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

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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]

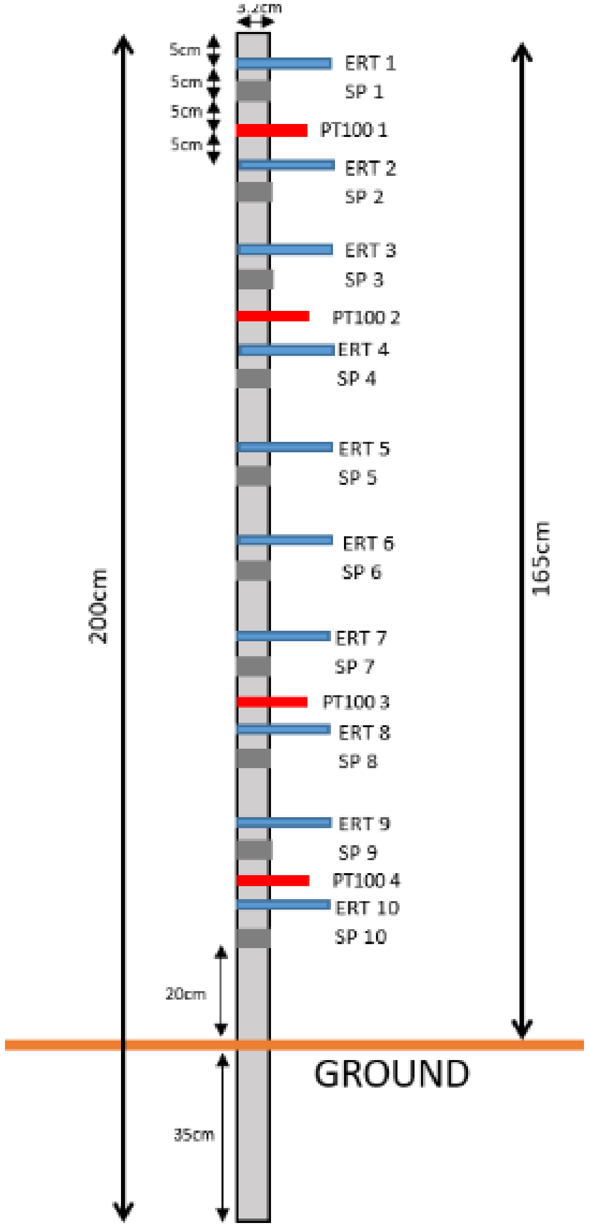
Self potential model for unsaturated snow

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

Col de Porte study site

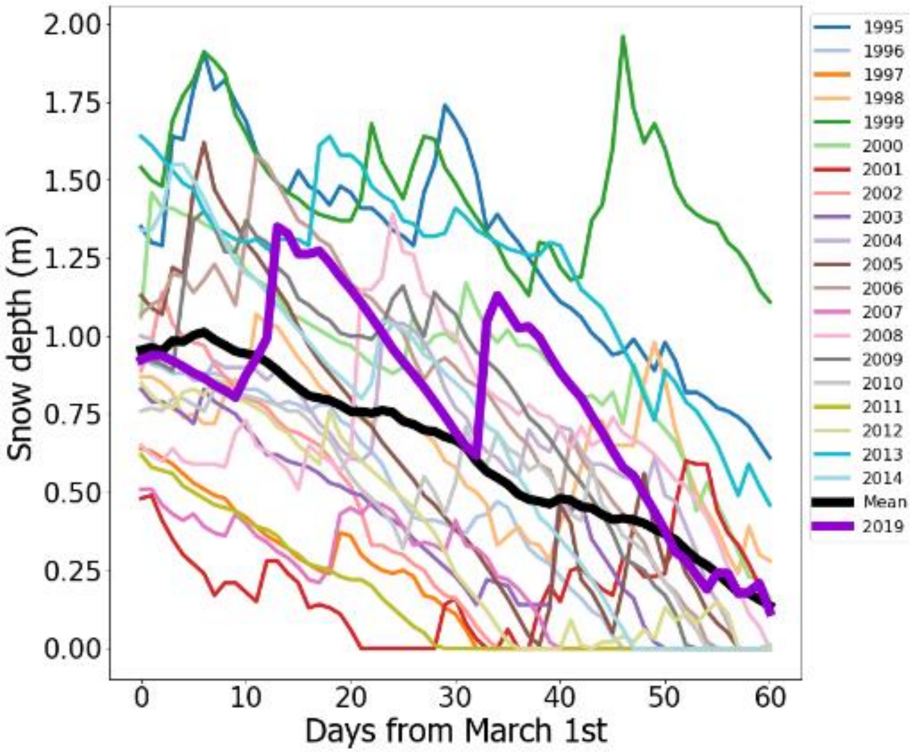
- Part of Meteo France's snow research centre (Centre d'Etude de la Neige)
- 1325m asl in Chartreuse Alps, near Grenoble, SE France
- Full meteorological and hydrological observations for driving and verifying snow models
- Site relatively mild so usually several snowmelt events each winter
- Possibility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

