Estimates of Atmospheric Potential Oxygen (APO) Fluxes Based on O_2/N_2 and CO_2 Concentration Measurements: What Can They Tell Us About The Global Carbon Cycle?

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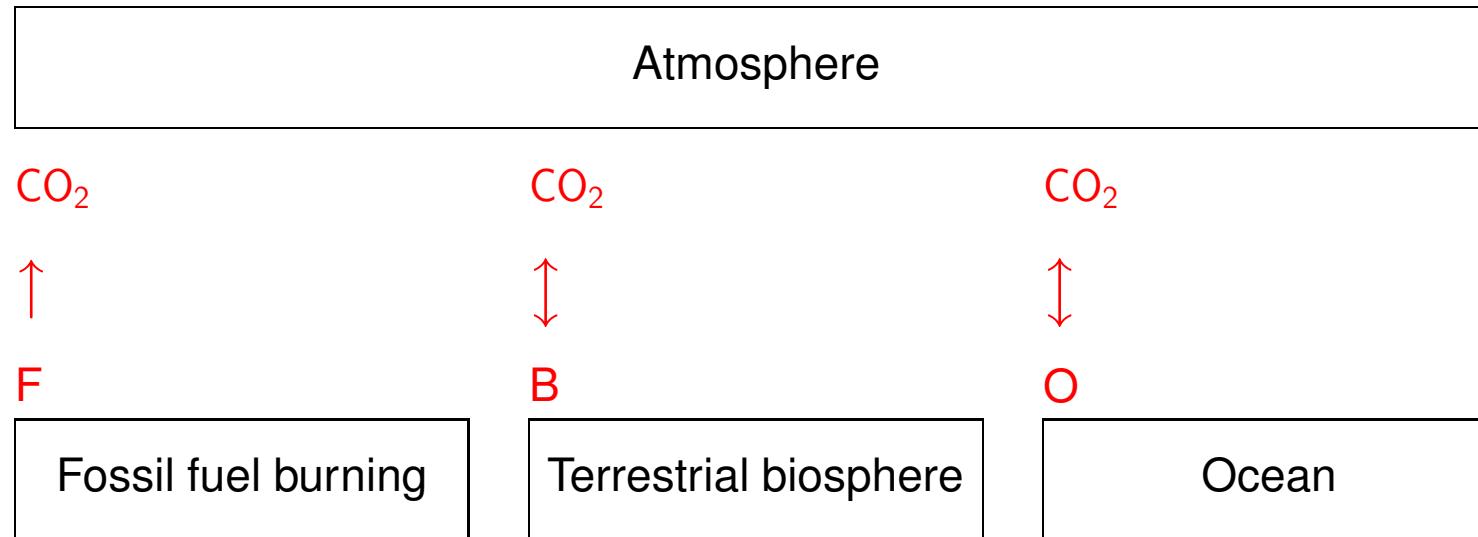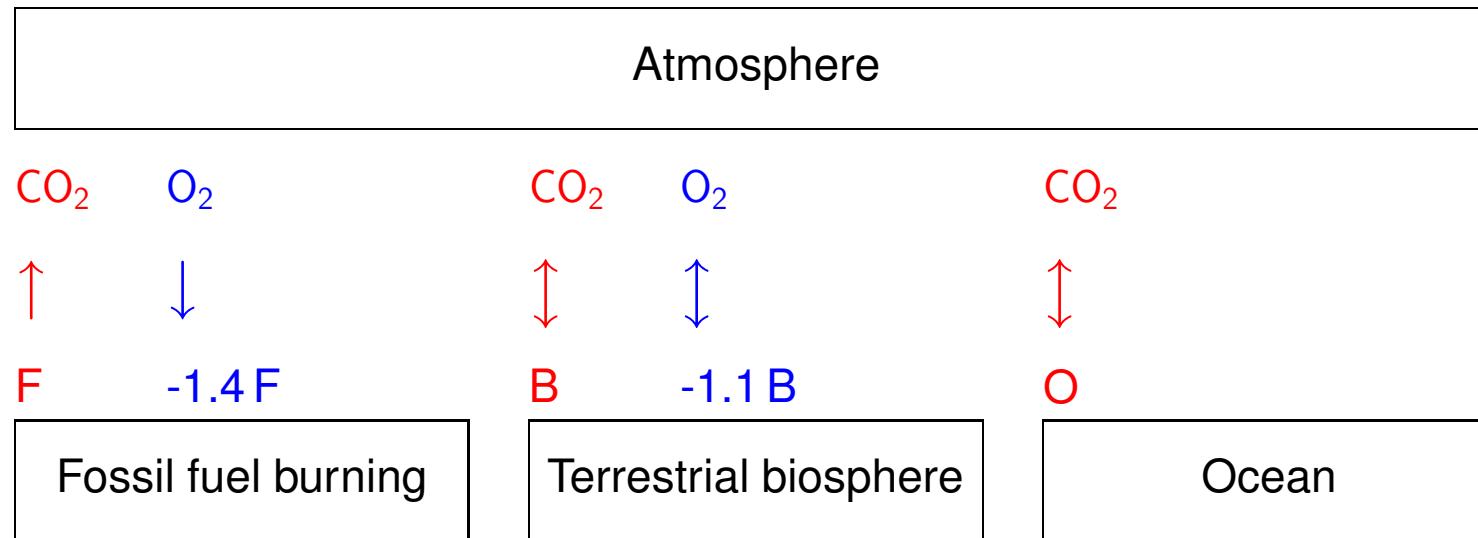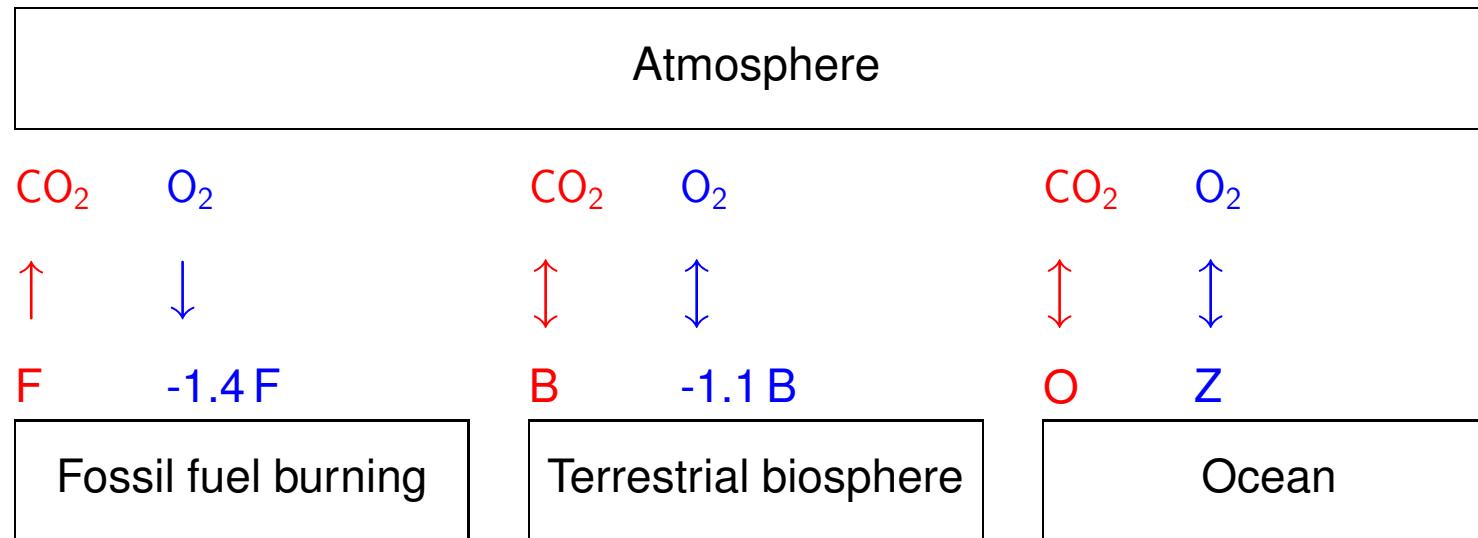
What is Atmospheric Potential Oxygen?

