TN15.1

Inventory of Aeolus Target Assimilation Systems

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CHANGE LOG

Version	Date	Comment
0.1	20 July 2011	MR: Initial attempt
1.0 draft	16 Aug 2011	MR: Draft version
1.1	16 Sep 2011	MR: updated following comments by reviewers
1.2	31 Jul 2012	MR: Add second questionnaire results and general tidy
1.3	18 Oct 2012	MR: Add final review comments
2.0	27 Nov 2013	MR: for MS4.3 payment, rename final version as 2.0

Contents

1 Introduction

This technical note aims to establish an inventory of NWP systems that, according to today's knowledge, can potentially benefit from Aeolus Level-2B data. This document compiles a list of the NWP systems' characteristic parameters and constraints which are thought to be of relevance to the Level-2B processing concept. It documents information such as: the forecast model resolution and estimated accuracy for wind, the employed data assimilation methods and the NWP centres' preferred observation sampling and thinning strategies.

This information should be useful to the L2B/C team when defining new observational requirements for the L2B processor when Aeolus is operating in continuous mode (CM). The document is intended to assist the team in the formulation of horizontal averaging strategies for Aeolus measurement data when creating wind observations suitable for data assimilation. This technical note was requested by ESA for Sub-task 1.1 of [AD1] and further documented in [AD2], work package 2710.

1.1 Documents

1.1.1 Applicable documents

	Title	Ref	Ver.	Date
[AD1]	Statement of Work for Change Request #4 "Aeolus Level 2B/C Processor - Implementation of Continuous Mode Operations & Extended Pre-Launch Support". Contract 18555/04/NL/MM	AE-SW-ESA-GS-038	1.0	Dec 2010
[AD2]	ESTEC Contract No. 18555/04/NL/MM "Change request for CCN No.4"	N/A	1.0	Feb 2011

1.1.2 References

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Brousseau, P., Berre, L., Bouttier, F. and Desroziers, G. (2011), Background-error covariances for a convective-scale data-assimilation system: AROME–France 3D-Var. Quarterly Journal of the Royal Meteorological Society, 137: 409–422. doi: 10.1002/qj.750

Desroziers, G., Berre, L., Chapnik, B. and Poli, P. (2005), Diagnosis of observation, background and analysis-error statistics in observation space. Quarterly Journal of the Royal Meteorological Society, 131: 3385–3396. doi: 10.1256/qj.05.108

Frehlich R, Sharman R. 2008. The use of structure functions and spectra from numerical model output to determine effective model resolution. Mon. Weather Rev. 136: 1537–1553.

Isaksen, L., M. Bonavita, R. Buizza, M. Fisher, J. Haseler, M. Leutbecher and Laure Raynaud, Ensemble of data assimilations at ECMWF, ECMWF tech. memo. no. 636, December 2010

Lambert, Steven J., 1984: A global available potential energy-kinetic energy budget in terms of the two-dimensional wavenumber for the FGGE year, Atmosphere-Ocean, 22:3, 265-282

Pannekoucke, O., Berre, L. and Desroziers, G. (2008), Background-error correlation length-scale estimates and their sampling statistics. Quarterly Journal of the Royal Meteorological Society, 134: 497–508. doi: 10.1002/qj.212

Skamarock, William C., 2004: Evaluating Mesoscale NWP Models Using Kinetic Energy Spectra. Mon. Wea. Rev., 132, 3019–3032.

1.2 Acronyms

AMV	Atmospheric motion vectors
ASCAT	EUMETSAT's Advanced SCATterometer on MetOp
BM	Burst mode
BRC	Basic Repeat Cycle
CAWCR	The Centre for Australian Weather and Climate Research
CM	Continuous mode
CMA	China Meteorological Administration
CMC/EC	Canadian Meteorological Centre/Environment Canada
CPTEC	Centro de Previsão de Tempo e Estudos Climáticos (Brazil)
DA	Data assimilation
DWD	Deutscher Wetterdienst
DWL	Doppler Wind Lidar
ECMWF	European Centre for Medium-Range Weather Forecasts
EDA	Ensemble data assimilation
EnKF	Ensemble Kalman Filter
EUMETSAT	The European Organisation for the Exploitation of Meteorological Satellites
FNMOC	Fleet Numerical Meteorology and Oceanography Center
GMAO	Global Modeling and Assimilation Office
HLOS	Horizontal Line Of Sight
HMC	HydroMeteorological Centre of Russia
IFS	Integrated Forecast System
JMA	Japan Meteorological Agency
KMA	Korea Meteorological Administration
KNMI	Royal Netherlands Meteorological Institute
LETKF	Local Ensemble Transform Kalman Filter
L2B	Level-2B
L2Bp	L2B processor
N/A	Not applicable
NCEP	National Centers for Environmental Prediction
NCMRWF	National Centre for Medium Range Weather Forecasting
NRL	Naval Research Laboratory

PSAS	Physical Space Assimilation System
SNR	Signal to noise ratio
TBD	To be determined
TN	Technical note
VHAMP	Vertical and Horizontal Aeolus Measurement Positioning
WGNE	Working Group on Numerical Experimentation
WMO	World Meteorological Organisation

2 Gathering the information

The information was acquired from a variety of sources. For example, details of NWP systems were obtained from the WMO's Working Group on Numerical Experimentation (WGNE) Meeting Reports. Early access to the 2011 report was obtained, which should be available on their website in the near future: http://www.wmo.int/pages/about/sec/rescrosscut/resdept_wgne.html. Searching the internet revealed information on NWP centres in presentations, which often detailed model settings and centre's future plans. The remaining information, as deemed useful for the Aeolus L2B team, was obtained via two questionnaires, copies of which are provided in the Appendix.

The first section of the first questionnaire was dedicated to acquiring details of NWP centres' operational global and regional/local forecast models and corresponding data assimilation systems. Much of this information was documented in WGNE reports, but it was decided to verify this information directly from the centres. Details were obtained about centre's present (2011) and future (defined as 2014-15) NWP implementations. Given Aeolus is (at the time of writing) planned for launch in 2015, it is important to know what NWP systems are expected to be capable of for that period.

The second section of the first questionnaire was dedicated to questioning on the following (some of which was of a more subjective nature):

- The accuracy of the model(s)
- Background error covariance characteristics
- What observation thinning is implemented
- How observations with high horizontal resolution are treated
- The data assimilation system's capability to handle non-profile information and whether dynamic error allocation is done
- Preferences for the spatial sampling of observations
- The human resources available for the data assimilation of Aeolus

The first questionnaire was emailed to satellite data assimilation experts at a dozen NWP centres (on the 9/6/11), namely: Met Office, Météo-France, NCEP, DWD, NRL, JMA, CMA, Env. Canada, CPTEC, CAWCR, HIRLAM consortium, ALADIN consortium. Some centres provided very detailed answers, whilst others were more perfunctory, although all responses were useful. Of course answers are also provided by ECMWF, when appropriate.

ESA felt that more some further questioning was required to help understand whether centres intend to use the L2B processor, or rely on externally processed L2B data. Also, the second questionnaire was an opportunity to provide centres with a detailed introduction to how the L2B processing works, allowing them to make an informed decision on how to deal with the data. A second questionnaire (including the introduction to Aeolus processing) was made and sent to the same centres on 3/5/12 (see the Appendix).

3 Inventory of NWP models

3.1 Details of NWP systems

Information gathered by the first section of the first questionnaire is presented; in particular regarding the forecast models and data assimilation systems of NWP centres. Information from the reports of the WGNE was used to partially complete each questionnaire, before sending them off to the centres for them to fill in the gaps and to amend any mistakes.

The information is documented in the following tables. Some of the fields are left blank, indicating that no information was available. A field with N/A indicates that there is no applicable answer to that query; mostly this is required when a centre has not yet implemented a system, but plan to for the future.

The columns of the table should be self-explanatory, however the "increment grid" column of the table refers to the grid resolution that is used in what is commonly referred to as the "inner loop" of the data assimilation method. That is, the grid used in the minimisation problem to produce analysis increments. Note that the majority of variational data assimilation systems employ an incremental approach, in which the departures (observation minus background) are calculated using the full resolution model fields — this is often referred to as the "outer loop". For example, at ECMWF in 2011 the outer loop is run at spectral truncation T1279 (~16 km grid spacing), matching the forecast model resolution.

Grid resolutions, quoted in kilometres, are only approximations (applicable at mid-latitudes) — the true grid resolution can be calculated accurately given the details of its formulation, however this information was not easily obtainable, at least via internet searches.

3.1.1 Global deterministic model forecast systems

Table 1 lists some pertinent parameters about the deterministic global forecast models (in contrast to probabilistic forecasts using ensembles) and their corresponding data assimilation systems, from a wide selection of NWP centres. Since Aeolus observations are most likely to be operationally assimilated in deterministic global models (at least initially), then Table 1 aims to provide the most relevant information for the L2B team (from this section of the document).

NWP centre (based in)	Model name	FORECAST MODEL Year: 2011 Horizontal Grid Resolution	Year: 2011 Vertical grid No. levels/top	Year: 2014-15 Horizontal Grid Resolution	Year: 2014-15 Vertical grid No. levels/top	DATA ASSIMILATION Year: 2011 Method	Year: 2011 Increment grid Resolution	Year: 2014-15 Method	Year: 2014-15 Increment grid Resolution
ECMWF (Europe)	Deterministic model	T1279/16 km	91/0.01 hPa (80 km)	T2047/10 km	137/0.01 hPa	4D-Var, EDA variance	T255 (80 km)	4D-Var, EDA covariance	T399 (50 km)
Meteo-France (France)	ARPEGE	T798C2.4/10-60 km	70/64 km (0.1 hPa)	T1200C2.2/8-36 km	105/80 km	4D-Var, EDA variance	T323 (60 km)	4D-Var, EDA covariance	50 km
Met Office (UK)	UM (global)	1024x769/25 km	70/85 km	/16 km	85/85 km	Hybrid Ens. 4D-Var	432x325 (60 km)	Hybrid Ens. 4D-Var	40 km
DWD (Germany)	GME, ICON	triangular grid/30 km	60/10 hPa	/20 km	80-100/0.1 hPa	3D-Var		3D-Var	20 km
NCEP (USA)	GFS	T574/27 km	64/0.2 hPa	T1148/~13km	91/	Advanced 3D-Var	T382	Hybrid EnKF-4D-Var	
FNMOC/NRL (USA)	NOGAPS, NAVGEM	T319/42 km	42/0.04 hPa (70 km)	T511/26 km	60/0.007 hPa (90 km)	4D-Var	T319 (42 km)	4D-Var	T511 (26 km)
CMC/EC (Canada)	GDPS, GEM	800x600/33 km	80/64 km (0.1 hPa)	1024x800/25 km	80/64 km (0.1 hPa)	4D-Var	T108 (170 km)	4D-Var	T180
CMA (China)	GRAPES_GFS	T639/31 km	60/0.1 hPa			3D-Var (NCEP)	320x160, 125 km		
JMA (Japan)	Global Spectral Model	T959/20 km	60/0.1 hPa	T959/20km	100/0.01 hPa	4D-Var	T159 (80 km)	4D-Var	T319 (50 km)
CPTEC/INPE (Brazil)	MCGA (GPSAS)	T213/63 km	42/2 hPa	T299/45 km	64/0.1 hPa	Global PSAS	63 km	LETKF	45 km
CAWCR (Australia)	ACCESS-G (UM)	/80 km	50/			4D-Var	100 km		
KMA (South Korea)	UM (Met Office)	640x481/40 km	50/60 km			4D-Var			
NCMRWF (India)	GDAS	T170/75 km	28/			3D-Var	T170		
HydroMetCentre (Russia)	SL-AV	400x251/75 km	28/5 hPa	1600x866/20-25 km	61/1 hPa	OI	1.5 deg	3D-Var	0.75 deg

Table 1. Deterministic global model system information

It can be seen that global models will tend to have forecast model grid spacings of 10-20 km by 2014-15. If we assume that a forecast model can resolve the atmosphere accurately at ~6-10 model grid spacings (see Skamarock, 2004 and Frehlich, 2008) this implies that global models will start to resolve the atmospheric wind accurately at scales of ~60-200 km in the 2014-15 timeframe, which has implications for the Aeolus L2B observation scale. There is also a trend towards higher resolution vertical grids, with typically 80-100 vertical levels (with model tops 0.1-0.01 hPa) by 2014-15. Note the vertical grid resolutions of the models are typically significantly higher than Aeolus rangebin resolutions.

Another trend noted is the shift of several centres to hybrid data assimilation systems (Météo-France made the transition in 2008, ECMWF and the Met Office in 2011). Hybrid methods make use of flow-dependent background error covariance information from the members of an ensemble data assimilation (EDA) system to improve the deterministic forecast. This will produce more flow-dependent analysis increments, potentially with shorter horizontal scales in dynamically active areas as compared to those from climatological covariances, see Section 3.2.3. Hence there is the potential for extracting relatively more information from densely spaced/higher resolution observations (assuming the observation errors are not significantly correlated in the horizontal, which often necessitates thinning of data).

Even during the "inner-loop" of data assimilation systems, horizontal grid resolution is set to increase to typically 30-50 km by 2014-15. The Met Office's global model is to be become sufficiently high resolution for them to phase out the North-Atlantic and European model, and instead to have a global model at 16 km grid-spacing and a UK domain very-high-resolution model (see UKV in Table 2). Similarly Météo-France is phasing out the regional ALADIN model over France since the global ARPEGE model resolution will be sufficiently high in future.

3.1.2 Deterministic regional/local area model forecast systems

In a similar style to Table 1, Table 2 provides a compilation of information for deterministic regional/local area models and their data assimilation systems. It can be seen that most NWP centres are now running regional or local area models or intend to be in 2014-15. Typically these will have horizontal grid-spacings of 1-10 km by 2014-15. Hence some models will be able to explicitly represent convection, however it will not be fully realistic as many convective and turbulent processes and plumes are still unresolved and need to be parameterized. Following the previous section's discussion, this means the models should be able to represent the atmosphere accurately at ~6-100 km horizontal scales and above. Regional models will generally have around 70 vertical levels, with model tops lower than the global models, so not compromising vertical resolution relative to global models.

Many models will continue to use the now well established variational data assimilation techniques, 3D-Var and 4D-Var, however some of the larger centres plan to implement hybrid systems incorporating a flow-dependent component to the background error covariances, a trend already noted for global models. Inner loop resolutions will tend to be the 1-2 times the forecast model grid spacings i.e. 1-20 km.

NWP centre (based in)	Model name	FORECAST MODEL Year: 2011 Horizontal Grid Domain/resolution	Year: 2011 Vertical grid No. levels/top	Year: 2014-15 Horizontal Grid Resolution	Year: 2014-15 Vertical grid No. levels/top	DATA ASSIMILATION Year: 2011 Method	Year: 2011 Increment grid Resolution	Year: 2014-15 Method	Year: 2014-15 Increment grid Resolution
Meteo-France (France)	ALADIN-FRANCE	W. Europe/7.8 km	70/64 km (0.1 hPa)	N/A	N/A	N/A	N/A	N/A	N/A
Meteo-France (France)	AROME	France/2.5 km	60/50 km	1.3 km	113/60 km	3D-Var	2.5 km	3D-Var	1.3 km
Met Office (UK)	NAE	N. Atlantic+Europe/12 km	70/85 km	to be phased out	N/A	4D-Var	36 km	N/A	N/A
Met Office (UK)	UKV	UK/1.5 km	70/40 km	1.5 km	70/40 km	3D-Var		4D-Var/EnDA	
JMA (Japan)	Mesoscale Model (MSM)	E. Asia/5 km	50/22 km			4D-Var	15 km	4D-Var	10 km
JMA (Japan)	Local Forecast Model (LFM)	N/A	N/A	Japan/2 km	60/			3D-Var	5 km
CMC/EC (Canada)	RDPS, continental	North America/15 km	80/64 km (0.1 hPa)	8 km	80/	3D-Var FGAT	100 km	4D-Var	
CMC/EC (Canada)	RDPS, LAMs	Canadian regions/2.5 km	58/0.1 hPa	2.5 km	58/	downscaling from cont.			
NCEP (USA)	NAM (WRF-NMM)	North America/12 km	60/2 hPa	12 km (using NMMB)	60/2 hPa	Advanced 3D-Var	12 km	EnKF/3D-Var hybrid	12 km
NCEP (USA)	NAM (WRF-NMM), LAMs	USA/4 km	35/50 hPa	1-6 km (using NMMB)	60/2 hPa	Advanced 3D-Var	12 km	EnKF/3D-Var hybrid	3-6 km
DWD (Germany)	COSMO-EU	Europe/7 km	40/20 hPa	5 km	80-100/0.1 hPa	observation nudging	7 km	3D-Var	5 km
DWD (Germany)	COSMO-DE	Germany/2.8 km	50/20 hPa	2 km	80/20 hPa	observation nudging	2.8 km	LETKF	2 km
FNMOC/NRL (USA)	COAMPS	Many areas/ 45, 15, 5 km	60/55 km	18, 6, 2 km		3D-Var	45, 15, 5 km	4D-Var/hybrid	18, 6, 2 km
CPTEC/INPE (Brazil)	ETA/RPSAS	South America/40 km	28/10 hPa	10 km	60/10 hPa	Regional PSAS	40 km	LETKF	20 km
HydroMetCentre (Russia)	COSMO	Russia/7 km	40/22 km	2km	80/35 km	None	N/A	3D-Var	7 km
CMA (China)	GRAPES_Meso	E. Asia/15 km	31/10 hPa			GRAPES_3DVAR			
CAWCR (Australia)	ACCESS-R (UM)	Australia/38 km							

Table 2. Deterministic regional/local area model system information

3.1.3 Global ensemble data assimilation systems

In a similar fashion to the previous tables, Table 3 provides information on ensemble prediction systems which incorporate data assimilation (limited to global models). Ensembles of data assimilation systems are predicted to increase in use and improve in ensemble size by 2014-15 — with the main aim of improving the deterministic forecast by using statistics from the ensemble members to estimate flow-dependent background error covariances. Due to the computational costs of running ensembles of data assimilation systems, the resolutions of each ensemble member tends to be lower than the deterministic global models, typically by a factor of 2. Vertical grids however tend to match their deterministic equivalents. The analysis increment grid spacings tend to be the same as the deterministic grid spacings.

