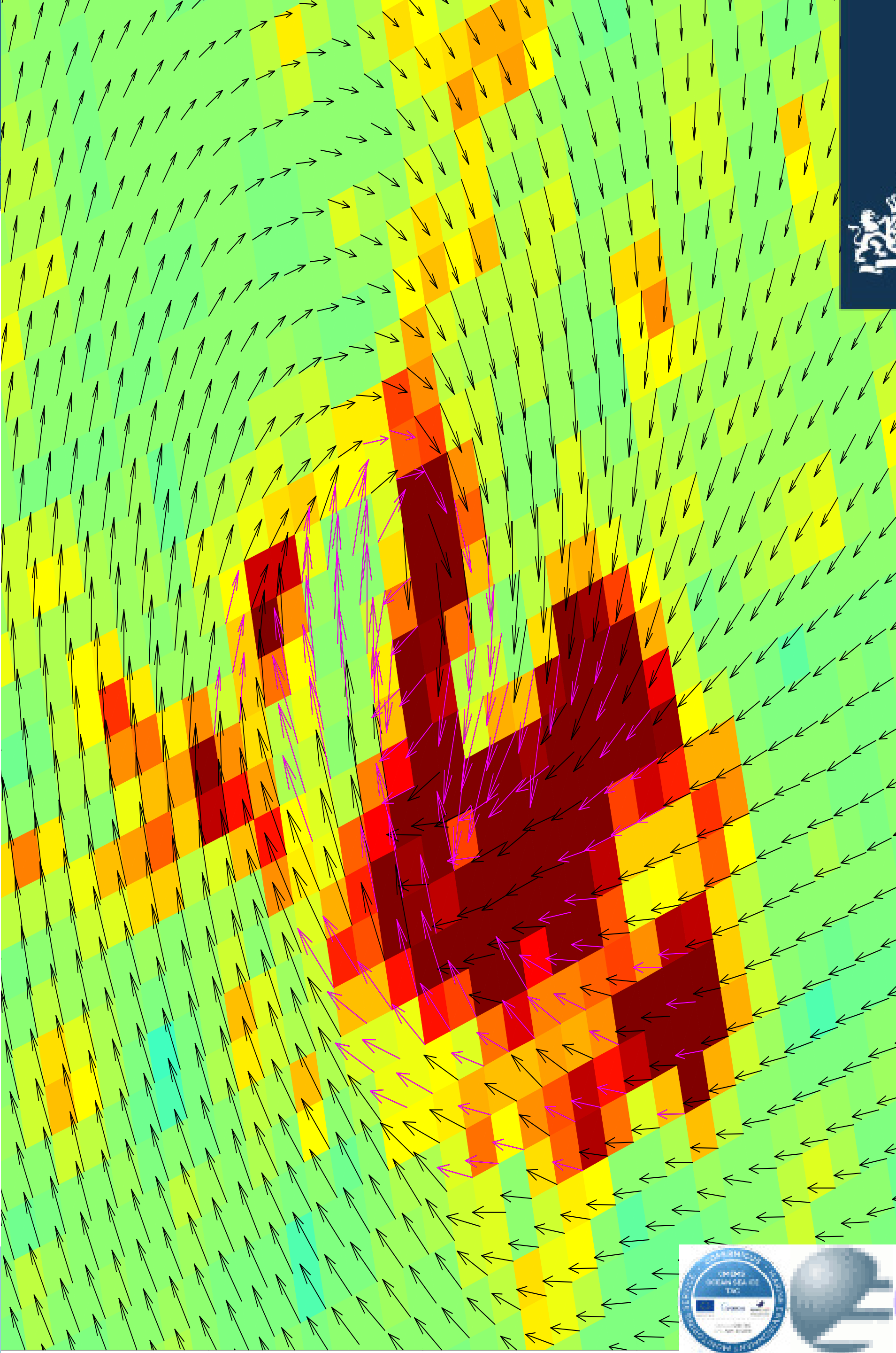


Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the Environment

Wind scatterometers, the tropics and the ECMWF model

Ad.Stoffelen@knmi.nl

Leader active sensing group
R&D satellite observations
KNMI

Jur Vogelzang, Anton Verhoef, Maria Belmonte, Jeroen Verspeek, Jos de Kloe
KNMI, the Netherlands

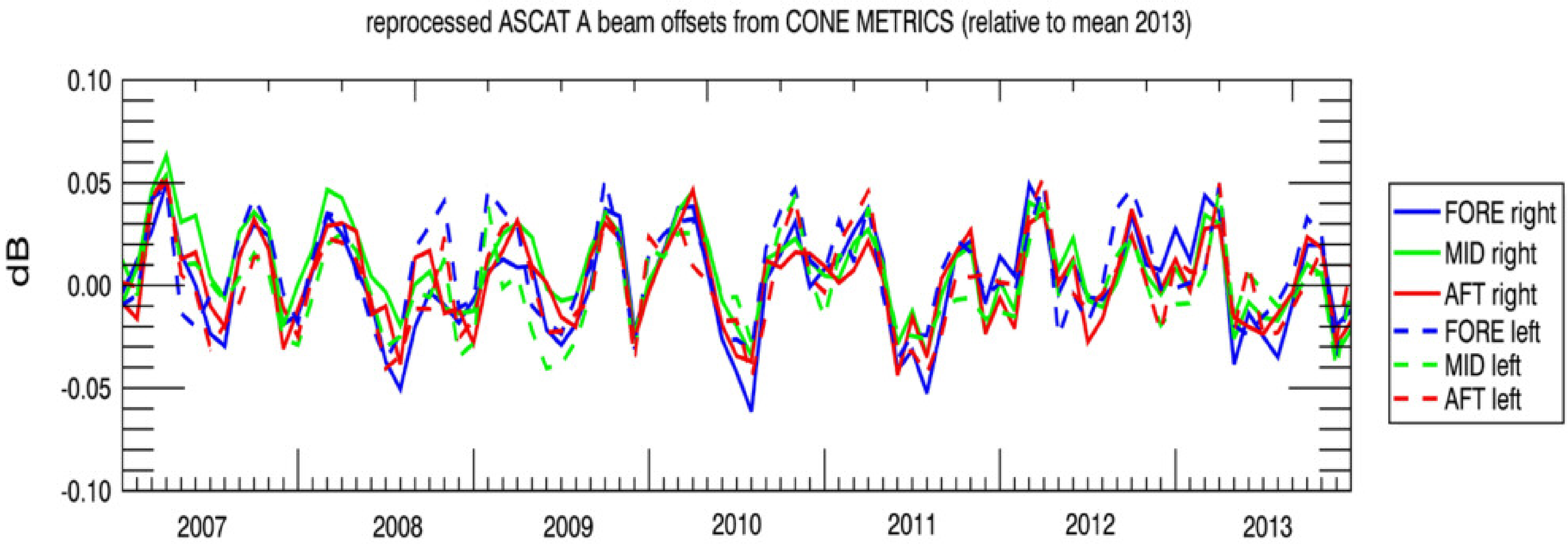
Wenming Lin, Marcos Portabella, Greg King
ICM, Spain

References

- W Lin, M Portabella, A Stoffelen, J Vogelzang, A Verhoef, 2016, On mesoscale analysis and ASCAT ambiguity removal, Quarterly Journal of the Royal Meteorological Society 142 (697), 1745-1756
- K Houchi, A Stoffelen, GJ Marseille, J De Kloe, Statistical Quality Control of High-Resolution Winds of Different Radiosonde Types for Climatology Analysis, Journal of Atmospheric and Oceanic Technology 32 (10), 1796-1812
- K. Houchi (thesis TU/e, the Netherlands; 5 april 2016)
- W. Lin et al., 2015, ASCAT wind quality under high subcell wind variability conditions, JGR Oceans, DOI: 10.1002/2015JC010861, http://onlinelibrary.wiley.com/doi/10.1002/2015JC010861/full
- Zadelhoff, G.-J Van, A Stoffelen, P W Vachon, J Wolfe, J Horstmann, M Belmonte Rivas, Atmospheric Measurement Techniques Retrieving hurricane wind speeds using cross-polarization C-band measurements, Atmospheric Measurement Techniques 02/2014; 7(2):437-449.
- Vogelzang, Jur, Gregory P. King, Ad Stoffelen, Spatial variances of wind fields and their relation to second-order structure functions and spectra, Journal of Geophysical Research: Oceans 01/2015
- King, Gregory P., Jur Vogelzang, Ad Stoffelen, Upscale and downscale energy transfer over the tropical Pacific revealed by scatterometer winds, Journal of Geophysical Research: Oceans 12/2014
- King, Gregory P., Jur Vogelzang, Ad Stoffelen, Second-order structure function analysis of scatterometer winds over the Tropical Pacific: Part 1. Spectra and Structure Functions, Journal of Geophysical Research: Oceans 12/2014,
- Mccoll, Kaighin A., Jur Vogelzang, Alexandra G Konings, Dara Entekhabi, María Piles, Ad Stoffelen, Extended Triple Collocation: estimating errors and correlation coefficients with respect to an unknown target, Geophysical Research Letters 10/2014,
- Wijnant, I.L., G.J. Marseille, A. Stoffelen, H.W. van den Brink and A. Stepek, Validation of KNMI Wind atlas with scatterometer winds (Phase of KNW project), KNMI Technical Report TR353, DOI:10.13140/RG.2.1.2707.8562
- J. Edson et al., COARE3.5 and wave boundary layer
- International Ocean Vector Winds Science Team meetings (IOVWST)

Very Stable

- ASCAT-A beams stay within a few hundreds of a dB (eq. to m/s)
- Cone position variation due to seasonal wind variability

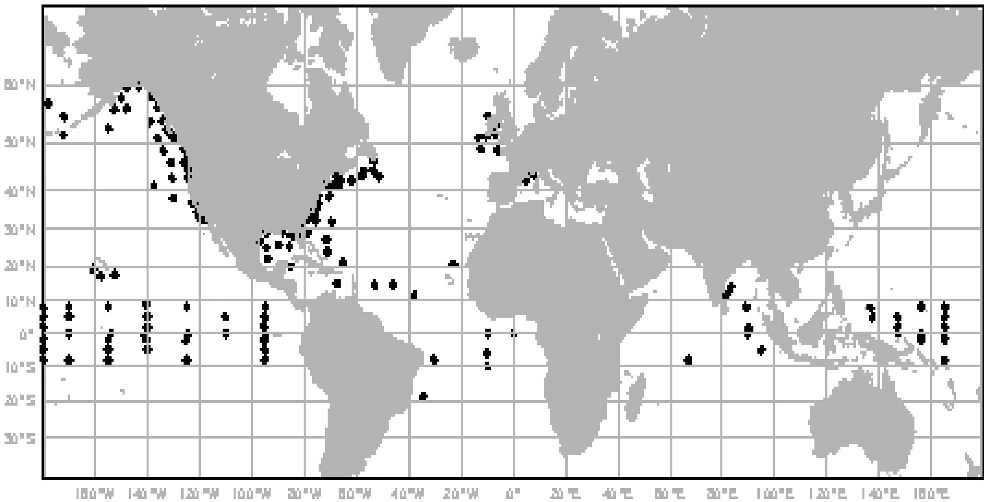


Stress-equivalent wind

- Radiometers/scatterometers measure ocean roughness
- Ocean roughness consists in small (cm) waves generated by air impact and subsequent wave breaking processes; depends on gravity, water mass density, surface tension σ, and e.m. sea properties (assumed constant)
- Air-sea momentum exchange is described by $\boldsymbol{\tau} = \rho_{air}\, u_* \boldsymbol{u}_*$, the stress vector; depends on air mass density ρ_{air} , friction velocity vector $\boldsymbol{u}_*$
- Surface layer winds (e.g., $\boldsymbol{u}_{10}$) depend on $\boldsymbol{u}_*$, atmospheric stability, surface roughness and the presence of ocean currents
- Equivalent neutral winds, $\boldsymbol{u}_{10\mathrm{N}}$, depend only on $\boldsymbol{u}_*$, surface roughness and the presence of ocean currents and is currently used for backscatter geophysical model functions (GMFs)

- Stress-equivalent wind, $\boldsymbol{u}_{10\mathrm{S}} = \sqrt{\rho_{air}} \cdot \boldsymbol{u}_{10\mathrm{N}} / \sqrt{\rho_0}$, is suggested to be a better input for backscatter GMFs, since more closely related to $\boldsymbol{\tau}$

How good are these winds?



Triple collocation errors

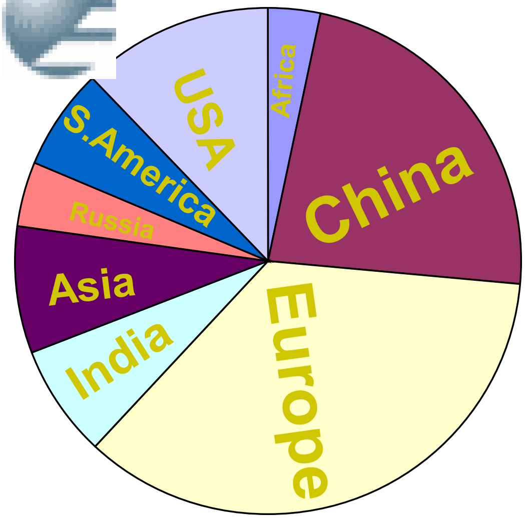
ASCAT, buoy and ECMWF data from winter 2012/ 2013

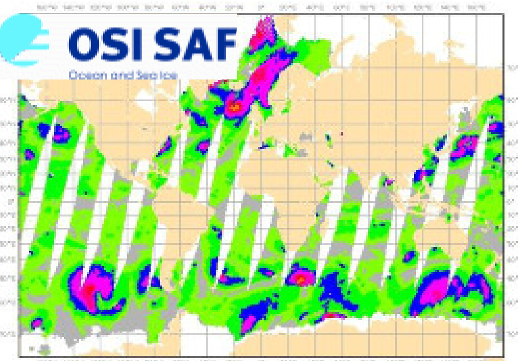
- Small scatterometer wind errors on scatterometer scale
- All scatterometers have very similar local quality
- Buoys measure local variability

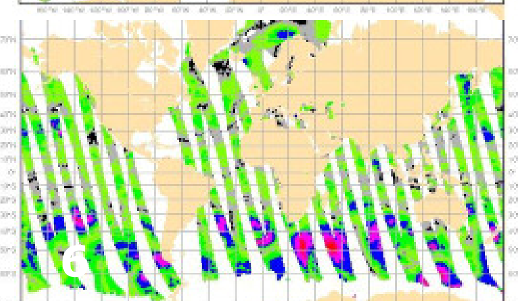
	Scatterometer		Buoys		ECMWF	
m/s	σ_u	σ_v	σ_u	σ_v	σ_u	σ_v
ASCAT-A 25-km	0.63	0.71	1.21	1.35	1.39	1.44
ASCAT-B 25-km	0.63	0.66	1.26	1.39	1.38	1.42

Jur Vogelzang, KNMI

EO Wind Services at KNMI







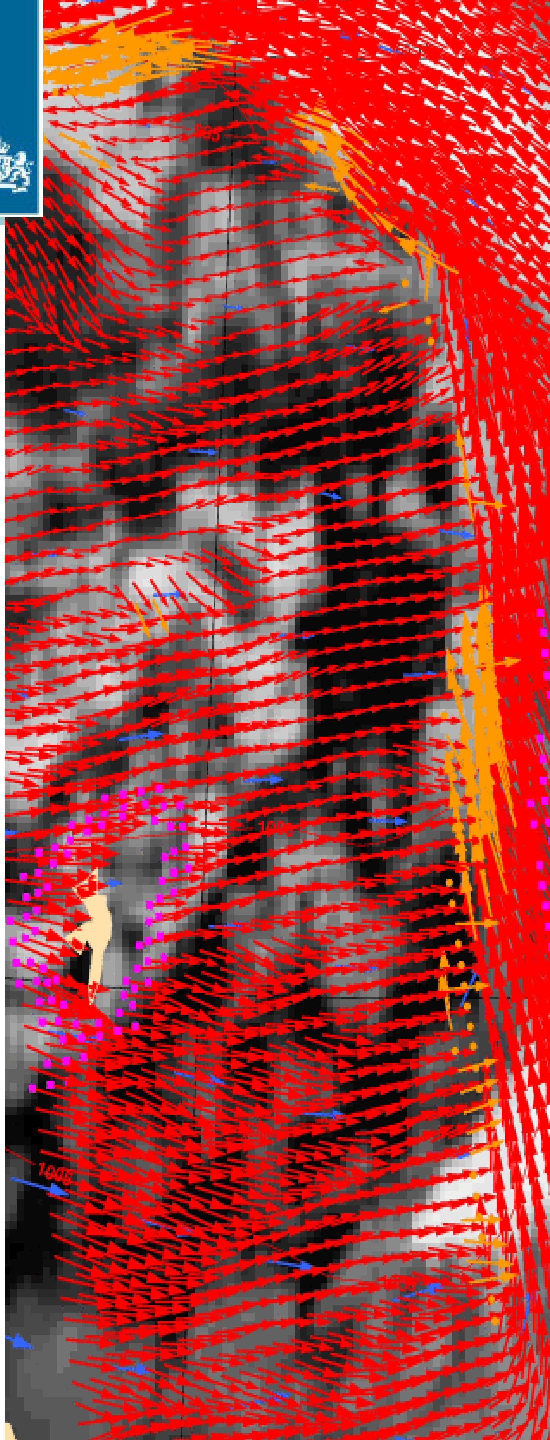
- 24/7 Wind product services (OSI SAF)
  - Constellation of satellites
  - High quality winds, QC
  - Timeliness 30 min. – 2 hours
  - Service messages
  - QA, monitoring
- Software services (NWP SAF)
  - Portable Wind Processors
  - Weather model comparison
- CMEMS L3 EO wind production
- Organisations involved: KNMI, EUMETSAT, EU, ESA, NASA, NOAA, ISRO, SOA, WMO, CEOS, ..
- Users: NHC, JTWC, ECMWF, NOAA, NASA, NRL, BoM, UK MetO, M.France, DWD, CMA, JMA, CPTEC, NCAR, NL, .

