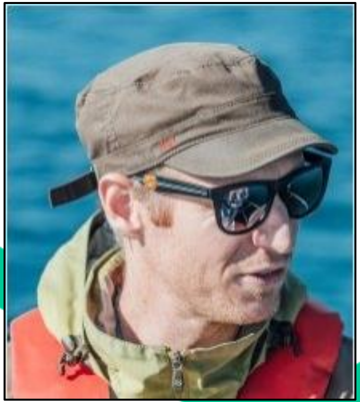
The increasing importance of sea surface data temperature records for global carbon assessments used to guide policy

(and how the carbon community is learning from the SST community and needs your help)

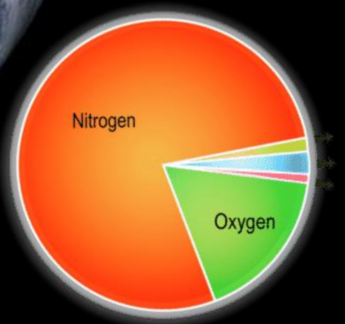
Jamie Shutler, Dan Ford



Eunice Foote
1856

Discovered the properties of green house gases

The importance of the oceans



Importance of the ocean

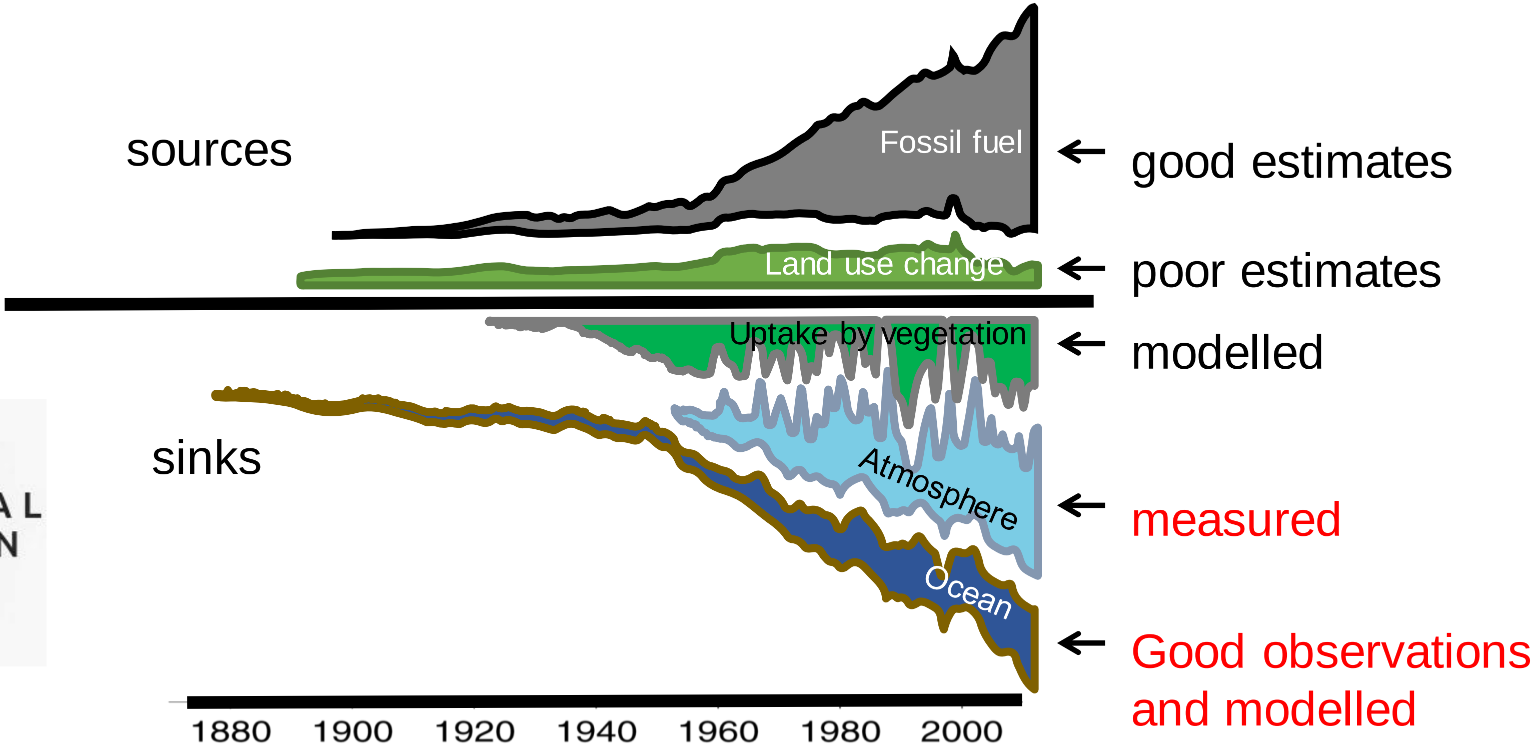
Global carbon budgets
The oceans and atmosphere provide the two main observational constraints on global carbon budgets use to guide policy.

Advising governments to guide and motivate action.

Food security and conservation
Identify regions and ecosystems at risk.

Global Carbon Budget – advising global policy

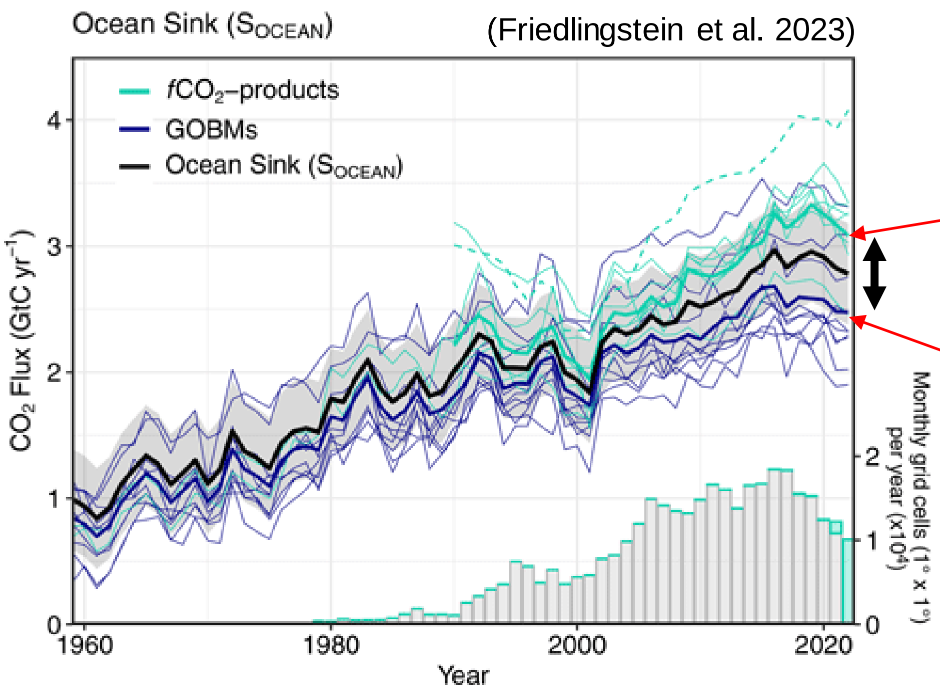
How uptake is partitioned between the atmosphere, land, and ocean



GLOBAL CARBON project

Ocean data and observations are a key constraint on global carbon budgets

Current ocean carbon sink estimates…



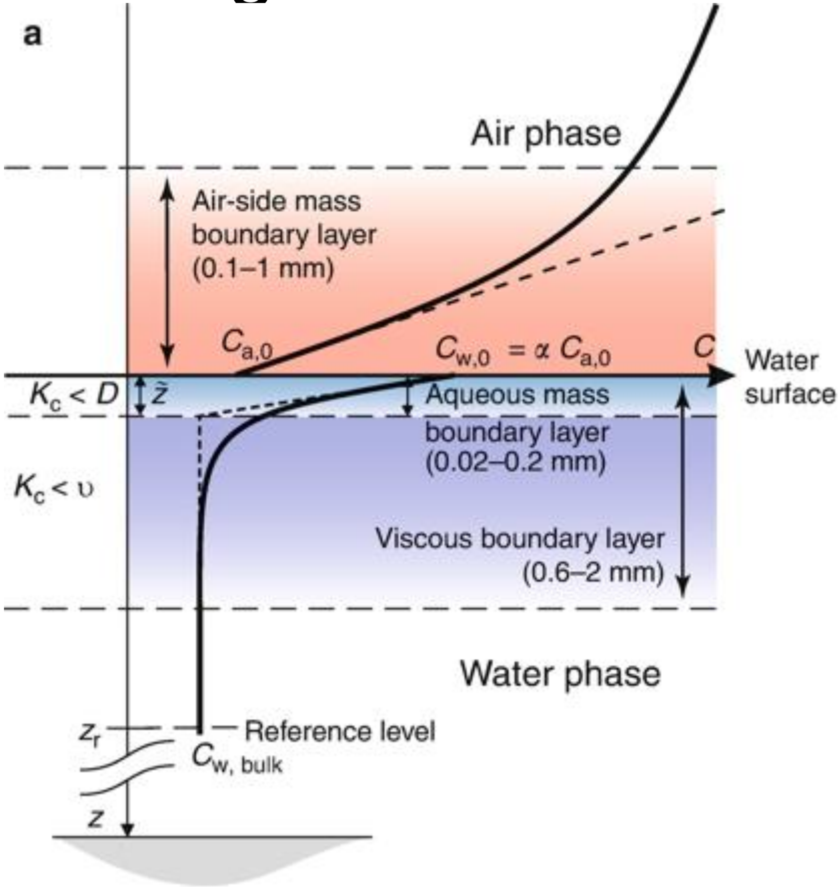
Is there a growing divergence between the observation-based products and global biogeochemical models?

Observation-based

Model-based

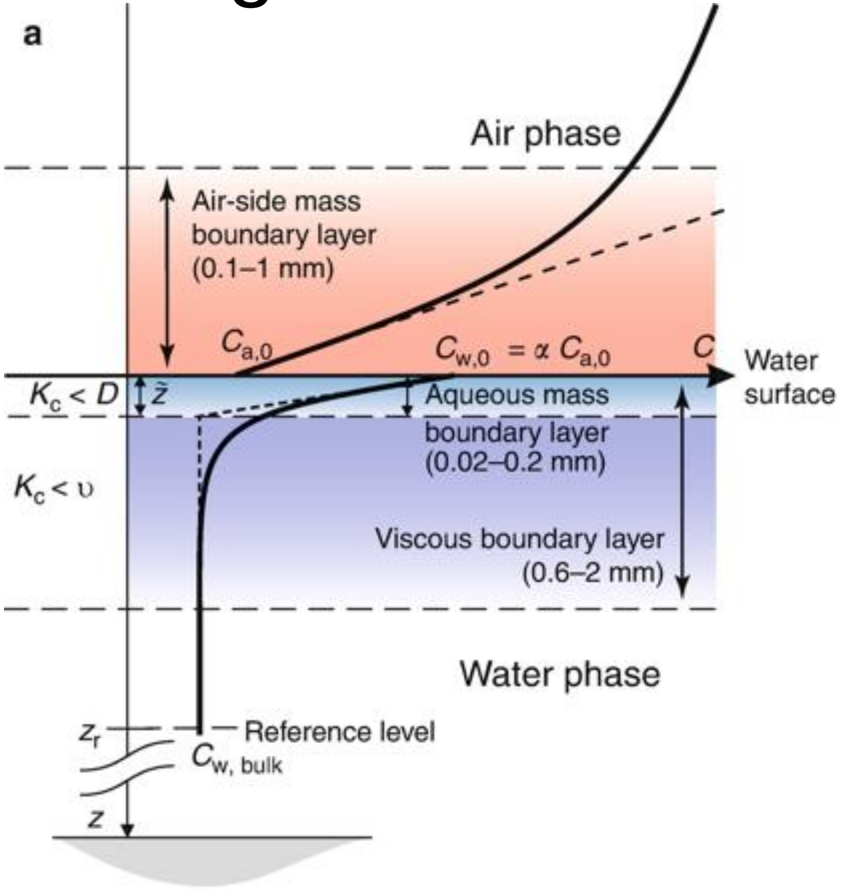
Growing realisation, the uncertainties for the observation-based products maybe underestimated…