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Atmosphere

CO_2 O_2 CO_2 O_2 CO_2

↑   ↓   ↕   ↕   ↕

F   -1.4 F   B   -1.1 B   O

Fossil fuel burning		Terrestrial biosphere		Ocean

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Atmosphere

CO_2 O_2 CO_2 O_2 CO_2 O_2

↑   ↓   ↕   ↕   ↕   ↕

F   -1.4 F   B   -1.1 B   O   Z
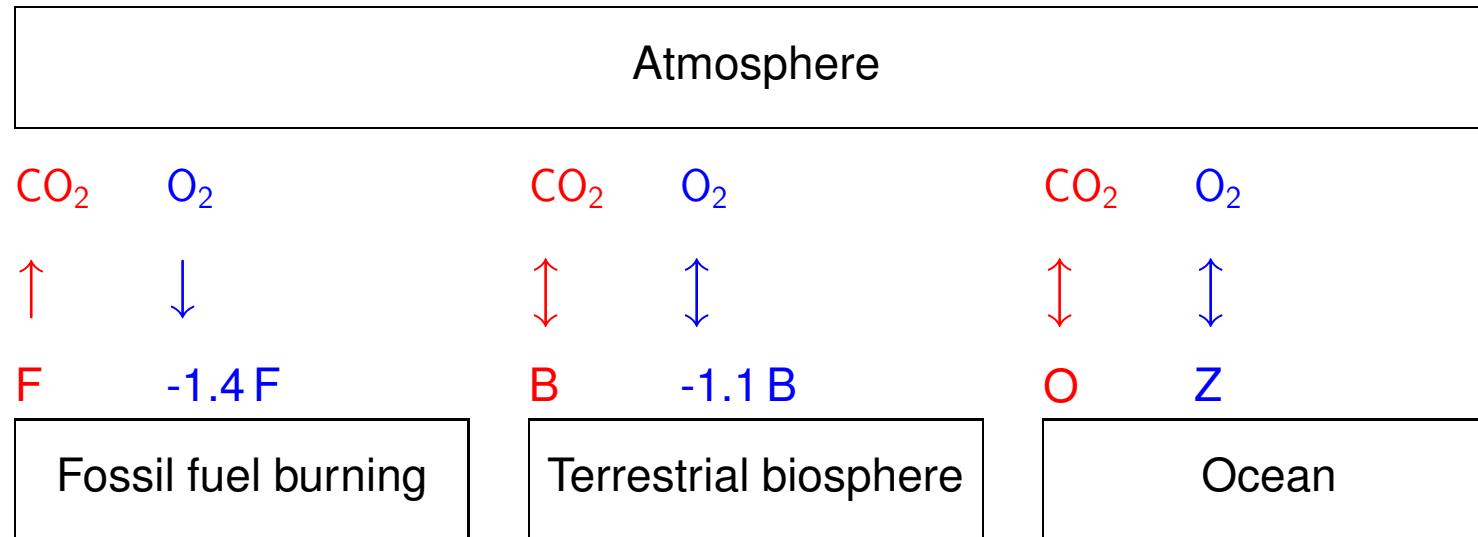
Fossil fuel burning	Terrestrial biosphere	Ocean

Decoupling CO_2, O_2:
- Carbonate chemistry (buffer effect)
- Physical transport (dilution)
- Warming / cooling (solubility changes)
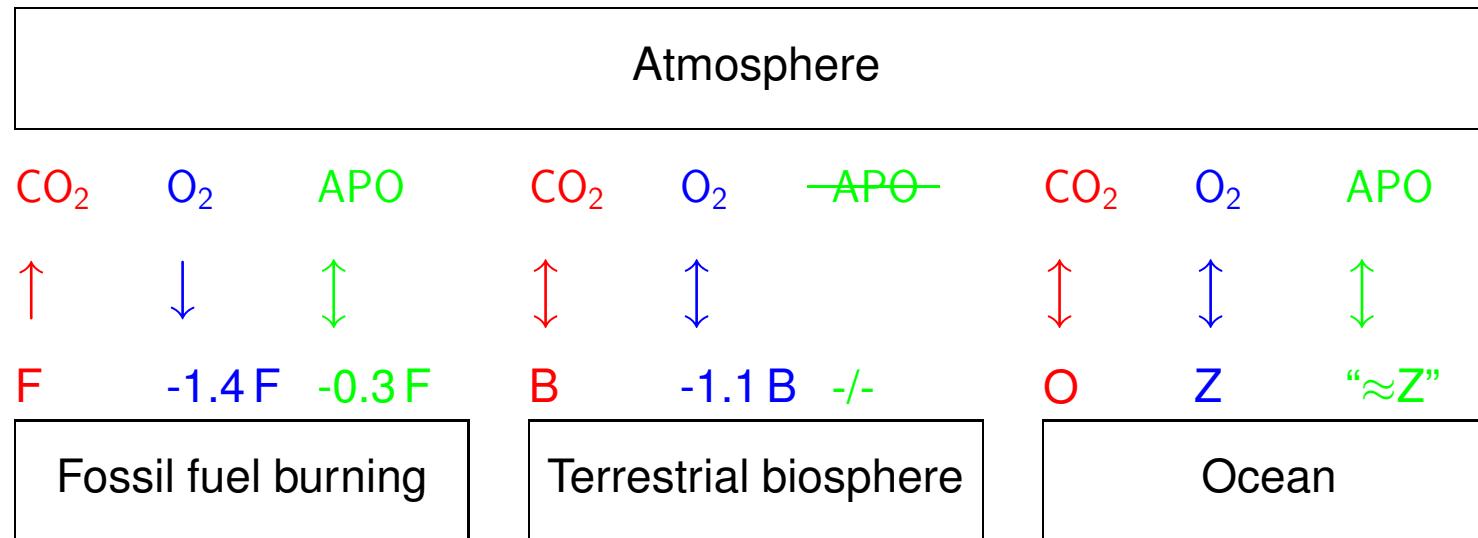
What is Atmospheric Potential Oxygen?

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

(Stephens et al., 1998)
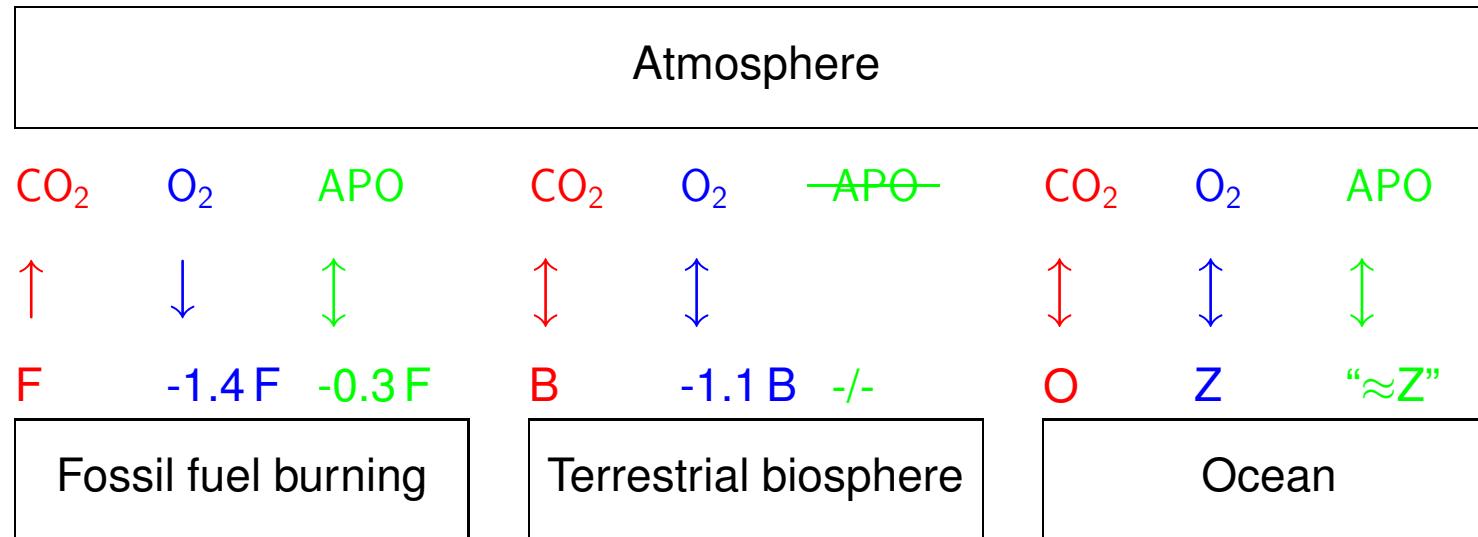
What is Atmospheric Potential Oxygen?

| Atmosphere |
|:---:|

CO_2	O_2	APO		CO_2	O_2	~~APO~~		CO_2	O_2	APO
↑	↓	↕		↕	↓			↕	↕	↕
F	-1.4 F	-0.3 F		B	-1.1 B	-/-		O	Z	"≈Z"

Fossil fuel burning		Terrestrial biosphere		Ocean

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

(Stephens et al., 1998)

What is Atmospheric Potential Oxygen?

