Statistical Evaluation of Sentinel-3 OLCI Ocean Color Data Retrievals

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Motivation / Methodology

How to ensure ocean color data accuracy?

1. In-situ / fiduciary reference measurements = Gold Standard. However:
   - Very few in-situ measurements compared to GBs of satellite derived ocean color data daily
   - Only select stations have continuous monitoring
   - Cruises are expensive, not frequent, and also geographically restricted (spatial and temporal limited)
2. Inter-sensor comparisons – more data overlap, but if results differ, which sensor is right?

Our approach:

- Over the global open ocean (where vast majority of satellite data retrievals are), the spatial distribution is more uniform, and temporal changes are generally gradual
- Thus, an appropriate spatial and temporal average of the same sensor data can be used as a baseline to evaluate the statistical consistency of ocean color retrievals
  - The spatial average should be wide enough to capture stable average, but smaller than mesoscale natural features
  - The temporal average should include independent retrievals over multiple days, but be shorter than main cycles of natural variability (seasonal change)
- The differences between the Level-2 ocean color retrievals and the spatial-temporal average baseline values (anomaly) are expected to be small in the open ocean, should represent the natural variability, and thus not depend on a range of retrieval parameters
- Thus, we can analyze the deviations from the average baseline values, and investigate their dependence on various retrieval parameters
  - Large deviations from average in certain retrieval conditions may indicate biases in the retrieval algorithms
- Averaging over global scale and yearly time period provides enough statistics to evaluate data consistency
- But using the same sensor data as a baseline in comparison does not help with sensor calibration issues, spectral shapes, etc.

Methodology

Analyze normalized water-leaving reflectance $\rho_{wN}(\lambda)$ spectra due to their essential role in determining ocean color product data (ocean optical, biological, and biogeochemical properties).

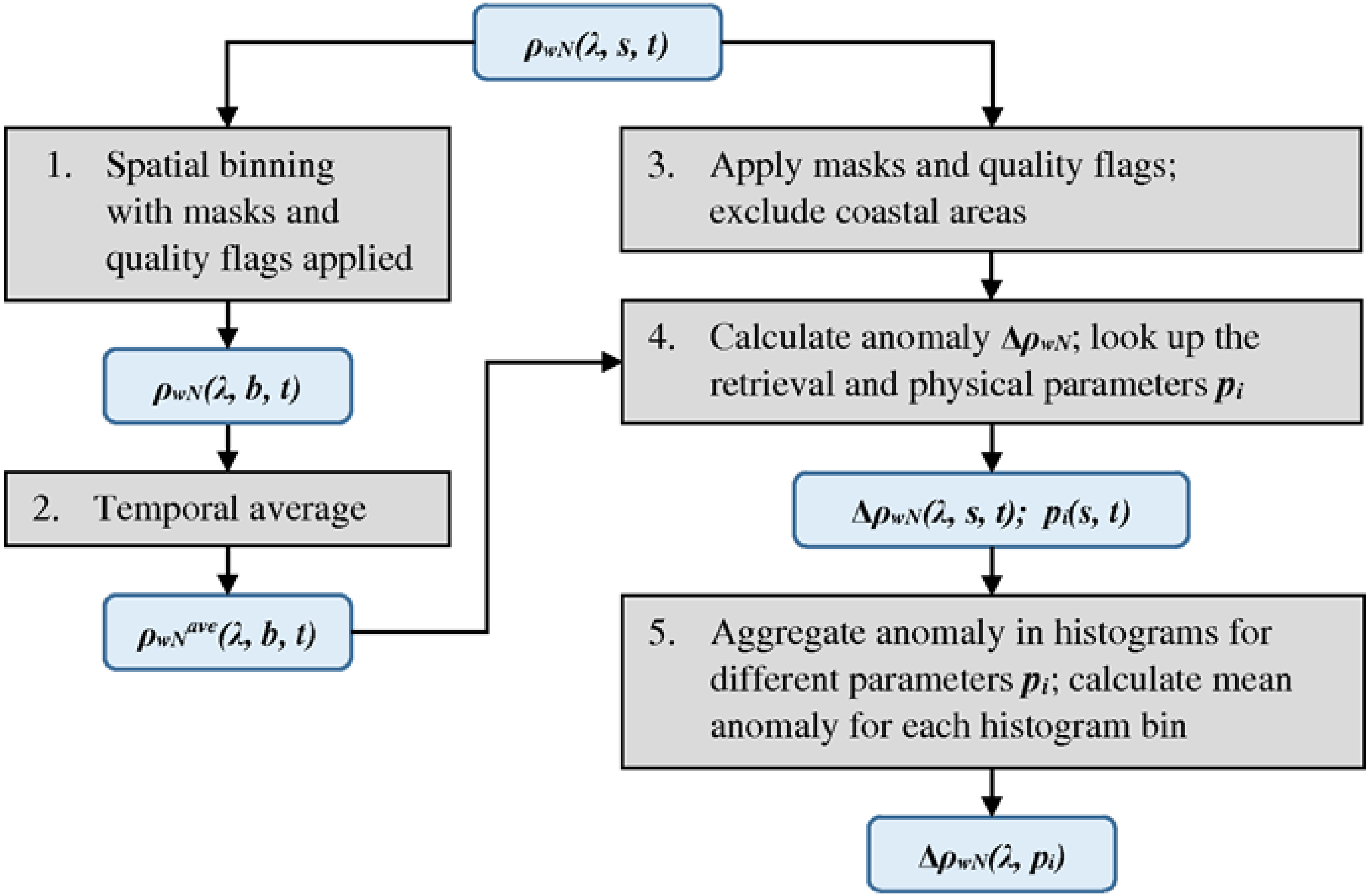
Main steps of data analysis:

1. Spatial binning of original L2 reflectance data $\rho_{wN}(\lambda)$ into ~9×9 km bins (with L2 flags applied)
2. Weighted temporal average over one OLCI revisit cycle (27 days)
3. Filter out poor retrievals (using L2 flags) and dynamic coastal/inland areas (water depth > 1 km) from the original L2 data
4. Calculate the anomaly $\Delta\rho_{wN}(\lambda)$ and collect the corresponding values of retrieval parameters
5. Aggregate values of anomaly in histograms w/r to each retrieval parameter
6. The required uncertainty in $\rho_{wN}(\lambda)$ for the blue bands is within ≈ 0.001 – 0.002 for the open ocean.

Relevant Retrieval Parameters

Solar – Sensor Geometry	Ancillary Data	Other Retrieval Parameters
Sample across swath	Wind Speed	Glint Coefficient
Solar-Zenith Angle	Water Vapor	Aerosol Optical Depth
Sensor-Zenith Angle	Air Pressure	Distance to Clouds
Relative Azimuth Angle	Ozone Concentration	QA Score

Methodology



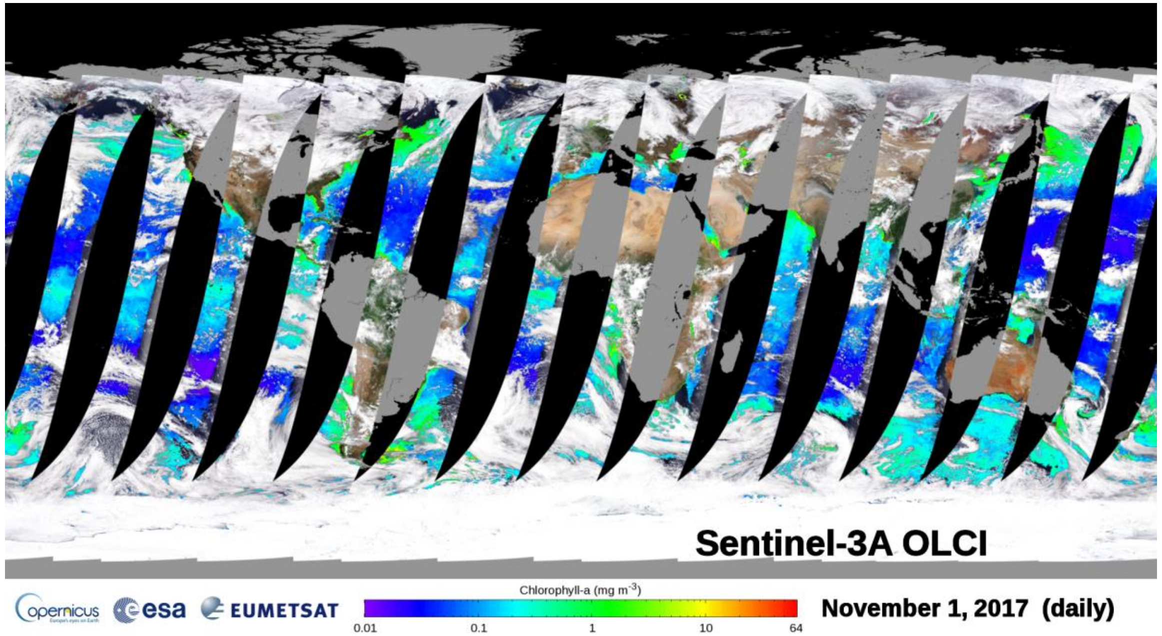
Methodology adopted from a previous study for VIIRS:

K. Mikelsons, M. Wang, and L. Jiang, "Statistical evaluation of satellite ocean color data retrievals", *Remote Sens. Environ.*, **237**, 111601 (2020). doi:10.1016/j.rse.2019.111601

Sentinel-3 OLCI

- Push-broom sensor type
- 4860 samples across the swath divided into five cameras
- Swath width 1270 km
- ~300 m spatial resolution
- 21 spectral bands
- Polar sun-synchronous daytime descending orbit
- 27-day revisit cycle

https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-3/overview/mission-summary



- **EUMETSAT** produces and distributes OLCI Level-1 data (TOA radiances), and Level-2 data (normalized water-leaving reflectance and derived data products; derived with **EUMETSAT IPF-OL-2** processing system).

- **NOAA Ocean Color** team receives OLCI Level-1 data from EUMETSAT and also produces Level-2 data using **NOAA MSL12** processing system.

Methodology

Data Sets and Processing Systems

Two data sets derived from the same Level-1 data with two different processing systems (**NOAA MSL12** and **EUMETSAT IPF-OL-2)** were independently analyzed with the same methodology.

One year (2019) of global Sentinel-3A OLCI L2 ocean color data analyzed from each processing system

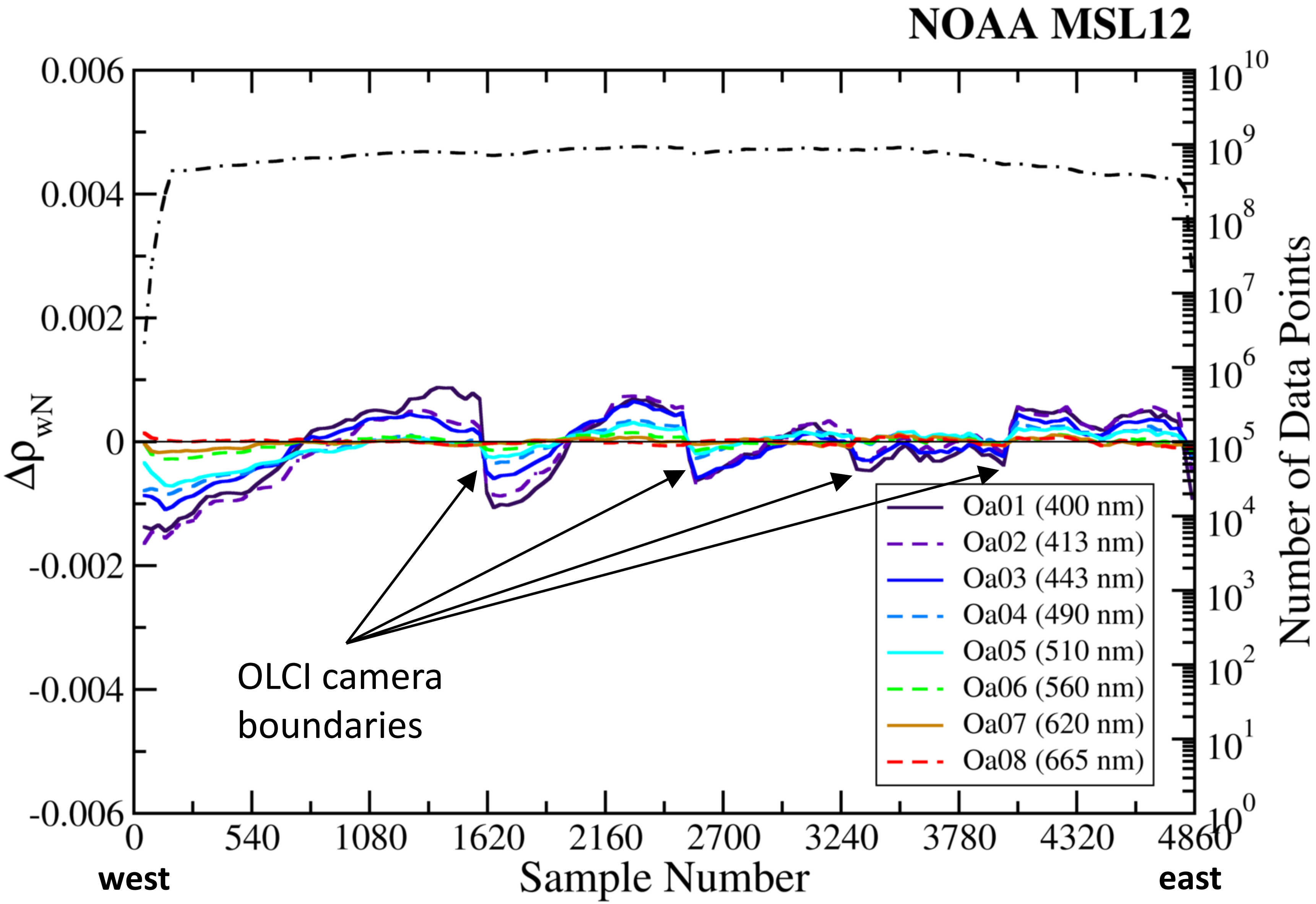
Differences in retrieval algorithms and implementations include:

- Atmospheric correction
- Aerosol models
- NIR reflectance correction
- Sun glint correction
- BRDF correction
- Cloud/straylight masking
- Ancillary data
- Different sets of L2 data quality flags

Notably, EUMETSAT IPF-OL-2 $\rho_{wN}(\lambda)$ data do not include corrections for the BRDF effects

