CAN SENTINEL DATA HELP NATURAL FLOOD MANAGEMENT?

Michele Caccia; CGI ITALIA SRL – Via E. Fermi 62, 00044 Frascati (RM);
michele.caccia@cgi.com; www.cgi.com

Abstract

Natural Flood Management (NFM) involves techniques that aim to work with natural hydrological and morphological processes, features and characteristics to manage the sources and pathways of flood waters. These techniques include restoration, enhancement and alteration of natural features and characteristics, but exclude traditional flood defence engineering that works against or disrupts these natural processes [1].
One of the key stages of a NFM project in a river basin is the identification of opportunity areas for runoff reduction in the catchment area. This stage may benefits from a high level of assessment of target areas within that catchment area prior to undertaking a more detailed identification and prioritisation of NFM measures. This is particularly the case for large catchments where scoping of the potential for NFM in the entire catchment is not feasible.
Remote sensing data can help the identification of opportunity areas, because at this phase information like land cover maps, vegetation parameters/structure and phenology are usually studied.
The potential of the Sentinel-1 and Sentinel-2 imagery for the information gathering used in Natural Flood Management is investigated. Sentinel data are related to the west Thames catchment area during the 2016 growing season (March-September). The whole potential of Sentinel-1 SAR signal is used for generating land cover maps, including a combination of co-polarised (VV) and cross-polarised (VH) images, and extracting the interferometric coherence and intensity over Single Look Complex product pairs. Sentinel-2 data cloud free composites are also created for extracting key vegetation parameters; such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Leaf Area Index (LAI), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) and Fraction of Vegetation Cover (FCOVER). The obtained results are combined together to provide a value added product that can be useful in Natural Flood Management activities.

Introduction

Remote sensing has the potential to help the NFM during the "identification of opportunity areas" phase, by providing useful information like land cover maps and vegetation indexes [2] with wide spatial coverage and up to date.

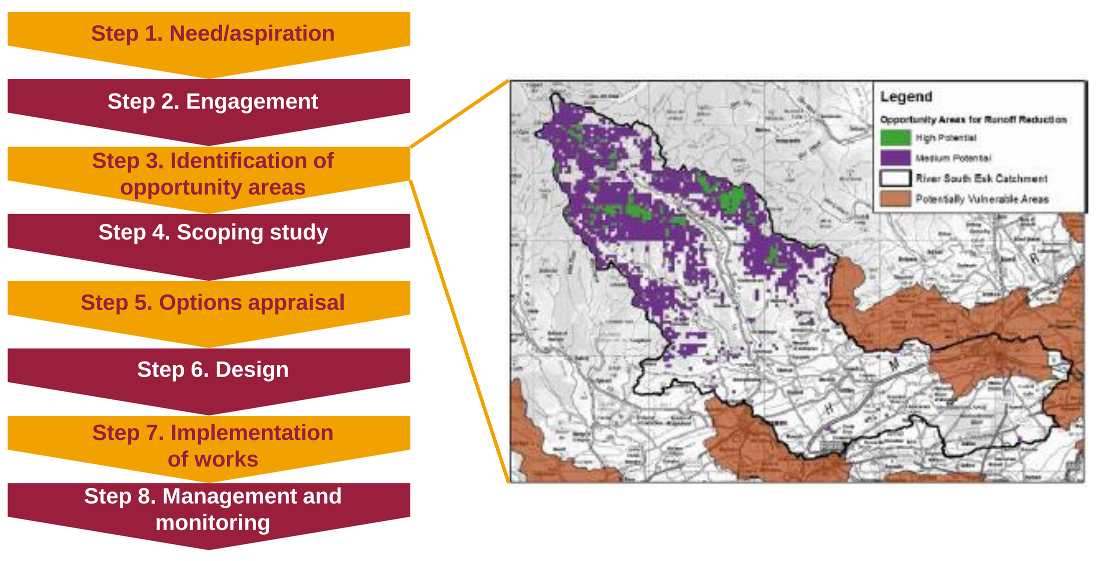

Fig. 1: Left: key steps involved in implementing an NFM project. Right: Example of output from SEPA's NFM maps showing areas with potential for runoff reduction in the River South Esk (Angus) catchment

Thanks to Copernicus, the European Earth observation programme, is possible to get open access to the data produced by the satellite missions called Sentinels. Sentinel 1 (SAR C band mission) and Sentinel 2 (high-resolution optical mission) families are already operational.
The research is an investigation about the potential exploitation of the free of charge S1 and S2 imagery for helping NFM projects.

