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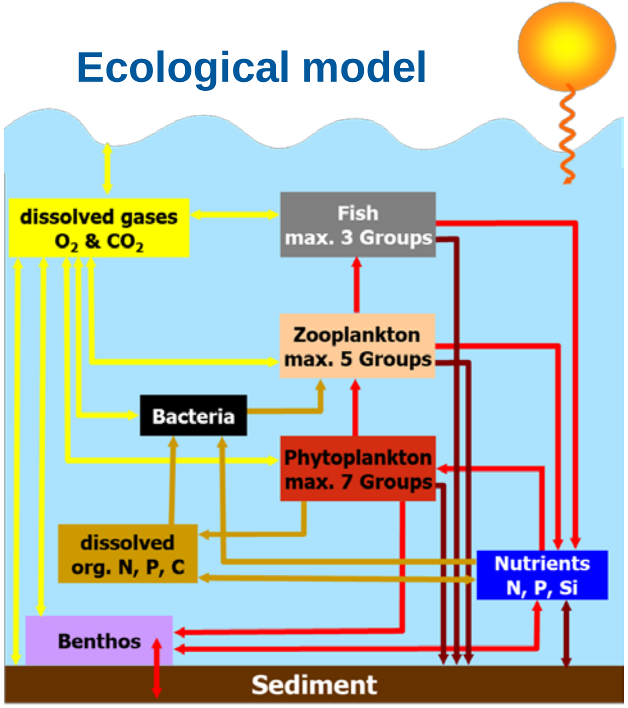
How to model a Lake?

