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- ▶ Marisa Roch
- ▶ 2nd year PhD student at GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany
- ▶ My research focusses on physical processes in the tropical Atlantic Ocean under climate variability and climate change
- ▶ Besides, I am a watersport enthusiast

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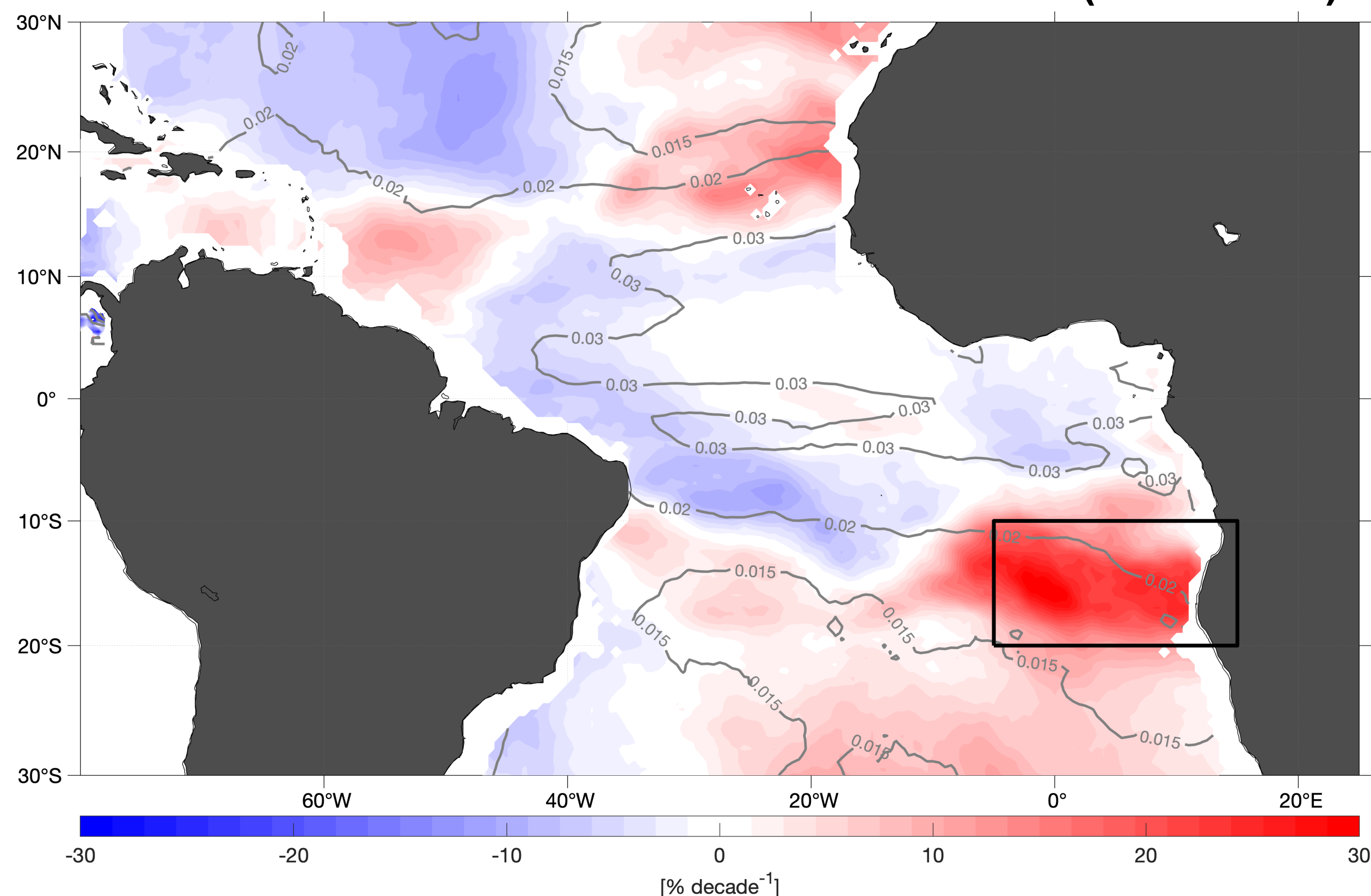
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Trend of the vertical stratification maximum (2006-2019):



- ▶ up to 30 % increase of the vertical stratification maximum in southeast tropical Atlantic (black box)

Fig. 1: Decadal trend of the vertical stratification maximum inferred from Argo observation for the period of 2006-2019. The decadal trend has been evaluated from the anomalies to the corresponding seasonal mean. Grey contour lines show overall mean stratification maximum field.

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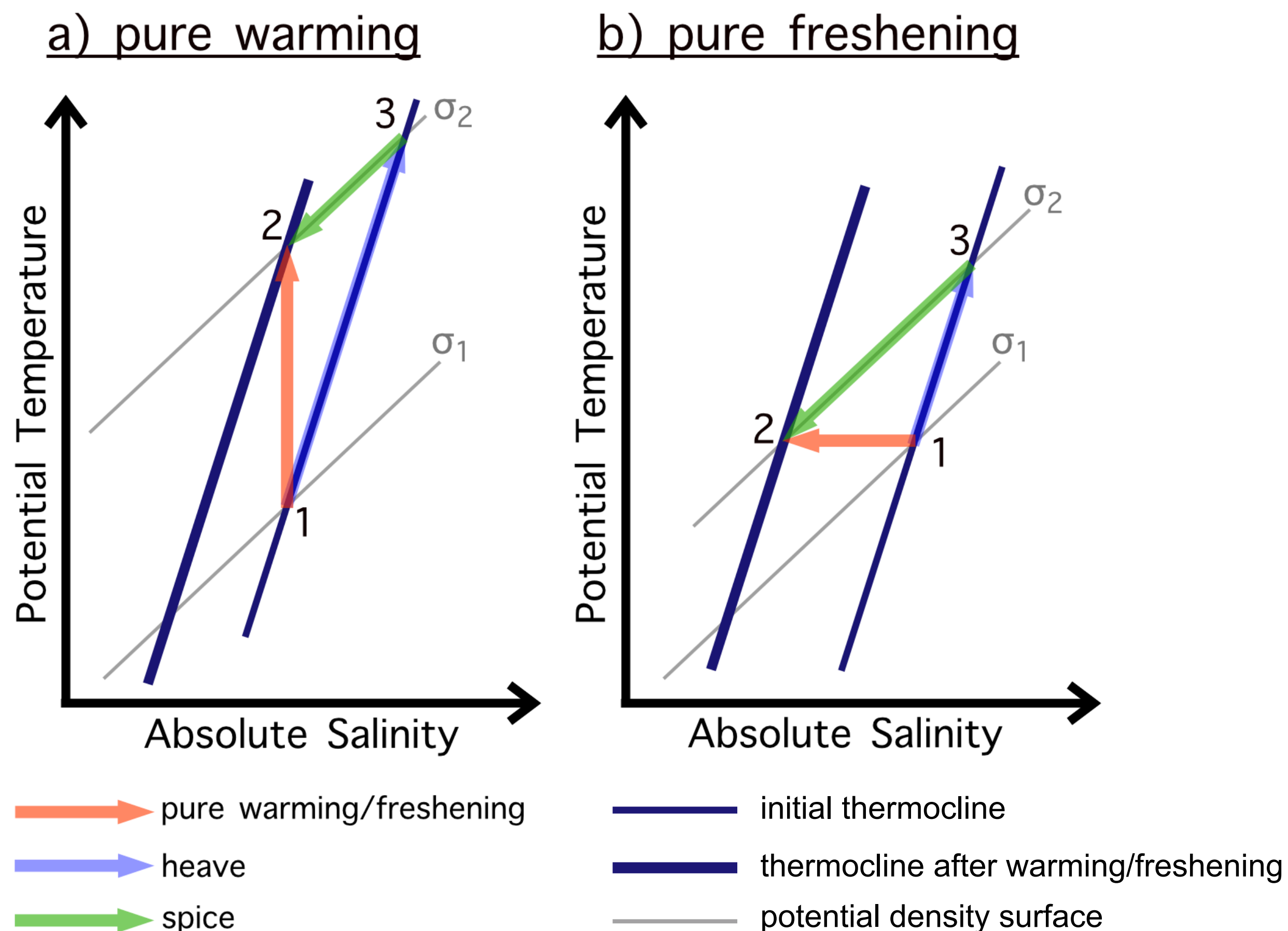
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Pure warming/freshening

Pure heaving



- ▶ for a typical subtropical stratification (warm/saline water layered above cool/fresh water) as in the SETA region, both processes (pure warming and pure freshening at fixed depth, orange arrows, 1→2) yield:
 - ▶ decreasing spice (green, 3→2) and
 - ▶ positive heave (downward displacement of isopycnal, blue, 1→3) [following Bindoff and McDougall, 1994]
- ▶ spice: change of characteristics on an isopycnal
- ▶ heave: vertical displacement of an isopycnal

