Snow processes and their drivers in Sierra Nevada (Spain), and implications for modelling.

M.J. Polo, **M.J. Pérez-Palazón,** R. Pimentel, J. Herrero

Granada,02 de November 2016

SECTIONS

1. Introduction
2. Study Site: Sierra Nevada
3. Physical model structure
4. Remote sensing
5. Examples

MOUNTAINOUS SITE: SNOW

- **Study of spatiotemporal evolution of the**
  - variability of the atmospheric agents
  - availability of water resources
- **Heterogenous medium on different sp**

MEDITERRANEAN CLIMATE

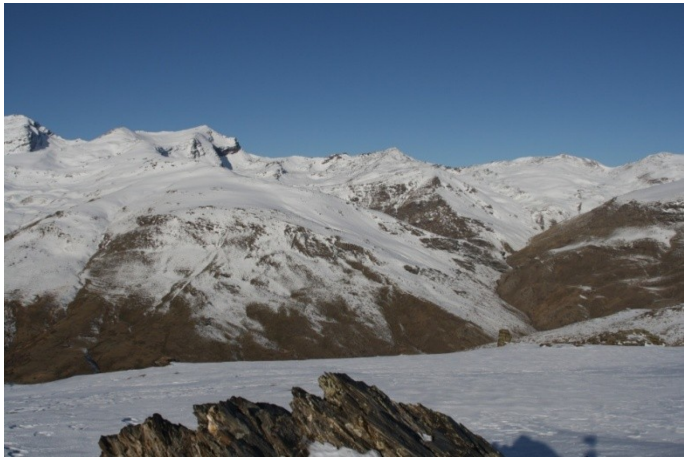
•High level of solar energy income throughout the year

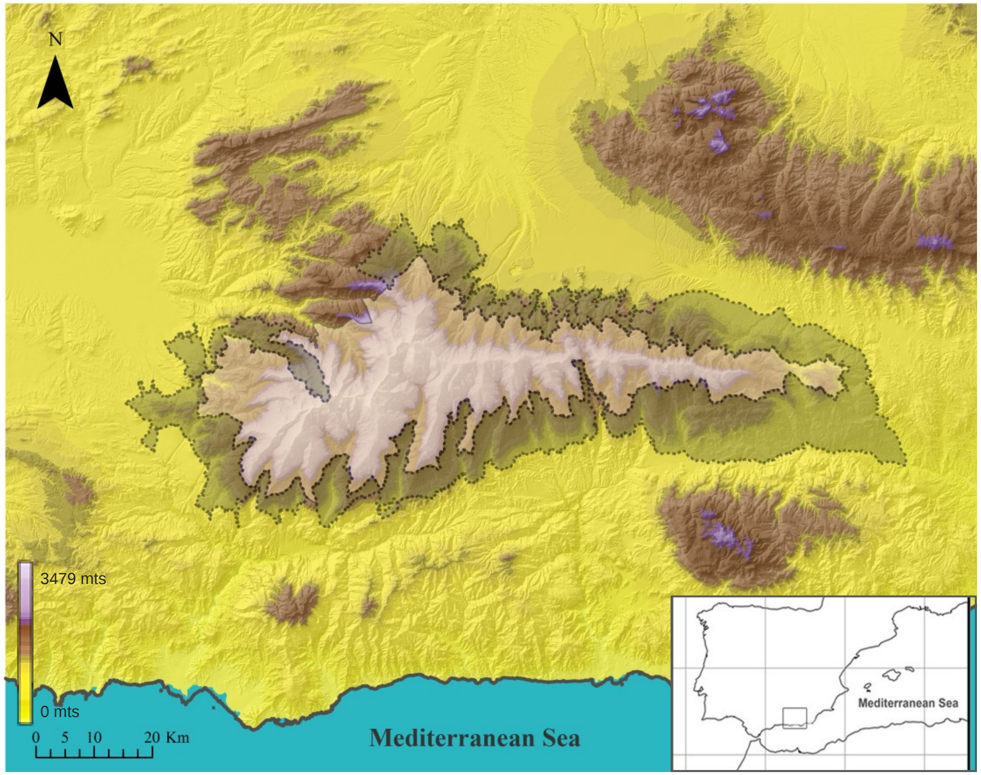
•Variable character with lower precipitation

HYDROLOGICAL REGIME

Extreme & Highly variable

High importance of WATER RESOURCES





Physical Descriptors

- Latitude: 37ºN
- Elevation: 3500 masl
- Distance to the sea (40
- Long (60 km)
- Altitudinal gradients
- Great differences

th

Vegetation

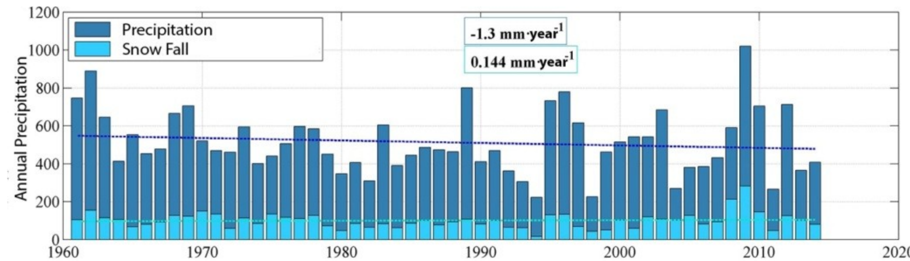
- Typical high mountain vegetation
- The scarcity of trees in areas with snow

Meteorological Features

- **High mountain + semiarid climate**
- Strong variability between years
    - Anual Precipitation
    - Average Temperature in snow season (-5,+5 ºC)
- Complete summer melt
- Several melting cycles per snow season

METEOROLOGICAL DATA (year)			
	Mean	Max	Min
Precipitation (mm)	490.8	888.6	222.5
Temp daily mean (ºC)	12.6	28.9	-3.4

Meteorological Features

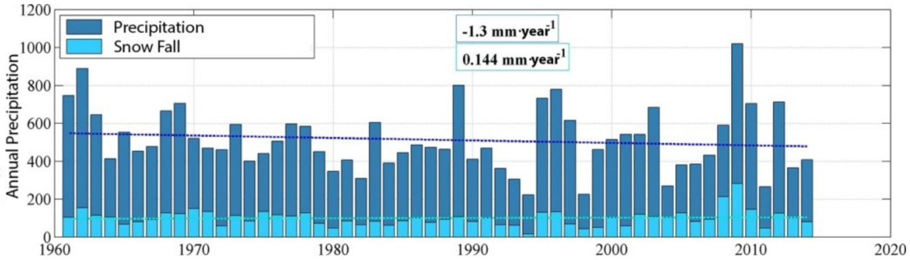


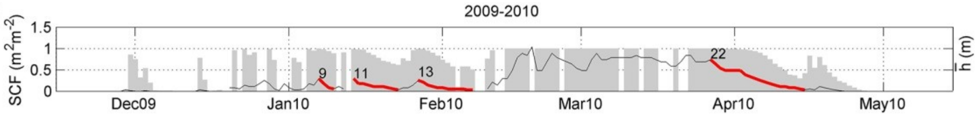
- High mountain + semiarid climate
- **Strong variability between years**
  - Anual Precipitation
  - Average Temperature in snow season (-5,+5 ºC)
- Complete summer melt
- Several melting cycles per snow season

