Management of Climatic Extreme Events in Lakes and Reservoirs for the Protection of Ecosystem Services

What are extreme events … their relations with episodic events ?

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MANTEL ITN Workshop

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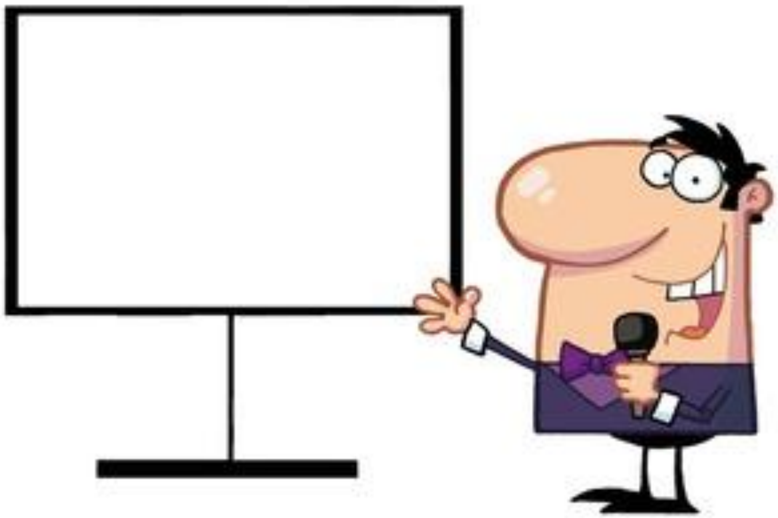
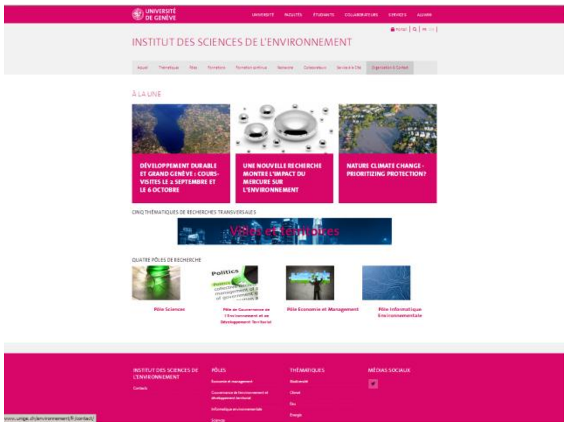
Summary

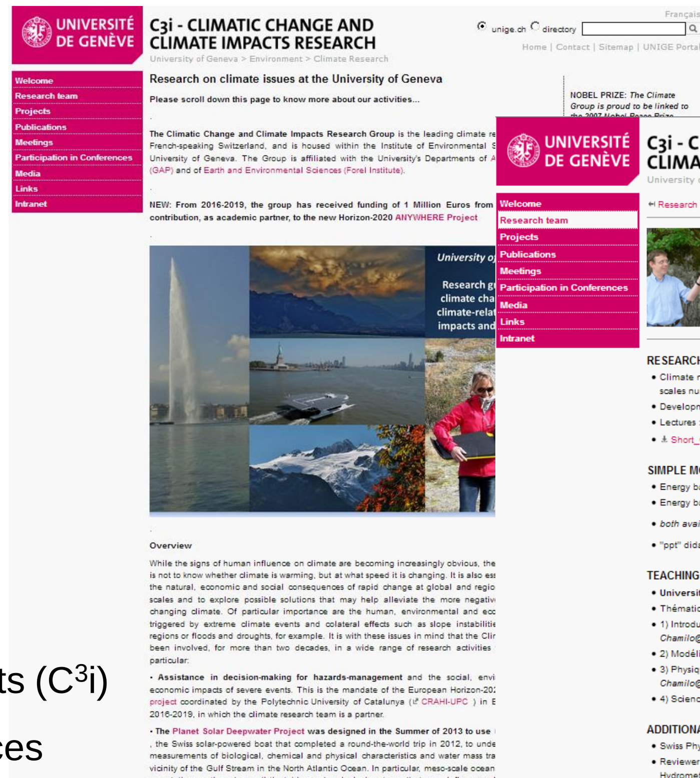


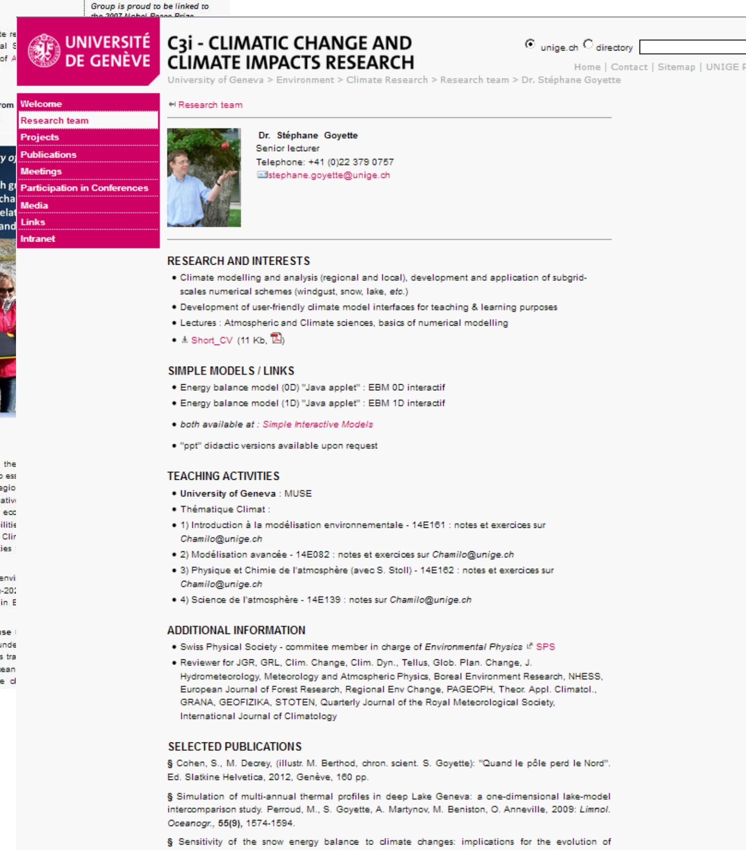
- Who I am
- Weather & climate
- Statistics
  - extreme events
  - cyclic & episodic events

University of Geneva

Institute for Environmental Sciences







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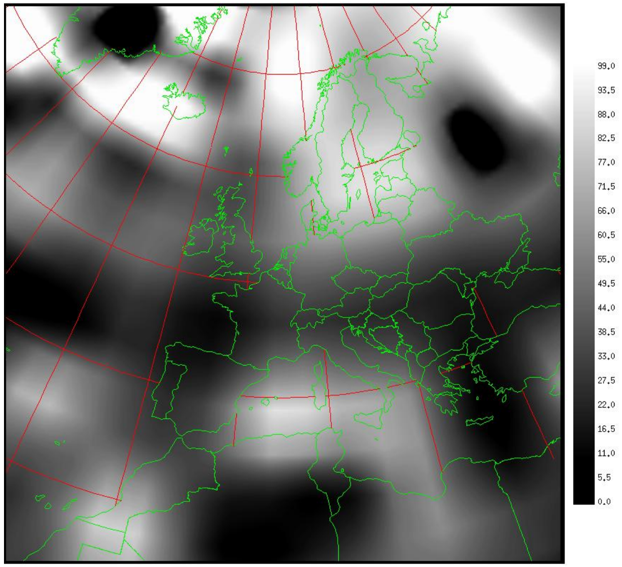
Main research interests

- Numerical modelling
  - GCM, RCM, EBM, *etc*
  - prognostics and diagnostics
    - applications
      - windstorms
      - atmospheric-lake coupling