Physical lake models

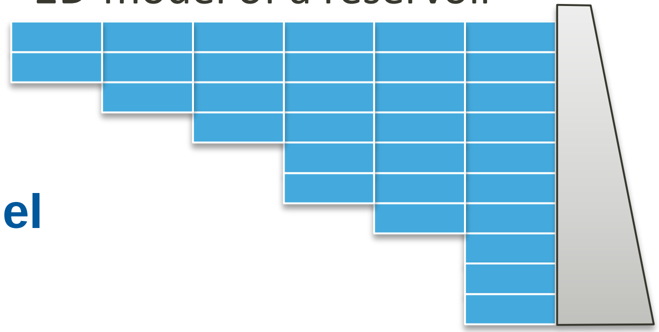
Coupled physical-ecological lake models

Diversity

Ecological model

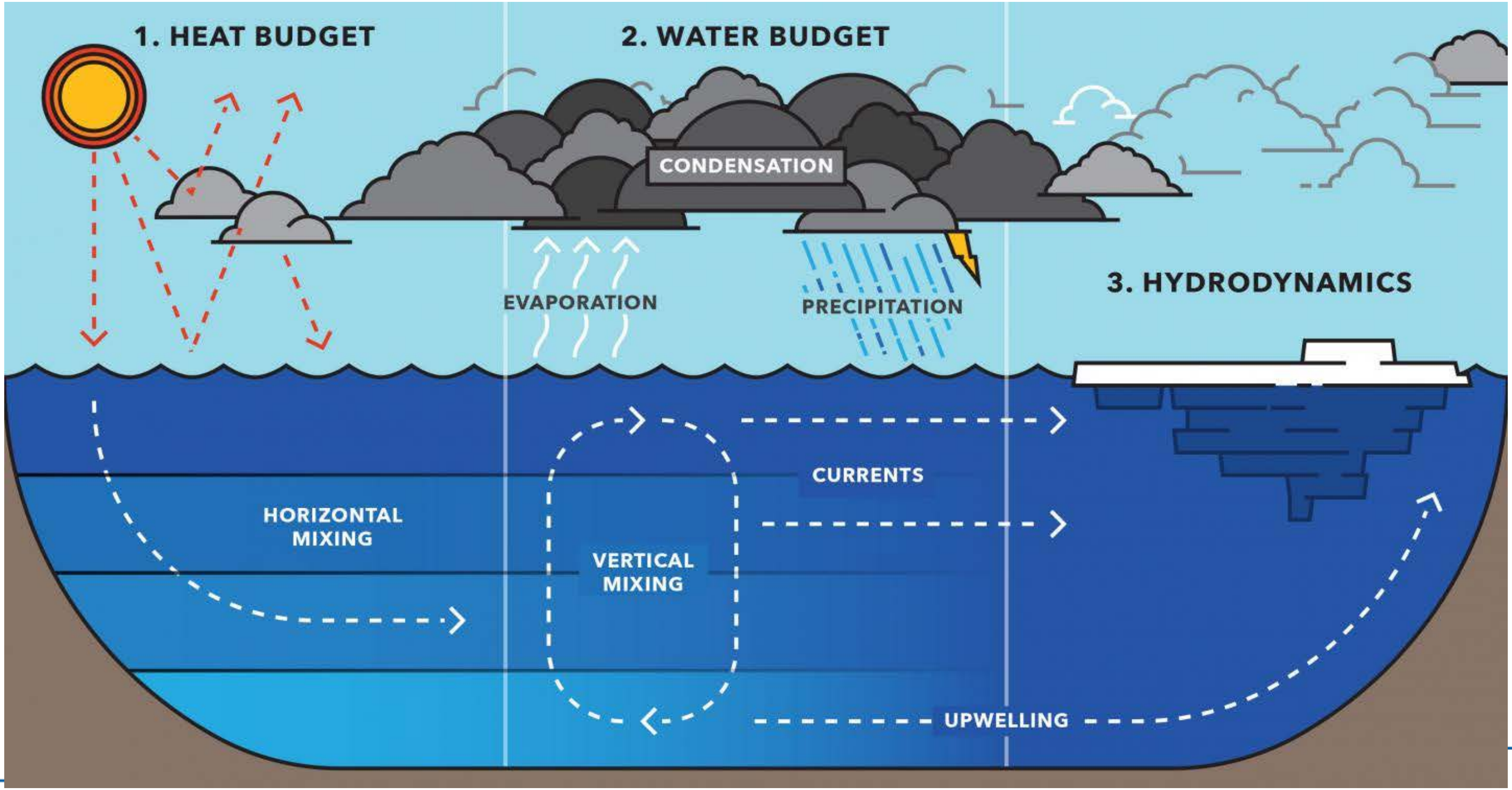


2D-model of a reservoir

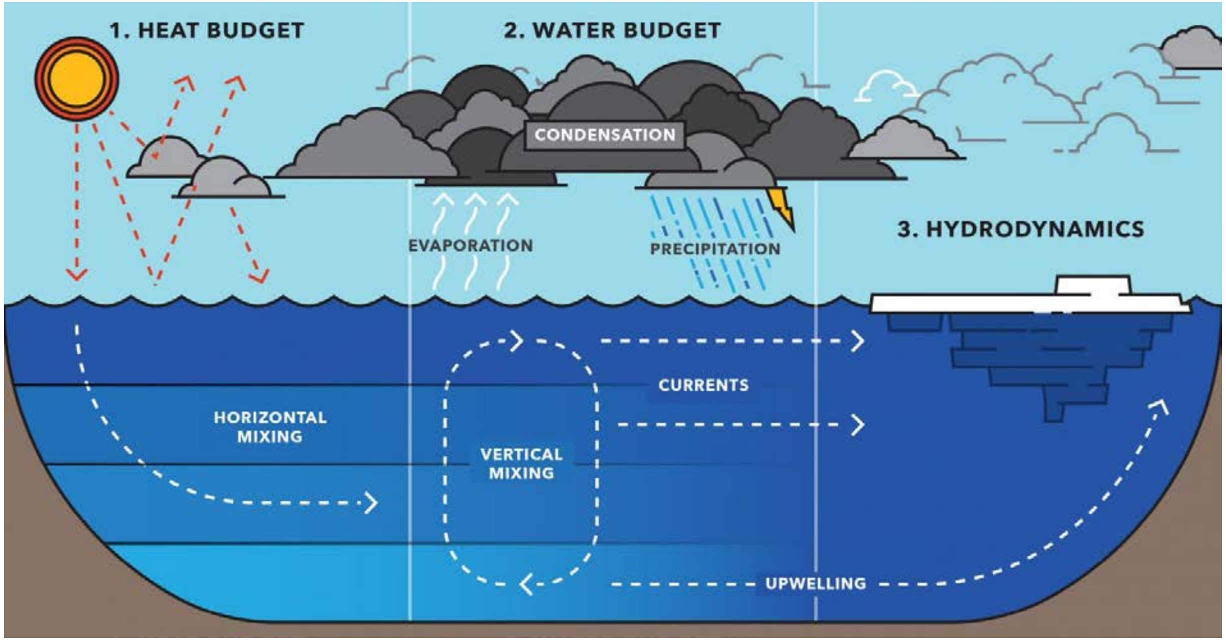


Hydrodynamic model in 1D, 2D or 3D

Three major ingredients: heat budget, water mass budget, momentum balance



Three major ingredients: heat budget, water mass budget, momentum balance



__Input data__

- Meteorological variables
- Inflow discharge
- Outflow discharge

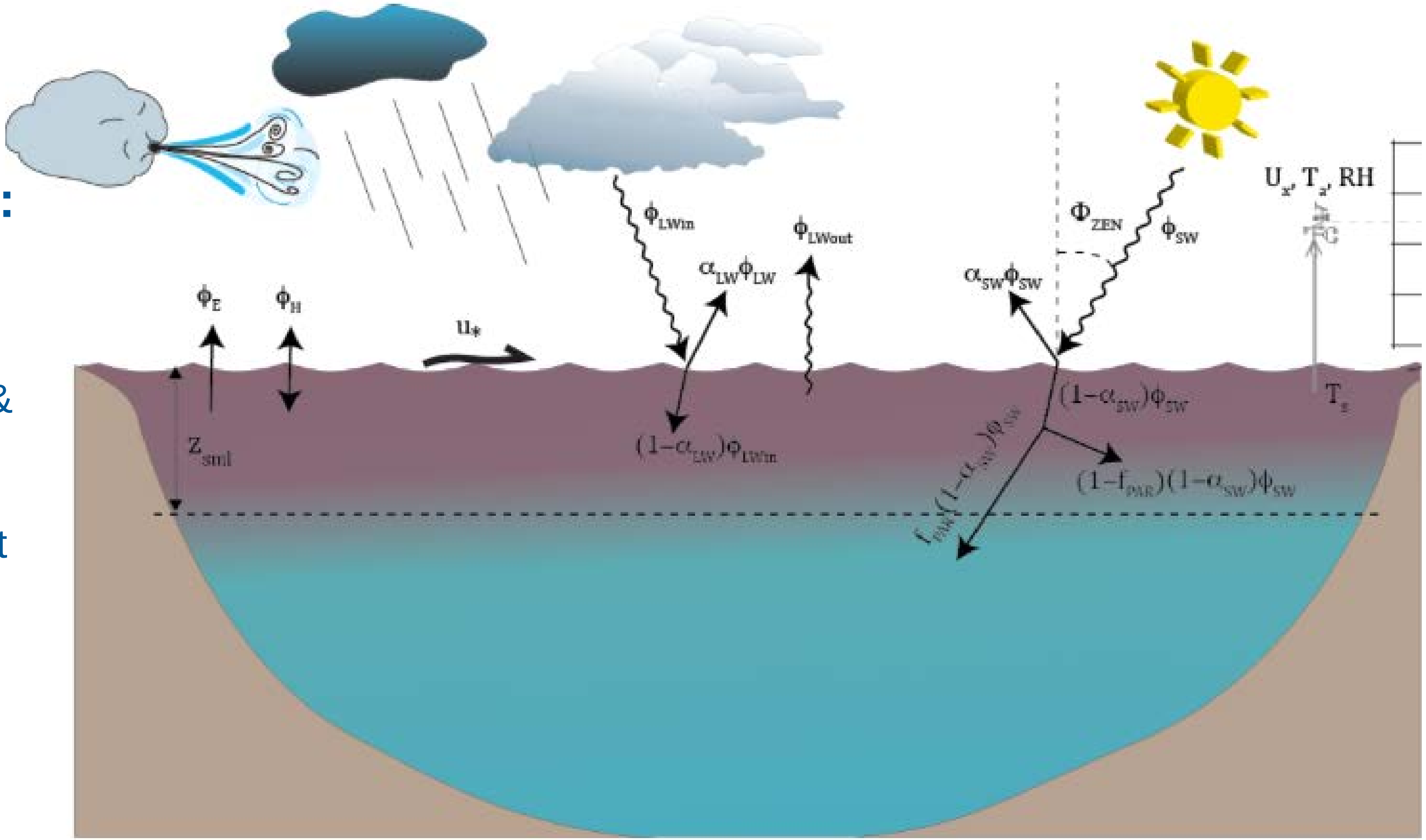
__Output data__

- Temperature (and salinity) in each layer over time

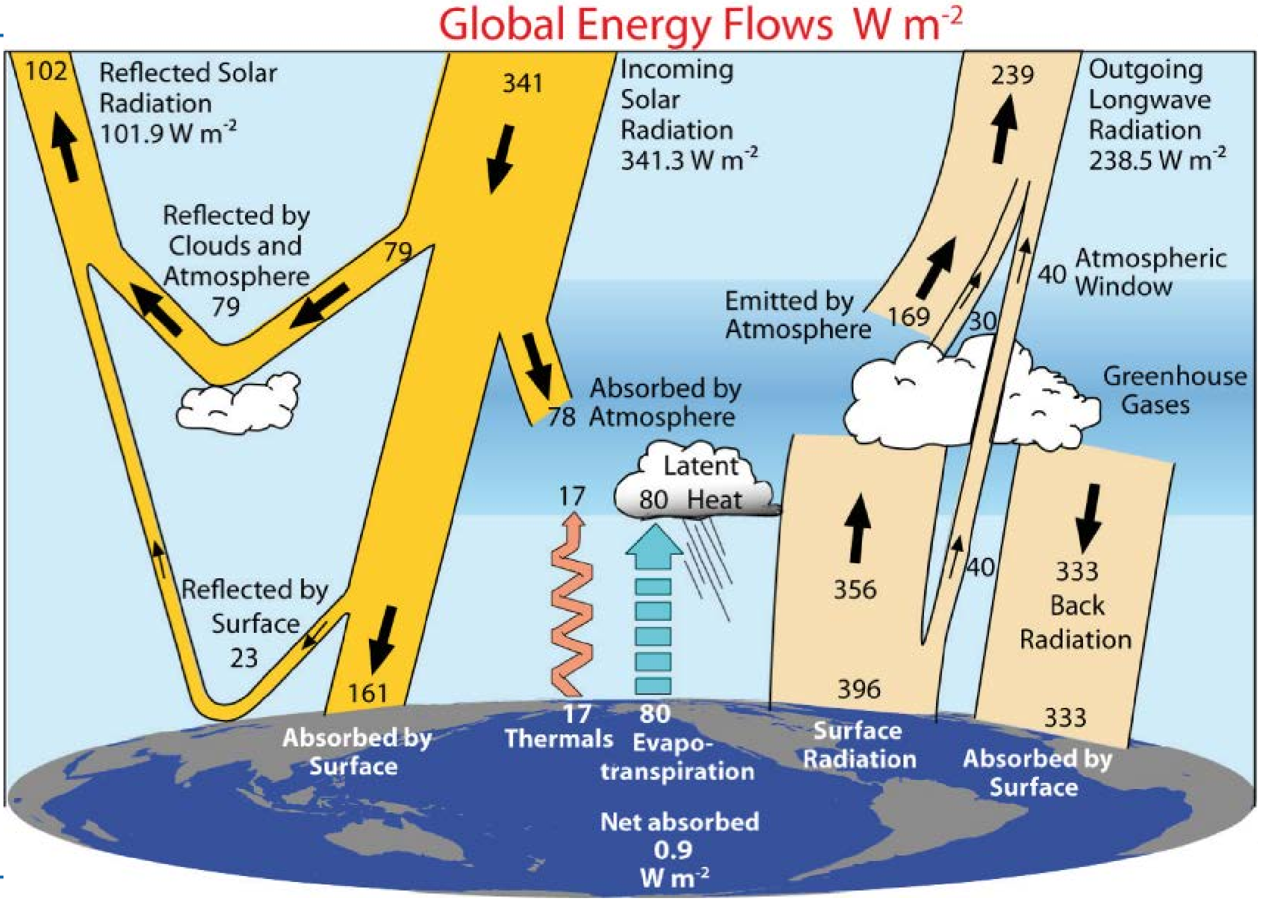
Heat budget:

Water surface
- Long wave radiation (in & out)
- Latent heat
- Sensible heat

Penetrative
- Short wave radiation

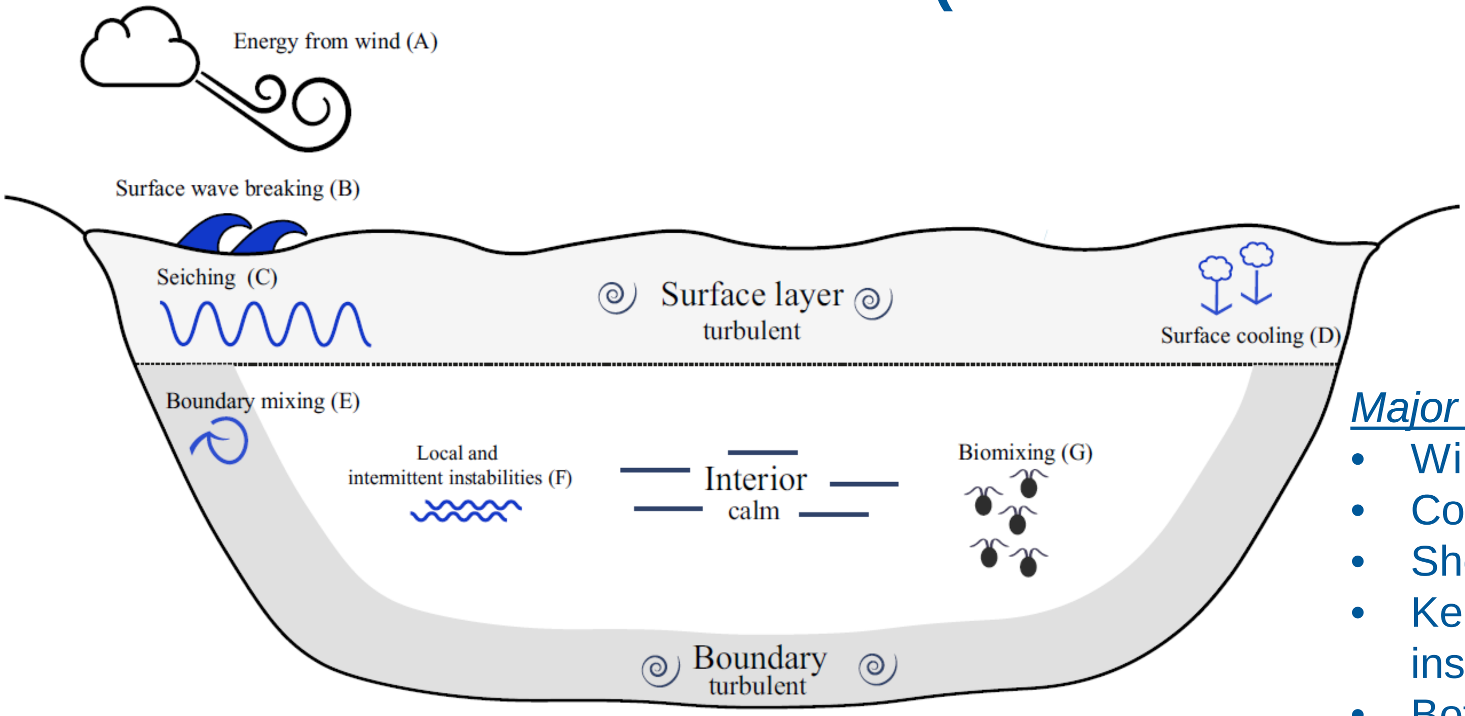


Heat balance



Trenberth, K. E., J. T. Fasullo and J. Kiehl (2009). Earth's global energy budget. Bull. Amer. Meteor. Soc., 90: 311-323.

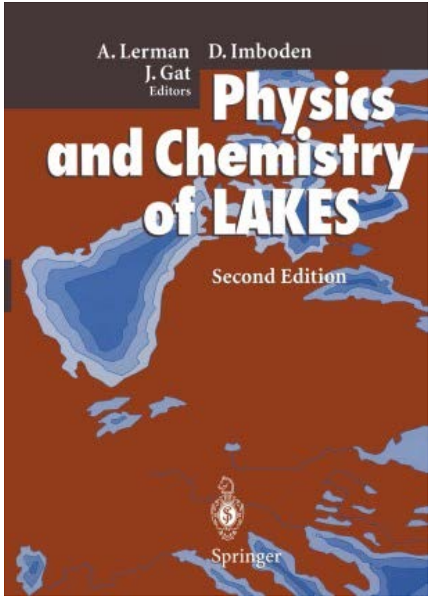
Hydrodynamics (= momentum & TKE balance)



Major sources of mixing

- Wind stirring (surface)
- Convection (surface)
- Shear mixing (interior)
- Kelvin Helmholtz instabilities (interior)
- Bottom friction (boundary/bottom layer)

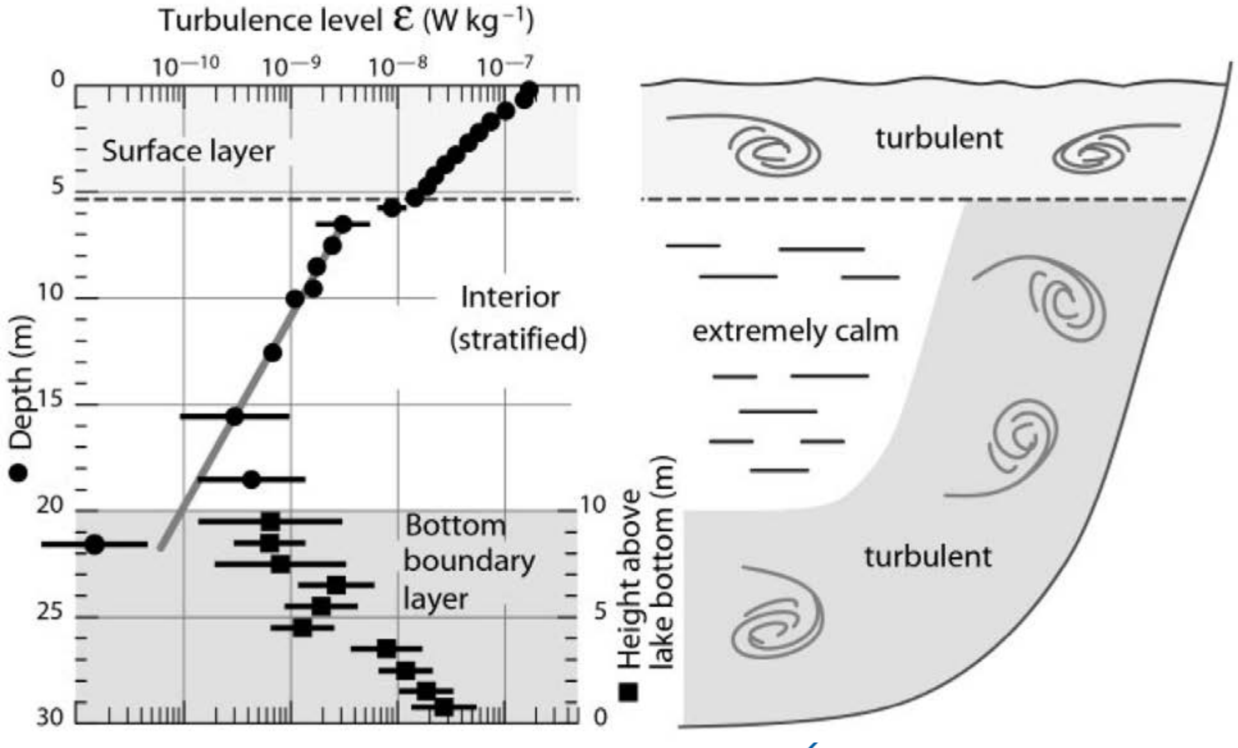
Mixing is not a continuous process in space and time



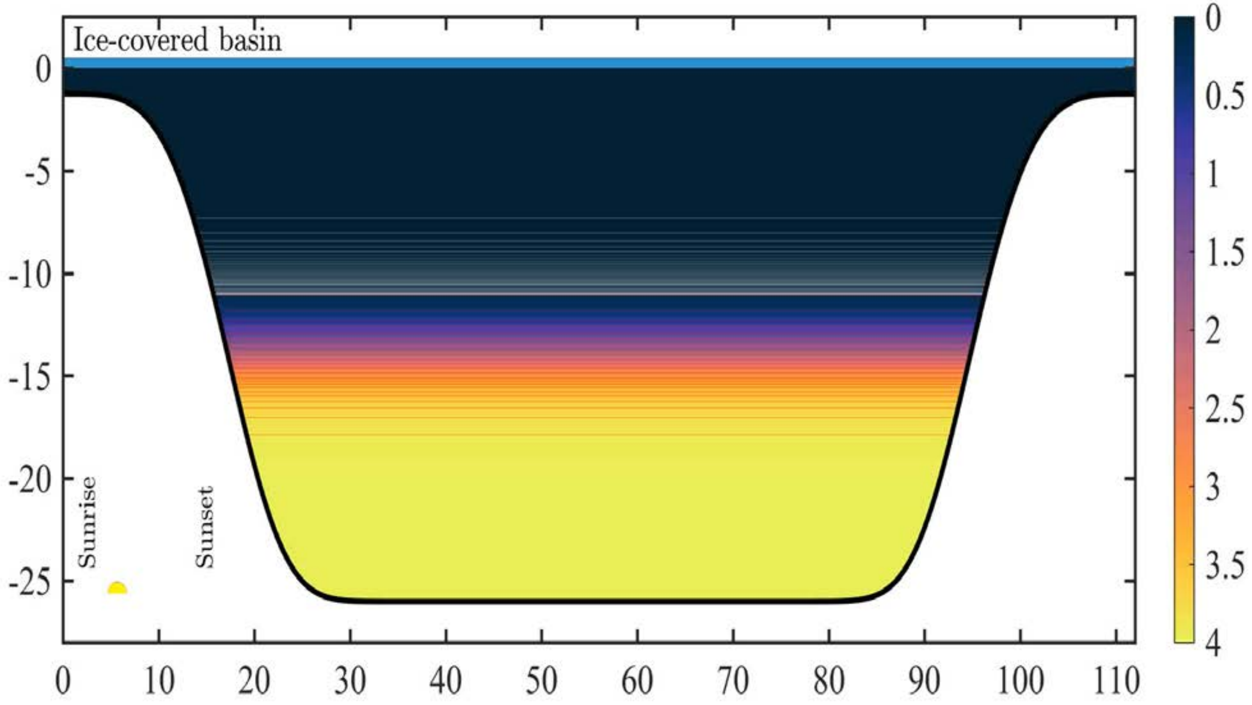
Annu. Rev. Fluid Mech. 2003. 35:373–412
doi: 10.1146/annurev.fluid.35.101101.161220

