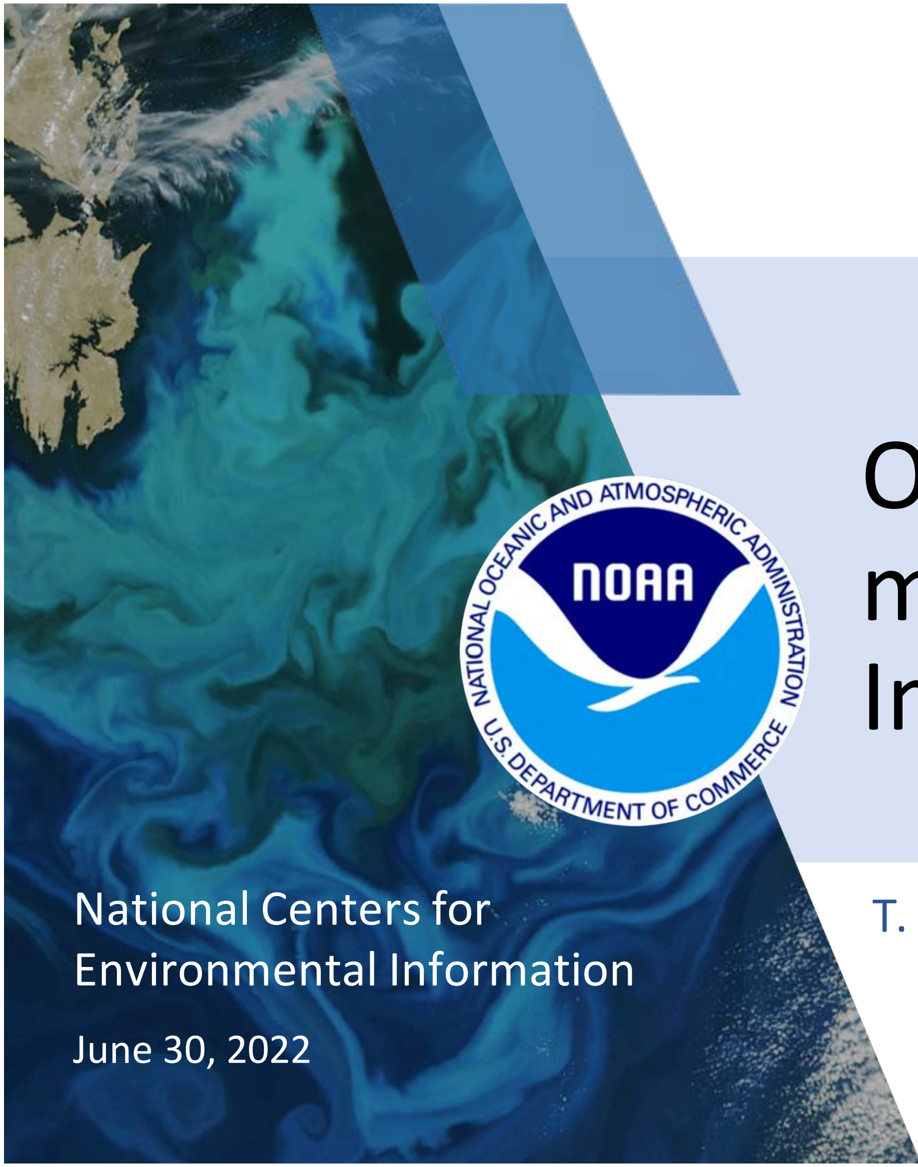


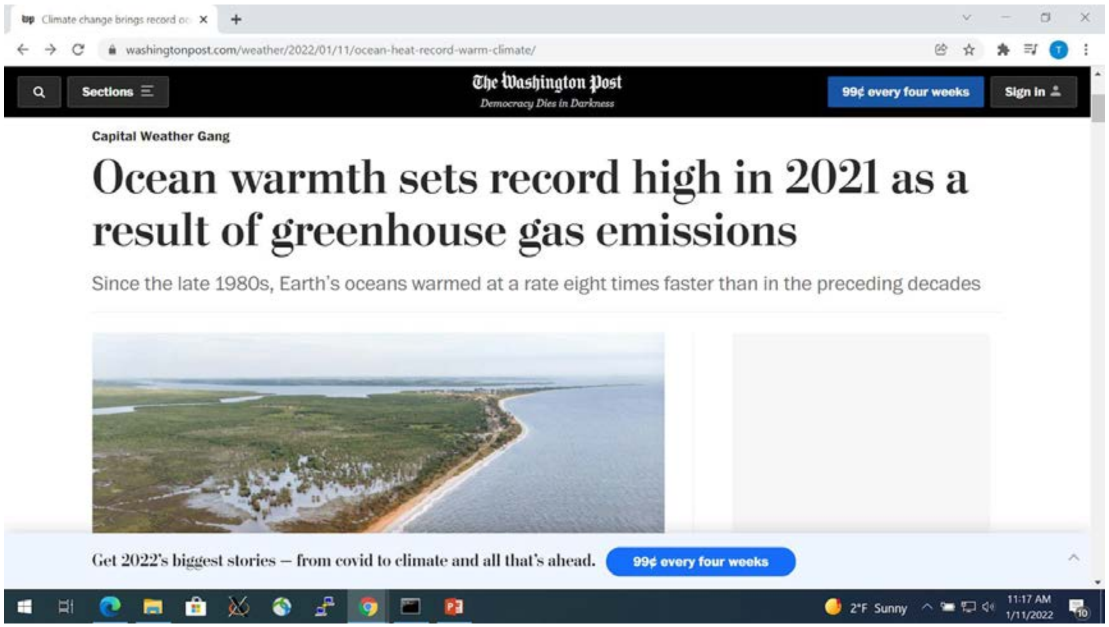
Ocean Heat Content as a measure of Earth's Energy Imbalance

