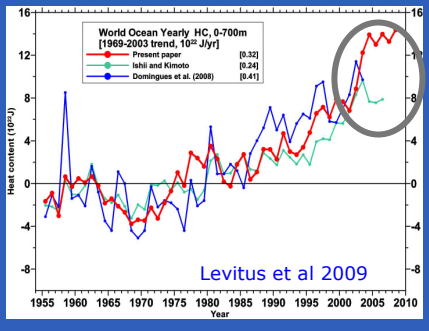
A pause in the rise in upper Ocean Heat Content

How unusual is it, and where did the heat go?

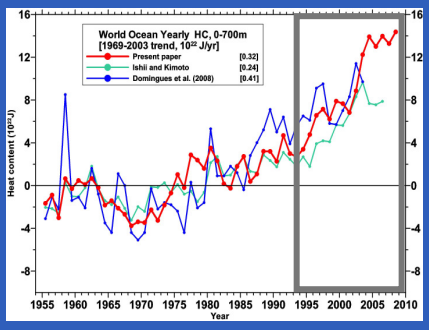
Caroline Katsman
Geert Jan van Oldenborgh

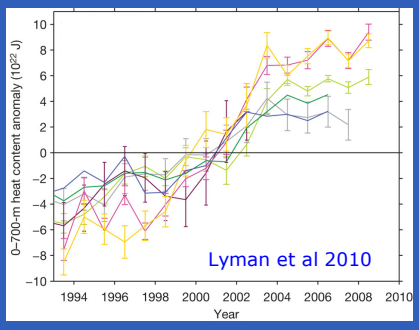
Royal Netherlands Meteorological Institute
KNMI - Global Climate Division
The Netherlands
Caroline.Katsman@knmi.nl

Pause in rise in Ocean Heat Content



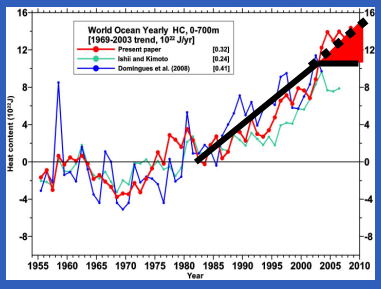
Pause in rise in Ocean Heat Content





1. How unusual is this, in light of greenhouse gas forcing?
2. Where did the heat go?

Earth's energy budget



missing heat
~ $0.3 \cdot 10^{22}$ J/yr = $9.5 \cdot 10^{13}$ W

area Earth = $5 \cdot 10^{14}$ m^2

⇒ heat budget change of only
0.2 W / m^2 over the past 7 yrs

– the imbalance in the Earth's energy budget due to greenhouse gas forcing is ~0.85 ±0.15 W/m^2 [Hansen et al 2005]

–satellites measure incoming shortwave radiation and outgoing longwave radiation at ~0.5 to 1.0 W/m^2 precision
[Trenberth et al 2010]

the ESSENCE ensemble

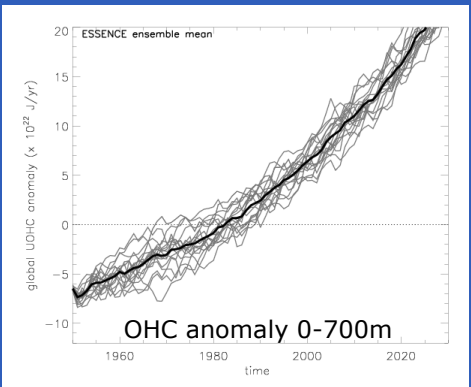
- 17-member ensemble of coupled climate model simulations [ECHAM5/MPI-OM]
  [see www.knmi.nl/~sterl/Essence]
- years 1950-2100, A1B emission scenario
- analysis of Ocean Heat Content

$$OHC = \iiint \rho \, c_p \, T_{ocean} \, dA_{ocean} \, dz$$

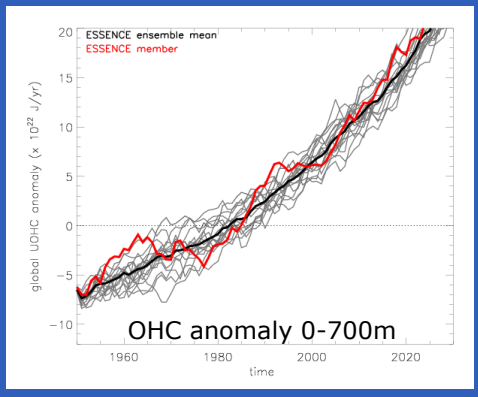
[ensemble mean deep-ocean drift correction applied]

