Better Ku-band scatterometer wind ambiguity removal with ASCAT-based empirical background error correlations in 2DVAR

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2D Variational Ambiguity Removal

- 2DVAR is the default ambiguity removal method in the KNMI C-band and Ku-band wind processors, AWDP and PenWP
- 2DVAR first constructs an analysis from the ambiguous scatterometer winds, a background wind field and specified errors, and next selects the ambiguity closest to the analysis
- 2DVAR similar to 3DVAR and 4DVAR data assimilation systems
- Quantities affecting the analysis:
  > observation error SDs (fixed, default 1.8 m/s)
  > background error SDs (fixed, default 2.0 m/s)
  > background error correlations, BECs (Gaussian; width 600 km in tropics and 300 km elsewhere)

Empirical Background Error Correlations (EBECs)

- EBECs can be derived from o-b data and specify the observed statistical mean BEC (*Vogelzang and Stoffelen*, 2011)
- EBECs have a range > 2000 km, much larger than the default Gaussian BECs (see last IOVWST)
- Yet, for ASCAT-coastal it has been shown that they are able to introduce small-scale structures in the analysis, leading to improved ambiguity removal
- Recent studies by *Lin et al.* showed the beneficial effect of EBECs in combination with flow-dependent error SDs for observation and background errors on 2DVAR for ASCAT
- Implemented in AWDP-v3.1 available at nwpsaf.eu
- What about application to Ku-band data (OSCAT, RapidScat)?

Derivation of EBECs

Well-calibrated observation and background (no bias),

$$o = t + \epsilon_o \qquad b = t + \epsilon_b$$

with t the common signal (truth) and ϵ_o and ϵ_b random errors,

$$o - b = \epsilon_o - \epsilon_b$$

and the autocorrelation of $o - b$ reads

$$\rho(o-b, o-b) = \rho(\epsilon_o, \epsilon_o) + \rho(\epsilon_b, \epsilon_b)$$

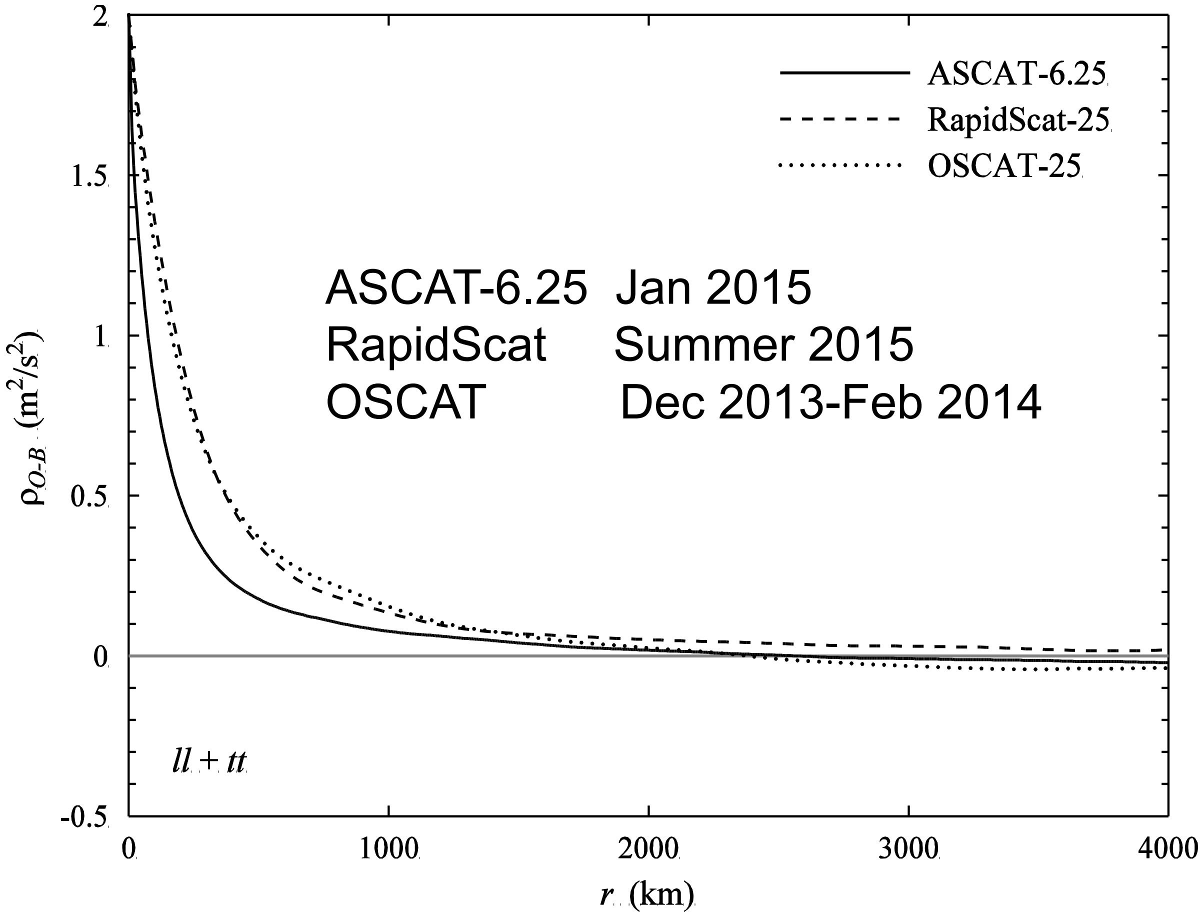
when $\rho(\epsilon_o, \epsilon_b) = \rho(\epsilon_b, \epsilon_o) = 0$ (observation and background are independent).

