



1 Introduction

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... M ... dr ... 1997 ...
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... M ... M ...
... dr ... 1996 ... 2001 ...
... a_{350} ... M ... 2001 ...
... CO_2 ... CO_2 ...
... Knępy and Cutter, 1994 ...
... 200 ... 2017 ... 200 ...
... 2015 ...
... CO_2 ...
... 1998 ... *in-situ* ...
... 1999 ... CO_2 ...
... 2000 ... CO_2 ... 2000 ... 1990 ...
... 2000 ...



M... 201... r... d... 2008... 5... 256... 5... 201... r... d... 5... 201... r... d...

2.5 Solid-phase extractable dissolved organic sulfur (DOS_{SPE})

... 50... 200... 50... 10... 2... 2008... 20... 5... 7... 100... 2... 15... 182... 1000... 5... 201... 2... 7... 28... 1... 26... 5... 6... 1... 0.015... 1... 89...

2.6 Shortwave radiation in the water column

... 18... 950... 25... 0... 8... 7... 6... 200... 60... 200... r... d... M... r... d... 60... 200... r... d... M... r... d... 200...



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2.7 Determination of gas diffusivity with microstructure profiles

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$\Phi_{dia} \approx \rho \cdot K_{\rho} \cdot \frac{\partial c}{\partial z}$

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2.8 Determination of OCS dark production rates

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$$15 \quad P_D = L_H = [OCS] \cdot k_h \quad (2)$$

1989

$$k_h = e^{(24.3 - \frac{10450}{T})} + e^{(22.8 - \frac{6040}{T})} \cdot \frac{K_w}{a[H^+]}$$

$$-\log_{10} K_w = \frac{3046.7}{T} + 3.7685 + 0.0035486 \cdot \sqrt{S}$$

20

$$\ln\left(\frac{P_D}{a_{350}}\right) = \frac{a}{T} + b \quad (5)$$

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2.9 Surface box models to estimate photoproduction rate constants

Surface box models were used to estimate photoproduction rate constants for C_2F_4 and C_2F_6 in the upper ocean mixed layer (MLD) during the 2017 cruise. The model was also applied to data from 1989 and 2001 cruises, and compared with *In-situ* measurements from 2000. The model was used to estimate the photoproduction rate constant k_{photo} for C_2F_4 and C_2F_6 in the MLD.

$$\frac{dc_{photo}}{dt} = \int_{MLD}^0 UV \cdot a_{350} \cdot p \quad (6)$$

The photoproduction rate constant k_{photo} was estimated from the *In-situ* measurements of C_2F_4 and C_2F_6 in the MLD. The model was used to estimate the photoproduction rate constant k_{photo} for C_2F_4 and C_2F_6 in the MLD.

The photoproduction rate constant k_{photo} was estimated from the *In-situ* measurements of C_2F_4 and C_2F_6 in the MLD. The model was used to estimate the photoproduction rate constant k_{photo} for C_2F_4 and C_2F_6 in the MLD. The model was used to estimate the photoproduction rate constant k_{photo} for C_2F_4 and C_2F_6 in the MLD.

The photoproduction rate constant k_{photo} was estimated from the *In-situ* measurements of C_2F_4 and C_2F_6 in the MLD. The model was used to estimate the photoproduction rate constant k_{photo} for C_2F_4 and C_2F_6 in the MLD. The model was used to estimate the photoproduction rate constant k_{photo} for C_2F_4 and C_2F_6 in the MLD.

2.10 1D water column modules for OCS and CS₂

1D water column modules were used to estimate the photoproduction rate constants for OCS and CS₂ in the upper ocean mixed layer (MLD) during the 2017 cruise. The model was also applied to data from 2001 and 2005 cruises, and compared with *In-situ* measurements from 2000. The model was used to estimate the photoproduction rate constant k_{photo} for OCS and CS₂ in the MLD.

The photoproduction rate constant k_{photo} was estimated from the *In-situ* measurements of OCS and CS₂ in the MLD. The model was used to estimate the photoproduction rate constant k_{photo} for OCS and CS₂ in the MLD. The model was used to estimate the photoproduction rate constant k_{photo} for OCS and CS₂ in the MLD.

