Impact of volcanic ash on snow and permafrost hydrology, Iceland

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1.0 Introduction

Extensive ash and aeolian dust on snow have significant impacts on the availability and quality of water resources in both volcanically active and other wind-blown regions.


Photo credit: Kathy L. Young

Fig. 1.1. Stream flowing through ash covered landscape carries a load of ash sediment.

While little dust or ash on snow surfaces can accelerate snowmelt and quicken the runoff [1], few studies have systematically explored the hydrological impacts of too much ash on arctic snowpacks, in particular its role in insulating and delaying snowmelt, promoting growth of permafrost (frozen ground) and altering surface and subsurface flow, especially in geothermally sensitive regions such as Iceland [2]. Coupled to this hydrological uncertainty is the added complexity of climate variability/change. For Iceland, recent climate change models predict higher temperatures, heavier precipitation (rainfall and snowfall) and more frequent wind storms [3, 4, 5].


Photo credit: Kathy L. Young

Fig. 1.2. Late-lying snowbed with a light ash cover. Ash is redistributed by aeolian activities.

Additional extreme events will trigger added occurrences of rapid flooding from ash/mud-choked streams further disrupting water supplies and affecting roads and bridges. Availability of suitable hydrological models and algorithms to explore and anticipate these events, both here and in other similar terrain are lacking.


Photo credit: Kathy L. Young

Fig. 1.3. Ash load in a stream and need for dredging.

2.0 Study Objectives

Field measurements and numerical modeling will provide new information on ash-snowmelt runoff processes in sporadic permafrost, volcanically active catchments, and with respect to climate change.
The goal of this study is to:

i) use field and experimental approaches to evaluate both slope and catchment runoff in response to varying volcanic ash cover across Iceland's diverse terrain including areas devoid of permafrost and geothermal activity versus sites containing sporadic permafrost and warm groundwater owing to "hot spots";

ii) refine and customize a cold regions hydrology model [6] with new algorithms for ash-snow-permafrost processes, including modifications for geothermally active terrain, ultimately improving understanding of these processes;

iii) integrate field and modeling work with GIS and remote sensing to identify source areas of potential water and ash/mud floods in non-glacial basins across Iceland under present conditions and future extreme events (climatic and volcanic eruptions).

