High Resolution Modeling of the Namibia Upwelling System during the Last Glacial Maximum

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Aim

Develop and run an eddy-resolving regional model to better understand the role of ocean margin upwelling for biological production and cycling of nutrients and CO$_2$ during extreme climatic states.

Sea level changes

- Upwelling locations

Wind changes

- Upwelling rates

Intermediate water characteristics

- Temperature and nutrient content of upwelling water
Strategy

Reconstruct sea surface conditions for the Last Glacial Maximum.

Produce regular grids from the reconstructed data.

Use the grids to drive a coarse-resolution global model.

Yield estimates for the glacial water mass distribution and the large-scale glacial circulation.

Use the output of the glacial and modern global experiments to initialize and force the regional model.
Last Glacial Maximum SST: GLAMAP 2000 Data (°C)

August

February

°C

-2 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28

Last Glacial Maximum SST: Gridded (°C)
Temperature and Transports in the Ventilated Thermocline (≈ 300-600 m)

Modern

Glacial
Regional Model: Vector Ocean Model (VOM)

- Variables stored in 1-D arrays
- Adaptive vertical coordinates
- Flooding and drying of cells in entire water column
- Open boundaries possible anywhere (e.g. on islands)
- Primitive equations with full kinematic surface and bottom boundary condition
- Implicit free surface
- Semi-implicit upstream or Arakawa-J7 advection for momentum
- Semi-implicit hybrid advection (upstream/central) for tracers
- Implicit vertical diffusion
- Variable horizontal exchange (Smagorinsky)
- Non-linear semi-implicit terrain-following seabed friction
- Terrain-following advection and diffusion at seabed
- Terrain-following isotropic resolution bottom Ekman layer
Model Topography

Horizontal resolution: $10' \times 10'$

$\approx 11000$ wet columns
Adaptive Grid

Vertical resolution:
15, 30,
60, 120,
240, 480 m
Adaptive Grid

Vertical resolution: 15, 30, 60, 120, 240, 480 m
Adaptive Grid

Minimum: 2
Maximum: 66
Average: 27

≈ 300,000 wet points
Experiments: Parameters

- Modern: based on global experiment using SST and SSS from WOA 98
- Glacial: using global results obtained with reconstructed SST and SSS (Paul and Schäfer-Neth, *Paleoceanography*, in press)

- Annual mean forcing for 6 years to reach approximate steady state
- Initial and surface forcing T and S from global model
- Wind field interpolated from atmospheric model runs (ECHAM/T42, G. Lohmann and S. Lorenz)
- SST/SSS restoring time constant: 30 days
- Open boundary forcing by T, S, and surface elevation from global model
The upwelling region shifts from 28°S to 24°S in the glacial run.
Results: Glacial minus Modern Temperature Anomaly (°C)

- The anomaly increases at the surface, but decreases at depth.
- These opposing trends can be explained in terms of changed upwelling.
Results: Temperature along 27°S, 0–500 m depth (°C)

- The lower boundary of coastal upwelling rises to 150 m (modern) and 250 m (glacial)
- In the glacial experiment, the upwelling becomes more intense and broader
- In the modern experiment, the cooling at depth is more pronounced
Standing eddies are generated in spite of smooth annual wind fields
Topographic features dominate influence of T/S forcing
Currents are slightly stronger in the glacial experiment
Both experiments develop quite similar patterns
Coastal upwelling intensifies in the glacial experiment
Highest velocities are found over the ridge and the seamounts
Coastal upwelling reaches only 10-50% of open ocean upwelling
Conclusions and Outlook:

- In the regional model, topographic influence on hydrography and circulation appears to be much stronger than surface forcing.
- Temperature and depth of upwelled water are realistically represented in the regional model.
- Location and intensity of coastal upwelling change in accordance with the glacial SST reconstructions.
- Include glacial-interglacial topography changes.
- Force with seasonal T, S, and surface elevation.
- Include daily wind variability.
- Employ heat and freshwater fluxes instead of T/S restoring.
- Develop biological sub-model: N, Si, functional plankton groups, Fe, Dust.