Analysing the advantages of high temporal resolution geostationary MSG SEVIRI data compared to Polar operational environmental satellite data for land surface monitoring in Africa

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Abstract

Since 1972, satellite remote sensing of the environment has been dominated by polar-orbiting sensors providing useful data for monitoring the earth's natural resources. However their observation and monitoring capacity are inhibited by daily to monthly looks for any given ground surface which often is obscured by frequent and persistent cloud cover creating large gaps in time series measurements. The launch of the Meteosat Second Generation (MSG) satellite into geostationary orbit has opened new opportunities for land surface monitoring. The Spinning Enhanced Visible and Infrared Imager (SEVIRI) instrument on-board MSG with an imaging

capability every 15 minutes which is substantially greater than any temporal resolution that can be obtained from existing polar operational environmental satellites (POES) systems currently in use for environmental monitoring. Different areas of the African continent were affected by droughts and floods in 2008 caused by periods of abnormally low and high rainfall, respectively. Based on the effectiveness of monitoring these events from Earth Observation (EO) data the current analyses show that the new generation of geostationary remote sensing data can provide higher temporal resolution cloud-free (< 5 days) measurements of the environment as compared to existing POES systems. SEVIRI MSG 5-day continental scale composites will enable rapid assessment of environmental conditions and improved early warning of disasters for the African continent such as flooding or droughts. The high temporal resolution geostationary data will complement existing higher spatial resolution polar-orbiting satellite data for various dynamic environmental and natural resource applications of terrestrial ecosystems.

Keywords: Africa, Meteosat Second Generation, POES, Early Warning Systems, NDVI

1 Introduction

The vast majority of land surface remote sensing of vegetation since 1972 has been achieved by polar orbiting satellite sensors (Goward et al., 1985; Tucker et al., 1985). This suite of sensors include the Advanced Very High Resolution Radiometer (AVHRR) (Cracknell, 1996) on National Oceanographic and Atmospheric Administration (NOAA) Polar Operational Environmental Satellite (POES) series, SPOT Vegetation (VGT) (Maisongrande et al., 2004), and more recently, the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on NASA’s Terra and Aqua platforms (Salomonson et al., 1992) among others. Medium to coarse resolution sensors such as MODIS, SPOT Vegetation and AVHRR image the entire earth at 1 to 2 day intervals. The higher resolution sensors, such as Landsat can only image the entire world with a patch work of coverage every 16 days. Yet all of these instruments face a challenge of achieving global cloud-free image data due to the frequent presence of clouds. The local overpass times of these sensors often coincide with the periods of maximum cloud built up and coverage. As a consequence, most single day coverage data are cloud contaminated and cloud-free data can only be achieved using data compositing methods over weeks to months (Holben, 1986). In the tropical cloud prone areas and during the growing (wet) season in most areas of the world a rather long composite period is required to reduce influence from cloud cover (Fensholt et al., 2007). These compositing methods do not only introduce biases in large scale surface measurements because of the tendency towards selection of forward scatter observations (Huete, 1992; Cihlar et al., 1994; Fensholt et al., 2010b) but dynamical events such as floods or droughts may not be captured in a timely manner. All these shortcomings of POES data limit the ability of near-real-time monitoring for emergency services thereby being unsuccessful in providing alerts in a timely manner to prevent developing disaster conditions (Lacaze and Bergés, 2003). For example, the POES systems are widely used for monitoring vegetation conditions by several early warning systems including the United States Agency for International Development (USAID) Famine Early Warning System (FEWSNET) and the Food and Agricultural Organization’s Global Information and Early Warning System (GIEWS). The persistent cloud coverage, especially during the critical crop growing season, has substantially hampered the usefulness of earth observation (EO) information for the development of an efficient EWS of the African continent (Anyamba et al., 2005).

Data from satellites in a geosynchronous orbit such as the Meteosat Second Generation (MSG) producing high temporal resolution data streams every 15 minutes are therefore an interesting alternative. Deployed on the MSG satellite is the Spinning Enhanced Visible and Infrared Imager (SEVIRI) instrument covering visible, near-infrared, shortwave infrared and thermal infrared wavelengths and hence providing a range of measurements that have only been available dring the last decade from POES sensors.

