In this document, we describe the model used to investigate O_2 variability in the North Pacific. Both the physical and biological components of the model used here are documented in the literature and we therefore provide only a brief overview of their salient characteristics. This description is excerpted from a manuscript in preparation:

C. Deutsch, L. Thompson, and S. Emerson, *Attributing the causes of North Pacific Oxygen Change*, [2004]

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Model Description

Ocean circulation is computed using a GCM that is based on the Hallberg Isopycnal Model (HIM). The model is configured for a North Pacific domain from 20°S to 60°N with 14 isopycnal layers and a horizontal resolution of 1 degree. Isopycnal layers outcrop at the surface into a Kraus-Turner mixed layer with spatially variable density. The interaction between isopycnal layers and the mixed layer is mediated by a buffer layer, through which winter mixed layer properties are detrained onto isopycnal surfaces. Circulation fields are derived from integrations forced by interannually varying atmospheric winds and surface air temperatures from NCEP reanalyses between 1948-2000. Changes in net air-sea fresh water flux (E-P) are not included in the variable forcing, and model sea surface salinity is restored to climatological values [Levitus et al].

Time-dependent tracer distributions are computed in an offline advection/diffusion routine using monthly averaged circulation fields from the GCM. The distribution of four tracers is determined: phosphate (PO_4), dissolved organic phosphorus (DOP), O_2, and ideal age. DOP and PO_4 are used to diagnose O_2 fluxes associated with the biological pump (see below), and ideal age is computed to provide a measure of the time elapsed since a water parcel was last at the surface. All tracers are diffused along isopycnal surfaces using an eddy diffusion coefficient of 2000 m^2/s. Diapycnal mass fluxes include a diffusive flux based on a constant diapycnal diffusivity of 0.1 cm^2/s. Within 5 degrees of the open boundaries of the model domain, PO_4 and O_2 are restored toward climatological values. We integrate all tracer distributions to a near-steady state (300 years) using mean circulation fields. Tracer distributions from the steady state integration are then used as initial conditions for the variable forcing simulation, which integrates tracer distributions for another 52 years (1948-2000) using the variable circulation derived from historical atmospheric forcing.

The sources and sinks of biogeochemical tracers are computed using parameterizations based on the Ocean Carbon Model Intercomparison Project (OCMIP) (see attached figure). In the OCMIP protocol, biological organic matter production is diagnosed by restoring model PO_4 toward climatological values in the upper 75 m, with a restoring time scale of 30 days. Of the total organic matter production, two thirds is converted to DOP, which is advected and diffused and decays back to PO_4 with a half-life of one year. The remaining one third is exported as sinking flux, which is instantly remineralized to PO_4 with depth using a standard "Martin curve". The production and remineralization of organic phosphorus pools produces and consumes O_2 in a constant stoichiometric O_2:P ratio of -170 mol O_2/mol P. Mixed layer O_2 concentrations are fixed at their (time-varying) saturation values.

The surface PO_4 fields used to compute organic matter export are constant throughout the simulation. However, export flux diagnosed through nutrient restoring can vary due to changes in nutrient supply. If the supply of PO_4 to surface waters increases, biological production must also increase in order to maintain constant observed surface PO_4 concentrations. This parameterization of the biological pump therefore represents only those biological changes that are associated with changes in nutrient supply. It is possible that changes in biological export production over the past few decades also resulted in a net change in surface nutrient distributions. Since there is little reliable data about whether or how surface nutrients changed in the late 20th century, we make the conservative assumption that they have not.

Biogeochemical GCM

- Isopycnal GCM (HIM)
  - North Pacific domain (20°S – 60°N)
  - 1° resolution, 14 layers + mixed layer
  - Offline tracer advection/diffusion
- Historical atmospheric forcing
  - NCEP, 1948-2000
  - Winds, Temp only (no salinity change)
- OCMIP protocol
  - surface PO_4 restoring
  - "Martin curve" remineralization
  - DOP with a 1-year half-life
  - constant O_2:P stoichiometry (170:1).
- O_2 set to saturation in mixed layer