INTERFACING SINGLE COLUMN LAKE AND ATMOSPHERIC MODELS: APPLICATION OVER LAKE GENEVA FOR OBSERVED AND WARMING CLIMATE SCENARIOS

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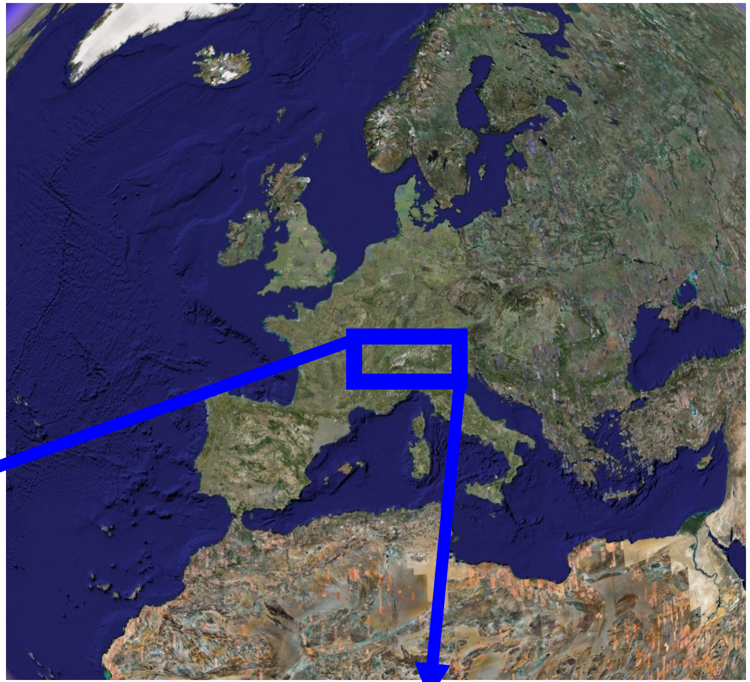
Introduction

- Evaluate the sensitivity of the water temperature profiles to warmer climatic conditions for a mid-latitude peri-alpine lake
- Lake Geneva is located on the Swiss and French borders: surface area 580 km^2, max depth 309 m at SHL2



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Model descriptions (1/3)

- Atmospheric driver : FIZC (column version of canadian GCMii)

Prognostic Eqs in GCMii,

Physics : vertical diffusion, convection, radiation, lower boundary conditions, …

$$\frac{\partial \Psi}{\partial t} = D_{\Psi} + P_{\Psi}$$

Dynamics : advection, Coriolis,…

where $\Psi = (T, q, u, v)$ function of φ, λ, p, and t

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Dynamics

- In FIZC D_Ψ is not computed explicitly, but
- In canadian GCMii, Physics tendencies were averaged and archived at regular intervals (24 h → $\overline{P}_\Psi$), so

$$\overline{D}_\Psi = \frac{\partial \Psi}{\partial t} - \overline{P}_\Psi$$

- To emulate daily variability in the Dynamics tendencies, «meteorological noise» is added

$$D^*_\Psi = R_\Psi \overline{D}_\Psi$$

FIZC prognostic equations

- For $\Psi = (T, q, u, v)$:

$$\frac{\partial \Psi}{\partial t} = D^*_\Psi + P^*_\Psi$$

or in discretized form :

$$\Psi_n = \Psi_{n-1} + \Delta t \left(D^*_{\Psi_{n-1}} + P^*_{\Psi_{n-1}} \right)$$

$n = 1, 2, 3, \ldots$; $\Delta t = 20$ min, D^*_Ψ is ***prescribed*** and P^*_Ψ is ***recomputed*** at each timestep