METEOROLOGICAL DATA (year)			
	Mean	Max	Min
Precipitation (mm)	490.8	888.6	222.5
Temp (ºC) daily mean	12.6	28.9	-3.4

Meteorological Features

- High mountain + semiarid climate
- Strong variability between years
  - Anual Precipitation
  - Average Temperature in snow season (-5,+5 ^{0}C)
- **Complete summer melt**
- **Several melting cycles per snow season**

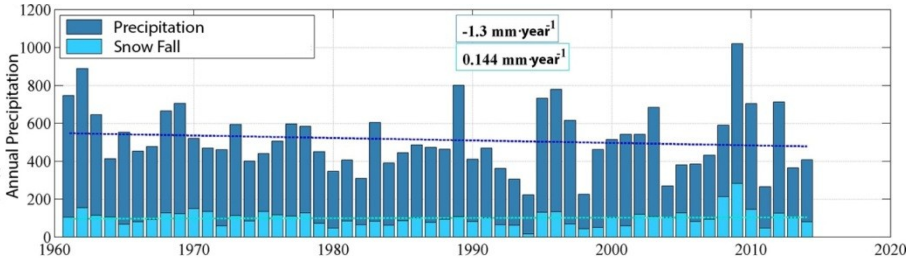


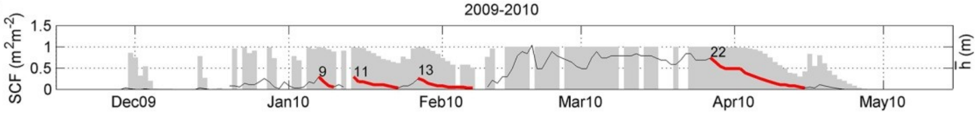


METEOROLOGICAL DATA (year)			
	Mean	Max	Min
Precipitation (mm)	490.8	888.6	222.5
Temp **daily mean** **(ºC)**	12.6	28.9	-3.4

Meteorological Features

- High mountain + semiarid climate
- Strong variability between years
  - Anual Precipitation
  - Average Temperature in snow season (-5,+5 ^{0}C)
- **Complete summer melt**
- **Several melting cycles per snow season**
- **Sunny days dominant even during winter**





Special protection

- UNESCO Biosphere Reserve (1986)
- Natural Park (1989) and National Park (1999) (1750 /862 Km2)

SNOW MODEL

HYDROLOGICAL MODELS
(Physical & Distributed)
Calibration & Validation

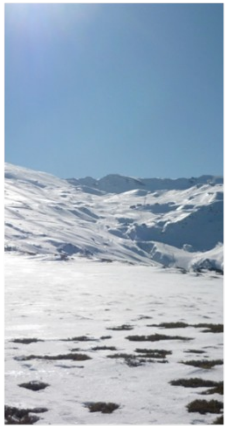
Mass and Energy Balance

SATELLITE REMOTE SENSING

NOAA , daily 1 km x 1km
MODIS, daily, 250 m x 250 m
Landsat, 16-day, 30 m x 30 m

SPATIAL RESOLUTION
limiting factor

LANDSAT IMAGERY



TERRESTRIAL PHOTOGRAPHY

IMAGES	SATELLITE	TERRESTRIAL
Spatial Resolution	Fixed	Variable
Temporal Resolution	Fixed	Variable

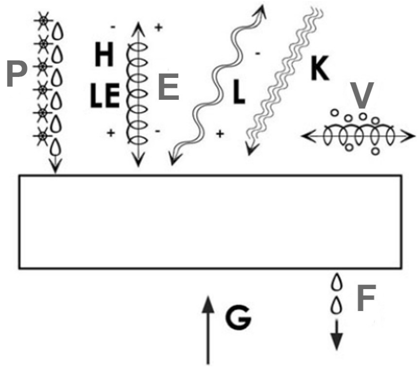
Preproccesing

Snow spatial extent

SNOW MODEL

- **WiMMed:** Physically based and totaly distributed hydrological model

- **Develop for Mediterranean regions:** Take into account the specific characteristic of the snow in semiarid areas



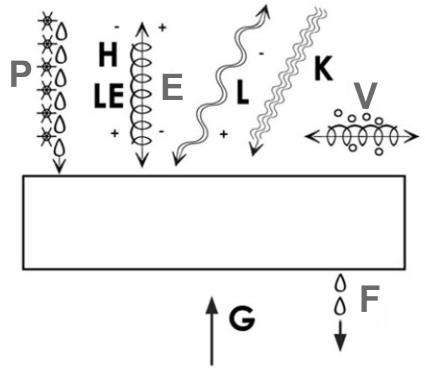
$$\frac{dSWE}{dt} = R - E - F + W$$

$$\frac{dU}{dt} = K + L + H + G + U_R - U_E - U_F + U_W$$

SNOW MODEL

- **WiMMed:** Physically based and totaly distributed hydrological model
- **Develop for Mediterranean regions:** Take into account the specific characteristic of the snow in semiarid areas

- Spatial resolution: 30x30m
- Temporal resolution : hour
- Calibration and validation
  - in-situ measurements
  - Remote sensing information

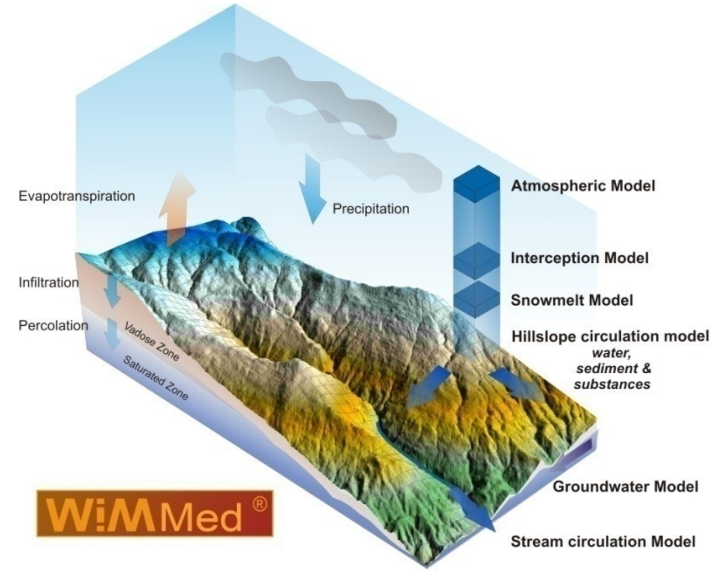


$$\frac{dSWE}{dt} = R - E - F + W$$

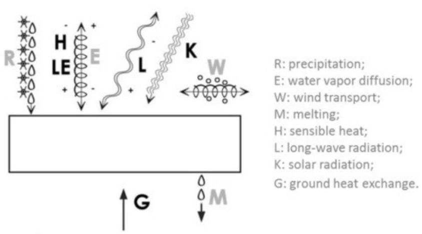
$$\frac{dU}{dt} = K + L + H + G + U_R - U_E - U_F + U_W$$

