Vegetation Cover Monitoring and Food Security

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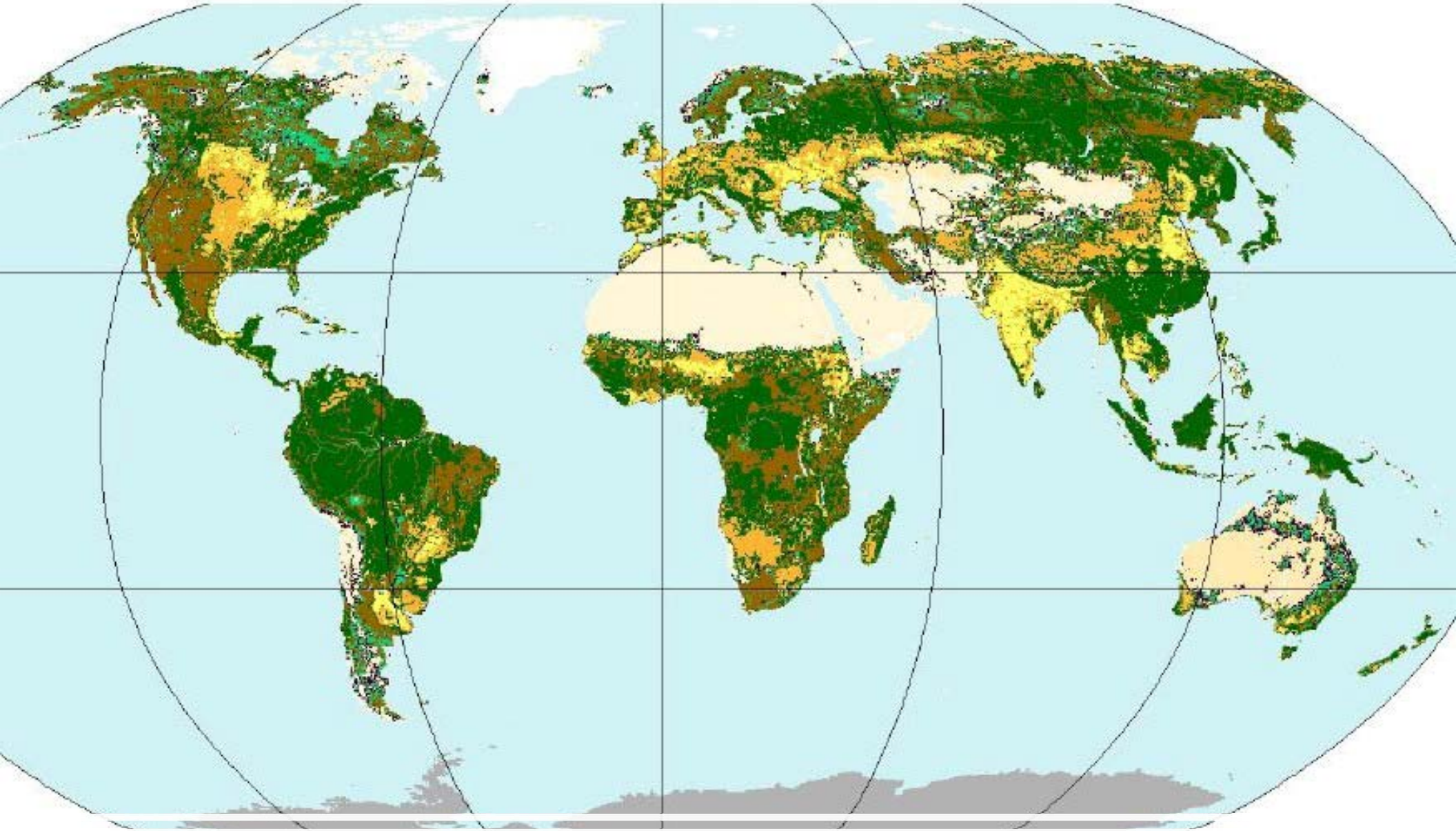
In this lecture:

- Information on the Vegetation Cover: Why do we need it
- Physical principles of vegetation cover monitoring
- NDVI: most popular vegetation-related index
- Examples of NDVI products: MODIS, VIIRS, geostationary satellites
- Vegetation health, other applications

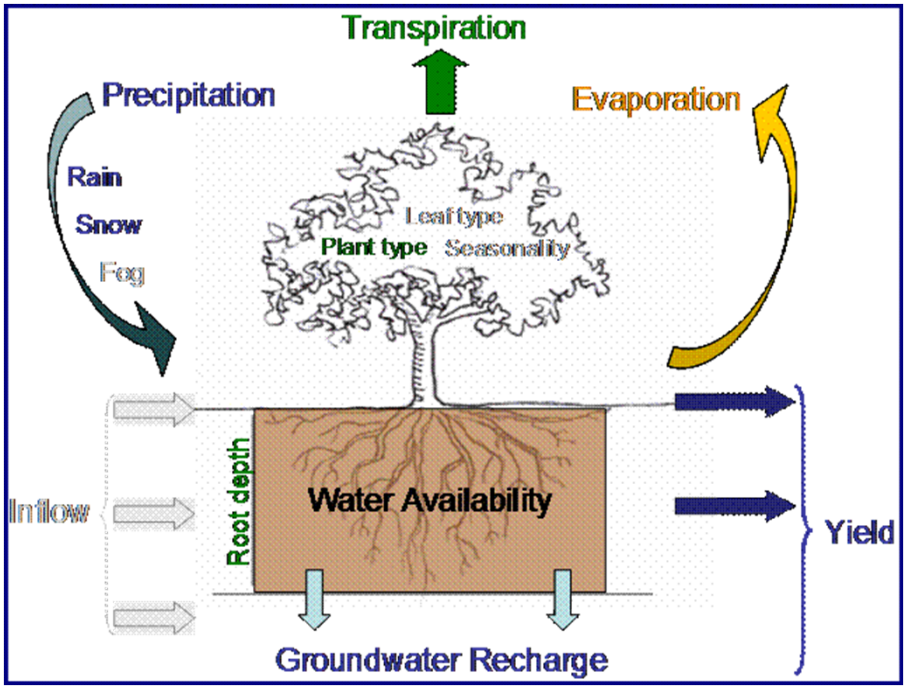


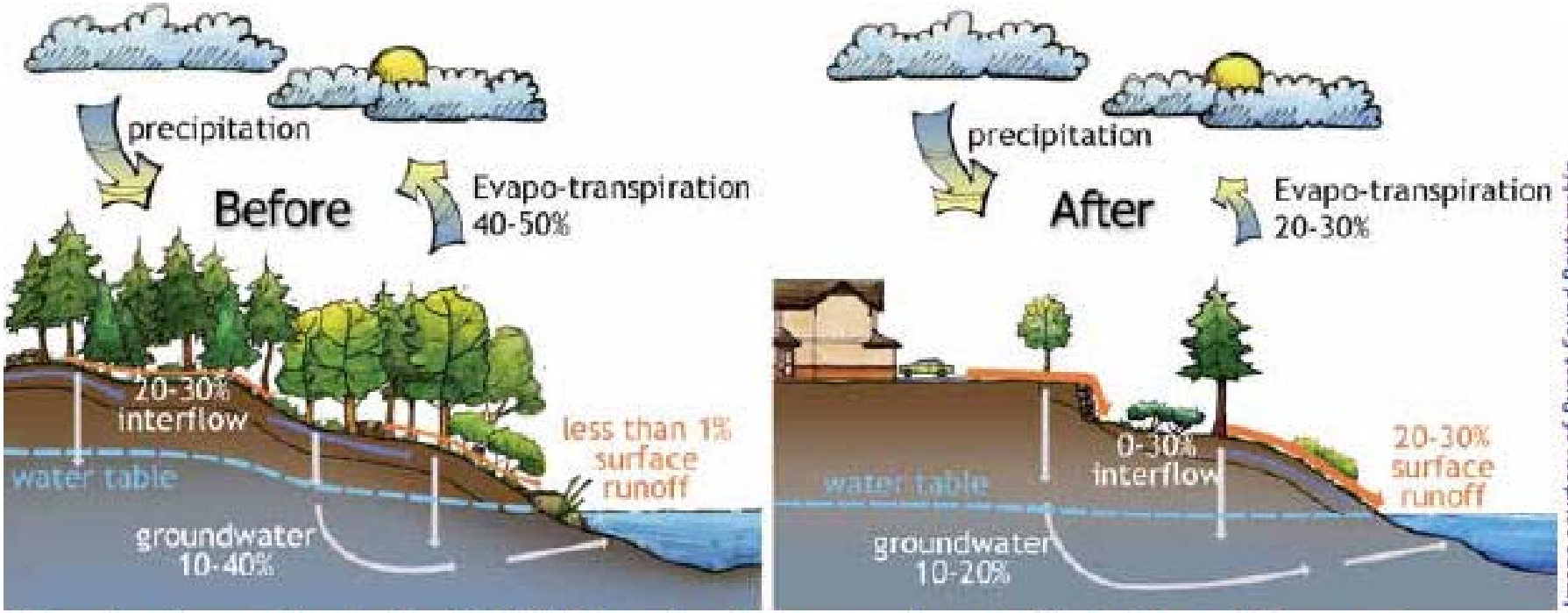
More than 76% of the Earth's land surface is covered by vegetation with perennial or seasonal photosynthetic activity

We need information on the vegetation cover because:

Plants affect water balance by

- Transpiration of water (evapotranspiration)
- Intercepting precipitation
- Changing surface runoff
- Affecting ground water storage



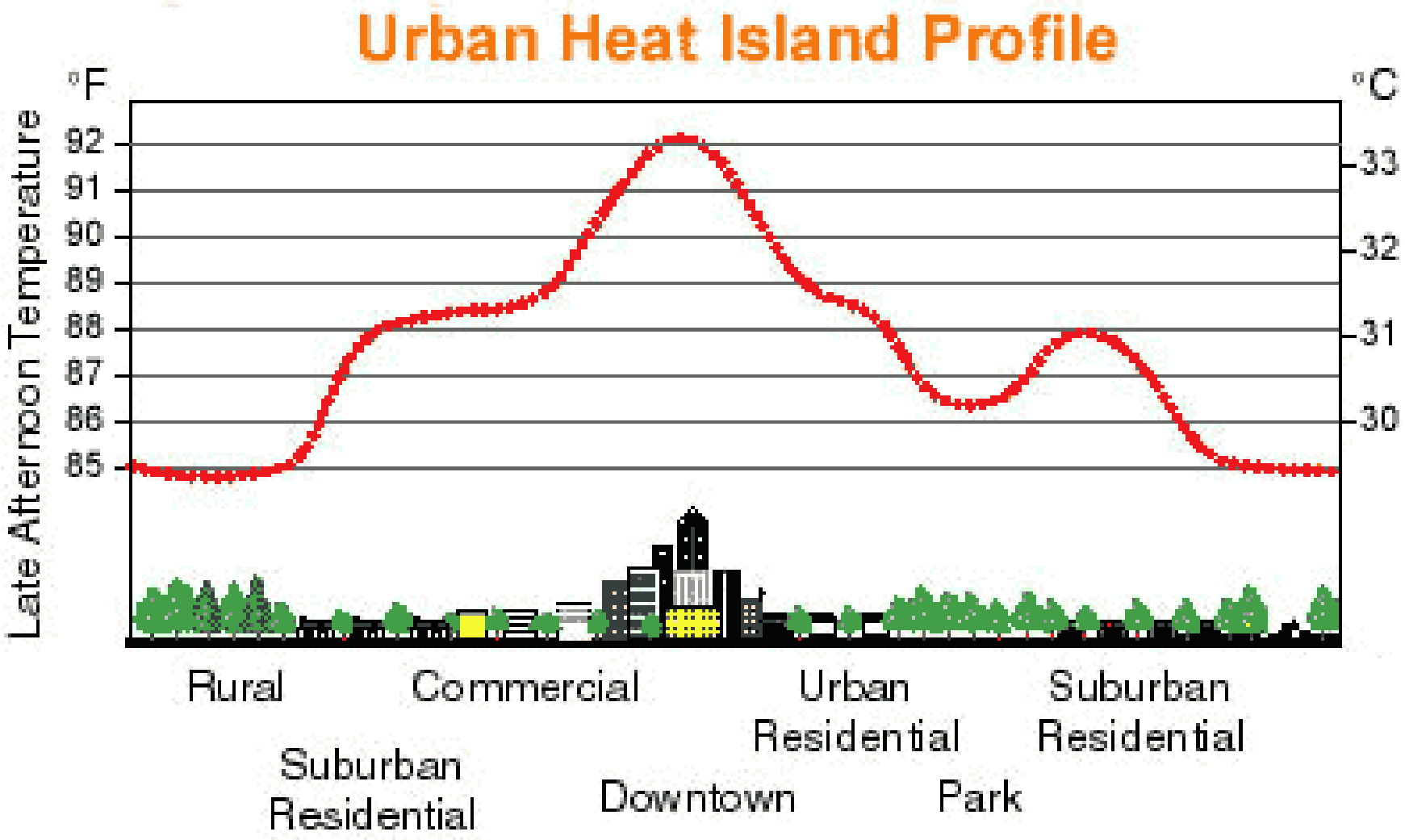


Before development almost all rainfall is taken up by plants, evaporates or infiltrates through the ground. After conventional development, surface runoff increases significantly while evaporation and infiltration into the ground decrease.

