Harmonie
Data assimilation

(first experiments using scatterometer)

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(KNMI)

Overview

- Context
- The Harmonie model
- Do observations improve Harmonie forecasts?
  - A case study
  - Scatterometer winds used in Harmonie
- Challenges of Harmonie data assimilation (and probably meso-scale DA in general)
  - Do model small-scale spatial structures verify?
- Conclusions
- How further ….. some suggestions

Context

- EU-funded MyWave project – 7th framework programme

A pan-European concerted and integrated approach to operational wave modelling and forecasting – a complement to GMES MyOcean services

  - increase the use of earth observations by improving data processing algorithms and data assimilation systems,
  - improve the physics in current wave models and provide a framework for coupled model systems (atmosphere/waves/ocean),
  - establish a new standard for probabilistic wave forecasts based on ensemble methods

see also: www.mywave.eu

- KNMI contribution
  - Provide scatterometer ocean surface winds to project partners
  - Provide Harmonie model 10-m wind/wind stress/MSLP with/without assimilated SCAT winds that serve as input to force wave models

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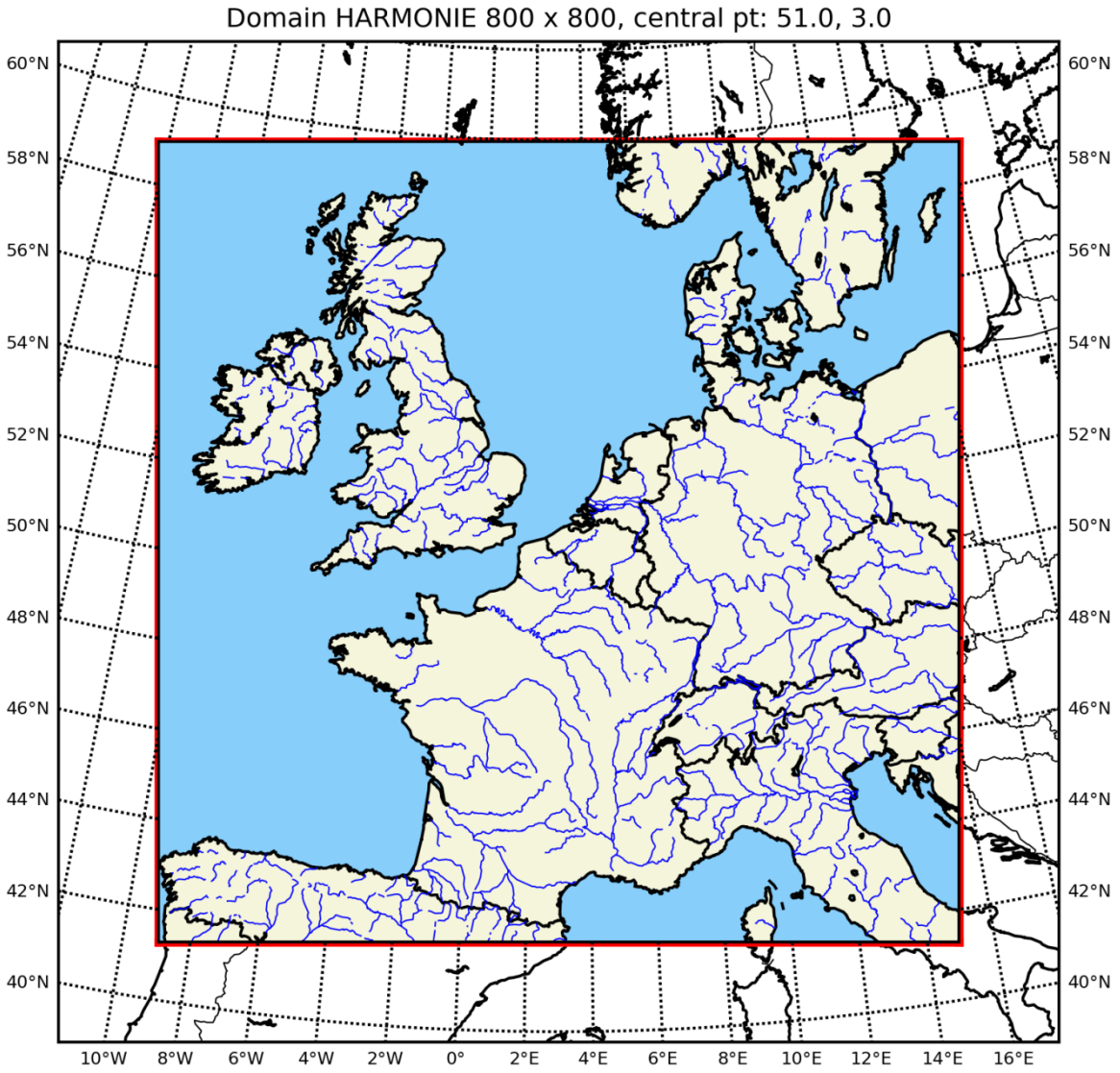
Harmonie model

(Hirlam ALADIN Research on Meso-scale Operational NWP in Euromed)



- Non-hydrostatic
- 800x800 grid
- 2.5 km grid, 60 levels
- 3D-var assimilation
  - 8 times per day
  - 48-hour forecast
- ECMWF boundaries
- Available since 1/1/2012
- Oper. cyle: cy36h1.4
- Research: cy37h1.2, soon cy38h1.1

Case study: closure Maeslantkering

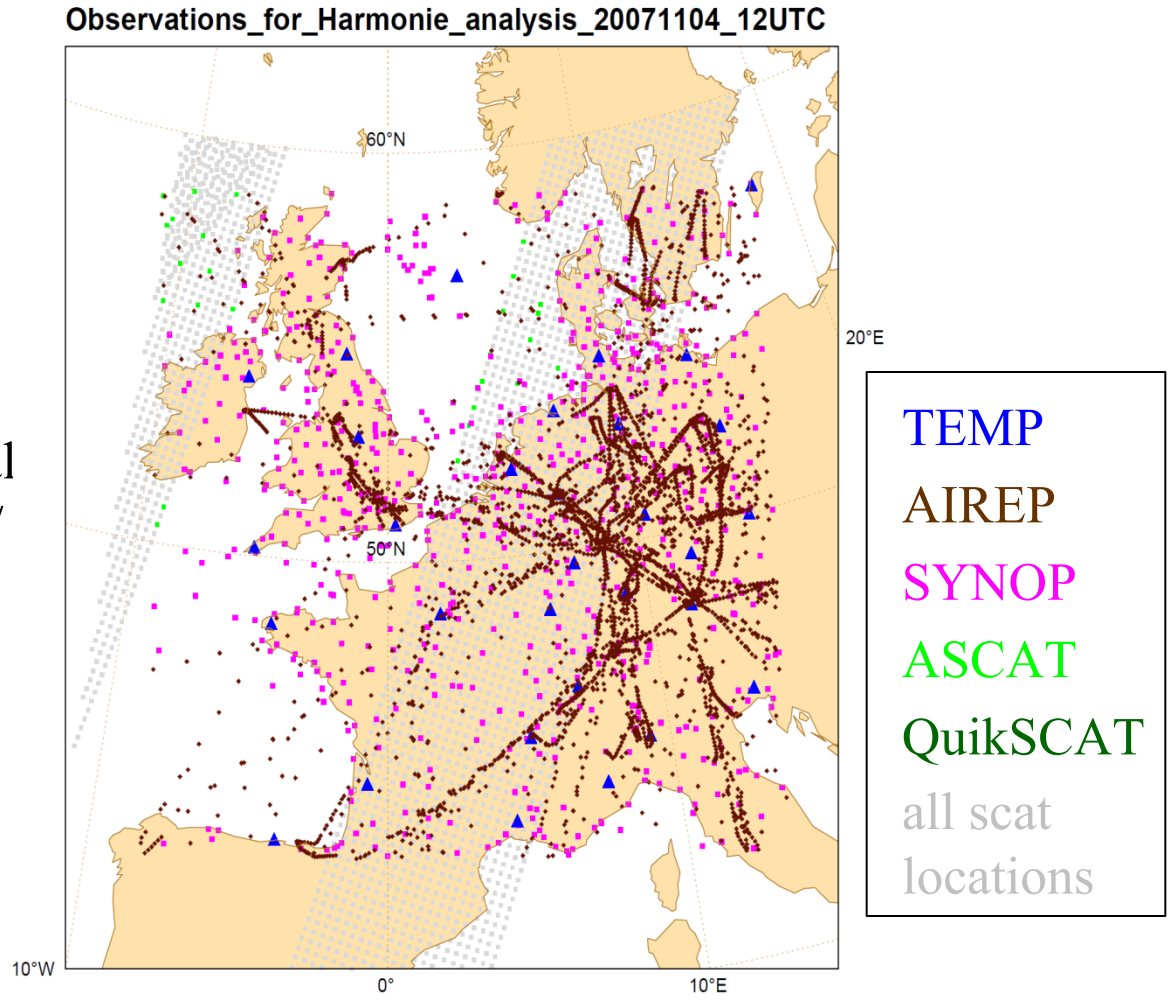
- Part of the Dutch Delta Works plan (initiated after the 1953 flooding disaster) to protect the South-Western part of the Netherlands for high sea levels

- Closed for the first time:
  - 9 November 2007
- Case study period
  - 4-11 November 2007

HARMONIE experiments

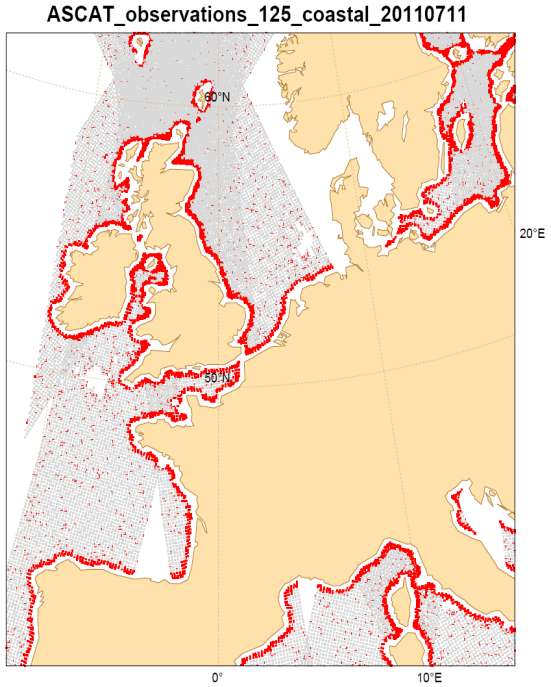
- Model cycle 37h1.2
- 3D-Var, 3-hour assimilation cycle

1. NoDA: No data assimilatio
2. Conv: Assimilation of conventional observations only (TEMP/Aircraft/ SYNOP)
3. Conv + ASCAT/QSCAT (default settings)
4. Conv + ASCAT – no thinning



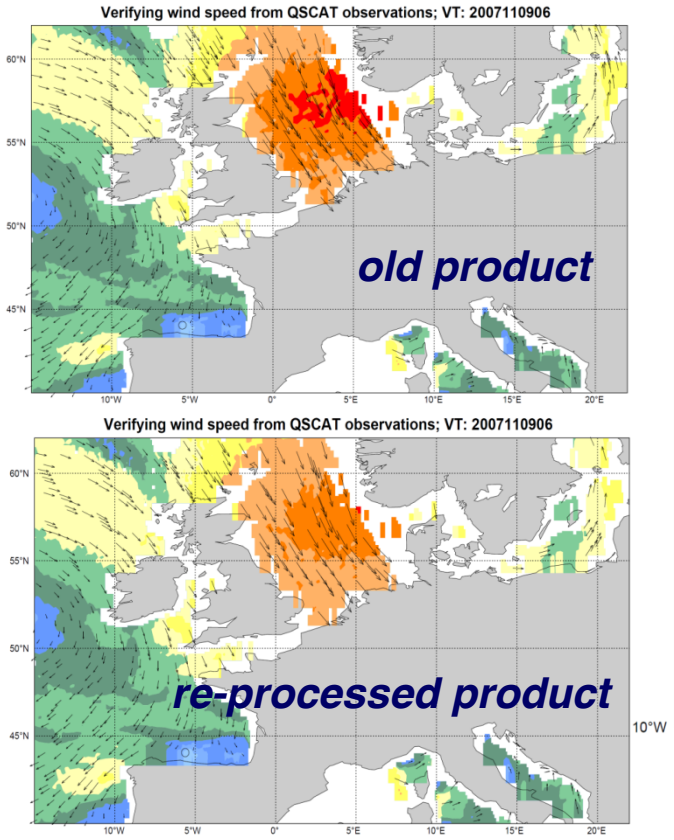
scatterometer data assimilated in Harmonie

ASCAT 12.5 km coastal product

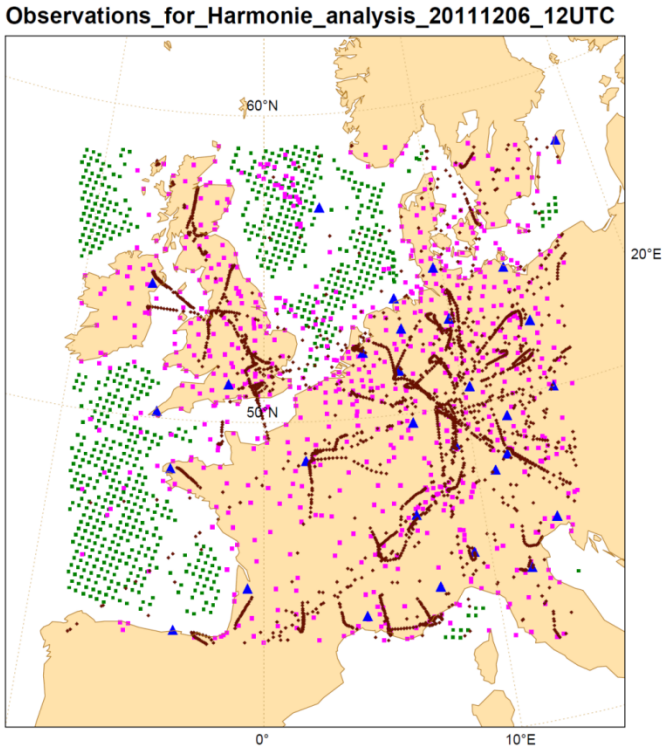


Distance to coast ~ 15 km, as compared to ~ 35 km for the nominal 12.5 km product

QuikScat 25 km re-processed product (resolves high wind speed biases)

