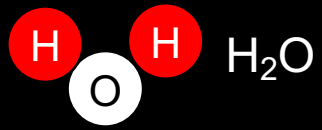
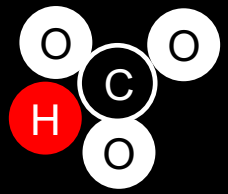
Exkurs 3: Karbonatchemie

Bicarbonationen (90%)

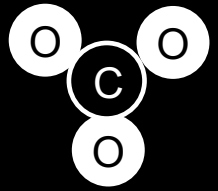
Carbonationen (9%)



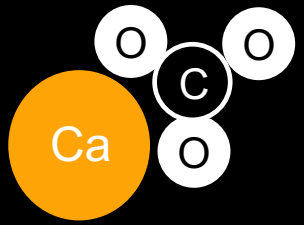
H_2O



HCO_3^-



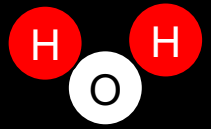
CO_3^{2-}



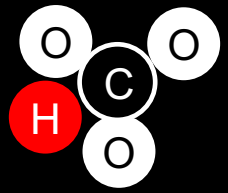
$CaCO_3$ (fest)

Zugabe von CO_2

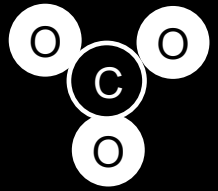
CO_2



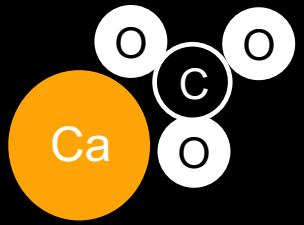
H_2O



HCO_3^-

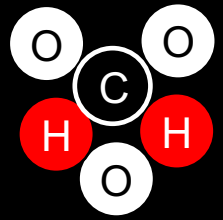


CO_3^{2-}

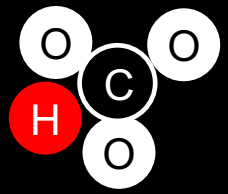


$CaCO_3$ (fest)

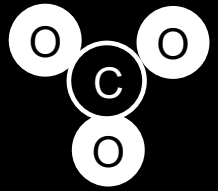
$$CO_2 + H_2O \longleftrightarrow H_2CO_3$$



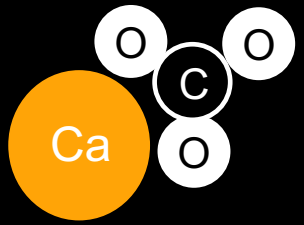
H_2CO_3



HCO_3^-

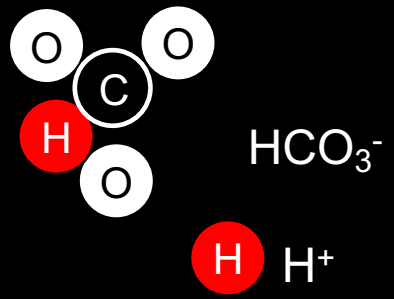


CO_3^{2-}



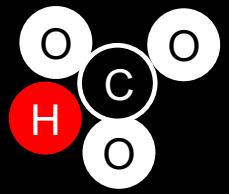
$CaCO_3$ (fest)

$$H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

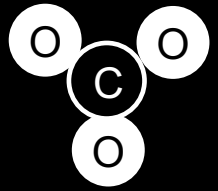


HCO_3^-

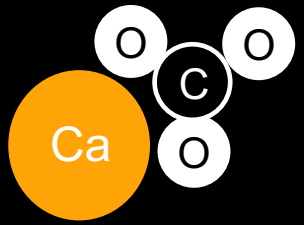
H^+



HCO_3^-

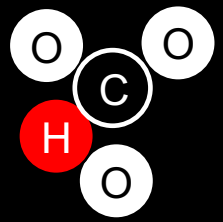


CO_3^{2-}

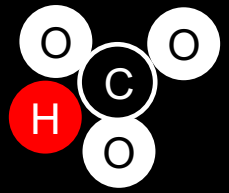


$CaCO_3$ (fest)