- the large amount of data allow for a statistically robust analysis of events and processes involved

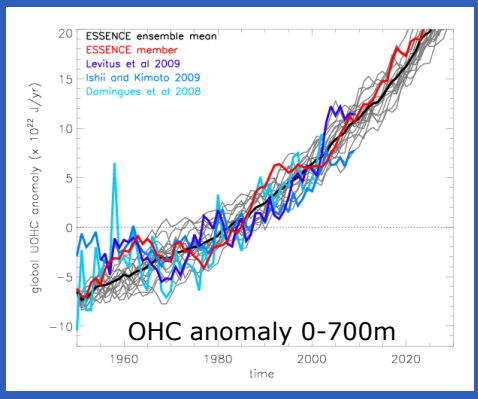
Upper OHC in ESSENCE



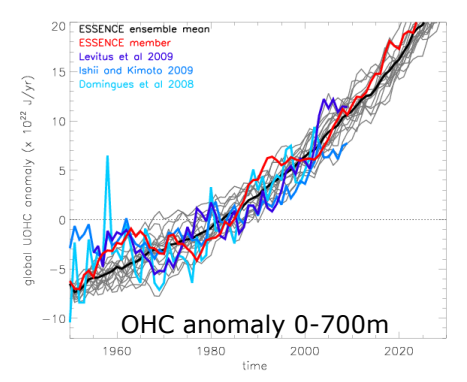
Upper OHC in ESSENCE

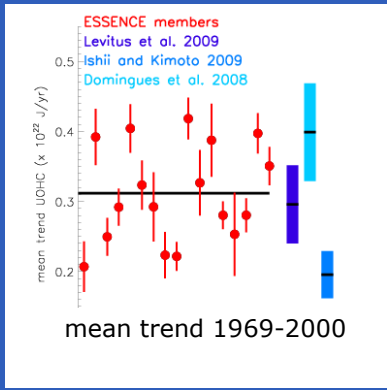


Upper OHC in ESSENCE



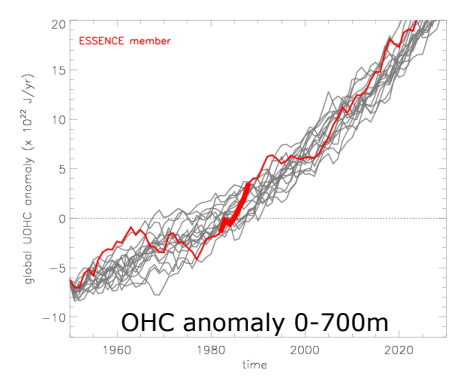
Upper OHC in ESSENCE

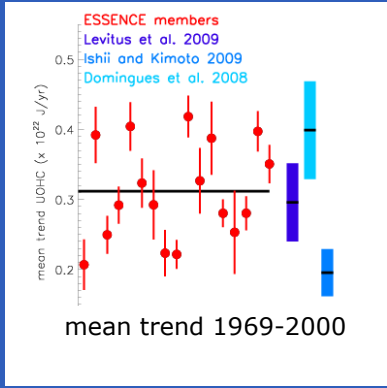




- long-term ESSENCE trends are in agreement with observation-based estimates
- variability model simulations encompasses observations

