Evolution of the Black Sea ventilation regime during the last decades

Arthur Capet, Luc Vandenbulcke, Marilaure Grégoire

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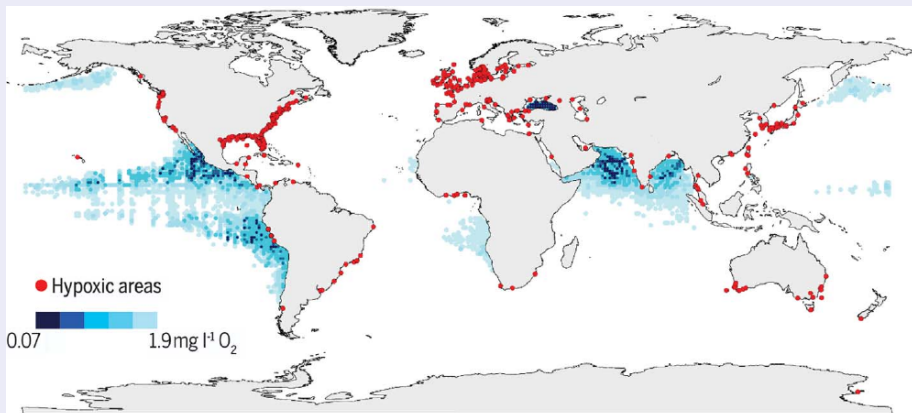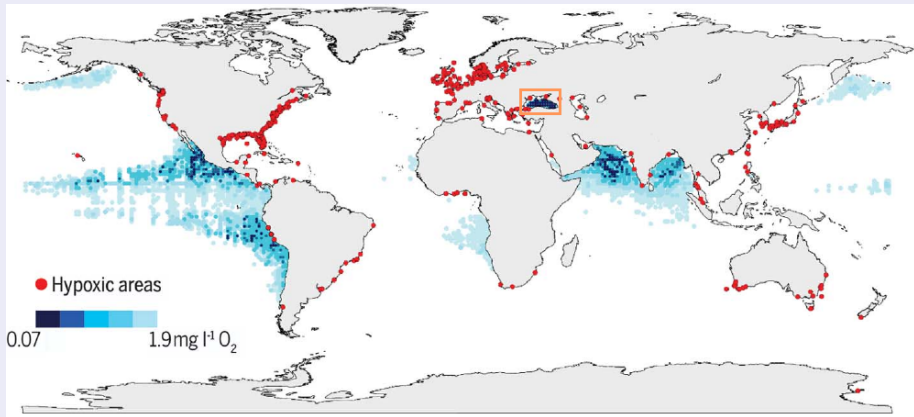
September 4, 2018

Introduction

Global Warming is aggravating marine deoxygenation worldwide

- Hypoxic areas

0.07 — 1.9mg l⁻¹ O₂

BREITBURG2018.
BOPP2013.

Introduction

The Black Sea: a natural laboratory to study deoxygenation

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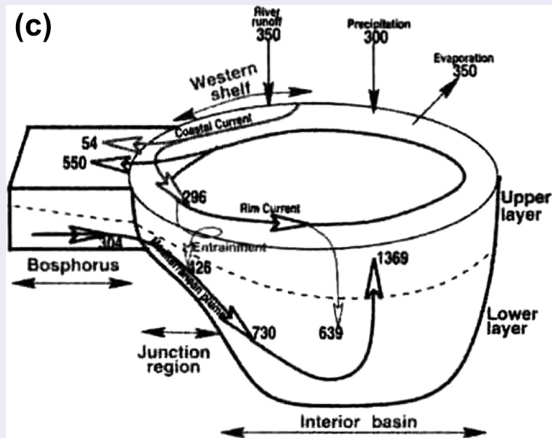
OGUZ2004.

