Detecting Snow Cover on GPS Antenna

ASEN6090 Final Project

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Outline

- Goals
- Sites
- Model
- MP_1 Results
- SNR Results
- Position Results
- Conlusions

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.

Sites

Sites for Primary Study

- P360 *
- P101 *
- AB33
- P455

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

Model

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

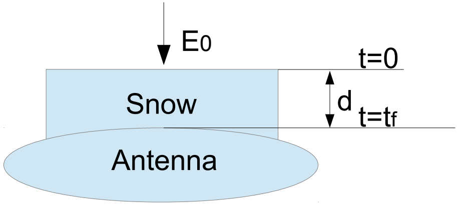
$$E = E_0 e^{j(k.r - \omega t)}, \tag{1}$$

Where,

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

However, If ϵ is complex

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



Model

- 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 - ϵ for Snow

- 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 ϵ_i and ϵ_a
  - The Dielectric constant of the combination is given by,

$$\epsilon_s E_S = \epsilon_i p_i E_i + \epsilon_a p_a E_a \tag{3}$$

  - 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 propogation in Snowy districts, no. 6, pp. 31-71, 1971*

Model - ϵ for Snow

- From [2]
  - The Dielectric constant of the combination is given by,

$$\epsilon_s = \epsilon_s' - j\epsilon_s''$$

Where

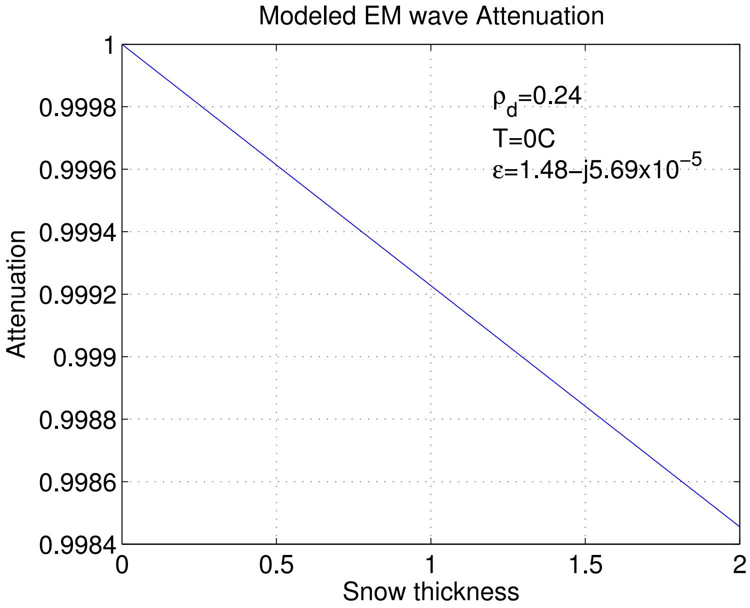
$$\epsilon_s' = 1 + 2\rho_d$$

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

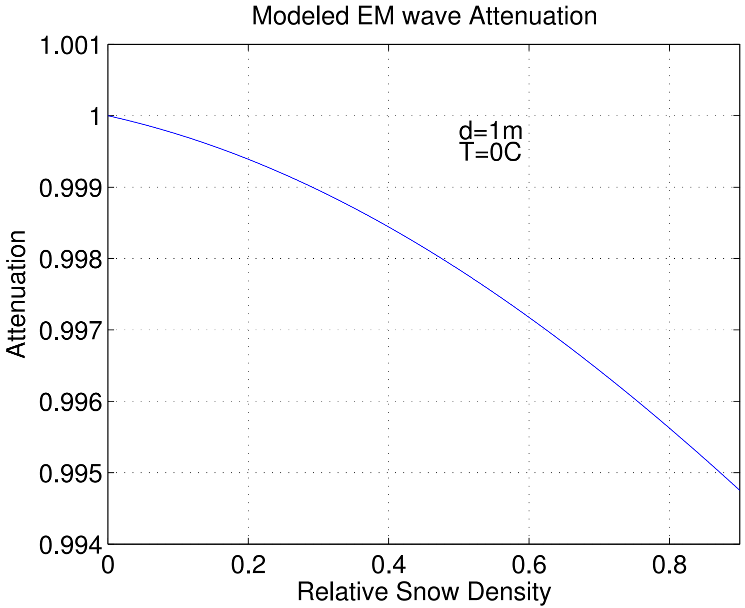
  - Where,
    ρ_d is relative density of dry snow
    T is the temperature of snow in Celsius.