Traditionally, geostationary satellites are used to monitor atmospheric "triggers" for severe weather conditions such as tornadoes, flash floods, hail storms or hurricanes. Previous studies have highlighted the potential of high temporal resolution SEVIRI data also for dynamic environmental monitoring, for example to estimate rainfall (Tucker and Sear, 2001) and air temperature (Stisen et al., 2007), to monitor volcanic activity (Pergola et al., 2008) and fires (Frost and Annegarn, 2007) or to produce near-real time UV maps (Schallhart et al., 2008). However, the use of MSG SEVIRI data to monitor vegetation or land surface vegetation related processes has been limited until recently. Sandholt et al. (2006) used SEVIRI data as an input to a regional hydrological model, Fensholt et al. (2006c) investigated diurnal SEVIRI NDVI for the African continent and Stisen et al. (2008) estimated regional evapotranspiration from SEVIRI data (Fensholt et al., 2006c; Sandholt et al., 2006; Stisen et al., 2008b). More recent studies have demonstrated the potential of SEVIRI data for evapotranspiration modelling (De Bruin, 2010; Ghilain et al., 2011; Sun et al., 2011), drought and water stress monitoring (Fensholt et al., 2010a; Rulinda et al., 2010), fire regime related studies (Roberts et al., 2008; Amraoui et al., 2010; Freeborn et al., 2011) and flooding (Proud et al 2011).

The objective of this paper is to assess the potential of geostationary EO for dynamic land surface monitoring by comparing MSG SEVIRI with commonly used POES data. Data compositing period lengths of standard Terra MODIS, SPOT VGT and NOAA-17 AVHRR products were compared to MSG SEVIRI for a drought and flooding event in East and West Africa in 2008, respectively. Cloud mask and quality flag information was used for all data products. Besides the spatial analysis, we explored time-series covering March-September 2008 for 6 locations directly affected by flooding and drought (Fig. 1) to investigate the performance of a MSG 5-day compositing scene as compared to the performance of the existing state-of-the-art POES sensors.

2 Study areas

Sub-Saharan Africa is one of the world's most cloud-prone regions and has presented a challenge to optical remote sensing from Polar Operational Environmental Satellites (POES) over the last 30 years. The region is characterised by persistent cloud cover generated by the tropical heat engine that produces cloud cover and rainfall all year round with minimum opportunities for acquiring cloud free surface measurements from satellite remote sensing. Different areas of the African continent were affected by droughts and floods in 2008 caused by periods of abnormally low and high rainfall, respectively. East Africa was affected by a creeping drought between March and June 2008 (UN UNOCHA, 2008) and many areas of West Africa were affected by floods between July and September 2008 (IFRC, 2008) (Fig. 1). The Greater Horn of Africa has a bimodal annual pattern of rainfall characterized by a short and a long rainy season. The short rainy season failed altogether in 2008 (Julian day 61-182) and the corresponding drought period was manifested by below average vegetation development (UN UNOCHA, 2008).

In equatorial regions flooding conditions are normally associated with periods of persistent cloud cover and above normal rainfall. On the other hand, drought events can also occur in the so-called rainy season characterized by widespread cloud cover, but without rainfall.

<Figure 1>

3 Data and methods

NDVI and cloud property datasets of the polar-orbiting NOAA-17 AVHRR, Terra MODIS, and SPOT VGT sensors and the geostationary MSG SEVERI are mapped and analysed for a common period in 2008. Normalized difference vegetation index (NDVI) which can be derived from the SEVIRI red and near-infrared bands was used in this study because it has been shown to be highly correlated with photosynthetically active biomass, chlorophyll abundance, the fraction of absorbed photosynthetically active radiation (fAPAR) and rainfall in the arid and semi-arid zones (Myneni et al., 1995; Nicholson et al., 1990; Tucker, 1979). Therefore NDVI can be used as an indicator for land surface variability from seasonal to interannual time scale (Myneni et al., 1996; Reynolds et al., 2000). To date, NDVI is one of the critical inputs to early warning systems for general environmental monitoring, predicting agricultural production and vector-borne disease monitoring as well as prediction (Anyamba et al., 2009; Hutchinson, 1991; Reynolds et al., 2000).

