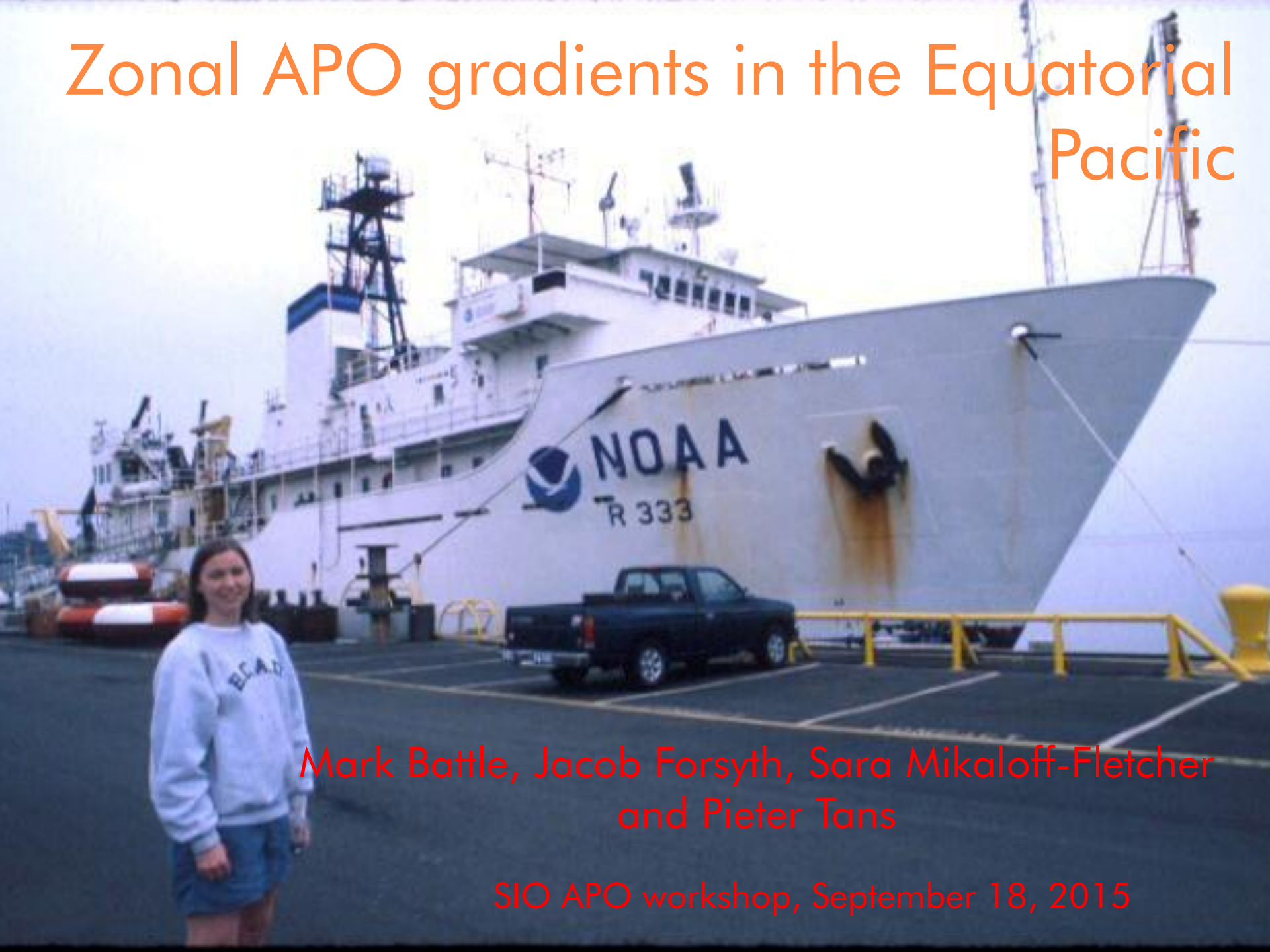
# Zonal APO gradients in the Equatorial Pacific




Mark Battle, Jacob Forsyth, Sara Mikaloff-Fletcher and Pieter Tans

SIO APO workshop, September 18, 2015

# Outline:

- Historical background
- Attempt #1
- Attempt #2
- Conclusions

# New wine in old bottles: a little history

GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 12, NO. 2, PAGES 213–230, JUNE 1998

## Testing global ocean carbon cycle models using measurements of atmospheric $O_2$ and $CO_2$ concentration

Britton B. Stephens,[1] Ralph F. Keeling,[1] Martin Heimann,[2] Katharina D. Six,[2] Richard Murnane,[3] and Ken Caldeira[4]

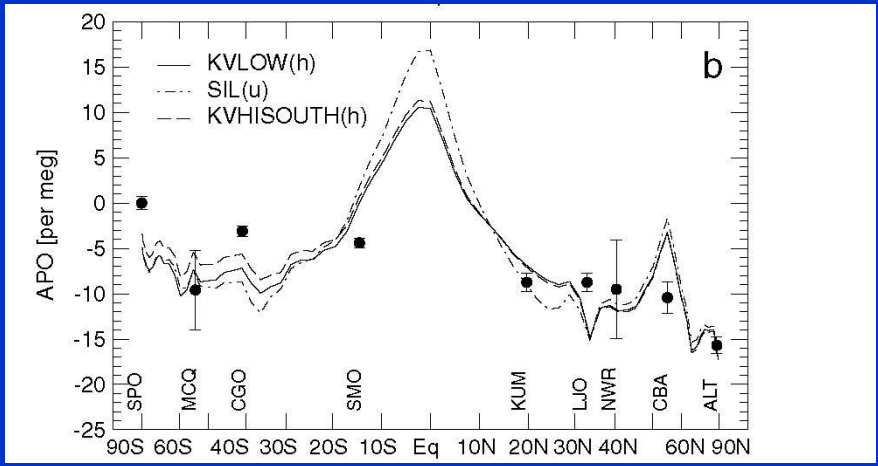
**Abstract.** We present a method for testing the performance of global ocean carbon cycle models using measurements of atmospheric $O_2$ and $CO_2$ concentration. We combine these measurements to define a tracer, atmospheric potential oxygen (APO $\approx O_2 + CO_2$), which is conservative with respect to terrestrial photosynthesis and respiration. We then compare observations of APO to the simulations of an atmospheric transport model which uses ocean-

GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 15, NO. 4, PAGES 783 803, DECEMBER 2001

# Air-sea flux of oxygen estimated from bulk data: Implications for the marine and atmospheric oxygen cycles

Nicolas Gruber,[1] Manuel Gloor,[2] Song-Miao Fan, and Jorge L. Sarmiento
Atmospheric and Oceanic Sciences Program, Princeton University, Princeton, New Jersey, USA

**Abstract.** We estimate the annual net air-sea fluxes of oxygen for 13 regions on the basis of a steady state inverse modeling technique that is independent of air-sea gas exchange parameterizations. The inverted data consist of the observed oceanic oxygen concentration after a



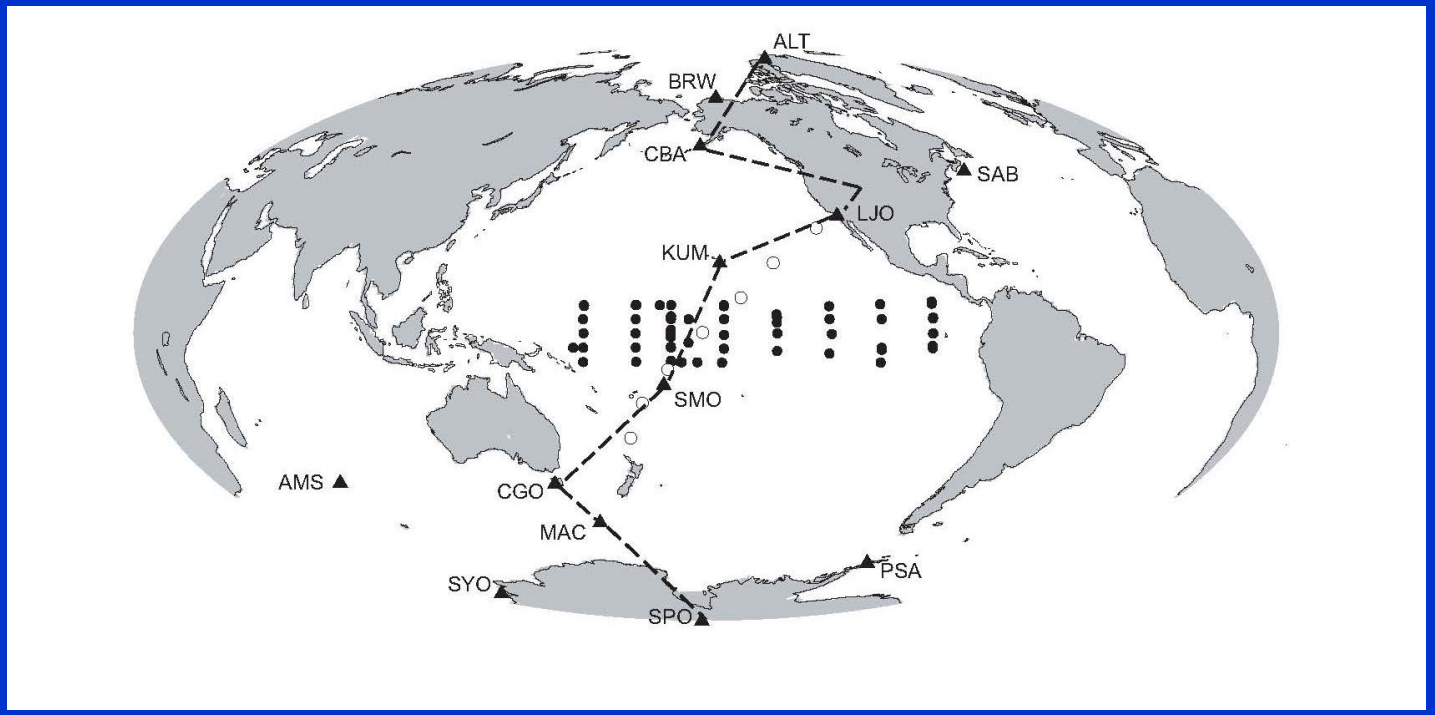
GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 20, GB1010, doi:10.1029/2005GB002534, 2006