Prototype design and installation

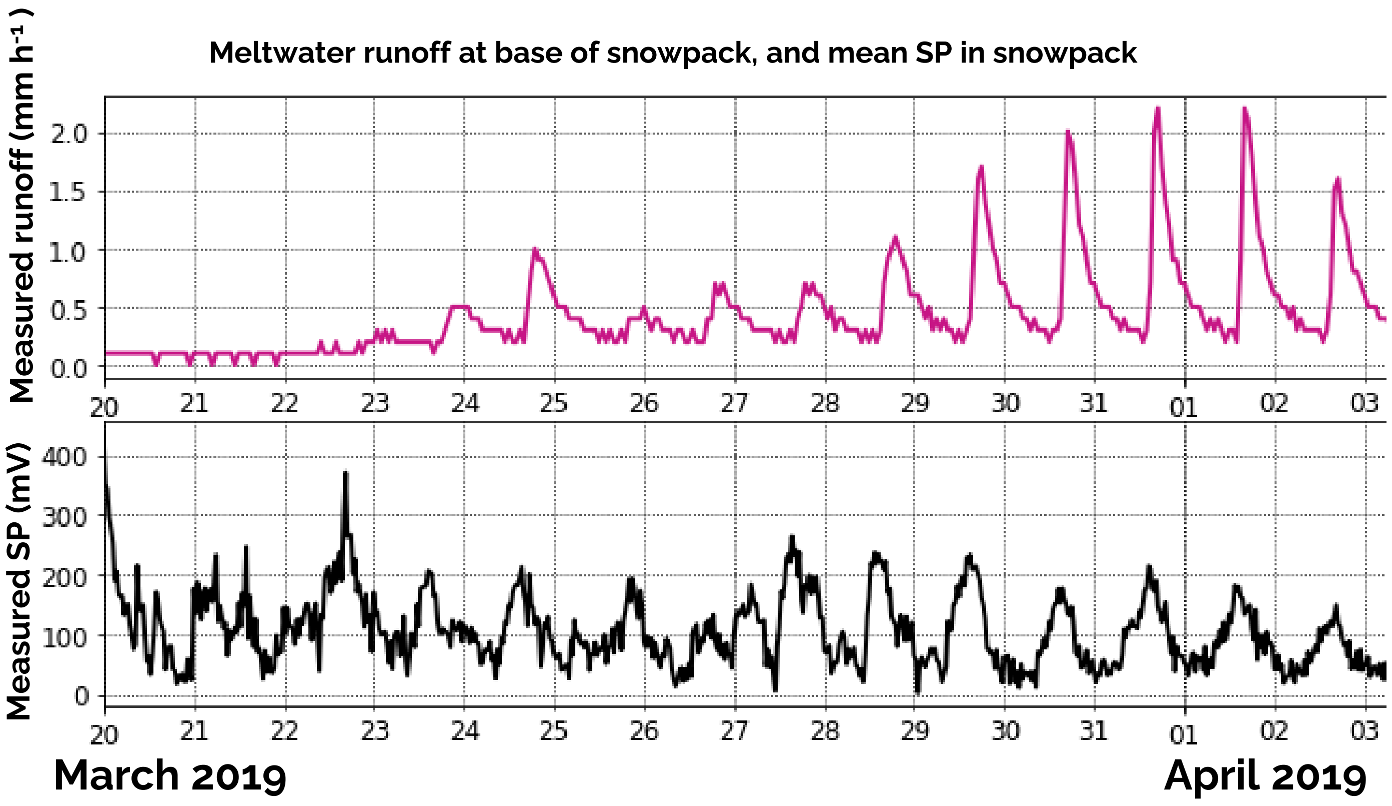


- recreated established manual survey protocol
- 4 poles with 10 lead electrodes each
- Campbell CR1000 logger and multiplexer chips measure potential between buried reference and pole electrodes
- Also included PT100 thermistors and soil moisture sensors

