PLANT: POLARIMETRIC-INTERFEROMETRIC LAB AND ANALYSIS TOOLS FOR ECOSYSTEM AND LAND-COVER SCIENCE AND APPLICATIONS

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ABSTRACT

PLANT (Polarimetric-interferometric Lab and Analysis Tools) is a new collection of software tools developed at the Jet Propulsion Laboratory to support processing and analysis of Synthetic Aperture Radar (SAR) data for ecosystem and land-cover/land-use change science and applications. PLANT inherits code components from the Interferometric Scientific Computing Environment (ISCE) to generate high-resolution, coregistered polarimetric-interferometric SLC stacks from Level-0/1 data for a variety of airborne and spaceborne sensors. The goal is to provide the ecosystem and land-cover/land-use change communities with rigorous and efficient tools to perform multi-temporal, polarimetric and tomographic analyses in order to generate calibrated, geocoded and mosaicked Level-2 and Level-3 products (e.g., maps of above-ground biomass and forest disturbance). In this paper we introduce the capabilities of PLANT and report first results obtained with the tools developed up to date.

1. INTRODUCTION

The increasing availability of high-quality SAR data from dedicated airborne campaigns as well as operational satellite missions has stimulated the development of SAR algorithms for ecosystem and land-cover/land-use change (LCLUC) applications. Techniques such as polarimetry, interferometry, polarimetric interferometry (PolInSAR) and tomography have reached a good level of maturity for the extraction of biophysical parameters of forests and crops. Algorithms, however, have increased in number as well as complexity. Application of PolInSAR and tomographic techniques, for instance, requires accurate stack processing of multiple baselines in order to estimate forest tree height and structure. This processing often represents an obstacle for research scientists interested directly in Level-2 and Level-3 products, such as geocoded maps of above-ground biomass, soil moisture and forest disturbance.

The goal of PLANT (Polarimetric-interferometric Lab and Analysis Tools) is to provide the Earth Science and remote sensing communities with a set of tools to support processing and analysis of SAR data from Level-0/1 to Level-2/3 specifically for ecosystem and LCLUC applications. The objectives of PLANT are to 1) offer a common software framework for implementing existing and new ecosystem and LCLUC algorithms; 2) support in-orbit and future airborne and satellite sensors; 3) enable efficient processing of large data volumes; 4) provide data structures and containers for multi-temporal, polarimetric, PolInSAR and tomographic data; 5) support multi-mission data fusion; 6) offer statistical data analysis and GIS-friendly visualization; and 7) provide an integrated environment for product calibration and validation.

PLANT's software architecture is based on the ISCE (Interferometric Scientific Computing Environment) framework [1]. Compared to existing SAR packages (e.g., PolSARPro [2] and RAT [3]), integration with ISCE allows for accurate handling of sensor orbit information and image geometry. This is a unique feature as it enables straightforward geocoding of products, conversion of map projections and merging of images from multiple geometries and data sources including lidar. PLANT is currently under development at the Jet Propulsion Laboratory. It is freely available for research under the WInSAR license agreement. In this paper we introduce the software architecture and show examples of output products generated using the PLANT tools developed up to date.

2. PLANT SOFTWARE ARCHITECTURE

PLANT adopts the object-oriented programming framework of ISCE. Higher-level code elements, including data structures, user interface and control of processing flow are written using Python language. Lower-level code elements that are computational intensive and require parallel programming as well as access to specialized libraries are written using C/C++ language. Higher-level and lower-level code elements are tightly integrated through Python bindings. Interoperability between the scripting Python language and the compiled C/C++ language offers great flexibility and modularity with the advantage of reusing legacy code and maintaining high performance.

