Evidence that Palmer Station Antarctica seasonal O_2 and CO_2 cycles understate regional marine boundary layer means (with significant implications for ocean model validation)

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ABSTRACT

The Scripps O_2 Program has collected biweekly CO_2 and O_2 flasks samples from Palmer Station, Antarctica (PSA) since 1996. These data have served as an invaluable representation of regional carbon cycle signals, and play an essential role in evaluating how well ocean models capture Southern Ocean dynamics and surface productivity. Atmospheric CO_2 data reflect interfering oceanic solubility, upwelling and productivity signals, and are buffered by carbonate chemistry. Because of this, atmospheric O_2, and the related "atmospheric potential oxygen" (APO) quantity provide a much clearer representation of seasonal oceanic carbon cycle processes than CO_2 alone. There is growing evidence in the oxygen measurement community, however, that Scripps Palmer Station APO data may not accurately represent a regional marine boundary layer (MBL) mean, possibly because of wind direction sampling selection criteria that tend to favor downslope flow from the glacier above the station, and mountains to the East. In-situ shipboard data taken on the ASRV Laurence M. Gould between 2012 and 2016 near Palmer Station confirm this suspicion: a comparison of two-harmonic fits to station and Gould data suggests that the flasks understate the regional mean MBL seasonal cycle by at least 15%. We present an observation- and modeling-based study of the differences in the two datasets, leveraging recent airborne data near Palmer Station from the ORCAS campaign on the NCAR Gulfstream V. We focus on addressing sampling bias, and reconciling prior measurements with current understanding so that scientists can better evaluate ocean models with representative data.

APO, a.k.a. Oceanic O_2 [per meg] = O_2 + (1.1/0.2094) * CO_2

O_2 (and Oceanic O_2) is reported in units of "per meg", notionally similar to "per mil", but a one part in a *million* deviation from a standard reference gas. A change of 5 per meg in O_2 is roughly equivalent to a ppm because it is relative to O_2 (~20.94% of atmosphere). Oceanic O_2 is computed by "removing" the measured atm. CO_2 associated with land photosynthesis/respiration assuming a stochiometry of 1.1 mol O_2:1 mol CO_2.

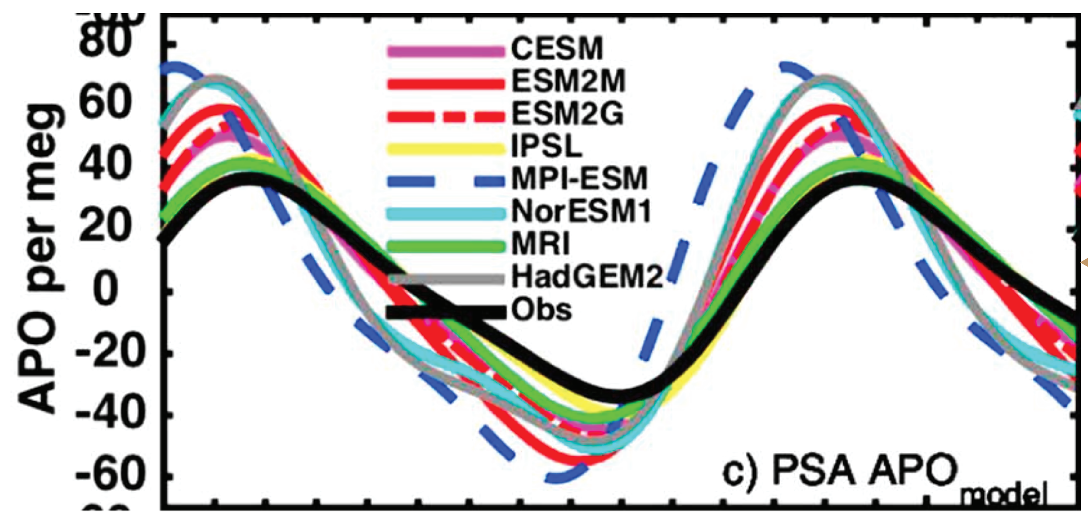

Figure 1. CMIP5 model atmospheric potential (oceanic) oxygen estimates from Nevison et al., 2016. All models anticipate the timing of, and overstate the amplitude of the seasonal cycle relative to observations at Palmer Station, Antarctica.