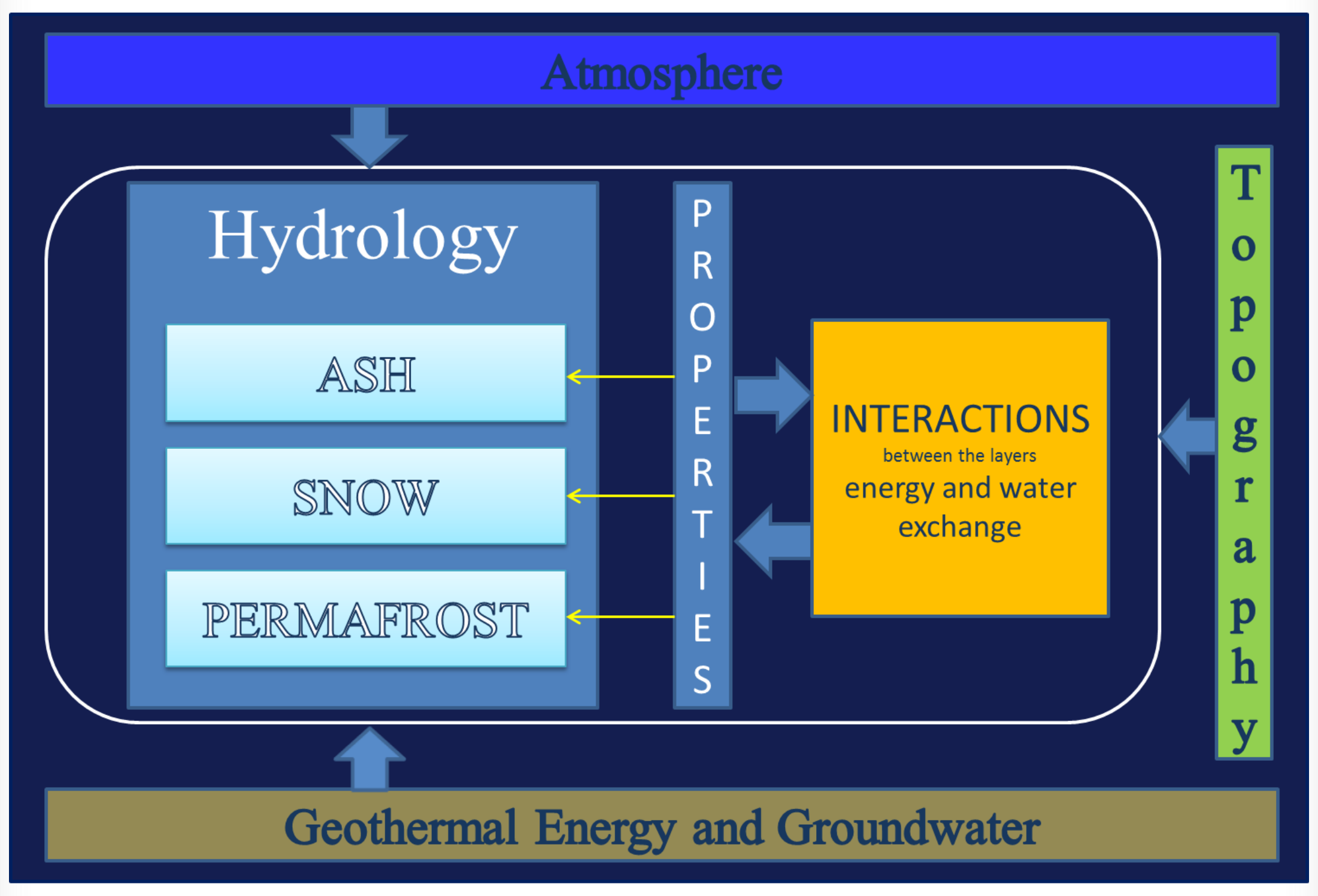
Atmosphere
Hydrology
ASH
SNOW
PERMAFROST
PROPERTIES
INTERACTIONS
between the layers
energy and water exchange
Topography
Geothermal Energy and Groundwater

Fig. 2.1. Schematic of the factors and processes affecting energy and water flow in ash/dust covered northern landscapes.

3.0 Study Sites

Two small catchments (< 1 km^2) have been selected for this research (Site 1 and Site 2 on Figure 3.1). Site 1 is located close to the southern coast of Iceland (63°34.2'N 19°32.70'W). It received dust from Eyjafjallajökull eruption (April 2010) and continues to receive it through aeolian activity but contains no permafrost and experiences heavy rainfall. An interior site (Site 2) (64°03.1'N 18°30.7'W) contains a late-lying snowbed and was dusted with ash from Grímsvötn eruption (May 2011). Due to its high elevation and cold winters the site likely contains sporadic permafrost. Geothermal hot spots are prevalent in the area.

