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Seasonal and Interannual Variations in the Dissolved Oxygen Budget of an Urbanized Tidal River: The Upper Delaware Estuary

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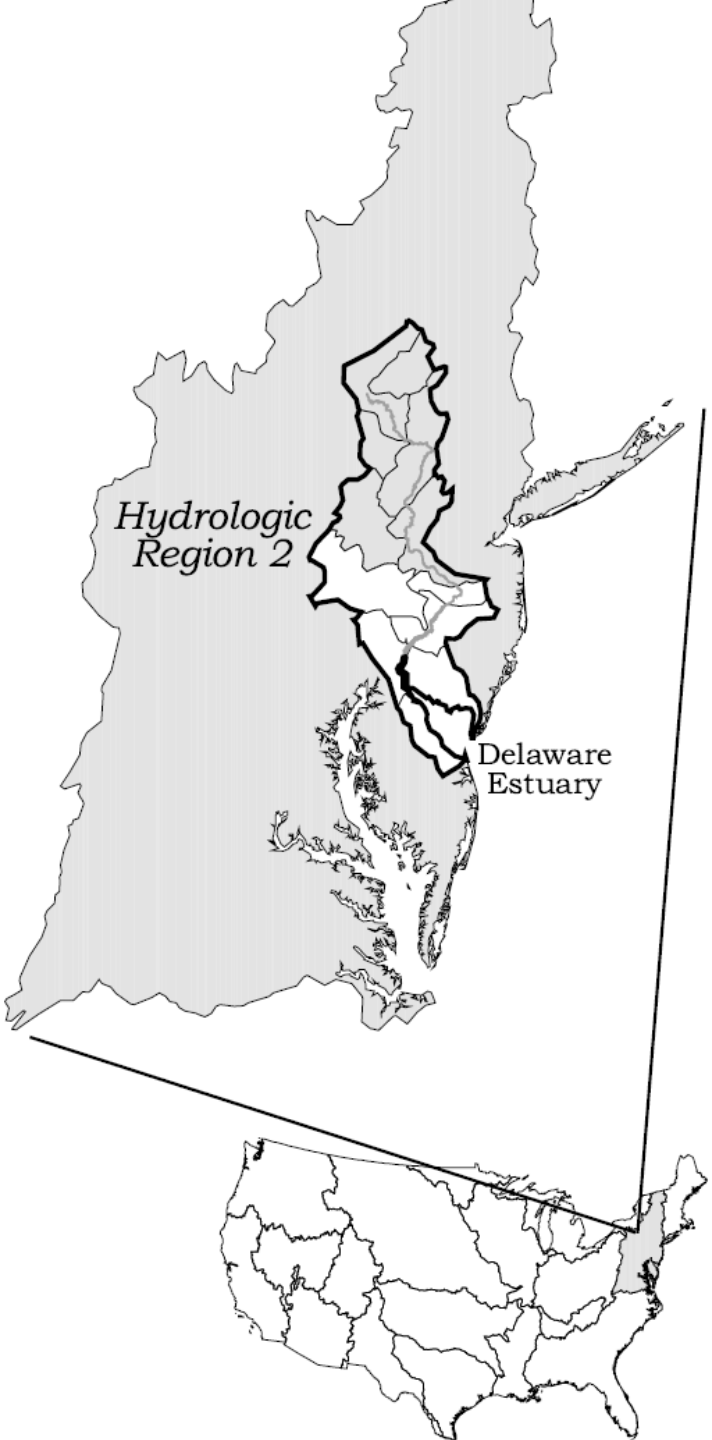
- Delaware River Watershed & Estuary. Image source: USEPA (2000).



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Delaware River Watershed

- Supplies 5% of United States drinking water (Sharp, 2009)
- History of water quality issues including hypoxic & anoxic conditions 1940-1960.
- Home to industry & shipping, but also natural habitat for American shad, striped bass, white perch, sturgeon, oysters, and blue crab.
  - Need oxygen to survive!

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Delaware River Watershed

- Clean Water Act of 1972 and subsequent amendments facilitated change in water quality for the region.
- Low summer dissolved oxygen concentrations began to increase.
  - More recent trends still show some low episodes.

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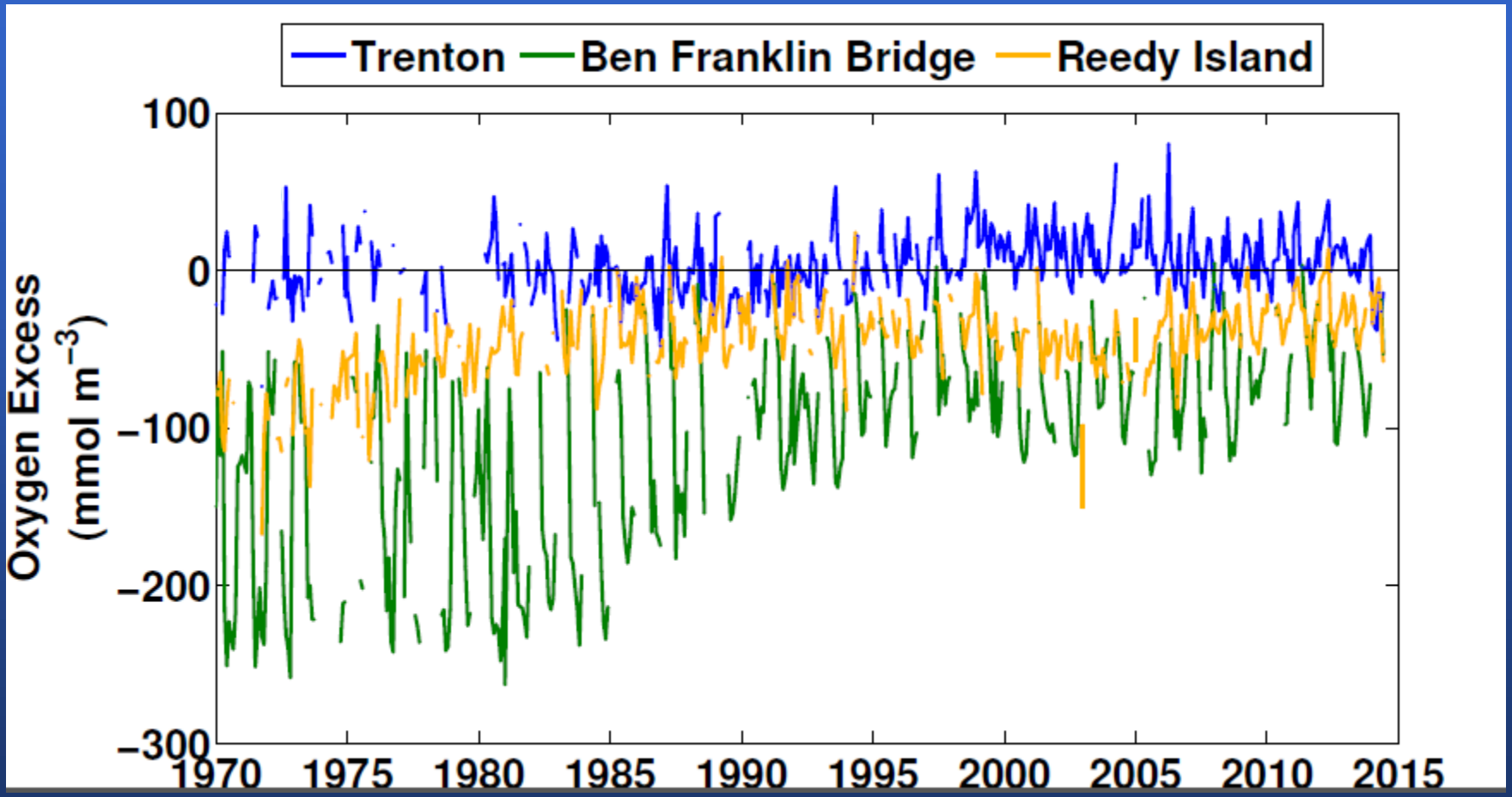
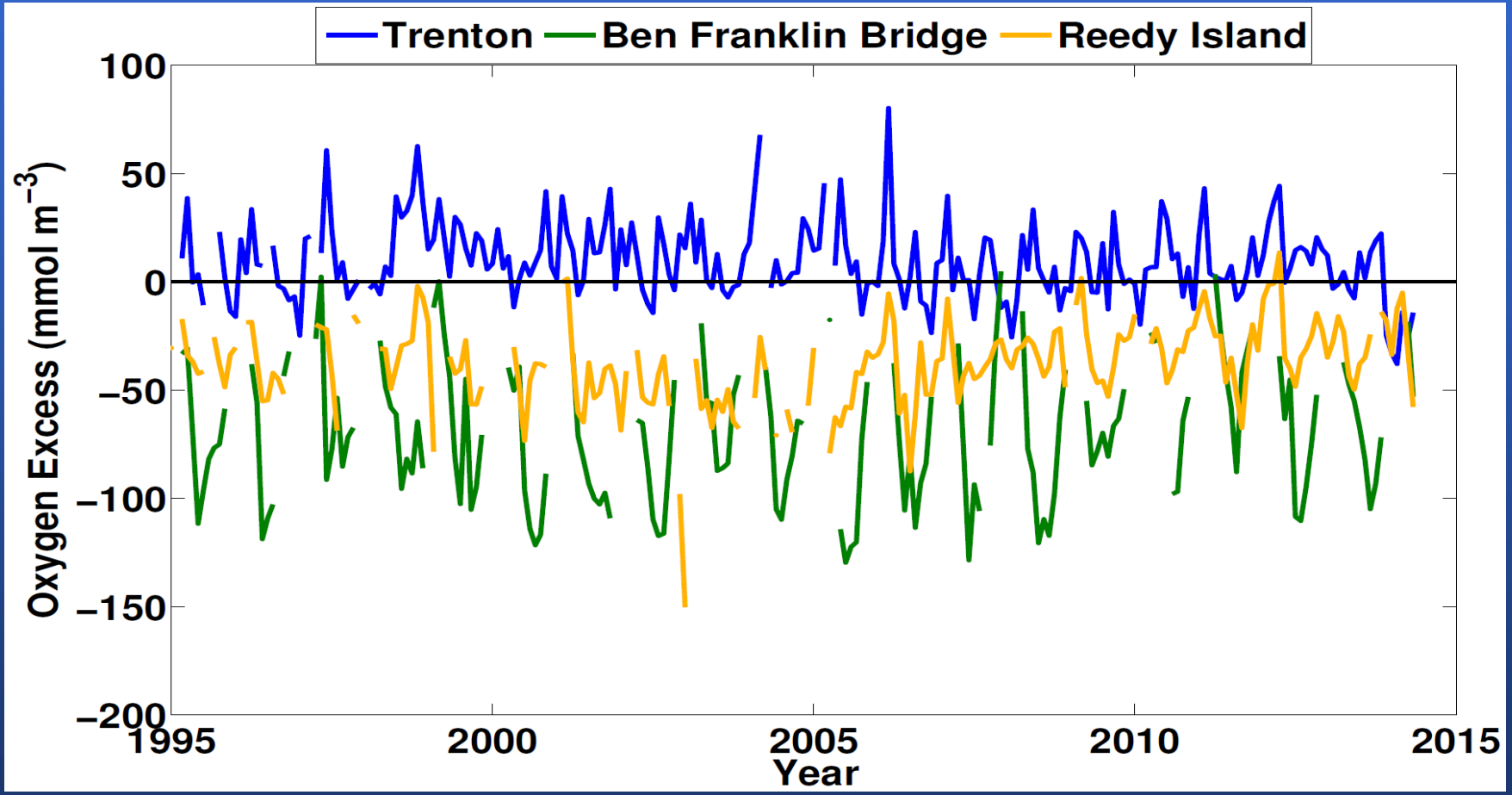