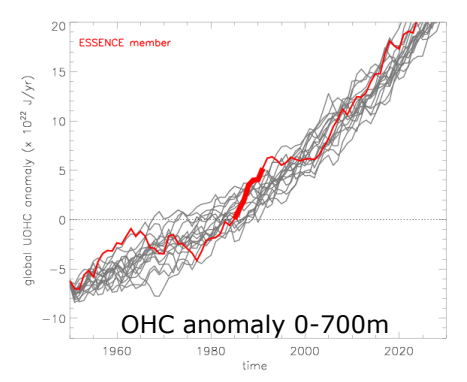
Upper OHC in ESSENCE

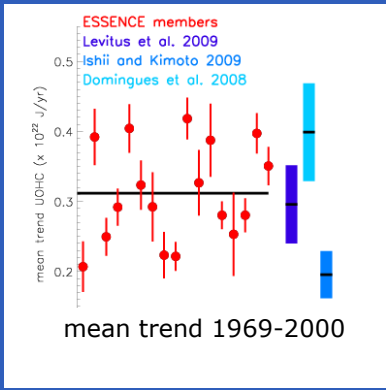




calculate 7-yr trends

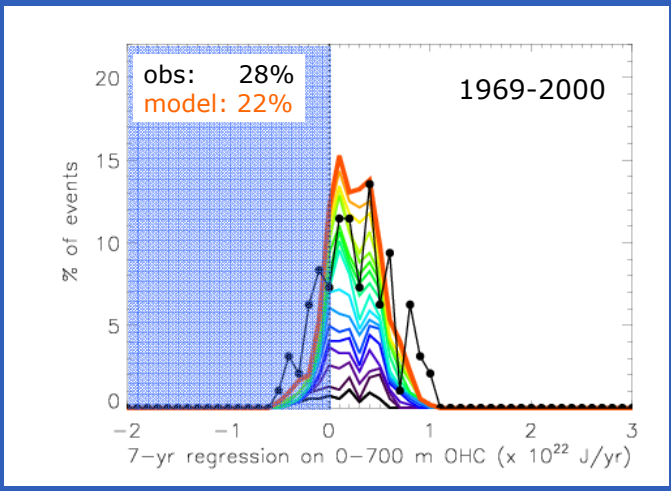
Upper OHC in ESSENCE





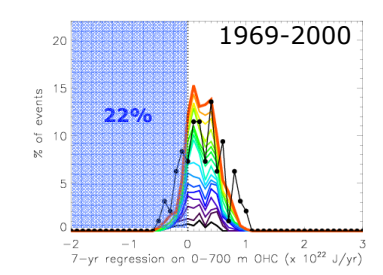
calculate 7-yr trends

distribution of 7-yr trends in OHC

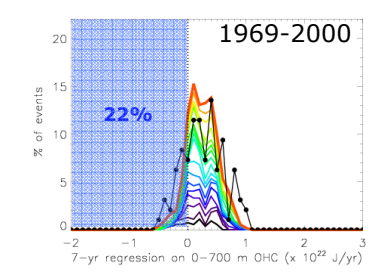


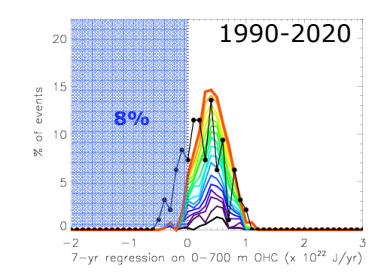
model: 32 yrs x 17 = 527 events
obs: 32 yrs x 3 = 96 events

how rare is a pause in the rise in OHC ?

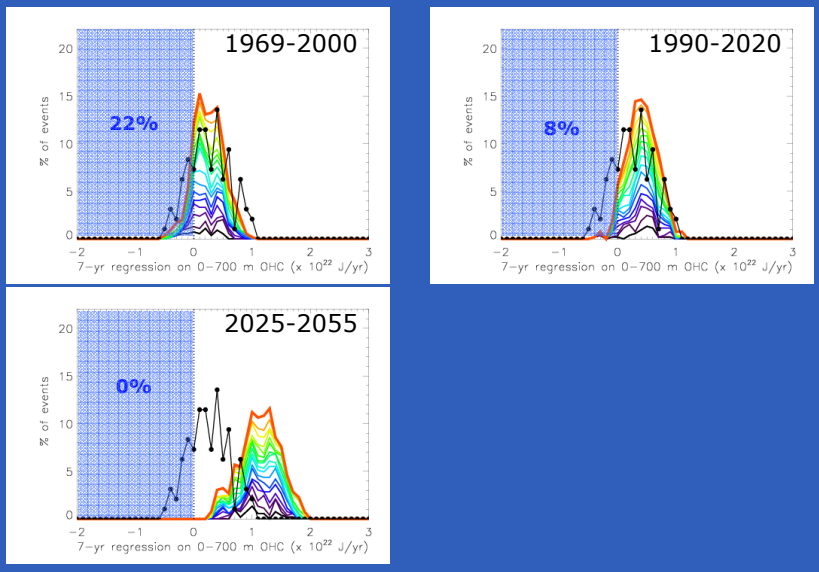


how rare is a pause in the rise in OHC ?

