Satellite remote sensing as a tool for monitoring vegetation seasonality.

O' Connor, B., Dwyer, N. and Cawkwell, F.

Coastal and Marine Resources Centre (CMRC), University College Cork, Naval Base, Haulbowline Island, Cobh, Co. Cork
Contact details: 00353 21 4703100; brian.oconnor@ucc.ie

Abstract

An increase in average air temperature across the island of Ireland has resulted in a change in the seasonality of vegetation. Evidence from phenological gardens suggests that spring is occurring earlier and therefore the growing season is being extended. This research will help in developing techniques to explore this phenomenon further. Initially, measures of vegetation greenness and hence seasonality across the whole island will be extracted from a multi-year time series of medium spatial resolution MERIS data. From these data, vegetation indices may be constructed and the fraction of photosynthetically absorbed radiation (FAPAR) - a measure of vegetation growth- can be calculated. Analysis of such measurements will allow a characterisation of the seasonality of vegetation that can be correlated with climatic factors such as temperature. Expected outputs will include final times-series map products of FAPAR over the whole island as well as a set of appropriate seasonality measures. This paper will present the preparatory stages of image compositing to minimise cloud influences, and the role of fieldwork in validating the satellite output. Initial findings suggest that a 10-day composite period should be optimal for Ireland given the high occurrence of cloud cover.

Keywords: *vegetation, seasonality, MERIS, FAPAR, growing season*

1. Introduction

Phenology is the study of the interrelationship between biotic growth and environment; vegetation phenology refers specifically to seasonal trends in vegetative growth and decline (Campbell, 2006). Changes in the timing of seasonality can be considered as the response of actively growing vegetation to regional climate warming and in Europe it has been shown that the growing season has been extended (Menzel and Fabian, 1999). These growing season trends are significant for the monitoring of the long term effect of climate changes on the biosphere.

Analysis of data from four Irish Phenological Gardens has suggested that the length of the growing season for a 30-year period from 1970-2000 has increased, particularly in south-west Ireland (Sweeney *et al*., 2002). Data were analysed for three species common across all four sites, with results showing an extension of the growing season by 9 days for *Betula pubescences*, 3 days for *Fagus sylvatica' Har'* and 7 days for *Tilia cordata*, for every 1°C rise in annual temperature. Although these observations have proved useful indicators of change at a few specific locations across the country, the need has arisen, in line with European (POSITIVE, 2000) and global efforts for a broad-scale method of vegetation phenological monitoring across the whole island.

Satellite data can address this need in Ireland with a significant advantage over ground observations as wide swath imagery can provide full coverage of the whole island in one pass. Annual time-series can reveal seasonal trends in vegetation and comparison of interannual data can reveal annual to decadal phenological variability. Phenological observations on the ground can provide a method of verifying the accuracy of satellite-derived trends; therefore, the two data sources are complementary.

Frequent, extensive cloud cover over mid-latitude, coastal regions of the Northern Hemisphere, such as Ireland, has presented a challenge to optical remote sensing of these areas. This work will seek to define an optimal period for compositing of daily imagery over Ireland in order to generate as much spatially continuous, cloud-free imagery as possible.

Satellite remote sensing has been used to monitor vegetation dynamics since the early 1980's with, for example, the generation of a global, AVHRR-derived, Normalised Difference Vegetation Index (NDVI) dataset (Justice *et al*., 1984). More advanced spectral indices, such as the MERIS Global Vegetation Index (MGVI), have been derived subsequently, with improved geometric error correction, atmospheric interference reduction and greater sensitivity to seasonal vegetation dynamics (Govaerts *et al*., 1999). The MGVI has been used as an estimate of the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), which is a biophysical measure of a plant's photosynthetic activity, recognised by the Global Climate Observing System as an essential climate variable (GCOS, 2004).