(1) Deforestation increases surface runoff and thus increases the probability of floods

…because:

(2) Plants affect surface air temperature, hence local climate

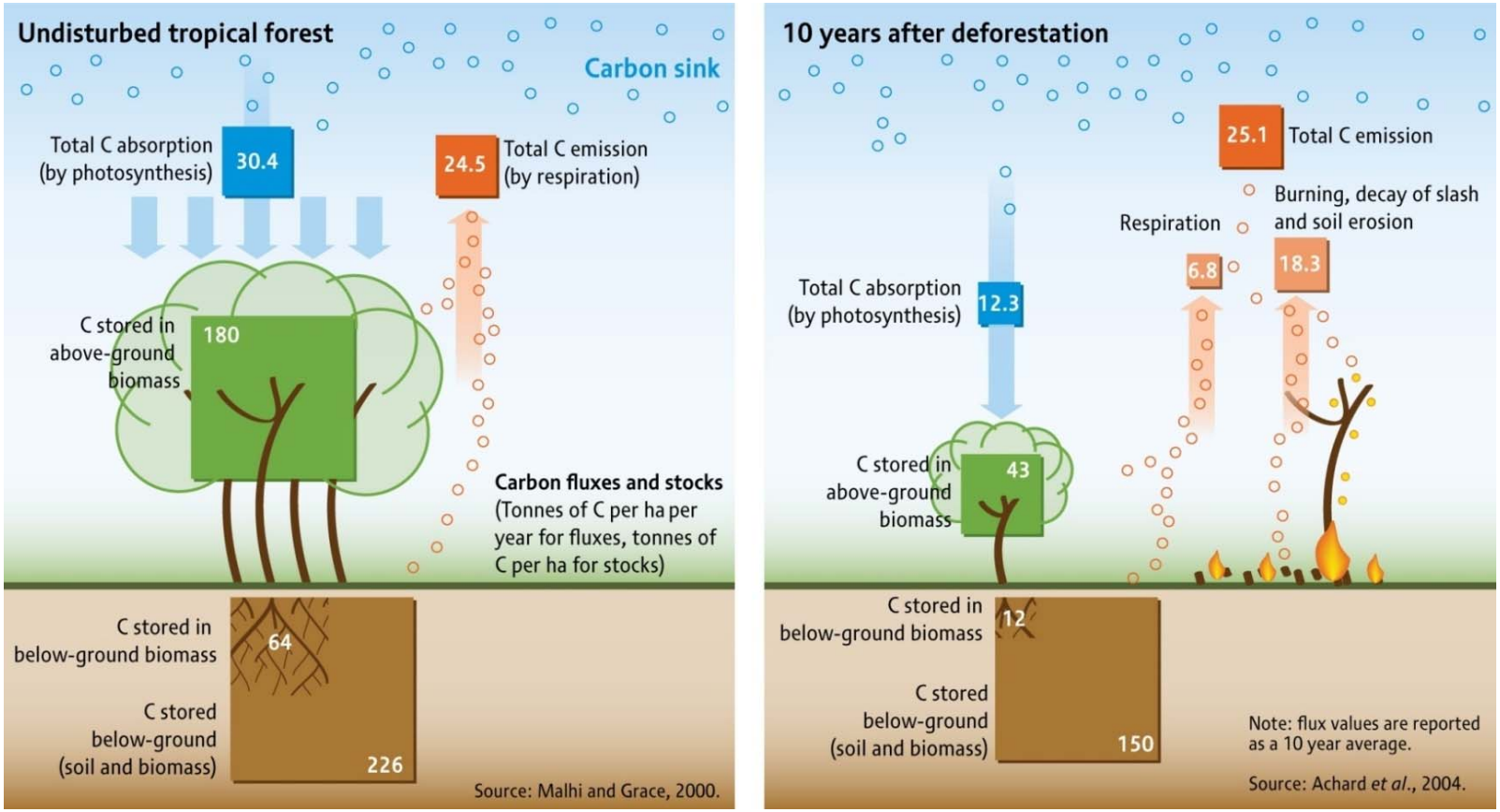


…because:

(3) Plants affect carbon balance

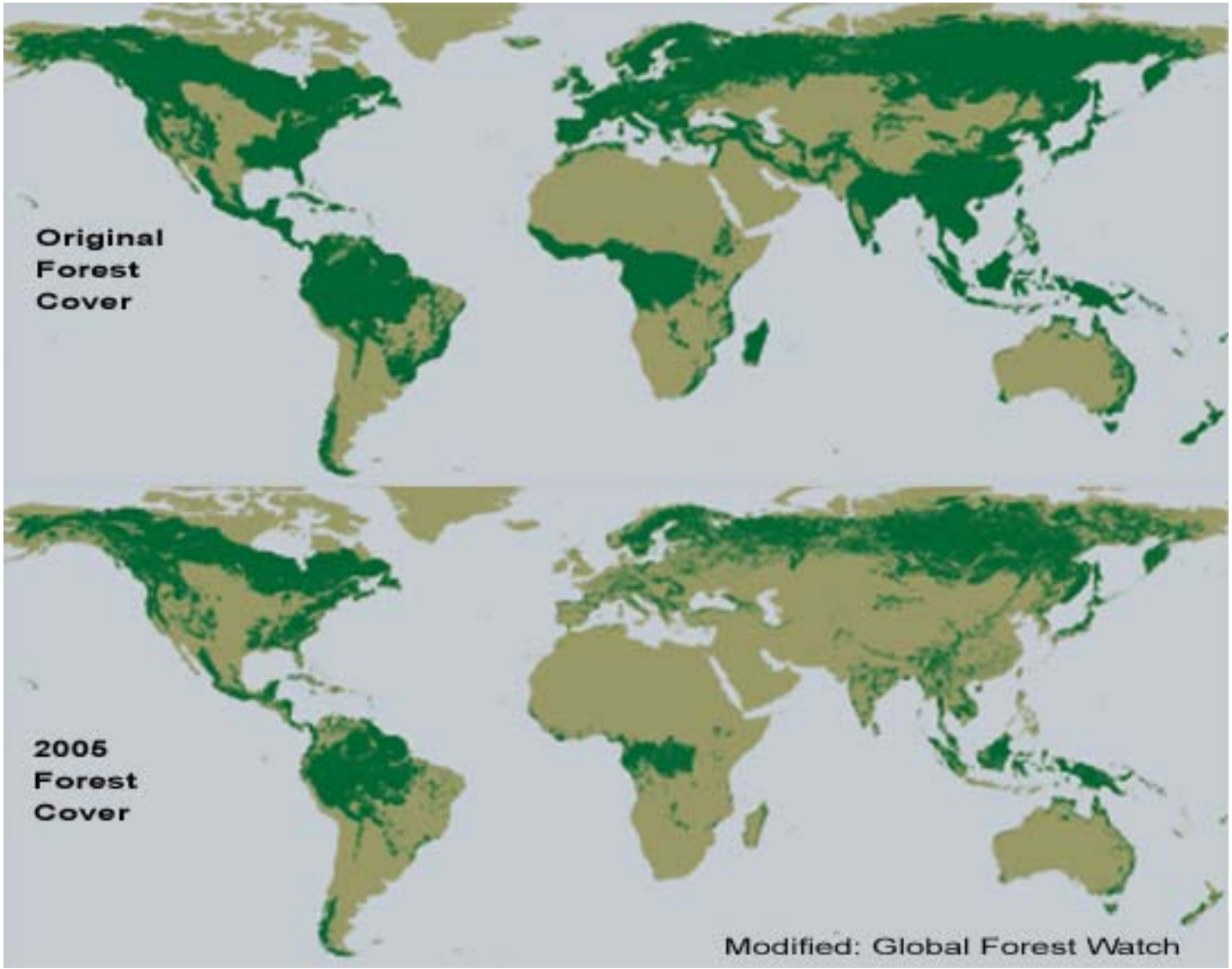
- Absorb carbon through photosynthesis
- Release carbon through burning and decay

CO_2 is the major greenhouse gas, changes in its concentration in the atmosphere result in climate change



…because:

(4) Forest cover changes with time (mostly because of humans)

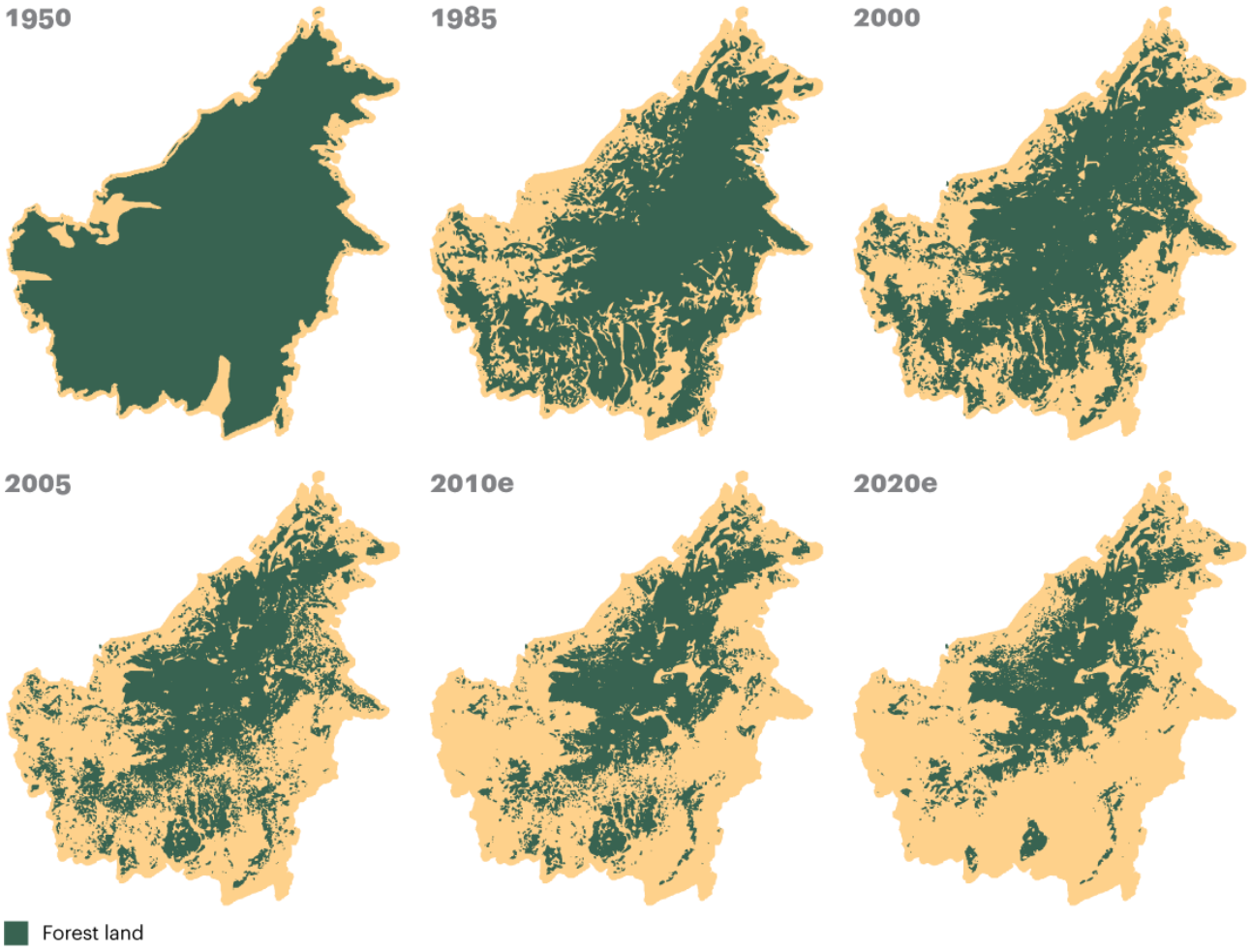


…because:

(4) Forest cover changes with time (mostly because of humans)

Figure 2

Deforestation in Borneo, 1950–2020



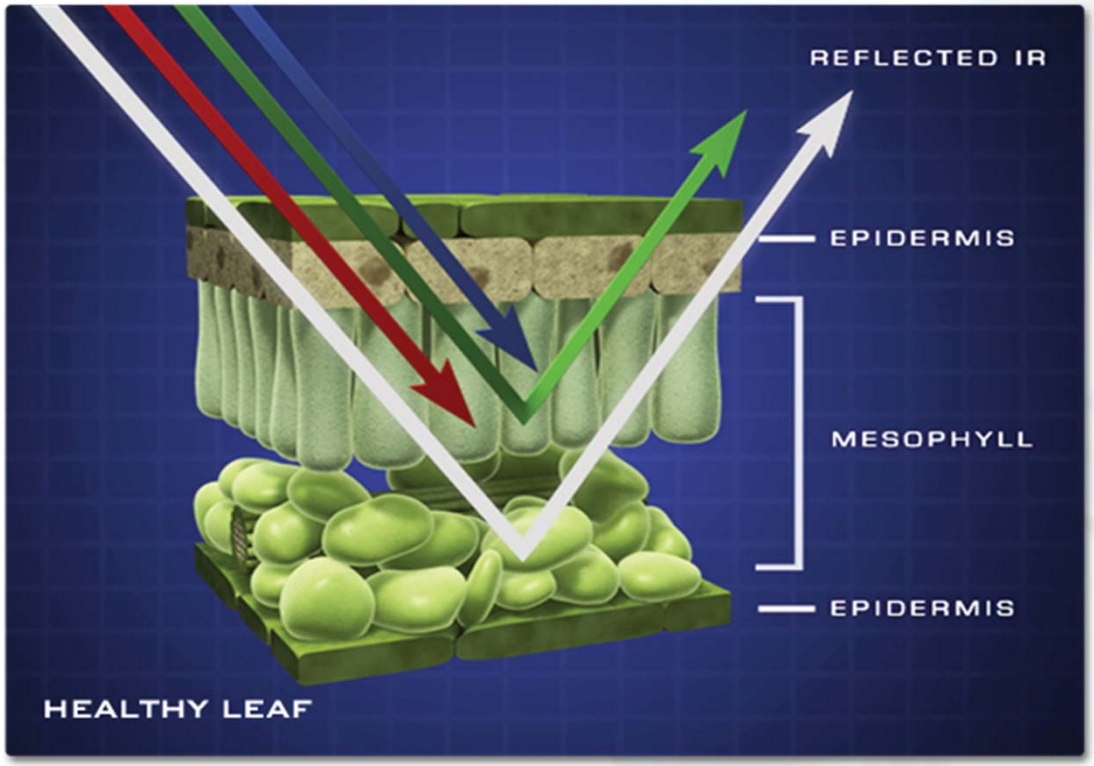
Source: WWF Germany

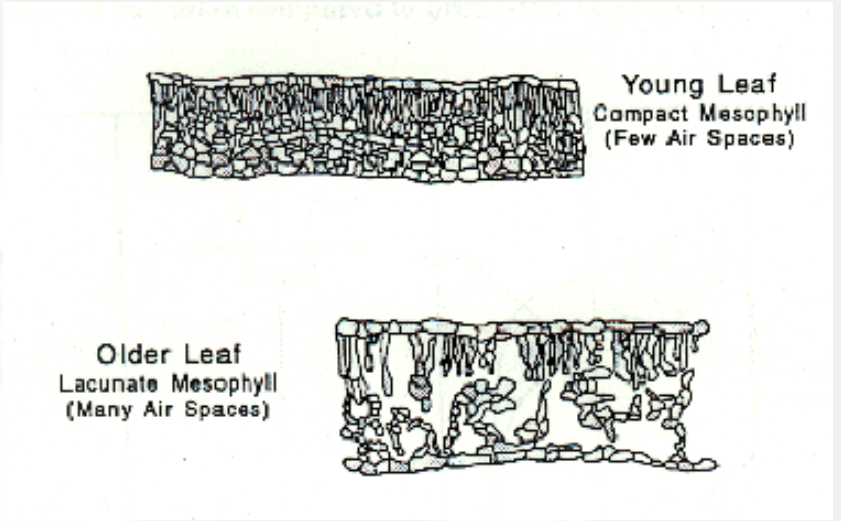
Other Applications

- Drought monitoring
- Agriculture
  - Crop monitoring
  - Soil moisture
- Plant phenology
- Fire danger
- Wildlife protection
- Forest management