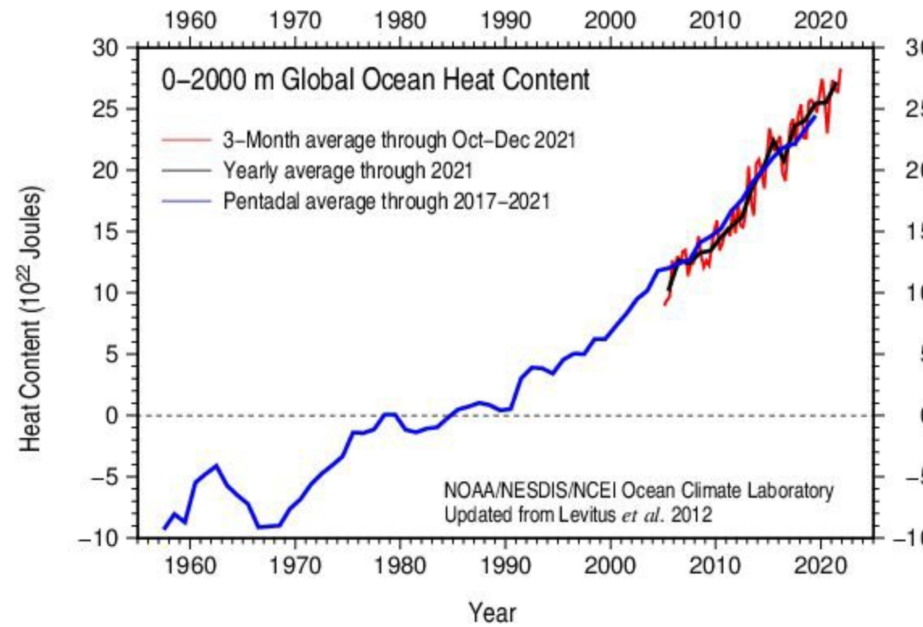
T. Boyer, R. Locarnini, A. Mishonov, J. Reagan, Z. Wang

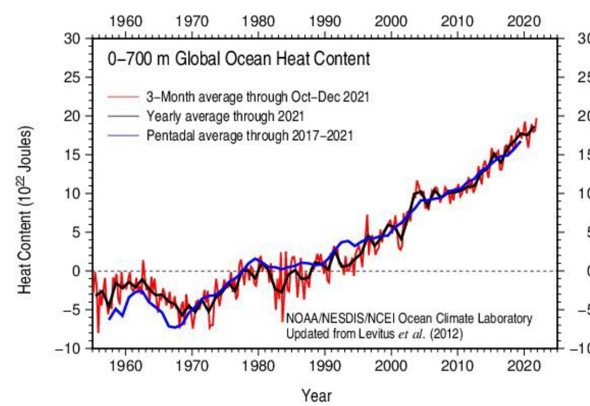
World Ocean Database team: Tim P. Boyer, Olga K. Baranova, Carla Coleman, Hernán E. García, Alexandra Grodsky, Ricardo A. Locarnini, Alexey V. Mishonov, Todd D. O’Brien, Christopher R. Paver, James R. Reagan, Dan Seidov, Igor V. Smolyar, Katharine W. Weathers, Z. Wang, M. Zweng