The data of the polar-orbiting sensors reach near-daily coverage at the equator but are usually produced as 16-day (Terra MODIS) and 10-day composites (SPOT VGT and NOAA-17 AVHRR) for vegetation products to minimize cloud cover contamination (Holben, 1986). Both Terra MODIS and SPOT VGT provide NDVI based on surface reflectances whereas the NOAA-17 AVHRR NDVI product is based on TOA (Top Of Atmosphere). All polar-orbiting data have embedded per-pixel cloud quality information or cloud flags which were extracted and used in this analysis.

3.1 NOAA-17 AVHRR 10-day composite NDVI

NOAA-17 AVHRR 10-day NDVI composite data with an 8 km spatial resolution were used in this study were processed at NASA Goddard Space Flight Center, Biospheric and Hydrological Sciences Laboratory. The AVHRR NDVI uses monthly NOAA National Environmental Satellite, Data, and Information Services (NESDIS) near real-time vicarious calibration coefficients to adjust for degradation of the visible channels (1, 2, and 3A). NOAA operational coefficients are based on vicarious calibrations and MODIS measurements over a radiometrically stable desert target (Libya, 21°-23°N; 28°-29°E) and cross calibration among POES sensors based on Simultaneous Nadir Overpass (SNO). In 2008 the equatorial crossing time of NOAA-17 was approximately at 10 am. For the daytime cloud detection at the pixel level the NOAA NESDIS Extended Clouds from AVHRR (CLAVR-x) processing system (Heidinger, 2006) in addition to temperature thresholding were utilized. With the CLAVR-x code an AVHRR data pixel is flagged as either cloudy or cloud-free. For the compositing the maximum NDVI of all pixels was used followed by a cloud check.

3.2 Terra MODIS 16-day composite NDVI (MOD13A1)

The 16-day MODIS composite product (MOD13A1) from the Terra MODIS sensor (equatorial crossing time at 10:30 am) was used in the current analysis. Global MOD13A1 data are provided at 500 m spatial resolution as a gridded level-3 product in the sinusoidal projection. The Terra MODIS MOD13A1 product is based on the Terra MODIS level 2 (L2G) daily surface reflectance product (MOD09 series), which provides red and near-infrared surface reflectance corrected for the effect of atmospheric gases, thin cirrus clouds and aerosols. The data quality assessment (QA data) product which is also embedded in the MOD13A1 product was used to obtain information on overall usefulness and cloud conditions on a per-pixel basis. For the MOD13A1 data Vegetation Index (VI) quality information is defined as a VI Usefulness Index (15 classes, 4 bit layer) ranging from “Perfect quality” to “VI not produced due to bad quality” (TBRS Lab At University of Arizona). In this analysis pixels within the classes 0–5 have been assigned as cloud-free and those within the classes 6–15 as cloudy (class 5 is termed “Intermediate quality” and class 6 is termed “Below intermediate quality”). Detailed explanation of MOD13A2 VI QA binary data may be found at (TBRS Lab At University of Arizona) and (Huete et al., 1999). MODIS data from the Terra platform has been chosen for this analysis over data from the identical Aqua platform

3.3 SPOT VGT 10-day composite NDVI (S10)

The SPOT VGT synthesis product (S10) is a full resolution product at 1 km resolution providing 10-day maximum value composite NDVI (Holben, 1986). Data for 2008 is imaged by the SPOT VGT sensor aboard SPOT 5 (equatorial crossing time of 10:30 am). The quality of S10 products is derived directly from the quality of P products (physical products). P products are TOA products for which the inputs for atmospheric correction are provided. Atmospheric correction is performed with the SMAC algorithm (Rahman and Dedieu, 1994) which corrects for molecular and aerosol scattering, water vapour, ozone and other gas absorption. Data inputs for the atmospheric correction of SPOT VGT are aerosol optical depth (AOD), atmospheric water vapour, ozone (Maisongrande et al., 2004) and a digital elevation model for atmospheric pressure estimation (Passot, 2000). P products are corrected for system errors (misregistration of the different channels, calibration of all the detectors along the line-array detectors for each spectral band) and resampled to a Plate–Carrée geographic projection (SPOT Vegetation User´s Guide). High absolute location and multi temporal registration accuracy are obtained with an absolute location accuracy estimation of 330 m RMS (Sylvander et al., 2000). Status maps are provided for each S10 product including per-pixel cloud-cover information. The cloud flag information is based on thresholding of the TOA reflectance in each of the four bands, which are compared to reference reflectance maps for each band (Lissens et al., 2000; SPOT Vegetation User´s Guide). The S10 products are available at http://free.vgt.vito.be .