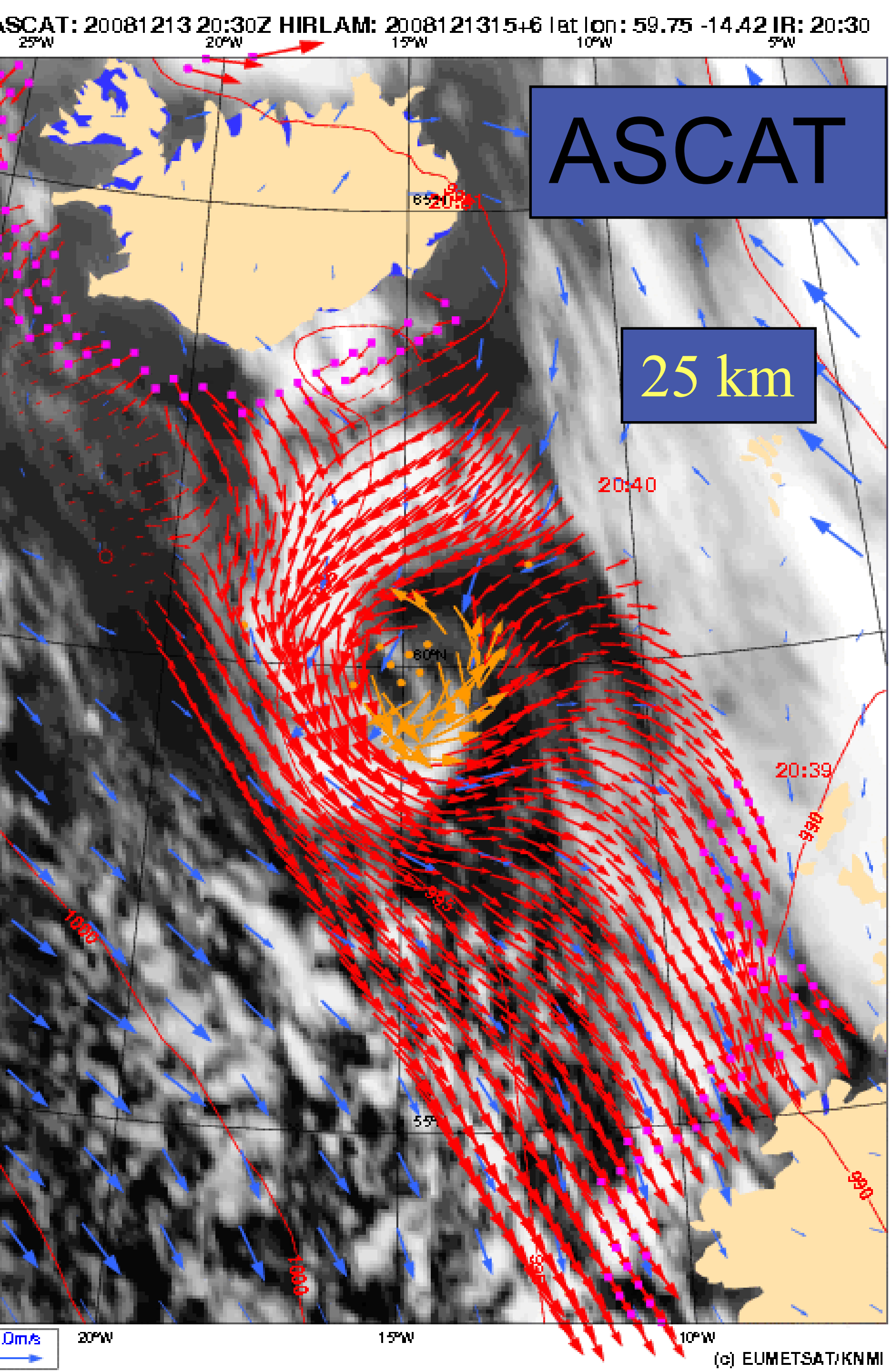
More information:

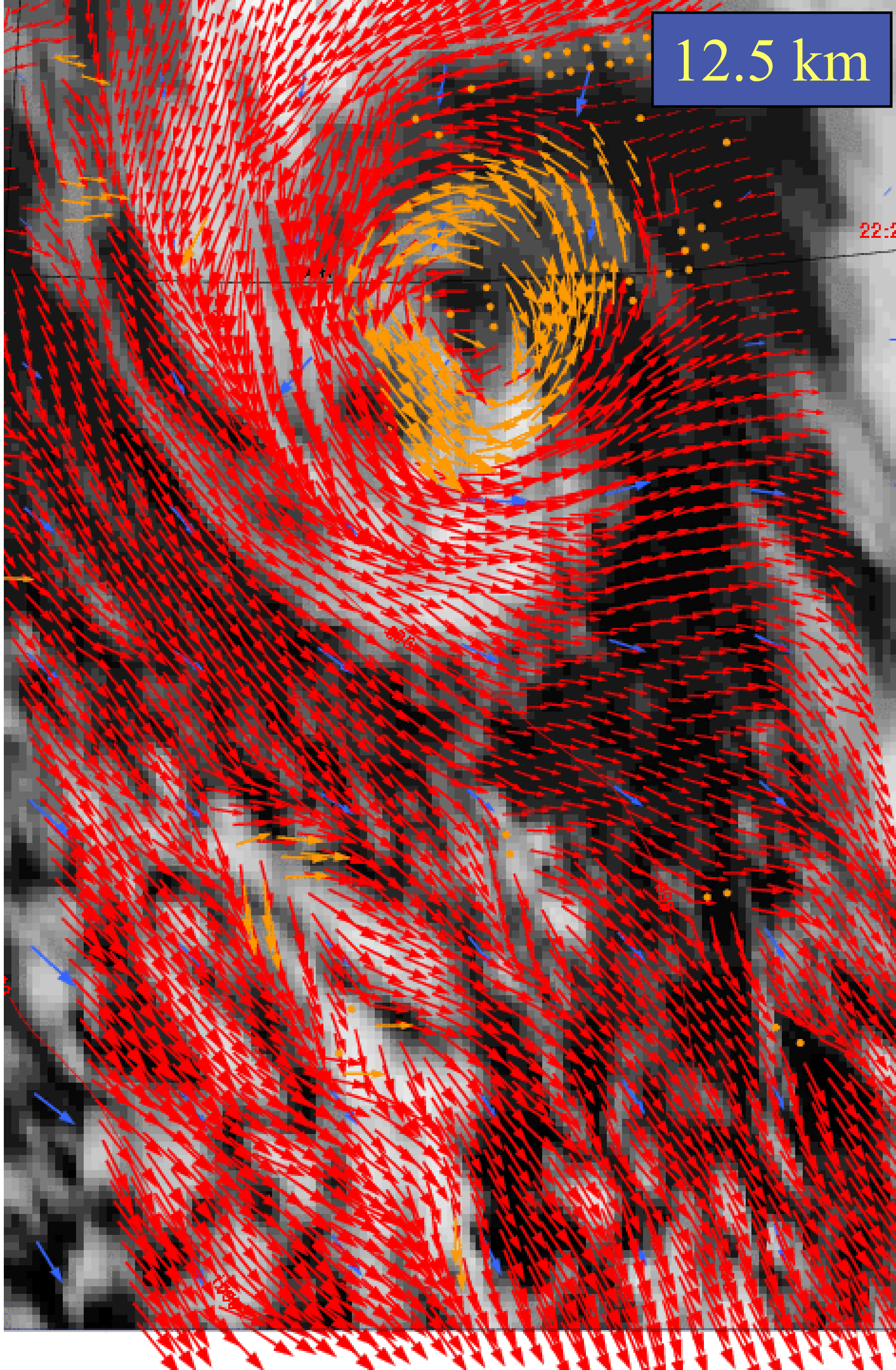
www.knmi.nl/scatterometer

Wind Scatterometer Help Desk

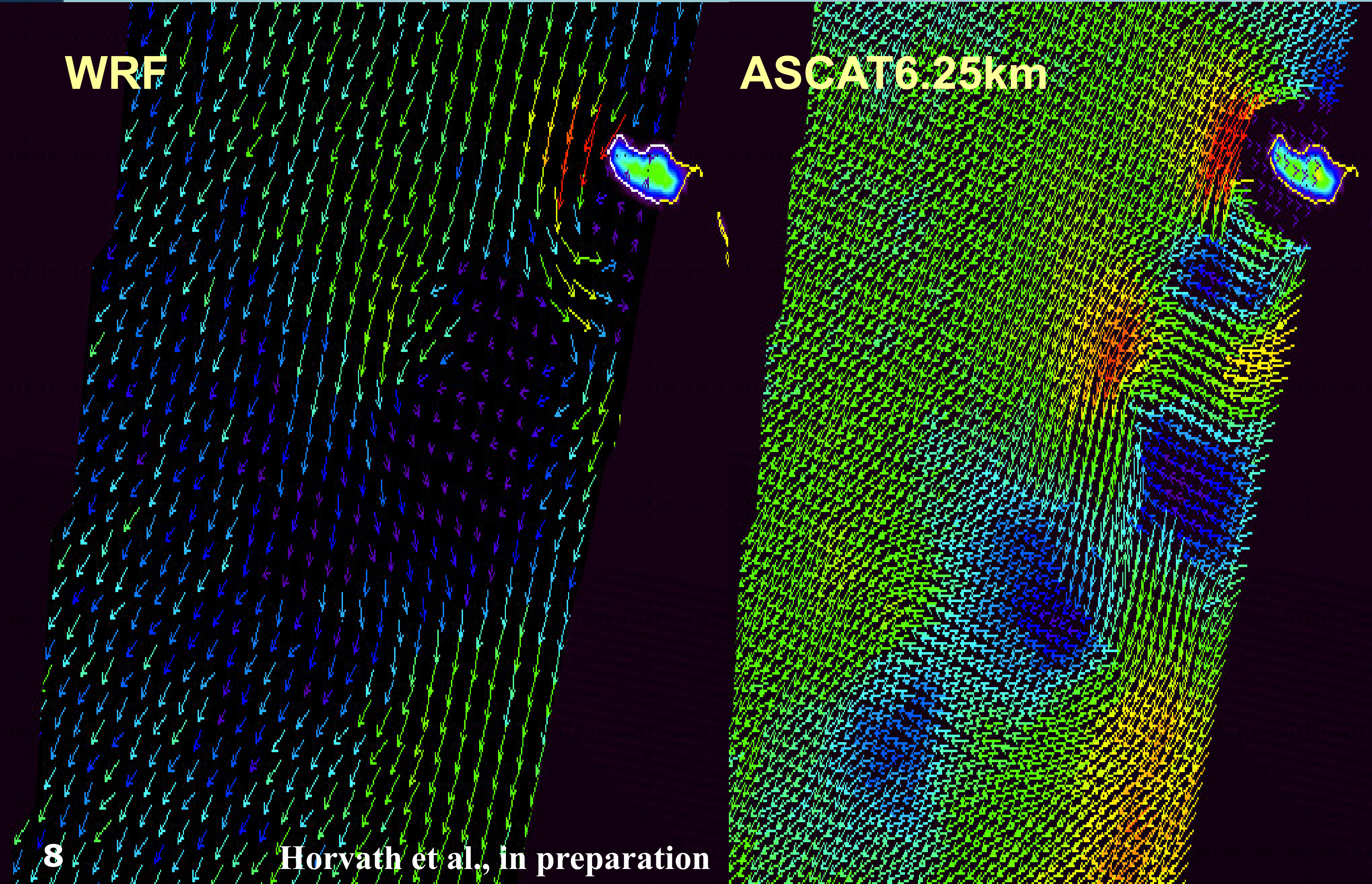
Email: scat@knmi.nl




ASCAT: 20081213 20:30Z HIRLAM: 2008121315+6 lat lon: 59.75 -14.42 IR: 20:30
ASCAT
25 km
20:40
20:39
(c) EUMETSAT/KNMI


12.5 km

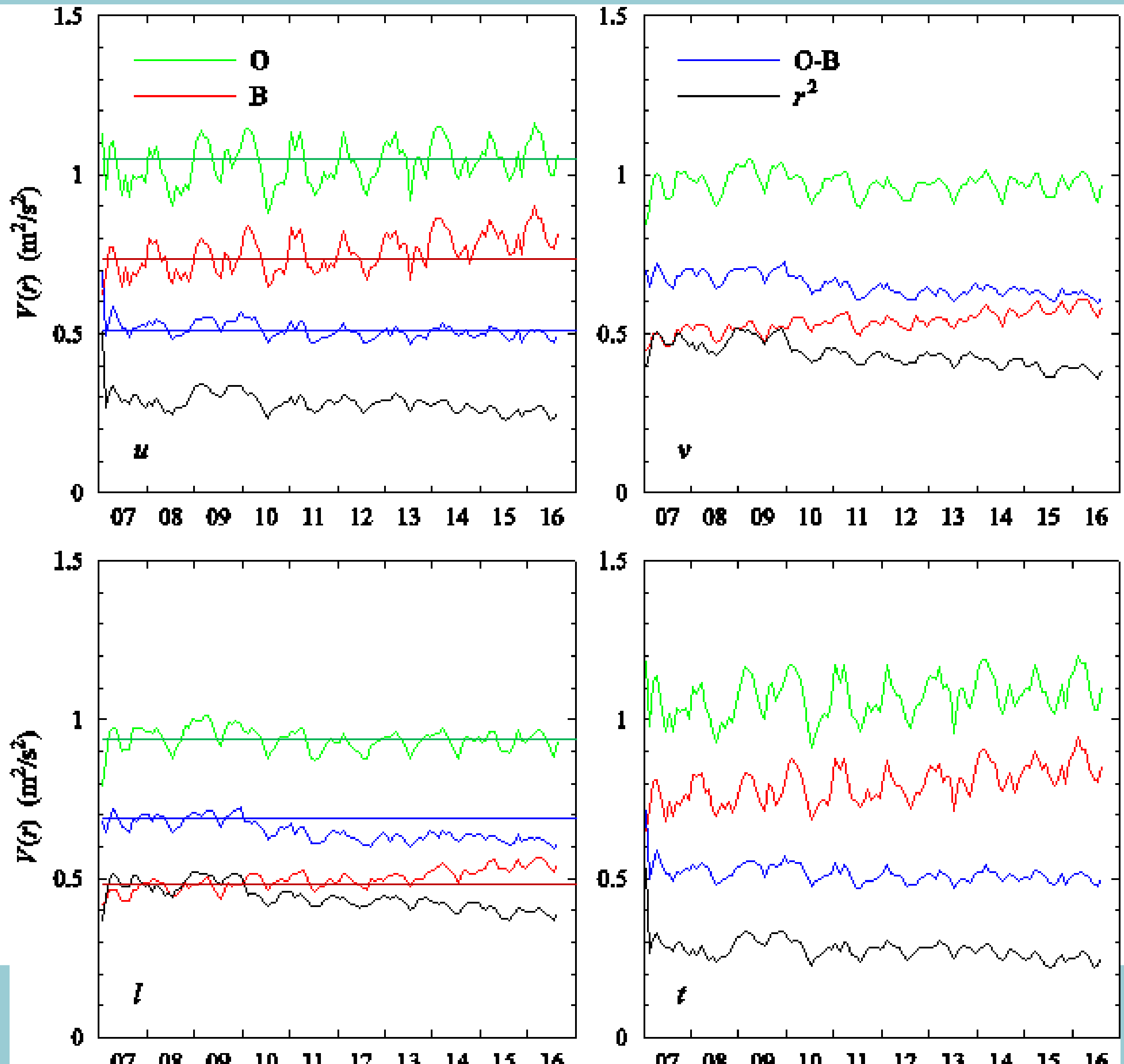
Observations and Models



Horvath et al., in preparation

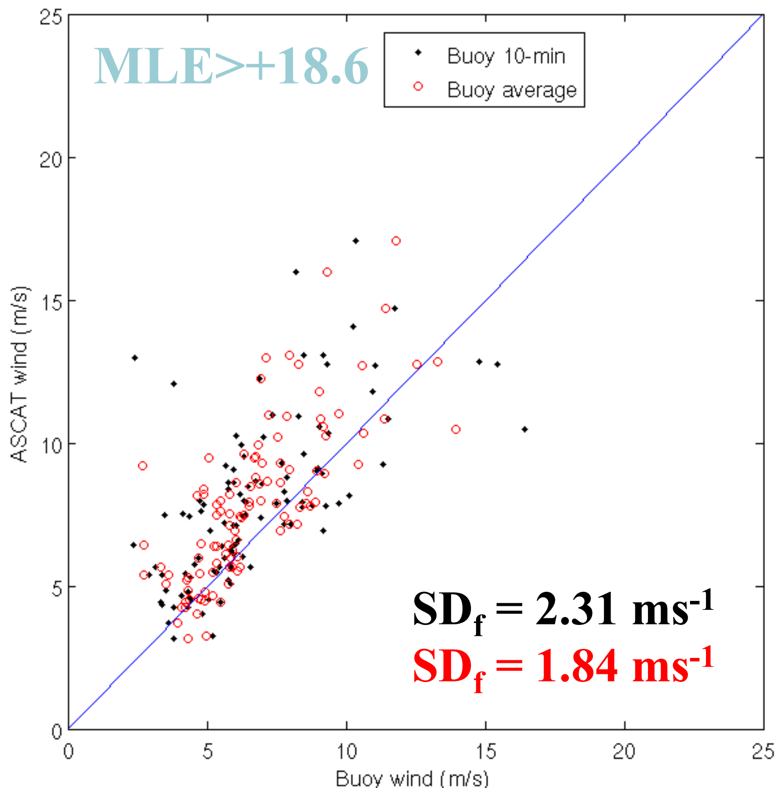
ECMWF OPS improves

- Scatterometer O variance under 200 km constant
- <200-km variance B increases to 80% (u), resp. 60% (v) of O
- O-B decreases, particularly for v
- l≈v and u≈t, but u≠v and l≠t

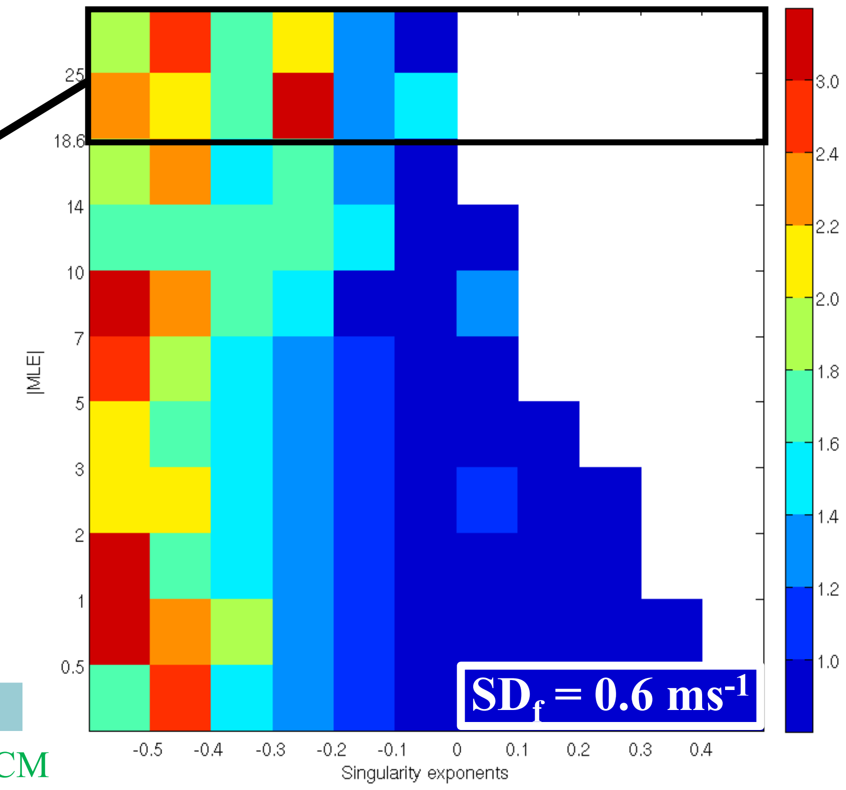


ASCAT QC

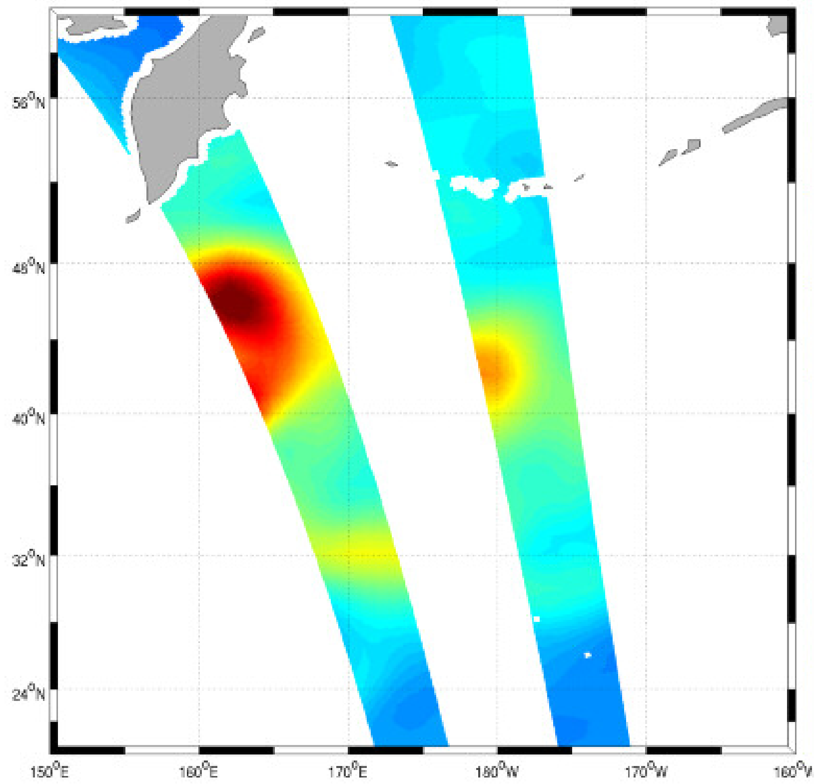
- We can produce winds with SD of buoy-scatterometer difference of 0.6 m/s, but would exclude all high-wind and dynamic air-sea interaction areas
- The winds that we reject right now in convective tropical areas are noisy (SD=1.84 m/s), but generally not outliers!
- What metric makes sense for QC trade-off?



