

# Detecting Snow Cover on GPS Antenna

## ASEN6090 Final Project

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# Outline

- ▶ Goals
- ▶ Sites
- ▶ Model
- ▶  $MP_1$  Results
- ▶ SNR Results
- ▶ Position Results
- ▶ Conclusions

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# Goals

- ▶ Generate an index representative of snow cover over GPS antenna.
- ▶ Considerations for Reflections study:
  - ▶ How much of an effect will Snow cover directly over the antenna have on received signal power from lower elevation angles.

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## Sites for Primary Study

- ▶ P360 \*
- ▶ P101 \*
- ▶ AB33
- ▶ P455

*\* sites have a digital camera installed on site.*

# Model

- Basic EM wave propagation (Plane solution to Maxwell's Equations)

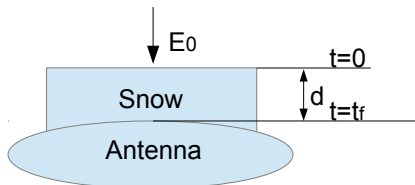
$$E = E_0 e^{j(k \cdot r - \omega t)}, \quad (1)$$

Where,

$$\frac{\omega^2}{k^2} = \frac{c^2}{\epsilon}$$

However, If  $\epsilon$  is complex

$$E = E_0 \exp[j(\text{Re}(k) \cdot r - \omega t)] \exp[-\text{Im}(k) \cdot r]. \quad (2)$$



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- ▶ Dielectric of Snow?
  - ▶ Phase velocity in a medium is dependent on the frequency of the wave-front.
  - ▶ As a consequence the dielectric constant of a medium is dependent on the frequency of the EM-wave.
  - ▶ Phase velocity of the wave is given by

$$v = \frac{\omega}{k} = \frac{c}{n}$$

Where,  $n$  is the refractive index of the the medium

$$n = \sqrt{\epsilon}$$

- ▶ Dielectric of Snow for GPS L1 frequency?

# Model - $\epsilon$ for Snow

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- ▶ Snow is a mixture of Ice, Air and Water.
- ▶ From [1]
  - ▶ Consider a 2 component mixture: ice and air
  - ▶ Let their volume fractions be  $p_i$  and  $p_a = (1 - p_i)$
  - ▶ let their dielectric constants be  $\epsilon_i$  and  $\epsilon_a$
  - ▶ The Dielectric constant of the combination is given by,

$$\epsilon_s E_s = \epsilon_i p_i E_i + \epsilon_a p_a E_a \quad (3)$$

- ▶ Where  $E_s$ ,  $E_i$  and  $E_a$  is the mean electric field strength for the EM wave under consideration in the different media.

[1] Y. Ozawa and D. Kuroiwa, "**Dielectric Properties of ice, snow and supercooled water**" in *Microwave propagation in Snowy districts*, no. 6, pp. 31-71, 1971

# Model - $\epsilon$ for Snow

- From [2]

- The Dielectric constant of the combination is given by,

$$\epsilon_s = \epsilon'_s - j\epsilon''_s$$

Where

$$\epsilon'_s = 1 + 2\rho_d$$

$$\epsilon''_s = \epsilon'_s \times 1.59 \times 10^6 \times \frac{0.52\rho_d + 0.62\rho_d^2}{7 + 1.7\rho_d + 0.7\rho_d^2} \\ \times (f_{L1}^{-1} + 1.23 \times 10^{-6} \sqrt{f_{L1}}) e^{0.036T}$$

- Where,

$\rho_d$  is relative density of dry snow

$T$  is the temperature of snow in Celsius.

[2] M.E. Tiuri, A.H. Sihvola, E.G. Nyfors, M.T. Hallikaiken, "**The complex dielectric constant of snow at microwave frequencies**", *IEEE J Ocean. Eng. OE-9* (5), pp. 377-382, 1984

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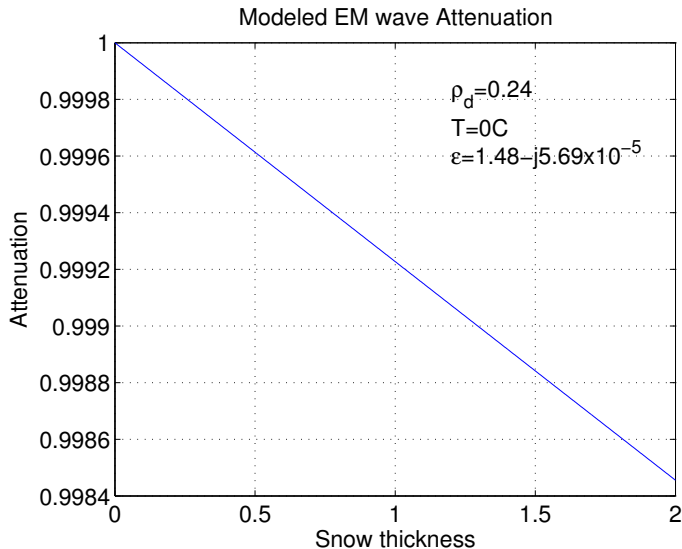
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# Model



