ICOS Open Science Conference, Helsinki, Sept 2016

Combining
Oceanic And
Atmospheric Carbon Data
to constrain CO_2 fluxes
in Europe and its surrounding oceans

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G.-H. Park, P. Peylin, K.B. Rodgers, T.P. Sasse, U. Schuster, J.D. Shutler, V. Valsala,
R. Wanninkhof, J. Zeng,

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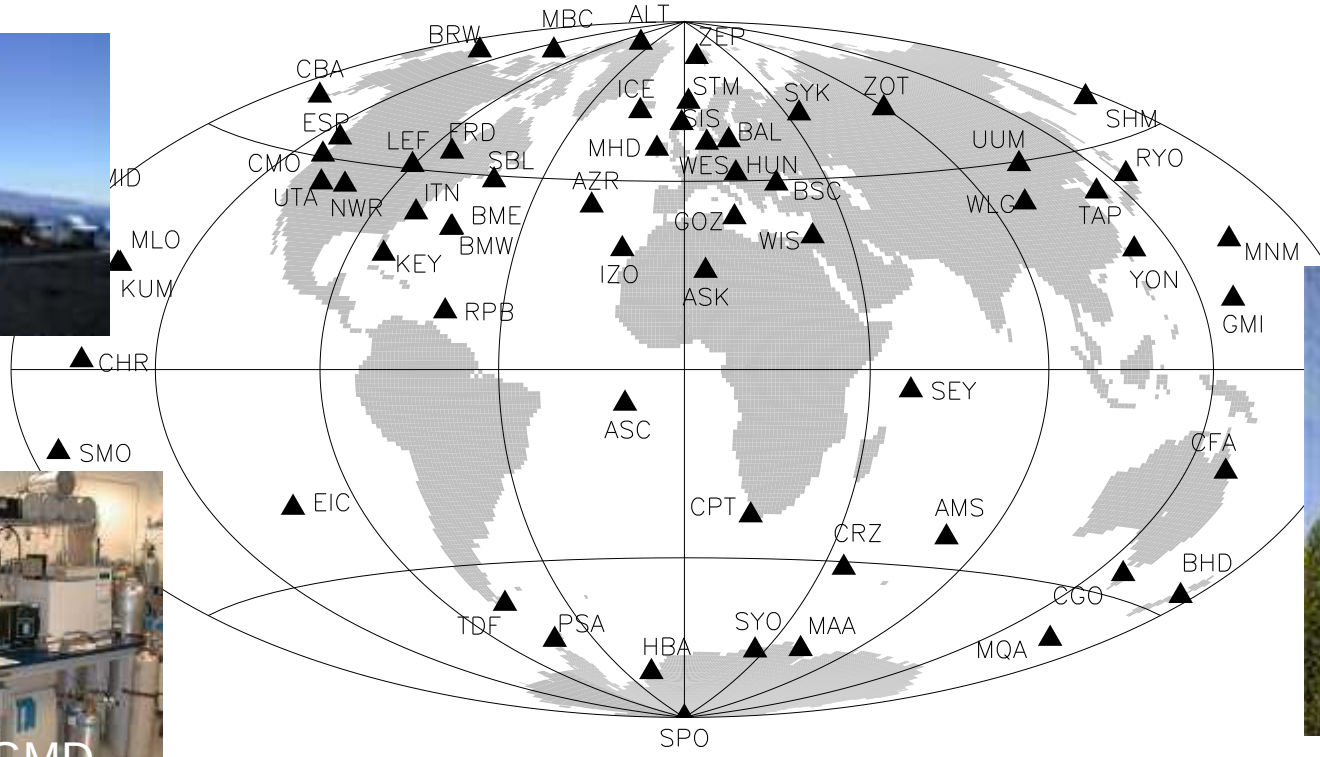
Data contributors, DKRZ, CarboChange, IMBER / SOLAS


8
MÖBIUS


MÖBIUS
8

Atmosphere

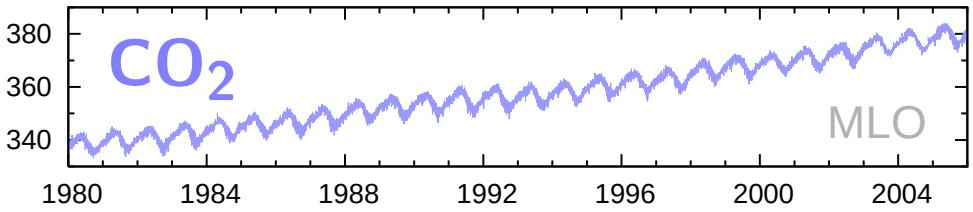

MLO


BRW
MBC
ALT
ZEP
CBA
ICE
STM
SYK
ZOT
SHM
ESP
SIS
BAL
LEF
FRD
MHD
UUM
RYO
CMO
SBL
WES
HUN
AZR
BSC
UTA
ITN
NWR
BME
GOZ
WLG
TAP
MLO
BMW
WIS
MNM
KEY
IZO
YON
KUM
ASK
GMI
RPB
CHR
SEY
ASC
SMO
CFA
EIC
CPT
AMS
CRZ
BHD
CGO
TDF
PSA
SYO
MAA
HBA
MQA
SPO

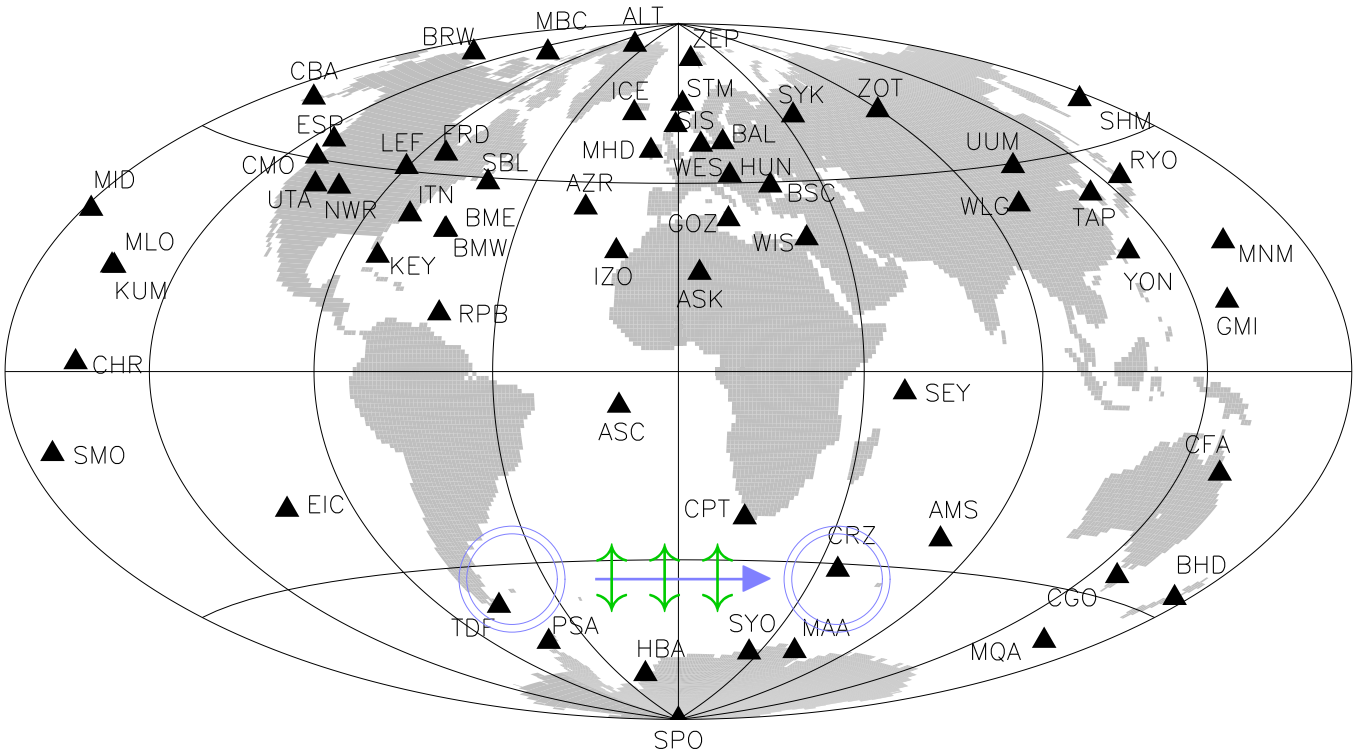

ZOT


NOAA/GMD


SPO


380
360
340
CO2
MLO
1980
1984
1988
1992
1996
2000
2004

Atmosphere



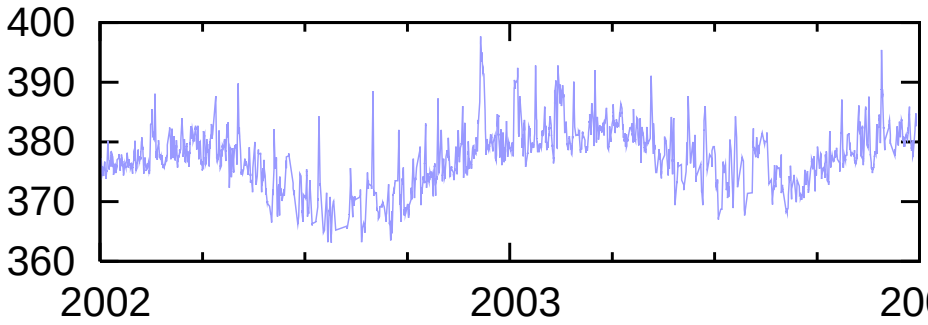
Causality: Fluxes, Transport $\longrightarrow$ Concentration gradient

Knowledge: $\sum$ Fluxes $\longleftarrow$ Concentration gradient, Transport

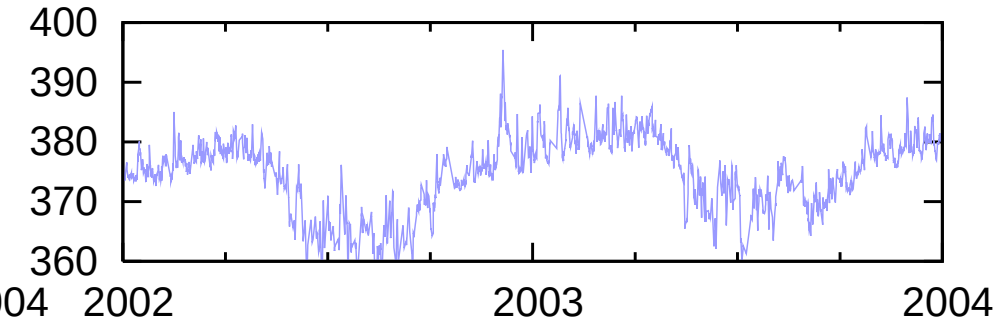
$$\mathbf{c}_{\text{meas}} \longleftrightarrow \mathbf{c}_{\text{mod}} = \mathbf{A}\mathbf{f} + \mathbf{c}_0$$

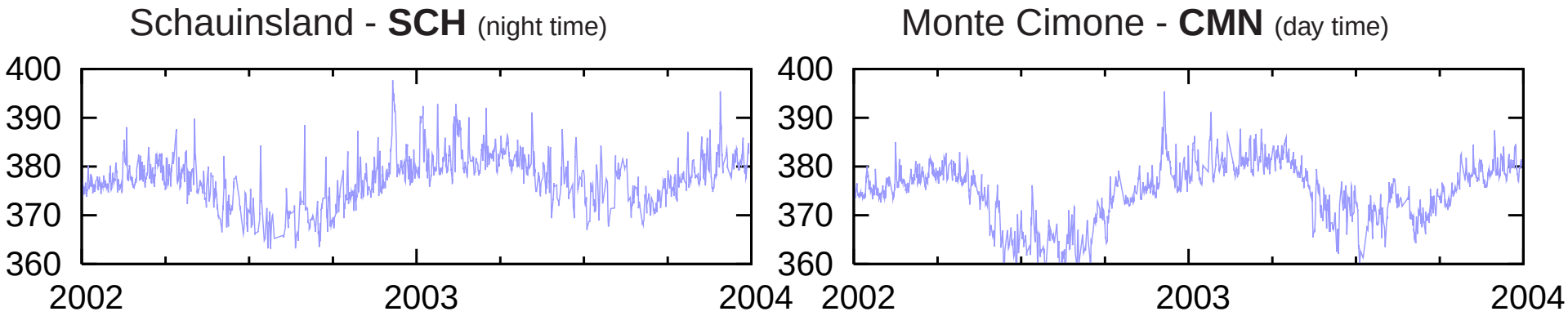
“Atmospheric Inversion” = Multidimensional linear regression

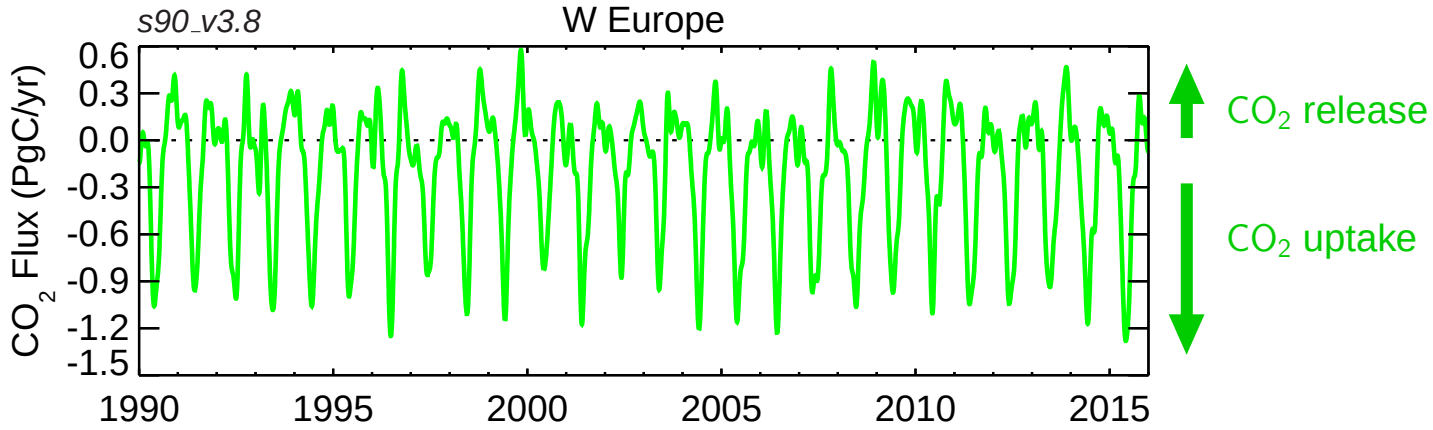
Schauinsland - **SCH** (night time)

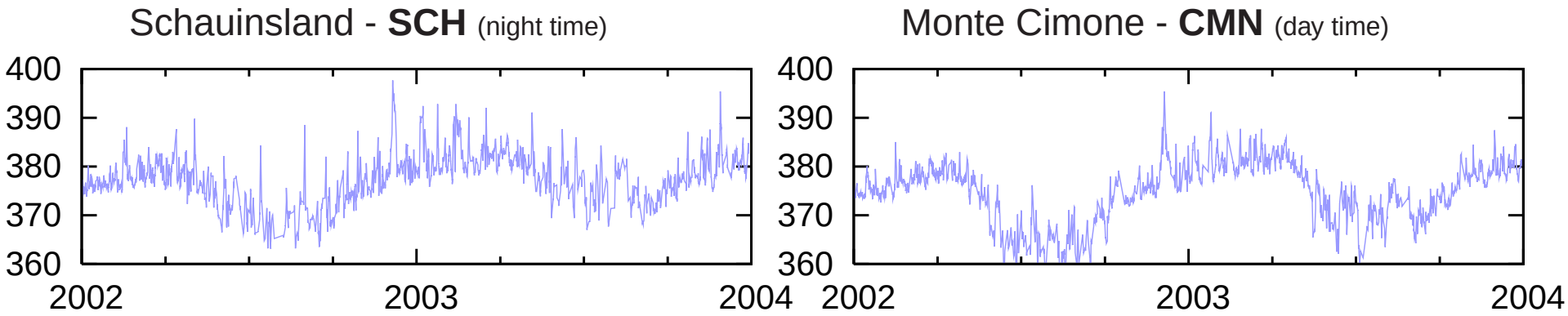


Monte Cimone - **CMN** (day time)




Schauinsland - SCH (night time)
Monte Cimone - CMN (day time)
400
390
380
370
360
2002
2003
2004


s90_v3.8
W Europe
CO2 Flux (PgC/yr)
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
1990
1995
2000
2005
2010
2015
CO2 release
CO2 uptake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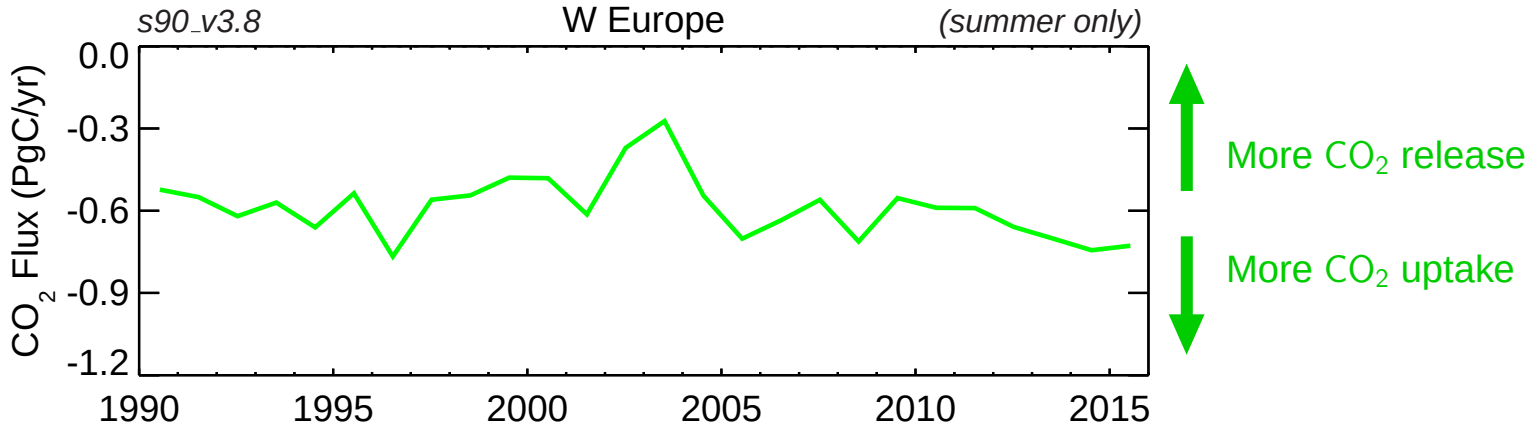
s90_v3.8
W Europe
(summer only)
CO2 Flux (PgC/yr)
0.0
-0.3
-0.6
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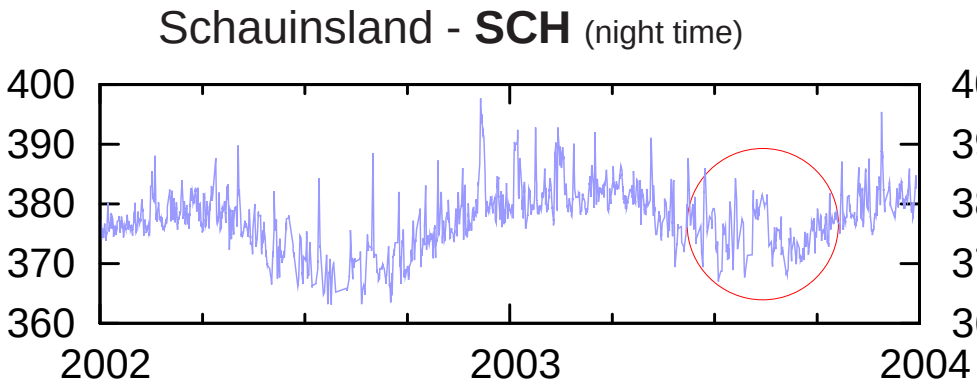
1990
1995
2000
2005
2010
2015
More CO2 release
More CO2 uptake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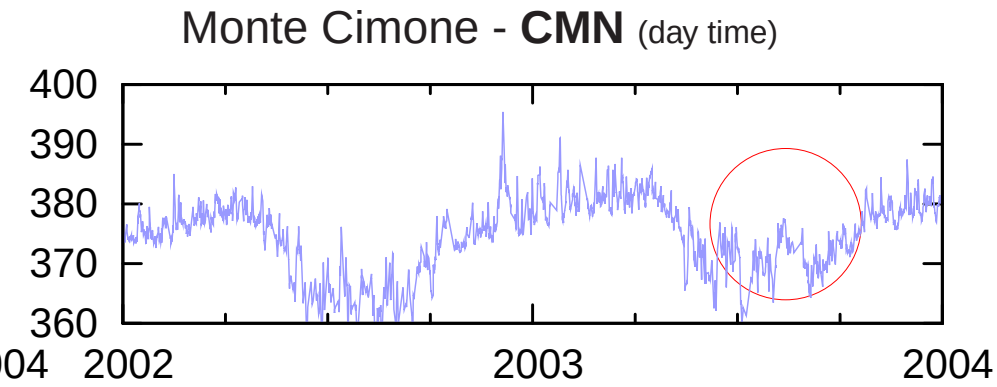
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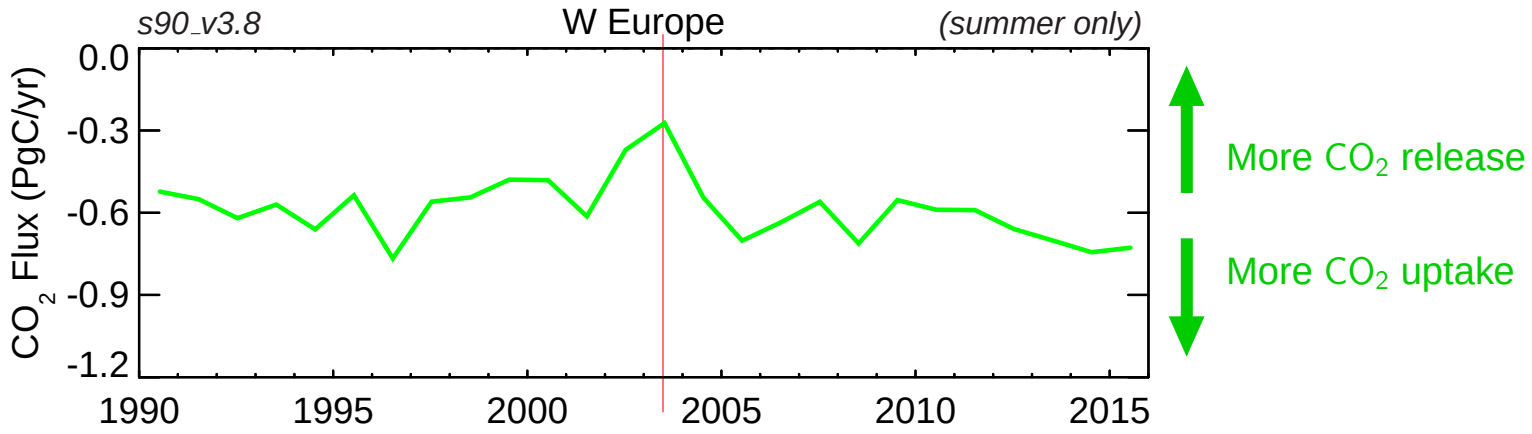
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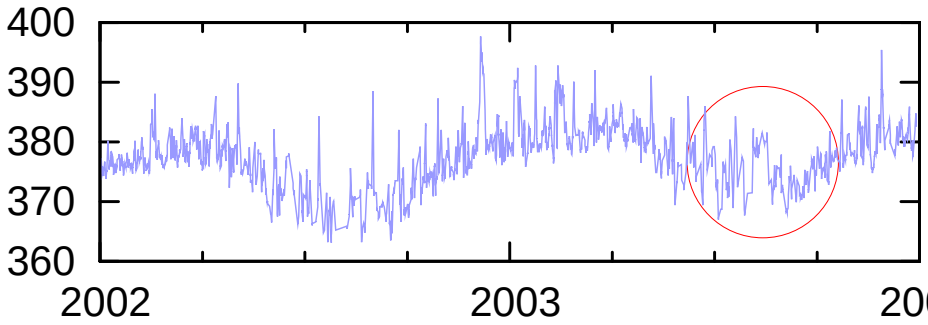

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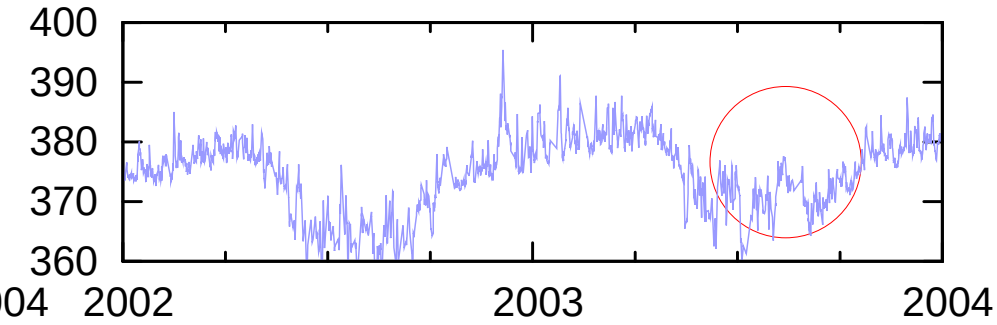
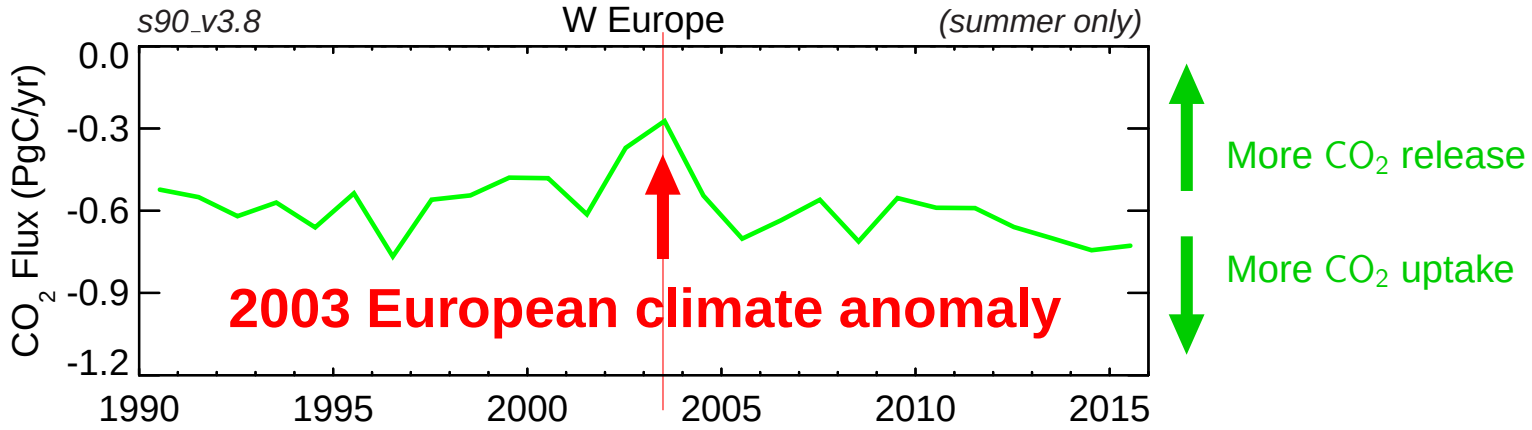
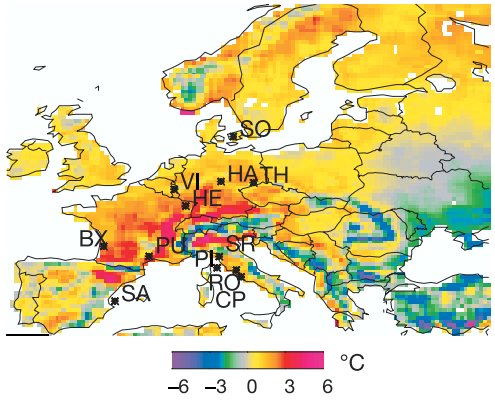
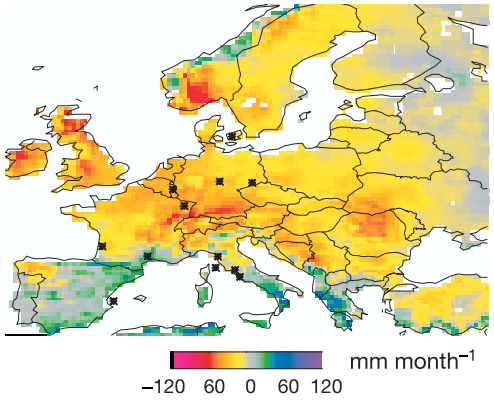




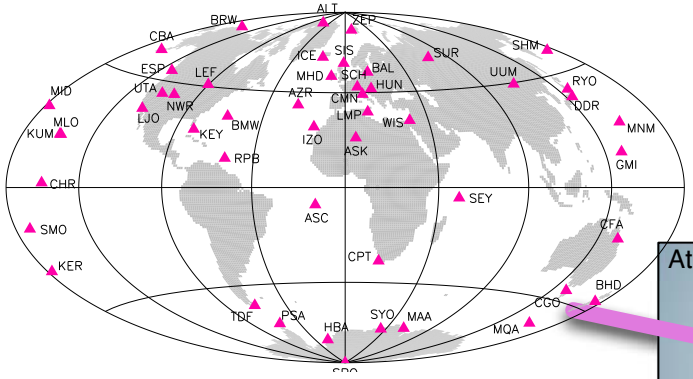
△ Temperature:



△ Precipitation: (Jul-Sep)