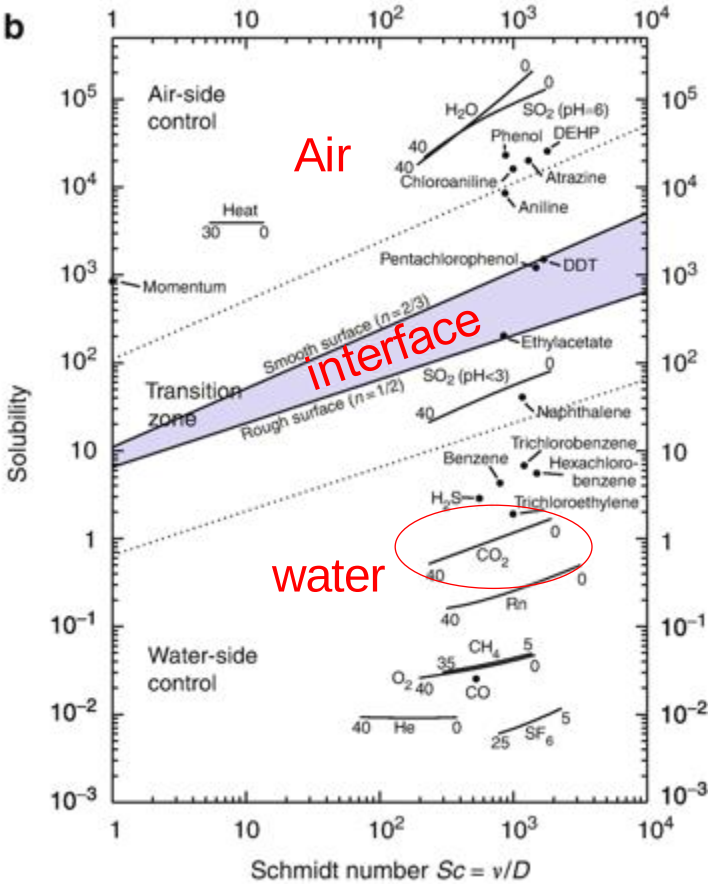
Exchange across the air-sea interface



Source: Transfer across the air-sea surface, (2013), *Springer*.

Exchange across the air-sea interface





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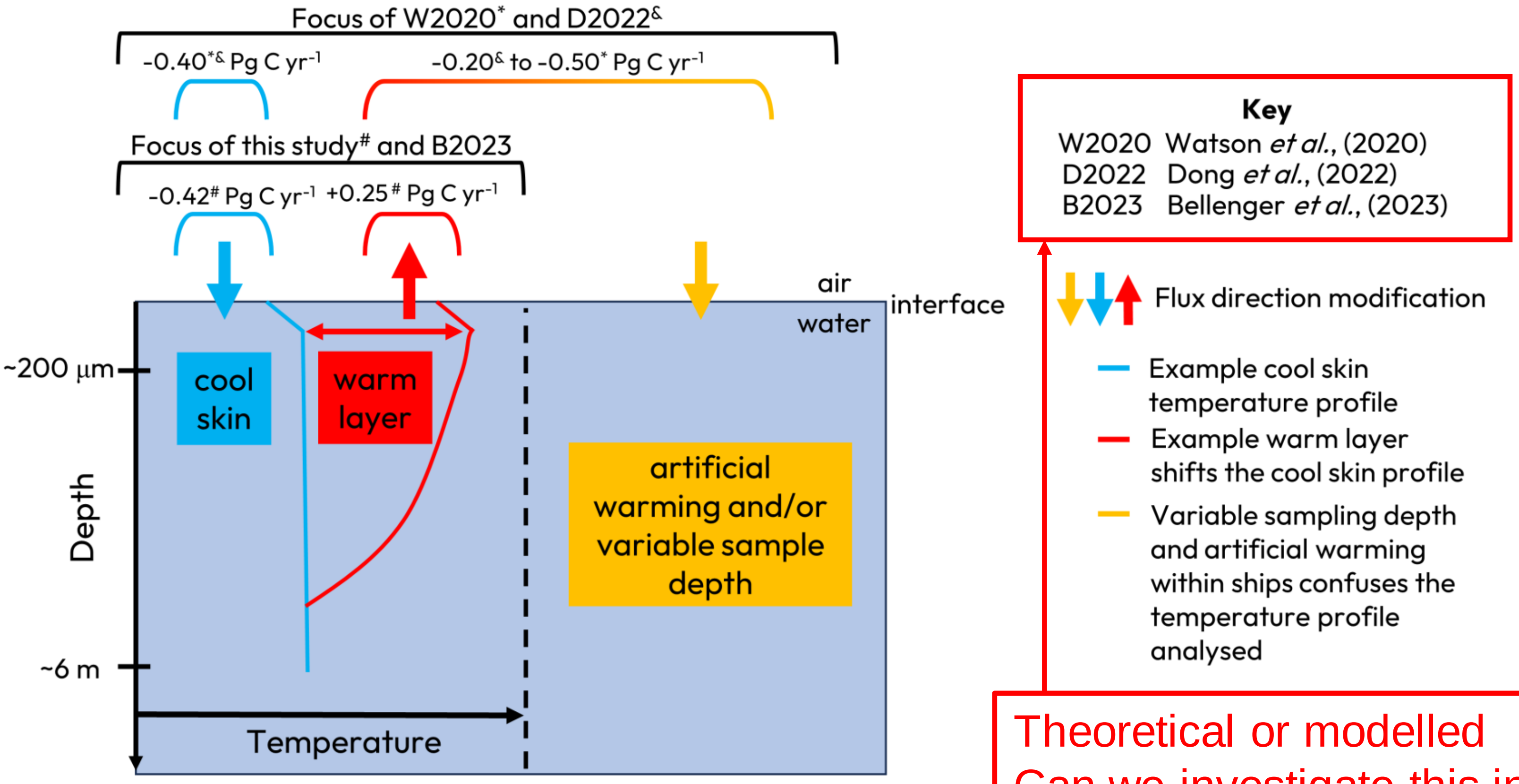
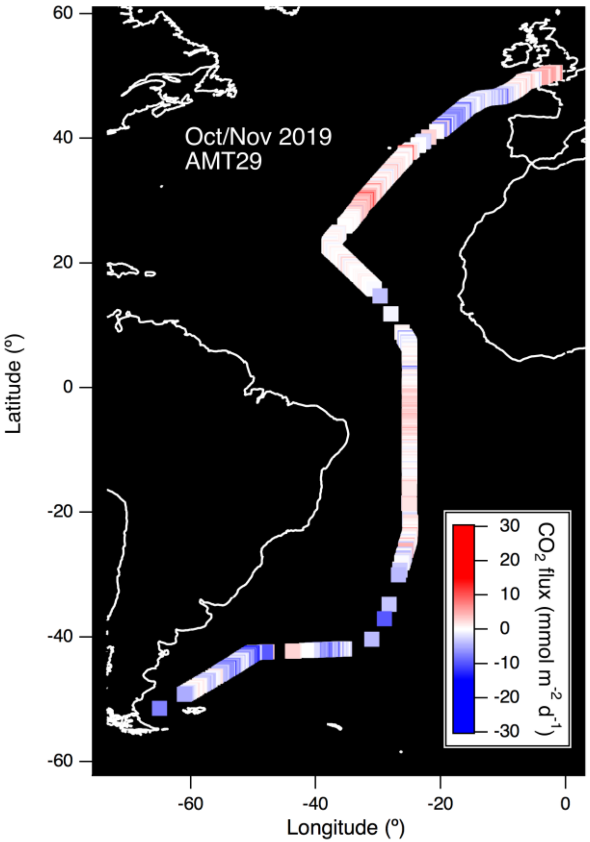
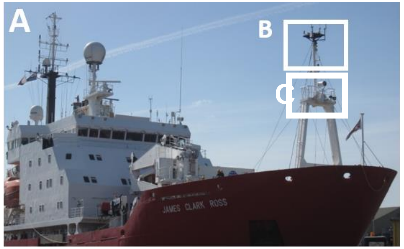
Competing near-surface temperature controls

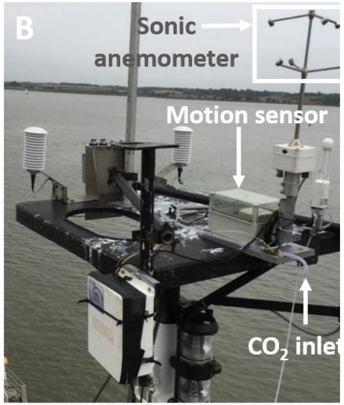


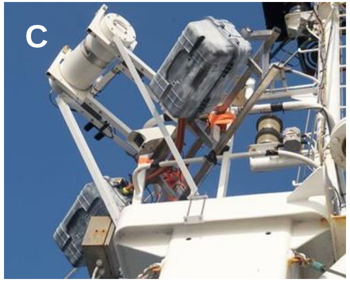
Theoretical or modelled
Can we investigate this in situ?

ESA OceanSatFlux and AMT4CO2Flux: *in situ* bulk and eddy covariance gas fluxes and SST skin