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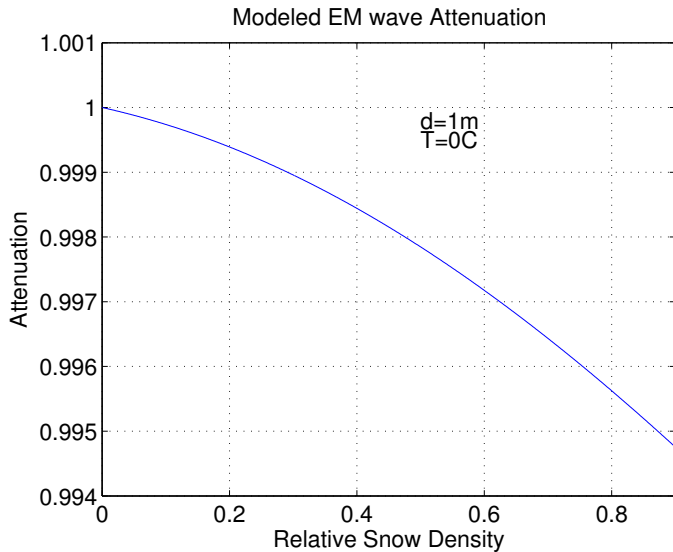
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# Model



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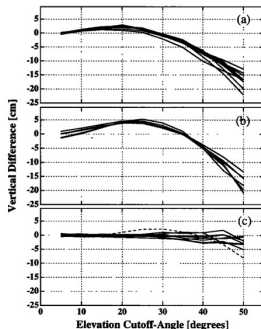
- ▶ R.T.K Jaldehag, J.M. Johansson, J.L. Davis, and P. Elosegui, " **Geodesy using the Swedish Permanent GPS Network: Effects of snow accumulation on estimates of site position**", Geophys. Res. Lett, 23, pp. 1601-1604, 1996

- ▶ Snow Cause:

- ▶ Scattering
  - ▶ Excess path length

- ▶ Vary elevation cutoff

- ▶ (a)  $\approx$  Snow on Antenna
  - ▶ (b)  $\approx$  Snow on Antenna
  - ▶ (c)  $\approx$  No snow



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- ▶ J. Stepanek, and W.C David, "**GPS signal reception under snow cover: A Pilot study establishing the potential usefulness of GPS in avalanche search and rescue**", Wilderness and Environmental Medicine, 8, pp. 101-104, 1997
  - ▶ Antenna buried under snow cover of incremental depths
    - ▶ 5,15,25,35,45,55cm, 1m, 1.5m
  - ▶ parameters measured: signal quality, number of satellites visible and signal strength
  - ▶ reference reading taken above snow cover
  - ▶ No SNR data.
  - ▶ deals with signal quality flag from commercial receiver

**Table 1.** Location A, February 10, 1996, snow density 0.6 g/cm<sup>3</sup>, humidity 78%, skycover 6/8, temperature 34°F

	<i>Cover</i>	<i>Reference</i>	<i>Depth of burial (cm)</i>						
			<i>0</i>	<i>5</i>	<i>15</i>	<i>25</i>	<i>35</i>	<i>45</i>	<i>55</i>
Latitude	No signal	43:59:32	43:59:31	43:59:32	43:59:31	43:59:32	43:59:32	43:59:29	43:59:32
Longitude	No signal	92:30:69	92:30:72	92:30:67	92:30:71	92:30:69	92:30:69	92:30:73	92:30:71
Altitude in feet	No signal	1290	1185	1392	1279	1141	1056	1124	1264
Signal quality	No signal	Q1	Q1	Q1	Q1	Q1	Q1	Q2	Q1
Satellite no./force	No signal	14/4	14/6	14/5	14/4	28/3	28/4	28/4	28/4
	No signal	19/6	19/4	19/4	19/4	19/4	19/3	19/0	19/0
	No signal	22/5	22/7	22/5	22/5	22/2	22/3	22/1	22/2
	No signal	25/1	25/5	18/6	18/6	18/5	18/4	18/3	18/2
	No signal	28/3	28/6	31/3	31/3	31/2	31/3	31/3	31/0
	No signal	29/6	29/7	29/6	29/5	29/5	29/3	29/6	29/4
	No signal								

