Oceans and Climate

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Large-scale ocean circulation

driven at the surface, by fluxes of

- momentum (wind)
- heat
- fresh water (evaporation-precipitation)

$\Rightarrow$ density sea water = function(T,salinity)

surface (~ 1000 m):
wind-driven circulation

deep ocean:
thermohaline circulation
This lecture

i. observing the ocean

ii. characteristics ocean circulation

iii. ocean and climate
   • abrupt changes in the thermohaline circulation
   • sea level rise
ocean observations
Observations

hydrographic sections:
• CTD (Conductivity-Temperature-Depth)
• XBT (eXpandable BathyThermograph)
• water samples (O$_2$, nutrients)

moored instruments
• current meters
• CTDs
Observations

satellites:
• sea surface height ⇒ currents
• sea surface temperature
• ocean color (biological activity)

autonomous instruments:
• profiling floats ⇒ 2 km depth
Argo float network
Atlantic Ocean section

salinity WOCE section A16 (25 W, Atlantic Ocean)

final contact with atmosphere determines characteristics (T,S,O$_2$..)
ocean circulation
wind-driven circulation

large-scale gyres
wind-driven circulation

large-scale gyres
strong currents on the western side of ocean basins
wind-driven circulation

large-scale gyres

strong currents on the western side of ocean basins

Antarctic Circumpolar Current
thermohaline circulation

currents driven by variations in ocean density (T, S)

- geometry basins / forcing determine convection
- characteristics ‘convective end product’ differ
  ⇒ specific watermasses at selected locations/depths
The “ocean conveyor belt”

[Broecker, 1991]
convective watermasses

NADW: warm (+2 °C) salty (35 ‰)
AABW: cold (-2 °C) fresh (34.6 ‰)
heat transport by oceans

- thermohaline circulation $\Rightarrow$ Atlantic Ocean
- wind-driven gyres $\Rightarrow$ Pacific Ocean
- small-scale instabilities $\Rightarrow$ Southern Ocean

[Trenberth and Caron, 2001]
oceans & climate

abrupt changes in the thermohaline circulation
multiple equilibria

temperature-driven
multiple equilibria

temperature-driven

salinity-driven
multiple equilibria
in a warming climate

- temperature-driven
- salinity-driven
multiple equilibria

- temperature
- salinity

possible abrupt change

ratio salinity/temperature-forcing

strength circulation
abrupt change in the past

Younger Dryas (12-13.000 BP):
- Greenland: -15°C
- Western Europe: -5°C

⇒ linked to reduction thermohaline circulation
abrupt changes in the future

forced collapse + greenhouse gas forcing

[“what if” scenario]

just after collapse
abrupt changes in the future

forced collapse

just after collapse

forced collapse + GHG

$T_{2100} - T_{2000}$
abrupt changes in the future
oceans & climate
sea level rise
Global mean sea level rise

IPCC 5AR (2013)
Global mean sea level rise

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Global mean sea level rise

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Global mean sea level rise

IPCC 5AR (2013)

- Reconstructions
- Tide gauges
- Satellites

1.7 mm/yr
3.2 mm/yr
Sea level budget [1971-2010]
Sea level budget [1993-2010]
Sea level projections

summed contributions of individual components

global mean thermal expansion

glaciers & ice caps

Greenland

Antarctica
Sea level projections

summed contributions of individual components

- Global mean thermal expansion
- Glaciers & ice caps
- Greenland
- Antarctica

36-82 cm

IPCC 5AR (2013)
oceans & climate

regional sea level rise
Observed sea level change

natural variability +
spatially varying long-term trends
Changes in ocean density and dynamics + atmospheric loading causes regional differences.
Causes regional differences
changes in Earth’s gravity field

changing ice sheet
⇒ mass distribution
⇒ gravity field
⇒ “state of rest” ocean surface

geoid
Self-gravitation effect

gravitational pull on ocean towards large (ice)mass
Self-gravitation effect

ice mass loss $\implies$ melt water added to the ocean
Self-gravitation effect

Ice mass loss $\Rightarrow$ melt water added to the ocean $\Rightarrow$ sea level tilts