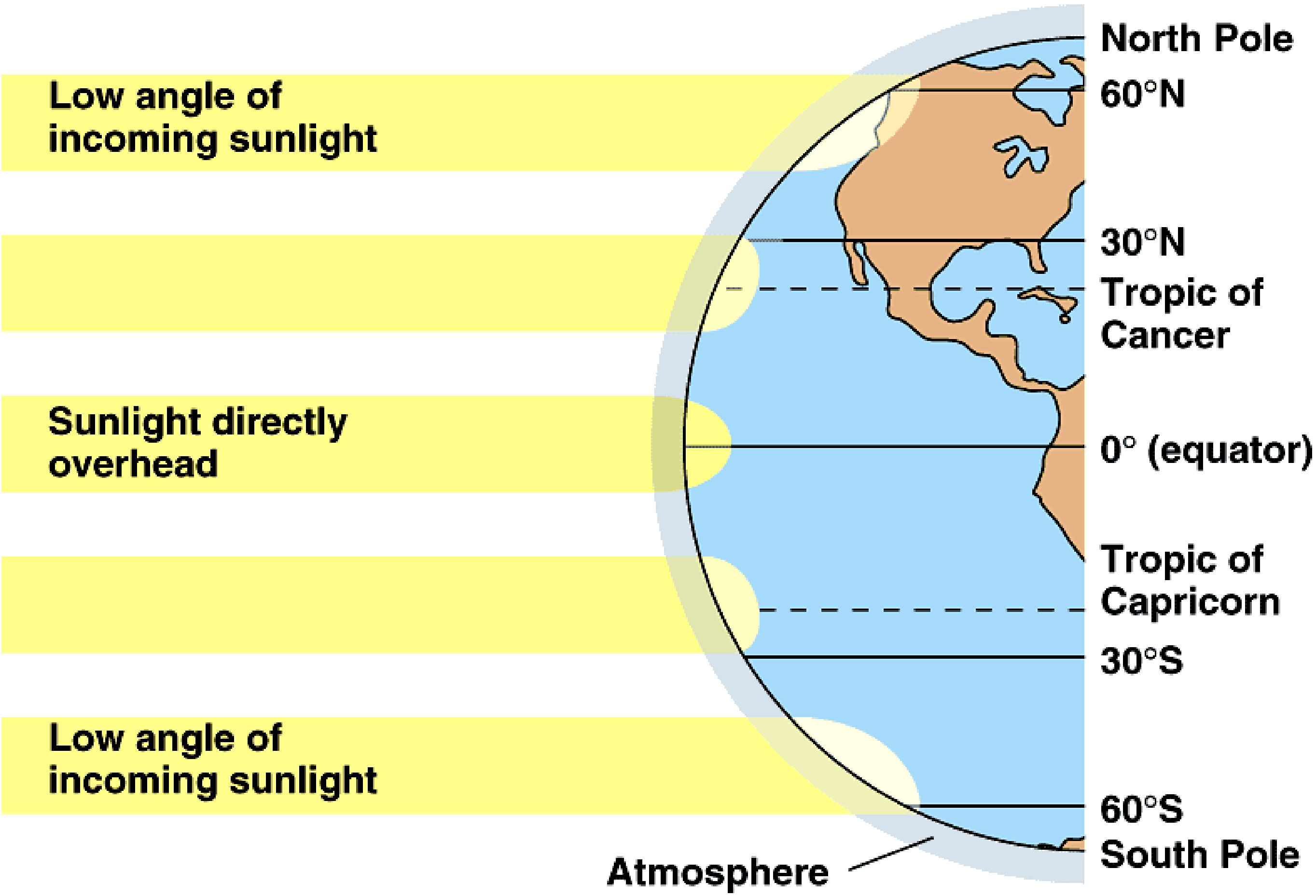


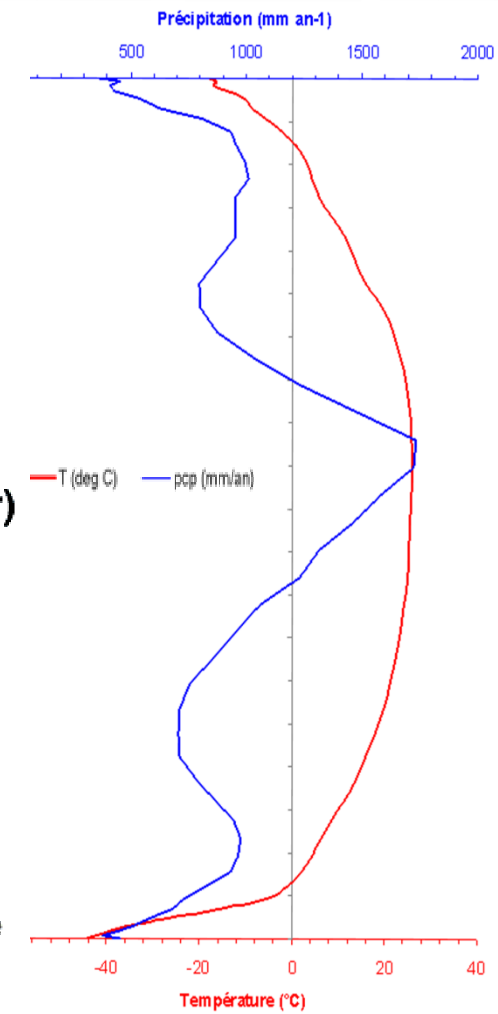
Difference between weather & climate

- Weather is a temporary combination of a number of variables defining the state of the atmosphere

- Whereas climate may be defines as
  - series of atmospheric states above a place in their usual evolution
  - climate may be described by the statistics of these variables
    - air temperature and precipitation are the «main» descriptors
    - cyclic evolution (seasons)
      - relation with episodic events ?!

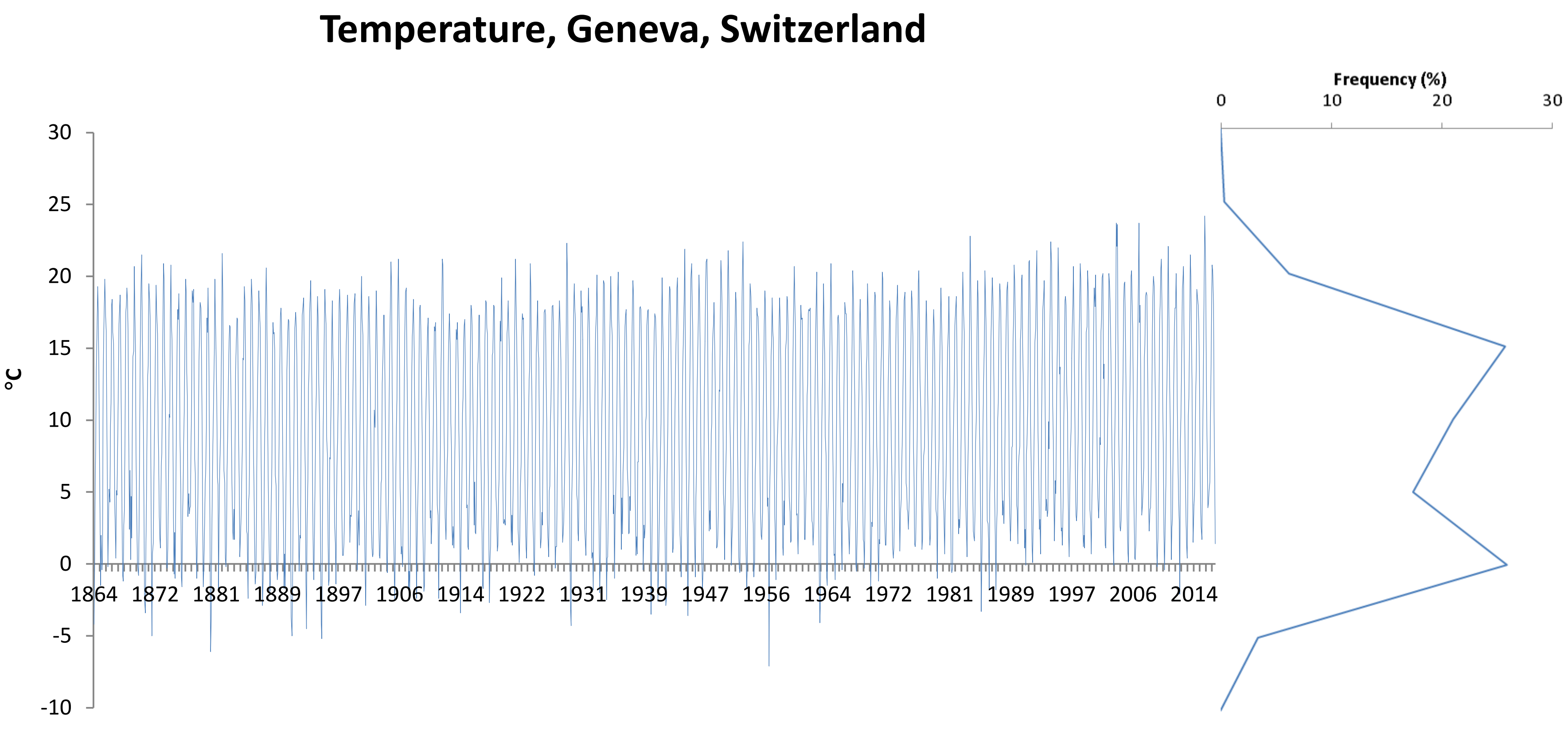
Zonal statistics





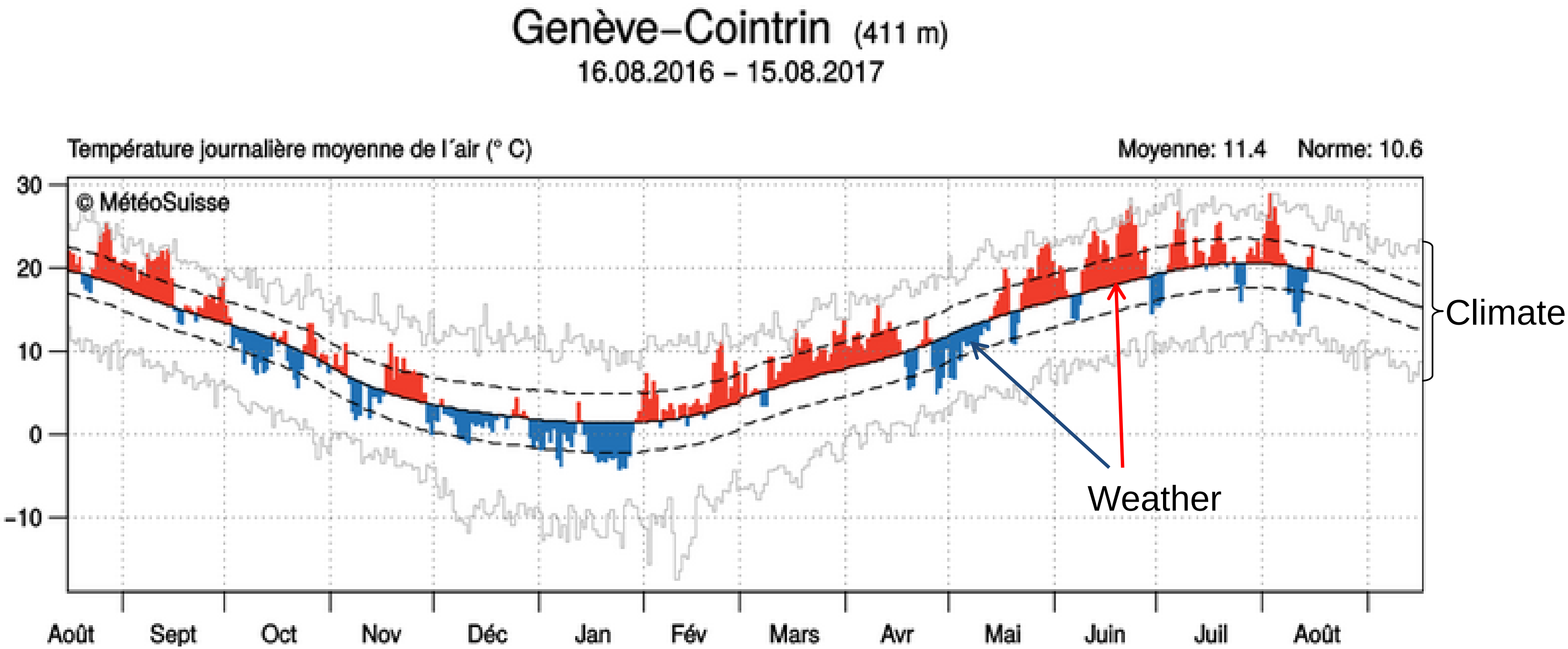
Global averages: $T \approx 15°C$, $pcp \approx 1005$ mm