3.4 MSG SEVIRI 5, 10 and 16-day composite NDVI

The MSG satellite is located at 0° longitude with a field of view covering all of Africa, much of Western Europe and northeast South America (EUMETSAT, 2005). A prototype of an operational real time processing system has been built at the Department of Geography and Geology, University of Copenhagen to process the MSG SEVIRI data (Fensholt et al., 2006c), using the MSG Data Manager Pro version (Taylor and Taylor, 2005). The input for the processor is Level 1.5 MSG SEVIRI data as delivered by EUMETSAT via the EUMETCast service. Images are represented as 10 bit data with a sampling distance of 3 by 3 km at the sub-satellite point. Output from the processor is atmospheric corrected reflectance in bands 1 (0.56–0.71 μm) and 2 (0.74–0.88 μm), which are used for the calculation of SEVIRI NDVI. The SEVIRI 15 minute data stream from MSG includes a Cloud Mask product (CLM) produced by EUMETSAT. The CLM product contains information on the presence of cloud (cloud/no cloud decision) on a pixel basis - the cloud detection is called scenes analysis (SCE). The SCE algorithm uses satellite, forecast, radiative transfer model output and auxiliary data (Lutz, 2007). Atmospheric correction is performed with the Simplified Method for the Atmospheric Correction of satellite measurements in the solar spectrum (SMAC) algorithm (Rahman and Dedieu, 1994; Proud et al., 2010a and b). Daily values of atmospheric composition (water vapor, aerosols, and ozone) as input for SMAC are derived from the Level-3 MODIS Terra and Aqua Atmosphere Daily Global Products.

MSG SEVIRI data are characterized by diurnal reflectance variations due to a varying solar zenith angle throughout the day. Surface anisotropy has been minimised by a modified version of the MODerate Resolution Imaging Spectroradiometer (MODIS) Bidirectional Reflectance Distribution Function (BRDF) method (Strahler et al. 1999, Schaaf et al. 2002) that produces Normalised BRDF Adjusted Reflectances (NBARs) that are normalised to common scene geometry (Proud et al. 2011). The modeling approach of the MSG SEVIRI NBAR product is similar in concept to the EUMETSAT Land Surface Analysis Satellite Applications Facility (LSA SAF) (Land Surface Analysis Satellite Applications Facility) daily BRDF SEVIRI based on the concept of Roujean et al. (1992).

Five, ten and sixteen-day composites of SEVIRI NBAR’s have been compiled based on cloud-free daily 15 minute observations. Five days has been chosen in order to provide the BRDF model with a suitably large selection of input reflectances to perform a robust model inversion (for the majority of the continent) whilst simultaneously allowing a short enough acquisition time to monitor short term land surface changes. Ten and sixteen-day composites of SEVIRI NBAR’s have been produced to be able to make direct comparisons with the state-of-the-art POES composite products. In order to determine the accuracy and success of the model inversion several quality flags are derived in addition to the kernel parameters applied by the model. If any of the quality values are found to be outside of a predetermined range then the inversion fails and no parameters are recorded for a given composite period. Quality flags also include a check for the range of solar zenith angle (SZA) and view zenith angle (VZA) of image acquisition. For SZA or VZA above 70 degrees observations are disregarded as beyond this value the atmospheric correction scheme is of low accuracy and the BRDF model may no longer be suitable (see Proud et al., 2011 for a detailed description of the BRDF model inversion). The successfully inverted NBARs (normalized to VZA and SZA of 0 degrees) (termed full inversion) are finally converted into NDVI values to be used for the analysis of vegetation trends. For lower quality of input data the algorithm uses a backup database of BRDF parameters. Accordingly, BRDF parameters are scaled based on the availability of SEVIRI data and the scaled BRDF parameters are used to produce the NBARs (termed magnitude inversion). This occurs when too few input observations are available or when the full inversion fails one or more quality checks.

