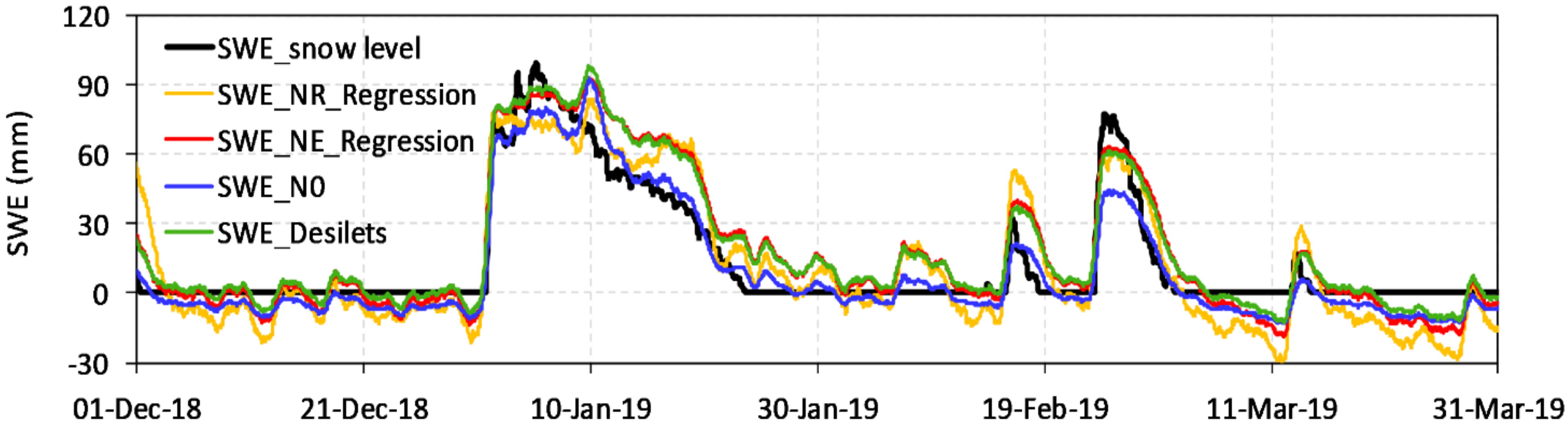

MONITORING OF SNOWPACK DYNAMICS WITH COSMIC-RAY NEUTRON SENSING: A COMPARISON OF FOUR CONVERSION METHODS

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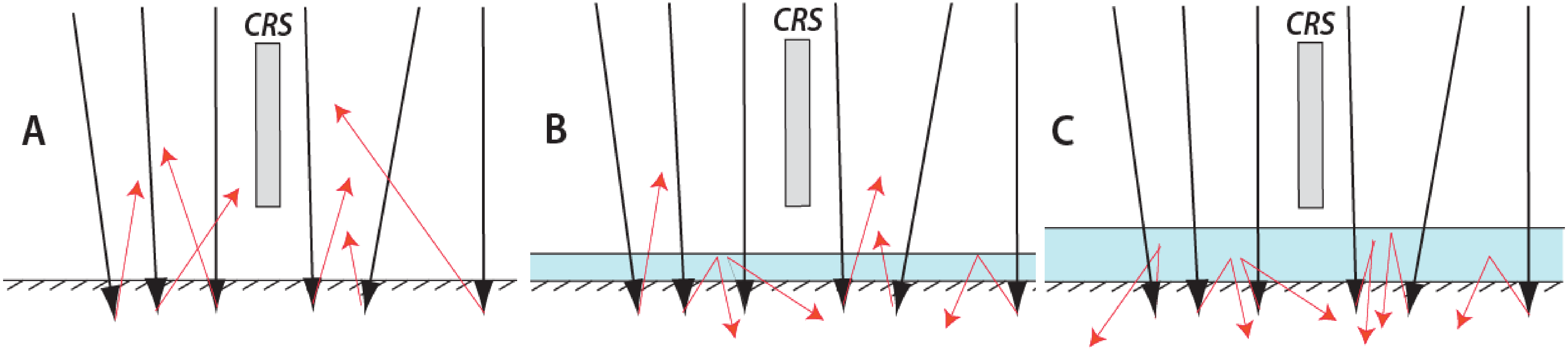
COSMIC-RAY NEUTRON INTENSITY IS AFFECTED BY SNOW COVER

A) No snow cover: Many neutrons produced in ground escape to atmosphere
B) Shallow snow cover: Some neutrons are blocked by the snow pack
C) Thick snow cover: Nearly all are blocked by the snow pack



Desilets, 2017

TESTED CONVERSION METHODS

- linear regression (fast neutrons and thermal to epithermal neutron ratio)
- standard N_0-calibration function (Desilets et al., 2010)

$$SWE = a_0 \left(\frac{N_{cor}}{N_0} - a_1 \right)^{-1} - a_2$$

- physically-based calibration approach (Desilets, 2017)

