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

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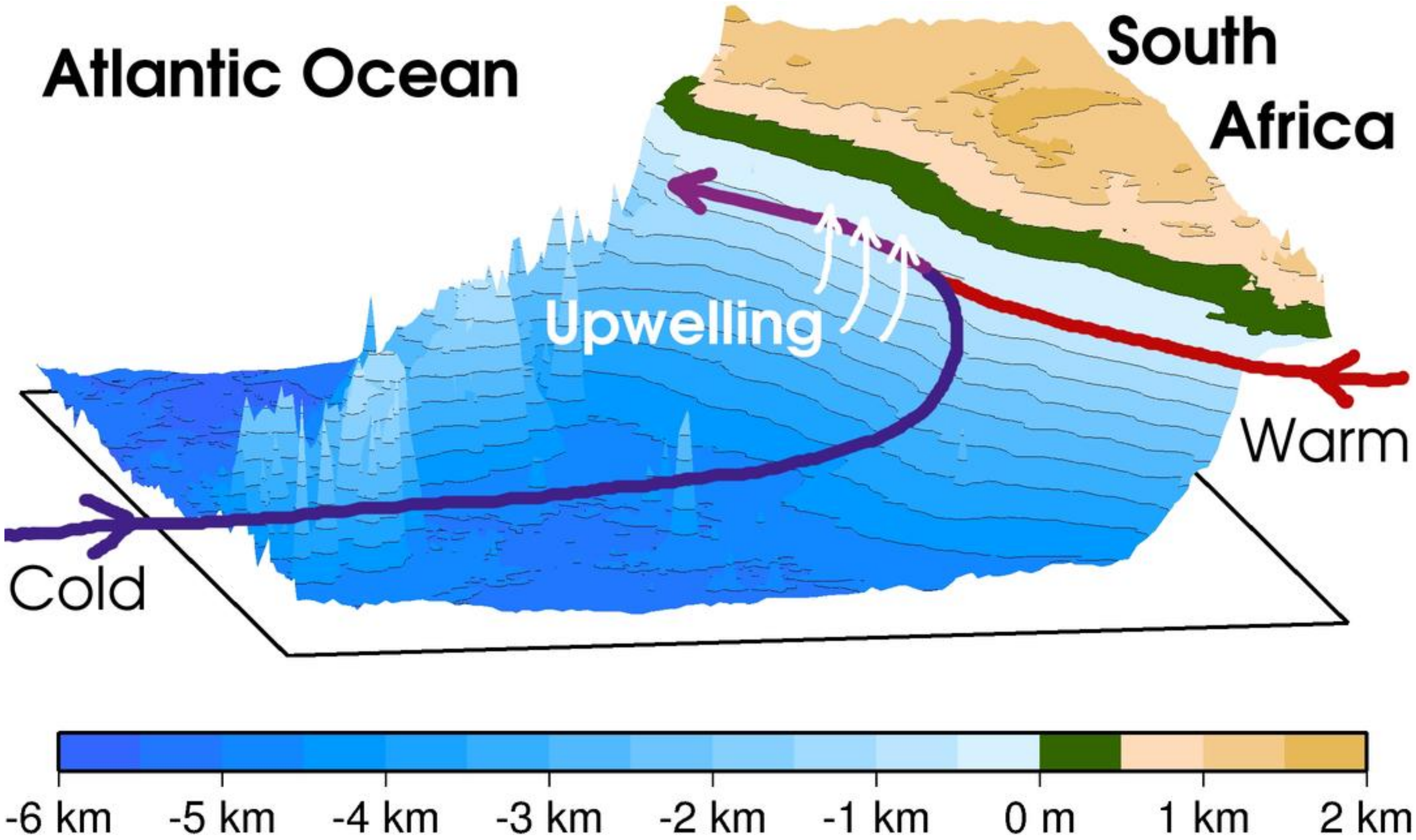
Aim

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.

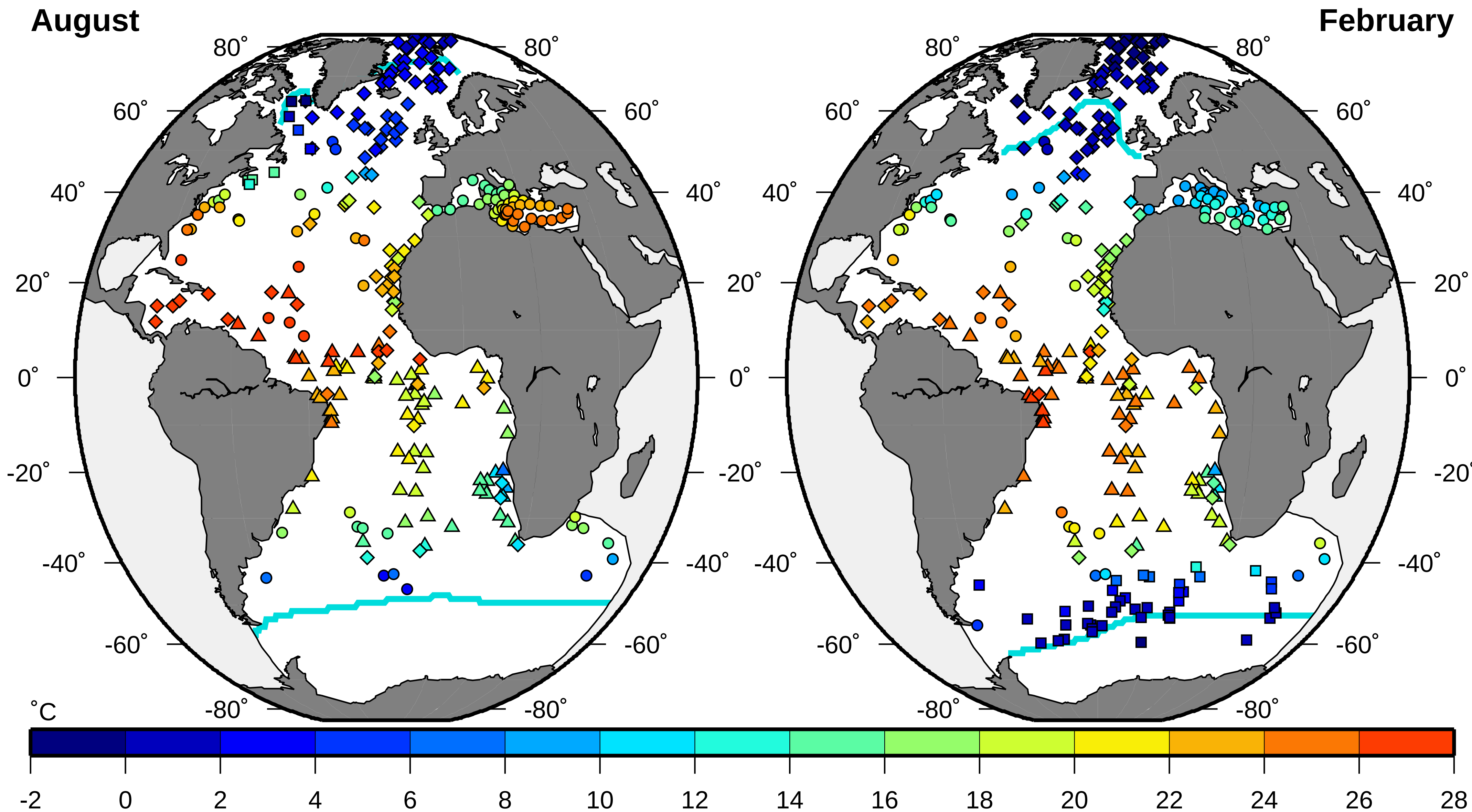
Produce regular grids from the reconstructed data.