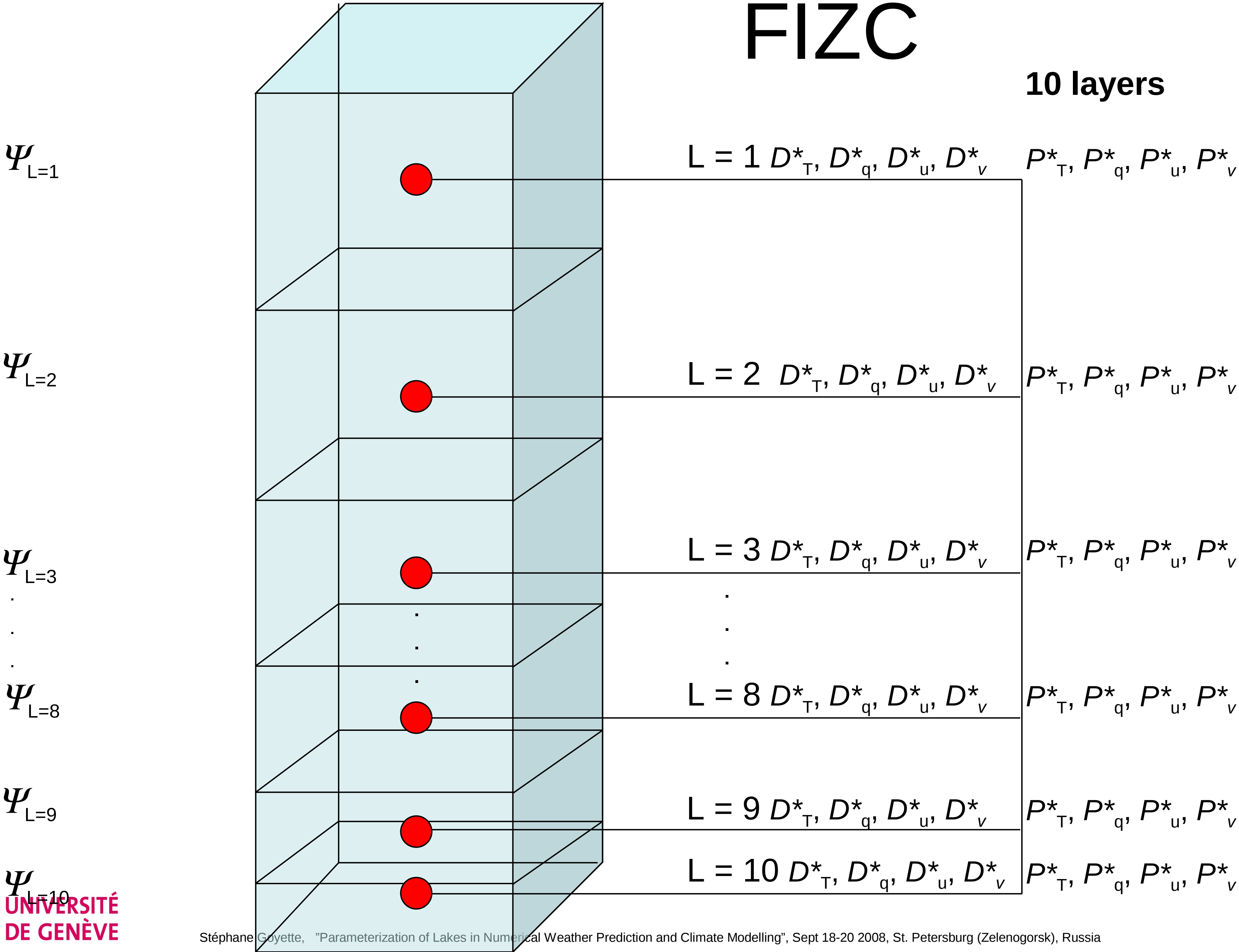
- Nuging with GCMii Ψ may also be applied :

$$\Psi_m = N_\Psi \Psi_{GCMii,m} + \left(1 - N_\Psi\right) \Psi_{FIZC,m}$$

m = 1,2,3…; $N_\Psi = [0, 1]$; $\Delta t_A = 12$ h

FIZC

10 layers



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Model descriptions (2/3)

- Lake model : k-ε
  (*cf* Marjorie Perroud)

Table 4. Governing equations of the κ–ε model and extensions included in SIMSTRAT (Goudsmit et al. 2002)

$$\frac{\partial T}{\partial t} = \frac{1}{A}\frac{\partial}{\partial z}\left(A\left(\nu_t' + \nu'\right)\frac{\partial T}{\partial z}\right) + \frac{1}{\rho_o c_p}\frac{\partial H_{sol}}{\partial z} + \frac{\partial A}{\partial z}\frac{H_{geo}}{A\rho_o c_p}$$

$$\frac{\partial U}{\partial t} = \frac{1}{A}\frac{\partial}{\partial z}\left(A\left(\nu_t + \nu\right)\frac{\partial U}{\partial z}\right) + fV$$

$$\frac{\partial V}{\partial t} = \frac{1}{A}\frac{\partial}{\partial z}\left(A\left(\nu_t + \nu\right)\frac{\partial V}{\partial z}\right) - fU$$

$$\frac{\partial k}{\partial t} = \frac{1}{A}\frac{\partial}{\partial z}\left(A\nu_k\frac{\partial k}{\partial z}\right) + P + P_{seiche} + B - \varepsilon$$

$$\frac{\partial \varepsilon}{\partial t} = \frac{1}{A}\frac{\partial}{\partial z}\left(A\nu_\varepsilon\frac{\partial \varepsilon}{\partial z}\right) + \frac{\varepsilon}{k}\left[c_{\varepsilon 1}\left(P + P_{seiche}\right) + c_{\varepsilon 3}B - c_{\varepsilon 2}\varepsilon\right]$$

$$P = \nu_t\left[\left(\frac{\partial U}{\partial z}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2\right] \qquad B = -\nu_t' N^2$$

$$\nu_t = c_\mu \frac{k^2}{\varepsilon} \qquad \nu_t' = c_\mu' \frac{k^2}{\varepsilon}$$

$$\nu_k = \frac{c_\mu}{\sigma_k}\frac{k^2}{\varepsilon} \qquad \nu_\varepsilon = \frac{c_\mu}{\sigma_\varepsilon}\frac{k^2}{\varepsilon}$$

Definitions:

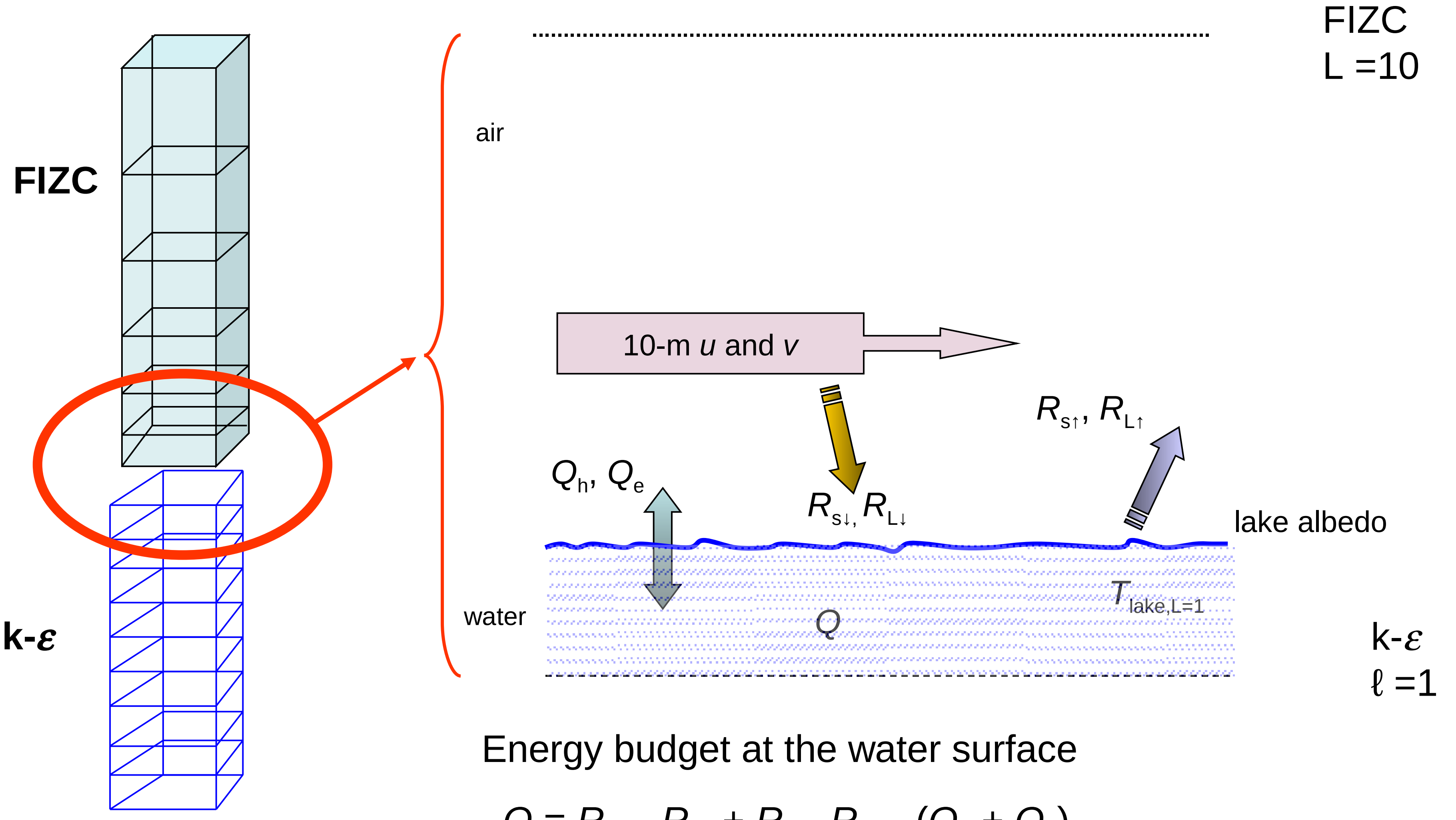
A	cross sectional area at z (m^2)
B	buoyancy flux ($W\ kg^{-1}$)
c_p	specific heat of lake water ($J\ kg^{-1}\ K^{-1}$)
f	Coriolis parameter (s^{-1})
t	time (s)
k	turbulent kinetic energy per unit of mass ($J\ kg^{-1}$)
H_{sol}	solar radiation at depth z ($W\ m^{-2}$)
H_{geo}	geothermal heat flux ($W\ m^{-2}$)
N	brunt-Väisälä frequency (s^{-1})
T	water temperature (°C)
U	horizontal velocity west-east ($m\ s^{-1}$)
V	horizontal velocity south-north ($m\ s^{-1}$)
P	production of k due to shear stress ($W\ kg^{-1}$)
P_{seiche}	production of k due to internal seiching ($W\ kg^{-1}$)
z	depth (positive upward) (m)
ε	dissipation rate of k ($W\ kg^{-1}$)
ρ_o	density of lake water ($kg\ m^{-3}$)
ν	molecular viscosity, $1.5 \times 10^{-6}\ m^2\ s^{-1}$
ν'	molecular diffusivity, $1.5 \times 10^{-7}\ m^2\ s^{-1}$
ν_t	turbulent viscosity ($m^2\ s^{-1}$)
ν_t'	turbulent diffusivity ($m^2\ s^{-1}$)
ν_ε	turbulent diffusivity of ε ($m^2\ s^{-1}$)
ν_k	turbulent diffusivity of k ($m^2\ s^{-1}$)

Constant of the $\tilde{\kappa}$–ε model:

$c_{\varepsilon 1}$	1.44
$c_{\varepsilon 2}$	1.92
$c_{\varepsilon 3}$	-0.4 if $B < 0$, else 1
c_μ	0.09
c'_μ	0.072
σ_k	1.00
σ_ε	1.3

Model descriptions (3/3)

- Coupling



Energy budget at the water surface

$$Q = R_{s\downarrow} - R_{s\uparrow} + R_{L\downarrow} - R_{L\uparrow} - (Q_h + Q_e)$$

Simulations

- Experimental setup
  - – 20 years of 1 x CO_2 (300 ppmv)
  - – 20 years of 2 x CO_2 (600 ppmv)

    - FIZC (10 layers), k-ε (391 layers),
    - Δt = 20 min, Δt_A = 24 h, $R_\Psi = S_\Psi R^*$

