Estimation of daily Snow Cover Area (SCA) in periods without available satellite information by using CELLULAR AUTOMATA.

A PRELIMINARY ASSESSMENT

E. Pardo, AJ. Collados, **D. Pulido**
(Researcher Fellow, Spanish Geological Survey, IGME)

COST Action ES1404:
A Euroepan network for a harmonised monitoring of snow for the benefit of climate change scenarios, hydrology and numerical weather prediction

INTRODUCTION (MOTIVATION): **Practical interest** of knowing SCA evolution

- **SCA** variable ⇒ operational modelling in **METEOROLOGY & HYDROLOGY**

- SCA REMOTELY SENSED observations ⇒ Most investigated measurements in hydrology (Liu et al., 2012)⇒ **SCA products** with **≠ s&t resolution** & **historical period** (eg. MODIS, NOAA)

- **ISSUE**: the estimation of SCA in periods without satellite information ⇒
  - **Estimation** of historical periods without data (eg. cloudy days, low temporal resolution satellite, short available historical periods)
  - **Prediction** of future values (data assimilation techniques)

INTRODUCTION (MOTIVATION): Practical interest of knowing SCA evolution

TECHNIQUES TO ESTIMATE SCA (IN PERIODS WITHOUT DATA):

❑ DETERMINISTIC MODELS

- CONCEPTUAL MODELS: Eg. SNOWMELT RUNOFF MODEL (Martinec *et al.,* 1994); DEGREE-DAY METHODS [empiric approach very employed (Hock, 2003)]. HYBRID-DEGREE-DAY METHODS = VARIABILITY (*s&t*
- ENERGY BALANCE MODELS: (eg. *Eg. Plüss, 1997; Herrero, 2007*)

❑ NON-DETERMINISTIC MODELS (↑interest in cases with ↓ nº data)

- REGRESSION TECHNIQUES (Richer et al., 2012; Mir et al., 2015)
- ARTIFICIAL NEURAL NETWORKS (Hou and Huang, 2014)
- ***CELLULAR AUTOMATA*** (Pardo-Igurquiza et al., 2016; Rusakov et al. 2014; Leguizamón, 2006)

INTRODUCTION (MOTIVATION): Review
Cellular Automata technique

Cellular Automata TH HISTORY & GENERAL CONCEPTS:

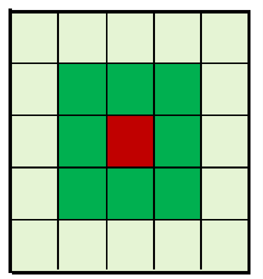
- Neumann & Ulam, 1940's ⇒ COMPLEX, DYNAMIC, & DISCRETE (s&t) model SYSTEMS (computational TH, maths, physics, biology & microstructure modelling)

$$S^i(t)=f(S^i(t-1), S^j(t-1), TransitionRules)$$

$S^i(t)$ = state of pixel i; $S^i(t-1)$ =previous state of pixel i; $S^j(t-1)$ =previous state of pixel j)

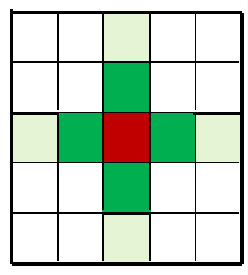
STEPs we should follow to define a CA = REGULAR GRID OF CELLS:

- The state in each cell = finite nº of possible states (k) (nº or properties)
- Neighbourhood pattern= set of cells influencing on new cell state taking into account a proximity pattern.



Neumann (only)
neighbourhood

Extended Neumann
neighbourhood (als)



Moore (only)
neighbourhood

Extended Moore (also)
neighbourhood

- Transition rules = "If" rules (explanatory variables) to approach system dynamic

Cellular Automata HISTORY & GENERAL CONCEPTS

Classic Example of CA application. THE GAME OF LIFE (Conways´s Rules)

Evolution of living organisms = by a grid of cells that can live, die or multiply depending on some transition rules

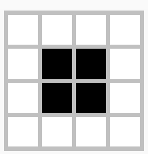
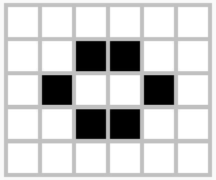
1) THE RULES

- For a space that is 'populated':
Each cell with one or no neighbours dies, as if by solitude.
Each cell with four or more neighbours dies, as if by overpopulation.
Each cell with two or three neighbours survives.

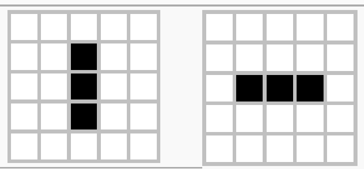
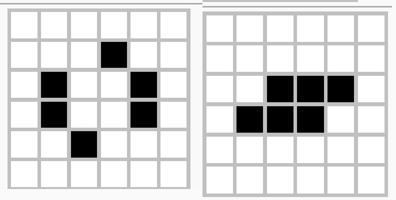
- For a space that is 'empty' or 'unpopulated'
Each cell with three alive neighbours becomes populated.

