Average seasonal cycles of atmospheric potential oxygen (APO) in the Pacific region: possible autumn ocean O_2 emissions

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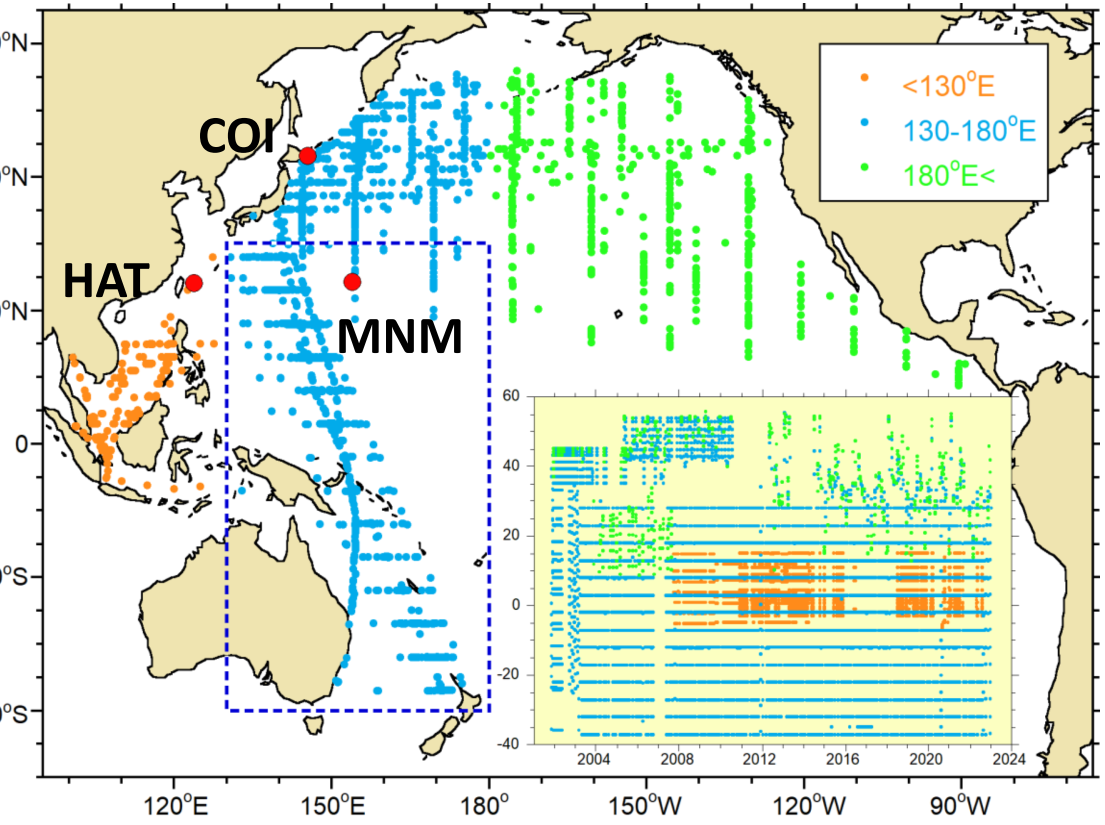
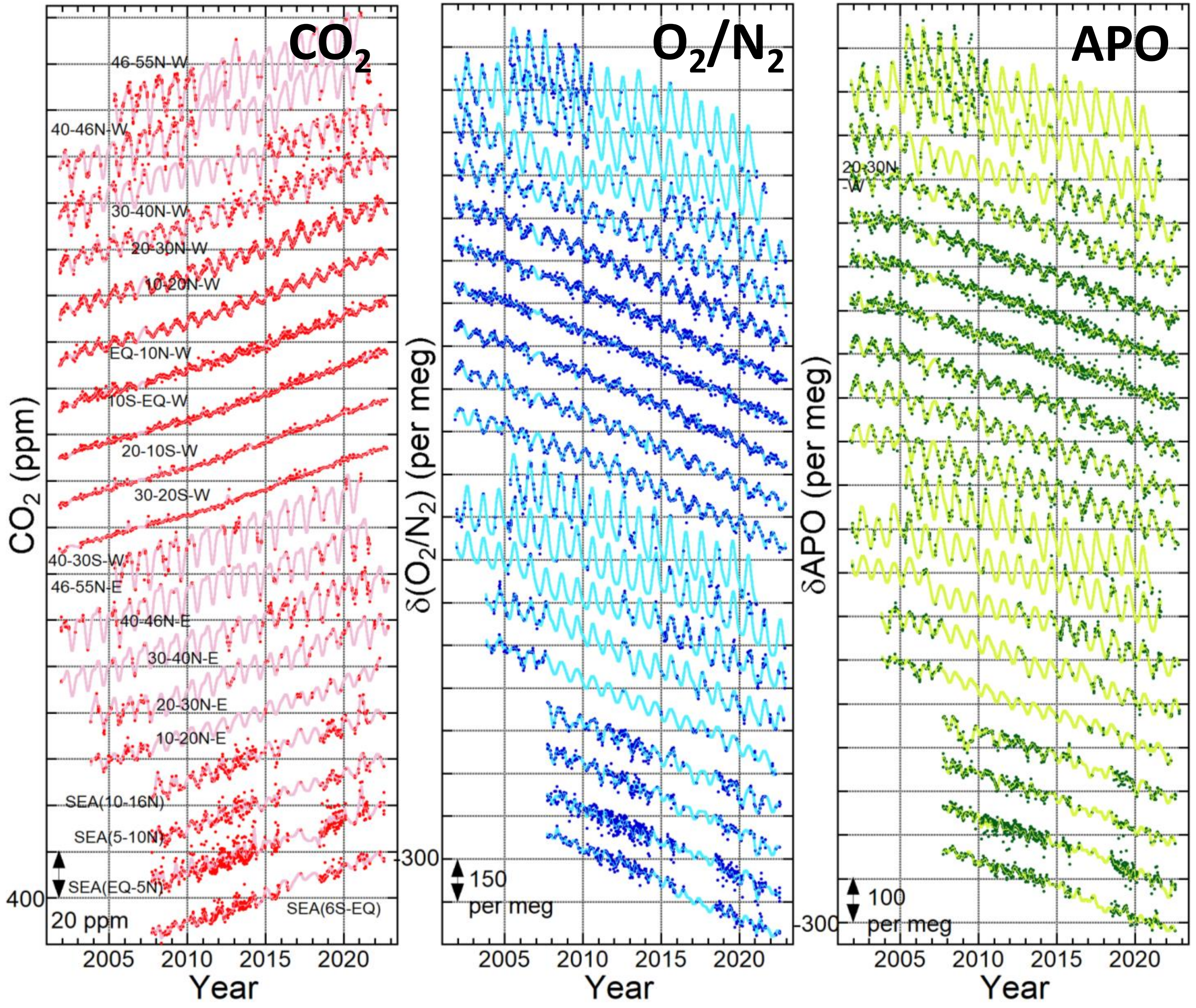
Observed time series of CO_2, O_2, and APO

Sampling Location





Global carbon budgets based on observed APO

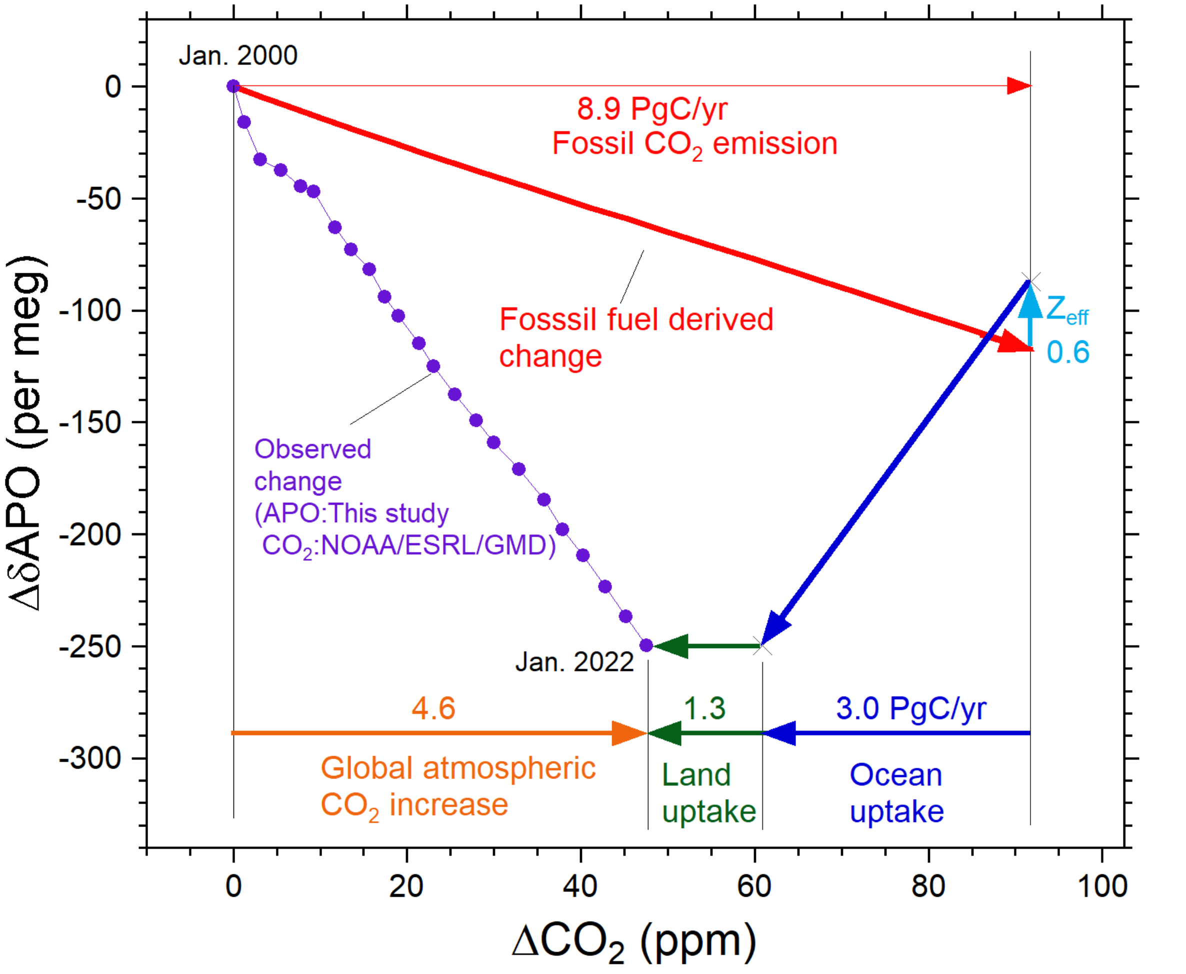
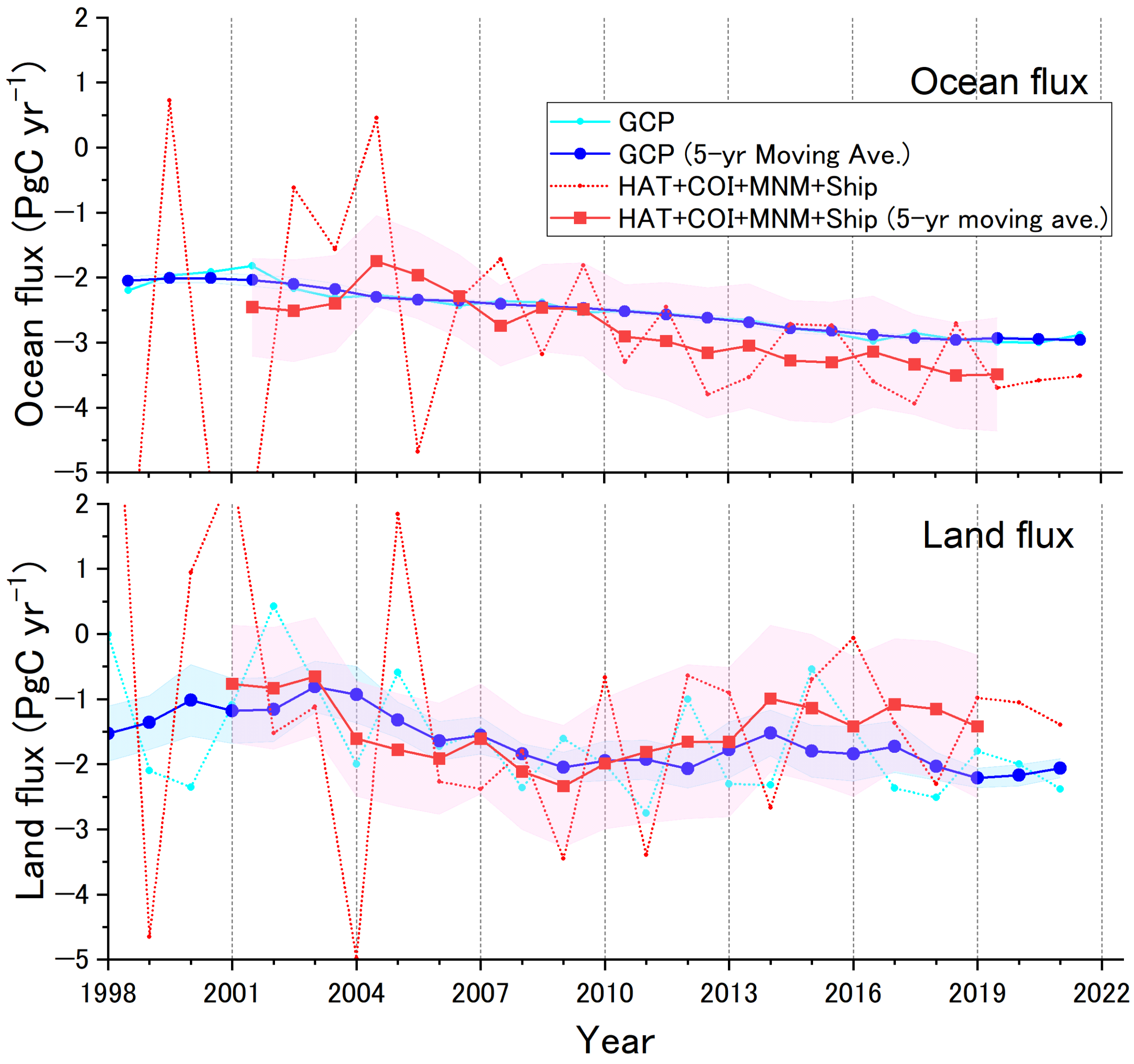
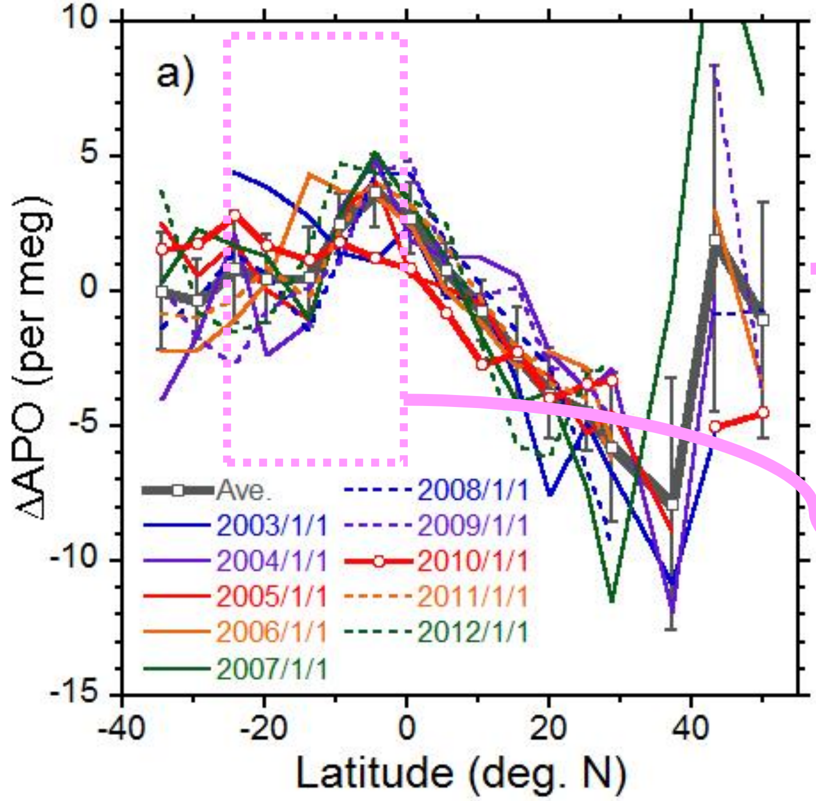


Fig. 6. Vector analysis showing the calculation of global carbon budget based on the atmospheric CO_2 and APO changes for the period from Jan. 2000 to Jan. 2022.