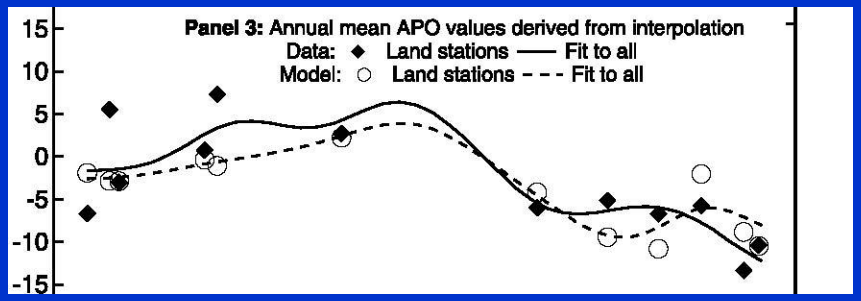
# Atmospheric potential oxygen: New observations and their implications for some atmospheric and oceanic models

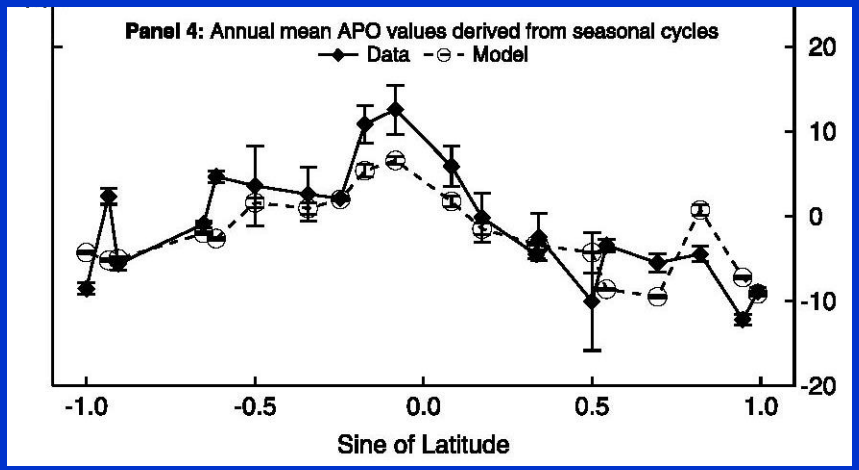
Mark Battle,[1] Sara Mikaloff Fletcher,[2] Michael L. Bender,[3] Ralph F. Keeling,[4] Andrew C. Manning,[4,5] Nicolas Gruber,[2] Pieter P. Tans,[6] Melissa B. Hendricks,[3] David T. Ho,[3,7] Caroline Simonds,[1,8] Robert Mika,[3] and Bill Paplawsky[4]

Received 14 April 2005; revised 10 October 2005; accepted 31 October 2005; published 17 February 2006.

[1] Measurements of atmospheric $O_2/N_2$ ratios and $CO_2$ concentrations can be combined into a tracer known as atmospheric potential oxygen ($APO \approx O_2/N_2 + CO_2$) that is conservative with respect to terrestrial biological activity. Consequently, APO reflects primarily ocean biogeochemistry and atmospheric circulation. Building on the work of Stephens et al. (1998), we present a set of APO observations for the years 1996–2003 with unprecedented spatial coverage. Combining data from the Princeton and Scripps air sampling programs, the data set includes new observations collected from ships in the low-latitude Pacific. The data show a smaller interhemispheric APO gradient than was observed in past studies, and different structure within the hemispheres. These differences appear to be due primarily to real changes in the APO field over time. The data also show a significant maximum in APO near the equator. Following the approach of Gruber et al. (2001), we compare these observations with predictions of APO generated from ocean $O_2$ and $CO_2$ flux fields and forward models of atmospheric transport. Our


ALT
BRW
CBA
SAB
LJO
KUM
SMO
AMS
CGO
MAC
SYO
PSA
SPO

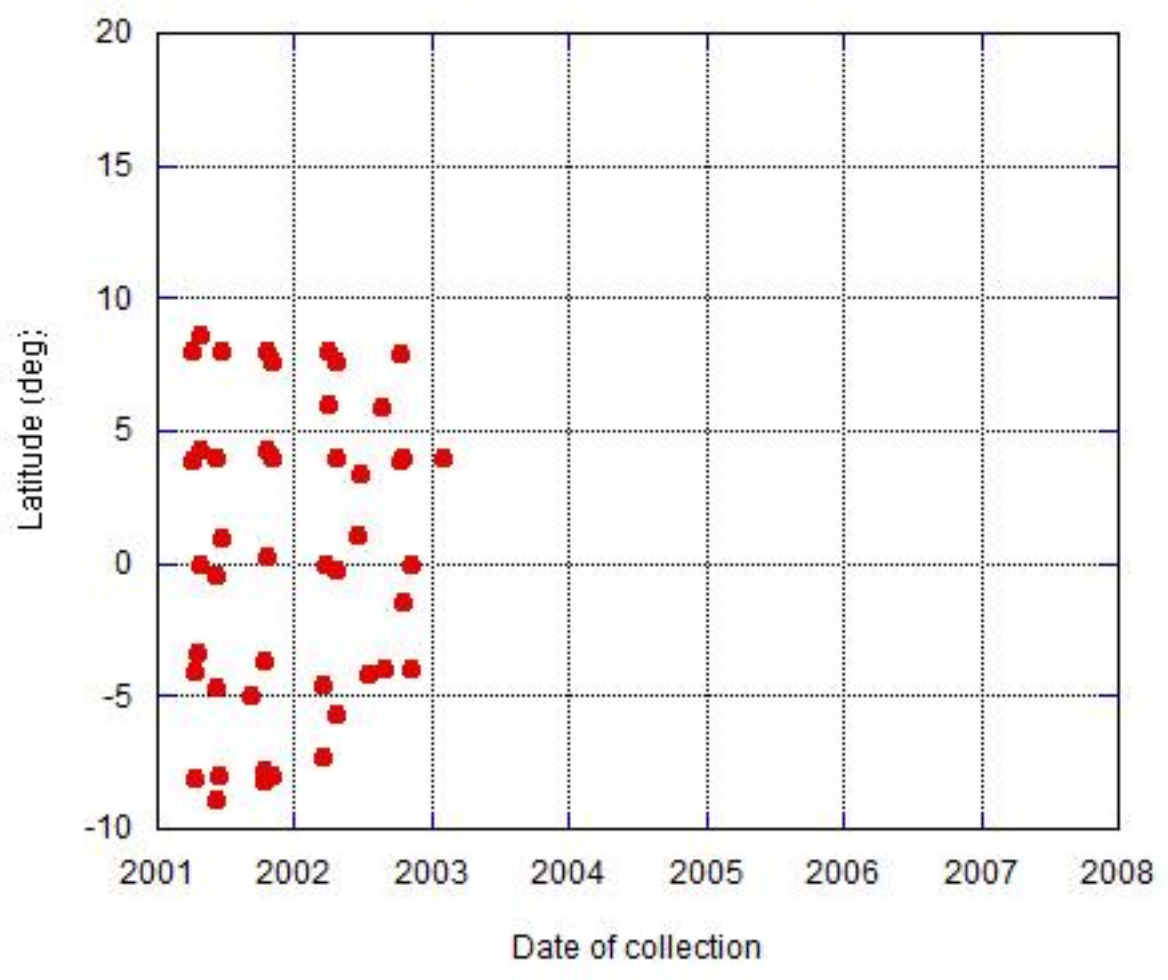

Panel 3: Annual mean APO values derived from interpolation
Data: ◆ Land stations —— Fit to all
Model: ○ Land stations - - - Fit to all
15
10
5
0
-5
-10
-15


Panel 4: Annual mean APO values derived from seasonal cycles
Data -⊖- Model
20
10
0
-10
-20
-1.0
-0.5
0.0
0.5
1.0
Sine of Latitude

…and many more recent, excellent, papers

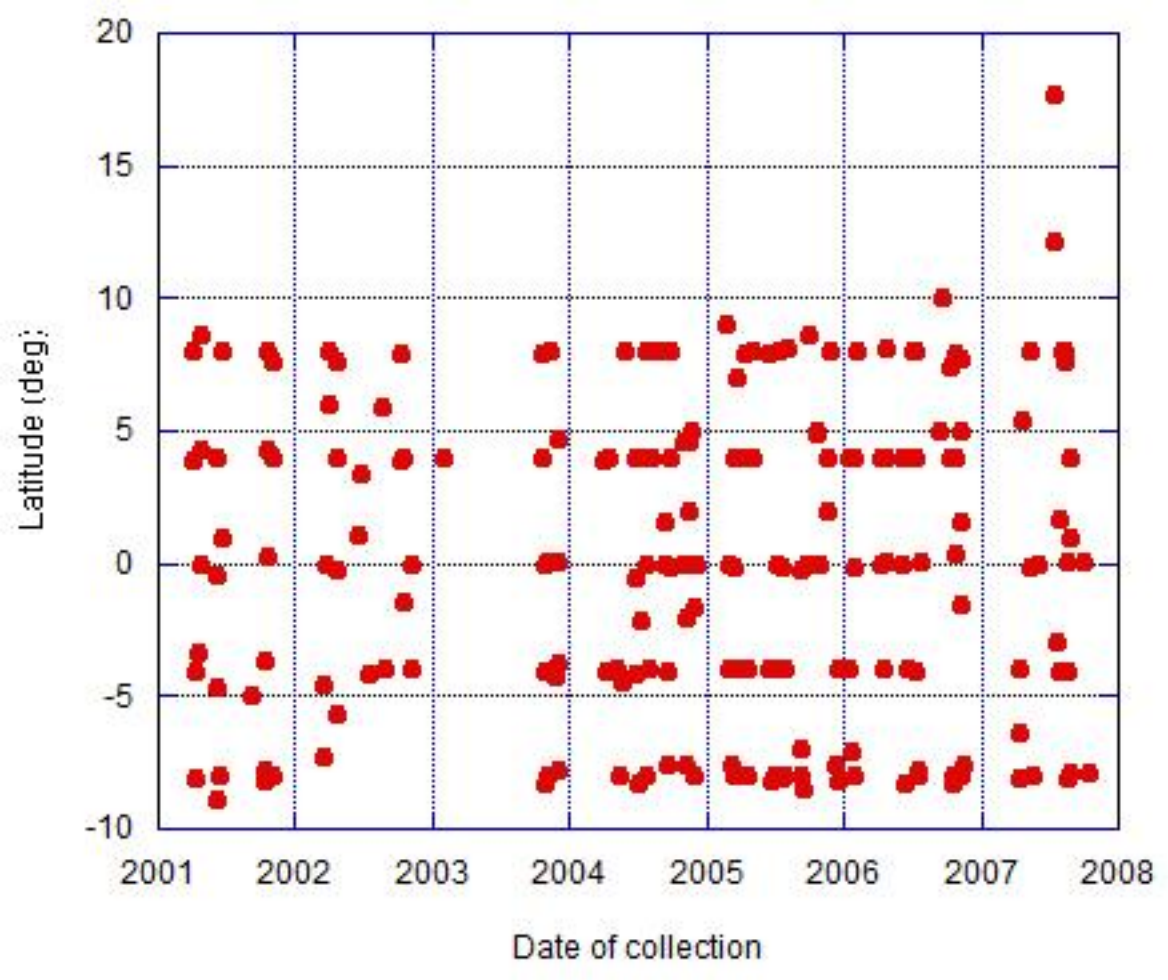
Our data collection didn’t end there…

# Shipboard data (NOAA ship Ka'imimo'ana)




Shipboard: Princeton/NOAA ESRL
KUM & SMO: SIO (thanks Ralph!)