If also the observations are independent EBECs emerge

$$\rho(\epsilon_b, \epsilon_b) = \rho(o-b, o-b) \text{ for } \Delta x \neq 0$$

See *Vogelzang and Stoffelen* (2011) for further details,
in particular the transformation to the potential domain

EBECs from Ku-band data



EBEC calculation converges when $\rho_{ll} + \rho_{tt}$ crosses zero

l : along-track
t : cross-track

Too much spatial error correlation in RapidScat and OSCAT $o - b$ below 1000 km => EBEC calculation FAILS!

- In fact, due to MSS spatial filtering in 2DVAR $\rho(\epsilon_o, \epsilon_o) > 0$; $\rho(\epsilon_b, \epsilon_o) \neq 0$

EBECs for Ku-band data

- But EBECs are a property of the background, not of the scatterometer, so we use ASCAT-derived EBECs for Ku-band ambiguity removal
- Data considered:
  - > RapidScat-25 and RapidScat-50 in summer 2015
  - > OSCAT-25 and OSCAT-50 in Dec 2013 – Feb 2014

Buoy comparison – 2DVAR analysis winds

	Run	Grid size (km)	σ_s (m/s)	σ_d (deg.)	σ_u (m/s)	σ_v(m/s)	Collocations
RapidScat	Standard	25	1.20	14.3	1.43	1.55	7930 (5553)
	NBEC	25	1.11	14.2	1.38	1.47	7930 (5553)
	Standard	50	1.24	15.1	1.47	1.56	8206 (5851)
	NBEC	50	1.19	14.5	1.43	1.51	8206 (5882)
OSCAT	Standard	25	1.48	17.0	1.98	1.98	8128 (6693)
	NBEC	25	1.38	16.3	1.91	1.91	8128 (6712)
	Standard	50	1.53	16.6	1.95	1.97	7252 (6060)
	NBEC	50	1.48	16.2	1.93	1.94	7252 (6072)

- ✓ ASCAT-derived EBECs yield better comparison of the 2DVAR analysis wind speed and direction with buoys, suggesting a better spatial resolution analysis.
- ✓ ASCAT-derived EBECs introduce more details into the analysis and provide a better fit to local observations

