Simulation of the regional climatic effect by black carbon and dust on snow in Central Italian Apennines with the WRF-Noah-MP/CHIMERE coupled model

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Center of Excellence CETEMPS Telesensing of Environment and Model Prediction of Severe events

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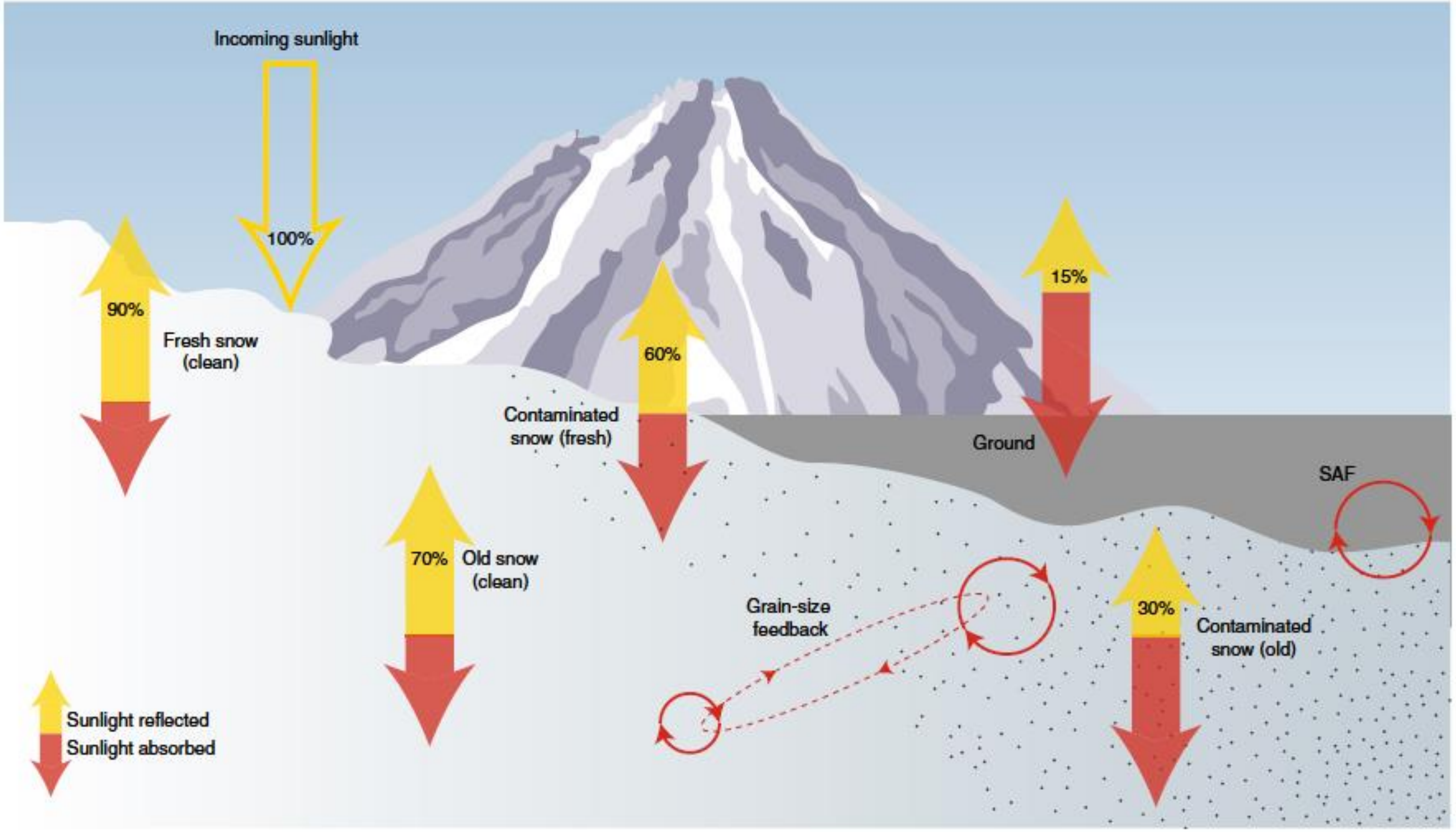
Snow Darkening Effect

- Snow darkening due to the deposition of radiation-absorbing aerosols (black carbon, dust, brown carbon)
- Albedo: fraction of incident radiation that is reflected by a surface or body
- Perturbation to the radiative balance

- Increasing of snow melting
- Reducing of snow duration
- Consequences on runoff and water supplies