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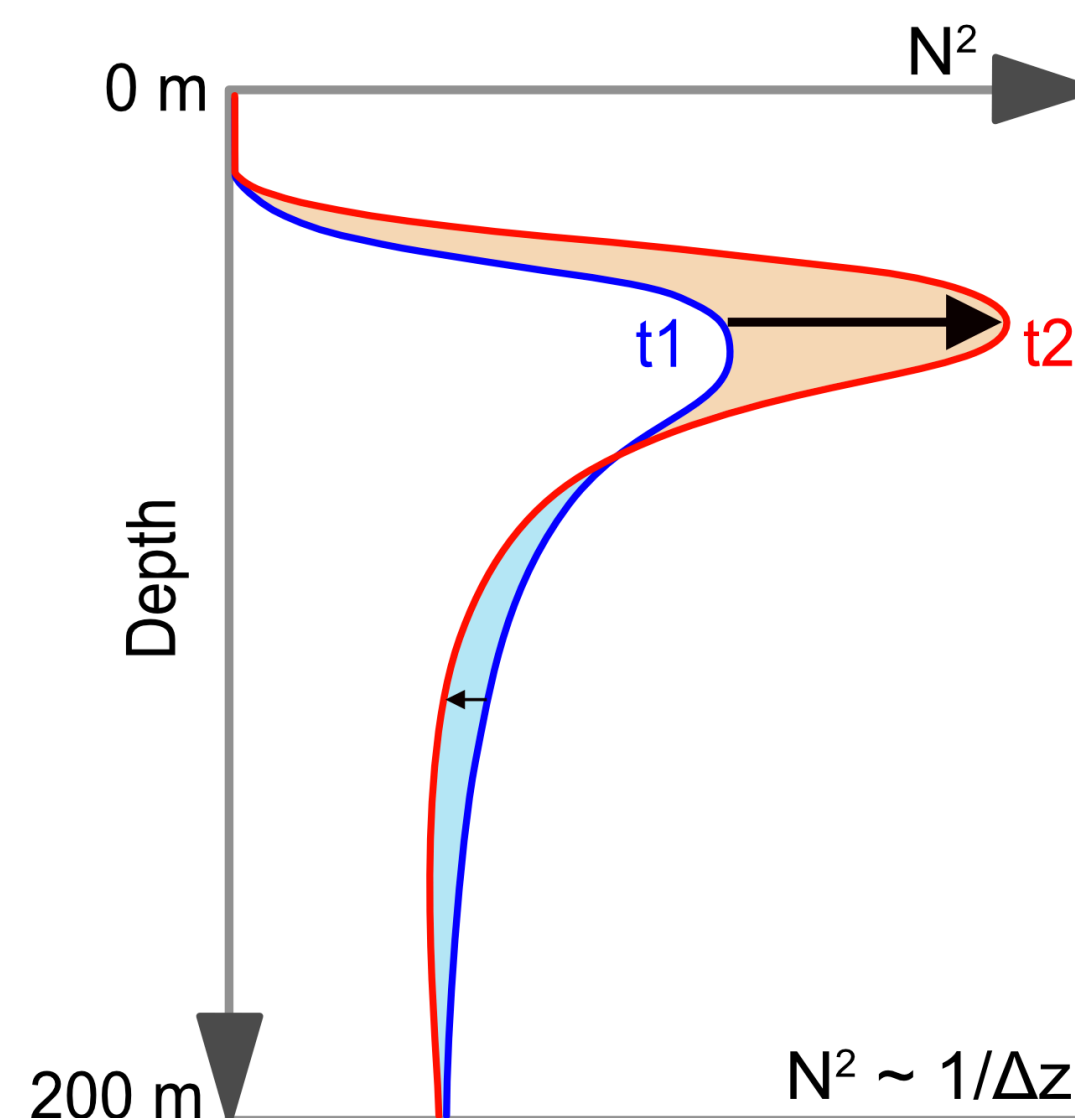
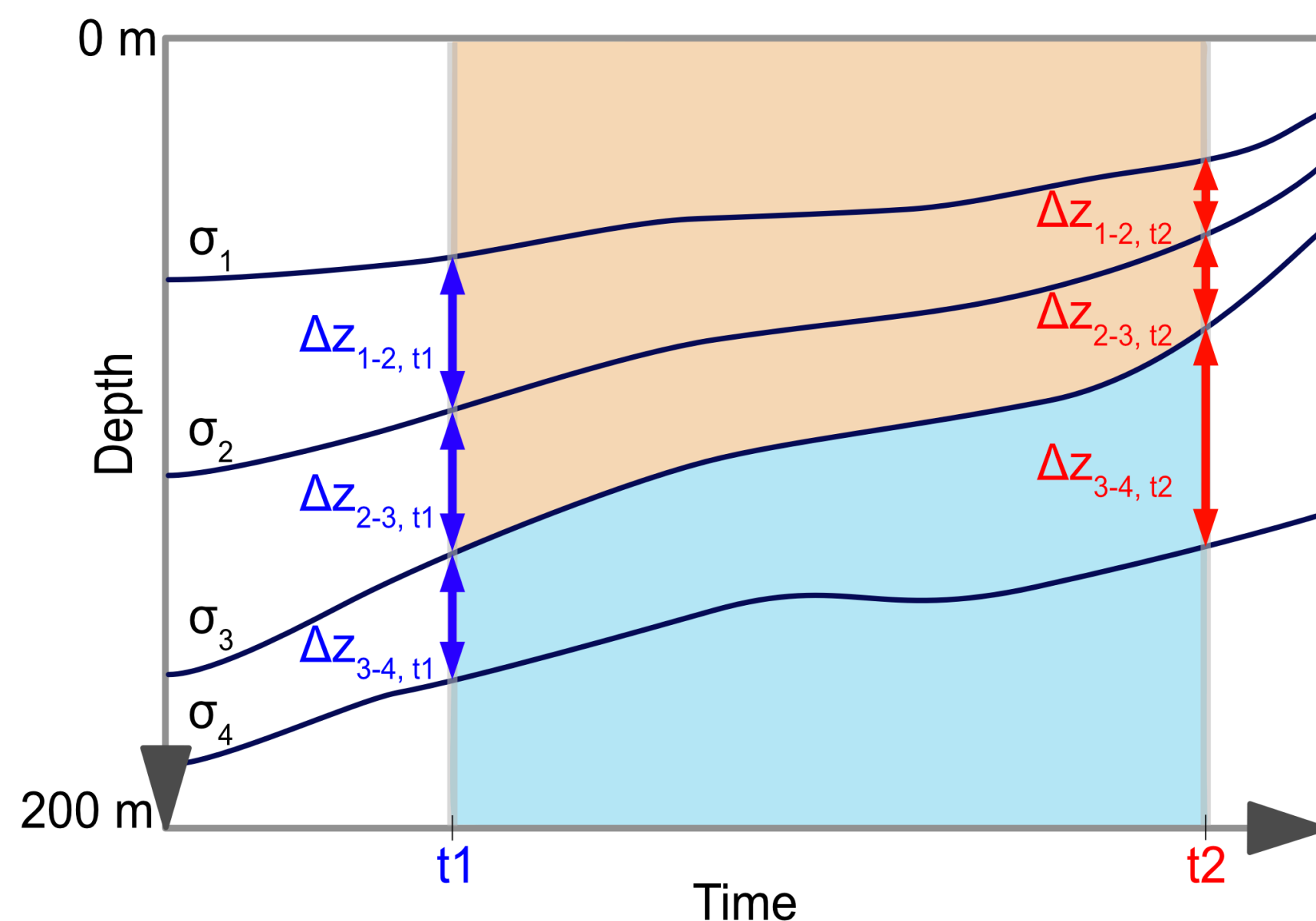
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Pure warming/freshening

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- ▶ stratification:
$$N^2 = -\frac{g}{\rho_0} \frac{\partial \rho}{\partial z} = g^2 \rho_0 \frac{\beta dS - \alpha dT}{dp}$$
- ▶ stratification can increase if the sea surface becomes less dense due to warming or freshening, however, pure heaving in terms of upwelling can also have an impact on stratification
- ▶ intensified upwelling makes isopycnals slope upward
- ▶ stratification N^2 is antiproportional to the height difference between isopycnals Δz , thus if Δz decreases N^2 intensifies as well

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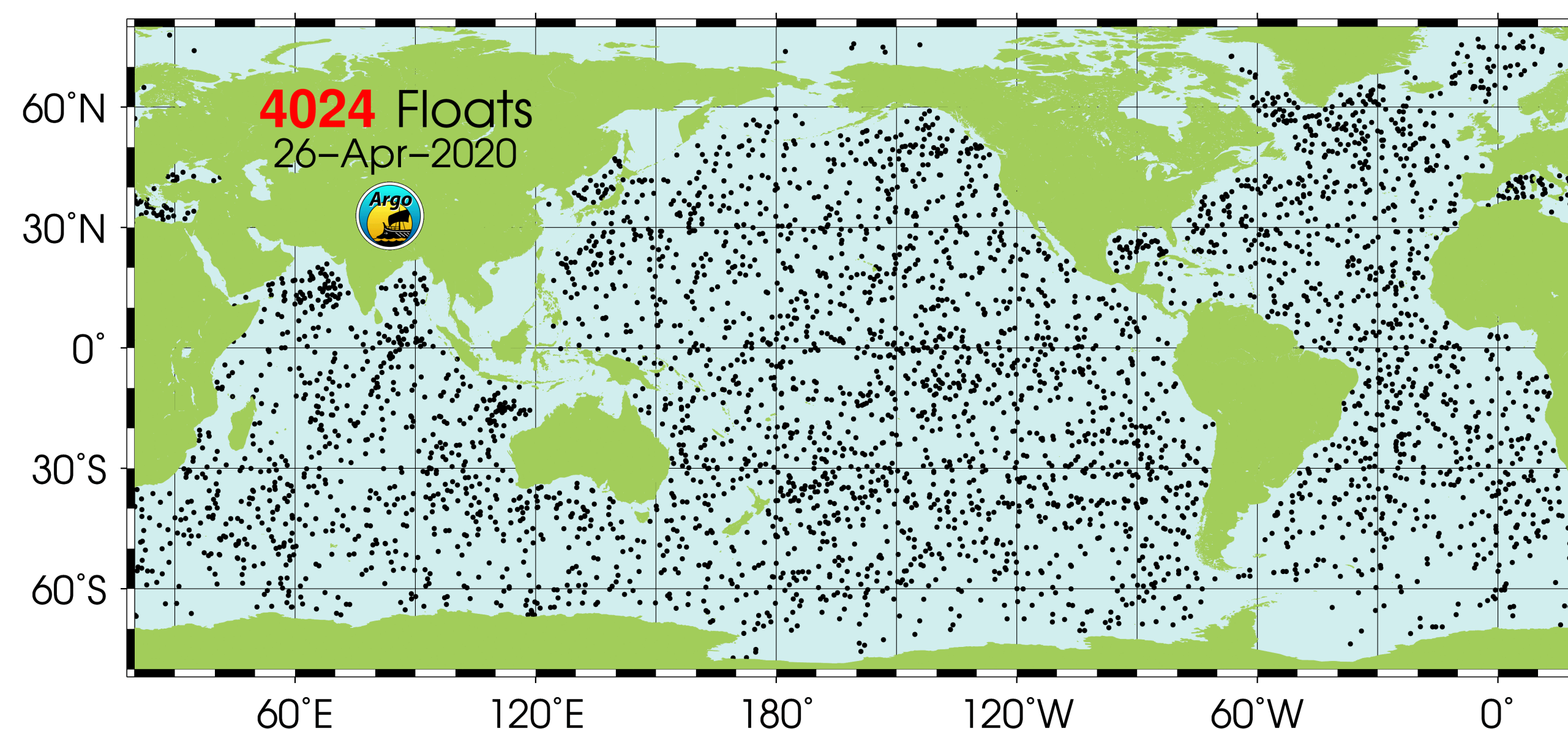
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- ▶ Argo observations from 2006-2019
- ▶ stratification estimate from Argo was verified by cruise measurements
- ▶ Mixed layer estimated following the Holte and Talley algorithm (2009)
- ▶ satellite products:
 - ▶ wind stress data from Copernicus Marine environment monitoring service (CMEMS: ASCAT METOP-A and METOP-B product): 2007-2019
 - ▶ net primary productivity from Ocean Productivity Site (Eppley VGPM: 2006-2019)