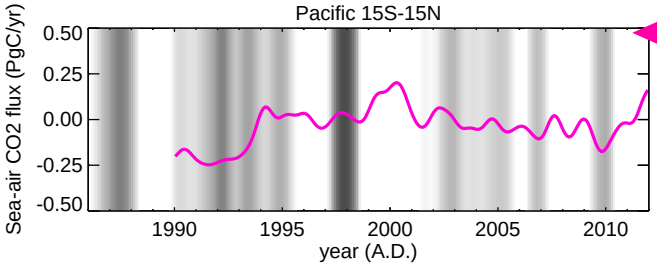


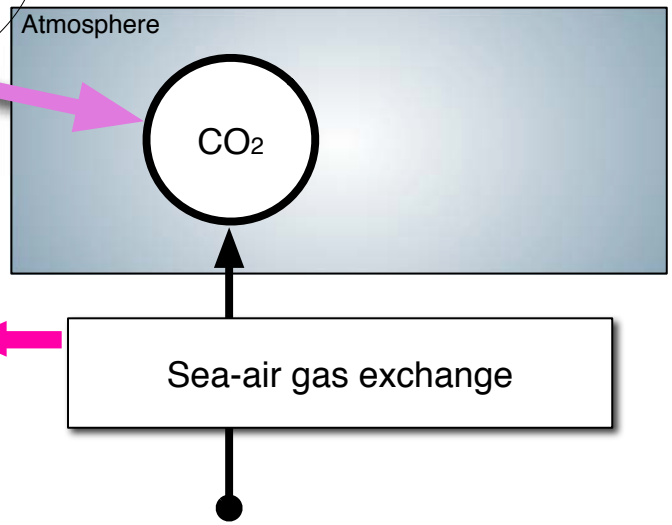
[Ciais et al., Nature (2005)]



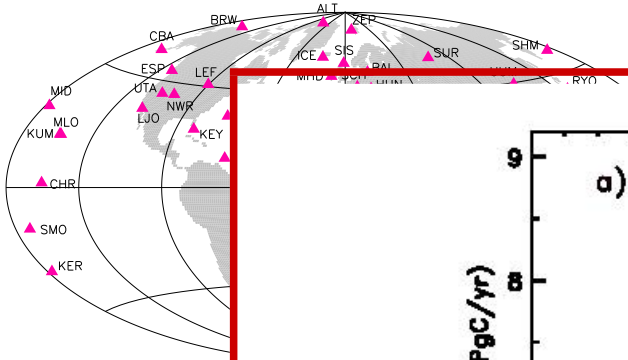
CO_2 **flux**

inferred from CO_2 inversion



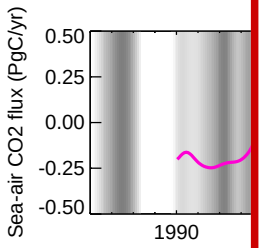


Carbon

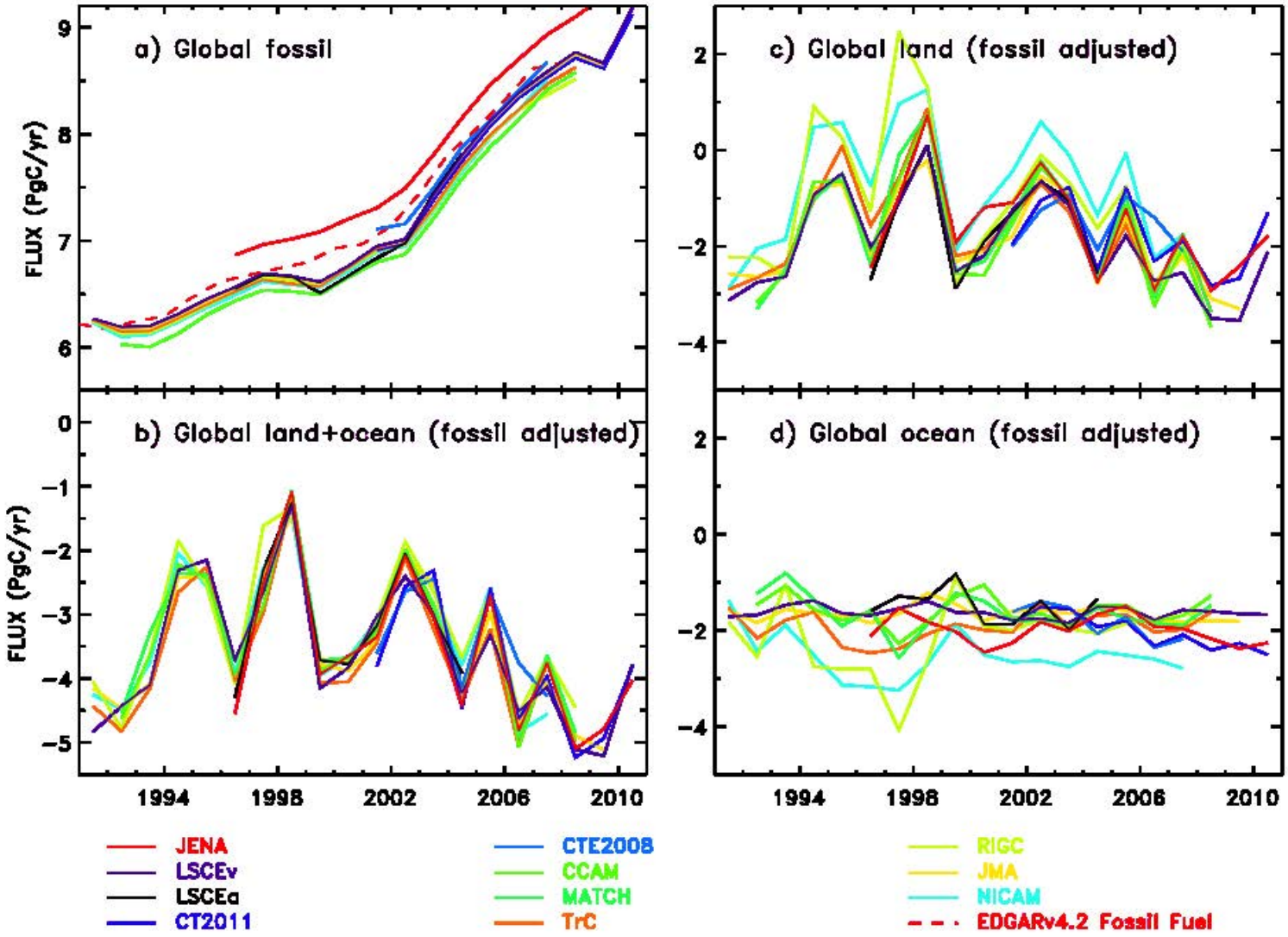


CO_2 **flux**

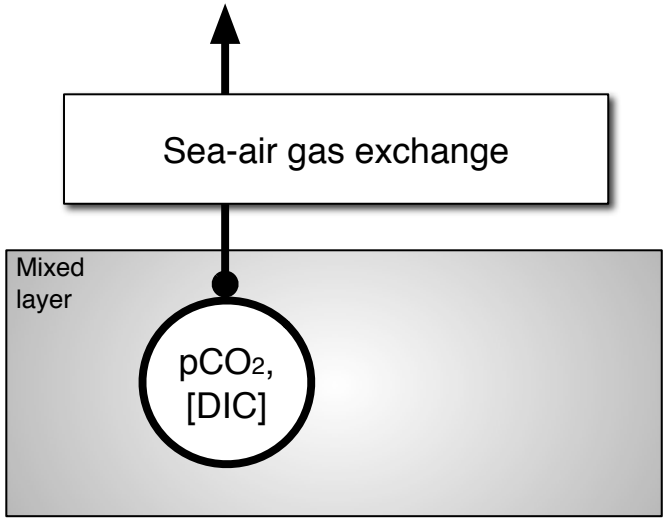
inferred fro



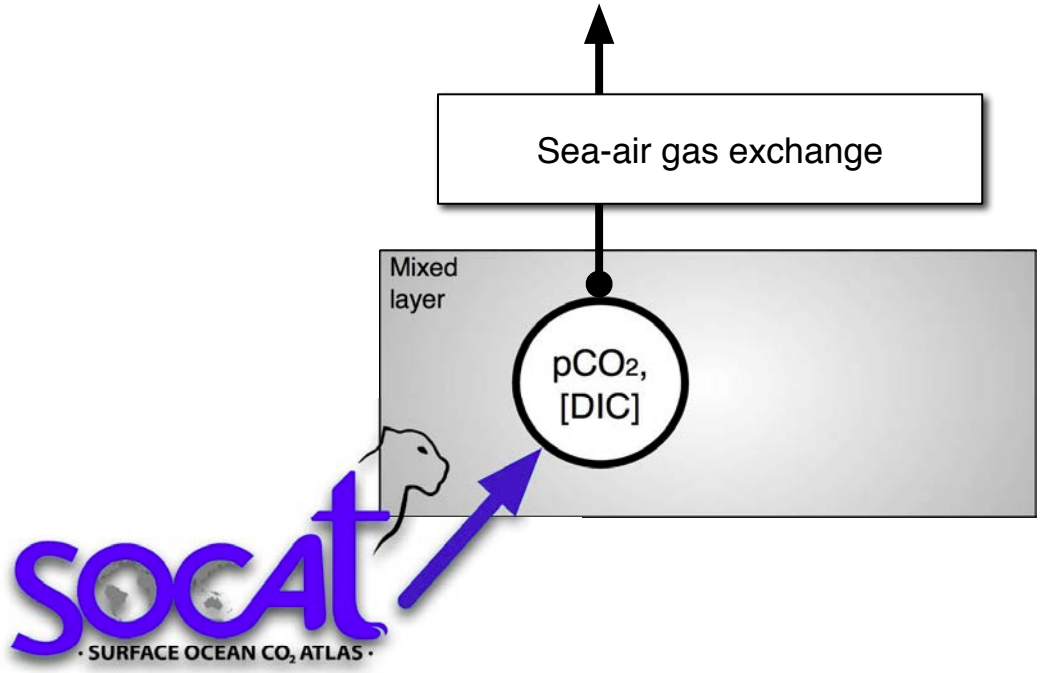
But:



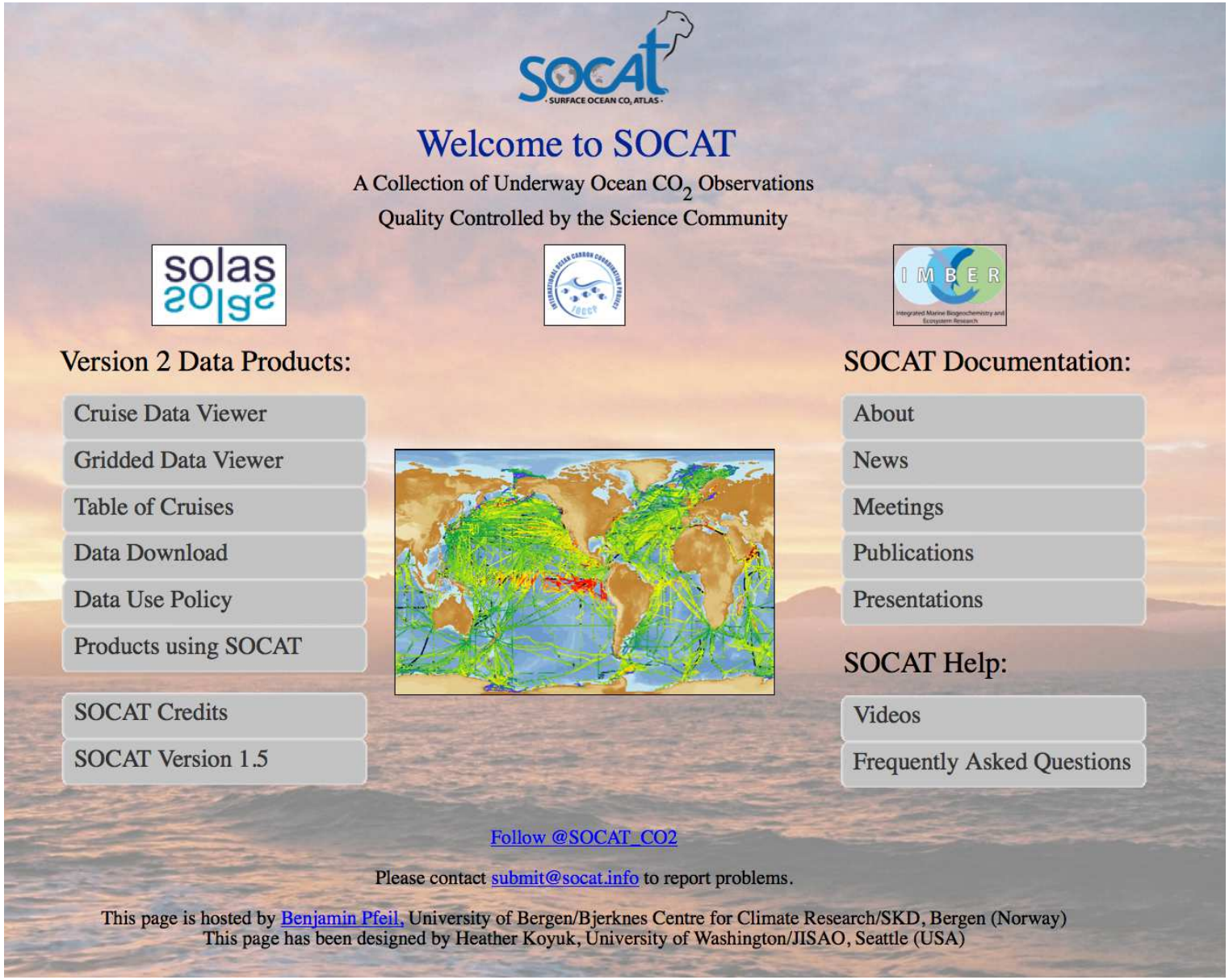
[Peylin et al., RECCAP (2013)]



Carbon

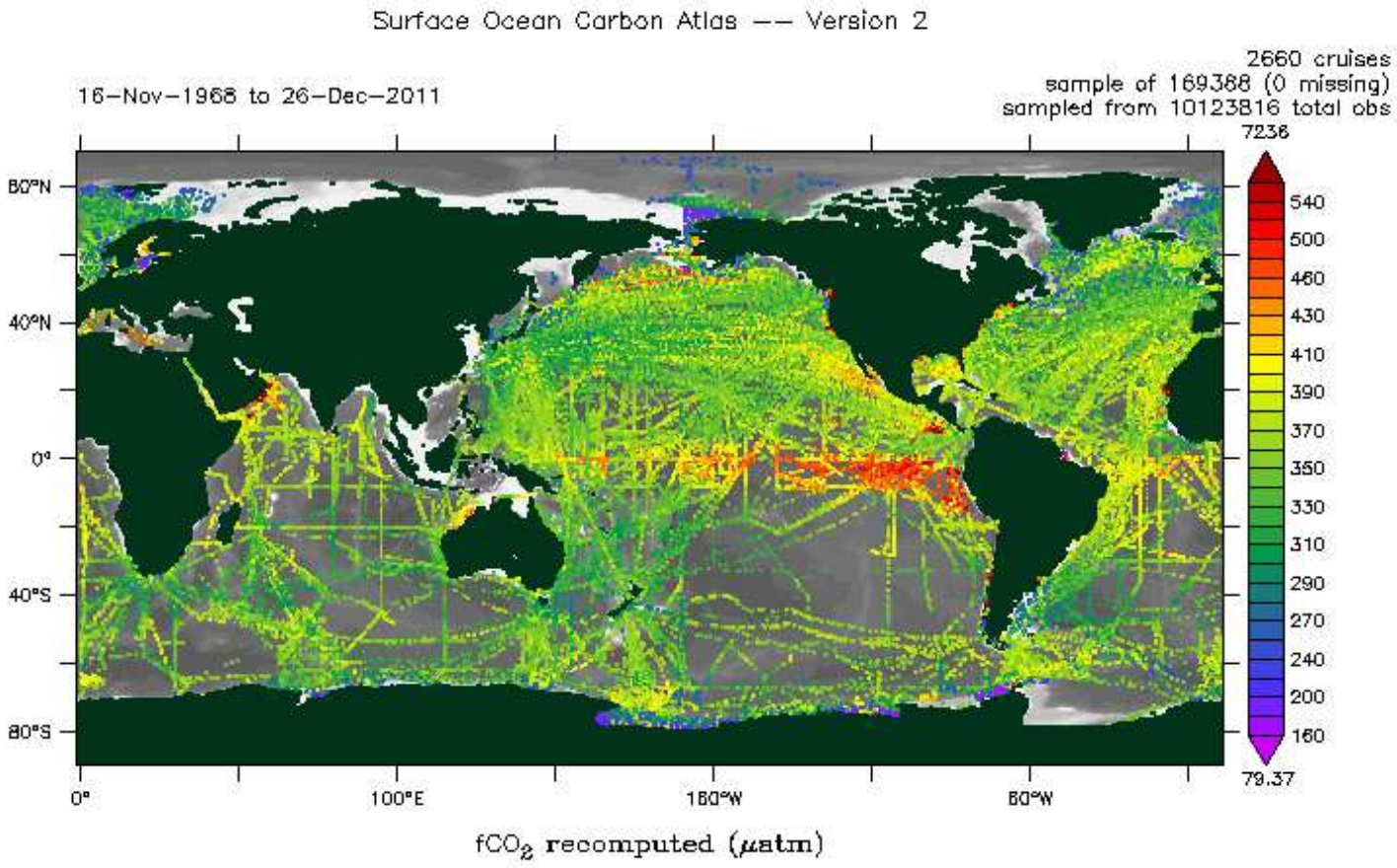

Sea-air gas exchange
Mixed layer
pCO2, [DIC]
SOCAT
· SURFACE OCEAN CO2 ATLAS ·

Carbon



[http://www.socat.info/]

Data density / distribution



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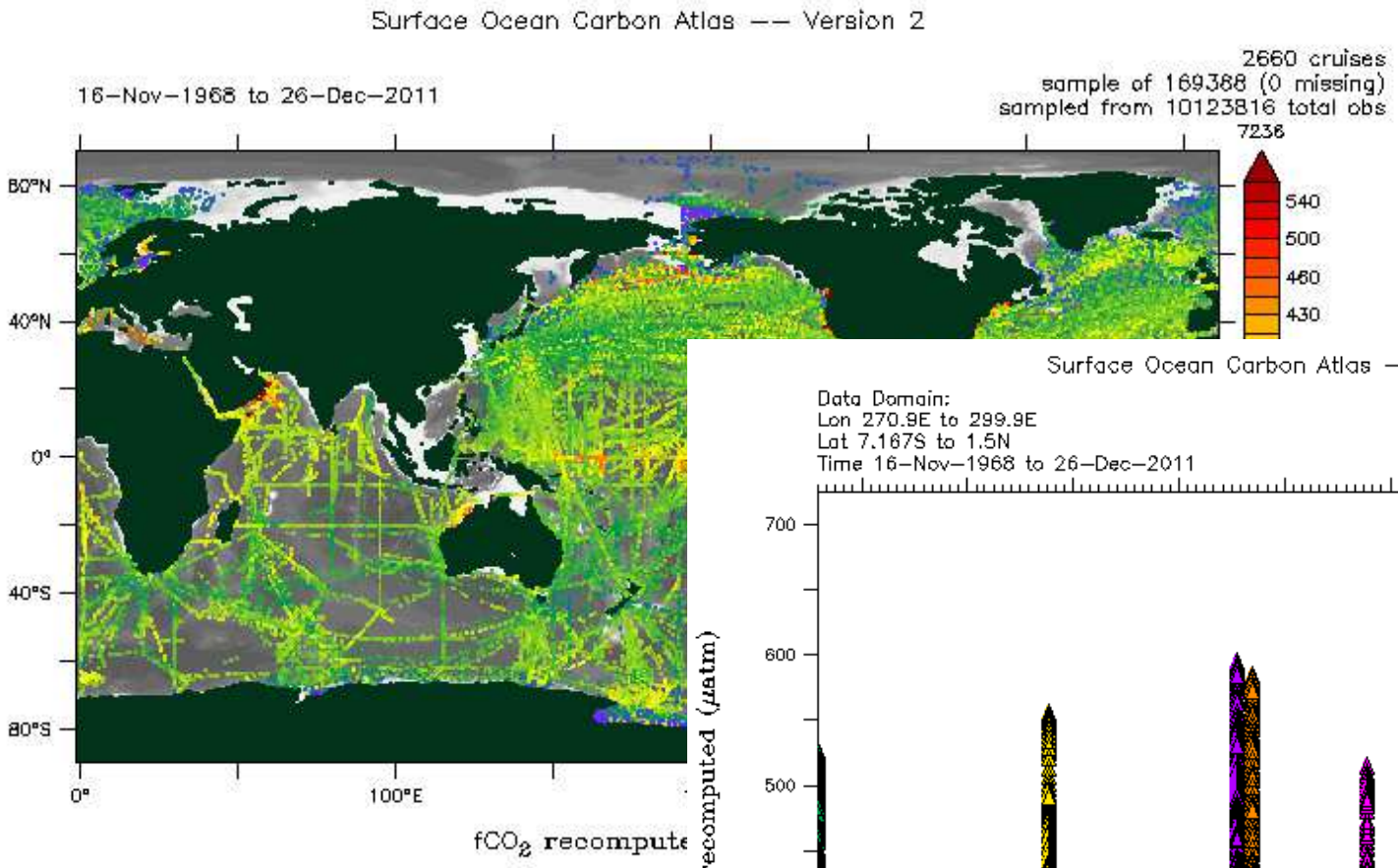
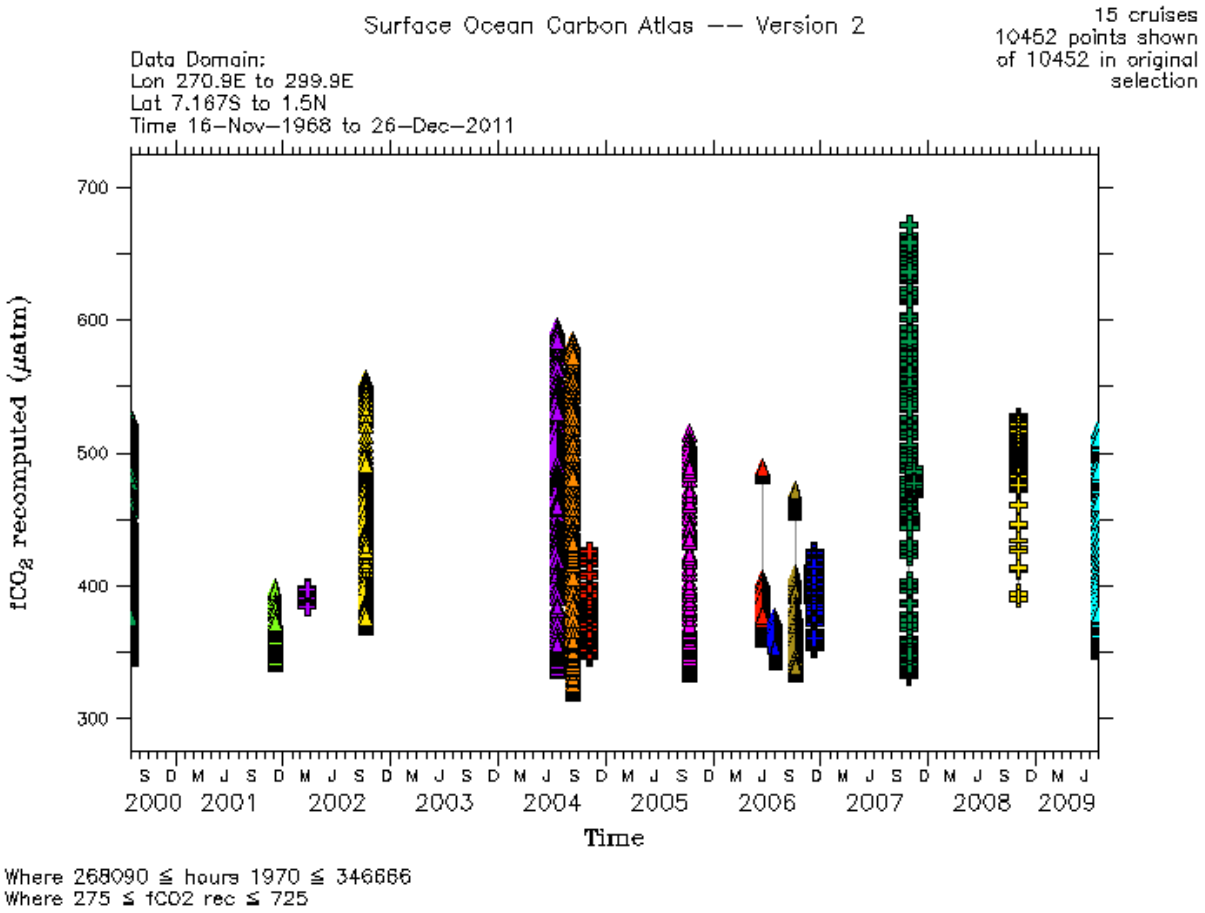
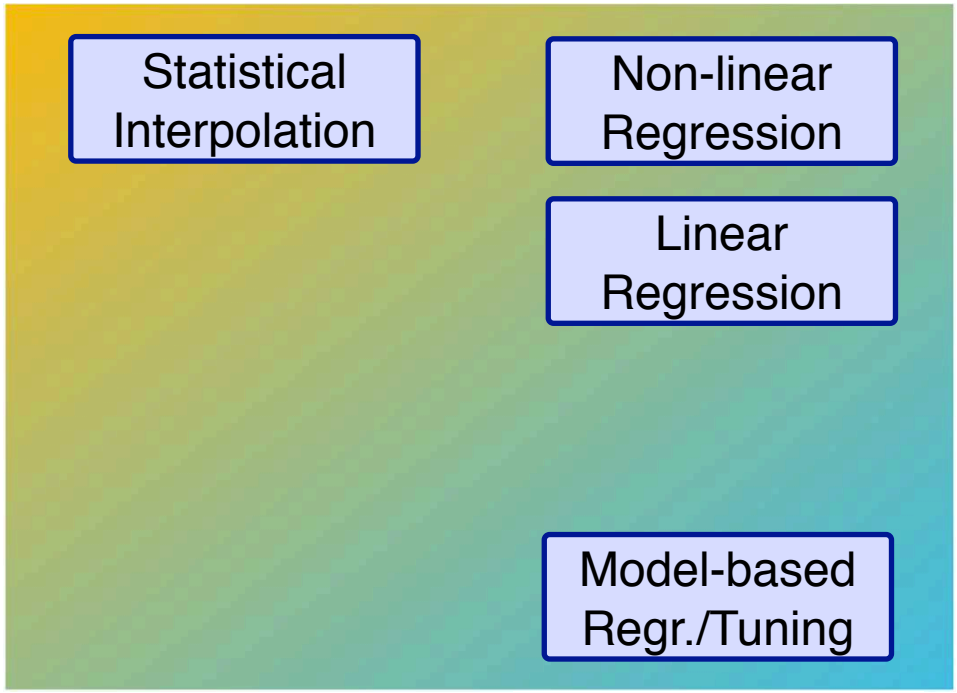


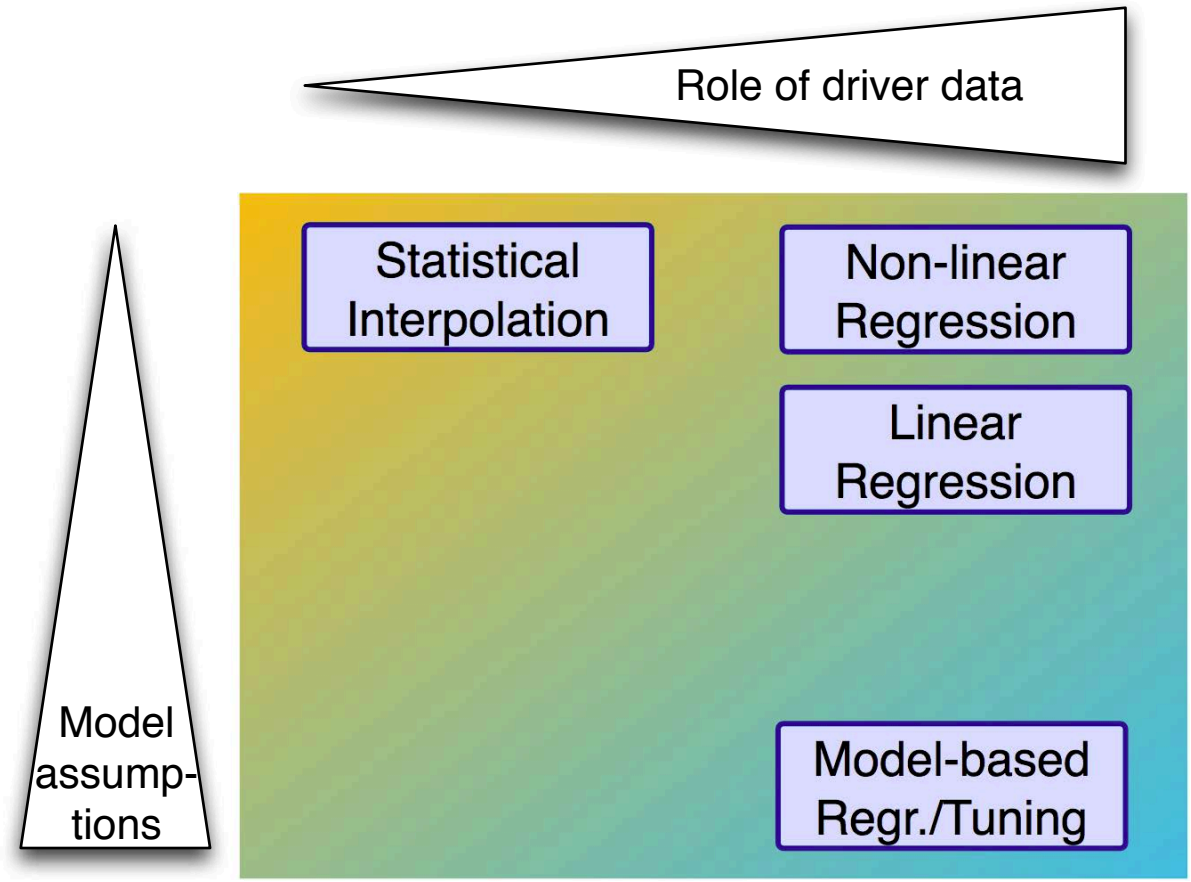
[www.socat.info]



