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Saildrone Baja Field Campaign: A Comparison of Surface Meteorology with GEOS Products

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SUMMARY

The Saildrone Baja field campaign was an international effort to collect measurements across the air-sea interface for a 62-day period between April 11-June 11, 2018. The field campaign was executed using a saildrone, an unmanned surface vehicle (USV) carrying a comprehensive suite of instruments to measure meteorological, ocean surface, and subsurface data. We use these data to validate near-surface meteorology and ocean surface temperature fields in the Global Earth Observing System (GEOS). This is the first study using Saildrone data to validate GEOS products. As these USV platforms become more prevalent, they could be used to improve model representation of the air-sea interface variables.

BACKGROUND

Measurements of the air-sea interface are essential to improve atmosphere-ocean interactions in climate models, including GEOS weather analysis and prediction system and to constrain and validate data assimilation systems, such as the GMAO Modern Era Retrospective analysis for Research and Applications Version 2 (MERRA-2). Saildrones are agile and cost-effective USVs, which with further development and capability studies, could partially replace shipboard observations of near-surface ocean conditions.

Introduction

The Saildrone Baja field campaign was designed to test the feasibility of using a saildrone to collect near-surface meteorological and seawater data in the Baja California region (Figure 1). The main research goals of the campaign included study the California current region and collection of air-sea interface measurements, including sea surface temperature (SST), ocean color and dissolved oxygen. More than 30 scientists from various universities, national agencies, and non-profit organizations collaborated in this effort. The field campaign results demonstrate instrument capability and the potential future applicability of such platforms for model and data assimilation improvement.

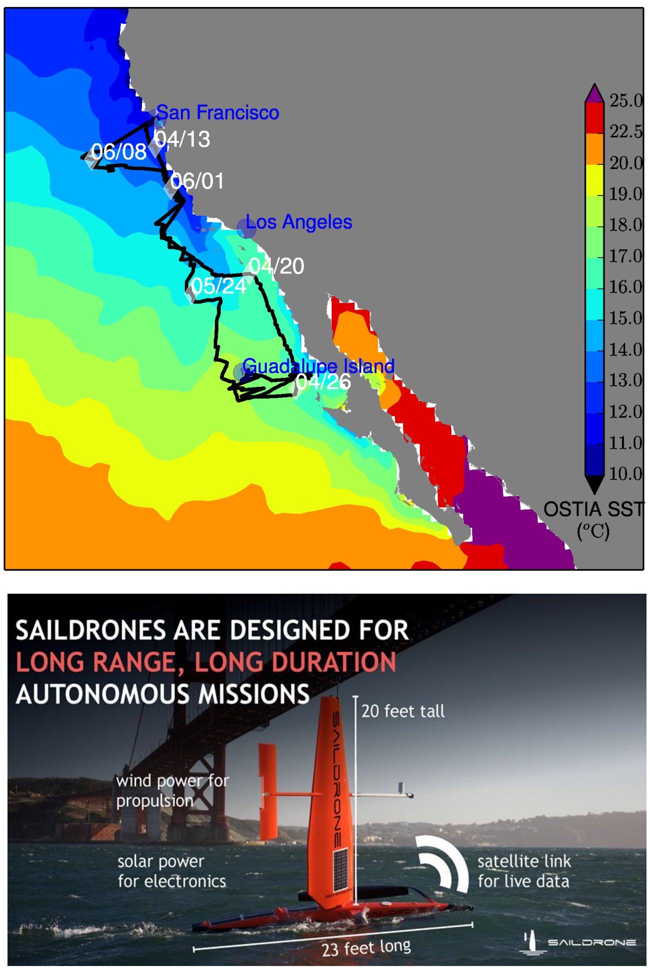

Figure 1. Track of the 2018 Saildrone Baja field campaign (black line) with the SST for May 2018 shown in color in the top panel. The USV left the San Francisco Bay on 04/11, collected samples down the California coast, turned westward to Guadalupe Island on 04/26, and sailed northward, against the California current, to reach SF on 06/11. Few select dates and locations are also shown. OSTIA sea surface temperature (Donlon et al., 2012) underlain for reference. The right panel shows dimensions of the USV. It is about 20 feet tall, 23 feet long, and weighs about 750 kg. It is both solar and wind powered. For more details, see https://www.saildrone.com/technology

2018 Saildrone Baja Field Campaign

The Saildrone Baja field campaign lasted 60 days between April 11 and June 11, 2018; with launch and recovery on the first and last days, respectively (Figure 1). From San Francisco Bay, the Saildrone moved with the southward flowing California Current (Chelton, 1981). It reached Guadalupe Island, Mexico, on about April 26, where it sampled the surrounding waters from April 27 to May 11. On May 12, the USV started its return journey against the California Current, reaching San Francisco Bay on June 11. En route the USV sampled westward extension of the California current between June 4-9. Though the basic cruise plan was set a priori, track details were relayed to the USV on a continuing basis as the field campaign progressed. The team collaborated in real time to change USV trajectory and speed if interesting features identified in near-real time high-resolution satellite SST products.