Winter 2018-19



March 2019 snowmelt



- 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

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

Hydrological modelling

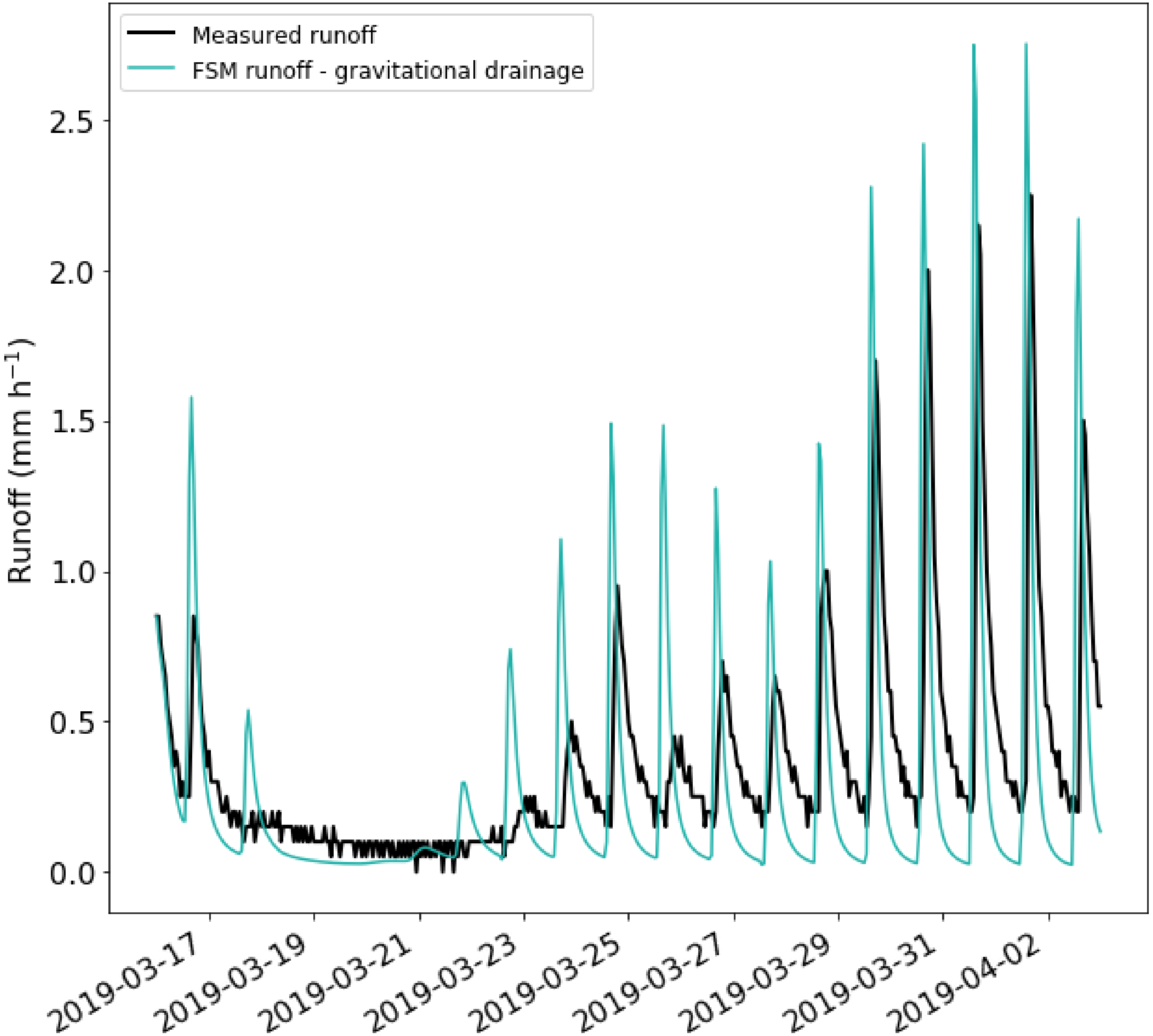
Flexible Snow Model

- 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

$$\Psi_1(t_n) = \frac{\varepsilon\,\zeta}{\sigma_{\mathrm{w}}}\,\frac{S_{\mathrm{w}}(t_n)}{S_{\mathrm{e}}^{n}(t_n)}\,\frac{1}{kA}\,Q(t_n)$$