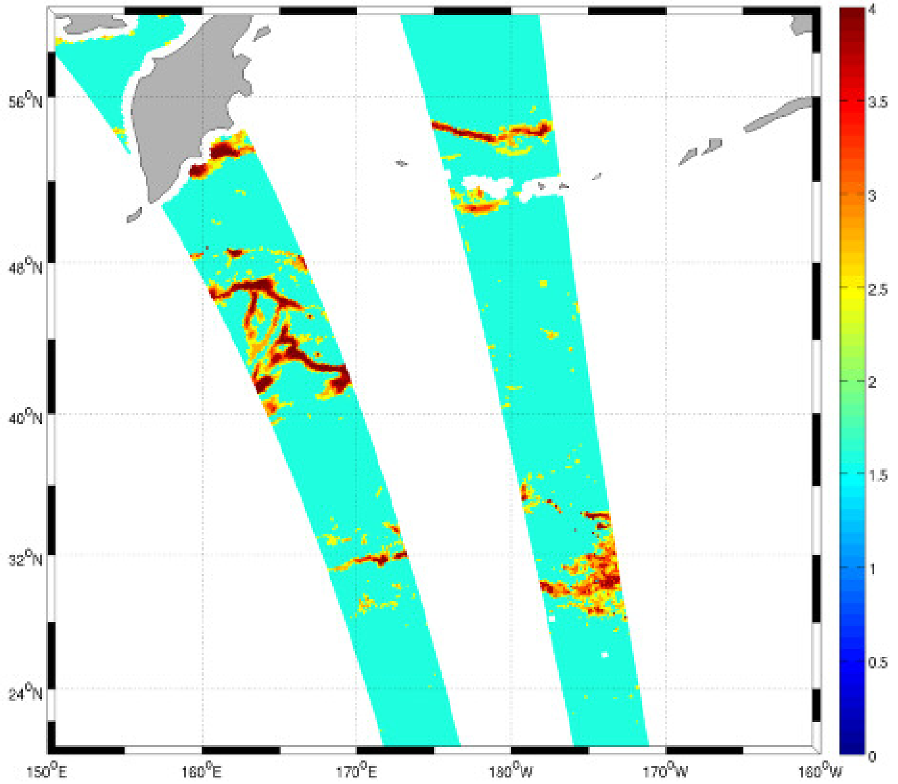
Wenming Lin, ICM



Estimated B error variances



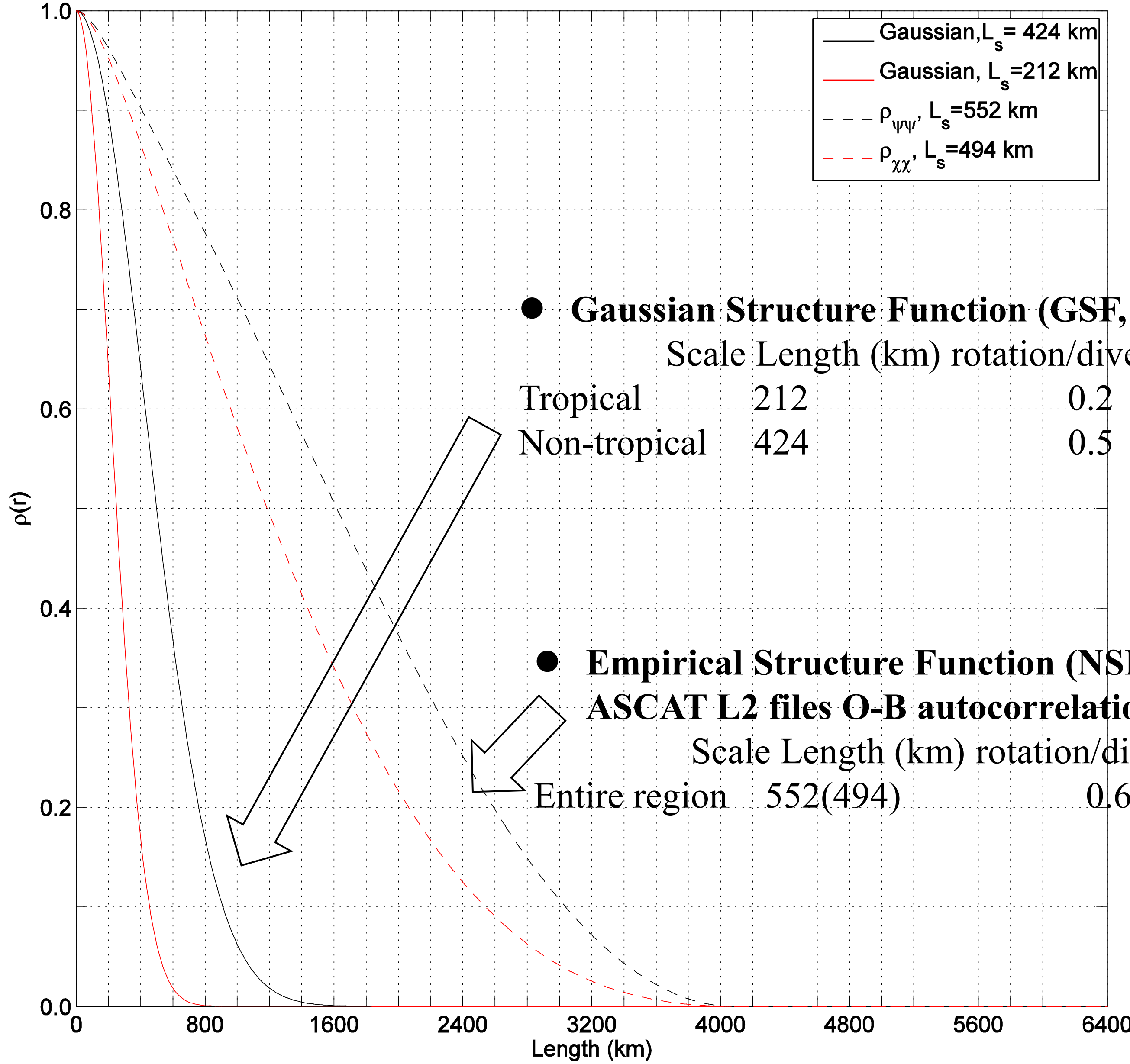
ECMWF Ensemble Data Assimilation (EDA background error)



ASCAT-derived ECMWF background error by triple collocation in QC classes

Wenming Lin, ICM

NWP Background spatial error correlation structure



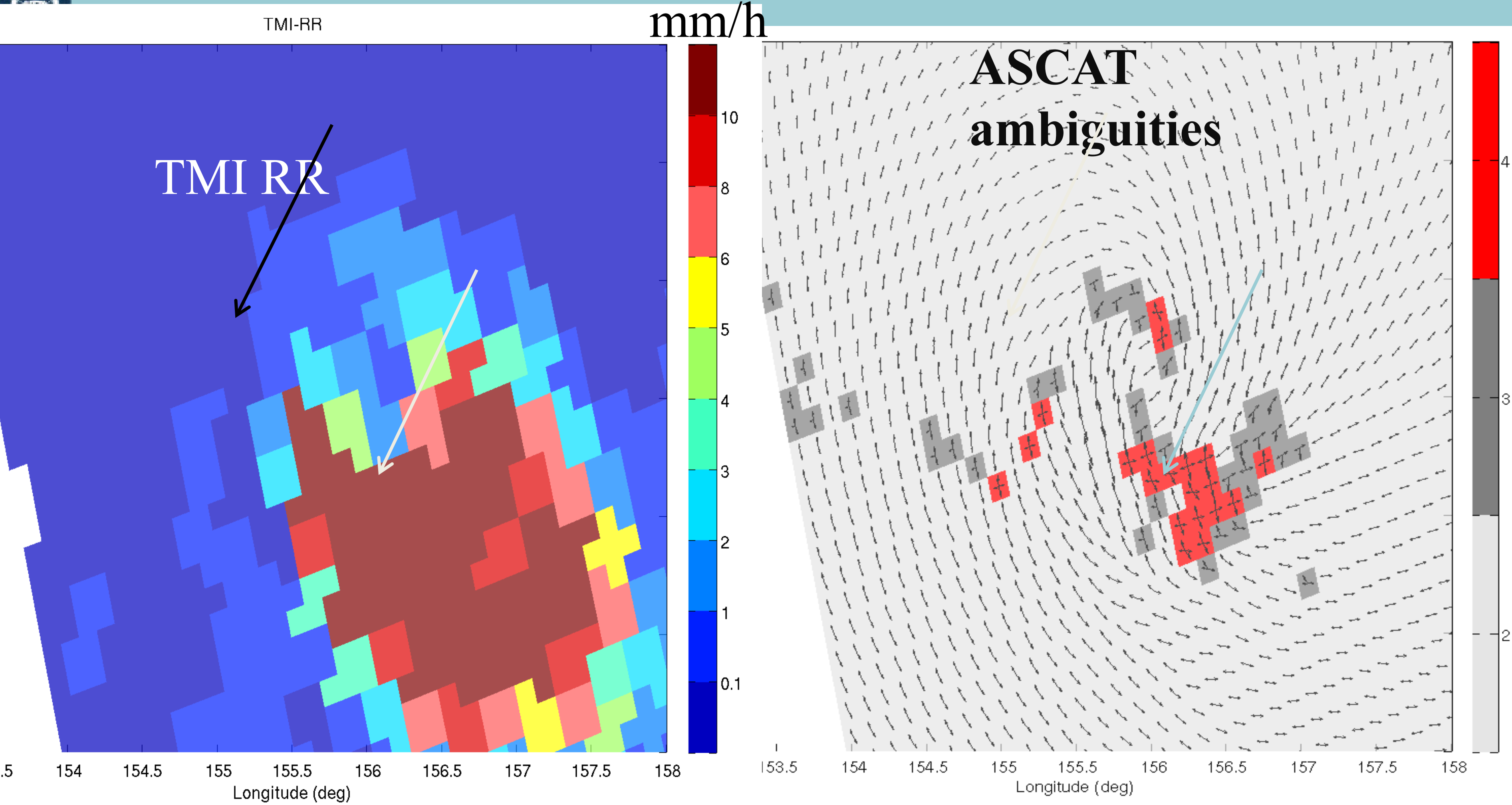
- **Gaussian Structure Function (GSF, default setting)**

	Scale Length (km)	rotation/divergence ratio
Tropical	212	0.2
Non-tropical	424	0.5

- **Empirical Structure Function (NSF, derived from ASCAT L2 files O-B autocorrelation, new setting)**

	Scale Length (km)	rotation/divergence ratio
Entire region	552(494)	0.62

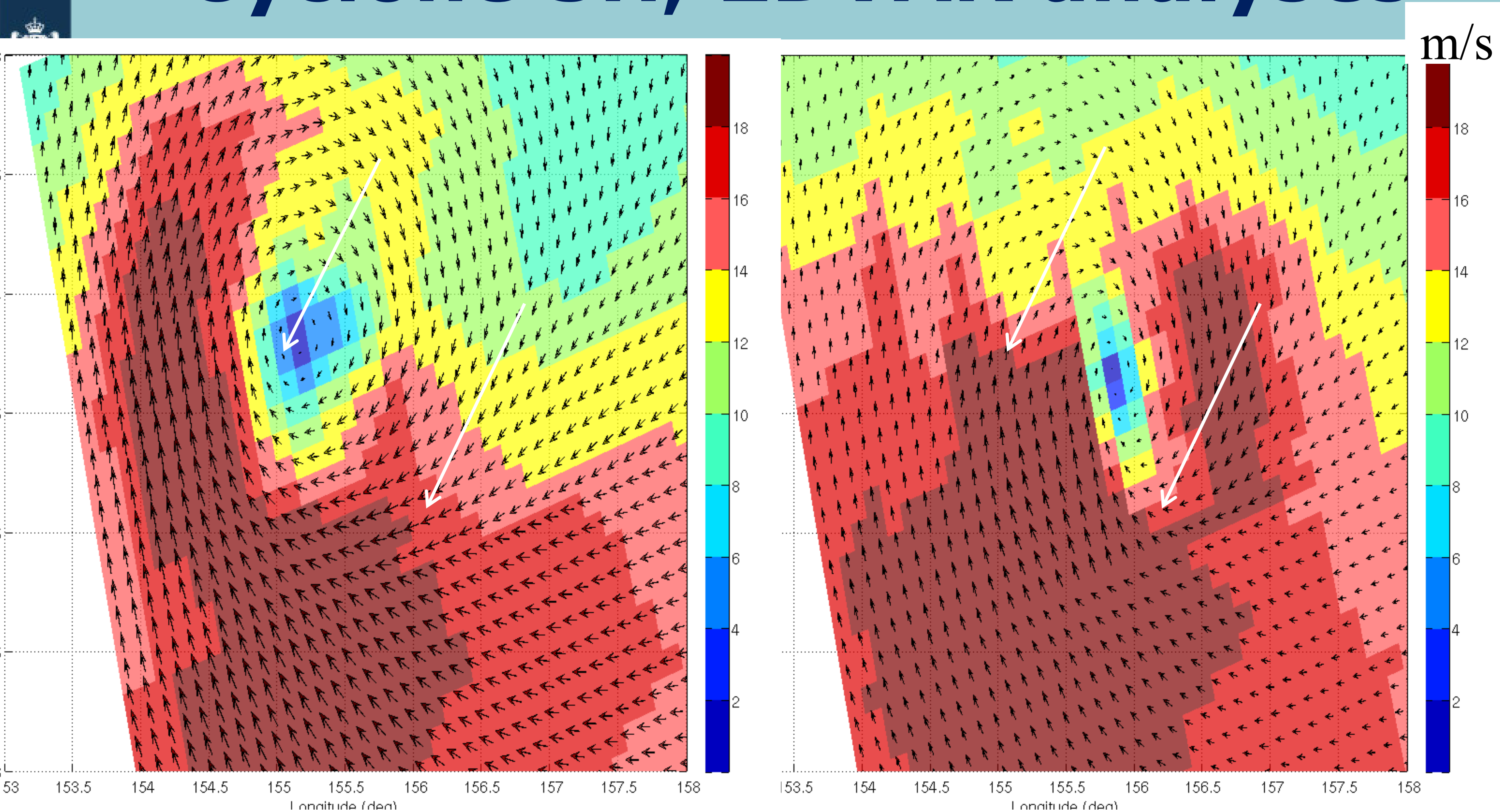
Cyclone SH



Wenming Lin, ICM

Number of ambiguities

Cyclone SH, 2DVAR analyses



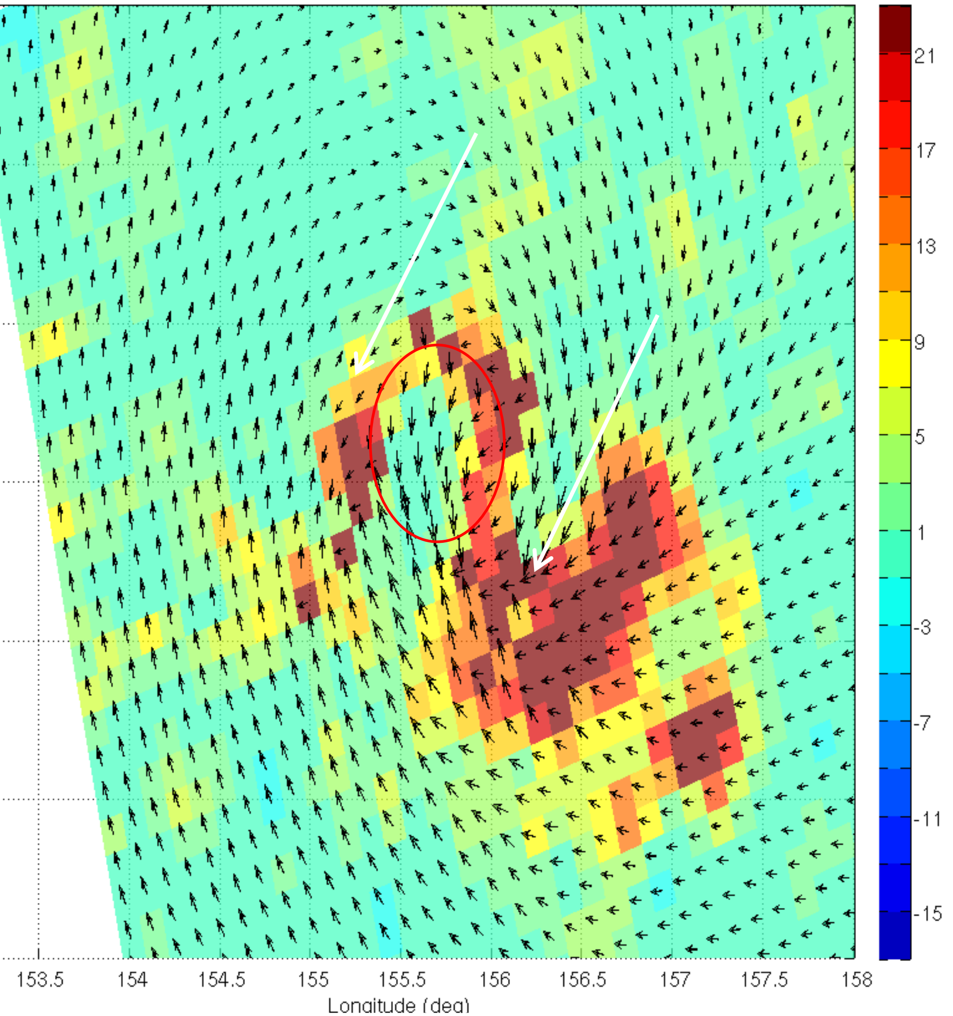
Default setting:

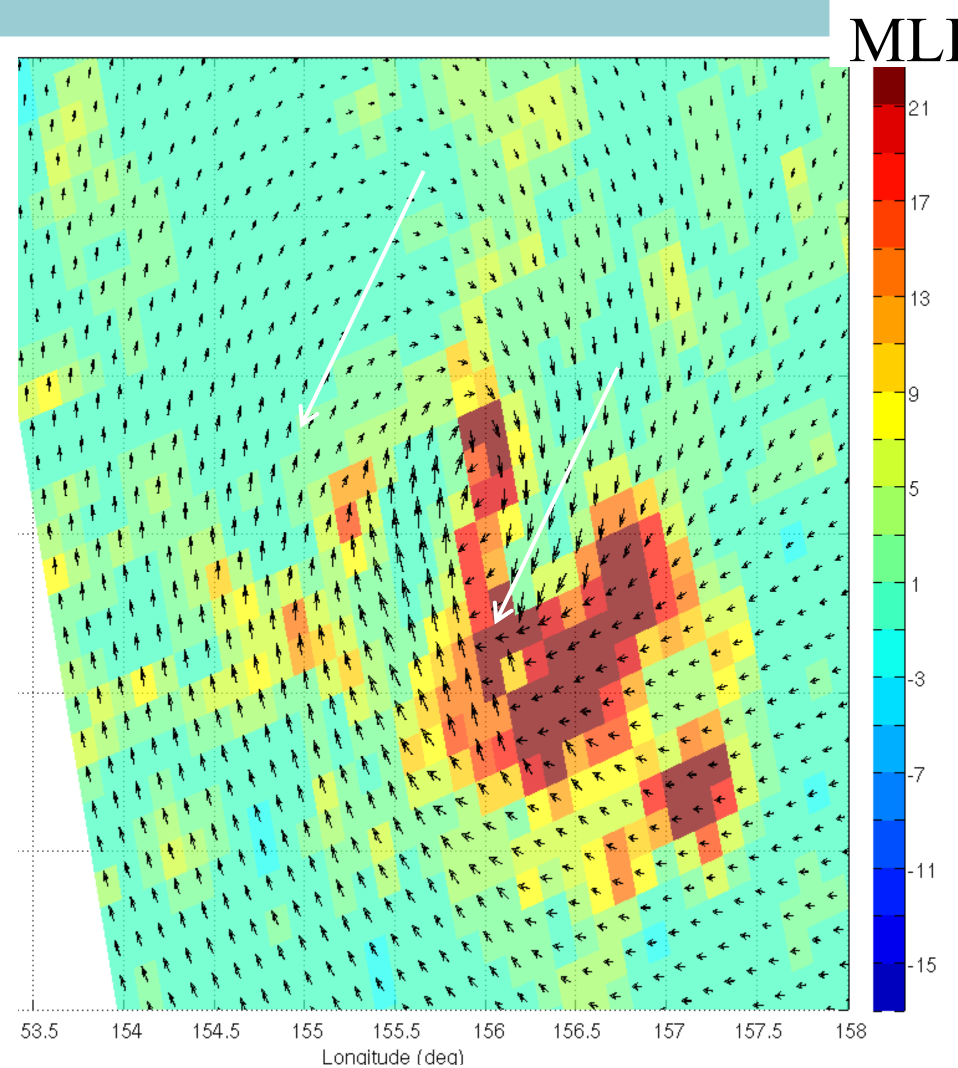
- Gaussian structure function
- Fixed O/B errors

New setting:

- Empirical structure function
- Flexible O/B errors

Cyclone SH, selected solutions



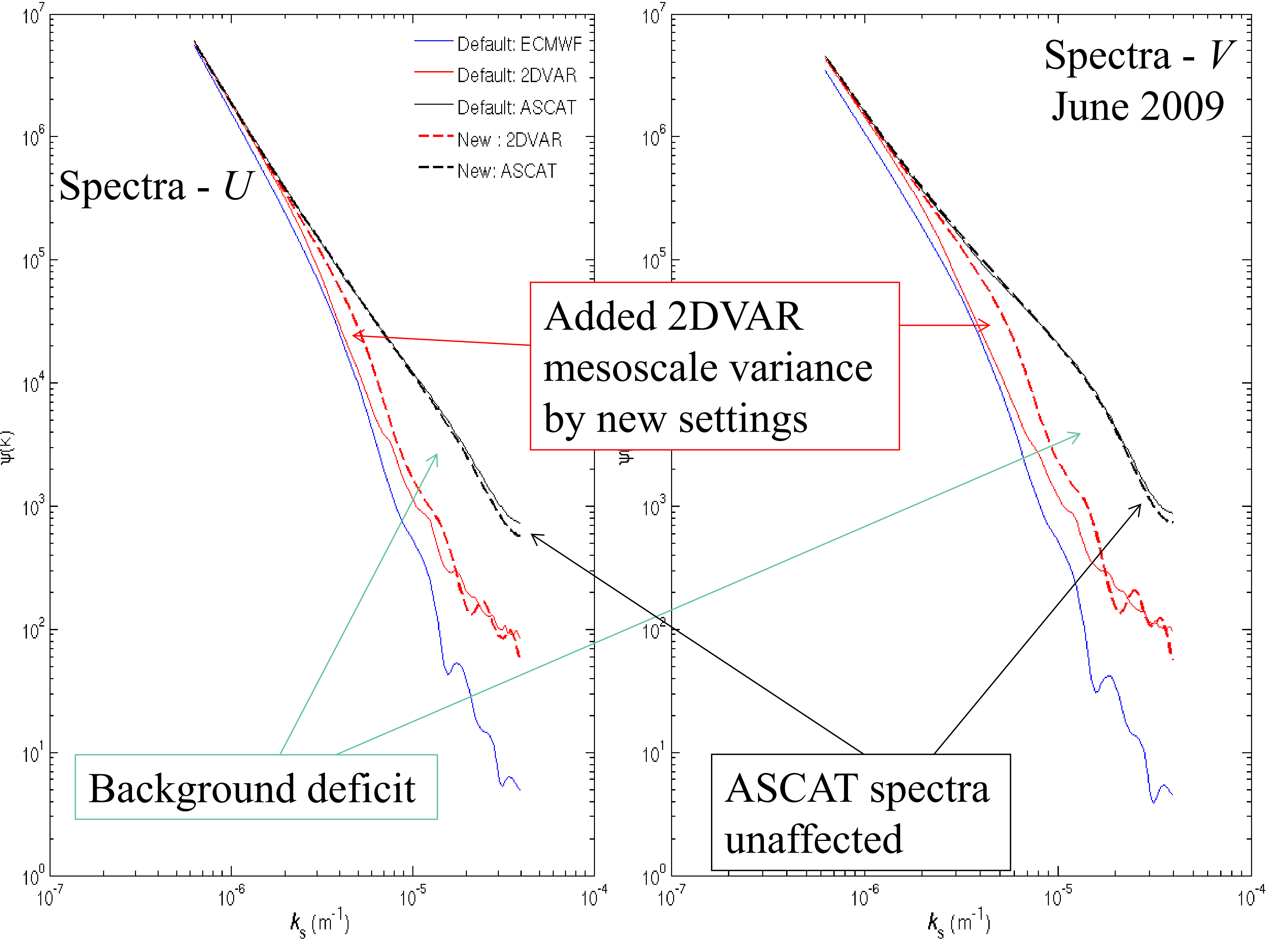


Default setting:

- Gaussian structure function
- Fixed O/B errors

New setting:

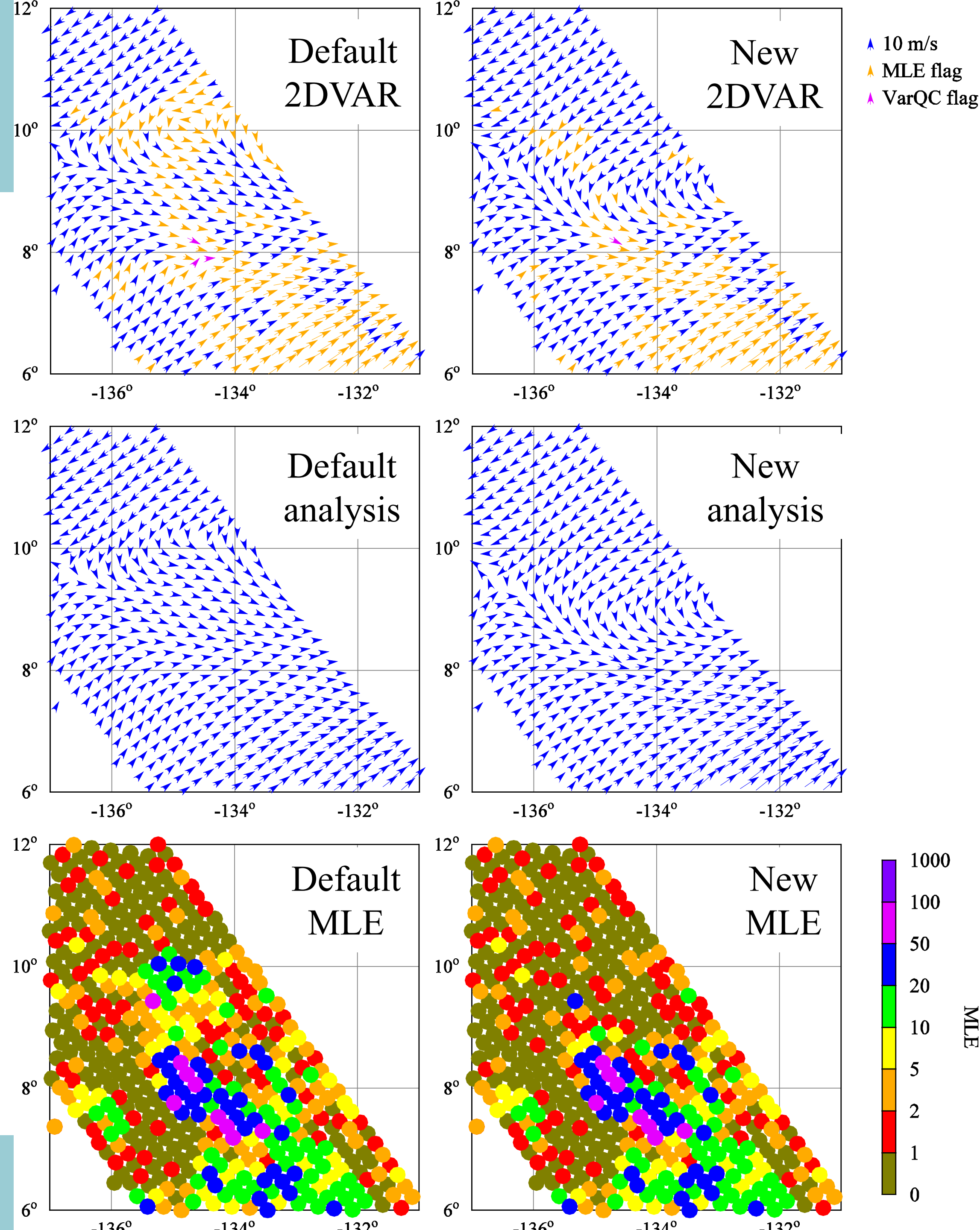
- Empirical structure function
- Flexible O/B errors


Default: ECMWF
Default: 2DVAR
Default: ASCAT
New : 2DVAR
New: ASCAT
Spectra - U
Spectra - V
June 2009
Added 2DVAR mesoscale variance by new settings
Background deficit
ASCAT spectra unaffected
ψ(k)
k_s (m^{-1})

RapidScat

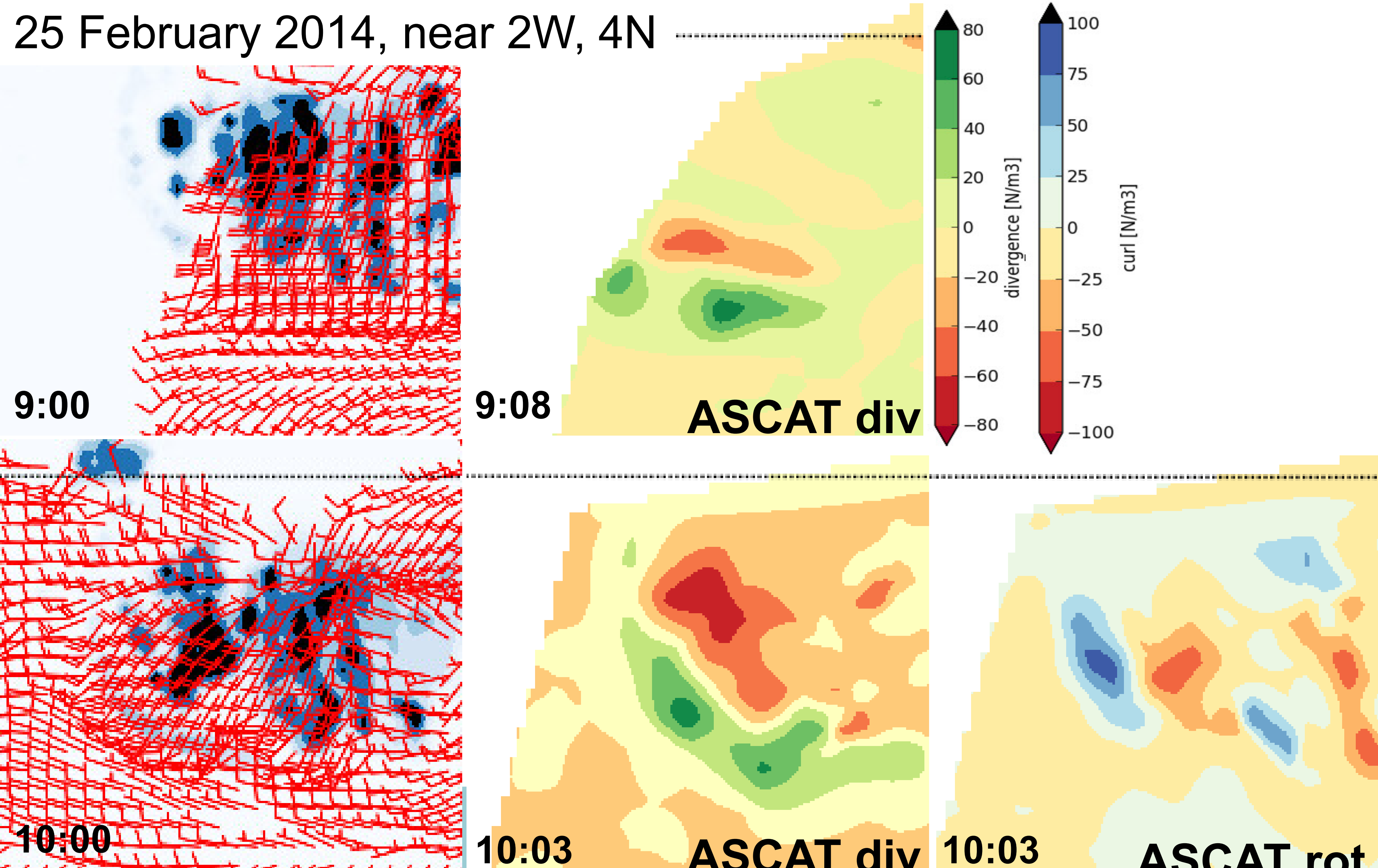
- Static background error correlations based on ASCAT
- Larger increments w.r.t background
- More mesoscale structure
- Lower MLE
- Better wind direction verification against buoys
- Works also for OSCAT