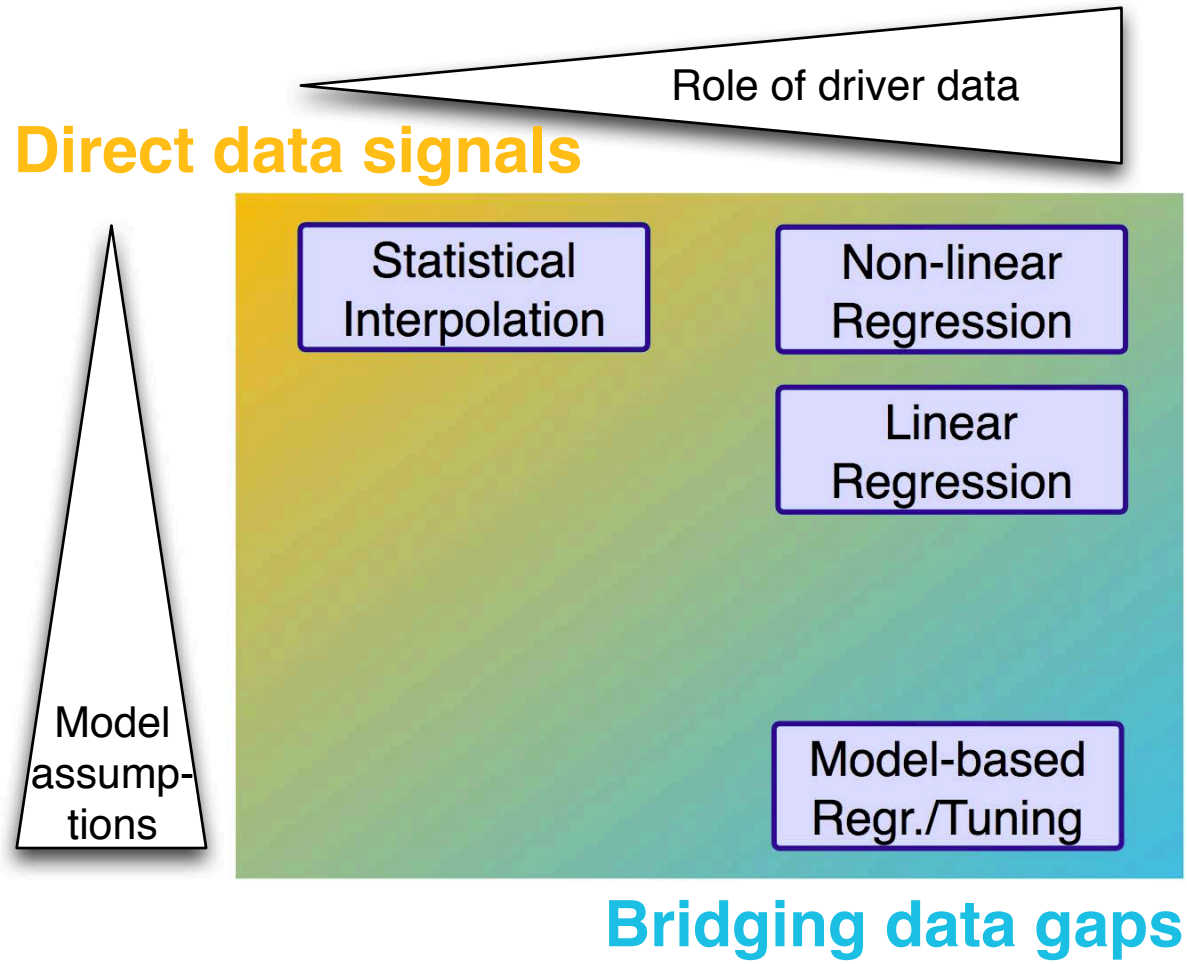
Mapping methods



Mapping methods



Mapping methods



⟶ **Interesting complementarity**

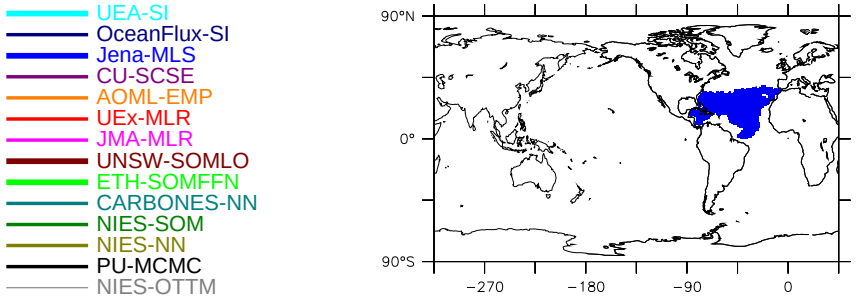
⟶ **Extracting robust features**

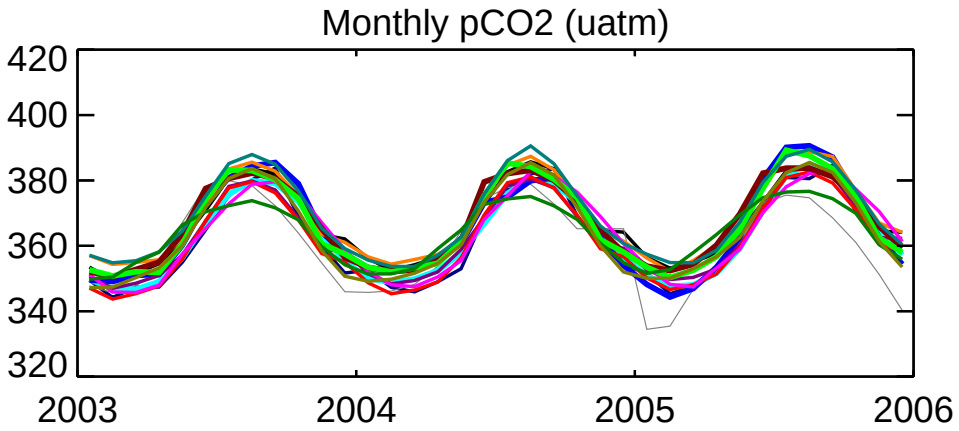
SOCOM: Collating 14 mapping methods

SOCOM

SURFACE OCEAN pCO_2 MAPPING INTERCOMPARISON

First SOCOM results [Rödenbeck et al., BG (2015)]





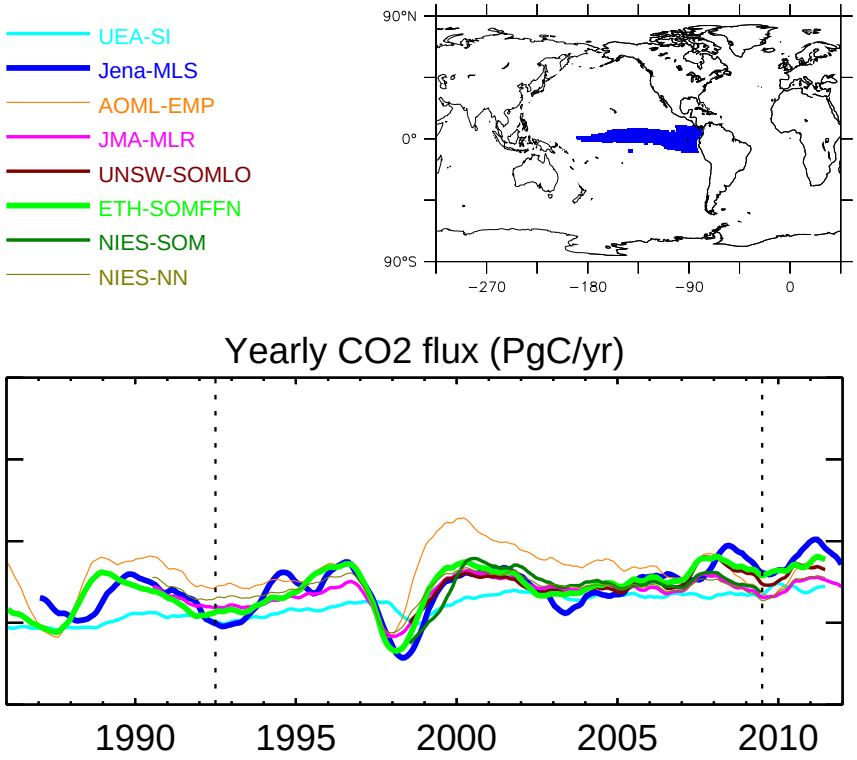
Seasonality:

Most methods roughly agree on phasing and amplitude

(also to Takahashi et al., 2009)

→ *Seasonality well constrained from data*

First SOCOM results [Rödenbeck et al., BG (2015)]



Interannual Variations (IAV):

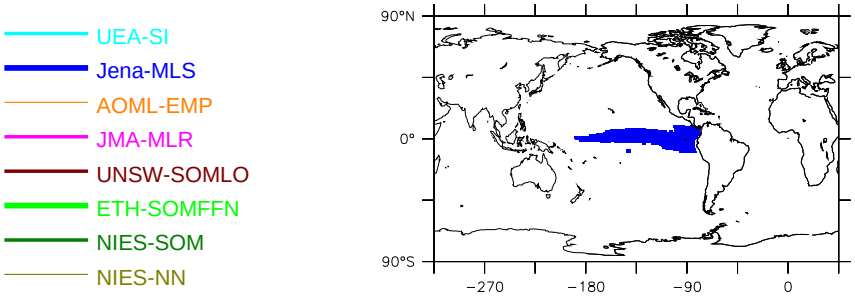
– Tropical Pacific:

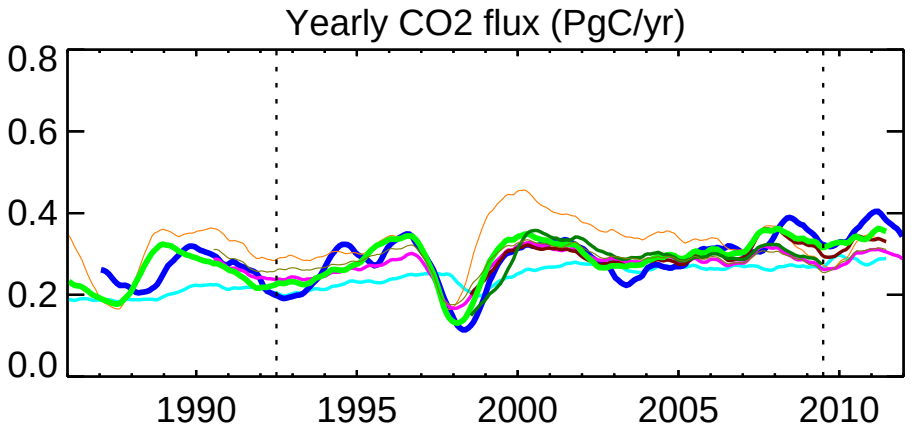
* Biome with largest IAV
* Link to ENSO

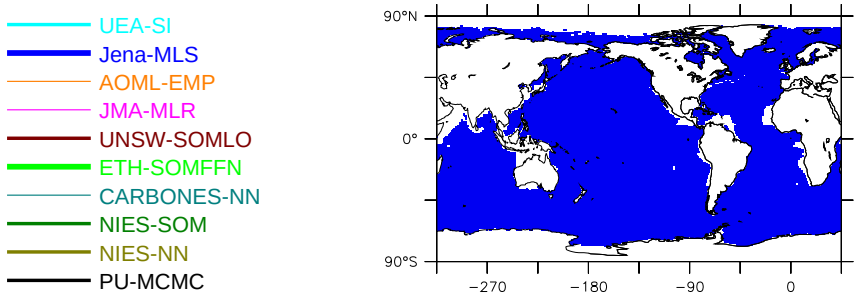
Methods selected / weighted by relative IAV mismatch to SOCATv2

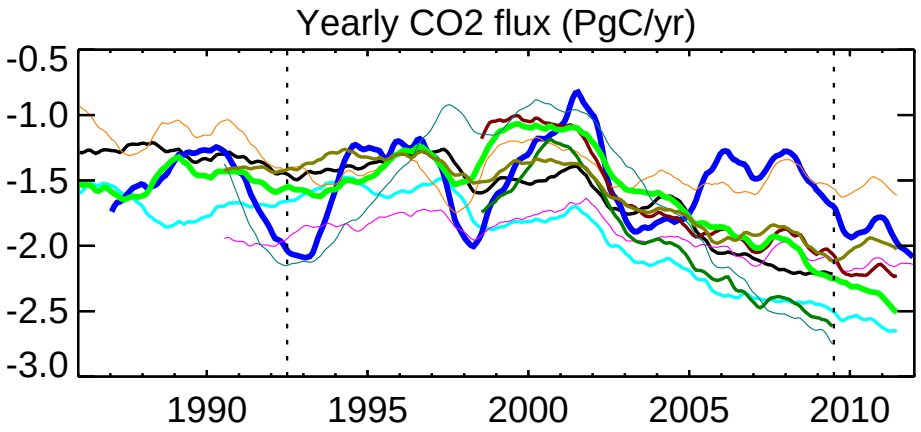
Thicker lines:
methods **better matching** the data
also **mutually agree** more closely

First SOCOM results [Rödenbeck et al., BG (2015)]









Interannual Variations (IAV):

– Tropical Pacific:
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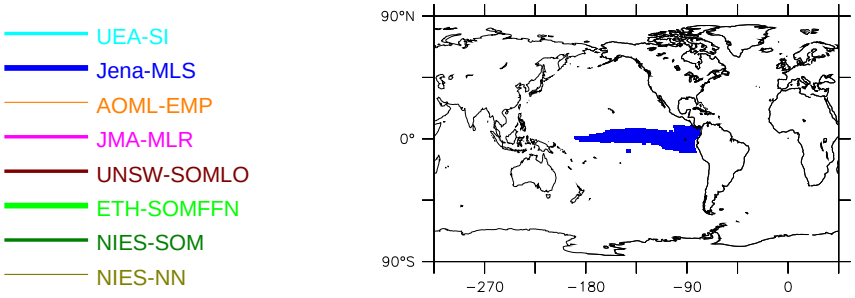
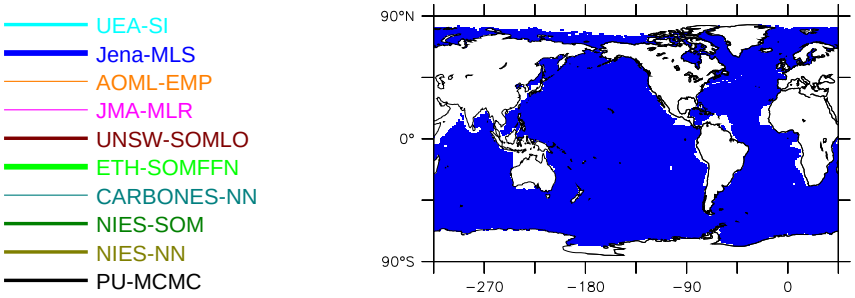
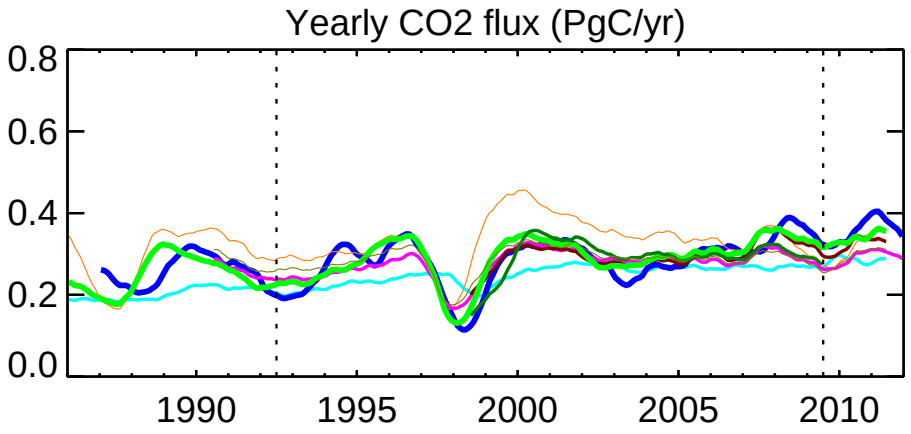
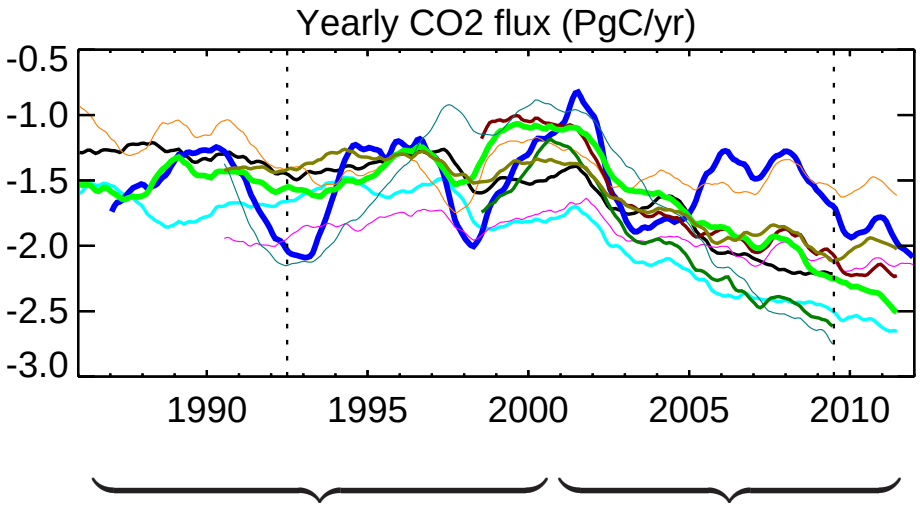
– Global Ocean:
  * Larger spread
    due to poorly constrained areas

First SOCOM results [Rödenbeck et al., BG (2015)]









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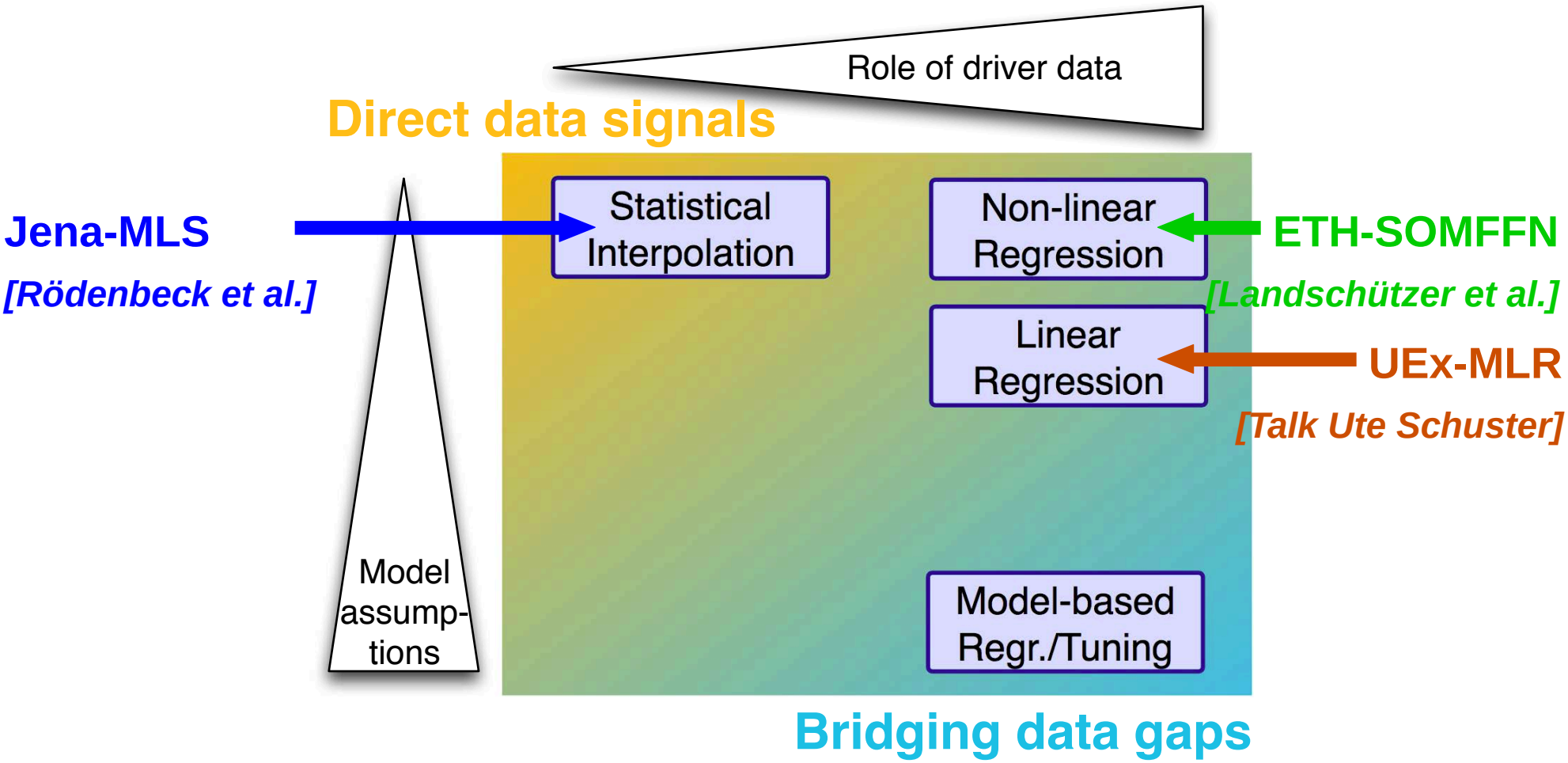
Mapping methods



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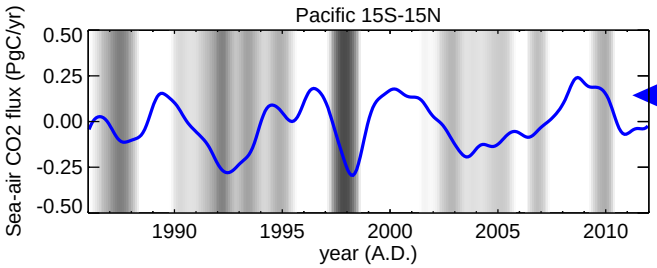
SOCOM: Collating 14 mapping methods

SOCOM

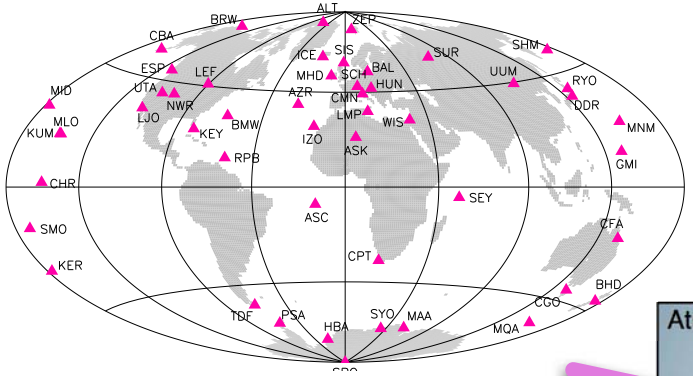
SURFACE OCEAN pCO_2 MAPPING INTERCOMPARISON

CO_2 **flux**

inferred from pCO_2 interpolation



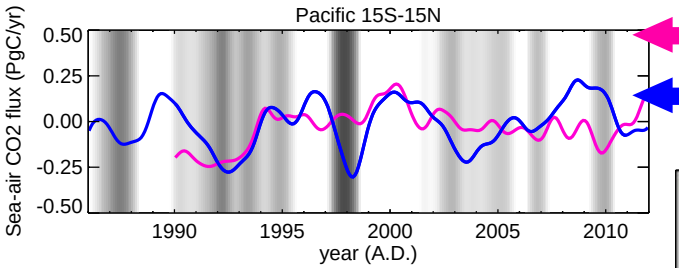
Carbon

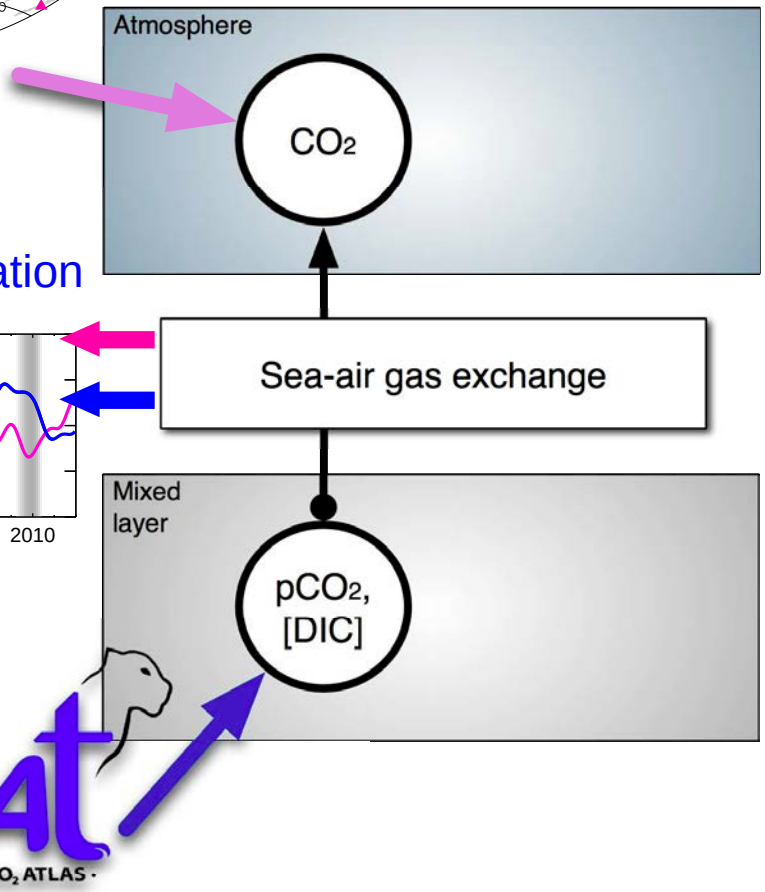


CO_2 **flux**

inferred from CO_2 inversion

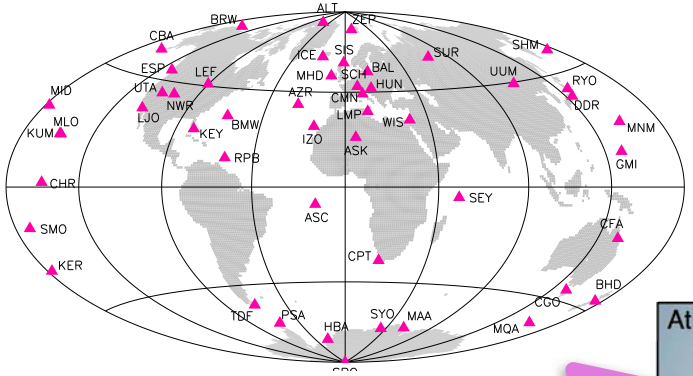
inferred from pCO_2 interpolation





SOCAT · SURFACE OCEAN CO_2 ATLAS ·

Carbon



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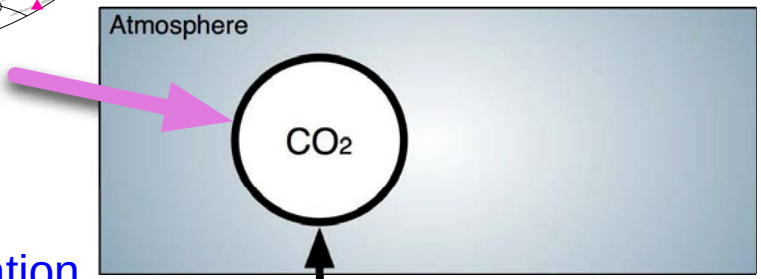
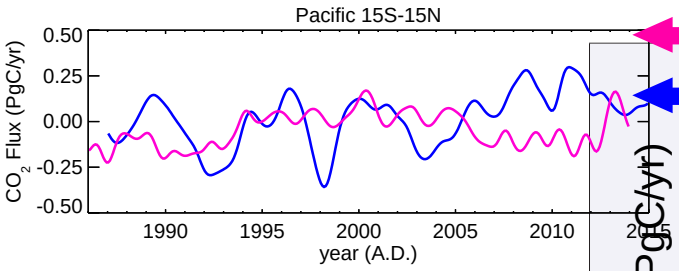
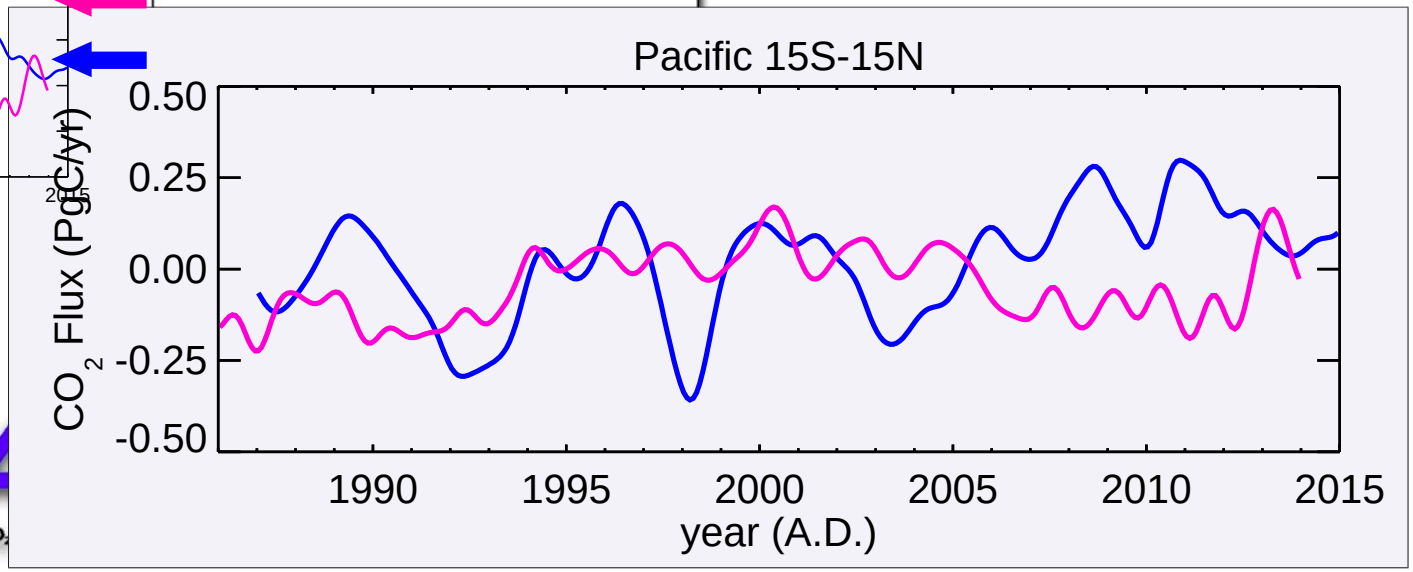
inferred from CO_2 inversion