The photoproduction rate constant k_{photo} was estimated from the *In-situ* measurements of OCS and CS₂ in the MLD. The model was used to estimate the photoproduction rate constant k_{photo} for OCS and CS₂ in the MLD. The model was used to estimate the photoproduction rate constant k_{photo} for OCS and CS₂ in the MLD.



00 d r d d d d d d d r d r r d in-situ
d r d r d d r r d r in-situ M
d r d r d r d r d r d
r d d r d r 1995 r d d r d 1998 r r₂ dd
5 r d r p r 6 d d r r M 2
d d d

dd r r r d r r r d d r r r r r₂ r
d r r r r r r d d r d r r r r d
r r r r r r r d r r r r r r r
10 d r 1 r r r₂ r r r d r r r r r r r r r 98 r 98 d
98 r d 2 r r₂ r d r r r d r r r
r r r r r r r r r d r r r r r r
r₂ r r d d r d r r r r r r r r r
r r r r r r₂ d r r d r

15 r d r d r r r r₂ r r r r r r r r r d r d
r r r r d r r r r d r r r r 10 r 25 r r r 98 r d
25 50 d r 98 d r r r d r d r r r r r r r r r r r r r r
r r r r 5 r d r r r r r r r r r r r r r
r d r r r r r r r r r r r d r r r r p
20 r r r r r r r r r r r 1 r d r r r r r r 1998
d r r r r r r r r r r d r r d 2 r r p
d r r r r d r r r r 6 r r r r r r r r r r r r r r
dd r r r r r r r

r r r r d r r 1 r r r d r r d r r d
25 r r r r r 2

3 Results

3.1 CDOM, FDOM and DOS_{SPE}

M d r
r r r r r r 50 r r a₃₅₀ 0 15 0.0 r r r r r r r r r
0 d r r r r d r r r r d r r r r r 17/20 r r 2 r r r r d r r r r r r r r r r r
r r r r r r r 201 r



...r d ... M ... r ... d ... d ...
... l ... d ... r ... M ...
... r ... r ... d ... 2007 ... 2 ...
... M ... M ... r ... d ... r ...
5 ... d ... r ... r ... r ... d ... r ... 2 ...
... 2 ...
... r ... d ... r ... r ... 0.16 ... 0.05 ...¹ ...
... r ... d ... 16 ... r ... d ... d ...
... r ... 2 ... r ... d ... r ... d ...
10 ... r ... d ... 2016 ...

3.2 Carbonyl Sulfide (OCS)

3.2.1 Horizontal and vertical distribution

... r ... r ... d ... 6 ... 1 ...¹ ... r ... 0.5 ...¹ ...
d ... r ... 2017 ... r ... r ... d ... r ...
15 ... r ... 8 ... 12 ... d ... r ... d ... 16 ... 2 ...
... d ... r ... d ... 2 ... 7 ... d ... 18 ... 10 ...¹ ...
... r ... 7 ... d ... 18 ... r ... d ...
... r ... d ... 5 ... d ... r ...
... r ... d ... 75 ... d ... r ... r ...
20 ... d ... 6 ...

3.2.2 Dark production

... d ... r ... d ... 0.86 ... d ... 1.81 ...¹ ...¹ ...
... d ... 0.16 ... d ... 0.81 ...¹ ...¹ ... 50 ...
... d ... r ... d ... r ... 5.66 ... 10⁻¹⁰ ...
25 ... r ... d ... r ... d ... r ... d ... r ...
...

$$P_b = a_{350} \cdot \exp\left(-\frac{15182}{T} + 53.1\right) \quad \square \quad \square \quad \square$$

... r ... d ... M ... r ...₂ ... d ... a_{350} ... 5 ... d ...
r ... d ... 50 ... d ... 6 ... r ... r ... d ... r ...
... d ... a_{350} ...