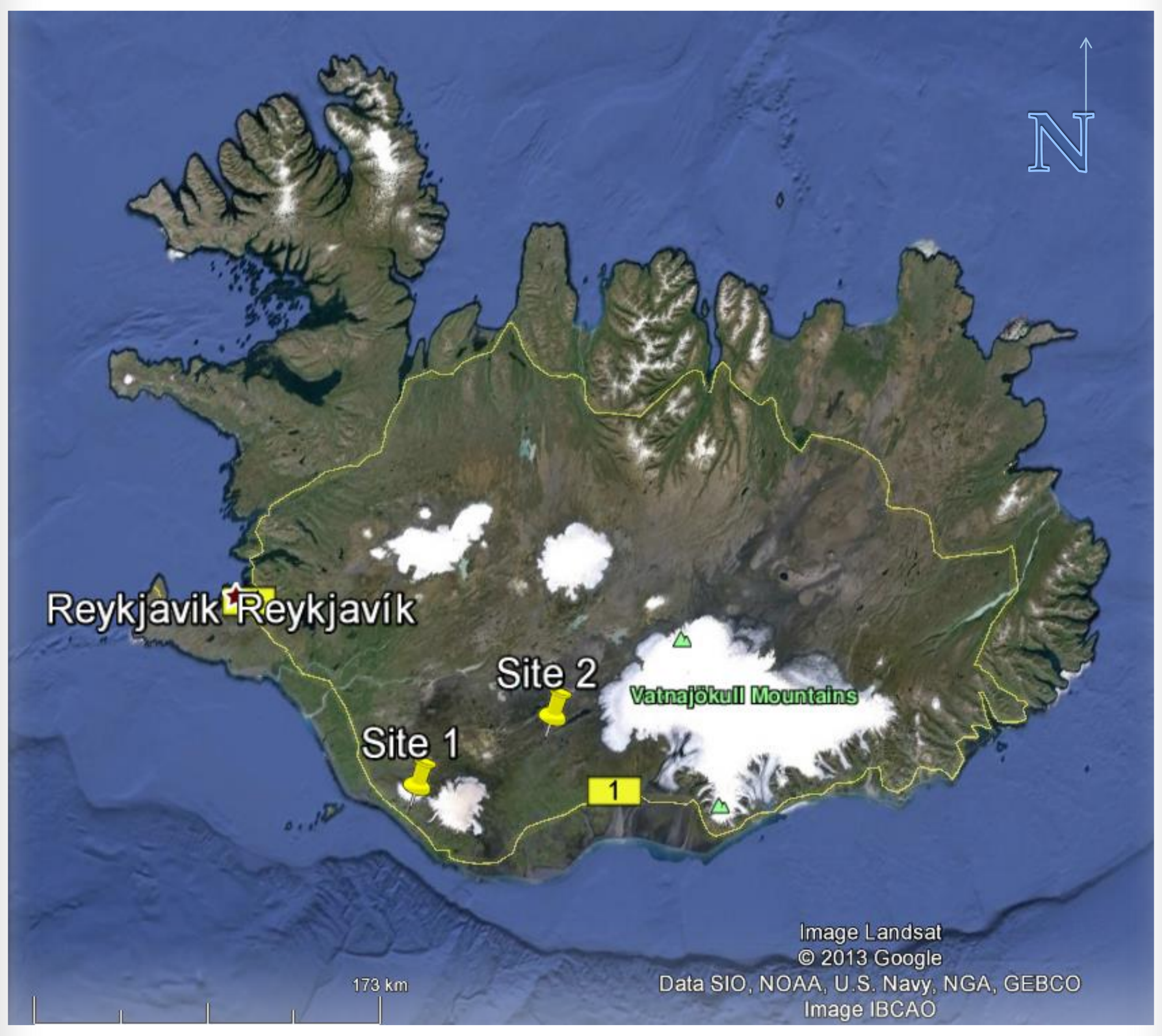

Image Landsat
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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Fig. 3.1 Location of study sites (Site 1 and Site 2) in Southern Iceland.

Climate and Weather

Gulf Stream moderates climate of Iceland. Mild Atlantic air comes in contact with cold Arctic air causing frequently changing and stormy weather. Dust storms are frequent in Iceland.
Following Köppen's Climate Classification, southern coastal Iceland experiences cold oceanic climate (on average 0°C in winter and 10-15°C in summer, mean annual precipitation >4000mm). The interior is characterized by tundra climate (on average -10°C in winter and 5-10°C in summer, mean annual precipitation 2000 – 4000mm)[7].

