Institut de Ciències del Mar

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Characterization of Aeolus wind measurement errors

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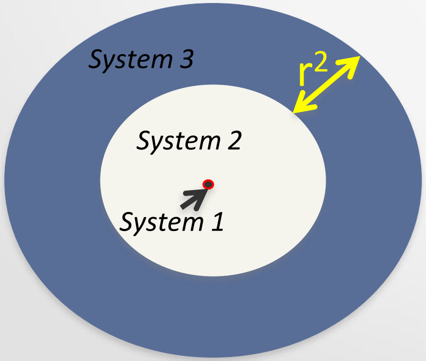
Outline

- The triple collocation method
- Triple collocation analysis of 3D wind observations
- Triple collocation analysis of 4D wind observations
- Conclusions

Triple collocation method

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



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

$$\boxed{x_i = a_i(t + \varepsilon_i) + b_i}$$

***bias** calibration coef.*

***scaling** calibration coef.*

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

TC error variances

Errors at the scale of system 3

$$
\begin{cases}
\sigma_1^2 = \dfrac{C_{11}}{a_1^2} - T + \left(\dfrac{C_{13}}{C_{23}} - 1\right) r^2 \\
\sigma_2^2 = \dfrac{C_{22}}{a_2^2} - T + \dfrac{C_{13}}{C_{23}}\left(1 - \dfrac{C_{13}}{C_{23}}\right) r^2 \\
\sigma_3^2 = \dfrac{C_{33}}{a_3^2} - T + \left(\dfrac{C_{13}}{C_{23}} - 2\dfrac{C_{12}C_{33}}{C_{23}^2}\right) r^2 + \dfrac{C_{33}}{C_{23}^2} r^4
\end{cases}
$$

where:

$C_{ij} = \langle x_i x_j \rangle - \langle x_i \rangle \langle x_j \rangle$: covariances

$T = \dfrac{C_{12}C_{13}}{C_{23}}$: common true variance

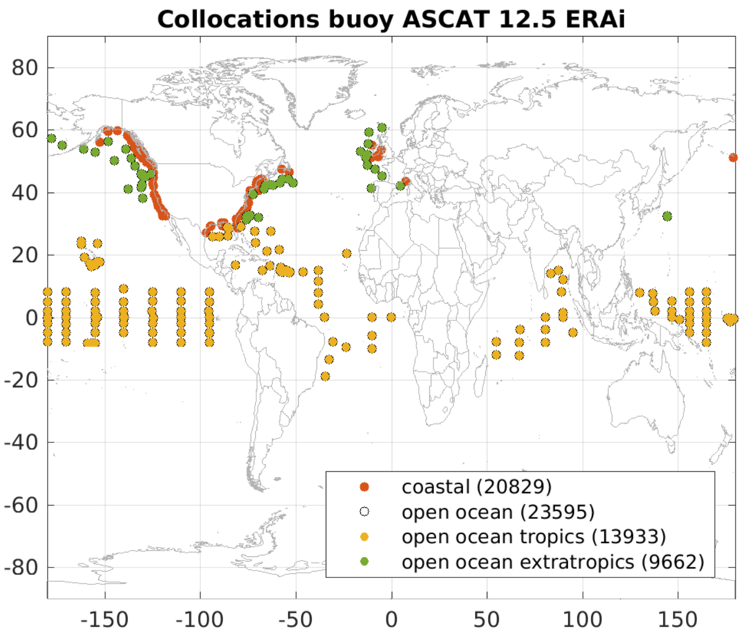
$a_1 = 1;\ a_2 = \dfrac{C_{23}}{C_{13}};\ a_3 = \dfrac{C_{23}}{C_{12}}$: calibration scaling coefficients

$x_{i,j}$: uncalibrated datasets (i,j=1,2,3)

r^2 : representativeness error

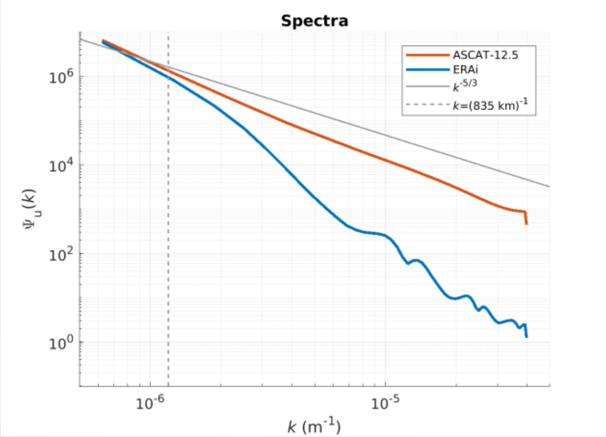
Triple collocation method: example

- $\mathbf{x_1}$: buoys (point measurements)
  $\mathbf{x_2}$: ASCAT 12.5 (scatterometer with 12.5 km horizontal resolution)
  $\mathbf{x_3}$: ECMWF ERA-Interim (78 km nominal horizontal resolution)
- Period: October 2008 to November 2009 (14 months)
- Collocations criteria:
  - time difference $\leq$ 30 minutes
  - distance $\leq \frac{\text{grid size}}{\sqrt{2}} = \frac{12.5\text{ km}}{\sqrt{2}} \sim 8.84$ km
- What is the representativeness error ($\mathbf{r^2}$) between $\mathbf{x_2}$ and $\mathbf{x_3}$?