<http://www.argo.ucsd.edu>, 27. April 2020



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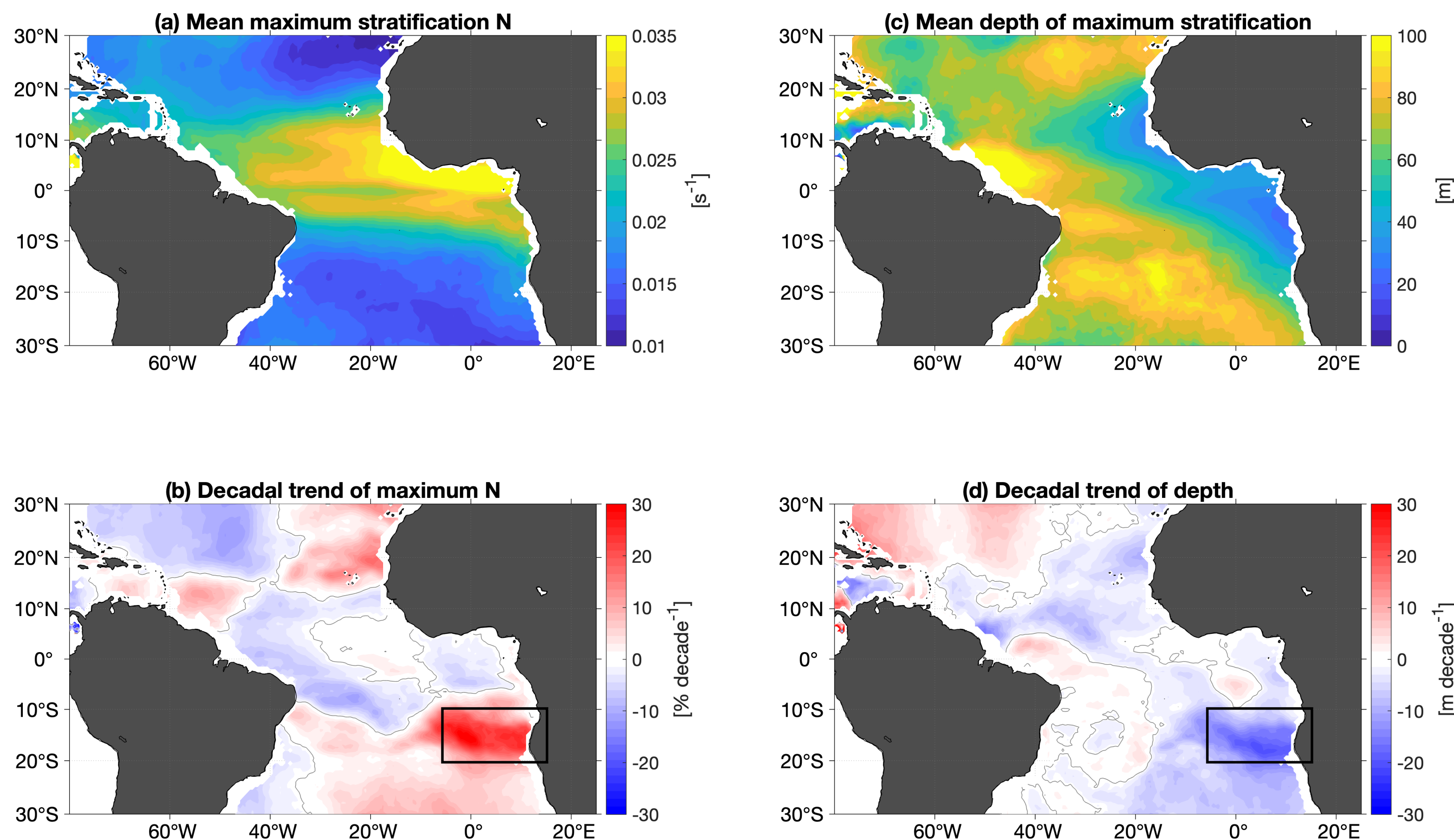
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- ▶ up to 30 % increase of the vertical stratification maximum
- ▶ shoaling depth of vertical stratification maximum where stratification increases

Fig. 1: (a) Mean vertical maximum stratification inferred from Argo for the time period of 2006-2019 and (b) its decadal trend. (c) Mean depth of the maximum stratification from (a) and (d) its decadal trend. The decadal trend for the variables has been evaluated from the anomalies to the corresponding seasonal mean. Please note, positive trend of depth refers to a deepening.

