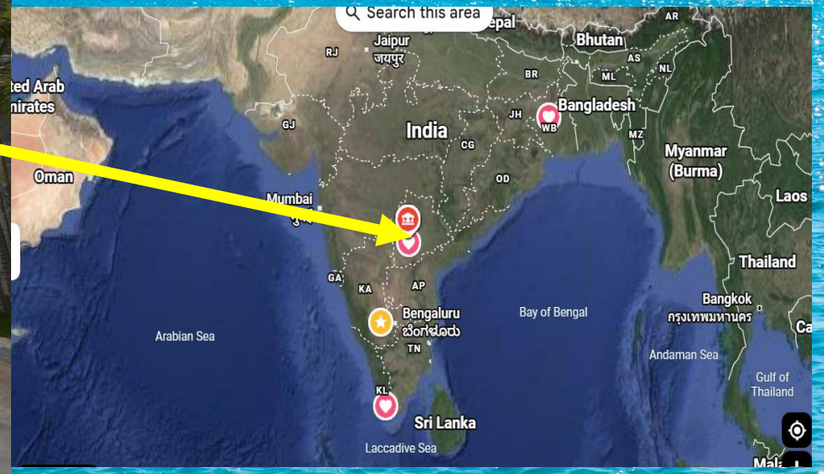
AMOC variability in INCOIS Global Ocean Reanalysis-IGORAv1

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Hyderabad,India





SynObs & Ocean Observing Co-Design Joint International Workshop 24 to August 29, 2026, Mutsu, Japan

Why Ocean Reanalysis?

What is Ocean Reanalysis:

Ocean reanalysis is a scientific method that uses ocean models, observations, and atmospheric forcing to create a record of ocean changes over time. It's a key tool for climate research and monitoring.

Limitations:

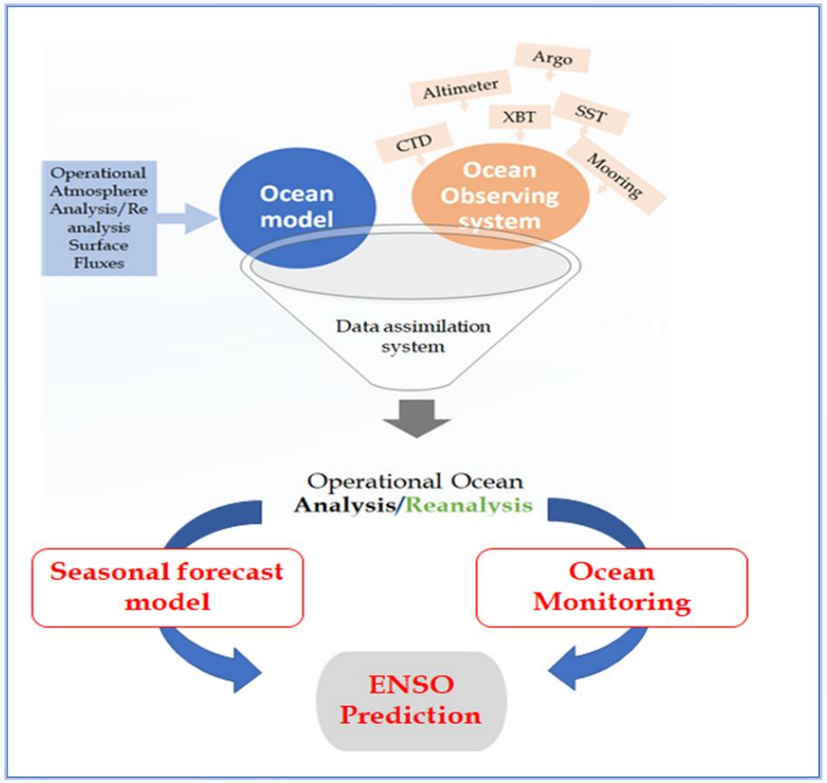
- Reanalysis products are based on models and may not perfectly capture all aspects of ocean dynamics, particularly in complex coastal regions.
- Uncertainties in ocean reanalyses mainly arise due to the deficiencies in numerical models, assimilation methods, observational data, and atmospheric forcing.

Observations + dynamics + data assimilation

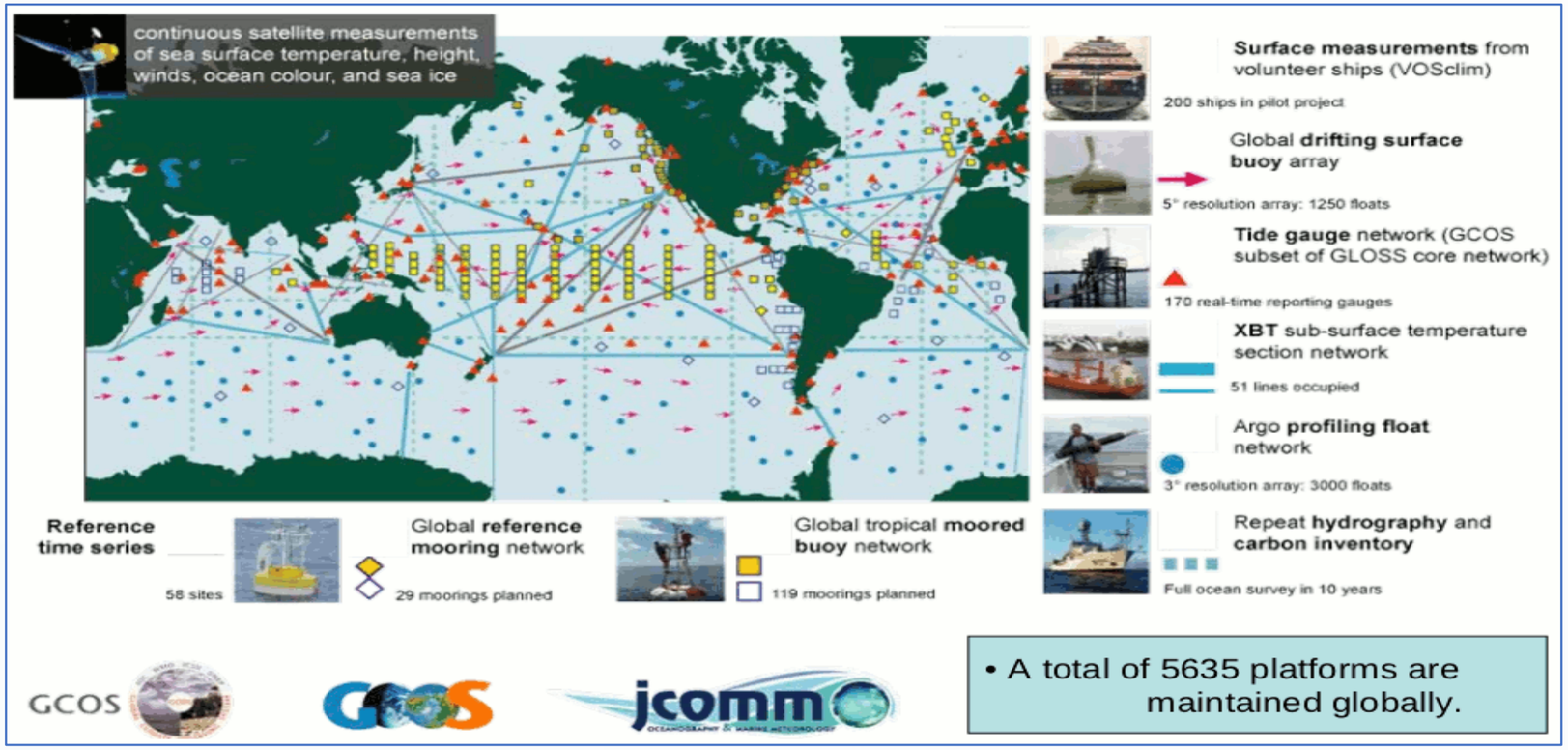
- **Climate Change Studies:**
  - Assessing long-term changes in ocean temperature and salinity to understand the impacts of climate change.
  - Identifying trends in ocean heat content and its role in global climate variability.
- **Initialization:**
  - Providing initial conditions for ocean prediction models to generate short-term forecasts.
  - Initialization of ocean and sea ice components of seasonal, decadal, and retrospective forecasts (Seasonal to Decadal prediction)
  - Improving the accuracy of weather forecasts by incorporating ocean conditions.
- **Environmental Monitoring:**
  - Tracking ocean pollution patterns and potential spill pathways.
  - Monitoring harmful algal blooms and other marine hazards
- **Research and Development:**
  - Studying ocean dynamics and circulation patterns
  - Evaluating the performance of ocean models
  - Developing new data assimilation techniques to improve reanalysis quality
- **AI/ML models :**
  - Crucial for training AI/ML models to forecast ocean conditions
  - Reconstruct missing data in sparse regions.