*[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*

Model


Modeled EM wave Attenuation
ρd=0.24
T=0C
ε=1.48−j5.69x10−5
Attenuation
Snow thickness
1
0.9998
0.9996
0.9994
0.9992
0.999
0.9988
0.9986
0.9984
0
0.5
1
1.5
2

Model


Modeled EM wave Attenuation
Attenuation
Relative Snow Density
d=1m
T=0C
1.001
1
0.999
0.998
0.997
0.996
0.995
0.994
0
0.2
0.4
0.6
0.8

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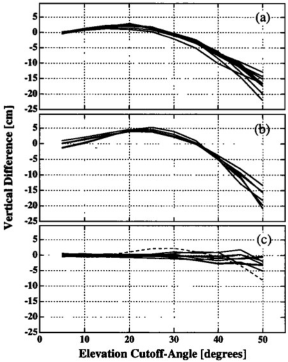
- R.T.K Jaldehag, J.M. Johansson, J.L. Davis, and P. Elosegui, "**Geodesy using the Swedish Permanent GPS Network: Effects of snow accumulation on estimates of site position"**, Geophys. Res. Lett, 23, pp. 1601-1604, 1996

- Snow Cause:
  - Scattering
  - Excess path length
- Vary elevation cutoff
  - (a) ≈ Snow on Antenna
  - (b) ≈ Snow on Antena
  - (c) ≈ No snow on Antena



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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 Environemental Medicine, 8, pp. 101-104, 1997
  - Antenna burried 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

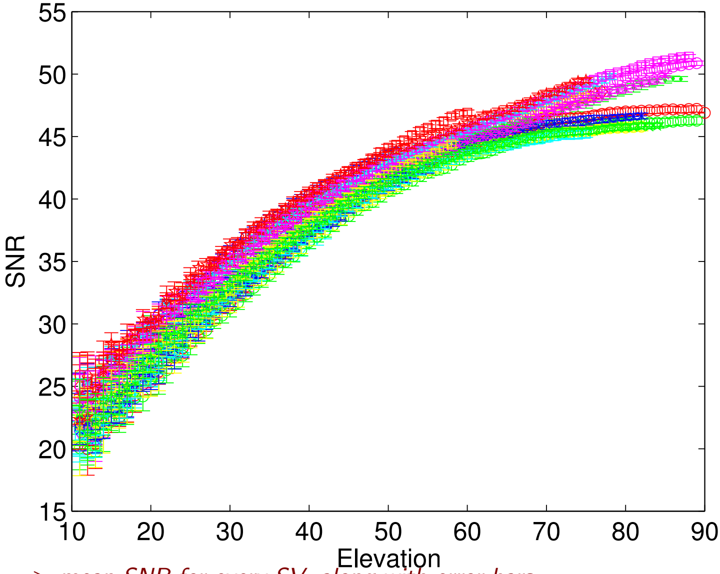
Table 1. Location A, February 10, 1996, snow density 0.6 g/cm^3, humidity 78%, skycover 6/8, temperature 34°F

	Cover	*Reference*	*Depth of burial (cm)*						
			0	*5*	*15*	*25*	*35*	*45*	*55*
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