Objective

The main objective is to provide Land Cover and Vegetation Indexes in the growing season of 2016 in the West Thames river basin (UK) area of interest, with focus on the Hendred Farm area.

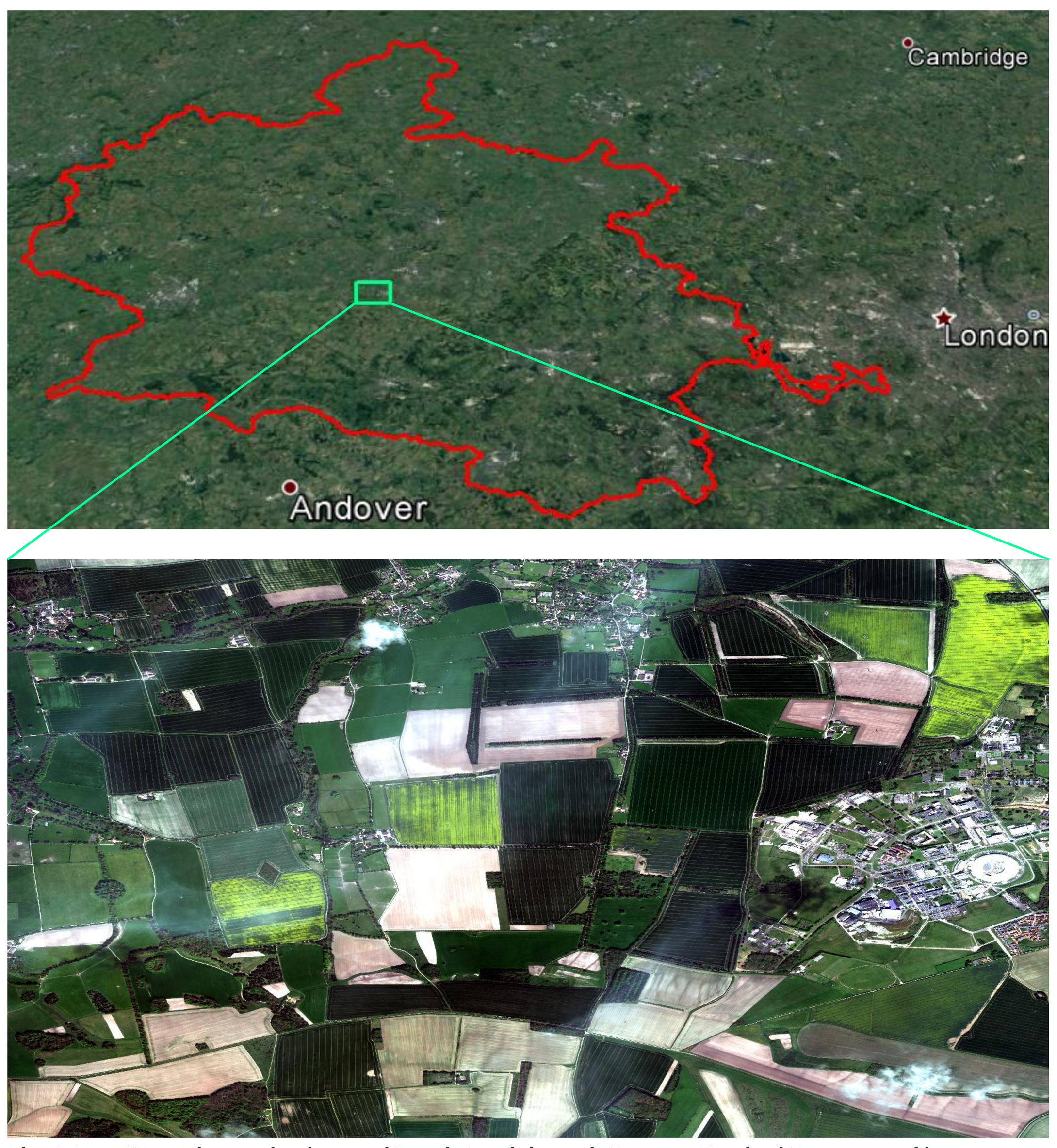

Fig. 2: Top: West Thames basin area (Google Earth image). Bottom: Hendred Farm area of interest (WorldView-3 image)

Also a step forward was performed, trying to produce an added value product, constituted by a GIS map that gives an estimation of runoff hazard, combining the land cover (from S1), vegetation indexes (from S2) and slope (from DEM).

