



# Oceaancirculatie en klimaat

0800/a010841/3827

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Mondiaal Klimaat (KS/MK)

<http://svs.gsfc.nasa.gov/vis/a010000/a010800/a010841/>

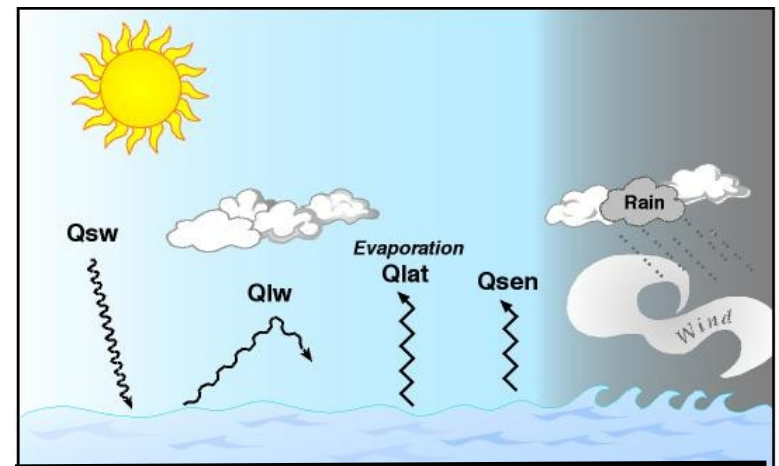


# grootschalige oceaancirculatie

- aangedreven aan het oppervlak, door fluxen van
    - impuls (wind)
    - warmte (straling, verdamping, voelbare warmte)
    - zoet water (verdamping / neerslag)
- ⇒ dichtheid  $\rho = \text{functie}(T, S, p)$

Oppervlak (~ 1000 m):  
windgedreven circulatie

diepzee:  
thermohaliene circulatie





# het komende uur...

- i. observaties
- ii. windgedreven circulatie (waarnemingen, theorie)
- iii. thermohaliene circulatie (waarnemingen, theorie)
- iv. oceaan en klimaat(-verandering)
  - zeespiegelstijging
  - verzwakking thermohaliene circulatie?

## (i) observaties

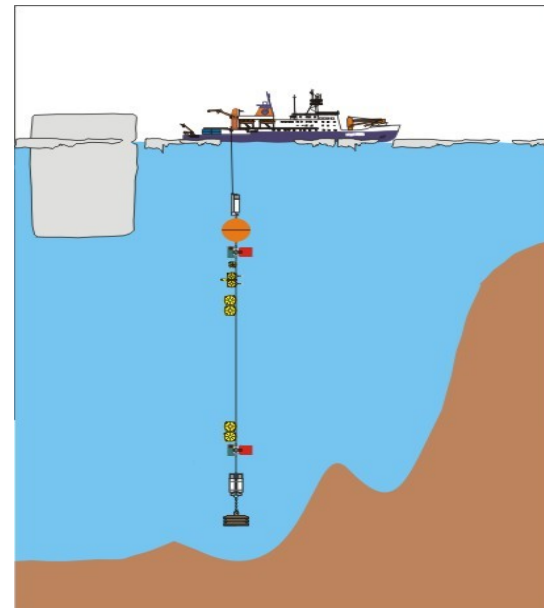


hydrografische secties:

- CTD (Conductivity-Temperature-Depth)
- XBT (eXpandable BathyThermograph)
- water monsters (zuurstof/nutrienten/calibratie CTD)

verankerde meetinstrumenten:

- stroommeters
- CTD-sensoren

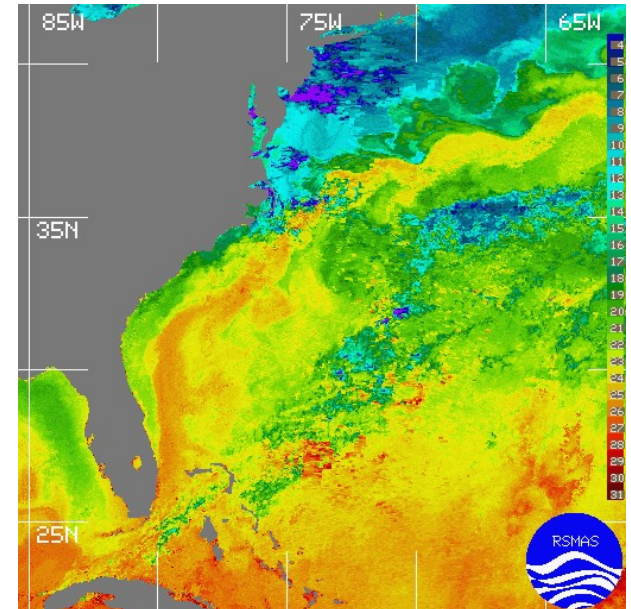




## (i) observaties

satellieten:

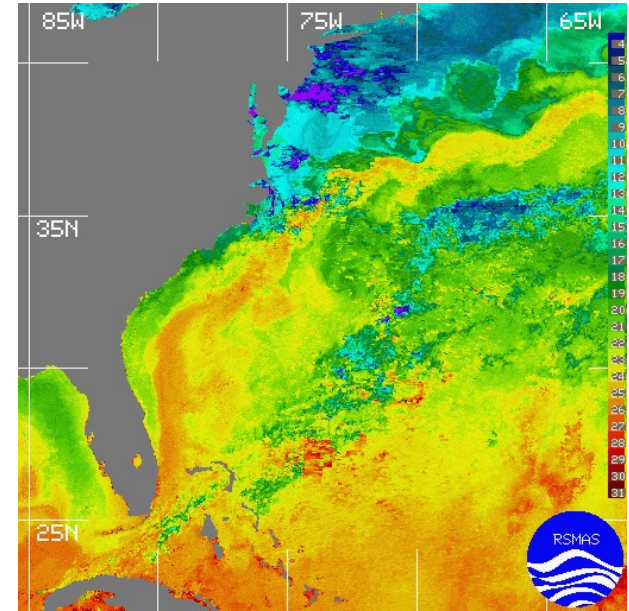
- hoogte zeeoppervlak  $\Rightarrow$  stromingen
- temperatuur oppervlak
- kleur zeewater (plankton)



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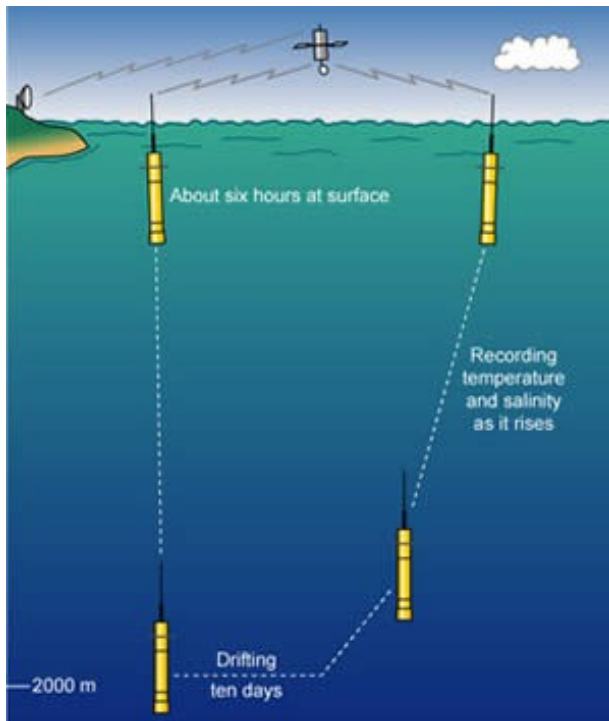
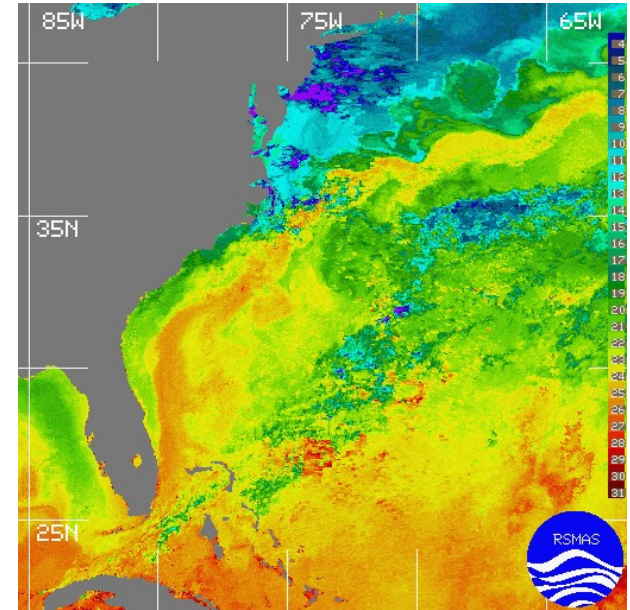
autonome instrumenten:

- drifters  $\Rightarrow$  oppervlakte

## (i) observaties

satellieten:

- hoogte zeeoppervlak  $\Rightarrow$  stromingen
- temperatuur oppervlak
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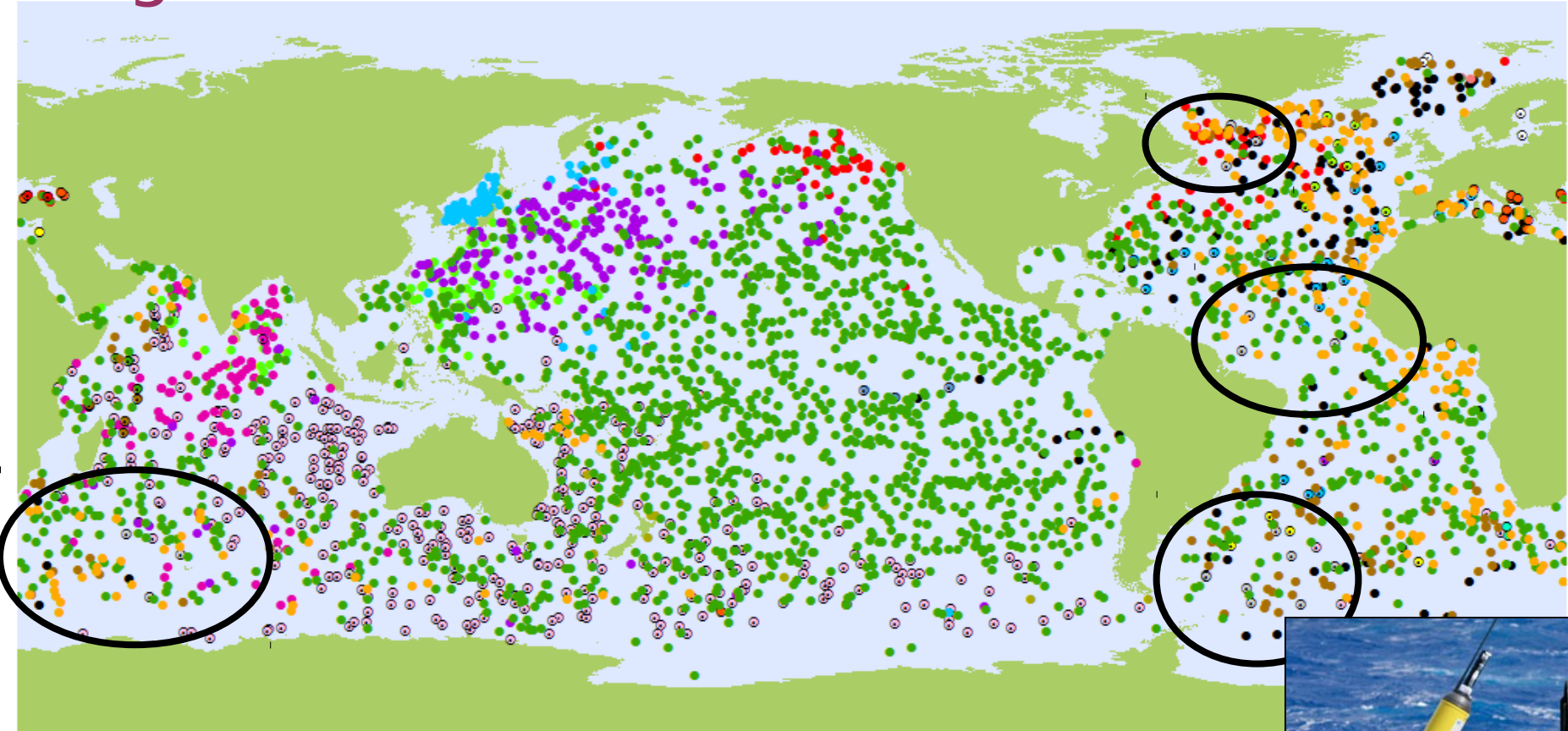


autonome instrumenten:

- drifters  $\Rightarrow$  oppervlakte
- profiling floats  $\Rightarrow$  2 km diepte

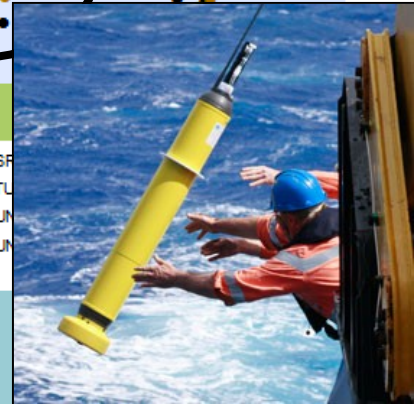


# Argo float network



3606 Floats

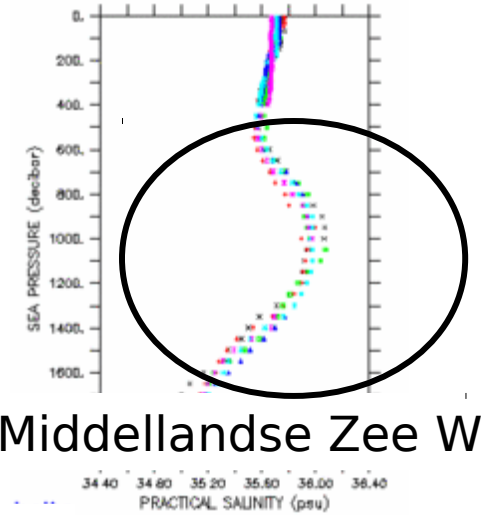
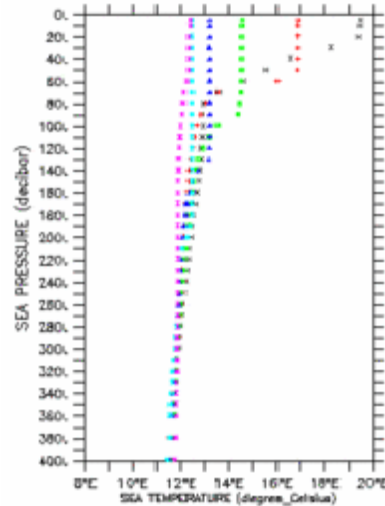
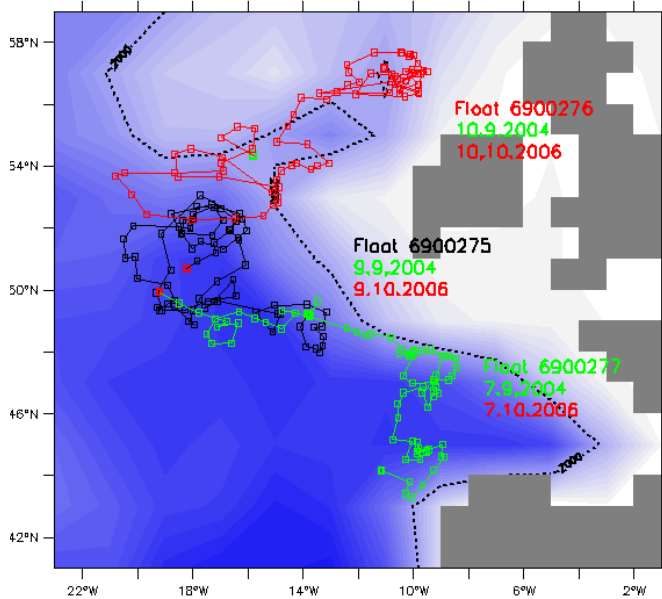
● ARGENTINA (4)	● CANADA (83)	● FRANCE (256)	● IRELAND (10)	● SOUTH KOREA (86)	● NEW ZEALAND (12)	● SPAIN (29)
● AUSTRALIA (389)	● CHINA (85)	● GABON (1)	● ITALY (19)	● LEBANON (1)	● NORWAY (2)	● TURKEY (1)
● BRAZIL (2)	● ECUADOR (3)	● GERMANY (166)	● JAPAN (208)	● MAURITIUS (3)	● SOUTH AFRICA (2)	● UNITED STATES (1)
● BULGARIA (3)	● FINLAND (5)	● INDIA (103)	● KENYA (3)	● NETHERLANDS (20)	● UNITED KINGDOM (1)	● UNITED STATES (1)



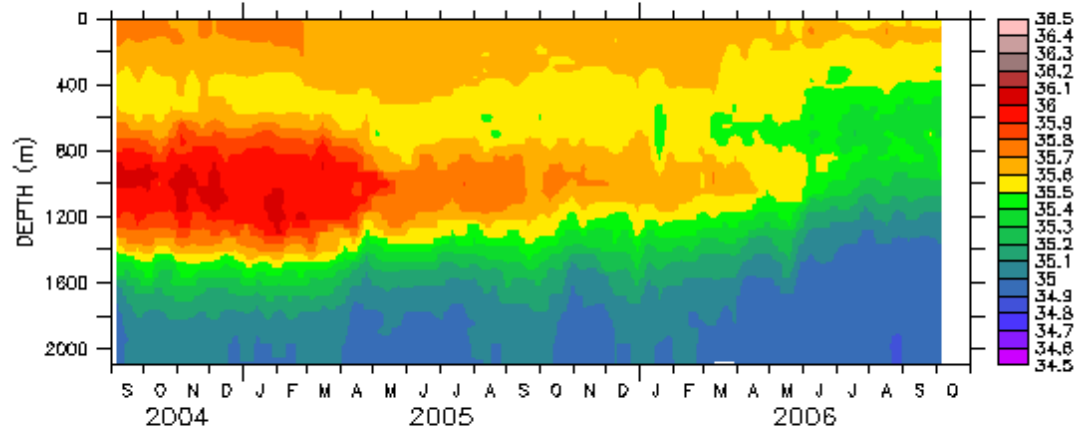
oktober 2013- 3606 floats  
Klimaforschung  
A. Sterl, 07.11.2013