Ocean Reanalysis

Overview



Ocean Observation Platforms



Ocean observations → Ocean model → Data assimilation → Reconstructed state

Model used : MOM5 (GFDL)

Domain: Global

Resolution: 50 km zonal and 25 km meridional, 40 vertical levels.

Atmospheric forcing: Fluxes from CORE II and NCEP reanalysis

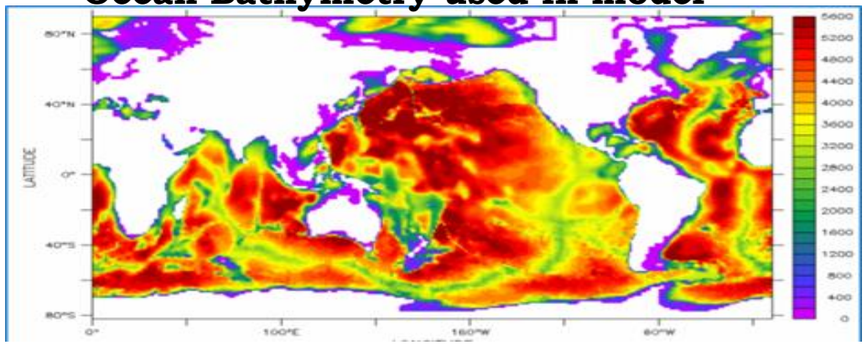
Data assimilation scheme: 3D VAR

Parameters assimilated: Temperature and salinity profiles from Argo, XBT, and moored buoys

Relaxation: ERSST (Huang et al. 2017)

Outputs: 1979-2023, Temperature, Salinity, SSH, and Currents

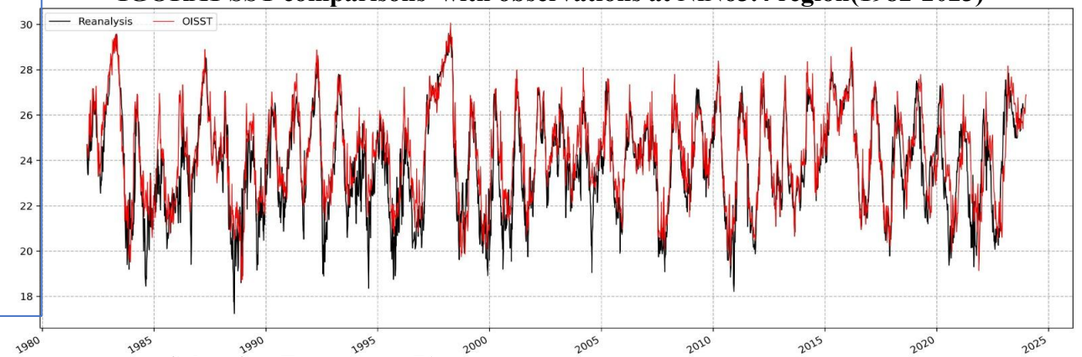
Ocean Bathymetry used in model



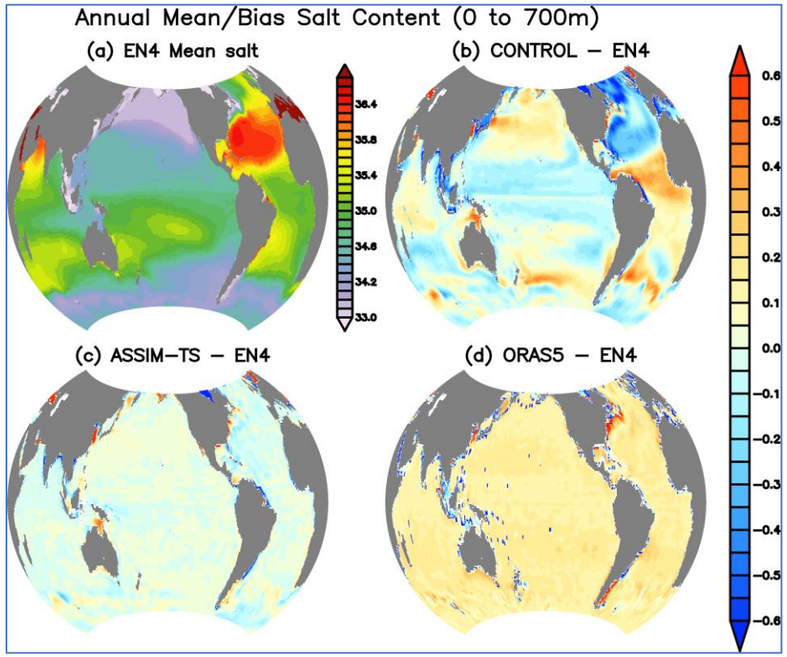
Ocean Reanalysis products from different centers

Name	Country/Organization	Time period
ECCO	NASA,USA	1992-2017
BRAN	BoM, Australia	1993-2021
SODA	University of Maryland, USA	1980-2020
NCEP-GODAS	NOAA/NCEP,USA	1980-present
IGORAv1	INCOIS,India	1979-2023
ORAS5	ECMWF,EU	1979-present
GLORYS	Mercator Ocean, France	1993-present
C-GLORS	CMCC Italy	1980-present
GloSea5	Met Office,UK	2014-ongoing

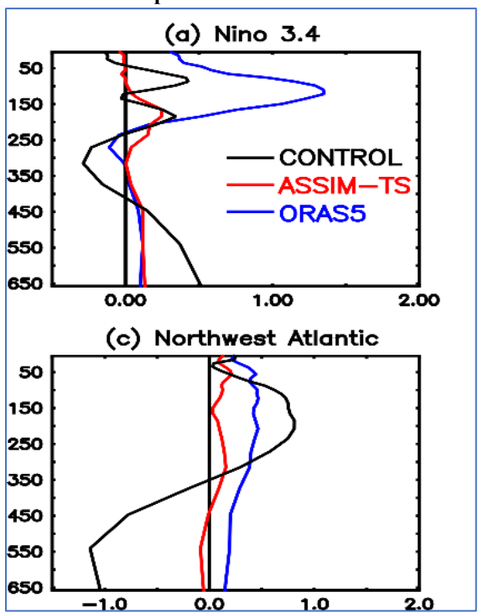
IGORA1 SST comparisons with observations at NiNo3.4 region(1982-2023)