4 Results and discussion

Cloud cover frequency maps for POES data and frequency maps of successful BRDF model inversion (full inversion) for MSG SEVIRI data were compiled for five, ten and sixteen-day composite periods for a drought period in East Africa (March 1-June 30 2008) and a flood period in West Africa (July 1-September 20 2008). In this analysis only full BRDF inversion is kept as an acceptable solution and if the model algorithm produces NBARS based on backup database BRDF parameters the inversion is treated as unsuccessful. These results are shown in Figs. 2, 3 and 5. Additionally, time series of NDVI for selected sites at these two African regions are presented in Fig. 4, to compare the temporal evolution of NDVI among the different sensors during the drought and flood periods. Note that NDVI is only used as an indicator for the variability of land surface conditions and differences in NDVI levels as caused by differences in sensor specific spectral response functions and data processing will not be discussed in details here.

4.1 Comparisons of cloud cover frequency between polar-orbiting and geostationary sensors

Frequency maps of MSG SEVIRI 10-day composites with successful BRDF model inversion (Fig. 2c) were compared with 10-day composite cloud/no cloud information from NOAA-17 AVHRR (Fig. 2a) and SPOT VGT (Fig. 2b) respectively. The results show that during approximately 50 % of the composite period (March 1-June 30) the drought impacted areas in East Africa were cloud covered when using NOAA-17 AVHRR data. When using SPOT VGT 10-day composites the percent cloud cover is moderately lower as compared to AVHRR. However, the SPOT VGT system is known to have a deficient cloud screening algorithm due to the lack of a thermal infrared band onboard the sensor, thereby underestimating the cloud influence on the surface products (Fensholt et al., 2006a; Swinnen and Veroustraete, 2008) and as a consequence underrating the number of composite periods masked as cloudy. Realistically the SPOT VGT cloud cover must be assumed to be in the same range as the one of AVHRR since the VGT sensor has a similar orbiting cycle and equator passing time as the NOAA-17 AVHRR sensor.

Interestingly, the MODIS MOD13A1 product did not produce much useful information in our analysis even though it is integrated over 16 days, i.e., the longest compositing period of all the NDVI products in this analysis. Drought affected areas covering eastern Tanzania and the borderland between Kenya, Somalia and Ethiopia are severely cloud covered and the percentage cloud cover of the composite periods reach close to 100 % in some areas meaning that no surface-condition information is available from the MODIS sensor throughout the entire drought period (Fig. 2d). The reason for the limited data availability of MODIS can be found in the accuracy of the cloud masking. The Terra MODIS 16-day composite product has been validated to have the most accurate cloud screening algorithm (Platnick et al., 2003) thereby reflecting the real state of data availability from a morning pass polar orbiting sensor.

On the contrary, the corresponding 16-day MSG SEVIRI composite product (Fig. 2e) based on the daily cloud-free 15-min observations shows close to 0% of the composite periods being masked as cloudy (a successful BRDF model inversion for 100 % of composite periods is obtained) over all of East Africa during the entire drought period except of some small areas of high topography around Mt. Kenya and Mt. Kilimanjaro with above 50 % of the composite periods being too cloud covered to perform a full BRDF inversion. Shortening the compositing period of the MSG SEVIRI to a 10-day period (Fig. 2c), comparable with NOAA-17 AVHRR and SPOT VGT, does not increase the percentage of cloudy composite periods considerably and for the majority of pixel where a full BRDF inversion was not obtained for all 10-day composites, it is only a single period failing.

Running the BRDF inversion using a 5-day MSG SEVIRI period (Fig. 2f) generally increases the area where full model inversion is not obtained for all 5-day periods. However, for the vast majority of these pixels it is still only a few composite periods out of 25 (1-10% interval) that are being too cloudy for a successful BRDF inversion on a 5-day basis.

