Ocean Warming 1955-2003

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INTRODUCTION:

WHY IS OCEAN WARMING IMPORTANT?

The earth's climate system is composed of several subsystems. These include the:

1) atmosphere;
2) hydrosphere (world ocean and lakes);
3) cryosphere (glaciers and sea-ice);
4) lithosphere (land).

All of these subsystems play important roles in determining the climate of earth's atmosphere. However, in terms of the heat content of the climate system, it is the world ocean that dominates and contributes substantially to the determination of atmospheric climate. The dominance of the world ocean in determining the heat content of the earth system was first suggested by Professor Carl Rossby in 1956. He made this suggestion based simply on the physical properties of water and air (specific heat and density).

As we document below in the box (TECHNICAL MATTERS), an average temperature increase of the entire world ocean by 0.01°C may seem small, but in fact it represents a very large increase in heat content. For example, if all the heat associated with this anomaly was instantaneously transferred to the entire global atmosphere (this can never happen we are only presenting a "thought" experiment) it would increase the average temperature of the atmosphere by approximately 10°C.

Thus, a small change in the mean (average) temperature of the ocean represent a very large change in the total heat content of the climate system.

Changes in the heat content of the various components of earth's climate system are important to quantify when scientists attempt to understand both the natural variability of earth's climate system and earth's response to the observed increases in greenhouse gases that has occurred since the beginning of the Industrial Revolution.

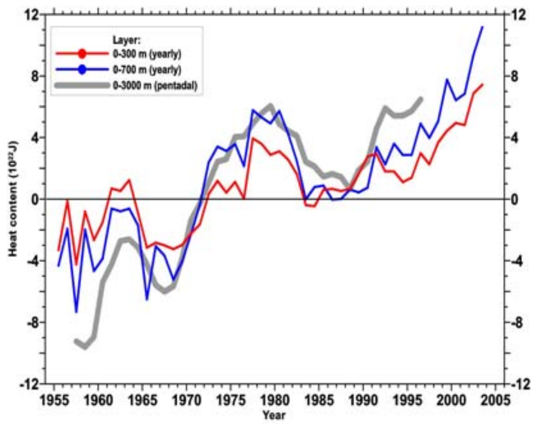

Figure 1. Time series of yearly ocean heat content (10^{22}J) for the 0-300 and 0-700 m layers and pentadal (5-year running composites for 1955-59 through 1994-98) ocean heat content (10^{22}J) for the 0-3000 m layer. Each yearly estimate is plotted at the midpoint of the year, each pentadal estimate is plotted at the midpoint of the 5-year period.

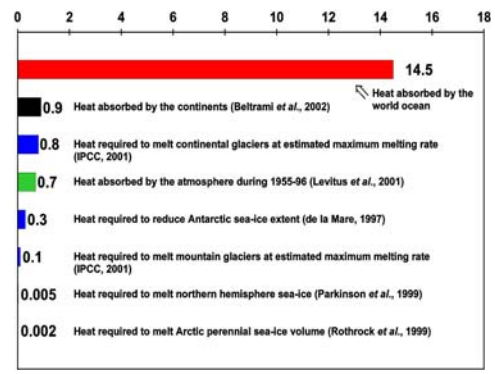

Figure 2. Estimates of earth's heat balance components (10^{22} J) for the 1955-1998 period.

WHAT DO TEMPERATURE OBSERVATIONS OF THE WORLD OCEAN TELL US ABOUT THE STATE OF EARTH'S CLIMATE SYSTEM?

Figure 1 shows the variability of ocean heat content for three different layers of the world ocean for the period 1955-2003:

1) 0-300 meters (approximately 1000 feet)
2) 0-700 meters (approximately 2300 feet)
3) 0-3000 meters (approximately 10,000 feet)

These results are based on approximately 7.3 million vertical profiles of temperature measured by a combination of research ships, naval vessels, merchant vessels, buoys, and other special instruments and observing platforms.