Saildrone Instrumentation

The Saildrone carries a comprehensive package of instruments to take measurements of meteorology and water (Figure 2). During the campaign, following parameters were sampled that will be compared with GEOS data:

Meteorology (300 s sampling rate)

- Wind speed and direction (5 m)
- Air temperature (2.4 m)
- Air pressure (0.2 m)

Ocean parameters (variable sampling rate)

- Ocean temperature at 60 s (-0.6 m)
- Ocean temperature at 2 s (-0.295 m, -0.985 m, -1.420 m, -1.785 m)

Using the measured water temperatures within the top 2 m depth, we are able to study diurnal warming of surface waters; however, due to uncorrected reflected sky radiation, skin SST measurements cannot be used in this study. Further instrument details and measured data are available at the following:
https://podaac.jpl.nasa.gov/dataset/SAILDRONE_BAJA_SURFACE?ids=Collections&values=Saildrone

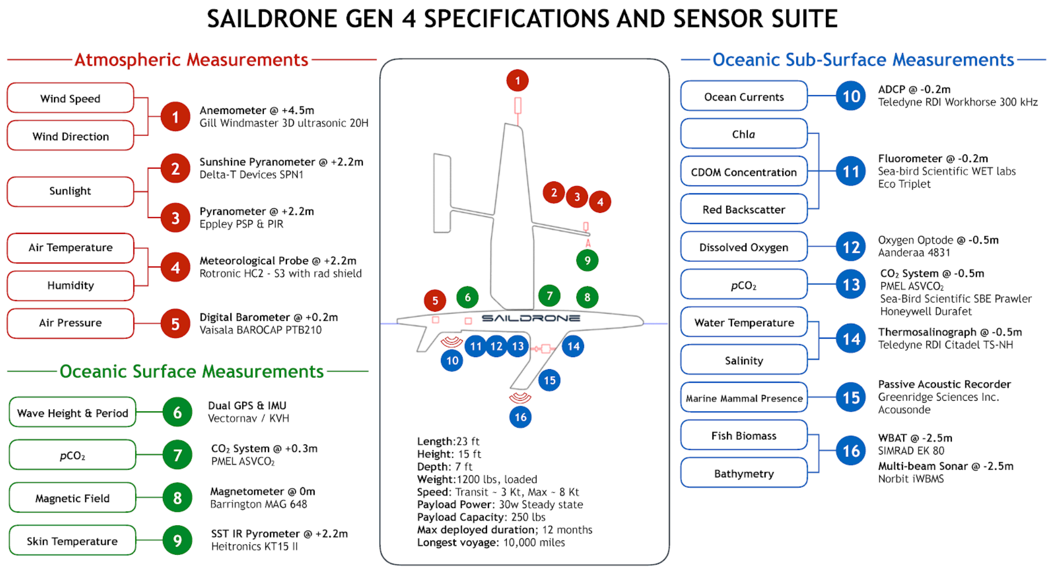

Figure 2. Salidrone USV instrument placement. Note that not all instruments shown were installed in this cruise, see text for sensor height. *Figure credit Saildrone, Inc.*

Concurrent GEOS Data

In this report, we compare data from following operational GEOS systems:

1. GEOS Forward Processing (GEOS-FP): a state-of-the-art data assimilation system based on a 12.5 km horizontal resolution weather prediction model, and analysis of satellite radiance and in-situ observations. This system is updated approximately twice per year. For further details and data download: https://gmao.gsfc.nasa.gov/weather_prediction

2. MERRA-2 is a reanalysis dataset that uses Version 5.12.4 of the GEOS system. It is described by Gelaro et al. (2016). Its horizontal resolution of about 50 km is about four times coarser than the current version of the GEOS-FP system. For further details and data download: https://gmao.gsfc.nasa.gov/reanalysis

Relevant to the measurement of SST diurnal warming is the inclusion of SST plus atmospheric analysis in the GEOS-FP version 5.16 onward. Data from GEOS-FP and MERRA-2 systems are available in near-real time. To match the USV measured data, between April and June 2018, we used the GEOS-FP version 5.17 and MERRA-2 data from the NASA Goddard Earth Sciences Data and Information Services Center.

Hourly two-dimensional time-averaged single level atmosphere (tavg1_2d_slv_Nx) and ocean (tavg1_2d_ocn_Nx) diagnostics files are used in this study. GEOS data are hourly averages; therefore, we calculated the corresponding hourly-averaged values from collocated Saildrone data.