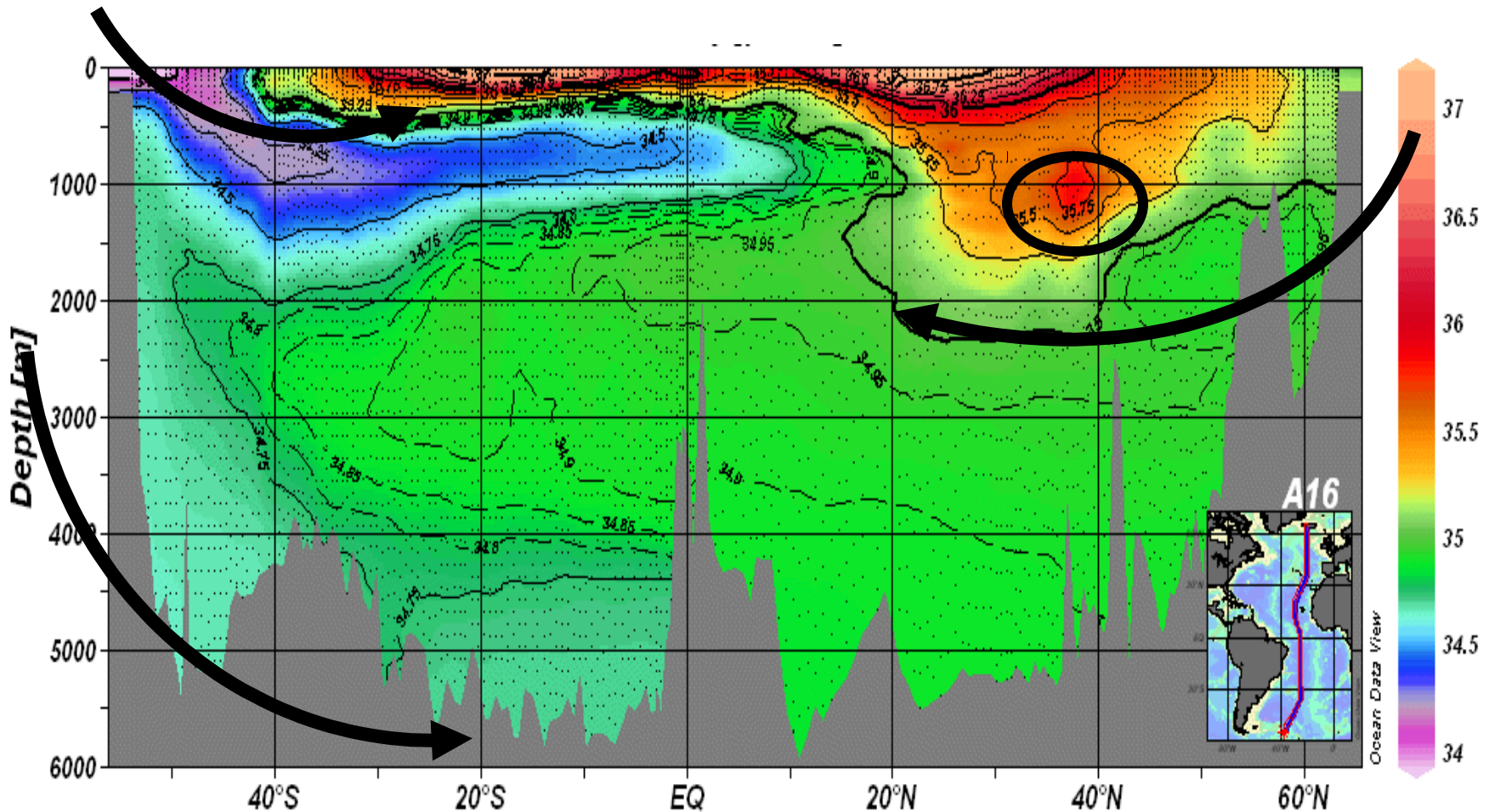
# float tracks en profielen



Middellandse Zee Water



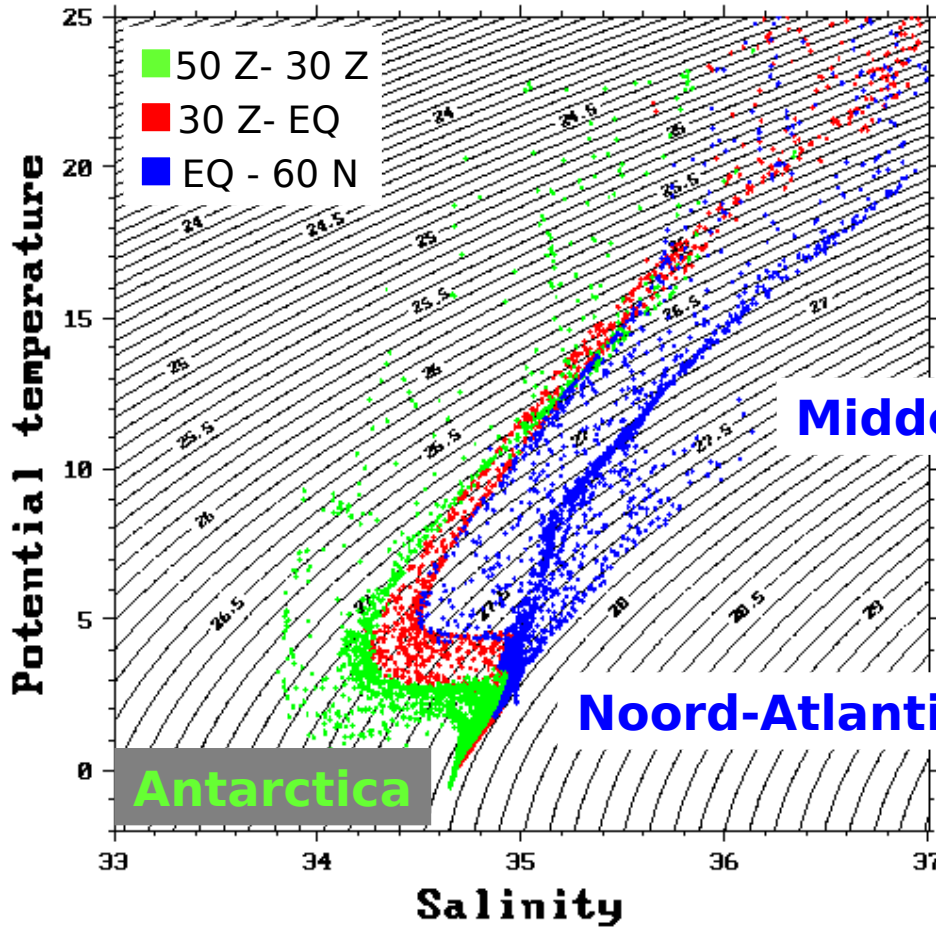
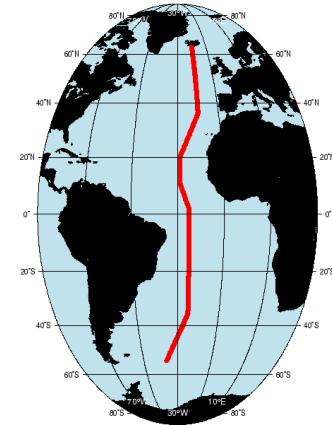
# voorbeeld hydrografische sectie



zoutgehalte WOCE sectie A16 (25 W, Atlantische Oceaan)

→ laatste contact met de atmosfeer bepaalt karakteristieken (T, S, O<sub>2</sub>, .....

# T-S diagram



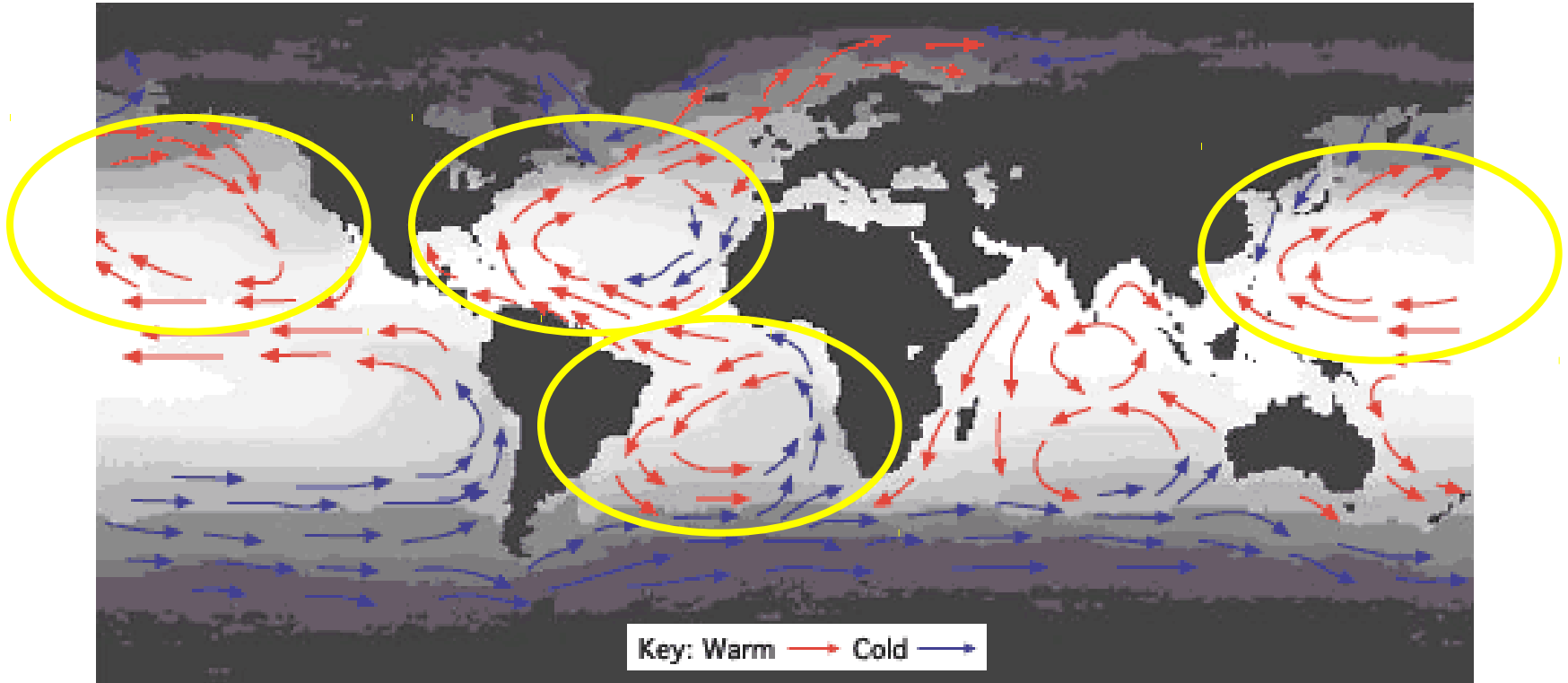
WOCE A16 - Atlantische Oceaan

A satellite-style map of the world showing wind-driven ocean circulation patterns. The map uses a color scale from blue (cold) to red (warm) to represent sea surface temperatures. The text "windgedreven circulatie" is overlaid in the center of the map.

windgedreven circulatie

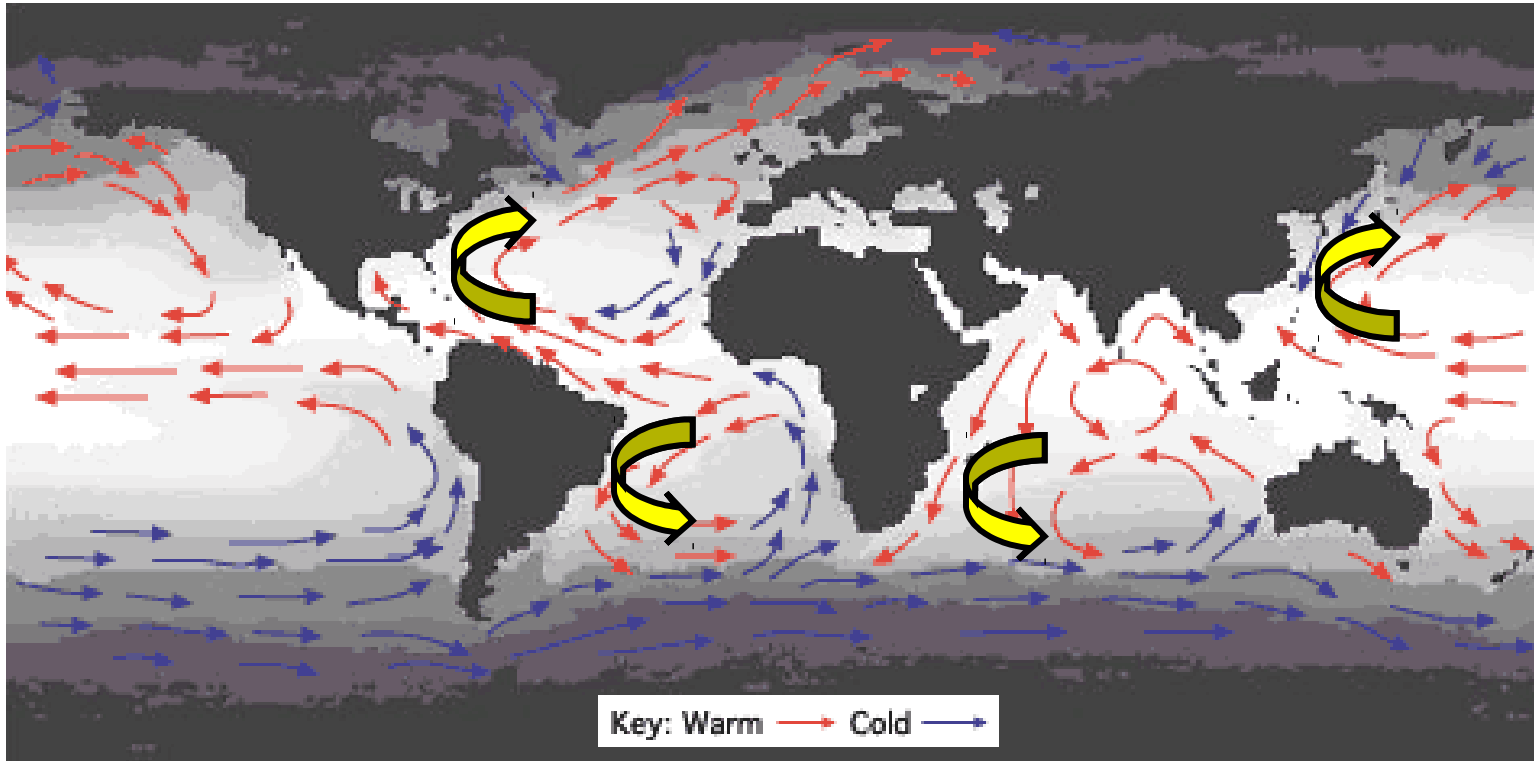


# windgedreven circulatie



gyres (grootschalige wervels)

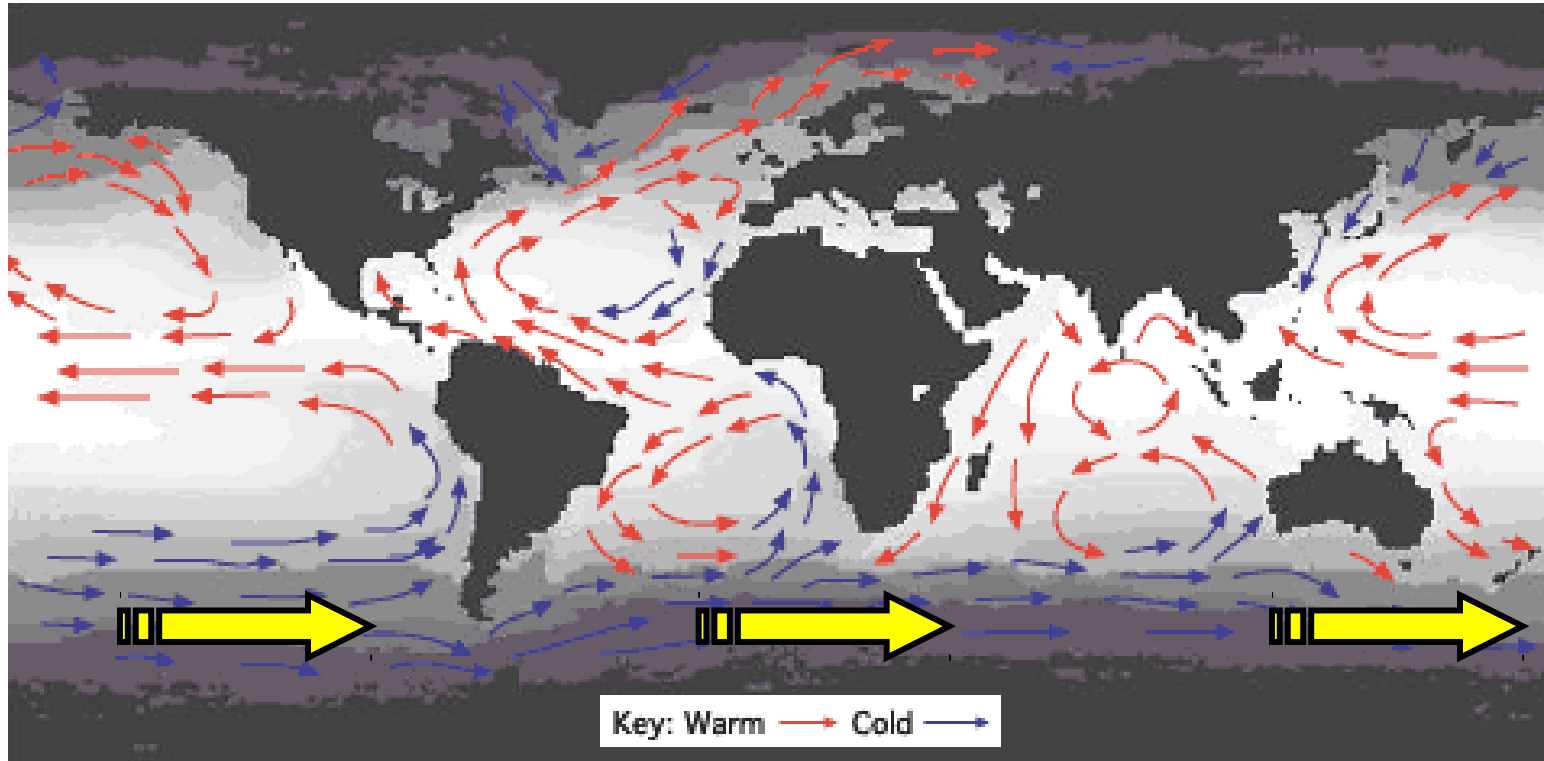
# windgedreven circulatie



gyres (grootschalige wervels)

sterke stromingen aan de westkant van de bassins

# windgedreven circulatie



gyres (grootschalige wervels)

sterke stromingen aan de westkant van de bassins

- sterke stroming helemaal rond Antarctica (ACC)