		FORECAST MODEL						DATA ASSIMILATION			
NWP centre (based in)	Model name	Year: 2011 Horizontal Grid **Resolution**	Year: 2011 Vertical grid **No. levels/top**	Year: 2011 No. of members	Year: 2014-15 Horizontal Grid **Resolution**	Year: 2014-15 Vertical grid **No. levels/top**	Year: 2014-15 No. Of members	Year: 2011 **Method**	Year: 2011 Increment grid **Resolution**	Year:2014-15 **Method**	Year: 2014-15 Increment grid **Resolution**
DWD (Germany)	ICON Ensemble	N/A	N/A	N/A	/40 km	80-100/0.1 hPa	40	N/A	N/A	Hybrid 3D-Var +ENKF	40 km
Meteo-France	ARPEGE ensemble	T399/50 km	70/0.1 hPa	6	T511/40 km	105/0.1 hPa	12	EnVar: 4D-Var	T107/187 km	EnVar: 4D-Var	T224/90 km
ECMWF (Europe)	EDA	T399/50 km	91/0.01 hPa	10	T639/31 km	137/0.01 hPa	50	EnVar: 4D-Var	T159/126 km	EnVar: 4D-Var	T399/50 km
CMC/EC (Canada)	GEPS	600x300/67 km	64/2 hPa	20	800x600/33 km	80/0.1 hPa	20	EnKF	400x200/100 km	EnKF	600x450/44 km
NCEP (USA)	Global ensemble	N/A	N/A	N/A	T254	91/	80	N/A	N/A	EnKF/3Dvar hybrid	
HydroMetCentre(Russia)	EPS	T169	31/10 hPa	14	/37 km	50-60/1 hPa	26	N/A	N/A	Hybrid 3D-Var	50 km
CPTEC/INPE (Brazil)	MCGA (LETKF)	N/A	N/A	N/A	T299/45km	64/0.1 hPa	60	N/A	N/A	LETKF	45 km

Table 3. Ensembles of data assimilation system information

3.2 Feedback on more subjective questioning from the first questionnaire

The second part of the first questionnaire requested information on topics which could be answered in a variety of ways, subject to the NWP centre's preferred methods and opinions. The following subsections provide some examples of the responses received from NWP centres, along with ECMWF's.

3.2.1 Answers to Q1

Q1. What are the estimated short-range (6-12 hours) errors, both systematic and random, in the horizontal wind fields of your NWP model(s)? *As a function of height if possible.*

DWD provided a table with estimates of model wind error via a statistical comparison of the model against radiosonde observations (therefore the statistics are a combination of model error, radiosonde error and representivity error):

The estimated 12 hour errors are:

Level [hPa]	*Bias [m/s]*	*RMS [m/s]*
1000	*0.4*	*2.2*
925	*0.2*	*2.4*
850	*-0.2*	*2.5*
700	*-0.4*	*2.5*
500	*-0.5*	*2.5*
400	*-0.5*	*2.8*
300	*-0.5*	*3.3*
200	*-0.7*	*3.6*
150	*-0.4*	*3.4*
100	*-0.4*	*2.8*
50	*-0.4*	*2.5*

In the Tropics, the errors are ~ 0.5 [m/s] larger

CMC/Env. Canada provided an answer also by a statistical comparison of the model to radiosonde observations:

We provide below the mean bias and RMS 12h forecast error (GDPS) for wind speed against radiosondes for the first five months of 2011 over the Northern Hemisphere, Tropics and Southern Hemisphere.
The units are m/s.

Wind speed 12h biases against radiosondes

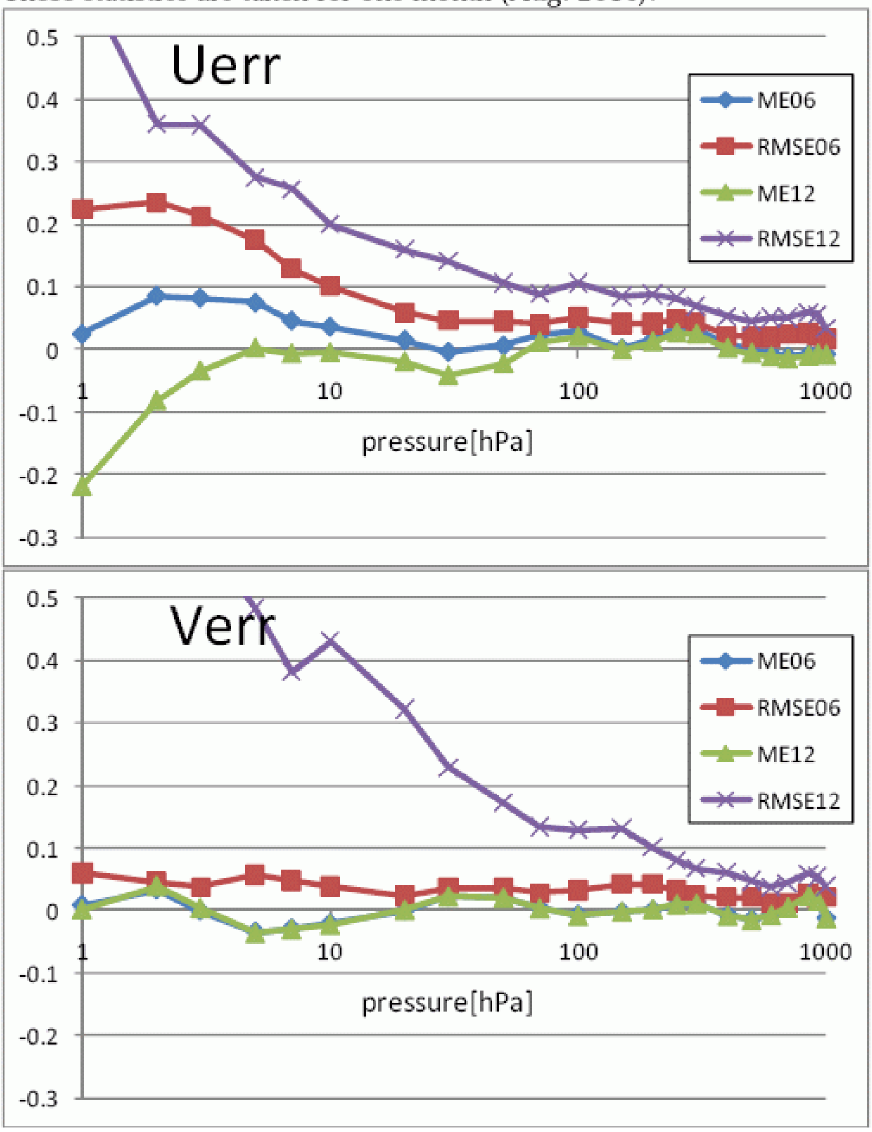
Levels (hPa)	*Northern H.*	*Tropics*	*Southern H.*
10	*-0.4*	*1.5*	*-0.2*
50	*-0.4*	*-0.4*	*-0.5*
100	*0.0*	*-0.2*	*0.4*
250	*-0.6*	*-0.4*	*-0.4*
500	*-0.4*	*-0.3*	*-0.3*
850	*-0.3*	*-0.4*	*-0.1*

Wind speed 12h RMS forecast errors against radiosondes

Levels (hPa)	*Northern H.*	*Tropics*	*Southern H.*
10	*5.0*	*6.0*	*5.2*
50	*3.7*	*5.0*	*4.0*
100	*4.0*	*5.9*	*4.6*
250	*4.6*	*5.3*	*5.1*
500	*3.9*	*4.4*	*4.2*
850	*3.6*	*4.1*	*4.1*

JMA's answer provided the following plots showing statistics of forecasts compared against own analyses. It gives mean error (ME) and root-mean-square error (RMSE) for 6 and 12 hour forecasts for both zonal and meridional wind components. It is unclear why the 12 hour RMSE is so much larger than the 6 hour for the Verr.

These statistics are taken for one month (Aug. 2010).



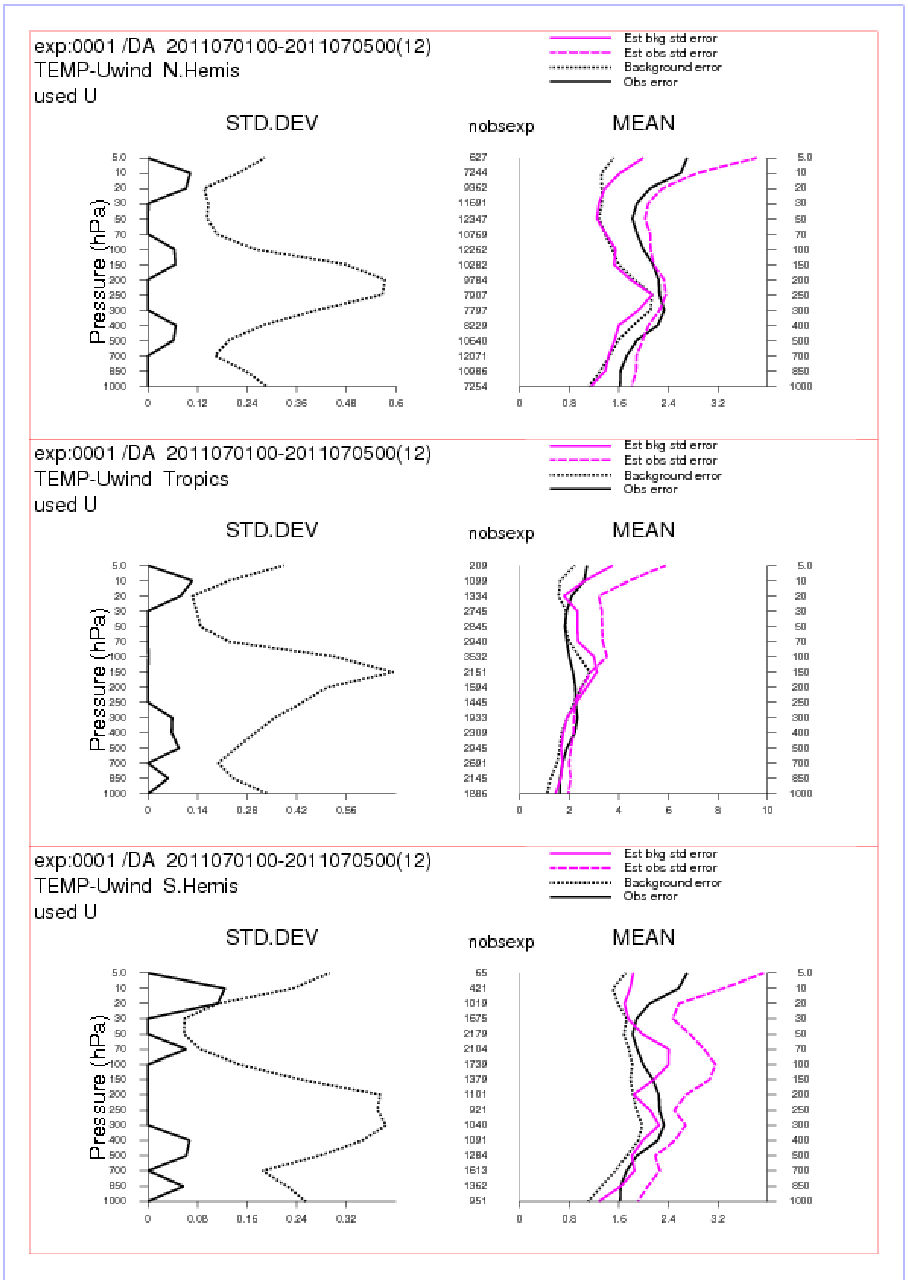
ECMWF's answer:

To examine the random component of the ECMWF background forecast error, the following two figures show five days of statistics from July 2011 of observation error and background error for horizontal wind components, U and V. Estimates of the errors (Est bkg std error and Est obs std error) were derived using radiosonde observation departures (O-B i.e. observation minus background and O-A i.e. observation minus analysis) by the method of Desroziers et al., 2005. The other values (Background error and Obs error) are those used in the assimilation. The statistics are from operational forecasts, where the model background will be up to a 12 hour forecast.

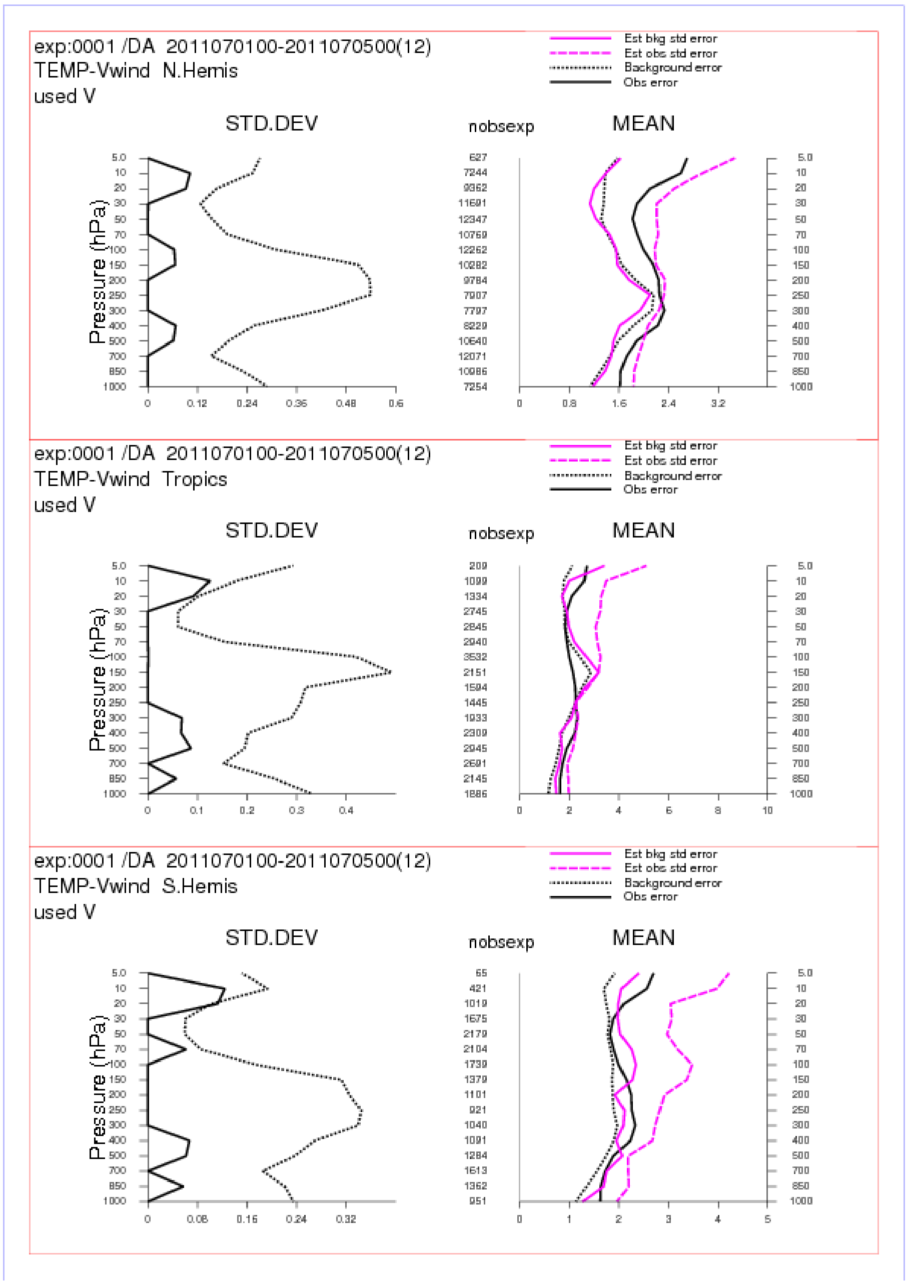
The reader should focus on the right-hand plots, under the title MEAN; this gives the mean values of estimated (magenta) and used (black) background or observation error (the left plot shows the standard deviation of the used background or observation error).

In the extratropics the background errors (both used and estimated) are typically 1-1.5 m/s for both wind components. In the tropics they are larger than in the extratropics by about 0.5 m/s. The fact that the 'used' errors do not always agree with the estimated errors suggests some further tuning may be necessary, especially in the southern hemisphere. Radiosonde obs error is typically larger than background error in the extratropics (note this will include representivity error), whereas in the tropics they are more similar.

Note it is unclear to which source, observation error or background error, the representivity error is partitioned. It will depend on the correlation length scales of each possible error term.



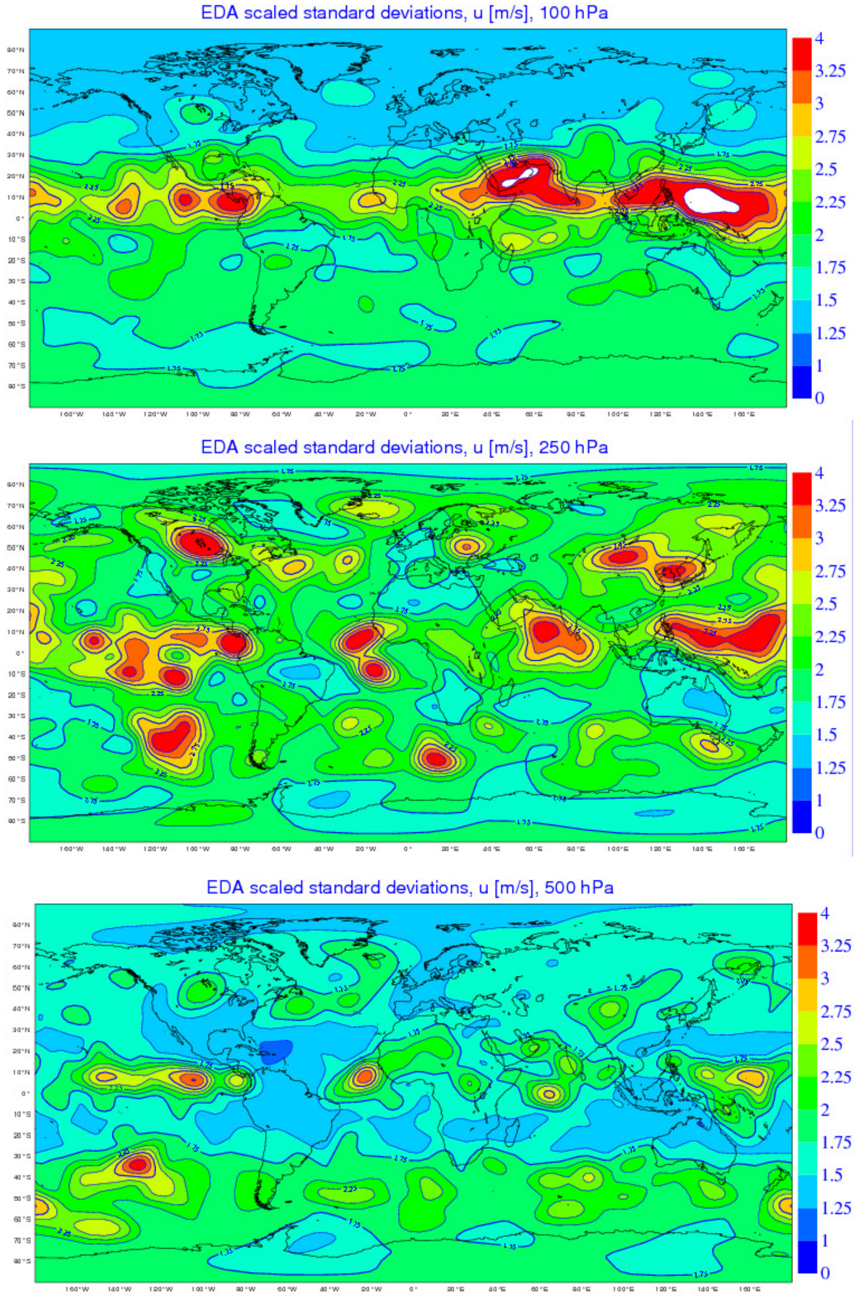
ECMWF statistics of background error and observation error derived from radiosonde departures for the u component of wind (zonal), x-axis units are m/s.