SMALL-SCALE HYDRODYNAMICS IN LAKES

Alfred Wüest and Andreas Lorke

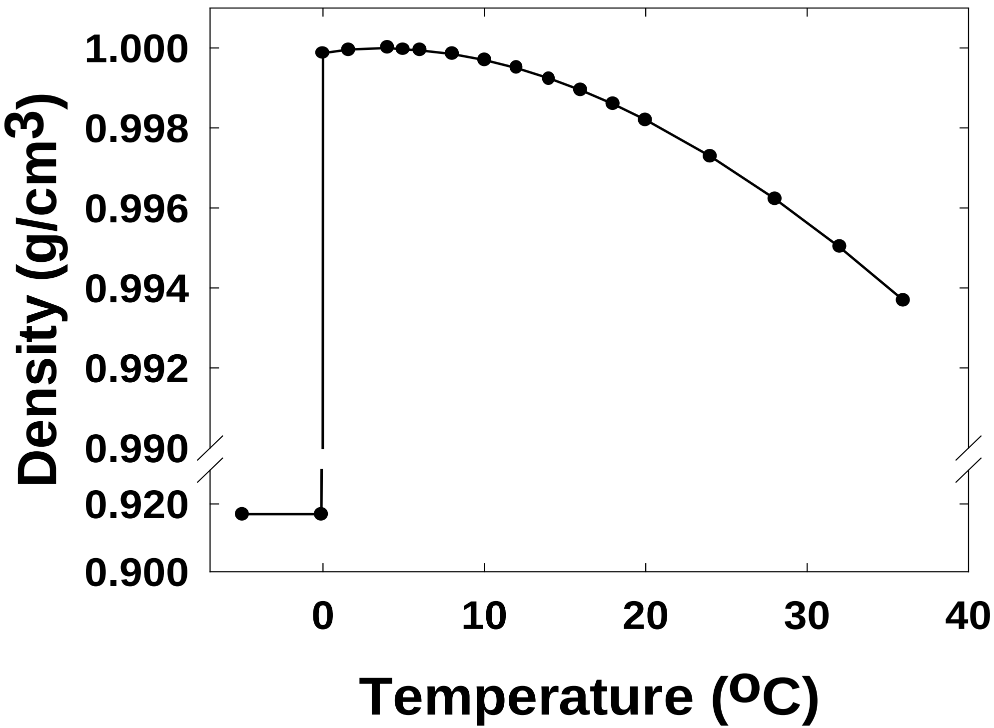


Mixing is not a continuous process in space and time

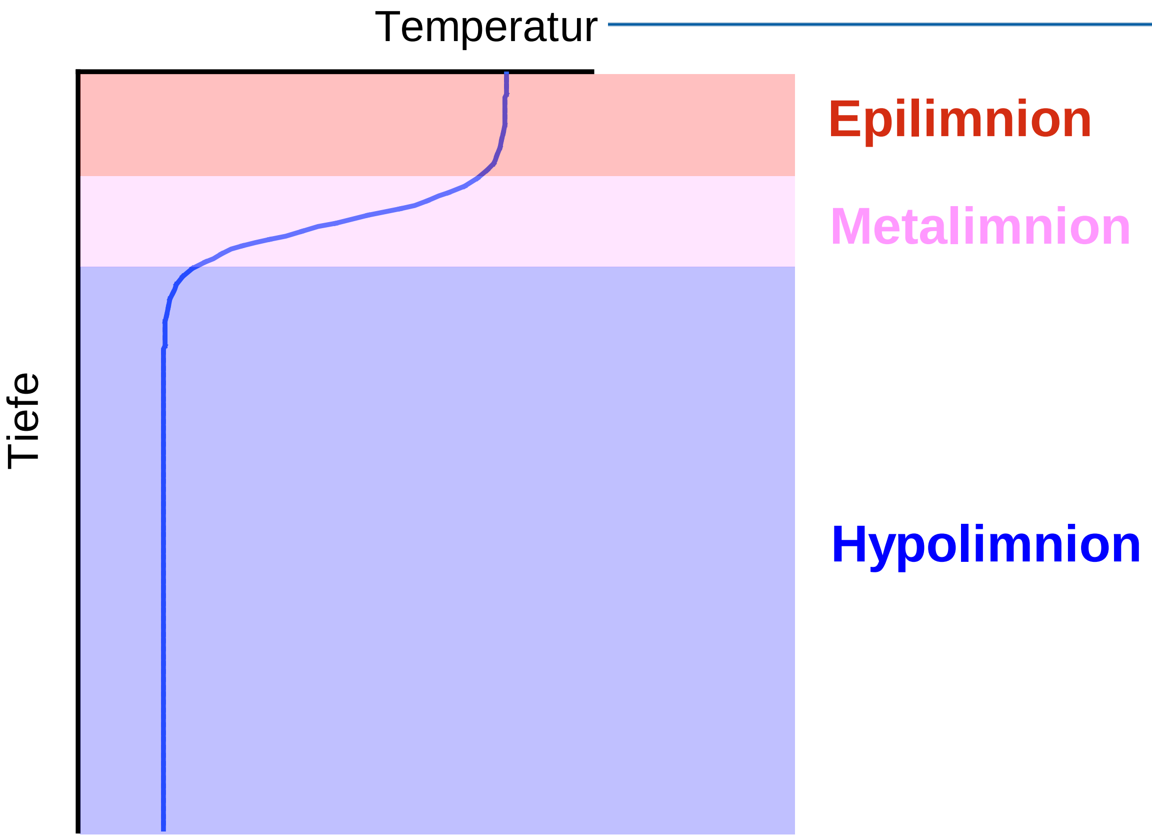


Source:
Ulloa & Wuest
EPFL

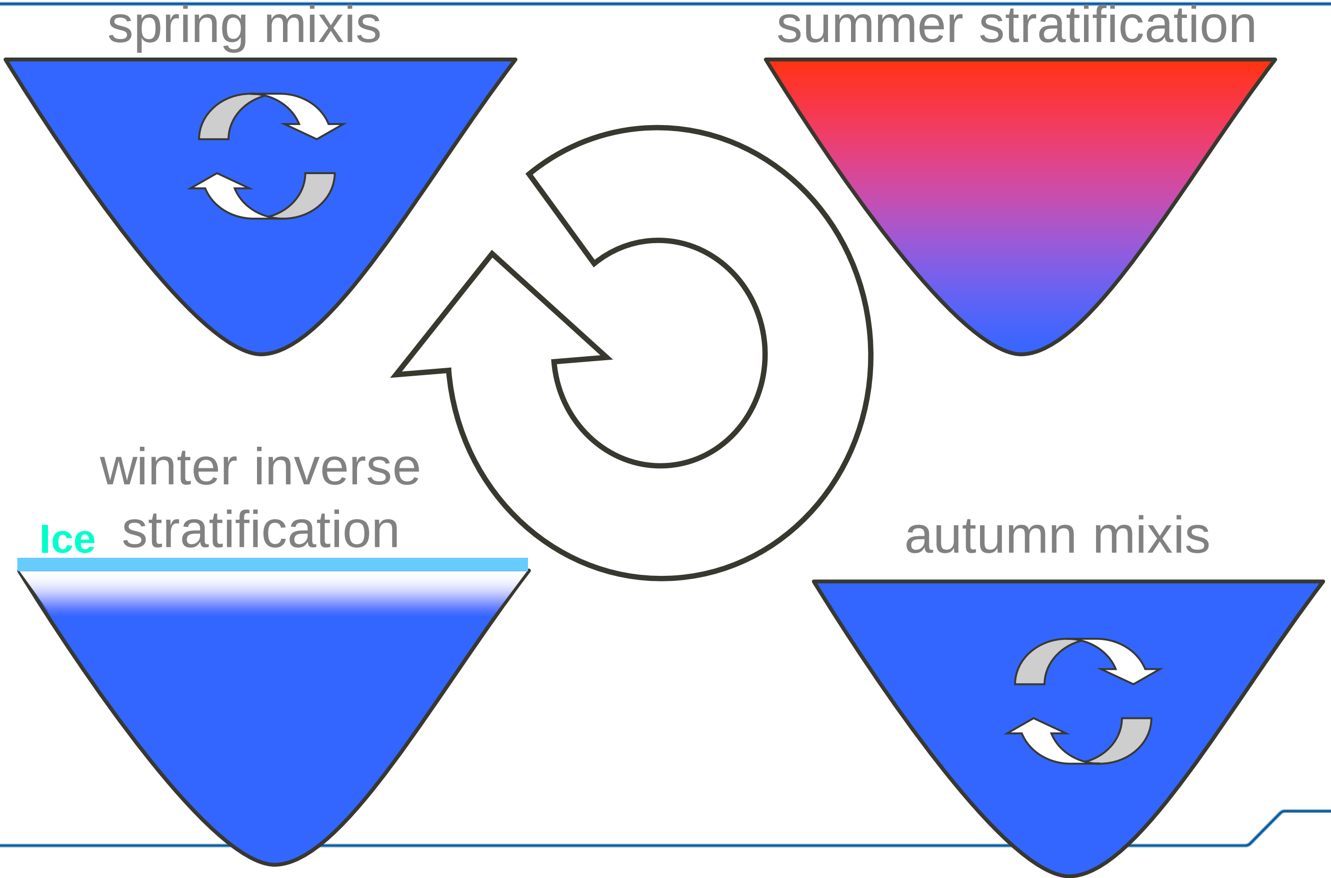
Density anomaly of water



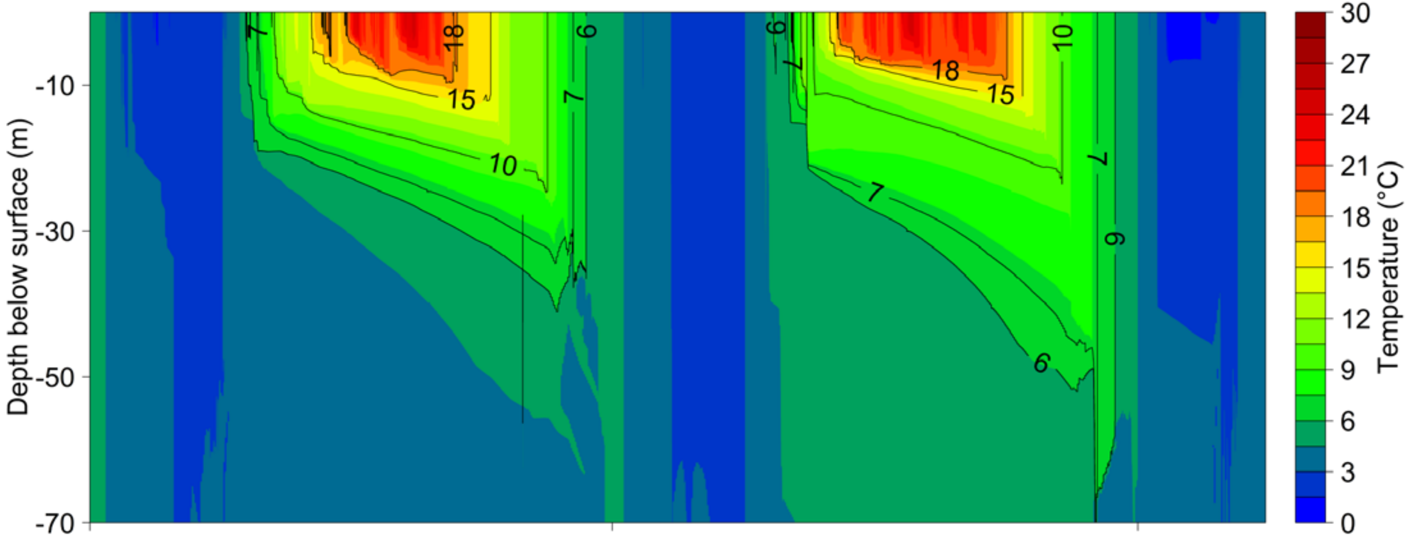
Stratification in lakes



Mixing regime in a dimictic lake



Simulation from January 2015 – March 2017



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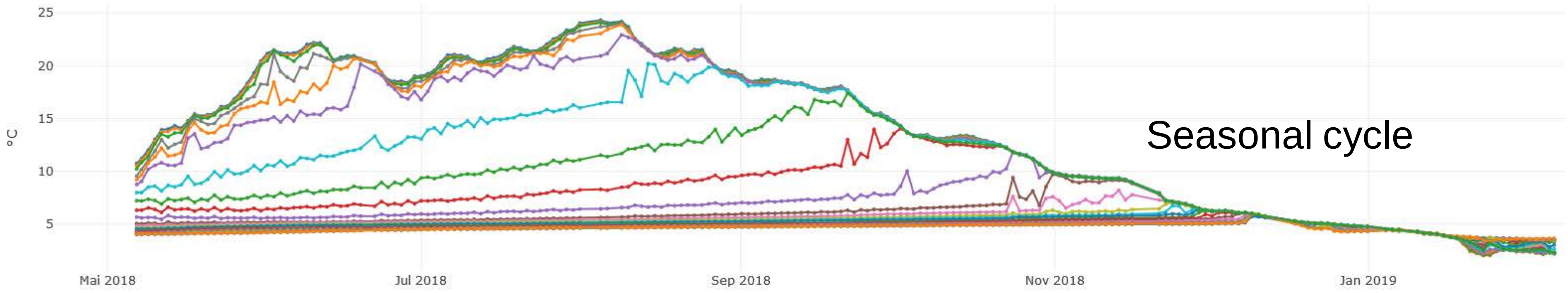
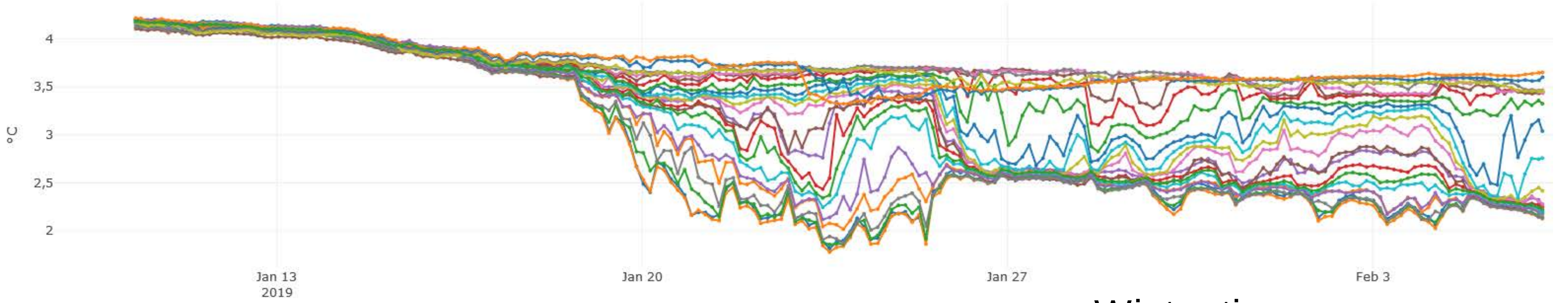
Vertical temperature dynamics in Rappbode Reservoir



Seasonal cycle



Winter time

Lake mixing types

amictic: lake never circulates (e.g. ice-covered for the whole year in arctic or alpine environments)

meromictic: lake circulates only partly (e.g. high density in bottom waters due [→ Monimolimnion] due to high salinity)

holomictic: lake circulates completely, several types can occur:

oligomictic: lake circulates NOT every year, e.g. large lakes in warm temperate climates where mixis only occurs in cold winters

monomictic: lake circulates once per year; cold-monomictic lakes circulate in summer, warm-monomictic lakes circulate in winter

dimiktisch: lake circulates twice per year (spring and autumn)

polymictic: lake circulate several times per year, e.g. shallow lakes (sometimes even daily: tropical shallow lakes)

