Atmospheric measurements of O_2 and CO_2 suggests increasing oceanic respiratory disorder

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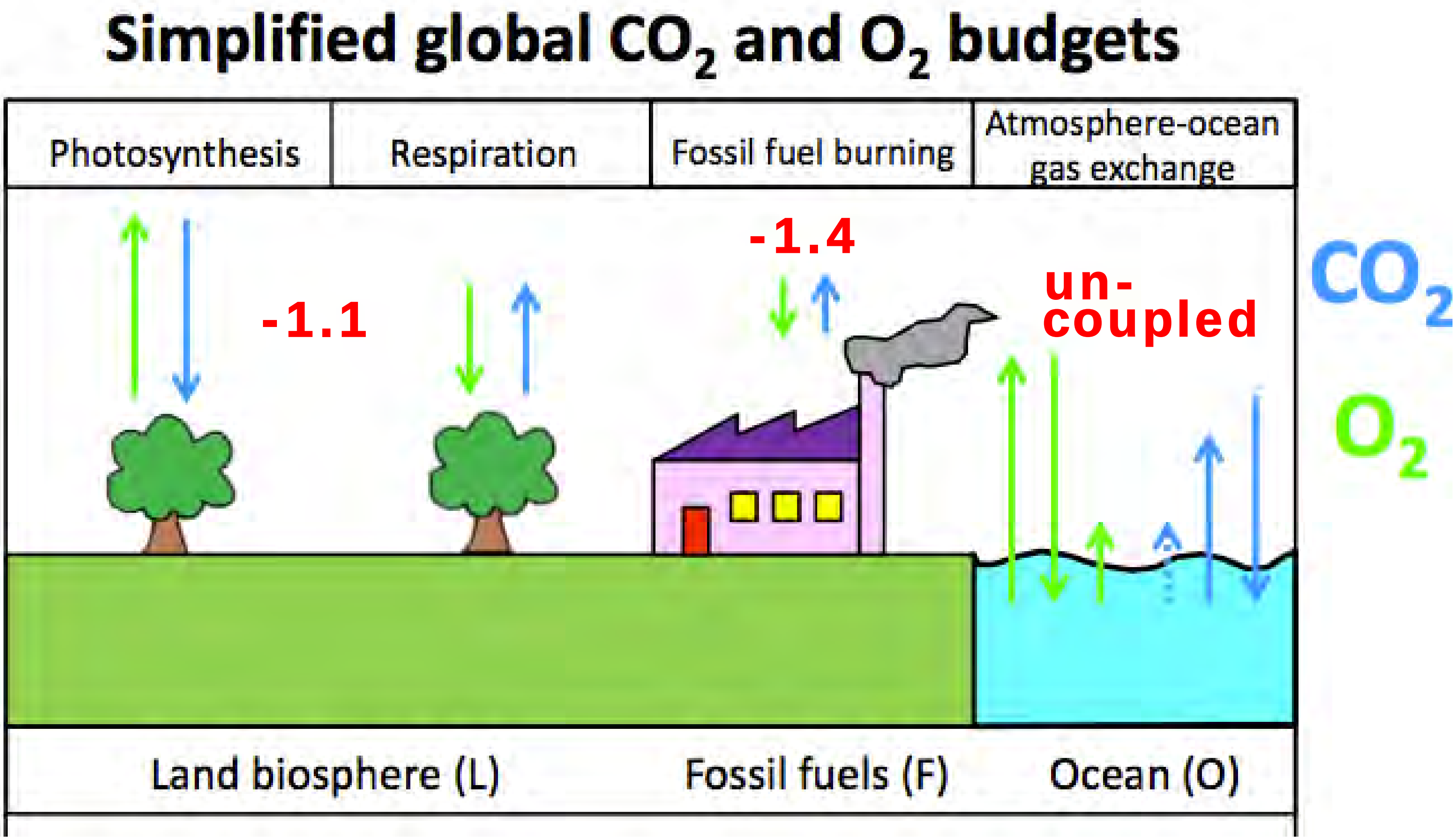
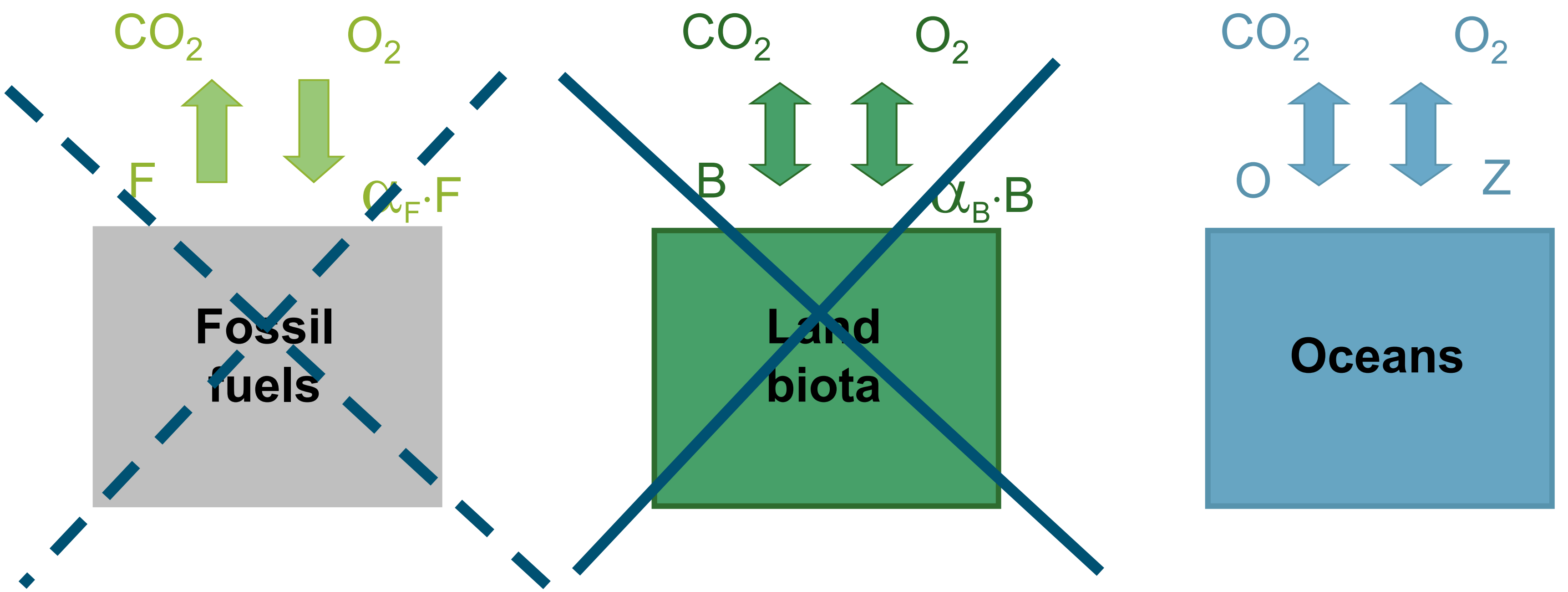

Simplified global CO_2 and O_2 budgets
Photosynthesis
Respiration
Fossil fuel burning
Atmosphere-ocean gas exchange
-1.1
-1.4
un-coupled
CO_2
O_2
Land biosphere (L)
Fossil fuels (F)
Ocean (O)

Atmospheric Potential Oxygen (APO)

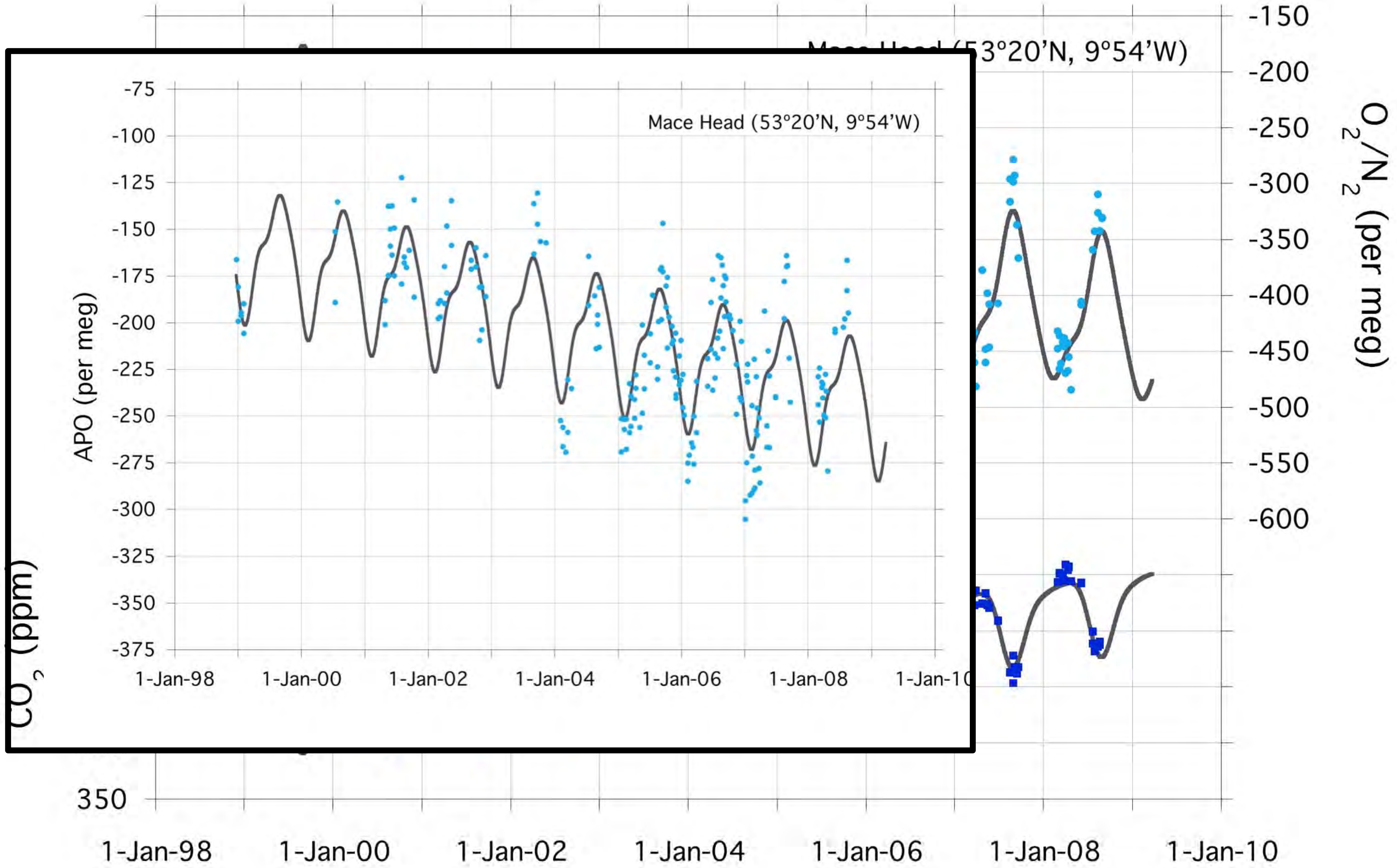
Atmosphere

$$\left.\begin{aligned}\Delta CO_2 &= F - B - O\\ \Delta O_2 &= -\alpha_F \cdot F + \alpha_B \cdot B + Z\end{aligned}\right\}\quad\begin{aligned}&\Delta APO = \mathbf{O_2 + \alpha_B \cdot CO_2}\\ &\Delta APO = (\alpha_B - \alpha_F)F - \alpha_B \cdot O + Z\end{aligned}$$



$$APO = -0.3\mathbf{F} - 1.1\mathbf{O}_{CO2} + \mathbf{Z}_{\mathbf{O2}}$$

Stephens et al 1998



PhD thesis Ingrid van der Laan-Luijkx

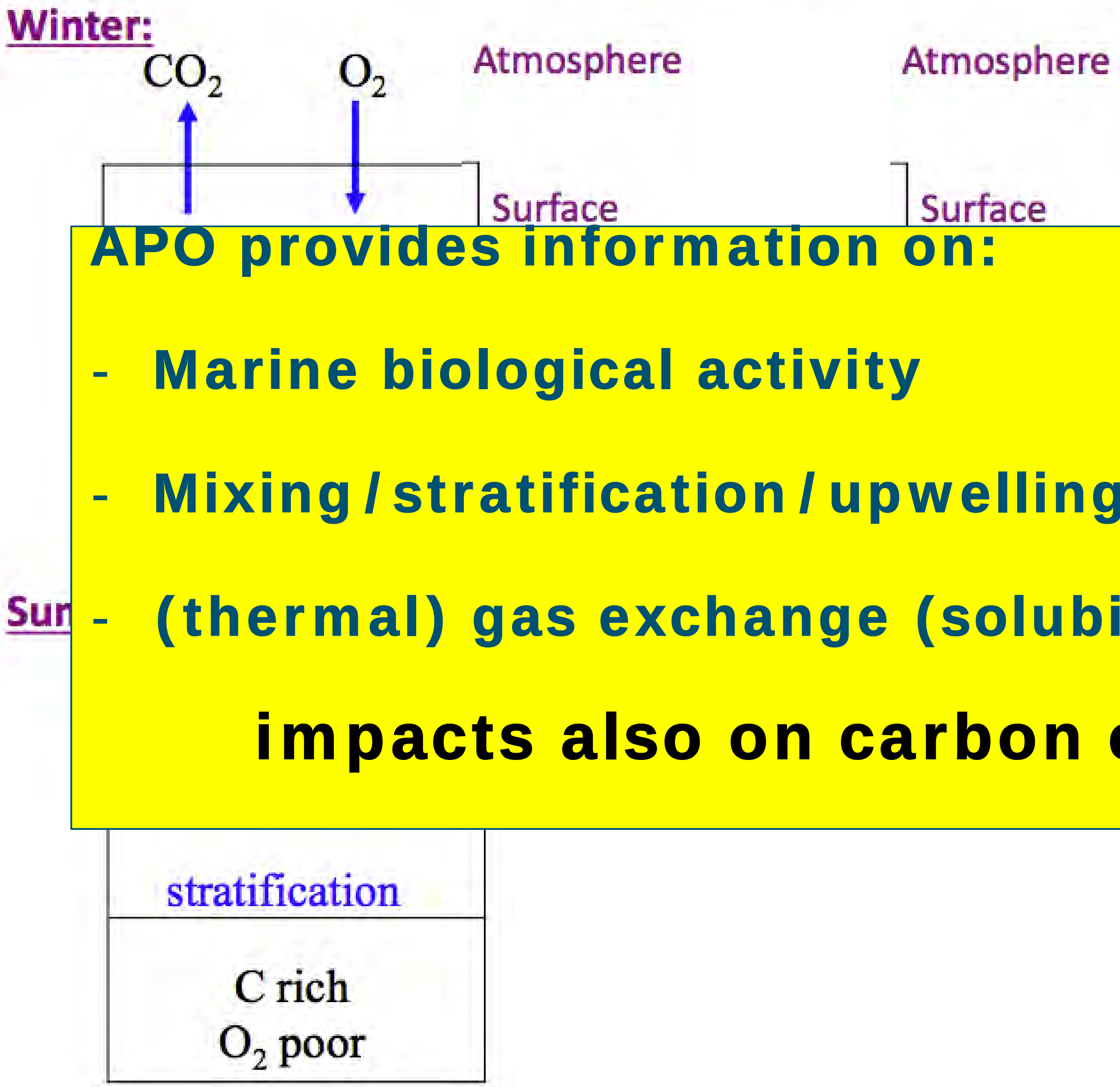
APO as an integrator of ocean surface - atmosphere exchange processes

$$APO = \Delta O_2 + 1.1 \cdot \Delta CO_2$$

Timescale	O_2	CO_2
Long-term trends (> 5yr)	-	+++
Longer-term mean spatial patterns	+	+
Interannual variability	++	+
Seasonal cycle	+++	+
Synoptic scale	+++	-