<Figure 2>

The results obtained from the analysis of percent cloudy composite periods and BRDF model inversion for the period affected by flooding in West Africa (July 1-September 20 2008) are presented in Fig. 3. The NOAA-17 AVHRR 10-day composites are highly contaminated by cloud cover in the countries along the Gulf of Guinea (including some of the areas severely affected by flooding) where only one to two 10-day periods out of 8 are cloud free (Fig. 3a). The impact of clouds on the SPOT VGT data are less pronounced (Fig. 3b), as it was for East Africa. However, again this is not reliable since the VGT and AVHRR sensors are acquiring data at approximately the same time and should encounter similar cloud conditions. With MSG SEVIRI data, on the contrary, 100 % 10-day composites of successful BRDF model inversion can be obtained for the majority of the region (Fig. 3c). The coastal areas in the Gulf of Guinea are most influenced by cloudiness with the full BRDF inversion failing for about 25% of the 10-day composites. In the equatorial coastal Central Africa there is an increased percentage of failing BRDF inversions caused by very persistent cloud cover in this particular area.

Terra MODIS 16-day composites (Fig 3d) are highly cloud contaminated, hence only limited information can be obtained on surface conditions for the period of flooding in the countries along the Gulf of Guinea. This is in contrast to higher frequency of MSG SEVIRI composite periods with a successful BRDF model inversion over flooded areas from both 16, 10 and 5-day products (Fig. 3c, e, f). Only the extremely cloud prone areas of coastal Central Africa (Nigeria) are severely affected characterized by a high percentage of failing BRDF inversions for the 5-day composites.

For the flooded areas however, the BRDF model inversion fails only for approximately one to three 5-day composite periods (out of the 17 periods covering the rainy season).

<Figure 3>

4.2 Comparison of time series under drought and flood conditions

Time series of NDVI from MSG SEVIRI and POES (NOAA-17 AVHRR, SPOT VGT and Terra MODIS) for three selected sites in East Africa (Fig. 1) are presented for the period March 1 to September 20 2008. In 2008, the short rainy season failed altogether (Julian day 61-182, shaded light brown color) and the corresponding drought period caused low vegetation development, shown here by the NDVI (Fig. 4a-c). The number of cloud-free SEVIRI observations (blue bars) for the three selected sites affected by drought underlines the potential for improved drought monitoring as compared to the time series information available from POES. The number of cloud-free SEVIRI observations passing the BRDF modelling quality check criterias within each composite period reveals that producing a 5-day composite period dataset (which is significantly better than what can be obtained from a POES system) generally remains high. It can be seen that only observations from the MSG SEVIRI provide sufficient information to guarantee continuous land cover monitoring for all sites. Terra MODIS on the contrary only provides a few cloud free 16-day composite observations throughout the entire drought period. Time series of NOAA AVHRR and SPOT VGT 10-day composite NDVI generally capture more composite values as compared to Terra MODIS. However, the quality of the information produced every 10 days must be questioned since the orbit design does not differ from MODIS and consequently fewer observations are available to produce NOAA AVHRR and SPOT VGT 10-day composites as compared to the Terra MODIS16-day composite.

Variations in the level and dynamic range of NDVI as produced from the different sensors are to be expected due to sensor differences in spectral response functions and atmospheric processing schemes (Fensholt et al., 2006b) (e.g., NOAA-17 AVHRR NDVI is based on TOA reflectances whereas NDVI from the rest of the sensors is based on Top Of Canopy (TOC) reflectances).

As it was the case for the 2008 spring drought in East Africa, it is evident in the case of the West African summer flooding that MODIS data failed to provide sufficient information on surface conditions. Comparing MSG SEVIRI 5-day and Terra MODIS 16-day composites capabilities to monitor dynamic earth surface properties for three regions representing flooded areas (Fig. 1) shows a remarkable difference (Fig. 4d-f).

The number of cloud-free MSG SEVIRI observations for the three sites is generally high for each 5-day period producing sufficient data input for a successful BRDF inversion in the majority of 5-day periods enabling a reliable NDVI estimate. For the Togo site however, it can be seen that the reduced amount of cloud-free observations causing the full BRDF inversion to fail more frequently and the 5-day NDVI is produced from magnitude inversion including a backup database of BRDF parameters (hatched bars). During the period of flooding (Julian day 183-263, indicated by the shaded light blue color) both SEVIRI- and POES-based NDVI fluctuated considerably for the Gambia and Togo site (Fig. 4d, f) probably associated with the presence of a mixed spectral signal in the pixels representing water and vegetation. Interestingly, for the Gambia and Guinea sites there is only one 16-day composite MODIS NDVI image available within the flooding period whereas for the Togo site no cloud free observations could be acquired (Fig. 4d, e). Also 10-day composite observations from NOAA-17 AVHRR are limited for the three sites whereas SPOT VGT succeeds in producing continuous measurements from the approximately same equator overpass time as

Terra MODIS and AVHRR (the SPOT VGT cloud mask is known to underestimate cloud and fractional cloud cover, as already discussed before).

