Carbon dioxide fluxes estimation merging satellite and in-situ data in the Mediterranean Sea

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IDEAS-QA4EO Cal/Val Workshop#4

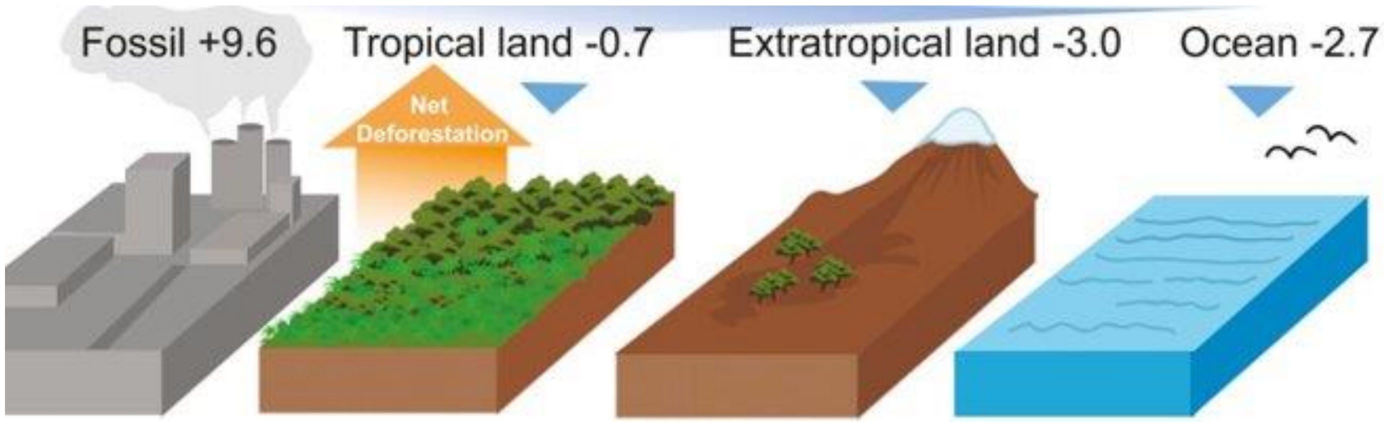
28th February - 2nd March 2023 Potsdam (Germany)

Outline:

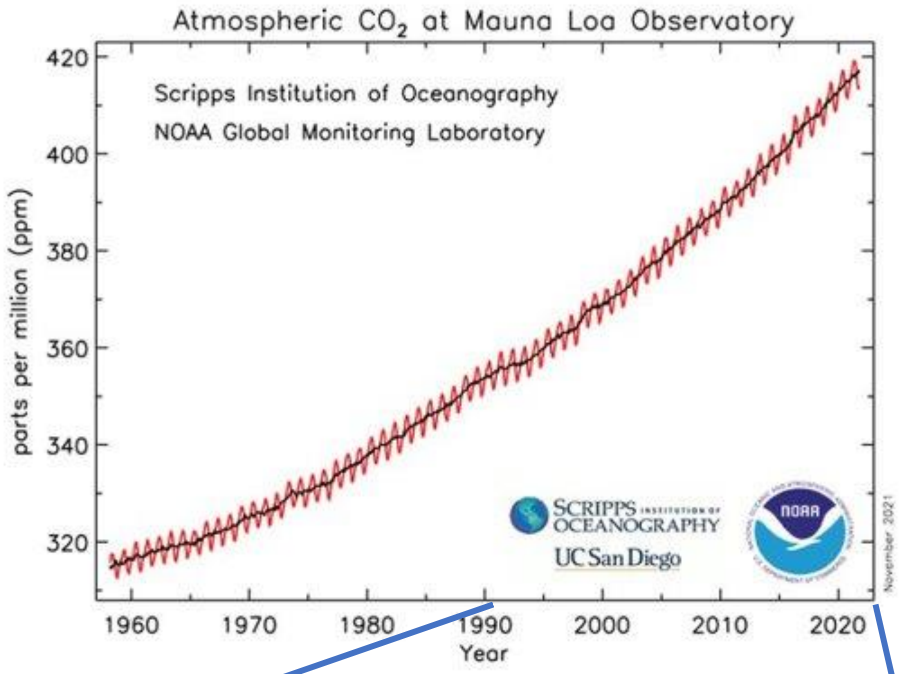
1. **Carbon cycle**
2. The Lampedusa site
3. Preliminary results
4. Next steps

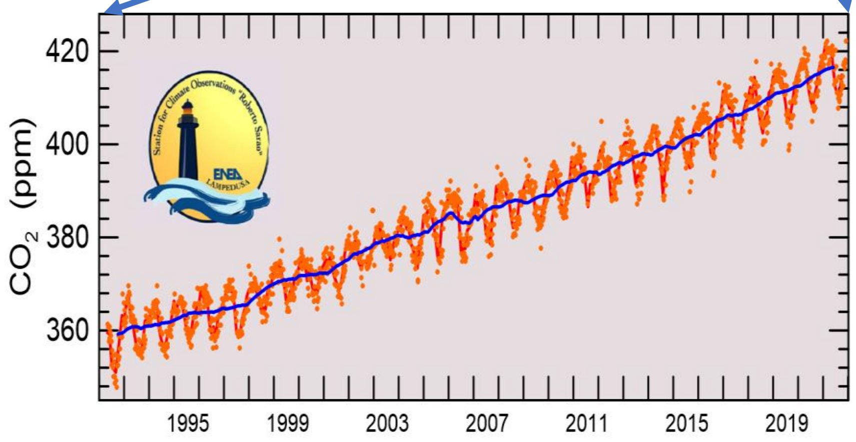
Carbon Cycle – Brief overview

Atmospheric CO_2 concentration increased from about 280 ppm in pre-industrial times to the actual value of about 420 ppm due to antropogenic activities



Atmospheric increase 4.7 Pg/y



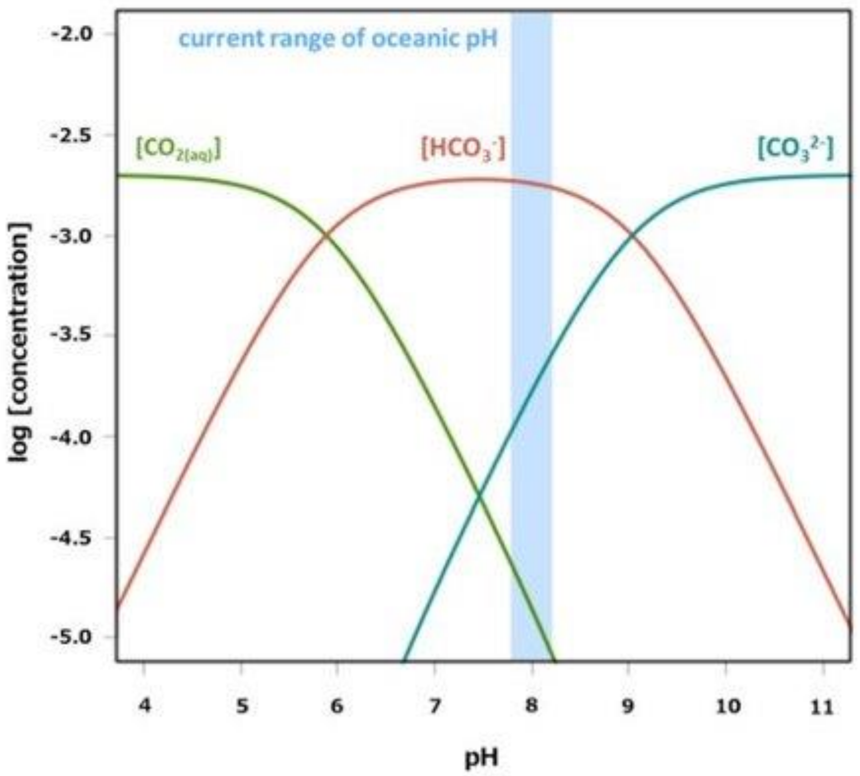


Earth system feedbacks lead to sinks that absorb about half of anthropogenic emissions