Sea level drop
Self-gravitation effect

ice mass loss $\Rightarrow$ melt water added to the ocean
$\Rightarrow$ sea level tilts

rise $<$ global mean
Self-gravitation effect

ice mass loss $\implies$ melt water added to the ocean
$\implies$ sea level tilts

rise $>$ global mean
Self-gravitation effect

Melt water distribution

Mitrovica et al (2001)
Glacial Isostatic Adjustment

a. Peak glaciation

b. During deglaciation
Land water storage

building of dams

NOTE: self-gravitational needs to be accounted for

groundwater mining
Regional projections

- Ocean expansion
- Glaciers & ice caps
- Greenland
- Antarctica
- GIA
- Land storage
Moderate

Warm

a.) Land ice (RCP4.5)

b.) Land ice (RCP8.5)

SL change (m)

0.0  0.1  0.2  0.3  0.4
e) Land water (CMIP3 - A1B)

f) Land water (CMIP3 - A2)
Moderate

Warm

e.) Land water (CMIP3 - A1B)
f.) Land water (CMIP3 - A2)

g.) Dynamic Ice Sheet

scenario independent

SL change (m)
Moderate  Warm

e.) Land water (CMIP3 - A1B)
f.) Land water (CMIP3 - A2)

g.) Dynamic Ice Sheet
h.) GIA
Moderate

Warm

a.) Scenario A sum

b.) Scenario B sum

SL change (m)
Spatial variations
To conclude...

The oceans plays an important role in climate and (natural and forced) climate change, but we still know surprisingly little about them.
To conclude...

“The oceans are the principal reservoir for the storage of CO$_2$, of heat and of ignorance”

(Walter Munk, The Evolution of Physical Oceanography in the Last Hundred Years, 2002)
Ocean heat uptake

World Ocean Yearly HC, 0-700m [1969-2003 trend, 10²² J/yr]
- Present paper [0.32]
- Ishii and Kimoto [0.24]
- Domingues et al. (2008) [0.41]

Ocean 93.4%
- Atmosphere 2.3%
- Continents 2.1%
- Glaciers & ice caps 0.9%
- Arctic sea ice 0.8%
- Greenland Ice Sheet 0.2%
- Antarctic Ice Sheet 0.2%
Caveats sea level projections

- vertical land movement (natural and human-induced)

Jakarta: 10-20 cm/yr subsidence
Caveats sea level projections

- vertical land movement
- ocean $\Rightarrow$ ice sheet interactions

Glacier acceleration triggered by ocean warming

Holland et al. (Nat. Geosc., 2008)
Caveats sea level projections

- vertical land movement
- ocean $\Rightarrow$ ice sheet interactions
- ice sheet $\Rightarrow$ ocean interactions

melt water affects ocean dynamics and sea level
Caveats sea level projections

- vertical land movement
- ocean $\Rightarrow$ ice sheet interactions
- ice sheet $\Rightarrow$ ocean interactions
- marginal seas are not resolved

IPCC 4AR models

IPCC 5AR models
AN INTEGRATED FLOOD RISK ASSESSMENT FOR THE NETHERLANDS
Sea level projections focused mostly on likely, global mean change coastal protection regional change, worst-case scenario
Integrated flood risk assessment

Greenland:
- Extrapolation of observations

Ice sheet dynamics
Ice sheet dynamics

Greenland
- Extrapolation of observations

Antarctica
persistence / acceleration of observed changes in
- Amundsen Sea Embayment
- marine glaciers East Antarctica
- northern Antarctic Peninsula
Storms & surges

Sterl et al (Oce. Sci, 2009)
Storms & surges

Sterl et al (Oce. Sci, 2009)
Extreme river discharge

- 1:1250 year discharge of the Rhine river increases by **5 to 40%** due to changes in the amount and character of precipitation in the catchment area

Extreme river discharge

- 1:1250 year discharge of the Rhine river increases by **5 to 40%** due to changes in the amount and character of precipitation in the catchment area.
- Upstream flooding in Germany will reduce the peak discharge before it reaches the Netherlands.
- Extreme discharge increases by **10%**

Impacts: Rotterdam harbour

Maeslant storm surge barrier - closure frequency
• current: once every 10 years

Impacts: Rotterdam harbour

Maeslant storm surge barrier - closure frequency
• current: once every 10 years
• 2100, with extreme sea level rise:
  once every few years – few months

Impacts: Rotterdam harbour

Maeslant storm surge barrier - closure frequency
• current: once every 10 years
• 2100, with extreme sea level rise:
  once every few years – few months
  - larger chance that closure of the barrier coincides with high river discharge