- Oxygen excess: $\Delta O_2 = [O_2] - [O_2]_{sat}$
- $[O_2]_{sat} = f(T,S)$



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Method

- Develop a dissolved oxygen (D.O.) budget based on long-term monitoring of D.O., temperature, and salinity data along the Delaware Estuary.
- Use the budget to study spatial and temporal trends in D.O.
- Divide Delaware Estuary into 2 boxes:
  - Box 1: Trenton to Ben Franklin Bridge
  - Box 2: Ben Franklin Bridge to Reedy Island

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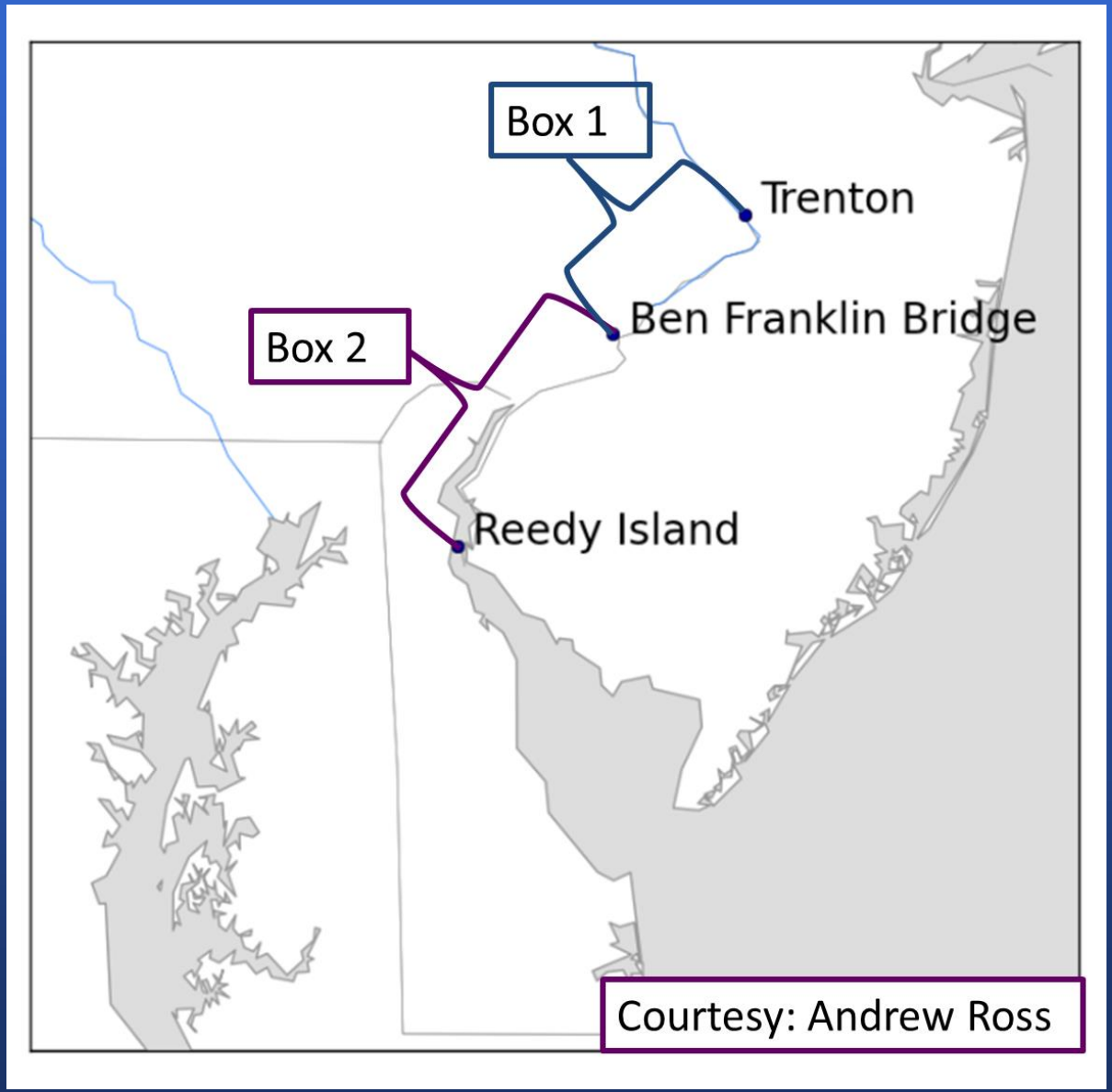
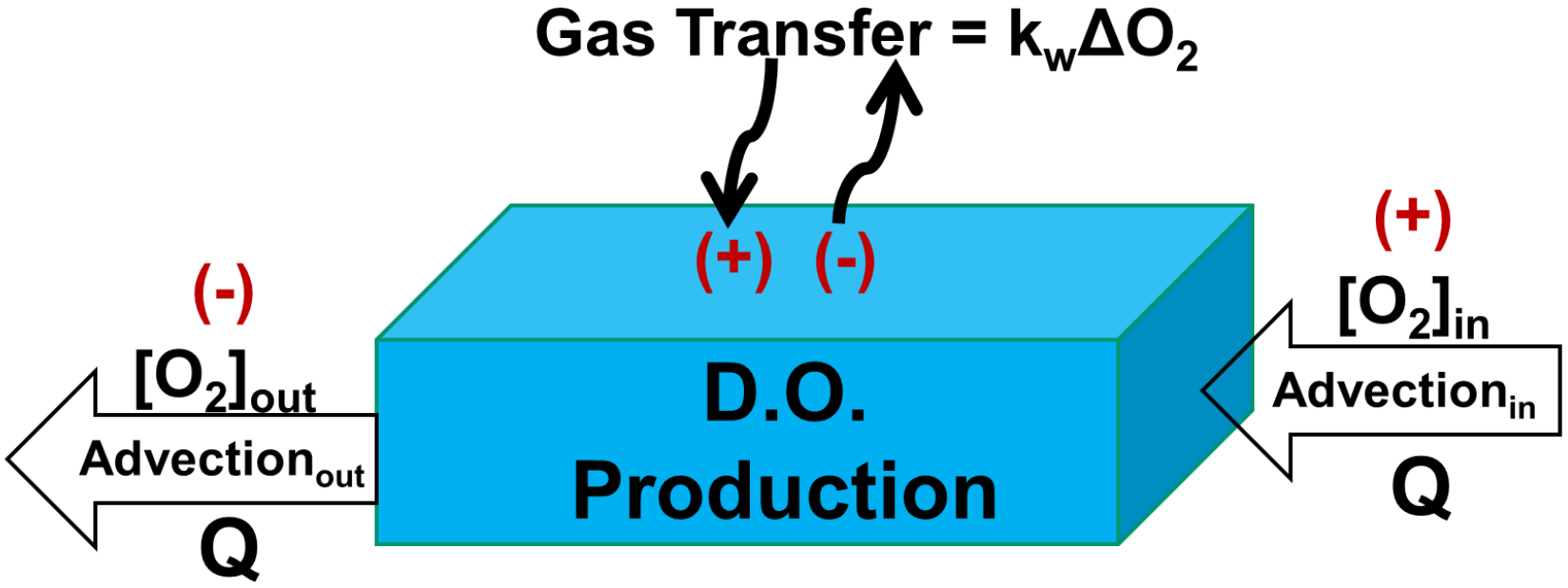