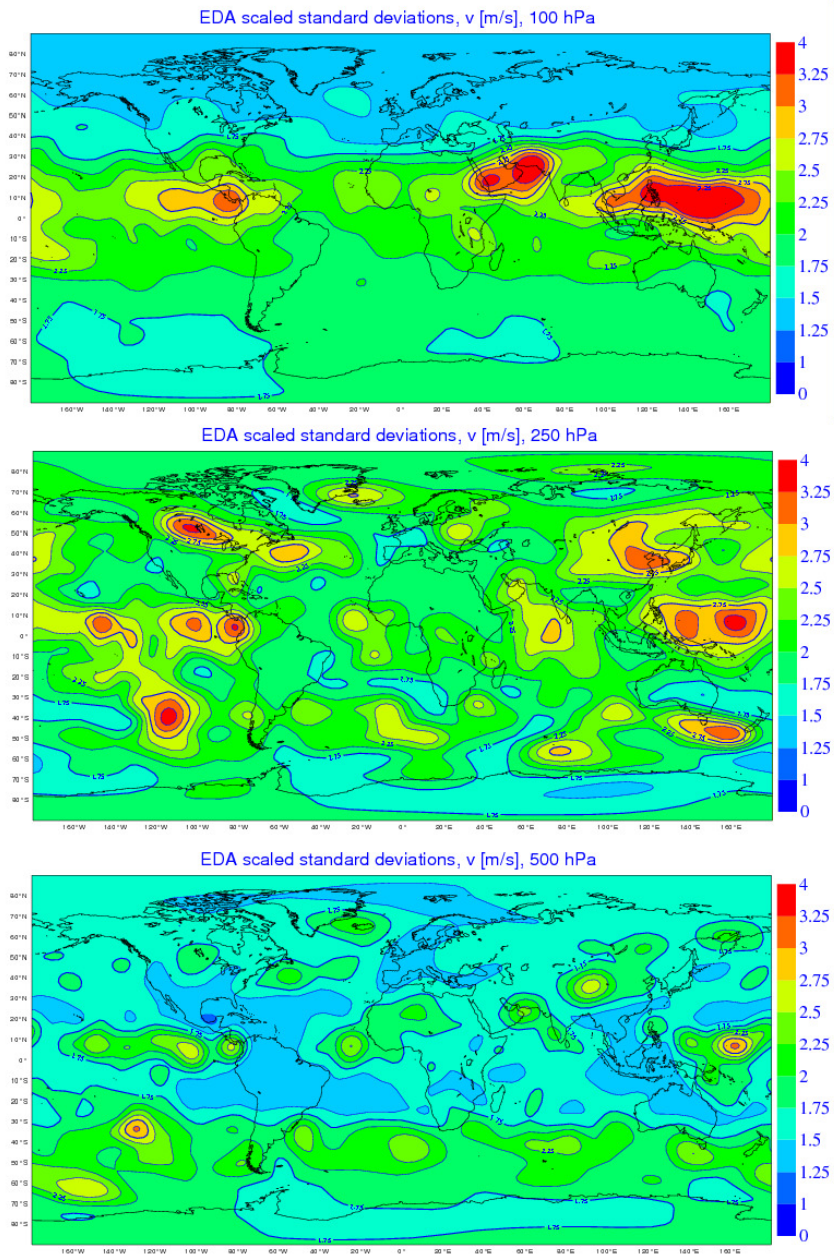
ECMWF statistics of background error and observation error derived from radiosonde departures for the v component of wind (meridional), x-axis units are m/s.

Systematic errors for wind components are generally less than 0.5 m/s, which is inferred from mean O-B statistics against radiosondes (plot not shown). Of course the forecasts could be biased towards the radiosondes (truth is unavailable).

The next two figures show results from the ensemble of 4D-Var data assimilations (EDA) method (Isaksen et al, 2010). The maps show scaled EDA standard deviations for the u and v components of horizontal wind for one cycle on 26 July 2011. These scaled standard deviations have been used operationally in the background error variance since CY37R2 went operational (18th May 2011) to provide an extra flow-dependent aspect to the ***B****-matrix — note only the balanced part of the* *variance (vorticity) is modified at present. The estimated random component of the background errors are mostly in the range 1-2 m/s, although there are many patches over 4 m/s, especially at higher altitudes in the tropics and at the polar jet stream level were the dynamics is particularly sensitive. Note this method can often underestimate variance, e.g. in areas which lack observations to be perturbed to generate the variance amongst ensemble members.*



ECMWF EDA scaled standard deviations for the u component at 100, 250 and 500 hPa (~17, 10 and 5 km)

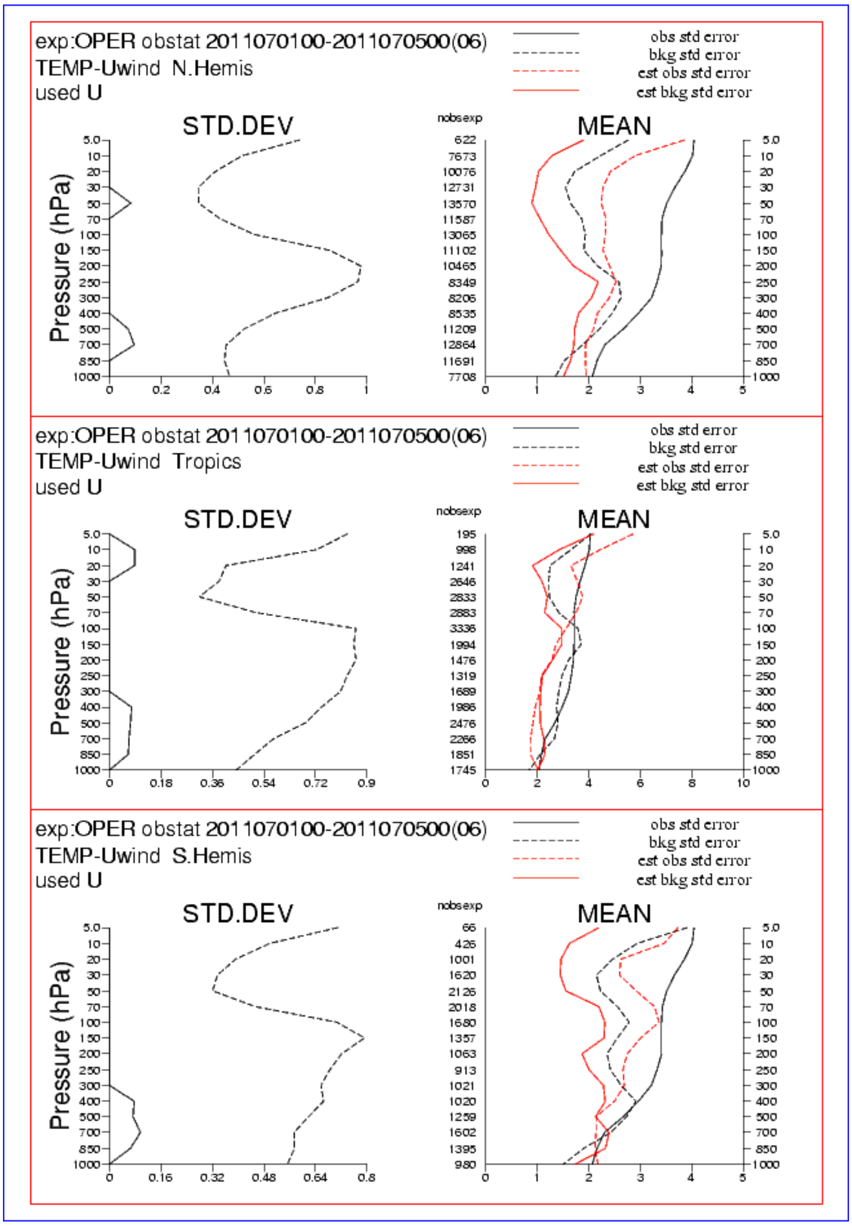


ECMWF EDA scaled standard deviations for the v component at 100, 250 and 500 hPa (~17, 10 and 5 km)

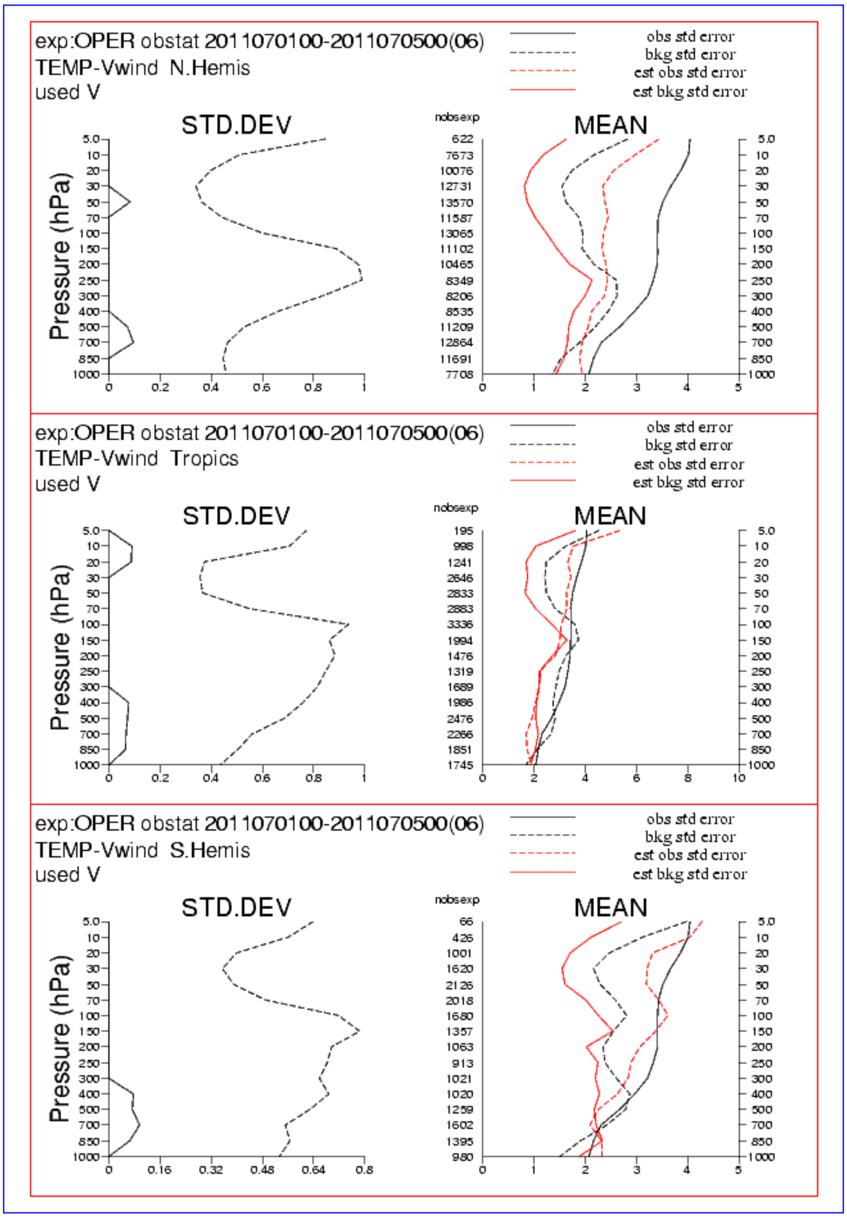
In conclusion, ECMWF background forecast wind components have random errors of typically 1-2 m/s (but increasing to 4 m/s in sensitive areas/times) and systematic errors of less than 0.5 m/s. Note the use of radiosondes provides estimates from well observed areas, so the background errors should be smaller than over poorly observed areas. Note the Met Office's answer stated that their model errors are similar to ECMWF's.

Météo-France's answer:

Mean error between 0 and -0.5 m/s. The following plots show the same type of statistics as shown from ECMWF, i.e. estimates of the background error (est bkg std error) and observation error (est obs std error) using radiosondes, based on the Desroziers method. Typically standard errors of the background of 1-2 m/s for both wind components are seen, a bit larger than ECMWF's in the extratropics.



Météo-France statistics of background error and observation error derived from radiosonde departures for the u component of wind (zonal), x-axis units are m/s.



Météo-France statistics of background error and observation error derived from radiosonde departures for the v component of wind (meridional), x-axis units are m/s.

HydroMetCentre's (Russia) answer:

Random rms errors:

At 1000 hPa: 2 m/s

At 300 hPa: 3 m/s

At 20 hPa: 4 m/s

At 5 hPa: 6 m/s

Systematic errors are not accounted for.

3.2.2 Answers to Q2

Q2. What do you estimate as the horizontal resolution of your forecast model horizontal wind fields? *i.e. at what horizontal scale does the model start to represent horizontal winds accurately, e.g. 6-8 times model grid-spacing, 2/3 the spectral truncation number. Perhaps you have model kinetic energy spectra; at what scale does the energy spectra begin to lose energy relative to observed/theoretical spectra? See e.g. Skamarock, William C., 2004: Evaluating Mesoscale NWP Models Using Kinetic Energy Spectra. Mon. Wea. Rev., 132, 3019–3032*

DWD's answer:

We have computed monthly average global model energy spectra for different model layers and different forecast ranges and find, that on average the model starts to represent horizontal wind fields at 150 km which is 5 times the model resolution of 30 km.

Given DWD's model resolution is expected to be 20 km by 2014-15 then their effective resolution is expected to be ~100 km in time for Aeolus.

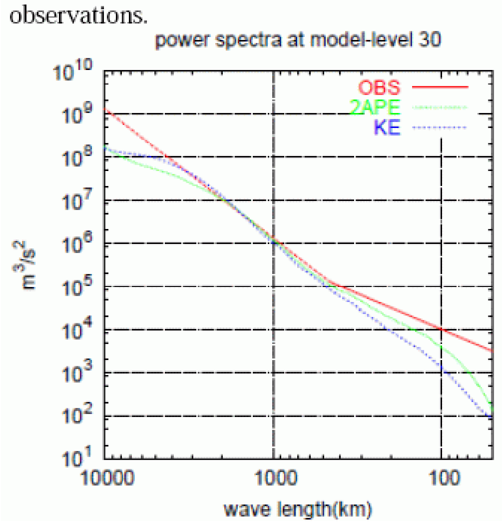
CMC/Env. Canada's answer:

In the next GDPS version (25 km resolution), the kinetic energy spectra at 250 hPa begins to lose energy relative to the theoretical spectra (i.e. k^{-3}) at wave number 400, which is around 7Δx. Therefore, the 'effective' horizontal resolution for winds is around 150 km at the jet level.

Note that given they do not judge the drop-off in energy relative to the $k^{-5/3}$ power law, there is some uncertainty over this estimate.

JMA's answer:

It might be in 120~300km range.
The following figure shows a power spectrum distribution (Tamiya 2009, in Japanese). The power spectrum was derived from the 216 hours forecast with GSM TL959L60 at about 230hPa. KE means kinetic energy, APE means available potential energy, and OBS means the approximate estimate of the observations.



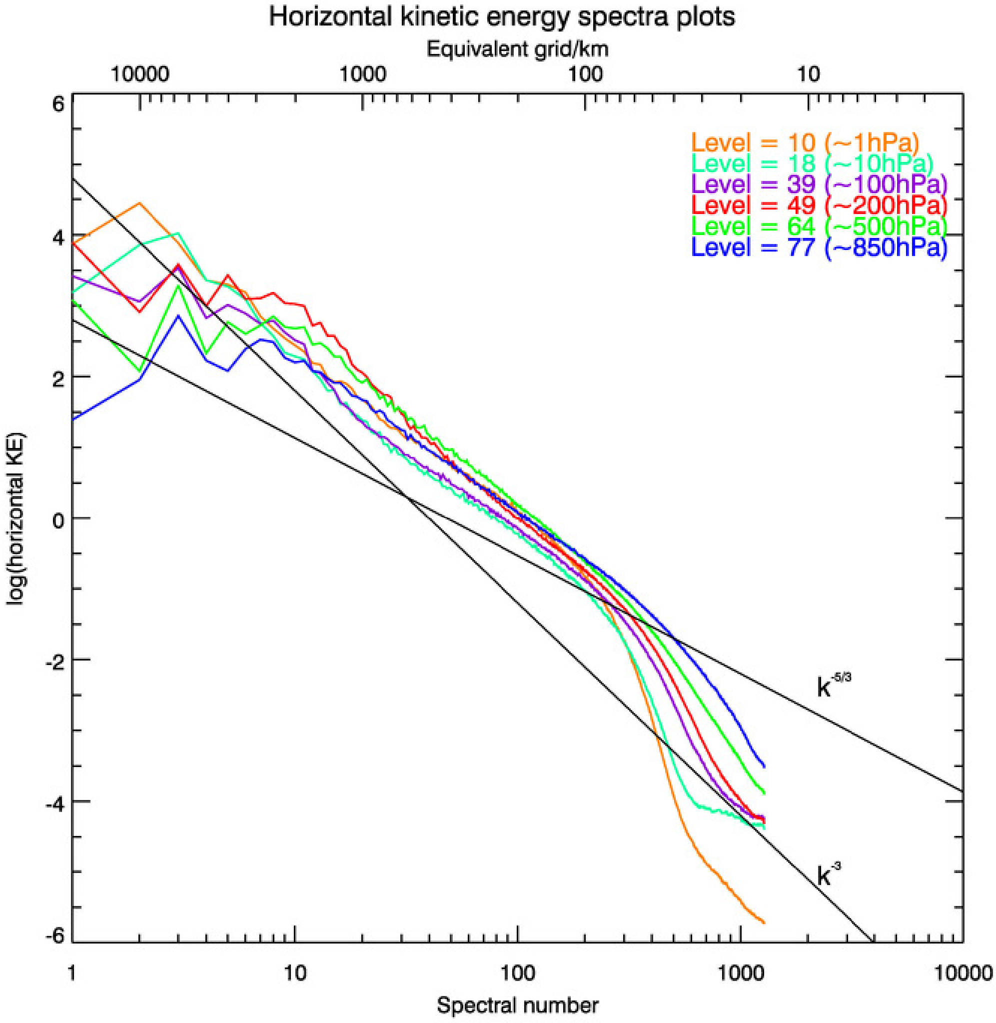
NCEP's answer:

For regional 8-10 times model grid-spacing (Norm Phillips' rule of thumb). KE Spectra not evaluated routinely for the global model. 1 km runs follow -5/3 power law.