Example : monthly-mean air temperature at screen level over a location



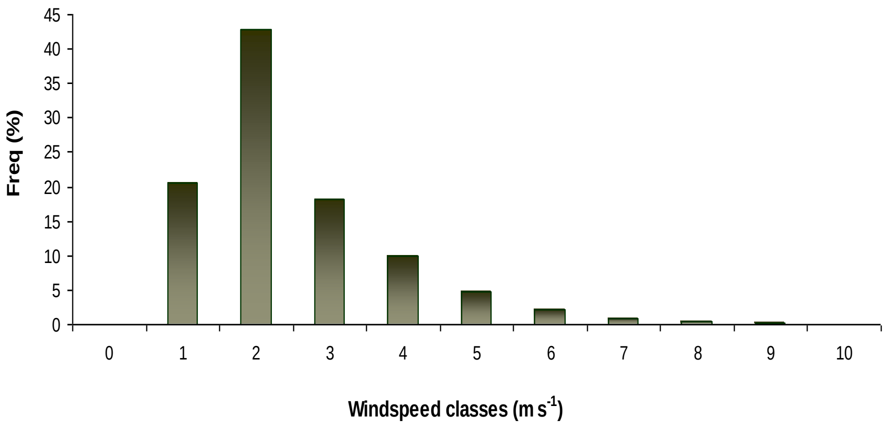
Average: T = 10.5°C

Schematic view of weather & climate

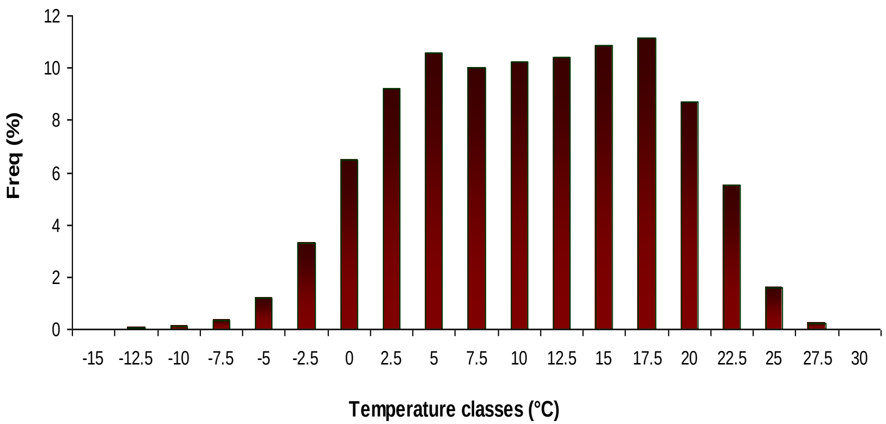


Other «climate» variables

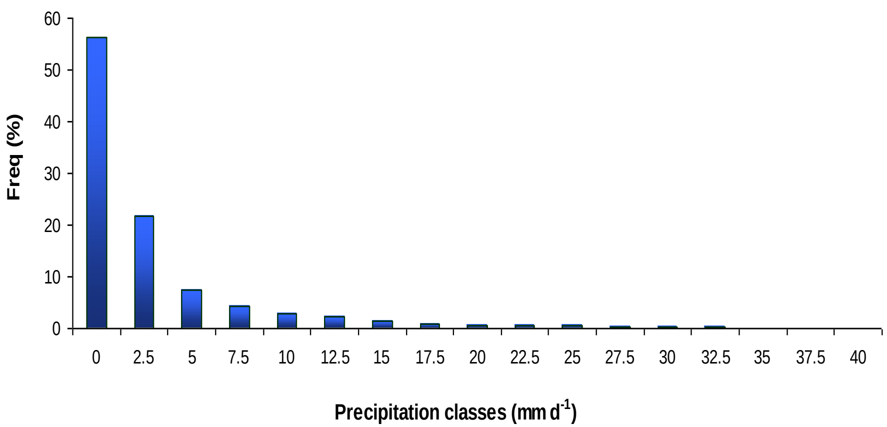
Daily-average windspeed distribution at Payerne 1981-2010



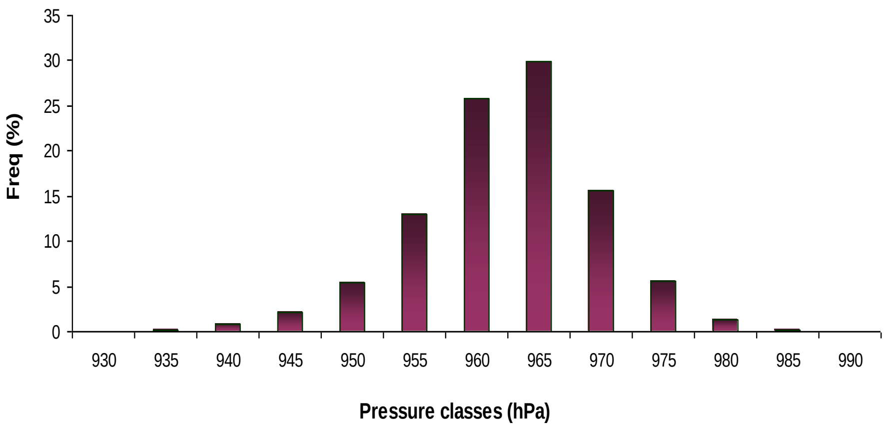
Daily-average 2m temperature distribution at Payerne 1981-2010



Daily-average precipitation distribution at Payerne 1981-2010

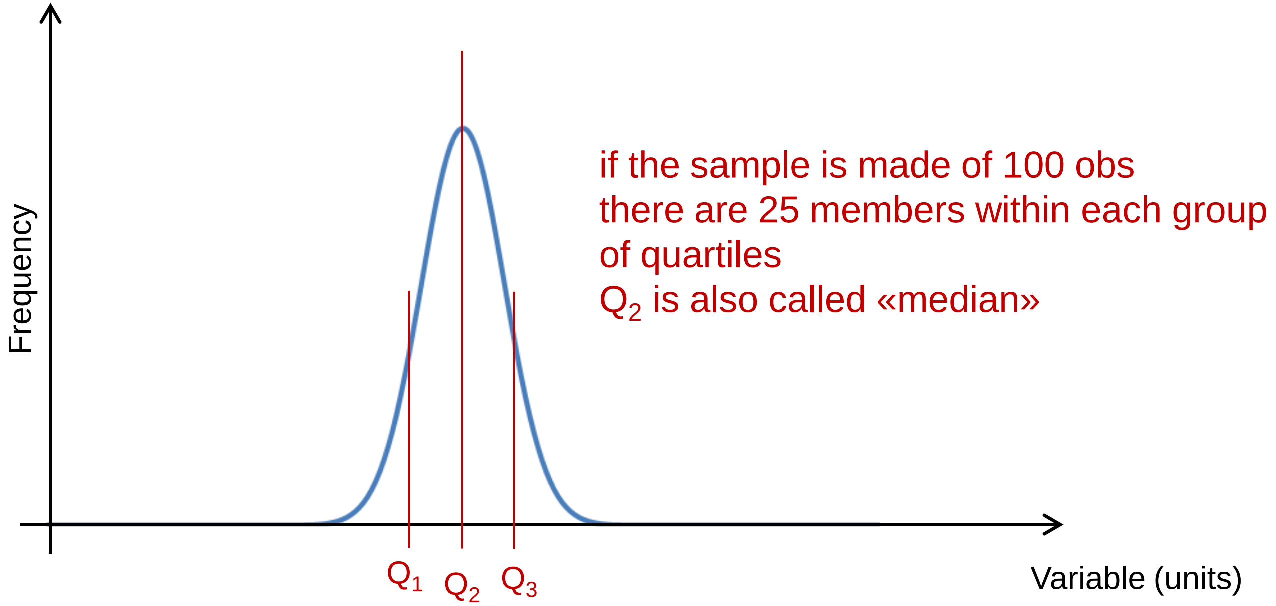


Daily-average surface pressure distribution at Payerne 1981-2010



Quantiles (Wikipedia)

- In statistics and the theory of probability, these are cutpoints dividing the observations in a sample into contiguous intervals with equal probabilities
  - there is one less quantile than the number of groups created



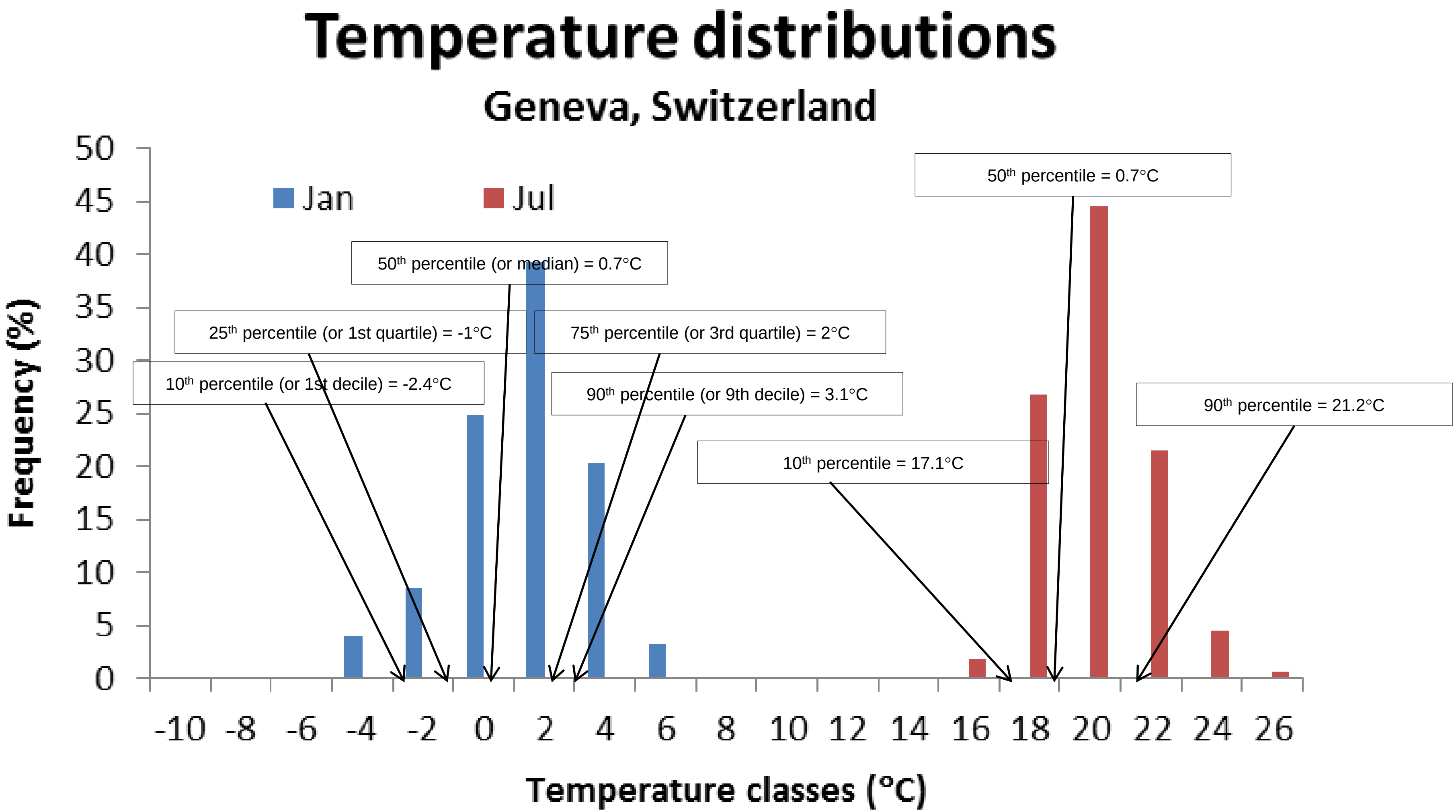
Definition of extreme events
(Beniston *et al*., 2007)