$P_D = a_{350} \cdot \exp\left(-\frac{16692}{T} + 58.5\right)$

3.2.3 Diapycnal fluxes

$P_D = 85.8 \cdot [FDOM\ C2] + 828.76$

3.2.4 Photoproduction

$p = 85.8 \cdot [FDOM\ C2] + 828.76$

$p = 85.8 \cdot [FDOM\ C2] + 828.76$



3.3 Carbon Disulfide (CS₂)

3.3.1 Horizontal and vertical distribution

CS₂ concentrations were measured at M... 178... 89...
... 7... 2015...
5... CS₂... 2... 2...
... CS₂... 2... 5... 18...
... CS₂... 200... 1... 1... 20...
10... CS₂... 15... 18... 10...
... CS₂...
... CS₂...

3.3.2 Diapycnal fluxes

CS₂... 18...
15... CS₂... *in-situ*... 2... 7... 18... *in-situ*...
... CS₂... 2... 5... 18...
... CS₂... M... 7... 6... 10¹¹... 10¹¹... 9... 10¹¹... 0.98...
2... 5... 7... 18... 1... 1... 18...
... CS₂... 0.98... 1... 0...¹...²...

20 3.3.3 Photoproduction of CS₂

CS₂... 5... 70...
... CS₂... 0.05... 0.08...
25... 8... 5... M... 1... M...
... CS₂... 2... 5... 7...
... 1998... 6... 98...
... CS₂... 98... 98...
0... CS₂... 98... 2.5...¹... 6...



198d 198
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4 Discussion

4.1 Carbonyl Sulfide

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...6d... CO_2 ...
...00...
...1999...
... CO_2 ...
... CO_2 ...200...5 10...¹...20...¹...
...200...*in-situ*...
... CO_2 ...
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20 5 Summary and conclusion

