

ON POTENTIAL ESTIMATION OF PERMAFROST-VEGETATION IN ARCTIC AREA

Maurizio Sarti⁽¹⁾, Lucio Mascolo⁽²⁾, Maurizio Migliaccio⁽³⁾, Ferdinando Nunziata⁽⁴⁾
Enrico Brugnoli⁽⁵⁾, Carlo Calfapietra⁽⁶⁾

⁽¹⁾ *Istituto di Biologia Agro-Ambientale e Forestale, Consiglio Nazionale delle Ricerche, V.le G. Marconi, 2, 05010, Porano, Italy, maurizio.sarti@cnr.it*

⁽²⁾ *Dipartimento di Ingegneria Elettrica ed Elettronica, Università degli Studi di Cagliari, Piazza d'Armi, 09123, Cagliari, Italy, lucio.mascolo@diee.unica.it*

⁽³⁾ *Dipartimento per le Tecnologie, Università di Napoli Parthenope Centro Direzionale, isola C4 - 80143 Napoli, Italy, maurizio.migliaccio@uniparthenope.it*

⁽⁴⁾ *Dipartimento per le Tecnologie, Università di Napoli Parthenope Centro Direzionale, isola C4 - 80143 Napoli, Italy, ferdinando.nunziata@uniparthenope.it*

⁽⁵⁾ *Dipartimento Terra e Ambiente, Consiglio Nazionale delle Ricerche, Piazzale Aldo Moro, 7, 00185, Roma, Italy, direttore.DTA@cnr.it*

⁽⁶⁾ *Istituto di Biologia Agro-Ambientale e Forestale, Consiglio Nazionale delle Ricerche, Viale G. Marconi, 2, 05010 Porano (Italy), carlo.calfapietra@ibaf.cnr.it*

ABSTRACT

Knowledge of the spatial distribution of permafrost-vegetation interface in the Arctic is important to climate change of this region. Vegetation is very limited in Arctic environments. Optical remote sensing data are currently used to identify permafrost-vegetation interface. This provide interesting information on Earth surface but are limited to cloud-free periods. For these reasons it is not possible an exhaustive monitoring of permafrost-vegetation interface in these areas with optical data. For this purpose, spaceborne fully polarimetric and time-series datasets show great potential for mapping permafrost-vegetation interface with a sufficient level of precision. Our goal is to evaluate fully polarimetric RADARSAT-2 (RS2) time-series datasets to identify the permafrost-vegetation interface dynamics. To achieve this, the radar vegetation index (*RVI*) is evaluated on five areas of interest (AOI) chosen in the fjord Kongsfjorden, located in Svalbard Archipelago and individuate how: Sea, Ice, Blomstrandhalvøya Island, Coastal Area and Ossian Sars Nature Reserve.

1. INTRODUCTION

Permafrost areas are of interest as important feedback elements in the climate system and as potentially sensitive indicators of climate change, especially at high latitudes. The longer-term warming has resulted in a loss of permafrost, and will result in changes in the regional ecosystems. Frozen soil is considered an air medium containing spherical ice particles and spherical rock particles covered with bound water film. In this contest, the vegetation is a primary reference factor to classify permafrost in this area. Since, plants flourish in permafrost area, the vegetation can be as an important index of discrimination. The vegetation structure and surface wetness conditions influence the backscattering

coefficients in SAR image. The backscattering coefficients are increasing at permafrost area because of its high wetness, with temperature increasing. The vegetation covered the permafrost will influence the permafrost detection, because of the volume scattering effect of vegetation. The complementarities of polarimetric high-resolution observations and time-series datasets will be necessary to provide enough information for general permafrost-vegetation identification. In this study investigates on polarimetric information to identify and monitor the permafrost-vegetation cover of the Svalbard Archipelago. The polarimetric parameter known as radar vegetation index *RVI* (Kim and Van Zyl, 2001) is proposed in this paper. This parameter is estimated making use of European Space Agency (ESA) software PolSARpro (Pottier et al., 2009) and Next ESA SAR Toolbox (NEST) applied on the data acquired by Radarsat-2 a jointly funded by Canadian Space Agency (CSA) and MacDonald Dettwiler Associated (MDA). PolSAR segmentation methodology proposed including multi-temporal analysis of permafrost-vegetation evolution is presented.