Atmosphere

CO_2	O_2	APO	CO_2	O_2	~~APO~~	CO_2	O_2	APO
↑	↓	↕	↕	↕		↕	↕	↕
F	-1.4 F	-0.3 F	B	-1.1 B	-/-	O	Z	"≈Z"

| Fossil fuel burning	Terrestrial biosphere	Ocean

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Information on:
- Marine biological activity
- Mixing/stratification, upwelling
- Gas exchange
- → *Impact also on carbon cycle*

What is Atmospheric Potential Oxygen?
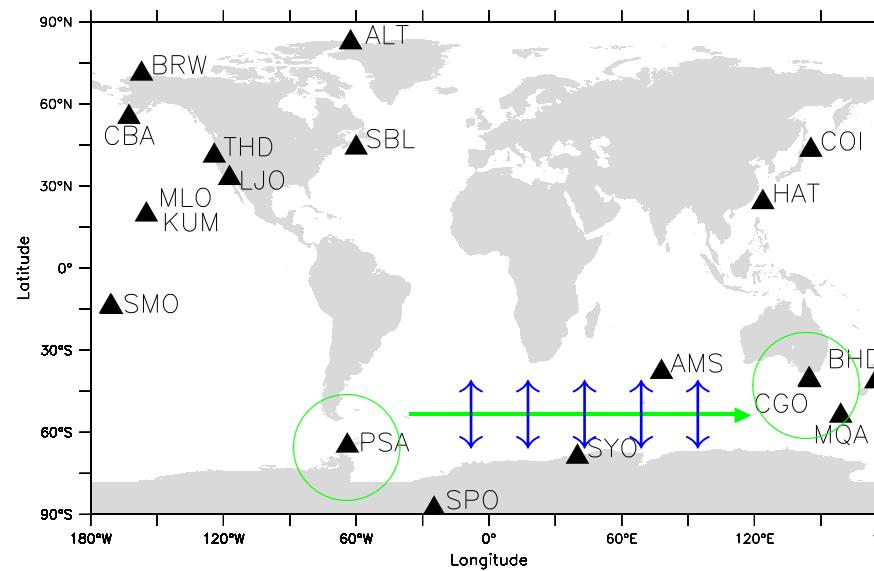
	Atmosphere							
CO_2	O_2	APO	CO_2	O_2	~~APO~~	CO_2	O_2	APO
↑	↓	↕	↕	↓		↕	↕	↕
F	-1.4 F	-0.3 F	B	-1.1 B	-/-	O	Z	"≈Z"
Fossil fuel burning			Terrestrial biosphere			Ocean		

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

Information on:
- Marine biological activity
- Mixing/stratification, upwelling
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- → *Impact also on carbon cycle*

Quantification:
- Based on atmospheric measurements
- Method: 'Atmospheric inversion'

Inversion principle
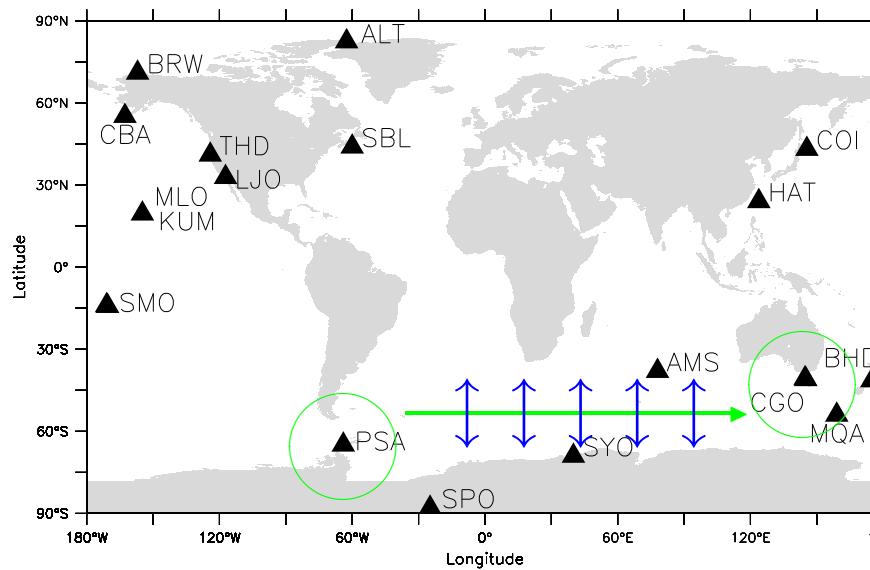
Causality: Fluxes, Transport $\longrightarrow$ Concentration gradient
Knowledge: $\sum$ Fluxes $\longleftarrow$ Concentration gradient, Transport

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

Inversion = Multidimensional linear regression

$$J(\mathbf{f}) = (\mathbf{c}_{\mathsf{meas}} - \mathbf{c}_{\mathsf{mod}})^{\mathrm{T}} \mathbf{Q_c} (\mathbf{c}_{\mathsf{meas}} - \mathbf{c}_{\mathsf{mod}}) \longrightarrow \mathsf{min}$$

Inversion principle

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

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

Inversion = Multidimensional linear regression

'A-priori information': $\boxed{\mathbf{f} = \mathbf{f}_{\text{fix}} + \mathbf{F}\mathbf{p}}$
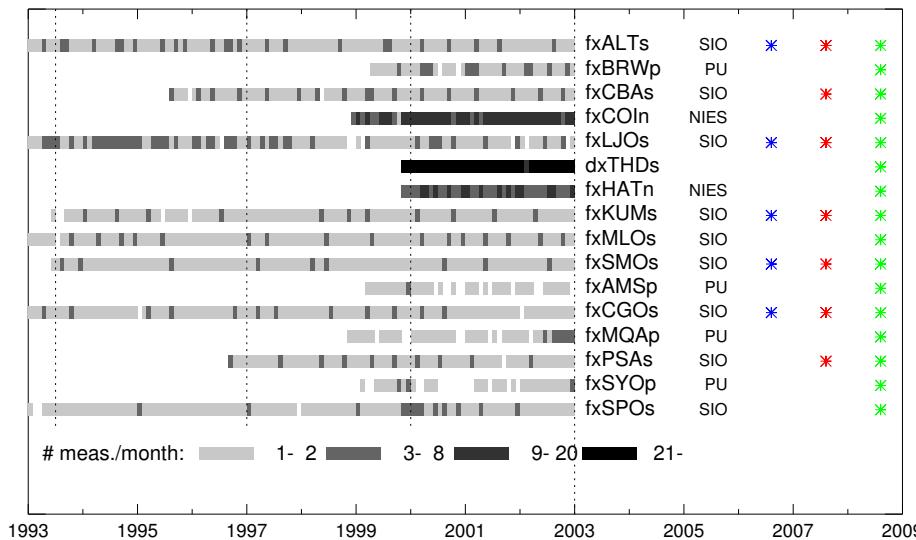
- Spatio-temporal weighting
- Spatial correlations
- Temporal correlations