SNOW MODEL

- **WiMMed:** Physically based and totaly distributed hydrological model
- **Develop for Mediterranean regions:** Take into account the specific characteristic of the snow in semiarid areas

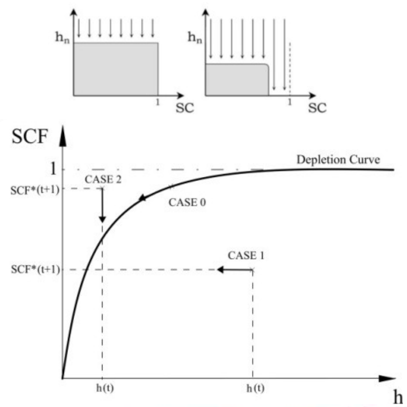


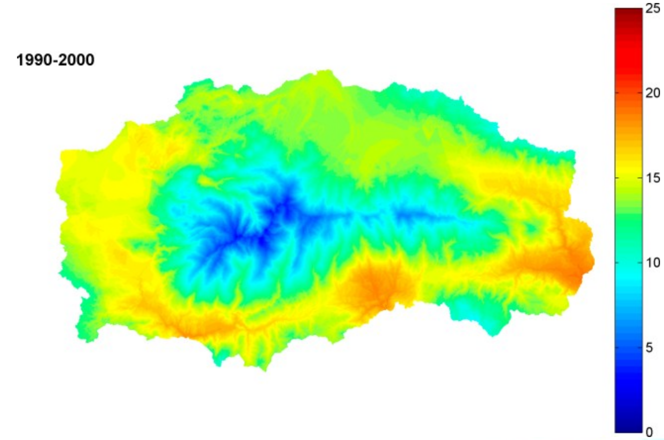
Distributed modelling



$$\frac{dm}{dt} = R - E + W - M$$

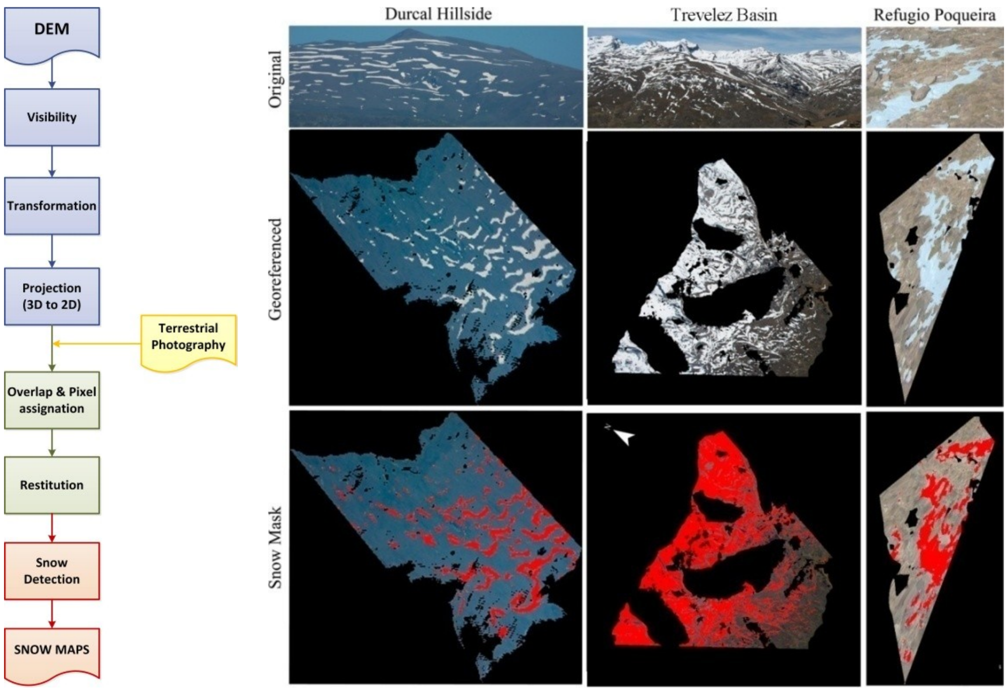
$$\frac{dU_n}{dt} = K + L + H + G + U_R - U_E + U_V - U_F$$





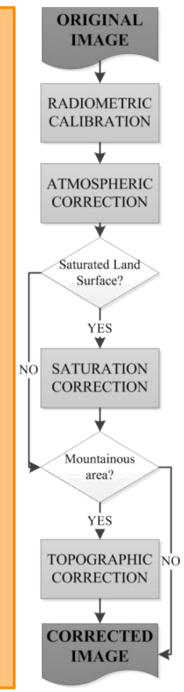
Using different remote sensing data to improve snow cover area representation