inferred from pCO_2 interpolation

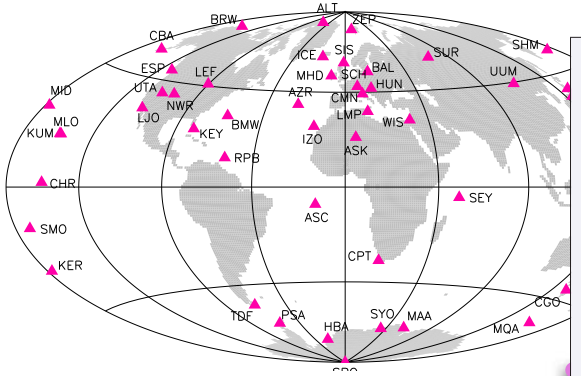






SOCA · SURFACE OCEAN CO

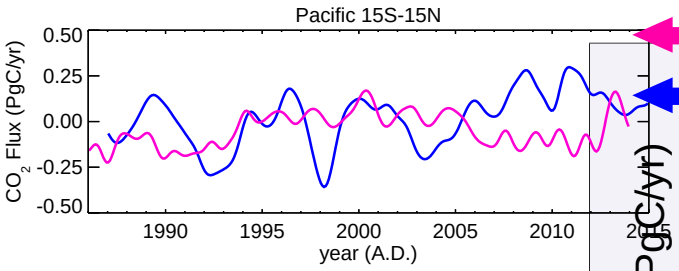
Carbon

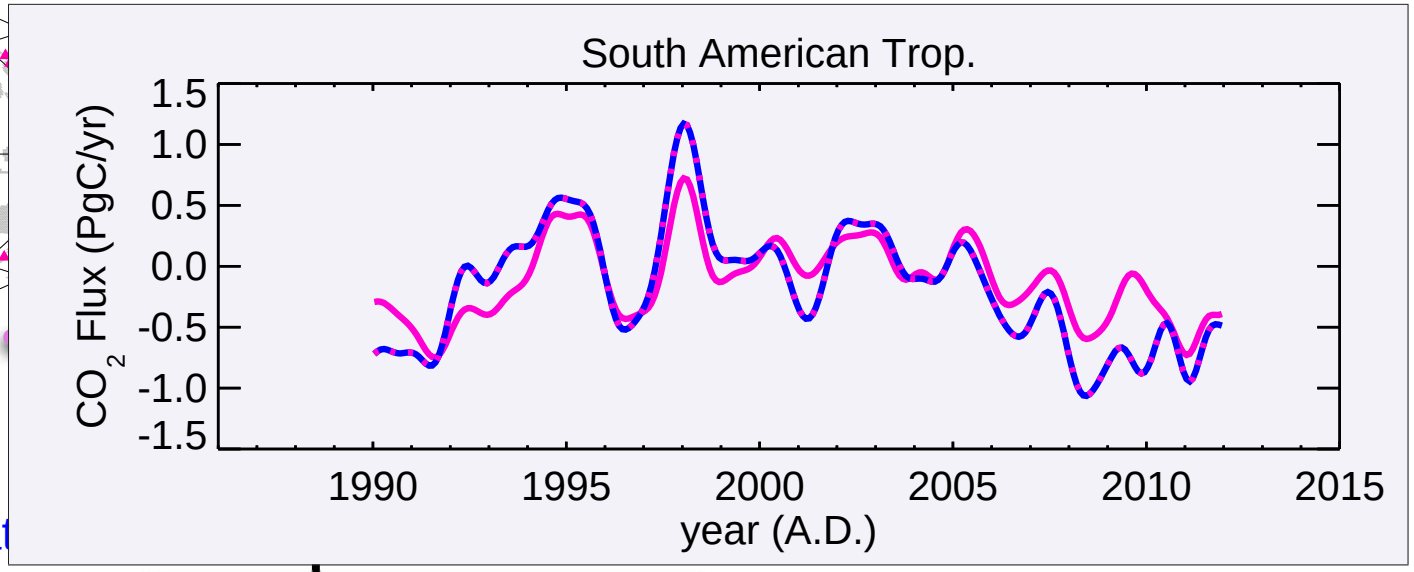


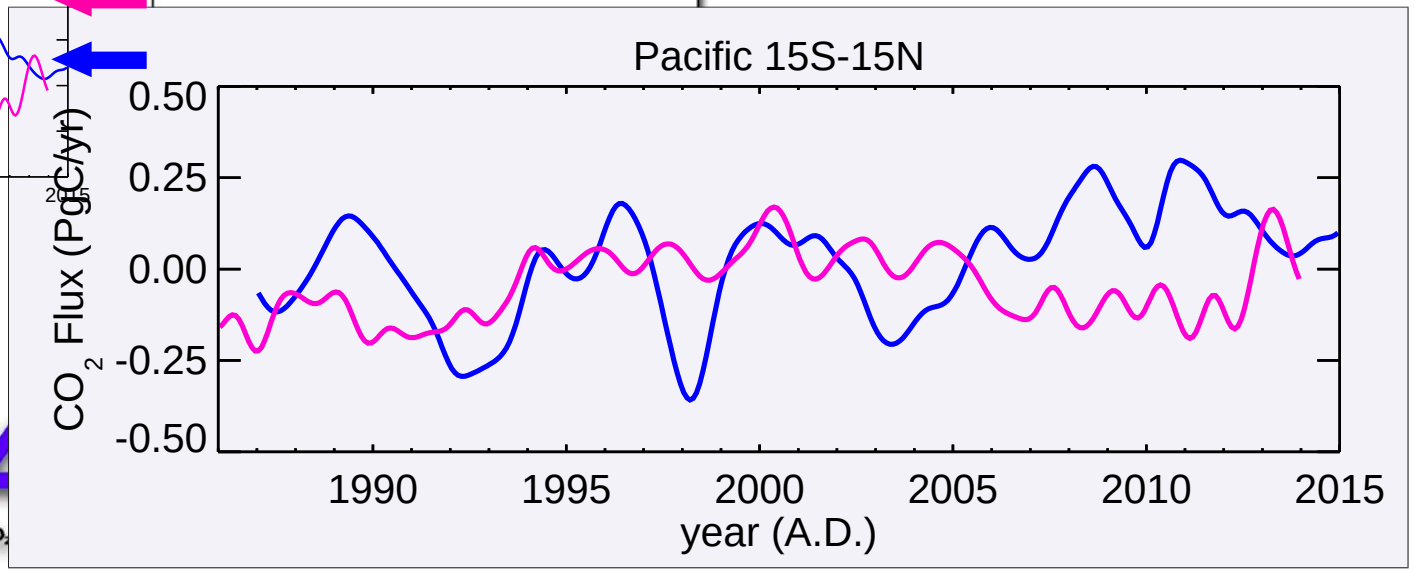
CO_2 **flux**

inferred from CO_2 inversion

inferred from pCO_2 interpolat

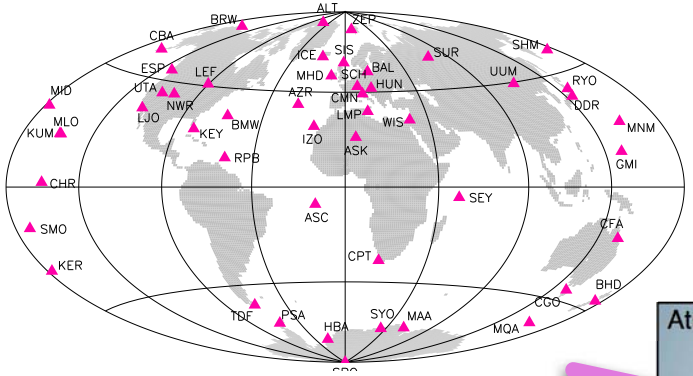






SOCA · SURFACE OCEAN CO

Carbon



CO_2 flux

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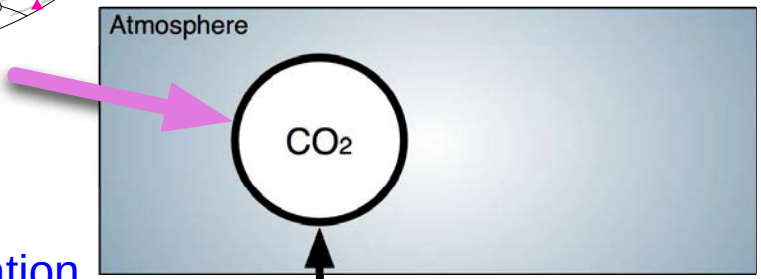
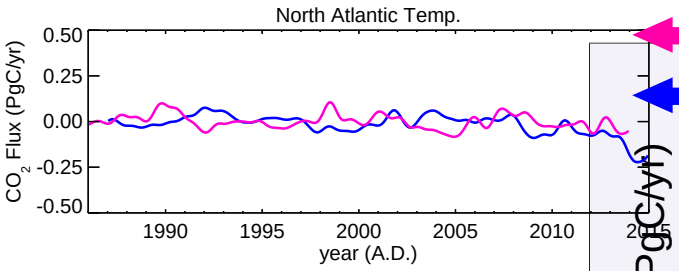
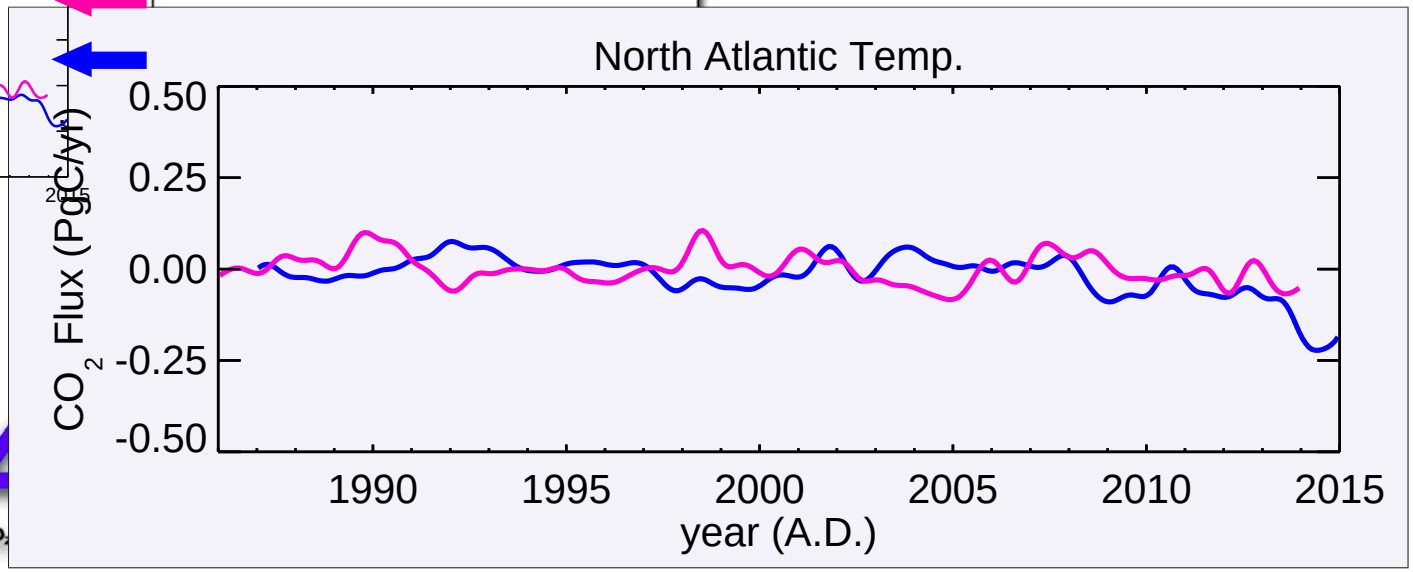
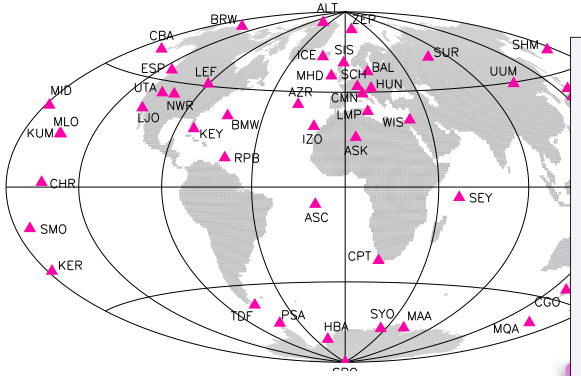






SOCA · SURFACE OCEAN CO

Carbon



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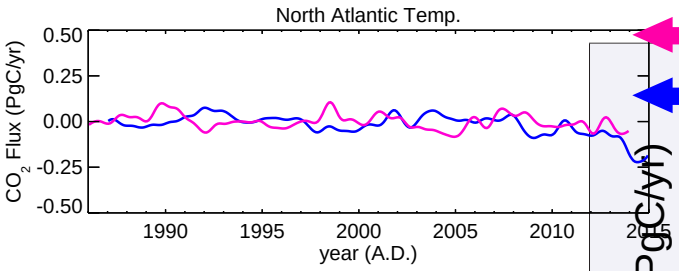

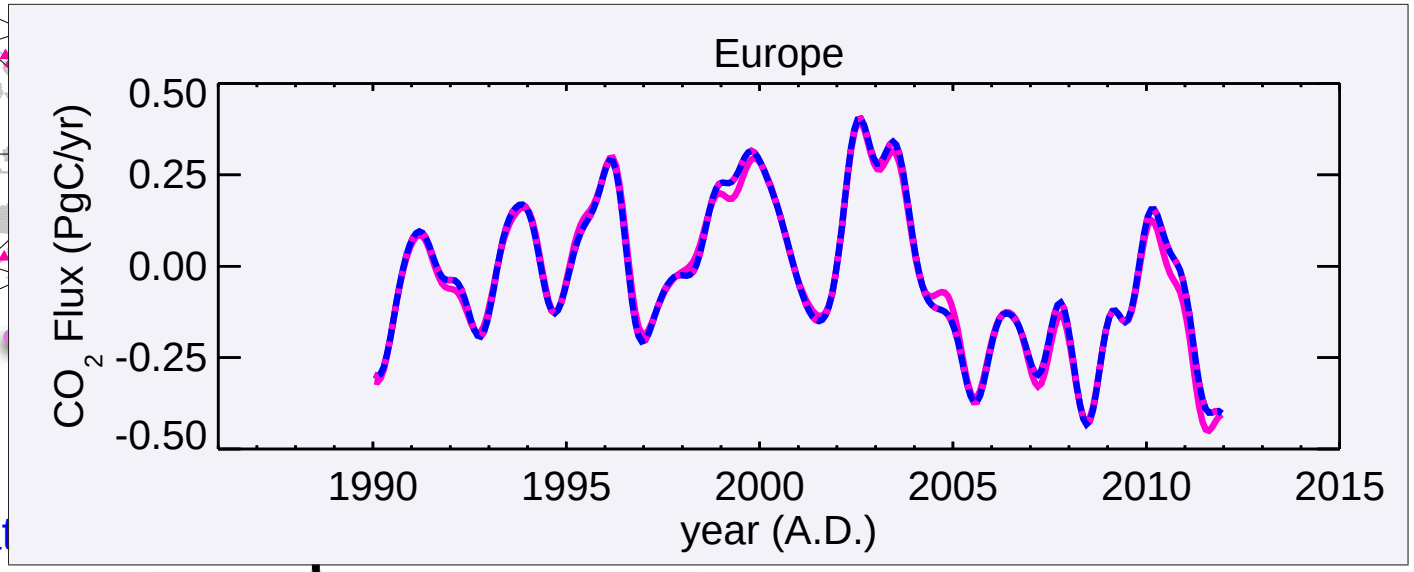

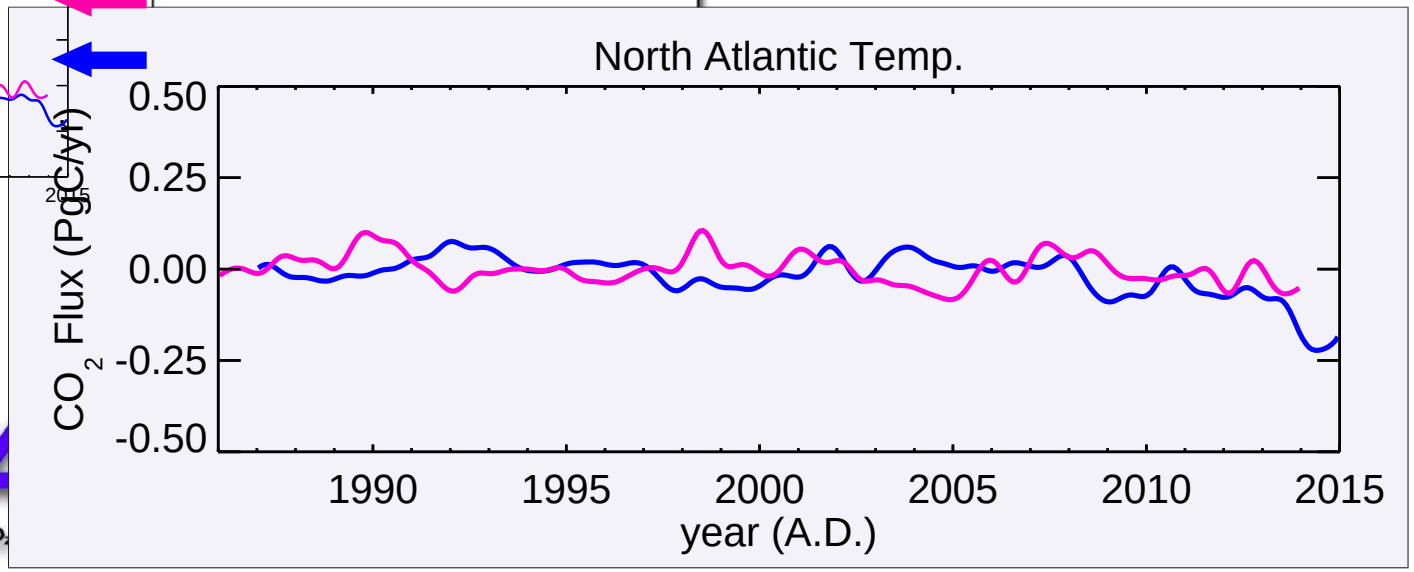

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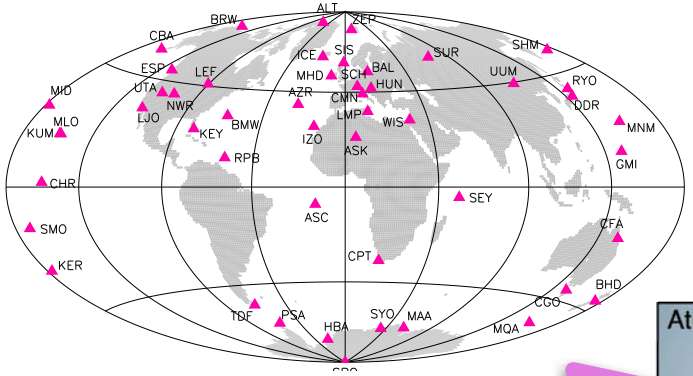
Carbon



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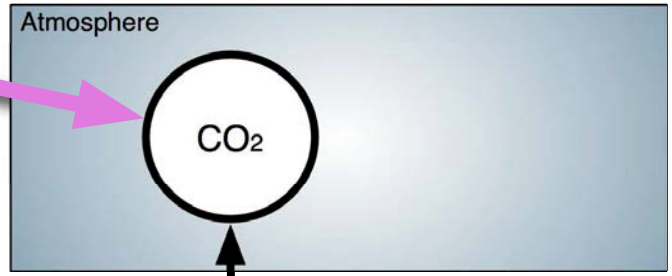
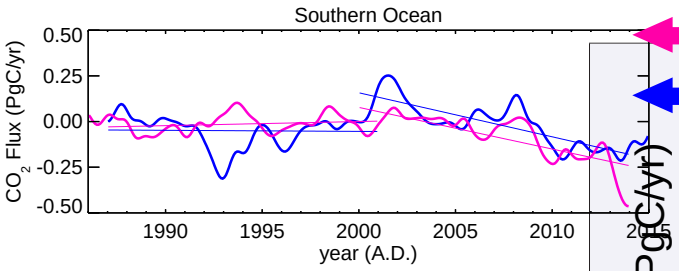
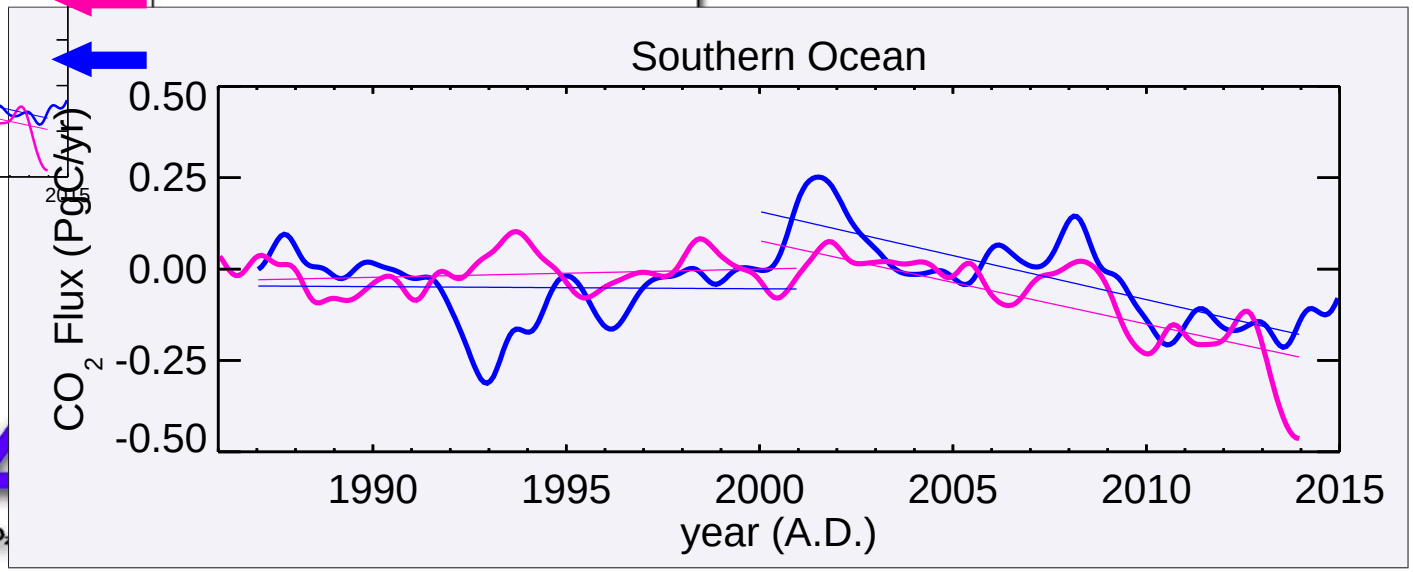


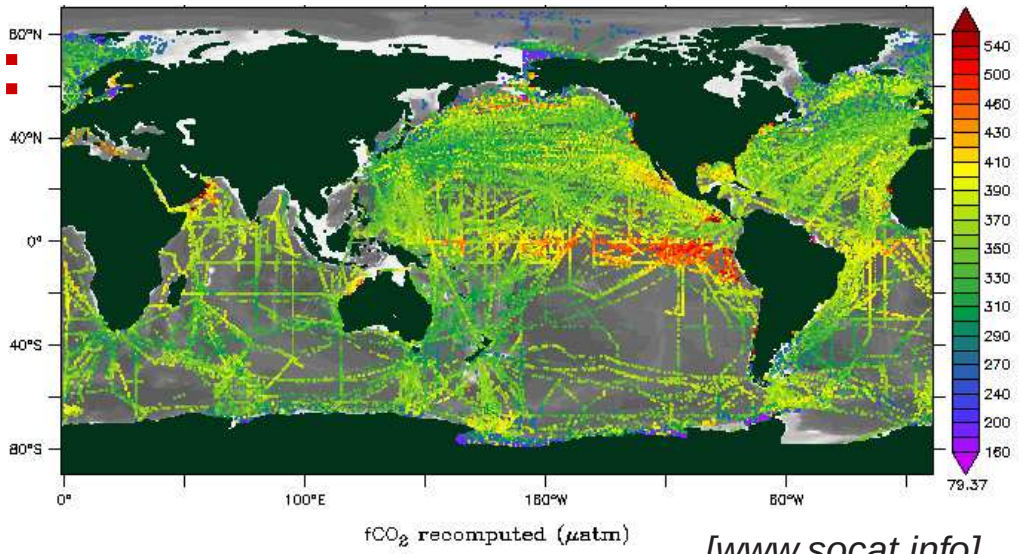




SOCA · SURFACE OCEAN CO

Carbon

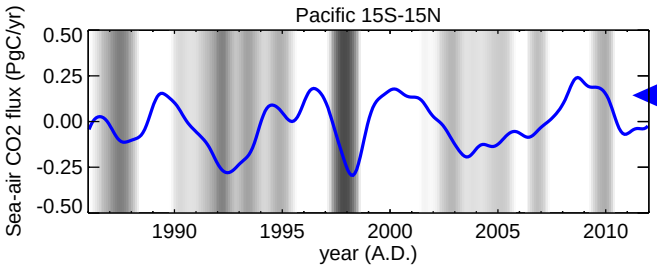
But:



[www.socat.info]

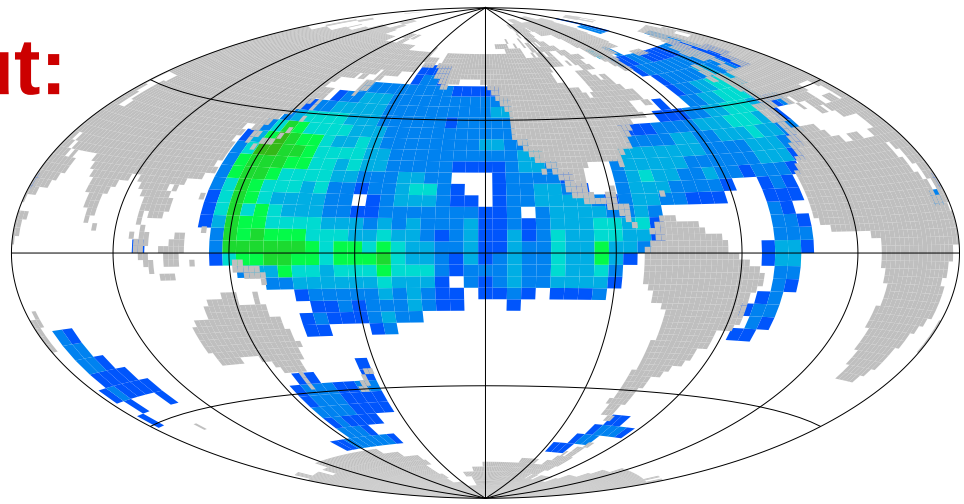
CO_2 flux

inferred from pCO_2 interpolation



Carbon

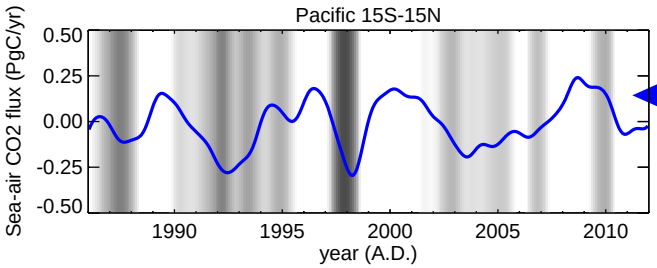
But:



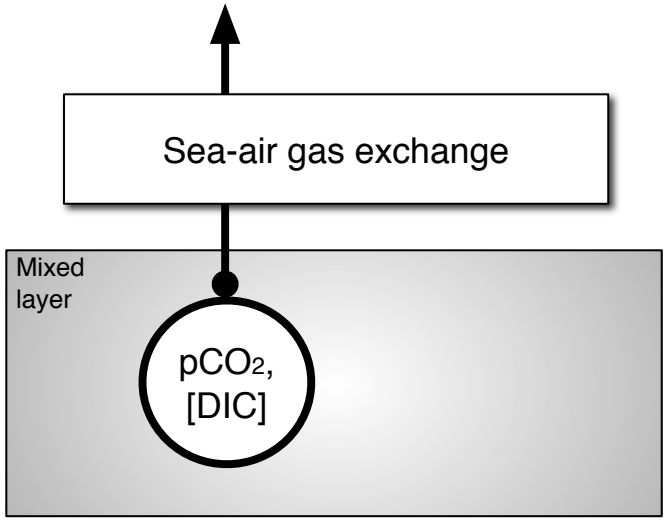
"Reduction of Uncertainty" of flux IAV

CO_2 flux

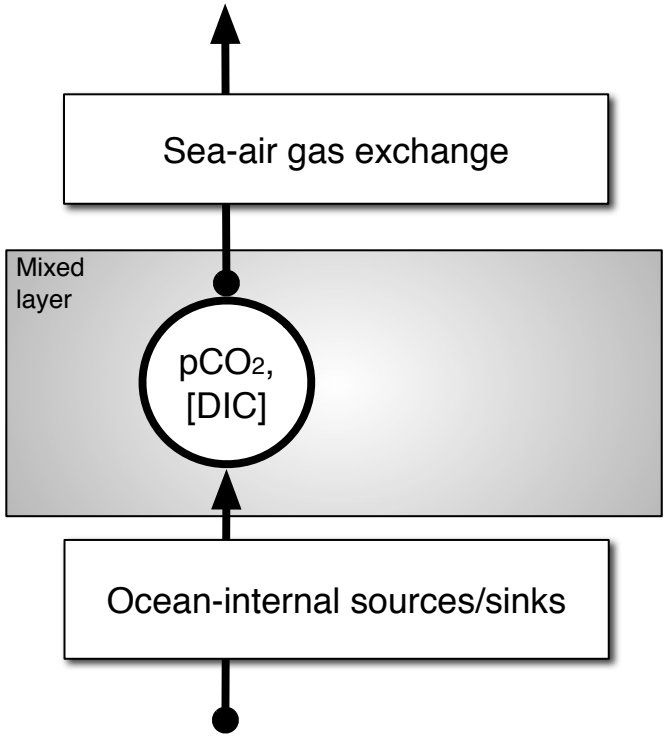
inferred from pCO_2 interpolation



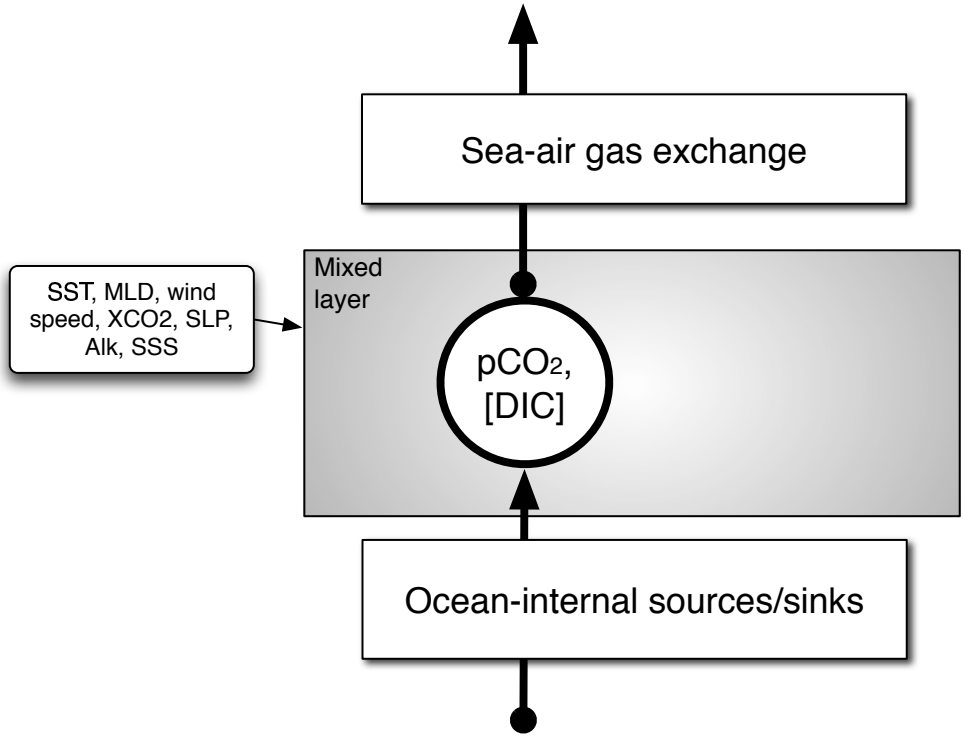
Carbon



Carbon


Sea-air gas exchange
Mixed layer
pCO2, [DIC]
Ocean-internal sources/sinks

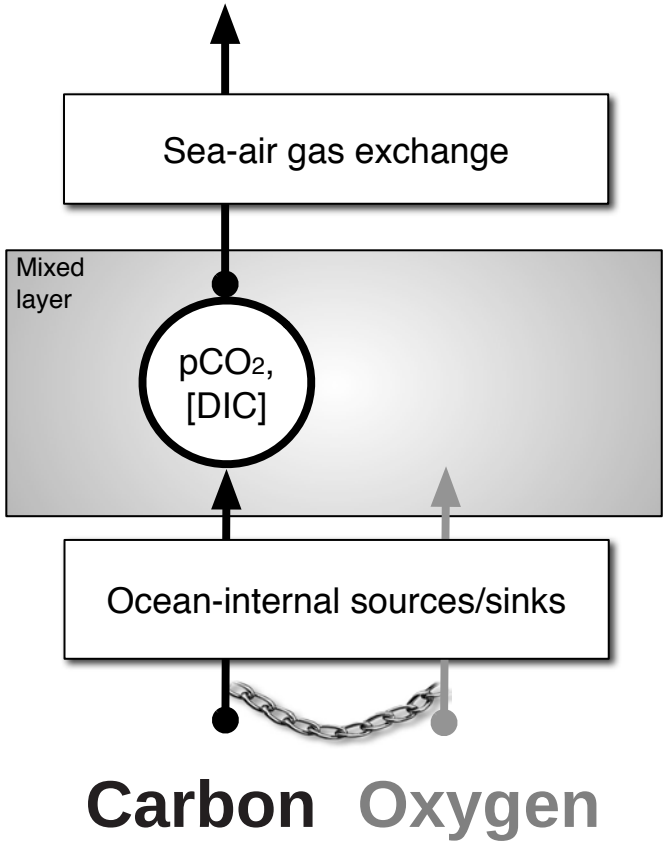
Carbon



$$h\frac{\mathrm{d}}{\mathrm{d}t}C = f_{\mathrm{ma}}(C) + f_{\mathrm{int}}$$

Using parameterizations of
– Solubility
– Sea–air gas exchange
– Carbonate chemistry
– Mixed-layer tracer budget

Carbon



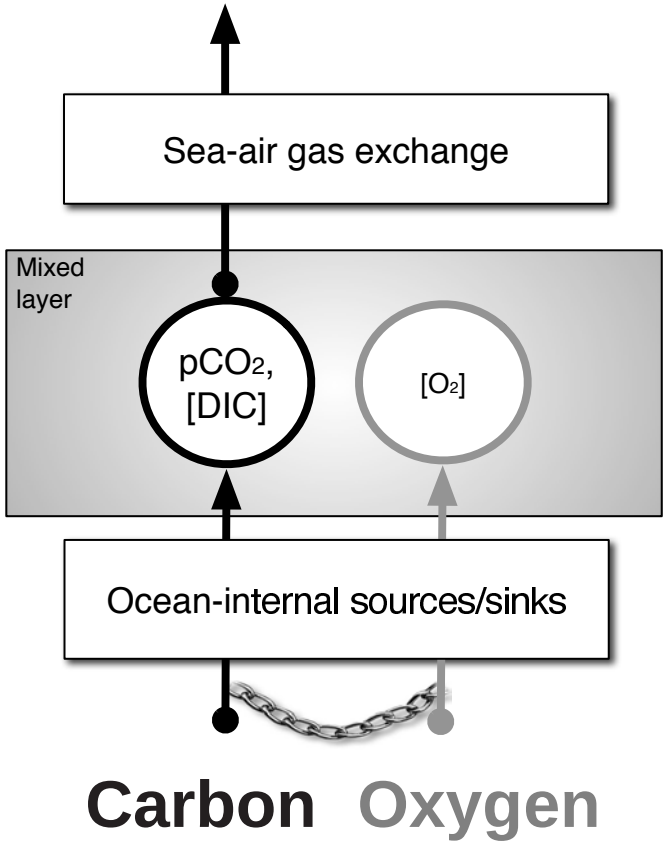
- **Biology:**

  Redfield stoichiometry

  $R_{\mathrm{O:C}} \approx -1.4$

- **Transport+Mixing:**

  Common pathways



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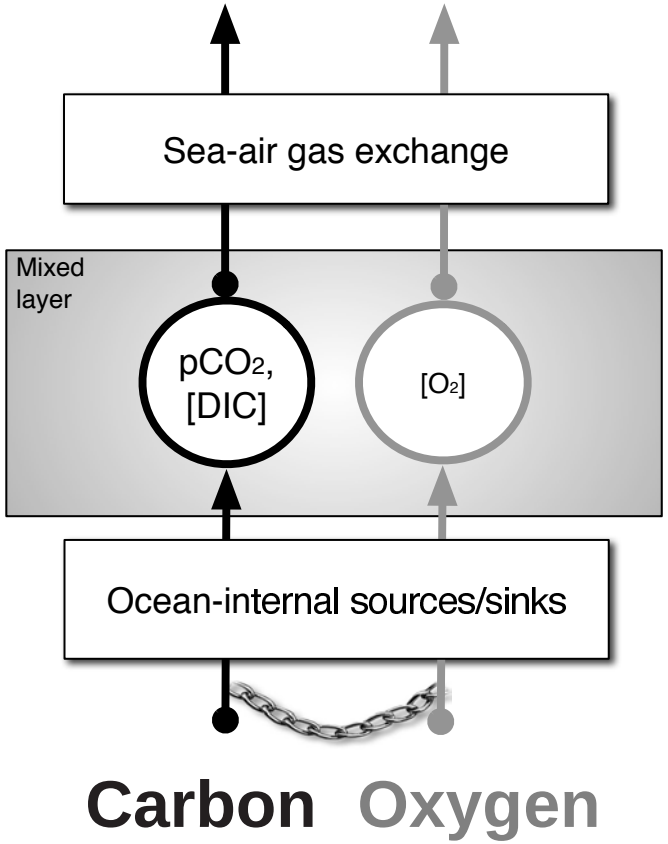

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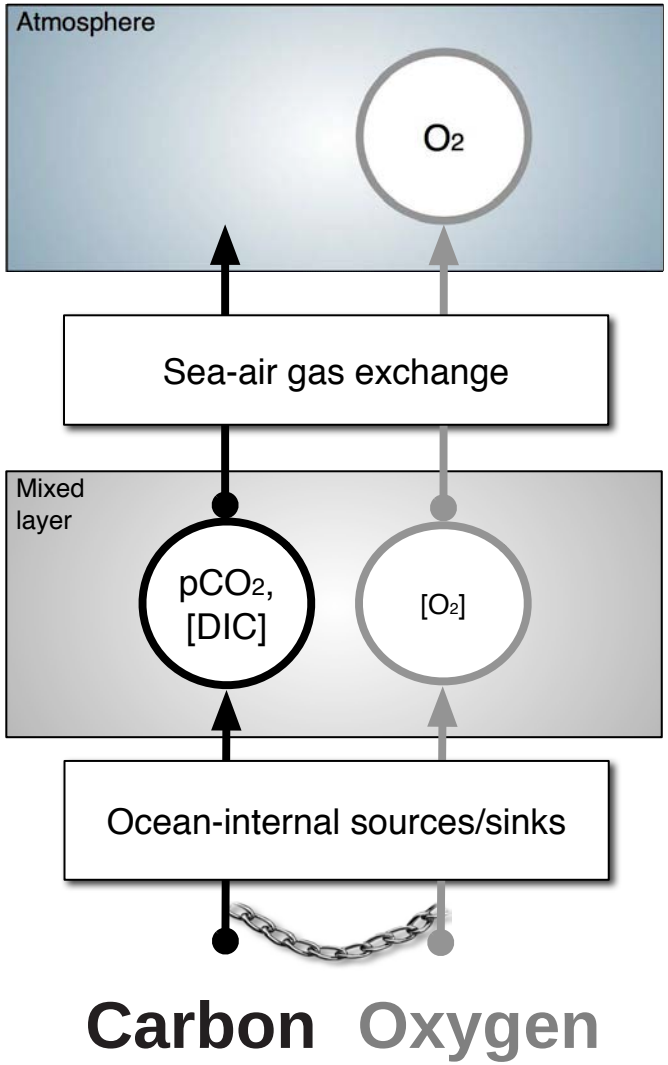

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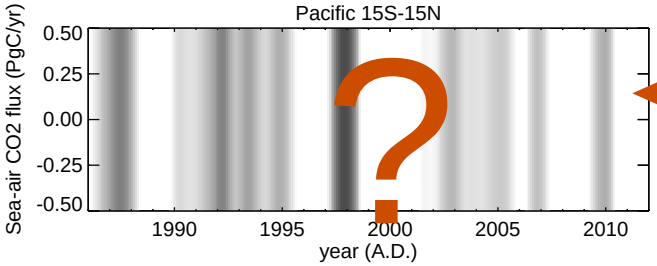
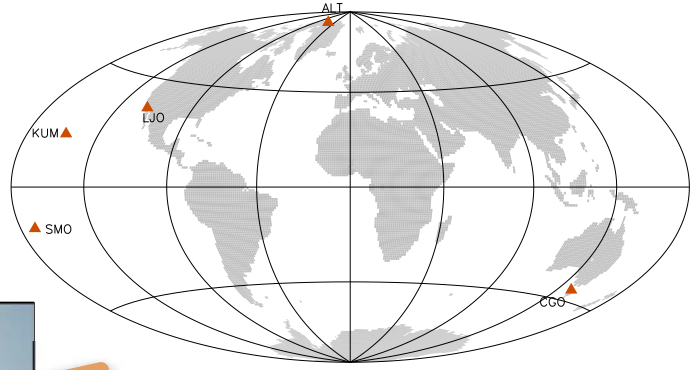
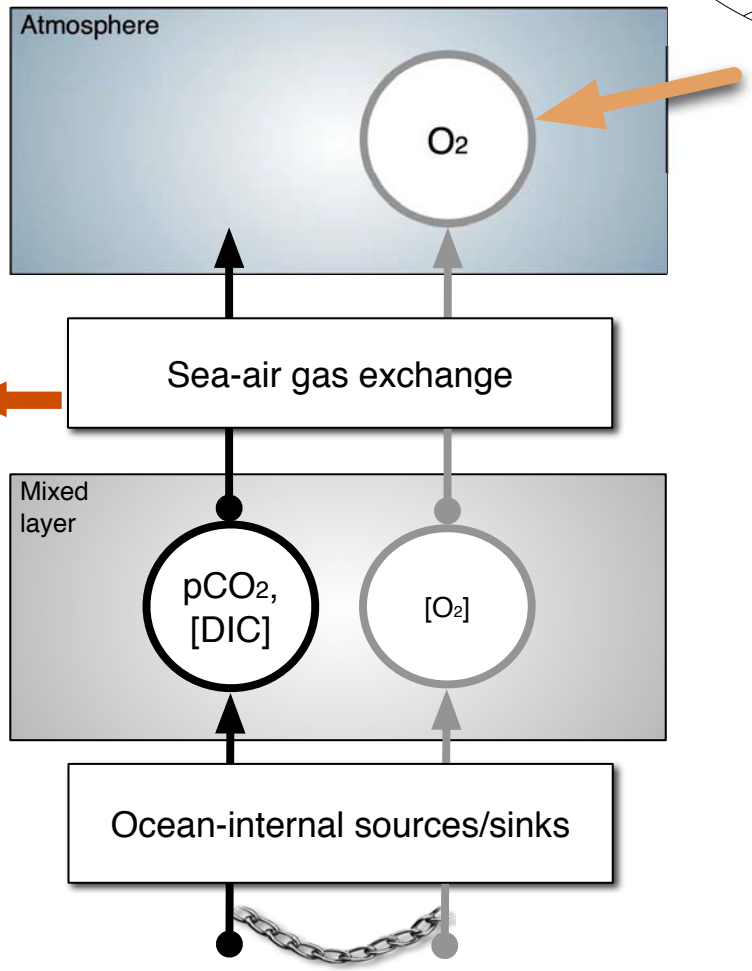
CO_2 **flux**

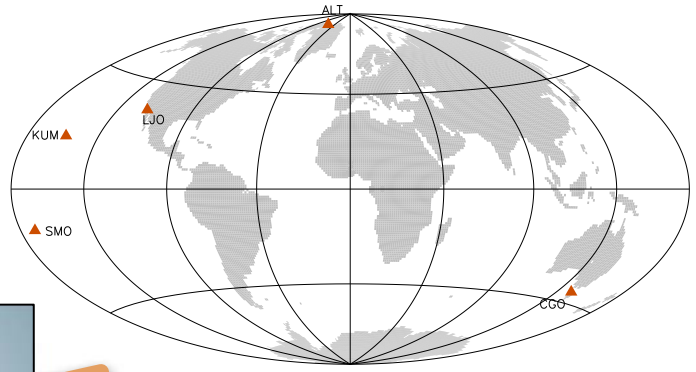
inferred from O_2/N_2

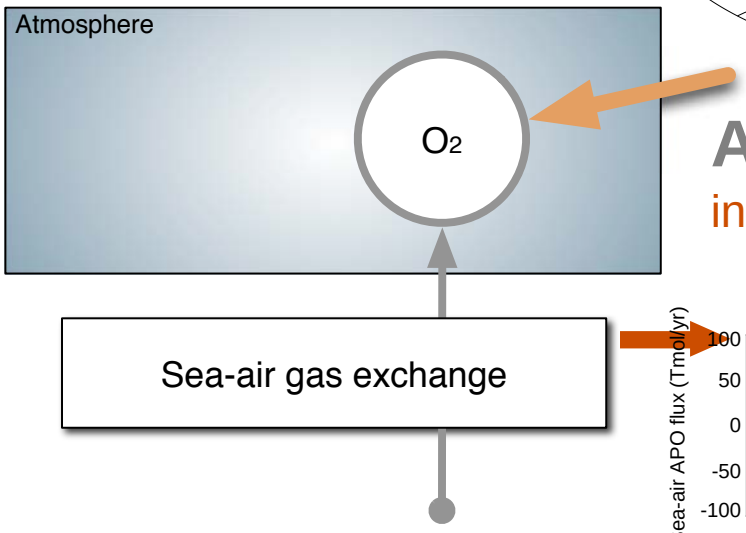






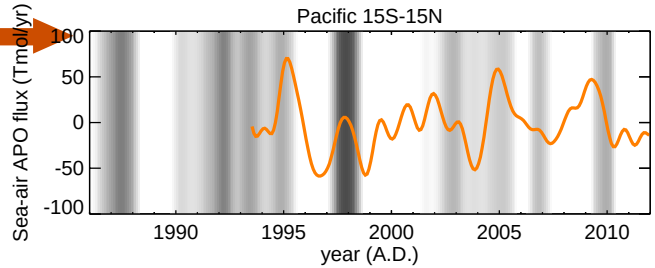
Carbon **Oxygen**



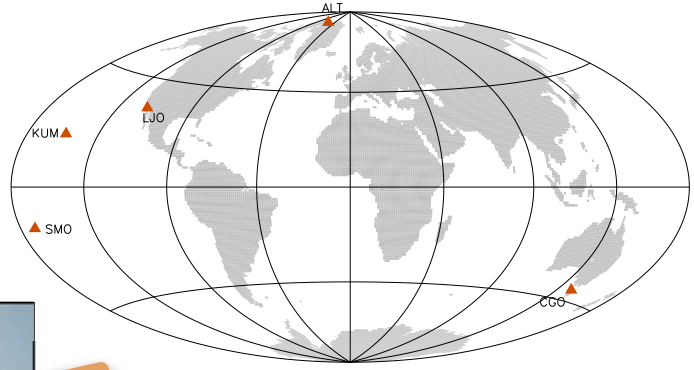


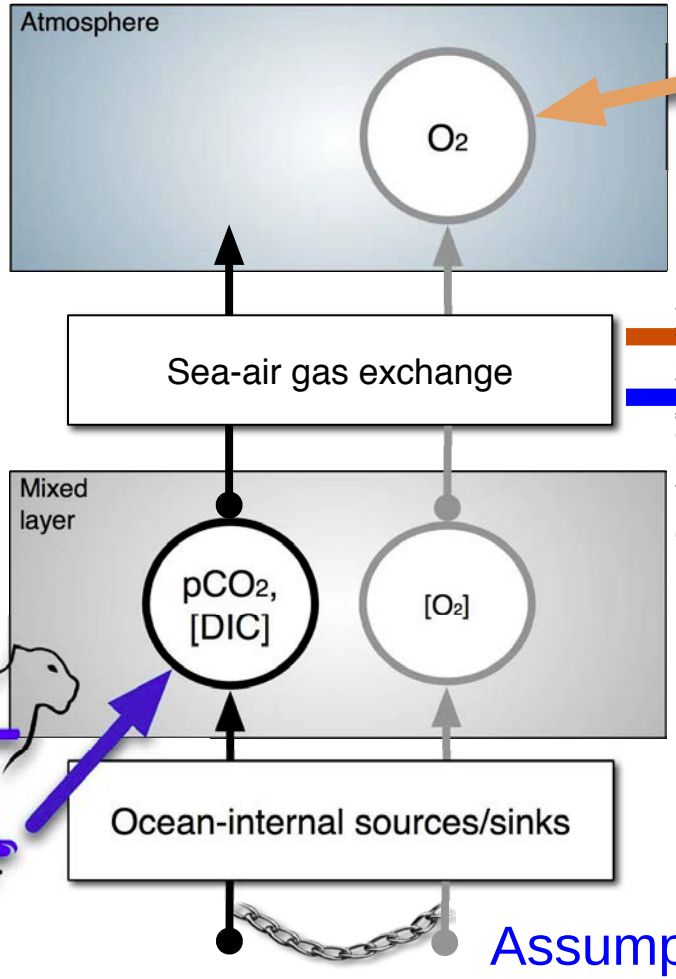
APO flux

inferred from APO inversion



Carbon **Oxygen**

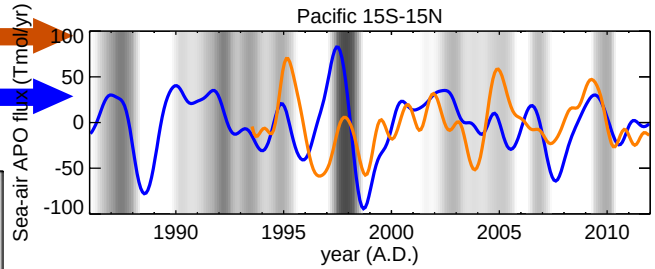




APO flux

inferred from APO inversion

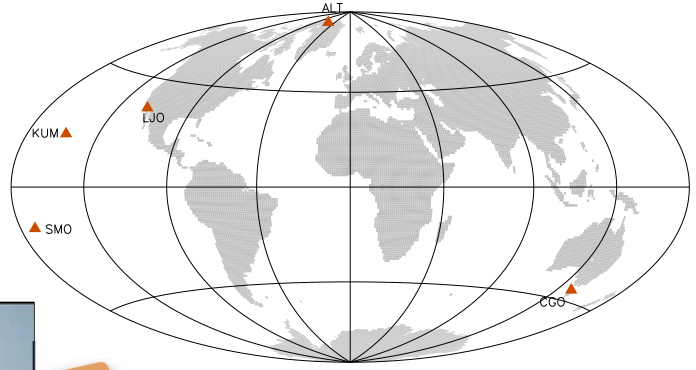
inferred from pCO_2

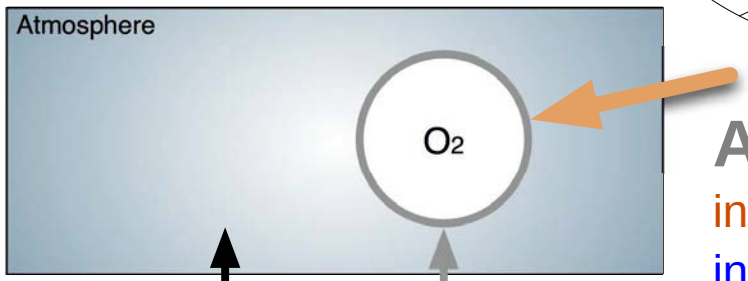


SOCAT · SURFACE OCEAN CO_2 ATLAS ·

Assumption: Linked à la **Redfield**

Carbon **Oxygen**





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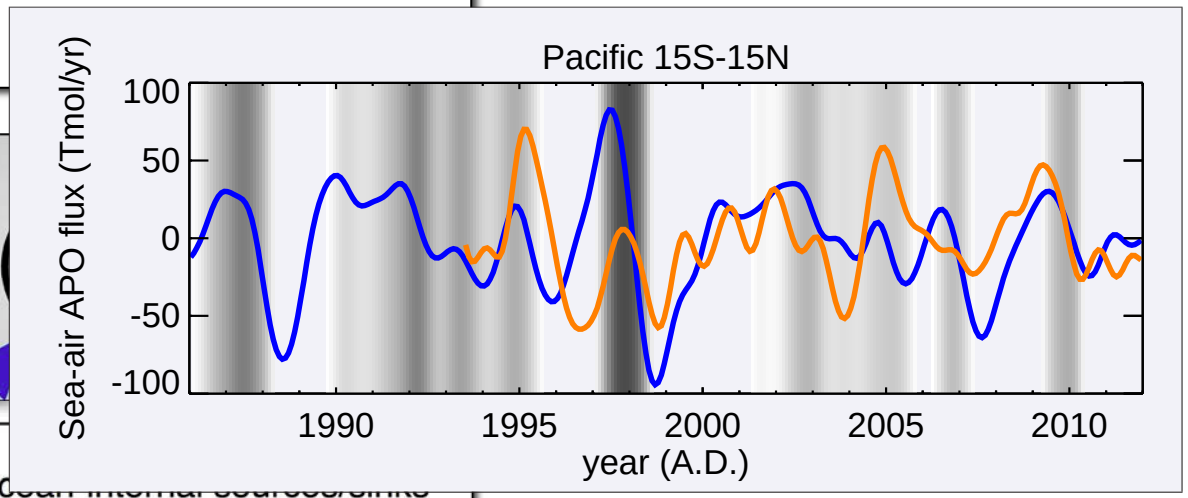

SOCAT · SURFACE OCEAN CO_2 ATLAS ·

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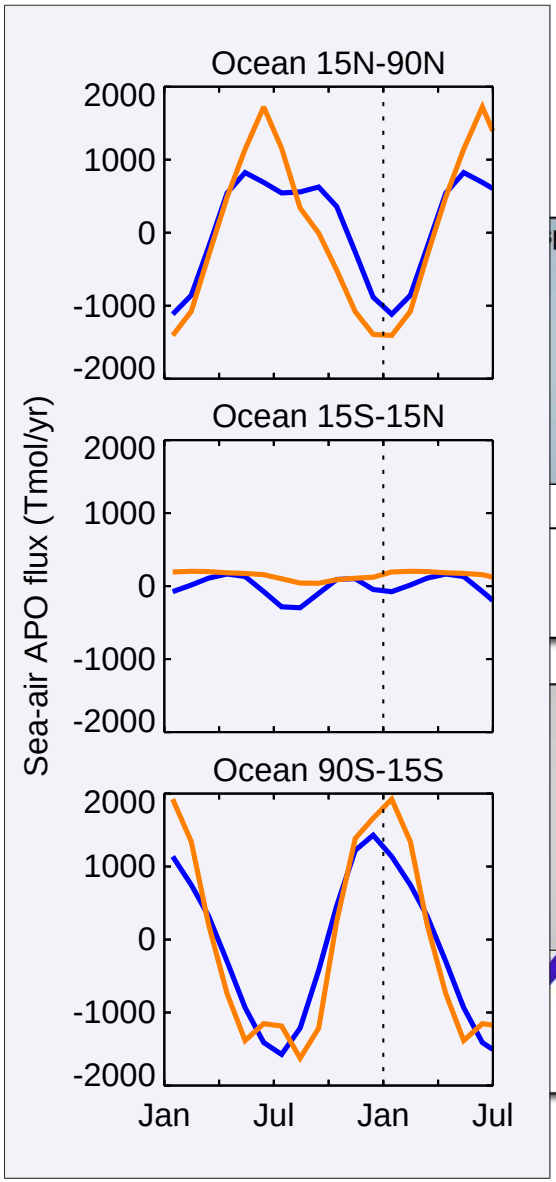

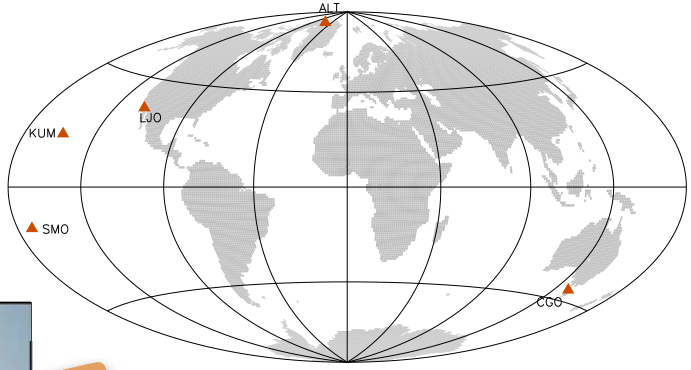

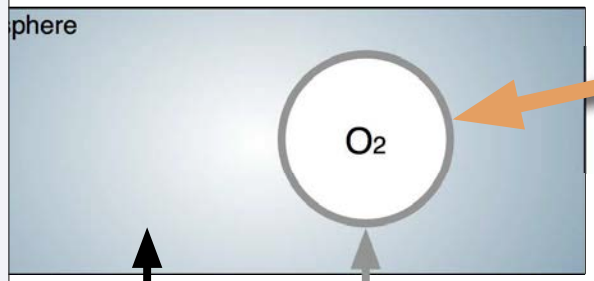

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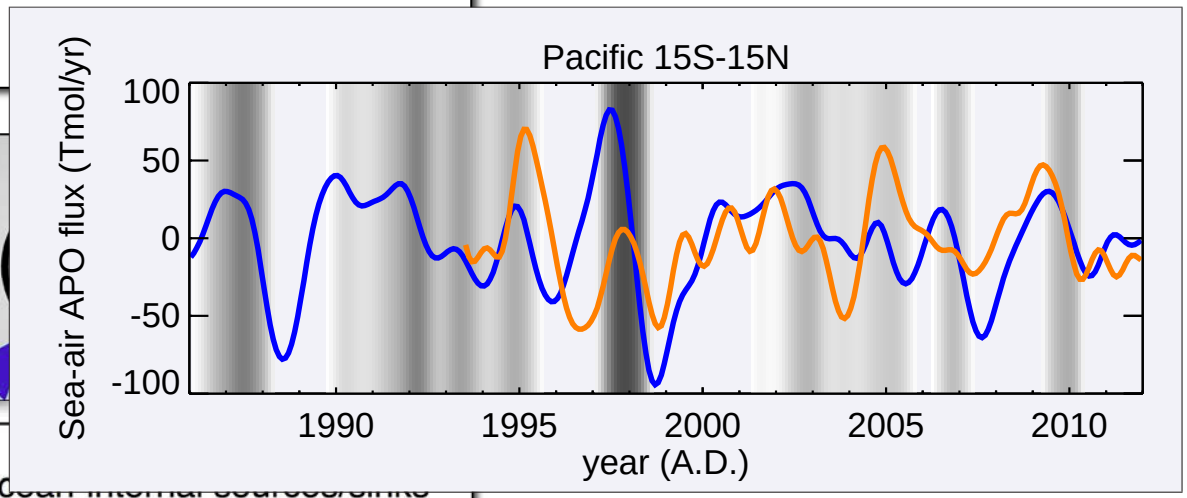