Sellers, P. J. et al., Observing carbon cycle–climate feedbacks from space. *Proceedings of the National Academy of Sciences of the United States of America*. National Academy of Sciences. https://doi.org/10.1073pnas.1716613115, 2018

Carbon Cycle – Brief overview

- Ocean interaction with CO_2 has a great spatio-temporal variability not fully characterised (net effect is sink)
- CO_2 absorption leads to the acidification of ocean waters which can trigger negative feedbacks on absorption efficency
- Climate feedbacks are unknown
- Lack of continuous insitu measurements
- Ocean CO_2 absorption efficiency is strongly related with climate evolution



Monitoring atmosphere-ocean exchanges is crucial

Heinze, C. et al., The ocean carbon sink - Impacts, vulnerabilities and challenges. *Earth System Dynamics*. Copernicus GmbH. https://doi.org/10.5194/esd-6-327-2015, 2015

Carbon Cycle – atmosphere-ocean fluxes

$$F = K_{wa}\, KH\, (\Delta pCO_2)_{sea\text{-}atm}$$

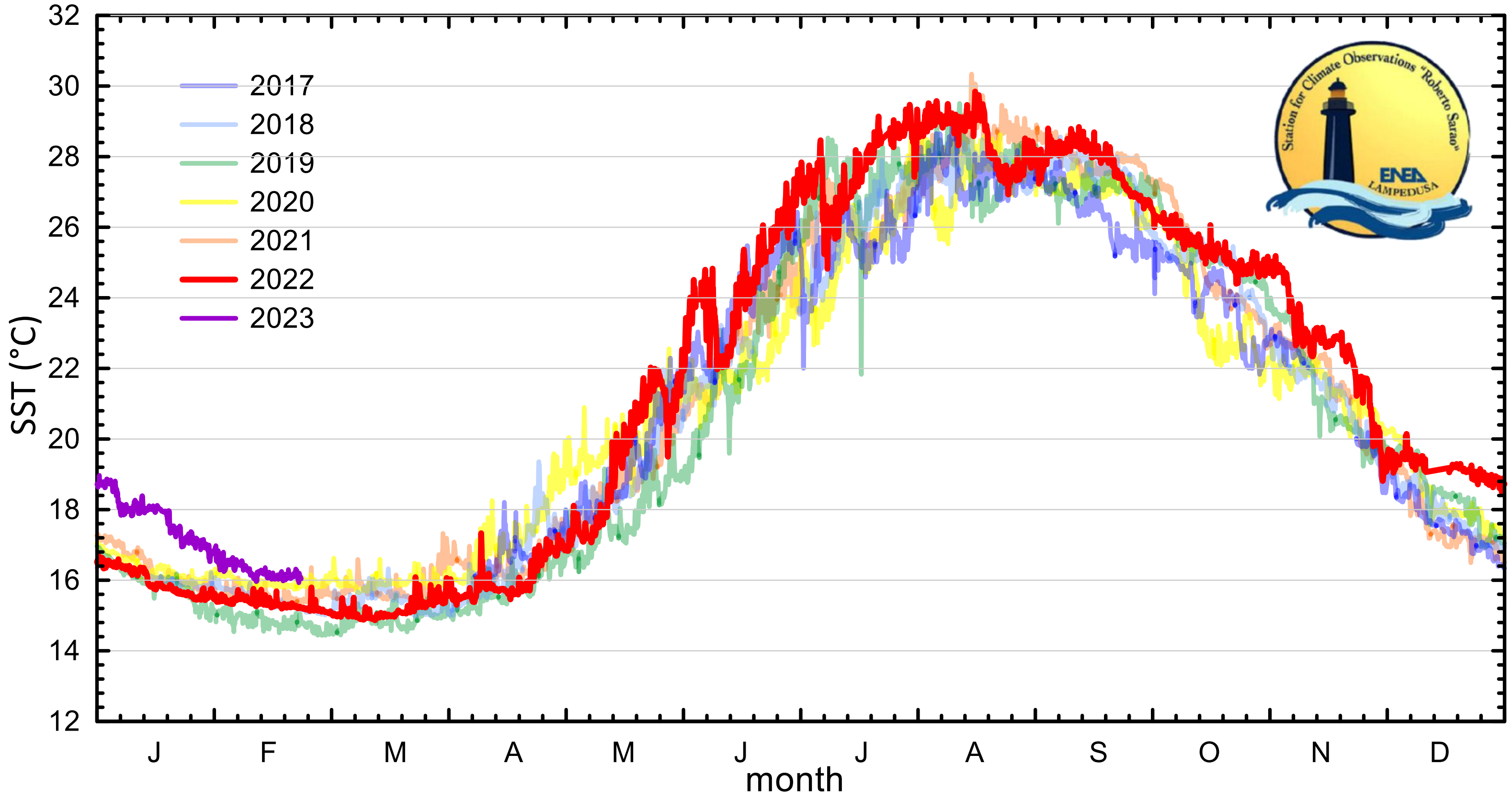
Where:

- $K_{wa} = 0.251 \langle U^2 \rangle (Sc/660)^{-0.5}$ is the Gas Transfer Velocity for $U < 15$ **m/s**
- $Sc = A + B*SST + C*SST^2 + D*SST^3 + E*SST^4$ is the Schmidt Number
- $\ln(KH) = A_1 + A_2*(100/SST) + A_3*\ln(SST/100) + SSS*[(B_1 + B_2*(SST/100) + B_3*(SST/100)^2]$ is the gas solubility
- **Sea pCO_2** can be measured or derived
- **Air pCO_2** can be measured or derived

Wanninkhof, R., Relationship between wind speed and gas exchange over the ocean revisited, *Limnol. Oceanogr. Methods*, 12, doi:10.4319/lom.2014.12.351, 2014

Carbon Cycle – The "Mediterranean problem"

- Climate hotspot
- Semi-enclosed basin under environmental stress
- Few carbon in-situ measurements
- Few studies on basin-wide carbon cycle



Outline:

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2. **The Lampedusa site**

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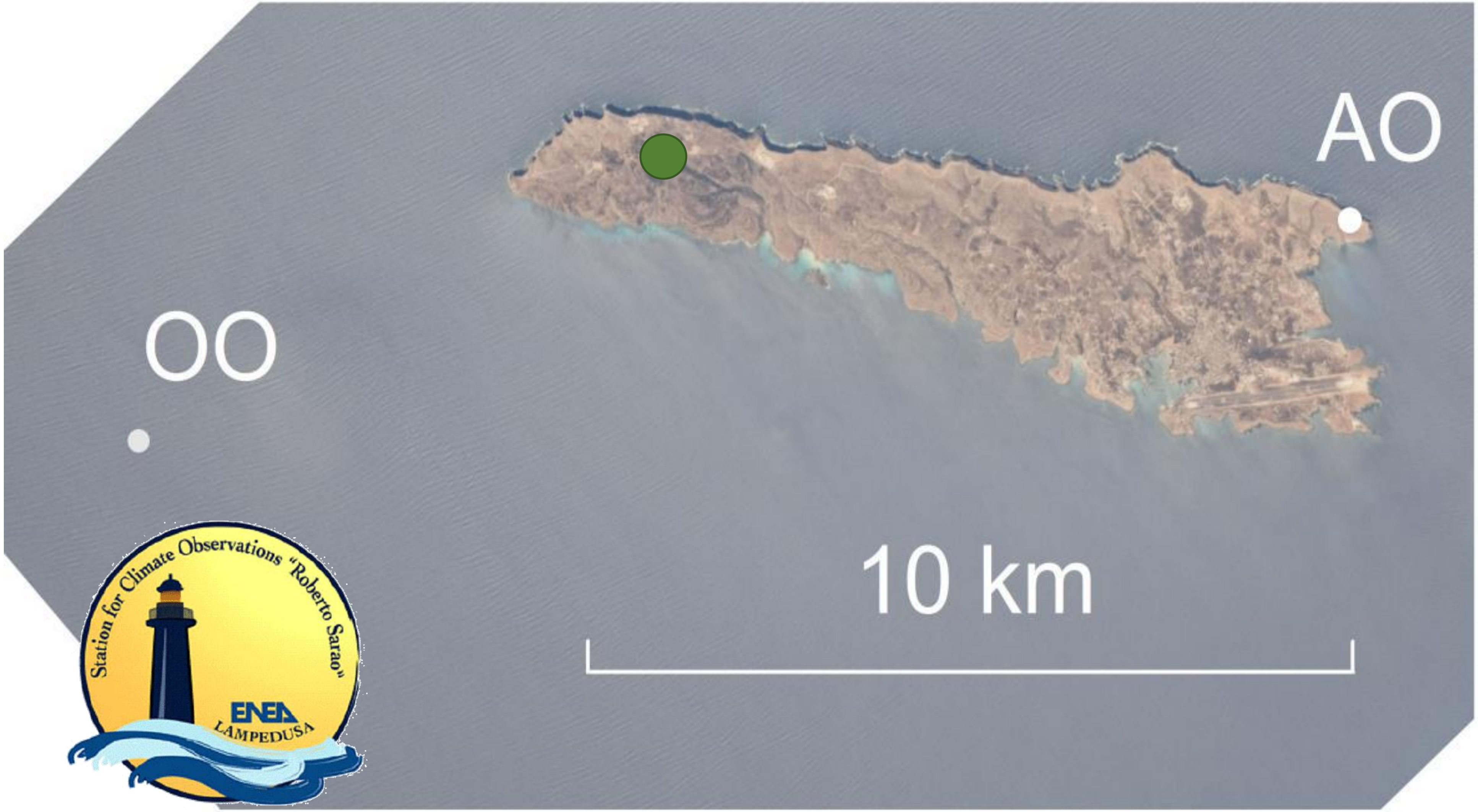
LAMPEDUSA ISLAND
MODIS Aqua – 11 Apr 2020

Main features

- 10 km wide and 20 km^2 island
- More than 130 km from continental land
- Simple orography
- Small local pollution sources
- Frequent cloud-free conditions

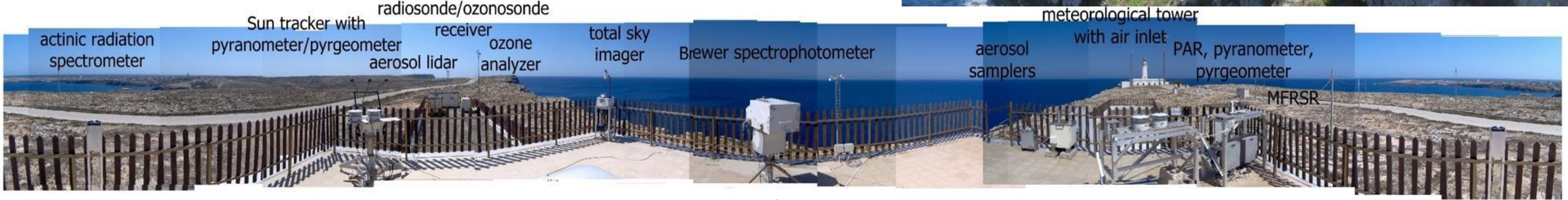
Main features

- **Far from large pollution sources**
- **Negligible interaction with mesoscale dynamics**
- **Representative of background conditions**
- **Open ocean site**
- **Support to satellite data**



Picture ISS 024-E-10246, Earth Science and Remote Sensing Unit at NASA Johnson Space Center

di Sarra et al., 2019



35.52°N, 12.63°E

ICOS | Integrated Carbon Observation System

ACTRIS Exploring the Atmosphere

emso ERIC EUROPEAN RESEARCH INFRASTRUCTURE CONSORTIUM

GLOBAL ATMOSPHERE WATCH

Atmospheric observatory instrument list

- Meteorological station [air pressure, temperature, humidity, wind direction and velocity, precipitation].
- Vaisala radiosondes [temperature, pressure, humidity, wind, ozone vertical profiles].
- Hat-Pro Microwave Radiometer [temperature and water vapor vertical profiles, liquid water content].
- Thies Clima LPM disdrometer [precipitation].
- Ott Hydromet rain gauge [precipitation].

- Cavity ring-down spectroscopy (CRDS) analyzer (CO_2, CO, CH_4).
- ***CRDS (N_2O)***
- ***CRDS (^{13}C in CO_2 and CH_4)***
- ENEA gas sampling unit.
- NOAA gas sampling unit [weekly analyses of CO_2, CH_4, SF_6, CO, ^{13}C, H_2, ^{18}O, made at NOAA, USA].
- ***ICOS sampling units for flasks and $^{14}CO_2$.***
- ***Heidelberg sampling for $^{14}CO_2$.***
- Ozone UV analyzer [ozone concentration, CNR].

- Aerosol lidar [together with University of Rome; aerosol backscattering and depolarization profiles].
- Ceilometer [Lufft Nimbus 15k; aerosol vertical distribution, cloud altitude]
- Visible Multi Filter Rotating Shadowband Radiometer [MFRSR; aerosol optical depth at several wavelengths, diffuse-to-direct irradiance ratio, column water vapor, aerosol single scattering albedo].
- PM-10/TSP aerosol sampler [daily chemical analyses performed at the University of Florence].
- Cimel sun photometer [aerosol optical depth and optical properties].
- Middleton sun photometer [aerosol optical depth, column water vapour].
- Aethalometer Magee AE33 [concentrazione di black carbon].
- Wet/dry deposition collector [DOC/DOM, metals, chemical composition; CNR and Univ. of Florence]

Atmospheric observatory instrument list

- Brewer MK III spectrophotometer [total ozone, spectral UV, aerosol optical depth].
- Precision Spectral Pyranometer/CMP21 [downward and upward shortwave irradiance; albedo].
- Precision Infrared Pyranometer/CGR4 [downward and upward longwave irradiance].
- Shaded Precision Spectral Pyranometer [diffuse downward shortwave irradiance].
- Photosynthetic radiation radiometer [downward photosynthetically active radiation].
- Actinic radiation spectrometer [actinic radiation spectra, photo dissociation rates].
- UV-Multi Filter Rotating Shadowband Radiometer [MFRSR; aerosol optical depth at several wavelengths, diffuse-to-direct irradiance ratio, UV irradiance].
- Satlantic HyperOCR and Trios Ramses irradiance spectrometers [spectral downward irradiance]

- Total sky imager [cloud cover].
- IR camera [cloud base height].
- *Doppler Cloud radar [cloud properties].*

