Final Project summary:

The overall objective of **TRANSFORM-EO** research was to develop a fundamental understanding of the ability of a remote sensing methodology named the "triangle" technique in deriving latent (LE) and sensible (H) heat fluxes LE/H fluxes, as well as of surface moisture content (SMC), and to provide a first investigation of the ability of this technique in deriving the above parameters when used with remote sensors which are planned to be launched by Space Agencies in the coming years. This specific technique has already been identified from previous works as one able to move forward on operational implementation. The lack of knowledge related to different aspects of this approach until the time when this research project was started was leading to direct problems and uncertainties when predicting the energy fluxes and SMC, making indispensable the present study. Thus, the proposed research greatly assisted the better understanding, from a remote sensing point of view, physical processes between the different components of the Earth system, a key direction identified for future research by the scientific community.

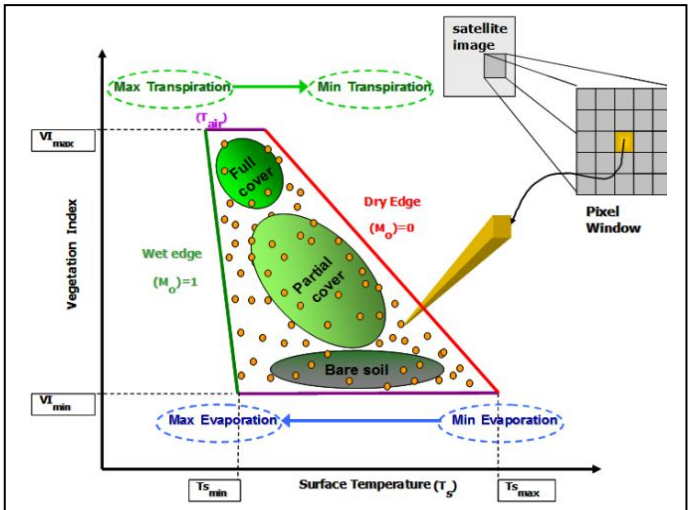

Figure 1: *Summary of the key descriptors and physical interpretations of the satellite-derived Ts/VI feature space (adopted from Petropoulos et al., 2009)*

The research outcomes of the project are provided in detail in the +15 research papers published to international journals, 4 book chapters and +25 conference contributions to international conferences which were produced (see project web site here: http://www.aber.ac.uk/en/iges/research-groups/earth-observation-laboratory/research/transform-eo/). A detail list of the publications is provided at the bottom of this report. In addition, this work resulted to developing a new open access software tool named Seviri PrePro (http://www.aber.ac.uk/seviriprepro) and developing further another one, specifically a land biosphere model named SimSphere (http://www.aber.ac.uk/simsphere) , also provided as open source.

Some of key finds of the research conducted include:

- Within **TRANSFORM-EO** a detailed sensitivity analysis (SA) to the SimSphere land biosphere model was completed on which the sensitivity of a large number of model outputs was examined using a sophisticated variance-based SA approach. The results showed that model outputs were sensitive to a small number of the model inputs. Notably, a significant amount of first-order interactions between the inputs was also found, suggesting strong coherence between the model inputs. Also, SA results showed that the assumption of different probability distribution functions (PDFs) for the model inputs/outputs did not have an important bearing on mapping the most responsive model inputs and interactions; yet they did have an effect on the absolute SA measures. Those results are significant in model parameterisation and further work in the model architectural development.
- In addition, within TRANSFORM-EO the ability of SimSphere to simulate the diurnal variation of key parameters characterising land surface interactions was evaluated at a range of ecosystem types in three continents (Europe, USA, Australia). Model predictions were compared against corresponding in-situ data acquired from several in-situ monitoring networks and a rigorous statistical analysis was carried out to quantify the agreement between the model predictions and in-situ (reference) data. Results showed a generally good agreement between the model predictions and the *in-situ* measurements, suggesting that the model, despite its inherent architectural limitations, can be applied in the future for solving various theoretical and applied tasks. This study presented the most detailed evaluation of SimSphere which has been done to date, and the first validation of it in Australian ecosystem types.