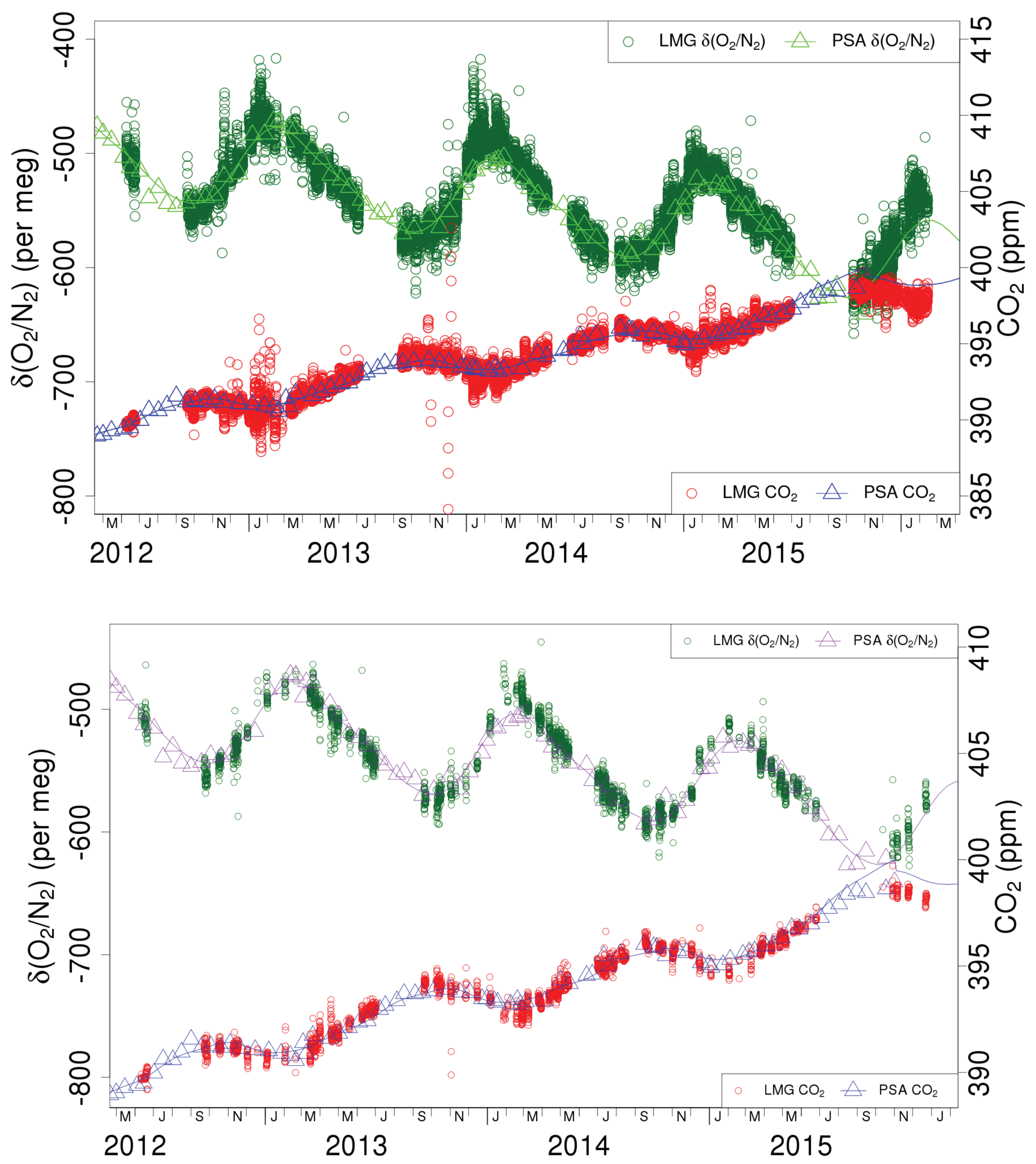

Figure 2. ASRV Gould *in situ* (LMG) and Palmer Station Flask data (PSA) compared using regional data south of 56 S (upper), and data just at Palmer Station (lower). Gould data show larger, earlier seasonal cycles in both cases, with differences between records much more pronounced in austral summer (January) than at the nadir (September).