2) THE **INITIAL PATTERN** CONSTITUTES THE ***SEED*** OF THE SYSTEM

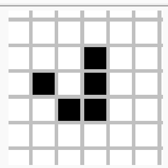
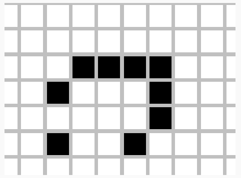
Still life systems

Block	
Beehive	

Oscilator systems

Blinker (period 2)	
Toad (period 2)	

Spaceships systems

Glider	
Lightweight spaceship (LWSS)	

https://en.wikipedia.org/wiki/Conway%27s_Game_of_Life

(HTTPS://EN.WIKIPEDIA.ORG/WIKI/CONWAY%27S_GAME_OF_LIFE)

INTRODUCTION (MOTIVATION): Review
Cellular Automata technique

Applications of Cellular Automata in SNOW modelling

- **Snow Avalanches** (eg. Kronholm and Birkeland 2005, Faillettaz et al., 2004)

- **Crystal Growth** (Ning et al., 2007)

- **SCA evolution** (Pardo-Igurquiza et al., 2016; Rusakov et al., 2014; Leguizamón, 2006)

Instituto Geológico y Minero de España

METHOD and MATERIAL: CA application = SIERRA NEVADA MOUNTAIN

- ❑ **Location** 36º55'-37º15'N, 2º56'-3º38' West;

+2000m S≈ 550 km^2; <40 kms snow areas - sea

- ❑ **Highest peaks:**

Mulhacén	3,482 m
Veleta	3,393 m
Alcazaba	3,371 m

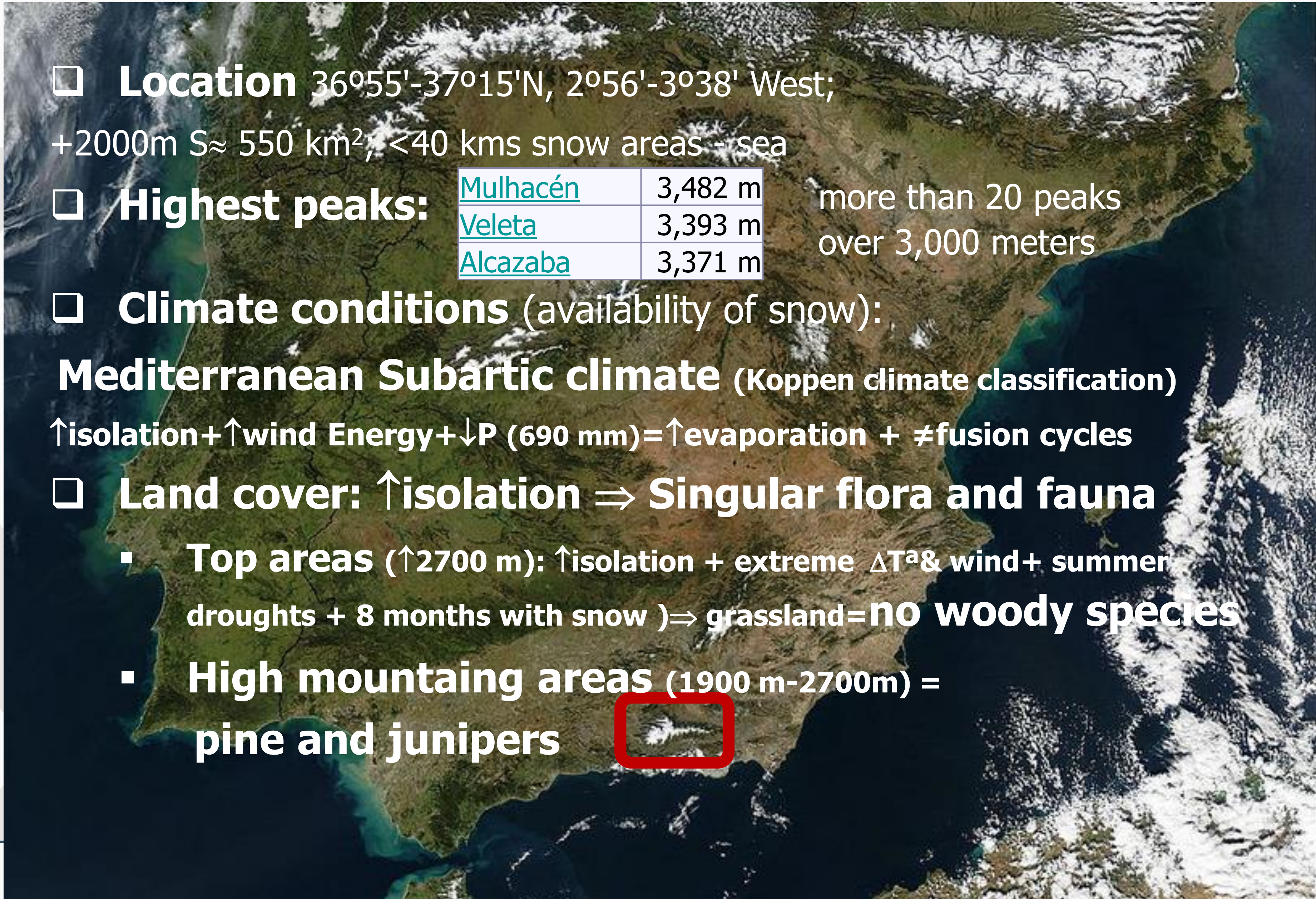
more than 20 peaks over 3,000 meters

- ❑ **Climate conditions** (availability of snow):

