The Ocean's Hidden Heat

December 12, 2016

Tim Boyer, National Centers for Environmental Information, NOAA

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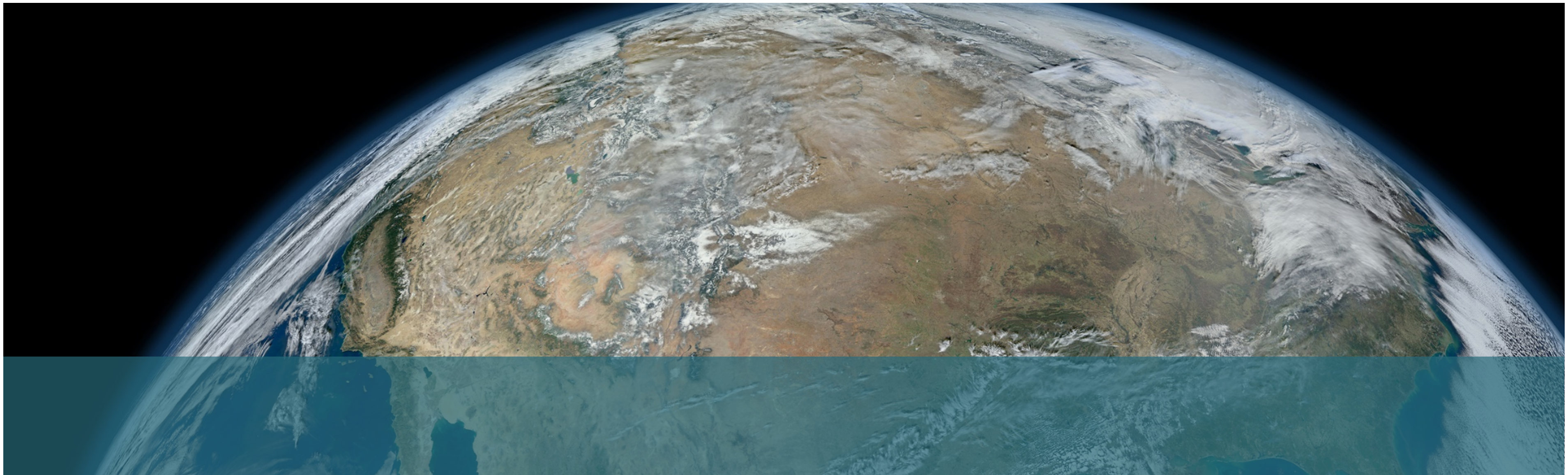

Ocean Heat Content
AGU Press Briefing

Tim Boyer

December 2016

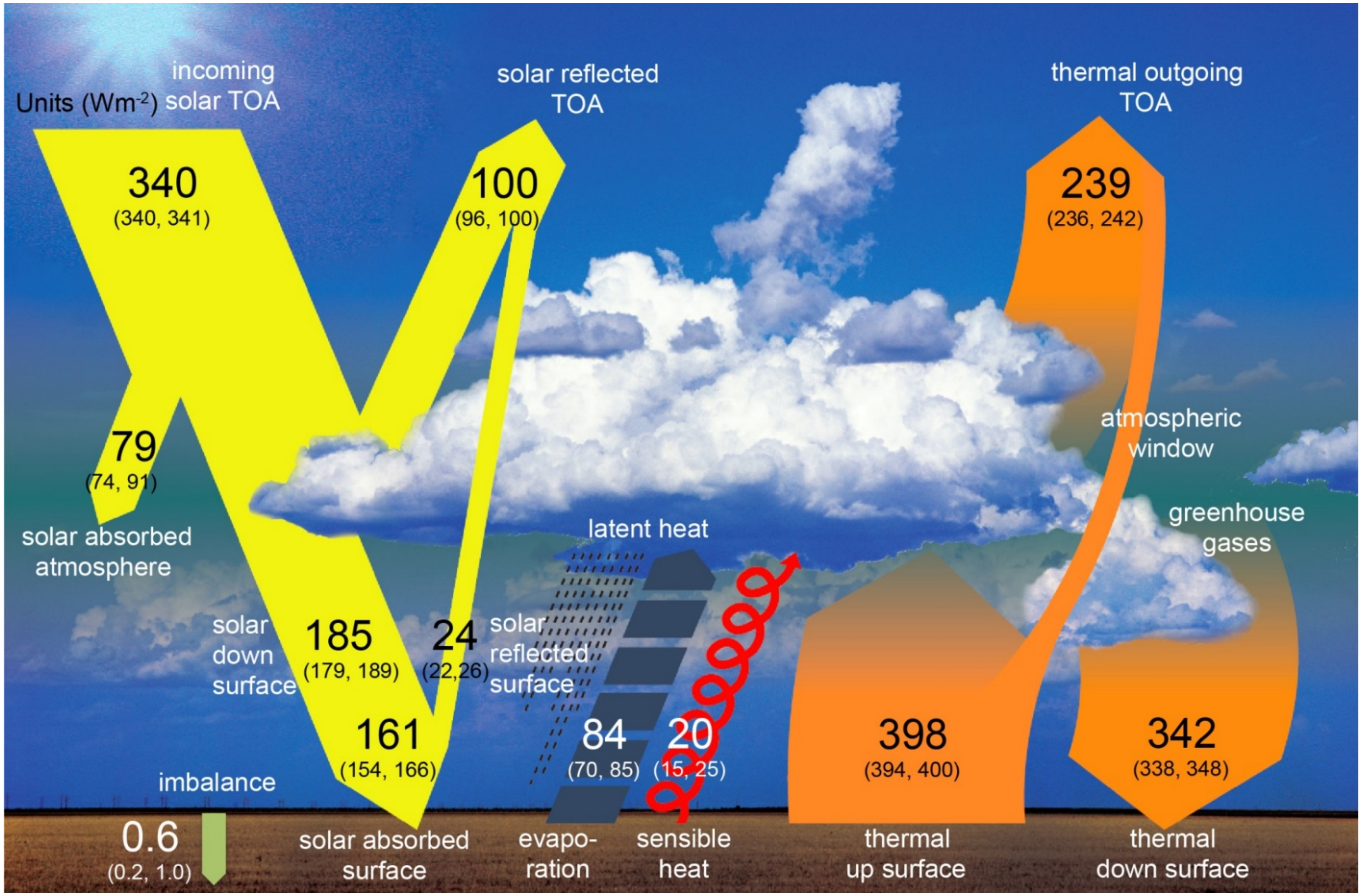

Figure 2.11: | Global mean energy budget under present-day climate conditions. Numbers state magnitudes of the individual energy fluxes in W m–2, adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the energy fluxes cover the range of values in line with observational constraints. (Adapted from Wild et al., 2013.)

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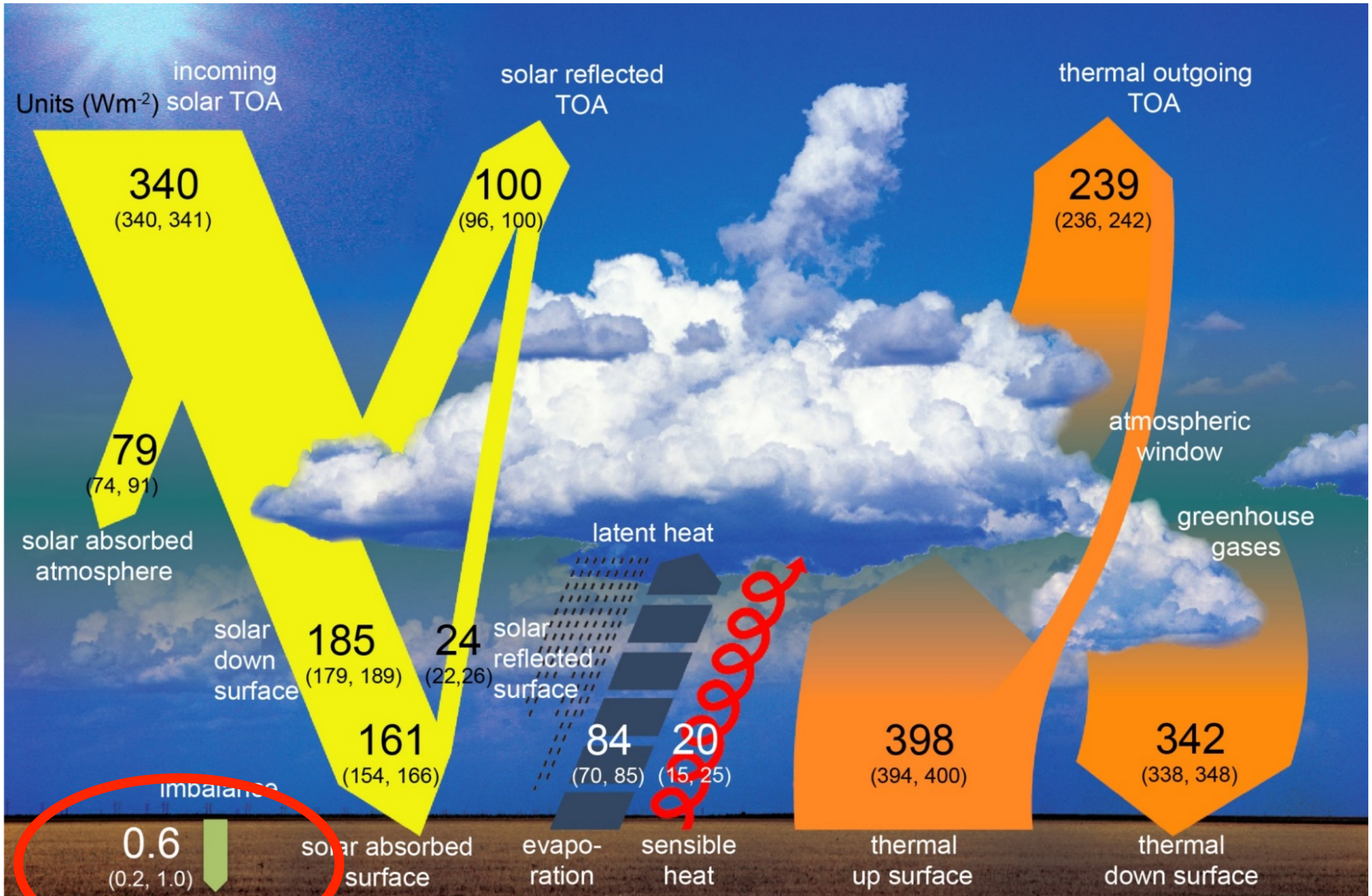

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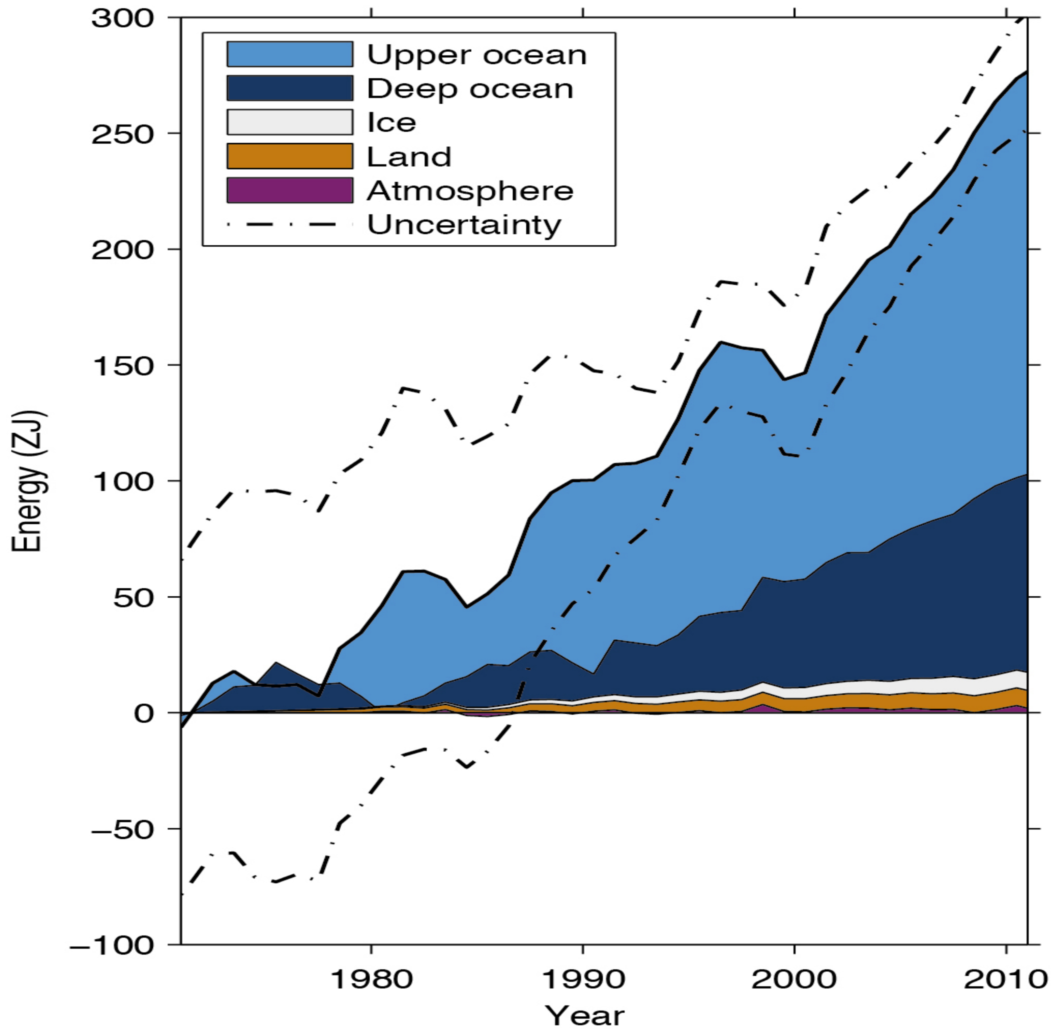
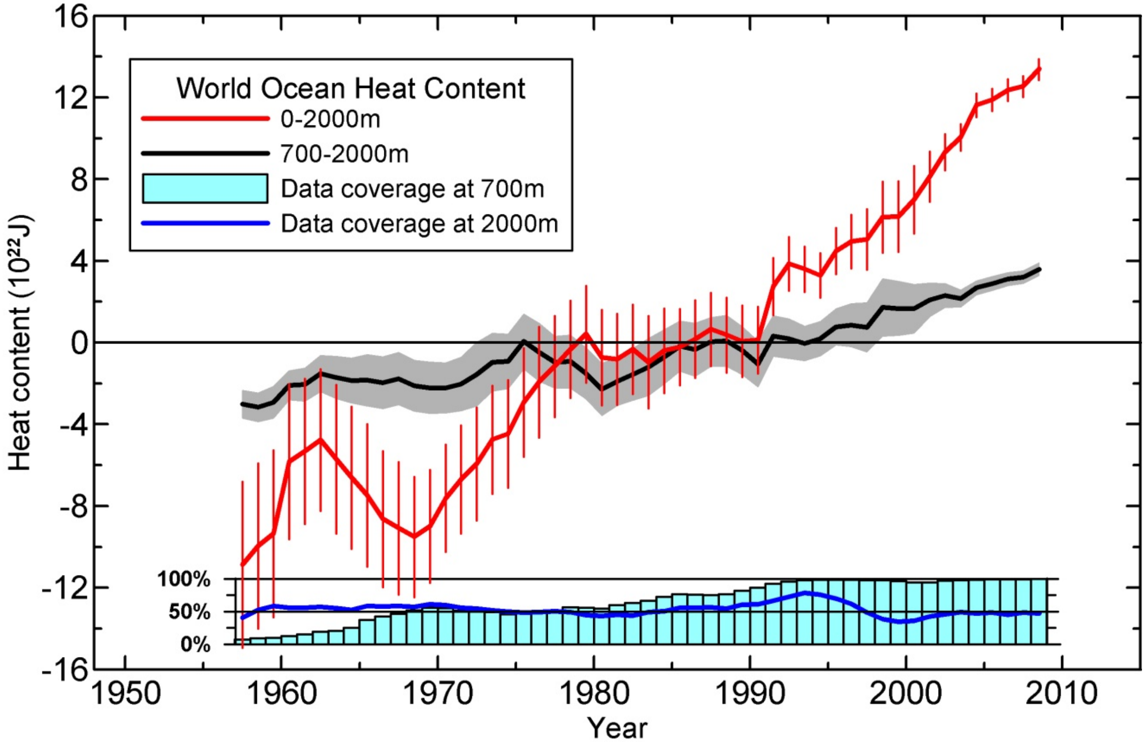