      R^*= randon number [-1, +1],

      S_T = 6, S_q = 6, S_u = 6, S_v = 6,

      N_T = 0.1, N_q = 0.1, N_u = 0.1, N_v = 0.1
    - $\varphi = \varphi_{SHL2}$ = 46.2°N, $\lambda = \lambda_{SHL2}$ = 6.3°E, z = 372 m

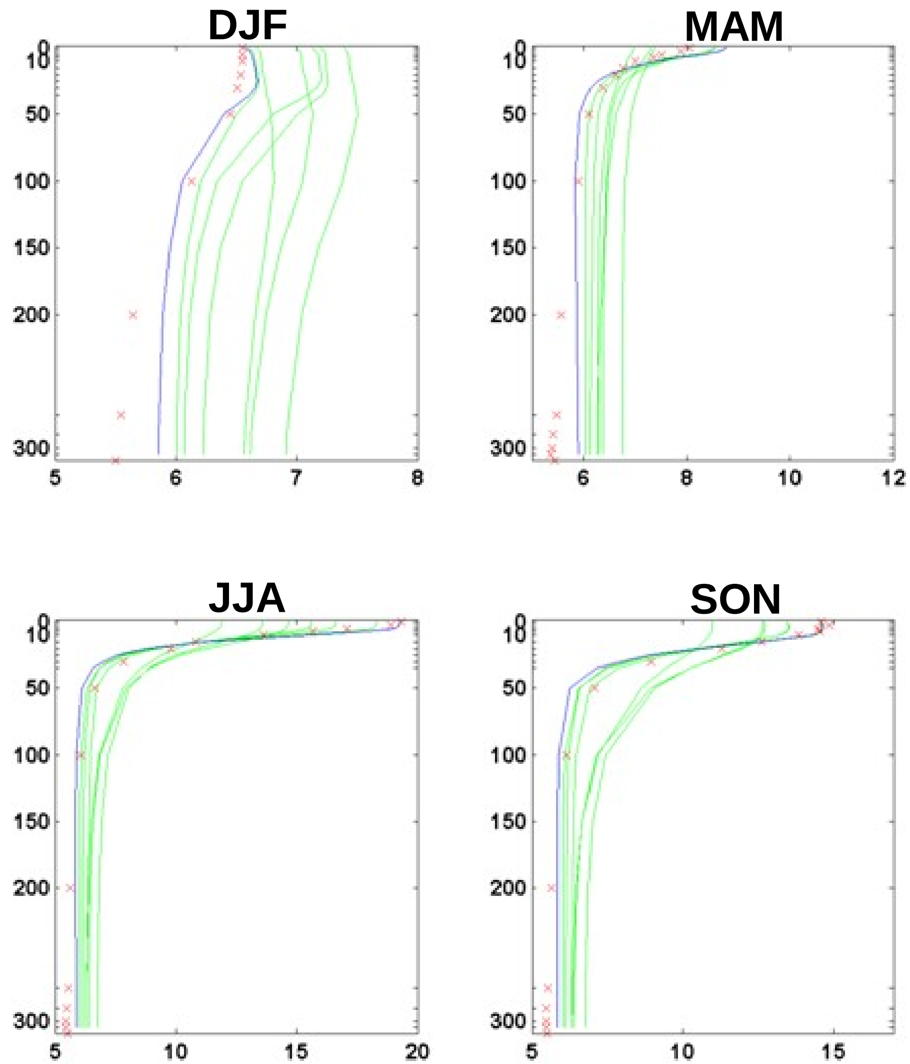
Results: lake temperature profiles : 1 x CO_2

