Identifying and Characterizing Subsurface Tropical Instability Waves in the Atlantic Ocean in Simulations and Observations

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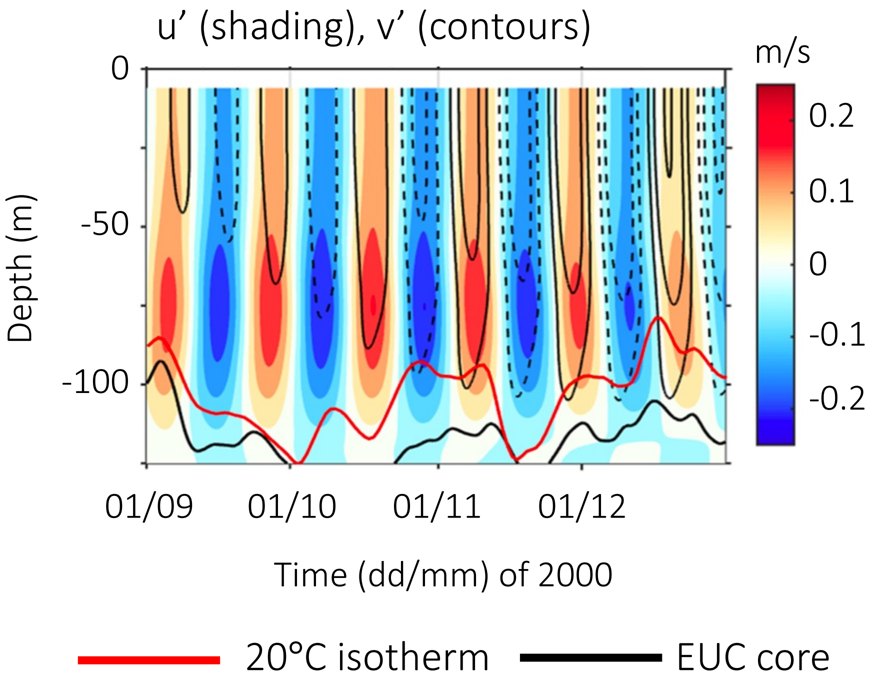
What are Subsurface Tropical Instability Waves?

A recent study based on mooring observations in the equatorial Pacific Ocean suggests the existence of subsurface tropical instability waves (subTIWs) *(Liu et al., 2019)*

- Manifested as subsurface velocity oscillations
- Characteristics and generation mechanisms similar to TIWs at the surface
- Altering shear and stratification
- Important for vertical mixing and heat flux
- May alter the impact of TIWs

> ➢ Results are based on a single mooring in the Pacific
> ➢ Existence of subTIWs in the Atlantic is not yet shown



Modified from Liu et al., 2019

Study Goals

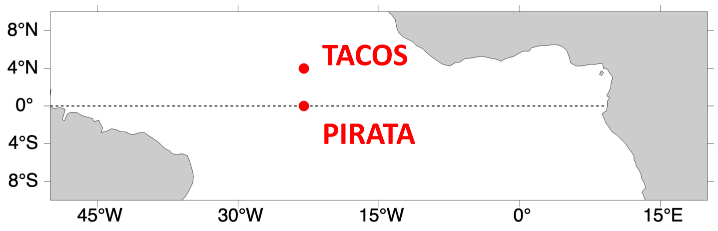
I. Use observations from PIRATA/TACOS moorings to show the existence of subTIWs in the equatorial Atlantic Ocean for the first time

II. Show that the OGCM ICON-O is able to realistically simulate subTIWs

III. Use a high-resolution ICON-O simulation to study the spatio-temporal characteristics of subTIWs in the Atlantic Ocean and their impact on vertical mixing

Data

I. **Observations** → Mooring data[1]



TACOS (4°N, 23°W)[2]:

- March 2017 to March 2018
- Velocity and temperature
- Upper 90 m depth

PIRATA (0°N, 23°W)[3]:

- March 2008 to September 2015
- Velocity and temperature
- 25 to 210 m depth

II. **Simulation** → High – resolution ICON-O simulation[4]

- Used to study the spatial extent and regional impact of subTIWs
- Comprehensive, global, ocean only setup
- Horizontal resolution: 10 km
- Vertical resolution: 128 vertical levels (increased in the upper ocean)
- Forced by hourly ERA5 reanalysis data from 1979 to 2019

- Using output of daily mean values for the analysis:

Period:	February 2003 until December 2019
Variables:	3D velocity field, temperature, salinity
Region:	10°S to 10°N and 60°W to 40°E

[1] https://www.pmel.noaa.gov/gtmba/pirata
[2] Perez, R. et al. (2019). *Direct measurements of upper ocean horizontal velocity and vertical shear in the tropical North Atlantic at 4°N, 23°W*, Journal of Geophysical Research: Oceans
[3] Bourles, B. et al. (2019). *PIRATA: A sustained observing system for tropical Atlantic climate research and forecasting,* Earth and Space Science
[4] Korn, P. (2017). *Formulation of an unstructured grid model for global ocean dynamics*, Journal of Computational Physics

Identifying subTIWs

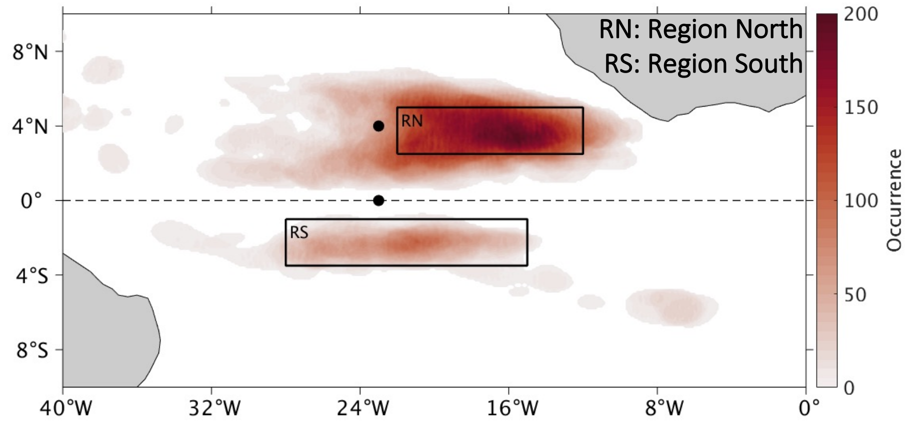
I. Filtering

The signal must be filtered in both time and space to remove all non-subTIW signals

