Long-term operation (16 years) of the *AERONET-OC* site *Pålgrunden* for the validation of multi-mission water colour satellite data products

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Background

The NASA AERONET network was established about 30 years ago. It is a global network for climate change research, consisting of autonomous ground-based monitoring stations **(Fig. 1)** that measure aerosol optical properties, such as Aerosol optical thickness and the Ångström exponent with CIMEL sun-photometers (Cimel Electronique, France). The data are transmitted to NASA via satellite, internet and GSM links and are available on the NASA AERONET web site: https://aeronet.gsfc.nasa.gov

AERONET - Ocean Color (AERONET-OC) is a subnetwork of AERONET whose radiometers measure the radiance emerging from the sea or inland waters (i.e., the water-leaving radiance) for satellite validation. The network consists of CE-318 (9-channel) and CE-318 (12-channel) sun-photometers (Cimel Electronique, Paris, France) operated on offshore platforms such as lighthouses, oil rigs and oceanographic towers **(Fig. 2).** AERONET-OC automated measurements comprise sky, sun and water surface to ensure radiometric data collected at specific viewing angles. The concept was verified during late 1990's (Hooker et al. 2000), consolidated (Zibordi et al . 2002) and successively implemented during early 2000's (Zibordi et al. 2006a).

Standardization and data levels

AERONET-OC is based on standardization of instruments, calibration, processing and distribution.

All calibrations, measurements and calculations are done applying the same protocols and methods, thus providing site-independent data of high quality. Annual pre- and post-calibrations are performed at Goddard Space Flight Center of the National Aeronautics and Space Administration. Normalized water-leaving radiances are provided at three levels (Zibordi et al., 2022):

Level 1.0 is the rawest quality of data and is provided close to real-time on the AERONET-OC web site. **Level 1.5** data, also accessible in almost real-time, includes automatic data screening (not affected by cloud, heavy wave or superstructure perturbations). The final data level, the so-called **Level 2.0**, implies the existence of pre- and post-field instrument calibrations and the application of strict automated quality checks (Zibordi et al., 2022).

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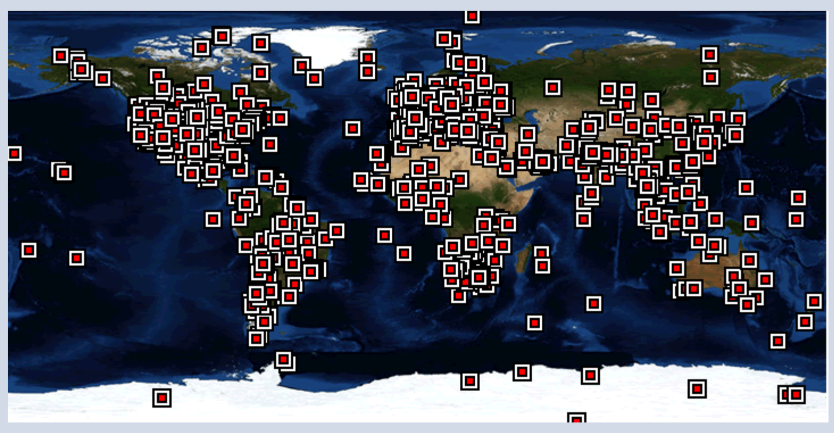

Fig. 1: The NASA AERONET currently consist of about 600 stations. The stations measure aerosol optical properties across the globe. © NASA.

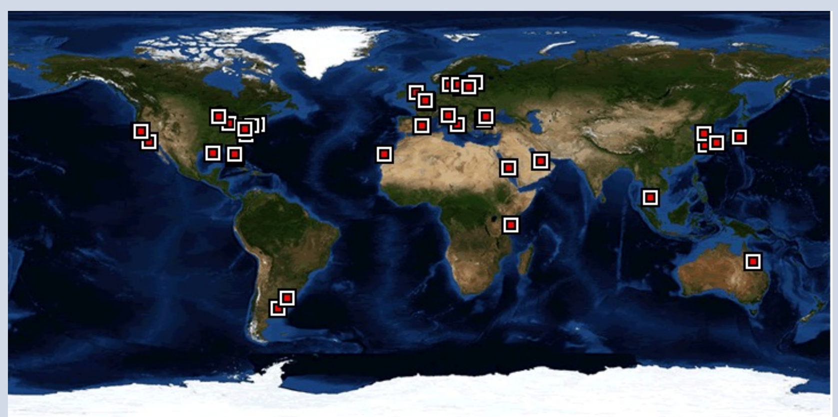

Fig. 2: NASA's AERONET-OC network currently consist of about 40 stations, and it is still expanding. © NASA.