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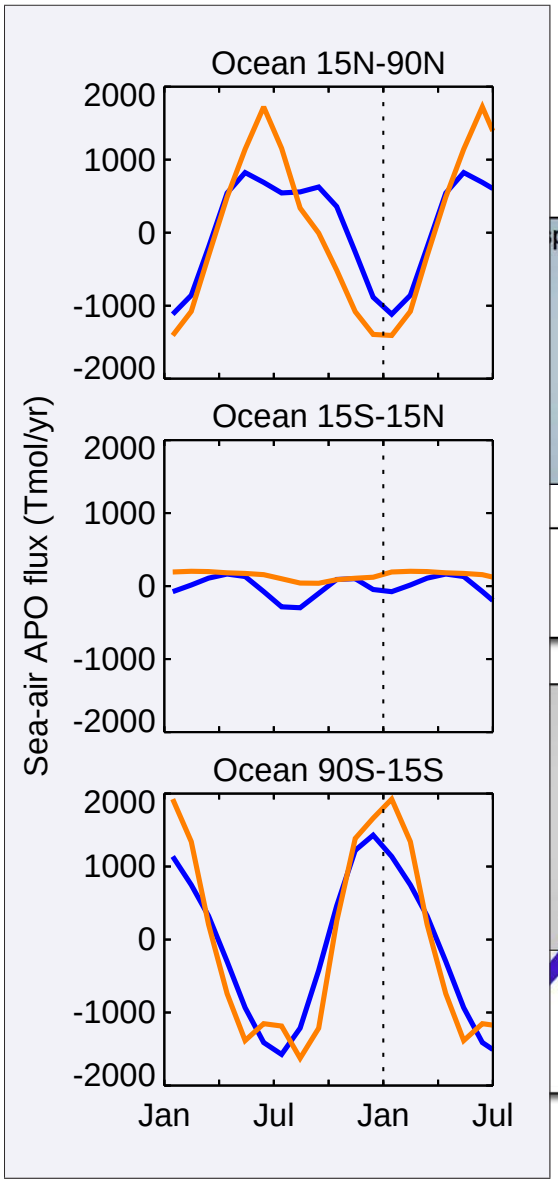
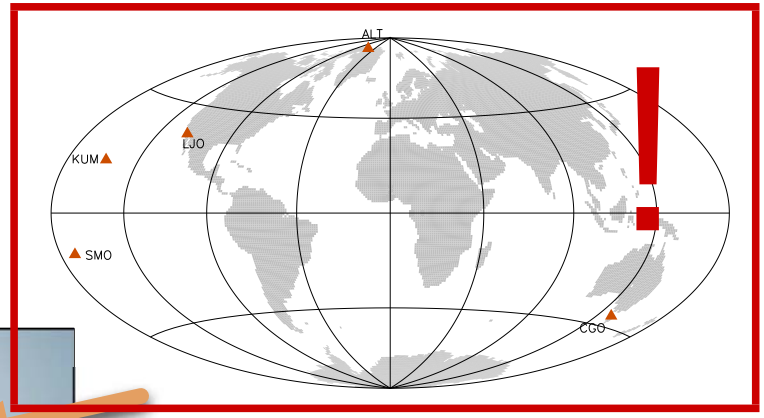
Carbon **Oxygen**





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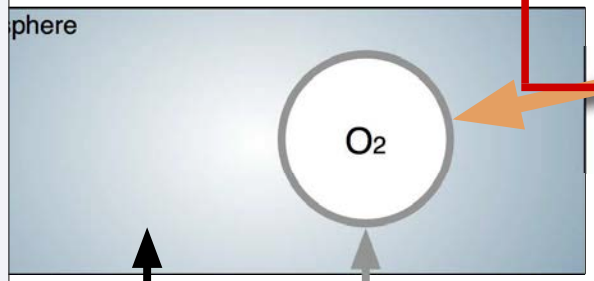

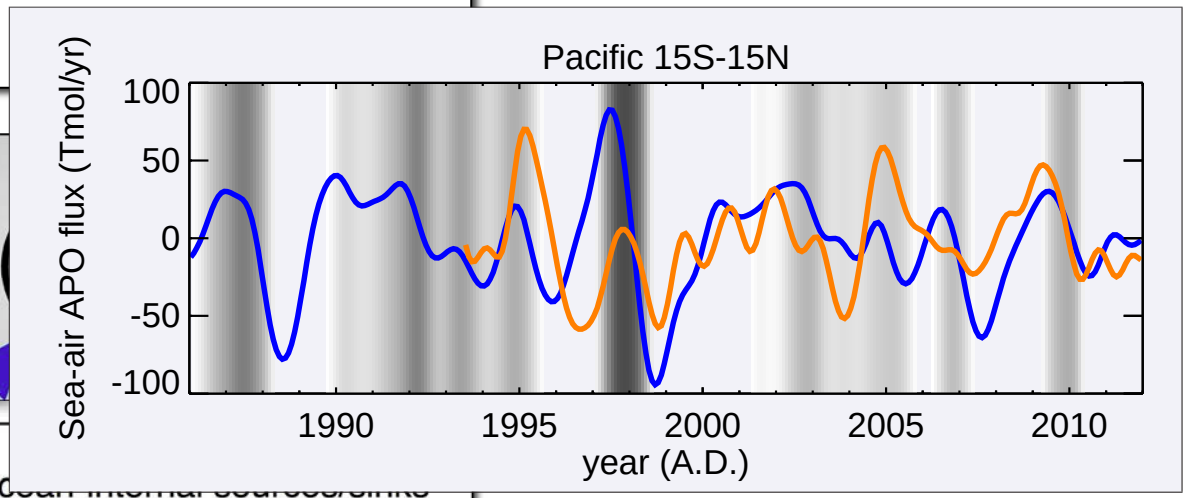

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Carbon **Oxygen**

What do the atmospheric stations “see”?

Testing existing and potential CO_2 observations (RINGO)

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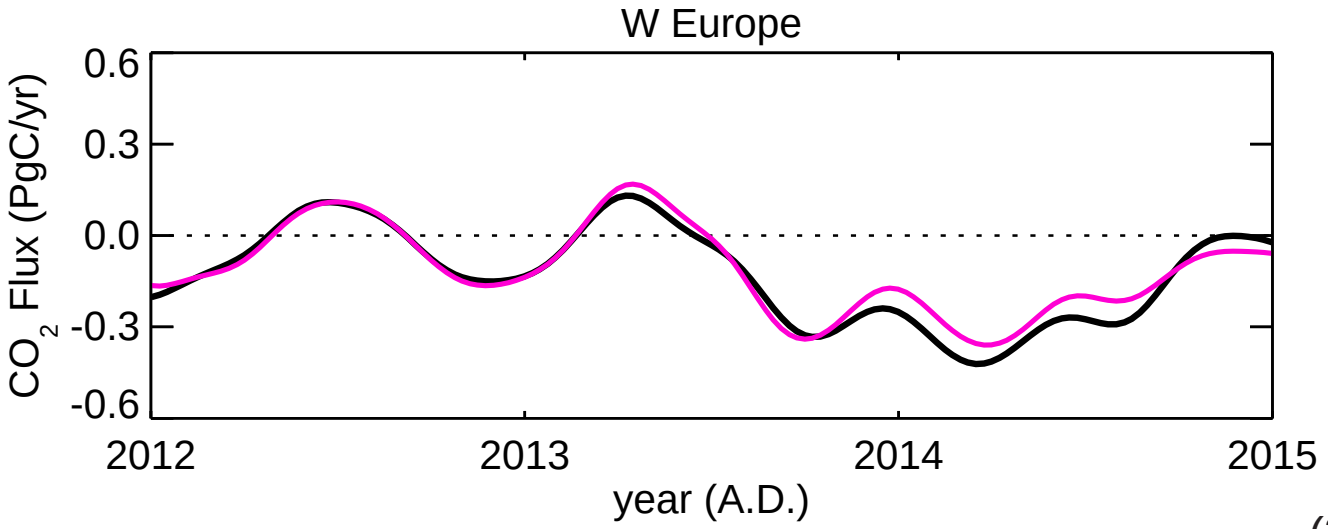
– **“Known truth”**
(OCN, Zaehle et al., 2010)

– **Retrieved** from “synthetic data”
(s04_v3.8 sites)



(3-monthly anomalies)

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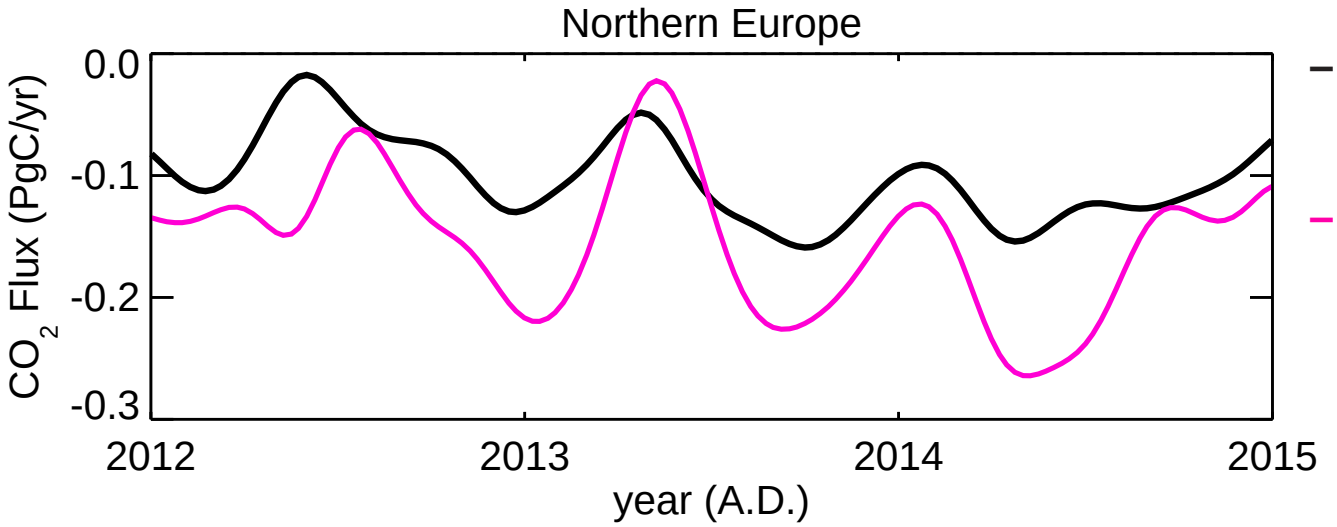

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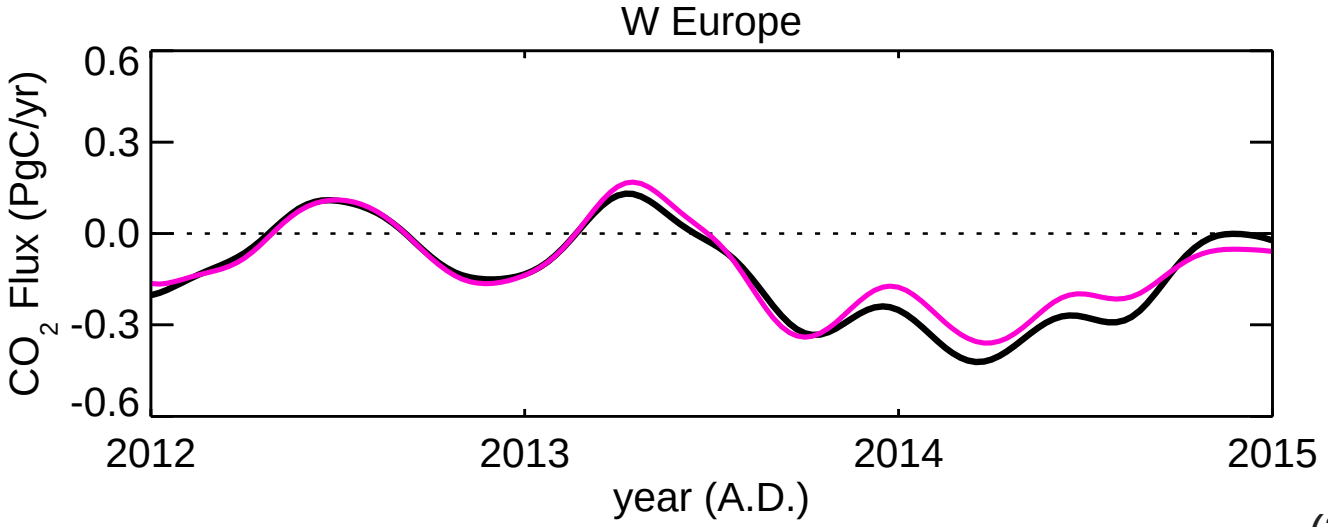

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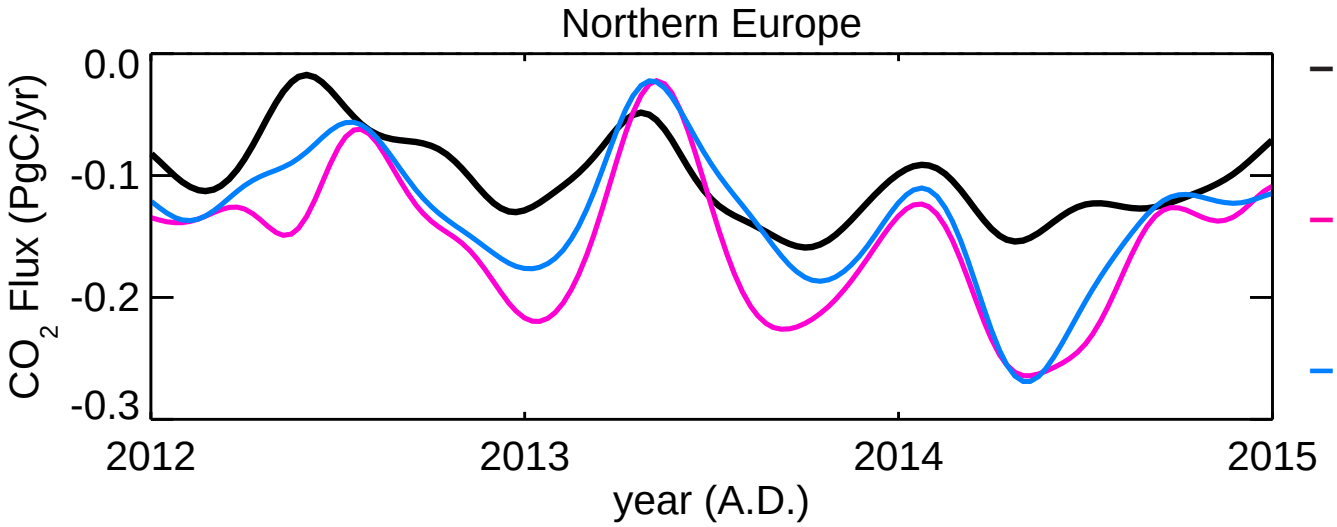

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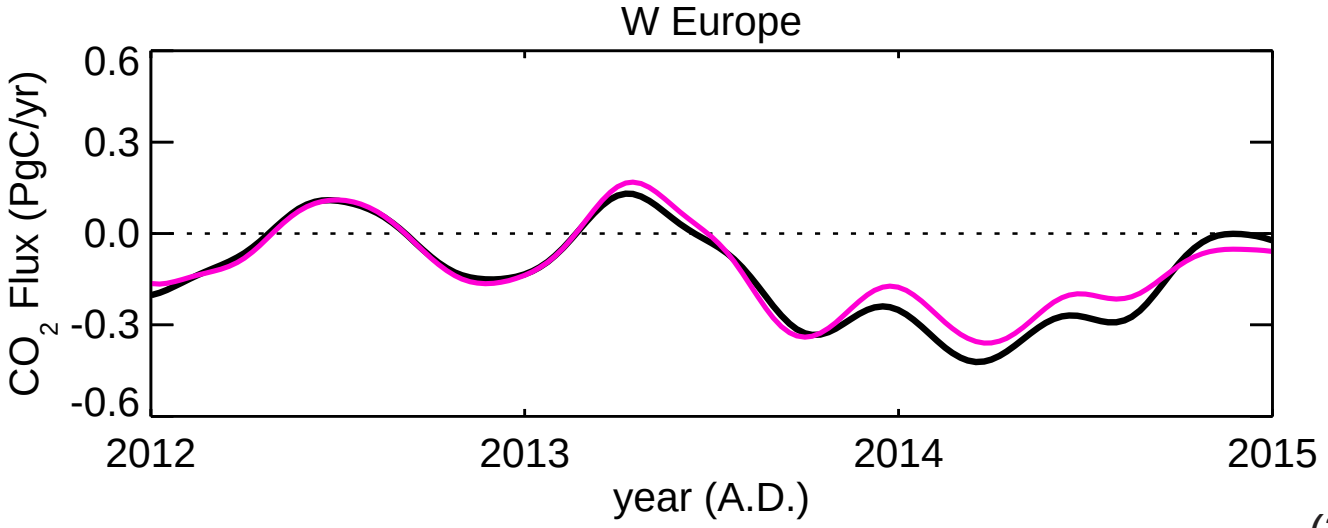
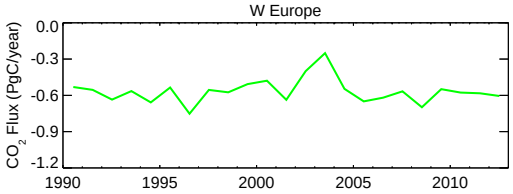
– **Retrieved** from “synthetic data”
(s04_v3.8 sites +
assumend FINNMAID data)



Travemünde ↔ Helsinki

(3-monthly anomalies)

Conclusions



Atmospheric CO_2 data & *inversion:*

- Constraint on land variability
- Southern Ocean trends

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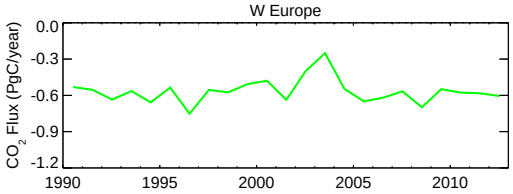

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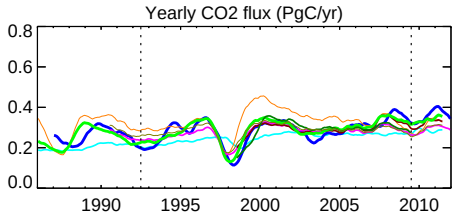
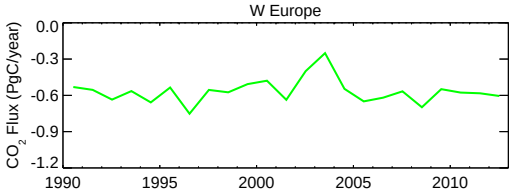


SOCOM
SURFACE OCEAN pCO_2 MAPPING INTERCOMPARISON

Conclusions



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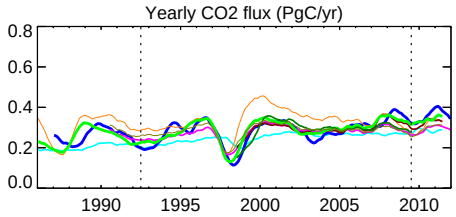
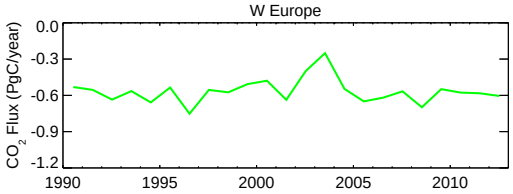


SOCOM
SURFACE OCEAN pCO_2 MAPPING INTERCOMPARISON

Ship-based atmospheric CO_2 meas.:

- Testing impact of additional data
- Potential for regional flux estimates

Conclusions



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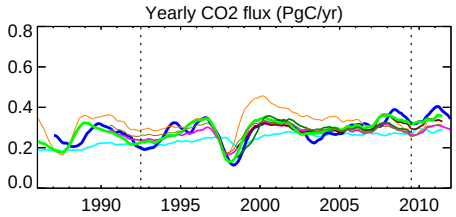


SOCOM
SURFACE OCEAN pCO_2 MAPPING INTERCOMPARISON

Ship-based atmospheric CO_2 meas.:

- Testing impact of additional data
- Potential for regional flux estimates

Products available for download:

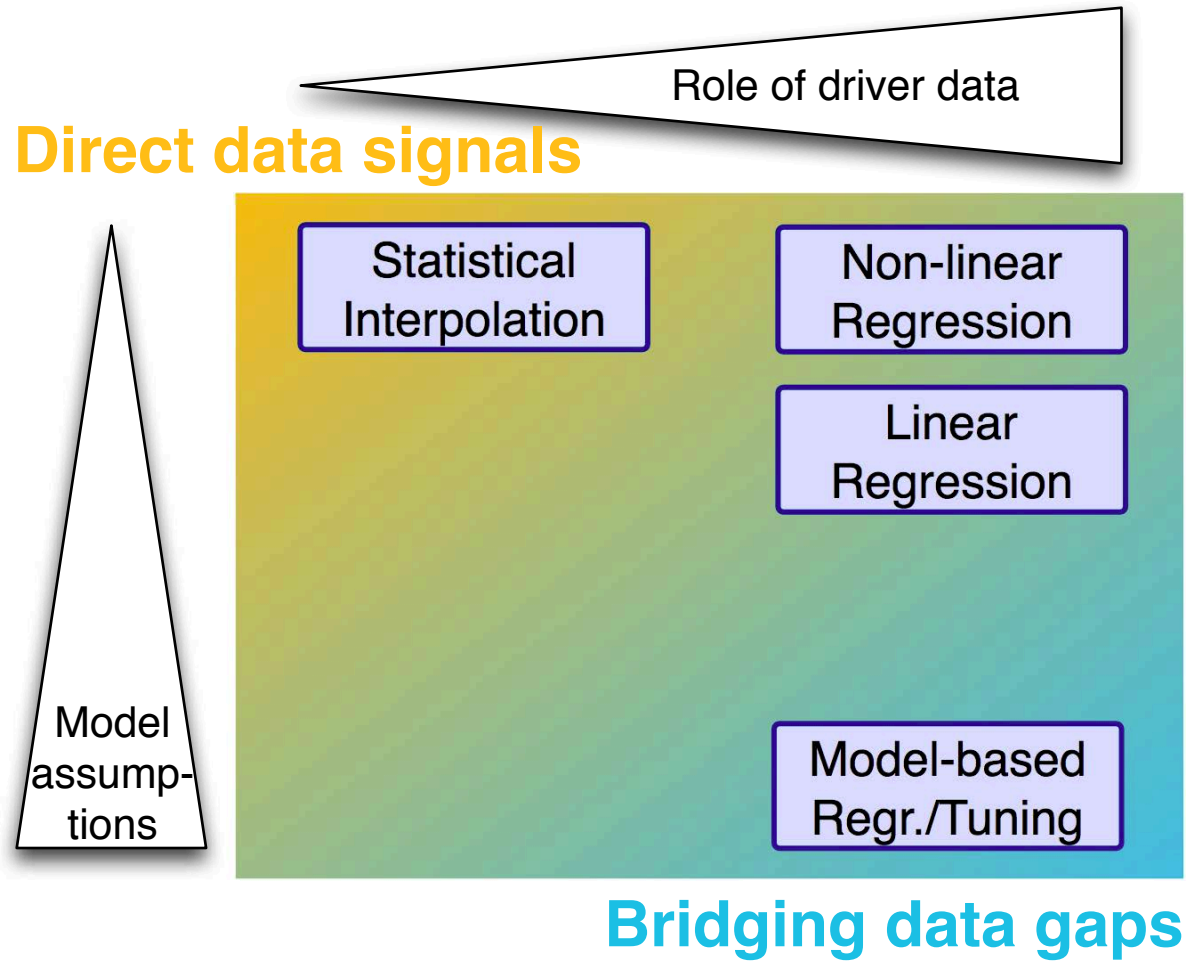
- Atmospheric CO_2 inversion
- pCO_2-based mixed-layer scheme
- Combined products, sensitivity cases, atm. fields

`www.BGC-Jena.mpg.de/CarboScope/`

Jena
CarboScope

BACK-UP SLIDES

Mapping methods



⟶ **Interesting complementarity**

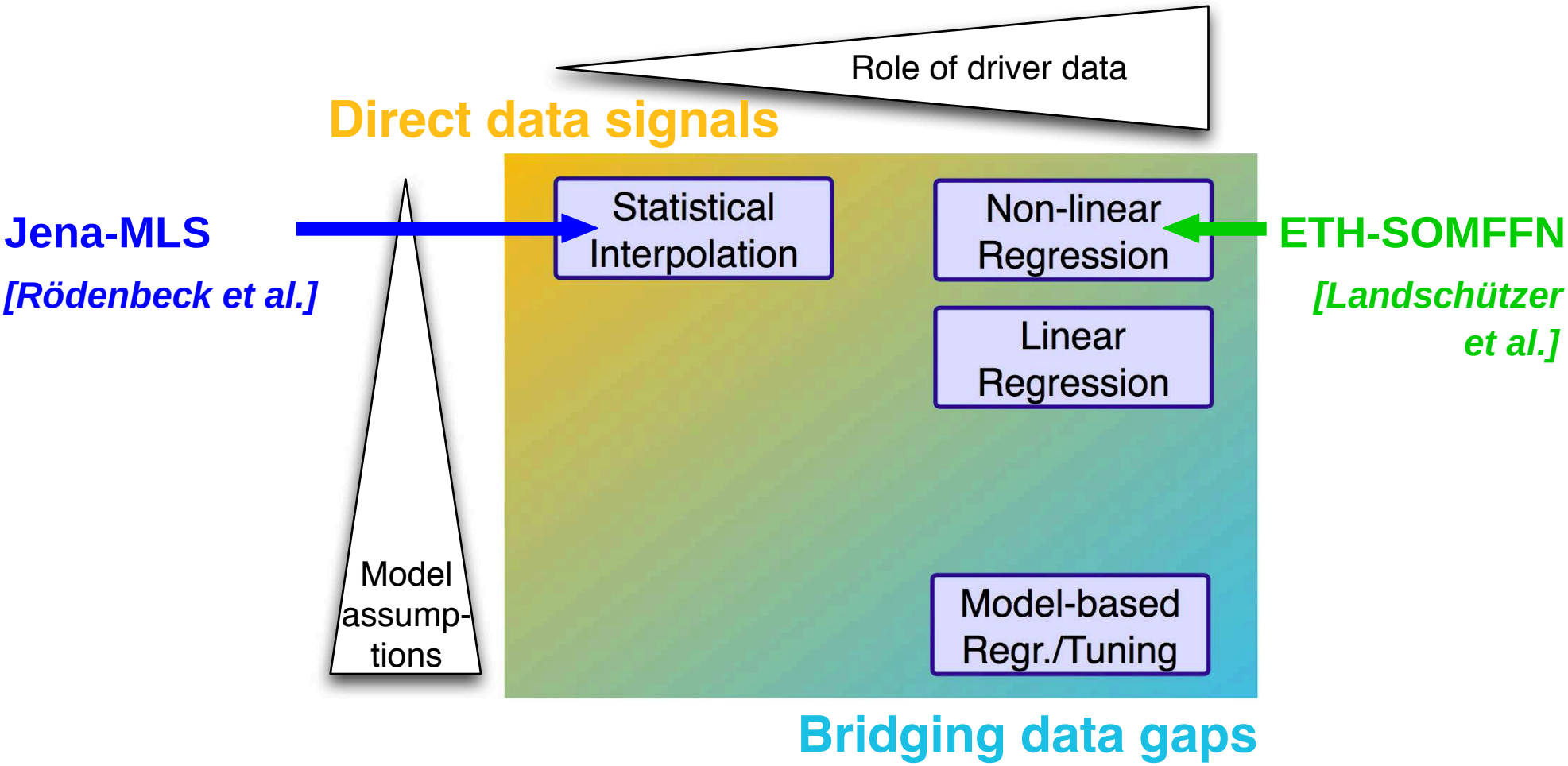
⟶ **Extracting robust features**

SOCOM: Collating 14 mapping methods

SOCOM

SURFACE OCEAN pCO_2 MAPPING INTERCOMPARISON

Mapping methods



⟶ **Interesting complementarity**

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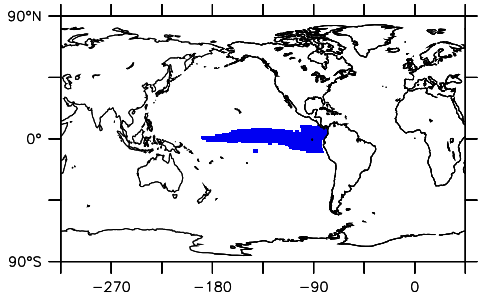
SOCOM