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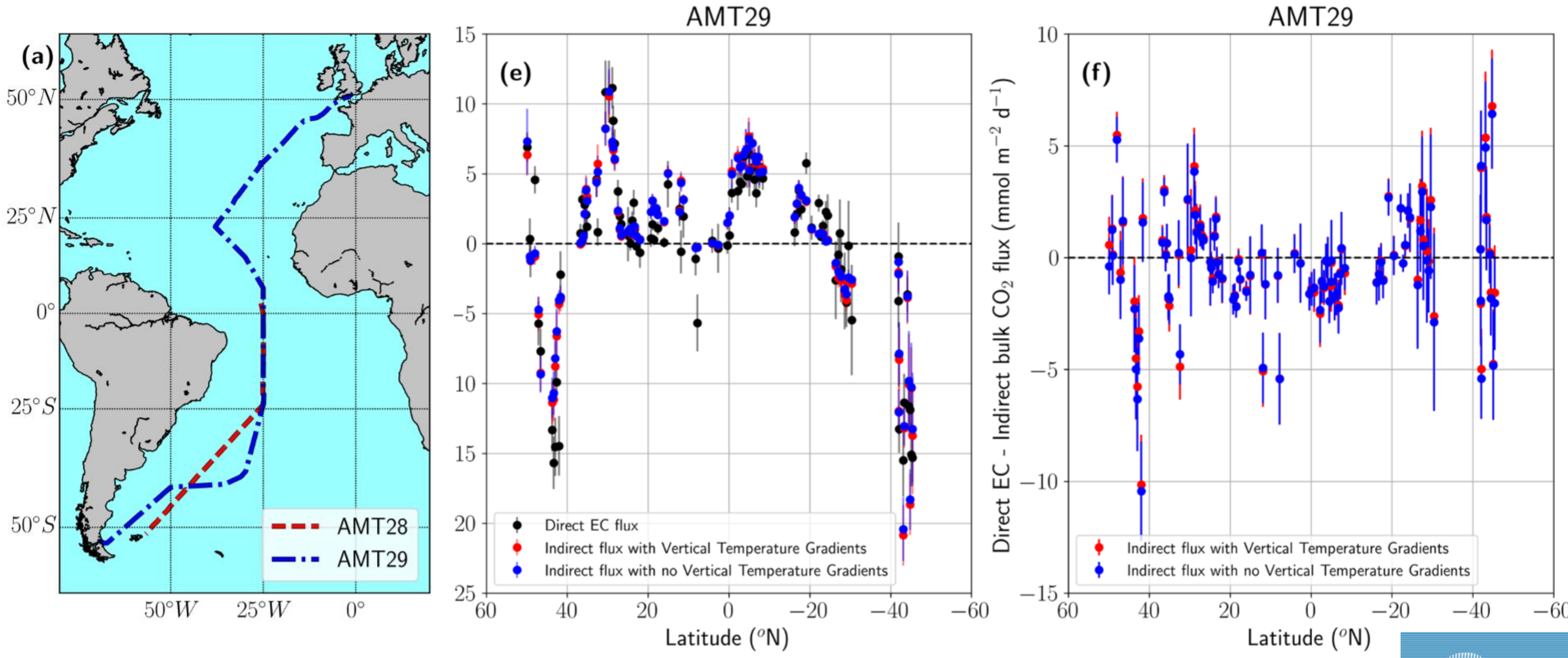
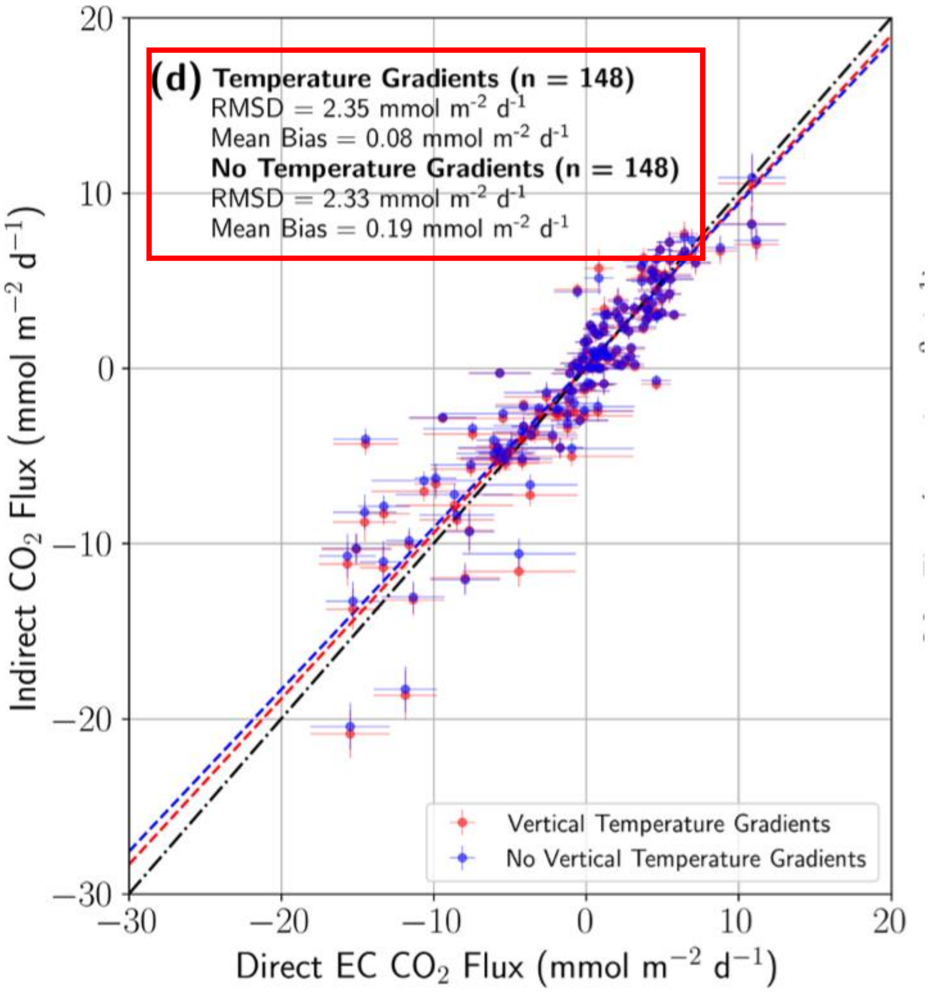


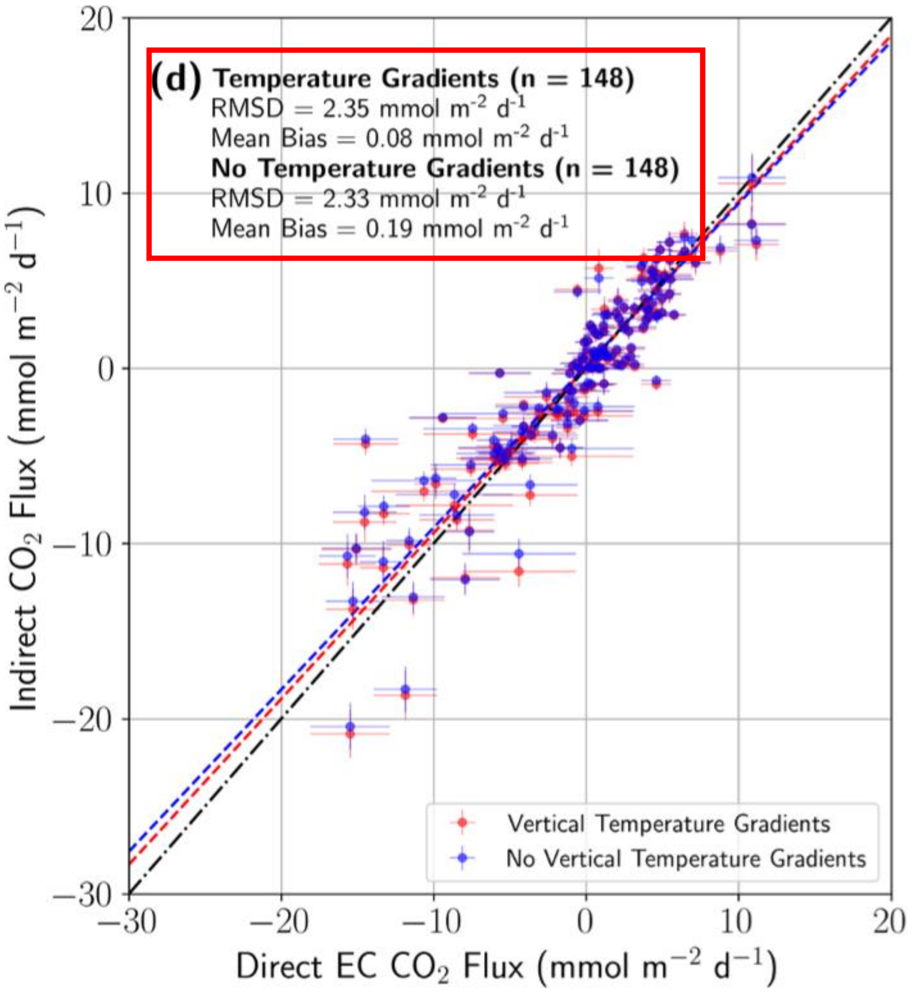
- Supports an increase in the Atlantic CO_2 sink of ~0.03 Pg C yr^{-1} (~7% of the Atlantic Ocean sink).



- Supports an increase in the Atlantic CO_2 sink of ~0.03 Pg C yr^{-1} (~7% of the Atlantic Ocean sink).

- Supports 0.18 Pg C yr^{-1} global bias due to neglecting natural vertical temperature gradients (~6 % underestimation of the global ocean sink).

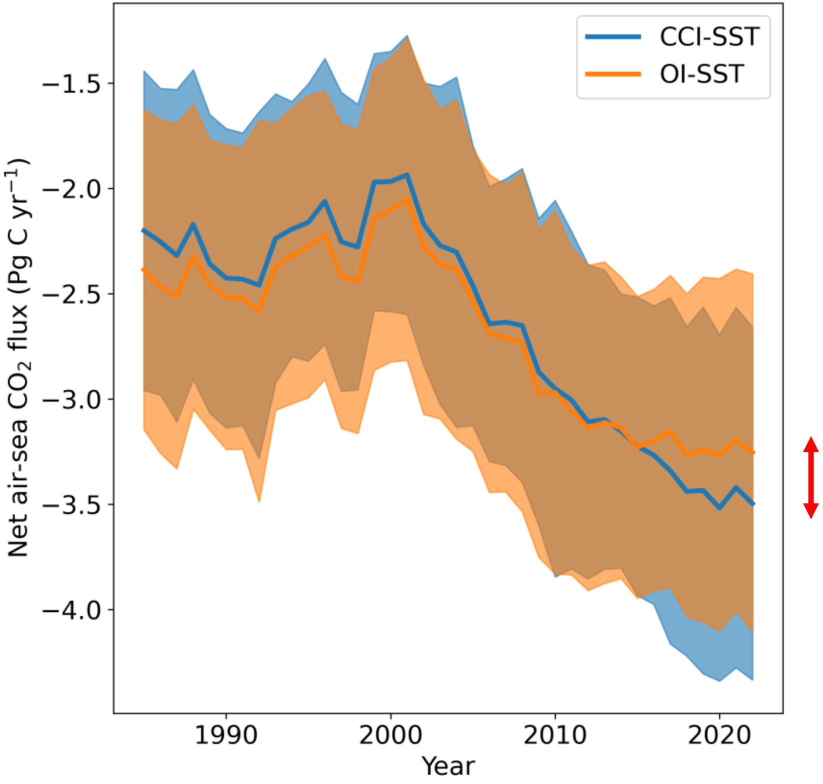
- Agrees with theory, lab work, previous observation-based global assessments and recent modelling study advances.



Which climate record should we use?

Most groups in the Global Carbon Budget assessments use OISST.

1980s to 2015 = CCI and OISST produce similar results.



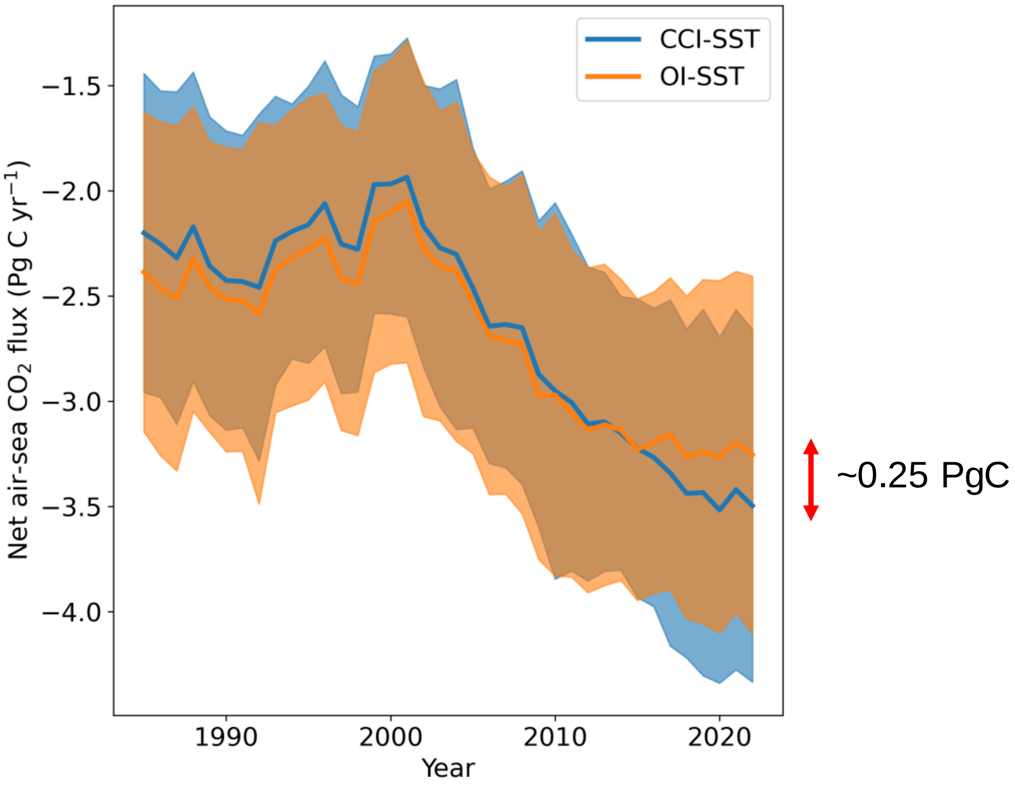
~0.25 PgC

Which climate record should we use?