Optical Properties of Lake Vänern

- The optical properties in Vänern are dominated by a_{CDOM} **(Fig 3)** while turbidity in the open lake is relatively low (Philipson, 2016).
- In spring, diatoms dominate while in summer the phytoplankton consists of a mix of cyanobacteria, cryptomonads, chrysophytes and dinoflagellates (https://miljodata.slu.se).
- The RS reflectance derived from MODIS was validated against AERONET-OC **(Fig. 4).**
- $R_{RS}(667)$ shows periodical changes between 2002 and 2021 with clear minima occurring between 2010-2013 **(Fig. 5).**

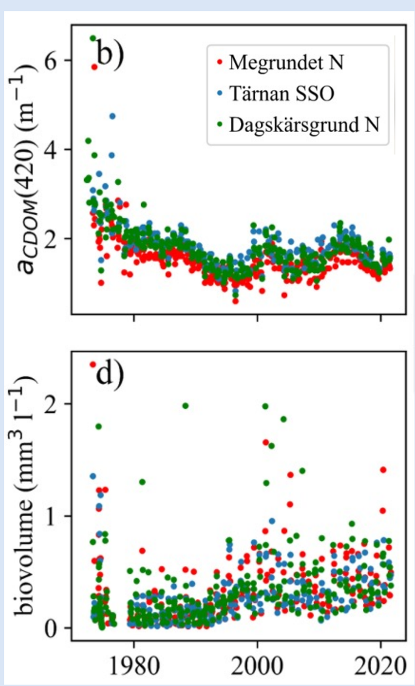

Fig. 3 (left): Variations of a_{CDOM} and biovolume in lake Vänern.

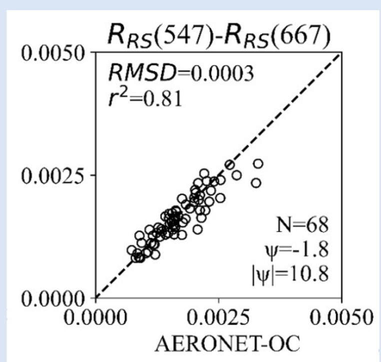

Fig. 4: Validation of MODIS reflectance difference, $R_{RS}(547)$ - $R_{RS}(667)$, against AERONET-OC data.