Slide courtesy by Martin Heimann

Atmospheric CO_2 vs O_2 seasonality



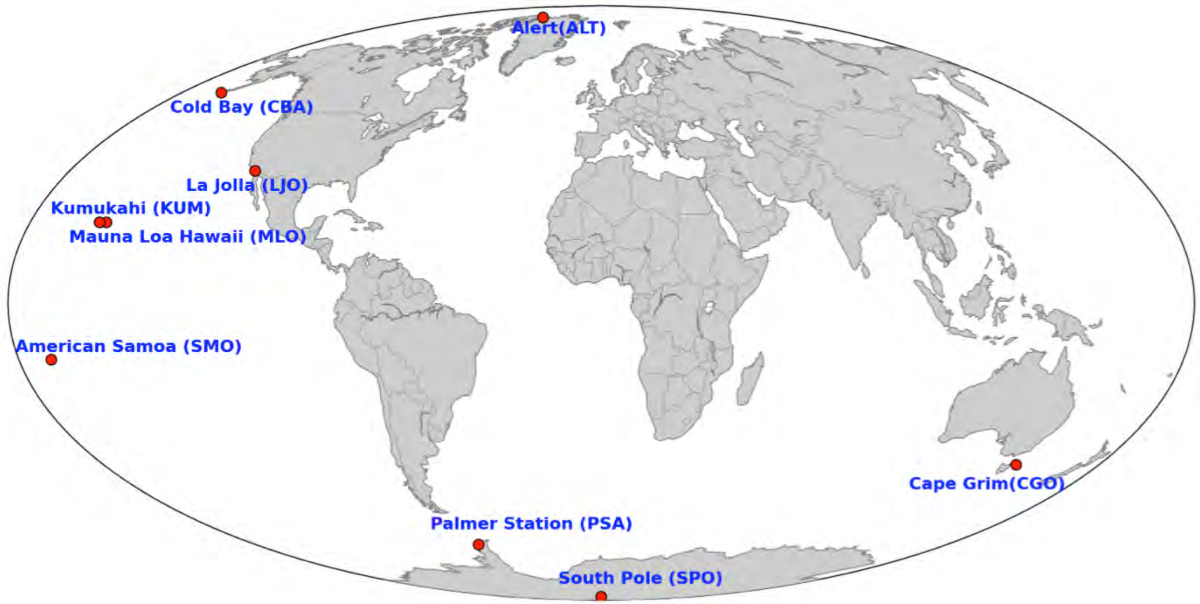
APO provides information on:

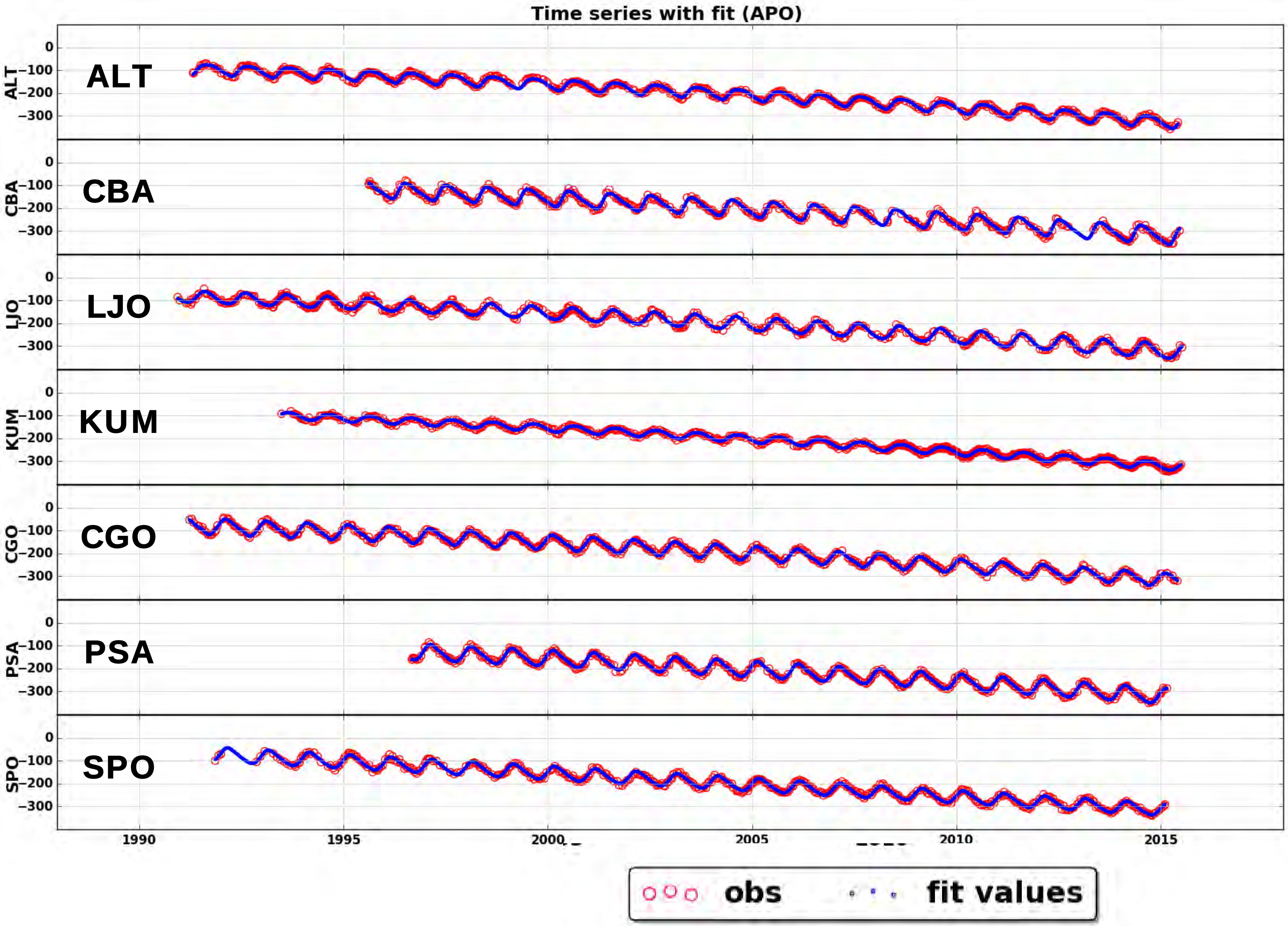
- **Marine biological activity**
- **Mixing / stratification / upwelling**
- **(thermal) gas exchange (solubility changes)**

impacts also on carbon cycle!

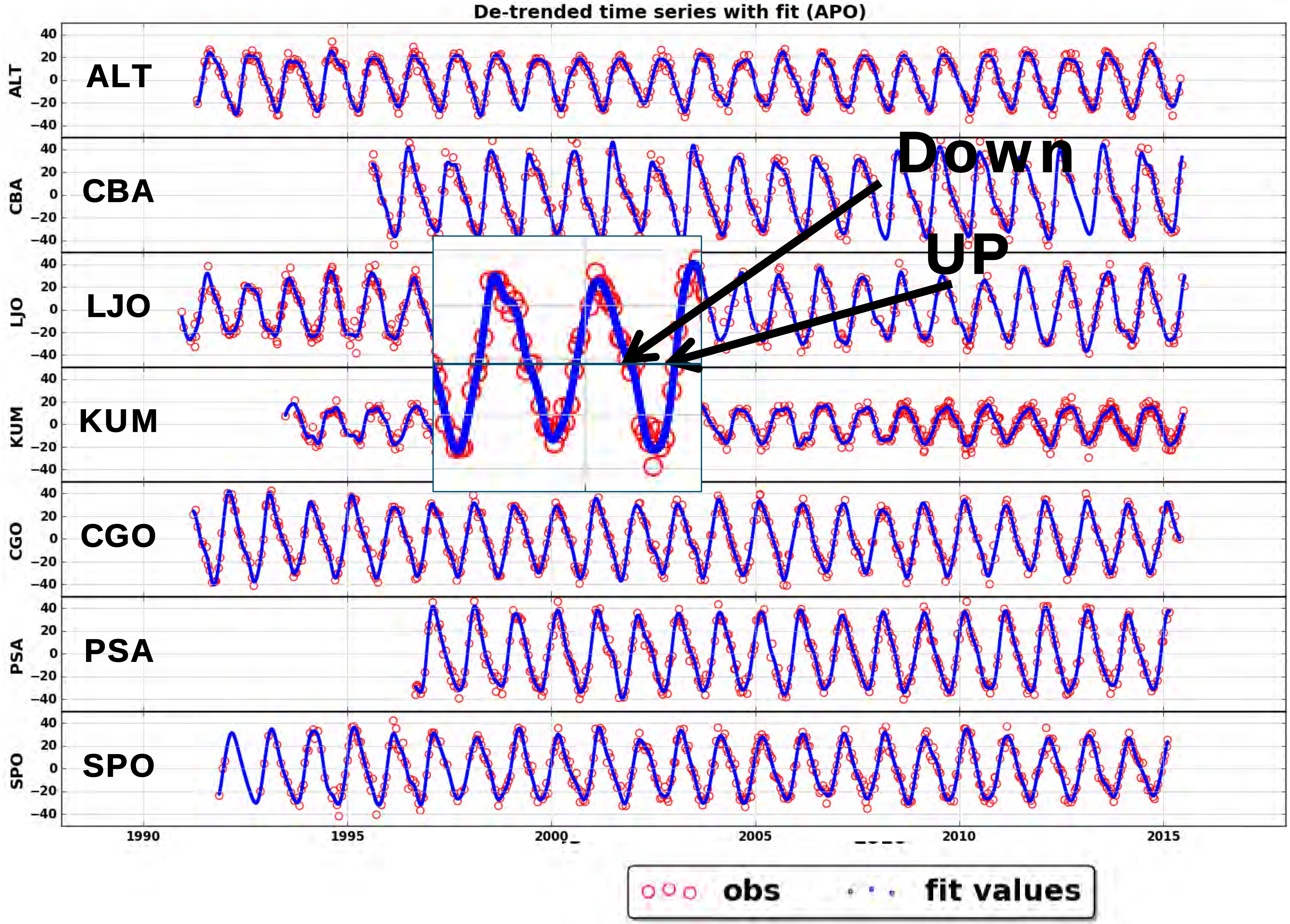
Methods

- APO flask data from Scripps network (Pacific focus)
- De-trend with CCGCRV curve fitting routines (Python version)
- Analysis: calculate potential LT trend in anomalies in
    - Zero crossings Up, Down
    - Season lengths
    - Max, Min dates
    - Surface areas
- Similar for model:
  NEMO-PISCES* + TM3