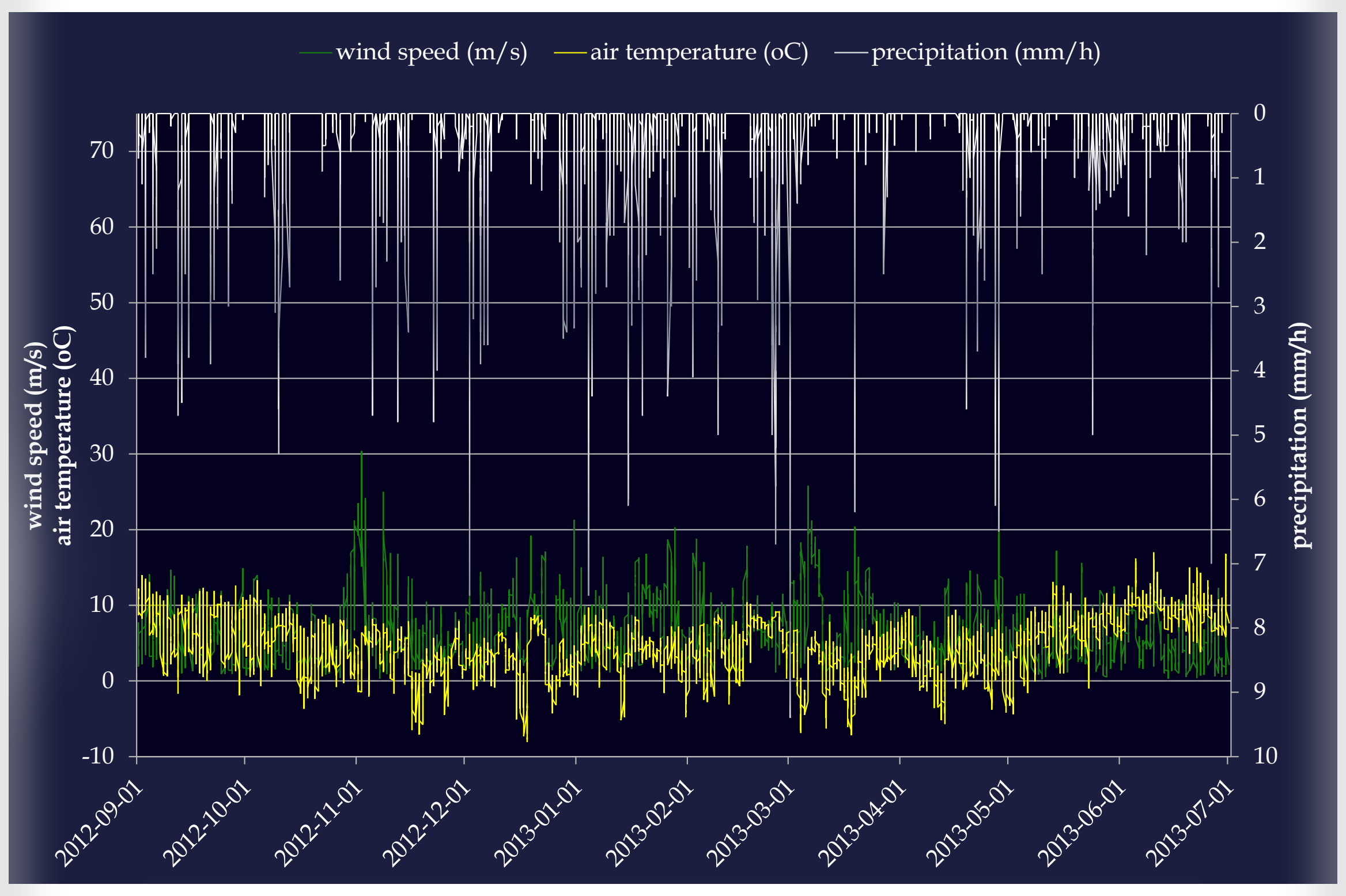


Fig.3.2. Meteorological data at Önundarhorn weather station, September 01, 2012 – July 01, 2013. This weather station is located ~10 km south from Site 1. Air temperature oscillates around zero during winter.