FINDINGS AND CONCLUSIONS:

ASRV Gould data show significantly earlier oceanic oxygen peaks (~1 month), and larger amplitudes (~15%) than Palmer Station flasks, with Gould values diverging substantially in austral summer (peak) times, but not during September (nadir) times. Wind domains for the two datasets at Palmer Station are very different, and HYSPLIT back trajectories suggest that sample air from the "Palmer" domain tends to descend over the Antarctic Peninsula before reaching the station, while "Gould" domain air tends to arrive at Palmer Station after traversing open ocean, largely marine boundary layer, conditions. Accordingly, the two wind domains represent very different provenances, with the "Palmer" domain representing roughly half boundary layer, and half free troposphere air. Analysis of interannually detrended vertical aircraft profiles sampled at the same latitude in the HIPPO and ORCAS campaigns shows that the vertical gradient in oceanic O_2 is steep at peak times, and virtually non-existent at the nadir, suggesting that a mixture of surface and deep troposphere air would be similar to surface values near the seasonal nadir, but very different from surface at the seasonal peak. This suggests that Palmer Station flask data do not represent marine boundary layer conditions well, especially at the seasonal atmospheric peak.

Several recent studies (e.g. Nevison et al. 2012, 2016, Rodgers et al. 2013) use oceanic O_2 to validate ocean biogeochemistry results over the Southern Ocean, as mentioned in the abstract. We suggest that future such studies rely on Gould observations as a representation of marine boundary layer conditions along the south edge of the Drake Passage for now. However, we anticipate producing an averaging kernel to represent the height spectrum of Palmer Station flask samples so that modelers can sample from multiple atmospheric levels for future Palmer Station comparisons.

Citations:

-Nevison, C. D., Manizza, M., Keeling, R. F., Stephens, B. B., Bent, J. D., Dunne, J., ... & Yukimoto, S. (2016). Evaluating CMIP5 ocean biogeochemistry and Southern Ocean carbon uptake using atmospheric potential oxygen: Present-day performance and future projection. Geophysical Research Letters, 43(5), 2077-2085.

-Nevison, C. D., et al. "Estimating net community production in the Southern Ocean based on atmospheric potential oxygen and satellite ocean color data." Global Biogeochemical Cycles 26.1 (2012).

-Rodgers, K. B., Aumont, O., Fletcher, S. M., Plancherel, Y., Bopp, L., Montégut, C. D. B., ... & Wanninkhof, R. (2014). Strong sensitivity of Southern Ocean carbon uptake and nutrient cycling to wind stirring. Biogeosciences, 11(15), 4077-4098.

