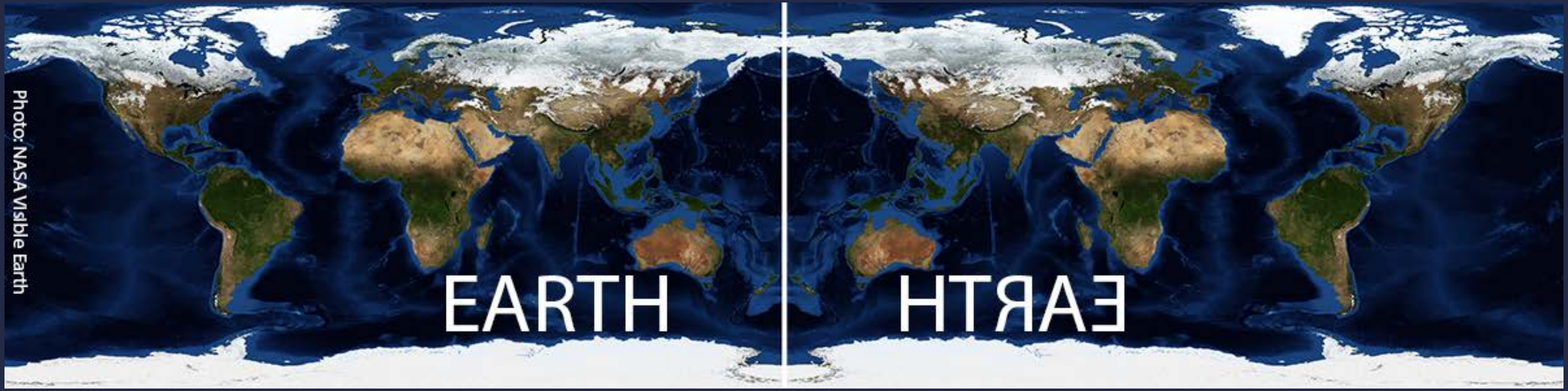
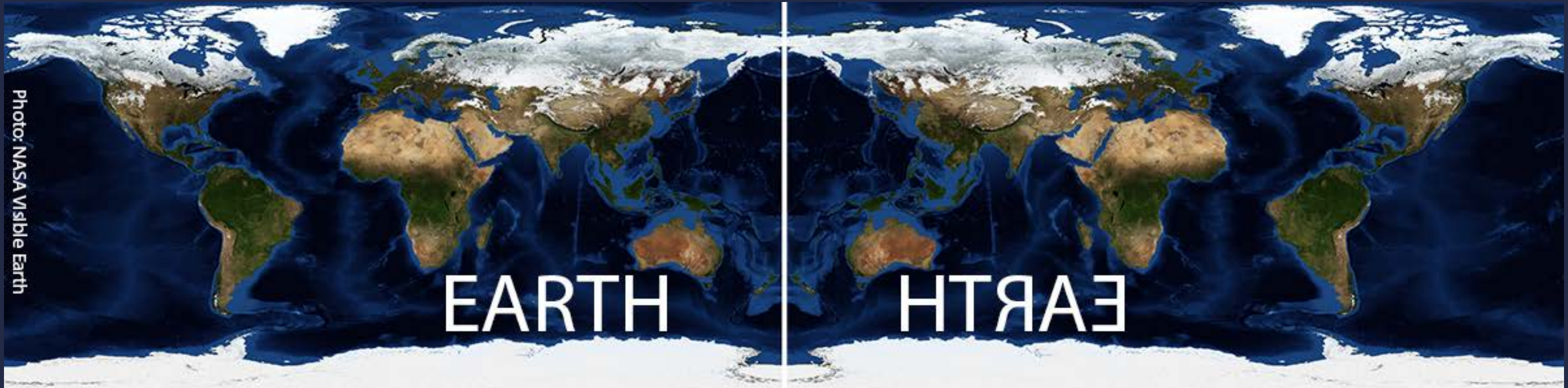
Visualization of a Retrograde Earth Experiment for Public Outreach



Niklas Röber, **Florian Ziemen**, Uwe Mikolajewicz, Guido Cioni, Martin Claussen, Klaus Fraedrich, Marvin Heidkamp, Cathy Hohenegger, Diego Jimenez de la Cuesta, Marie Kapsch, Alexander Lemburg, Thorsten Mauritsen, Katharina Meraner, Hauke Schmidt, Katharina Six, Irene Stemmler, Talia Tamarin-Brodosky, Alexander Winkler, Xiuhua Zhu, and Bjorn Stevens

Deutsches Klimarechenzentrum, Hamburg; Max-Planck-Institut für Meteorologie, Hamburg; International Max Planck Research School on Earth System Modeling, Hamburg; Universität Hamburg; University of Reading

What is a retrograde earth?

