Coupled Modelling of Water Fluxes and Electrical Self Potential in Melting Snow

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Abstract

Modelling and monitoring seasonal snow are critical for water resource management, flood forecasting and avalanche risk prediction. Snowmelt processes are of particular importance. The behaviour of liquid water in snow has a big influence on melting processes but is difficult to measure, monitor and model. Recent work has shown the promise of electrical self potential measurements for monitoring snow hydrology. To further this aim, detailed modelling of internal water fluxes in melting snow was carried out with FSM and Crocus. These models were coupled to an electrical model of unsaturated flow in snow to create synthetic electrical self potential observations. These synthetic observations were compared to measurements made during two winter field seasons at Col de Porte in the French Alps with a prototype geophysical array installed in October 2018. Different representations of liquid water flow were used to force the electrical model to evaluate its ability to reproduce the measured self potential signals, and to investigate the suitability of the self potential array as part of a coupled geophysical monitoring and modelling system.

Coupled modelling of meltwater fluxes and electrical self potential in melting snow

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Introduction

- Liquid water in snow is an important control on melt timing, runoff generation, and consequently flood and avalanche risk
- It is difficult to measure, both in situ and remotely
- This talk outlines the development of a prototype geophysical measurement system for monitoring liquid water movement in seasonal snow
- This was combined with an electrical model to attempt to detect internal water fluxes in a seasonal snowpack

Background

Self potential measurements have been successfully used in the cryospheric sciences using manual surveying techniques:

Cross-coupled flow modeling of coincident streaming and electrochemical potentials and application to subglacial self-potential data

Bernd Kulessa,[1] Bryn Hubbard, and Giles H. Brown[2]

Centre for Glaciology, Institute of Geography and Earth Sciences, University of Wales, Aberystwyth, UK

Integrated electrical resistivity tomography (ERT) and self-potential (SP) techniques for assessing hydrological processes within glacial lake moraine dams

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Bulk meltwater flow and liquid water content of snowpacks mapped using the electrical self-potential (SP) method

Sarah S. Thompson[1,a], Bernd Kulessa[2], Richard L. H. Essery[3], and Martin P. Lüthi[4,a]

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Self potential theory

- **Passive** measurement
- Tiny electrical potentials are generated when liquid flows through a permeable material due to charge separation at the liquid/solid interface
- The greater the liquid flow and liquid water content, the greater the electrical potential
- These potentials can be measured in snow with a high impedance voltmeter

Theory and numerical modeling of electrical self-potential signatures of unsaturated flow in melting snow

B. Kulessa,[1] D. Chandler,[2] A. Revil,[3,4] and R. Essery[5]

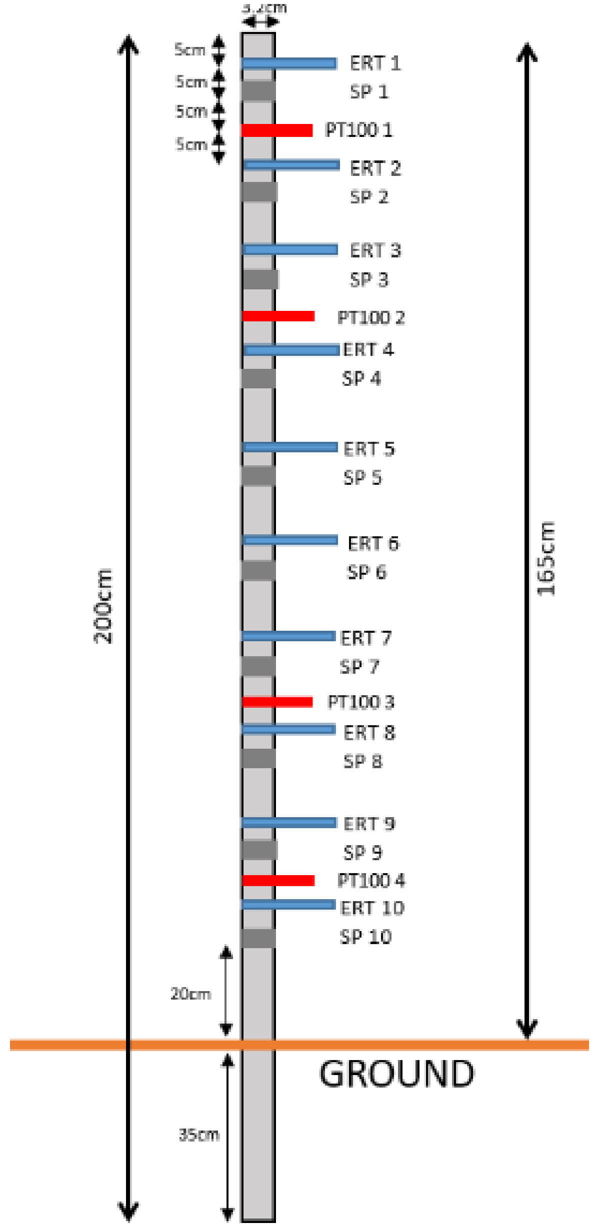
Self potential model for unsaturated snow