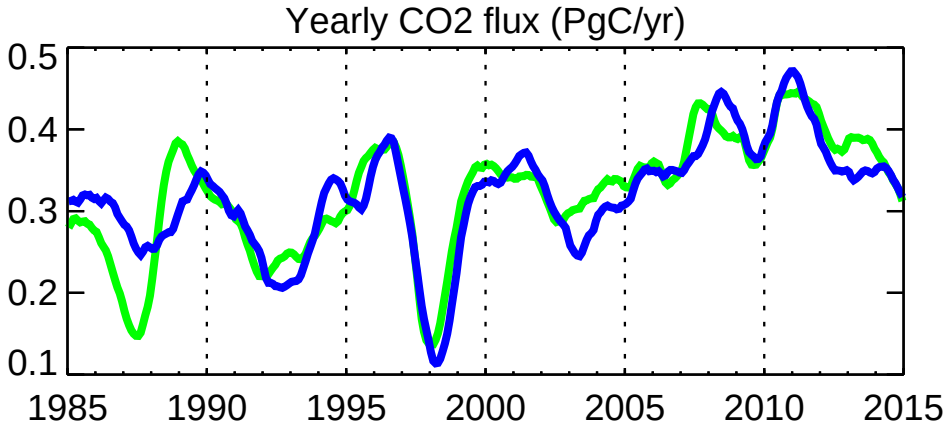
SURFACE OCEAN pCO_2 MAPPING INTERCOMPARISON

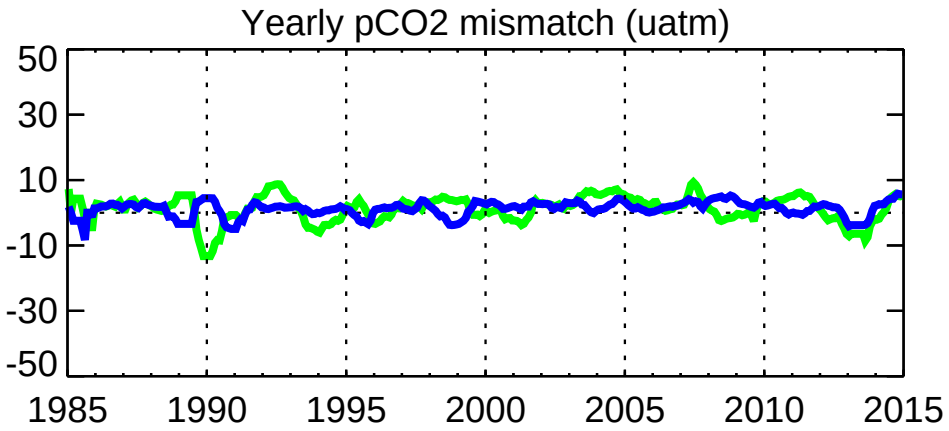
Cross Validation

(18.%) Jena oc_v1.4S

(28.%) ETH-SOMFFN2016







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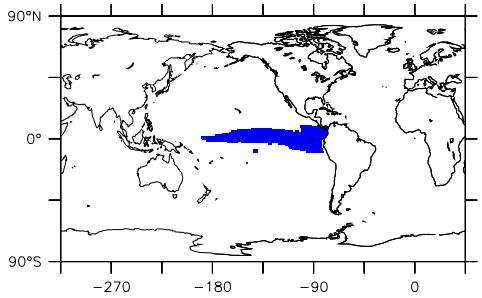

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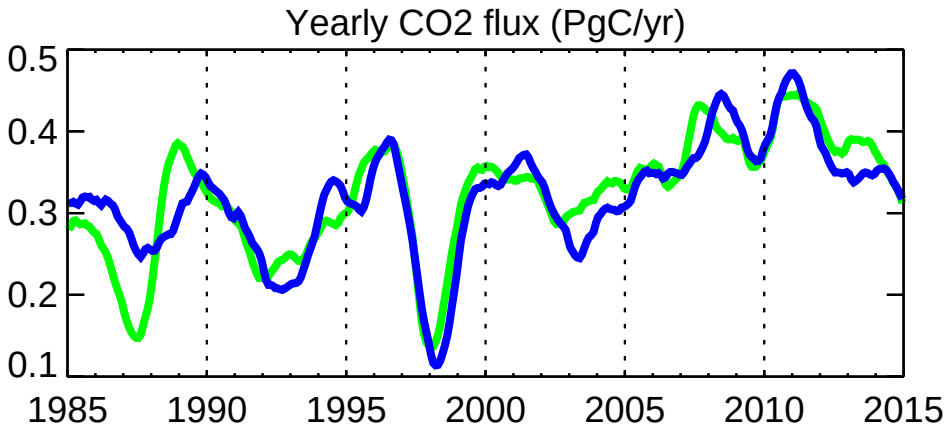

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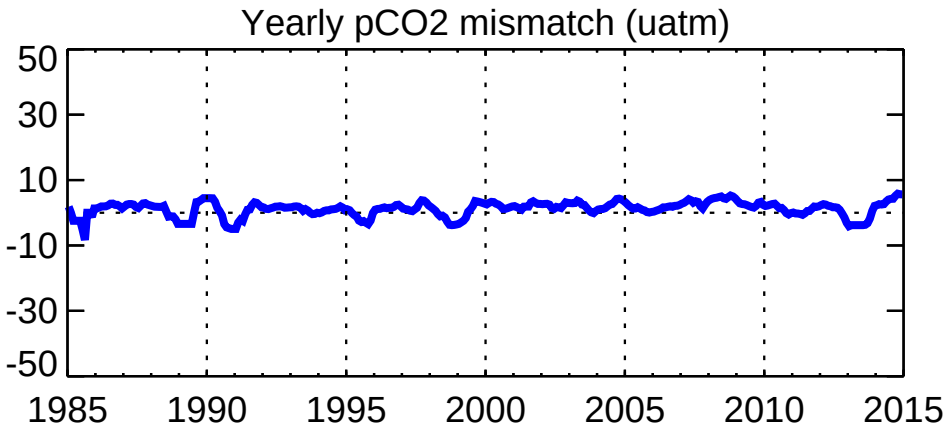

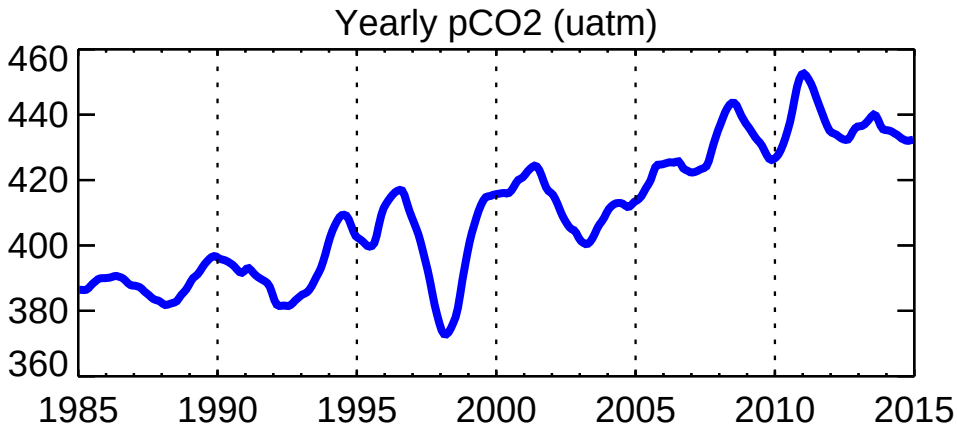

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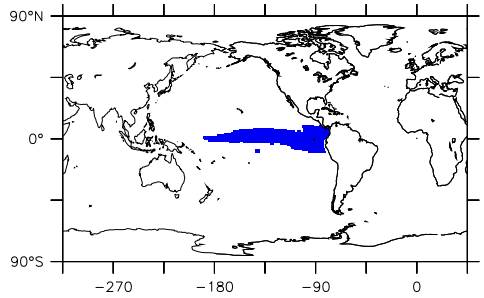
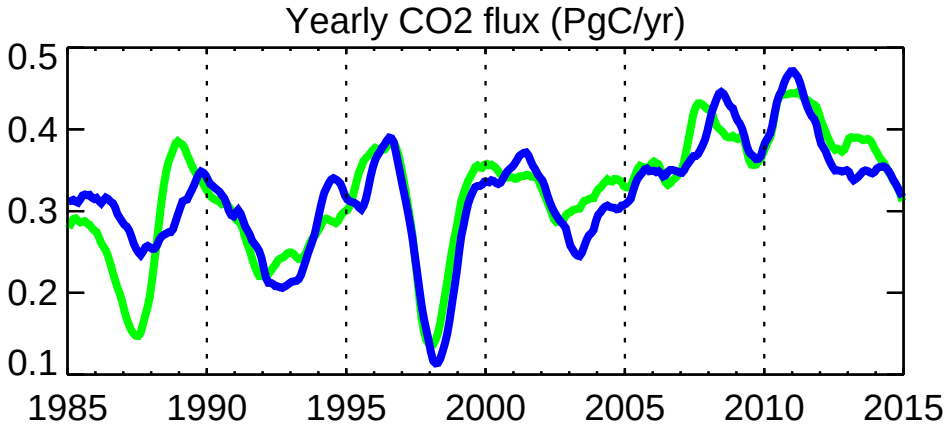


“Benchmark”:

Keep seasonality+trend, but **no IAV**

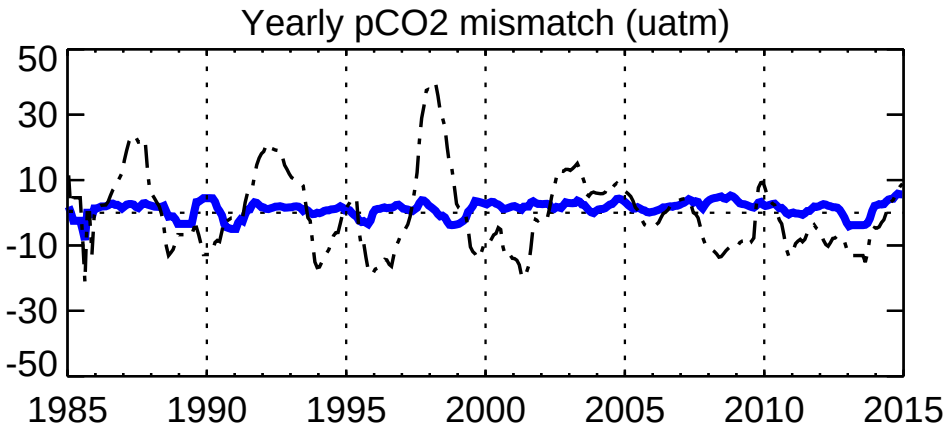
→ Mismatch ≈ signal size

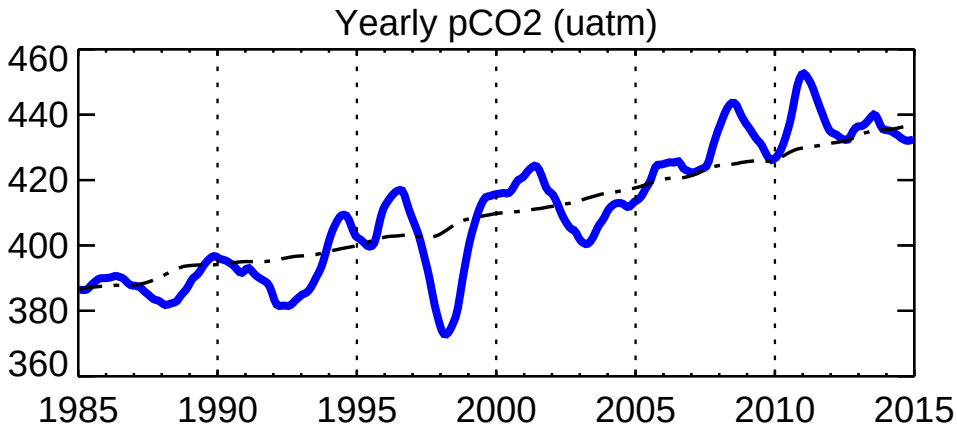
→ “100% error”



(18.%) Jena oc_v1.4S

(100.%) Jena oc_v1.4S Benchmark





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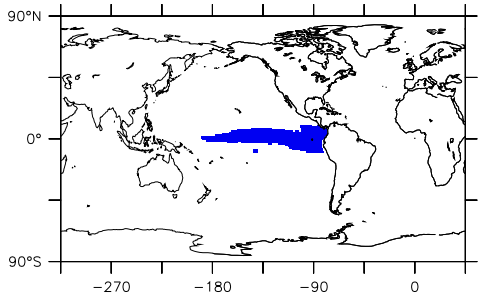
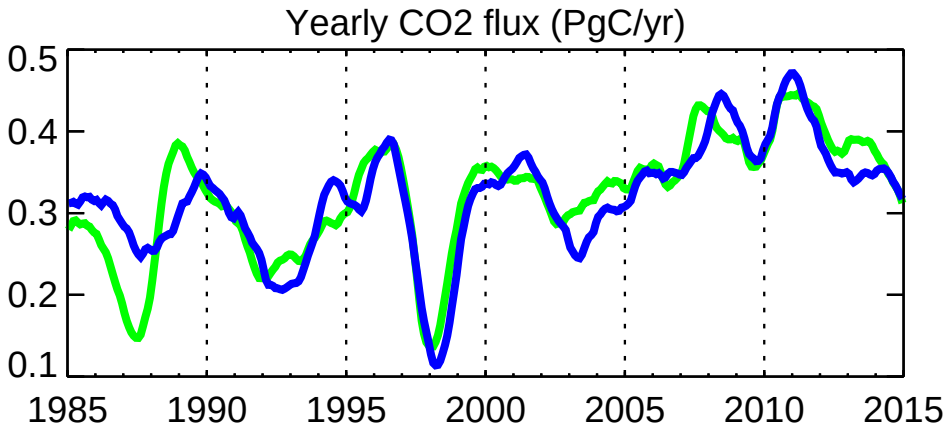
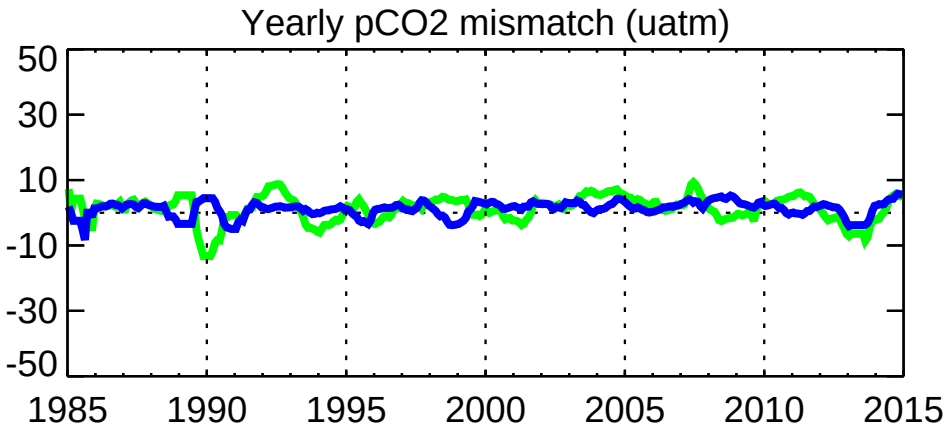


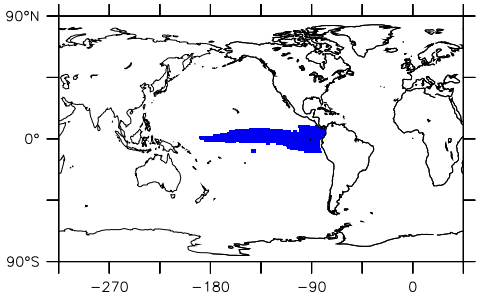




Interpolation:
Time-dep. DoF's
→ Any IAV possible

Regression:
Constant DoF's
→ IAV from drivers

Cross Validation



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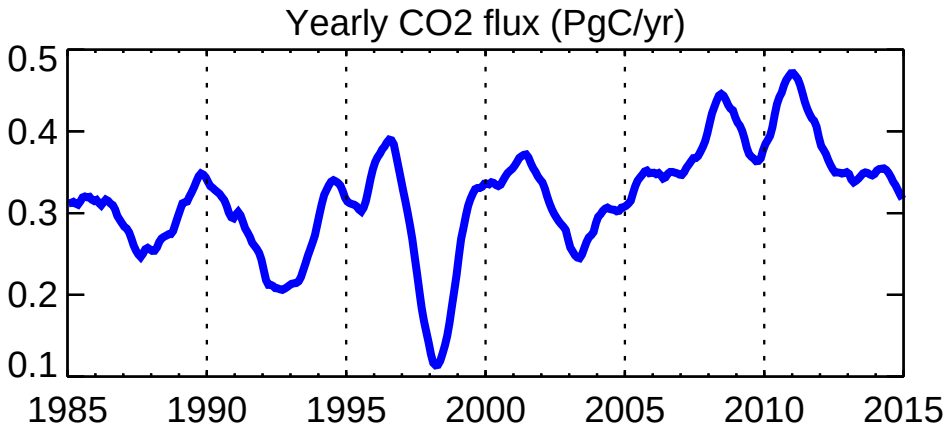
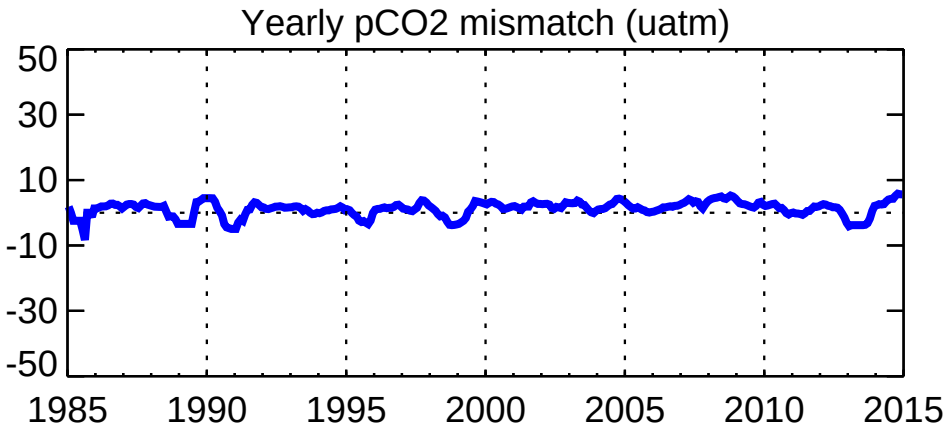
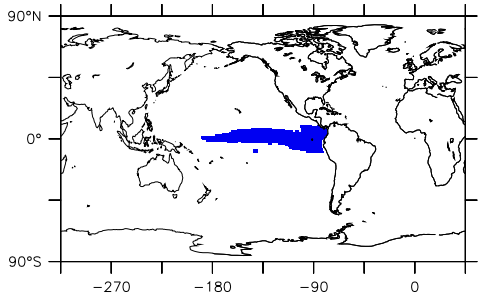


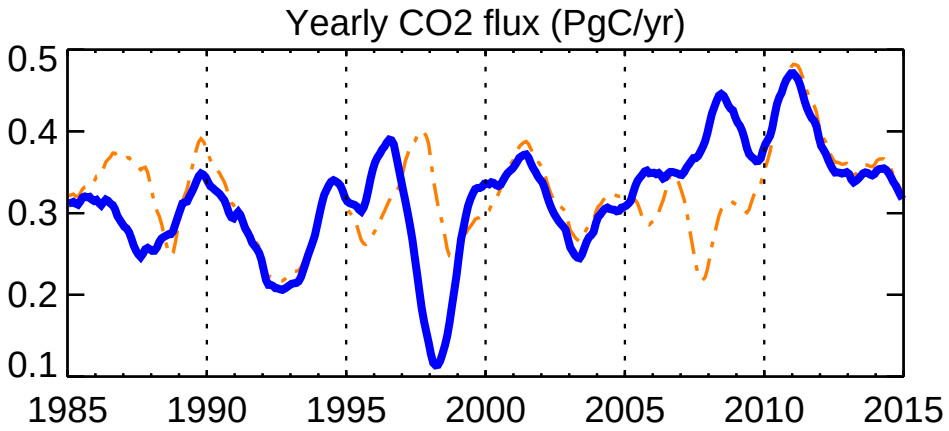


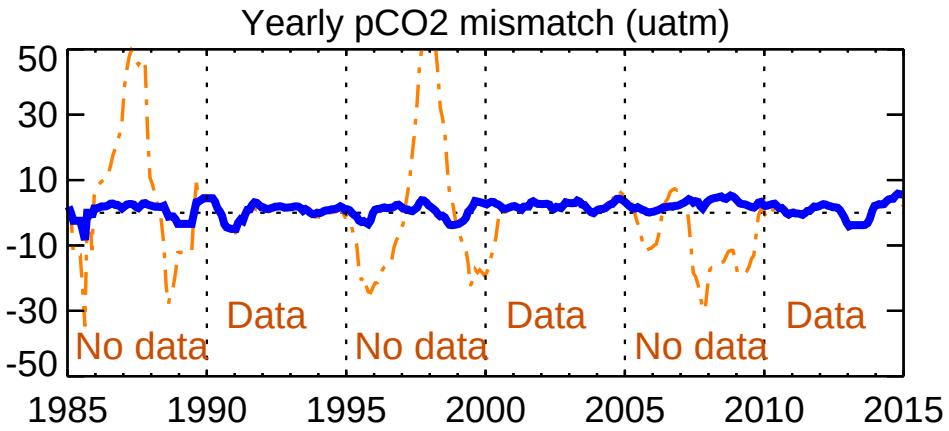
Cross Validation

(18.%) Jena oc_v1.4S

(121.%) Jena oc_v1.4S (CrossVal5yr0)

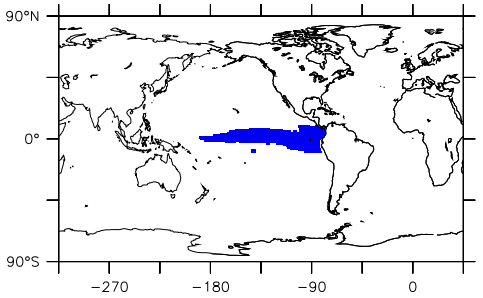






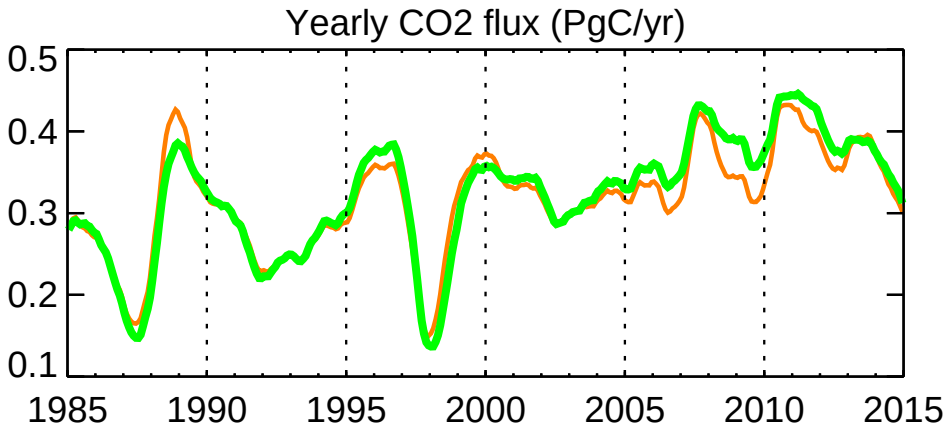
→ Data-only interpolation
cannot bridge multi-year gaps

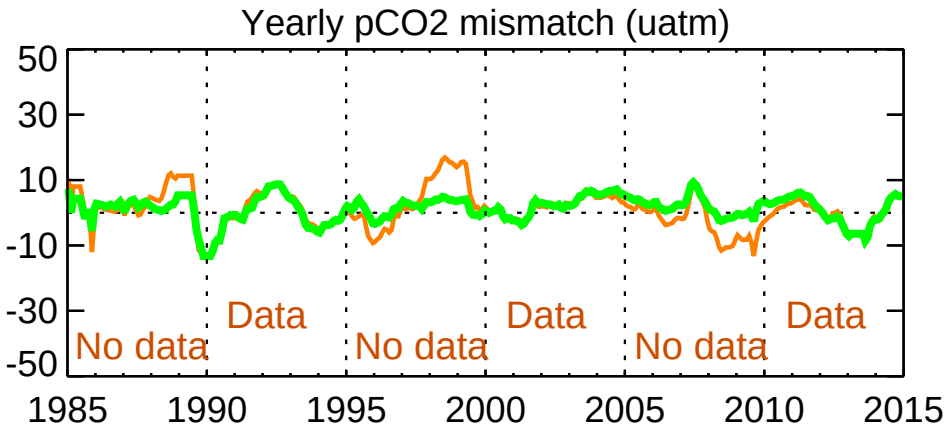
Cross Validation



(28.%) ETH-SOMFFN2016

(48.%) ETH-SOMFFN2016 (CrossVal5yr0)





→ Regression against drivers (SST, SSS, Chl-a, atm. CO_2) offers some bridging capacity

Cross Validation

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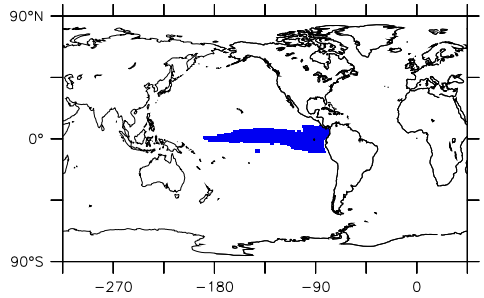
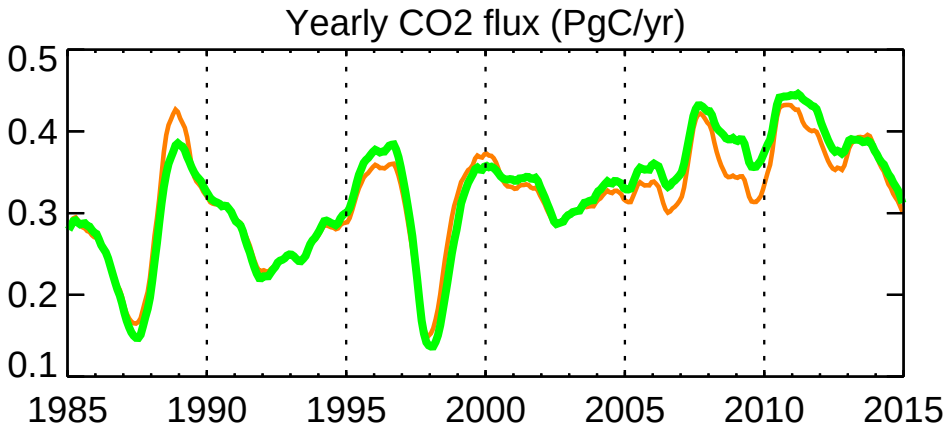
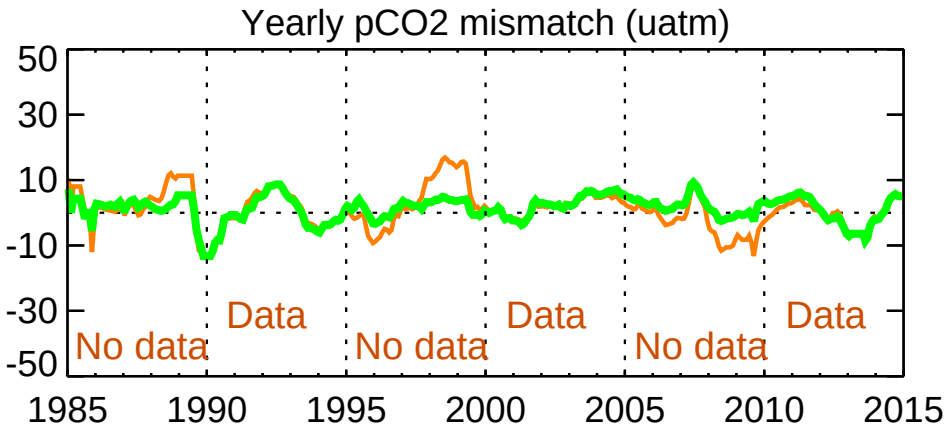
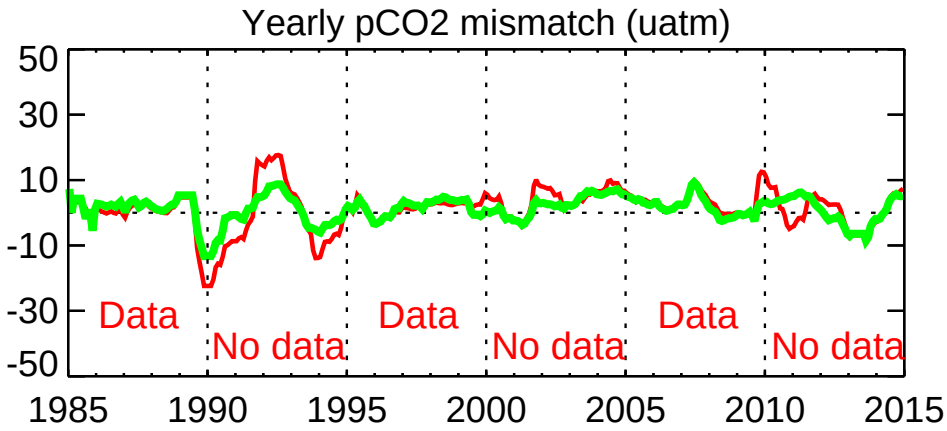