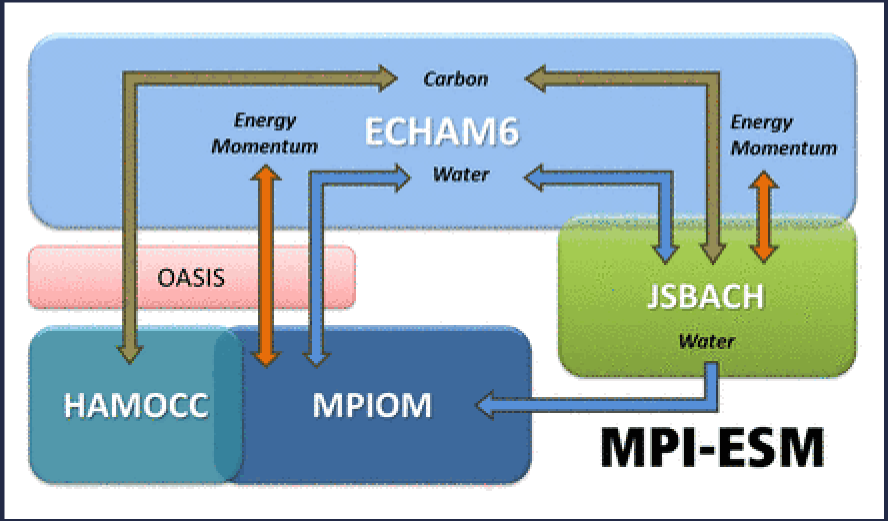


We present the climate of an earth with **reversed (*retrograde*) direction of rotation**. This reversal **equals the creation of a mirror-image** of the topography. The reversal **conserves all major properties** like the sizes of continents and ocean basins while **creating vastly different conditions for the interactions** between topography, weather systems and ocean currents. The change is easy to understand but has fundamental consequences, allowing us to challenge and **improve our understanding of the basic principles** controlling the climate system. This makes this type of experiment **ideal for outreach activities**.

The model and experiments

Earth's rotation influences the climate in two ways. One is the direction of the apparent path of the Sun around the Earth, other is the Coriolis effect, which deflects motions in a rotating system. Both changes were implemented in MPI-ESM. The model is ideal for this type of experiment because it contains all major parts of the climate system, from the atmosphere down to the deep ocean.

We conducted two experiments with pre-industrial climate conditions: one for prograde rotation (hereafter referred to as CNTRL) and one for retrograde rotation (RETRO).



The simulations were performed with the coarse resolution setup, allowing for multi-millennial spin-ups at a reasonable cost.

The presentation

The model results were visualized with Paraview and combined into a prezi-based interactive presentation on a touch-screen display.

The atmosphere

Wind speed 2h

The zonal wind patterns are reversed in the two simulations, which results in easterly jets and westward trade winds in the experimental run. Therefore, continents in the subtropics and mid-latitudes become colder on their western and warmer on their eastern margins. The storm track in the South Pacific is more pronounced, which is related to the changes in ocean circulation, specifically the subtropical gyre in the South Pacific.

Surface temperature (2h)

The surface temperature of Earth strongly depends on the annual and diurnal cycle of the sun. Further, the atmospheric and oceanic circulation determine local temperature patterns. This simulation of 2-hourly surface temperatures emphasizes the differences in the diurnal cycle, best evident in the tropics over South America and Africa.

Surface temperature (month)

Monthly surface temperatures indicate the differences in the seasonal cycle. The most prominent differences are evident over South America and the Sahara during the Northern Hemispheric summer and western Europe and the North Atlantic during winter. The simulations also show that east-west temperature gradients over continents are reversed in the experiment and are pronounced over North America and South Africa.

Evaporation

Evaporation is strongly controlled by the thermal heating of the sun. Over the continents the diurnal cycle of the evaporation follows the diurnal cycle of the surface temperatures. As evaporation largely determines the amount of water vapor in the atmosphere it is linked to cloud formation and rainfall. This link can be seen by weather systems slowly propagating over the global oceans in both simulations.

