Introduction to Earth Observation for Agriculture

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Why focus Agriculture?

World population will reach 9 billion in next 40 years (Future demand)

- Challenges to meet the Sustainable Develop goals (Current)

1 NO POVERTY
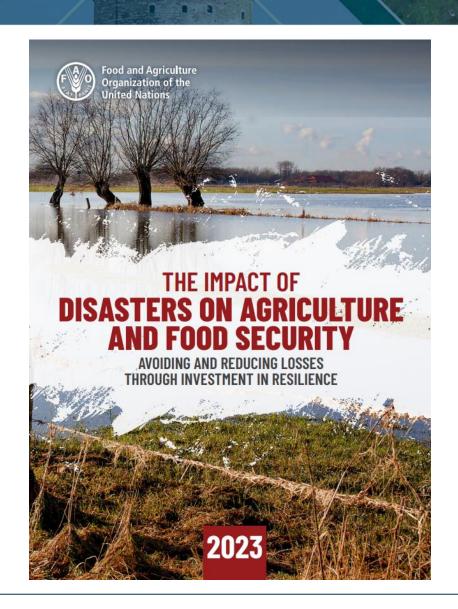
70 % rural population, Growth in agriculture is twice as effective

2 ZERO HUNGER

Increase agricultural production, reduce hunger

15 LIFE ON LAND
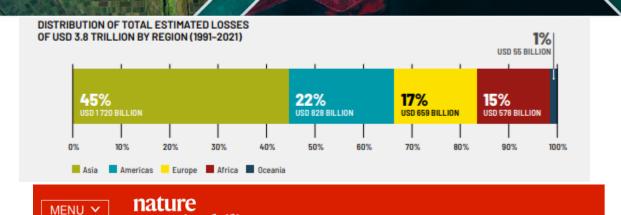
Increase efficiency in agricultural, minimize loss of resource

Why focus on Agriculture

THE IMPACT OF **DISASTERS ON AGRICULTURE AND FOOD SECURITY** — AVOIDING AND REDUCING LOSSES THROUGH INVESTMENT IN RESILIENCE — 2023

Food and Agriculture Organization of the United Nations

DISTRIBUTION OF TOTAL ESTIMATED LOSSES OF USD 3.8 TRILLION BY REGION (1991–2021)

Region	Share	Value
Asia	45%	USD 1720 BILLION
Americas	22%	USD 828 BILLION
Europe	17%	USD 659 BILLION
Africa	15%	USD 578 BILLION
Oceania	1%	USD 55 BILLION

nature sustainability

MENU ⌄

News & Views | Published: 07 October 2019

AGRICULTURAL TECHNOLOGY

Satellites and crop interventions

Jadunandan Dash ✉

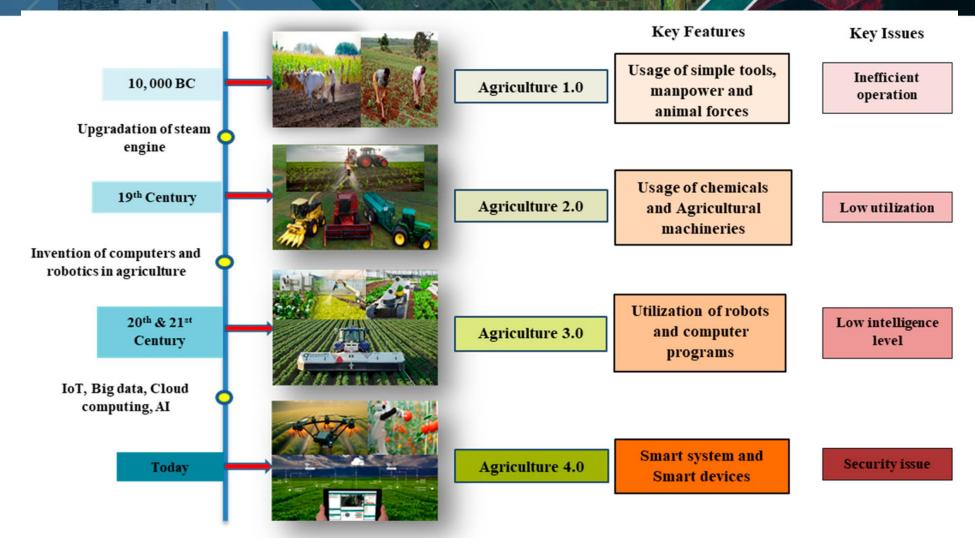*Nature Sustainability* **2**, 903–904(2019) | Cite this article