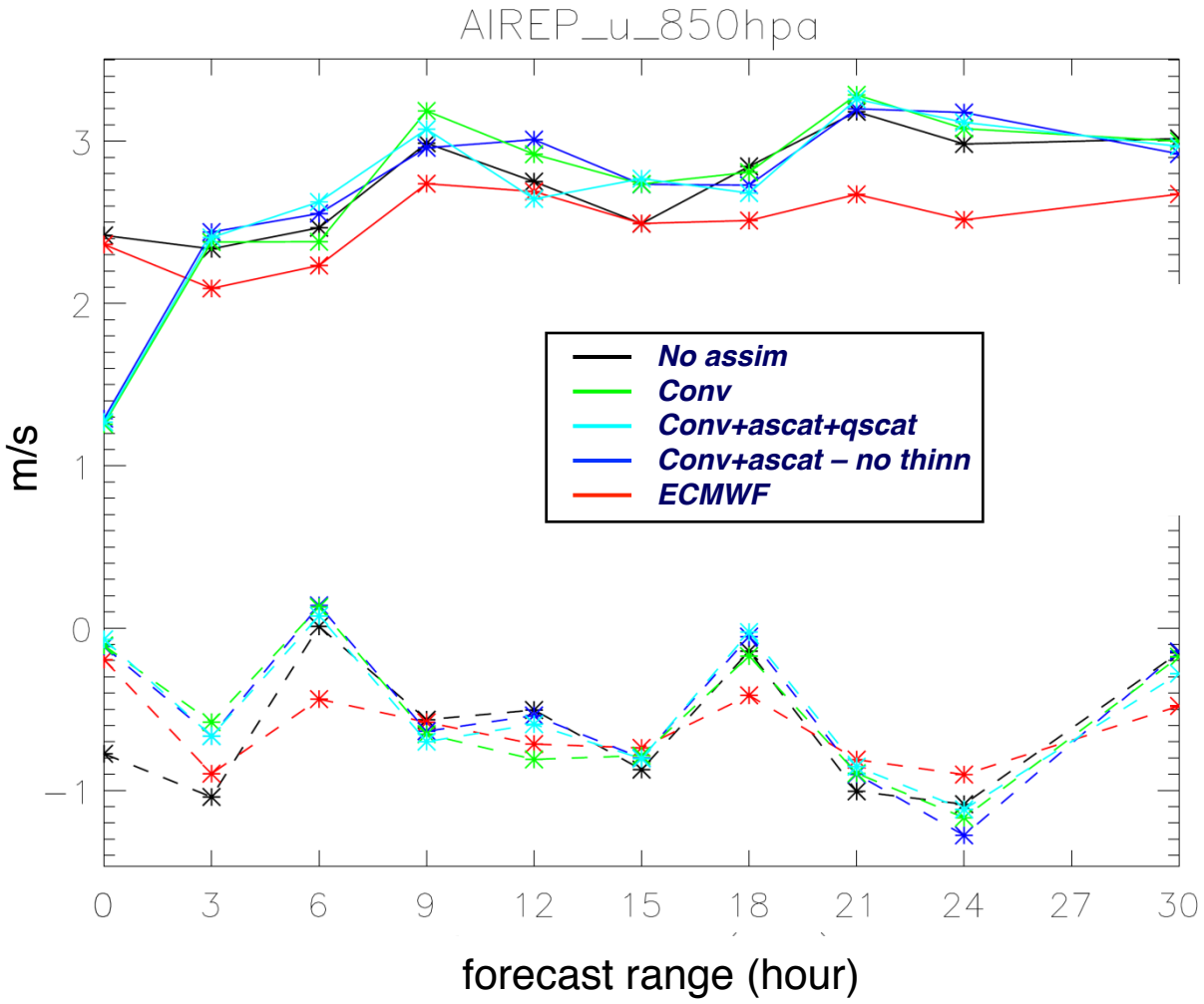


OSCAT 25 km product



OSCAT available since 2009, so not used in this particular case

Forecast verification against aircraft observations



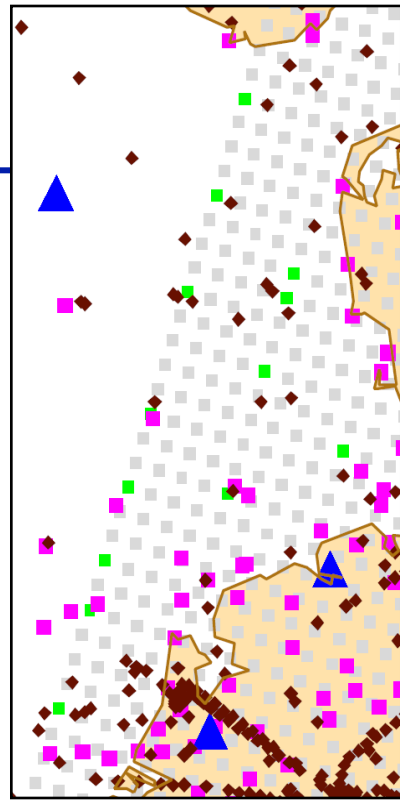
850 hPa zonal wind
Harmonie DA

- Does improve analysis
- does not improve 850hPa u-wind component forecast
- ECMWF outperforms Harmonie
- Result is typical for other parameters

➢ Why performs ECMWF better than Harmonie?

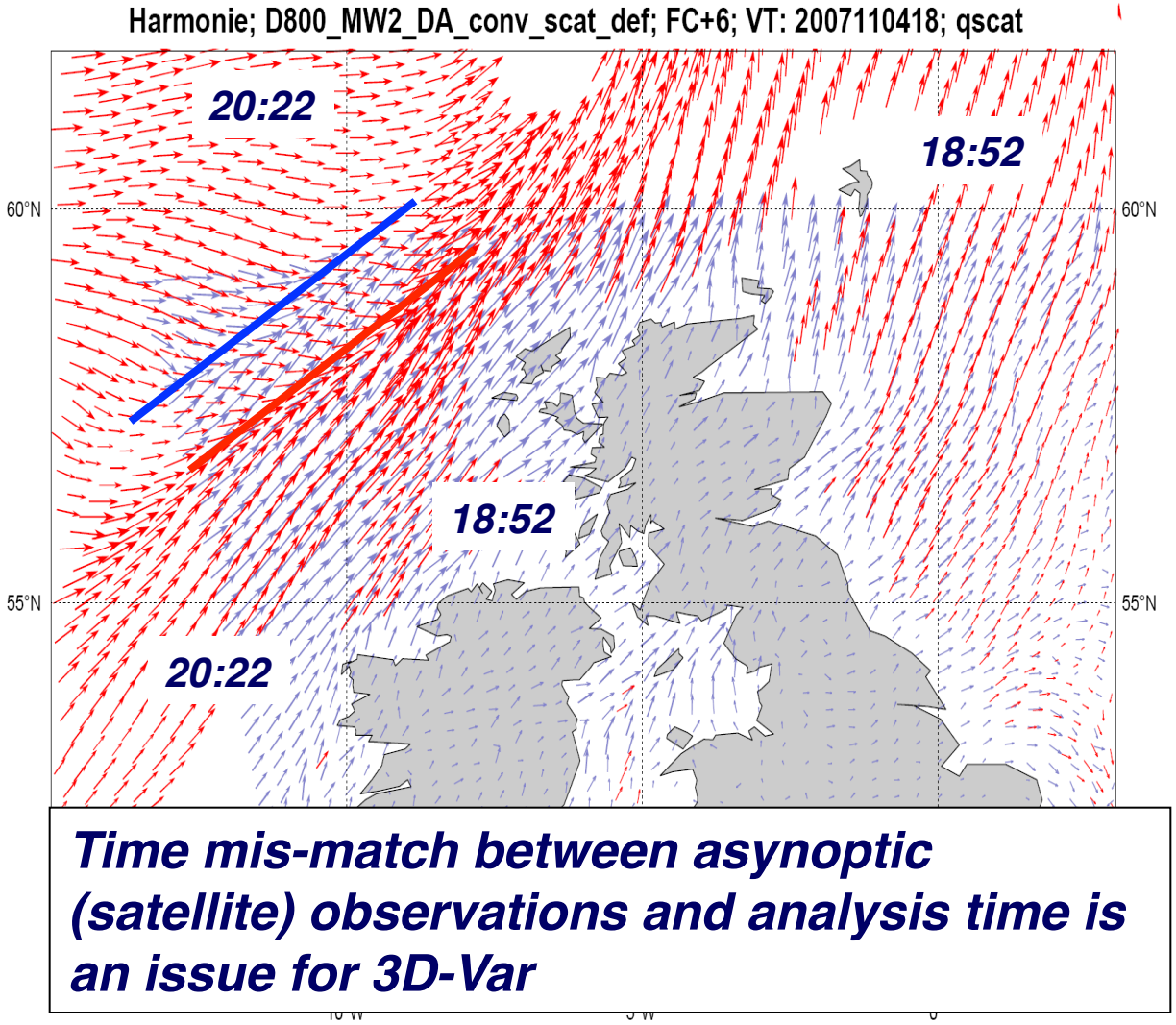
➢ Why do observations not improve the Harmonie forecast?

Possible explanations



- Harmonie integration in ECMWF – IFS
  - Observation thinning strategies optimal for ECMWF, probably not for Harmonie. Needs revisiting.
- HIRLAM heritage
  - Large-scale mixing; spectral mixing of ECMWF and Harmonie fields; worked well for HIRLAM
- B-matrix formulation
  - Climatological; 6-h background + rescaling to 3-h
  - (o-b)/(o-a) statistics: currently too much weight given to observations
- 3-h DA window size may be too large for 3D-Var
- Harmonie exaggerates strong winds, rain downbursts?
- Do Harmonie model small-scale structures verify?

Issue 1: assimilation window length



Time mis-match between asynoptic (satellite) observations and analysis time is an issue for 3D-Var

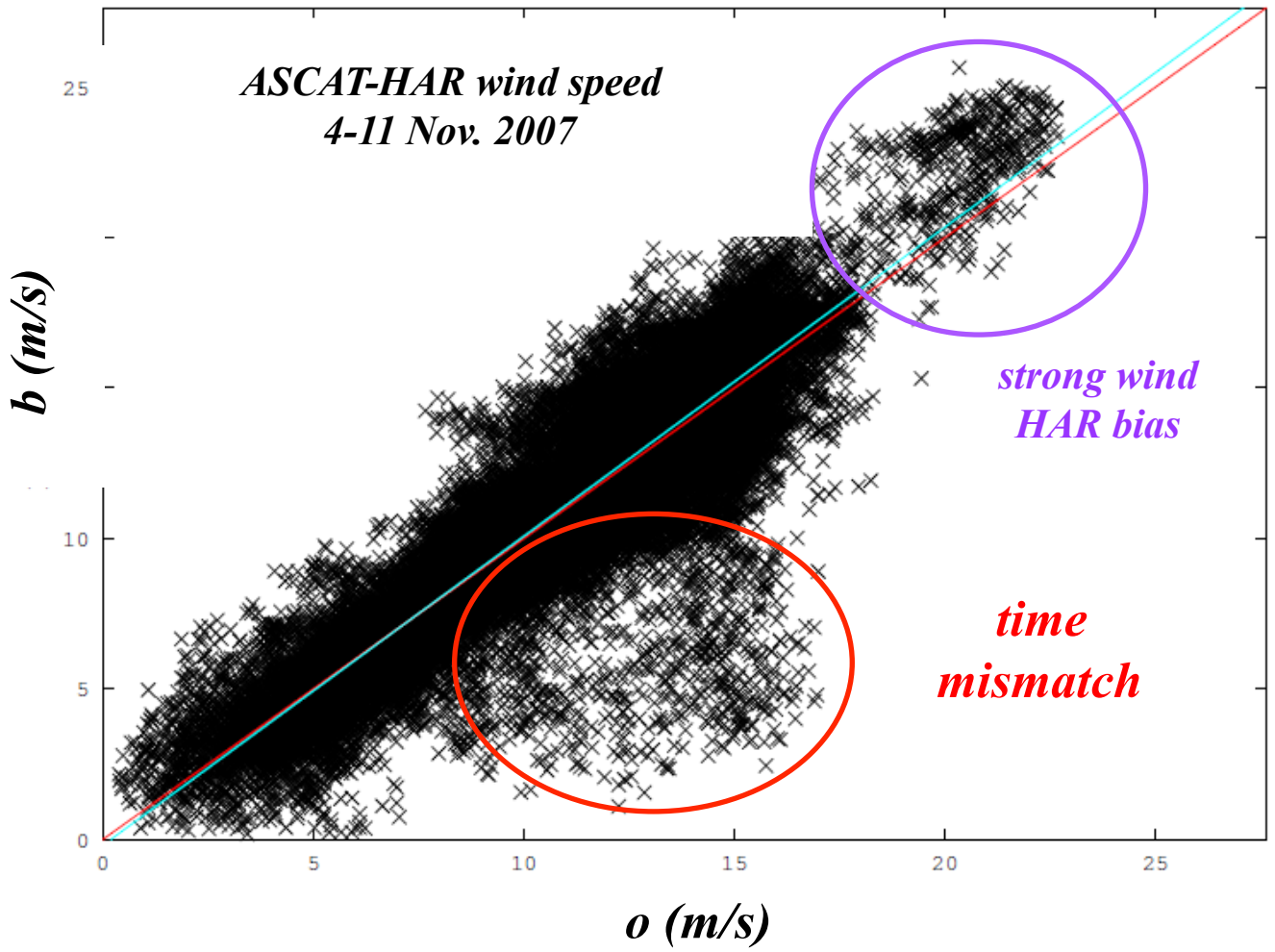
- Position of frontal zone north of Ireland is incorrectly positioned in Harmonie

- Really?
- QuikSCAT observations north of Ireland are almost 2.5 hours after analysis time

