A multi-resolution ocean simulation of the anthropogenic radiocarbon transient

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We have implemented ^{14}C and further abiotic tracers (^{39}Ar, CFC-12, and SF_6) into the state-of-the-art ocean circulation model FESOM2 (Danilov et al. 2017; Scholz et al. 2019). Different to other global ocean circulation models, FESOM2 employs unstructured meshes with variable horizontal resolution. This approach allows for improvements in areas which are commonly poorly resolved in global ocean modelling studies such as upwelling regions, while keeping the overall computational costs still sufficiently moderate. Here, we present results of a transient simulation running from 1850-2015 CE tracing the evolution of the bomb radiocarbon pulse with a focus on the evolution of marine radiocarbon ages (MRAs). In addition, we explore the potential of ^{39}Argon to complement ^{14}C dating of marine waters.

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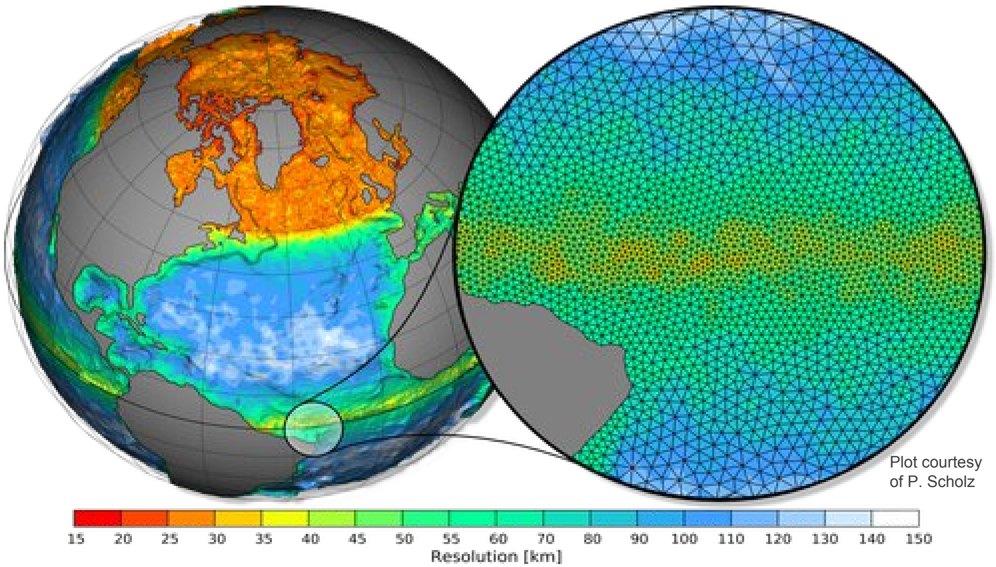
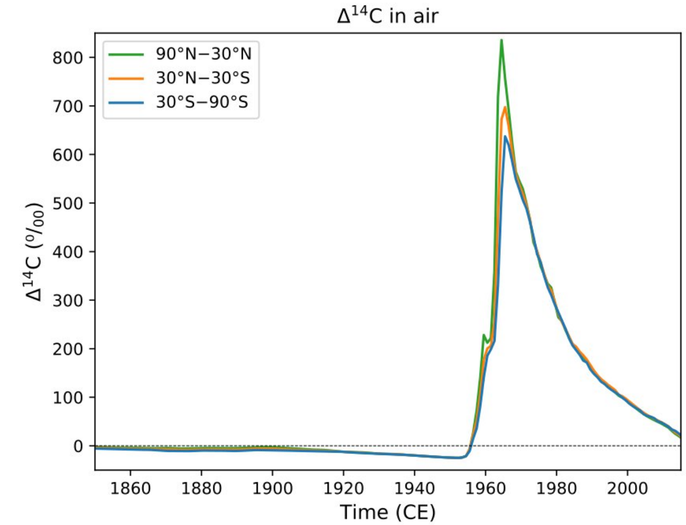
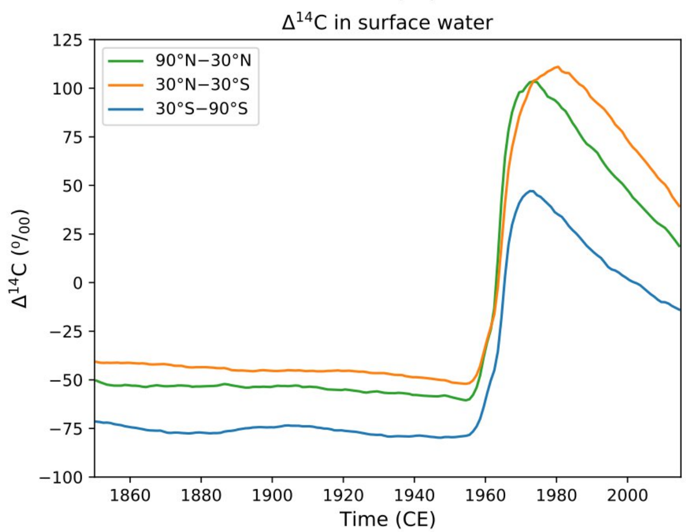
Model setup