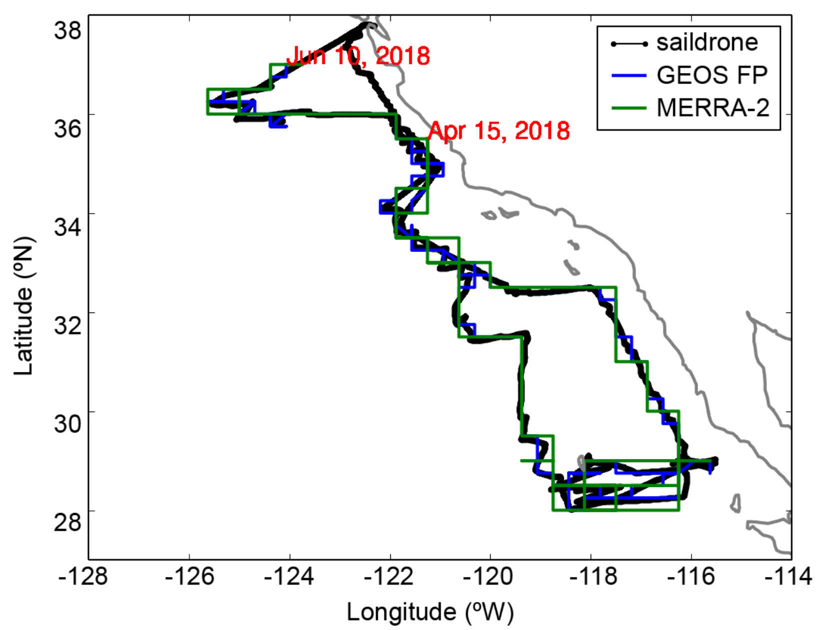

Figure 3. Saildrone track between 15 April and 10 June with collocated GEOS-FP and MERRA-2 grid boundaries.

Meteorological Data Comparison

We compared Saildrone measured winds, air temperature, and pressure with corresponding values from GEOS systems. The GEOS operational systems did not assimilate the Saildrone measurements, hence this data serves as independent data.

Saildrone measured zonal (U-) and (V-) meridional wind components, respectively and U2M (two-meter wind speed toward the east) and V2M (two-meter wind speed toward the north) from GEOS-FP and MERRA-2 systems show overall good agreement (Figure 4). Though Saildrone measurements were at 5 m, the difference between 2 m and 10 m GEOS winds was negligible. Therefore, we did not scale GEOS winds from 2 m to the Saildrone measurement height. Modeled hourly variability in U-wind is better resolved than the predominantly southerly V-wind, with the GEOS-FP system consistently outperforming the MERRA-2, though the reversal of U-wind (east to westward) around May 24 is missed in both GEOS systems. Table 1 provides correlation coefficients between Saildrone measurements and GEOS-FP and MERRA-2 systems.

Saildrone-measured air temperature (at 2.4 m) demonstrates reasonable long-term agreement with modeled T2M (Figure 5). As observed in the wind comparison, the GEOS-FP system better captures the variability in temperature than MERRA-2. Differences in excess of 2°C between the measured and GEOS-FP can be seen on a few days (e.g., April 24-27, May 4-8, May 24-28). When the Saildrone was near the coastline, on its return trip to San Francisco Bay, MERRA-2 air temperature shows spikes around June 1-3, possibly due to a mixed land-ocean signal due to the coarse grid resolution (Figure 3).

Surface pressure in the GEOS systems captures the diurnal range but not the absolute magnitude of Saildrone-measured air pressure (Figure 6). A consistent bias of about 15 hPa exists in the GEOS-FP and MERRA-2 systems, possibly due to the fact that the pressure sensor measurement was at 0.2 m height, whereas in both GEOS systems, the model level closest to the surface is at about 985 hPa (and thickness of bottom cell is 15hPa), which is at ~275 m height. (See Appendix B of https://gmao.gsfc.nasa.gov/GMAO_products/documents/GEOS_5_FP_File_Specification_ON4v1_2.pdf for description of vertical levels in GEOS systems.) Given that observed surface pressure from a vast network of ocean drifting buoys is assimilated in the GEOS systems, this rather large systematic bias warrants further investigation.