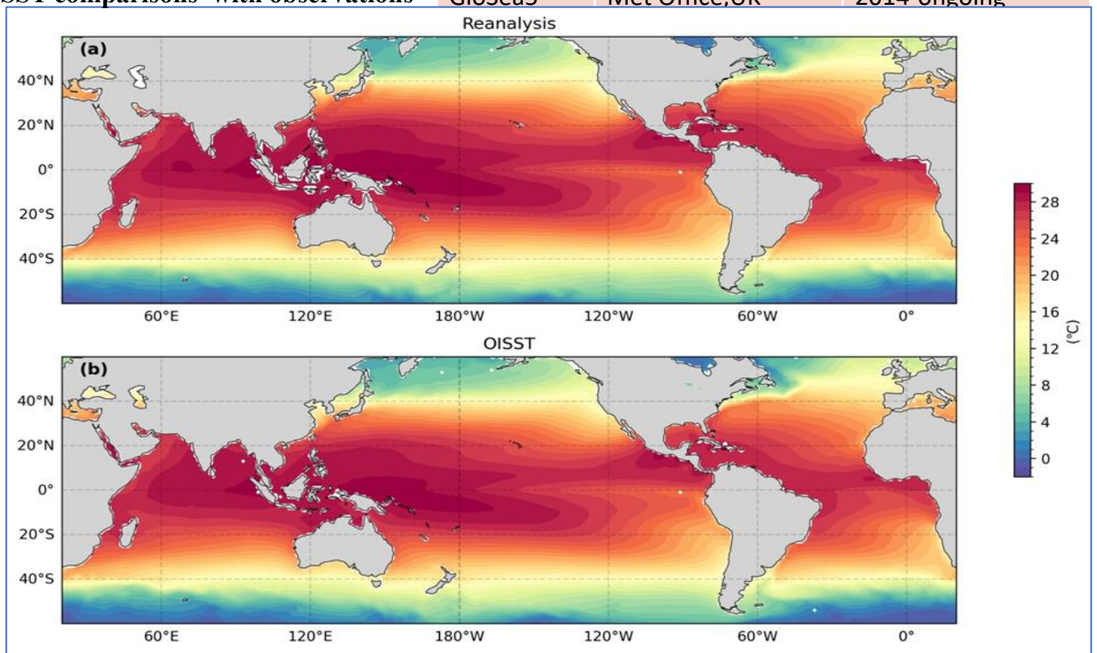
Annual Mean/Bias Salt Content (0 to 700m)



Subsurface Temperature Bias with respect to EN4 observations



SST comparisons with observations



Rahaman et al. 2025, Modeling Earth Systems and Environment, Rahaman et al. 2025

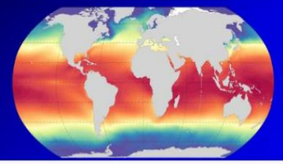
Indian National Centre for Ocean Information Services
(An Autonomous Body under the Ministry of Earth Sciences, Govt. of India)

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Modelling & Research

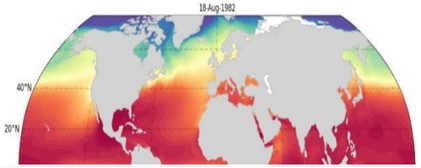
MODELLING & RESEARCH



Home › Modelling & Research › IGORA

INCOIS Global Ocean Reanalysis (IGORA) Version-1.0

Summary



To understand climate change and current weather extremes, it is important to have observations of the Earth system going back as far as possible in time. The Ocean is the major component of the Earth system. However, observations over the Ocean have always been unevenly distributed and come with errors. Even satellite observations alone cannot provide a complete and accurate picture of the 3D state of the Ocean at a given point in time. Reanalyses fill the gaps in the observational record, and they do so in a way that is consistent in time, thus minimizing any spurious signals of change by combining models and observations. Accurate ocean reanalyses are essential, as they provide the most realistic representations of past oceanic conditions, serving as benchmarks



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Comparison Table References

Metadata

Recent Updates

- Overview of current atmospheric reanalyses
  3 months 3 weeks ago
- Reanalyses.org Home Page
  3 months 3 weeks ago
- The International Surface Pressure

Overview of current ocean reanalyses

Created by Cathy.Smith@noaa.gov on Thu, 10/07/2010 - 14:05 - *Updated on 06/06/2025 13:41*
The University of Hamburg has a list of ocean datasets including many reanalyses and may be more up-to-date.
https://www.cen.uni-hamburg.de/en/icdc/data/ocean/easy-init-ocean.html.

Individual Descriptions

Why to study AMOC

Heat and Climate Control

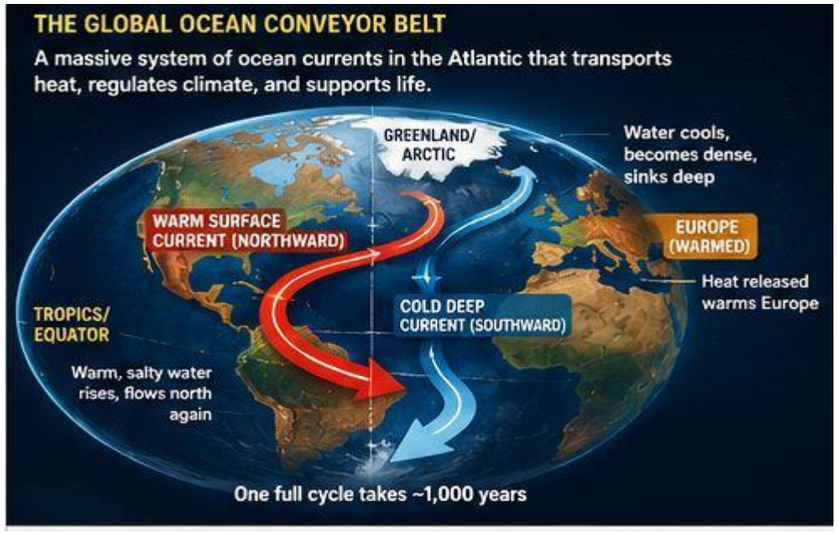
- Northward Heat Transport: Moves about 1.2 petawatts of thermal energy toward the pole.
- Regional Mildness: Keeps winters in the UK and Western Europe much warmer than matching latitudes in Canada.
- Interhemispheric Balance: Transfers enough heat to make the entire Northern Hemisphere slightly warmer than the Southern Hemisphere.

Weather and Rainfall

- Monsoon Stability: Shifts the tropical rain belt (ITCZ) north or south. This shift feeds vital summer rains for Asian and African monsoons.
- Extreme Weather Buffer: Prevents extreme temperature divides between the equator and the poles.