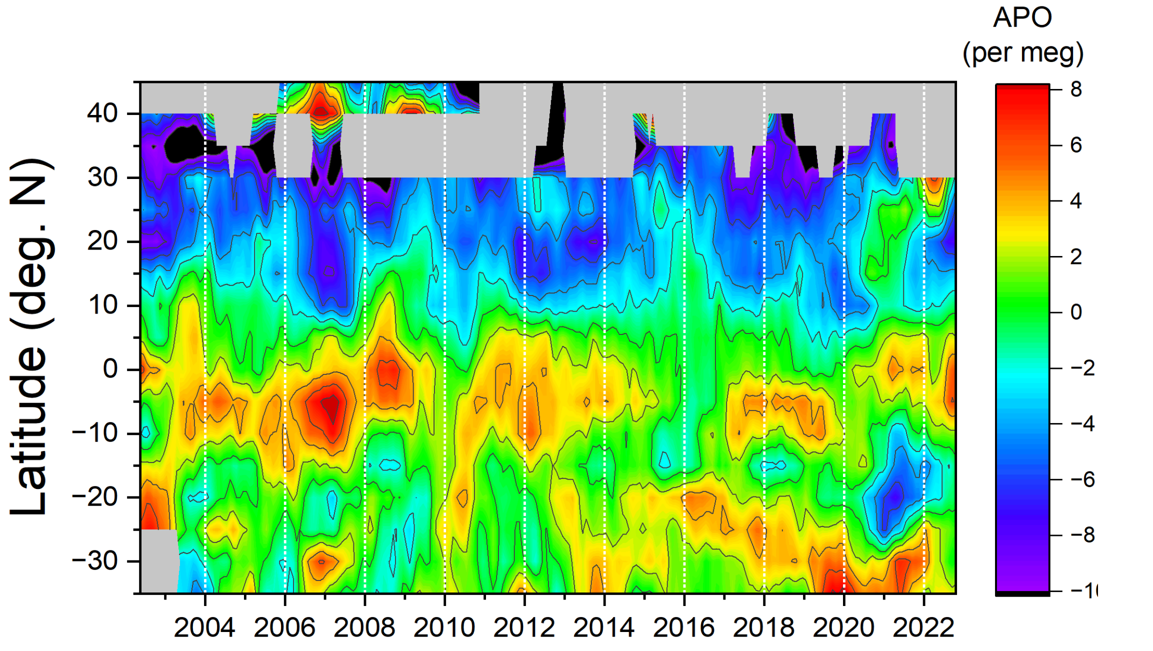


(Tohjima et al. [2019] and the extended data)

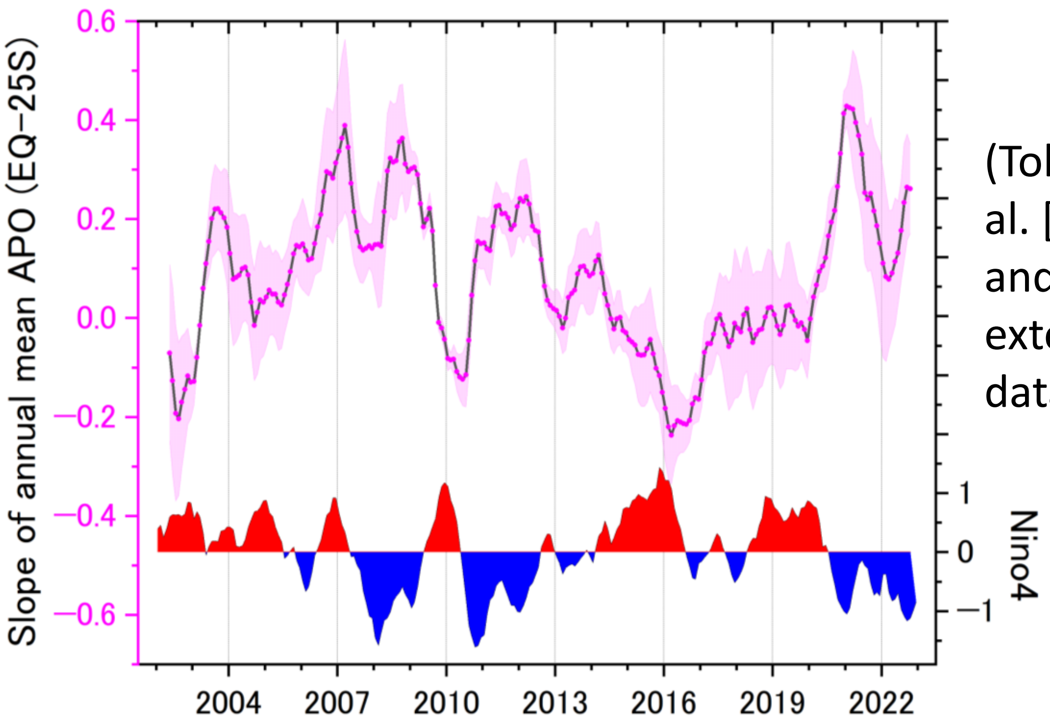
Temporal variation in the latitudinal distribution of annual mean APO (AM-APO)



Time-latitude distribution of AM-APO

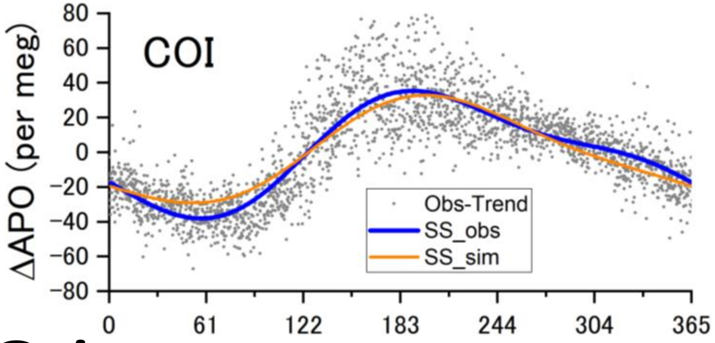


Temporal variation in gradient between 25S and Equator.



(Tohjima et al. [2015] and the extended data)

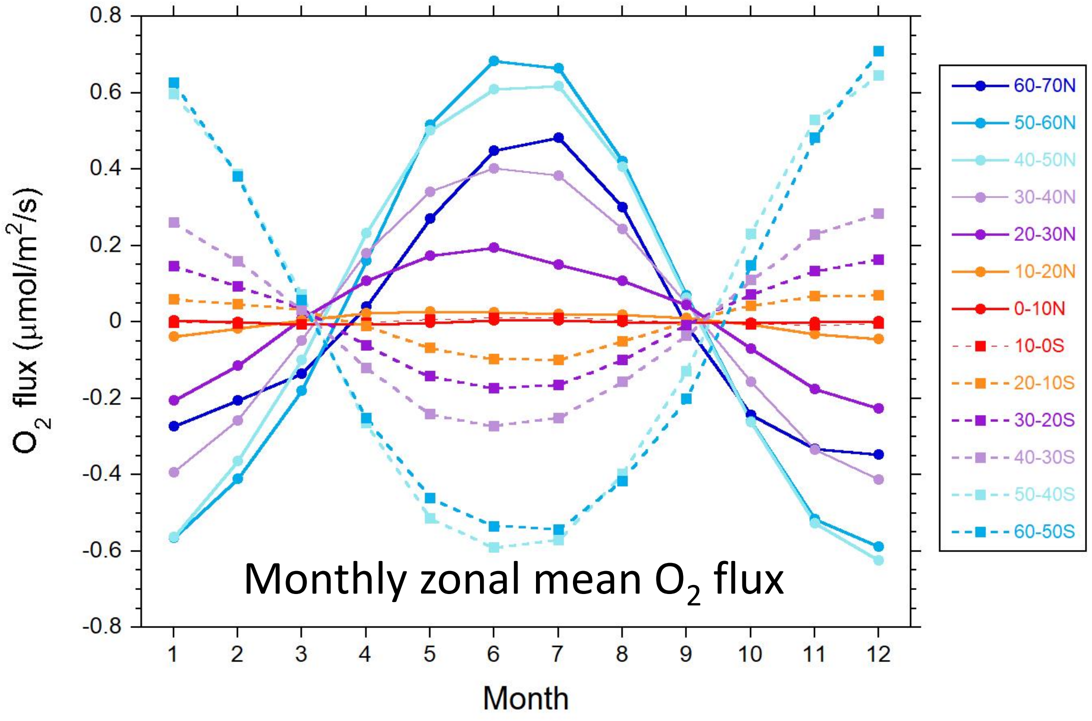
Outline of today’s presentation･･･

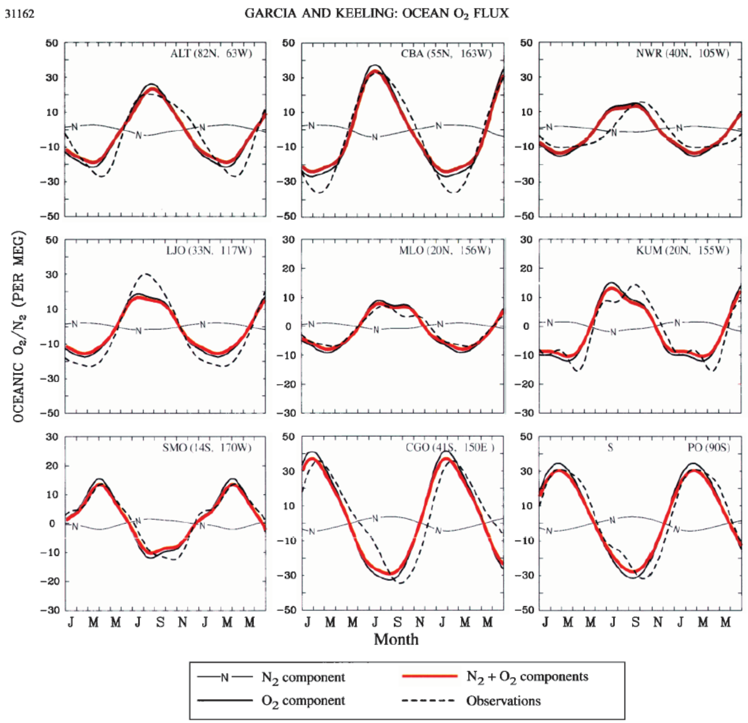


- Calculate average seasonal cycles of APO in Pacific region based on the flask samples.
- Compare seasonal cycles between observation and simulation.
  - Climatological ocean O_2 fluxes from Garcia and Keeling (2001) was used to simulate APO.
- Examine the difference from the viewpoint of air-sea O_2 fluxes.

Garcia & Keeling (2001): Global monthly climatology of air-sea O_2 fluxes

- Air-sea O_2 fluxes were estimated from ocean heat flux anomalies and linear regressions between the heat flux anomalies and air-sea O_2 flux.



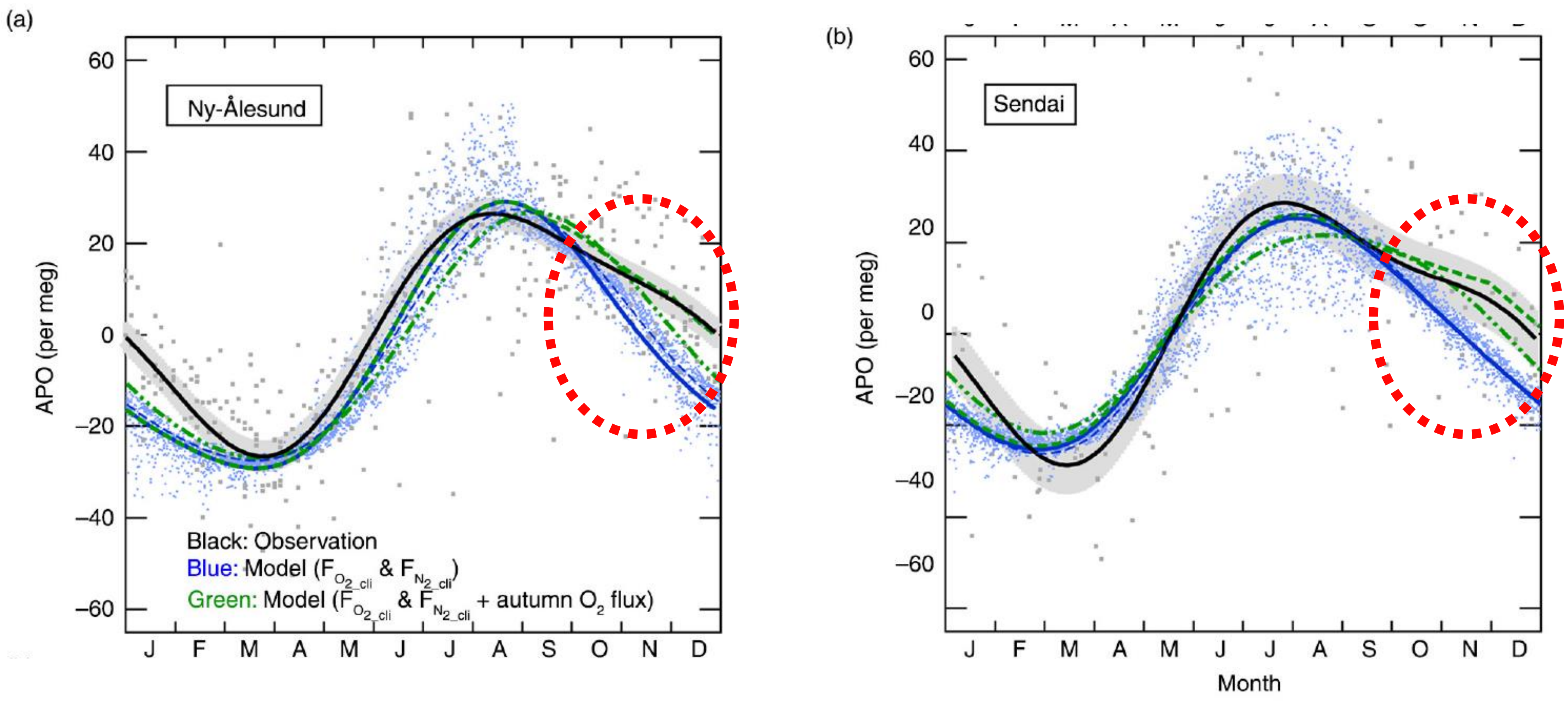


"The simulated O_2/N_2 variations ... lead the atmospheric observations by slightly less than a month. … some phase lag is expected on the basis of mixed layer equilibration time for O_2 of a few weeks…" (Garcia and Keeling, 2001)