National Centers for Environmental Information

June 30, 2022



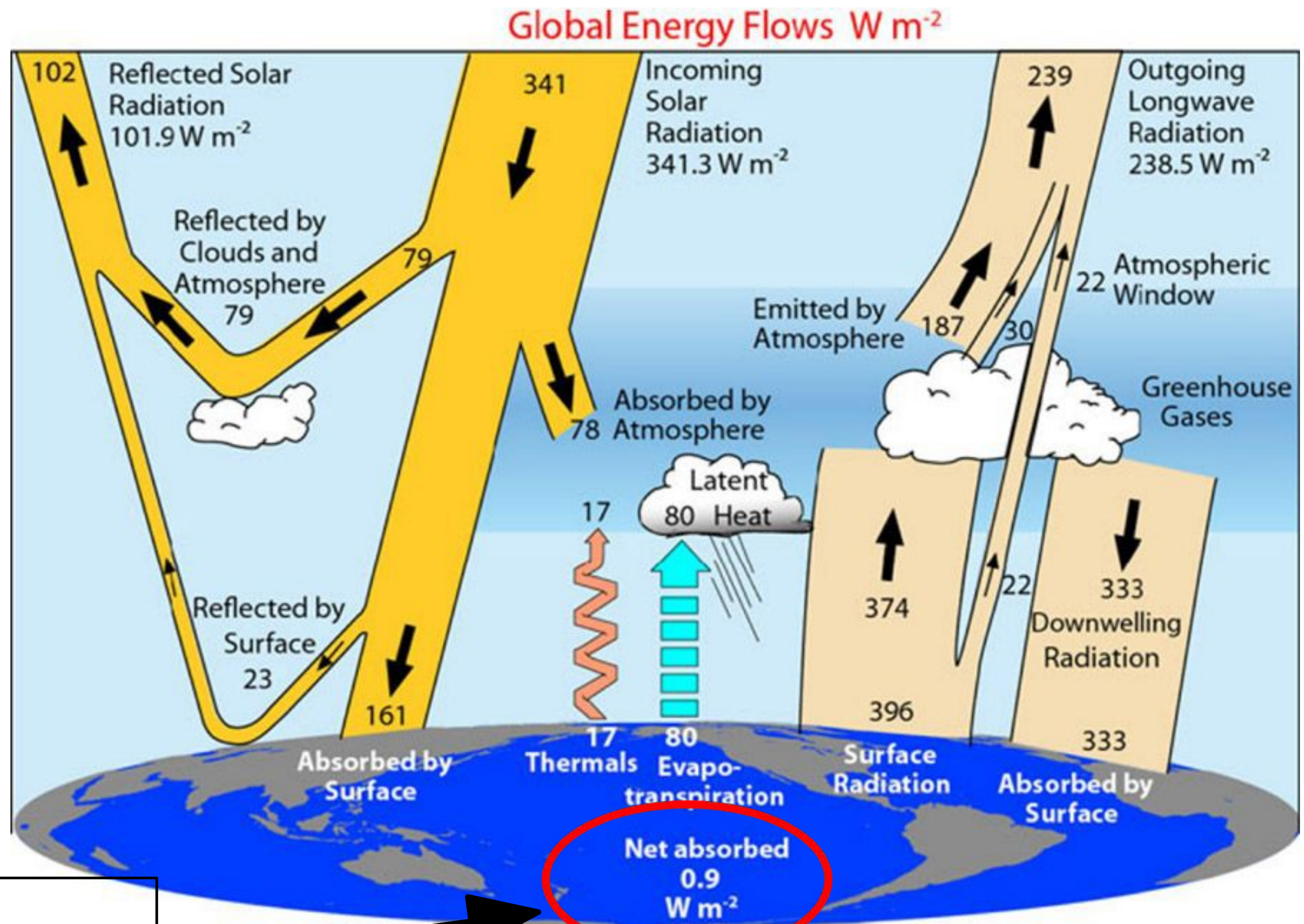




Another Record: Ocean Warming Continues through 2021 despite La Niña Conditions
Cheng et al. 2022

https://doi.org/10.1007/s00376-022-1461-3

Earth's Energy Imbalance: Incoming Solar Radiation (Yellow) > Outgoing Longwave Radiation (White)



IPCC AR6 (prelim):
1971-2018: 0.57 [0.43 to 0.72] W m^{-2}
2006-2018 0.79 [0.52 to 1.06] W m^{-2}

Kevin Trenberth, John Fasullo and Jeff Kiehl

https://scied.ucar.edu/image/radiation-budget-diagram-earth-atmosphere

> 90% of Earth's Energy Imbalance is Absorbed by the Global Ocean

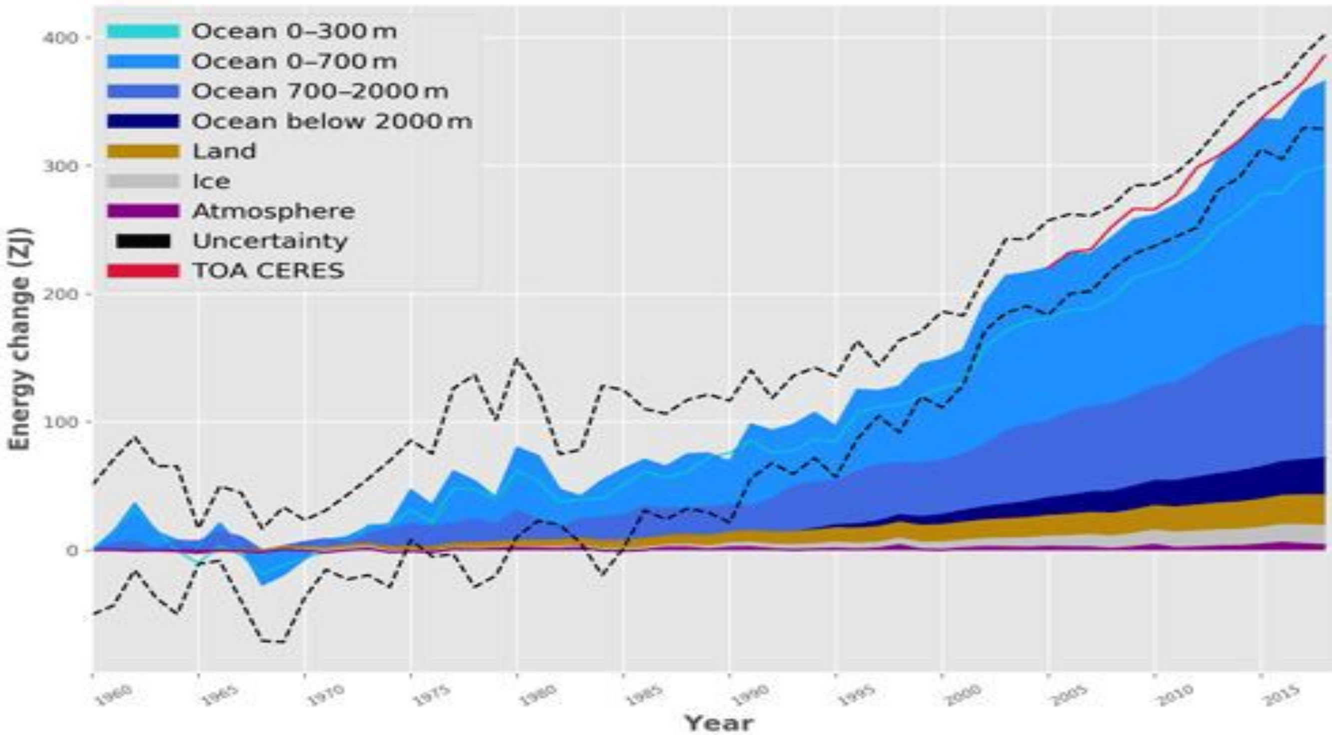
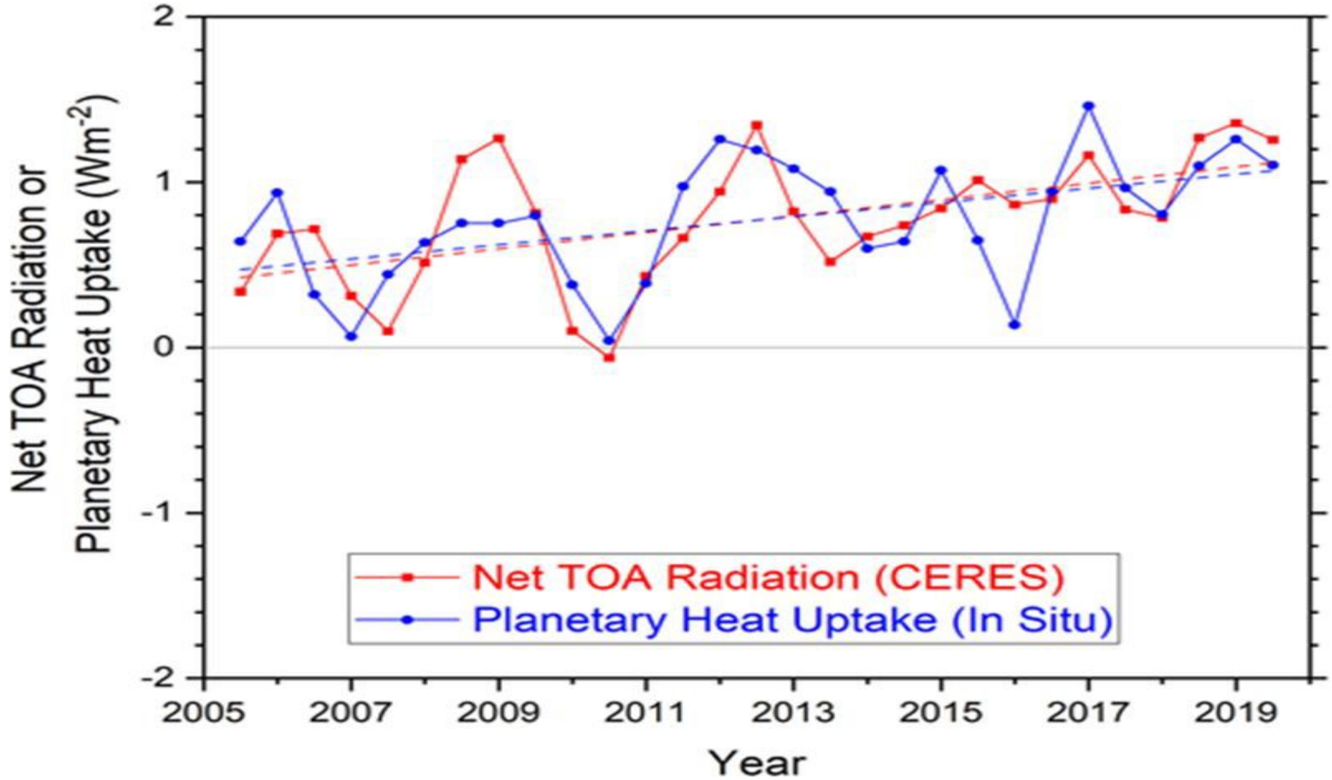
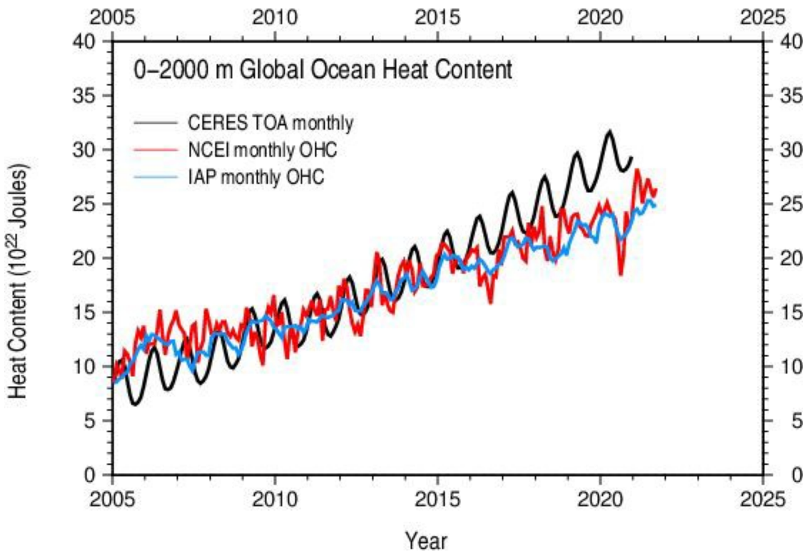