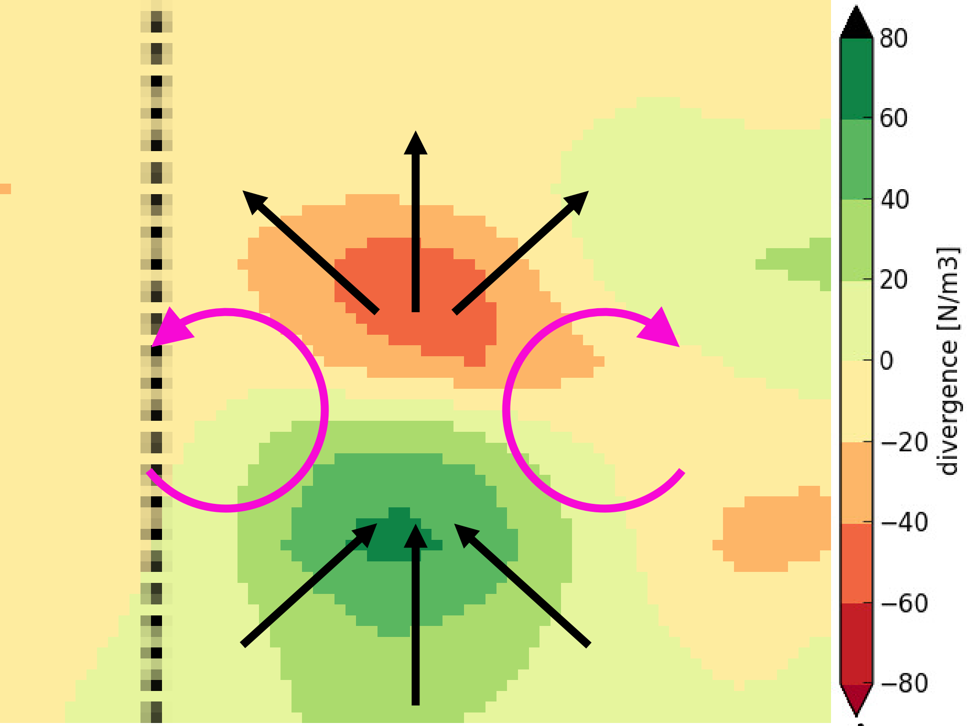
Jur Vogelzang, KNMI

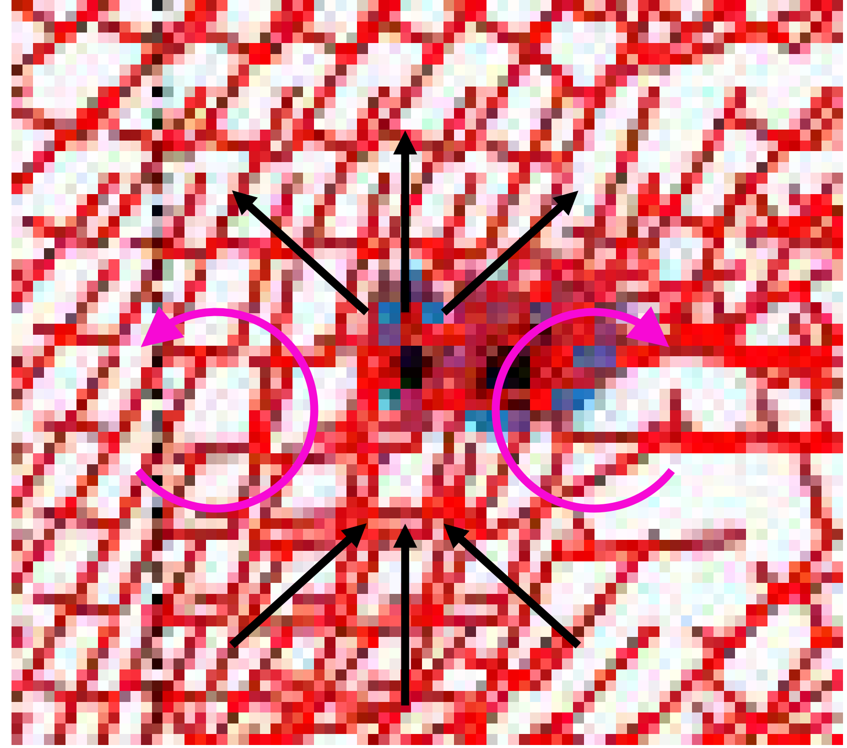


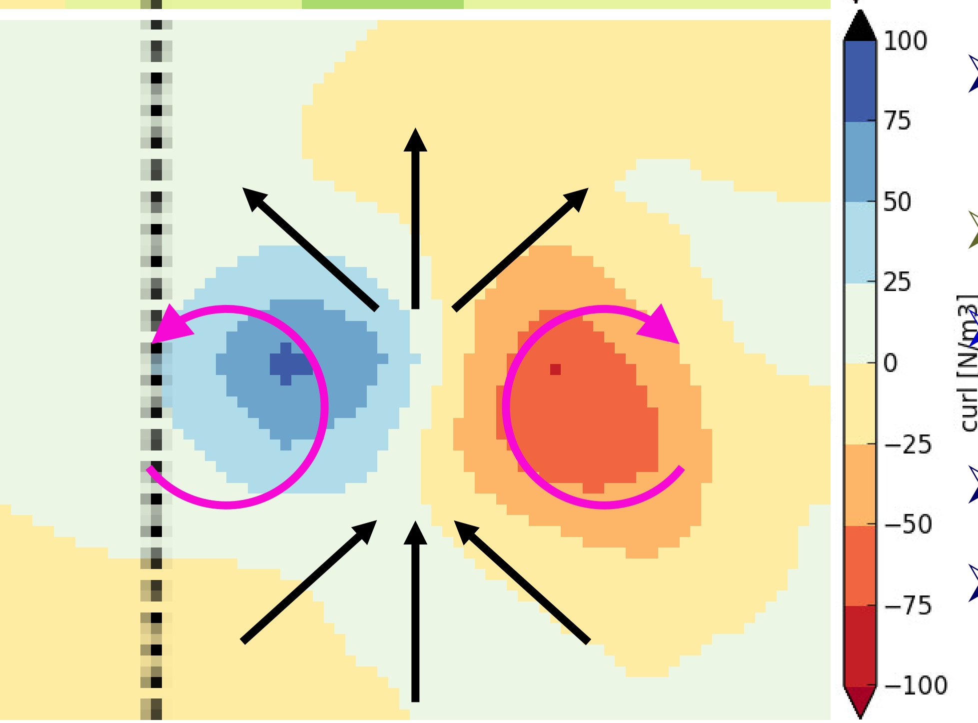
Developing gust band

25 February 2014, near 2W, 4N



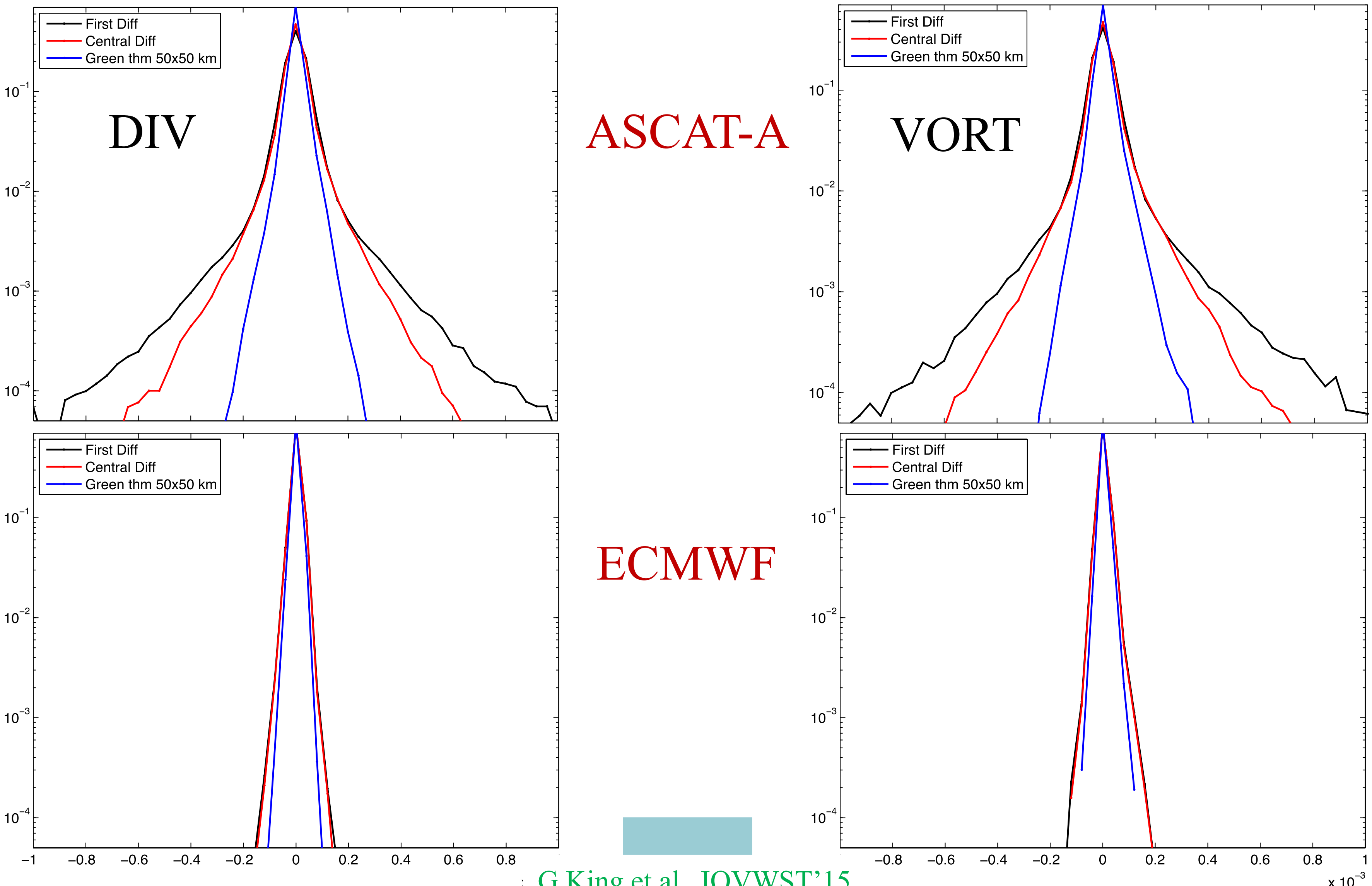


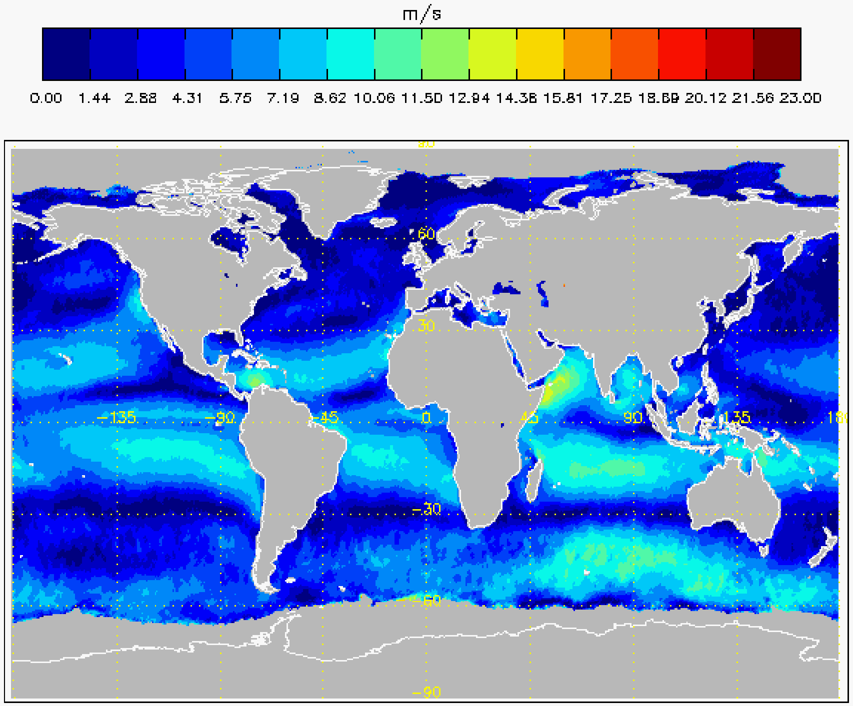


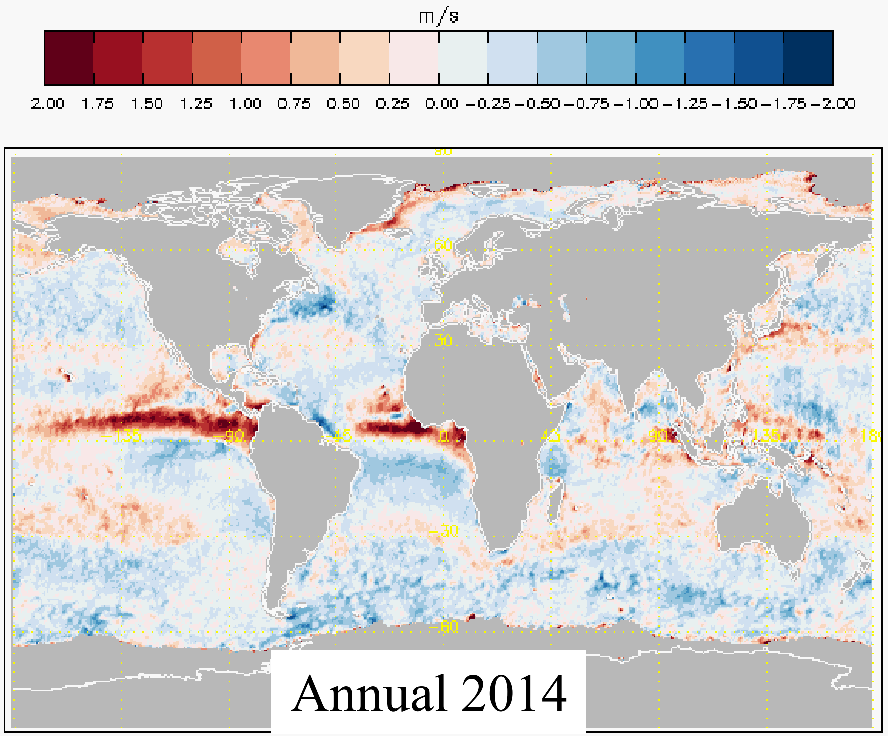


- Convergence and curl structures associated with convective cell
- Inflow convergence
- Precipitation is associated with wind downburst
- Shear zones with curl (+ and -)
- Abundant air-sea interaction

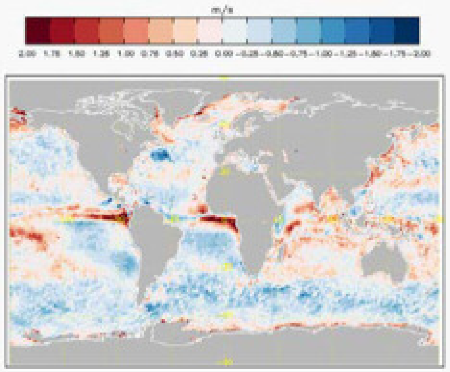
PDFs of DIV and VORT



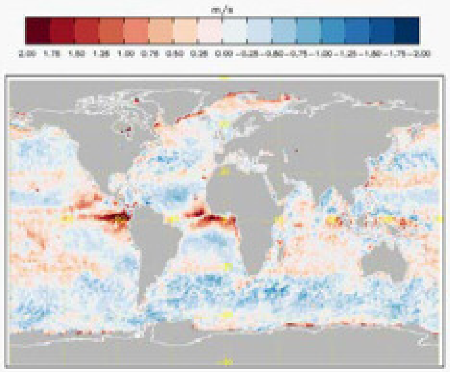




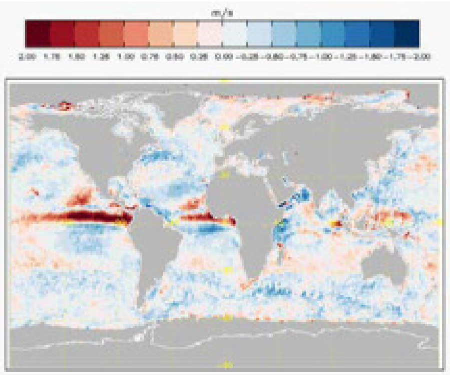
DJF



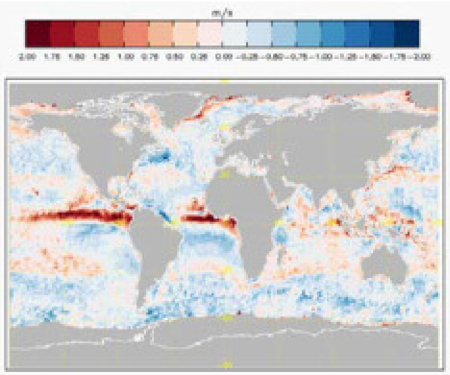
MAM



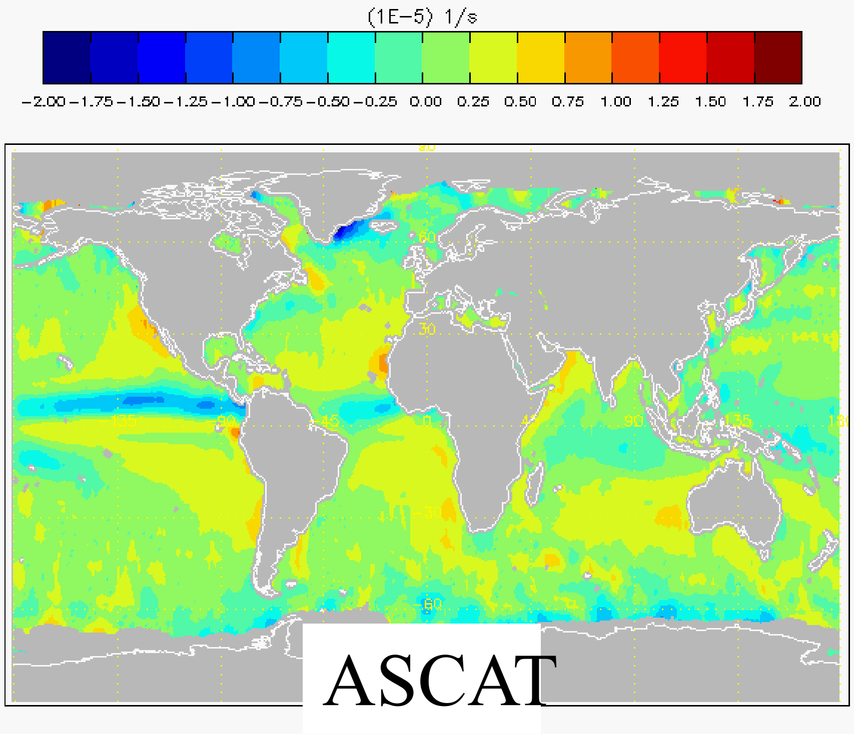
JJA

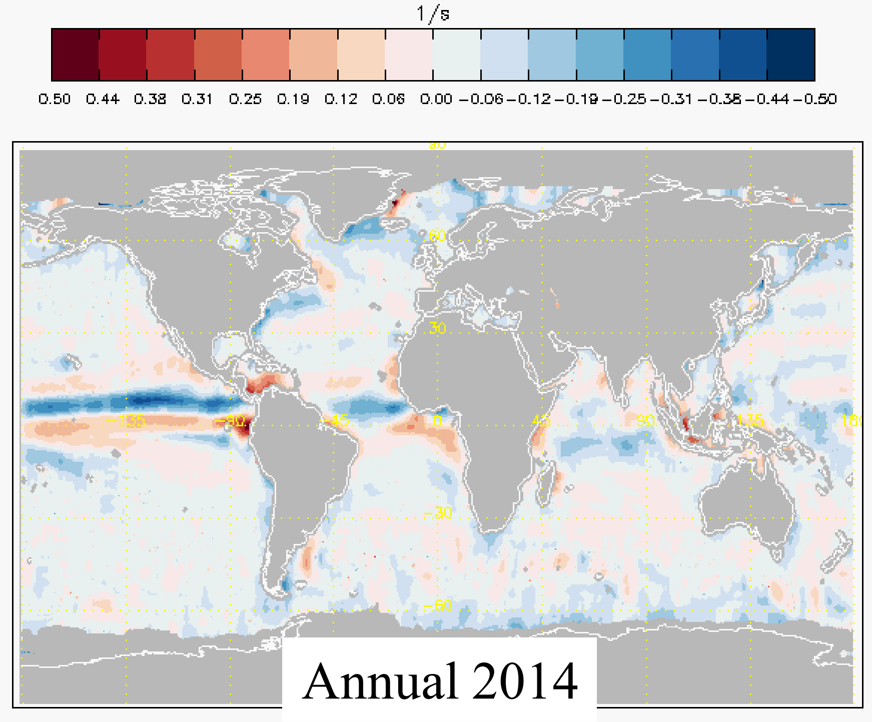


SON

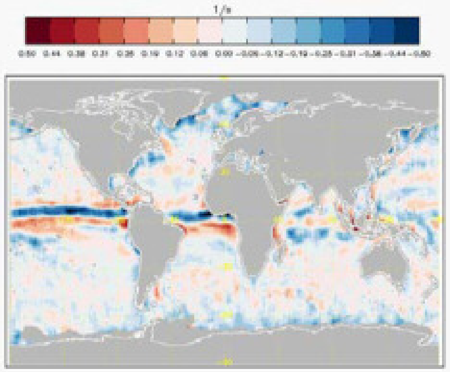


Wind speed difference (ASCAT-NWP)

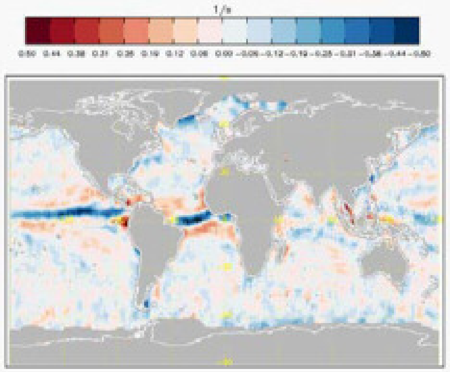




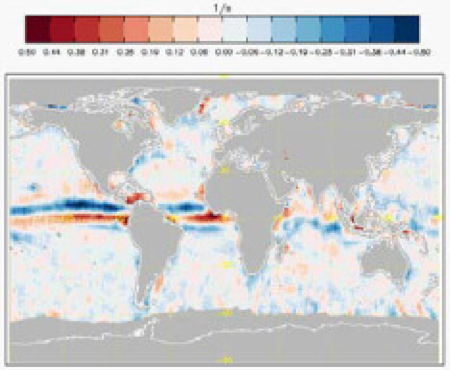
DJF



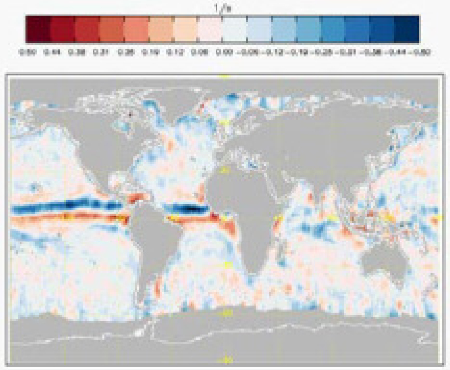
MAM



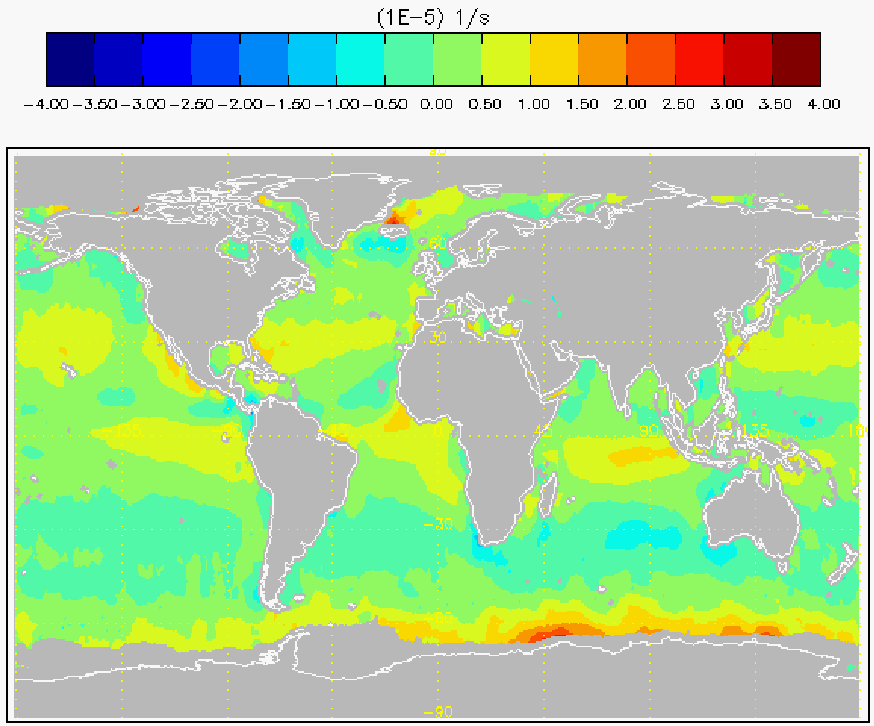
JJA

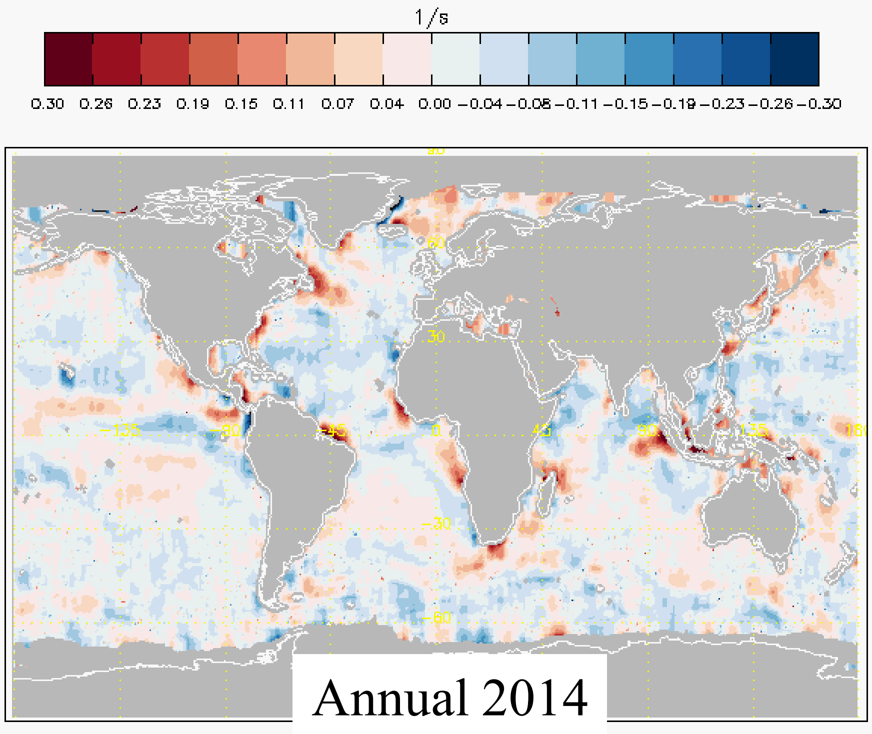


SON

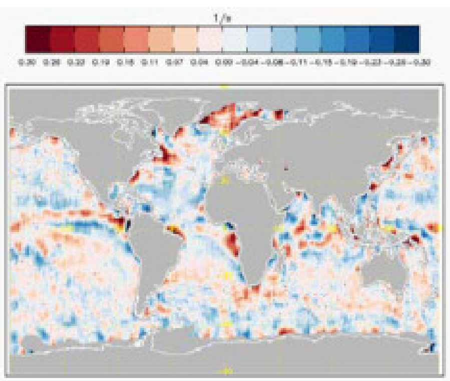


Wind divergence difference (ASCAT-NWP)