Ocean Carbon and Nutrients

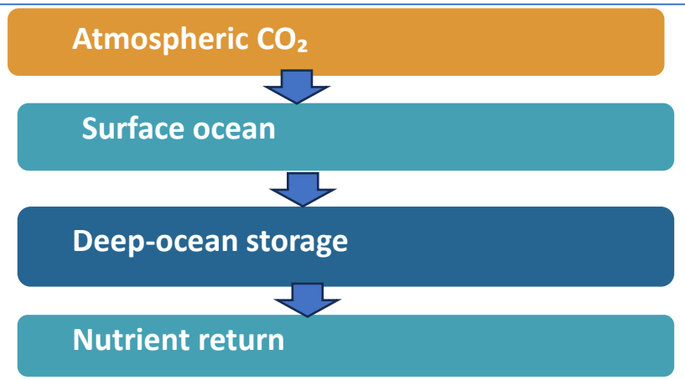
- Carbon Sink: Pulls carbon from the atmosphere down into the deep ocean via sinking cold water.
- Nutrient Delivery: Circulates life-sustaining minerals across the Atlantic basin to support fisheries and marine life





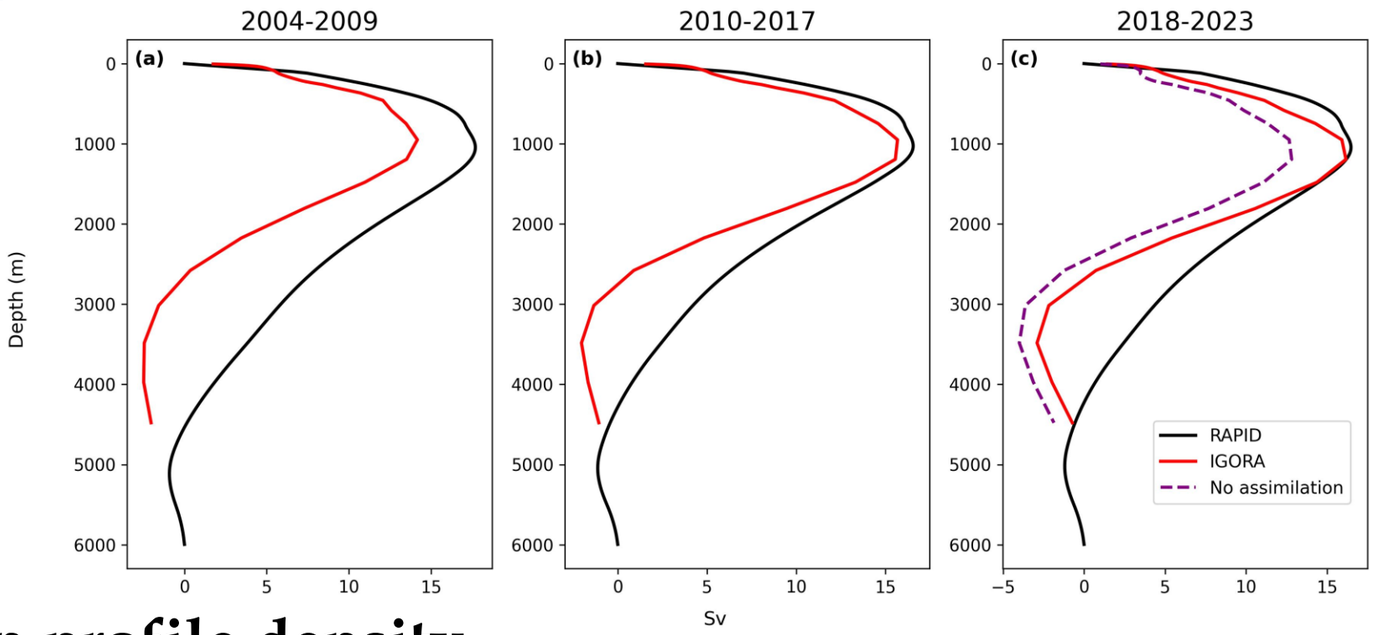


- On average, around **30-40 million people** are affected by floods each year in India. This includes displacement, loss of livelihood, and damage to property.
- In severe drought years, **up to 330 million people** can be affected, primarily in rural areas where agriculture is the mainstay.

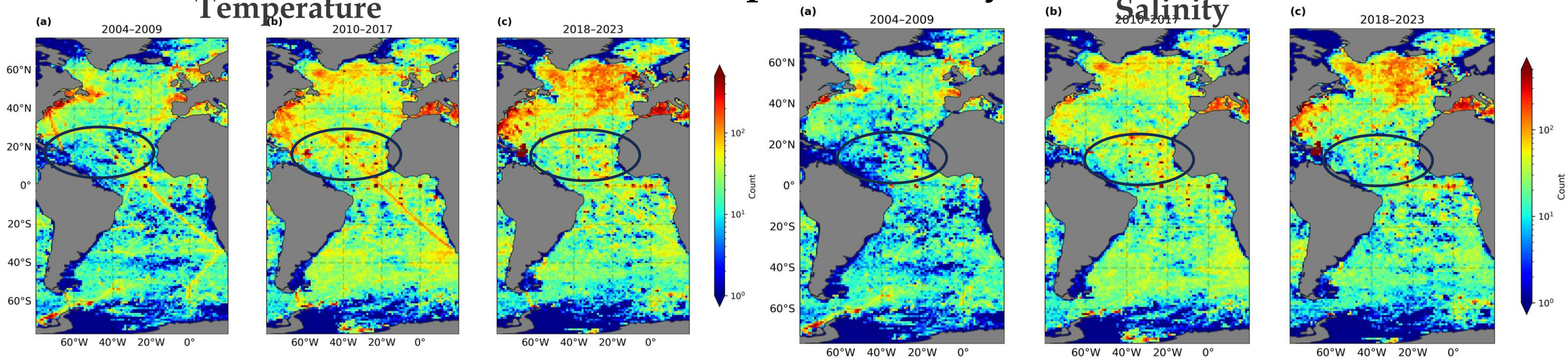


Statistics of AMOC transport between IGORA and RAPID at 26.5°N

AMOC Strength (Sv)	RAPID	IGORA	RAPID	IGORA	RAPID	IGORA	RAPID	IGORA
Time	2004-2009		2010-2017		2018-2023		2004-2023	
Mean (Sv)	17.87	14.19	16.72	15.66	16.66	15.94	17.05	15.29
Standard deviation (Sv)	3.35	4.29	3.17	3.81	2.97	4.20	3.20	4.12
RMSE (Sv)	5.42		2.71		3.03		3.81	
Correlation	0.47		0.76		0.71		0.60	
Number of points	69		96		62		227	