II. Signal depth

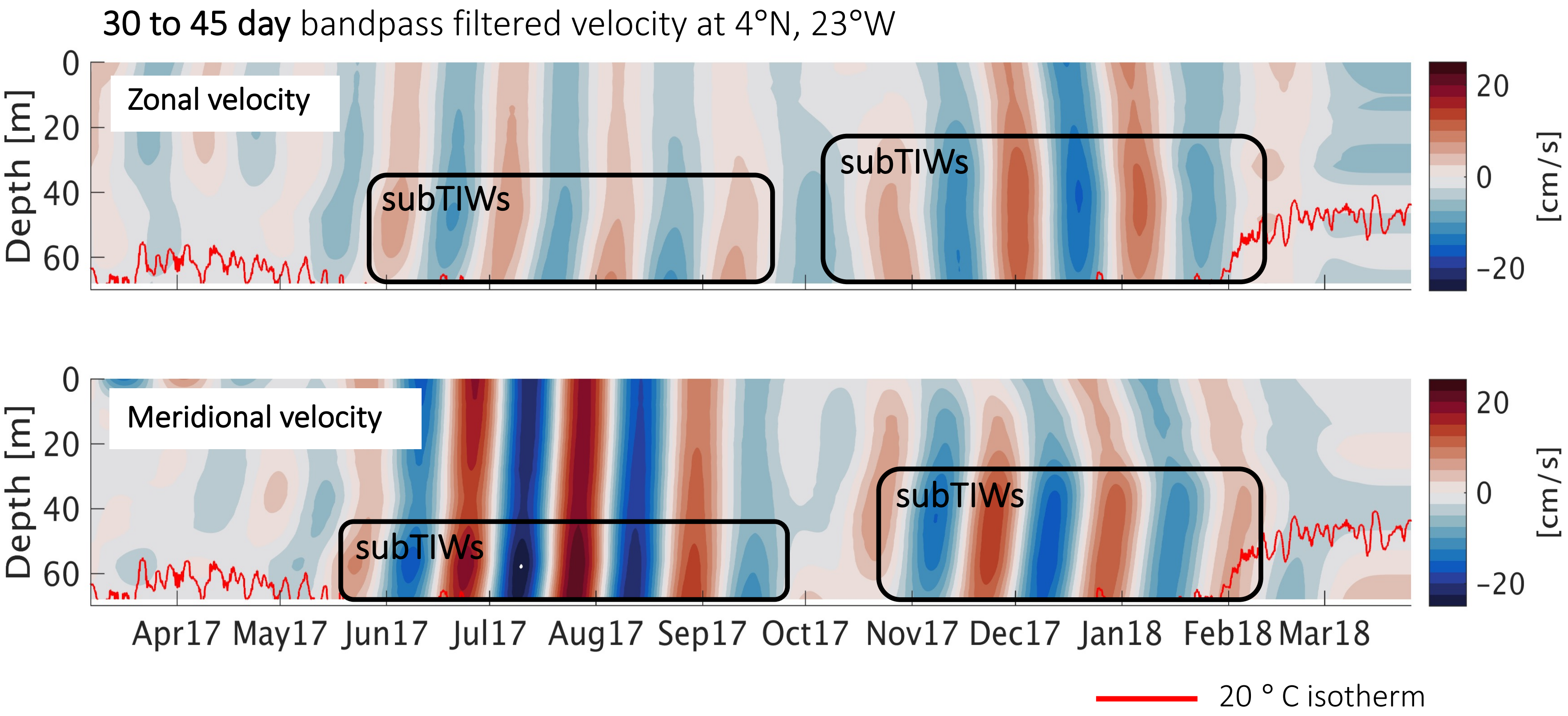
Find the depth in which subTIWs are most pronounced → 64 m

III. Finding regions of pronounced subTIW activity



- Establish a threshold over which subTIW activity is considered "strong"
- Threshold: 90th percentile of temperature standard deviation in a 4 months moving average window
- Count events above given threshold for each gridpoint to create a 2D histogram of strong subTIW events