> 90% of the imbalance in the Earth's heat budget goes into the ocean.

Box 3.1, Figure 1 | Plot of energy accumulation in ZJ (1 ZJ = 1021 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).

Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang, 2013: Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ocean Heat Content has been rising 1955-present



Levitus, S., et al. (2012), World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010, Geophys. Res. Lett., 39, L10603, doi: [10.1029/2012GL05110](10.1029/2012GL05110)

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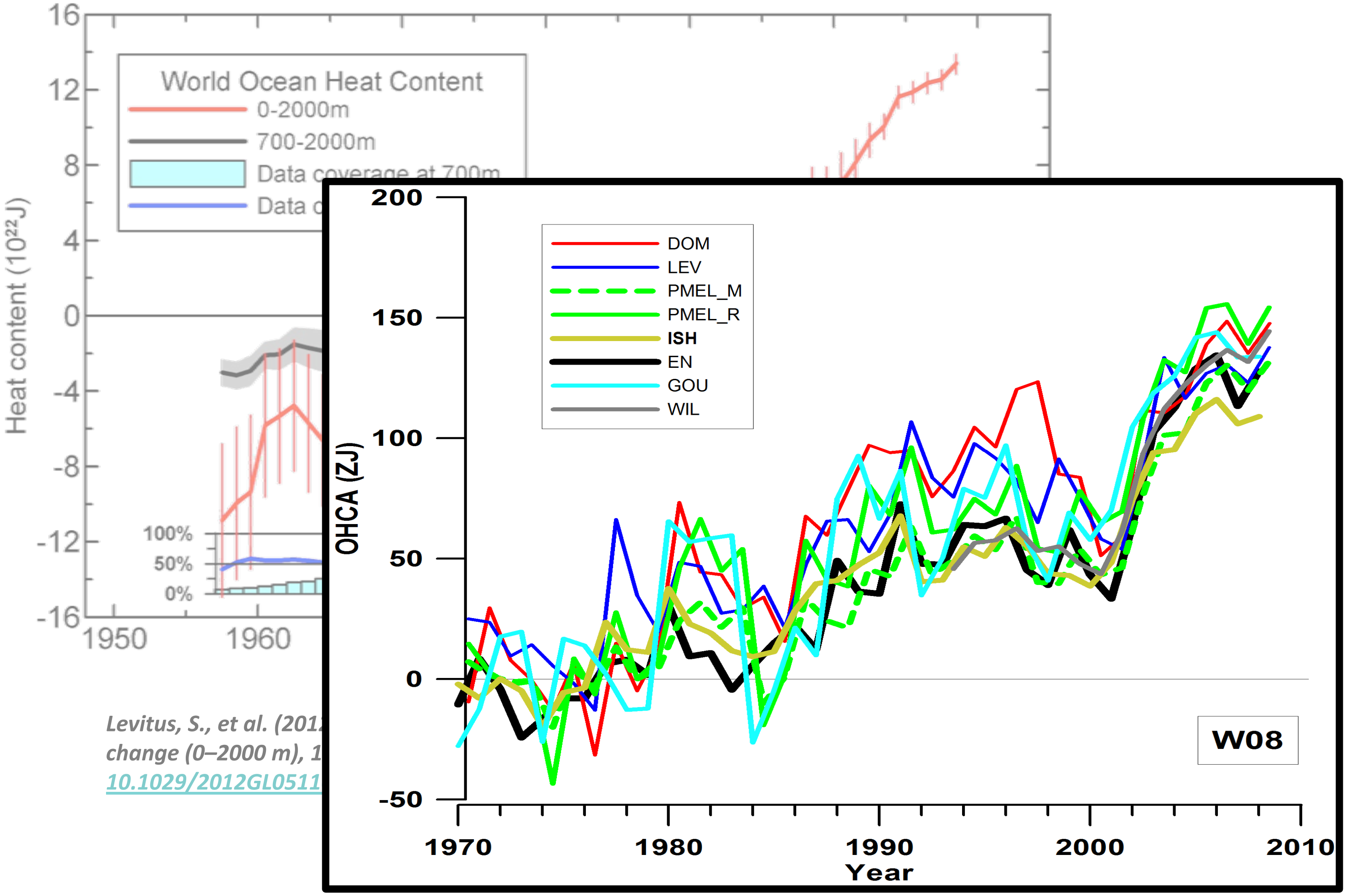
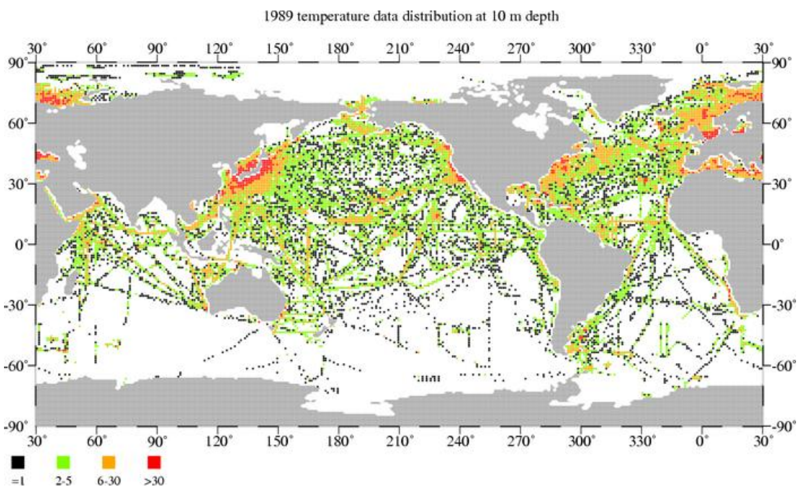


But large uncertainty between calculation methods from in situ data

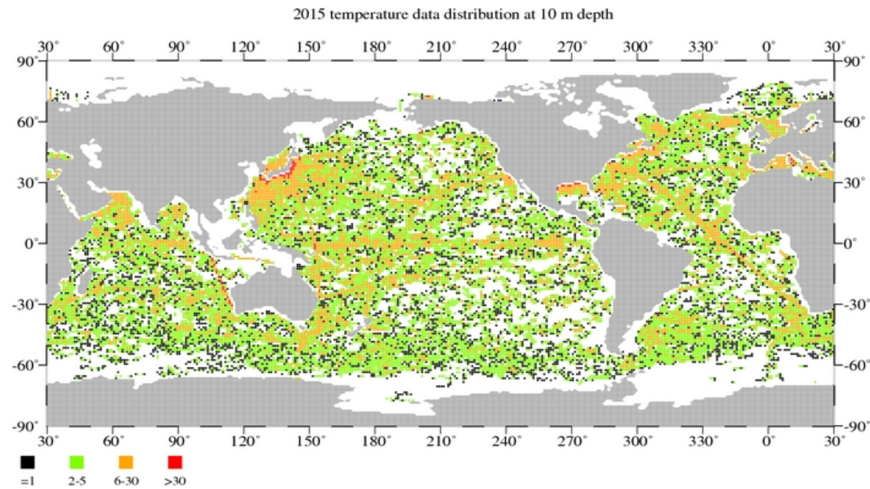
Boyer, T., C.M. Domingues, S.A. Good, G.C. Johnson, J.M. Lyman, M. Ishii, V. Gouretski, J.K. Willis, J. Antonov, S. Wijffels, J.A. Church, R. Cowley, and N.L. Bindoff (2016): Sensitivity of global upper-ocean heat content estimates to mapping methods, XBT bias corrections, and baseline climatologies. J. Climate, 29(13), 4817–4842, doi: 10.1175/JCLI-D- 15-0801.1.

. . .Due to incomplete ocean coverage

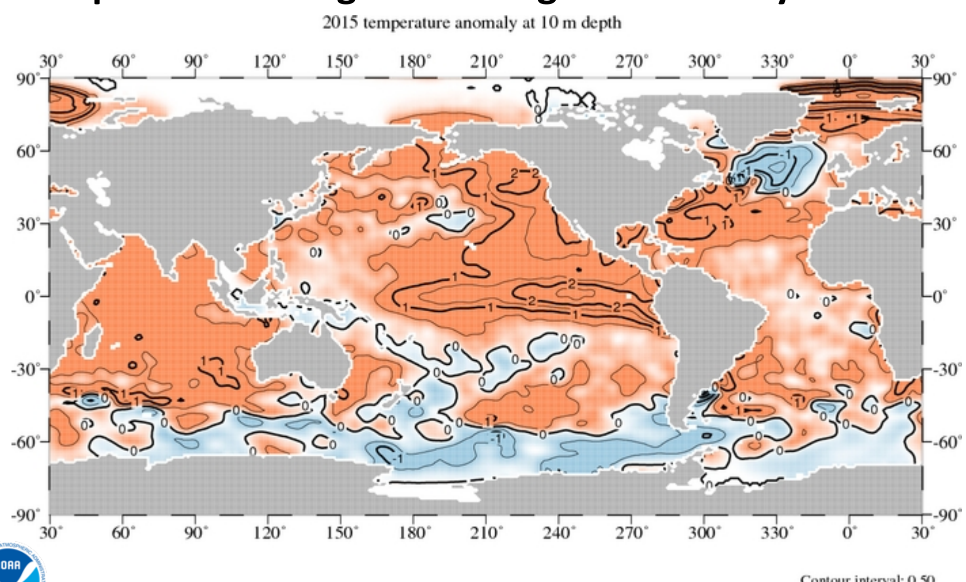
***in situ* measurements 10m depth year 1989**



***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[1,2] and Terence J. Sabaka[1]

[1]NASA Goddard Space Flight Center, Greenbelt, MD

[2]Department of Astronomy, University of Maryland at College Park

Contact: robert.h.tyler@nasa.gov

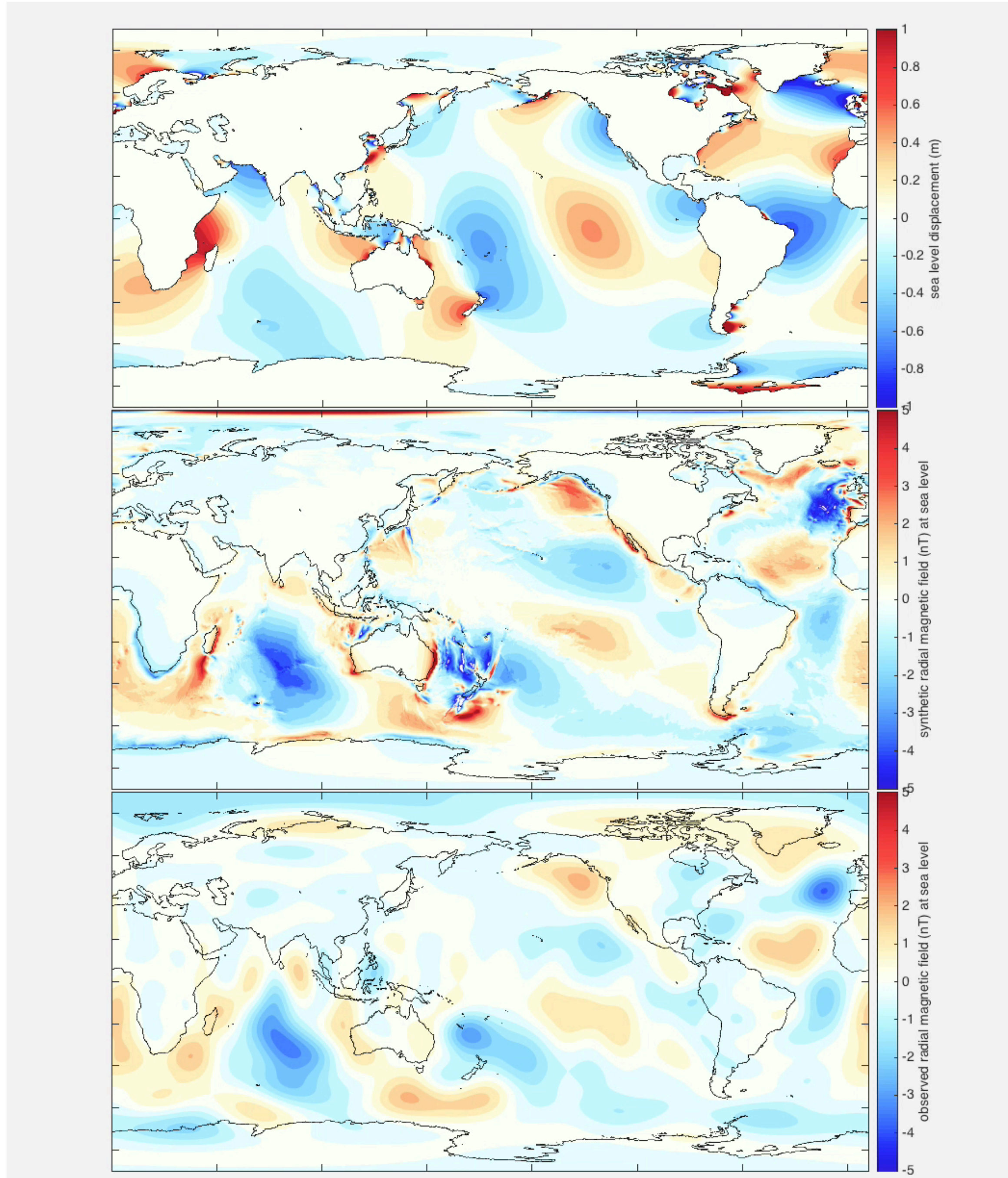
The phenomenon exploited:
Magnetic fluctuations induced by ocean tides