Most groups in the Global Carbon Budget assessments use OISST.

1980s to 2015 = CCI and OISST produce similar results.

But OISST and CCI results diverge after 2015, causing a 8% change in ocean sink by 2022.



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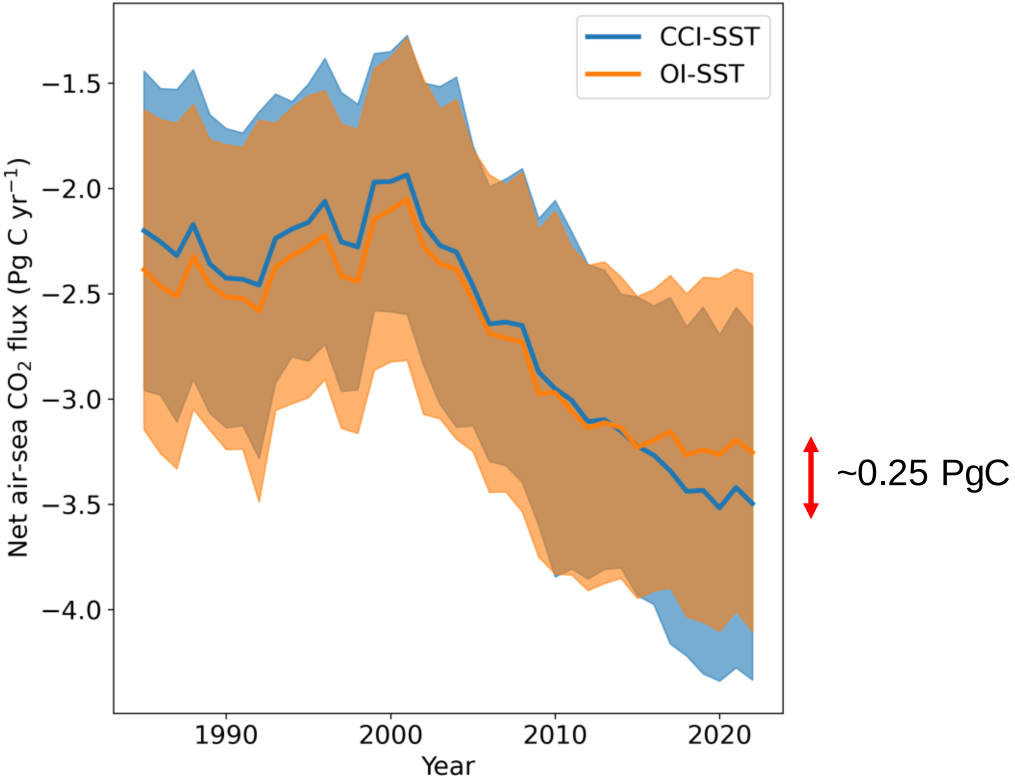
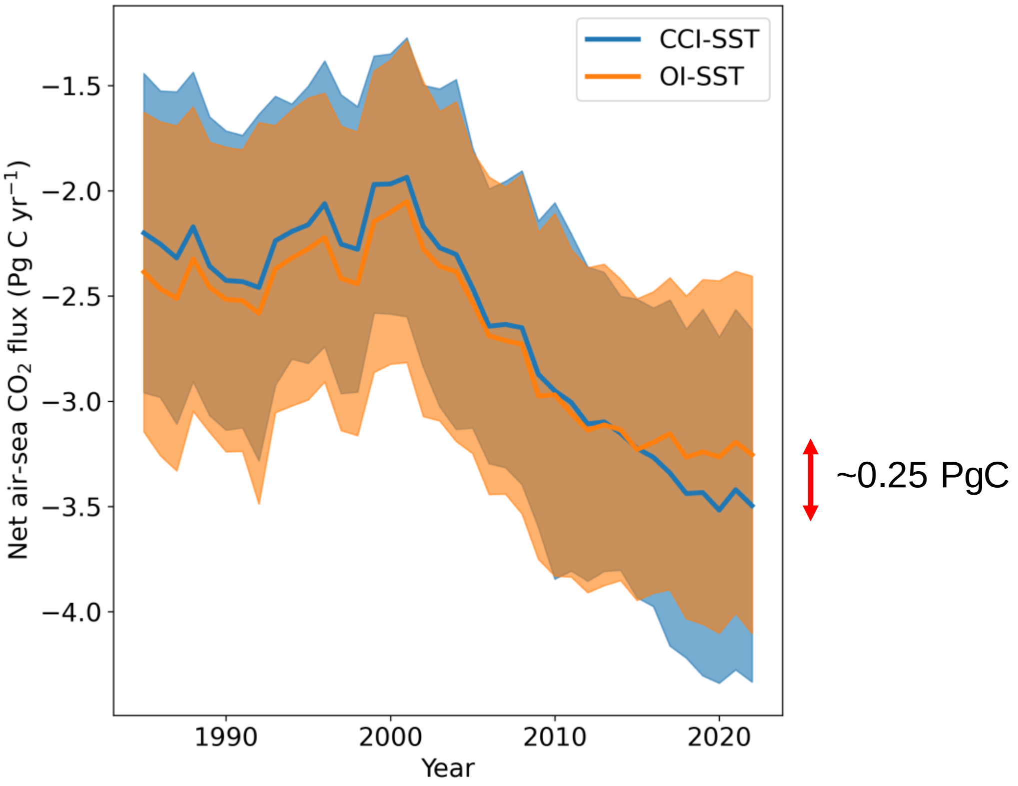
Global bias between OISST and CCI does not appear to change during this period, but regional changes in the temperate in northern latitudes and Southern Ocean could cause the observed discrepancy.



Which climate record should we use?

Global bias between OISST and CCI does not appear to change during this period, but regional changes in the temperate in northern latitudes and Southern Ocean could cause the observed discrepancy.

These regional biases increase from 2015 through to 2021, which combined with high gas exchange in polar regions could explain the shift between OISST and CCI results…



Standard framework for uncertainties

A need for complete uncertainty budgets has been identified and adopted by many fields in recent years

These uncertainty budgets assess all sources of uncertainty, however small the component may be

These uncertainty budgets follow the ethos of the BIPM (BIPM, 2008) developed by the metrology community.
Uncertainties are determined as either:
Type A: calculated uncertainties using standard propagation techniques
OR
Type B: uncertainty determined by other techniques/expert judgement

In situ observations as Fiducial Reference Measurement

- Ocean colour radiometers (Bialek et al. 2020)
- Skin temperature observations (Wimmer and Robinson. 2016)

Satellite based products

- Ocean Colour Climate Change Initiative (CCI) (Sathyendranath et al. 2019)
- Sea surface temperature CCI (Merchant et al. 2019)

Standard framework for uncertainties

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Type … …**ques**

Type… …**nent**

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Fiducial Refere…
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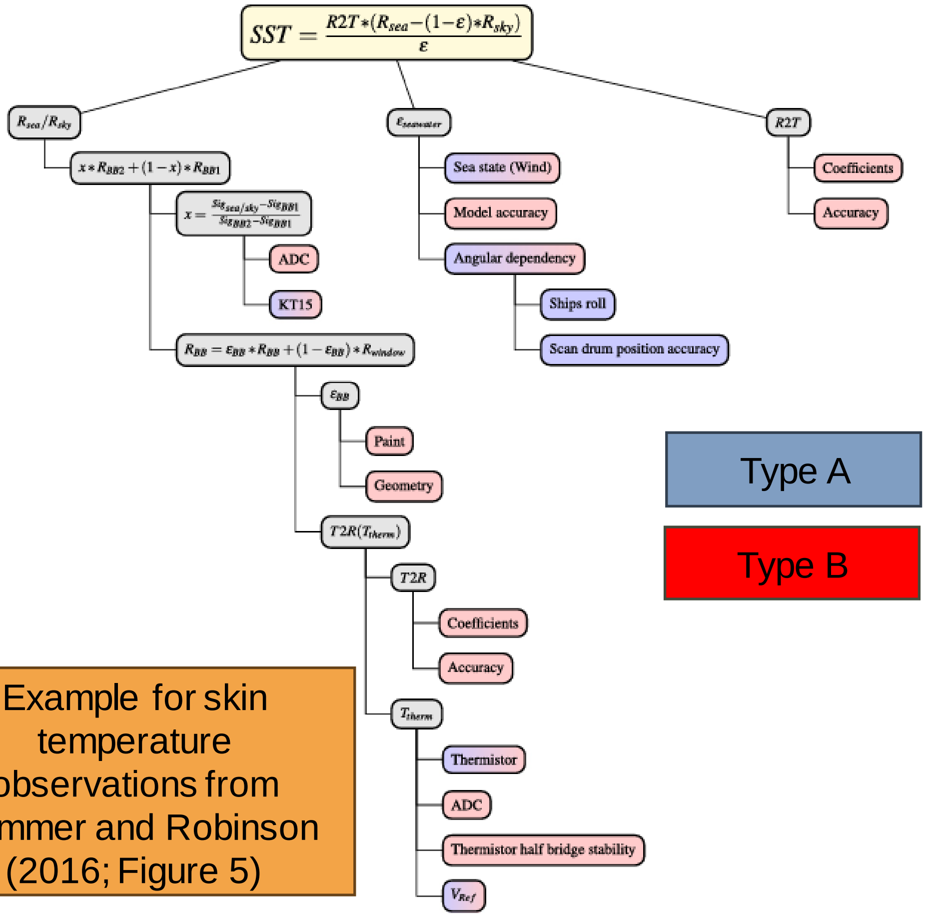
Sk… c… (… Ro…



Example for skin temperature observations from Wimmer and Robinson (2016; Figure 5)