2. STUDY AREA

The Svalbard Archipelago is located only 1000 m away from the North Pole at an average latitude of 79°N. Its climate is strongly influenced by the Gulf Stream which touches its western coasts and mitigates the weather. The study area comprises the landmasses around the fjord Kongsfjorden (79° N 12° E) in the north-western part of the Svalbard Archipelago (Fig. 1). The study is conducted on the peninsula Brøggerhalvøya, the hill Ossian Sars Nature Reserve and the island Blomstrandhalvøya. Ny-Alesund (78°56' N, 11°53' E), a small permanent settlement at Brøggerhalvøya, has a mean temperature for 2010 of 5.7 and 3.6 during the summer months of July and August, and -9.4° C during

the winter from October to April (data of Climate Change Tower Integrated Project). The mean monthly precipitation values for these periods are 7.5, 11.4 and 39.3 mm, respectively (data of Norwegian Meteorological Institute). On the landmasses surrounding Kongsfjorden, temperature generally increases from west to east (Joly et al., 2003). Snow starts accumulating around mid-September and is redistributed by wind, causing complex spatial variations in snow depth (Beck et al., 2005). The snow cover becomes thinner from the end of May and most of the snow has disappeared by the end of June (Lloyd, 1999). The landscape mainly consists of Alpine areas, which are partially covered by ice, marine terraces (especially at Brøggerhalvøya), calcareous ridges and moraines (Beck et al., 2005). At Brøggerhalvøya, vascular plants are mainly restricted to the coastal platforms that contrast heavily with the steep interior mountains. At Blomstrandhalvøya and Ossian Sars Nature Reserve, the vegetation extends to more mountainous terrain as well.



Figure 1. Map of Kongsfjorden. © Norwegian Polar Institute.

3. SAR DATASETS PRESENTATION

Different fully-polarimetric RADARSAT-2 datasets is acquired in ascending orbit (15:23 - GMT) and in Fine Quad Polarisation mode (SLC products), thus presenting a nominal swath width of 25km with a spatial resolution of 11.1m (near range) to 10.5m (far range) x 7.6m (azimuth). FQ9 beam is used that corresponds to a radar incidence angle range from 28.0° (near range) to 29.8° (far range). This project is set from May 2010 to September 2010 (6 images) over the study site.

4. METHODOLOGICAL ISSUES

Radarsat-2 data are processed using PolSARPro software (Pottier et al., 2009). The first step of processing is the extraction 4x4 scattering coherence matrix \mathbf{T}_4 . The eigenvectors decomposition of \mathbf{T}_4 leads three real non negative eigenvalues, while the fourth one is zero $\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq \lambda_4 \geq 0$. The second step is applying the

polarimetric speckle filtering (a Boxcar of 7x7). In presence of noise on polarization channels λ_4 increase. λ_4 correspond to the average noise power and we assuming this equal in all polarimetric channels. The third step is remove the remaining noise on coherence matrix 3x3 \mathbf{T}_3 . According to Hajnsek et al., 2003, an additive noise filtering is applied to \mathbf{T}_3 :

$$\mathbf{T}_{3F} = \mathbf{T}_3 - \lambda_4 \mathbf{I}_3$$

where \mathbf{T}_{3F} is the coherence matrix filtered and \mathbf{I}_3 is the 3x3 identity matrix. The last one step is the evaluation of polarimetric parameters by decomposition of coherency matrix \mathbf{T}_{3F} . In order to identify vegetated surfaces, we propose to use the combination of polarimetric parameter: the entropy H , the anisotropy A , the pedestal height PH and the radar vegetation index (RVI) for this segmentation process. The entropy (H) indicates the degree of statistical disorder of the scattering phenomenon. Low entropy ($H \sim 0$) indicates a single scattering mechanism while high entropy ($H \sim 1$) indicates a random mixture of scattering mechanisms and a depolarizing target:

$$H = - \sum_{i=1}^3 p_i \log_3 p_i$$

where $p_i = \lambda_i / \sum_{i=1}^3 \lambda_i$.

