Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

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Air–Sea Interaction in the Central Mediterranean Sea: Assessment of Reanalysis and Satellite Observations

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1. *The Mediterranean Sea and its heat budget closure problem. An opportunity for Air-Sea Heat fluxes assessment.*

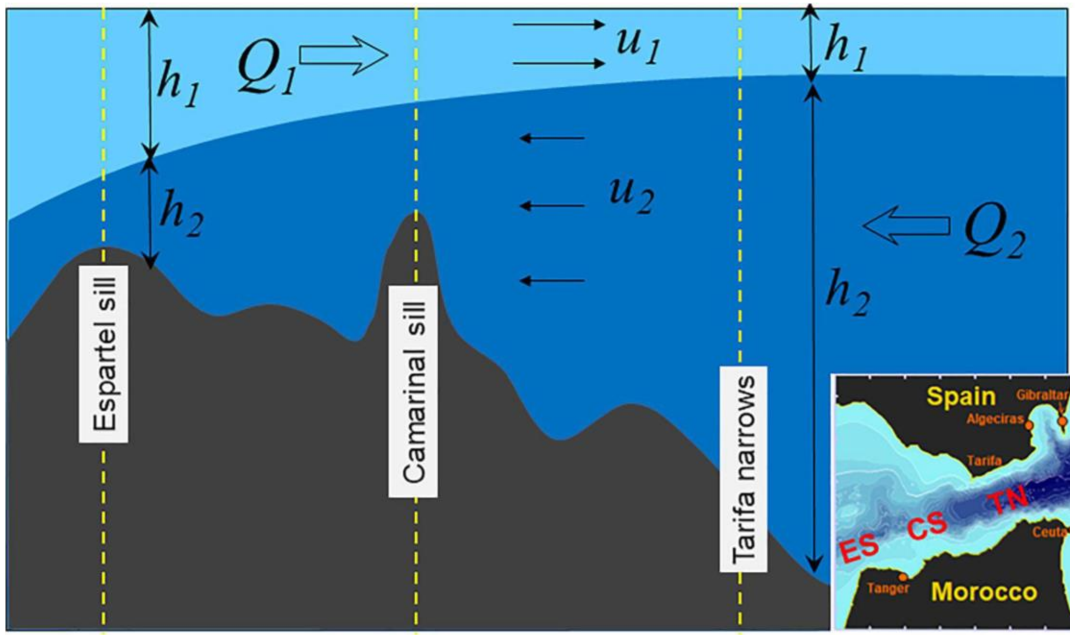
2. *In situ measurements, satellite data and assessments.*

The Mediterranean Sea is a concentration basin, where ***evaporation*** *exceeds* ***precipitation****. In the surface layer there is an inflow (Q_1) of Atlantic water and outflow of Mediterranean water mainly composed by West Mediterranean Deep Water (****WMDW****) and Levantine Intermediate Water (****LIW****). Bryden and Kinder 1991, estimated* ***Q1=0.94 Sv*** *and* ***Q2=0.88 Sv*** *→ Basin* ***evaporation=0.6 m/year equivalent to 0.04 Sv.***

Should the Mediterranean be in a steady state, the net water and heat transport through the straits (horizontal advection) must balance the vertical fluxes integrated over the basin (F. Criado-Aldeanueva et al., 2012)

Sanchez-Gomez et al. (2011) mention that various estimates of heat flux entering from Gibraltar into the Mediterranean range from a minimum **of 3 W/m²** to a maximum of **12 W/m²** (Béthoux 1979; Bunker et al. 1982; McDonald et al. 1994; Harzallah, 2018).

The two fluxes do not solve the Mediterranean closure problem!



From: García-Lafuente, et l., (2021). *Hotter and Weaker Mediterranean Outflow as a Response to Basin-Wide Alterations. Frontiers in Marine Science, 8,* 150.

Table 2. Basin-Averaged Annual-Mean Budget of Qnet (Unit: W m^{-2}) and Four Individual Components, SW, LW, LH, and SH (Unit: W m^{-2})[a]

Name	Qnet	SW	LW	LH	SH
NCEP 1	1 (±116)	191 (±75)	−79 (±2)	−97 (±31)	−14 (±14)
NCEP 2	9 (±133)	216 (±89)	−83 (±1)	−111 (±34)	−12 (±15)
CFSR	8 (±119)	207 (±83)	−85 (±2)	−105 (±27)	−10 (±10)
ERA-interim	7 (±114)	198 (±81)	−84 (±2)	−95 (±27)	−11 (±10)
JRA-55	−12 (±109)	198 (±77)	−79 (±6)	−112 (±25)	−19 (±9)
MERRA	21 (±122)	203 (±80)	−89 (±7)	−82 (±23)	−11 (±7)
CORE.2	−19 (±117)	182 (±76)	−81 (±9)	−101 (±23)	−19 (±14)
NOCSv2	4 (±93)	149 (±61)	−45 (±3)	−88 (±27)	−12 (±6)
OAFlux+ISCCP	3 (±124)	185 (±79)	−76 (±4)	−93 (±34)	−13 (±15)

[a]Not that Qnet = SW+LW+LH+SH. The values in the parentheses denote the seasonal STD.

