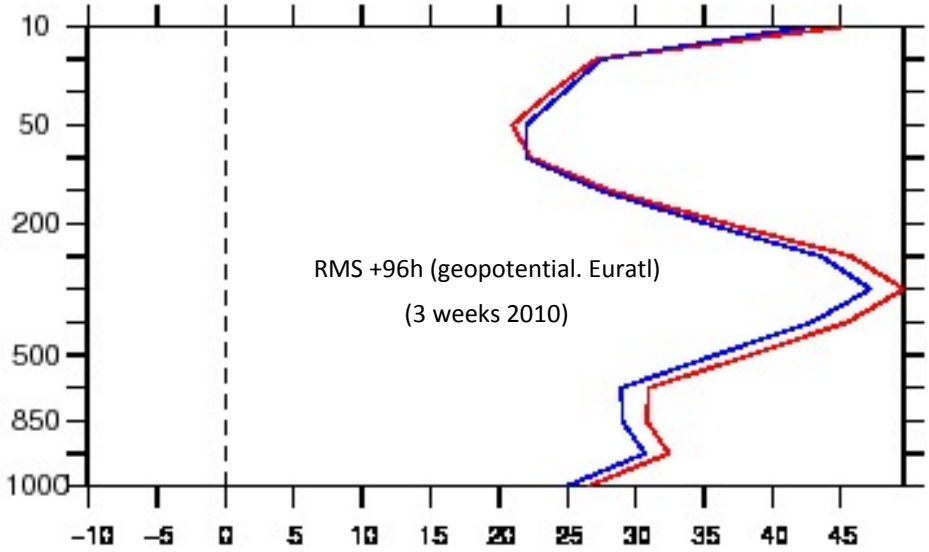
(Old operational horizontal length scales = 100 km uniform)

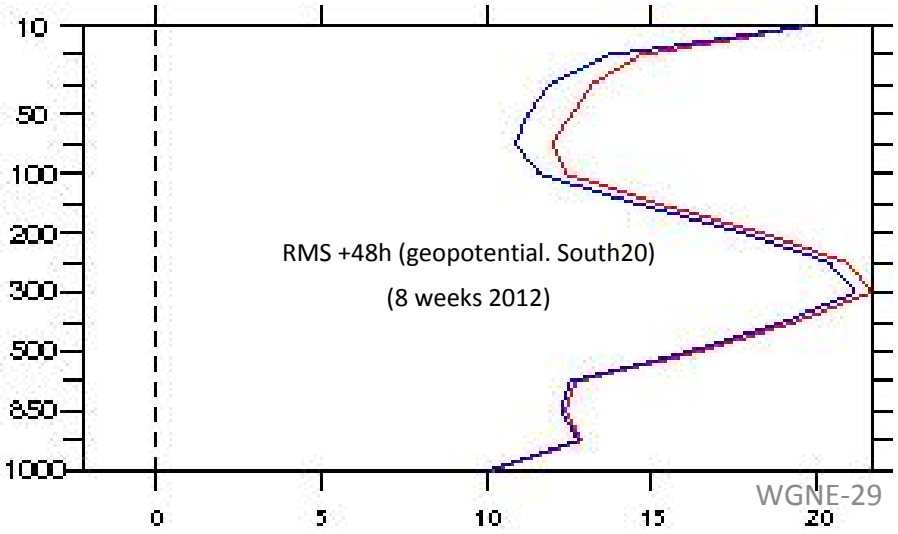
Used in operations since July 2013

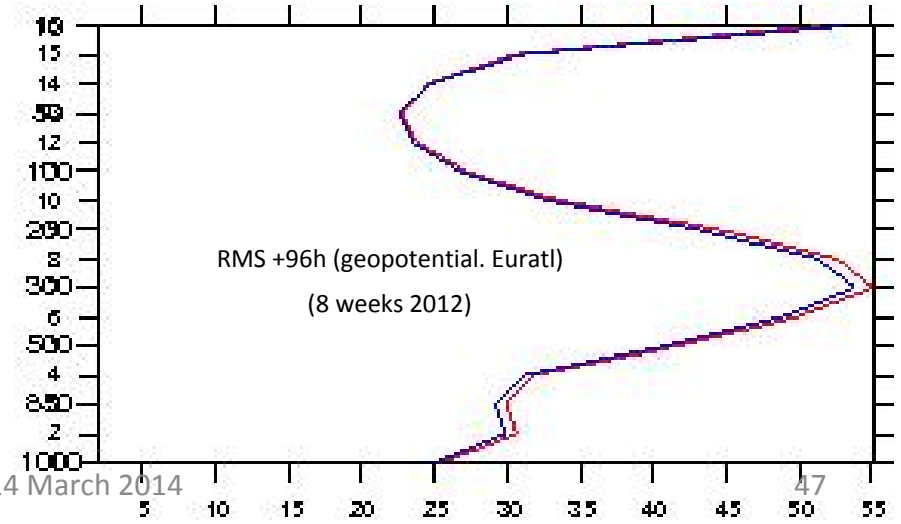
(Varella et al, 2012)