136 Accesses | **6** Altmetric | Metrics

Lack of good-quality monitoring and evaluation data is a key barrier to large-scale uptake of agriculture interventions. Data from low-cost microsatellites have a strong potential to bridge this gap and promote sustainable intensification targets.

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What do We need to know?

Information requirement varies: national to farm scale

National information (yield (*gap*)): Planning -> policy

Farm scale decision making: management practices

Time critical, spatial coverage, easy accessible

Development in agriculture
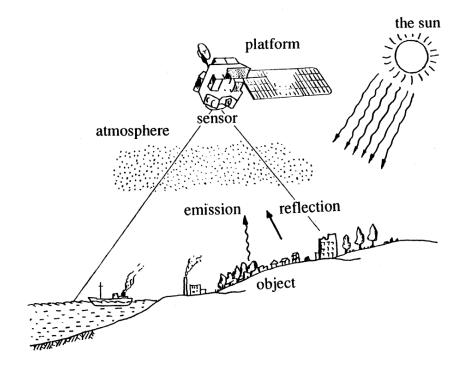

https://www.mdpi.com/2624-7402/7/3/89

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Why spectral measurements

At the heart of quantitative RS in the optical region

Characterise meaningful objects in a scene

Characterise 'reference endmembers'

Hypothesis testing

Post-launch satellite sensor calibration

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Spectral Reflectance
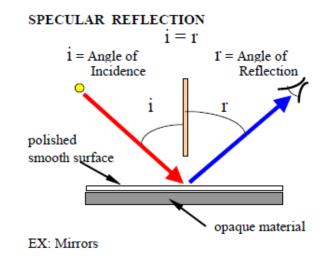
Reflection is measured as the ratio of the amount of radiant energy that is reflected to the total incident radiant energy falling on the surface.
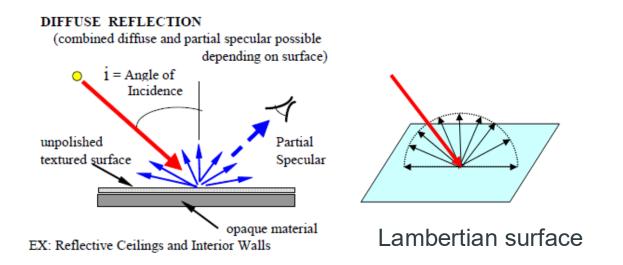
Specular Reflection- angle of the reflected light is equal to the angle of incident light.

Diffuse reflection - reflected light is scattered in all directions.

Most of the surfaces are a mix of specular and diffuse reflection

A **Lambertian surface** reflects (diffuse reflection) light or radiation equally in all directions. e.g. talcum powder

SPECULAR REFLECTION
i = r
i = Angle of Incidence
r = Angle of Reflection
i   r
polished smooth surface
opaque material
EX: Mirrors

DIFFUSE REFLECTION
(combined diffuse and partial specular possible depending on surface)
i = Angle of Incidence
unpolished textured surface
Partial Specular
opaque material
EX: Reflective Ceilings and Interior Walls

Lambertian surface

Spectral Reflectance

Incoming/Reflected	Directional	Conical	Hemispherical
Directional	Bidirectional CASE 1	Directional–conical CASE 2	Directional–hemispherical CASE 3
Conical	Conical–directional CASE 4	Biconical CASE 5	Conical–hemispherical CASE 6
Hemispherical	Hemispherical–directional CASE 7	Hemispherical–conical CASE 8	Bihemispherical CASE 9

G. Schaepman-Strub, et al., 2006, Reflectance quantities in optical remote sensing—definitions and case studies, Remote Sensing of Environment, Volume 103, Issue 1, 15.

