# Energies
# Marine Environment

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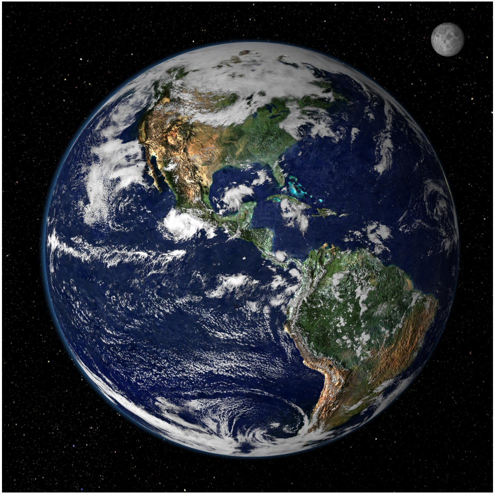
# Ocean



# Oceanic research at GHER

$$\nabla\cdot \boldsymbol{v} = 0$$

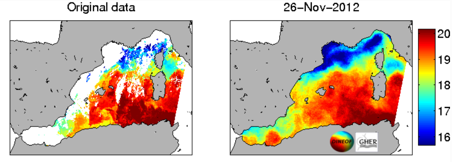
$$\frac{\partial \boldsymbol{u}}{\partial t} + \nabla\cdot(\boldsymbol{v}\boldsymbol{u}) + f\boldsymbol{e}_3\wedge\boldsymbol{u} = -\nabla_h q + \frac{\partial}{\partial z}\left(\nu\frac{\partial \boldsymbol{u}}{\partial z}\right)$$

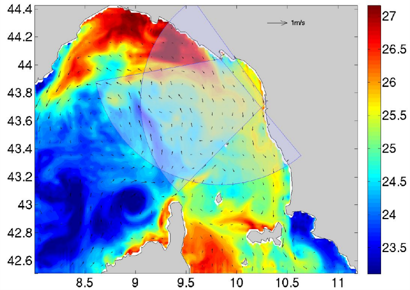
$$\frac{\partial q}{\partial z} = b$$

$$\frac{\partial T}{\partial t} + \nabla\cdot(\boldsymbol{v}T) - \frac{\alpha T}{\rho_0 c_p}\frac{Dp}{Dt} = \frac{\partial}{\partial z}\left(\lambda^T\frac{\partial T}{\partial z}\right) + \frac{Q^e}{c_p}$$

$$\frac{\partial S}{\partial t} + \nabla\cdot(\boldsymbol{v}S) = \frac{\partial}{\partial z}\left(\lambda^S\frac{\partial S}{\partial z}\right)$$

$$\boldsymbol{v} = \boldsymbol{u} + w\boldsymbol{e}_3, \quad \nabla = \nabla_h + \boldsymbol{e}_3\frac{\partial}{\partial z}$$

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# Power: from kinetic energy of horizontal flow

Power $P$ given by

$$P = \frac{1}{2} c \rho S V^3 \tag{1}$$

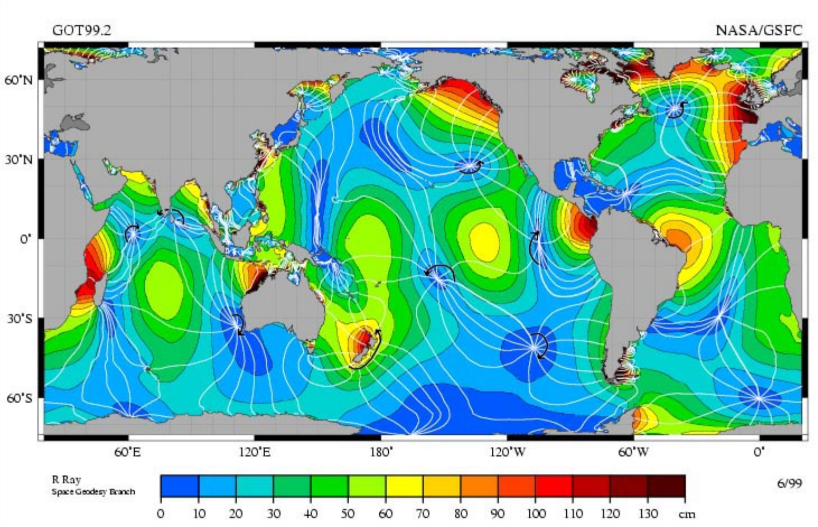
- power coefficient $c$, less than Betz limit 16/27 [Betz (1966)] and surface $S$ defined by geometrical design,
- density $\rho$ and velocity $V$ by environment.