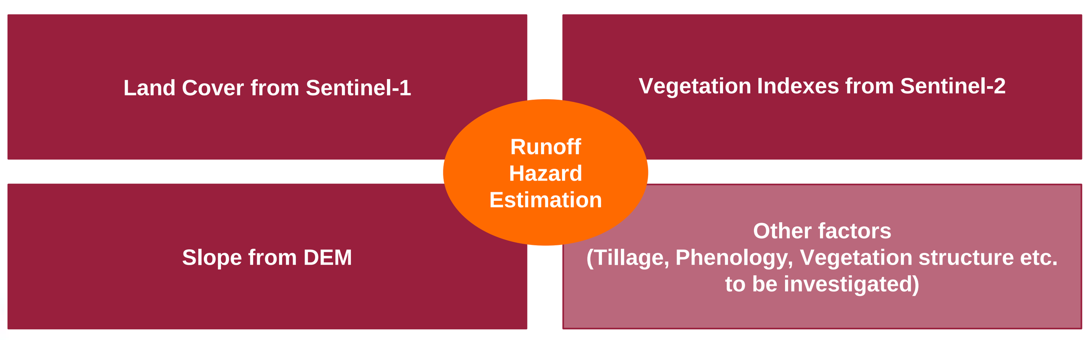

Fig. 3: Runoff hazard estimation factors

Results: Thematic Layers

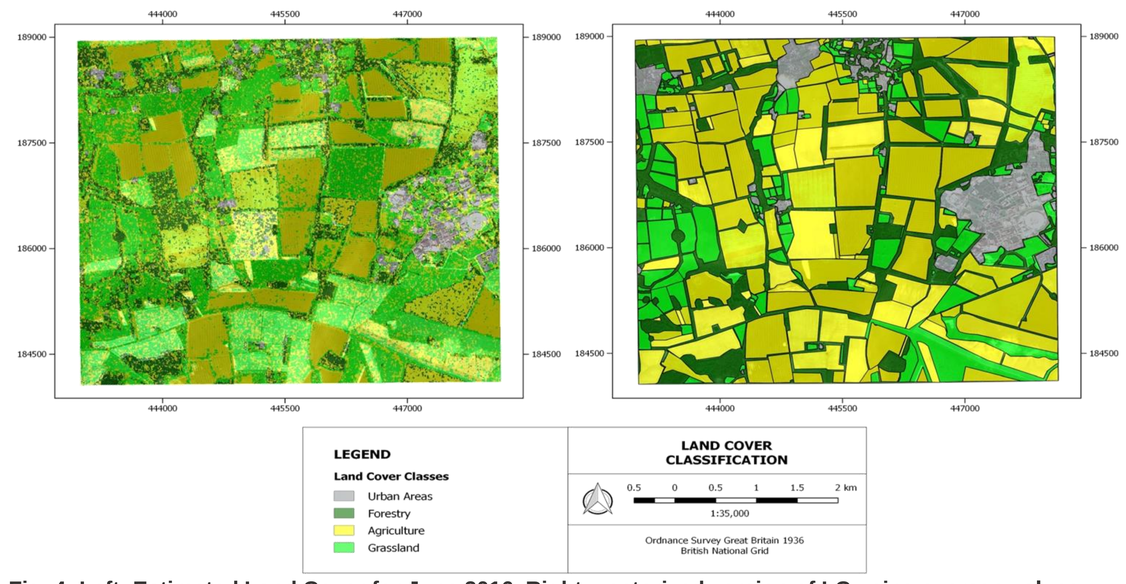

Fig. 4: Left: Estimated Land Cover for June 2016. Right: vectorized version of LC using average values.

Fig. 5: Left: NDVI computed for June 2016. Right: vectorized version of NDVI using average values.

