Towards triple collocation analysis of 4D wind observations

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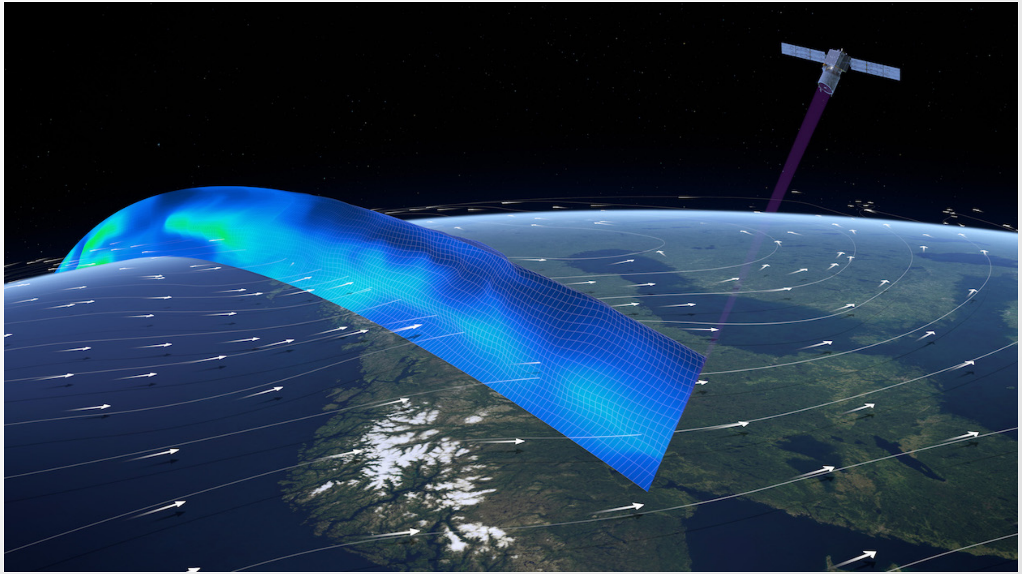


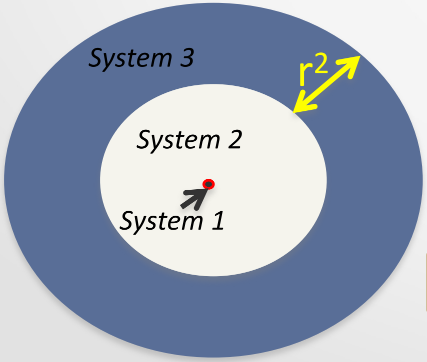
EUMETSAT WIND-4D Fellowship

BEC
Barcelona Expert Center

- Project title: "*On the 4-D consistency of satellite wind products for regional NWP data assimilation (WIND-4D)*"
- 3-year fellowship hosted at the Institute of Marine Sciences (ICM-CSIC) in Barcelona, Spain
- Collaborations with: AEMET (Spain), KNMI (the Netherlands), IPMA (Portugal)
- Project goals:
  - 1) characterize the spatial scales and errors of different satellite wind observations (ASCAT, Aeolus, AMVs)
  - 2) improve the 4D (including time) consistency between the different horizontal and/or vertical satellite wind products under study
  - 3) improve wind data assimilation into regional NWP models (HARMONIE-AROME)

Triple collocation method

- The triple collocation (TC) method (Stoffelen, 1998) is used to inter-calibrate three independent measurement systems ($\mathbf{s}_1$, $\mathbf{s}_2$ and $\mathbf{s}_3$) with different resolutions
- The method gives an estimate of their measurement errors $\boldsymbol{\delta}_1$, $\boldsymbol{\delta}_2$ and $\boldsymbol{\delta}_3$
- The three systems must be collocated in space and time
- The representativeness error ($\mathbf{r}^2$) between $\mathbf{s}_2$ (intermediate resolution system) and $\mathbf{s}_3$ (lower resolution system) must be provided