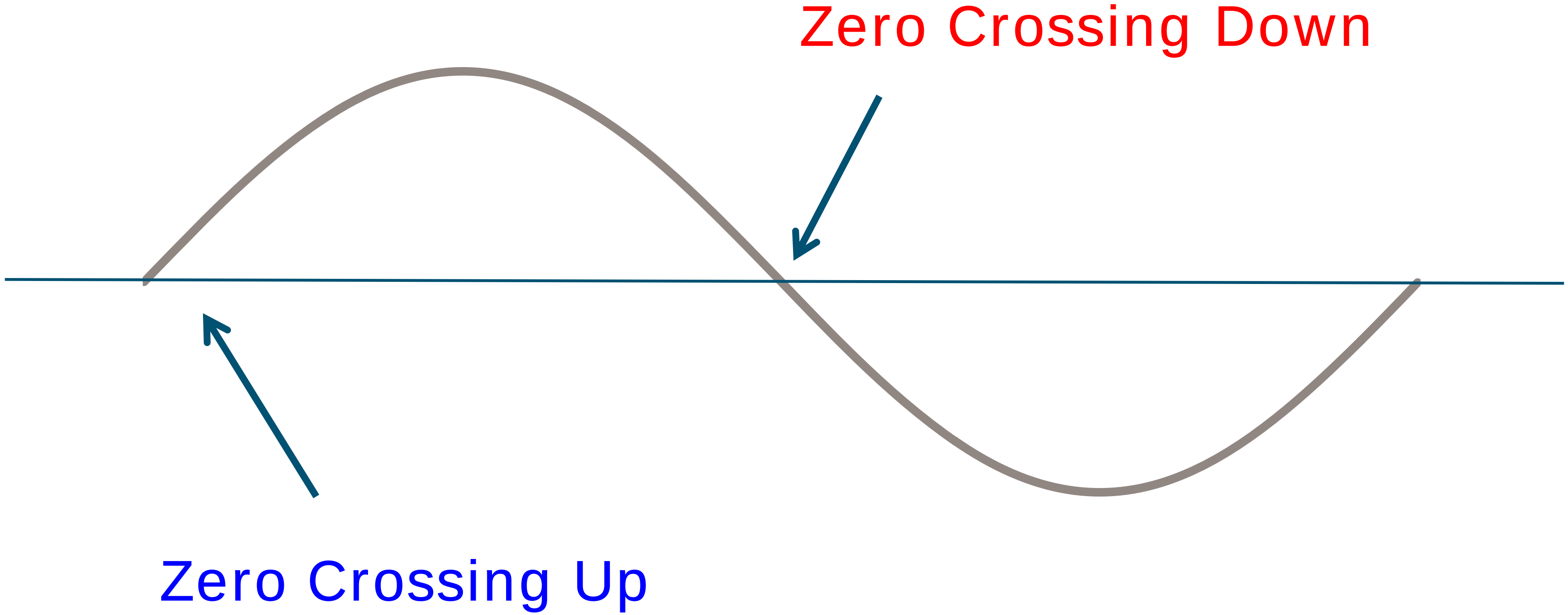




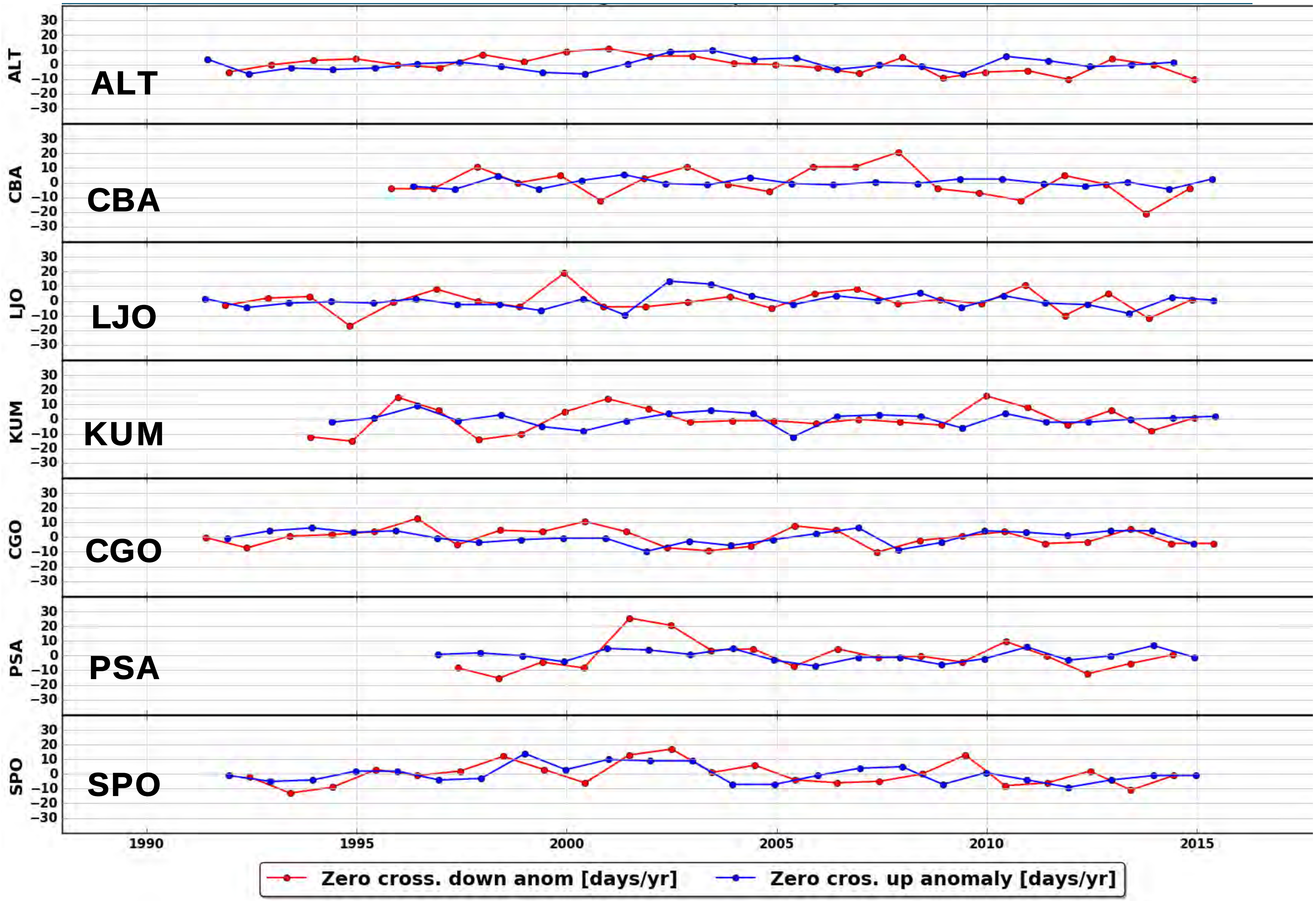
Time series with fit (APO)
ALT
CBA
LJO
KUM
CGO
PSA
SPO
0
-100
-200
-300
1990
1995
2000
2005
2010
2015
obs
fit values

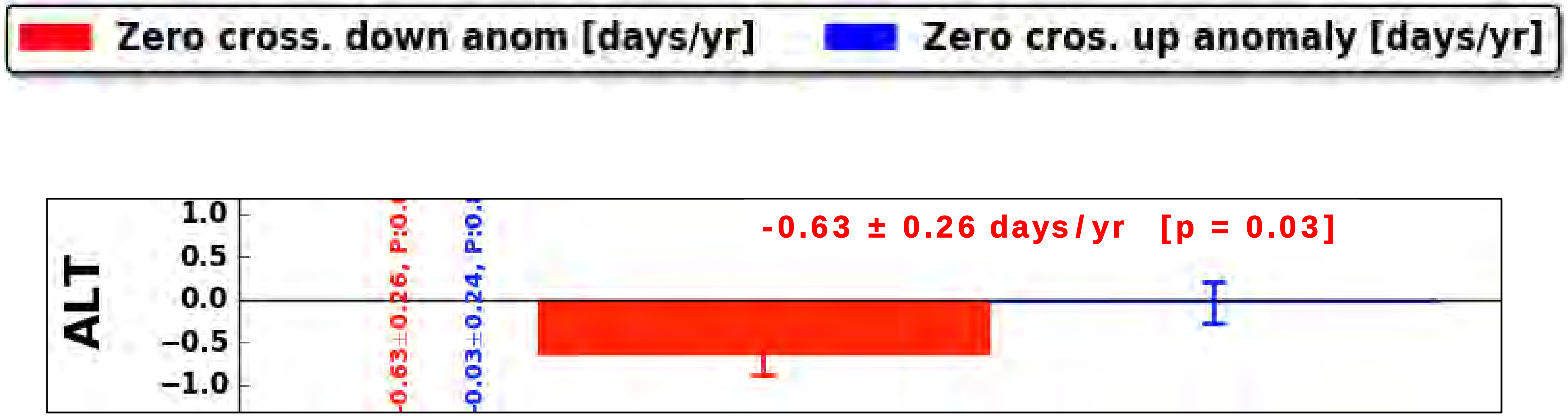

De-trended time series with fit (APO)
ALT
CBA
LJO
KUM
CGO
PSA
SPO
Down
UP
40
20
0
-20
-40
1990
1995
2000
2005
2010
2015
obs
fit values

Zero-Crossings

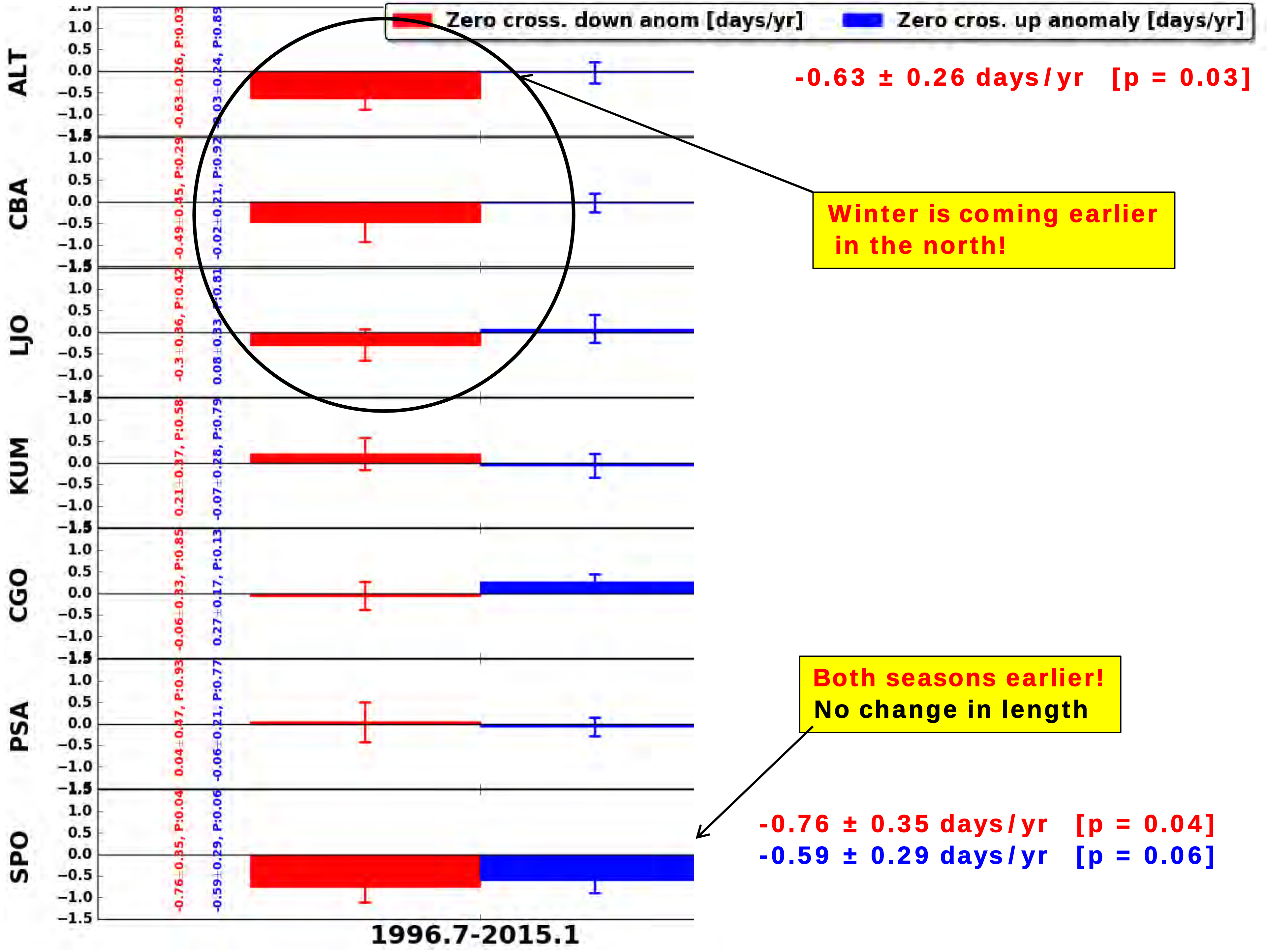


Zero crossings anomalies



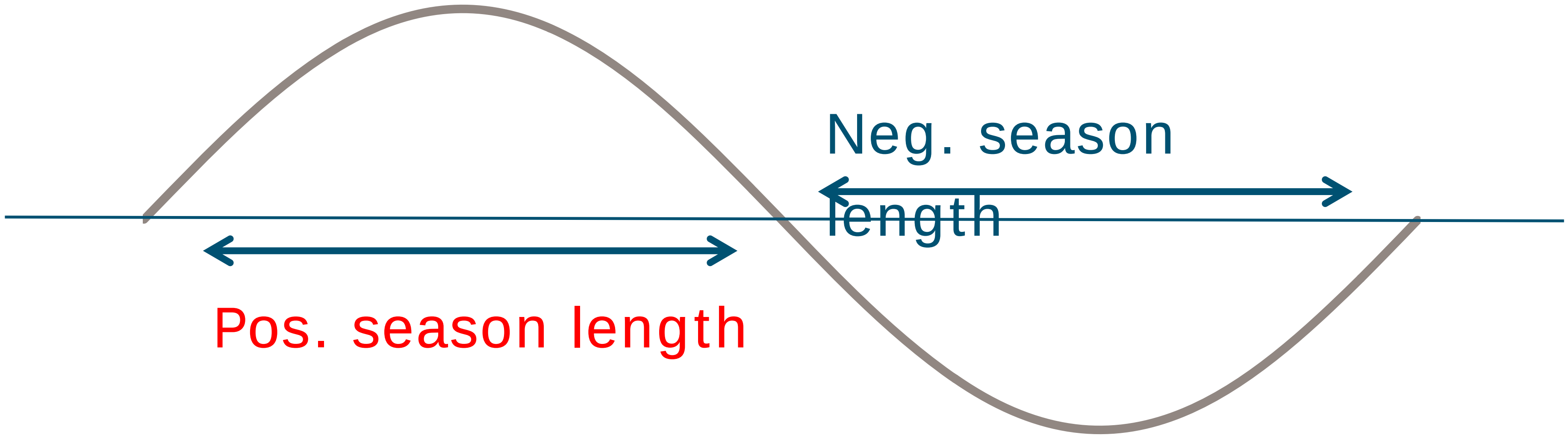


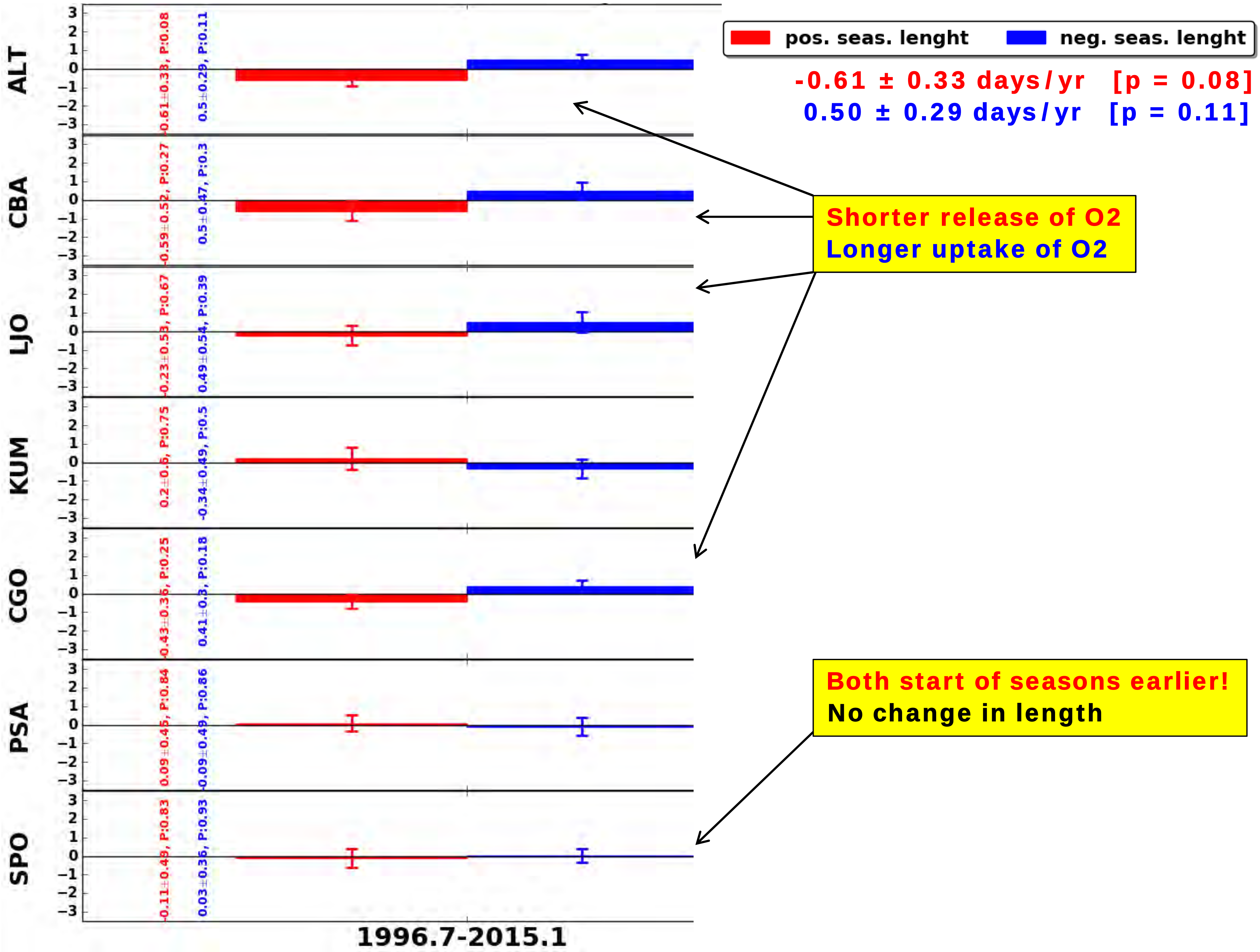
O_2 uptake period (Winter) is coming earlier !