Physics of the Problem



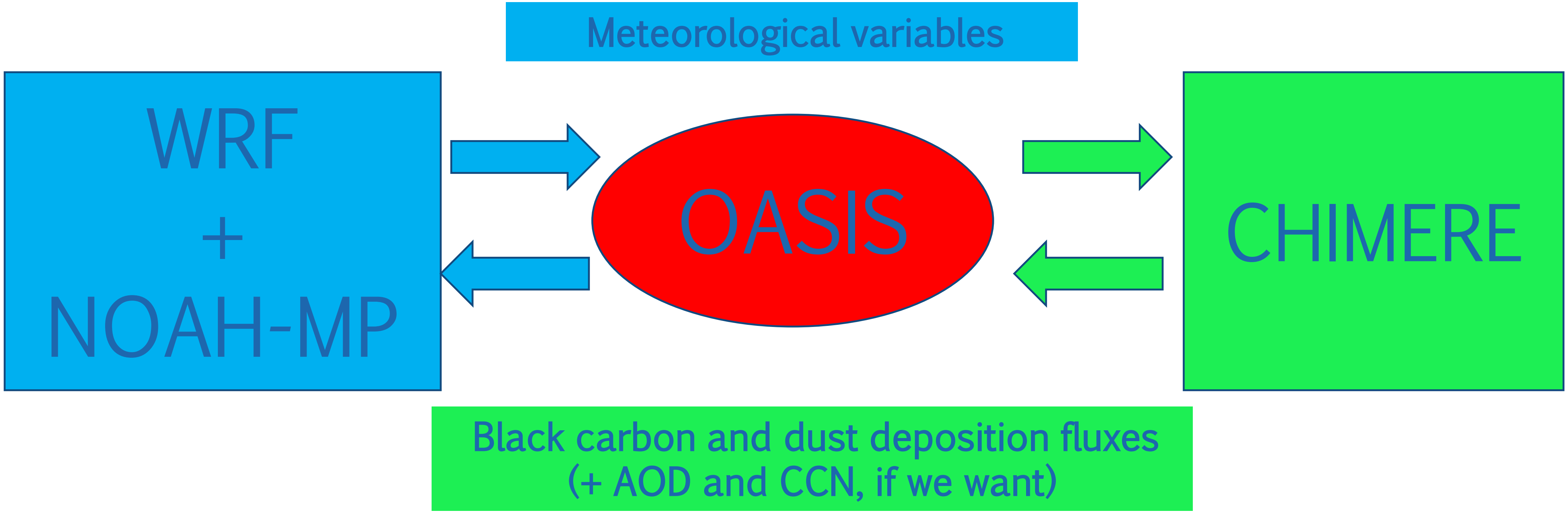
- Fresh snow: small grain dimension (100 um) and relative large albedo
- Old snow: large grain dimension (1000 um) and relative low albedo
- The presence of radiation-absorbing aerosol lowers the snow albedo. The perturbation is lager for the old snow

- The presence of radiation-absorbing aerosols increases the snow grain growth. As a consequnce, the snow aging is faster, with further snow albedo decreasing (grain-size feedback).

[Skiles et al., NCG, 2018]

WRF-CHIMERE development

- Snowpack model coupled with a soil model embedded in an atmospheric model
- Snow aging scheme within snowpack model (snow grain growth and snow albedo parameterization)
- Dry and wet deposition fluxes of black carbon, organic carbon and dust on the snow surface
- Transport scheme of carbon and dust within snowpack
- Albedo perturbation scheme from black carbon, brown carbon, and dust



Noah-MP Land Surface Model:

- Augmented version of Noah model
- 3-layers snow model (with liquid water treatment)
- 2 snow albedo schemes
- Two-stream radiative transfer applied to vegetated fraction
- Included in WRF

The scheme that we have implemented:

Snow Grain Growth
(dry and wet snow methamorphisms, melting/refreezing cycles)

→ **Snow Albedo**
(SNICAR model)

