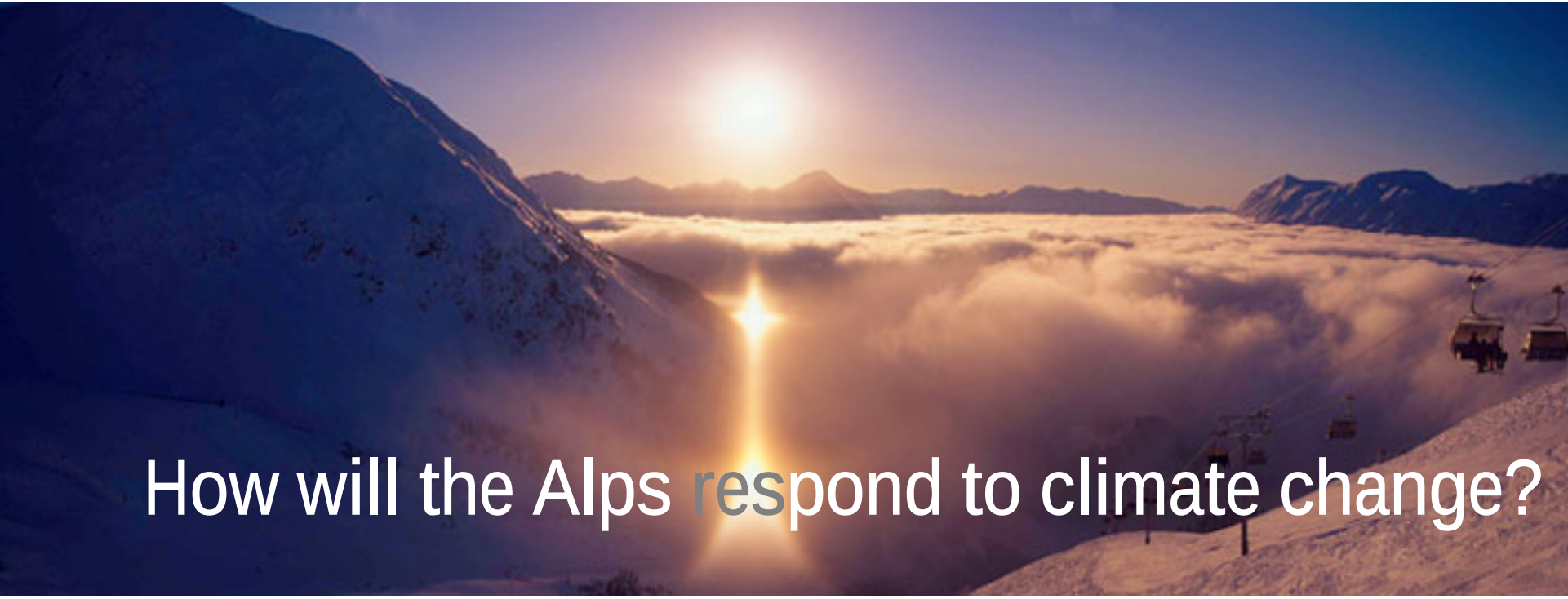
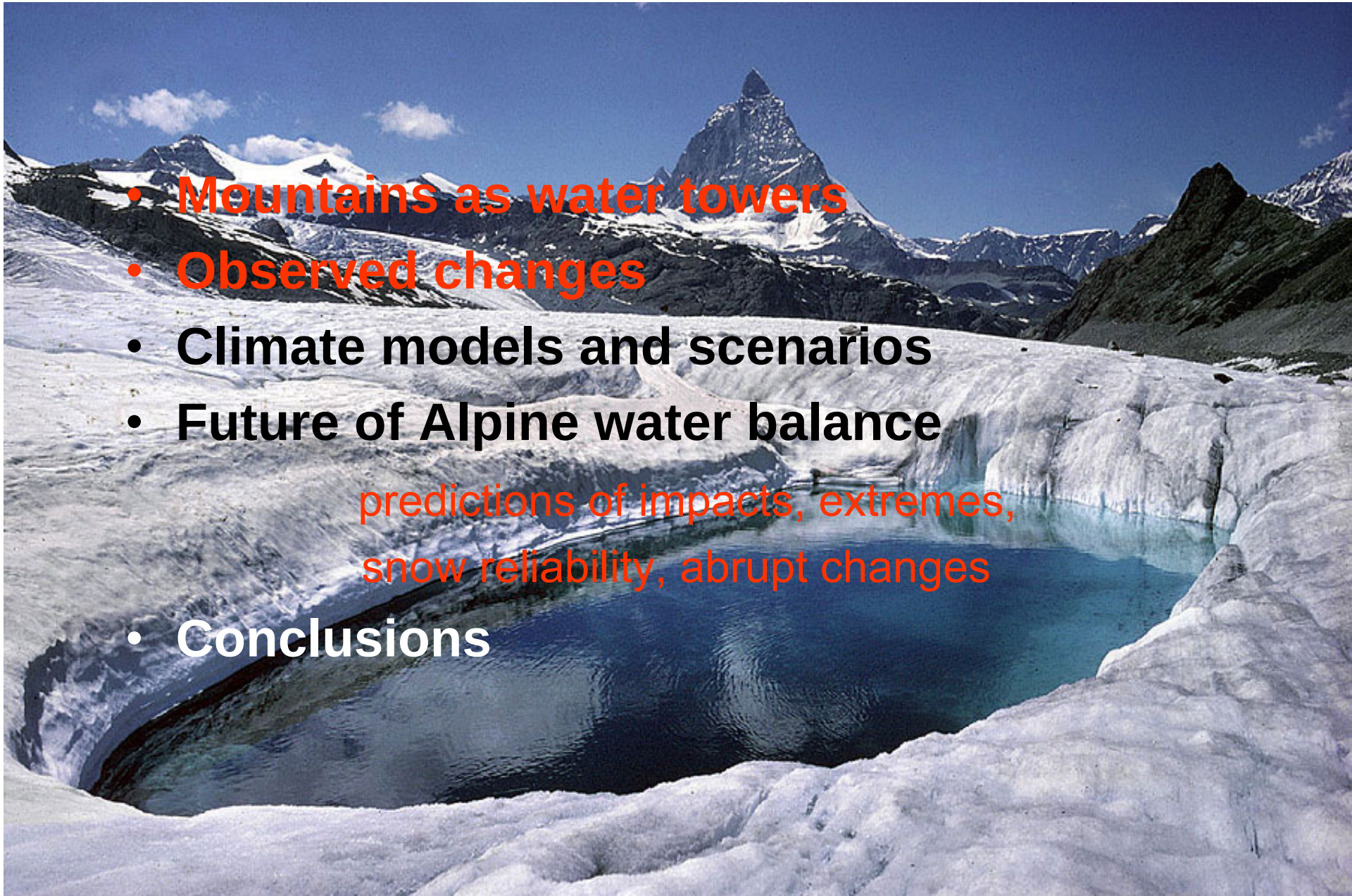


Scenarios for the future of Alpine waters

Lučka Kajfež-Bogataj
University of Ljubljana
IPCC WG2 Vice chair

Outline



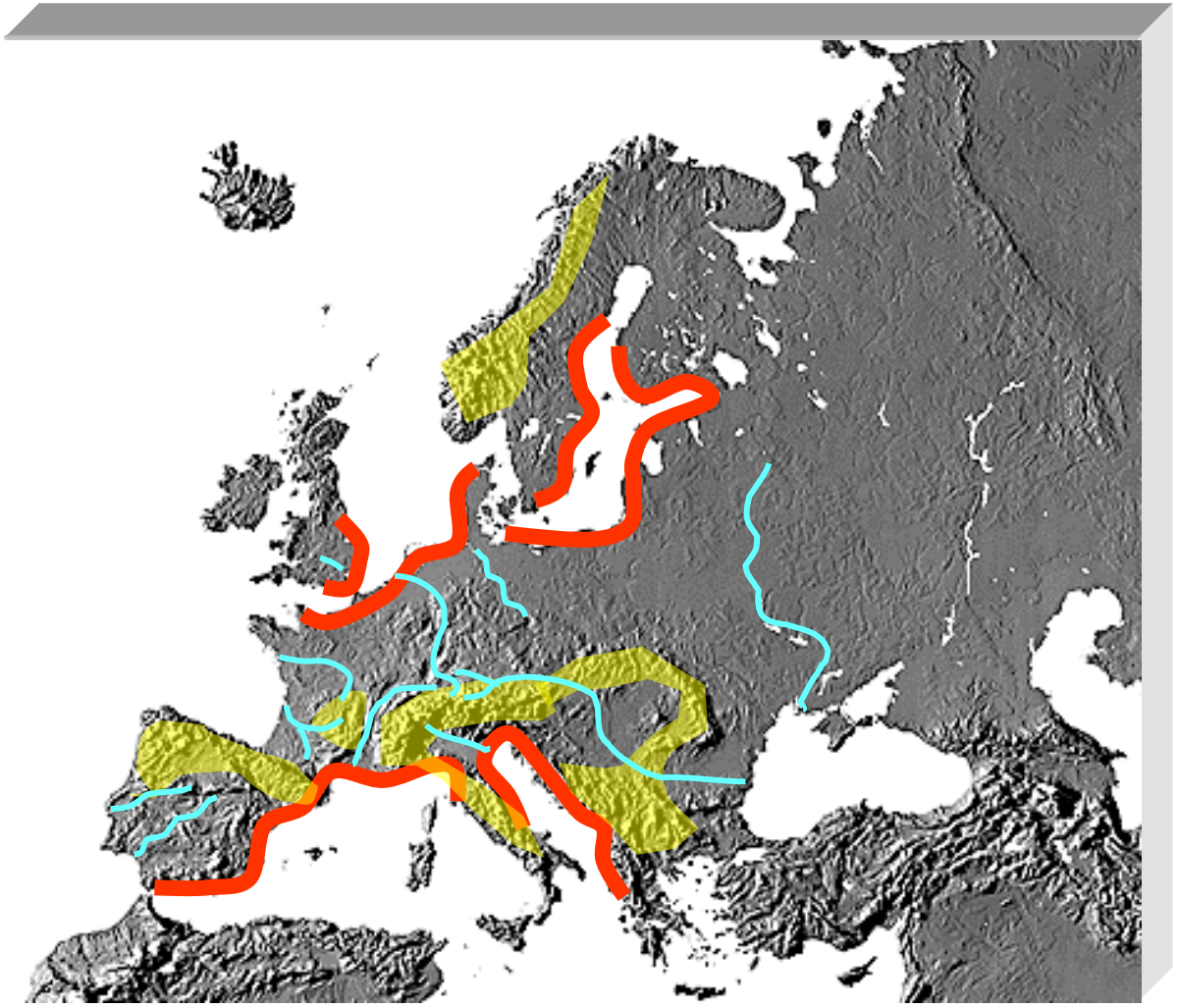
- **Mountains as water towers**
- **Observed changes**
- **Climate models and scenarios**
- **Future of Alpine water balance**

