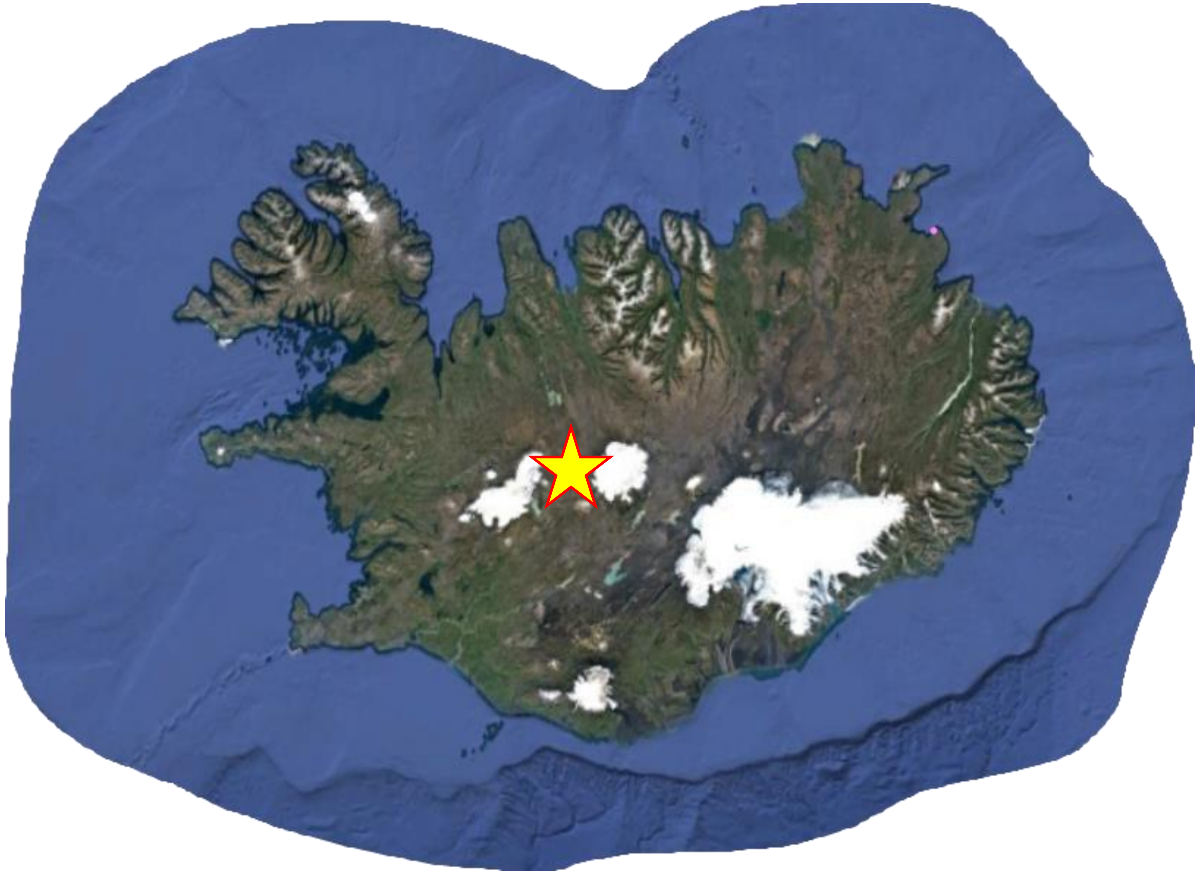
Trends in soil temperature in the Icelandic highlands



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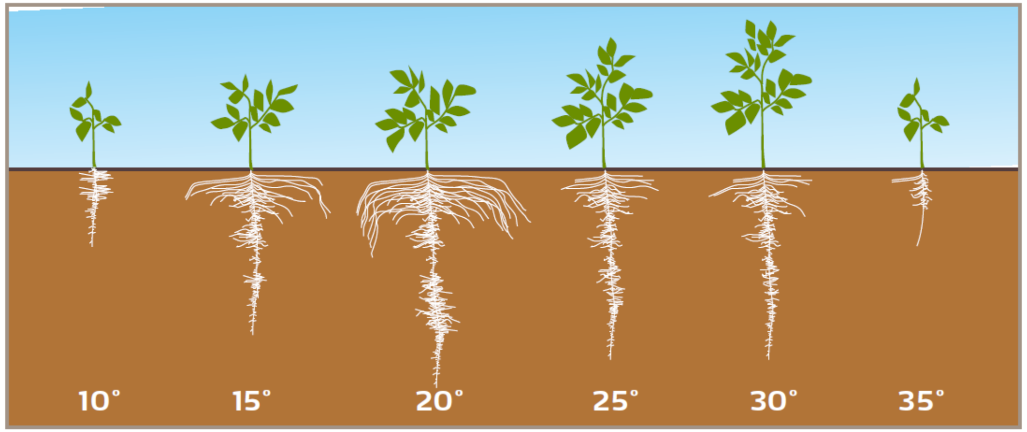
Veðurstofa Íslands

Why do we measure soil temperature?