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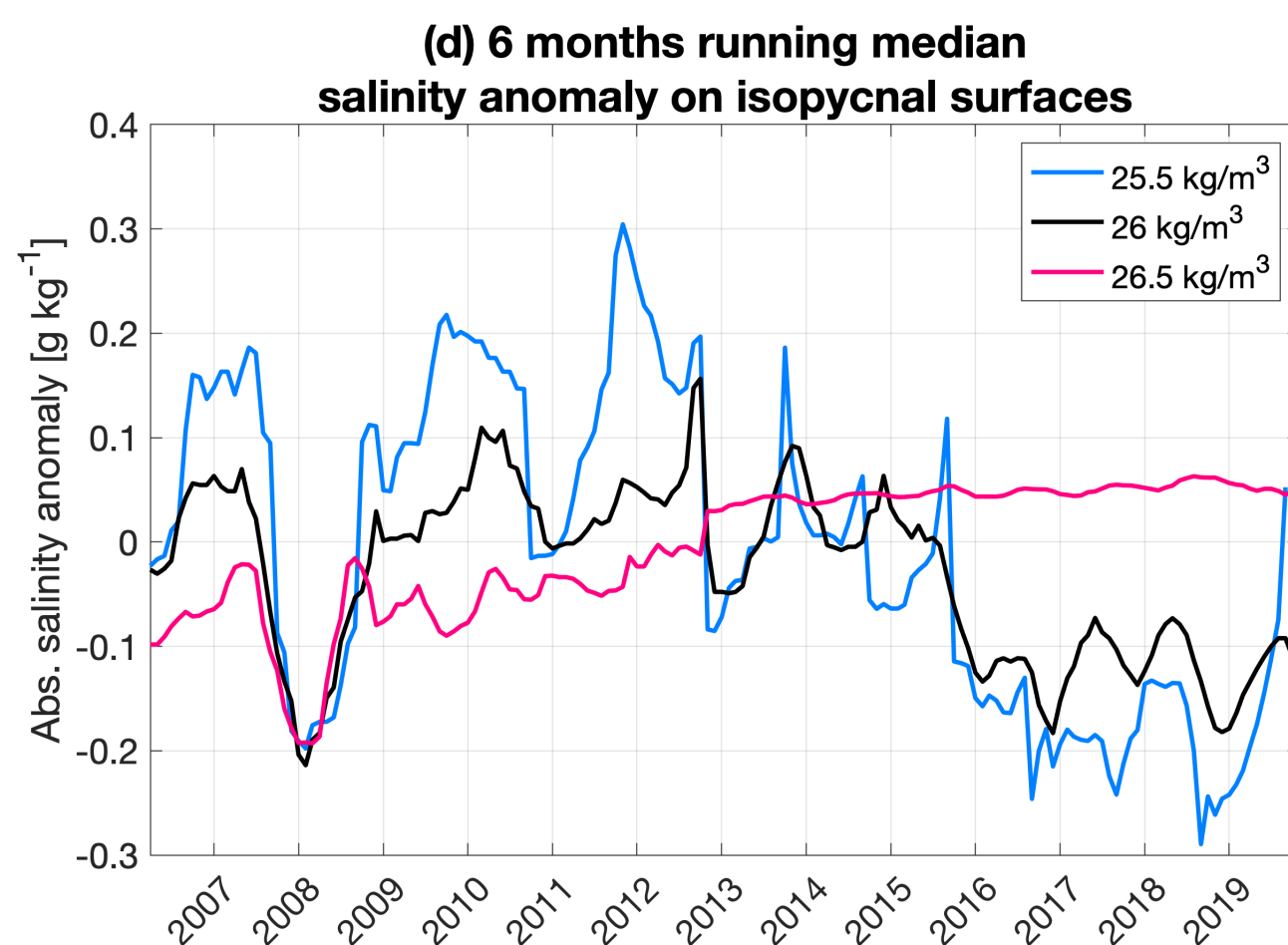
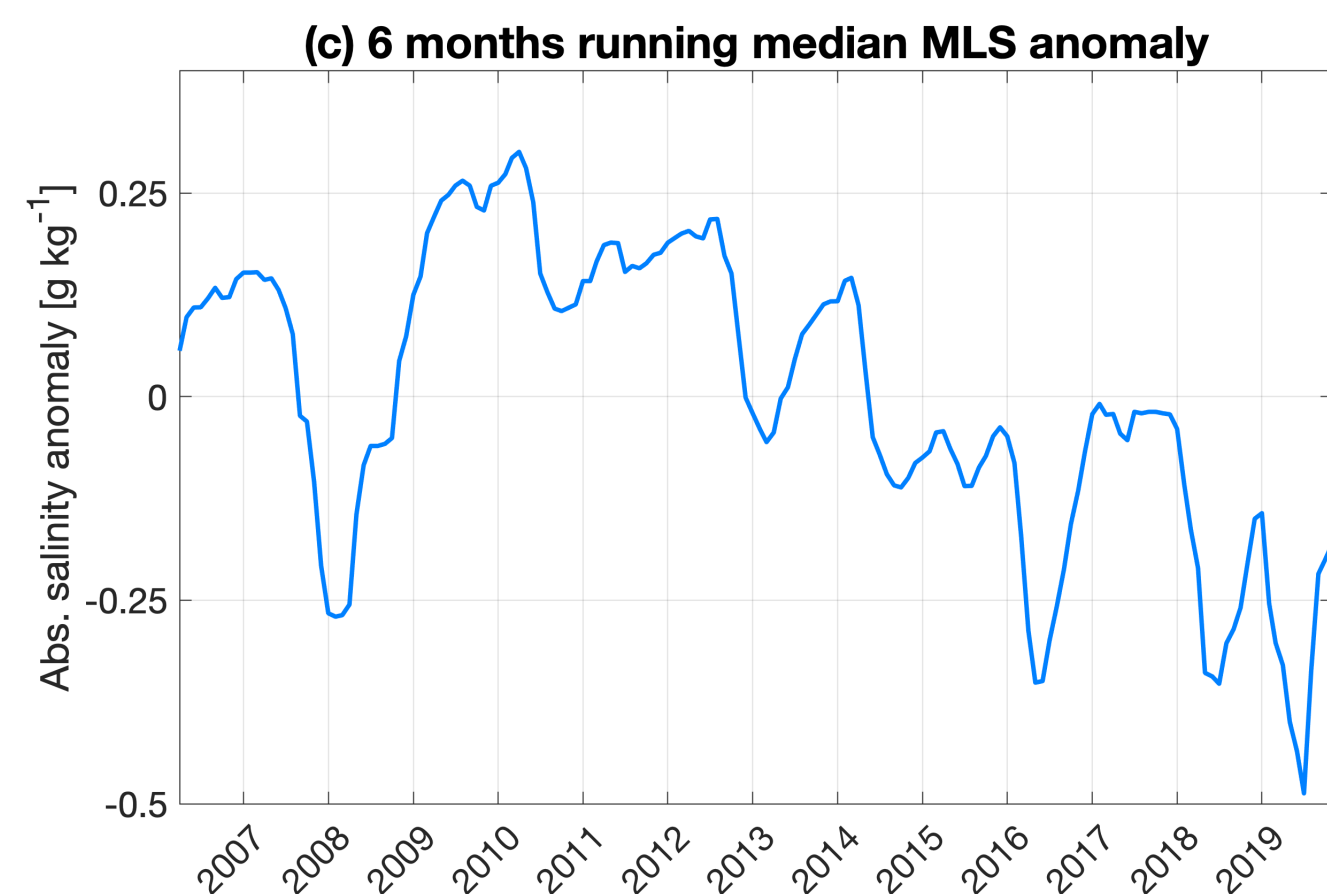
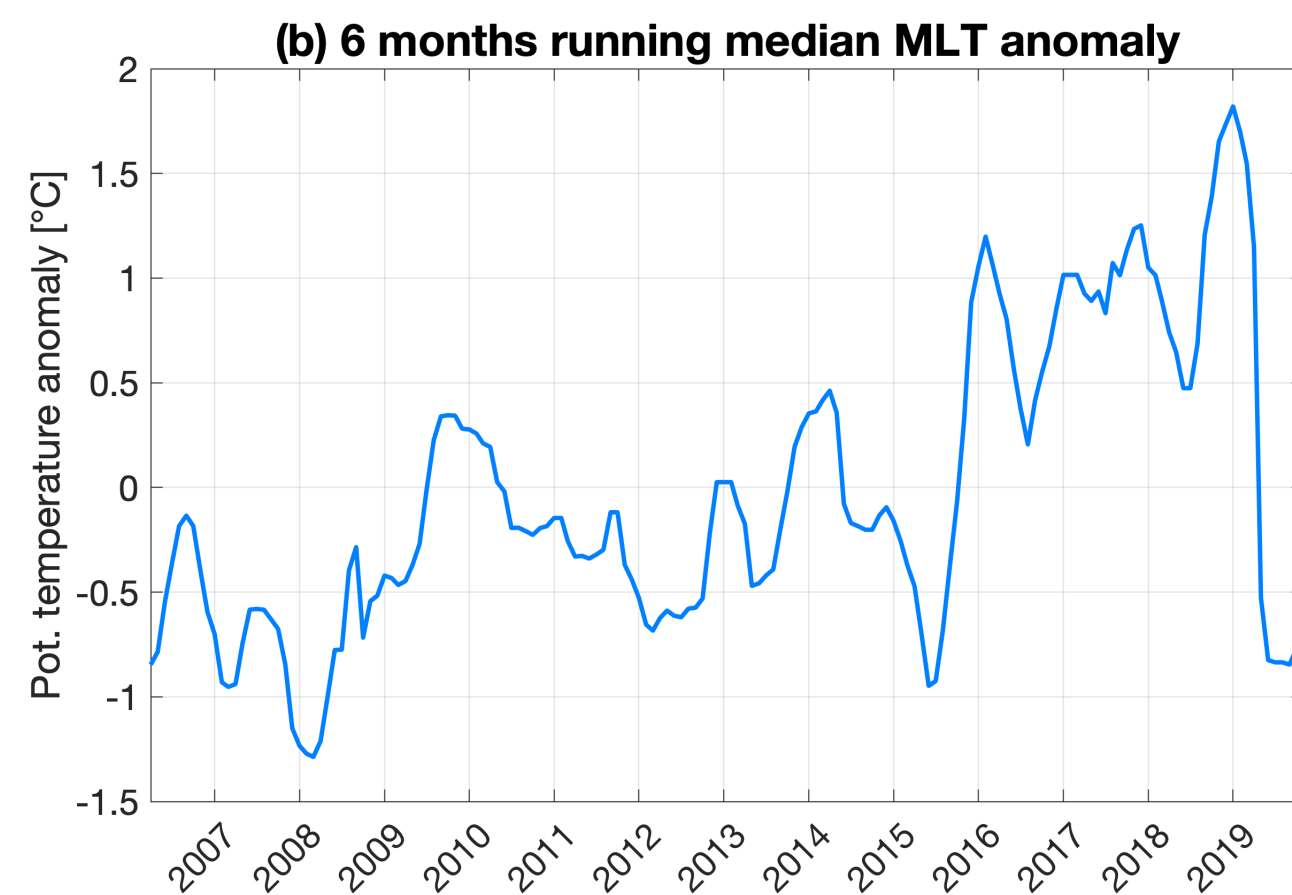
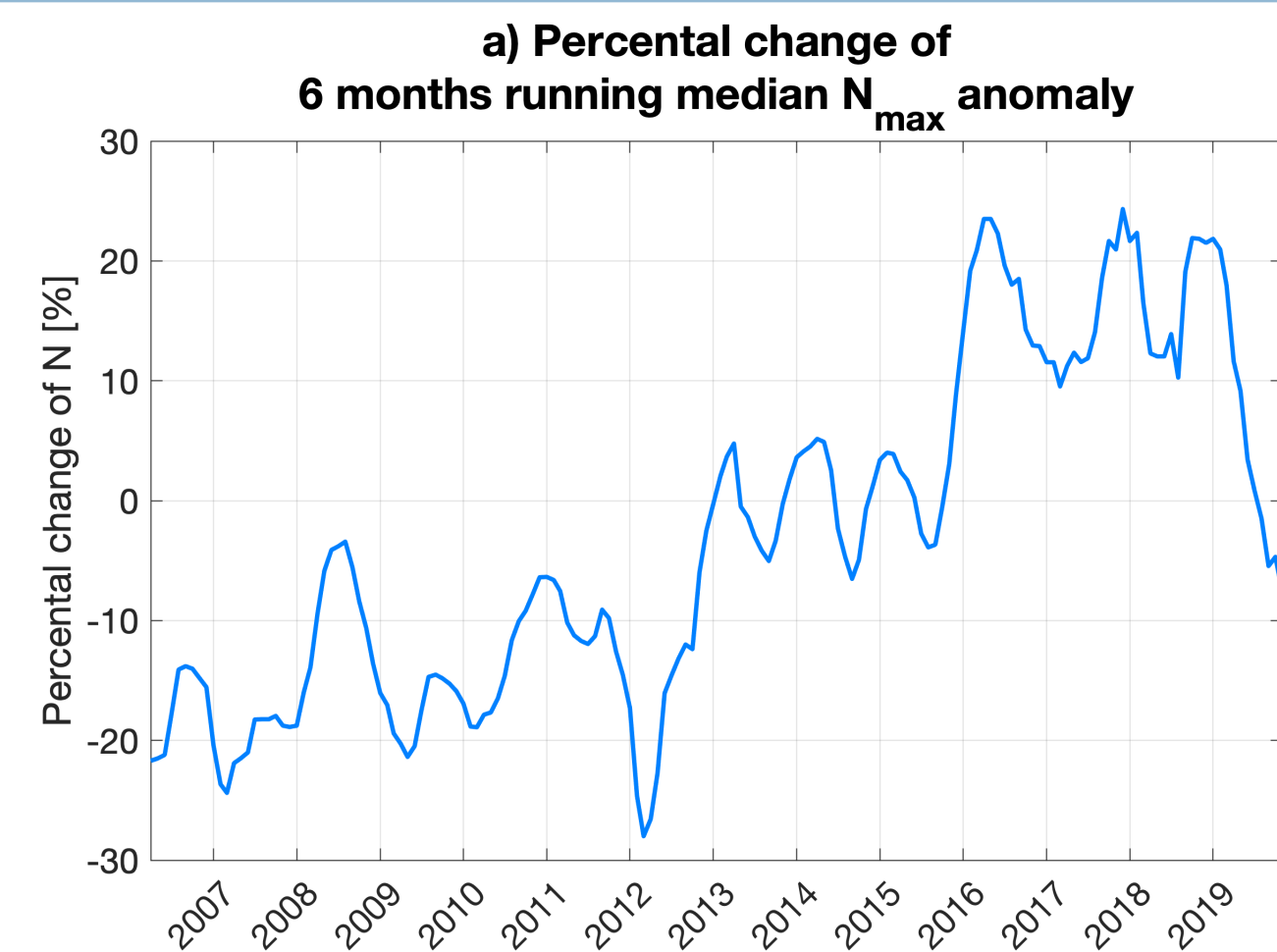
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Time series of SETA

T-S diagram

Heaving

- ▶ about 30-40 % increase of stratification maximum $N_{\max}$
- ▶ warming and freshening of the mixed layer
- ▶ spice salinity anomalies of 25.5 and 26.0 kg/m^3 are decreasing since 2012; 26.5 kg/m^3 : salinity increase

Fig. 1: Six months running median of [a] percentil change of stratification anomaly of its vertical maximum, [b] MLT anomaly, [c] MLS anomaly, [d] salinity anomaly on the isopycnal surfaces (i.e. spice anomaly) in SETA (10°S - 20°S , 5°W - 15°E). Anomalies are computed to the seasonal mean.



