European Union's Seventh Framework Programme
Grant Agreement Nº: 603521

Project Acronym: **PREFACE**

Project full title: **Enhancing prediction of tropical Atlantic climate and its impacts**

Instrument: Collaborative Project

Theme: ENV.2013.6.1-1 – *Climate-related ocean processes and combined impacts of multiple stressors on the marine environment*

Start date of project: 1 November 2013 Duration: 48 Months

Deliverable Reference Number and Title:

D3.1

"Object-Seasonal heat and fresh water ML-balance"

Lead work package[1] for this deliverable: GEOMAR

Lead contractor[1] for this deliverable: GEOMAR

Due date of deliverable: 30.04.2015

Actual submission date: 30.04.2015

Project co-funded by the European Commission within the Seven Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the Consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	

[1] Name of beneficiary (=institute/organisation/university)

Contribution to project objectives – with this deliverable, the project has contributed to the achievement of the following objectives (see Annex I / DOW, Section B1.1.):

N.º	Objective	Yes	No
1	Reduce uncertainties in our knowledge of the functioning of Tropical Atlantic (TA) climate, particularly climate-related ocean processes (including stratification) and dynamics, coupled ocean, atmosphere, and land interactions; and internal and externally forced climate variability.	X	
2	Better understand the impact of model systematic error and its reduction on seasonal-to-decadal climate predictions and on climate change projections.		X
3	Improve the simulation and prediction TA climate on seasonal and longer time scales, and contribute to better quantification of climate change impacts in the region.	X	
4	Improve understanding of the cumulative effects of the multiple stressors of climate variability, greenhouse-gas induced climate change (including warming and deoxygenation), and fisheries on marine ecosystems, functional diversity, and ecosystem services (e.g., fisheries) in the TA.		X
5	Assess the socio-economic vulnerabilities and evaluate the resilience of the welfare of West African fishing communities to climate-driven ecosystem shifts and global markets.		X

Authors of this deliverable: Marcus Dengler, Willi Rath, GEOMAR

Report on the deliverable:

A new seasonal climatology for different components of the heat and freshwater budget in the mixed layer was compiled for the equatorial and eastern boundary upwelling regions in the Atlantic.

The compilation used all publically available hydrographic data sets from global data repositories including most recent Argo floats, surface drifter, and glider measurements as well as previously unpublished hydrographic data from the EAF Nansen program and other programs of the PREFACE partners. The seasonal climatology was computed on a ¼-degree grid. The chosen interpolation scheme included an isobath-following component and a front-sharpening component (Schmidtko et al., 2013). In addition, the data set includes monthly values of mixed-layer depth, heat and salt tendency, lateral-advective heat and salt fluxes as well as air-sea fluxes of heat and freshwater. The data set covers the tropical Atlantic between 30°S and 30°N and east of 35°W.

The climatological estimates of the atmospheric heat fluxes were computed from the monthly-mean fields of atmospheric fluxes provided in the Tropflux (Kumar at al., 2012) data set. Evaporation rates for the atmospheric freshwater fluxes were derived from Tropflux climatology while precipitation rates were obtained from monthly mean fields of the Global Precipitation Climatology Project version 2.2 (Huffman et al., 2009). Advective heat and salt fluxes was derived from the climatological hydrographic data set and from a climatological velocity data set derived from direct surface velocity measurements using surface drifters from the Global Drifter Project (Lumpkin et al., 2013) and surface trajectories of Argo floats as compiled in the updated YoMaHa07 (Lebedev et al., 2007) data set (Version: March 2015).

The climatology also includes hydrographic stations from the EAF-Nansen program. Data sets from this program are restricted to the country owning the data and are not publically available. The PREFACE partners Instituto National de Investigacao Pesqueira, Angola, the Namibian Ministry of Fisheries & Marine Resources in Swakopmund, and the Senegalese Centre de Recherches Océanographiques in Dakar contributed more than 6000 hydrographic stations from Angolan territorial waters, 3500 stations from Namibian territorial waters and 1000 stations from Senegalese territorial waters, respectively. Additionally, previously not publically available hydrographic data from IOW, Germany, and data from the PIRATA service cruise program by IRD, France were included. Finally, hydrographic data collected by more than 20 glider missions in the eastern tropical Atlantic by GEOMAR, Germany (http://gliderweb.geomar.de) were subsampled and added to the climatology.

Currently, the data sets and updates are available for download at:

https://doi.pangaea.de/10.1594/PANGAEA.868927

Huffman, G.J, Adler, R.F., Bolvin, D.T., Gu, G. (2009) Improving the Global Precipitation Record: GPCP Version 2.1, *Geophys. Res. Lett.*, 36, L17808, doi:10.1029/2009GL040000.

Kumar, B.P., Vialard, J., Lengaigne, M., Murty, V.S.N., McPhaden, M.J. (2012) TropFlux: air-sea fluxes for the global tropical oceans—description and evaluation, *Clim. Dyn.*, 38, 1521–1543, doi:10.1007/s00382-011-1115-0.

Lebedev, K., Yoshinari, H., Maximenko, N.A., Hacker, P.W. (2007) YoMaHa'07: Velocity data assessed from trajectories of Argo floats at parking level and at the sea surface, IPRC, 1141 Technical Note, No. 4(2), June 12, 16p.

Lumpkin, R., Grodsky, S.A., Centurioni, L., Rio, M-H., Carton, J.A., Lee, D. (2013) Removing spurious low-frequency variability in drifter velocities, *J. Atmos. Oceanic Technol.*, 30, 353-360, doi:10.1175/JTECH-D-12-00139.1.

Schmidtko S., Johnson G.C., Lyman J.M. (2013) MIMOC: A global monthly isopycnal upper-ocean climatology with mixed layers, *J. Geophys. Res.*, 118, 1658–1672, doi:10.1002/jgrc.20122.

