# Algorithm Theoretical Basis Document for Normalized Difference Vegetation Index

## PRODUCTS: LSA-410 AND LSA-453 (ENDVI10)

| | |
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| **Prepared by :** | H. Eerens, E. Swinnen, B. Smets, W. Heyns, B. Ooms, T. Jacobs | 23/12/2013 | |
| **Approved by :** | Land SAF Project Manager (I. Trigo) | | |

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# 1. Introduction

The Satellite Application Facility (SAF) on Land Surface Analysis (LSA) is part of the SAF Network, a set of specialized development and processing centers, serving as EUMETSAT (European organization for the Exploitation of Meteorological Satellites) distributed Applications Ground Segment. The SAF network complements the product-oriented activities at the EUMETSAT Central Facility in Darmstadt. The main purpose of the LSA SAF is to take full advantage of remotely sensed data, particularly those available from **EUMETSAT** sensors, to measure **land surface** variables, which will find primarily applications in meteorology (http://landsaf.ipma.pt/).

The EUMETSAT Polar System (EPS) is Europe's first polar orbiting operational meteorological satellite and the European contribution to a joint polar system with the U.S. EUMETSAT will have the operational responsibility for the "morning orbit" with Meteorological-Operational (Metop) satellites, the first of which was successfully launched on October 19, 2006. Despite the wide range of sensors on-board Metop (http://www.eumetsat.int/), most LSA SAF parameters make use of the Advanced Very High Resolution Radiometer (AVHRR) and, to a lesser extent, of the Advanced Scatterometer (ASCAT).

The Metop/AVHRR S10 ("ENDVI10") are near-global, 10-daily composite images which are synthesized from the "best available" observations registered in the course of every "dekad" by the orbiting earth observation system Metop/AVHRR, as shown a yearly composite of 2009 in Figure 1.

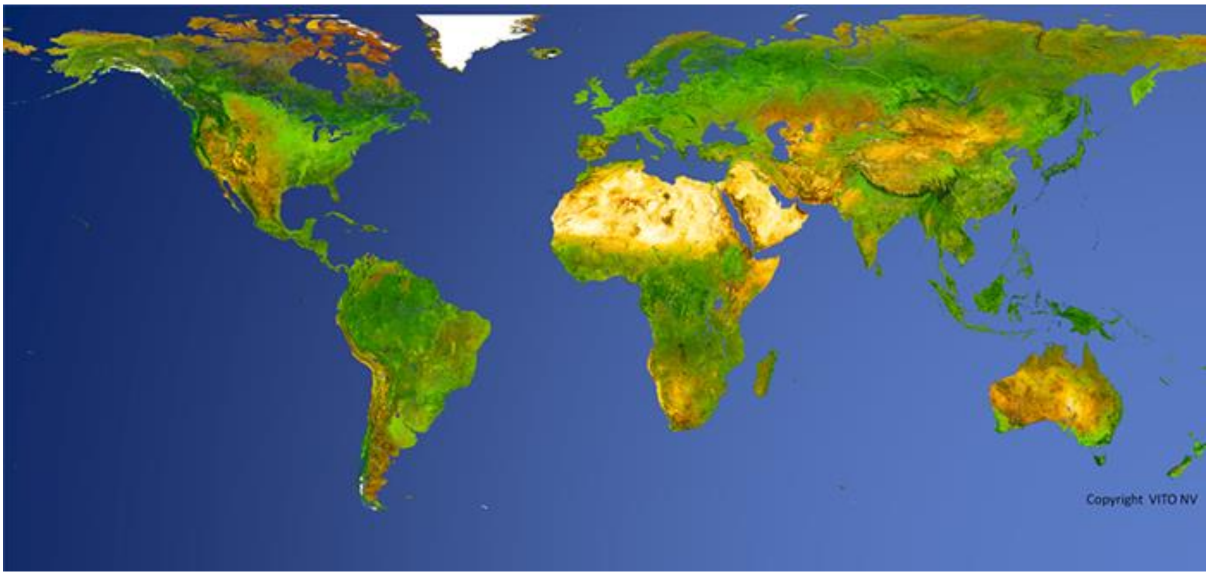



Figure 1 – ENDVI10 product example.

On behalf of the JRC-MARS program of the EC, VITO has developed a processing chain for the treatment of NOAA-AVHRR data over Europe. Individual tracks/orbits are ingested, corrected in different steps (calibration, geometric correction, atmospheric correction, cloud/snow labeling) and then composited to 10-daily "Synthesis" images (S10). With this chain all the daytime-observed NOAA data registered since 1981 were treated by different stations in Europe. Recently the procedures were adapted for AVHRR/Metop level 1b data. The resulting S10-composites from METOP-AVHRR are very comparable with the ones delivered by VITO's

SPOT-VEGETATION processing chain: 1km resolution, near-global coverage, frequency of 10 days ("dekad") and similar spectral contents (RED, NIR, SWIR - no BLUE but two thermal bands). In addition to the basic information layers (surface reflectances, angles of the sun/view geometry, status map, etc.), the dekadal composites also comprise two "value-added" image layers: NDVI and LST (Land Surface Temperature).

The Metop-AVHRR S10 is operated in the LSA SAF System II at VITO. ENDVI10 is available as a Climate Data Record (LSA-453) starting in March 2007 and an Interim Climate Data Record (LSA-410) performing continuous updates in Near Real Time of LSA-453. In both cases, ENDVI10 consists of composites representing a Normalized Difference Vegetation Index and are distributed together with a set of ancillary dataset layers (surface reflectances, sun and view angles, quality indicators). The product and ancillary dataset layers described in this document refer to both LSA SAF products: the ENDVI10 Climate Data Record (LSA-453) and ENDVI10 Interim Data Record (LSA-410). The Land Surface Temperature ancillary layer is added on courtesy of VITO, whereof EUMETSAT does not take any liability, responsibility and ownership. The products can be acquired from http://www.metops10.vito.be/index.html.