The bidirectional reflectance distribution function (BRDF)

... a mathematical function "relating the irradiance incident from one given direction to its contribution to the reflected radiance in another direction" (Nicodemus et al., 1977)

- an inherent property of the surface.
- conceptual, not measurable.
- a mathematical function, not a single value.

$$\text{BRDF} = f_{\text{r}}(\theta_{\text{i}}, \phi_{\text{i}}; \theta_{\text{r}}, \phi_{\text{r}}) = \frac{\mathrm{d}L_{\text{r}}(\theta_{\text{i}}, \phi_{\text{i}}; \theta_{\text{r}}, \phi_{\text{r}})}{\mathrm{d}E_{\text{i}}(\theta_{\text{i}}, \phi_{\text{i}})} \ [\text{sr}^{-1}].$$
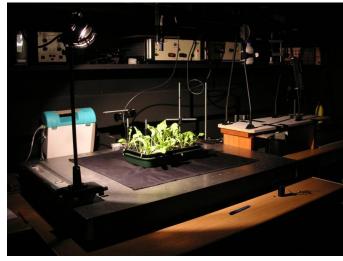
Bidirectional Reflectance Factor (BRF) , is BRDF normalized by the reflectance of a reference Lambertian surface, identically illuminated and observed.

Spectral property of vegetation

Incident light

Reflected light
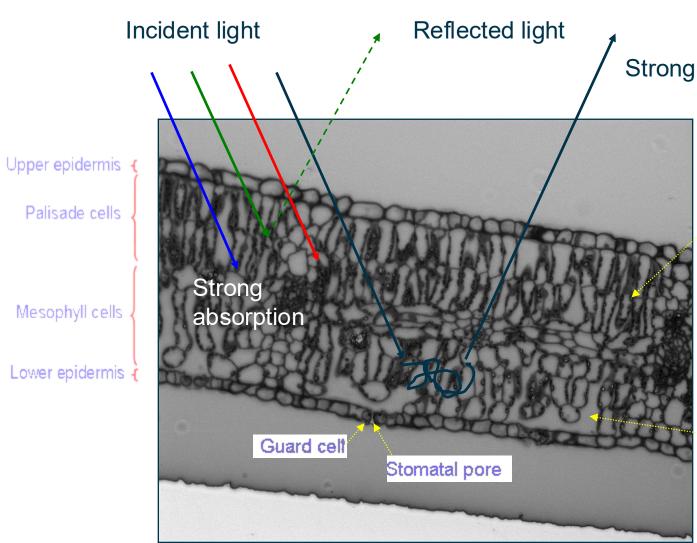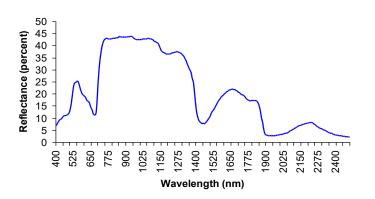
Strong reflection of NIR