Seasonal averages over 8 years

X observations

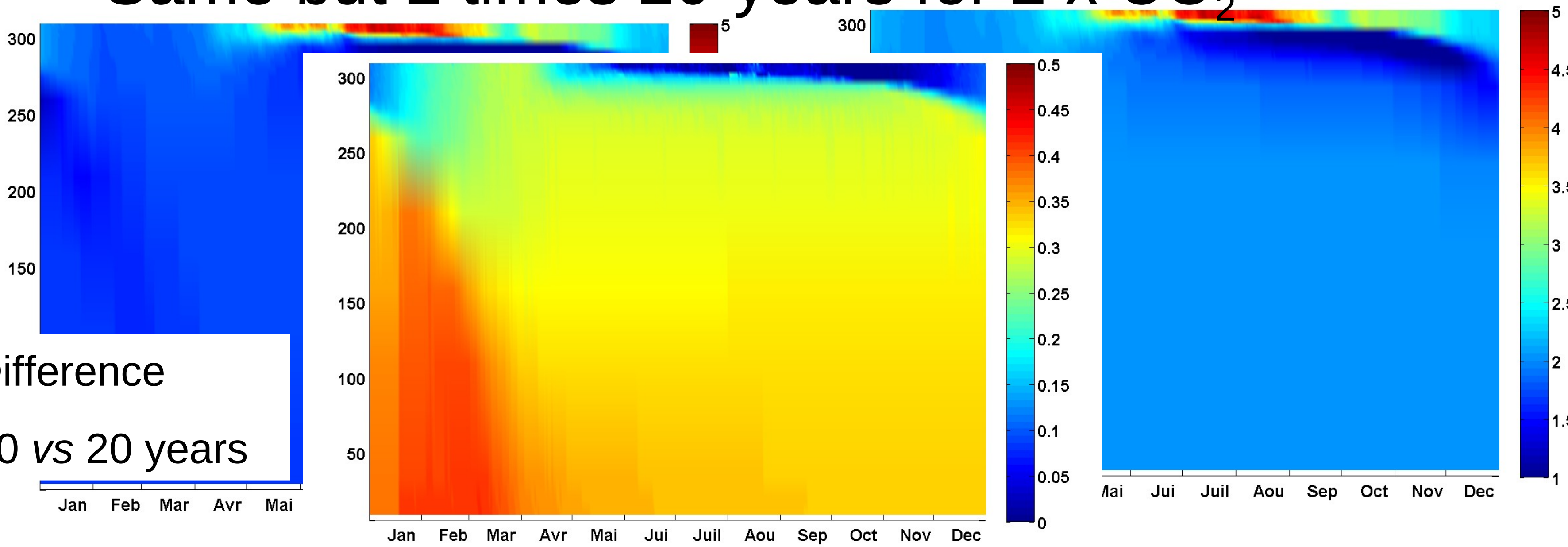
$S_{\Psi} = 6$, $N_{\Psi} = 0.1$

others settings



Results

- One 20 years
  - Differences 2 x CO_2 and 1 x CO_2 of daily water temperature averaged over the last 10 years
- Two 20 years
  - Same but 2 times 20-years for 2 x CO_2



Difference

40 *vs* 20 years

Summary

- Current parameter optimisation (R_Ψ and N_Ψ)
  - current climate $\Delta_o T$ profiles [-2°C... +0.8°C]
  - lake at equilibrium ?! drift ?! [less sfc but more in depth Jan-Feb]
  - future warming climate ΔT profiles [4.5°C (sfc), 2.3°C (bot)], similar to Marjorie's

Outlook

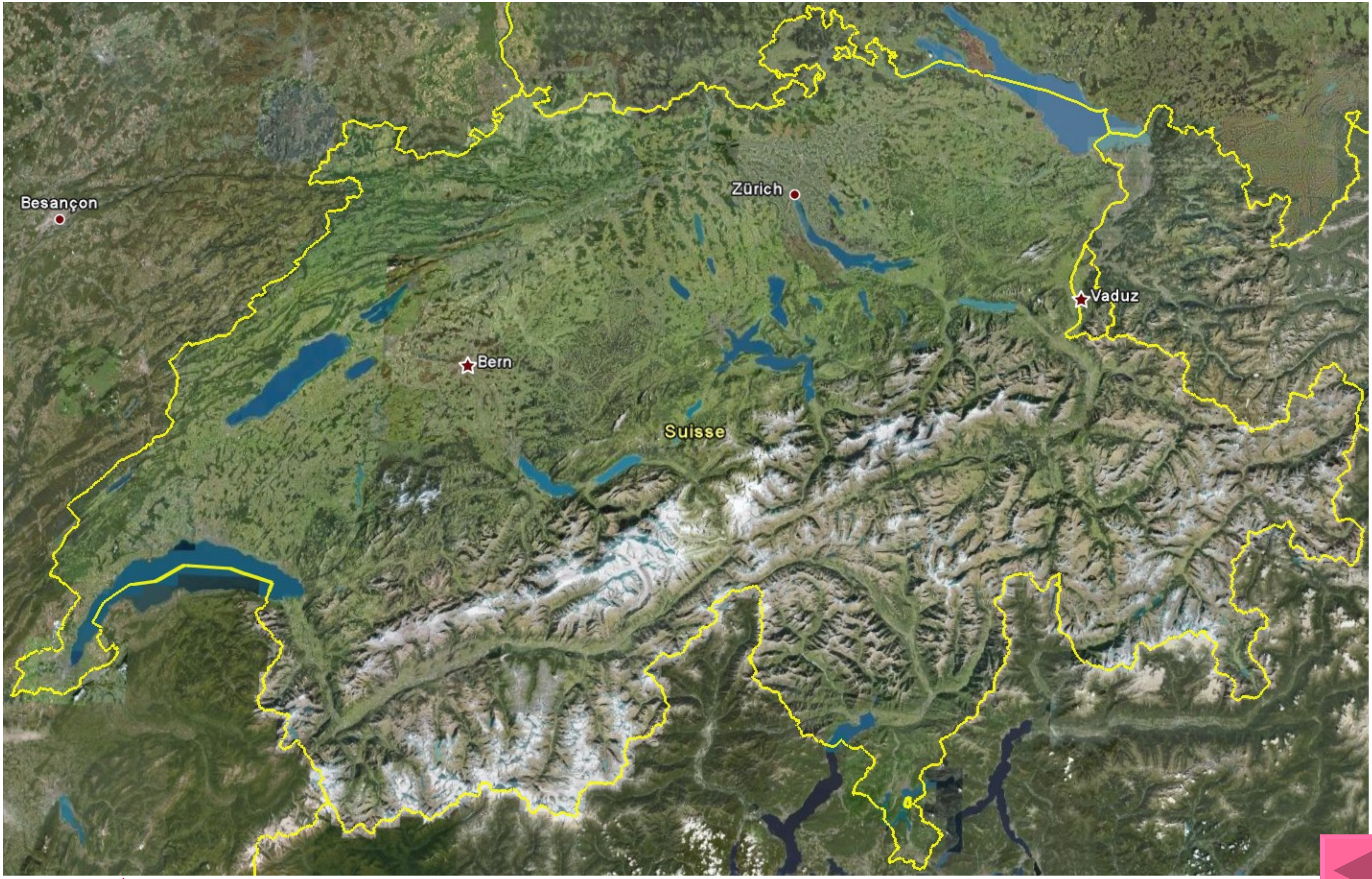
- Extend the simulations beyond 20 years
- Assess « transient » climatic change and comparison with « equilibrium » 2 x CO_2
- Implement a « thermodynamic ice module »
- Increase the number of atmospheric layers in FIZC
- Optimize the variations in D^*_Ψ
- Use FIZC in a regional mode (*i.e.*, FIZR, Goyette and Laprise, 1996) to assess the sensitivity of a number of Swiss lake to climatic change
- Other lakes !?
- Contacts:
  - marjorie.perroud@unige.ch & stephane.goyette@unige.ch

- Reference:

Goyette, S., and R. Laprise, 1996: Numerical investigation with a physically based regional interpolator for off-line downscaling of GCMs: FIZR. *J. Climate,* 9, 3464-3495.