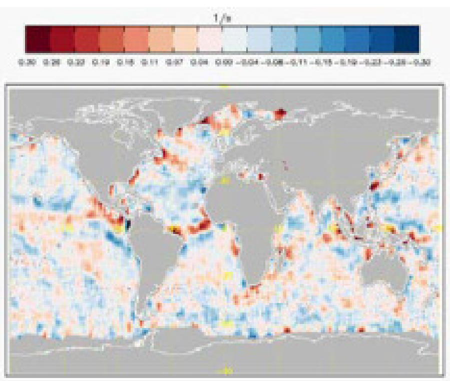




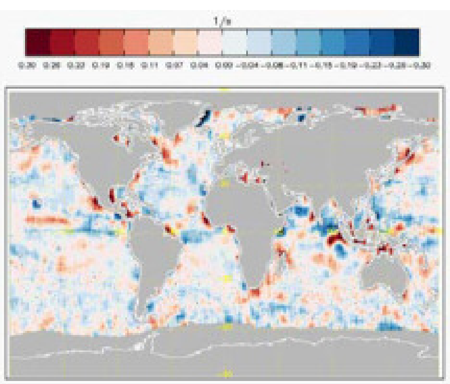
DJF



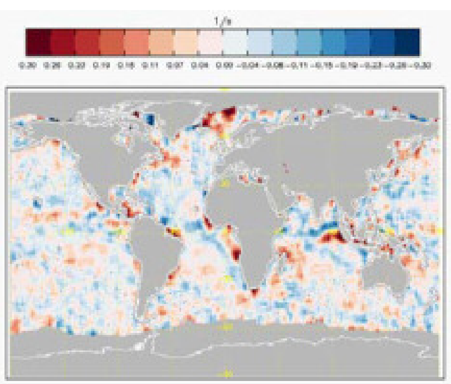
MAM



JJA



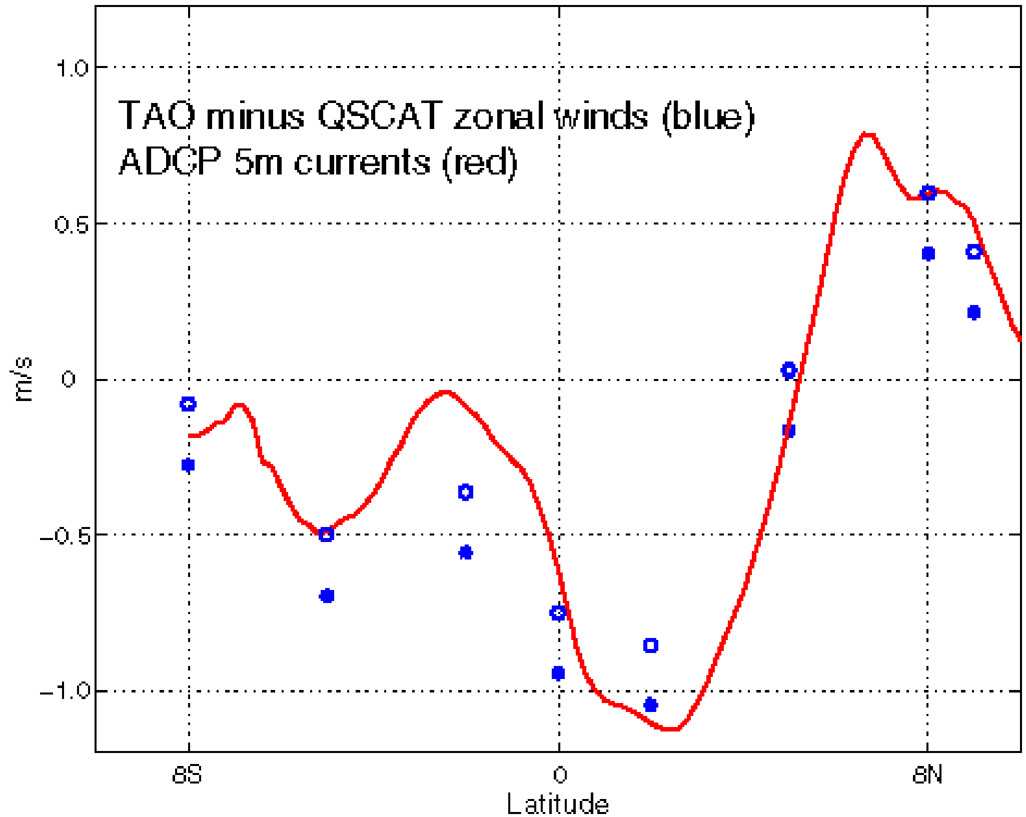
SON



Wind curl difference (ASCAT-NWP)

Currents

- *Scatterometer roughness relates to the relative atmosphere-ocean motion, as fluxes do*
- *Buoy and model winds are absolute with respect to the earth frame*



Mean differences between scatterometer winds and TAO anemometer winds are due to ocean currents.

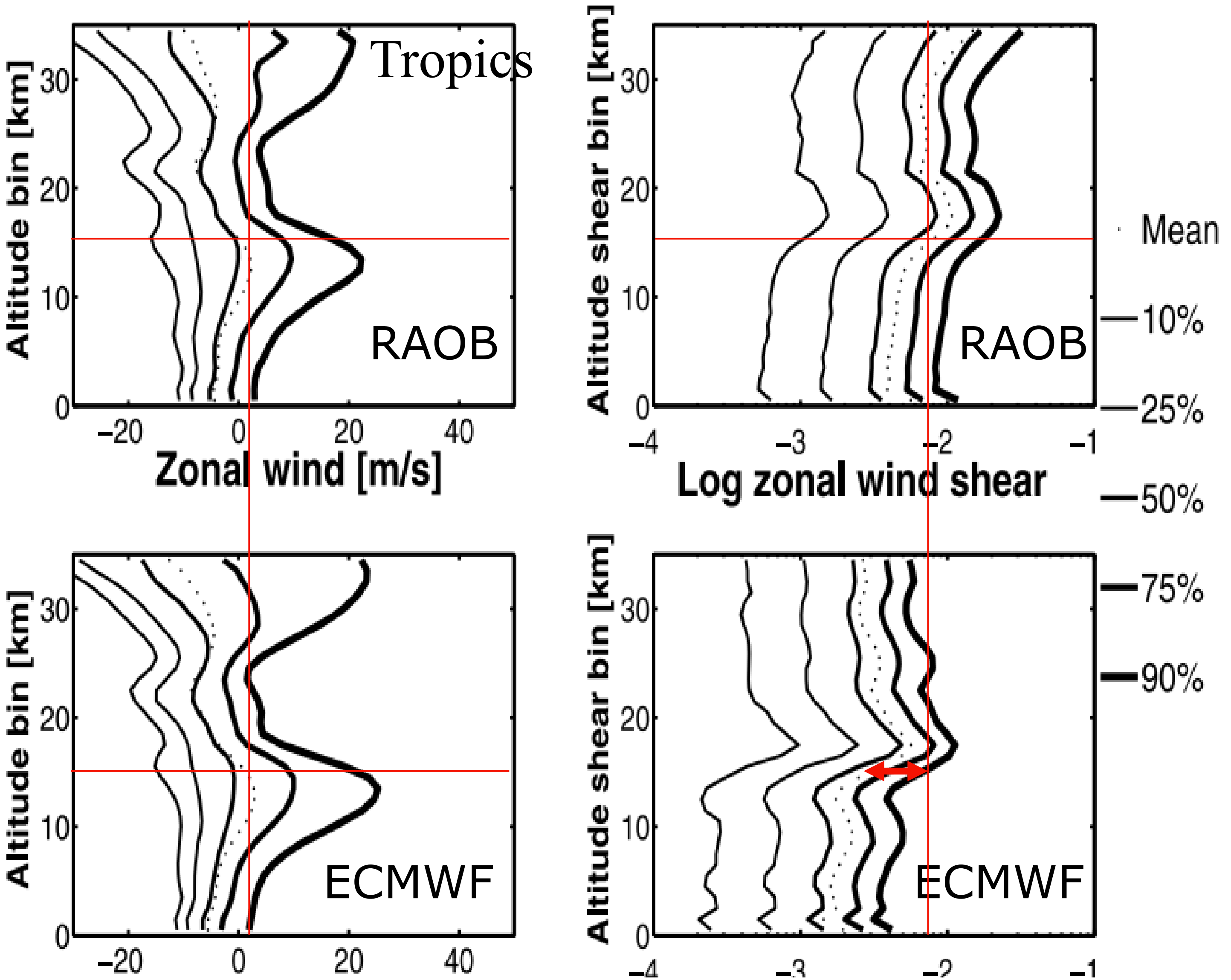
- ADCP zonal currents extrapolated to 5-m depth averaged over three meridians (155°, 140°, 125°W) from TAO buoy servicing cruises Fall of 1999.
- Average difference between TAO and QuikSCAT zonal wind components at TAO buoys before (asterisks) and after (open circles) removing a 0.2 ms^{-1} bias.
- *The 1 ms^{-1} differences between the anemometer and scatterometer winds are clearly due to the ocean currents.*

K.A. Kelly, S. Dickinson, M.J. McPhaden and G.C. Johnson, submitted to GRL

Hi-res radiosonde shear

- ✓Collocation data base
- ✓ECMWF winds agree very well
- ✓Shear in ECMWF model 2-3 times lower, however
- ✓Tropical tropopause strongly variable

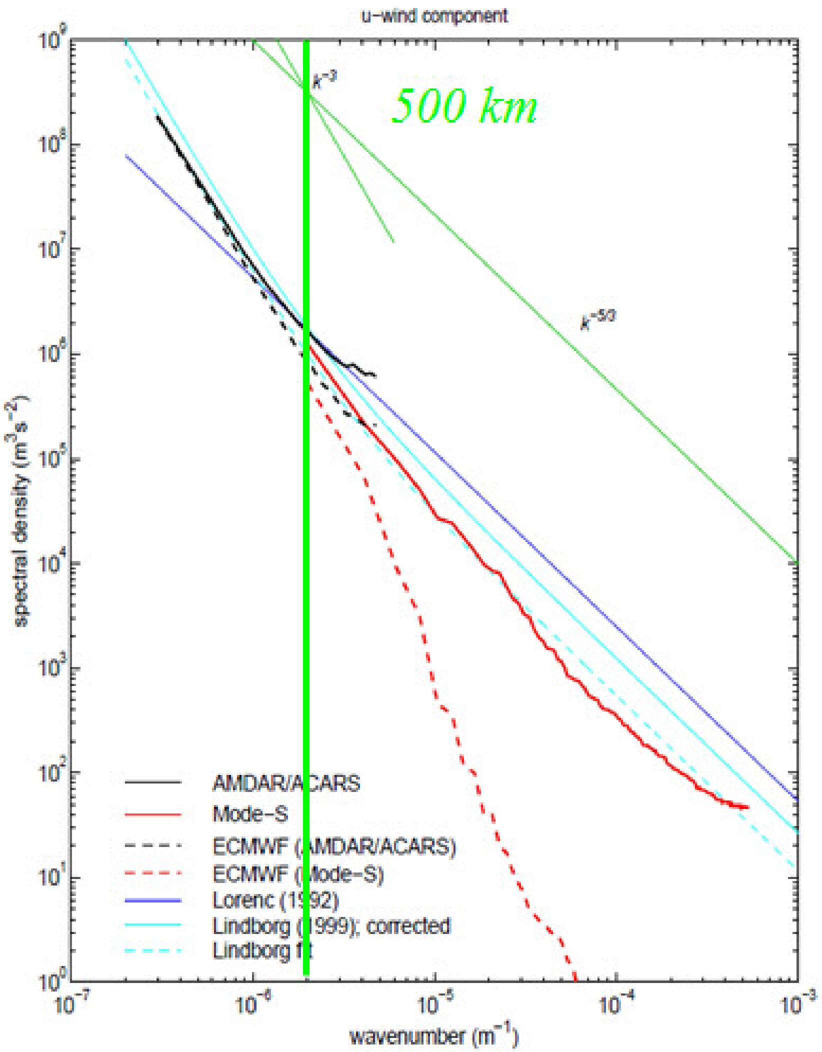
- ➢Shear determines mixing of air, cloud forming, ..



Houchi et al. 2010

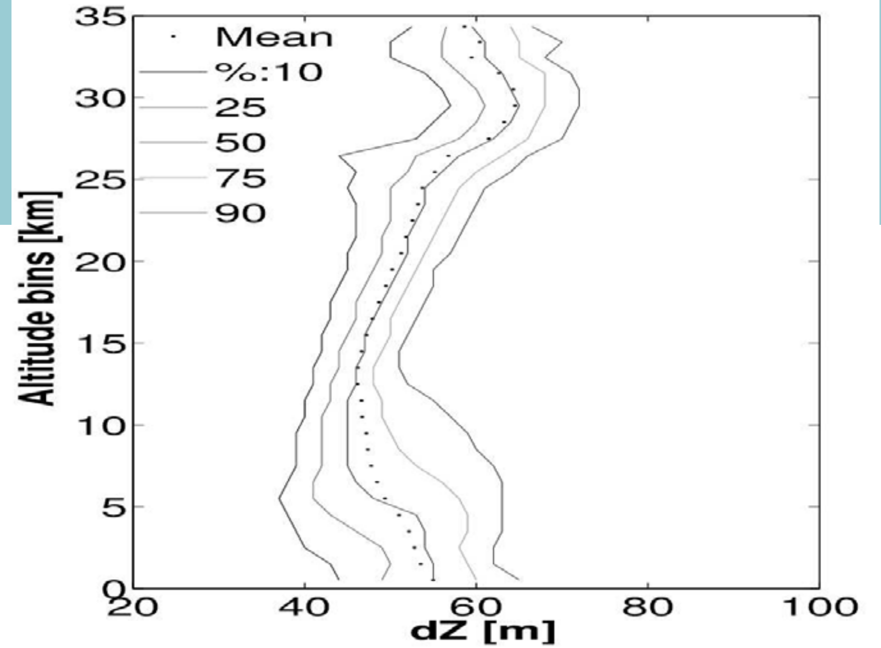
Flight level spectra

- Observed -5/3 turbulence spectrum below 500km, just like at the surface, down to km scale
- Collocated ECMWF spectra are much steeper, both MARS and IFS
- VHAMP final report

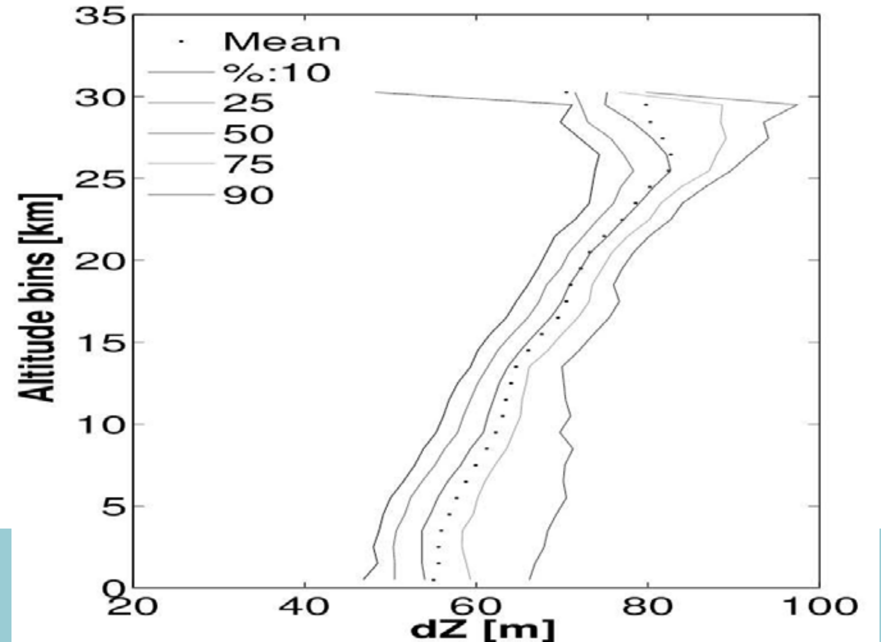


Vertical motion

- Ascent rate about 5 m/s
- Depends on initial mass; mass distribution spread causes ~ constant ascent rate spread with height
- Depends on balloon drag, perhaps enhanced by precip. loading, but no slow branch visible
- Depends perhaps on flow around balloon, but air stability dependence is expected small
- Ascent rate depends on cooling rate balloon, which is mainly an internal redistribution process in the balloon
- ➢ Asymmetric tropospheric ascent distribution, probably enhanced by cloud updrafts



^ de Bilt v AMMA



Houchi et al. 2015

Take home issues

Global NWP models

- Lack scales below 200 km
- Lack convection and associated wind downbursts
- Have a weak diurnal cycle
- Lack air-sea interaction and PBL structure
- Are rather neutral stability and show large direction errors
- Lack meridional flow
- Are rather inaccurate on the ocean eddy scale
- Are relative to the fixed earth rather than the moving water
- Lack substantial wind shear (on vertical km scale and horizontal 100-km scale)