Mediterranean Subartic climate (Koppen climate classification)

↑isolation+↑wind Energy+↓P (690 mm)=↑evaporation + ≠fusion cycles

- ❑ **Land cover: ↑isolation ⇒ Singular flora and fauna**
  - **Top areas (↑2700 m): ↑isolation + extreme ΔTª& wind+ summer droughts + 8 months with snow)⇒ grassland=no woody species**
  - **High mountaing areas (1900 m-2700m) = pine and junipers**



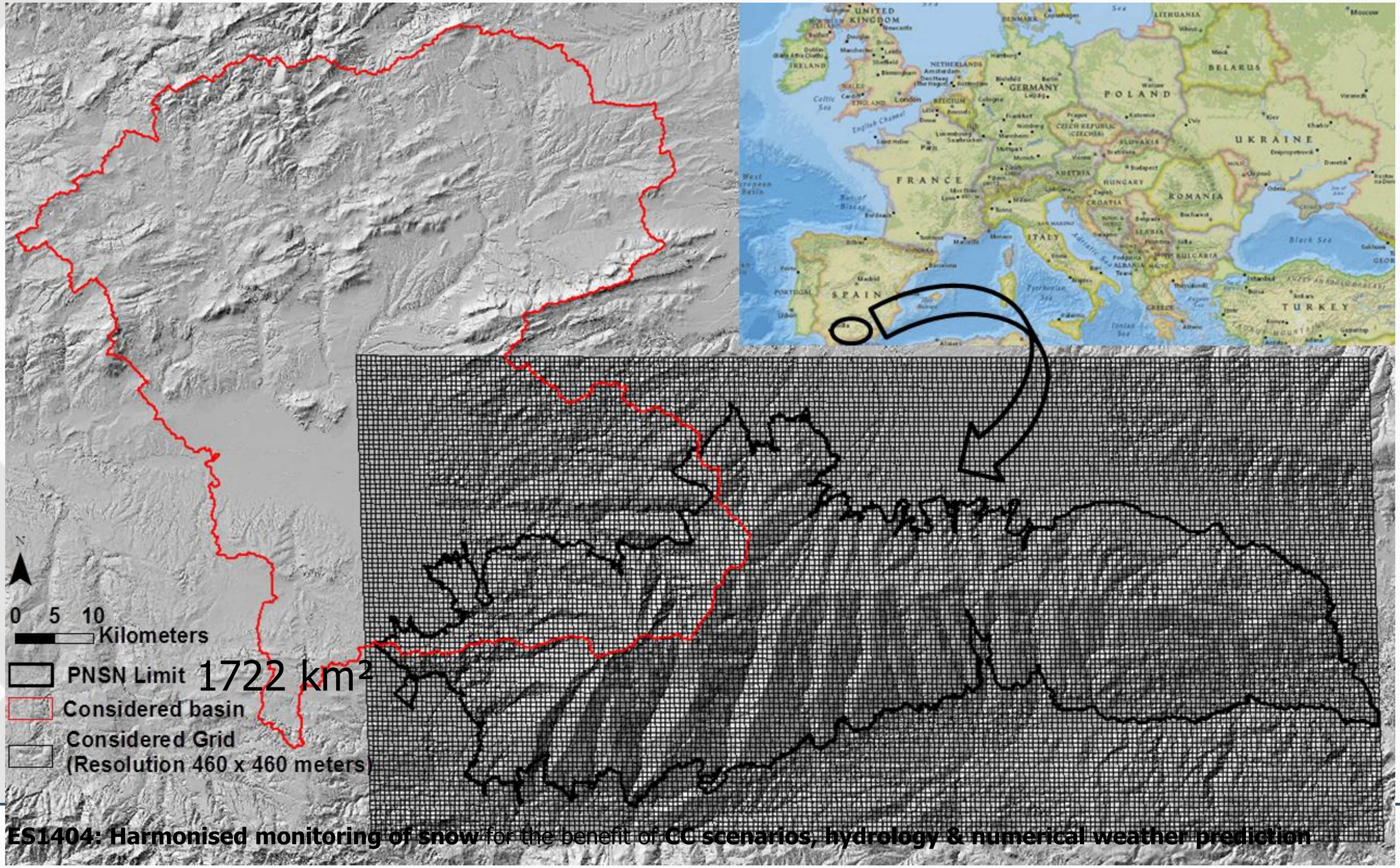
METHOD and MATERIAL: CA technique application (Sierra Nevada Mountain)

CA to simulate **daily SCA in S. Nevada**

$S_i(t)=f(S_i(t-1), S_j(t-1), TransitionRules)$

1) **Definition of CA components**
2) Calibration & validation

1A) Definition of a REGULAR GRID (460x460 m cells) in S. Nevada (Spain).