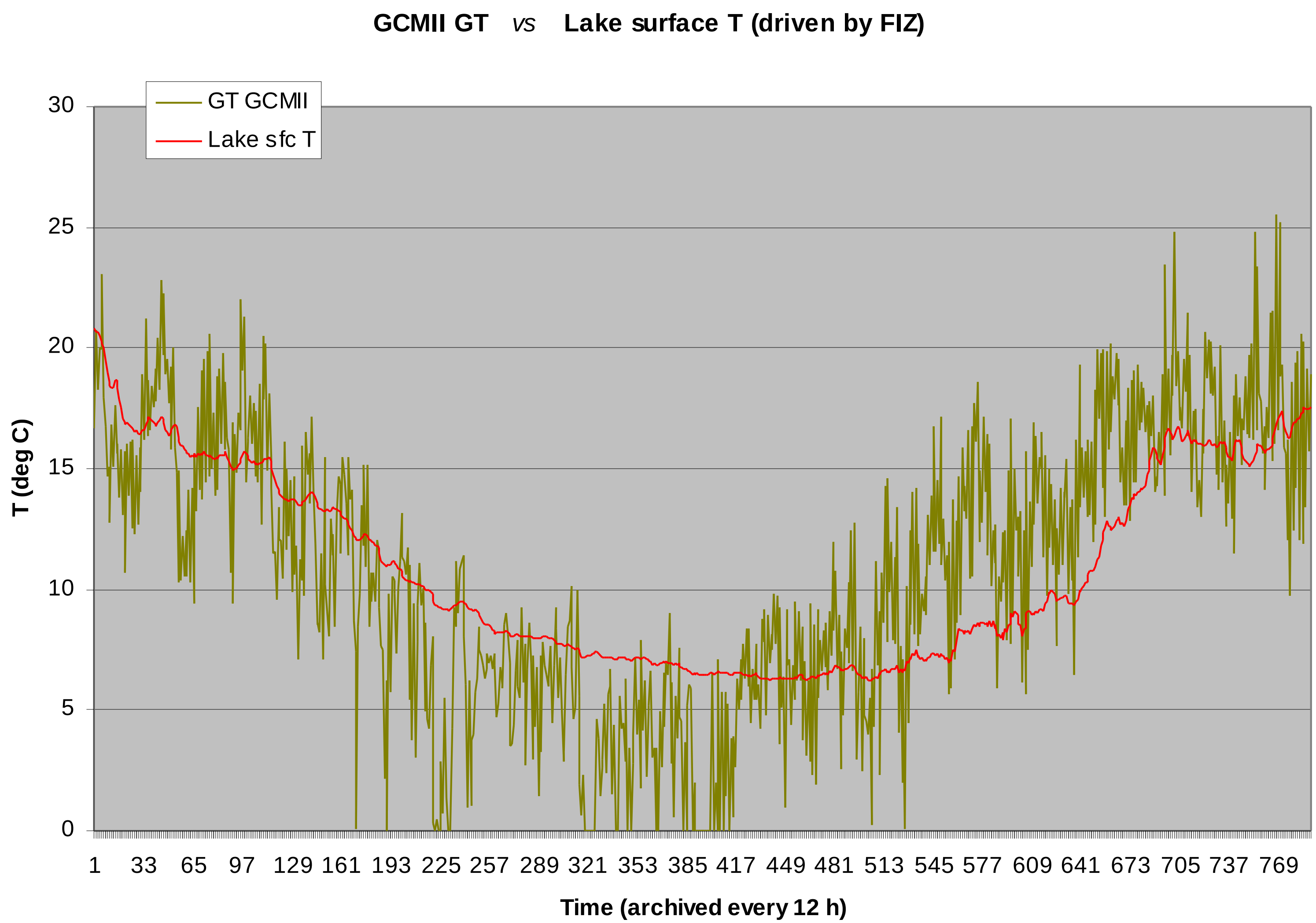
Thank you for your attention !