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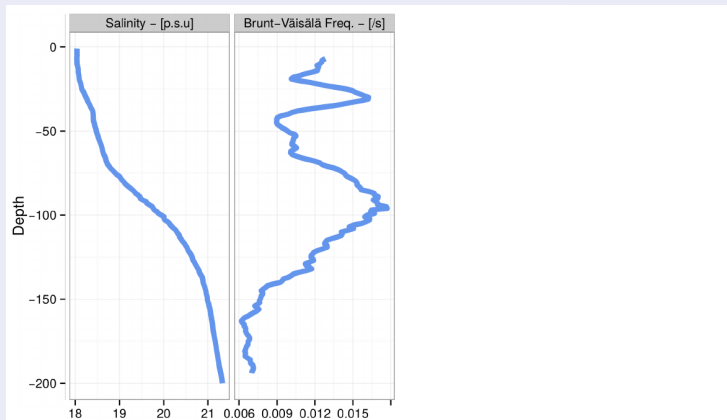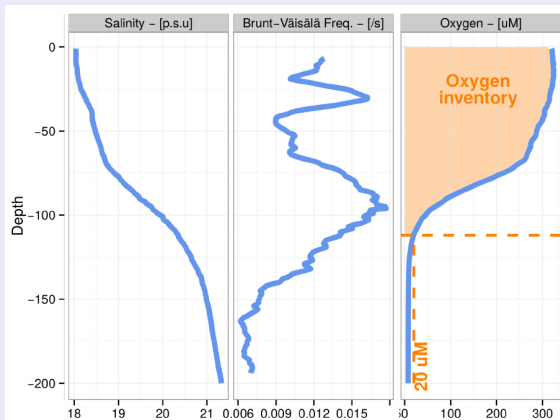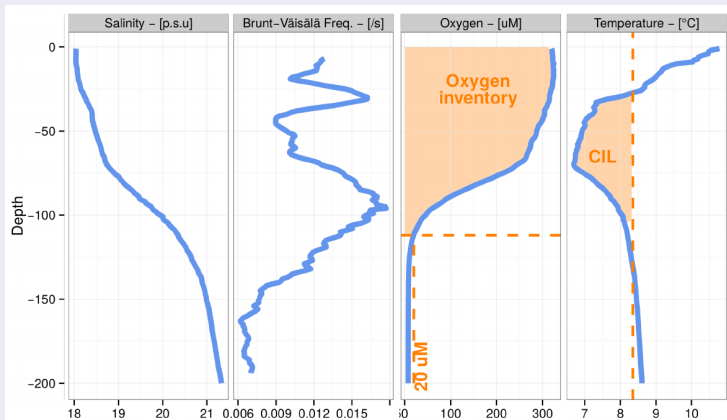
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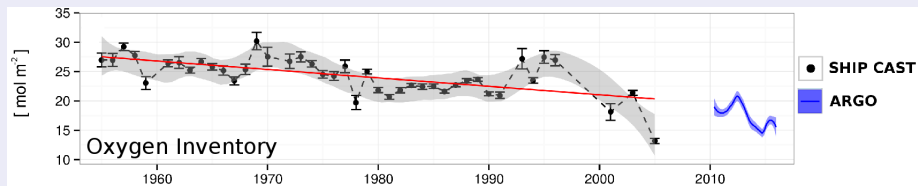
CAPET2016.

Introduction

The Black Sea: a natural laboratory to study deoxygenation
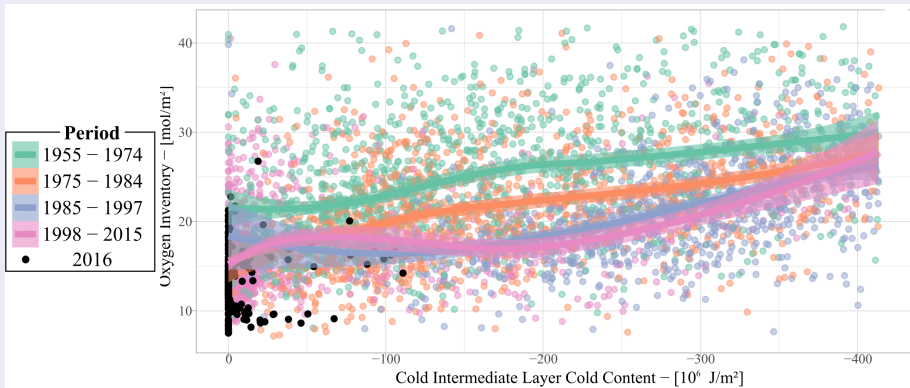
CAPET2016.

Question

How did CIL formation rate change during the past and recent years ?