- Relates main snow hydrology variables to electrical behaviour
- Successfully used in manual laboratory and supraglacial snow experiments

Col de Porte study site

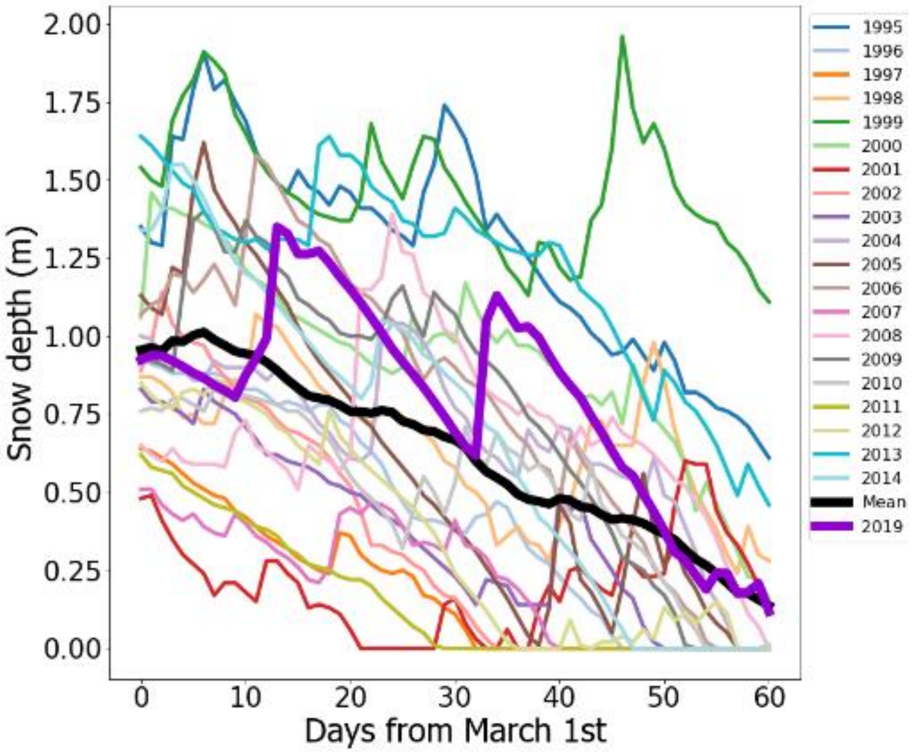
- Part of Meteo France's snow research centre (Centre d'Etude de la Neige)
- 1325m asl in Chartreuse Alps, near Grenoble, SE France
- Full meteorological and hydrological observations for driving and verifying snow models
- Site relatively mild so usually several snowmelt events each winter
- Possibility of rain-on-snow events