Addendum: Quality assessment of the new PREFACE seasonal heat and fresh water mixed-layer balance climatology

Data Coverage

Data availability for the new PREFACE climatology exceeded all existing climatologies by several 10k hydrographic profiles due to access to data that was not publically available and due to the inclusion of new Argo float, surface drifter, and glider data. Figure 1 shows the availability of new data in the new PREFACE climatology measured as the number of data points influencing the respective grid box in colors. The black dots show the positions of each of the newly included measurements (including ARGO float positions). The exceptionally high data availability at the continental margins of Angola and Namibia, a key region within the EU-PREFACE program, resulted from access to the EAF Nansen hydrographic data owned by the coastal states. Data availability is still low in the equatorial region of the Atlantic east of Greenwich meridian.

Estimates of mixed-layer depth, mixed-layer temperature and mixed-layer salinity

In comparison to existing mixed-layer depth climatologies by de Boyer Montégut et al. (2004) and the MIMOC climatology by Schmidtko et al. (2013), the new product shows deeper mixed-layer estimates in the previously only sparsely covered Gulf of Guinea (Figure 2). Furthermore, it captures the shallow near-shore mixed layer depths along the western coast of African that was ill resolved in the two existing climatologies. A comparison of climatological mixed-layer temperature (Figure 3) and mixed-layer-salinity distributions (Figure 4) between MIMOC and the new product shows that the improved availability of data off Angola and off Namibia also contribute to removing artifacts present in the MIMOC climatology.

One of the major benefits of the new product is improved near-coastal estimates of mixed-layer depth, temperature and salinity. As evident in Figures 5 and 6 comparing the properties of the different products along zonal sections at 16^{o}N and at 12^{o}S, the seasonal variability of mixed-layer depth, temperature and salinity in the mixed layer near the coast are much better reflected. The relatively coarse-resolution product of de Boyer Montégut et al. (2004), that includes all publically available hydrographical stations collected before the year 2002, fails to capture the shallow mixed-layers that prevail near the coast. The MIMOC climatology shows improvements of representing the mixed-layer depth variability near the coasts which is probably due to the fact that MIMOC includes data until the year 2012, and thereby profits from the substantial improvements in ARGO coverage in recent years. The new product shows realistically shallow near-shore mixed layers throughout the year. Furthermore, the increased temporal variability of near-shore mixed-layer temperature and salinity seen in the new product can be considered a substantial improvement. This is a direct consequence of the inclusion of the Nansen data in the new product.

Horizontal advection of heat and salt

Another achievement of the new product is the compilation of a 2.5°x2.5° climatology of near-surface velocities which allow for a computation of basin wide horizontal advection of heat and salt in the mixed layer. Larger horizontal grid spacing was necessary to achieve statistically reliable estimates for the horizontal currents from the relatively sparse drifter and float data. Particularly in the eastern boundary upwelling regions, the combination of improvements in the near-shore mixed-layer hydrography and of the improvements in the velocity estimates now allows for a 3-dimensional (geographic position and time) assessment of lateral advection of heat and salt by the mean flow.

Comparison of heat budgets

Several regional mixed-layer heat budget studies from the central and eastern tropical Atlantic have recently been published. Figure 9 and 10 compares the results of two of these studies to the heat budgets from the new PREFACE climatology. In Foltz et al. (2013) a region in the north eastern Atlantic from 18°W to 28°W and from 15°N to 25°N was analyzed. Their results compare well to the different terms of the heat budget of the new PREFACE climatology (Figure 9). In particular, the seasonal cycle of horizontal heat advection is very similar in both data sets. In the new PREFACE climatology, residual heat flux is somewhat reduced compared to Foltz et al. (2013) due to a larger heat storage rate (tendency) and small negative horizontal heat flux contributions from June to November. Hummels at al. (2014) found that the seasonal heat budget at 10°S, 10°W can be explained by a balance between net surface heat flux and heat storage rate determined from an extensive data set collected by the PIRATA mooring at this cite. The new PREFACE climatology reveals reduced amplitude of the heat-storage term during January through April compared to the study by Hummels et al (2014). However, the new PREFACE climatology confirms that horizontal heat advection in this region is negligible.

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de Boyer Montégut, C., Madec, G., Fischer, A.S., Lazar, A., Ludicone, D. (2004) Mixed layer depth over the global ocean: An examination of profile data and a profile-based climatology, *J. Geophys. Res.*, 109 (C12), doi:10.1029/2004JC002378.

Foltz, G.R., Schmid, C., Lumpkin, R. (2013) Seasonal cycle of the mixed layer heat budget in the northeastern tropical Atlantic ocean, *J. Clim*, 26 (20), 8169–8188, doi:10.1175/JCLI-D-13-00037.1.

Hummels, R., Dengler, M., Brandt, P., Schlundt, M. (2014) Diapycnal heat flux and mixed layer heat budget within the Atlantic Cold Tongue, *Clim. Dyn.*, 43 (11), 3179–3199, doi:10.1007/s00382-014-2339-6.

Schmidtko, S., Johnson, G.C., Lyman, J.M. (2013) MIMOC: A global monthly isopycnal upper-ocean climatology with mixed layers, *J. Geophys. Res.,* 118 (4), 1658–1672, doi:10.1002/jgrc.20122.