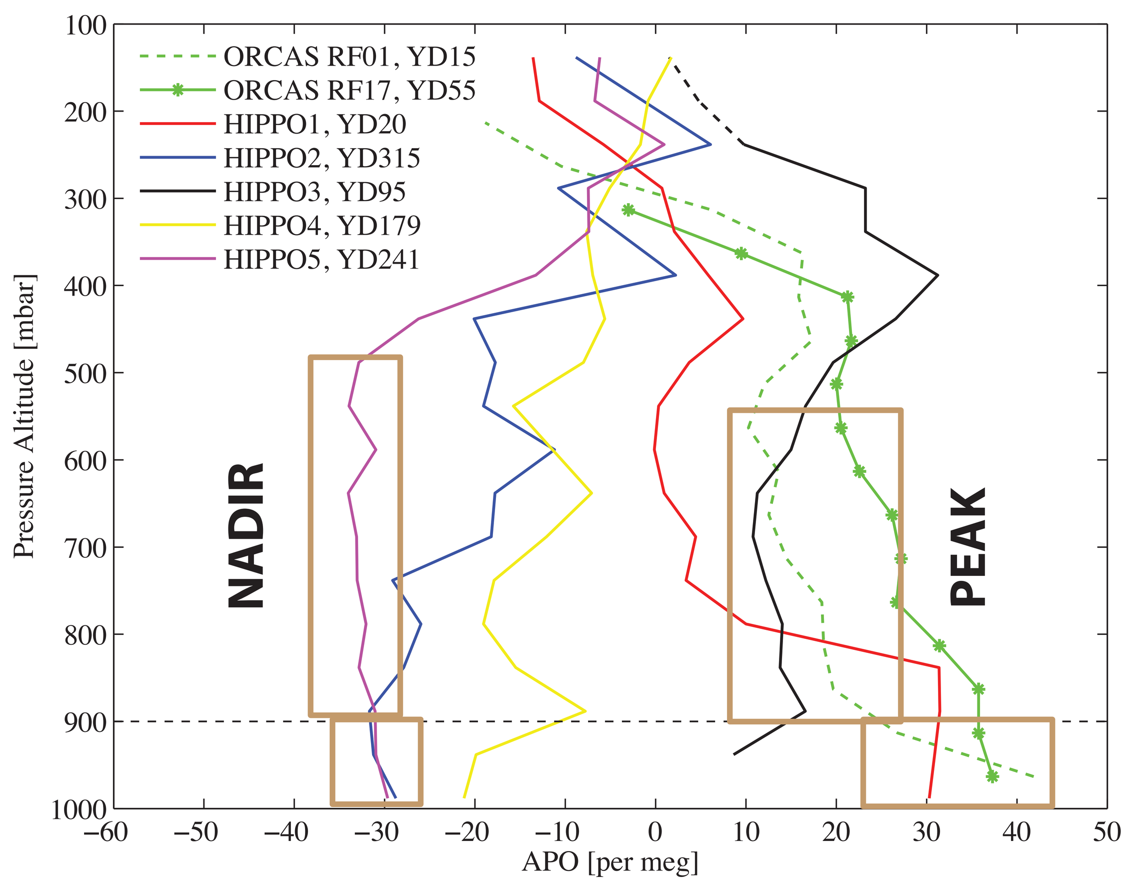

Figure 6. Vertical profiles of APO from HIPPO and ORCAS campaigns, showing that the boundary layer and free troposphere are quite different in value depending on time of year, with little expected offset from surface values at the nadir, but with large (~10+ per meg) offsets expected due to mixing of back-trajectory particles at peak.