- Dielectric permittivity (ε)
- Zeta potential (ζ)
- Relative saturation (S_{w})
- Discharge (Q)
- Cross-sectional area (A)
- Predicted self potential (Ψ_1)
- Porewater electrical conductivity (σ_{w})
- Effective saturation (S_{e})

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

Parameterised permeability (Shimizu 1970)

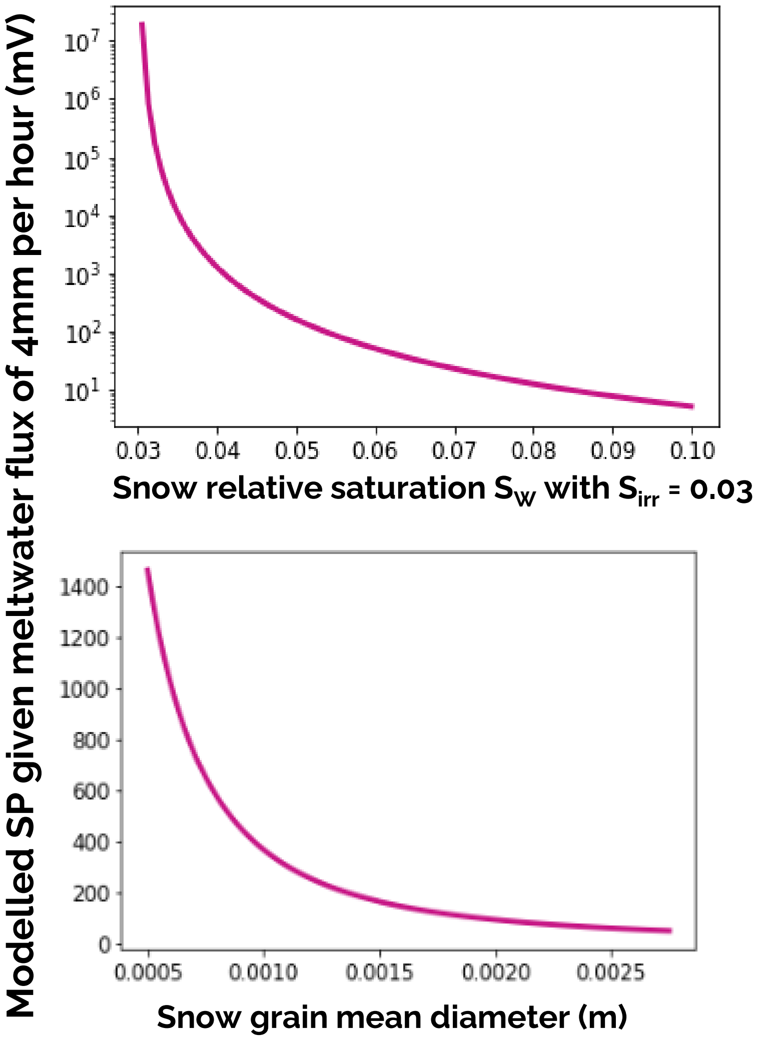
- Snow density (ρ_s)
- Snow grain diameter (d)

$$S_{\mathrm{e}} = \frac{S_{\mathrm{w}} - S_{\mathrm{w}}^{\mathrm{ir}}}{1 - S_{\mathrm{w}}^{\mathrm{ir}}}$$

- Irreducible water saturation ($S_{\mathrm{w}}^{\mathrm{ir}}$)