No a-priori phase information
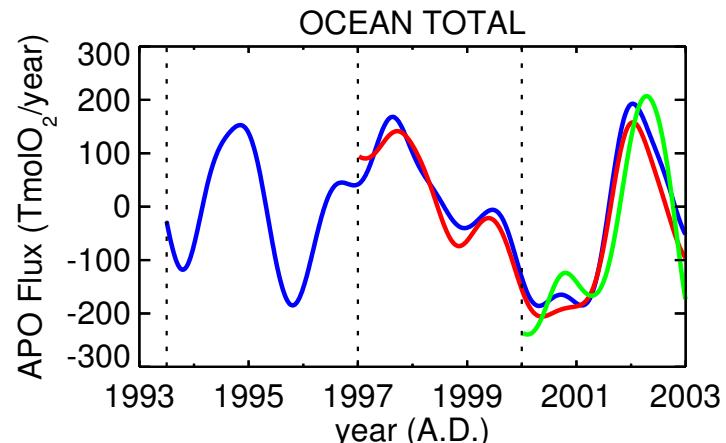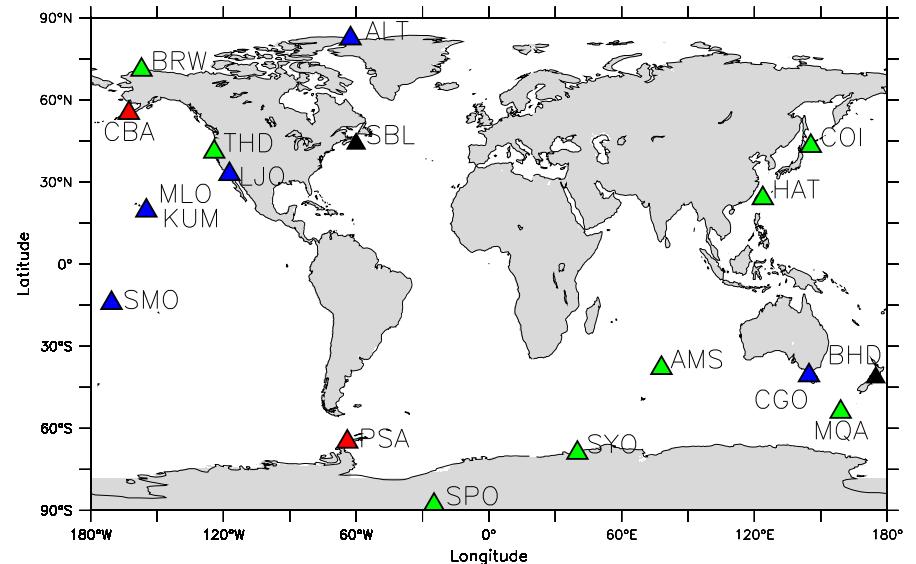
Oxygen (APO) Data

Data availability:

Sampling locations:

Inversion runs based on:
 5 sites
 7 sites
16 sites
(at least latitudinal coverage)
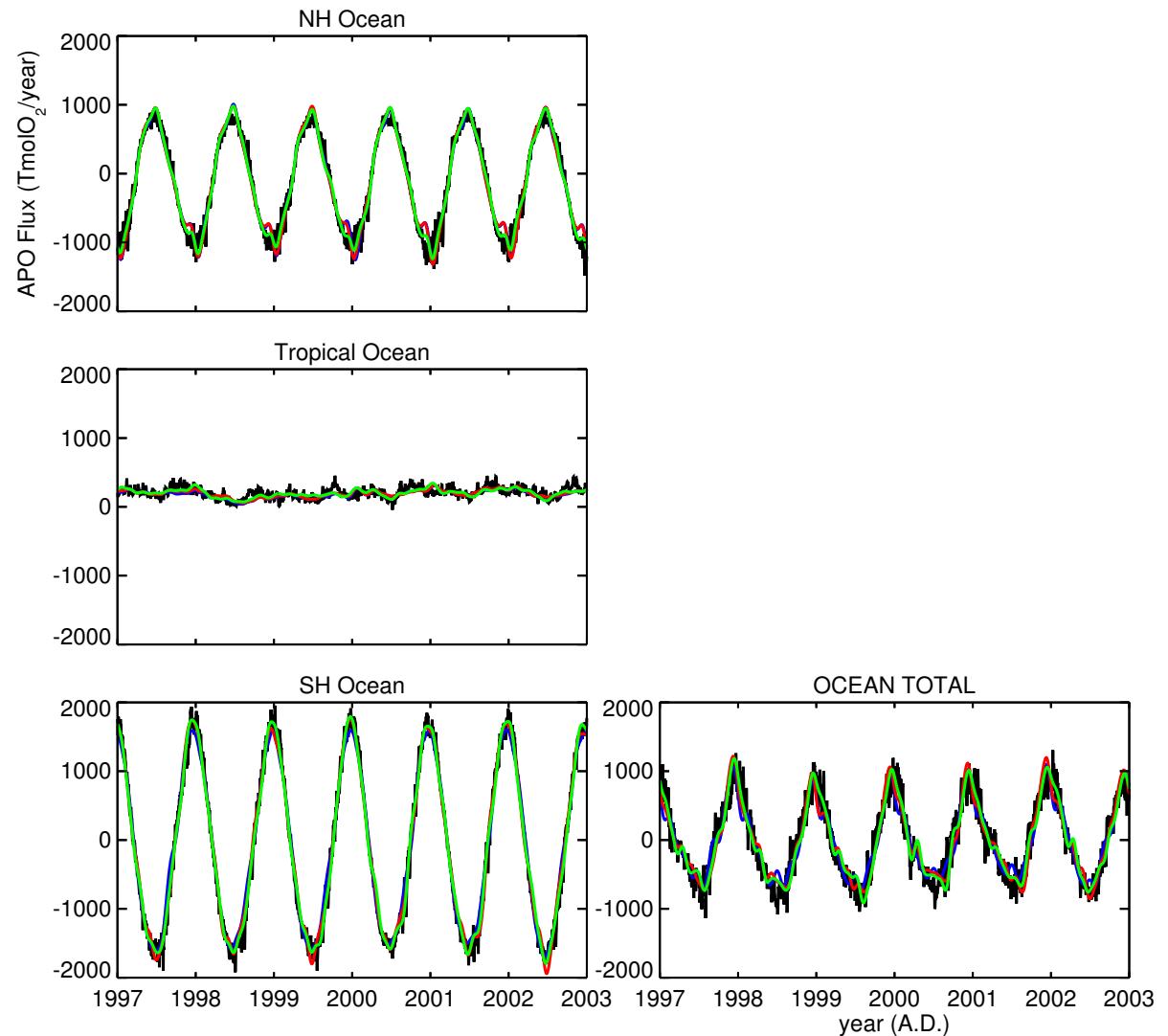
Do We Have Enough Information?

Inverting synthetic data
(at actual locations and times):

Retrieval of
"Known thruth"

