Assessing the impact of Radio Frequency Interference on GNSS Radio Occultation Measurements

Maria Jose Parra Ortega

Spacecraft Operations Engineer for Serco Services GmbH at EUMETSAT

13 September 2024

Agenda

Introduction and Objectives

Data Collection and Preprocessing

Prediction Tool Validation

Method: Kernel Density Estimation

Results: GRAS, Sentinel-6, PlanetiQ, Spire, Yunyao

Conclusion

Introduction and Objectives

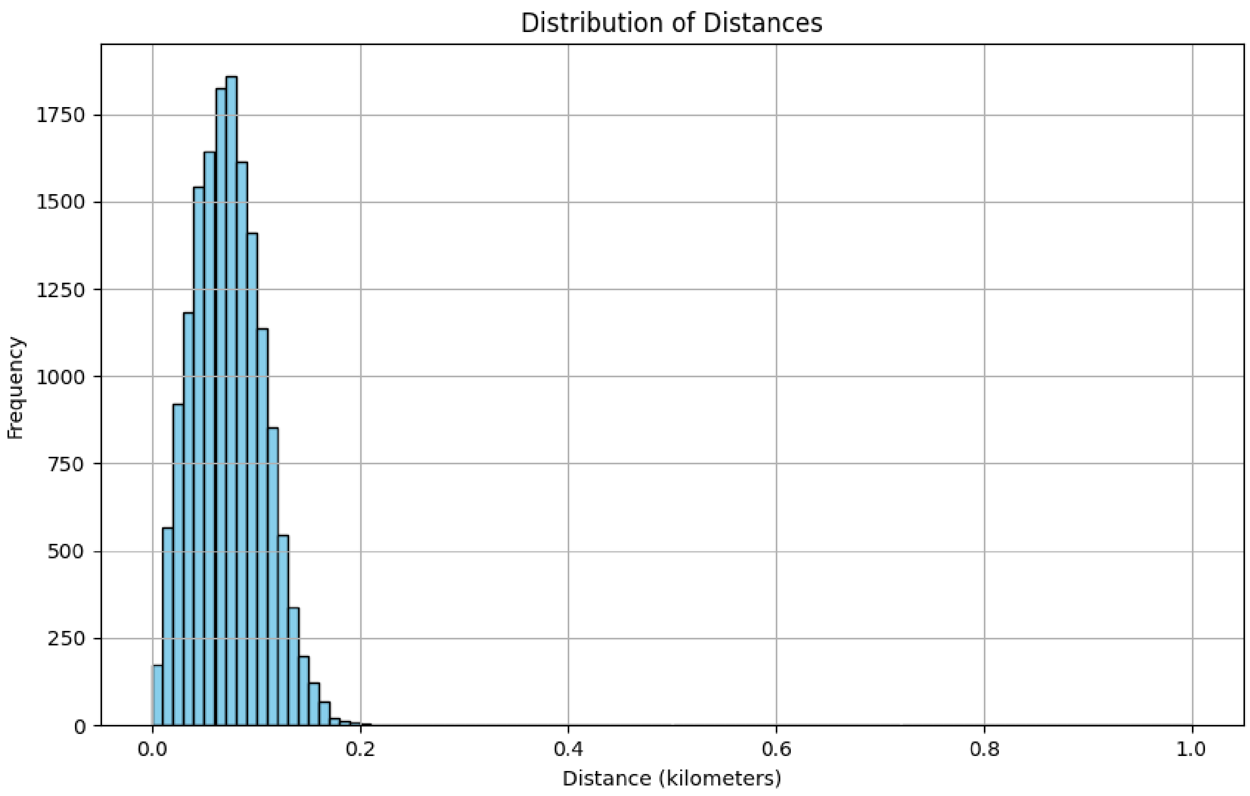
- Radio Occultation is a technique based on the refraction of GNSS signals transmitted by different constellations and picked up by a receiver on a LEO satellite.
- Radio Frequency Interference for GNSS signals: Jamming is the presence of a competing signal that prevents the GNSS receiver from decoding the true satellite signal.
- Previous studies showed that RFI could be detected in GRAS measurements, but that the data quality was not significantly affected for the occultations being available (Isoz *et al*., 2014). The paper did not address, however, if the number of occultations was in any way affected.
- An analysis of average annual GPS L1 and L2 SNR distributions observed by Spire POD receivers for 2020-2023 showed a clear reduction of GPS power on L1 and L2 signals in several regions, in particular Europe and the Middle East (Wu, 2024).
- How did the idea come about? Observed change in the rate of gain change, which is related to the noise power variation, confirmed to be correlated with ground-based interference sources.
- OBJECTIVES: identify regions with reduced numbers of occultations, correlate these regions with RFI and assess whether the impact of RFI is consistent across different missions.

Data Collection and Preprocessing

- Working with two types of datasets:
  - REAL data: L1b processed data or bending angles
  - PREDICTED data: predicted occultations based on satellite orbits
- The "prediction tool" was developed in EUMETSAT by the POD department and calculates when the FOV of the LEO satellite antenna would see a GNSS satellite rise or set above the Earth's horizon (based on the position of the GNSS satellites and the position calculated for the LEO satellites).
- Spatio-temporal position data of the occultation measurement is obtained for each satellite, being the reference time, longitude, latitude, antenna azimuth and GNSS satellite identifier.
- Mainly GRAS (GNSS Receiver for Atmospheric Sounding) onboard the Metop satellites. Metop-B and Metop-C data for at least one month from 2021 to 2024 have been analyzed.
- At least one month of 2022 has also been analyzed for the GNSS-RO Sentinel-6 mission.
- Additional real data available through ROMEX-1 that has been analyzed: PlanetiQ, Spire and Yunyao.

“Prediction Tool” Validation

To demonstrate that the tool can predict occultations with some accuracy.



How? Finding matching occultations filtered by:

- LEO satellite
- GNSS satellite identifier
- Reference time (± 5 minutes)

Calculating the geodesic distance between the points (lat, lon).

For a given ray path, most of the atmospheric bending occurs within a horizontal interval of 200-300km centered on the tangent point.

Kernel Density Estimate

- KDE is a nonparametric technique used for estimating the probability density function of a random variable.

$$\hat{f}(x) = \frac{1}{nh^d} \sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right)$$

- Weighted distances of all observations from various locations on a linearly spaced set of points.
- The great circle distance is the angular distance between two points on the surface of a sphere.

$$d_H(x, X_i) = 2 \arcsin\left[\sqrt{\left(sin^2\left(\frac{x_{lat} - X_{i_{lat}}}{2}\right) + \cos(x_{lat}) \cos(X_{i_{lat}})\, sin^2\left(\frac{x_{lon} - X_{i_{lon}}}{2}\right)\right)}\right]$$