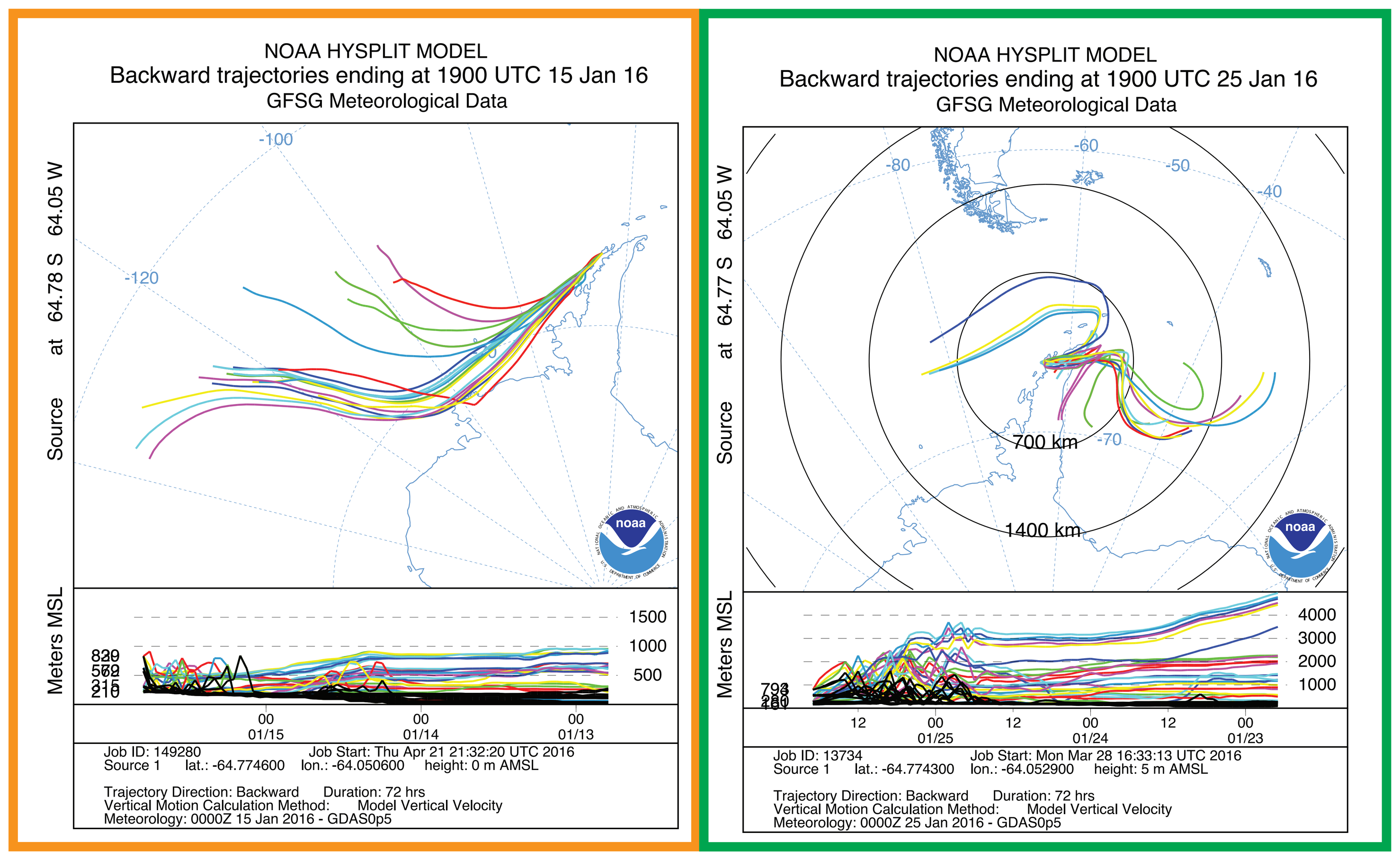

Figure 5. Comparison of typical back-trajectories for Gould *in situ* (left) and Palmer Flask (right) wind domains, showing that the Antarctic Peninsula and Anvers Island Glacier strongly influence the origin of particles, causing Palmer flask samples to be representative of a rough average of the atmospheric column, while Gould samples represent almost exclusively marine boundary layer air.