Zero cross. down anom [days/yr]
Zero cros. up anomaly [days/yr]
ALT
CBA
LJO
KUM
CGO
PSA
SPO
-0.63±0.26, P:0.03
-0.03±0.24, P:0.89
-0.49±0.45, P:0.29
-0.02±0.21, P:0.92
-0.3±0.36, P:0.42
0.08±0.33, P:0.81
0.21±0.37, P:0.58
-0.07±0.28, P:0.79
-0.06±0.33, P:0.85
0.27±0.17, P:0.13
0.04±0.47, P:0.93
-0.06±0.21, P:0.77
-0.76±0.35, P:0.04
-0.59±0.29, P:0.06
1996.7-2015.1
-0.63 ± 0.26 days/yr [p = 0.03]
Winter is coming earlier in the north!
Both seasons earlier!
No change in length
-0.76 ± 0.35 days/yr [p = 0.04]
-0.59 ± 0.29 days/yr [p = 0.06]

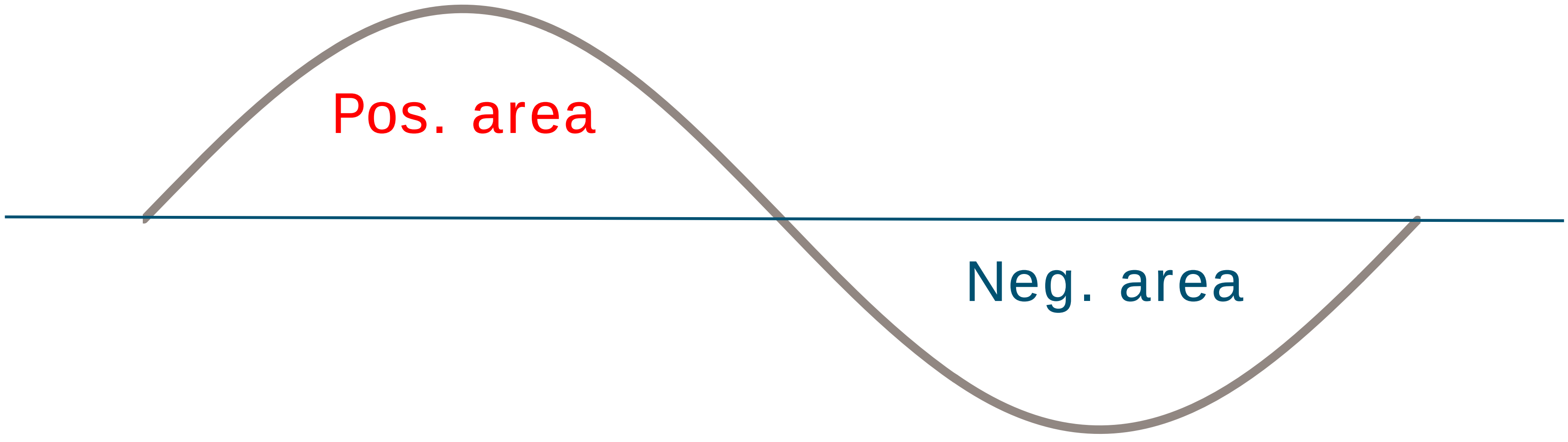
Season lengths

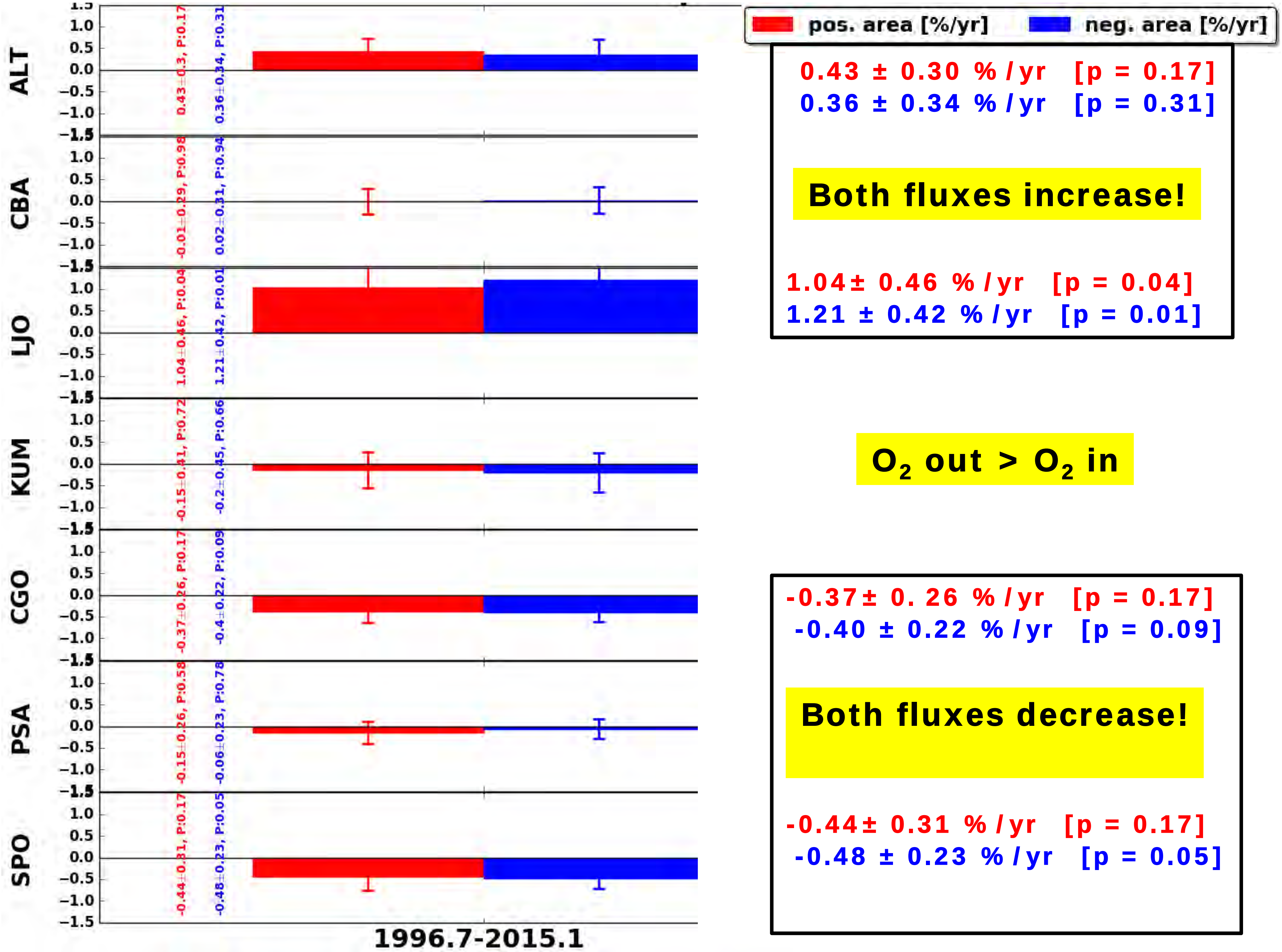




pos. seas. lenght
neg. seas. lenght
-0.61 ± 0.33 days/yr [p = 0.08]
0.50 ± 0.29 days/yr [p = 0.11]
Shorter release of O2
Longer uptake of O2
Both start of seasons earlier!
No change in length
ALT
CBA
LJO
KUM
CGO
PSA
SPO
-0.61±0.33, P:0.08
0.5±0.29, P:0.11
-0.59±0.52, P:0.27
0.5±0.47, P:0.3
-0.23±0.53, P:0.67
0.49±0.54, P:0.39
0.2±0.6, P:0.75
-0.34±0.49, P:0.5
-0.43±0.36, P:0.25
0.41±0.3, P:0.18
0.09±0.45, P:0.84
-0.09±0.49, P:0.86
-0.11±0.49, P:0.83
0.03±0.36, P:0.93
1996.7-2015.1

Areas





0.43 ± 0.30 % / yr [p = 0.17]
0.36 ± 0.34 % / yr [p = 0.31]

Both fluxes increase!

1.04 ± 0.46 % / yr [p = 0.04]
1.21 ± 0.42 % / yr [p = 0.01]

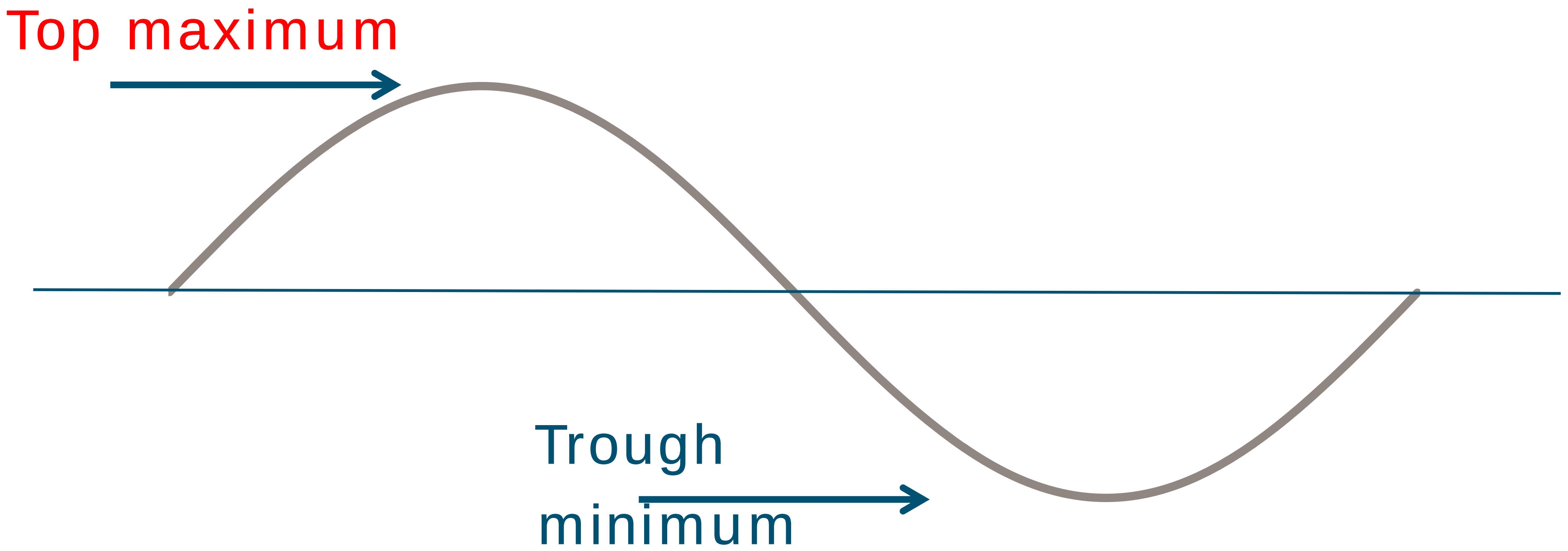
O_2 out > O_2 in

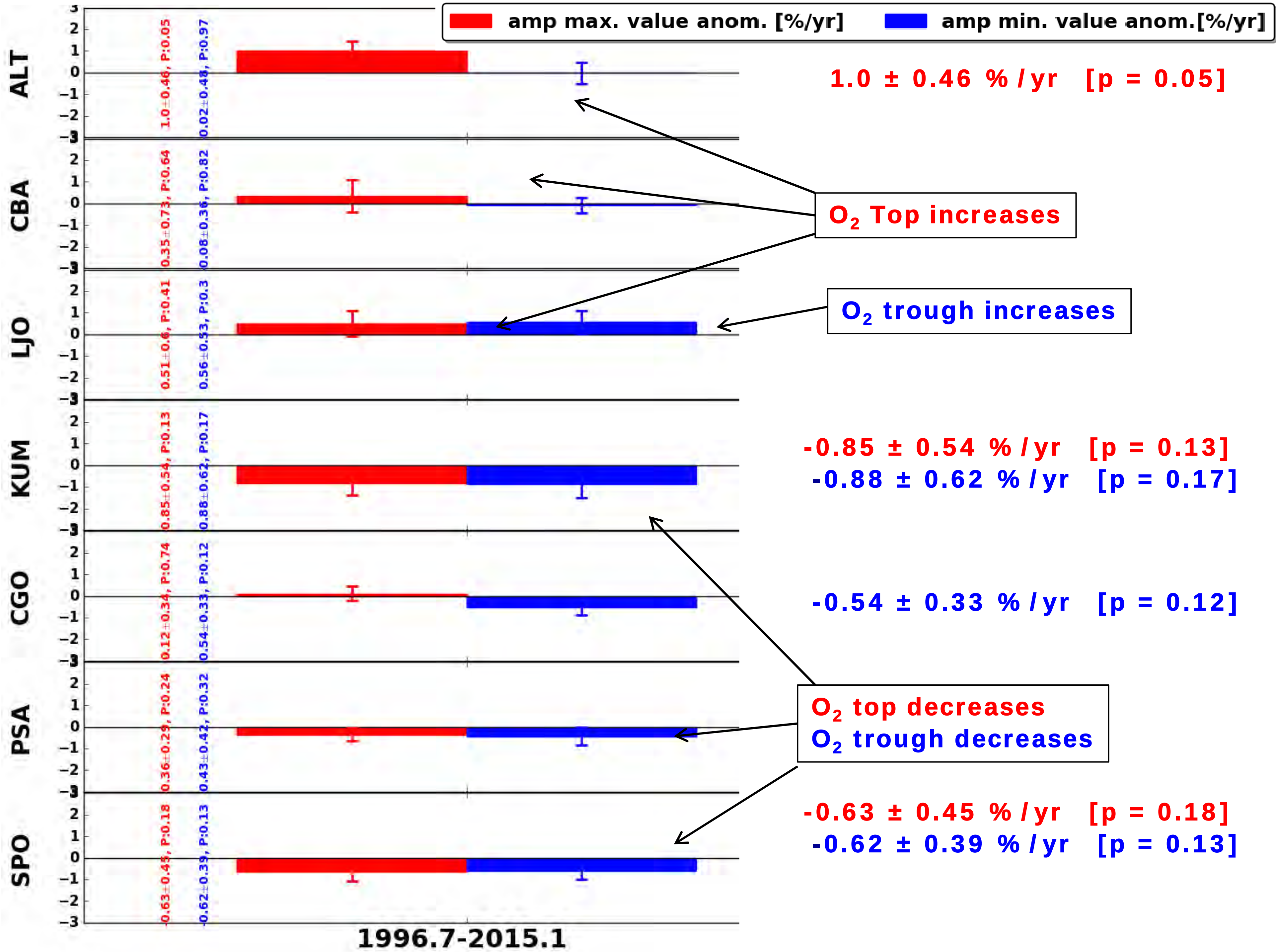
-0.37 ± 0. 26 % / yr [p = 0.17]
-0.40 ± 0.22 % / yr [p = 0.09]

Both fluxes decrease!