  predictions of impacts, extremes,

  snow reliability, abrupt changes

- **Conclusions**

Climate change: vulnerable regions in Europe

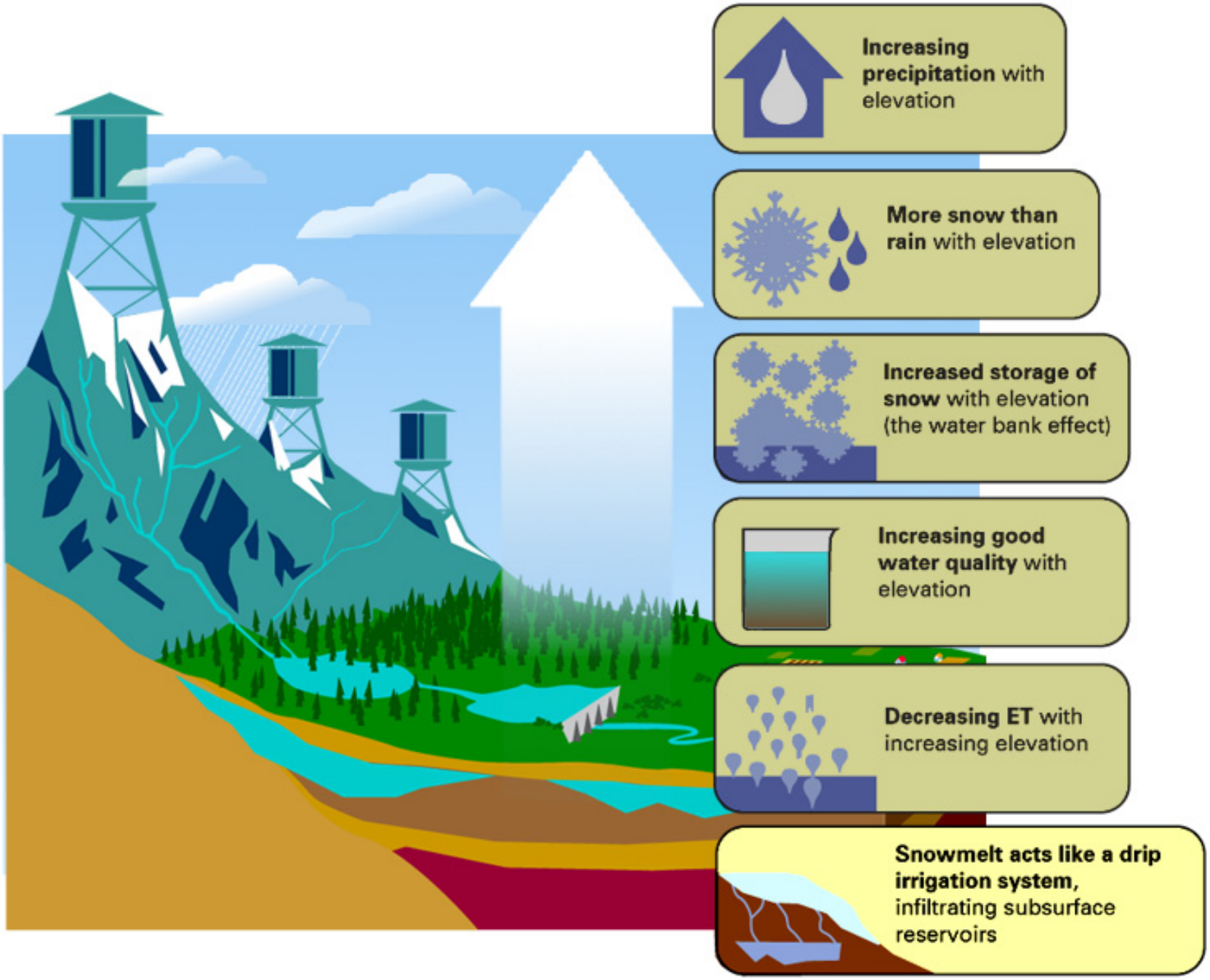


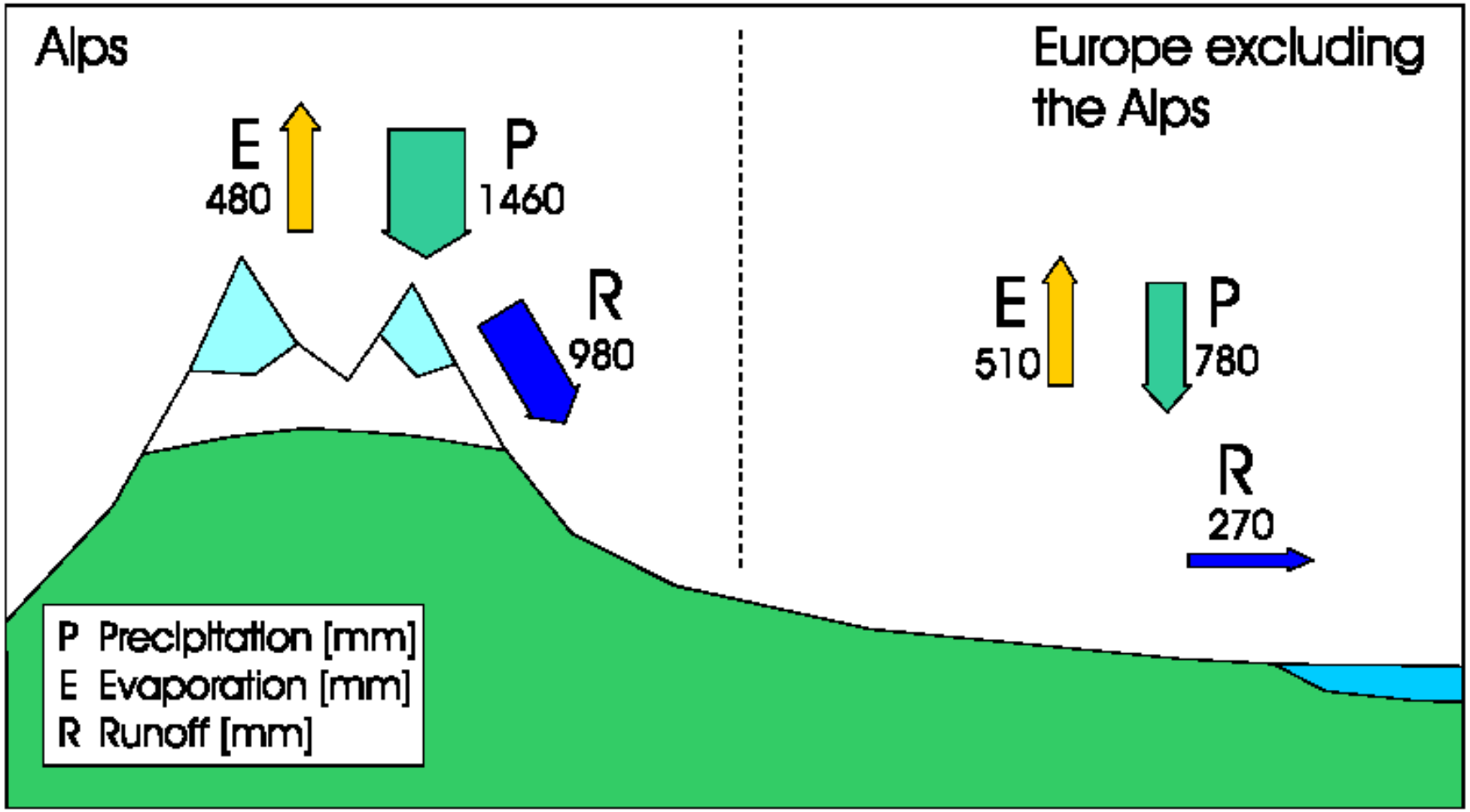
Coastal regions

Mountain regions

Rivers

IPCC, 2001


Increasing precipitation with elevation
More snow than rain with elevation
Increased storage of snow with elevation (the water bank effect)
Increasing good water quality with elevation
Decreasing ET with increasing elevation
Snowmelt acts like a drip irrigation system, infiltrating subsurface reservoirs