Water vapor

The patterns of vertical integrated water vapor follow the patterns of evaporation and precipitation. The largest differences are over the North Pacific, due to a shift in the ocean circulation, as well as over North Africa, South America and East Asia. Further, a spatial shift in the amount of water vapor from the eastern margins of the continents to the western margins is evident in the experiment, particular over North America.

Precipitation (2h)

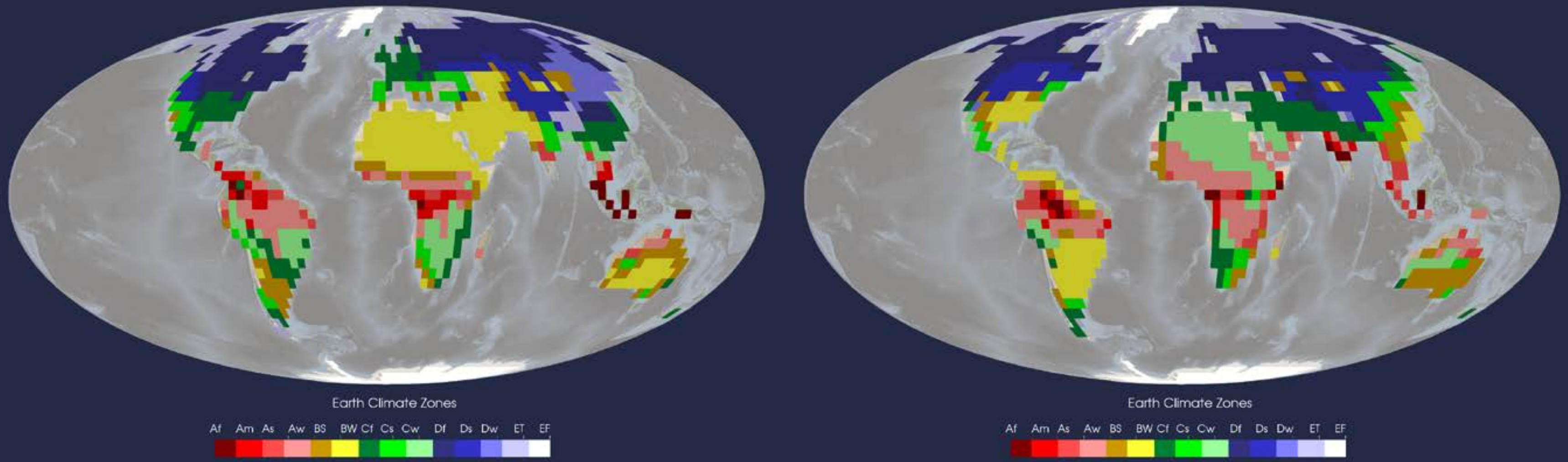
2-hourly precipitation data shows strong convective systems pulsate on a daily basis in the tropics. The annual cycle shifts them to the north in summer, and to the south in winter. In the retrograde experiment, they reach into the Sahara Desert in summer and turn it into a forest. In the mid-latitudes, the cyclone systems follow the main flow of the atmosphere, moving eastward in the control simulation and westward in the retrograde simulation.

Precipitation (month)

Monthly averaged precipitation indicates how the tropical rain belt of the Intertropical Convergence Zone (ITCZ) is moving through the seasons. The general movement is similar in the two simulations, while a reorganization of the tropical ITCZ is evident. Differences are most pronounced over the tropical Atlantic, central Pacific and the Middle East. Note, that the Sahara suddenly becomes very wet!