- A part of the meteorological monitoring suite
- An vital part of agricultural meteorology
  - Temperature, changes and fluctuations impact plant growth
- Important for monitoring some natural hazard, e.g. landslides in cold regions and water floods
  - In a warming climate the risk of landslides increases as permafrost decreases on mountain sides that then become unstable

Effects of Soil Temperature on Root Development



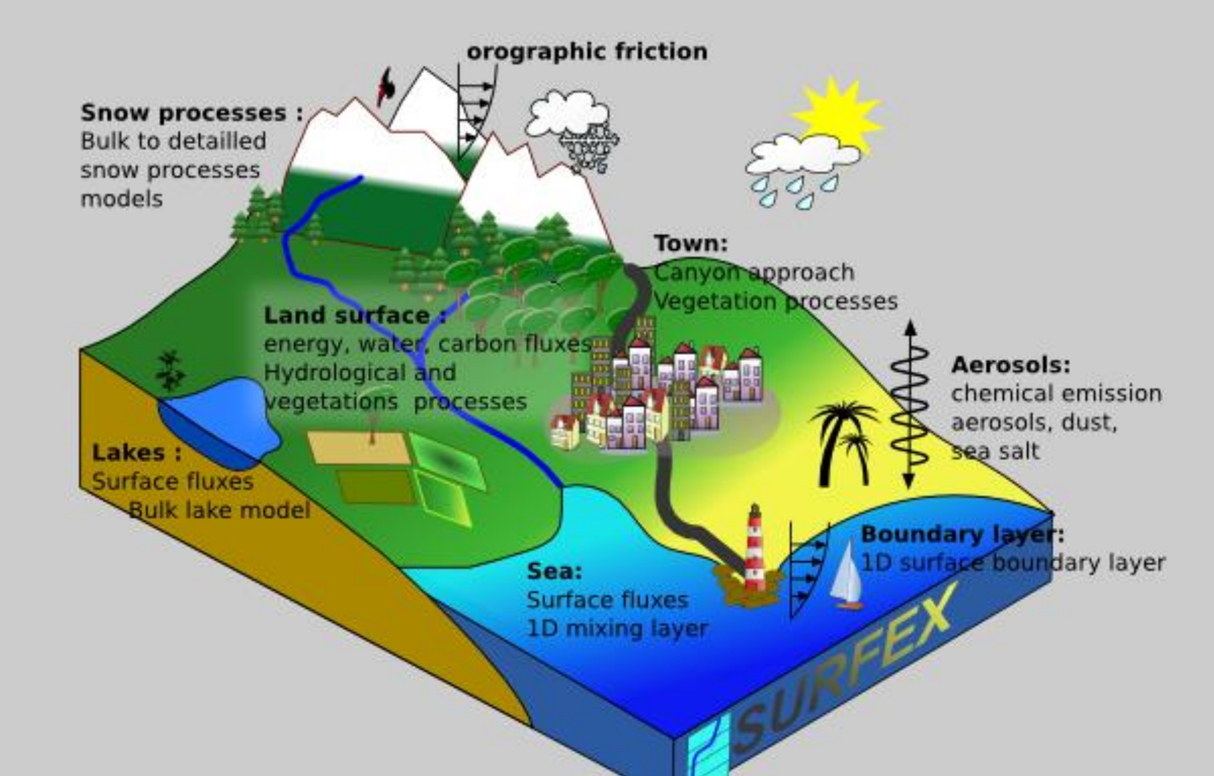
http://www.yara.us

REF: SATTELMACHER ET AL - 1990

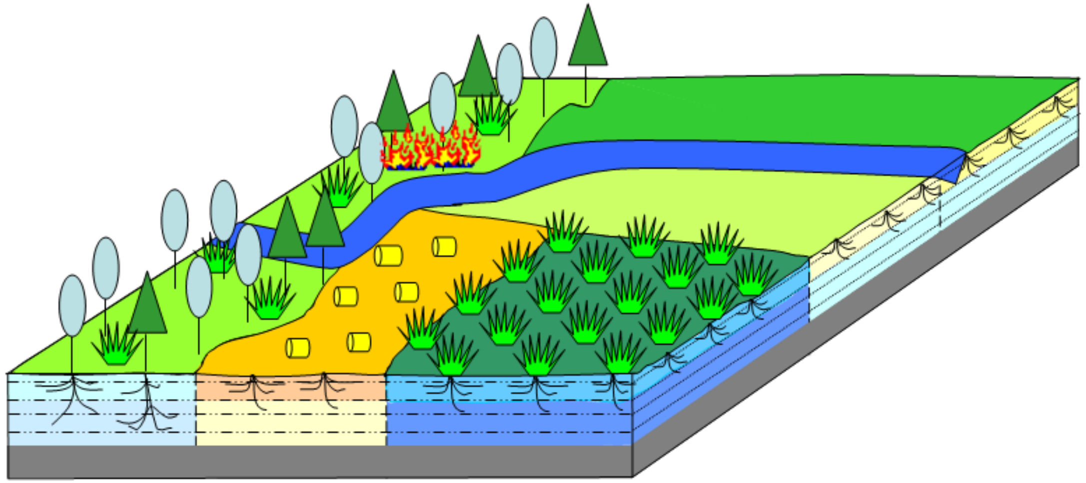
Ice-cemented block:
- 12 m wide and 4 m high
- A part of a debris slide
- N-Iceland, Sept 2012

Soil temperature is becoming important for NWP

- Numerical weather prediction models are connected to surface models
- Increasing refinement and resolution of NWP demands better information on the status of the surface and the top layers of the soil
- Verification of subsurface processes