5 sites
7 sites
16 sites

→ Seasonality 'seen'
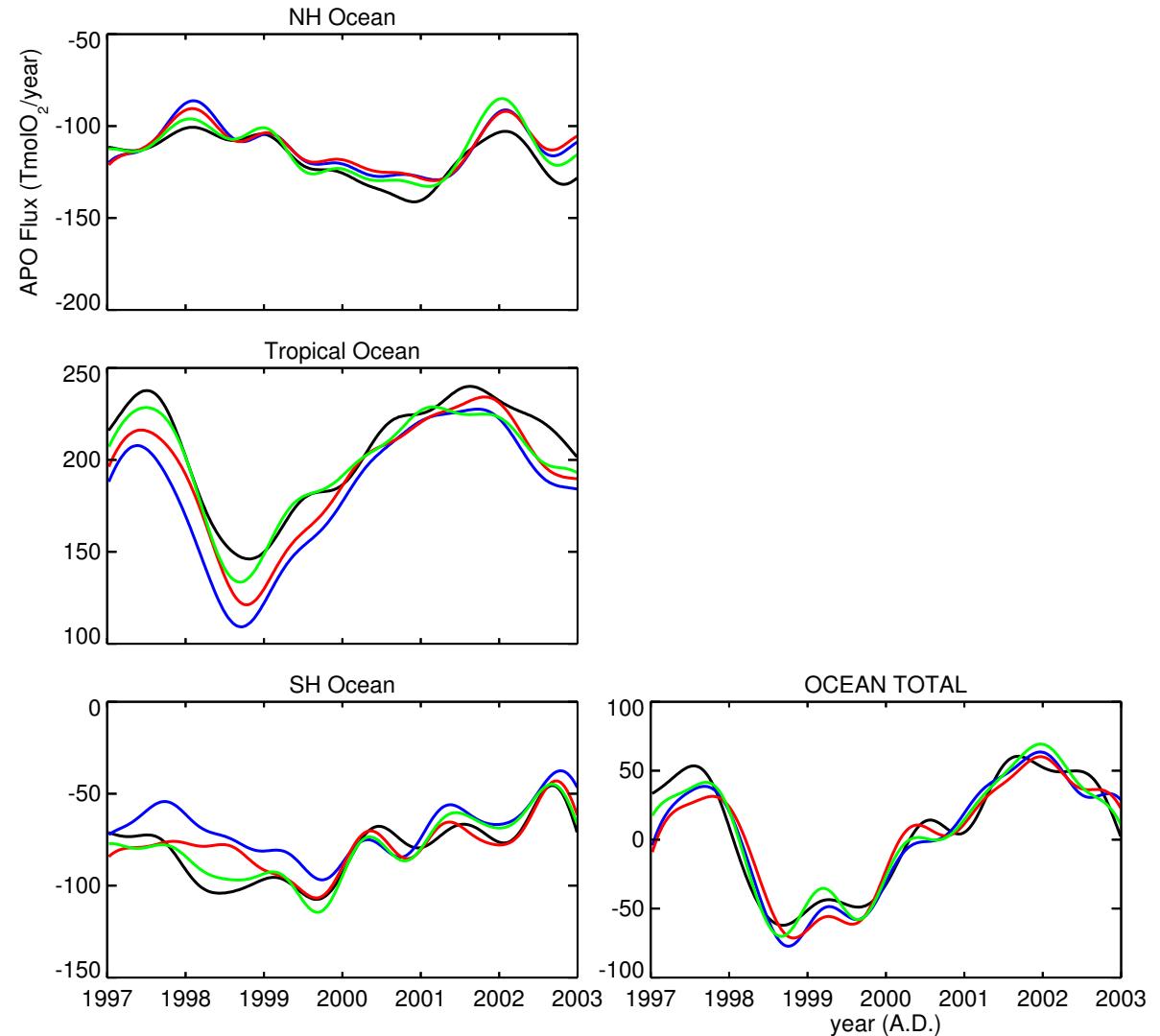
Do We Have Enough Information?

Inverting synthetic data
(at actual locations and times):

Retrieval of
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5 sites
7 sites
16 sites

→ Main interannual patterns 'seen'
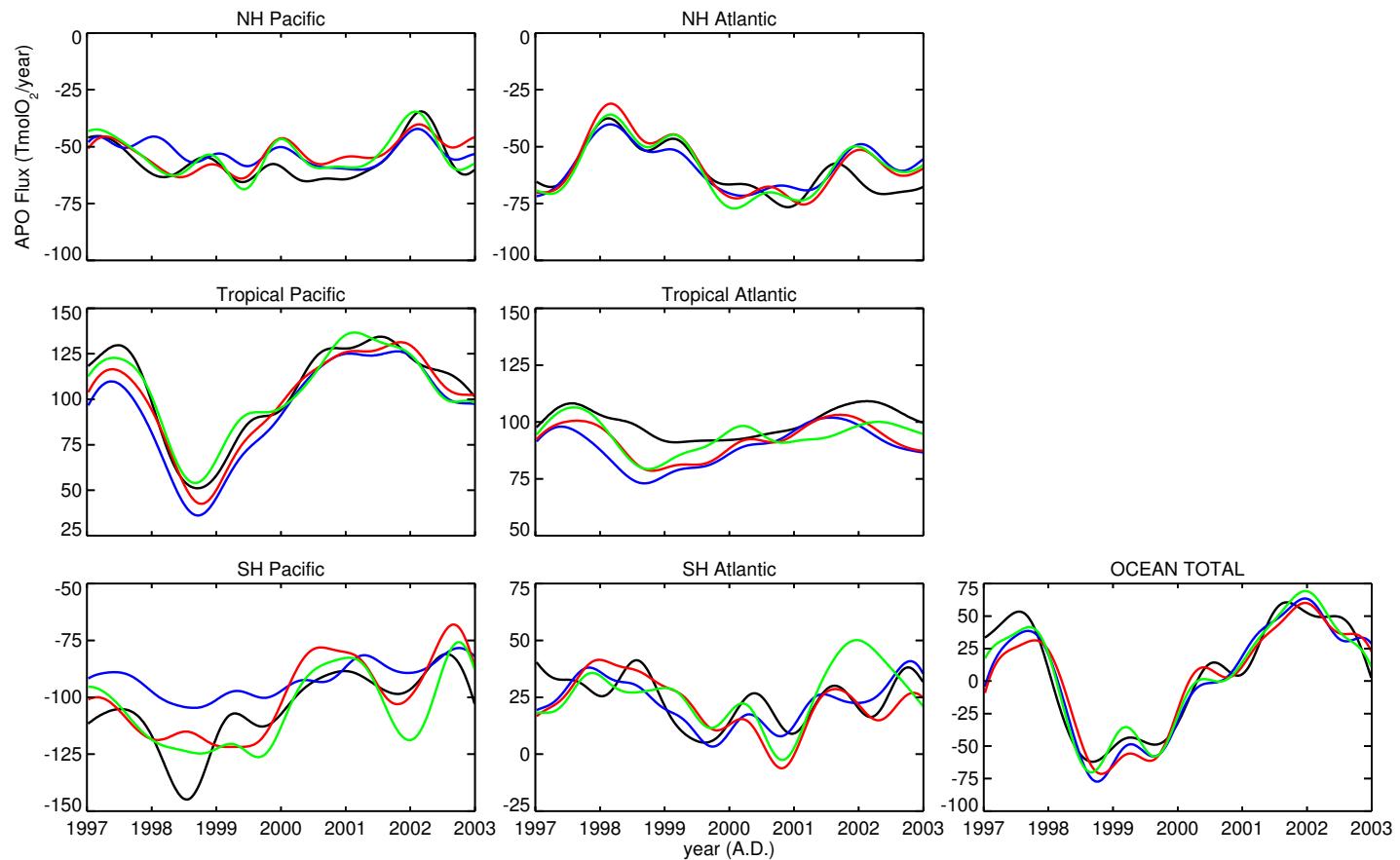
Do We Have Enough Information?

Inverting synthetic data (at actual locations and times):

Retrieval of "Known thruth"

5 sites
7 sites
16 sites

→ Southern ocean: split incompletely resolved
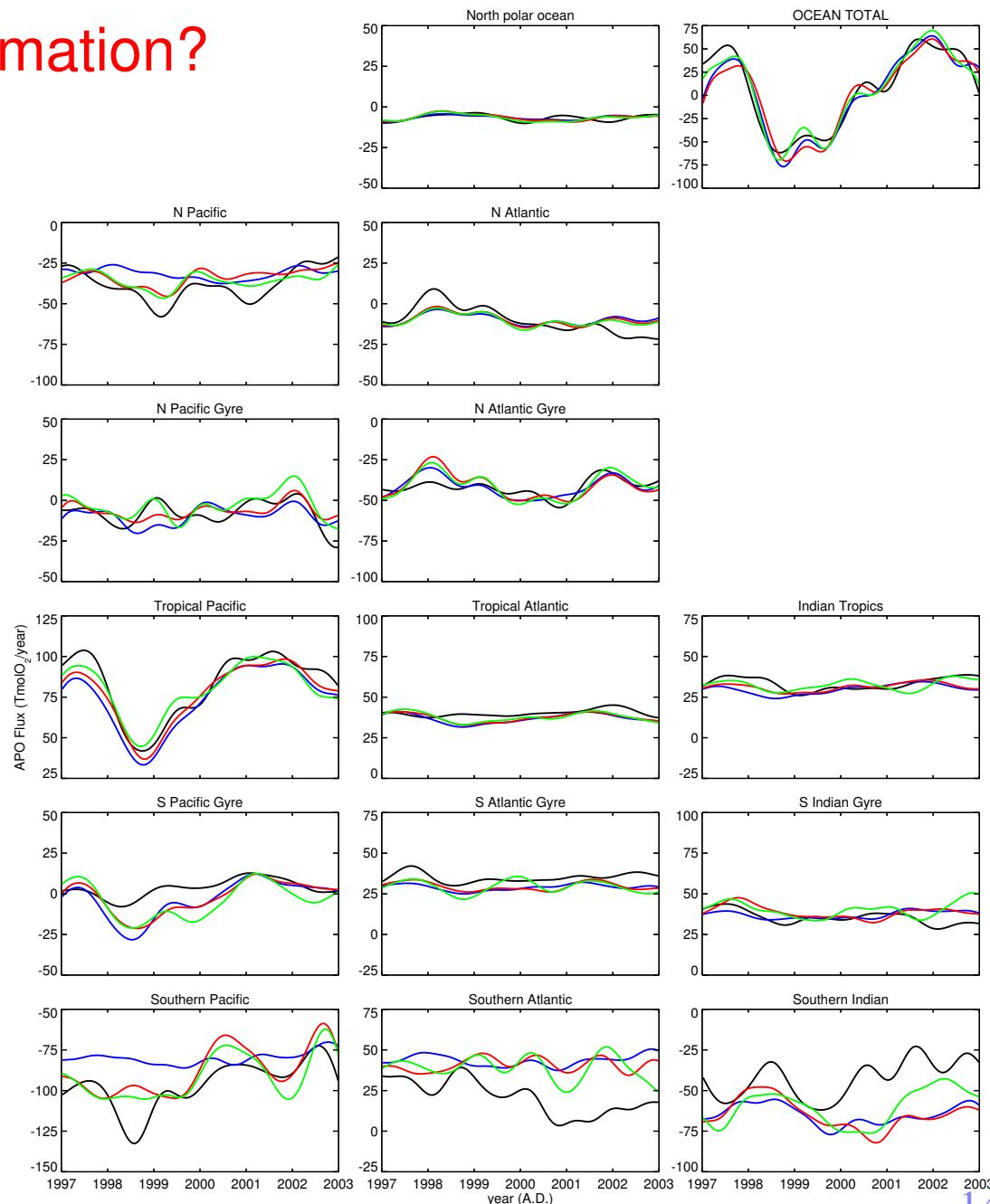
Do We Have Enough Information?