- Global multiresolution mesh with 127 000 2D-vertices (rectangular analog ~0.7°) and 47 layers
- CORE-II climate forcing (Large and Yeager 2009)
- Radiocarbon is simulated as $\Delta^{14}C$
- Spinup integration over 10 000 years
- Transient simulation from 1850-2015 with atmospheric ^{14}C by Graven et al. (2017) and CO_2 by Meinshausen et al. (2017)

Temporal evolution of $\Delta^{14}C$ (1)

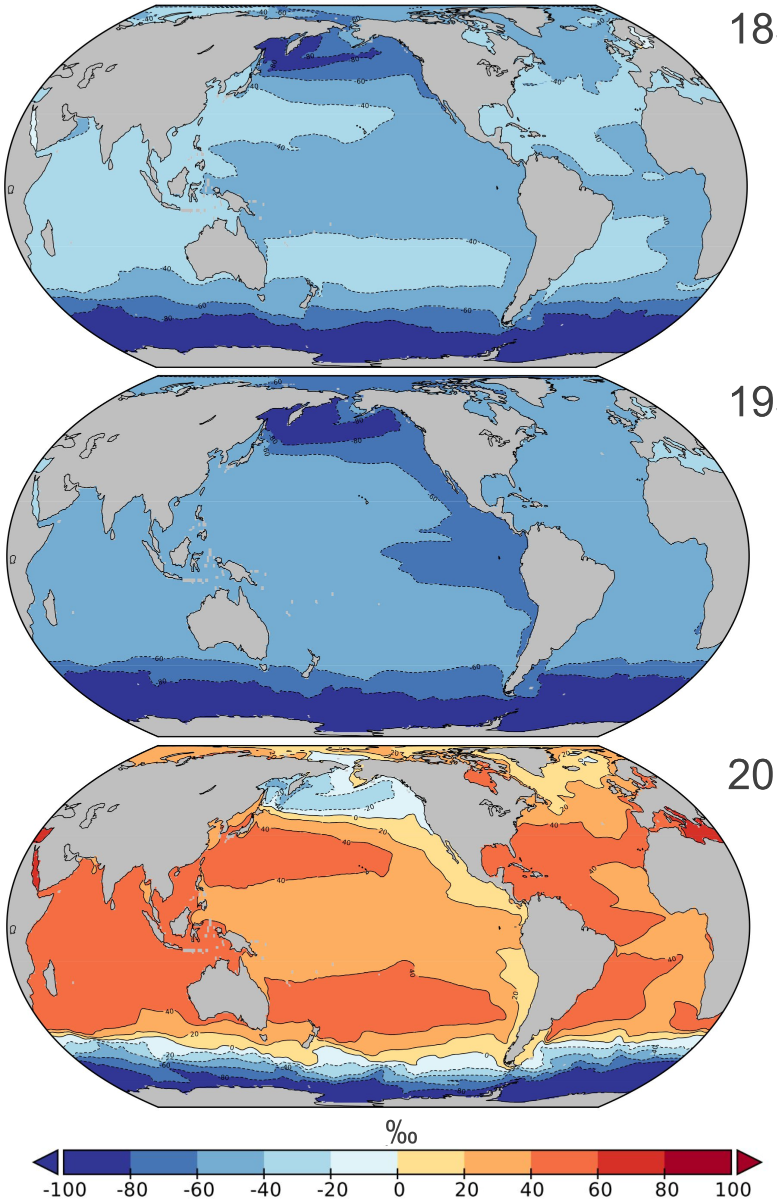




Atmospheric $\Delta^{14}C$ values (reconstructed by Graven et al. 2017) peaked around 1964-1965. Hemispheric differences are due to the asymmetric geographic distribution of test sites, as most nuclear devices were fired in the Northern Hemisphere. The post-bomb decline is due to the uptake by the ocean and the terrestrial biosphere as well as due to fossil fuel emissions devoid of ^{14}C (Graven et al. 2020).

Simulated marine $\Delta^{14}C$ values in the extratropical oceans peak around 1972. Maximum values in surface water are found in the low-latitude oceans about ten years later. The enrichment is due to ^{14}C transport from higher latitudes rendered by the shallow overturning circulation (not shown).

Temporal evolution of $\Delta^{14}C$ (2)



1850 CE

The figures show $\Delta^{14}C$ of surface water.

Preindustrial $\Delta^{14}C$ values are ~ -50‰ in the global mean. Stronger depletion is simulated in the Sea of Okhotsk, the Bering Sea, and the Southern Ocean.

1950 CE

Prenuclear $\Delta^{14}C$ values decrease by about 10‰ in the global mean reflecting the Suess effect, i.e. the oceanic uptake of fossil fuel CO_2 devoid of ^{14}C.

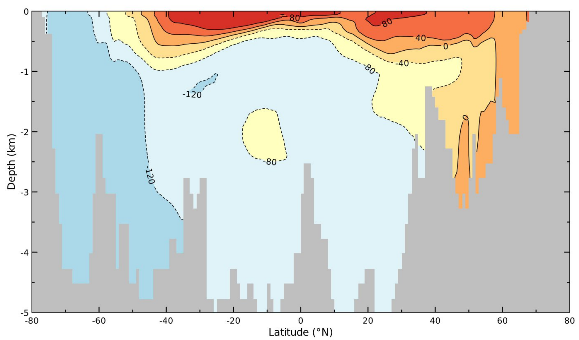
2015 CE

Postnuclear $\Delta^{14}C$ values are widely still positive reflecting the input of bomb ^{14}C. Negative $\Delta^{14}C$ values emerge in the northern North Pacific (still elevated above prenuclear levels) and in the Southern Ocean.