➢ 6-hour assimilation window is too large, in particular for extreme events

➢ Same conclusion holds for 3-hour window

Issue 2: Harmonie exaggerates strong wind

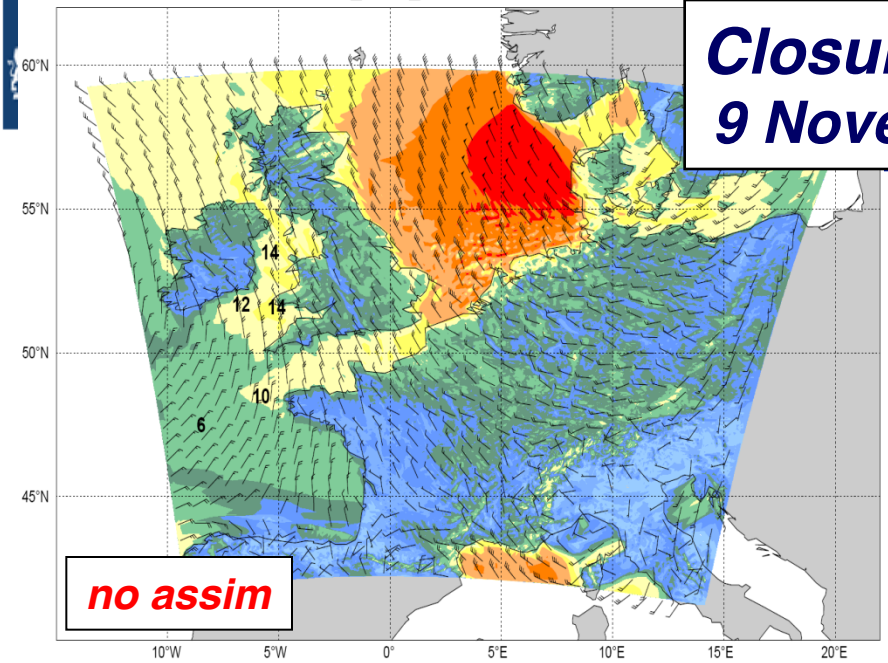


- ASCAT (o) versus Harmonie (b) 10-m wind speed

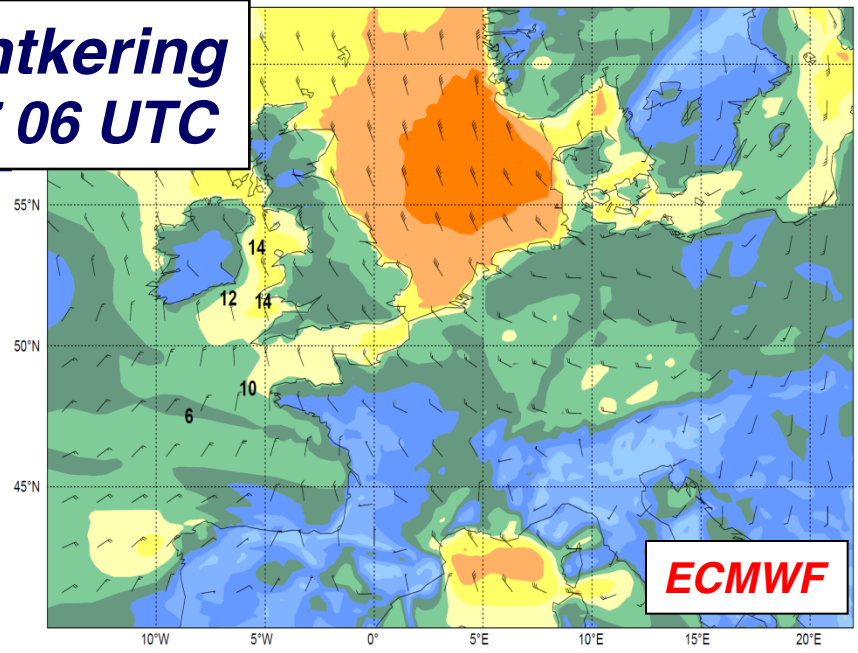
➢ Harmonie exaggerates strong winds

Closure Maeslantkering
9 November 2007 06 UTC

Harmonie; D800_MW2_noassim; AN: 2007110900; FC+6



ECMWF; AN: 200711090; FC+6



Bft

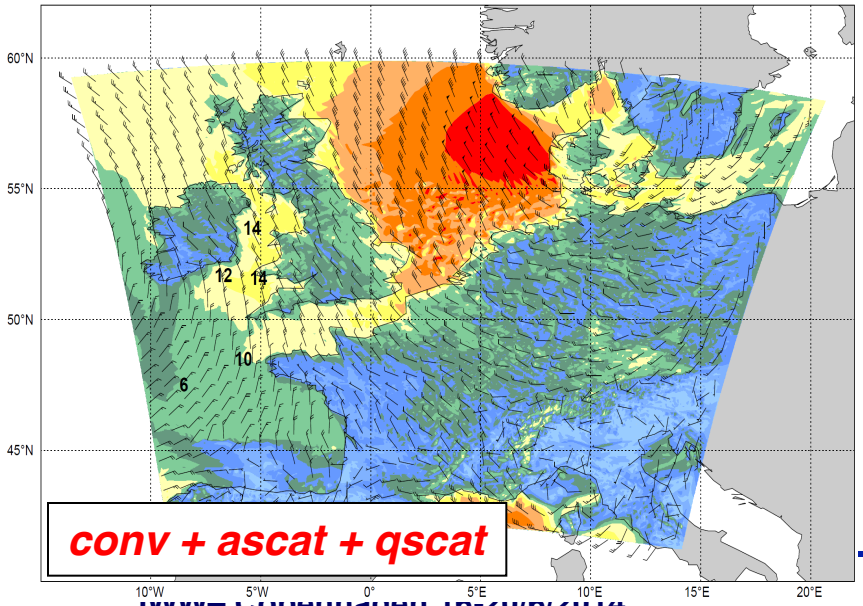
12	6
11	5
10	4
9	3
8	2
7	1

surface wind speed

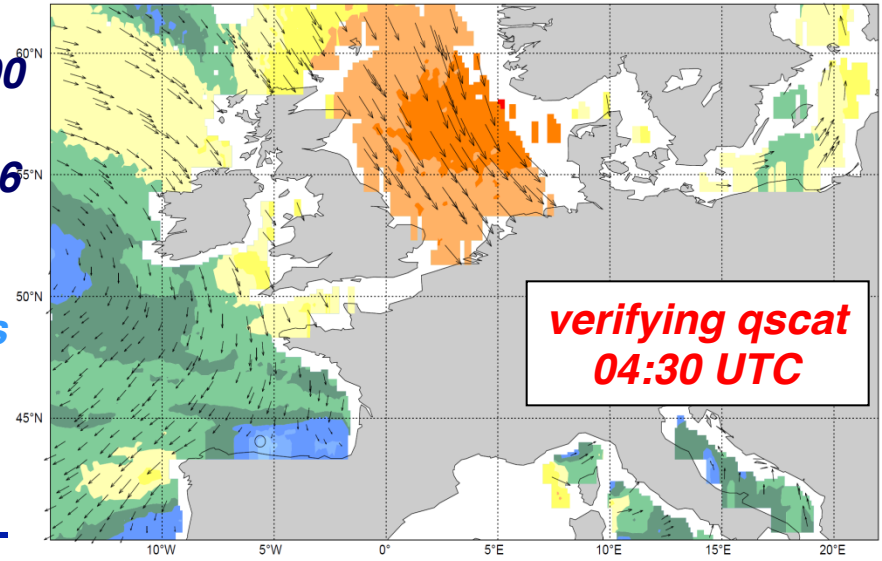
AN: 2007110900
FC+6
VT: 2007110906

Harmonie overestimates wind over North Sea

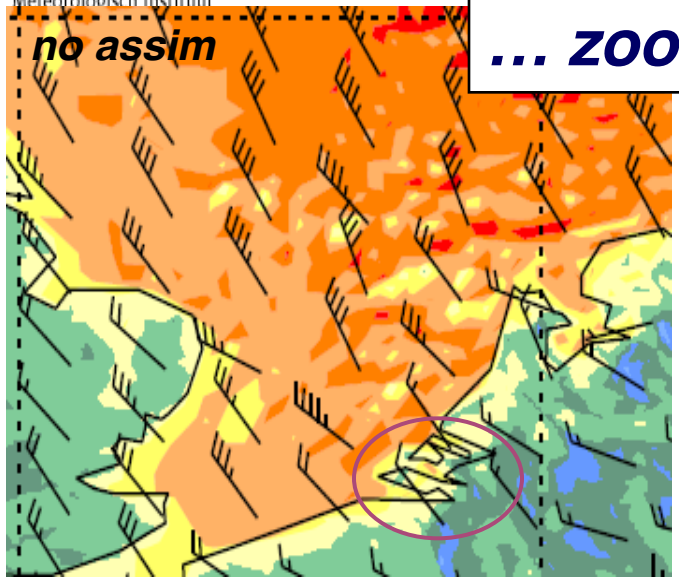
Harmonie; MyW_DA_win3h; AN: 200711090; FC+6

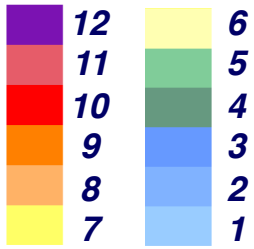


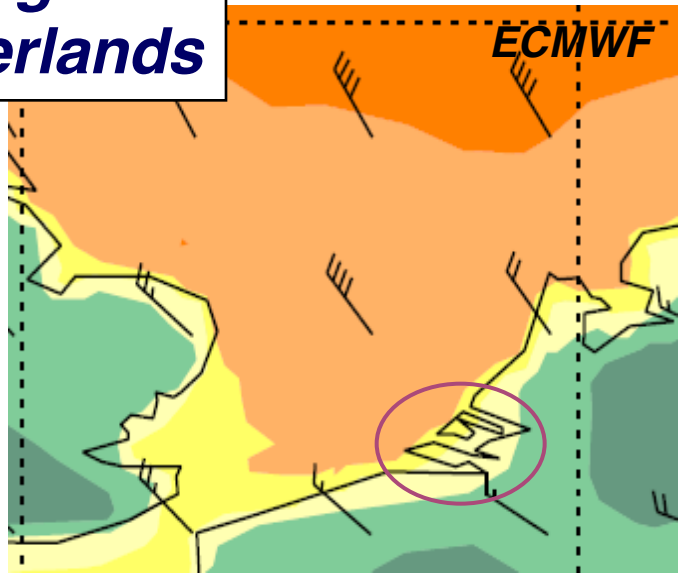
Verifying wind speed from QSCAT observations; VT: 2007110906



Closure Maeslantkering … zooming in to The Netherlands

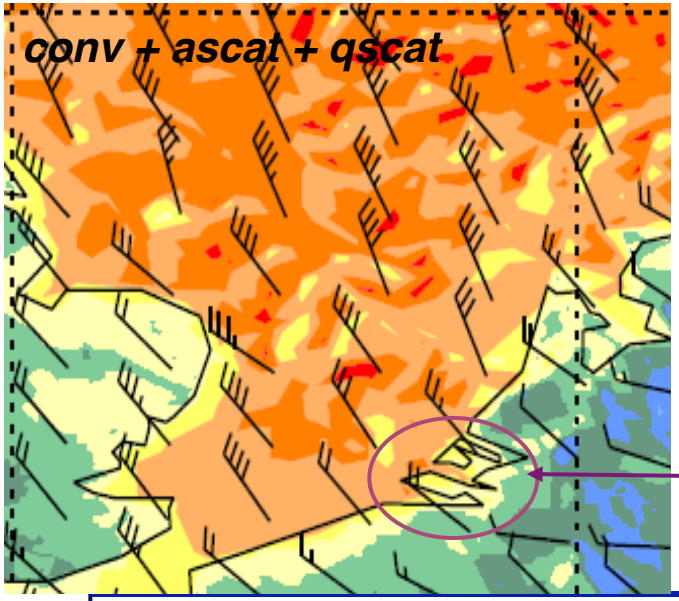




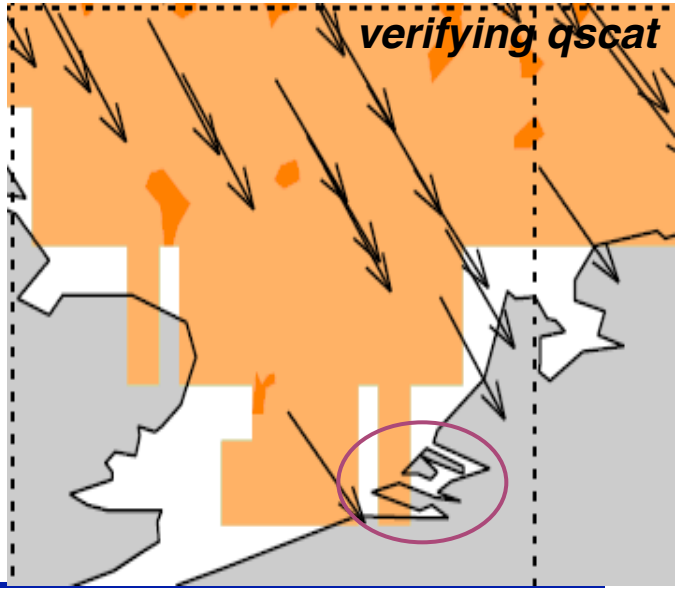


surface
wind speed

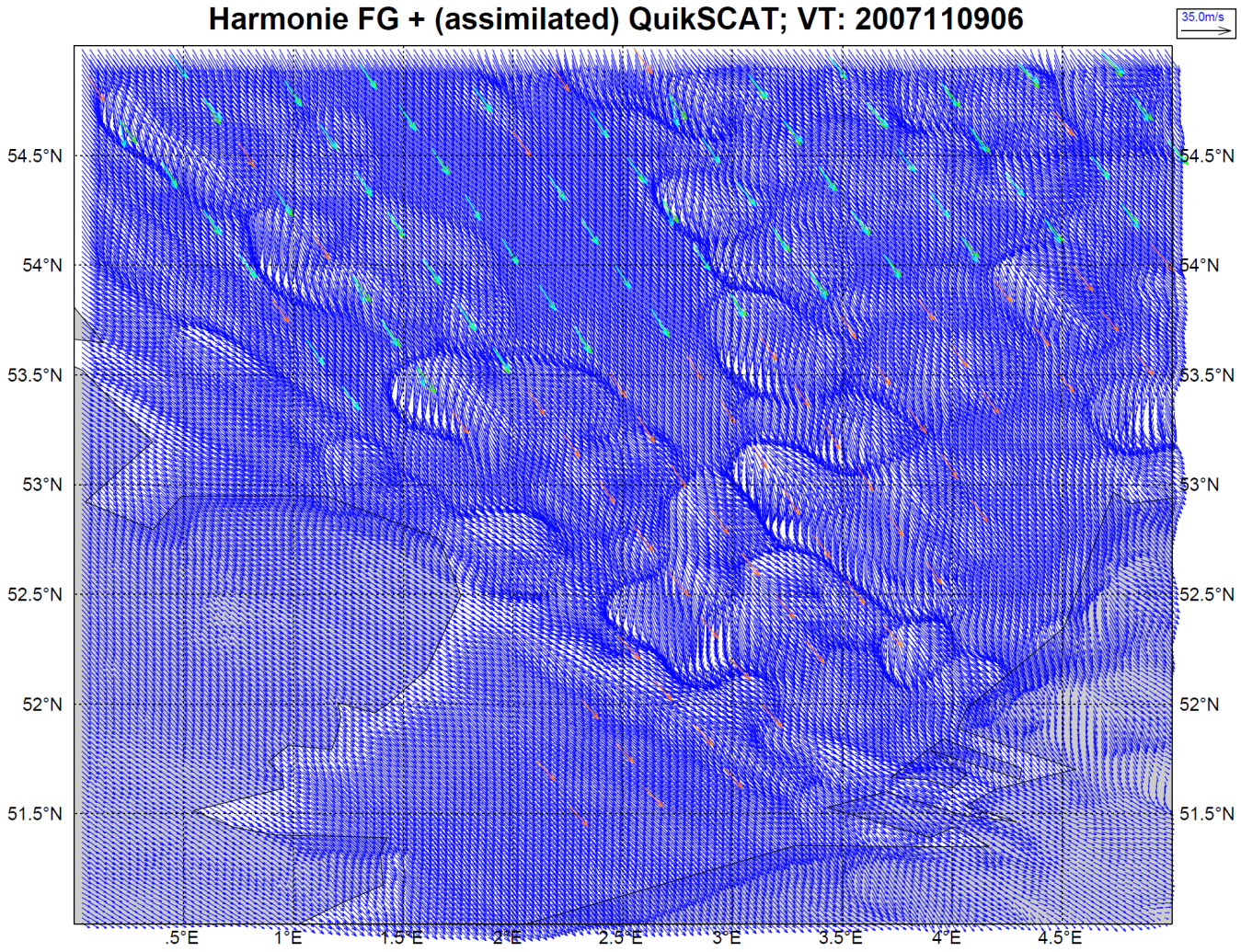
AN: 2007110900
FC+6
VT: 2007110906



Note the small-scale structures in the Harmonie model fields, lacking in both ECMWF and QuikSCAT