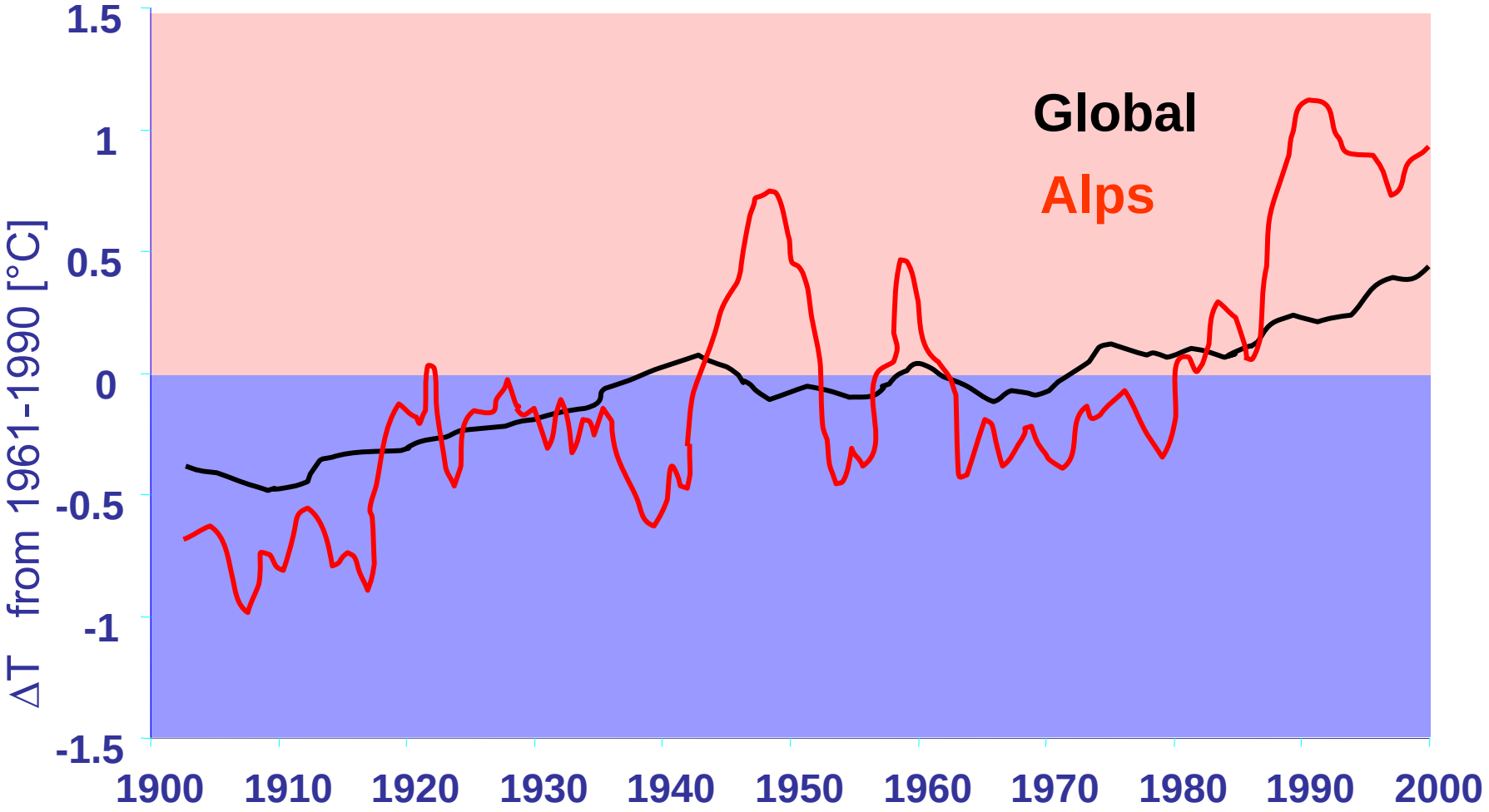
- Precipitation doubles
- ET: little change
- Runoff: 4x greater

Baumgartner et al., 2004

Observed climate change in Alps

Global temperature and temperature in Alps

Säntis - Switzerland (2490 m) and Sonnblick - Austria (3106 m) last century's warming exceeded 1.5 °C, which is more than twice the global average warming



Observed climate change in Alps

- **Precipitation:**
- Annual prec. slightly rising in French Alps
- Regional trend differences (particularly between NW and SE part of Alps: 10 % increase in the NW and 10 % decrease in the SE)
- Some long-term trends have abruptly changed into their opposites (SE part of the Alps: winter prec. decreasing since 1980, autumn prec. increasing since 1990)
- **Snow:**
- Snow parameters in the Alps are characterized by a marked declining gradient (the duration of continuous snow cover is clearyl declining at all elevations and it melts much earlier)
- Shrinkage of mountain glaciers (glaciers have lost one third of their area and one half of their mass from 1850 to 1990)
- **Sunshine duration:**
- Annual sunshine shows clear trend of “brightening” at higher elevations (above 2000 meters), elevations below 1000 meters show weaker to not significant trend

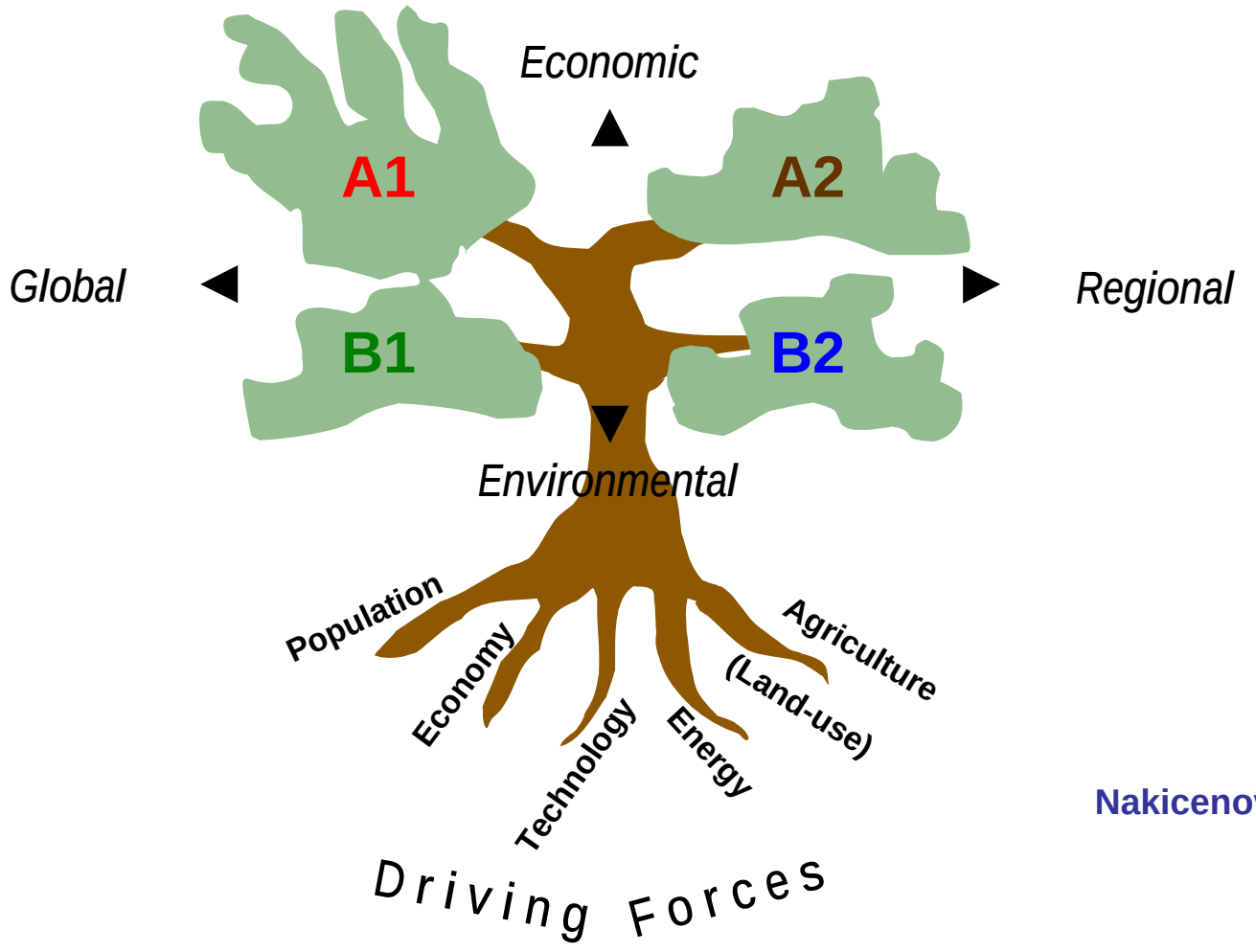
Climate Models and Climate Scenarios

Climate models and other types of models are used for future estimates.

- Depict physics, chemistry and biology of the environment in form of mathematical equations, solved by a computer program.
- Require large amounts of input data (emissions, topography, historical climate data).
- Have uncertainties.

Results of climate model: projections of the response of the climate system to future emissions scenarios