# SNR

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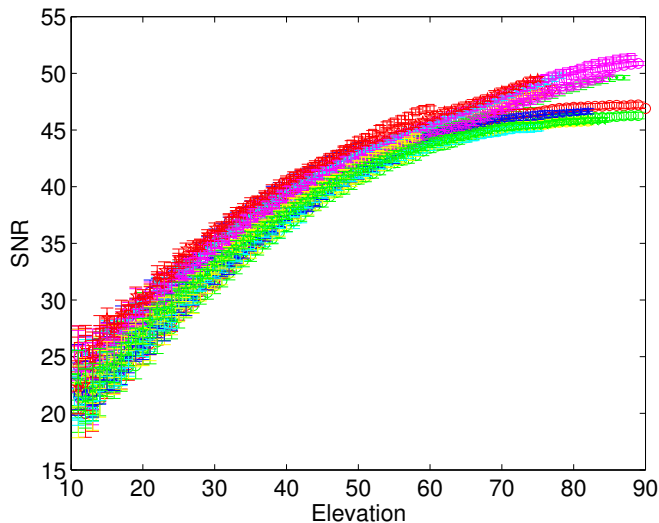
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- ▶ Generate a statistical map of expected SNR values w.r.t Elevation angle.
- ▶ Data from 2011 DOY 200-250 was used to generate the map
- ▶ Each SV was considered separately
  - ▶ Individual Tracks could be tagged as 'Bad'
  - ▶ Each SV has varying transmit power

# SNR Map



*32 lines – > mean SNR for every SV, along with error bars.*

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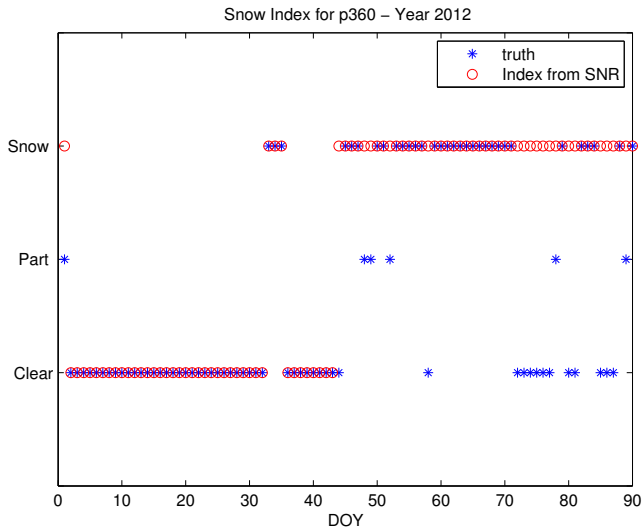
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# SNR Index



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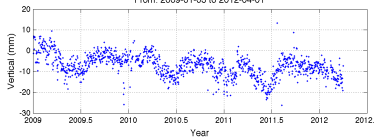
Conclusion



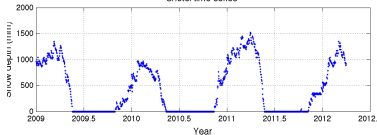
# Position Time Series - P360

## ► 2009 to 2012

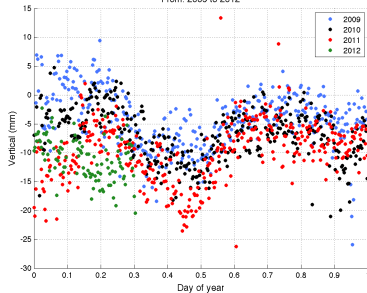
Position time series  
From: 2009-01-03 to 2012-04-01



Snotel time series



Vertical position variation vs. day of year  
From: 2009 to 2012



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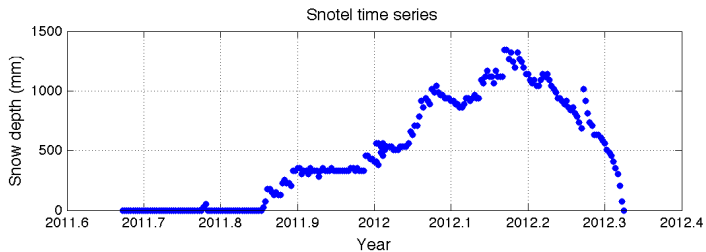
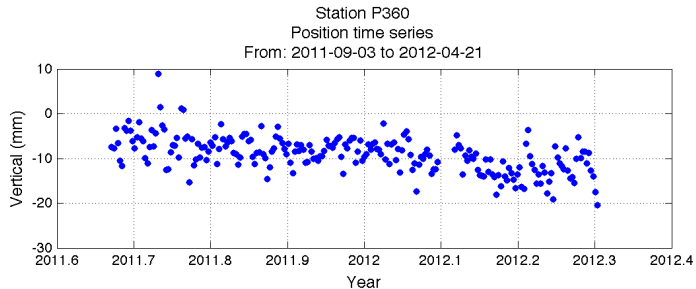
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# Position Time Series - P360