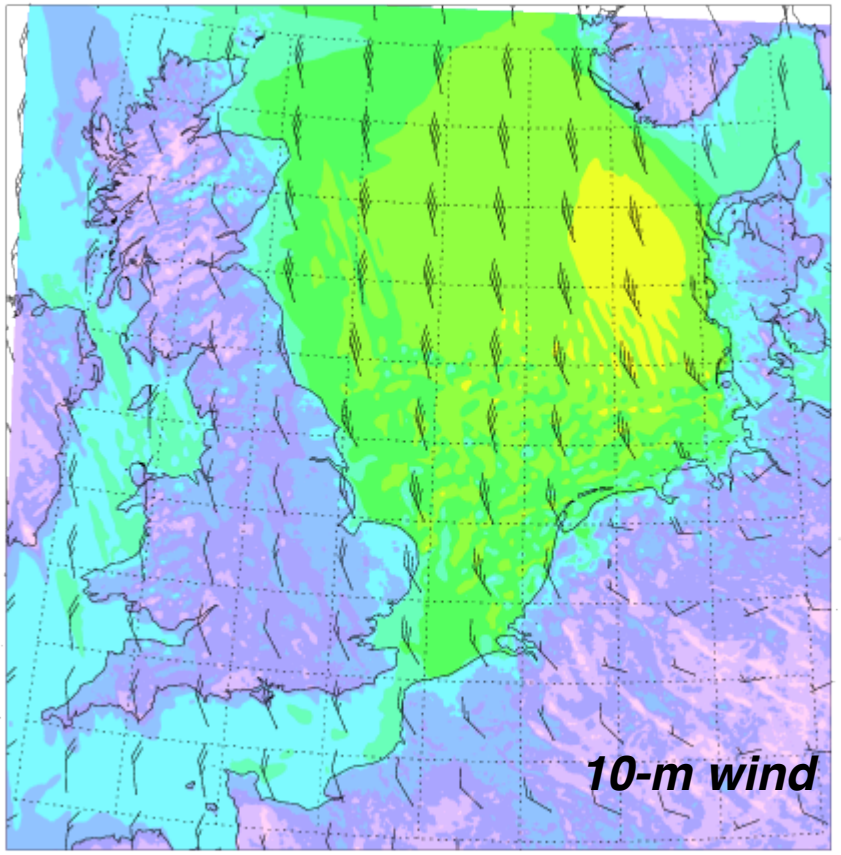


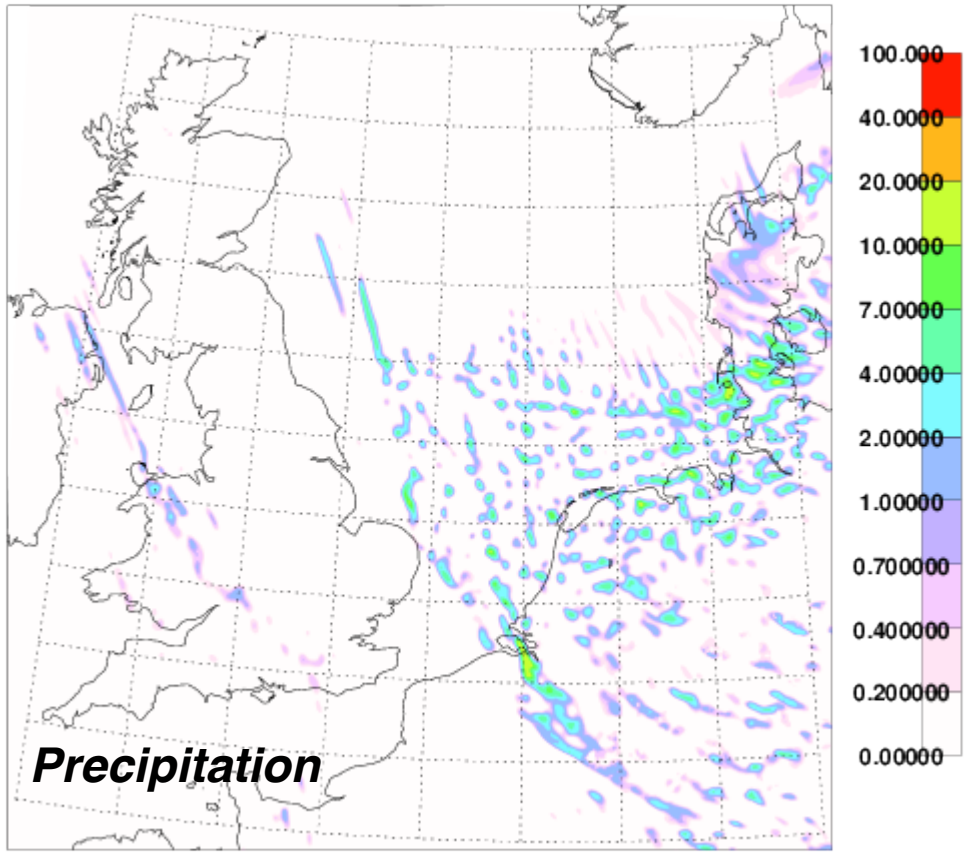
Harmonie small-scale structures



- Surface winds (10m)
- Harmonie shows structures not observed by QuikSCAT
- Note: QuikSCAT footprint is about 50 km^2

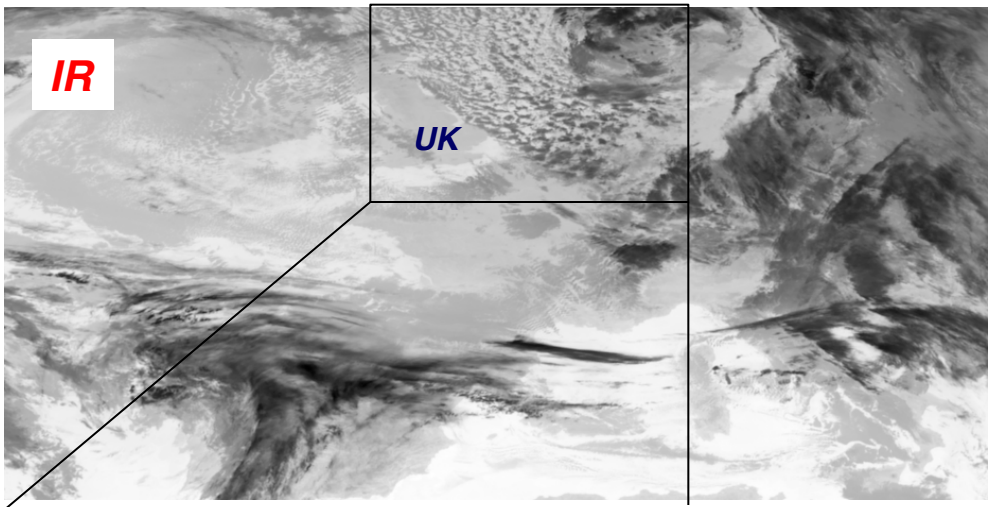
Downbursts due to rain in the model?

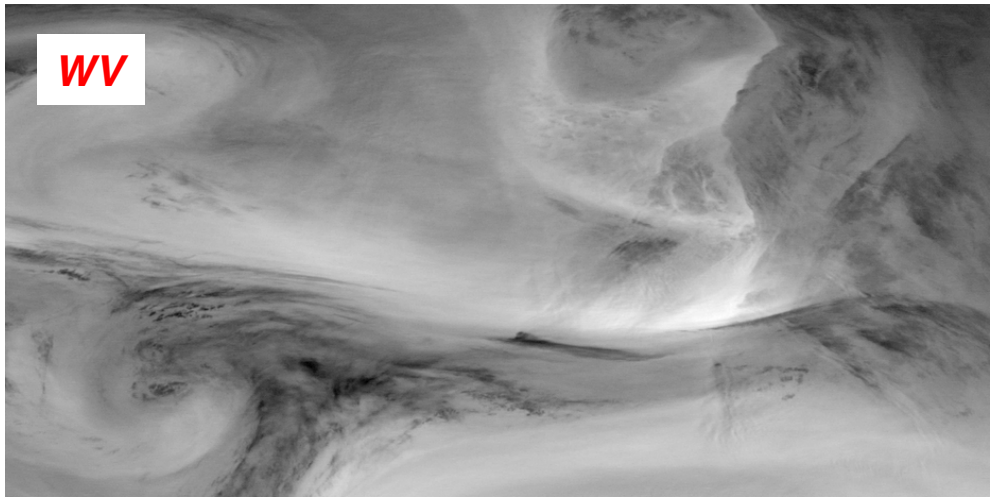




Courtesy Peter Baas - KNMI

Satellite imagery

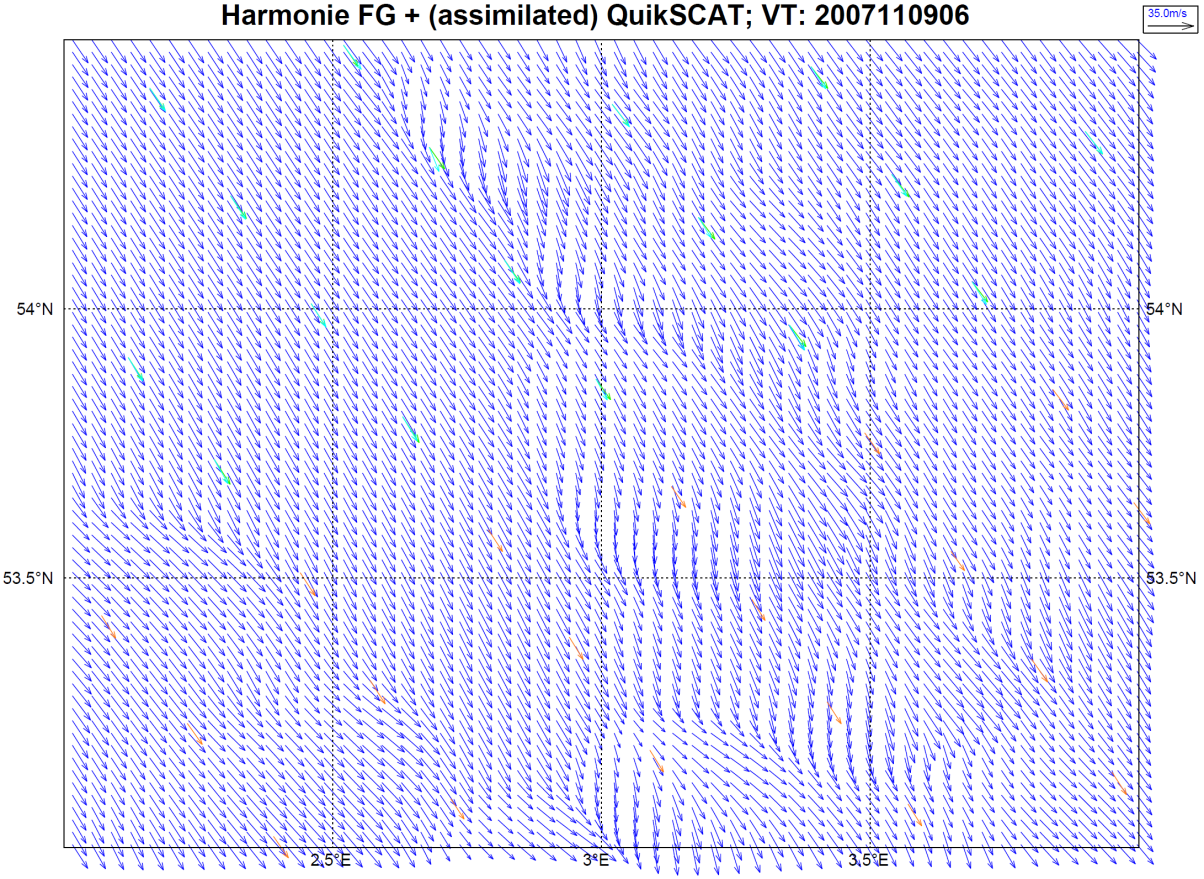


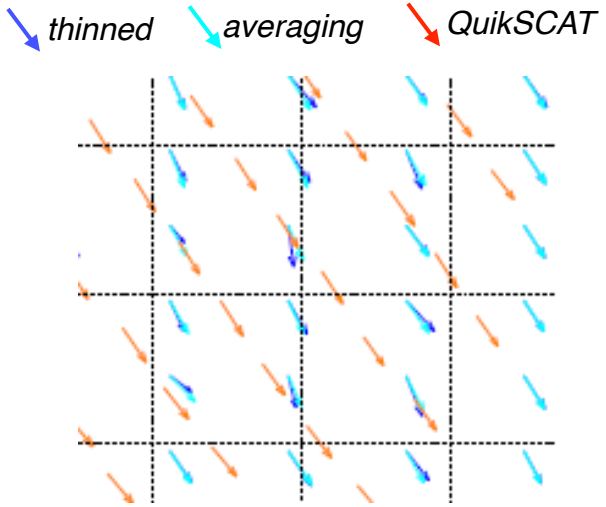


- Convective cells developing over the Southern North Sea
- Well represented by Harmonie
- Flow from polar region. But convective cell development starts only at domain boundary

➢ Cells most probably out of phase

…. zoomed in





- Averaged model winds compare better to observations
- Small-scale model structures realistic but probably not real