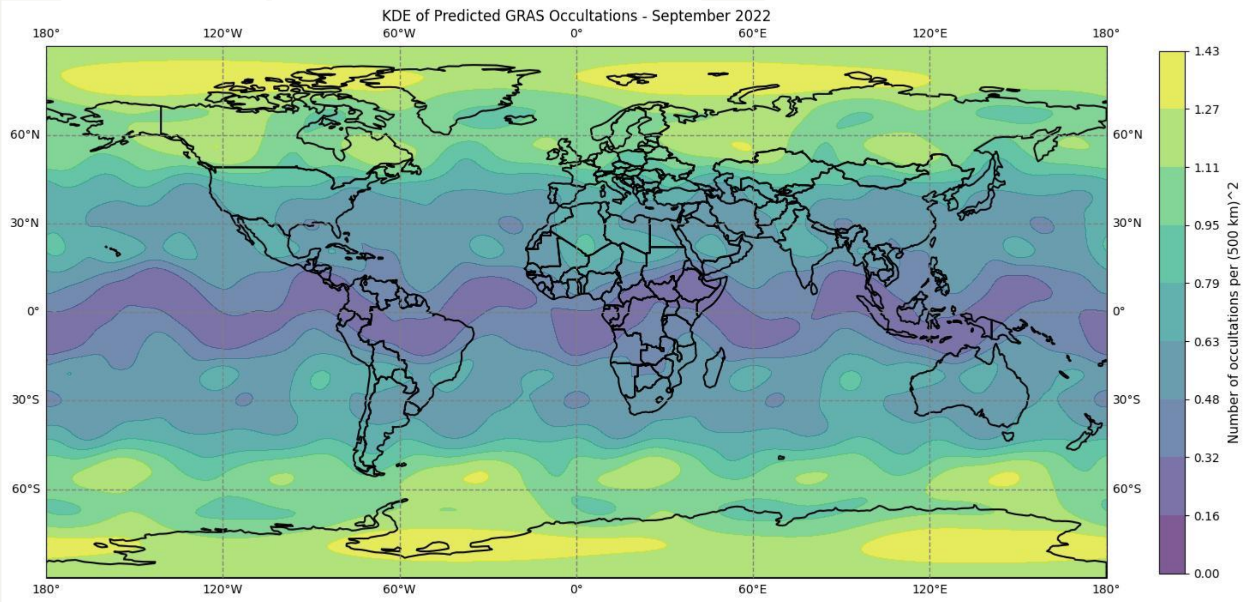
- The kernel function (Gaussian) specifies how to compute the probability density given the distance.

$$K(u) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{u^2}{2}\right) \quad \text{where } \left(u = \frac{d_H(x, X_i)}{h}\right)$$

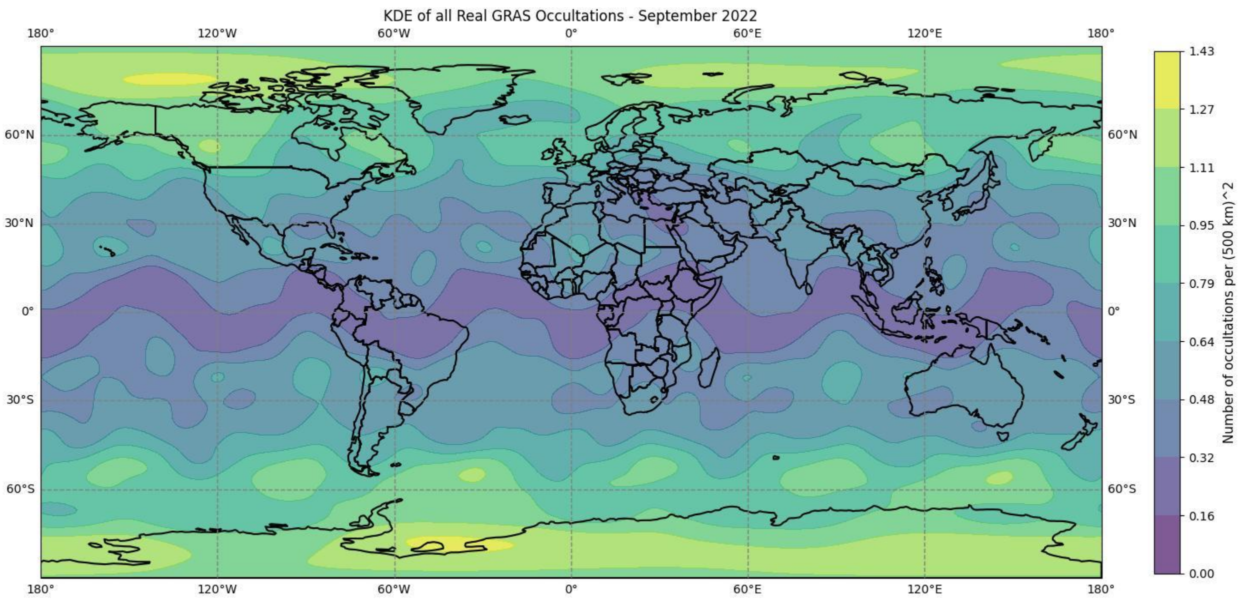
- The selected bandwidth controls how smooth the estimated density curve is. It has been calculated using a cross-validation approach (h = 0.067 which is ~ 427 km).