For high entropy values a complementary parameter is necessary to fully characterize the set of probabilities. The anisotropy (A) is defined as the relative importance of the secondary scattering mechanisms. A becomes 0 if both of these secondary scattering mechanisms are of equal proportion, while the larger values of A ($A \sim 1$) indicates that the third mechanism is weak compared to the second one:

$$A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3}$$

The pedestal height (PH) is equivalent to measuring the ratio of the minimum eigenvalue to the maximum eigenvalue, this is a useful measure of the randomness of the scattering process. PH becomes 0 if the third mechanism is weak compared to the first one, while the larger values of PH ($PH \sim 1$) indicates that these scattering mechanisms are of equal proportion:

$$PH = \frac{\lambda_3}{\lambda_1}$$

The RVI is a parameter sensitive to the biomass level. Since the scattering mechanism changes as vegetation grows, one can use a time-series of RVI data to retrieve the phenological stage. We used RVI defined as:

$$RVI = \frac{4\lambda_3}{\lambda_1 + \lambda_2 + \lambda_3}$$

5. RESULTS AND DISCUSSION

The data of air temperature and precipitation are shown respectively in Fig. 2 and 3. From Figs. 2-3 is possible identify the time period of transition freezing-thawing, the potential of start phenologic stage and the influence of meteorological condition in SAR image. The Landsat 7 *NDVI* values in Fig. 4 are acquired on 23 August 2010. This identify vegetated surfaces for $NDVI > 0.1$. In Fig. 5 the *RVI* map on 08 July 2010 with 5 AOIs is shown, while in Fig. 6 the *RVI* values time-series data of five AOIs are shown. In AOIs Blomstrandhalvøya Island, Coastal Area and Ossian Sars Nature Reserve the *RVI* time series is evaluate where a mask on pixel data are applied ($H > 0.7$, $A < 0.5$ and $PH > 0.1$), whereas other two no-vegetated AOIs are opportunely select. The preliminary results show that SAR data in C-band are sensitive to permafrost-vegetation interface. Where we are sure of physical characteristic of no-vegetated AOIs (e.g. ice and sea) the dynamic of temporal evolution of *RVI* parameter is about ± 0.1 while mean value for ice and sea are respectively 0.25 ± 0.08 and 0.12 ± 0.09 . While in the case of permafrost-vegetation interface the mean and dynamic value of *RVI* are respectively at least 0.43 and ± 0.13 always more large of no-vegetated AOIs. In particular for Blomstrandhalvøya Island the mean *RVI* is 0.44 ± 0.15 , while in Coastal Area is 0.49 ± 0.13 and finally in Ossian Sars Nature Reserve is 0.43 ± 0.20 .

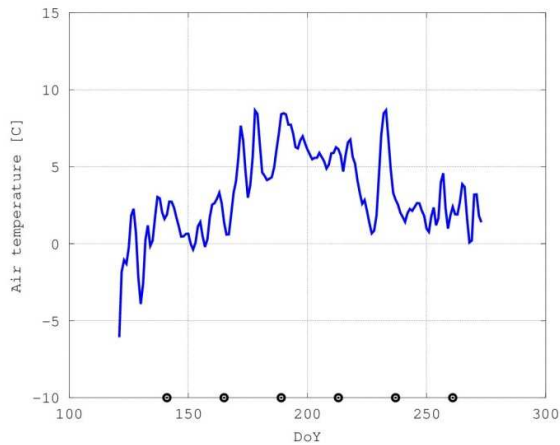


Figure 2. Air Temperature time series. • day of RADARSAT-2 data acquisition. Data of of Climate Change Tower Integrated Project.

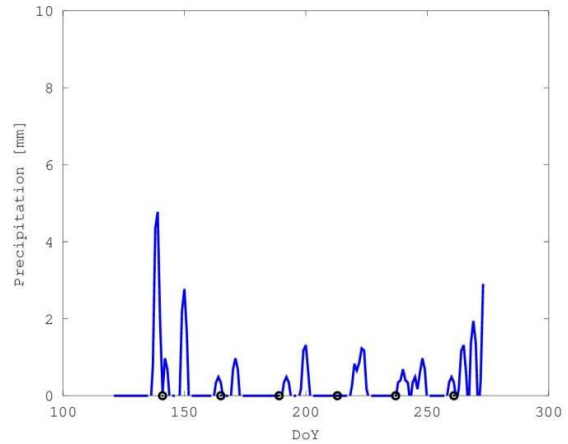


Figure 3. Precipitation time series. • day of RADARSAT-2 data acquisition. Data of Meteorological Norwegian Institute.

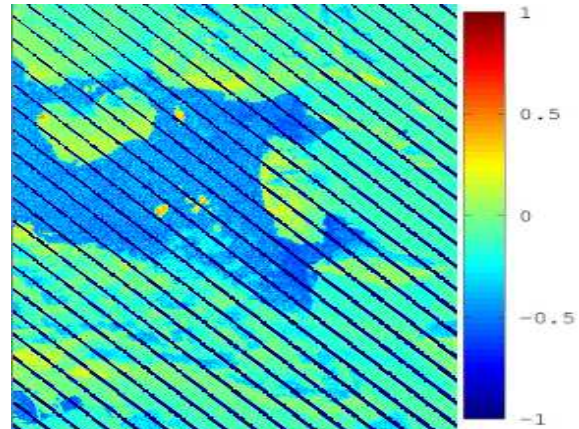


Figure 4. Landsat 7 *NDVI* image acquired on 23 August 2010.