TERRESTRIAL PHOTOGRAPHY



LANDSAT TM & ETM+

CORRECTIONS



SNOW COVER FRACTION MAPS

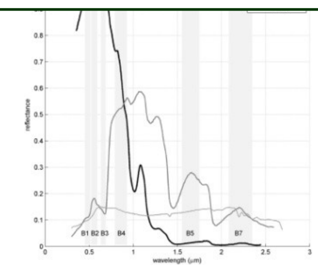
SNOW DETECTION

$$NDSI = \frac{(TM2 - TM5)}{(TM2 + TM5)}$$

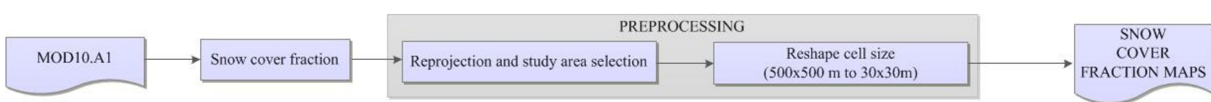
$$NDSI > 0.15$$

$$TM1 > 0.06$$

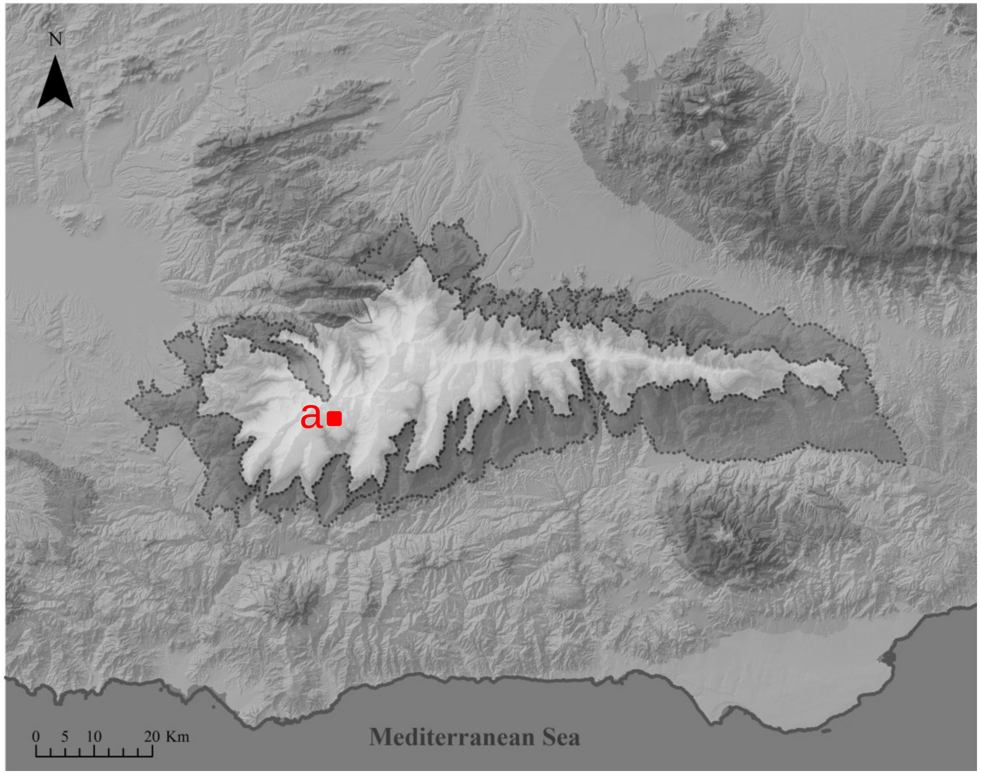
SPECTRAL MIXTURE



MODIS (MOD10.A1)



Using different remote sensing data to improve snow cover area representation

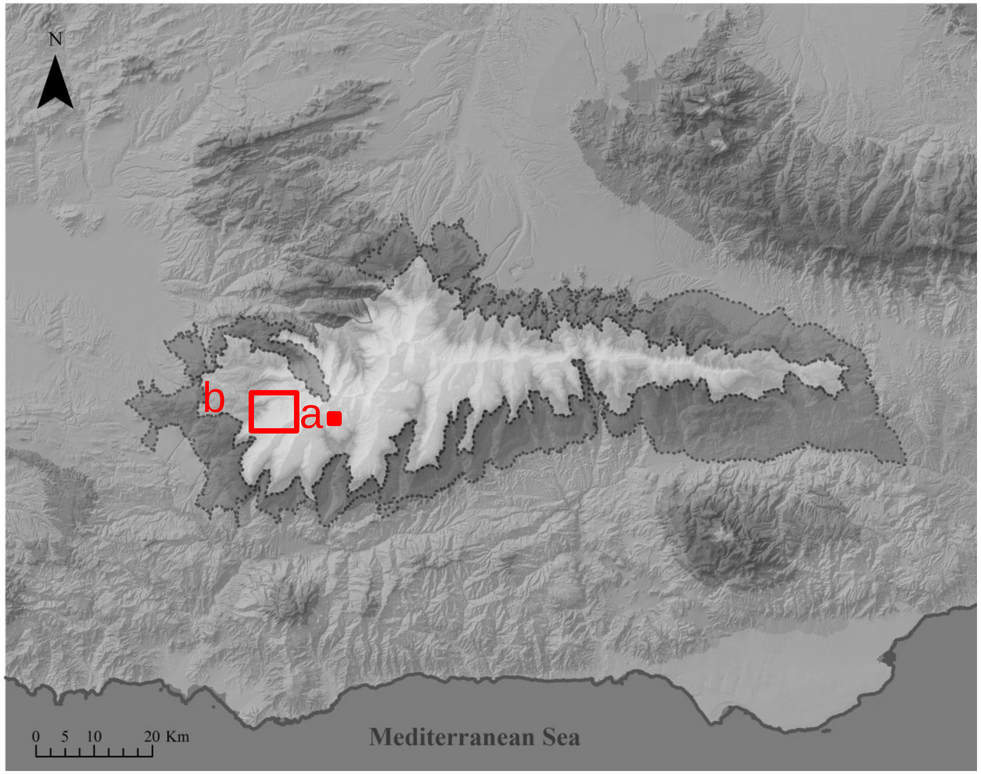


a) DETAIL SCALE

Terrestrial Photography

	a	b	c
Study site	**REFUGIO POQUEIRA**	**CABALLO HILLSIDE**	**SIERRA NEVADA**
Area	~900 m^2	~2500 m^2	~4585 Km^2

Using different remote sensing data to improve snow cover area representation



a) DETAIL SCALE

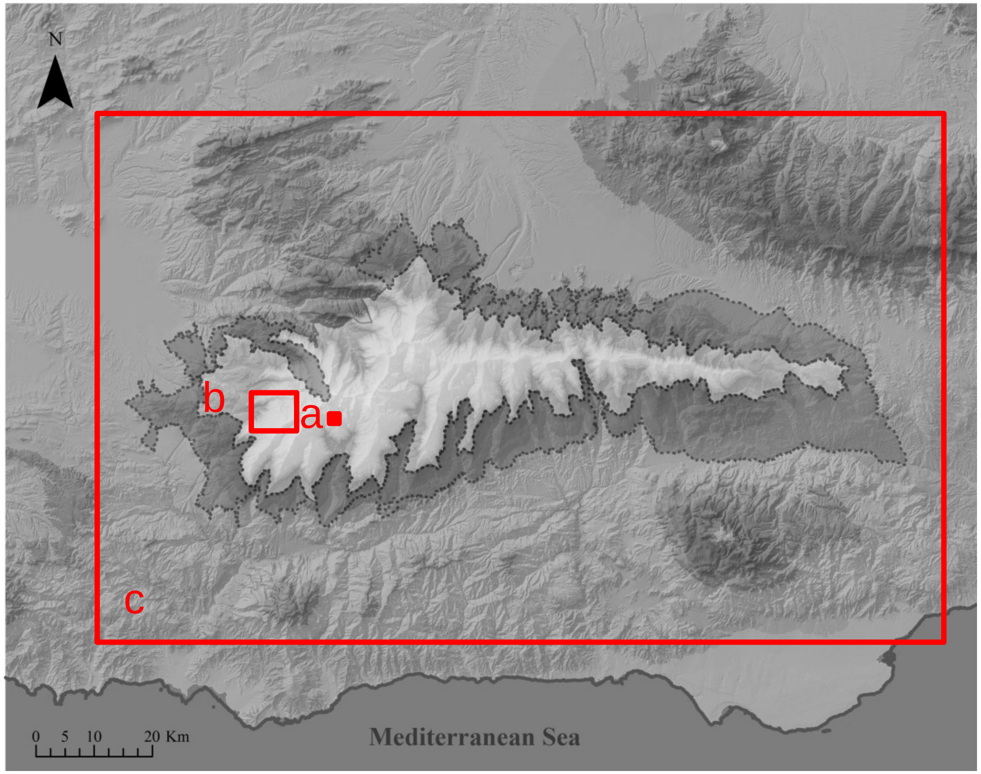
Terrestrial Photography

b) HILLSIDE SCALE

Terrestrial Photography

	a	b	c
Study site	**REFUGIO POQUEIRA**	**CABALLO HILLSIDE**	**SIERRA NEVADA**
Area	~900 m^2	~2500 m^2	~4585 Km^2