Real vs. Predicted GRAS Occultations

Distribution of Predicted GRAS Occultations



Distribution of Real GRAS Occultations

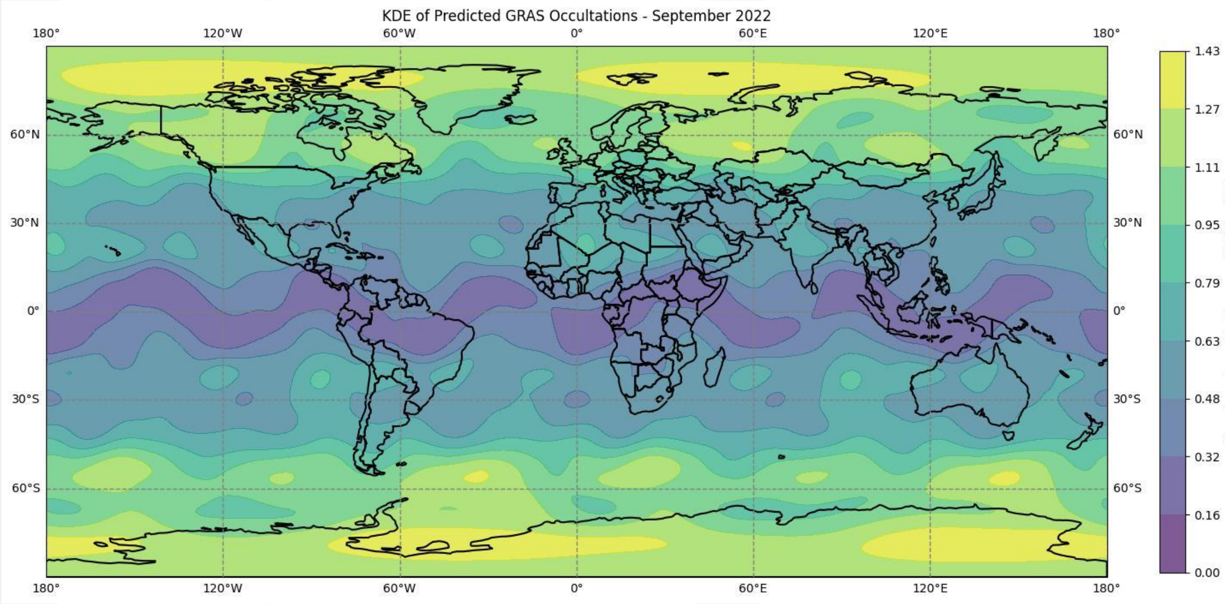


Real vs. Predicted GRAS Occultations

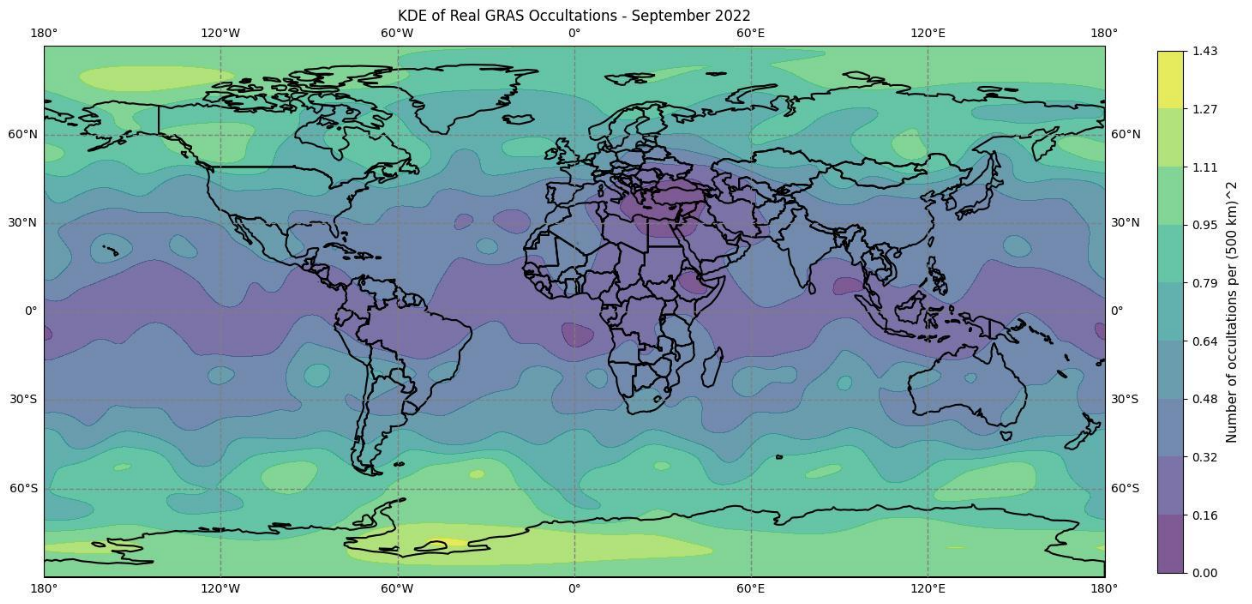
serco

www.eumetsat.int

Distribution of Predicted GRAS Occultations



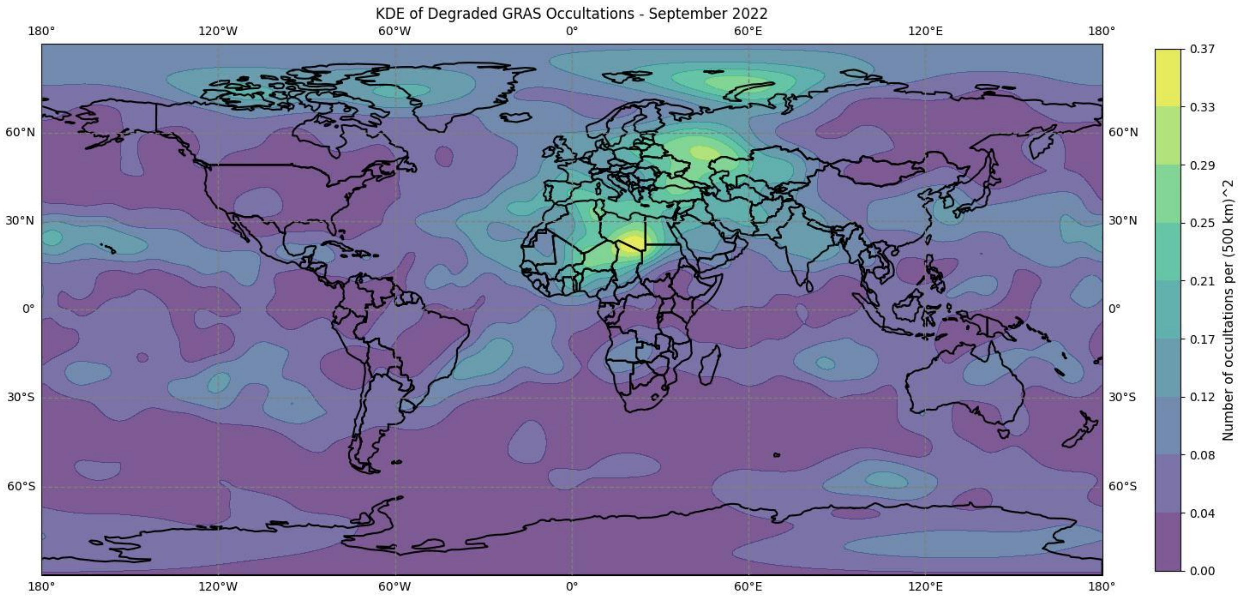
Distribution of Real Good GRAS Occultations



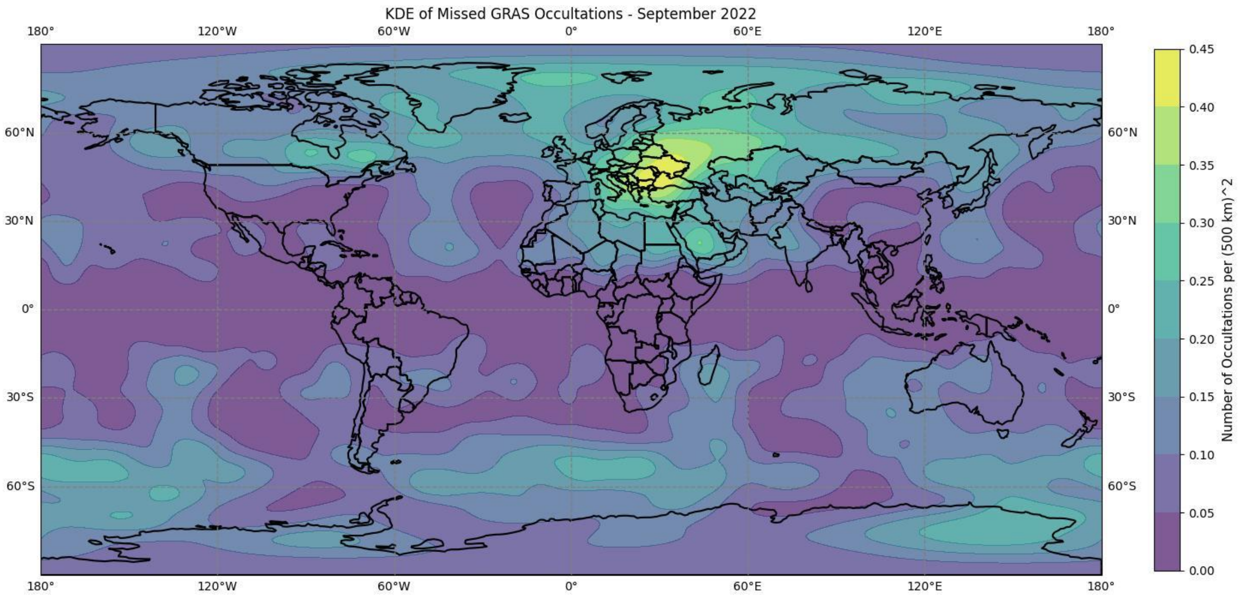
Degraded vs. Completely Missed GRAS Occultations