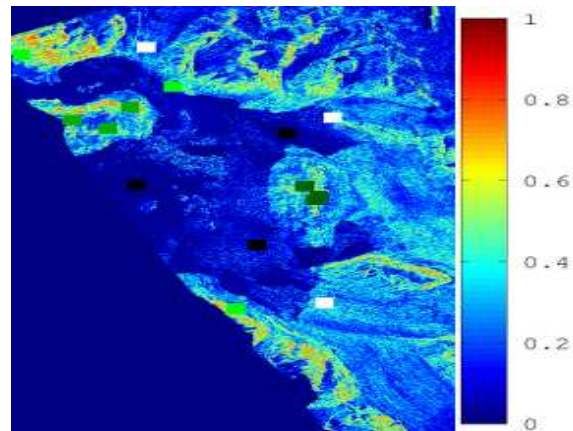
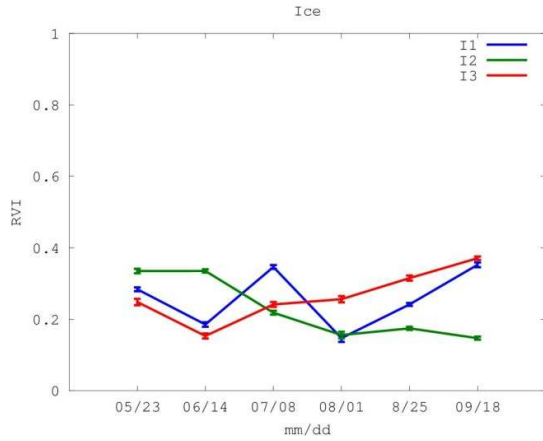
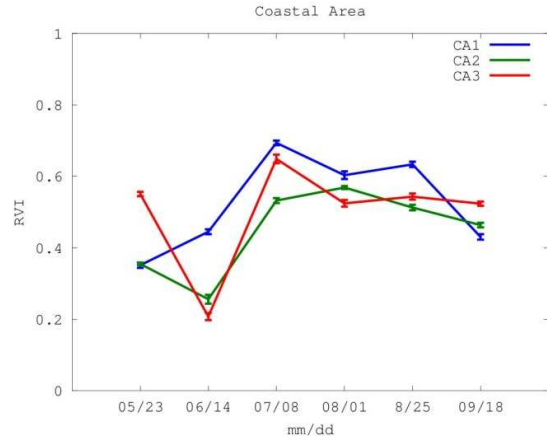


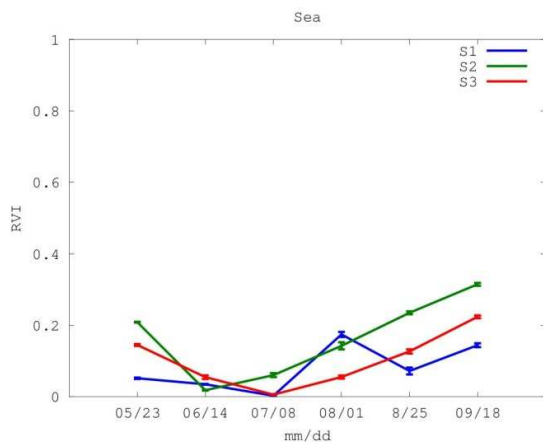
Figure 5. *RVI* map on 08 July 2010 with 5 AOIs: Ice □, Sea ■, Blomstrandhalvøya Island ■, Coastal Area ■ and Ossian Sars Nature Reserve ■.