From Song and Yu 2017

Components of the of air-sea heat fluxes integrated over the basin must be estimated

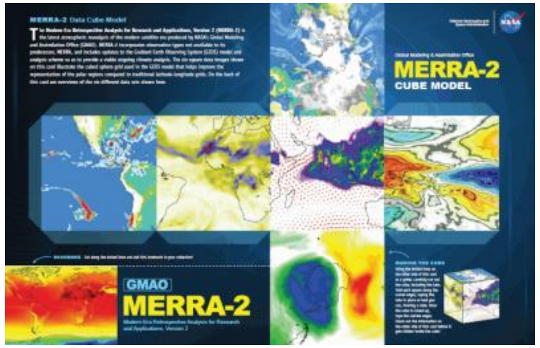
$$Q_{net} = SW + LW + Q_E + Q_H \quad (Radiative + Turbulent)$$

Basin average time series from Re-analysis and/or Satellite data

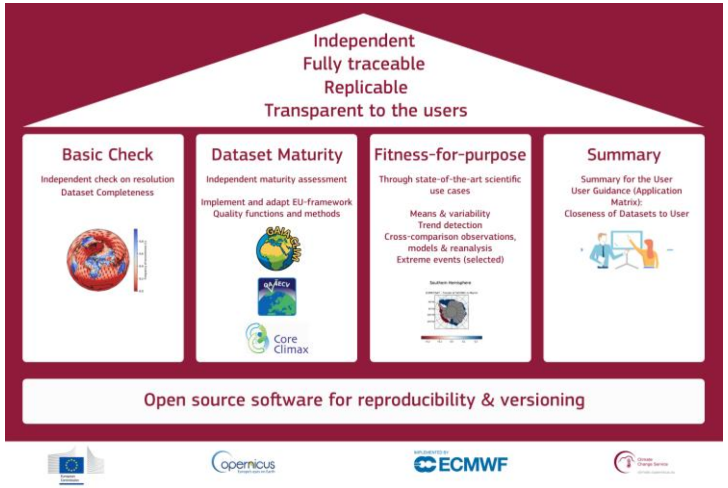
ERA5 (1979 to present) + ERA5 back extension (1950-1978)

Meteosat radiative fluxes

EUMETSAT
OSI SAF
OCEAN AND SEA ICE



C3S_511 Independent Evaluation



In situ measurements

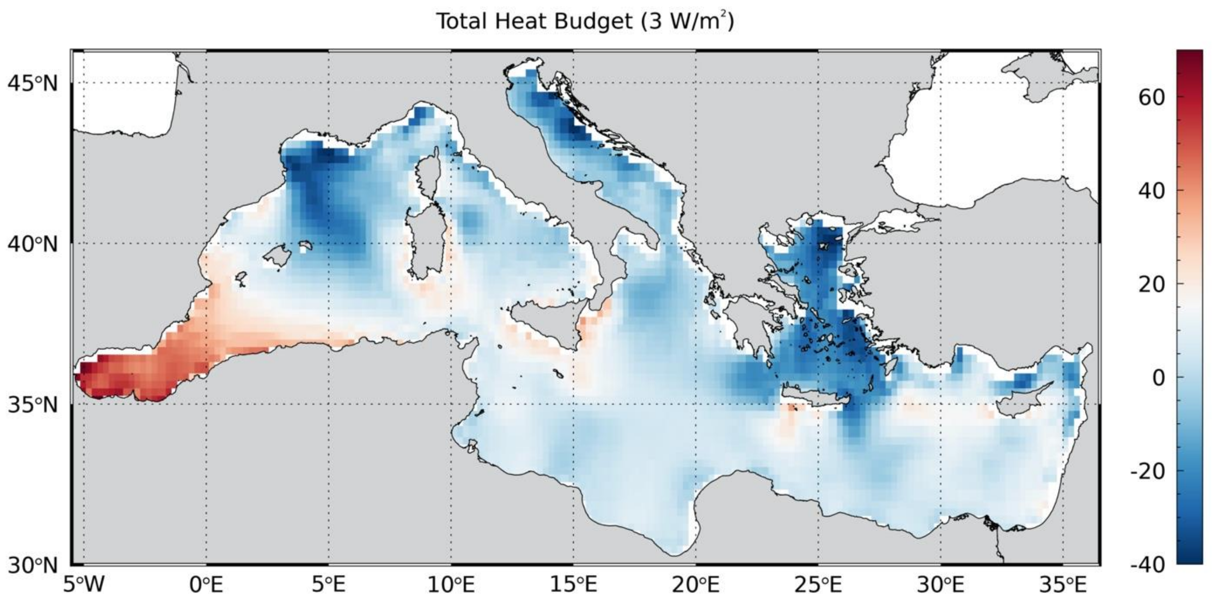
AERONET
AEROSOL ROBOTIC NETWORK

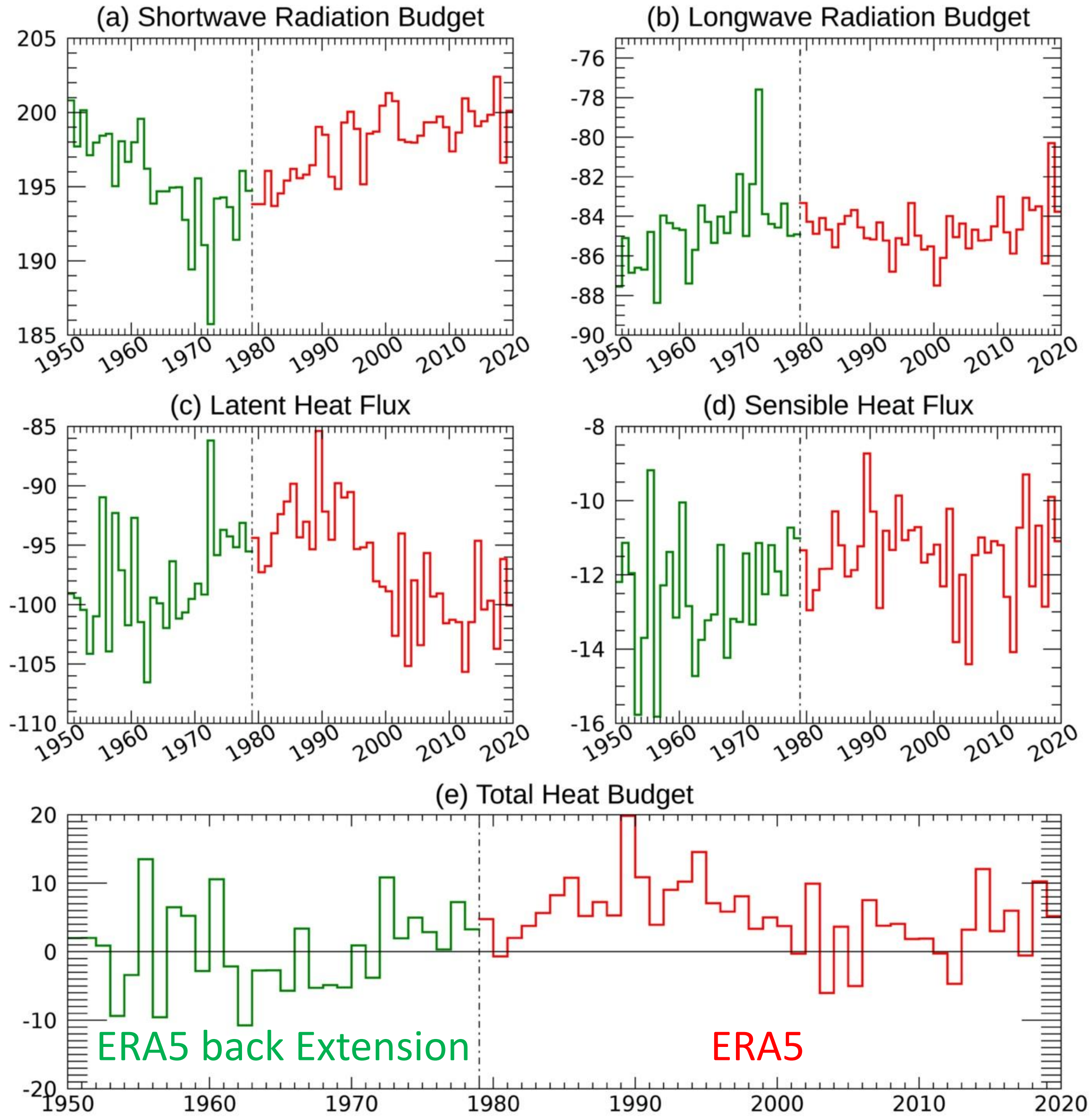
Station for Climate Observations "Roberto Sarao"
ENEA LAMPEDUSA