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

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

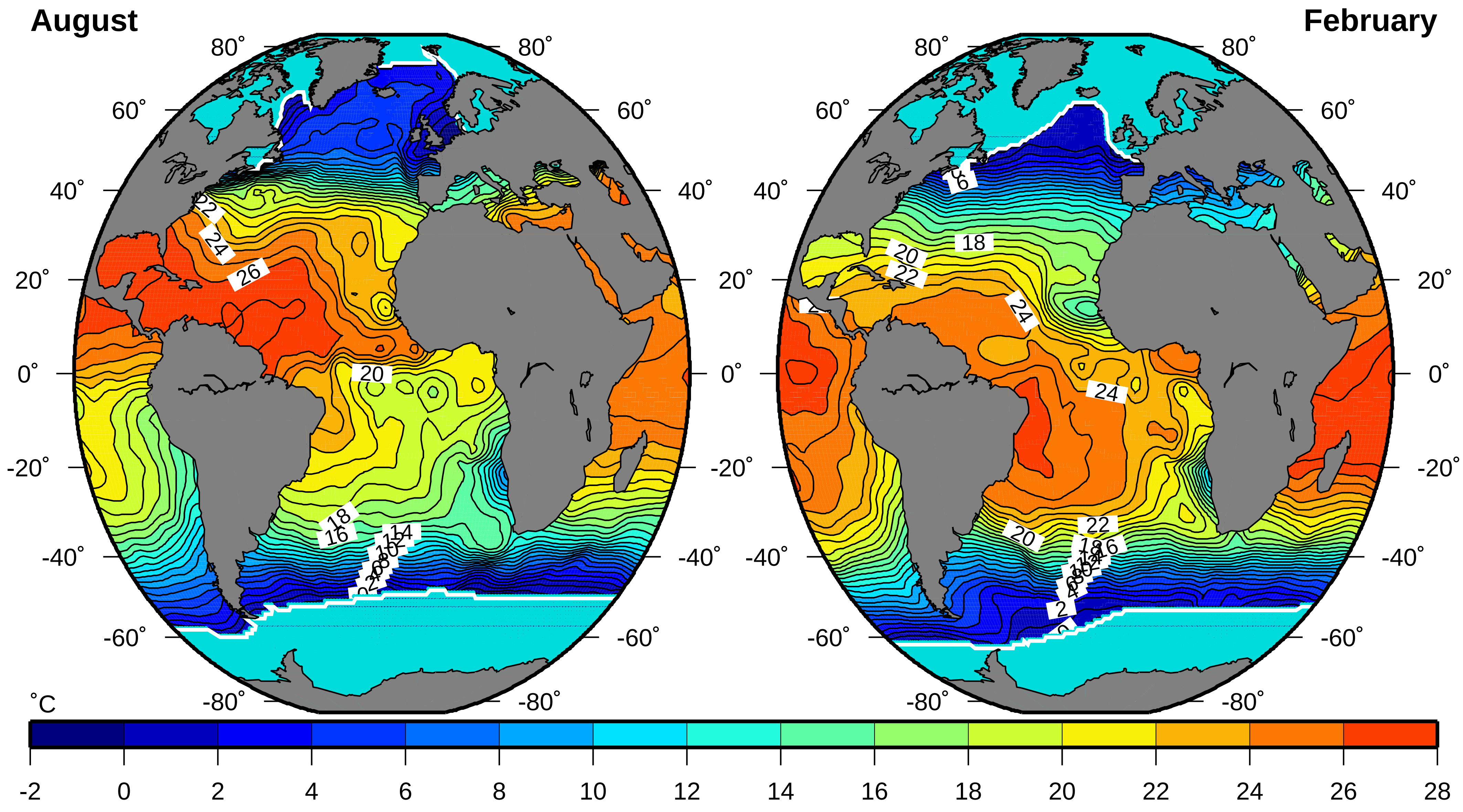
Use the output of the glacial and modern global experiments to initialize and force the regional model.

Last Glacial Maximum SST: GLAMAP 2000 Data (°C)