Box 1
Trenton
Ben Franklin Bridge
Box 2
Reedy Island
Courtesy: Andrew Ross



O_2 Change = O_2 Production + Gas Transfer + Advection

$$V\frac{\partial[O_2]}{\partial t} = \boldsymbol{J^{O_2}V} - k_w\Delta[O_2]A + Q\{[O_2]_{in} - [O_2]_{out}\}$$

***Note: Tidal diffusion is ignored based on estimates.**

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Research Questions

- Which budget term(s) are dominant in Box 1 and Box 2?
- How do the budget terms vary with time?
- What is the metabolic state of the Upper Delaware Estuary and what environmental factors regulate biological rates?

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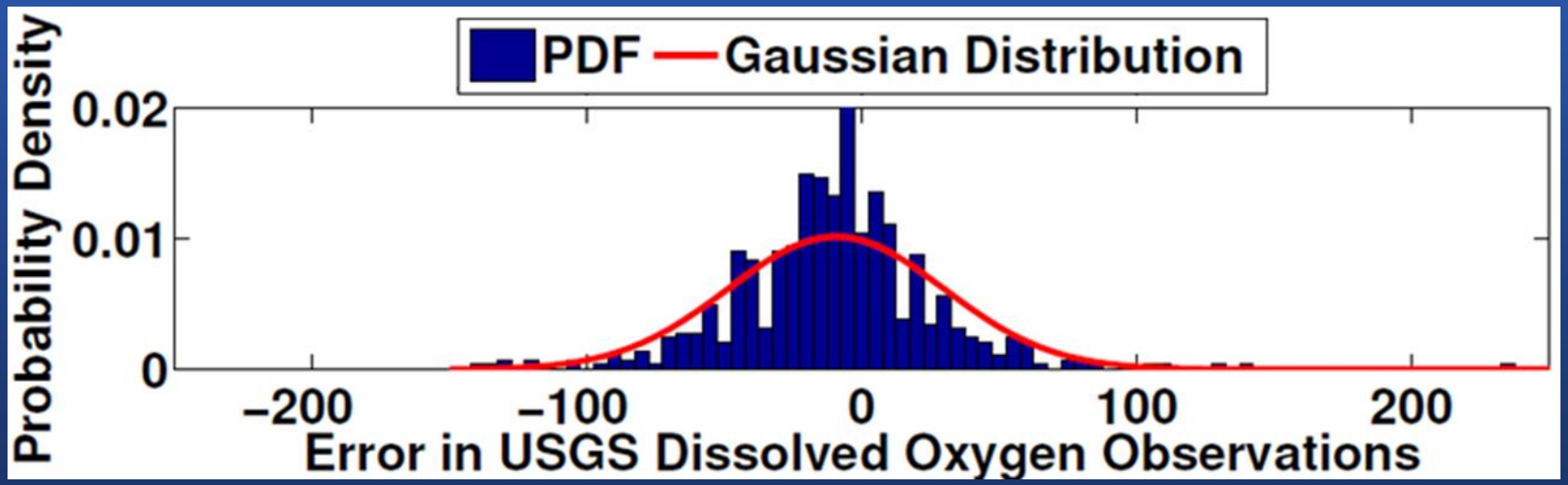
Analysis of USGS Observations

- USGS daily data were checked for errors by comparing with cruise data from Sharp, 2009



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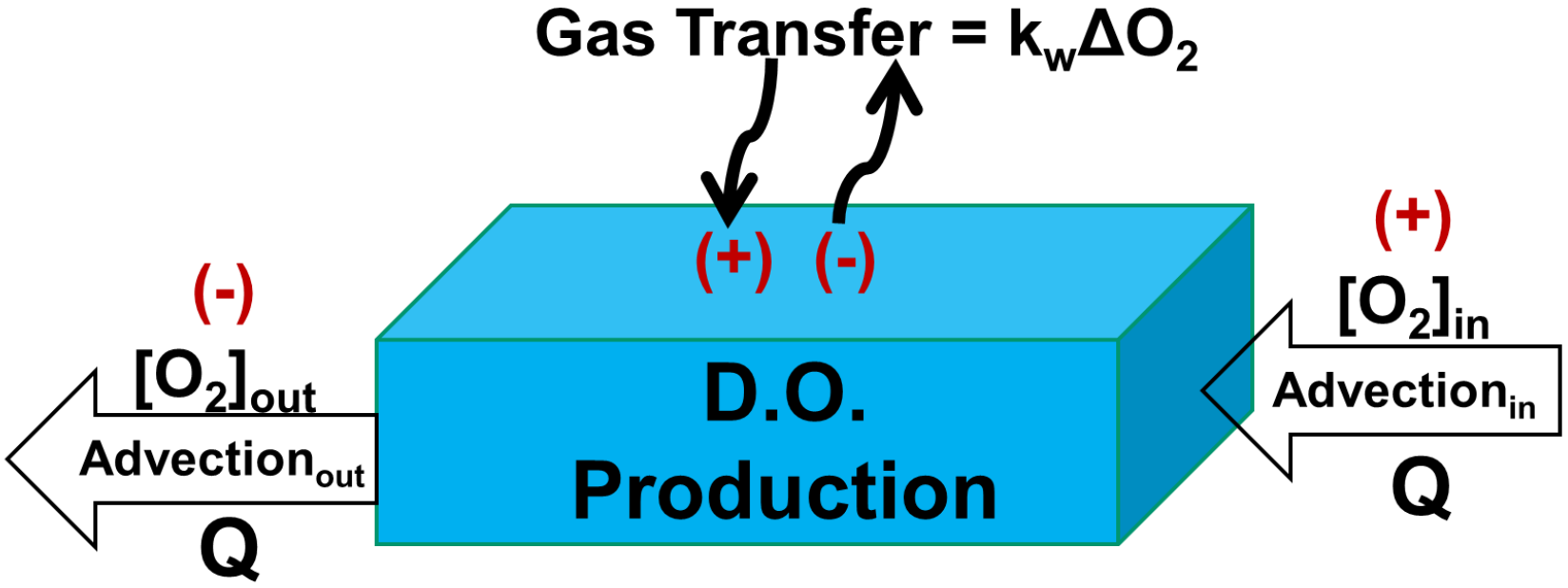