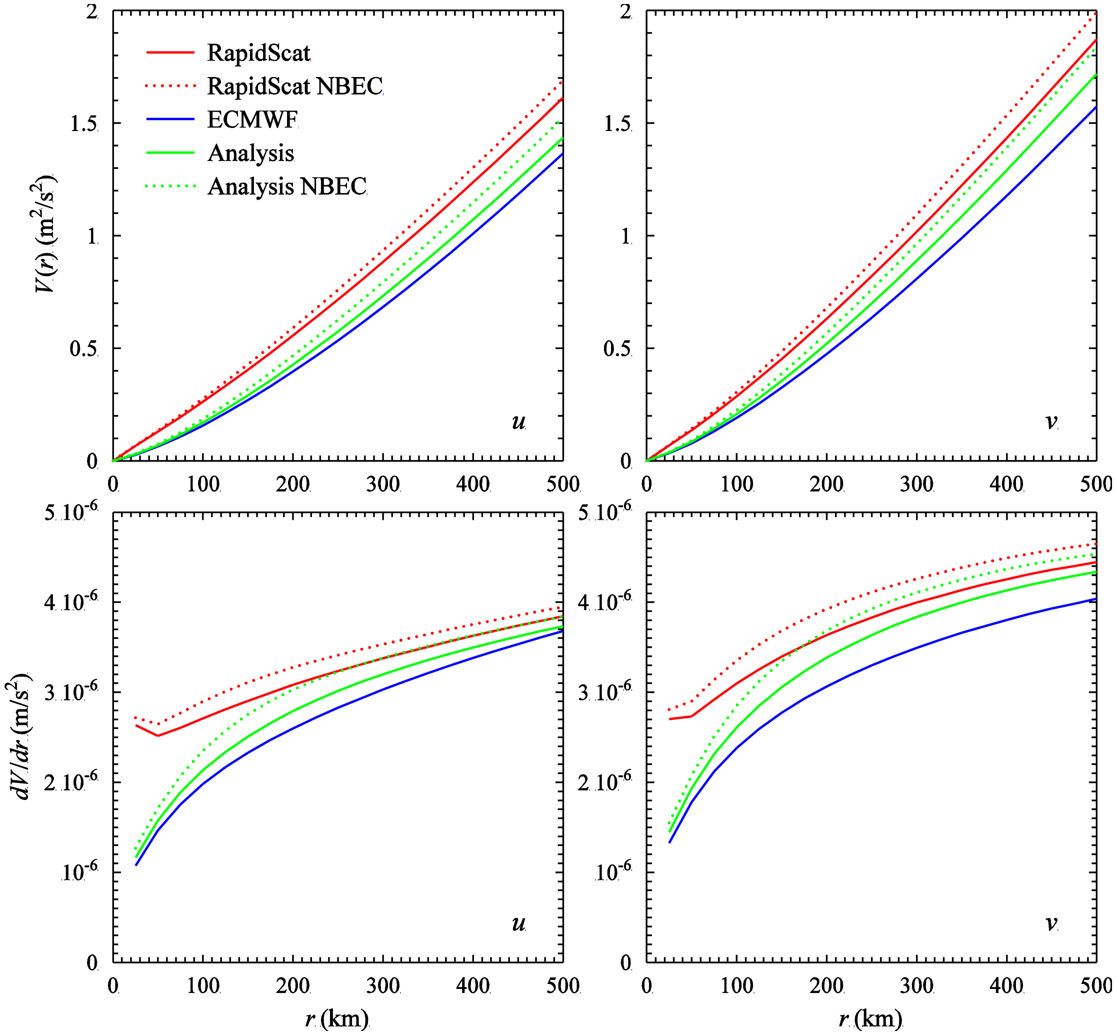
Buoy comparison – 2DVAR selected winds

	Run	Grid size (km)	σ_s (m/s)	σ_d (deg.)	σ_u (m/s)	σ_v(m/s)	Collocations
RapidScat	Standard	25	0.99	15.7	1.41	1.53	7930 (5775)
	EBEC	25	0.99	15.2	1.38	1.49	7930 (5783)
	Standard	50	1.06	15.7	1.45	1.54	8206 (6032)
	EBEC	50	1.06	15.4	1.42	1.52	8206 (6028)
OSCAT	Standard	25	1.28	17.7	1.95	1.95	8128 (6887)
	NBEC	25	1.27	17.2	1.93	1.91	8128 (6897)
	Standard	50	1.34	17.2	1.91	1.92	7252 (6209)
	NBEC	50	1.34	17.0	1.91	1.91	7252 (6216)

Wind direction statistics only for wind speeds > 4 m/s (number in brackets)

- ✓ ASCAT-derived EBECs have little effect on wind speed (2DVAR selection works more on direction choice)
- ✓ EBECs improve wind direction comparison for all by 0.3 – 0.7 deg.