www.eumetsat.int

Distribution of Degraded GRAS Occultations

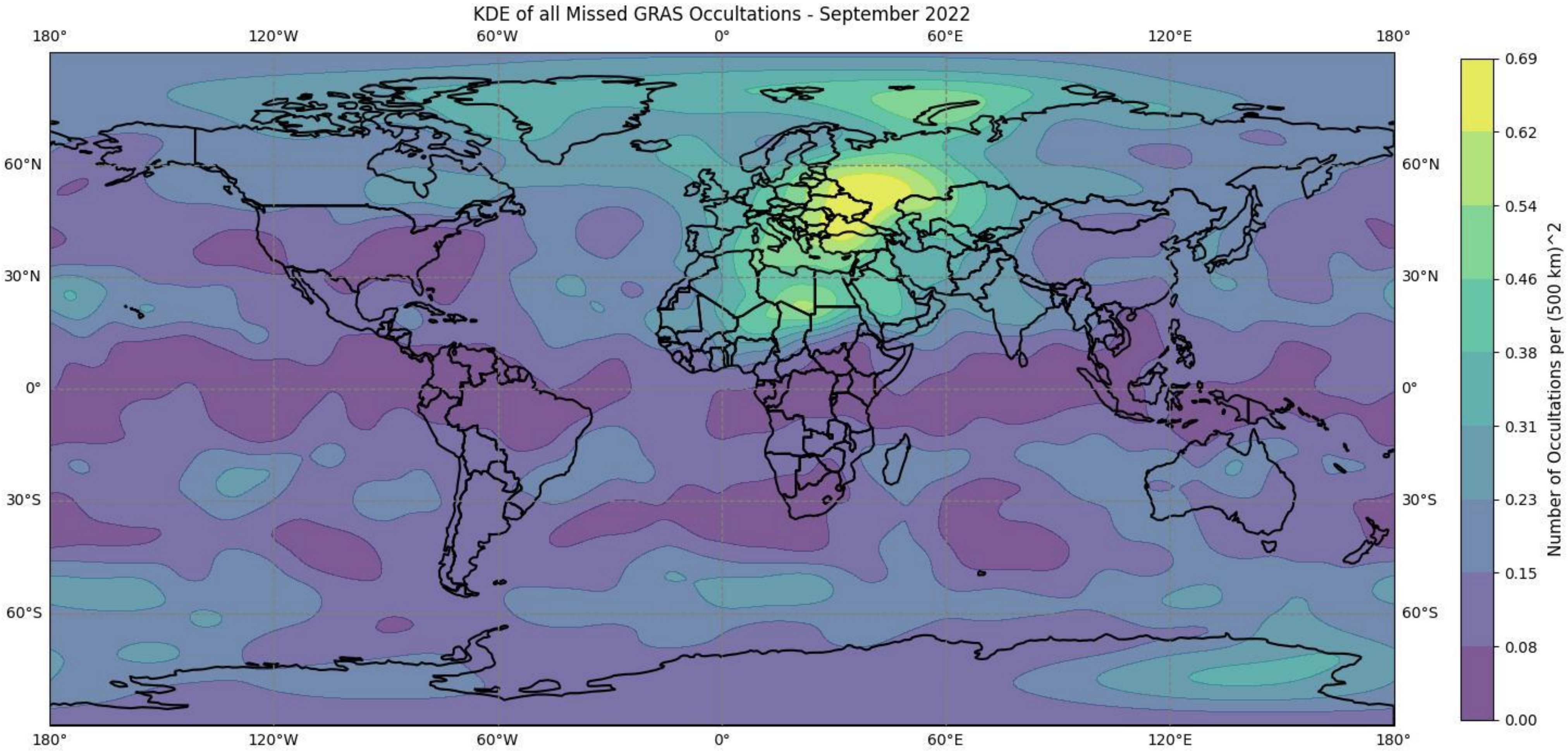


Distribution of Missed GRAS Occultations



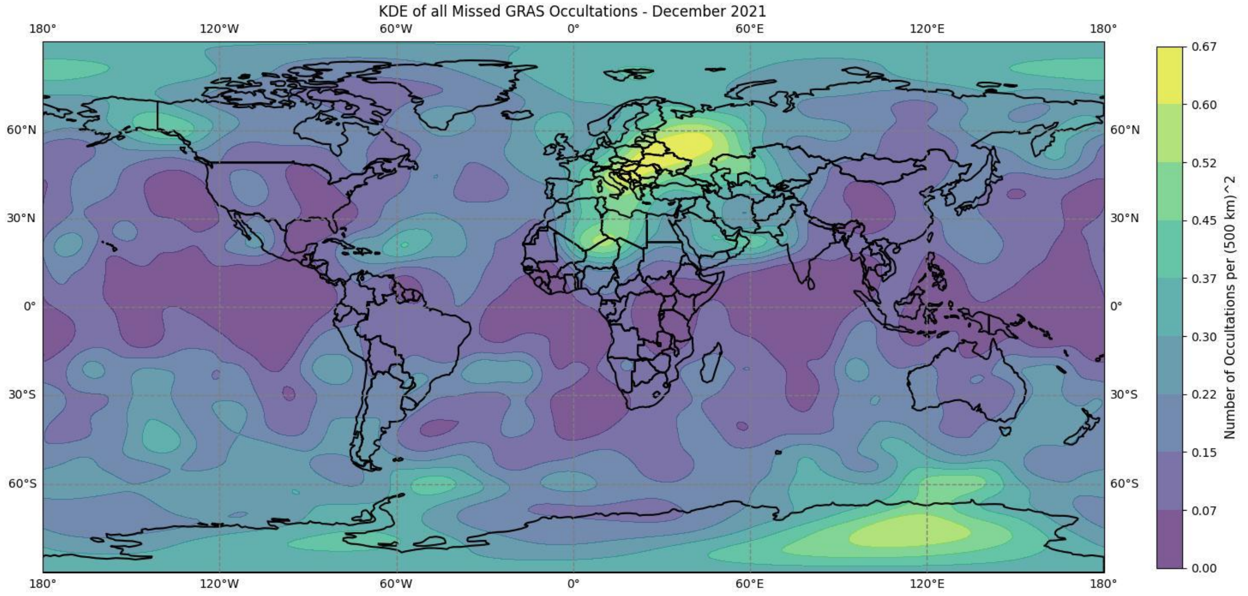
All Missed GRAS Occultations

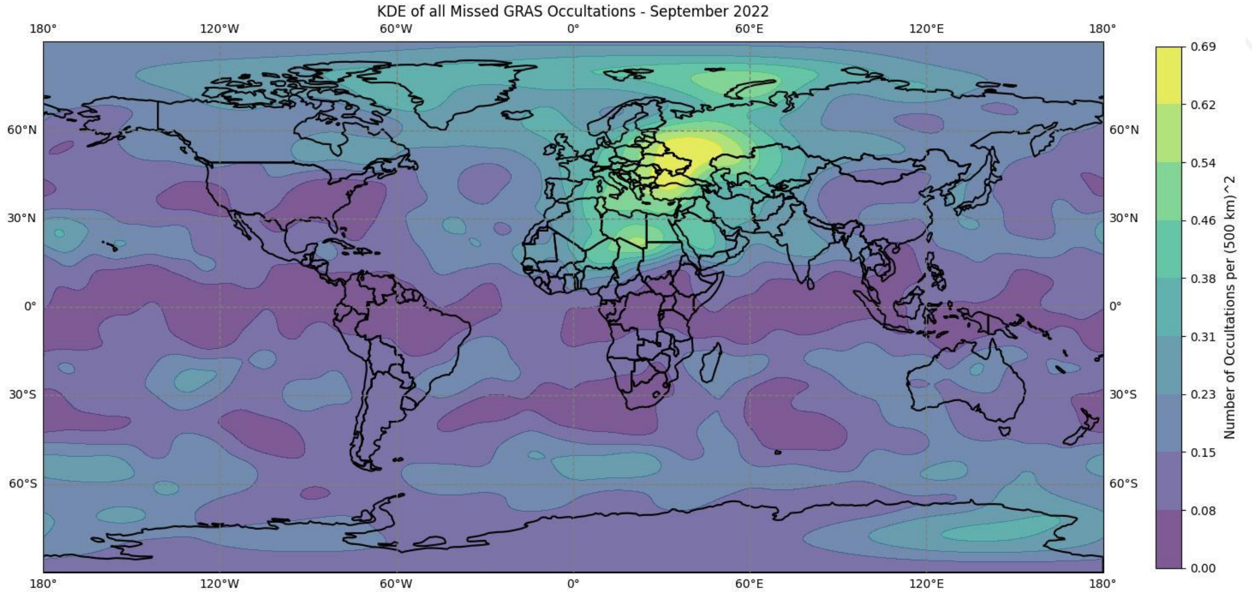
Distribution of all Missed GRAS Occultations