Prototype design and installation

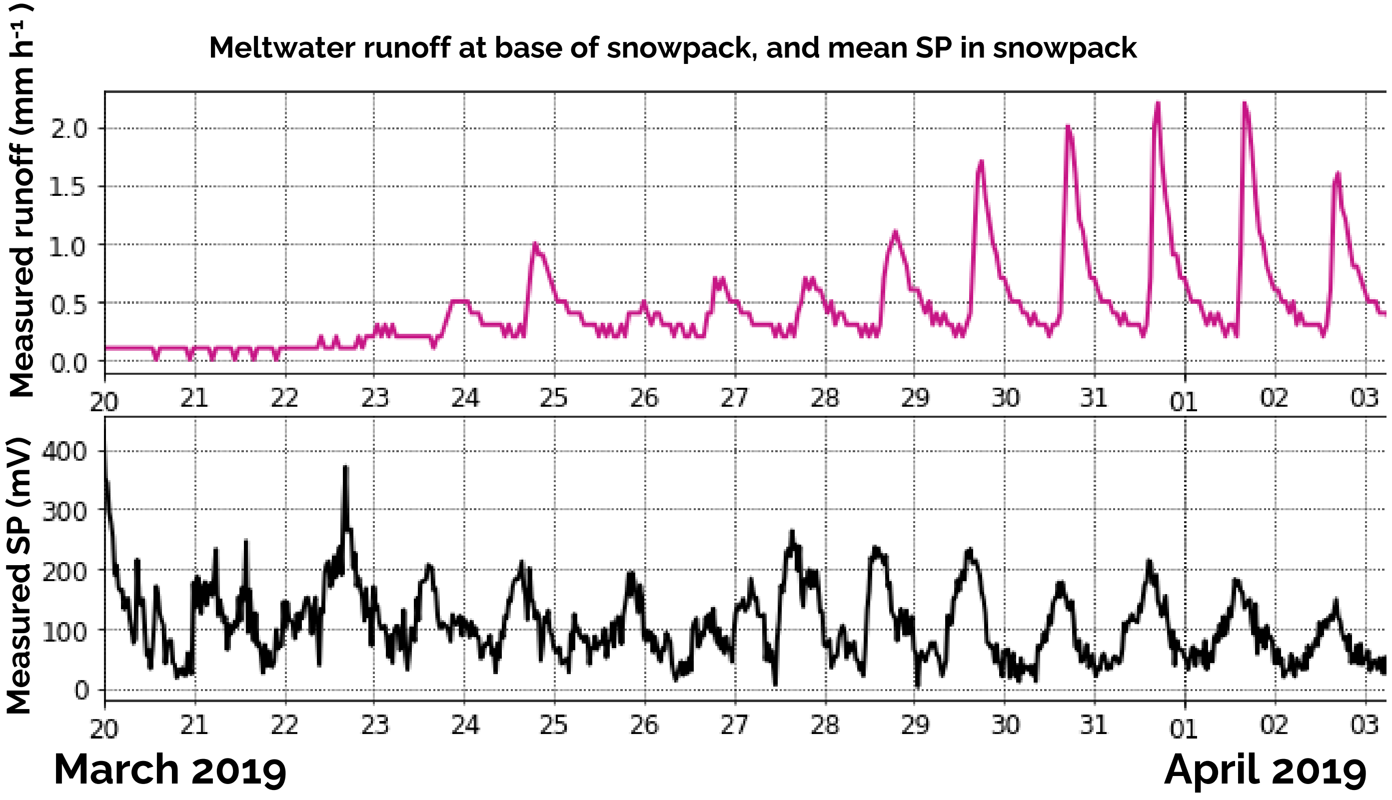


- recreated established manual survey protocol
- 4 poles with 10 lead electrodes each
- Campbell CR1000 logger and multiplexer chips measure potential between buried reference and pole electrodes
- Also included PT100 thermistors and soil moisture sensors