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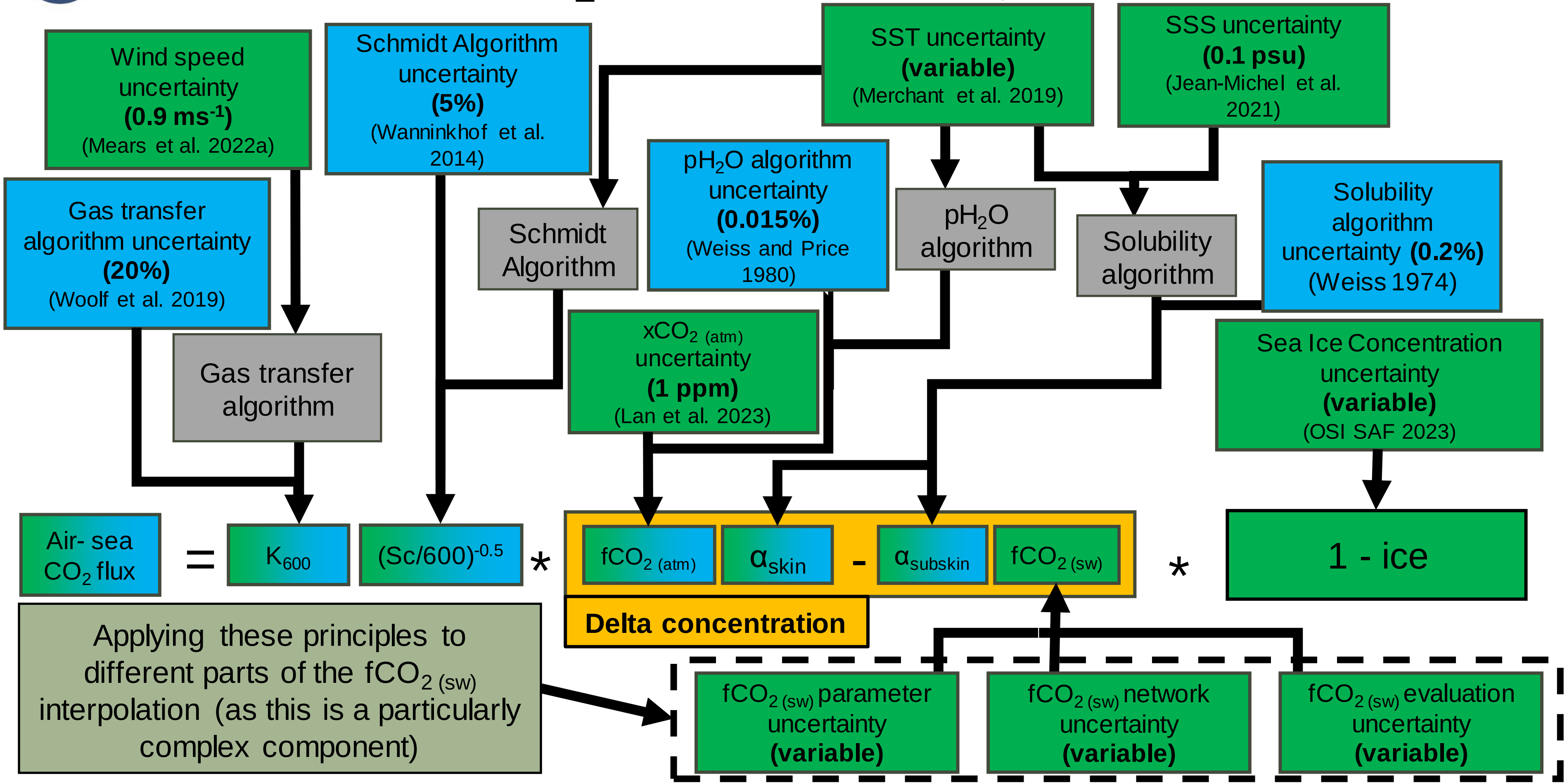
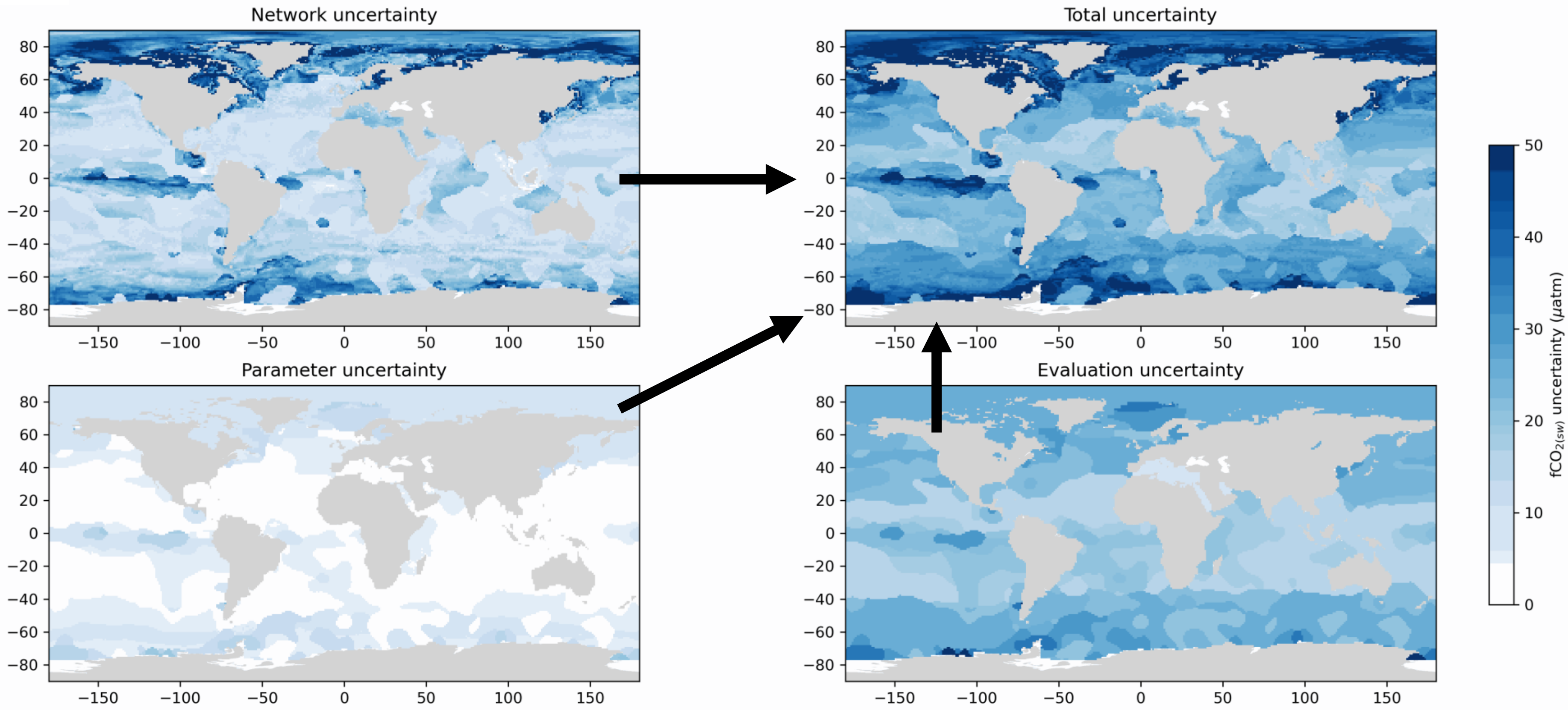
These principles and uncertainty framework can be applied to the air-sea CO_2 fluxes, data-product interpolation schemes and the global integrated ocean sink

The air-sea CO_2 flux uncertainty framework



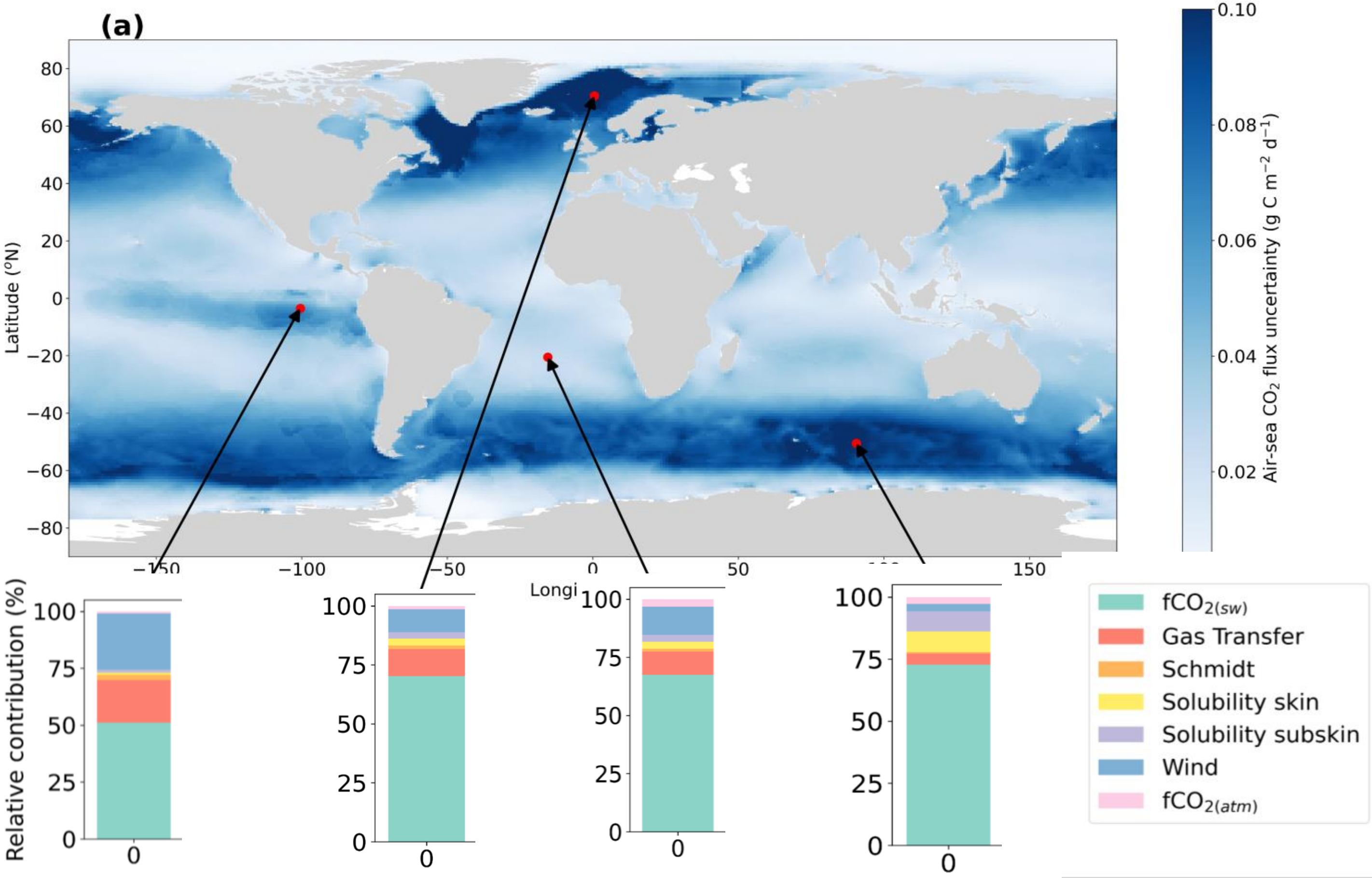
Spatial and temporal $fCO_{2\ (sw)}$ uncertainties