-0.44 ± 0.31 % / yr [p = 0.17]
-0.48 ± 0.23 % / yr [p = 0.05]

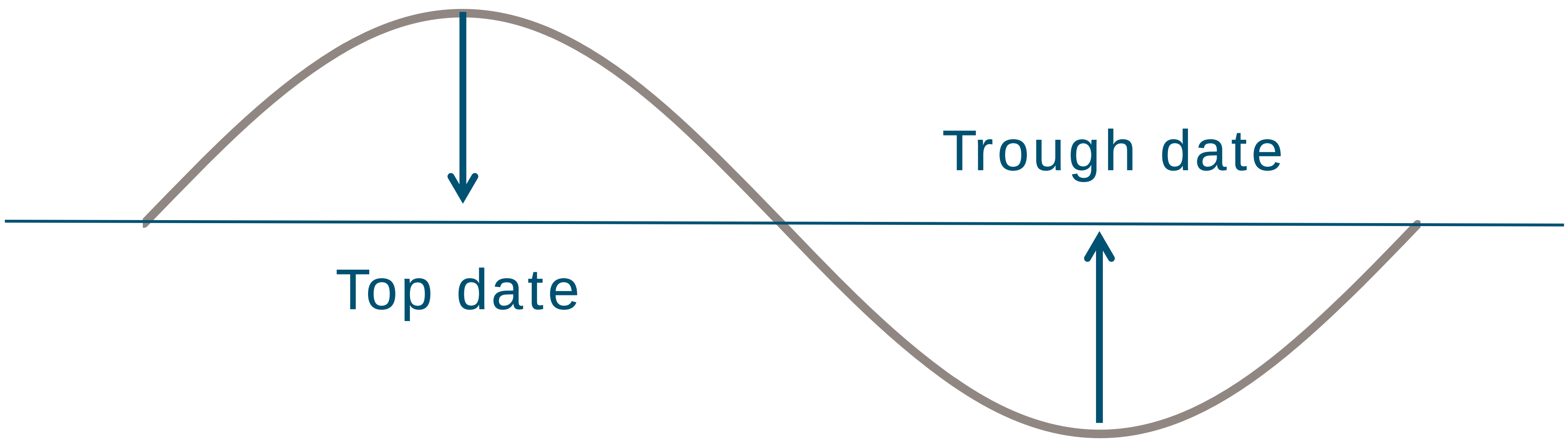
Maximum/minimum values

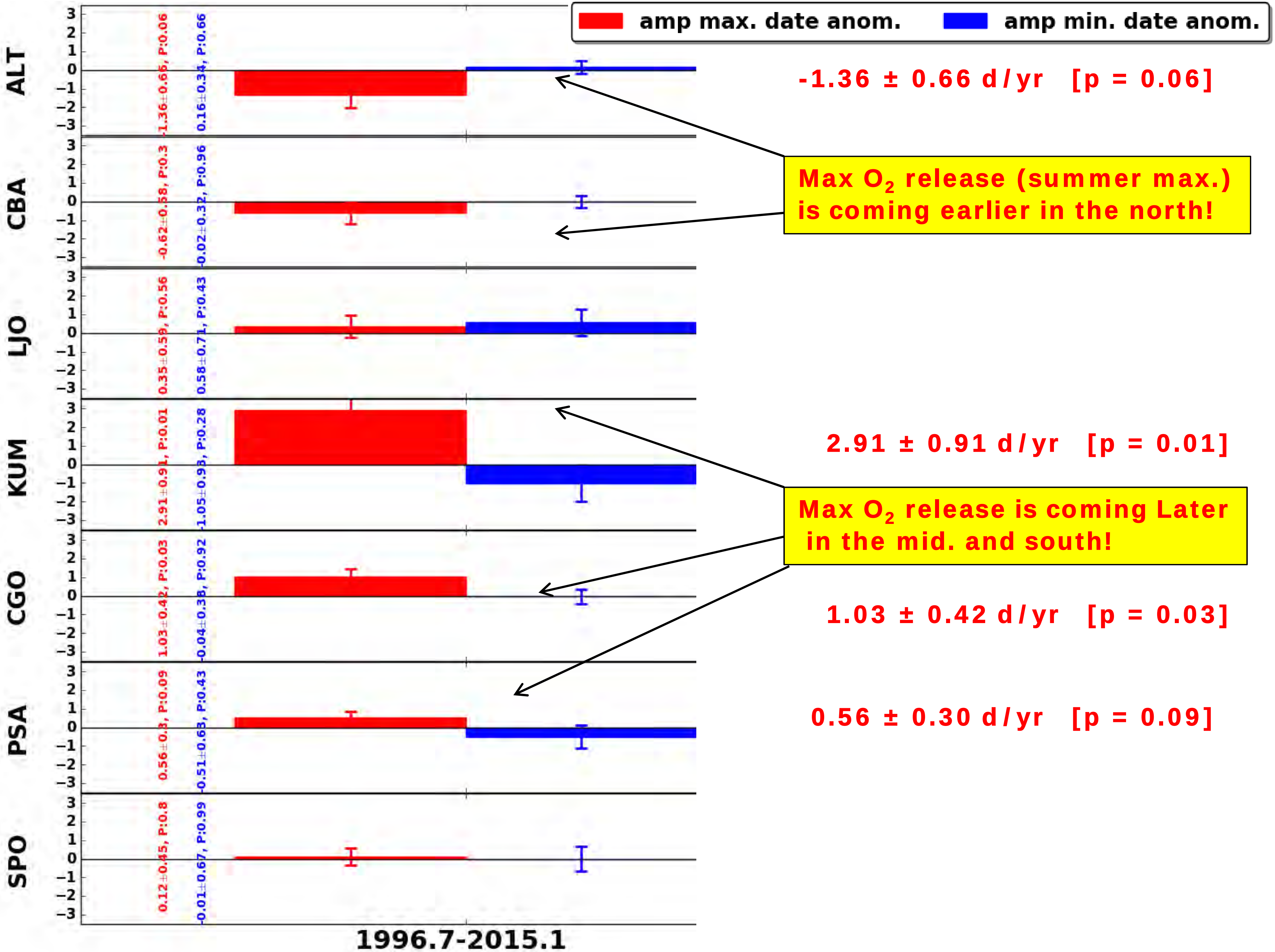




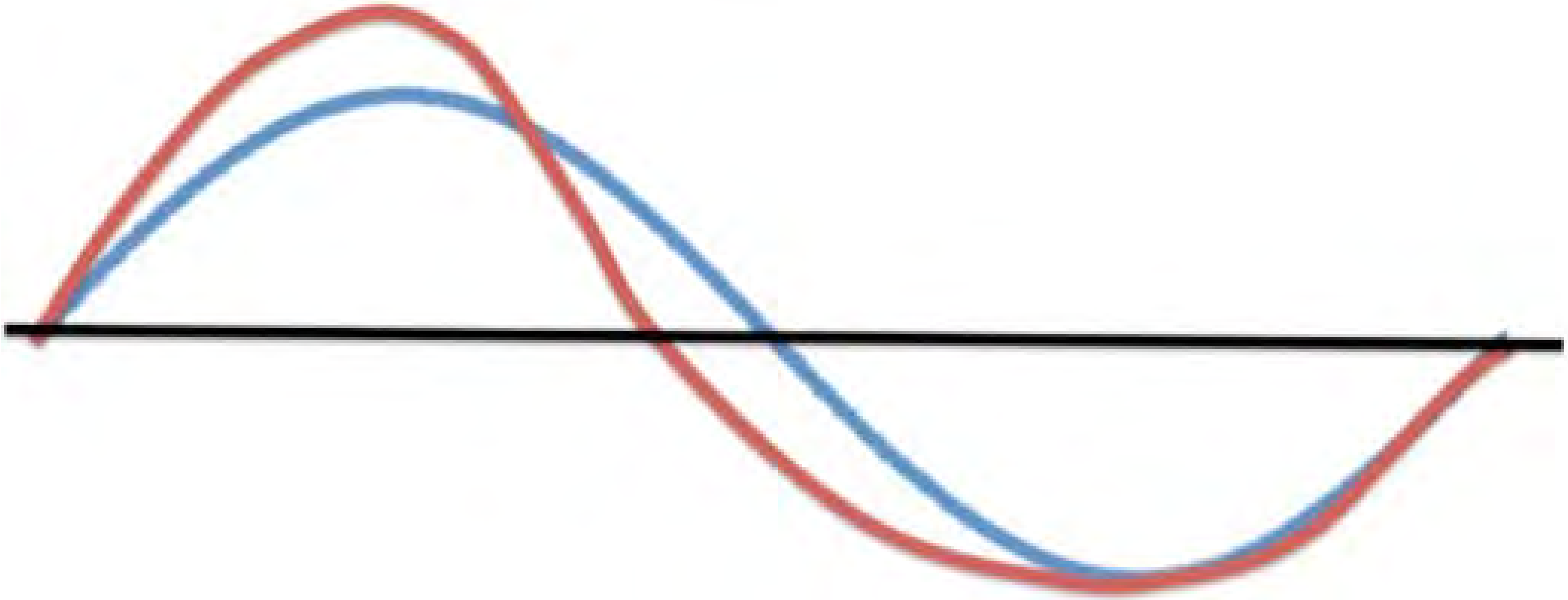
amp max. value anom. [%/yr]
amp min. value anom.[%/yr]
ALT
CBA
LJO
KUM
CGO
PSA
SPO
1.0±0.46, P:0.05
0.02±0.48, P:0.97
0.35±0.73, P:0.64
0.08±0.36, P:0.82
0.51±0.6, P:0.41
0.56±0.53, P:0.3
-0.85±0.54, P:0.13
-0.88±0.62, P:0.17
0.12±0.34, P:0.74
-0.54±0.33, P:0.12
-0.36±0.29, P:0.24
-0.43±0.42, P:0.32
-0.63±0.45, P:0.18
-0.62±0.39, P:0.13
1996.7-2015.1
1.0 ± 0.46 % / yr [p = 0.05]
O2 Top increases
O2 trough increases
-0.85 ± 0.54 % / yr [p = 0.13]
-0.88 ± 0.62 % / yr [p = 0.17]
-0.54 ± 0.33 % / yr [p = 0.12]
O2 top decreases
O2 trough decreases
-0.63 ± 0.45 % / yr [p = 0.18]
-0.62 ± 0.39 % / yr [p = 0.13]

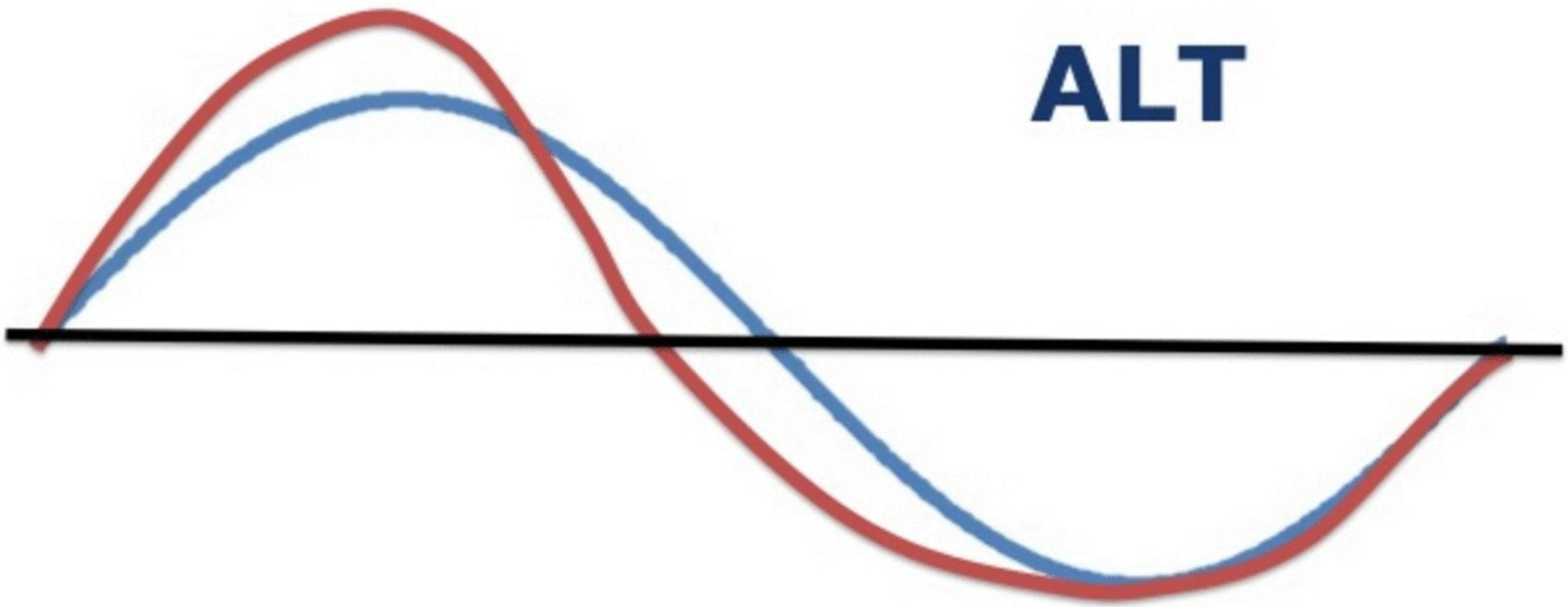
Maximum/minimum dates




amp max. date anom.
amp min. date anom.
ALT
CBA
LJO
KUM
CGO
PSA
SPO
-1.36±0.66, P:0.06
0.16±0.34, P:0.66
-0.62±0.58, P:0.3
0.02±0.32, P:0.96
0.35±0.59, P:0.56
0.58±0.71, P:0.43
2.91±0.91, P:0.01
-1.05±0.98, P:0.28
1.03±0.42, P:0.03
-0.04±0.38, P:0.92
0.56±0.3, P:0.09
-0.51±0.63, P:0.43
0.12±0.45, P:0.8
-0.01±0.67, P:0.99
1996.7-2015.1
-1.36 ± 0.66 d / yr [p = 0.06]
Max O2 release (summer max.) is coming earlier in the north!
2.91 ± 0.91 d / yr [p = 0.01]
Max O2 release is coming Later in the mid. and south!
1.03 ± 0.42 d / yr [p = 0.03]
0.56 ± 0.30 d / yr [p = 0.09]

ALT




ALT

Comparison with model output:

Method

1) IPSL interannual variability + NCEP interannual variability
2) IPSL interannual variability + ERA interannual variability

1) IPSL interannual variability + NCEP climatological
2) IPSL climatological + NCEP interannual variability

Results:

1) Changes in start of seasons mainly atributed to changing wind patterns
2) Changes in uptake/release due to processes within the ocean (ventilation/circulation)

Preliminary conclusions
:

North:

- Winter comes earlier
- Both uptake and release increase

[->wind patterns]

Questions ?