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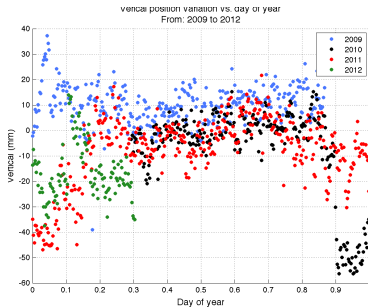
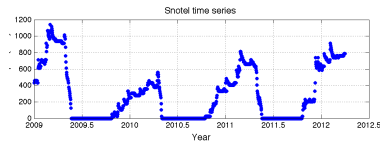
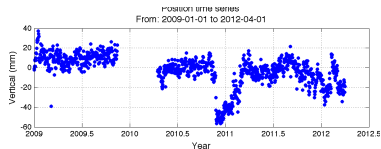
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# Position Time Series - AB33

## ► 2009 to 2012



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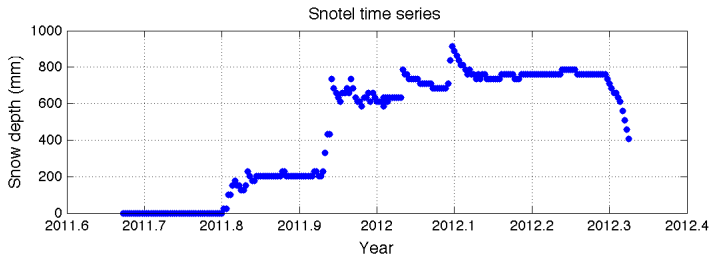
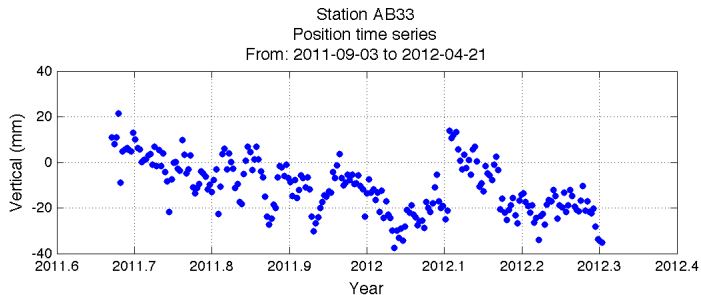
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# Position Time Series - AB33



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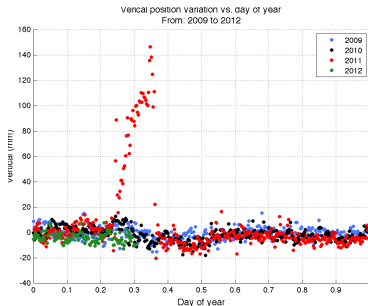
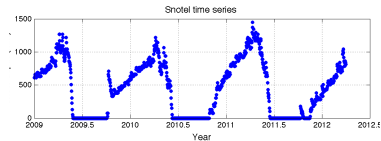
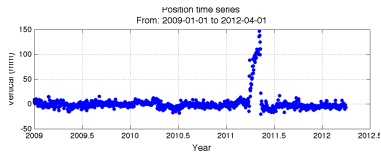
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# Position Time Series - P455

## ► 2009 to 2012



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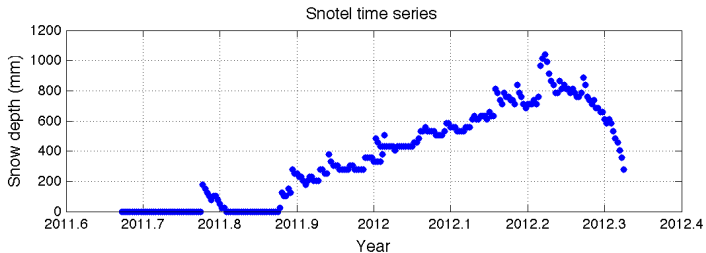
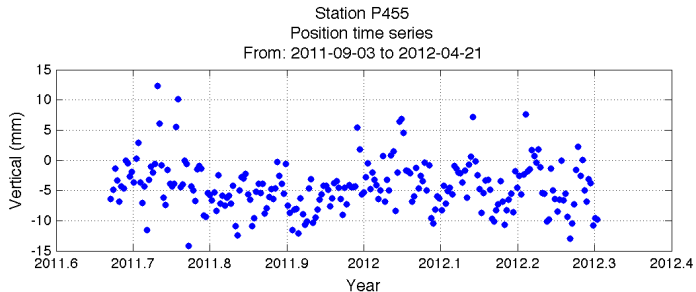
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# Position Time Series - P455



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