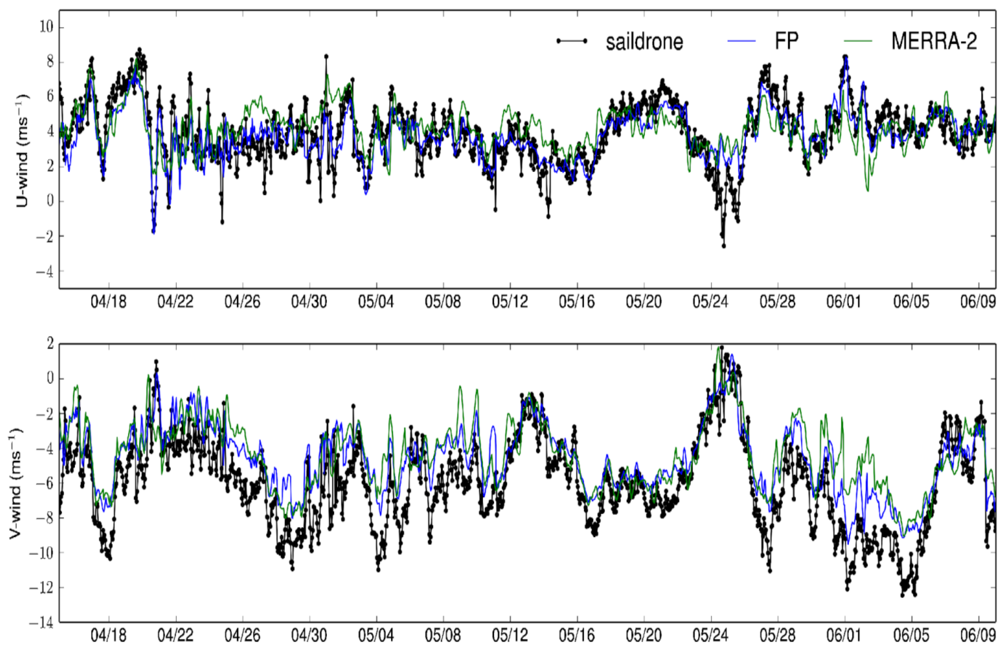

Figure 4. Comparison of Saildrone-measured zonal (U; top) and meridional (V; bottom) winds with GEOS-FP and MERRA-2.

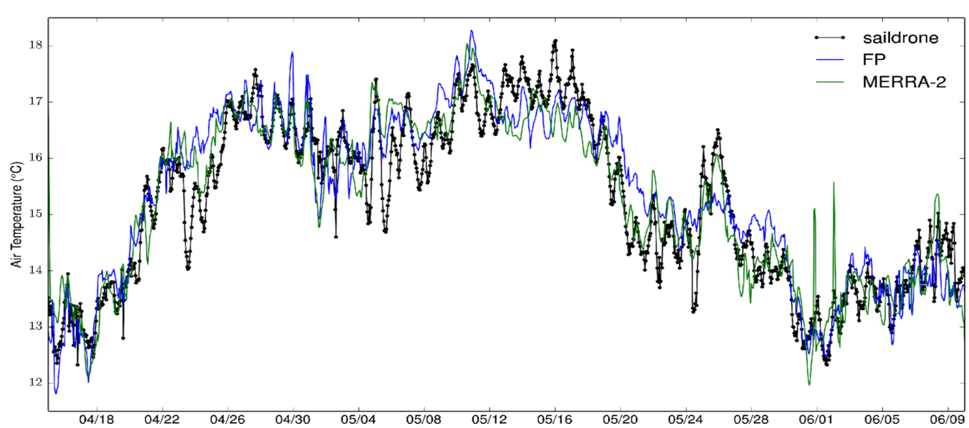

Figure 5. Same as in Figure 4 but for air temperature.

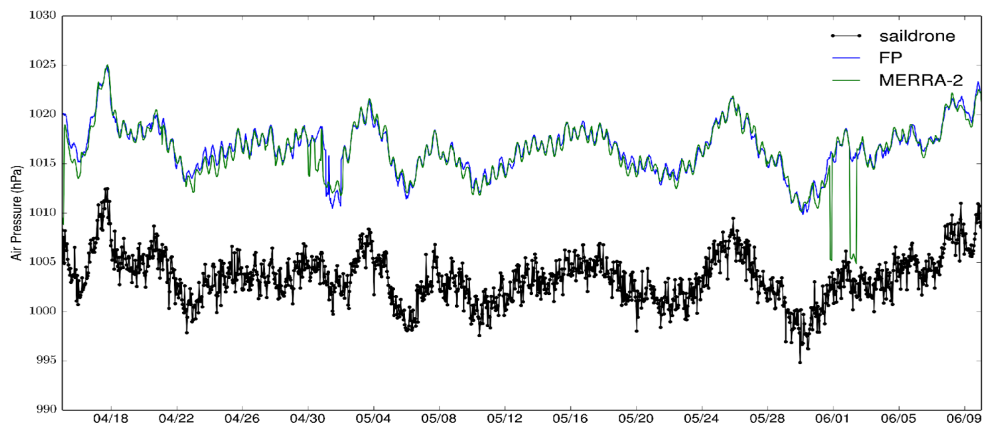

Figure 6. Same as in Figure 4 but for air pressure.

Variable	GEOS-FP	MERRA-2
U-Wind	0.784	0.507
V-Wind	0.882	0.770
Air Temperature	0.927	0.918
Surface Pressure	0.891	0.798

Table 1. Correlation coefficients between Saildrone measurements and GEOS-FP and MERRA-2 systems for meteorological variables (winds, air temperature and pressure).