This document describes the algorithm and the main characteristics of the vegetation index (NDVI plus accompanying reflectance bands and LST) generated from AVHRR/Metop data. The characteristics of AVHRR based vegetation indices provided by the LSA SAF are described in Table 1. Further details on the LSA SAF product requirements may be found in the Product Requirements Document (PRD) available at the LSA SAF website http://landsaf.ipma.pt.

Since the algorithm is based on the NOAA-AVHRR data, several parts of the algorithm are described within this context and describe the adaptations required to support the METOP/AVHRR system.

Table 1 : Product Requirements for ENDVI, in terms of area coverage, resolution and accuracy.

| Product Name | Product Identifier | Coverage | Resolution | | Accuracy | | |
|---|---|---|---|---|---|---|---|
| | | | Temporal | Spatial | Threshold | Target | Optimal |
| ENDVI10 | LSA-453<br>LSA-410 | Global | 10-daily | 1km | R>0.80 | R>0.90 | R>0.95 |

where R = coefficient of determination.

# 2. Input Data

## 2.1. Metop/AVHRR

The 1km resolution image data registered all over the globe by Metop/AVHRR are systematically captured by the antenna in Svalbard (Norway) and further channelled to EUMETSAT (Germany). EUMETSAT immediately applies some crucial pre-processing steps: the raw observations are calibrated and transformed into top-of-atmosphere radiances (TOA), accurate “Lon/Lat-planes” are added with the geographical position of each pixel in the raw segment, and also a mask is added indicating the status of each observation (clear, cloud, snow). The resulting data stream is cut into segments of 3 minutes (1080 scanlines) which are distributed in near-real time via the EUMETCast broadcasting system in the form of EPS-formatted Level1B-files.

While Metop follows a "morning orbit" with daytime registrations in descending mode, the NOAA18 oppositely has a noon orbit with daytime scanning in ascending mode. Both platforms carry the same AVHRR3 sensor, but Metop has some advanced features. First, the orbit is better stabilized and attitude variations are limited – which will facilitate the geometric correction. Second, Metop stores all the 1km-data of the last orbit on board – such that Darmstad now receives global imagery at 1km. EUMETSAT collects the data, pre-processes them to a basic level (1B) and transmits the results freely via the EARS-system (EUMETCast Advanced Retransmission Service).

For Metop/AVHRR, the data are cut into segments of 3 minutes (1080 lines) and distributed via a completely new so-called EPS-format. Three important differences with NOAA/AVHRR:

- The Metop-data are global.
- The SW-calibration is already executed by EUMETSAT, hence the EPS-files contain TOA-radiances.
- The Lon/Lat-planes, computed by EUMETSAT and stored inside the EPS files.

Missing Metop-data can be ordered via the UMARF-system in EPS format.

The AVHRR-3 sensor on board of Metop registers in five spectral bands, as shown in Table 2. During the day band 3 operates in the SWIR (3A), during the night it is switched to MIR (3B).

| Band nr. | Bandwidth(µm) | Spectral domain | Band abbreviation |
|---|---|---|---|
| 1 | 0.58 - 0.68 | Shortwave | VIS (visual) or RED |
| 2 | 0.725 - 1.00 | Shortwave | NIR (near infrared) |
| 3A | 1.58 - 1.64 | Shortwave | SWIR (shortwave infrared) |
| 3B | 3.55 - 3.93 | Middle infrared | MIR |
| 4 | 10.3 - 11.3 | Longwave thermal infrared | $TIR_4$ |
| 5 | 11.5 - 12.5 | Longwave thermal infrared | $TIR_5$ |

Table 2 : Metop/AVHRR spectral bands

The Level1b files are provided with a timeliness of 2 h 15 minutes from sensing with a Product Dissemination Unit (PDU) of 3 minutes, also known as a product ‘granule’. These granules follow a strict file name convention as:

<instrument_id>_<product_type>_<processing_level>_<spacecraft_id>_
<sensing_start>_<sensing_end>_<processing_mode>_<disposition_mode>_<processing_time>

, so an example AVHR_xxx_1B_02_....

The EPS segments always provide the longitude and latitude on the WGS84 geodetical datum for a subsample of pixels. These "Lon/Lat-planes" are needed for the mapping of the raw images towards a geographical projection system.

### 2.2. Meteorological data

Meteorological data are needed to perform Atmospheric Correction on the reflective channels and to compute the accompanying LST-parameter. The following ancillary data is used:

- Ozone content is obtained from climatology data of the TOMS dataset. One global set is available for each month. The monthly data are considered to represent day 15 of the month. Resolution of the dataset is 0.25°.
- Water vapour is derived from the actual data from ECMWF (global, at 0.5°, every 6 hours).

- Tropospheric aerosol is a simple Gaussian curve from north to south. There is no variation in longitude, nor in time. Latitudinal resolution of the dataset is 0.25°.
- Pressure is calculated from a DEM by means of the formula:

$$pressure = 1013.25 \cdot \left(1 - \frac{0.0065 \cdot altitude}{288.16}\right)^{5.31}$$

The meteorological input data is interpolated in space to the resolution of the AVHRR images. The nearest input in time is always used.