Garcia and Keeling (2001)

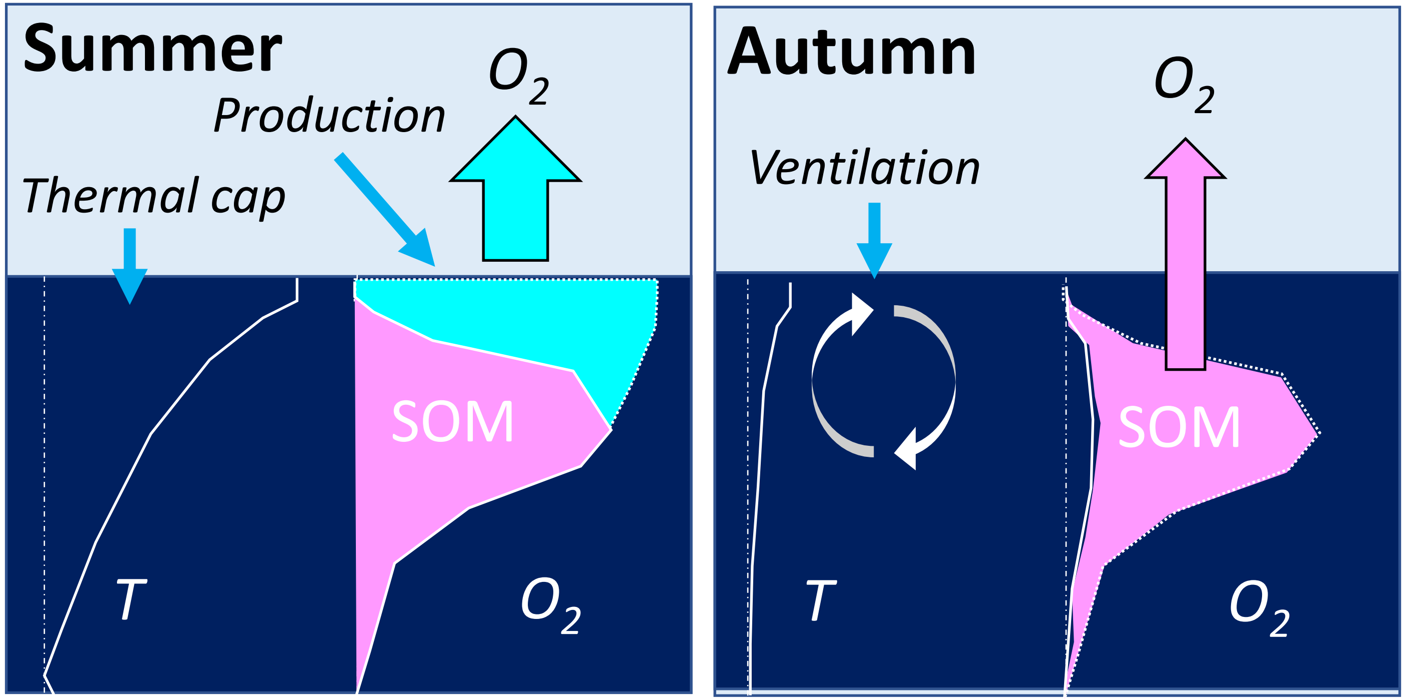
Discrepancy in APO seasonal cycle between observation and model in fall

(Ishidoya et al., 2016)



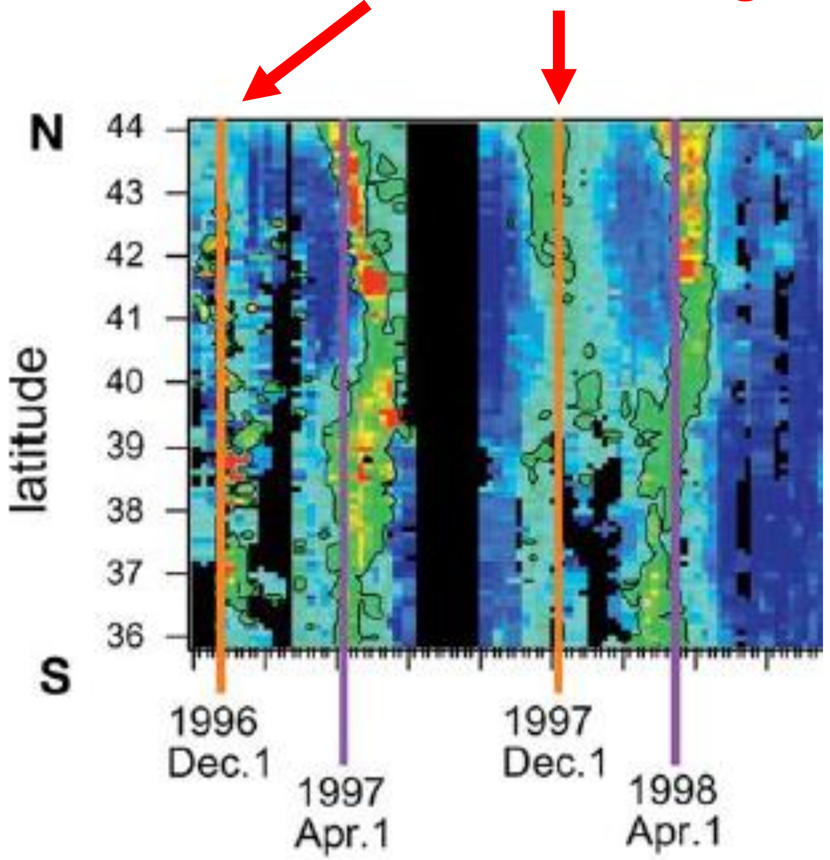
Potential mechanisms for ocean O_2 emissions in fall

□ O_2 emission from SOM associated with fall overturning



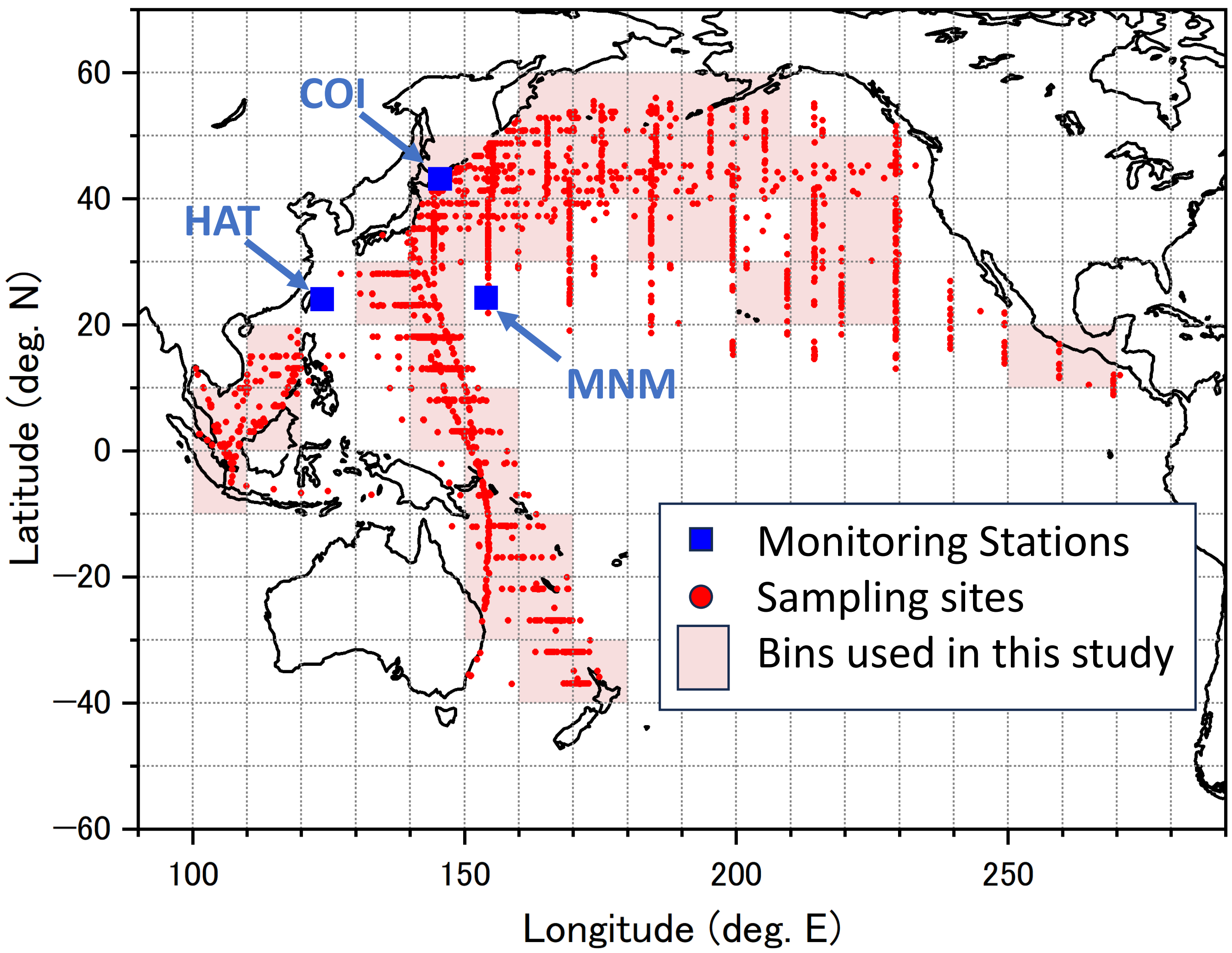
Mechanisms of formation and disappearance of subsurface shallow oxygen maximum (SOM)

□ O_2 emission associated with fall blooming



Chlorophyll *a* concentration from satellite

Average APO seasonal cycles for three fixed sites and 42 10ºx10º bins



Fixed sites:
HAT (Hateruma Island, Jul. 1997~)
COI (Cape Ochiishi, Dec. 1999~)
MNM (Minamitorishima, 2011~)

Onboard cargo ships:
North America route (Dec. 2001~)
New Zealand/Australia route (Dec. 2001~)
Southeast Asia route (Sep. 2007~)

The APO data from the cargo ships were binned into 10º × 10º bins (see left figure). The 42 bins, that have enough data number for the seasonal analysis, were used in this study.

Model simulation and regression analysis

Table 1 Model and data used in simulation

Data sources & model	References
Atmos. Trans. model	NIES-TM
Meteorological data	JRA55 reanalysis data
Calculation period	2000-2016
Ocean fluxes	
O_2 annual mean	Gruber et al. (2001)
N_2 annual mean	Gloor et al. (2001)
O_2 seasonal anomaly	Garcia & Keeling (2001)
N_2 seasonal anomaly	Blaine (2005)
CO_2 monthly mean	Takahashi et al. (2009)
Fossil fuel O_2 and CO_2 fluxes	CDIAC(2016) CO_{2}_ff x -1.4

Calculation of seasonal cycle

1) Remove the long-term trend (quadratic polynomial) from the data of the fixed site or the 10x10 bin.

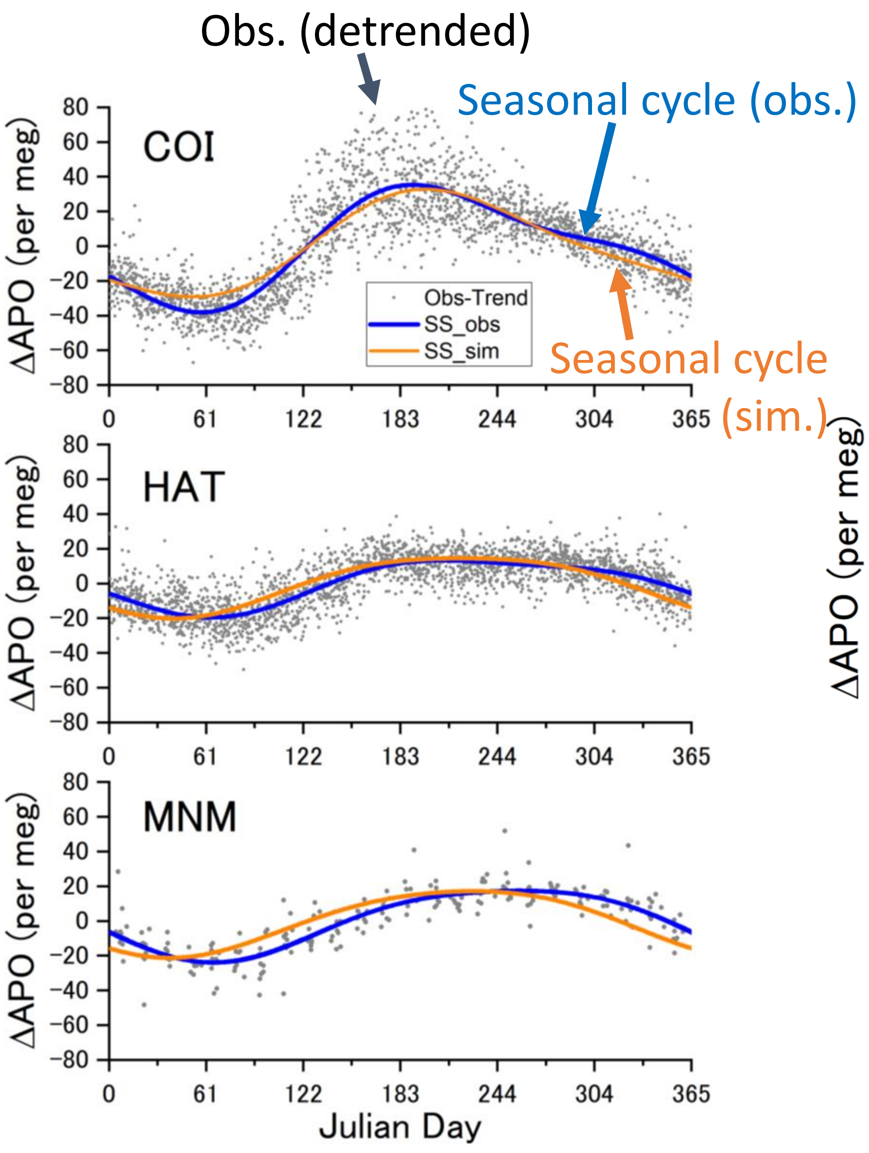
2) Prepare the dataset of the same size as the original dataset of the detrended APO by random sampling with replacement.

