Airborne Oxygen Measurements Over the Southern Ocean as an Integrated Constraint of Ocean Biogeochemical Processes

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Modelers: Sara Mikaloff Fletcher (NIWA), Prabir Patra (JAMSTEC)

Goals

1. Apply curtain average metric and see whether it reduces disagreement between transport model runs with same ocean fluxes.
2. How large is the seasonal cycle of the atmospheric column (curtain average) relative to surface observations?
3. How do models perform relative to observations with transport model uncertainty reduced?
4. How do Garcia and Keeling (2001) dissolved climatologies perform on amplitude and phase?

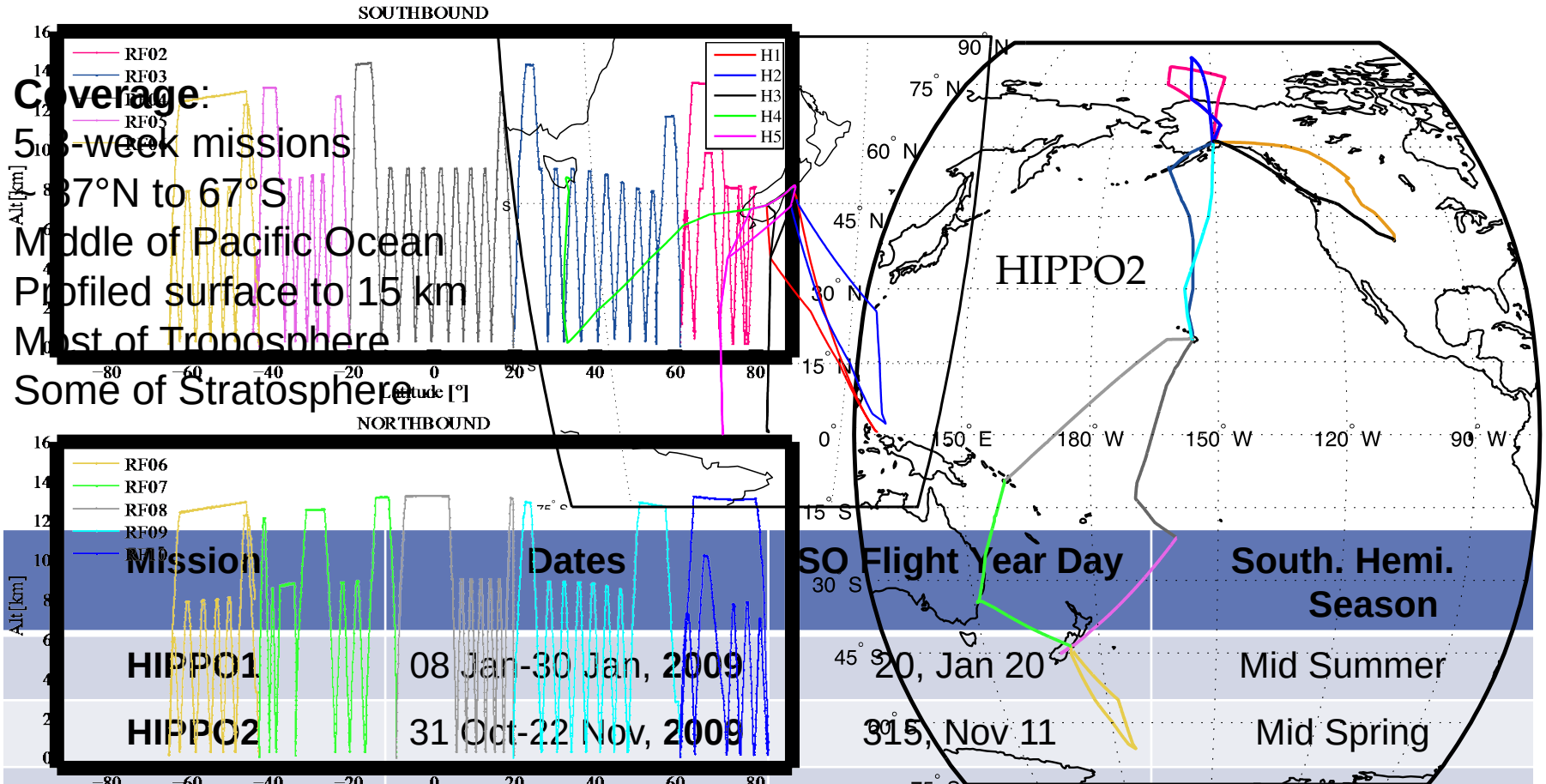
1. HIAPER Pole to Pole Observations

High-performance Instrumented Airborne Platform for Environmental Research

[Photos: J. Bent, B. Stephens]

HIPPO: Coverage

Coverage:
5 3-week missions
87°N to 67°S
Middle of Pacific Ocean
Profiled surface to 15 km
Most of Troposphere
Some of Stratosphere



Mission	Dates	SO Flight Year Day	South. Hemi. Season
HIPPO1	08 Jan-30 Jan, **2009**	20, Jan 20	Mid Summer
HIPPO2	31 Oct-22 Nov, **2009**	315, Nov 11	Mid Spring
HIPPO3	24 Mar-16 Apr, **2010**	95, Apr 5	Early Fall
HIPPO4	14 Jun-11 Jul, **2011**	179, Jun 28	Early Winter
HIPPO5	09 Aug-09 Sep, **2011**	241, Aug 29	Late Winter

SIO/NCAR Contribution

AO2

Dried Flasks (32/RF)