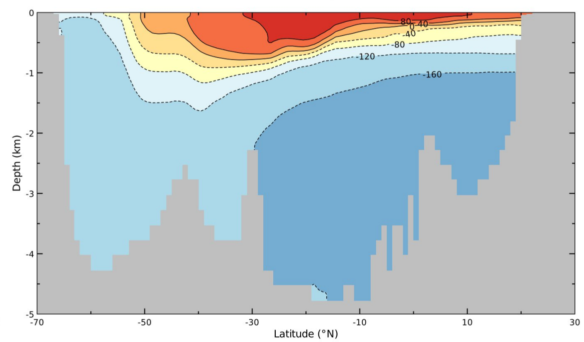
Model evaluation

Model Atlantic | Indian Ocean | Pacific

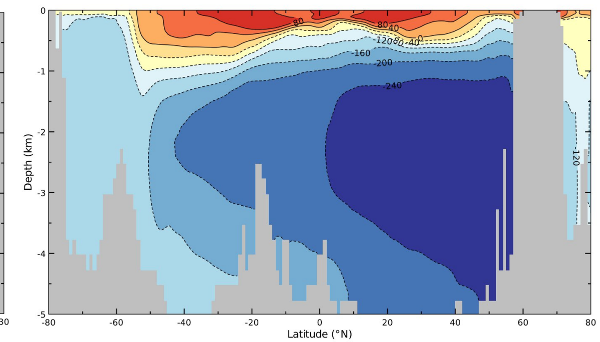
Simulated Δ¹⁴C along 30°W in 1985



Simulated Δ¹⁴C along 90°E in 1995



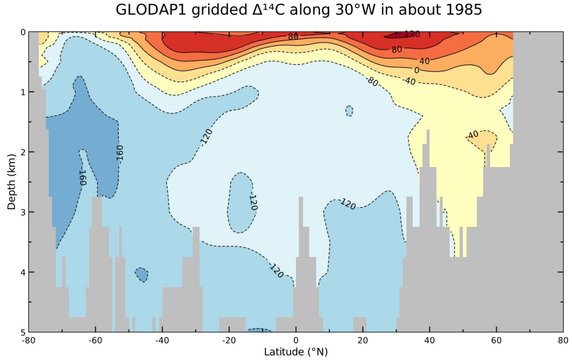
Simulated Δ¹⁴C along 150°W in 1993



The simulation tends to overestimate $\Delta^{14}C$ in the South Atlantic and in parts of the Southern Ocean. It agrees with the GLODAP1 reconstruction (by Key et al. 2004) in the Indian Ocean but underestimates $\Delta^{14}C$ in the deep North Pacific.

Reconstruction

GLODAP1 gridded Δ¹⁴C along 30°W in about 1985



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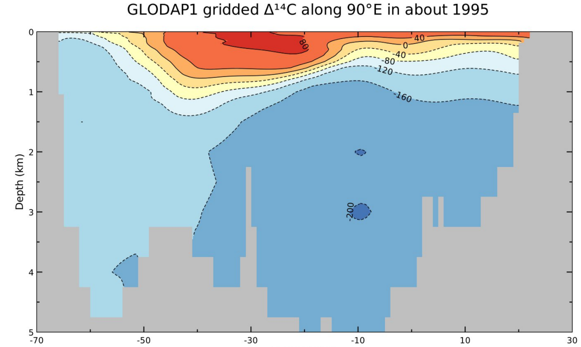

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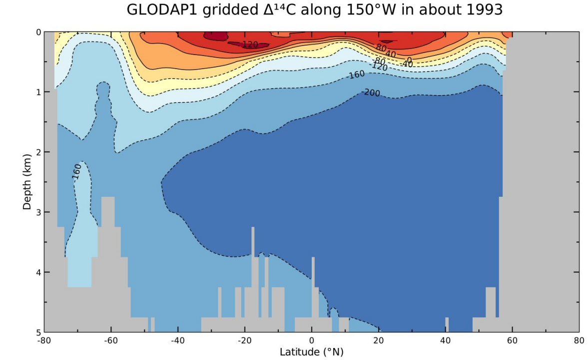