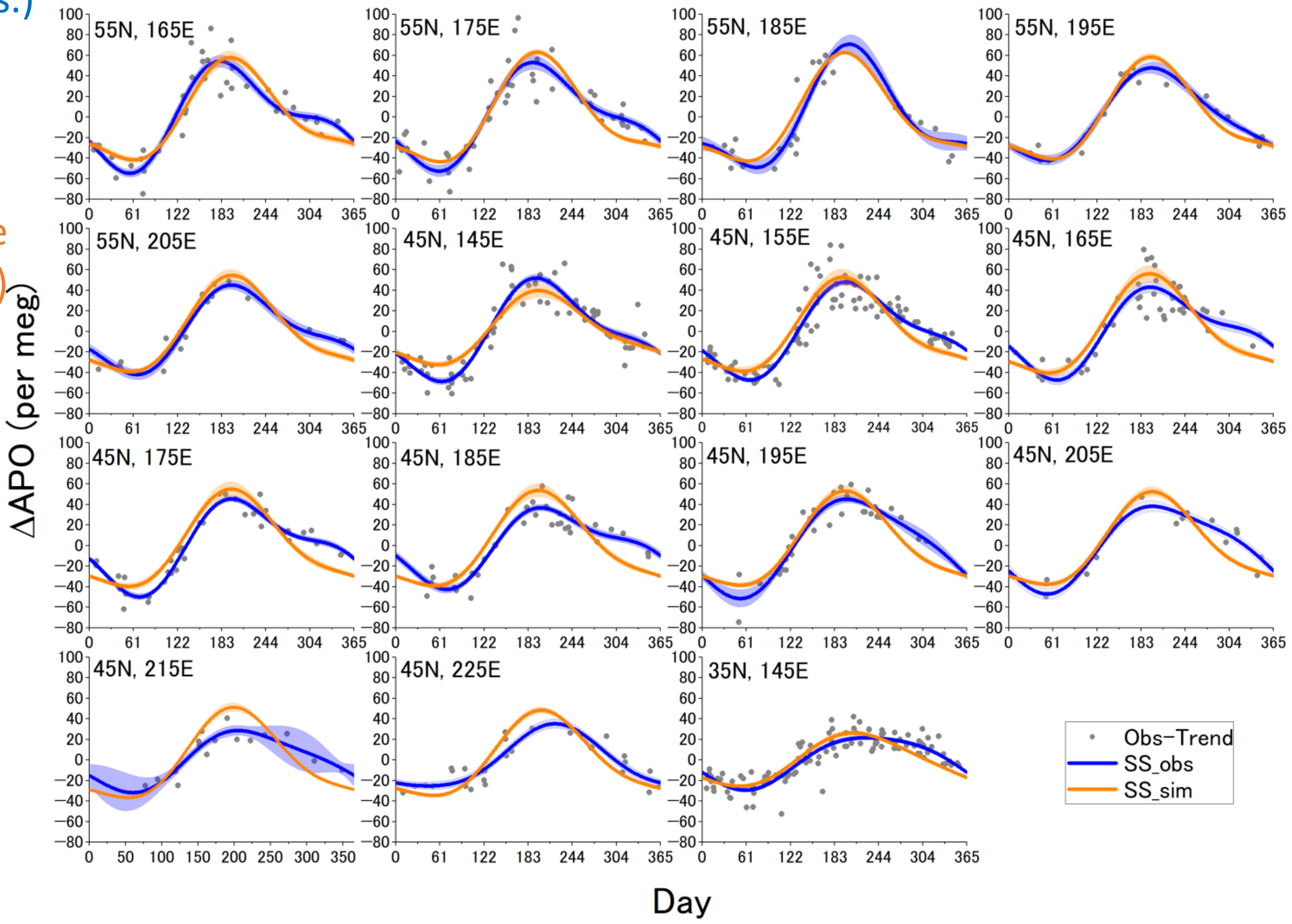
3) Fit the above dataset with a function of sum of first and second harmonics by a least square method.

$$y = \sum_{i=1}^{2} \{a_i sin(2\pi i t) + b_i cos(2\pi i t)\}$$

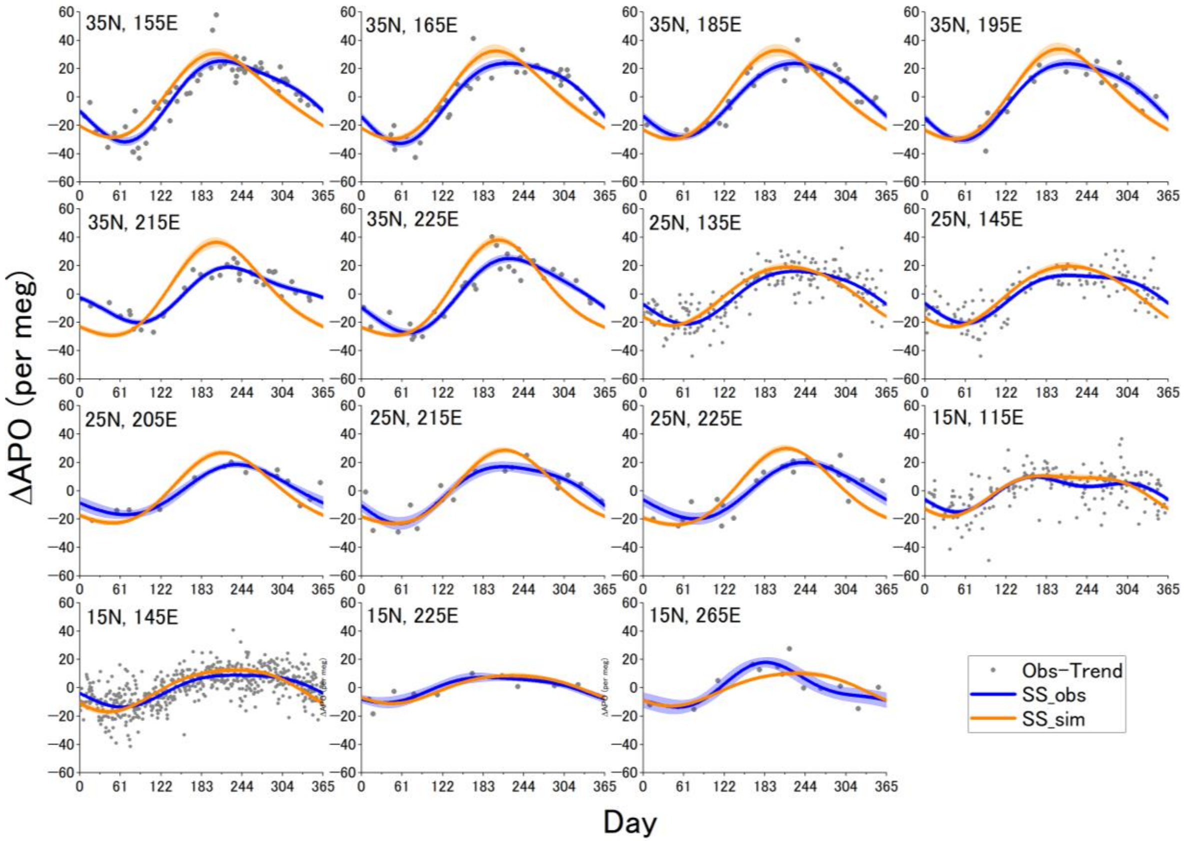
4) Repeat above procedure (n=10000).

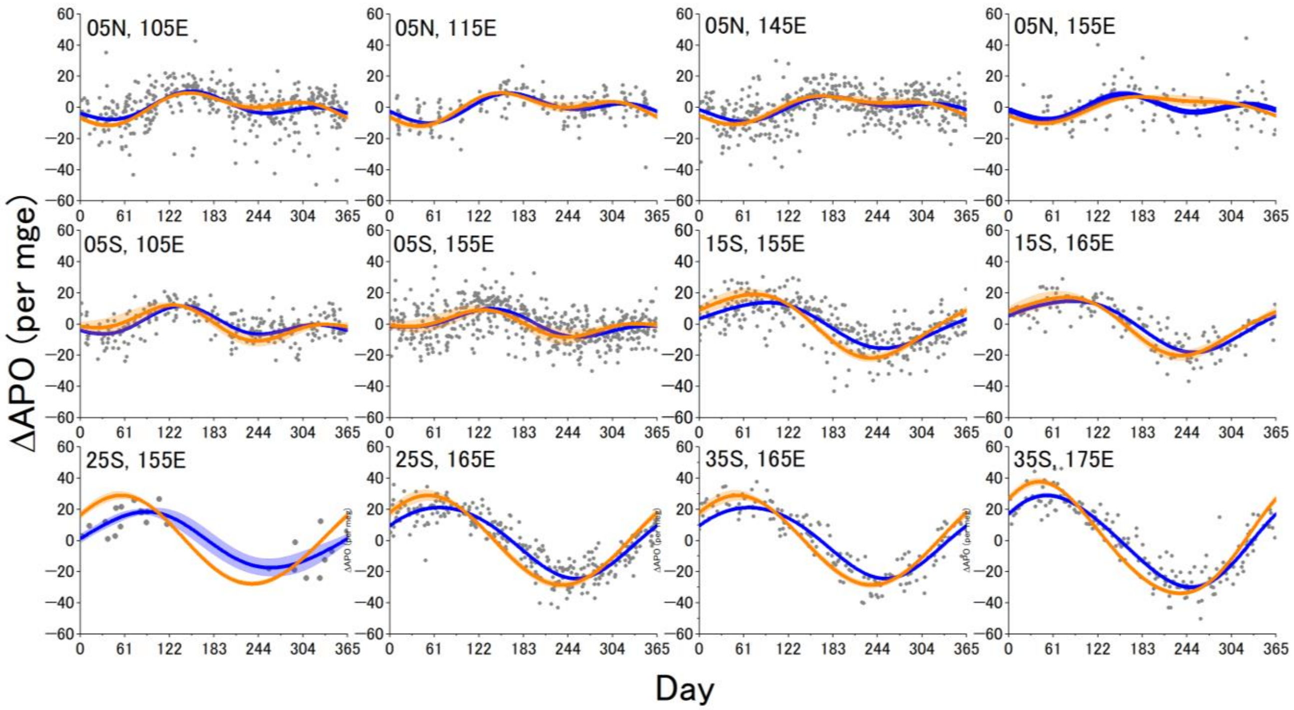
Average seasonal cycles in Pacific region