Upper epidermis

Palisade cells

Mesophyll cells

Lower epidermis

Strong absorption

Chloroplast – site were light is captured by chlorophyll for photosynthesis

Guard cell

Stomatal pore
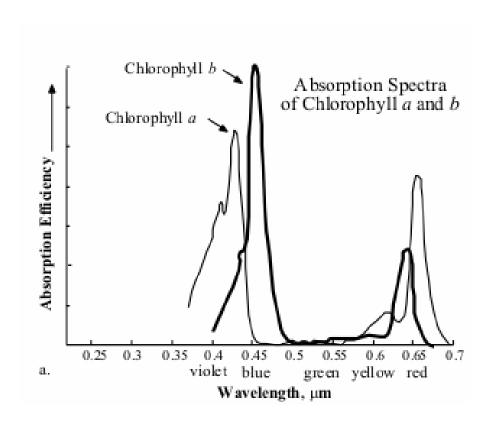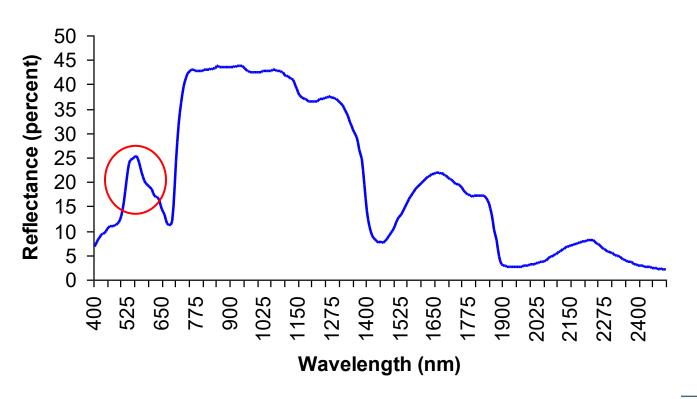
Air space exchange of CO_2 O_2 and H_2O between plant and atmosphere

Reflectance (percent)

Wavelength (nm)

Spectral property of vegetation

Optical region

Chlorophyll-a and Chlorophyll-b absorb portion of blue and red light

Spectral property of vegetation
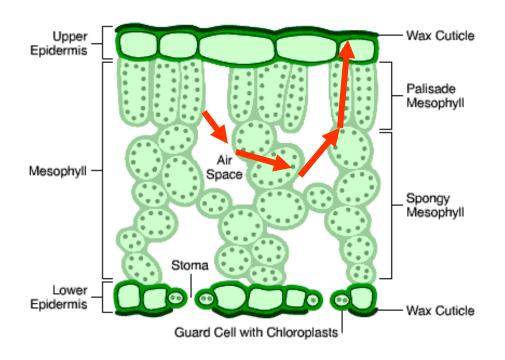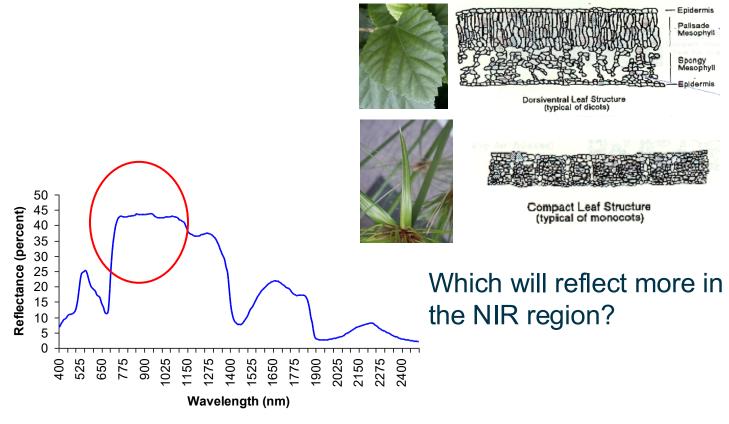
Interaction in the NIR wavelength

- **Occurs at the upper half of the leaf and more importantly between cell and air spaces**

- **High reflectance**

Dorsiventral Leaf Structure
(typical of dicots)

Compact Leaf Structure
(typical of monocots)

Which will reflect more in the NIR region?