Impact of correlations wavelets (versus oper spectral, winter 2010 and 2012)









Plans in assimilation

Next e-suite: New resolutions Aearp (EDA)/Arpege/Pearp(EPS)/Arome
From 6 to 25 members for Aearp (EDA)
New configuration of 4D-Var (iterations number, outer loops)
RTTOV 10 (internal interpolation)
Thinning at higher resolution for satellite obs and radars
Revisit tuning of some so, sb
VarBC for GPS. New channels (SSMI/S, CrIS)
Assimilation SAPHIR sounder channels (if available) on MEGHA-TROPIQUES
Surface and radiosoundings (high resolution) in BUFR format
Activation of Ts inversion over land for IASI and use of cloud detection
Radar data V2 « double polarisation » from CMR (Arome only)
Assimilation des vents du radar en bande X du Mt Colombis (Arome only)

Longer term: 4D EnVar for Arpege and Arome

CMA

Recent Upgrades of GRAPES_VAR

Global GRAPES_3DVAR

•Revise to solve the wind-mass balance equation in terrain-following model grid space rather than by virtue of using ancillary pressure level

- Over the tropics: linear balance equation + statistics

•Implementation of Var-QC for conventional data

•New GNSS/RO QC

•Optimization of vertical correlation structure of background error

Regional GRAPES_3DVAR

•GPS/PW QC and assimilation

- Data sources: CMA (303 stations) & CEA (243 stations)
- Key issue: QC (Homogenization)

•New height adjustment algorithm of FY-2D/2E AMV

•New bias correction method of sounding RH

•Cloud analysis, DFI + cloud water nudging

•Implementation of Var-QC

Future plan of GRAPES_VAR

- Global 3DVAR in 2014
  - 0.5/37L 3DVAR + new conventional data preprocessing quasi-operational running
  - 0.25/0.5degree, L58 3DVAR, model top to ~37000m
  - Add more satellite : Suomi-NPP/ATMS, FY-3AB/MWHS, FY-3C/MWTS, NOAA-19/METOP-B AMSUA, NOAA/METOP/MHS, METOP/ASCAT, METOPA/IASI, AQUA/AIRS.
- Regional 3DVAR in 2014
  - 10km50L 3DVAR operational running, with GTS data, GPS/PW, GPS retrieval T&Q profile, radar VAD wind, 3D cloud analysis, FY-2 AMV (60km), RH2m, VarQC, and updated radio-sound humidity QC.
  - Add more obs.: Surface precipitation nudging, more Radar mosaic data in 3D cloud analysis
- Global 4DVAR in 2014
  - Parallel computing, perform 4DVAR analysis (1deg, 37L, 6h windows) within 1 hour;
  - Update GRAPES TL and ADJ model;
  - More satellite data used in 4DVAR
- Var in 2015 and after
  - Unified 10km MESO/RAFS(3hour) system, with 3DVAR analysis;
  - Global 3DVAR with 0.25degree, model top ~0.1hpa, more FY etc. satellite data;
  - Global 4DVAR analysis similar quality to operational 3DVAR, more satellite data used;
  - Regional hybrid EnKF+3DVAR develop and trial running

JMA

Hybrid EnKF-Var for Global Analysis

Method

- Generation of ensembles: EnKF(LETKF)
- Hybrid background error covariance (B) using extended control variables (Lorenc 2003, Buehner 2005)
- Time evolution of perturbations by TL/AD model

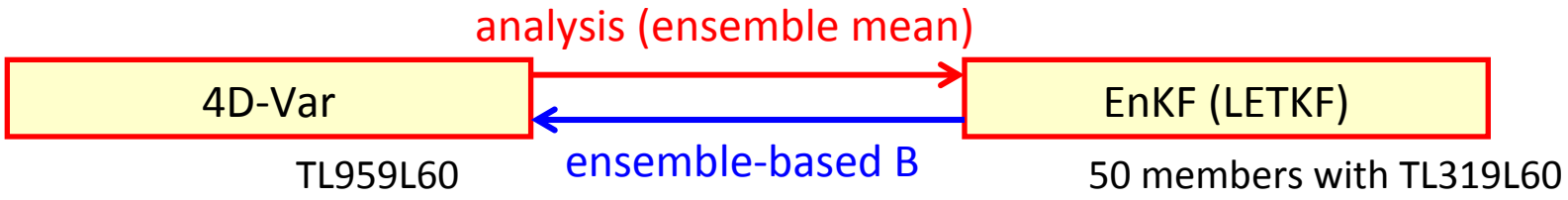
$$J(\mathbf{x}',\alpha_1,\ldots,\alpha_k)=\frac{1}{2}\mathbf{x}'^{\mathrm{T}}\mathbf{x}'+\frac{1}{2}\sum_{k=1}^{K}\alpha_k^{\mathrm{T}}\alpha_k$$