Using different remote sensing data to improve snow cover area representation



a) DETAIL SCALE

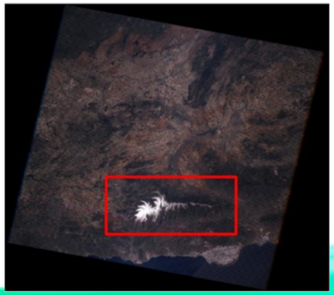
Terrestrial Photography

b) HILLSIDE SCALE

Terrestrial Photography

c) WATERSHED SCALE

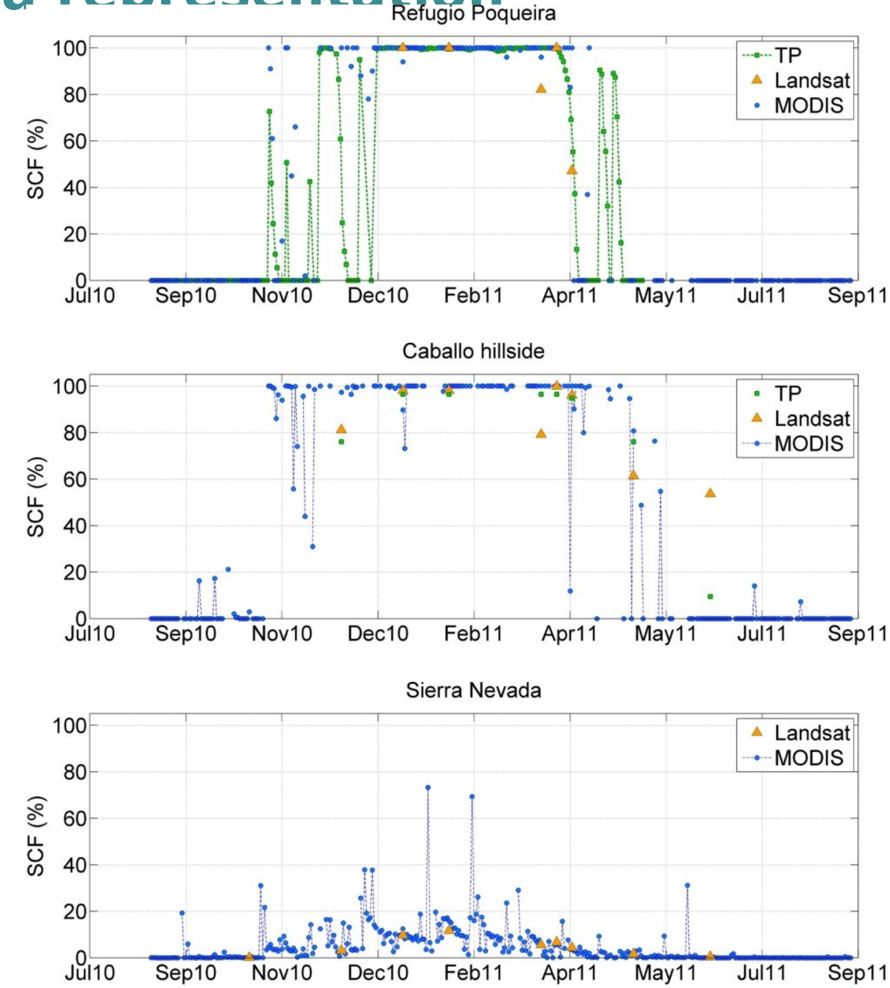
Landsat imagery



	a	b	c
Study site	**REFUGIO POQUEIRA**	**CABALLO HILLSIDE**	**SIERRA NEVADA**
Area	~900 m^2	~2500 m^2	~4585 Km^2

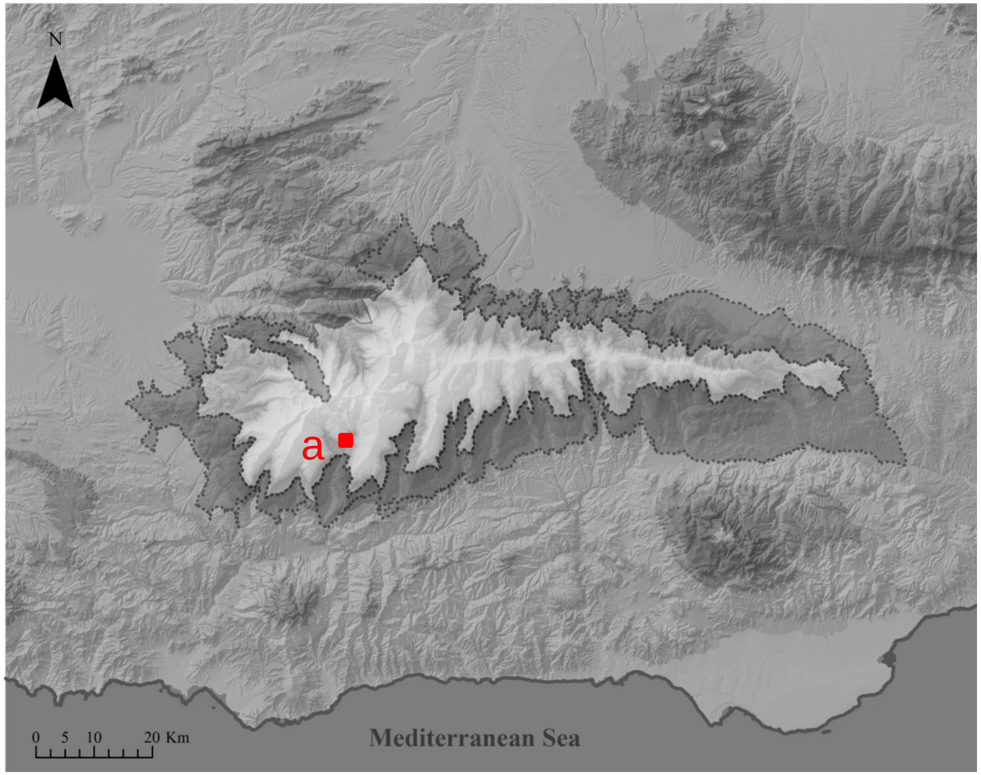
Using different remote sensing data to improve snow cover area representation

AVERAGE ANALYSIS



- Hillslope scale
  - TP constitute de best technique
  - TP is able to reproduce the interaction between small topography and snow
- Watershed scale
  - MODIS overestimate Landsat snow cover area
  - TP is not a real option

MODELING + REMOTE SENSING AT DIFFERENT SCALES



a) DETAIL SCALE

Terrestrial
Photography
+
Snow Modelling

	a	b	c
Study site	**REFUGIO POQUEIRA**	**TREVELEZ HILLSIDE**	**SIERRA NEVADA**
Area	~900 m^2	~320 Km^2	~4585 Km^2