Spectral property of vegetation
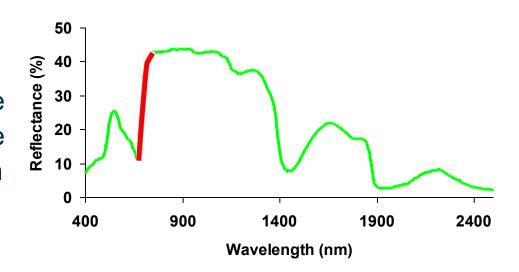
Red edge

Sharp change in reflectance

Occurrence of **red edge**

Red edge position (REP) is   the **point of maximum slope** of the curve in red/near infrared region

Red edge position is sensitive to amount of chlorophyll content

Spectral property of vegetation

Interaction in the Middle infrared waveleng
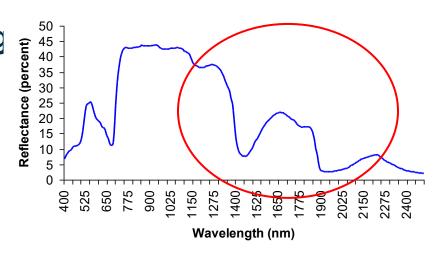
Dominated by water absorption
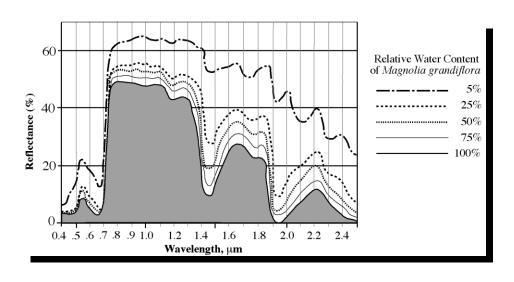
Amount of reflectance is inversely proportional to water content

Three major water absorption

bands

- **1.4 μm**
- **1.9 μm**
- **2.7 μm**

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Spectral property of vegetation
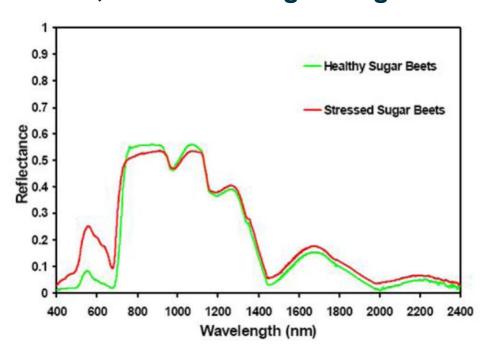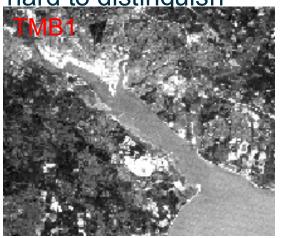
If you were designing a sensor solely to measure the health of the sugar beets, what wavelength range would you want the sensor to detect?
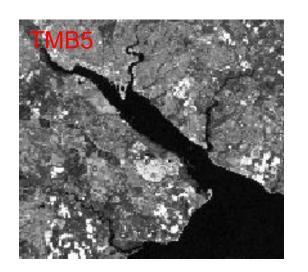
Moving to image

In one band its hard to distinguish

TMB1

TMB5
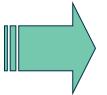
Composites provide a better idea

True

FCC
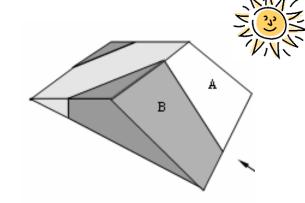
We need to use more than one band to get more information

What about band ratio?

Two objects of identical material will appear different if they are receiving different amount of illumination.

The ratio between matching pixels in each band will remain same

DN on slope facing away from Sun			
Unit	Red	NIR	R/NIR
A	45	60	0.75
B	20	40	0.5

DN on slope facing Sun			
Unit	Red	NIR	R/NIR
A	60	80	0.75
B	30	60	0.5

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Vegetation indices

• **Better sensitivity than individual spectral bands for detection of biomass**

Ideal VI "the index should be particularly sensitive to vegetative covers, insensitive to *soil background*, little affected by *atmospheric effects*, *environmental effects* and *solar illumination geometry* and *sensor viewing conditions* (Jackson et al., 1983)

There are a lot of vegetation indices (more than 50)

Commonly used VI

•Simple Ratio (SR)

•Normalised Difference Vegetation Index (NDVI)