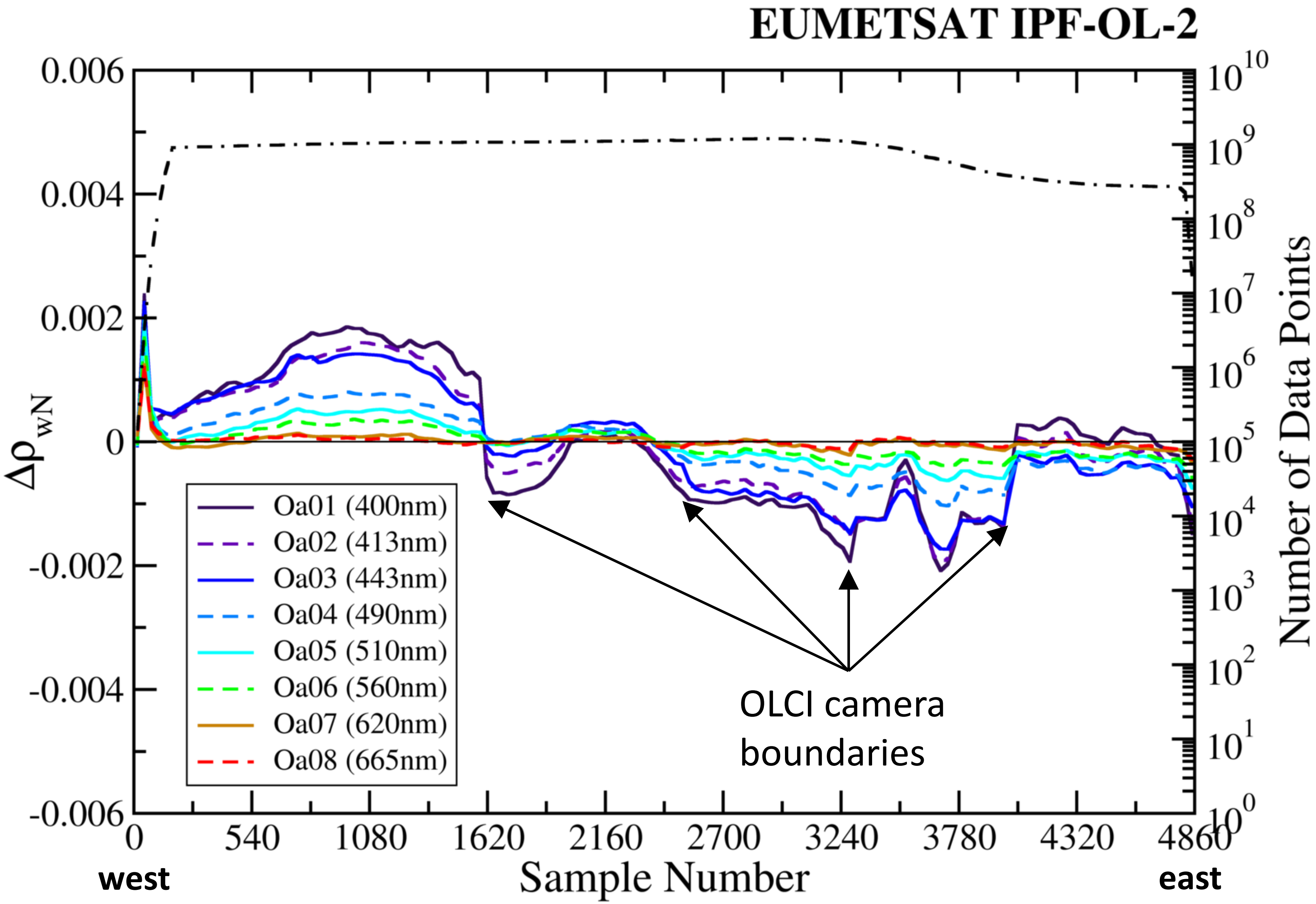
Results: Solar – Sensor Geometry

Variation with sample across swath



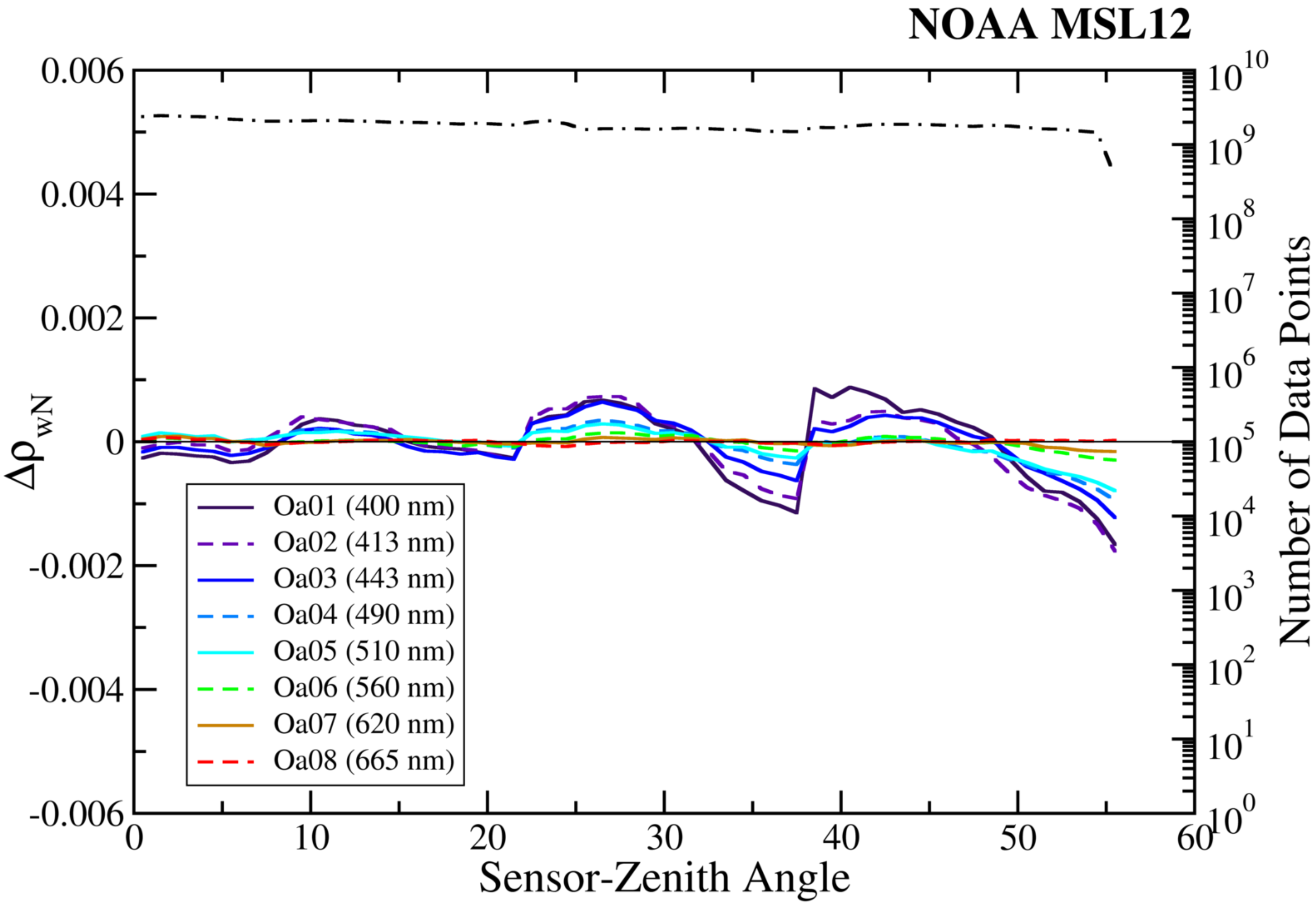
Results: Solar – Sensor Geometry

Variation with sample across swath



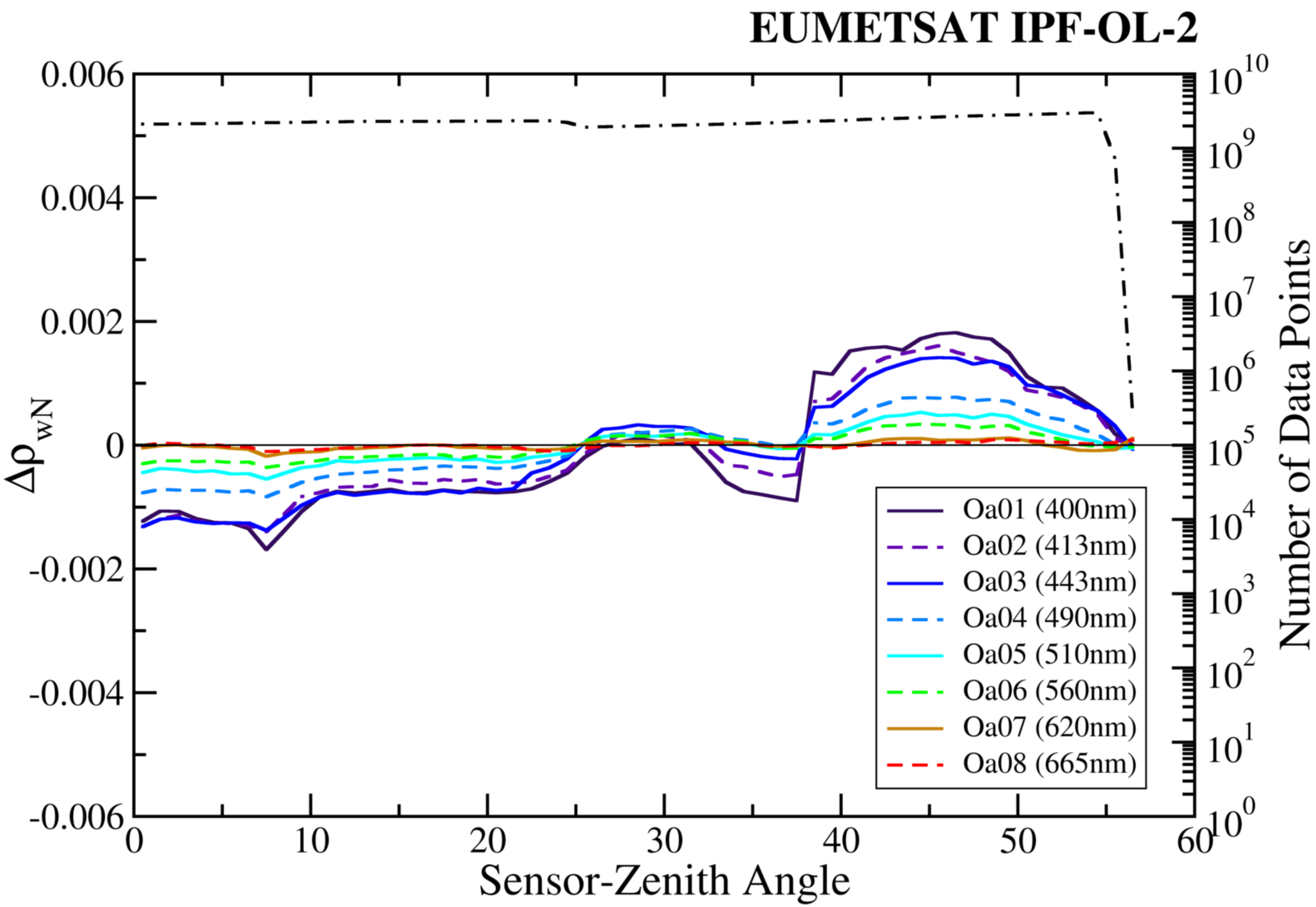
Results: Solar – Sensor Geometry

Sensor-Zenith angle



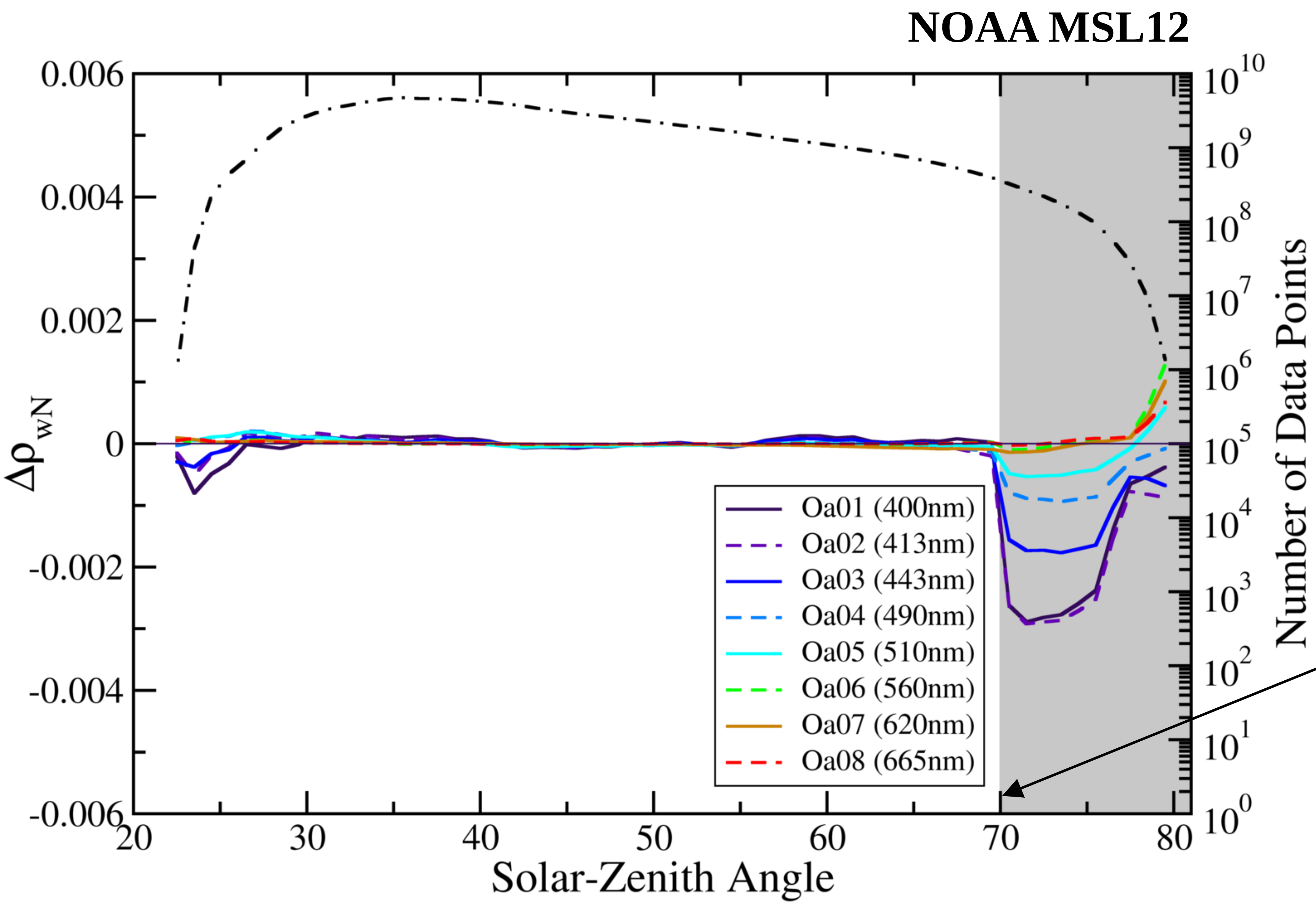
Results: Solar – Sensor Geometry

Sensor-Zenith angle



Results: Solar – Sensor Geometry

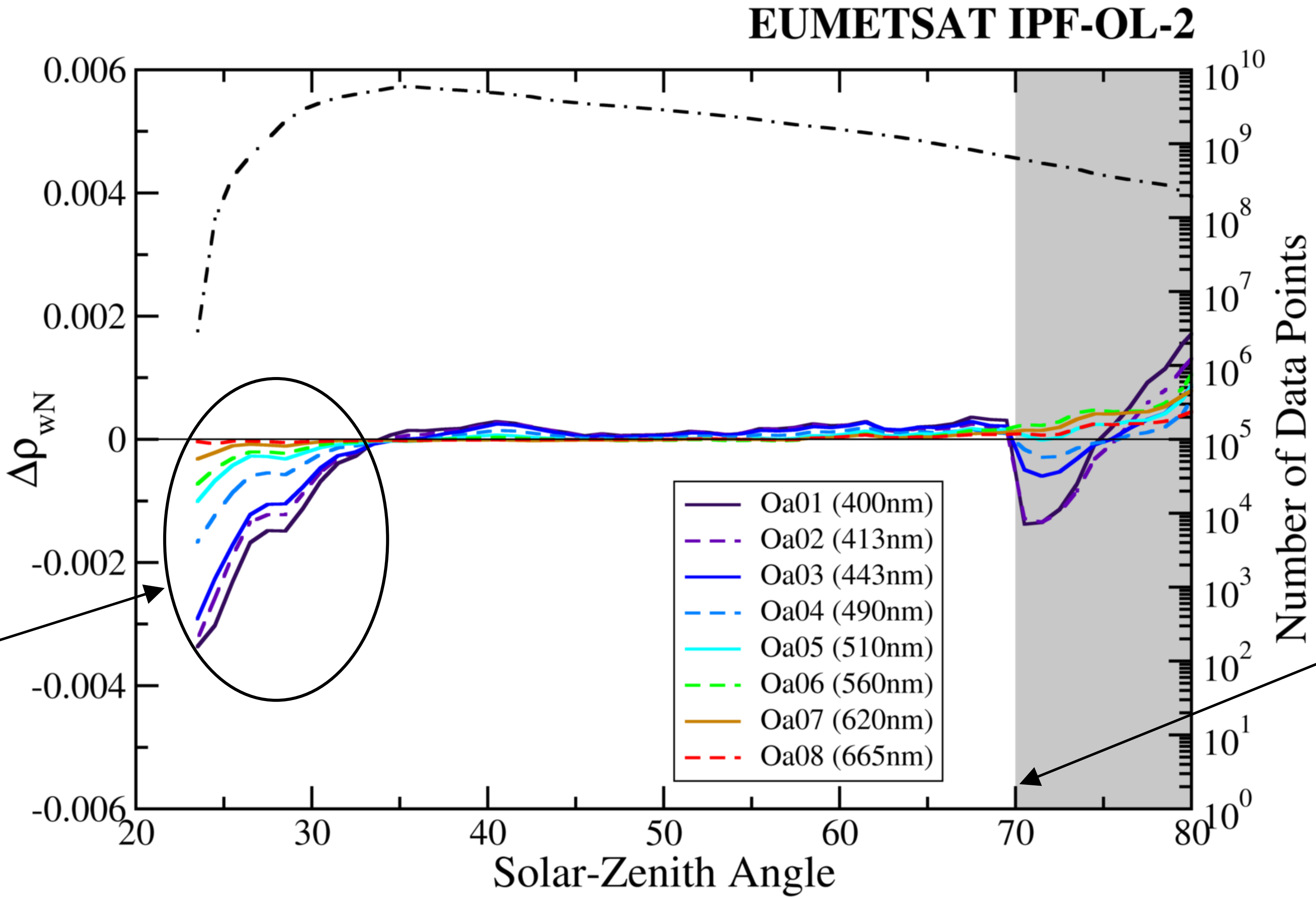