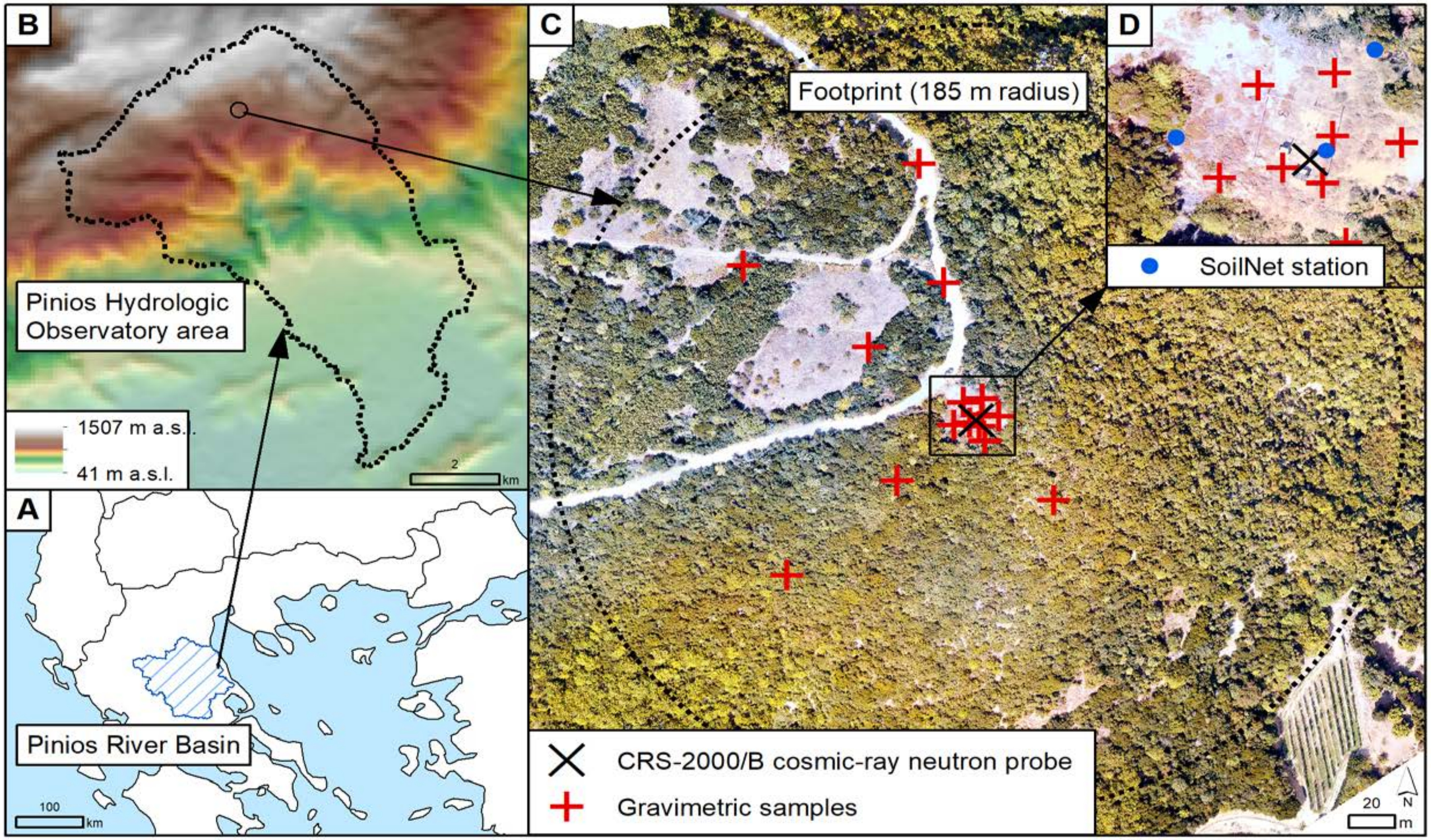
$$SWE = -\Lambda ln \left(\frac{N - N_{snow}}{N_{SWC} - N_{snow}} \right)$$

$\Lambda =$ neutron attenuation by snow water

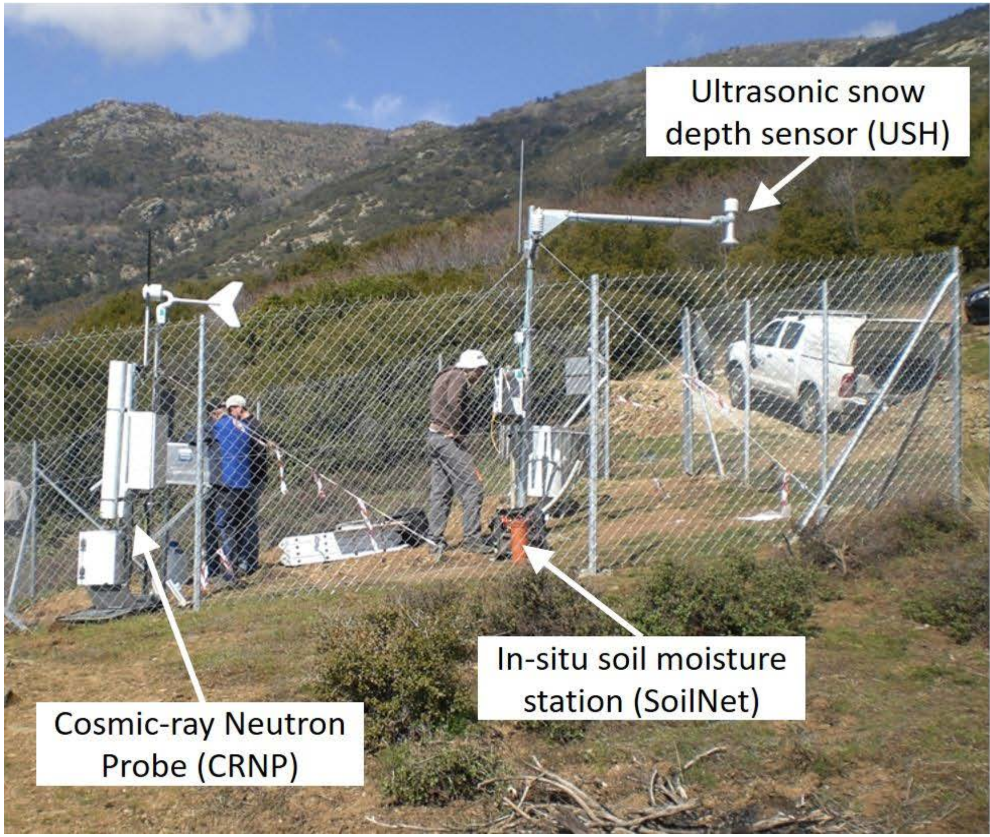
$N_{snow} =$ neutron count rate for an infinite snow depth

$N_{SWC} =$ neutron count rate in the absence of snow cover

PINIOS HYDROLOGIC OBSERVATORY AND THE CS3 TEST SITE



INSTRUMENTATION OF THE CS3 TEST SITE



DATA OVERVIEW

Temp. and Precip.