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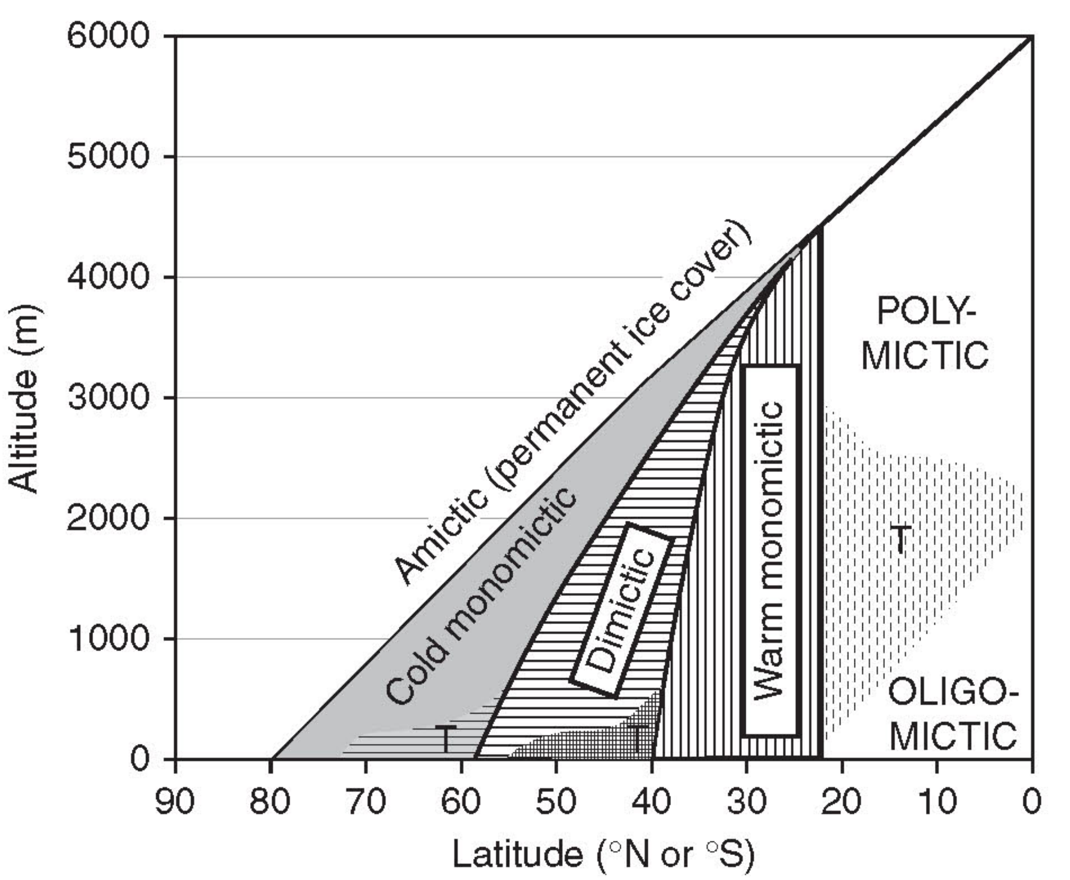
Overview stratification types



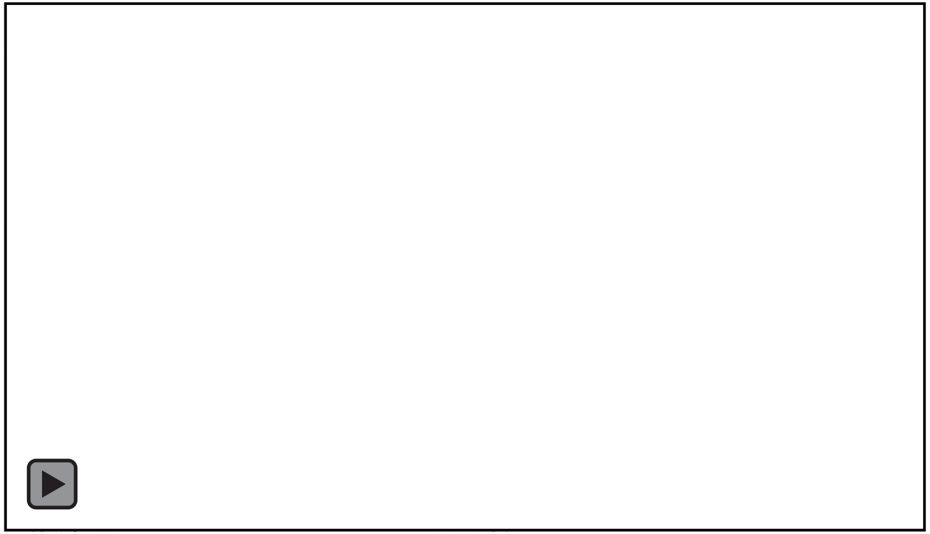
Example of a 2D lake model: CEQUAL model grid