***Truth** at the scales commonly resolved by all 3 data sources*

$$\boxed{s_i = a_i S + b_i + \delta_i}$$

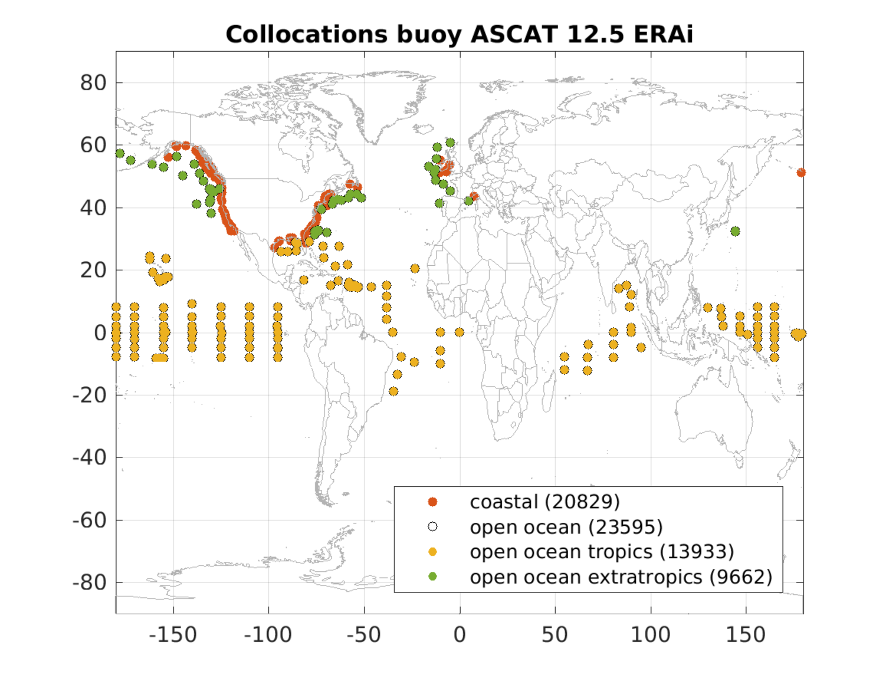
*random measurement **error** (gaussian)*

***scaling** calibration coef.*

***bias** calibration coef.*

Triple collocation method: example

- s_1: buoys (point measurements)
  s_2: ASCAT 12.5 (scatterometer with 12.5 km horizontal resolution)
  s_3: ECMWF ERA-Interim (78 km nominal horizontal resolution)
- Period: October 2008 to November 2009 (14 months)
- Collocations criteria:
  - time difference <= 30 minutes
  - distance <= 8.84 km
- What is the representativeness error (r^2) between s_2 and s_3?