Mediterranean ERA5 Heat flux time series (1950 – Present time)

Few W/m² enter from Gibraltar then the the Med should loose heat to the Atmosphere! …. But … The ERA5 basin budget is not negative!

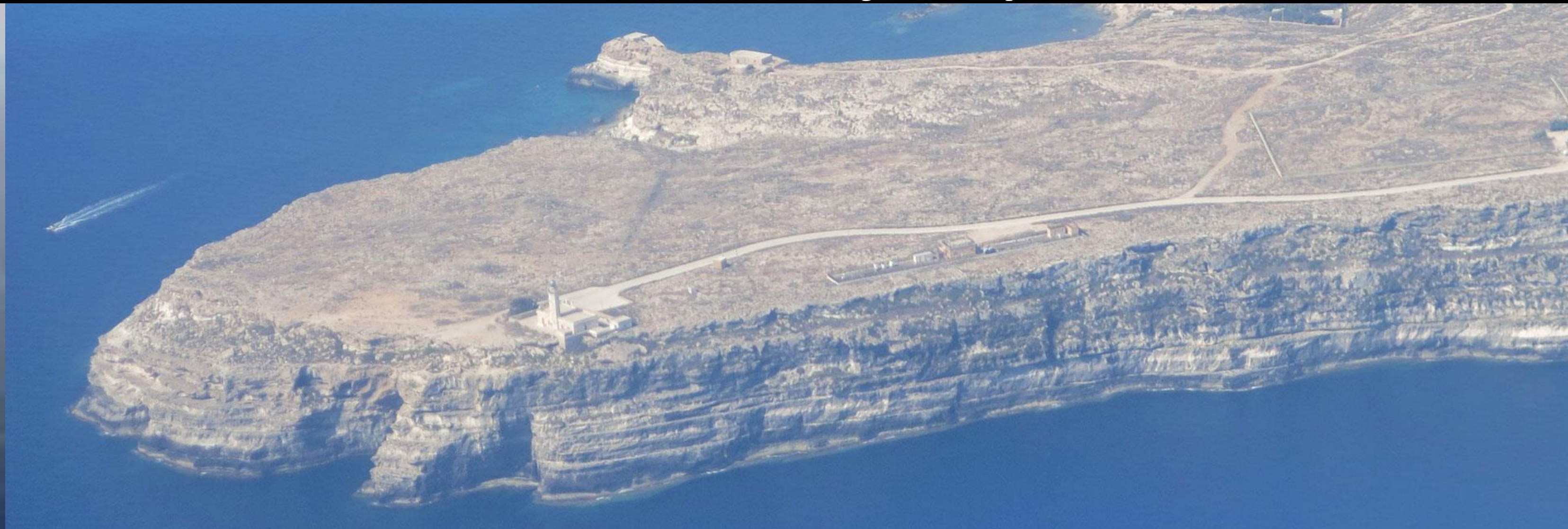
Is something wrong in one of the two estimates?