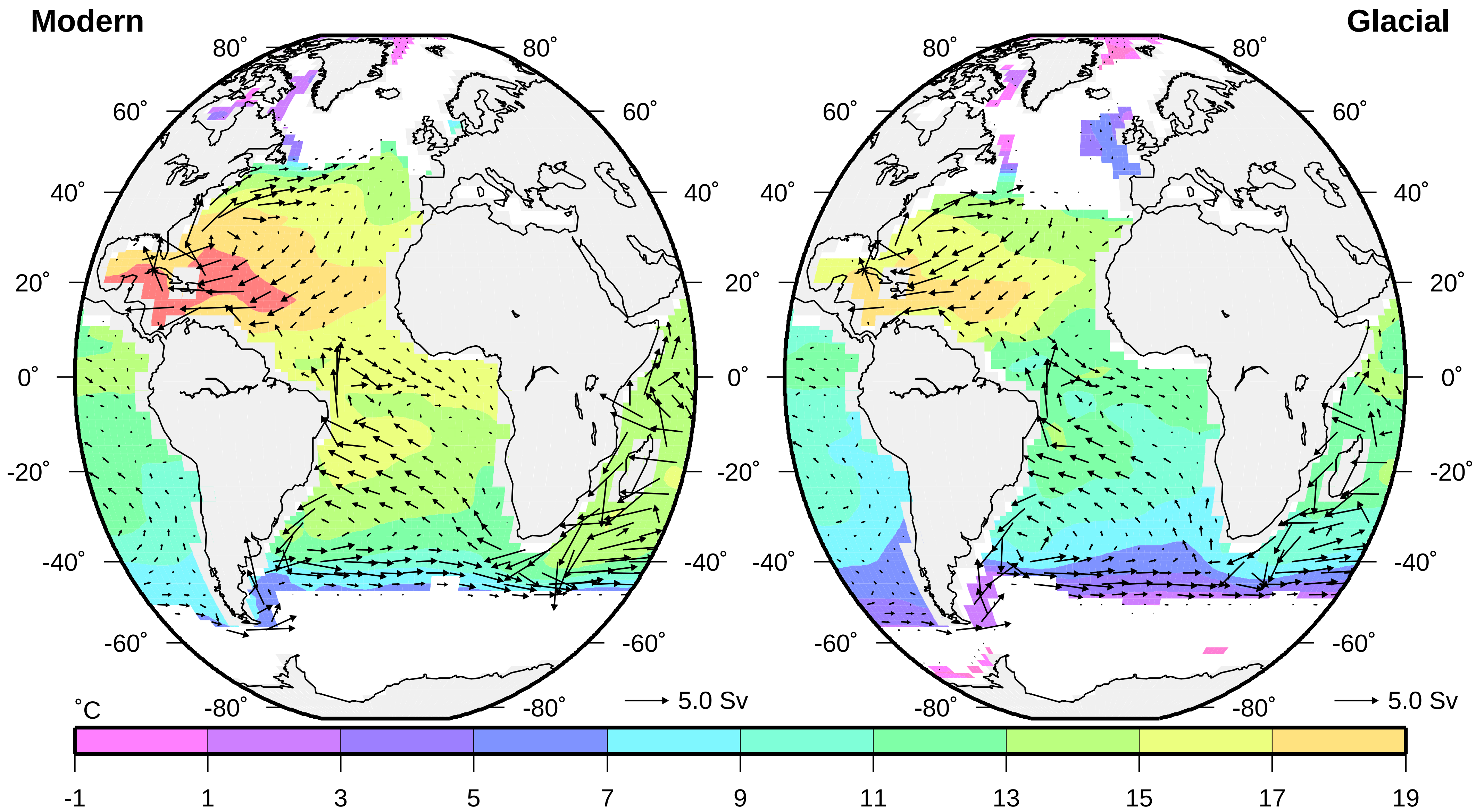


△: Niebler et al. 2003. ◇: Pflaumann et al. 2003. □: De Vernal et al. 2000 (Aug), Gersonde et al. 2003 (Feb). ○: Prell 1985 (Atlantic), Bigg 1994 (Mediterranean). Ice edges: Pflaumann et al. 2003; De Vernal et al. 2000; Gersonde and Zielinski 2000. Shade: SST from CLIMAP (1981).

Last Glacial Maximum SST: Gridded (°C)



Temperature and Transports in the Ventilated Thermocline (≈ 300-600 m)



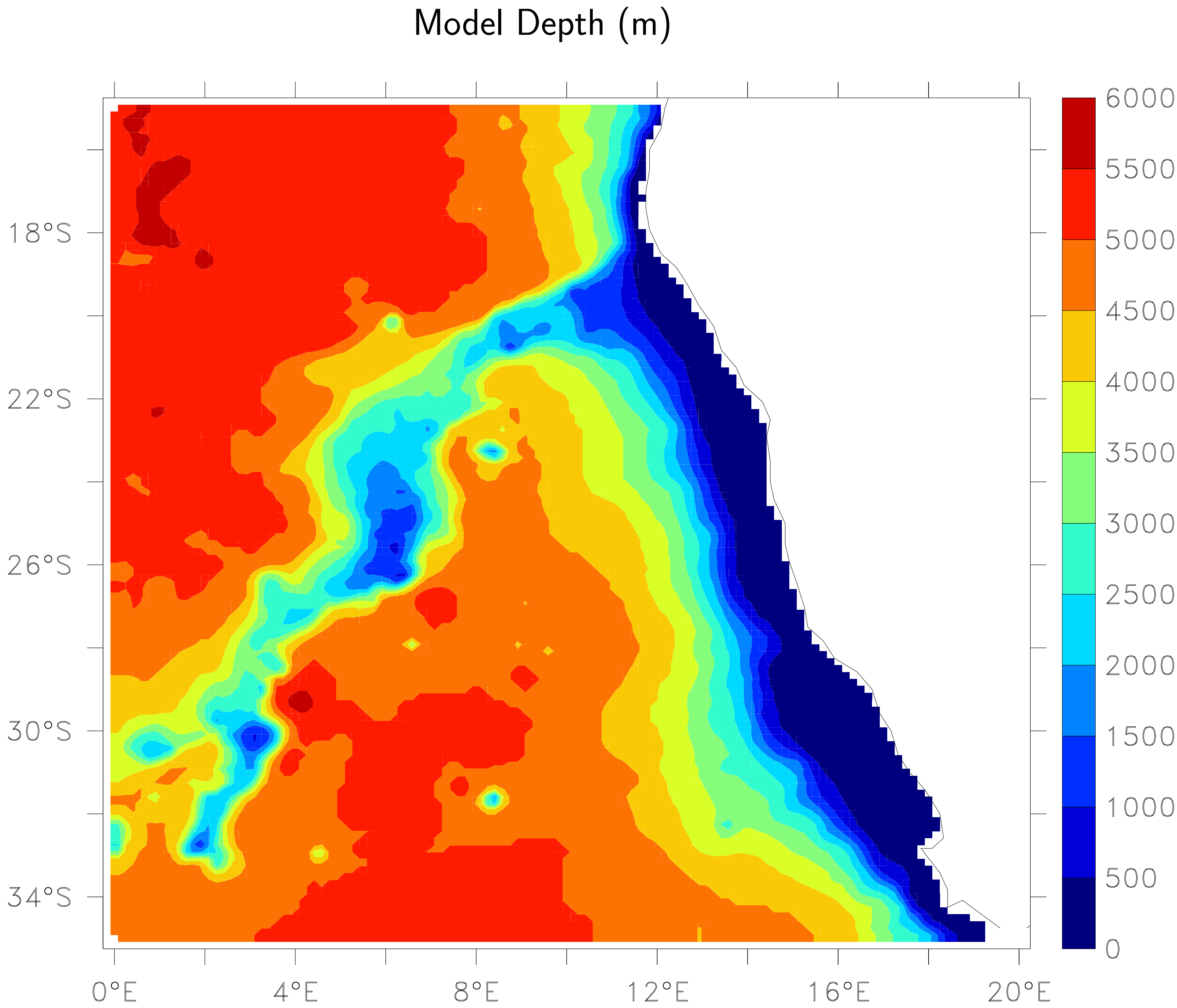
Regional Model: Vector Ocean Model (VOM)