The land

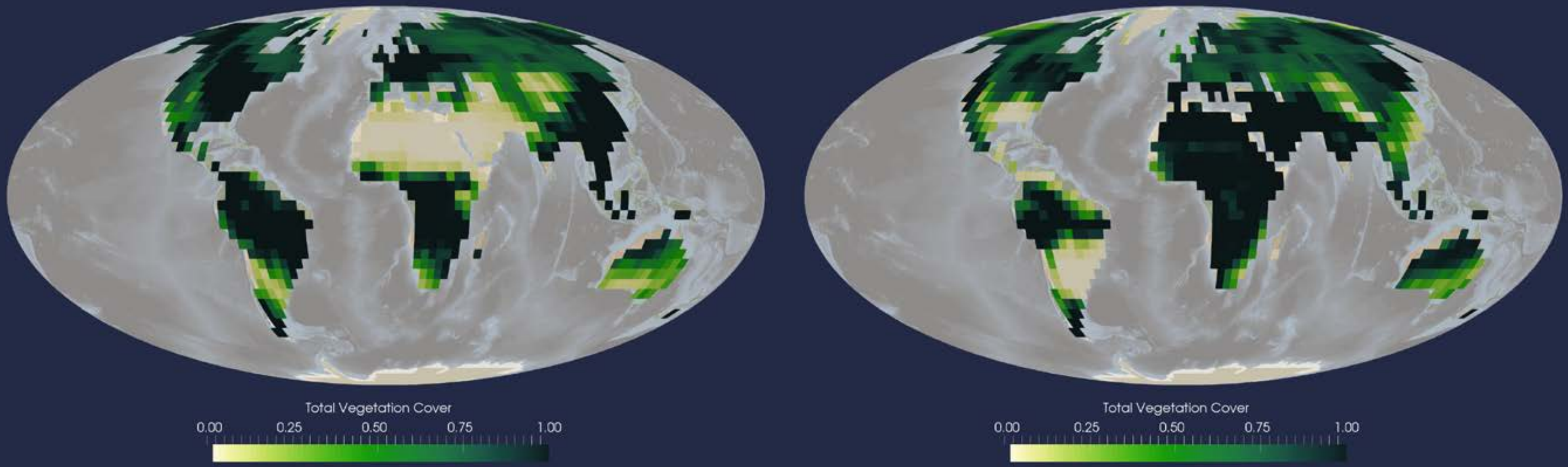
Climate zones



A = equatorial, B = arid, C = warm temperate, D = snow, E = polar, ET = tundra, EF = ice cap
W = desert, S = steppe, f = fully humid, s = summer dry, w = winter dry, m = monsoonal

Due to the changes in the atmospheric and oceanic circulation the climate zones have shifted in the experimental run. As Africa becomes colder and wetter, desert and desert-like climate vanish and appear in South America. The cooling over Europe leads to a snowy and fully humid climate.

Vegetation cover

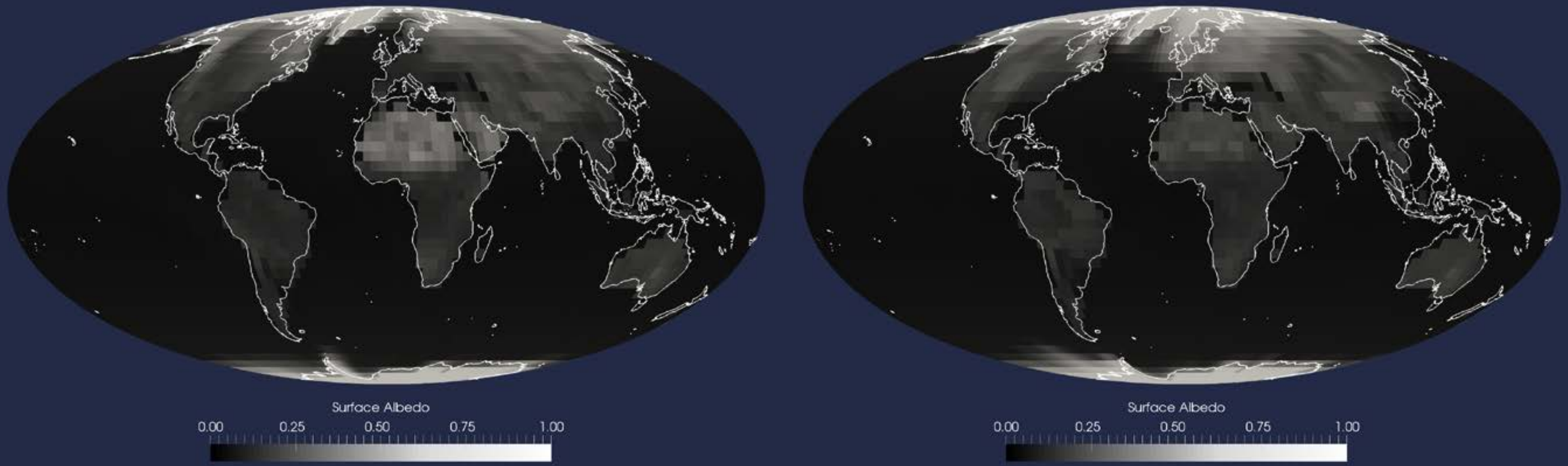


The change in total vegetation cover is closely related to changes in the dominant vegetation. The desert belt from the Western Sahara to the Middle East becomes significantly greener, while North America and South America become deserted in the experimental run. In general, fewer extensive deserts exist.