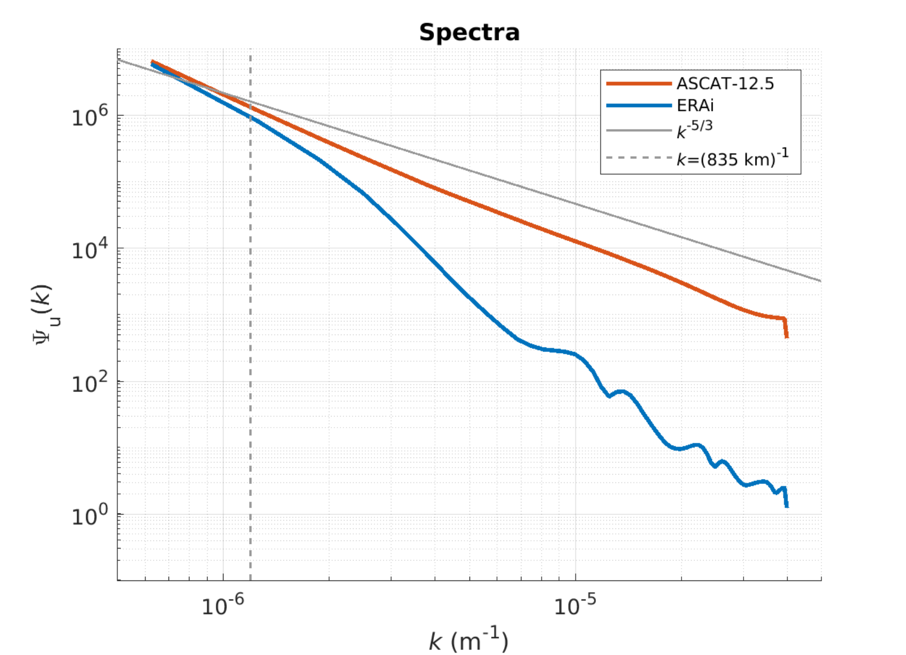


Methods for estimating r^2

- One $\mathbf{r^2}$ value for each wind component ($\mathbf{r^2_u}$, $\mathbf{r^2_v}$)
- Available methods:
  - Spectral integration (Vogelzang et al. 2011)
  - Spatial variances (Vogelzang et al. 2015)
  - Optimal intercalibration (Lin et al. 2015)

$$\mathbf{r^2_{u,v}} = (\ \mathrm{Area}_{\mathrm{ASCAT}} - \mathrm{Area}_{\mathrm{ERAi}}\ )_{\mathbf{u,v}}$$

r^2 value depends on left integration limit $k \approx (800\ \mathrm{km})^{-1}$



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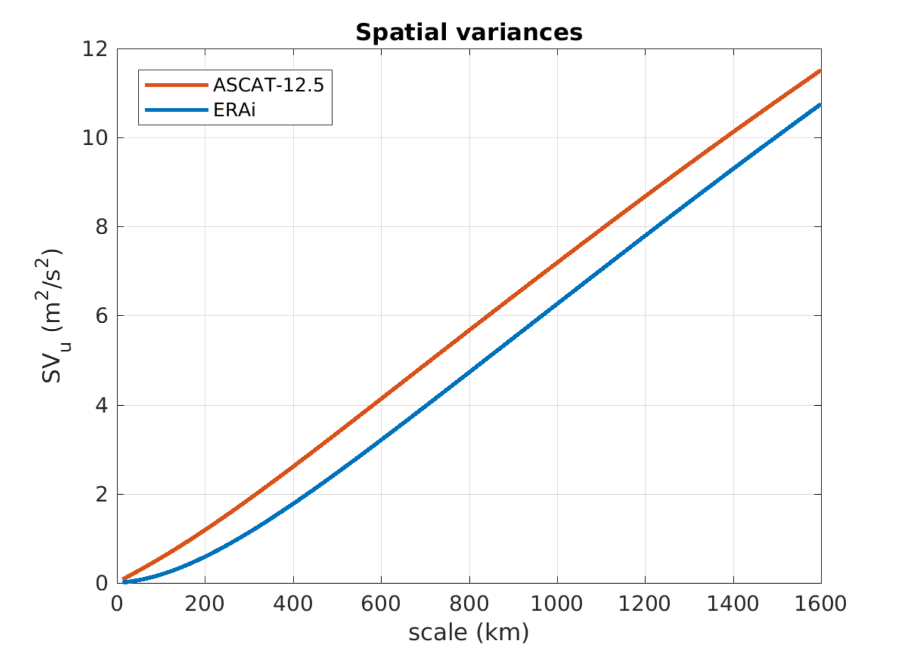
$$r^2_{u,v} = (SV_{ASCAT} - SV_{ERAi})_{u,v}$$