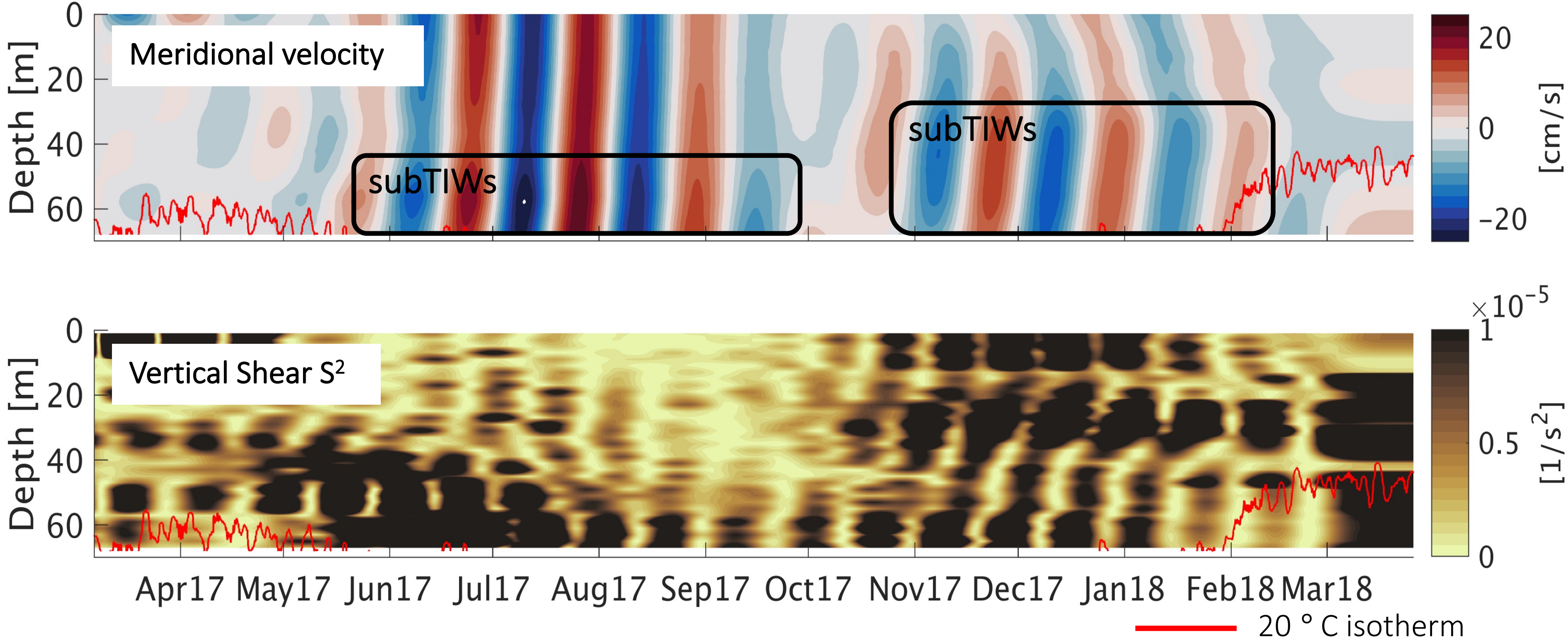
Observational evidence for subTIWs in the Atlantic



→ subTIWs are expressed as oscillating subsurface velocity maxima

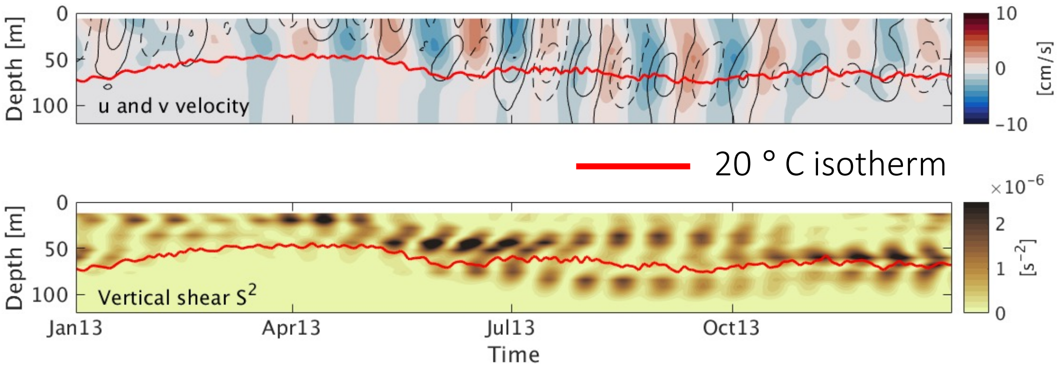
subTIWs impact vertical shear and thereby have the potential to impact mixing

Vertical shear of horizontal momentum: $S^2 = \left(\frac{du}{dz}\right)^2 + \left(\frac{dv}{dz}\right)^2$ → Indicator for increased vertical mixing