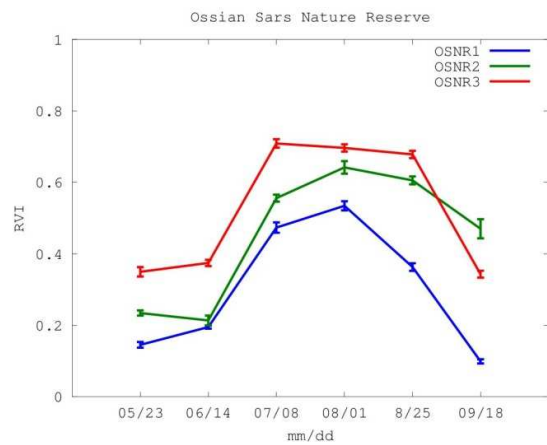
(a)



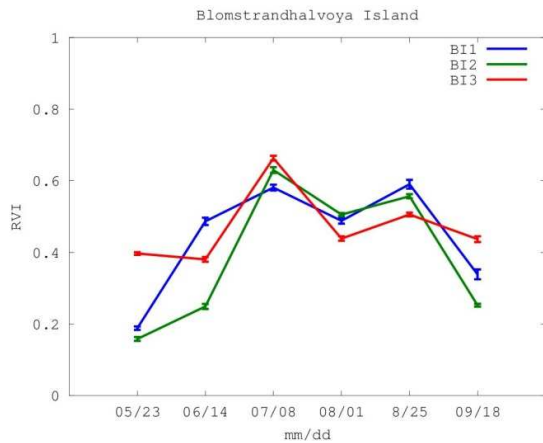
(d)



(b)



(e)



(c)

(e) Figure 6. Mean (\pm SEM) of temporal variation of RVI during the vegetative period in three sampling points of 3×3 pixels for five AOIs: (a) Ice, (b) Sea, (c) Blomstrandhalvøya Island, (d) Coastal Area and (e) Ossian Sars Nature Reserve.

6. CONCLUSION

Discrimination between no-vegetated and permafrost-vegetation interface using RVI is demonstrated. Future work will focus on determining potential discrimination using other parameters from Radarsat-2 imagery. However, more ground truth data are required to verify the accuracy of these results.

ACKNOWLEDGMENTS

This work is supported by Science and Operational Applications Research Education International for Radarsat-2 program (SOAR-EI 5195). The authors would like to thank the CSA and the MDA GEOSPATIAL SERVICES INC. for providing the Radarsat-2 data. The rainfall data analyzed for the work in this paper are publicly available from the Norwegian Meteorological Institute through the website [eklima](http://eklima.no)

(eklima.met.no). The authors wish to thank the DTA-CNR for supporting the realization of the Climate Change Tower Integrated Project (CCTIP) and in particular M. Mazzola and A.P. Viola from ISAC for managing instrumentation and data.

REFERENCE

- [1] Beck, P.S.A., Kalmbach, E., Joly, D., Stien, A., Nilsen, L. (2005). Modelling local distribution of an Arctic dwarf shrub indicates an important role for remote sensing of snow cover. *Remote Sensing of Environment*, vol. 98, no. 1, pp 110-121.
doi:10.1016/j.rse.2005.07.002
- [2] Hajnsek, I.; Pottier, E.; Cloude, S.R. (2003). Inversion of surface parameters from polarimetric SAR. *IEEE Transactions on Geoscience and Remote Sensing*, vol.41, no.4, pp.727-744.
doi: 10.1109/TGRS.2003.810702
- [3] Joly, D., Nilsen, L., Fury, R., Elvebakk, A., Brossard, T. (2003). Temperature interpolation at a large scale: Test on a small area in Svalbard. *International Journal of Climatology*, 23, 1637-1654.
doi: 10.1002/joc.949
- [4] Kim, Y., Van Zyl, J. (2001). Comparison of forest parameter estimation techniques using SAR data. *Proceedings of Geoscience and Remote Sensing Symposium, 2001. IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2001*, vol.3, pp.1395-1397.
doi: 10.1109/IGARSS.2001.976856.
- [5] Lee, J.S., and Pottier, E. (2009). *Polarimetric Radar Imaging: From basics to applications*, CRC Press, Taylor & Francis editor, 397 pages, janvier 2009, ISBN: 978-1-4200-5497-2
- [6] Lloyd, C. R. (1999). Final Report of the Land Arctic Physical Processes (LAPP) Project, contract No. ENV4-CT95-0093 (pp. 134). Brussels European Commission, Climate and Environment Programme.
- [7] Pottier, E., Ferro-Famil, L., Allain, S., Cloude, S., Hajnsek, I., Papathanassiou, K., Moreira, A., Williams, M., Minchella, A., Lavalley, M., Desnos, Y.L. (2009). Overview of the PolSARpro V4.0 software. the open source toolbox for polarimetric and interferometric polarimetric SAR data processing, *IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2009*, vol.4, pp. 936-939.
doi: 10.1109/IGARSS.2009.5417532