Météo-France's answer:
AROME effective resolution around 15 km (6 times 2.5 km). ARPEGE effective resolution around 60 km (6 times 10 km) over Europe.

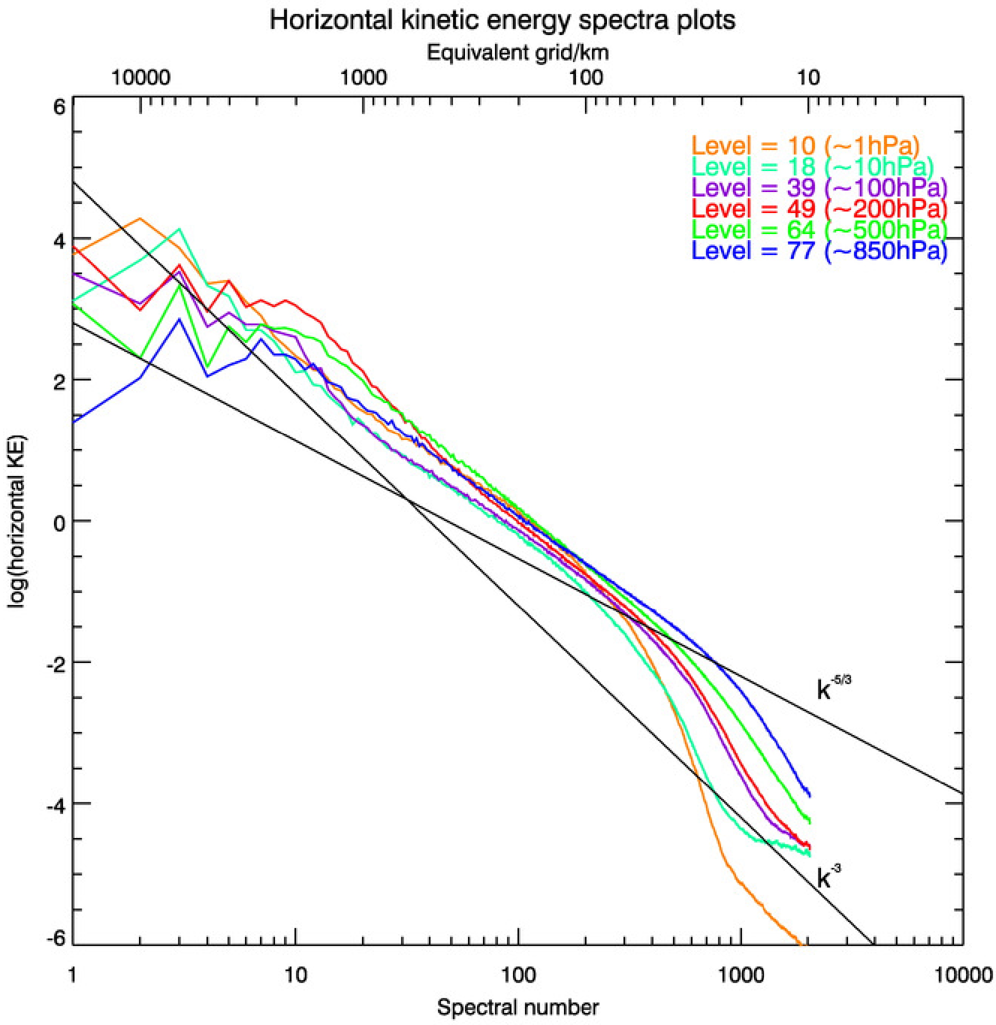
ECMWF's answer:

To estimate the effective resolution of the model, horizontal kinetic energy spectra are examined. The following plot shows spectra at various vertical levels from the operational ECMWF global model (CY37R2, 2011). This is calculated as the sum of the divergent and rotational kinetic energy for each wavenumber for the whole globe, as derived from the spectral representation of divergence and vorticity of the horizontal wind field; the method is explained in Lambert (1984). The plot is an average of 12 hour forecasts, one day per month, for the period January to July 2011, at a resolution of T1279 (~16 km grid-spacing). The energy spectra start to lose energy significantly relative to the $k^{-5/3}$ power-law (expected at mesoscales) at around T200 i.e. ~100 km. Note this is around 6 times the equivalent grid-spacing. The drop-off in energy is larger for higher levels, especially higher than 10 hPa (~30 km altitude), which is approximately the upper range for Aeolus data. Note the transition to the $k^{-5/3}$ power-law is mostly due to the divergent part of the kinetic energy (plot not shown). Note these esimates focus on the gradient of the energy spectra, rather than the absolute scale of the energy.



Horizontal kinetic energy power spectrum from the operational T1279 (~16 km) at various model levels

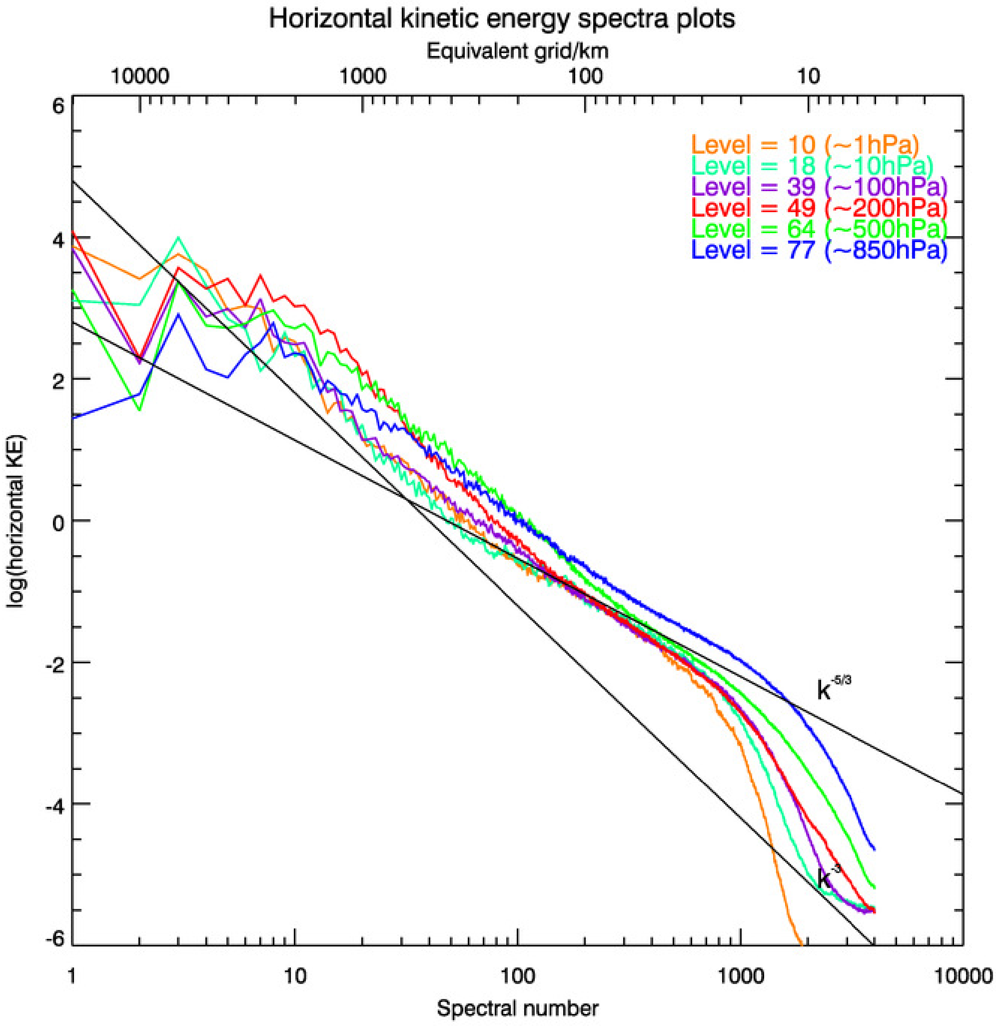
The next plot shows horizontal kinetic energy spectra for a horizontal resolution that is expected to be operational for 2014-15, T2047 (~10 km). This is an average of spectra from 12 hour forecasts, one day per month, for February to October 2009. The spectra are improved relative to the T1279 plot, tending to lose energy significantly at ~T300 (~60-80 km), which is 6-8 times the equivalent grid-spacing.



Horizontal kinetic energy power spectrum for T2047 (~10 km) at various model levels.

Finally the next plot shows horizontal kinetic energy spectra of a very high resolution version of the IFS (experimental), T3999 (~5 km), at various model levels for one 12 hour forecast (only one available, hence noisier than previous results). The spectra appear to capture the $k^{-5/3}$ power-law better than T1279 and T2047 can, but with the transition at perhaps the incorrect resolution. There is a significant loss of energy at around T1000-500 (~20-40 km), which is 4-8 times the equivalent grid-spacing.

For the estimates of an effective model resolution there is clearly some uncertainty. At higher levels the T1279 and T2047 do have a transition at around 500 km from k^{-3} power-law to a less-steep gradient, but the transition is not to a perfect $k^{-5/3}$ power-law, the gradient is somewhere between the two. Note the effective resolution estimates quoted earlier are based on a significant drop in energy, by over an order of magnitude. The lower levels struggle to get the transition at all, tending to remain at an in-between gradient for the whole spectra. The $k^{-5/3}$ gradient is captured by the experimental T3999 spectra but with the transition occurring at around 100 km, which does not agree with observations.



Horizontal kinetic energy power spectrum for T3999 (~5 km) at various model levels

Small-scale energy in the model is expected to become more realistic in 2014-15, not only by increases in model resolution, but also by improvements in the numerical modelling. For example, work is currently underway which improves the model kinetic energy spectra significantly for all model resolutions, boosting the lower resolution models' energy spectra closer to the higher resolution models. This is achieved by a dealiasing procedure aimed at ensuring an alias-free simulation on the linear grid. This change is also improving forecast scores in testing. Also, work is underway to better capture the $k^{-5/3}$ *spectra observed at the smallest scales by enhancing the formulation of turbulence. There is however the issue that introducing small-scale turbulent features to the model may not always improve deterministic medium-range weather forecasting, but there are benefits to ensemble spread.*

In summary, the effective model resolution for the current operational model, in terms of kinetic energy spectra, appears to be about 100 km. This decreases to ~40 km for a state-of-the-art global model with resolution of T3999. The effective resolution expected for 2014-15 can be expected to be at least as good as the T2047 resolution run (effective resolution ~60-80km) for the reasons discussed in *the previous paragraph and also because of an increase in vertical levels from 91 to 137.*

3.2.3 Answers to Q3

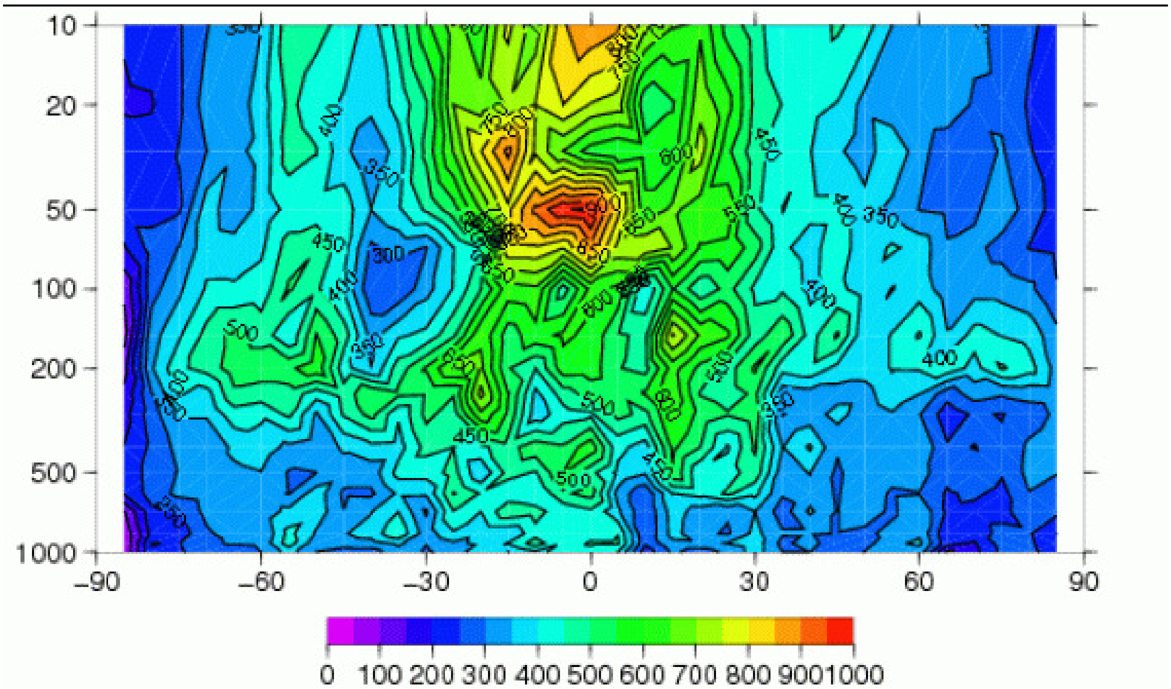
Q3. What are the typical background error correlation length-scales for horizontal wind fields? *e.g. full width at half maximum distance, perhaps split by tropics/extra-tropics, altitude.*

DWD's answer:

The background error correlation length scale is around 400 km. We do not split between tropics/extra-tropics.

JMA's answer:

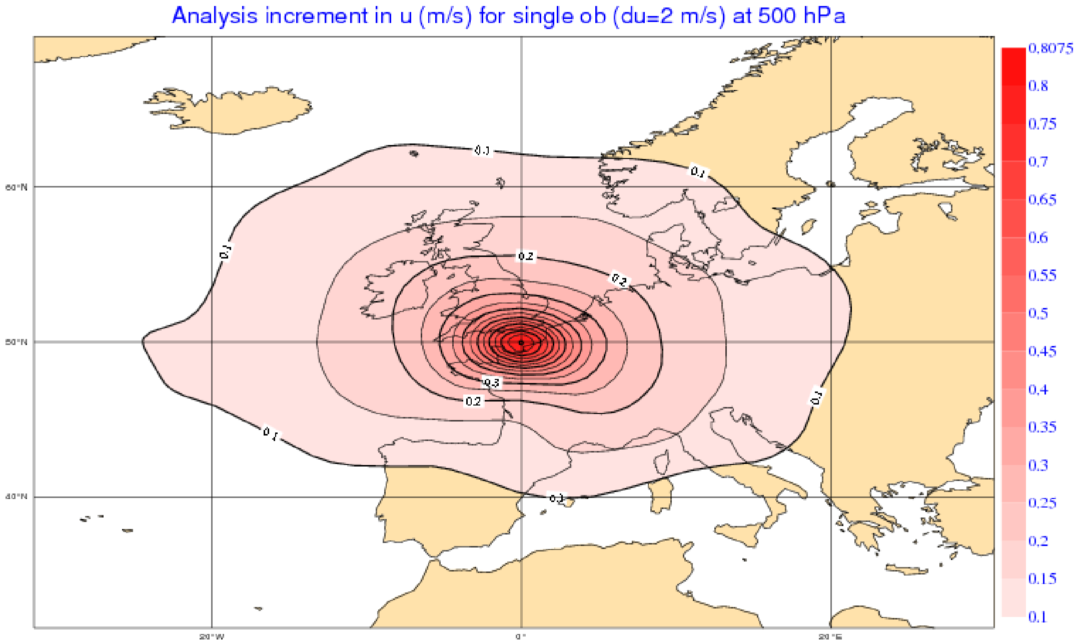
The following figure shows the estimated forecast error correlation length scales for U component. The correlation length scale in this figure is defined as the estimated length with the forecast error correlation coefficient of 0.5. The forecast error was derived from the difference of 24hours forecast and 48hours forecast at every 5 degree grid point in the latitude along 180 degree E. The study period is one month (Aug. 2010). Note that these statistics are taken not from the original resolution forecast field but the 1.25 degree grid field, so the length might be over-estimated. The scale unit is km and the contour lines are drawn every 50km.



Météo-France's answer:
For ALADIN around 20 km in the lower troposphere and 50 km in the higher troposphere. ARPEGE around 80 km in mid-latitudes at 500hPa and 150 km in the tropics at 500 hPa. These values were obtained from a wavelet filtering technique.