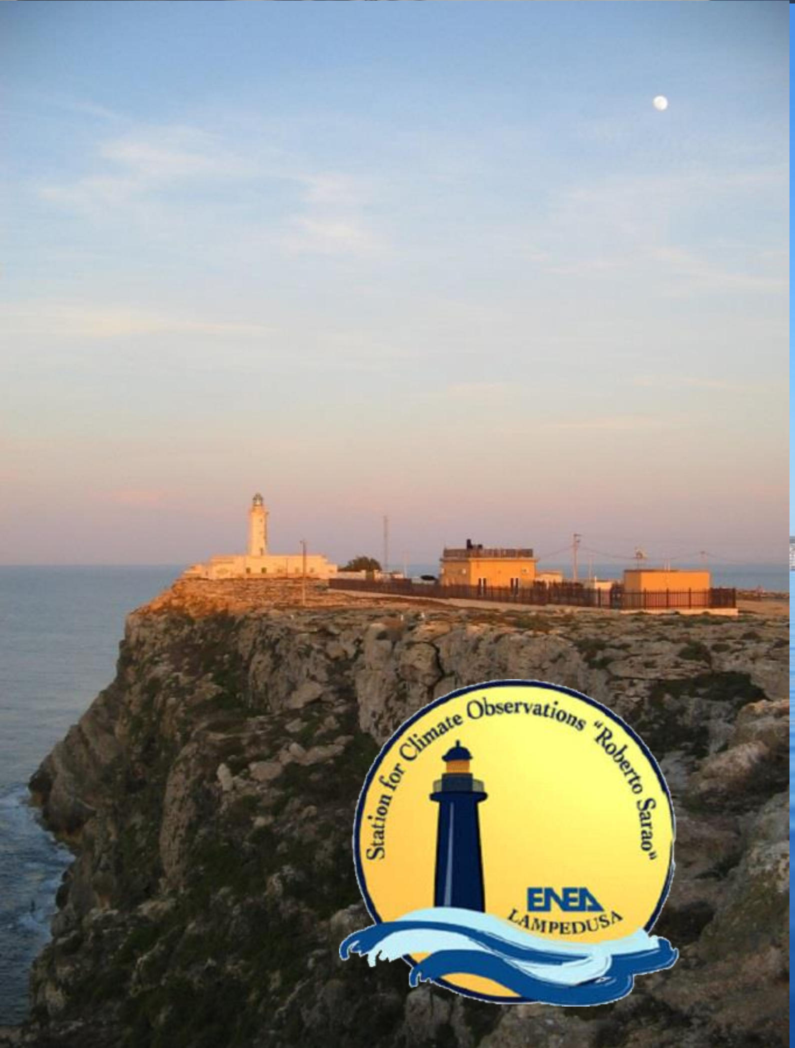


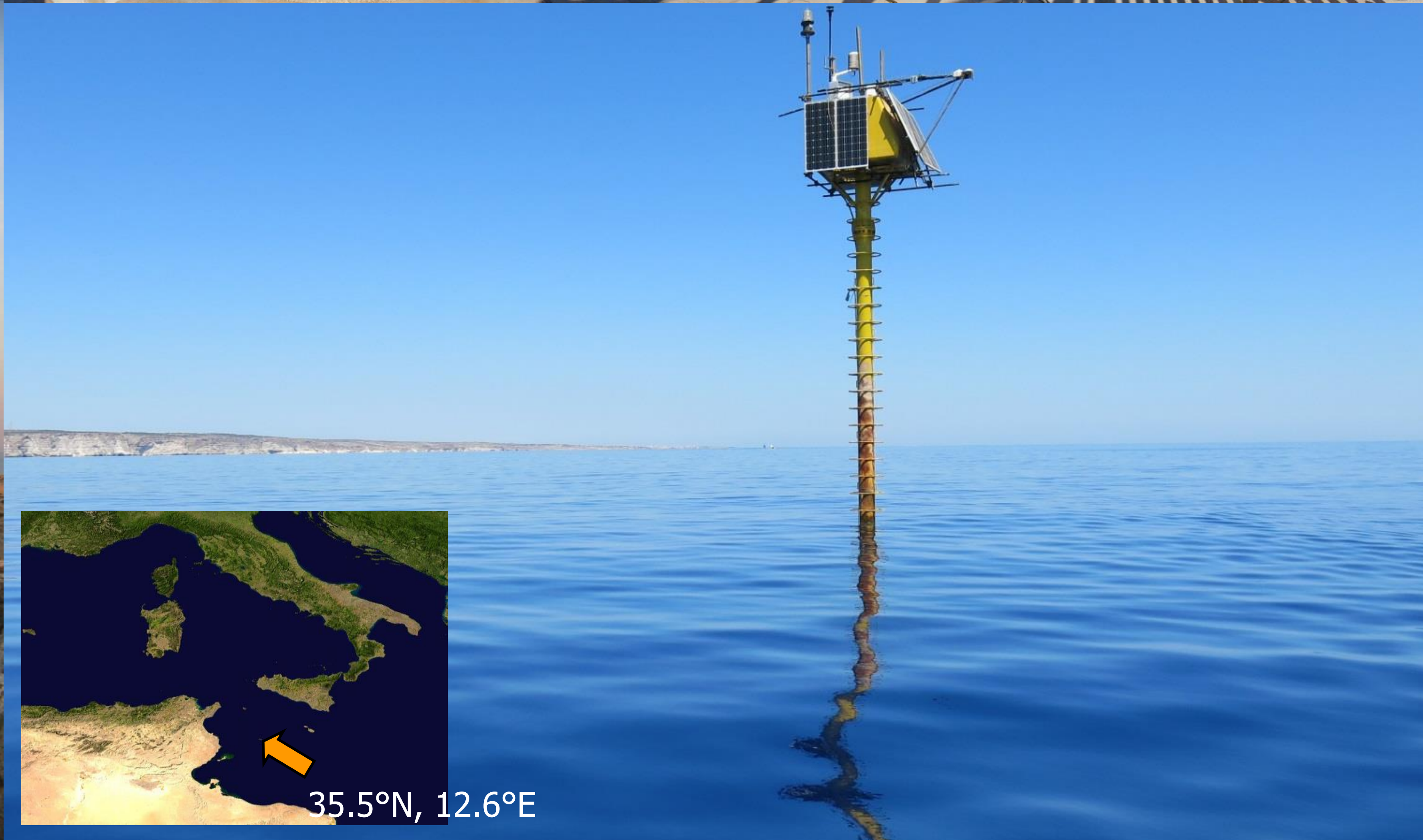


Can In situ high quality, dedicated measurements help?

