The Ocean’s Hidden Heat

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Tim Boyer, National Centers for Environmental Information, NOAA
Robert Tyler, NASA Goddard Space Flight Center
Catherine Walker, NASA Jet Propulsion Laboratory
Stephanie Schollaert Uz, NASA Goddard Space Flight Center
Ocean Heat Content
AGU Press Briefing

Tim Boyer

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Figure 2.11: Global mean energy budget under present-day climate conditions. Numbers state magnitudes of the individual energy fluxes in W m$^{-2}$, adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the energy fluxes cover the range of values in line with observational constraints. (Adapted from Wild et al., 2013.)
Figure 2.11: Global mean energy budget under present-day climate conditions. Numbers state magnitudes of the individual energy fluxes in W m$^{-2}$, adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the energy fluxes cover the range of values in line with observational constraints. (Adapted from Wild et al., 2013.)
> 90% of the imbalance in the Earth’s heat budget goes into the ocean.

Box 3.1, Figure 1 | Plot of energy accumulation in ZJ (1 ZJ = 10^21 J) within distinct components of the Earth’s climate system relative to 1971 and from 1971 to 2010 unless otherwise indicated. See text for data sources. Ocean warming (heat content change) dominates, with the upper ocean (light blue, above 700 m) contributing more than the mid-depth and deep ocean (dark blue, below 700 m; including below 2000 m estimates starting from 1992). Ice melt (light grey; for glaciers and ice caps, Greenland and Antarctic ice sheet estimates starting from 1992, and Arctic sea ice estimate from 1979 to 2008); continental (land) warming (orange); and atmospheric warming (purple; estimate starting from 1979) make smaller contributions. Uncertainty in the ocean estimate also dominates the total uncertainty (dot-dashed lines about the error from all five components at 90% confidence intervals).

Ocean Heat Content has been rising 1955-present

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But large uncertainty between calculation methods from in situ data

Due to incomplete ocean coverage in situ measurements 10m depth year 1989

Due to incomplete ocean coverage in situ measurements 10m depth year 2015

Temperature change from long-term mean year 2015

Even into the Argo era (2005-present) there are data gaps leading to uncertainty in in situ estimates of ocean heat content.
Magnetic remote sensing of ocean heat content

Robert H. Tyler\textsuperscript{1,2} and Terence J. Sabaka\textsuperscript{1}

\textsuperscript{1}NASA Goddard Space Flight Center, Greenbelt, MD

\textsuperscript{2}Department of Astronomy, University of Maryland at College Park

Contact: robert.h.tyler@nasa.gov
The phenomenon exploited:
Magnetic fluctuations induced by ocean tides
Surface displacement of semi-diurnal (M2) ocean tide —> 

Magnetic fluctuations expected from theory (i.e. radial component at surface from numerical model) —> 

Magnetic fluctuations extracted from observations —>
By monitoring these ocean-tidal magnetic fluctuations may we infer any ocean parameters?

Yes. These magnetic fluctuations depend on the electrical conductance of the ocean. We can attempt to numerically invert the magnetic observations to gain ocean conductance.
If we can infer ocean conductance from remote magnetic observations...so what?

Ocean measurements show a strong linear relationship between conductance and depth-integrated ocean temperature (heat content) —>

(i.e., monitoring conductance can amount to monitoring heat content)
Where are we in developing the proximate goal of inferring conductance from remote magnetic observations?

We have demonstrated an important proof-in-concept (our inversion method recovers highly accurate maps of conductance from the *theoretically generated* tidal magnetic fields).

Conductance inverted from the *observed* magnetic fields is, however, currently limited in accuracy by noise in the observations and/or imperfect modeling. But, we are early in our efforts to improve the methodology and the three ESA-Swarm satellites are currently measuring the Earth’s magnetic field in unprecedented resolution.
Catherine Walker

NASA Jet Propulsion Laboratory
Measuring the Southern Ocean

International Argo profiling float program: since 2000

3739 Floats
6-Dec-2016

MEOP: CTD-tagged seals since 2005

Palmer Station Long Term Ecological Research program (PAL LTER): annual CTD grid since 1993
Ocean heat around Antarctica

Pritchard et al. (2012), Nature 484, 502-505

World Ocean Circulation Experiment Southern Ocean Atlas:
Estimated average sea-floor potential temperatures (°C)
Antarctica’s floating ice

West Antarctic Peninsula: Seal-tagged CTD measurements 2005-2011@300 m depth

Marguerite Bay > 1.5°C
Continental shelf infiltration?

Rising temperatures on the Peninsula since 1993

- Depth [m]
- Temperature [°C]

Bathymetry [m]
-1200
-800
-600
-400
-200
0

Rising temperatures on the Peninsula since 1993

2014: 2003
2013: 2002
2012: 2001
2011: 2000
2010: 1999
2009: 1998
2008: 1997
2007: 1996
2006: 1995
2005: 1994
2004: 1993

0 5 10 km

Mount Balfour
Forster Ice Piedmont
Hariot Glacier
Prospect Glacier

0 50 100 km

Temperature [°C]

Depth [m]
Flow in & around Antarctica

Gardner et al. (2016): Velocities

Nilsson et al. (2016): elev. change

Fretwell et al. (2013): BEDMAP2
Stephanie Schollaert Uz

NASA Goddard Space Flight Center
(Global Science & Technology Inc.)
The impact of warming and circulation changes upon microscopic life in the ocean

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The impact of warming and circulation changes upon microscopic life in the ocean

Physical differences drive biological differences by vertical motion that brings nutrients from depth to the surface.
Basin-wide chlorophyll reconstructed 1958-2008

CHL averaged 5°N-5°S
Basin-wide chlorophyll reconstructed 1958-2008

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East edge of warm pool:
~ 0.1 mg m^{-3} CHL contour
Basin-wide chlorophyll reconstructed 1958-2008

CHL averaged 5°N-5°S

East edge of warm pool:
~ 0.1 mg m⁻³ CHL contour

← El Niño

→ La Niña
Reconstruction highlights interannual differences

- weakened easterly trade winds
- less upwelling, biological productivity
- intensified easterly trade winds
- more upwelling, biological productivity
Reconstruction highlights differences in El Niño patterns

**East Pacific El Niño**

Nutrient layer deepens across basin, suppressed nutrient supply to surface

**Central Pacific El Niño**

Nutrient layer deepens locally, biology most depressed west of 180° (not basin-wide)
Questions?

reconstructed chlorophyll using correlation to proxies (temperature and sea level)
END

(FURTHER SLIDES ARE BACKUP)
Argo float measures temperature and salinity profile from 2000m up to surface every 10 days.