Instituto Geológico y Minero de España

METHOD and MATERIAL: CA technique application (Sierra Nevada Mountain)

CA to simulate **daily SCA in S. Nevada**

$$S_i(t)=f(S_i(t-1), S_j(t-1), \text{TransitionRules})$$

1) **Definition of CA components**

2) Calibration & validation

1B) Finite **possible states** (k) in each cell (nºs or properties): **S = 0** (without snow) **S = 1** (with snow)

4 possibilities of state evolution:

$S_i(t) = 0$ & $S_i(t-1) = 0$; $S_i(t) = 0$ & $S_i(t-1) = 1$;

$S_i(t) = 1$ & $S_i(t-1) = 1$; $S_i(t) = 1$ & $S_i(t-1) = 0$;

1C) **Neighbourhood pattern** = set of cells that influence on new state

11	12	13	14	15
10	2	3	4	16
9	1	0	5	17
24	8	7	6	18
23	22	21	20	19

Extended Neumann neighbourhood

Instituto Geológico y Minero de España

METHOD and MATERIAL: CA technique application (Sierra Nevada Mountain)

CA to simulate **daily SCA in S. Nevada**

$S^i(t)=f(S^i(t-1), S^j(t-1), TransitionRules)$

1) **Definition of CA components**

2) Calibration & validation

1D) **Transition rules** "If" rules (explanatory variables) to approach system dynamic

explanatory VARIABLES/PARAMETERS

- Altitude (**A**): Classes A_k = [A_0<1700<A_1<1900<A_2<2400<A_3 <2500<A_4<2700<A_5<3200]
- Mean precipitation in the basin (**P**): Classes P_k [P_0<5<P_1]
- Mean Temperature in the basin (**T**): Classes T_k [T_0<4<T_1<6<T_2<8<T_3<10<T_4< 15<T_5<20]

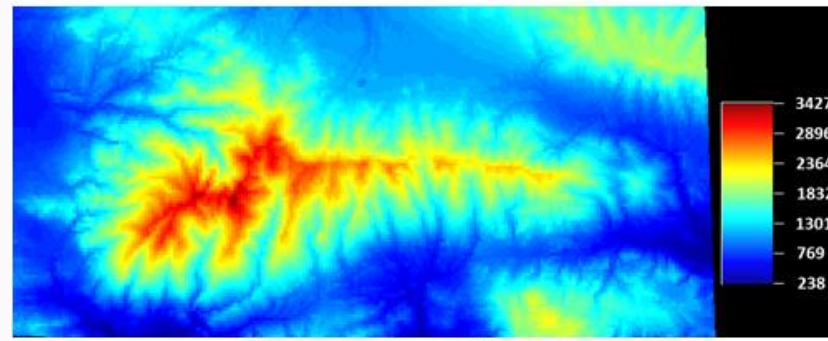


Figure 2. Map of Altitude (m)

Related spatial continuity function for the variables Snow and Altitude

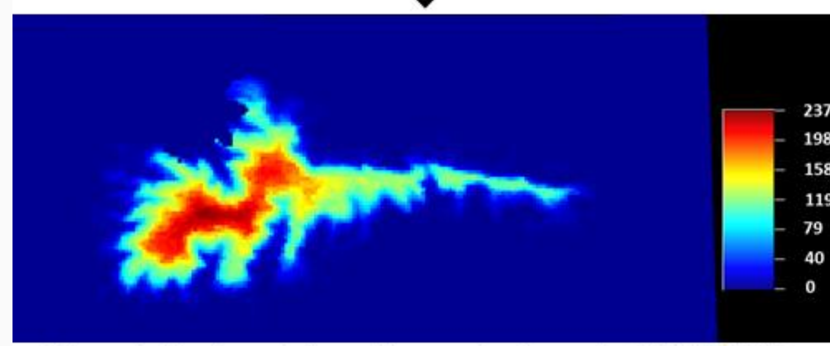


Figure 3. Number of days with snow for the period 01/07/2010 to 30/06/2011

METHOD and MATERIAL: CA technique application (Sierra Nevada Mountain)

CA to simulate **daily SCA in S. Nevada**

$S^i(t)=f(S^i(t-1), S^j(t-1), TransitionRules)$

1) **Definition of CA components**
2) Calibration & validation

1D) Transition rules "If" rules (explanatory variables) to approach system dynamic

explanatory VARIABLES/PARAMETERS (Mean P and T in the basin (**P, T**))

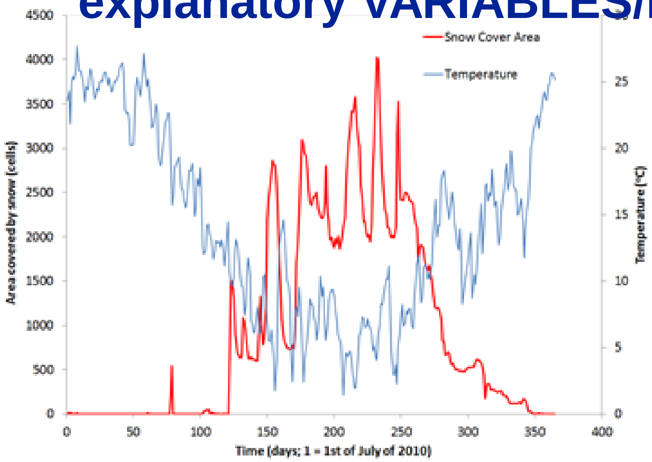


Figure 4. Snow cover area and Temperature in the zone for the period 01/07/2010 to 30/06/2011

Precipitation and temperature series of a basin related with Sierra Nevada Mountain. The basin represent the changes of the variables but not the absolute value.