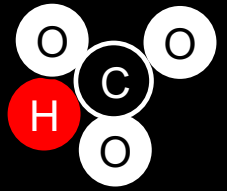
$$H^+ + CO_3^{2-} \longleftrightarrow HCO_3^-$$



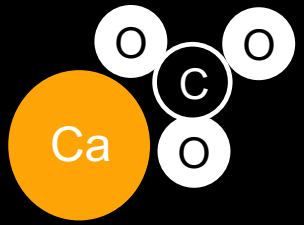
HCO_3^-



HCO_3^-

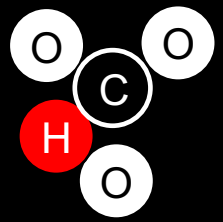


CO_3^{2-}

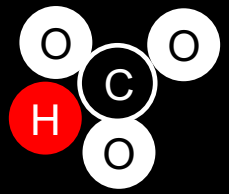


$CaCO_3$ (fest)

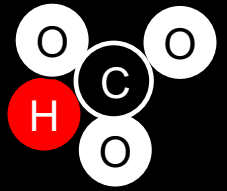
$$CaCO_3 \longleftrightarrow Ca^{2+} + CO_3^{2-}$$



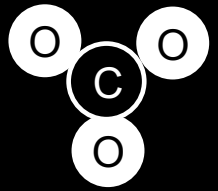
HCO_3^-



HCO_3^-

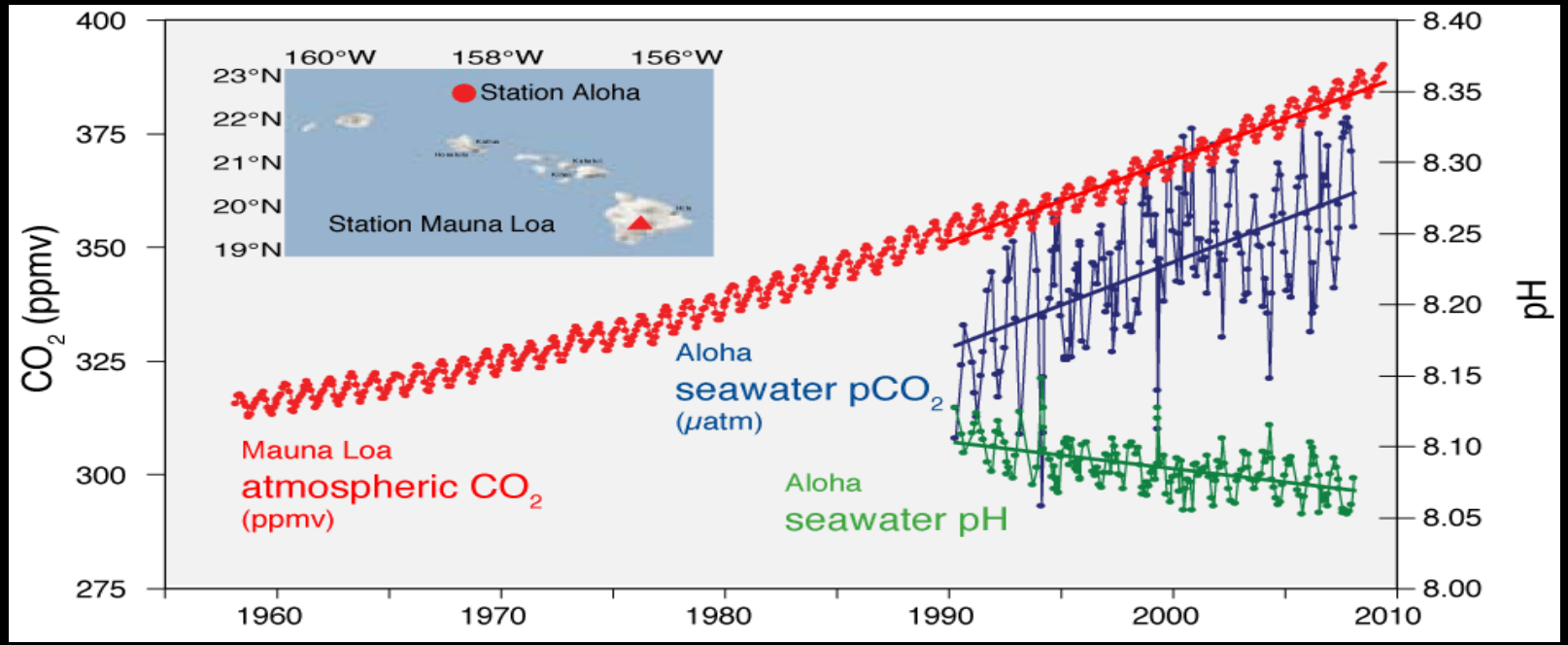


HCO_3^-



Ca^{2+} (dissolved)

.. die Ozeane werden saurer



- Seit 1750 hat der pH um 0.1 abgenommen (26% Zunahme in H+ Konzentration)

Aufdatiert von Feely et al. (2008)

Ozeanversauerung: Auswirkung auf kalkbildende Organismen

pH = 8.1
Today’s surface ocean pH

100 µm

pH = 7.8
Future surface ocean pH

Zukünftige Änderungen

Physikalische Gesetze