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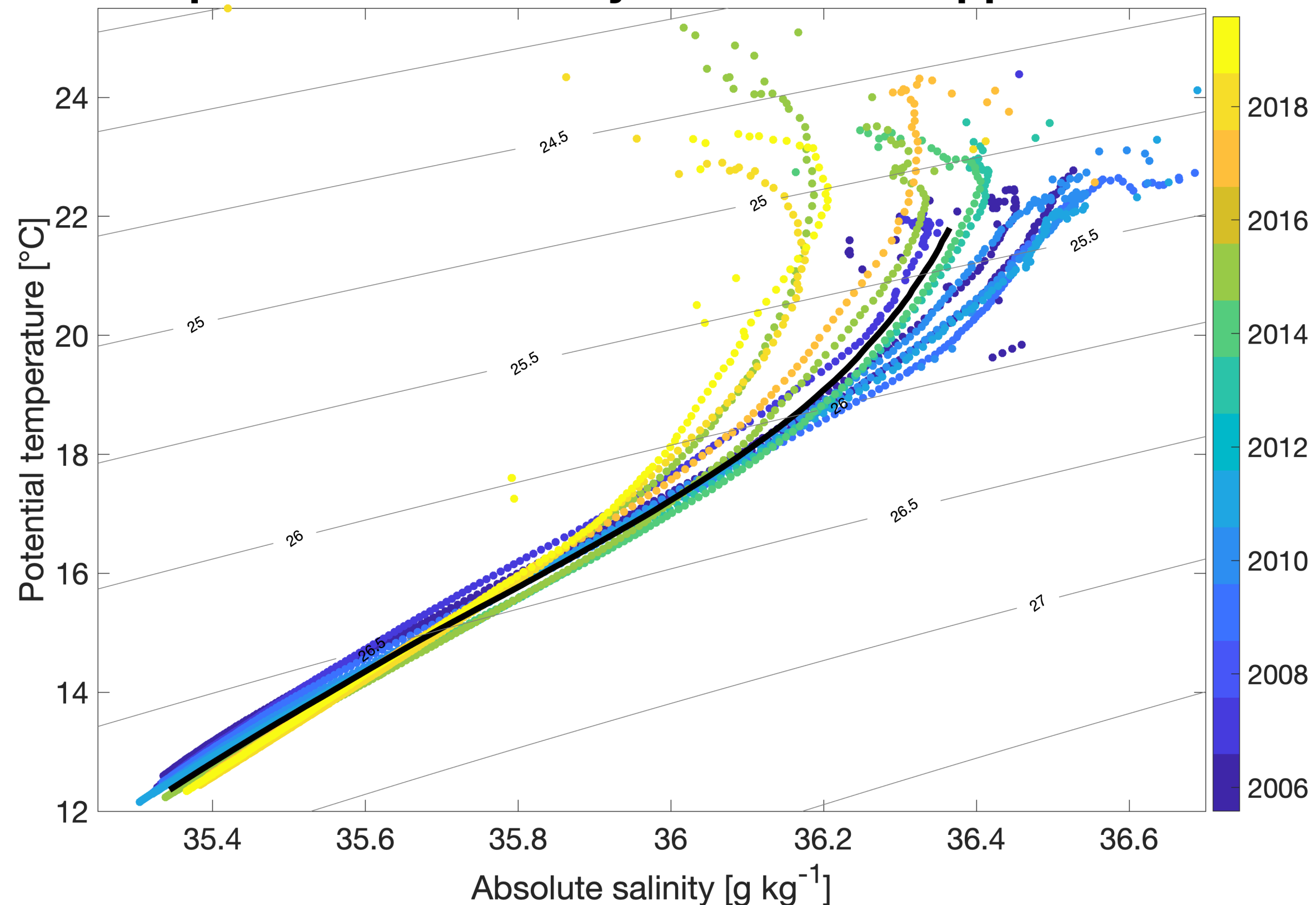
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T-S diagram from annual mean temperature and salinity values in the upper 200 m



- ▶ typical subtropical stratification: warm/ saline water above cool/ fresh
- ▶ subtropical stratification develops toward a tropical stratification with warmer and fresher surface waters resulting in increased stratification

Fig. 1: T-S diagram of annual mean temperature and salinity values of the upper 200 m in the SETA region (10°S-20°S, 5°W-15°E). Black circles show the overall mean.

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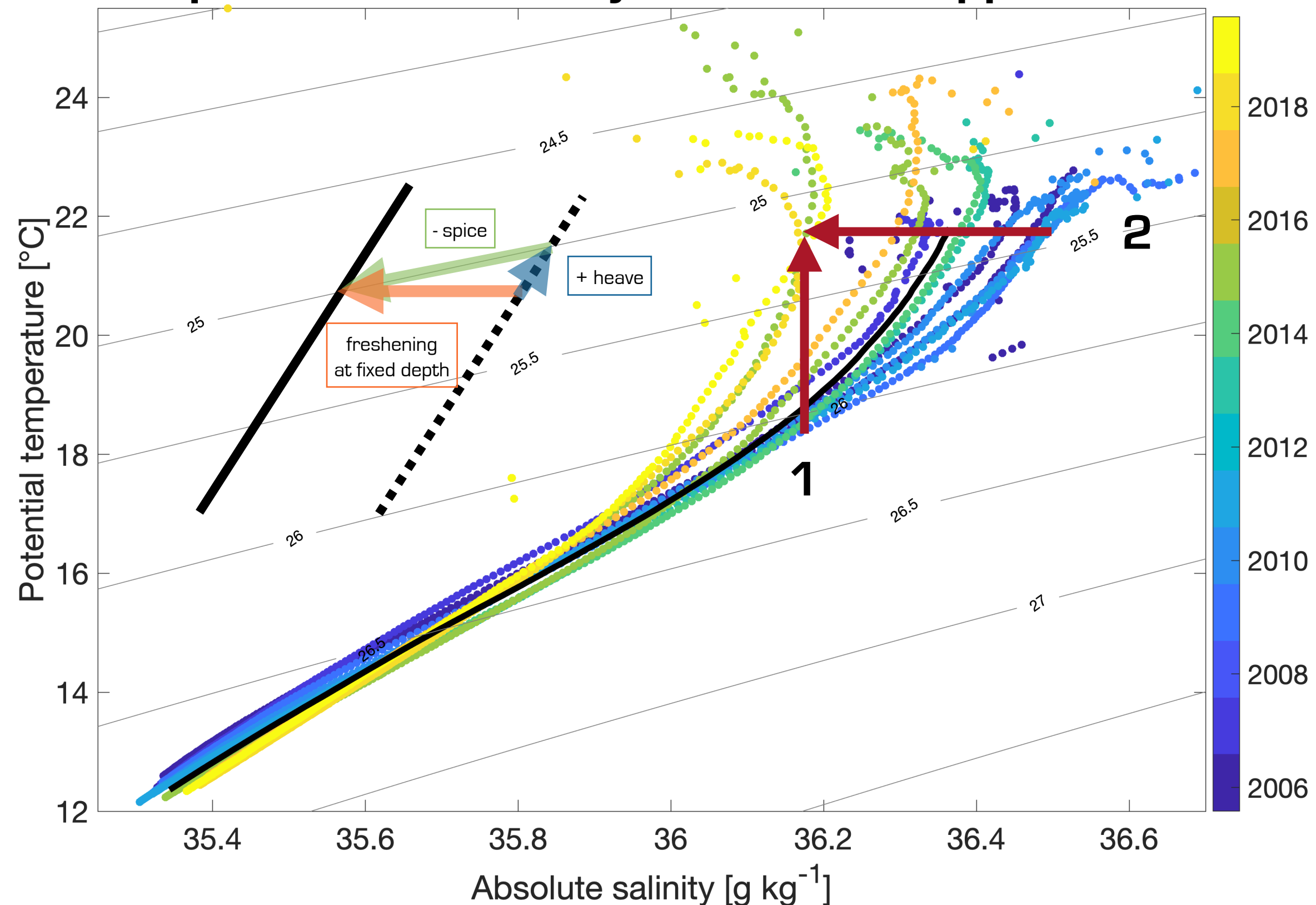
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T-S diagram from annual mean

temperature and salinity values in the upper 200 m



- ▶ typical subtropical stratification: warm/ saline water above cool/ fresh
- ▶ subtropical stratification develops toward a tropical stratification with (1) warmer and (2) fresher surface waters resulting in increased stratification (red arrows)

➔ We observe both: a freshening and warming of the mixed layer as well as a reduction in spice, however, what about the heave, i.e. vertical displacement of the isopycnals?

Fig. 1: T-S diagram of annual mean temperature and salinity values of the upper 200 m in the SETA region (10°S-20°S, 5°W-15°E). Black circles show the overall mean.