PLANT tools are provided as standalone Python scripts accessible directly from command line. User-defined parameters supplied as inputs to the scripts are used by the Python interpreter to configure the Python and C/C++ code components. These components are executed sequentially or in parallel to perform the desired processing and generate output

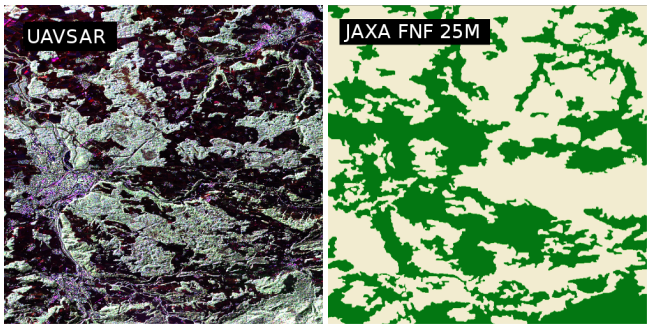

Fig. 1. Full-polarimetric UAVSAR backscatter acquired over the Traunstein Forest in Germany (left) and Forest/Non-Forest 2015 (FNF) map generated from ALOS-2 with green indicating forest cover (right). PLANT automatically downloads, projects and merges FNF tiles to match the user-defined bounding box or the input SAR data (UAVSAR in this example).

products. The user may process data interactively using the available tools, or build customized workflows by accessing directly the Python components. Extending existing tools and incorporating new workflows in ISCE/PLANT is relatively easy as processing blocks are separated in configurable Python components.

PLANT inherits the single-look-complex and interferogram product formats from ISCE. Intermediate and final data files are accompanied by XML header files that contain the necessary information to correctly read, process and visualize the data. Formats for multi-dimensional products (multi-polarization, multi-baseline, multi-angle, multi-frequency, etc.) are being added to the family of supported formats. PLANT supports both raster and vector data types. Vector data are important in ecosystem and LCLUC applications, where it is often required to use polygons or external GIS layers in order to analyze, calibrate or validate the final products.

3. PLANT CAPABILITIES AND TOOLS

PLANT interoperates with ISCE and inherits several of its features. ISCE can efficiently process Level-0 (unfocussed) and Level-1 (single-look-complex) SAR data to generate high-resolution stacks of coregistered single-look-complex images. Precise orbit, DEM and geographic information are stored with the data, allowing the user to easily geocode the output products or project geocoded data to slant range. Generation of accurate auxiliary products such as maps of incidence angle, interferometric baseline or vertical wavenumber is also possible. These products are important inputs to several ecosystem and LCLUC algorithms. Satellite (ALOS-1/2, Sentinel-1, TerraSAR-X, Envisat, COSMO-SKYMED, KOMPSAT, RADARSAT, RISAT and ERS) and airborne sensors (UAVSAR, AirMOSS, F-SAR and ECOSAR) are supported.

Integration with the Geospatial Data Abstraction Library (GDAL) enables handling of hundreds of file formats, including TIFF, GeoTiff, ENVI, GDAL Virtual (.vrt), CEOS, NetCDF, HDF5 and more. Furthermore, GDAL provides modules for map projection, resampling and mosaicking. Tools in PLANT are categorized in four groups: 1) data analysis and visualization, 2) utilities, 3) science product generation and 4) calibration and mosaicking.

3.1. Data analysis and visualization

The tools for data analysis and visualization provide several functions to display and perform quantitative analyses over multiple datasets. As an example, we are improving and extending mdx, the JPL's command-line tool for fast visualization of binary data. The improved mdx allows now generating histograms from multiple images, scatter plots, line/column profiles and average profiles, image masks and image statistics within polygons specified directly from command line. In addition, the tool automatically visualizes polarimetric covariance matrices based on the information contained in the metadata. A command-line visualization tool with statistical functions is helpful for analyzing multi-temporal polarimetric data or interferogram stacks. Fig. 2 shows three quad-polarimetric ALOS-2 coherence maps acquired with different temporal intervals and the corresponding overlapping HV histograms along with the mode (vertical bar) for each histogram.

3.2. Utilities

Utilities in PLANT are used to perform basic operations and data manipulations. Up to date we have implemented three main utilities. The first utility downloads and re-projects seamlessly the Forest/Non-Forest layers distributed by JAXA, which include annual global forest coverage maps and PALSAR-1/2 HH and HV backscatter data from 2007 to 2015 (Fig. 1) [4]. The second utility downloads and extract forest height based on lidar data collected between 2003 and 2009 by the NASA's ICESat mission (Fig. 3). The third downloads and re-projects the GlobCover [5] and GLCF [6] land cover maps, counting 22 and 17 land cover classes, respectively.