# windgedreven gyres

een ijsberg drijft niet met de wind mee !  
 [Nansen, 1898]

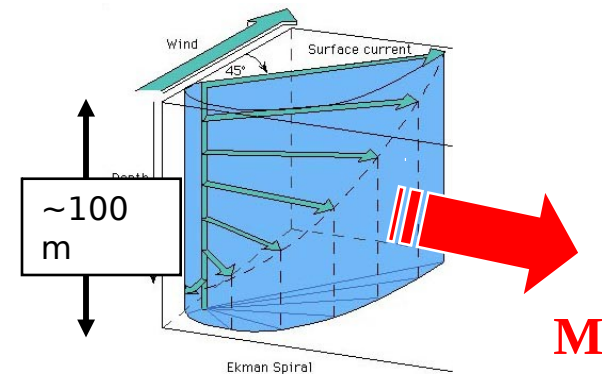
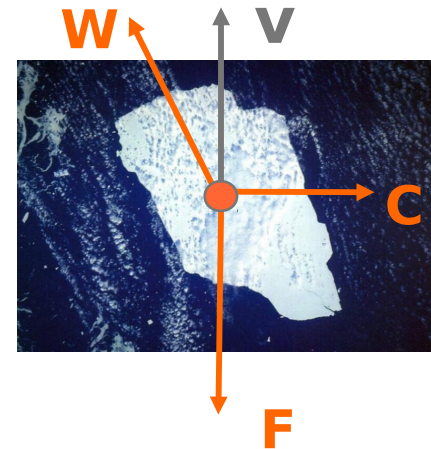
**Wind + Fricctie + Coriolis = 0**

stroming aan het oppervlak  
 maakt een hoek van  $45^\circ$  met de  
 wind; hoe dieper hoe groter de  
 hoek

massatransport loodrecht op de  
 wind  
 [Ekman, 1902]

windgedreven gyres in de oceaan  
 worden veroorzaakt door spatiële  
 variaties in het Ekman transport

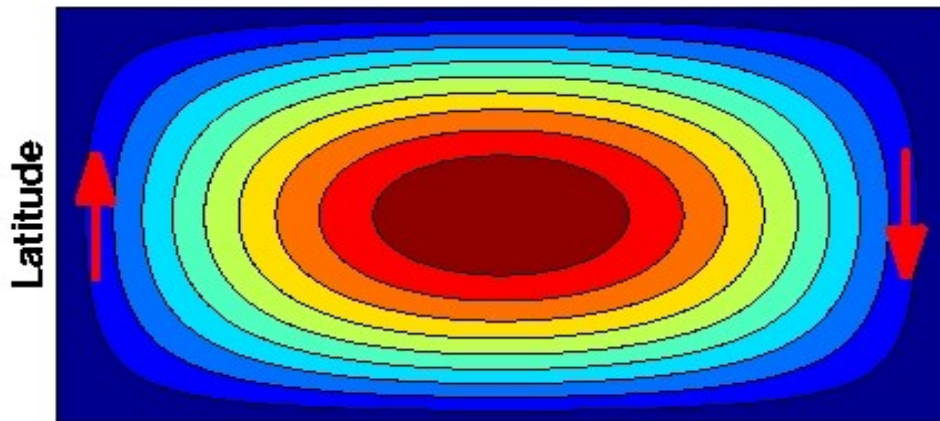
[Sverdrup, 1947]





# westelijke versterking

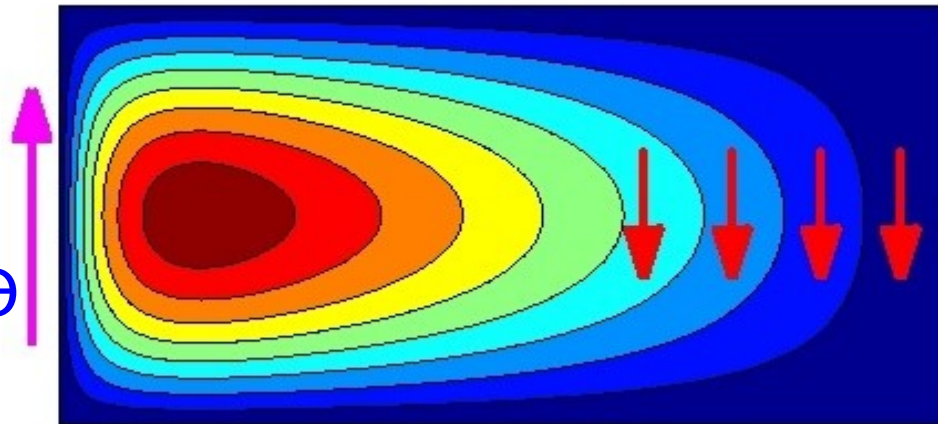
oorzaak: variatie van de aardrotatie met de breedtegraad  
[Stommel, 1948]



$f = \text{constant}$

...

$f = 2\Omega \sin \theta$



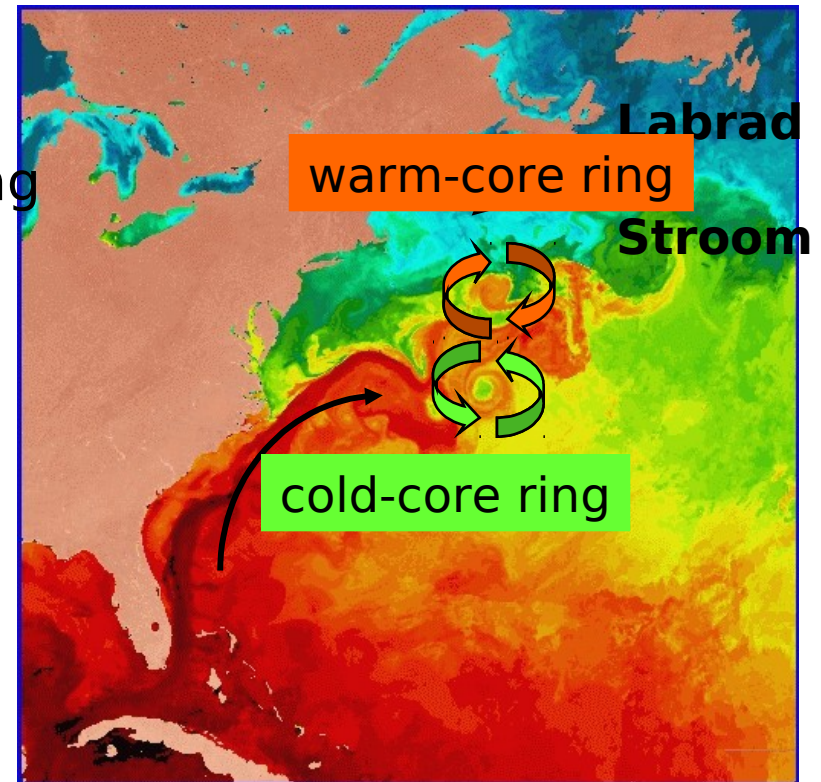
# variabiliteit windgedreven circulatie

fluctuaties / wervels:

- ~ 100 km, tijdschaal: weken-jaren
- ontstaan door
  - variaties windforcering
  - instabiliteit oceaanstroming

van belang voor

- warmtetransport
- menging
- dissipatie

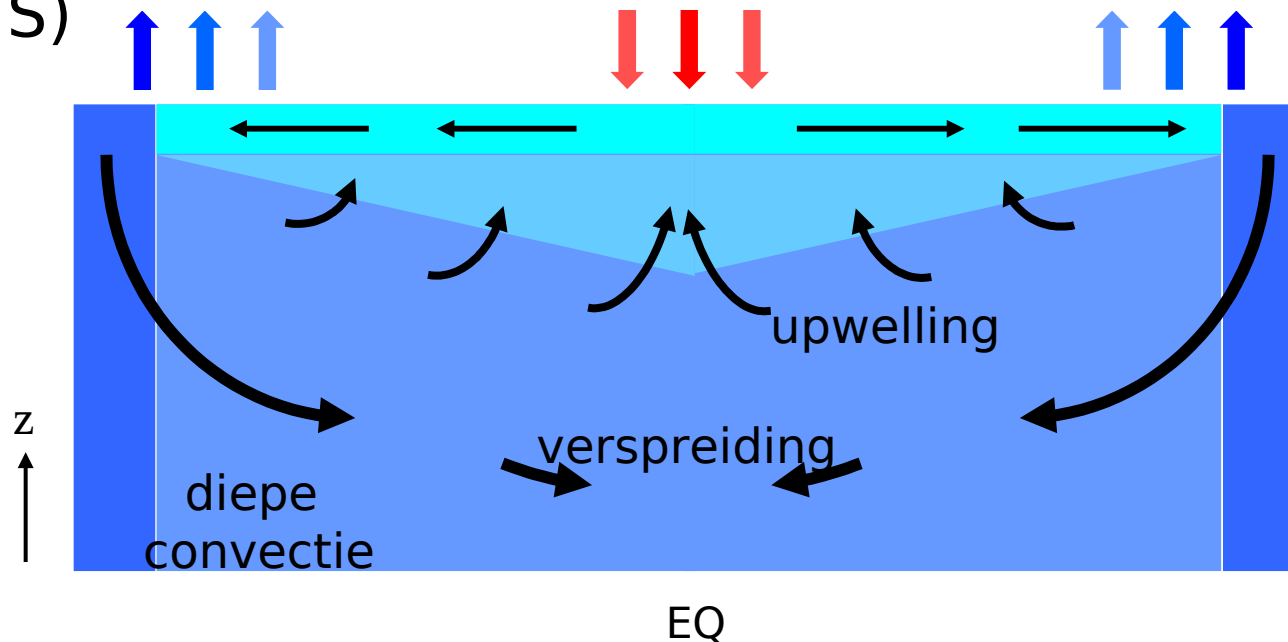




thermohaliene circulatie

# thermohaliene circulatie

stromingen gedreven door variaties in dichtheid  
(T, S)

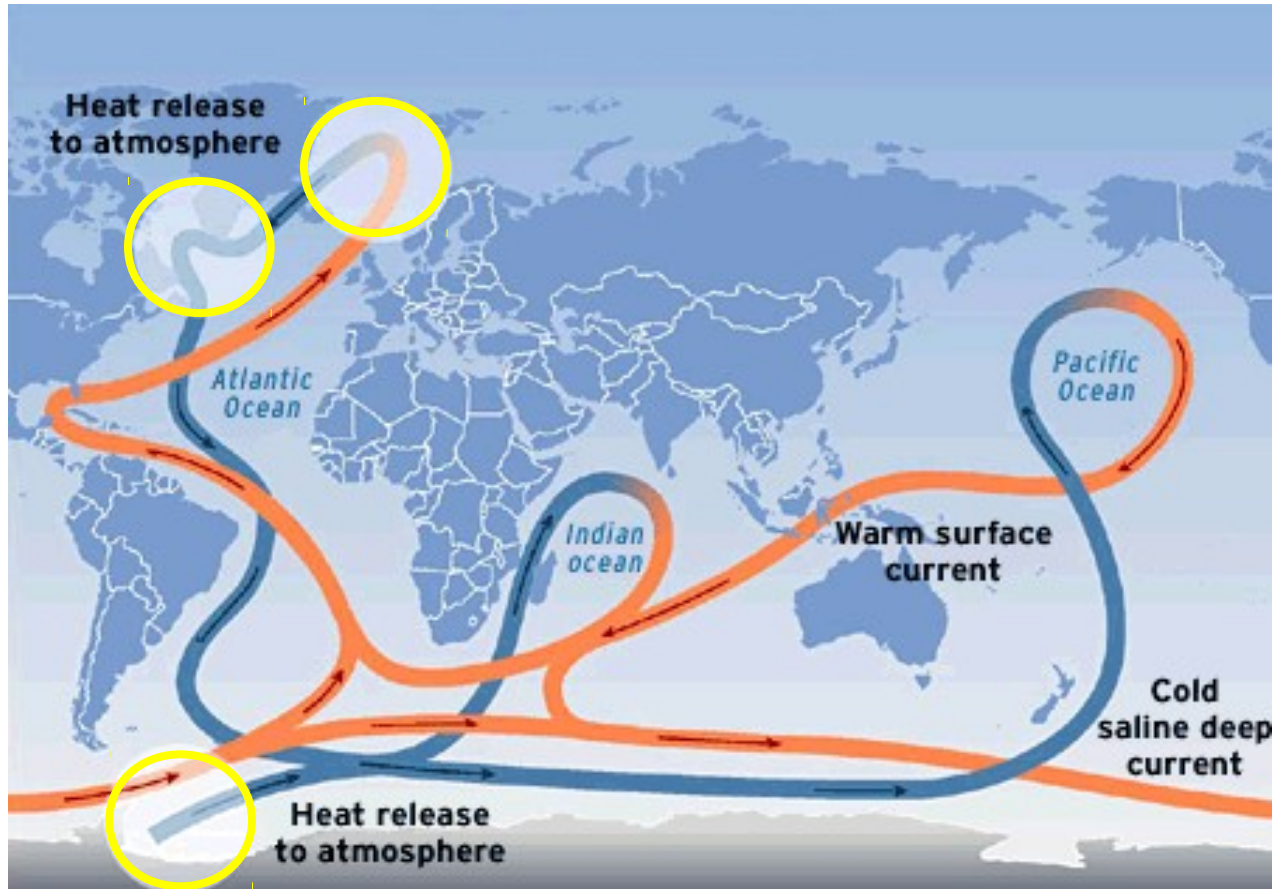


- geometrie bassins / forcering bepalen waar convectie optreedt
- eigenschappen van het 'convectieve eindproduct' verschillen  
→ specifieke watermassa's op karakteristieke diepte



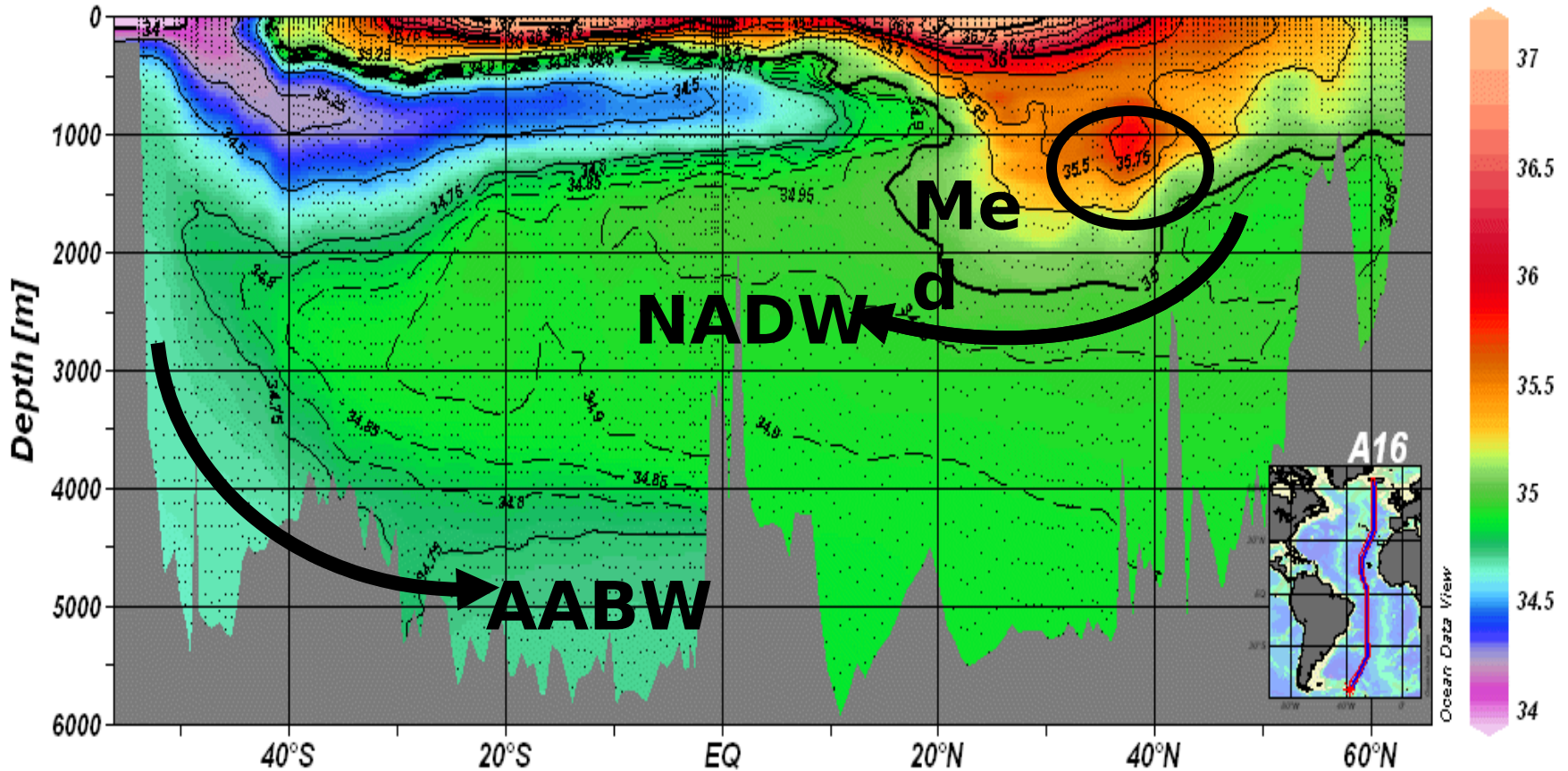


# de transportband van de oceaan



'The great ocean conveyor' [Broecker, 1991]