# Shipboard data (NOAA ship Ka'imimo'ana)




Shipboard: Princeton/NOAA ESRL
KUM & SMO: SIO (thanks Ralph!)

# Goals

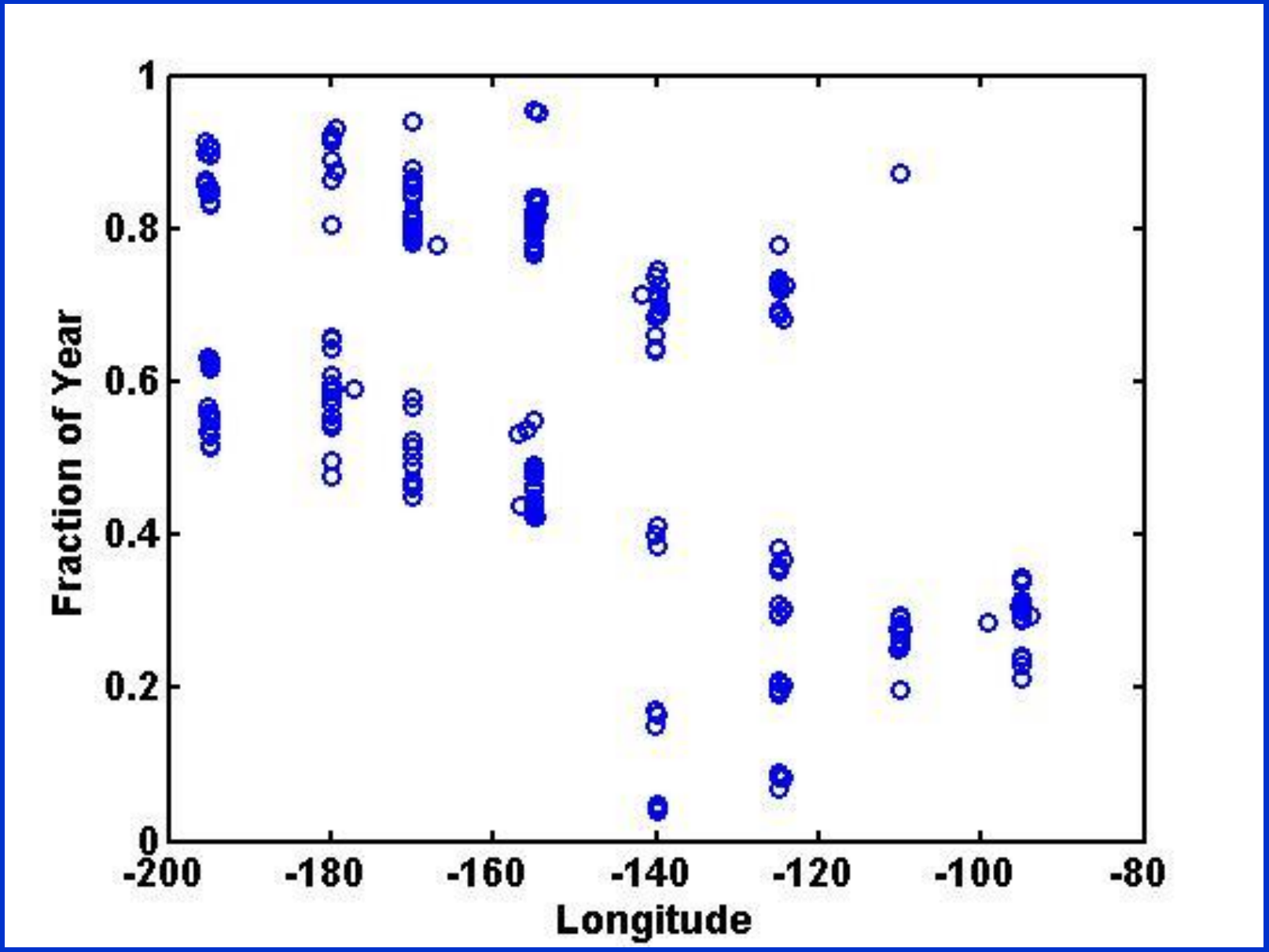
- Characterize east-west structure of APO across the Equatorial Pacific
- From this, learn about oceanic and atmospheric processes

# Challenges

- Likely a small signal
- Trend in APO
- Seasonal cycle in APO

# Challenges

- Likely a small signal
- Trend in APO
- Seasonal cycle in APO
- Sparse and irregular sampling


Fraction of Year
1
0.8
0.6
0.4
0.2
0
-200
-180
-160
-140
-120
-100
-80
Longitude

# Challenges

- Likely a small signal
- Trend in APO
- Seasonal cycle in APO
- Sparse and irregular sampling
- Missing locations of samples

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- Trend in APO
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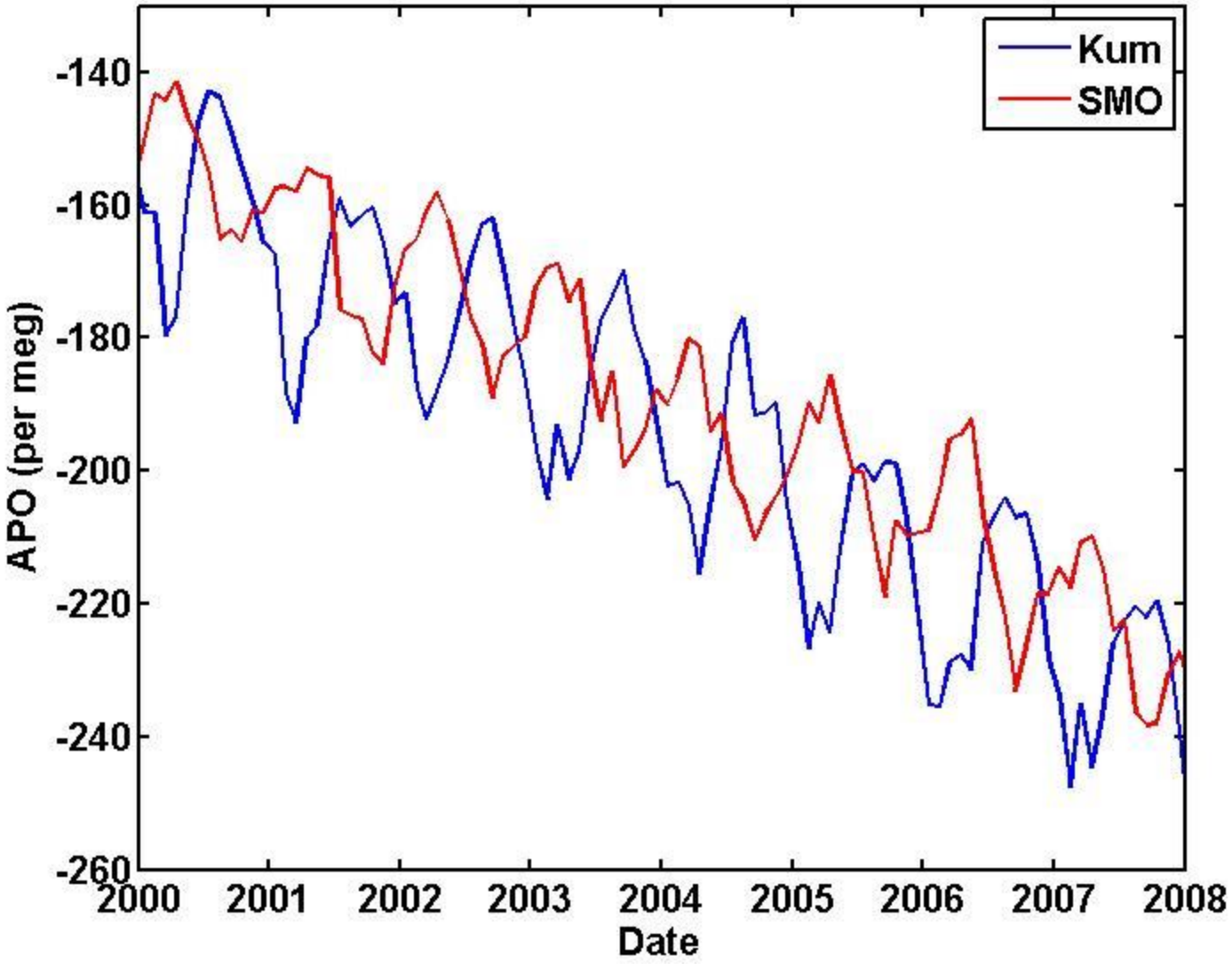
Thanks to: Paul Freitag, Cathy Cosca, Brian Lake, Wendy Bradfield-Smith

# Approach #1: Intuition

(Jacob Forsyth)

- Detrend (CCGVU using KUM)