ENEA Station for Climate Observations on the island of Lampedusa



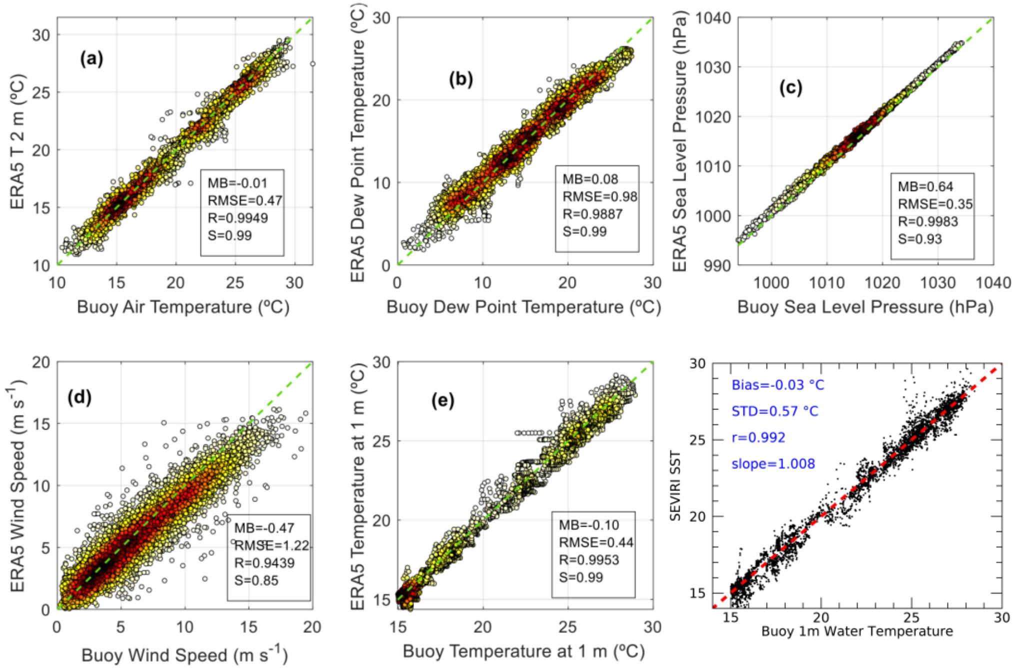

Station for Climate Observations "Roberto Sarao"
ENEA
LAMPEDUSA


35.5°N, 12.6°E

Sensor	Parameter	Position
Kipp and Zonen CMP21	Downwelling Solar Irradiance	7.8 m.a.s.l.
Kipp and Zonen CGR4	Downwelling Infrared Irradiance	7.8 m.a.s.l.
Vaisala HMP155	temperature, relative humidity	8.0 m.a.s.l.
Gill Windsonic	wind speed and direction	10.0 m.a.s.l.
Vaisala Baro-1QML	Pressure	8.0 m.a.s.l.
SeaBird SBE39Plus	temperature and pressure	1 m depth
SeaBird SBE39Plus	temperature and pressure	2 m depth

Step 1: Evaluation of variables used air-sea fluxes formulae at the Lampedusa Site

One year of data since June 2017



Sensor	Parameter	Position
Kipp and Zonen CMP21	Downwelling Solar Irradiance	7.8 m.a.s.l.
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Vaisala HMP155	temperature, relative humidity	8.0 m.a.s.l.
Gill Windsonic	wind speed and direction	10.0 m.a.s.l.
Vaisala Baro-1QML	Pressure	8.0 m.a.s.l.
SeaBird SBE39Plus	temperature and pressure	1 m depth
SeaBird SBE39Plus	temperature and pressure	2 m depth

The Bulk Formulae Approach

$$Q_H = \rho_a c_{pa} C_h \overline{W} (T_s - T_a)$$

$$Q_E = \rho_a L_e C_e \overline{W} (q_s - q_a)$$

$$LW \uparrow\downarrow = \epsilon\sigma T_s^4 - [\sigma T_a^4 (0.653 + 0.00535 e)](1 + 0.1762 c^2)$$

$$SW = SW_{Clear}(1 - 0.62C + 0.0019\beta)(1 - \alpha)$$

C_h *and* C_e : Turbulent Transfer Coefficients, q_a and q_s are the specific humidity at z and the saturation humidity at the sea surface temperature T_s

Step 2: Evaluation of Radiative Fluxes (ERA5 & SEVIRI) at the Lampedusa Site

ERA5:

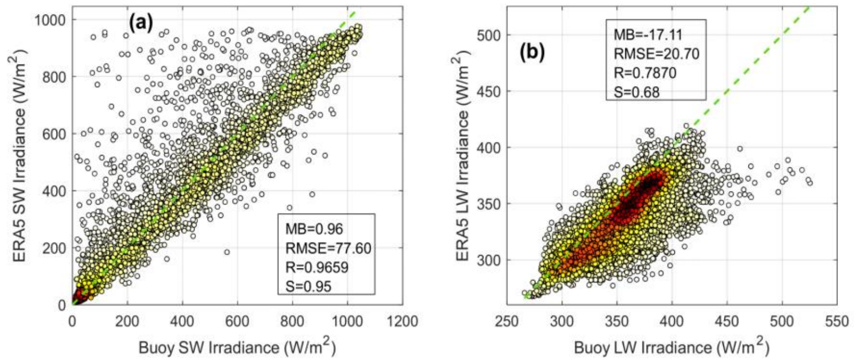
- Data processing for ERA5 (longwave and shortwave) is carried out by ECMWF, using ECMWFS' Earth System model IFS, cycle 41r2.
- SSRD (Surface Solar Radiation Downwards) includes diffuse and direct radiation.
- SSRD can be considered to be what would be measured by a global pyranometer at the surface, and SSRD
- Over oceans the albedo is a simple function of the solar zenith angle

SEVIRI:

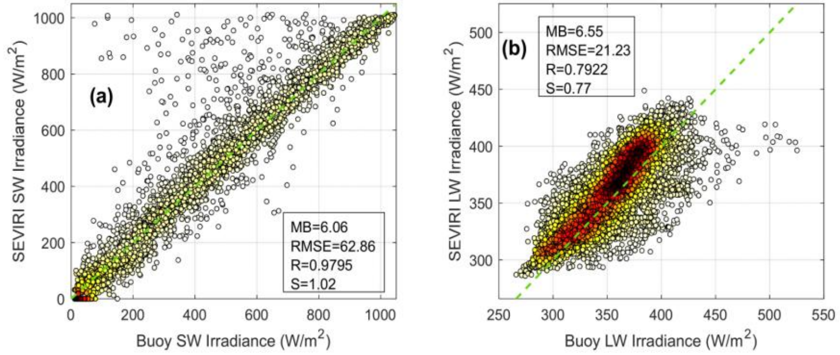
- Surface Solar Irradiance (SSI) and Downward Longwave Irradiance (DLI), are produced by the EUMETSAT OSI SAF.
- The algorithm to derive the longwave irradiance is an empirical parameterization that uses the outputs of the ECMWF NWP model and corrects it with the cloudiness information obtained from the satellite.
- SSI from a physical parameterization including conversion from the narrow band of the satellite to the broader band of the solar spectrum and a parameterization of the effect of cloud cover