- Winter and summer come earlier
- Both uptake and release decrease
- [->ocean circulation/solubility/net production]

- Differences are small but net effect: suggest net O_2 release

Additional slides

Atmospheric measurements of O_2 and CO_2 suggests increasing oceanic respiratory disorder

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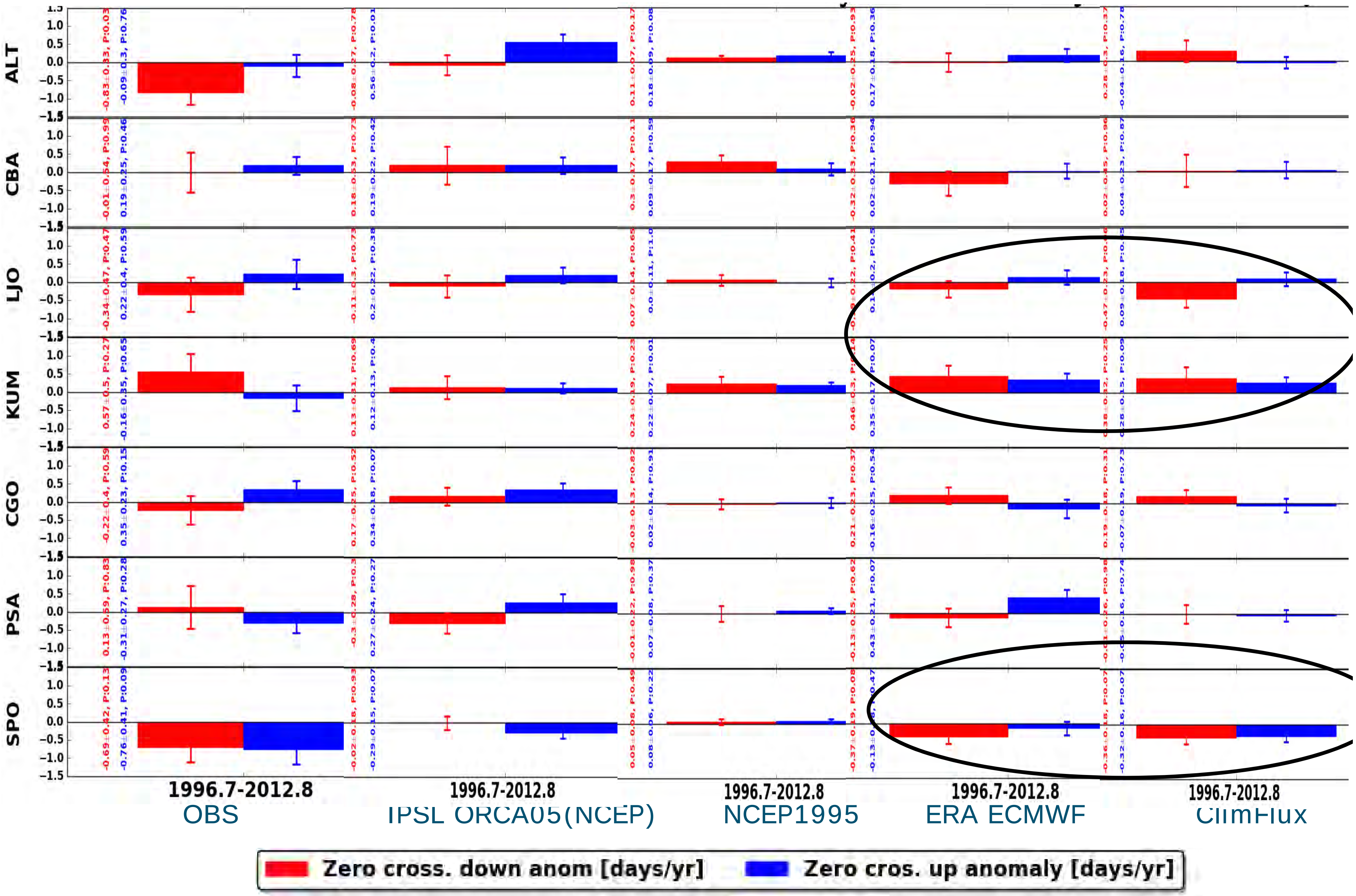
Obs vs. models [1996.7-2012.8]

Zero Crossings

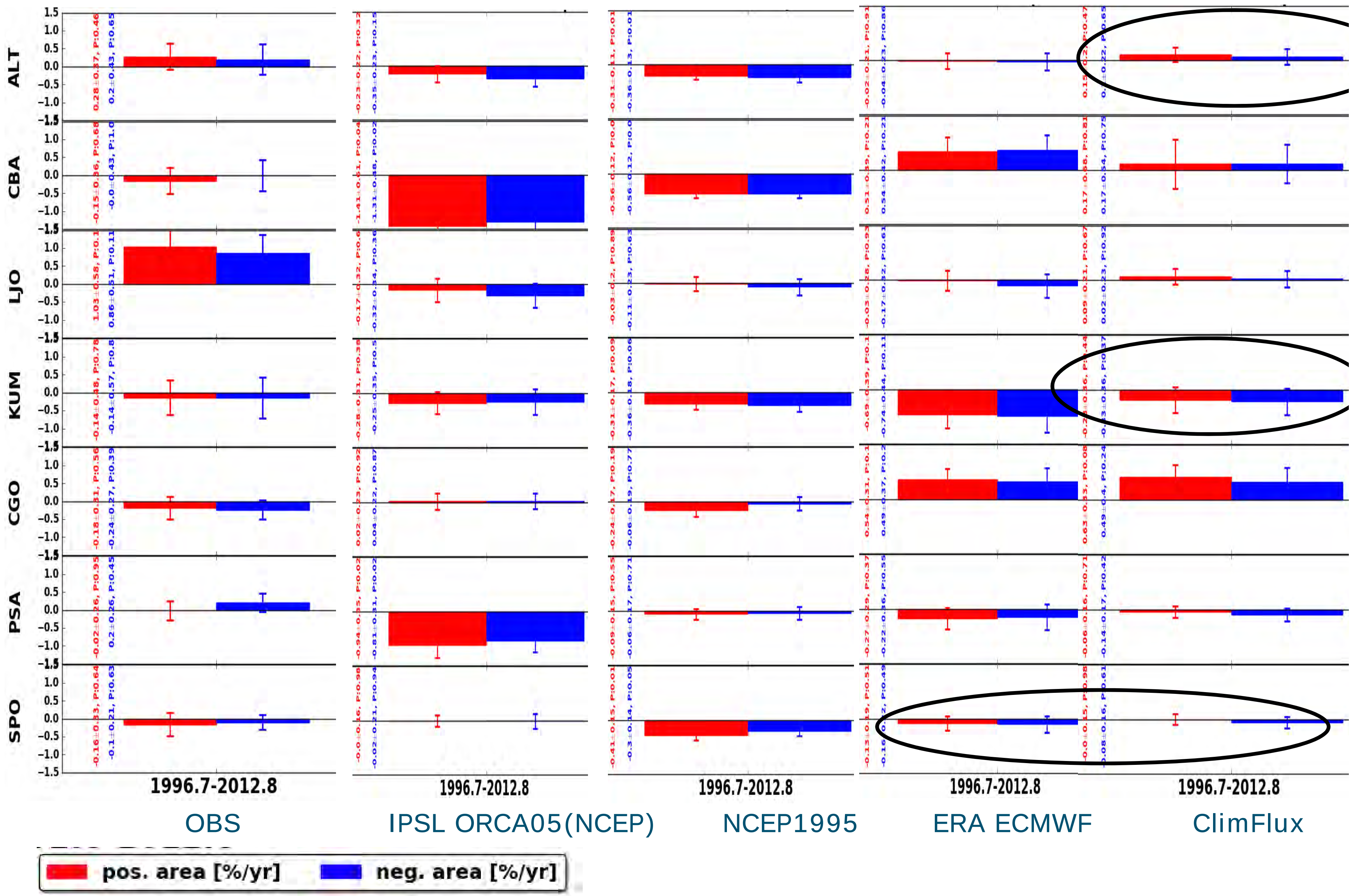


NEMO PISCES & TM3

[**N**ucleus for **E**uropean **M**odelling of the **O**cean **P**elagic **I**nteractions **S**cheme for **C**arbon]

Obs vs. models [1996.7-2012.8]

Area



NEMO PISCES & TM3

[**N**ucleus for **E**uropean **M**odelling of the **O**cean **P**elagic **I**nteractions **S**cheme for **C**arbon]

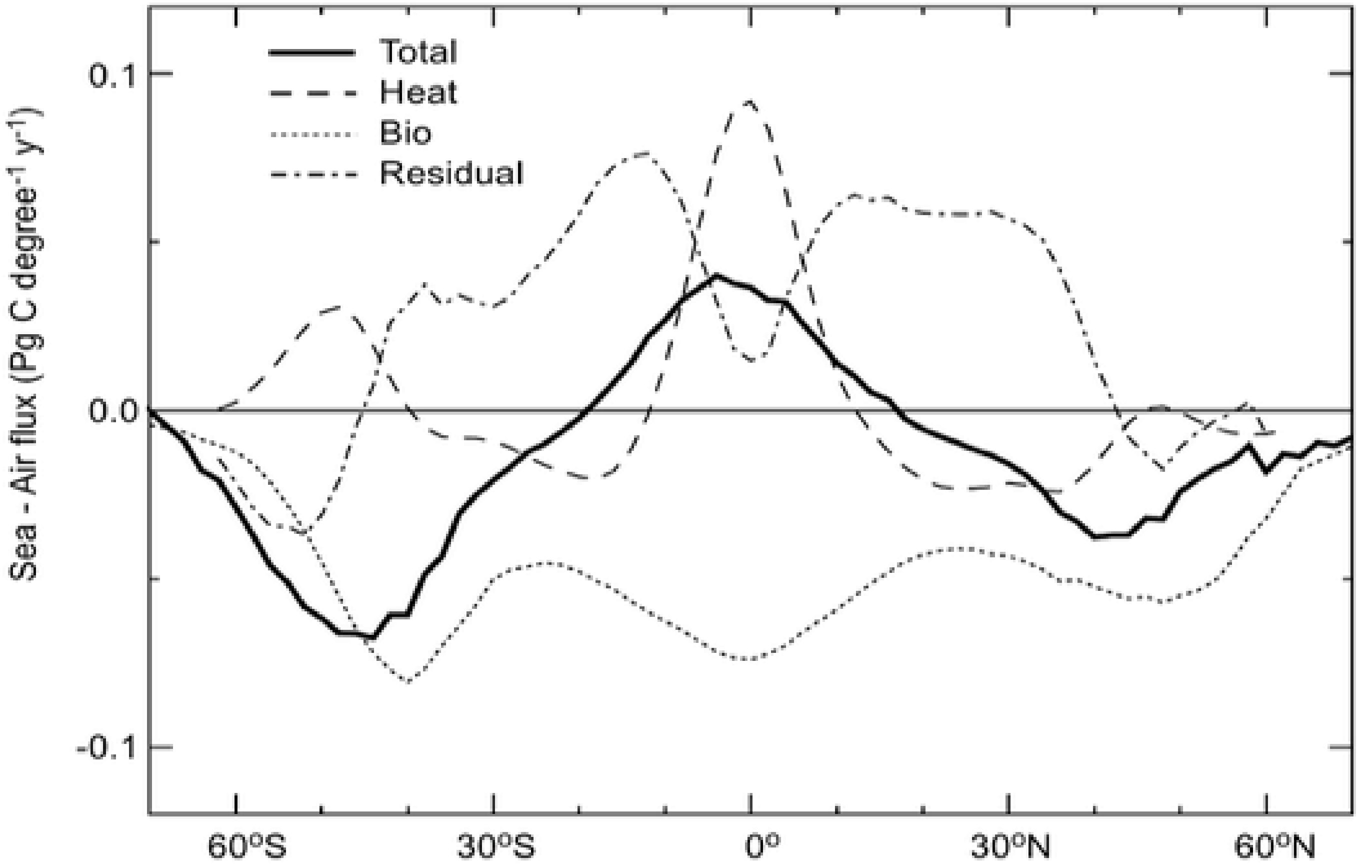
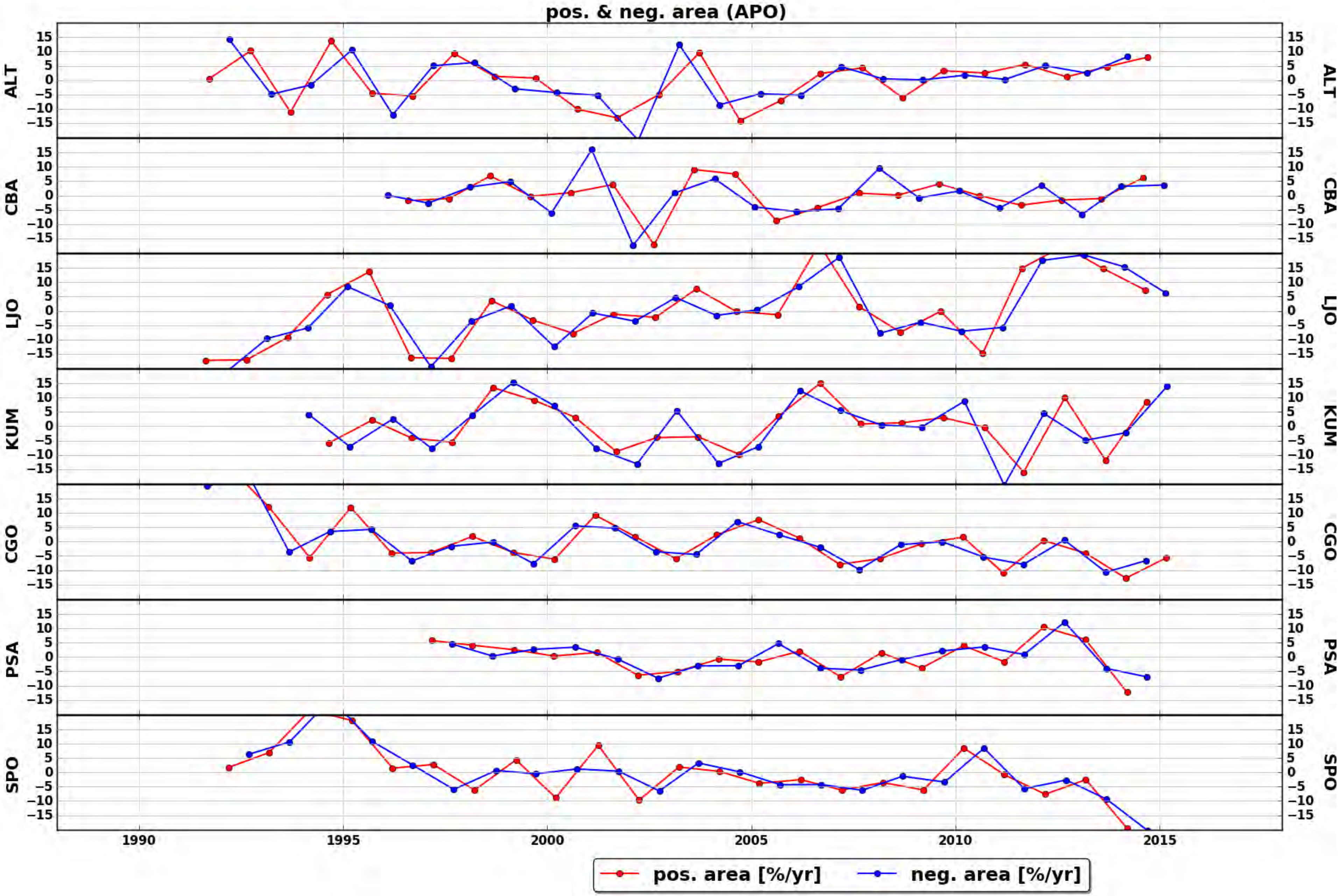
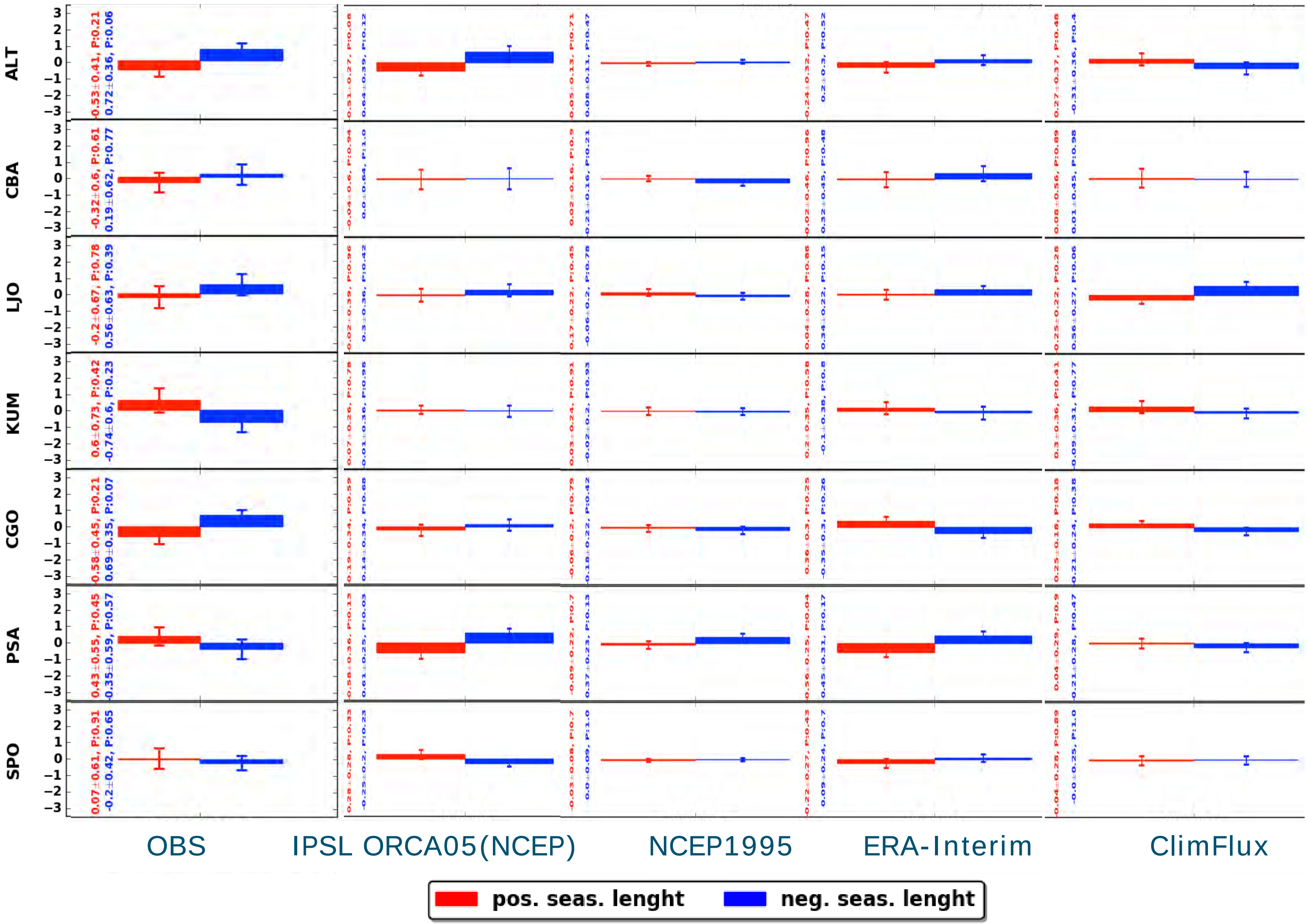