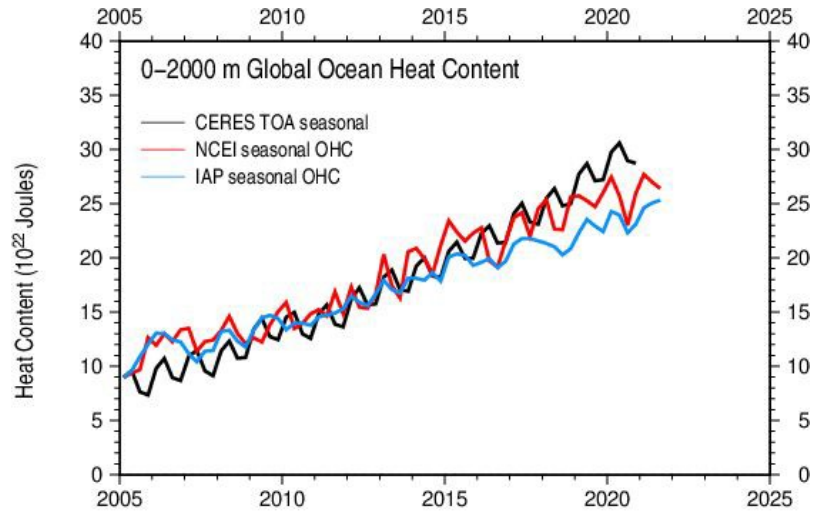
Figure 6. Earth heat inventory (energy accumulation) in ZJ (1 ZJ =10^{21} J) for the components of the Earth's climate system relative to 1960 and from 1960 to 2018

Von Schuckmann et al. (2020) https://doi.org/10.5194/essd-12-2013-2020, 2020.