Near-Surface Water Temperature Comparison

When comparing Saildrone-measured and GEOS near-surface water temperatures, the following details are noteworthy. Current GEOS-FP and MERRA-2 systems do not include a representation of the full 3-D ocean; both rely on an external data source for SST and sea ice concentration information. However, GEOS-FP 5.16 (operational between Jan 24-Nov 1, 2017) and onward resolve near-surface SST variability by including the near-surface SST diurnal warming and cool-skin layers (Akella et al., 2017). The modeled SST at any depth (z) is calculated as

$$SST(z) = OSTIA\ SST + \Delta T_w(z) - \Delta T_c(z) \qquad (1)$$

where ΔT_w and ΔT_c denote the changes in temperature due to diurnal warming and cool-skin layers respectively. SST from Operational Sea Surface Temperature and Sea Ice Analysis system (OSTIA; Donlon et al., 2012) provides an estimate of foundation SST devoid of any diurnal variability at 2 m depth. We assume that the temperature change due to diurnal warming (cool-skin) monotonically increases (decreases) with depth. The skin SST, denoted by TS is the temperature of the air-sea interface layer:

$$TS = OSTIA\ SST + \Delta T\_w - \Delta T\_c \qquad (2)$$

The temperature at the top of the diurnal warm layer, denoted by $TDEL = OSTIA\ SST + \Delta T\_w$, as shown in Figure 7.

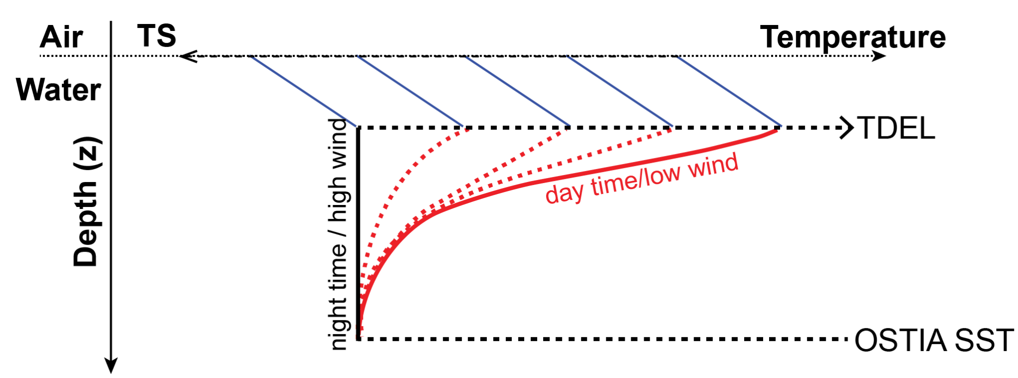

Figure 7. A schematic of the modeled near-surface SST variation in GEOS. The OSTIA SST is used as foundation temperature (assumed to be free of diurnal variation) and at 2 m depth. Due to solar radiation, near-surface waters exhibit thermal stratification due to diurnal warming. The temperature at the top of the diurnal warm layer is denoted by TDEL. The temperature of the air-sea interface, which is in contact with the atmosphere, is denoted by TS. TS is always cooler than TDEL due to the presence of a thin cool-skin layer.

GEOS-FP constrains the modeled skin SST using thermal infrared satellite radiance measurements from all assimilated satellite data. With the GEOS assimilation technique, SST is assimilated along with the atmospheric state in a coupled fashion (cf. Akella et al., 2017). Although the modeled diurnal warming compares well with other data products, it has known biases during late afternoon (local time) and for low wind speeds (Gentemann and Akella, 2018). Updates to the GEOS-FP to address these biases (Akella and Suarez, 2018) are being tested at the time of writing this report. Because MERRA-2 is based on an older system of GEOS, these SST related developments were not yet implemented; therefore, skin SST in MERRA-2 is derived from OSTIA SST For an overview of MERRA-2 SST, see Gelaro et al., 2017.

A comparison of Saildrone measured near-surface water temperatures (-0.295 m and - 1.785 m), GEOS-FP TDEL, MERRA-2 TS, and OSTIA SST demonstrate that the magnitude of modeled temperatures is well represented when the Saildrone is in open water (Figure 8). However, when the USV is in proximity to the coastline, the coarse horizontal resolution of MERRA-2 (Figure 3) results in mixed ocean land TS values. This mixing results in a non-negligible difference between MERRA-2 TS and OSTIA SST on April 30-May 2 and May 30-June 2. Interestingly, OSTIA SST does not exhibit the temperature variability observed by the Saildrone 1.785 m depth. Since calculation of TDEL is based on the assumption that OSTIA SST is a foundation temperature at a nominal depth of 2m, differences in OSTIA SST and true water temperature will lead to corresponding differences in modeled and measured temperatures at shallower depths.

Based on the difference between the measured temperatures at 0.295 m and 1.785 m depth, thermally stratified waters were likely sampled on April 21, May 14, and May 24-26. Though GEOS-FP frequently models a diurnal warming of 0.5°C, only during thermal stratification is there agreement between the model and measurements. In the following section, we focus on these specific diurnal warming cases, since MERRA-2 does not include near surface SST variability, it is excluded from further analysis.