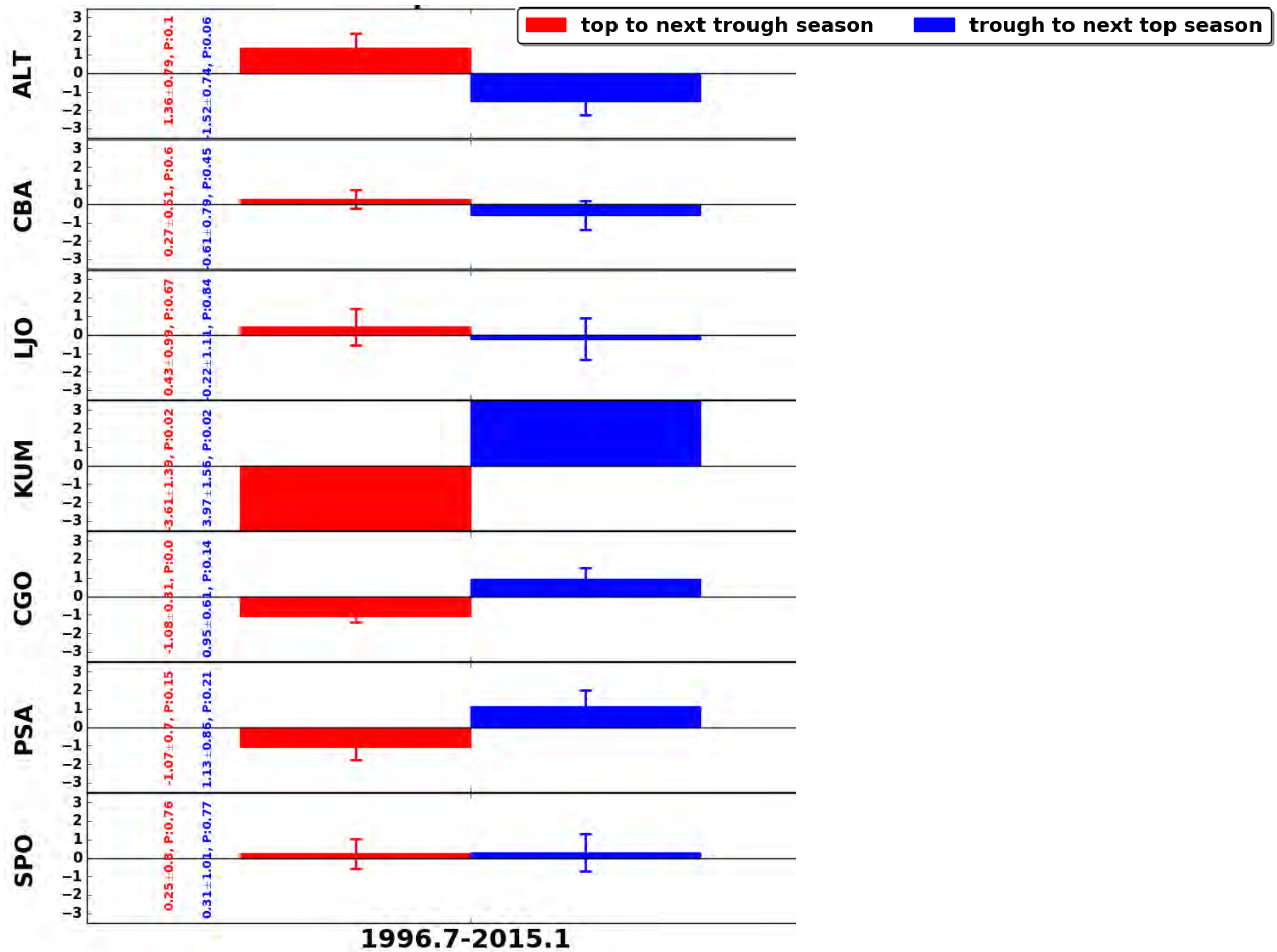
Figure 12.1. Sea-air CO_2 flux by latitude band (PgC degree^{-1} y^{-1}). Negative values indicate a flux from the atmosphere to the ocean. The total CO_2 flux was estimated by Takahashi et al. (2002) based on ocean pCO_2 observations. The contribution of the biological export production was estimated using SeaWiFS chlorophyll observations averaged over 1997–2001, Behrenfeld and Falkowski's (1997) primary production, and Laws et al.'s (2000) ef-ratio. The contribution of the heat flux was estimated using NCEP heat fluxes averaged over 1985–1995 with the formulation of Murnane et al. (1999). The biology and heat contributions were smoothed with a 5° running mean corresponding to the grid used by Takahashi et al. (2002). Contributions from the biology and heat flux assume an infinite gas exchange. The residual flux is estimated from the total minus the biological and heat contributions. It represents ocean transport and anthropogenic uptake as well as the error associated with the other estimates.


pos. & neg. area (APO)
ALT
CBA
LJO
KUM
CGO
PSA
SPO
15
10
5
0
−5
−10
−15
1990
1995
2000
2005
2010
2015
pos. area [%/yr]
neg. area [%/yr]

Obs vs. models [1996.7-2012.8]

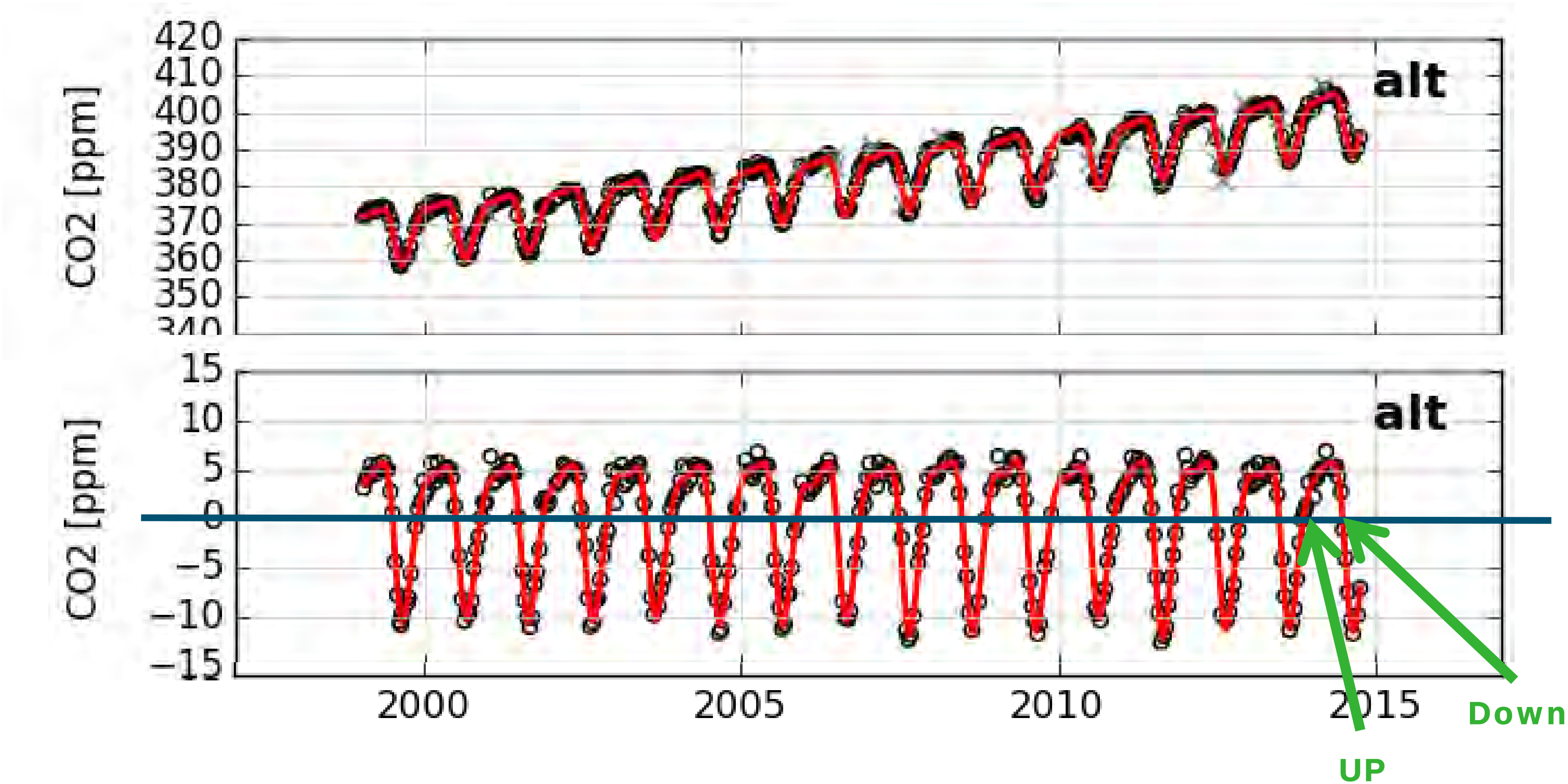
Length of season



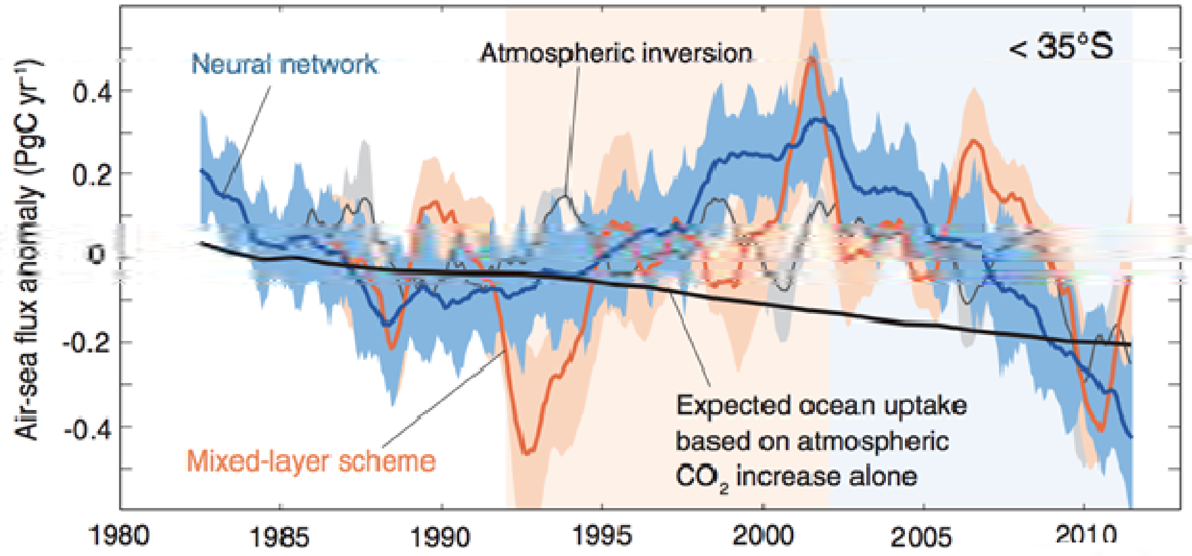

top to next trough season
trough to next top season
ALT
1.36±0.79, P:0.1
-1.52±0.74, P:0.06
CBA
0.27±0.51, P:0.6
-0.61±0.79, P:0.45
LJO
0.43±0.99, P:0.67
-0.22±1.11, P:0.84
KUM
-3.61±1.39, P:0.02
3.97±1.56, P:0.02
CGO
-1.08±0.31, P:0.0
0.95±0.61, P:0.14
PSA
-1.07±0.7, P:0.15
1.13±0.86, P:0.21
SPO
0.25±0.8, P:0.76
0.31±1.01, P:0.77
1996.7-2015.1