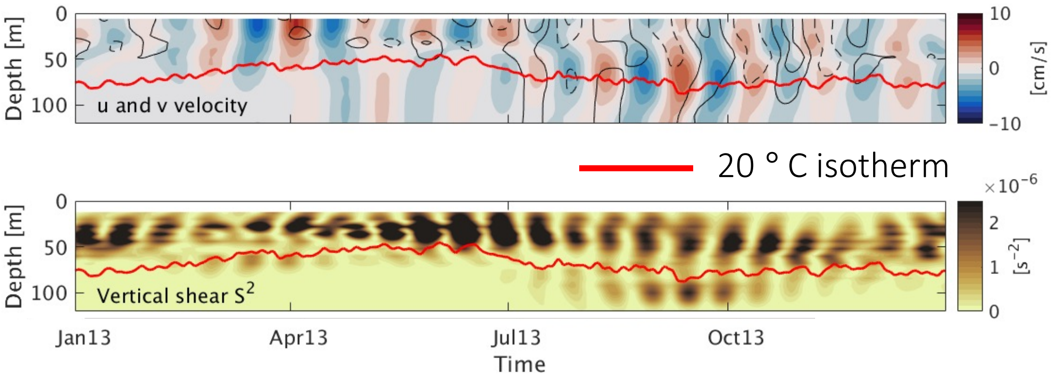
Simulated subTIWs in ICON-O

Region North



- Frequent subsurface velocity maxima between 38 and 88 m
- SubTIWs most pronounced in the meridional velocity component
- Vertical two-layer shear structure with shear maxima directly below and above velocity peaks

Region South

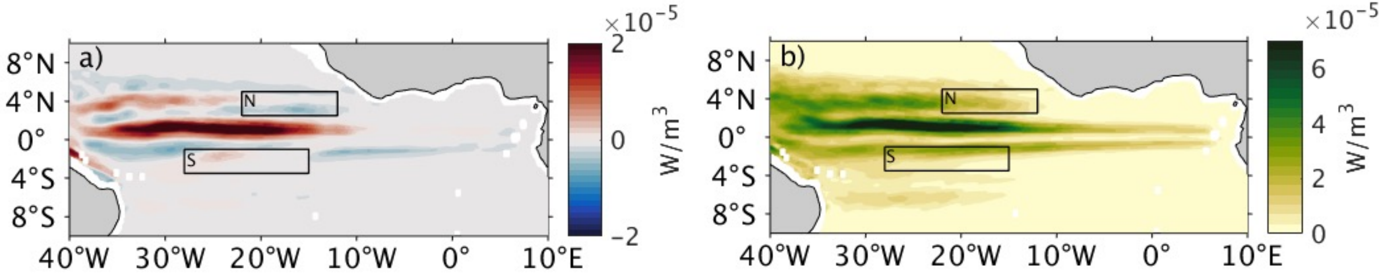


- Subsurface velocity maxima between 36 and 84 m
- Greater impact of zonal velocity component compared to Region North