- **Rare**
  - Events that occur with relatively low frequency/rate. For example, the IPCC (2001) defines "an extreme weather event" to be an event that is rare within its statistical reference distribution at a particular place. Definitions of "rare" vary, but an extreme weather event would normally be as rare or rarer than the 10th or 90th percentile

- **Intense**
  - Events characterized by relatively small or large values (*i.e.* events that have large magnitude deviations from the norm); ATT! not all intense events are rare
    - for example, low precipitation totals are often far from the mean precipitation but can still occur quite frequently

- **Severe**
  - Events that result in large socio-economic losses; severity is a complex criterion because damaging impacts can occur in the absence of a rare or intense climatic event
    - for example, thawing of mountain permafrost leading to rock falls and mud-slides

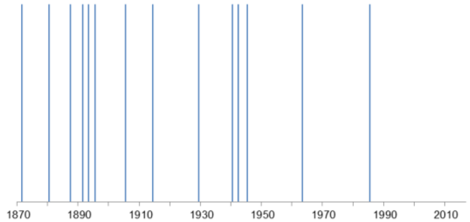
Distributions & quantiles (1)



Distributions & quantiles (2)

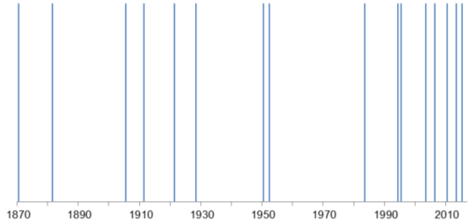
- Cold events in January when $T < T_{10thperc}$

  1864, 1871, 1880, 1887, 1891, 1893, 1895, 1905, 1914, 1929, 1940, 1942, 1945, 1963, 1985

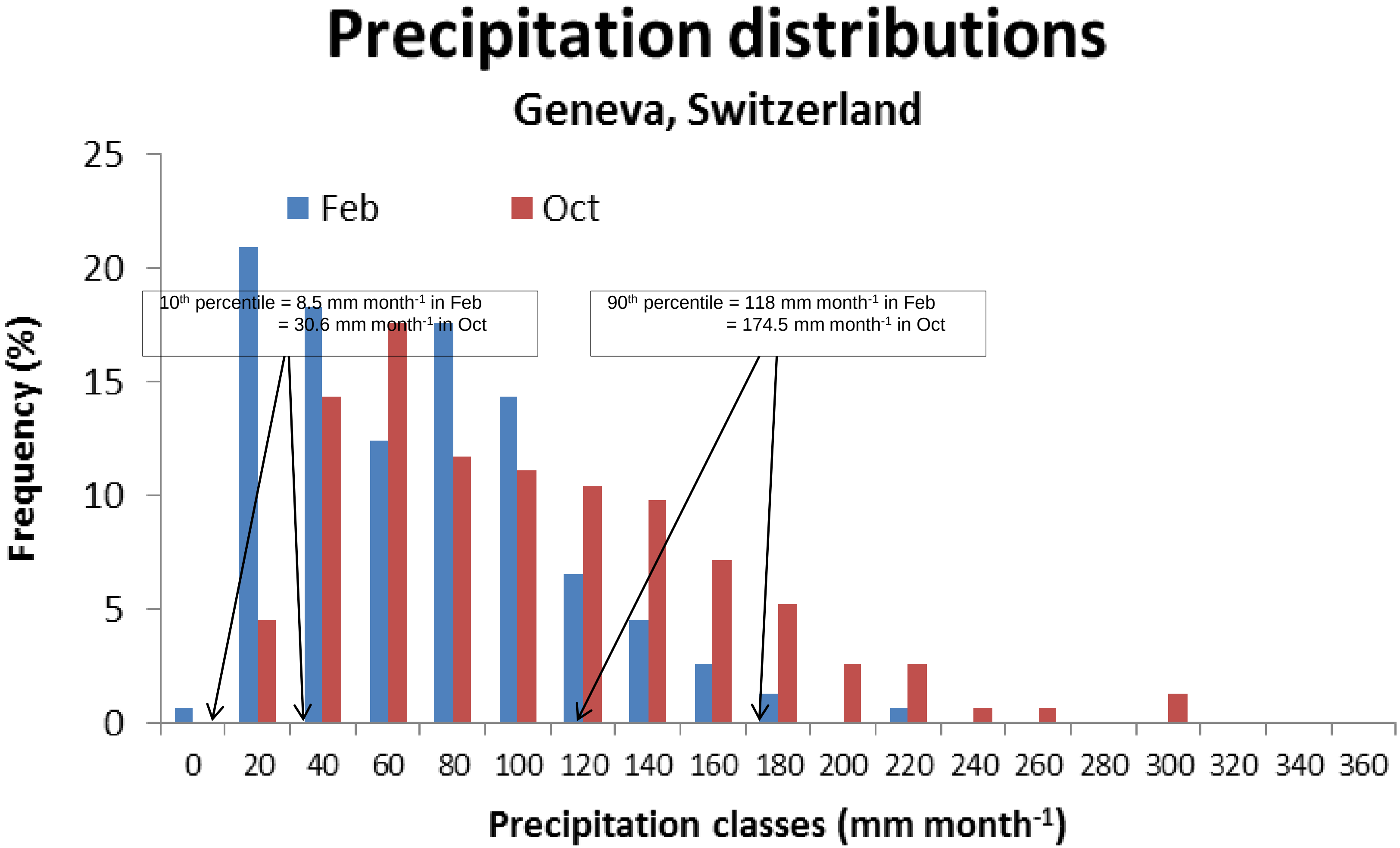


- Hot events in July when $T > T_{90thperc}$

  1870, 1905, 1911, 1921, 1928, 1950, 1952, 1983, 1994, 1995, 2003, 2006, 2010, 2013, 2015



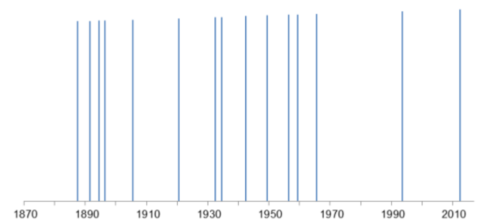
Distributions & quantiles (3)



Distributions & quantiles (4)

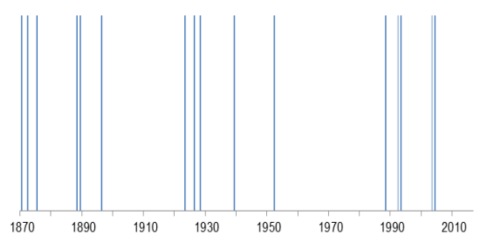
- «Dry» February when $pcp < pcp_{10thperc}$

  1868, 1887, 1891, 1896, 1905, 1920, 1932, 1934, 1942, 1949, 1956, 1959, 1965, 1993, 2012



- «Wet» Oct when $pcp > pcp_{90thperc}$

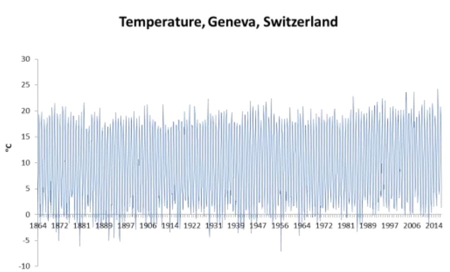
  1870, 1872, 1875, 1889, 1896, 1923, 1926, 1928, 1939, 1952, 1988, 1992, 1993, 2003, 2004

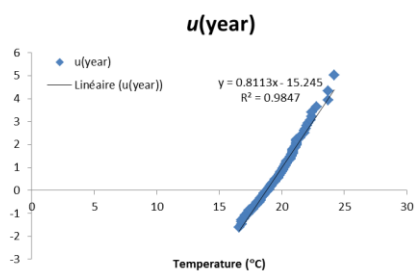


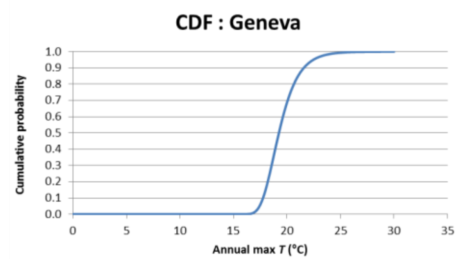
Extreme value distributions

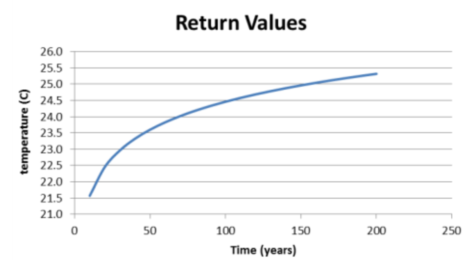
«a simple example»

- Given monthly mean T, from 1864-2016, so N = 153 (cf slide #7)
- Select yearly maximum values, T_{max}, and order them in increasing magnitude (m = 1, 2, …, N)
- Assign empirical probabilities ($\frac{m}{N+1}$) to these ordered T_{max} so as to determine CDF(T_{max})
- Compute u = -ln{-ln[CDF(T_{max})]}
- Fit a straight line to (T_{max} ; u)
- Probability of T_{max} not being exceeded is trivial
  - $CDF(T_{\max}) = e^{-e^{-u}}$, and thus return values can be computed !