Shortwave Longwave

ERA5



SEVIRI



	Bias	RMSE	R	Slope
ERA Lw	-17.11	20.70	0.79	0.68
ERA Sw	0.96	77.60	0.97	0.95
SEVIRI Lw	6.55	21.23	0.79	0.77
SEVIRI Sw	6.06	62.86	0.98	1.02

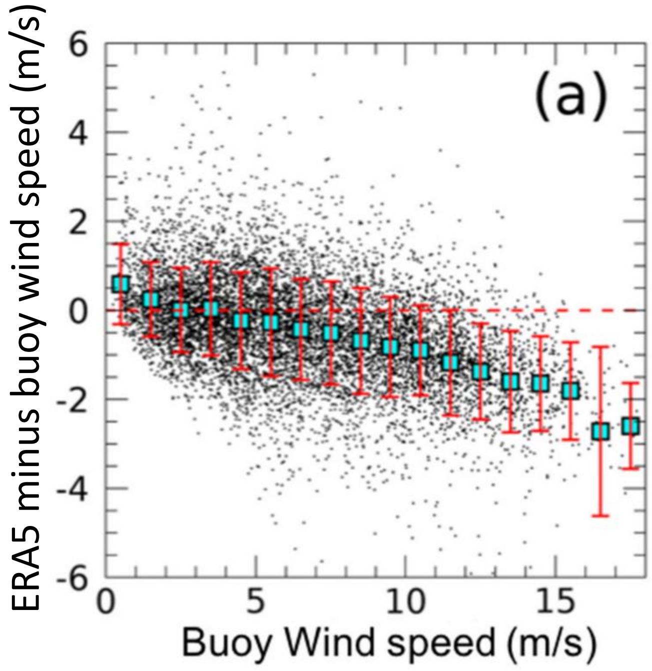
Summary of re-analysis and satellite data validation:

	ERA5 T_a (°C)	ERA5 T_d (°C)	ERA5 SLP (hPa)	ERA5 Wind (m/sec)	ERA5 SST (°C)	SEVIRI SST (°C)
Bias(*)	-0.02	0.08	0.64	-0.47	-0.10	-0.03
RMSE	0.47	0.98	0.35	1.22	0.44	0.57
R	0.995	0.989	0.998	0.944	0.995	0.992
Slope	0.99	0.99	0.93	0.85	0.99	1.01

Statistical parameters of the of the validation against in situ direct measurements are generally quite small.

	ERA5 Sw (W/m^2)	SEVIRI Sw (W/m^2)	ERA5 Lw (W/m^2)	SEVIRI Lw (W/m^2)
Bias(*)	0.96	6.06	-17.11	6.55
RMSE	77.60	62.86	20.70	21.23
R	0.966	0.980	0.787	0.792
Slope	0.95	1.02	0.68	0.77

ERA5 and Satellite Irradiances show larger deviations from in situ data.



(*) Bias=Estimate-Buoy measure

Similar wind bias dependence from wind speed has already been observed for previous re-analysis products

From Ruti et al., 2008

Table 2
Statistical parameters for the wind speed: Mean Bias Error — MBE, Root Mean Square Error — RMSE, correlation coefficient R, slope and intercept of the regressed line

Gulf du Lion	Intercept m s^{-1}	Slope	CorrC	MBE (m s^{-1})	RMSE (m s^{-1})	No. of pairs
QuikSCAT	0.02	1.06	0.97	0.52	1.44	1890
ECMWF	0.66	0.85	0.92	−0.52	1.77	1428
ERA40	0.77	0.60	0.84	−2.28	3.33	961
NCEP	1.60	0.70	0.78	−0.81	2.90	1428
NCEPB	3.38	0.54	0.52	−0.19	4.36	1428

Gulf of Lion buoy.

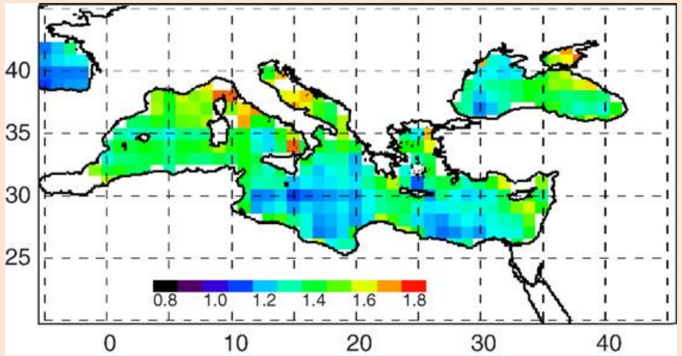
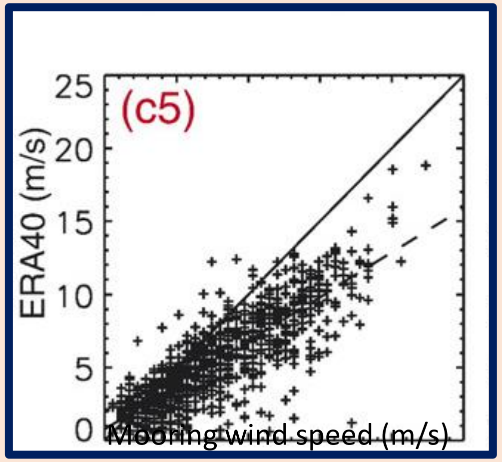
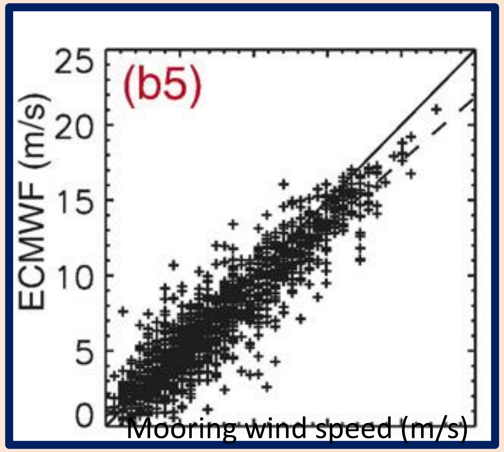


Fig. 5. Linear fit (slope) between ERA40 and QuikSCAT over the Mediterranean basin for year 2000.