Lakes in Switzerland



Extra slides

Solid surface vs. water surface temperatures



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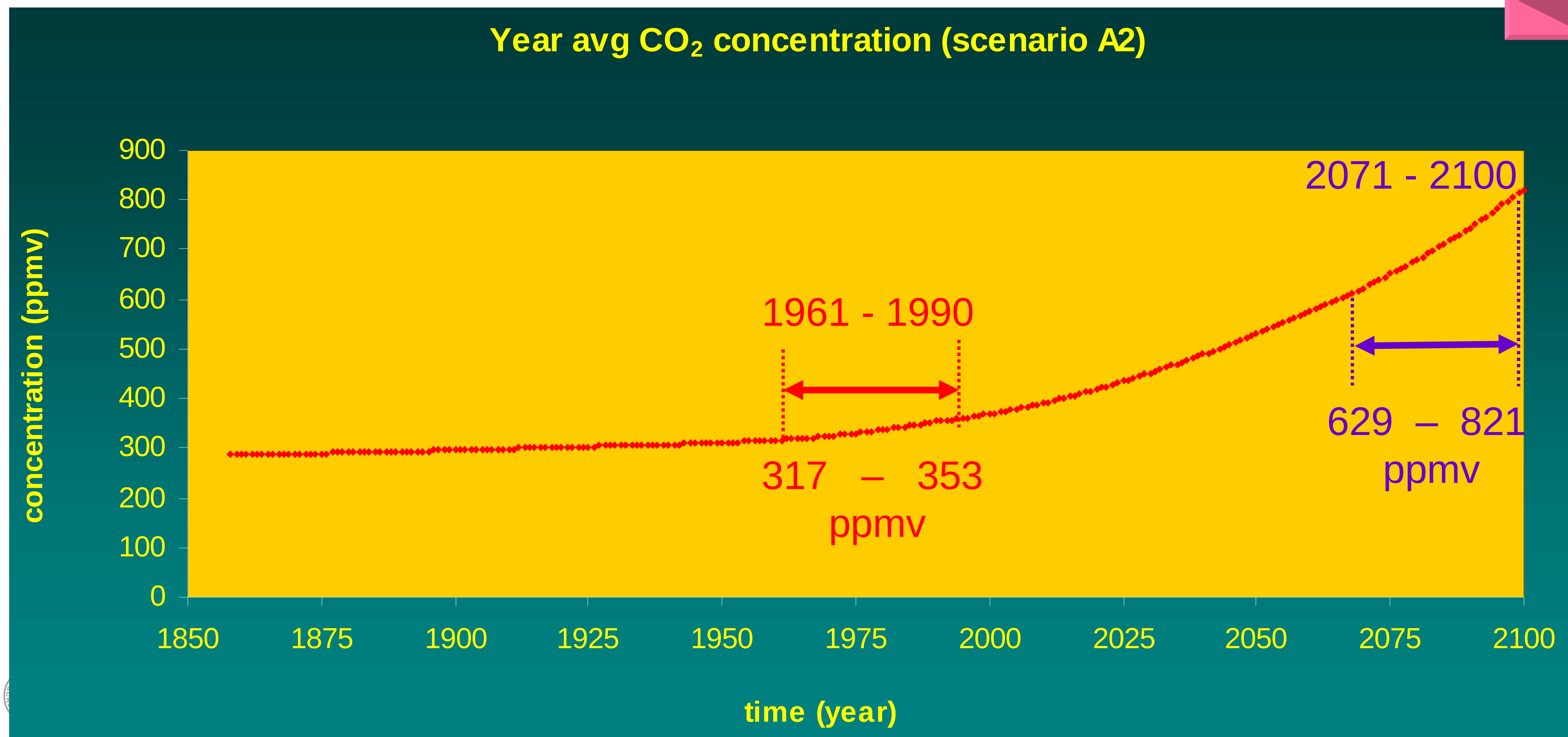
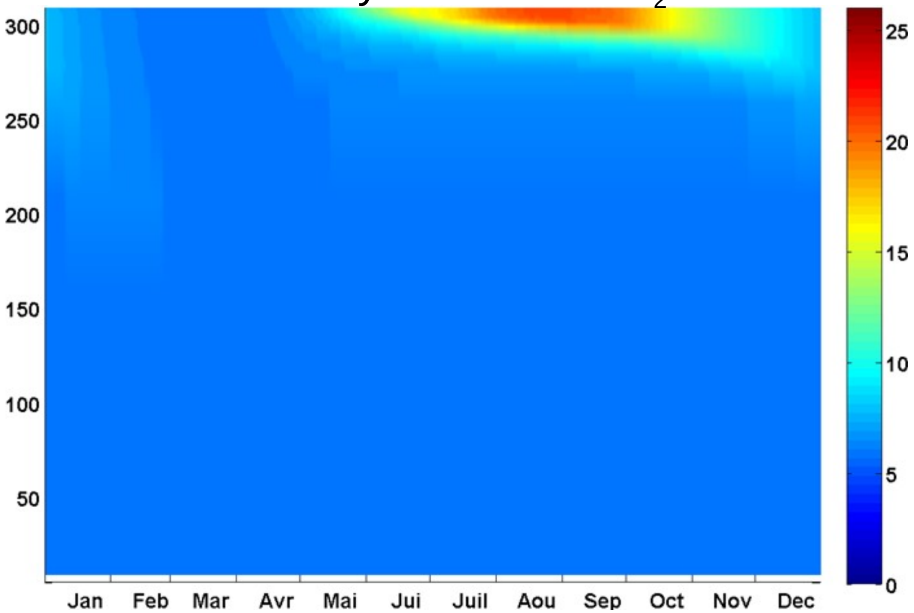
IPCC SRES A2 scenario

A future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Major underlying themes are economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income. In this world, people pursue personal wealth rather than environmental quality.