Inverting synthetic data
(at actual locations and times):

Retrieval of
"Known thruth"

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7 sites
16 sites

→ Finer regional split
poorly resolved
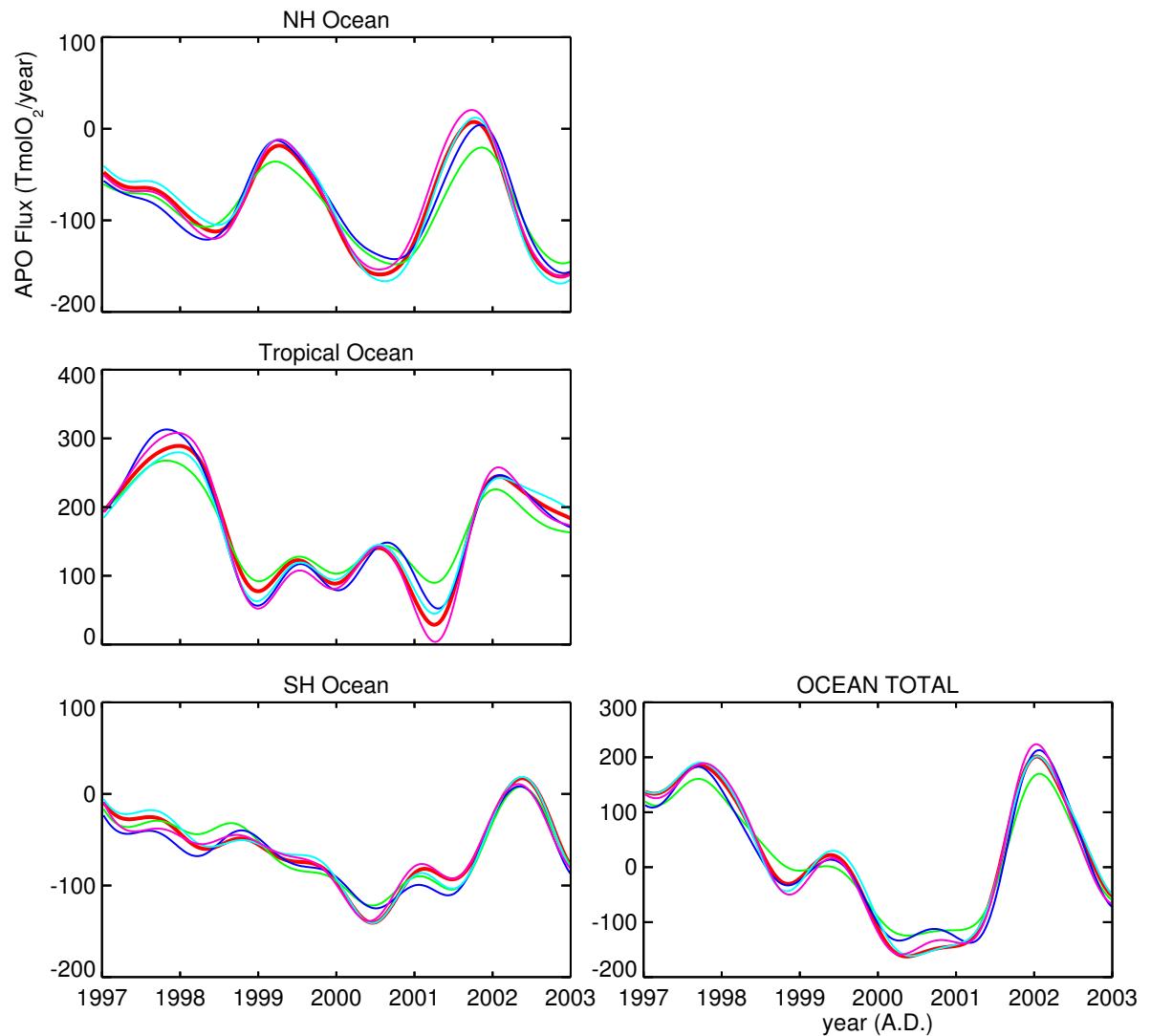
Robustness?

Varying a-priori assumptions:

- (Standard)
- Uncertainty
- Spatial correlations
- IAV spatial weighting
- Temporal correlations
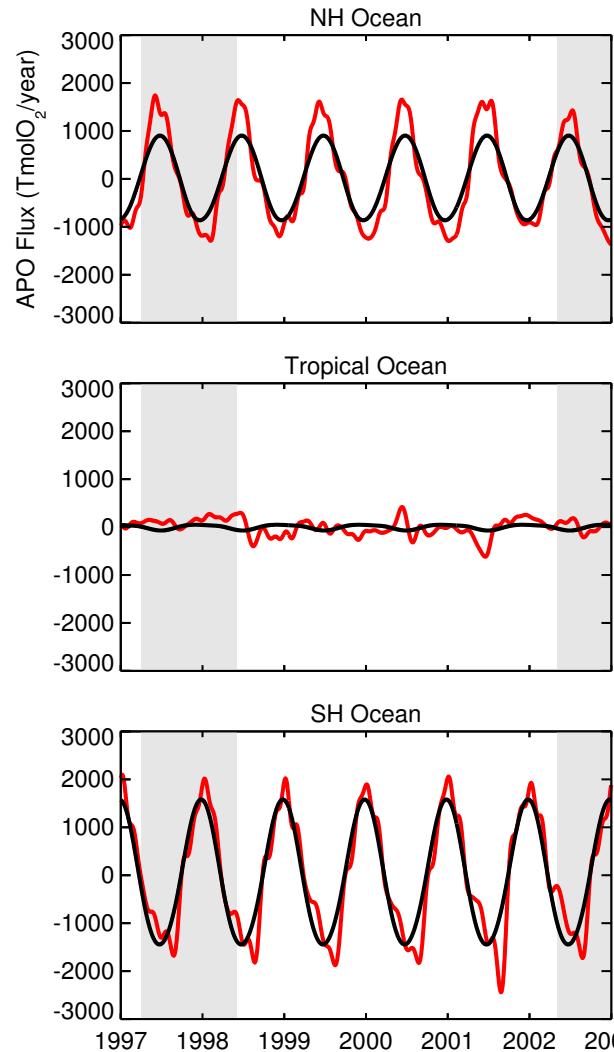
$\rightarrow$ Main patterns stable