… Then questions are:

- Are re-analysis or satellite data uncertainties small enough for applications?
- Can we apply empirical corrections to data before use it in bulk formulae?

The overall effects of the corrections are more cooling by the turbulent heat fluxes by about 22 W/m2 and about 0.25 m/yr more evaporation. (Pettenuzzo et al., 2010)

Operational Models often use Meteo-data in Bulk Formulae: CMEMS Mediterranean Operational Model The model interactively computes air-surface fluxes of momentum, mass, and heat. The bulk formulae implemented are described in Pettenuzzo et al. (2010) and are currently used in the Mediterranean operational system (Tonani et al., 2015).

Impact of air-sea flux parameterization on the upper ocean vertical structure evolution

Impact of Flux Differences on Numerical Simulations, a Case Study: the General Ocean Turbulence Model (GOTM)

The steps this impact study are to:

1. Understand how relevant are these differences with respect to the subsequent applications
2. Understand the extent to which the available datasets are interchangeable
3. establish user recommendations, based on the results findings.

GOTM is forced with different heat components datasets:

1. Measured at the Lampedusa observatory.
2. Provided by ERA5.
3. Estimated from satellite data.

Fluxes were either prescribed or interactively computed by the model.

Initial condition 4 June 2017

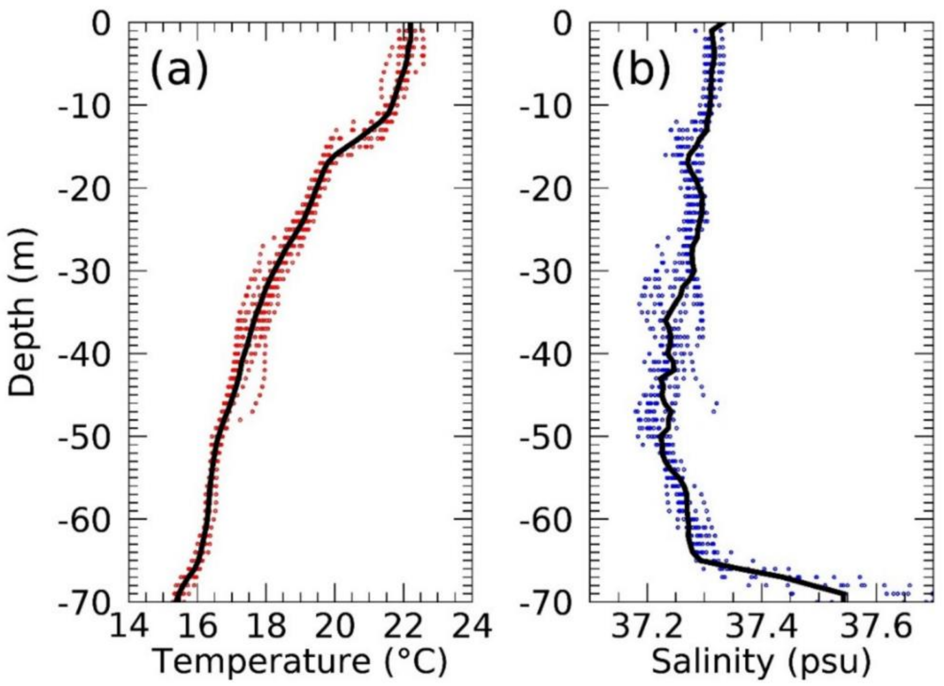
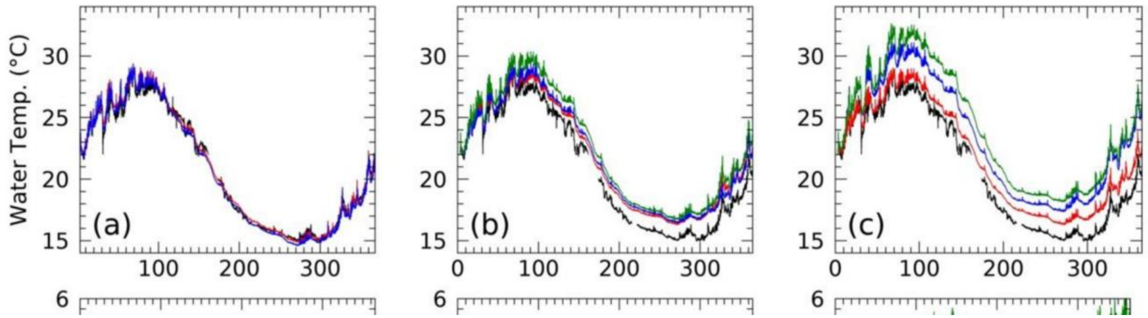


Figure 6. In situ CTD casts made from 3 June 2017 at 14:00 UTC to 4 June 2017 at 07:56:00 UTC close to the Oceanographic Observatory. Dots represent individual CTD casts. The black lines represent the average profiles for temperature (**a**) and salinity (**b**) used as initial condition for the simulation.

Table 3. Options for the different GOTM parameters.