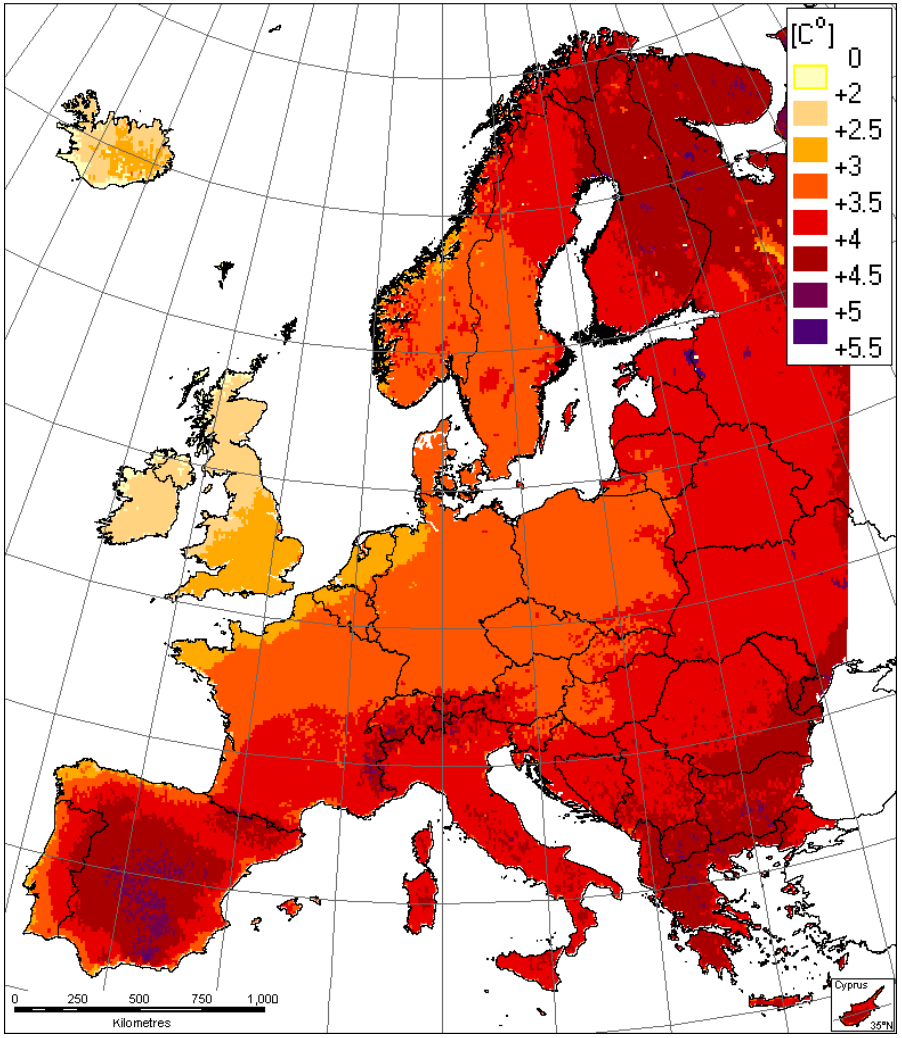
The SRES driving forces and storylines



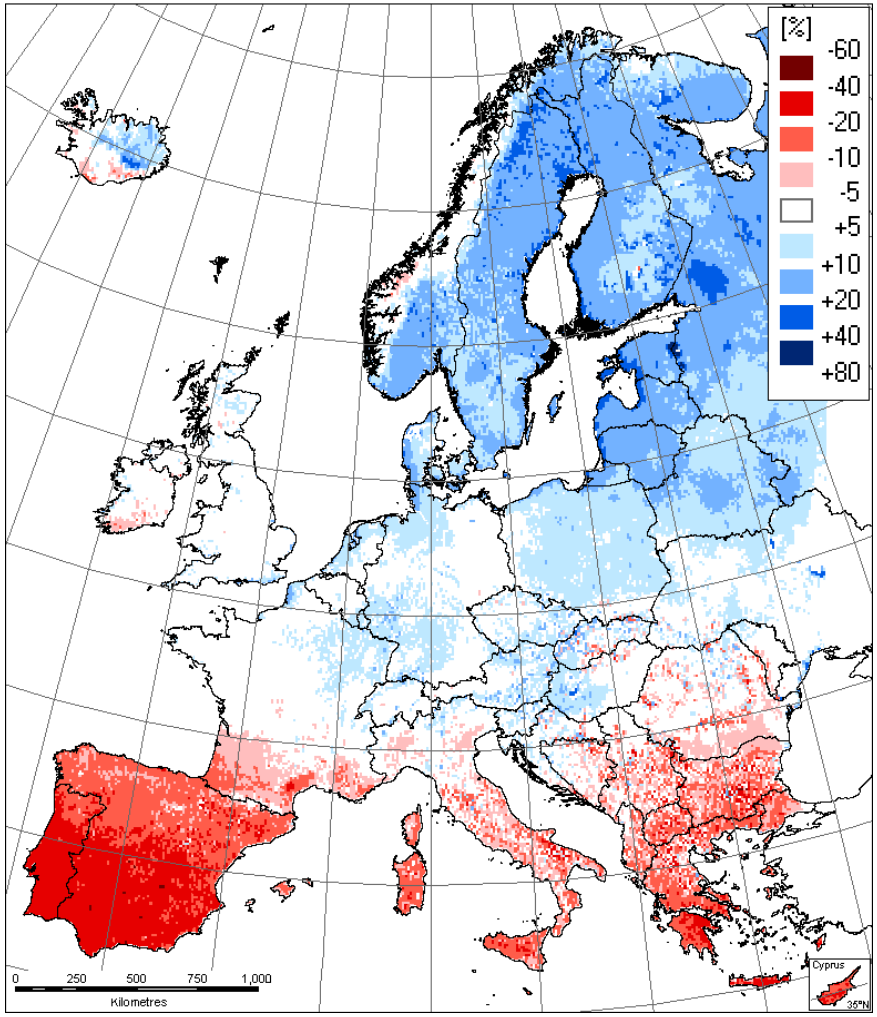
Nakicenovic et al. (2000)

Figures are based on IPCC SRES scenario A2. The projected climate impacts are estimated for 2071-2100 relative to 1961-1990. The maps are based on DMI/PRUDENCE data (http://prudence.dmi.dk)

Temperature: change in mean annual temperature [C°]



Precipitation: change in annual amount [%]



THE ALPS:

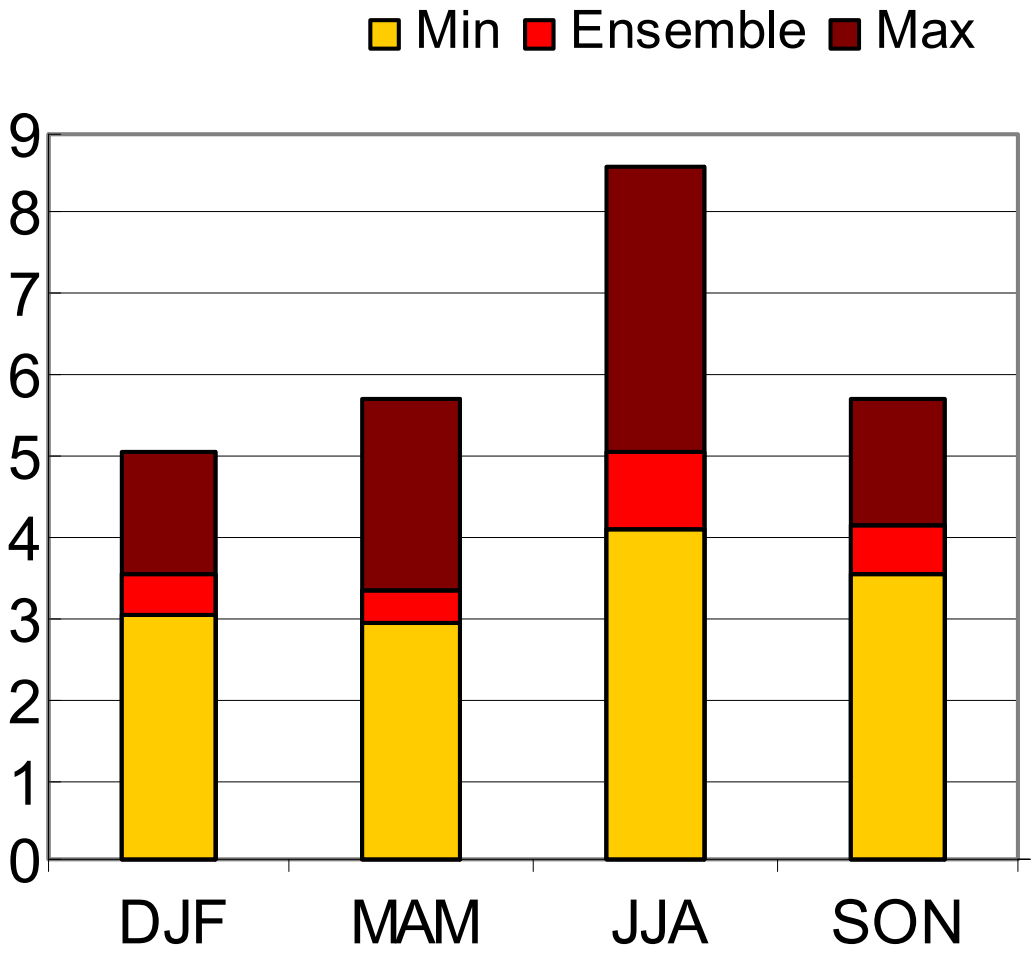
Key environmental pressures

- **Changes in temperature (affect snow-cover, snow pack and biodiversity)**
- **Changes in precipitation patterns, particularly extreme weather events (droughts and floods)**
- **Changes in the wind regimes (the foëhn effect associated in leeward sides can affect the snow and vegetation distribution and human health).**
- **Land-use changes and conflicts (arise from urbanisation and competition between different sectors).**
- **Increase in air and noise pollution on transit routes, major roads and in cities affect human health.**

THE ALPS: Key vulnerability issues

- Changes in water balance
- Increasing vulnerability of settlements and infrastructure to natural hazards
- Changes in biodiversity and stability of ecosystems
- Increasing risks of economic losses in winter tourism and summer tourism due to heat waves