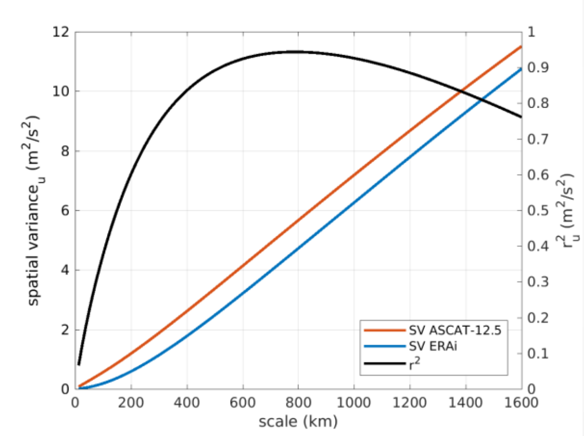


Methods for estimating r^2

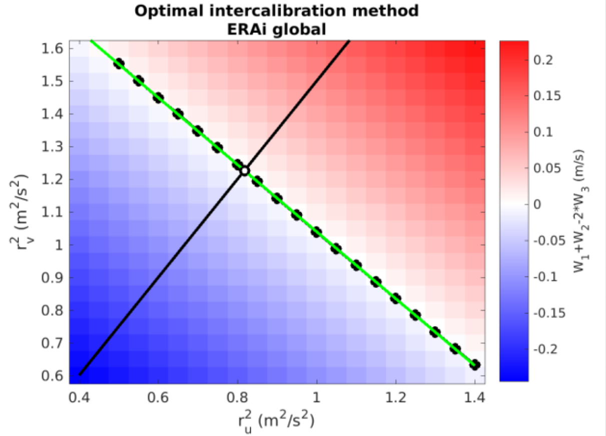
Spectral integration



Spatial variances

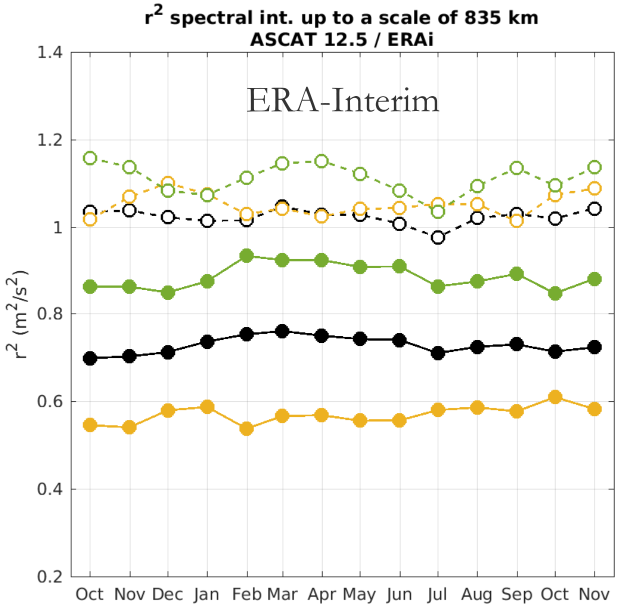


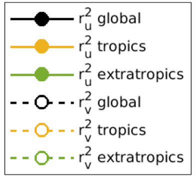
Optimal intercalibration



r^2 results: spectral integration

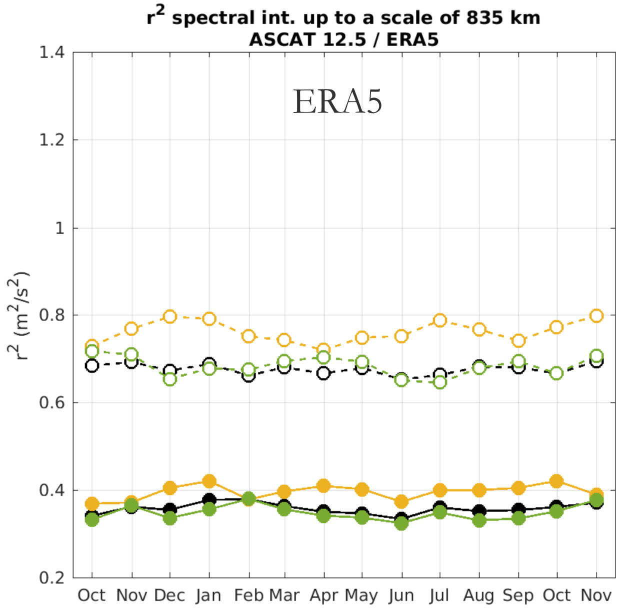
- A r^2 value is obtained for each **wind component** (u and v), for each of the **14 months** considered, for three **different areas** (global, open ocean tropics, open ocean extratropics), for two **different model outputs** (ERA-Interim and ERA5) and for three **different methods** (spectral integration,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





$r^2_u < r^2_v$

$r^2_{ERA5} < r^2_{ERA\text{-}i}$



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	
σ_u, σ_v (m/s)	σ_u, σ_v (m/s)	σ_u, σ_v (m/s)	r^2_u, r^2_v (m^2/s^2)
1.50, 1.59	1.11, 1.29	1.60, 1.48	0.74, 1.01

- Error standard deviations at ASCAT scale:

Buoy	ASCAT 12.5	Era-Interim	
σ_u, σ_v (m/s)	σ_u, σ_v (m/s)	σ_u, σ_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: $(\sigma^2_{u,v})^{\text{ASCAT scale}} = (\sigma^2_{u,v})^{\text{ERA-I scale}} \pm r^2_{u,v}$

  −: buoy and ASCAT
  +: Era-Interim

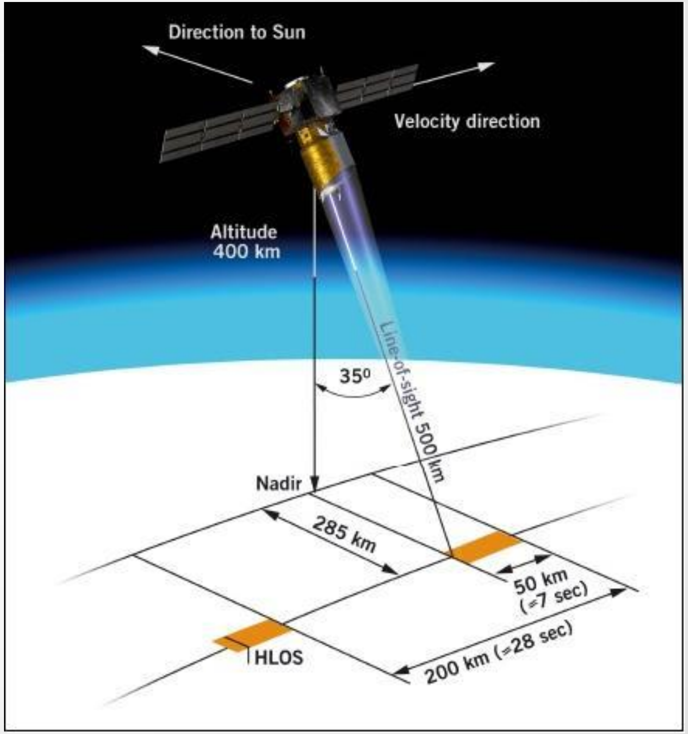
- ASCAT winds show the lowest uncertainty at both NWP and scatterometer scales (consistent with previous works)

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).

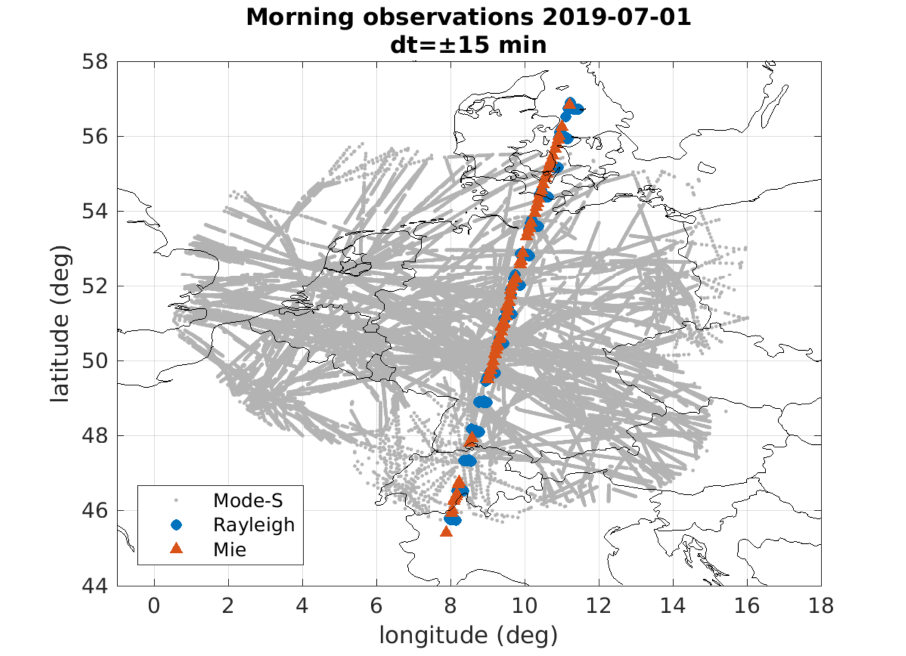
- Aeolus is a demonstrator mission, however it is expected to improve the analysis of the global three-dimensional wind field thanks to its excellent horizontal and vertical sampling as well as quick data availability.



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

Aeolus/Mode-S/ECMWF collocations

- We performed triple collocations between Aeolus, Mode-S and ECMWF IFS model output.
- Observations period: 28 Jun 2019 – 26 Dec 2019
- Aeolus data provided by KNMI are already collocated with ECMWF.
- Mode-S observations are meteorological observations from commercial aircrafts.
- Mode-S observations are more numerous compared to Aeolus, however they are not uniformly distributed in space and time. Because of this, it is not possible to interpolate them to Aeolus locations easily.