2. Methodology

2.1 Data Source (MERIS)

The Medium Resolution Imaging Spectrometer (MERIS), launched in 2002, aboard the Envisat platform, is in a sun-synchronous, polar orbit with an acquisition time of 10 a.m. mean local solar time, (ESA, 2006). Data are acquired in 15 spectral bands, of which bands 2, 5, 8 and 13 are most useful to the monitoring of vegetation growth (ESA, 2006). Geophysical data products from MERIS, such as FAPAR, are available at the full spatial resolution of 300 m or at the reduced resolution of 1.2 km.

2.2 FAPAR/MGVI Product from the Joint Research Centre (JRC)

The Institute for Environment and Sustainability within the JRC of the European Commission, in Italy, has generated an FAPAR product for Western Europe since 1997, using a range of sensors. The MGVI-derived product was chosen due to the ready availability of a long time series going back to 2002, and the reduced spatial resolution for its suitability for a national scale study.

2.3 G-POD Processing

The G-POD (Grid Processing on Demand) processing engine of the European Space Agency (ESA) applies a user-defined time-compositing algorithm to daily MGVI data with the output accessible through an online web portal[1]. A publishing server was set up to automatically download the MGVI dataset from the G-POD for further processing.

2.4 Criteria for Optimal Period

As there is no standard approach, a set of criteria was devised in order to determine the minimum number of days per compositing period needed to monitor seasonality within Ireland. These criteria were established to maximise sensitivity to seasonality dynamics while minimising cloud interference.

a) The period is of a sufficient length to include at least one cloud-free day for each image pixel.

b) The period is short enough to remain sensitive to seasonality change.

c) The period takes into account the spatial distribution of cloud across the island.

In order to achieve this, daily 9 a.m. cloud observations from the Armagh Observatory (one of the cloudier areas on the island) were analysed with a view to establishing the annual trends in cloud cover, to which the criteria for compositing were applied. For 2007, these cloud estimates were shown to mirror cloud trends as detected in the satellite data over the whole island.

2.5 Fieldwork

The approach adopted by Soudani *et al.* (2008), in monitoring the phenology of individual trees representative of a larger plot of similar species and age, was implemented on a smaller scale in an area of mixed woodland near Cork Harbour. Thirty trees of six different species types were marked for observation. The age, orientation, height, health and location of each tree was noted and weekly phenological observations recorded for a 12-week period from the beginning of March to the beginning of June, 2008, when all the trees were recorded to have 100% leaf cover. Photo documentation supported the qualitative estimates of the percentage of budburst and percentage of leafout in the tree canopy.

---

[1] http://gpod.eo.esa.int/

3. Results and discussion

3.1 Optimal Compositing Period

Based on previous studies, ten day, monthly (Gobron *et al*., 2005) or twice-monthly image composites (Townshend, 1994) are standard. Analysis of the field results suggested that monthly or twice monthly composites would not be of sufficient temporal resolution to detect seasonality change but that a 10-day, or possibly 7-day, period would be more appropriate to characterise spring greening. Daily cloud observations at Armagh were averaged over 10 and 7 day intervals from February to October (i.e. the growing season) from 2005 to 2007, with the results of 10-day averaging shown in Figure 1.

Due to the anomalously low cloud amounts during the spring of 2007, 7-day and 10-day MERIS composites from 2006 were compared to investigate the effect of shortening the composite period on data loss due to cloud cover. Figure 2 illustrates the percentage of pixels recorded as being cloud covered for a 7-day and 10-day composite period between the beginning of March and end of June, deemed to be the critical period to capture spring growth. The large number of peaks of high cloud cover in the 7-day data suggest that compositing over such a period could result in significant data gaps due to cloud interference. For optimal monitoring of vegetation seasonality, it was determined that fewer than 10% of pixels should be cloud covered within the composite; this was achieved on 77% of the 10-day composites, compared with 50% of the 7-day composites.