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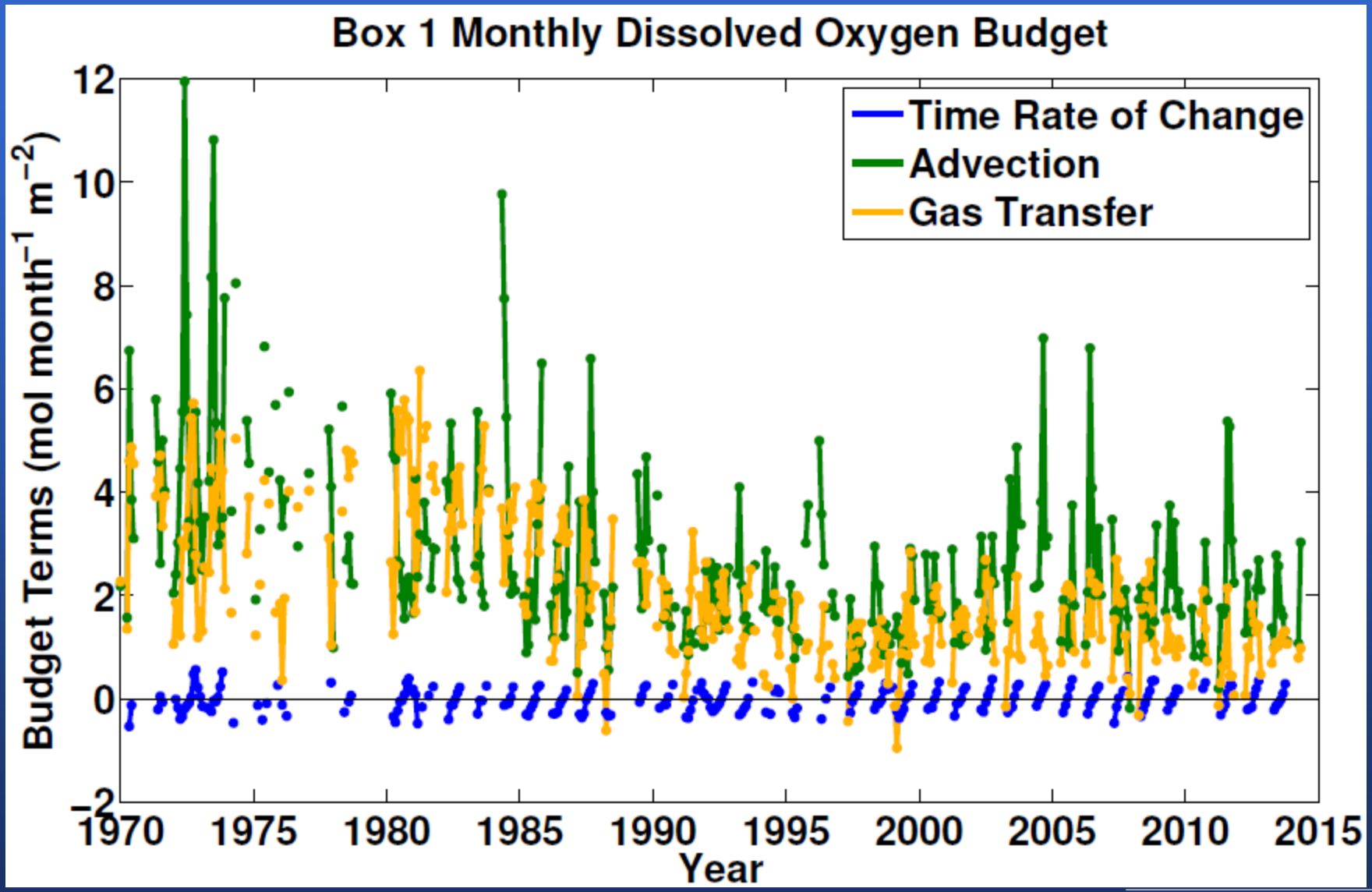
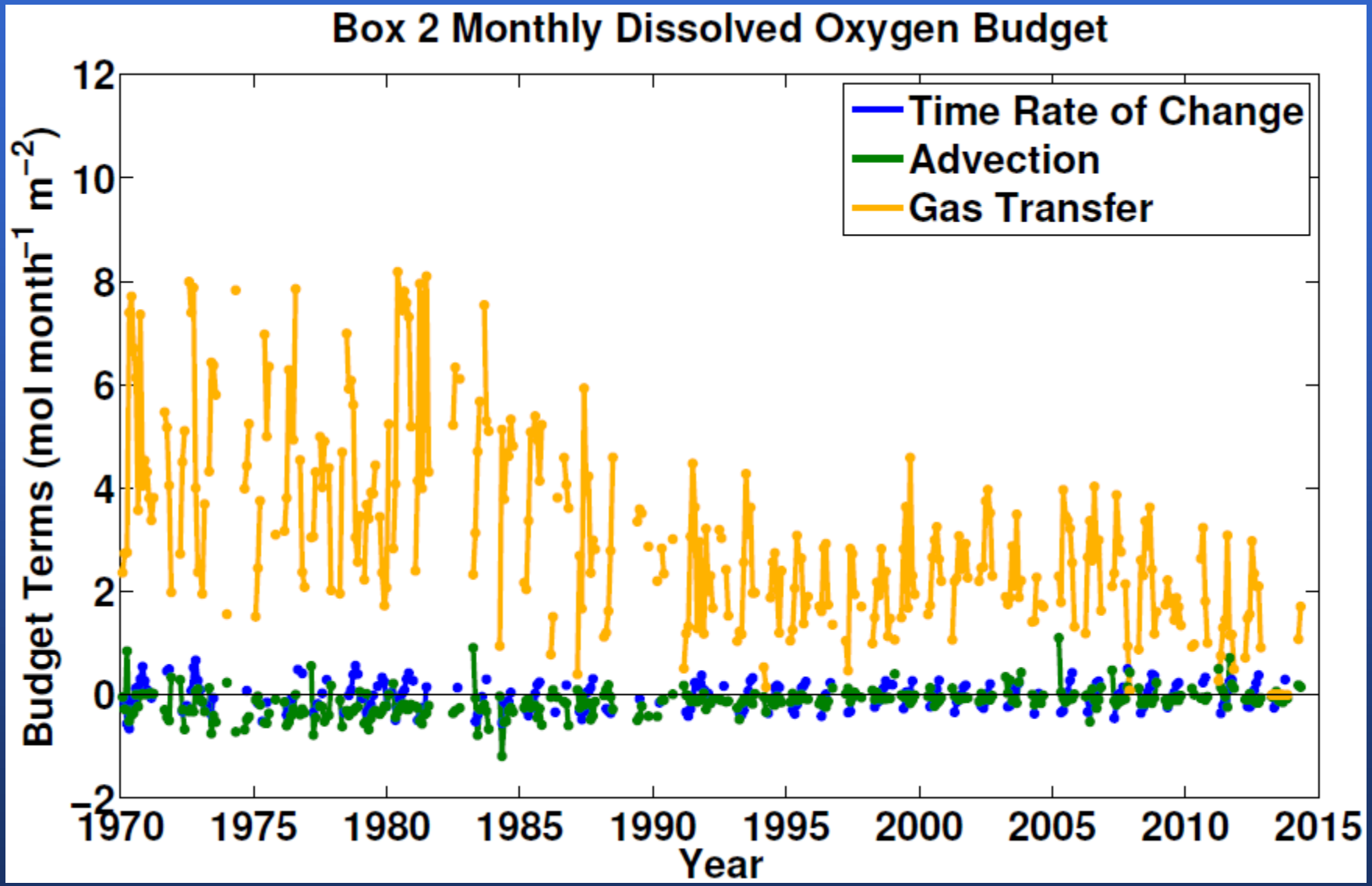
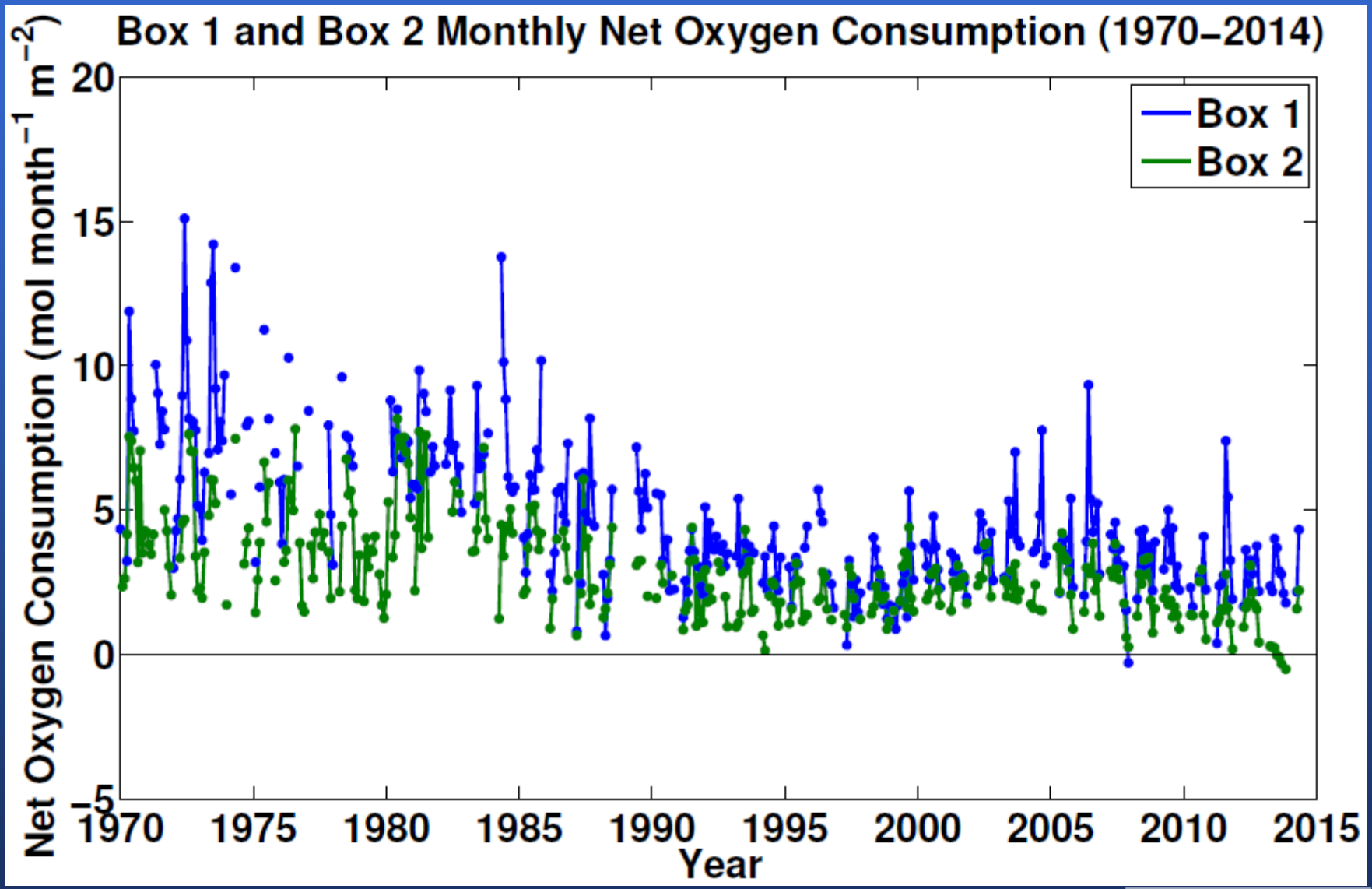