(in practice turbines work only in a range of velocities $V$).

# Atmosphere versus Ocean

| Phenomenon | Length Scale $L$ | Velocity Scale $U$ | Time Scale $T$ |
|---|---|---|---|
| *Atmosphere*: $\rho = 1.2$kg/m$^3$ | | | |
| Microturbulence | 10–100 cm | 5–50 cm/s | few seconds |
| Thunderstorms | few km | 1–10 m/s | few hours |
| Sea breeze | 5–50 km | 1–10 m/s | 6 hours |
| Tornado | 10–500 m | 30–100 m/s | 10–60 minutes |
| Hurricane | 300–500 km | 30–60 m/s | Days to weeks |
| Mountain waves | 10–100 km | 1–20 m/s | Days |
| Weather patterns | 100–5000 km | 1–50 m/s | Days to weeks |
| Prevailing winds | Global | 5–50 m/s | Seasons to years |
| Climatic variations | Global | 1–50 m/s | Decades and beyond |
| *Ocean*: $\rho = 1024$kg/m$^3$ | | | |
| Microturbulence | 1–100 cm | 1–10 cm/s | 10–100 s |
| Internal waves | 1–20 km | 0.05–0.5 m/s | Minutes to hours |
| Tides | Basin scale | 0.01–1 m/s | Hours |
| Coastal upwelling | 1–10 km | 0.1–1 m/s | Several days |
| Fronts | 1–20 km | 0.5–5 m/s | Few days |
| Eddies | 5–100 km | 0.1–1 m/s | Days to weeks |
| Major currents | 50–500 km | 0.5–2 m/s | Weeks to seasons |
| Large-scale gyres | Basin scale | 0.01–0.1 m/s | Decades and beyond |

Cushman-Roisin and Beckers (2011)




Tidal dissipation (friction): 3.7 TW (slows down earth rotation) [Lambeck (1975)] 20% of todays man's energy consumption, but only a fraction can be used.

# Rance Tidal Power Station

# Features

http://businesses.edf.com/

- Large tidal amplitude (8 m average, up to 13 m)
- 750 m wide estuary
- 24 turbines
- Up to 240 MW (average 62 MW)

Variable flow (penalized by $V^3$), but PREDICTABLE and DISTRIBUTED

# Other tide dependent sources

- Underwater oscillating hydroplanes (1.5 MW, Shetland)
- Underwater turbines (0.3 MW, Hammerfest)

ANDRITZ HYDRO

Near shore use and relying on strong tidal currents.
Go offshore ?

# Offshore underwater turbines

Currently (to my knowledge) no commercial underwater implementation connected to the grid.

# Offshore underwater turbines

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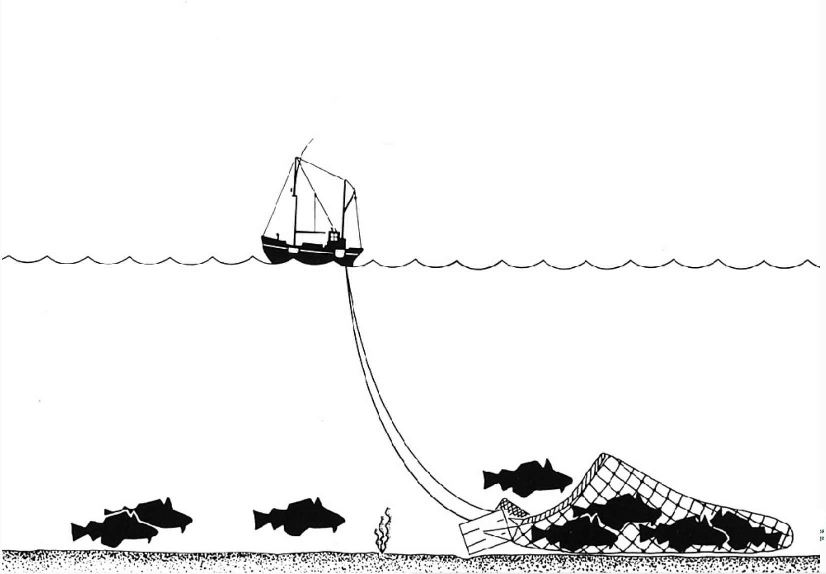