Video available at http://svs.gsfc.nasa.gov/12450

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 —>



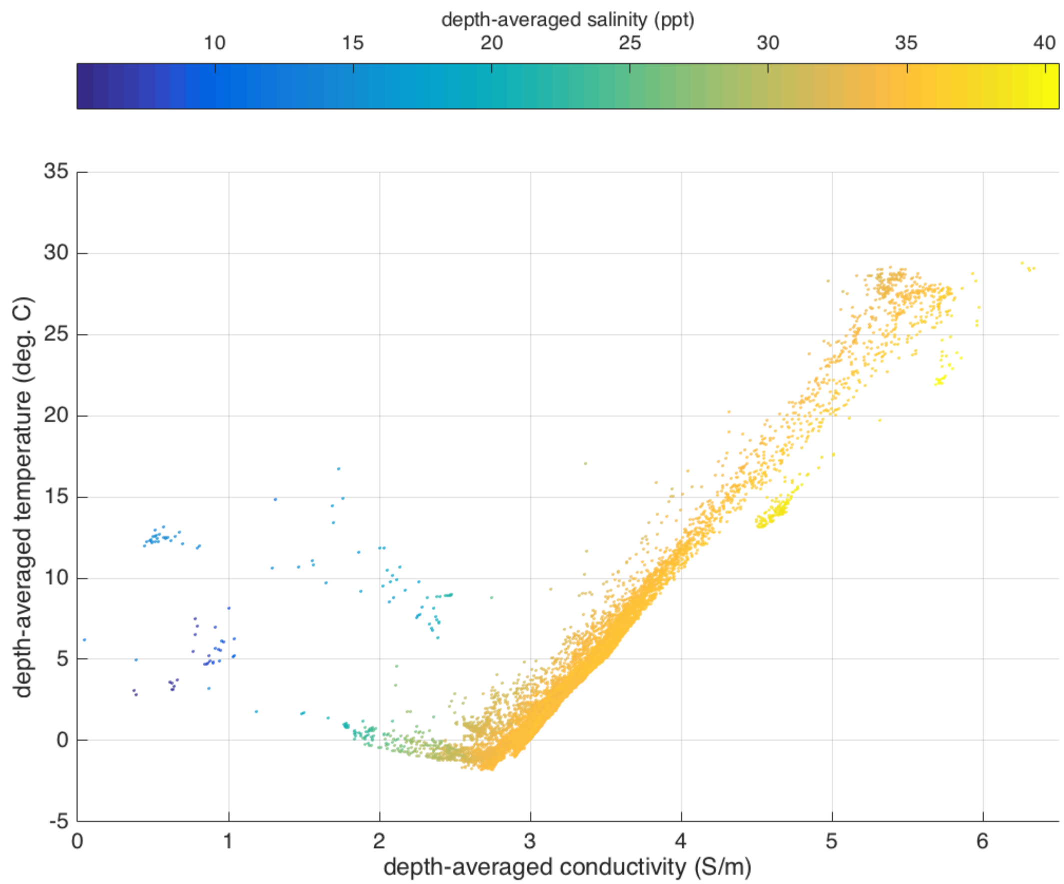
By monitoring these ocean-tidal magnetic fluctuations may we infer any ocean parameters?

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?

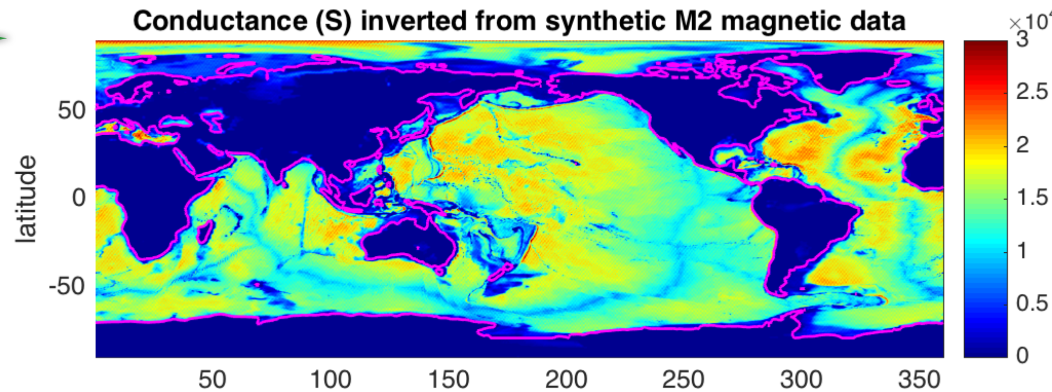
Ocean measurements show a strong linear relationship between conductance and depth-integrated ocean temperature (heat content) —>

(i.e., monitoring conductance can amount to monitoring heat content)

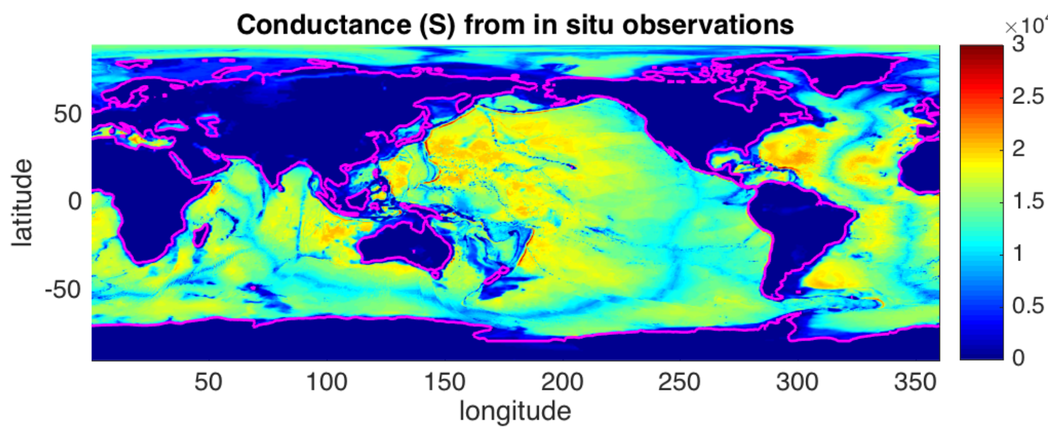


Where are we in developing the proximate goal of inferring conductance from remote magnetic observations?

✓ 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.