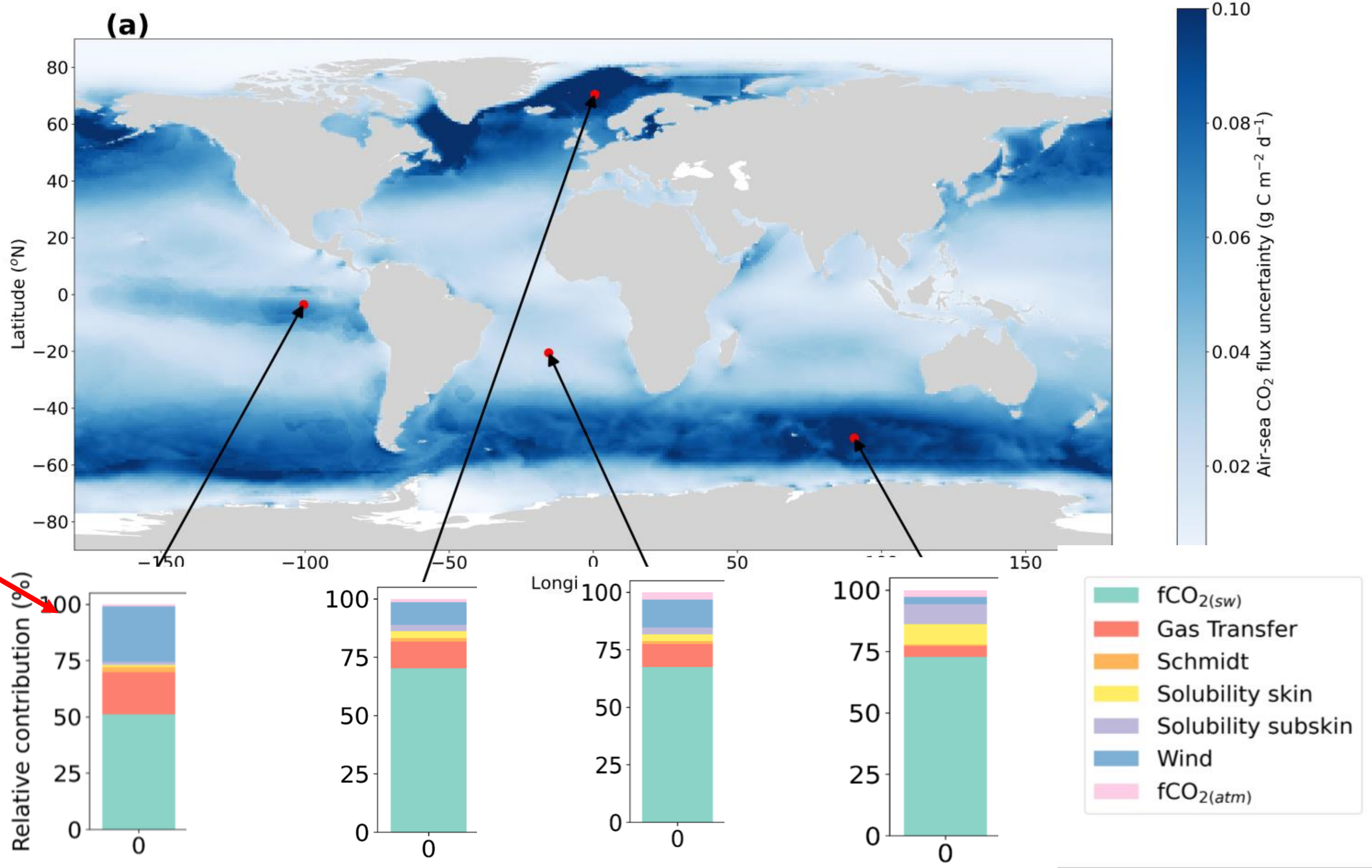
Dominance of each component to the total $fCO_{2\ (sw)}$ uncertainty varies spatially and temporally

Spatial and temporal air-sea CO_2 flux uncertainties

Significance of each uncertainty component varies in time and space

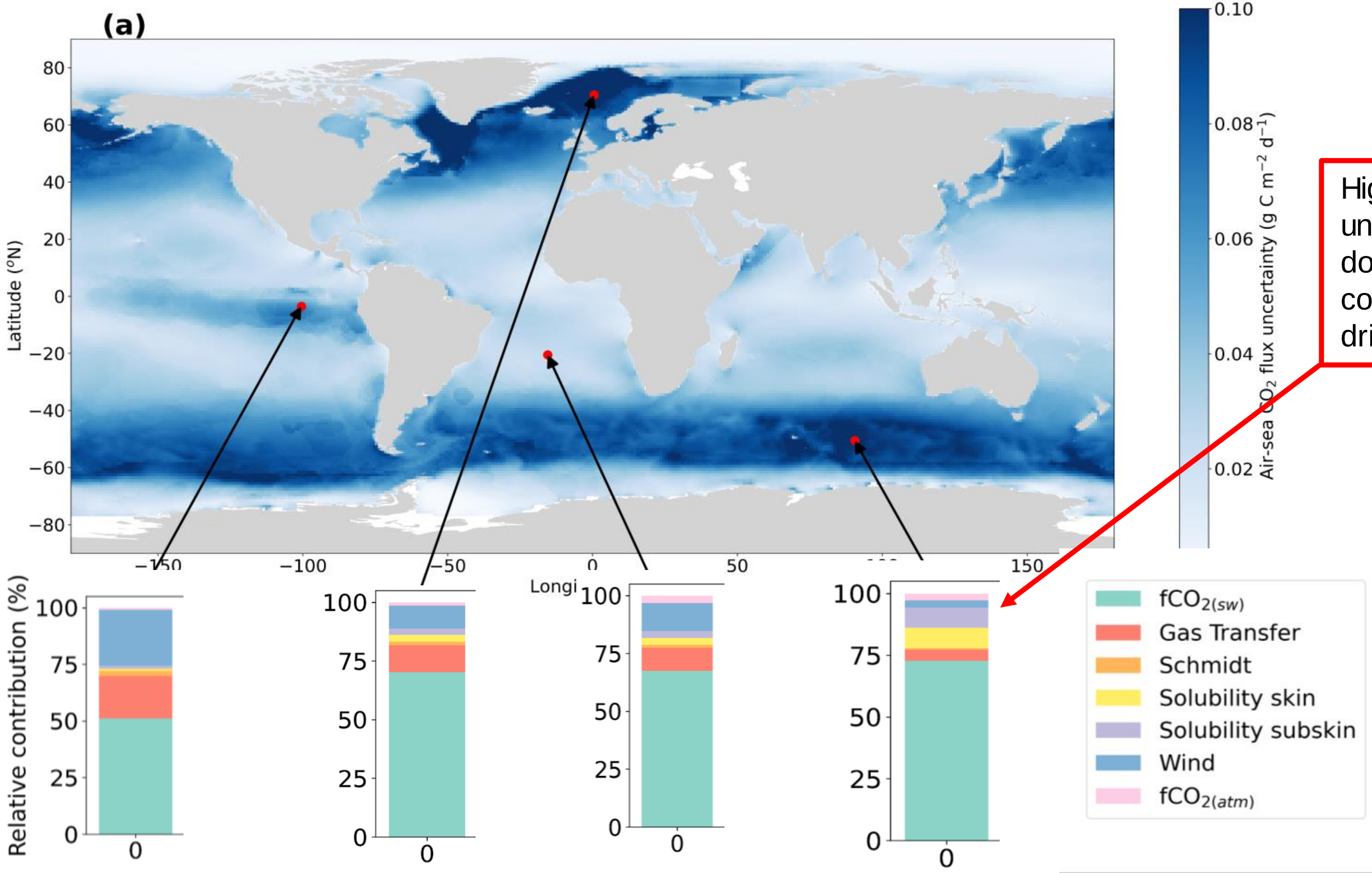


Spatial and temporal air-sea CO_2 flux uncertainties



Equatorial uncertainties have near equal split between components driven by wind and SST.

Spatial and temporal air-sea CO_2 flux uncertainties



Higher latitude uncertainties dominated by components driven by SST.

Conclusions

OceanICU
Understanding Ocean Carbon

- *in situ* evidence supporting theory of how near-surface temperature gradients alter atmosphere-ocean CO_2 gas fluxes and ocean carbon sink estimates.

Shutler, JD, *et al*., (2024). The increasing importance of satellite observations to assess the ocean carbon sink and ocean acidification. *Earth-Science Reviews*, *250*, 104682-104682

Co-funded by the European Union

UK Research and Innovation

This work was funded by the European Union under grant agreement no. 101083922 (OceanICU) and UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee [grant number 10054454, 10063673, 10064020, 10059241, 10079684, 10059012, 10048179]. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Research Executive Agency.
Neither the European Union nor the granting authority can be held responsible for them.

Conclusions

OceanICU
Understanding Ocean Carbon

- *in situ* evidence supporting theory of how near-surface temperature gradients alter atmosphere-ocean CO_2 gas fluxes and ocean carbon sink estimates.

- SST climate data records have diverged since 2015 influencing carbon assessments and resulting policy advice.
- Seems to be caused by regional biases at high latitudes.
- Conclusion supported by a comprehensive uncertainty assessment (spatially and temporally varying air-sea CO_2 flux uncertainties).

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- SST climate data records have diverged since 2015 influencing carbon assessments and resulting policy advice.
- Seems to be caused by regional biases at high latitudes.
- Conclusion supported by a comprehensive uncertainty assessment (spatially and temporally varying air-sea CO_2 flux uncertainties).

- Identifies the importance of the careful choice of consistent temperature data records.
- Need for SST community to help guide, support and collaborate with the carbon community (Shutler *et al.,* 2024, IOCCG, CEOS) through an expert guidance group.

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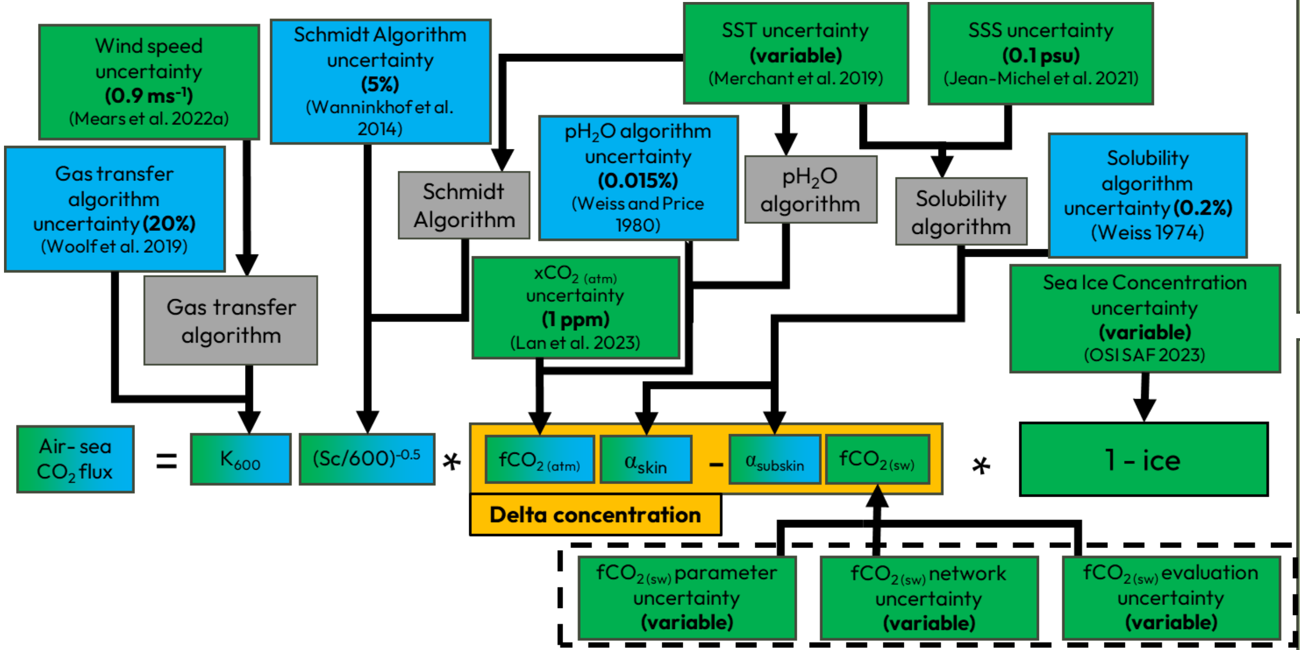
Integrating uncertainties (for the net sink result)