ECMWF's answer:

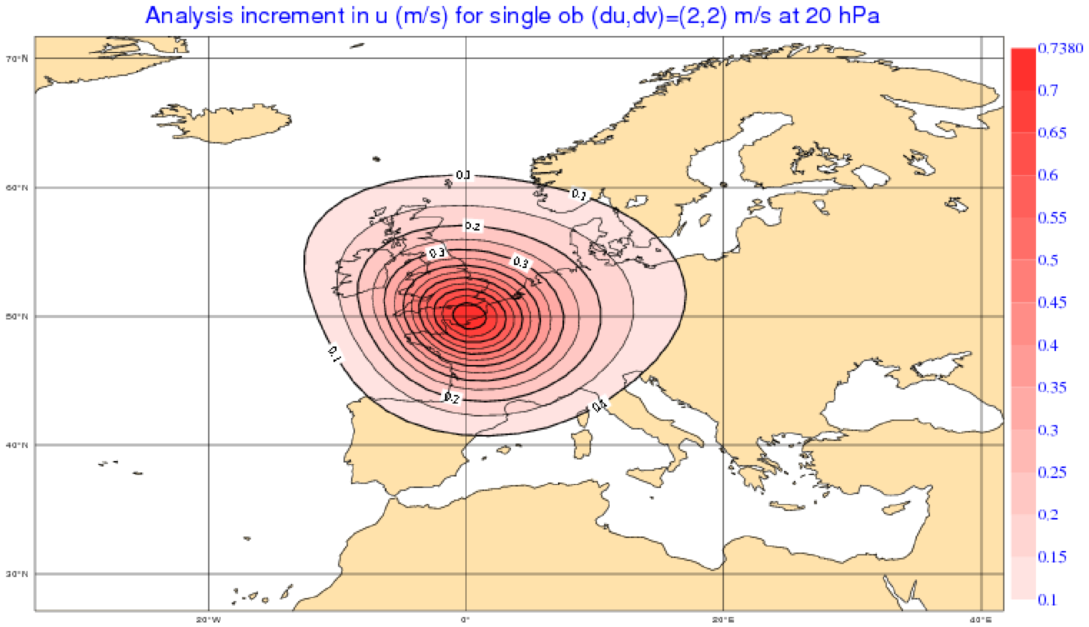
In variational data assimilation a perturbation of a given background state at a given location is accompanied by adjustments elsewhere that are in near balance (geostrophic, hydrostatic) with the perturbation as controlled by the background error covariance ***(B)*** *matrix. The correlation structure of the* ***B****-matrix can be examined by looking at the analysis increments generated from assimilating a single observation. These increments effectively show* $\boldsymbol{BH^T}$*, and with a simple observation operator (*$\boldsymbol{H}$*) this means the analysis increment is proportional to a column of* ***B****. The following figure shows the analysis increments in zonal wind (u) at 500 hPa (~5 km) when assimilating a single wind vector at 500 hPa at the start of the 4D-Var time window. The wind vector was defined to produce a departure of (du,dv)= (2,0) m/s and is located at (latitude, longitude)= (50,0) degrees. Note this is using a CY37R2 set-up (early 2011, but without the scaled variances of EDA).*



Map of analysis increments in u at 500 hPa from a single wind vector assimilated at start of 4D-Var time window (increments shown at start of time window)

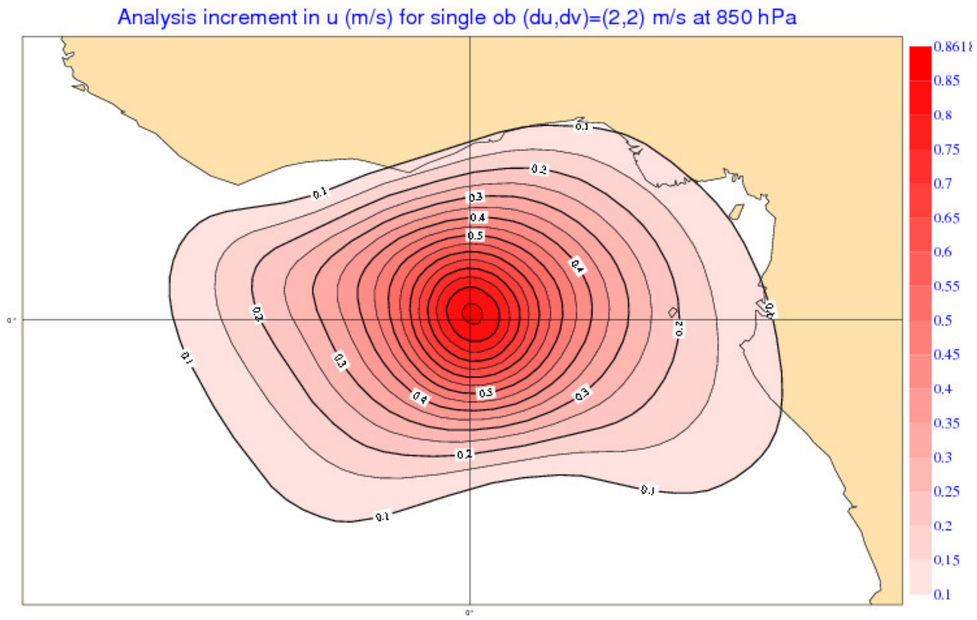
The magnitude of the increments decreases to 0.5 times the maximum value (i.e. from 0.8 to 0.4 m/s) at horizontal distances of roughly 200-300 km (distance calculated separately). This distance is typically seen for single wind vectors at a variety of latitudes and heights. The inhomogeneity i.e. elongation of the increment is due to the background error variance varying horizontally (by a randomisation technique, this was prior to EDA scaled variances).

The following figure is for the same set-up as the previous figure except for a departure of (du,dv)=(2,2) m/s at 20 hPa (~26 km), here the scale is more like 300-400 km.



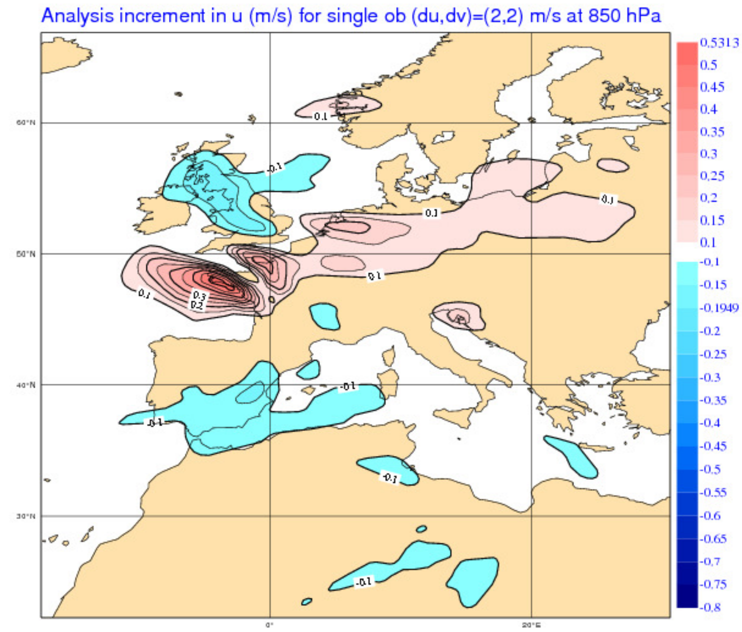
Map of analysis increments in u at 20 hPa from a single wind vector assimilation.

The horizontal scale is similar for a wind vector of departure (2,2) m/s at 850 hPa (~2 km) in the tropics at (latitude, longitude)= (0,0) degrees, see below.

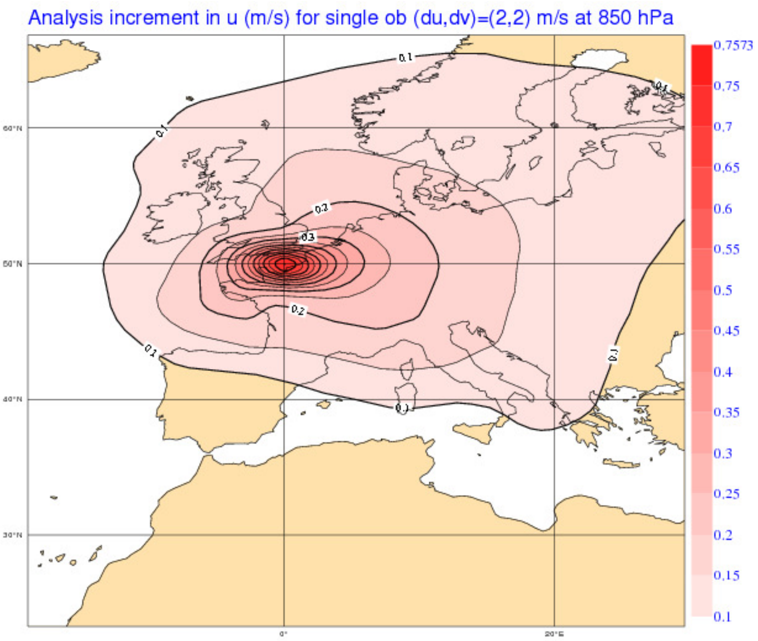


Map of analysis increments in u at 850 hPa from a single wind vector assimilation in the tropics

*Assimilating a single wind vector at the end of the 4D-Var time window leads to a much more complicated structure to the increment due to the propagation by the forecast model of the initial **B**-matrix to the time of the observation (see e.g. Bannister, 2008) i.e. some flow-dependence is* *introduced. The u increments in the plots below, with (du,dv)=(2,2) m/s at 850 hPa at the end of the assimilation window in a) and at the start in b), demonstrate this effect.*



a)



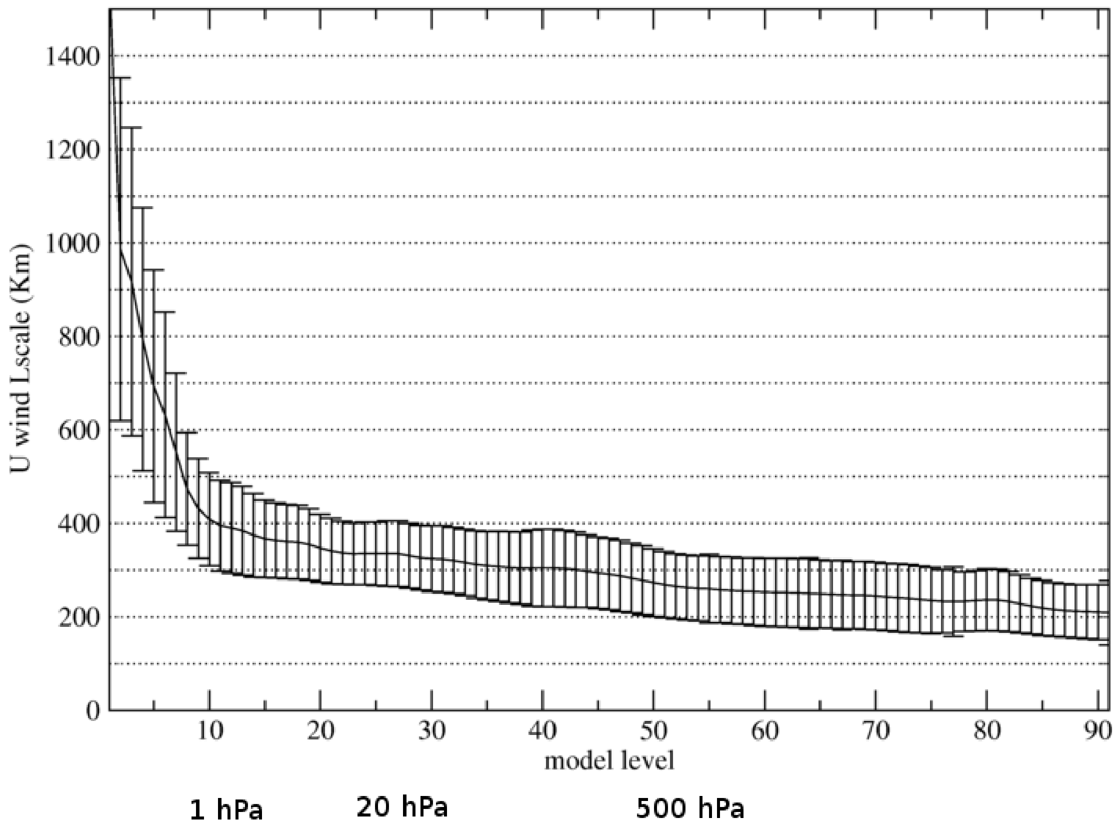
b)

Map of analysis increments in u at 850 hPa from a single wind vector assimilated at a) the end of the 4D-Var window (plot valid at end of time window) b) start of the time window (plot valid at start of time window)

Note the ***B****-matrix responsible for the above increments is an approximation to the true one. This is necessary because the true atmospheric state is never known and also the size of* ***B*** *is prohibitive (~10^{16} elements), therefore methods to avoid explicitly storing it have been developed — instead it is* *constructed from various assumptions of balance and spatial seperability, which are intended to capture what are believed to be the important features of the true **B**-matrix.*

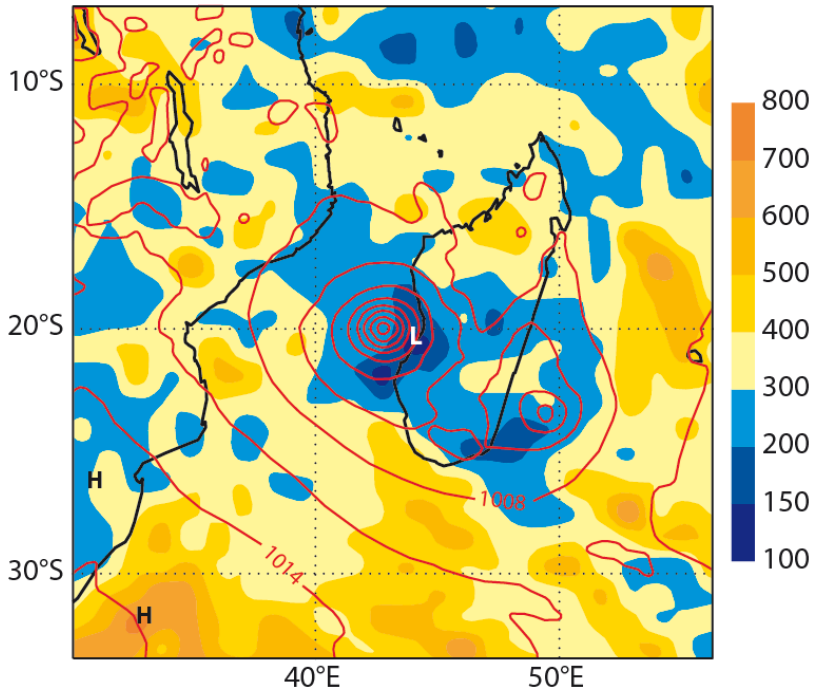
*The previous plots used a **B**-matrix that is mostly climatological, i.e. based on 40-day averages of statistics from ensemble data assimilation (EDA) differences. However there is some flow dependence via the use of non-static variances and also by the non-linear balance operator and omega equation (however switching these operators off made little difference to these particular examples).*

The following plot shows the globally averaged background error zonal wind length-scale, as calculated using the BPB method of Pannekoucke et. al. 2008, from several days of EDA differences. The typical length-scales of 200-400 km agree well with the single ob experiment values quoted previously.



Zonal wind background error horizontal length-scale as a function of ECMWF model level (approximate pressures shown). The error bars are standard deviation.

In the next few years, full background error covariances of-the-day (not just EDA scaled variances) are likely to be used in deterministic 4D-Var. To assess the potential implications of this, EDA estimates of background error correlation length are shown in the Figure below for one cycle. The correlation lengths are for the logarithm of surface pressure and are computed from a 20 member EDA. This shows that smaller correlation lengths (100-150 km) can occur near active weather systems, like the tropical cyclone seen below (see low pressure, L), west of Madagascar. This may be due to an interaction with the local orography (surface pressure length scales are strongly influenced by orography, see Pannekoucke et al 2008) — however note the small correlation length-scale wraps around the cyclone over the ocean.



Map of surface pressure correlation lengths (km, see colour bar) for an EDA ensemble for a specific cycle. The red contours show the background's surface pressure field.

As models move to higher resolution then the increase in background error-variance in the small scales (as can be extracted from EDA statistics) leads to smaller horizontal and vertical correlation scales, leading to sharper analysis increments, see Brousseau et al (2011). Therefore observing networks need to have a good spatial coverage and geographical density in order to control the behaviour of such data assimilation systems effectively. There is a positive feedback since higher density observing systems then lead to sharper background error correlations.

It is seen that most NWP centres are currently reporting correlation lengths for global models of around 200-400 km with the exception of Météo-France which have much shorter correlations of 80-150 km; a significant amount of variation in the estimates may be down to the different methods chosen to determine the values.

3.2.4 Answers to Q4

Q4. What thinning of wind observations is performed (to what horizontal/vertical distances) in your assimilation system and for what reasons?

DWD's answer:

At the moment we use radiosonde, windprofiler, pilot, aircraft. AMV and scatterometer wind observations. In the case of radiosonde/pilot observations we use the main pressure levels and the significant levels with no horizontal thinning. For aircraft we do a vertical thinning of 100 hPa and a horizontal thinning of 60 km. AMVs are thinned to every 200 km and scatterometer to 60 km.

CMC/Env.Canada's answer:

The thinning depends on data type:
AMV: 1.5° x 1.5°
ASCAT: 100km x 100km
Aircraft wind reports: 1° x 1°

Our thinning strategy is based on the horizontal resolution of the measurements, the expected observation error correlation and the resolution of the analysis increments (currently T108 in our global data assimilation system).

JMA's answer:

All geostationary winds are thinned in 2° by 2° by 100 hPa boxes for GSM and MSM. A minimum horizontal distance is 200km.
All polar winds are thinned in 1.5° by 1.5° by 100 hPa boxes for GSM. A minimum horizontal distance is 150km.
Observation errors are summarized in the following table.

Observation errors for GSM

Level (hPa)	1000	850	700	500	300	200	100	50	30	10
Error for ALL AMV (m/s)	4.5	4.5	4.5	4.5	5.3	5.8	6.8	7	7.2	7.6

Observation errors for MSM

Level (hPa)	1000	850	700	500	300	200	100	50	30	10
Error for MTSAT AMV (m/s)	3	3	3	3	3.5	3.9	4.5	4.7	4.8	5

The thinning intervals are decided under consideration the observation error correlation length.

Met Office's answer:

AMV: Geostationary thinned in 2x2 deg by 100 hPa boxes. Polar winds thinned in 200x200 km by 100 hPa boxes. AMV errors are known to be quite strongly correlated.
Scatterometer winds (including WindSat): are thinned to one observation in a 92 km box global and 46 km NAE/UK. Global will go to 80 km in July 2011.

Météo-France's answer:
One observation per 2.5°x2.5° grid box (horizontal). One observation per standard level (vertical). Avoid correlated observations.

ECMWF's answer:

Radiosonde and pilot winds are used on all reported levels.

Aircraft winds are horizontally thinned to approximately 60 km along flight tracks. Ascending and *descending aircraft are thinned in the vertical to the model resolution.*

Wind profilers are thinned to 5 hPa separation in the vertical. Data from American, European and Japanese networks are used.

AMV: All winds thinned in 200 km by 200 km by 50-175 hPa boxes. Vertical extent varying according to the nearest standard pressure level. There are 16 vertical boxes.

Scatterometer: every 4th observation, i.e. thinned to 100 km for 25 km gridded data.

HydroMet Centre's (Russia) answer:

We perform averaging to the representative scale (and even to a somewhat larger scale): currently, to 200 km in the horizontal and 50 mb in the vertical for two reasons. First, to filter out subgrid-scale components. Second, to reduce the possible influence of spatial obs-error correlations.

3.2.5 Answers to Q5

Q5. Do you assimilate dense observations that sample small-scale atmospheric features (smaller than the model can represent), and if so do they receive any special treatment? *e.g. inflation of obs errors, averaging such observations to more representative scales?*

DWD's answer:

We thin the wind data so that we don't use observations which sample smaller scales than the model represents. Therefore we do not use any special treatments.

NCEP's answer:

No. When dense observations occur we either thin the data or create super-obs depending on observation type.

CMC/Env. Canada's answer:
Not yet for satellite data.

JMA's answer:
Not explicitly

Météo-France's answer:
No.

ECMWF's answer:
Radiosondes and pilots are in situ measurements, therefore sampling very small-scale atmospheric features, this is dealt with by increasing the observation error (effectively taking into account representivity error). Although not stated this is implicitly done by other NWP centres.

HydroMet Centre's (Russia) answer:
We perform averaging to the representative scales.

3.2.6 Answers to Q6

Q6. Does your data assimilation system have the capability to use observation errors which vary per observation (sometimes referred to as 'dynamic' errors), now or in 2014-15?

All NWP centres that responded said they have the capability to use 'dynamic' observation errors, however only a few currently choose to implement them.

e.g. Met Office's answer:

For AMVs, observation errors are calculated individually for each wind using estimates of error in the vector, error in height and variation in background wind column. Scatterometer ob errors are fixed.