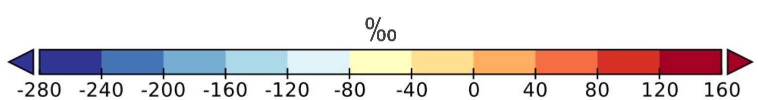

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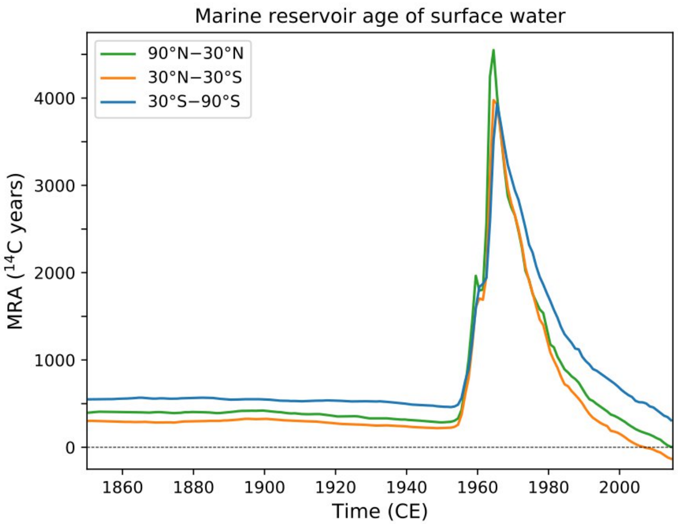
Temporal evolution of marine ^{14}C ages (1)



In the hemispheric mean, MRAs run parallel to the atmospheric $\Delta^{14}C$ transient (cf. slide 3). The bomb peak translates into MRAs of more than 4000 years around 1964-1965. In the 21st century MRAs become negative (while the $\Delta^{14}C$ of surface water is still elevated above prenuclear levels, cf. slide 3). This indicates that parts of the ocean have become a source of ^{14}C.