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- ▶ upward moving isopycnals, i.e. negative heave
- ▶ this implies another process has to be involved: wind stress curl-driven upwelling
- ▶ however, it does not contradict the enhancement of stratification
- ▶ stratification N^2 is antiproportional to the height difference between isopycnals Δp , thus if Δp decreases N^2 intensifies as well

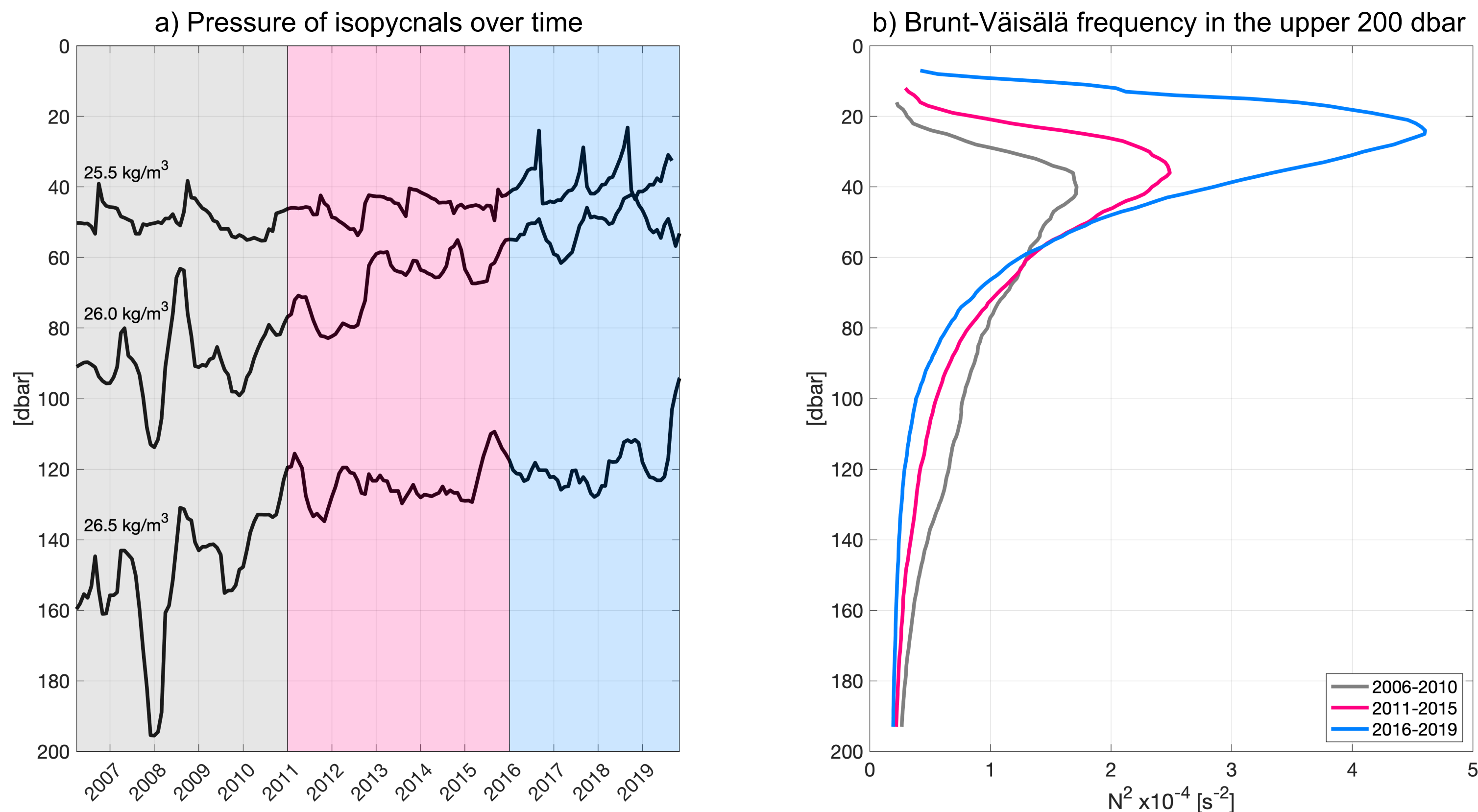


Fig. 1: (a) Six months running median pressure anomaly of three isopycnals onto the mean pressure of the corresponding isopycnal in the SETA region (10°S-20°S, 5°W-15°E). Shaded colors show time periods of mean Brunt-Väisälä-frequency profile in (b). Grey implies the mean of 2006-2010, pink the mean of 2011-2015 and blue for the mean of 2016-2019.

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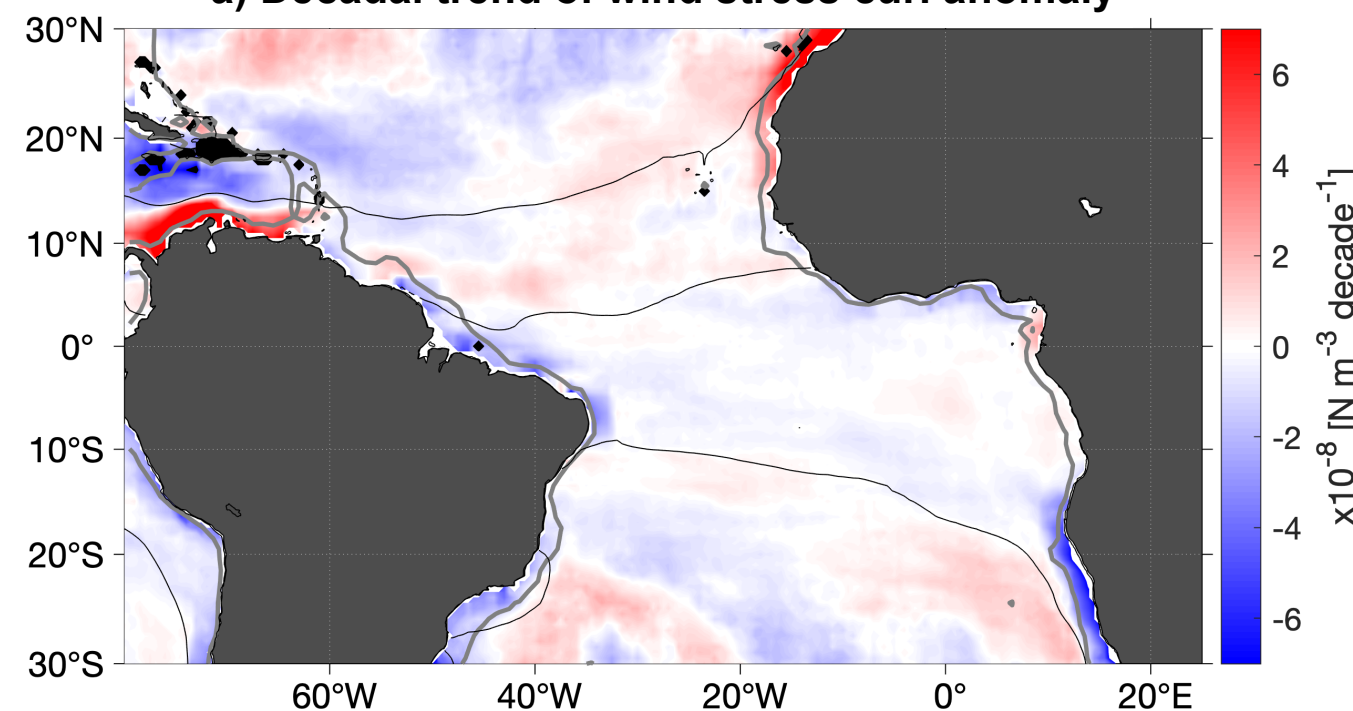
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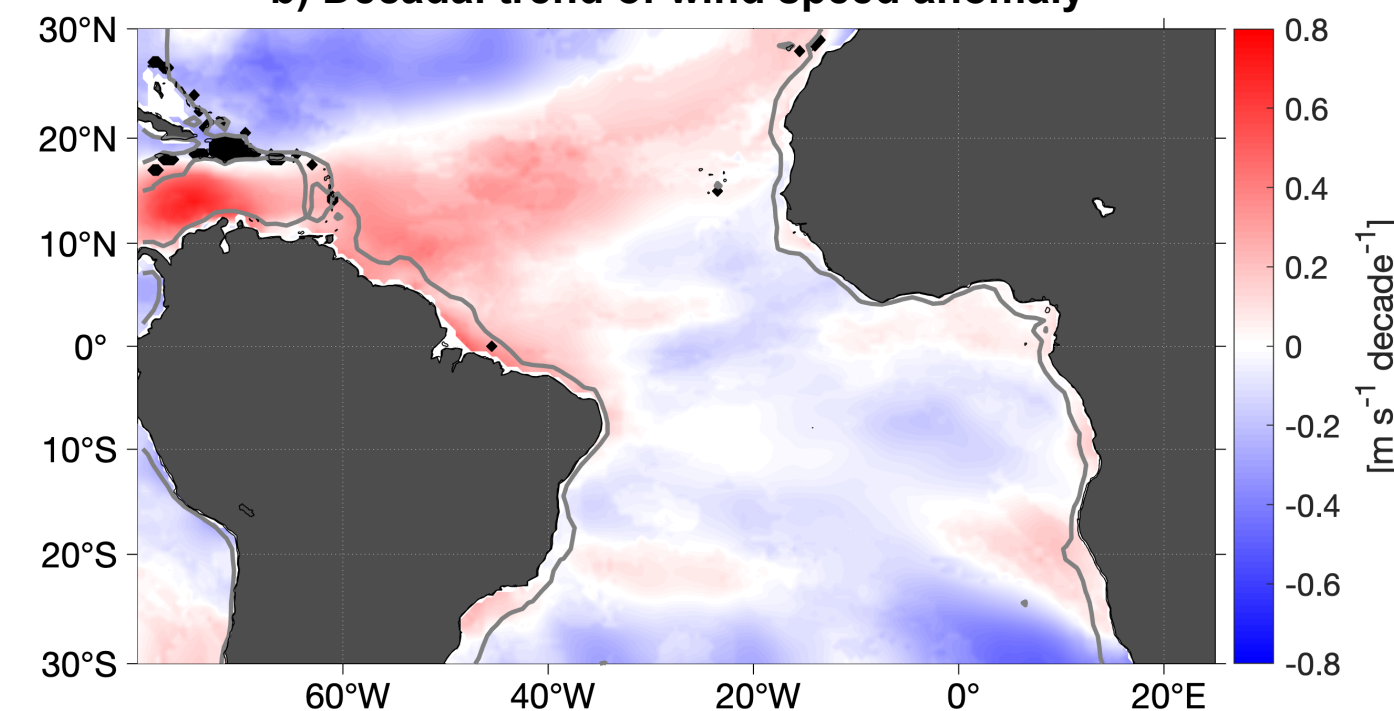
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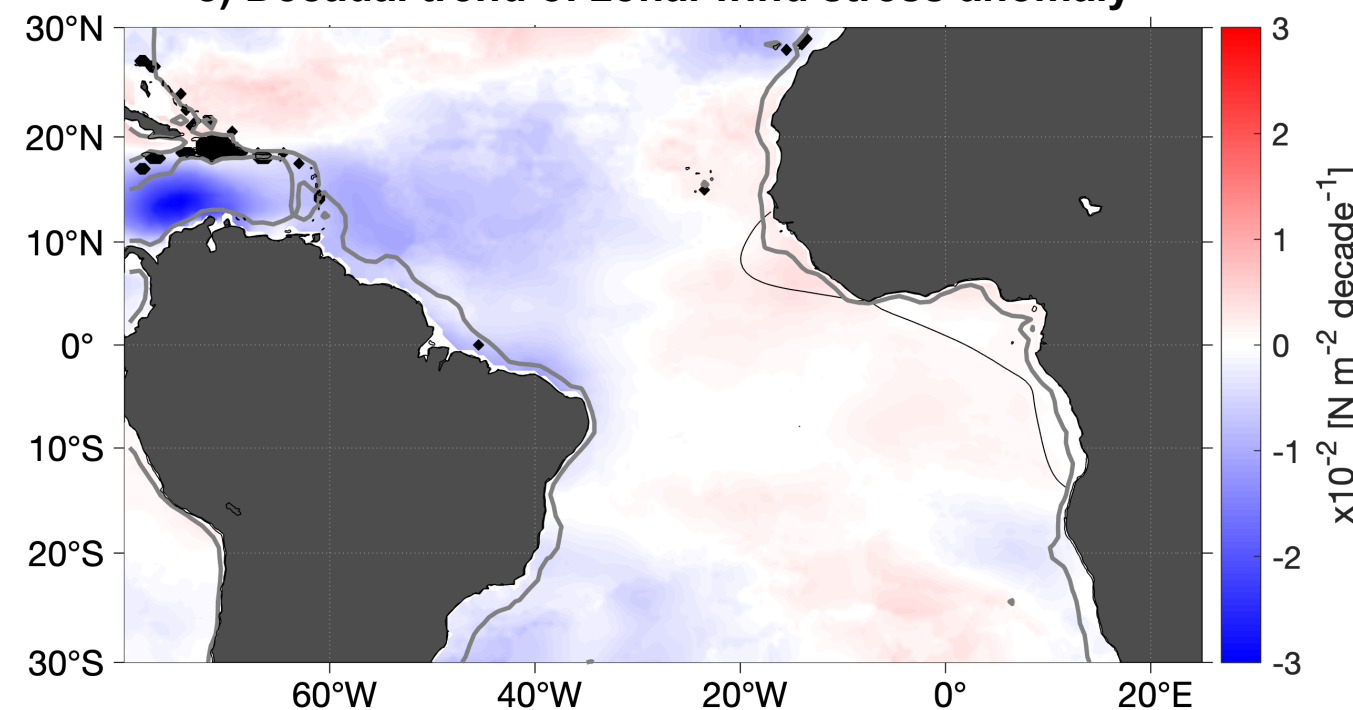
a) Decadal trend of wind stress curl anomaly