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Figures

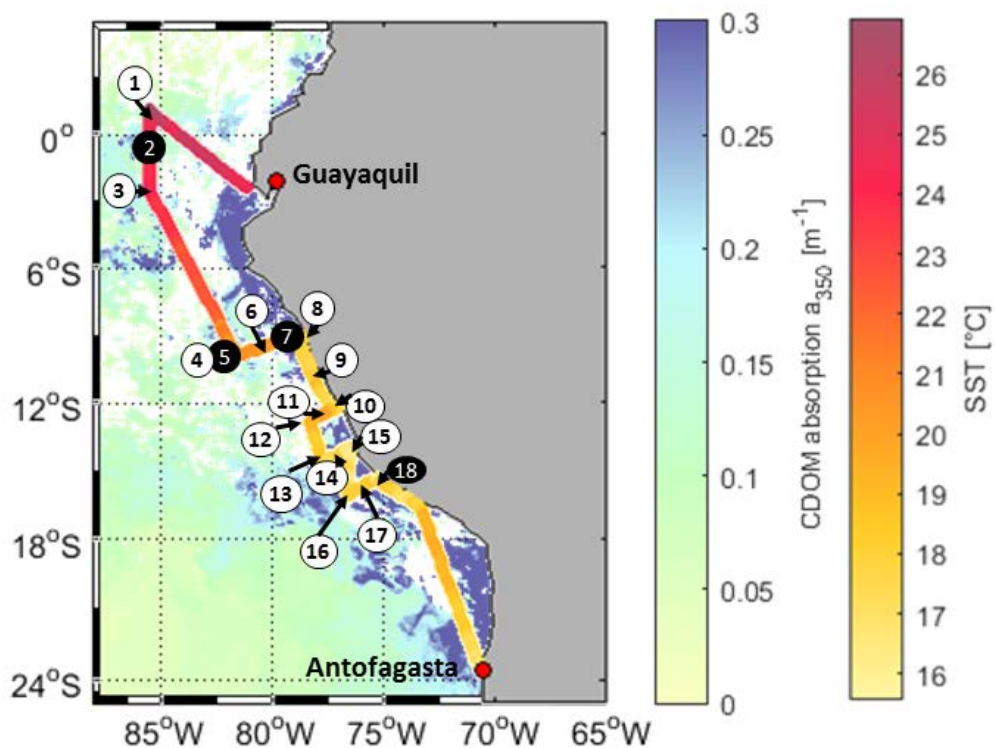


Figure 1: Cruise track of ASTRA-OMZ with stations 1-18 (in black circles: stations where OCS profiles were taken). The cruise track shows sea surface temperature (SST) measured onboard. For visualization only, the background is Aqua MODIS satellite data for the absorption of CDOM and detritus corrected from 443 nm to 350 nm with the mean slope of our *in-situ* measurements (0.0179, 300-450 nm, Aqua MODIS composite for October 2015). Note: As a monthly composite does not necessarily reflect the exact conditions during the cruise, *in-situ* measurements are illustrated in Fig. 2e. White areas: not satellite data available.