# Offshore underwater turbines

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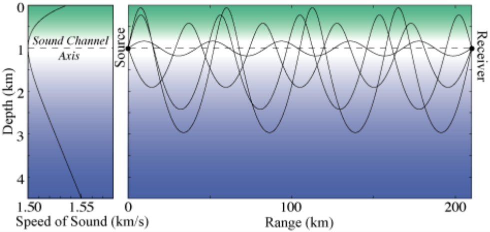


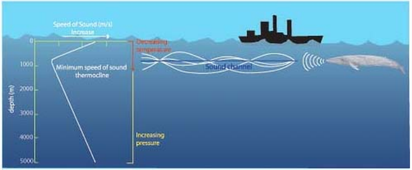


Long distance sound propagation because of sound channels (SOFAR and shelf)

# Offshore underwater turbines

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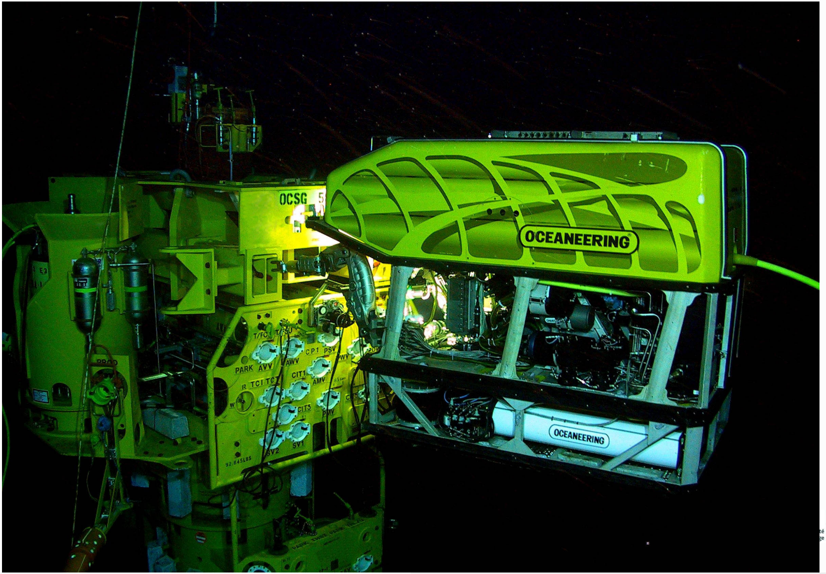

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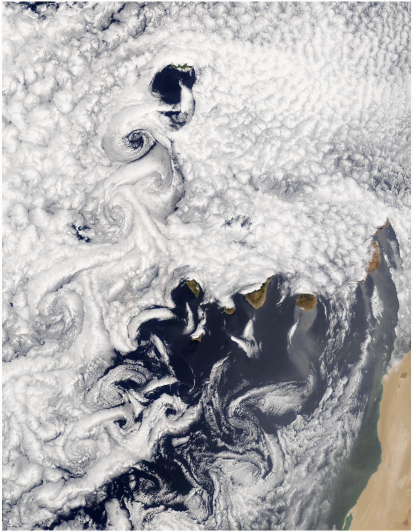