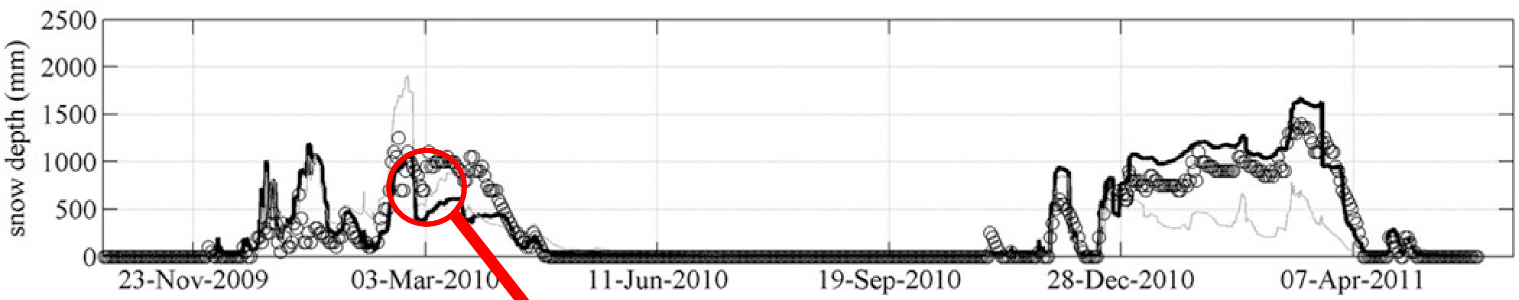
MODELING + REMOTE SENSING: Detail scale

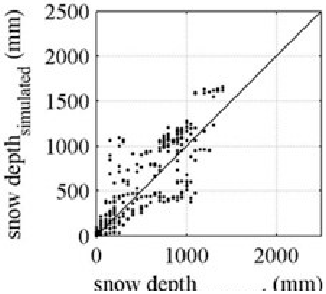
- Data assimilation schemes

$$x^a = x^f + K\,(d - Hx^f)$$

Kalman Filter

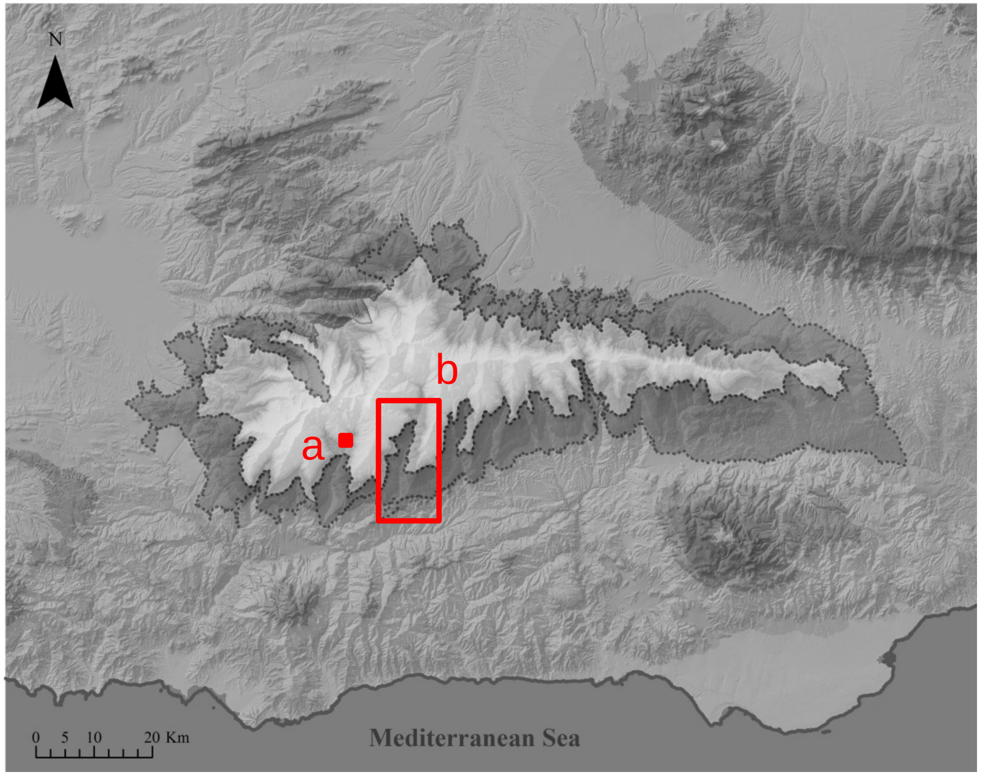
$$K = P^f H^f (HP^f H^T + R)^{-1}$$





WIND

MODELING + REMOTE SENSING AT DIFFERENT SCALES



a) DETAIL SCALE

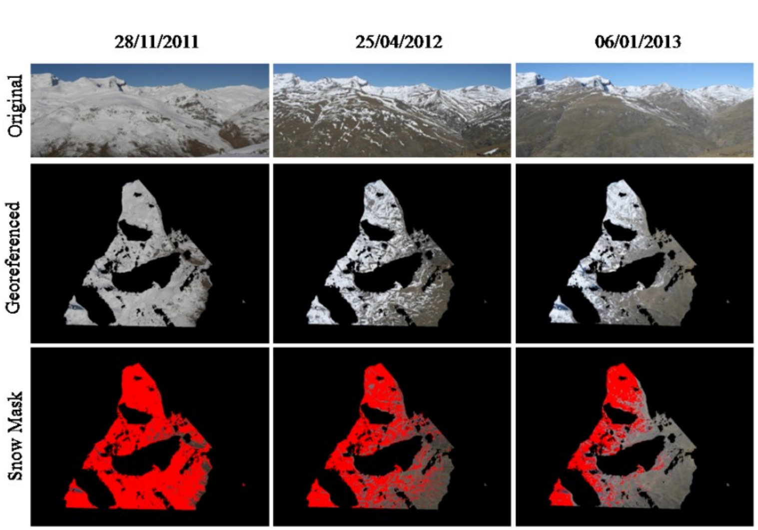
Terrestrial Photography + Snow Modelling