Observation profile density



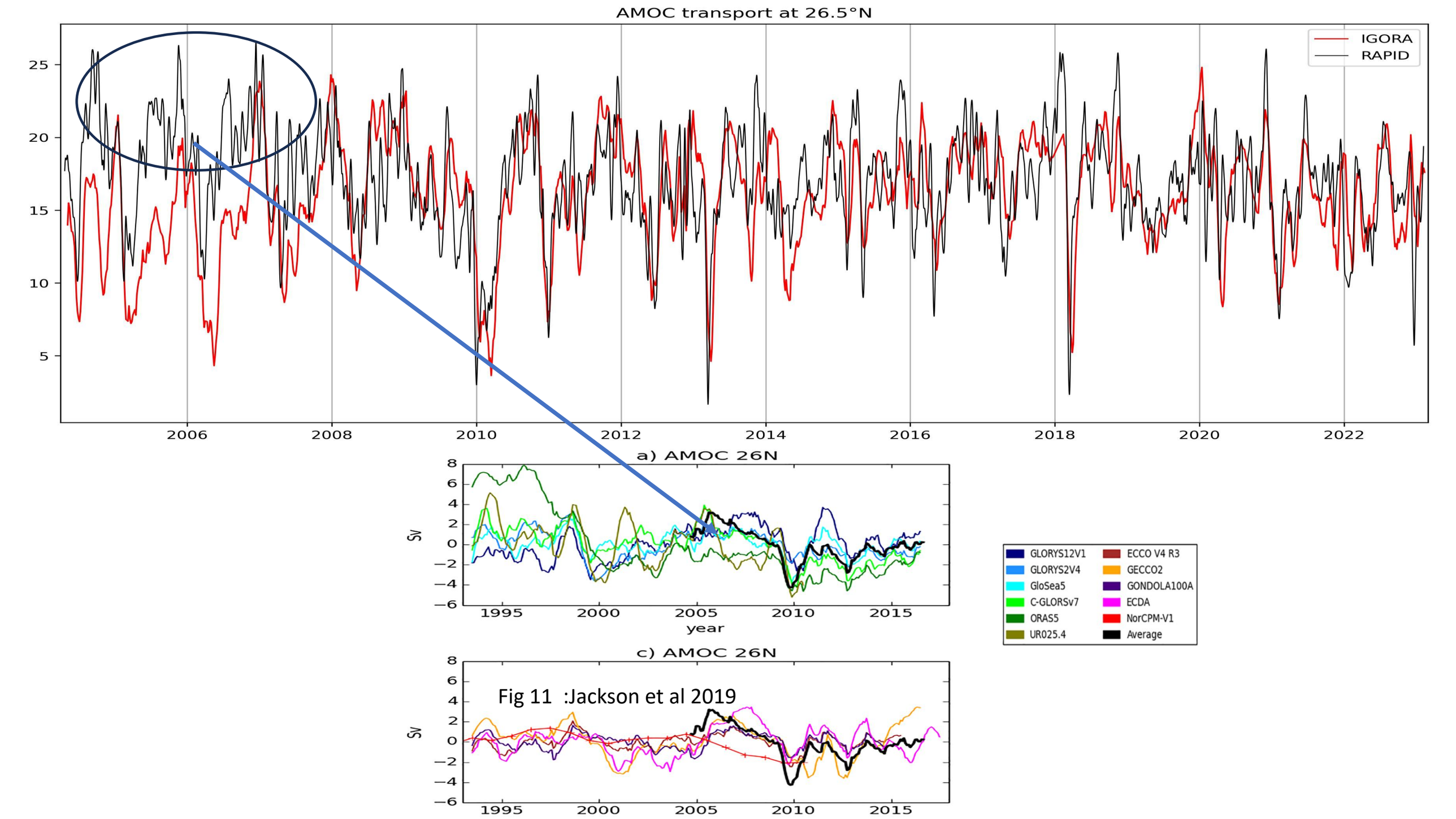
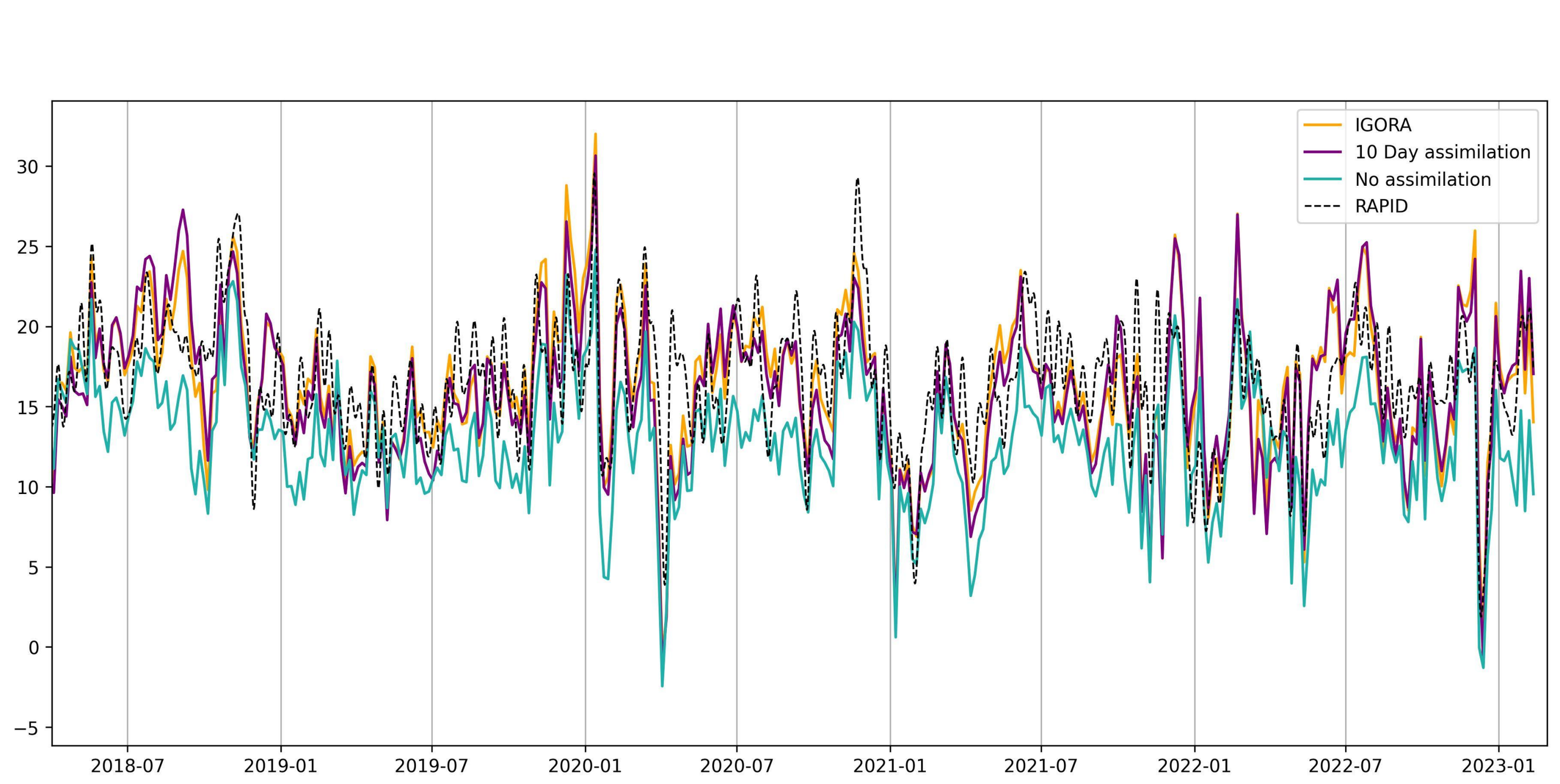
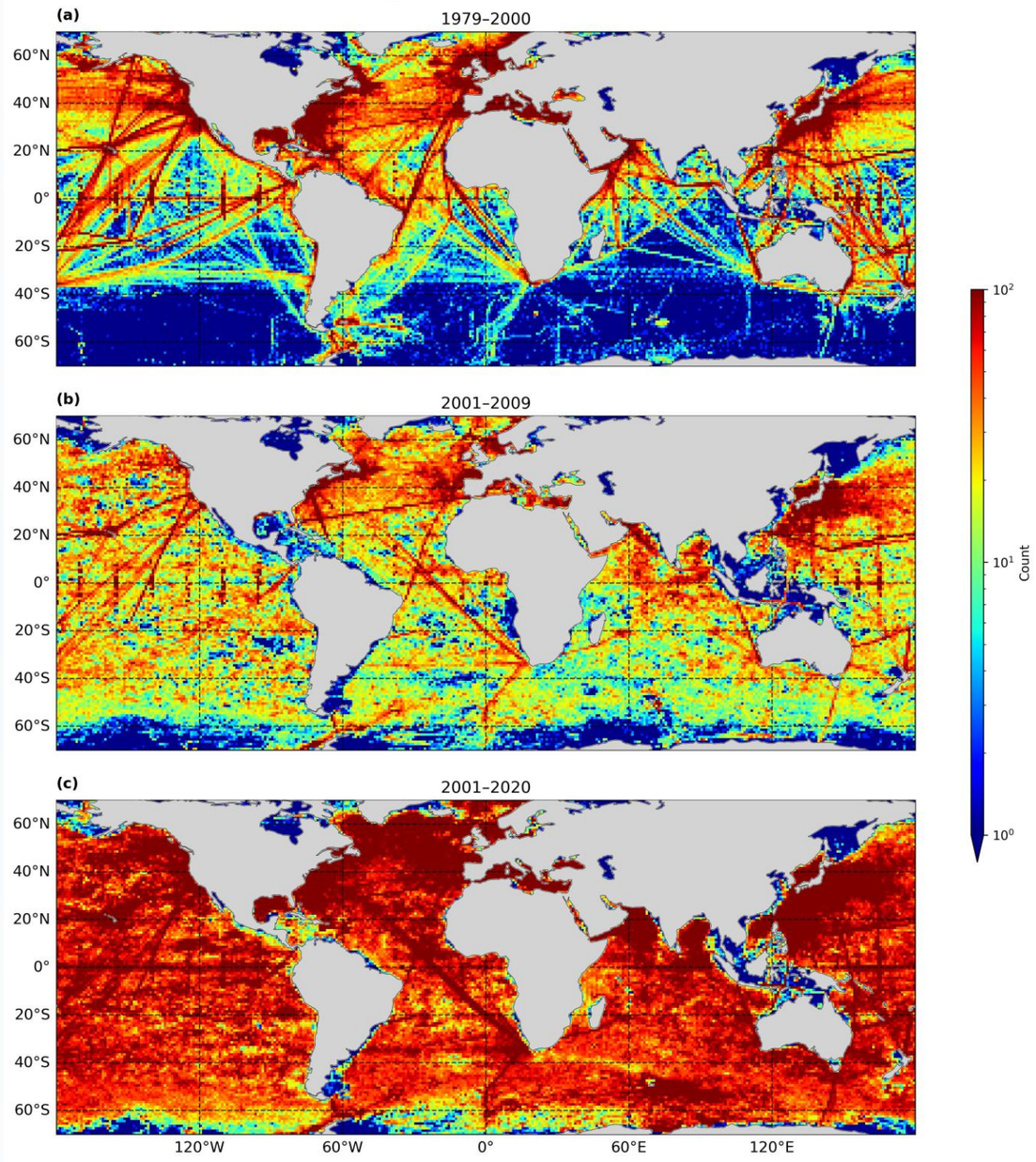