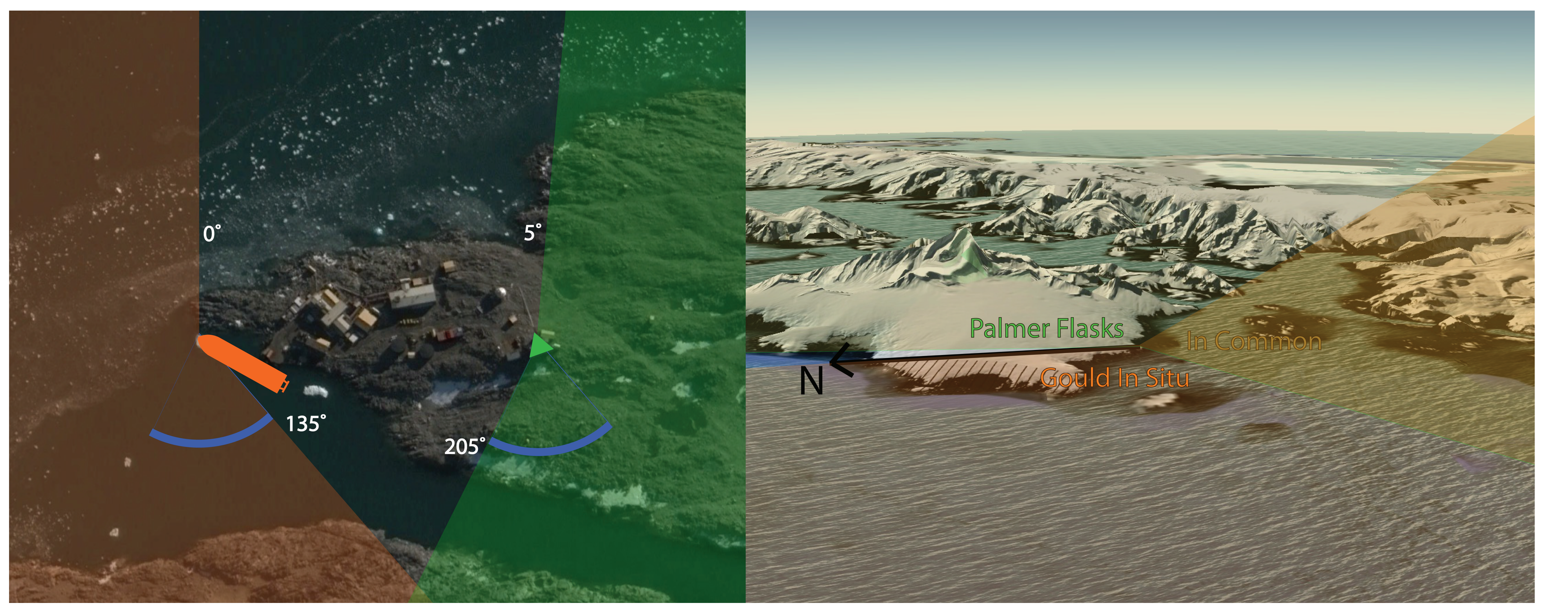

Figure 4. Palmer Station and ASRV Gould acceptable sampling wind domains, and local spheres of influence.

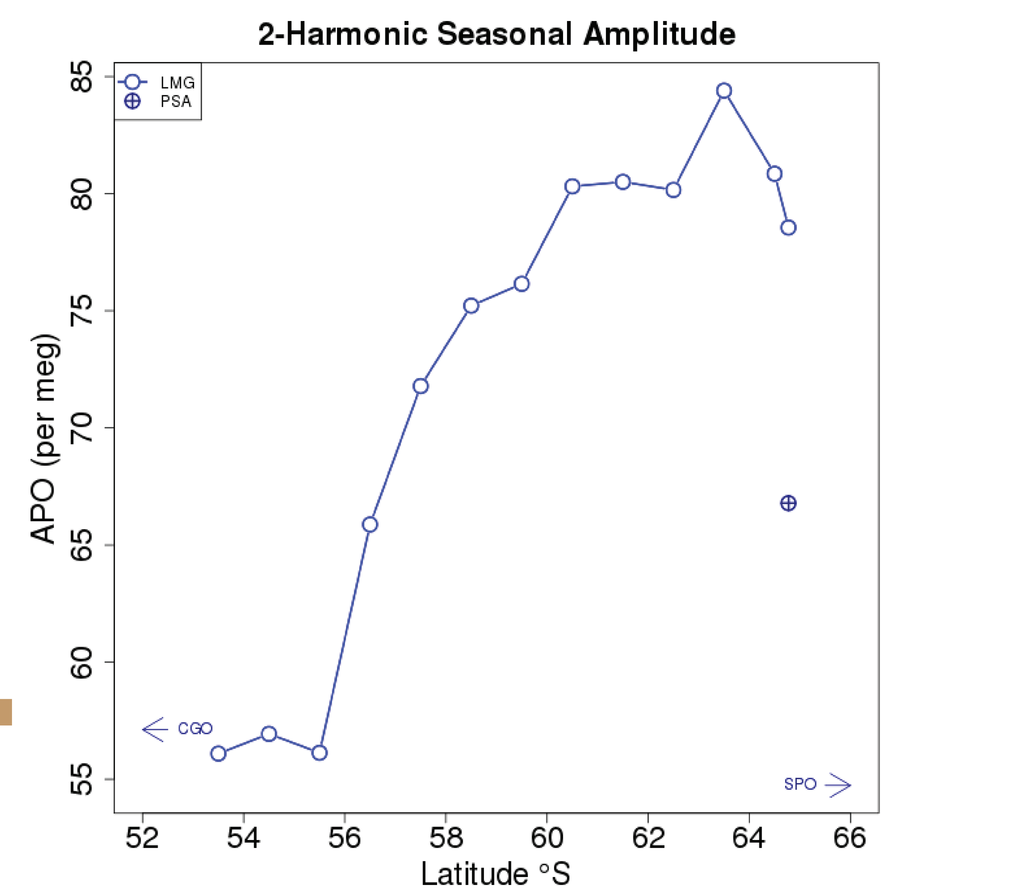

Figure 3. 2-harmonic seasonal amplitude of Gould in situ data by 1-degree bins (circles), showing that shipboard data predicts much larger seasonal amplitudes south of 57°S than Palmer Station (circle with cross) shows.