Solar - Zenith angle



High Solar-Zenith angle threshold

Results: Solar – Sensor Geometry

Solar - Zenith angle

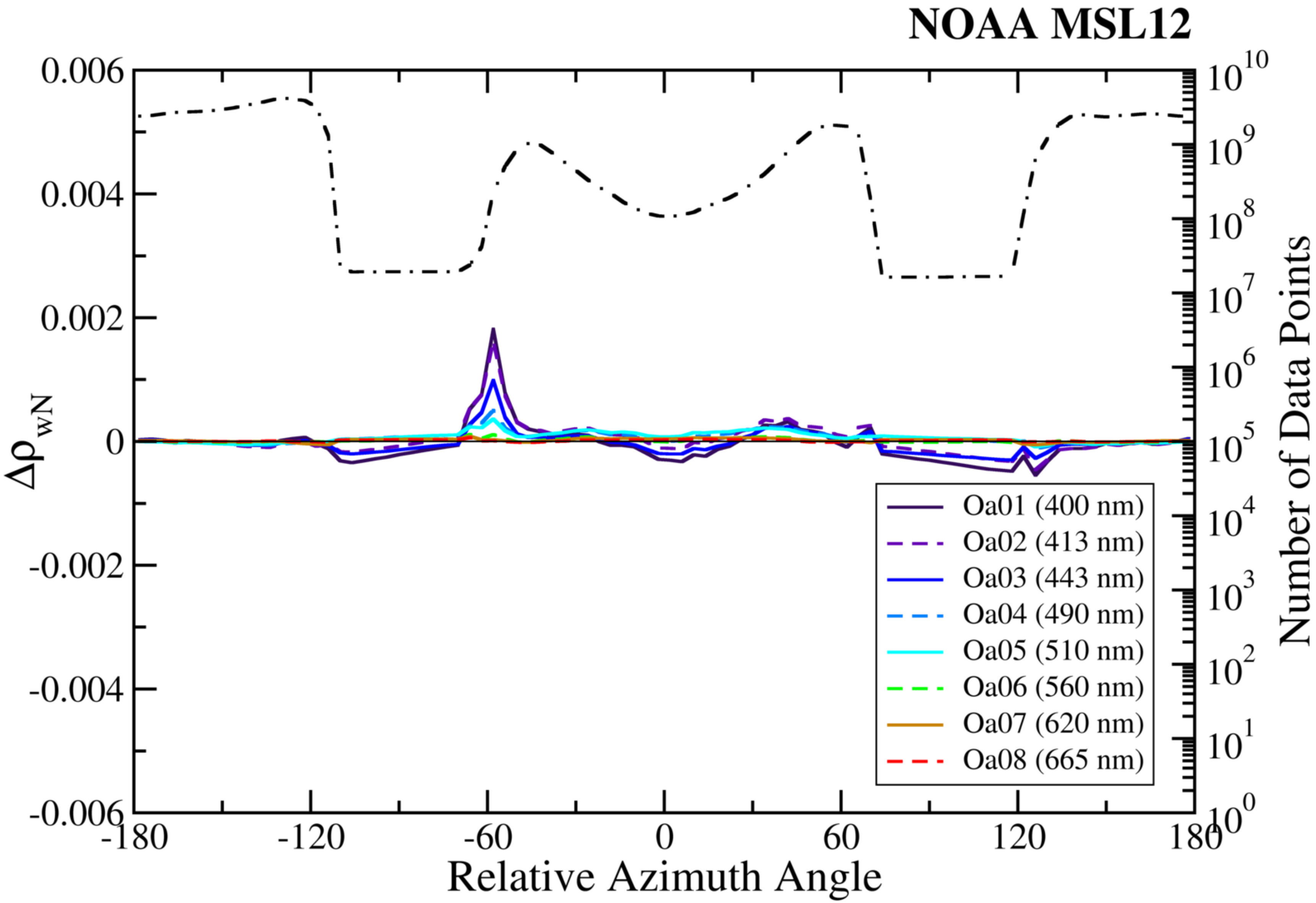


Low Solar-Zenith angle often coincides with medium to high glint for OLCI

High Solar-Zenith angle threshold

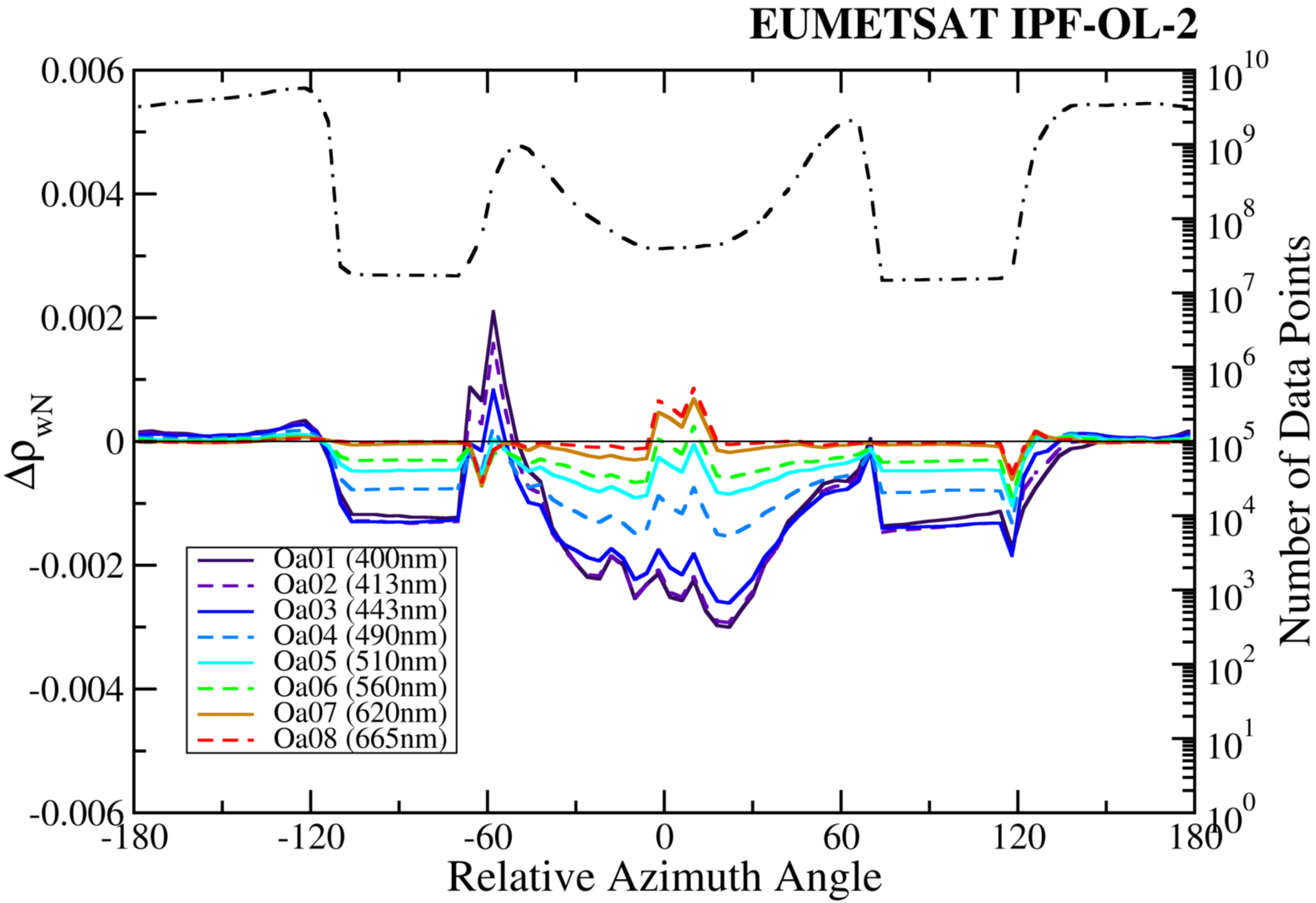
Results: Solar – Sensor Geometry

Relative Azimuth Angle



Results: Solar – Sensor Geometry

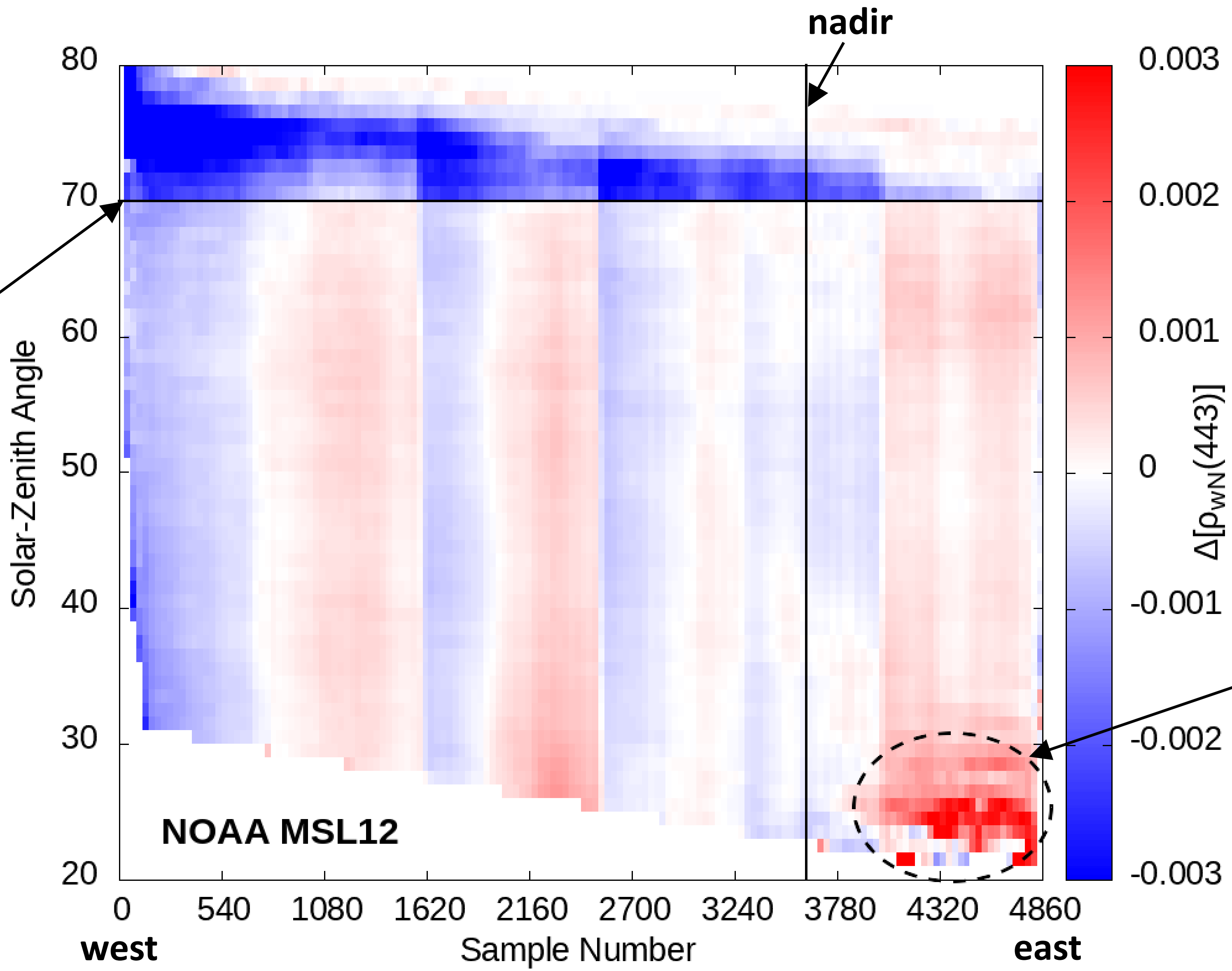
Relative Azimuth Angle