CHIMERE Deposition Fluxes

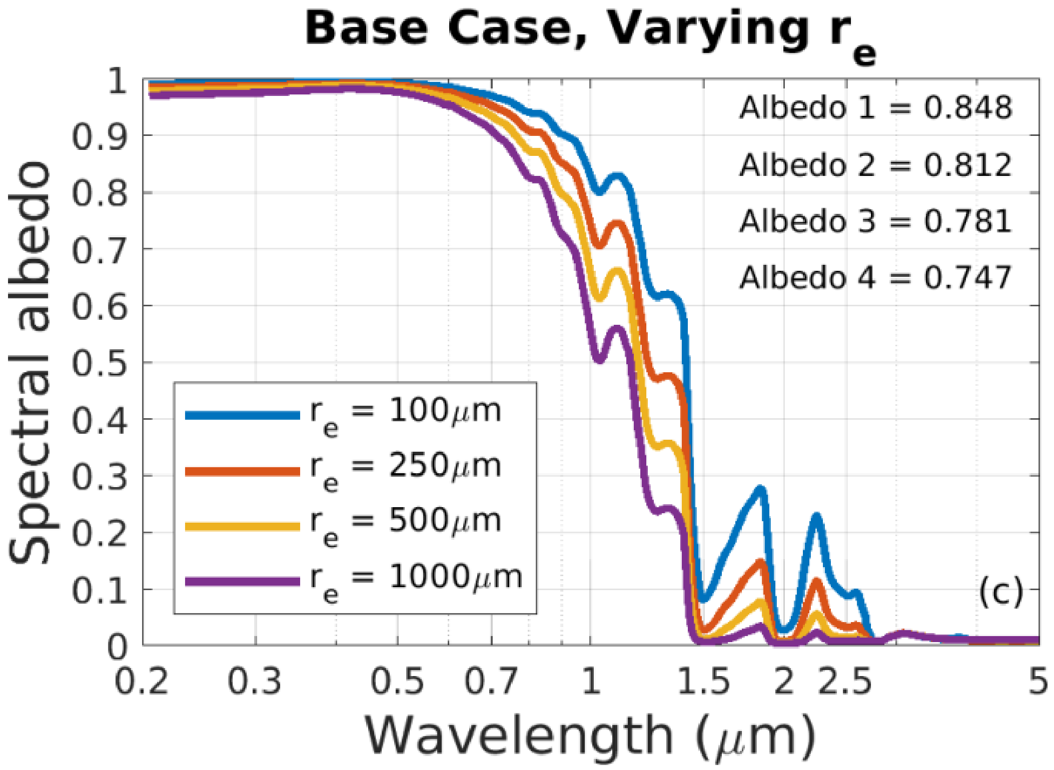
→ BC, Brc and dust in snow

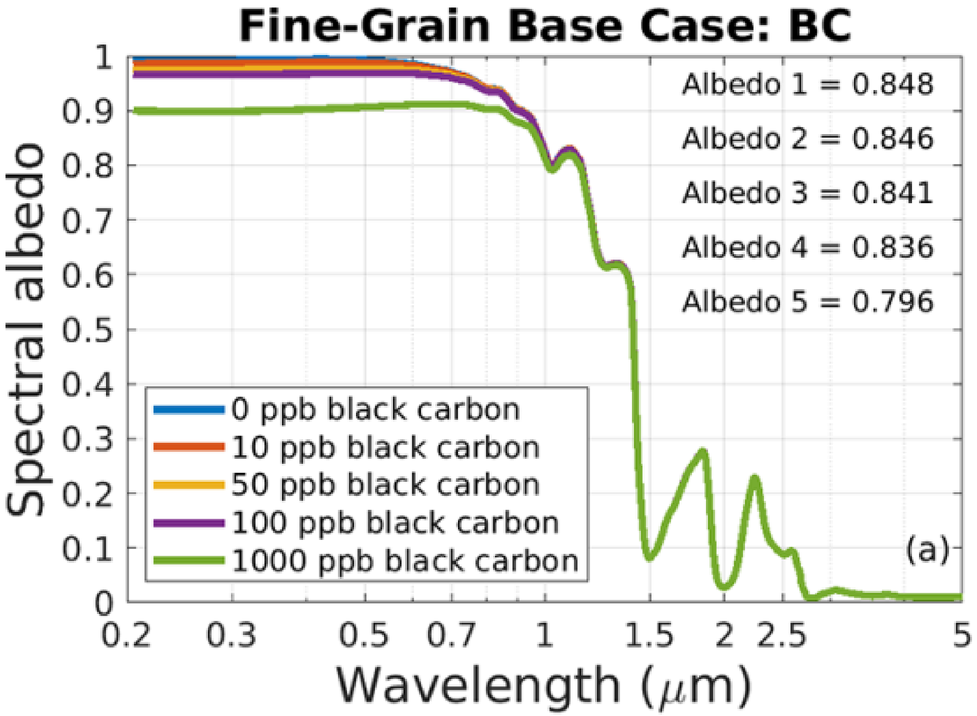
$$\frac{dC_i}{dt} = k(C_{i+1}L_{i+1} - C_iL_i) + F_d$$

↑ Snow Albedo

The Snow Albedo Model

Snow albedo may be calculted by using the *The Snow, Ice, and Aerosol Radiative* model (SNICAR) [Flanner et al., GMD, 2021], with the two-stream Adding-Doubling solution (SNICAR-AD) [Dang et al., 2019]. SNICAR accounts for snow albedo dependence on snow grain dimension and form, radiation-absorbing aerosol concentration, snow water equivalent, solar zenith angle, and surface background albedo.