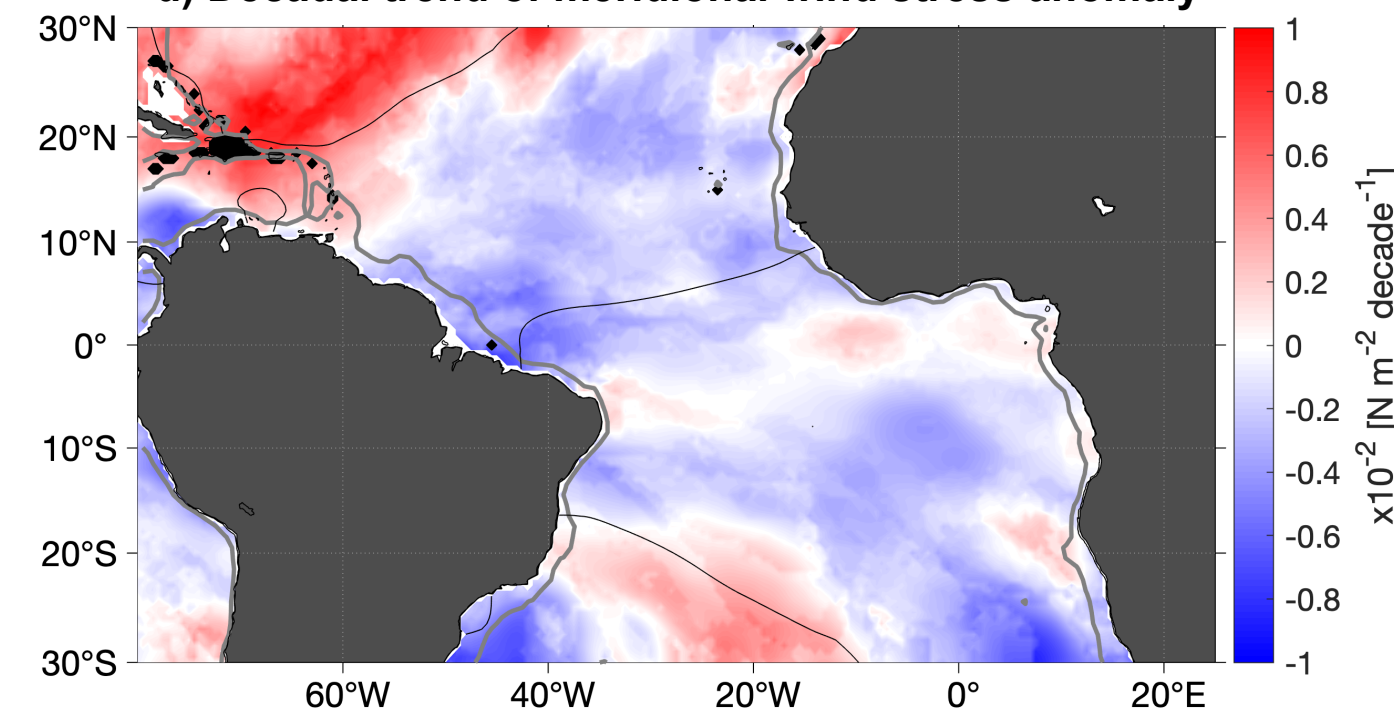
b) Decadal trend of wind speed anomaly



c) Decadal trend of zonal wind stress anomaly



d) Decadal trend of meridional wind stress anomaly



- ▶ close to the coast in SETA: negative trend of wind stress curl
→ wind stress curl becomes more negative, i.e. increased curl-driven upwelling while west of the zero-line wind stress curl becomes more positive, i.e. more downwelling
→ Is this true? Or is this an artifact of the satellite product near coastlines?
- ▶ SETA: increased wind speed and southward wind stress anomaly in the north of this region, while in the south slightly northward anomaly
- ▶ meridional wind along the coast becomes generally more southward → development toward coastal downwelling favoring conditions

Fig. 1: Decadal trend of [a] wind stress curl, [b] wind speed, [c] zonal wind stress component and [d] meridional wind stress component from Copernicus Marine environment monitoring service (CMEMS) from ASCAT scatterometers on METOP-A and METOP-B satellites for the time period of 2007-2019. Trend is computed from the anomaly to the monthly mean. Black line indicates the zero-line of the overall mean fields, respectively.



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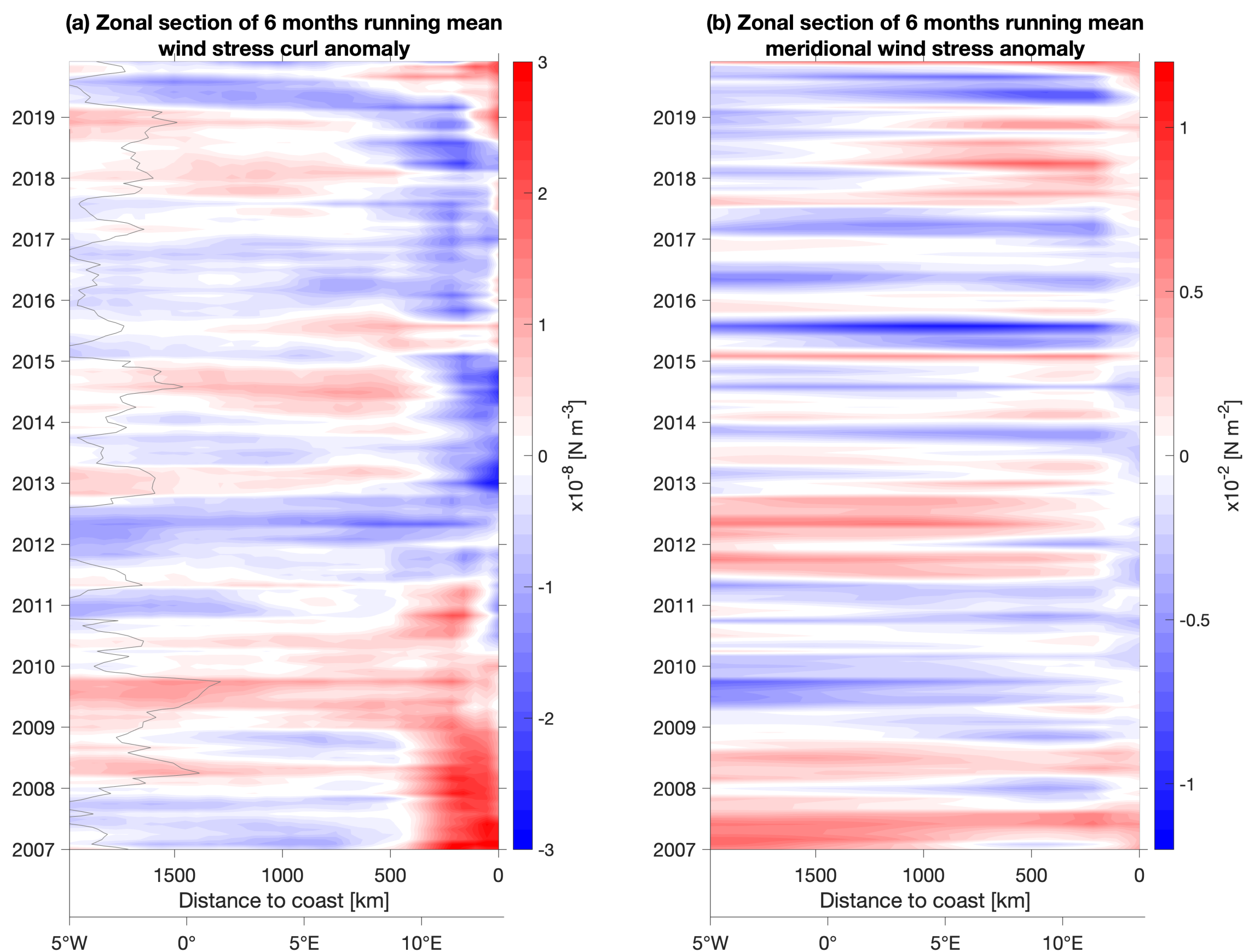
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- ▶ especially within 200 km of the coast the wind stress curl becomes more negative while the meridional wind stress component shifts from northward anomalies (2007-2009) toward southward anomalies in the following years
- ▶ southward meridional wind stress anomalies might be the reason for the transport of warmer and fresher surface waters toward the SETA region

Fig. 1: Zonal section of six months running mean of (a) wind stress curl anomaly and (b) meridional wind stress anomaly in SETA (10°S-20°S, 5°W-15°E) as a function of distance to the coast (ca. 13.5°E) inferred from Copernicus Marine environment monitoring service. Anomalies are computed to the monthly mean of the period of 2007-2019.