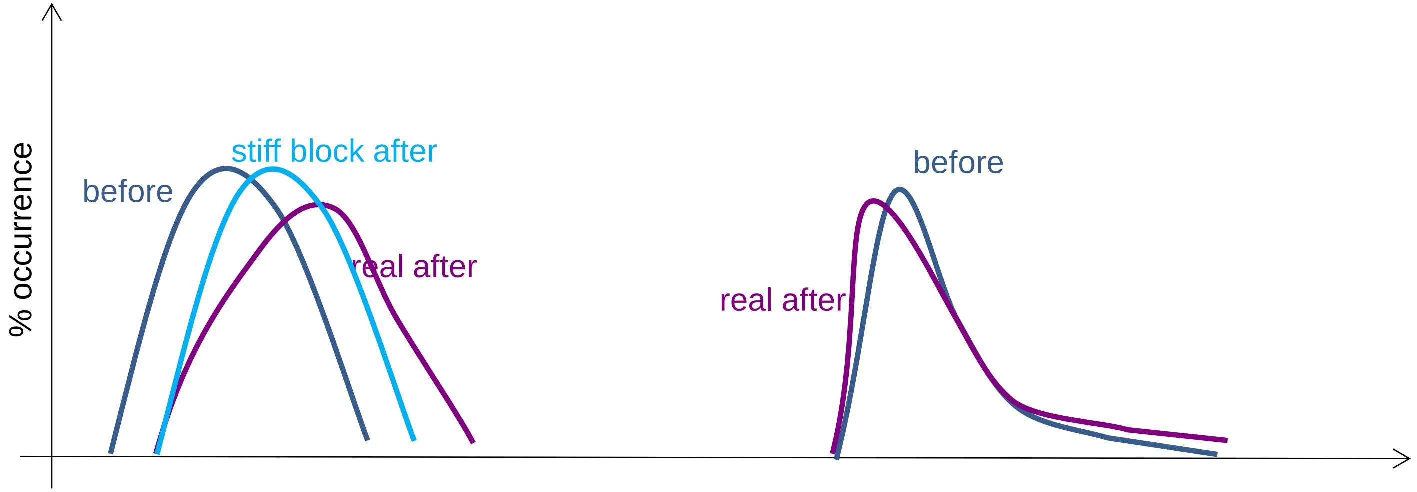


Quantile regression

- Quantile regression aims at estimating either the conditional median or other quantiles of the response variable
  - «extension» of the linear regression

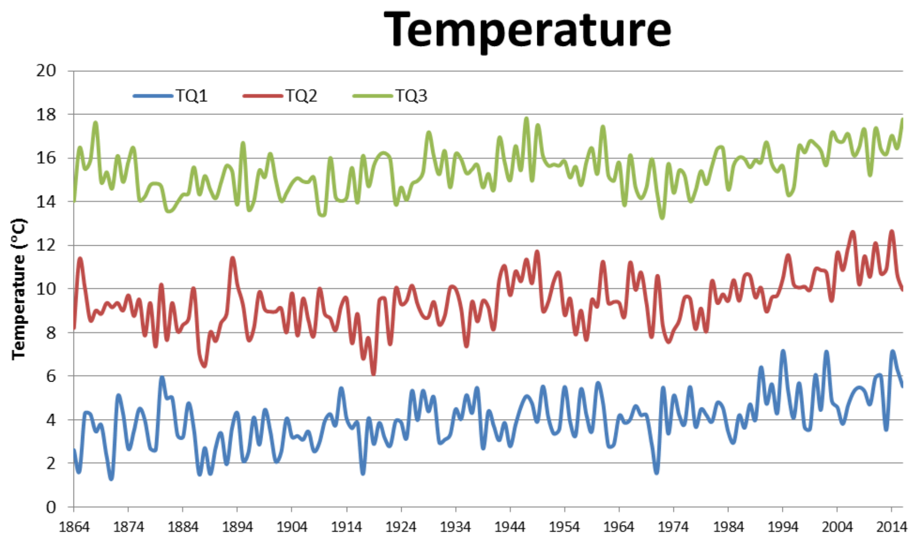
Why QR ?

- QR analysis relevant if a distribution does not evolves a stiff block over time

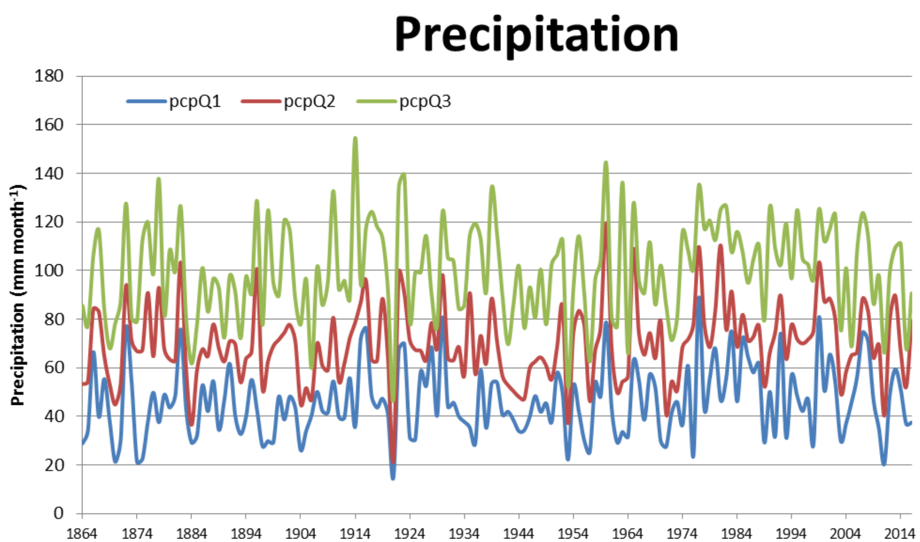


- You may want to know more about the evolution of some extreme values such as 90th centile (or other quantiles) !

Example: evolution of the yearly «quartiles» 1864 - 2016 in Geneva



Variations
1.4°C
2.1°C
2.0°C



Variations
8.5 mm
7.3 mm
8.8 mm

- … similar analyses can be carried out with HF observations
- Results may show (or not) some
  - periodicity, more or less frequent
  - these latter may also vary with time
    - tendencies
    - return periods/values

How can episodic events be determined, identified ?!

- Are these events ***episodic*** ?
  - passage of fronts, monsoon, mid-latitude wind storm, «the course of seasons» ?!
  - thunderstorms
  - forest fires
  - seasonal river discharge in a lake

- Link(s) with «periodic events» … if any ?!
- Link(s) with «extreme events» … if any ?!

How can episodic events be defined?

- In the atmosphere ! (not heard about this so far…)
- In lakes !
  - in combination with surface forcing ?!
    - low/high winds
    - low/high temperature
    - low/high precipitation
    - low/high river discharge

links with extremes ?!

- Def. (Jennings et al., 2012)
  - In lakes, [episodic] events are characterised by abrupt changes in physical, chemical and/or biological parameters that are distinct from previous background levels and are often driven by sudden changes in weather and in particular extremes in precipitation, wind or temperature

594 *E. Jennings* et al.

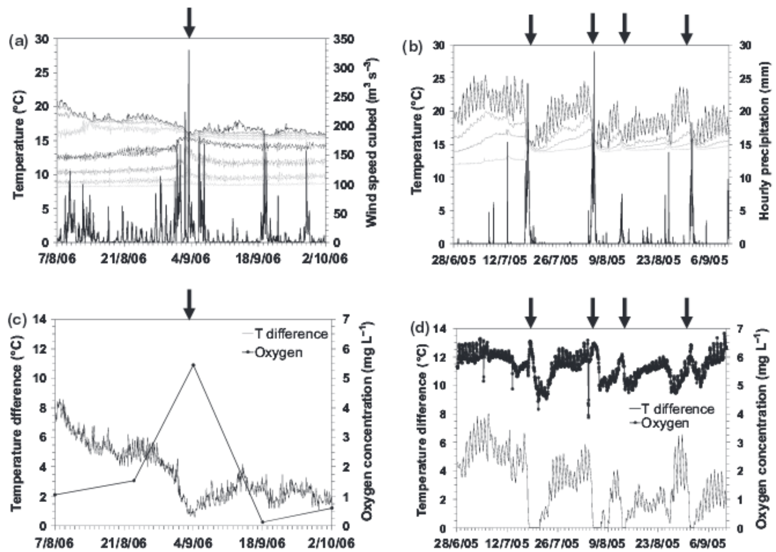
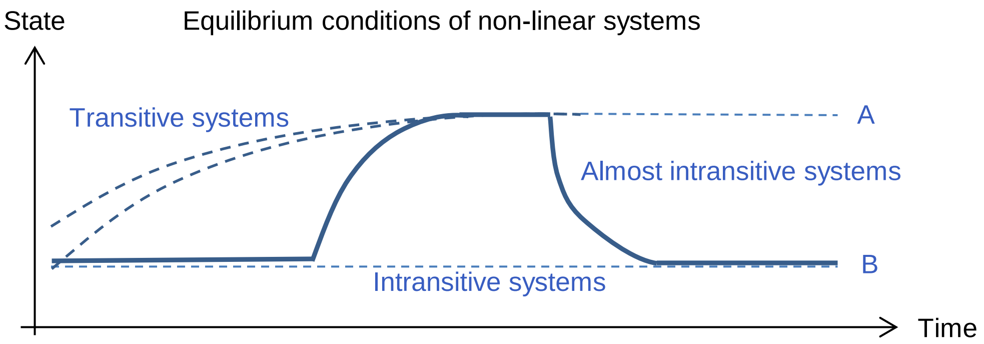


Fig. 1 (a) water temperatures in Blelham at depths of 1–8 m (thin black line–thin grey line and dashed thin black line–dashed thin grey line) and cube of the wind speed (thick black line); (b) temperatures at Yuan Yang at depths of 0–3 m (thin black line–thin grey line) and hourly precipitation (thick black line); (c) temperature difference in Blelham between 1 and 5 m (thin line) and oxygen concentration at 5 m (thick line and circles); (d) temperature difference in Yuan Yang between epilimnion and hypolimnion (thin line) and oxygen concentration at 0.5 m (thick line and circles). Black arrows indicate timing of change in meteorological driver.

Questions

- Should these changes induce «permanent» impacts / regime shifts in lakes?
- Should we expect transitive - intransitive - almost intransitive changes ?!