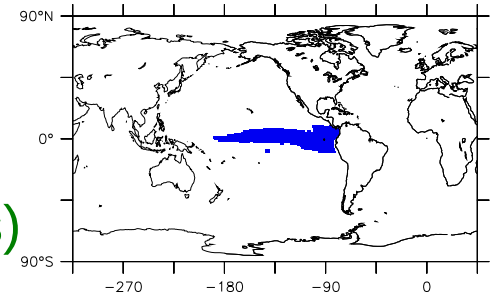


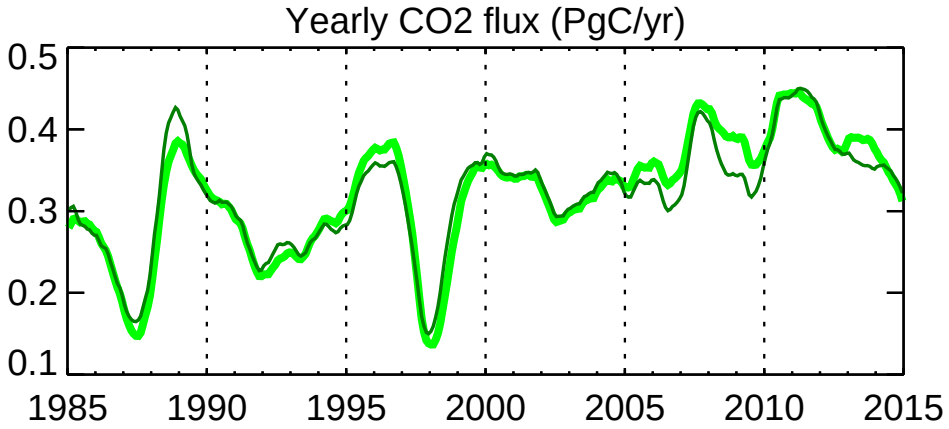


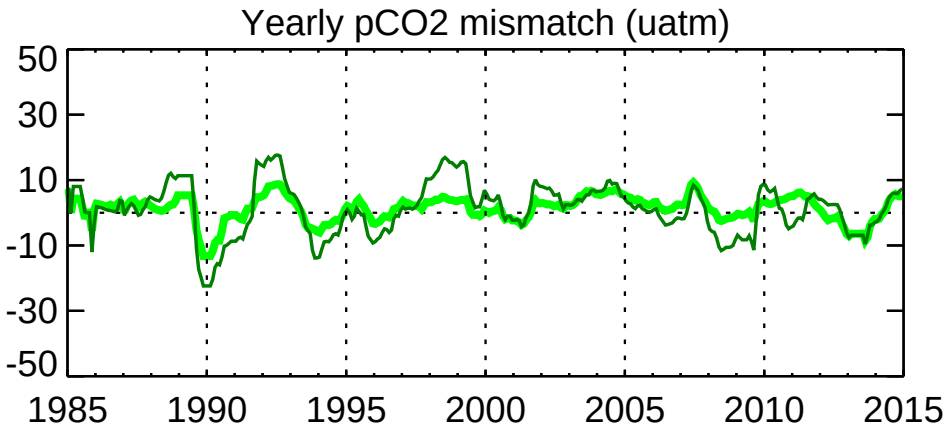
Cross Validation

(28.%) ETH-SOMFFN2016

(62.%) ETH-SOMFFN2016 (Unconstrained periods)







→ Regression against drivers (SST, SSS, Chl-a, atm. CO_2) offers some bridging capacity

Cross Validation

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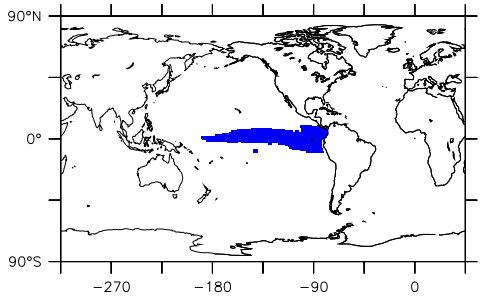
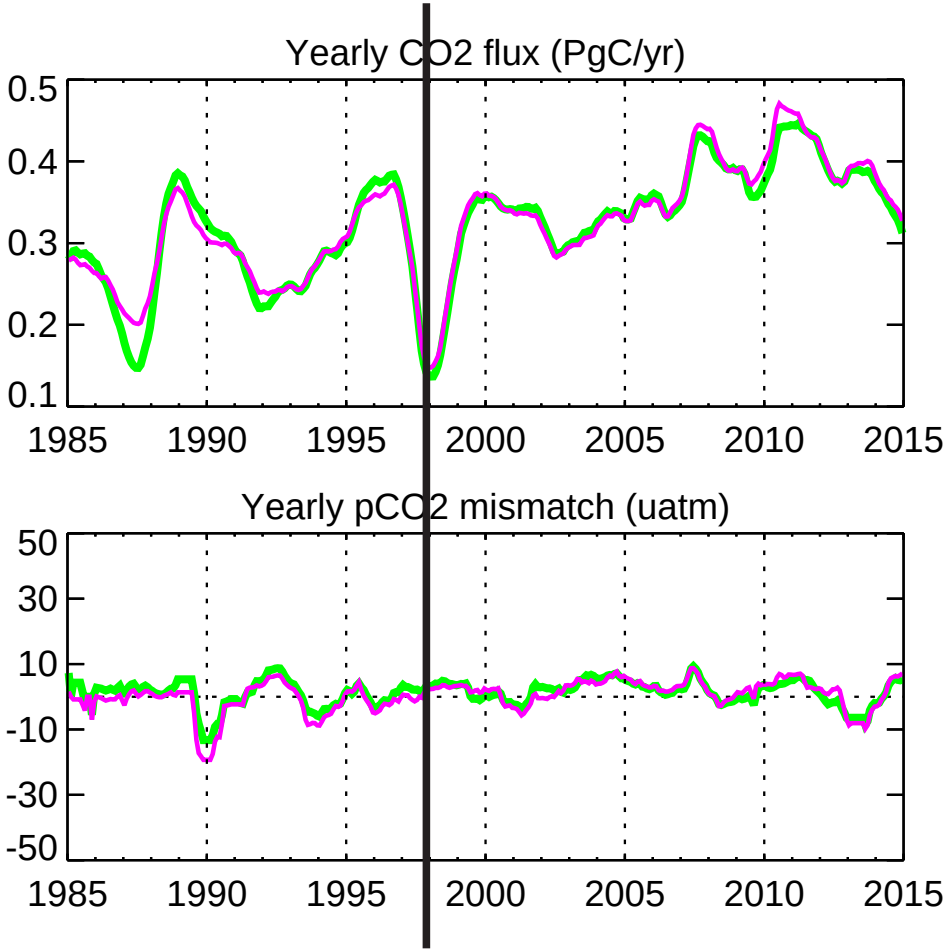
(35.%) ETH-SOMFFN2016, regr. SST & SSS





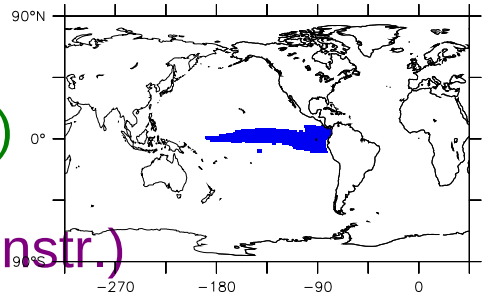
Chl-a data only available since 1998

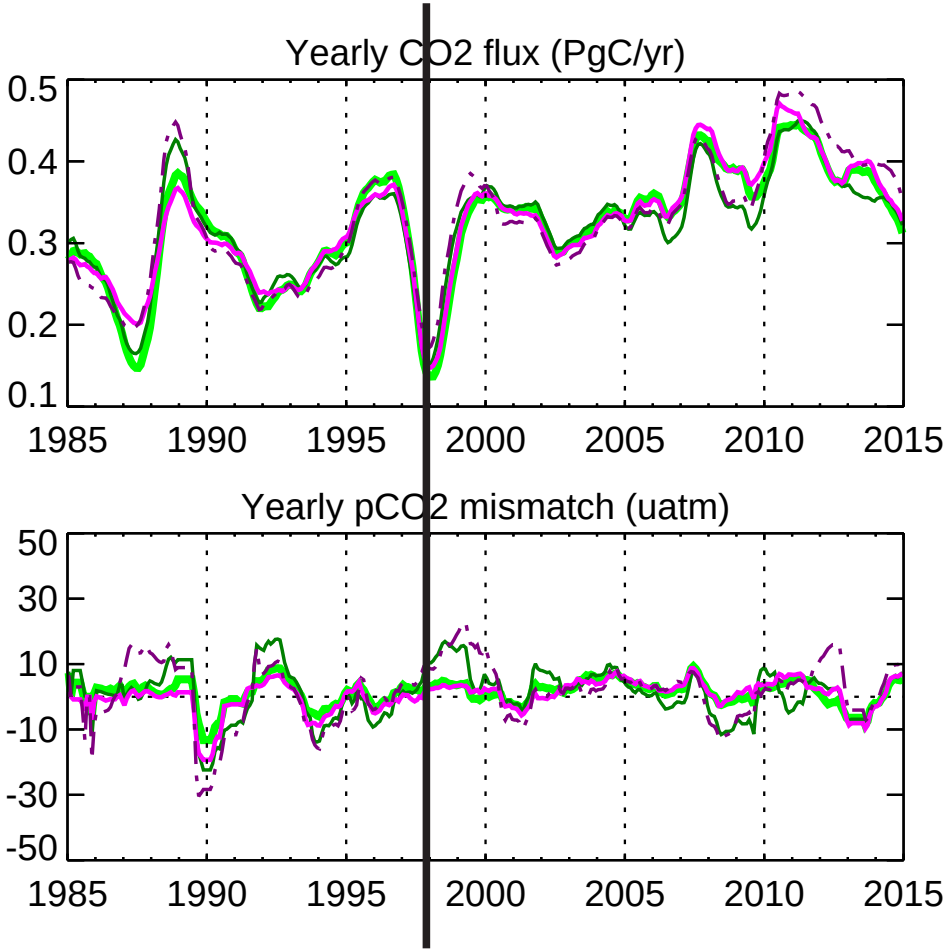
– do SST and SSS suffice?

→ Less fitting capacity
(but main modes similar)

Cross Validation

(28.%) ETH-SOMFFN2016
(62.%) ETH-SOMFFN2016 (Unconstrained periods)
(35.%) ETH-SOMFFN2016, regr. SST & SSS
(77.%) ETH-SOMFFN2016, regr. SST & SSS (Unconstr.)





Chl-a data only available since 1998

– do SST and SSS suffice?

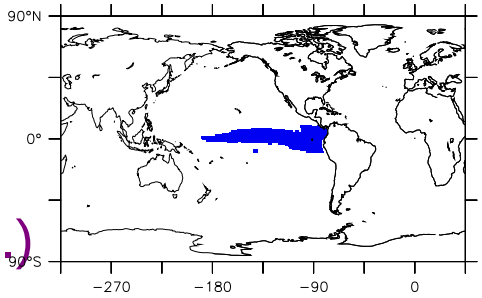
→ Less fitting capacity
(but main modes similar)
→ Less bridging capacity

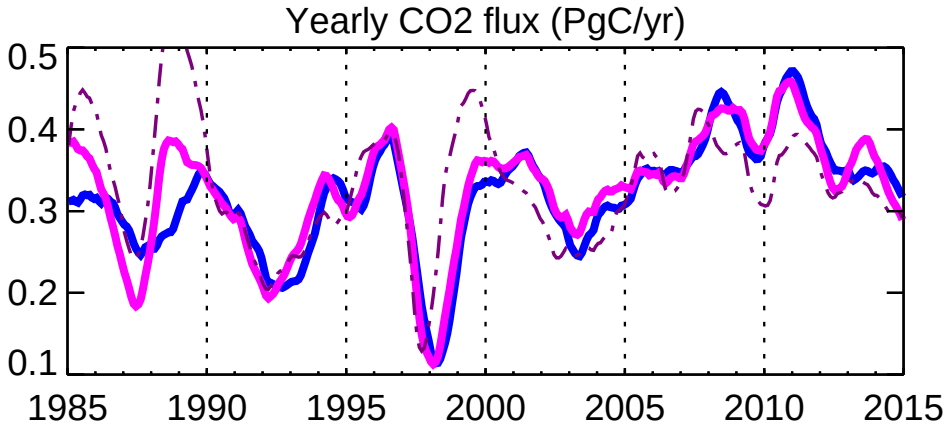
Cross Validation

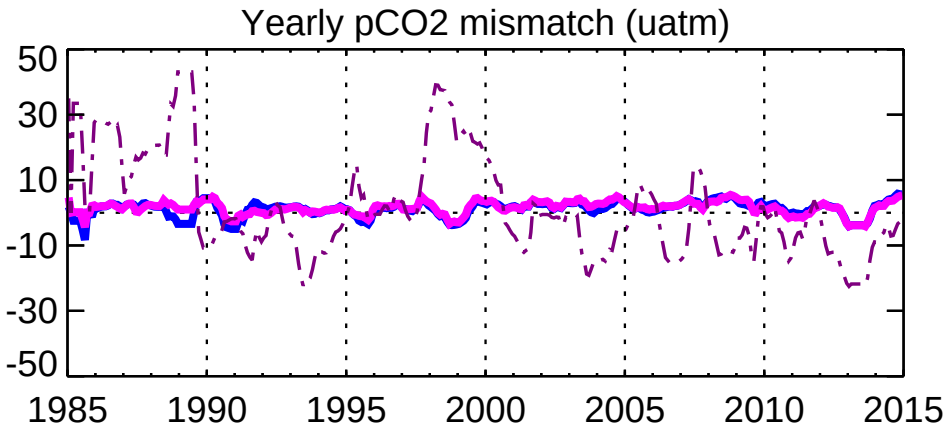
(18.%) Jena oc_v1.4S

(16.%) Jena oc_v1.4S, regr. SST & SSS

(131.%) Jena oc_v1.4S, regr. SST & SSS (Unconstr.)

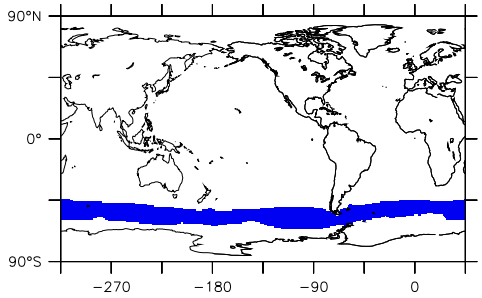


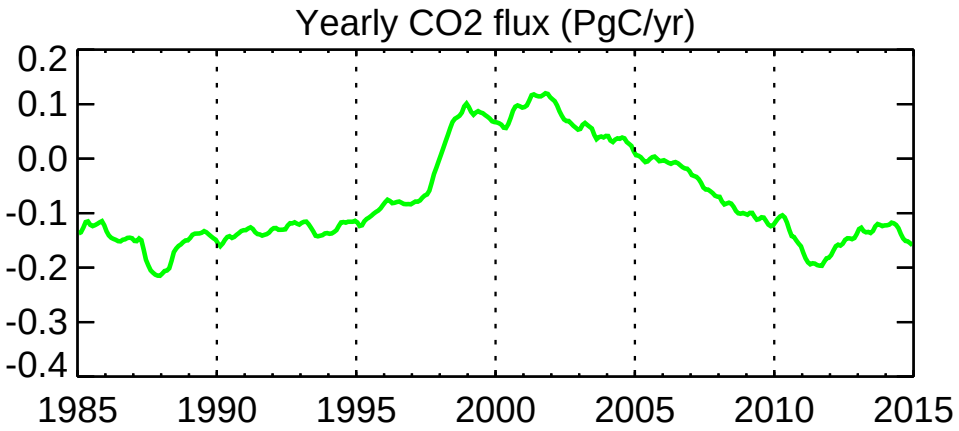


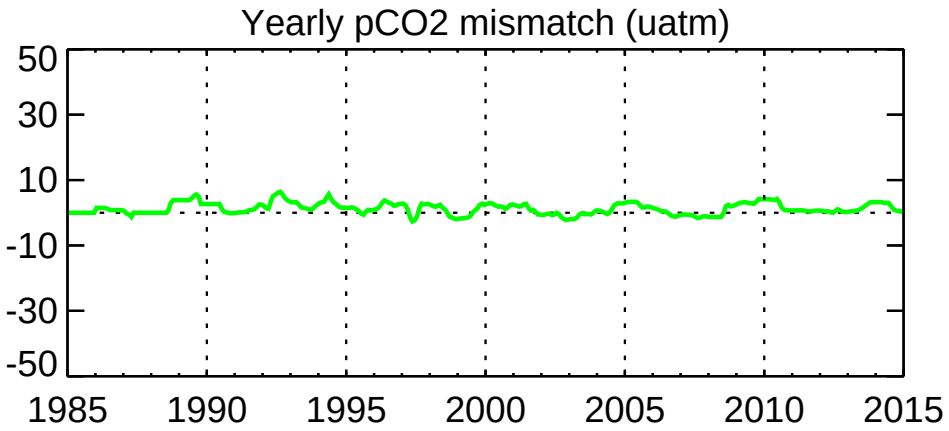


Cross Validation

(47.%) ETH-SOMFFN2016





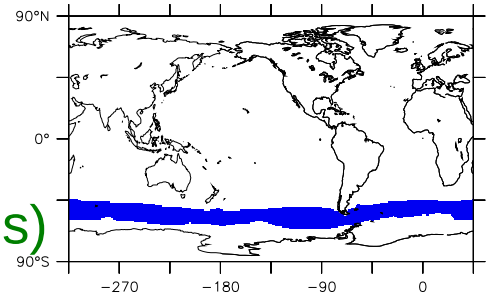


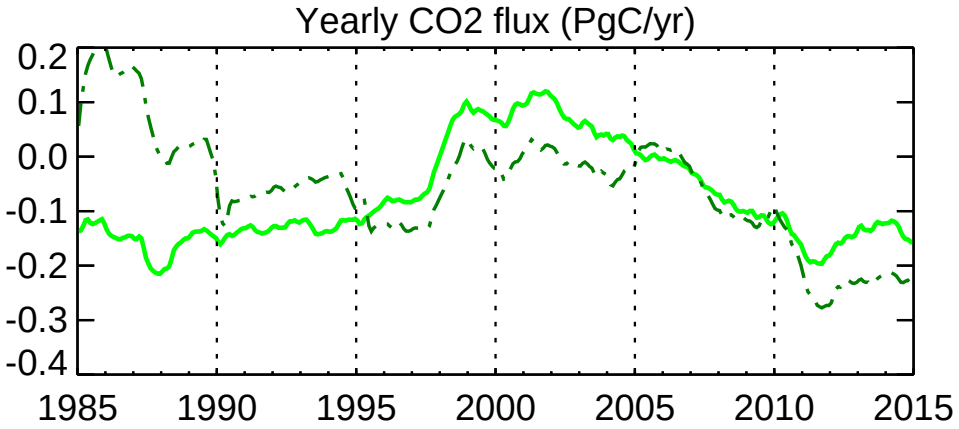
Southern Ocean – sparse data

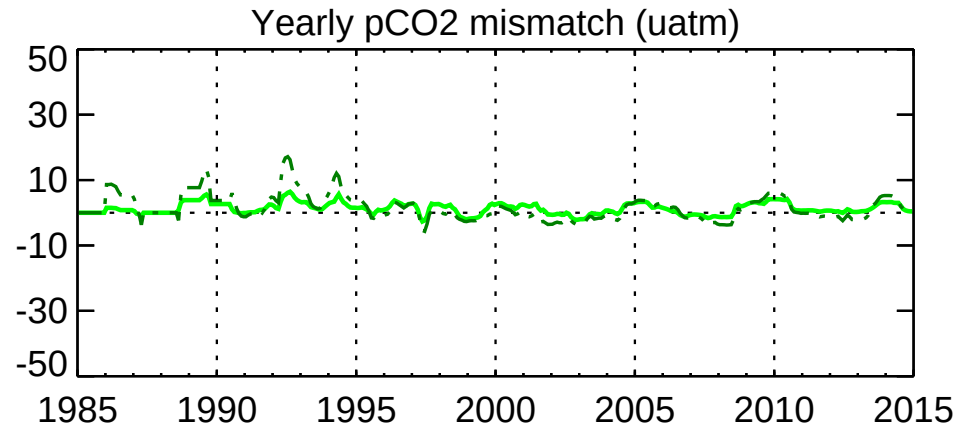
Cross Validation

(47.%) ETH-SOMFFN2016

(106.%) ETH-SOMFFN2016 (Unconstrained periods)







Southern Ocean – sparse data

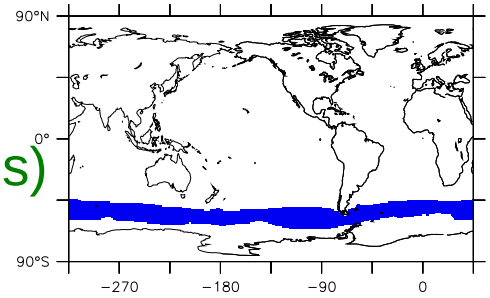
→ Bridging difficult &
difficult to test

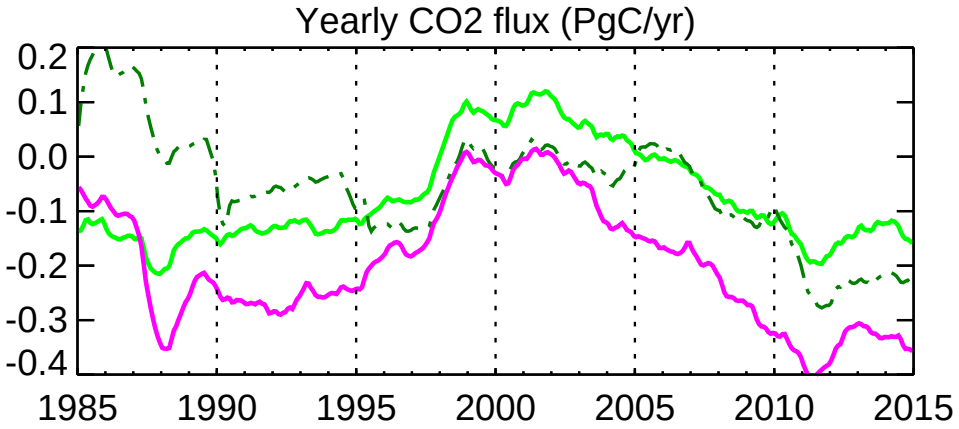
Cross Validation

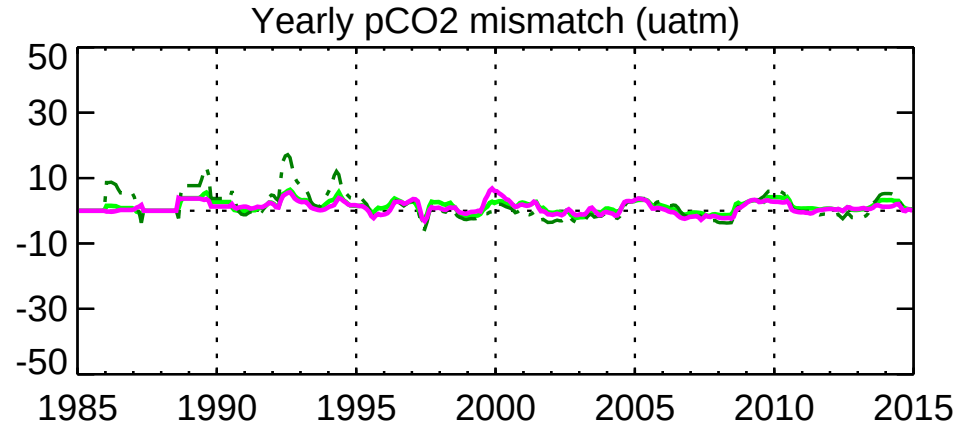
—— (47.%) ETH-SOMFFN2016

– · – (106.%) ETH-SOMFFN2016 (Unconstrained periods)

—— (53.%) ETH-SOMFFN2016, regr. SST & SSS







Southern Ocean – sparse data

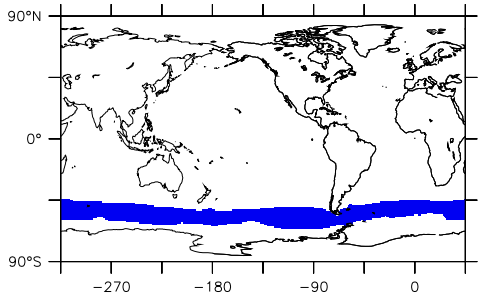
→ Bridging difficult &
difficult to test

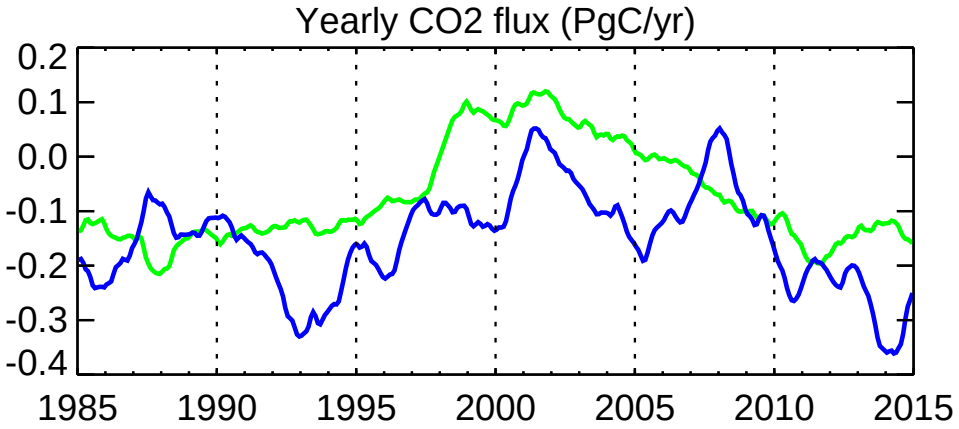
→ again main modes similar w/o Chl-a

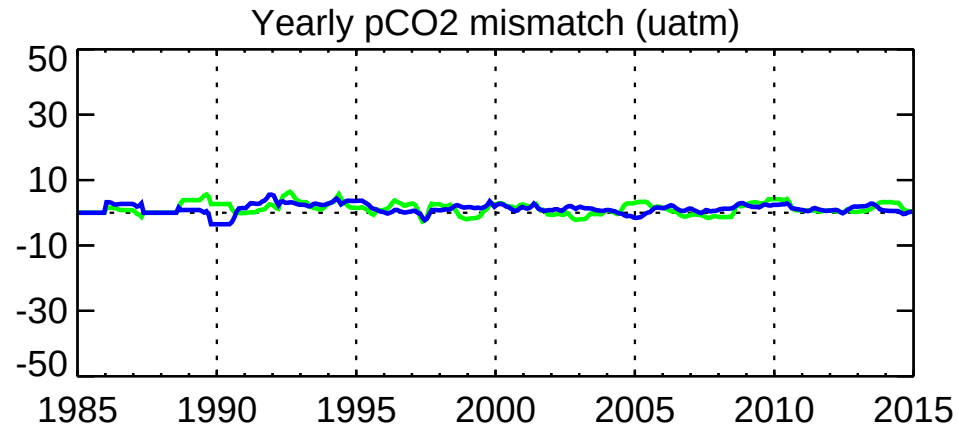
Cross Validation

(37.%) Jena oc_v1.4S

(47.%) ETH-SOMFFN2016







Southern Ocean – sparse data

→ Bridging difficult &
difficult to test

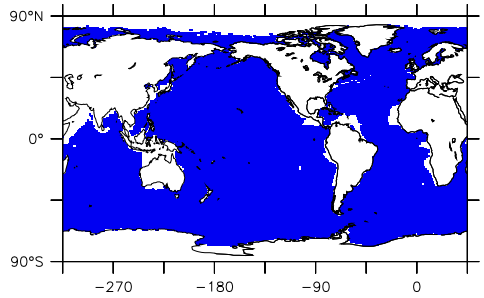
→ again main modes similar w/o Chl-a

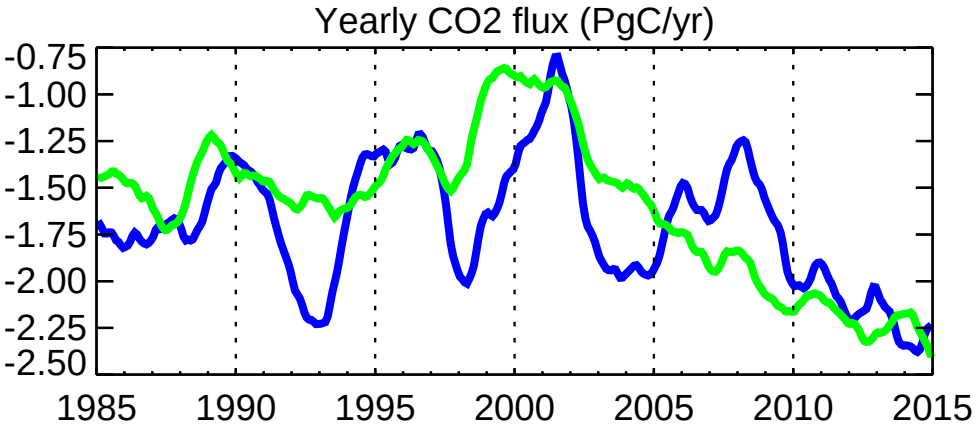
→ Decadal trends also from data directly

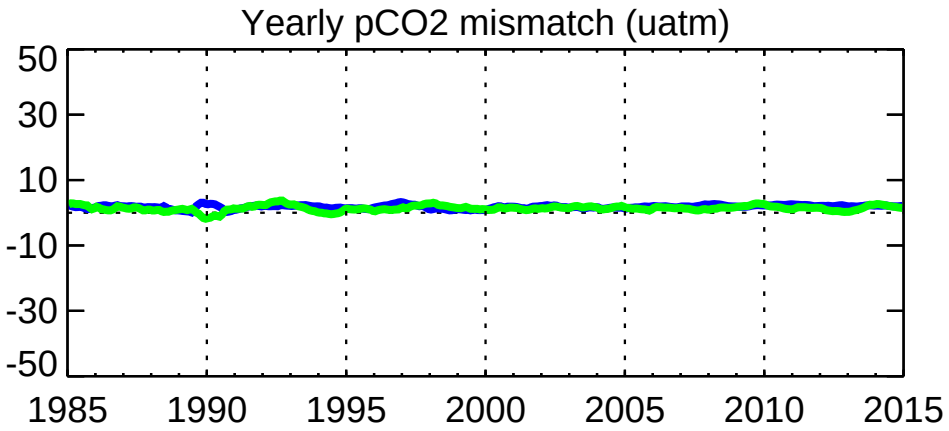
Cross Validation

(25.%) ETH-SOMFFN2016

(18.%) Jena-MLS14SSS







Global Ocean flux
– affected by data-sparse regions

→ Complementary mapping methods (interpolation, regression) help to assess robustness