SNR

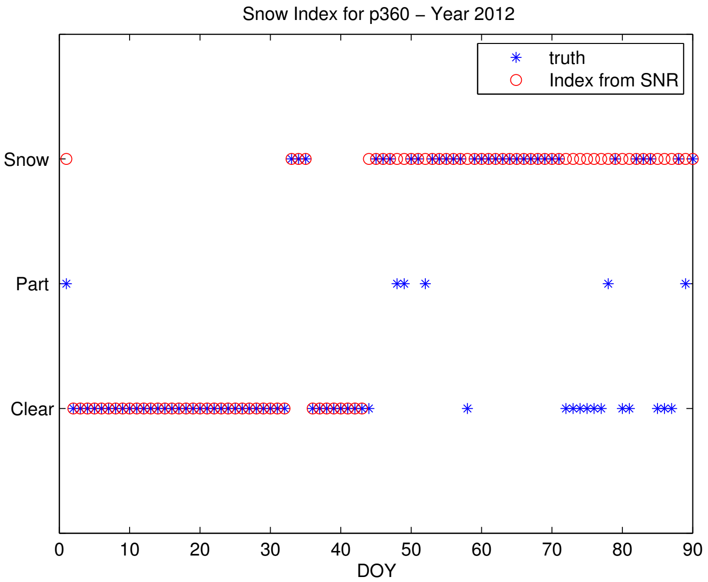
- Generate a statistical map if expected SNR values w.r.t Elevation angle.
- Data from 2011 DOY 200-250 was used to generate the map
- Each SV was considered seperately
  - Individual Tracks could be tagged as 'Bad'
  - Each SV has varying transmit power

SNR Map



32 lines $->$ mean SNR for every SV, along with error bars.

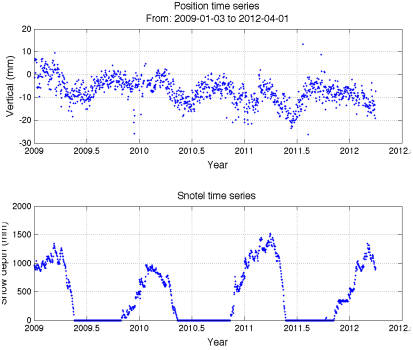
SNR Index

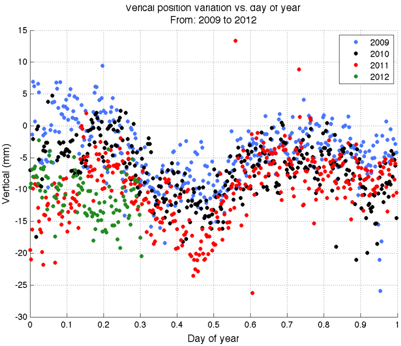


Snow Index for p360 – Year 2012
truth
Index from SNR
Snow
Part
Clear
0
10
20
30
40
50
60
70
80
90
DOY