- 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

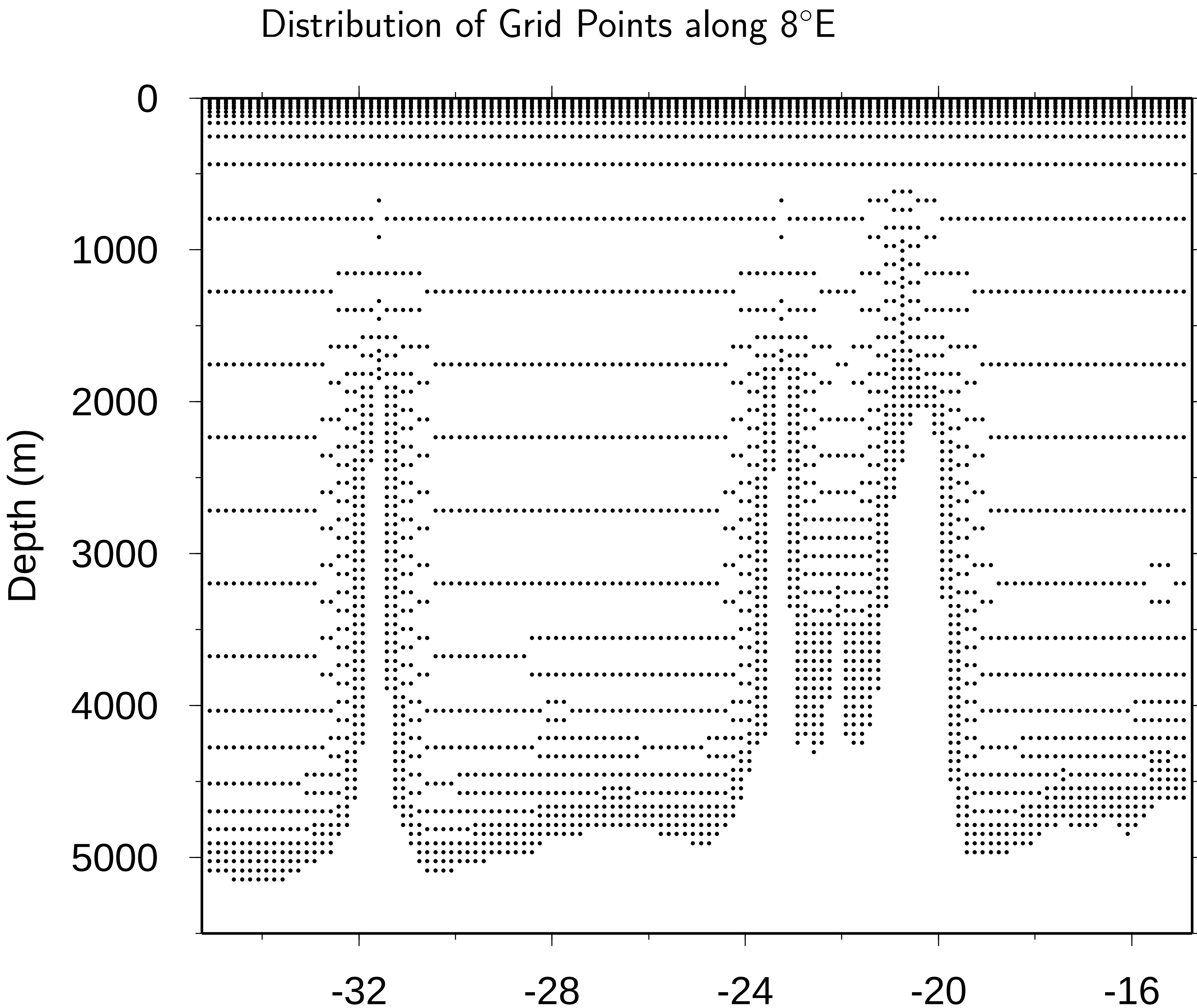
Horizontal resolution:
10' × 10'

≈ 11 000 wet columns



Adaptive Grid

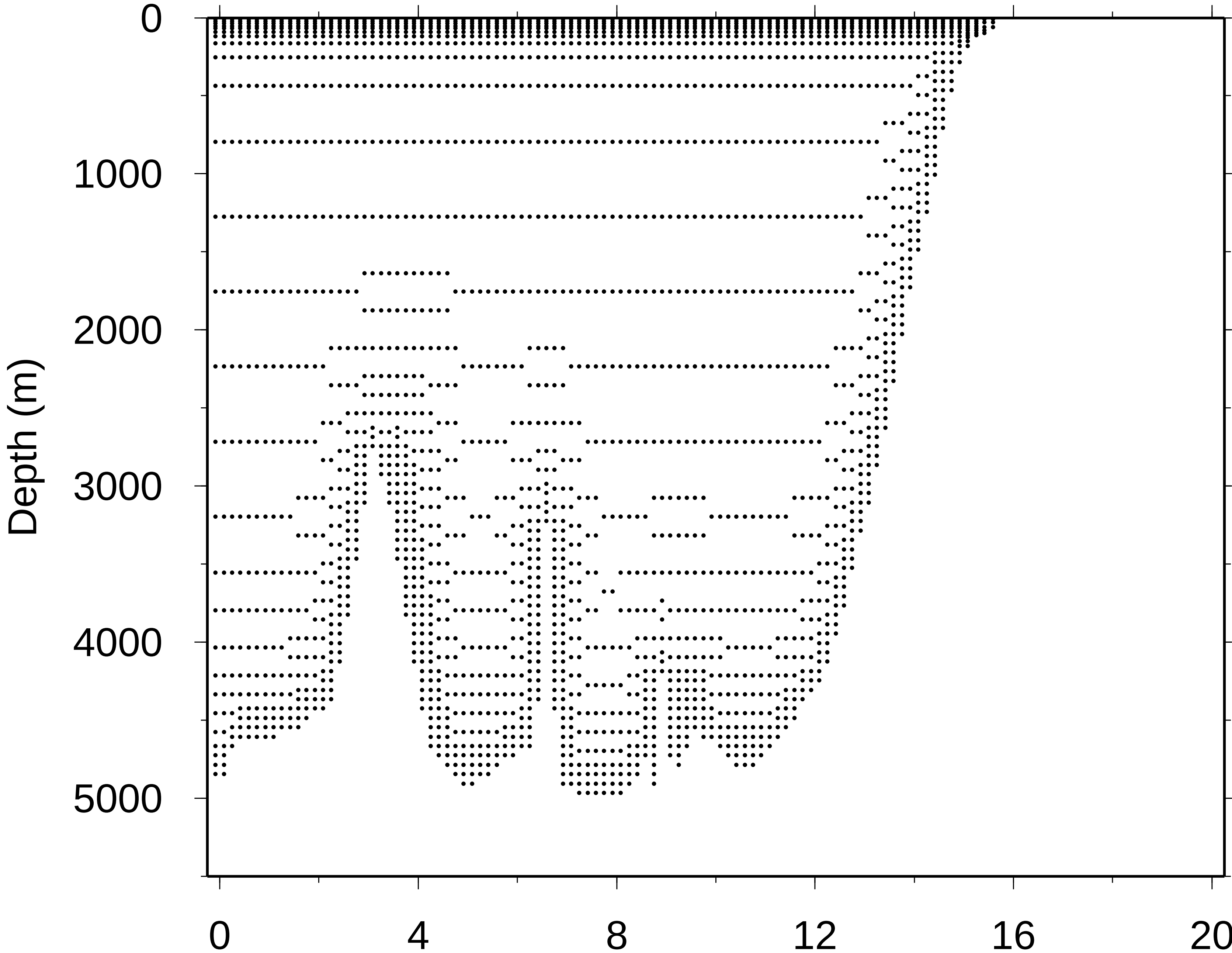
Vertical resolution: 15, 30, 60, 120, 240, 480 m