Leaf Area Index

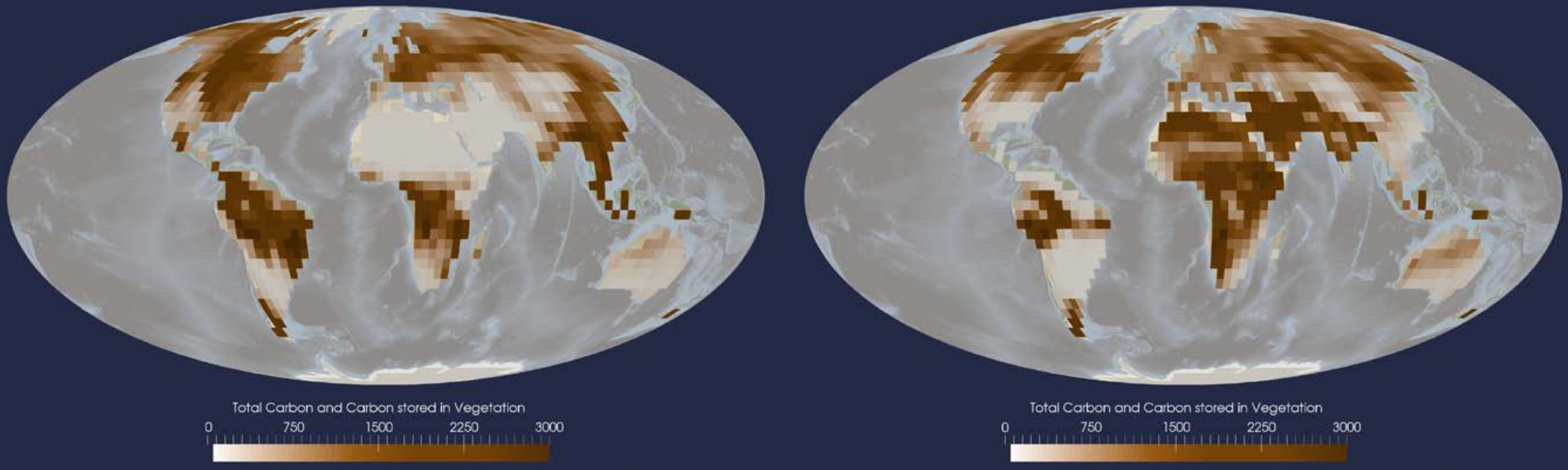
The simulation shows the seasonal cycle of the leaf area index and the transition form northern hemispheric winter to summer. A significant greening occurs over Europe and North America in both experiments during this transition. While the Sahara is deserted in the control experiment, it shows a strong seasonal cycle in the experimental run.

Albedo



The changes in the surface albedo are dependent on snow and vegetation cover. Due to the cooling over Europe and the shift to a snowy climate, the albedo over Europe increases. Over the Sahara, the shift to a wet climate leads to the growths of vegetation and an associated decrease in the albedo. Note the differences in albedo over the Nordic Seas, due to higher sea-ice concentrations in this area.

Carbon content

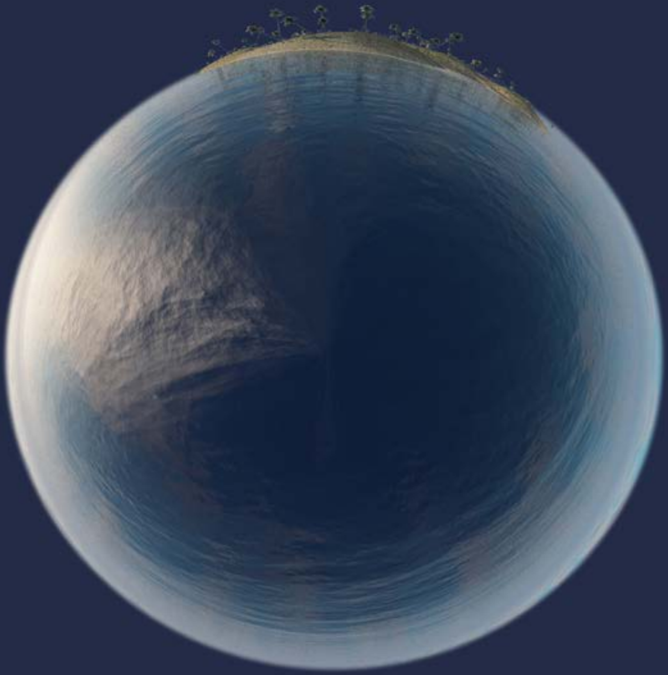


The distribution of total vegetation determines the distribution of stored carbon. Thus, the patterns look very similar to the patterns of the total vegetation cover. The global carbon storage on land in the retrograde run is significantly higher than in the control run. This difference is a result of the increase of vegetation in the Sahara, West Africa and the Northern Hemisphere, compensated by the loss of vegetation in South America.