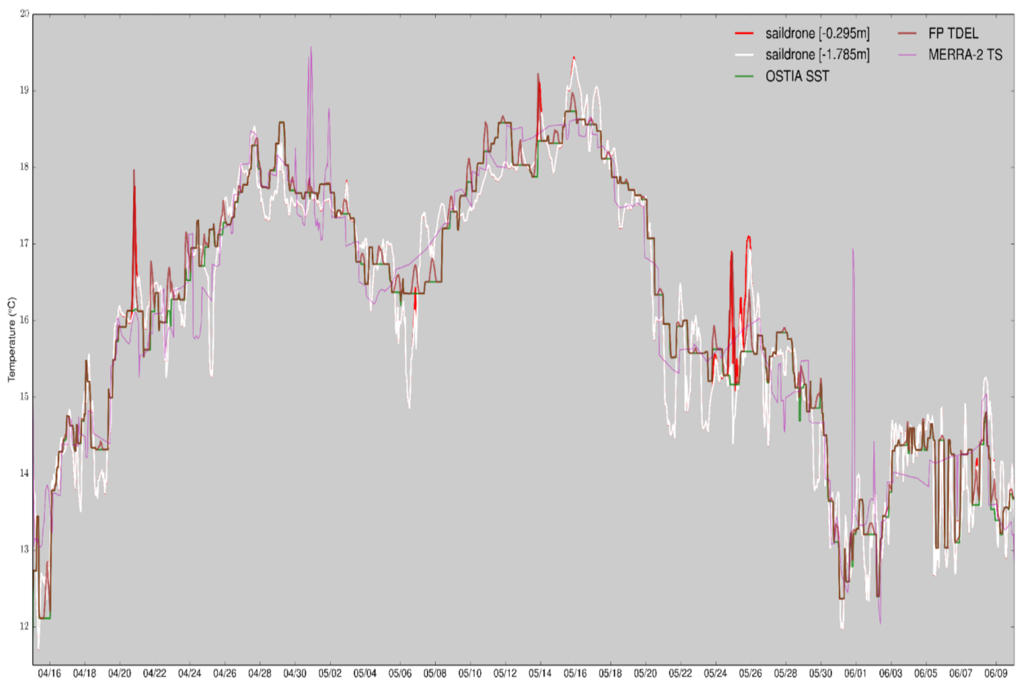

Figure 8. Time series of saildrone measured water temperatures at about 0.3 m (1.8 m) depth shown in red (white), OSTIA SST, GEOS-FP TDEL and MERRA-2 TS.

Diurnal Warming Events

Diurnal warming (DW) is driven by solar radiation and modulated by winds. Three diurnal warming events observed by the Saildrone and modeled by GEOS-FP occur around April 21, May 14, and May 24-26 (Figure 9). Observed and modeled air temperature behave similarly during the first two diurnal warming events, diverge during the third event. Despite this, the net heat flux, calculated using GEOS-FP modeled net surface shortwave and longwave radiations, sensible and latent heat fluxes, remains relatively consistent. However, in all instances, both modeled and observed wind speeds are depressed. Though, during the May 24-26 event, modeled wind speeds are somewhat faster than observed wind speeds. In depth analysis of these DW events follows.