# convectieve watermassa's

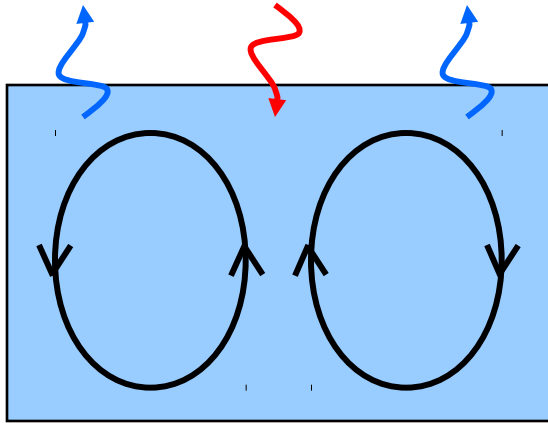


NADW: warm (+2 °C)  
zout (35 ‰)

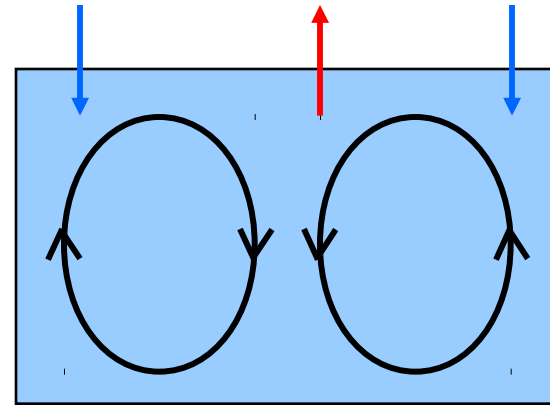
AABW: koud (-2 °C)  
zoet (34.6 ‰)



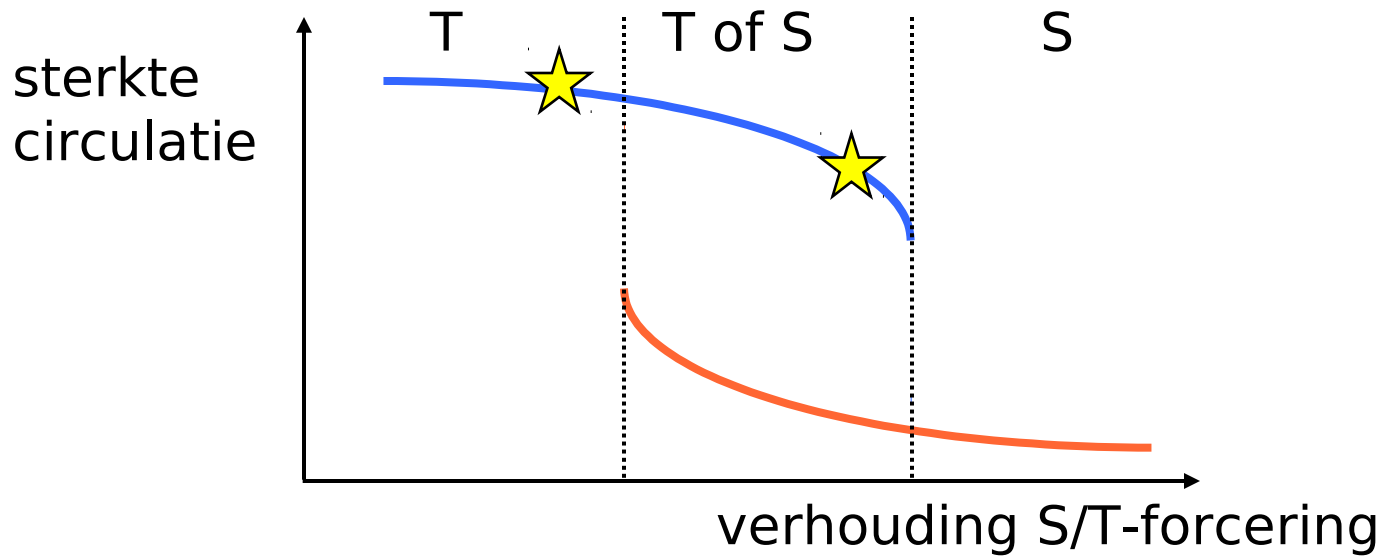
# meervoudige evenwichten



temperatuur-gedreven



zout-gedreven

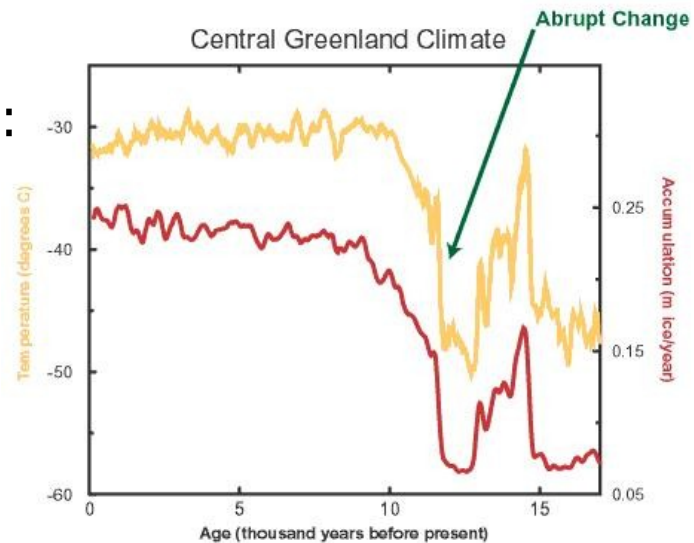


# variabiliteit thermohaliene circulatie

- interne processen: oscillaties thermohaliene circulatie (~50-1000 jaar)
- externe processen: overgangen tussen meervoudige evenwichten  
glaciatie/deglaciatie ⇒ smeltwater ⇒ sterkte thermohaliene circulatie (~20-100 jaar)

- Younger Dryas (12-13.000 BP):
  - Groenland: -15°C
  - West-Europa: -5°C

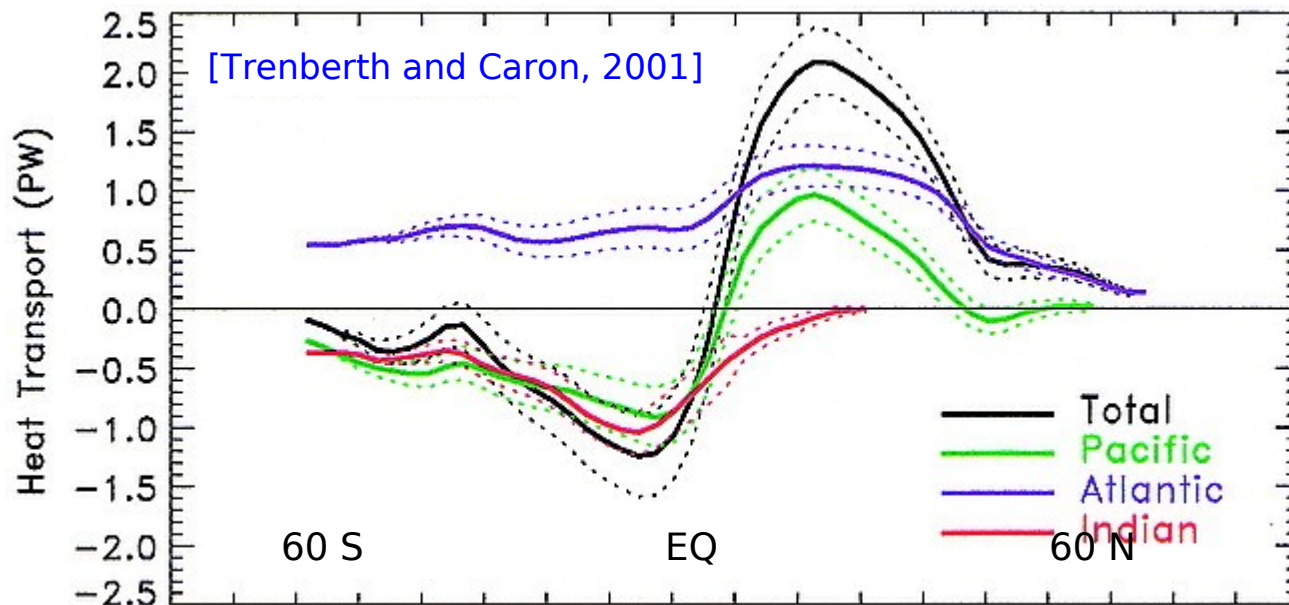
⇒ reductie thermohaliene circulatie



# warmtetransport in de oceaan

50% van het totale warmtetransport vindt plaats in de oceaan

- thermohaliene circulatie ⇒ Atlantische Oceaan naar het noorden!
- windgedreven gyres ⇒ Stille Oceaan
- wervels ⇒ Zuidelijke Oceaan





A satellite-style map of the world, showing continents in shades of green and brown, and oceans in dark blue. The map is centered on the Atlantic Ocean, with North and South America on the left, Europe and Africa in the center, and Asia and Australia on the right. The text is overlaid on the map.

ocean en klimaatverandering  
zeespiegelstijging



# zeespiegelstijging

## nieuw water

- smelten ijskappen Antarctica en Groenland
- smelten gletsjers en landijs
- veranderingen in hydrologische cyclus (rivierafvoer, bodemvocht, grondwater, stuwmeren)

## oud water

- thermische expansie

20<sup>e</sup> eeuw: **10-20 cm**



# Wereldwijde zeespiegelstijging

peilschalen:

$18 \pm 5$  cm / eeuw

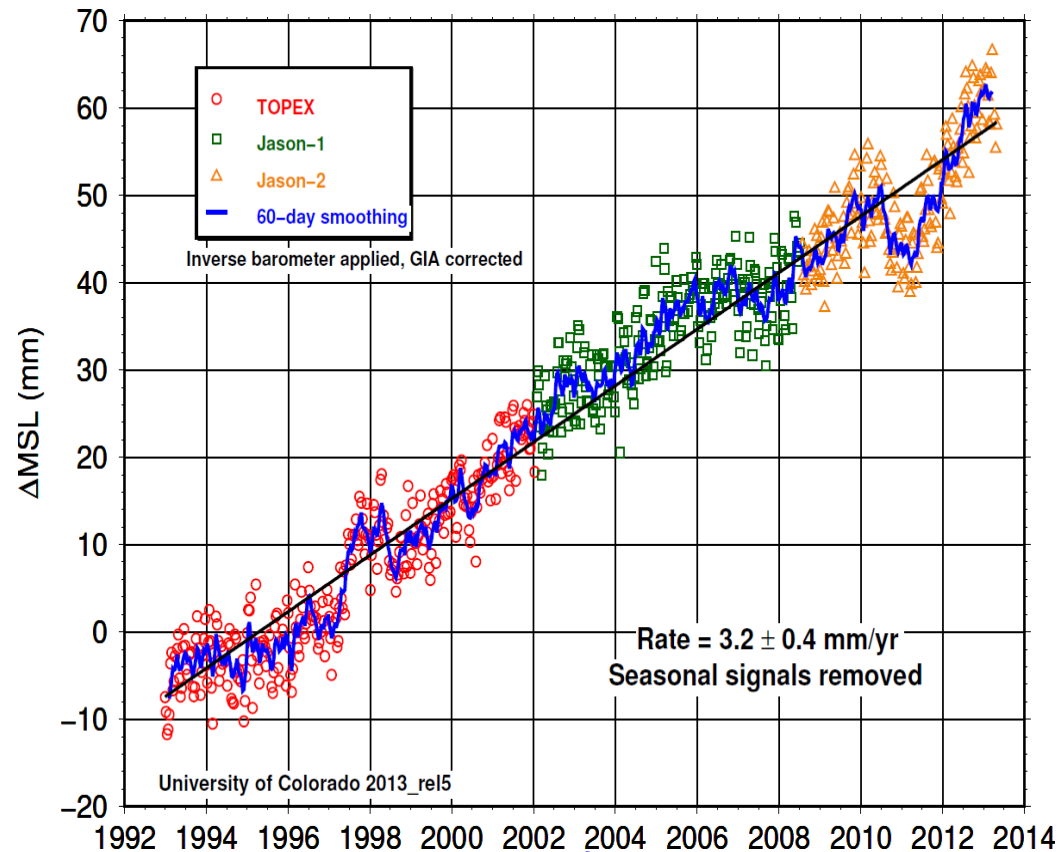
satellieten:

$32 \pm 4$  cm / eeuw

[1993-2013],

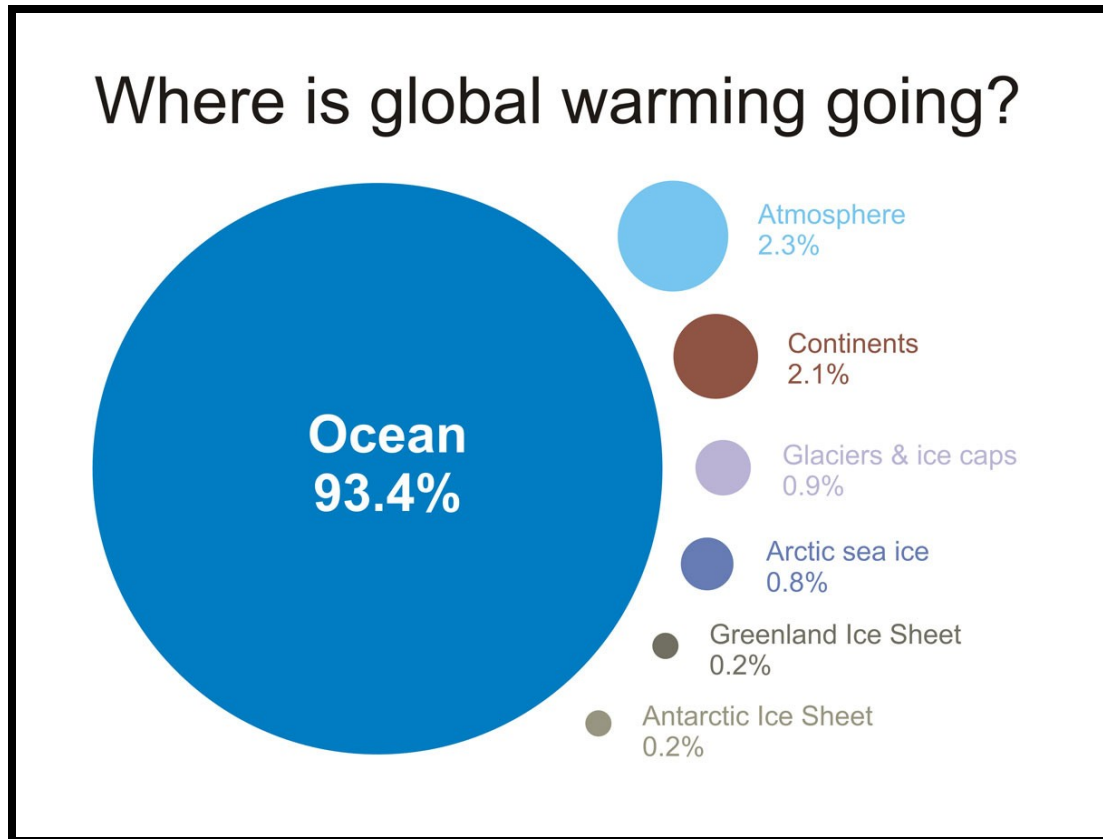
waarvan helft uitzetting

trend of tijdelijke  
versnelling?