<Figure 4>

The total number of per-pixel cloud free observations from MSG SEVIRI data (passing the BRDF modelling quality check criterias) available during the periods of drought and flooding were compiled for the two affected regions and shown in Fig. 5. During the period of widespread flooding in West Africa, July 1-September 20 2008, most of the flooding affected areas have more than 500 cloud free MSG SEVIRI observations (Fig. 5a). For the semi-arid areas of Senegal, Burkina Faso and Niger, this time period (covering the onset until peak of the rainy season) was characterized by > 1000 cloud-free observations. For the period of drought in East Africa (March 1-June 30 2008) the number of cloud-free MSG SEVIRI observations generally was in the range of 200 to 2000 for the drought affected areas (Fig. 5b). Only the highlands of Ethiopia and high mountain regions of Kenya and Tanzania are characterised by small areas of severe cloud contamination, where cloud-free data availability dropped to below 50 to100 observations throughout the period of drought.

<Figure 5>

5 Implications for environmental monitoring

Daily changes in surface reflectance as observed from POES should be interpreted with caution since reflectance measurements are characterised by wavelength dependant anisotropy and vary with the angles of observation and illumination as described by the bidirectional reflectance distribution function (BRDF) (Gao et al., 2002; Jin et al., 2002; Schaaf et al., 2002; Fensholt et al., 2010b). The fixed viewing angle of geostationary satellites provides an interesting alternative to POES data characterized by day-to-day variations in the sun-target-sensor geometry. A fixed viewing angle has important implications for the effectiveness to interpret these variations in measured surface reflectances, in particular for areas affected by dynamic events such as floods or droughts. Geostationary data on the other hand are characterised by varying solar zentih angles (SZA) over the course of the day. The high temporal resolution of MSG data, however, provides a significantly higher number of observations as compared to POES making it possible to correct for varying SZA with the requirement of only a few days of observations. A BRDF-corrected reflectance product is provided as based on MODIS data (MOD43B4) by inverting multidate, multiangular, cloud-free, atmospherically corrected, surface reflectance observations acquired over a 16-day period (Schaaf et al., 2002). However, the requirement of multidate and multiangular cloud-free observations for a given pixel compromises the ability of retaining a high temporal resolution data in the modeled output. To compensate for this, the most recent MODIS BRDF product is processed using a 16-day rolling acquisition period in which a new composite is started every 8 days to better capture rapid changes in surface reflectance that would not be immediately apparent if a simple 16-day period was used. For the coastal areas in Sub-Saharan Africa there is an annual BRDF inversion success rate of close to 0% for the MOD43 product though (Proud et al. 2011).

In contrast, the 15 minute temporal resolution of MSG SEVIRI data allows for a much larger number of acquisitions to be collected and used for a robust BRDF inversion. BRDF corrected SEVIRI reflectance observations modeled on a daily basis (>40 observations, depending on the solar zenith acceptance angle) can provide cloud-free NBAR reflectance observations computed on a daily basis for many areas of the world, yet still with a robust model inversion accuracy. Currently MSG SEVIRI BRDF cloud-free reflectance observations computed on a daily basis as based on a linear kernel-driven BRDF model (Roujean et al., 1992) are provided by the EUMETSAT Land Surface Analysis Satellite Applications Facility (LSA SAF) (Land Surface Analysis Satellite Applications Facility). However, despite the influence from the diurnal varying solar zenith angles, the reflectances measured every 15 minutes also contain new and valuable information. When analyzing the diurnal pattern of reflectance/emittance for a pixel characterized by the presence of vegetation while affected by drought, the bell shape of the diurnal canopy surface temperature observations will be influenced due to plant stomatal closure at some point during the day, and thereby valuable information on plant water stress/evapotranspiration can be obtained (Benoit et al., 2008; Stisen et al., 2007).