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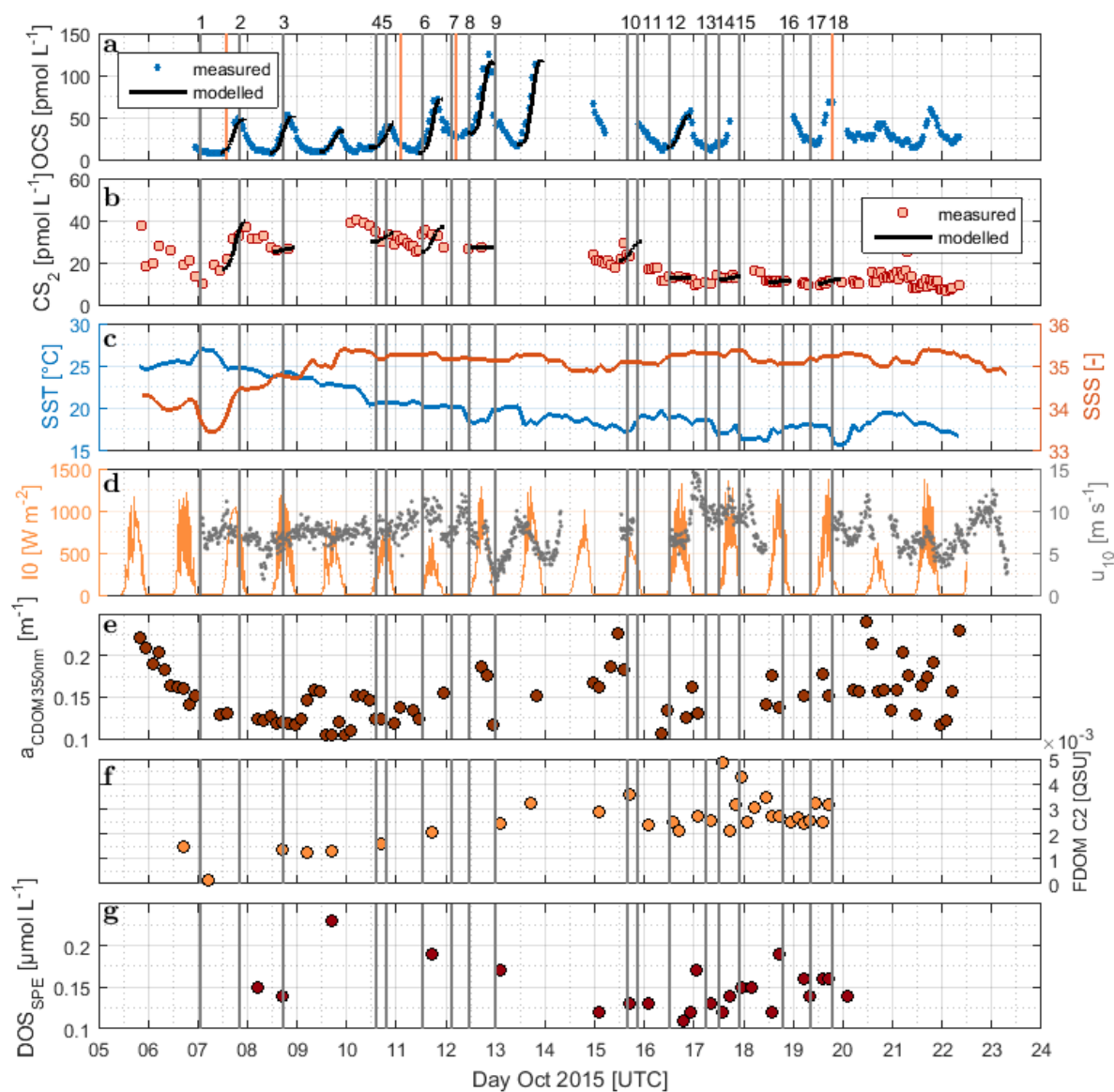
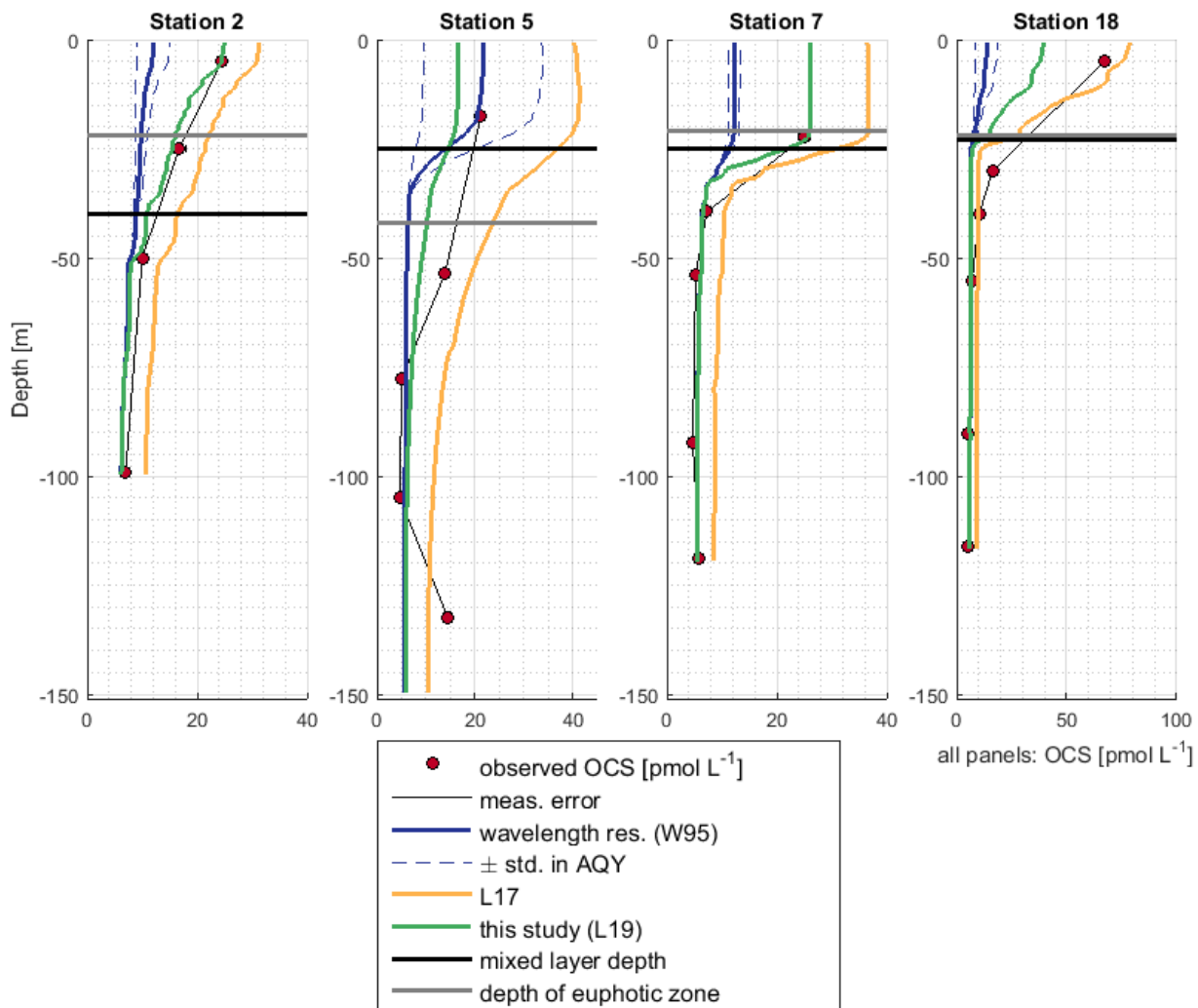