# 3. Methodology

Level1B files are received of the EUMETCast Reception Station (one base, one spare). However, for the production of the ENDVI10 only the daytime segments are used (hence band 3 is always SWIR).

The algorithm [Eerens et al, 2009] consists of two steps being (1) segment processing and (2) compositing.

## 3.1. Segment Processing

First each individual segment is then treated as follows :

- ***Segment selection***:

  The continuous data stream comprises all kinds of Metop/AVHRR imagery, registered over land and sea, during the day and the night. But as the focus is on global vegetation monitoring, only the daytime segments with at least some land pixels are retained for further processing.No further attempts are made to process the sea pixels. And the elimination of the night time registrations implies that band 3 always corresponds with the SWIR (B3A).

- ***Spatial - Remap***:

  Using the mentioned Lon/Lat-planes, included by EUMETSAT in the Level1b EPS data, and a "nearest neighbour" resampling scheme, the five spectral bands of AVHRR are converted to the WGS84 Geographical Lon/Lat system with a framing and resolution pixel size of 1°/112 (≈ 1 km along a great circle).

- ***Spatial - Angles***:

  Similar images are computed providing for each pixel the angular position (zenith/azimuth) of the sun and the sensor at the moment of the registration.

- ***Spectral - Shortwave***:

  The on-board registered radiances are converted into surface reflectance factors by means of the SMAC algorithm SMAC v4 [Rahman et al, 1994] which removes (at least partially) the unwanted atmospheric and angular impacts on the ground signal. The SMAC-coefficients for METOP's three shortwave channels (RED, NIR, SWIR) were computed on behalf of the MARS-project [Berthelot et al, 2008]. They are also made available via CESBIO's SMAC-website (http://www.cesbio.ups-tlse.fr/fr/smac.htm). In addition to these band-specific coefficients, SMAC also needs the input of the atmospherical state at registration time, in terms of water vapour, aerosol load and ozone content, as described in paragaraph 2.2.

  After the atmospheric correction, the Normalised Difference Vegetation Index (NDVI) is computed from the surface reflectances: NDVI = (NIR-RED)/(NIR+RED).

- ***Spectral - Longwave***:

  Land surface temperatures (LST) are derived, separately for land and sea pixels, from the two TIR brightness temperatures using the split window technique [Coll and Caselles, 1997], which also requires the input of water vapour and TIR emissivities. For water vapour, the same six-hourly ECMWF data are used as for SMAC. The TIR emissivities of the land pixels are assessed via a simple linear equation from their NDVI. More details are provided in paragraph 3.3.

- ***Quality - Masking***:

  Each pixel's observational state is expressed via subsequent 0/1-switches in a bitmap image. This "status mask" classifies each pixel according to criteria such as: land↔sea, and clear↔cloud↔snow/ice. While the GLC2000 map [Bartholomé et al, 2005] is used to separate land from sea pixels, the distinction between "clear↔cloud↔snow/ice" is fully based on the results of the cloud/snow detection added by EUMETSAT in the Level1b-files [EUMETSAT, 2004].

## 3.2. Compositing

The processed segments are composited in daily composites before the final ten-daily composites (S10):

- ***Spatial aspects***:

  The composite images follow the same map system as the corrected segments, i.e. WGS84 Geographical Lon/Lat with a resolution of 1°/112. But while the segments only cover limited zones, the S10-composites always extend over the same near-global area, ranging from -180° to +180° in longitude and from -56° to +75° in latitude (40 320 columns x 14 673 lines). The composites only contain information for the land pixels. All the water pixels are flagged with unique missing values codes.

- ***Temporal aspects***:

  Every month is divided in three "dekads". The first two always comprise ten days (1-10, 11-20), the third one has variable length as it runs from day 21 until the end of the month. The procedure starts with the selection of all segments registered within the concerned dekad and overlapping at least partially with the mentioned target zone.

- ***Spectral aspects***:

  In general, for each land pixel in the composite, different observations are available, from different segments or registration dates. The compositing selects the "best available" observation and transfers all its components (reflectances, temperatures, angles, status, ...) to the corresponding layers in the S10 synthesis.

  The selection is realised per pixel as follows. For each pixel the available observations are first classified based on their status (clear, snow/ice, cloud) and their geometry ($\Theta_s$=*sun zenith angle,* $\Theta_v$=*view zenith angle)* as shown in Table 3.

| OBSERVATION STATUS | REGISTRATION GEOMETRY | | |
|---|---|---|---|
| | BAD $\theta_s$>75° or $\theta_v$>45° | ACCEPTABLE $\theta_s$<75° and 40°<$\theta_v$<45° | GOOD $\theta_s$<75° and $\theta_v$<40° |
| Cloud | Not used | C2 | C1 |
| Snow/Ice | Not used | B2 | B1 |
| Clear | Not used | A2 | A1 |

Table 3 : Compositing rule

All observations in the BAD category are immediately discarded. The remaining ones (if any) are grouped in six classes with the following hierarchy: *A1>A2>B1>B2>C1>C2*.

Then the highest non-empty class is searched. If it contains only one observation, that one is selected, else it will be the one with the highest NDVI (which promotes the cloud and snow free data). If a pixel has no GOOD or ACCEPTABLE observations, its position in the composite is flagged with special codes in all spectral layers. But in all other cases (at least one acceptable measurement), the composite will contain the values of the best observation (reflectances, angles, etc.), while its nature (clear, cloudy,...) is expressed via the Composite Status Map.

This method favours the near-nadir views and suppresses the observations which are still partly affected by clouds, snow and water (which all have low NDVI).