www.umr-cnrm.fr



www.pik-potsdam.de

Soil temperature is dependent on several factors and impacts many processes

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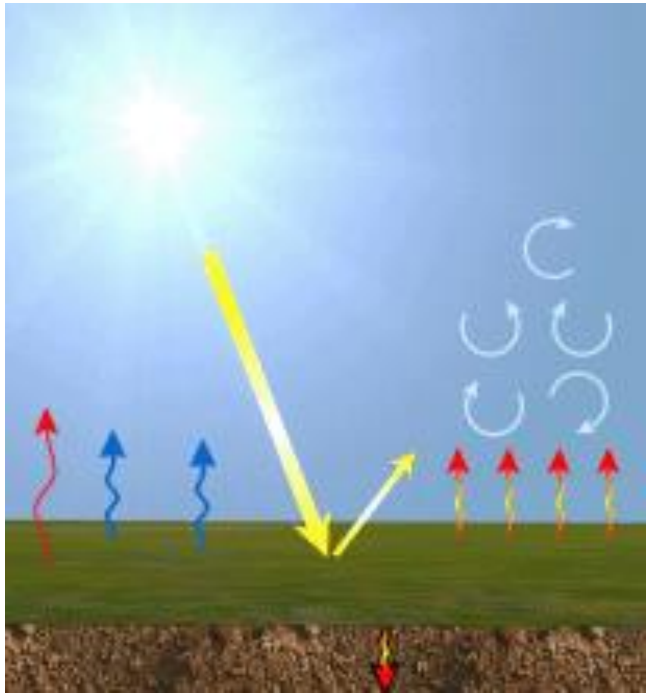
Determined by

- Latitude
- Altitude
- Season
- Global radiation
- Soil composition
- Soil humidity
- Surface cover
- Weather

Impacts

- Physical processes
- Biological processes
- Chemical processes
- Plant growth (more than air temperature)



comet.ucar.edu

Excluding local and seasonal factors:

Soil temperature is directly and indirectly dependent on

- **Heat energy absorbed by the soil**
- **Heat energy needed to change the temperature**
- **Energy needed for surface processes, such as evaporation**

Heat transport in soil is a slow process

- Most of the radiation energy that reaches the surface is used for evaporation from the ground and plants, radiated back or reflected
- Only ~10% of incoming solar radiation is absorbed by the surface and used the warm the ground
- Occurs mainly by conduction
- Water and air in the soil can also transport heat by convection
- Slow process that dampens and lag in time with depth:

0 - 20 cm: The largest temperature gradient
0 - 40 cm: Diurnal variation dampens down
40 -> cm: Little or no diurnal variation Seasonal variation dampens and lags in time with depth

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Soil temperature measurements have been a part of the meteorological network since ~1920

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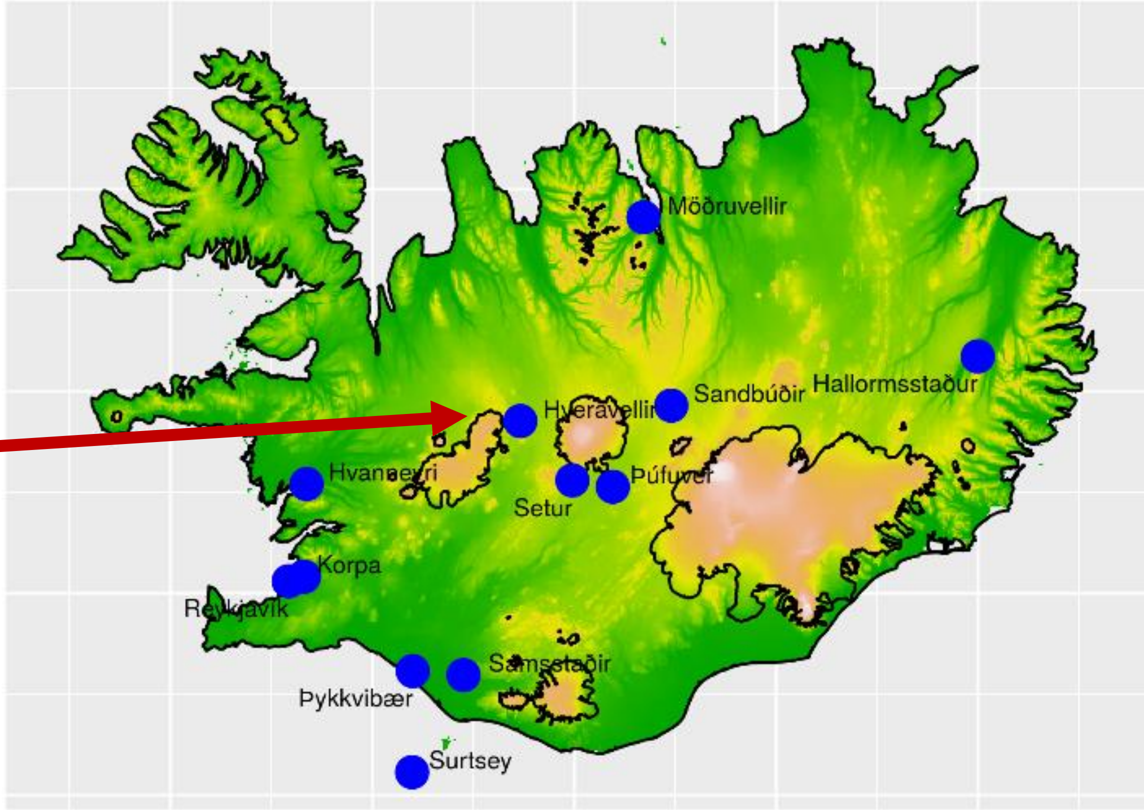
- Originally manned but now all automatic
- Location mainly agricultural or in the highland (most owned by hydropower)
- The longest records in electronic databases at IMO are for
  - Hveravellir station (641 m a.s.l.):
    Manned: 1977 - 2000 (on paper since 1969)
    Automatic: 2000 ->



Hveravellir – a highland station (641 m a.s.l.)