Adaptive Grid

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

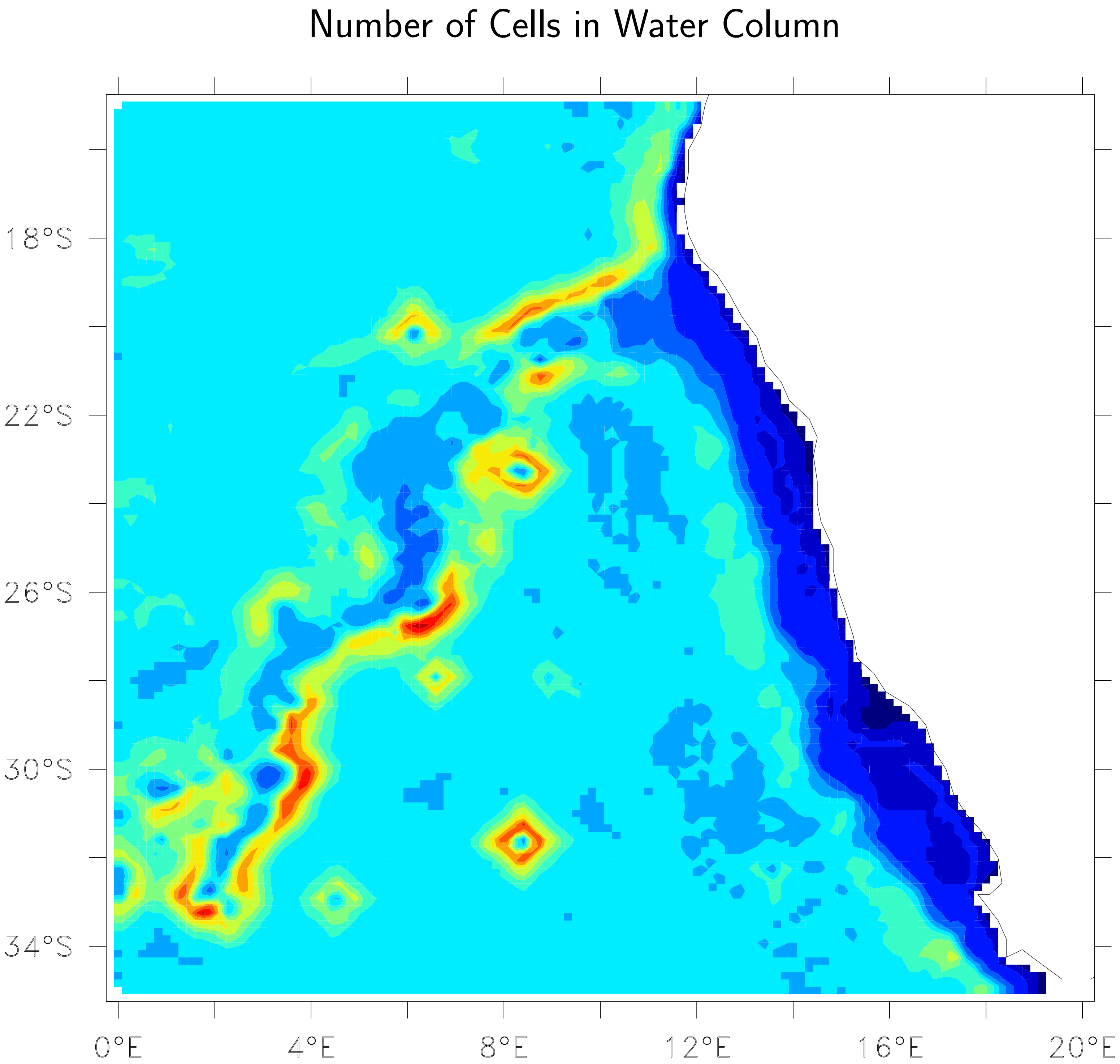
Distribution of Grid Points along 27°S



Adaptive Grid

Minimum: 2
Maximum: 66
Average: 27

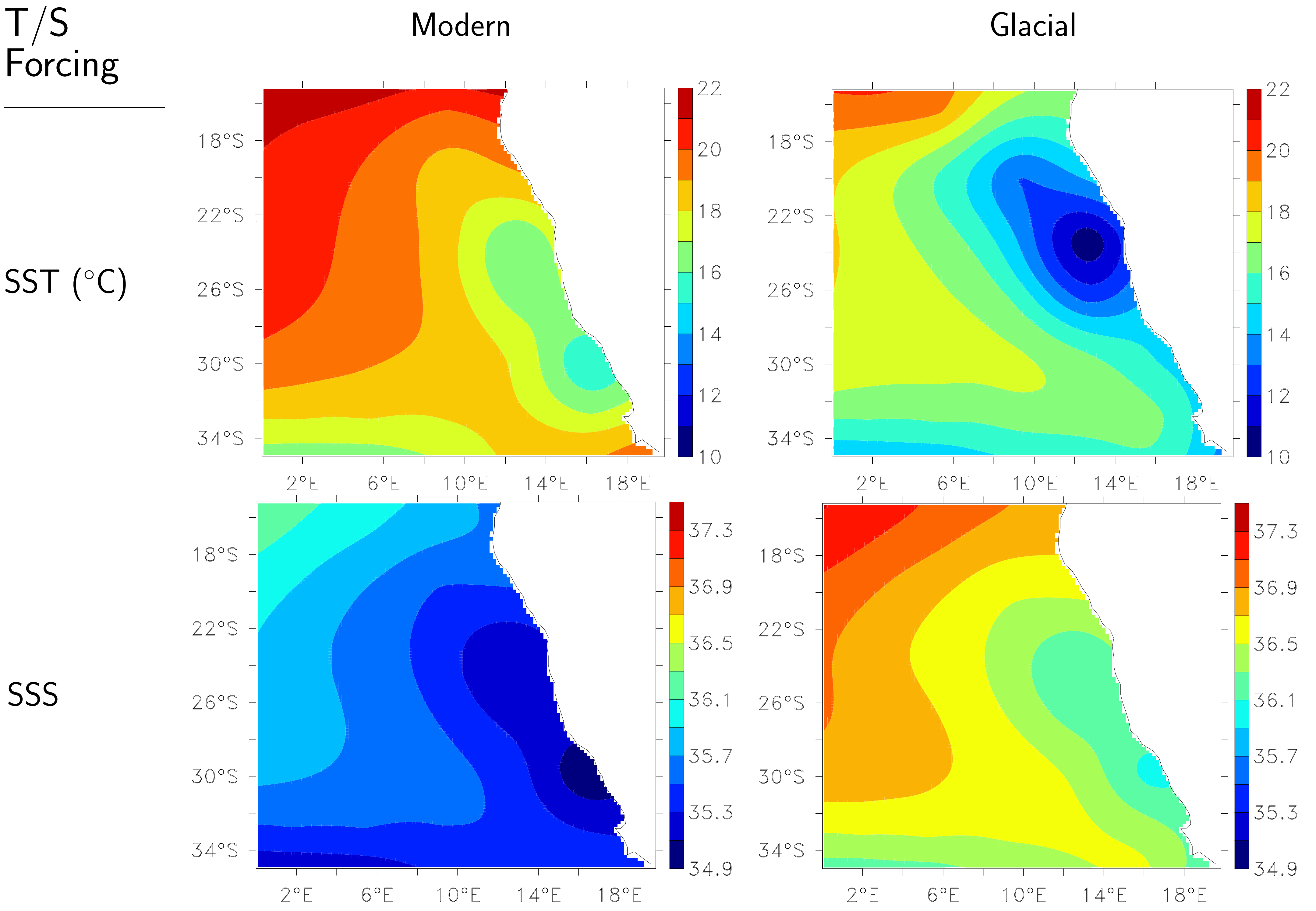
≈ 300 000
wet points



Experiments: Parameters

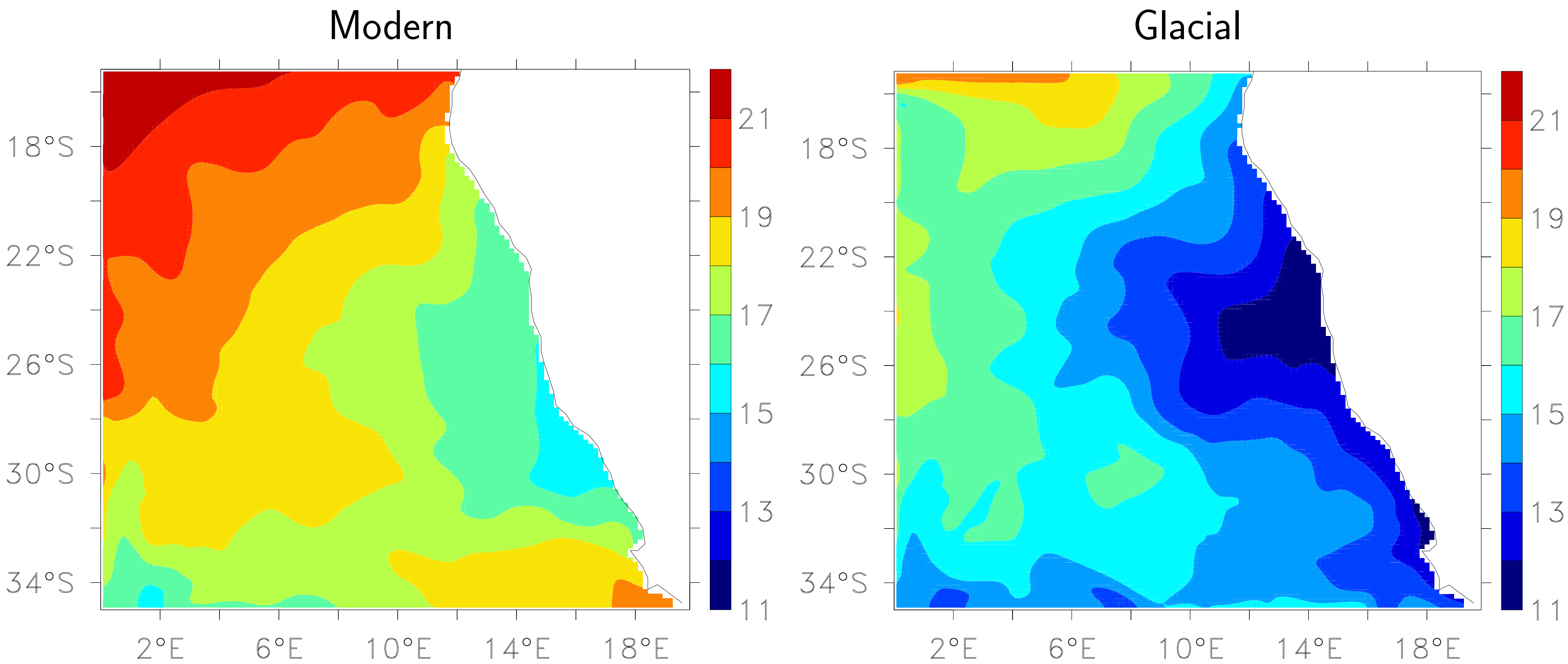
- Modern: based on global experiment using SST and SSS from WOA 98
- Glacial: using global results obtained with reconstructed SST and SSS (Paul and Schäfer-Neth, *Paleoceanography*, in press)

- 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



T/S Forcing
Modern
Glacial
SST (°C)
SSS
18°S
22°S
26°S
30°S
34°S
2°E
6°E
10°E
14°E
18°E
22
20
18
16
14
12
10
37.3
36.9
36.5
36.1
35.7
35.3
34.9

Results: SST (°C)