Physical principles of vegetation monitoring

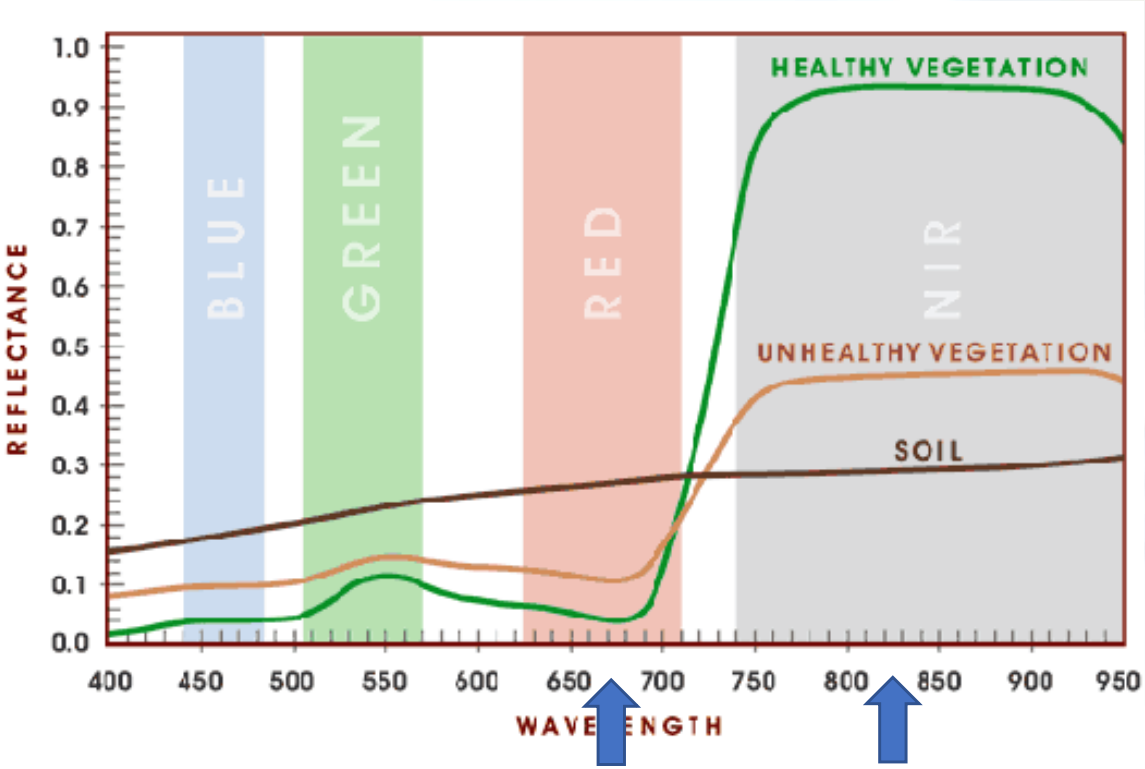
Leaf Reflectance

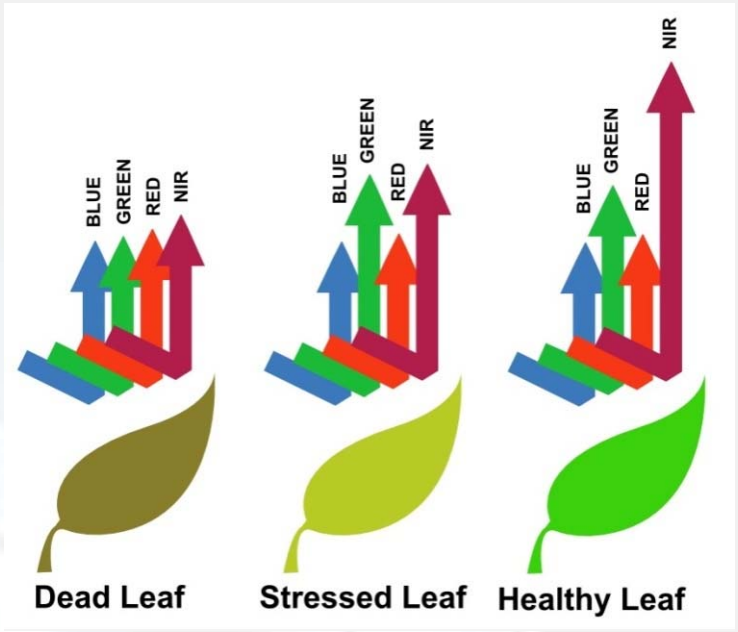




- Healthy vegetation absorbs blue- and red-light energy to fuel photosynthesis
- NIR radiation is scattered/reflected by the leaf spongy mesophyll.
- Mesophyll is composed of cells and air spaces (many scattering surfaces)
- When leaves die the structure of Mesophyll changes reducing NIR scattering

Basics of Vegetation Monitoring





Primary bands in vegetation cover observations

- When moving from non-vegetated to vegetated land most substantial changes in the surface reflectance occur in the visible and near infrared spectral bands.
- Therefore observations in the red and NIR spectral bands are most efficient for monitoring vegetation cover and vegetation state from space

NDVI

Normalized Difference Vegetation Index **(NDVI) :**

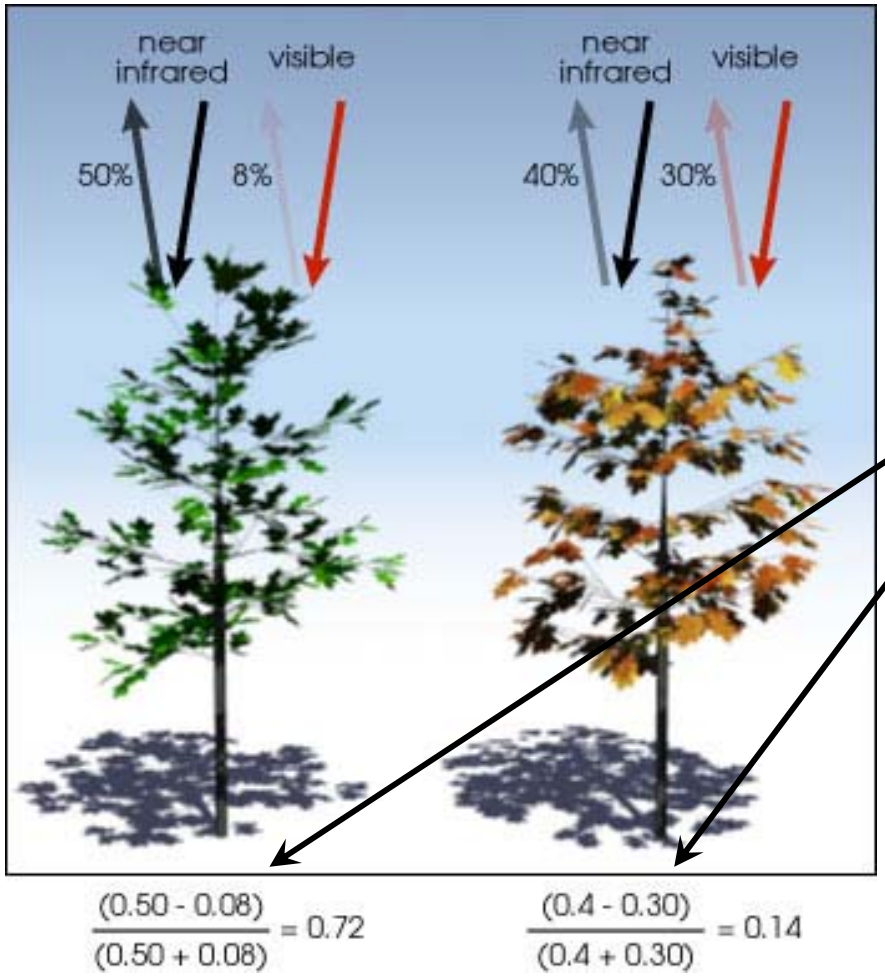
$$\mathbf{NDVI = (R_{NIR} - R_{RED}) / (R_{NIR} + R_{RED})}$$

$\mathbf{R_{NIR}}$ **:** reflectance in the near infrared (~0.8 µm)

$\mathbf{R_{RED}}$ **:** reflectance in the "red" part of spectrum (~0.6 µm)

All imaging sensors onboard polar orbiting weather satellites since early 1980s and many geostatonary satellite sensors provide observations in the visible and near infrared. This allows for using their data to derive NDVI.

NDVI: Typical Values



VIS reflectance depends on Chlorophyll Carotenoid

NIR reflectance depends on water content and cell structure

NDVI theoretical range: -1.0 to +1.0

NDVI=0.4-0.7 : healthy green vegetation,

NDVI=0.1-0.2: stressed or sparse vegetation

NDVI= 0.0-0.1: Bare rock or soil

NDVI of snow and clouds is zero or negative

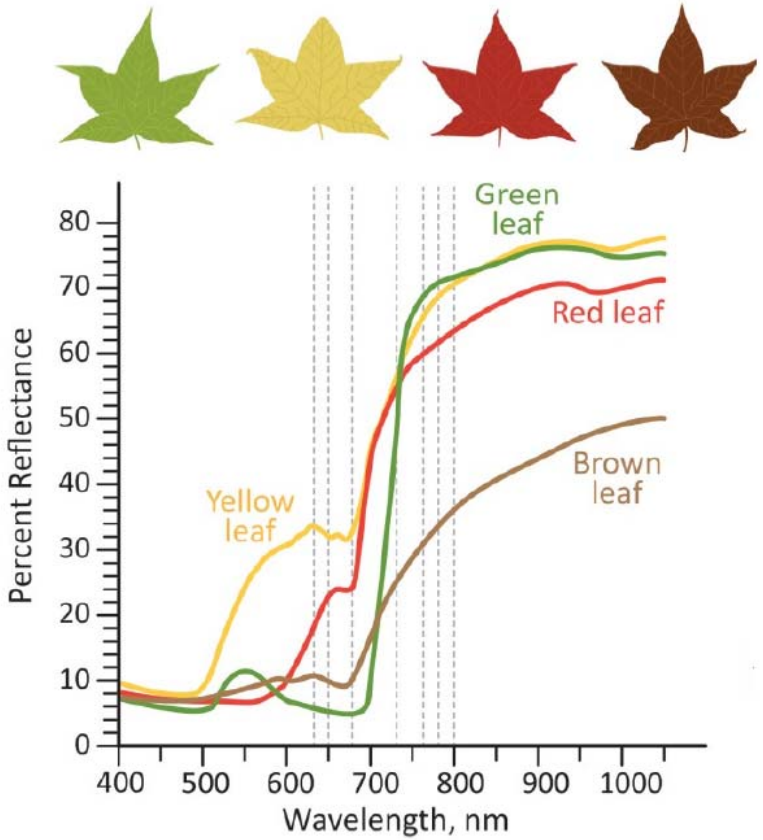
NDVI is the most popular spectral index vegetation cover and density

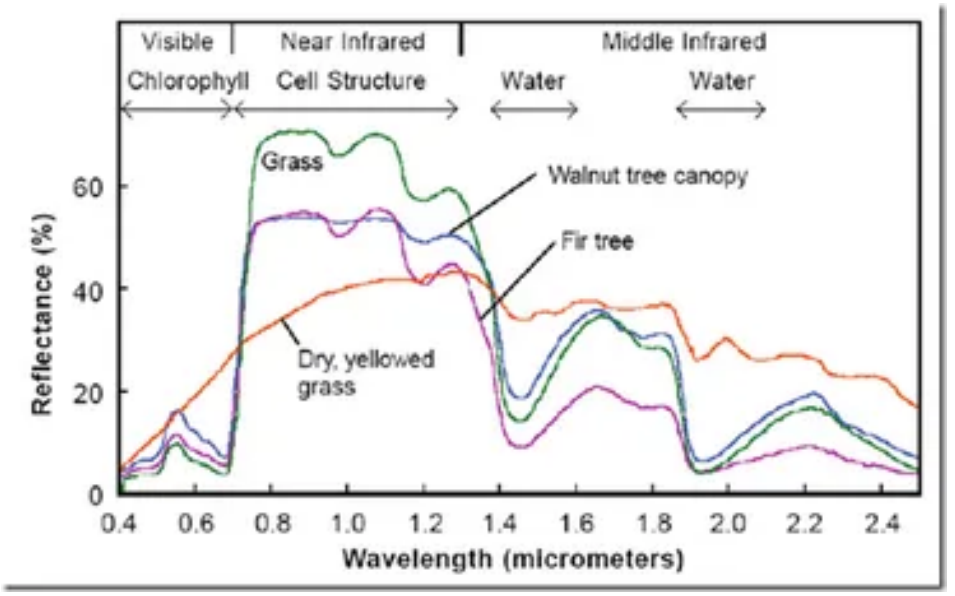
NDVI is technically very easy to implement

NDVI characterizes the “greeness” of a scene being observed

NDVI is closely related to biomass volume

Reflectance of Vegetation





Other vegetation-related indices

Several other spectral indices involving different combinations of satellite observed reflectance in the visible and near infrared have been proposed, but are rarely used. The second most popular index is

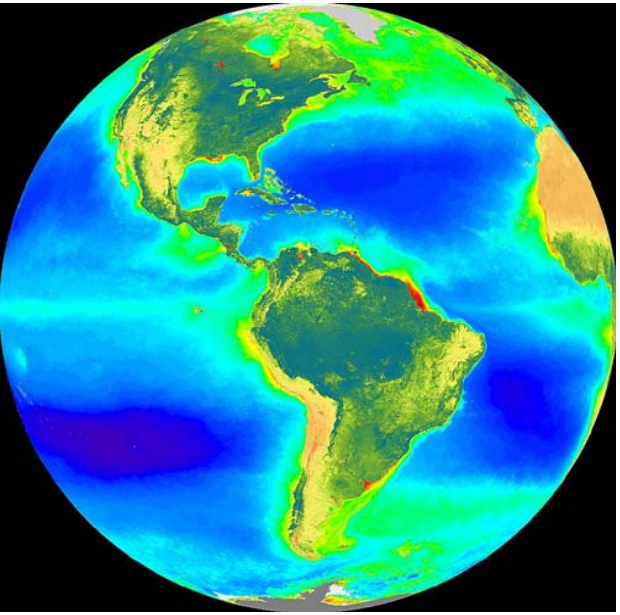
Enhanced vegetation index (EVI)

$$EVI = 2.5\ (R_{NIR} - R_{RED}) / (R_{NIR} + 6\ R_{RED} - 7.5\ R_{BLUE} + 1)$$

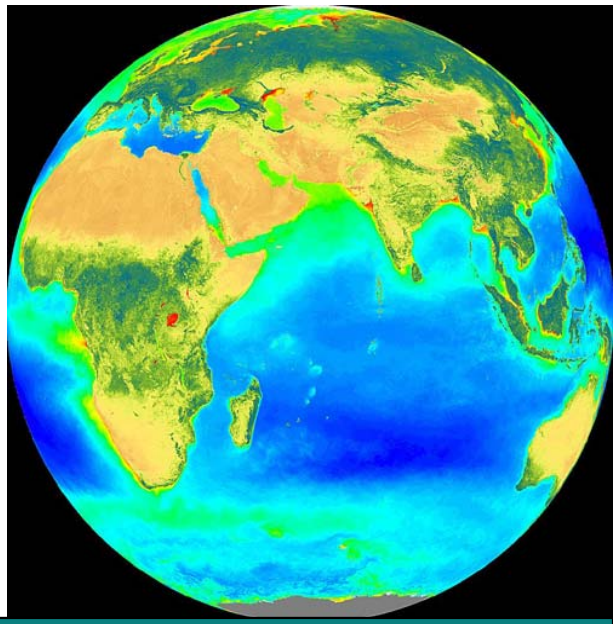
R_{NIR} : reflectance in the near infrared (~0.8 µm)
R_{RED} : reflectance in the "red" part of spectrum (~0.6 µm)
R_{BLUE} : reflectance in the "blue" part of spectrum (~0.4 µm)