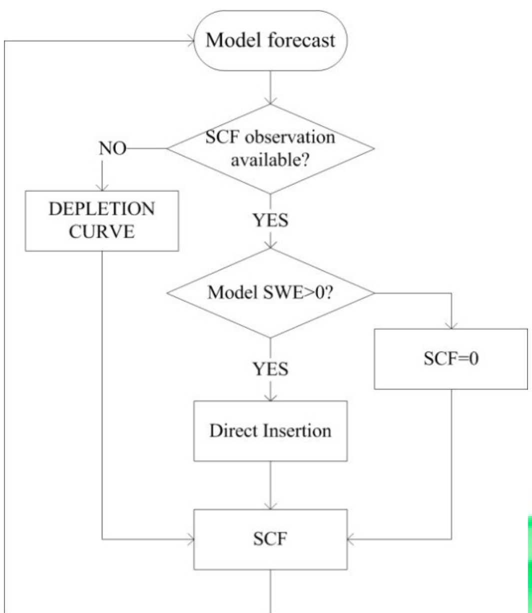
b) HILLSIDE SCALE

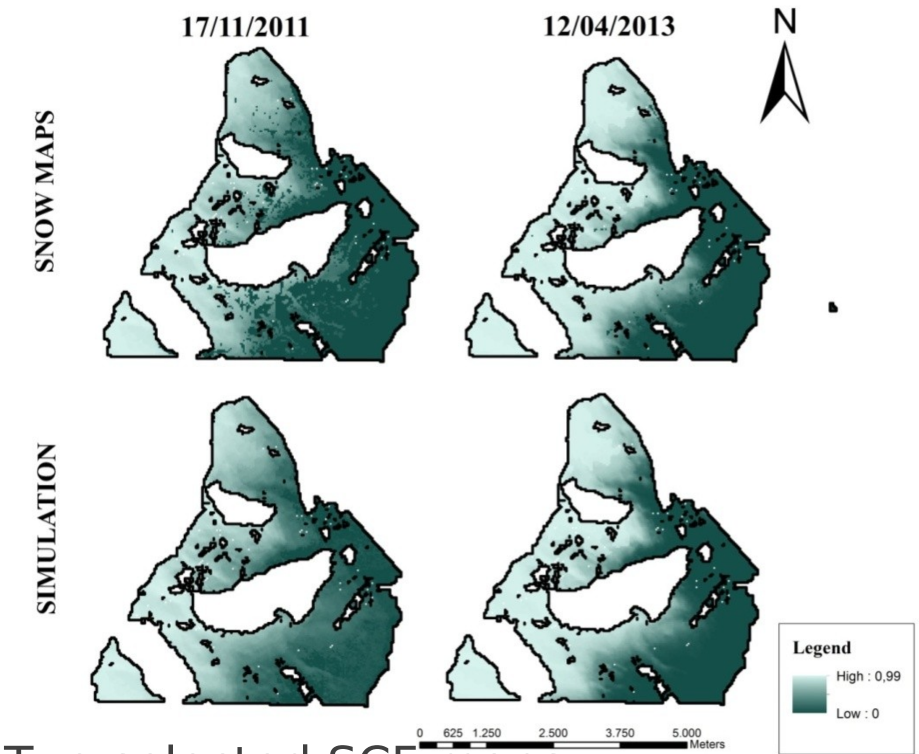
Terrestrial Photography + Snow Modelling

	a	b	c
Study site	**REFUGIO POQUEIRA**	**TREVELEZ HILLSIDE**	**SIERRA NEVADA**
Area	~900 m^2	~320 Km^2	~4585 Km^2

MODELING + REMOTE SENSING: Hillside scale





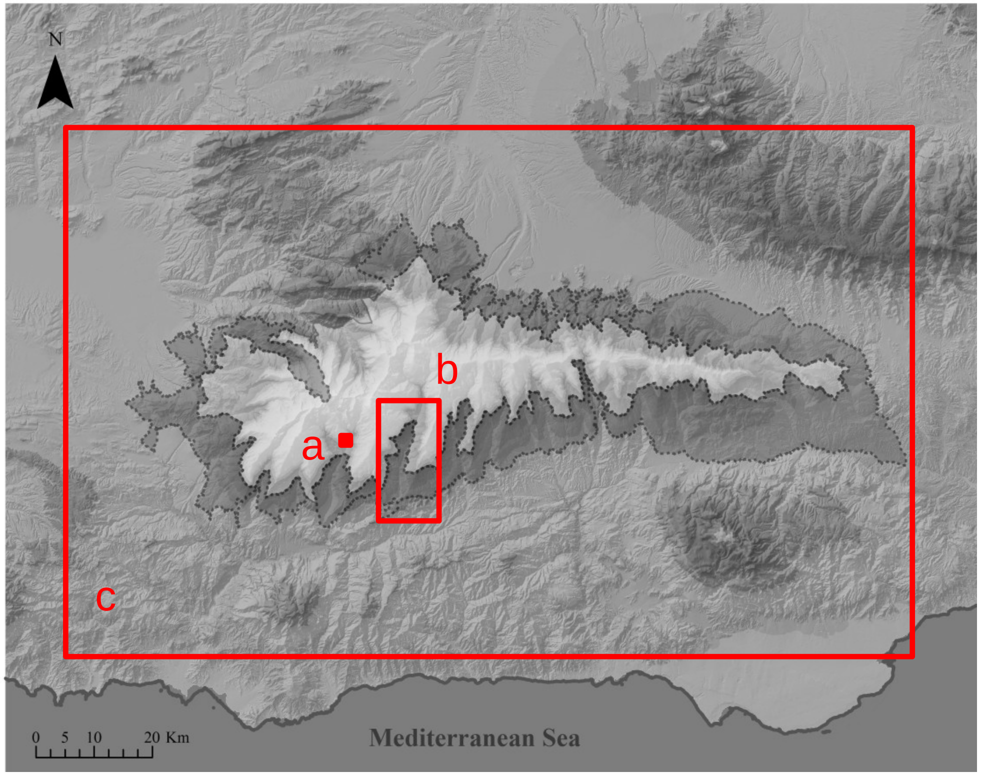


- Two selected SCF maps
- Small different are due to a high influence of the factors not included in the model