6 Conclusion and outlook

The Geostationary MSG SEVIRI sensor produces high temporal resolution data covering optical, near infrared, shortwave infrared, and thermal infrared domains and has opened up new possibilities for satellite-based environmental monitoring at a shorter (5-day) time scale than is currently available from POES sensors. The improved spectral resolution of the geostationary SEVIRI sensor can be used for vegetation monitoring by using optical/near infrared wavelengths (Fensholt et al., 2006c) and canopy water stress monitoring based on the shortwave infrared reflectance sensitivity to canopy water content (Fensholt et al., 2010a; Rulinda et al., 2010) or by combining the optical/near infrared domain with thermal information (the so called “triangle method”) (Stisen et al., 2008a). Combining the improved spectral resolution with the high temporal resolution makes MSG SEVIRI, not only a complementary data source to POES, but advances large scale disaster monitoring in cloud prone areas of the world covered by the sensors field of view. So far geostationary data are not considered for assessing large scale natural hazards and disasters (Joyce et al., 2009), even though cloud coverage and revisit times signify important limitations for near real-time monitoring and assessment of such events (Gillespie et al., 2007). For example, the MODIS NDVI product is widely used in operational environmental monitoring systems but as illustrated in this paper, during the period of a natural hazard, only insufficient information was available from the MODIS sensor.

Our analysis illustrates that areas affected by flooding and drought can effectively be monitored at significantly shorter time scales with MSG data as compared to any of the POES systems. These findings suggest that space agencies world-wide should consider deploying and operating a constellation of sensors for environmental remote sensing, i.e., covering the optical, near infrared, shortwave infrared, and thermal infrared spectral range, in geostationary orbit to improve cloud free monitoring of the land surface within a latitude range covering ± 60 degrees to provide capabilities for improved early warning in disaster situations. At present only the SEVIRI sensor onboard MSG and the Indian INSAT-3A, located at 93.5° East longitude (ISRO), payloads can provide such data. The forthcoming GOES-R multi-spectral Advanced Baseline Imager (ABI) with similar spectral bands as SEVIRI is expected to be launched in 2014 enabling geostationary-based environmental monitoring of the continents of North and South America (Schmit et al., 2005).

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Figure captions

Figure 1:

MSG SEVIRI (band 1, 2 and 3) 10-day composite map (Sept. 1-10) overlaid with areas affected by drought and flooding in East and West Africa 2008 (IFRC, 2008; UN UNOCHA, 2008).

Figure 2:

Maps of percentage cloudy composite periods / pixels of no MSG SEVIRI BRDF inversion for the period characterized by drought in East Africa (March 1-June 30, 2008); (a) NOAA17-AVHRR, (b) SPOT VGT (c) MSG SEVIRI 10-day composite periods (≈12 periods), (d) Terra MODIS, (e) MSG SEVIRI 16-day (≈8 periods) (f) MSG SEVIRI 5-day (≈25 periods) composite periods.

Figure 3:

Maps of percentage cloudy composite periods / pixels of no MSG SEVIRI BRDF inversion for the period characterized by flooding in West Africa (July 1-September 20, 2008). (a) NOAA-17 AVHRR , (b) SPOT VGT (c) MSG SEVIRI 10-day composite periods (≈8 periods), (d)Terra MODIS, (e) MSG SEVIRI 16-day (≈6 periods), (f) MSG SEVIRI 5-day (≈17 periods) composite periods.

Figure 4:

Time series of NDVI for selected sites (Fig. 1) characterized by drought and flooding (January 1-September 20, 2008) extracted from Terra MODIS 16-day, NOAA-17 AVHRR, SPOT VGT 10-day and MSG SEVIRI 5-day BRDF corrected composite data (green dots indicate full BRDF inversion and green/white dots indicate magnitude inversion). MSG SEVIRI total number of good quality cloud free observations is included for each 5-day composite period (blue bars indicate full BRDF inversion and hatched blue bars indicate magnitude inversion).

Figure 5:

Maps of total number of good quality cloud free MSG SEVIRI observations during the periods of drought and flooding for (a) West Africa, July 1-Sept 20 and (b) East Africa, March 1.-June 30.