Marine reservoir ages (in ^{14}C years) are calculated a posteriori as follows:

$$MRA = \lambda^{-1} \ln [(1 + 0.001\ \Delta^{14}C_{atm}) / (1 + 0.001\ \Delta^{14}C_{mar})]$$

where

$\Delta^{14}C_{atm}$, $\Delta^{14}C_{mar}$ = $\Delta^{14}C$ ratios in atmosphere and ocean, respectively

λ^{-1} = 8033 years = conventional decay constant of ^{14}C

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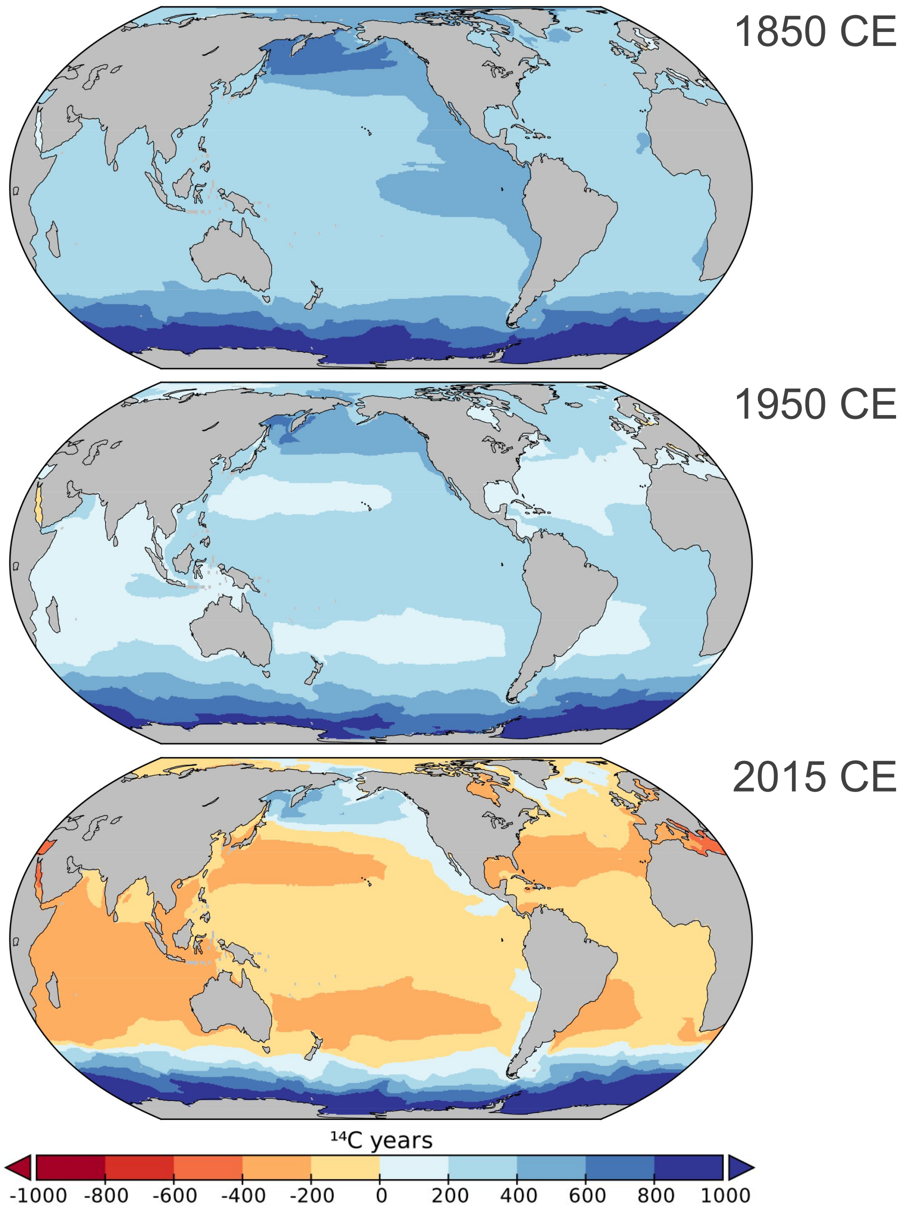
Temporal evolution of marine ^{14}C ages (2)