Figure 2: Time series of a) OCS, b) CS₂, c) SST and SSS, d) I₀ and wind speed at 10m, e) absorption coefficient of CDOM at 350 nm, f) humic-like FDOM component 2, and g) DOS_{SPE} sampled from the underway system along the cruise track of ASTRA-OMZ from 5 to 23 October 2018. Vertical lines indicate stations of ASTRA-OMZ for comparison with location (see Fig. 1).



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Figure 3: Profile measurements of OCS concentrations and 1D model results for the OCS model experiments described in Table 1.

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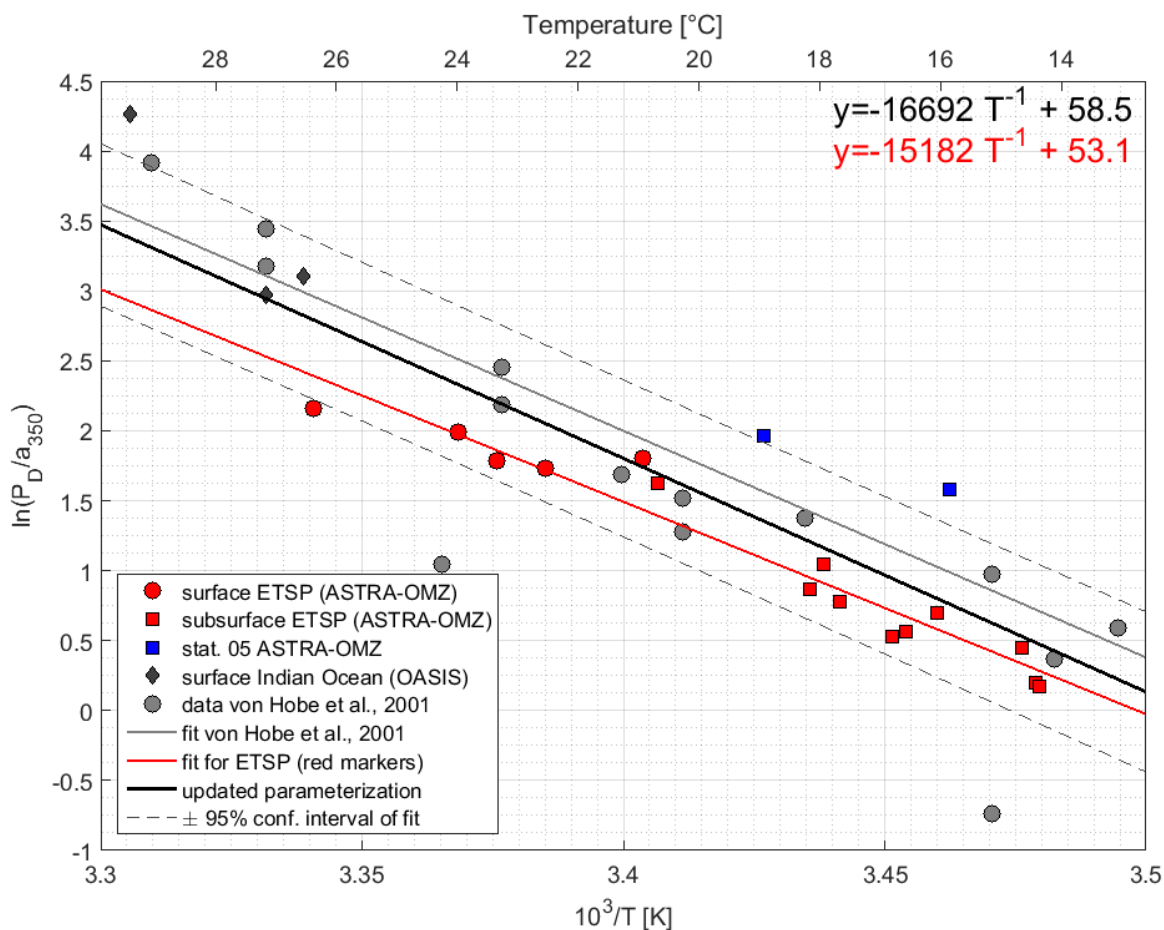
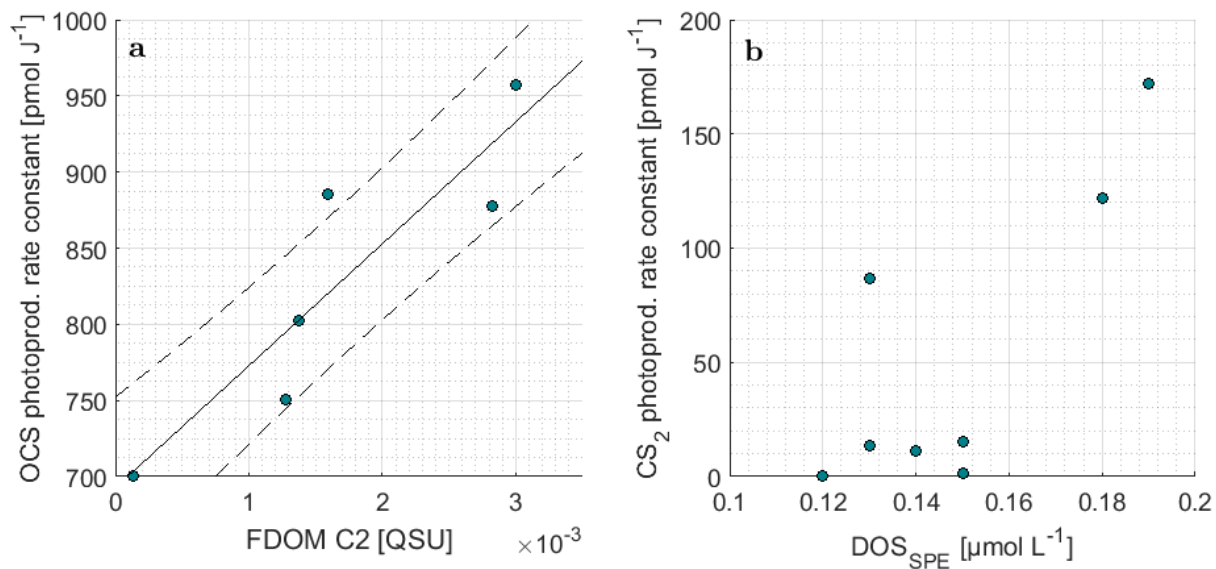