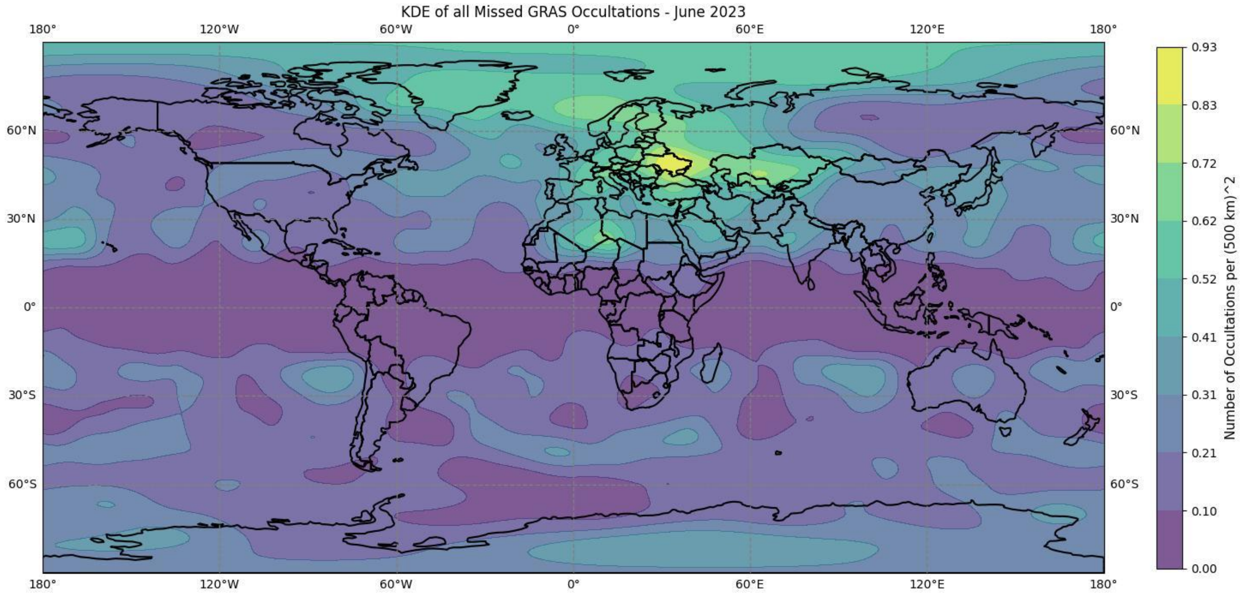


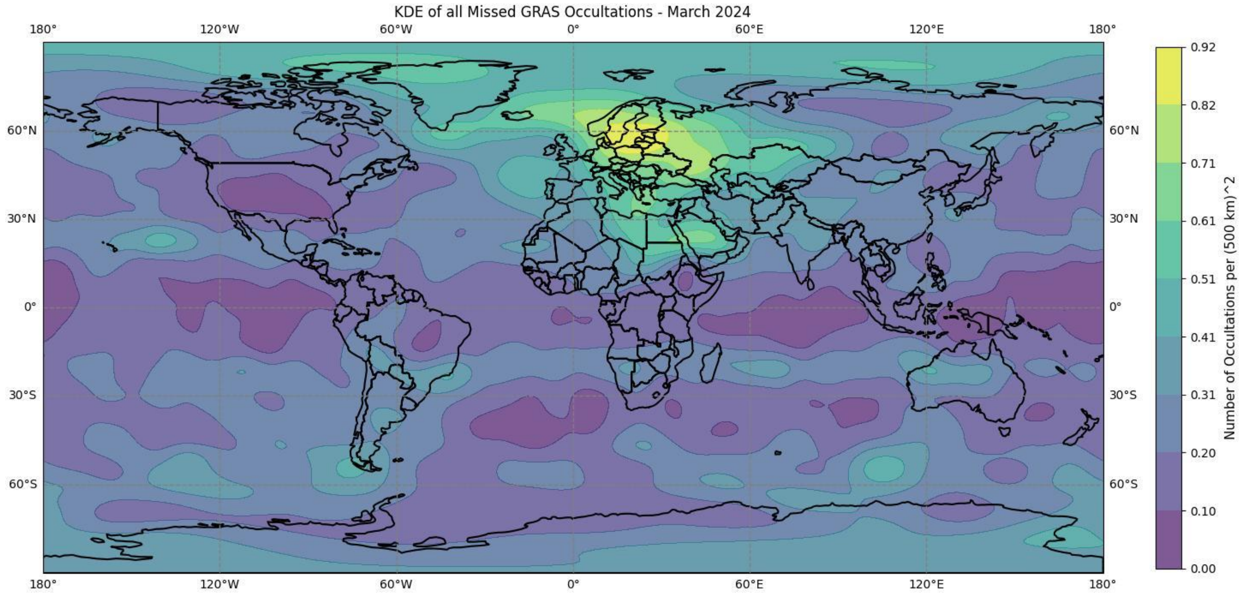
Missed GRAS Occultations in 2021 - 2024

serco









GRAS Occultations in Figures

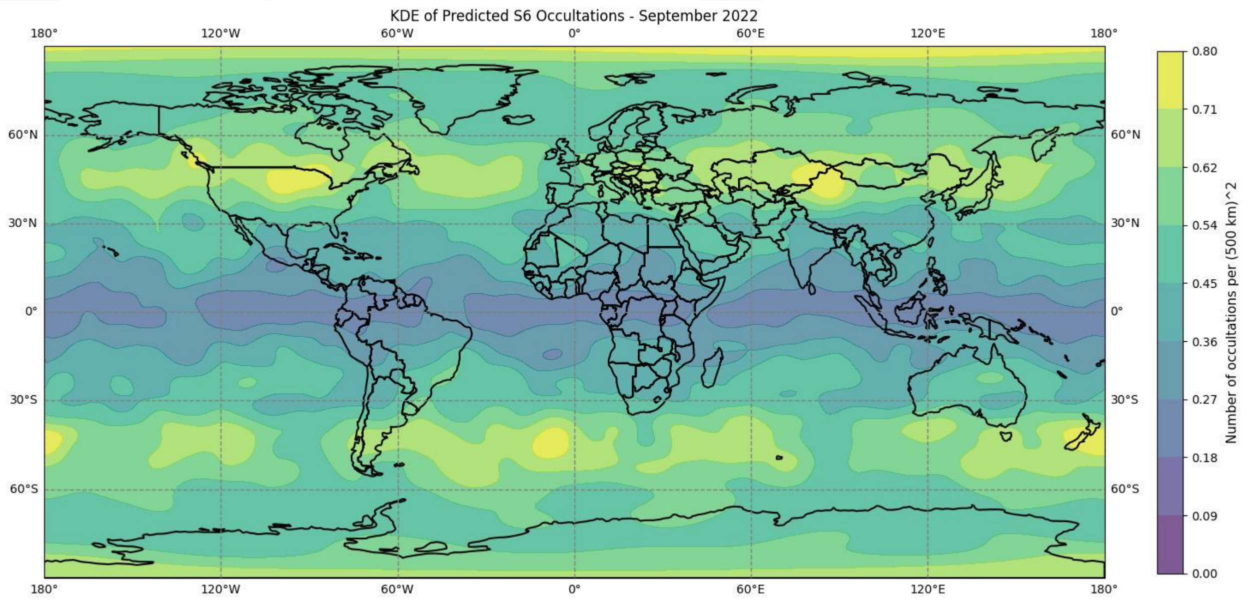
Comparison of GRAS occultations across different months

Time period	December 2021	September 2022	June 2023	March 2024
All Real Occ.	34,275	36,128	35,671	36,583
Real Occ. OK	31,166	31,966	31,047	28,476
Degraded Occ.	3,109	4,162	4,624	8,107
Degraded in %	9.07	11.52	12.96	22.16
Predicted Occ.	41,597	41,575	42,686	42,697
Missed Occ.	7,322	5,449	7,018	6,124
All Missed Occ.	10,431	9,610	11,640	14,231
% Missed Occ.	17.60	13.11	16.44	14.34
% All Missed Occ.	25.08	23.11	27.27	33.32