Figures

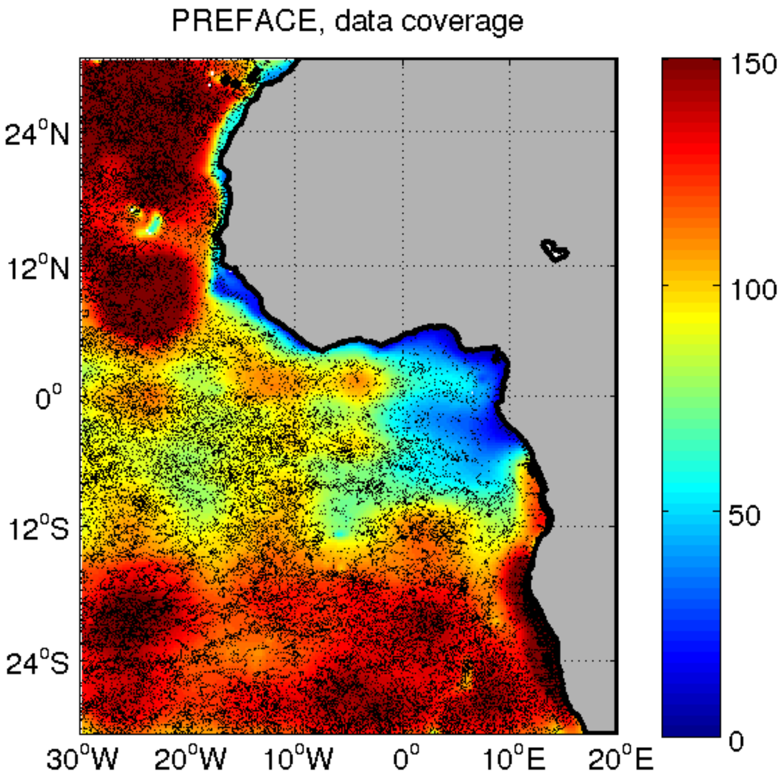

Figure 1: Distribution of data included in the new PREFACE hydrographic climatology. Colors show the number of data points influencing the respective ¼-degree grid box. Black dots show positions of newly included data (including ARGO float profiles) in reference to the MIMOC climatology.

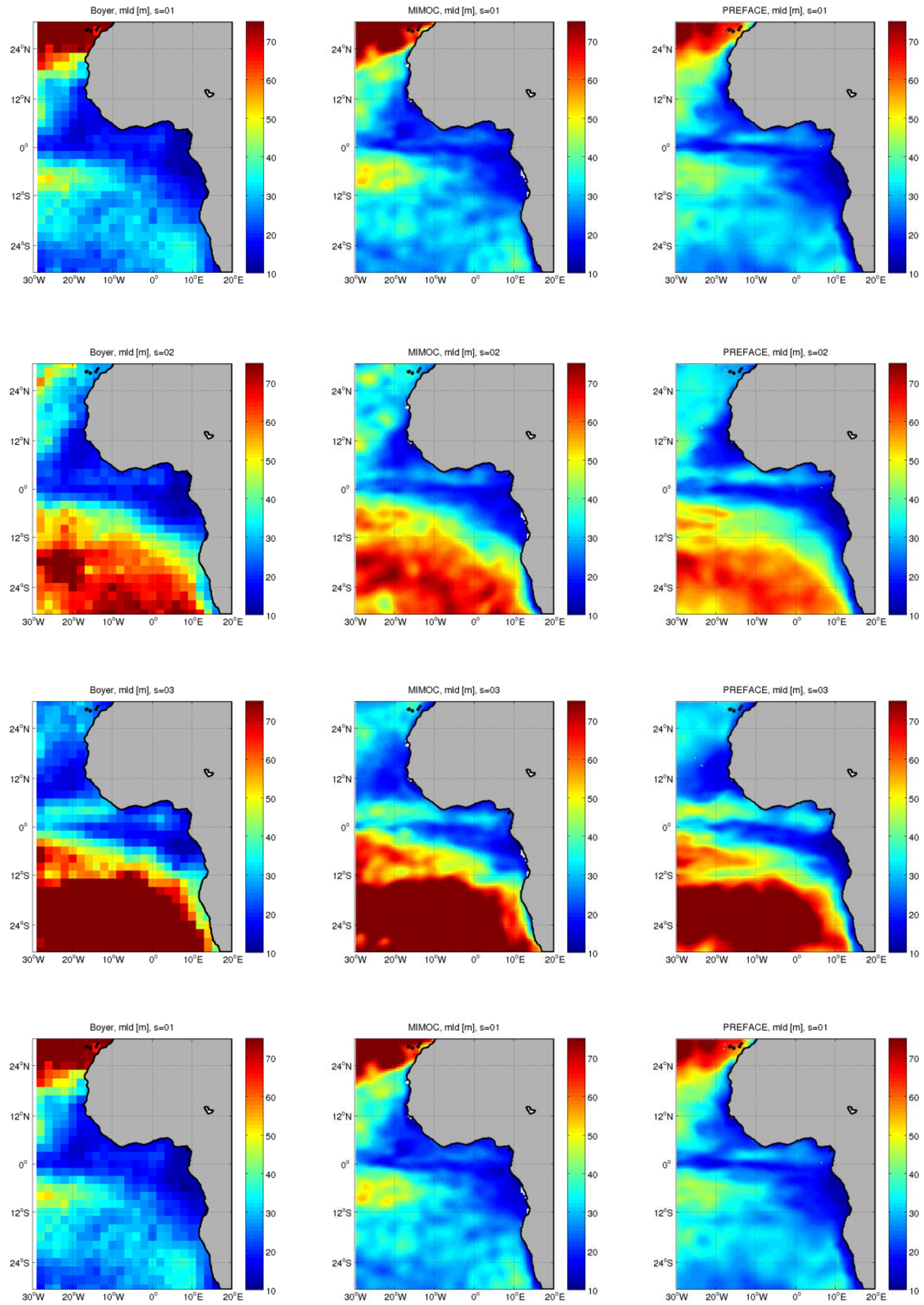

Figure 2: Mixed-layer depth from de Boyer Montégut et al. (2004) (left panels), MIMOC (middle panels) and the new PREFACE product (right panels) for the seasons January to March (upper panels), April to June (upper mid panels), July to September (lower mid panels), and October to December (lower panels).