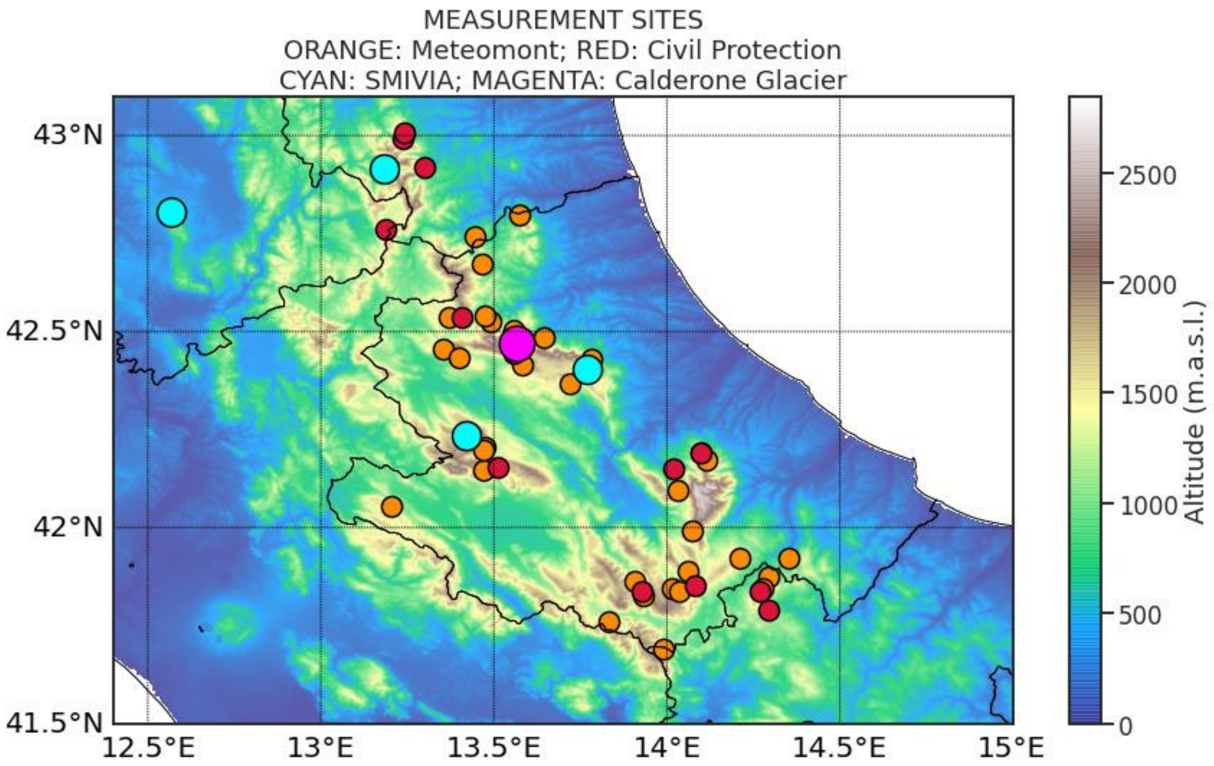




A special thanks to Cenlin He and Mark Flanner for sharing the code! [Flanner et al., GMD, 2021]