[bron cijfers: IPCC 4AR, 2007]

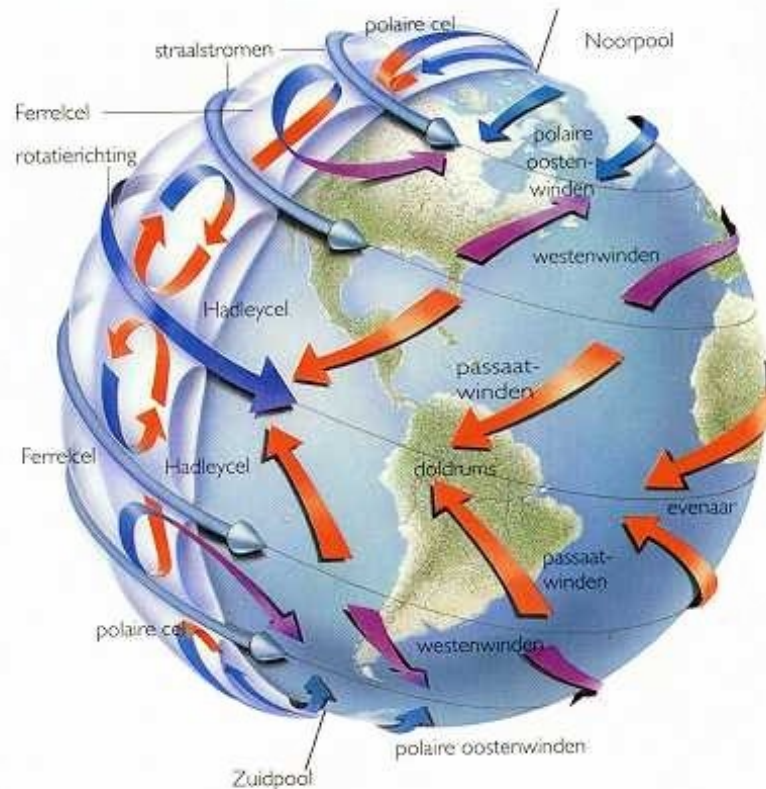
# opwarming oceaan



visualizatie op basis van  
cijfers IPCC (2007) voor 1993-2003

# Oorzaken lokale verschillen

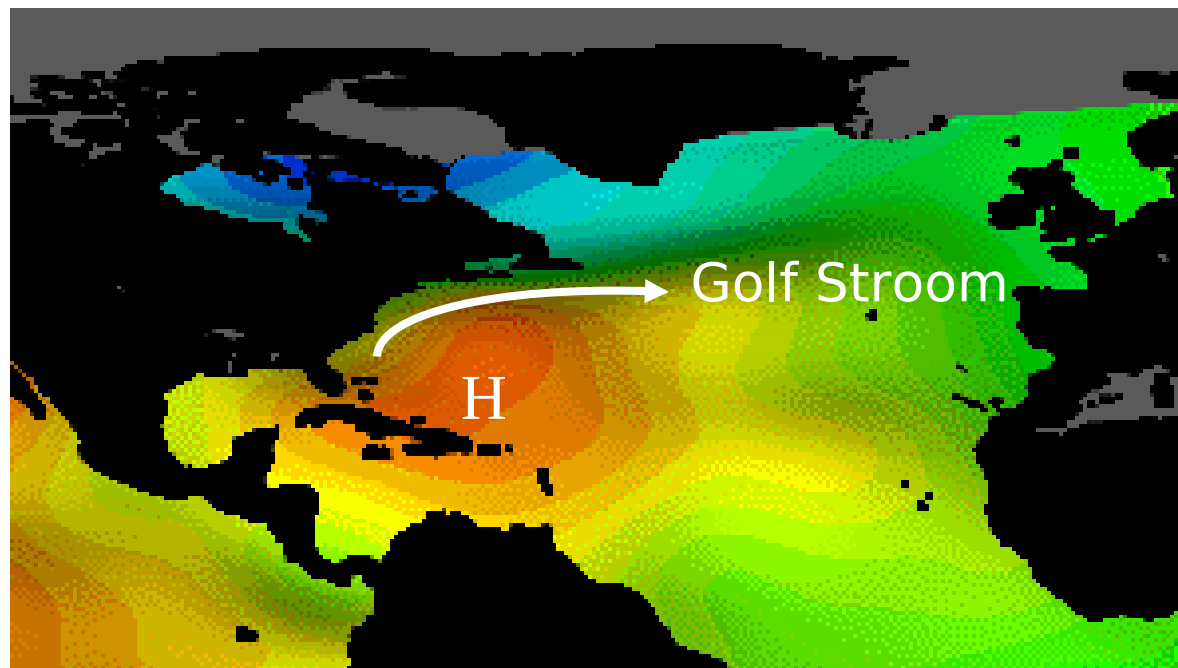
1. (veranderingen in) wind patronen





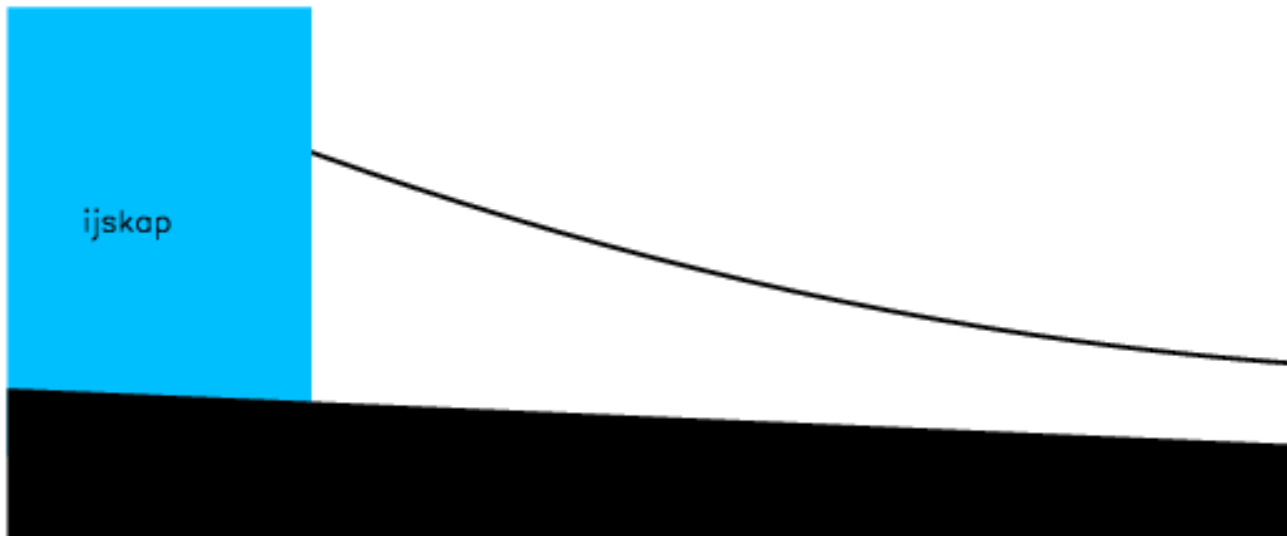
# Oorzaken lokale verschillen

1. (veranderingen in) wind patronen
2. (veranderingen in) oceaanstromingen



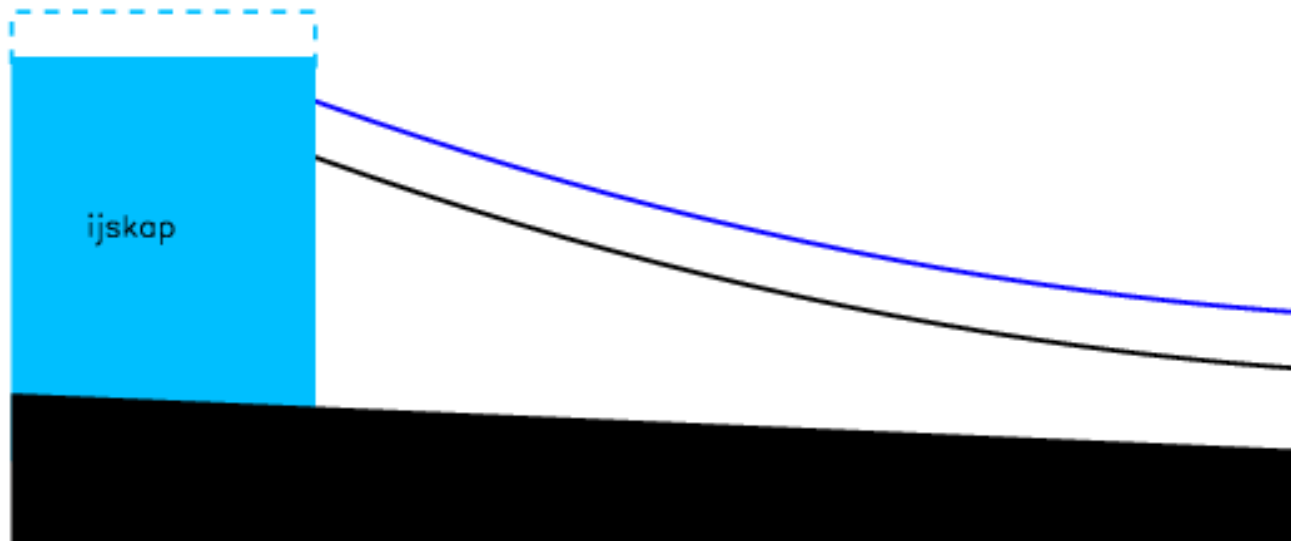
# Oorzaken lokale verschillen

1. (veranderingen in) wind patronen
2. (veranderingen in) oceaanstromingen
3. (veranderingen in) zwaartekrachtsveld



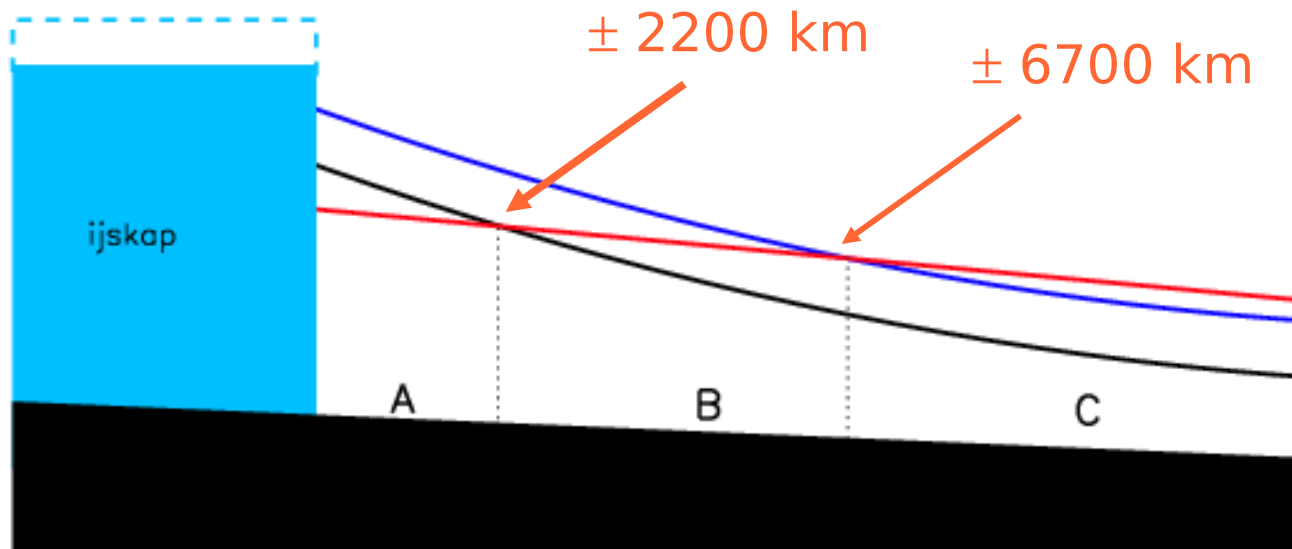
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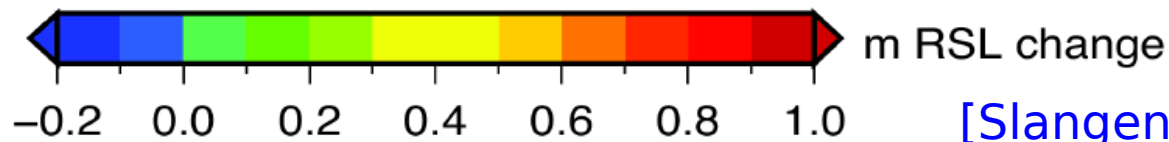
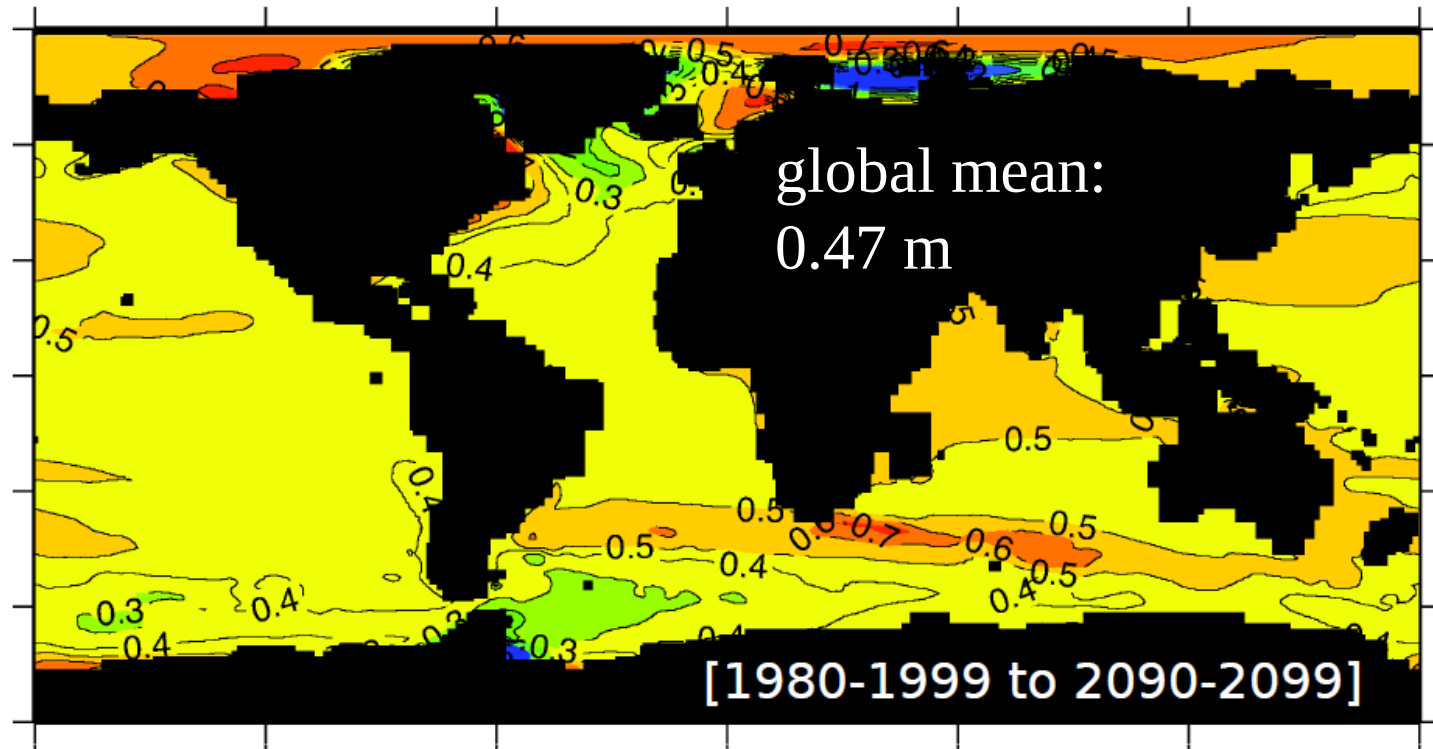
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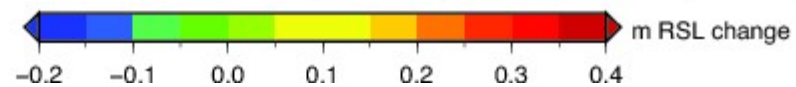
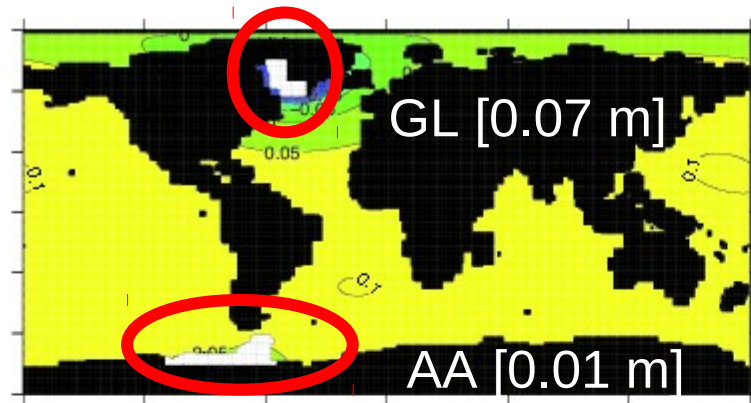
## regionale projectie (1990-2100)



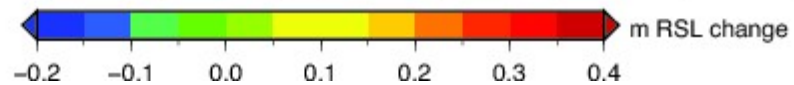
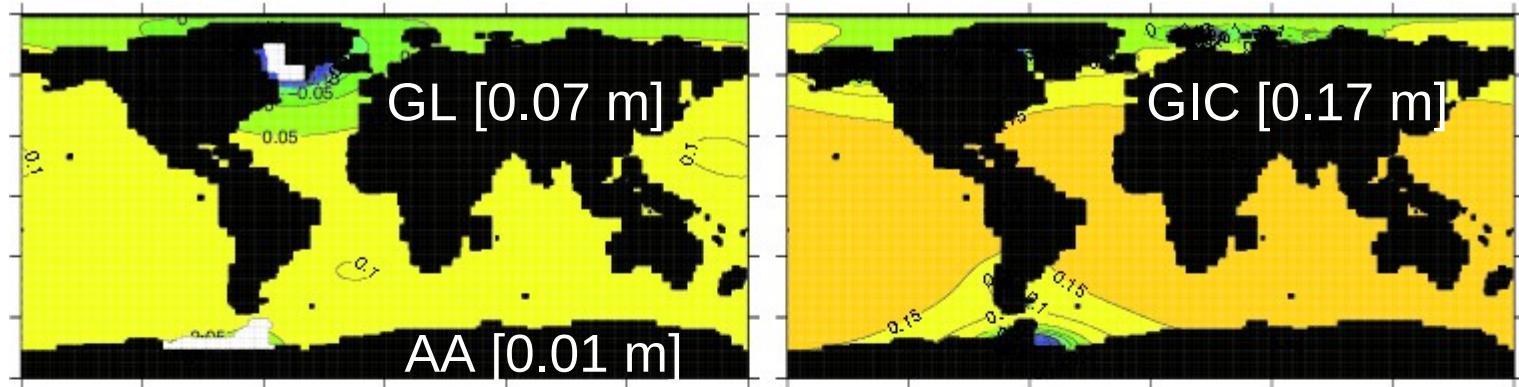
[Slangen et al. (2012)]