3 Mass Specs, LiCor

CO_2
O_2/N_2

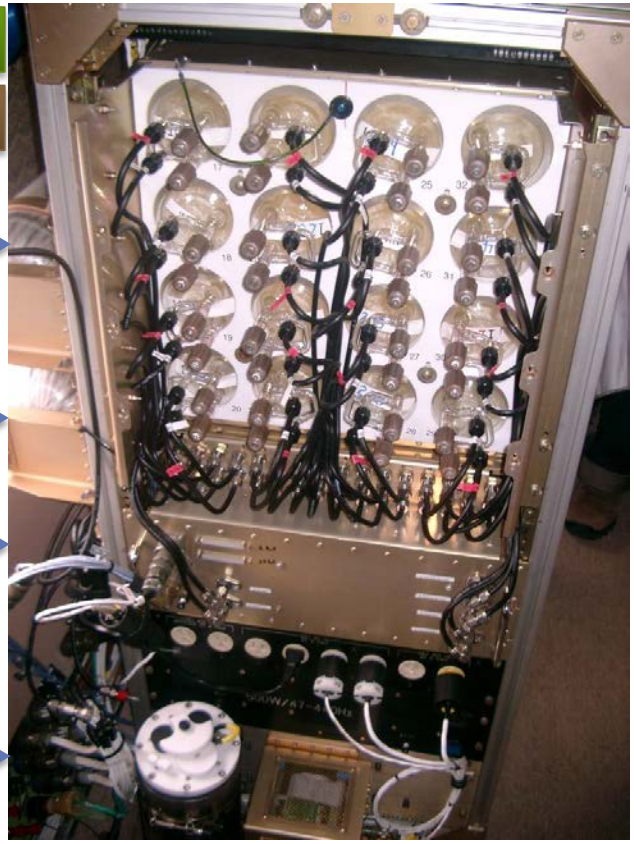
Ar/N_2

$^{13}CO_2$
$C^{18}O^{16}O$

$^{14}CO_2$

Vacuum UV, LiCor

In Situ: 1+ Hz

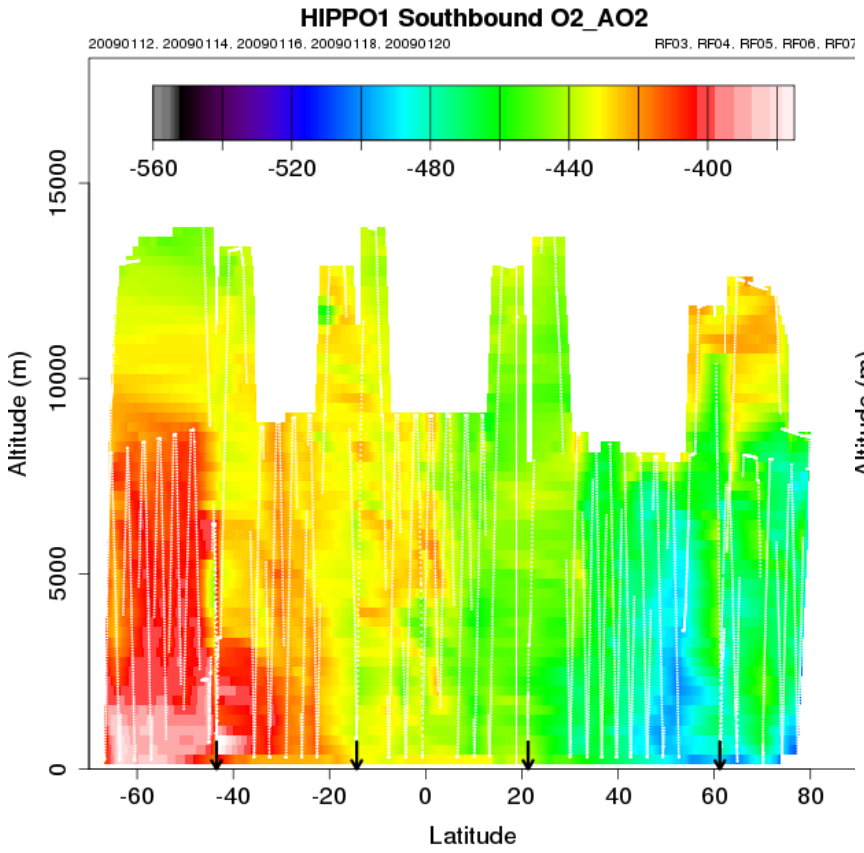


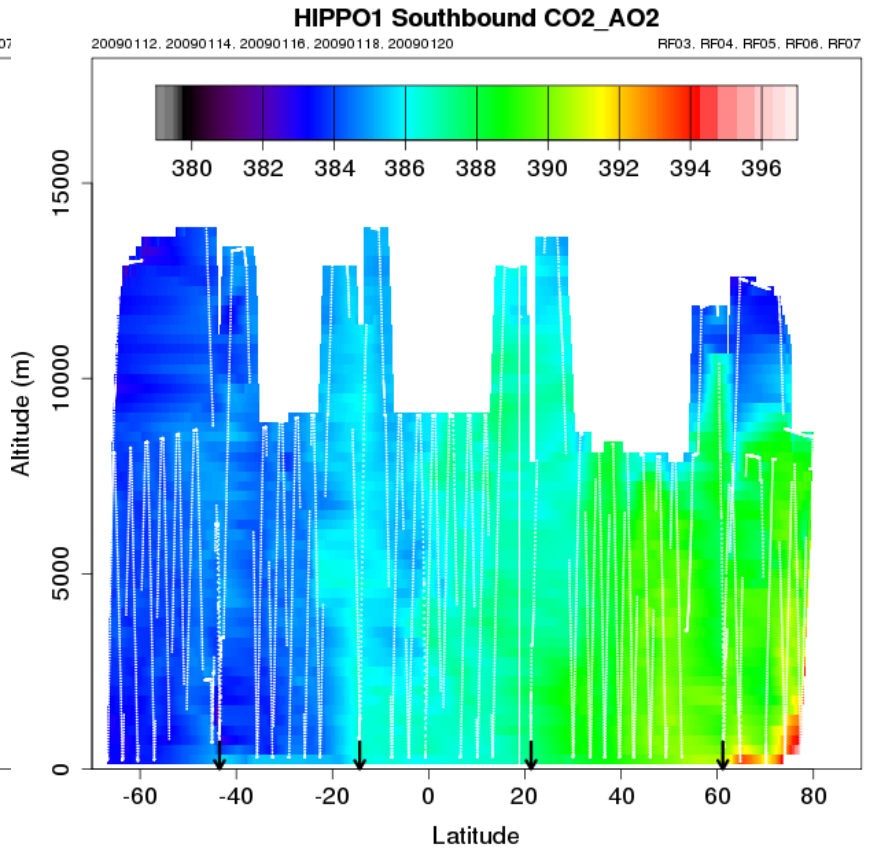
Medusa

[Photos: J. Bent; Figure: B. Stephens]