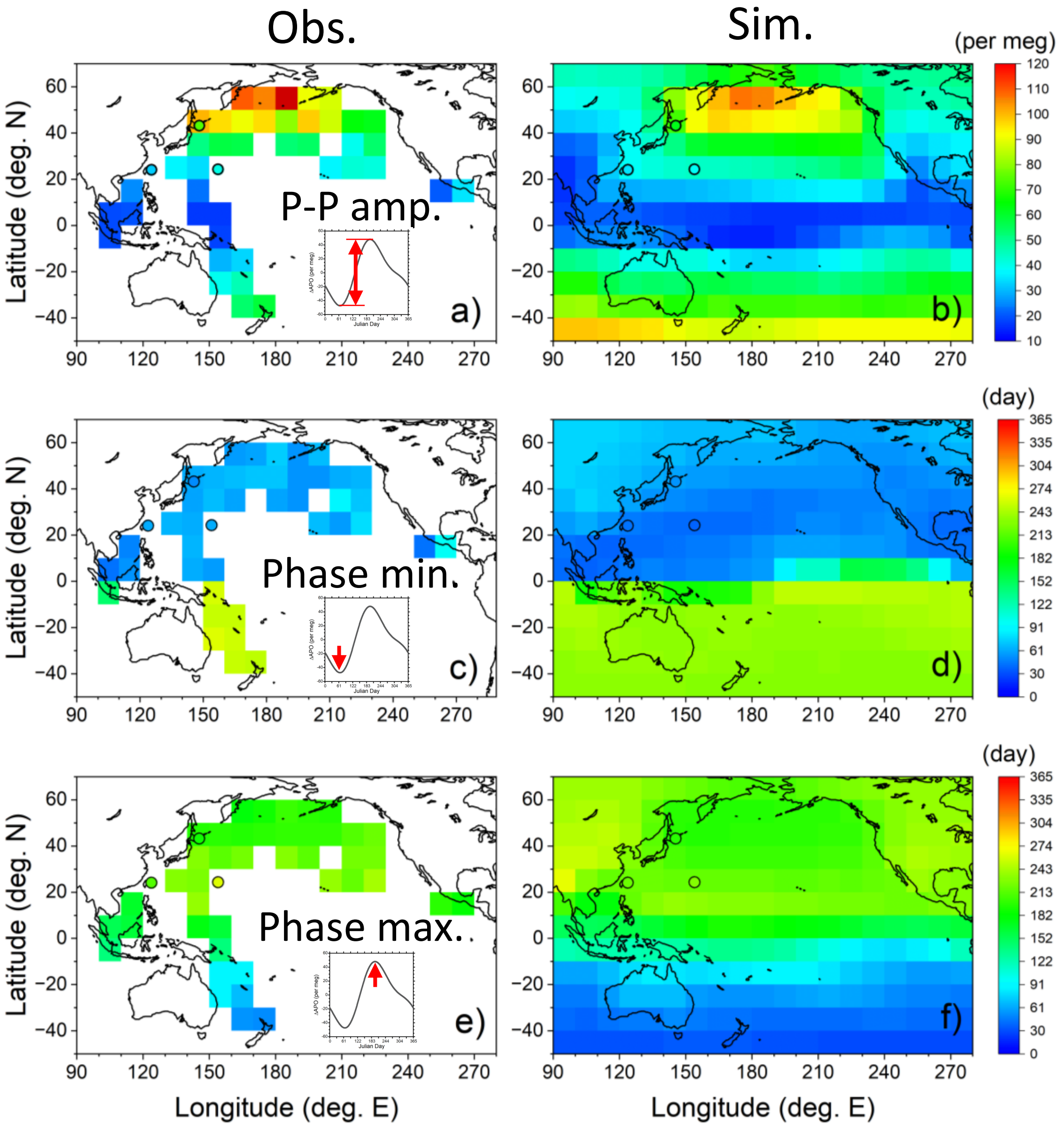


Average seasonal cycles in Pacific region

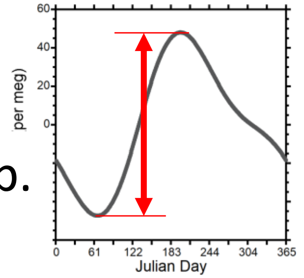


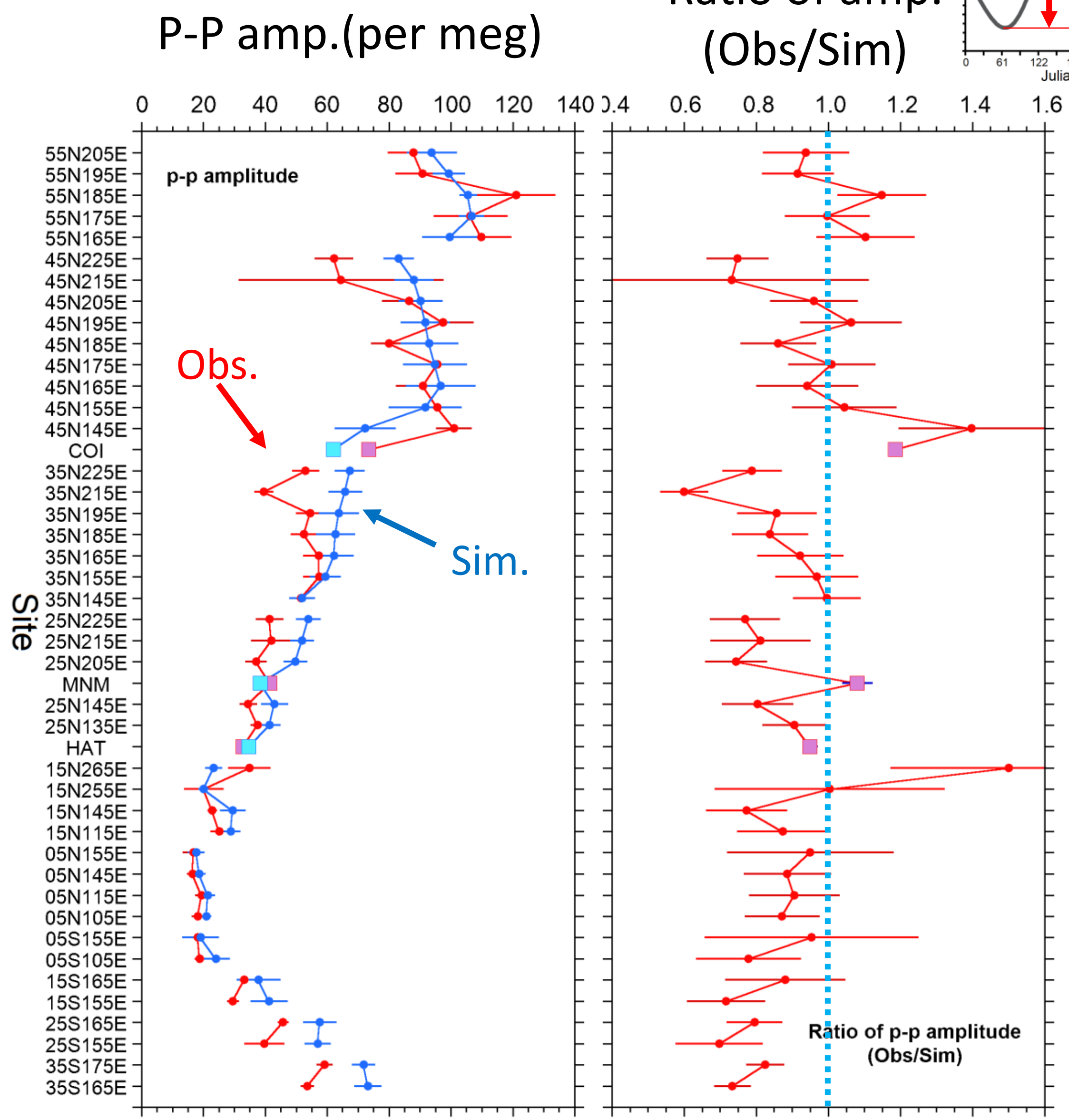


Comparison of APO seasonality

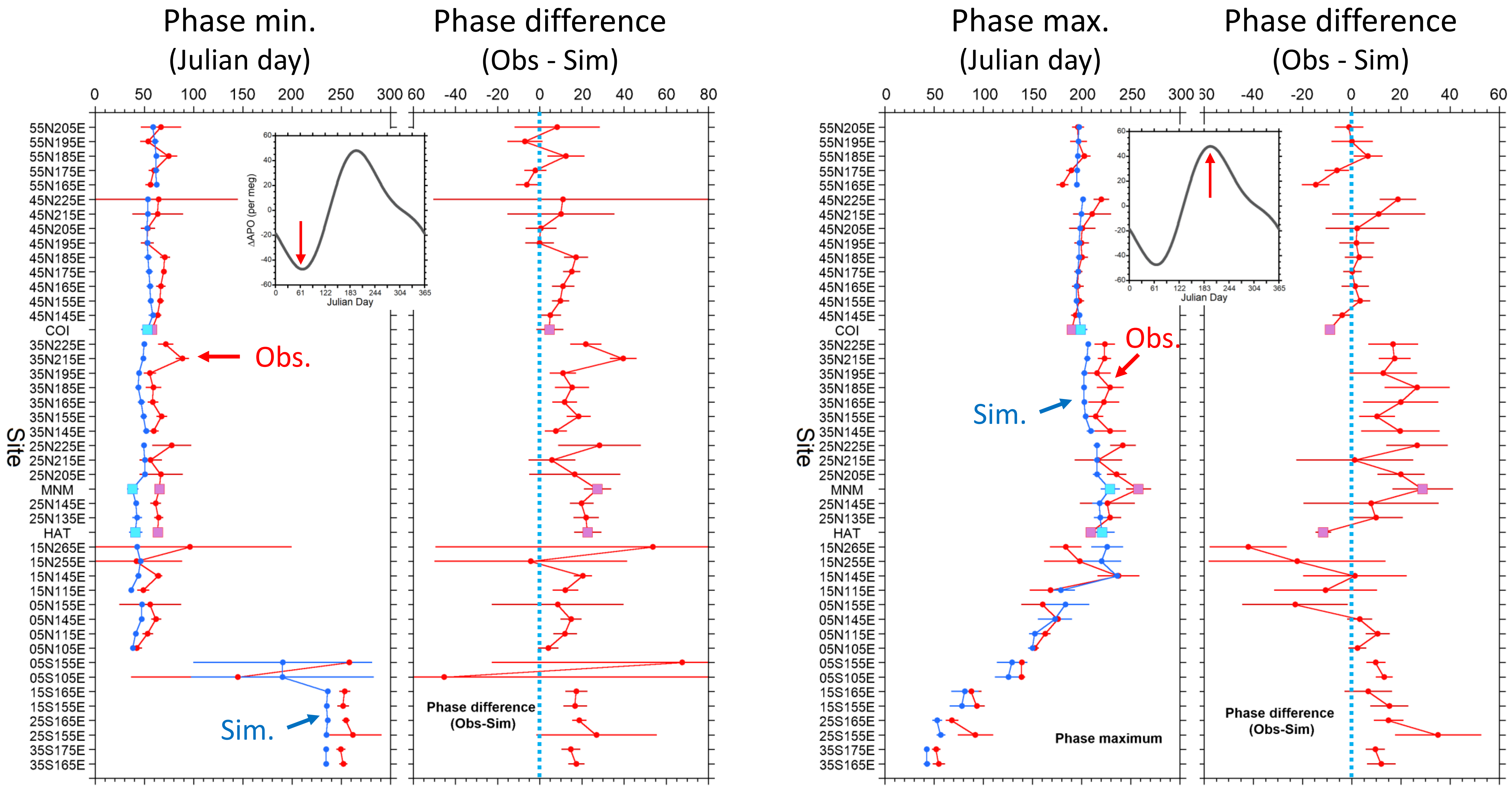


Peak-to-Peak amplitud

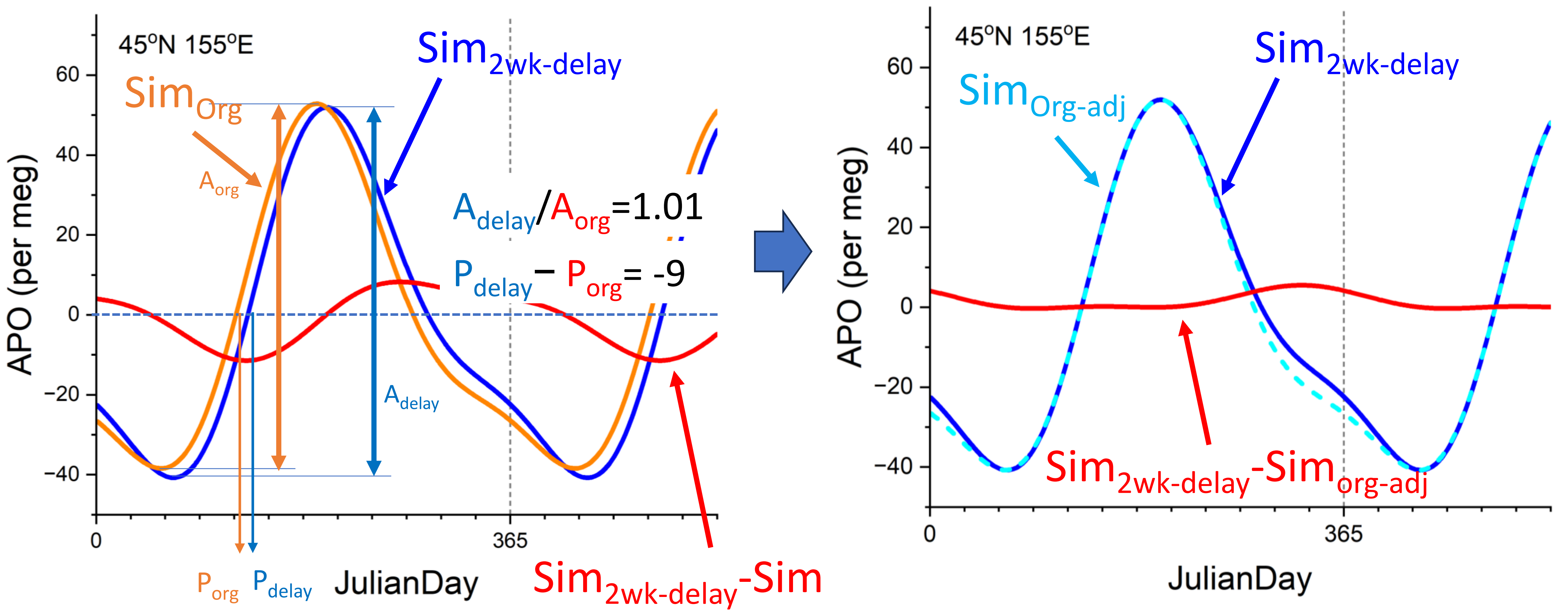




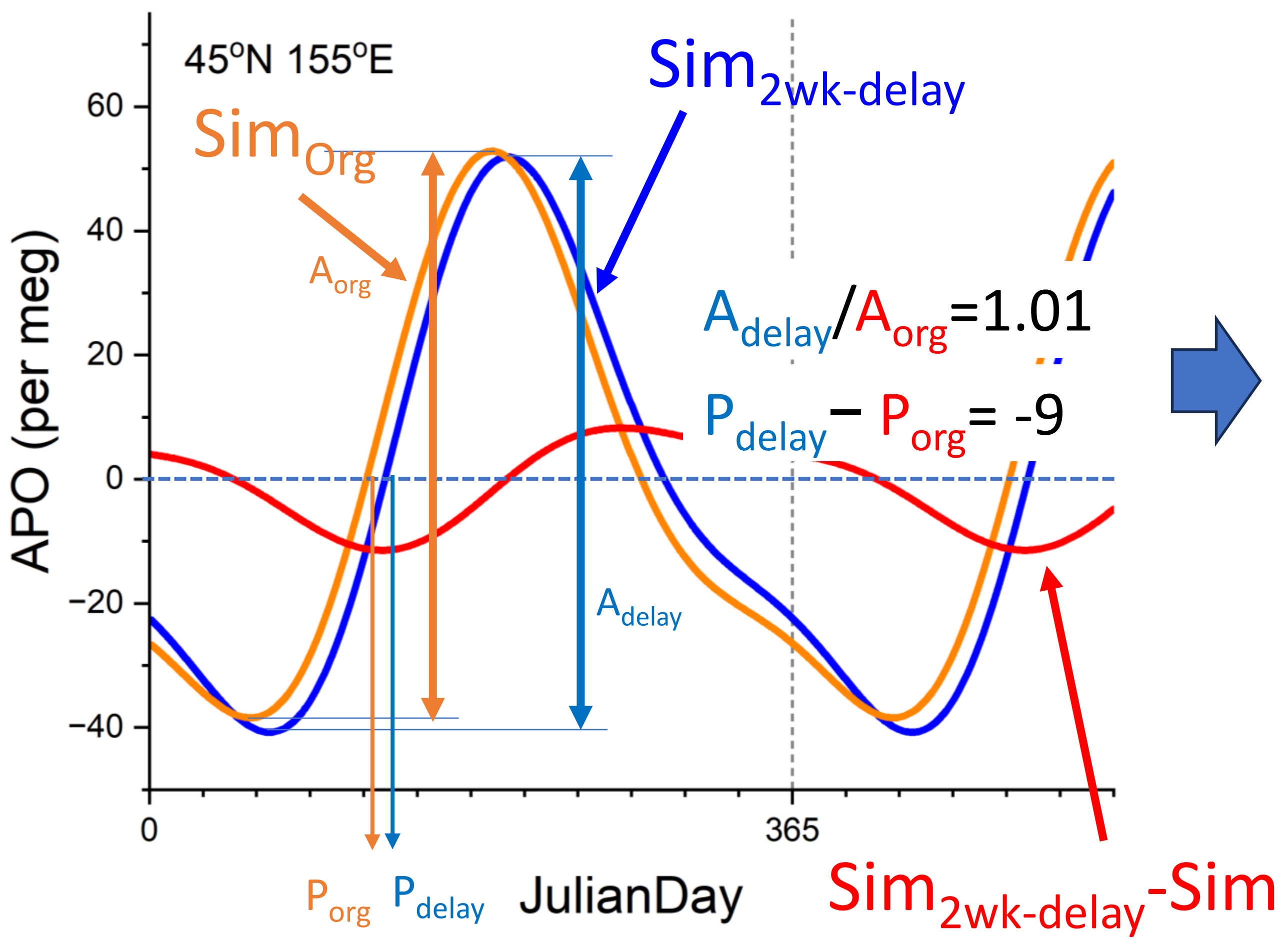
Comparison of APO seasonality

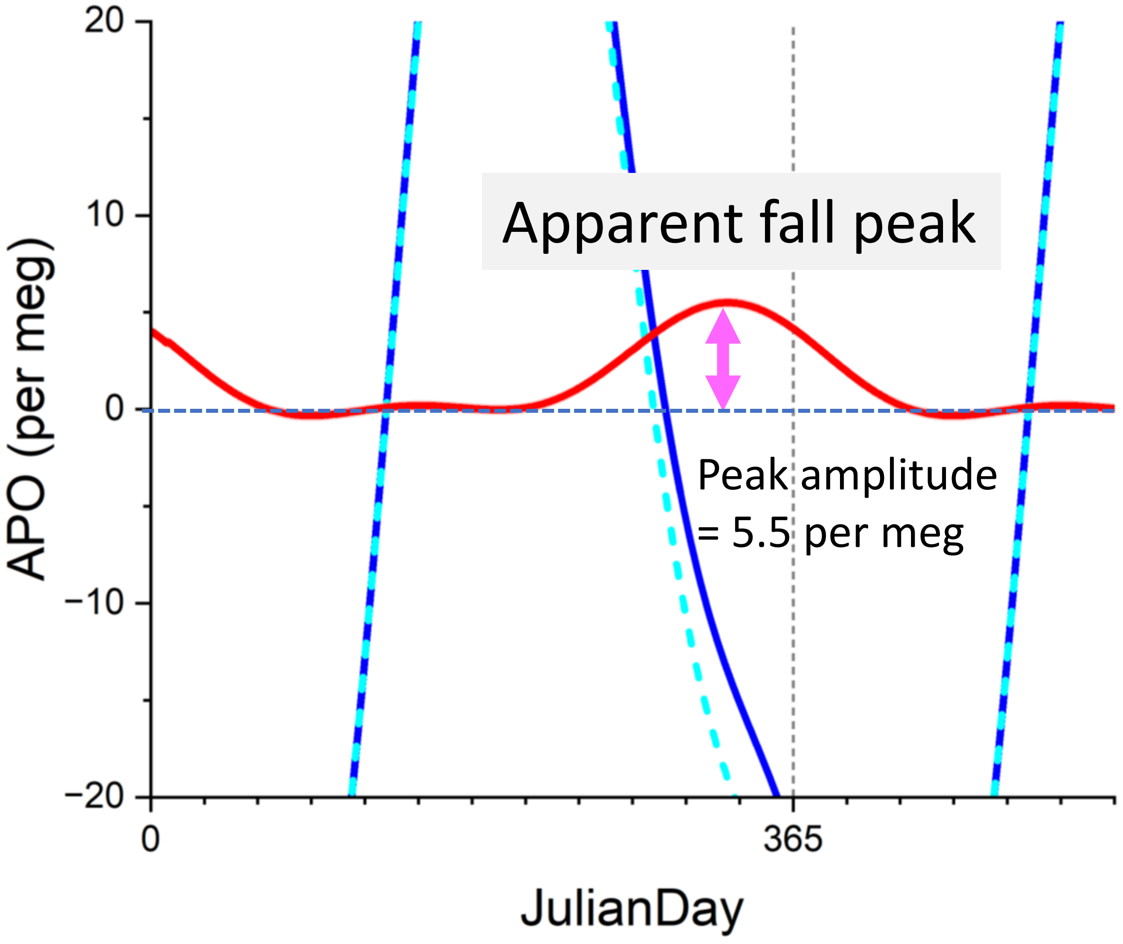


Simulated APO seasonal cycles vs. those based on 2-week delayed O_2 fluxes