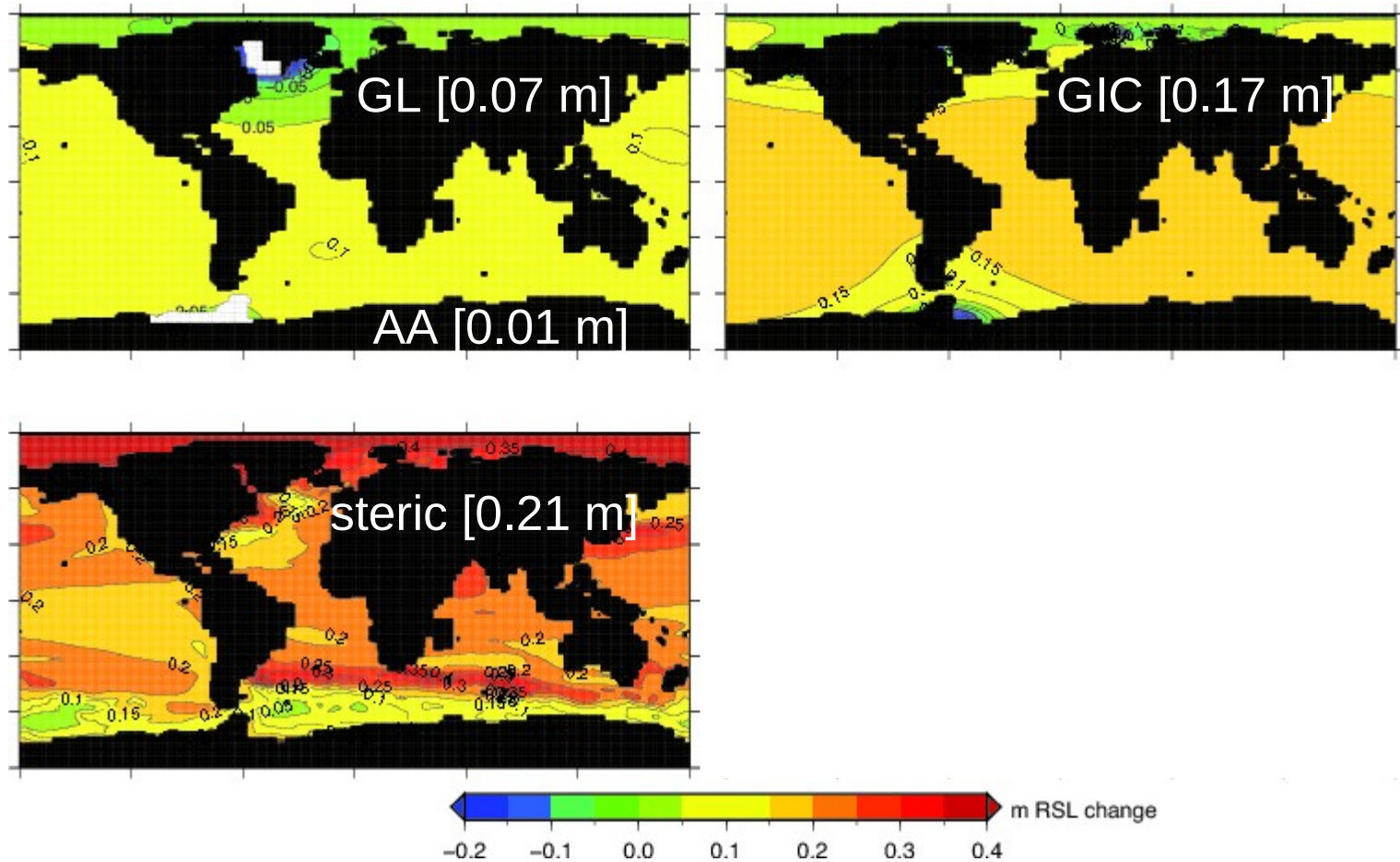
# Regional projection (SRES A1B)



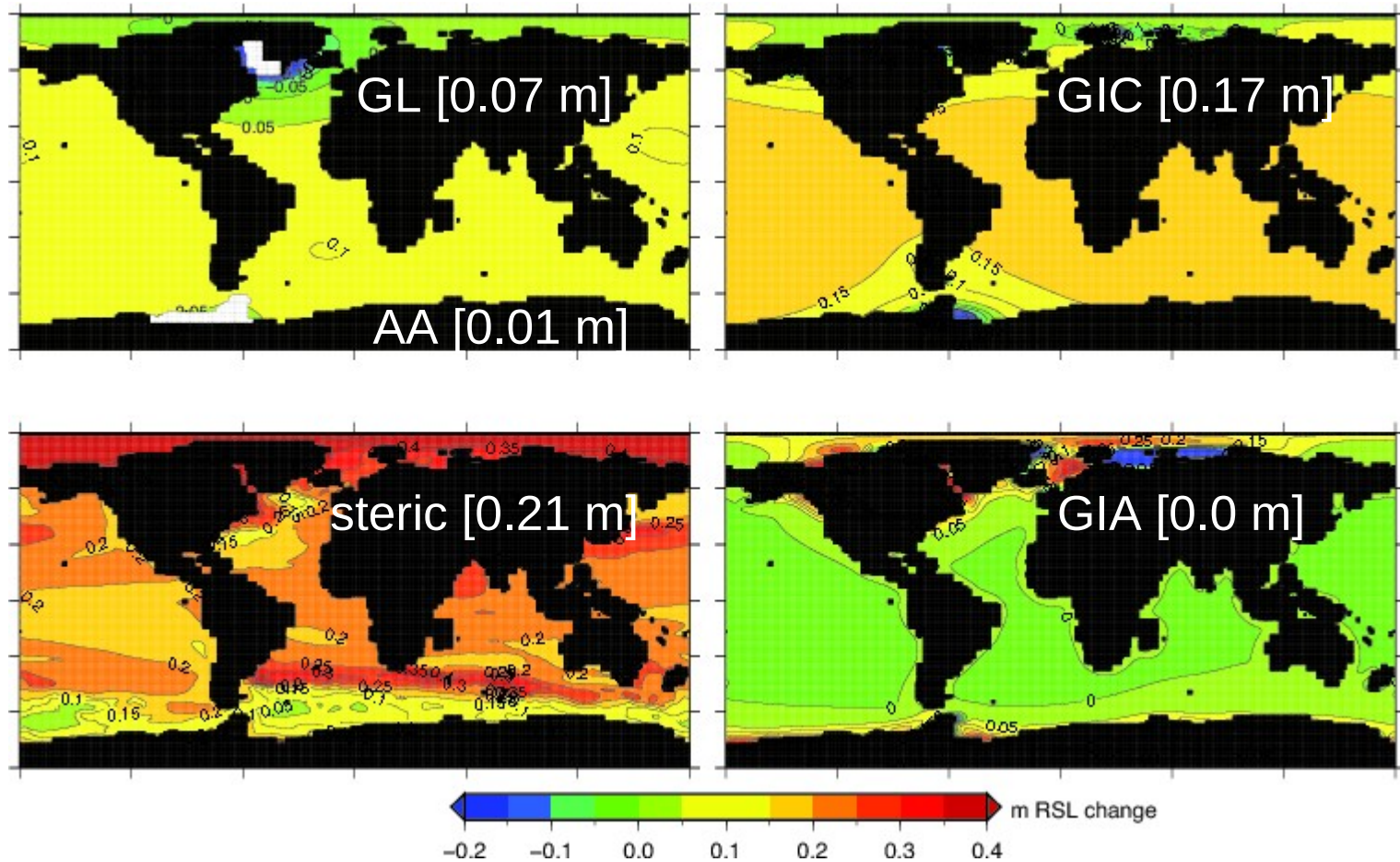
# Regional projection (SRES A1B)



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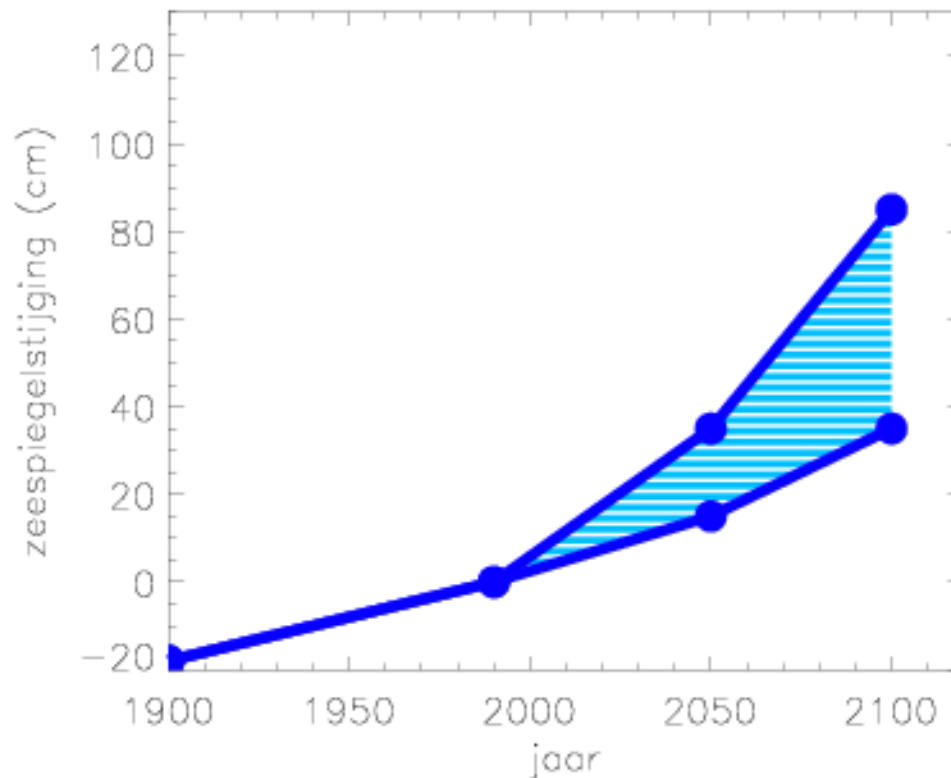
# Regional projection (SRES A1B)





# KNMI klimaatscenario

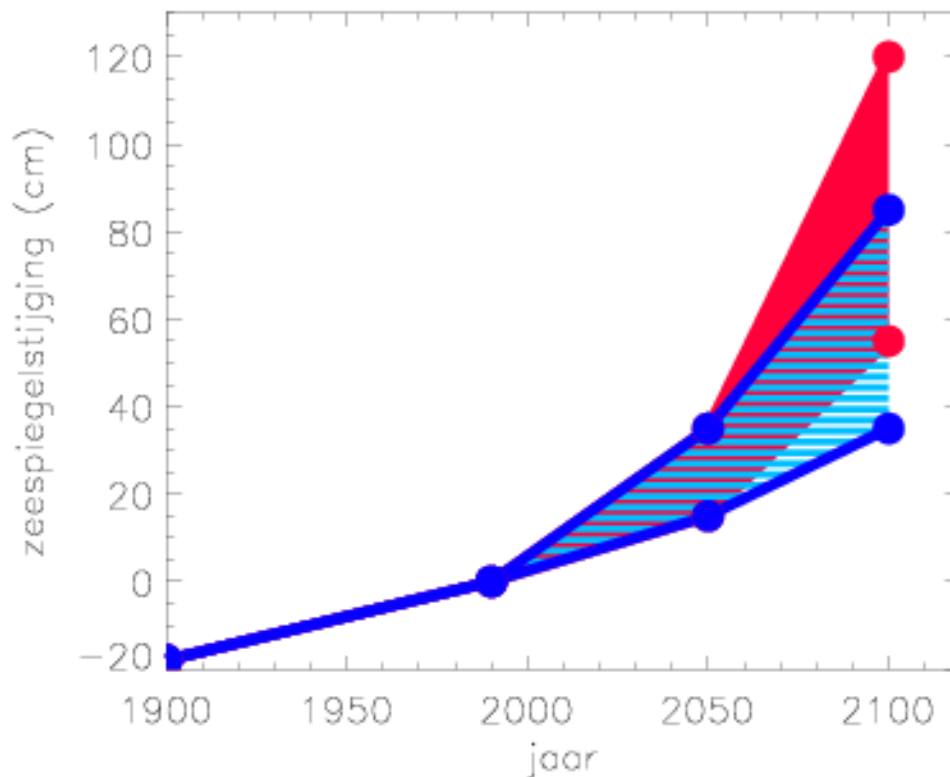
Lokale zeespiegelstijging van **35 tot 85 cm** (2100 t.o.v. 1990)





# Delta Commissie scenario

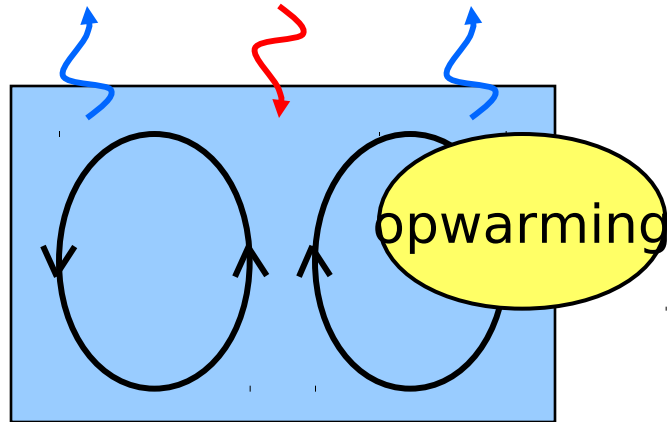
Plausibele **bovengrens** voor lokale zeespiegelstijging van **55 tot 120 cm**  
(65 tot 130 cm inclusief bodemdaling)



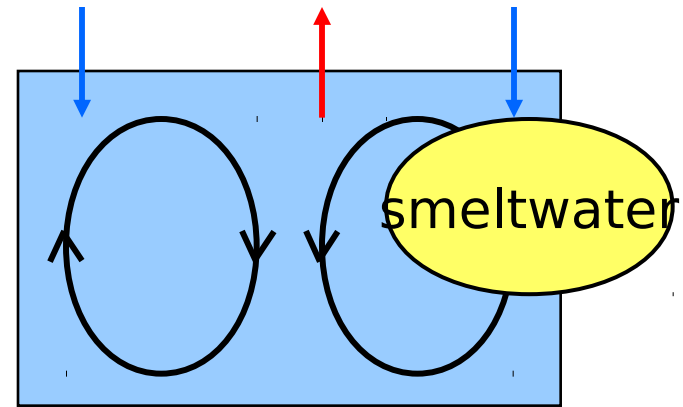
A satellite-style map of the world, showing continents and oceans. The map is centered on the Atlantic Ocean, with North and South America on the left, Europe and Africa in the center, and Asia and Australia on the right. The text is overlaid on the map.

ocean en klimaatverandering  
verzwakking thermohaliene  
circulatie?