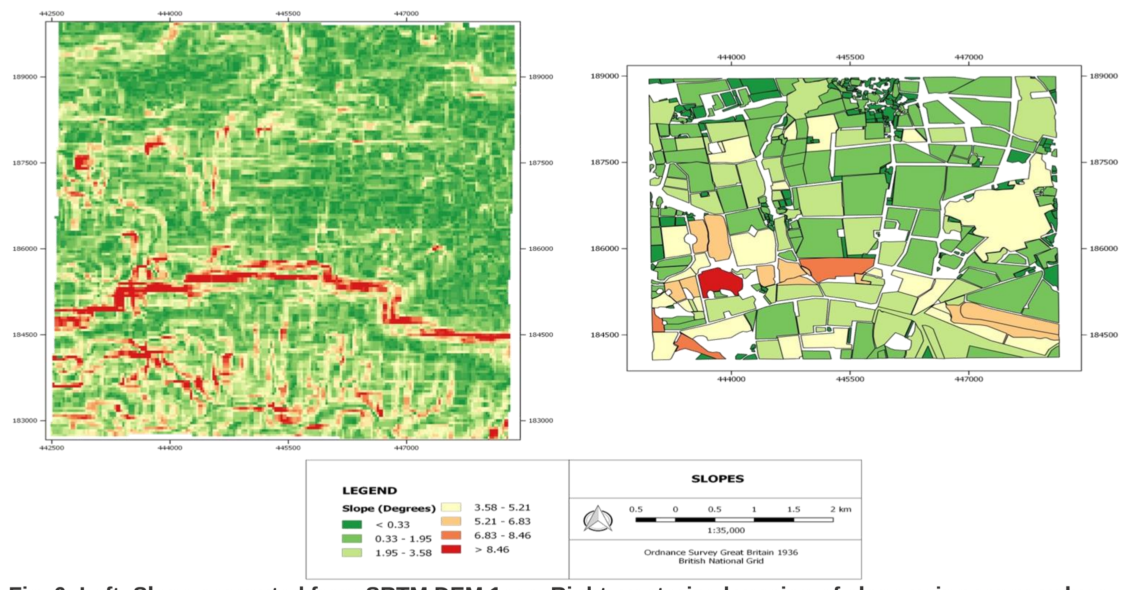

Fig. 6: Left: Slope computed from SRTM DEM 1sec. Right: vectorized version of slope using range values.

Methods

- **Land Cover** map strategies, both using Sentinel-1 images and SNAP software:

1) *Using SLC images*
2) *Using GRD images*

1) SLC images were used to compute intensity (average and ratio) and interferometric coherence over images pairs, only for the co-polarized channel. An average of the retrieved quantities was computed on a monthly basis. Ground truth data (water, bare soil, vegetation, forestry and urban areas) were collected from very high resolution image (WorldView-3). The statistics computed on such areas were applied to identify thresholds to perform the classification on the overall image.

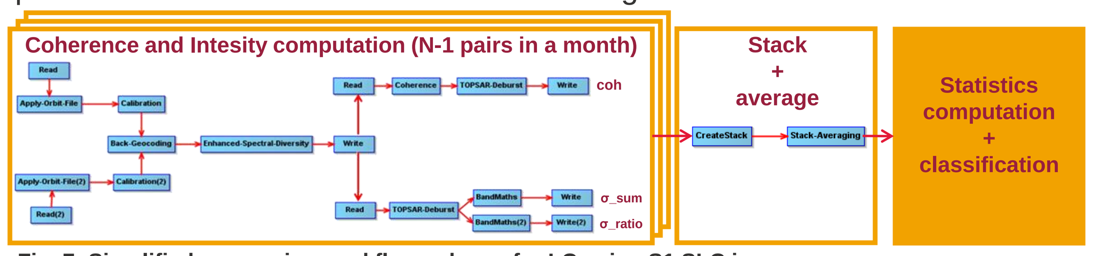

Fig. 7: Simplified processing workflow scheme for LC using S1 SLC images

2) GRD dual polarization images were stacked on a monthly basis and the averaged backscatter was computed for both polarization channels. The VV, VH and VH/VV ratio were given, together with ground truth data from WV-3, to the Random Forest Classifier [3] tool available in SNAP to classify urban, forestry, agriculture and grassland areas.