$$+\frac{1}{2}\left[\mathbf{HM}\left(\beta_1\mathbf{B}^{1/2}\mathbf{x}'+\beta_2\sum_{k=1}^{K}\mathbf{X}_k'\circ\left(\mathbf{C}^{1/2}\alpha_k\right)\right)-\mathbf{y}'\right]^{\mathrm{T}}\mathbf{R}^{-1}\left[\mathbf{HM}\left(\beta_1\mathbf{B}^{1/2}\mathbf{x}'+\beta_2\sum_{k=1}^{K}\mathbf{X}_k'\circ\left(\mathbf{C}^{1/2}\alpha_k\right)\right)-\mathbf{y}'\right]+J_c$$

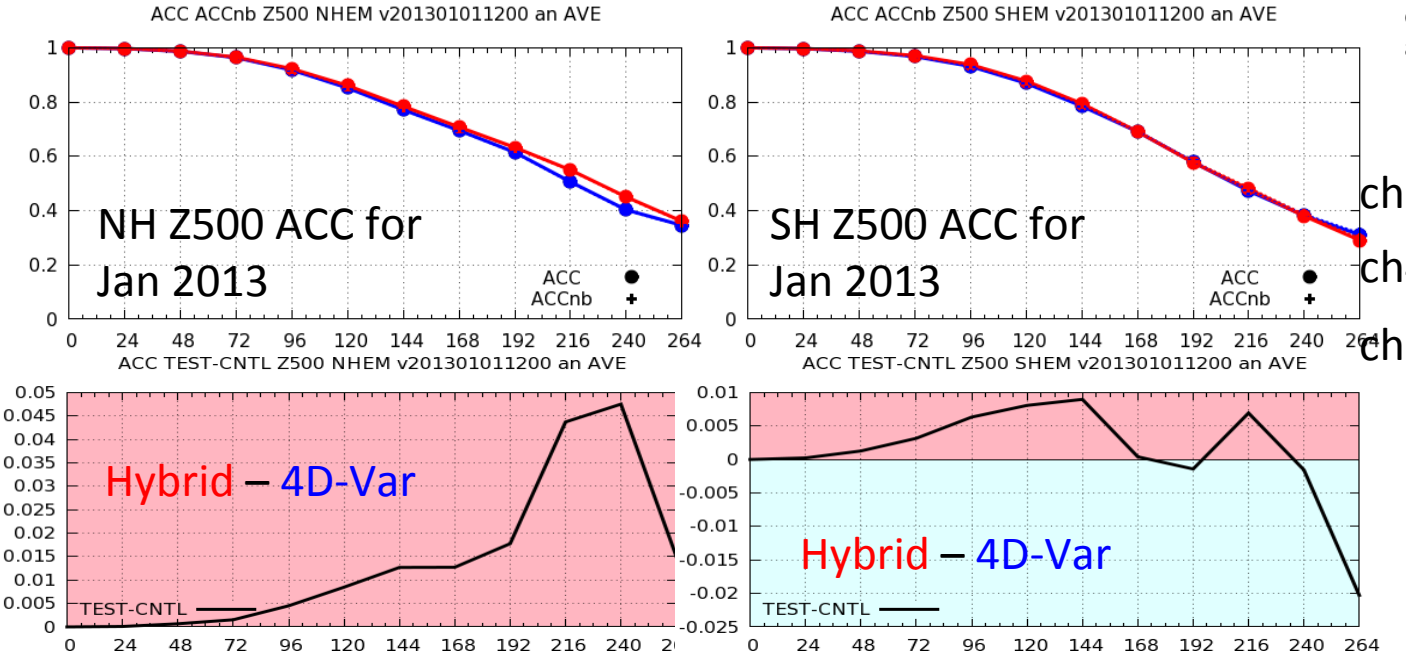
$\mathbf{B}$: static background error covariance, $\mathbf{H}$: observation operator, $\mathbf{R}$: observation error covariance, $\mathbf{M}$: tangent linear model, $\mathbf{y}'=\mathbf{y}\text{-}H(\mathbf{x}_b)$: innovation, $\mathbf{x}'$: control variable, α_k: extended control variable, $\mathbf{X}'$: ensemble perturbations

(Using β_1=1 and β_2=0 results in strong constraint 4D-Var with static B.)