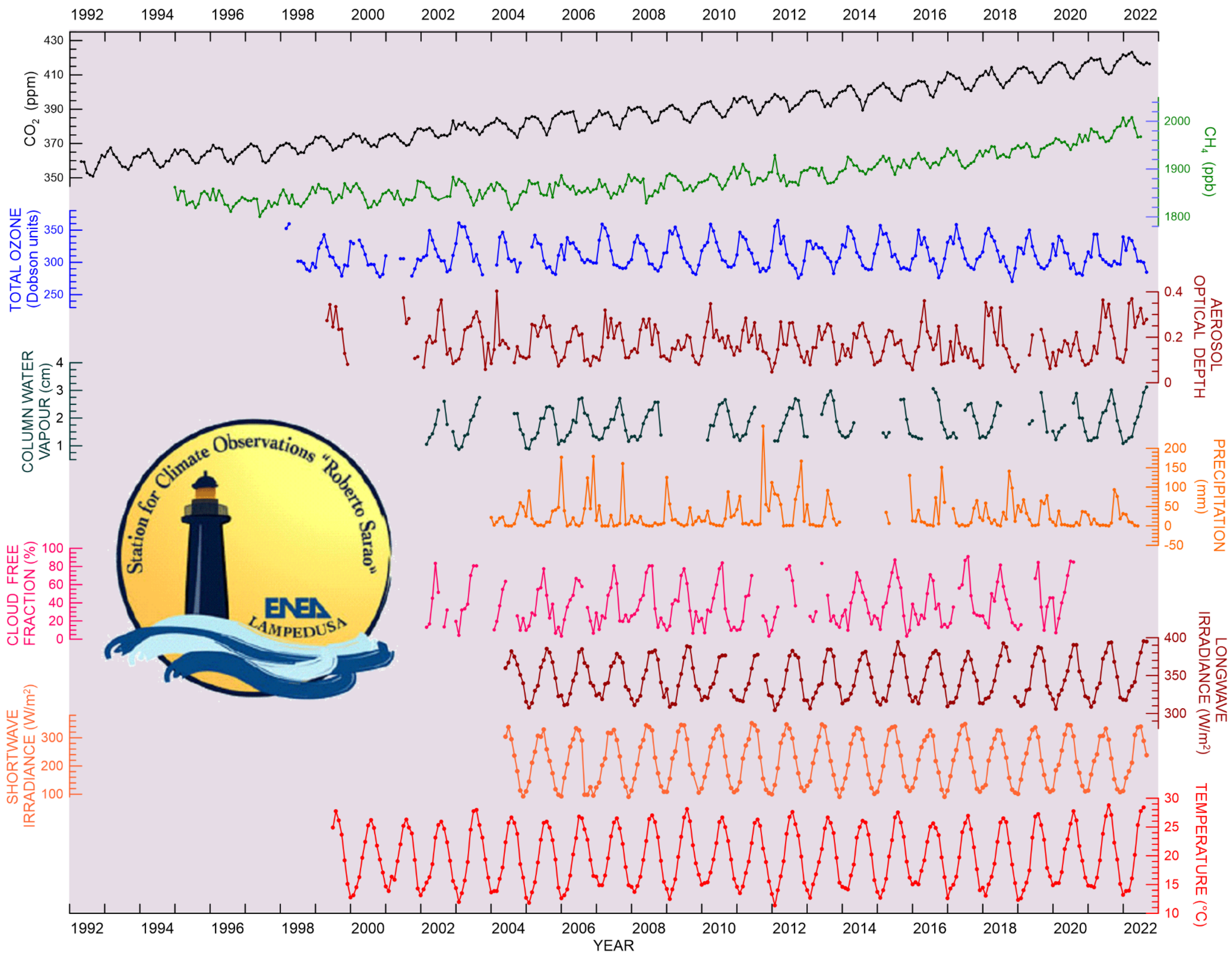
- ***^{222}Rn analyzer***

- GPS antenna [ionospheric scintillations; INGV].
- Seismometer [INGV].
- Investigation on sustainable energy sources.

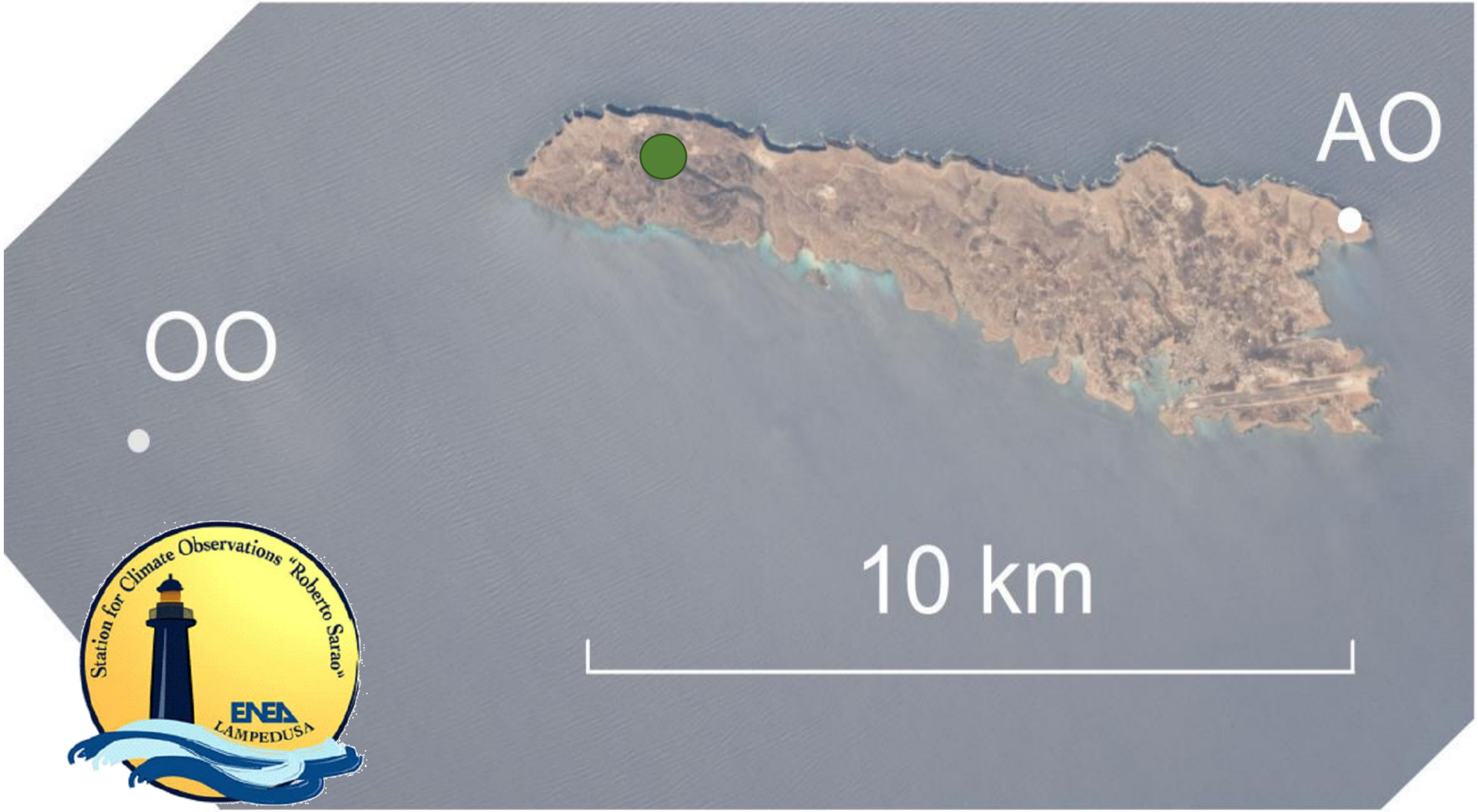
World Meteorological Organization
Weather · Climate · Water