Box 1 Monthly Dissolved Oxygen Budget
Time Rate of Change
Advection
Gas Transfer
Budget Terms (mol month^{-1} m^{-2})
12
10
8
6
4
2
0
−2
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year


Box 2 Monthly Dissolved Oxygen Budget
Time Rate of Change
Advection
Gas Transfer
Budget Terms (mol month^{-1} m^{-2})
12
10
8
6
4
2
0
-2
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year


Box 1 and Box 2 Monthly Net Oxygen Consumption (1970–2014)
Net Oxygen Consumption (mol month^{-1} m^{-2})
Year
Box 1
Box 2
20
15
10
5
0
−5
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

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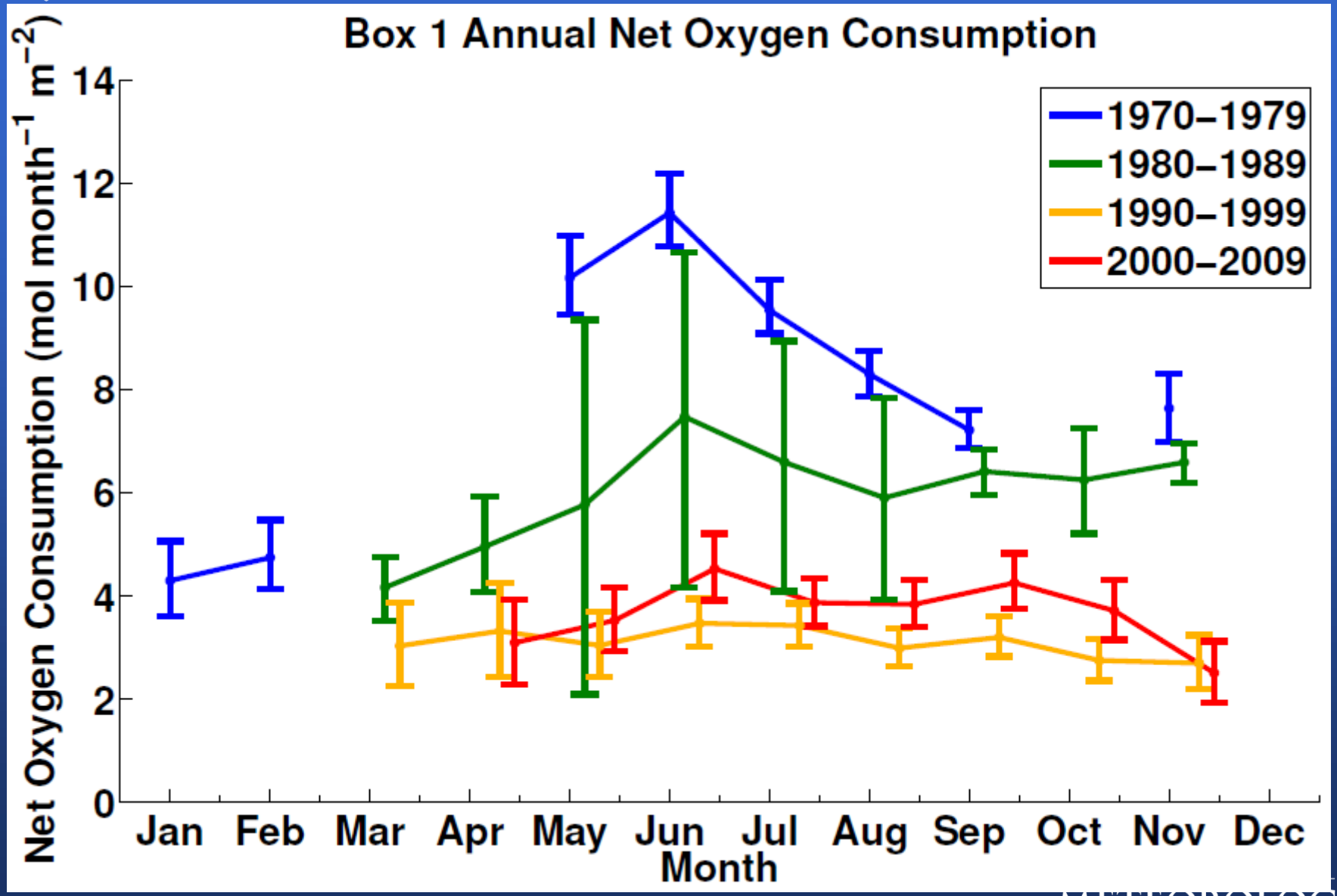