No evidence that Harmonie turbulence is too excessive on scales observed by SCAT

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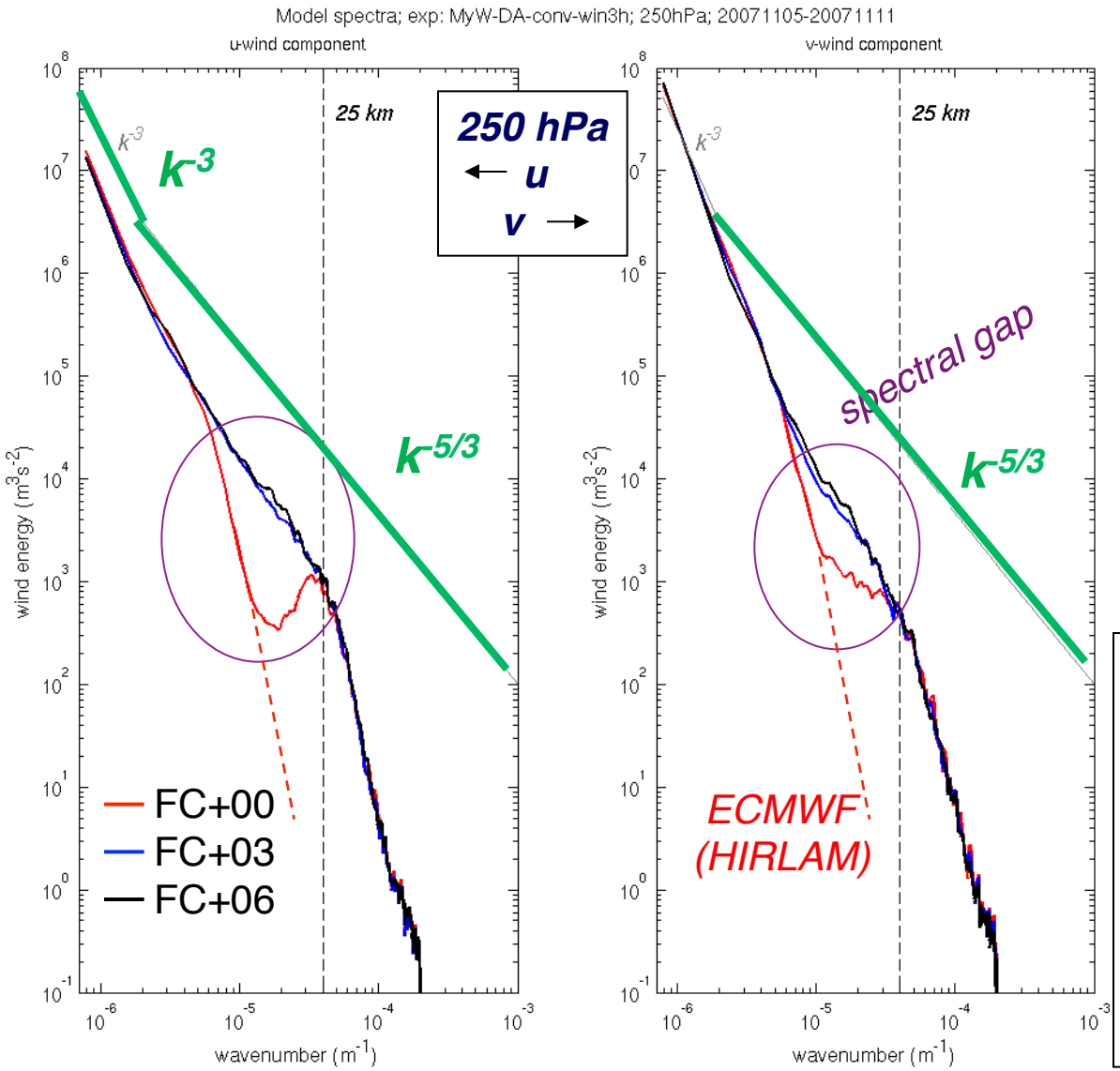
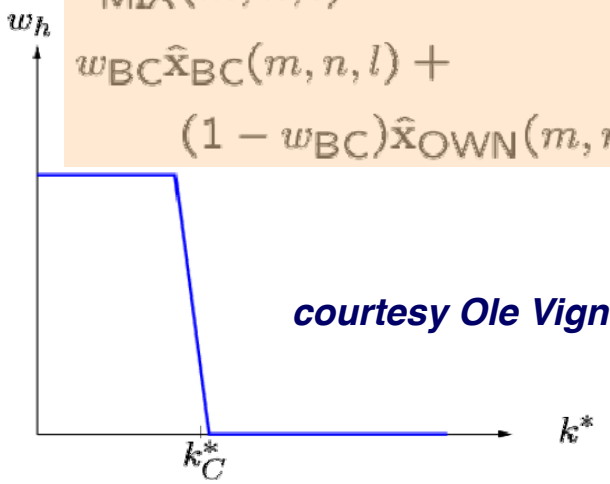
Issue 3. Large scale mixing (LSM) – default in 37h1.2



Harmonie spectral mixing with ECMWF

$$\hat{x}_{MIX}(m,n,l) = w_{BC}\hat{x}_{BC}(m,n,l) + (1-w_{BC})\hat{x}_{OWN}(m,n,l)$$

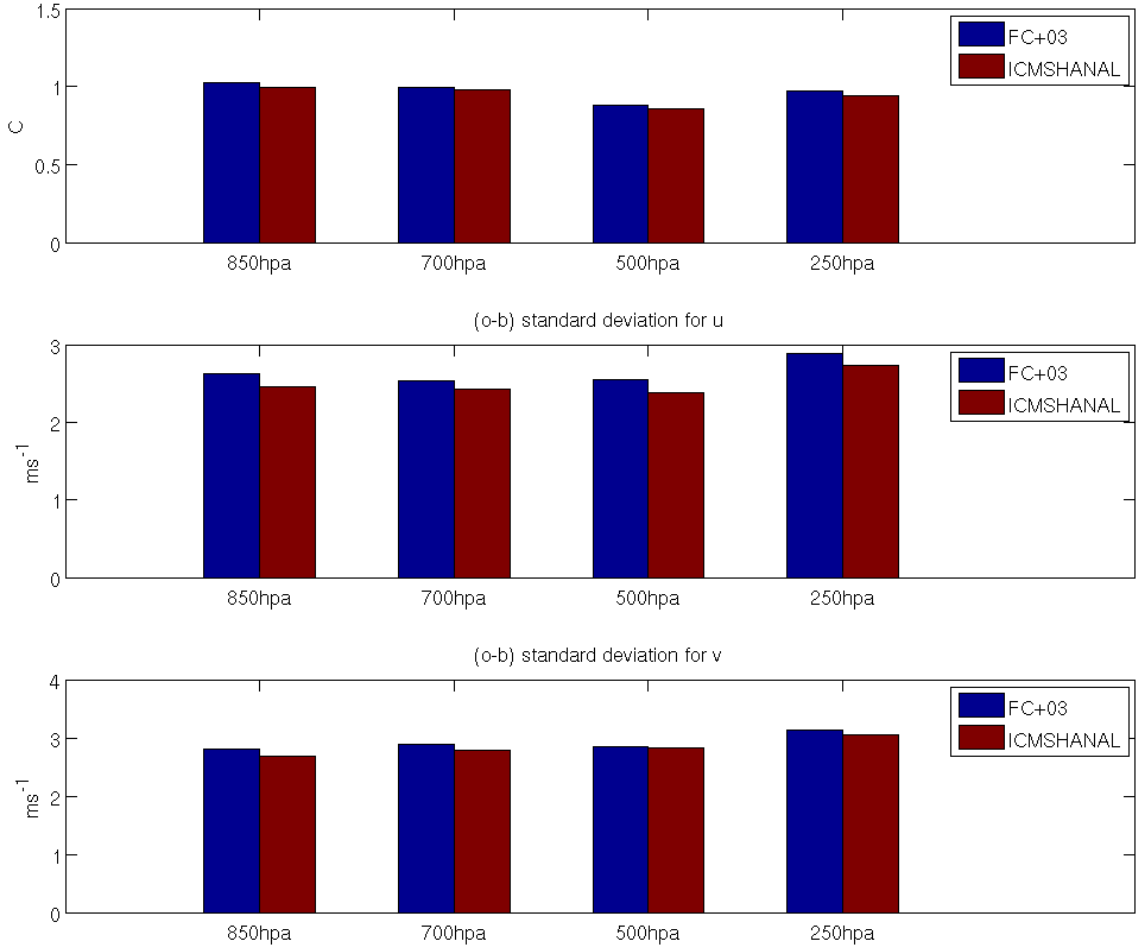


courtesy Ole Vignes

- Motivation: ECMWF is superior on large scales
- Spectral gap physically unrealistic; violated balance?
- Spectral gap filled within 3 hours

(o-b)

FC+3 **ICMSHANAL**



observations *o*: AMDAR

background *b*:

1. FC+3 (blue)
2. FC+3 + LSM + surface analysis (ICMSHANAL) (red)

- $(o\text{-}b)_{\mathrm{LSM}} < (o\text{-}b)_{\mathrm{HAR}}$
- Removing model small scales improves fit to observations

…. have a closer look at (o-b)

Following Lorenc (1986): "*t* is the vector of coefficients obtained by projecting the true state of the atmosphere onto the model basis"

$$
\begin{aligned}
& o - b \\
&= t_o + \varepsilon_o - b \\
&= t_{ha} + t_{o-ha} + \varepsilon_o - b \\
&= t_{o-ha} + \varepsilon_o + (t_{ha} - b)
\end{aligned}
$$

t_o is the true state averaged over the sampling volume
t_{ha} is the true state on scales that Harmonie can resolve

$$
\begin{aligned}
& \left\langle (o-b)^2 \right\rangle \\
&= \left\langle t_{o-ha}^2 \right\rangle + \left\langle \varepsilon_0^2 \right\rangle + \left\langle (t_{ha} - b)^2 \right\rangle
\end{aligned}
$$

repr. err + instr. err + backgr. err

Harmonie: $\langle (o-b)^2 \rangle$ = instr. error + repr. error + background error

\> = < >>

ECMWF : $\langle (o-b)^2 \rangle$ = instr. error + repr. error + background error

➢ ***Harmonie (small) scales do not verify with observations***

Conclusions

- Use 3D-Var with (at least) 3-hour assimilation window
  - 1-h seems to be preferred for extreme events (TBD)
- Harmonie seems to overdo
  - strong winds over the ocean surface are exaggerated
  - But, no evidence for excessive turbulence
- ECMWF outperforms Harmonie
  - Engineering solution: large scale mixing (LSM), but balance equations violated
  - Caveat: ECMWF runs only twice per day (4 times for early delivery)
- DA does not improve Harmonie forecasts (except for T at 850 hPa)
  - Added value of scatterometer winds (and other obs) could not be demonstrated
  - Structures filling the spectral gap overwhelm the analysis increment?
  - Additional small-scale structures do not verify with observations:
    $(o\text{-}b_{ec}) < (o\text{-}b_{ha})$ and $(o\text{-}b_{ha+LSM}) < (o\text{-}b_{ha})$

➢ ***Removing Harmonie small scales might help***

How further ….

- **B**-matrix
  - Now based on 6-hour FG, should be 3-hour! How useful is climatological **B**-matrix in extreme weather events?
  - Flow-dependent **B** has proven useful for ECMWF …..
- Data usage
  - Too much weight given to observations? What is the optimal density and weight?
  - Averaging/thinning of high-resolution observations: Mode-S/radar wind/SCAT/...
- Footprint of some observing systems (SCAT, future Aeolus Doppler wind lidar, …) exceeds model grid size
  - Optimal use of observation information requires averaging in model domain
- Improve Harmonie, e.g. excessive ocean surface wind
- 3D-Var Rapid Update Cycle (1-hr window); first exps are ongoing
- 4D-Var; experimental suite up and running

ECMWF/Harmonie	o-b	o-a
u	1.27/1.68	0.91/0.58
v	1.43/1.53	1.03/0.57

(o-b) => (o-a)
28% / 65%
28% / 63%

How further (ctd.)

- Harmonie DA should focus on the larger scales > 50-100 km
  - positive impact ASCAT and Mode-S in Hirlam
  - Observing network too coarse to analyze < 50-100 km spatial scales
  - Benefit relative to global models is: higher-frequency cycling, improved representation of scales not resolved by global models

Apparently, DA on meso-scale is something completely different than on global scale and as is done in Hirlam (equally smooth and same effective resolution as ECMWF). We have to be smarter (and possibly find new ways) to make use of observation information for meso-scale models

BACKUP

Do Harmonie small scales verify?

Do Harmonie small scales verify?

ECMWF

$$o - f_{ec}$$
$$= t_o + \varepsilon_o - f_{ec}$$
$$= t_{ec} + t_{o-ec} + \varepsilon_o - f_{ec}$$
$$= t_{o-ec} + \varepsilon_o + (t_{ec} - f_{ec})$$

$$\left\langle (o - f_{ec})^2 \right\rangle$$
$$= \left\langle t_{o-ec}^2 \right\rangle + \left\langle \varepsilon_0^2 \right\rangle + \left\langle (t_{ec} - f_{ec})^2 \right\rangle$$

repr. err + instr. err + forecast err

HARMONIE

$$o - f_{ha}$$
$$= t_{o-ha} + \varepsilon_o + (t_{ha} - f_{ha})$$

$$\left\langle (o - f_{ha})^2 \right\rangle$$
$$= \left\langle t_{o-ha}^2 \right\rangle + \left\langle \varepsilon_0^2 \right\rangle + \left\langle (t_{ha} - f_{ha})^2 \right\rangle$$

repr. err + instr. err + forecast err

$$\left\langle (o - f_{ha})^2 \right\rangle \begin{matrix} < \\ = \\ > \end{matrix} \left\langle (o - f_{ec})^2 \right\rangle$$

Rewrite (o-f_{ha})

$$o - f_{ha}$$
$$= (t_o - t_{ha}) + (t_{ha} - t_{ec}) + t_{ec} + \varepsilon_0 - f_{ec} - (f_{ha} - f_{ec})$$

$$\langle (o - f_{ha})^2 \rangle$$
$$= \langle (t_o - t_{ha})^2 \rangle + \langle (t_{ha} - t_{ec})^2 \rangle + \langle \varepsilon_0^2 \rangle + \langle (t_{ec} - f_{ec})^2 \rangle + \langle (f_{ha} - f_{ec})^2 \rangle - 2\langle (t_{ha} - t_{ec})(f_{ha} - f_{ec}) \rangle$$
$$= \langle (o - f_{ec})^2 \rangle + \langle (f_{ha} - f_{ec})^2 \rangle - 2\langle (t_{ha} - t_{ec})(f_{ha} - f_{ec}) \rangle$$

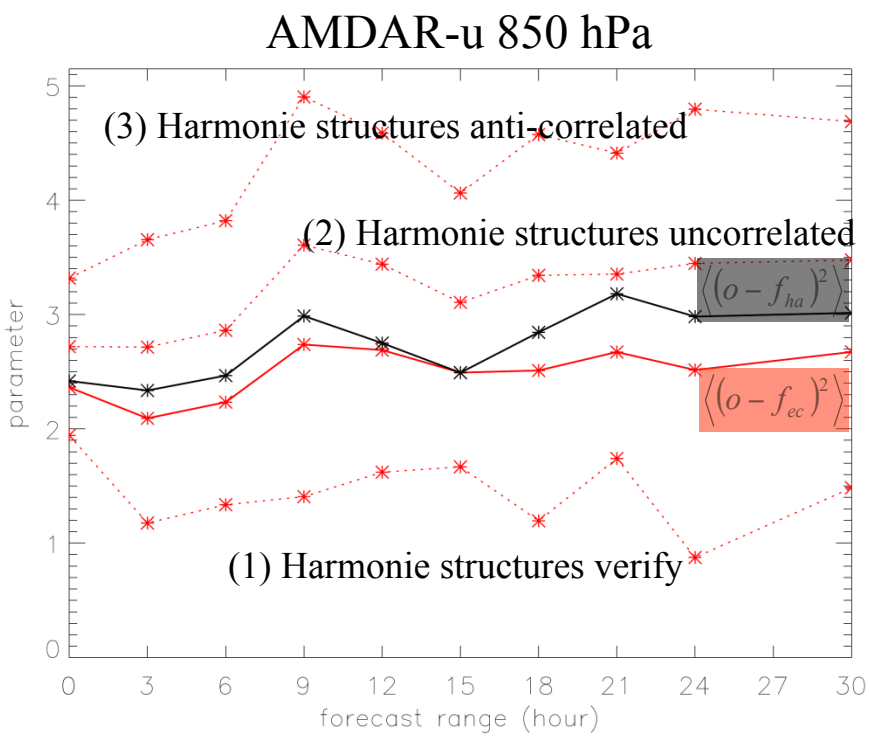
Small scale Harmonie model structures (not in ECMWF)