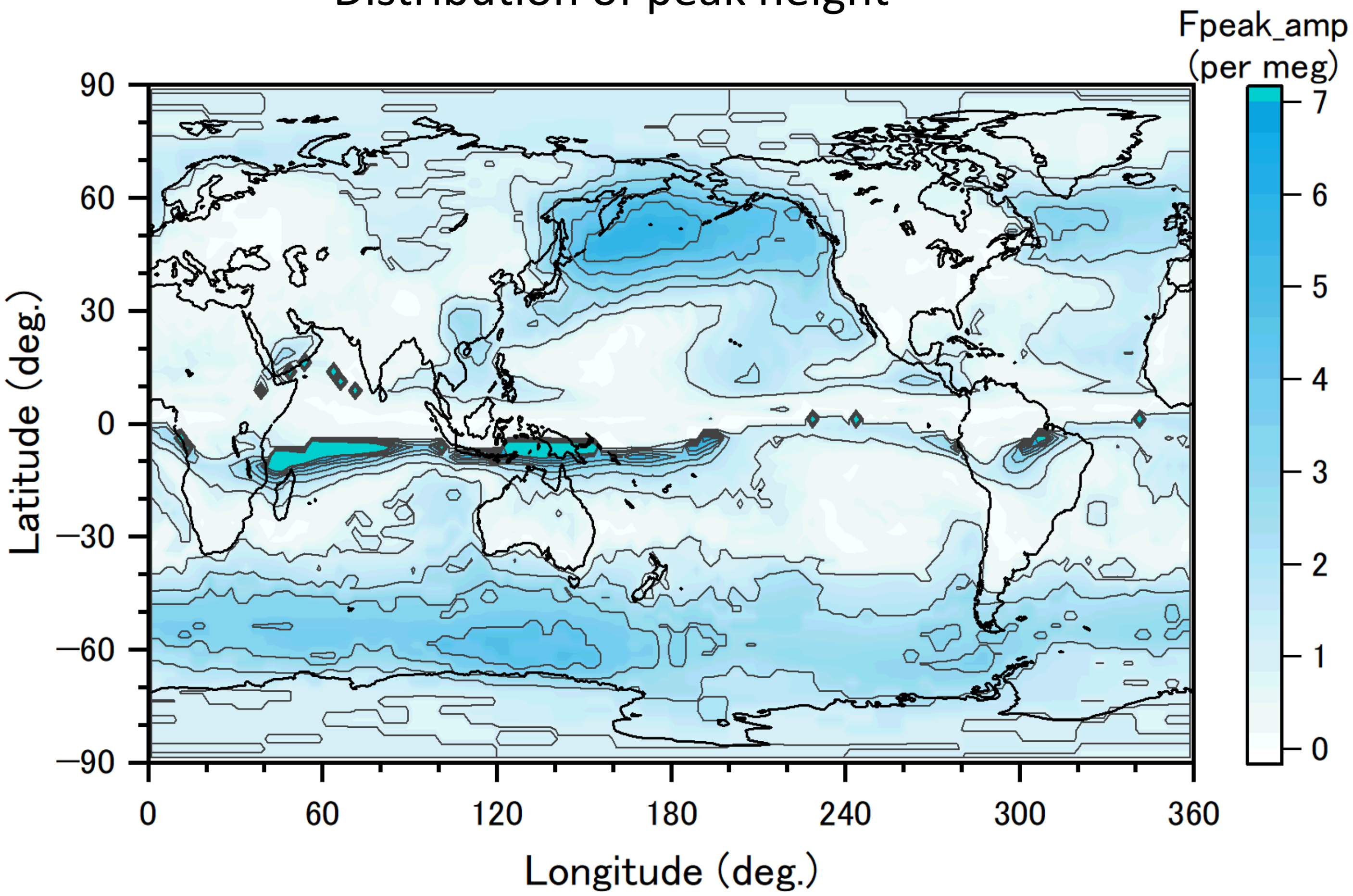
Simulated APO seasonal cycles vs. those based on 2-week delayed O_2 fluxes



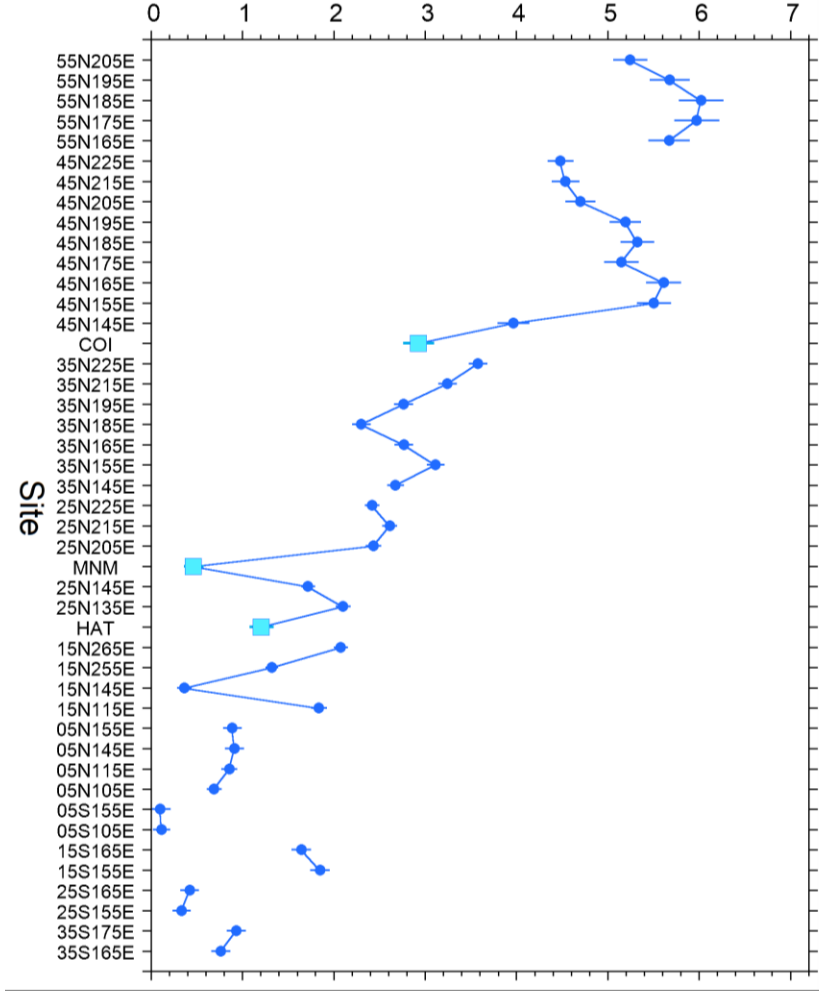


Distribution of peak height of the apparent fall peak derived from 2-week delayed air-sea O_2 fluxes

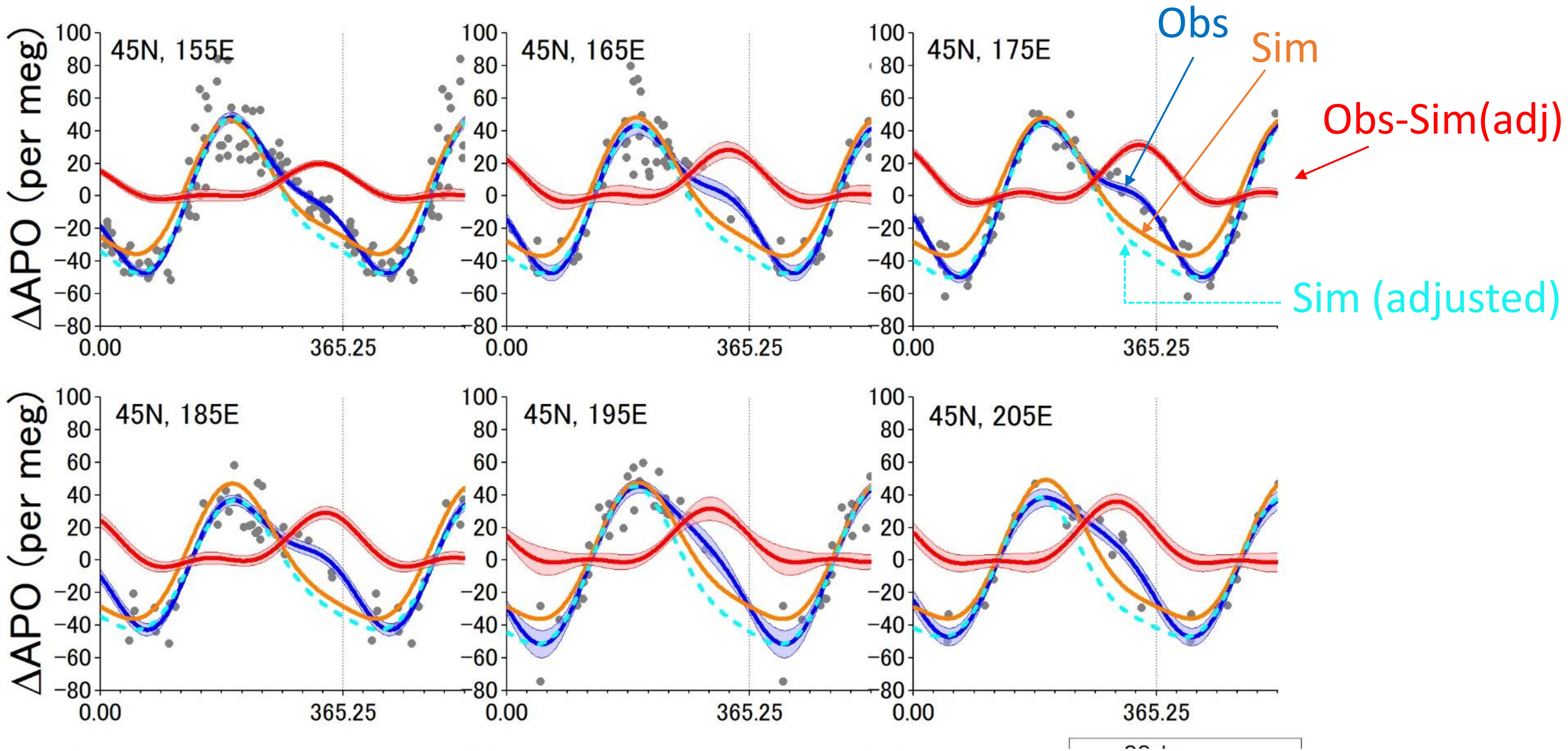
Distribution of peak height



Peak height along 42 bins (per meg)



Comparison of APO seasonal cycle between observation and simulation after adjustment of peak amplitude and phase differences