- 24-hour synoptic station from 1966-2004
- Traditional measurements as well as observations of northern lights, icing on lines and snow density
- Now automatic
- Mean annual temperature: 0.5°C
- Mean annual precipitation: 665 mm
- Snow observation:
  - First snow appeared in September
  - Snow cover thin during autumn
  - Maximum thickness in March-April
  - All snow removed in general in June (varied btw. middle of May and into July)

Soil temperature measurement period: 1977-2019

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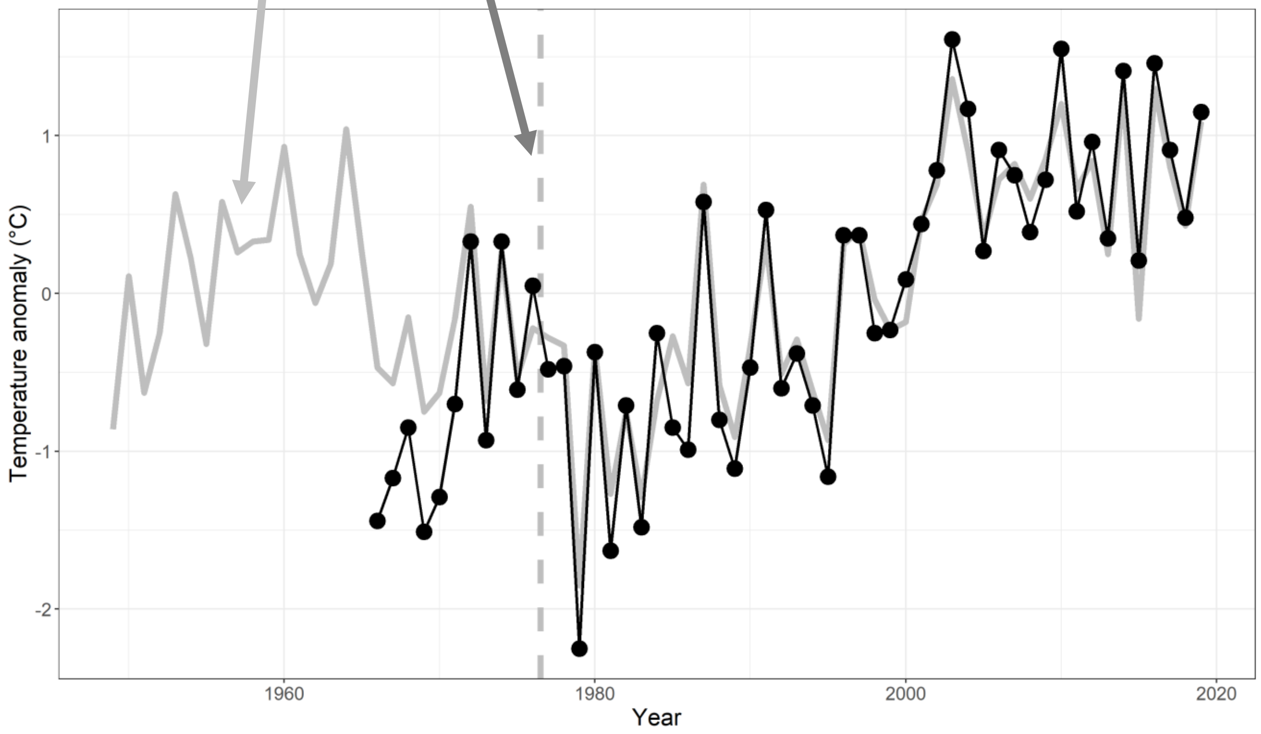
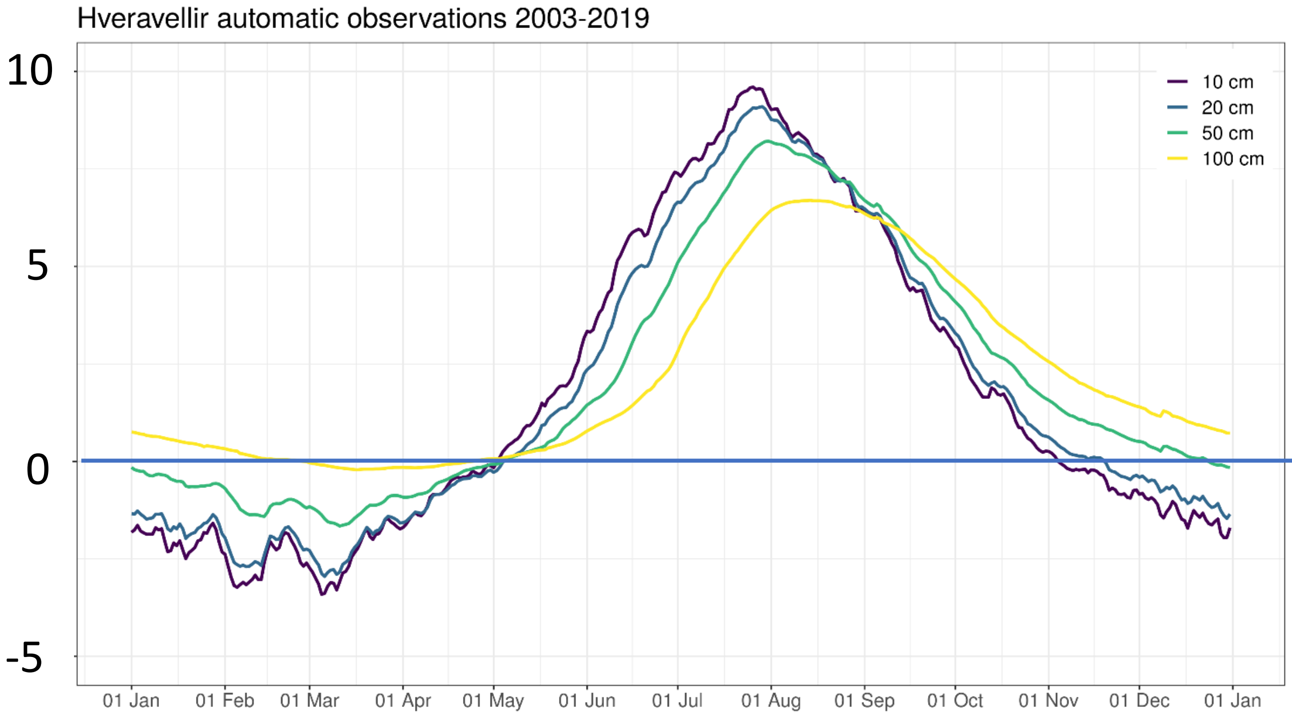
- Manned (1977-2000)
- Automatic (2003->)
- Missing data for 2001 & 2002
- Depths 10, 20, 50 and 100 cm depth
- In total 42 years
- Excellent data set to investigate temporal change in soil temperature during 4 decades
- Note that the measurements started during a local cold period