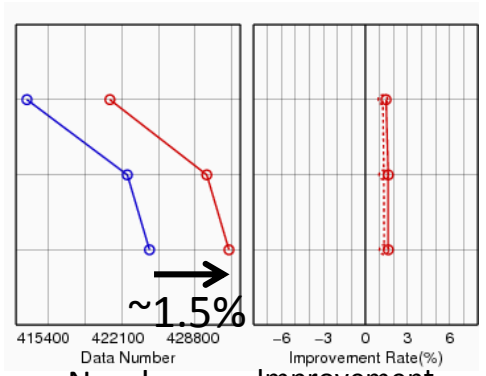
β_1=0.7 and β_2=0.5 are used for the experiment.

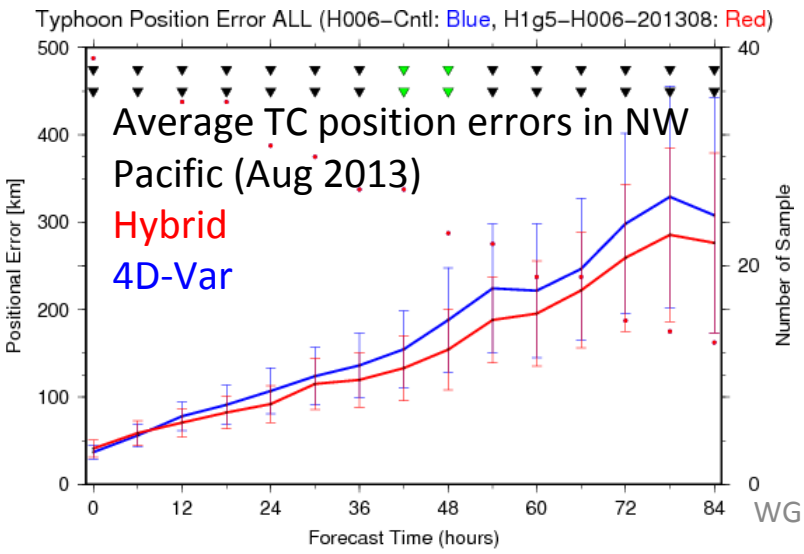


Verification results



Number of assimilated MHS (NOAA18) observations and improvement rate of analysis RMS difference from MHS





- Closer analysis and background fit to satellite radiance observations
- Relatively large forecast improvements in winter hemisphere (not so much for summer)
- Improvement on the forecast of tropical cyclones
- Large change on analysis of stratosphere in Tropics (need further investigation)

NRL

NRL DA Development and Plans
0 to 18 months

- Add assimilation of
  - surface temperatures over land
  - IASI water vapor radiances
  - NPP OMPS/NOAA SBUV/2 Ozone
  - IASI sounding channels in the ozone band
  - IASI from MetOp-B
  - MDCRS humidity
  - HDOB flight level obs (tropical and winter storm reconnaissance)
  - SSMIS Upper Atmosphere Sounding Channels
  - OceanSat scatterometer “OSCAT”
  - Suomi NPP CrIS assimilation
  - DMSP F19 SSMIS (launch April 3, 2014)
  - Radiances for mesoscale DA
  - SST radiance assimilation in NCODA (Navy Coupled Ocean Data Assimilation) system
- Refine data prep and assimilation methods
  - Prepare for upcoming transition to BUFR raob, SYNOP and aircraft reports
  - GPS-RO tropospheric error update
  - Account for radiosonde drift positions
  - Modifications to specified ob error variances and background error covariances
  - “Anchor channels” for some sounders
  - Holm moisture transform
  - Mesoscale 4D-Var
  - TLM and adjoint of semi-lagrangian model (NAVGEM)
- Data assimilation specific diagnostics and verification methods

Longer term plans

- Hybrid 4D-Var with testing of 4D-EnVar (code is in place for both)
- Coupled ocean/atmosphere data assimilation
- Land surface assimilation
- New 4-dimensional data assimilation algorithms
- Assimilation of new sensors/better utilization of existing observation sources
- Increased platform-specific QC and bias correction
- Account for correlated observation errors

RHMC

Variational/hybrid approach

Global DA

Operational: **The HydroMetCentre of Russia's (RHMC) 3D-Var** based on a spatial-auto-regression covariance model (*original development, not published yet*) with the external background (6-h GFS forecast)

Operational trials: **RHMC 3D-Var** in the cycling mode with the RHMC semi-Lagrangian model SL-AV

Research: Development of a hybrid EnVar scheme has started.

Regional DA

Research: RHMC 3D-Var (using stretched geometry) with the COSMO-Ru model

Tests on two domains, Sochi and Siberia, showed reasonable results.

Radar radial winds DA is being developed.

Satellite data assimilation (Research)

Collaboration with Environment Canada (P.Houtekamer and H.Mitchell) is underway on a technique aimed at optimal use of satellite observation-error correlations in EnKF without explicitly treating non-diagonal covariance matrices.

Authors: M Tsyrulnikov, P Svirenko, M Gorbunov, D Gayfulin, A Ordin, A Rakitko