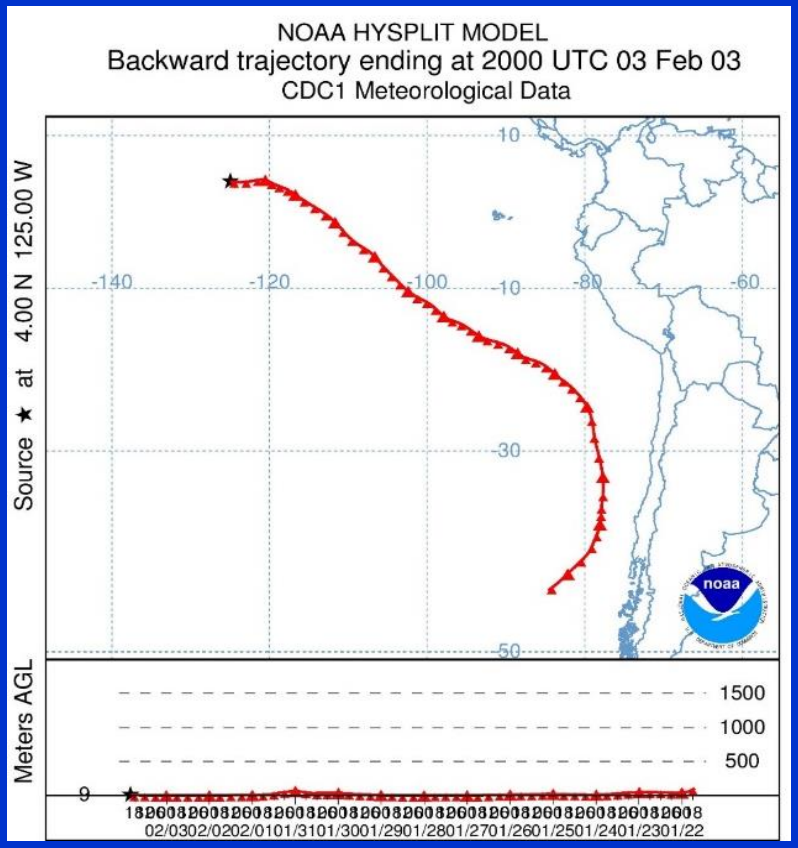


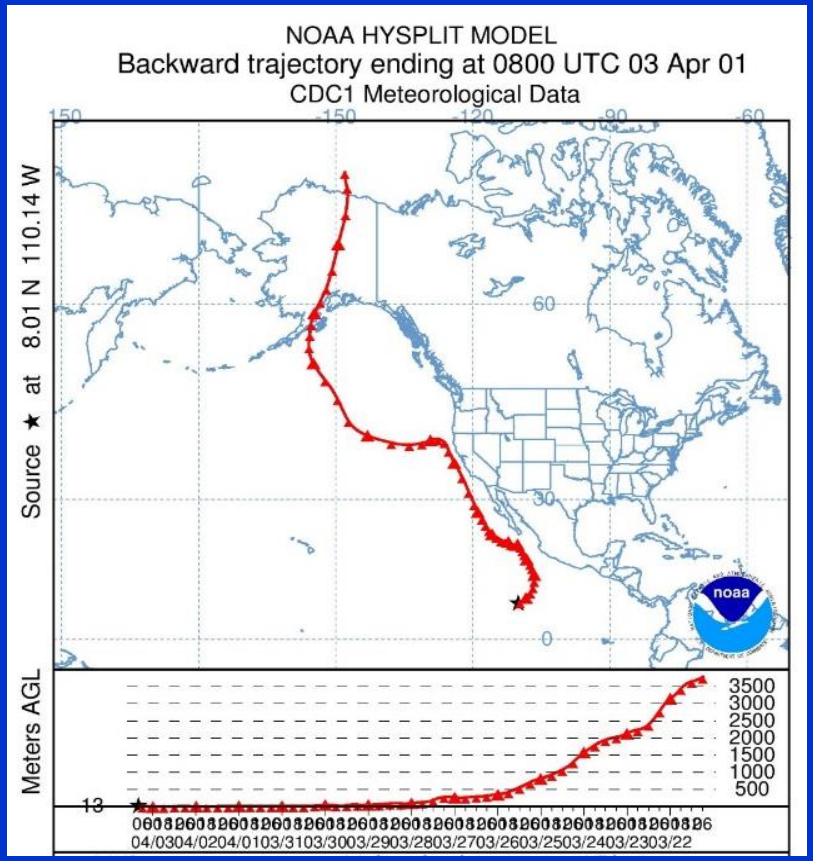

Data courtesy of Keeling lab.

# Approach #1: Intuition

(Jacob Forsyth)

- Detrend (CCGVU using KUM)
- Find origin of air mass (HYSPLIT)


NOAA HYSPLIT MODEL
Backward trajectory ending at 2000 UTC 03 Feb 03
CDC1 Meteorological Data
Source ★ at 4.00 N 125.00 W
Meters AGL
1500
1000
500
02/0302/0202/0101/3101/3001/2901/2801/2701/2601/2501/2401/2301/22


NOAA HYSPLIT MODEL
Backward trajectory ending at 0800 UTC 03 Apr 01
CDC1 Meteorological Data
Source ★ at 8.01 N 110.14 W
Meters AGL
3500
3000
2500
2000
1500
1000
500
04/0304/0204/0103/3103/3003/2903/2803/2703/2603/2503/2403/2303/22

# Approach #1: Intuition

(Jacob Forsyth)

- Detrend (CCGVU using KUM)
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- Subtract seasonal cycle (KUM or SMO)

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# Approach #1: Intuition

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- Detrend (CCGVU using KUM)
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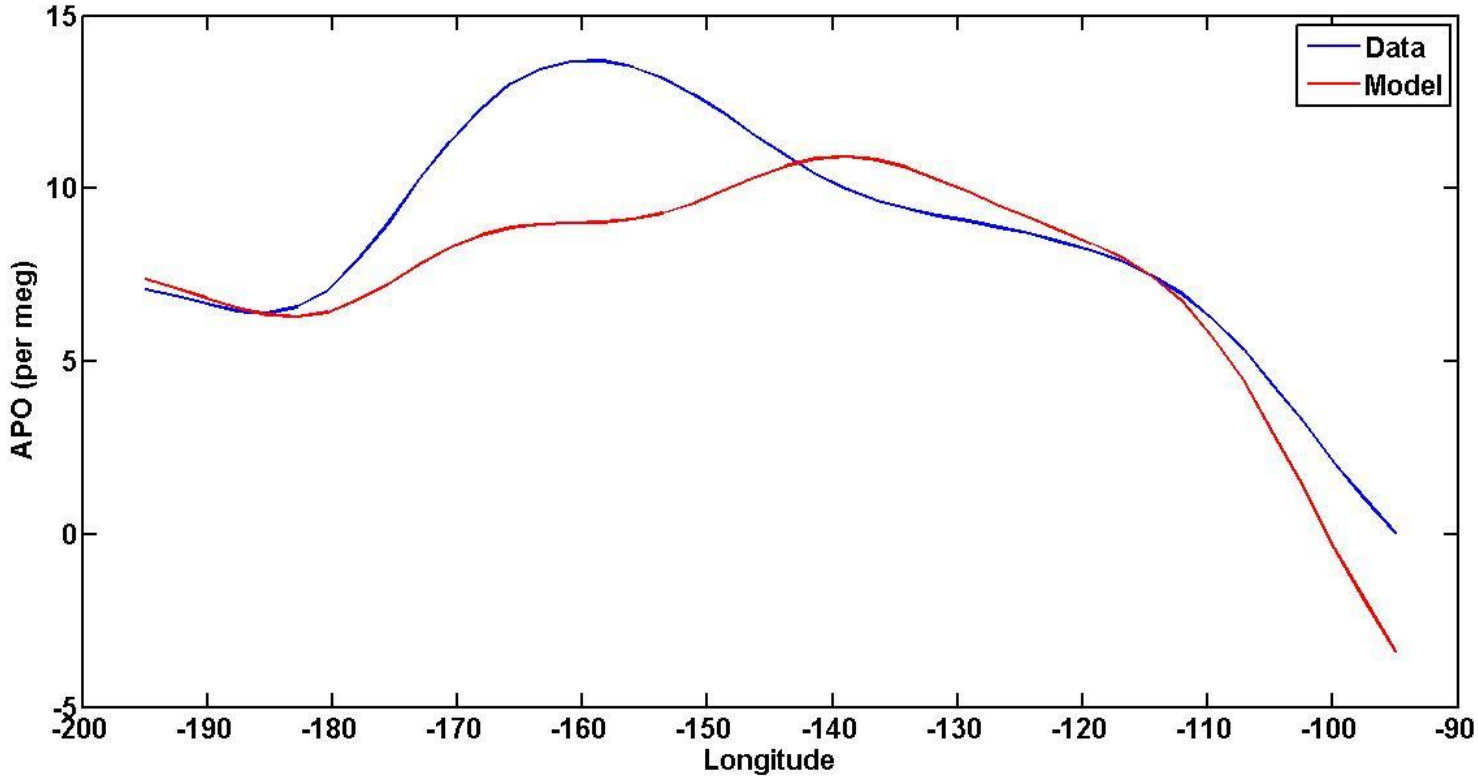
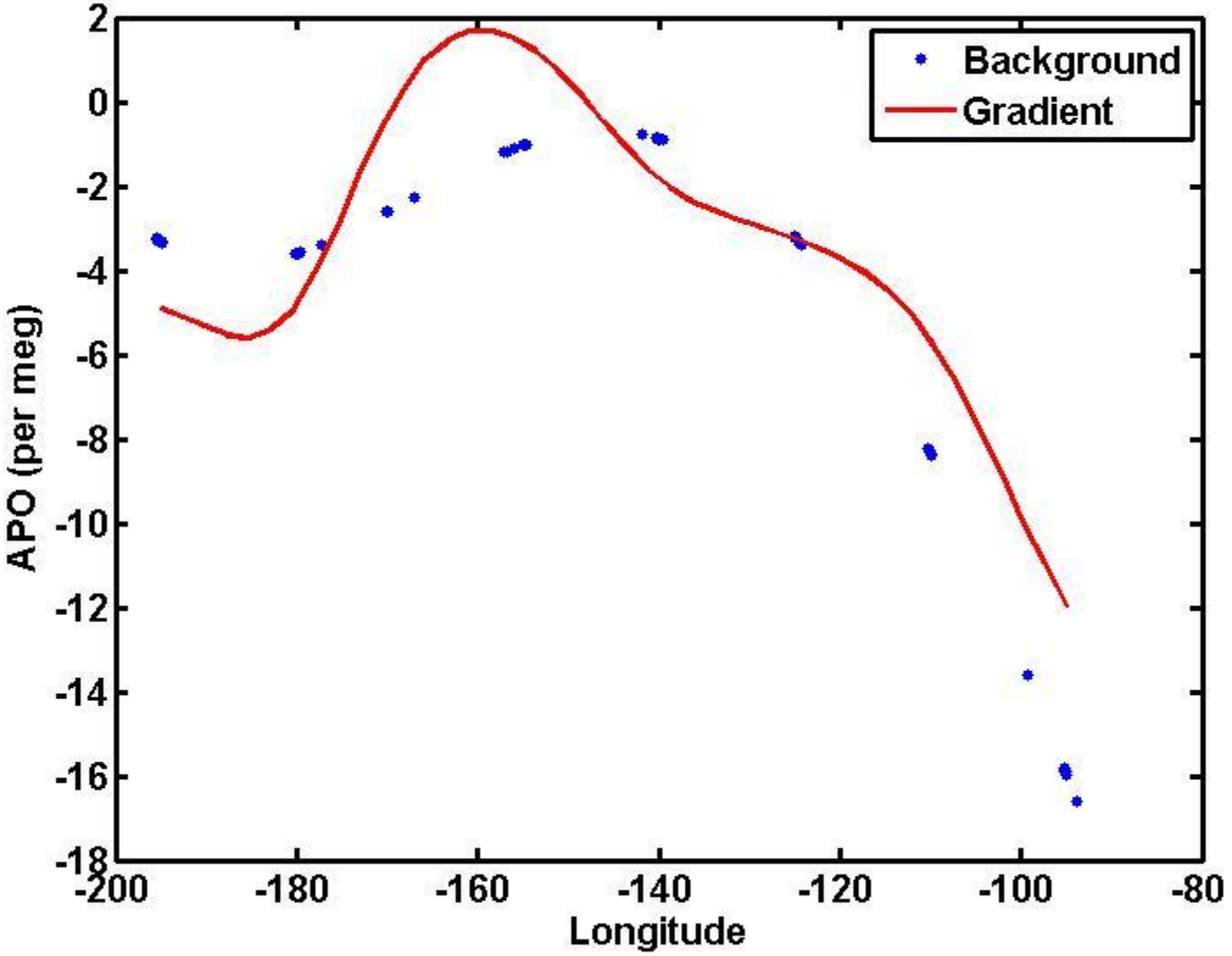
- Subtract seasonal cycle (KUM or SMO)
- Average over time
- Fit gradients with Butterworth filter