Spatial variance



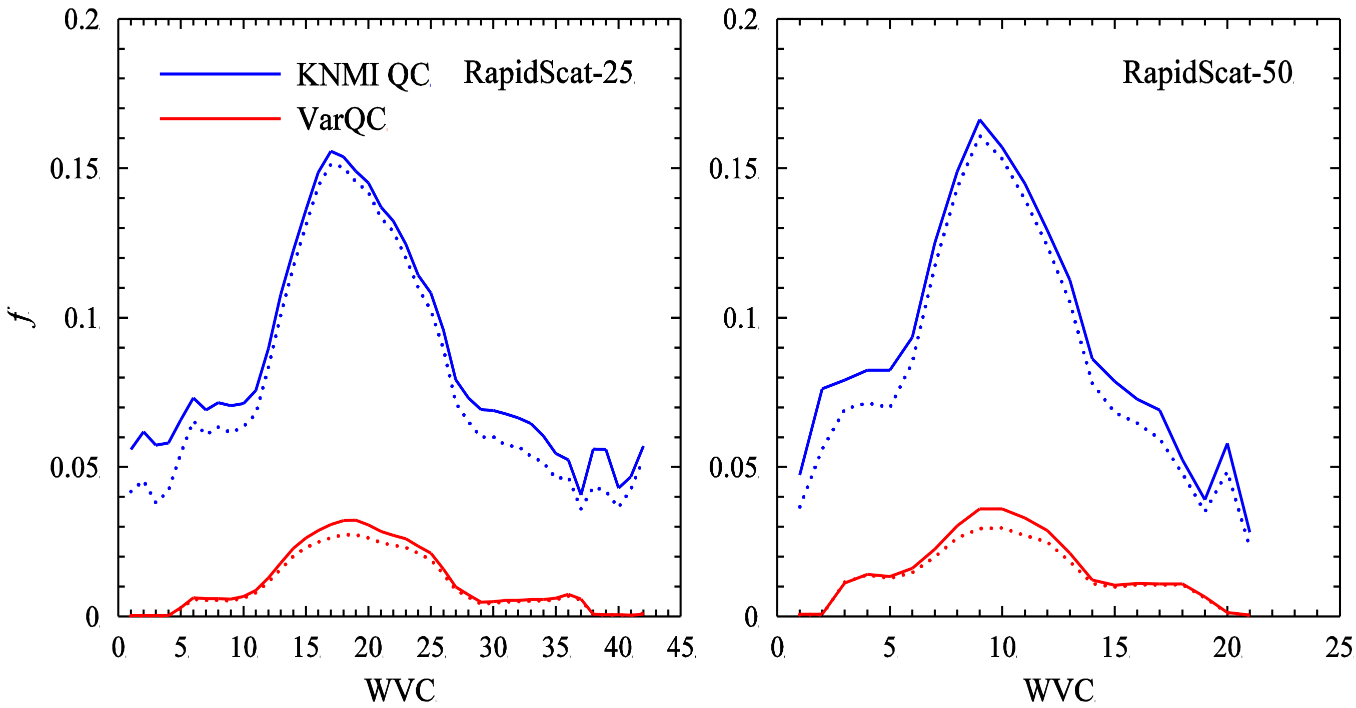
Cumulative variance

EBECs increase the signal content of the analysis – and hence improve the selection – at intermediate and small scales