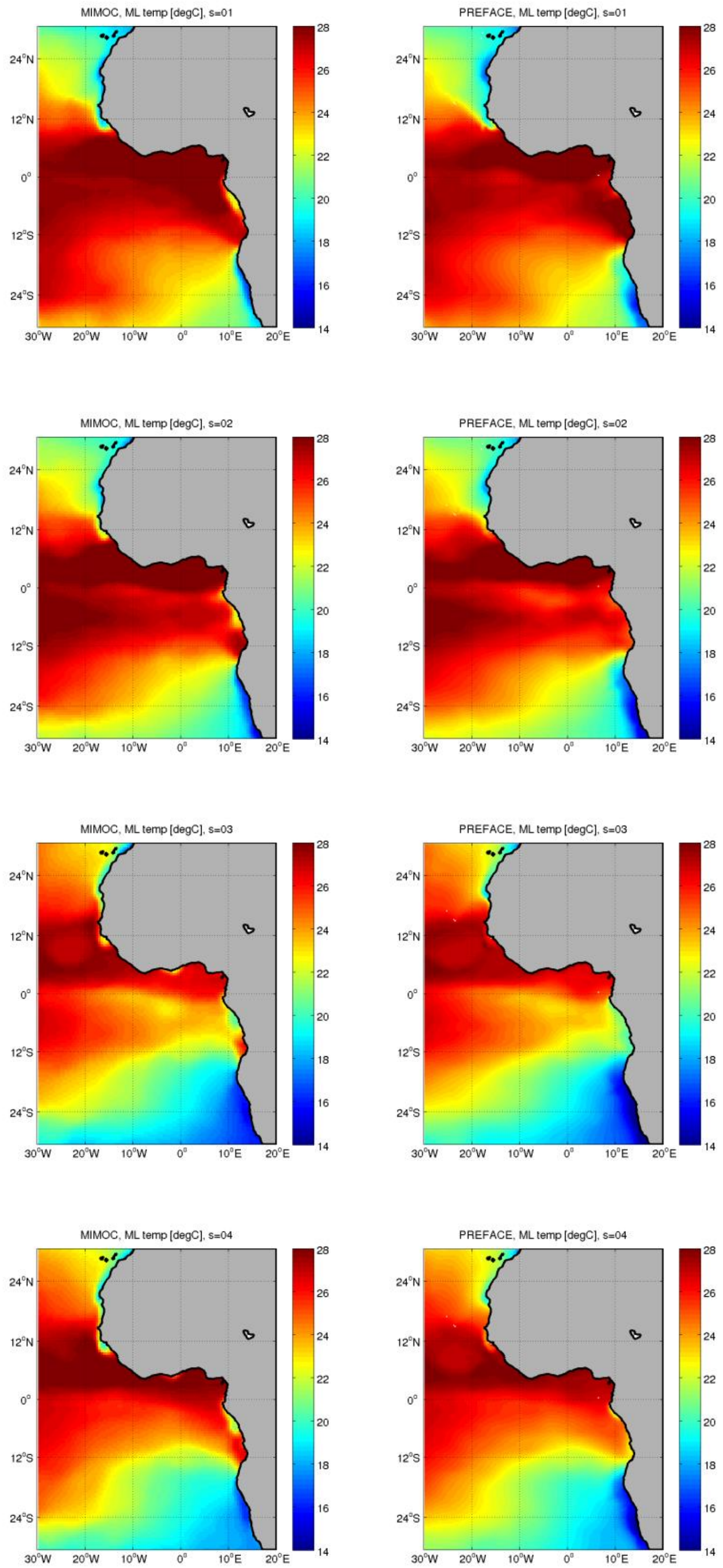

Figure 3: Mixed-layer temperature from MIMOC (left panels) and the new PREFACE product (right panels) for the seasons January to March (upper panels), April to June (upper mid panels), July to September (lower mid panels), and October to December (lower panels).