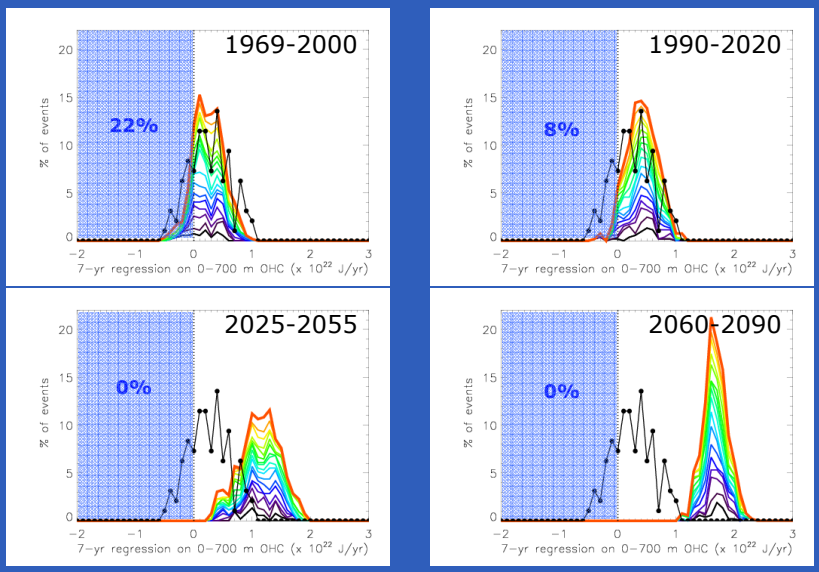




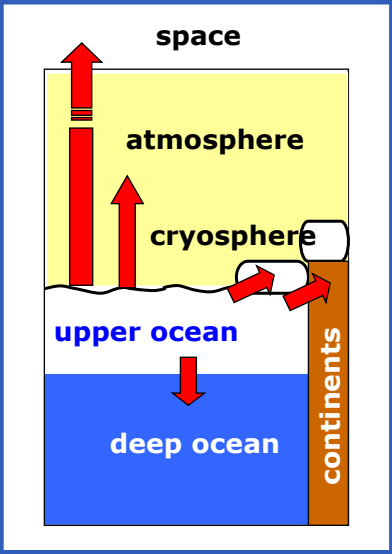
how rare is a pause in the rise in OHC ?



how rare is a pause in the rise in OHC ?



Where does the heat go?

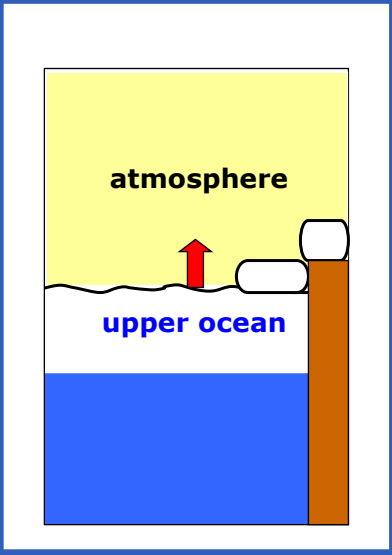


missing heat
7 yr x 0.3 10^{22} J/yr = 2 $\cdot 10^{22}$ J

if absorbed in the ocean then
$\Delta T_{ocean} \approx +0.02$ K

- atmosphere
- continents
- cryosphere
- radiation to space
- deep ocean

Where does the heat go?

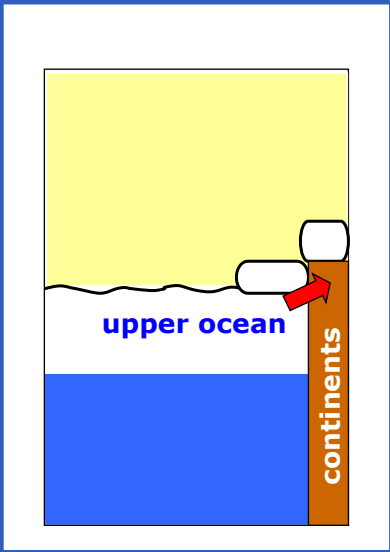


missing heat = 2 $\cdot 10^{22}$ J

atmosphere
- takes much less energy to warm one m^3 of air
  (vol. heat capacity x 3000)
- larger volume (x 20)

$\Rightarrow \Delta T_{atm} \approx +3$ K

Where does the heat go?