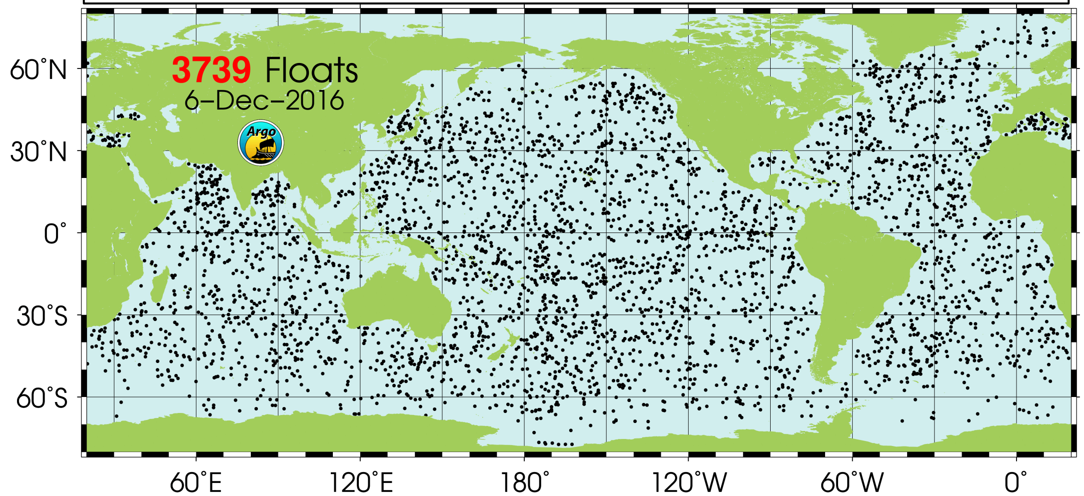


Catherine Walker

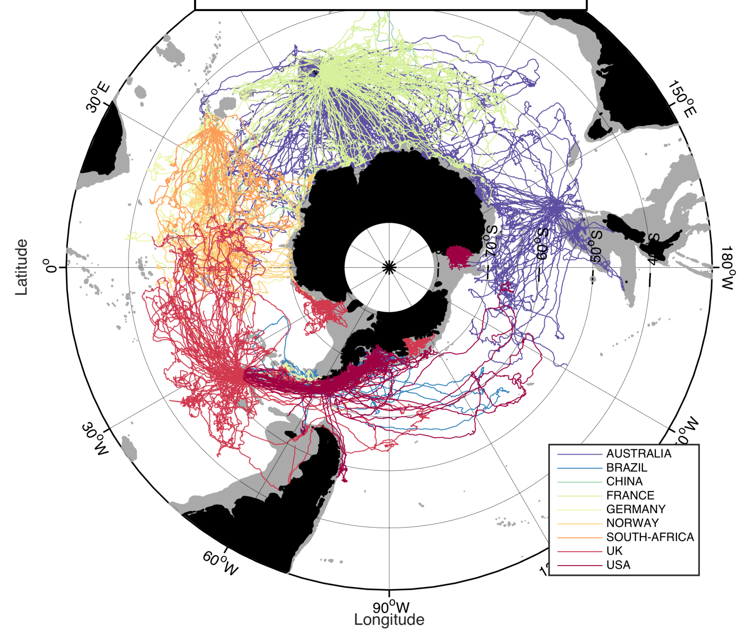
NASA Jet Propulsion Laboratory

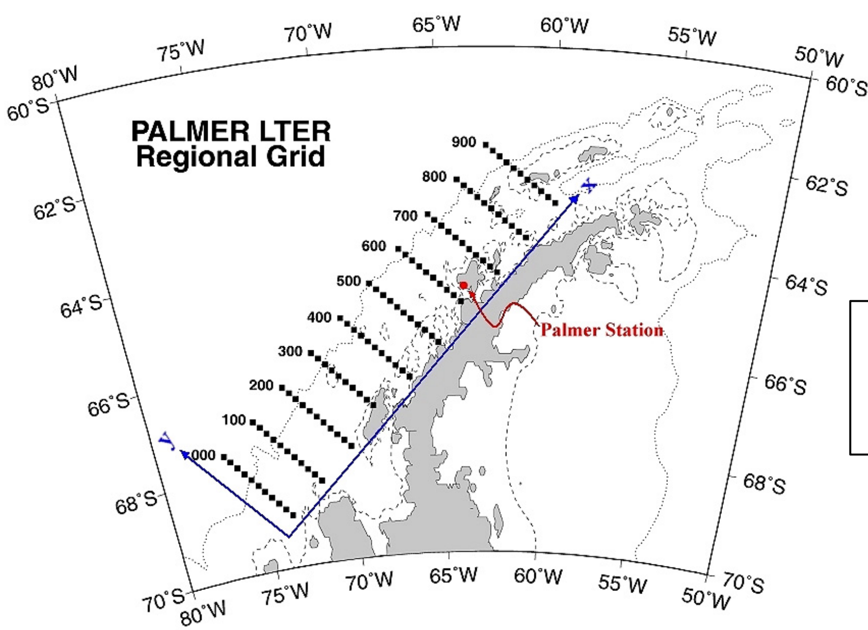
Measuring the Southern Ocean

International Argo profiling float program: since 2000



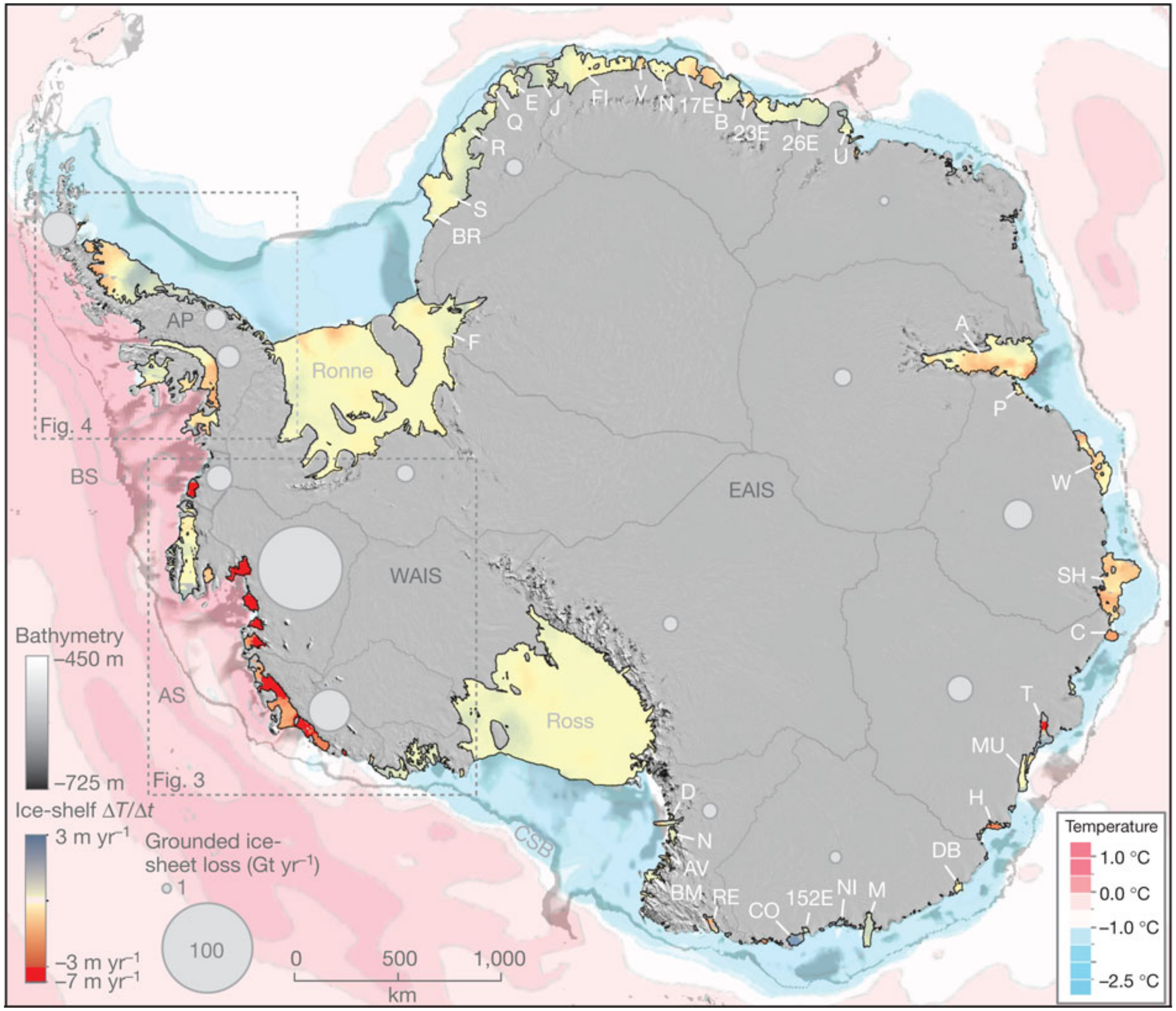
MEOP: CTD-tagged seals since 2005





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

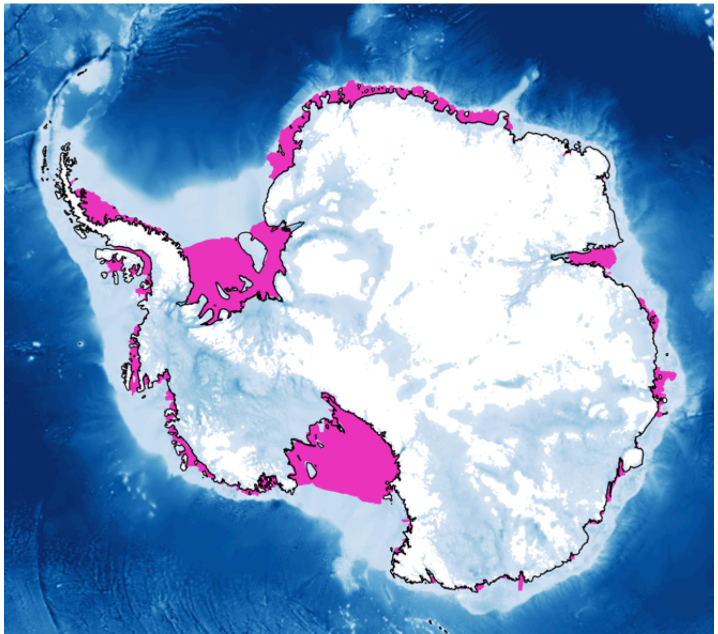
Ocean heat around Antarctica

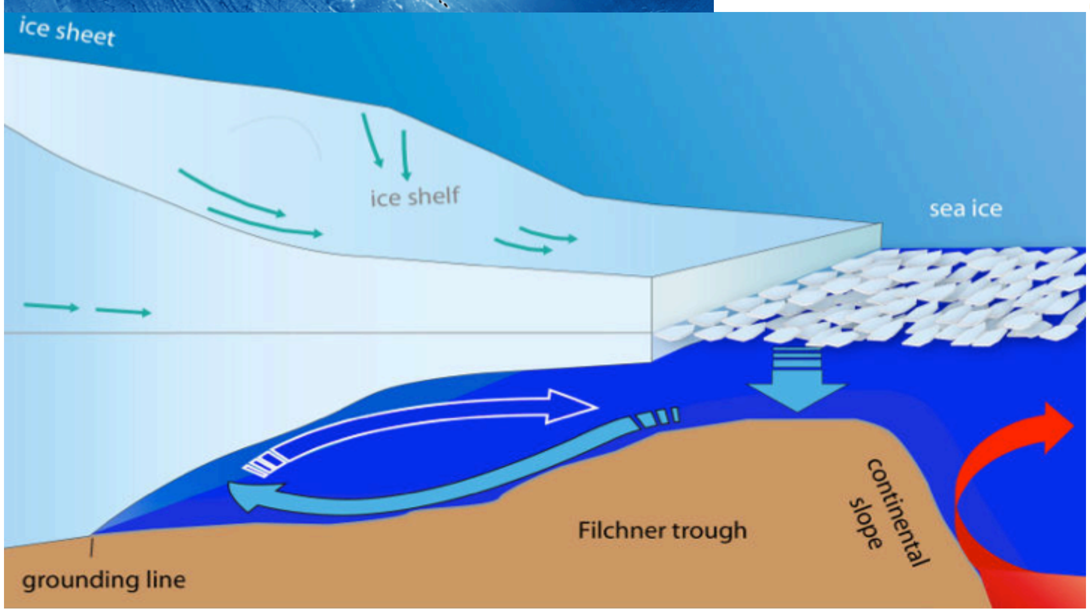


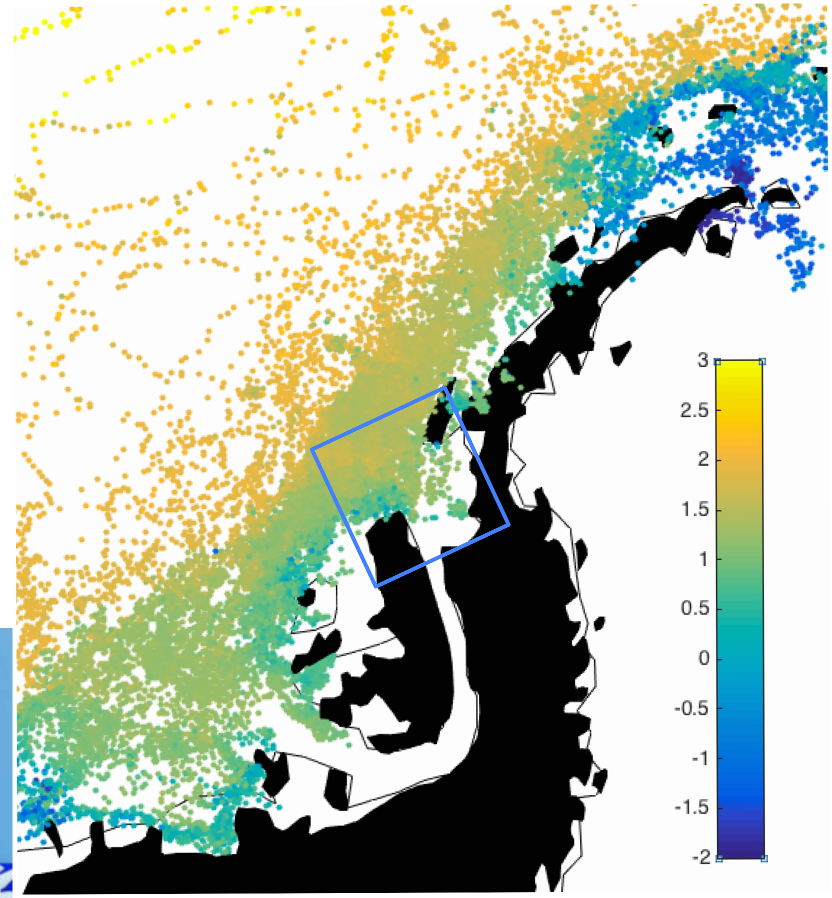
Pritchard *et al.* (2012), *Nature* 484, 502-505

World Ocean Circulation Experiment Southern Ocean Atlas: Estimated average sea-floor potential temperatures (°C)