Fig 11 :Jackson et al 2019


IGORA
10 Day assimilation
No assimilation
RAPID
30
25
20
15
10
5
0
−5
2018-07
2019-01
2019-07
2020-01
2020-07
2021-01
2021-07
2022-01
2022-07
2023-01

Observation profile density

Temperature

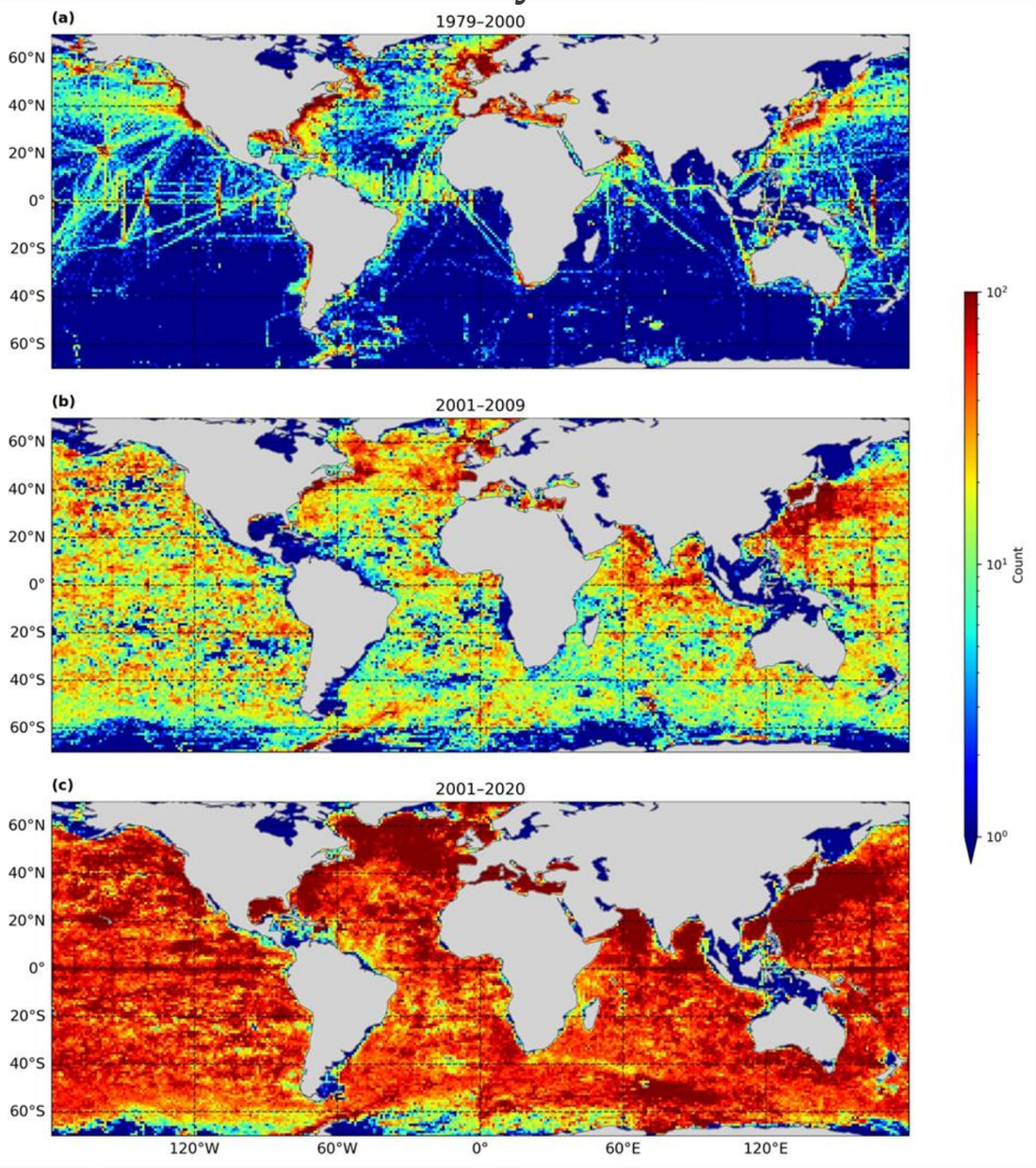


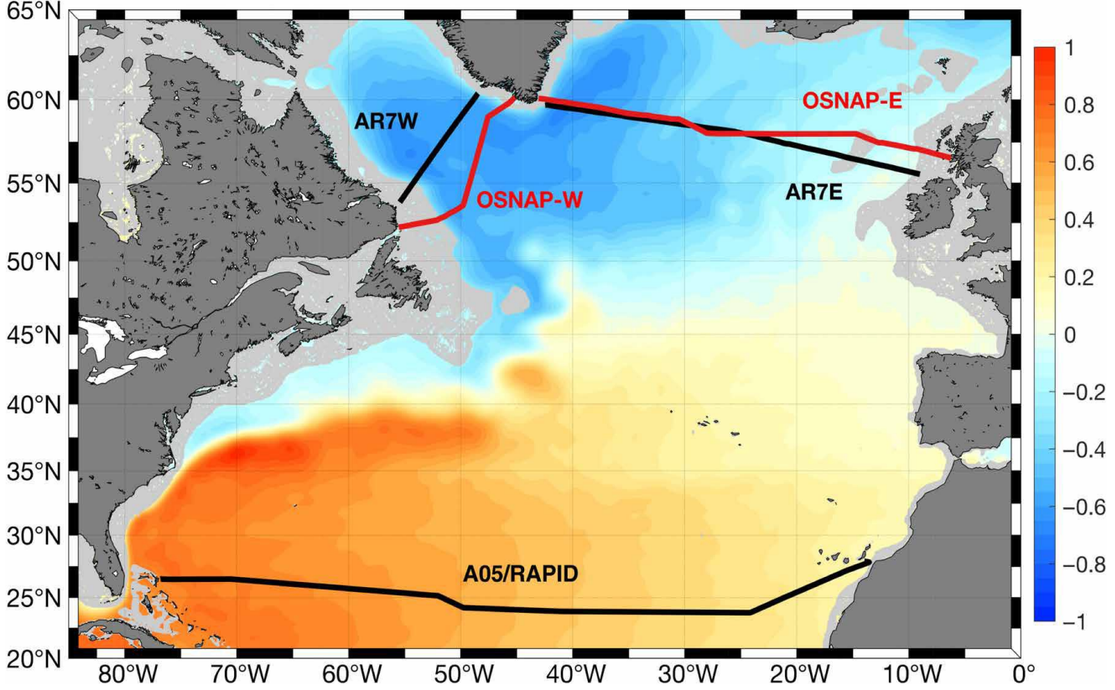