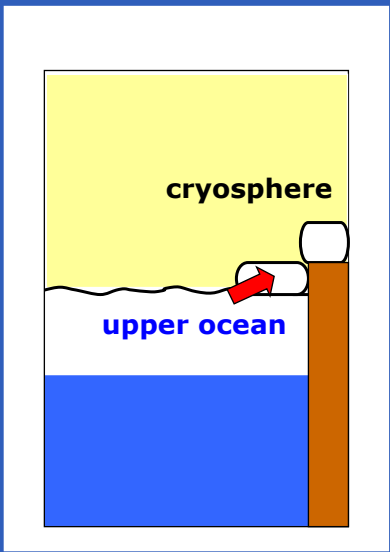
missing heat = $2 \cdot 10^{22}$ J

continents

- takes 40% less energy to warm one m^3 of rock
  (vol. heat capacity x 0.6)
- heat penetrates only over ~50m in a few years

$\Rightarrow \Delta T_{land} \approx +1$ K (upper 50m)

Where does the heat go?



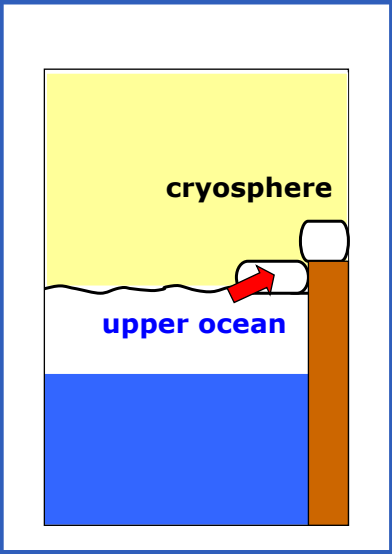
missing heat = $2 \cdot 10^{22}$ J

cryosphere [warming]

- takes half the energy to warm one m^3 of ice
  (vol. heat capacity x 0.5)
- volume of the ice sheets over which heat can be absorbed is much smaller

$\Rightarrow \Delta T_{ice} \approx +6$ K (upper 100m)

Where does the heat go?



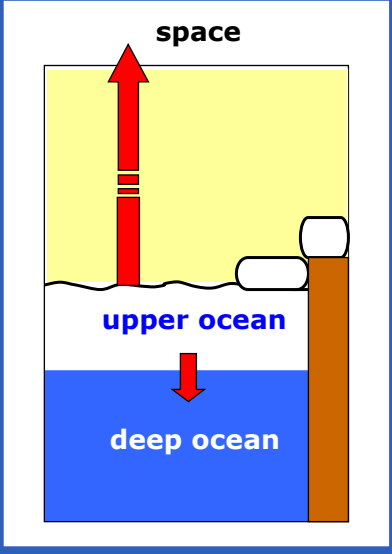
missing heat = 2 ·10^{22} J

cryosphere
- melt 6 ·10^{16} kg ice

⇒ global mean SLR ≈ +0.17m (x 8 observed)

⇒ 3 x current sea ice extent Arctic Ocean

Where does the heat go?



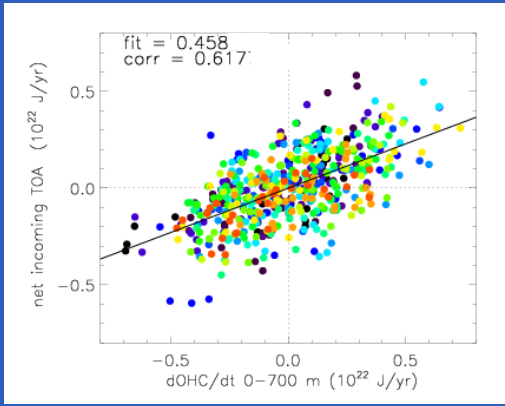
missing heat
7 yr x 0.3 10^{22} J/yr = 2 ·10^{22} J

