Calibrations and Experiments

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Introduction

To remotely measure or estimate pasture biomass, satellite-based instruments need to be calibrated relative to a "ground truth" or a reference value for consistency. Because of both locally and regionally varying soil conditions, reliable estimates of pasture biomass require local calibration (sub-paddock). Put more simply, there is no "one rule fits all category" for calibration. This document outlines the key experiments that need to be undertaken for calibration.

Aims

The aim of this document is to briefly outline both aspects of literature and to discuss the most appropriate way to validate satellite-based measurements to C-DAX measurements.

Downloading Satellite Data

As mentioned in the previous document there are a variety of sources to download satellite data. These often come in `.nc` or `.hdf` file formats and can be opened with `h5py` or `pyhdf` python libraries. An 8 Day historical record of NDVI or EVI can be downloaded from the following link. Other sources of data include Sentinel Hub, which provides an extensive selection of data from the Sentinel programme, which is updated in near-real time.

NDVI and EVI

Satellites can estimate pasture biomass through various indexes, such as the Normalised Vegetation Index (NDVI), Enhanced vegetation index (EVI) and Leaf Area Index (LAI). These metrics are the most representative of pasture biomass.

The Normalized difference vegetation index (NDVI) is a useful quantity for pasture management. This is computed through examining the relative difference in absorption of bio-matter in the visible-near-infrared wavelengths. Surfaces such as dry-soil, have largely negative NDVI's, whereas oceans and lakes have values close to zero. Dry biomass/pasture tends to reflect more red light and less near-infrared light comparison to 'healthy biomass'. High values of NDVI determine healthy suitable pasture for grazing. At lower values of NDVI (0.4–0.6), there is a strong relationship between NDVI and pasture biomass ($r^2 = 0.8$). However, the NDVI function saturates at larger values, and thus the proportionality is non-linear.

However, measurements of NDVI are sensitive to the time that they are measured. **This means two measurements of NDVI at different times of the day, can be very different**. This happens when comparing two estimates from different satellites. Because most polar-orbiting satellites are sun-synchronous, they are sampled at the same time every-day and therefore this effect is negligible. However, for satellite constellations that sample at different times of the day (e.g `Planet`).

The radiances used for the NDVI and EVI should be atmospherically corrected (e.g to account for ozone absorption and rayleigh scattering). The NDVI is chlorophyll sensitive and saturates in regions of high biomass, making it less useful in places like New Zealand. The EVI is more responsive to canopy structural variations, including leaf area index (LAI), canopy type, plant physiognomy, and canopy architecture. Thus, the EVI is often a better product to use for time-series analysis or to understand pasture growth rates. However, given their similar physical representation, both indexes should be tested. To compute the LAI, the following radiative transfer model is run.

In addition to the NDVI and EVI, the LAI is often used to estimate plant biomass. The LAI uses soil information and also considers the geometry of the surface (pasture) and runs a radiative transfer model (ProSail) for a better measure of pasture biomass. Literature has long indicated that there is a strong relationship between NDVI/EVI/LAI and pasture biomass. However, various other aspects such as soil moisture, air temperature and season (solar zenith angle) affect these relationships and should be considered when calibrated C-DAX measurements to satellite-based instruments.

0.1 Applications

Previous studies have investigated the relationship between satellite-derived pasture measurements and in-situ observations such as RPM and C-DAX and have found strong agreement. The SPACE product by LIC, has documented some of the validation results and outlines some of the product shortcomings in the following article. Most importantly, there is limited testing to the wide variety of environmental conditions present in New Zealand farms.

Microwave satellite-based biomass metrics

One of the largest shortcomings with visible satellite-base biomass metrics is cloud cover and cloud shadows. Often there are periods of weeks, where visible satellite imagery of the farm is not available, how can we then provide biomass estimates? The answer comes from using microwave-based instruments which are able to penetrate through clouds.

0.2 Summary

In summary, the main advantages of using microwave instruments are:

- Provides an all-weather pasture biomass estimates when cloud cover is present.
- Provides information about soil quality.
- Inaccurate measurements after rain events (particularly X-Band)
- Shorter wavelength microwave bands are affected to some degree by clouds.

Therefore to determine the usability of microwave sensors, validations need to be performed against C-DAX and visible sensors on a wide variety of conditions, some which are summarised below:

- After light and heavy events of rainfall.
- During both light and heavy rainfall events (install rain gauges on the farm).
- During events of thin and thick overhead cloud cover.
- Clear days at different times of the season (i.e Spring when soil is moist vs summer).