Results: Solar – Sensor Geometry

Solar-Zenith Angle and Sample Number combined dependence

High Solar-Zenith angle threshold

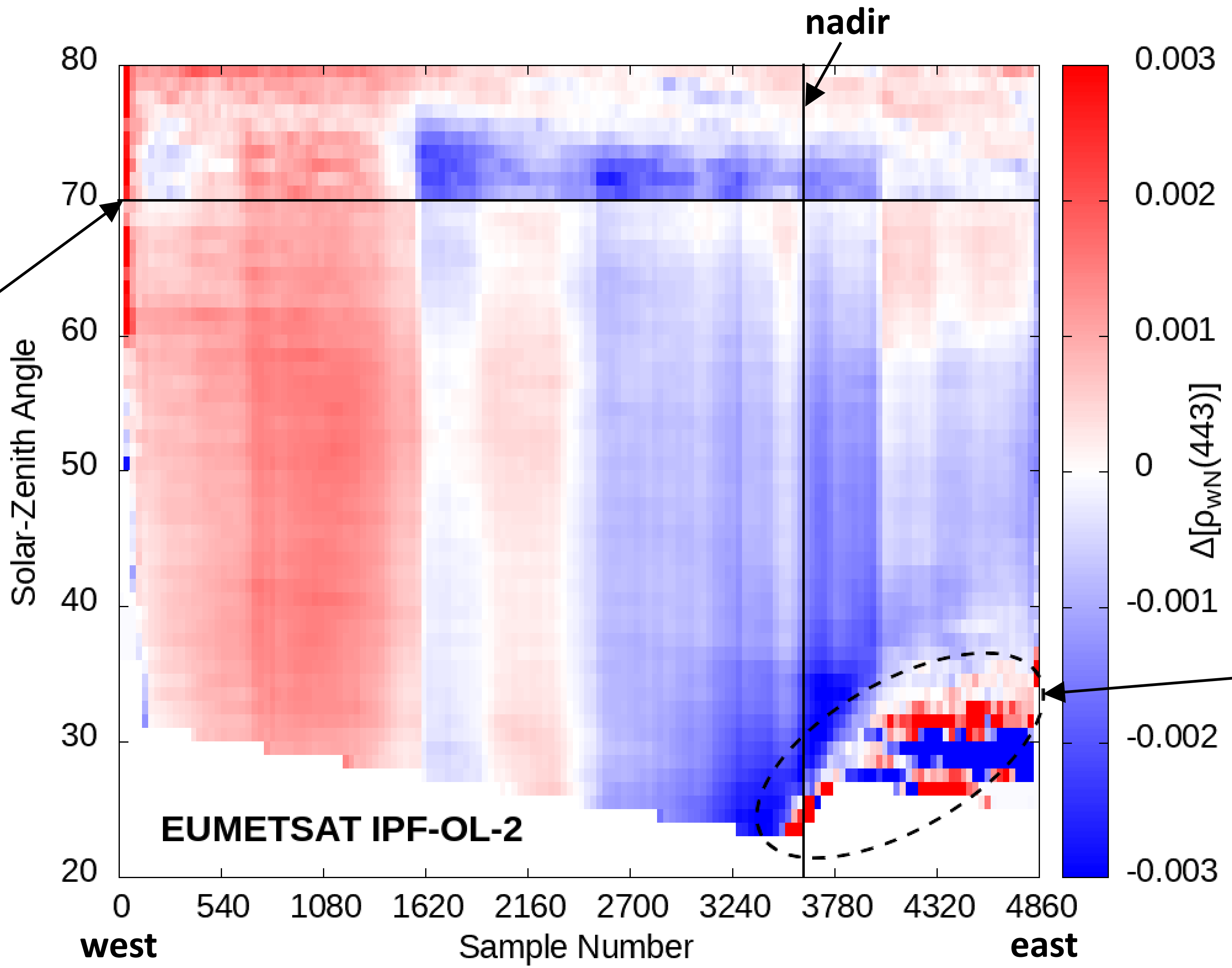


Sun glint conditions:

- less retrievals
- more noise
- slight overestimate of $\Delta\rho_{wN}(443)$

Results: Solar – Sensor Geometry

Solar-Zenith Angle and Sample Number combined dependence



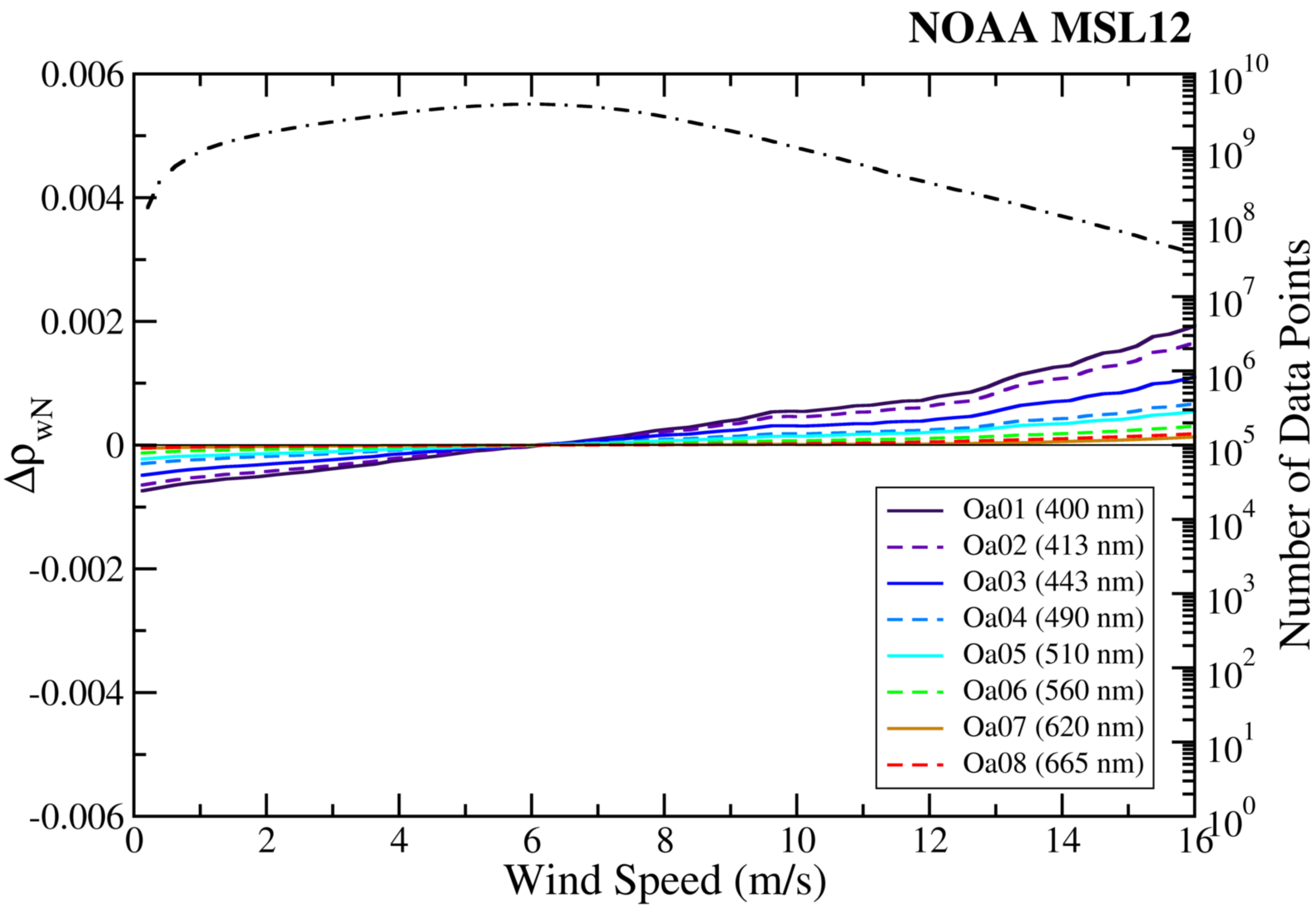
High Solar-Zenith angle threshold

Sun glint conditions:

- less retrievals
- more noise
- underestimate of $\Delta\rho_{wN}(443)$

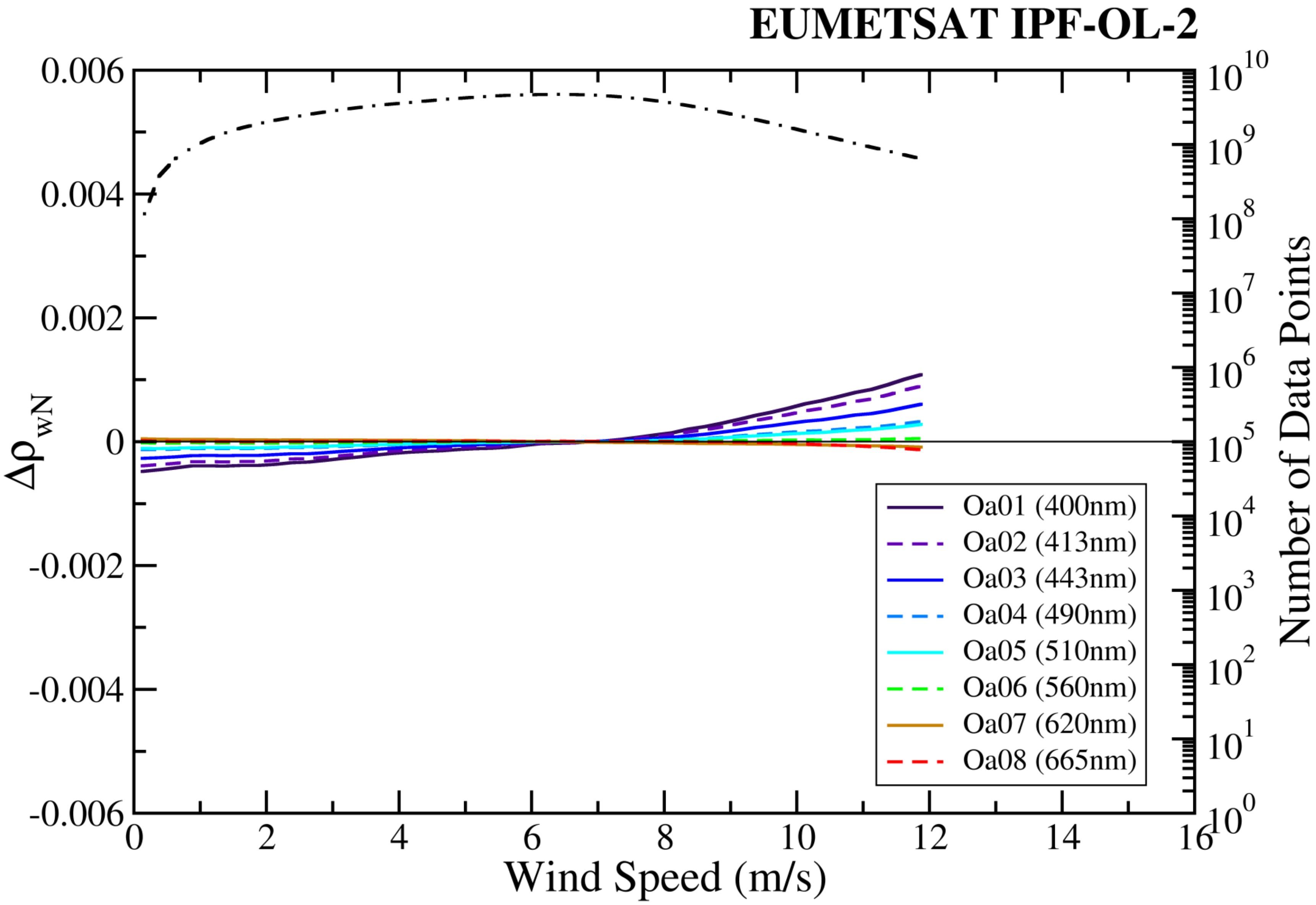
Results: Ancillary Data Dependence

Wind Speed



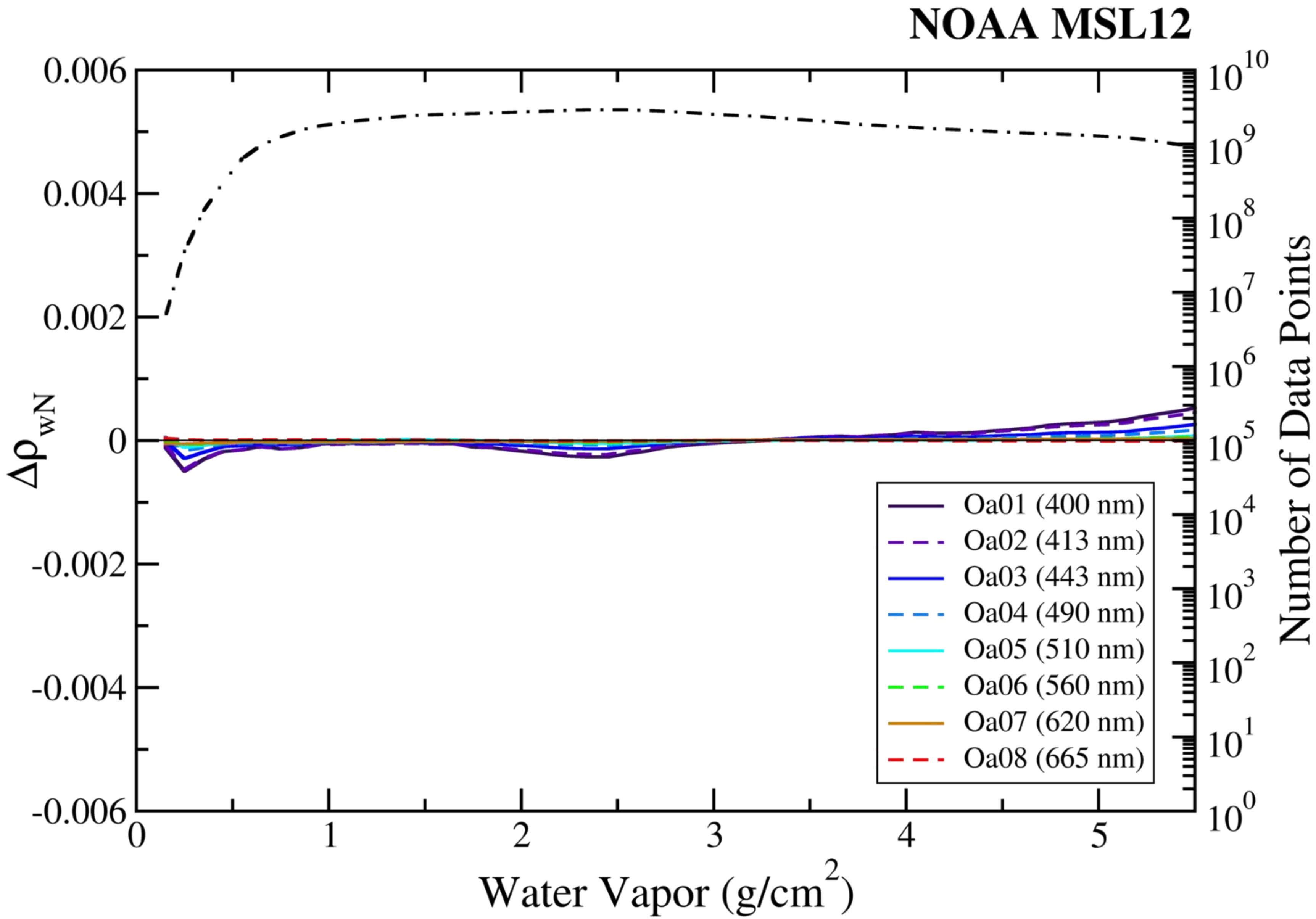
Results: Ancillary Data Dependence

Wind Speed



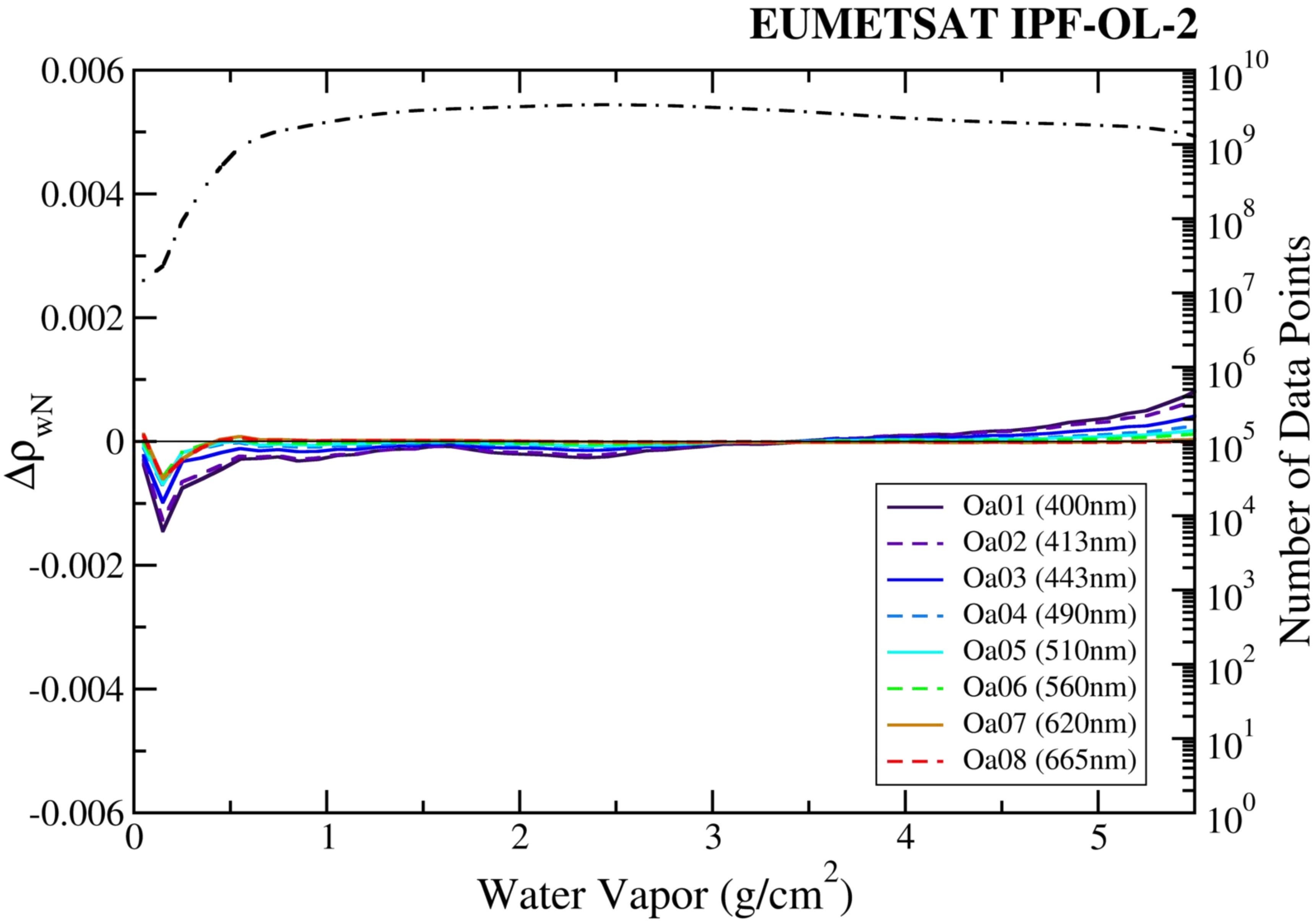
Results: Ancillary Data Dependence

Water Vapor



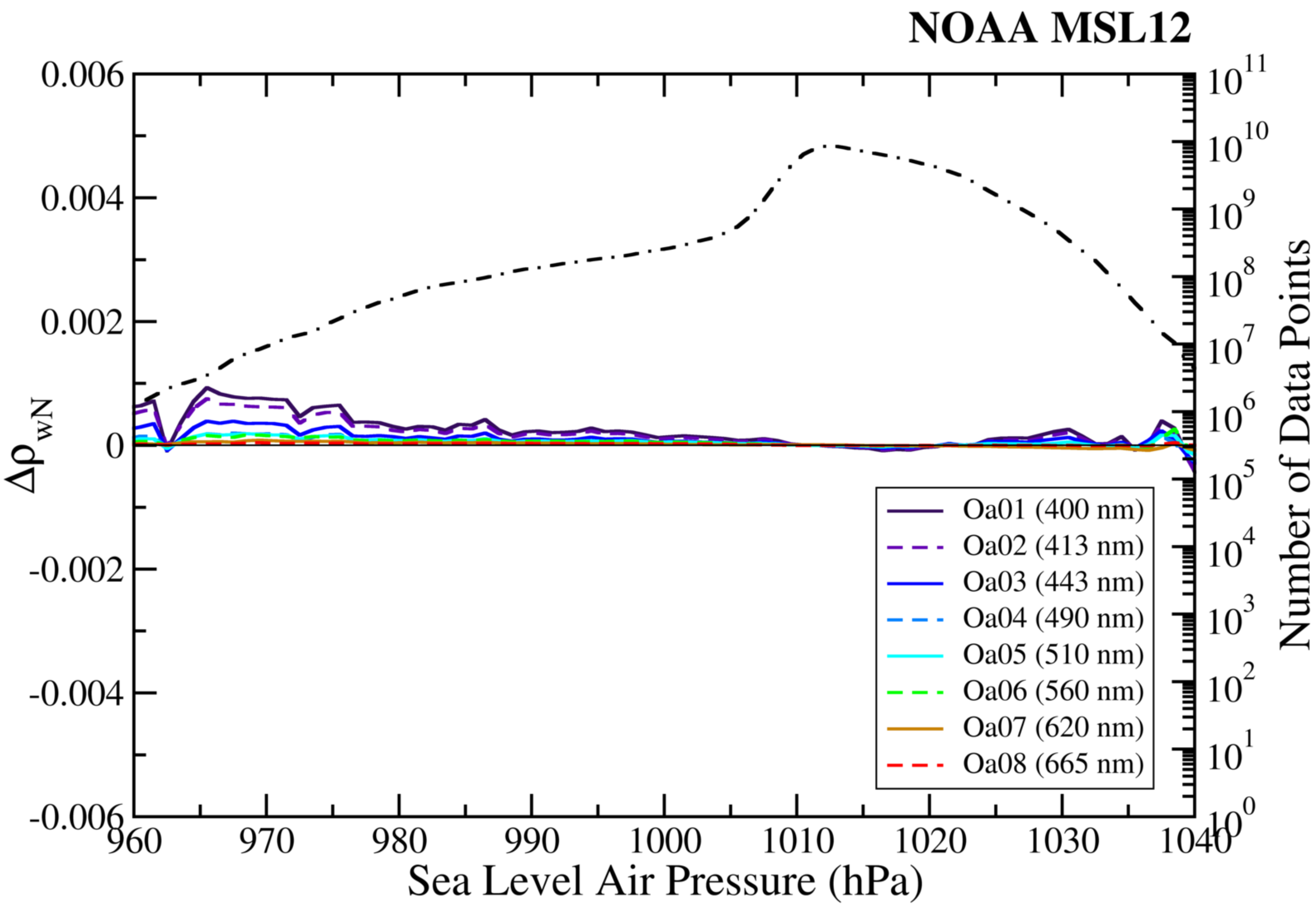
Results: Ancillary Data Dependence

Water Vapor



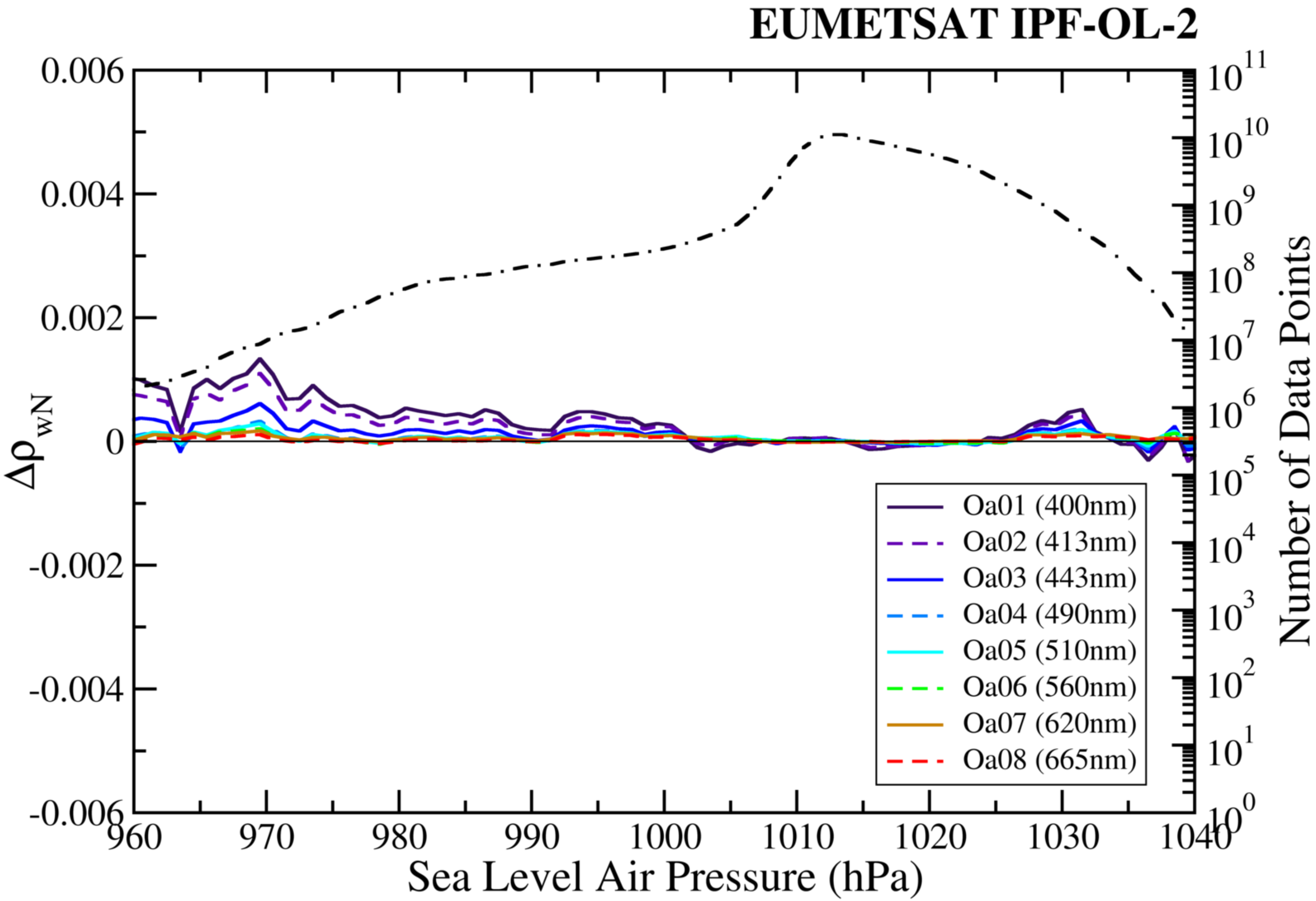