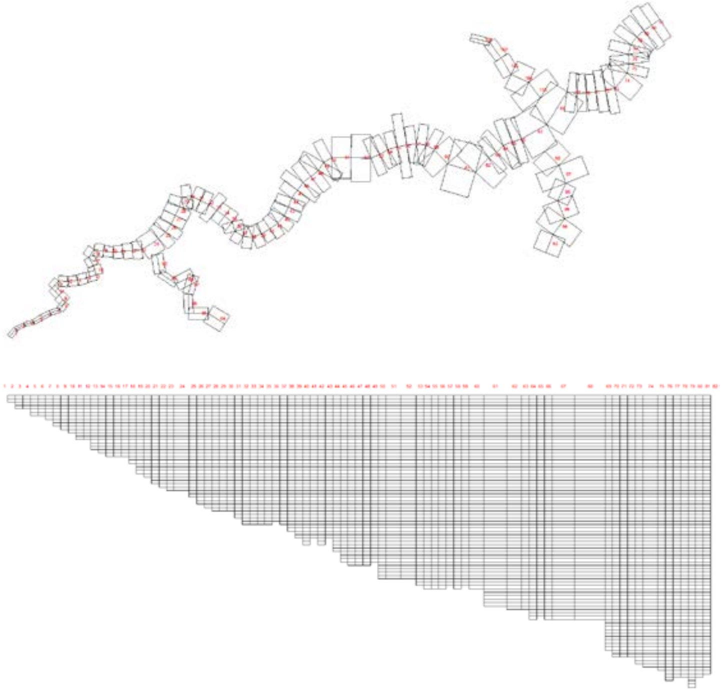
Temperature

0°C

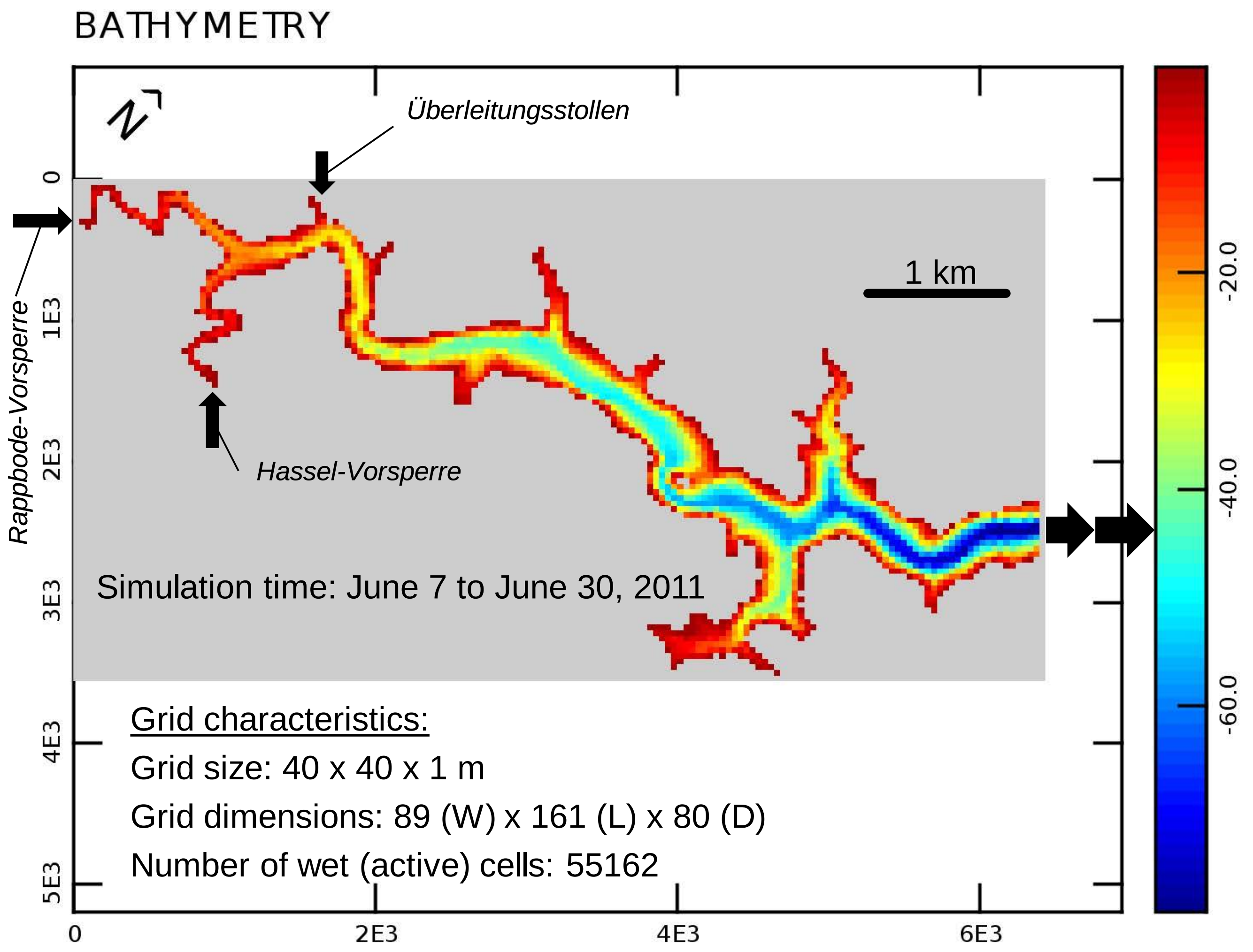
30°C

Depth

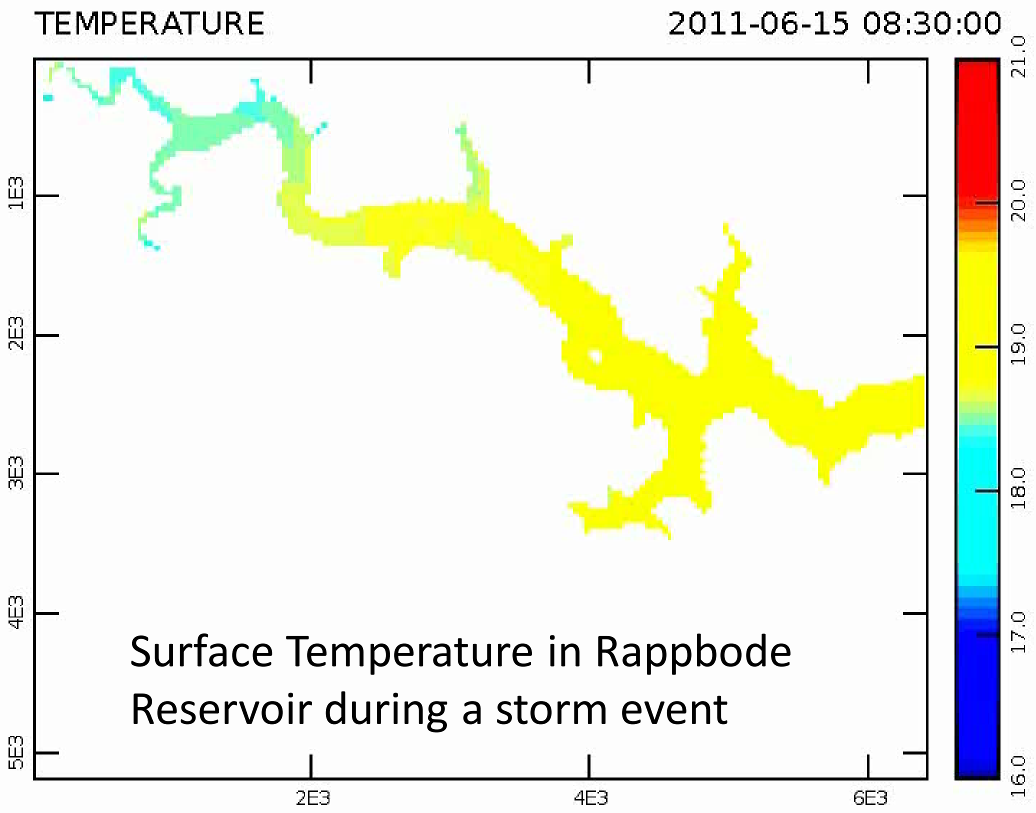




Example of a 3D lake model: ELCOM model grid



Examples of 3D lake simulations



Surface Temperature in Rappbode Reservoir during a storm event

Primary production in different ecosystems

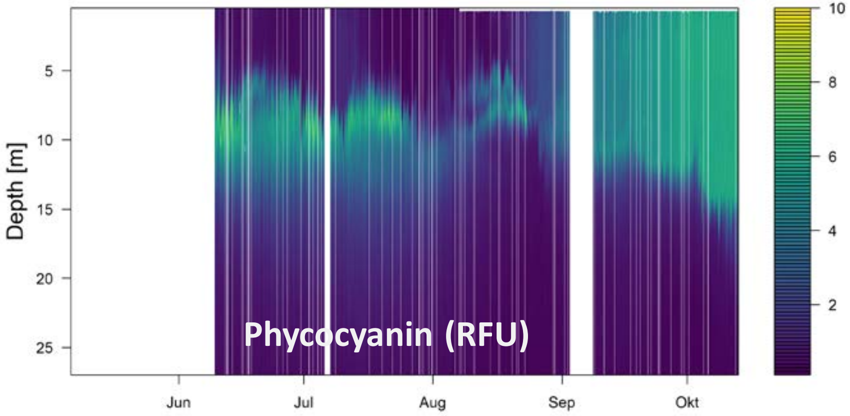
$$\frac{World\ NPP[ta^{-1}]}{World\ biomass[t]} =$$

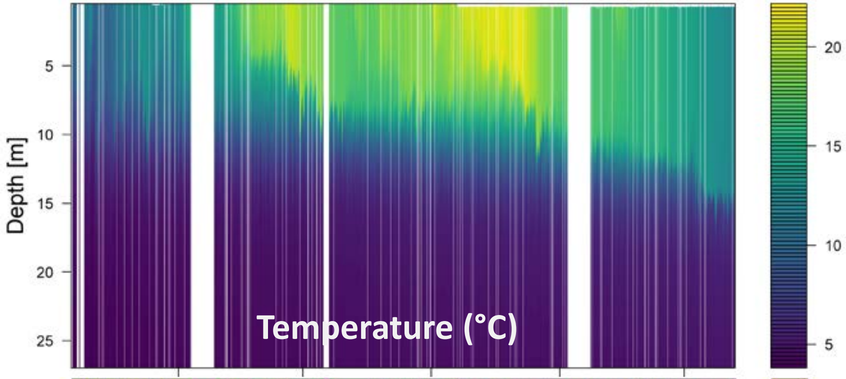
$$Biomass\ turnover\ rate\ [a^{-1}]$$

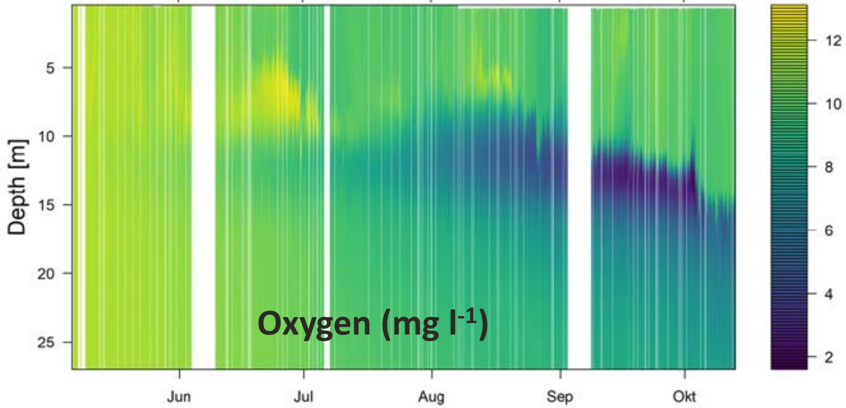
Ecosystem	Turnover [a^{-1}]
Tropical rain forest:	0,049
Boreal forest:	0,040
Cultivated land:	0,650
Open ocean:	41,500
Lakes & streams:	10,000