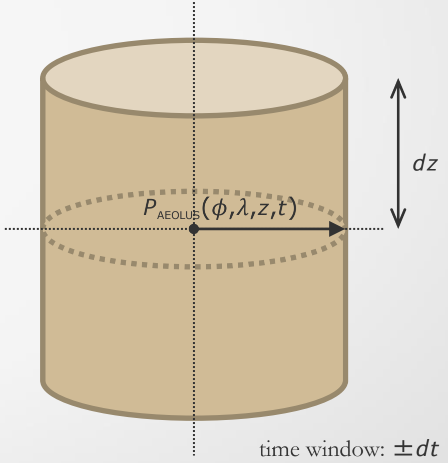


Collocation box

- Mode-S observations are collocated using a collocation box (cylinder) of radius R, height ±dz and temporal size ±dt around each Aeolus observation of coordinates $P_{\text{AEOLUS}}(\phi,\lambda,z,t)$.
- All Mode-S observations that fall inside the box are considered as candidates.
- The selected collocation is the observation that minimizes the normalized distance D:

$$\mathrm{D} = \sqrt{(\Delta R)^2 + (100\ \Delta z)^2 + (1000\ \Delta t)^2}$$

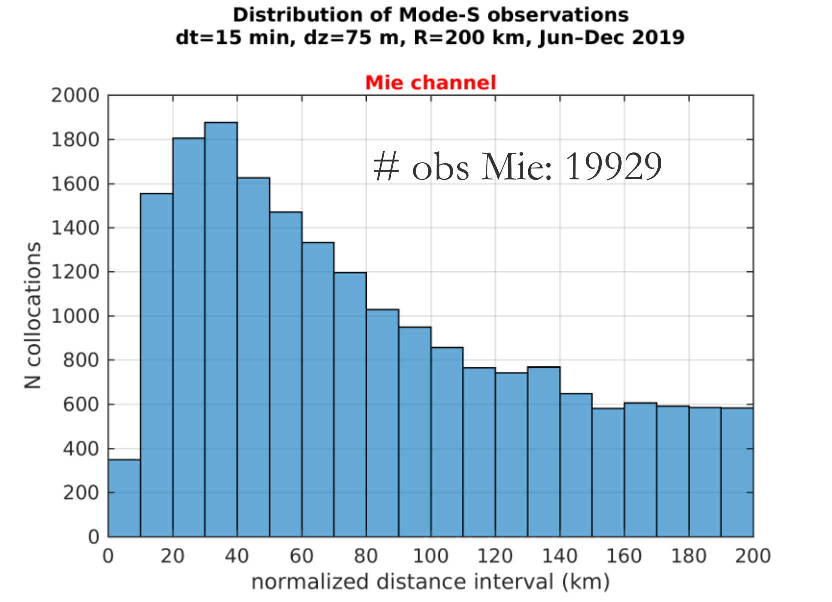
where ΔR (m) is the horizontal distance, Δz (m) is the vertical distance and Δt (min) is the temporal distance of Mode-S from Aeolus.

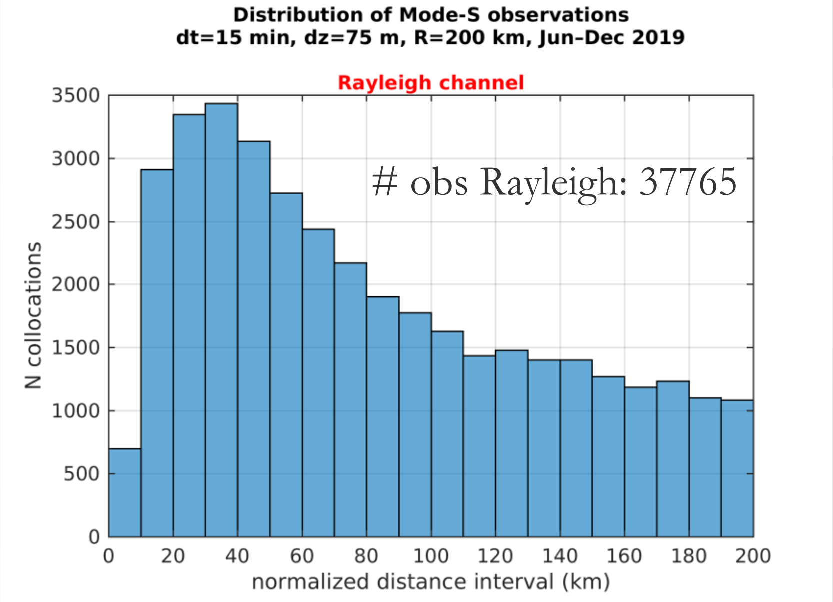


- Mode-S wind speed/direction must be converted to HLOS wind to have the same type of observation that Aeolus provides.

Normalized distance distribution

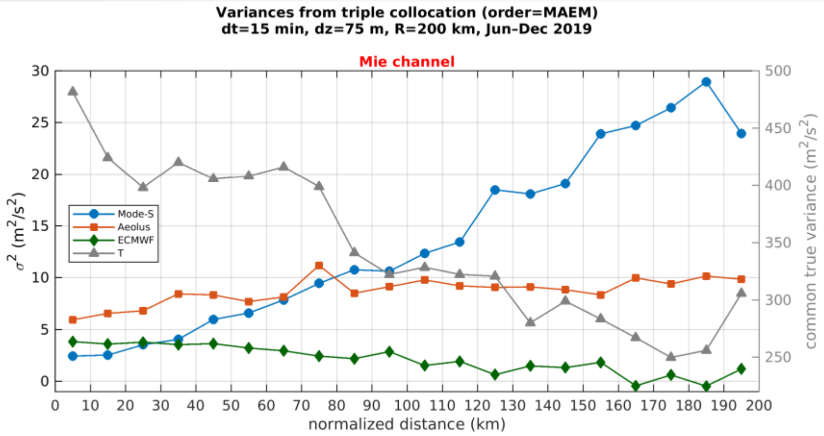
Collocation parameters: dt=15 min, dz=75 m, R=200 km

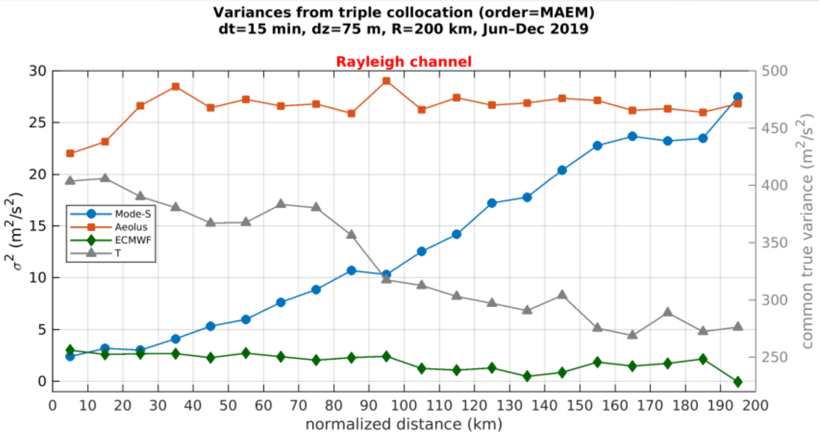




Triple collocation results: error variances

Error variances (with r^2=0 m^2/s^2)