Generation mechanisms of subTIWs

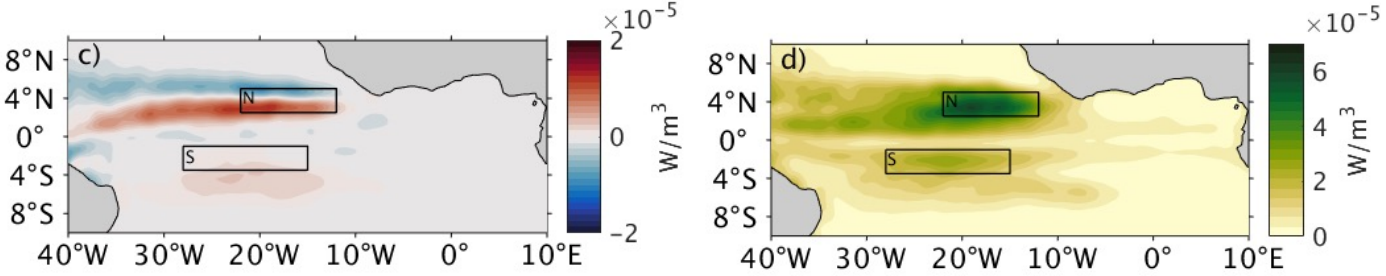
Barotropic Conversion

$$\mathrm{bartro_{conv}} = -\rho\overline{u'v'}\frac{\partial U}{\partial y}$$



Baroclinic Conversion

$$\mathrm{barclin_{conv}} = -g\overline{\rho'w'}$$

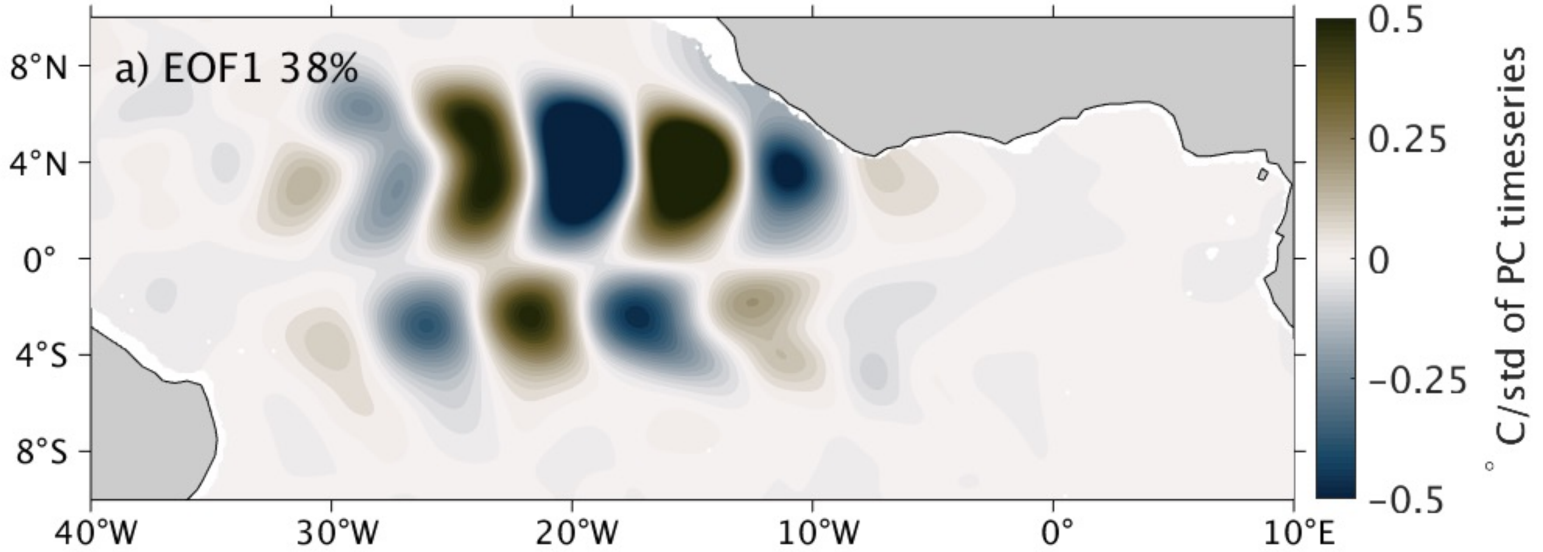


Region North: subTIWs generated through **baroclinic** conversion

Region South: subTIWs generated thorugh both **baroclinic and barotropic** conversion