Snow cover

The seasonal cycle of the snow cover is shown in this simulation. Most significant is the difference in winter snow cover over North America and Europe. As Europe becomes much colder in the experimental run, the snow cover extends further south and south-west into Europe. The circulation changes and the associated winter drying over the east coast of the US explains the lag of snow cover over North America in winter.

Changes in the oceans



Ocean currents

In the experimental runs, the fastest currents can be observed at the American West Coast and in the Indian sector of the Antarctic Circumpolar current. The North Atlantic Current has vanished, and only a weak boundary current at the African West coast moves water northward in the Atlantic. In the tropics, strong wave-features can be observed.

Sea surface temperature

The North Atlantic drastically cools in the retrograde run. This is due to a shutdown of the Atlantic Meridional Overturning Circulation and its associated heat transport. The North Atlantic current turns into a weak current separating from the Spanish coast and traveling towards America. The southern margin of the Atlantic warms.

Sea ice cover

In the retrograde run, much more sea ice is formed in the North Atlantic and the Nordic Seas. This is related to a shift of the deep water formation into the Pacific and drastically reduced ocean heat transports in the North Atlantic. The west coast of the Antarctic Peninsula sees a drastic increase in sea ice.

Sea surface salinity

In the retrograde run, the Mediterranean Sea freshens strongly and develops an estuarine circulation. Similar effects can be seen in the Arabian Sea. This is due to increased precipitation over northern Africa and Arabia. The North Atlantic current can also be seen in the Sea Surface Salinity. It reverses its direction and flows much more southward. Strong increases in salinity can be observed in Eastern Asia.

Mixed layer depth

The mixed layer thickness indicates the locations of deep water formation. They follow the winter season. In the retrograde run, the northern sites shift from the Atlantic to the Pacific, while the Antarctic bottom water formation areas redistribute along the Antarctic coast.

Ocean Temperature

In the experimental run, a strong warming at the western continental margins in the tropics indicates a shift of the boundary currents. The deep ocean temperatures remain low.

Ocean Salinity

In the experimental run, the highest salinities can be found at the east coast of Asia, while the Atlantic freshens and the Mediterranean switches to an estuarine circulation with low salinity. The deep ocean stays at moderate salinity values and does not follow the surface patterns.

Dissolved oxygen content

In upwelling zones, nutrients are brought from the deep to the surface, leading to high biological activity, and the production of large amounts of organic matter. This organic matter is remineralized while sinking to greater water depths. Remineralization requires oxygen, so in regions with high organic matter fluxes oxygen minimum zones (OMZs) develop. In the retrograde experiment, a massive OMZ forms in the Indian ocean.

Ocean N* content

$N^* = NO_3 - 16PO_4$ is a measure for denitrification, i.e. when bacteria use nitrate instead of oxygen to degrade organic matter. Negative values of N* indicate lack of nitrate and abundance of phosphate. This process of denitrification occurs only in oxygen minimum zones. It reveals its implication on biological productivity of most marine plants when water with low N* values reaches the surface and limits plant growth. In the retrograde experiments very low values of N* are found especially in the Indian Ocean.

Ocean PO_4^* content

$PO_4^* = PO_4 + 172\ O_2$ is used to estimate contributions of deep water formed in the North (low values) and Antarctic Bottom Water (AABW, high values). The mixing of water from AABW and North Atlantic Deep Water (prograde) or North Pacific Deep Water NADW (retrograde) leads to intermediate PO_4^* values in the Northern Pacific or Northern Atlantic, respectively. In the retrograde experiment the Indian Ocean is dominated by high-PO_4^* waters revealing the weakness of the PO_4^* concept in regions with high denitrification (see N*).

Atmosphere–ocean heat flux

The dominant signal is the annual cycle with strong heat fluxes into the ocean in summer, and massive heat release in the deep water formation areas in Winter. In the exprerimental run, these losses have largely shifted from the North Atlantic to the North Pacific. Further heat losses can be seen in the boundary currents, that in the experimental run have shifted to the west coasts of the continents.