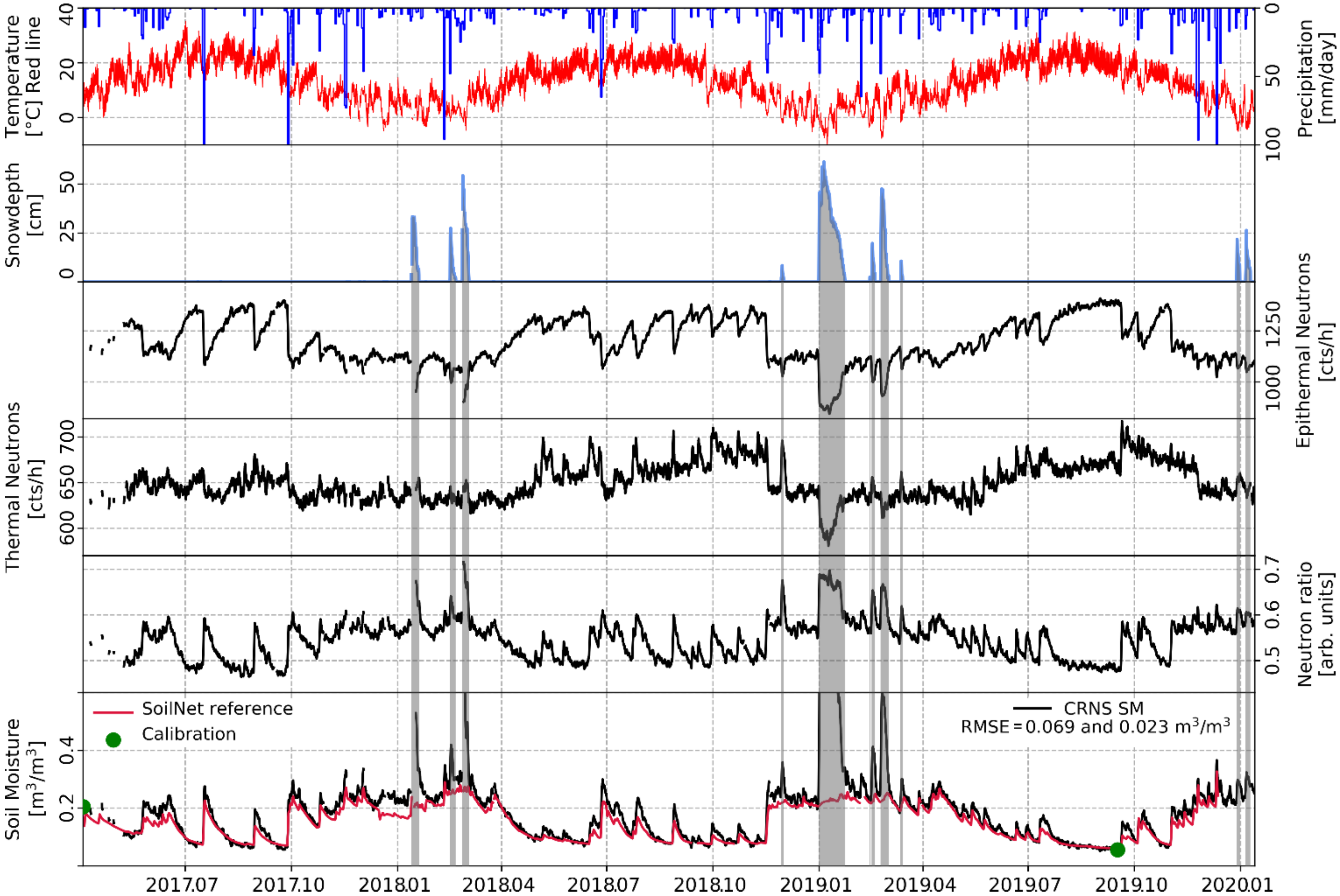
Snow depth

Epitherm. neutrons

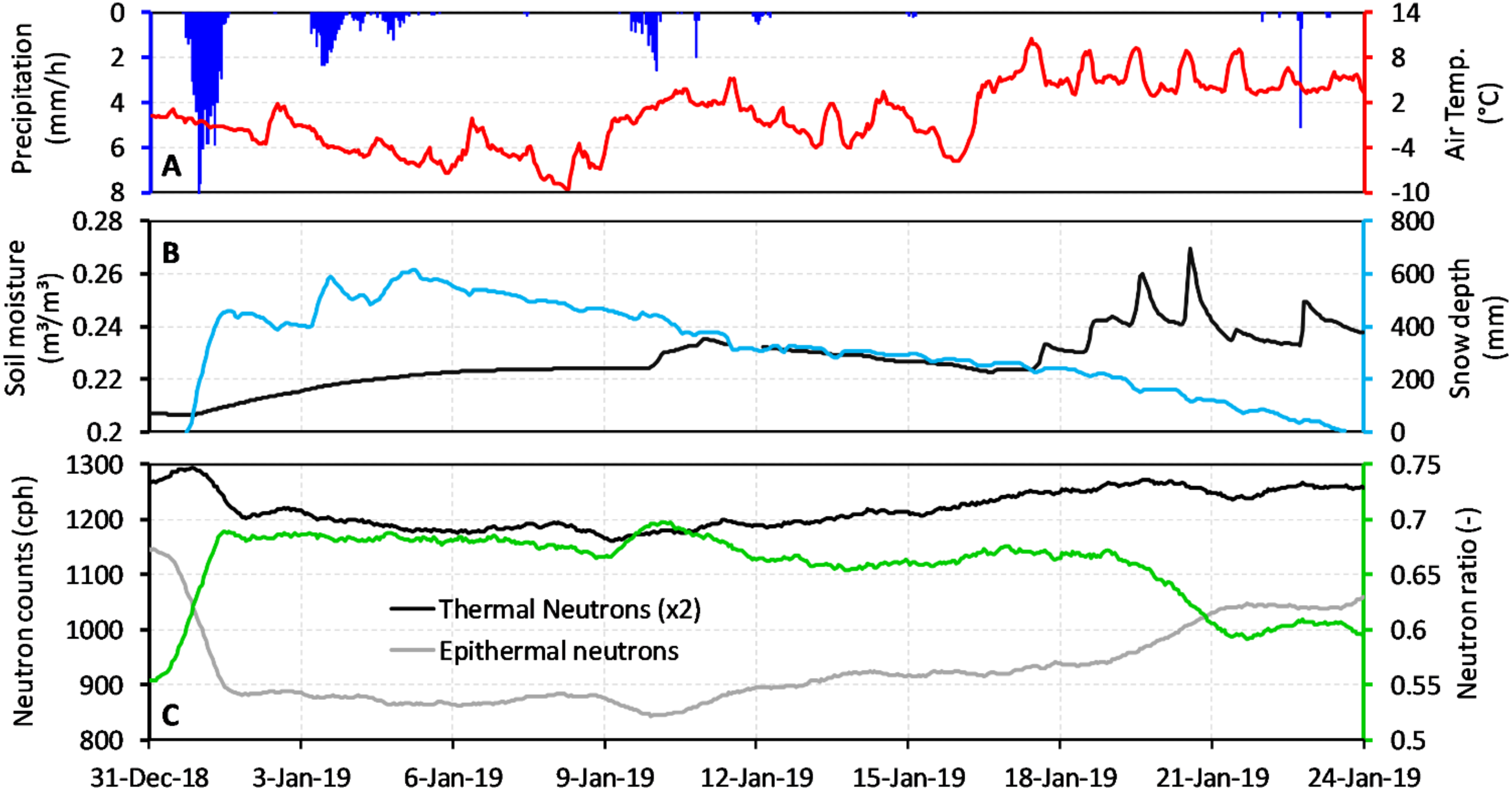
Therm. neutrons

Neutron ratio

In-situ and CRNP soil moisture