r^2 value depends on scale



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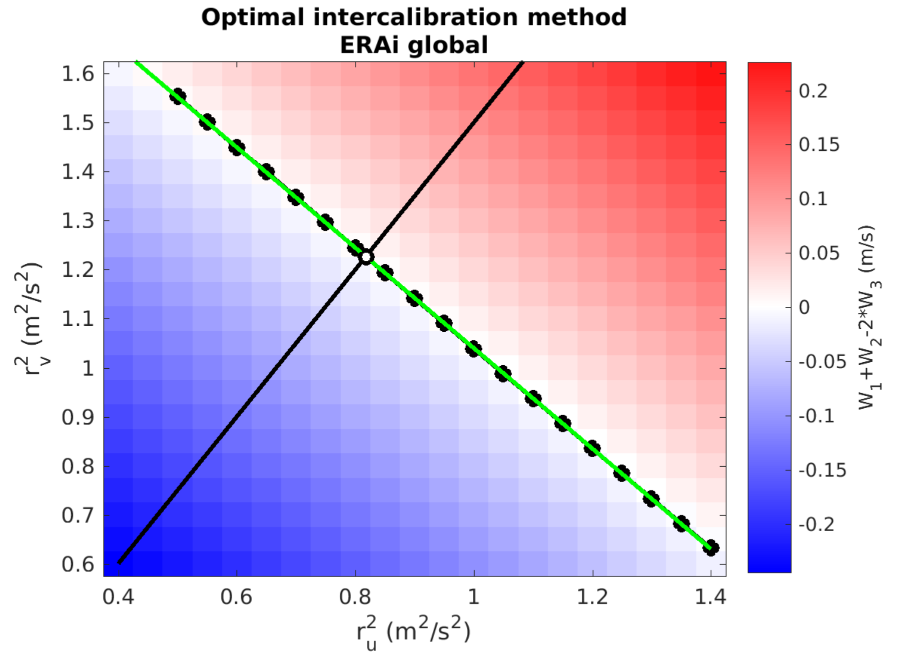
optimal $\mathbf{r}^2_{\mathbf{u,v}}$ when $(W_1 + W_2 - 2{*}W_3)_{\mathbf{u,v}} \longrightarrow 0$

where $W_{1,2,3}$ = wind speed of system 1, 2, 3

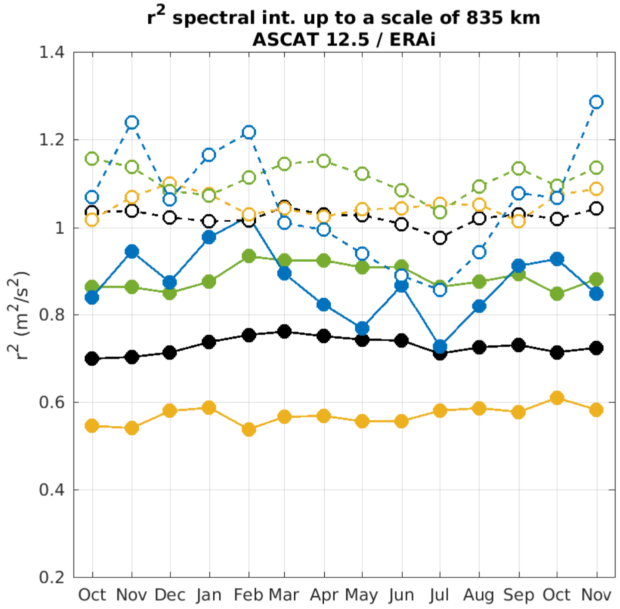
with constraint $\mathbf{r}^2_{\mathbf{v}} / \mathbf{r}^2_{\mathbf{u}} \approx 1.5$