Hveravellir: Annual 2-m temperature anomaly, deviating from the 1981-2010 average.
Dashed line shows start of soil measurements
In grey: Reykjavík.



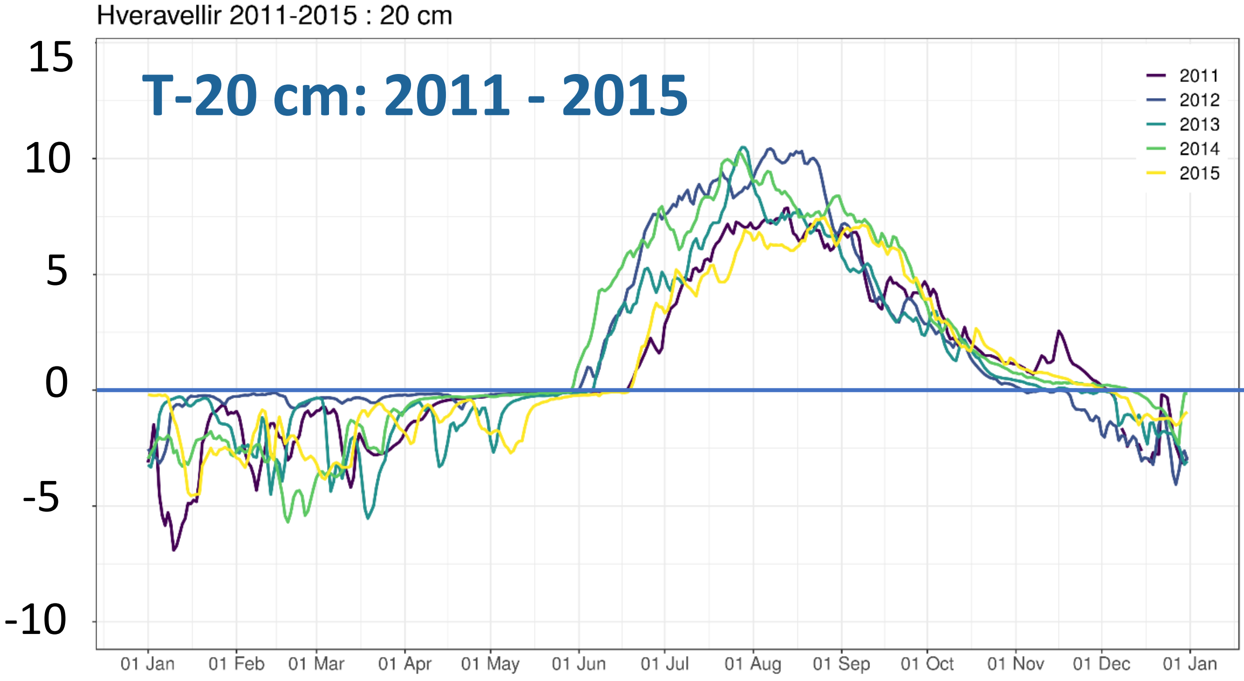
Hveravellir: mean annual variation

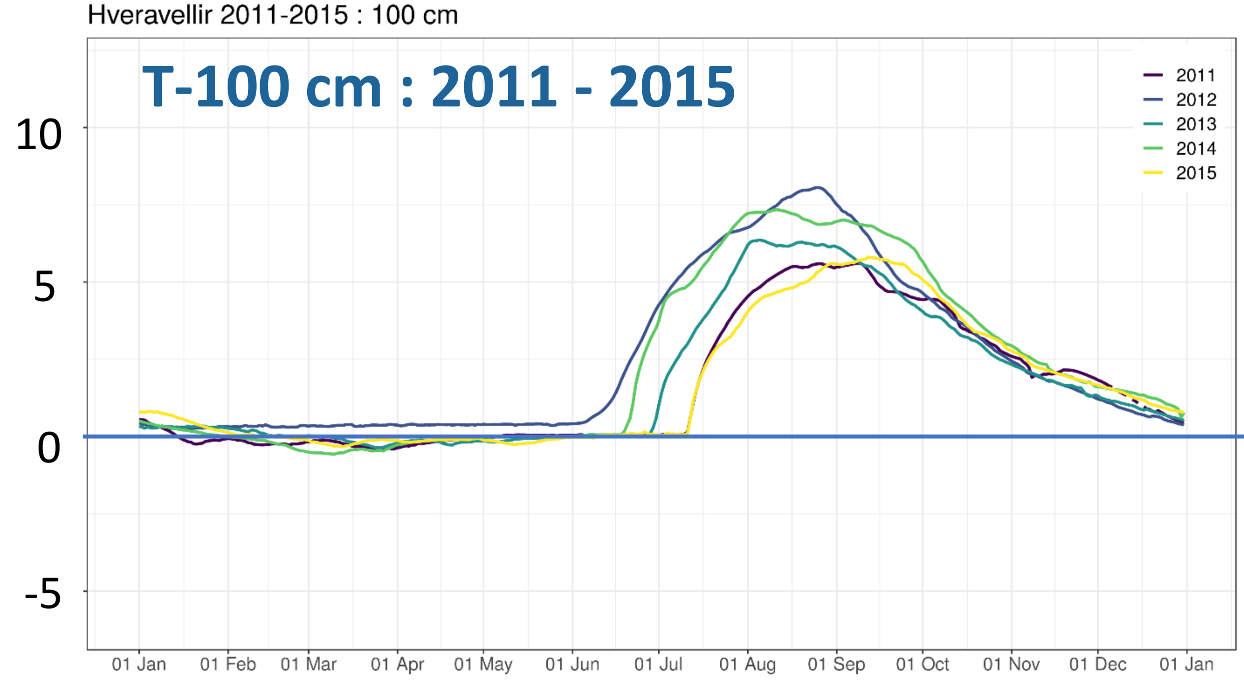
- During winter the highest T at lowest level and lowest closest to the surface
- T-100 cm on average above freezing except Feb-April
- Shallow depths, T-10 & T-20 cm, freezing occurs already in Nov
- Overturning of temperature gradient rapid: at the end of April and start of Sept
- Magnitude of annual variation much larger in the shallow layers
- Time lag of extreme is 2-3 weeks between shallow and deep layers