Standalone Python scripts allow the user to specify the desired bounding box, the pixel spacing and other parameters such as the type of masking to be applied, the temporal interval of data collection and resampling method. Geocoded data, such as DEMs and SAR images, can also be provided as input, in which case PLANT automatically downloads and generates the selected product coregistered with the input reference SAR data.

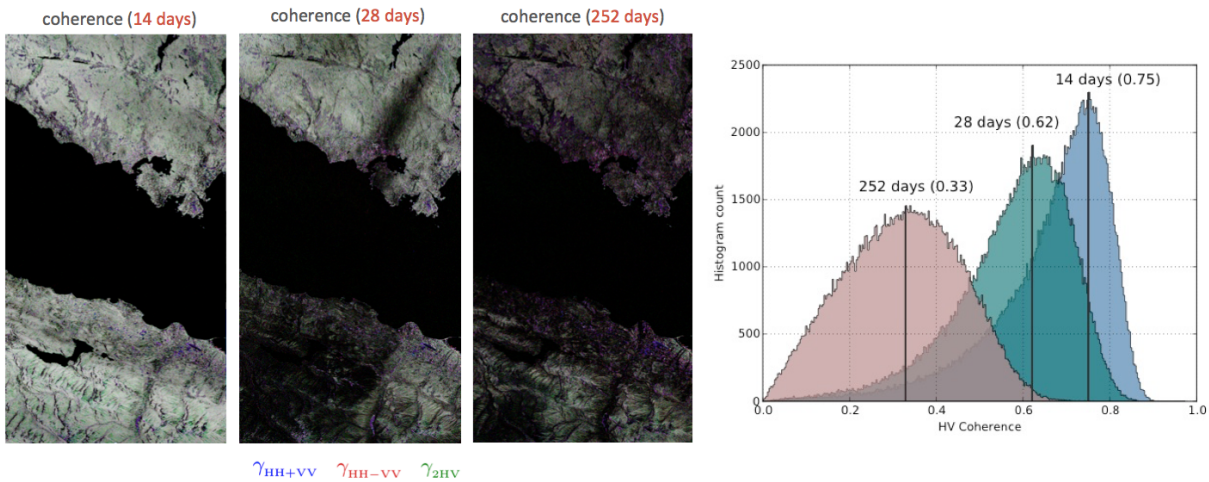

Fig. 2. ALOS-2 interferometric coherence estimated for three increasing temporal intervals near the Olympic National Park (United States). Each image on the left shows the RGB composition of the coherence in the Pauli polarimetric channels. The histograms on the right have been generated using the improved mdx tool and show how the HV coherence decreases for longer temporal intervals.

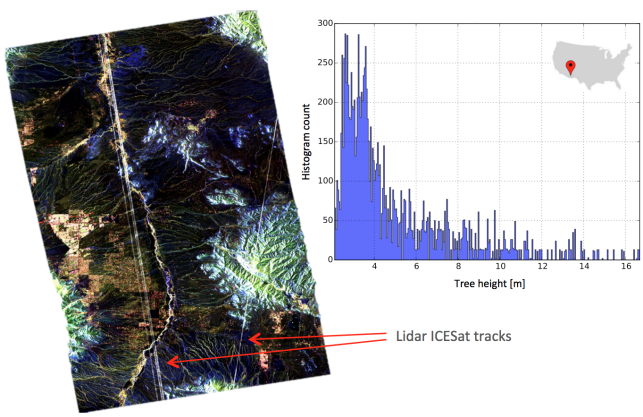

Fig. 3. ICESat lidar tracks (unmasked) overlapped with a Pauli polarimetric image acquired by ALOS-2 over Arizona in March 2015. PLANT provides a command-line tool to automatically download and resample lidar data to the input SAR data.

3.3. Science product generation

The tools for the generation of science products are currently under development and include selected ecosystem and LCLUC algorithms to estimate above-ground biomass (AGB), separate scattering mechanisms, delineate crop area, map inundations and detect forest disturbances.