Introduction

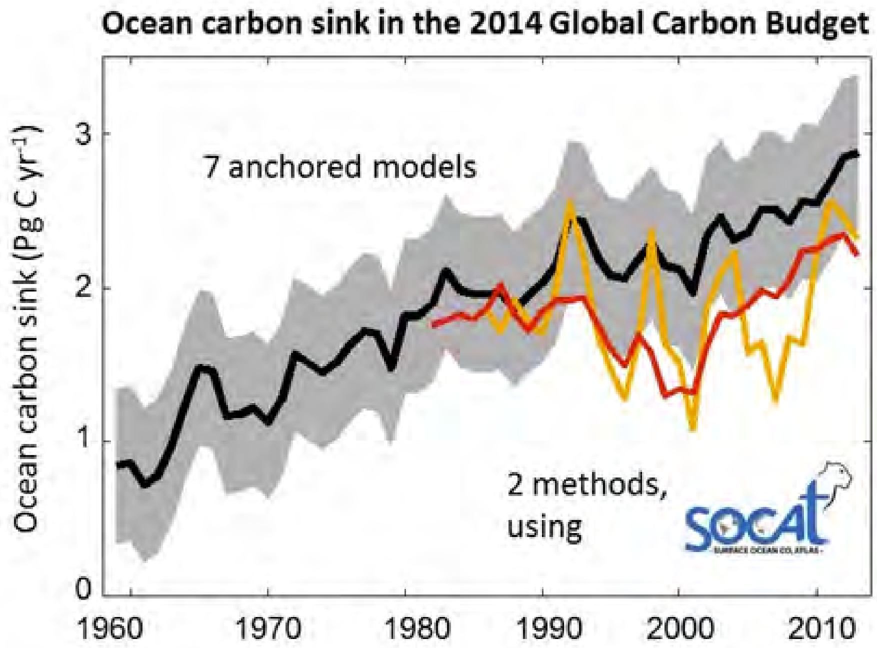
Piao et al. (Nature, 2008) found land biosphere climate response, from atmospheric CO_2 measurements (trend in ‘zero crossing’).



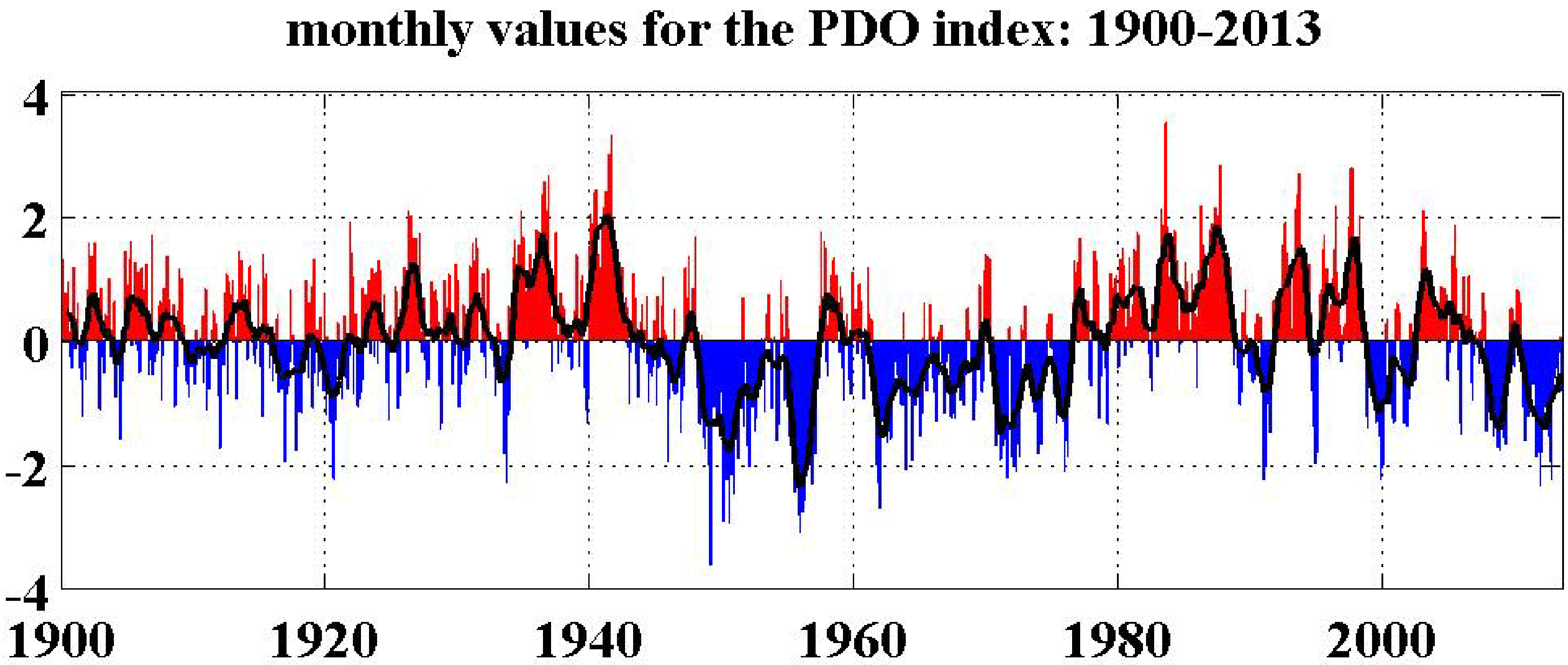
Is it related ?



Lanschutzer et al 2015, Science

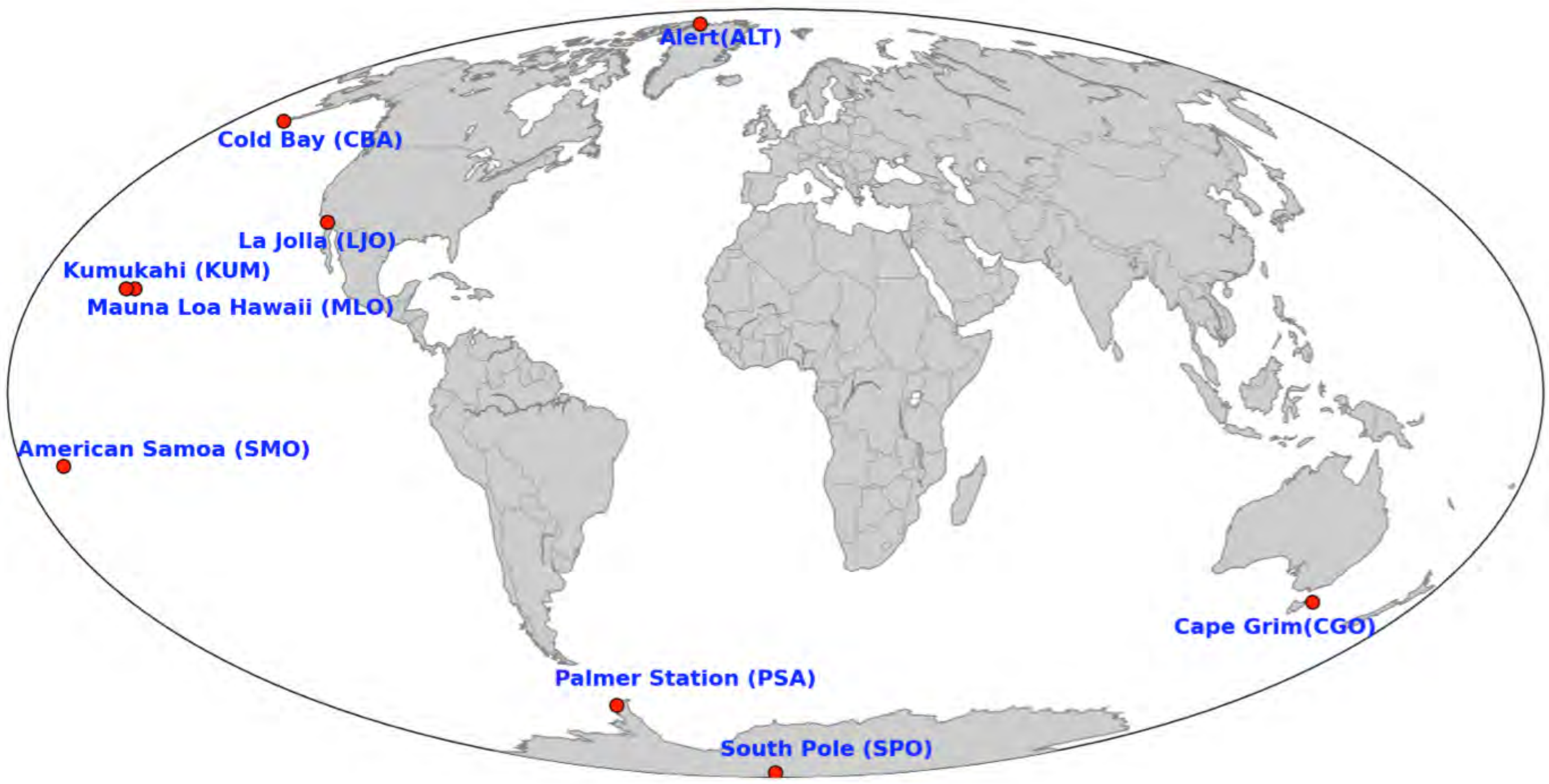


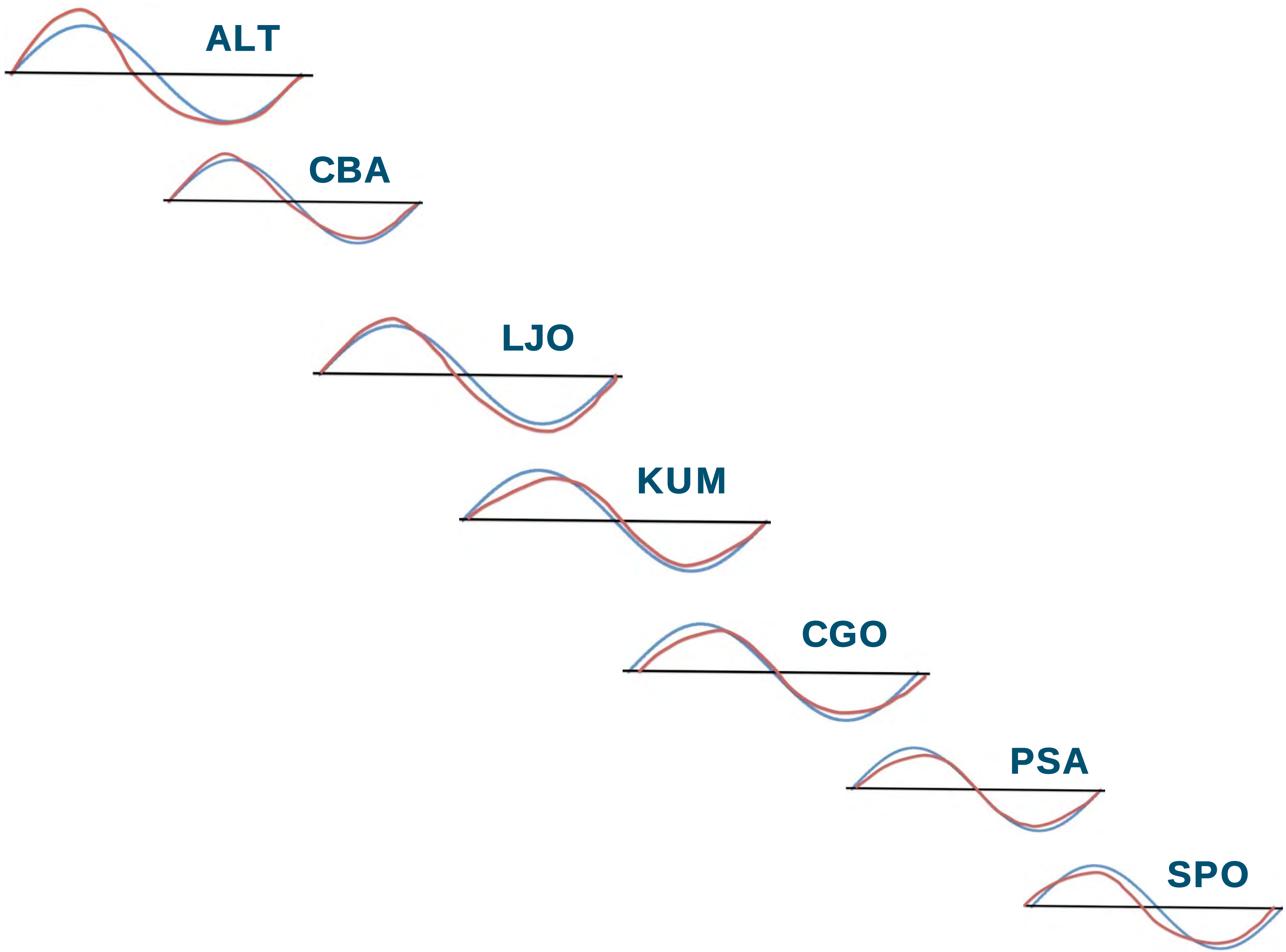
Additional slides



Introduction

How about the marine biosphere? → **APO**




ALT
CBA
LJO
KUM
CGO
PSA
SPO