- Furthermore, within TRANSFORM-EO, the "triangle" inversion modelling technique was implemented using both high (ASTER) and low (AATSR) spatial resolution data synergistically with SimSphere and different issues related to this technique implementation were investigated. Predictions of the spatiotemporal distributions of the energy fluxes and SMC by this technique were compared against corresponding in-situ data acquired at different European ecosystems. Results showed that the "triangle" was able to provide estimates of those parameters at satisfactory accuracy, which can be of practical value for many practical applications. To our knowledge, this study is the first validation of the triangle's ability to predict key parameters of the Earth's water cycle derived from the "triangle" technique at meso-scale resolution, and also the first investigation into the effect of atmospheric correction to their retrievals.
- Also, within TRANSFORM-EO, a new, more-physically-based method for the retrievals of the daytime energy fluxes of LE and H has been proposed which has been validated using ASTER data and preliminary results have shown a good promise of this technique to be implemented more widely, replacing potentially the way those parameters have be traditionally estimated so far.
- In addition, within the project implementation a new methodology to derive estimates of SMC from the synergy between the SMOS and SEVIRI satellites was developed and extensively validated using in-situ data from ground observational networks. This method is a variant of the so-called "triangle" method and allows deriving estimates of SMC at previously unattained spatiotemporal resolutions. This study clearly demonstrated that the synergy of SMOS and SEVIRI provides a pathway to enhance water cycle EO capabilities taking full advantage of the new observational records of SSM and operational geostationary information.
- Finally, within the project, some key software tools were developed and distributed now open access. Those included interventions which were done to the SimSphere land biosphere model and also the development of a new open source software tool for the pre-processing of a series of operational products which are derived from the SEVIRI geostationary orbit satellite.

Innovation & Impact

TRANSFORM-EO aimed to address key outstanding issues of global scientific interest today related to understanding Earth's global energy and water balance, those being closely related to the water and food availability on our planet. Indeed, findings of the project will assist in improving our capabilities in better understanding land surface interactions and monitoring key parameters of the Earth's energy and water cycle. In addition, the project addressed fundamental gaps in our knowledge which are critical for implementing the "triangle" inversion modelling approach with EO data, and our general understanding of spatio-temporal estimation of energy fluxes and/or SMC from EO at different ecosystem conditions. The research work also involves significant innovation in another four principle directions: 1) high expected impact regarding the potential usage of the proposed products by the scientific and general community, 2) important input and impact locally, particularly to to water and food-limited environments in our planet, 3) contribution towards the achievement of the scientific challenges and targets of key priority subjects for further research and development by national space agencies as well as of organisations/institutes, enhancing at national and international level, and 4) support strong complementarities to the operational products anticipated to be delivered by space agencies.

Key publications of TRANSFORM-EO:

1. Anagnostopoulos, V. & Petropoulos, G.P. (2017): A Modernized Version of a 1D Soil Vegetation Atmosphere Transfer model for use in Land Surface Interactions Studies. *Environmental Modelling & Software*, 90 pp. 147-156. doi.org/10.1016/j.envsoft.2017.01.004
2. Petropoulos, G.P. & V. Anagnostopoulos (2016): SEVIRI PrePro: A Novel Software Tool for the Pre-processing of SEVIRI Geostationary Orbit EO Data Products. *Environmental Modelling & software*, doi.org/10.1016/j.envsoft.2016.03.015

3. Piles, M., G.P. Petropoulos, N. Sanchez, A. González-Zamora & G. Ireland (2016): Towards improved spatio-temporal resolution soil moisture retrievals from the synergy of SMOS and MSG SEVIRI spaceborne observations. *Remote Sensing of Environment* [in press], doi.org/10.1016/j.rse.2016.02.048
4. Petropoulos, G.P., H.M. Griffiths, T.N. Carlson, P. Ioannou-Katidis & T. Holt (2014): SimSphere Model Sensitivity Analysis Towards Establishing its Use for Deriving Key Parameters Characterising Land Surface Interactions. *Geoscientific Model Development*, 7, 1873-1887, doi: 10.5194/gmd-7-1873-2014.

Software tools (open source) developed/extended during TRANSFORM-EO:

1. **SimSphere** software tool software updates were developed to the model code. The SimSphere tool is distributed globally from http://www.aber.ac.uk/simsphere
2. **SEVIRI PrePro** software tool for the automation of pre-processing of satellite data and products of the geostationary satellite SEVIRI PrePro. Software tool available one access from: http://www.aber.ac.uk/seviriprepro

The TRASNFORM-EO project web site is http://www.aber.ac.uk/en/iges/research-groups/earth-observation-laboratory/research/transform-eo/