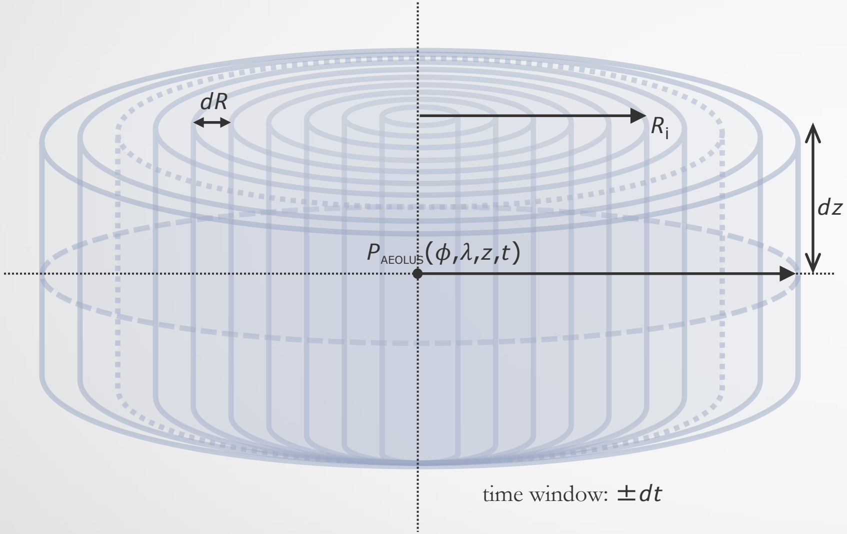


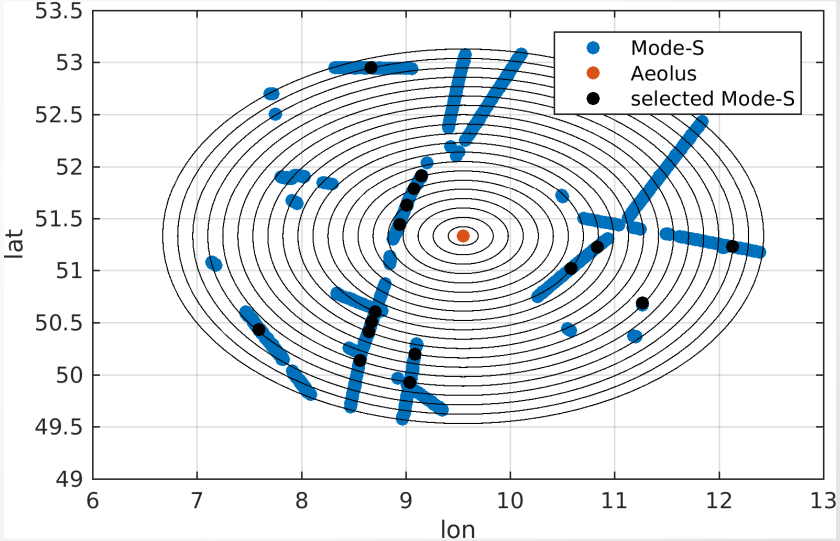


Limited sampling for larger distances

Collocation box: “rings” version

The collocation box is subdivided horizontally using concentric rings of increasing radius



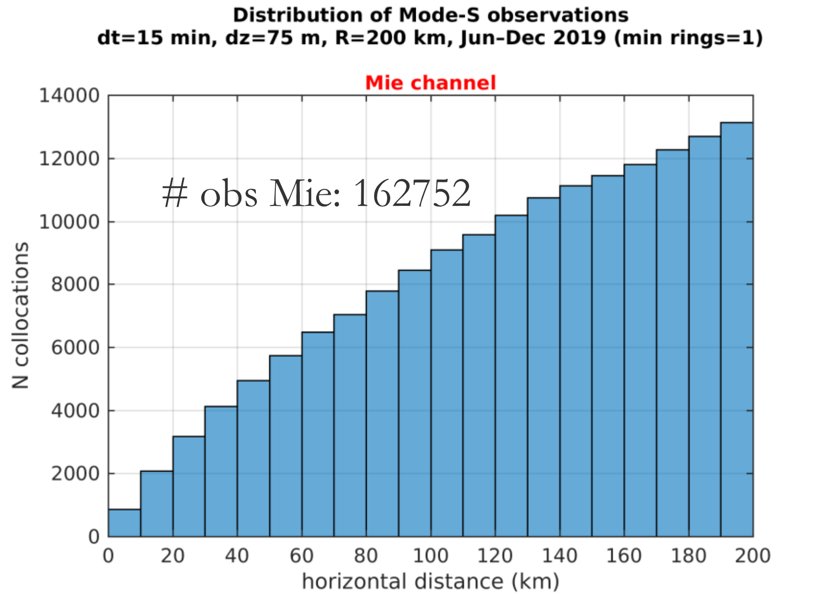


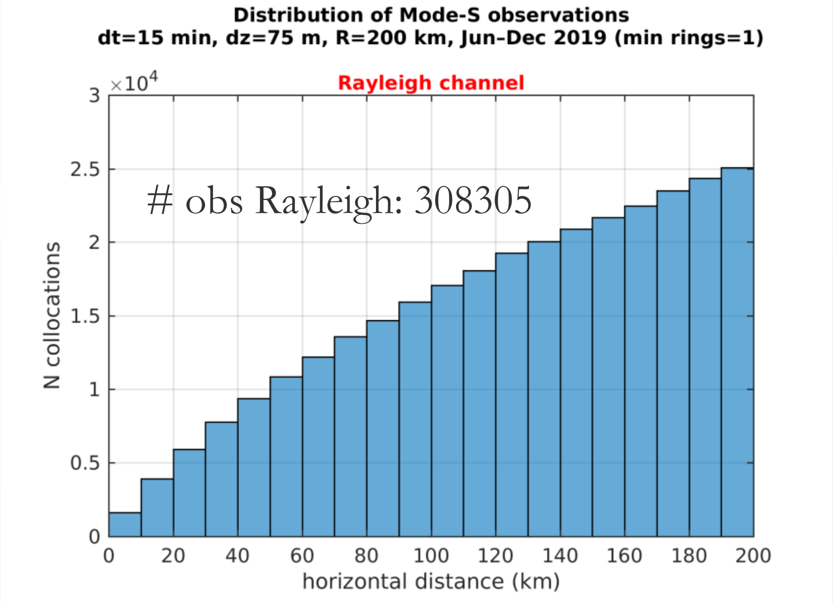
dt=15 min, dz=75 m, R=200 km, dR=10 km

R_i=10, 20, 30, …, 180, 190, 200 km

Collocations distribution with “rings”

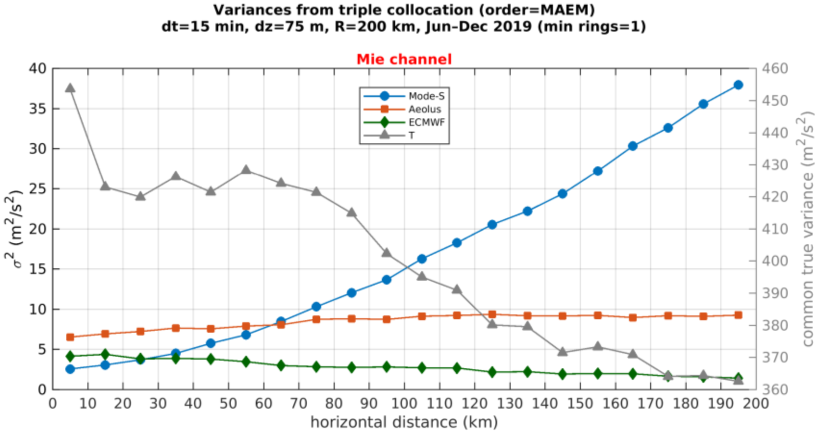
Collocation parameters: dt=15 min, dz=75 m, R=200 km, rings width=10 km

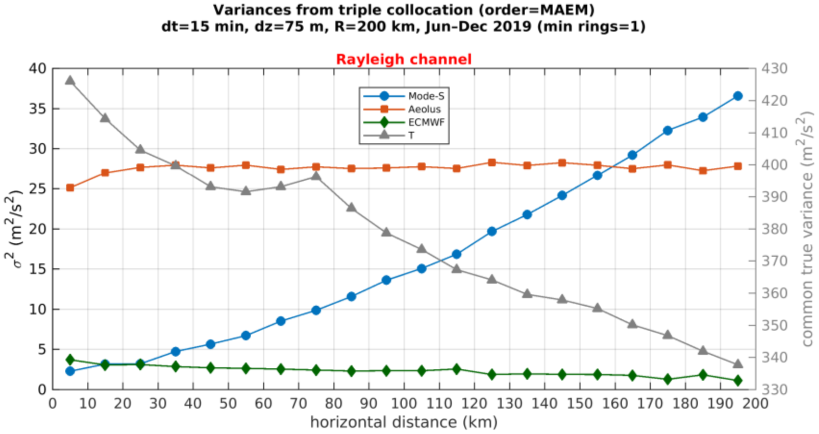




Triple collocation results: “rings” version

Error variances (with r^2=0 m^2/s^2)