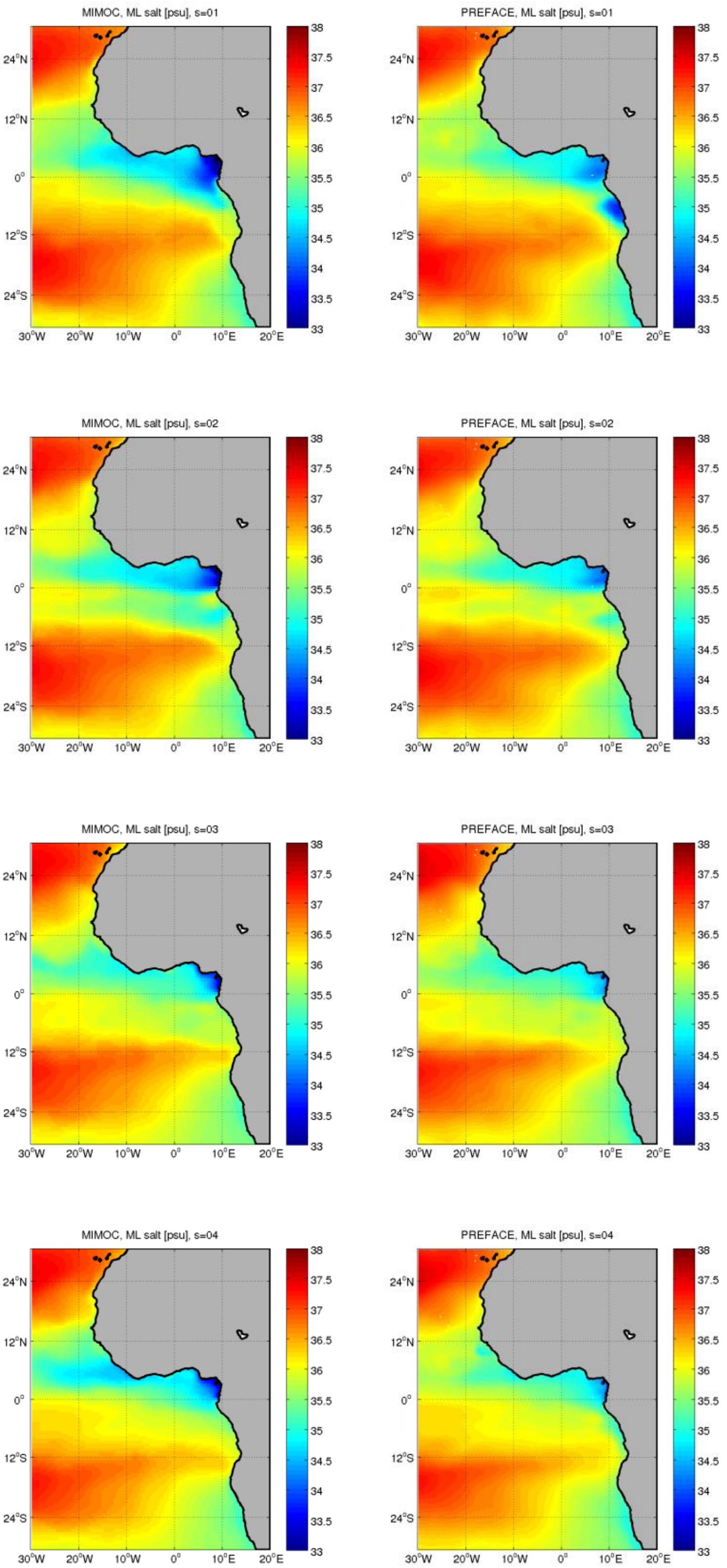

Figure 4: Mixed-layer salinity from MIMOC (left panels) and the new PREFACE product (right panels) for the seasons January to March (upper panels), April to June (upper mid panels), July to September (lower mid panels), and October to December (lower panels).

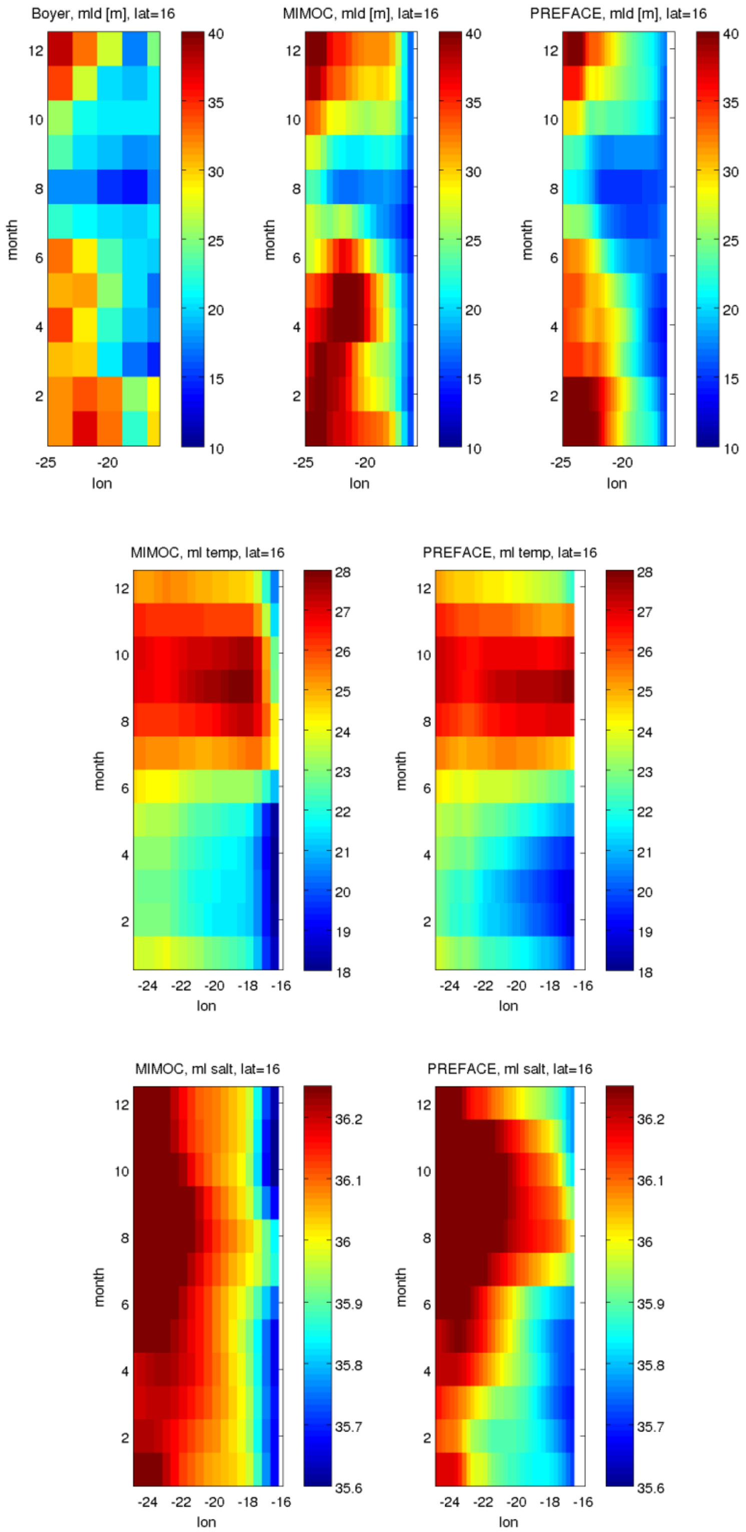

Figure 5: Seasonal cycle of mixed-layer depth, temperature and salinity estimates along 16°N from 25°W to the coast of West Africa. The upper panels depict mixed-layer depth from de Boyer Montegut et al. (2004) (left panel), MIMOC (middle panel) and the new PREFACE product (right panel). The middle and lower panels show mixed-layer temperature and salinity from MIMOC and from the new PREFACE product in the left and right panels, respectively.