Same for RapidScat-50, OSCAT-25, and OSCAT-50

Variance density

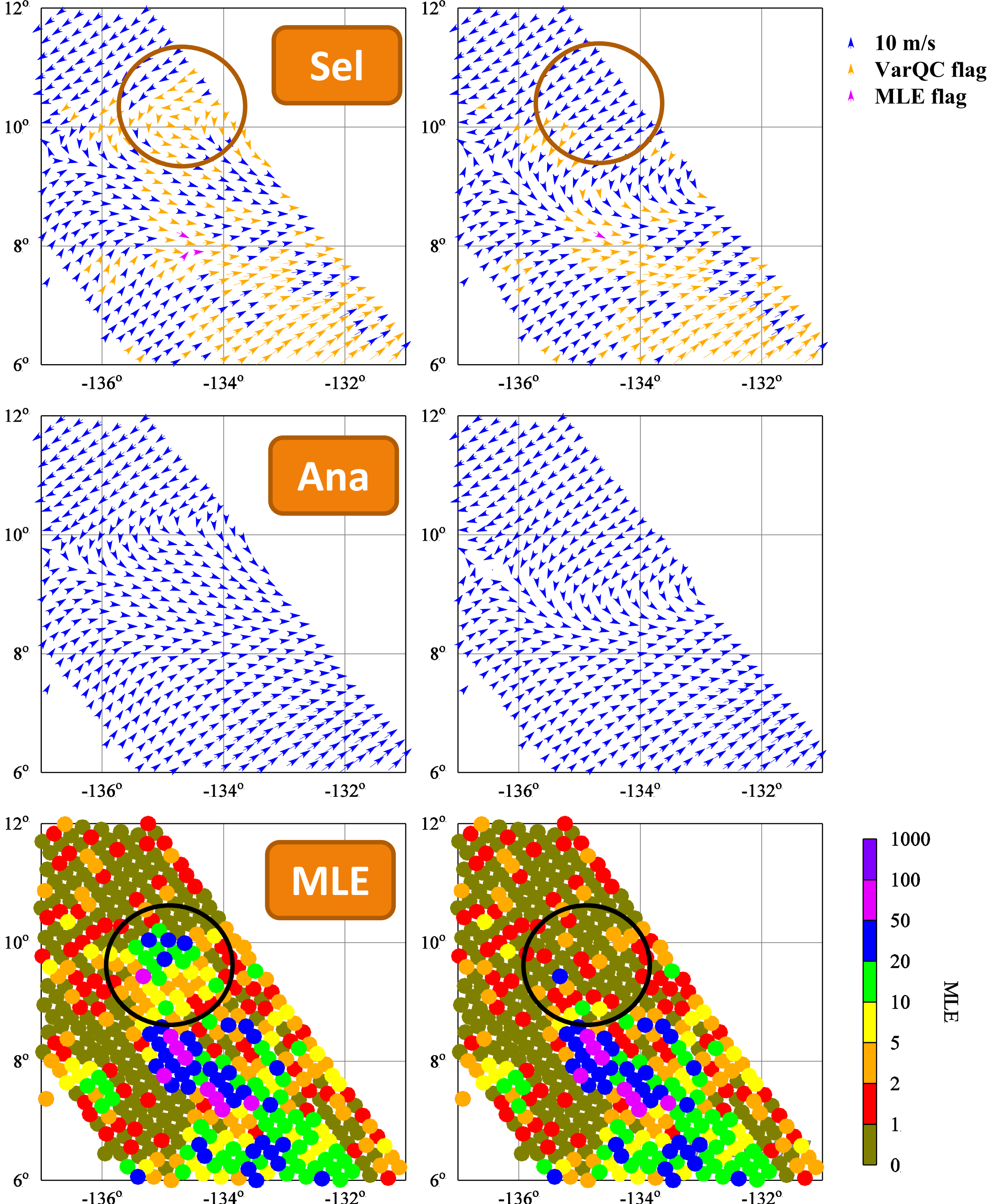
Flag setting frequency



Solid curves: standard

Dotted curves: EBECs

✓ ASCAT EBECs decrease the frequency with which the KNMI QC and VarQC flags are set, because the analysis better fits the observations and more representative ambiguities are selected
(less extreme MLE; higher probability; more spatially consistent)