3.2.7 Answers to Q7

Q7. Does your system allow for the assimilation of profile observations with a varying horizontal position within the profile (rather than as a profile with fixed horizontal position) now or in 2014-15? *e.g. accounting for the horizontal drift of radiosondes, GPSRO tangent point drift.*

The answers were mostly 'yes' to having the ability to handle profile observations that have some horizontal drift, however a couple of centres cannot handle this at present (e.g. the Met Office cannot at present, but should be able to by 2014). ECWMF's system is set-up to treat each Aeolus L2B wind observation as an independent observation with its own geolocation i.e. not restricted to a profile with fixed horizontal position.

3.2.8 Answers to Q8

Q8. For data assimilation, would you prefer observations sampled at relatively small horizontal scales, say ~40 km horizontal resolution every 40 km along the orbit track, with relatively high noise or observations averaged to ~200 km, every 200 km, with lower noise and possibly reduced representiveness error (but of course this depends on your model)? *Or put more succinctly, what would be your preferred horizontal averaging scale for Aeolus DWL data in your data assimilation systems?*

NCEP's answer:

Depends on modelling system. In both global and regional, however, we would prefer to receive high resolution data and to perform the appropriate observation averaging ourselves.

CMC/Env. Canada's answer:
It is true that the optimal choice may depend on the model. In the next version of our global forecast system, wind fields will be well resolved for scales greater than 150 km or so. Therefore, DWL data every 100 km to 150 km may be a good compromise for us if the quality of the data is expected to be better at this resolution than at higher resolution.

DWD's answer:
In principle, it would be good for us to receive the ADM profiles with full resolution (vertical and horizontal), so that we can adjust the appropriate thinning strategy for our system.

JMA's answer:
We prefer to use the higher resolution data (40km) and want to make super observation by ourselves, if needed.

Met Office's answer:
Higher resolution (but noisier) data say every 40 km.

Météo-France's answer:
Preferred horizontal resolution of ~200 km for the global model ARPEGE and of ~40 km for the limited area model AROME. Since ARPEGE is a global model with a variable resolution the 60 km effective resolution is only achieved over North Atlantic, elsewhere the effective resolution is more around 150 km. Another reason is the fact that the increments are also computed at coarse resolution. Our LAM models run 3D-Var at the model resolution, therefore a higher resolution of the data is more stringent.

ECMWF's answer:
We feel that averaging over horizontal lengths of up to 1 BRC (86 km) should suffice for our data assimilation system, given the current models effective resolution of ~100 km. However we realise that if the laser energy is too low then averaging over longer scales may be required to reach adequate SNR (to avoid gross errors in processing), hence having the flexibility to choose the averaging length in the L2B processor is a useful facility. Assuming such flexibility is not too complicated to implement i.e. it should not distract from work on calibration issues which are felt to be more important to the success of the mission.

HydroMet Centre's (Russia) answer:
We prefer to have observations at the highest possible/available resolution. We are going to perform spatial/temporal averaging (super-obbing) of dense observations by ourselves according to the actual analysis resolution.

The responses were fairly mixed, several centres wish to receive data at its highest resolution (with 40 km quoted, in practice Aeolus will deliver "measurement" level data at 3 km), others feel that 100-200 km is more appropriate to their current (2011) model effective resolutions. Some specify a preference to do the averaging (super-obbing) themselves, which ideally means they should have their own implementation of the L2Bp. Whether they realise the practical implications of running such a processor is not known (note that the Met Office and DWD are aware of this). Efforts will be made to contact NWP centres regarding the final burst mode release of the L2Bp and then inform them about what needs to be done to run their own processor. *The previous statement is taken care of by the second questionnaire, see section 3.3.*

3.2.9 Answers to Q9

Q9. Do you plan to assimilate Aeolus data when it becomes available? If so, what human resources do you plan to allocate to enable its assimilation?

NCEP's answer:

Yes. Collaboration with NASA / GMAO.

DWD's answer:

Yes we plan to use the ADM observations in our data assimilation system I will work almost half of my time for ADM and we have cooperation with DLR so that they can assist us with using the data.

CMC/Env. Canada's answer:

Yes. We plan to allocate roughly 1 PY (2 people at 50%)

JMA's answer:

Yes, we have a plan. But the expected human resource may be 0.5, which means that the person will not work only for the Aeolus data but also for the other data.

Met Office's answer:

Yes. 0.5 person-years for each of 2012/13 & 2013/14.

Météo-France's answer:

Yes, human resources not yet allocated. Currently we have one person for all satellite winds with a small involvement in the preparation of Aeolus.

ECMWF's answer:

Being the meteorological processing facility for Aeolus L2B data, ECMWF will be employing 1 researcher to work full-time on it, plus operational support.

HydroMet Centre's (Russia) answer:

Yes, one full-time person, probably, for half a year.

Most larger NWP centres will be able to allocate some time to assimilating Aeolus. Given most can only allocate 1 PY or 0.5 of a person, then it is likely they would need substantial help implementing the L2Bp from the team, if they chose to do so. Help will also probably be needed even if only assimilating the L2B product as processed by another centre e.g. KNMI plan to process data on EUMETSAT's behalf.

3.3 *The second questionnaire*

ESA requested some further questioning of the NWP centres via a second questionnaire. The questions and the responses received are as follows. Note the answers may have been influence by the information provided by the "introduction to Aeolus L2B processing" document which was sent with the questionnaire (see the Appendix).

3.3.1 Answers to Q1

Q1. Do you intend to install and run the Aeolus L2B processor locally at your NWP centre with the intention of operationally assimilating the L2B product? If not, what do you intend to do?

CMC/Env. Canada's answer:
Yes, but this will also depends on the availability of the L2B product and its impact on our forecasts. Since the HLOS data from the Rayleigh channel are moderately sensitive to the background temperature (i.e. a variation of 1^o leads to a variation of 0.1 m/s in HLOS), then it would be worth assessing the difference between our own HLOS retrieval using our background field and the L2B products from the data provider. If the HLOS differences are small and the impact of both approaches on forecasts is equivalent, we will use the L2B product if the time delay for delivery of this product is acceptable for our regional prediction system (see answer to question 6) and if the L2B product is available as soon as the L1B data will be after the launch date. Otherwise, we may use the L2B processor locally after these tests.

Met Office's answer:
Yes, for evaluation and potential operational use if the NRT L2B HLOS is not available from external sources nor does not meet requirements.

DWD's answer:
At the moment, we plan to install and run the Aeolus L2B processor locally within our 3-DVAR assimilation system. Since it is recommended in a technical note by KNMI "Guide on applying L2B processed winds" that one should install both, the subroutine call version of the L2B and the stand-alone version in order to compare the output of both versions, we will additionally install also the stand-alone version of the L2B processor.

JMA's answer:
Yes, we have a plan to install and run the L2B processor locally.

CPTEC's answer:
Our preference would be to process wind data here at CPTEC-DSA (Satellite Division) using the L2B processing algorithm. The processor shall require auxiliary data from the numerical models, so this option would give us opportunity to test quality of the processed data from different input models.

Besides of providing this data for assimilation purposes, they might turn very useful as validation parameters for evaluation of our present model of estimate winds from satellite data.

HMC's answer:
Yes, we would like to run the Aeolus L2B processor at our centre with the intention of operationally assimilating the L2B product.

ECMWF's answer:
Of course, we will be running the L2B processor here in stand-alone mode.

Météo-France's answer:
Yes, we have been involved since several years in the evaluation of the portability of the Aeolus L2B processor on our Météo-France NEC HPCs.

All centres that responded want to run their own L2B processor — at least to evaluate the difference relative to some externally produced product (if one is available).

3.3.2 Answers to Q2

Q2. How do you intend to run the L2B processor: e.g. as a stand-alone processor or via subroutines calls to the L2B Fortran code from within an existing NWP code?

CMC/Env. Canada's answer:
If possible, we will install the L2B Fortran code in our data assimilation system like the RTTOV code, which is called via a few interface subroutines. This would be the easiest way for us to run the processor and provide all the inputs that this processor would need. We could however consider other strategies like the one adopted at ECMWF.

Met Office's answer:
Stand-alone on an 'upstream' compute server ('Radsat'). We envisage incoming L1B in BUFR over GTS as input (though FTP of EE files is not ruled out) and L2B BUFR as output for ingest into the operational MetDB database. By 2014, it is possible that ODB may be the interface with our NWP pre-processing system (OPS) , but it is not clear yet if data would be ingested directly into ODB or would

need to go into the MetDB (or replacement) first. For now, we need to assume BUFR as the required L2B format, whether local or external.

On balance, this seems a simpler option than ingesting the much larger L1B data into the operational database and thence NWP system; messing with operational code and dealing with the ever-changing calibration datasets which would have to me archived and managed for re-running trial periods and high maintenance of the NWP interfaces.

Should external HLOS be available and useful, this could easily replace the standalone local processing, the NWP code would not know the difference and it would not leave unused legacy code in the operational code base. Local management of the regularly updated calibration files is a problem that external data would solve also.

DWD's answer:
Since we do not have a similar COPE system as the ECMWF at the moment, we plan to run the L2B processor via subroutine calls within out 3-DVAR assimilation system.

In order to run the L2B processor we would like to get the L2B data in Bufr format instead of the EE format. We think, it is much cost effective (storage place) to distribute the L1B data in Bufr format compared to the EE Format (20 MB/orbit compared to 85 MB/orbit). Normally, we store all of the observation data we receive in out archive system and it is much more effective to store only 20 MB instead of 85 MB. Our recommendation is to run the EE2BUFR Convertor centralized somewhere and redistribute the Bufr Format to the single NWP centres.

JMA's answer:
We would like to use the L2B processor via subroutines calls from our NWP code.

CPTEC's answer:
Stand alone.

HMC's answer:
A stand-alone processor would be preferable.

Météo-France's answer:
Our strategy regarding that matter will follow closely the ECMWF one since we share the same NWP code for the assimilation. In consequence, a stand-alone processor is preferred since the interface between AEOLUS data and ODB data bases has proved to be extremely complex.

There is a mix of answers, some prefer stand alone, and some prepare integrating the processor into their current NWP code, so the team should ensure both options remain viable for users.

3.3.3 Answers to Q3

Q3. How do you intend to provide the temperature and pressure information (AUX_MET data from a short-range forecast) that is needed for the L2B processor in the Rayleigh-Brillouin correction?

CMC/Env. Canada's answer:
If the L2B code is installed in our data assimilation system, then background state, which is immediately accessible, will be used. On the other hand, if the L2B processor can only be run externally, then we will have to develop some code and scripts to provide the inputs needed to run the processor in a stand-alone manner.

Met Office's answer:
The Radsat system is being used for more upstream processing functions, and it is planned to have model background fields copied to this server for these applications. Requirements for L2B processing have been included in this planning. Interfacing between these fields and the L2BP is TBD.

DWD's answer:
The relevant temperature and pressure information are available as first guess fields within our 3-DVAR system.

JMA's answer:
We would like to use the result from our forecast model.

CPTEC's answer:
We will use our global NWP model. However, would be also desirable if ESA could provide such temperature and pressure profiles, should this data flow do not create any problem with the transmission band. This would give us additional data for validation of our outputs.

HMC's answer:
From the background fields used as a background in our data assimilation systems.

Météo-France's answer:
The creation of AUX_MET data will be produced by a background model trajectory that will feed the ODB data bases. The approach should follow the plans of the new observation pre-processing that the COPE project (developed in collaboration between ECMWF and Météo-France) will address.

All centres intend to use their own NWP background fields to generate AUX_MET input to their own L2B processor, although there is clearly uncertainty at this stage as to exactly how they will implement this.

3.3.4 Answers to Q4

Q4. What is the acceptable time delay for delivery of L1B and corresponding auxiliary data from ESA to run your own L2B processing? *where time delay=time difference between observation time and your NWP centre receiving the L1B data*

CMC/Env. Canada's answer:

This depends on the computational cost for processing the Aeolus data within the assimilation window. We will assume here that this cost is about the same as processing the equivalent amount of satellite radiances. The cut-off time for running our regional data assimilation system is around 1h30. This means that 1.5-h delay would be acceptable for the reception of L1B data. The shorter the better!

Met Office's answer:

Global: <3h & preferably nearer 2h
Regional/UK: <1h30m & preferably <1h
UK/Nowcasting <30mins

While 'delay' is usually specified from an engineering and supplier point of view, for NWP users, it is the percentage of data for the NWP cycle window (usually a nominal 6 hours) arriving before the model cut-off wall-clock time (say T+3h). A simple case of all data having a delay of 3h in the above scenario results in only 50% of the data being available in time to be assimilated.

Delay of weekly aux files is (we assume) not critical unless the calibrations have to be applied in strict sync with the L1B data and the HLOS quality is very sensitive to the wrong calibrations (in which case, all the more reason for someone else to have this matching-up job!)

To a first approximation, for most asymptotic (e.g. satellite) data, the delay is proportional to number of observations assimilated which in turn is proportional to impact. Hence the smaller the delay the larger the impact. The ultimate threshold is a delay for which no data meets the cut-off at one and 100% arrives before the cut-off at the other.

DWD's answer:

The time delay should not be more than 2 hours.

JMA's answer:

It is preferable for us to be delivered within 2h 20m after observation. That is the cut off time for our global (early) analysis system for the global forecast. The second deadline is 5h 20m. That is the cut off time for our cycle (late) analysis on 06 and 18 UTC. And the third deadline is 11h20m. That is the cut off time on 00 and 12 UTC.

CPTEC's answer:

The acceptable time delay for availability of data to assimilation process is 1 hour after terminated the window time. For instance, the data assimilation process for analysis to 00:00 UTC using window time from 9:00pm to 3:00am, the data assimilation system is started at 4:00am. Consequently, L2B *processing could have 1 hour to process the observation from this window time. Different configuration can be used in future and smaller time delay can be required, but 1 hour is acceptable today and can be adapted in the future with some changes in the window time in the assimilation.*

HMC's answer:
For the GLOBAL application: 2 hours.
For the REGIONAL application: 1 hour.
For the LOCAL application: 0.5 hour.

Météo-France's answer:
For global applications a 2h timeliness is acceptable but a 1h30 target would be better.
For regional applications the timeliness should be less than 1h.

Most centres are asking for a time delay of preferably less than 2 hours for the L1B data. The ESA System Requirements Document states that "To serve the operational weather prediction centres, the measurement data from Aeolus must be downlinked, processed and delivered in near real time (max delay 3 hours from sensing to delivery)." By measurement data, they are referring to L1B data.

3.3.5 Answers to Q5

Q5. If you do not intend to run the L2B processor locally then perhaps you would like to receive a L2B product processed externally for data assimilation? If yes, why is this your choice?

CMC/Env. Canada's answer:
As stated in the answer to question 1, we will prefer to assimilate L2B retrievals if their impact on forecasts is similar to those from our own retrievals and if the time delay for delivery of this product is acceptable for our regional prediction system. This would make the data processing for Aeolus data easier in our data assimilation systems. We are already assimilating near surface wind retrievals from ASCAT, which is a similar product provided by KNMI. We are very pleased with this product and also with the technical support from KNMI.
As for the ASCAT product, it would be nice to have retrievals at different resolutions like 100 km (for our global model) and 50 km (for our regional model). It is not obvious that higher resolution retrievals would be useful due to the significant increase in standard deviation error.

Met Office's answer:
If L2B data is produced in NRT ***which meets requirements****, then we would use that instead of local in-house processing.*

If such an external product did not meet requirement (not timely, inappropriate averaging, poor R-B correction…) then we would continue with local processing (assuming that ***did*** *meet requirement).*

3.3.6 Answers to Q6

Q6. What is the acceptable time delay for delivery of L2B data from an external source for your data assimilation system(s)? *where time delay=time difference between observation time and your NWP centre receiving the L2B data*

CMC/Env. Canada's answer:
The cut-off time for running our regional data assimilation system is around 1h30. This means that 1.5-h delay would be acceptable for the reception of L2B products. The shorter the better!

Met Office's answer:
Global: <3h & preferable nearer 2h.
Regional/UK: <1h30m & preferably <1h
UK/Nowcasting <30mins
A small additional delay (<15 minutes for Global) over L1B data is acceptable depending on how critical the cut-off limits restrict the L2B wrt L1B. Same issues as noted for L1B data delay.

Note, the L2B product will be further delayed (timing unclear at present) relative to the promised delivery time of L1B products by ESA, as highlighted in Q4.

3.3.7 Answers to Q7

Q7. What do you think would be the most appropriate averaging length (horizontal scale) of the measurement level data to produce HLOS winds suitable for your data assimilation system(s) in the 2014-15 timeframe? *Detailed answers are welcome.*

CMC/Env. Canada's answer:
According the answer we provide in question 8 of your first Aeolus questionnaire, a resolution between 100 km and 150 km would be acceptable for our global NWP system that will be run in the 2014-15 timeframe. According to the Table 1 of this questionnaire, 100 km seems to be an optimal choice for the coming global NWP model. In the 2014-15 timeframe, we plan to run our regional model at 2.5 km horizontal resolution. Although the random error increases significantly with the horizontal resolution, an averaging length of 50 km for the regional model may be more appropriate.

Met Office's answer:
In 2014/15 we can expect the Global model grid to be around 12-16km (assimilation grid twice that). Assuming a rough estimate of true model resolution/representivity of 4-5 grid lengths suggests an averaging of 50-100km

DWD's answer:

Investigations of the energy spectra of our global model suggests, that atmospheric structures between 100 and 140 km can be resolved by out model. Therefore we think that an appropriate averaging length of approximately 100 km would be suitable. If possible, the ratio between swath wide and averaging length should be in whole-numbers.

JMA's answer:

Since I think we will continue using the current inner model (TL319) for our global 4D-Var data assimilation system in the 2014-15 timeframe, we hope the averaging length will be about 60km.
I think the longer averaged data is not preferable because we can make the longer averaged data by using shorter averaged data, but the reverse processing is impossible.

CPTEC's answer:

In principle, it would be necessary to know the spatial resolution of CPTEC's Model that would be expected to use the wind LIDAR wind profiles in 2015. This question not has easy answer today, because we have intention of using ensemble process in the CPTEC's data assimilation system, which require high computational power for high resolution products. Nowadays, the horizontal scale used in the data assimilation process is 40km.

The data assimilation process could apply the thinning process in the data from produce HLOS selecting more appropriated spatial resolution. Some investigations will be necessary to determine which the horizontal scale more suitable.

We think that it should be better to receive the finest scale once that this widens the range of data use beyond assimilation. It would be possible do go from a finer scale to a lower one, but to go opposite would not be valid.

HMC's answer:

The GLOBAL application: 50-75 km.
The REGIONAL application: 10-20 km.
The LOCAL application: 3-7 km.

In indicating these numbers I suppose that there is no error correlation in the Aeolus data. If the error correlation will be, in fact, present, then the averaging length should be increased.