Erdsystemmodelle

- Die Erde ist in 3-D Gitterzellen aufgeteilt
- Viele Prozesse abgebildet (z.B. Kohlenstoffkreislauf)

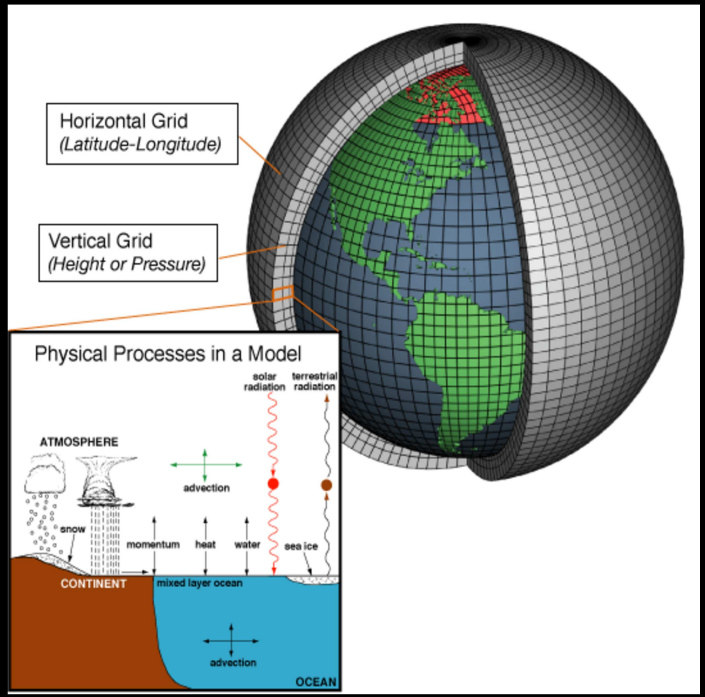
MASS Density of the fluid

ACCELERATION How velocity experienced by a particle changes with time

FORCE All the forces that are acting on the fluid

$$\rho\left(\frac{\partial V}{\partial t} + V\cdot\nabla V\right) = \nabla P + \rho g + \mu\nabla^2 V$$

- $\frac{\partial V}{\partial t}$: Change in velocity over time
- $V\cdot\nabla V$: The speed and direction which the fluid is moving
- ∇P: **Internal pressure gradient** of the fluid (the change in pressure)
- ρg: **External forces** acting on the fluid (such as gravity)
- $\mu\nabla^2 V$: **Internal stress forces** acting on the fluid (taking into consideration viscous effects)