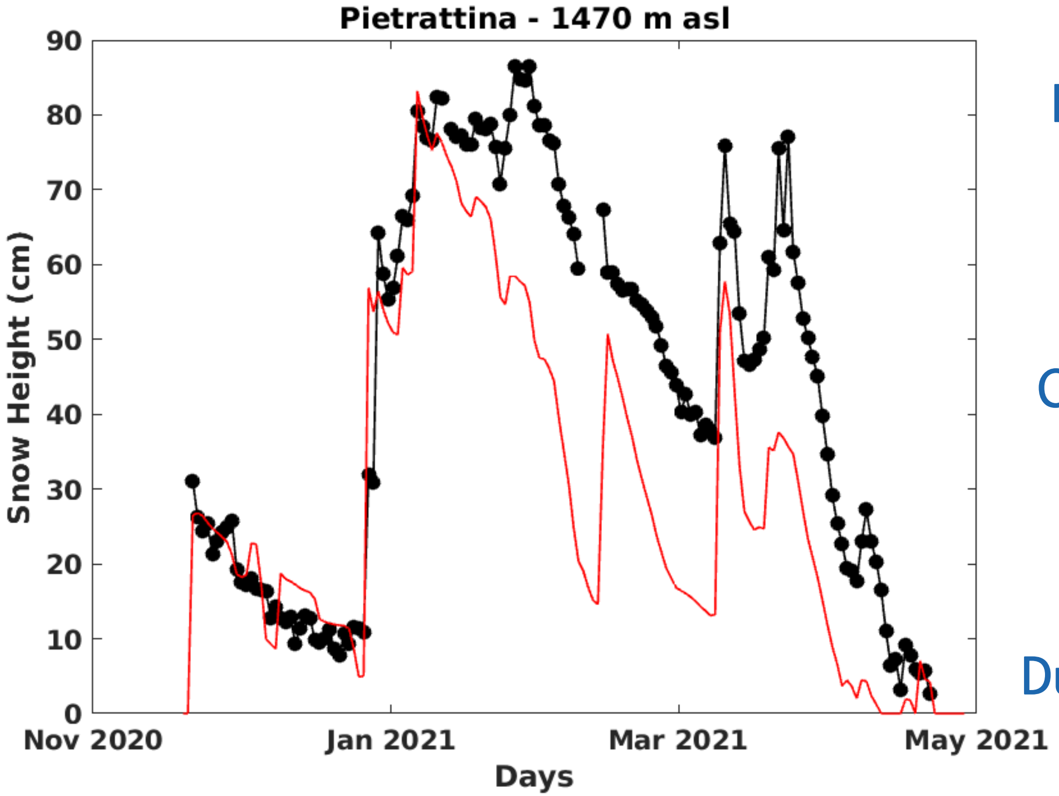
Model Application

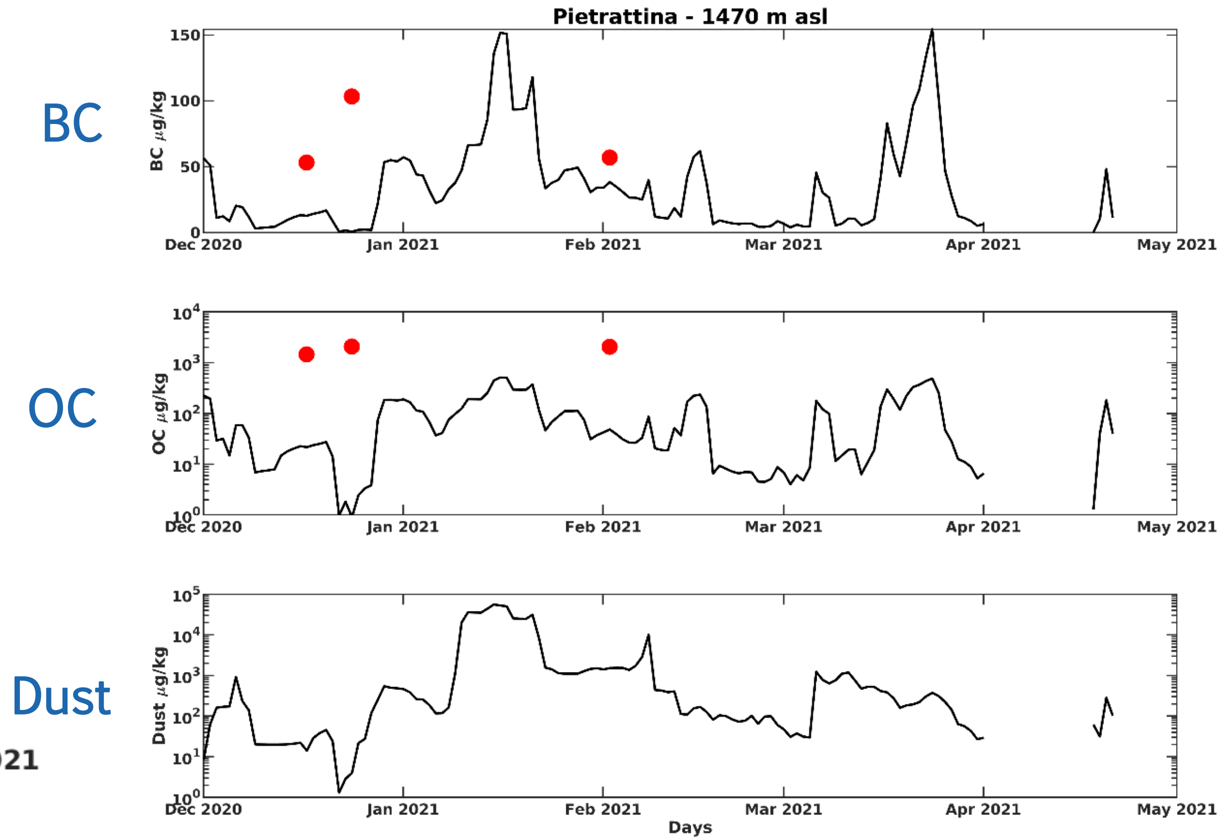
The model has been applied on the Central Italian Apennines at 3 km resolution during the 2020/2021 winter season.