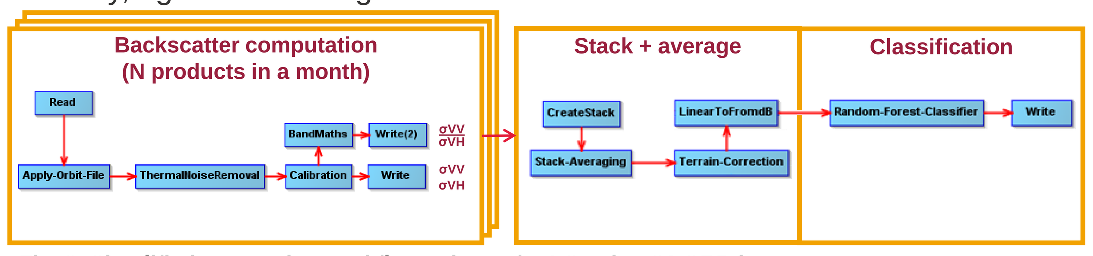

Fig. 8: Simplified processing workflow scheme for LC using S1 GRD images

From a visual check between LC maps and optical S2 data of the same month it was chosen to keep the urban area from method 1) and forestry, agriculture, grassland areas from 2).

- **Vegetation Indexes** and biophysical variables such as LAI, fAPAR, FCOVER, NDVI [4], BSI and NDWI were derived from Sentinel-2 images using the biophysical processor [5] available in SNAP and band math combinations.
- **Slope** was computed starting from SRTM 1-arc-second DEM (30 meters of resolution) by using QGIS.
- **Tillage** presence or absence was visually checked through very high resolution WorldWiew-3 optical image.
- **Vectorized layer** of the Hendred Farm area was built starting from the WV3 image and using QGIS.
  This layer was used together with the QGIS zonal statistics plugin to associate a single value of the above quantities to each polygon.
- **Runoff hazard map** was created by integrating different thematic layers (vectorized version of land cover, tillage, slope and NDVI) which are considered to have an impact on the runoff hazard.
  A system of ranks and weights was assigned to the layers according to their importance to the runoff hazard.

Thematic layer	Weight	Rank 1 (Factor=3)	Rank 2 (Factor=2)	Rank 1 (Factor=1)
Land Cover	20	Bare soil, built-up area	Agriculture, grassland	Forest
Slope	15	High	Moderate	Low
NDVI	15	Low	Moderate	High
Tillage	10	Presence + high slope	Presence + moderate slope	Presence + low slope

Table 1: Ranks and weights for runoff hazard estimation model

Ranks and weights were combined to have the estimated hazard index as follows:

$$HazardIndex = \sum_{l=1}^{numLayers} Rank_{factor}(l) * Weight(l)$$

Results: Runoff Hazard

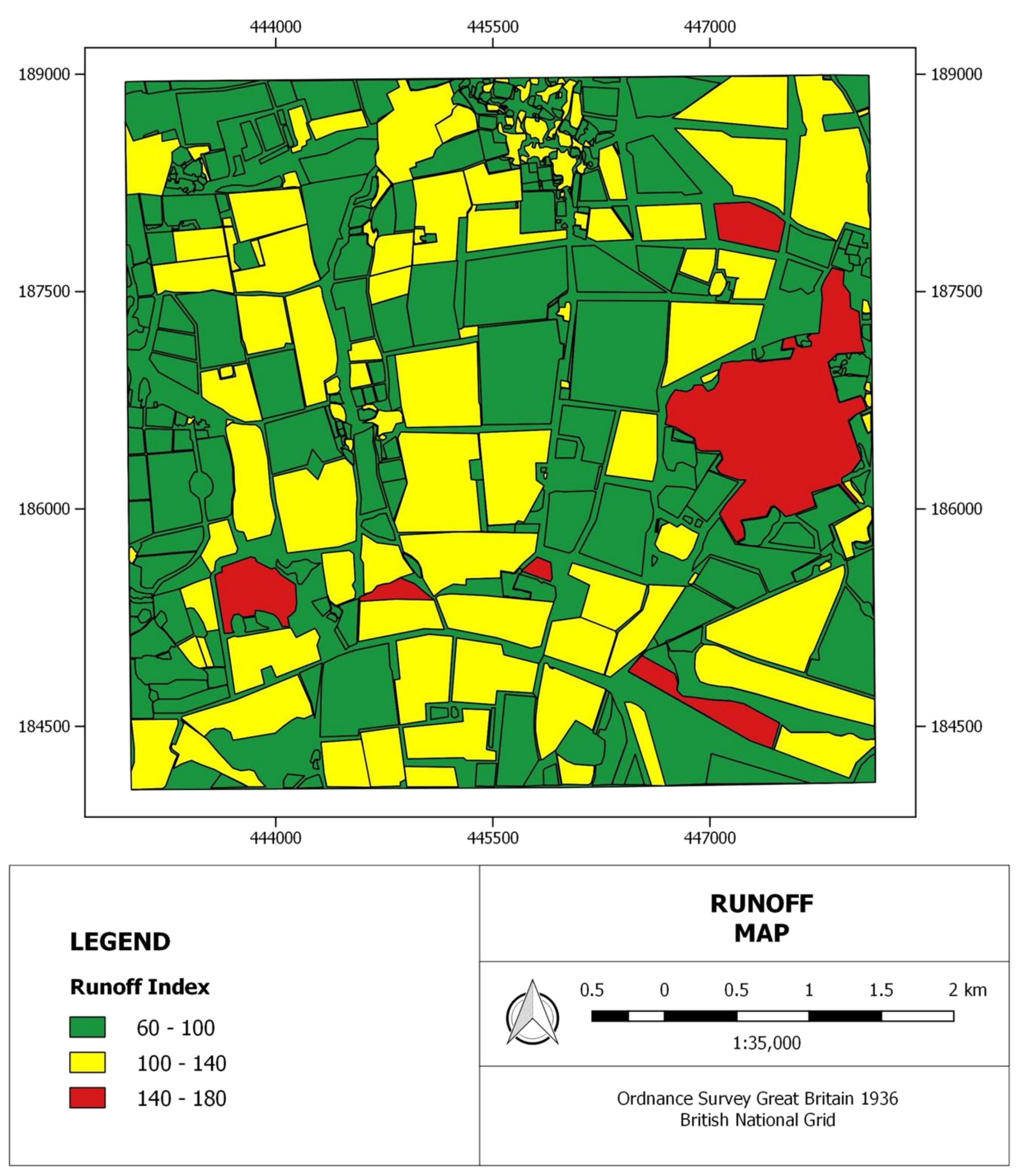

Fig. 9: Runoff Hazard index map (June 2016).
Green=low hazard; Yellow=Moderate hazard; Red=High hazard .

Discussion

- **Estimation accuracy of LC map** is at an early stage of assessment:
  - Urban areas are well classified, except for very small areas for a combination of sensor resolution limit and not precise vectorization.
  - The most frequent error is the exchange between agriculture and grassland.
  - Forestry is well classified, with some false positive in agriculture areas.
- **Other LC classification strategies** should be investigated:
  - Combining the best of the proposed ones. The more automatic method (2) that takes as input also the interferometric coherence as (1), trying to classify also water and bare soil as for starting intention.
  - Other ideas? (Other classifiers? Neural network? SVM? Other input/output quantities?).
- **Vegetation Indexes (VI)** to be further exploited:
  - Test usefulness of the other indexes.
  - A correlation model between S1 measurements and VI (where S2 data is available) is under study to estimate VI also when S2 data is missing.
- **Runoff hazard** to be correlated with physical models:
  - To assess validity.
  - To enhance it identifying additional factors to the hazard estimator.

Conclusions

- **An investigation about Sentinels data exploitation to help Natural Flood Management projects has been performed.**
- **Two Land Cover estimation methods using Sentinel-1 images have been presented together with results.**
- **Several biophysical parameters have been computed using Sentinel-2 images.**
- **An integrated approach that involves remote sensing imagery and GIS techniques for runoff hazard estimation has been investigated.**
- **A first demonstration of application for runoff hazard estimation has been illustrated over the Hendred Farm area, in the West Thames valley.**
  Results shall be validated against physical flood hazard models.

Major References

[1] Scottish Environment Protection Agency, "Natural Flood Management Handbook", December 2015.

[2] Henning Skriver, Francesco Mattia, Giuseppe Satalino, Anna Balenzano, Valentijn R. N. Pauwels, Niko E. C. Verhoest, Malcolm Davidson, "Crop Classification Using Short-Revisit Multitemporal SAR Data", in *IEEE journal of selected topics in applied earth observations and remote sensing*, Vol. 4, no. 2, June 2011.

[3] Breiman L., "Random Forests", in *Machine Learning*, Issue 1, pp 5–32, Volume 45, October 2001.

[4] Rouse J.W, Haas R.H., Scheel J.A., Deering D.W., "Monitoring Vegetation Systems in the Great Plains with ERTS." in *Proceedings, 3rd Earth Resource Technology Satellite (ERTS) Symposium*, vol. 1, p. 48-62, 1974.

[5] Weiss Marie, Baret Fred, "S2ToolBox Level 2 products: LAI, FAPAR, FCOVER", Version 1.1. Date Issued: 02.05.2016.

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