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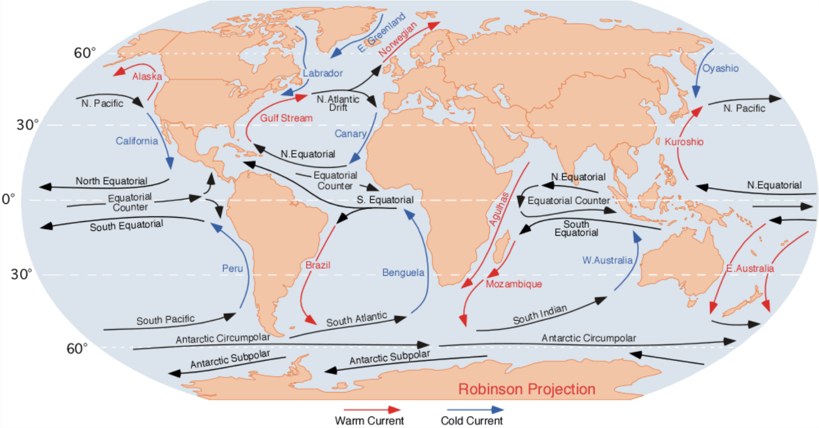

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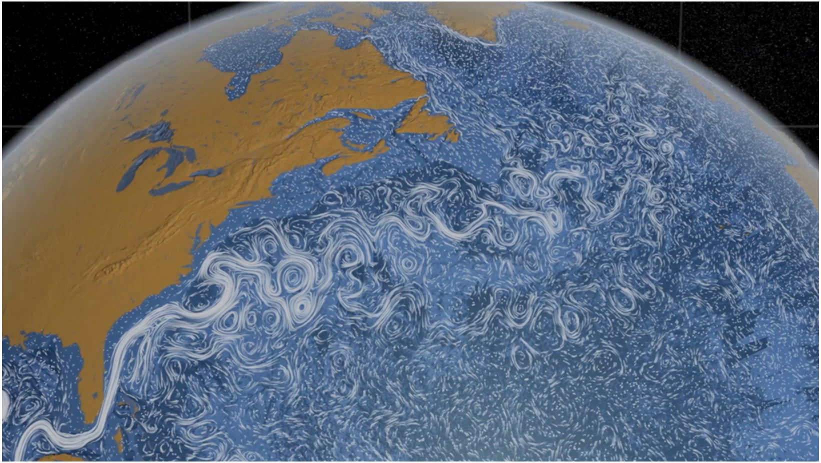
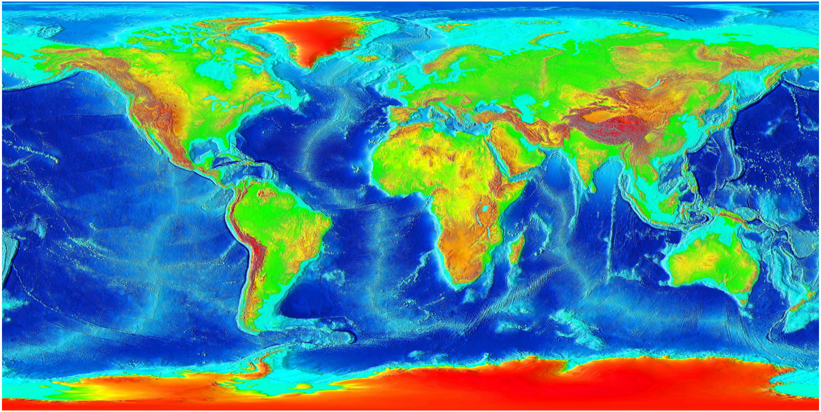


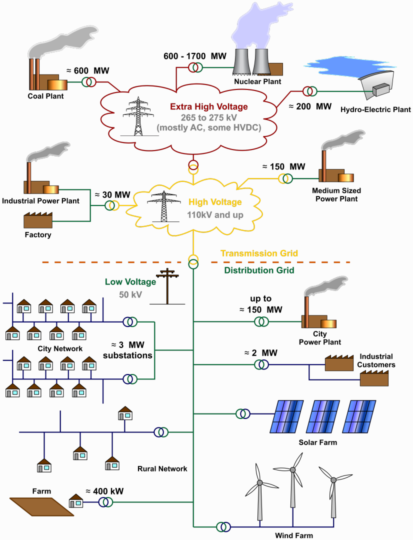
NASA/SVS

# Offshore underwater turbines



Continental shelf only 8% of ocean surface

# Offshore underwater turbines



# Offshore underwater turbines

Currently (to my knowledge) no commercial underwater implementation connected to the grid.