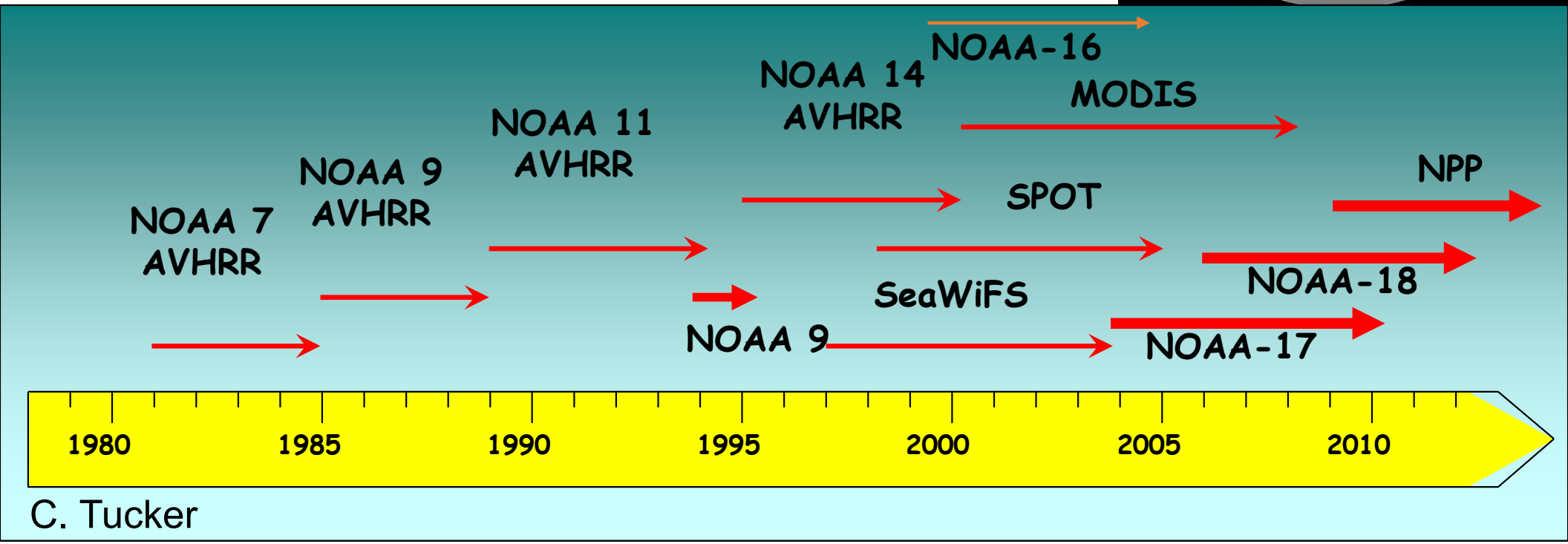
EVI is considered to be more sensitive than NDVI to vegetation cover changes over dense vegetation (e.g., over rainforests)

EVI is derived only with MODIS and VIIRS data since AVHRR does not provide observations in the "blue" band at 0.4 µm.



Satellite NDVI data sources





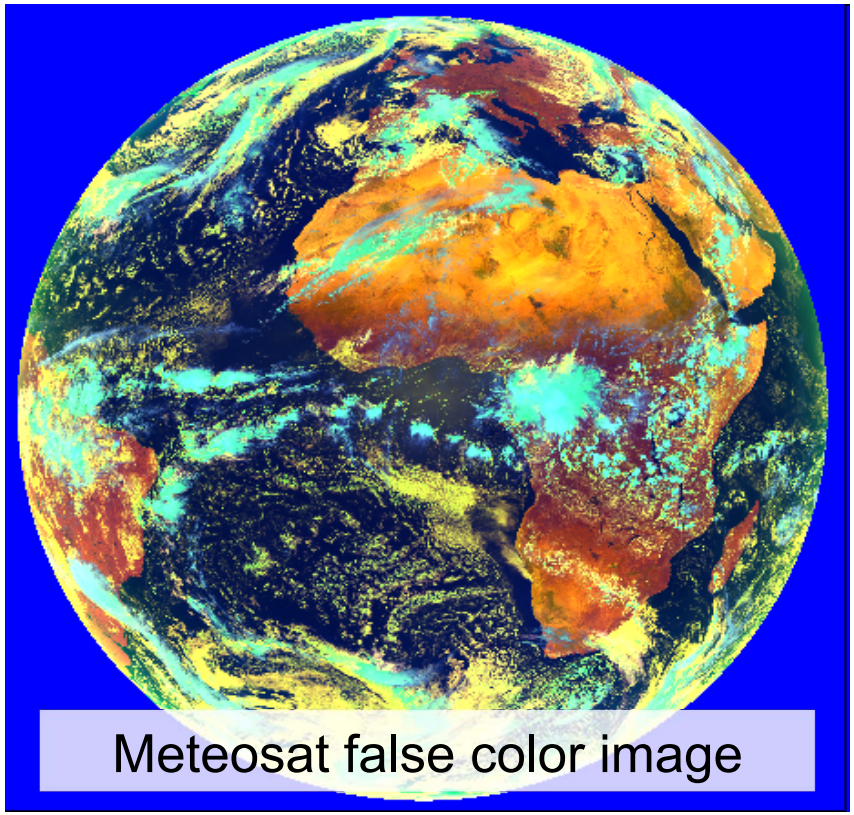
NDVI observations from satellites have been available since early 1980s. This allows for generating more than 30-years long time series of NDVI.

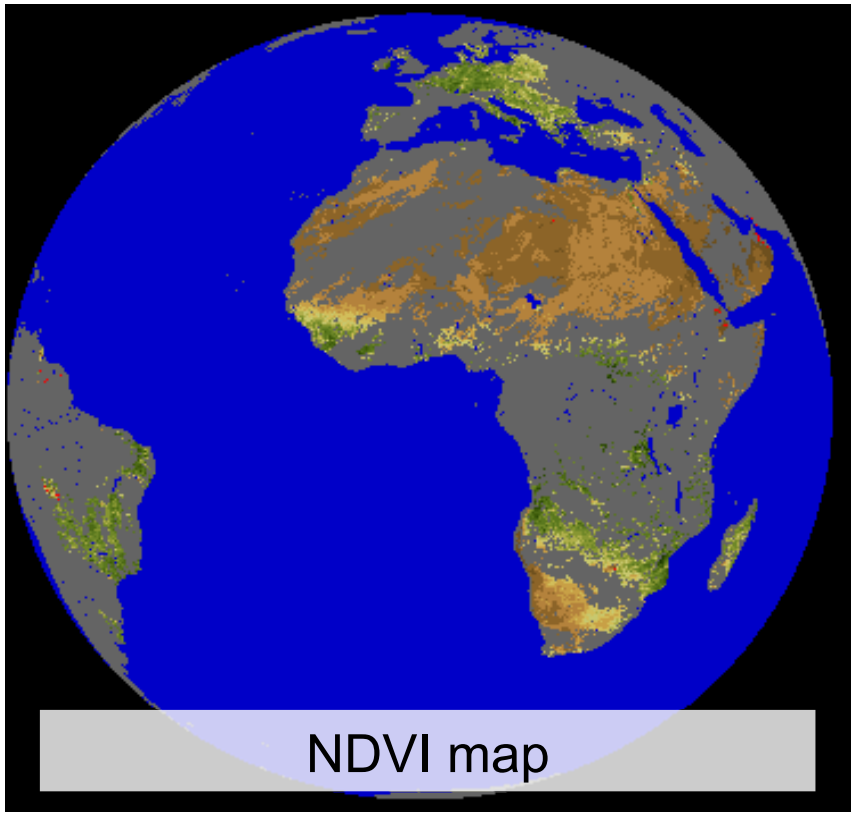
NDVI: Reducing cloud obscuration

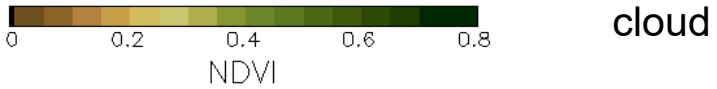
NDVI: Clouds Obscure the View

Principal problem:

NDVI maps derived from instantaneous images are **obscured by clouds**.
This complicates the spatial analysis of NDVI and its temporal dynamics
Techniques to reduce cloud obscuration and get “clearer” view are used







- Despite clouds desert and forest are clearly seen due to different NDVI

Max/Min Value Image Compositing

- Technically simple and efficient procedure to reduce cloud obscuration

- Accumulates images collected within a certain period of time and retains observations with the largest or smallest value of certain parameter.

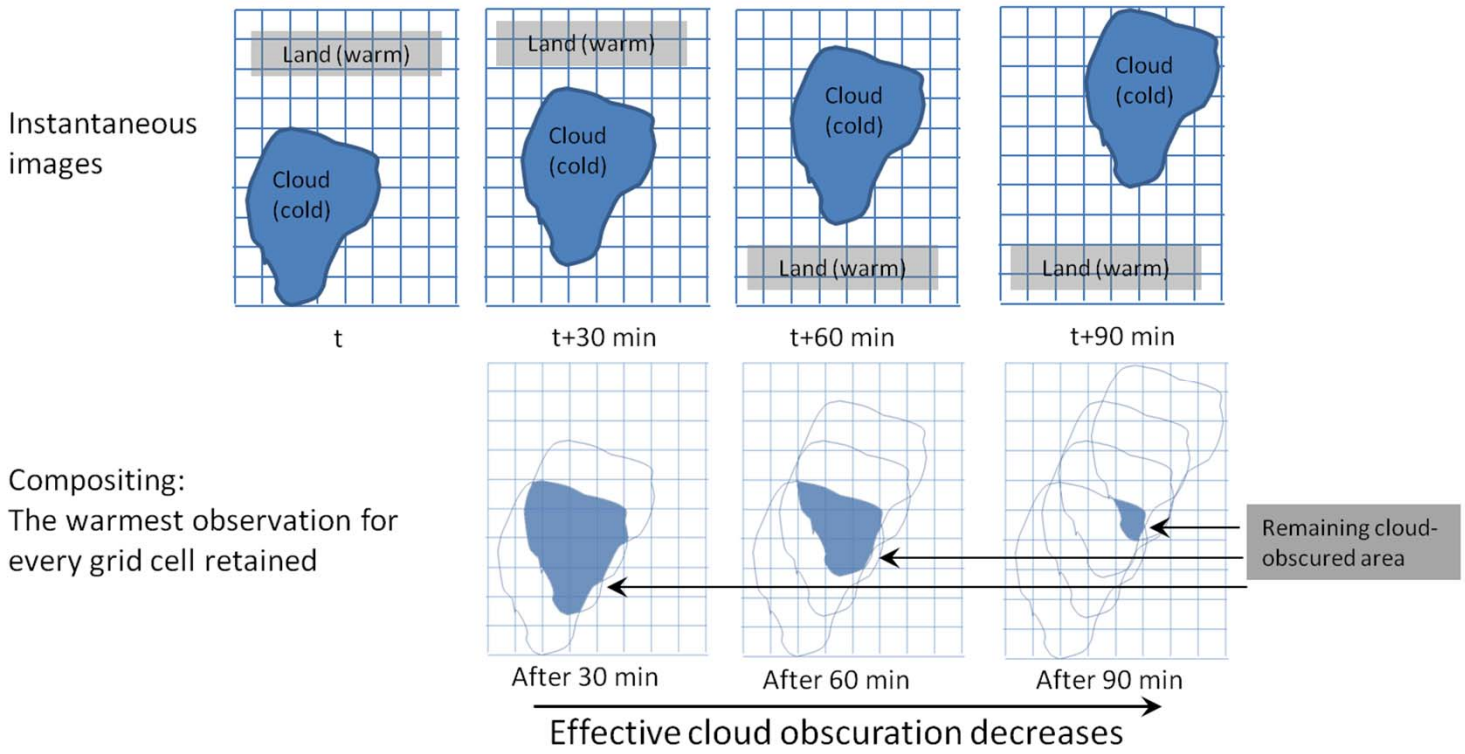
- Cloud-clear compositing can be performed by retaining observations with

    - Maximum infrared temperature, or
    - Minimum visible reflectance, or
    - Maximum NDVI (typically used in vegetation studies)

<u>Important:</u> Cloud-clear compositing reduces cloud obscuration but also reduces the temporal resolution of the product.

Image Compositing: How it works

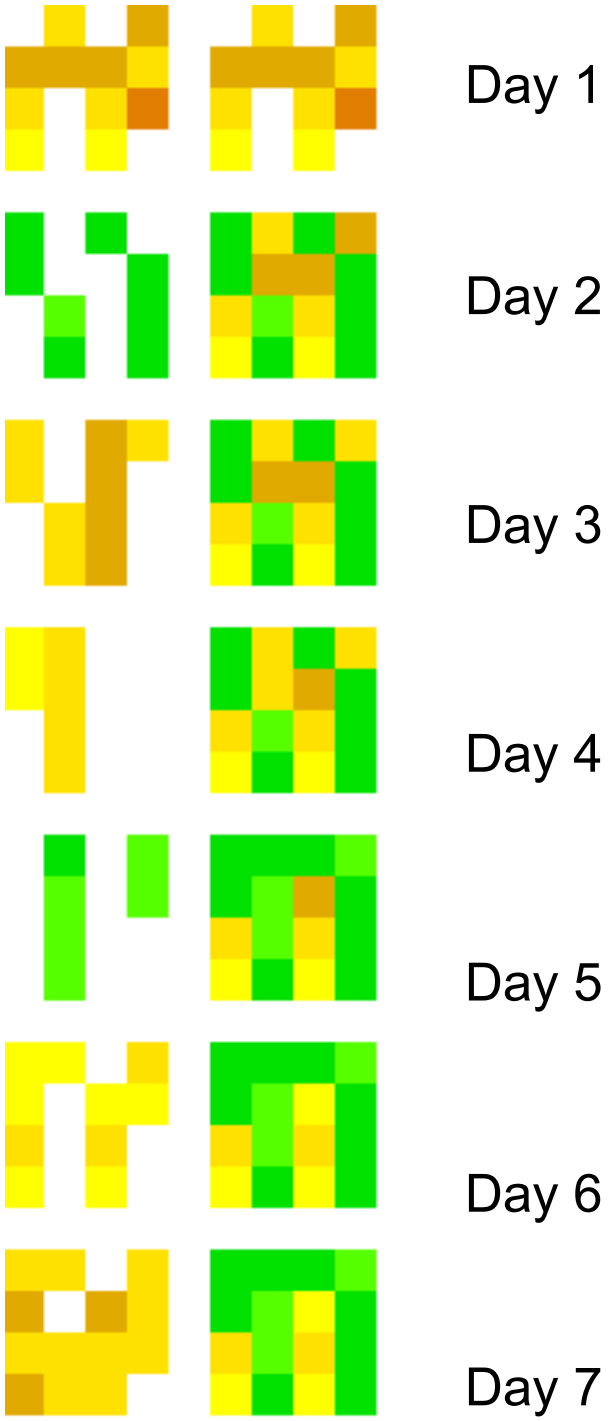
- Maximum temperature compositing: Uses the fact that clouds move and that clouds are "colder" than the land surface
- Algorithm retains the warmest observation for each grid cell (which is likely the most cloud- clear one)



- Maximum NDVI compositing: The same algorithm but NDVI is used instead of temperature
- Algorithm retains observation with max NDVI for each grid cell (which is likely the most cloud-clear one)

NDVI weekly composite using daily observations from AVHRR sensor

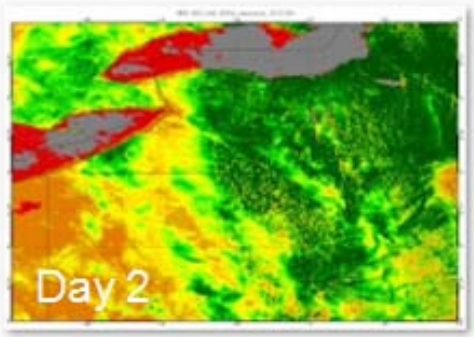
With longer compositing period the composited image becomes less cloud-contaminated and more pixels represent NDVI of cloud-clear land surface



Eastern USA. (x=2647 y=1159.)