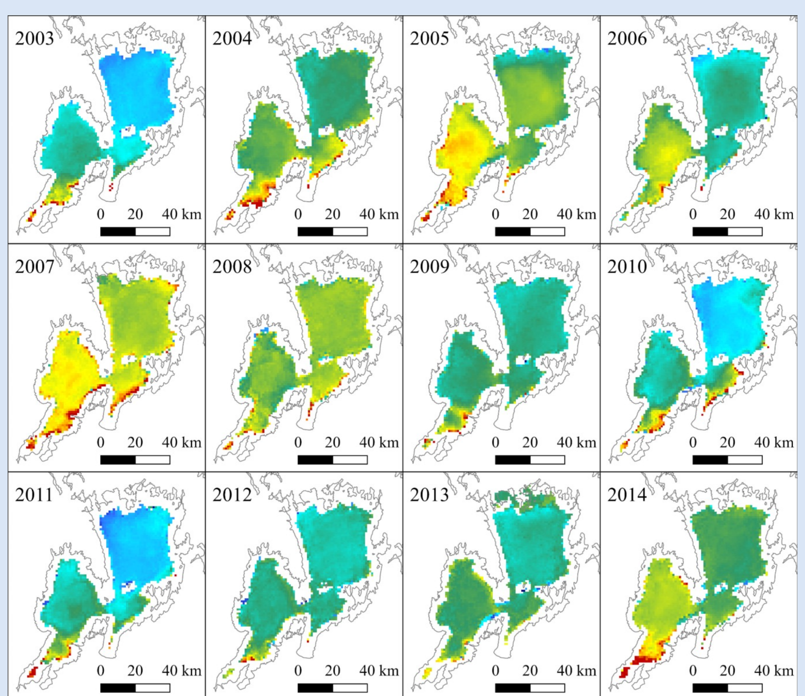

Fig. 5 (left): Changes in $R_{RS}(667)$ in Lake Vänern during 2004-2021. $R_{RS}(\lambda)$ assessed against *in situ* $R_{RS}(\lambda)$ from Pålgrunden showed good agreement at several spectral bands. Significant correlations were observed between $R_{RS}(\lambda)$ and turbidity, and also between $R_{RS}(\lambda)$ and total biovolume (Cazzaniga et al, 2023).

Acknowledgements

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AERONET-OC Pålgrunden

Originally, the CIMEL CE-318 sun photometer (#194, Stockholm University) was operated in northern Gotland (1999-2004) as part of AERONET (AERONET-OC site: **Gotland).** The station was then moved to Norrköping (station name: **SMHI**) where it was operated from 2004-2006. Through joint efforts between Stockholm University (SU), Strömbeck Consulting (SC) and the Joint Research Centre (JRC) in Ispra, Italy, the CIMEL CE-318 was converted to an AERONET-OC instrument and was deployed at Pålgrunden Light House **(Fig. 6)** in lake Vänern (AERONET-OC site: **Palgrunden**). In 2019 the sun photometer was replaced by a CIMEL 318-T (JRC).

Fig. 6: Vänern is the largest lake in the EU. It has a maximum depth of 106 m and its average depth is 28 m. Pålgrunden light house has been operated since 1958. The light house is not open to the public, and is managed and serviced by the Swedish National Maritime Administration. The CIMEL is deployed ca. 5 m above lake level and 49 m above sea level. **Photos:** Niklas Strömbeck. **Map and MERIS Chl-a image:** Philipson *et al*., 2016.

Advantages of the new CIMEL 318-T

- Wavelength bands matching those of OLCI Sentinel-3.
- More sensitive optics allowing for more accurate measurements.
- Potential for programming a higher number of measurements per hour (from 2 per hour allowed by the former CE-318 up to at least 6 per hour with the recent CE-318T).
- Faster microprocessor and larger memory.
- Built-in GPS for accurate position and time determination.
- Data transmission using GSM (instead of satellite)
- Completely new and more developed user interface.

Relevance of AERONET-OC Pålgrunden

- Pålgrunden is one of the few high latitude stations deployed in freshwater environments and one of the few high CDOM stations.
- It contributes substantially to the validation of ocean colour processors in Case 2 and freshwater environments **(Fig. 7).**

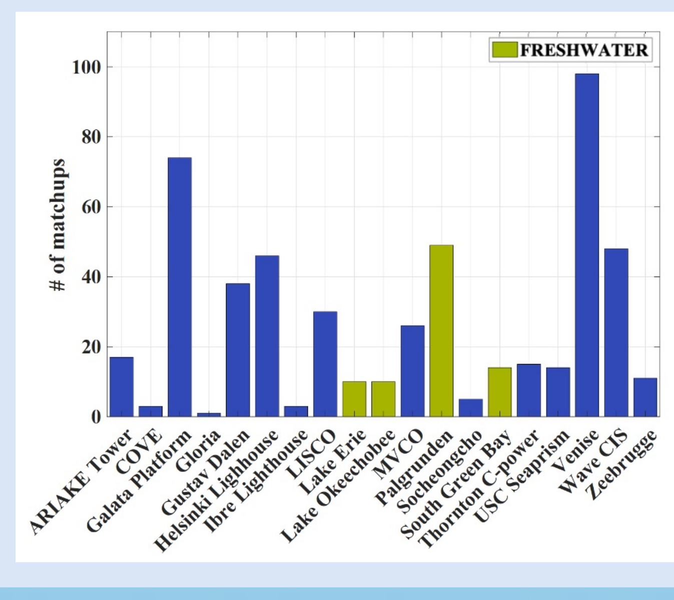

Fig. 7: Distribution of valid AERONET-OC match-up data for the POLYMER atmospheric correction processor. Note that 17% of the data originate from freshwater environments, and more than 50% are from Palgrunden (Pahlevan et al 2021).