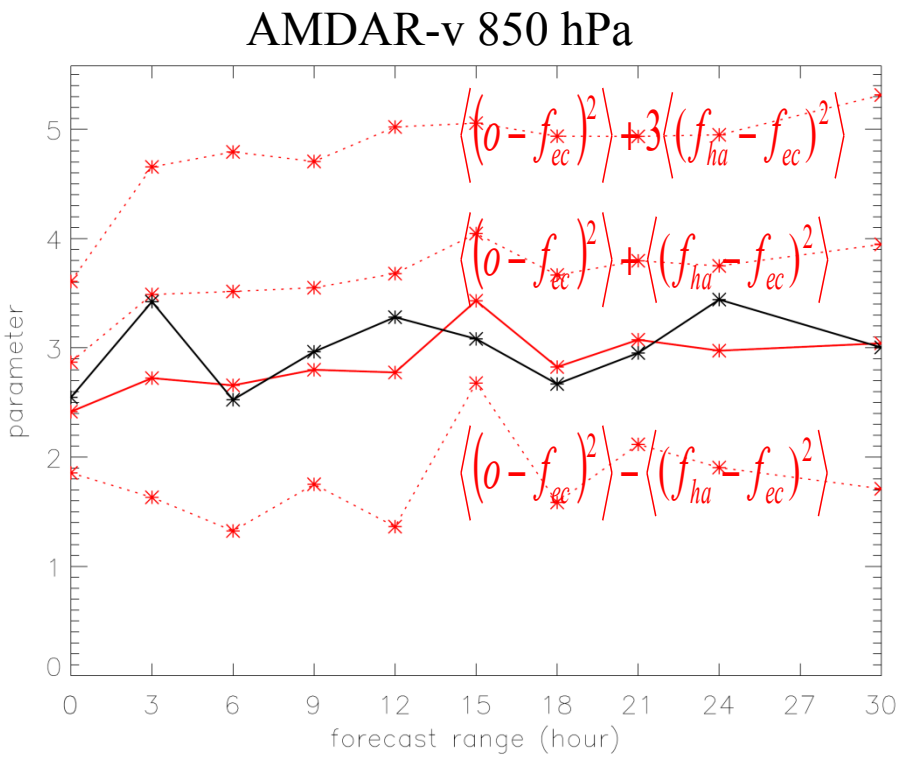
1. verify with atmosphere $\Rightarrow$ $f_{ha} - f_{ec} = t_{ha} - t_{ec}$
2. do not verify (independent)
   $\Rightarrow$ $\langle (f_{ha} - f_{ec})(t_{ha} - t_{ec}) \rangle = 0$
3. anti-correlated $\Rightarrow$ $f_{ha} - f_{ec} = -(t_{ha} - t_{ec})$

$$\langle (o - f_{ha})^2 \rangle \overset{1}{=} \langle (o - f_{ec})^2 \rangle - \langle (f_{ha} - f_{ec})^2 \rangle$$
$$\overset{2}{=} \langle (o - f_{ec})^2 \rangle + \langle (f_{ha} - f_{ec})^2 \rangle$$
$$\overset{3}{=} \langle (o - f_{ec})^2 \rangle + 3\langle (f_{ha} - f_{ec})^2 \rangle$$

1 = best case, 2 = negative, 3 = worst case

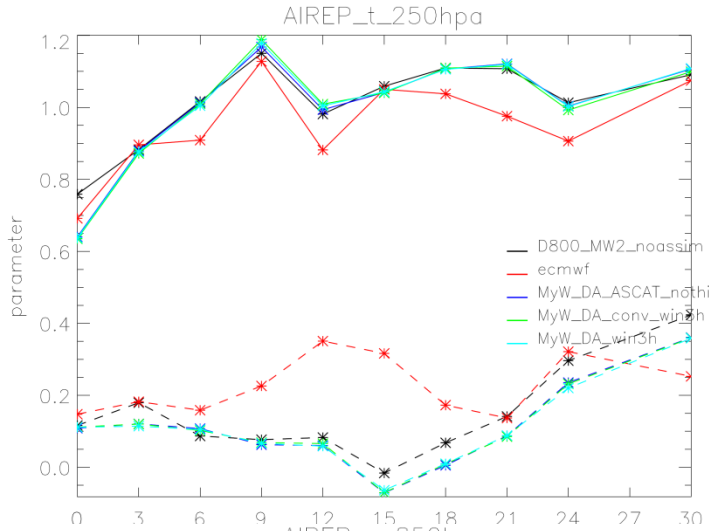
Verification of Harmonie small-scale structures

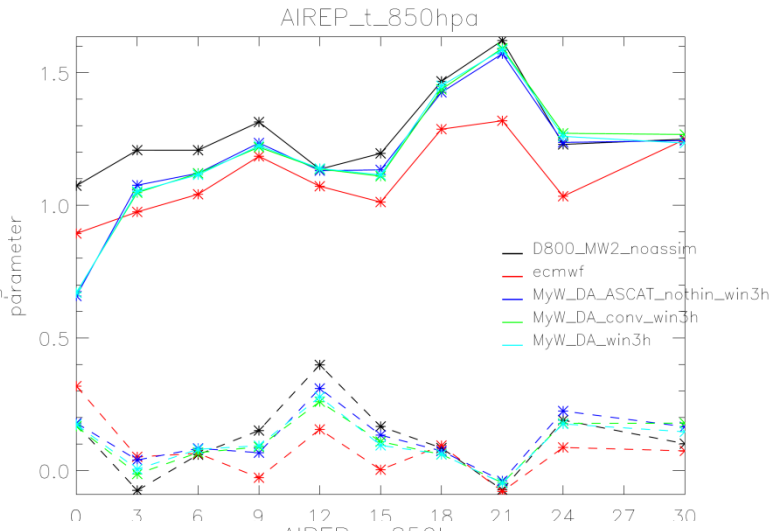


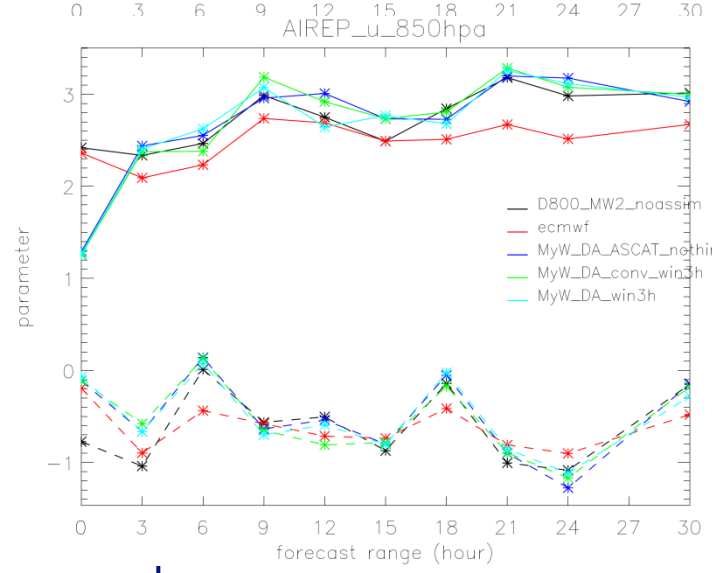


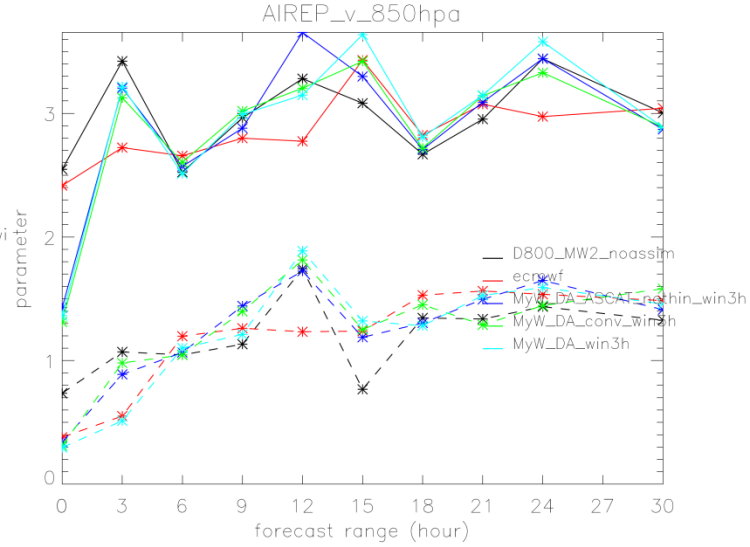
- Harmonie small-scale spatial structures *partly* verify with observations (real atmosphere)

Forecast verification using aircraft observations









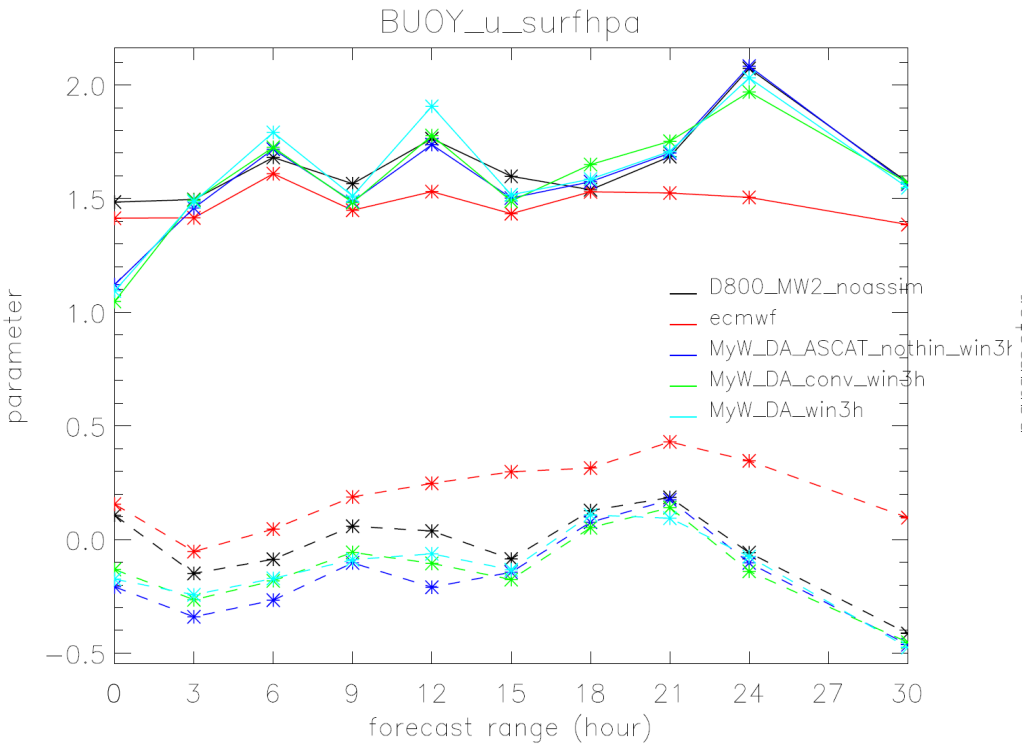
Harmonie DA

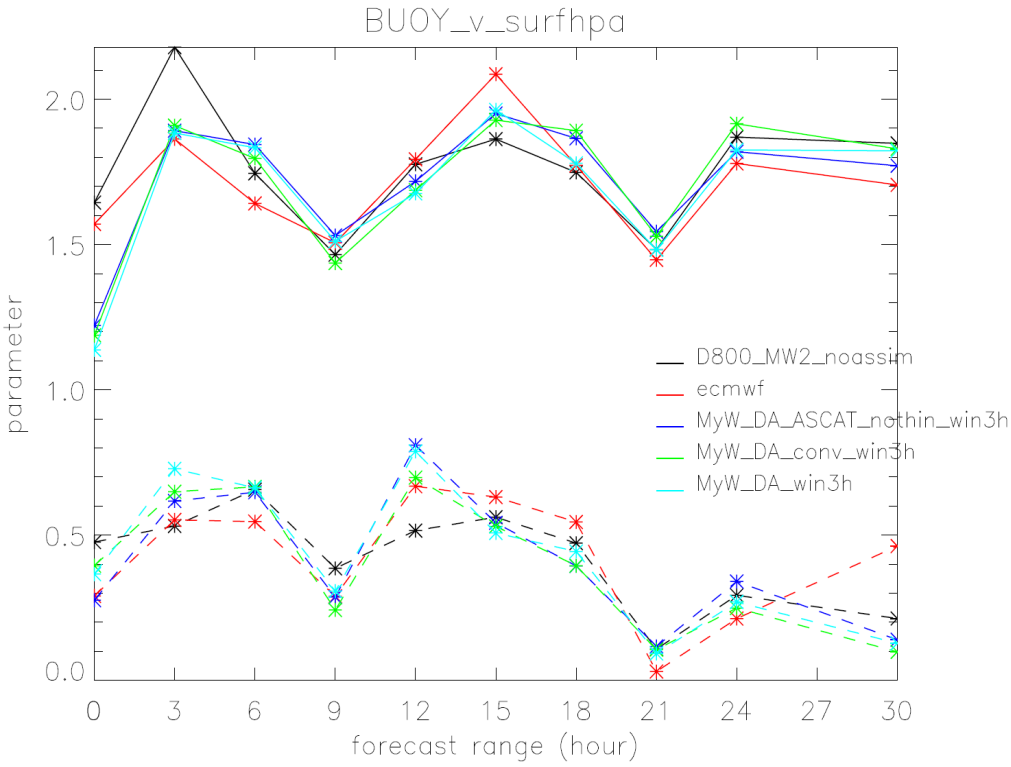
- Does improve analysis
- does not improve 250hPa-T forecast
- does improve 850hPa-T forecast

No assim
Conv
Conv+ascat+qscat
Conv+ascat – no thinn
ECMWF

- does not improve 850hPa-u forecast
- Scat impact on model wind at 850 hPa, not at 250 hPa (deviation green/blue/cyan)