NPP VIIRS Weekly Composite for Vegetation Health Products

USA_NDVI_VGVI.G500m.C01.npp.P2012162.png



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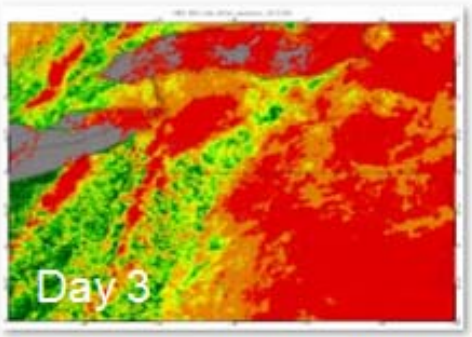

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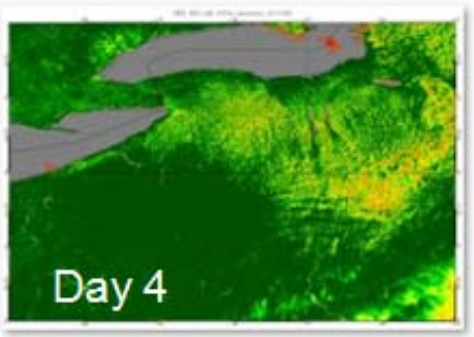

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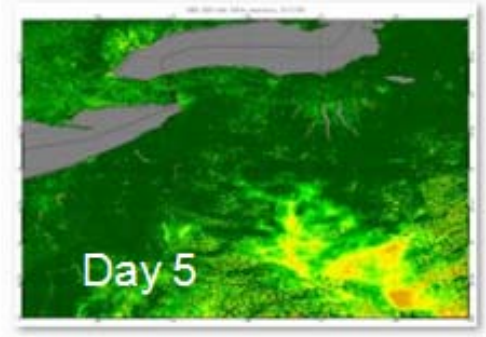
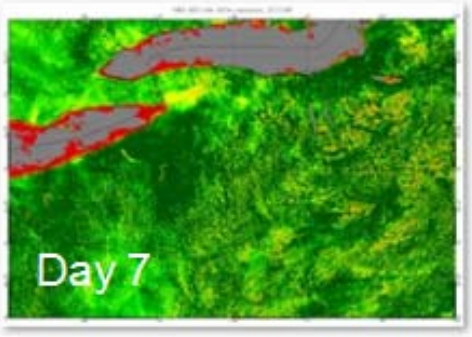


USA_NDVI_VGVI.G500m.C01.npp.P2012166.png

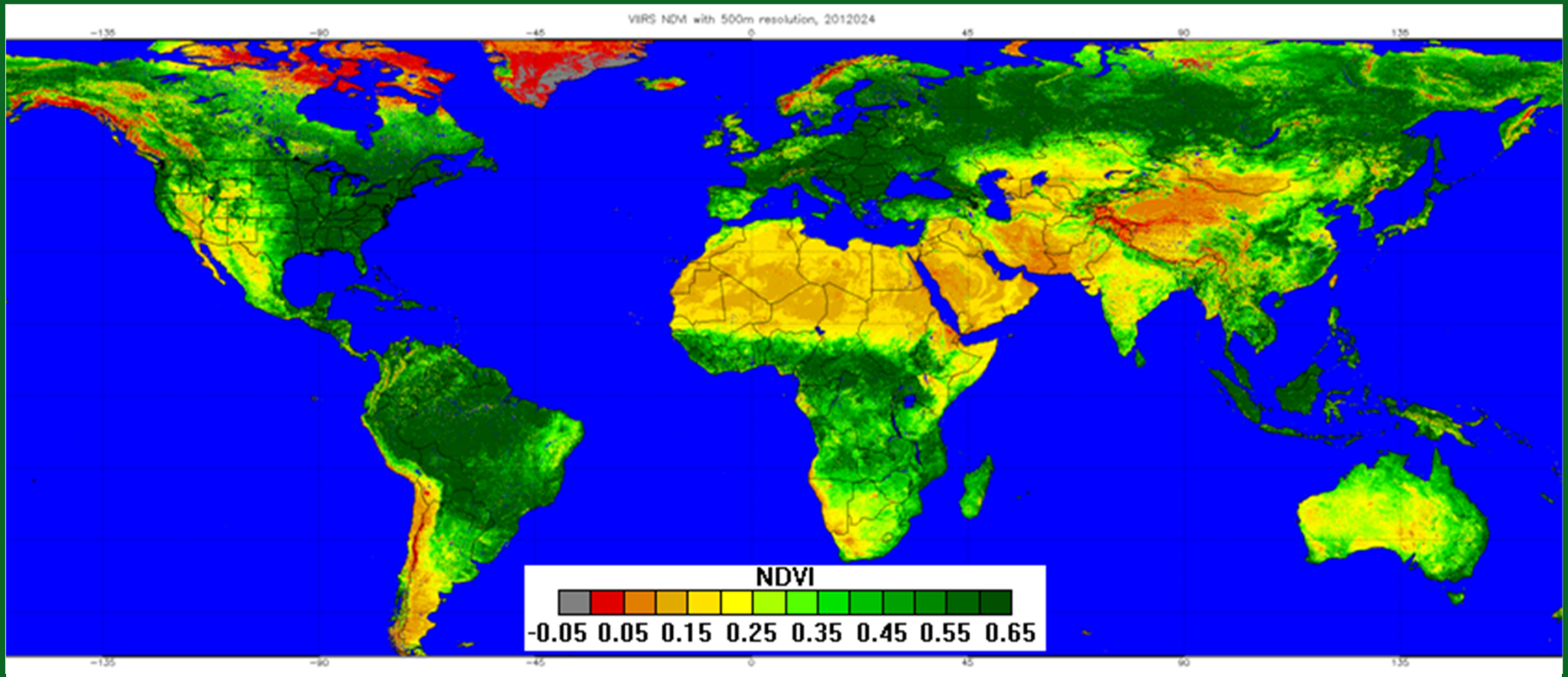
USA_NDVI_VGVI.G500m.C01.npp.P2012167.png



USA_NDVI_VGVI.G500m.C01.npp.P2012168.png

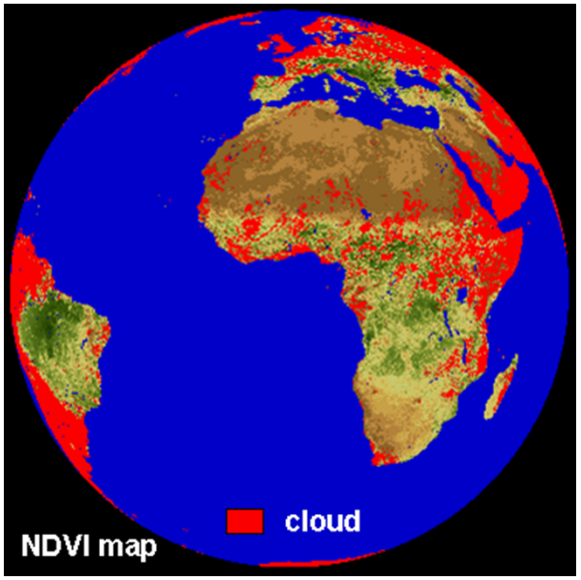
USA_NDVI_VGVI.G500m.C07.npp.P2012024.S162.E
168.png

VIIRS Weekly Composite was created from VIIRS daily maps by Maximum NDVI value compositing.

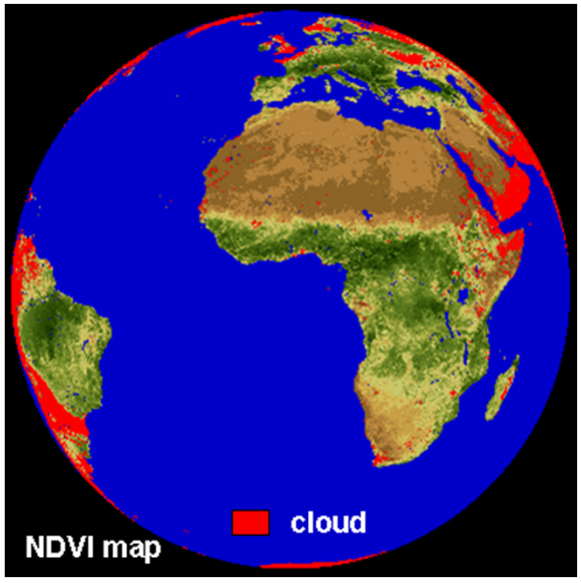


VIIRS Global NDVI map (sampled from 500m data set)

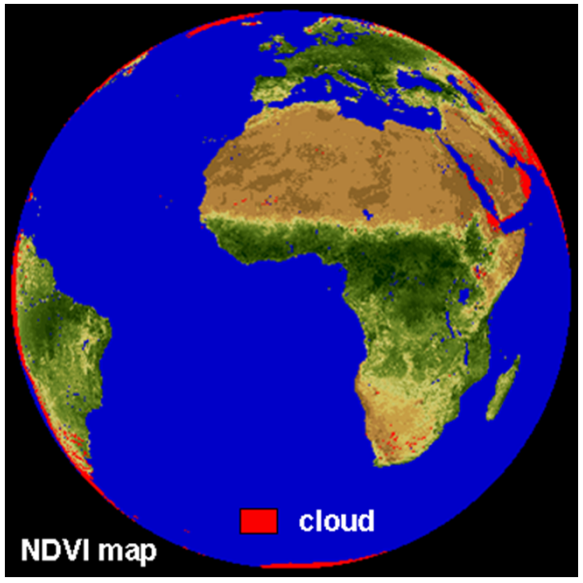
Effect of Cloud-Clear Compositing on NDVI, Geostationary Satellite Example



Instantaneous image
13.15 UTC



Daily max NDVI composite



Weekly max NDVI composite

June 23, 2007

Week June 16-23, 2007

The more frequent in time observations are the “clearer” is the product

Important: The length of the compositing period should be smaller than the typical time scale of the event to be studied.

NDVI from MODIS, VIIRS, AVHRR

Time series of global NDVI maps are available from

NOAA Advanced Very High-Resolution Radiometer (AVHRR)

- 4, 8 16 km spatial resolution
- Weekly max-NDVI composites
- Since 1981

Moderate Resolution Spectroradiometer (MODIS) onboard Terra and Aqua

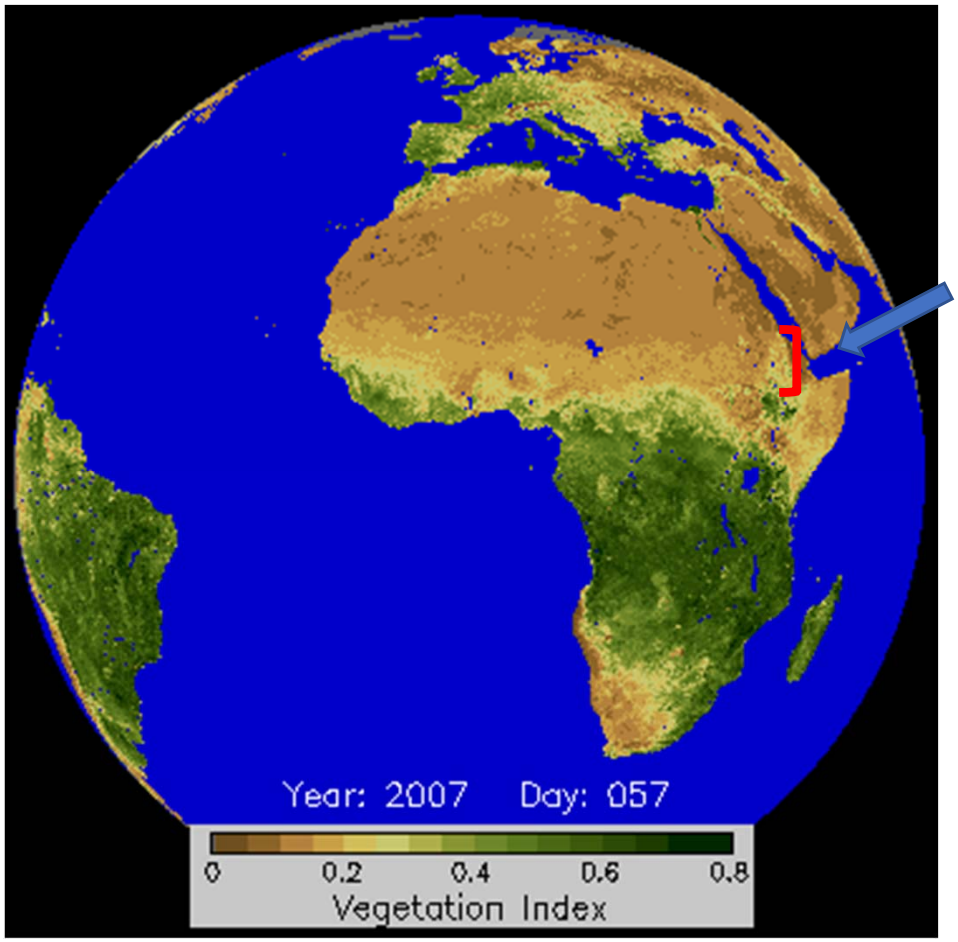
- 0.5, 1, 5 km spatial resolution
- 16-days max-NDVI composites, EVI index is also derived
- Since 1999 (Terra), since 2002 (Aqua)

Visible and Infrared Radiometer Suite (VIIRS) onboard SNPP satellite

- 375m spatial resolution
- Gridded composited datasets are being developed

Applications of satellite-derived NDVI

Seasonal Change of NDVI

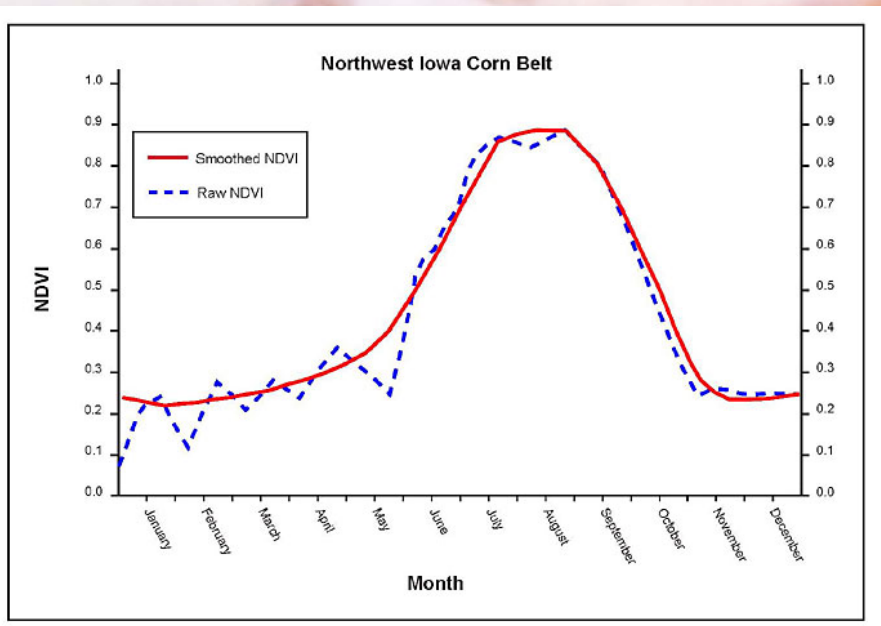


Agriculture in this latitude zone is very seasonal in nature due to a well pronounced wet/dry yearly cycle

Animation involves weekly max NDVI composites.