Antarctica’s floating ice



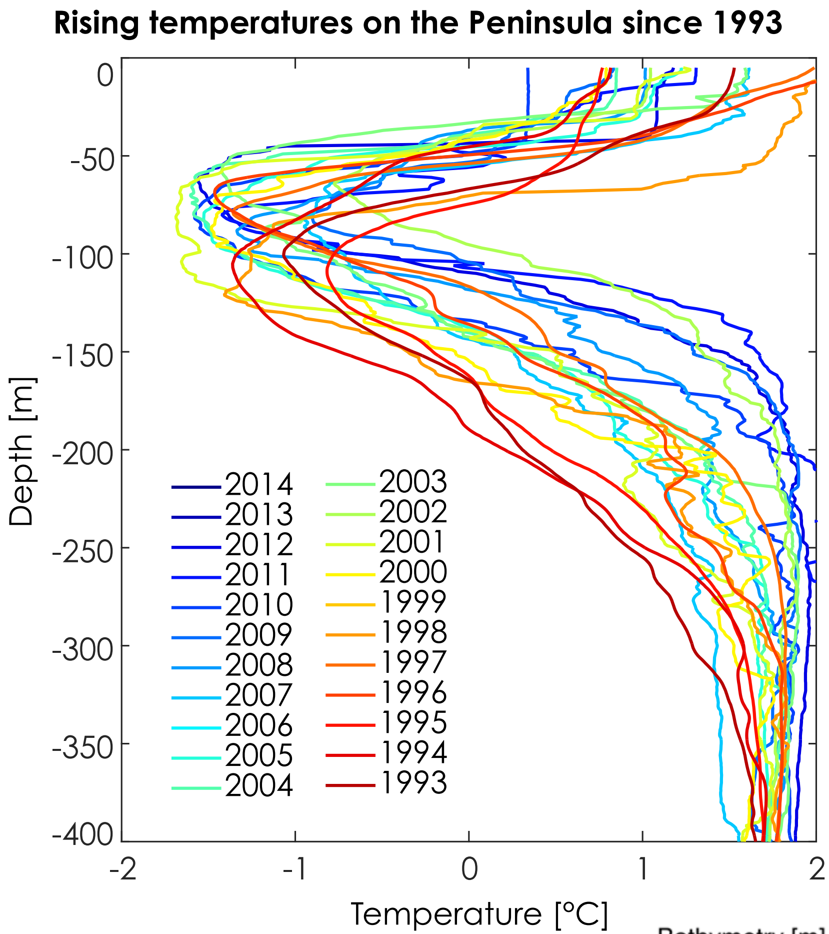


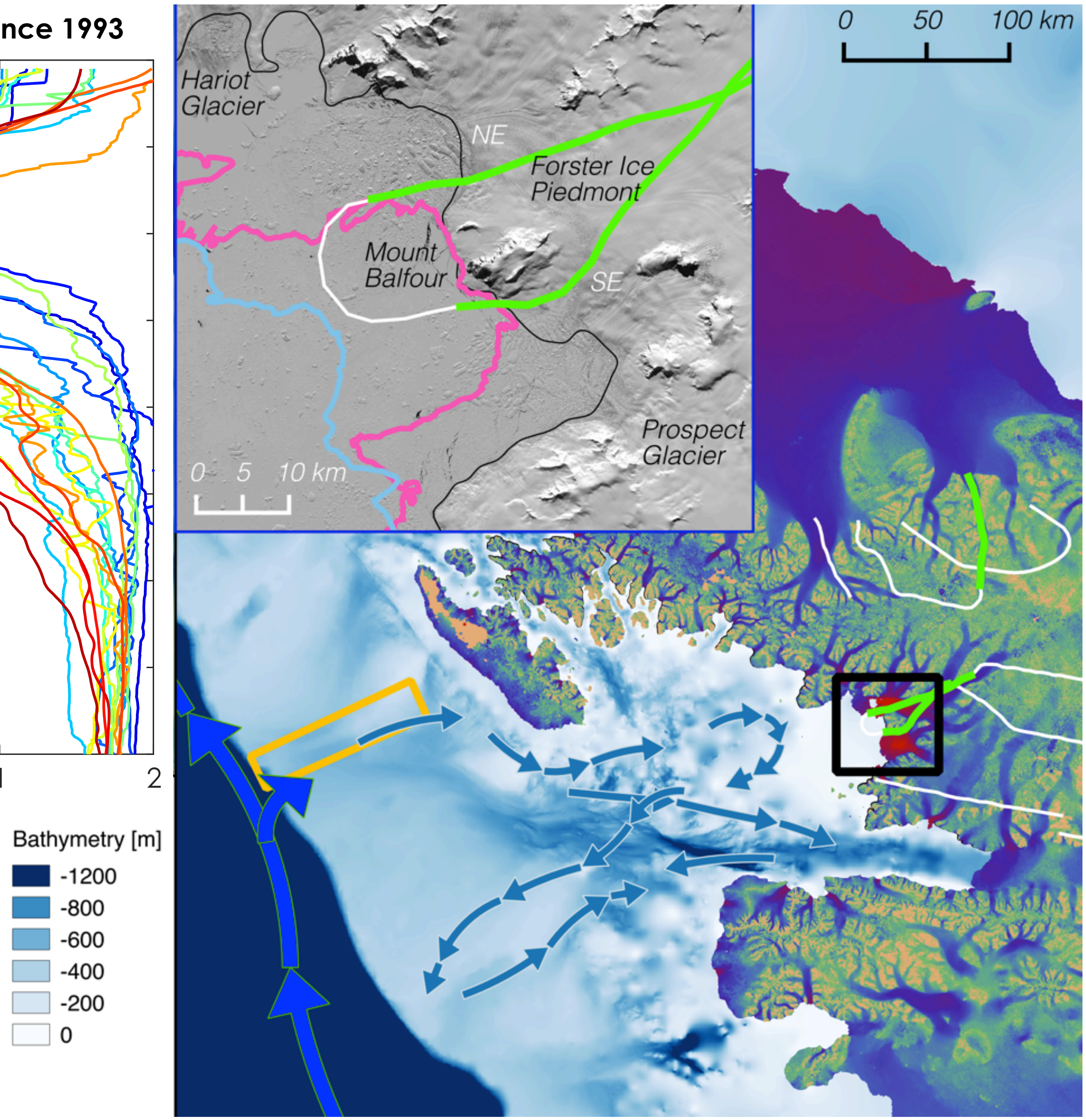


West Antarctic Peninsula:
Seal-tagged CTD measurements
2005-2011@300 m depth

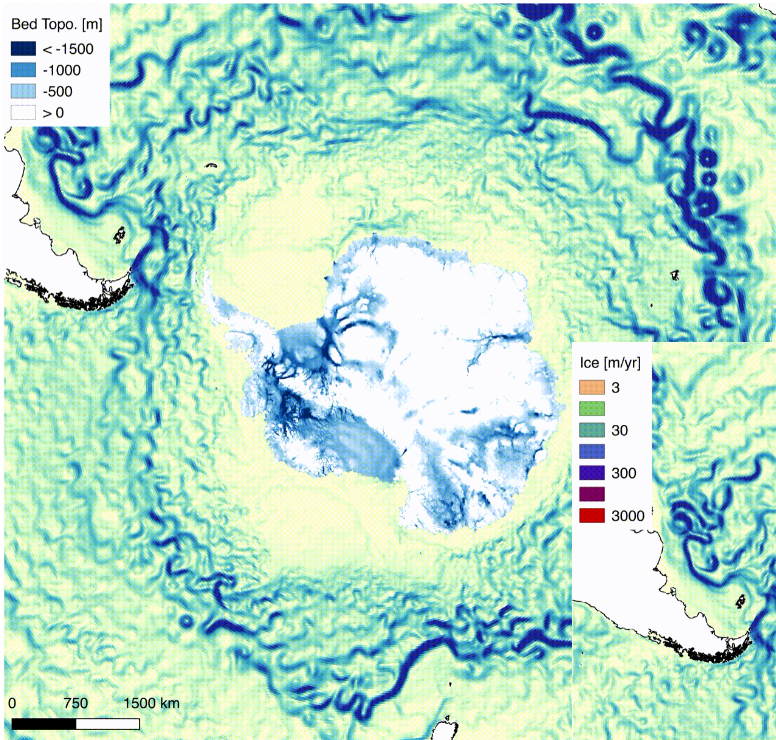
Marguerite Bay > 1.5°C

Continental shelf infiltration?