- Automatic weather station with nivometer from Civil Protection
- Manual measurements from avalanche warning service
- Automatic and manual measurements from supersites managed by University of L'Aquila with the support of MeteoAquilano association
- Chemical analysis of snow samples for BC, OC, and dust in snow
- Black carbon concentration in atmosphere

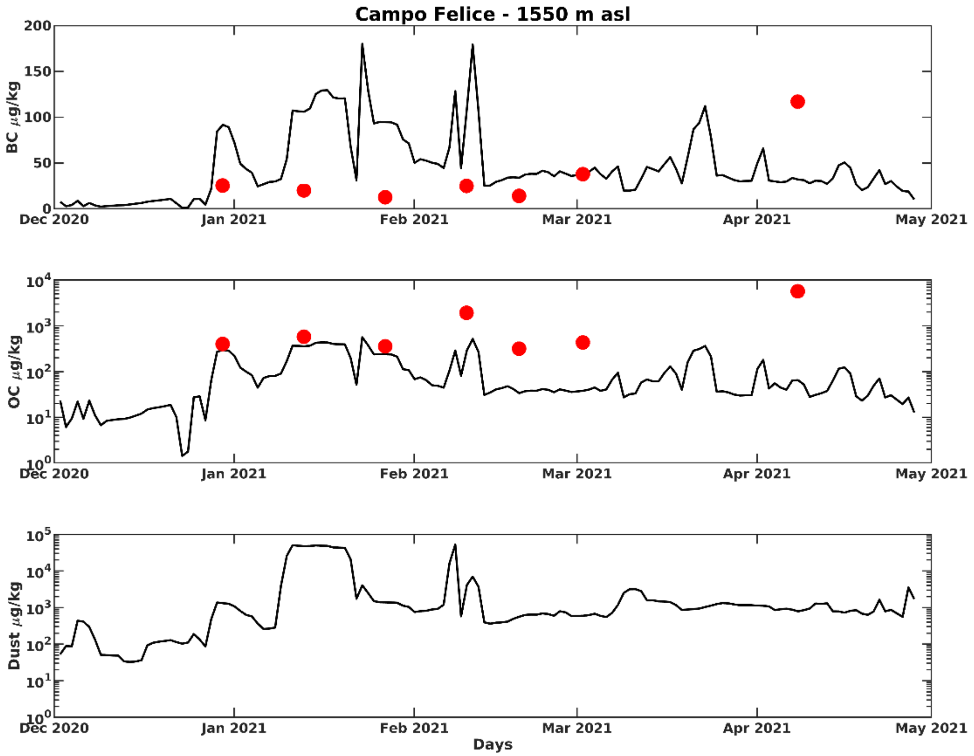
Model Evaluation





	Observed (ug/kg)	Model (ug/kg)
BC	71	34±34
OC	1866	95±119
Dust	-	3973±1115

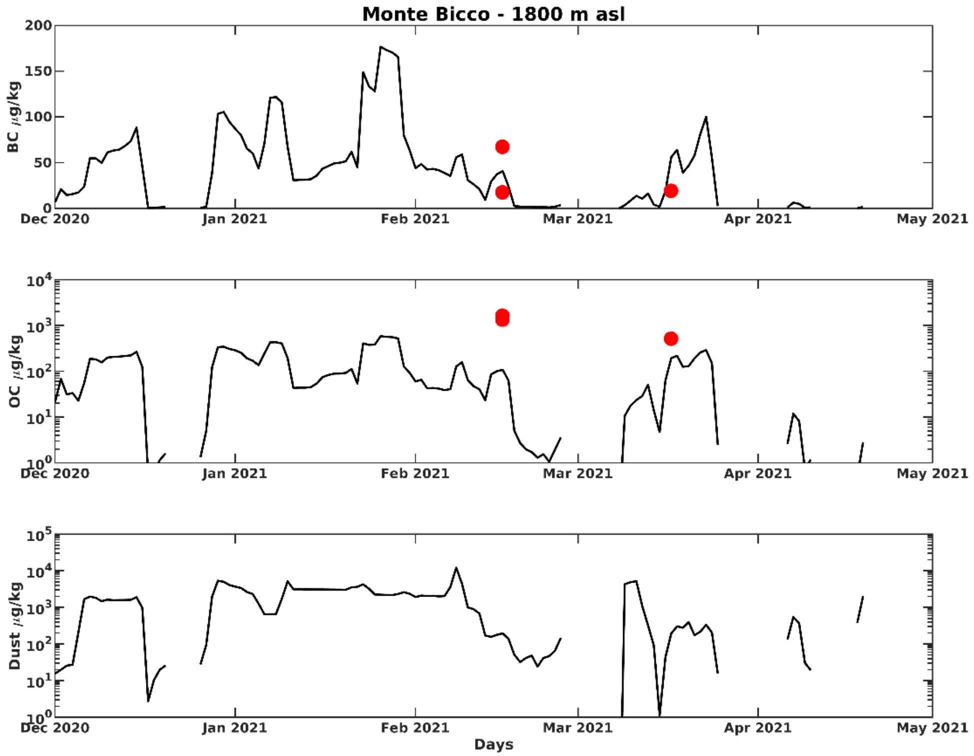
Model Evaluation



BC

OC

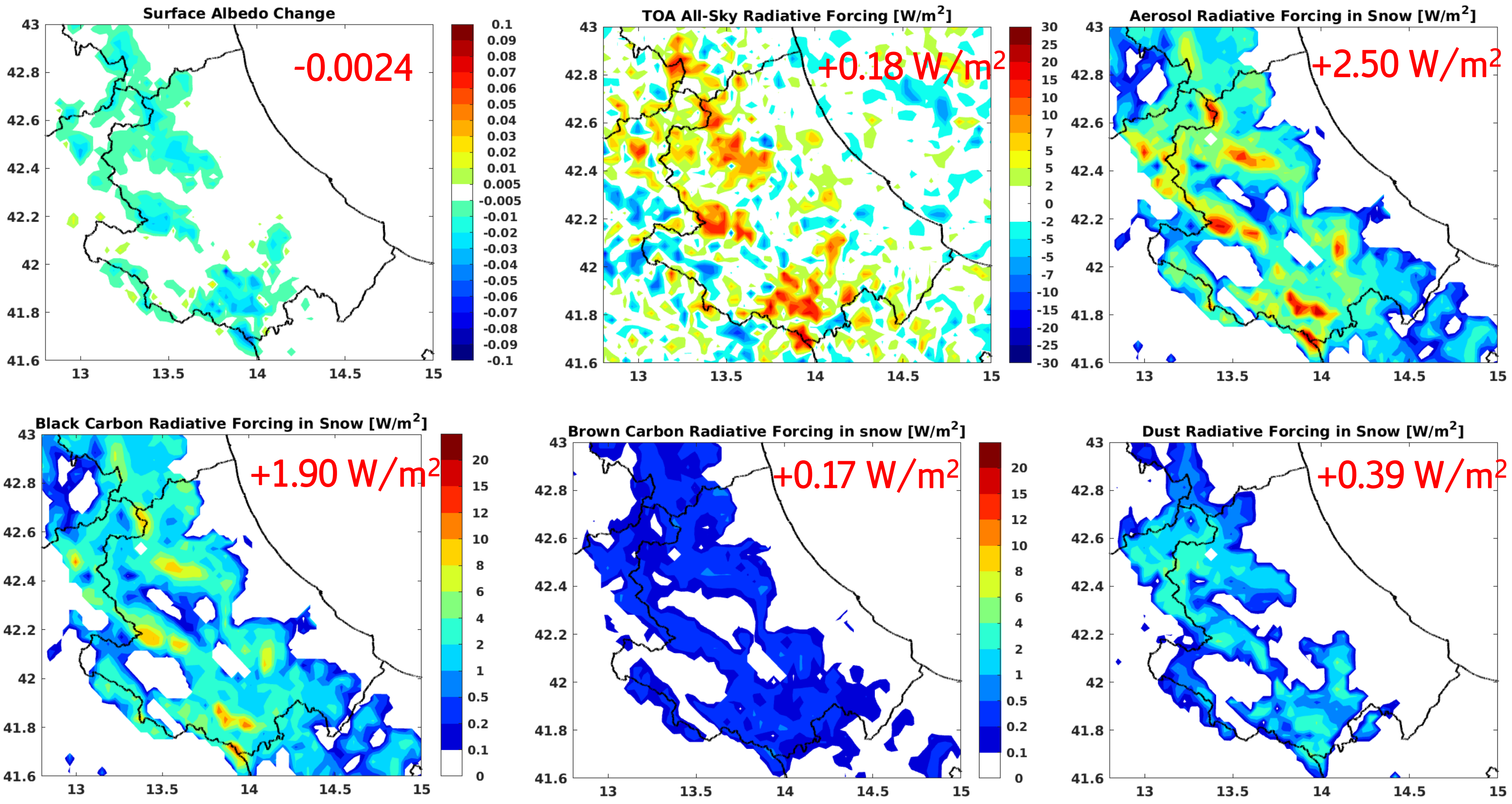
Dust



	Observed (ug/kg)	Model (ug/kg)
BC	36	46±37