Météo-France's answer:

A short averaging length (~50 km) is certainly preferable since the model resolutions will increase by the time the observations become available. Having the highest resolution would allow to develop "in-house" averaging procedures. The impact of other averaging lengths could be evaluated if this option is made available with the L2B processor.

Users gave a similar response to the first questionnaire; they would like to choose their own averaging lengths based on their various models resolutions. However, typically for global model usage, averaging lengths of 50-100 km are likely to be chosen.

4 Conclusions

The information on NWP systems gathered for this report shows a continuing trend towards the use of higher resolution forecast models. Future global NWP models (when Aeolus is launched) are expected to be able to represent smaller-scale wind fields better than today's models, as shown by kinetic energy spectra which better match the observed. For example, ECWMF intend to run a forecast model with an effective horizontal resolution of ~80 km by 2014-15, with a corresponding data assimilation system with inner loop grid spacing of 50 km. In 2011 global NWP systems typically have effective horizontal resolutions of ~100-200 km. It should be noted that these estimates are for the average situation, and that in certain situations much sharper horizontal changes in the wind field can occur, e.g. over one grid-point (in frontal zones), as seen within the 2011 ECMWF model (~16 km grid).

With the implementation by many centres of ensemble data assimilation (EDA) there is a clear move towards flow-dependent background error covariances rather than climatological ones. This has the potential to reduce horizontal error correlation scales (and hence reduce the horizontal spread of observation information via analysis increments) for wind background errors to scales much shorter than the climatological average in active weather systems. To exploit these higher resolution covariances (and in fact to help generate them in the first place), relatively high resolution observation data with better sampling around such active weather systems is required.

Several centres expressed a desire for Aeolus data at relatively high horizontal resolution. However a couple of centres felt 100-200 km averaged data would be more beneficial for their systems — some preferred to have access to high resolution data to do their own super-obbing. For comparison, in today's global models, ASCAT wind data is typically thinned to one observation per 60-100 km box, with the observations representing similar scales to the thinning distance. This is similar to the requested scales for Aeolus data.

Generally, regional models are increasing in resolution to be able to partially resolve the convective-scale, implying a preference for higher resolution data to try to constrain these scales. Global models that parameterise convection will clearly have no benefit from winds at the convective scale (a few kms).

We hope therefore that Aeolus can meet its mission requirements to be able to provide good quality (around 2 m/s random error) HLOS retrievals within a 100 km integration length, since anything less than this will struggle to give reasonable winds if averaged to smaller scales. Given the uncertainty as to the most appropriate averaging length, and given that the forecast models have a broad range of resolutions and aims; it seems wise to have the flexibility to allow for varying integration lengths that continuous mode makes possible.

Various NWP centre forecasts have wind component biases less than 0.5 m/s relative to radiosondes (i.e. in well observed areas), which gives the order of magnitude for the systematic errors that should be targeted for Aeolus (i.e. should aim to be better than the background forecasts). Model random errors are decreasing compared to when Aeolus was first envisaged e.g. ECMWF is estimated to have background standard errors of typically 1-2 m/s, but reaching around 4 m/s in more dynamically active and poorly observed areas. This reiterates the need for Aeolus to meet its mission requirements to ensure a large impact in NWP; however remember Aeolus is sampling many areas to which the current observing system is lacking.

It will be important to maximise Aeolus' impact in a given NWP system by optimising the horizontal resolution and thinning (if observation error correlations are present) of the observation. The accompanying ESA-contracted scientific studies i.e. the VHAMP and ECMWF's study (Impact of Aeolus CM operation on NWP), should help in answering this issue.

The responses to the second questionnaire show that most centres wish to run their own L2B processor, allowing them to refine the L2B processing settings to match their system. They expect the input L1B data products to be delivered within 1-3 hours after measurements have taken place to allow a sufficient amount of data to be assimilated. A couple of centres suggested that if an externally processed L2B product can be shown to be as good as processing their own, they would be happy to switch to using the externally processed product.

5 Acknowledgments

I would like to thank the NWP centres for the many detailed responses received and also Lars Isaksen, David Tan, Nils Wedi and Gabor Radnoti for assistance in providing the ECMWF answers. Thanks also to ESA, KNMI and Météo-France for their feedback and suggestions. I am grateful to the WGNE for providing an up-to-date spreadsheet with details on current and future NWP model information.

6 Appendix

A blank copy of the two questionnaires used to obtain information from NWP centres is provided as follows:

6.1 Questionnaire 1, sent 9/6/2011

Purpose of the questionnaire

The Atmospheric Dynamics Mission (ADM-Aeolus) is the second of the European Space Agency's (ESA) Earth Explorer core missions. Its objective is to provide high-quality wind profiles from the surface up to 20-30 km, using a Doppler wind lidar (DWL) instrument in a polar orbit. The wind information will be the horizontal line-of-sight component only, perpendicular to the satellite track. The mission has a projected lifetime of three years and is currently planned to be launched November 2013.

ECMWF is leading the project to develop ADM-Aeolus data processing software up to Level 2B and 2C, that is, wind retrieval and assimilation of Aeolus winds. The L2B wind retrieval algorithms are developed in collaboration with KNMI, Météo-France, DLR and LMD/IPSL. For further information on the mission and the L2B/C processing see *Tan, D. G. H., et. al. (2008), The ADM-Aeolus wind retrieval algorithms. Tellus A, 60: 191–205*.

Recently it was decided by ESA to change the operation of the ADM-Aeolus from burst mode to continuous mode to aid the stability of the instrument. This means the laser is firing pulses continuously, rather than being switched off for regular intervals, as was intended with burst mode. Given the power constraints of the instrument, continuous mode effectively means the observations will have a lower Signal to Noise Ratio over a given scene (of say 50 km horizontally) compared to the burst mode operation, but there will be no gaps in the coverage along the orbit track, so there is an overall increase in the energy delivered to the atmosphere.

To optimise the usage of continuous mode data, the processing options for the L2B processor require re-evaluation. By completing this questionnaire you have the opportunity to influence the choices we shall make for the processing. In particular you can influence the horizontal and vertical sampling strategies, which will be chosen with the aim of maximising Aeolus' impact in NWP. We will take into account the expected implementation of your NWP systems for the 2014-15 period.

Please provide responses to: Michael P. Rennie
Data Assimilation Section
ECMWF, Shinfield Park, Reading, RG2 9AX, UK
Email: Michael.Rennie@ecmwf.int
Phone: +44 118 949 9417
Fax: +44 118 986 9450

The questionnaire

Name of organisation:

Internet reference for organisation:

Name and affiliation:

Title and full name:	
Position within organisation:	
Address:	
Email address:	

Section I

Please summarise your organisation's operational forecast model(s) and data assimilation method(s). We would like to know what is currently implemented (in 2011, middle columns) and what is expected to be in 2014-15 (right columns). We appreciate that providing definitive information for 2014-15 is impossible, nevertheless estimates are still desirable if possible.

For any boxes/questions to which an appropriate value/answer cannot be given, please write N/A (not applicable). Please limit your answers to systems that will potentially assimilate Aeolus Doppler wind lidar wind-component observations.

1. Operational global NWP system(s):

1a. Deterministic forecast system: yes ☐ no ☐
If no, move to subsection 1b

Forecast model:

	Present-day	**2014-15**
System name:		
Horizontal grid (*preferably spectral truncation or number of grid points, followed by approximate grid-spacing in km*):		
Number of vertical levels:		
Model top (*in km or hPa*):		
Forecast range in days:		
Computer system: (*name of super-computing system and operating system e.g. IBM AIX*)		

Data assimilation:

	Present-day	**2014-15**
Method:		
Horizontal grid:		

1b. Ensemble data assimilation system: yes ☐ no ☐

Forecast model (used for each ensemble member):

	Present-day	**2014-15**
System name:		
Horizontal grid:		
Number of vertical levels:		
Model top:		
Forecast range in days:		
Number of ensemble members:		

Data assimilation:

	Present-day	**2014-15**
Method:		
Horizontal resolution:		

2. Operational limited area NWP system(s)

2a. Deterministic system: yes ☐ no ☐

Forecast model:

	Present-day	**2014-15**
System name:		
Domain:		
Horizontal resolution:		
Number of vertical levels:		
Model top:		
Forecast range in days:		

Data assimilation:

	Present-day	**2014-15**
Method:		
Horizontal grid:		

2b. Ensemble data assimilation system: yes ☐ no ☐

Forecast model (used for each ensemble member):

	Present-day	**2014-15**
System name:		

Domain:		
Horizontal grid:		
Number of vertical levels:		
Model top:		
Forecast range in days:		
Number of ensemble members:		

Data assimilation:

	Present-day	**2014-15**
Method:		
Horizontal resolution:		

Section II

We would like to collate information about your organisation's data assimilation (DA) methods. The answers will aid our decisions regarding Aeolus Doppler wind lidar observation processing strategies (e.g. resolution and quality), to maximise its impact in NWP. Please relate your answers to models which will potentially assimilate Aeolus DWL observations.

1. What are the estimated short-range (6-12 hours) errors, both systematic and random, in the horizontal wind fields of your NWP model(s)? *As a function of height if possible.*

2. What do you estimate as the horizontal resolution of your forecast model horizontal wind fields? *i.e. at what horizontal scale does the model start to represent horizontal winds accurately, e.g. 6-8 times model grid-spacing, 2/3 the spectral truncation number. Perhaps you have model kinetic energy spectra; at what scale does the energy spectra begin to lose energy relative to observed/theoretical spectra? See e.g. Skamarock, William C., 2004: Evaluating Mesoscale NWP Models Using Kinetic Energy Spectra. Mon. Wea. Rev., 132, 3019–3032*

3. What are the typical background error correlation length-scales for horizontal wind fields? *e.g. full width at half maximum distance, perhaps split by tropics/extra-tropics, altitude.*

4. What thinning of wind observations is performed (to what horizontal/vertical distances) in your assimilation system and for what reasons?

5. Do you assimilate dense observations that sample small-scale atmospheric features (smaller than the model can represent), and if so do they receive any special treatment? *e.g. inflation of obs errors, averaging such observations to more representative scales?*

6. Does your data assimilation system have the capability to use observation errors which vary per observation (sometimes referred to as 'dynamic' errors), now or in 2014-15?

7. Does your system allow for the assimilation of profile observations with a varying horizontal position within the profile (rather than as a profile with fixed horizontal position) now or in 2014-15? *e.g. accounting for the horizontal drift of radiosondes, GPSRO tangent point drift.*

8. For data assimilation, would you prefer observations sampled relatively small horizontal scales, say ~40 km horizontal resolution every 40 km along the orbit track, with relatively high noise or observations averaged to ~200 km, every 200 km, with lower noise and possibly reduced representiveness error (but of course this depends on your model)? *Or put more succinctly, what would be your preferred horizontal averaging scale for Aeolus DWL data in your data assimilation systems?*

9. Do you plan to assimilate Aeolus data when it becomes available? If so, what human resources do you plan to allocate to enable its assimilation?

6.2 Second questionnaire, sent 3/5/2012

Overview of Aeolus and the L2B processing and new questions for the 'Target Assimilation Systems' report

Firstly, thank you for your responses to the first questionnaire (emailed to you in mid-2011). The responses were very useful to the Aeolus team, and provided much of the content for a first version of the "Inventory of Aeolus target assimilation systems" report. This should have been emailed to you in September 2011 (if not, I can send it to you on request). However, for some of the questions, we felt in hindsight that they may have been answered differently if we had provided you with some background on Aeolus L2B processing. This may have influenced your answers about preferences for the averaging scale of the product. A major issue we did not ask you about is whether you intend to process Aeolus from L1B measurements to L2B wind data locally, or would like to receive a L2B product from an external source (assuming one becomes available).

Therefore we now provide some background information about the L2B product followed by some extra questions for you to answer please. Of course, some of you will already know a great deal about Aeolus in which case you will already understand the options and may answer the additional questions directly.

Overview of Aeolus and the L2B processing

1. Aeolus introduction

Aeolus is an ESA Earth Explorer mission carrying a Doppler wind lidar, with a planned lifetime of 3 years. The launch date is currently set for mid-2014. It will fly in a polar orbit, sensing the atmosphere 35 degrees off-nadir below the satellite. The instrument is a UV lidar with two receivers designed to detect the Doppler frequency shift (and hence atmospheric wind) from radiation elastically scattered from particles (aerosol/water droplets) via the Mie channel, and from molecules via the Rayleigh channel. The Rayleigh channel will provide the bulk of the wind data, since it provides the best data in clear air conditions (or with low particle loading). For more detailed information see the Aeolus science report document, available at:
http://www.esa.int/esaLP/ESAES62VMOC_LPadmaeolus_0.html

Some Aeolus wind observation facts:

- Only the horizontal line-of-sight (HLOS) wind component is retrieved (as indicated in Figure 1)
- The laser pointing direction is mostly in the zonal direction at low latitudes i.e. 7 degrees from zonal at the equator, but becomes near to meridional close to poles (see Figure 2)
- Observations will be provided from the surface to ~30 km altitude, with a vertical resolution varying from 0.25 to 2 km (see Figure 1); the vertical bins are configurable in flight (8 times per orbit)
- Rayleigh channel HLOS wind requires correction for temperature and pressure effects (Rayleigh-Brillouin correction), with typical sensitivities of d(HLOS)/dT~0.1 ms^{-1}/K, d(HLOS)/dp ~ 0.003 ms^{-1} /hPa.

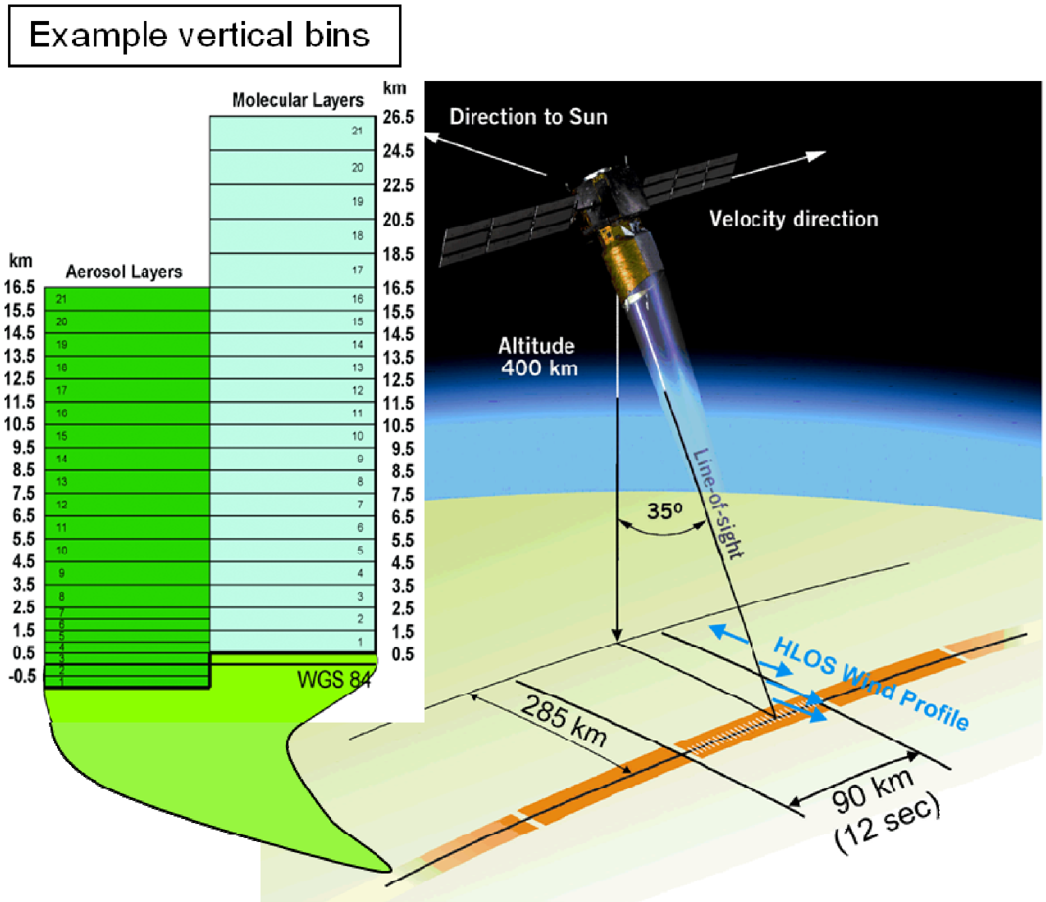


Figure 1. A schematic of the observation geometry along with example vertical sampling.

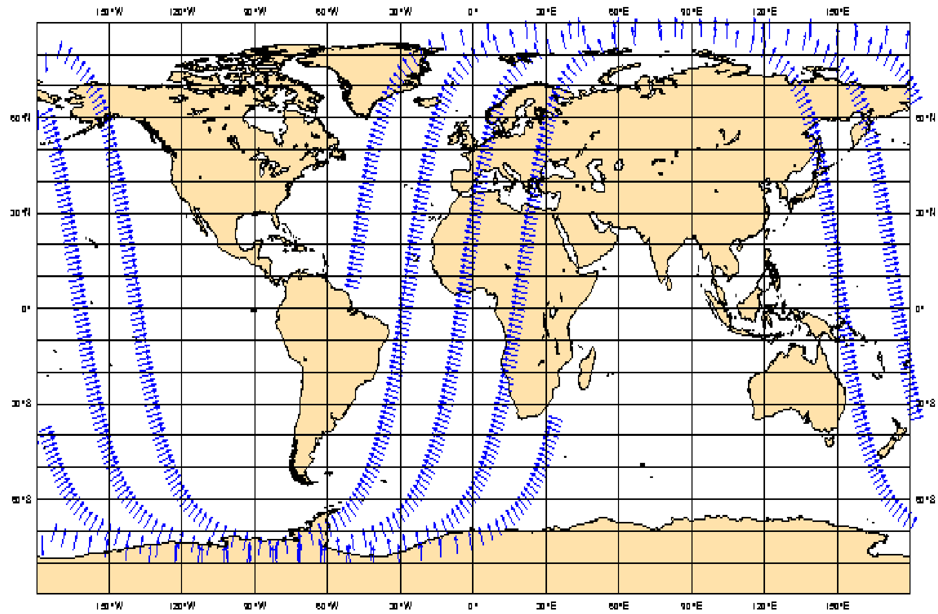
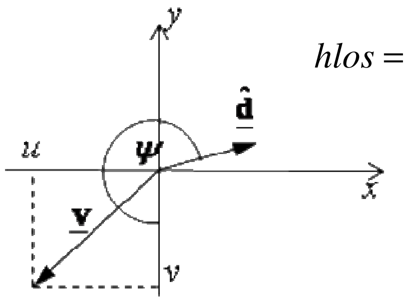


Figure 2. An example of 6 hour coverage with laser pointing direction (azimuth angle) plotted

From the data assimilation point of view, the simplest HLOS wind observation operator is to calculate the dot-product of the model wind vector $\underline{\mathbf{v}}$ and the unit-vector pointing in the laser direction $\underline{\mathbf{d}}$

(projected onto the horizontal). The azimuth angle is measured clockwise from South.



$$hlos = \underline{\mathbf{v}} \cdot \underline{\hat{\mathbf{d}}} = \begin{pmatrix} u \\ v \end{pmatrix} \cdot \begin{pmatrix} \sin(\psi - \pi) \\ \cos(\psi - \pi) \end{pmatrix} = -u \sin\psi - v \cos\psi$$

Figure 3. The simplest HLOS observation operator

Facts about the L2B processor (L2BP):

- It is being developed by the Aeolus L2B team, which includes ECMWF, KNMI and Météo-France.
- The purpose of the L2BP is to produce HLOS wind observations (L2B data) suitable for data assimilation in NWP and for scientific research.
- The inputs to the L2BP are calibrated L1B data and auxiliary meteorological data.
- The main steps in the L2BP are:
    - Scene classification of measurements into either cloudy or clear based on the scattering ratio followed by selective averaging (weighted) of those scenes, see Figure 4 and Figure 5.
    - L2B winds are referred to as “Observations” = averaging of small-scale (3km) “measurements” (from L1B data) up to a chosen scale.
    - The averaged signals (spectrometer counts) are then inverted to a HLOS wind observation, the value of which is representative of the scenes over which the averaging took place.
    - Rayleigh-Brillouin correction is applied (using *a priori* information ideally from your background forecast, this is referred as AUX_MET data)
    - Producing error estimates (derived from signal amplitudes) and data quality indicators.