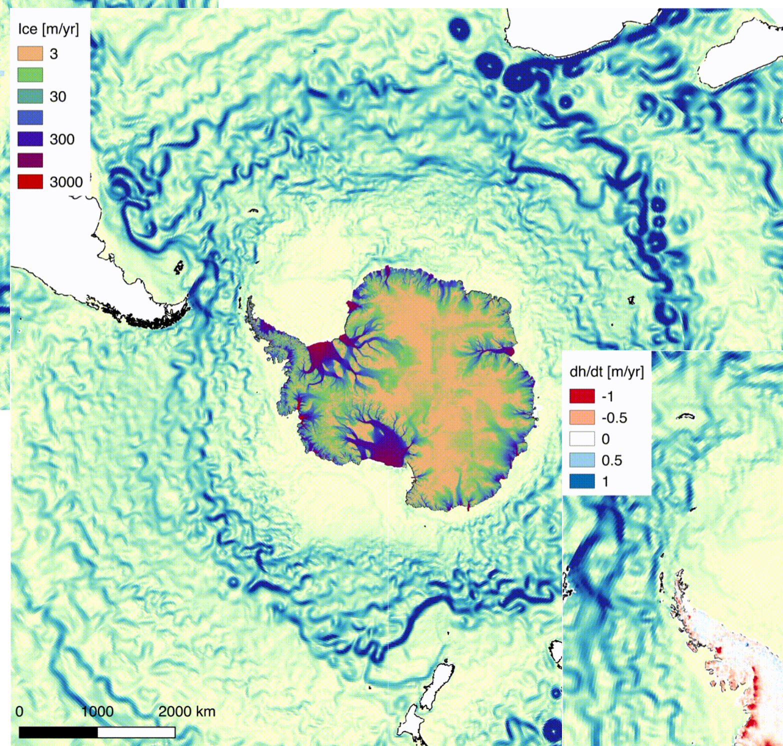


Flow in & around Antarctica

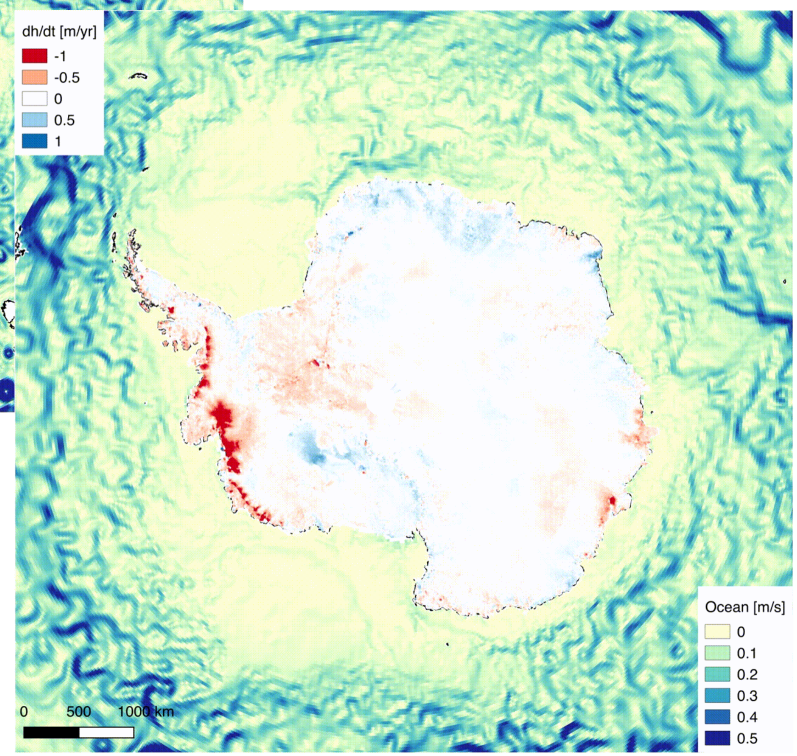


Fretwell et al. (2013): BEDMAP2

Gardner et al. (2016): Velocities



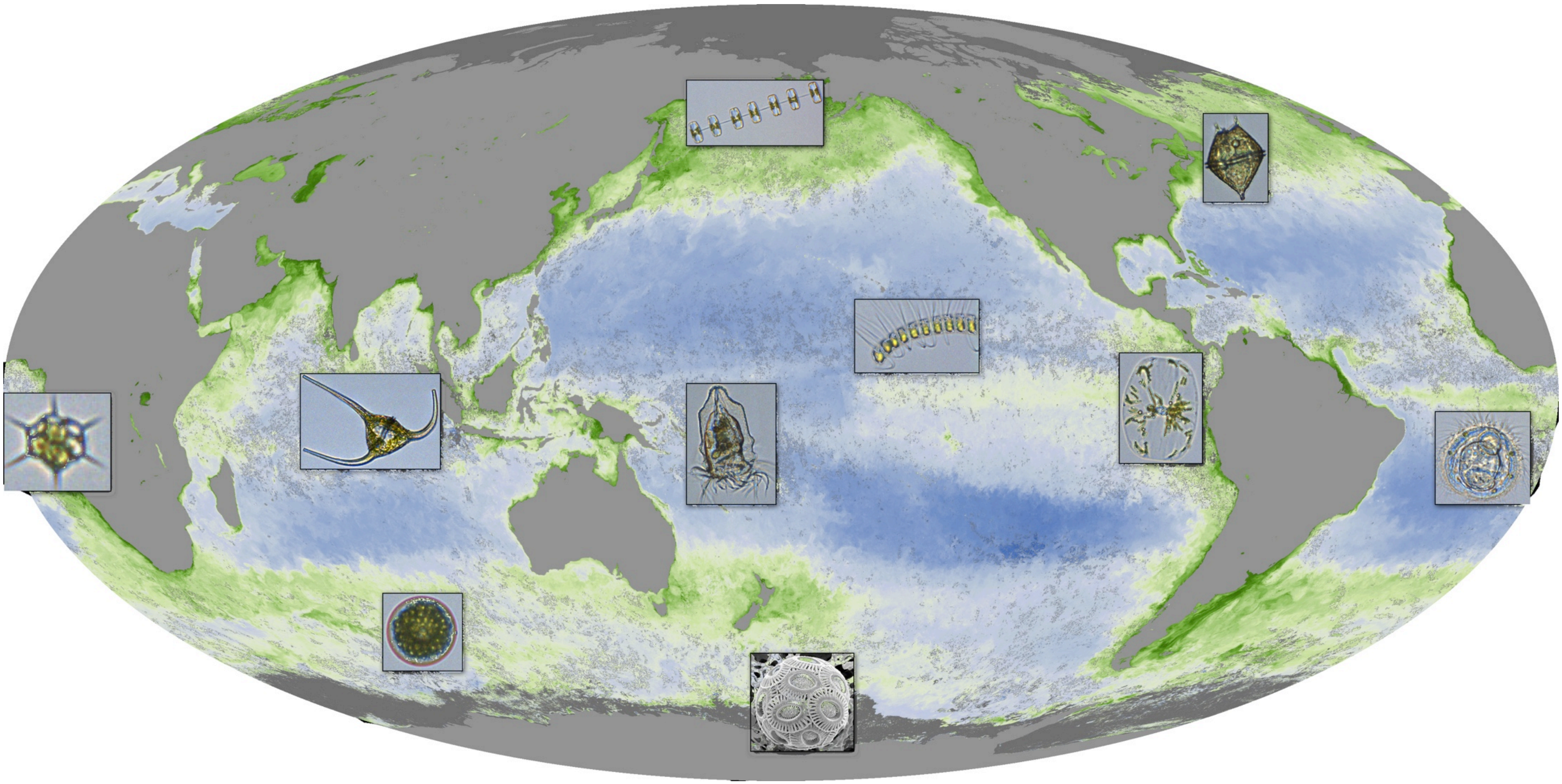
Nilsson et al. (2016): elev. change



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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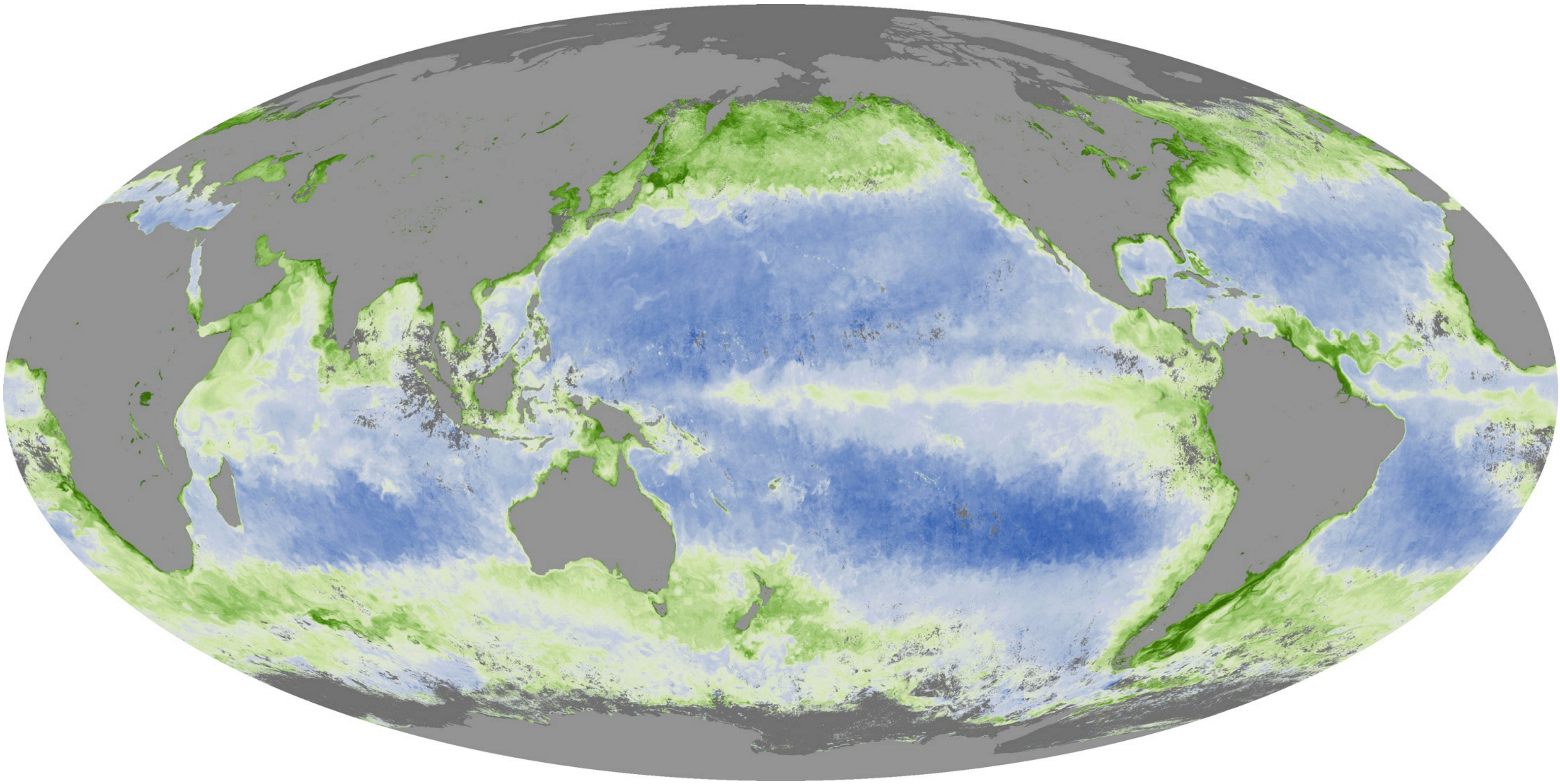
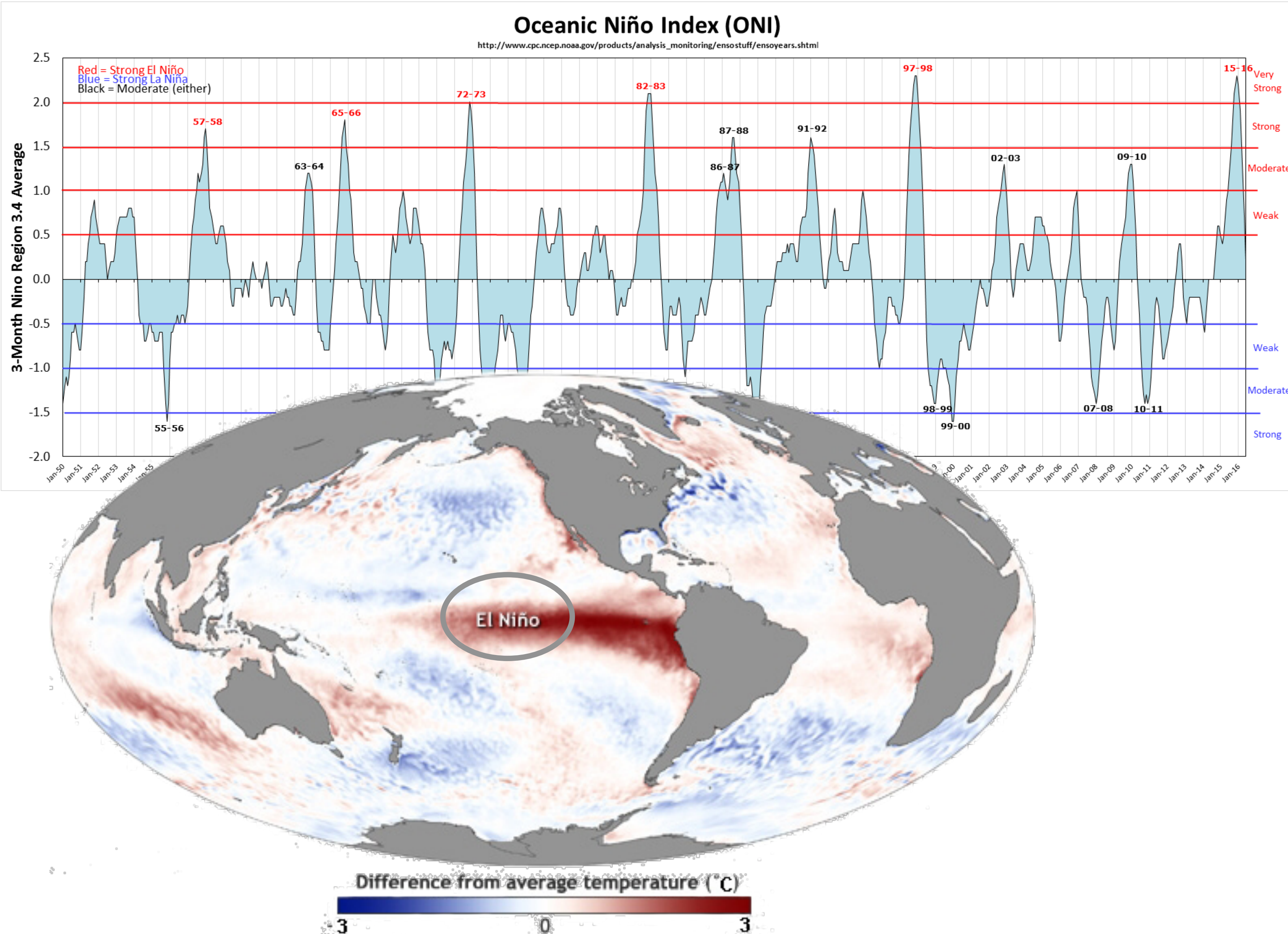


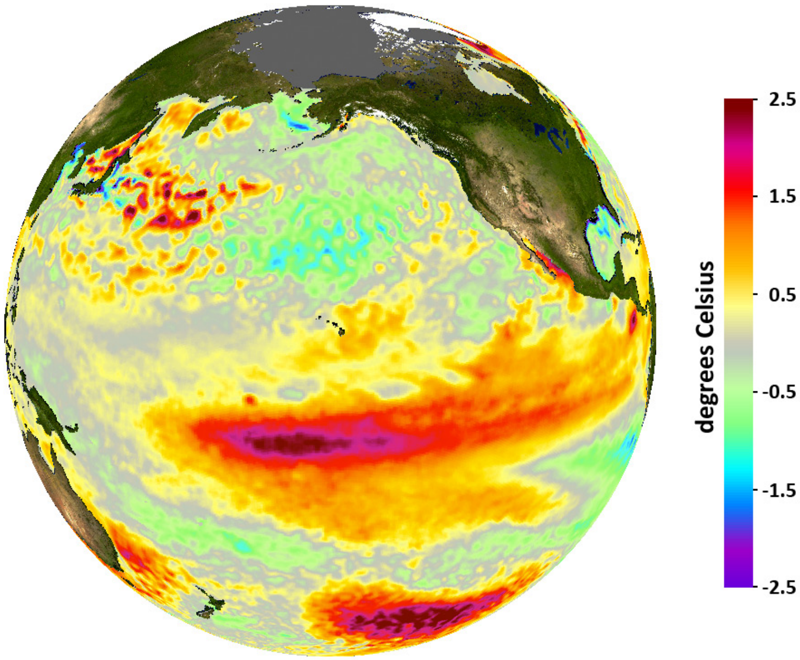
In review - *J. Climate*: Schollaert Uz, S., A.J. Busalacchi, T.M. Smith, C.W. Brown, M.N. Evans and E.C. Hackert.



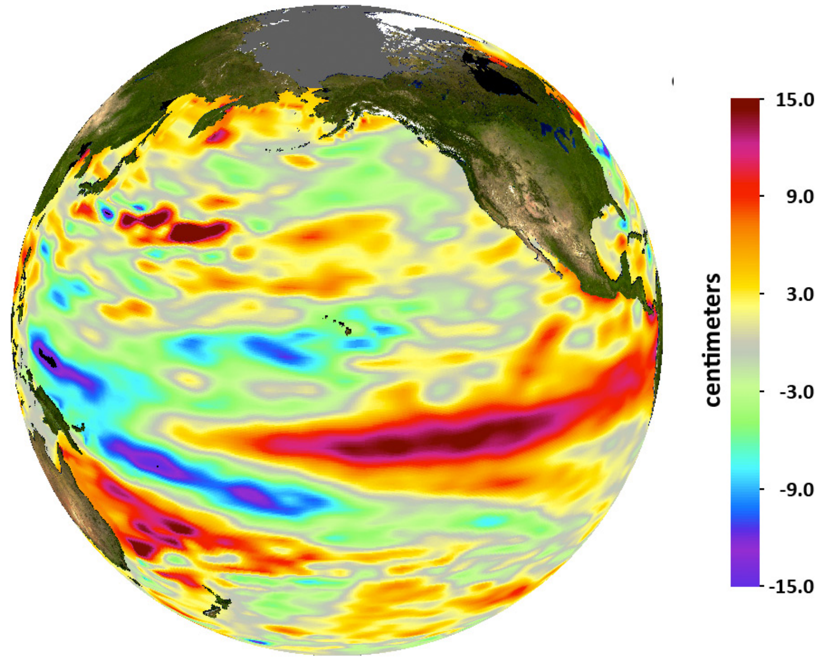
[NOAA Climate Prediction Center](#) Ocean Niño Index

Physical differences drive biological differences by vertical motion that brings nutrients from depth to the surface

Sea Surface Temperature Deviation From Normal



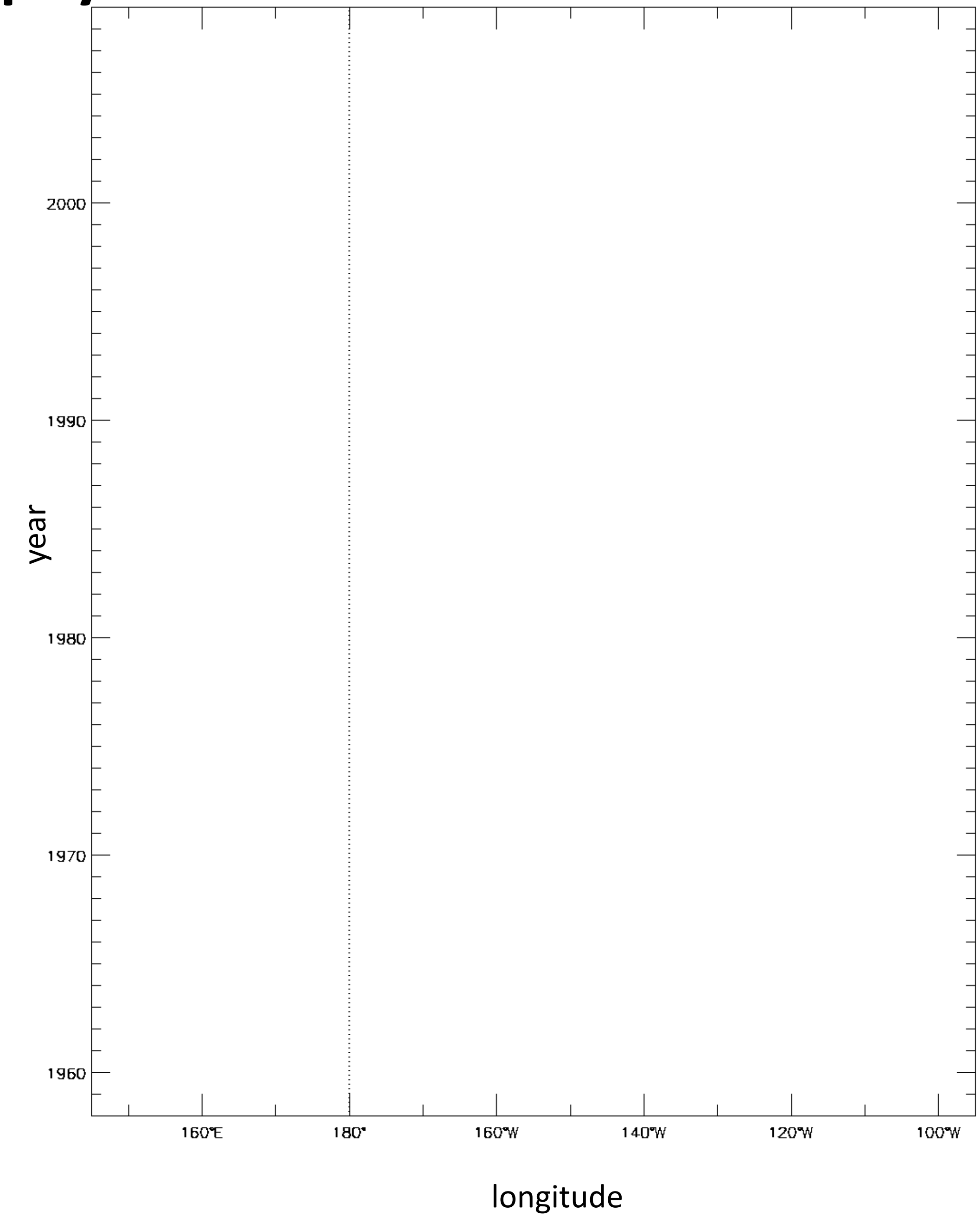
Sea Surface Height Deviation From Normal

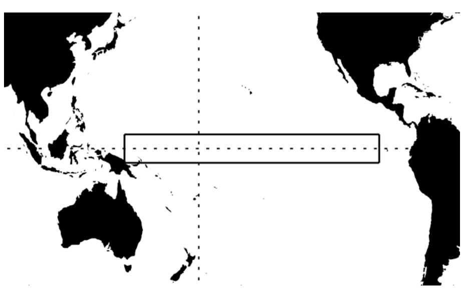


Figures courtesy NASA/JPL-NOAA and UC Irvine

Basin-wide chlorophyll reconstructed 1958-2008

CHL averaged 5°N-5°S





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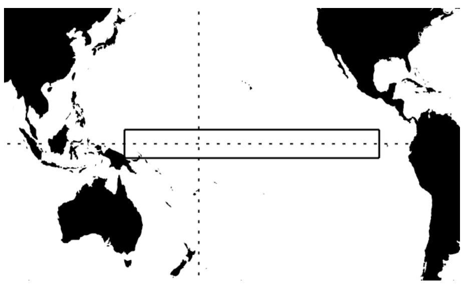