GLOBAL ATMOSPHERE WATCH

NOAA Cooperative Air Sampling Network
AERONET; MWRNet
ICOS, ACTRIS, EMSO

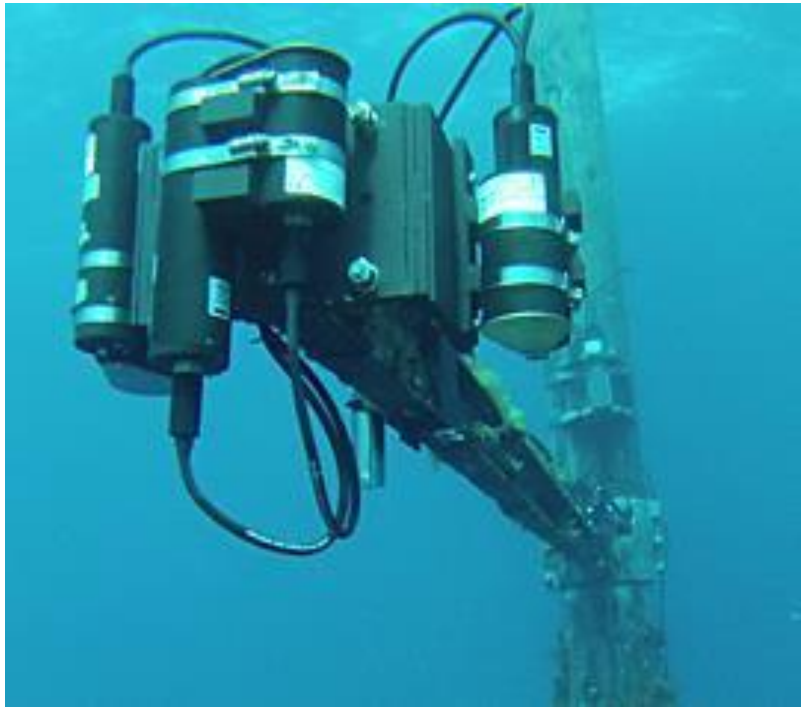


CO_2 (ppm)
CH_4 (ppb)
TOTAL OZONE (Dobson units)
AEROSOL OPTICAL DEPTH
COLUMN WATER VAPOUR (cm)
PRECIPITATION (mm)
CLOUD FREE FRACTION (%)
LONGWAVE IRRADIANCE (W/m²)
SHORTWAVE IRRADIANCE (W/m²)
TEMPERATURE (°C)
YEAR
Station for Climate Observations "Roberto Sarao"
ENEA
LAMPEDUSA

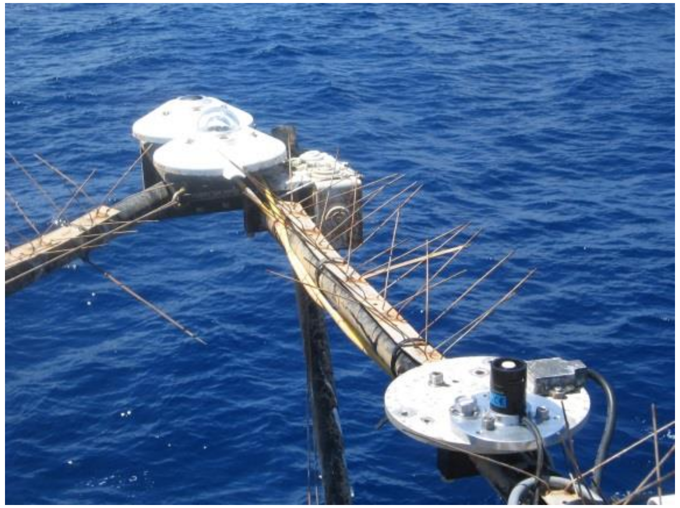


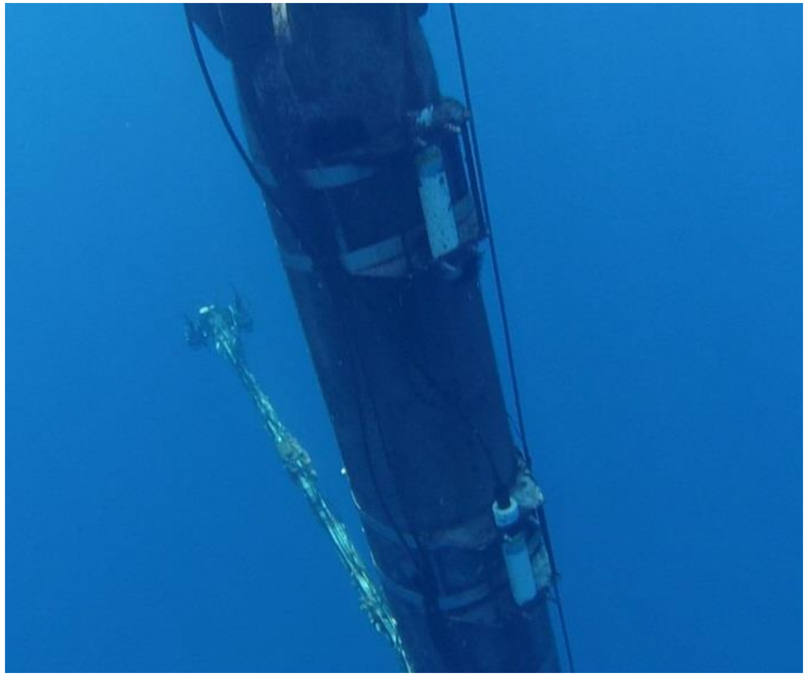
Picture ISS 024-E-10246, Earth Science and Remote Sensing Unit at NASA Johnson Space Center