The Clouds and the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) Top of the Atmosphere (TOA) net radiation flux is highly correlated with in situ measured planetary heat uptake Loeb et al. 2021: https://doi.org/10.1029/2021GL093047



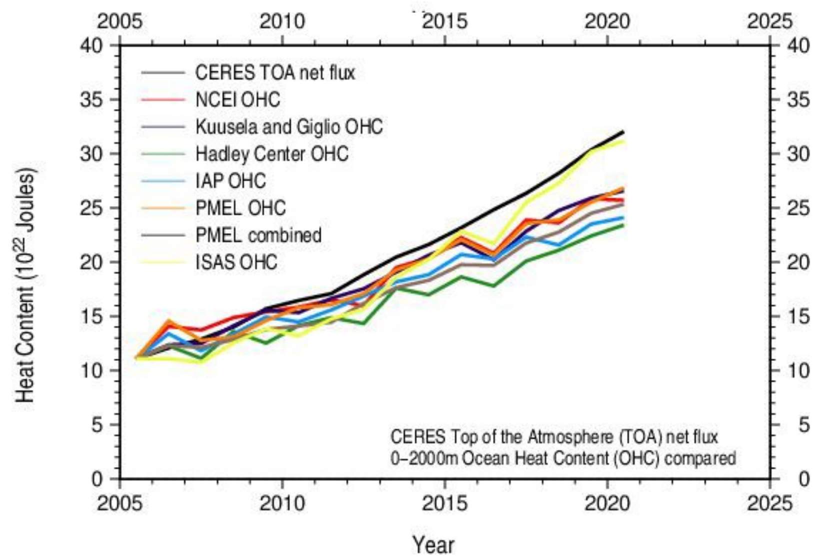


Ocean Heat Content compared to CERES Top of the Atmosphere net flux at a) monthly, b) seasonal and c) annual

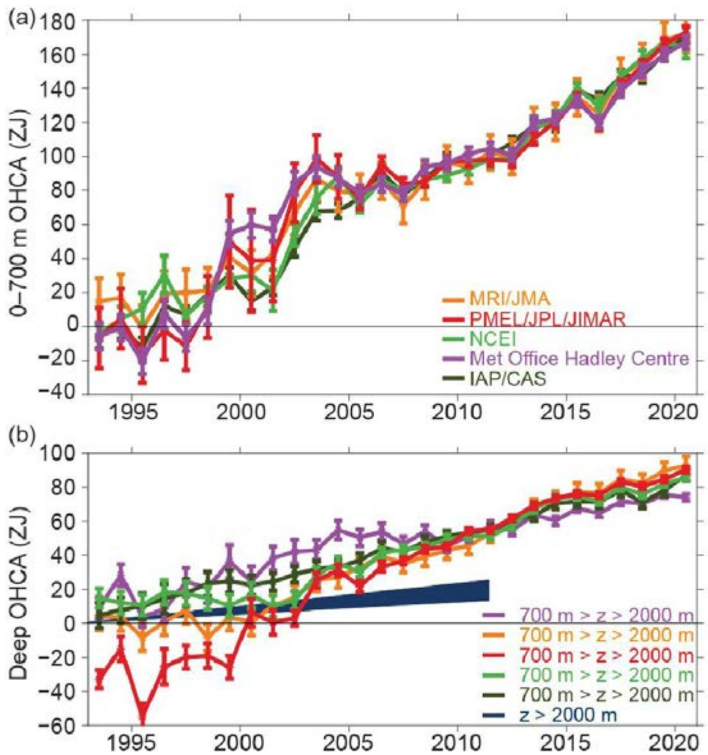
All time series adjusted to same initial value

Uncertainty of ocean heat content on the order of 0.5 – 1.0 x 10^{22} J

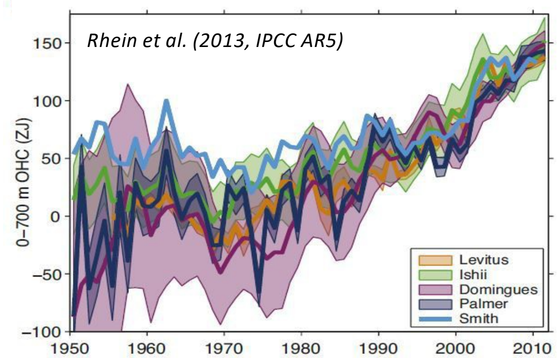
CERES, IAP, and Kuusela and Giglio(KD) calculated at monthly time period, seasonal and annual are averages. KD to 1850 m, not 2000m



Uncertainties in global ocean heat content time series



Johnson et al. (2021, BAMS State of the Climate 2019)