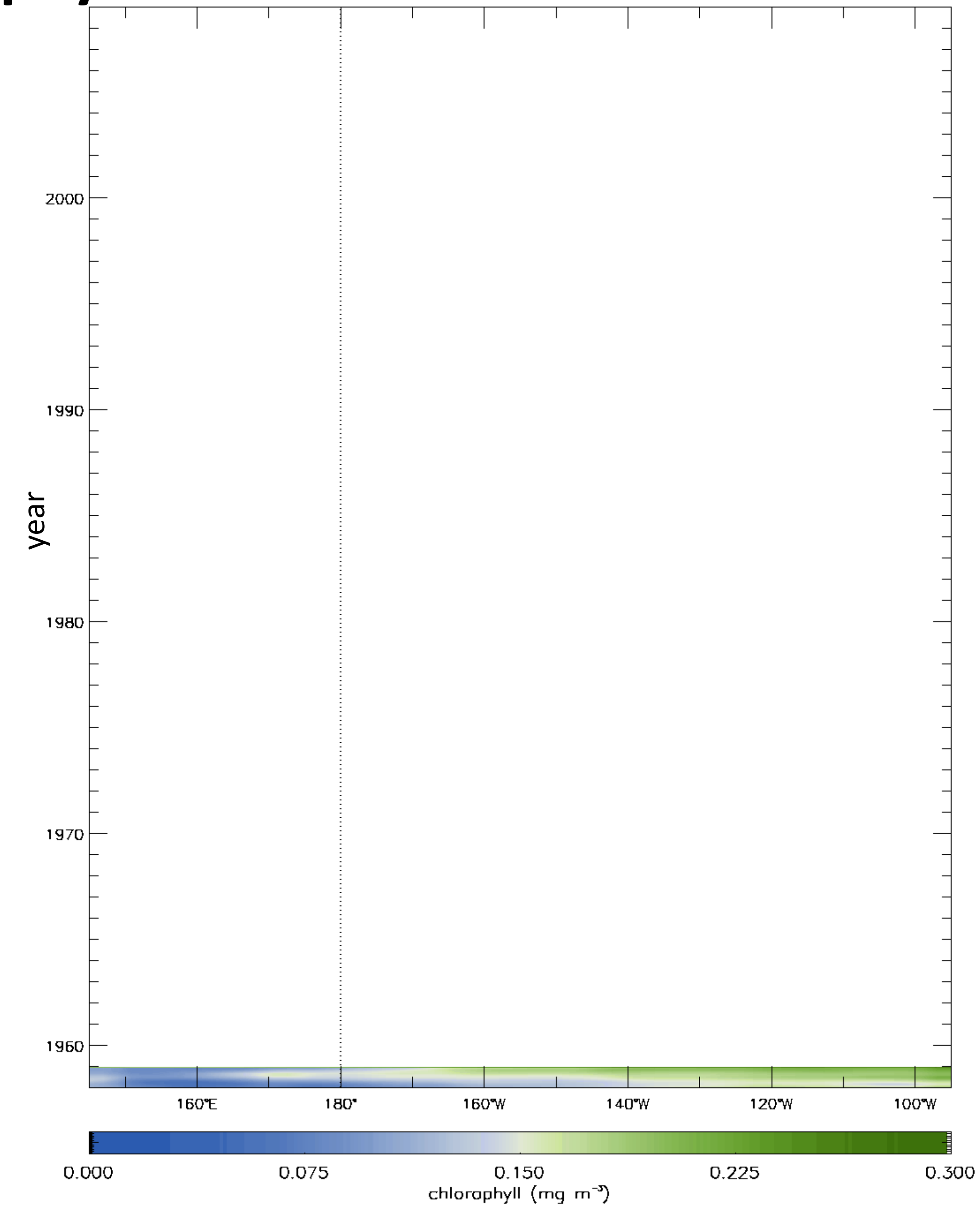

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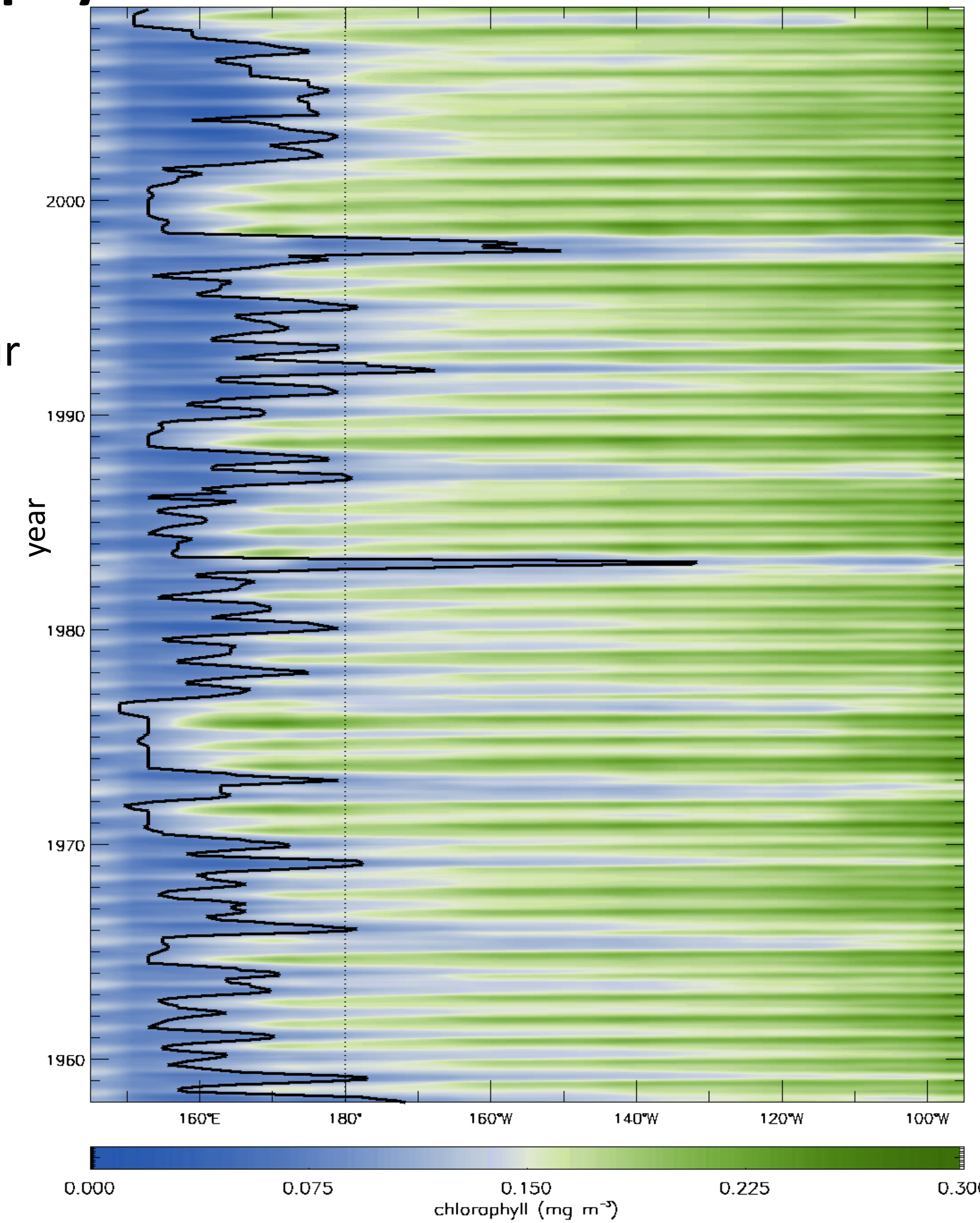
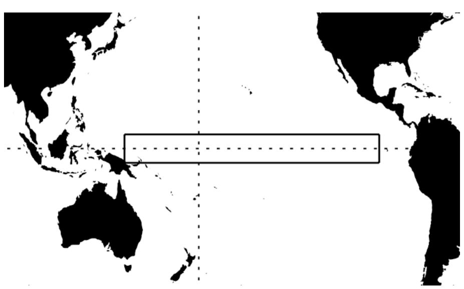
CHL averaged 5°N-5°S

East edge of warm pool:
~ 0.1 mg m^{-3} CHL contour





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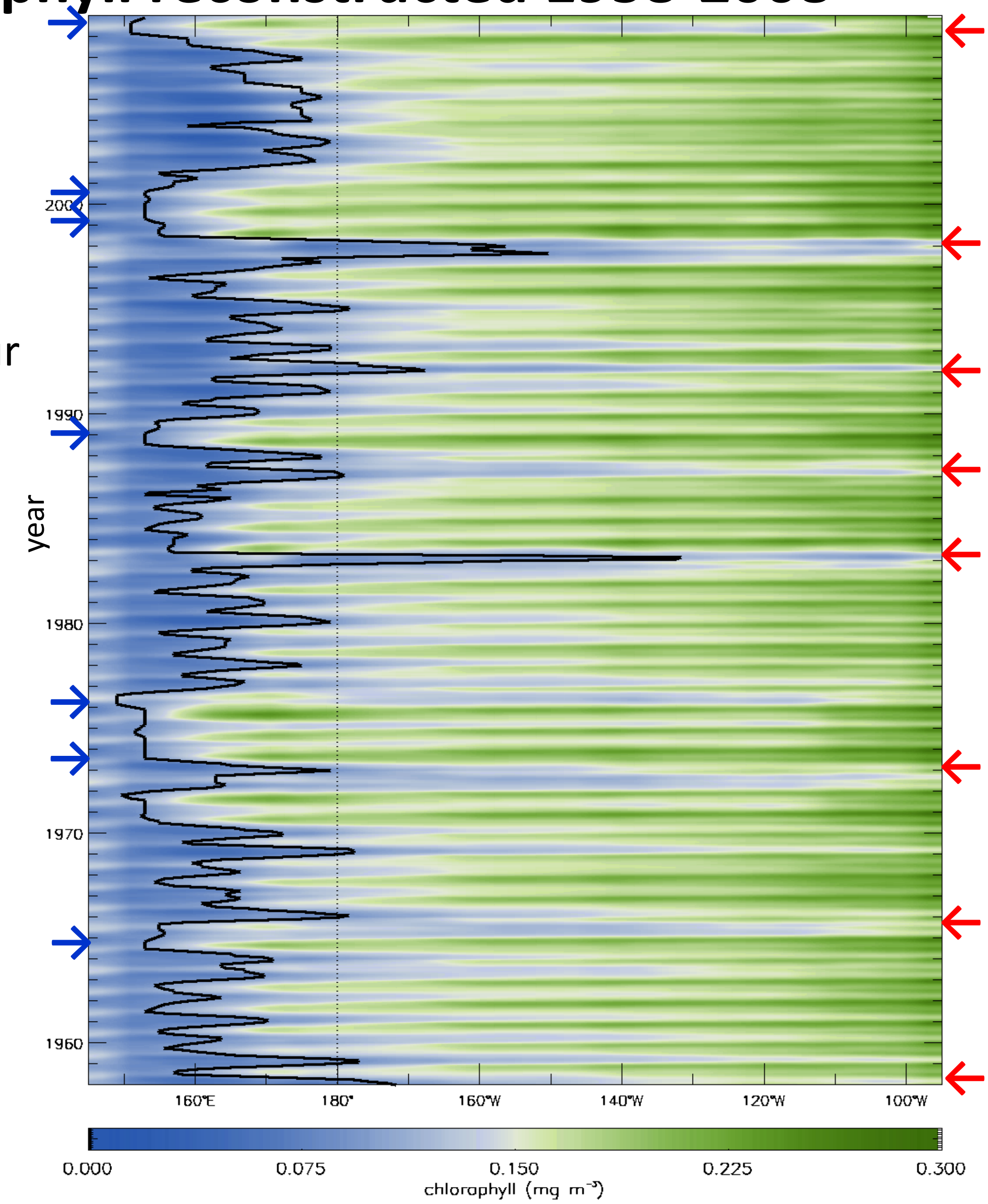
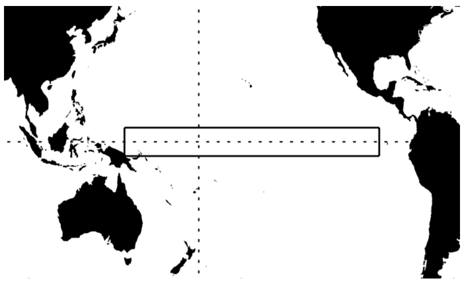
← El Niño