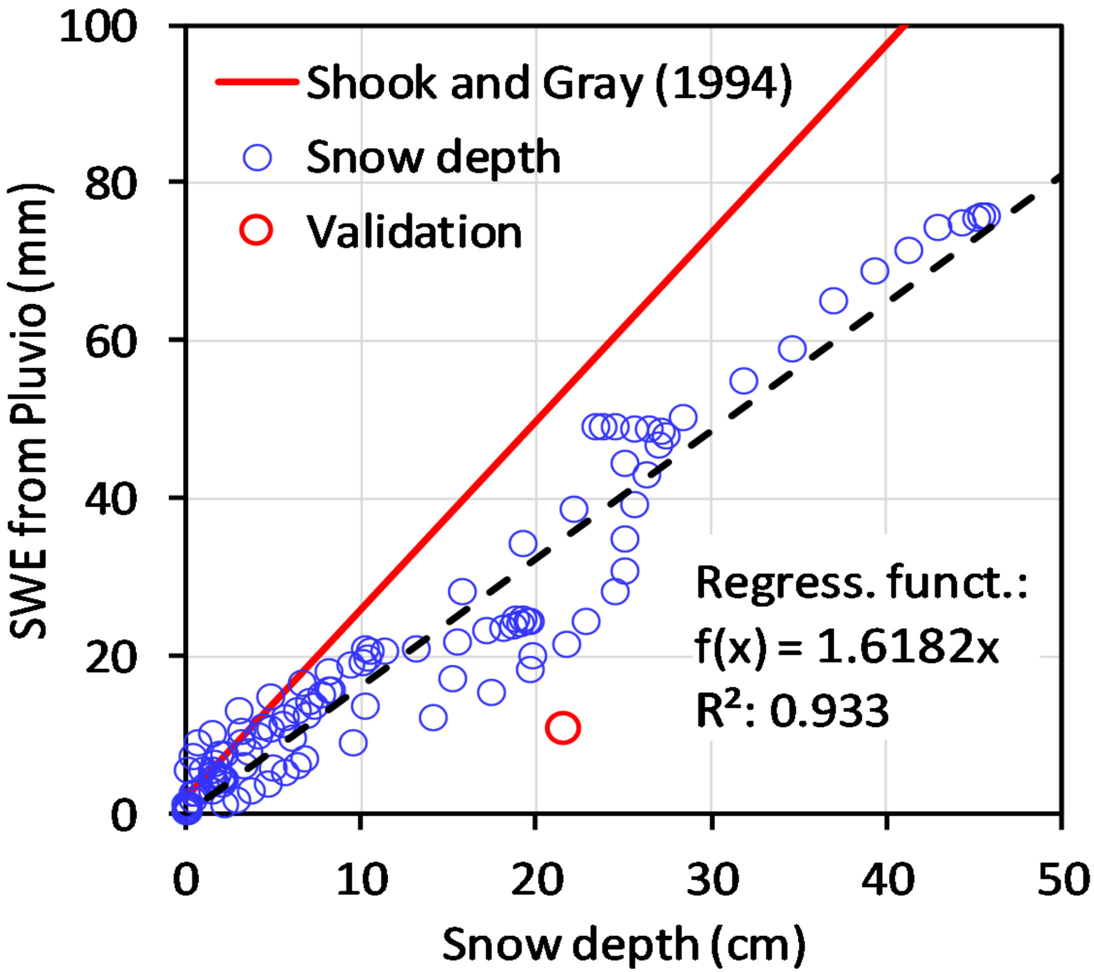


A SINGLE SNOW EVENT



RELATIONSHIP BETWEEN SNOW DEPTH AND SNOW WATER EQUIVALENT

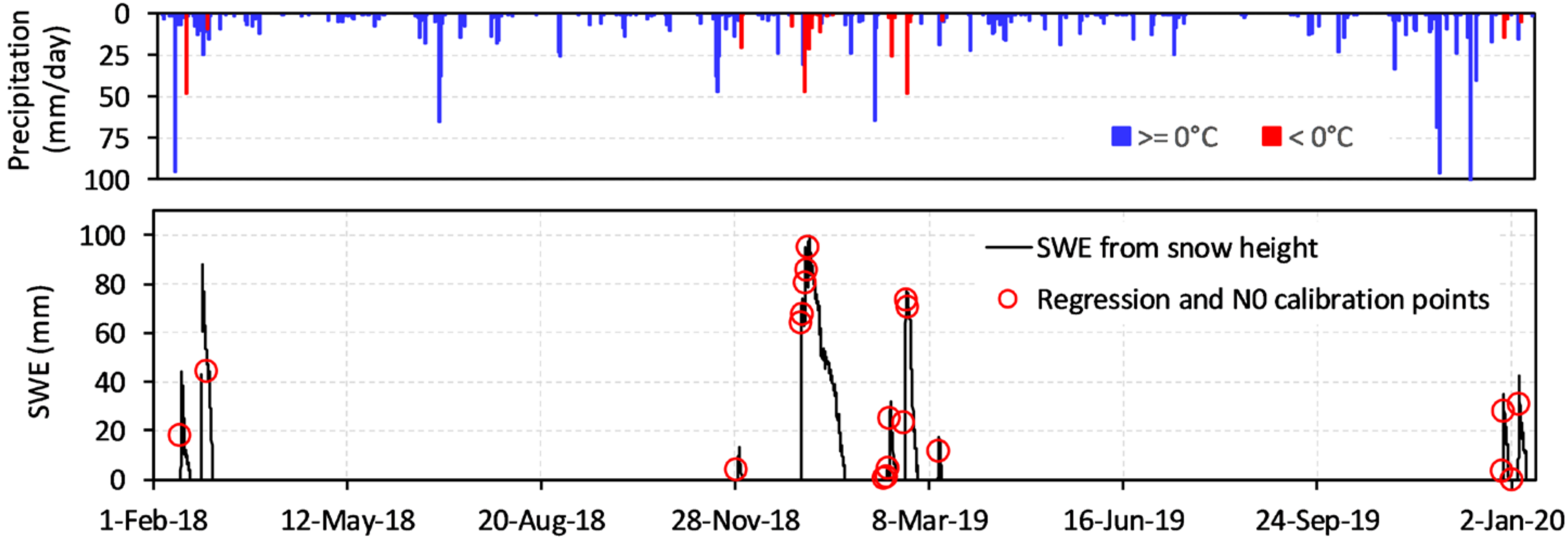
Weighing precipitation gauge (PLUVIO)