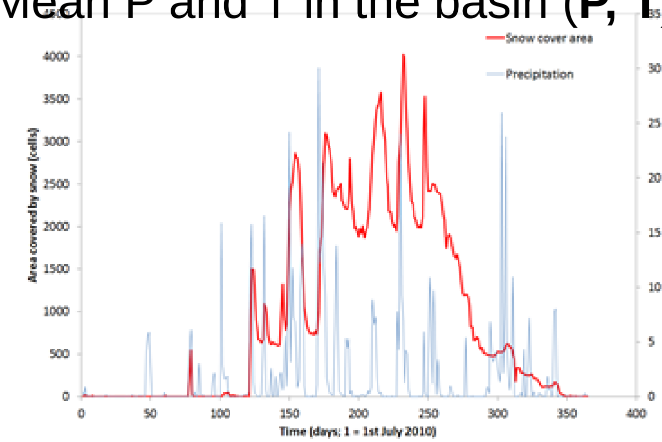


Figure 5. Snow cover area and precipitation in the zone for the period 01/07/2010 to 30/06/2011

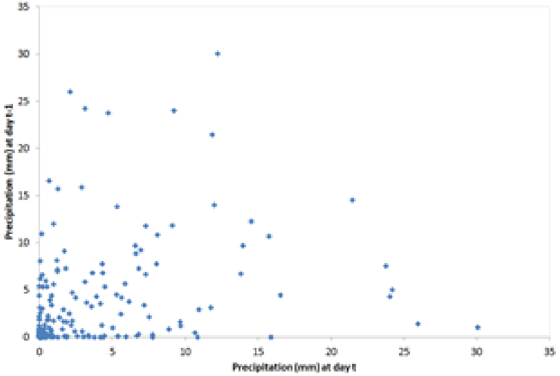


Figure 6. Precipitation correlation with the previous day for the period 01/07/2010 to 30/06/2011

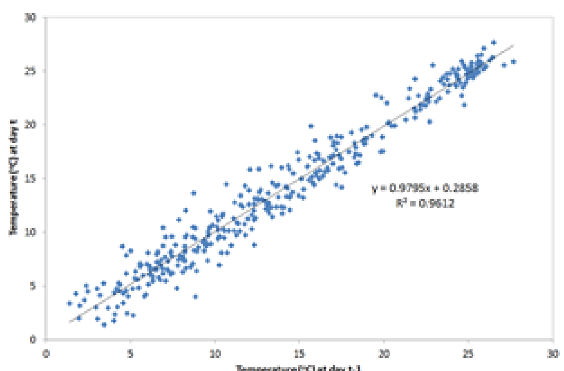


Figure 7. Temperature correlation with the previous day for the period 01/07/2010 to 30/06/2011

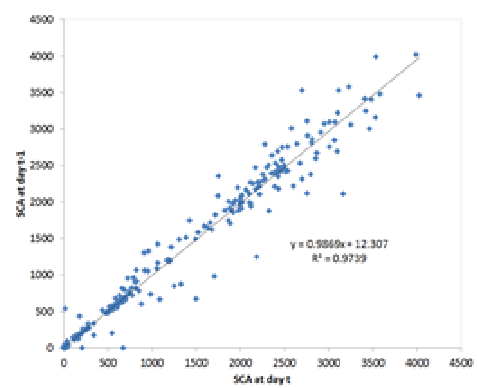


Figure 8. SCA correlation with the previous day for the period

METHOD and MATERIAL: CA technique application (Sierra Nevada Mountain)

CA to simulate **daily SCA in S. Nevada**

$S^i(t)=f(S^i(t-1), S^j(t-1), TransitionRules)$

1) **Definition of CA components**
2) Calibration & validation

1D) **Transition rules** "If" rules (explanatory variables) to approach system dynamic

Explanatory VARIABLES/PARAMETERS

- Altitude (**A**): Classes $A_k = [A_0<1700<A_1<1900<A_2<2400<A_3<2500<A_4<2700<A_5<3200]$
- Mean precipitation in the basin (**P**): Classes P_k $[P_0<5<P_1]$
- Mean Temperature in the basin (**T**): Classes T_k $[T_0<4<T_1<6<T_2<8<T_3<10<T_4<15<T_5<20]$

MODES

- **Increasing mode** (IM): IF Tk(t)<Tk(t-1)
- **Decreasing mode** (DM): IF Tk(t)>Tk(t-1)
- **Snowing mode** (SM): IF P>5 AND (T<20 AND A>3200 OR T<15 AND A>2700 OR T<12.5 AND A>2500 OR T<10 AND A>2400 OR T<7.5 AND A>1900 OR T<12.5 AND A>2500 OR T<5 AND A>1700)

Calibration of transition RULES

IF MODE = SM THEN $S_i(t)=1$
IF MODE = IM AND SM AND $S_i(t-1)=1$ THEN $S_i(t)=1$
IF MODE = IM AND SM AND $S_i(t-1)=0$ AND $S_j(t)=1$ with $n_j>13$ THEN $S_i(t)=1$
IF MODE = DM AND $S_i(t-1)=1$ AND $S_j(t)=1$ with $n_j>13$ THEN $S_i(t)=0$

METHOD and MATERIAL: CA technique application (Sierra Nevada Mountain)