Ecosystem Type	Area	Mean NPP	World NPP	Mean Biomass	World Biomass
	(10^6 km²)	(g/m²/yr)	(10^9 tons/yr)	(kg/m²)	(10^9 tons)
Tropical Rain Forest	17	2200	37.4	45	763
Tropical Seasonal Forest	7.5	1600	12	35	260
Temperate Evergreen Forest	5	1300	6.5	35	175
Temperate Deciduous Forest	7	1200	8.4	30	210
Boreal Forest	12	800	9.6	20	240
Woodlands & Shrublands	8.5	700	6	6	50
Savanna	15	900	13.6	4	60
Temperate Grasslands	9	600	5.4	1.6	14
Tundra & Alpine	8	140	1.1	0.6	5
Desert & Semi-Desert	18	90	1.6	0.7	13
Extreme Desert & Ice	24	3	0.07	0.02	0.5
Cultivated Land	14	650	9.1	1	14
Swamp & Wetland	2	2000	4	12.3	30
Lake & Stream	2	250	0.5	0.02	0.05
-- Total Continental	**149**	**773**	**115**	**12.3**	**1837**
Open Ocean	332	125	41.5	0.003	1
Upwelling Zones	0.4	500	0.2	0.02	0.008
Continental Shelf	26.6	360	9.6	0.01	0.27
Algal Bed & Reef	0.6	2500	1.6	2	1.2
Estuaries	1.4	1500	2.1	1	1.4
-- Total Marine	**361**	**152**	**55**	**0.01**	**3.9**
---- Grand Total	**510**	**333**	**170**	**3.6**	**1841**

Real ecosystem dynamics







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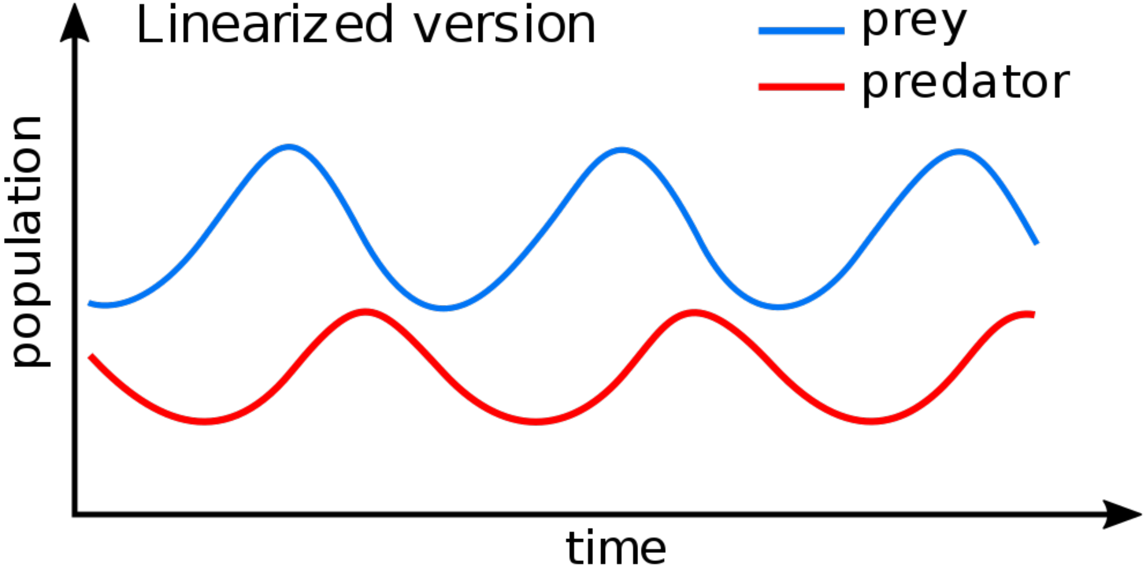
Lake Ecosystems

(Internal) Ecosystem dynamics

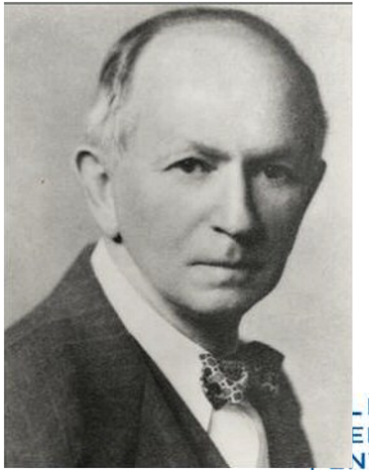
Jörg Imberger:
Physics are controling everything in freshwater ecosystems

Günter Blöschl:
Hydrology is controling everything in freshwater ecosystems

Predator-prey-dynamics

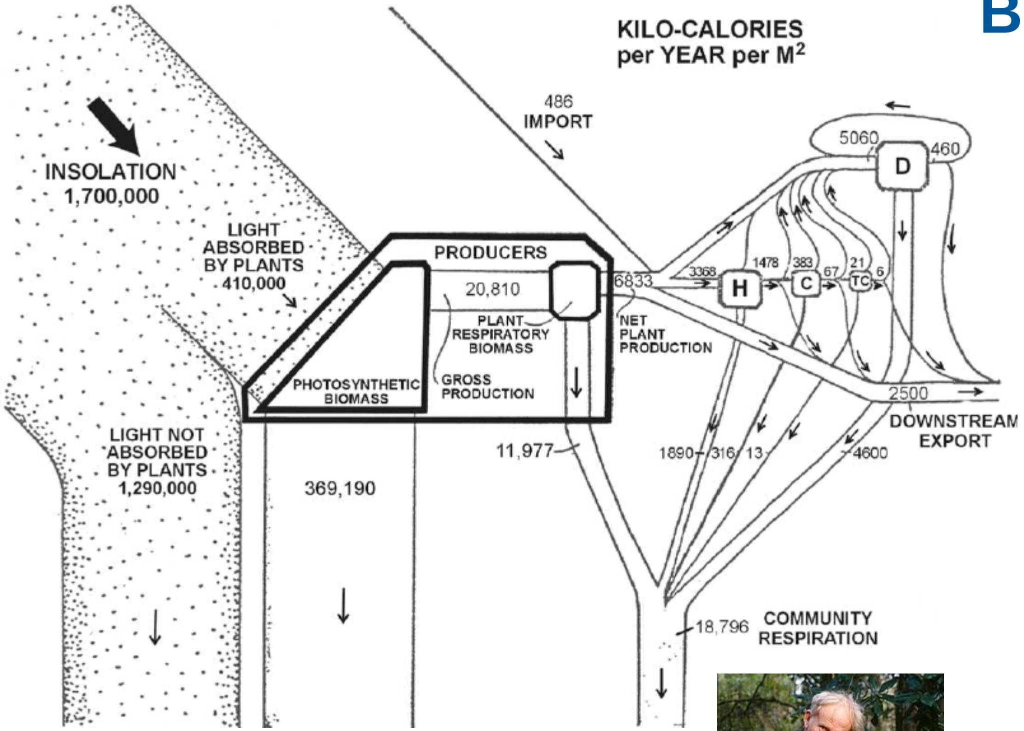


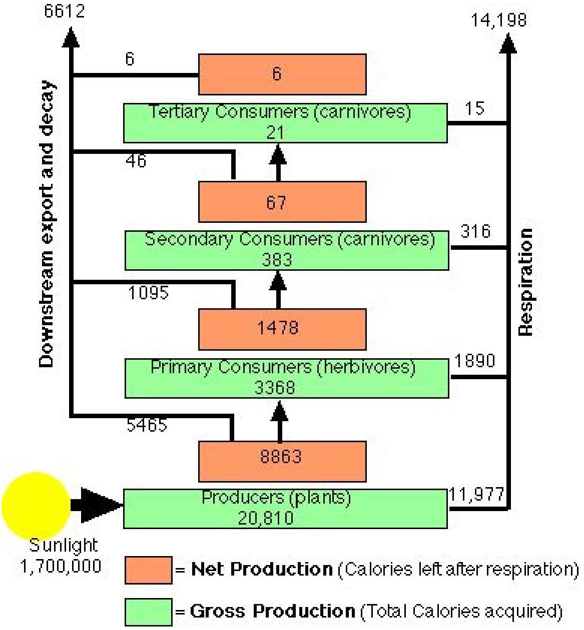
Vito
Volterra



Alfred
Lotka

Budgeting ecosystems





Silver Springs foodweb

H=Herbivores

C= Carnivores

TC=top carnivores

D=Detritus

Howard T. Odum

TROPHIC STRUCTURE AND PRODUCTIVITY OF SILVER SPRINGS, FLORIDA[1]

HOWARD T. ODUM
Institute of Marine Science, The University of Texas, Port Aransas, Texas

TABLE OF CONTENTS

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Important things I have not mentioned:

- How to chose the right complexity of your model specification
- The tremendous difficulty to identify parameters in ecological models
- The pain from preparing the input data and the compromises involved (data gaps, missing variables,…)
- Handling huge masses of output data
- Missing observational data
- ….

Questions?