Ultrasonic Snow depth sensor

SELECTED SNOW DEPTH OBSERVATIONS

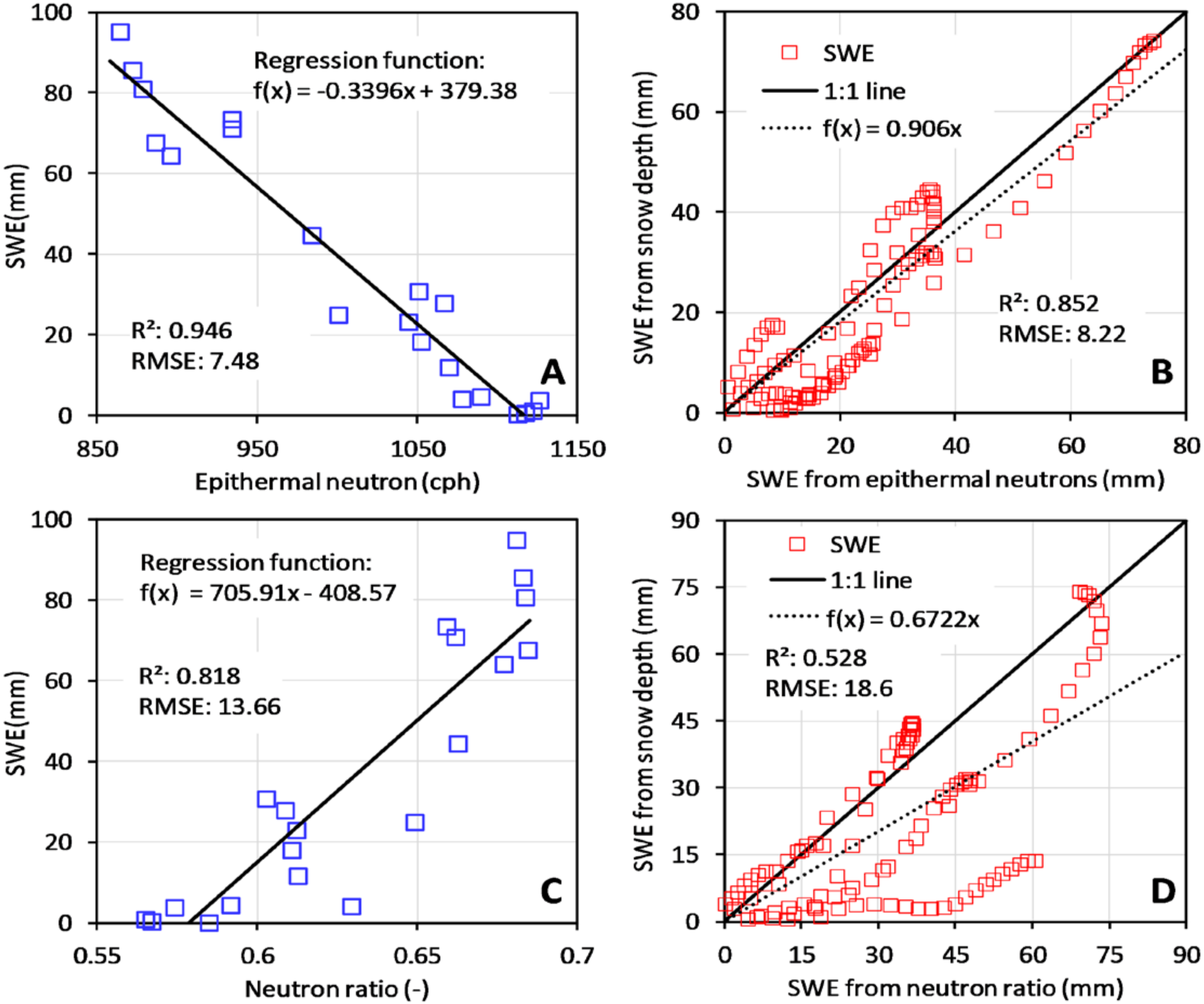
Only snow depth measurements during the build-up phase of the snowpack to exclude any possible influence of snowmelt, density changes in the snowpack, or evaposublimation