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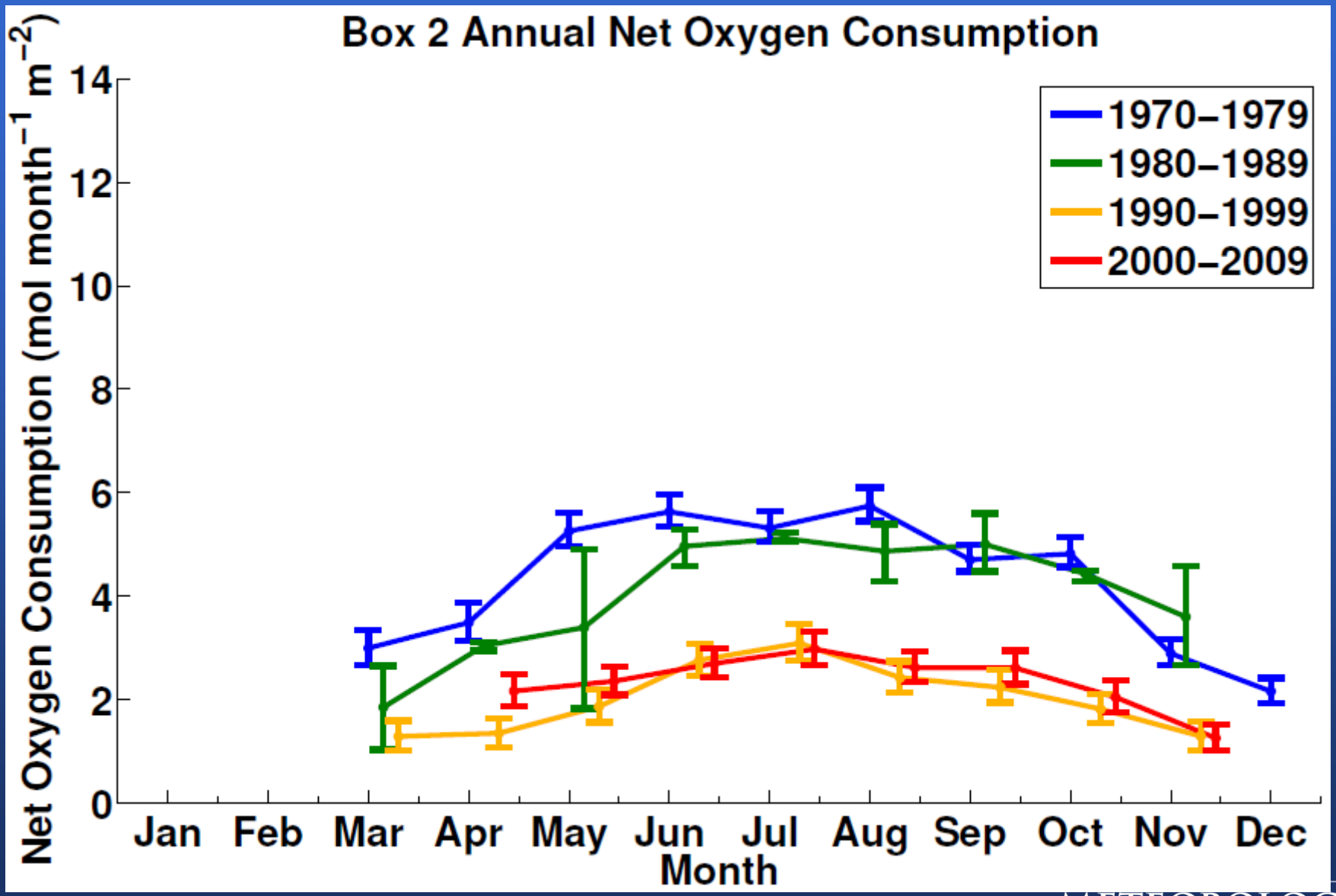
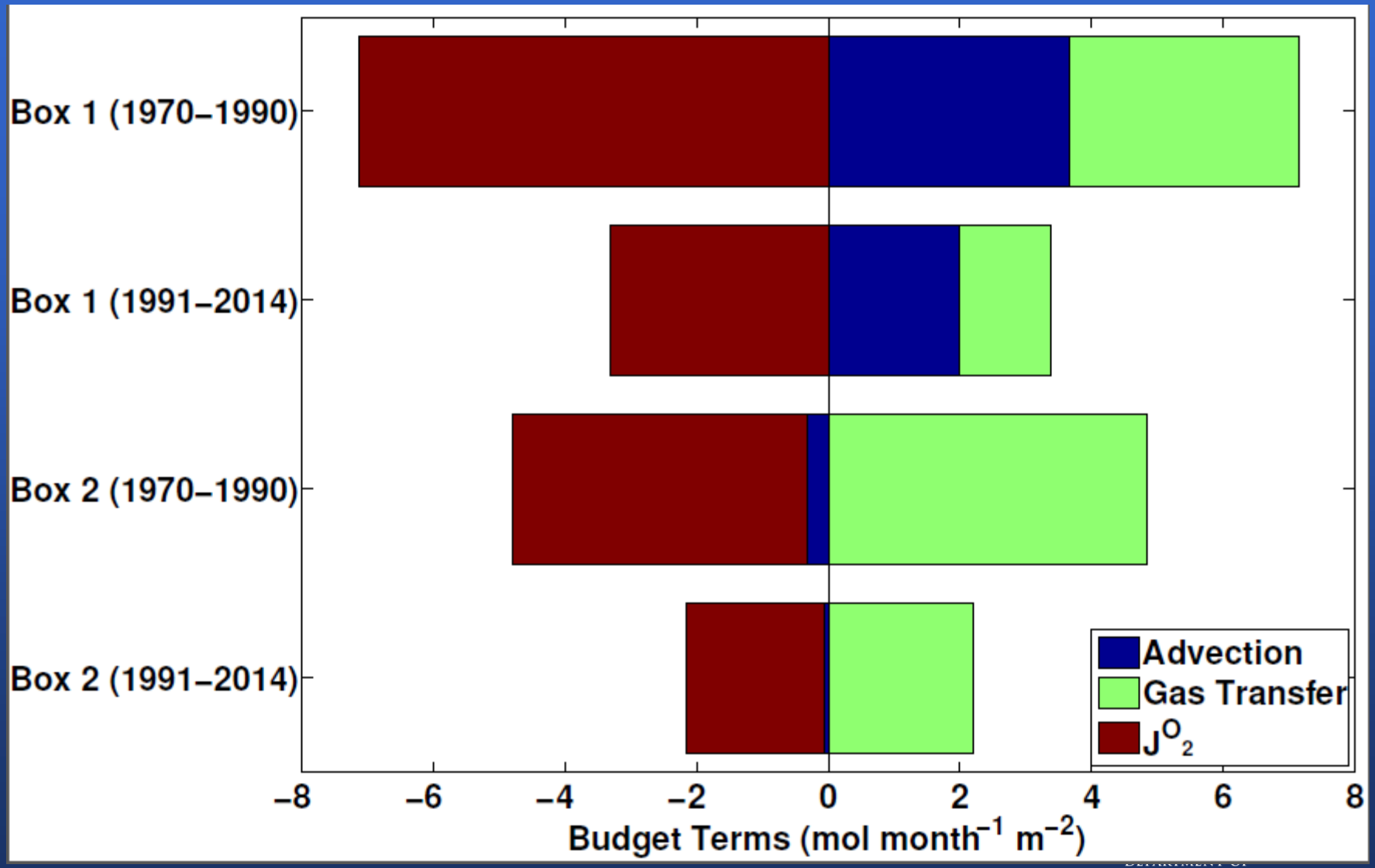

Box 2 Annual Net Oxygen Consumption
Net Oxygen Consumption (mol month^{-1} m^{-2})
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
1970–1979
1980–1989
1990–1999
2000–2009


Box 1 (1970–1990)
Box 1 (1991–2014)
Box 2 (1970–1990)
Box 2 (1991–2014)
Advection
Gas Transfer
J^{O}_{2}
−8
−6
−4
−2
0
2
4
6
8
Budget Terms (mol month^{-1} m^{-2})