Data
Model
APO (per meg)
Longitude
15
10
5
0
-5
-200
-190
-180
-170
-160
-150
-140
-130
-120
-110
-100
-90

# Approach #1: Intuition

(Jacob Forsyth)

- Detrend (CCGVU using KUM)
- Find origin of air mass (HYSPLIT)
- Subtract seasonal cycle (KUM or SMO)
- Average over time
- Fit gradients with Butterworth filter
- Problems: Aliasing


Background
Gradient
APO (per meg)
Longitude
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-200
-180
-160
-140
-120
-100
-80

# Approach #2: Model-guided

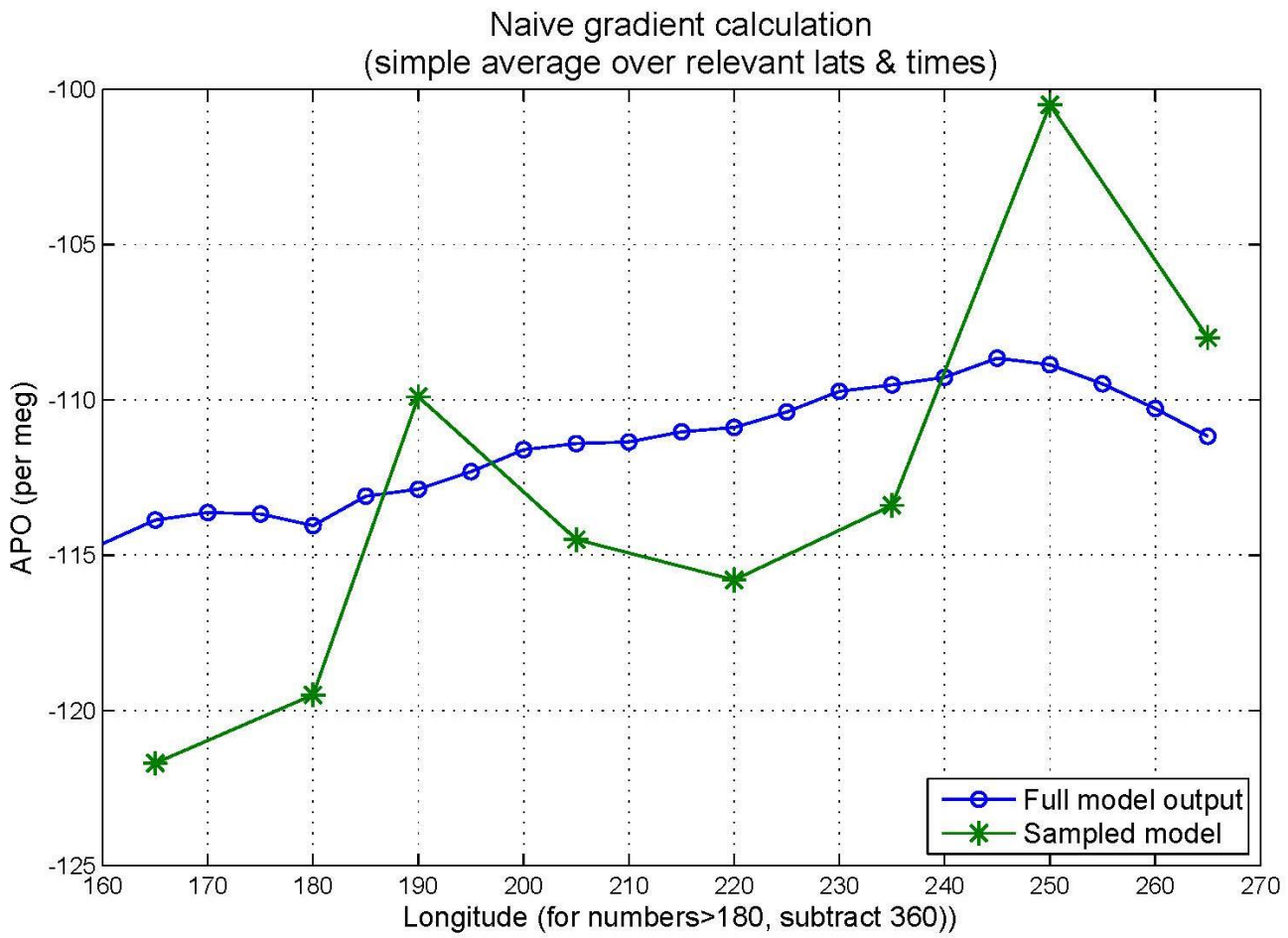
Use model to develop an analysis protocol that gives the same gradients for sparse and full sampling.

# Model details

- Atmospheric transport: TM3
- Annual Mean $O_2$ and $N_2$ fluxes: Ocean inversion (Gloor *et al.*, 2001, Gruber *et al.*, 2001)
- Seasonal $O_2$ and $N_2$ (Garcia & Keeling 2001
- $CO_2$ from oceans (Takahashi et al., 2009);
- $CO_2$ from fossil fuels (CDIAC)

Modeling: Sara Mikaloff-Fletcher

# Simplest starting point



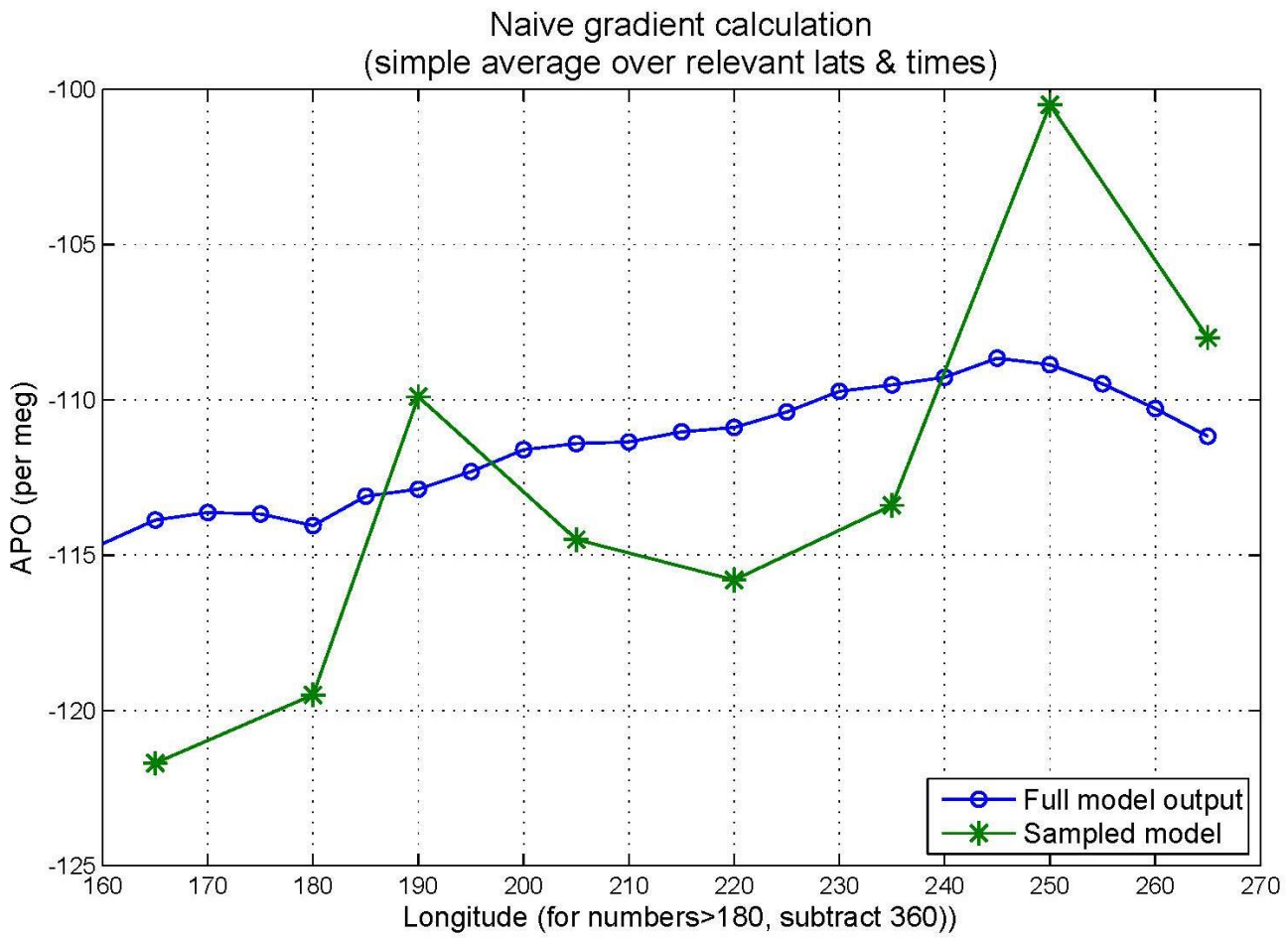
# Approach #2: Model-guided

- Detrend (CCGVU using KUM)