- Biofouling
- Corrosion
- Fisheries
- Sound effects, injuries
- Cavitation
- Maintenance cost
- Wakes in farms
- Need for strong and persistent flows
- Need to connect to grid

Go into the air !

# Offshore windfarms

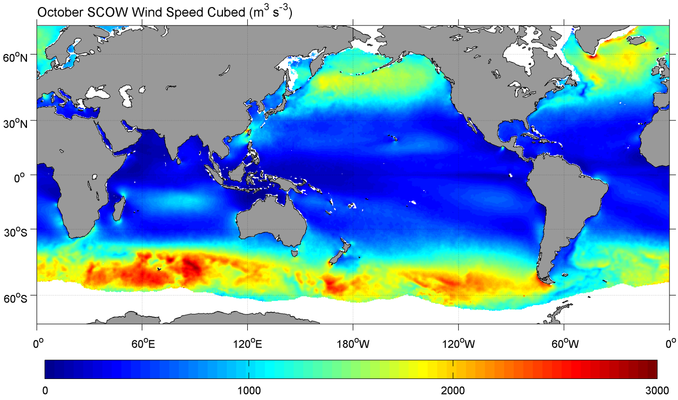
- Biofouling
- Corrosion
- Fisheries
- Sound effects, injuries
- Cavitation
- Maintenance cost
- Wakes in farms
- Need for strong and persistent winds
- Need to connect to grid

\- Visual impact

\+ Less perturbing ocean flow, niches for ecosystems

\- Avoid turbulent layer, reach into higher winds: tall towers

# Wind energy

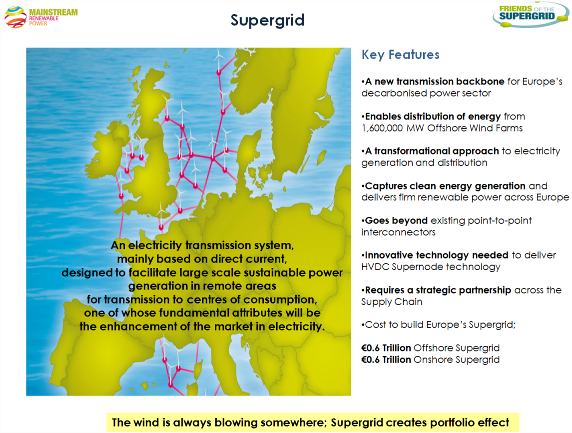

October SCOW Wind Speed Cubed (m3 s-3)
60°N
30°N
0°
30°S
60°S
0°
60°E
120°E
180°W
120°W
60°W
0°
0
1000
2000
3000

# Some ideas on power


Argyriadis et al. (2009)

- Per turbine 5-7.5 MW capacity today (planned 25 MW in 2020)
- 200 MW capacity for large farms, 4.3 GW in EU 2012 (planning 40 GW in 2020)
- Thornton Bank (Belgium): 215 MW before third phase in 2015 (up to 315 MW)

# Supergrid



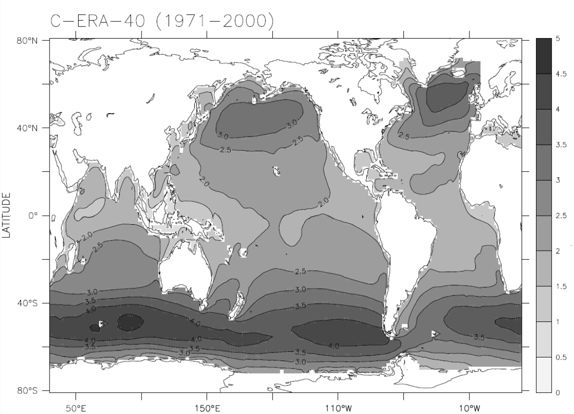

Strong lobbying at EU level ...

# Longer term

Floating structures, but tallness vs. stability ! Grid access.