References

- Beniston, M., et al., 2007 : Future extreme events in european climate: an exploration of regional climate model projections. *Clim. Change*, **81,** 71 - 95.
- Jennings, E. et al., 2012: Effects of weather-related episodic events in lakes: an analysis based on high-frequency data. *Freshwater Biology,* 57, 589–601
- MeteoSwiss : `www.meteosuisse.admin.ch`

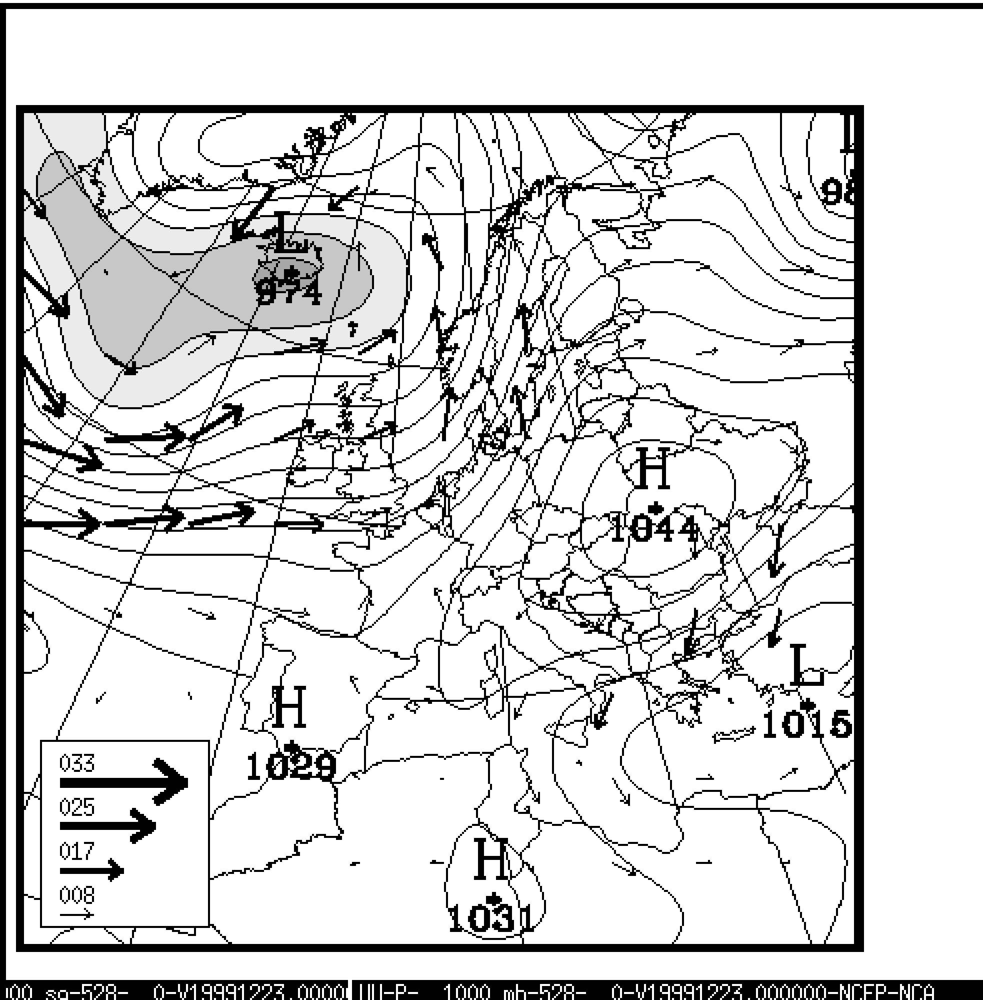
Discussion and synthesis

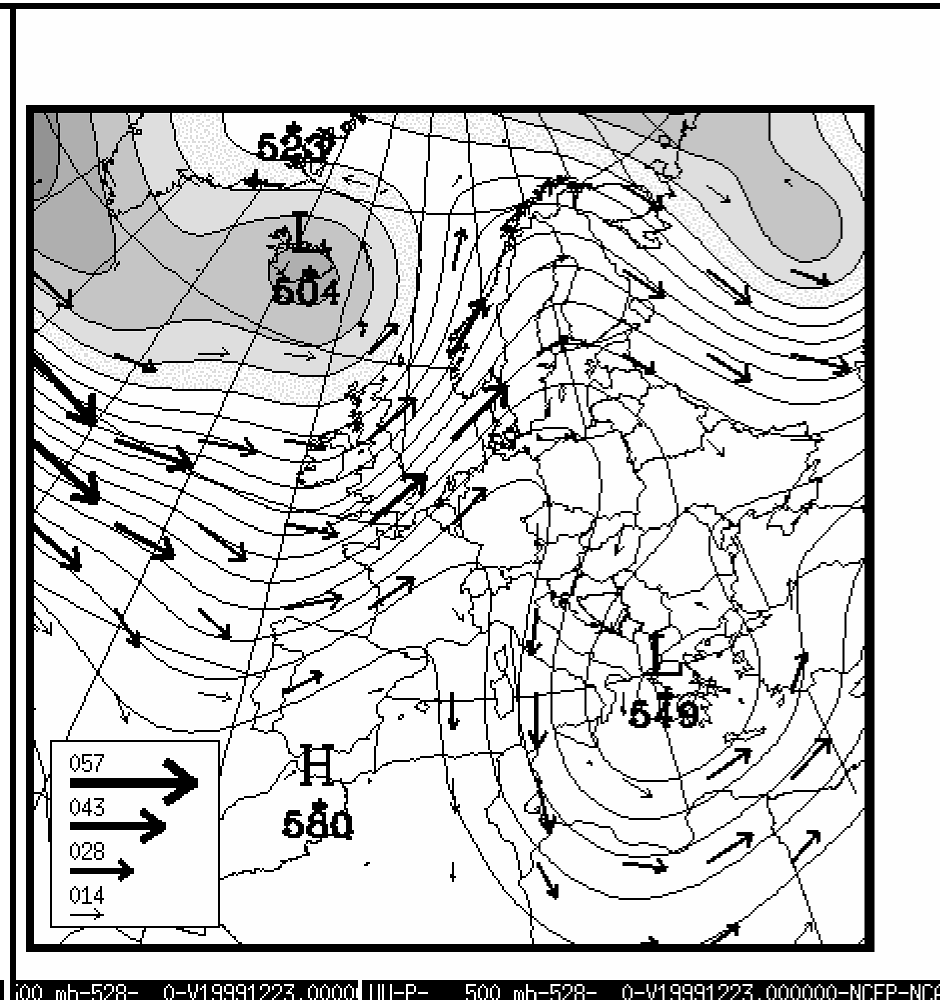
EXTRA SLIDES

Synoptic conditions

Dec 24-27 1999

grid spacing 60 km





Multiple dowscaling

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D13, 4374, doi:10.1029/2002JD002646, 2003

Application of a new wind gust parameterization: Multiscale case studies performed with the Canadian regional climate model

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Received 12 June 2002; revised 18 December 2002; accepted 12 March 2003; published 1 July 2003.

[1] The implementation of a physically based parameterization scheme for computation of wind gusts in a numerical regional climate model (RCM) is described in this paper. The method is based on an innovative approach proposed by *Brasseur* [2001] that assumes that gusts occurring at the surface result from the deflection of air parcels flowing higher in the boundary layer. Our parameterization scheme is developed so as to use quantities available at each model time step: consequently, the gusts are also computed for each of these time steps. To illustrate the performances of this novel method, gusts simulated for two severe midlatitude windstorms with the Canadian RCM at various resolutions are compared with observed gust speeds. The study is carried out concurrently for the complex terrain of Switzerland and for the smoother topography of Belgium. A preliminary analysis indicates that this parameterization performs equally well over flat and over mountainous regions; it also responds properly in the strengthening as well as the weakening phases of wind storms. The storm-dependent results rely on the model configuration associated with the downscaling procedure, as well as on the accuracy of the simulated flow fields. The model response is dependent on the resolved topography distribution and height and on the types of lower boundary conditions that affect the stability of the boundary layer. The simulated gusts are generally more realistic at higher resolution over the complex topography of Switzerland but are less sensitive to resolution over the flat terrain as in Belgium. On the basis of these two storms, this study also shows that simple scaling coefficients relating gust speeds and resolution are not an appropriate method for addressing such issues. *INDEX TERMS:* 3307 Meteorology and Atmospheric Dynamics: Boundary layer processes; 3379 Meteorology and Atmospheric Dynamics: Turbulence; 3329 Meteorology and Atmospheric Dynamics: Mesoscale meteorology; 3322 Meteorology and Atmospheric Dynamics: Land/atmosphere interactions; *KEYWORDS:* gusts, parameterization, regional climate model, downscaling, turbulence, PBL

Citation: Goyette, S., O. Brasseur, and M. Beniston, Application of a new wind gust parameterization: Multiscale case studies performed with the Canadian regional climate model, *J. Geophys. Res.*, *108*(D13), 4374, doi:10.1029/2002JD002646, 2003.

1. Introduction

[2] It is well recognized that weather and climatic extremes can have serious and damaging impacts on humans, infrastructures, as well as on forests and wildlife [*Kunkel et al.*, 1999; *Meehl et al.*, 2000]. Among the list of extreme events that occurred over the last decade, one can identify intense midlatitude cyclones forming in the north Atlantic. They produce strong mean winds that may be amplified by excessive gusts over various regions in western Europe and the alpine regions (e.g., the wind storms "VIVIAN" 1990 and "LOTHAR" 1999).

[3] There have been worldwide efforts to improve the sampling of gusts [*Beljaars*, 1987], to diagnose and forecast turbulence [*McCann*, 1999] and/or wind gusts with empirical relationships relevant to many applications in weather forecasting, particularly for winds within hurricane [*Jagger et al.*, 2001; *Darling*, 1991]. Other studies focused on high winds in general using model-generated soundings [*Hart and Forbes*, 1999], on the temporal and spatial structure of wind gusts per se [*Mitsuta and Tsukamoto*, 1989] or in