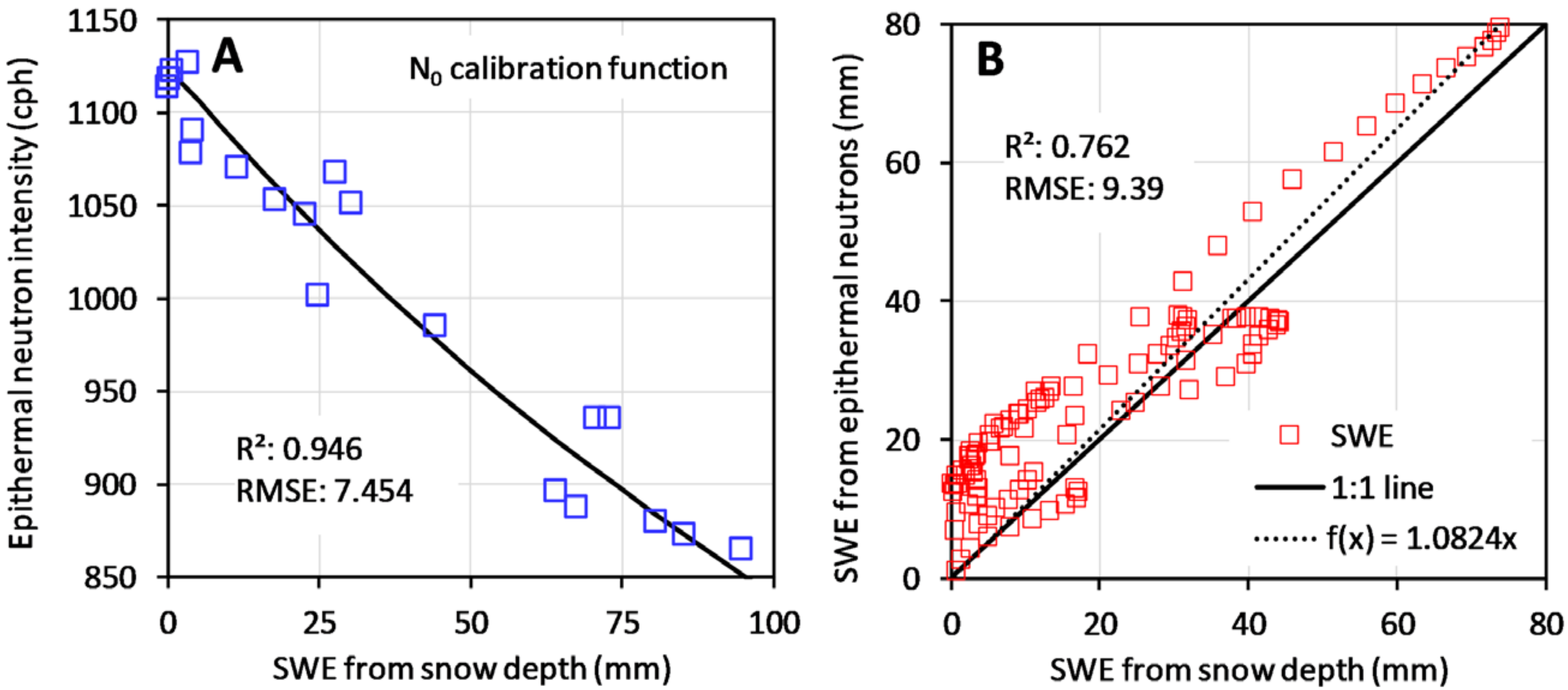
RESULTS - REGRESSION FUNCTIONS

Epitherm. neutrons

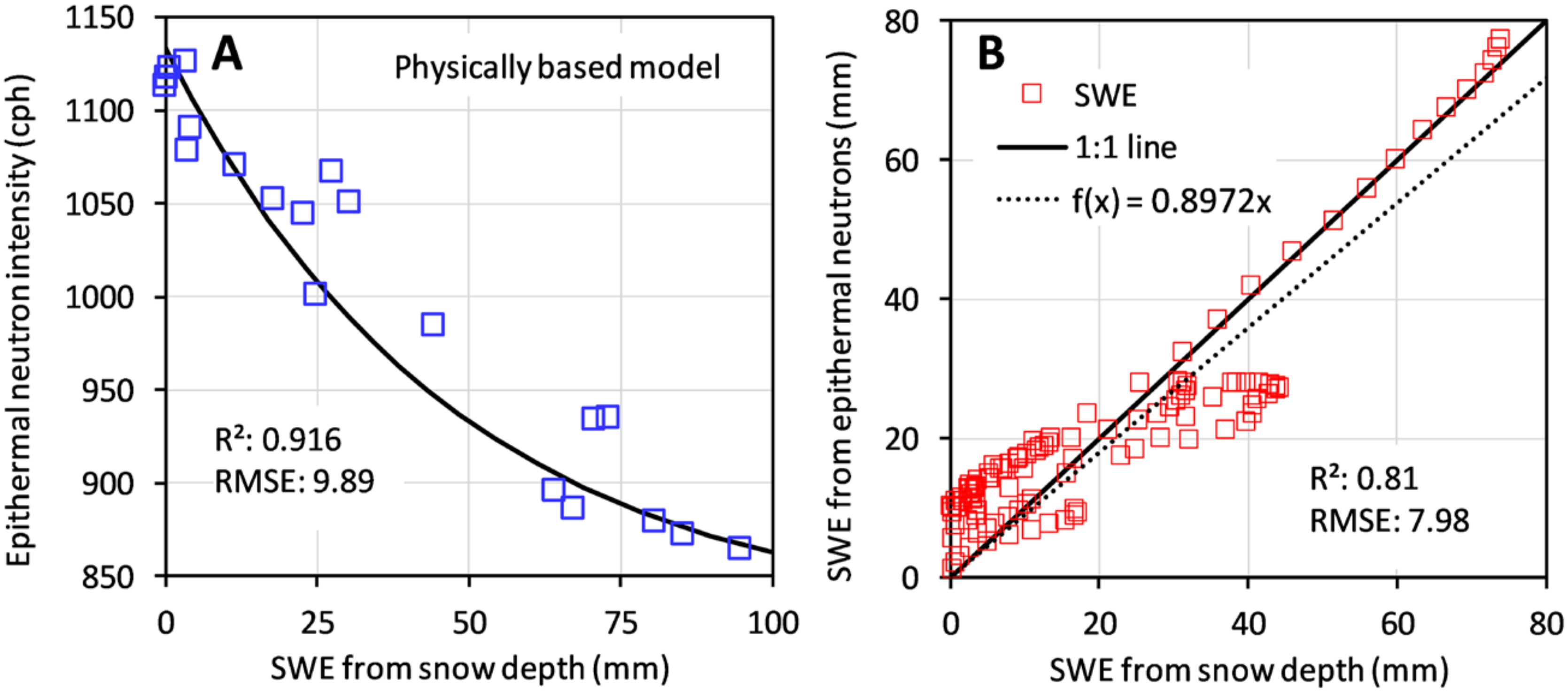
Therm. neutrons



N_0 CALIBRATION FUNCTION



PHYSICALLY-BASED CALIBRATION



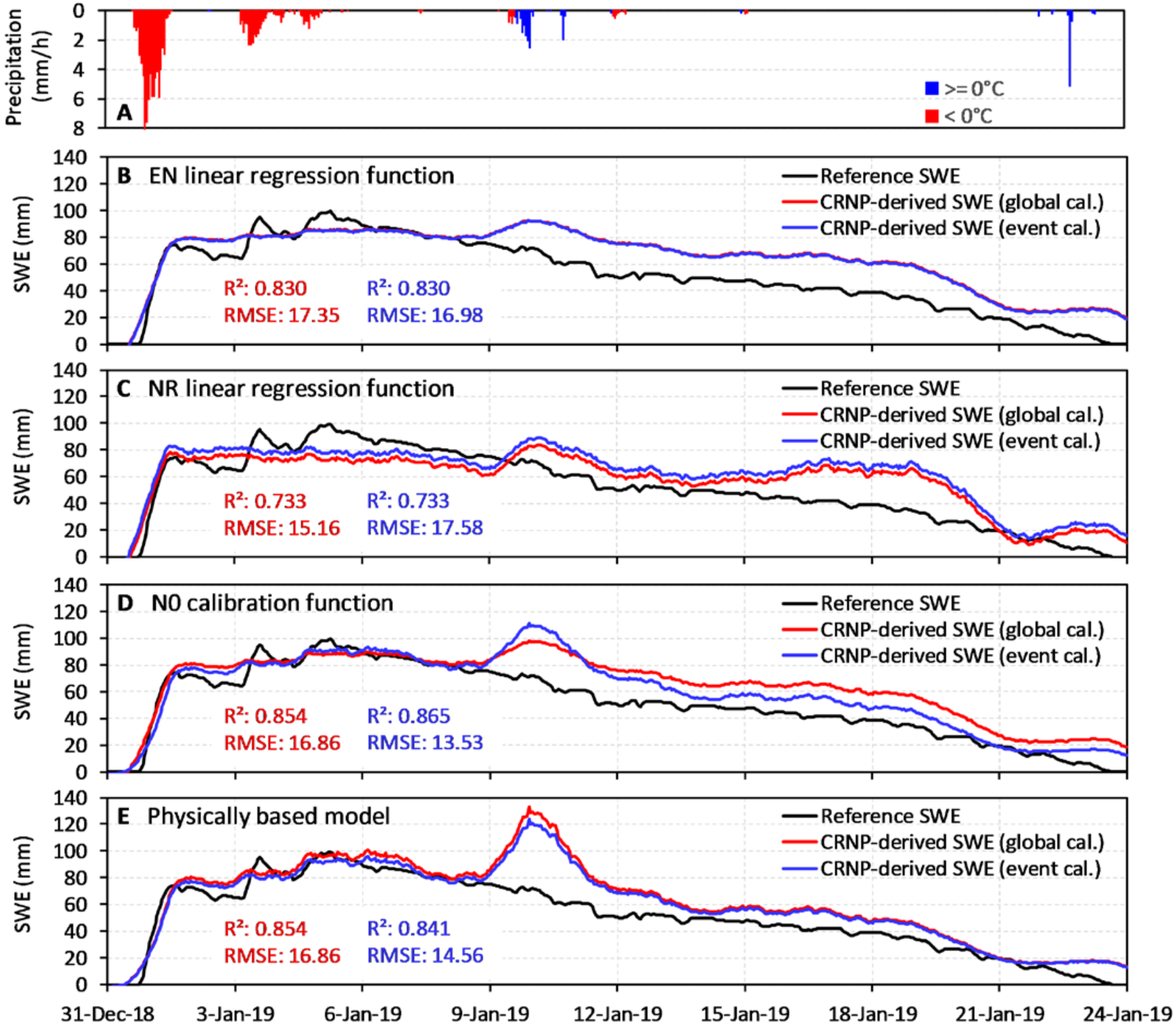
COMPARISON – EVENT SCALE

Epitherm. neutrons regression function

Neutron ratio regression function

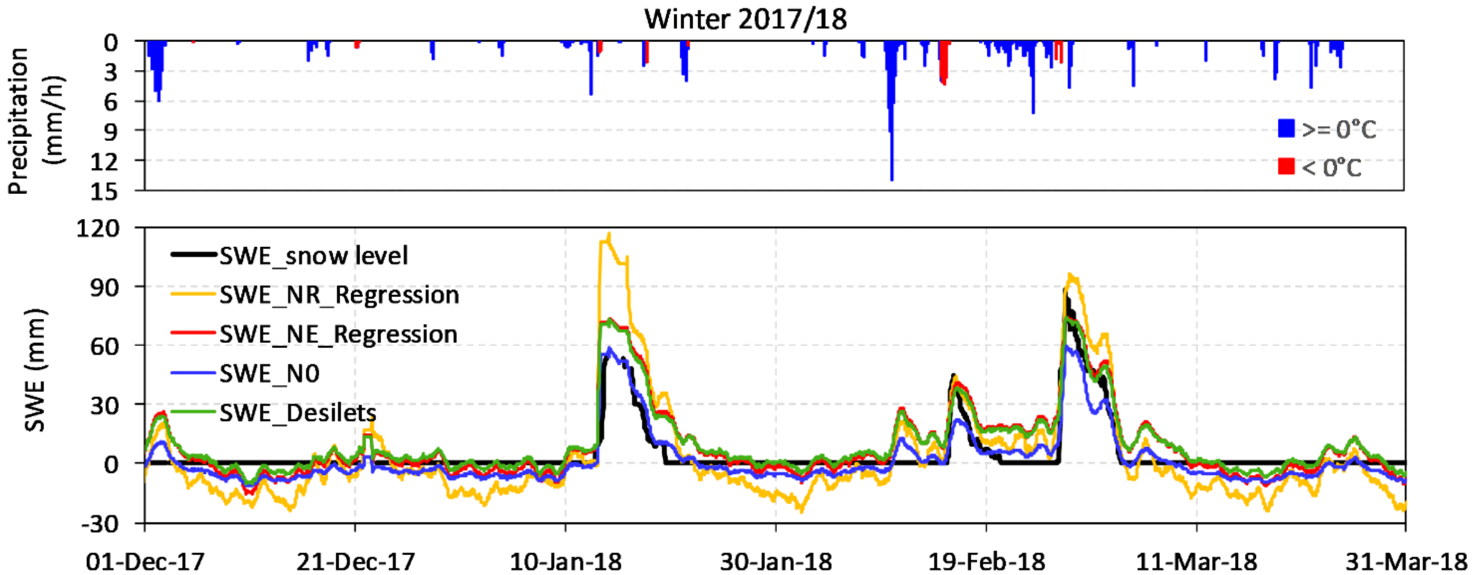
N_0 calibration function

Physically based model

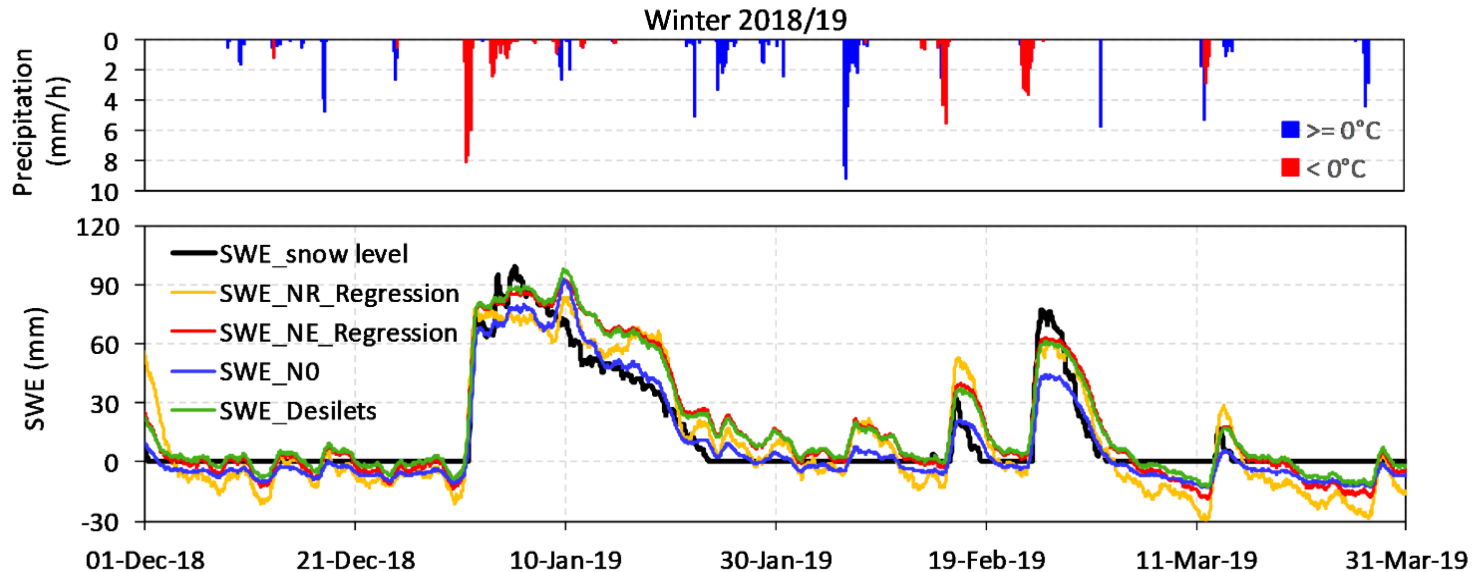