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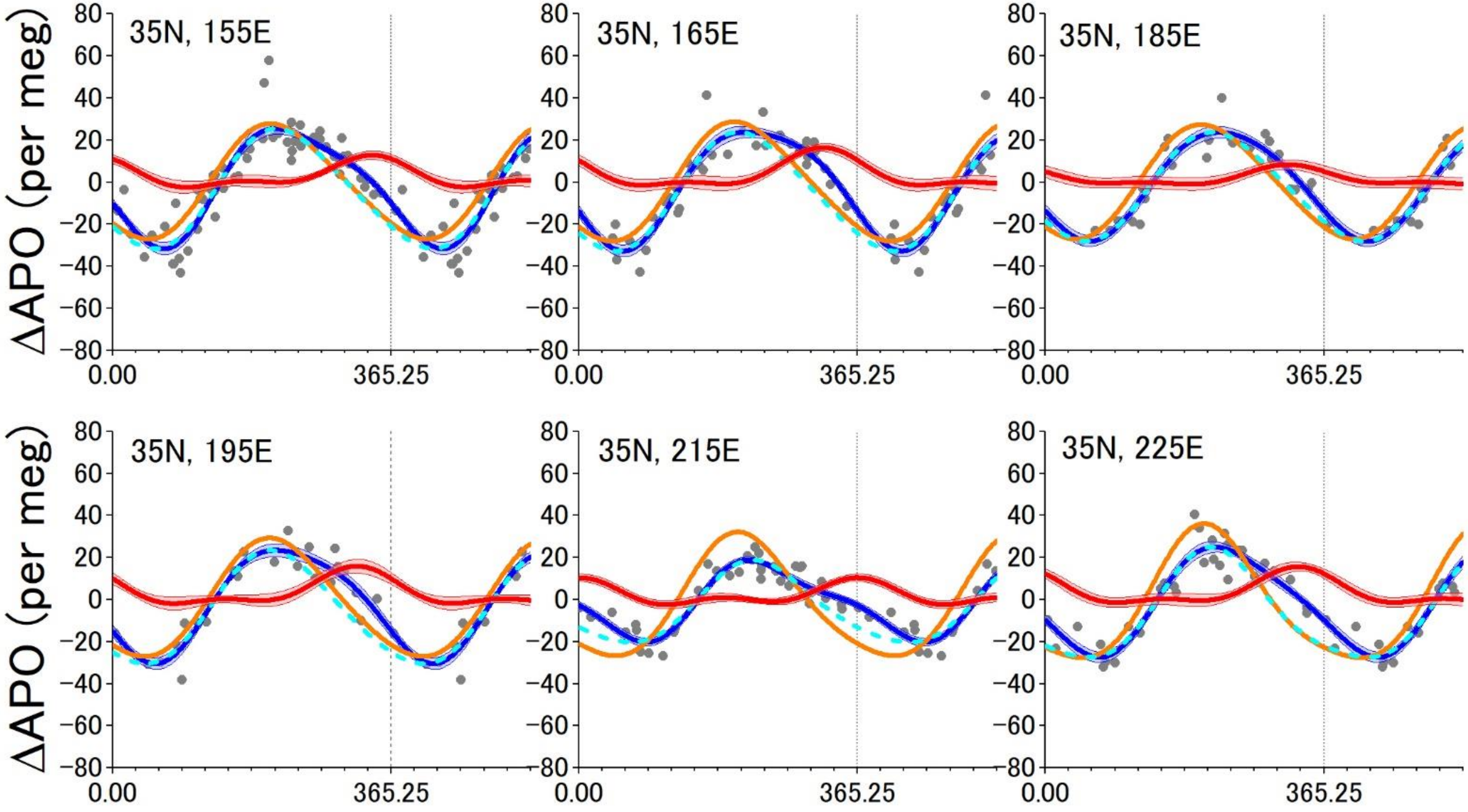
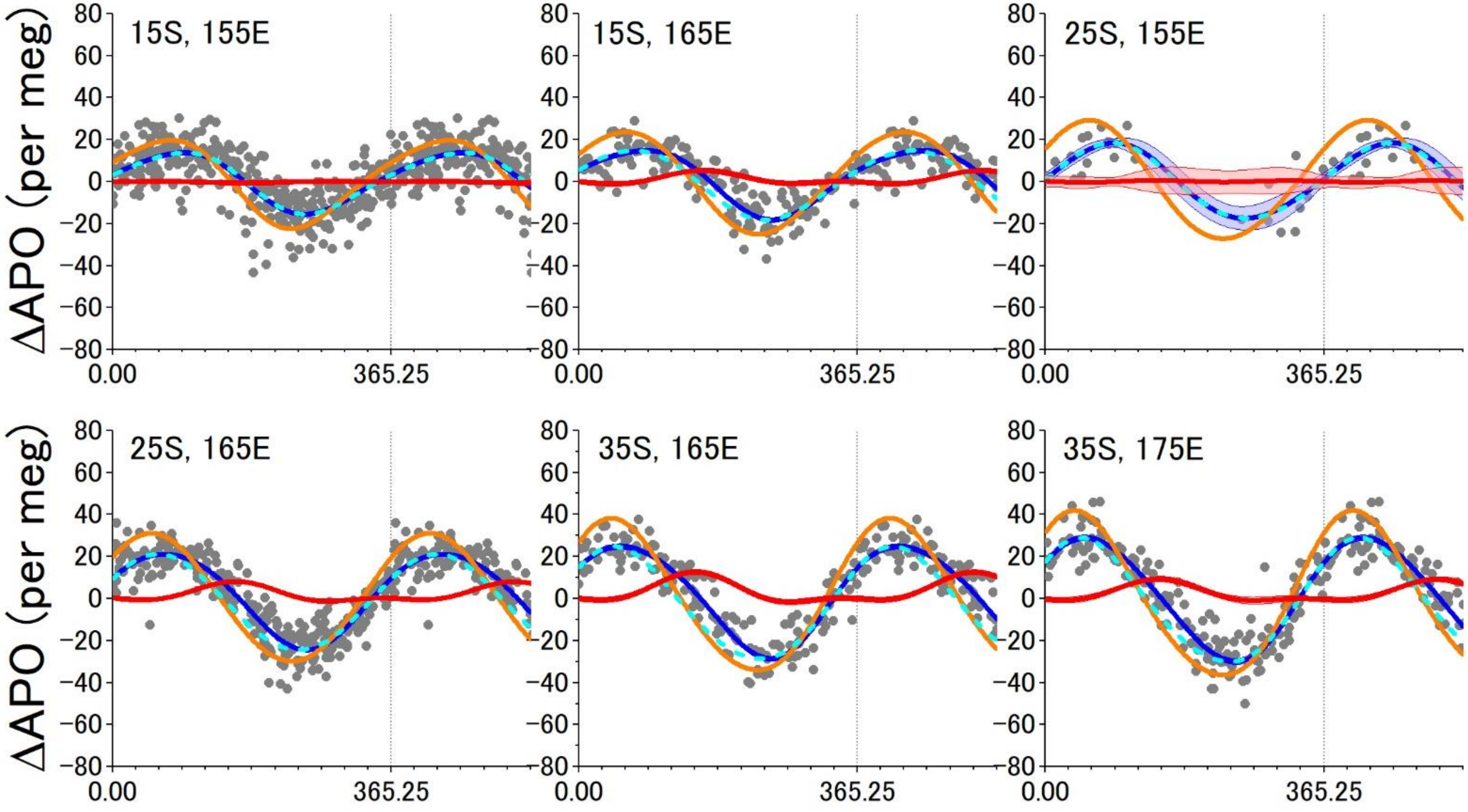
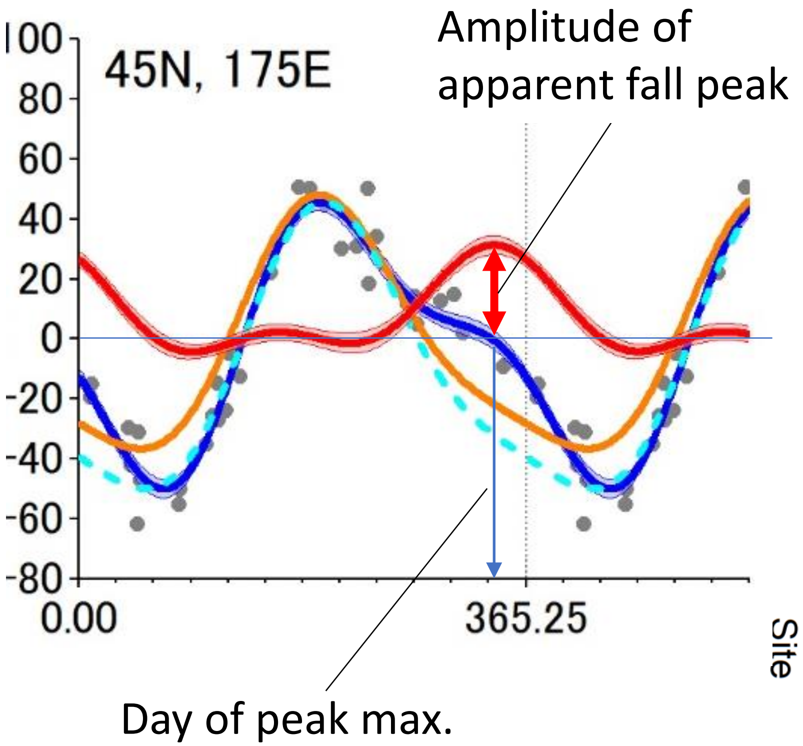
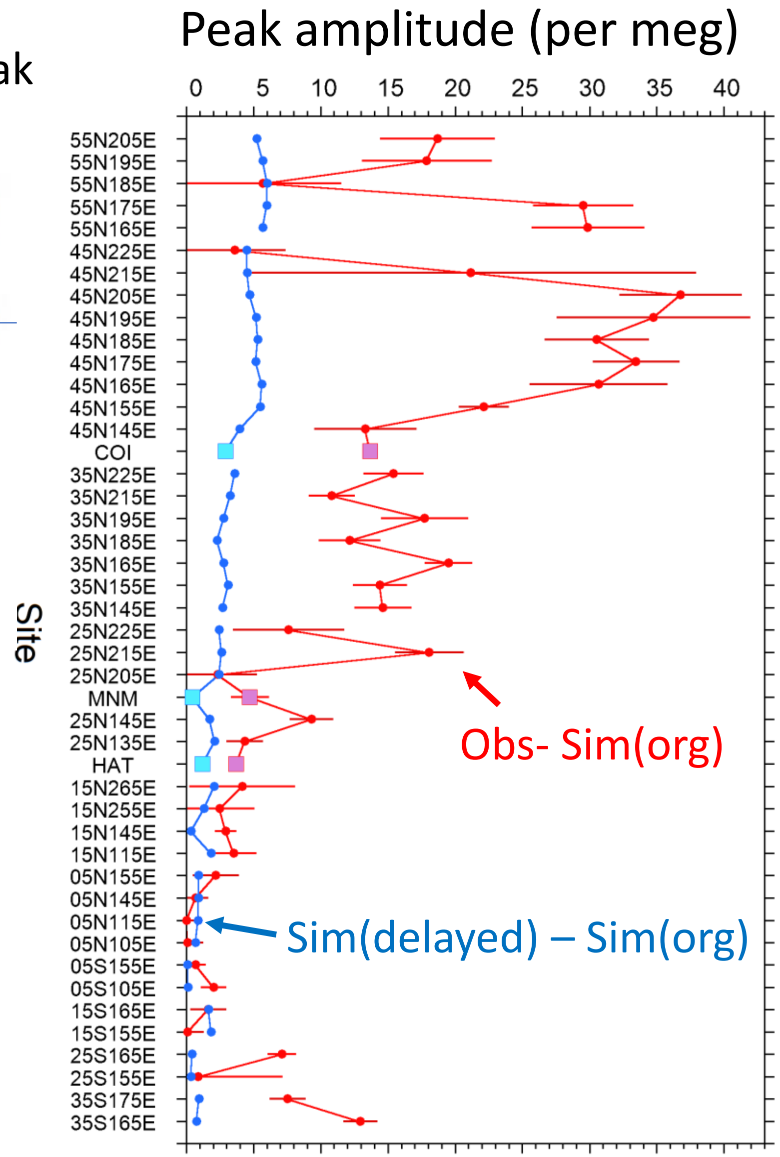


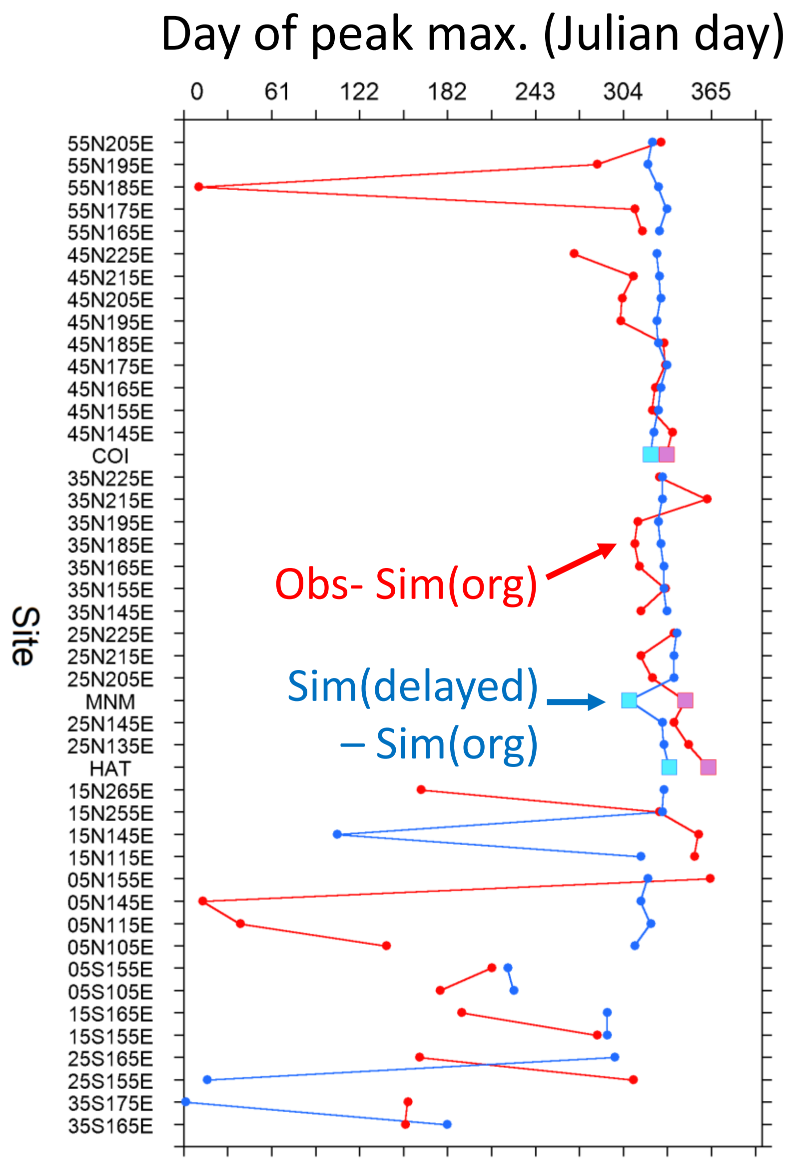
Comparison of APO seasonal cycle between observation and simulation after adjustment of peak amplitude and phase differences



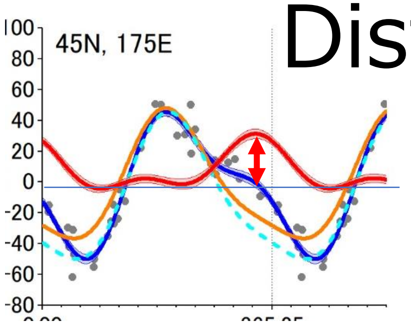
Apparent fall peak derived from observation and simulation



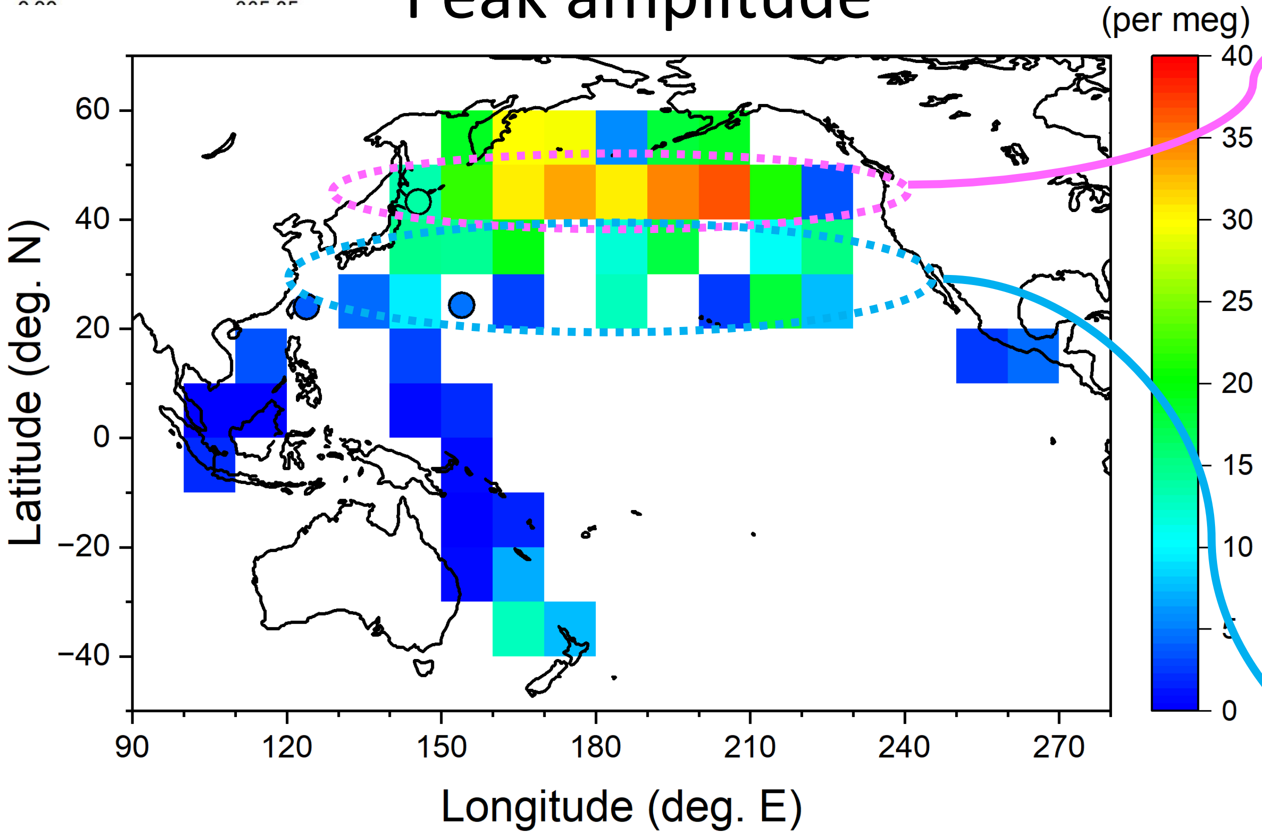




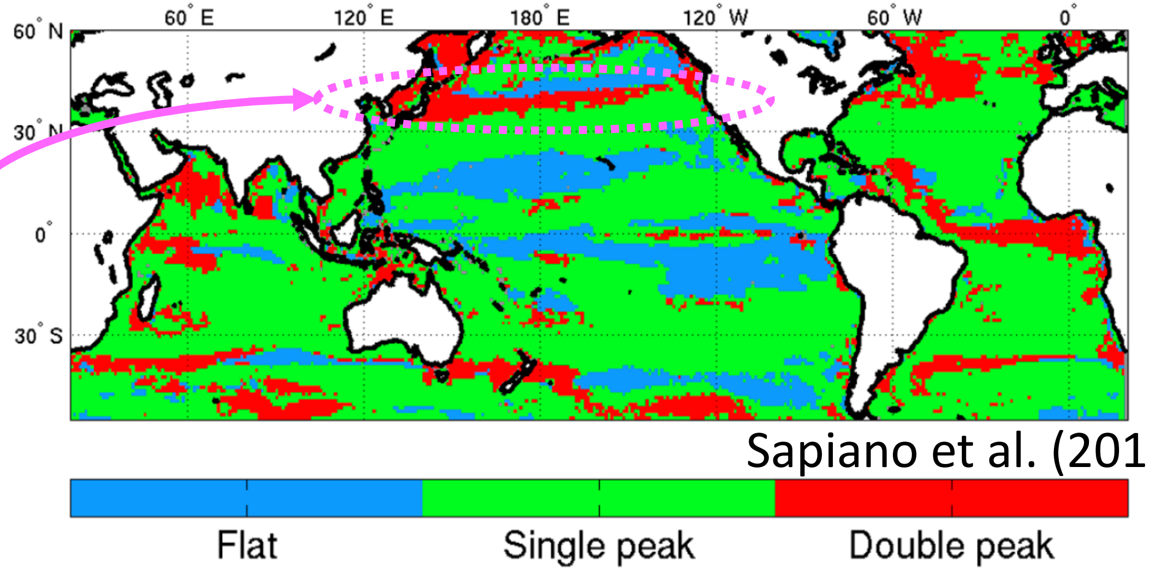
Distribution of amplitude of apparent fall peaks