# Wind also generates waves

# Surface waves



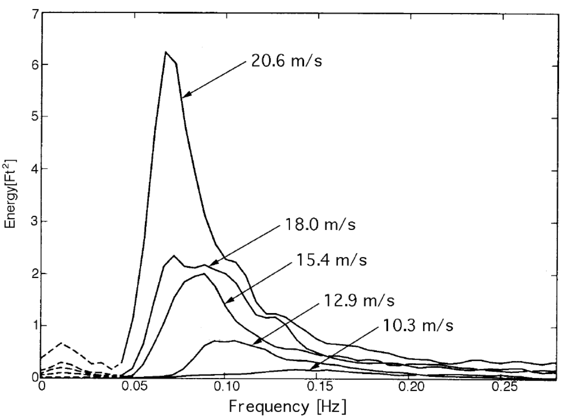

Sterl and Caires (2005)

# Explorations

- ANACONDA (floating rubber tubes with internal turbine)
- Oscillating floaters: linear or orbital
- Fixed horizontal plane under which wave generate flows
- Submerged flaps induced pumping and compression used onshore to produce electricity
- Floating rods with generators at connections
- ...

More than 50 designs, a dozen prototypes but no large farms yet. Capacity factor similar to wind. Cost above windfarms but private companies invest and believe in cost reductions.

# Spectral information needed




Pierson Jr and Moskowitz (1964)

Now via combination of observations and modelling (Data assimilation)

# Seawater is

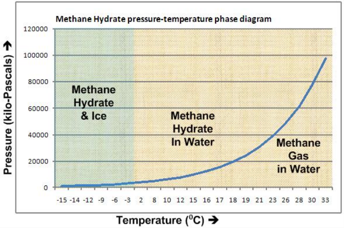
# Osmotic power

Desalinisation plants use energy to make fresh water from salty water. Here inverse operations:

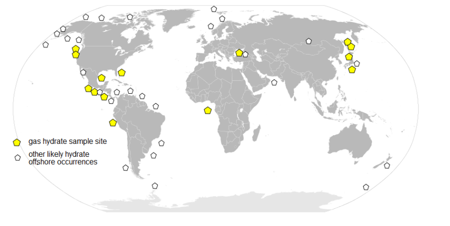
- Salty water have higher osmotic pressure $\Pi$ than fresh water
- A membrane allows water to flow but not salt with a specific permeability $A$
- Water flux $F$ between two sides given by $F = A(\Delta\Pi - \Delta P)$
- $\Delta\Pi$ equivalent to 270 m water column
- Resulting hydrostatic pressure difference $\Delta P$ used to pump fresh water into system and drive turbine

A few kW systems under operation. $CO_2$ friendly, but costly membrane and brackish-water generation.

# Methane: clathrates

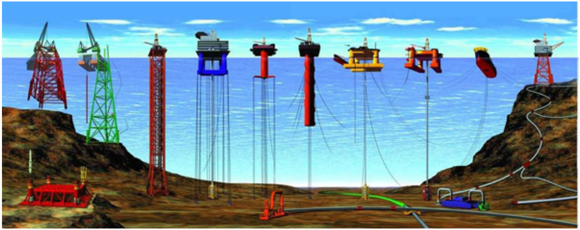



Estimation: 500-2000 GtC (compare to natural gaz estimation 230 GtC) but dispersed and low concentrations.



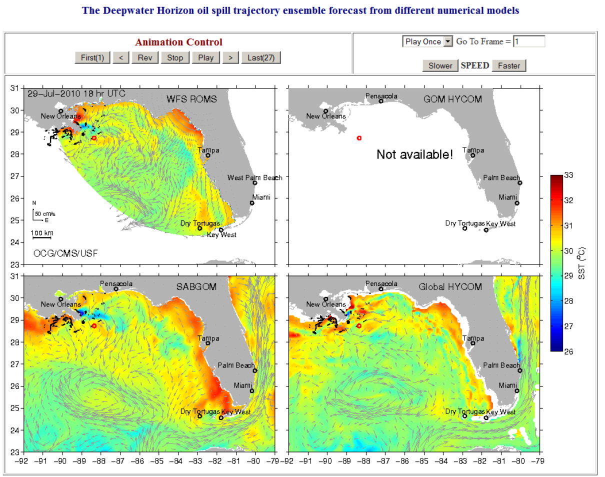

Could also be a timebomb in climate change.