❑ Calibration of the CA model

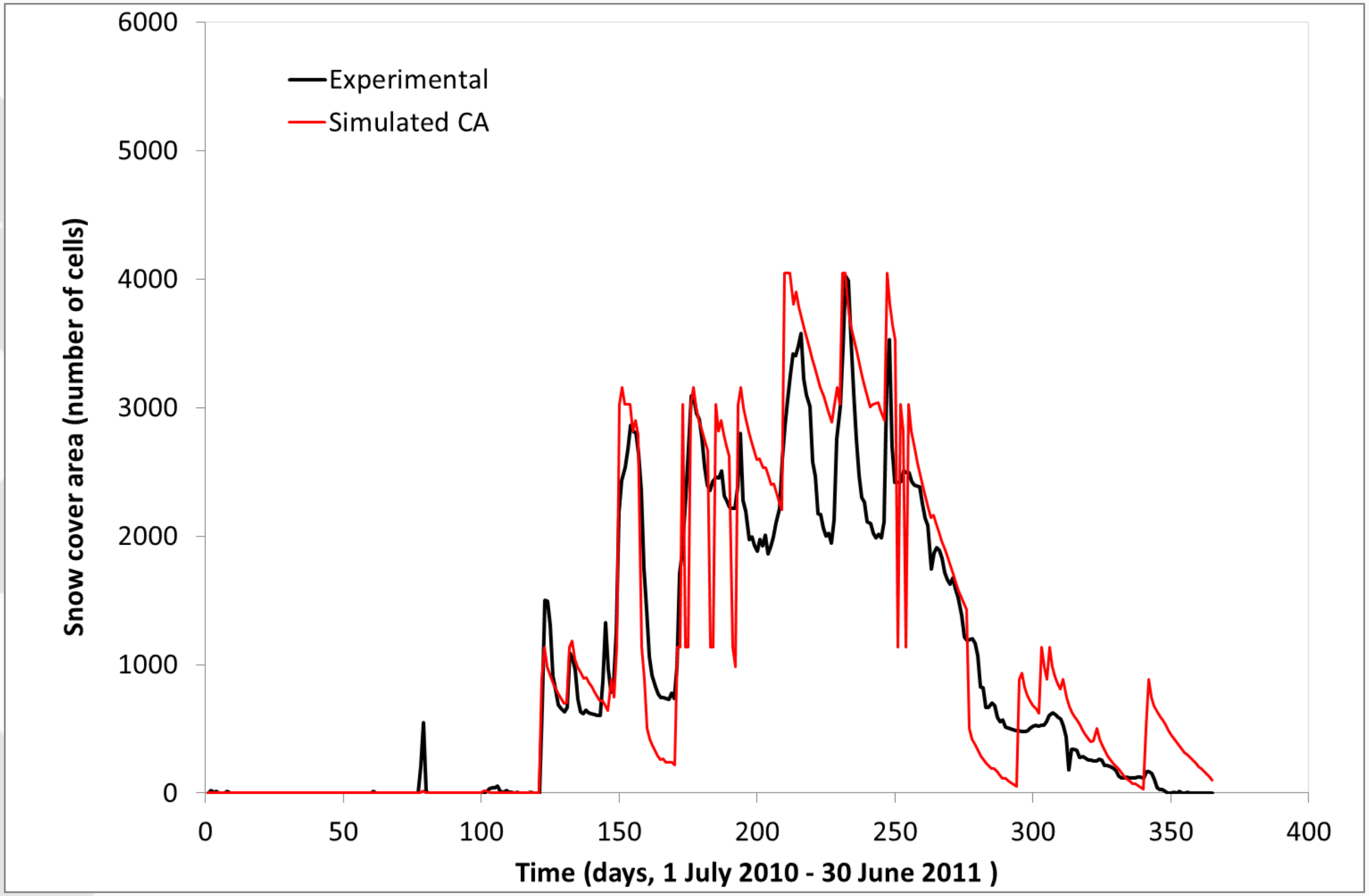


Figure 9. Experimental and simulated SCA for the year 2010-2011

Instituto Geológico y Minero de España

METHOD and MATERIAL: CA technique application (Sierra Nevada Mountain)