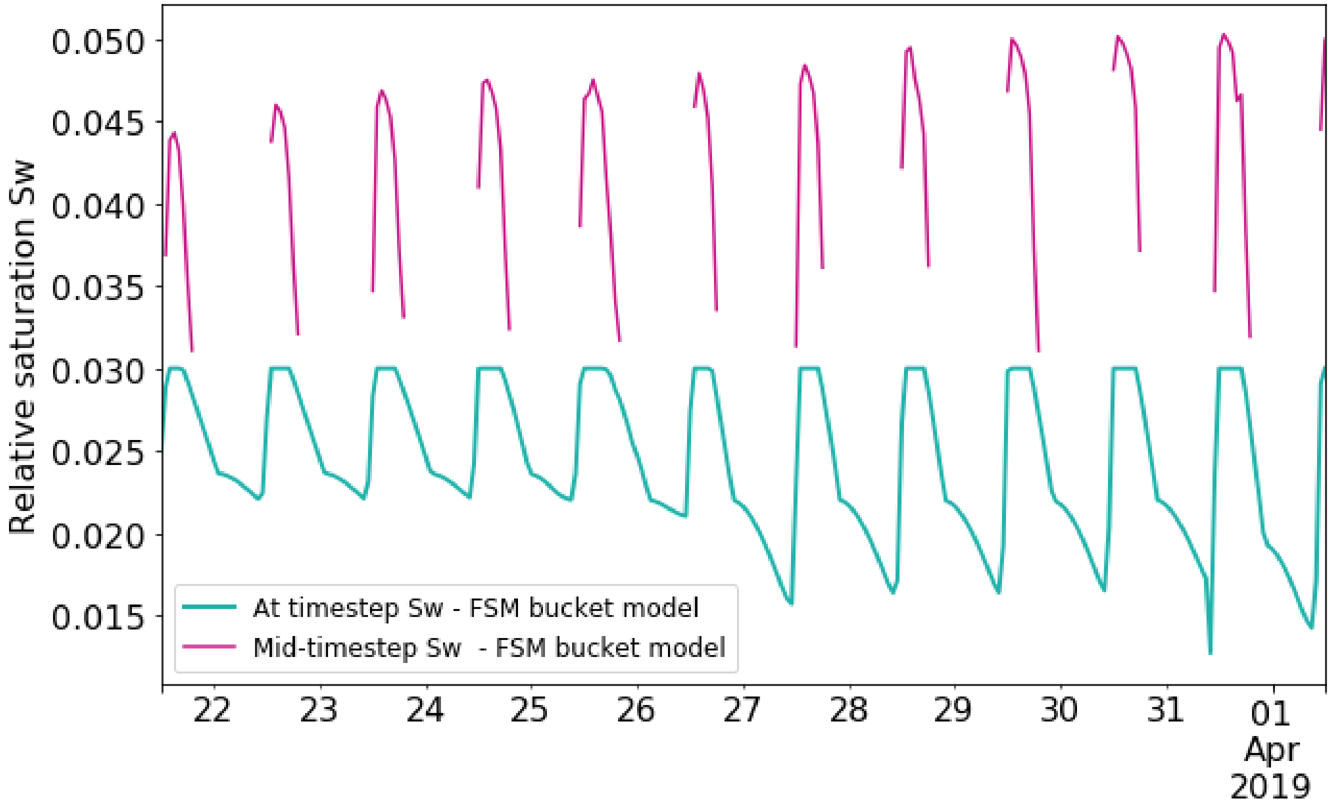
Kulessa et al. (2012) and Thompson et al. (2016)