	Parameters	Option
1	Surface fluxes (heat and momentum)	Prescribed (From ERA5, in situ measurements or Satellite data)
		Calculated (using meteorological inputs: measured or ERA5)
2	Shortwave radiation	Prescribed (From ERA5, in situ measurements or Satellite data)
		Calculated (using ERA5 Cloud Cover): Rosati and Miyakoda 1988 [29] + Payne 1972 [55] for the albedo
3	Longwave radiation	Prescribed (From ERA5, in situ measurements or Satellite data)
		Bignami et al. [25]: Calculated (using ERA5 data or in situ measurements)

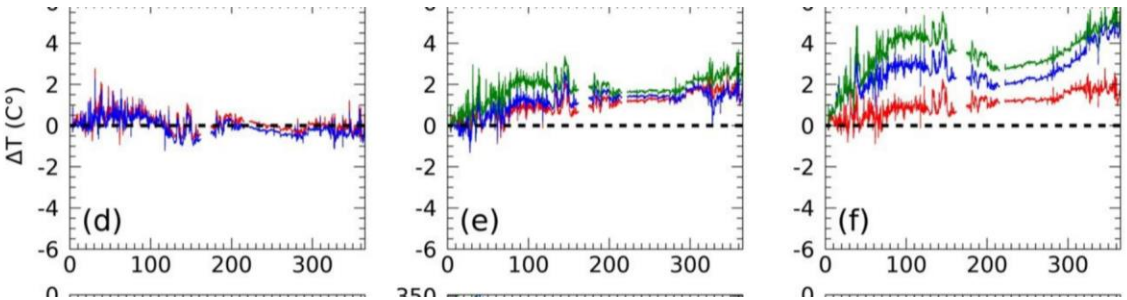


(**g**) Ocean heat flux loss (latent + sensible + net longwave) using bulk formulae with ERA5 meteorological parameters (experiment 1, red line) or bulk formulae with in situ meteorological parameters (experiment 2, blue line).

(**h**) Shortwave component of the heat fluxes from direct in situ measurements (blue), ERA5 (red) and SEVIRI (green).

Ocean heat flux loss (latent+sensible+net longwave) for ERA5 (red), ERA5 except for the longwave irradiance, which is form in situ (blue) and by ERA5 except for the longwave irradiance, which is estimated by SEVIRI(green)

Sea Surface temperature simulated by GOTM from 4 June 2017 to 4 June 2018.



Black line: In situ measurements (SBE39Plus)

(**a**) Simulations using Heat and momentum fluxes computed by the model at each time step, using bulk formulae with ERA5 meteorological parameters (experiment 1, red line) or bulk formulae with in situ meteorological parameters (experiment 2, blue line).

(**b**) Simulations using air–sea heat and momentum fluxes obtained by ERA5 (experiment 3, red line), by ERA5 except for the shortwave irradiance, which is from in situ measurements (experiment 4, blue line) and by ERA5 except for the shortwave irradiance, which is estimated by SEVIRI (experiment 5, green line).

(**c**) Simulations using air–sea heat and momentum fluxes obtained by ERA5 (experiment 3, red line), by ERA5 except for the longwave irradiance, which is form in situ observations at the buoy (experiment 6, blue line), by ERA5 except for the longwave irradiance, which is estimated by SEVIRI (experiment 7, green line).

From Marullo et al., 2021

In Numbers….

Experiment n°	Forcing	Air-Sea Fluxes: Heat Loss (W/m^2)	Heat Gain (W/m^2)	Net Heat (W/m^2)	SST (1 m) temperature: MB	RMSE	R
1	Heat and momentum fluxes computed by the model using bulk formulae and ERA5 meteorological data	−215.2	217.4	2.2	−0.08 °C	0.40 °C	0.997
2	Heat and momentum fluxes computed by the model using bulk formulae and meteorological in situ data	−215.8	217.4	1.6	0.13 °C	0.42 °C	0.997
3	Heat fluxes from ERA5	−198.8	216.6	17.8	1.07 °C	0.55 °C	0.995
4	Heat fluxes from ERA5 but shortwave from in situ measurements	−198.8	215.7	16.9	1.17 °C	0.58 °C	0.994
5	Heat fluxes from ERA5 but shortwave from SEVIRI	−198.8	221.7	22.9	1.80 °C	0.61 °C	0.991
6	Heat fluxes from ERA5 but longwave from in situ measurements	−182.6	216.6	34	2.68 °C	0.95 °C	0.978
7	Heat fluxes from ERA5 but longwave from SEVIRI	−176.2	216.6	40.4	3.54 °C	1.08 °C	0.973

From Marullo et al., 2021

Conclusion:

- The semienclosed concentration Mediterranean Basin is an ideal natural laboratory for air-sea interaction studies and air-sea flux products evaluation.
- The Mediterranean heat and mass closure problem is not yet fully resolved: ERA5 produce a net mean flux from the atmosphere to the Mediterranean Sea of 3 W/m^2 in contrast with modelled and measured fluxes at Gibraltar.
- The Lampedusa case study confirms the good quality of ERA5 meteorological parameters but wind speed still suffers for increasing bias with wind intensity.
- The 1D numerical experiment suggests that impact of differences between different heat fluxes parametrization is not negligible.
- For this case study OSI SAF DLI and SSI have been used. The OSI SAF SSI algorithm is a physical parameterization applied to a visible channel (Meteosat or GOES-East radiometer), after Gautier et al. 1980 and Frouin and Chertock, 1992. The OSI SAF DLI algorithm is a bulk parameterization using air temperature and humidity predicted by a NWP model and cloud information derived from satellite data
- Two studies (Ineichen et al., 2009 and Ineichen 2010) conclude that the products from the different SAFs have comparable biases and precisions, showing that the OSI SAF parameterizations compare favourably with the more complex RTM methods.
- However the comparison should be extended to ocean surfaces.
- Latent and sensible fluxes need more attention. Actually, are mainly based on microwave data that empirically estimate meteorological variables, that in turn enter in the bulk formulae.
- Future microwave missions, such as CIMR, will contribute to estimates of air–sea turbulent heat and moisture fluxes from simultaneous SST, wind speed, sea surface salinity, sea ice, rain rate and integrated cloud liquid water, opening a new era for unprecedented satellite applications.