Retrieving freeze/thaw state of the soil surrounding a GPS antenna

Clara Chew

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Questions

• What is freeze/thaw and why is it important?
  – How is freeze/thaw currently measured?
• How might we infer freeze/thaw state using GPS?
• What do model simulations tell us about the ability of GPS to infer freeze/thaw state?
• How do model simulations compare with field data?
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What is freeze/thaw and why is it important?

• Freeze/thaw is the transition of the environment from frozen to thawed conditions.
  – Frozen: $\text{Soil}_{\text{temp}} < 0^\circ\text{C}$
  – Thawed: $\text{Soil}_{\text{temp}} > 0^\circ\text{C}$

• “On/off” switch for soil hydrology, biology, and ecology [1]

• Defines the vegetation growing season [1]

• Strongly affects microbial activity in the soil [2]
  – Linked to respiration and CO$_2$ exchange
How is freeze/thaw currently measured?

• Surface air temp is a good estimator
  – But, density of met stations in the Arctic is inadequate [2]

• Passive radiometers and active radar
  – Radiometers passively collects information coming out of the soil: big pixel size (40 km on a side)
  – Radars (usually) measure backscatter: how the soil/vegetation/snow responds to an incident electric field
How is freeze/thaw currently measured?

- Passive radiometers and active radar

Microwaves are nice because they ‘see’ through cloud cover and aren’t attenuated much by the atmosphere.

Image from: http://www.sp.phy.cam.ac.uk/SPWeb/research/thzcamera/WhatIsTHzImaging.htm
How is freeze/thaw currently measured?

- SMAP (soil moisture active passive)
  - Launch ~2014
  - Will measure soil moisture and freeze-thaw state of the globe
- SMAP’s measurements will have to be validated
  - My thesis: create a soil moisture dataset that can be used to validate SMAP using GPS
  - This presentation: Can we also use GPS to see freeze/thaw state?

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How might we infer freeze/thaw state using GPS?

- GPS antennas and receivers that have been installed to measure plate movement can also measure soil moisture, vegetation state, and snow depth [3][4][5].

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GPS multipath signals (the ones that are reflected off of the ground) are affected by the ground’s permittivity.

Soil, snow, vegetation, buildings, etc...

\[
\varepsilon' + i\varepsilon''
\]

Related to the energy stored in the ground

Related to how the ground absorbs energy

At a given frequency (for us, ~1.22 GHz), permittivity of soil is primarily a function of:

1. Moisture content
2. Temperature
How might we infer freeze/thaw state using GPS?

If the permittivity of the ground changes with respect to temperature, we should be able to see this in SNR data.

So, SNR data could perhaps tell us the temperature of the soil surrounding the antenna, which then tells us about freeze/thaw state surrounding the antenna.
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- 1D, single-scattering, electrodynamic model developed in [6].
- Can be used for bare soil, soil with vegetation/snow.
- Currently, can convert soil moisture profiles over depth to permittivity profiles. BUT, the soil moisture/permittivity relationships used do not include temperature effects.

What do model simulations tell us about the ability of GPS to infer freeze/thaw state?

- Modify the existing model to include the effects of temperature on soil permittivity.
  - Values taken from [7]: permittivity for a silty soil with 0.30 volumetric moisture content at different temperatures.
- Assume the entire soil column has the same temperature and moisture content.
- Assume bare soil conditions.
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5-30 degrees

![Graph showing the effect of satellite elevation angle on power output (Volts or Watts)].
What do model simulations tell us about the ability of GPS to infer freeze/thaw state?

5-30 degrees

When the soil warms up from -10°C to 0°C:
- \( A \): decreases by \( \sim 3 \) volt/volt
- \( \Phi \): increases by \( \sim 14 \) degrees
What do model simulations tell us about the ability of GPS to infer freeze/thaw state?

- **5-30 degrees**
- **5-15 degrees**
- **30-40 degrees**
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Challenges:
• Field data are noisy—especially in Alaska
• Model assumes field sites are flat
• Permittivity model does not account for soil moisture changes
• Cable temperature and un-quantified effects on SNR amplitude
• No soil temperature/moisture sensors for ground truth
• Need sites with bare ground
How do model simulations compare with field data?

Site 1: AC 23

- Located on Kenai Peninsula, Alaska
- Ancillary data:
  - SCAN station ‘Schor Garden’
  - Soil moisture and temperature at 10 cm depth
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Site 1: AC 23
How do model simulations compare with field data?

Site 2: AC 61

- Located SE of Fairbanks
- Ancillary data:
  - SNOTEL station ‘Granite Creek’
  - Soil moisture and temperature at 2 cm depth

Data look bad
How do model simulations compare with field data?
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Future Work

• Find a site that is very cold in the winter, ideally without much snow.
  • Install temperature and soil moisture probes for ground-truthing
• Expand the model:
  • Allow soil moisture to vary in addition to temperature.
  • Include temperature effects on the permittivity of Arctic vegetation, like tundra.
Summary

• Signal-to-Noise Ratio Data might be able to provide us information about freeze/thaw around a GPS antenna.
  • This is because:

  Temperature  ➔  Permittivity of the ground  ➔  SNR data

• Soil moisture, vegetation water content, and snow also affect permittivity, so teasing out the effects of just temperature on SNR data is really hard, especially when you have hardly any data for ground-truthing.
  • Modeling can help isolate the effects of just one of these variables.
References