1979-2000

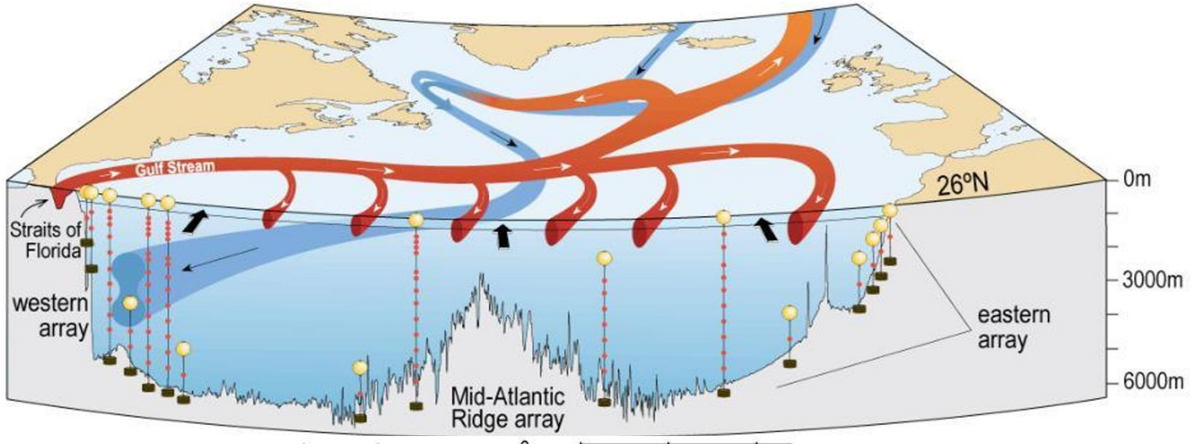
2001-2009

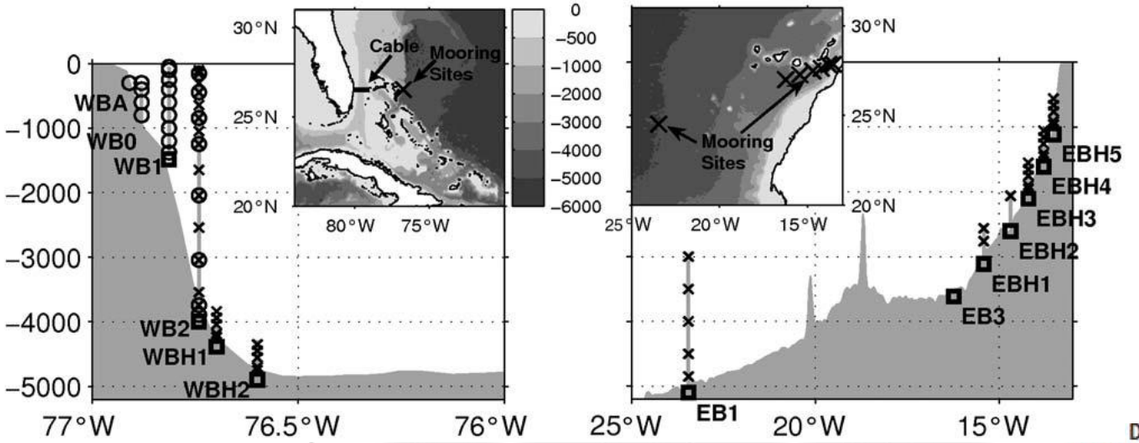
2001-2020

Salinity

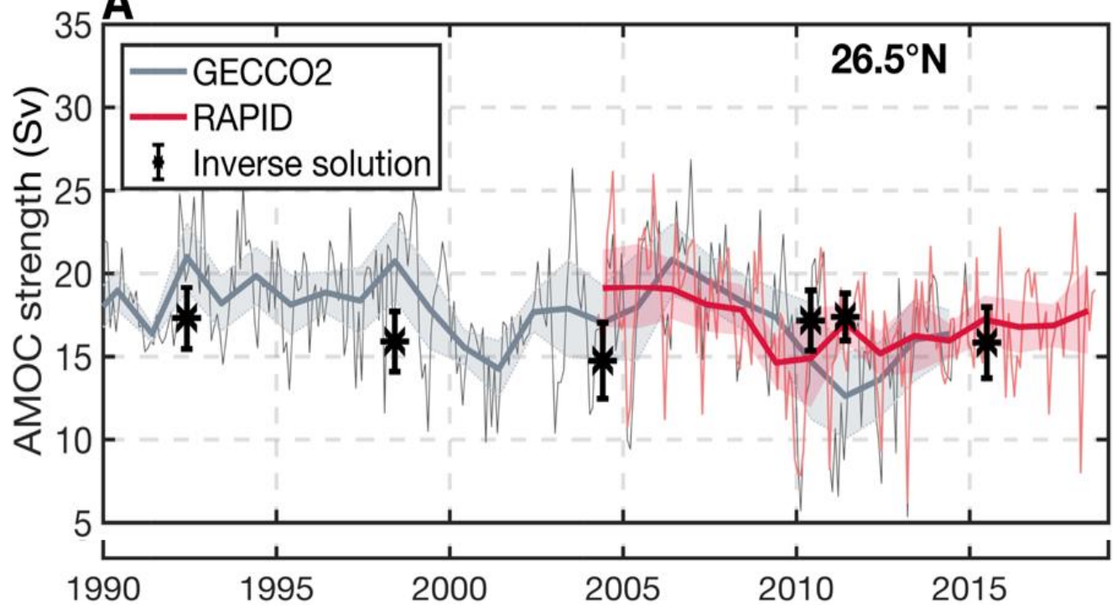


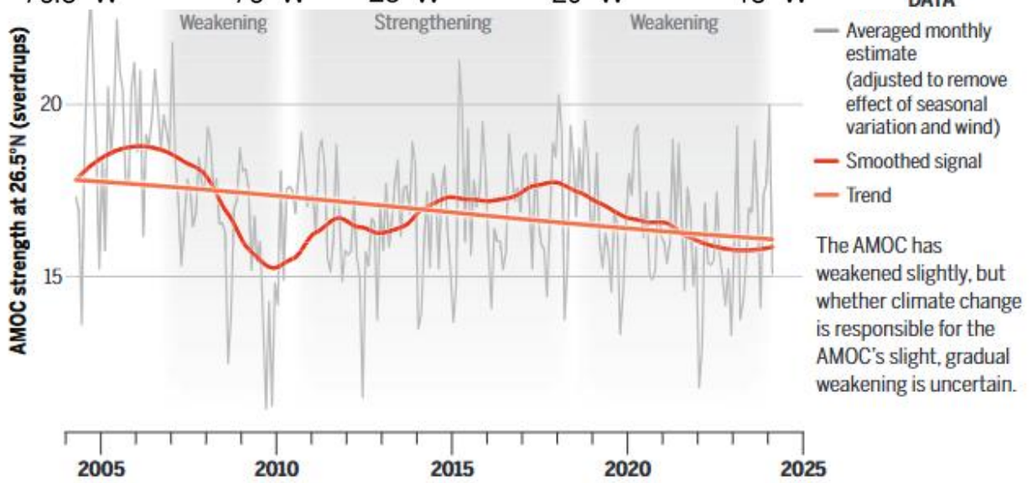






Fu et al 2020 Science Advances





How accurate does the AMOC transport observed values ?