COMPARISON – SEASONAL SCALE

Winter 2017/18

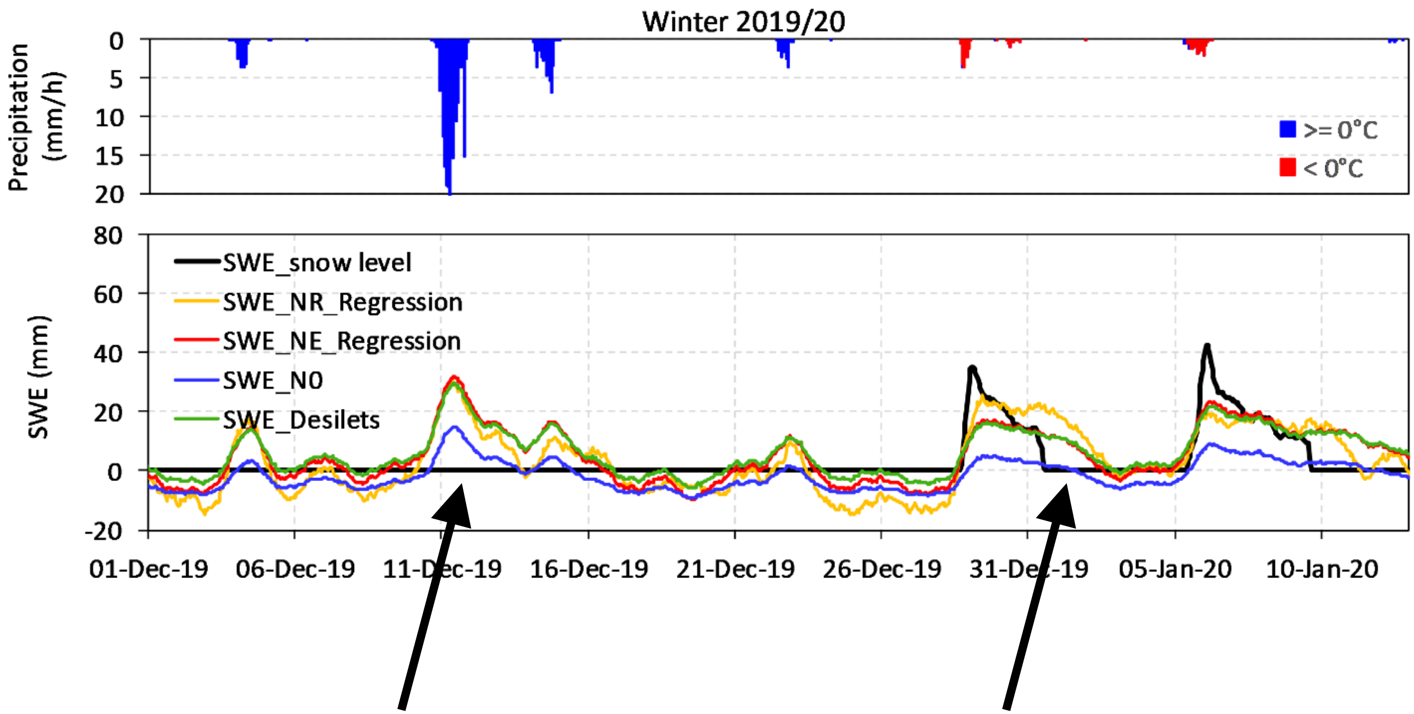


Winter 2018/19



COMPARISON – SEASONAL SCALE

Winter 2019/20



Rainfall with ponding occured

Mismatch in snow cover ending

COMPARISON – ALL SCALES

SWE conversion method	RMSE (mm)		
	Whole period	Winter periods	Snow events
Epithermal neutron regression function	**44.89**	12.50	7.81
Neutron ration regression function	36.69	**16.32**	**9.16**
N_0 calibration function	19.87	**8.92**	**6.37**
Physically based model	**15.44**	9.89	7.42

SUMMARY

- N_0-calibration function and the physically-based calibration function performed best
- Above-ground CRNP can be used for continuous SWE determination
- However, heavy rainfall can lead to erroneous indications of snow events, e.g. due to the occurrence of ponding water
- Future research should seek to improve characterization of onsets and endings of snow cover events, e.g. by combing with other sensors