RapidScat-25
June1, 2015

Pacific

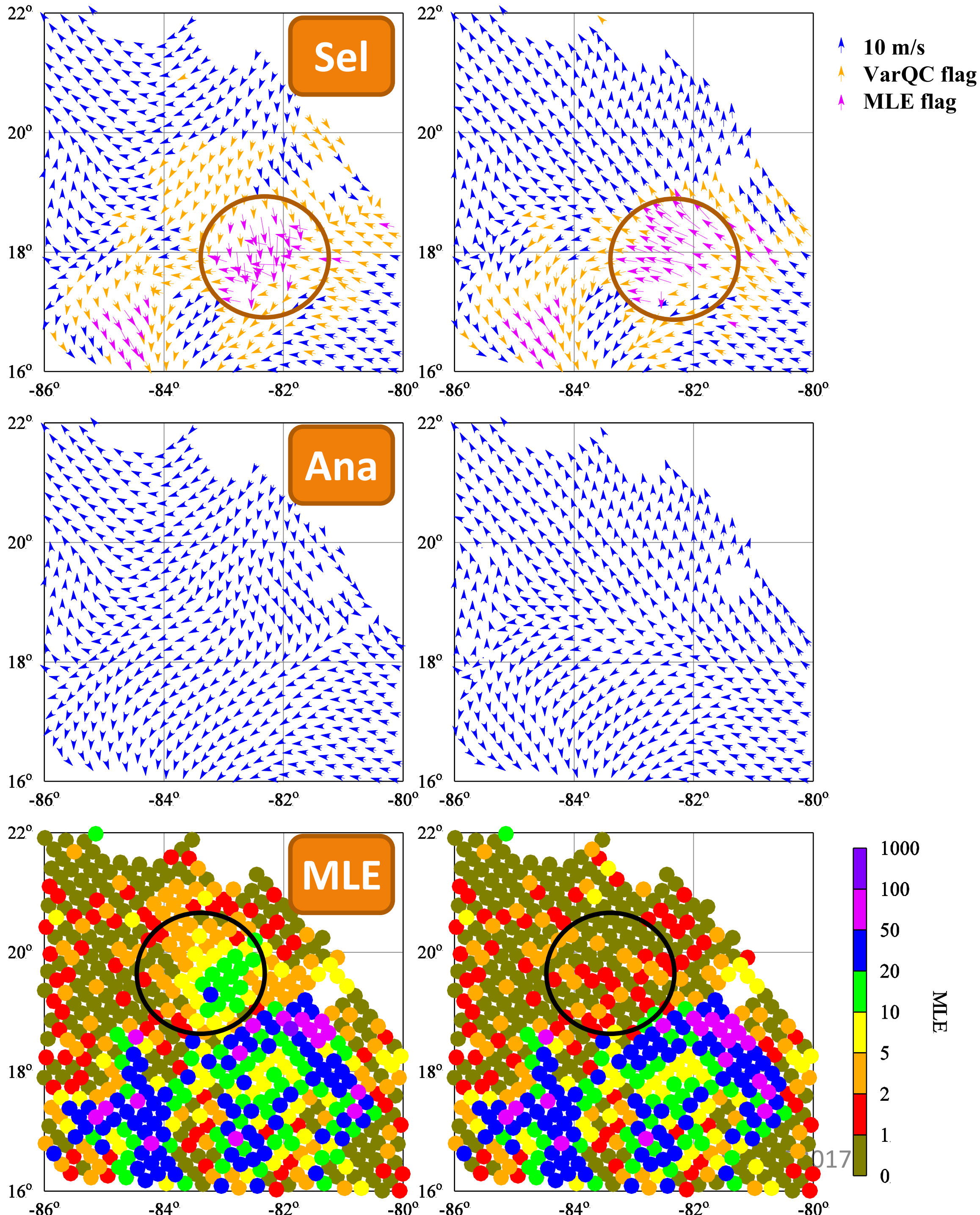
left: standard
right : EBECs

Flow around high pressure saddle point

upper: 2DVAR selection: less KNMI QC (MLE) flagged winds

middle: 2DVAR analysis: change in flow pattern

bottom: MLE: ambiguities with smaller MLE selected => more consistent wind field



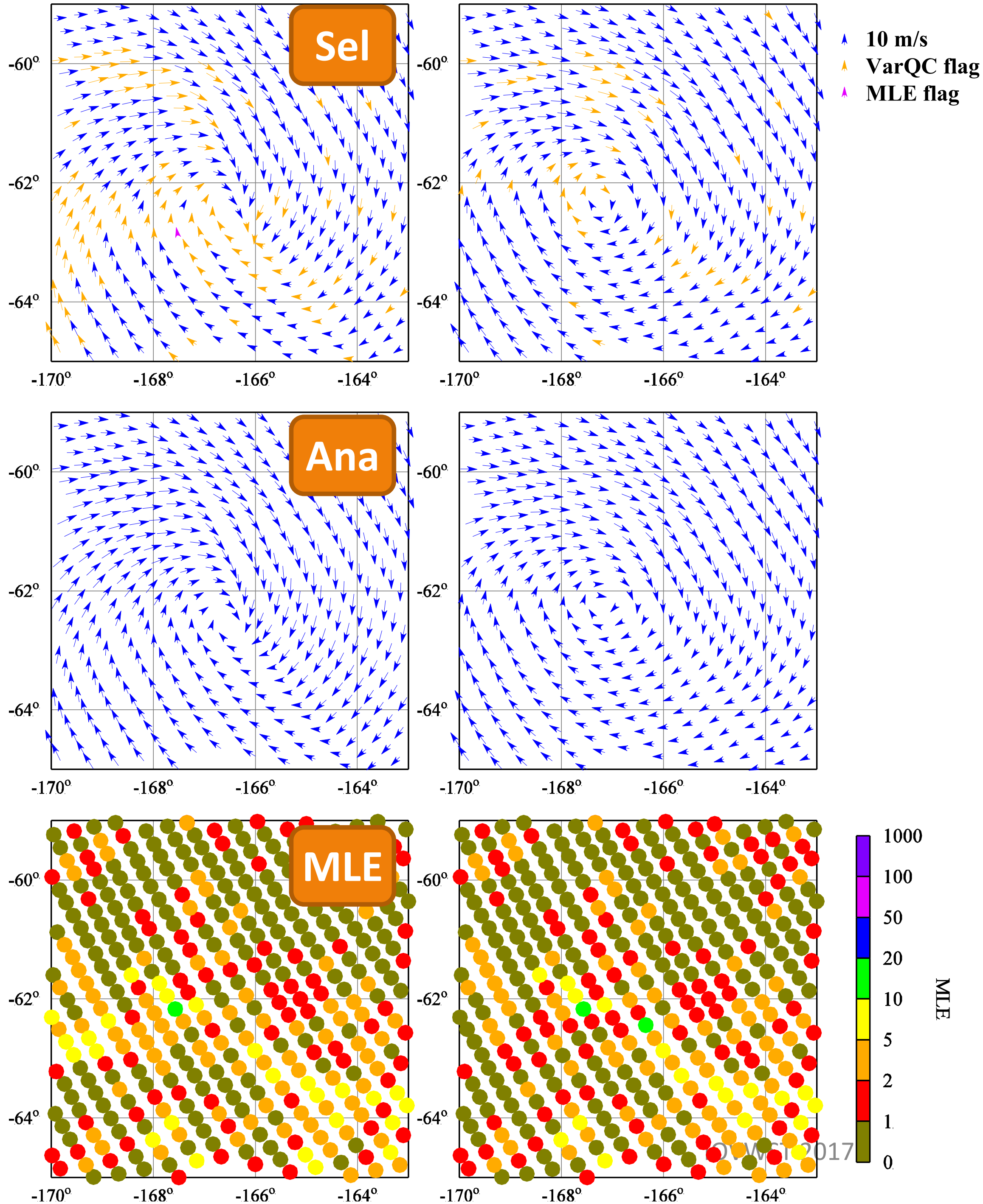
RapidScat-25
June 6, 2015

Gulf of Mexico

upper: 2DVAR selection: less ambiguity removal errors

middle: 2DVAR analysis: different flow pattern

bottom: MLE: ambiguities with smaller MLE selected in northern part



OSCAT-25
Jan 14, 2014

Southern Pacific

Extratropical cyclone

upper: 2DVAR selection: better defined cyclone center with EBECs and less KNMI QC flagging

middle: 2DVAR analysis: better defined cyclone center

bottom: MLE: no large differences in this case

Effect of ASCAT EBECs - resume

- 2DVAR analysis winds compare better with buoy winds
- 2DVAR selected winds compare better with buoy winds
- 2DVAR analysis winds deviate more from initial background (not shown here)
- More variance at small and intermediate scale in 2DVAR analysis and selected winds
- Less KNMI QC and VarQC flagging: 2DVAR analysis fits observations and EBECs better
- Observation part of the 2DVAR cost function decreases (not shown)
- Total 2DVAR cost function decreases (not shown)

Conclusions

- ASCAT-derived EBECs have a clear beneficial effect on Ku-band ambiguity removal with 2DVAR:

  > better buoy comparison

  > spatially and statistically more consistent wind fields

  > smaller MLE and better rain screening

- Broad static background error correlations are able to introduce fine details in the analysis – suitable EBECs allow more weight on observations and better fits? Still puzzling!

- Available as option in latest version of PenWP software, freely available at nwpsaf.eu