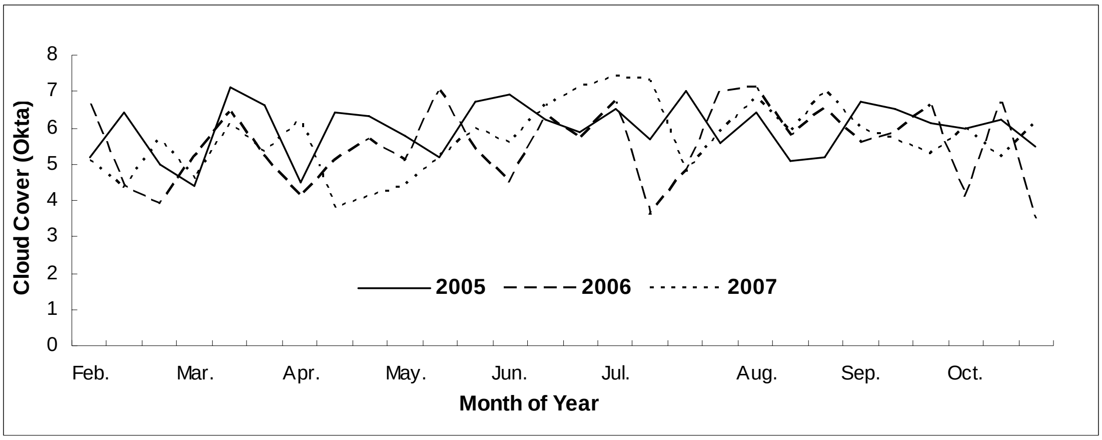

Figure 1: *Daily cloud observations from Armagh Observatory averaged over 10-day periods during the growing seasons of 2005-7 (note that 8 okta represents total cloud cover)*

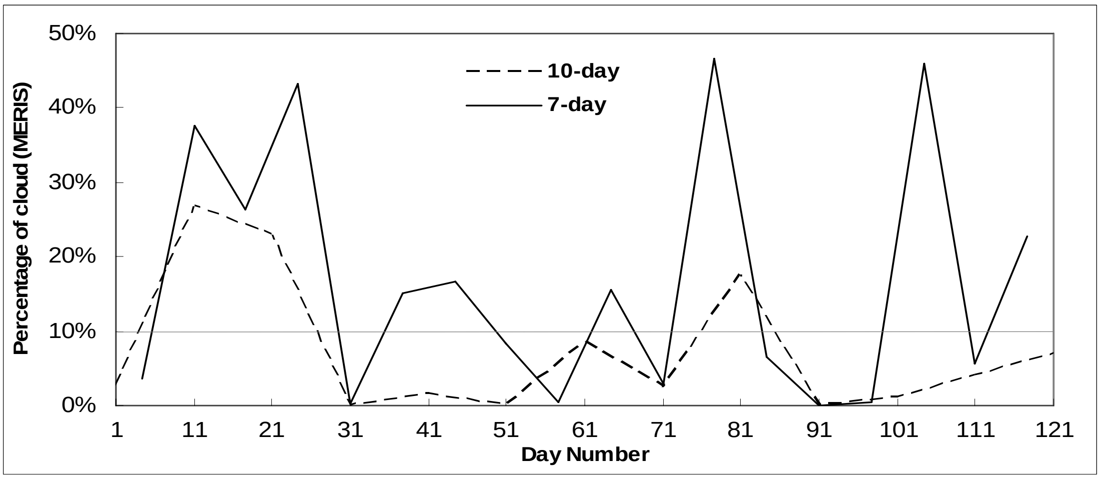

Figure 2: *A comparison of the percentage of MERIS pixels over the island of Ireland that are cloud-covered per 7-day and 10-day composite period during spring, 2006 (Day 1 represents March 1st and day 121, June 29th).*

3.2 Fieldwork

There was a significant change in the woodland observed over the weekly sampling period with the most rapid transition during the month of May. From the photographic data it proved possible to estimate the percentage of leaf cover on a single branch at any one time. However, in undertaking the fieldwork it was evident that even within a very small sample of trees of the same species, there could be considerable variation in the timing and rate of green-up. Given the very mixed nature of Irish vegetation, it is therefore anticipated that at the 1.2km scale of the MERIS imagery there will be considerable variability that is averaged to produce a single pixel value that may in effect not be a true record of change for any single plant within that pixel. Nevertheless it would still be expected to be able to generate an overview record of spatial and temporal change that is representative of the country as a whole from such imagery. Although not an extensive survey, the methodological approach to ground-based phenology showed the value of having observations to support analysis of the imagery and will be implemented on a larger scale for the 2009 growing season.