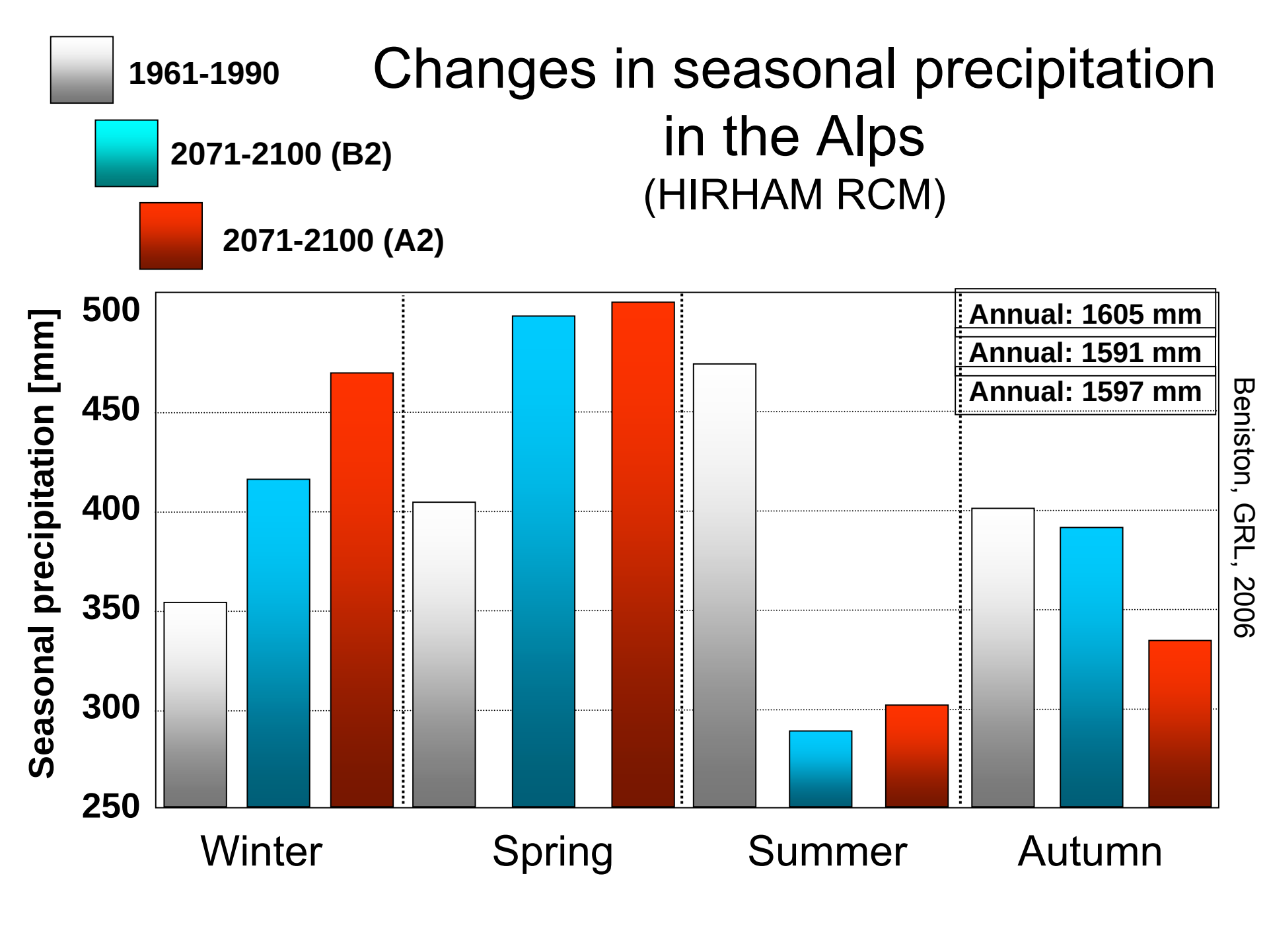
ALPS: Change in seasonal mean 2-m temperature by the end of this century



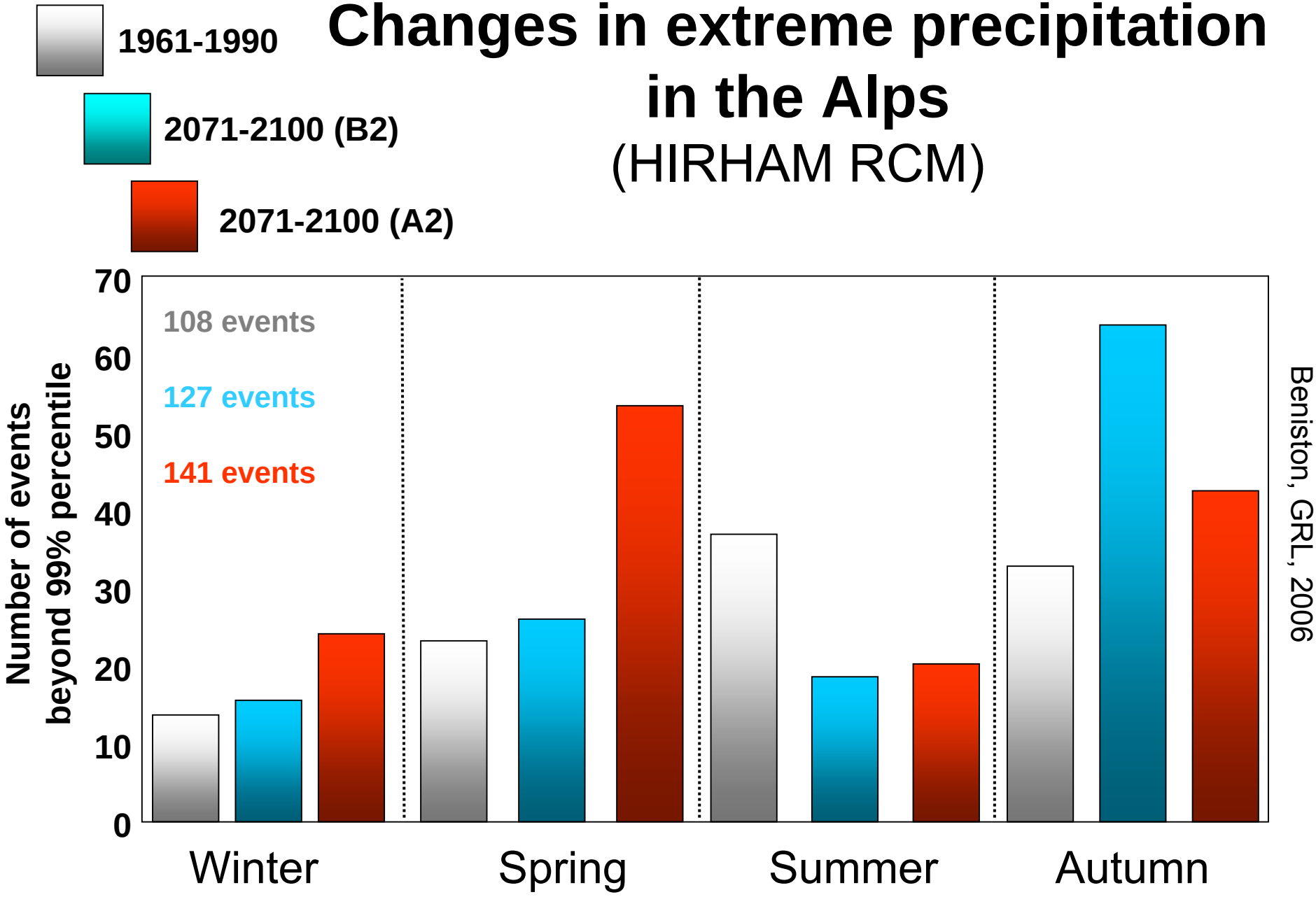
- Increased temperature variability in summer (inter-annual and daily time scales)
- Decreased temperature variability in winter

Consequences for water balance

- Enhanced hydrological cycle in Alps: higher rates of evaporation, greater proportion of liquid to solid prec. (soil moisture, groundwater reserves, frequency of droughts and floods)
- The duration of snow cover is expected to decrease by several weeks for each °C of temperature increase
- An upward shift of the glacier equilibrium line is expected from 60 to 140 m/°C
- Small glaciers will disappear, while larger glaciers will suffer a volume reduction between 30% and 70% by 2050


1961-1990
2071-2100 (B2)
2071-2100 (A2)
Changes in seasonal precipitation in the Alps
(HIRHAM RCM)
Seasonal precipitation [mm]
500
450
400
350
300
250
Annual: 1605 mm
Annual: 1591 mm
Annual: 1597 mm
Winter
Spring
Summer
Autumn
Beniston, GRL, 2006

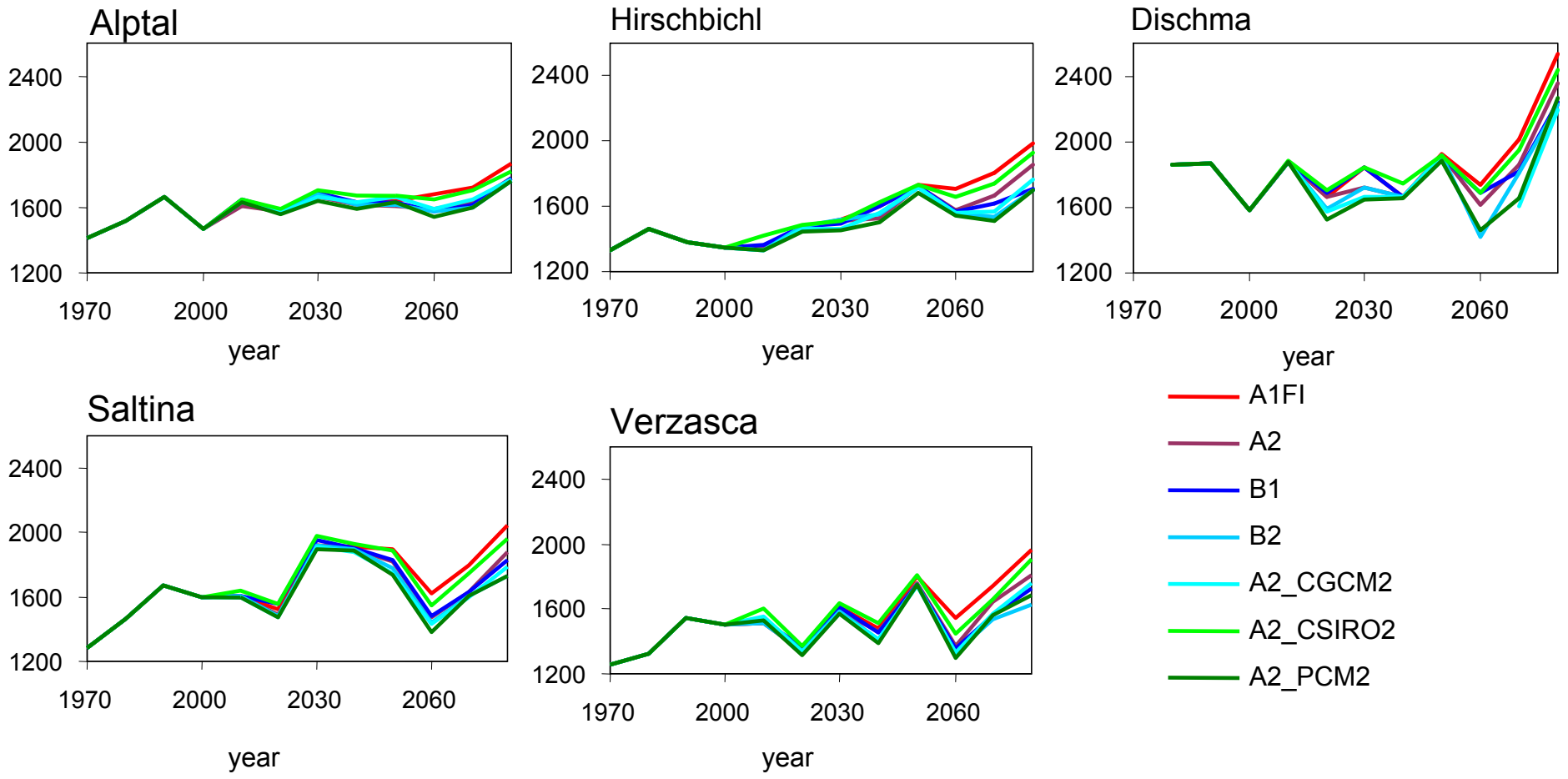
Changes in extreme precipitation in the Alps
(HIRHAM RCM)