O_2 and CO_2 Curtain Plots from HIPPO1

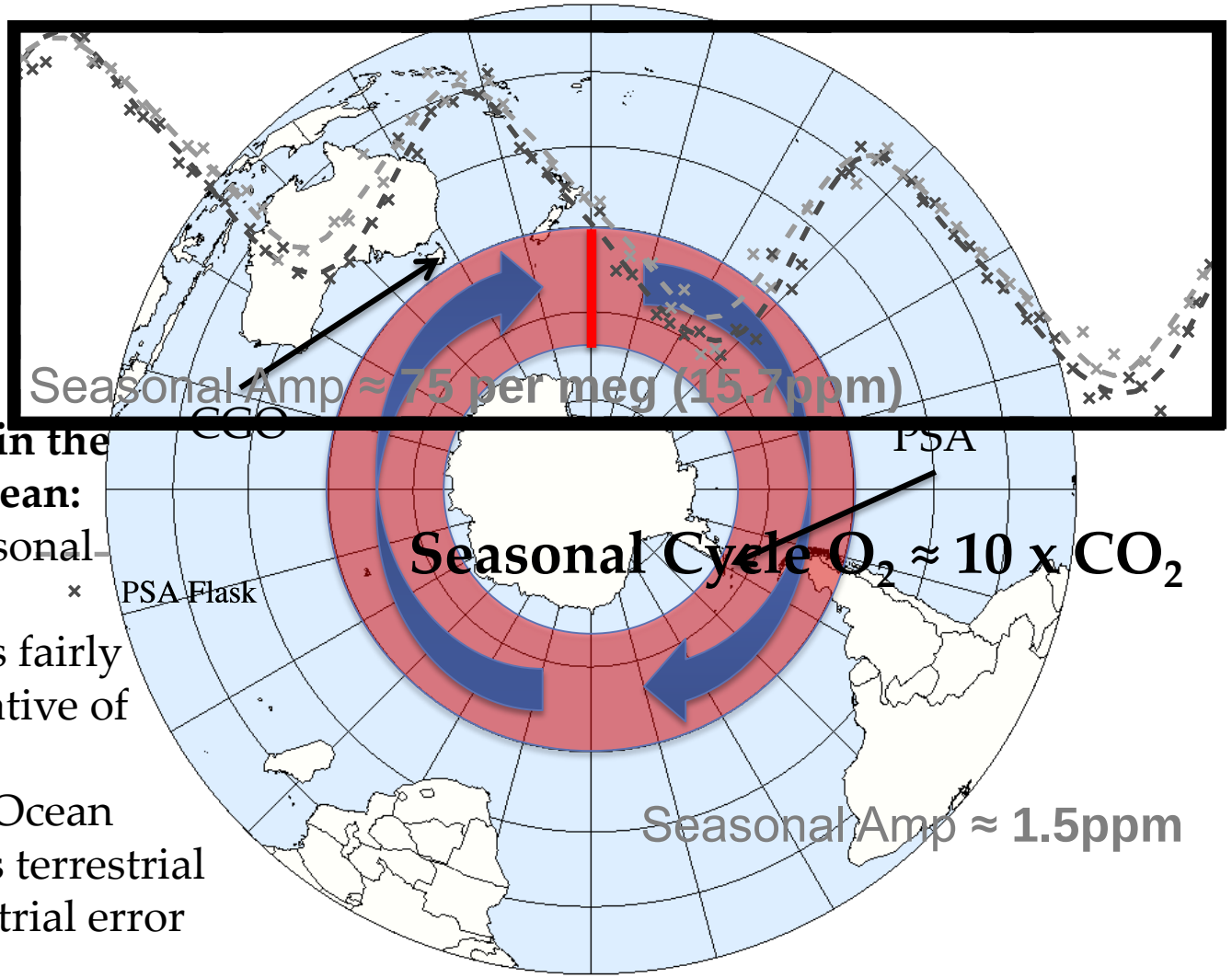
January 2009, Mid Austral Summer





[Figures: B. Stephens]

Palmer Station, Antarctica (PSA)
Cape Grim Observatory, Tasmania (CGO)
O_2 and CO_2 Records