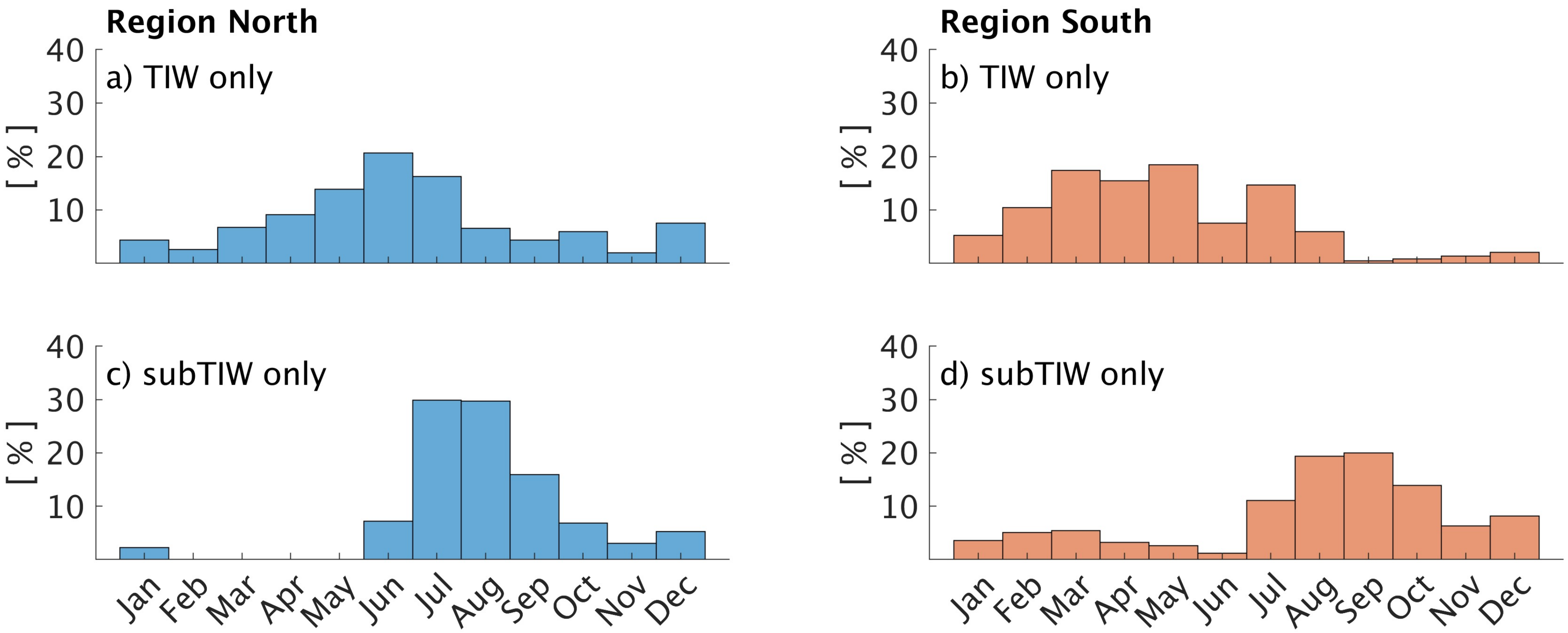
Spatial Characteristics of subTIWs in ICON-O

Empirical Orthogonal Function (EOF)
→ Values are change of temperature in °C per standard deviation of the PC timeseries



- Oscillating temperature pattern both north and south of the Equator
- Further northward expansion

Occurrence time of simulated subTIWs in ICON-O



subTIWs occur approximately 1 to 3 months later than TIWs at the surface

Are TIWs and subTIWs independent features?

Differences in:
I. Generation mechanism
II. Occurrence time
III. Spatial extent

	TIW	subTIW
Generation mechanism	Primarily barotropic energy conversion	Barotropic and baroclinic energy conversion Baroclinic energy conversion more important, in particular north of the Equator
Occurrence time	May onwards	August onwards
Spatial extent	Mainly north of the Equator	North and South of the Equator

Summary

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- subTIWs are be observed in the tropical Atlantic Ocean for the first time
- subTIWs are realistically simulated in ICON-O
- Using a high-resolution ICON-O simulation allows for characterizing TIWs and subTIWs as distinct features and for spatial analysis of subTIWs
- SubTIWs induce a vertical multi-layer shear structure which likely enhances vertical mixing
- Unlike surface TIWs, subTIWs are also regularly present south of the Equator
- SubTIWs are generated by both baroclinic and barotropic conversion south of the Equator and mainly by baroclinic conversion north of the Equator