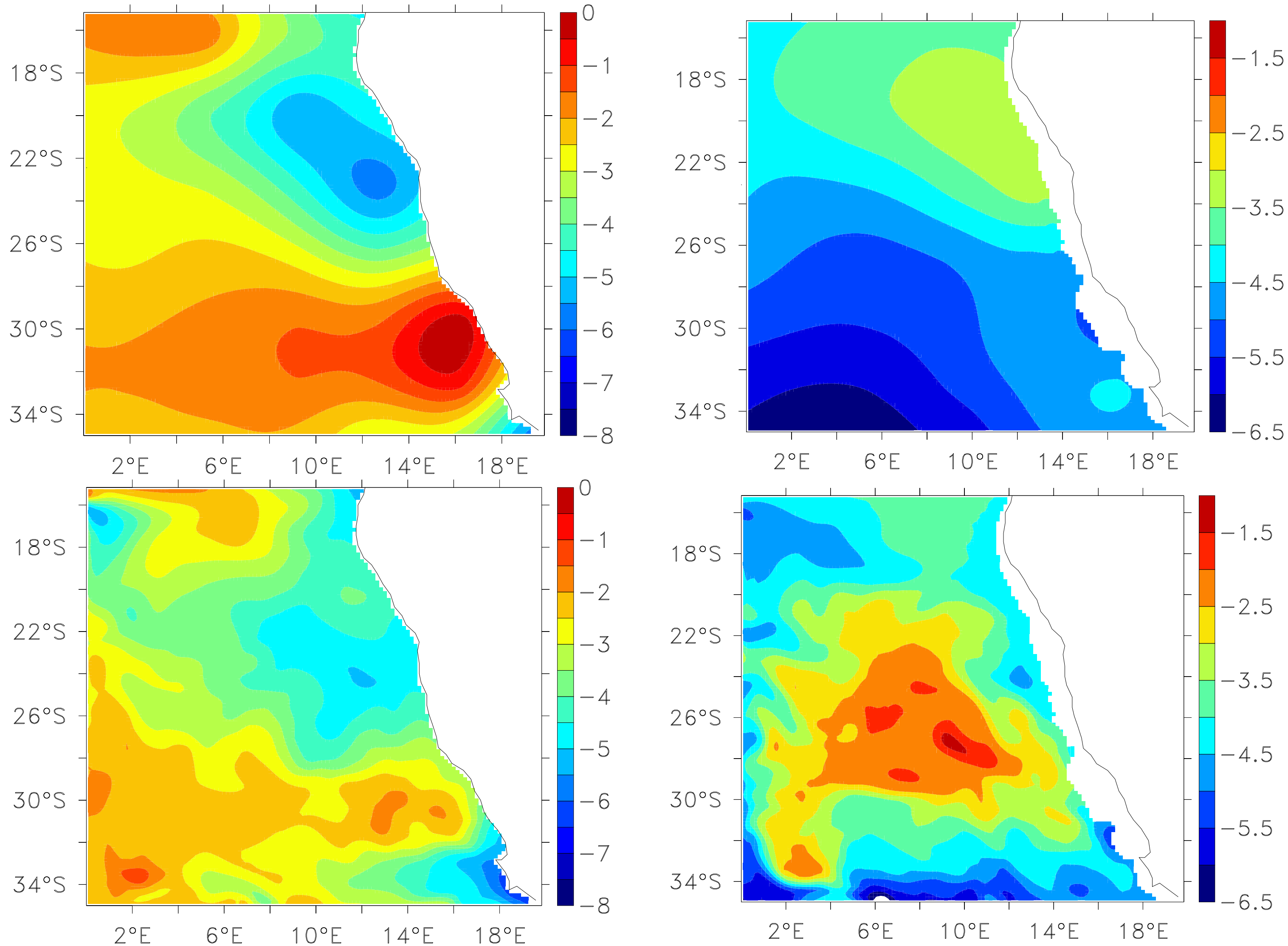
- The upwelling region shifts from 28°S to 24°S in the glacial run

Results: Glacial minus Modern Temperature Anomaly (°C)