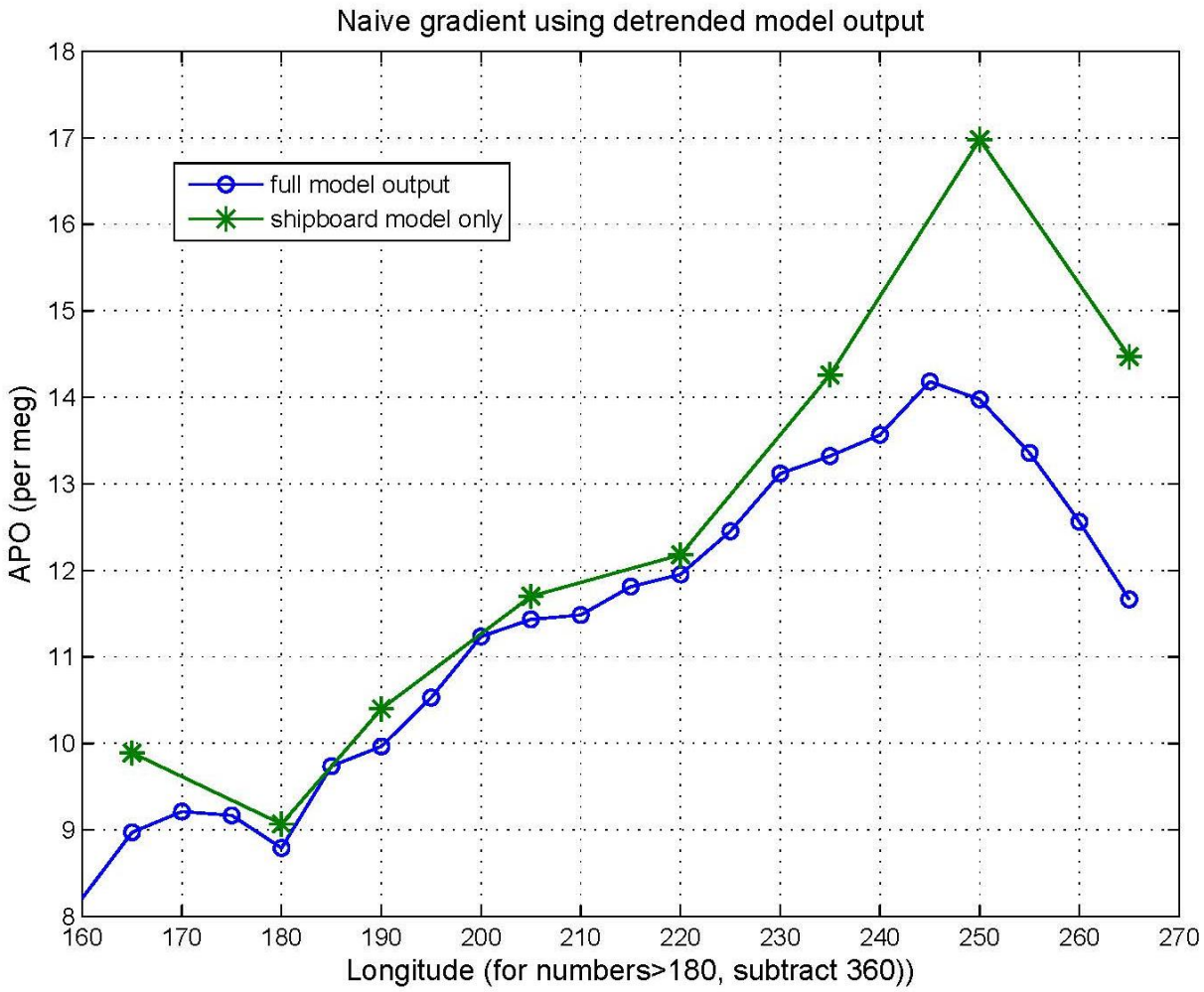
# Approach #2: Model-guided

- Detrend (CCGVU using KUM)
- Zero each latitude band and combine

# Simplest starting point



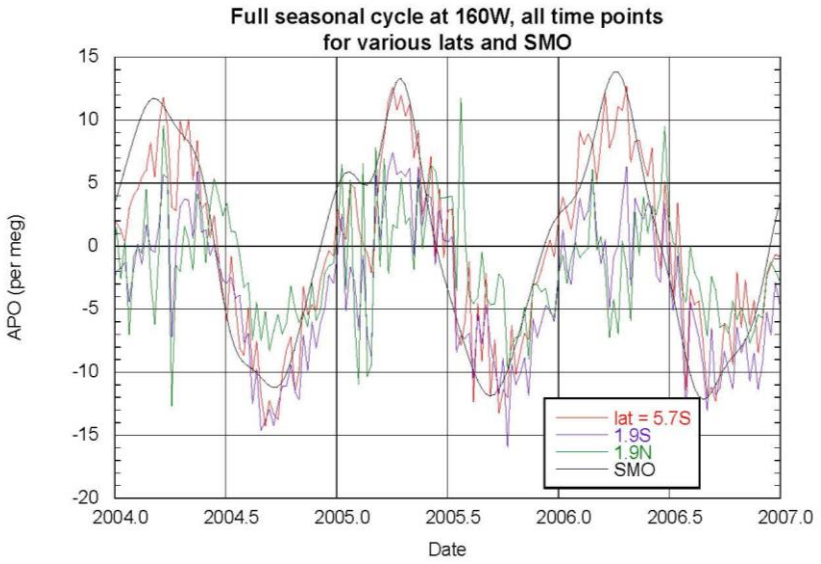
# Detrended and zeroed (by lat)

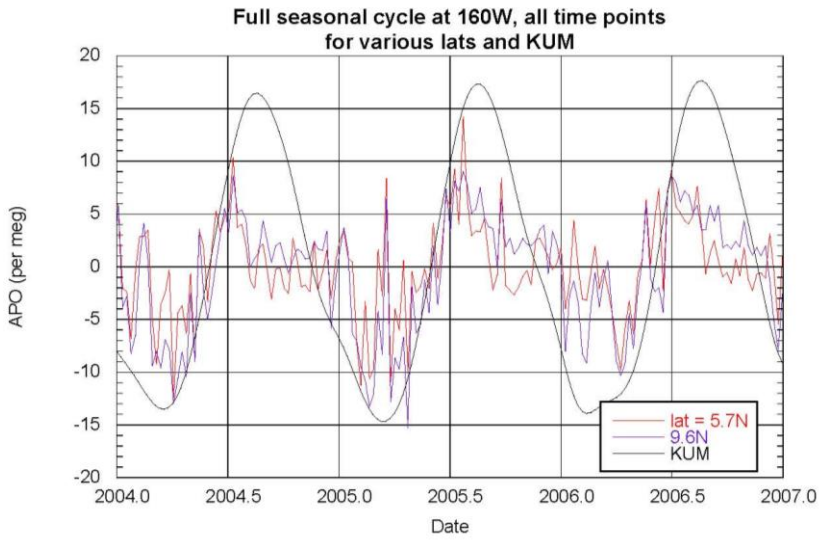


# Approach #2: Model-guided

- Detrend (CCGVU using KUM)
- Zero each latitude band and combine
- Subtract scaled seasonal cycle (KUM or SMO) by latitude

# Scale factors for seasonal cycles



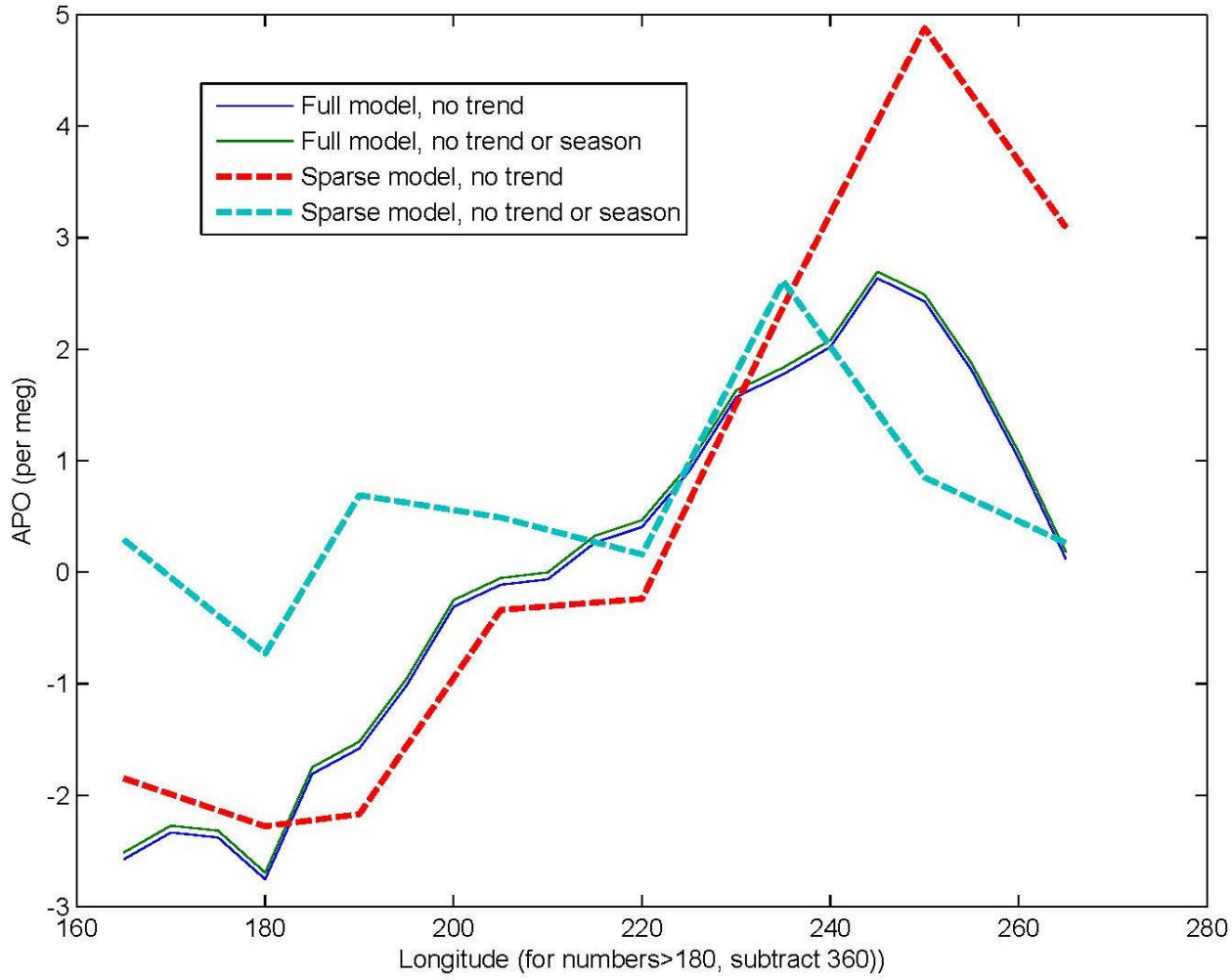




| Lat | 8S | 4S | 0 | 4N | 8N |
|---|---|---|---|---|---|
| Ref site | SMO | SMO | SMO | SMO | KUM |
| Scale factor | 0.82 | 0.66 | 0.62 | 0.18 | 0.37 |