Weekly and 2-weeks vegetation cover products are very common since vegetation cover doesn't change much on a daily basis.

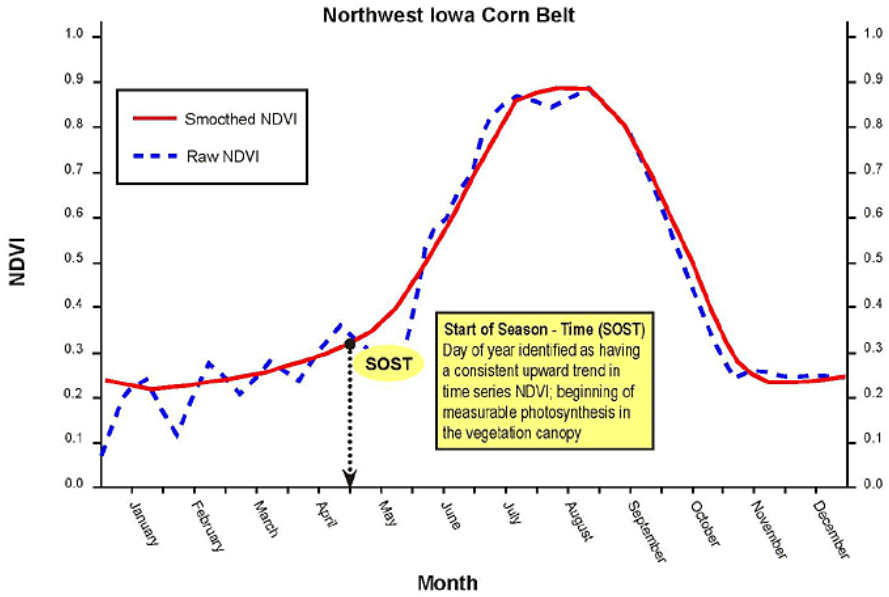
Weekly composites may still contain some clouds



NDVI: Use in Plant Phenology

- Plotting time-series NDVI data produces a **<u>temporal curve</u>** that summarizes the various stages that green vegetation undergoes during a complete growing season.
- Such curves can be analyzed to extract key phenological variables, or metrics, about a particular season, such as the start of the growing season (SOS), peak of the season (POS), and end of the season (EOS).
- These characteristics may not necessarily correspond directly to conventional, ground-based phenological events, but do provide indications of ecosystem dynamics.

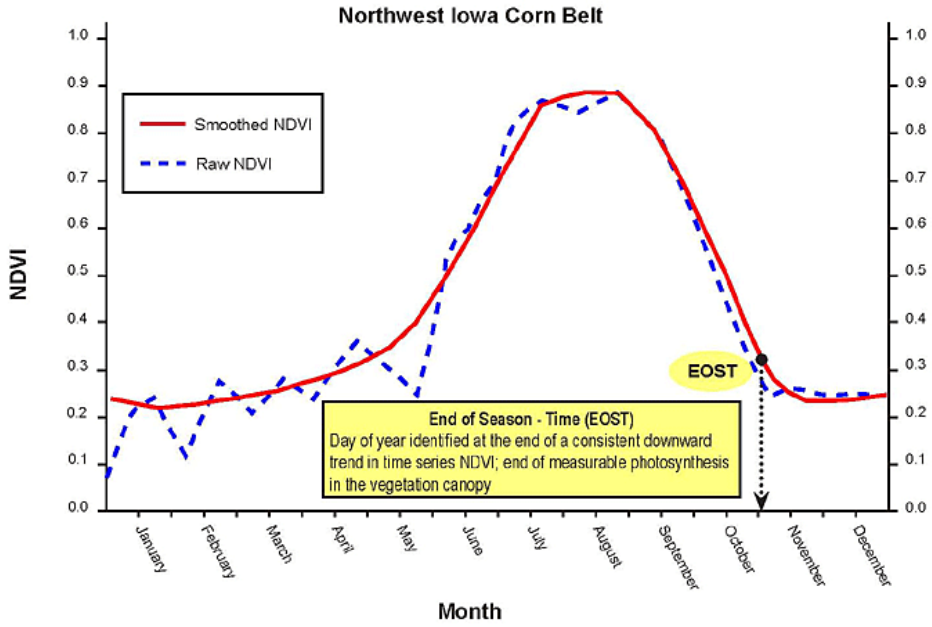
NDVI: Plant Phenology Metrics



Start of Season - Time

Identifies the beginning of measurable photosynthesis in the vegetation canopy.

Defined as day of year having a consistent upward trend in time series NDVI

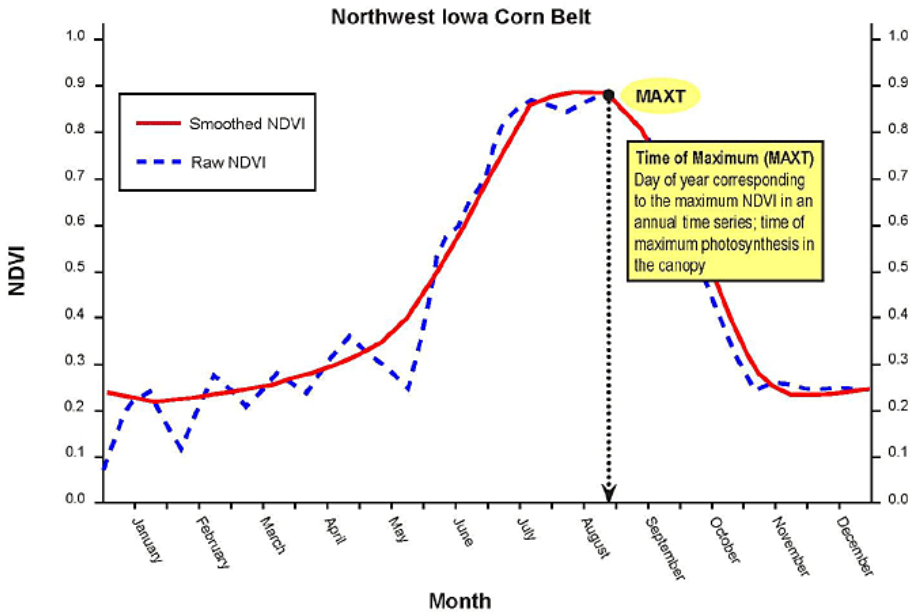


End of Season - Time

Identifies the end of measurable photosynthesis in the vegetation canopy.

Defined as day of consistent downward trend in time series NDVI

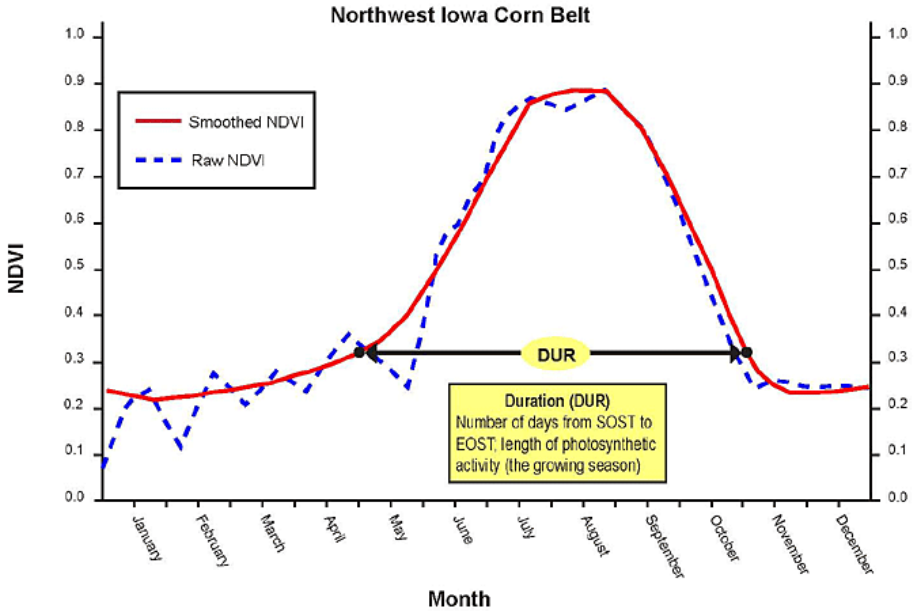
NDVI: Plant Phenology Metrics (Cont'd)



Maximum

Time of maximum photosynthesis in the canopy

Day of year corresponding to the maximum NDVI in an annual time series

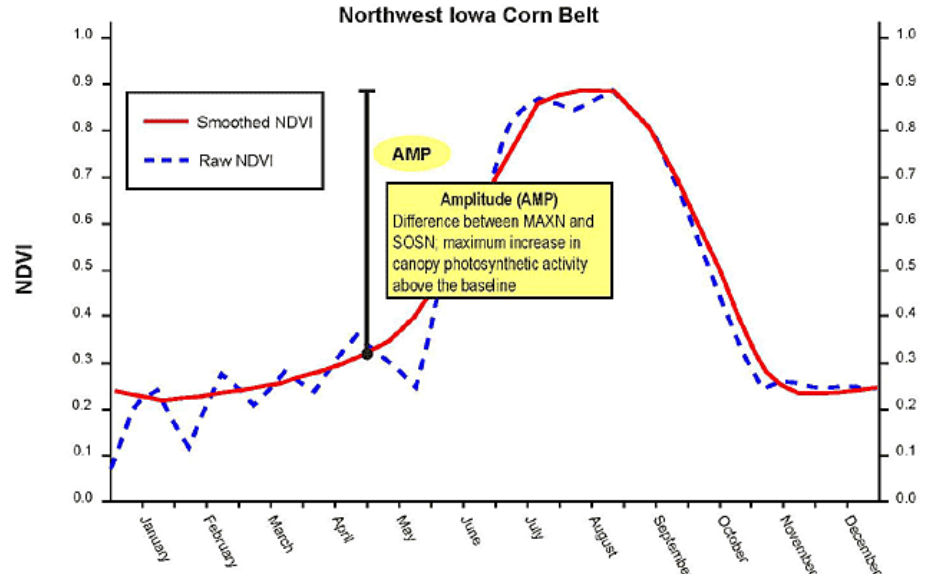


Duration

Length of photosynthetic activity (the growing season).

Number of days from the Start of Season to the End of Season

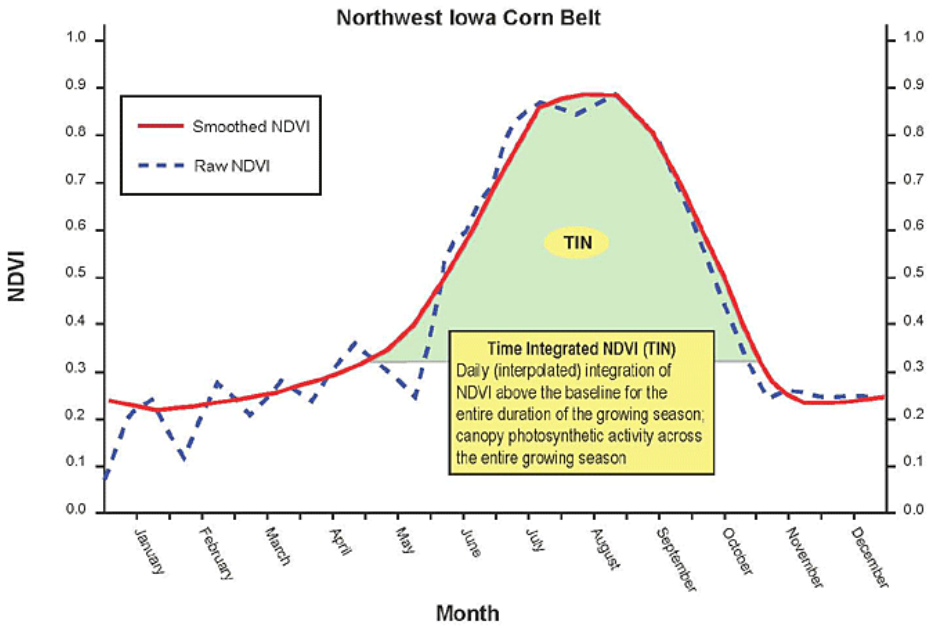
NDVI: Plant Phenology Metrics (Cont'd)



Amplitude

Maximum increase in canopy photosynthetic activity above the baseline

Difference between NDVI values at the start and at the end of the season



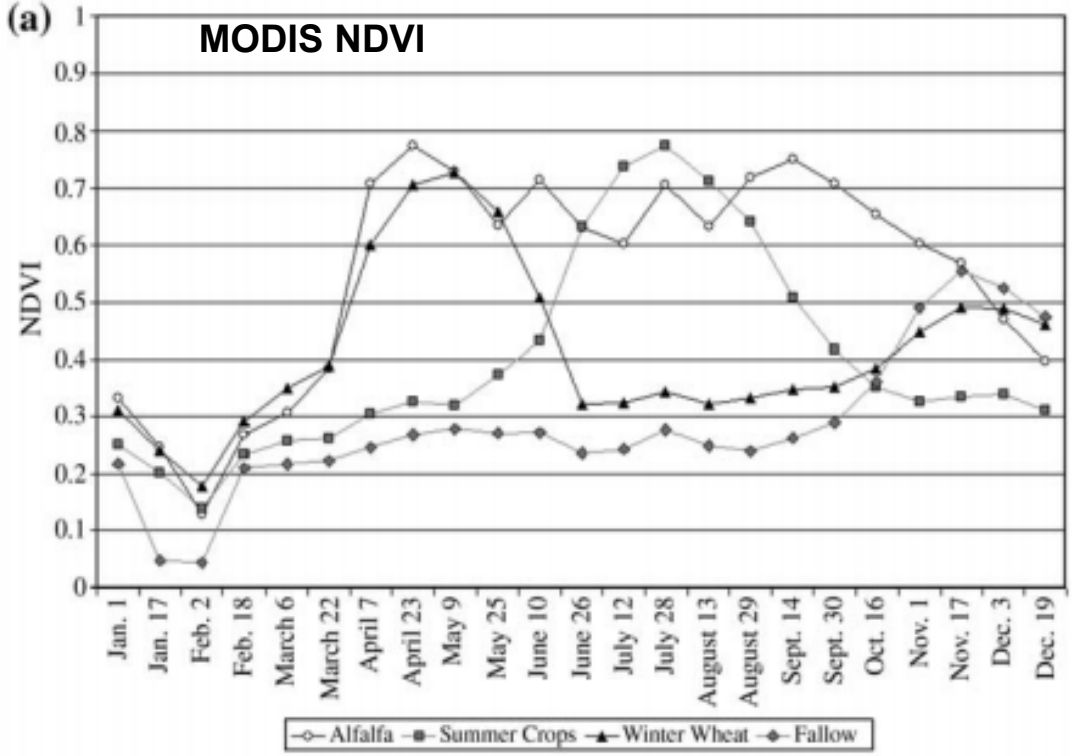
Time integrated NDVI

Canopy photosynthetic activity across the entire growing season

Daily integration of NDVI above the baseline for the entire duration of the growing season