The literature about microwave sensors is significantly less established than visible-based estimates of pasture biomass.

0.3 Literature Review

Because of the longer wavelength of microwaves, they are able to penetrate through the cloud-top and reveal information about the surface. Microwave sensors are typically active rather than passive, as microwave emission from the earth's surface is relatively low. Various studies have indicated that C-band (TerraSAR-X) microwave sensors are optimal for estimating for biomass. Studies have indicated that X-band sensors are only good for the growing season, as they are very sensitive to water on the plants/grass. However, C-band experiments indicated less sensitivity. Thus C-band measurements are more strongly correlated with estimates of pasture biomass. However, C-band measurements need to be calibrated on a seasonal basis, as C-band is exhibiting some sensitivity to soil moisture–which changes seasonally. The longer wavelength L-band shows significantly less sensitivity to surface-water, and provides a good estimate of soil moisture. To conduct a study on soil moisture using microwave instruments, soil moisture data from SMOS products SMOS-IC (V105) and L2 soil moisture daily product (V650) can be downloaded from here. Because NDVI/EVI and pasture biomass variables are sensitive to soil moisture, incorporating it into a predictive pasture biomass model could reduce errors in satellite pasture products. For more information about remote sensing of soil moisture see the following review. Additionally, for more information about the importance of soil moisture see the following resource.

It is important to note that while microwave sensors can penetrate through clouds, there is Rayleigh scattering which can significantly reduce the output intensity of the beam. For relatively clouds with relatively small droplets, the effects on X and C-band will be relatively small, and negligible for longer wavelength instruments. However, for optically thicker clouds this effect becomes significant and requires correcting for. Failure to incorrect for these effects will result in incorrect estimates of NDVI/EVI. For domains with rain, the effects on the L-band radars also become significant.

Majority of satellites that have microwave sensors onboard will also contain visible imaging instruments. To understand how significant the effects cloud cover has on correlations between NDVI and radar reflectivity (from microwave sensors), samples need to be correlated on cloudy (partially cloud so that there are measurements of NDVI are obtainable) and clear days. If the correlation between NDVI and radar reflectivity is strong on both cloudy and clear days, then microwave instruments may be able to provide pasture information even when the farm is entirely obscured by cloud.

Experiments

The Google Earth Engine provides a relatively simple python API with a wide variety of satellites to use. The satellite data from the Sentinel/LandSat/MODIS is uploaded to the server in real-time. The Google Earth Engine is a free service for non-profit research. There are also similar services to Google, such as LandViewer and Sentinel-Hub. These services also have a significant cost associated with them. However, these services are definitely not as extensive, and not as easy to implement. LandViewer has an easy region of interest tool, which enables the user to examine statistics within a particular location.

0.4 Sampling

Sampling and calibration are crucial to remotely determining pasture biomass. The following list outlines a variety of conditions and events that need to be considered to correctly estimate both growth rates and pasture biomass. As NDVI/EVI is sensitive to soil moisture it is important to calibrate the measurements by both time of day, when a cloud is present and when cloud cover is not present. First, we will discuss the calibration of RPM/C-DAX measurements to visible satellite-based instruments. Ideally, to provide reliable estimates of pasture of biomass experiments need to be performed under a wide variety of conditions. To correctly estimate growth rates during the "growing season", To initialise the process, the following tests must be performed.

- Obtaining retrievals/measurements on cloud and non-cloudy days. While non-cloudy days are preferable, this will test the accuracy of satellite measurements on non-cloudy days. We expect the accuracy of satellite retrievals (clear regions on cloudy days) to be worse as the amount of water vapour in the atmosphere is higher.
- Obtaining data from a wide variety of satellites (microwave and visible). While the operating frequency of each satellite may be similar to the instrument and its impulse response are different and need to be calibrated to a reference instrument. Furthermore, there are varying spatial resolutions and thus interpolation may be necessary. Main satellites are LandSat, Sentinel and MODIS.
- Calibrating RPM to NDVI (visible) and microwave-sensor satellites on cloudy, clear and rainy days. This enables us to understand what weather conditions we can trust satellite-based estimates.
- Determining growth rates and seasonality from RPM and C-DAX measurements. To fast track the development of a growth model,
- Identifying precipitation events (and their intensity) and examining the growth rates in non-grazing paddocks after these events. This will help us understand how sensitive pasture growth is to rainfall, and can help with forecasting pasture.
- Identifying drought/ events with an absence of precipitation. This can be done by examining the times with an absence of precipitation.