Notes on calculating surface temperature corrections for surface *f*CO_2 data

Andy Watson

In the Watson et al (2020) paper we correct surface fCO_2 data for two surface temperature effects, each of which alters the calculation of ocean-atmosphere flux in a different way.

tl;dr

1. Correct SOCAT intake fCO_{2w} to the subskin temperature using for example the takahashi rule of thumb as in the Holding et al product. Interpolations of fCO_2 are performed on these corrected data.
2. Calculate $C_w = S_{subskin}.fCO2_w$ at subskin T, where S is calculated at the subskin T and S.
3. calculate $C' = S_{skin}.fCO2_{atm}$ where S_{skin} is calculated at the skin temperature and salinity.
4. calculate flux $F = K.(C_w - C')$ where K is the gas exchange coefficient.

"Inlet-to-subskin temperature correction":

There is an observed temperature difference between "inlet temperature" to which SOCAT data are corrected, and the "subskin" temperature (at around 0.2 – 0.5 m depth) as reported from remote sensing of SST, e.g. the "OISST" data product, described by Reynolds et al, (2007). This temperature deviation can be substantial and the subskin can be either warmer or colder than the inlet temperature, but on average it is colder by ~0.2 degrees C. Note that though satellites actually measure the surface "skin", the satellite SST products document the subskin temperature because they calibrate to in-situ ship and buoy data. Careful bias corrections are incorporated by Reynolds et al, to account for biases – with ship data especially, where engine-room intake or hull sensor data is typically biased warm.
This deviation has been recognised for several years and Holding et al (2019: https://doi.pangaea.de/10.1594/PANGAEA.905316) detail a correction and provide SOCAT fCO_2 corrected to OISST temperatures. They use the Takahashi et al (2003) "rule of thumb": $\Delta fCO_2=\exp(0.0423*\Delta T)$ to correct for this deviation. Though this is clearly not optimal, it is the same method that is used in SOCAT to correct from the equilibrator temperature (at which the fCO_2 is actually measured), to the "inlet" temperature. The Watson et al (2020) paper uses the Holding et al version of corrected SOCAT data to correct for the inlet-subskin difference.

Skin temperature flux deviation:

In addition, the cool (and salty) skin of the ocean affects the flux calculation. The flux is given by

$$F = K.(Cw - C')$$

where Cw, C' are the concentrations of dissolved CO_2 at the bottom and top respectively of the mass boundary layer, the top~100µm of the water column. If we know the fugacity, fCO_2, the concentration of dissolved CO_2 is given by $S.fCO2$ where S is solubility.
The concentration at the top of the boundary layer is given by equilibration with the atmosphere, e.g. $C' = S.fCO2atm$. where S is the solubility at the skin temperature and

salinity. We have calculated a (monthly, 1-degree) climatology of the skin temperature deviation from ESA CCI data (Merchant et al, 2019). There is no product available for salt deviation but we use +0.1 psu for the skin (salt effect is small however).
The concentration at bottom of the boundary layer is not measurable by conventional techniques, but Woolf et al (2016) give the argument that the best approximation to it is given by ($S.fCO2w$) at the subskin temperature.

REFERENCES

Holding, Thomas; Ashton, Ian G C; Shutler, Jamie D (2019): Reanalysed (depth and Temperature consistent) surface ocean CO_2 atlas (SOCAT) version 2019. PANGAEA, https://doi.org/10.1594/PANGAEA.905316

Merchant, C.J., Embury, O., Bulgin, C.E., Block, T., Corlett, G.K., Fiedler, E., Good, S.A., Mittaz, J., Rayner, N.A., Berry, D., Eastwood, S., Taylor, M., Tsushima, Y., Waterfall, A., Wilson, R., Donlon, C. Satellite-based time-series of sea-surface temperature since 1981 for climate applications (2019) Scientific Data, 6 (1), art. no. 223,

Reynolds, Richard W; Smith, Thomas M; Liu, Chunying; Chelton, Dudley B; Casey, Kenneth S; Schlax, Michael G (2007): Daily High-Resolution-Blended analyses for sea surface temperature. Journal of Climate, 20(22), 5473-5496, https://doi.org/10.1175/2007JCLI1824.1

Watson, A. J., Schuster, U. Shutler, J. D., Holding, T., Ashton, I., Landschützer, P. Woolf, D. K., and Goddijn-Murphy, L., Revised estimates of ocean-atmosphere CO_2 flux from surface data are consistent with ocean carbon inventory. Nature Communications 11, art no. 4422 (2020)

Woolf, David K; Land, Peter Edward; Shutler, Jamie D; Goddijn-Murphy, L M; Donlon, Craig (2016): On the calculation of air-sea fluxes of CO2 in the presence of temperature and salinity gradients. Journal of Geophysical Research: Oceans, 121(2), 1229-1248, https://doi.org/10.1002/2015JC011427