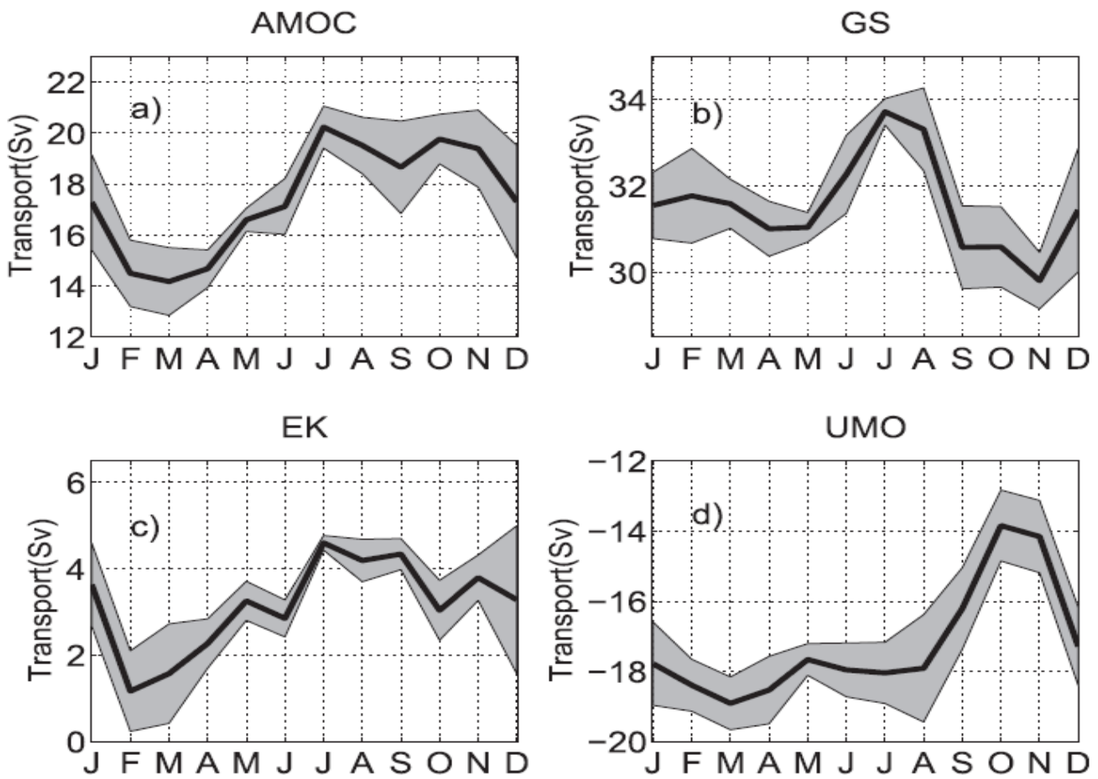


FIG. 3. Seasonal cycle (black solid lines) of (a) AMOC, (b) GS, (c) EK, and (d) UMO, as obtained from monthly averages of the 26.5°N time series between April 2004 and April 2011. The gray envelopes represent the std error of each month.

The MOC transports in the subtropical Atlantic at 26°N comprise three components:

- transport through the Florida Straits (Gulf Stream (GS)
- flow induced by the interaction between wind and the ocean surface (Ekman transport) in the top 100 m (EK)
- Geostrophic transport related to the east-west difference in sea water density between the American and African continents between Bahamas and Africa (UMO)

At **26.5°N**, the RAPID–MOCHA–WBTS has **three major sub-arrays**:

- **Western Boundary Array** — near the Bahamas/American margin
- **Mid-Atlantic Ridge (MAR) Array** — moorings on **both flanks of the Mid-Atlantic Ridge**
- **Eastern Boundary Array** — near the African margin

The current RAPID dataset describes observations from these three regions: Western Boundary (~76.9–69.4°W), Mid-Atlantic Ridge (~52.1–40.9°W), and Eastern Boundary (~24.2–12.2°W).

Does present RAPID array is enough to accurately measure the AMOC transport ?

Monitoring large-scale AMOC variability, the 26.5°N observing system is considered a scientifically robust and highly valuable system—**but individual components are not equally well observed.**

The RAPID array measures the boundary density structure, while combining it with Florida Current and wind-stress information to reconstruct the basin-integrated overturning.

However, there are several caveats:

- **Boundary arrays cannot perfectly resolve the interior ocean.**
- Mooring observations **have gaps and instrument uncertainties**.
- The Ekman component depends on the quality **of atmospheric wind products**.
- The AMOC has substantial **short-term variability**, including strong fluctuations on daily to interannual timescales.
- A 26.5°N array does **not directly measure the AMOC everywhere in the Atlantic or the entire global overturning circulation**.

- The **initial 2004 deployment had 19 moorings** across the three sub-arrays, **but 10 were the principal moorings** used to construct the boundary/MAR hydrographic profiles for the **geostrophic transport calculation**.
- The array evolved substantially. **Around 2010,** the trans-Atlantic RAPID array had **24 moorings**, together with bottom-pressure landers

Summary

Key Findings from IGORA AMOC Variability at 26.5°N

- **IGORA captures the major temporal variability of the observed AMOC**, with a reasonably good overall agreement with RAPID over 2004–2023 (**r = 0.60; RMSE = 3.81 Sv**).

- **The agreement improves substantially with time:** correlation increases from **0.47 (2004–2009)** to **0.76 (2010–2017)** and **0.71 (2018–2023)**, indicating improved representation of AMOC variability in the later periods.

- **IGORA systematically underestimates the mean AMOC strength**, with the bias decreasing from **−3.68 Sv (2004–2009)** to **−1.06 Sv (2010–2017)** and **−0.72 Sv (2018–2023)**. Over the full 2004–2023 period, the mean is **15.29 Sv in IGORA compared with 17.05 Sv in RAPID**.

- **Major AMOC fluctuations, including the pronounced weakening around 2009–2010, are captured by IGORA**, although the amplitude of some short-term extremes differs from RAPID.

- **The improved agreement during 2010–2023 is consistent with the increasing ocean-observational constraint**, particularly the much higher observation density evident in the temperature and salinity fields during the later period.

- **The vertical transport structure is reasonably reproduced**, with IGORA showing a similar upper-ocean maximum and depth-dependent decline to RAPID. The comparison with the **no-assimilation experiment**, particularly during 2018–2023, highlights the important role of **data assimilation in constraining the AMOC structure and variability**.



Thank you for your kind attention

Contact: rahman@incois.gov.in