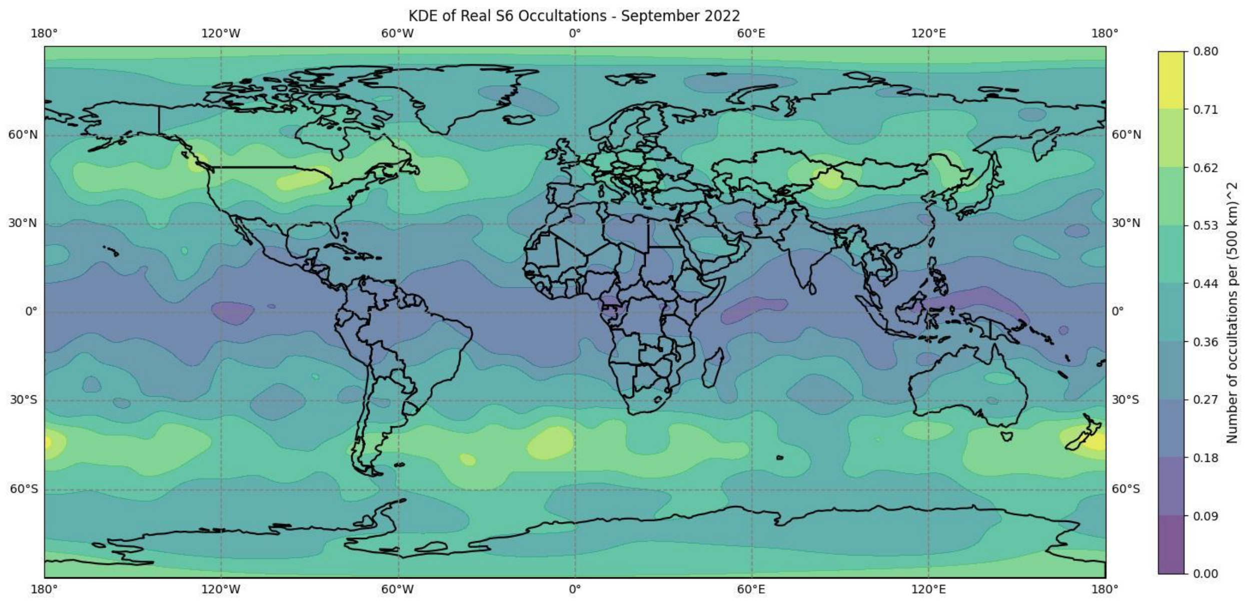
Real vs. Predicted Sentinel-6 Occultations