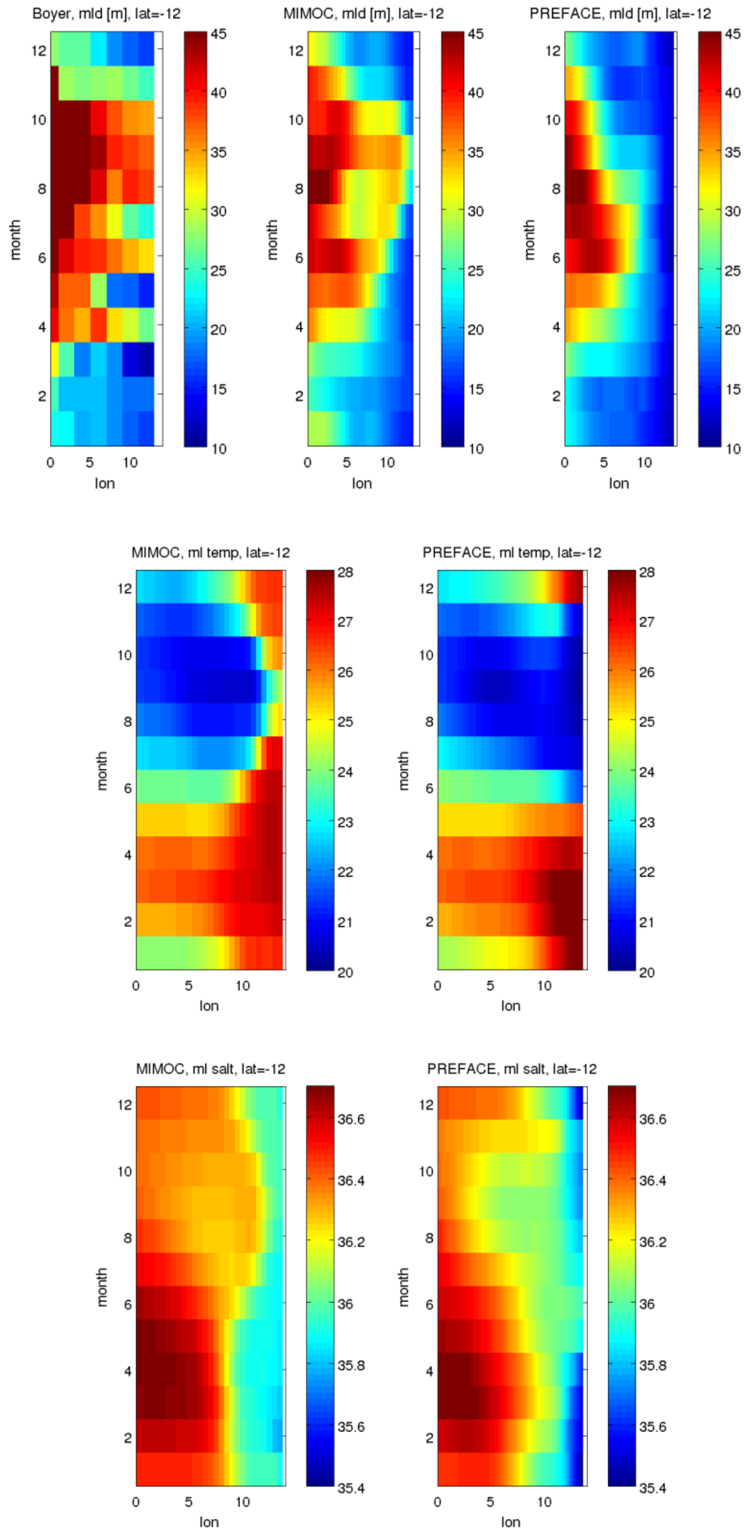

Figure 6: Seasonal cycle of mixed-layer depth, temperature and salinity estimates along 12°S from 0°E to the coast of West Africa. The upper panels depict mixed-layer depth from de Boyer Montegut et al. (2004) (left panel), MIMOC (middle panel) and the new product (right panel). The middle and lower panels show mixed-layer temperature and salinity from MIMOC and from the new PREFACE product in the left and right panels, respectively.