Large year-to-year variations

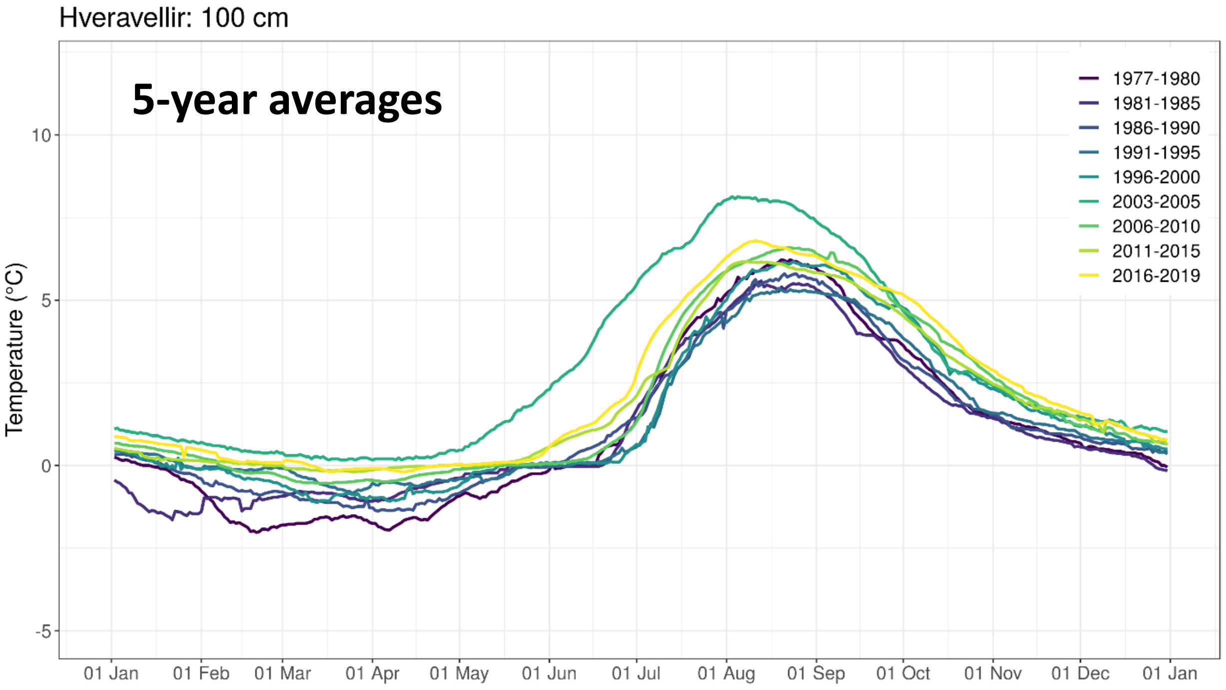
- T-20 cm:
  - 2012: close to freezing from Jan to start of June => snow covered ground
  - Other years: large variation during winter => thin, discontinuous or absent snow cover
- T-100 cm:
  - Little year-to-year difference during autumn and winter
  - Difference during summer mirror the ones at T-20 cm
- In the melting season the temperature stays at freezing level, i.e. is decoupled from air temperature
- Temperature increase in spring when all snow and ice on/in ground is melted: large variations at both levels.
- Autumn cooling less variable