The results document that the world ocean has warmed during the past 50 years although not monotonically. The linear trend of ocean heat content is consistent with the amount of warming of earth's climate system expected due to the observed increase in greenhouse gases in earth's atmosphere since the beginning of the Industrial Revolution. The interdecadal variability, particularly the decrease in ocean heat content that occurred after 1980, is most likely associated with a phenomenon known as the Pacific Decadal Oscillation. This is an example of variability in the earth systems' heat content associated with internal variability of the atmosphere-ocean subsystems.

Based on the linear trend, the upper 3000 m of the world ocean has warmed by approximately 0.037°C during the past 50 years. This may seem very small to the layman but in fact represents a large change in heat content of the earth system.

The time series of heat content that we show represents values for the entire world ocean. The magnitude of the heat content changes varies regionally and in fact some ocean regions (*e.g.*, subarctic North Atlantic) exhibit cooling during much of the past 50 years. This is not unexpected.

Figure 2 shows the change in heat content of different subsystems of earth's climate system for the 1955-98 period. It is clear that the world ocean dominates earth's heat balance.

WHAT DOES THE PRESENT STATE OF THE WORLD OCEAN TELL US ABOUT THE FUTURE STATE OF THE ATMOSPHERE?

Ocean heat content is now recognized as being a critical metric for monitoring the state of earth's climate system and for understanding how earth's climate system works. In fact, this was strongly suggested in a report published by the U.S. National Research Council in 1979. The report emphasized the enormous capacity of the world ocean to absorb heat while exhibiting relatively small temperature change. However, now we have quantified this hypothesis.

The observed increase of heat in the world ocean is quantitatively consistent with what is expected from the observed increase in greenhouse gases in the atmosphere. Even if there were no further increase in greenhouse gases in earth's atmosphere, the observed increase in heat content of the world ocean means that the atmosphere will continue to warm until a new climate system equilibrium is reached.

Several atmosphere-ocean general circulation models reproduce the liner trends of ocean heat content shown in Figure 1. However, they only do so when the model atmosphere is forced by the same observed increase of greenhouse gases that have been documented for the real atmosphere.

WHY IS THIS WORK IMPORTANT TO POLICYMAKERS?

The work described here indicates that the world ocean is responding to the increase of greenhouse gases in the earth's atmosphere as expected. Policymakers need to be aware that because of the heat already put into the world ocean, we can expect more warming of the lower atmosphere and melting of sea-ice and glaciers. This is expected to happen even if no additional greenhouse gases are put into the atmosphere.

There is no longer controversy that the earth system will warm due to the increase of greenhouse gases in earth's atmosphere. The only question is how much warming will occur.

Critical questions include but are not limited to:

1) How much (and where) the atmosphere will warm?;
2) How much melting of sea-ice and glaciers will occur?;
3) How might the circulation of the atmosphere and ocean change in response to increasing greenhouse gases in the atmosphere?

The answers to such questions can only be answered with the use of atmosphere-ocean-cryosphere general circulation models.

FUTURE WORK

Substantial amounts of historical and modern ocean temperature profiles continue to become available as a result of ocean data management and observation programs. In particular, NOAA:

1) supports ocean observation program (*e.g.*, Argo profiling floats) that will produce improved estimates of ocean heat and freshwater content that are critical to the monitoring of the world ocean and to understanding the physics of climate change.

2) location and acquisition of historical oceanographic data that improves data coverage for the past 100 years and in particular, for the past 50 years.

During 2006 the ocean heat content estimates presented here will be updated with an additional 900,000 historical and modern temperature profiles and our time series of ocean heat content will be extended through the year 2005. Adding more historical data reduces the uncertainty associated with these estimates.

TECHNICAL MATTERS

The heat content (H) of a particle of water or air depends on the product of its mass (m), specific heat (c_p), and the temperature anomaly (ΔT) associated with this parcel.

If we consider the entire world ocean we can write this as an equation of the form $H_o = m_o c_{po} \Delta T_o$.
For the entire global atmosphere we can write this as an equation of the form $H_a = m_a c_{pa} \Delta T_a$.
If we equate these two equations we find that $\Delta T_a = (m_o c_{po} \Delta T_o)/ (m_a c_{pa})$.

Substituting in representative values into this equation we find that: $\Delta T_a = 1057 \Delta T_o$

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