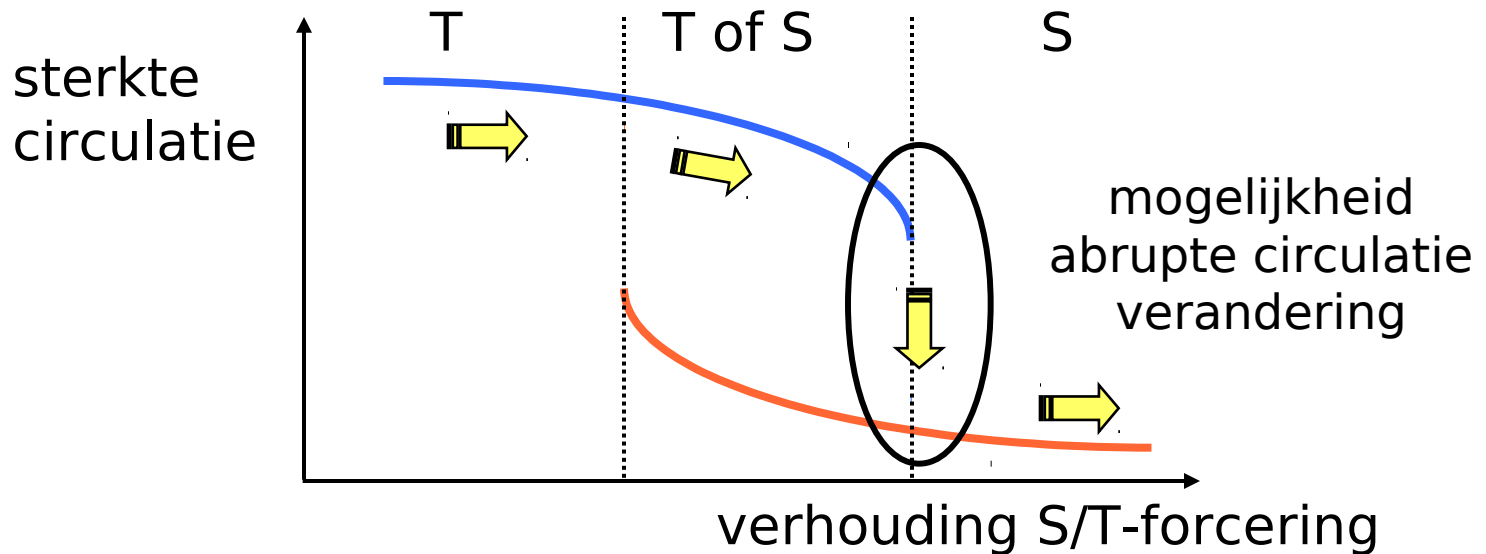
# meervoudige evenwichten



temperatuur-gedreven



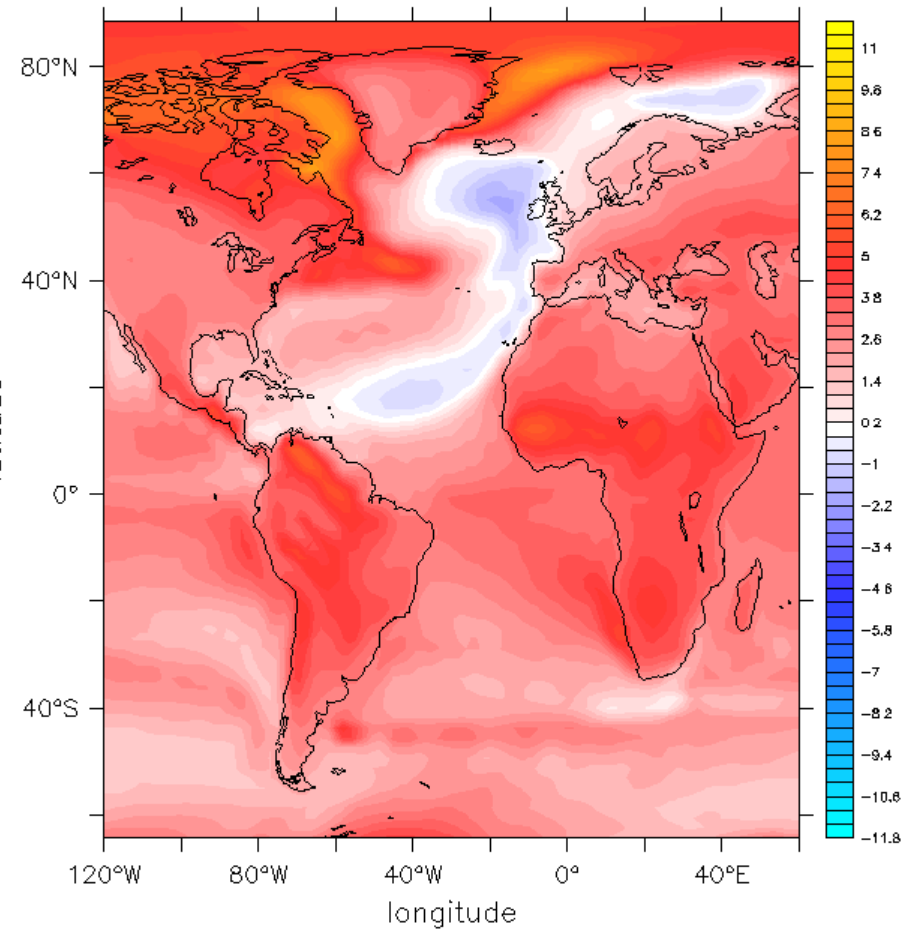
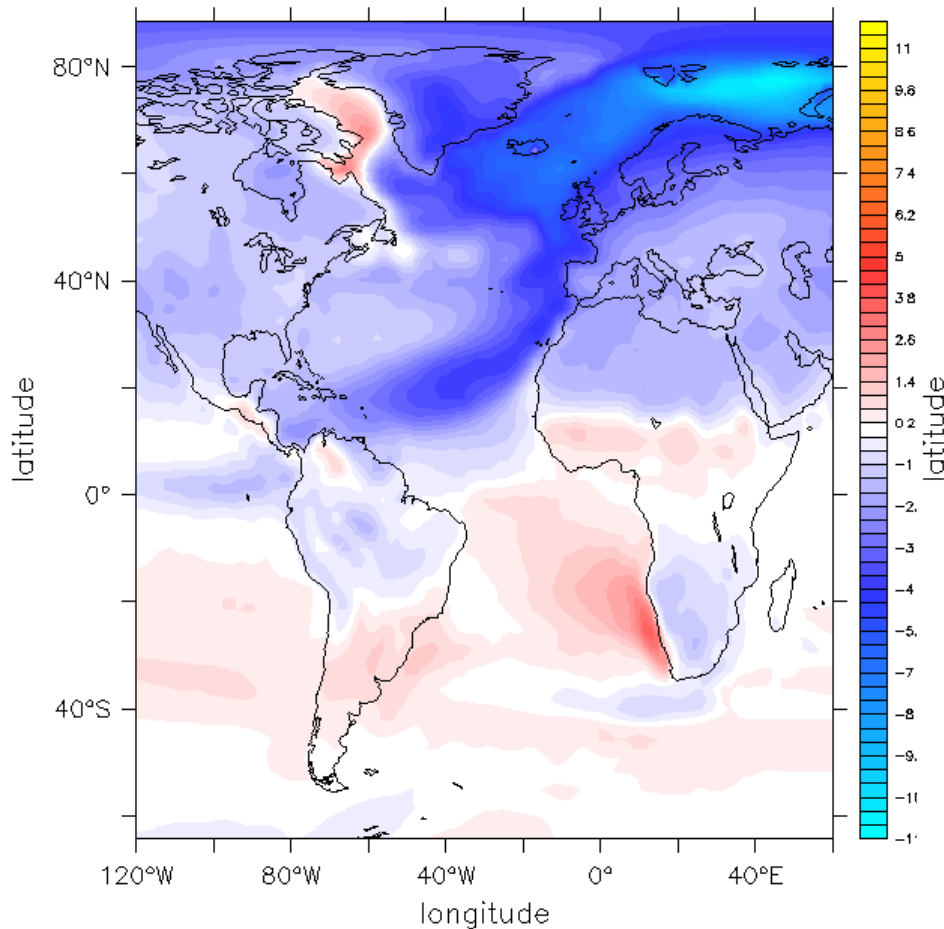
zout-gedreven



# Temperatuur verschil 2100-2000

Thermohaliene circulatie stort in

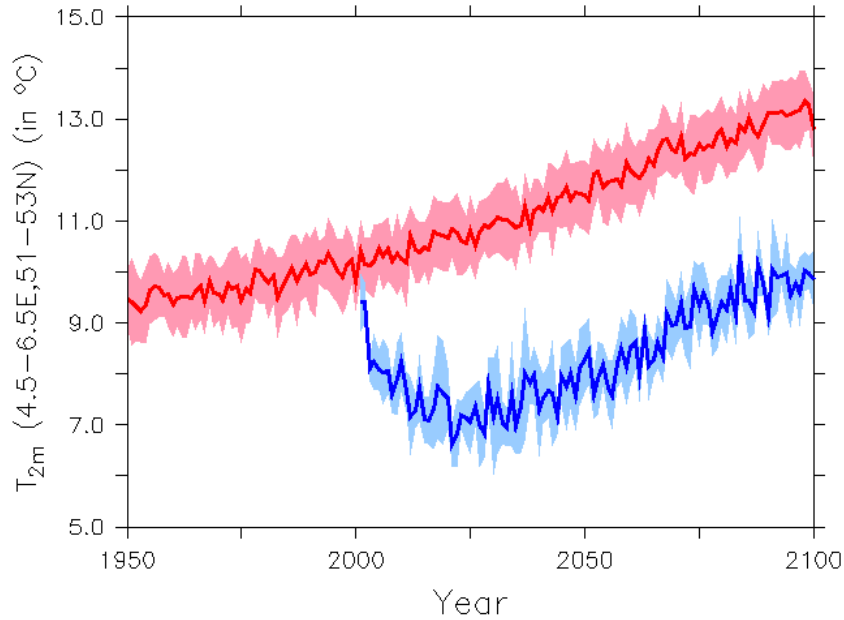
Thermohaliene circulatie stort in  
+ broeikas effect



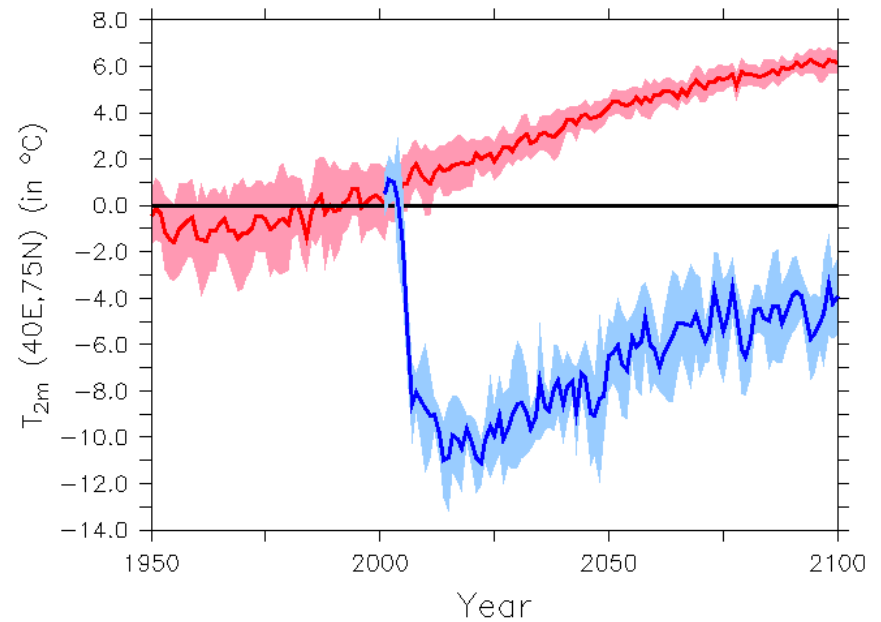


# Temperatuur verschil 2100-2000

Nederland



Spitsbergen



A world map showing the continents and oceans, serving as a background for the text.

To conclude...

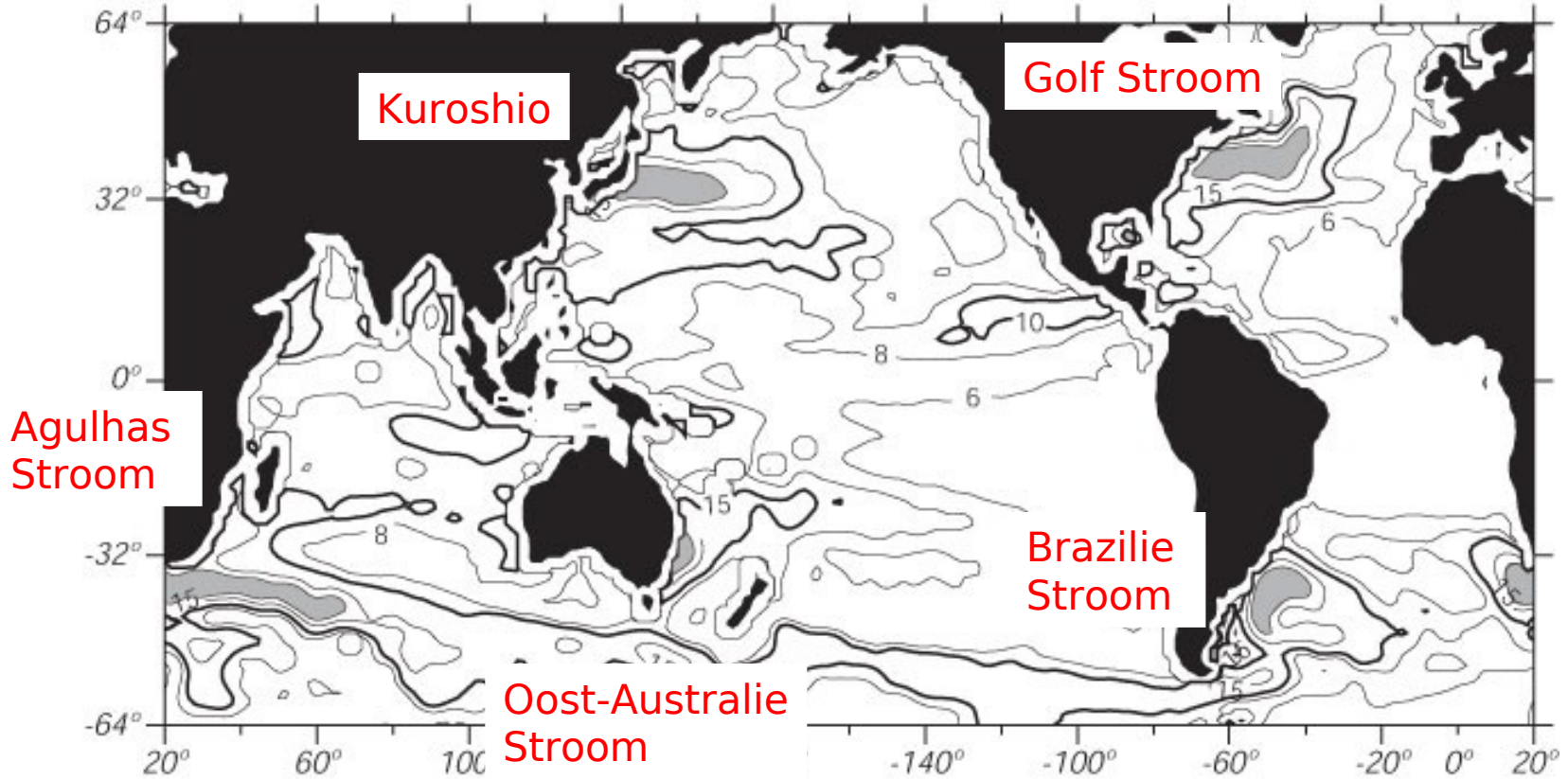
**The oceans plays an important role in climate and (natural and forced) climate change, but we still know surprisingly little about them**

**“The oceans are the principal reservoir for the storage of CO<sub>2</sub>, of heat and of ignorance”**

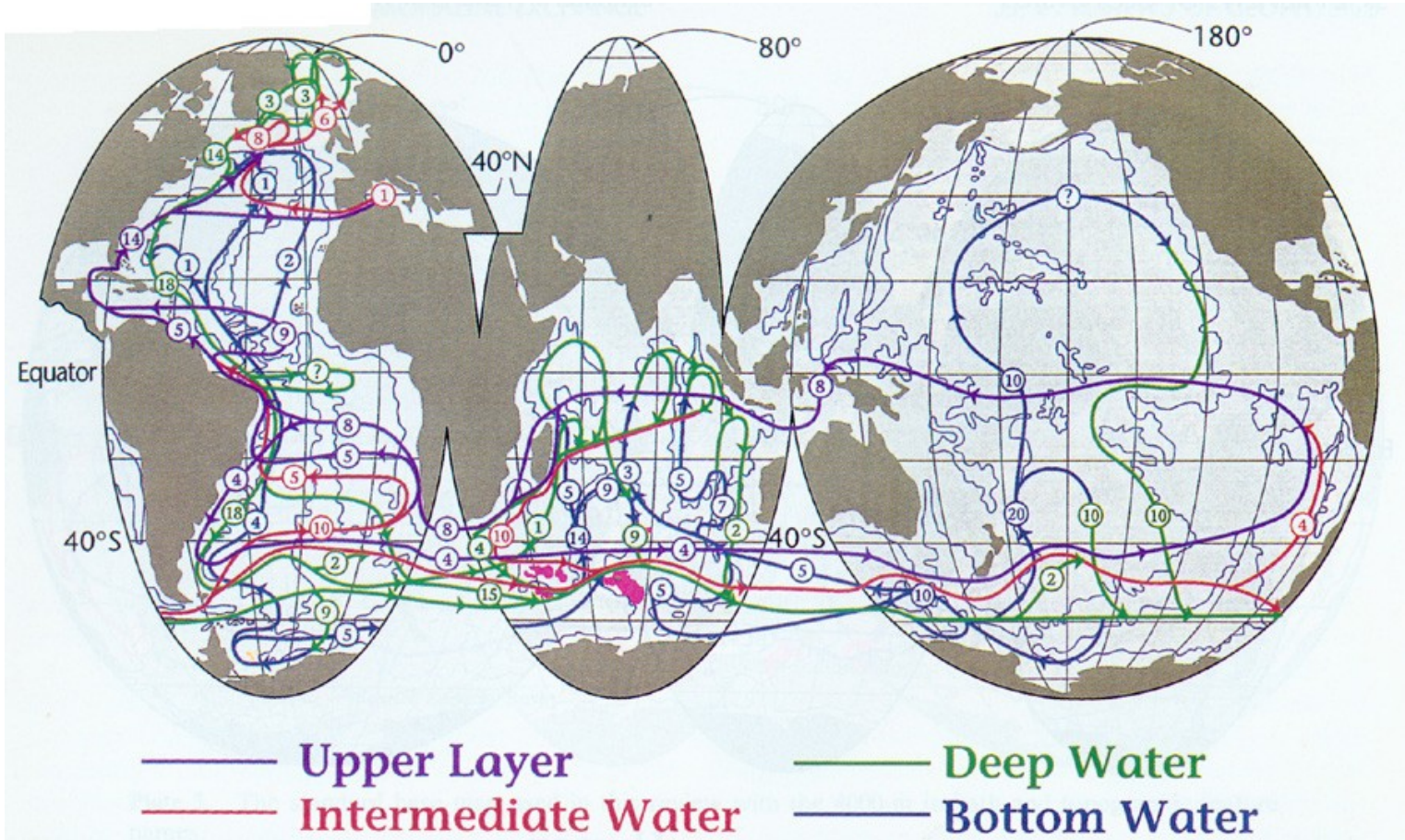
**(Walter Munk, The Evolution of Physical Oceanography in the Last Hundred Years, 2002)**