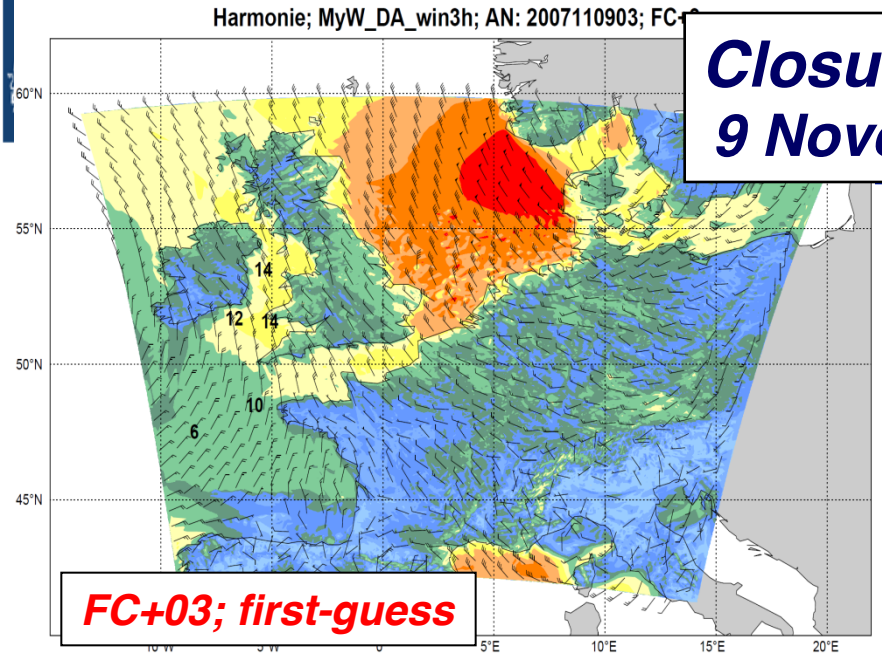
Forecast verification against buoys

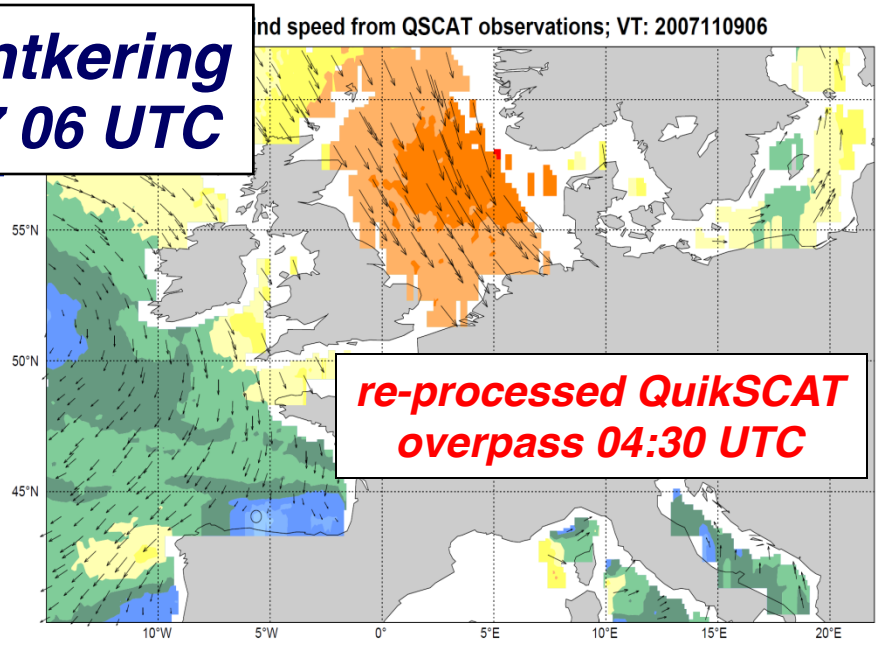




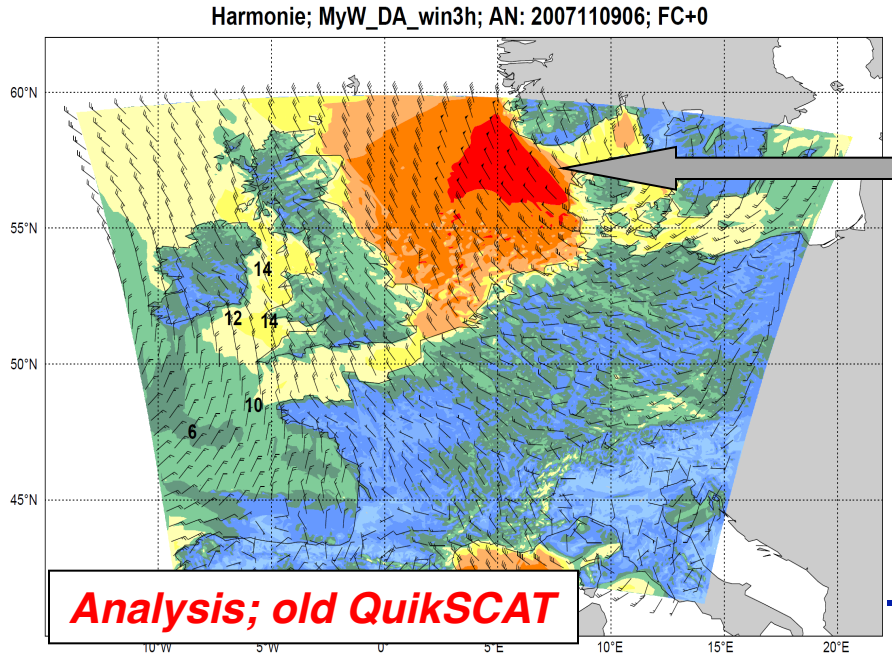
……. ?

Closure Maeslantkering
9 November 2007 06 UTC

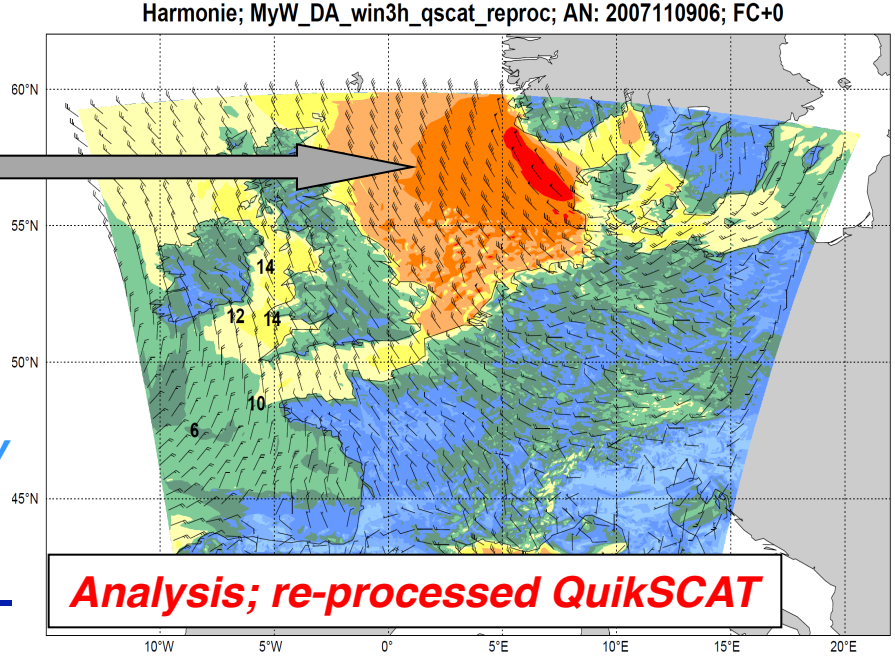




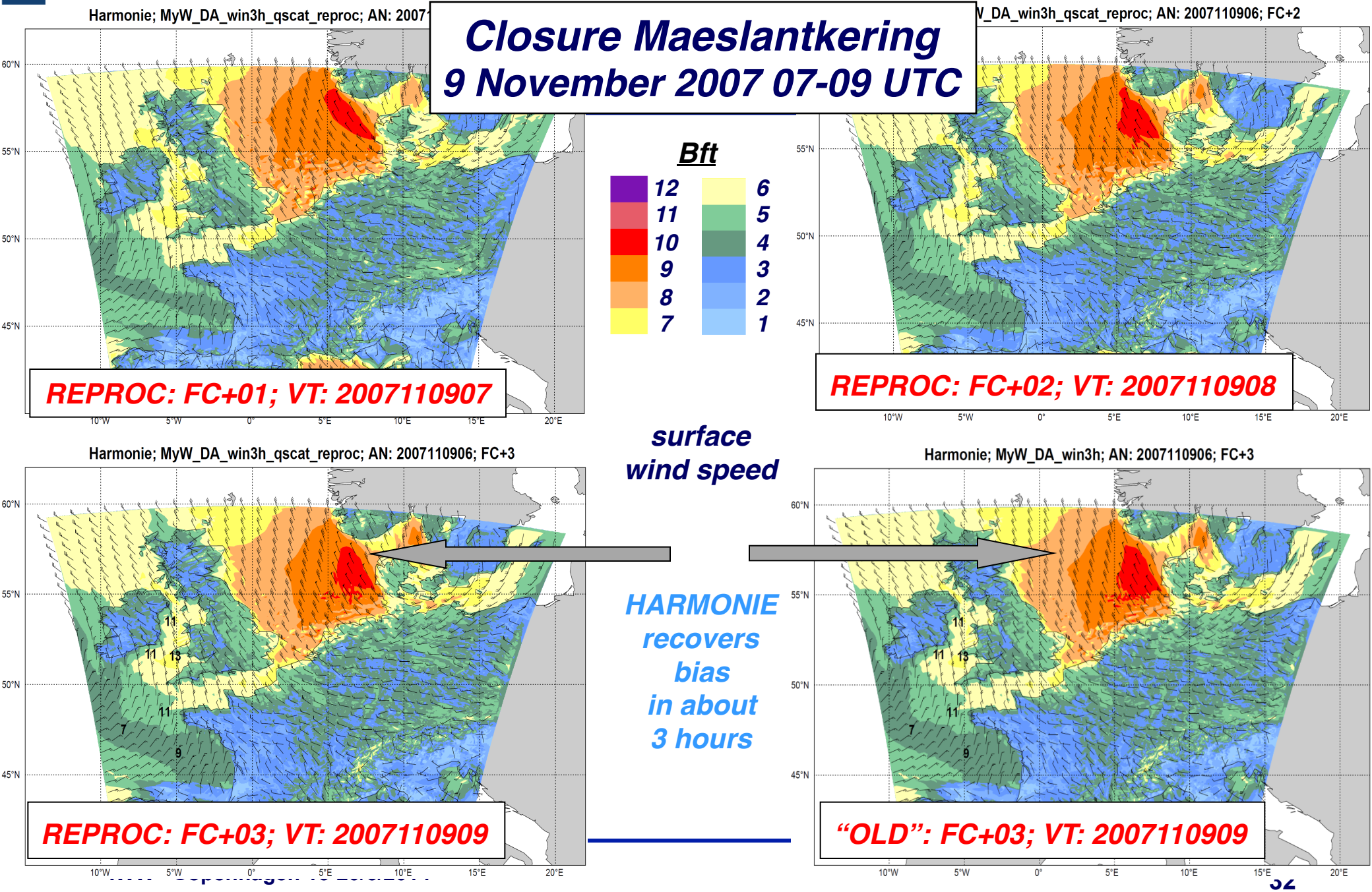
surface wind speed



QuikSCAT reduces HARMONIE bias substantially



Closure Maeslantkering
9 November 2007 07-09 UTC



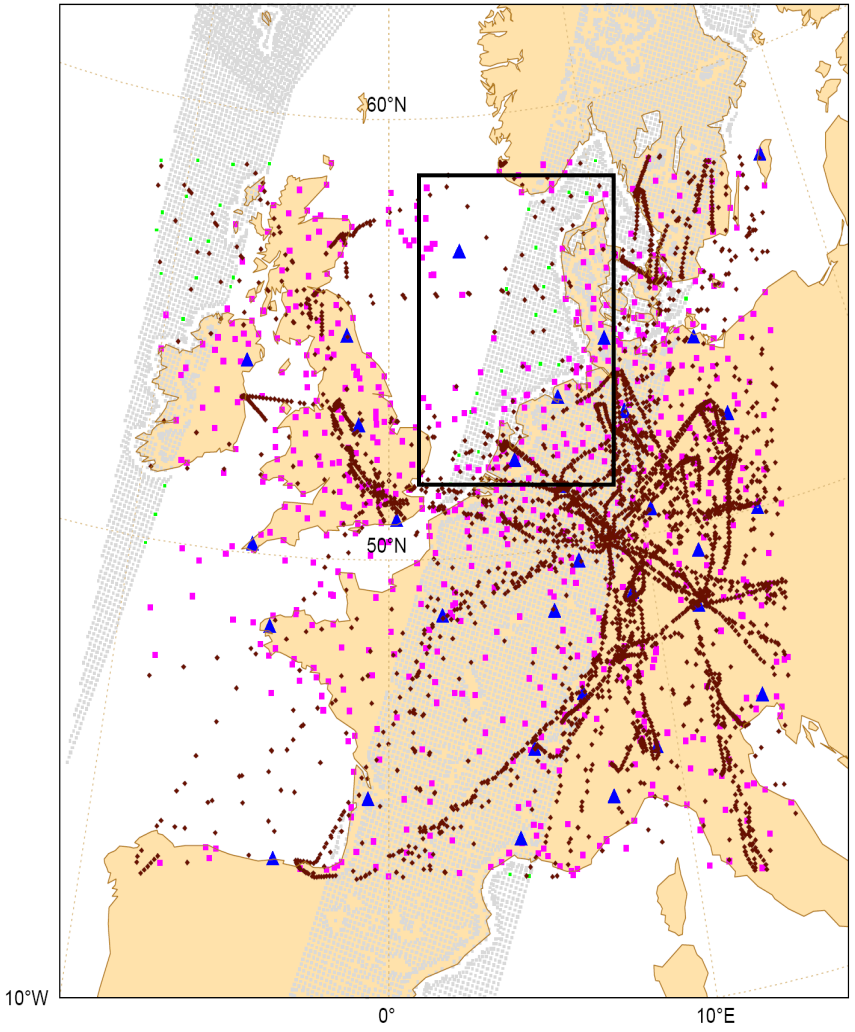
Harmonie DA default settings – 37h1.2

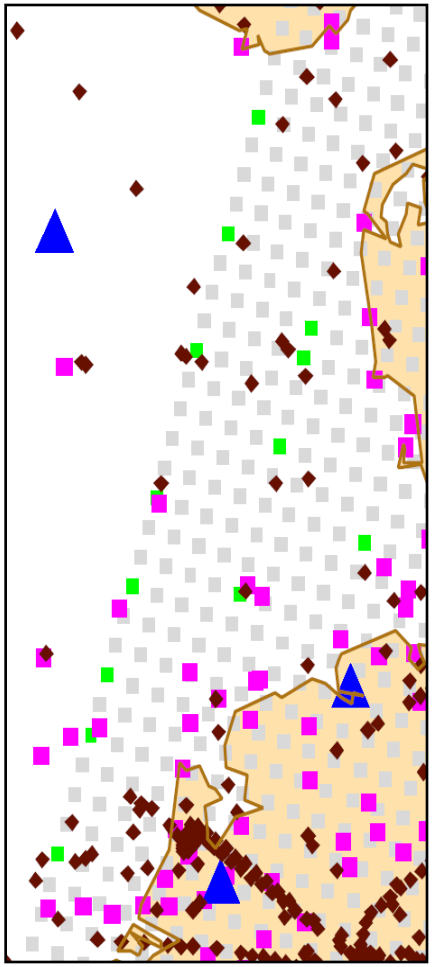
- 6-hour assimilation window
- ASCAT thinning
  - Factor 4 in both directions => ~94% not used
  - Probably based on ASCAT 25-km product assimilation in ECMWF and 100 km observation separation used by ECMWF + error inflation
- QSCAT: no thinning
  - Probably based on use of 50-km product by ECMWF + error inflation

➢ SCAT assimilation needs to be done with great care
  - HARMONIE data thinning is based on a single parameter for each observing system, irrespective of the sampling of the used product