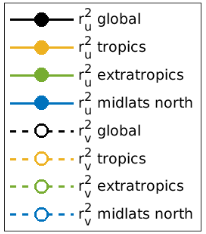
r^2 value depends on constraint



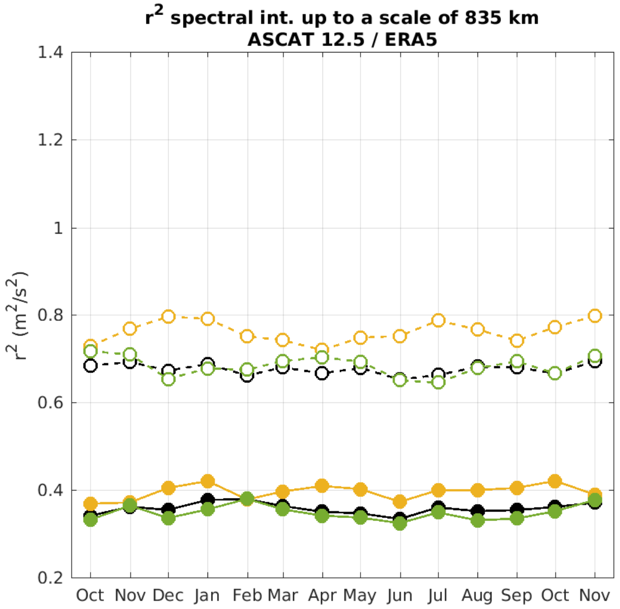
r^2 results

- A $\mathbf{r^2}$ value is obtained for each **wind component** (u and v), for each of the **14 months** considered, for three **different areas** (global, open ocean tropics, open ocean extratropics), for two **different model outputs** (ERA-Interim and ERA5) and for three **different methods** (spectral integration, spatial variances and optimal intercalibration).



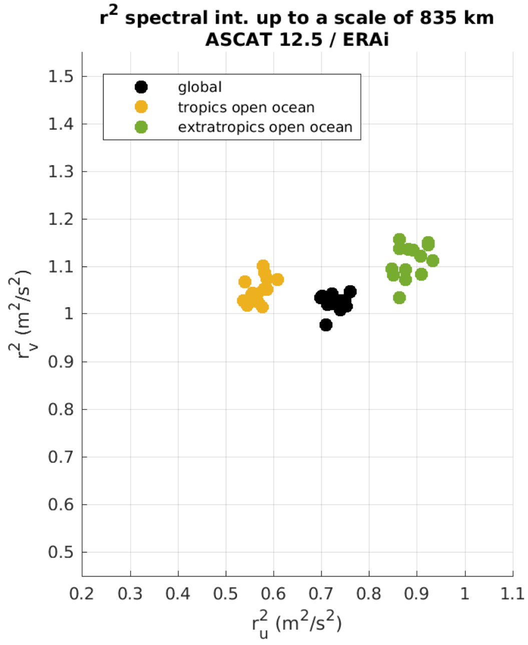


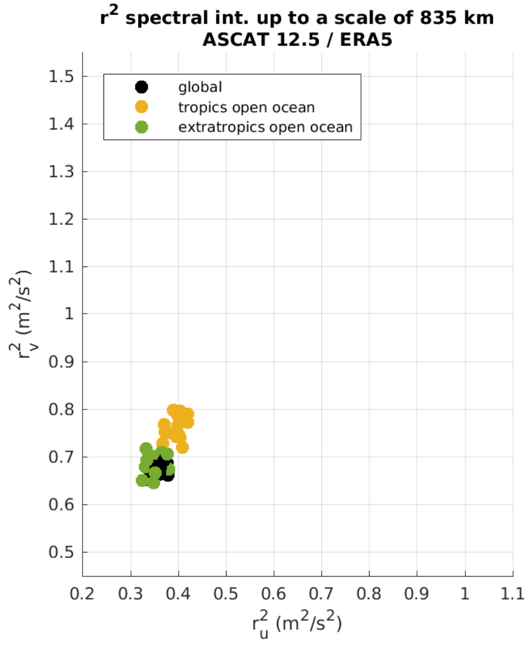
- more true variability in the meridional than in the zonal component
- Northern hemisphere seasonal wind variability well captured
- smaller $\mathbf{r^2}$ values with ERA5 than with ERAi, since the former contains smaller scales



r^2 results

- Same results as the previous slide, but grouped differently, with $\mathbf{r^2_u}$ on the x-axis and $\mathbf{r^2_v}$ on the y-axis. The “clouds” of scattered points represent the seasonal variability.