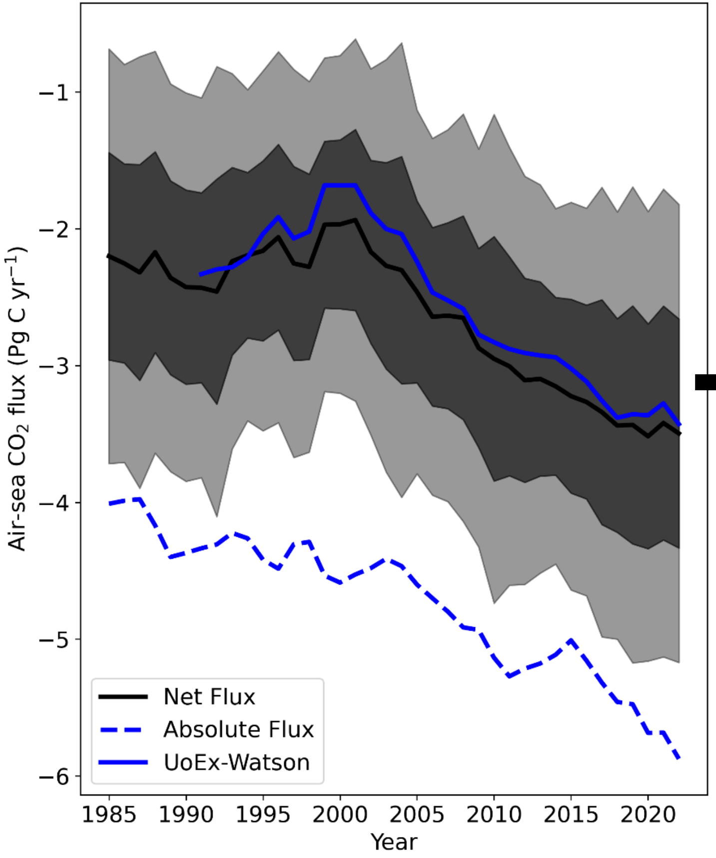
Integration of these uncertainty components globally is not a trivial matter. Some uncertainties are likely to be correlated globally (blue boxes), but others may only correlate regionally (green boxes) or locally

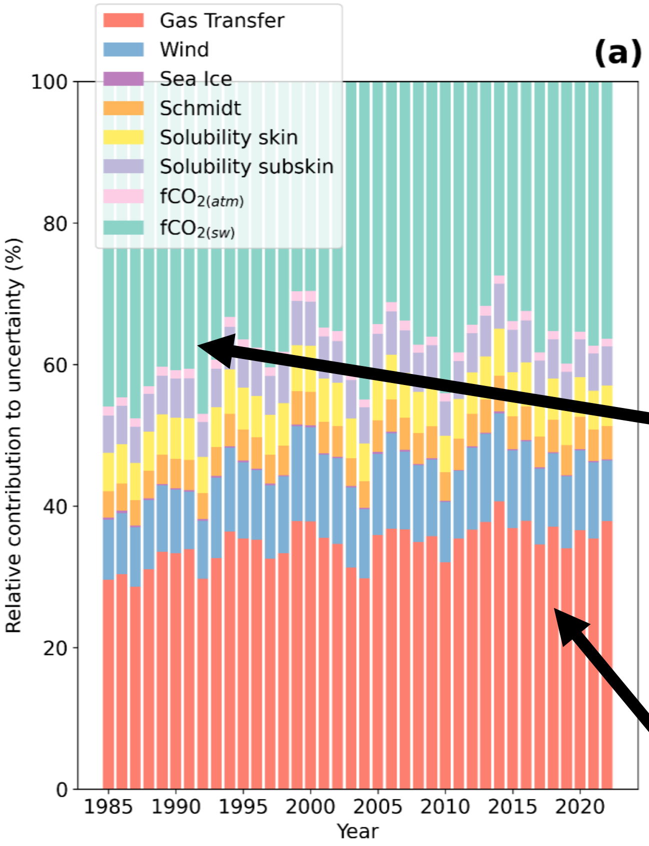


An estimate of the length scale that these spatially correlated components decorrelate at must be made

A semi-variogram analysis with a Monte Carlo propagation used to estimate these spatially correlated components

Integrating into global uncertainties





All components contribute to the uncertainty and their dominance changes in time

$fCO_{2\,(sw)}$ the dominant component before 2000

Gas transfer becomes the more dominant component in recent years

Integrating into global uncertainties

Component	This study (1σ) (Pg C yr^{-1})	GCB estimate (Pg C yr^{-1})
Gas transfer	0.47	0.2
Wind	0.14	0.1
Sea ice	0.003	N/A
Schmidt	0.06	N/A
Solubility skin	0.08	N/A
Solubility subskin	0.07	N/A
$fCO_{2\,(atm)}$	0.02	N/A
$fCO_{2\,(sw)}$	0.51	0.2
In situ $fCO_{2\,(sw)}$	0.20	0.2
Riverine flux	0.15 (1σ)	0.3 (2σ)
Standard deviation of ensemble	N/A	0.3
Total	**0.76**	**0.6**

Total derived mean uncertainty this study:
0.76 Pg C yr^{-1} (1σ)
1.52 Pg C yr^{-1} (2σ)

Compared to GCB fixed value:
0.6 Pg C yr^{-1} (1σ)
1.2 Pg C yr^{-1} (2σ)

The current approach for observation-based product uncertainties

GCB observation-based product uncertainty (1σ)
0.6 Pg C yr^{-1}

Standard deviation of observation-based product ensemble
0.3 Pg C yr^{-1}

Gas transfer coefficient
0.2 Pg C yr^{-1}

$fCO_{2\,(sw)}$ mapping
0.2 Pg C yr^{-1}

Wind speed
0.1 Pg C yr^{-1}

In situ $fCO_{2\,(sw)}$
0.2 Pg C yr^{-1}

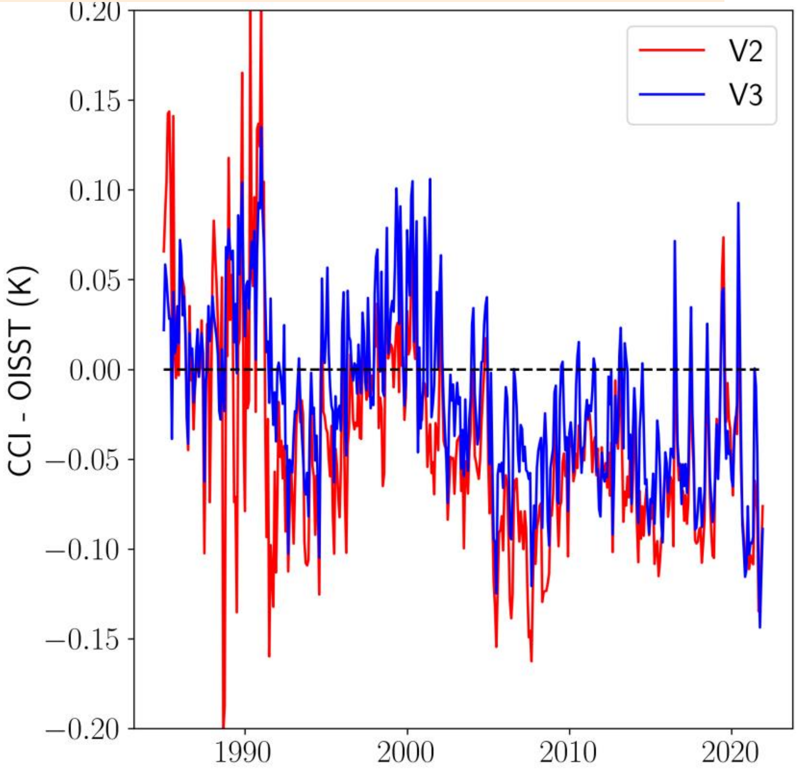
Riverine flux
0.3 Pg C yr^{-1} (2σ)

But, Hauck et al. (2023) suggest the observation-based product uncertainty is likely greater than 0.6 Pg C yr^{-1} before the in situ $fCO_{2\,(sw)}$ and riverine flux uncertainties are included…

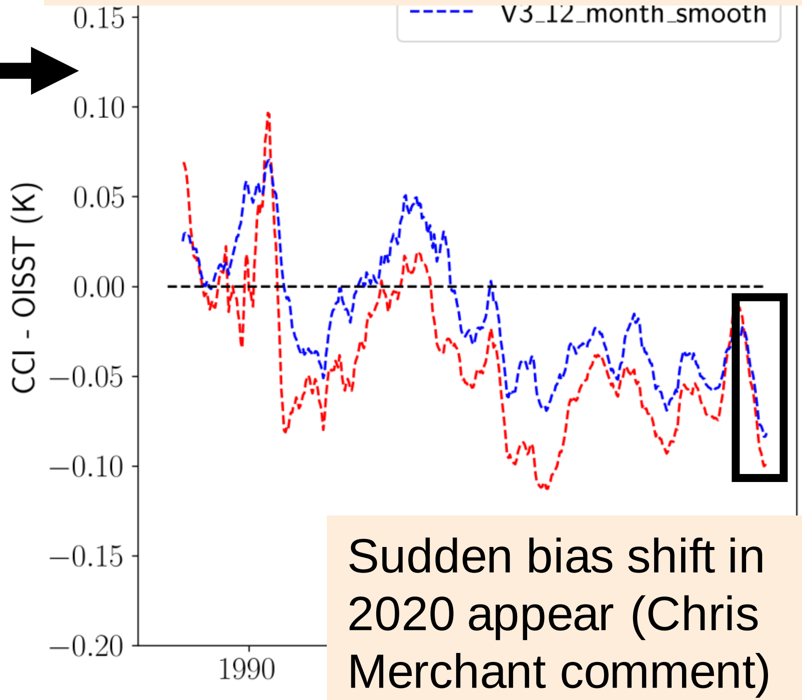
Uncertainties are temporally fixed/static

CCISSTv2 vs CCISSTv3 – Temporal changes

Comparing CCISSTv2 and v3 to the OISST temporal changes are observed…



CCIv3 generally slightly warmer than v2 globally due to corrections in dust regions.
After 2005, both CCI v2 and v3 are cooler than OISST

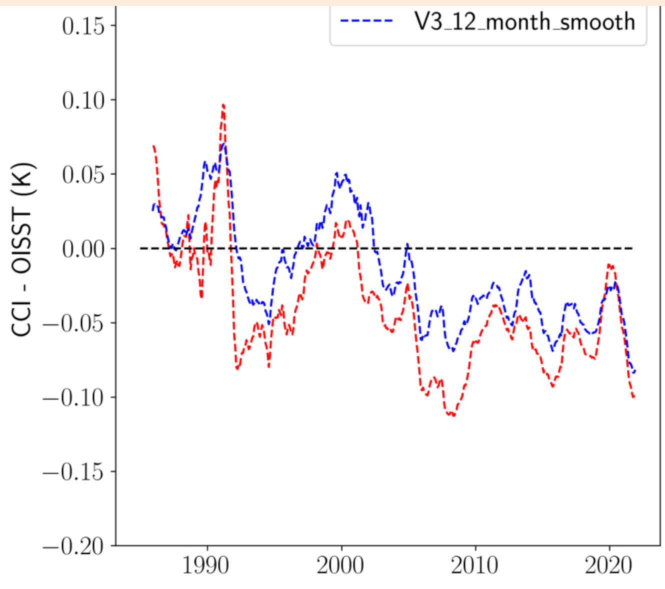


Sudden bias shift in 2020 appear (Chris Merchant comment)