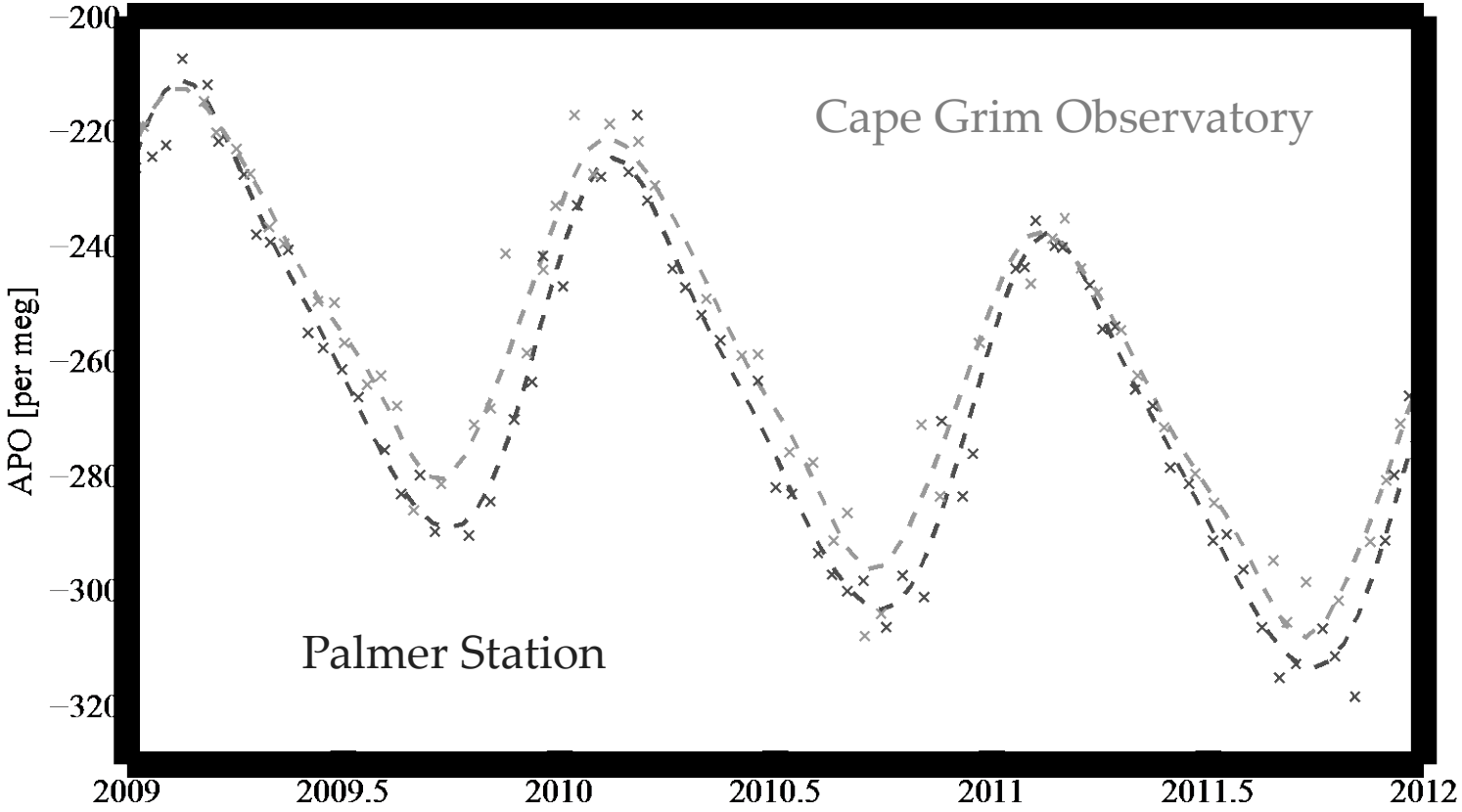


Advantages in the Southern Ocean:

- Large Seasonal Cycles
- Dateline is fairly representative of zone
- Southern Ocean minimizes terrestrial and industrial error

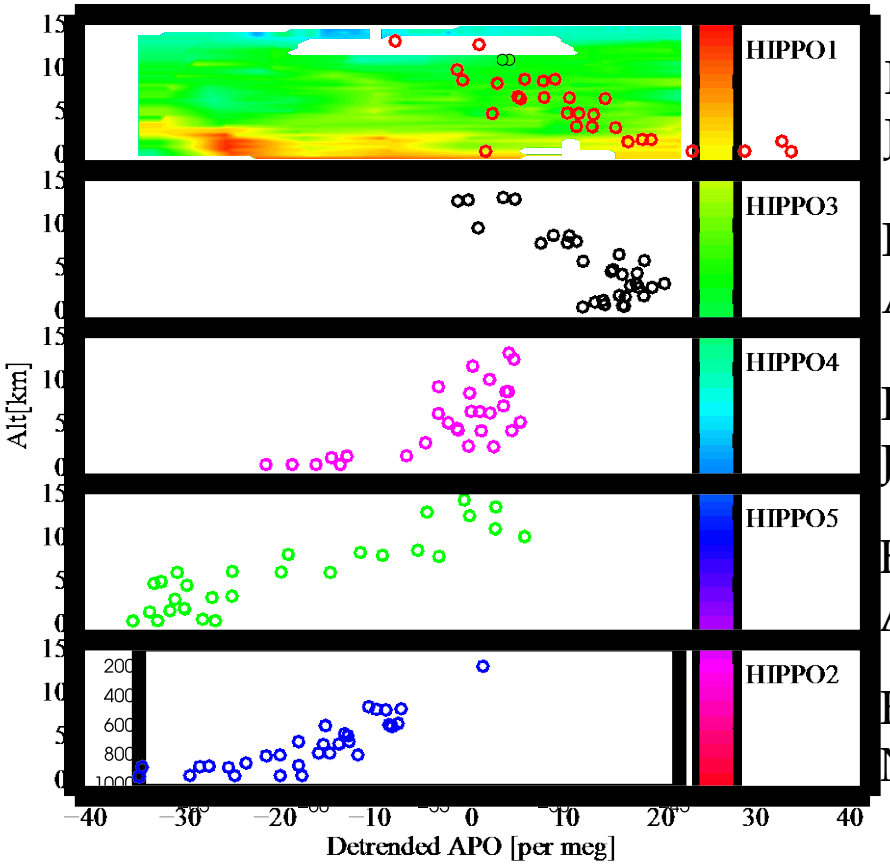
PSA, CGO Atmospheric Potential Oxygen

Seasonal P2P ~ **70 per meg (~14.7 ppm)**
Interannual: 140/14=-10 per meg/yr



APO concentrations over the Southern Ocean Slice: AO2 and Medusa

Medusa Flasks from 45°-67°S



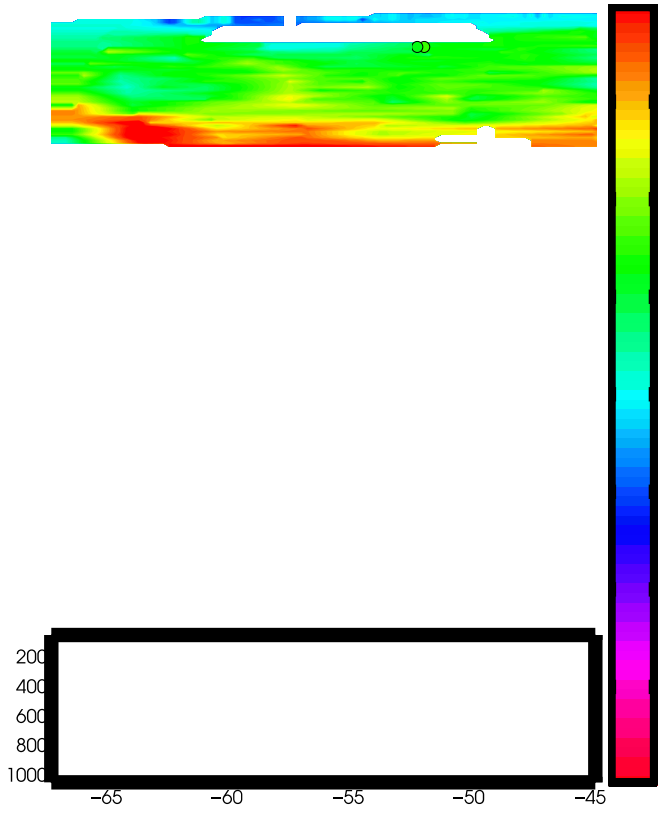
HIPPO1
Jan, Mid summer

HIPPO3
Apr, Early Fall

HIPPO4
June, Early Winter

HIPPO5
Aug, Late Winter

HIPPO2
Nov, Mid Spring



Modeling Methodology

TM3
(Sara Mikaloff Fletcher, NIWA)

NEMO-PISCES-T (LeQuéré, 2007)
NEMO-CNTRL (Rodgers, 2014)
NEMO-WSTIR (Rodgers, 2014)

MOM4 (Dunne, 2010)

CCSM3 (Collins, 2006)
CESM (Long, 2013)