Winter 2018-19



March 2019 snowmelt



- Strong diurnal SP signal occurs during melt period, but does not correlate well with **bulk** runoff

- Dye tracing experiments showed strong water fluxes within the snowpack not reaching the base as runoff
- SP signals must be being generated **within** the snow

Hydrological modelling

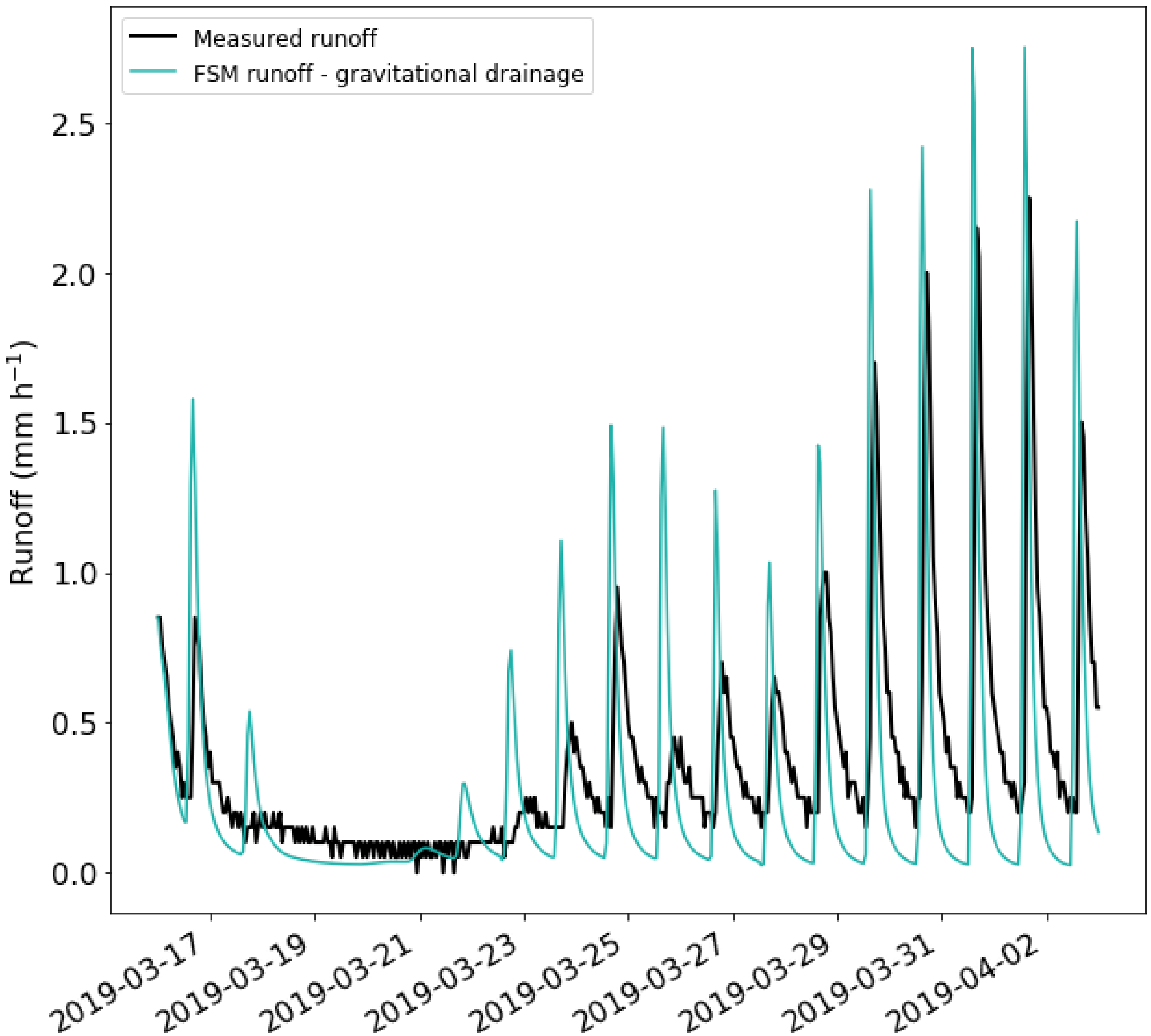
Flexible Snow Model

- Investigative snow model developed by Richard Essery
- Allows easy switching of parameterisations
- Latest version includes diagnostics of inter-layer liquid water flux, and a gravitational drainage hydrology scheme
- Used configurations with free-draining hydrology, bucket hydrology, and gravitational drainage

CROCUS

- Meteo France operational snow model