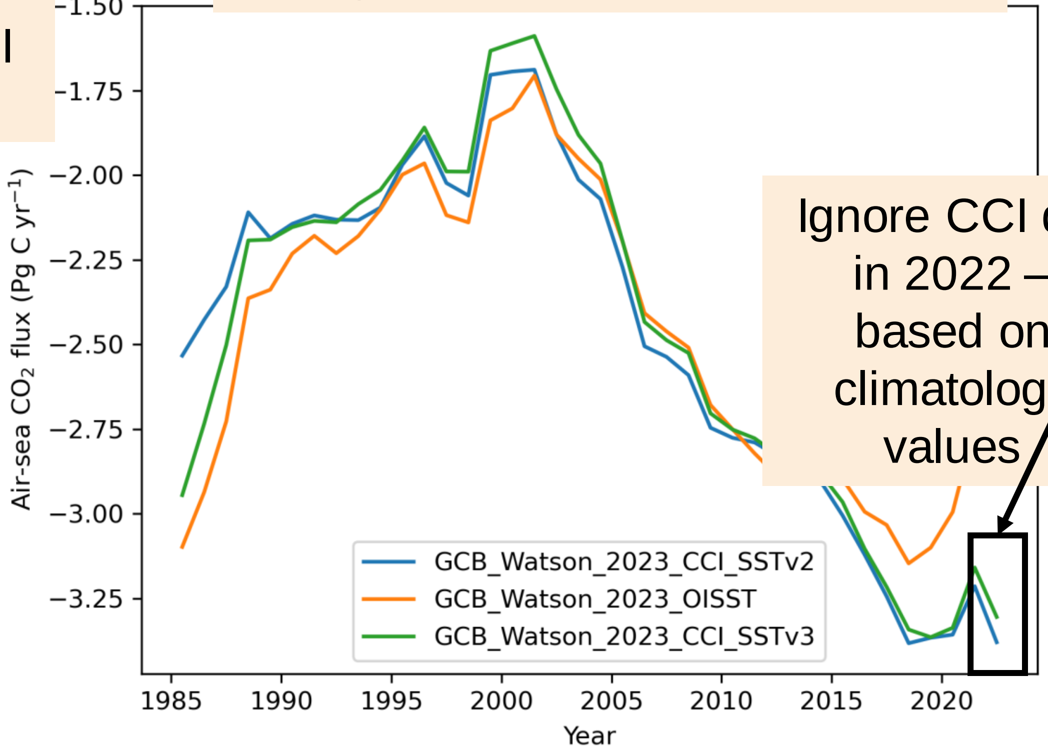
CCISSTv2 vs CCISSTv3 – Changes in the global air-

CCIv3 (green) shows generally weaker CO_2 sink globally to v2

Periods where CCI suggest weaker CO_2 sink compared to OISST (orange) coincide with periods CCI is warmer than OISST

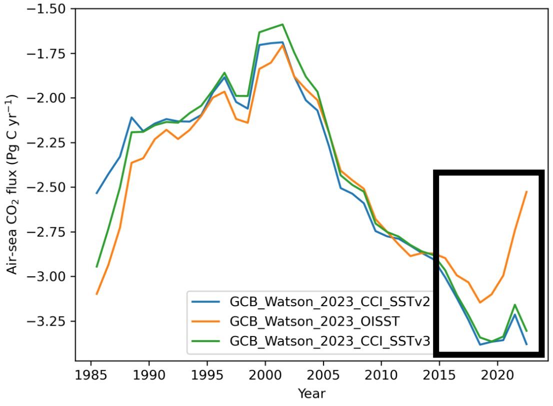


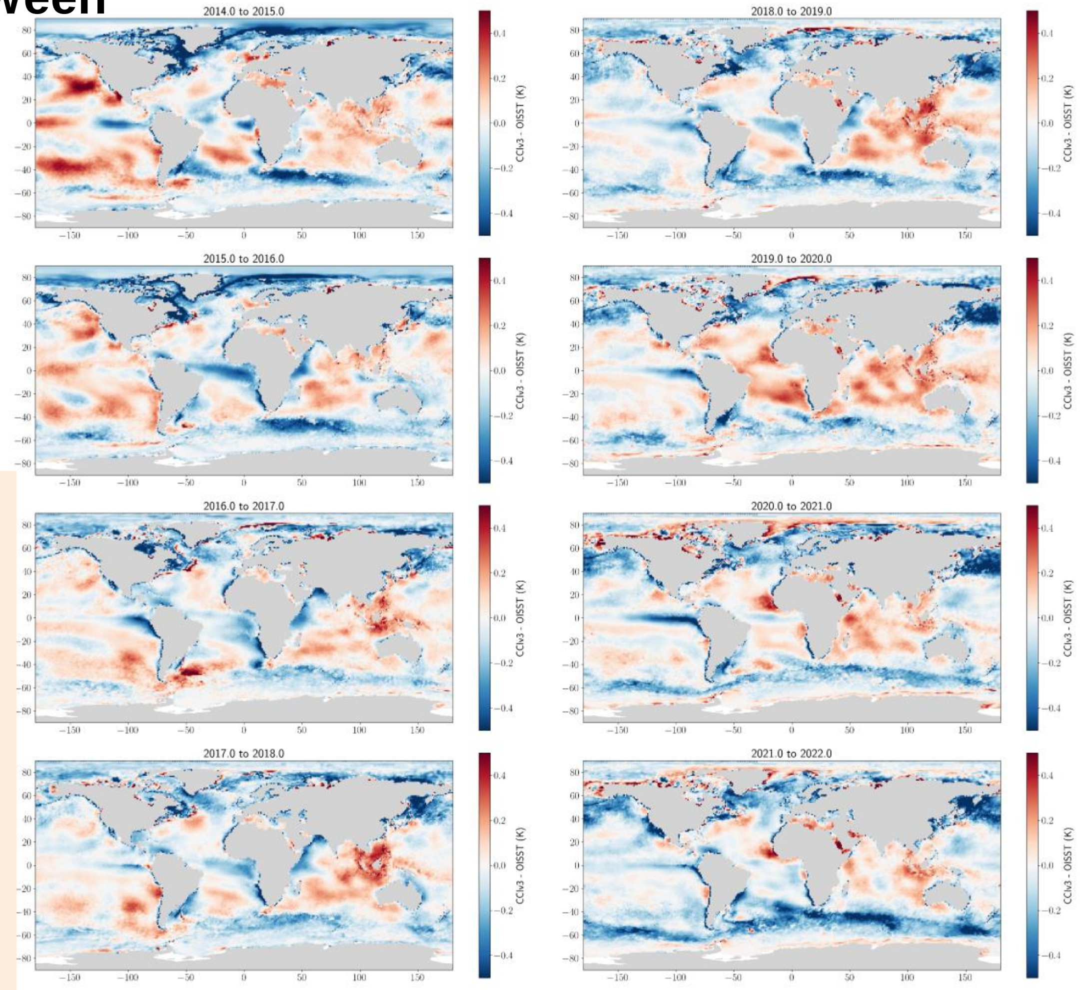
Discrepancy between OISST and CCI after 2015 cannot be explain by a global temperature bias change…



Ignore CCI dip in 2022 – based on climatology values

Air-sea CO_2 flux discrepancy between





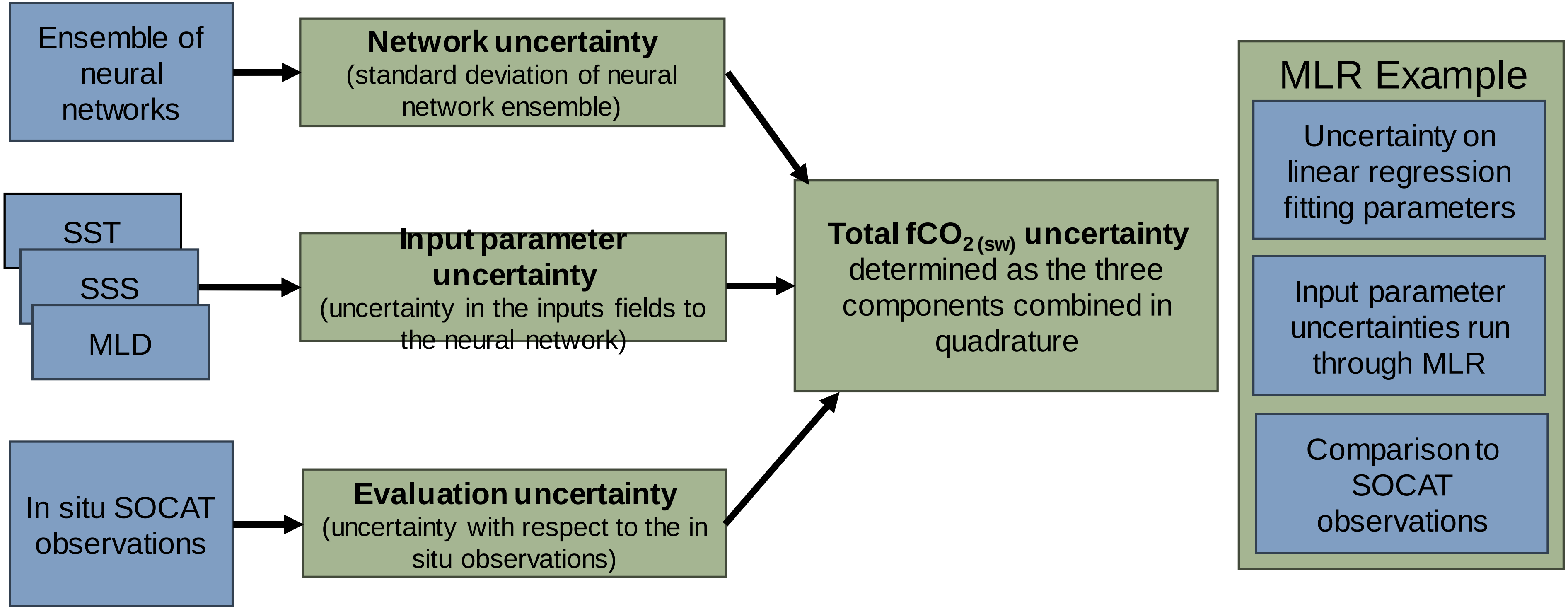
Regional SST biases can explain

Global bias between OI and CCI doesn’t appear to change during this period, but regional changes in the temperate northern latitudes

These biases increase from 2015 through to 2021, which combined with high gas exchange would explain the shift between OI and

Spatial and temporal $fCO_{2\ (sw)}$ uncertainties

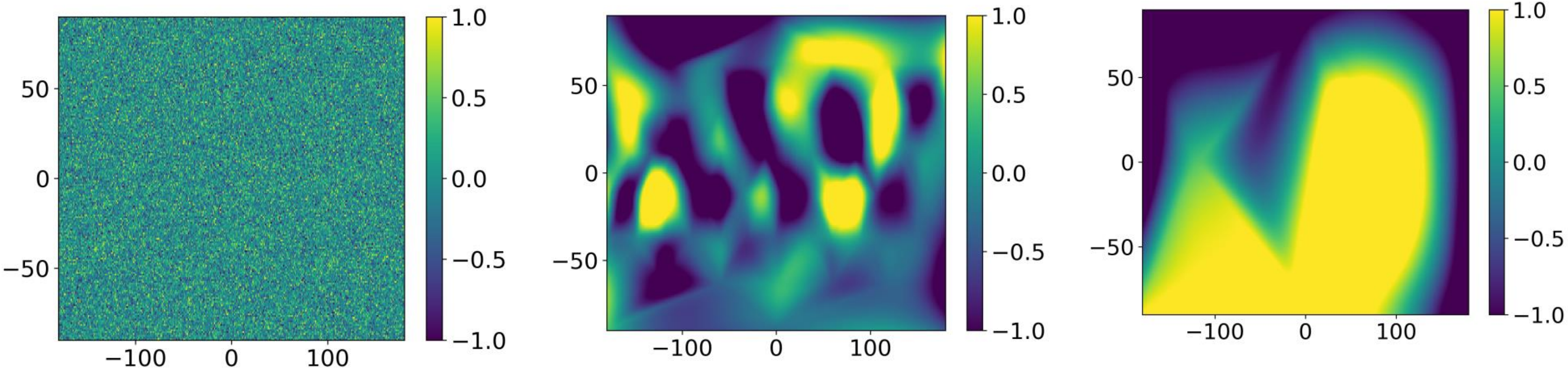
We apply the same principle to our $fCO_{2\ (sw)}$ interpolation approach and identify the sources of uncertainties.
In this example we assess three sources of uncertainties within a feed forward neural network scheme
but principles can be applied to other methods



Integrating uncertainties (for the net sink result)

What do we mean by spatially correlated uncertainties?

Spatial structures where uncertainties are correlated, but over larger scales become decorrelated



Increasing decorrelation length