Geothermal Energy

The temperature gradient in the crust in Iceland ranges from 0 to 500 °C/km. It depends on the distance from the volcanic rift zone, depth, availability of groundwater, regional heat flow through the crust, hydrothermal activity, residual heat in extinct volcanic centres, and porosity of the rock (which affects the mode of heat flux: conduction for dense basaltic rock and convection for porous lava) [8].
Geothermal areas in Iceland are divided into high temperature fields and low temperature fields (Figure 3.3). The high temperature fields are located in the volcanic rift zone. The temperature within the high temperature fields are usually around 200°C at 1km depth. The upper layer of permeable rock is cooled by the flow of groundwater. Temperature at low temperature fields is less than 150°C.

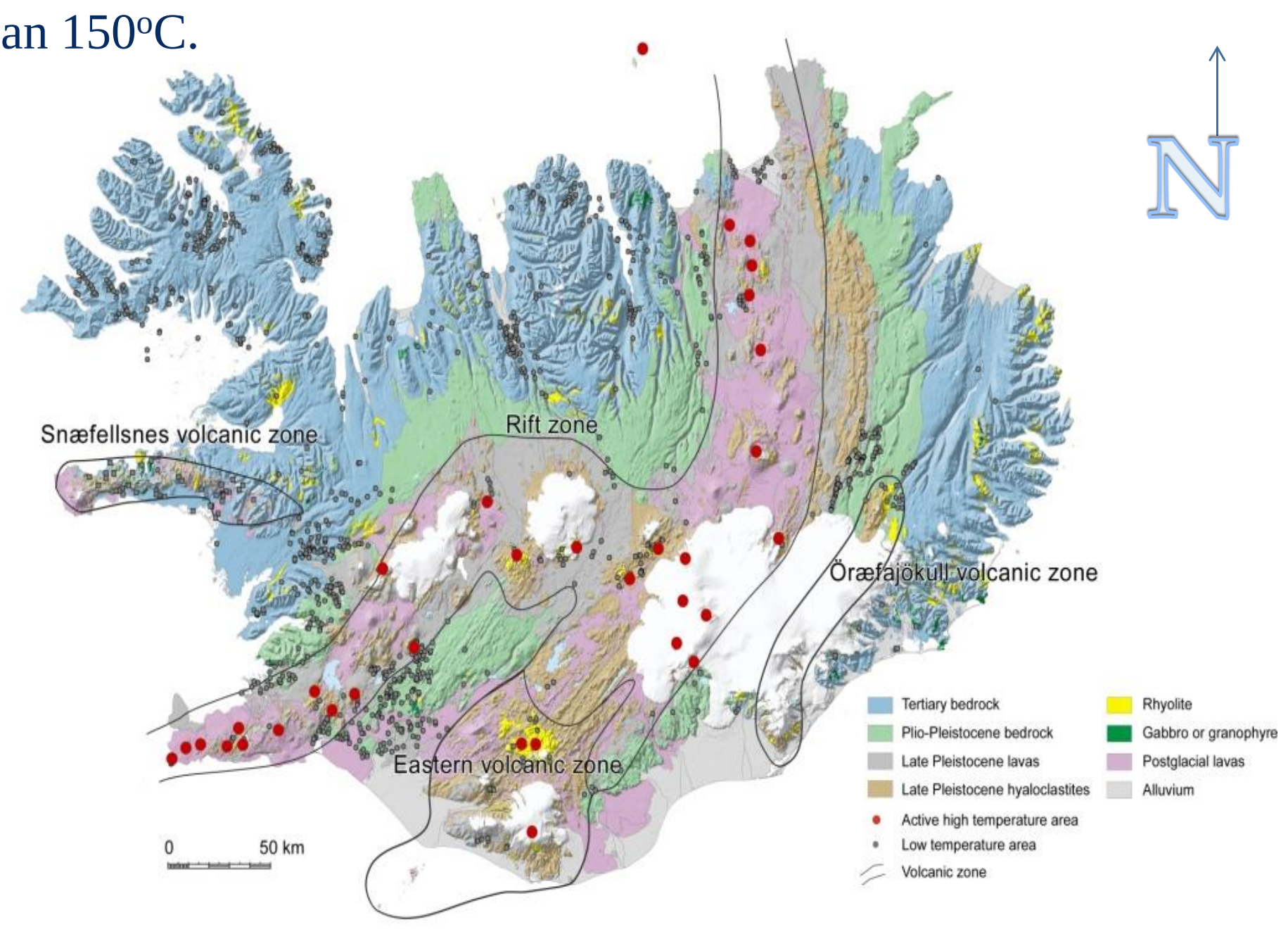


Fig.3.3. Geothermal map of Iceland.