SNOW AND PERMAFROST

- Snow is one of the substances which reacts the most quickly and visibly to ambient temperature.
- More than any other substance it shows what global warming really means
- For every °C increase in T snowline will on average rise by 150 m (at lower elevations by more than this average)
- A2 scenario: As a consequence to 4°C shift in mean winter T. snow duration is likely to be reduced by 50 % at altitudes 2000 m to 95 % at levels below 1000 m.
- The lower elevation of permafrost is likely to rise by several hundred meters (destabilisation of mountain walls and increase in the frequency of rock falls)

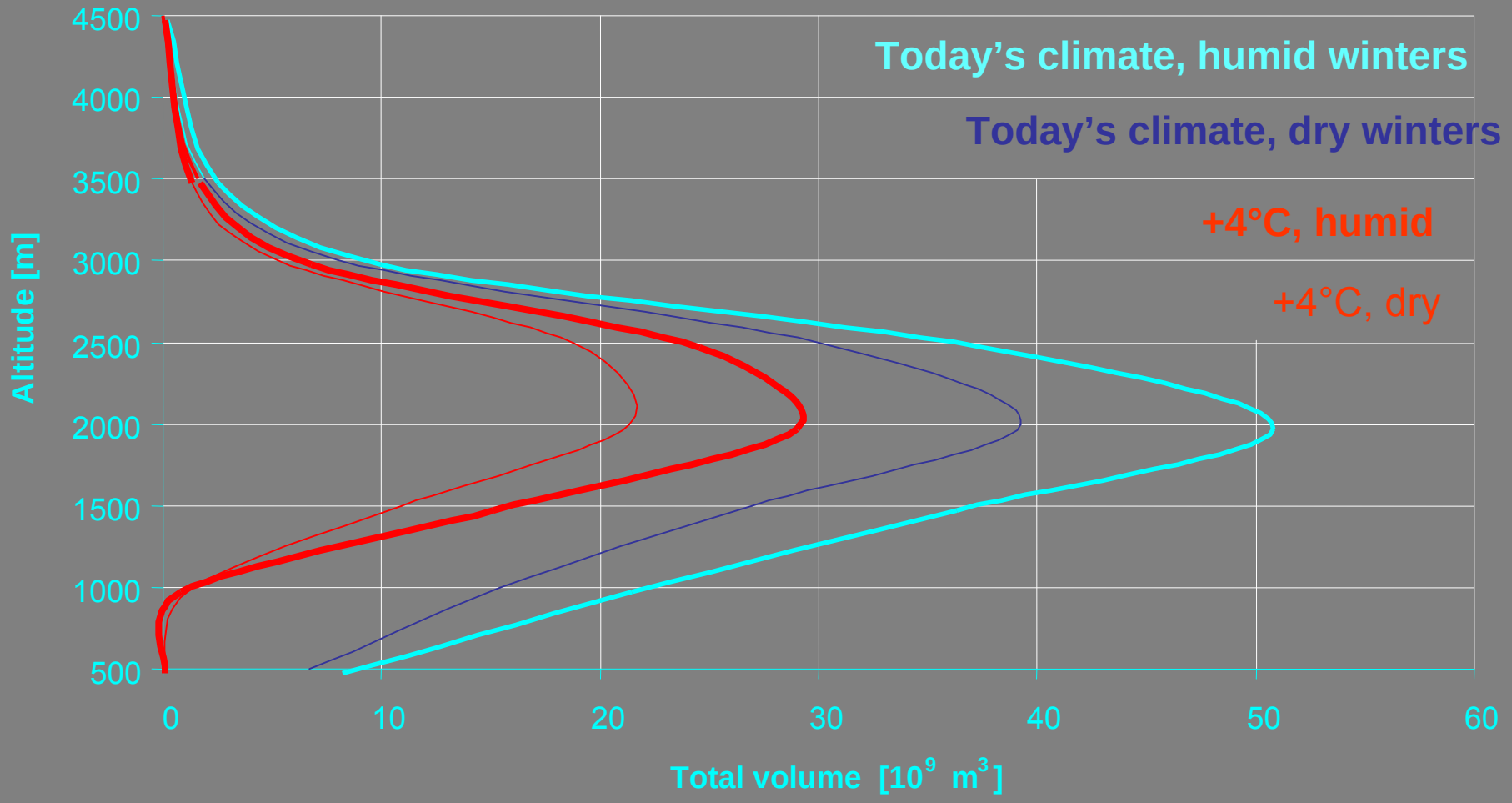
Elevation of snow reliability (m a.s.l.)



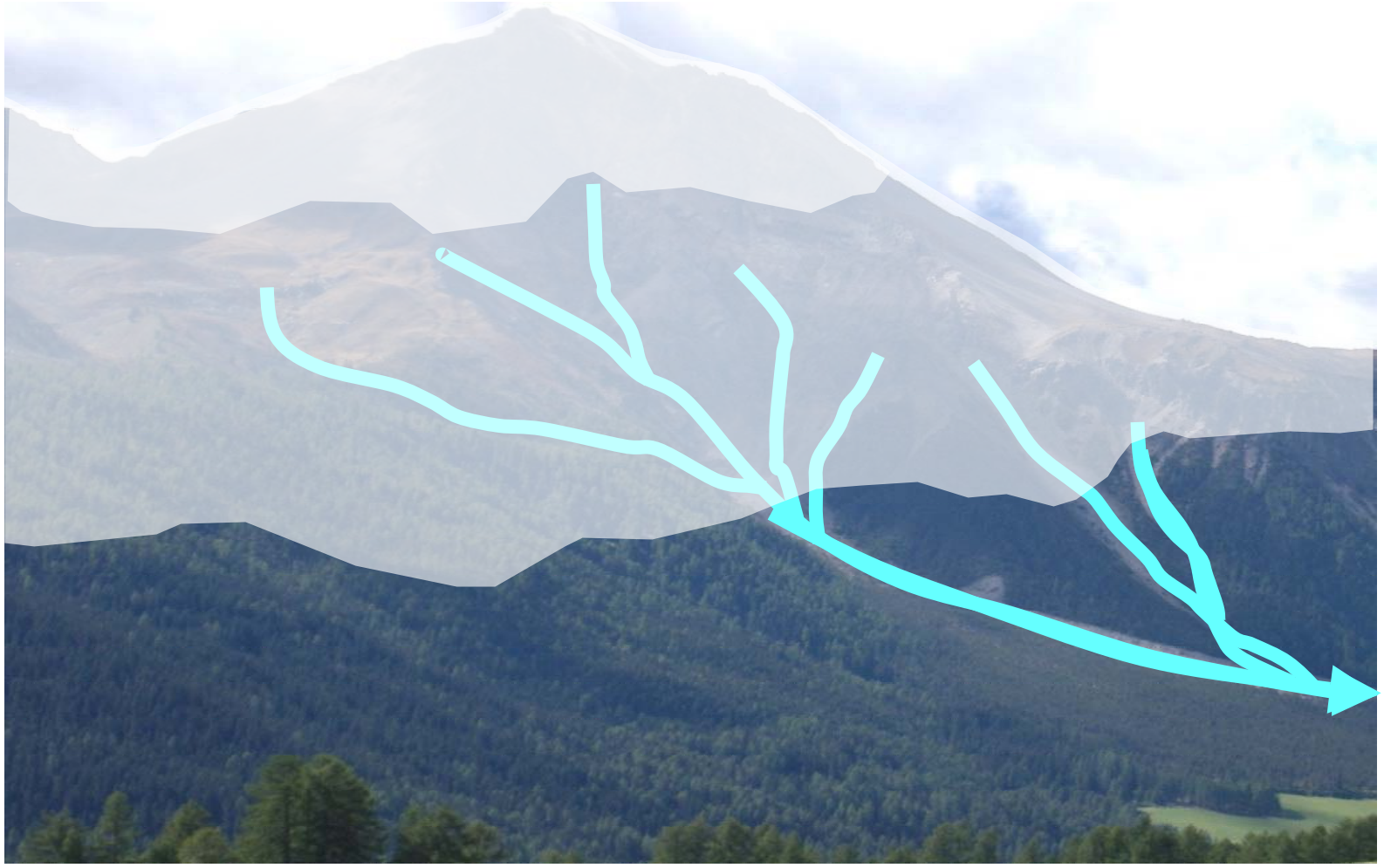
Elevation moves up ca. 150 m/ 1°C warming.

Zierl et al. 2004 (in prep).

