Dense Dark Vegetation

or

the making of the most surveyed pixels in the Netherlands

Dense Dark Vegetation is the name of an algorithm developed in 1988 by two scientists working at the NASA Goddard Space Flight Center. The function of the algorithm is to aid in automatic removal of the atmosphere from satellite imagery of the earth's surface, in order that we might better study the ground. In these images the thick column of the earth's atmosphere—its water vapours, gases and particulate matter—are considered noise. Having been removed, the resultant image of the ground conforms to our perceptual expectations of it. The pixels denoting green grass exhibit a colour of grass green. However, not once in the production of this image are adjustments made by the human eye. From the reception and translation by satellite onboard sensors of electromagnetic radiation reflected from earth's surface, to the conversion of this data through a long chain of algorithmic processes into a visual representation that we, the public, can freely download, the image's appearance is but a side-effect of a long chain of statistically meaningful adjustments to its data. These adjustments are informed by scientific models—representations and assumptions—about the surface of the earth, from the ground at the bottom of the atmosphere to its top.

What began as an investigation into the process of producing data at the level of satellite multispectral sensors, through to their post-processing into a geographic-visual language expressed in pixels, led us to an exploration of on-the-ground validation and calibration practices that inform (and are informed by) those models of the earth. The Cabauw atmospheric research facility, located west of the town of Lopik in the province of Utrecht, the Netherlands, is a site where the groundwork of atmospheric science intersects with in-situ measurements that inform how remotely sensed data is processed. We propose that this site makes up some of the most surveyed pixels in the Netherlands, the density of observations upon it and the volume of data produced from it informing expectations of how and what we interpret from afar.

Captions to slides

The Cabauw atmospheric research facility located west of the town of Lopik, in the province of Utrecht, has been conducting observations of the atmosphere since the construction of its mast in 1972. These observations inform models of the weather and models of the atmosphere which, among other things, directly inform how remotely sensed multispectral data is translated into earth observation images used to study the ground. In the production of these images, atmospheric models and atmospheric data are used to algorithmically separate ground from sky, in order to see the ground more resolutely.

This photograph, taken at Cabauw around 10.30am on August 25th 2023, shows in the foreground an array of ground-based sensors placed in a field north of the mast. These sensors make observations which are used to model complex ground-atmosphere interactions, including any possible impact of the growth of the grass on their results. This field site was moved from its original location south of the mast, due to unacceptable levels of interference from a newly planted field of corn nearby.

The European Space Agency's Copernicus Sentinel-2 mission is designed to observe the ground. It consists of a twin set of satellites, Sentinel 2A (launched 2015) and Sentinel 2B (launched 2017). Each satellite is equipped with an identical MultiSpectral Instrument (MSI) which is sensitive to select ranges, or bands, of electromagnetic (EM) radiation reflected from the earth's surface. This EM radiation is sunlight reflected, refracted and scattered by the earth's ground and through the thickness of its atmosphere. As the satellite orbits the earth, the MSI captures this reflected EM radiation and converts it into data, each pixel constituting information thick with the earth's surface, from ground through sky. The 100km x 100km tile area 31UFT (red), where the Cabauw atmospheric research site is located, displays data captured at 10:36 as part of a single Sentinel 2B 290km x 10,000km 'datatake' (green) on 25th August 2023.

LEFT. Level 1c RGB. This image represents EM radiation reflected from the surface of the earth and captured by Sentinel 2B's MSI at 10.36am on 25th August 2023, the morning we visited Cabauw. Between its capture and its translation into a first dataset and its eventual translation into this image, lies a long chain of algorithmic processes which are not readily accessible to the public. The data displayed in this image has been processed to express the intensity of reflectance of EM radiation across visible R-G-B bands 4-3-2. It has also been radiometrically and geometrically adjusted according to the quality of direct sunlight at the time of capture, an orthographic projection of the earth, and reference datasets constructed from amalgams of validated past Sentinel 2 data. Ground pixels in this image appear bluish-green, a visual representation in “true” colour of EM reflectance from the surface as if seen from ‘the top of the atmosphere’.

RIGHT. Level 2a RGB. The data displayed in this image is derived from the image (left), but has been processed one level further by a suite of algorithms to remove the influence of atmospheric aerosols, atmospheric water vapour and cirrus clouds. Here the atmosphere has been effectively removed* from all pixels in order to ‘see’ the ground more resolutely. This image is a visual representation in “true” colour of EM reflectance as if from ‘the bottom of the atmosphere’. Both image levels are made available to the public, every 5 days, for every square metre of land surface on earth.

*Unlike aerosols and cirrus clouds, dense clouds cannot be reasonably ‘removed’, therefore in this image areas of the ground obscured by cloud contain no information and are displayed as blank.