- ***Quality Control***:

Scenes of NOAA-AVHRR are often affected by radiometric errors (stripes, waves) or geometrical shifts, especially when a platform reaches its nominal lifetime. Hence, after the pre-processing each individual segment is visually checked by an operator who identifies and rejects the bad scenes. Without this measure, the bad segments can spoil the quality of the final composites. But after one year of similar checks on the AVHRR data of Metop, no such errors could be detected. So as an alternative, we now only check the daily global composites, which are produced as well in the background. This requires less time and is as effective as checking hundreds of individual segments (480 per day).

## 3.3. LST Calculation

In the LST calculation process the vegetation cover fraction is calculated using the NDVI. For each pixel the fraction is determined using the pixels within the imagery with maximum and minimum NDVI.

The vegetation cover fraction ($P_v$ ) is calculated using the median of the pixels with the 5% highest NDVI values is $NDVI_v$ and the median of the pixels with the 5% lowest NDVI NDVI values is $NDVI_g$.

$$P_v = \frac{NDVI - NDVI_g}{NDVI_v - NDVI_g}$$

with:

| | |
|---|---|
| $P_v$ | : Vegetation fraction [-] |
| NDVI | : Normalized Difference Vegetation Index of the pixel [-] |
| $NDVI_g$ | : maximum Normalized Difference Vegetation Index of a bare soil pixel [-] |
| $NDVI_v$ | : minimum Normalized Difference Vegetation Index of a fully vegetated pixel [-] |

The calculation procedure consists of the following steps:

- Sort all pixels from the smallest to the largest value, leaving out doubles;
- Select pixels with the x % (default is 5%) highest and x % (default is 5%) lowest NDVI-values. The median of the x % highest is $NDVI_v$ and the median of the x % lowest is $NDVI_g$;
- For each pixel calculate $P_v$.

For the determination of the land surface temperature a split window method is implemented. The brightness temperatures from ch4 and ch5 are combined with the surface emissivity (correcting for grey bodies) and the atmospheric water content is taken into account.

The emissivity (ε, -) is calculated according to Valor and Caselles (1996) and Rubio et al. (1997):

$$\varepsilon = \varepsilon_v \cdot P_v + \varepsilon_g \cdot (1 - P_v) + 4 \cdot \langle d\varepsilon \rangle \cdot P_v \cdot (1 - P_v)$$

with:

| | |
|---|---|
| ε | : pixel emissivity [-] |
| $\varepsilon_v$ | : the emissivity of a fully vegetated pixel [-] |
| $\varepsilon_g$ | : the emissivity of a bare soil pixel [-] |
| dε | : the estimated mean error on the values of $\varepsilon_v$ and $\varepsilon_g$ [-] |

The difference of emissivity (Δε) as a function of the vegetation cover fraction ($P_v$) is calculated as:

$$\Delta\varepsilon = \left(\Delta\varepsilon_{(P_v=1)} - \Delta\varepsilon_{(P_v=0)}\right) \cdot P_v + \Delta\varepsilon_{(P_v=0)}$$

with:

| | |
|---|---|
| Δε | : pixel emissivity difference between channel 4 and 5 [-] |
| $\Delta\varepsilon_{(Pv=1)}$ | : the difference in emissivity of a fully vegetated pixel [-] |
| $\Delta\varepsilon_{(Pv=0)}$ | : the difference in emissivity of a bare soil pixel respectively [-] |

Corrections of the atmospheric influence on the brightness temperature:

$$\alpha = W^3 - 8 \cdot W^2 + 17 \cdot W + 40$$

$$\beta = 150 \cdot \left(1 - \frac{W}{4.5}\right)$$

$$offset = \alpha \cdot (1 - \varepsilon) - \beta \cdot \Delta\varepsilon$$

with:

α, β and offset : corrections for emissivity and water content in the atmosphere [-]
W : the water content in the atmosphere [$g.cm^{-2}$], see paragraph 2.2.

Finally the land surface temperature (LST) is determined according to the split-window principle (Coll and Caselles, 1997):

$$LST = BT4 + [1.34 + 0.39 \cdot (BT4 - BT5)] \cdot (BT4 - BT5) + 0.56 + offset$$

with:

BT4, BT5 : the brightness temperatures of channel 4 and 5 [K]

# 4. Product Characteristics

In a spectral/thematic sense, each S10-composite comprises the 12 image layers listed in tables Table 4and Table 5.