WIND TRANSPORT

- Not very large difference which

MODELING + REMOTE SENSING AT DIFFERENT SCALES



a) DETAIL SCALE

Terrestrial Photography + Snow Modelling

b) HILLSIDE SCALE

Terrestrial Photography + Snow Modelling

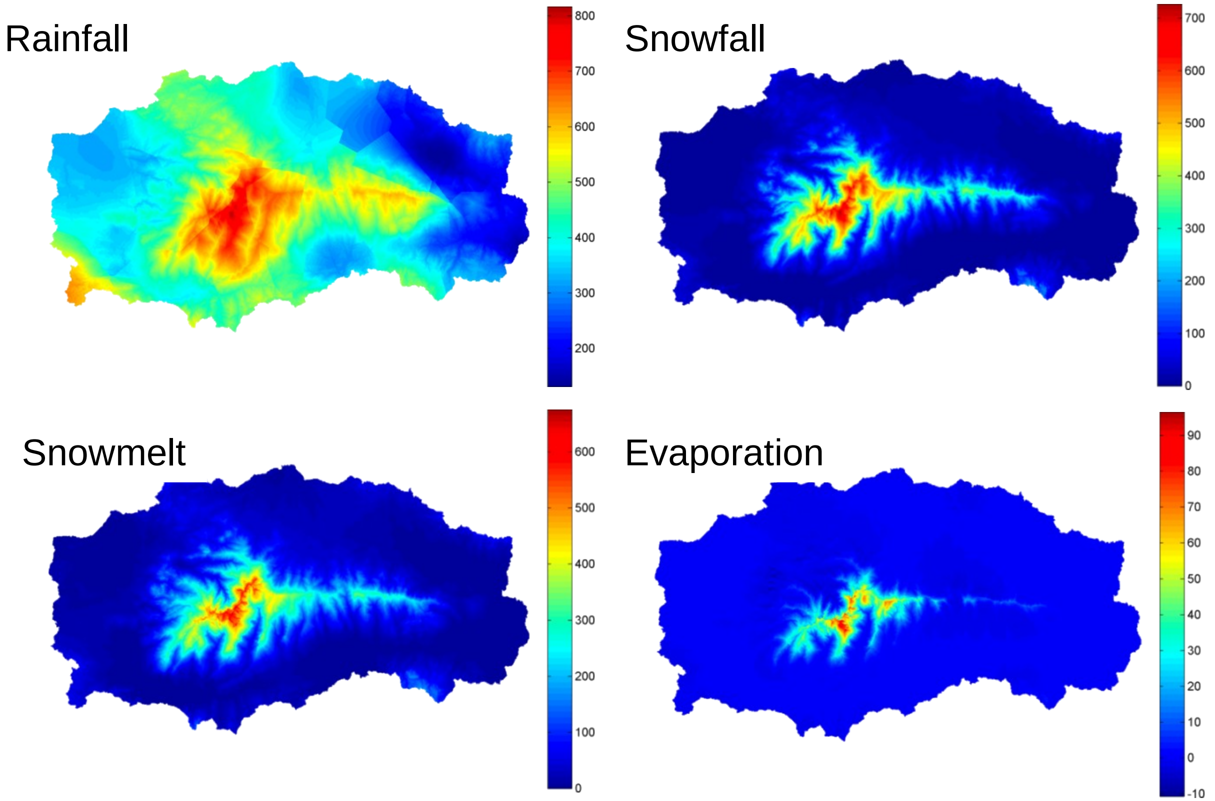
c) WATERSHED SCALE

Snow Modelling

	a	b	c
Study site	**REFUGIO POQUEIRA**	**TREVELEZ HILLSIDE**	**SIERRA NEVADA**
Area	~900 m^2	~320 Km^2	~4585 Km^2

MODELING : Watershade scale.

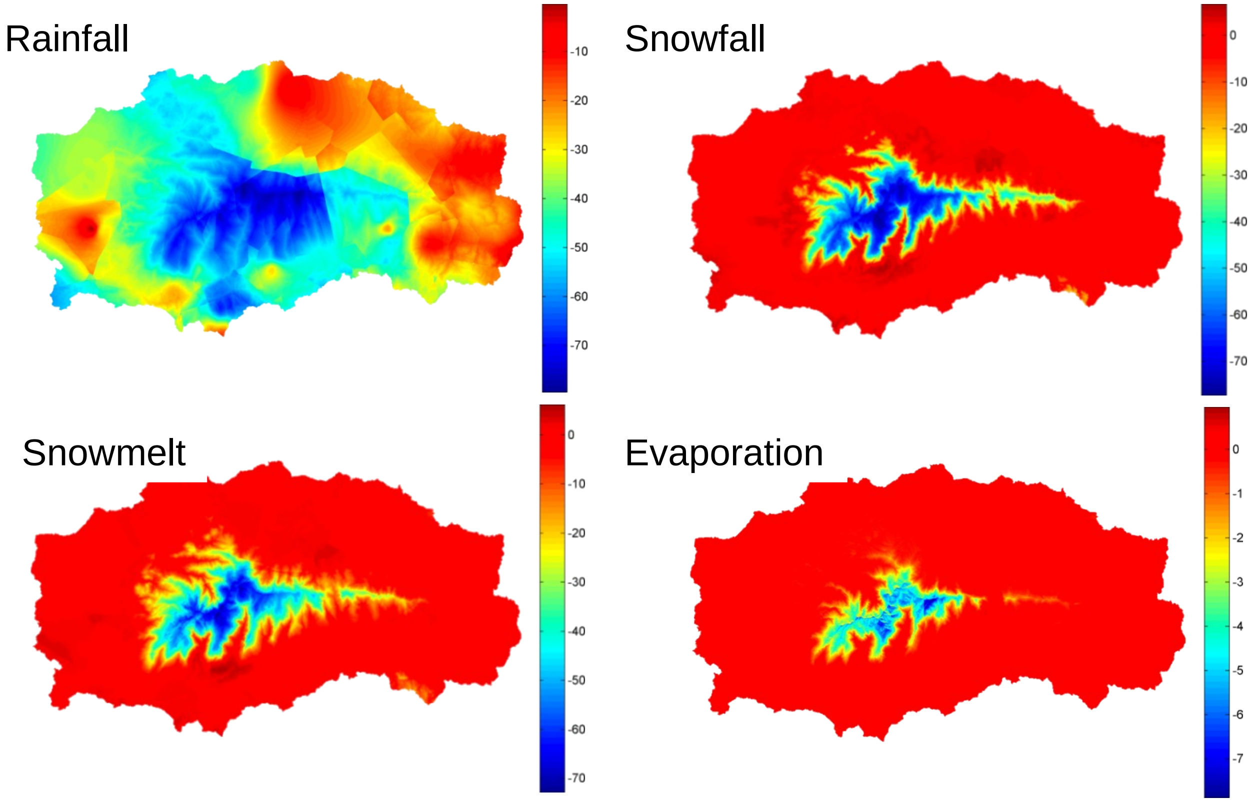
- **Study period:** 2000-2010
- **Distributed snow modeling:** Mean values



- Two differents areas in all selected variables. (Permanent and sporadic)
- Zoning between the values and height.
- High correlation between values of precipitation and snowfall (r=0.98)

MODELING : Watershade scale.

- **Study period:** 2000-2010
- **Distributed snow modeling:** Trend values



- Decreasing values trends
- Rainfall always has negative values , being most pronounced in heights.
- Similar, the case of the snowfall.
- The correlation between snowmelt and precipitations high

- **On the Mediterranean variability of watershed processes**
  Spatial variability/temporal resolution
  Need of physical modelling for scenarios simulation

- **On the physical distributed modelling approach**
  Extreme gradients and sudden changes in energy and water balance modelling.
  Simultaneous calculation at different time scales along the watershed.
  Good agreement degree of results, despite the possibly high number of parameters
  Snow transport by wind, energy fluxes trends, and soil sensible heat flux contribution
  Spatial scales issues by terrestrial photography data
  Implementation of the wind transports
  The importance of the evaposublimitation in the model

- **On the applications for water resource planning**
  Change of soil use scenarios, climate change scenarios effects,....
  Uncertainty “flow” from the meteorological agents to the state variables through the equations

Thank you for your attention

ACKNOWLEDGEMENT:

This work has been supported by the Spanish Ministry of Science and Innovation (Research Project CGL 2014-58508-R, “Global monitoring system for snow areas in Mediterranean regions: trends analysis implications for water resource management in Sierra Nevada“) and the Spanish Ministry of Agriculture, Food and Environment (Biodiversity Foundation, Project “Influence of global change on ecosystem services related to hydrology in the Sierra Nevada National Park”). The present work was partially developed within the framework of the Panta Rhei Research Initiative of the International Association of Hydrological Sciences (IAHS) (Working Group Water and energy fluxes in a changing environment). And the Agency of Environment and Water for t

GOBIERNO DE ESPAÑA
MINISTERIO DE AGRICULTURA, ALIMENTACIÓN Y MEDIO AMBIENTE
Fundación Biodiversidad
GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
UNIÓN EUROPEA
FONDO EUROPEO DE DESARROLLO REGIONAL
UNA MANERA DE HACER EUROPA
Panta Rhei Everything Flows
SIERRA NEVADA
PARQUE NACIONAL
PARQUE NATURAL