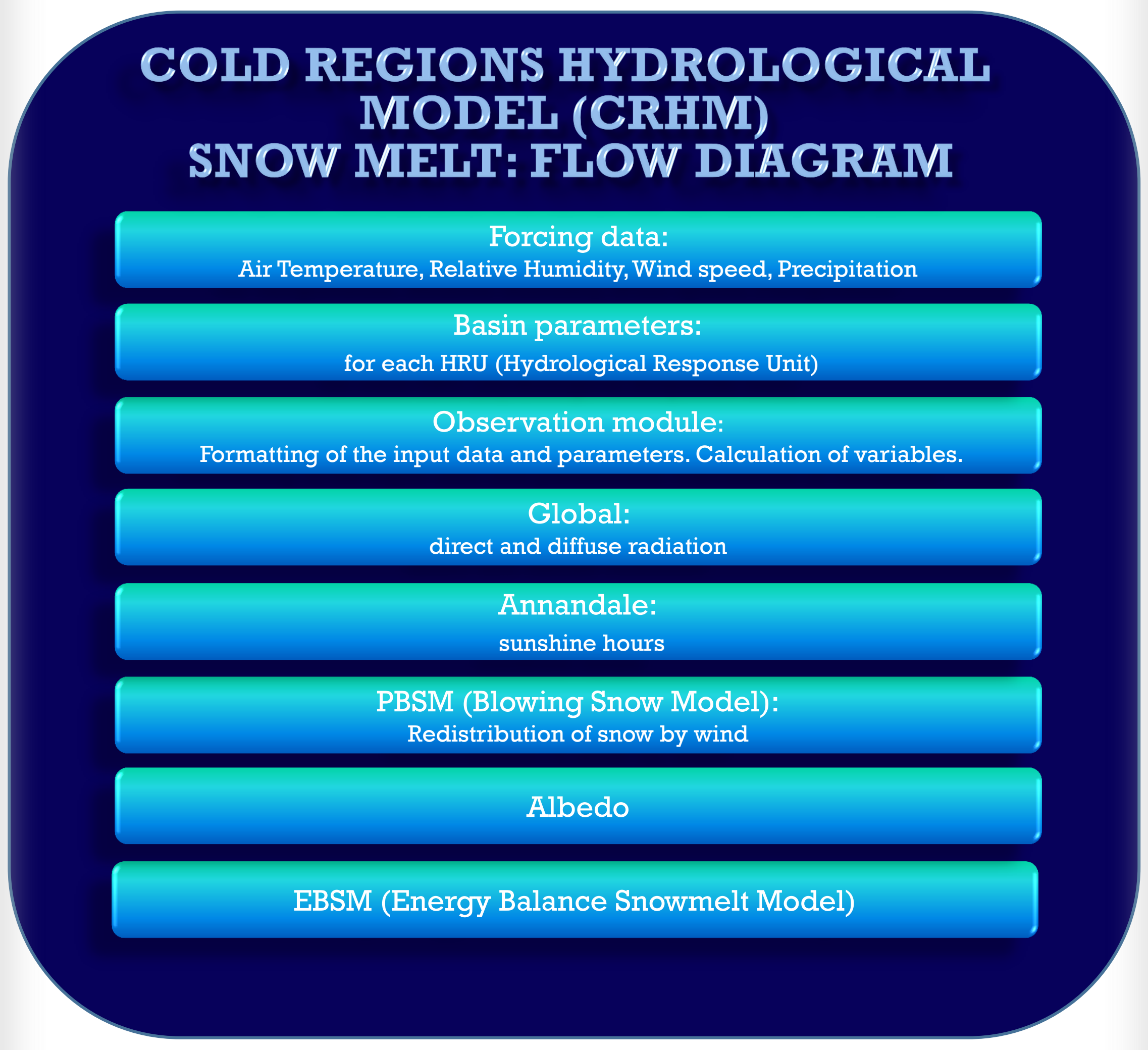
Source: Basemap: Geological map of Iceland by Haukur Jóhannesson and Kristján Sæmundsson 1999. Iceland. 1:1.000.000. Icelandic Institute of Natural History.