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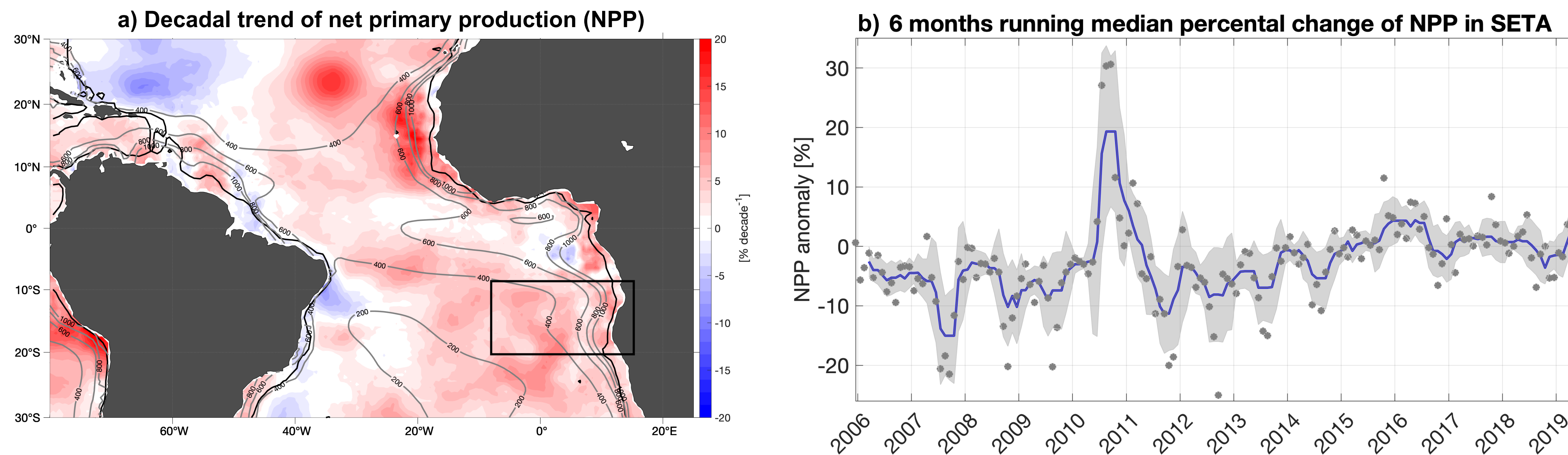


Fig. 1: [a] Decadal trend of net primary production (NPP) from the Ocean Productivity Site for the period of 2006-2019. Grey contourlines indicate the mean field. Black contourlines indicates the 2000 dbar isobath. [b] Six months running median percental change of NPP in SETA region (10°S-20°S, 5°W-15°E). Blue line denotes the median, grey dots the monthly values and the grey shading the limit of the standard deviation.

- ▶ in contrast to climate predictions, increasing NPP in areas of intensified stratification
- ▶ large maximum of NPP in SETA region in 2010 - maybe due to cold event prior to Benguela Niño 2011
- ▶ since 2012 NPP seems to intensify in SETA region
- ▶ uncertainties of NPP? Increasing NPP might be associated with shoaling mixed layers as NPP might be compressed to a thinner layer

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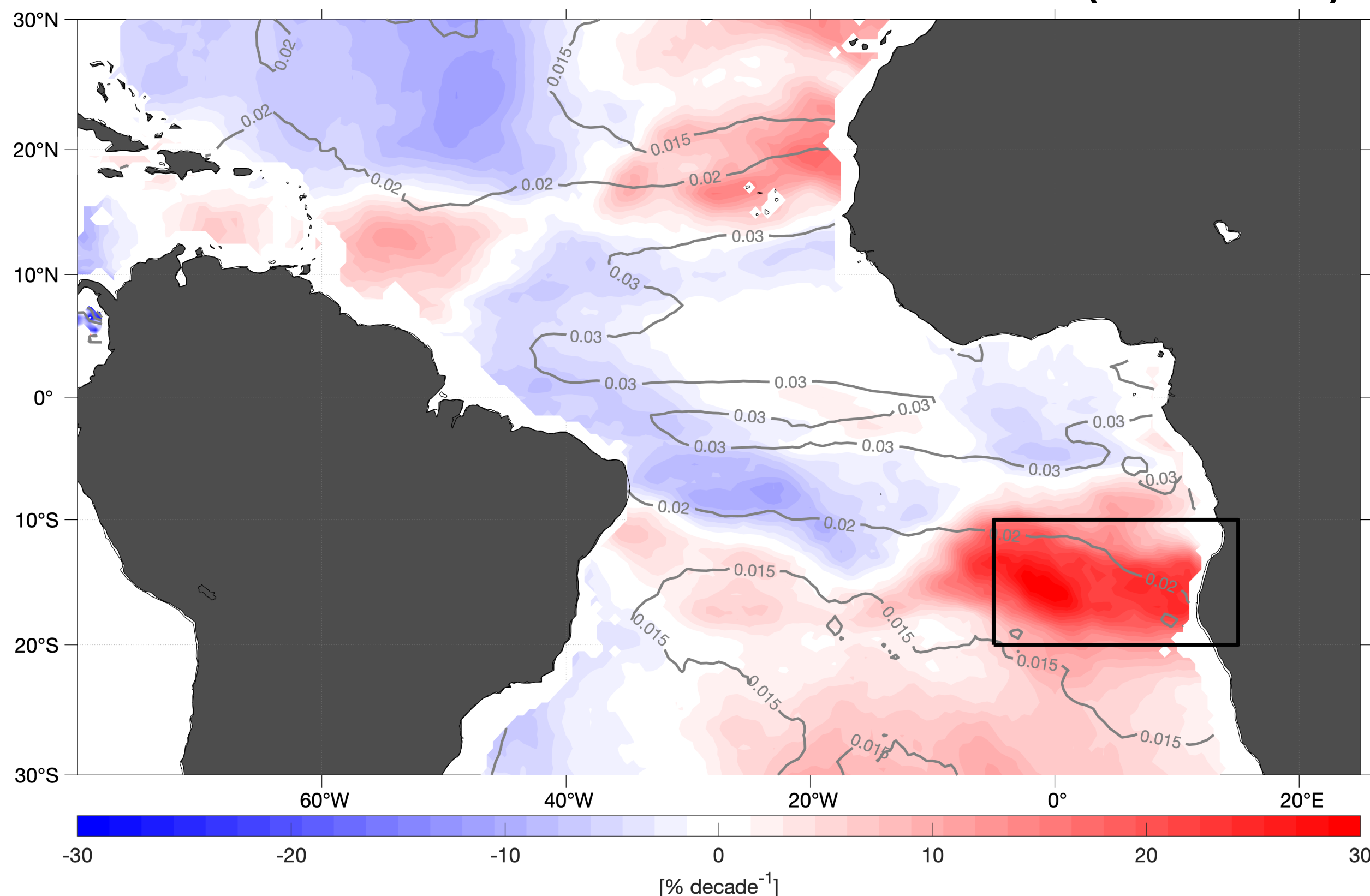
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Trend of the vertical stratification maximum (2006-2019):



- ▶ warming, freshening and shallowing of the ML, surface density reduces
- ▶ development from a subtropical stratification with salinity maximum at the surface toward a tropical stratification with warm and fresh surface waters at the top
- ▶ stratification strongly increases
- ▶ wind curl-driven upwelling intensifies leading to rising of isopycnals
- ▶ intensified coastal downwelling by alongshore winds partly counteracting the wind curl-driven upwelling
- ▶ might further impact marine ecosystems, productivity and fisheries of Angolan and northern Namibian upwelling systems

Fig. 1: Decadal trend of the vertical stratification maximum inferred from Argo observation for the period of 2006-2019. The decadal trend has been evaluated from the anomalies to the corresponding seasonal mean. Grey contour lines show overall mean stratification maximum field.

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Thank you very much!

**Feel free to contact me in case of any questions:
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References:

- ▶ Argo (2019). Argo float data and metadata from Global Data Assembly Centre (Argo GDAC) - Snapshot of Argo GDAC of November 13st 2019. SEANOE. <https://doi.org/10.17882/42182#68322>
- ▶ Bindoff, N. L., & Mcdougall, T. J. (1994). Diagnosing climate change and ocean ventilation using hydrographic data. Journal of Physical Oceanography, 24(6), 1137-1152.
- ▶ Holte, J., & Talley, L. (2009). A new algorithm for finding mixed layer depths with applications to Argo data and Subantarctic Mode Water formation. Journal of Atmospheric and Oceanic Technology, 26(9), 1920-1939.
- ▶ Wind product: https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=WIND_GLO_PHY_CLIMATE_L4_REP_012_003
- ▶ Net primary production: <http://sites.science.oregonstate.edu/ocean.productivity/index.php>