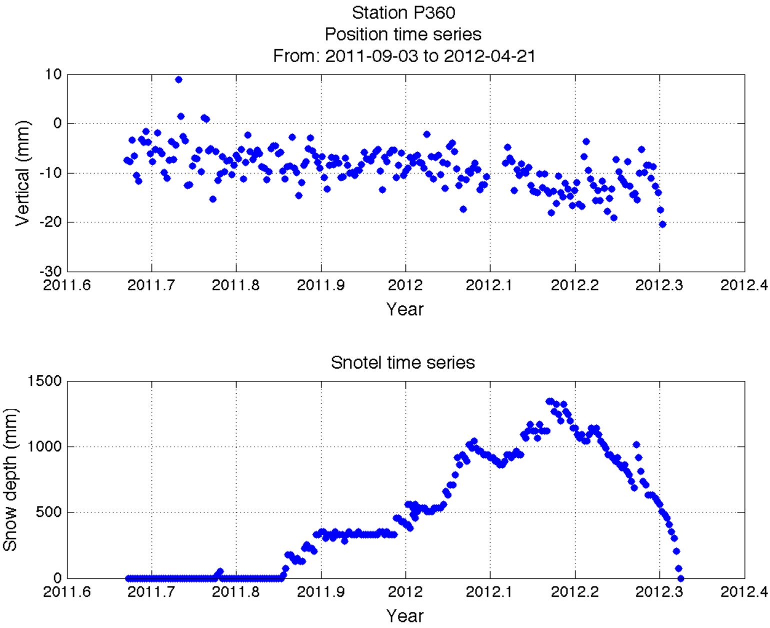
Position Time Series - P360

- 2009 to 2012



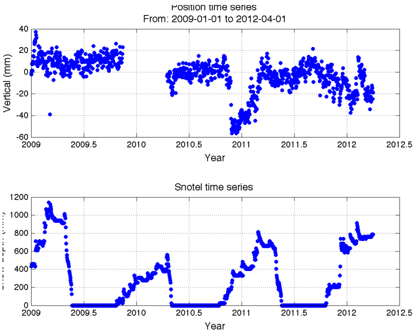


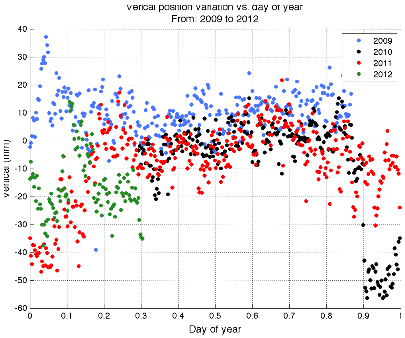
Position Time Series - P360



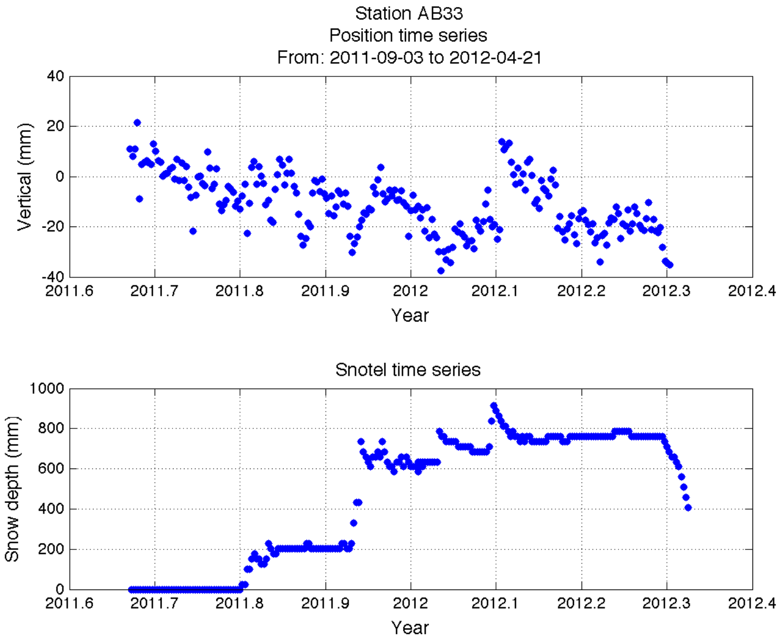
Position Time Series - AB33

- 2009 to 2012



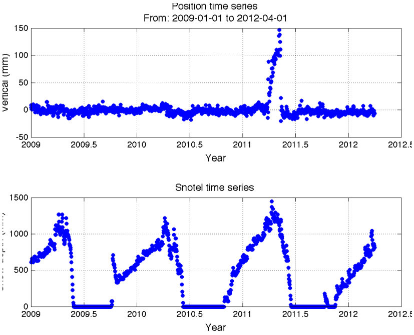


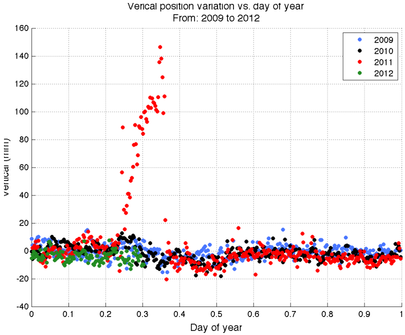
Position Time Series - AB33



Position Time Series - P455

- 2009 to 2012





Position Time Series - P455