OC	1387	950±1241
Dust	-	4863±1253

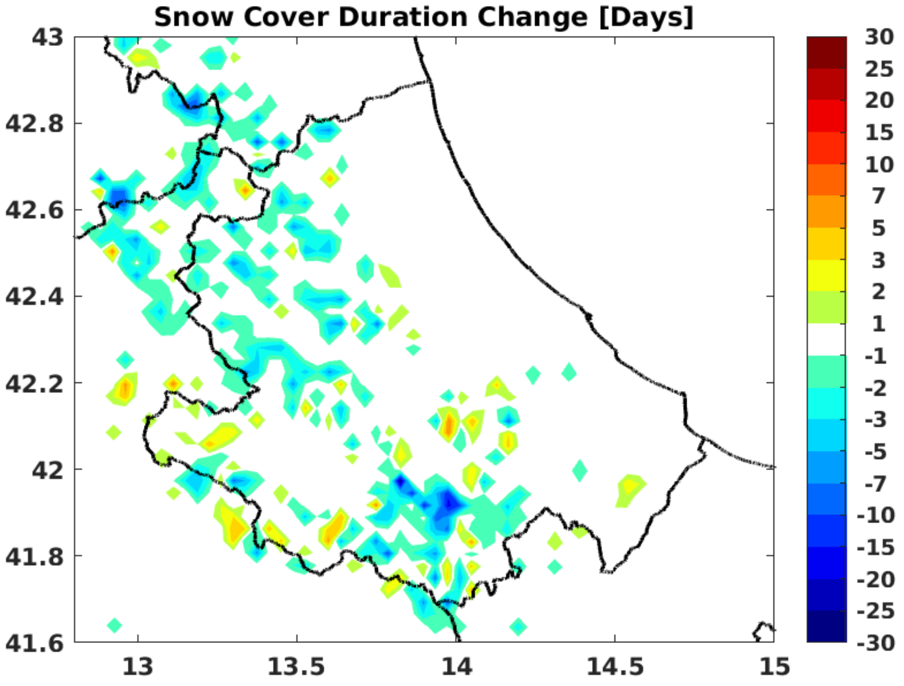
	Observed (ug/kg)	Model (ug/kg)
BC	34	45±43
OC	1163	1244±1483
Dust	-	1267±1809

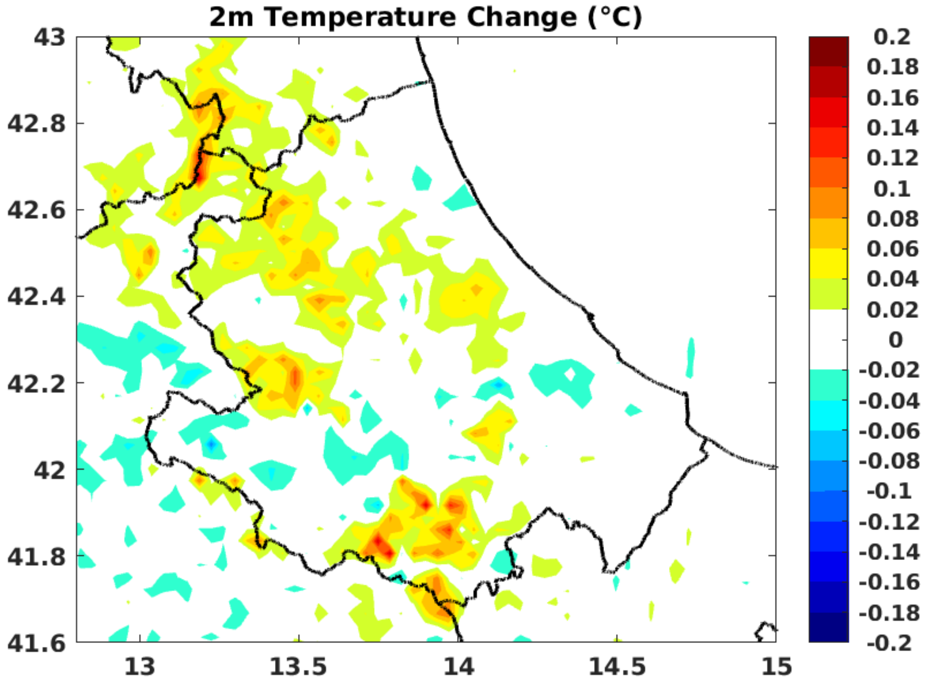
Regional Climatic Impact



- The albedo perturbation and RFs are calculated at 12 UTC
- Aerosol RF is the cryospheric forcing (averaged only when a grid-point is covered by snow), the average energy absorbed by snowpack

Regional Climatic Impact





The snow cover duration is reduced from 1-2 days up to more one week. Here, we do not see the change at the highest elevation, beacuse they were still covered by snow at the end of this simulation.

The temperature change at 12 UTC does not seem to be large, up to +0.10/+0.15°C in some subregions. This could depend on WRF initialization.

Future Developments

- Exploring the sensitivity of snowpack simulation with WRF to model parameterizations
- Exploring the sensitivity of snowpack simulation and climatic impact from aerosol in snow to model initialization
- Exploring the impact of secondary organic aerosols in OC concentration in the snow
- Model evaluation with other data (snow water equivalent, snow density, snow grain dimension, snow temperature, surface albedo)
- Model evaluation with dust data and with snow top concentrations
- Multi-year simulations (2021-2023)