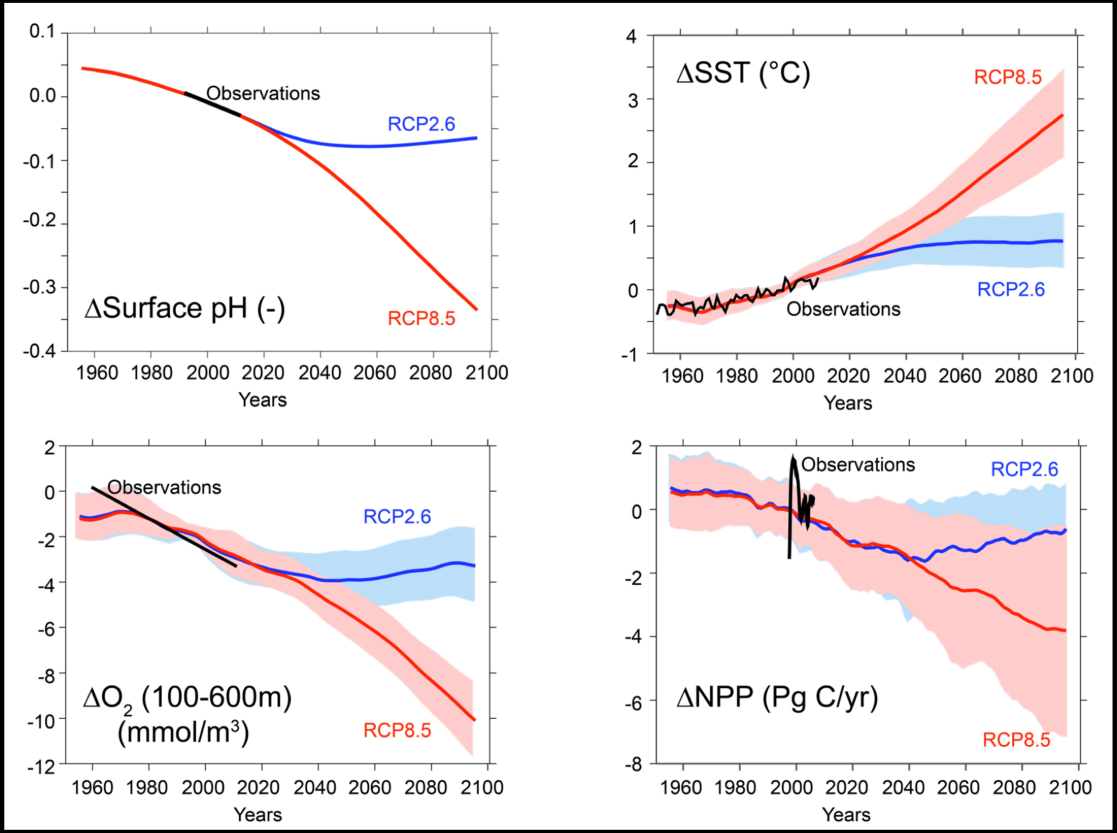
Erdsystemmodelle

1 Million Linien Modellcode

```
integer :: id_grid_xu, id_grid_yu

integer :: id_potrho_bounds,     id_potrho_axis
integer :: id_neutralrho_bounds, id_neutralrho_axis
integer :: id_theta_bounds,      id_theta_axis

integer :: id_restart(3)
integer :: neutral_rho_method=0

real, allocatable, dimension(:) :: potrho_bounds
real, allocatable, dimension(:) :: neutralrho_bounds
real, allocatable, dimension(:) :: theta_bounds

! salinity and temperature pointers to aid readability
real, dimension(:,:,:), pointer :: salinity    => NULL()
real, dimension(:,:,:), pointer :: temperature => NULL()

real    :: potrho_interval
real    :: neutralrho_interval
real    :: theta_interval
character*128 filename

integer :: stdoutunit,stdlogunit
stdoutunit=stdout();stdlogunit=stdlog()


if ( module_is_initialized ) then
  call mpp_error(FATAL, &
    '==>Error in ocean_density_mod (ocean_density_init): module already initialized.' )
endif

module_is_initialized = .TRUE.

tau             = Time%tau
taup1           = Time%taup1
taum1           = Time%taum1
vert_coordinate = ver_coordinate

num_prog_tracers = size(T_prog(:))
do n=1,num_prog_tracers
   if (T_prog(n)%name == 'temp')   index_temp   = n
   if (T_prog(n)%name == 'salt')   index_salt   = n
   if (T_prog(n)%name == 'fdelta') index_fdelta = n
   if (T_prog(n)%longname == 'Conservative temperature') temp_variable = CONSERVATIVE_TEMP
   if (T_prog(n)%longname == 'Potential temperature')    temp_variable = POTENTIAL_TEMP
   if (T_prog(n)%longname == 'Practical Salinity')       salt_variable = PRACTICAL_SALT
   if (T_prog(n)%longname == 'Preformed Salinity')       salt_variable = PREFORMED_SALT
enddo
```