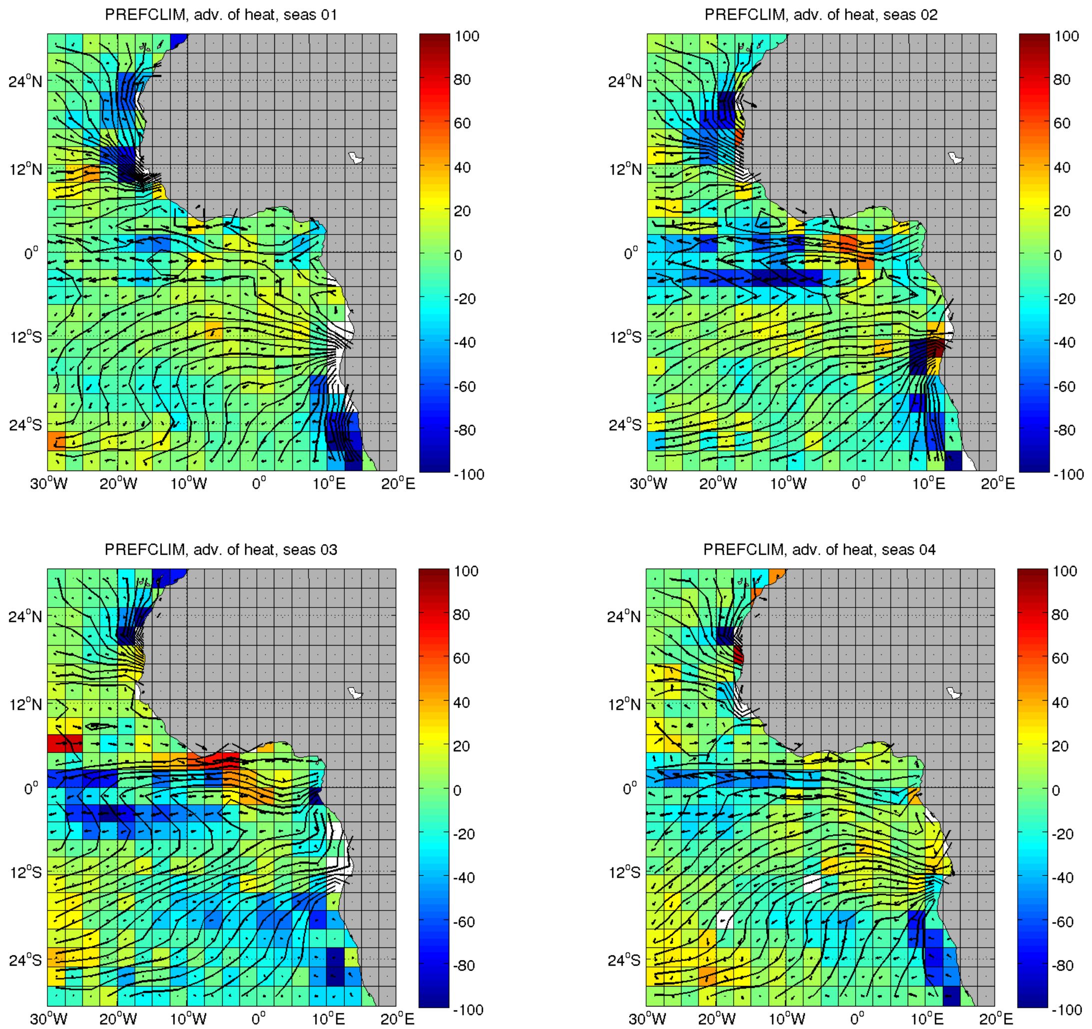

Figure 7: Three-monthly means of lateral advection of heat from the new PREFACE product. Colors depict the contribution of lateral heat advection in W/m^2. Black contour lines show mixed-layer temperatures in 0.5°C intervals. Vectors indicate direction and strength of mean currents. Seasons indicated are January to March (upper left), April to June (upper right), July to September (lower left), and October to December (lower right).

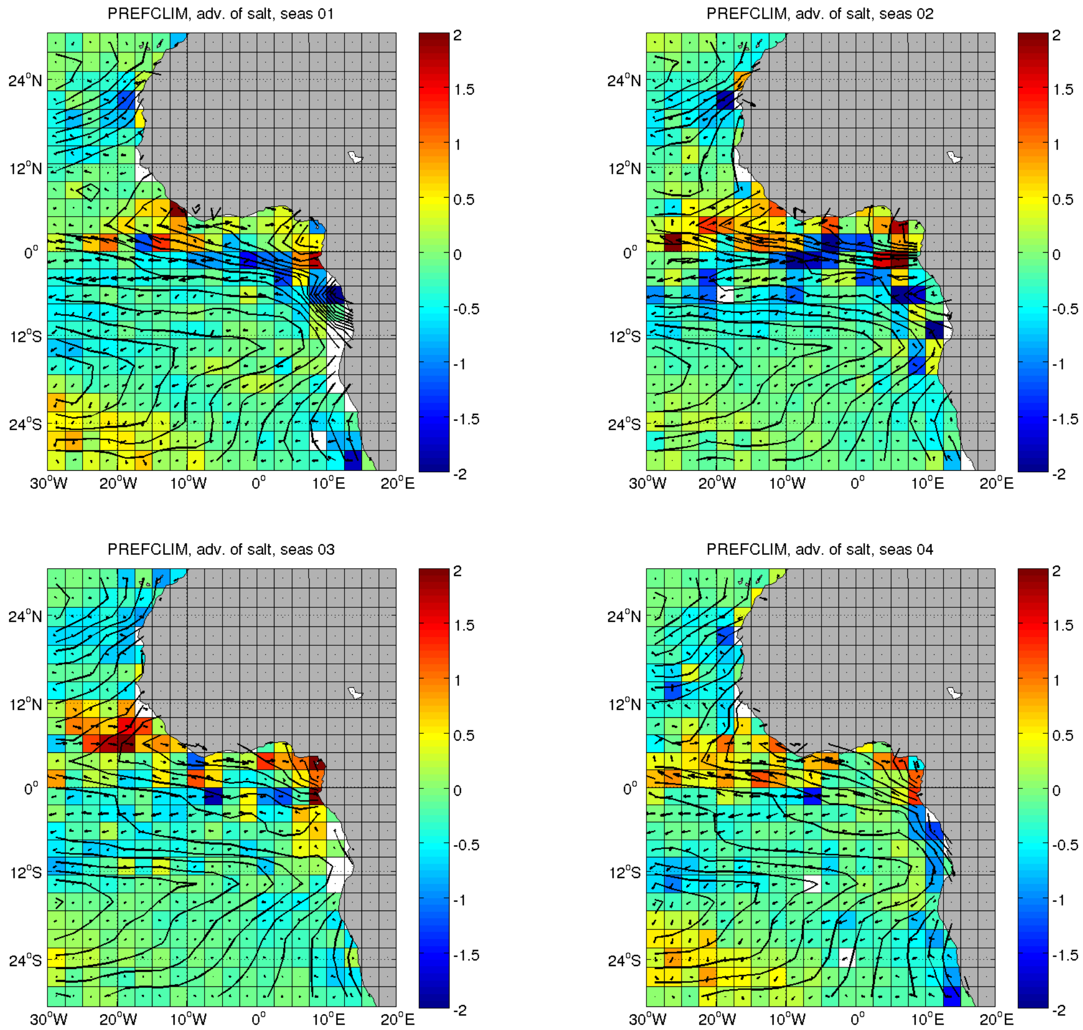

Figure 8: Three-monthly means of lateral advection of freshwater from the new PREFACE product. Colors depict the contribution of lateral advection of freshwater to the salt budget equivalent to a change of 10^{-7} *psu/s* (≈0.26 *psu/month*). Black contour lines show mixed-layer salinity in 0.2psu intervals. Vectors indicate direction and strength of mean currents. Seasons indicated are January to March (upper left), April to June (upper right), July to September (lower left), and October to December (lower right).