Dissolved Climatologies

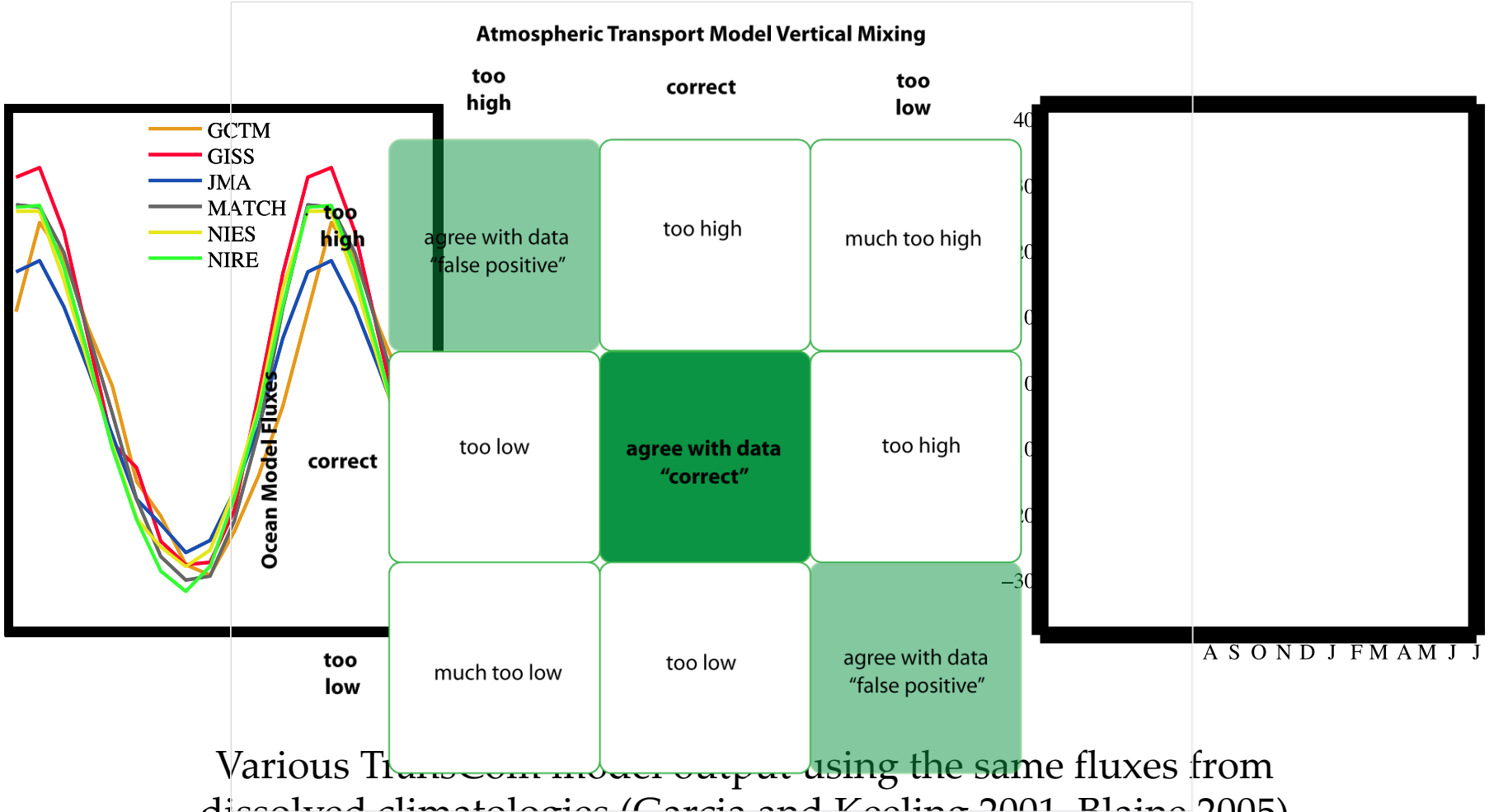
O_2 (Garcia and Keeling 2001),
CO_2 (Takahashi 2009),
N_2 (Blaine 2005)

ACTM
(Prabir Patra, JAMSTEC)

Dissolved Climatologies

Wanninkhof (1992) Gas Exchange Velocity: $K_{av}=a_q\ u_{av}^2\ (Sc/660)^{-0.5}$, where a_q = 0.39, the global gas exchange scaling factor

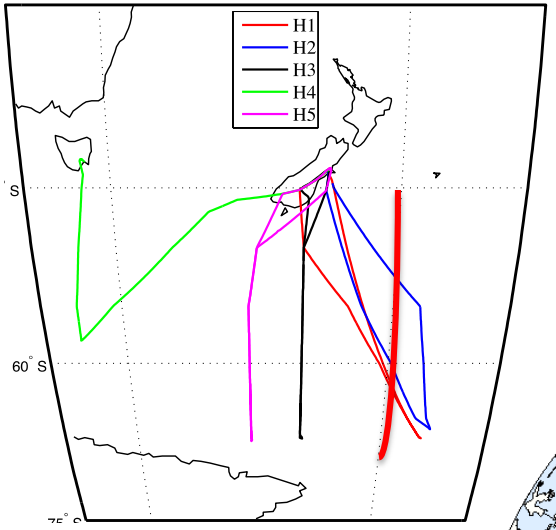
TRANSCOM models show improved agreement when averaged over the vertical column



Various TransCom model output using the same fluxes from dissolved climatologies (Garcia and Keeling 2001, Blaine 2005)

