18 Feb 2014

The maximum temperature for the day was recorded around 17\_C, 14\_C and 8\_C in the Bhang, Solang and Dhundi observatories respectively. Due to this high temperature there was a melting of 6 cm, 11 cm and 7 cm of snow within a span of less than 12 hours recorded at the three observatories respectively.

07 Feb 2012

During this descending pass acquisition, the in-situ measurements were collected around the Bhang observatory and the temperature was recorded around - 2C.

08 Feb 2013

The minimum temperature recorded at the Bhang, Solang and Dhundi observatories were - 3\_C, - 7.5\_C and - 7\_C respectively. There was a 11 cm snow melt observed on the previous day (7 Feb 2013) due to a maximum temperature of 11\_C recorded at the Bhang observatory. However, the surface snow would have refrozen during the acquisition because of the recorded low temperature (- 3\_C). For cases with clear nights and temperatures close or below 0\_C, radiative emission from the snow surface (and also volume) causes a refreeze of the snow surface. The snow surface can freeze many cm deep during night, while the lower lying snow volume is still wet. Therefore, especially for acquisitions in the early morning hours, a higher contribution from the snow volume is expected. This is clearly observed from the estimation that the volume snow wetness is higher than the surface snow wetness.

Field data

The snow fork instrument has been used to measure the snow wetness in the field. The snow fork is a portable instrument which measures the resonant frequency, attenuation and the 3-db bandwidth (Sihvola and Tiuri, 1986). These measurements are then used to calculate the complex dielectric constant of snow. The snow density and the wetness are calculated using semi-empirical equations. The measurements from this instrument are reliable as it does not compress the snowpack and the measurements are easily repeatable and the results can be checked by calibration measurement in the air. These measurement were taken over the observatory areas which were almost at.

The observed density range in the map is possibly due to the increased grain size by the snowpack compaction. This is understood by studying the meteorological record at Dhundhi observatory (Fig. 4(a),(b)). From 6 to 7 Feb. 2012, the recorded temperature increased from 2\_C to 5\_C and wind speed of 2{4 km/hr, causing snow metamorphism. Also during this period the snowpack depth has reduced by 33 cm as per the observatory data. Both the temperature and the wind speed together might have caused for the reduction of snow depth and the compaction of the snowpack ( (Mel\_ysund et al., 2007)). In the map (Fig. 3(a)) around 25% of the study area shows dense forest and geometric distortions (Table. 3). All the Radarast-2 descending pass data over this region possibly shows this distortions. During the same period in the following year (8 Feb. 2013), the density was estimated in the range of 0.2{0.3 gcm􀀀3 as shown in Fig. 3(b). This range of density values covers around 15% of the entire study area as shown in Table. 3. However, snow free/wet snow regions in the snow density map were around 38% as seen in Table. 3. This might be because of the maximum temperature recorded on 7 Feb. 2013. The observed temperatures at the Bahang, Solang and Dhundhi observatories on 7 Feb. 2013 were 11\_C, 7\_C and 6\_C (Fig. 4(c)) respectively which were higher than 2012. However, It can be observed that the snow density values are lower than the previous year (7 Feb. 2012). This may be because of the fresh snow fall on 6 Feb. 2013. Even though high temperature was observed on 7 Feb. 2013, the snowpack might not have compacted \_rmly during the acquisition on 8 Feb. 2013 as compared to the multiple melt-freeze condition in 2012.

The estimated snow density map and the observatory measurements for the 18 Feb. 2014 data (Fig. 3(c)) shows a similar trend as that of 7 Feb. 2012. Unlike the 7 and 8 Feb, the 18 Feb. 2014 data was acquired in an ascending pass. It can be seen in Table. 3 that 34% of the area was covered with the snow density values in the range of 0.2{0.35 gcm􀀀3. There was no fresh snow fall recorded for a week prior to the acquisition on 18 Feb. 2014. Moreover, a large variation can also be observed between the maximum and the minimum temperatures on 18 Feb. 2014 (Fig. 4(d)). So the old snowpack has undergone multiple melt-refreeze process, which has increased the snowpack grain size and consequently the snow density.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Pixel Count | | | Area | | |
| Dielectric range | 7Feb 2012 | 8Feb2 013 | 18Feb 2014 | 7Feb 2012 | 8Feb2 013 | 18Feb 2014 |
| 1-2 | 46703 | 66658 | 63361 | 13.77 | 17.03 | 17.54 |
| 2-3 | 82896 | 98888 | 71997 | 24.44 | 25.26 | 19.93 |
| >3 | 62115 | 46610 | 63317 | 18.31 | 11.91 | 17.53 |
| total | 479579 | 553140 | 510620 |  |  |  |
| Out pixel | 140348 | 161640 | 149337 |  |  |  |
| Original tot.pixel | 339231 | 391500 | 361283 |  |  |  |
| No.of inverted pixels (%) | 56 | 54 | 55 | 56.52 | 54.2 | 55 |