Model sensitivity to snow properties

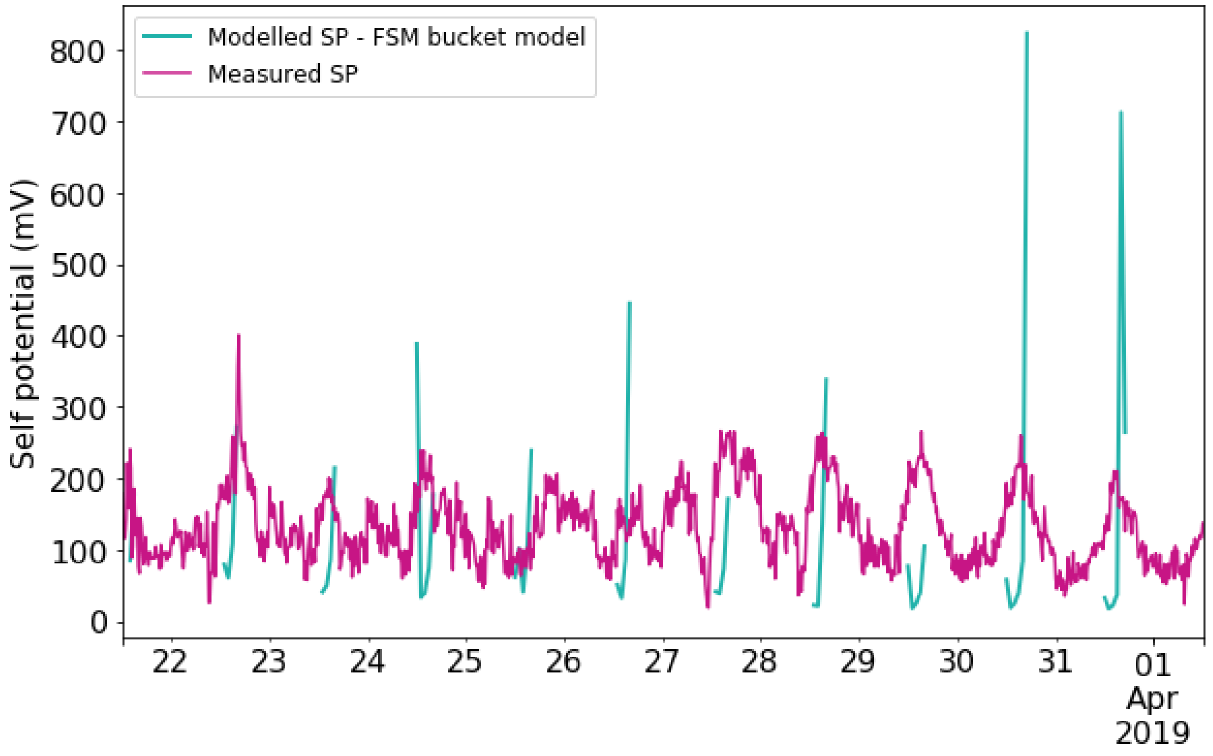


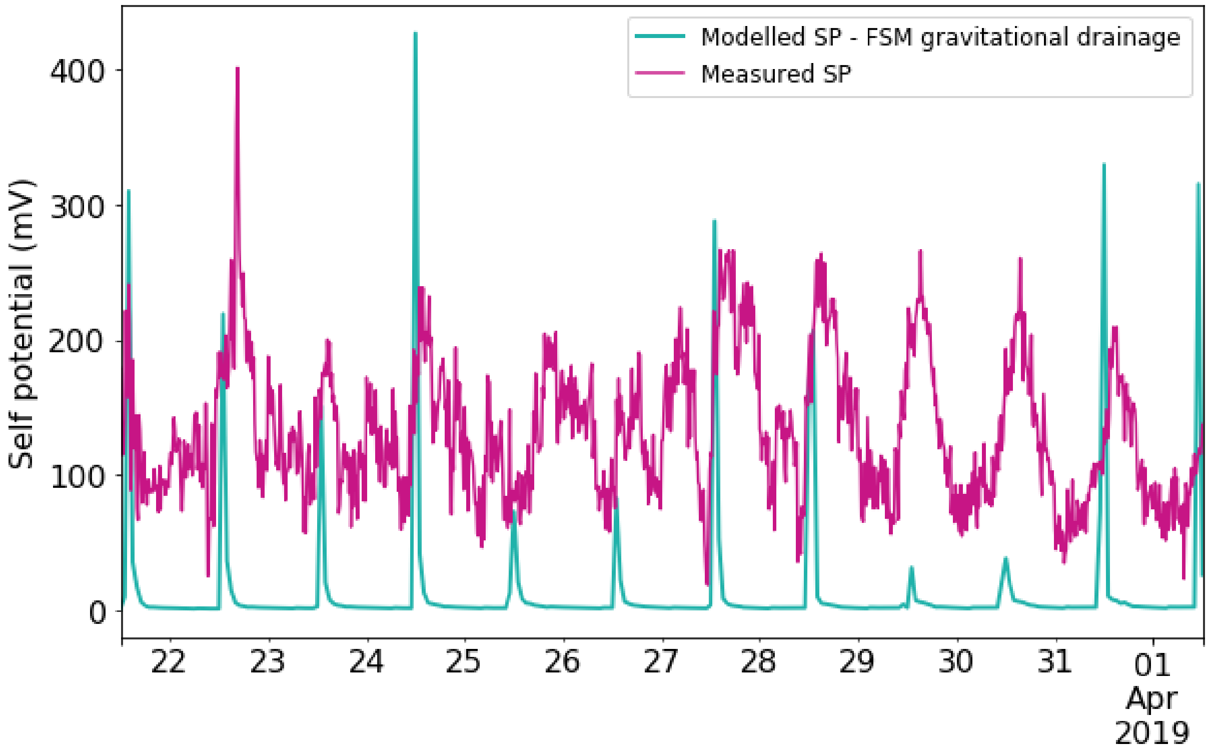
Model coupling

- 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



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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