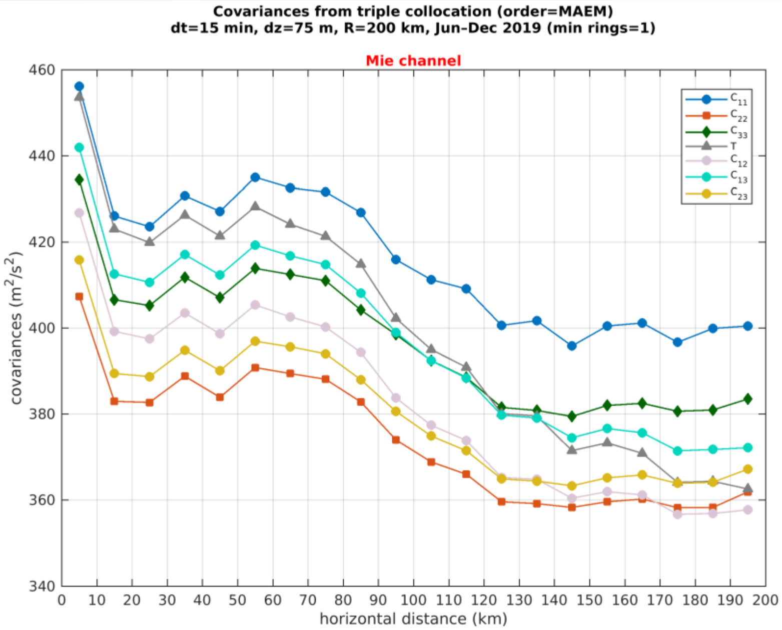


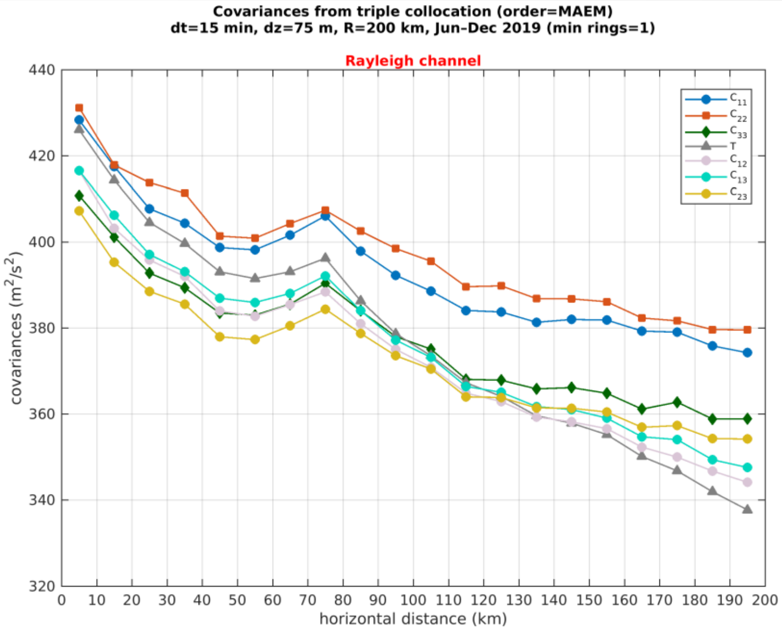


Smoother lines thanks to increased sampling

Triple collocation results: “rings” version

Covariances

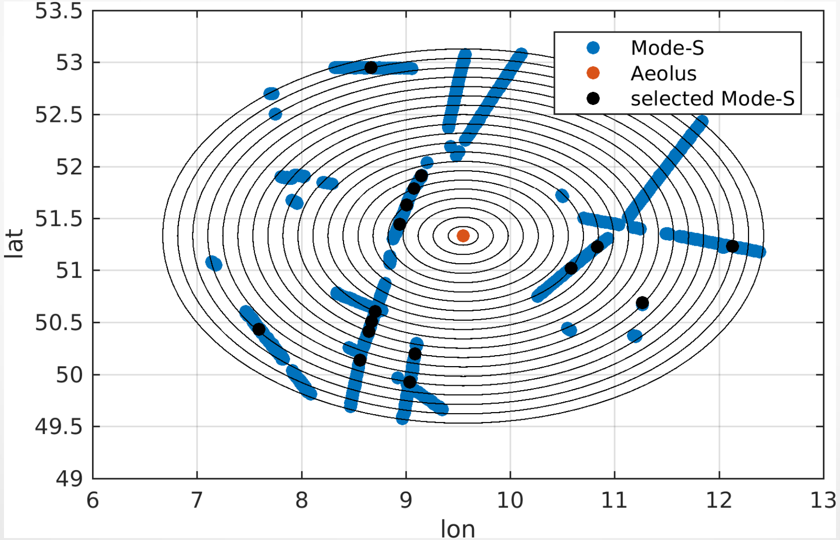




C_{22}, C_{33} and C_{23} variations only due to sampling differences

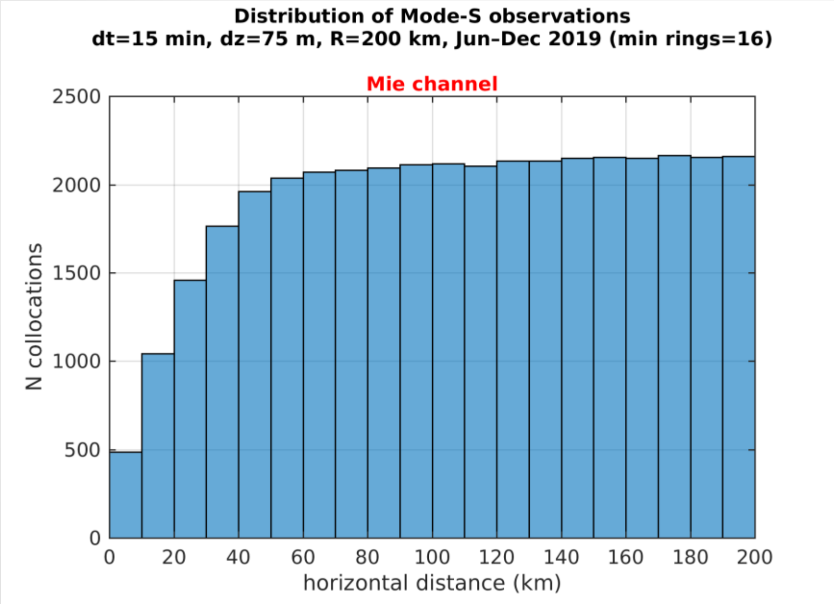
New “rings” version

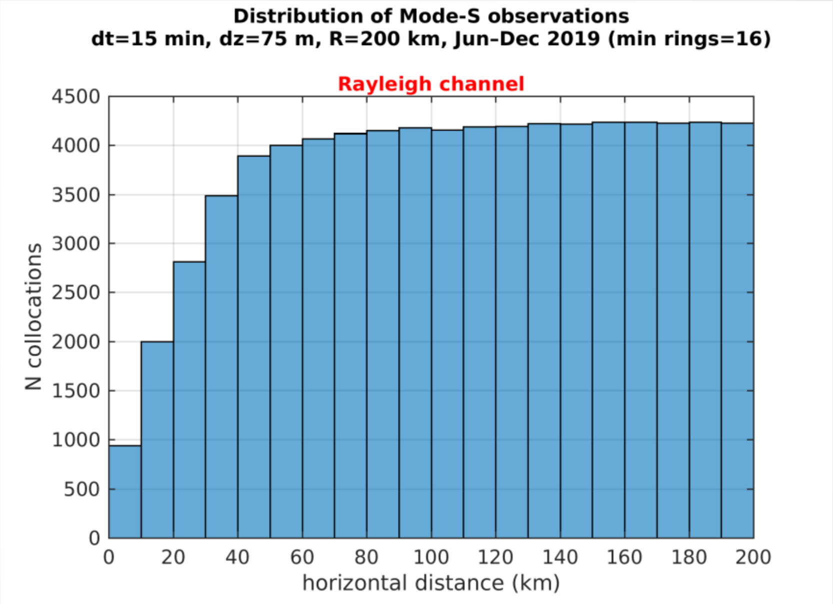
We impose a minimum number of rings to be filled with Mode-S observations to obtain a more homogeneous weather sample.