Regional models

- Need improved PBL (LLCJ), surface layer and moist convection parameterisations

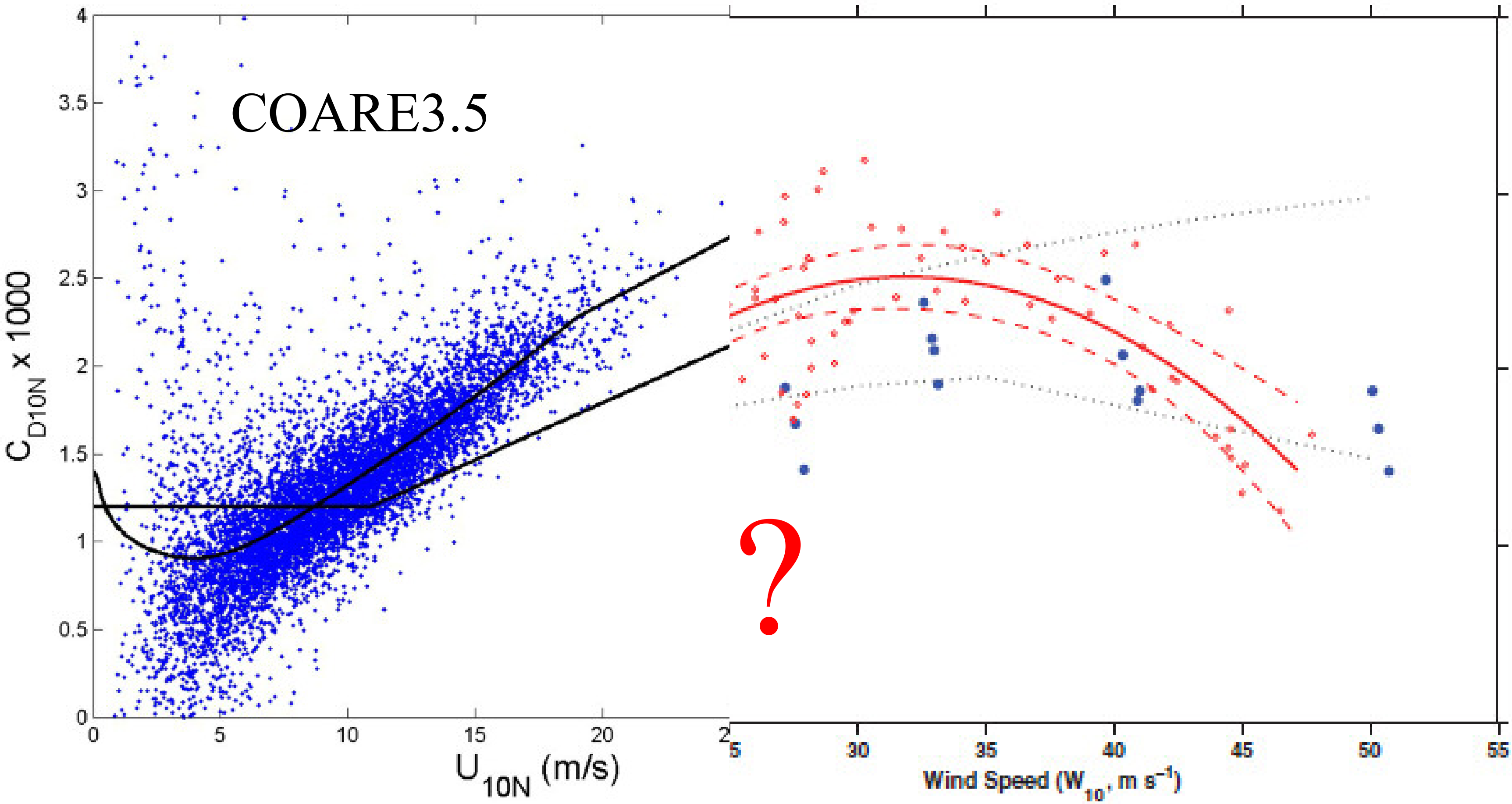
What's next?

Aeolus

- Provides averages with a reasonable aspect ratio for vertical and horizontal structures (in clear air)
- Thus provides large-scale statistical properties of the trop- and stratospheric flow in the 3D turbulence regime

Back-up slides

Surface Stress and Roughness at Extreme Winds



Refinement of DC Stress Measurements

How do we quantify the behavior at Extreme Winds?

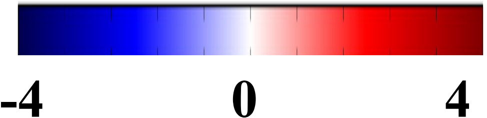
Wave surface layer

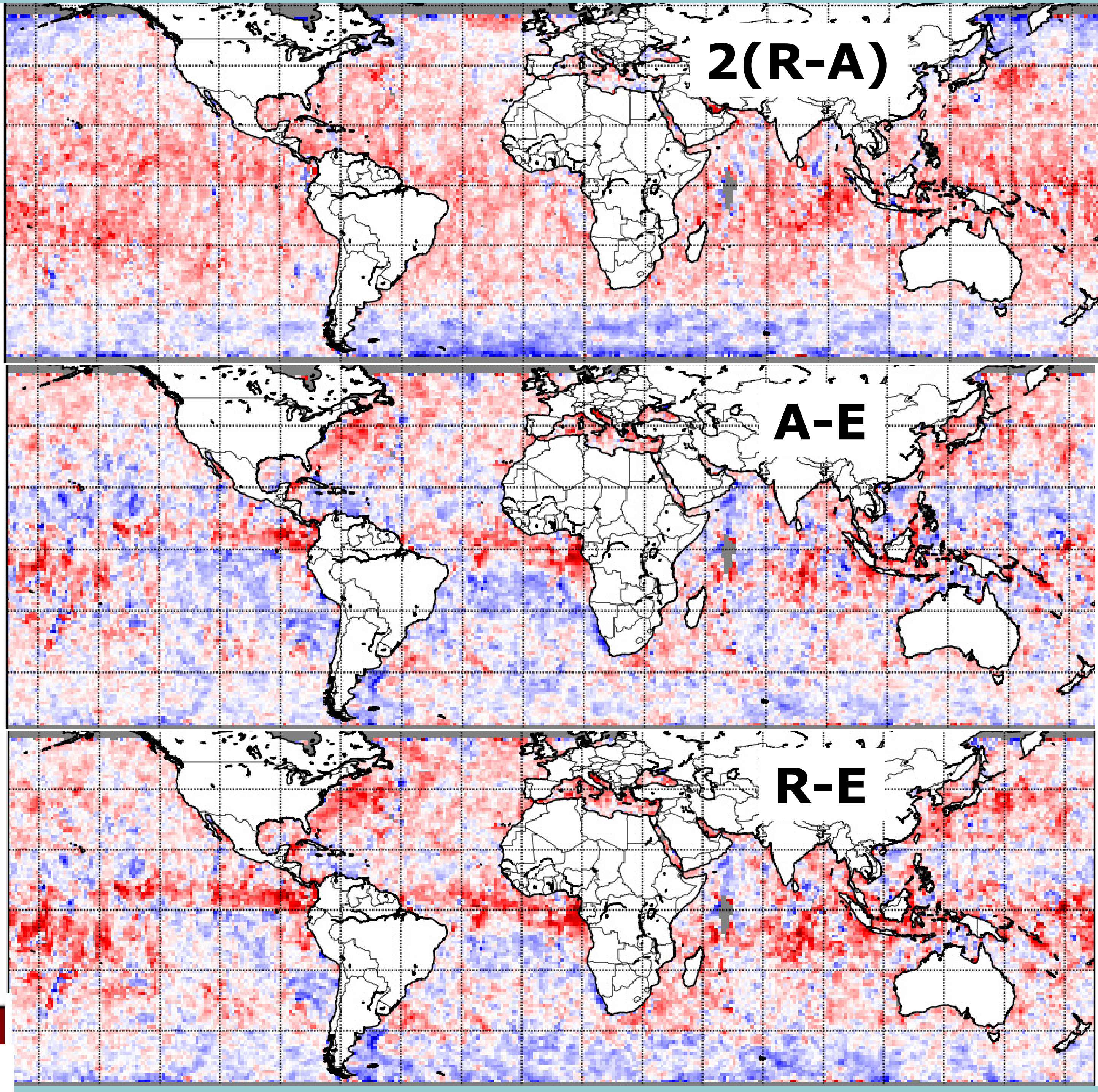
- https://www.dropbox.com/s/hys9ekhvzji5y5o/Winds%20on%20waves.avi?dl=0

- Scatterometers only see roughness/stress and retrieval residuals do not depend on sea state (so far)

All Δs

- All WVCs accepted by both
- A/RSCAT rejects 1/10%
- ➢ High latitude low bias RSCAT
- ➢ Convection stands out vs ECMWF
- ➢ RSCAT and ASCAT much agree on small scales! (must be wind, no rain!)
- ➢ RSCAT little more red though in tropics (rain?)
- ➢ Currents?





2-Month Average Wind Stress Magnitude and SST Contours

(Spatially High-Pass Filtered)

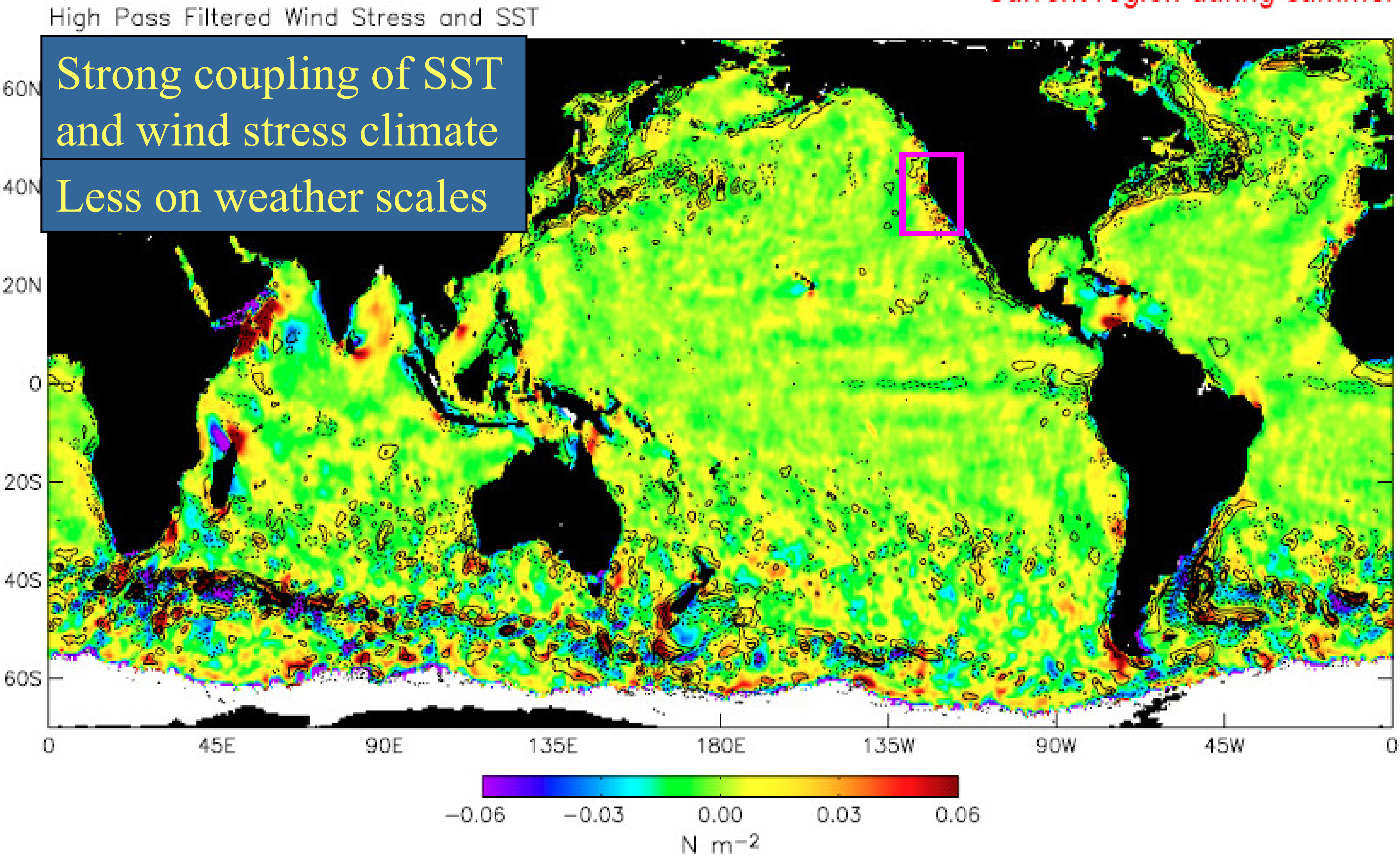
QuikSCAT, July–August 2003

Northern Hemisphere Summer

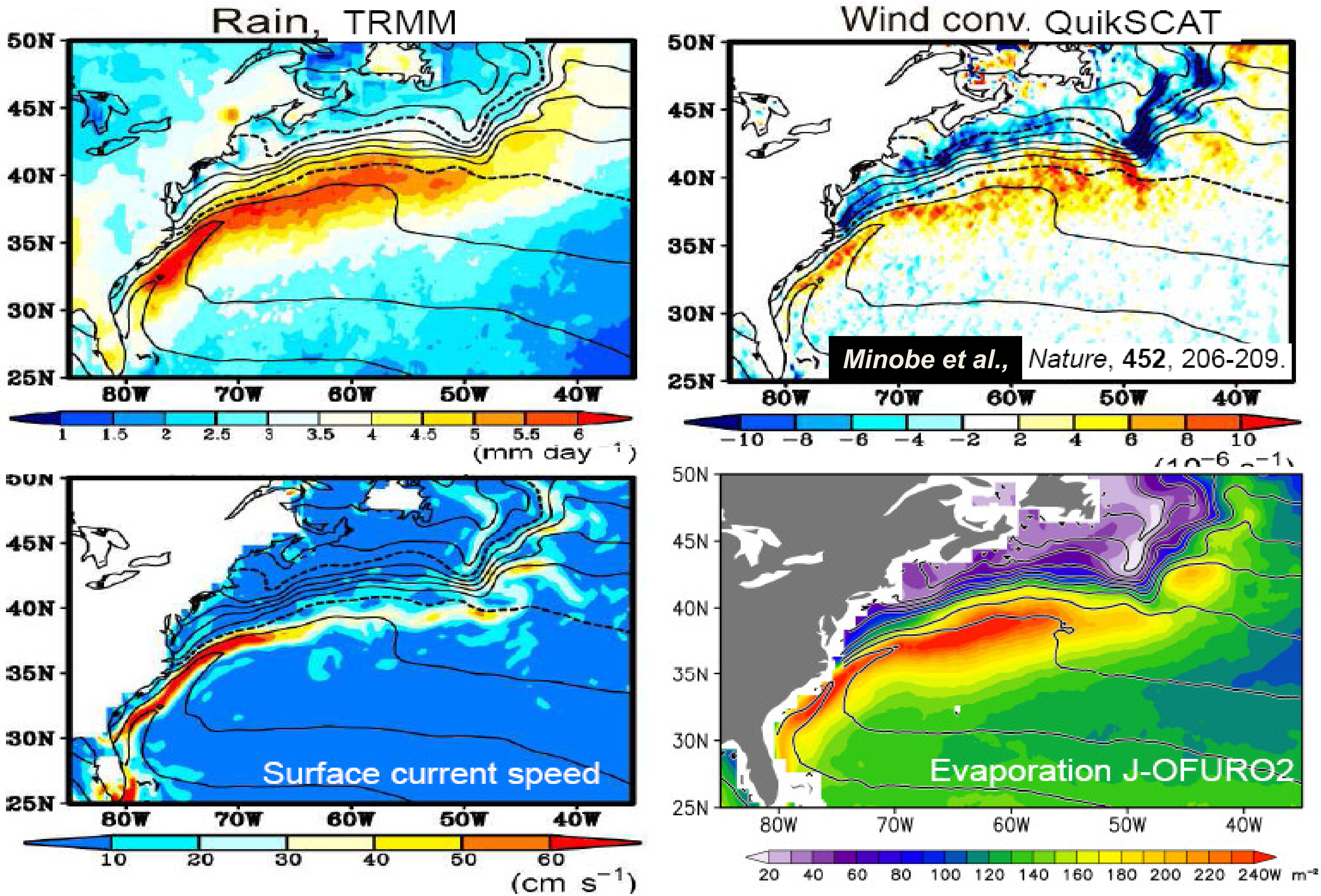
Small-scale structure is well developed in the California Current region during summer

Strong coupling of SST and wind stress climate

Less on weather scales



Coupling ocean and atmosphere (climate scales)



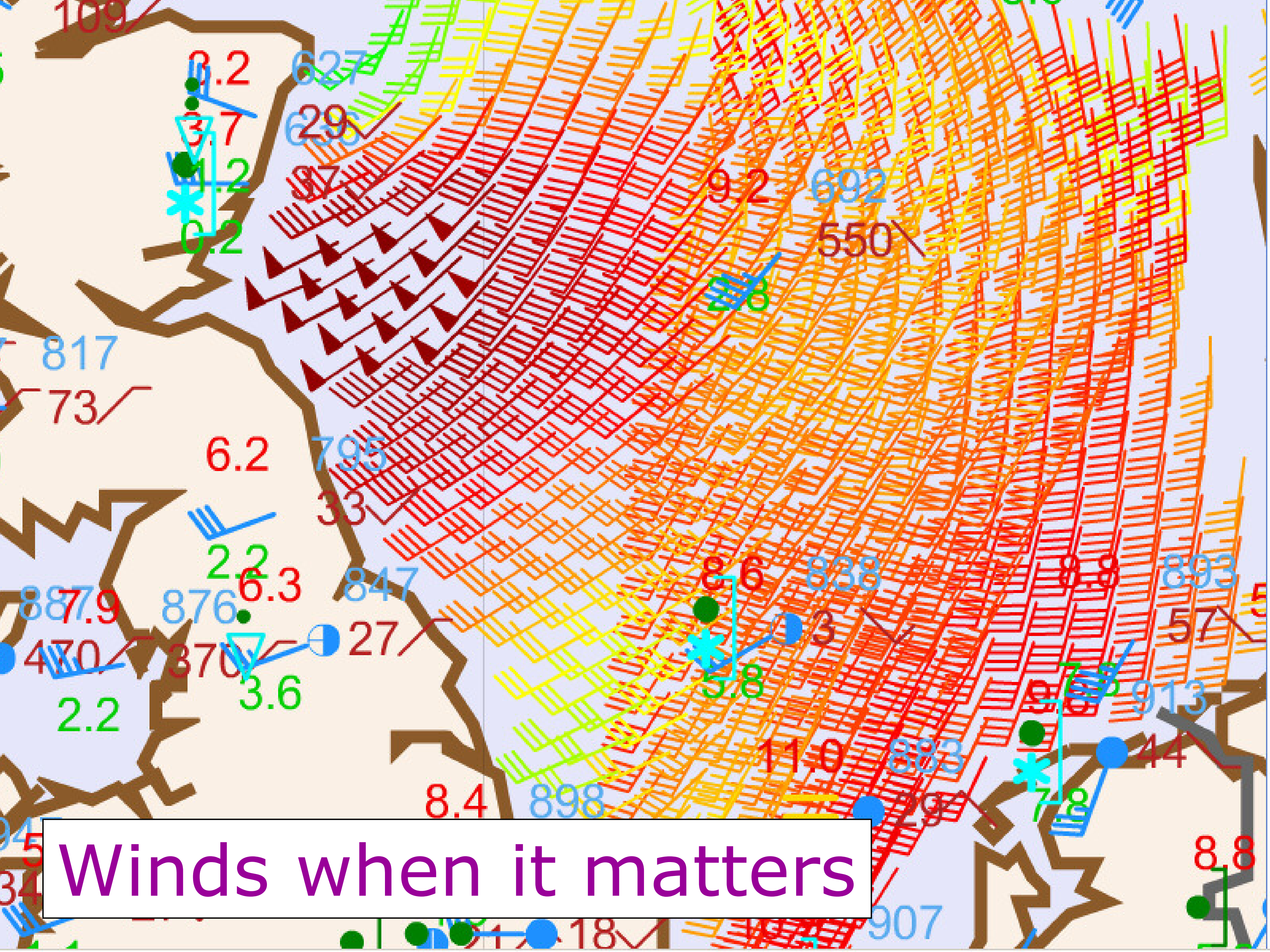
RapidScat on ISS

http://www.telegraaf.nl/tv/opmerkelijk/23929606/Astronaut_filmt_ISS_met_GoPro__.html