This photograph shows the Cabauw remote sensing field, located south east of the mast. Here sensors deployed by various organisations and research groups conduct observations of the atmosphere from the ground up, for the purpose of calibrating satellite-mounted instruments and validating remotely sensed data. These ground-based sensors record atmospheric conditions such as clouds, aerosols, moisture content and temperature. Experiments extend through the atmospheric column, from the ground up to the satellites in orbit. We learn that scientists studying the atmosphere see the ground as noise, finding ways to remove it from their observations. Scientists studying the ground see atmosphere as noise, and use atmospheric data to remove it from their observations. More and more sensors have been placed here over the years for the benefits of data sharing and collaboration between research organisations and their experiments, but we learn that those studying the ground rarely converse with those studying the thick column of the sky.

The Cabauw research facility forms part of various networks and communities of atmospheric observation including AERONET; a network of hundreds ground-based sites positioned across the planet. 24 of these sites contribute to a regularly updated calibration dataset for the Sentinel 2 mission, comprising different land cover types and atmospheric conditions. This dataset informs how the algorithms process remotely sensed Sentinel 2 MSI data into usable imagery, such as from Level 1c to Level 2a. One of the sustained observations AERONET contributes to this dataset is Aerosol Optical Thickness (AOT); a measure of the visual transparency of the atmosphere at Cabauw, otherwise known as haze. If AOT is known for an area of the earth at the time of a Sentinel 2 recording, the effect of AOT can be automatically removed from those pixels.

LEFT. Level 1c Band 12. This image displays the intensity of EM reflectance across Short Wave InfraRed (SWIR) captured in tile 31UFT at 10.36am on 25th August 2023, the morning we visited Cabauw. Band 12 is used by the algorithm Dense Dark Vegetation (DDV) to estimate Aerosol Optical Thickness (AOT) across areas of the earth for which it has not been directly measured. DDV assumes that areas of dense vegetation, such as coniferous or pine forest, act as ideally uniform, matte surfaces with no reflectance, and should therefore present as dark pixels; a true black point. To derive AOT, DDV identifies dense dark vegetation pixels and assumes an increase in their recorded brightness in Band 12 due to AOT.

RIGHT. Level 2a Band 12. Here, the image appears darker in the shadow-tone range than its precursor (left); after atmospheric removal, dark areas now present as dark pixels. Other algorithms automatically employed to remove other atmospheric effects between levels 1c and 2a result in further tonal adjustments, brightening the mid-tones and stretching the tonal range overall. Although visually similar adjustments could be made perceptually in Photoshop, here the specific set of histogram adjustments are are determined by a globally connected meshwork of scientific methods, models, legacies, sites, and practices which condition how such visual shifts are meaningful adjustments.

Are these the most surveyed pixels in the Netherlands?

EM reflectance is translated by the Sentinel 2B MSI into pixels with a discrete set of values across the spectral bands. Each pixel in a Sentinel 2 image represents EM radiation reflected from a 10m x 10m area of the earth's surface. Each displayed pixel value in each band is absolute, but successively adjusted, through levels of automatic algorithmic processing to remove surface conditions (such as the atmosphere) considered noise to any particular observational need. The value assigned to such a pixel in 'true colour' is therefore considered accurate—although a representational approximation—to the way in which the data should be displayed.

The 'true colour' pixels that mark the instrumentation field north of Cabauw's mast are displayed as single values within the RGB colour space, flattening detail within them. We've used these RGB values to colour the foreground and sky of our photographs taken during our visit to Cabauw on the morning of August 25th 2023. We wanted to show how the Sentinel 2 mission (as well as other earth observation missions employing MultiSpectral Instruments) strives to present the colours of the earth's surface as a rough approximation of what we, here on the ground, might actually perceive them to be. But from the conception of the earth as a Blue Marble to the earth seen in Google Earth in vibrant green, we propose that interpretation of colour in the visual field requires continual perceptual adjustment.

Credits

Lili Carr & Matthew Harvey
2023
Dense Dark Vegetation

Mentoring & Advising from:
Miha Turšič (Waag | Space Lab)
Zoénie Deng (Waag | Space Lab)
Federico Franciamore (Space4Good)
Sujata Majumdar (Space4Good)

With special thanks to:
Frans Snik (University of Leiden)
Jessica Strickland (KNMI | Cabauw atmospheric research facility)

Earth Observation images produced from ESA-European Space Agency remote sensing data.
AERONET data from NASA's Goddard Space Flight Center.

Supported by Waag Futurelab | Space Lab's Planetary Public Stack workshop series with Space4Good and Leiden Observatory