- Used for coupled land-atmosphere simulations and operational avalanche forecasting
- In February 2020 during a research visit to CEN I added an inter-layer liquid water flux diagnostic
- Used configuration with bucket hydrology

Runoff simulations



Electrical modelling

$$\Psi_1(t_n) = \frac{\varepsilon\zeta}{\sigma_w}\frac{S_w(t_n)}{S_e^n(t_n)}\frac{1}{kA}Q(t_n)$$

- ε: Dielectric permittivity
- ζ: Zeta potential
- $S_w(t_n)$: Relative saturation
- $Q(t_n)$: Discharge
- A: Cross-sectional area
- $\Psi_1(t_n)$: Predicted self potential
- σ_w: Porewater electrical conductivity
- S_e: Effective saturation
- k: Parameterised permeability (Shimizu 1970)

$$k = 0.077 d^2 e^{-0.0078\rho_s}$$

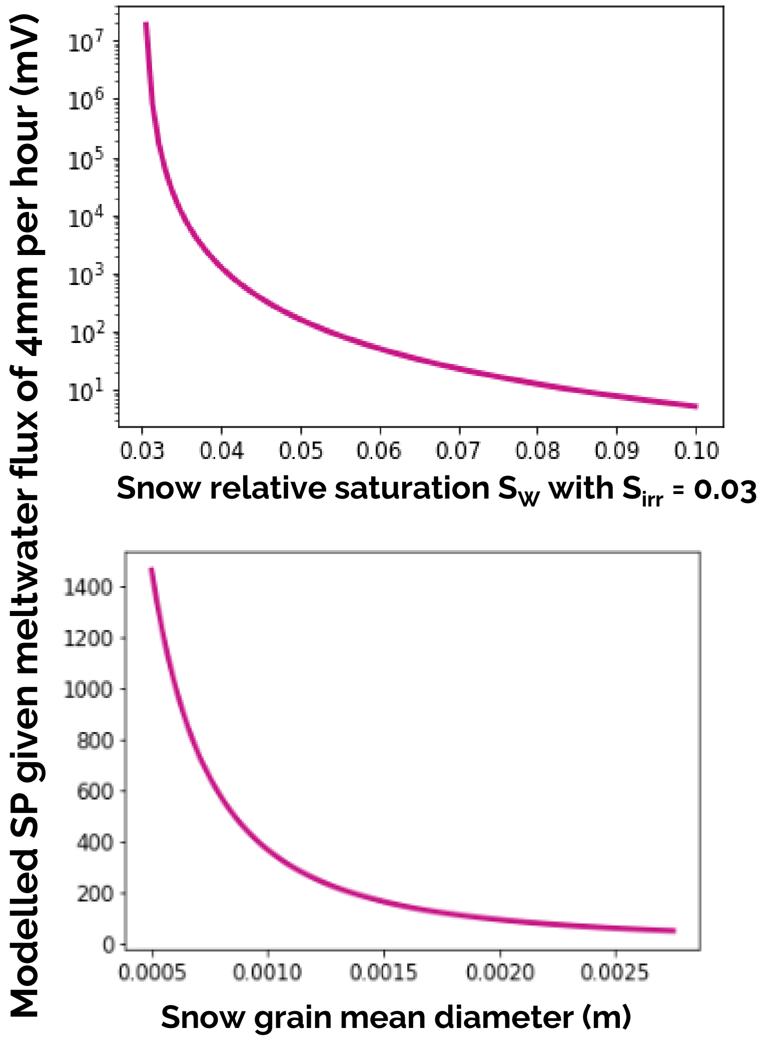
- ρ_s: Snow density
- d: Snow grain diameter