Collocations distribution with minimum 16 rings

Collocation parameters: dt=15 min, dz=75 m, R=200 km, rings width=10 km, min rings=16



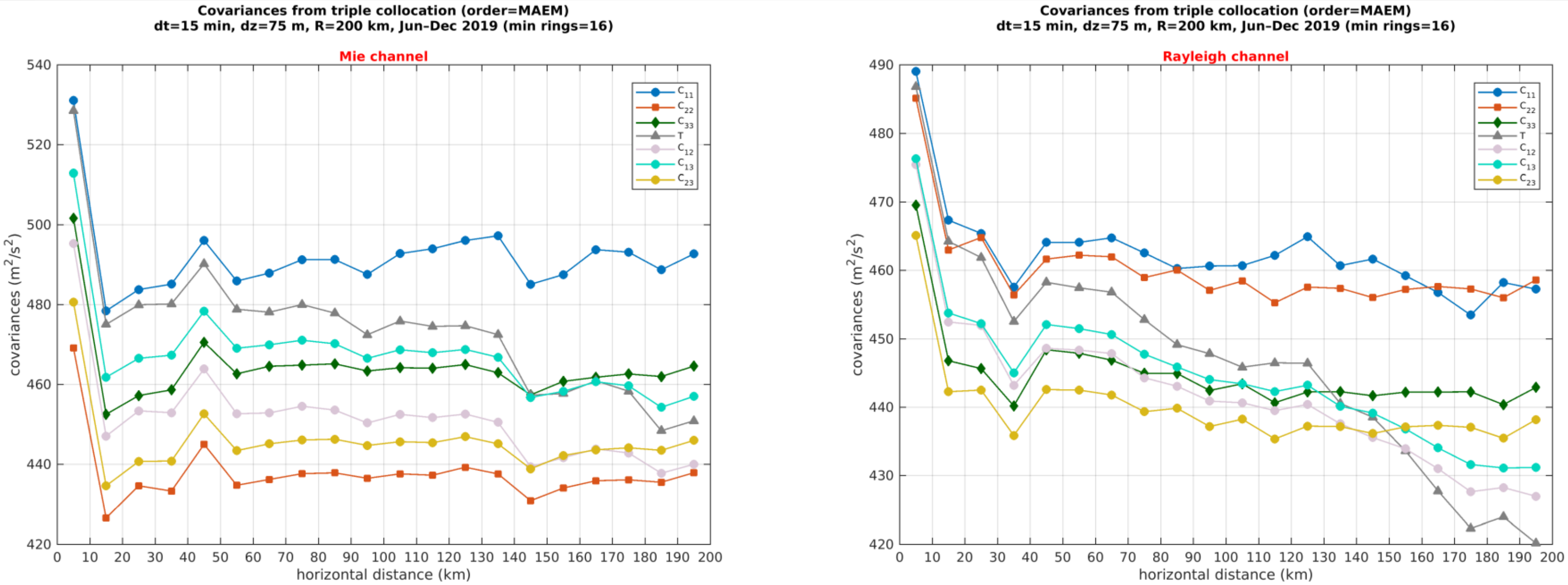


obs Mie: 38550

obs Rayleigh: 75819

Covariances with a more homogeneous weather sample

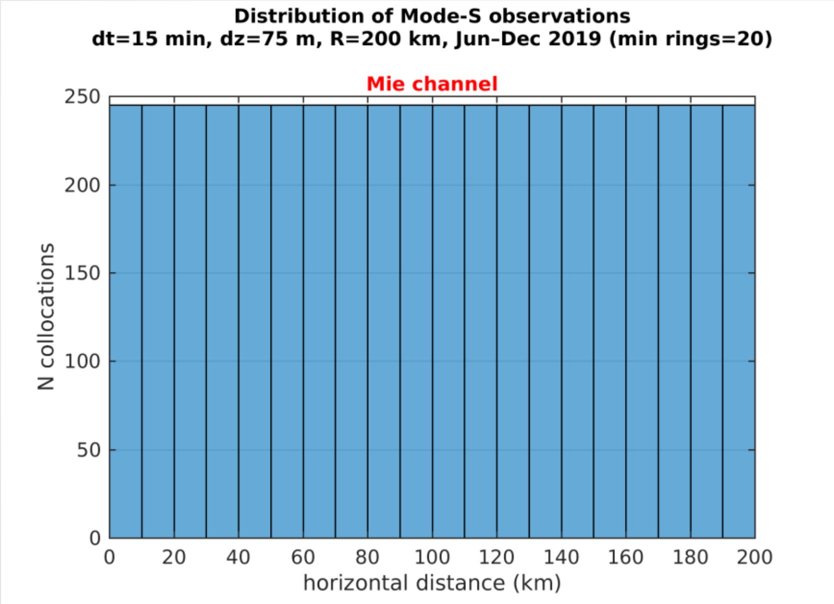
Covariances (min rings=16)

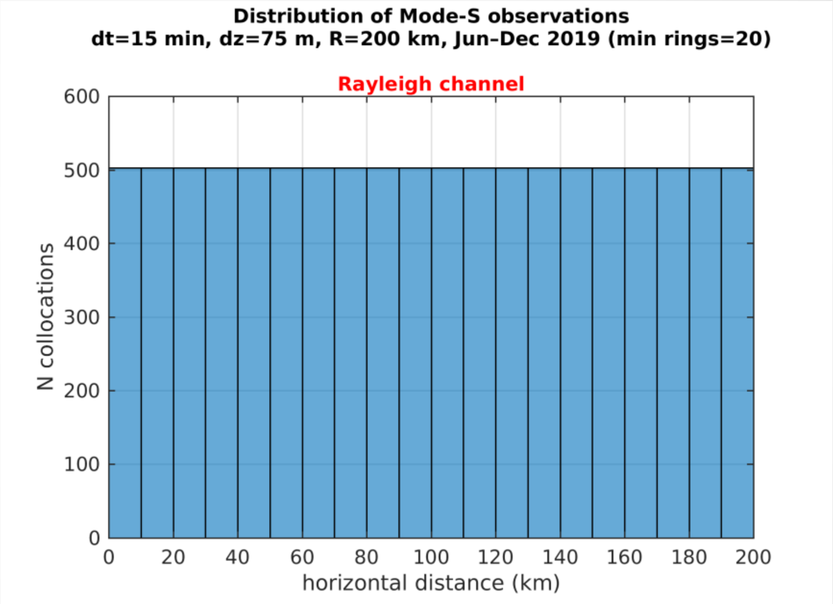


C_{22}, C_{33} and C_{23} are more uniform

Collocations distribution with minimum 20 rings

Collocation parameters: dt=15 min, dz=75 m, R=200 km, rings width=10 km, min rings=20