Here, we briefly describe three methods already implemented in PLANT for estimating AGB from SAR backscatter. The first method [7] is based on the simplified distorted Born approximation (DBA) model. According to this model, SAR backscatter can be described as

$$\sigma_p = f_v \left[A_p(1 - e^{-B_p b}) + C_p b^{\alpha_p} e^{-B_p b}\right] + (1 - f_v)\sigma_p^g \quad (1)$$

where b is the AGB, σ_p^g is the backscatter from bare soil, and A_p, B_p, C_p, α_p are calibration coefficients pre-estimated for a given vegetation structure and polarization $p = (hh, hv, vv)$. If the vegetation fraction, f_v, is assumed unitary over forests, a single polarization (typically HV) is sufficient for estimating AGB; otherwise, at least two polarizations are needed to solve for the two unknowns in (1).

The second method [8] is similar to (1), but incorportes soil-moisture and soil-penetration depth in place of vegetation fraction, requiring full-polarimetric data to estimate biomass.

The third method is the water-cloud model [9], which relates the backscatter to AGB through a logarithmic curve, requiring only the HV polarimetric channel in order to estimate AGB.

The calibration coefficients control the sensitivity of backscatter to AGB for different forest structures and land cover classes. These coefficients are supplied by the user and stored in an XML file. PLANT offers a flexible mechanism for defining the coefficients for each class in the GlobCover and GLCF land cover maps, and applies automatically the coefficients to individual SAR pixels based on their geographic location.

Fig. 4 shows the *uncalibrated* AGB estimated from dual-polarimetric UAVSAR data acquired over a tropical forest during the February 2016 AfriSAR campaign near Mondah in Gabon. Preliminary calibration coefficients and the GlobCover classification map were used. Note that AGB is larger than 100 Mg/ha, the reference saturation point of the backscatter-biomass curve at L-band [7]

3.4. Calibration and mosaicking

PLANT provides basic tools for calibration, validation and mosaicking of SAR data. Capabilities currently available in-

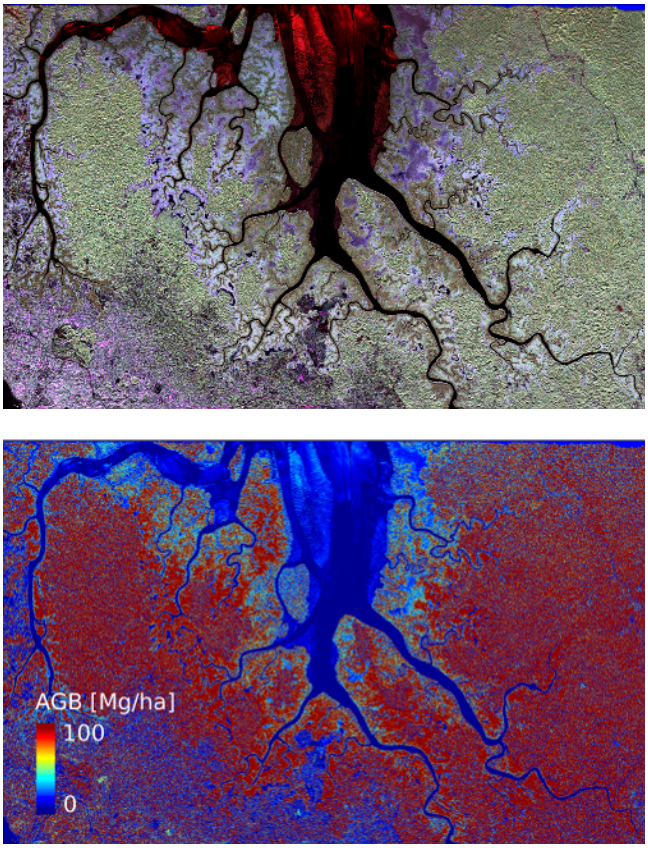

Fig. 4. Full-polarimetric UAVSAR backscatter acquired over a tropical forest in Gabon during the February 2016 AfriSAR campaign (top). Uncalibrated AGB map generated from the HH/HV portion of the UAVSAR data using (1).

clude absolute radiometric calibration, polarimetric radiometric calibration, polarimetric orientation compensation [10], Faraday rotation estimation and correction, and radiometric terrain correction [11, 12].