$\mathbf{r^2}$ uncertainty estimation:

- for both spectral and spatial variance methods, larger $\mathbf{r^2}$ (wind variability) in the extratropics with ERAi TC set; however, the opposite is shown with ERA5 TC set
- for the optimal intercalibration method, both TC sets show higher variability in the tropics

- The optimal intercalibration method allows for $\mathbf{r^2}$ estimation in coastal areas

Measurement errors from triple collocation

- Once $\mathbf{r}^2$ has been estimated with one of the previous methods, the triple collocation method can be applied to the three uncalibrated data sets.
  In this case, $\mathbf{r}^2$ was computed with: spectral integration, global, 2009-01, ERA-Interim.

- Error standard deviations at Era-Interim scale:

Buoy	ASCAT 12.5	Era-Interim	
δ_u, δ_v (m/s)	δ_u, δ_v (m/s)	δ_u, δ_v (m/s)	r^2_u, r^2_v (m^2/s^2)
1.50, 1.59	1.11, 1.23	1.60, 1.48	0.74, 1.01

- Error standard deviations at ASCAT scale:

Buoy	ASCAT 12.5	Era-Interim	
δ_u, δ_v (m/s)	δ_u, δ_v (m/s)	δ_u, δ_v (m/s)	r^2_u, r^2_v (m^2/s^2)
1.24, 1.23	0.71, 0.80	1.82, 1.79	0.74, 1.01

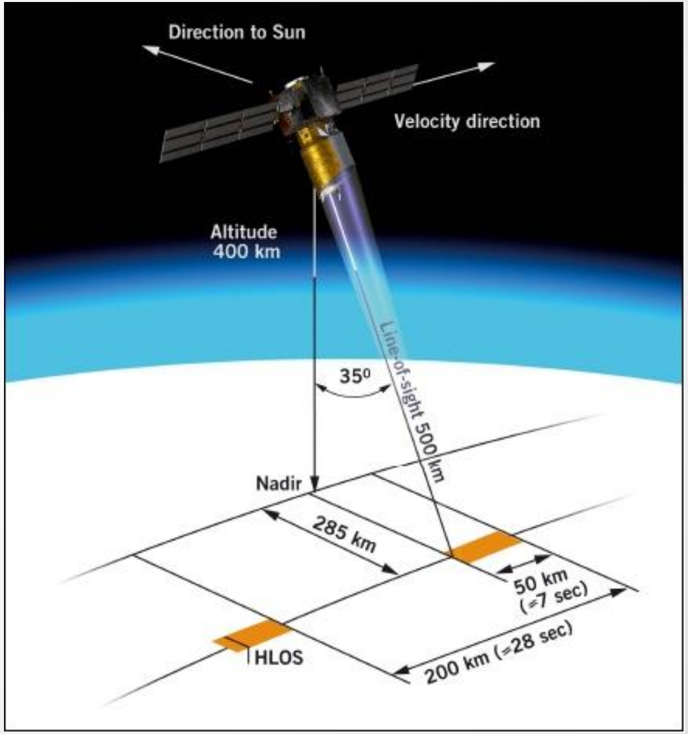
- Conversion between scales: $(\delta^2_{u,v})^{\text{ASCAT scale}} = (\delta^2_{u,v})^{\text{ERA-I scale}} \pm \mathbf{r}^2_{u,v}$

  −: buoy and ASCAT
  +: Era-Interim

- ASCAT winds show the lowest uncertainty at both NWP and scatterometer scales (consistent with previous works)