www.eumetsat.int

Distribution of Predicted S6 Occultations



Distribution of Real Good S6 Occultations

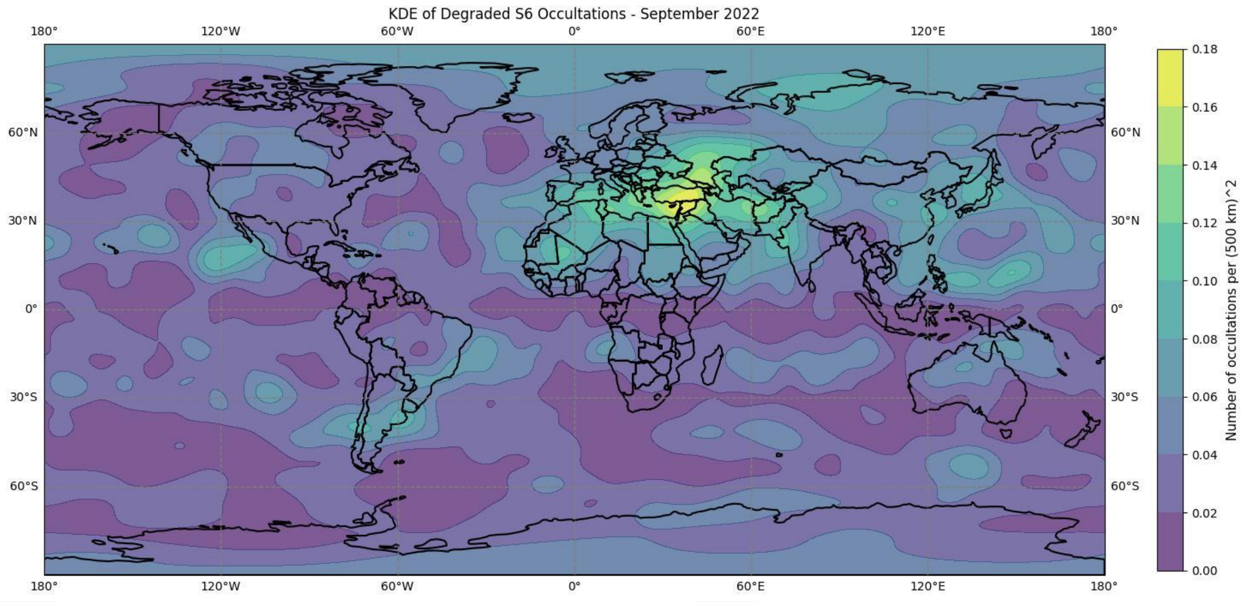


Degraded vs. Completely Missed S6 Occultations

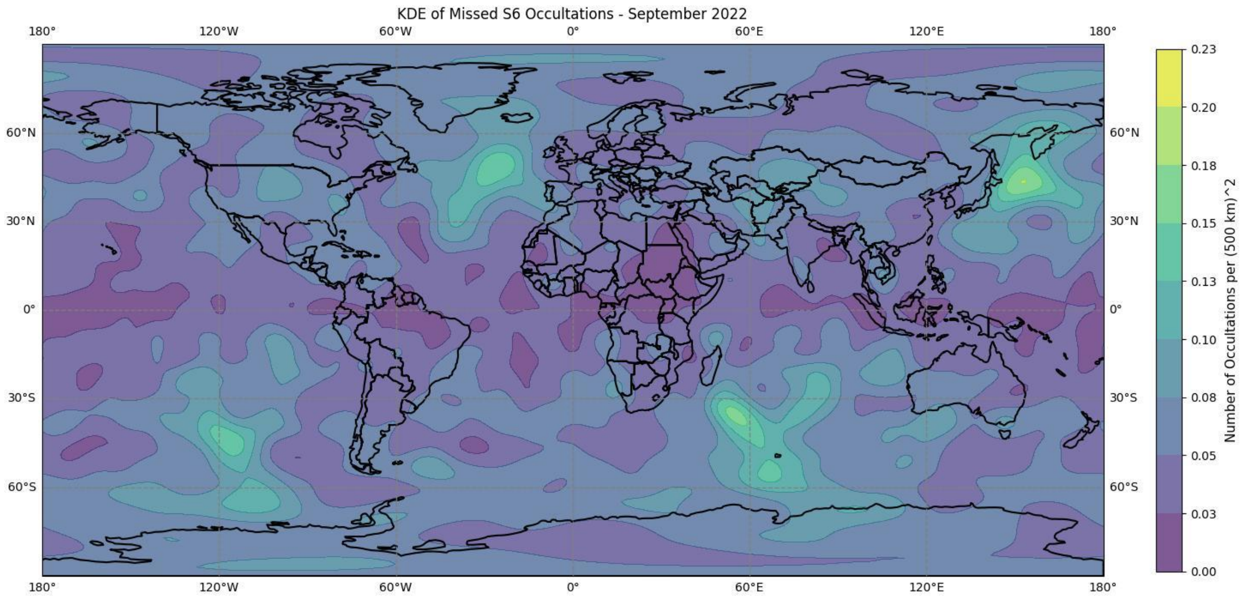
serco

www.eumetsat.int

Distribution of Degraded S6 Occultations



Distribution of Missed S6 Occultations

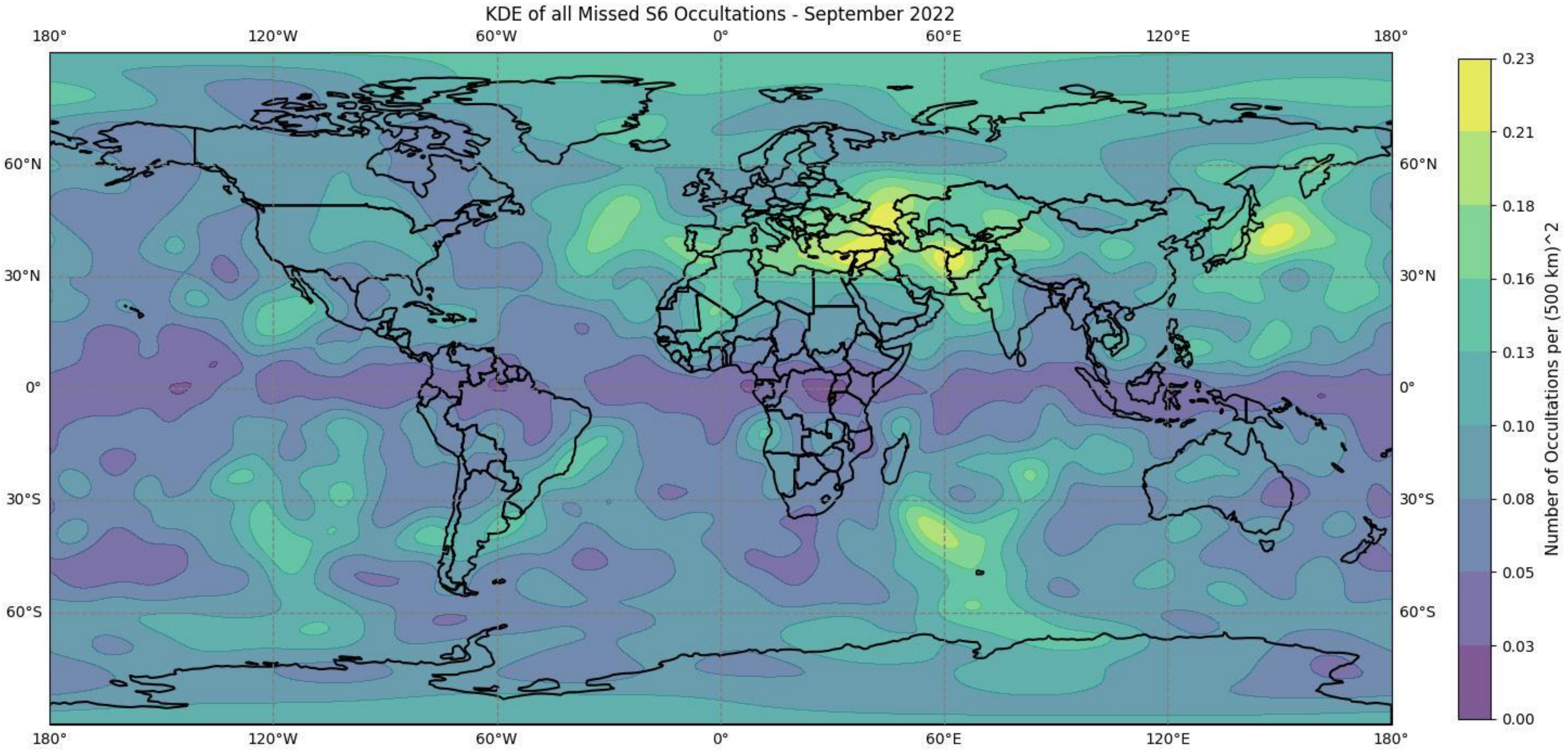


All Missed Sentinel-6 Occultations

serco

www.eumetsat.int

Distribution of all Missed Sentinel-6 Occultations

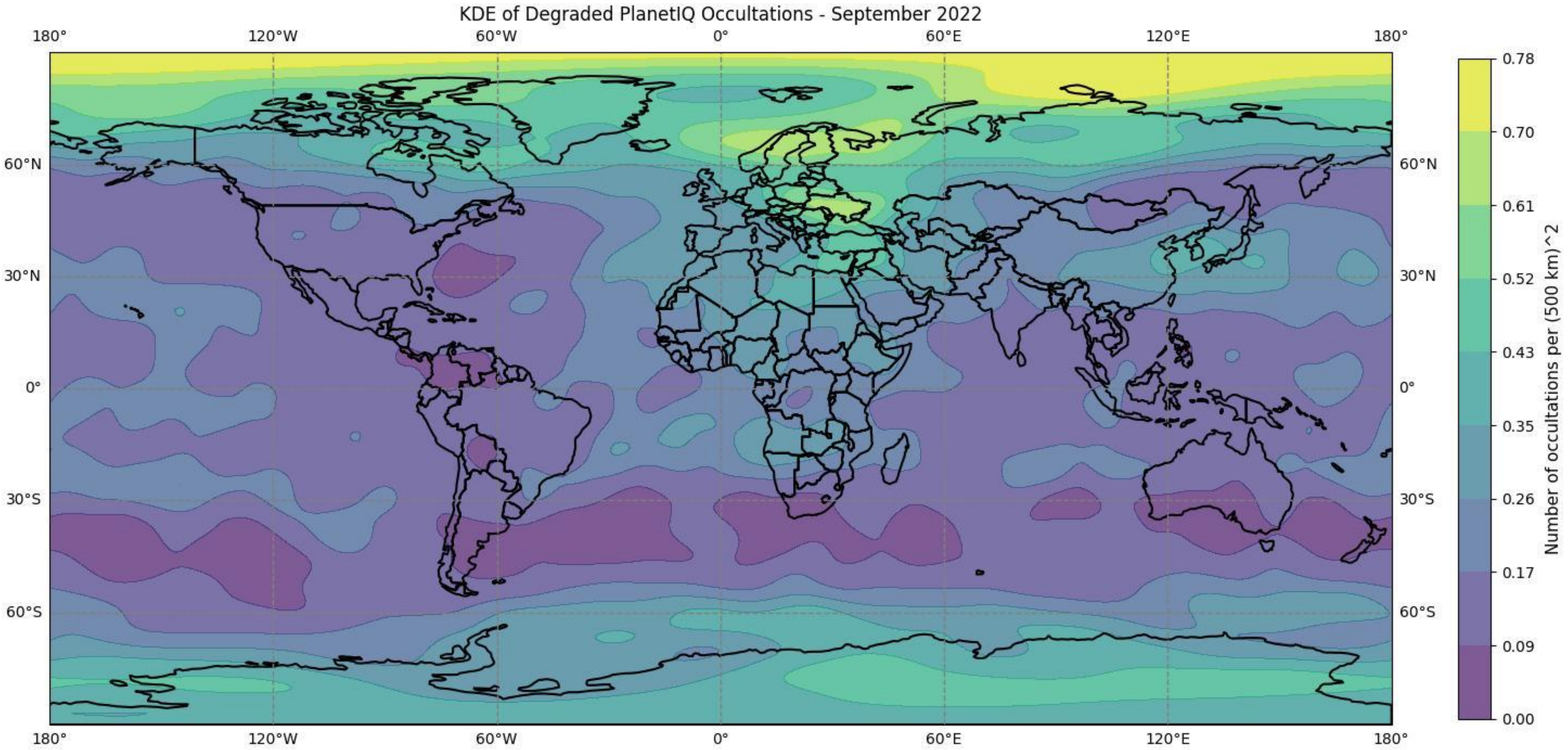


Degraded PlanetiQ Occultations

serco

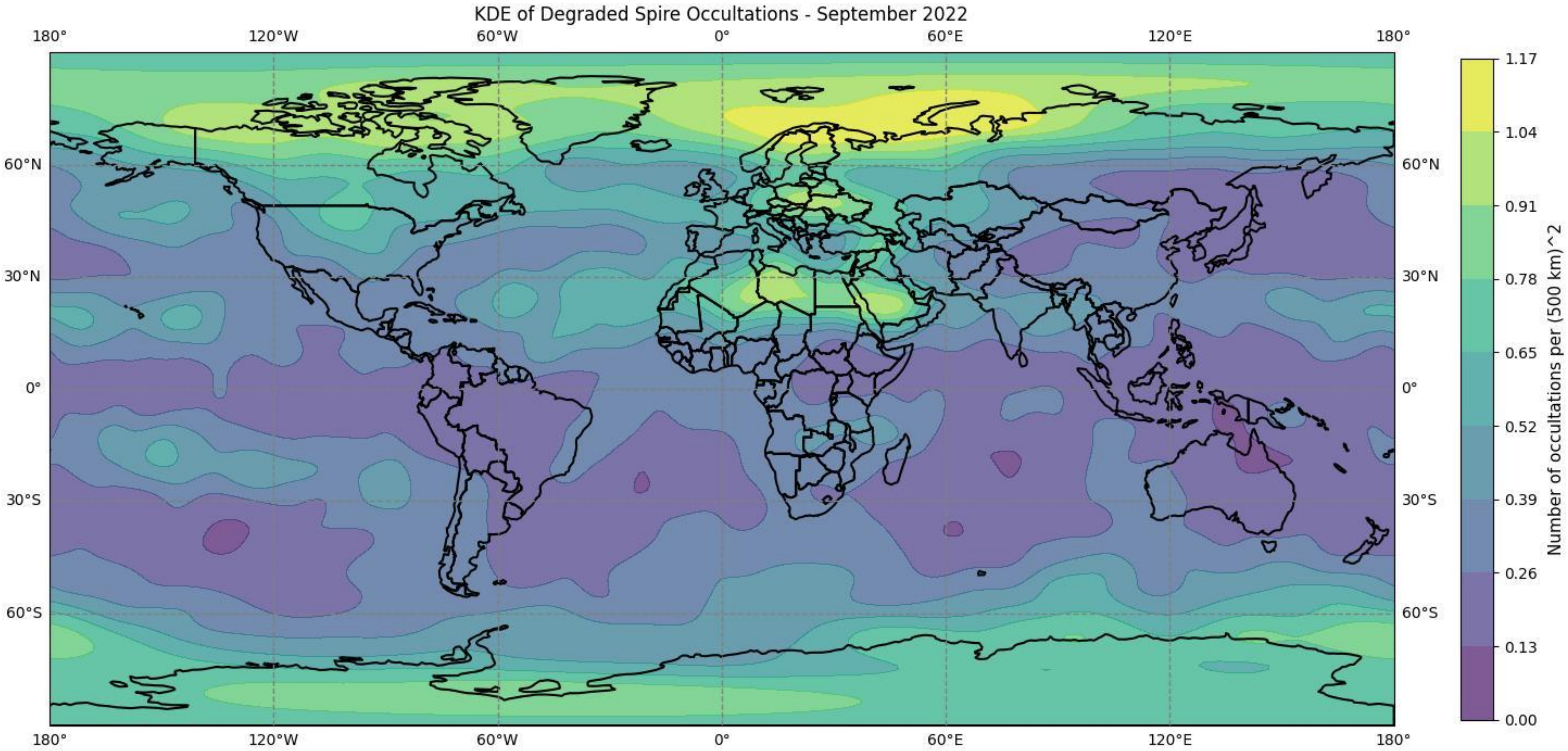
www.eumetsat.int

Distribution of Degraded PlanetiQ Occultations



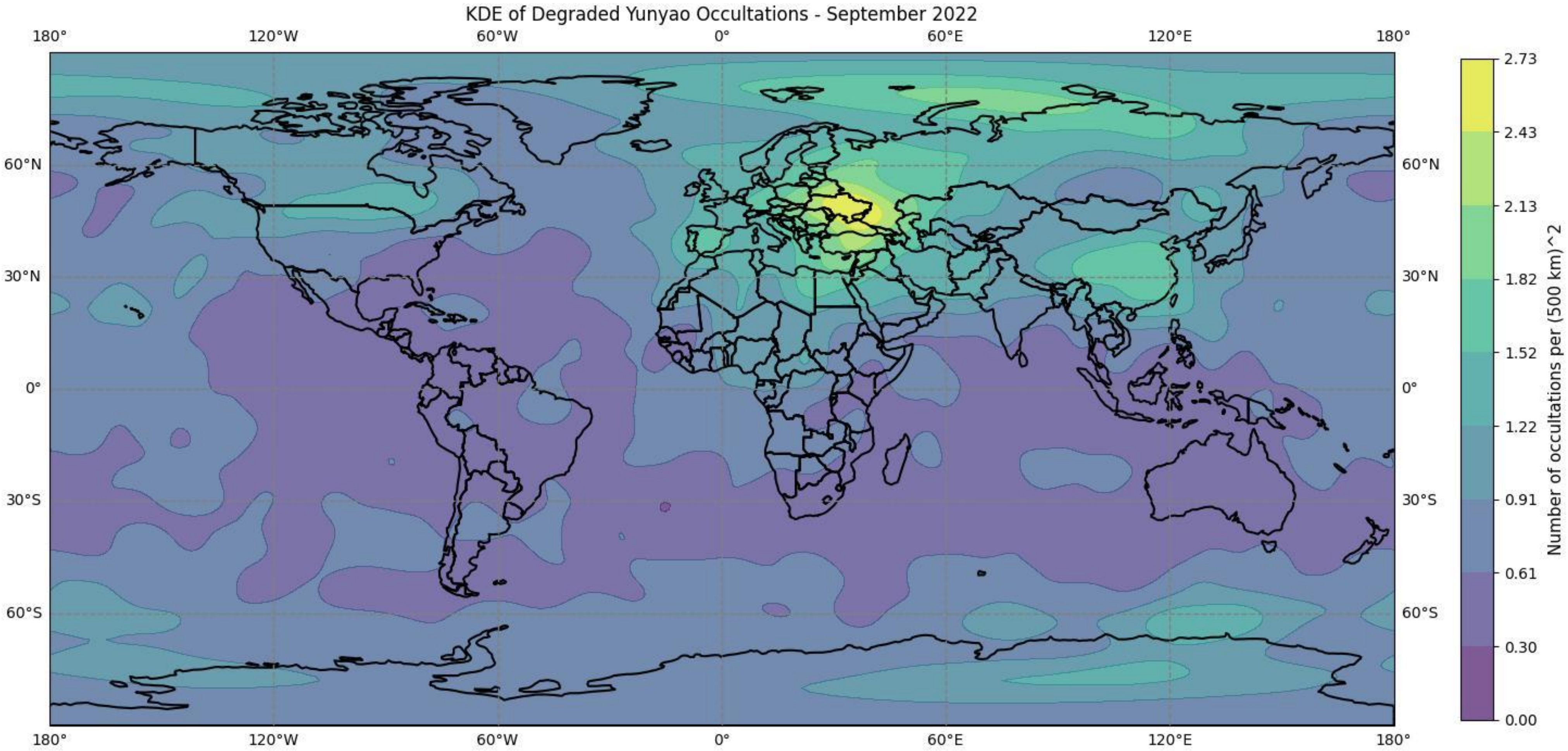
Degraded Spire Occultations

Distribution of Degraded Spire Occultations



Degraded Yunyao Occultations

Distribution of Degraded Yunyao Occultations



Conclusion

- The analysis of GRAS data from 2021 to 2024 revealed a clear increase in both missed and degraded occultations, particularly in Eastern Europe, correlating with reported RFI activity linked to geopolitical events, such as the Russo-Ukrainian conflict (Roberts *et al*., 2022; Hanks, 2024).
- Comparing GRAS, Sentinel-6, Spire, PlanetiQ, and Yunyao data from September 2022 revealed that not all missions are equally affected by RFI. Furthermore, concentrations of degraded occultations suggest that other factors may also be contributing.
- Implementing monitoring systems, like the EUMETSAT “prediction tool” presented here, serves an important function in providing reference data to track missed occultations.

Thank you!

Questions are welcome.

María José Parra Ortega
MariaJose.ParraOrtega@external.eumetsat.int

Christian Marquardt
Christian.Marquardt@eumetsat.int

Axel Von Engeln
Axel.VonEngeln@eumetsat.int

Francisco Sancho
Francisco.Sancho@eumetsat.int