Comparison to other data?
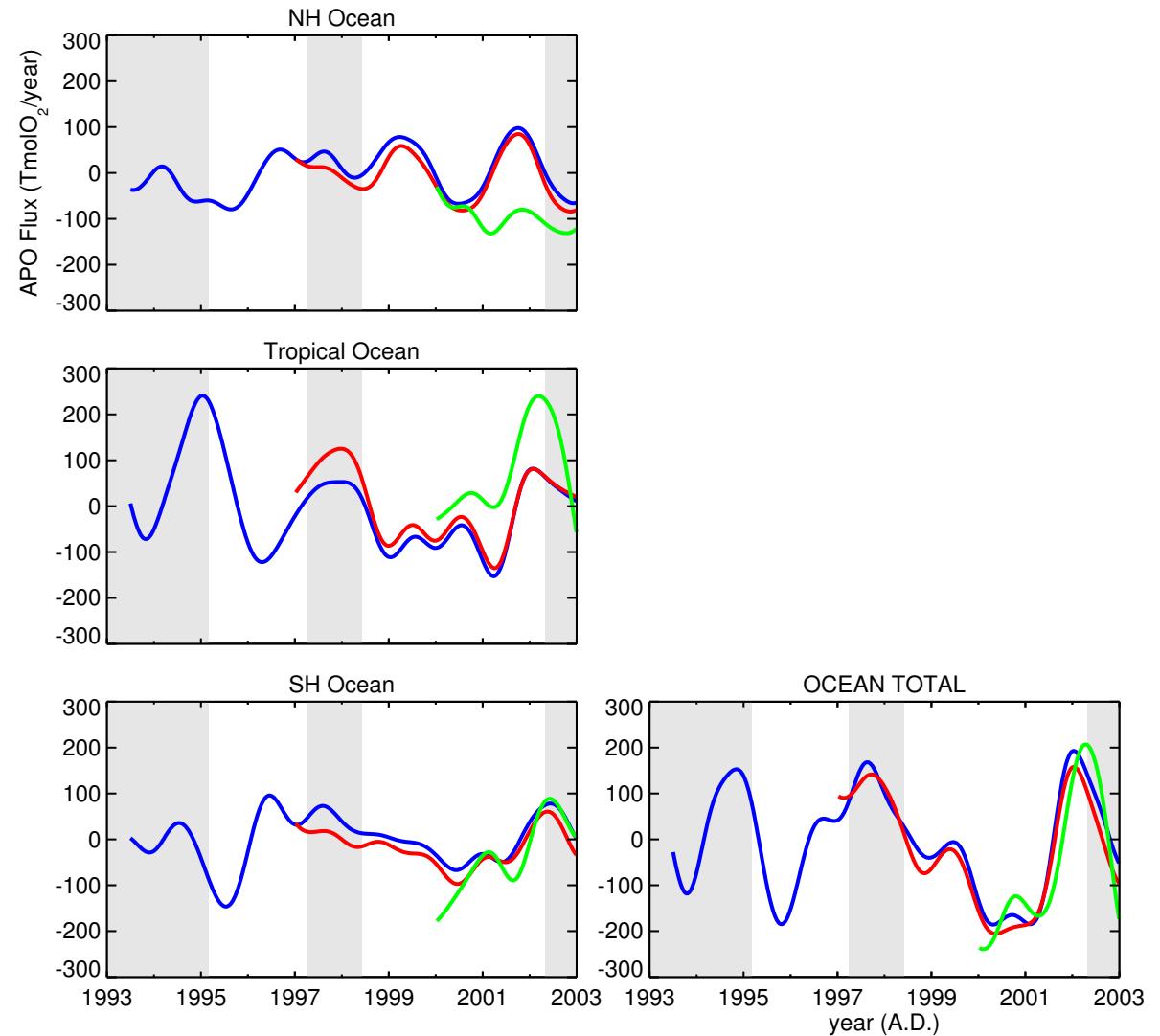
Seasonality:

- Phase agreement with
  $\triangle p O_2$-based fluxes

  [Garcia & Keeling (2001)]

- Similar amplitudes
  (but larger in Northern
 Extratropics)
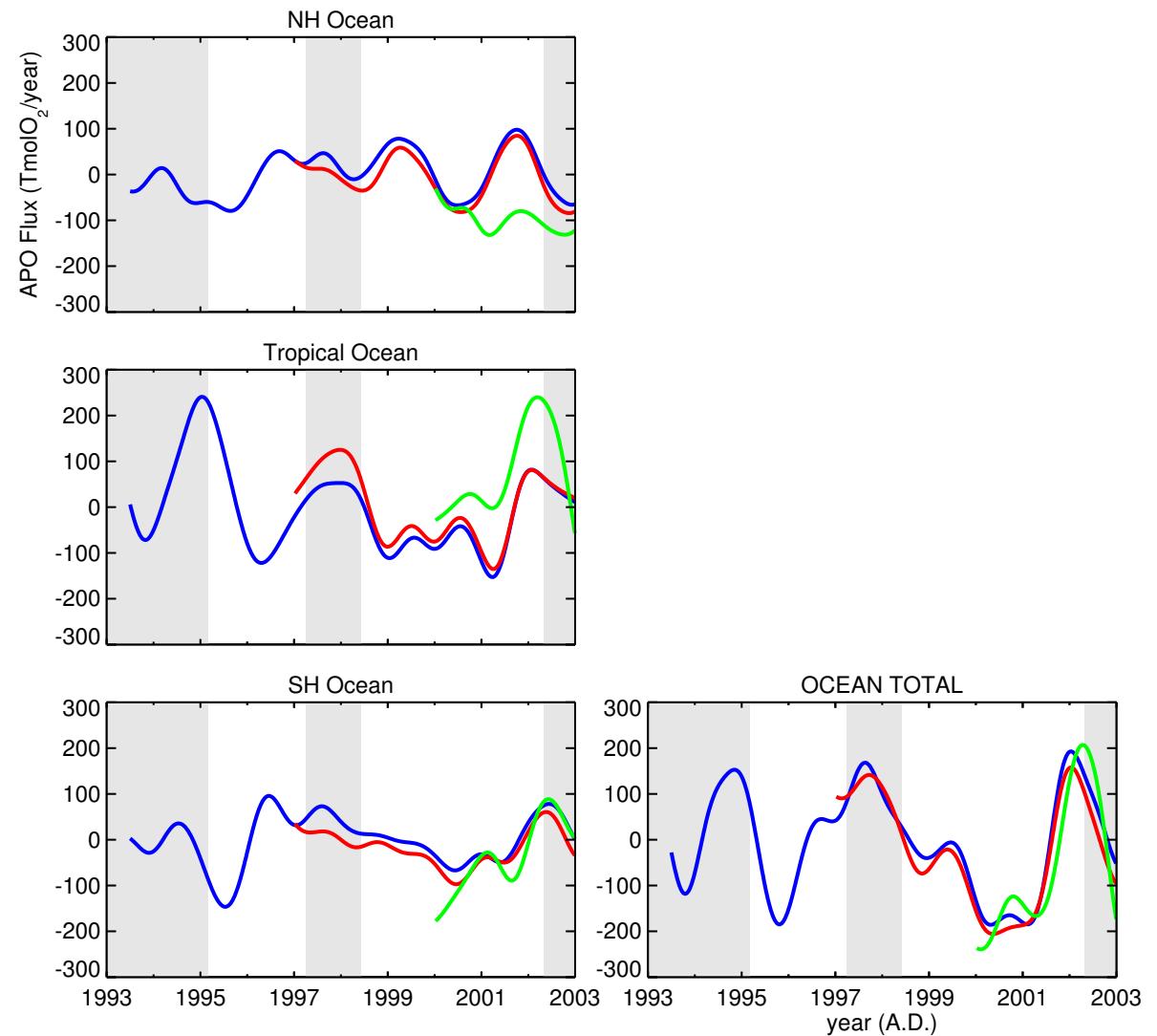
First Discussion