| IMAGE | | Physical Values Y | | | Scaling | Digital Values V | |
|---|---|---|---|---|---|---|---|
| SUF | DT | CONTENT | UNIT | $Y_{lo} \rightarrow Y_{hi}$ | Y=A+B*V | $V_{lo} \rightarrow V_{hi}$ | $V_{flag}$ |
| SR1 | 1 | $R_{s,RED}$ | % | 0 → 62.50 | Y=0.250*V | 0 → 250 | 255 |
| SR2 | 1 | $R_{s,NIR}$ | % | 0 → 83.33 | Y=0.333*V | 0 → 250 | 255 |
| SR3 | 1 | $R_{s,SWIR}$ | % | 0 → 62.50 | Y=0.250*V | 0 → 250 | 255 |
| BT4 | 2 | BT-Band 4 | K | 0 → 3276.7 | Y=0.100*V | 0 → 32767 | -1 |
| BT5 | 2 | BT-Band 5 | K | 0 → 3276.7 | Y=0.100*V | 0 → 32767 | -1 |
| SZA | 1 | Sun Zenith | dec.degree | 0 → 125 | Y=0.500*V | 0 → 250 | 255 |
| VZA | 1 | View Zenith | dec.degree | 0 → 125 | Y=0.500*V | 0 → 250 | 255 |
| SAA | 1 | Sun Azimuth | dec.degree | 0 → 360 | Y=1.500*V | 0 → 240 | 255 |
| VAA | 1 | View Azimuth | dec.degree | 0 → 360 | Y=1.500*V | 0 → 240 | 255 |
| NVI | 1 | NDVI | - | -0.08 → 0.92 | Y=-0.08 + 0.004*V | 0 → 250 | 255 |
| LST | 1 | Land Surf. Temp | °C | -50 → 75 | Y=-50 + 0.5*V | 0 → 250 | 255 |
| TVO | 1 | Valid obs. | - | 1 → 255 | Y=V | 1 → 255 | 0 |
| TCO | 1 | Clear obs. | - | 1 → 255 | Y=V | 1 → 255 | 0 |
| DAY | 1 | Day in Dekad | - | 1 → 11 | Y=V | 1 → 11 | 0 |
| SID | 2 | Segment_ID | - | 1 → 32767 | Y=V | 1 → 32767 | 0 |
| STM | 1 | Status Map | - | bit-interpretation (see Table 6.2) | | 1 → 255 | 0 |

Table 4: Image layers comprised in each 10-daily composite of METOP/AVHRR (ENDVI10).

With:

- DT=Datatype: 1=Unsigned Byte (V=0→255), 2=Signed Short (V=-32768→32767)
- $V_{lo}$-$V_{hi}$=Significant V-range. The scaling only holds for this range. Values beyond $V_{lo}$-$V_{hi}$ are flags.
- $V_{flag}$: Per IMG, there is only one flag to indicate all "aberrant" states (sea, NoData, NoValidData, error).

The SM-image contains more information on the quality of the observations, as shown in Table 5.

| **Decimal** | 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
|---|---|---|---|---|---|---|---|---|
| **Val** | **Bit7** | **Bit6** | **Bit5** | **Bit4** | **Bit3** | **Bit2** | **Bit1** | **Bit0** |
| **1** | Land | ValidObs | Never | Never | Acceptable | CloudORshadow | Cloud | Snow |
| **0** | Sea | No Obs | Always | Always | Good | None of these | No Cloud | No Snow |

Table 5 :Bit-interpretation of the Status Map (Bit7=MSB).

with:

- No shadow detection applied, hence always bit2=bit1.
- The compositor classifies each pixel's observations in three categories depending on the sun and view zenith angles: "good", "acceptable" and "bad". The last group is definitely withdrawn, but in the absence of "good" observations "acceptable" ones may creep into the composites. This is indicated by bit3.
- Bits 4 and 5 are unused and always 0.

Sea pixels can be easily recognised because all bits are 0 (thus also the decimal value is zero).

# 5. Quality

## 5.1. Radiometric Quality

The quality of the 10-daily composites derived from Metop/AVHRR is compared to their 1km homologues of NOAA/AVHRR and SPOT/VGT. Some specific zones are investigated as shown in Figure 3.

The METOP_AVHRR is compared to NOAA-AVHRR, as shown in Figure 2. The analysis is limited to the European continent because we do not have global NOAA data at 1km resolution.

In a qualitative way, the METOP-composites are always better "filled" than the corresponding NOAA-syntheses. A quantitative comparison between METOP and NOAA is performed similar to METOP and VGT. The 12 used composites were extracted from the year 2009. And the analysis was done both for NDVI and the brightness temperatures in AVHRR-band4 (BT4). As pointed out by figure, in both cases the linearity is very strong with $R^2$ values of 96%., in spite of the following:

- The considered year 2009 was covered by two different NOAA-platforms: NOAA18 until dekad 19, and NOAA19 from dekad 20 onwards (until today).
- NOAA occupies the noon-orbit (local overpass around 14h LST) while METOP follows a morning orbit (9h30). So the differences in the illumination/viewing geometries are quite high.