Touzi- optimized DOP

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Pixel Count | | | Area | | |
| Dielectric range | 7Feb 2012 | 8Feb2 013 | 18Feb 2014 | 7Feb 2012 | 8Feb2 013 | 18Feb 2014 |
| 1-2 | 48382 | 69302 | 66065 | 13.91 | 17.61 | 18.21 |
| 2-3 | 89488 | 108530 | 78711 | 25.3 | 26.37 | 21.04 |
| >3 | 68666 | 51924 | 71820 | 18.9 | 12.64 | 17.86 |
| total | 479579 |  |  |  |  |  |
| Out pixel | 140348 |  |  |  |  |  |
| Original tot.pixel | 339231 |  |  |  |  |  |
|  | 60 | 58 | 60 | 58.11 | 56.52 | 57.11 |

Each pixel = 411.73 m2

In both the maps high altitude regions are not able to invert (out of inversion (OFI)) surface dielectric values. This may be because of the dry snow cover which produces snowpack volume as a dominant scattering mechanism.

On 7 Feb 2012

* Over the obseravatory locations the estimation shows 1.5-2, following the measured values
* More than 25 % areas are >3 dielectric
  + Mostly these areas are high altitude along with the high slope
  + Earlier day the observed high temperature causes for more than 15 cm melting over Dhundhi observatory.
  + This melting rate will be much higher over the terrains with slope than the flat observatory locations.
  + However, during the descending pass acquisition (6.15 am IST) the observed low temperature might have frozen the melted water over the snow surface in few centimeters, which are lower in the slope areas than the flat areas.
  + These conditions clearly evidence that low surface dielectric over flat areas (mostly low altitudes in the map) and high over slop terrains. Over the slop terrains the high dielectric caused by the near surface wet snow layers.
  + These slope areas have been already reported with the high wetness and density for the same data set (references SW & SD)

On 8 Feb 2013

* The dielectric map on 8 Feb. 2013 almost follows the same trent as the previous year (7 Feb. 2012) estimation.
  + The observed maximum temperature observed on 7 Feb. 2013 11, 7 and 6 C at Bahang, Solang and Dhundhi. The snowpack melted on that particular day was around 11, 23 and 9 cm respectively.
  + The observed low temperature during the descending pass acquisition (at the Bahang (-3), Solang (-7.5) and Dhundi (-7)) might have frozen the snowpack surface.
  + Observed snowpack wetness and density reported (reference)
  + The dielectric values >3 in this map is less than 7 Feb 2012 (Table 1), this could be because of the melting of snowpack was less on the earlier day.

18 Feb. 2014

* Ascending pass data acquired at 6.30 PM IST. The different range of dielectric values with snow covered areas for 18 Feb 2014 is shown in Table.
  + Mostly the areas with high slopes and in the eastern direction shows high dielectric range than other areas.
  + This might be because of the high temperature observed on that day at Bahang, SOlang and Dhundhi are 17, 14 and 8 C respectively. The eastern slopes directly getting this

**Results and discussion for JSTARS**

1. The optimized degree of polarization maps derived from AGU and Touzi methods are shown in figure.
2. Touzi and AGU optimization techniques increased the DOP values more than 0.5 at most of the study areas but AGU-DOP shows low values (<0.5) over the high altitude regions. These high altitude low slope areas produce volume scattering as a dominant scattering mechanism because of the snowpack surface frozen due to the low temperature during the acquisition.