Results: Ancillary Data Dependence

Sea Level Air Pressure



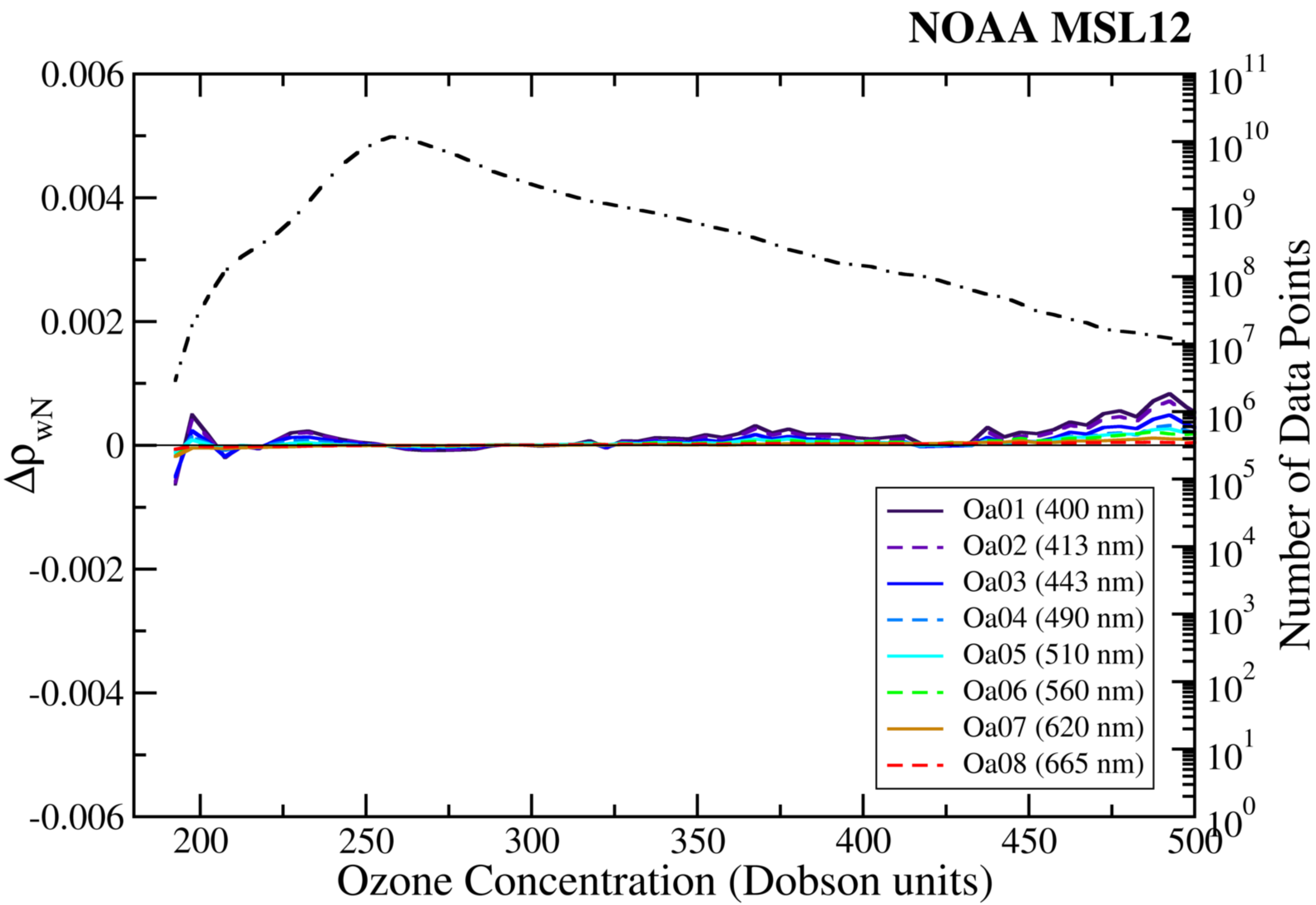
Results: Ancillary Data Dependence

Sea Level Air Pressure



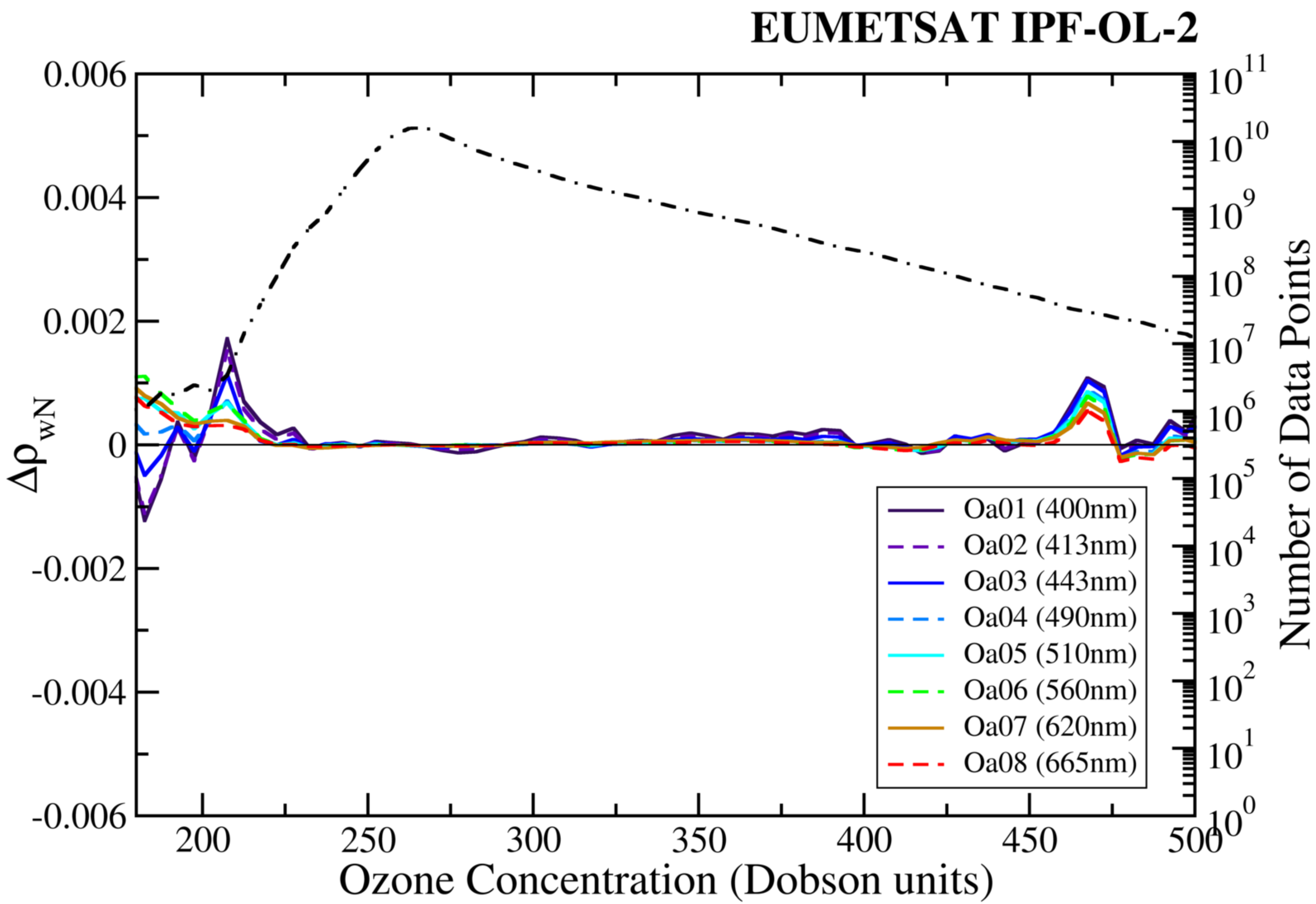
Results: Ancillary Data Dependence

Ozone Concentration



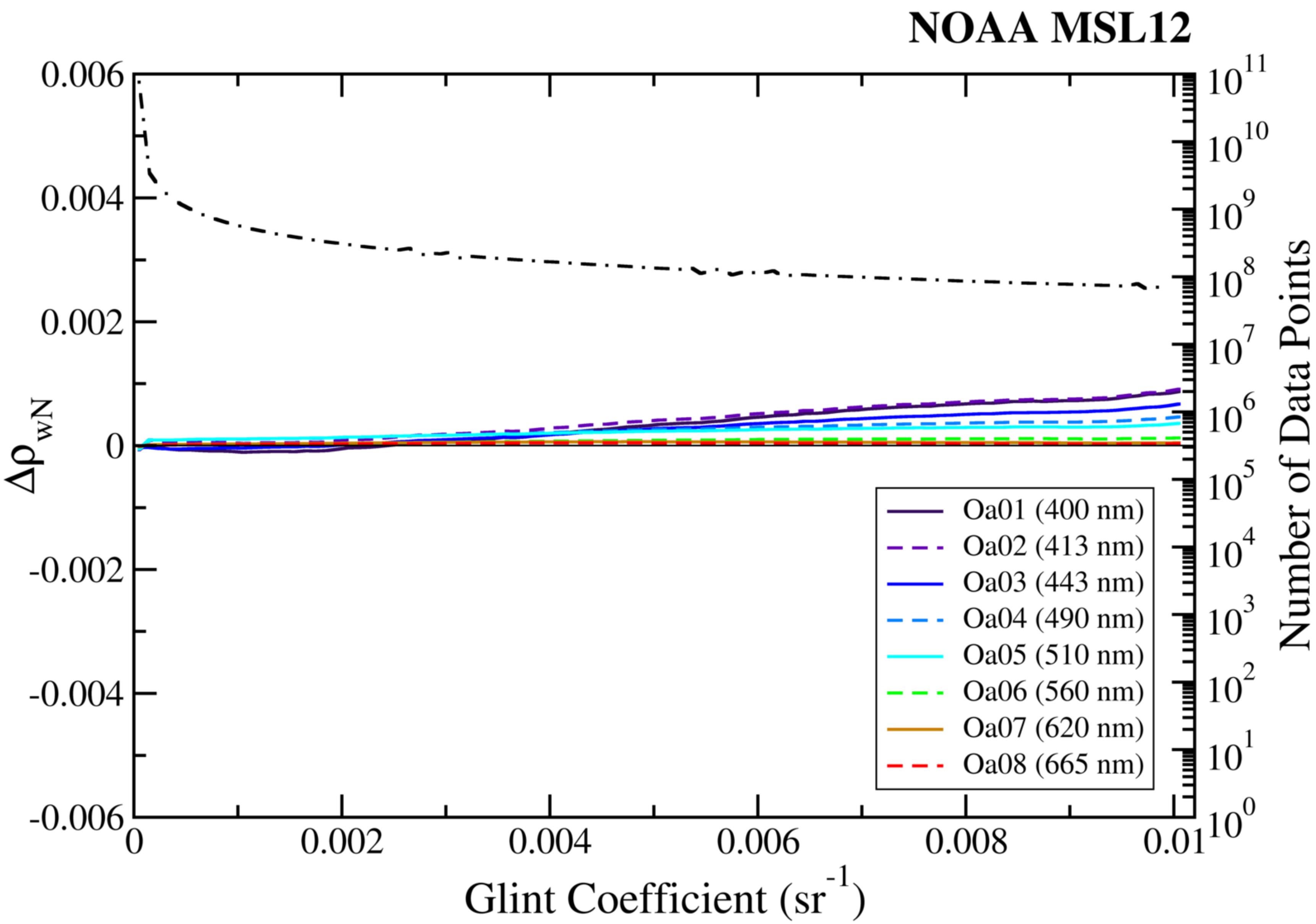
Results: Ancillary Data Dependence

Ozone Concentration



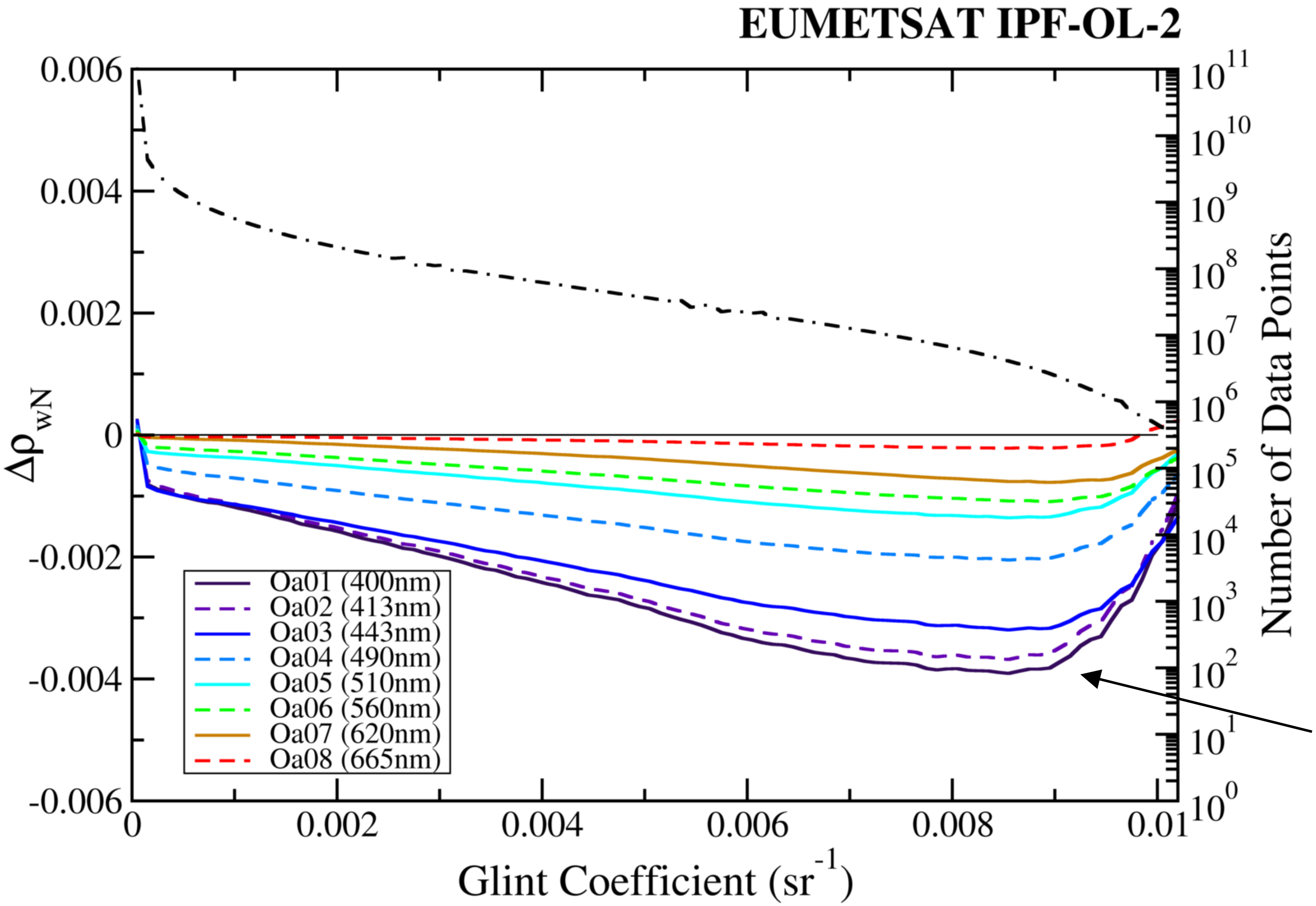
Results: Intermediate Retrieval Parameters