ISS Expedition 42_US EVA2 GoPro

Statistics of RSCAT Buoy Comparisons

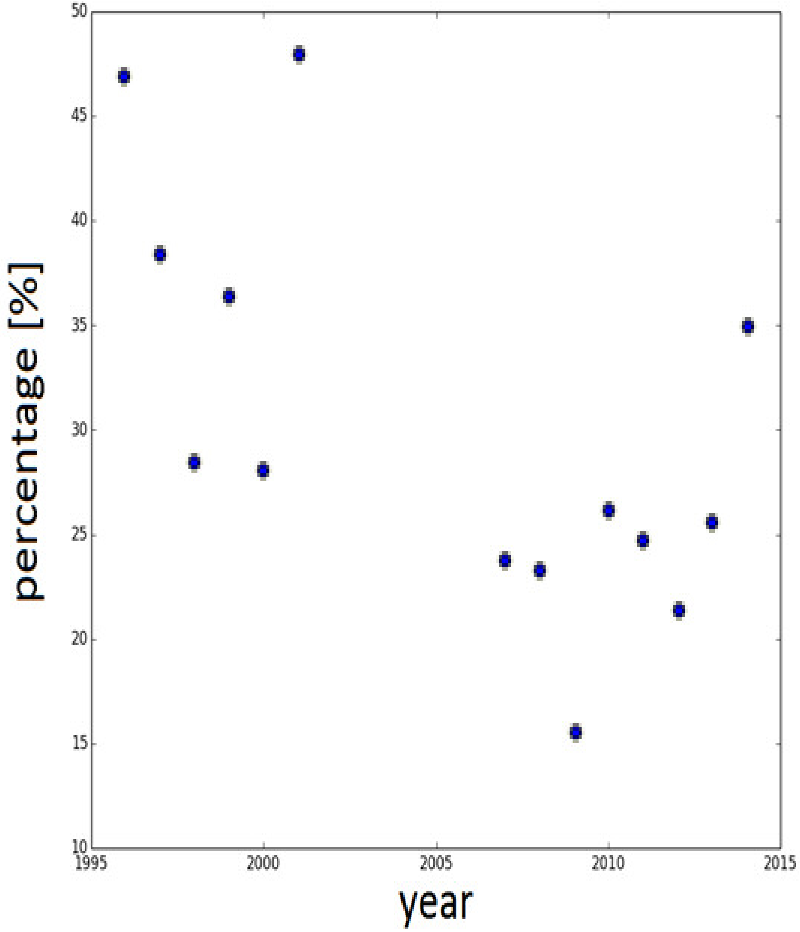
	Nudged	DIRTH	NC	KNMI
Spatial resolution	25	25	12.5	25
Wind Speed (m/s)				
Number of data	3,184	3,184	1,675	2,334
Bias	-0.07	-0.05	0.23	0.22
Rms difference	1.16	1.11	1.11	0.98
Correlation	0.938	0.943	0.944	0.954
Wind Direction (deg.), wind speed > 3 m/s				
Number of data	2,813	2,813	1,490	2,064
Bias	1.5	0.9	1.6	3.2
Rms difference	25.6	23.7	20.4	19.4
Correlation	0.962	0.967	0.977	0.977



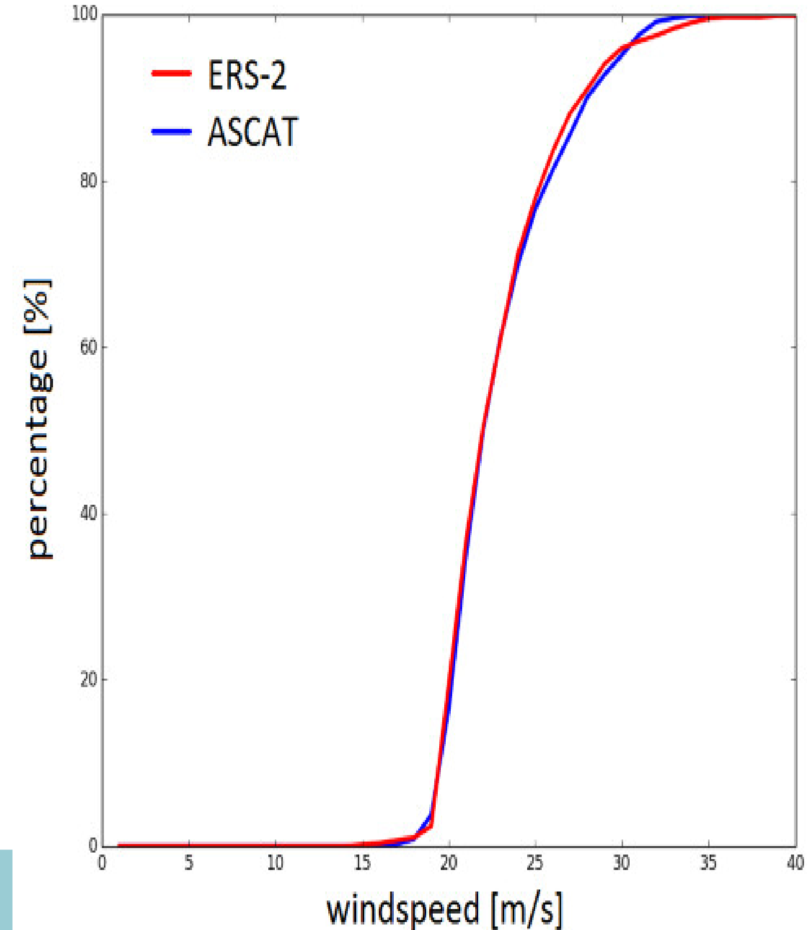
Winds when it matters

Climate extremes

PERCENTAGE OF HURRICANES >20 M/S IN ERA-INTERIM FOR SCAT WINDS > 20 M/S

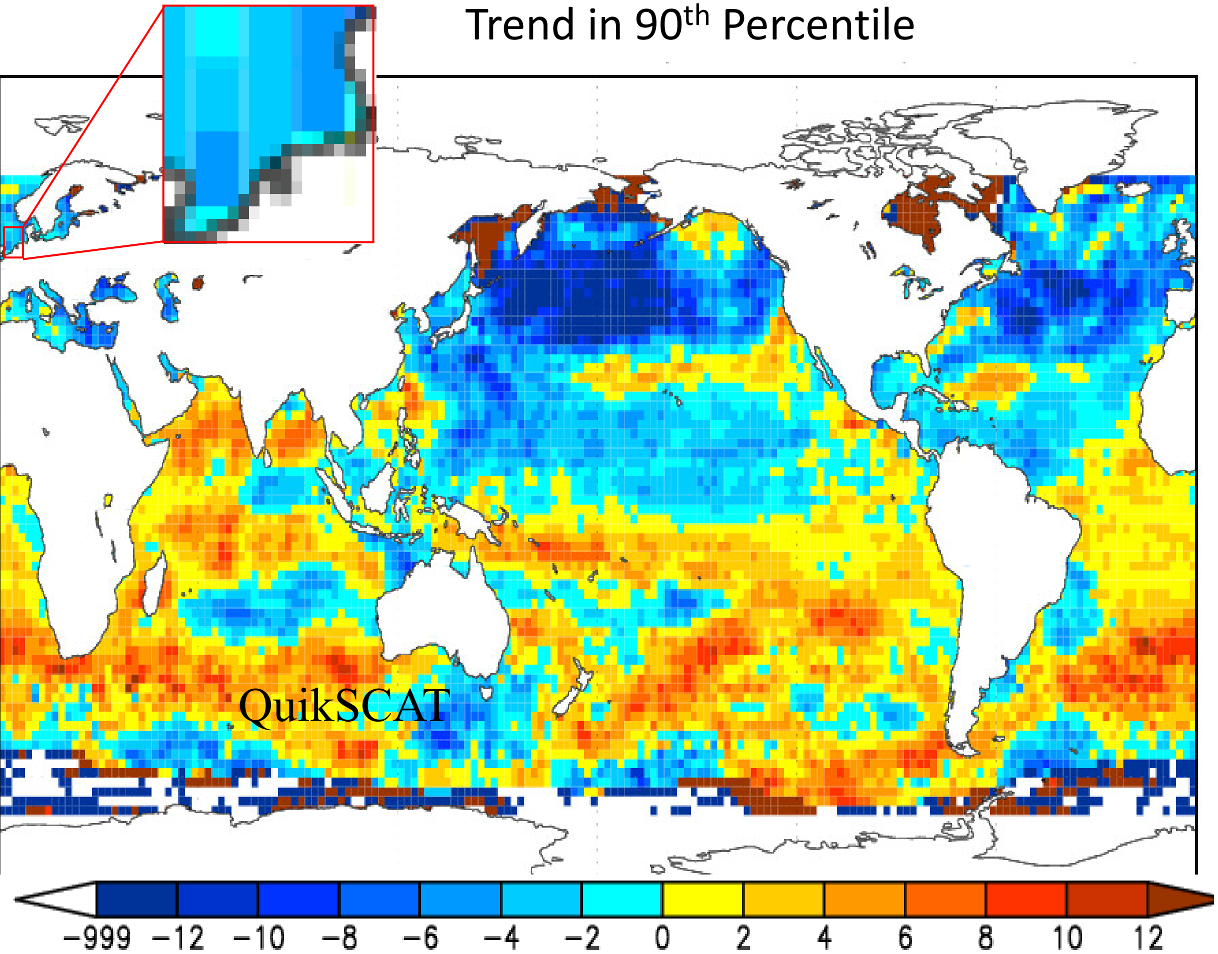


ACCUMULATED PDF OF SCATTEROMETER WINDS ABOVE 20 M/S



Trends in extreme wind speed

Trend in 90th Percentile



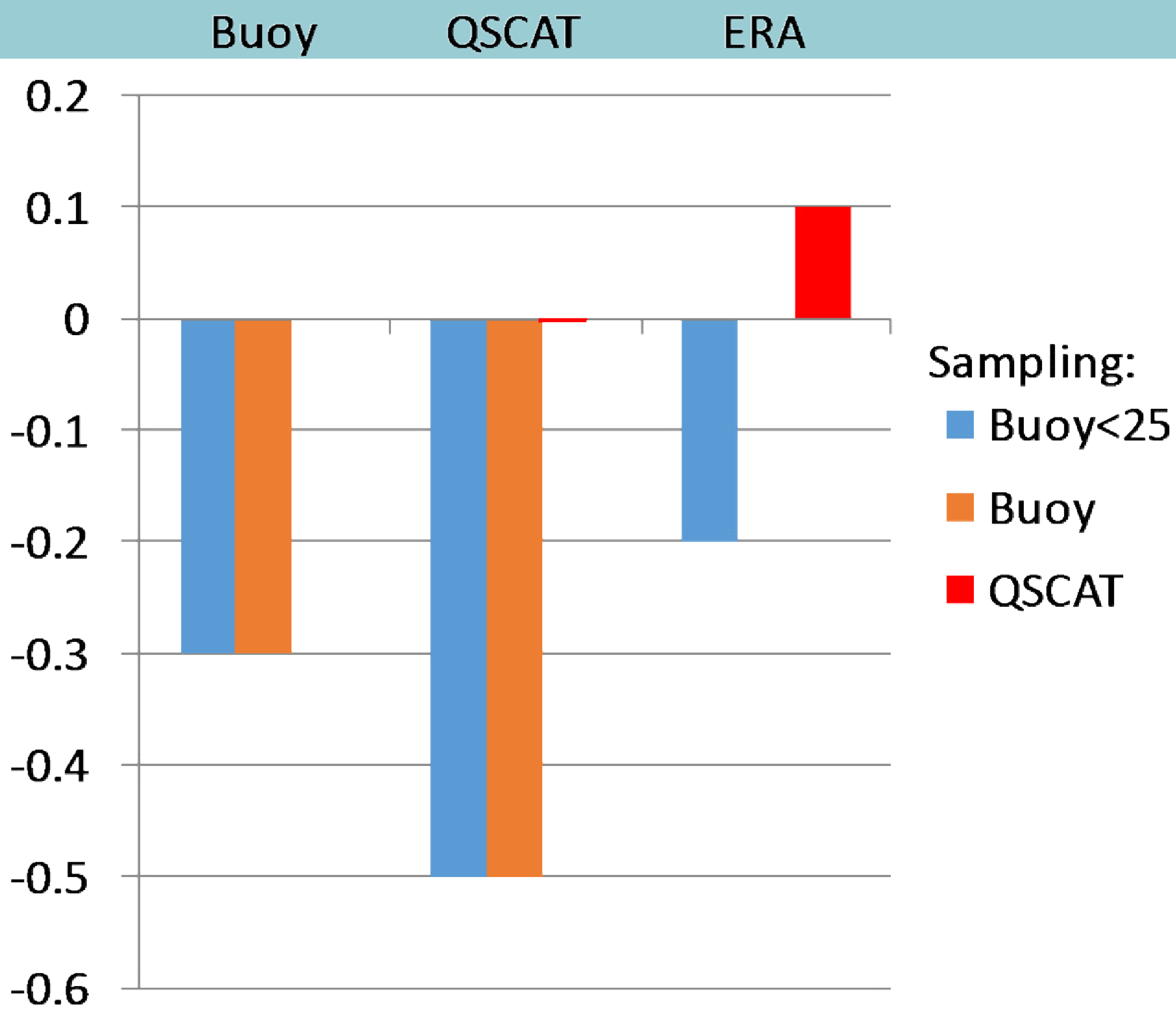
Trend in Wind Speed (in 0.1 m/s per 10 year)

- Controversy in trends of mean and extremes
- Wentz, F. J., and L. Ricciardulli, 2011, *Science*
- Young, I. R., S. Zieger, and A. V. Babanin, 2011: *Science*
- Local trends of 1 m/s are quite feasible
- Satellite, NWP and buoy sampling see different trends

Figure by Jason Keefer and Mark Bourassa, FSU

Climate trends 1999-2009

- Required accuracy is 0.1 m/s per 10 years (GCOS)
- Trends sampled at buoys are different from global trends sampled by QSCAT or ERA
- Moored buoys are **absolutely** needed for satellite calibration
- Moored buoys do not represent the global climate (SH lacking)
- Satellites can measure global climate change

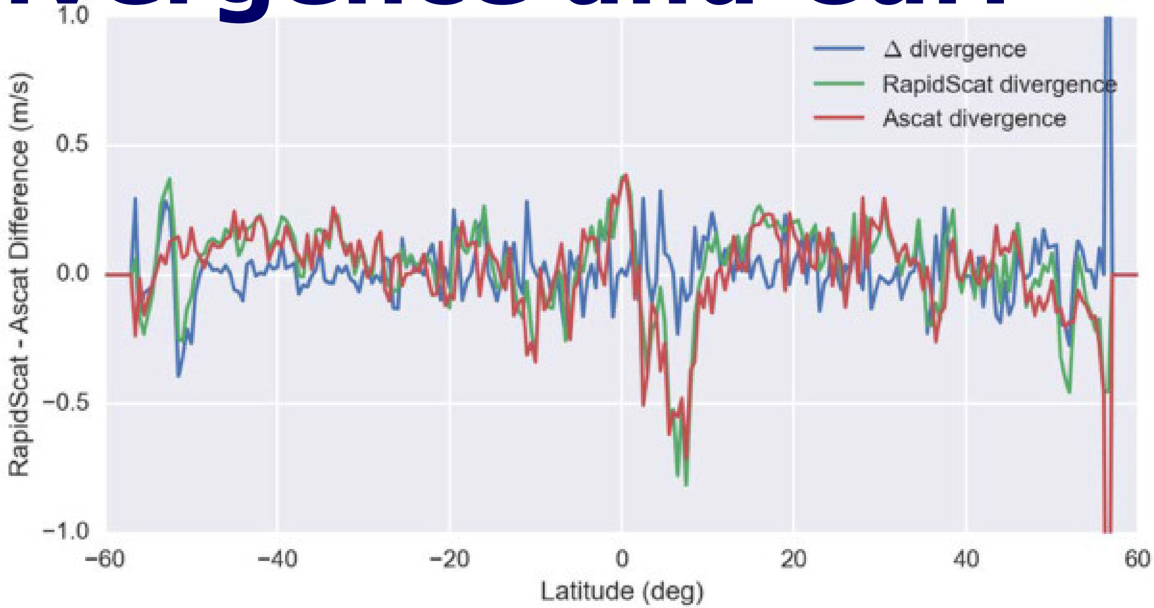


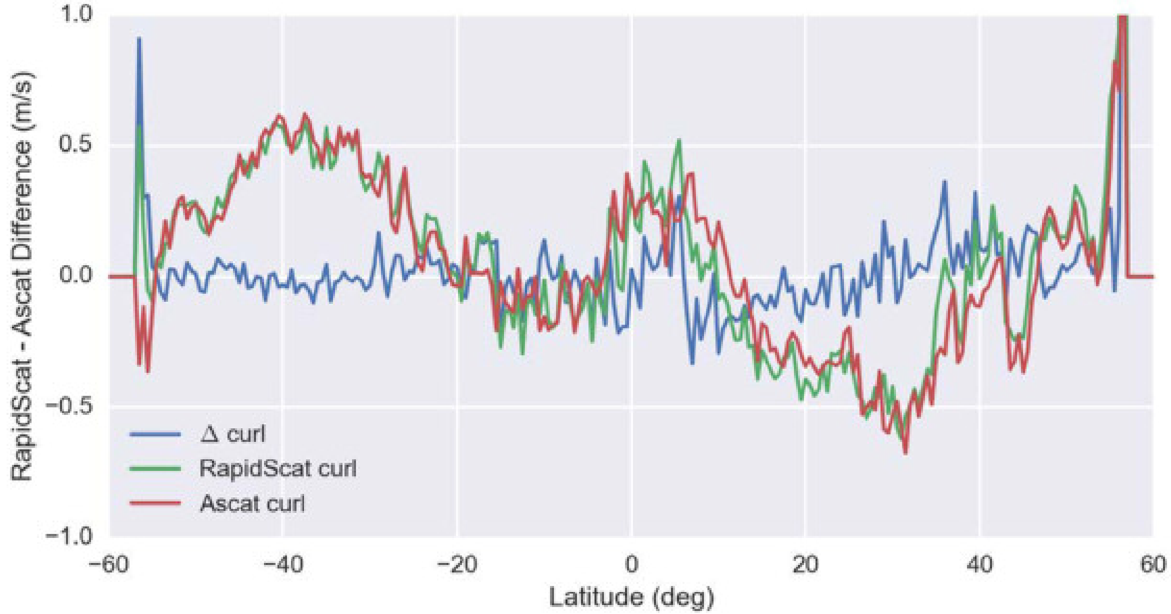
Project ERA*

- KNMI produced ERA-interim U10S at full resolution
- ERA-interim is interpolated to scatterometer WVCs
- Difference PDFs between ERA and scatterometers are locally accumulated to correct ERA-interim; these identify:
  - NWP artefacts
    - Lack of ocean current
    - Excessive mixing in stable air (Randu)
    - Lack of ocean eddy-scale structure (Chelton)
    - Poor tropical dynamics, particularly convective scales
  - Scatterometer artefacts, presumably small

Zonally Averaged Wind Divergence and Curl

- C- and Ku-band winds are very similar
- Also, curl and divergence show very similar latitudinal variation
- Not hindered by a Ku-band rain effect





E.Rodriguez, JPL