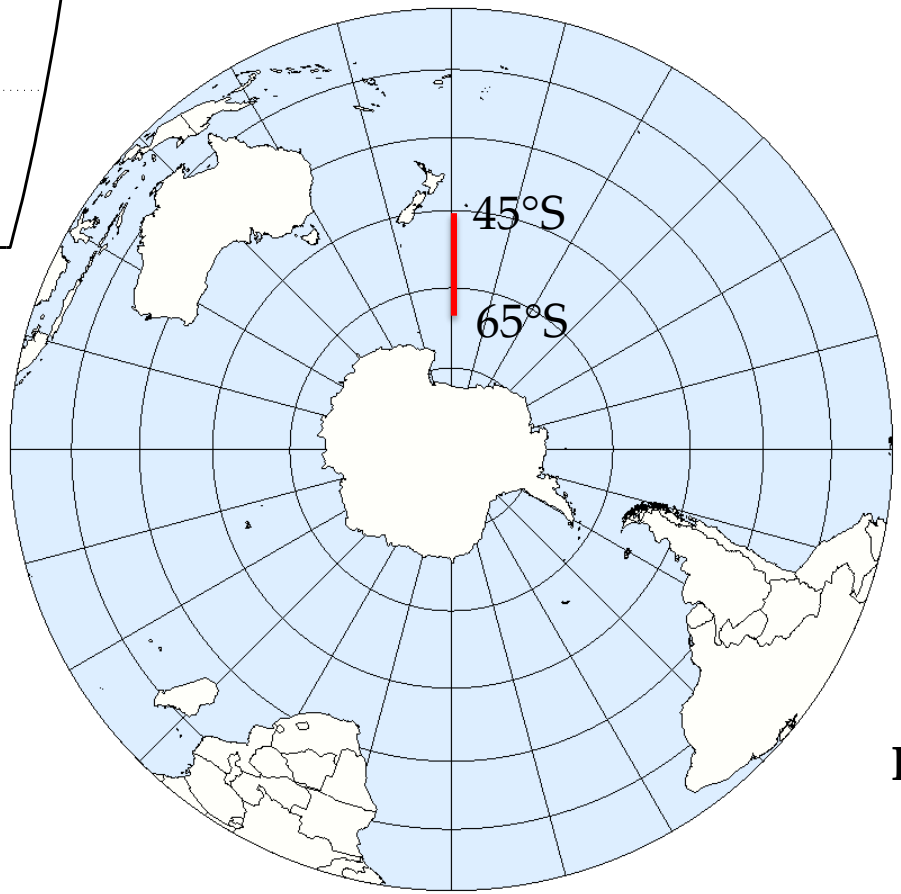
This shows that by removing vertical mixing uncertainty, transport models using the same ocean fluxes agree much better.

3. The Southern Ocean Curtain Average



Southern Ocean Slice

$$MI(C) = \frac{\sum_{i=-65^{\circ}}^{-45^{\circ}} \sum_{j=p_{surface}}^{300mb} C(i,j) * w(i,j)}{\sum_{i=-65^{\circ}}^{-45^{\circ}} \sum_{j=p_{surface}}^{300mb} w(i,j)}$$



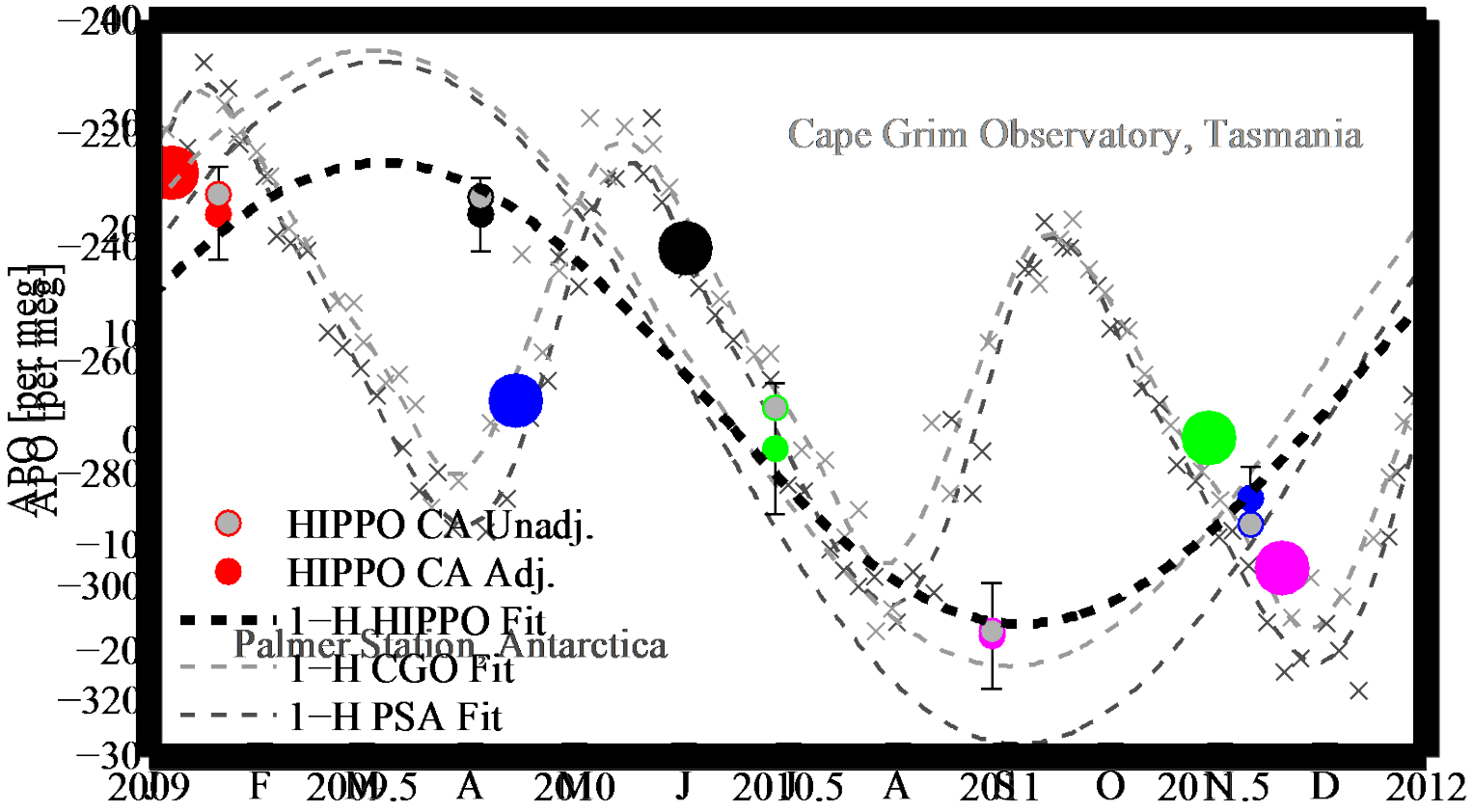
Curtain Average: Weighted average of APO performed along a meridian (roughly) on model output or observations. only possible with data throughout atmospheric column