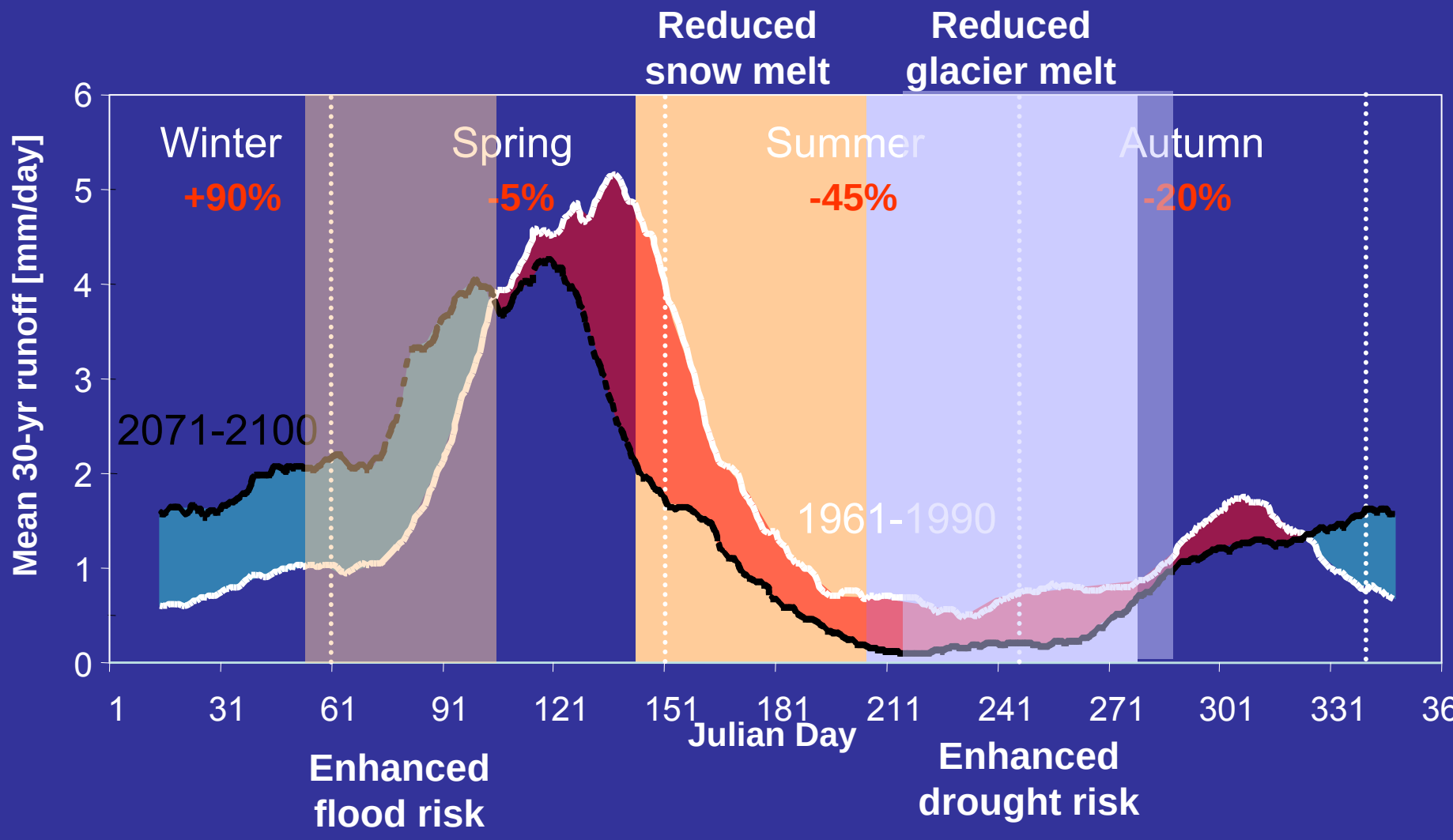
Snow volume in Alps (as a function of altitude)



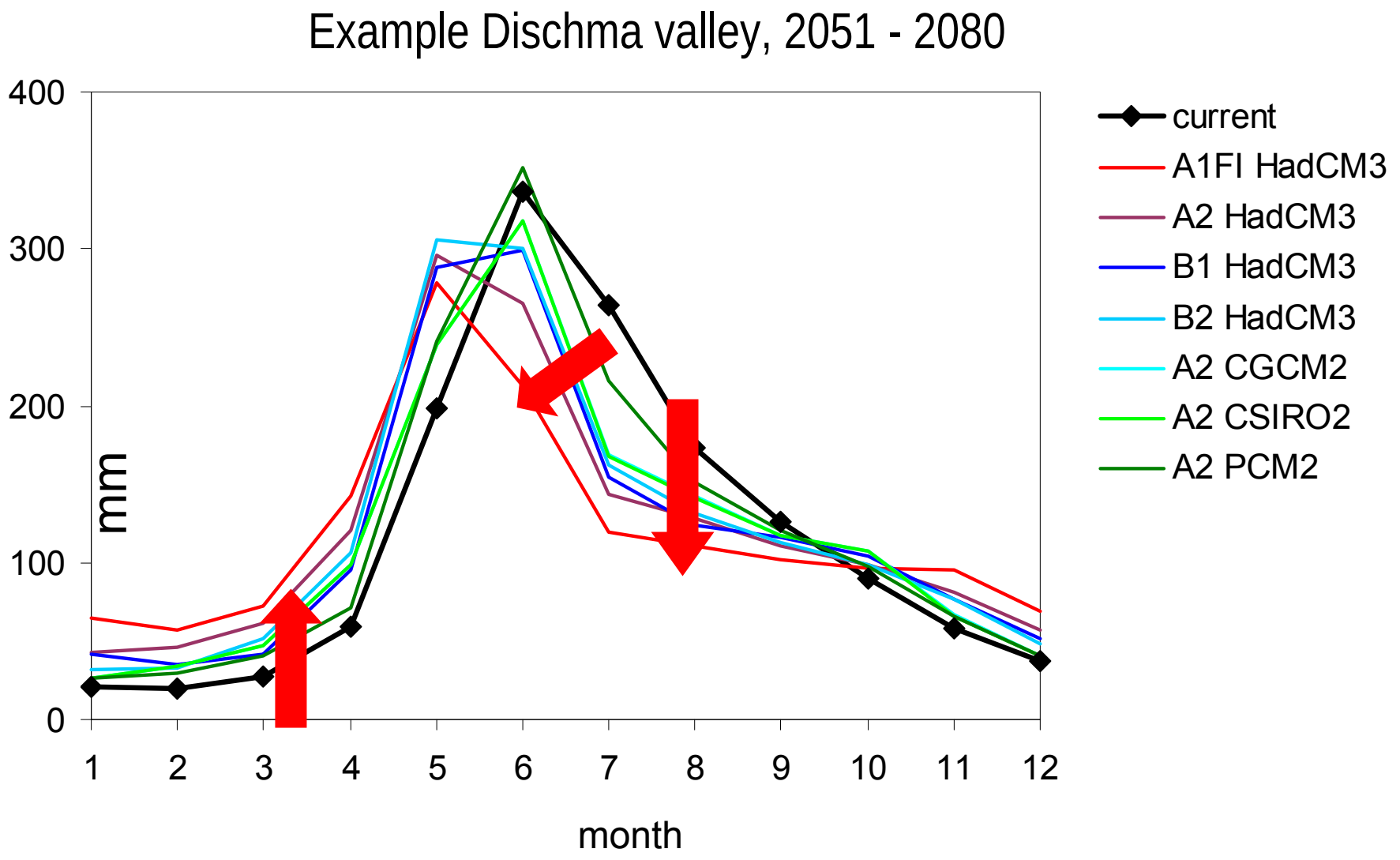
Consequences for floods: the buffering effects of snow



Shifts in seasonality of runoff in central Alps (HIRHAM RCM)