Question

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Approach

- One metric, four data sets
- → Composite time series
- → Descriptive models

One metric

Cold Intermediate Layer (CIL) cold content
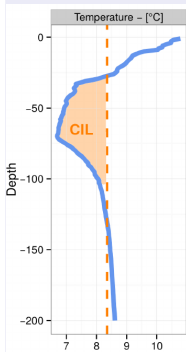
One metric

Cold Intermediate Layer (CIL) cold content
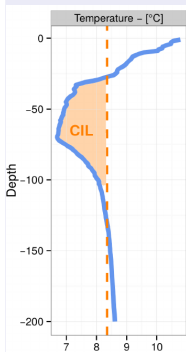
$$\text{Cold content} = -c_p \int_{CIL} \rho(T - T_{CIL}) \, dz \qquad (1)$$

Units : J m^{-2}

One metric

Cold Intermediate Layer (CIL) cold content
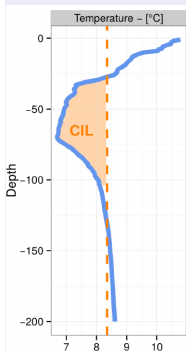
$$\text{Cold content} = -c_p \int_{CIL} \rho(T - T_{CIL}) \, dz \qquad (1)$$

Units : $\mathrm{J\,m^{-2}}$

$\rightarrow$ Integrated diagnostic of the CIL state.

$\rightarrow$ Annual/spatial average: Proxy for CIL formation rate.

Source 1 : Ship Casts

In-situ ship-cast profiles
- World Ocean Database
- KNORR campaigns

DIVA detrending methodology

Data

DIVA

Spatial Variability

Temporal Variability

CAPET2014.
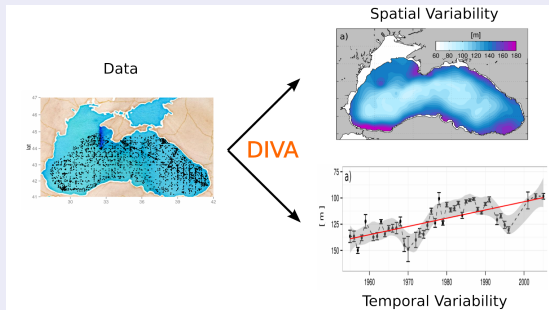
Source 1 : Ship Casts

Results

CIL_Trends_GRL_BEAMER_files/figure-beamer/Nat DIVA-1.pd

Source 2 : Atmospheric Predictors

Stepwise Multilinear Regression

- Reproduce the CIL cold content time series with a linear combination of environmental descriptors.

CAPET2014.

A. Capet et al. (MAST, Uliège)   Shift in the Black Sea ventilation Regime   September 4, 2018   10 / 1

Source 2 : Atmospheric Predictors

Stepwise Multilinear Regression

- Reproduce the CIL cold content time series with a linear combination of environmental descriptors.
- *Proposed*

CAPET2014.

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  - ▸ Winter/summer air temperature

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    - ▸ Wind Curl/Magnitude

CAPET2014.

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CAPET2014.

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  - Winter/summer air temperature
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- *Best* : $C_y = 0.86 AT_y^{winter} + 0.5 AT_{y-1}^{winter} + 0.28 AT_{y-2}^{winter} + 0.18 AT_{y-3}^{winter}$

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- → Partial refill and Feed-Back.

CAPET2014.
STANEV2003.

Source 2 : Atmospheric Predictors

Results

CIL_Trends_GRL_BEAMER_files/figure-beamer/Nat Atmos, -1

Source 3 : 3D hydrodynamic model

The GHER 3D model

- Used in several studies.
- $\Delta x \sim 5$ km
- free of any form of data assimilation.
- ERA-Interim set of atmospheric forcings..

STANEV1999.
VANDENBULCKE2010.
CAPET2012.

Source 3 : 3D hydrodynamic model

Results

CIL_Trends_GRL_BEAMER_files/figure-beamer/Nat 3D, -1.pd

Source 4 : Argo

Argo Spatial Distribution ([2005-2017])

CIL_Trends_GRL_BEAMER_files/figure-beamer/ARGODATA-1.pd

Source 4 : Argo

Results

CIL_Trends_GRL_BEAMER_files/figure-beamer/NAT Argo, -1.