$$S_e = \frac{S_w - S_w^{ir}}{1 - S_w^{ir}}$$

- S_w^{ir}: Irreducible water saturation

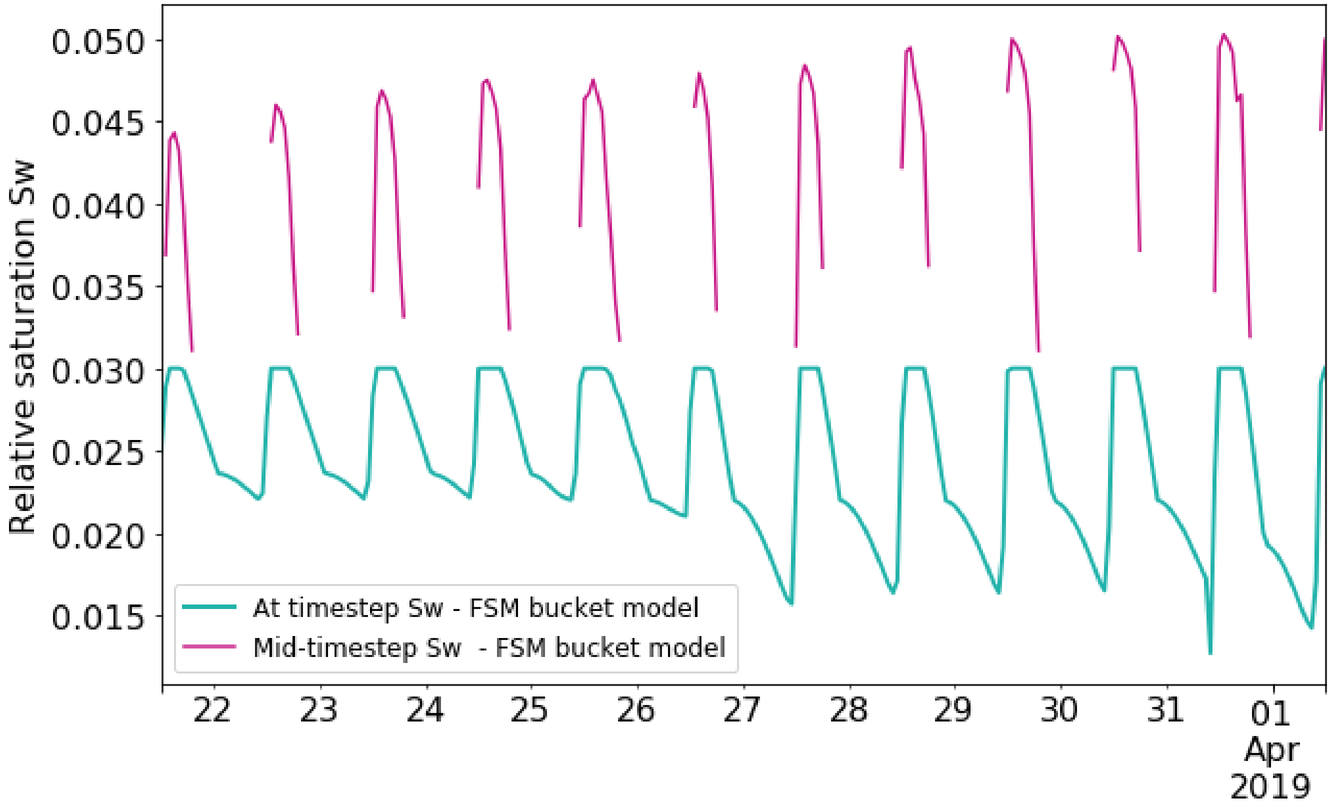
Kulessa et al. (2012) and Thompson et al. (2016)