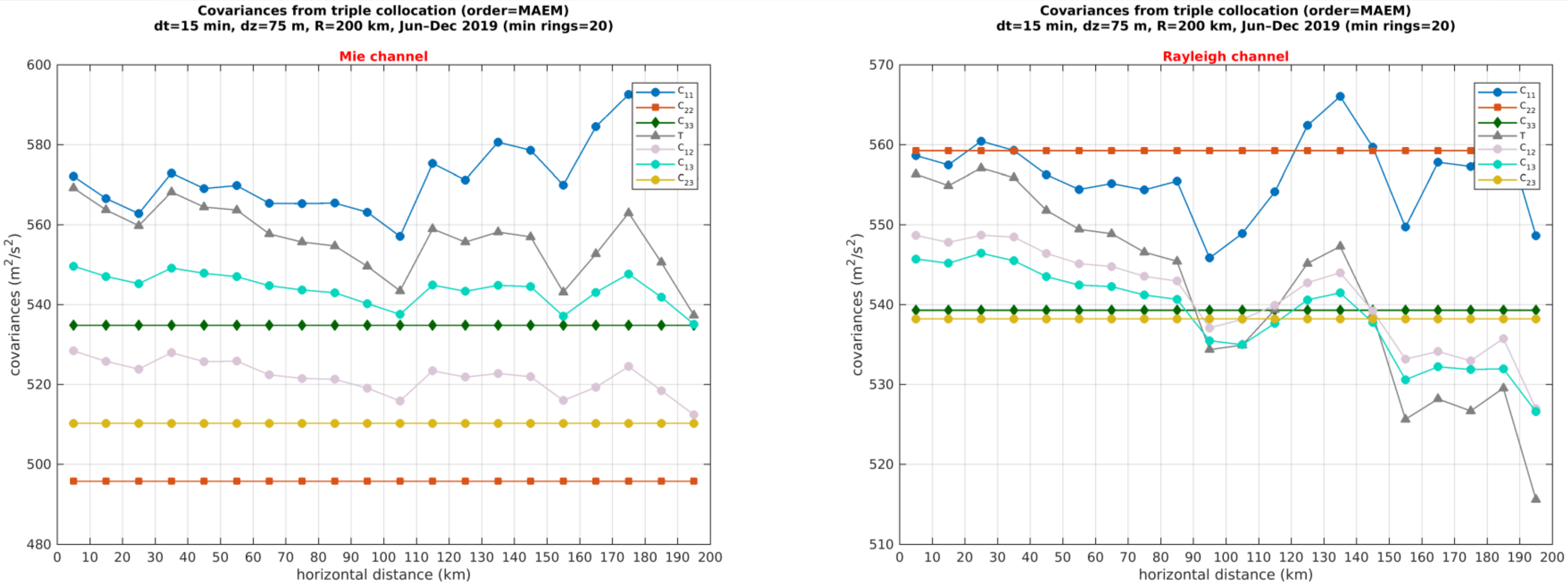


obs Mie: 4900

obs Rayleigh: 10060

Covariances with homogeneous weather sample

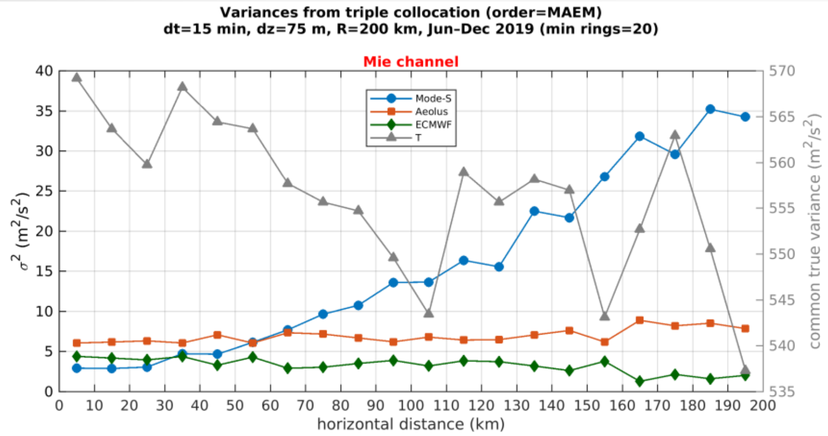
Covariances (min rings=20)

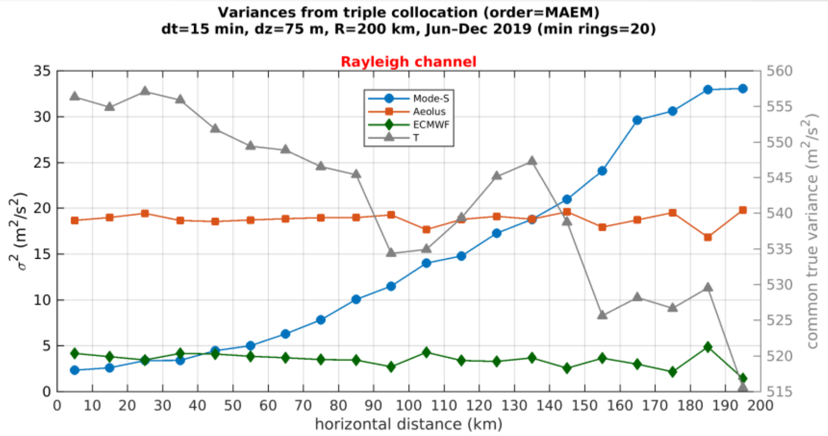


C_{22}, C_{33} and C_{23} are now constant for all distances

Triple collocation results with minimum 20 rings

Error variances (with r^2=0 m^2/s^2 , min rings = 20)

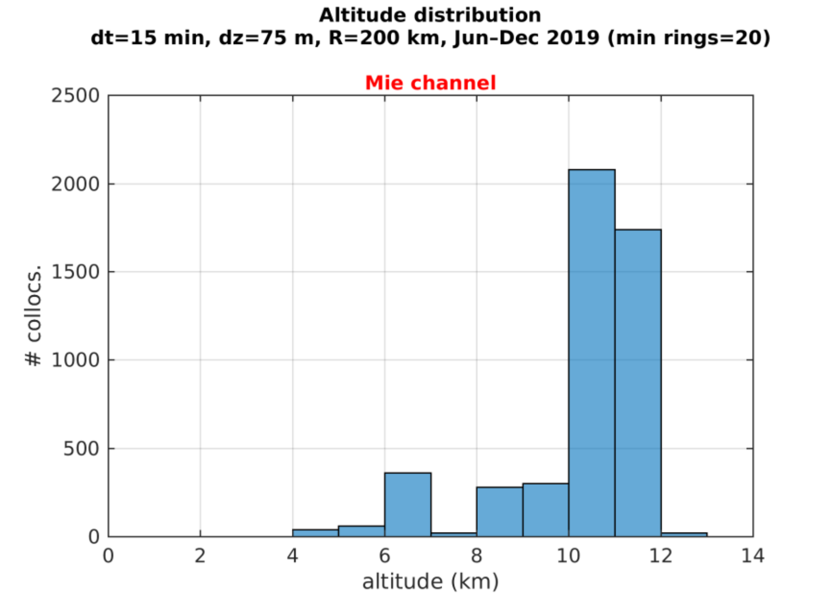


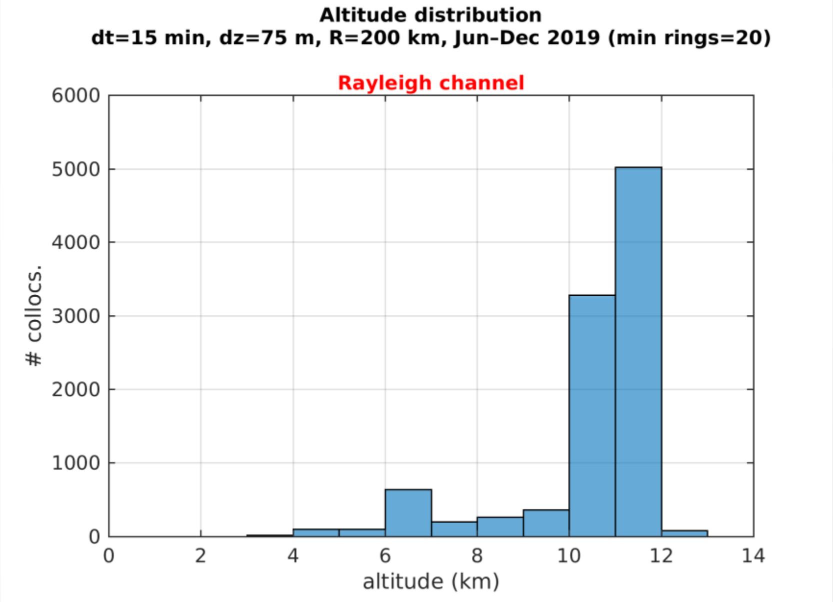


More correct approximation but presence of oscillations due to limited sampling

Altitude distribution

Different layers have different wind regimes.

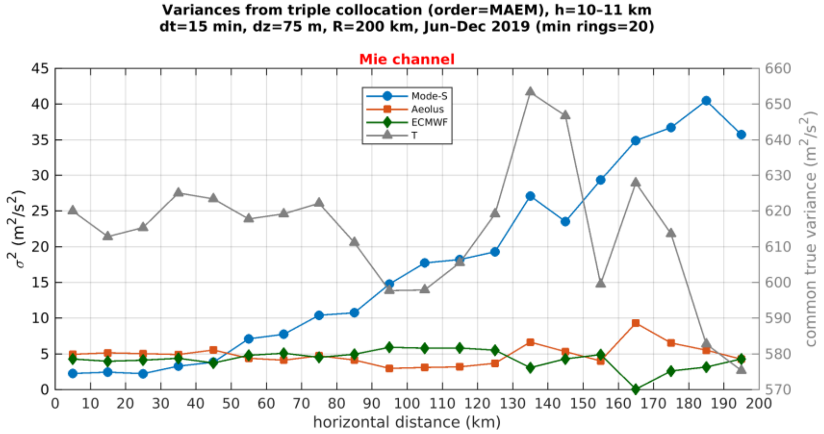


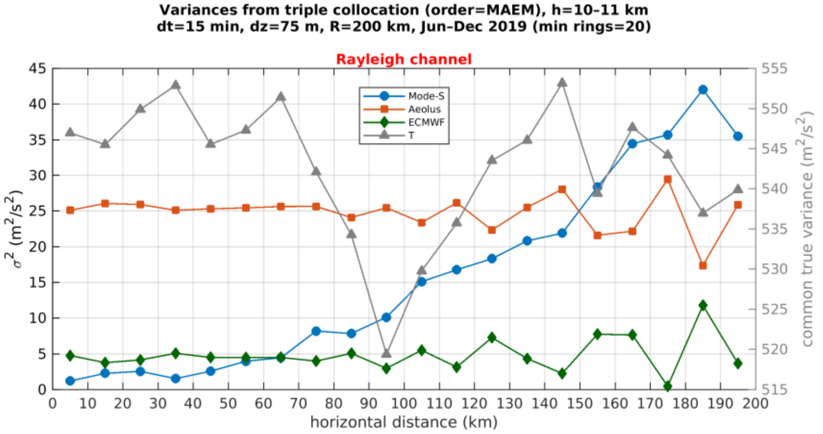


We select the 10-11 km layer and perform TC analysis on the collocations belonging to this layer.