Figure 4: Arrhenius-plot of dark production rates from ASTRA-OMZ (this study, red and blue markers), data from the Indian Ocean (OASIS cruise, Lennartz et al. (2017)) and previously published rates (von Hobe et al., 2001, grey markers, note that P_D was converted from original units of $\text{pmol m}^{-3} \text{s}^{-1}$ to $\text{pmol L}^{-1} \text{h}^{-1}$, for reversion subtract 1.28). The red linear fit and equation shows the parameterization for ASTRA-OMZ only, whereas the black fit and equation is an updated parameterization including dark production rates from this and previous studies (see Von Hobe et al. (2001)).



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Figure 5: Correlations of the photoproduction rate constant from inverse surface box modelling for a) OCS and FDOM component C2 and b) CS₂ and DOS_{SPE}.

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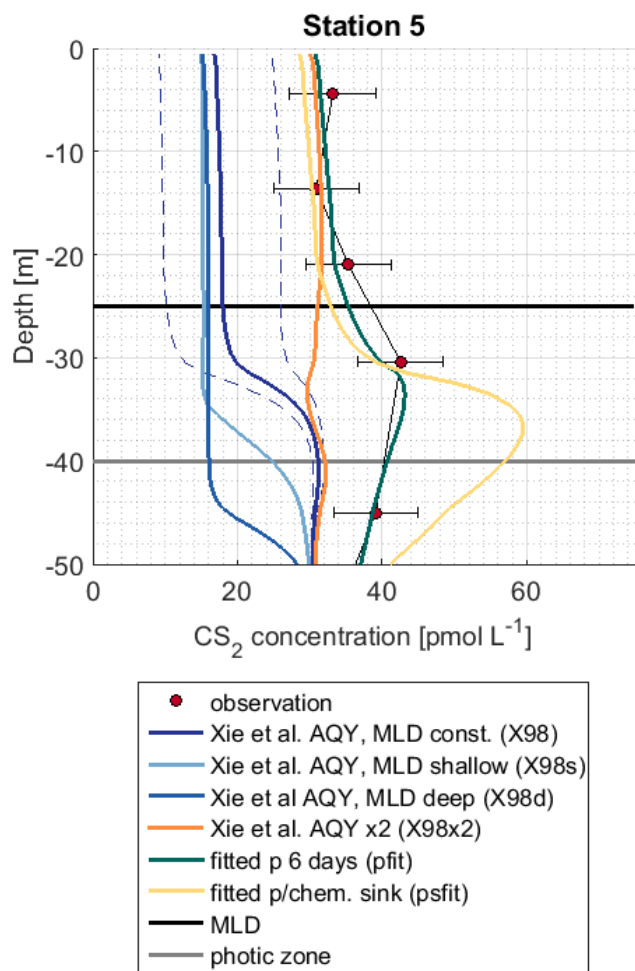


Figure 6: Observation and model sensitivity simulations at station 5. AQY=apparent quantum yield, MLD=mixed layer depth, chem. Simulation names in brackets refer to Table 1. Dashed lines indicate confidence interval of AQY as reported in Xie et al. (1998).

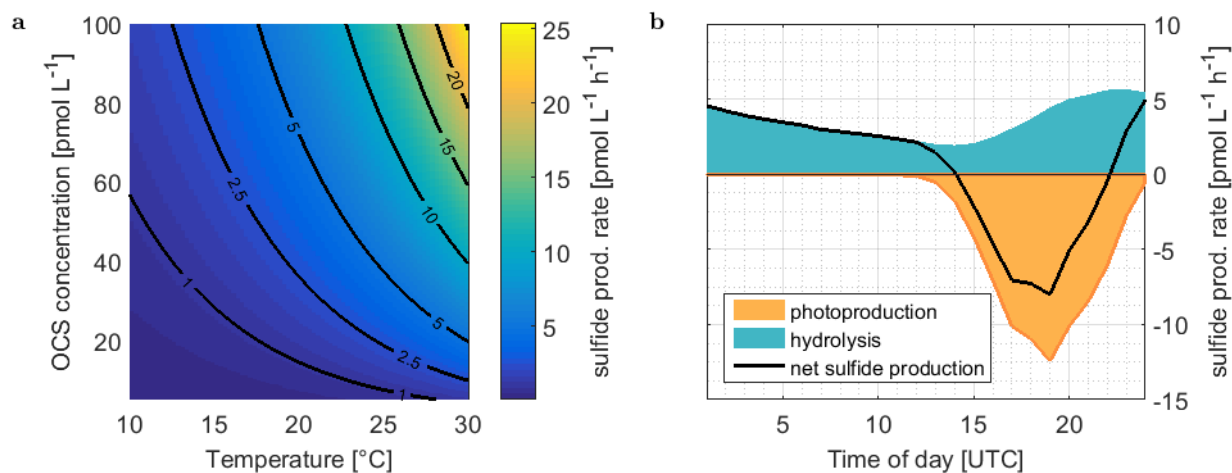


Figure 7: a) Rate of sulfide production due to OCS hydrolysis as a function of temperature and OCS concentration, calculated with eq. (3)-(4). b) Average consumption of S (organic or inorganic sulfide) by OCS photoproduction and production of sulfide during hydrolysis of ASTRA-OMZ (average 7 October – 14 October).

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