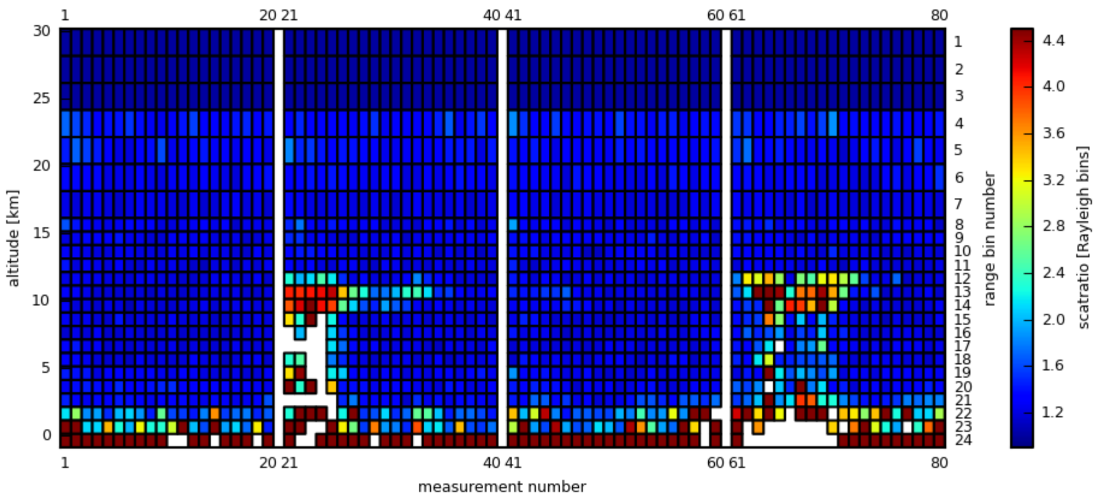


Figure 4. L1B scattering ratio, showing the measurement level data in small bins (~3km wide).

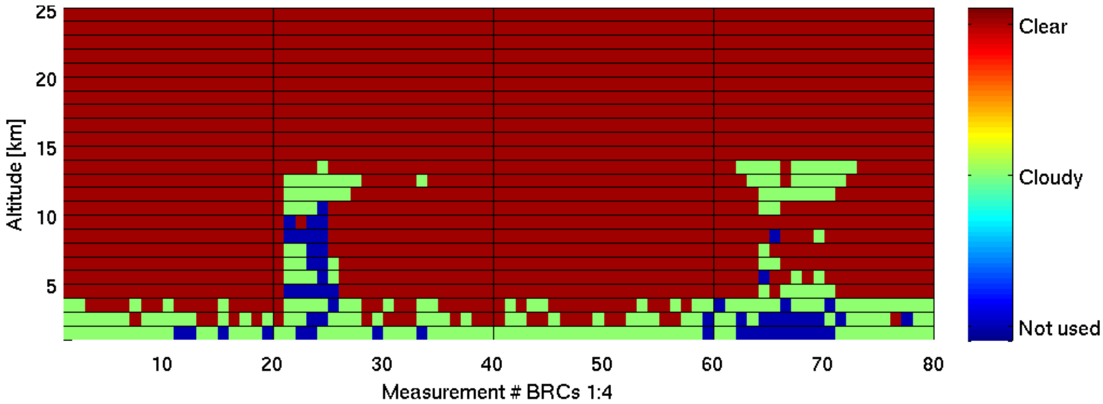


Figure 5. Example of classification of the measurement level data based on scattering ratio.

- HLOS winds are provided with associated geolocation information which is necessary for data assimilation: geometric height above geoid, latitude/longitude and azimuth angle (laser pointing direction) and time.
- The L2BP is a portable source code made freely available to the scientific community for use in three processing modes:
    - Real-time processing at NWP centres for their own data assimilation
    - Operational processing at ECMWF for product delivery to ESA
    - Re-processing at ESA for delayed data
- It is mostly written in Fortran-90, along with some C code, Python scripts and Linux csh scripts.
- It is easy to install and compiles successfully with many types of Fortran compiler.
- The algorithms are also thoroughly tested on many computer systems.
- It is easy to run the processor from the compiled executables.
- The L2B processor and documentation can now be downloaded from the ECMWF website: http://data-portal.ecmwf.int/data/t/software/aeolus However, at present only a burst-mode operation processor (which is obsolete) is available, a continuous mode operation processor will become available in around June 2012.
- The input data files (L1B data, see Table 5) will be provided in NRT from ESA to NWP centres interested in using the data (via FTP). ESA and ECMWF will not be providing L2B products in NRT, but EUMETSAT may.

2. The change to continuous mode operation

Aeolus was originally designed to operate in so-called burst mode (BM). This meant firing laser pulses over 50 km along-track, then switching the laser off for 150 km, then repeating this cycle. Due to technical problems with burst mode, the laser operation has been changed to continuous mode (CM), which means firing laser pulses all the time, but at a lower frequency (lower number of pulses sent per unit time). CM will deliver the same energy to the atmosphere as a 50 km BM burst over about twice the distance. Note that overall CM will deliver about twice as much energy to the atmosphere compared to BM, since it is firing pulses when BM would have been switched off. These concepts are illustrated in Figure 6.

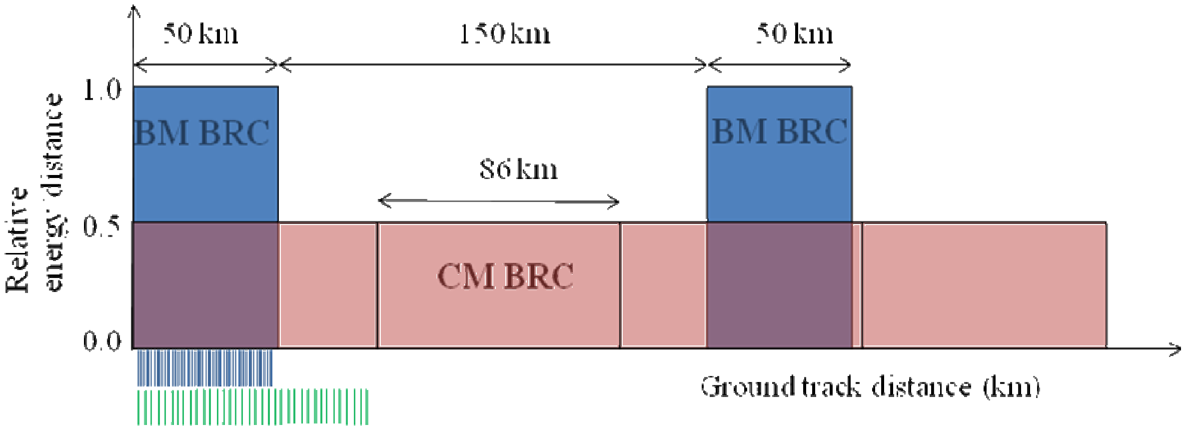


Figure 6. Comparison of continuous mode (CM) operation to burst mode (BM) operation in terms of energy delivered to the atmosphere as a function of along-track distance.

CM data is effectively a plane of measurements through the atmosphere. The averaging of measurement level data (along-track) can be done over any accumulation length assuming there are no gaps in the data or jumps in the vertical range-bin heights. Adaptations to the L2B processor to better take advantage of CM are underway - in particular averaging that is not restricted to the so-called basic repeat cycle (BRC).

3. Thoughts on averaging

The random error for the HLOS wind over 100 km averaged scene is expected to be around 2 m/s in the free troposphere. Better accuracy is possible in the boundary layer for Mie winds and in layers of high particle loading due to the higher signal-to-noise ratio. Poorer accuracy for Rayleigh winds will occur higher in the atmosphere, due to the exponentially decreasing atmospheric density with altitude.

Table 4 Expected Aeolus-CM HLOS wind error standard deviation of Rayleigh channel upper tropospheric winds as a function of accumulation length as provided in the top row.

Length (km)	43	86	100	150
Error (m/s)	3.05	2.16	2.00	1.63

Along-track averaging of measurement-scale data is necessary to reduce the random error of the HLOS wind observations (e.g. see Table 4 above), assuming the same scene is being repeatedly measured, with the aim of producing winds more suitable for NWP models. However in practice the atmospheric winds will vary along the track and this variance is situation dependent. It is unclear what length horizontal averaging is best suited for data assimilation in different systems. Averaging to the horizontal scales for which your background forecast starts to represent wind accurately would probably be a good start. Very long averaging (say 300 km) is possible, but should be replicated in an observation operator i.e. averaging model fields along-track (2D operator) - these lengths will hopefully be unnecessary, except perhaps at the highest Rayleigh vertical bins in the stratosphere. Another option that could potentially be implemented in the L2BP is to superob in the vertical too, thus allowing shorter horizontal accumulations to achieve a given SNR. Investigations are being undertaken to understand the effects of sampling/thinning of wind data in assimilation systems through ESA contract work currently underway.

Hence, there is a choice between less-averaged noisier observations sampled more regularly along the track (although of course this data could be horizontally thinned), or longer averaged, less noisy (but potentially less representative) winds spaced more sparsely along the track. In practice only investigations with real data will provide the best answer. Therefore, the CM L2BP has so far been designed to be flexible in this respect.

4. Options for operational data assimilation of the L2B product

Documentation explaining the expected work required for different options for running your own L2B processor is given with 'NWP SAF style' documentation available from the ECMWF download website. Here we summarise the options.

Running the L2B processor in your own system:

Advantages:

- The ability to tune the L2B processing to your own system's needs:
    - You have control of the averaging process (by a series of easily controlled parameter settings); in particular the horizontal integration length will be controllable.
    - Also you have freedom to improve the L2B code (improvements you would then pass on to the Aeolus L2B team, see the license agreement when before downloading the software), i.e. making a contribution to this demonstration mission.
- You can use your own forecast model's a priori temperature and pressure information for the Rayleigh-Brillouin correction.

Disadvantages:

- The time/effort to implement it in a NWP system:
    - Finding a suitable place to run the processor in your system.
    - Making a priori T, p profiles available to the processor for the Rayleigh-Brillouin correction. This AUX_MET data needs to consist of temperature and pressure profiles as a function of height, preferably at the resolution of your model's levels. The profiles need to be sufficiently close (in terms of horizontal distance and time) to the Aeolus data which shall be corrected - the processor simply chooses the closest in space and time.
- Acquiring the input files (in NRT) for the L2B processor.

Assimilating L2B HLOS processed by an external centre:

Advantages:

- Less time/effort.
- Less expertise on DWL lidar data required.

Disadvantages:

- No guarantee (as yet) of NRT processing being available[1]
- Some time delay relative to L1B data
- Not using your own a priori T, p profiles (AUX_MET)[2]
- Less control over the product.

[1]It is intended (though not yet confirmed) that L2B products be produced in NRT (near real-time) by KNMI through EUMETSAT funding, which if you have restricted human resources could be a solution.

[2]However, this can be resolved by implementing a slightly more complicated observation operator to

account for differences in a priori temperature and pressure from your system relative to the reference. Reference pressure and temperature, along with 1st order sensitivities (dHLOS/dT, dHLOS/dp) are provided in the L2B product. Note however error due to non-linearity can still exist.

5. L2B product file format issues

With the switch to CM data it was decided that the file format which was designed with BM data in mind was not optimal for CM (particularly since flexibility is desirable). The old L2B format stored wind results as profiles for every observation type (Mie clear, Mie cloudy, Rayleigh clear, Rayleigh cloudy) despite a significant fraction of missing values being present in the profiles (particularly for the Mie observations).

CM has the potential for a more flexible averaging at different vertical levels to accumulate measurement data up a user-defined scale or e.g. when a defined SNR has been achieved (this is a future development, not yet implemented). Strictly enforcing observation profiles no longer made any sense, particularly if the averaging on different levels is over significantly different scenes. Note however profiles are still available if wanted, since the new CM L2B format also provides profiles via lists of indices to the individual HLOS wind results.

It is better to consider Aeolus data (from CM) as individual winds. Of course when considering Aeolus data as a whole, it will have good vertical and horizontal (along the orbit) coverage, but this is too inconsistent to warrant its treatment as radiosonde-like profiles. Think of Aeolus data as a 2D-plane of the atmosphere, but with some gaps in the plane, mainly due to thick clouds aloft (see Figure 5).

6. Inputs to the L2B processing and local installation at ECMWF

The L2B processing software uses as input L1B data (spectrometer counts, calibration data etc.) and auxiliary data (calibration of the Rayleigh-Brillouin correction) that will be provided to users by ESA. Table 5 lists the files which an NWP centre will need to acquire from ESA.

Table 5. Files obtained by NWP centres from ESA for L2B processing

File type	Short-hand name	Delivered format(s)	Nominal frequency and time of delivery	Typical file size	Purpose	Created by
Aeolus Level 1B Product	ALD_U_N_1B	EE-format or BUFR	One file per orbit, every ~93 min. Times variable.	85 MB/orbit (EE-format), 20 MB/orbit (BUFR)	Input to the L2B processor. Level 1B Wind velocity and spectrometer measurements.	PDS:APF
Rayleigh-Brillouin Correction Table	AUX_RBC_L2	EE-format	Following each calibration of Aeolus. Perhaps weekly.	34 MB	Input to the L2B processor	PDS:ACMF
Climatology Lookup Table	AUX_CLM_L2	EE-format	Once per year (TBC)	~200 KB	Input to the L2B processor	PDS:ACMF
L2 Calibration Coefficient Auxiliary File	AUX_CAL_L2	EE-format	Once per year (TBC)	3.65 MB	Input to the L2B processor	PDS:ACMF

The L1B data is provided in Earth Explorer format (ESA's own format) but we have a tool to convert L1B EE to L1B BUFR if required. Currently the intention at ECMWF is not to use L1B BUFR, but to use ESA's EE-format as input to the L2B processor. Note that at present the L2BP standalone processor requires L1B in EE-format to work (i.e. it cannot yet handle L1B BUFR). A tool may be developed to convert L1B BUFR back to EE format in future if necessary.

The original aim for L1B in BUFR format was so that NWP centres (including ECMWF) could get the L1B data into their assimilation systems (using existing software). Once the L1B data is in an NWP's centres assimilation system (i.e. data available in the Fortran code), then you can call the L2BP via subroutine calls.

This was the method intended for running the software at ECMWF prior to 2011 i.e. Fortran subroutine calls from the IFS code, which has access to model short-range forecast (background) information for the Rayleigh channel correction. However, thanks to a new processing system at ECMWF (called COPE, Continuous Observation Processing Environment), this method has now been superseded by the simpler option of running the processor via stand-alone executables outside of and prior to the 4D-Var environment (and with EE-format data as input). At ECMWF we have access to the model short-range forecast trajectory within this COPE system which is need for the AUX_MET data. It was discovered at ECMWF that to implement the L2BP via subroutine calls of an NWP data assimilation system leads to a lot of interfacing, since the L1B data is fairly complex, whereas standalone running is simple and clean. The subroutine-call version of the L2BP in the IFS was never finished.

From ECMWF's perspective, the easiest option is to run the L2BP standalone and then convert the relatively simple L2B product from ESA EE format to something suitable for your system e.g. BUFR or perhaps ODB (which ECMWF use). A L2B BUFR template is available (but will need updating for the new CM L2B format). At ECMWF we have implemented a Fortran routine that reads the L2B EE product and then extracts the HLOS wind, height, azimuth angle, error estimate, type of wind (Rayleigh/Mie clear/cloudy) into ODB-2 format to later be ingested into the assimilation system.

In the next section we ask a few questions. If you have any questions about Aeolus, then please contact me.

Please provide responses to: Michael P. Rennie
Data Assimilation Section
ECMWF, Shinfield Park, Reading, RG2 9AX, UK
Email: Michael.Rennie@ecmwf.int
Phone: +44 118 949 9417
Fax: +44 118 986 9450

The second questionnaire

Name of organisation:

Internet reference for organisation:

Name and affiliation:

Title and full name:	
Position within organisation:	
Address:	
Email address:	

Wherever possible please provide explanations for your choices.

10. Do you intend to install and run the Aeolus L2B processor locally at your NWP centre with the intention of operationally assimilating the L2B product? If not, what do you intend to do?

If you answered that you **do not** intend to process Aeolus to L2B product locally at your NWP centre, then please go to question 5.

11. How do you intend to run the L2B processor: e.g. as a stand-alone processor or via subroutines calls to the L2B Fortran code from within an existing NWP code?

12. How do you intend to provide the temperature and pressure information (AUX_MET data from a short-range forecast) that is needed for the L2B processor in the Rayleigh-Brillouin correction?

13. What is the acceptable time delay for delivery of L1B and corresponding auxiliary data from ESA to run your own L2B processing? *where time delay=time difference between observation time and your NWP centre receiving the L1B data*

If you answered that you **do** intend to process your own L2B product, then please skip questions 5 and 6 and go to question 7.

14. If you **do not** intend to run the L2B processor locally then perhaps you would like to receive a L2B product processed externally for data assimilation? If yes, why is this your choice?

15. What is the acceptable time delay for delivery of L2B data from an external source for your data assimilation system(s)? *where time delay=time difference between observation time and your NWP centre receiving the L2B data*

16. What do you think would be the most appropriate averaging length (horizontal scale) of the measurement level data to produce HLOS winds suitable for your data assimilation system(s) in the 2014-15 timeframe? *Detailed answers are welcome.*