❑ Calibration of the CA model

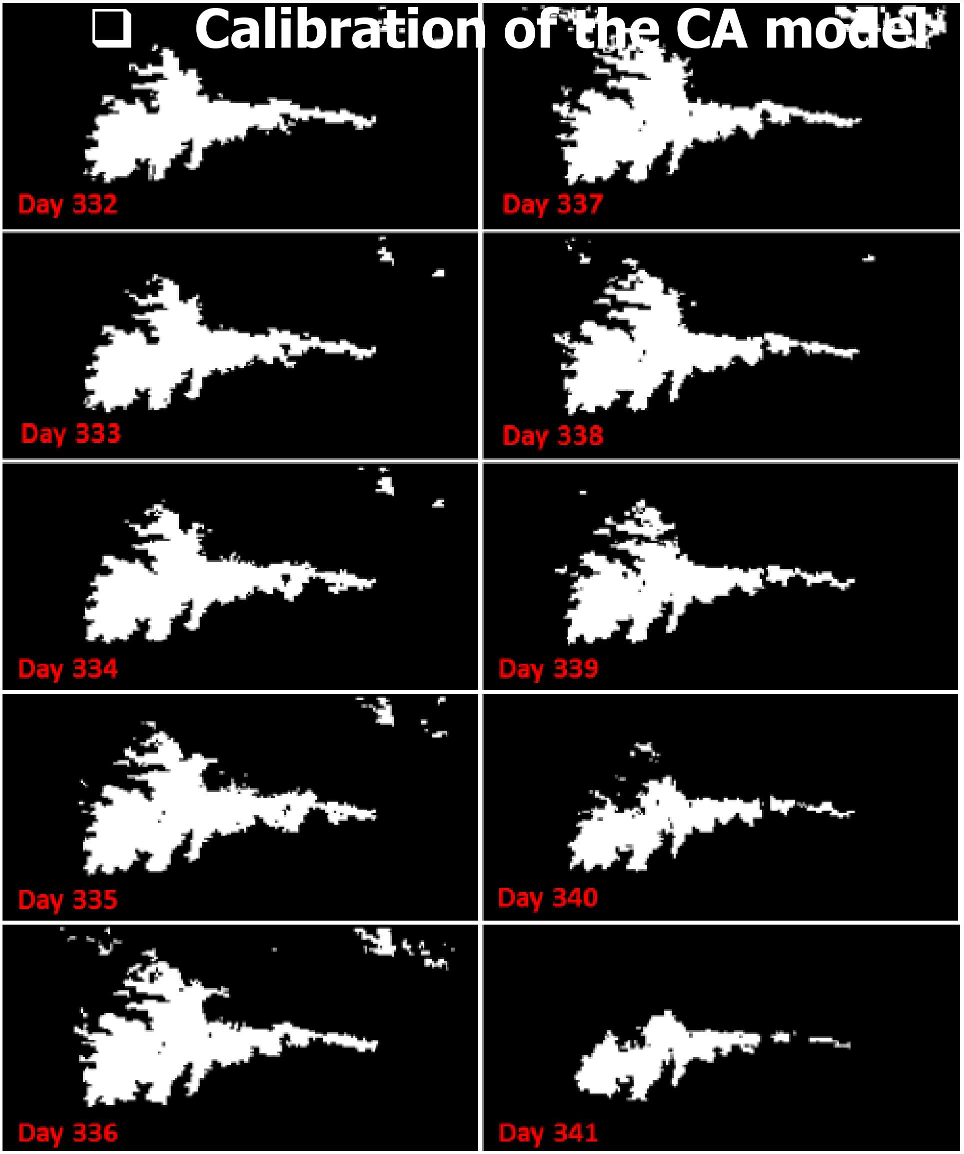


Figure 11. SCA maps of experimental data for the year 2010

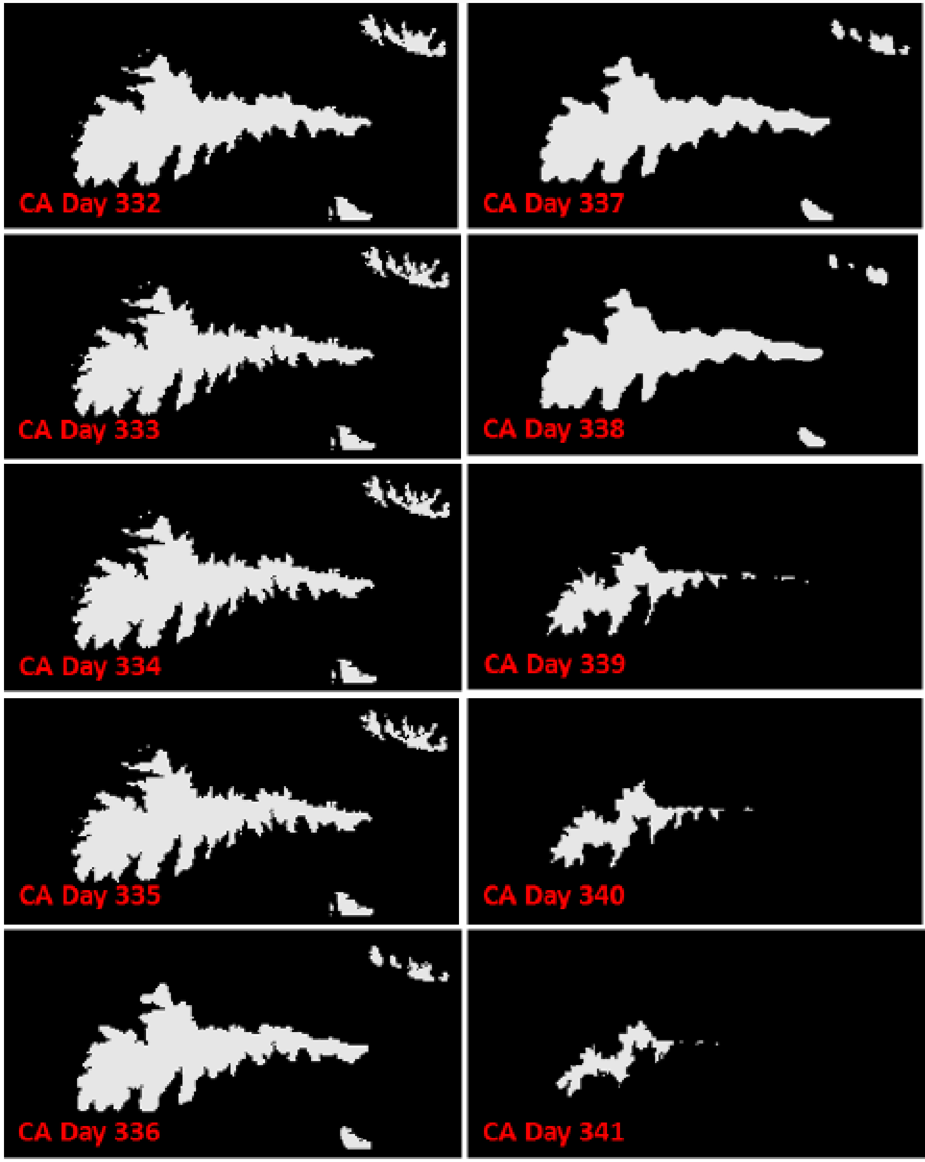


Figure 12. SCA maps of simulated data for the year 2010

APLICATION TO A CASE STUDY (Sierra Nevada Mountains): RESULTS AND DISCUSSION

❑ Validation of the CA model

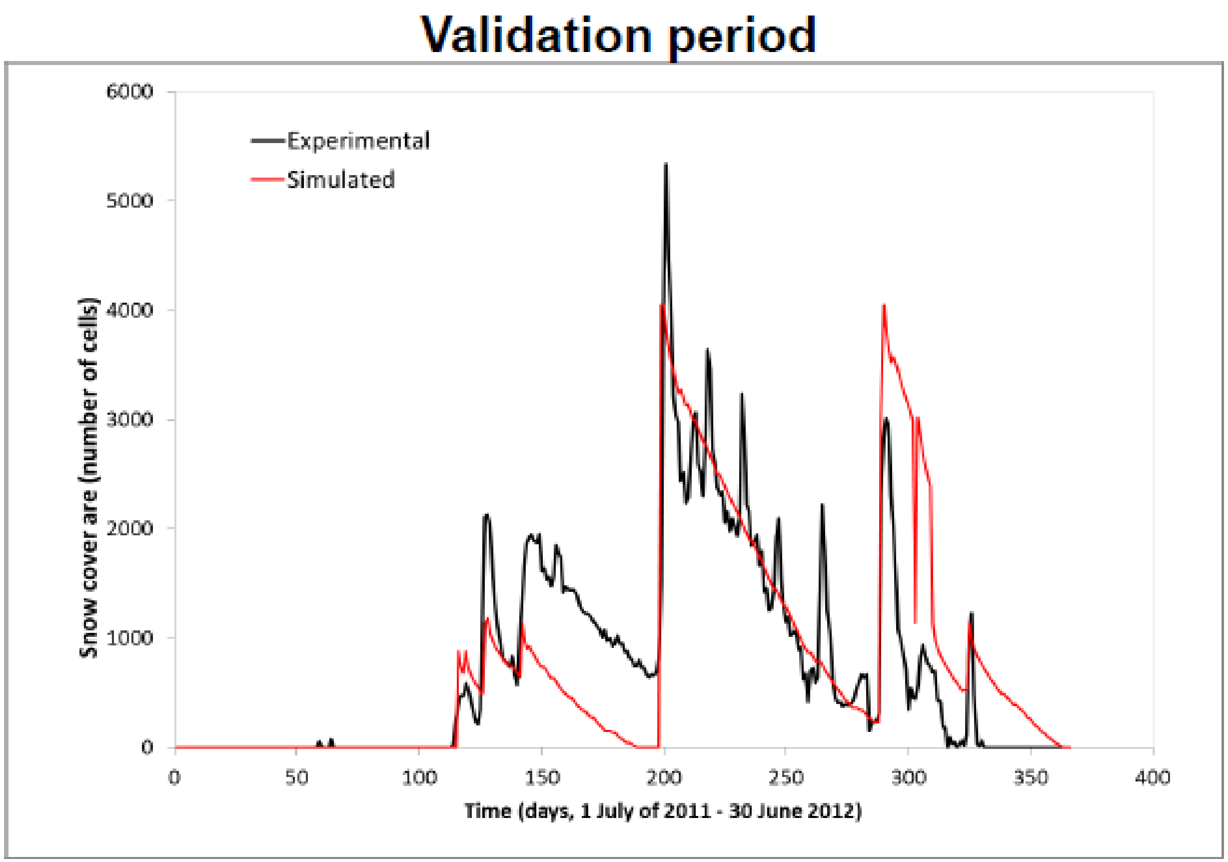


Figure 10. Experimental and simulated SCA for the year 2011-2012

Estimation of daily SCA in periods without available satellite information by using CA: **CONCLUSIONS**

- **A non-deterministic CA method can be employed to simulate SCA**:

  1) DEFINITION OF CA COMPONENTS

     a) REGULAR GRID OF CELLS

     b) Finite possible states (k) in each cell (n^{os} or properties)

     c) Neighbourhood = set of cells that influence on new state.

     4) Transition rules

     5) Initial conditions

  2) CALIBRATION 3) VALIDATION 4) SIMULATION

- **Its usefulness** to simulate SCA has been demonstrated in S. Nevada

- **More research works are in progress. It could be used to:**

  - **Estimate** historical periods without data
  - **Predicting** future values (data assimilation techniques)

THANK YOU FOR YOUR ATTENTION!!