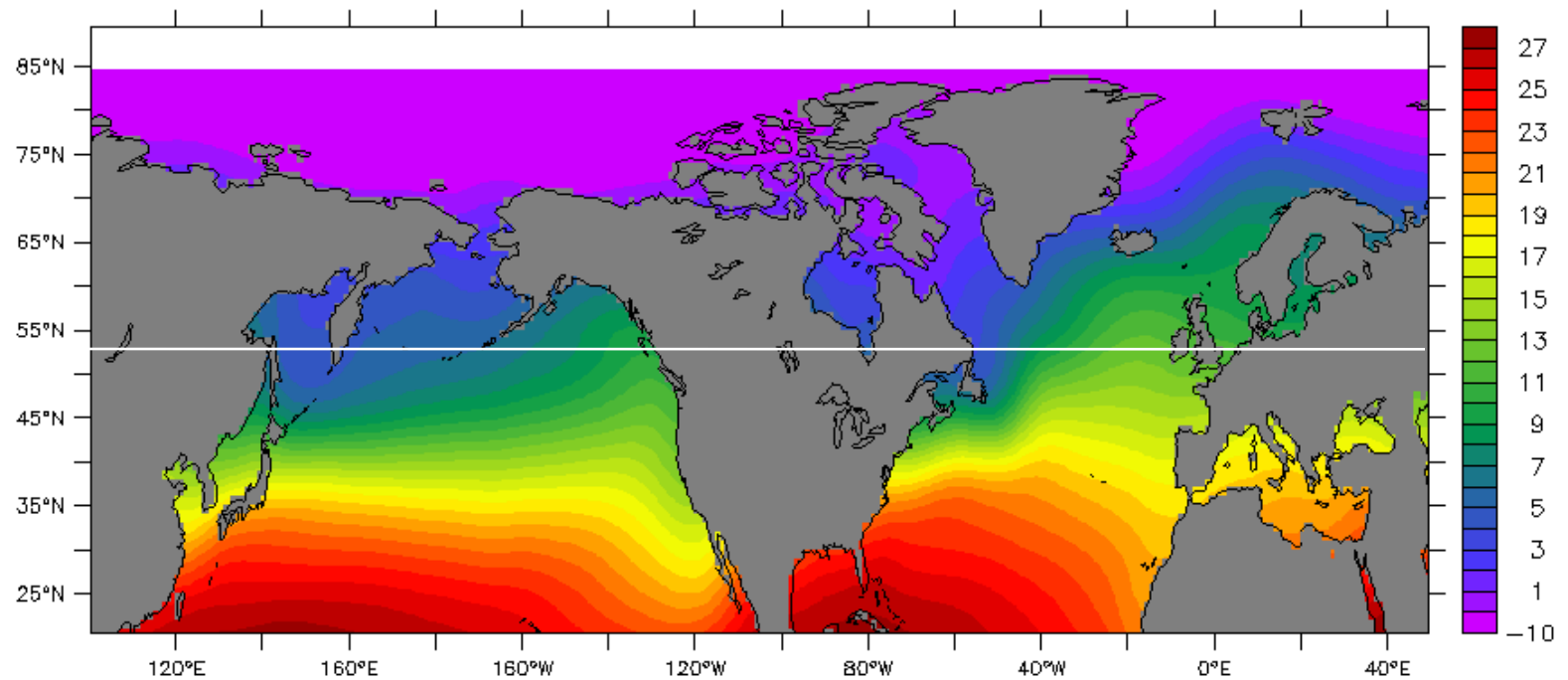
# variabiliteit zeehoogte



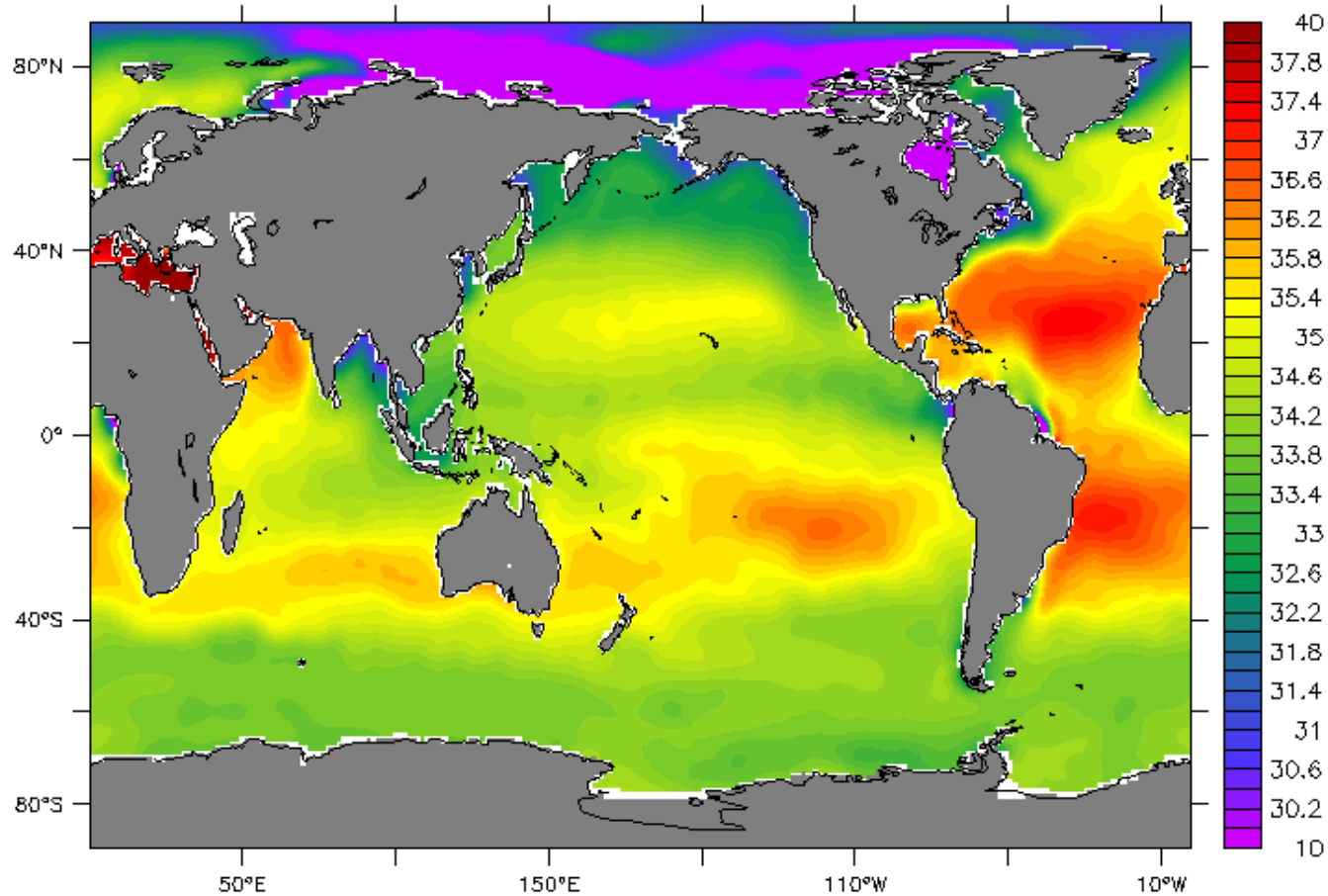
# 4-lagen perspectief THC



# temperatuur aan het oppervlak



# Convectie in de Stille Oceaan?



neerslag - verdamping  
cm/jaar

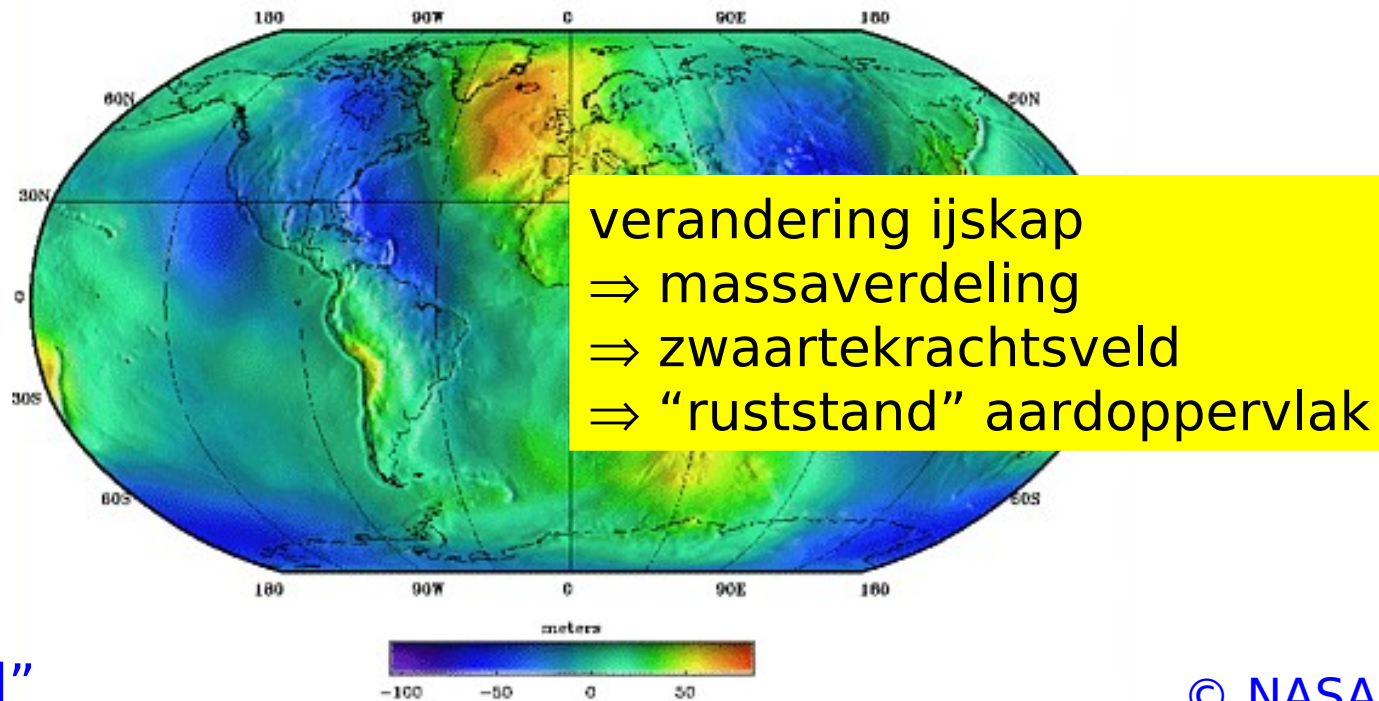
Atlantische Oceaan: -40

Stille Oceaan +10 cm/jaar



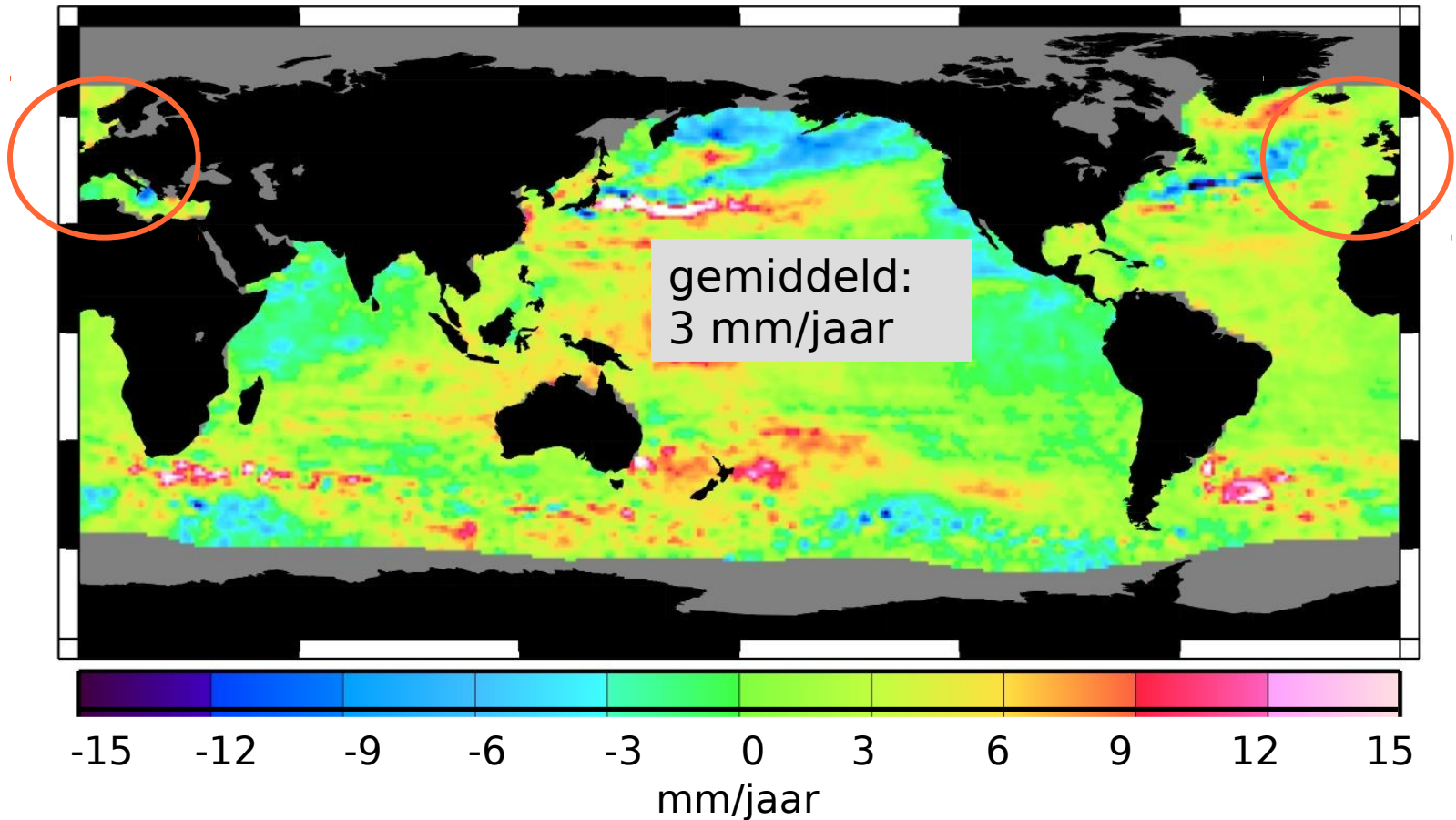
# Oorzaken lokale verschillen

1. (veranderingen in) wind patronen
2. (veranderingen in) oceaanstromingen
3. (veranderingen in) zwaartekrachtsveld



••••  
"ruststand"  
oppervlak

# regionale zeespiegelstijging

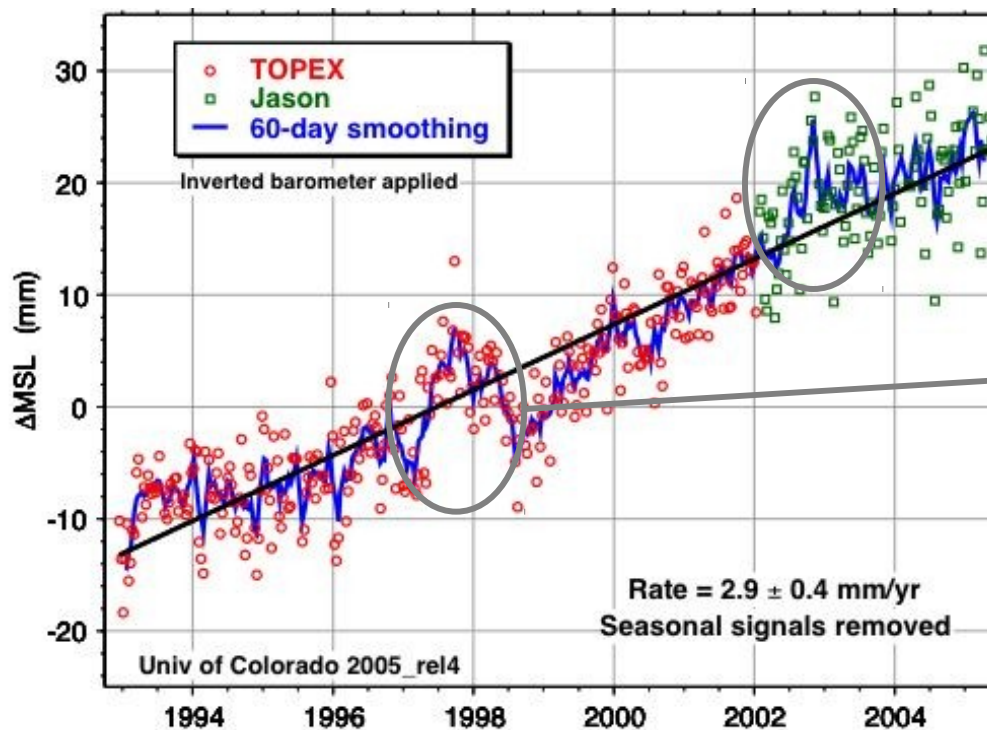


waargenomen trend in zeehoogte 1993-2005 (bron: University of Colorado)



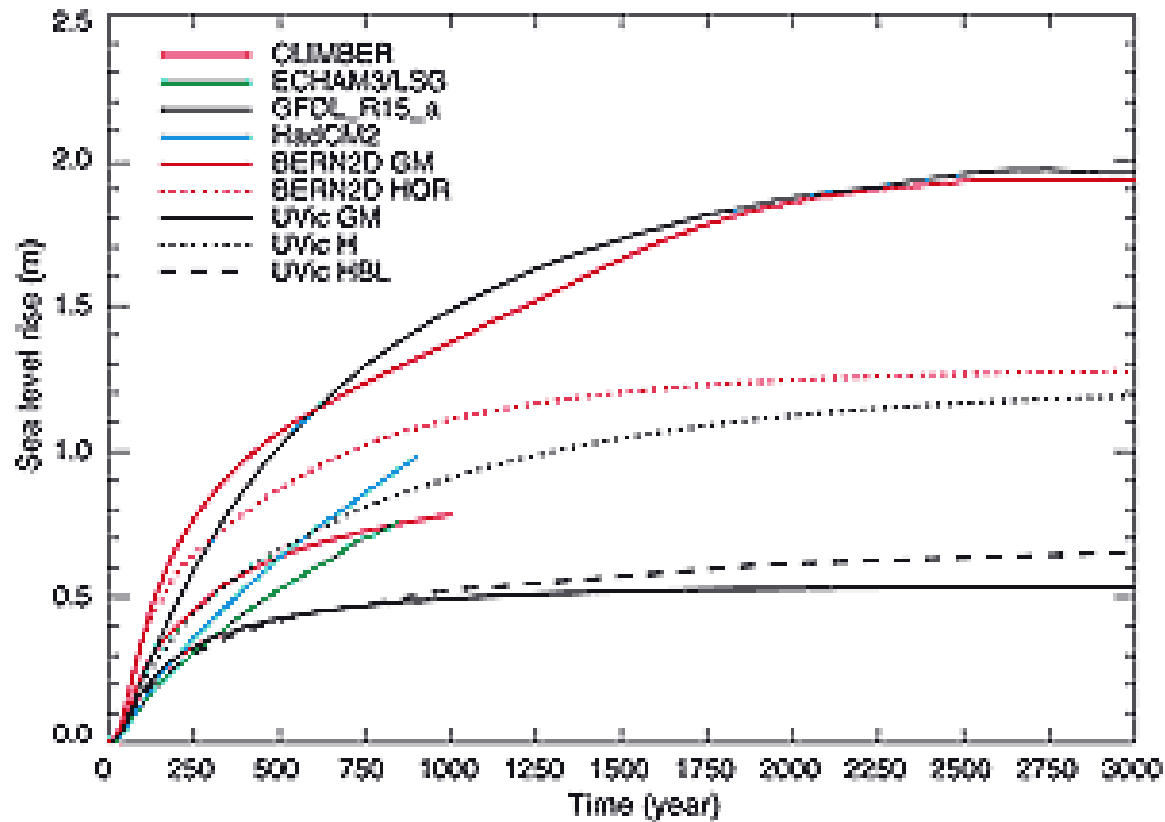
# oorzaken voor regionale variaties

- variaties zeehoogte ↔ patronen  
oceaancirculatie
- korte tijdserie ⇒ decadale variaties?
- ⇒ langjarige trends?



El Niño  
1997-98

# naijlen zeespiegelstijging



stabilisatie bij 2x CO<sub>2</sub> (2070)

thermische expansie