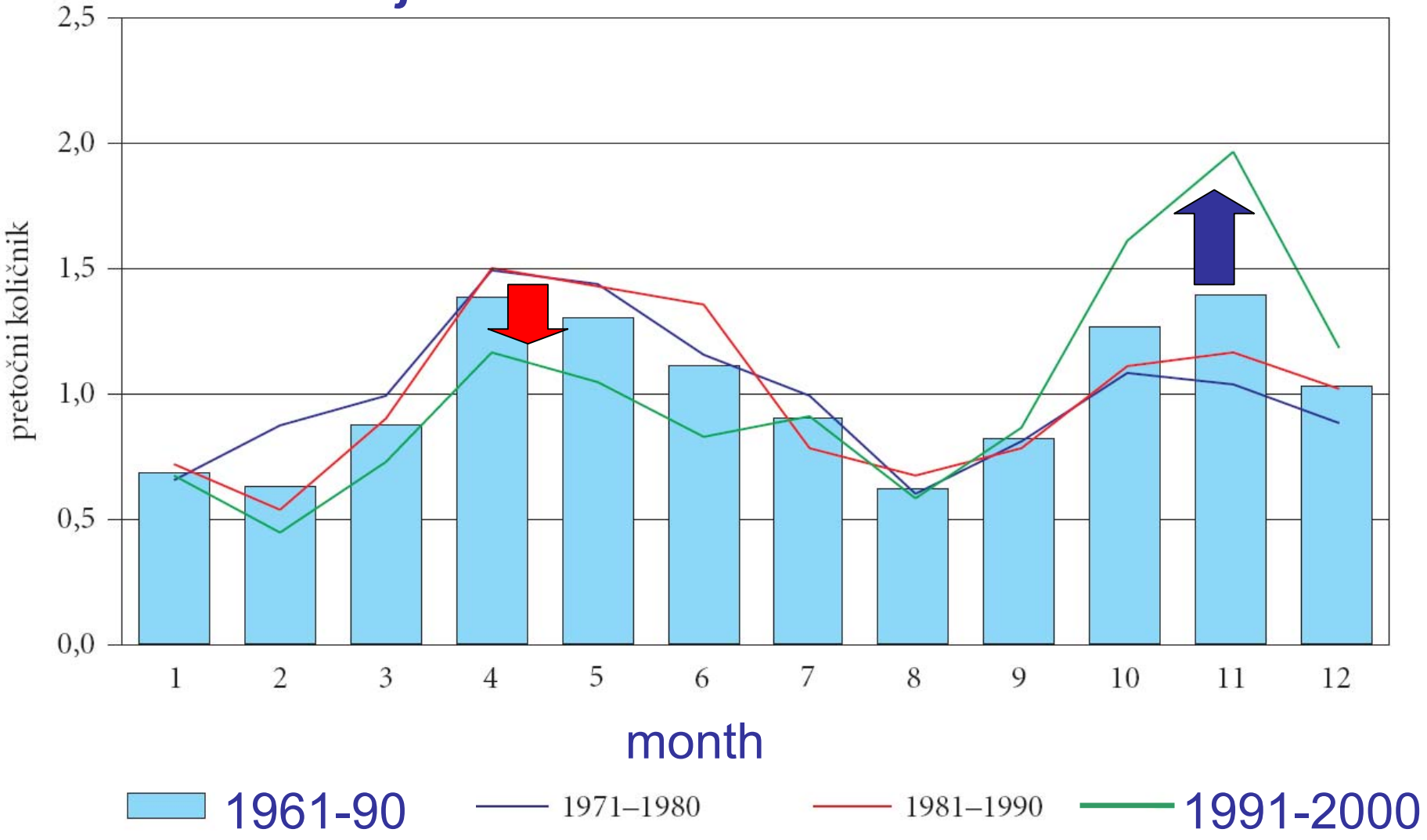


Alpine runoff regimes

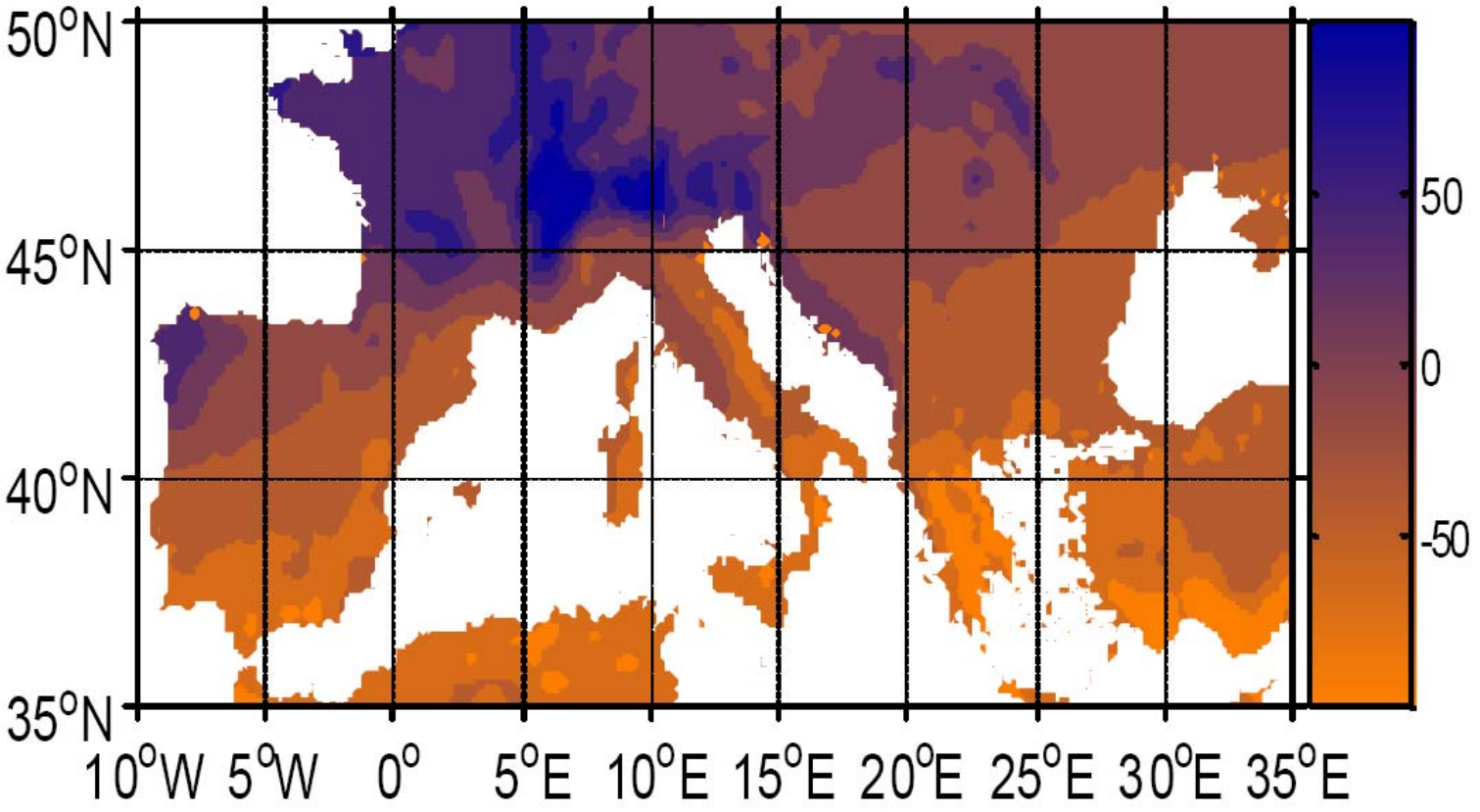


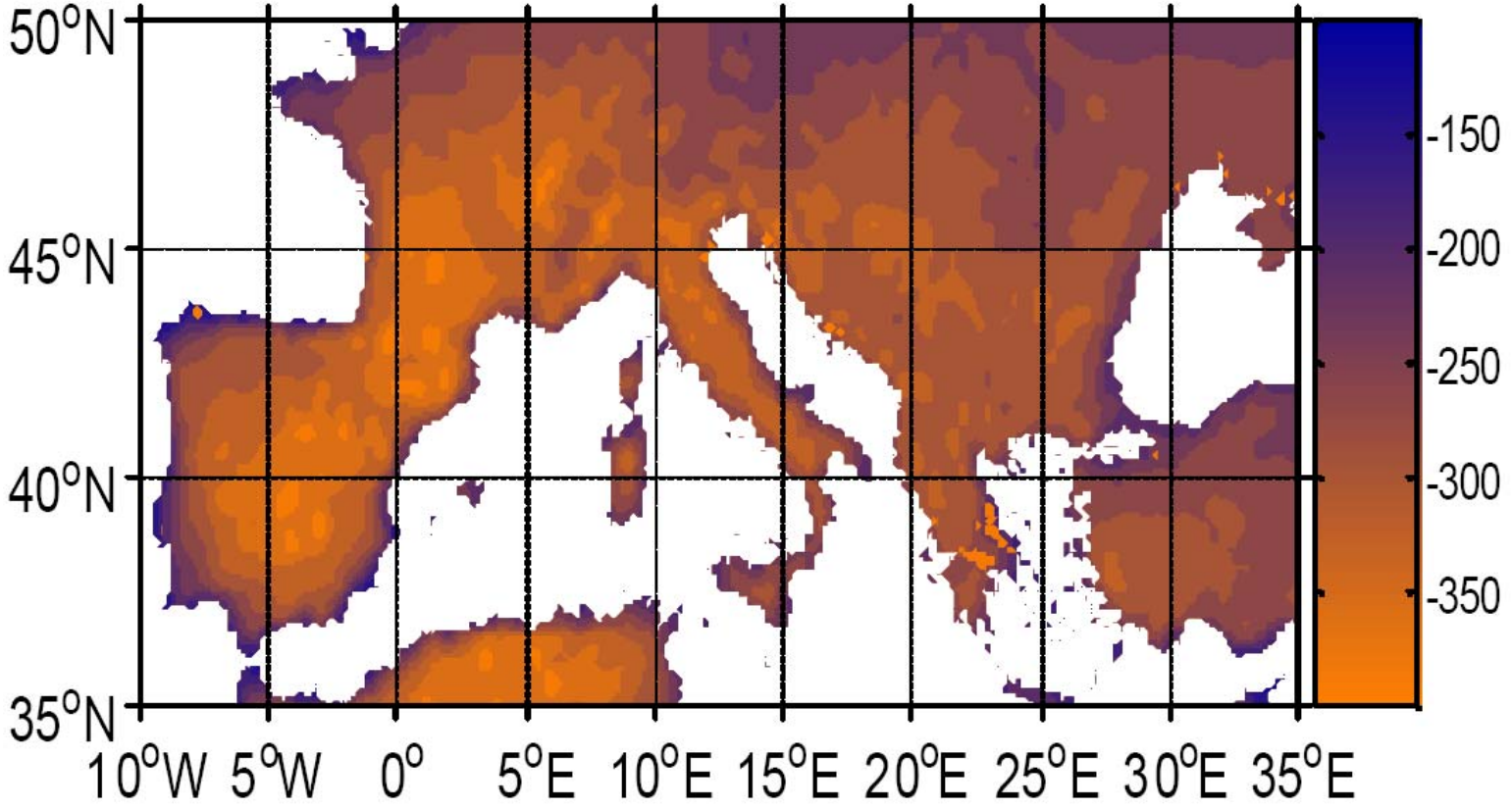
Zierl et al. 2004 (in prep).

Observed changes in seasonality of discharge
*River **Savinja in Slovenia***



Mean change in winter potential water availability (mm) over the Mediterranean region for the A2 emissions scenario for 2071-2100 compared with 1961-1990





Mean change in summer potential water availability over the Mediterranean region for the A2 emissions scenario for 2071-2100 compared with 1961-1990

CONCLUSIONS

- The Alps are particularly vulnerable to climate change and already suffering from higher increases in temperature than the European average.
- Climate change is already affecting discharge of alpine rivers and is increasing natural hazards.
- It leads to economic losses in winter tourism especially in areas at lower altitudes.
- These trends are projected to be exacerbated under enhanced climate change.

CONCLUSIONS

- The water regime in alpine high mountains will undergo fundamental change.
- Because the Alps are the primary source for such major rivers as the Rhine, Danube, Rhone, … the impact of reduced mountain precipitation would be felt far beyond mountainous regions themselves
- The average flow of alpine rivers will increase in winter and significantly decrease in summer – reduction in water availability for industry, agriculutre and domestic use
- Flash floods would probably increase significantly
- Drastic change in climate could significantly increase the existing danger of mudflows

CONCLUSIONS

- By 2030 from 20 to 75% of today's glaciers (30 to 70% in terms of area) will disappear (by 2100 from 60 to 95% and 45 to 90% in terms of area)
- The guaranteed snowfall altitude would rise from 1300 to about 1300 to 1600 m by 2030. Elevation of a reliable snow cover will rise between 200 and 400 m from about 1300 m today to 1500 m to 1700 m at the end of the 21st century.
- Retreat and upward shift of the permafrost will cause

  - a widespread reduction in stability of formerly glacierized or perennially frozen slopes.

  - increased risk of land-slides and sediment loads in rivers and lakes

  - destabilisation of infrastructure in high altitudes

  - increased need for additional avalanche barriers and flood protection facilities

Thank you for your attention