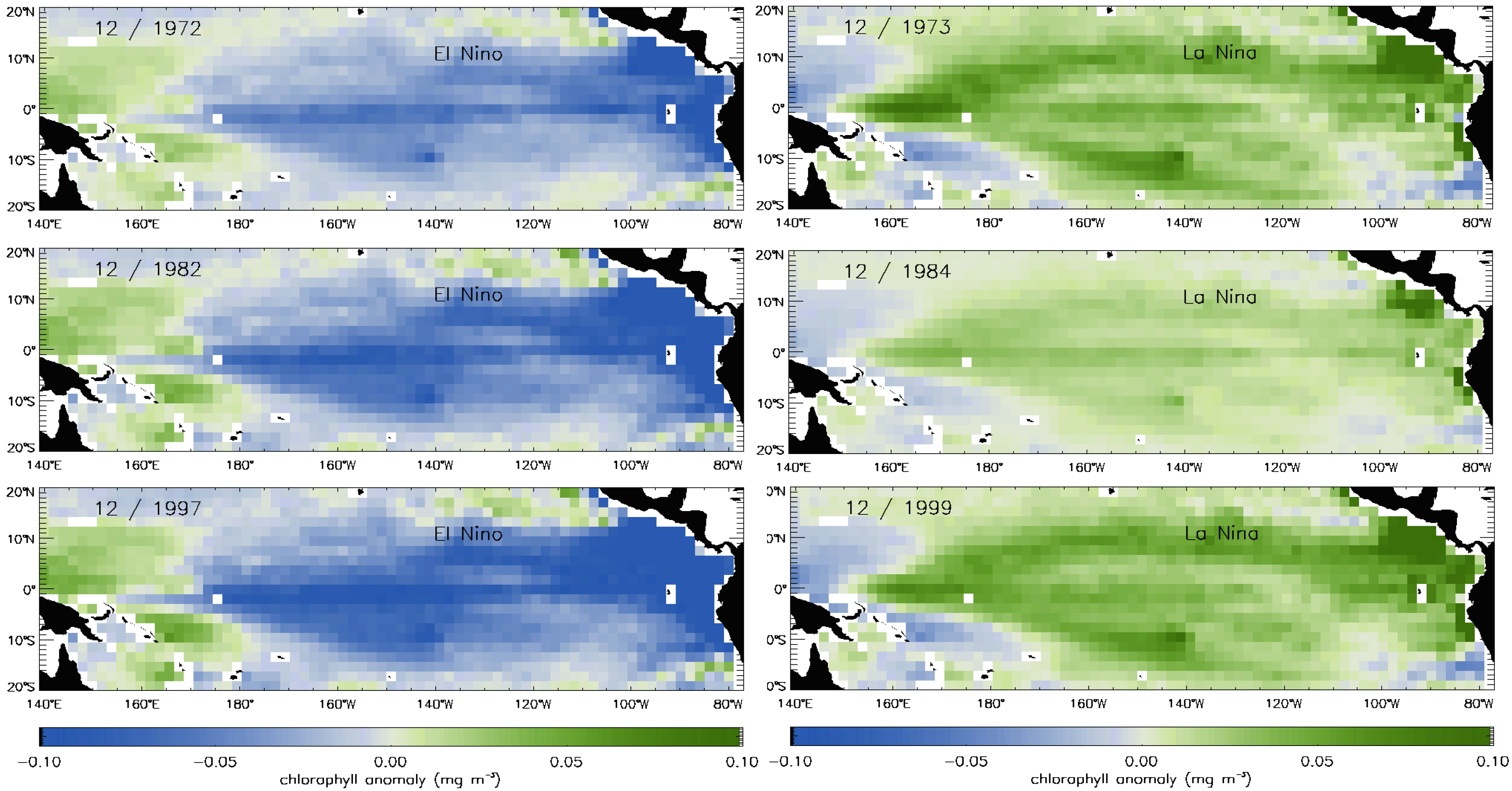
→ La Niña





Reconstruction highlights interannual differences

El Niños La Niñas

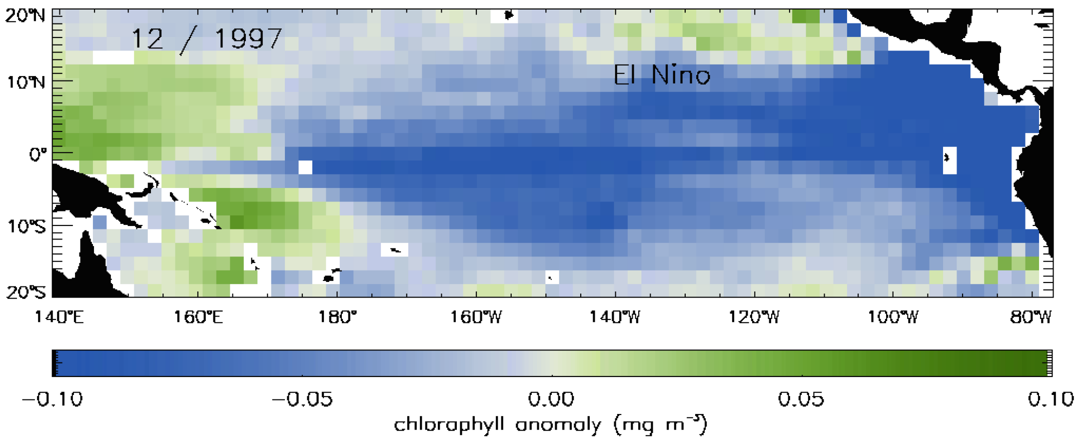


- weakened easterly trade winds
- less upwelling, biological productivity

- intensified easterly trade winds
- more upwelling, biological productivity

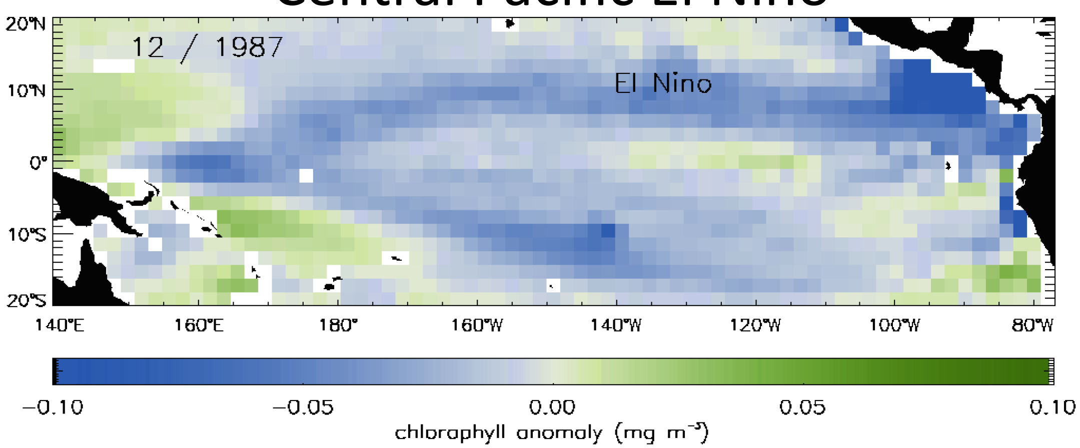
Reconstruction highlights differences in El Niño patterns

East Pacific El Niño



Nutrient layer deepens across basin, suppressed nutrient supply to surface

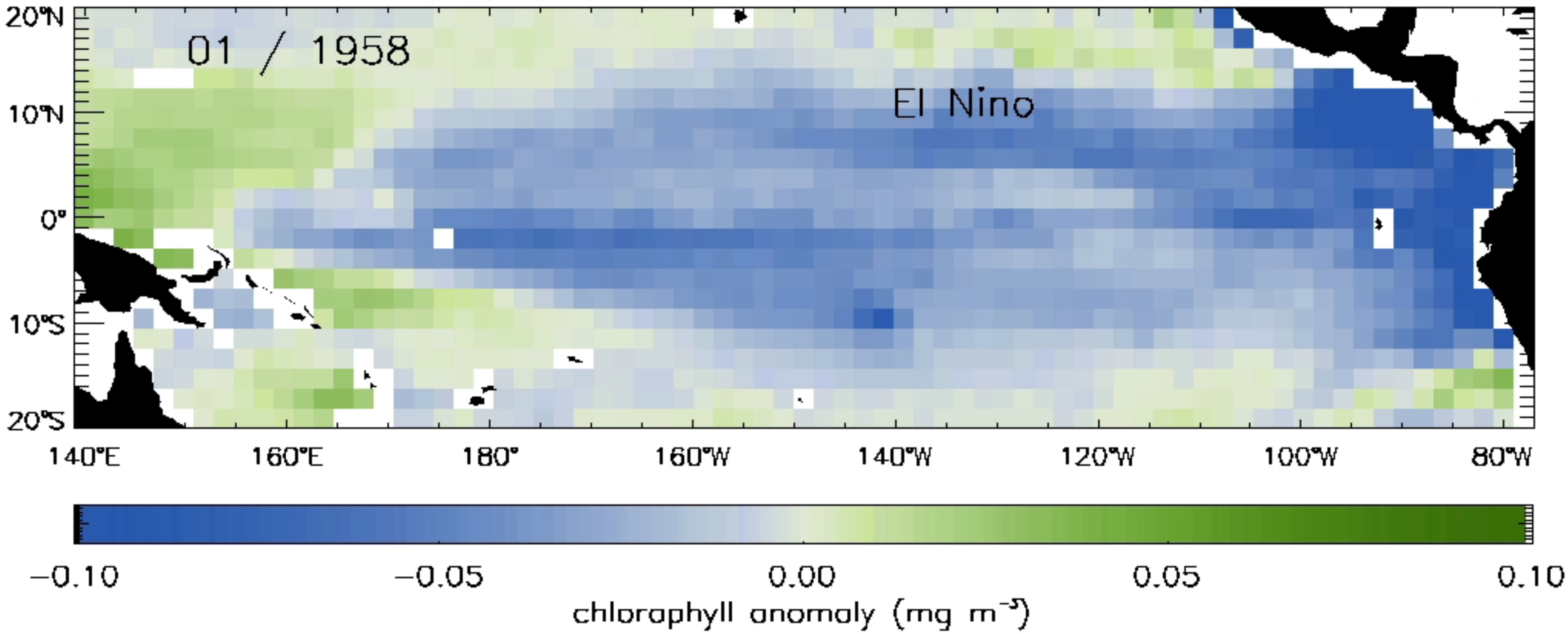
Central Pacific El Niño



Nutrient layer deepens locally, biology most depressed west of 180^{o} (not basin-wide)

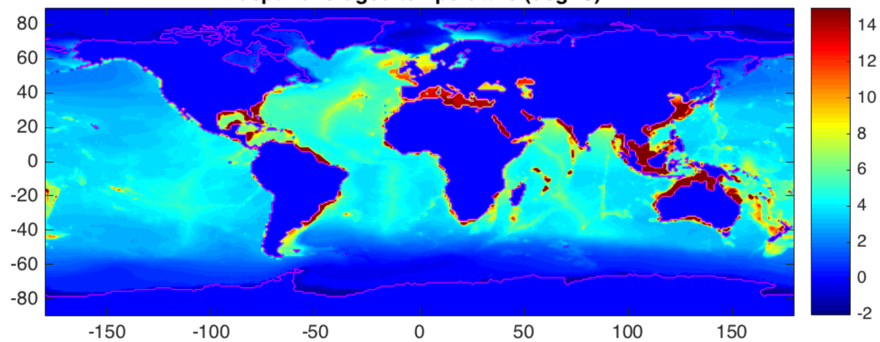
Questions?

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

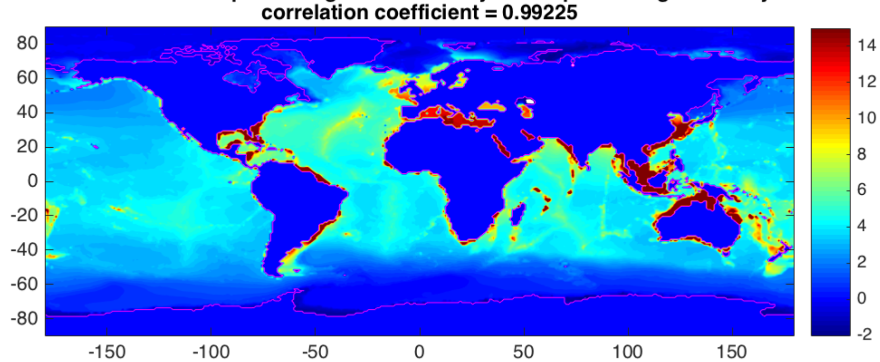


END
(FURTHER SLIDES ARE BACKUP)

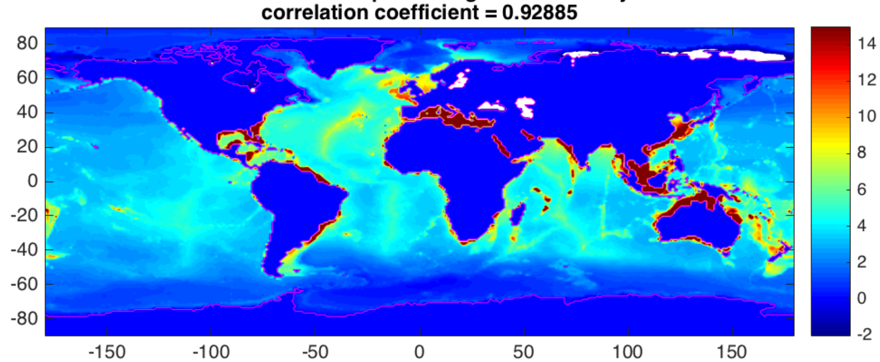
depth-averaged temperature (deg. C)

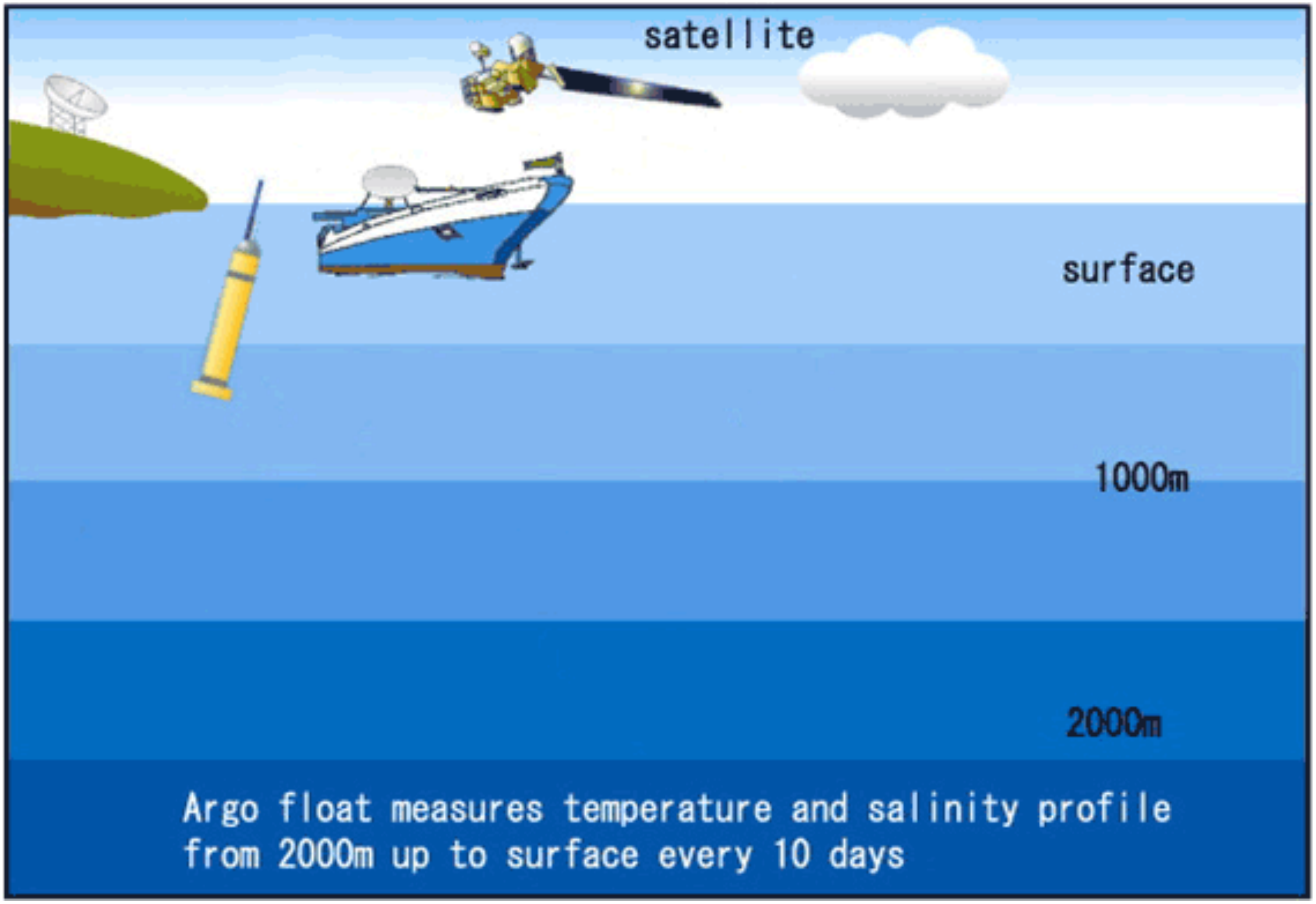


depth-averaged temperature (deg. C)
obtained from depth-averaged conductivity and depth-averaged salinity
correlation coefficient = 0.99225



depth-averaged temperature (deg. C)
obtained from depth-averaged conductivity
correlation coefficient = 0.92885





Original graphic courtesy of JAMSTEC
Animation by NASA/Matthew Radcliff