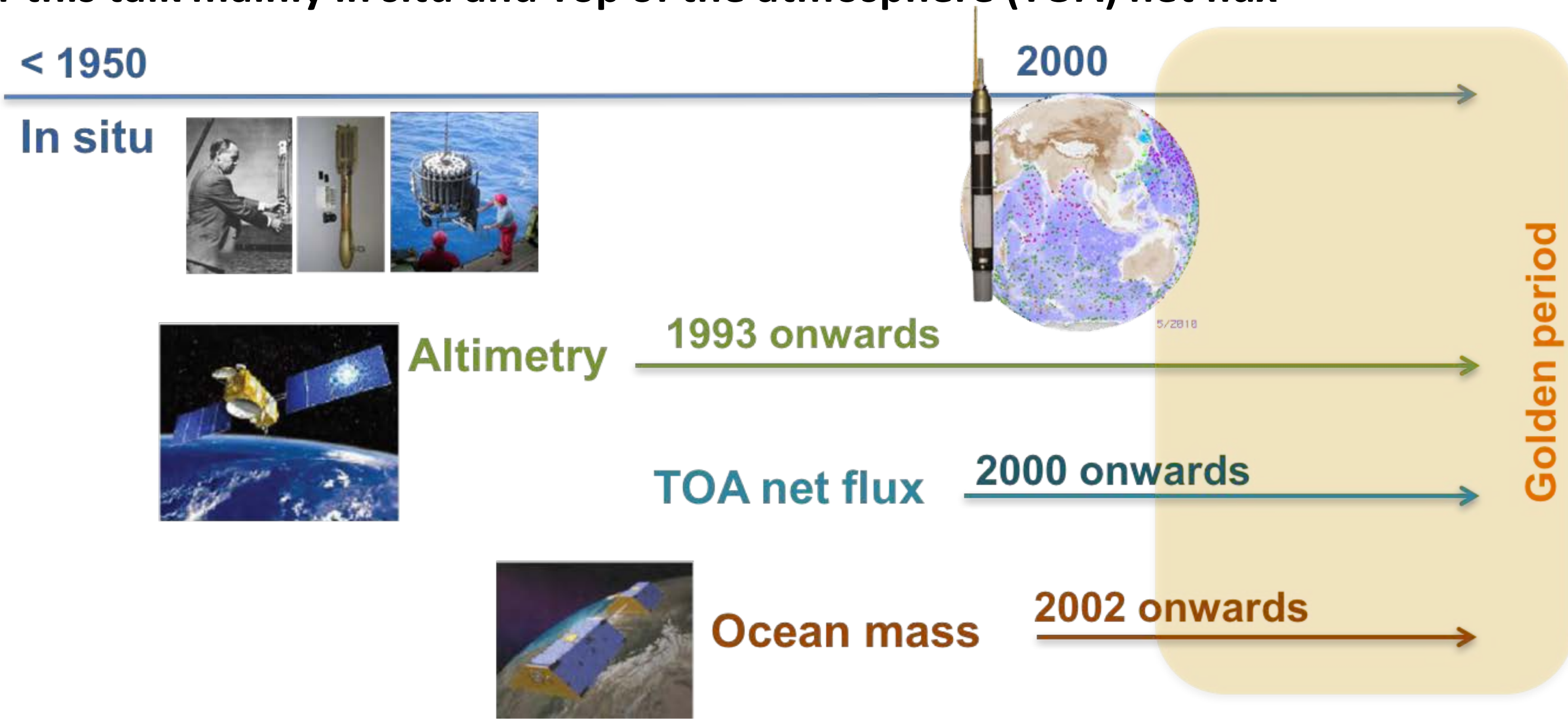


Argo floats 2006-2020 near global coverage <2000 m

Before Argo era:

uncertainties are larger
as we go further back in time
(historical record)

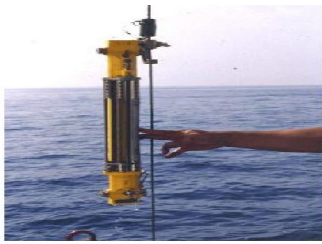
GEWEX EEI will look at different time spans, observing systems, but initially focus on the ‘golden period’ of global Argo coverage (roughly 2005-present) – for this talk mainly in situ and Top of the atmosphere (TOA) net flux



Observing Systems for Earth’s Energy Imbalance (EEI) and Ocean Heat Content (OHC)

Meyssignac et al. (2019) **https://doi.org/10.3389/fmars.2019.00432**

World Ocean Database: World’s largest publicly available oceanographic profile database



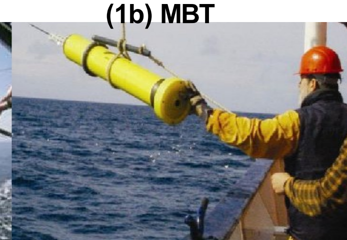
(1a) Bottle

(1b) MBT

(1c) XBT

(1d) CTD

(1e) Towed CTD



(1f) Profiling floats (Argo)

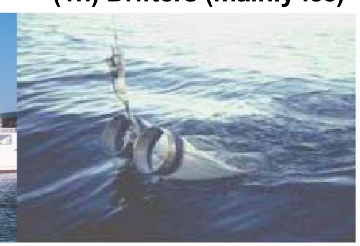
(1g) Moored Buoys

(1h) Drifters (mainly ice)