All Sources

Native temporal resolution

CIL_Trends_GRL_BEAMER_files/figure-beamer/Nat ALL, , -1

All Sources

Annual means

CIL_Trends_GRL_BEAMER_files/figure-beamer/Time Series A

All Sources

Composite time series

CIL_Trends_GRL_BEAMER_files/figure-beamer/Time Series-1

All Sources

Composite time series

CIL_Trends_GRL_BEAMER_files/figure-beamer/Time Series C

Regime Shift Analysis

CIL_Trends_GRL_BEAMER_files/figure-beamer/Regime Shif-3

Regime Shift Analysis

CIL_Trends_GRL_BEAMER_files/figure-beamer/Regime Shif-2

Intermittent Ventilation Regime

Native temporal resolution

CIL_Trends_GRL_BEAMER_files/figure-beamer/Nat ALL, , -1

Descriptive models: Selection

Linear

CIL_Trends_GRL_BEAMER_files/figure-beamer/Time Series L

Descriptive models: Selection

CIL_Trends_GRL_BEAMER_files/figure-beamer/Time Series P

Descriptive models: Selection

CIL_Trends_GRL_BEAMER_files/figure-beamer/Regime Shif-2

Descriptive models : Selection

Problem

Additional parameters always decrease model misfits.
Residual sum of squares (RSS) is not enough to compare models.

Descriptive models : Selection

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The Akaike Information Criterion (AIC)

Quantifies a models misfits and penalizes the number of model paramters.

Descriptive models : Selection

Problem

Additional parameters always decrease model misfits.
Residual sum of squares (RSS) is not enough to compare models.

The Akaike Information Criterion (AIC)

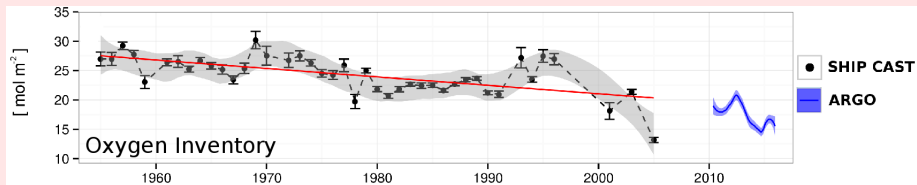Quantifies a models misfits and penalizes the number of model paramters.

CIL_Trends_GRL_BEAMER_files/figure-beamer/unna

Building-bricks Conclusion
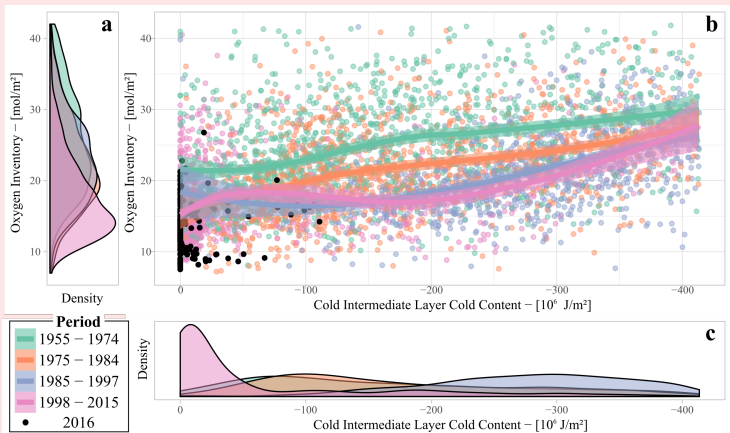
Brick 1

Decline in the Black Sea oxygen inventory.

Building-bricks Conclusion

Brick 2

Close relationship between Oxygen inventory and CIL cold content.

Brick 3

Winter Air temperature are best predictors for CIL cold water formation.

CIL_Trends_GRL_BEAMER_files/figure-beamer/Time Series Annu

Building-bricks Conclusion

Brick 4

Cold water formation is best described by a regime shift model.

CIL_Trends_GRL_BEAMER_files/figure-beamer/Regime Shif-2.pdf

Building-bricks Conclusion

Brick 1

Decline in the Black Sea oxygen inventory.

Brick 2

Close relationship between Oxygen inventory and CIL cold content.

Brick 3

Winter Air temperature are best predictors for CIL cold water formation.

Brick 4

Cold water formation is best described by a regime shift model.

Take-Home Message

Global Warming induced a shift towards an intermittent Black Sea ventilation regime that accelerated the decline of its oxygen inventory.

Thank for your attention

CMEMS follow-up:

- Black Sea Monitoring and Forecasting Center
- Ocean Monitoring Indicator

Distribution

CIL_Trends_GRL_BEAMER_files/

Occurence

CIL_Trends_GRL_BEAMER_files/