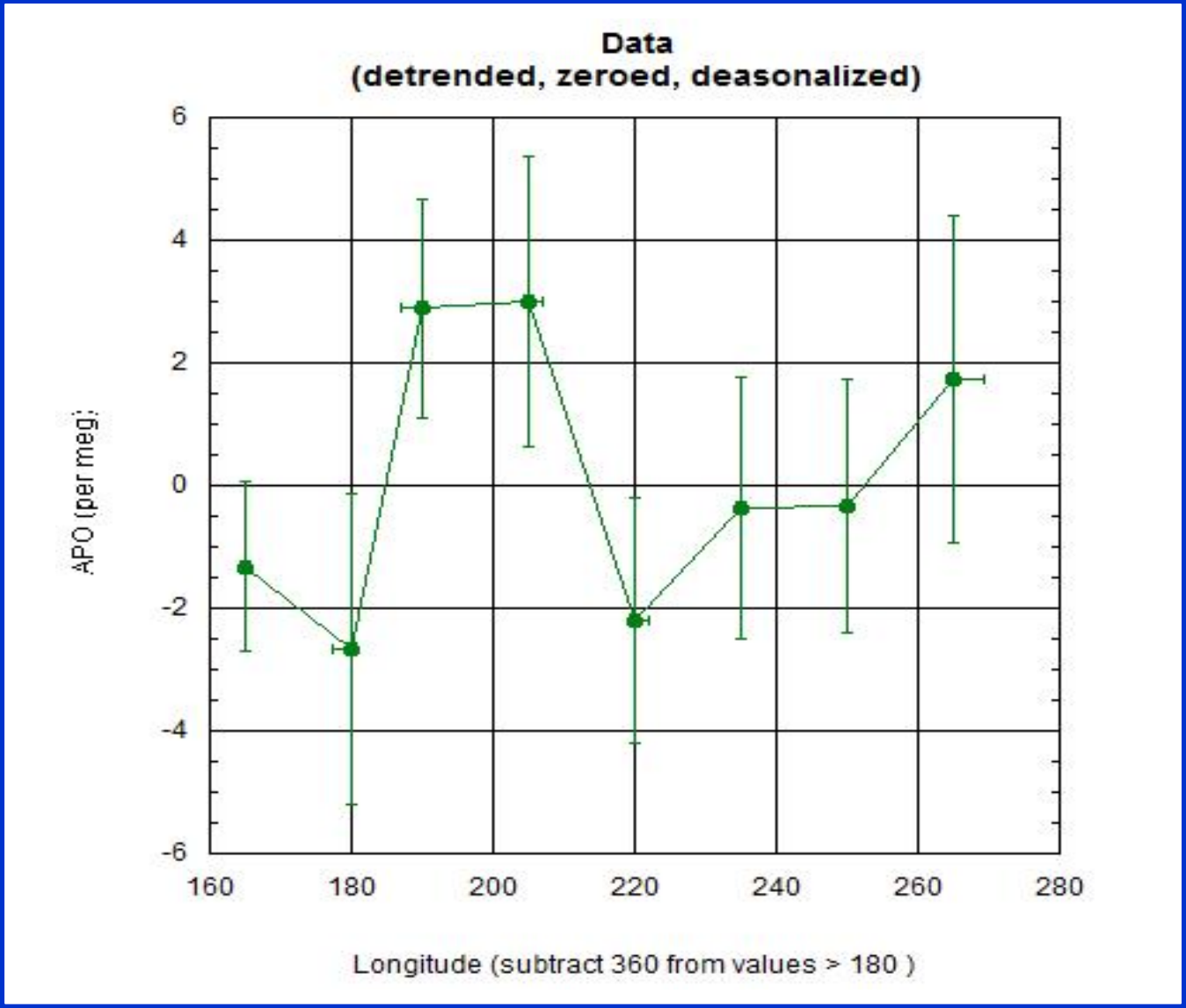
# Approach #2: Model-guided

- Detrend (CCGVU using KUM)
- Zero each latitude band and combine
- Subtract scaled seasonal cycle (KUM or SMO) by latitude
- Average over all times