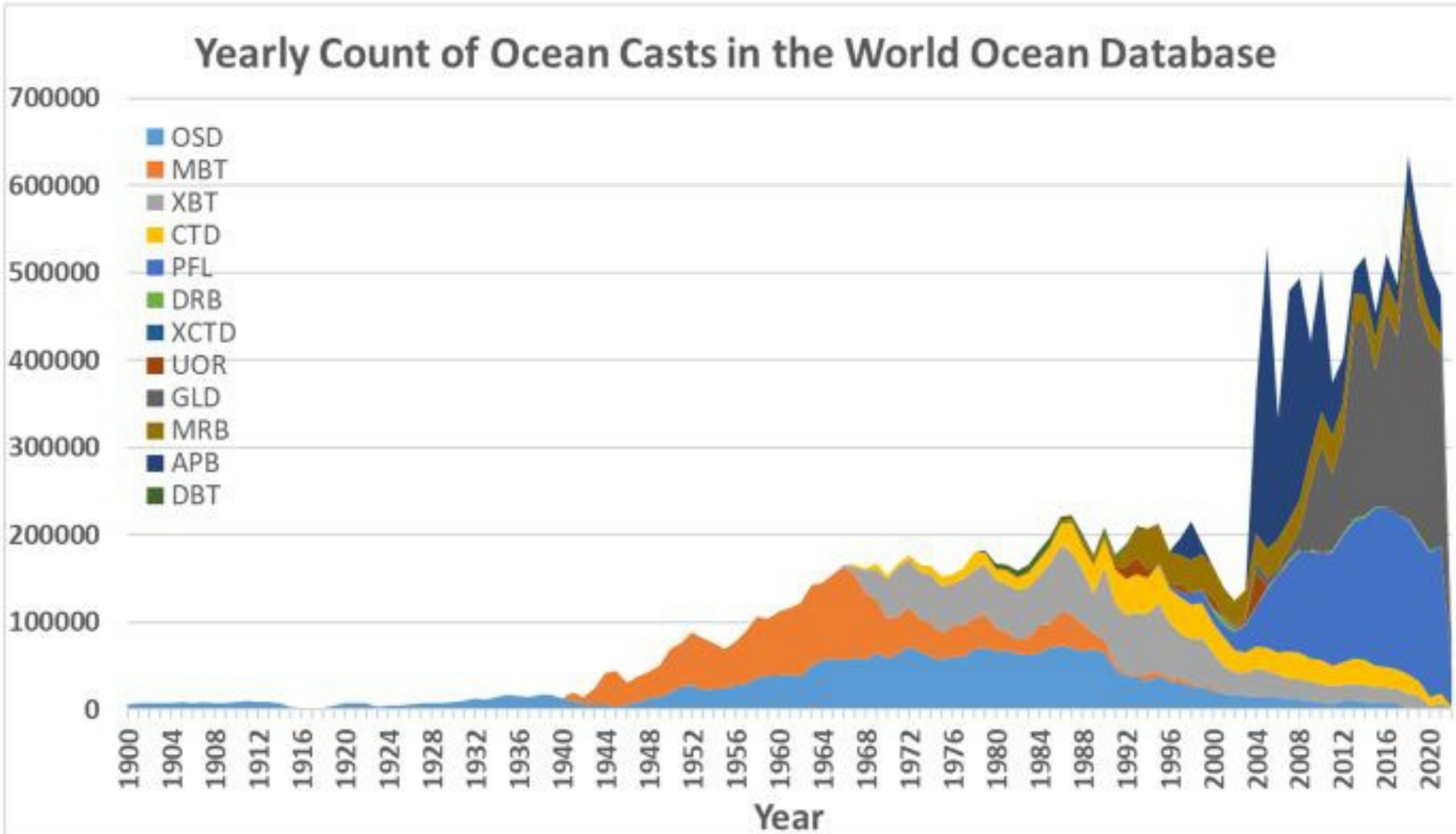
(1i) Instrumented pinniped

(1j) Gliders

(1k) surface-only

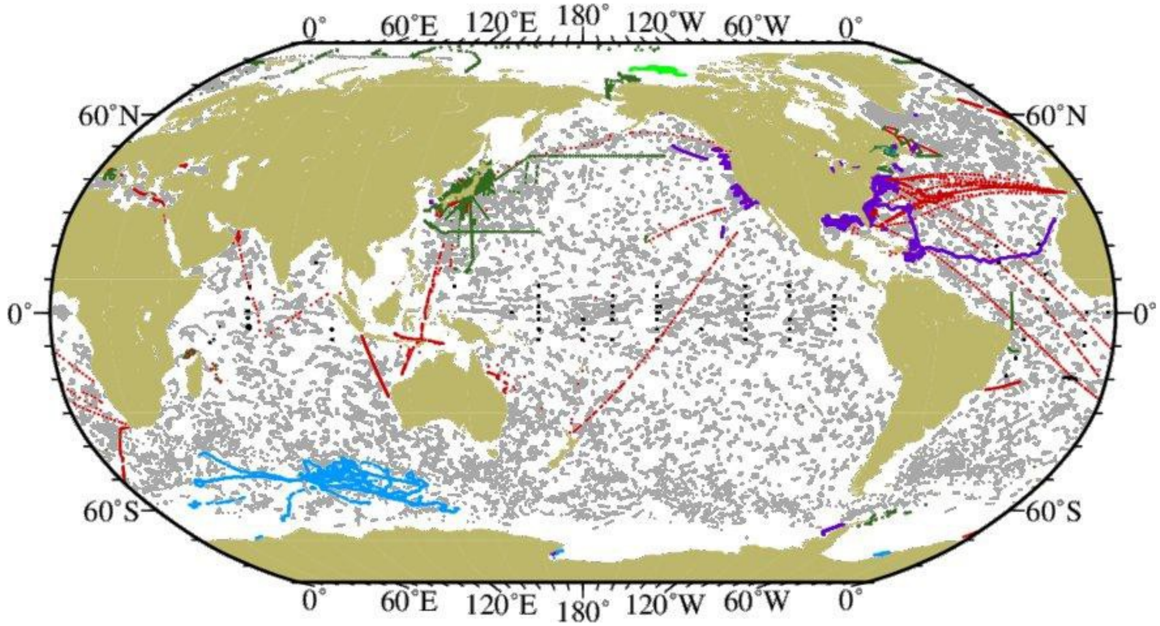


(1l) Plankton tows



Number of subsurface ocean temperature profiles yearly in the World Ocean Database.

World Ocean Database Quarterly Updates: 490,674 casts added by current update bringing total to 17,698,513



- 43,219 Argo cycles
- 2,816 bottle/CTD casts
- 2,756 XBT drops
- 428,256 glider cycles
- 5,066 tropical moored buoy daily means
- 8,019 pinniped dives
- 542 ice-tethered profiler cycles

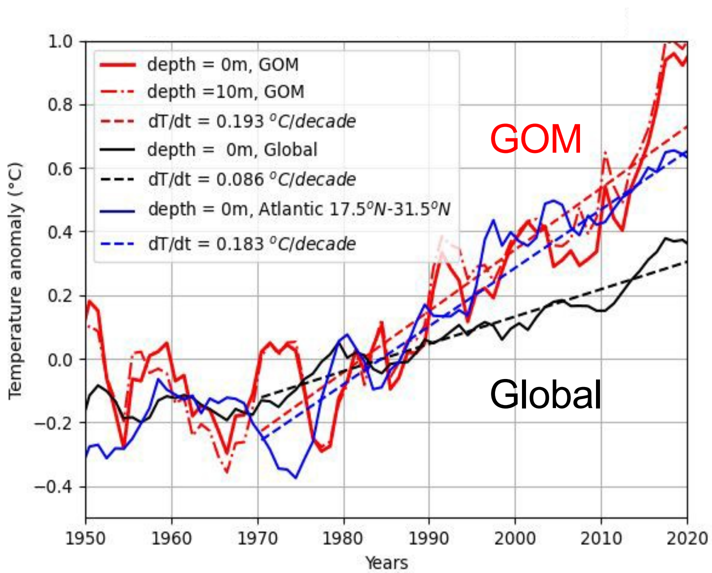
Contributions from: PMEL tropical moored buoys, Global Temperature and Salinity Profile Program (GTSPP), CCHDO, Argo program, Ice Tethered Profiler Program (WHOI), CLIVAR, Carbon Hydrographic Office (CCHDO), University of Washington Applied Physics Lab, IOOS