0 m | 250 m

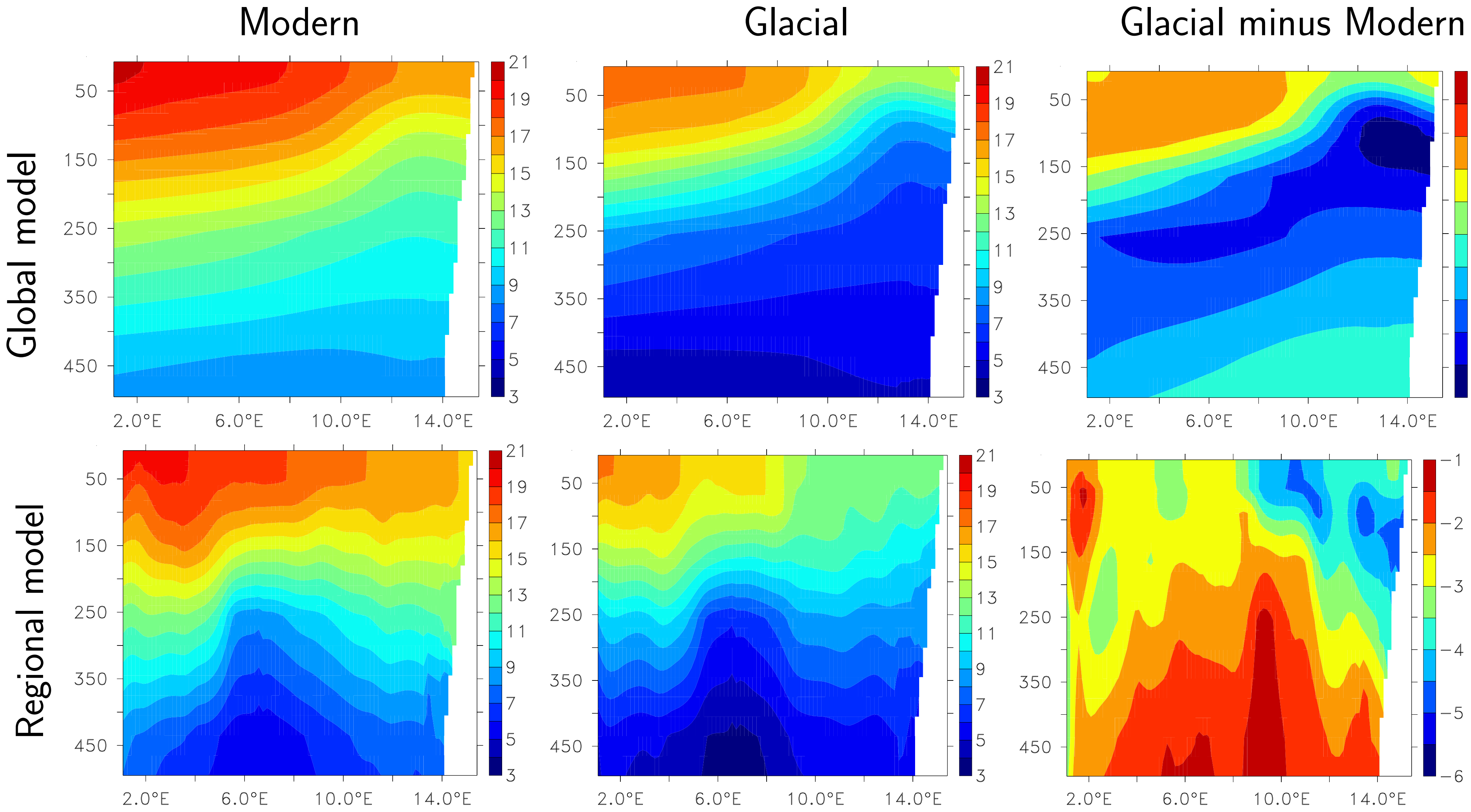
Global model

Regional model



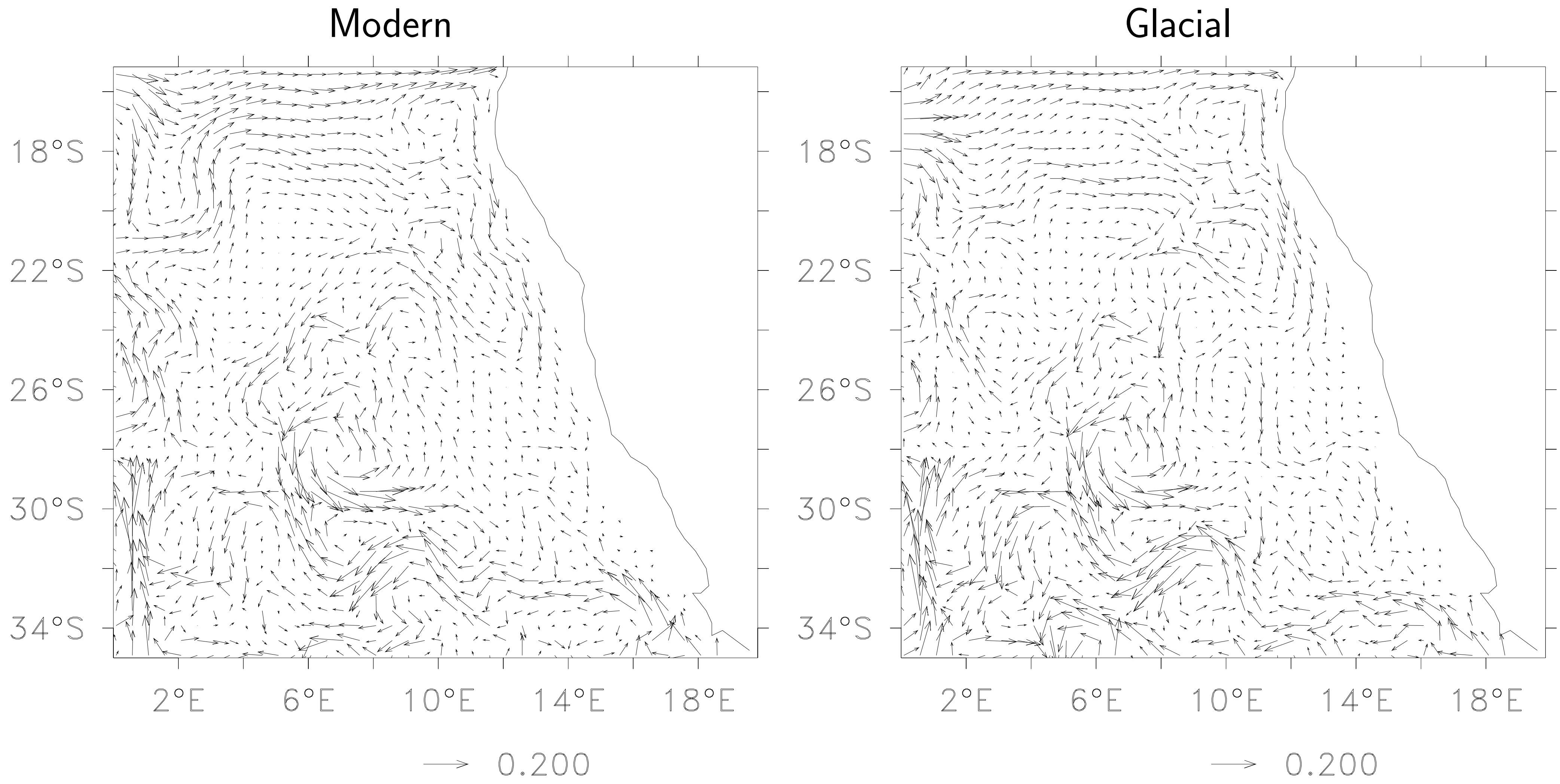
- The anomaly increases at the surface, but decreases at depth
- These opposing trends can be explained in terms of changed upwelling

Results: Temperature along 27°S, 0–500 m depth (°C)



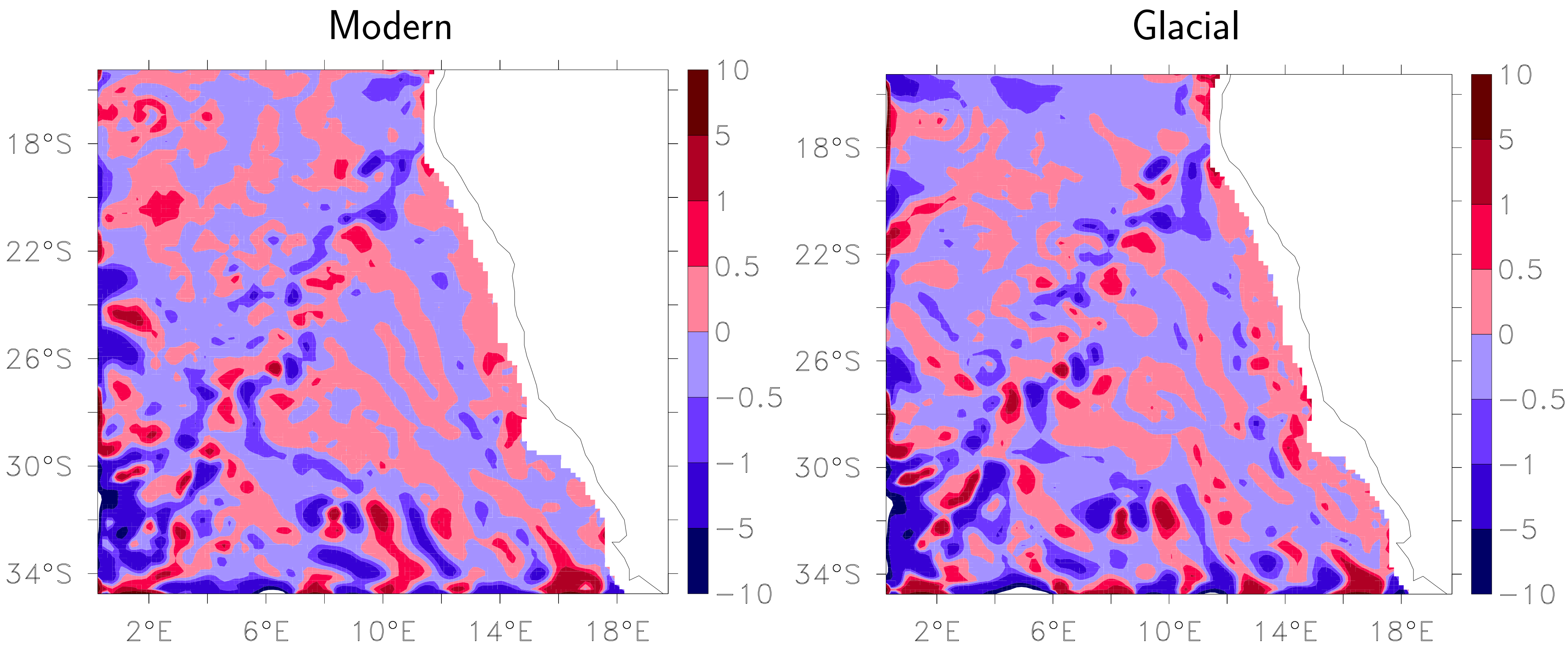
- The lower boundary of coastal upwelling rises to 150 m (modern) and 250 m (glacial)
- In the glacial experiment, the upwelling becomes more intense and broader
- In the modern experiment, the cooling at depth is more pronounced

Results: Horizontal Velocity at 250 m depth (m/s)



- 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

Results: Vertical Velocity at 150 m depth (m/d)



- 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