# Petrol and Gaz

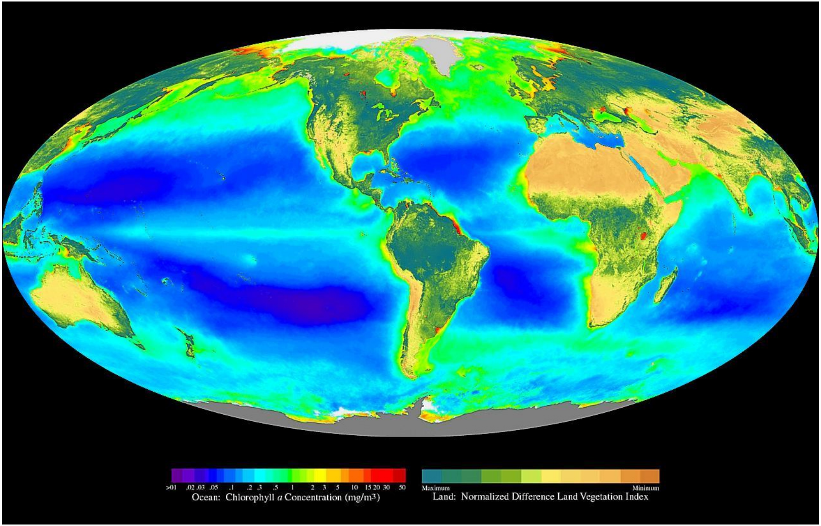


Originally on continental shelfs, now into deep ocean and Arctic ocean. Obvious potential environmental problems.

# Use of ocean models

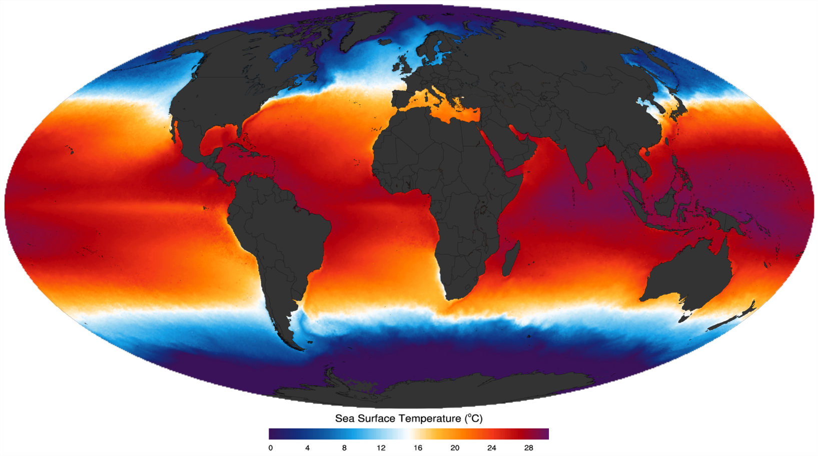



# Photosynthesis

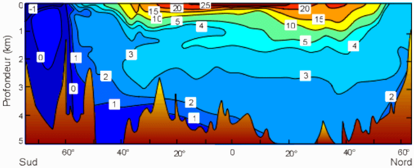



Use of algae to produce biofuel: experimental

# Heated water



# Efficiency



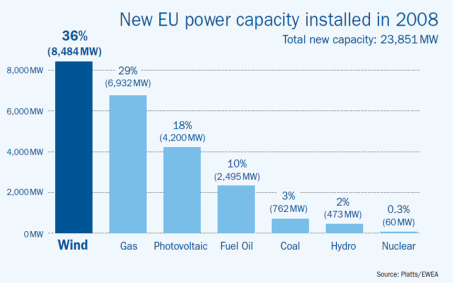

- Weak temperature difference (inefficient thermodynamic cycle: a few %)
- Pumping needed
- Release of $CO_2$ (cold deep waters), but overall budget beneficial
- Release of heated waters into deeper ocean
- Mostly all other "strutures in the ocean" related problems
+ Fertilisation, aquaculture
+ Combination with desalinisation
+ Air conditioning

Only useable in tropical regions, a few installations of 10 MW.

# Other ocean uses in energy supply

# Summary

- Wind farms most important renewable energy resource in the ocean.
- Niche applications or experimental setups of other technologies.



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