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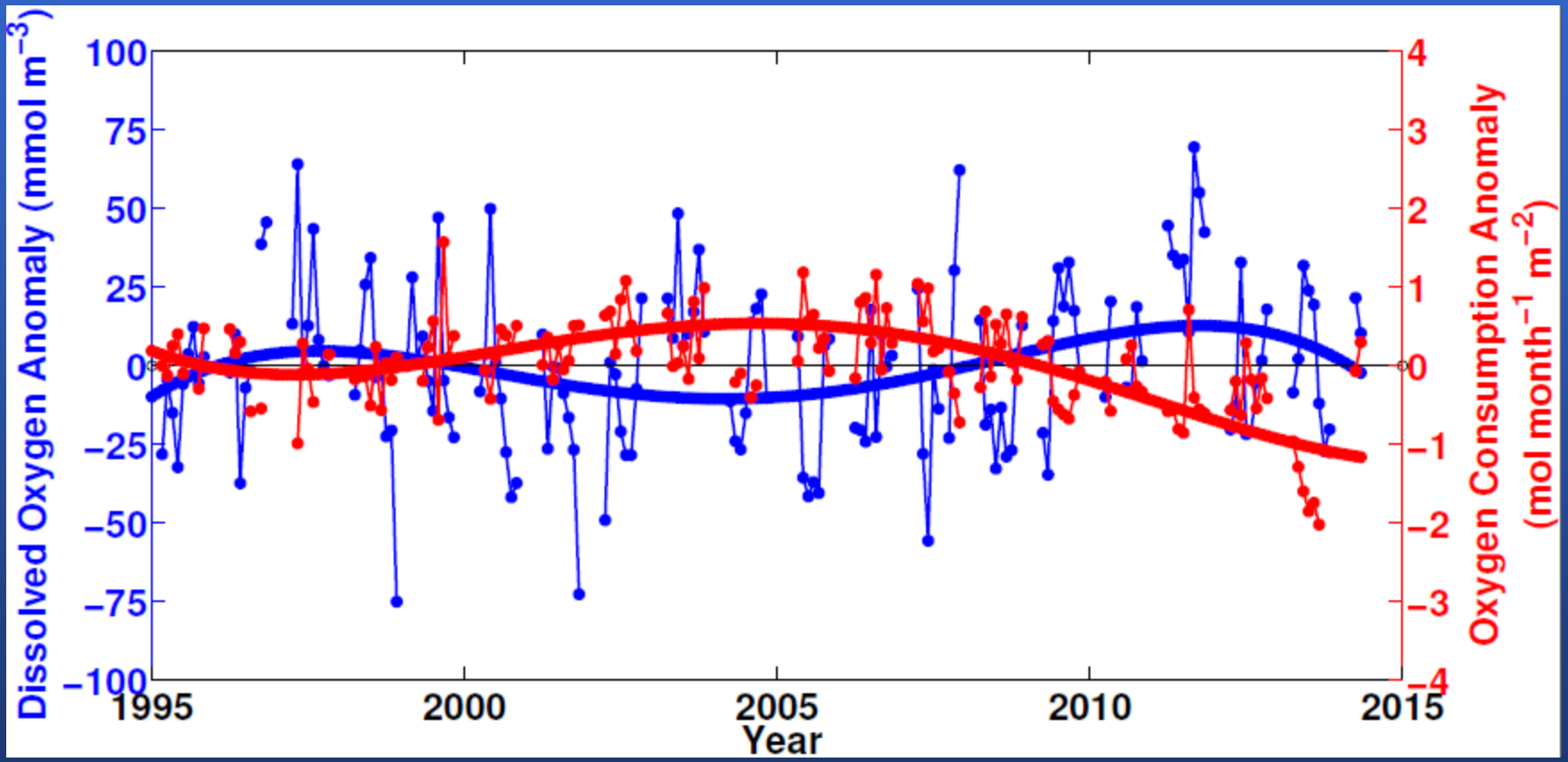

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Trends in Respiration

- Area averaged primary production (P) data from Sharp (2009) was used to calculate respiration (R) using $R = P - J^{O_2}$
- An index of the degree of heterotrophy is the ratio $R{:}P$. This ratio ranges from approximately 2-4 in the summer months to values greater than 10 in March and November.