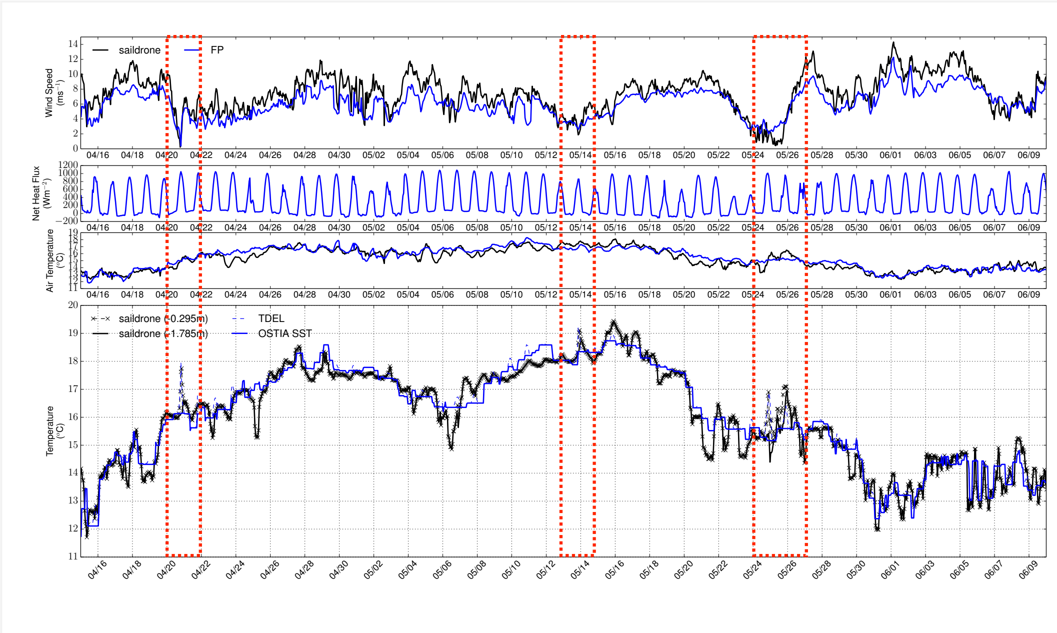

Figure 9. Time series of wind speeds, net surface heat flux, air and water temperatures are shown in top to bottom panels. GEOS-FP wind speeds and air temperatures are the same as in Figures 4 and 5, respectively. The water temperatures are same as in Figure 8. Thermally stratified waters were sampled around 04/21, 05/14 and 05/24-26, indicated with dashed red boxes.

The modeled total magnitude of the diurnal warming (TDEL-OSTIA SST) reasonably matches the peak difference between the Saildrone observed temperatures at 0.295 m and 1.785 m during the DW event April 21 (Figure 10). This implies reasonable agreement between the modeled and observed SST diurnal cycles. Comparing the modeled and observed temperatures within the diurnal warm layer (i.e., below TDEL) reveals a weak modeled diurnal cycle. The stratification and lag seen in the 0.6 m and deeper measurements (in the late afternoon local time) is entirely absent in the modeled temperatures. This is despite the fact that the low wind speeds matched up the measurements (top panel of Fig. 9) and OSTIA SST is within 0.5°C of the measurement closest to 2m depth.

Figures 11 and 12 depict the same model deficiencies for the DW events on May 14 and May 24-26, respectively. The sensitivity of modeled diurnal warming (ΔT_w) to wind speed is evident comparing the modeled diurnal warming on May 24 and May 26 (Figure 12); recall from Figure 4 that the GEOS-FP system did not capture the switch of eastward to westward winds. These deficiencies and those also studied by Akella and Suarez, 2018, could be addressed by revisiting the parameterized form of the modeled diurnal warming profile: $\Delta T\_w(z)$.

In summary, the GEOS-FP and MERRA-2 near-surface meteorology and water temperatures were compared to Saildrone USV measurements in the Baja California region, during April-June 2018. Overall, there is a good agreement between observed data and the GEOS-FP and MERRA-2, for wind (Fig. 4), air temperature (Fig. 5) and air pressure (Fig. 6), and correlations summarized in Table 1. However, on select days significant differences were noted (e.g., meridional wind speed plotted in Fig. 4), in particular, a systematic bias of about 15 hPa for the air pressure (Fig. 6), and quick decay of diurnal warm layer after sunset (Fig. 10-12) were observed. Observations such as these provide high quality validation data for further improvement of GEOS-FP and MERRA reanalyses.

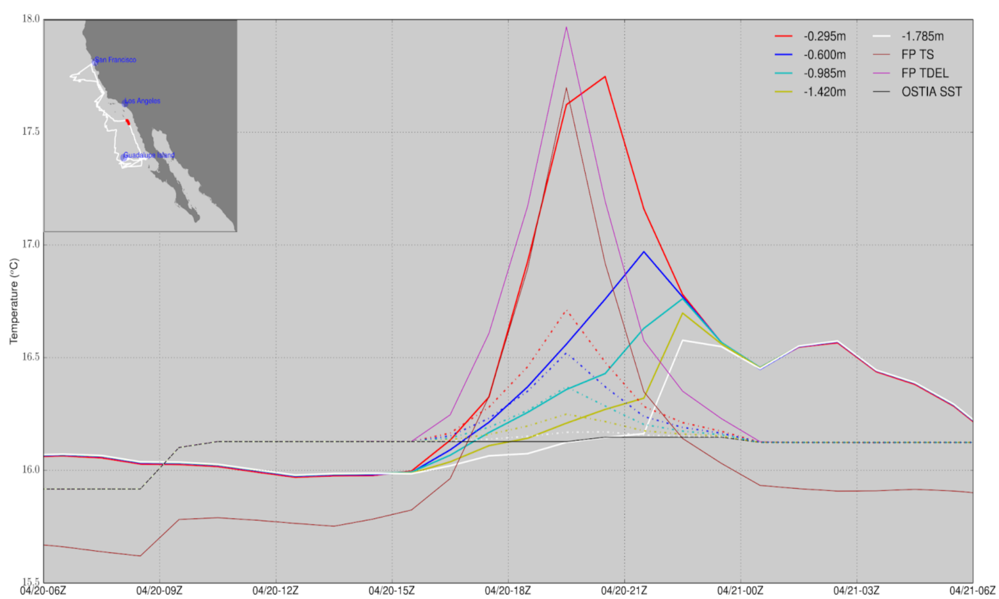

Figure 10. Comparison of near-surface measured and modeled temperatures between 06UTC April 20 and 06UTC April 21. Saildrone-measured (GEOS-FP) water temperatures are plotted with thick (dash) lines. Red, blue, cyan, yellow and white color lines depict temperatures at 0.295 m, 0.6 m, 0.985 m, 1.42 m and 1.785 m depths, respectively. For sake of completeness, we also show TS (brown) and TDEL (magenta) from GEOS-FP and the OSTIA SST (black). The inset shows the position of the saildrone in red colored line during this period.