TC variances for altitude 10-11 km

Error variances (with r^2=0 m^2/s^2 , min rings = 20, h = 10-11 km)





Oscillations due to limited sampling and Mode-S "scattering" effect.

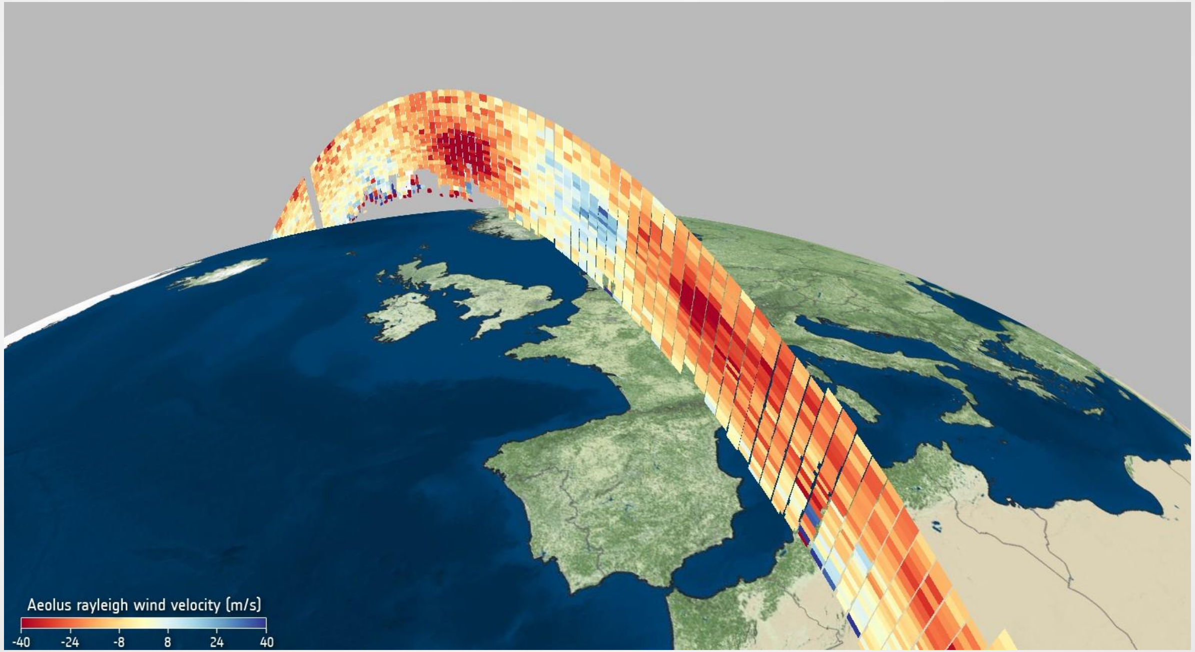
Summary (1)

- The triple collocation method is useful for calibrating independent observational data sets and for characterizing them in terms of their spatial scales and measurement errors.
- Different methods exist for computing the representativeness errors.
- 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 measurement errors derived with the triple collocation method show that ASCAT 12.5 km observations are more accurate than buoy observations and ECMWF model output.

Summary (2)

- 4D wind collocations of Aeolus/Mode-S/ECMWF are being used to characterize Aeolus observations.
- A collocation method based on concentric rings around Aeolus observations is proposed to select Mode-S collocations.
- The errors computed with the triple collocation analysis depend on the distance between observations and on the sampling.
- We are still working on a way to compute $\mathbf{r}^2$ for 4D winds that will allow a better estimate of the errors.
- The TC results will be further refined by extending the data set (new domain over the Iberian peninsula) and by analyzing different altitude layers.
- A similar analysis will be conducted by interpolating ECMWF to Mode-S locations (instead of Aeolus).

Thank you for your attention!



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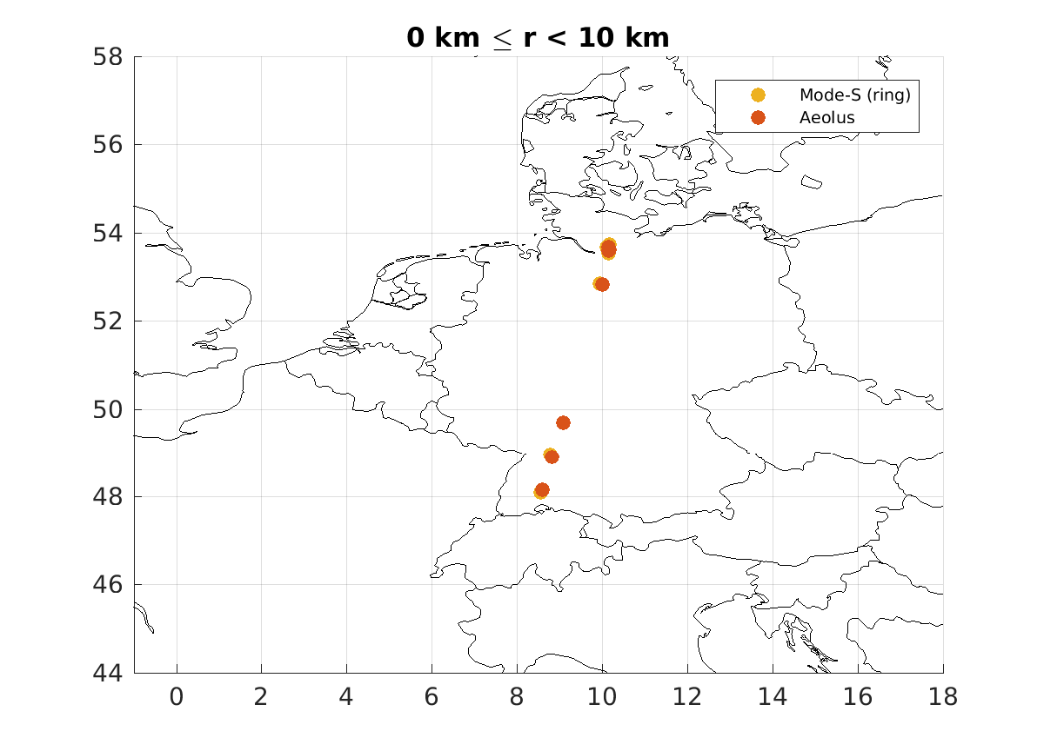
Mode-S locations as a function of ring



TC error variances (moments formulas)

Errors at the scale of system 3

$$\begin{cases} \delta_1^2 = M_{11} - M_{12} + r^2 \\ \delta_2^2 = M_{22} - M_{12} + r^2 \\ \delta_3^2 = M_{33} - M_{13} \end{cases}$$

(calibration reference: system 1)

Errors at the scale of system 2

$$\begin{cases} \delta_1^2 = M_{11} - M_{12} \\ \delta_2^2 = M_{22} - M_{12} \\ \delta_3^2 = M_{33} - M_{13} + r^2 \end{cases}$$

$M_{ij} = \langle x_i x_j \rangle$: mixed second order moments

$x_{i,j}$: calibrated datasets (i,j=1,2,3)

r^2 : representativeness error