di Sarra et al., 2019



Rotation < 5°
Pitch/roll < 10°
Bottom at 74 m





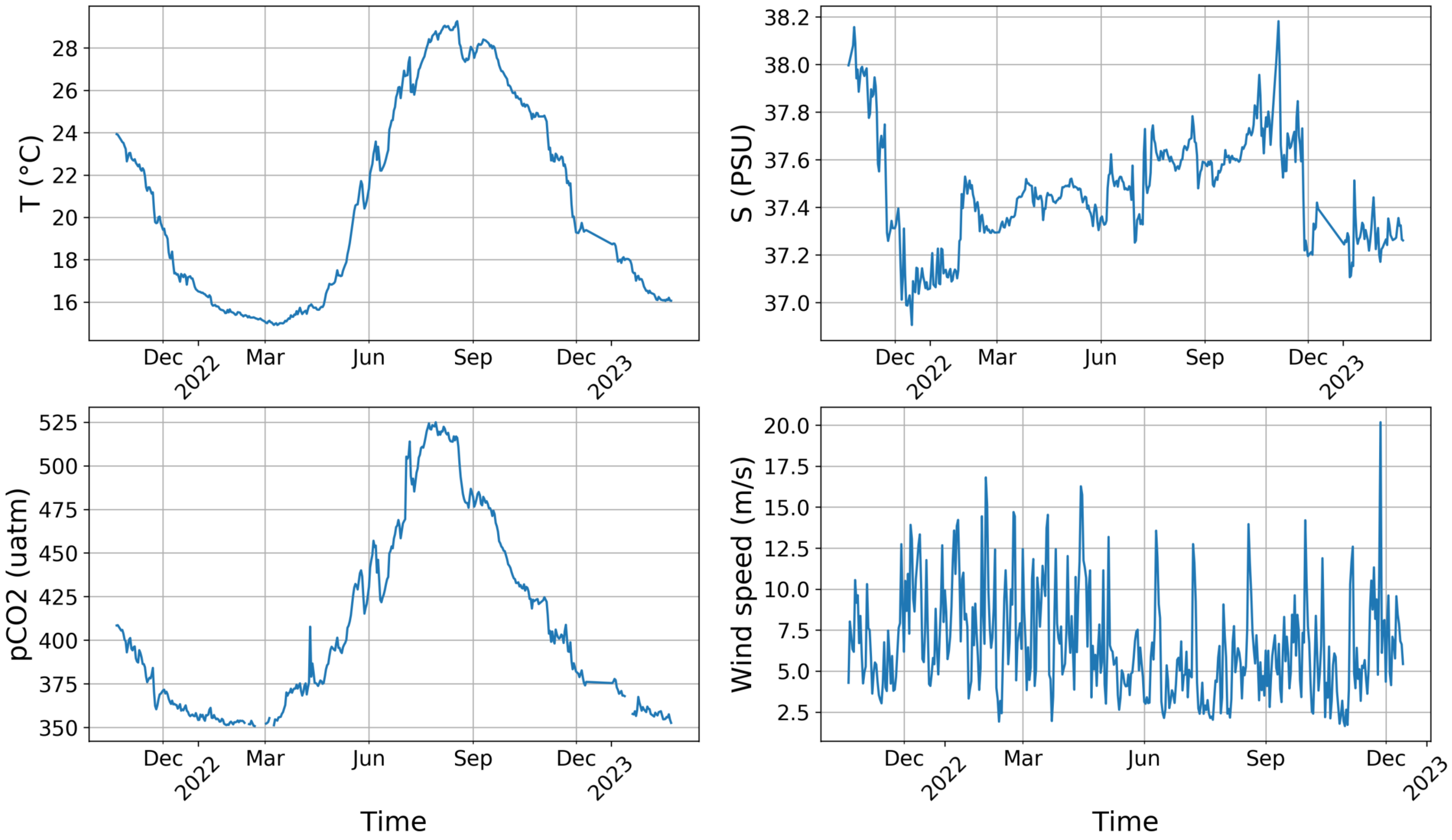
35.49°N, 12.47°E

Oceanographic observatory instrument list

- Meteorological station [air pressure, temperature, humidity]
- Gill Windsonic anemometer [wind speed and direction]
- CMP21 pyranometer [downward shortwave irradiance]
- CGR4 pyrgeometer [downward longwave irradiance]
- Photosynthetic radiation radiometer [downward photosynthetically active radiation]
- Electronic level [radiometers' attitude]
- Satlantic Hyper-OCR [spectral downwelling irradiance; CNR]

- Seabird SBE39P at 1 m depth [ocean pressure and temperature]
- Seabird SBE39P at 2 m depth [ocean pressure and temperature]
- 2 x Satlantic Hyper-OCR at 2.5 m depth (downwelling and upwelling spectral irradiance; CNR]
- Seabird SBE50 at 2.5 and 6 m depth [pressure; CNR]
- Seabird PAR sensor at 2.5 m [PAR irradiance]
- **Seabird EcoTriplet at 5 m depth [backscattering, chlorophyll, F-DOM]**
- **ProOceanus Pro CO2 V at 5 m depth [pCO_2]**
- **Seabird SBE16 at 5 m depth [temperature, salinity, pressure, dissolved oxygen]**
- **Seabird SeaFET at 5 m depth [pH]**
- Satlantic HyperOCR at 6 m depth (downwelling spectral irradiance; CNR]
- Satlantic HyperOCRS at 6 m depth [upwelling spectral radiance; CNR]
- Seabird SBE50 at 6 m depth [pressure; CNR]
- Seabird SBE37 at 18 m depth [ocean pressure, temperature, salinity, dissolved oxygen]
- Seabird EcoTriplet at 17 m depth [backscattering, chlorophyll, F-DOM; CNR]
- 40 m thermistor chain [temperature at 12 depths]
- *Acoustic Doppler Current Profiler at 42 m [current in the 0-40 m depth range]*


200


T (°C)
28
26
24
22
20
18
16
Dec
2022
Mar
Jun
Sep
Dec
2023
S (PSU)
38.2
38.0
37.8
37.6
37.4
37.2
37.0
pCO2 (uatm)
525
500
475
450
425
400
375
350
Time
Wind speed (m/s)
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5

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Carbon Cycle – atmosphere-ocean fluxes

$$\mathbf{F = K_{wa}\ KH\ (\Delta pCO_2)_{sea\text{-}atm}}$$

Where:

- $K_{wa} = 0.251\ \mathbf{\langle U^2 \rangle}\ (Sc/660)^{-0.5}$ is the Gas Transfer Velocity for **U < 15 m/s**
- $Sc = A + B*\mathbf{SST} + C*\mathbf{SST^2} + D*\mathbf{SST^3} + E*\mathbf{SST^4}$ is the Schmidt Number
- $\ln(KH) = A_1 + A_2*(100/\mathbf{SST}) + A_3*\ln(\mathbf{SST}/100) + \mathbf{SSS}*[(B_1 + B_2*(\mathbf{SST}/100) + B_3*(\mathbf{SST}/100)^2]$ is the gas solubility
- Sea pCO_2 can be measured
- Air pCO_2 can be derived as $0.001*\mathbf{X_{[CO2]}}*(\mathbf{P}\text{-}pH_2O)$ where $\mathbf{X_{[CO2]}}$ is the molar fraction and
- $pH_2O = 1013.25\exp[24.4543 - 67.4509(100/\mathbf{SST}) - 4.8489\ \ln(100/\mathbf{SST}) - 0.000544*\mathbf{SSS}]$

Weiss R. F. and B. A. Price, Nitrous oxide solubility in water and seawater. Mar. Chem. 8:347-359, doi:10. 1016/ 0304- 4203(80)90024-9, 1980