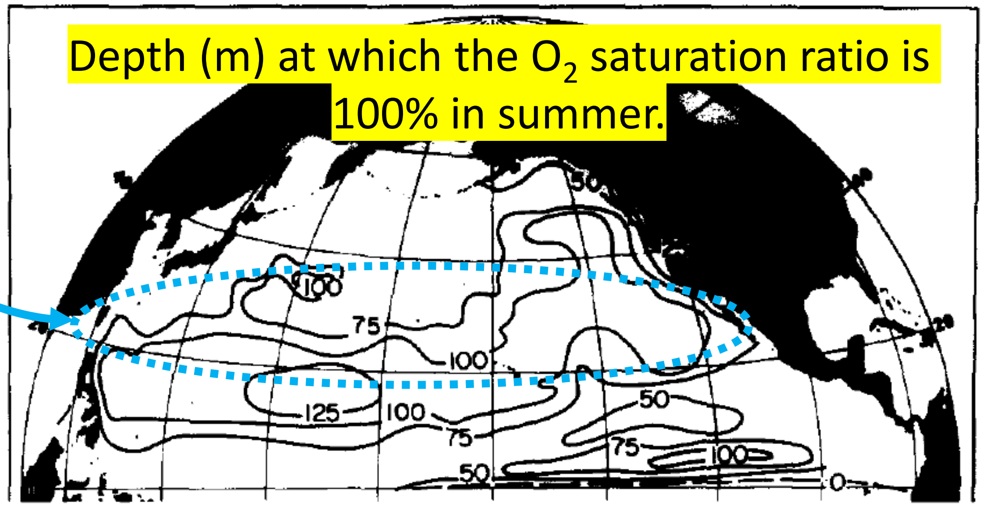
Peak amplitude



Type of annual cycle of chlorophyll concentration

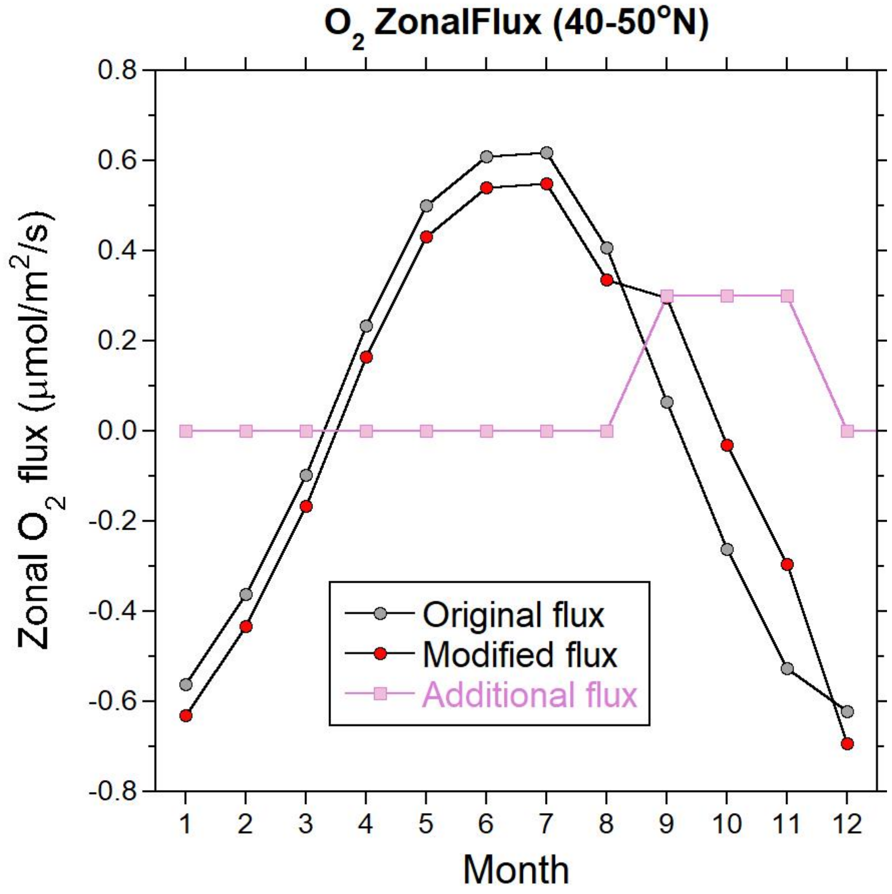


Sapiano et al. (2012)



Shulenberger & Reid, DSR, (1981)

Experimental simulation: modified air-sea O_2 flux



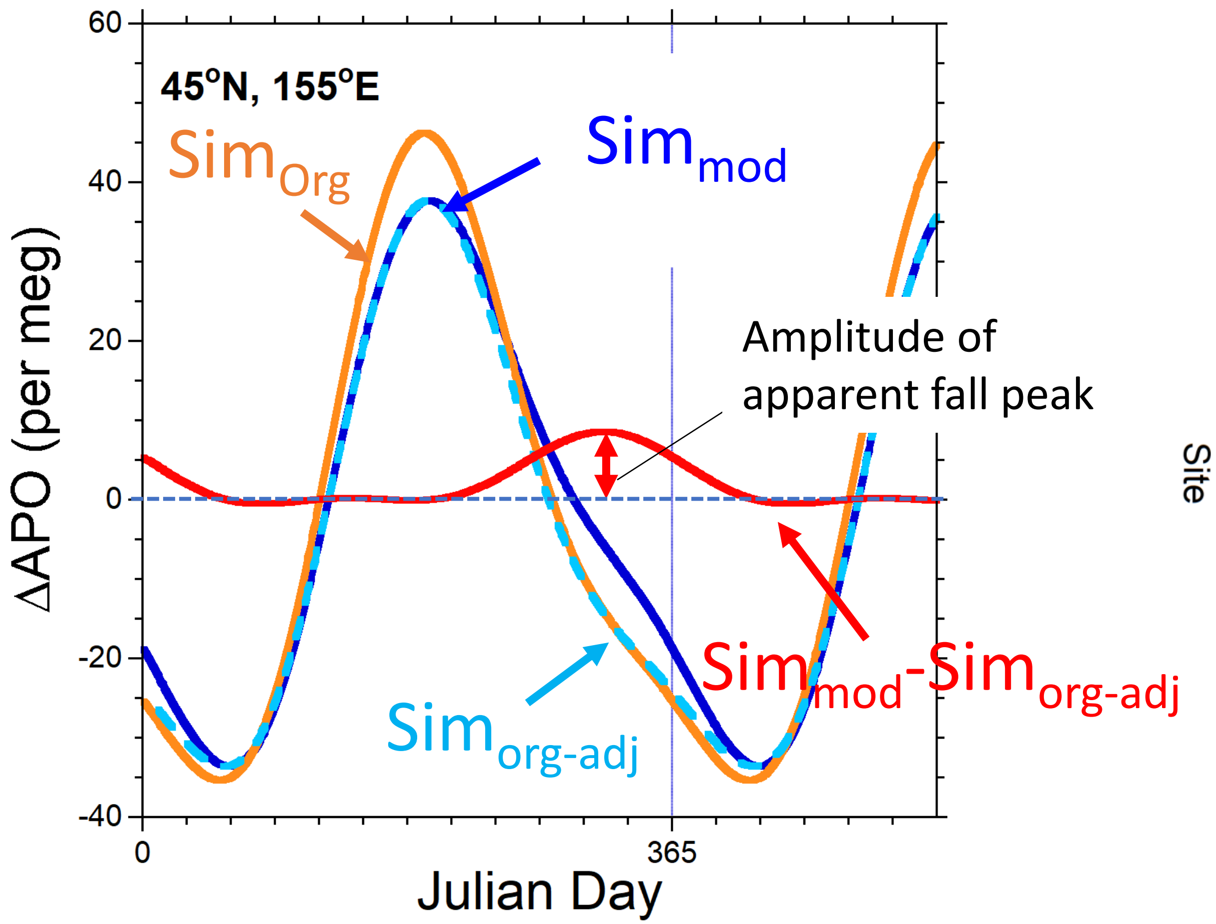
- Following flux is added to the original air-sea O_2 fluxes from Garcia and Keeling (2001)

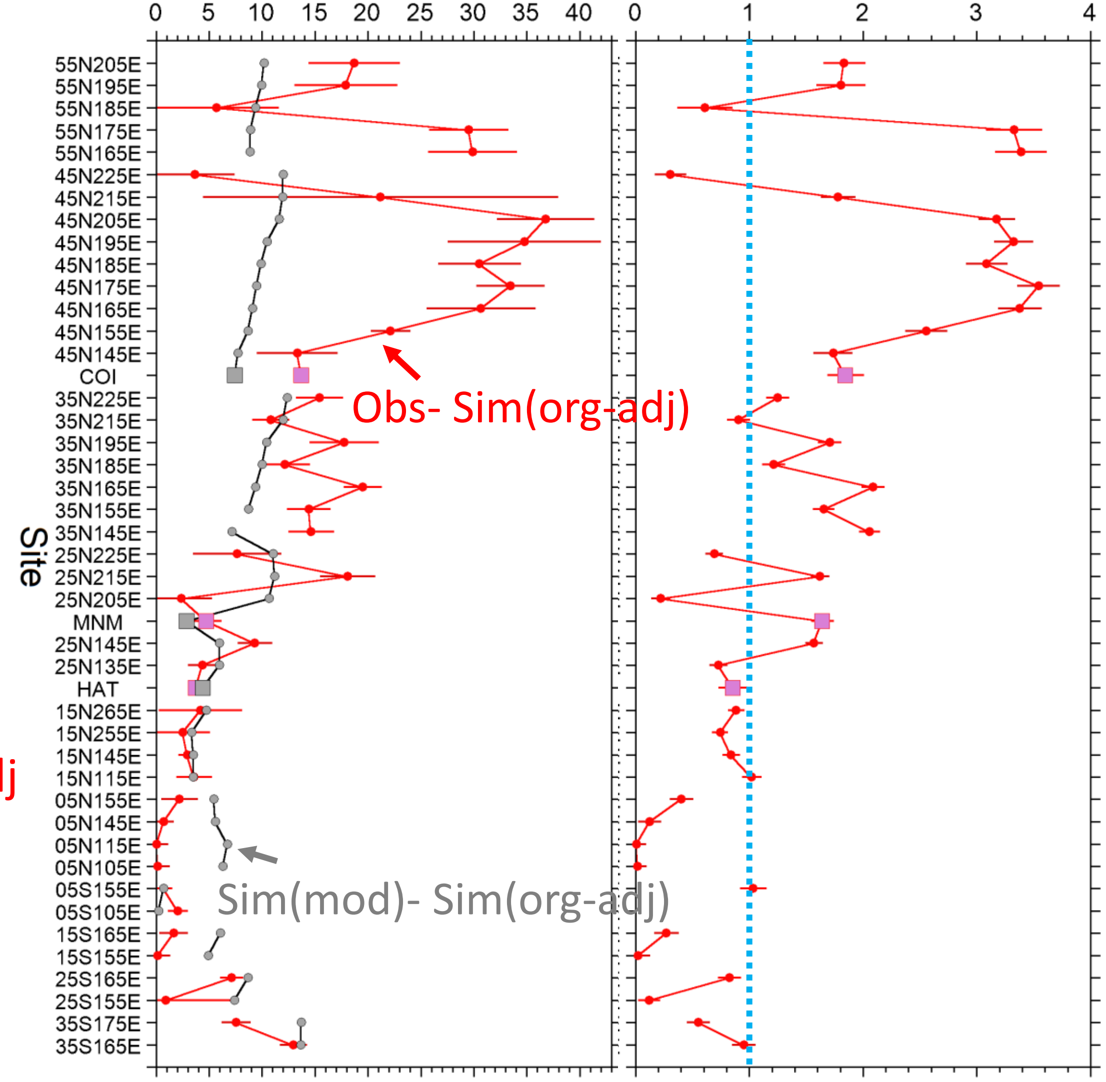
0-60°N	Sep.-Nov.	+0.3µmol/m²/s
60°S-0	Mar.-May	+0.3µmol/m²/s

- The O_2 fluxes were vertically shifted so that the annually integrated O_2 flux is zero.

Comparison of apparent fall peaks

Experimental vs. original simulations





Summary

- Simulated seasonal cycles based on climatological air-sea O_2 flux (Garcia and Keeling, 2001) and NIES-TM transport model were compared.
- The differences in the seasonal cycles (obs-sim) showed enhancements during fall-winter (apparent fall peaks).
- The amplitude of the apparent fall peaks are markedly high in latitudinal band of 20-60^oN, especially in that of 40-60^oN.
- Above fall APO enhancements may be attributed to the oceanic O_2 emissions associated probably with fall blooming in the northern North Pacific and with disappearance of SOM in the mid-latitudinal North Pacific.
- Additional air-sea O_2 fluxes of 0.3μmol/m^2/s for 0-60^oN in Sep.-Nov. seem not to be enough to explain the above fall peaks in 30-60^oN.

Important notice (last message)

- Because of my retirement in this fiscal year, the measurements of the flask samples from NIES's network will be taken over by Ishidoya-san (AIST) from next April.
- Therefore, Ar/N_2 measurement coverage will also be expanded as well as O_2/N_2 measurement coverage.
- The O_2/N_2 data for the previous NIES's flasks are now available via NIES's Global Environmental Database (GED).
    - ➢ https://db.cger.nies.go.jp/ged/ja/
    - **HAT:** 10.17595/20230830.001
    - **COI:** 10.17595/20230830.002
    - **MNM:** 10.17595/20230830.003
    - **Ship:** 10.17595/20230830.004