- radiation to space
- deep ocean

plateau in upper OHC
⇔ downward trend superposed on longterm upward trend
⇔ 7-yr trends with respect to the longterm trend

period 1990-2020

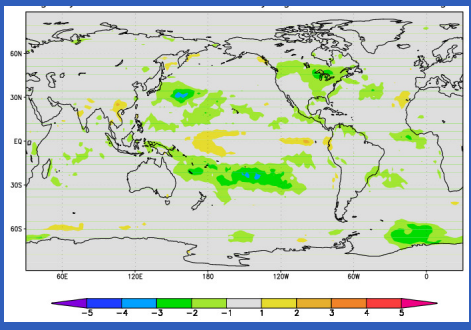
Top of the Atmosphere (TOA) Radiation



46% of the variation in upper OHC is associated with a variation in the net incoming TOA radiation

upper ocean cooling ⇔ less net radiation in ⇔ more radiation out

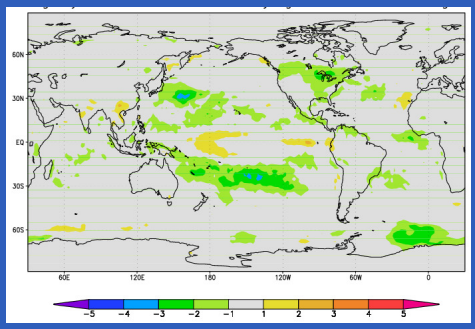
Top of the Atmosphere Radiation



signal is most pronounced in the off-equatorial Pacific Ocean

⇒ (decadal) ENSO

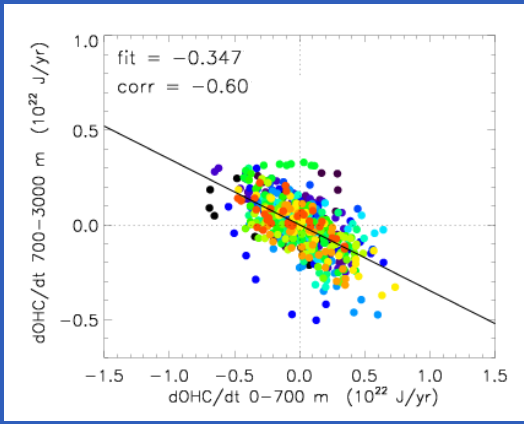
Top of the Atmosphere Radiation



upper ocean heat content reduces about 2 yrs after a period with more El Niño's than La Niña's

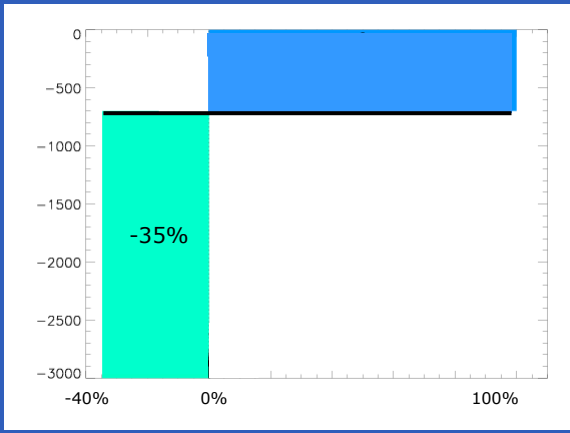
El Niño ⇒ sea surface warmer than usual ⇒ larger heat loss ⇒ ocean heat content reduced after a while

Deep Ocean Heat Content



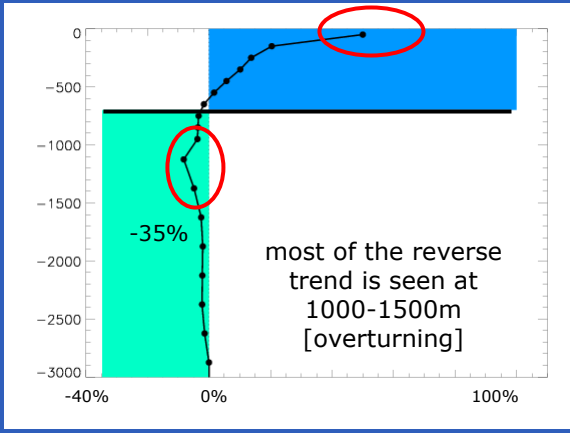
35% of the decrease in upper OHC (0-700 m)
is associated with an increase in deep OHC (700-3000 m)