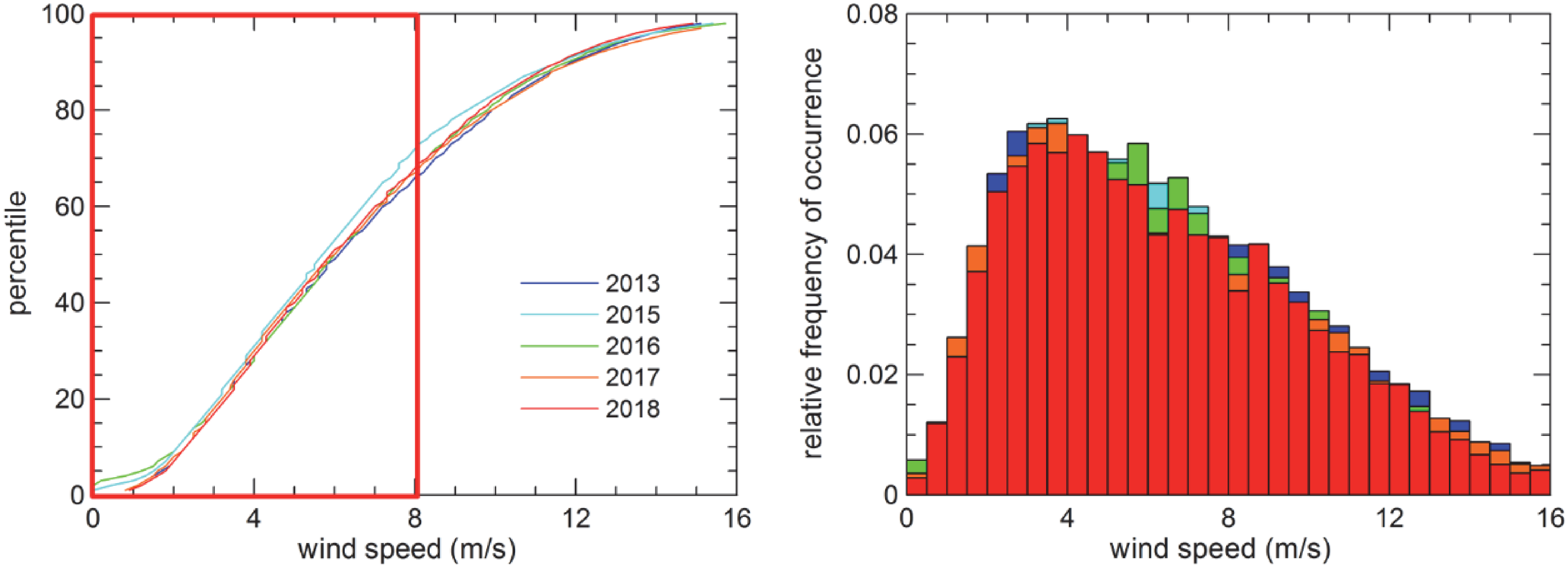
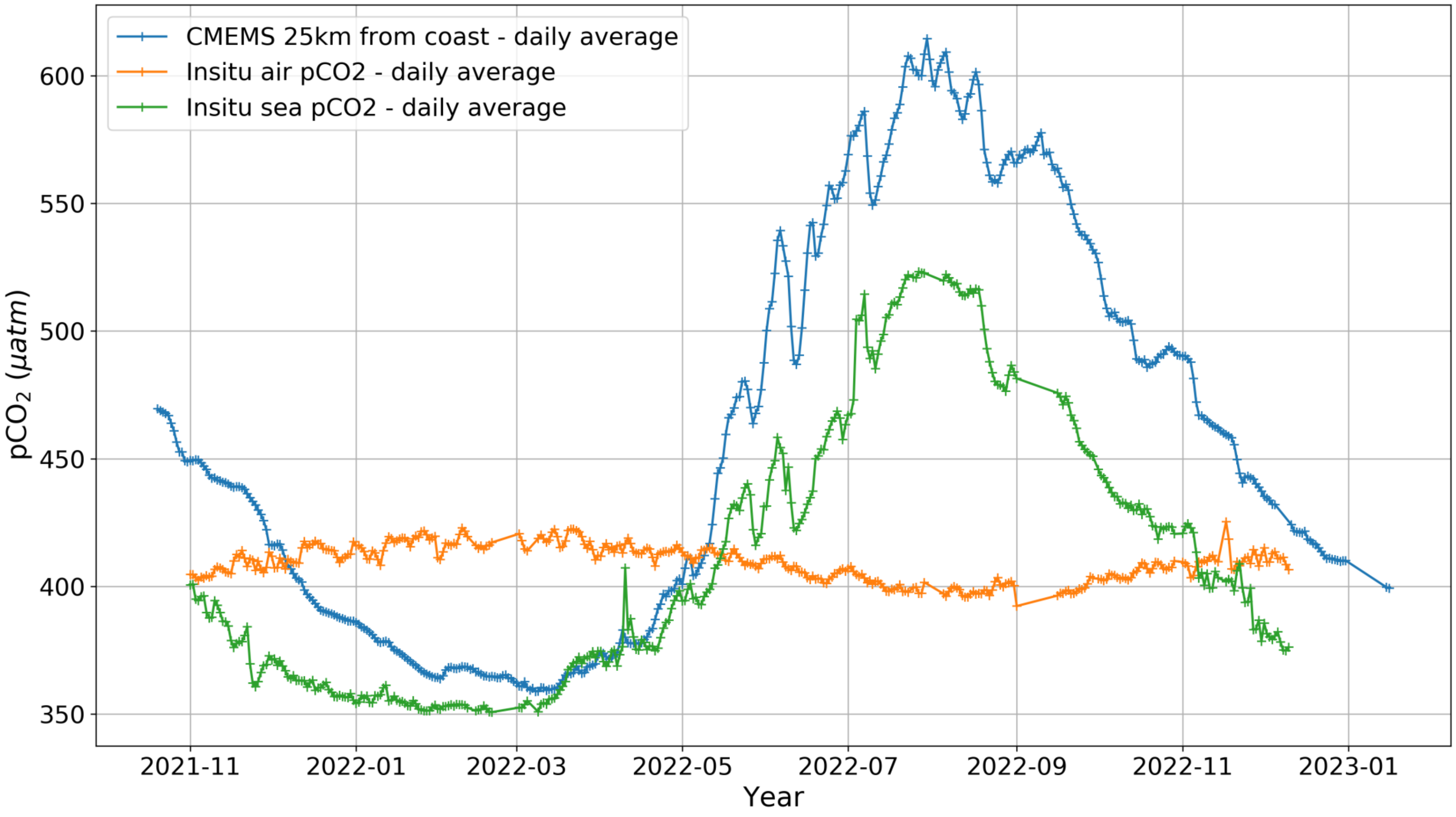
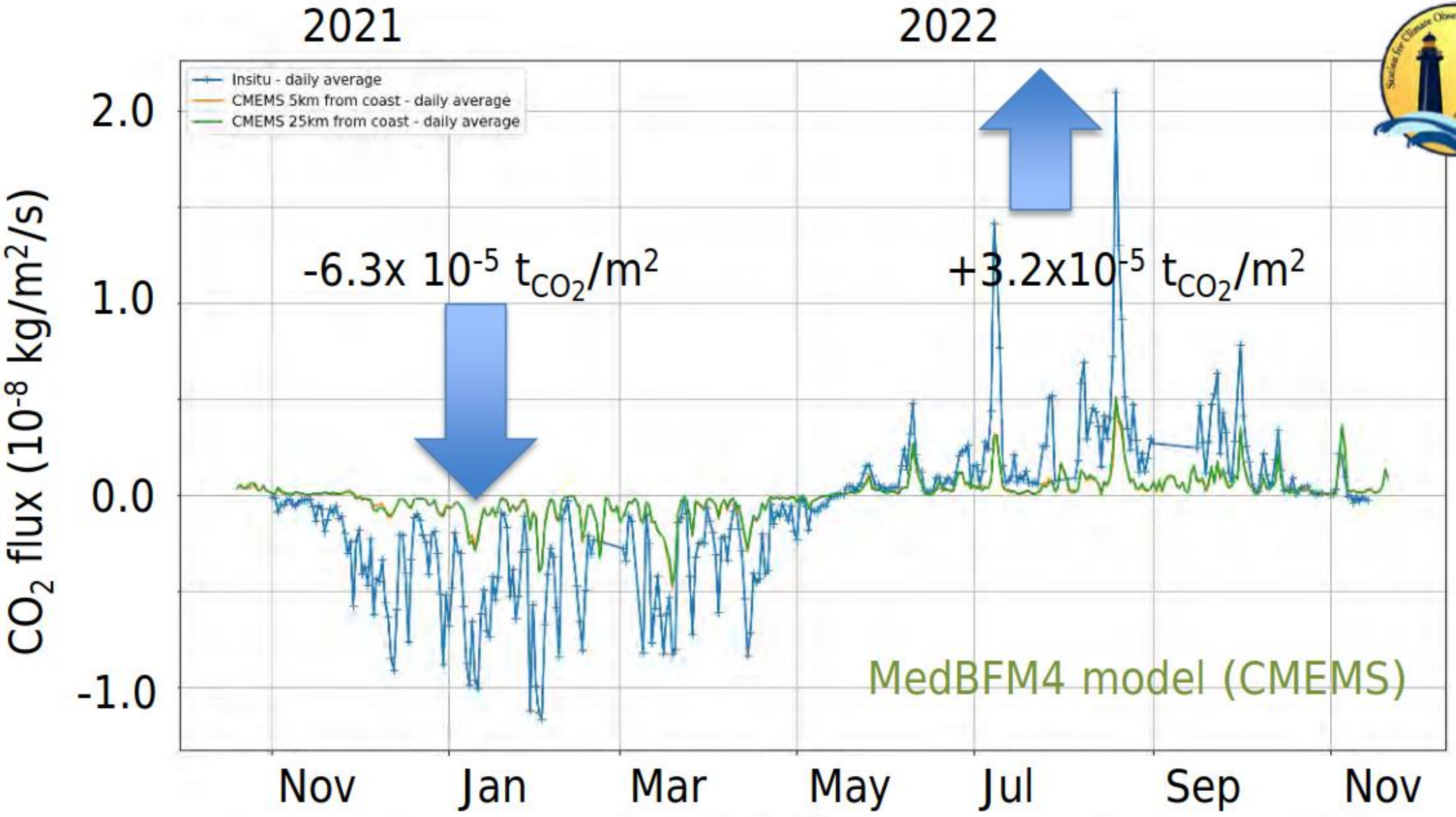


Figure 11. Cumulative distribution (**left**) and histogram of relative occurrence (**right**) of the wind speed at Lampedusa. The different curves/histograms are relative to years 2013, 2015, 2016, 2017, and 2018.