Glint Coefficient



Results: Intermediate Retrieval Parameters

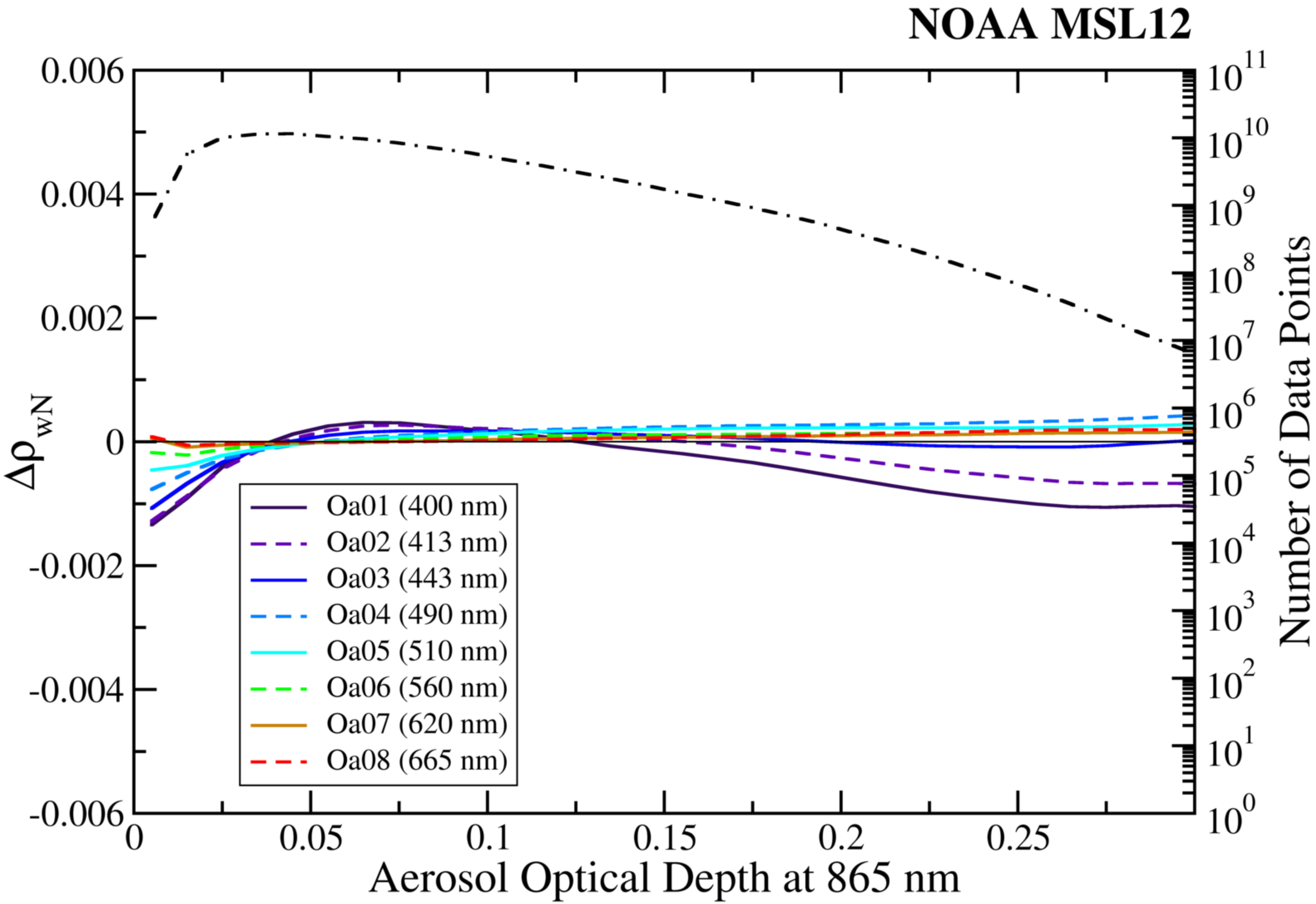
Glint Coefficient



Underestimate possibly/likely related to missing BRDF correction

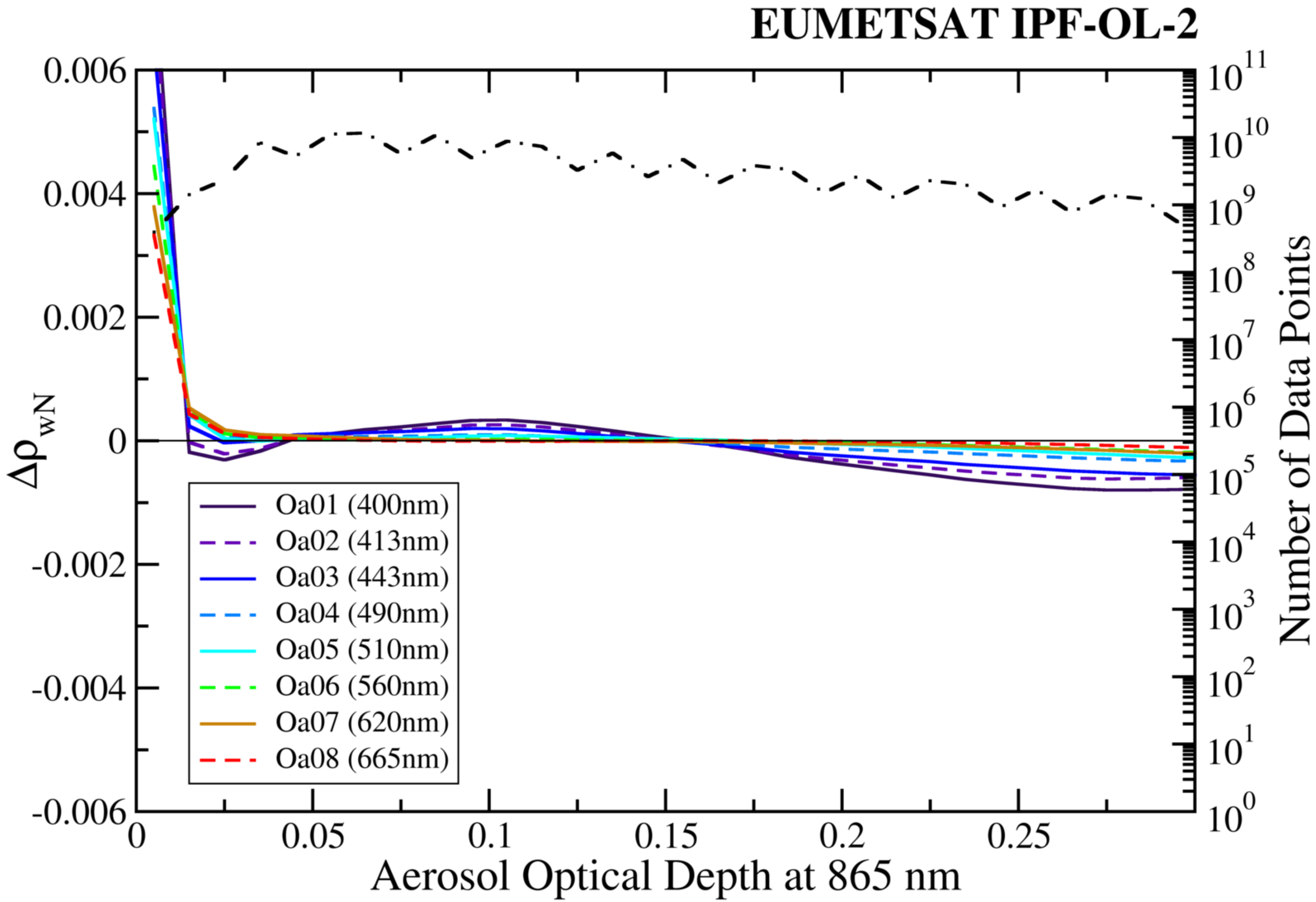
Results: Intermediate Retrieval Parameters

Aerosol Optical Depth



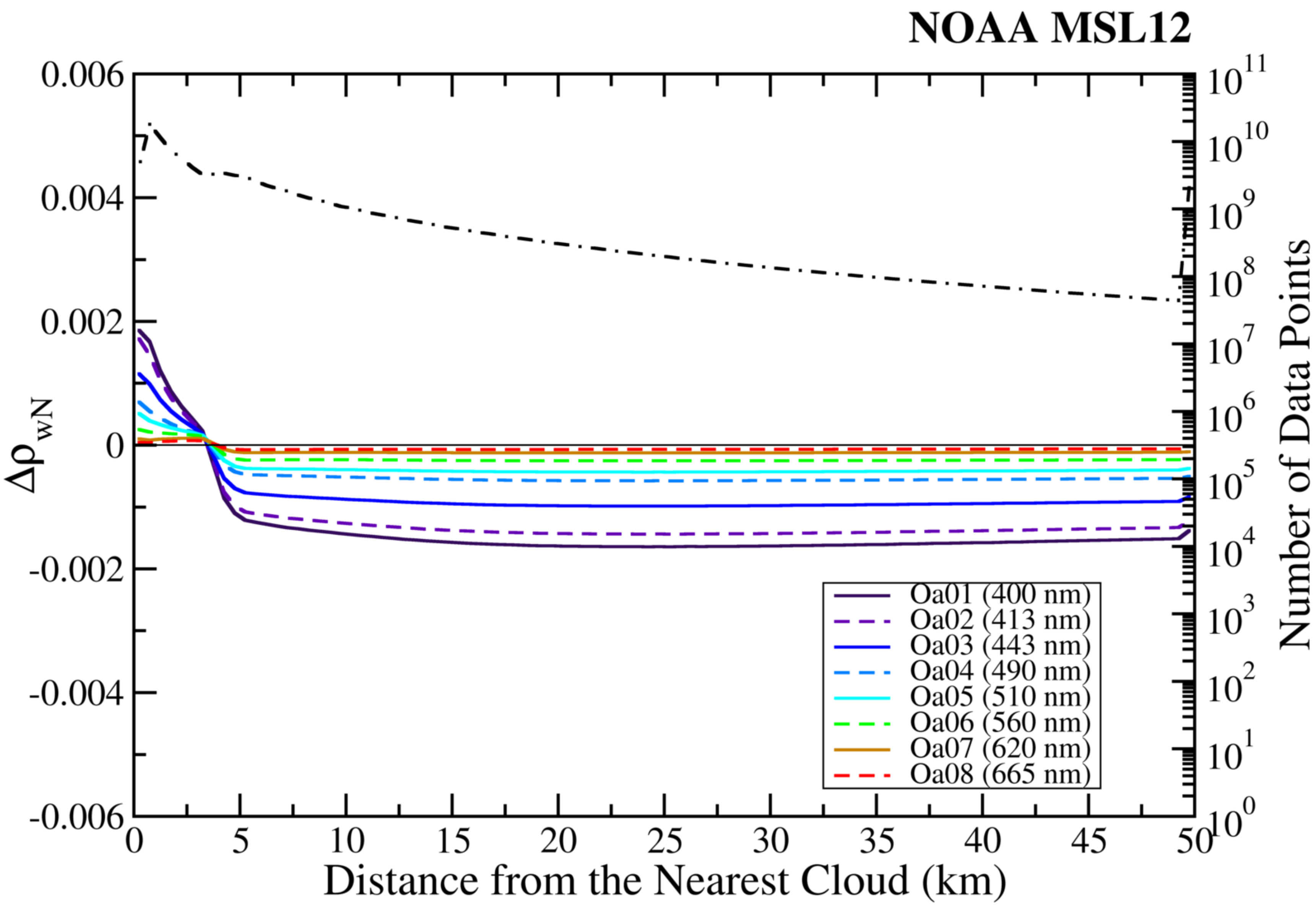
Results: Intermediate Retrieval Parameters

Aerosol Optical Depth



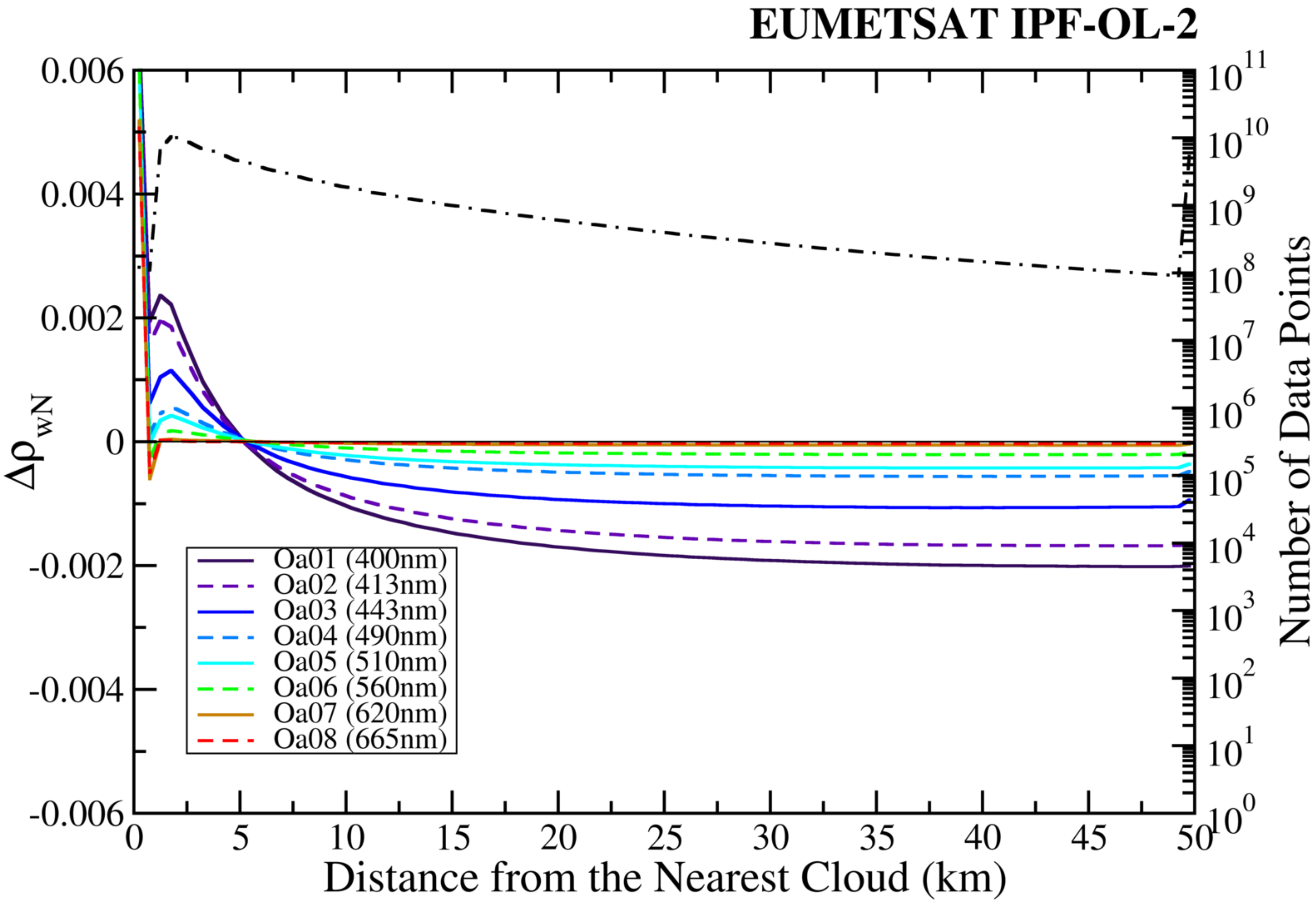
Results: Intermediate Retrieval Parameters