Default ASCAT thinning

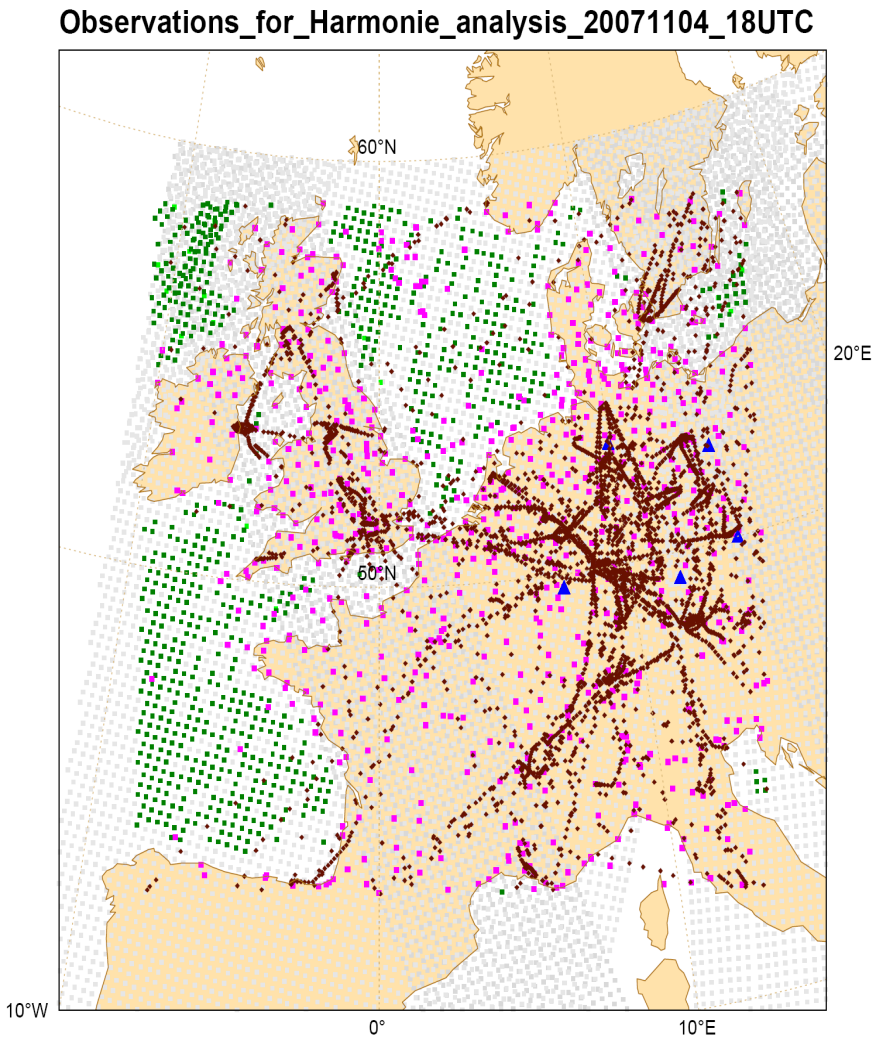
Observations_for_Harmonie_analysis_20071104_12UTC





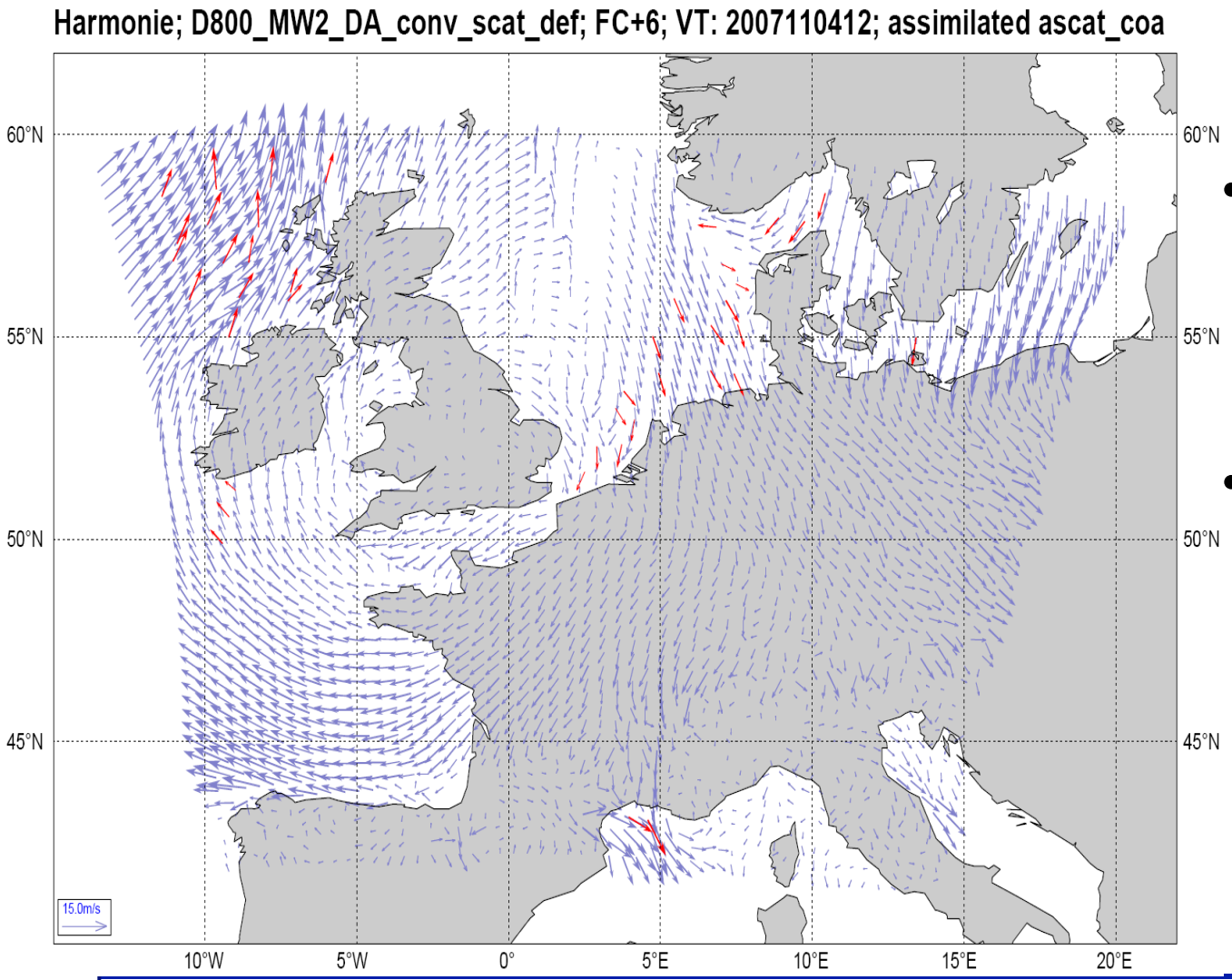
- Analysis 4 Nov. 2007 12UTC
- Assimilation of
  - TEMP
  - AIREP
  - SYNOP
  - ASCAT
  - QuikSCAT
  - all scat locations

6 hours later .....



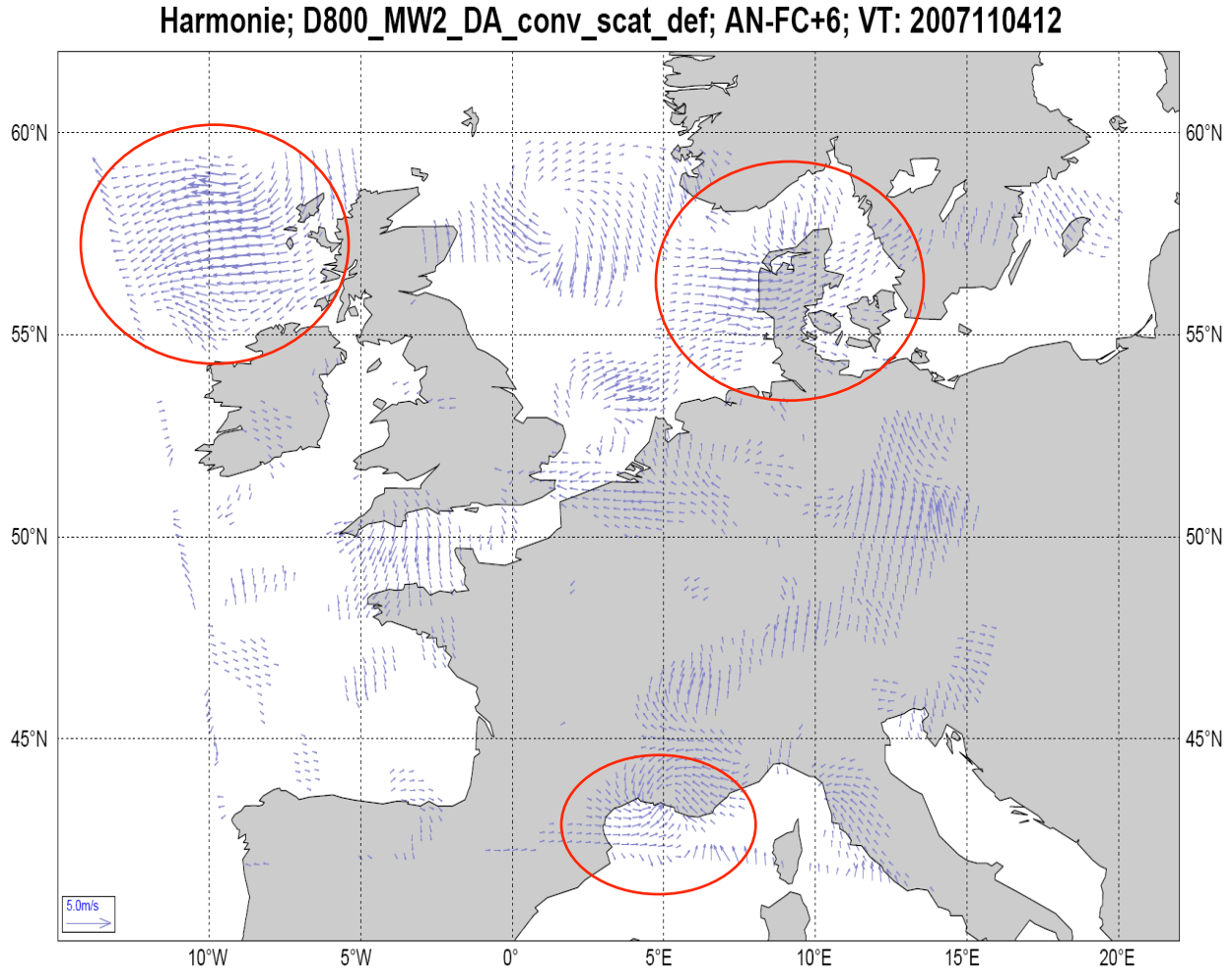
- Analysis 4 Nov. 2007 18UTC
- Assimilation of
  - TEMP, AIREP, SYNOP, ASCAT, QuikSCAT (all scat locations)
- ASCAT coastal product
  - Default thinning setting is 4 times the observation spacing
- QuikSCAT 25-km product
  - No thinning has been implemented (because the nominal product was 50-km resolution)

Harmonie 10-m wind field + ASCAT scatterometer winds



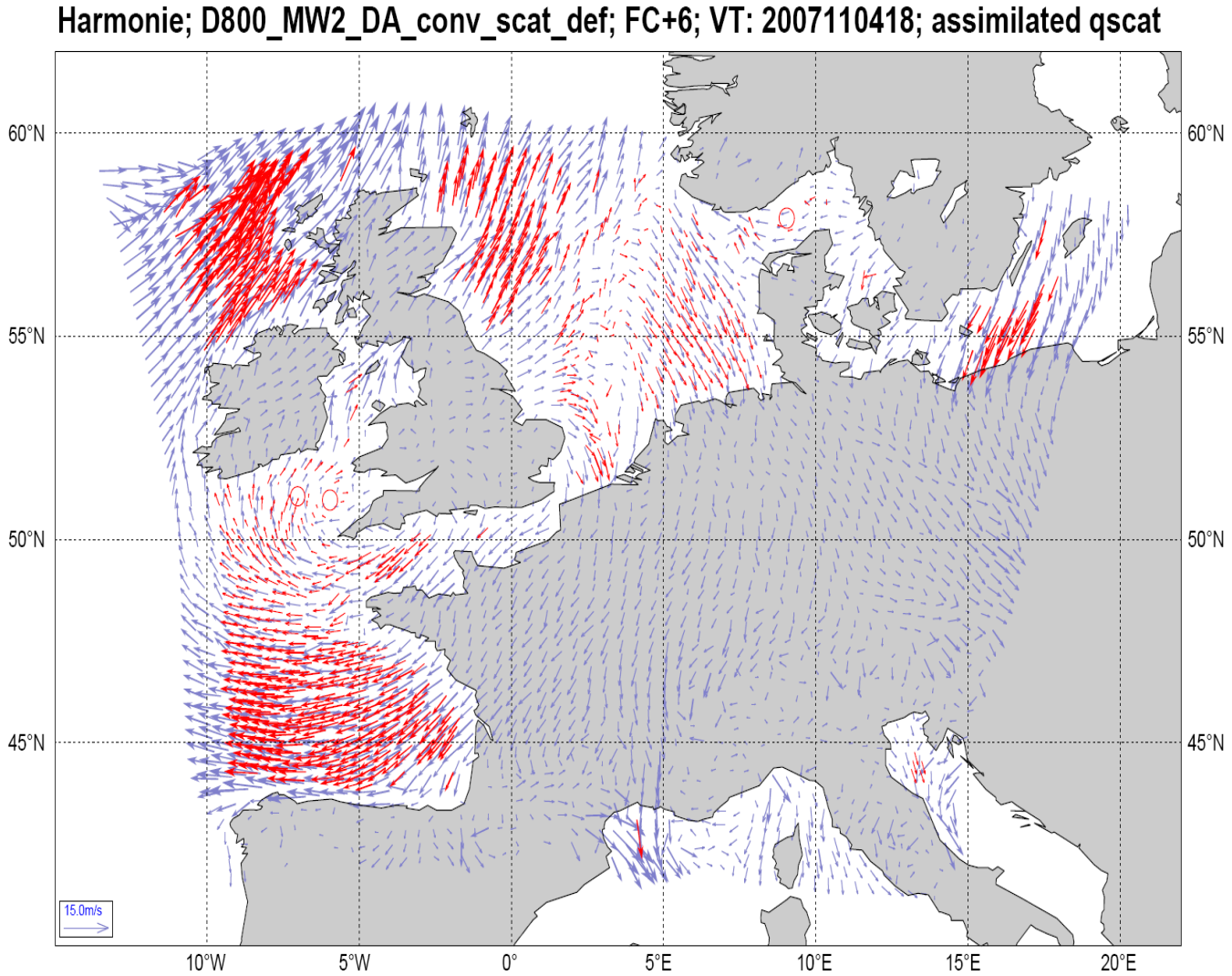
- Harmonie 10-m wind field + assimilated ASCAT scatterometer winds
- Default observation thinning reduces data coverage substantially and reduces ASCAT information content

Observations impact (analysis increment)



- Red circles: analysis increment mainly from assimilation of scatterometer
- Scatterometer corrects model winds in the order of a couple of ms^{-1}

Harmonie 10-m wind field + QuikSCAT scatterometer winds



- Harmonie 10-m wind field + assimilated QuikSCAT scatterometer winds
- DA system is smart enough to reject most winds close to the frontal zone!