4D wind observations: Aeolus mission

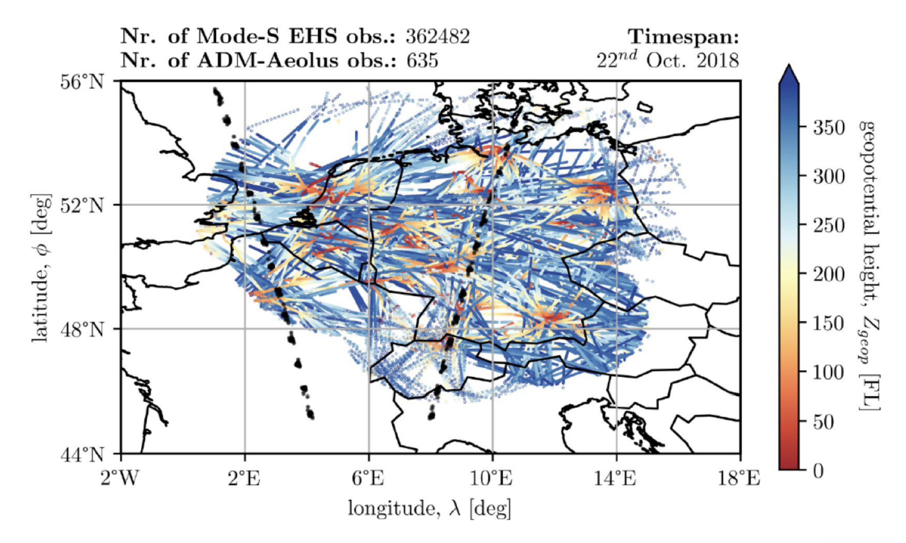
- ESA's Aeolus satellite is providing vertical **wind profiles** across the globe since September 2018.
- Its onboard instrument, a doppler wind lidar, measures wind speed along the horizontal line-of-sight (**HLOS**) in two different channels: **Rayleigh** (air molecules) and **Mie** (aerosols and cloud particles).
- Aeolus is a demonstrator mission, however it is expected to improve the analysis of the global three-dimensional wind field thanks to its excellent horizontal and vertical sampling as well as quick data availability.



Nominal measurement geometry and coverage of ADM-Aeolus (image credit: ESA/ESTEC)

4D wind observations: Mode-S

- Mode-S is a novel type of aircraft-derived meteorological observational data (atmospheric pressure, temperature and wind speed).
- Mode-S data are provided by KNMI and they cover a part of Western Europe.
- Mode-S observations are relative to ascending/descending tracks as well as cruising altitudes.
- They can be used for validation of Aeolus observations as well as direct assimilation into NWP models.



Mode-S observations (in color) and Aeolus tracks (in black) passing over Mode-S domain (image credit: Steven Albertema, KNMI)

Triple collocation of 4D wind observations

- We are planning to perform triple collocations between Aeolus, Mode-S and ECMWF IFS model output.
- Aeolus data provided by KNMI are already collocated with ECMWF.
- Currently working on a 4D interpolator tool for collocating Mode-S with Aeolus.
- Mode-S wind speed/direction must be converted to HLOS wind to have the same type of observation that Aeolus provides.
- More triple collocations analyses are expected in the future using Atmospheric Motion Vectors (AMVs) and Infrared Atmospheric Sounding Interferometer (IASI) wind profiles.

Summary

- The triple collocation method is useful for characterizing independent observational data sets, in terms of their spatial scales and measurement errors.
- Different methods exists for computing the representativeness errors.
- $\mathbf{r}^2$ depends on the relative resolution of the three observing systems, but it also varies according to wind component, month, area and method.
- The optimal intercalibration method is useful for estimating $\mathbf{r}^2$ in localized areas, such as coastal areas, where the other two methods cannot be applied.
- The measurement errors derived with the triple collocation method show that ASCAT 12.5 observations are more accurate than buoy observations and ECMWF model output.
- Currently working on triple collocation of 4D wind observations.
- Once these observational data sets are properly characterized and their consistencies analyzed, they will be ready to be assimilated into regional NWP models.

Questions

- For any question, please contact me at cossu@icm.csic.es