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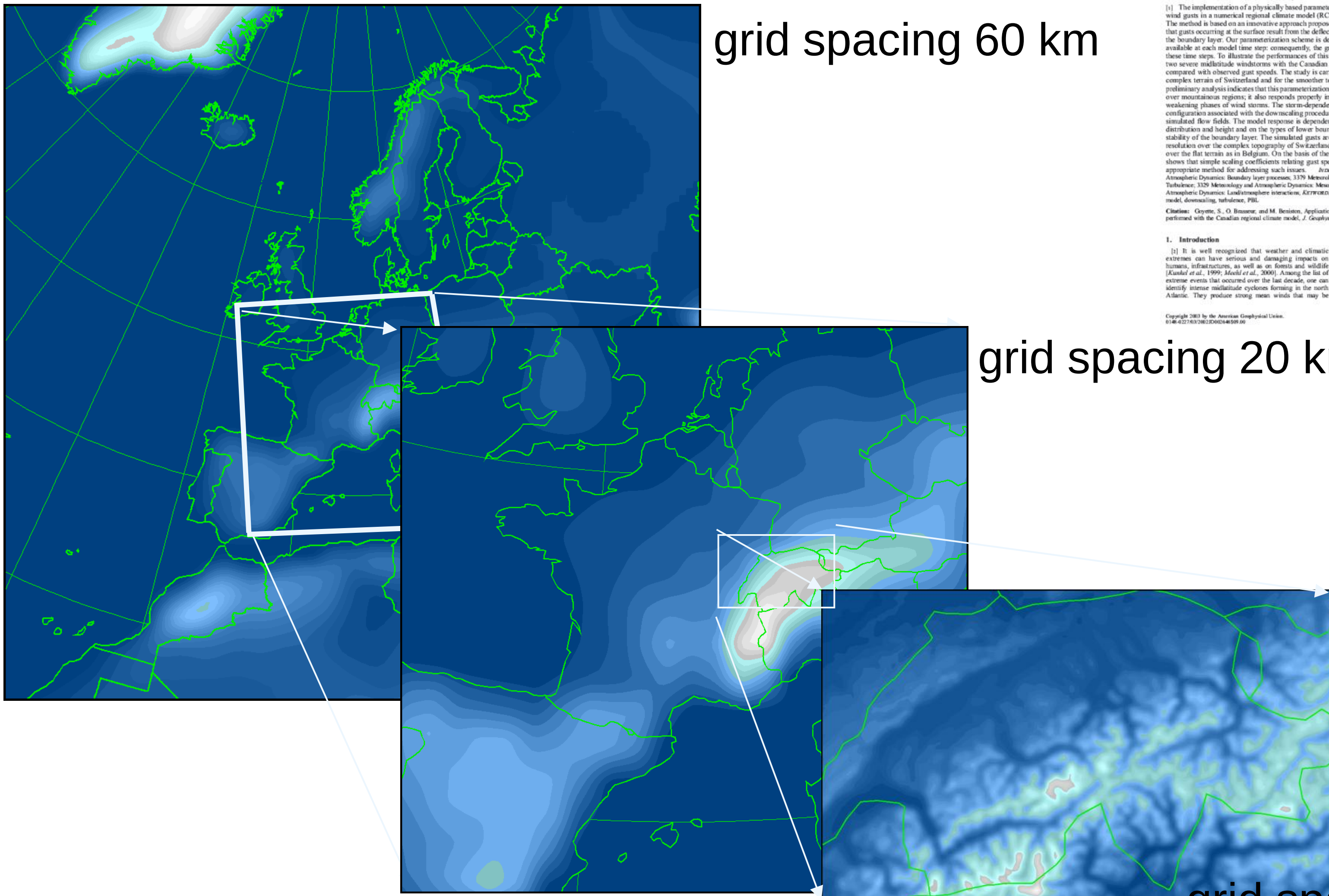

Atmosphere-lake coupling (1)

1) Application using a RCM

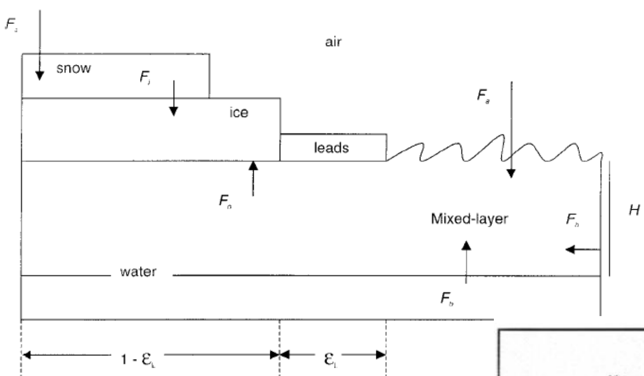

Fig. 1 Schematic of the fluxes involved in the mixed-layer and thermody

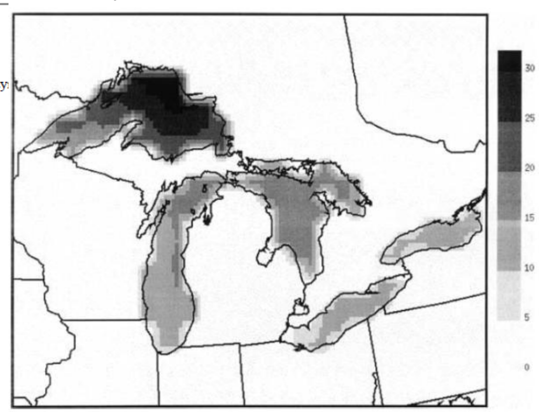

Fig. 2 Laurentian Great Lakes "annual mean" mixed-layer depths in m. Isobaths shaded every 5 m.

Table 1. Great Lakes mixed-layer depths in metres.

Mixed-layer depths (m) in CRCM	Superior	Michigan	Huron/ Georgian Bay	Erie	Ontario
Mean value	25	14	16	11	13
Maximum	32	18	20	14	15
Minimum	17	5	5	5	11

Application of the Canadian Regional Climate Model to the Laurentian Great Lakes Region: Implementation of a Lake Model

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[Original manuscript received 12 January 1999; in revised form 6 March 2000]

ABSTRACT *This study reports on the implementation of an interactive mixed-layer/thermodynamic-ice lake model coupled with the Canadian Regional Climate Model (CRCM). For this application the CRCM, which uses a grid mesh of 45 km on a polar stereographic projection, 10 vertical levels, and a timestep of 15 min, is nested with the second generation Canadian General Circulation Model (GCM) simulated output. A numerical simulation of the climate of eastern North America, including the Laurentian Great Lakes, is then performed in order to evaluate the coupled model. The lakes are represented by a "mixed layer" model to simulate the evolution of the surface water temperature, and a thermodynamic ice model to simulate evolution of the ice cover. The mixed-layer depth is allowed to vary spatially. Lake-ice leads are parametrized as a function of ice thickness based on observations. Results from a 5-year integration show that the coupled CRCM/lake model is capable of simulating the seasonal evolution of surface temperature and ice cover in the Great Lakes. When compared with lake climatology, the simulated mean surface water temperature agrees within 0.12°C on average. The seasonal evolution of the lake-ice cover is realistic but the model tends to underestimate the monthly mean ice concentration on average. The simulated winter lake-induced precipitation is also shown, and snow accumulation patterns on downwind shores of the lakes are found to be realistic when compared with observations.*

RÉSUMÉ *Cet article décrit un modèle de lac interactif de type «couche mélangée/glace thermodynamique» qui a été couplé avec le Modèle Canadien de Climat Régional (MCCR). Pour cette application, le MCCR, utilisant une maille de 45 km sur une projection stéréographique polaire, dix niveaux dans la verticale et un pas de temps de 15 minutes, est piloté par des données simulées avec le Modèle de Circulation Générale canadien de seconde génération (MCGII). Une simulation numérique du climat sur l'est de l'Amérique du Nord, incluant les Grands Lacs Laurentiens, est réalisée afin d'évaluer le modèle couplé. Les lacs sont*

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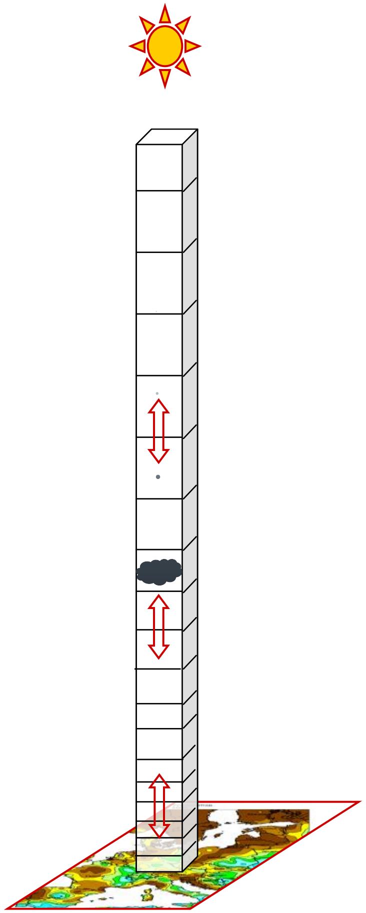
ATMOSPHERE-OCEAN 38 (3) 2000, 481–503 0705-5900/2000/0000-0481$1.25/0

Atmosphere-lake coupling (2)

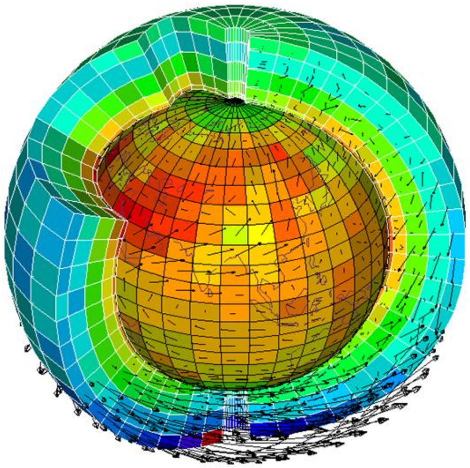
1) Application using a Single Column Model



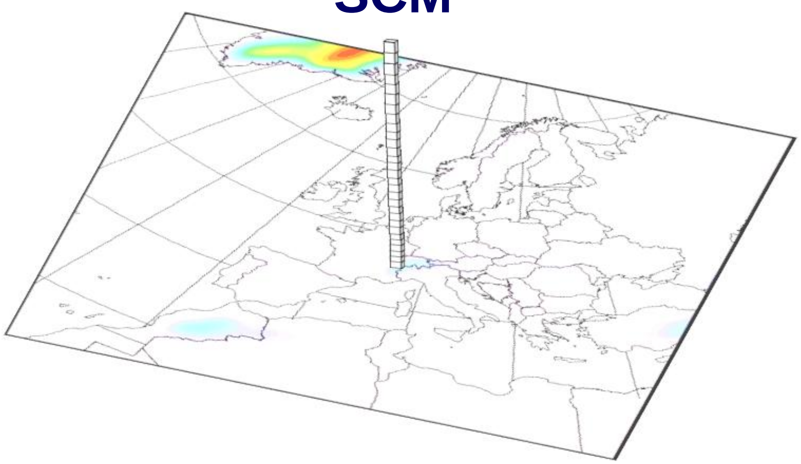
What’s a SCM ?