Distance to Clouds



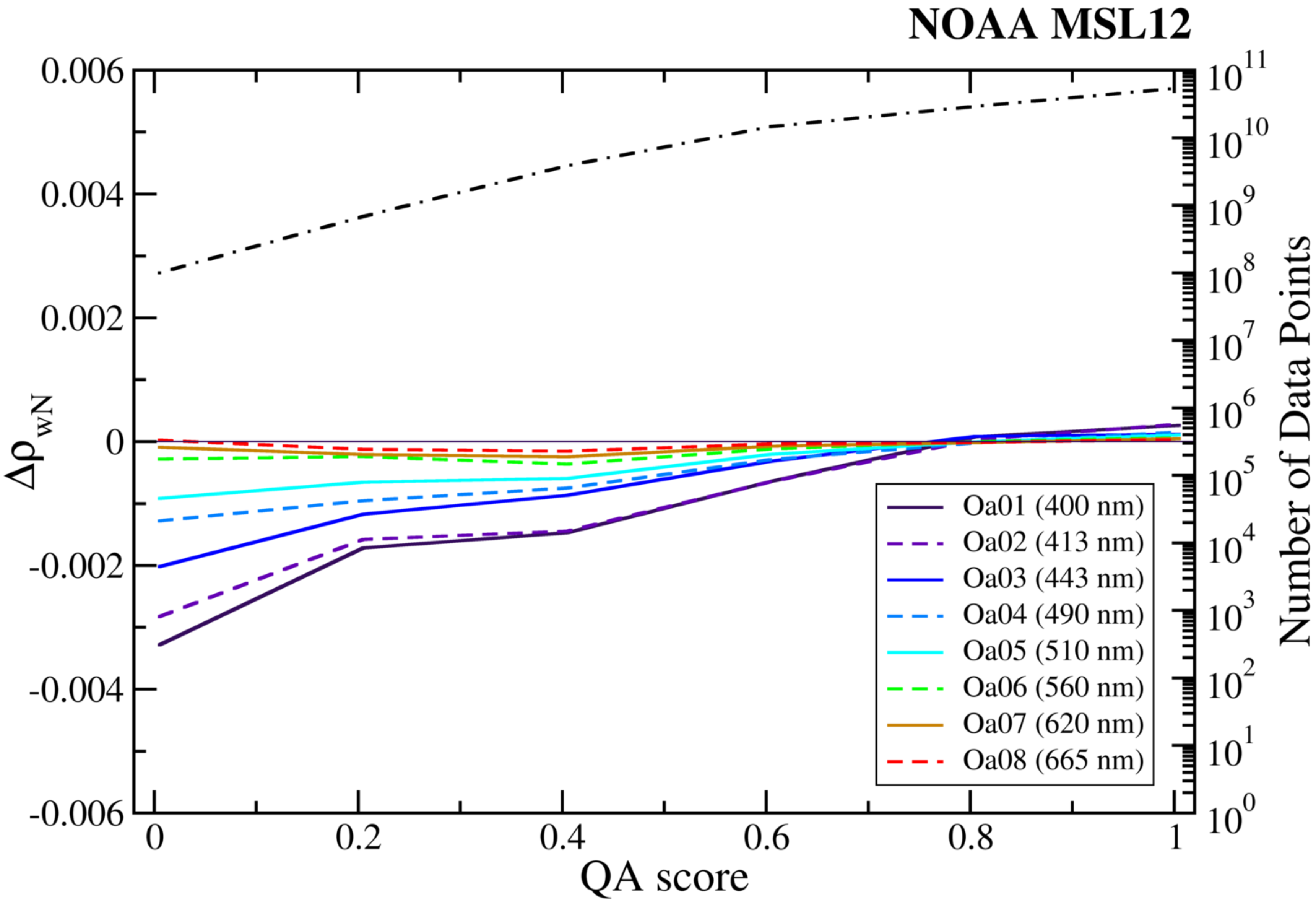
Results: Intermediate Retrieval Parameters

Distance to Clouds



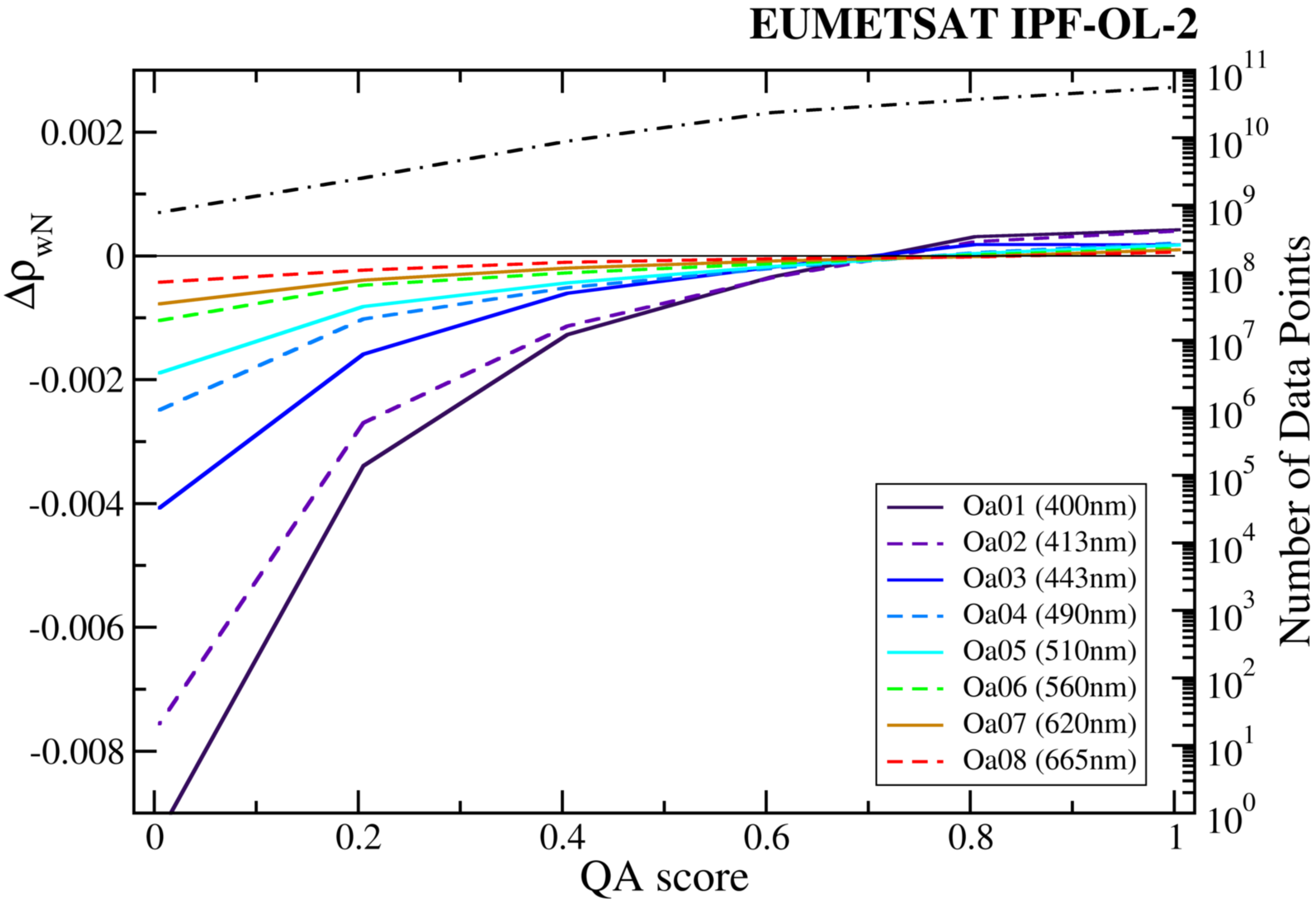
Results: Intermediate Retrieval Parameters

QA score



Results: Intermediate Retrieval Parameters

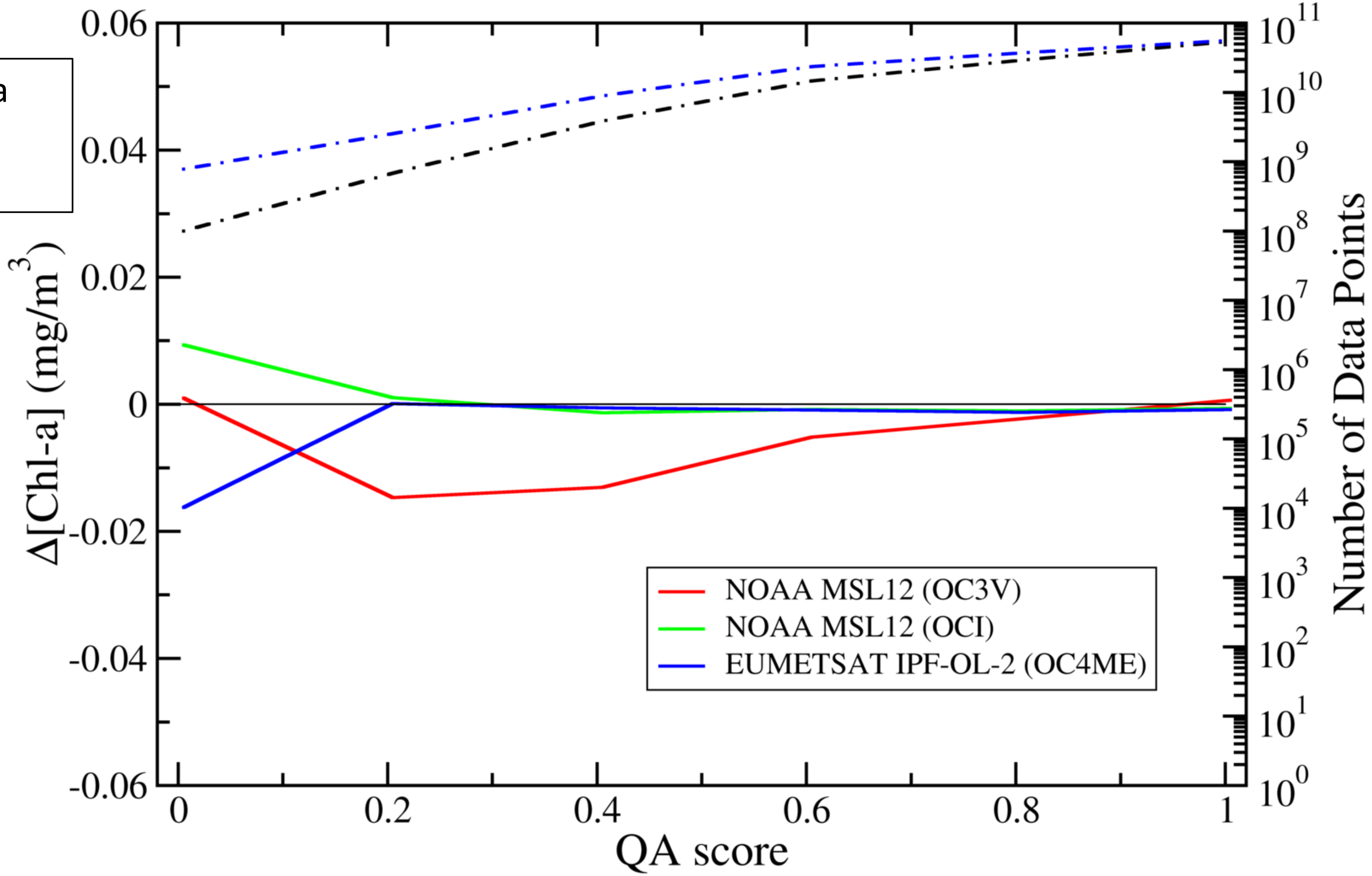
QA score



Results: Intermediate Retrieval Parameters

Effect on Chl-a (QA score)

Median of Chl-a anomalies used here

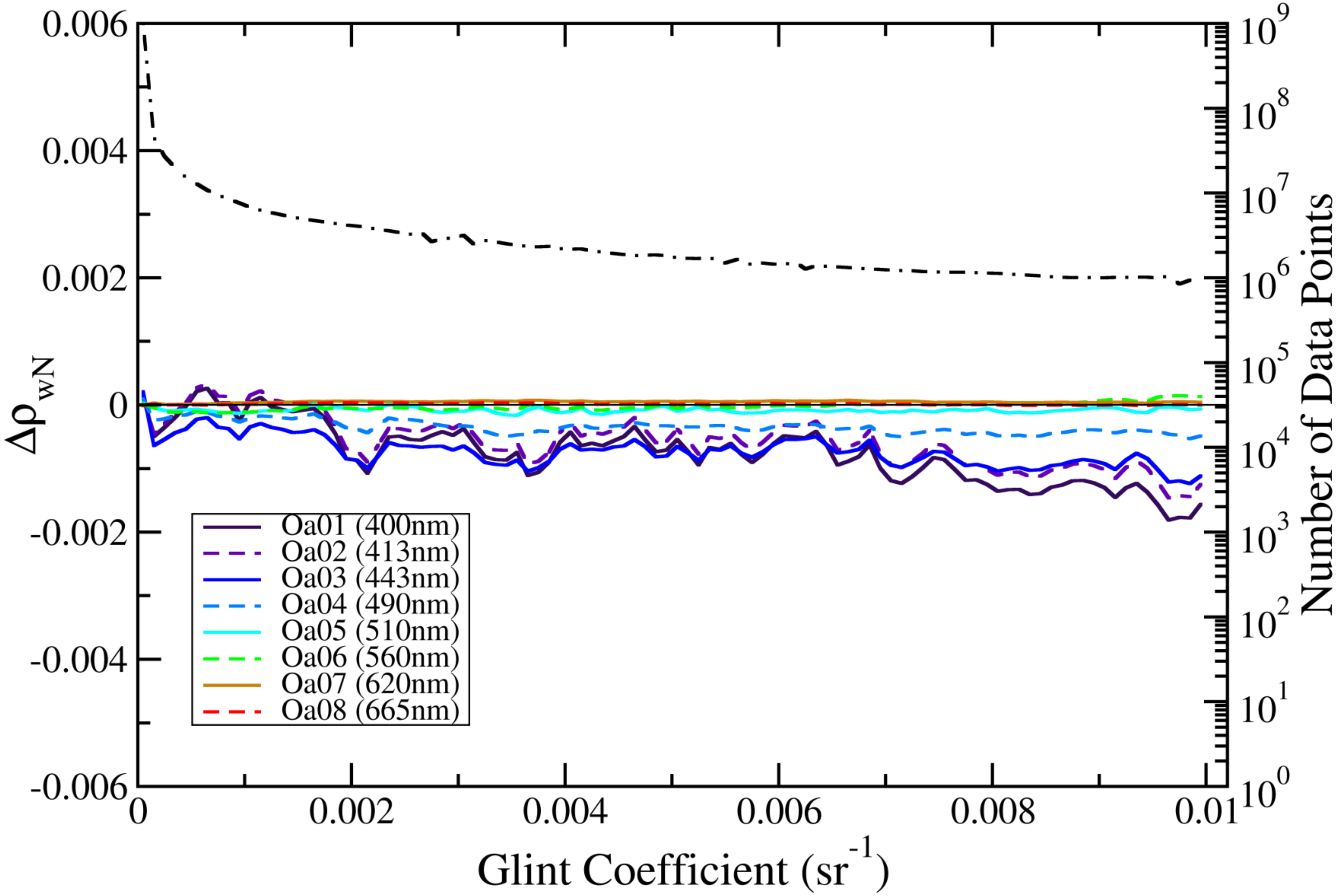


No significant deviations w/r to:

- Sample Number
- Solar-Zenith Angle
- Glint Coefficient

Results: Effect of BRDF correction

NOAA MSL12 without BRDF correction applied
[4 days of data (Jan 1, Apr 1, Jul 1, Oct 1, 2019)]



Switch to slight underestimate of $\Delta\rho_{wN}(\lambda)$ in moderate glint conditions

Conclusions

1. Both NOAA MSL12 and EUMETSAT IPF-OL-2 show small deviations that are generally within the acceptable accuracy range
2. Slightly uneven reflectance across OLCI camera boundaries
3. Elevated $\Delta\rho_{wN}(\lambda)$ spectra for large wind speeds (> 10 m/s)
4. EUMETSAT IPF-OL-2 retrievals underestimate reflectances for low solar-zenith angles, and medium to high sun glint conditions – most likely at least to some extent due to missing BRDF correction
5. Both data sets show poor retrieval consistency for high solar zenith angles over 70°
6. Most systematic deviations in reflectance spectra translate into very small deviations in Chl-a results

K. Mikelsons, M. Wang, E. Kwiatkowska, L. Jiang, D. Dessailly, and J.I. Gossn, "Statistical evaluation of Sentinel-3 OLCI ocean color data retrievals", *IEEE Trans. Geosci. Remote Sens.*, **60**, 4212119 (2022). 10.1109/TGRS.2022.3226158