Deigned to monitor specific property

• Enhanced Vegetation index (EVI)

• MERIS Terrestrial Chlorophyll Index (MTCI)

Normalised Difference Vegetation Index (NDVI)

Proposed by Rouse et al., in 1973

The specific parameter employed is the Band Ratio Parameter (BRP) defined as the difference in the ERTS radiance value measured in bands 5 and 7, divided by their sum. The normalization procedure is used to eliminate seasonal sun angle differences and to mini-

$$NDVI = \frac{NIR - red}{NIR + red}$$

NDVI value range from -1 to +1

For vegetation NDVI typically starts from 0.1

For soil/ bare ground NDVI is close to zero

What will be NDVI for water?

Normalised Difference Vegetation Index (NDVI)

NDVI has been extensively used in remote sensing for a number of applications:

Primary productivity
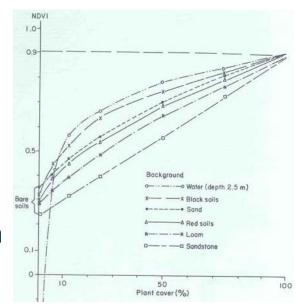
Identifying eco regions
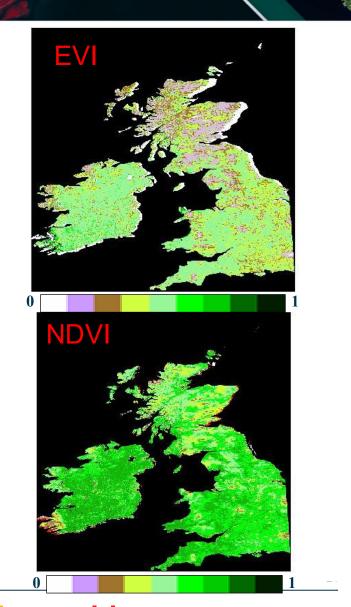
Monitoring phenological pattern

Assessing Season length

Disadvantages
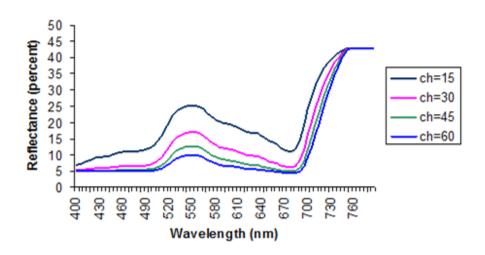
1. Saturates at high biomass content
2. Influence by atmospheric noise
3. Very sensitive to background variation

Red Edge position
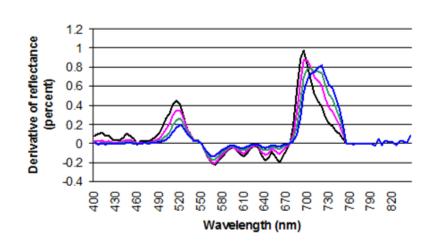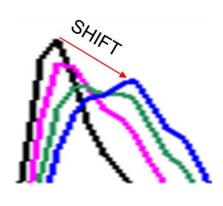
Red edge position is point of maximum change

❑ Increase in chlorophyll content

    ❑ Broadens chlorophyll absorption feature

    ❑ Shifts REP to longer wavelength.

Red Edge position
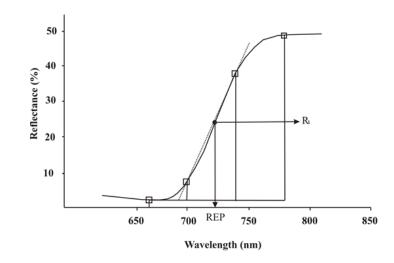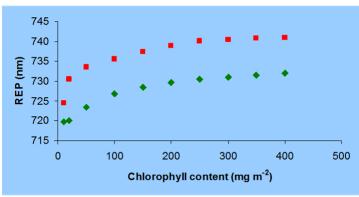
1. Derivative spectrum