65°-45°S
Surface->300mb
Flight Track or 180°W

Synoptic and spatial adjustments

Station vs. HIPPO APO Curtain Average

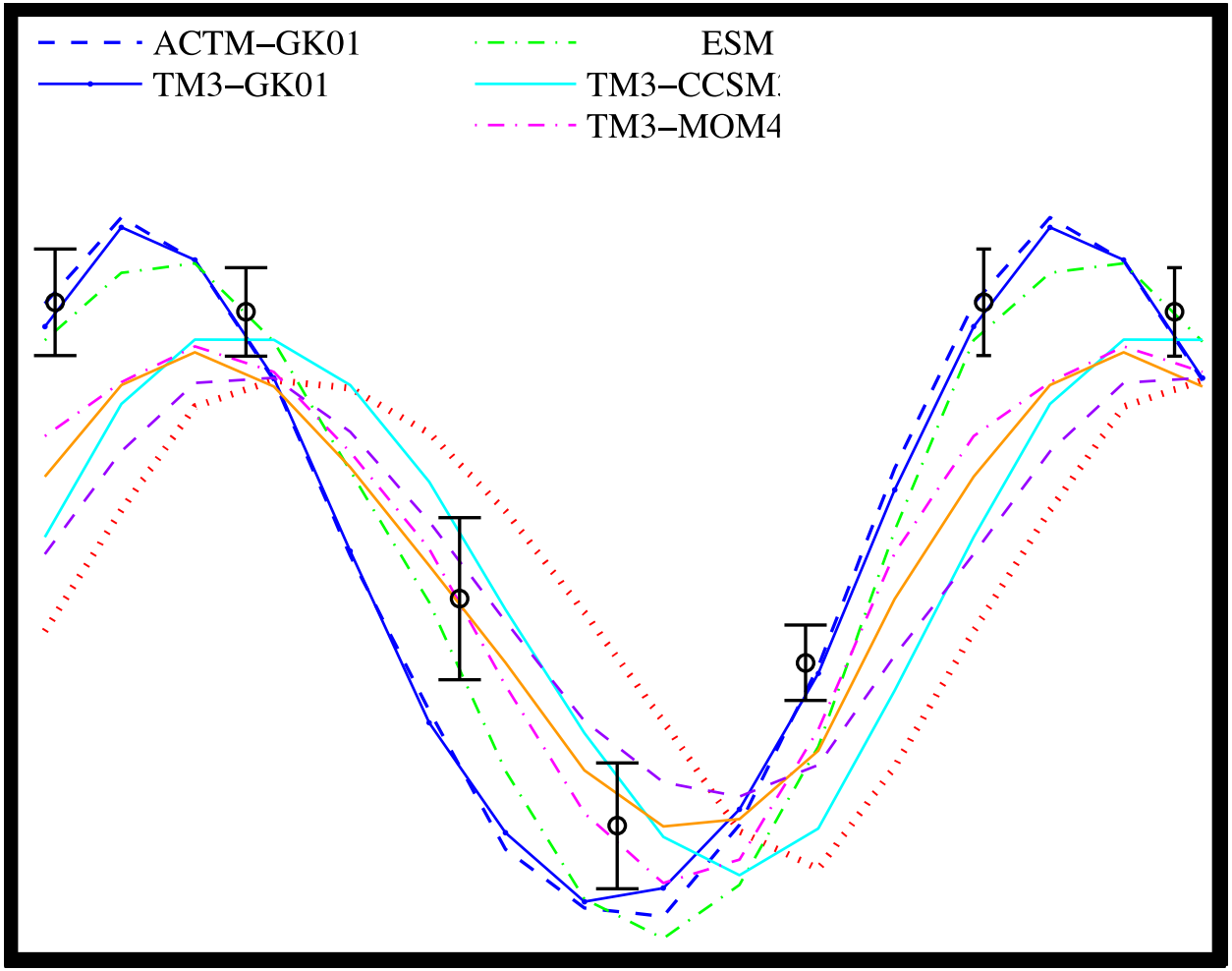
CGO: 58.7 per meg **PSA 65.0 per meg**



1-Harm Fit: **43.7 per meg**

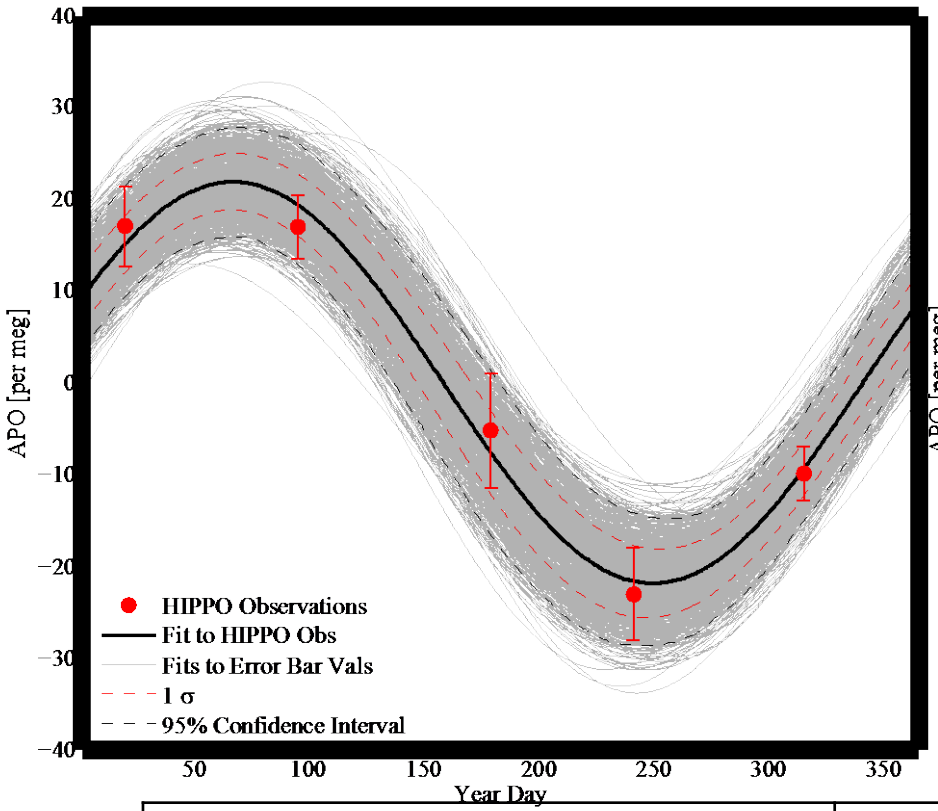
~70% Surface Cycle

Model Comparison

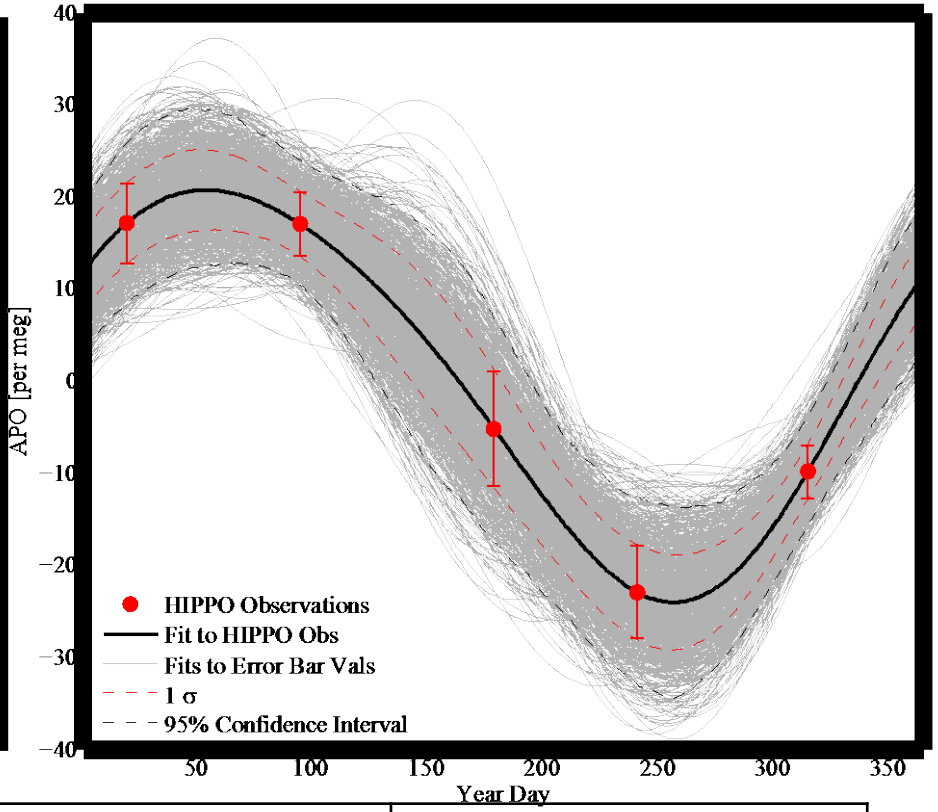


Monte Carlo Fit Error Assessment

1-Harm



2-Harm



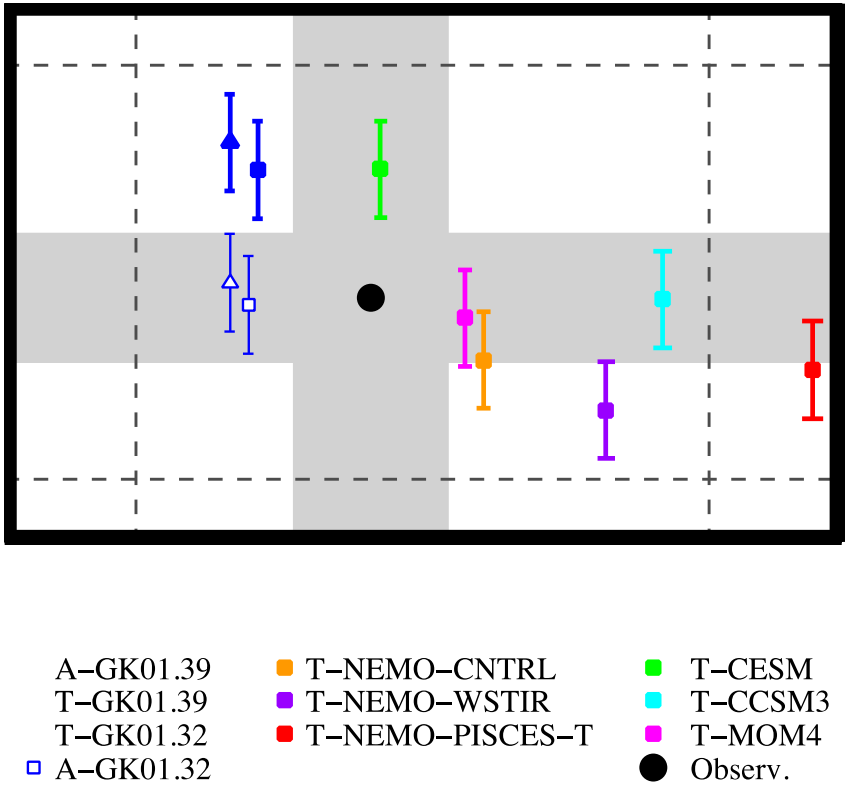
	1 Harmonic	2 Harmonics
Peak Day Uncert (Days)	**8.3**	24.0
Amplitude Uncert (per meg)	**5.3**	5.7

Peak timing vs. Amplitude

$K_{av}=\mathbf{a_q}\ u_{av}^2\ (Sc/660)^{-0.5}$

GK01, a_q=0.39 (~20% too large)

Naegler '06, a_q =0.32



Conclusions: Curtain Average

- Curtain average overcomes vertical mixing uncertainty in atmospheric transport models
- Southern Ocean slice curtain average has a seasonal cycle of 43.8 (±5.3) per meg for 1-Harmonic fits with peak at YD67
- Curtain Average suggests atmospheric column seasonal cycle is about 70% as large as seasonal cycle at surface
- MOM4 and NEMO-CNTRL ocean models reproduce this most successfully
- Dissolved climatology runs suggest Garcia and Keeling (2001) O_2 fluxes are too large (~20%), and too early (~2 weeks)
- (GK01 shape seems too symmetrical—new analysis recommended with new scaling factor and 2001-2014 O_2 measurements.)

Thanks

Measurements:

Ralph Keeling

Britt Stephens

Modelers:

Sara Mikaloff Fletcher (TM3)

Prabir Patra (ACTM)

Keith Rogers, Olivier Aumont (NEMO)

Corinne LeQuere (NEMO-PISCES-T)

John Dunne (MOM4)

Matt Long, Scott Doney, Ivan Lima (CCSM3, CESM)

Funding

HIPPO NSF grants:

ATM-0628575, ATM-0628519, ATM-0628388 ATM-0628452, and ATM-1036399

Interpretive work NSF grant OCE-1130976

NOAA

NCAR