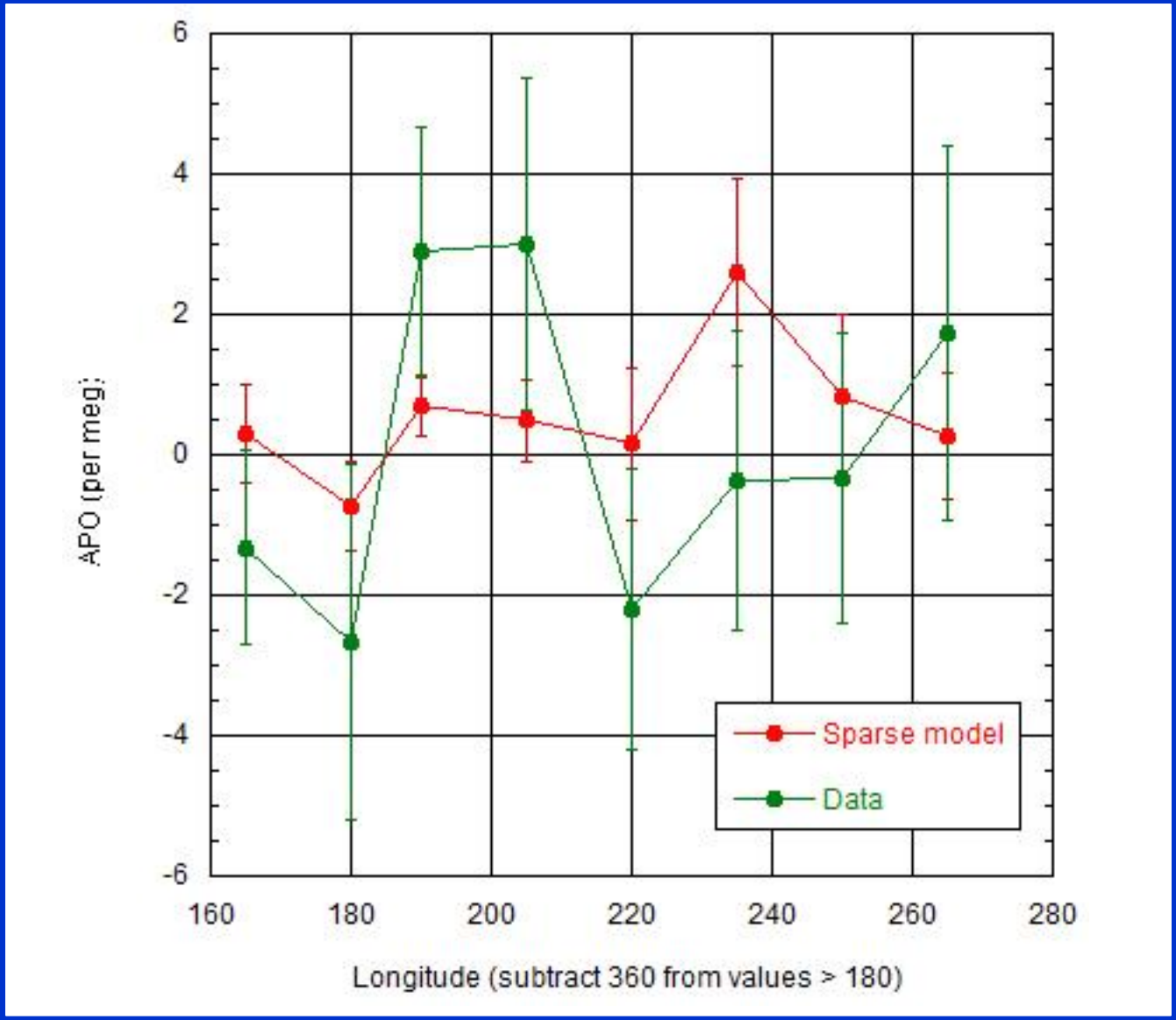
# Impact of deseasonalizing



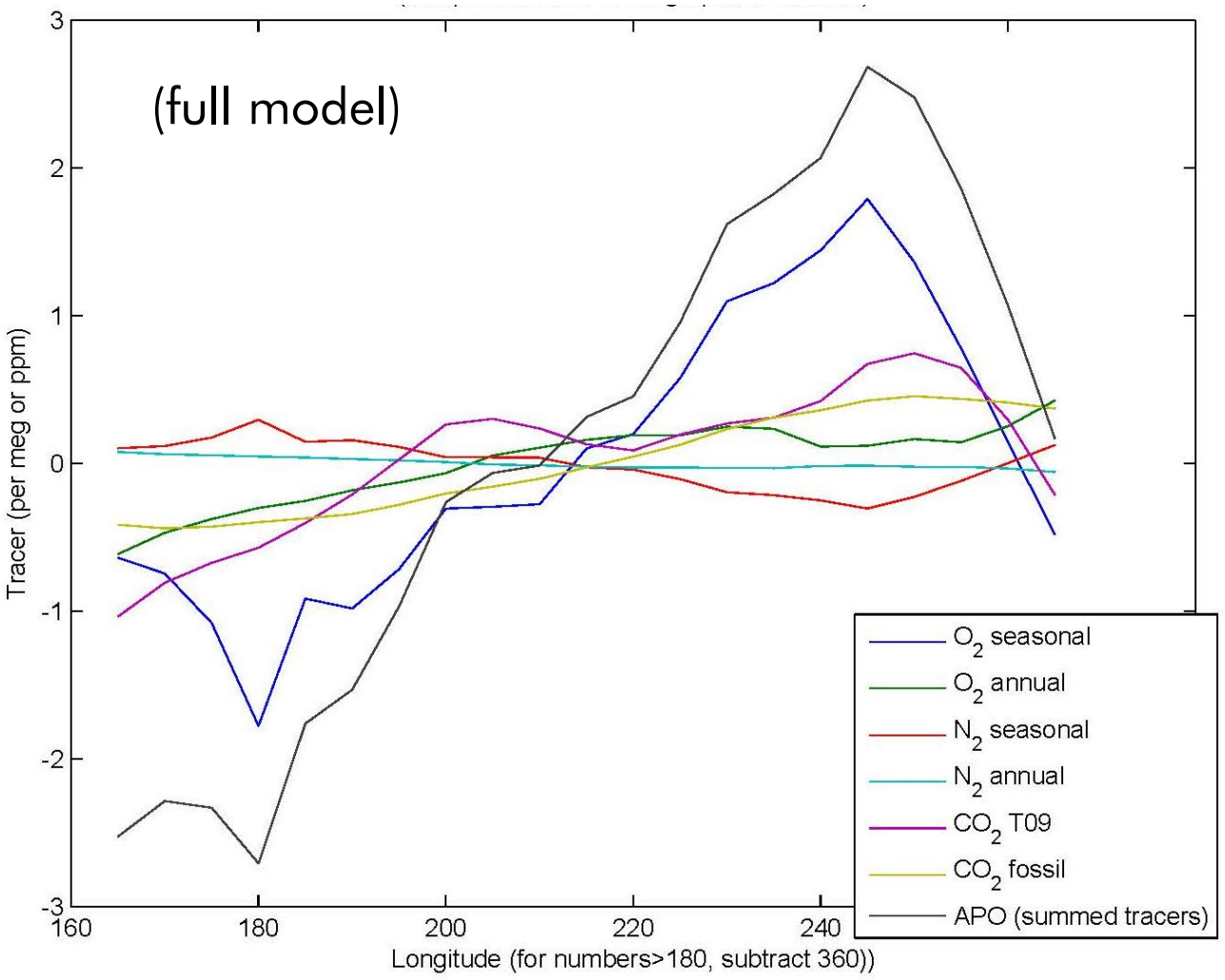
# Data: fully processed



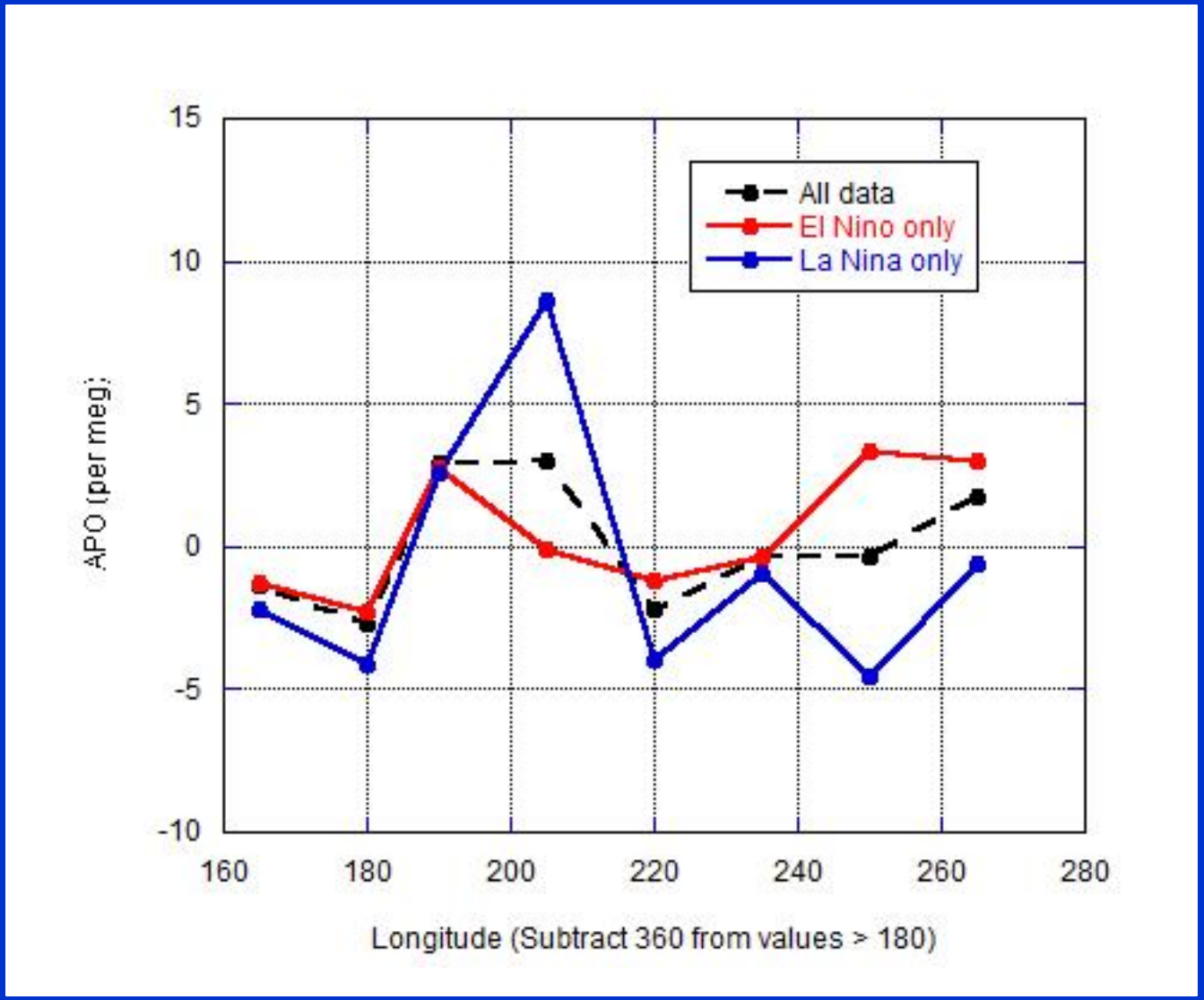
# Data-model comparison



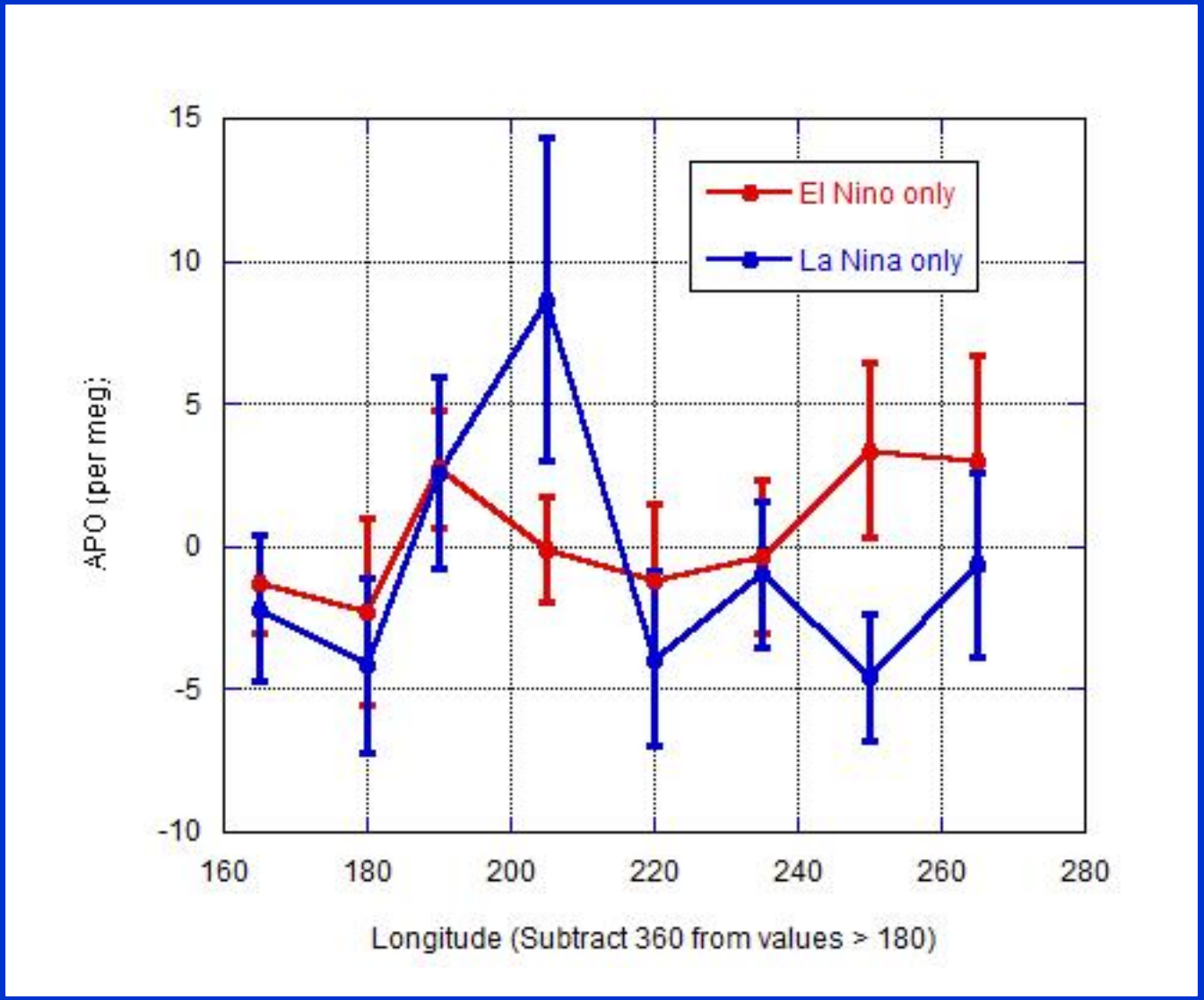
# What determines the gradient?



# Temporal dependence?



# Temporal dependence?



# Conclusions

- Eq. Pac. APO gradients are modest
- Correcting for sparse sampling is hard
- Model not obviously wrong
- Model suggests any gradient is due to seasonal O2 fluxes
- Hints of ENSO dependence

# Impact of the analysis