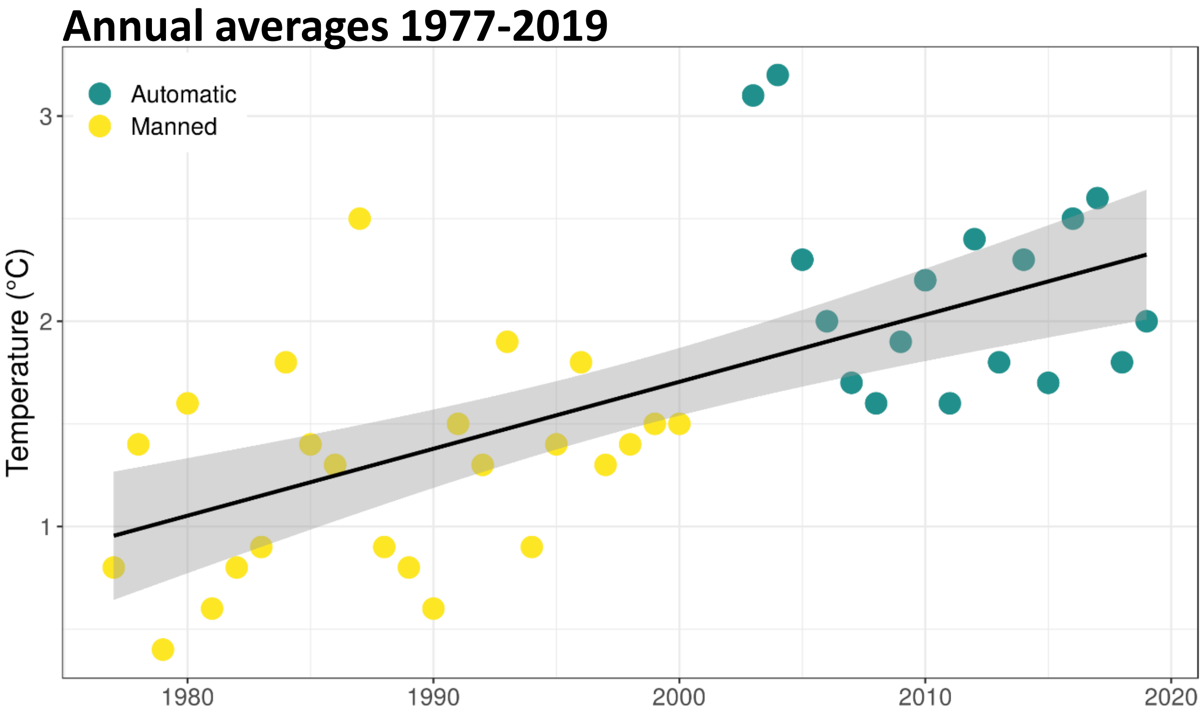




Annual & 5-year averages of T-100 cm

- ~5-year averages:
  - General increasing temperature
  - Period 2003-2005 is an outlier
  - Winter is warmer than at the start of the data set
  - Summer is getting warmer
  - Autumn cooling is happening later, i.e. the winter in the soil has been delayed by 2-3 weeks since 1977-1980
- Annual averages:
  - Increasing T-100 cm of 0.3°C/decade (R=0.4)
  - 2003 & 2004 are outliers: exceptionally warm years, among the warmest in Iceland
  - Largest trend in October: 0.6°C/decade
  - Smallest trend in June: 0.08°C/decade, related to large variation in climate timing and duration of the melting season

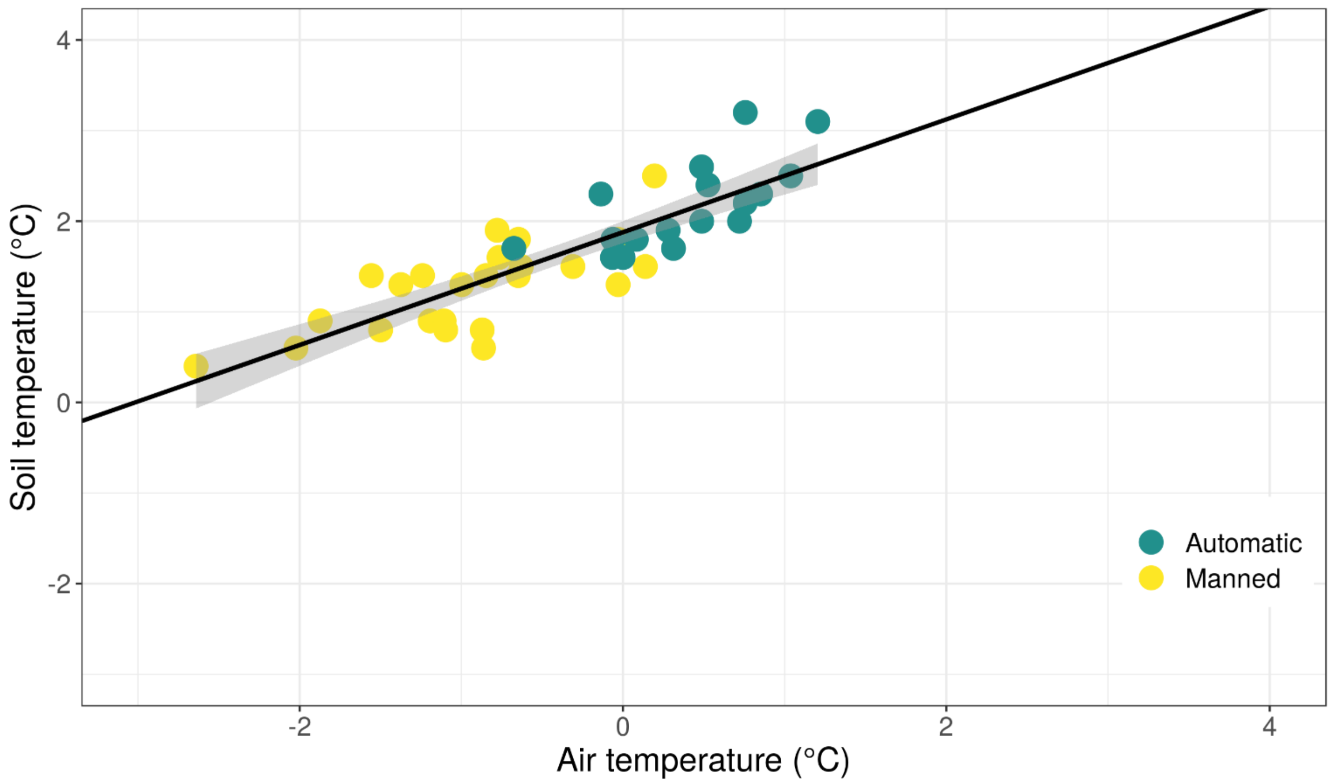




The soil warming is directly linked to warming of the 2-m air

- There is a clear relationship between the air temperature and the soil temperature
- For T-100 cm:
  - 0.6°C for each 1°C increase in T-2m (air)
  - R = 0.72