NDVI: Seasonal Dynamics

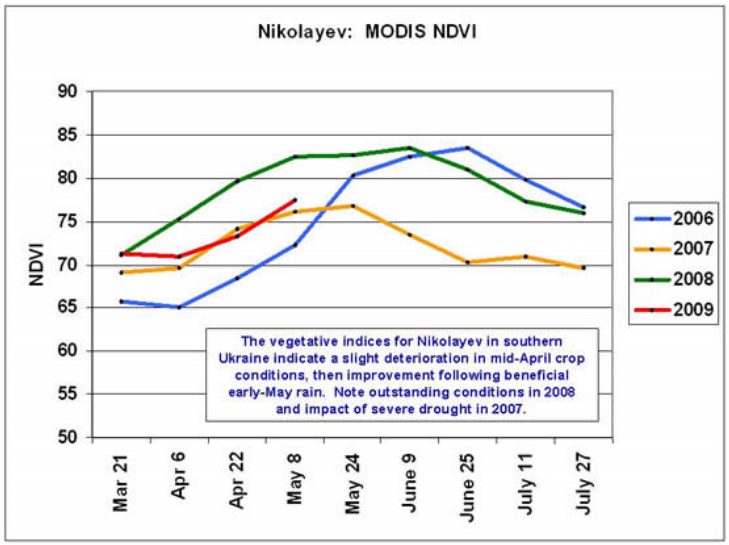
From D. Wardlow et al, 2007



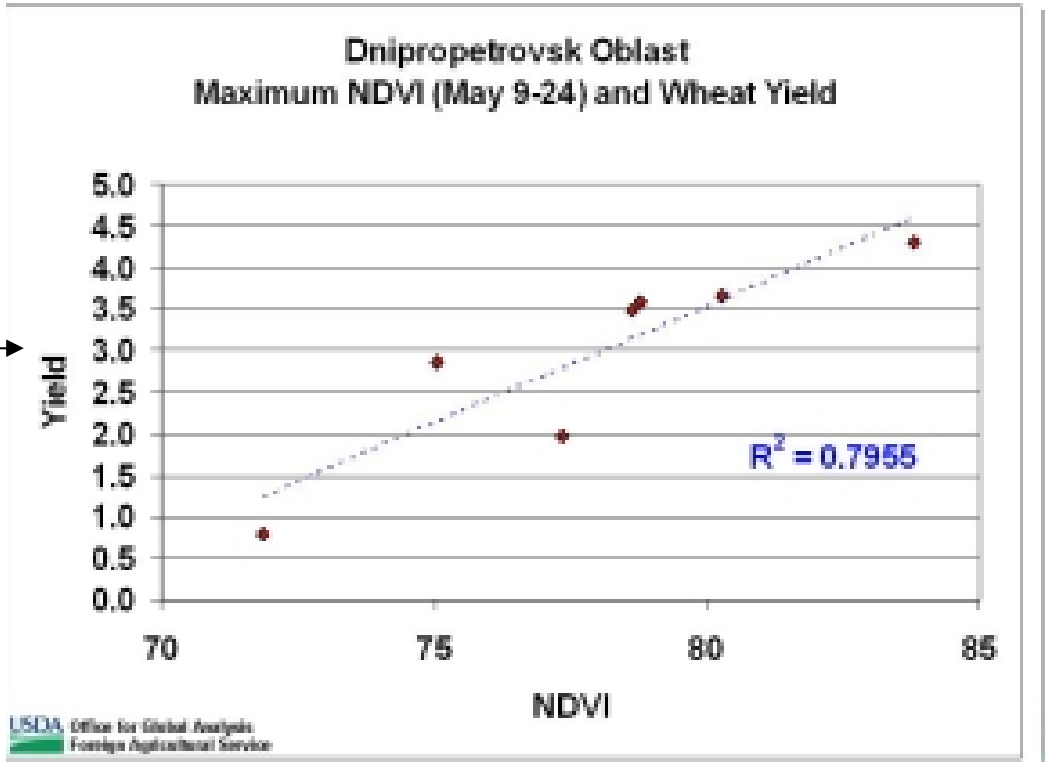
Seasonal change of NDVI and other NDVI metrics may vary depending on the climate zone, vegetation type, water availability, agricultural practices and other factors

Examination NDVI value along with its seasonal dynamics allows for discriminating forested and agriculture areas and even distinguish between different crop types.

NDVI: Use in Agriculture



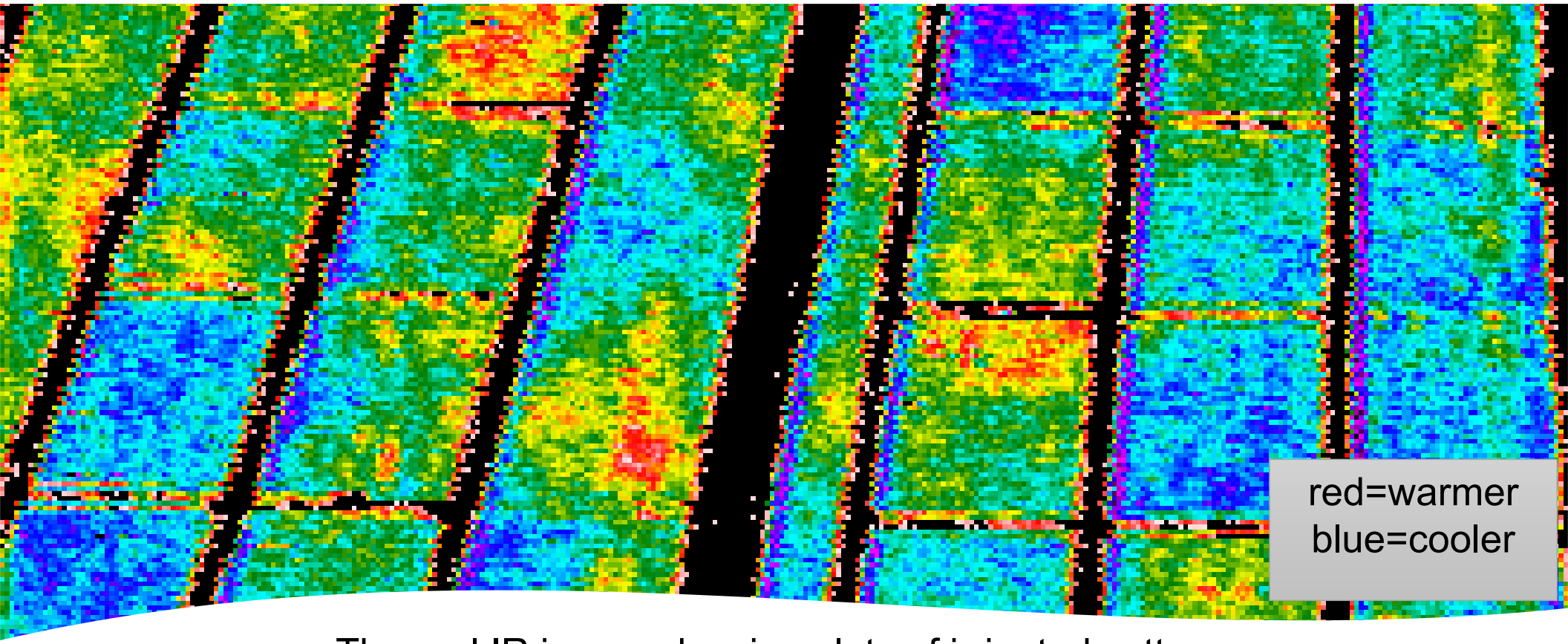
Smaller than usual NDVI early in the growing season is indicative of poor crop development. This often results in lower crop yield in the fall



USDA data for Ukraine

Drought identification and monitoring

with NDVI and thermal data combined

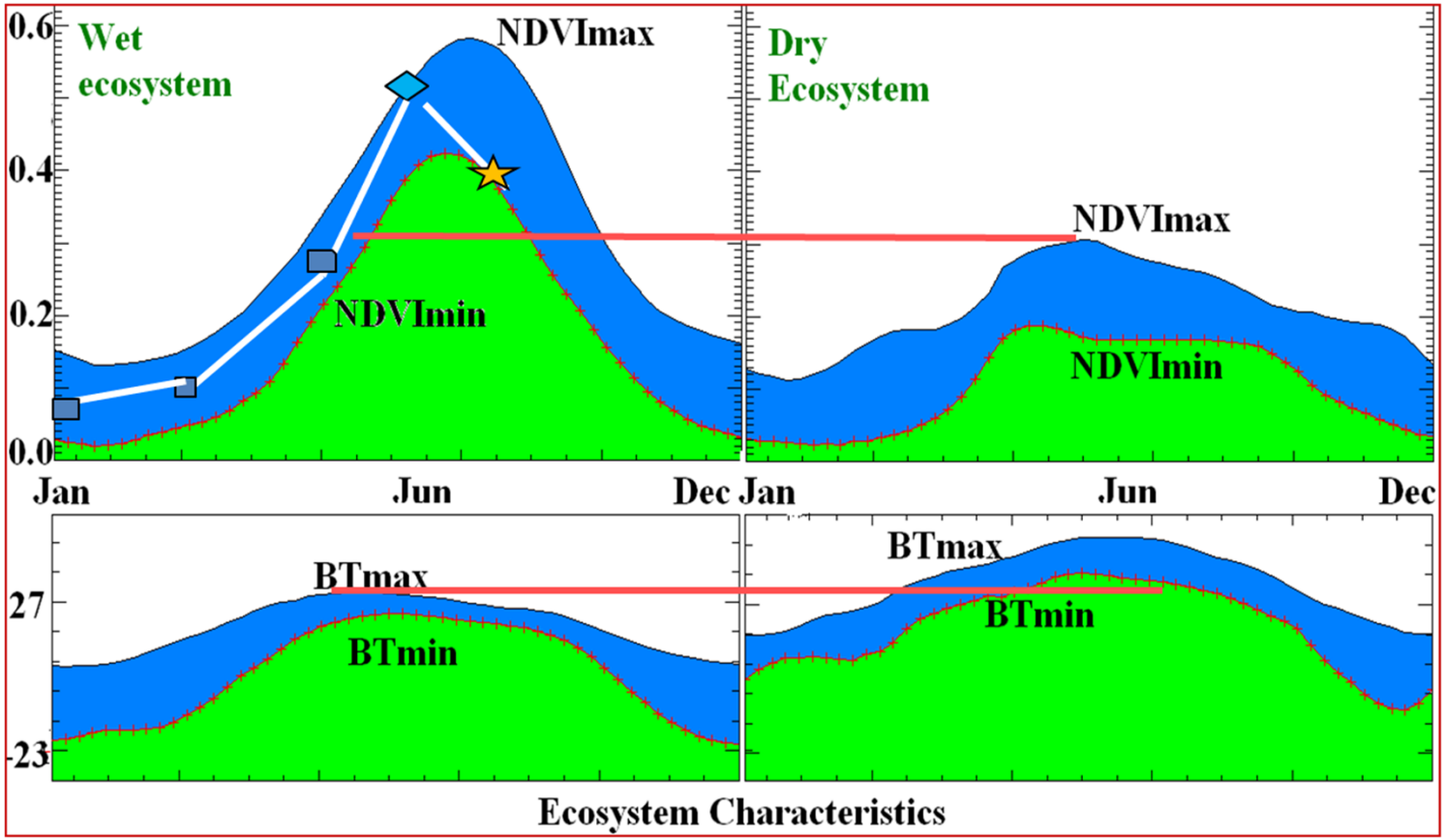


Thermal IR image showing plots of irrigated cotton

Thermal Emission and Plant Water Stress

- Measures of thermal emission can be used to derive surface temperature for a crop
- As water transpires from a plant, it's leaves are cooled
- If a plant is stressed, transpiration is reduced and leaf temperature increases

NDVI + Surface Temperature = Drought Identification



- At NOAA the drought identification system uses observations of NDVI combined with observations of the infrared brightness temperature.
- Instead of absolute values it monitors NDVI and temperature ranged between corresponding seasonal min and max values for every location.

Three vegetation health indices are used:

Vegetation condition index (VCI),

$$VCI=(NDVI-NDVI_{min})/(NDVI_{max}-NDVI_{min}) *100$$

Characterizes MOISTURE status

Temperature condition index (TCI)

$$TCI=(BT_{max}-BT)/(BT_{max}-BT_{min}) *100$$

Characterizes THERMAL status

Vegetation Health Index (VHI)

$$VHI=a*VCI+(1-a)*TCI$$

Characterizes VEG. HEALTH

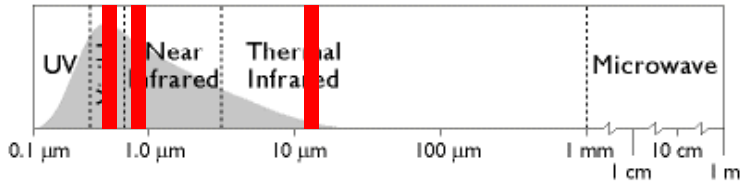
$NDVI_{min}$, $NDVI_{max}$, BT_{min}, BT_{max} are min and max values for every location

Index values:

0 – indicates extreme stress

100 – indicates favorable conditions

CASE STUDY: California, 2014

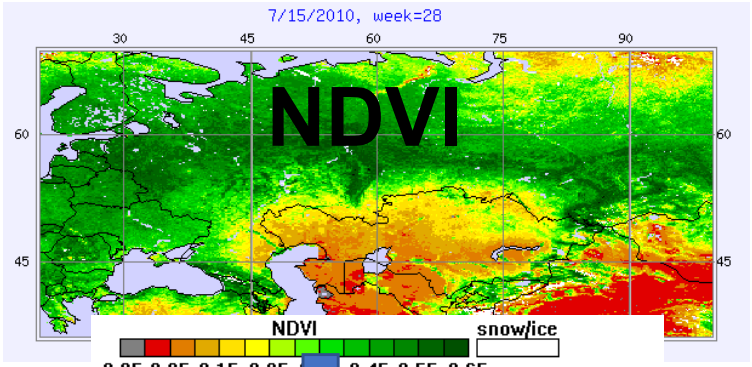


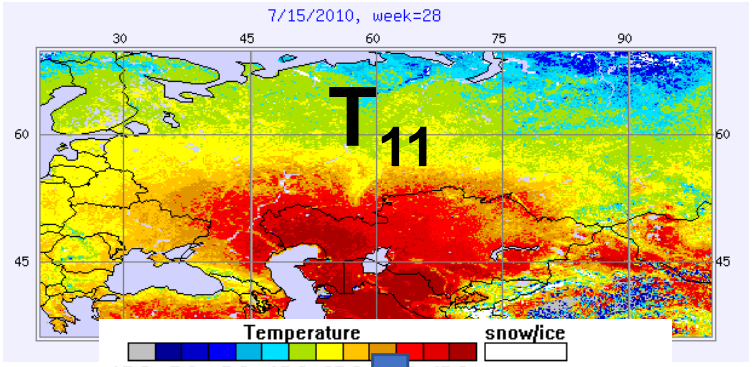
Severe drought conditions persisting in California , state-wide water restrictions implemented .