Radiometric corrections are applied based on the information provided in the ISCE metadata. Input backscatter is typically expressed as either beta-naught, β^0, or sigma-naught, $\sigma_e^0 = \beta^0 \sin\theta_e$, where θ_e is the incidence angle relative to the ellipsoid. Radiometric terrain corrections are applied by using the DEM-derived local incidence angle θ_i and projection angle ψ to obtain sigma-naught, σ^0, and gamma-naught, γ^0, [11, 12] (Fig. 5)

$$\sigma^0 = \beta^0 \cos\psi, \quad \gamma^0 = \beta^0 \frac{\cos\psi}{\cos\theta_i} \tag{2}$$

PLANT supports also mosaicking of sets of images with different strategies for merging the overlapping samples (e.g., mean, coherence level). All tools in PLANT can be executed with a bounding box and pixel size supplied by the used or read from an input file in ISCE format.

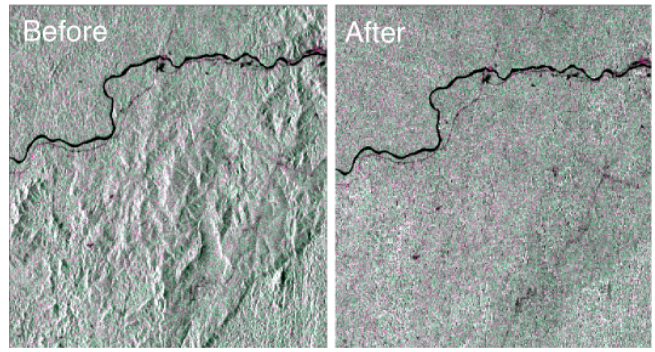

Fig. 5. Polarimetric RGB backscatter before and after radiometric terrain correction for a forested area in Gabon imaged by the ScanSAR mode of ALOS-2.

4. ACKNOWLEDGMENTS

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5. REFERENCES

[1] P. A. Rosen, E. Gurrola, G. Sacco, and H. Zebker, "The InSAR scientific computing environment," in *Synthetic Aperture Radar, 2012. EUSAR. 9th European Conference on*, April 2012, pp. 730–733.

[2] E. Pottier et al., "Overview of the PolSARpro V4.0 software: The open source toolbox for polarimetric and interferometric polarimetric SAR data processing," in *Geoscience and Remote Sensing Symposium, 2009 IEEE International*, July 2009, vol. 4, pp. IV–936–IV–939.

[3] A. Reigber and O. Hellwich, "RAT (Radar Tools): A free SAR image analysis software package," *EUSAR, Proceedings of, Germany*, 2004.

[4] Masanobu Shimada, Takuya Itoh, Takeshi Motooka, Manabu Watanabe, Tomohiro Shiraishi, Rajesh Thapa, and Richard Lucas, "New global forest/non-forest maps from ALOS PALSAR data (2007-2010)," *Remote Sensing of Environment*, vol. 155, pp. 13–31, Dec. 2014.

[5] O. Arino et al., "GlobCover: ESA service for global land cover from MERIS," in *2007 IEEE International Geoscience and Remote Sensing Symposium*, July 2007, pp. 2412–2415.

[6] Mark A. Friedl et al., "MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets," *Remote Sensing of Environment*, vol. 114, no. 1, pp. 168 – 182, 2010.

[7] S. Hensley, S. Oveisgharan, S. Saatchi, M. Simard, R. Ahmed, and Z. Haddad, "An error model for biomass estimates derived from polarimetric radar backscatter," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 52, no. 7, pp. 4065–4082, July 2014.

[8] M. L. Truong-Loi, S. Saatchi, and S. Jaruwatanadilok, "Soil Moisture Estimation Under Tropical Forests Using UHF Radar Polarimetry," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 53, no. 4, pp. 1718–1727, April 2015.

[9] E. P. W. Attema and Fawwaz T. Ulaby, "Vegetation modeled as a water cloud," *Rad. Scien.*, vol. 13, no. 2, pp. 357–364, 1978.

[10] D.L. Schuler, Jong-Sen Lee, and G. De Grandi, "Measurement of topography using polarimetric SAR images," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 34, no. 5, pp. 1266–1277, Sep 1996.

[11] F. T. Ulaby, R. K. Moore, and A. K. Fung, *Microwave Remote Sensing: Active and Passive*, vol. 3, Artech House, 1986.

[12] L. M. H. Ulander, "Radiometric slope correction of synthetic-aperture radar images," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 34, no. 5, pp. 1115–1122, Sep 1996.