4.0 Methods

At these two sites a detailed water budget approach will be used to evaluate inputs of snowmelt and rainfall and to assess water losses such as evaporation, surface and subsurface flow. Instrumentation will consist of climate stations, water wells, ground temperature sensors and flumes to capture surface runoff and probe warm groundwater pathways, results needed to validate model simulations. Ash-snow lysimeter treatments at study sites will signal thresholds for melt/insulation; data needed for the new model algorithms. GIS and acquisition of remote sensing imagery for these study sites, and similar catchments across Iceland will allow for spatial distribution and upscaling of modelled hydrological results.

Cold Regions Hydrological Model: basic simulations

A snowmelt model was constructed using CRHM (Cold Regions Hydrological Model) platform. The model was run for nine HRUs (Hydrological Response Units), forced with 2011 – 2014 meteorological data from Önundarhorn automatic weather station located in Southern Iceland.


COLD REGIONS HYDROLOGICAL MODEL (CRHM)
SNOW MELT: FLOW DIAGRAM

Forcing data:
Air Temperature, Relative Humidity, Wind speed, Precipitation

Basin parameters:
for each HRU (Hydrological Response Unit)

Observation module:
Formatting of the input data and parameters. Calculation of variables.

Global:
direct and diffuse radiation

Annandale:
sunshine hours

PBSM (Blowing Snow Model):
Redistribution of snow by wind

Albedo

EBSM (Energy Balance Snowmelt Model)

Fig.4.1.CRHM. Snowmelt: flow diagram.

According to the IPCC Forth Assessment Report (AR4) [4], 2.4 degrees of warming is expected in Iceland by the end of the 21st century. Precipitation is projected to increase on average by 5%. Climate model projections do not show a significant change in the wind speed near Iceland. However, according to CMIP5 (Coupled Model Intercomparison Project) [5], wind storms in Iceland will be more frequent. For the purpose of climate change simulations, the above predictions were applied to observations from Önundarhorn weather station.