Deep Ocean Heat Content



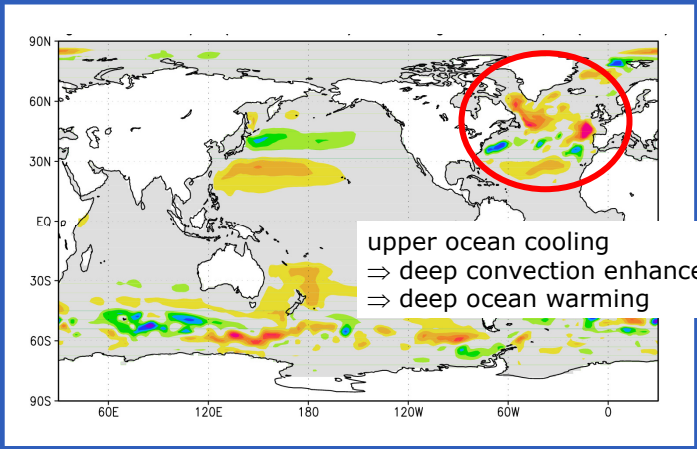
Deep Ocean Heat Content

50% of the trend in UOHC (0-700m) is a signal in the upper 100 m [thermocline]



trend HC over depth associated with UOHC trend over 0-700m

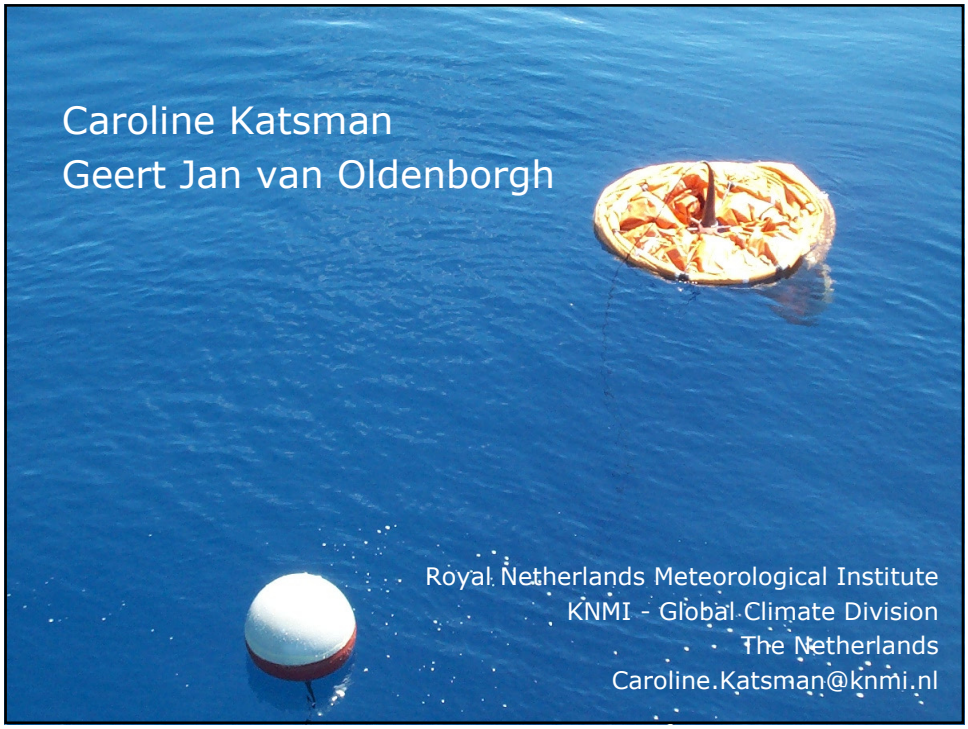
Deep Ocean Heat Content



local trend in deep OHC (700-3000 m) associated with a relatively cool upper ocean (0-700m)

Summary

- A pause in the rise in upper Ocean Heat Content as recently observed is not unusual in the late 20th / early 21st century, despite greenhouse gas forcing [model: 22% chance of negative 7-yr trend]
- According to the model simulations, such events become more rare as time progresses, and will be absent in the second half of the 21st century
- A pause in the rise in upper OHC is associated with increased radiation to space (~45%) and an increase in the deep OHC (~35%)
- The causes for these energy exchanges are the variability in (decadal) ENSO and in the Atlantic Meridional Overturning Circulation


Caroline Katsman
Geert Jan van Oldenborgh
Royal Netherlands Meteorological Institute
KNMI - Global Climate Division
The Netherlands
Caroline.Katsman@knmi.nl