- As the name suggests, an SCM is analogous to a grid column of a more complete global/regional climate model

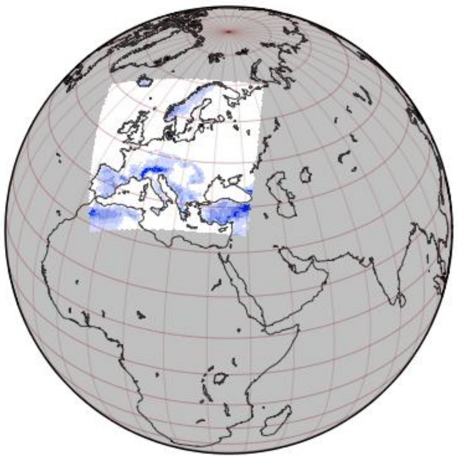
GCM



SCM



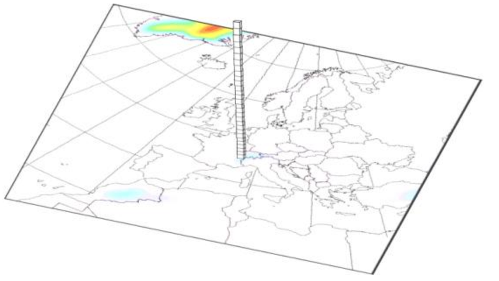
RCM



Why doing SCM

- Cheap in terms of computer resources
- Results "easier" to analyse
- Useful to test parameterizations
- Sensitivity studies
  - impact of changing surface types : land → open water

Application to Lake Geneva



- Model setup
  - column located at 46.2°N ; 6.1°E
  - simulation : one year 1990
    - control run : solid surface
    - experiments : lake (open water)

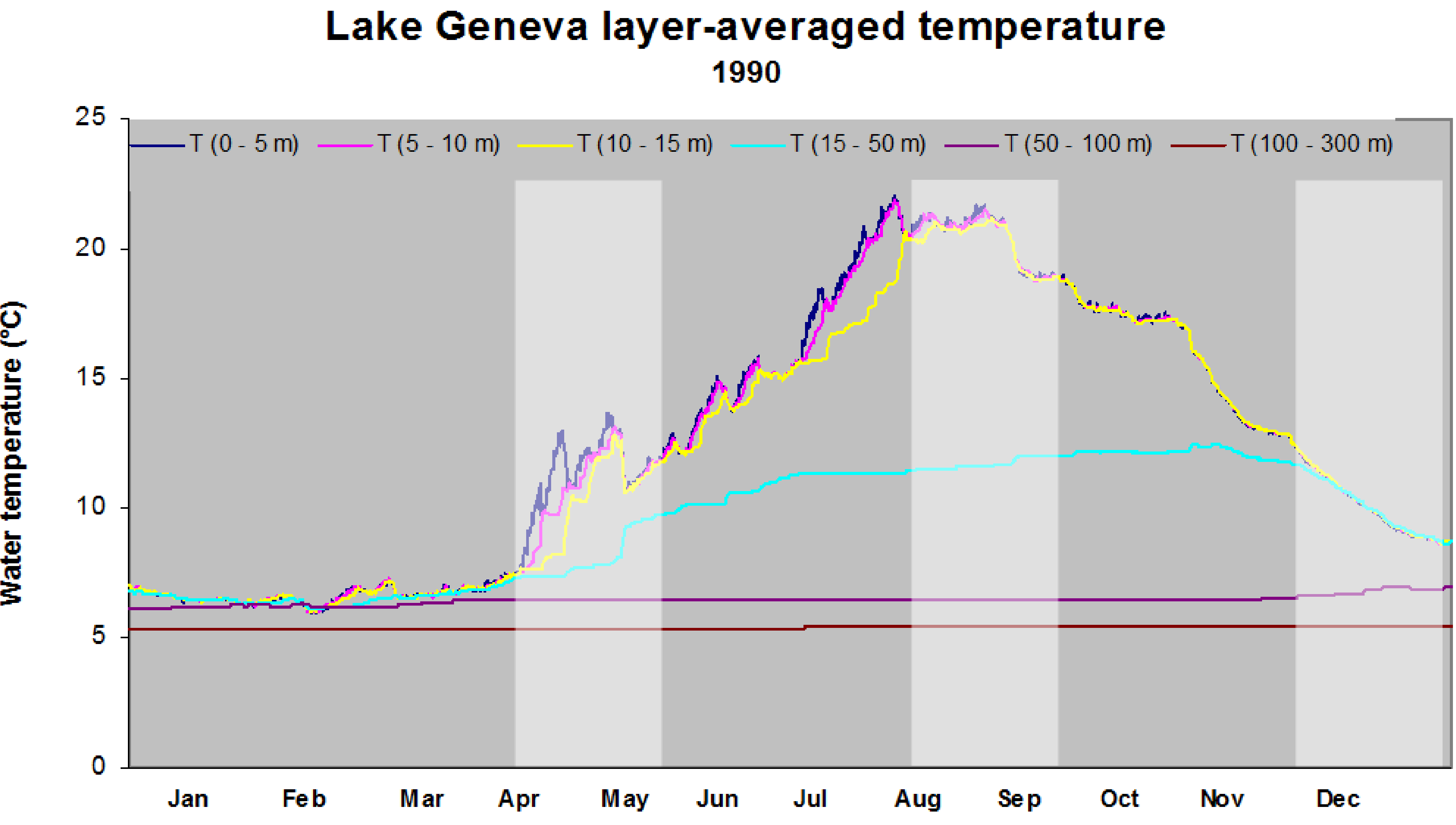


Figure 2. Evolution of Lake Geneva layer-averaged water temperature from January 15 to December 31, 1990. Also highlighted the three time-periods selected for the analysis of this case study: first one from April 28 to May 30, the second from Aug 13 to September 16, and the third from November 26 to December 30, 1990.

Atmospheric profiles

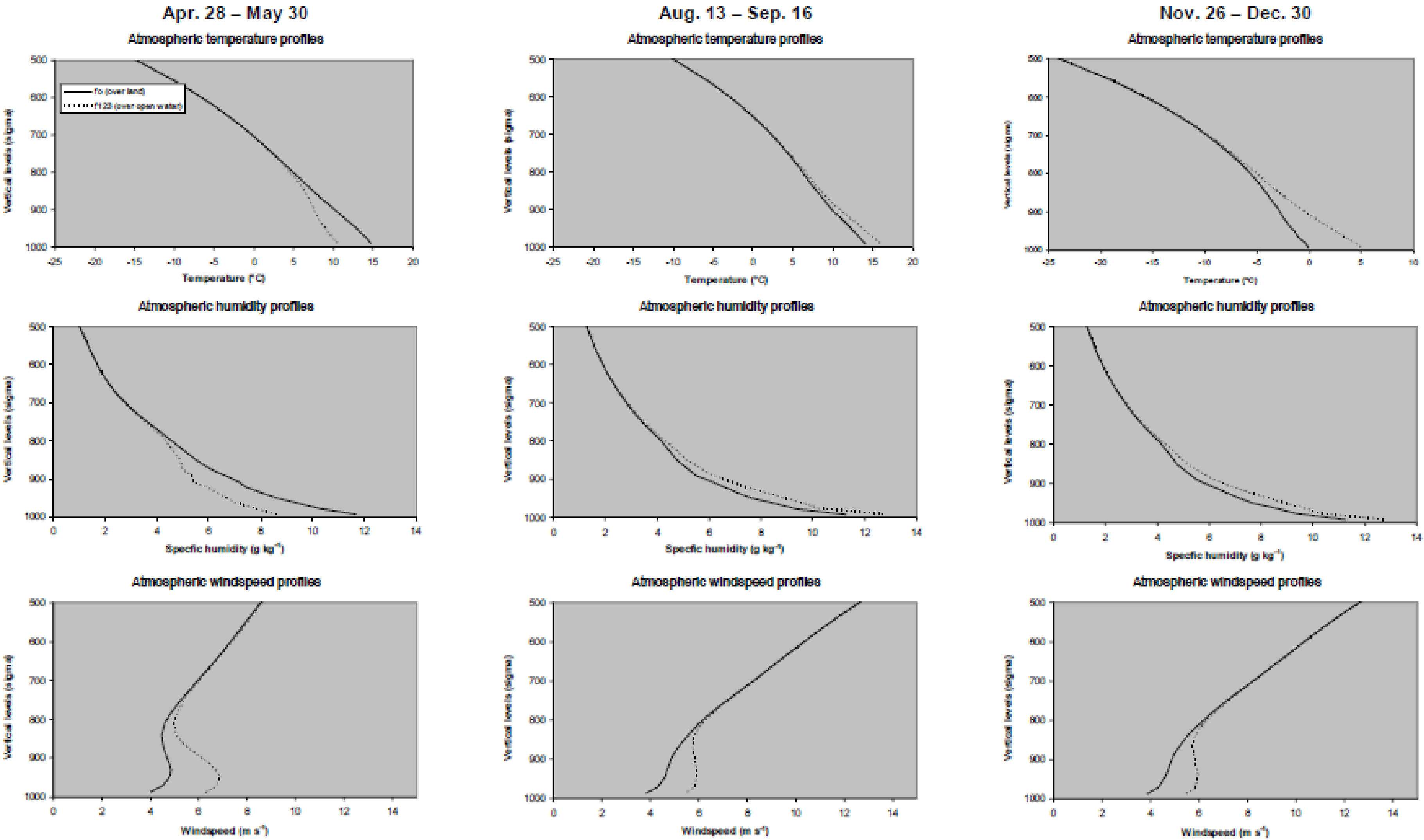


Figure 1. Atmospheric temperature, specific humidity, and windspeed mean profiles over solid and open water surfaces for the three time-periods selected for the analysis of this case study: first one from April 28 to May 30, the second from Aug 13 to September 16, and the third from November 26 to December 30, 1990.

Rare events

- On Feb. 18, 1979, low altitude areas of the Sahara desert recorded their first snowfall in living memory

- In 2005, Alaskans spotted their state's first ever tornado

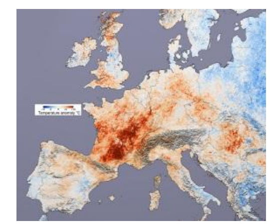
- The town of Marble Bar in Western Australia is legendary for its hot weather. From Oct. 31, 1923, to April 7, 1924, the tiny town scorched with 160 consecutive days over 100ºF (37.8ºC) → a world record

- *etc*…

Intense events

- Katrina was the fifth hurricane of the 2005 Atlantic hurricane season; it was an extremely destructive storm that hit the Gulf Coast of the United States in August 2005

- Summer 2003 heat wave
- January 2017 European cold wave



- *etc*…

A frozen fountain in Rome on 7 January 2017

Severe events

- Persistent rainfall, snowmelt, or high levels of ground water flowing through cracked bedrock may trigger a movement of soil or sediments
- Debris flows (e.g. Illgraben, Switzerland)

The Mameyes mudflow disaster, in barrio Tibes, Ponce, Puerto Rico, was caused by heavy rainfall from Tropical Storm Isabel in 1985. The mudflow destroyed more than 100 homes and claimed an estimated 300 lives.

A frozen fountain in Rome on 7 January 2017