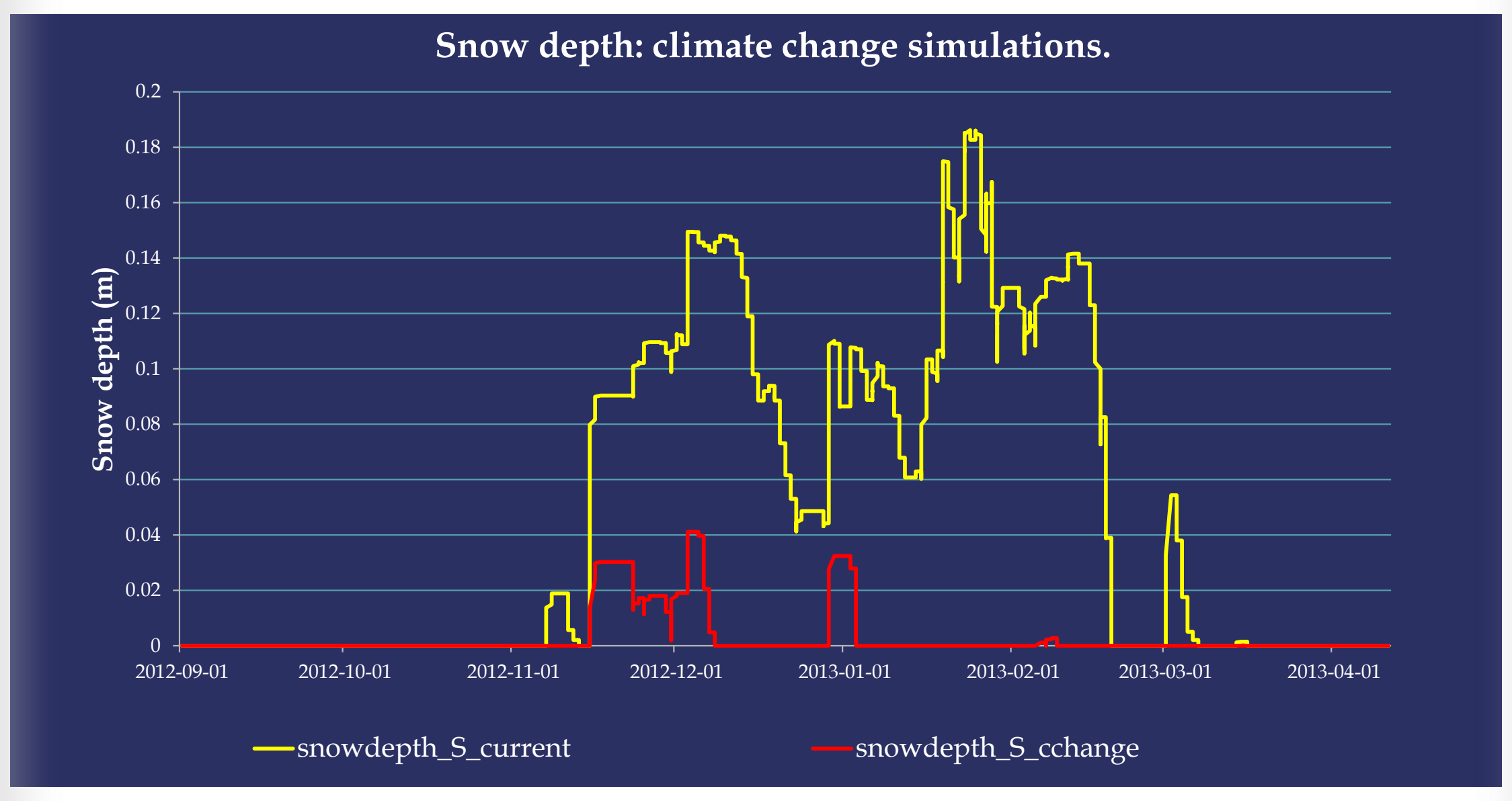


Fig.4.2. Modelled snow depth as a response to climate change simulations.

5.0 Scientific Contributions

This research will provide new data and further the understanding of ash-snowmelt runoff in geothermal areas both at the present time as well as simulating conditions in the future. An improved arctic hydrological model for volcanically active or dusty regions will provide for water resource managers an analytical tool to address hazardous conditions, including water quality/quantity and delivery issues.

6.0 References

[1] McKenna-Neumann, C. (1993). *Progress in Physical Geography* 17, 2: 137-155. **[2]** Kellerer-Pirklbauer, A., et al. (2007). *Permafrost and Periglacial Processes, 18*(3), 269-284. **[3]** ACIA (2005). *The Arctic Climate Impact Assessment*. Cambridge University Press. **[4]** Solomon, S. (2007). *The physical science basis: contribution of Working Group I to the Fourth Assessment Report of the IPCC*. Cambridge Univ. Press. **[5]** Vavrus, S. J. (2013). *Geophysical Research Letters*, 40(23), 6208–6212. **[6]** Pomeroy, J. W., et al. (2007). *Hydrological Processes, 21*(19), 2650-2667. **[7]** Einarsson, M.A. (1984). *World Survey of Climatology: 15: Climates of the Oceans*. Elsevier, Amsterdam, 673-697. **[8]** Flóvenz, Ó. G., et al. (1993). *Tectonophysics, 225*(1–2), 123–138.

7.0 Acknowledgements

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