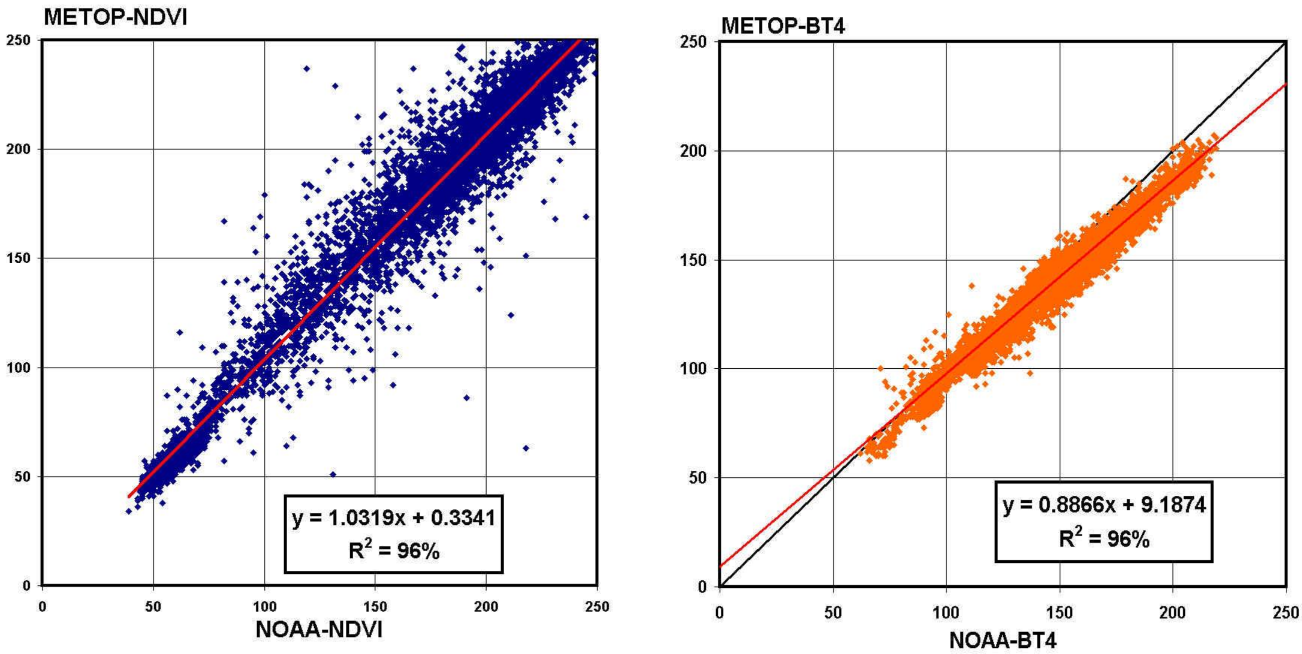



Figure 2*: Comparison of NDVI and BT4 from NOAA and METOP, derived from the European data sets of the year 2009 (rois EUa and EUo).*

Figure 4 shows some of the results of a small test which was made in August 2009: different zones were extracted from the global S10s of SPOT/VGT and Metop/AVHRR of the same dekad (early August 2009). The pictures were presented to a number of VITO-colleagues, all experienced image analysts, who were asked to discern both sensors. In general, none of them was able to do so, which indicates that the quality of both systems is quite comparable. There is however one important difference: the VGT-results have a more smoothed or blurred appearance than the ones of Metop. The reason is that the VGT-data are resampled with the cubic convolution method, while for Metop the nearest neighbour technique is used. However, this was a deliberate choice: if the data are needed for analytical purposes, nearest neighbour is the best option.

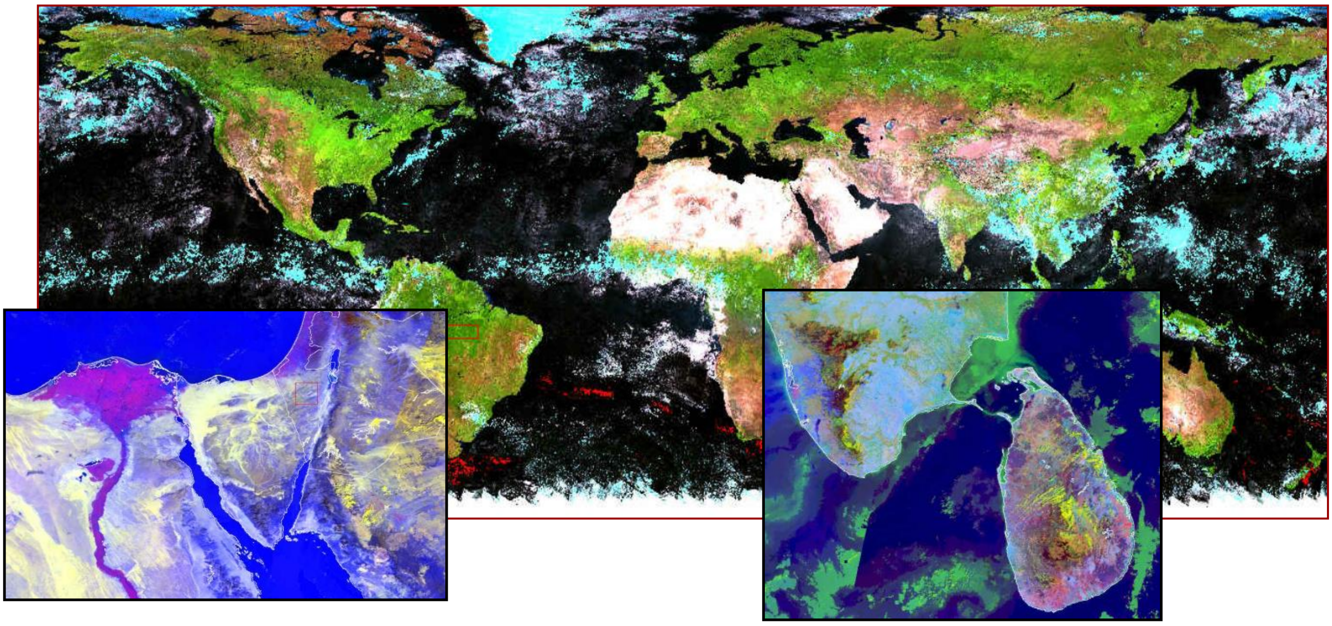


Figure 3 : Example of a Global S10-composite derived from Metop/AVHRR, with zoom on two regions: the Nile delta and Sri Lanka.