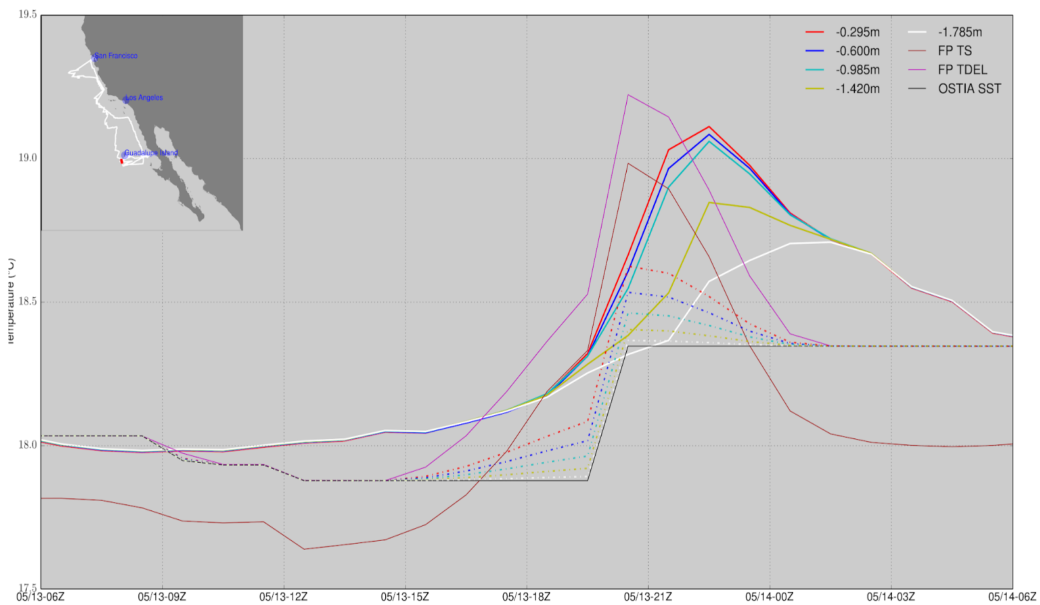

Figure 11. Same as Fig.10, but for the DW event observed around May 14, 2018.

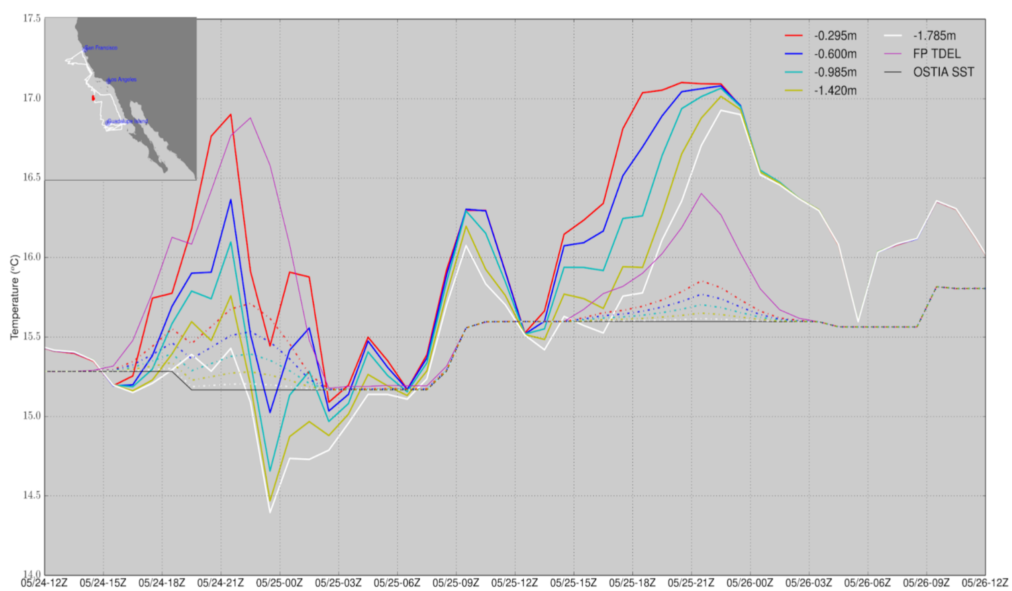

Figure 12. Same as Fig.10, but for the DW event observed around May 24-26, 2018.

Acknowledgements

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