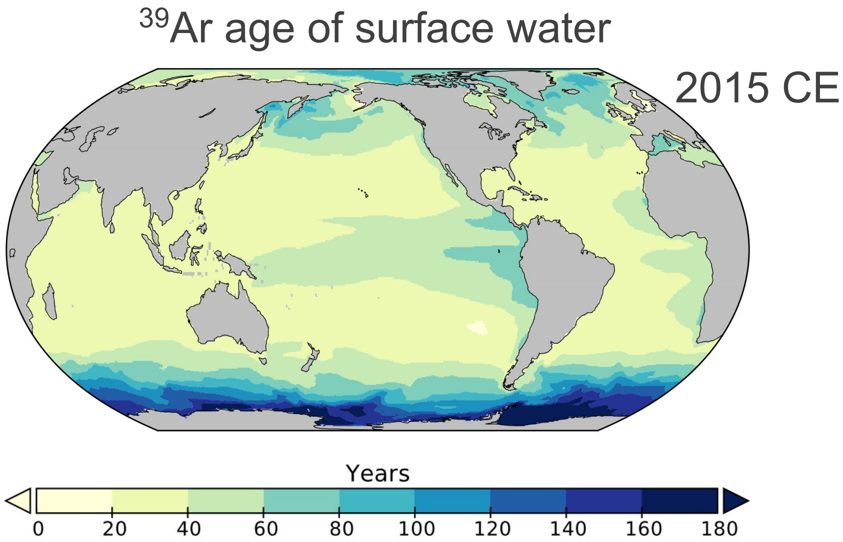
The figures show marine reservoir ages.

Preindustrial MRAs range from 300 to 1100 years. The highest values are simulated in the Southern Ocean.

Prenuclear MRAs widely decrease by about 100 years due to the Suess effect.

Postnuclear MRAs are negative in the middle and low latitudes, indicating that anthropogenic ^{14}C is redistributed by the shallow overturning circulation in these regions.

^{39}Argon as a complementary tracer



The shallow overturning circulation operates on a time scale of a few decades. This can be illustrated by preliminary model results of ^{39}Ar ages of surface water. Having a half-life of 269 years, ^{39}Ar could complement ^{14}C on shorter time scales but measurements are still sparse.

References

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