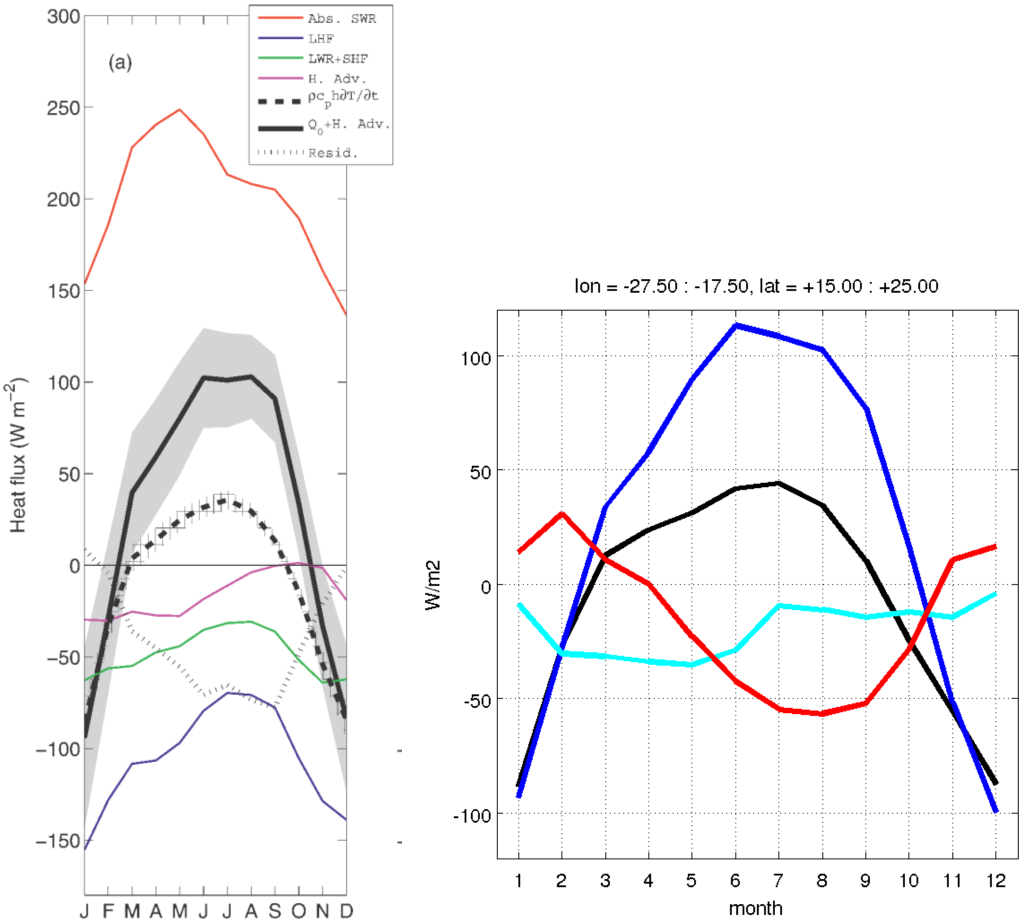

Figure 9: Heat budget in a box in the northeastern tropical Atlantic from 18°W to 28°W and 15°N to 25°N from Foltz et al. (2013) (left panel) and from the new PREFACE climatology (right panel). Solid lines in right panel represent heat storage rate $\rho c_p H\ \partial T/\partial t$ (black), horizontal heat advection (cyan), net surface heat flux (blue), and residuum (red).

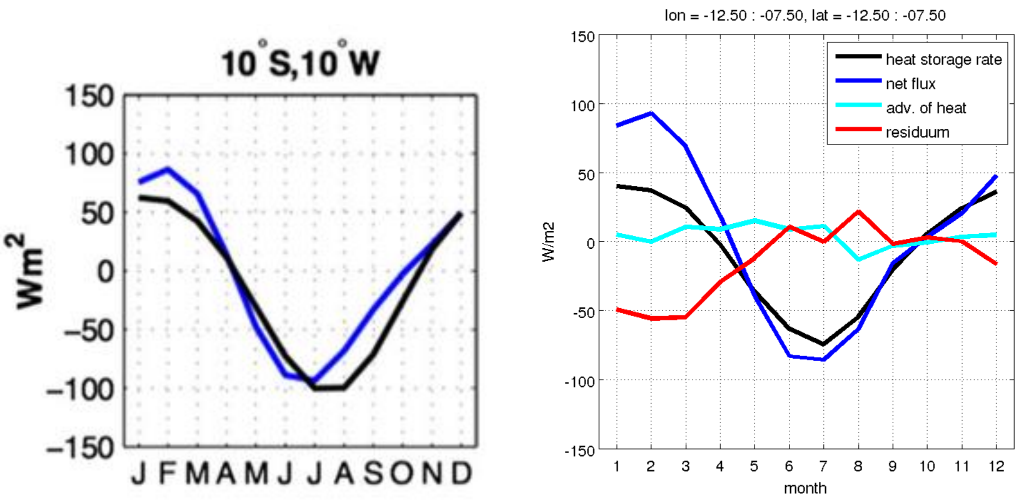

Figure 10: Heat budget at 10°S, 10°W from Hummels et al. (2014) (left panel) and from the new PREFACE climatology (right panel). Solid lines in both panels represent heat storage rate $\rho c_p H\, \partial T/\partial t$ (black) and net surface heat flux (blue). In the right panel, horizontal heat advection (cyan), and residual heat flux (red) is additionally shown.