Supercomputer in Lugano:
Computerpower von 350‘000 Macbooks

Modellprojektionen



Frölicher et al. (2016, Global Biogeochemical Cycles)

Die Ozeane im Jahre 2100

Erwärmung
+1.3°C bis 3.5°C

Versauerung
-0.17 bis -0.39

Sauerstoffverlust
-3.8% bis -5.5%

Marine Hitzewellen
41x häufiger und intensiver

Nährstoffverlust
-2% bis -9%

Meeresspiegel
+0.69m bis +0.82m

Risiken für marine Ökosysteme

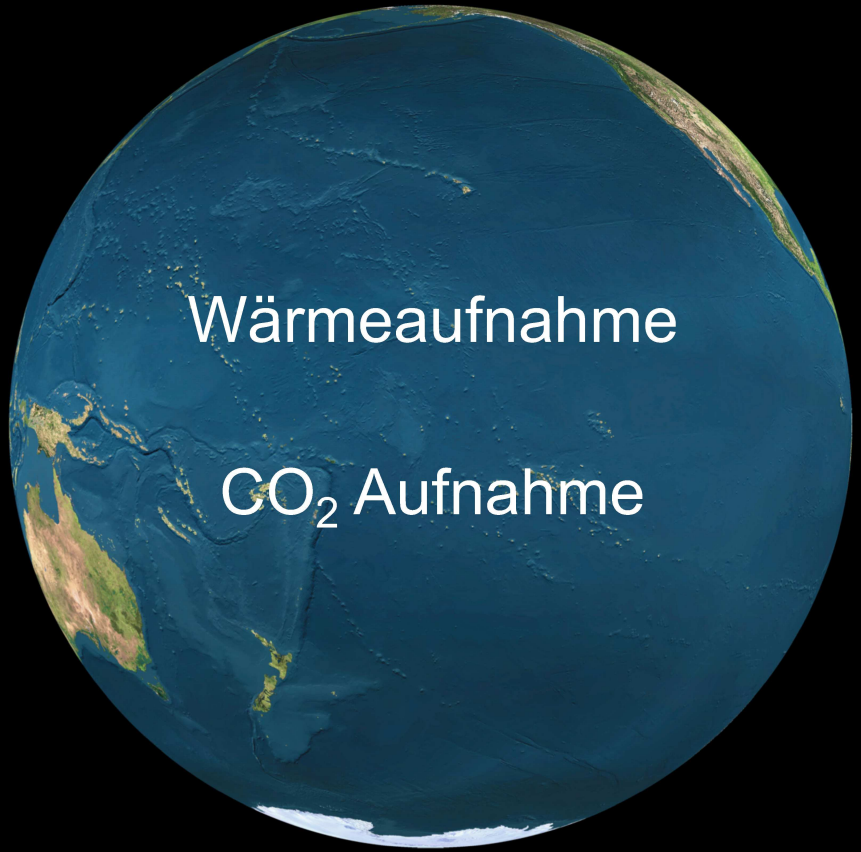
Korallenriffe

Fischfang

1.5°C	2°C
-70% bis -90%	>-99%
-1.5 Millionen Tonnen	-3 Millionen Tonnen

Basierend auf IPCC SR15 (2018), Cheung, Frölicher et al. (2016)

Ökosystemdienstleistungen der Weltmeere



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