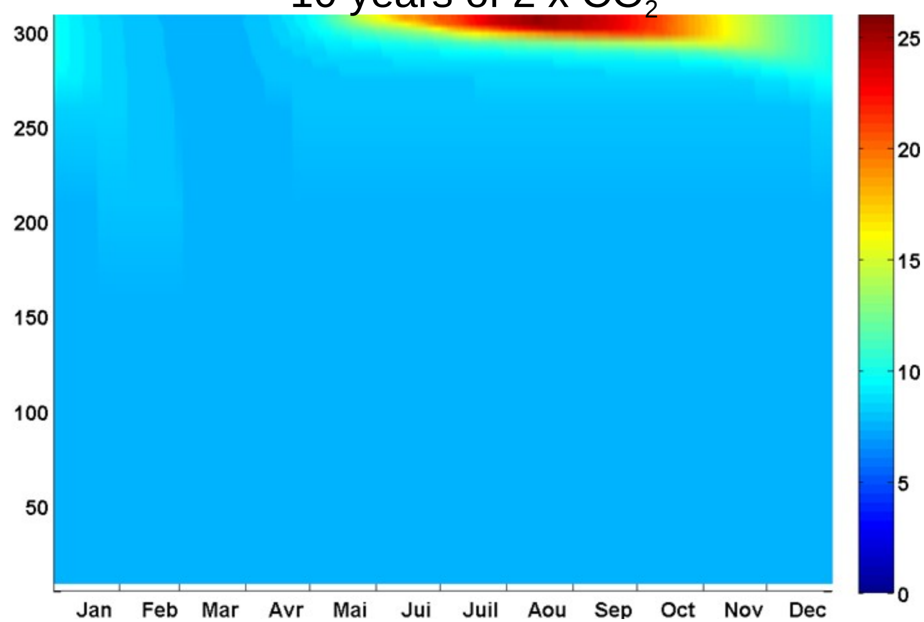


FIZC + k-ε

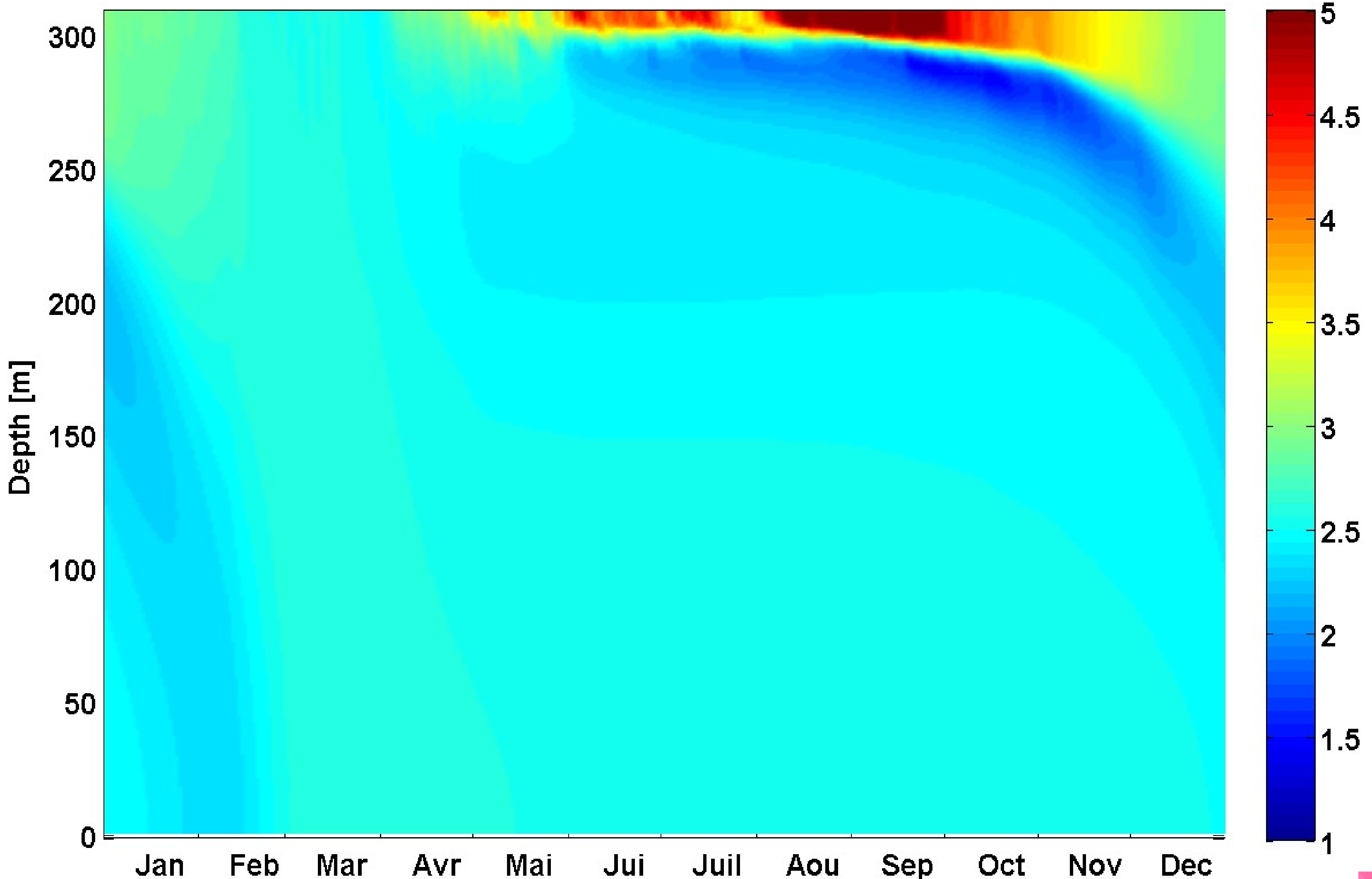
10 years of 1 x CO_2



10 years of 2 x CO_2



K-ε 110 years %method (*cf* M Perroud)



Seasonal differences (Obs - 1 x CO_2)