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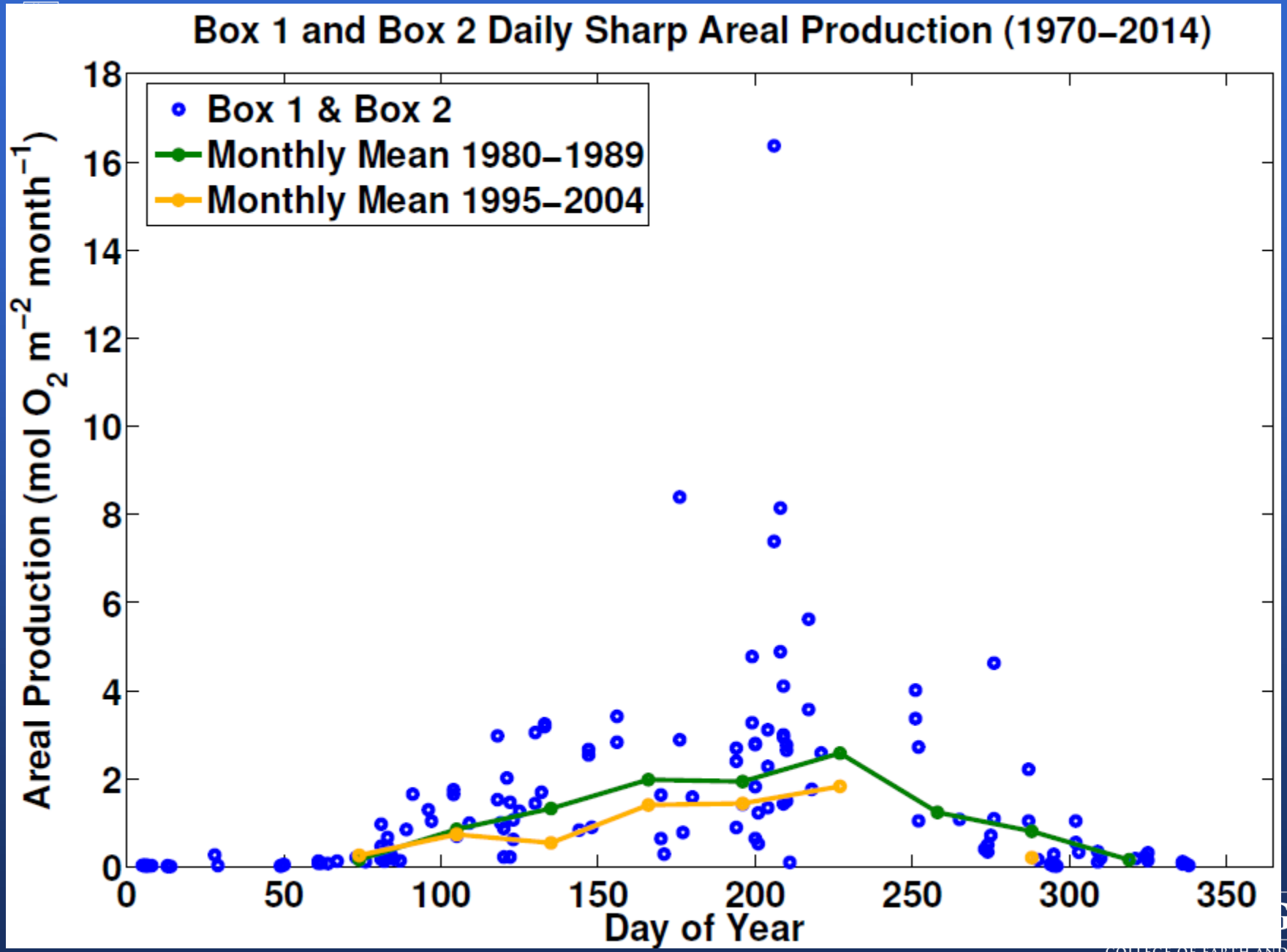
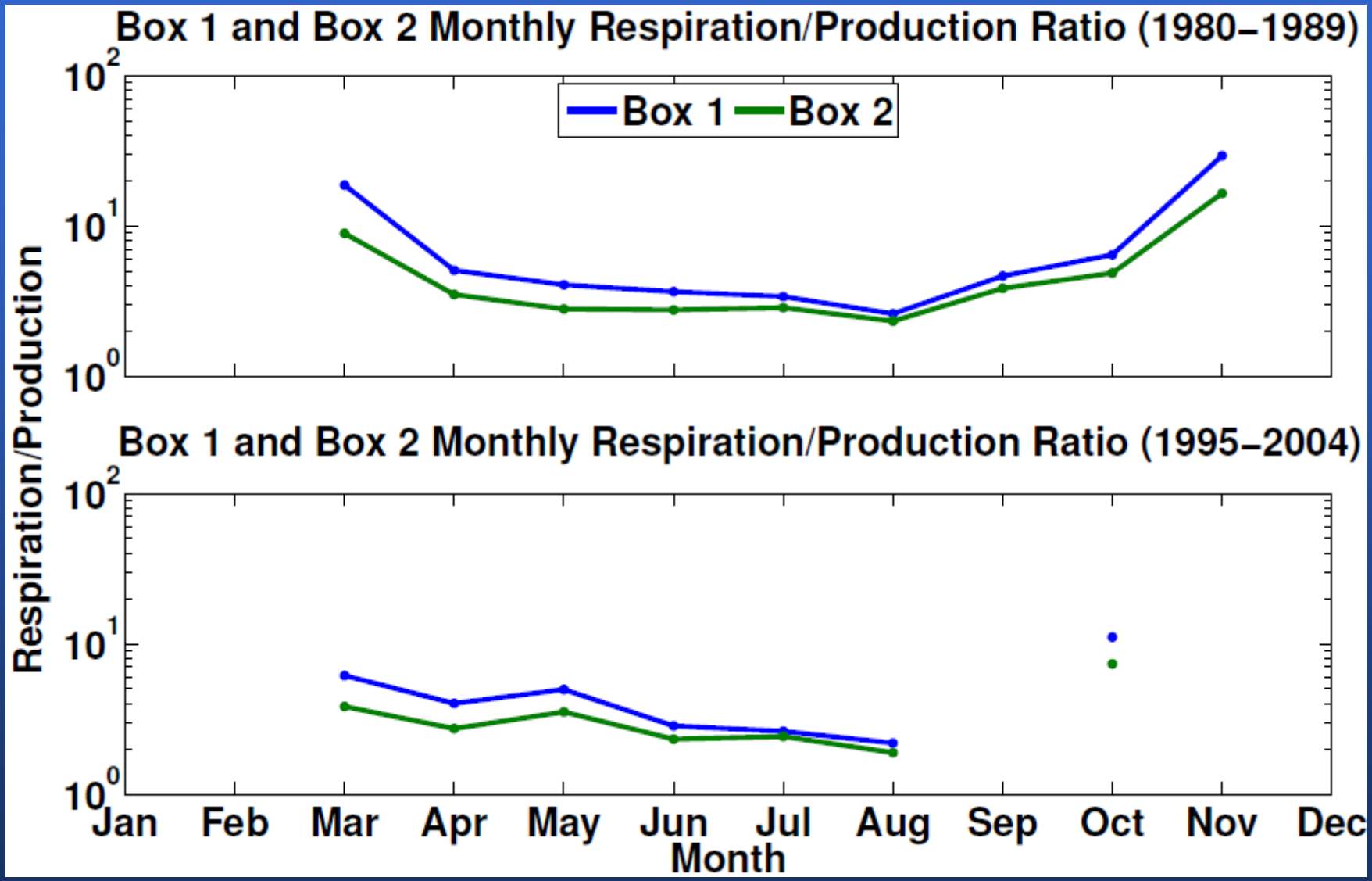
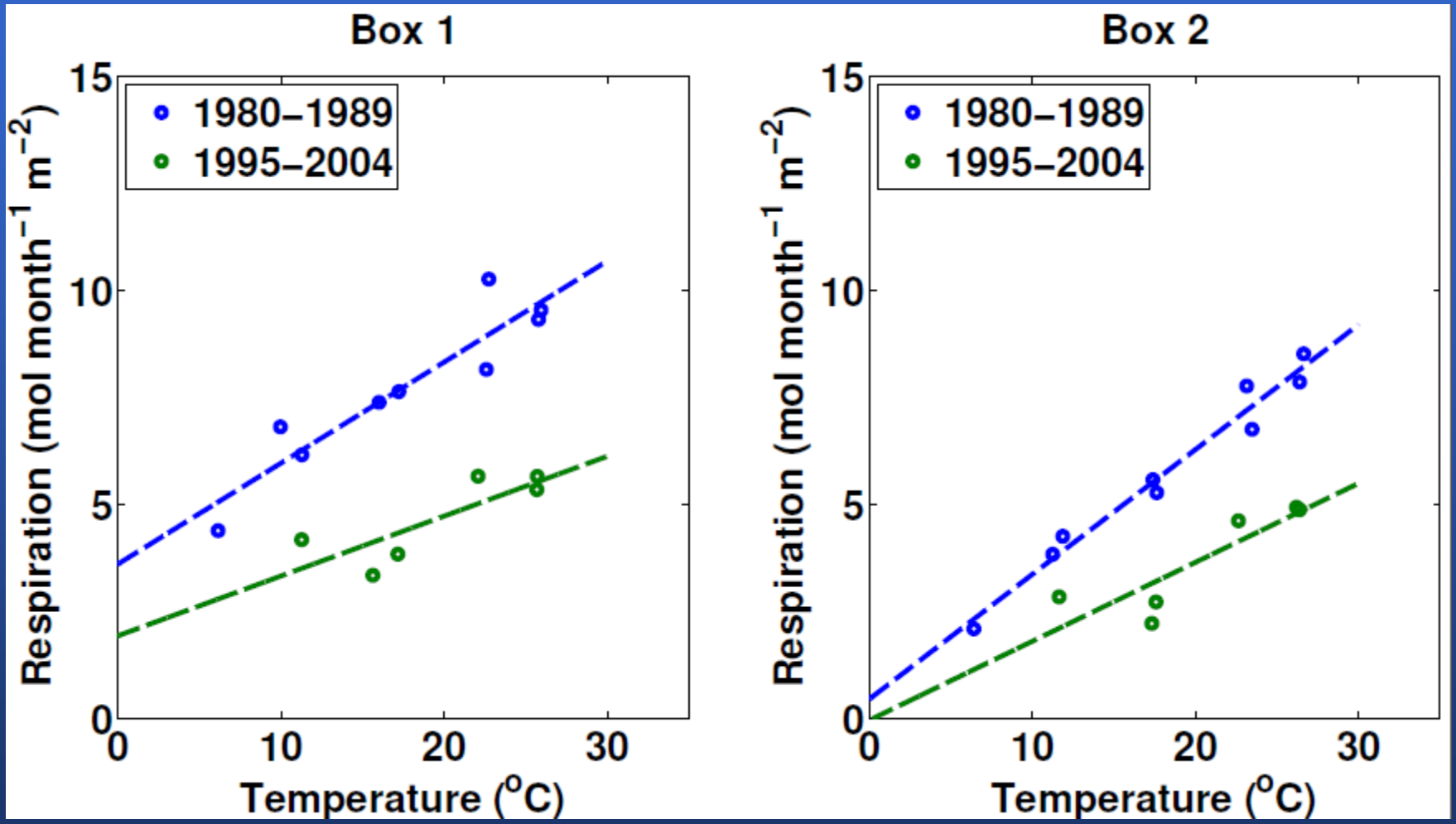

Box 1 and Box 2 Daily Sharp Areal Production (1970–2014)
Box 1 & Box 2
Monthly Mean 1980–1989
Monthly Mean 1995–2004
Areal Production (mol O_2 m^{-2} $month^{-1}$)
Day of Year
0
2
4
6
8
10
12
14
16
18
0
50
100
150
200
250
300
350


Box 1 and Box 2 Monthly Respiration/Production Ratio (1980–1989)
Box 1
Box 2
Box 1 and Box 2 Monthly Respiration/Production Ratio (1995–2004)
Respiration/Production
10^2
10^1
10^0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


Box 1
Box 2
1980–1989
1995–2004
Respiration (mol month^{-1} m^{-2})
Temperature (^{o}C)
0
5
10
15
0
10
20
30

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Conclusion

- Net oxygen production is negative (i.e., region is characterized by net oxygen consumption or net heterotrophy).
- Gas transfer and advection are dominant budget terms in Box 1
- Gas transfer is the dominant budget term in Box 2
- Net consumption is highest in summer for both boxes.
- Oxygen consumption has an overall decreasing trend since 1970 & D.O. levels rose in response.

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Current/Future Work

- Analysis of alkalinity and pH trends in the upper Delaware Estuary, the Chesapeake Bay, and the tributaries of the Chesapeake Bay
- Prognostic approach to dissolved oxygen model. Understand changes in advection, gas transfer, and biology.

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