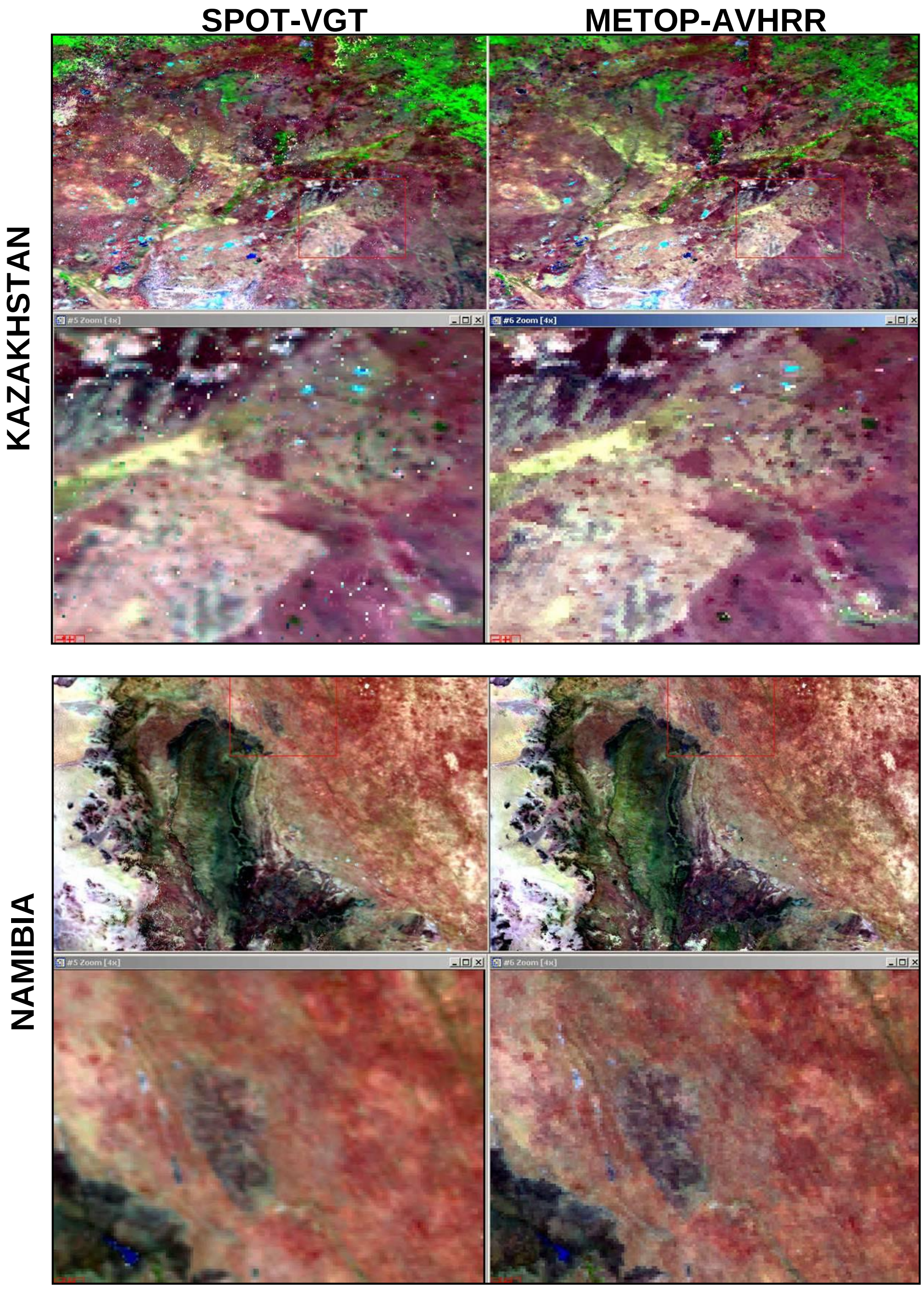



Figure 4 :Two zones in Kazakhstan and Namibia, extracted from the global S10-composites of SPOT/VGT and Metop/AVHRR of the same dekad (start of August 2009). The lower figures zoom in on the red rectangle marked in the upper figures. R/G/B=SWIR/NIR/RED.

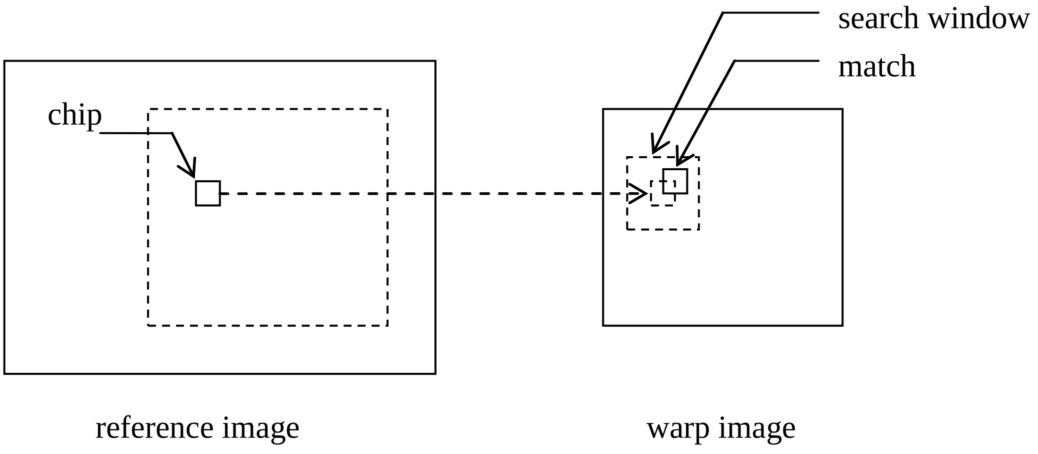
## 5.2. Geometric quality

The geometric accuracy is validated using a chip-matching method as follows:

- Select a chip position (using a list of predefined chip positions or using a random generator).
- Map the chip position to the reference window and retrieve the $N_1$ x $N_1$ chip window from the reference image.
- Map the chip position to the warp image, giving $(x_0,y_0)$, and search the position $(x_1,y_1)$ in the $N_2$ x $N_2$ search window for which the correlation between the warp image and the chip image is maximal.
- A match is found if certain conditions are fulfilled, e.g. the correlation value has to be above a certain threshold, the correlation peak has to be sharp enough, etc..
- Repeat the above steps until N matching chips have been found and determine the polynomials $f_x(x,y)$ and $f_y(x,y)$ that map the $(x_1,y_1)$ coordinates into $(x_0,y_0)$ coordinates:

  $f_x(x_1,y_1) = x_0$

  $f_y(x_1,y_1) = y_0$
- Generate the warped image using the polynomials $f_x$ and $f_y$ to determine for each pixel position of the warped image the corresponding 'nearest neighbour' pixel in the warp image. Only the tiles with a sufficient fill level are warped and the others are removed from the image.




The accuracy of the warp image is calculated from the $(x_0,y_0)$ and $(x_1,y_1)$ coordinates of the N matching chips:

$$accuracy = \frac{\sum[(x_1,y_1)-(x_0,y_0)]}{N}$$

The root mean square error provides a measure for the accuracy of the warping and is calculated as:

$$RMSE = \sqrt{\frac{\sum\left[(f_x(x_1,y_1)-x_0)^2-(f_y(x_1,y_1)-y_0)^2\right]}{N}}$$

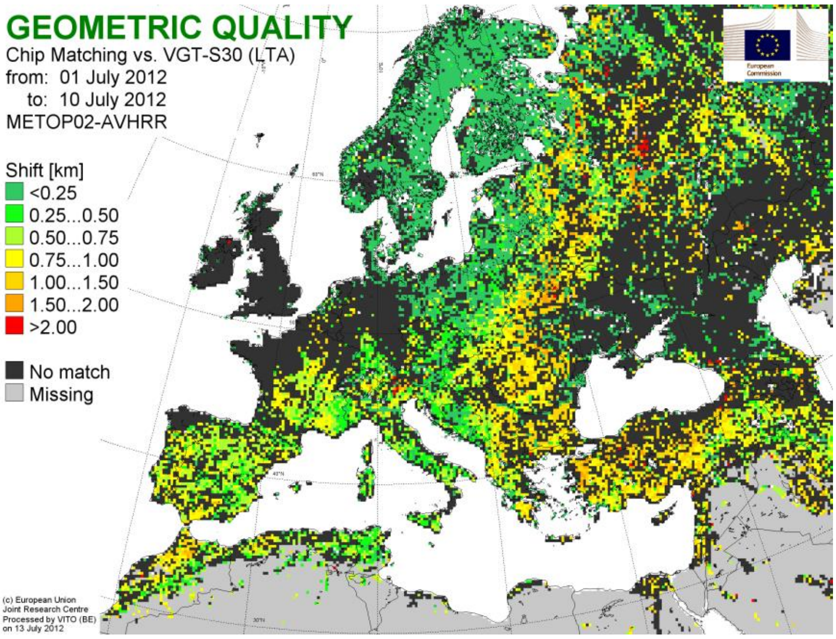



Figure 5 : Geometric Quality example 1st Dekad July 2012

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# Appendix A. Acknowledgements

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# Appendix B. Glossary

| | |
|---|---|
| AOI: | Area Of Interest |
| ATBD: | Algorithm Theoretical Baseline Description |
| AVHRR: | Advanced Very High Resolution Radiometer |
| Col: | Column |
| CVB: | Center for Image Processing, also known as CTIV |
| Dekad: | 10-daily period starting on 01, 11 or 21st of month |
| EC: | European Commission |
| ECMWF: | European Center for Mid-term Whether Forecast |
| ENDVI: | EPS NDVI |
| ENDVI10: | 10-daily EPS-NDVI |
| EPS: | EUMETSAT Polar System |
| EUMETSAT: | European Meteorological Satellite Organisation |
| EUR: | Europe |
| FTP: | File Transfer Protocol |
| GLC2000: | Global Land Cover map from year 2000 |
| HDR: | Header |
| IPMA: | Instituto de Meteorologia (Portugal) |
| IMG: | Flat binary image |
| JRC: | Joint Research Center |
| MA10: | Metop AVHRR 10-daily, same as ENDVI10 |
| NIR: | Near Infrared Radiation |
| Lat: | Lattitude |
| Lon: | Longitude |
| LSA: | Land Surface Analysis |
| LST: | Land Surface Temperature |
| MARS: | Monitoring Agriculture through Remote Sensing |
| METOP: | Meteorological Operational polar satellites of EUMETSAT |
| MIR: | Medium Infrared |
| NDVI: | Normalized Difference Vegetation Index |
| NOAA: | National Oceanic and Atmospheric Administration (USA) |
| ORR: | Operational Readiness Review |
| PUM: | Product User Manual |
| PRD: | Product Requirements Document |
| R: | Coefficient of determination |
| Rec: | Record (line) |
| RED: | Red radiation channel |
| S10: | 10-daily composite starting on 01, 11 or 21st of month |
| SAF: | Satellite Application Facility |
| SMAC: | Simplified Method for the Atmospheric Correction |
| SWIR: | Short Wave Infrared |
| TOA: | Top of Atmosphere |

| | |
|---|---|
| TOC: | Top of Canopy |
| TIR: | Thermal Infrared |
| VGT: | Vegetation sensor on board of SPOT satellites |
| VITO: | Flemish Institute for Technological Research |
| WGS: | Wold Geodetic System |
| ZIP: | File format used for data compression and archiving |