- Tropics: El Niño signal
 (Signal from *differences*)
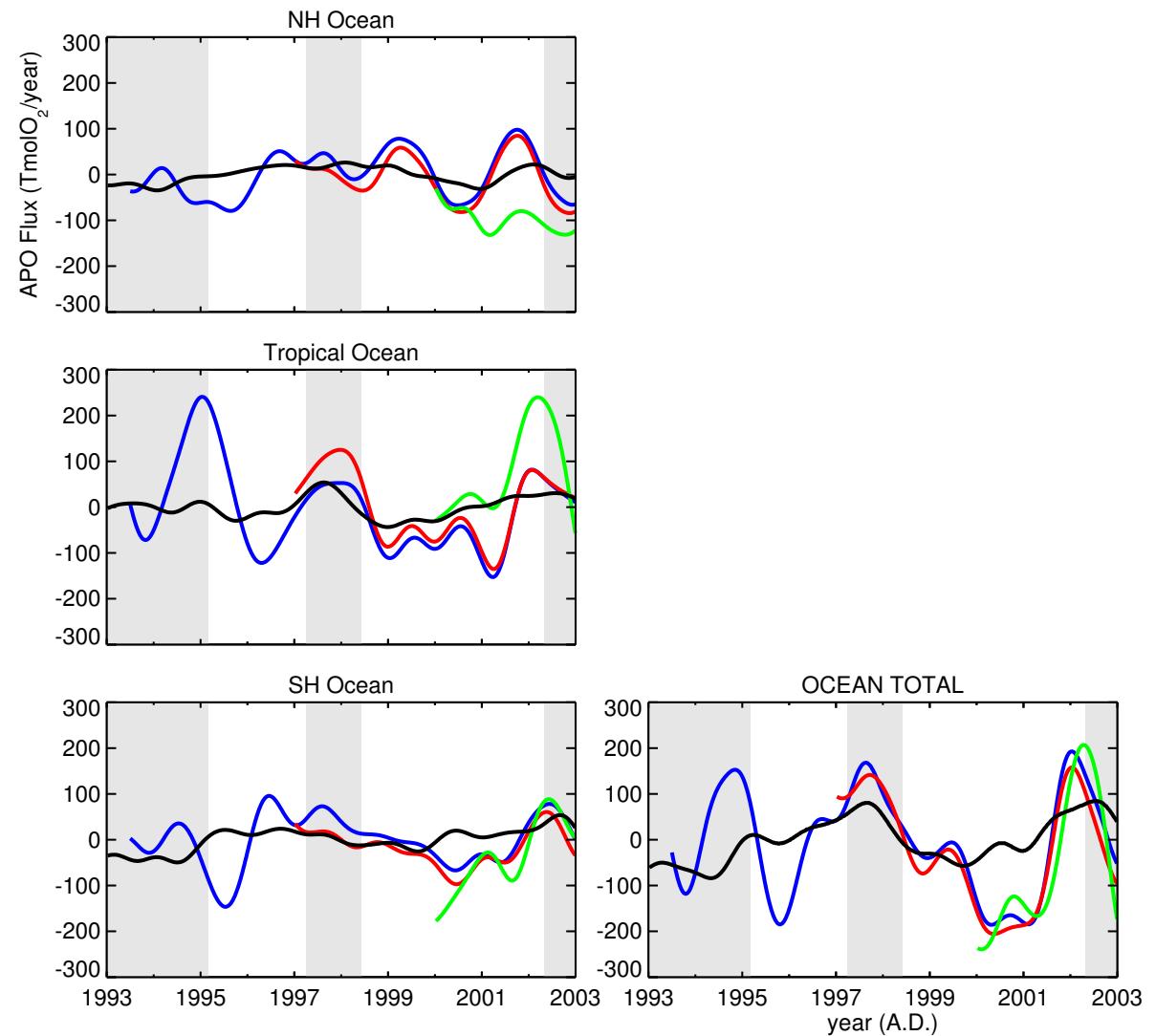
First Discussion

- Tropics: El Niño signal

- Important interann. variab. also in Extratropics
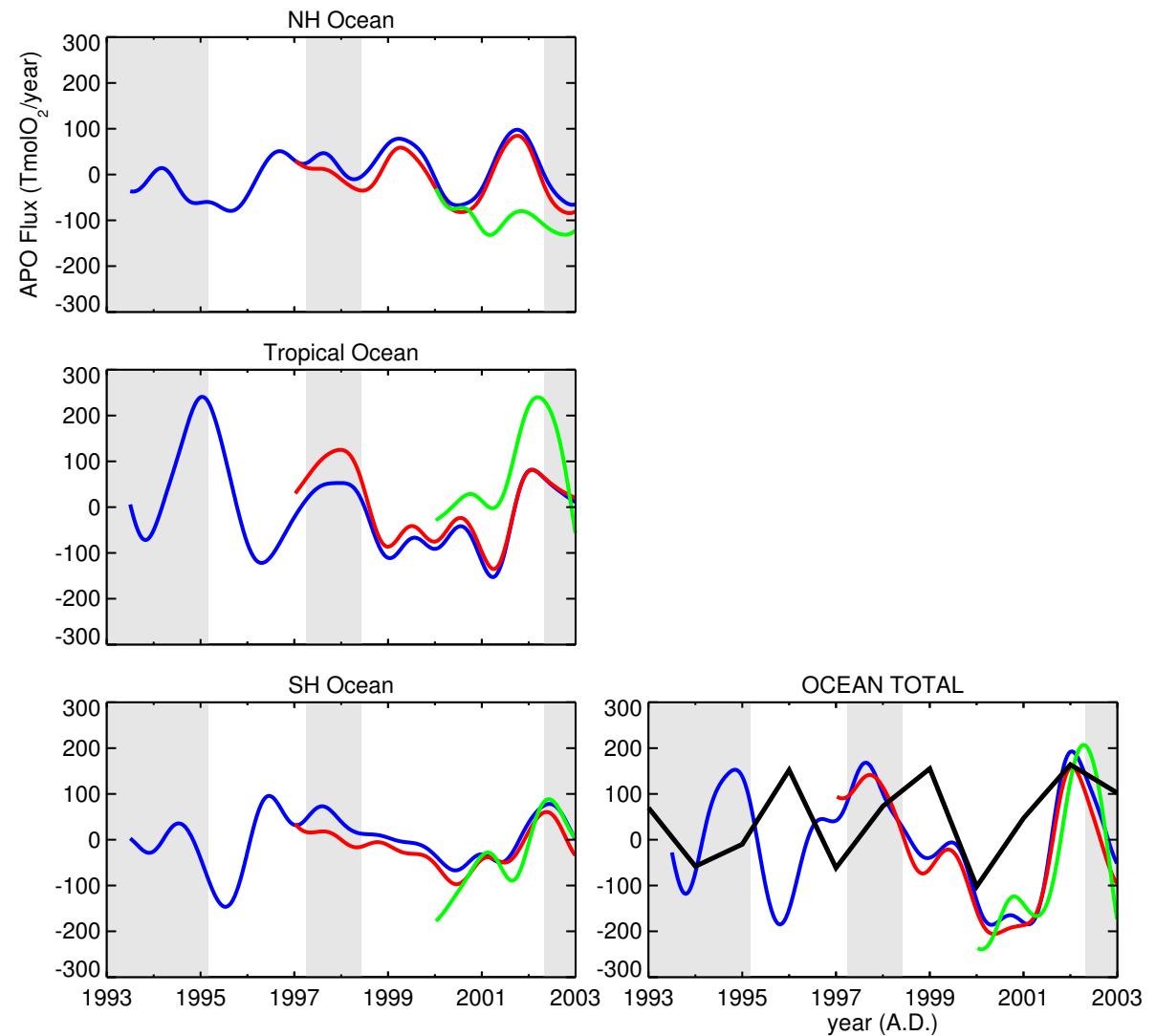
First Discussion

- Tropics: El Niño signal

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- Compare to ocean models:

  - Larger amplitudes
  - Little phase agreement

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  – Larger amplitudes

  – Little phase agreement

- Relation to heat flux?

  (change in heat content
  [Levitus et al., GRL 32 (2005)]
  assuming 6.1 nmolO$_2$/J)

  – Cannot use heat flux
    to calculate CO_2 budget
    on short ($\approx$5 year) time scale

Conclusion – Outlook

- **Interannual atmospheric inversion of APO:**

  At least 3 latitudinal bands resolved

- **Further research questions:**

  – Quantifying climate impacts on oxygen signal
    - $\rightarrow$ O_2-based oceanic carbon budgets?
  – Climatic trends
    - $\rightarrow$ increasing ocean stratification?
  – Quantifying air-sea gas exchange
  – Improving CO_2 inversions by oxygen constraint