Model sensitivity to snow properties



Model coupling

- Modelling self potential requires liquid water **flux** in the snow, and S_w to be greater than S_{irr}
- In a bucket or free-draining hydrological model, $S_w = S_{irr}$ at the end of each timestep
- The flux occurs **between** timesteps, when $S_w > S_{irr}$
- Therefore need to calculate **mid-timestep flux** and **mid-timestep S_w**



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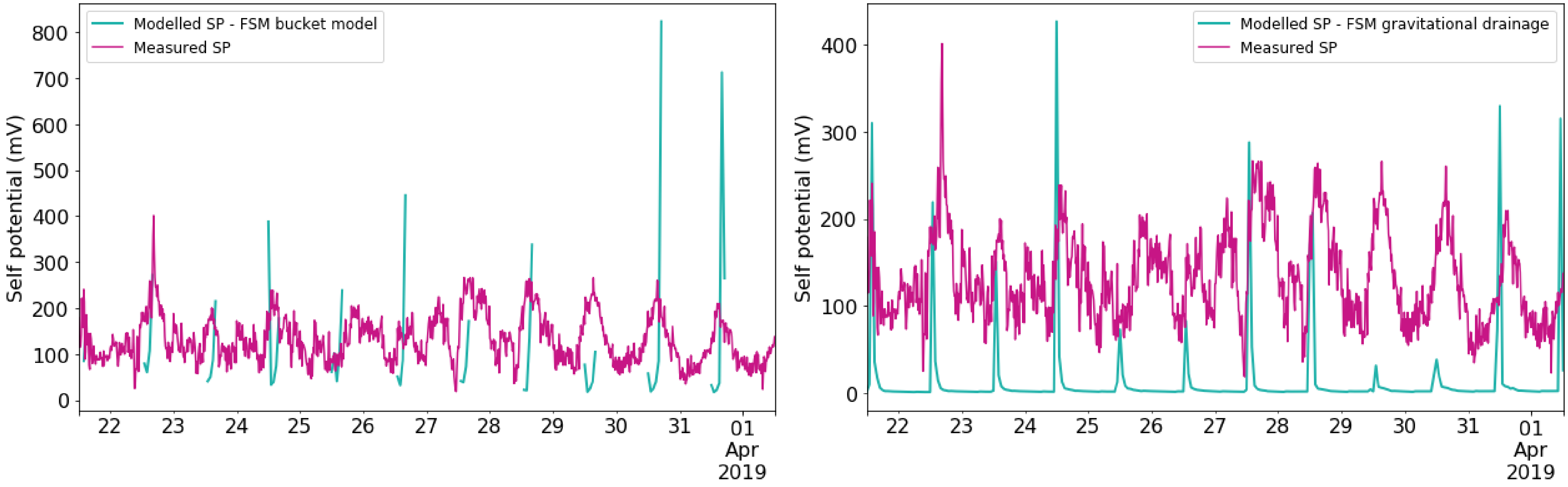
Modelled internally-generated self potential for lowest 3 layers



Measured SP is mean over 4 poles and 3 lowest electrodes, and modelled SP is 3 lowest layers of snow model

Conclusions and further work

- It is possible to make reasonable predictions of self potential in snow by modelling internal water fluxes
- The better the bulk runoff simulation, the better the self potential prediction, and hence the better the internal water flux representation in the models
- Gravitational drainage hydrology produces the best self potential predictions

Future plans:

- I will investigate other parameterisations of snow properties and look at their effect on self potential prediction, and hence internal flux simulation
- Inversion of the self potential measurements should in theory yield predictions of snow properties, but models are needed to constrain inversions

Thanks for watching!

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