Summary

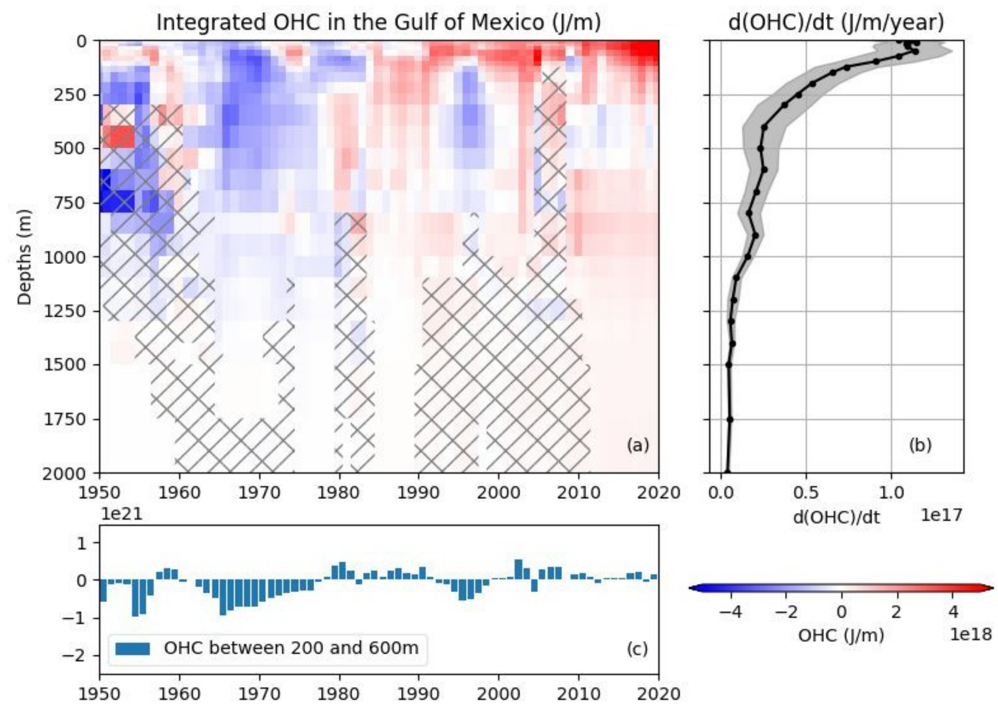
- In 2021, Ocean Heat Content reached the highest level on record, 16 ± 10 ZJ over 2020 (~0.9 Wm^{-2})
- Ocean Heat Content a steadier measure of Earth’s Energy Imbalance than Global Mean Surface Temperature (GMST, 4^{th} highest in 2021)
- Calculation of ocean heat content is with lowest uncertainty is from in situ ocean profile measurements
- Argo is the main global observing system – ushered in a global ‘Golden Age’ of ocean observation
- Important questions of uncertainty and optimal time period for calculation of ocean heat remain
- Historical to recent estimates of ocean heat content are critical for understanding the time evolution (past/present/future) of our climate system
- Continued work on aggregation and quality control of historical and recent data in the World Ocean Database is critical to achieve a better understanding of historical to recent ocean heat content

Warming trend in the GOM

Subsurface Warming



- SST increased more than 1.0 ℃ from 1970 to 2020
- The warming trend (0.193 ˚C decade^{-1}) in the GOM is twice that for the global ocean
- Comparable to the warming trend based on satellite SST



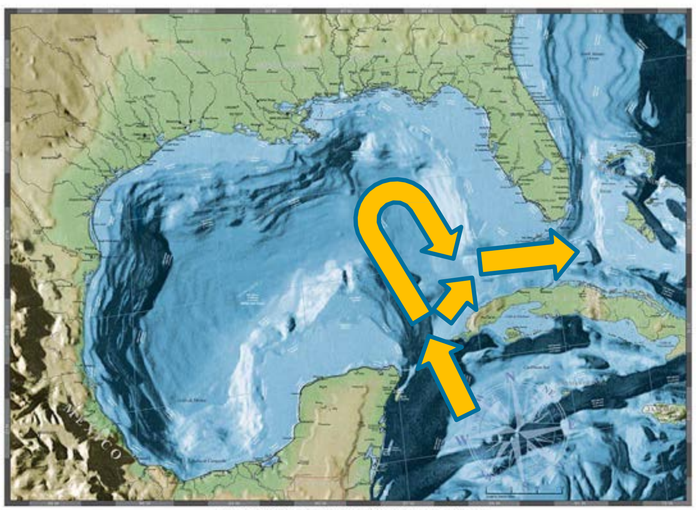
Overall GOM warming = 0.76±0.18 W m^{-2} in the upper 2000m
Global ocean warming rate = 0.36-0.42 W m^{-2} (Johnson and Lyman, 2020)

Ocean Heat Budget in the GOM

Heat Storage Rate | Net Surface Heat Flux | Advective heat flux

$$Q_t = Q_{net} + Q_v$$

Assume geothermal heat flux is ignorable.



GULF OF MEXICO SEAFLOOR

Heat Storage Rate:

0-2000m: $Q_t = \frac{\partial OHC}{\partial t}$ = 1.21±0.28 TW (1 TW = 10^{12} W)

below 2000m: **~0.17 TW** (Ochoa et al. 2021)

Total Qt: 1.38±0.28 TW in the GOM

Advective Heat Flux:

$$Q_v = \rho_w c_{pw} V \delta T$$

δT = 0.36±0.02 °C

V = 27.6±4.0 Sv is the Loop Current transport.

Net advective heat flux
Q_v = 40.7±6.3 TW

Summary

- GOM warming at a rate approximately twice that for the global ocean at both surface and subsurface.
- Warming in the GOM can be roughly explained by the balance between the advective heat flux and the annual net surface heat flux from ECCO.
- Answered the debate about net surface heat flux question (GOM should lose heat to the atmosphere annually at ~39 TW). Source of heat in the GOM is advection, not atmosphere
- **Wang, Z.,** T. Boyer, J. Reagan, P. Hogan, 2022, Upper Oceanic Warming in the Gulf of Mexico between 1950 and 2020, Journal of Climate, under review

- **U. N. Decade of the Ocean emphasis on connecting global variable observation to regional NOAA is well positioned to do this with highly developed coastal/regional observing systems**
- **Regional monitoring of essential ocean variables more difficult than global – more factors than air-sea flux, more highly variable areas**