Liberti, G.L. et al., European Radiometry Buoy and Infrastructure (EURYBIA): A Contribution to the Design of the European Copernicus Infrastructure for Ocean Colour System Vicarious Calibration. *Remote Sens. 12*, 1178. https://doi.org/10.3390/rs12071178, 2020



Mediterranean Sea Biogeochemistry Analysis and Forecast -
https://doi.org/10.25423/cmcc/medsea_analysisforecast_bgc_006_014_medbfm3



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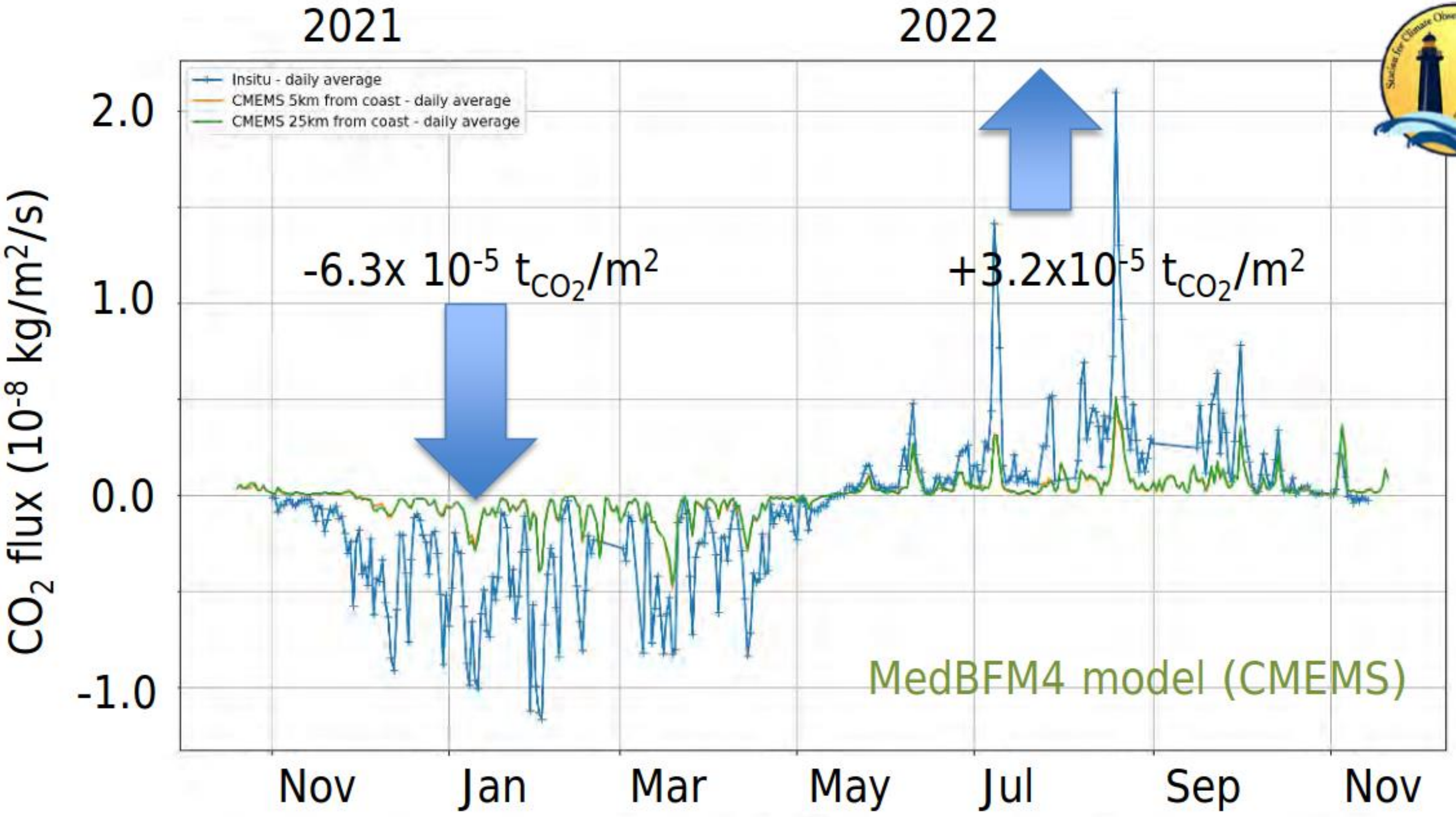

-3.1x10^{-5} t_{CO_2}/m^2

Outline:

1. Carbon cycle

2. Lampedusa site

3. Preliminar results

4. **Next steps**

WP deliveries

1. CO_2 fluxes using in-situ data in Lampedusa

2. Ocean pCO_2 satellite estimation in Lampedusa

3. Comparison of satellite and in situ CO_2 ocean-atmosphere fluxes

WP deliveries

1. CO_2 fluxes using in-situ data in Lampedusa - in progress

- Computation of fluxes using in-situ data
- Analysis of fluxes sensitivity with respect to the used variables
- Analysis of associated uncertainties
- Possible investigation of other flux parameterisation to include U > 15 m/s

WP deliveries

2. **Ocean pCO_2 satellite estimation in Lampedusa**

- Satellite possible proxy vs in-situ data comparison – in progress
    - SST
    - SSS
    - Photosynthetically active radiation (PAR)
    - wind

- Multiparametric regression (literature and/or developed ad hoc)

    - **pCO_2 = A SST + B SSS +C log10[Chla] +D**

Krishna, K.V. et al., A Multiparametric Nonlinear Regression Approach for the Estimation of Global Surface Ocean pCO2 Using Satellite Oceanographic Data, in *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 13, pp. 6220-6235, 2020, doi: 10.1109/JSTARS.2020.3026363., 2020

WP deliveries

3. **CO_2 ocean-atmosphere fluxes with satellite and in-situ data in Lampedusa**

- Space-time consistency of in situ and satellite data
- Optimization of retrieval based on satellite observations
- Verification against in situ data and uncertainty assessment
- Use of satellite data to construct a longer time series

Future developments

Estension to basin scale

- Validation of pCO_2 estimation using other in-situ data (e.g., ICOS Mediterranean data)

- Spatial data homogenization

- Characterize spatial variability

Collaborators:

Fabrizio Anello, Giorgia Cinelli, Lorenzo De Silvestri, Alcide Giorgio di Sarra, Tatiana Di Iorio, Toni Iaccarino, Daniela Meloni, Francesco Monteleone, Giandomenico Pace, Mattia Pecci, Salvatore Piacentino, Damiano Sferlazzo

Station for Climate Observations "Roberto Sarao"
ENEA
LAMPEDUSA

Thank you

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