Annual T-100 cm as a function of annual T-2m (air)



Conclusions

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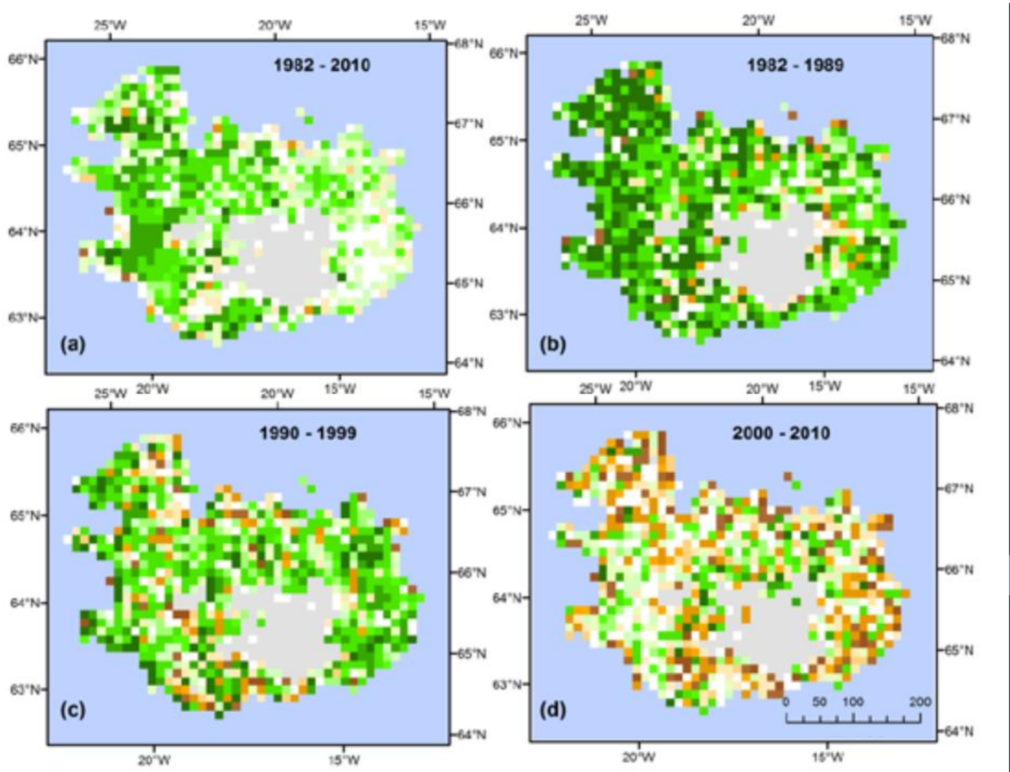
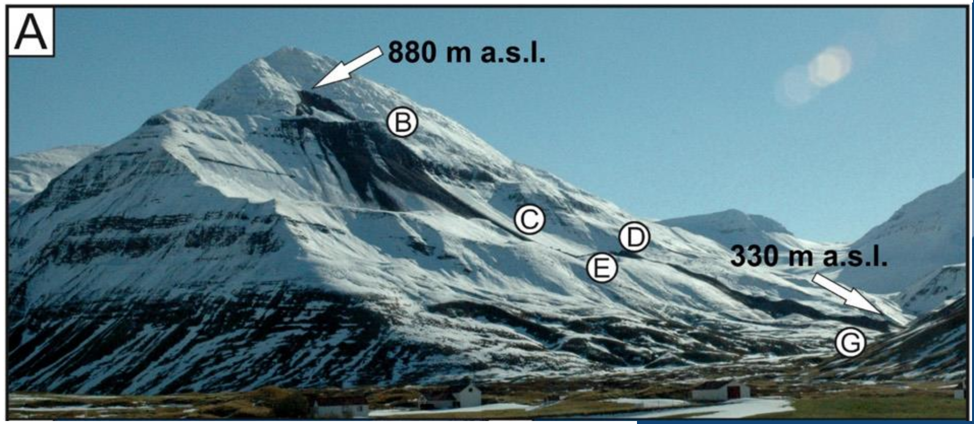
- The warming trend observed in the atmosphere can be detected in the ground, although at slower rate
- The soil at 100 cm depth has warmed by 0.3°C/decade
- Annual warming is in line with reported warming at other sites
- The fact that the time series start at a local cold period may affect this trend
- On average, for every 1°C increase in air temperature the 100 cm soil temperature increases by 0.6°C
- Autumn cooling is delayed by 2-3 weeks
- Large variability in the end of the melt season => small warming trend
- Summers in the soil are warmer and longer than in the 1980s

Implications for the terrestrial ecosystem in Iceland

- In terms of flora, fauna and agriculture:
  - The growing season has become longer
  - Where conditions are otherwise favourable, vegetation is increasing
- In terms of natural hazards:
  - The ongoing warming is resulting in warming and eventually thawing of permafrost in mountainous regions
  - This means, at least temporally, an increased risk of landslides
  - 5 landslides in the last 2 decades have originated in permafrost regions

Changes in NDVI (Normalized Difference Vegetation Index) – Iceland is becoming greener
Björnsson et al. (2018)





Sæmundsson et al. (2018)