4. Conclusions

Ireland demonstrates some specific characteristics which provide a challenge to defining phenological change from satellite imagery. The island suffers frequent, extensive cloud cover which limits the use of daily imagery to record change but 10 day composites of daily images provide a good compromise to allow rapid changes to be monitored, without excessive data loss due to cloud-contaminated pixels. Vegetation cover is very heterogeneous which favours the use of higher spatial resolution imagery; should the methodology used for the extraction seasonality measures be successful, the use of higher spatial resolution products will be considered. This work is ongoing and will provide a supplementary phenological dataset to national efforts to augment the phenology network in Ireland. Outputs from this work will include a set of metrics for the determination of phenological phases from satellite data as well as maps showing spatio-temporal trends in phenology across the island.

Acknowledgements –*The Environmental Protection Agency has provided funding for this project under the STRIVE initiative, 2007. The authors are also grateful to the staff at the Institute for Environment and Sustainability, JRC, Ispra, Italy as well as the G-POD technical team at the European Space Agency's ESRIN facility for their input.*

5. References

CAMPBELL, J.B., 2006, *Introduction to Remote Sensing, Fourth Edition* (London: Taylor & Francis), pp. 467-469.

EUROPEAN SPACE AGENCY (ESA), Envisat Home Page, 2006. http://envisat.esa.int/category/index.cfm?fcategoryid=61. Accessed 26th June, 2008.

GCOS, 2004. Summary Report of the Eighth Session of the GCOS/GTOS Terrestrial Observation Panel for Climate (WMO/TD-No. 1238) April 6-7, Ispra, Italy, GCOS-93/GTOS-35.

GOBRON, N., PINTY, B., TABERNER, M., MELIN, F., VERSTRAETE, M.M. and WIDLOWSKI, J.L., 2005. Monitoring the photosynthetic activity of vegetation from remote sensing data. Advances in Space Research, **38**, pp. 2196-2202.

GOVAERTS, Y.M., VERSTRAETE, M.M., PINTY, B. and GOBRON, N., 1999. Designing optimal spectral indices: a feasibility and proof of concept study. Int. J. Remote Sensing **20**, pp.1853-1873.

JUSTICE, C.O., TOWNSHEND, J.R.G., HOLBEN, B.N. and TUCKER, C.J., 1984. Analysis of the phenology of global vegetation using meteorological satellite data. Int. J. Remote Sensing **6**, pp. 1271-1318.

MENZEL, A. and FABIAN, P., 1999. Growing Season Extended in Europe. *Nature*, **397**, pp. 659.

POSITIVE, Phenological Observations and Satellite Data (NDVI): Trends in the vegetation cycle in Europe, 2001. http://www.forst.tu-muenchen.de/EXT/LST/METEO/positive/. Accessed 26th June, 2008.

SOUDANI, K., LE MAIRE, G., DUFRENE, E., FRANCOIS, C., DELPIERRE, N., ULRICH, E. and CECCHINI, S., 2008. Evaluation of the onset of green-up in temperate deciduous broadleaf forests derived from Moderate Resolution Imaging Spectroradiometer (MODIS) data. Remote Sensing of Environment, **112,** pp. 2643-2655.

SWEENEY, J., DONNELLY, A., McELWAIN, L., and JONES, M., 2002. Climate Change, Indicators for Ireland, Final Report. Environmental Protection Agency.

TOWNSHEND, J.R.G., 1994. Global data sets for land applications from the Advanced Very High Resolution Radiometer: an introduction. Int. J. Remote Sensing **15,** pp. 3319-3332.