2. Curve fitting

3. Langrangian interpolation

4. Linear interpolation

$$R_i = \frac{(R_{670} + R_{780})}{2}$$

$$REP = 700 + 40 \frac{(R_i - R_{700})}{(R_{740} - R_{700})}$$

MERIS Terrestrial chlorophyll Index
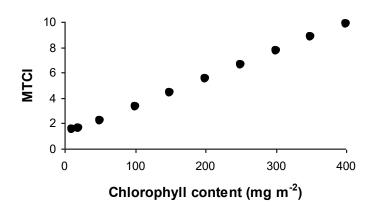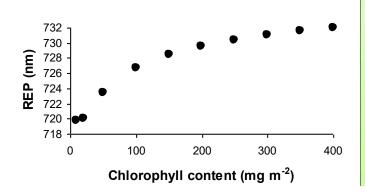
- ❑ MTCI developed as a surrogate estimator of the Red-edge position (REP).
- ❑ Overcome the saturation effect of Red edge Position
- ❑ Easy to calculate

$$MTCI = \frac{R_{Band\ 10} - R_{Band\ 9}}{R_{band\ 9} - R_{band\ 8}} = \frac{R_{753.75} - R_{708.75}}{R_{708.75} - R_{681.25}}$$

November-2003

Observed Issues and Recommendations

New L2 products

- Need for defining new L2 land products by fully exploiting the capabilities of the MERIS instrument not available from other sensors.
  - ➢ ESA response:
    - for the land community at present we have MGVI, NDVI, rectified reflectances at 665 and 865nm, DDV AOT, surface pressure.
    - new MERIS Terrestrial Chlorophyll Index (MTCI) will be provided in the L2 product replacing the NDVI.
    - algorithms for experimental MERIS products, i.e.LAI, fraction cover, chlorophyll content, surface reflectance under development; shall be made available in source code under the BEAM software
- Need for defining new atmospheric L2 products:
  - Aerosol path radiance at 665 nm
  - Particular Matter: PM 10
  - Aktinic fluxes

DASH, J. and CURRAN, P. J., 2004, The MERIS Terrestrial Chlorophyll Index. *International Journal of Remote Sensing*, 25, 5003-5013.

Some other indices

Spectral Chlorophyll Indices	Name	Formulation	References
MTCI	*MERIS Terrestrial chlorophyll index*	$(r740 - r705) / (r705 + r665)$	Dash and Curran (2004)
NDVI	*Normalized Difference Vegetation Index*	$(r842 - r665) / (r842 + r665)$	Kreigler et al. 1989
CI 590	*Chlorophyll index 590*	$(r842 / r560)-1$	Gitelson & Merzlyak 1997
GNDVI	*Green Normalized Difference Vegetation Index*	$(r842 - r560) / (r842 + r560)$	Gitelson and Merzlyak 1998
PSSRa	*Pigment Specific Simple Ratio*	$R783 / r665$	Blackburn 1998
PSNDa	*Pigment Specific Normalized Difference*	$(r783 - r665) / (r783 + r665)$	Blackburn 1998
OSAVI	*Optimized Soil-Adjusted Vegetation Index*	$[(1+0.16)*(r842-r665)]/(r842+r665+0.16)$	Rondeaux et al. 1996
MCARI	*Modified Chlorophyll Absorption in Reflectance index*	$[(r705 - r665) - 0.2*(r705 - r560)]*(r705 / r665)$	Daughtry et al. 2000
TCARI/OSAVI	*Transformed Chlorophyll Absorption Ratio Index/OSAVI*	$3*[(r705-r665)-0.2*(r705-r560)*(r705/r665)]$	Haboudane et al. 2002

Zeng, Y., Hao, D., Huete, A. *et al.* Optical vegetation indices for monitoring terrestrial ecosystems globally. *Nat Rev Earth Environ* **3**, 477–493 (2022). https://doi.org/10.1038/s43017-022-00298-5

How to design your own Spectral index?

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