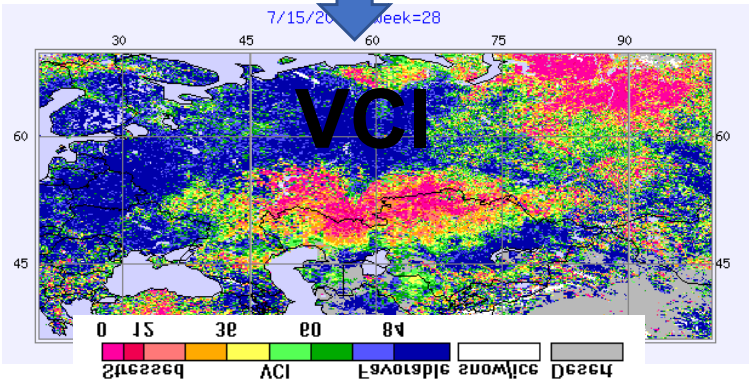
VHI
0 6 12 24 36 48 60 72 84 100
snow/ice or missing
Desert

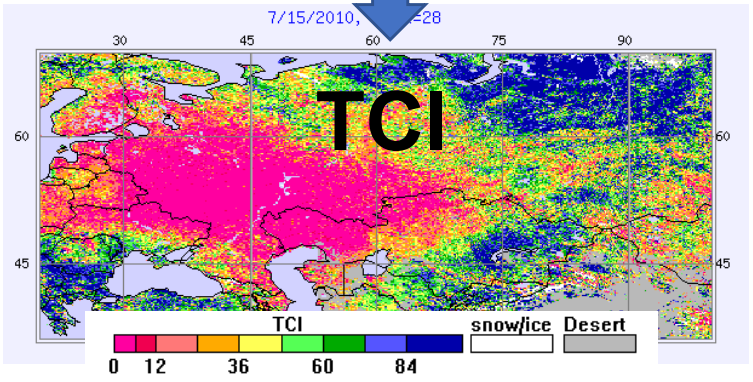
Vegetation Health Index, Aug 11-17 2014

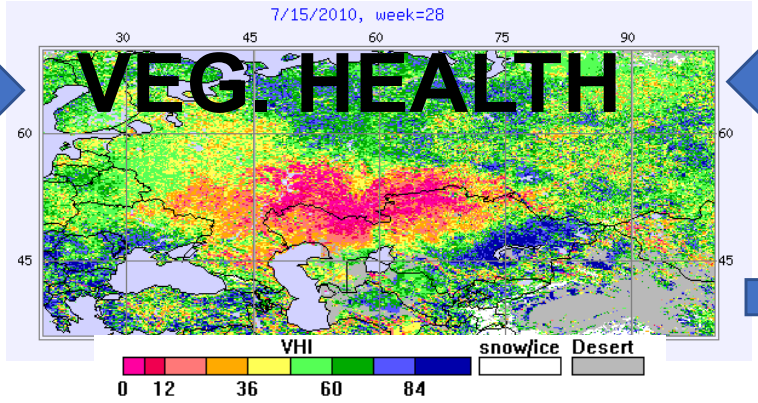
CASE STUDY: RUSSIA, JULY 2010

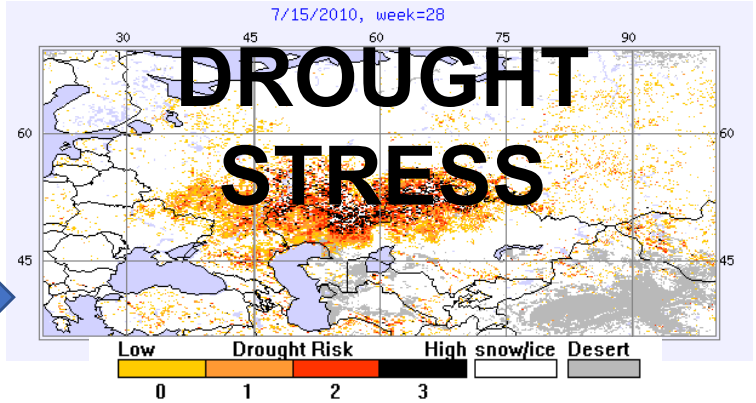




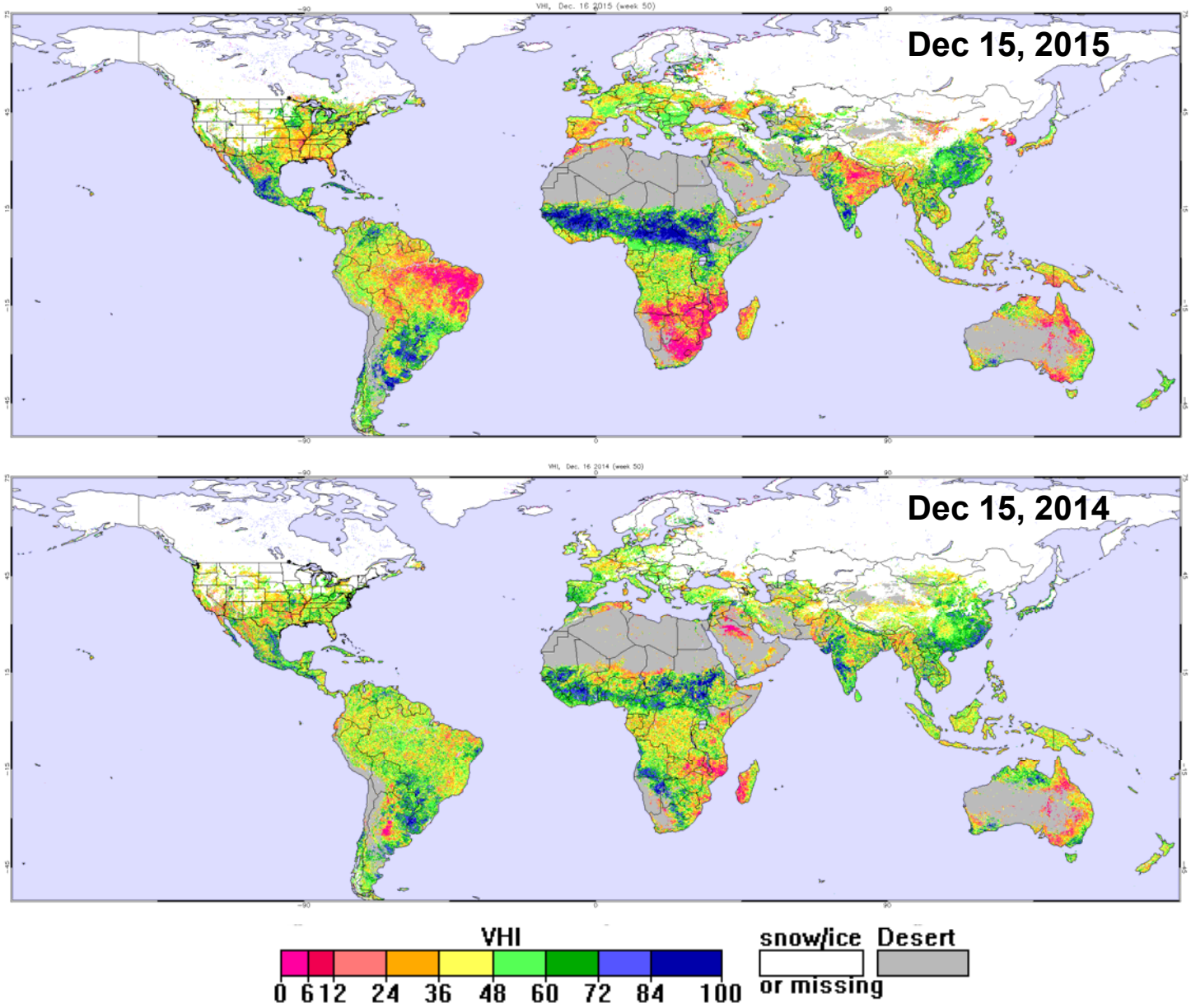








Vegetation Health Index (VHI)



Example of weekly global VHI maps

Dryer conditions in South America and Southern Africa in 2015 may be caused by El Nino which started developing earlier in 2015.

Similar pattern was observed during previous El Nino events

USAID FROM THE AMERICAN PEOPLE

iMMAP

Food and Agriculture Organization of the United Nations

NDVI Difference

1-10 May

REGIONAL FOOD SECURITY ANALYSIS NETWORK

Explanation

Anomalies represent a subtraction of the mean Normalised Difference Vegetation Index (NDVI values) for a -10day period from current-year values for the same period, rendering an image where negative values (brown) portray less vigorous vegetation than average, and positive values (green) represent areas that are more vigorous in the current year.

Mean Anomaly- Anomalies represent a subtraction of the mean NDVI values (2015-2001) for a 10 day period from current-year values for the same period, rendering an image where negative values portray less vigorous vegetation than average, and positive values represent areas that are more vigorous in the current year.

Previous Year Difference –The difference image is a subtraction of the current year NDVI values from those of the previous year.

Anomaly/ Difference Classification: The absolute difference and anomaly images are stretched from - 0.3 to 0.3 NDVI. The area of relatively no difference is approximately 0.05 – 0.05-.

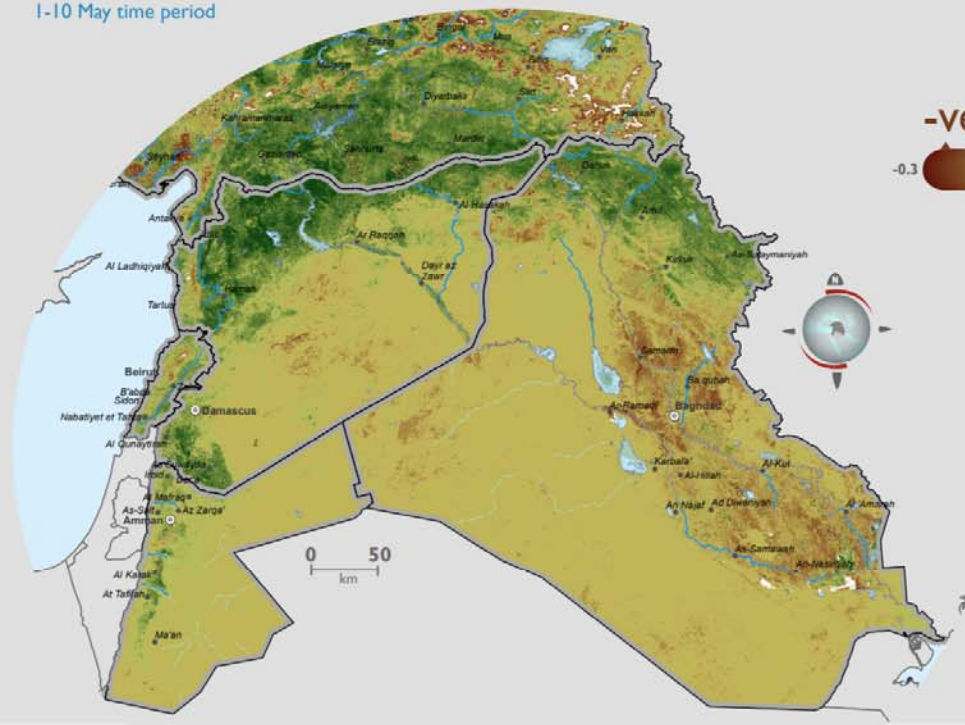
Analysis

Weather conditions have remained favourable across agricultural areas in the region. Vegetation conditions in agricultural areas remain better than the same time period for the previous year, and also better than the 15 year average. Some negative response is detected in the central areas of Iraq (especially when compared to the same time period in 2014), where the planting season has been disrupted by conflict, with wheat production still expected to be significantly lower than previous years.

In Syria, a recovery of agricultural production is still expected compared to the dry period of 2014. It however remains to be seen how conflict and access to inputs will affect the harvest. Once the harvest is conducted, access to markets will potentially be affected by conflict. Vegetation conditions in southern Turkey, Lebanon, Jordan and Kurdistan suggest good establishment of crops, with Turkey and Kurdistan expecting higher than average harvests, although production could still be affected in Kurdistan due to conflict.

2015 - 2014

1-10 May time period

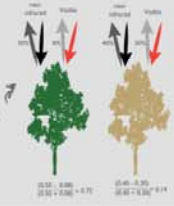


-ve +ve

-0.3 +0.3

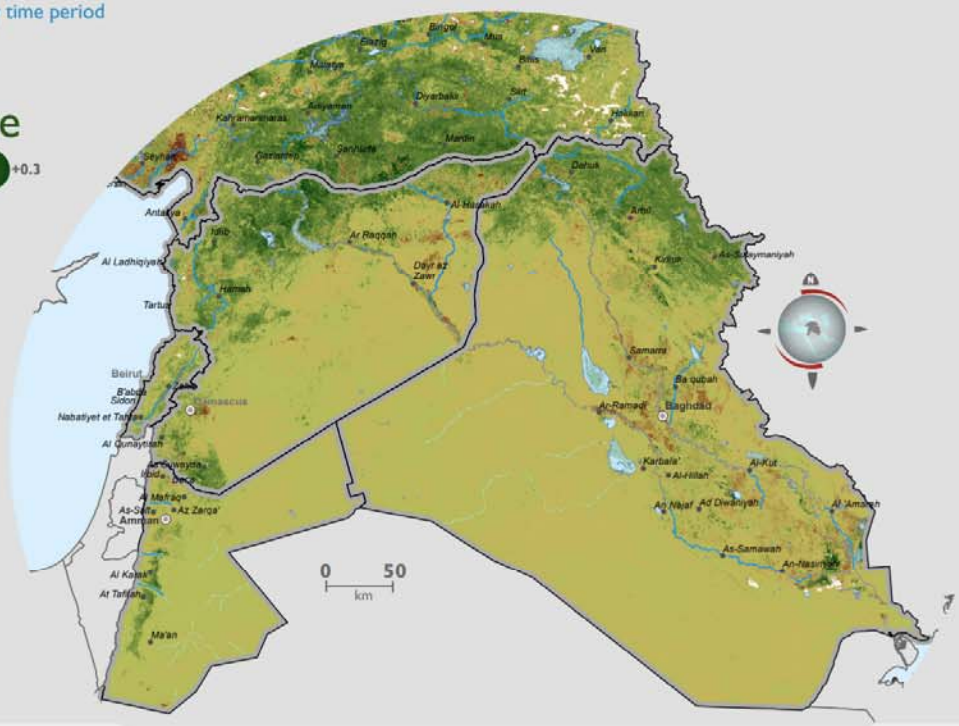
No difference

Snow/ No data



2015 - 15 Year average

1-10 May time period



Data Sources:
NDVI – eMODIS 250m, USGS and FEWS NET;
Administration boundaries: FAO/GAUL; Cities, Waterbodies – ESRI;
Cities, Waterbodies: Environmental Systems Research Institute (ESRI)

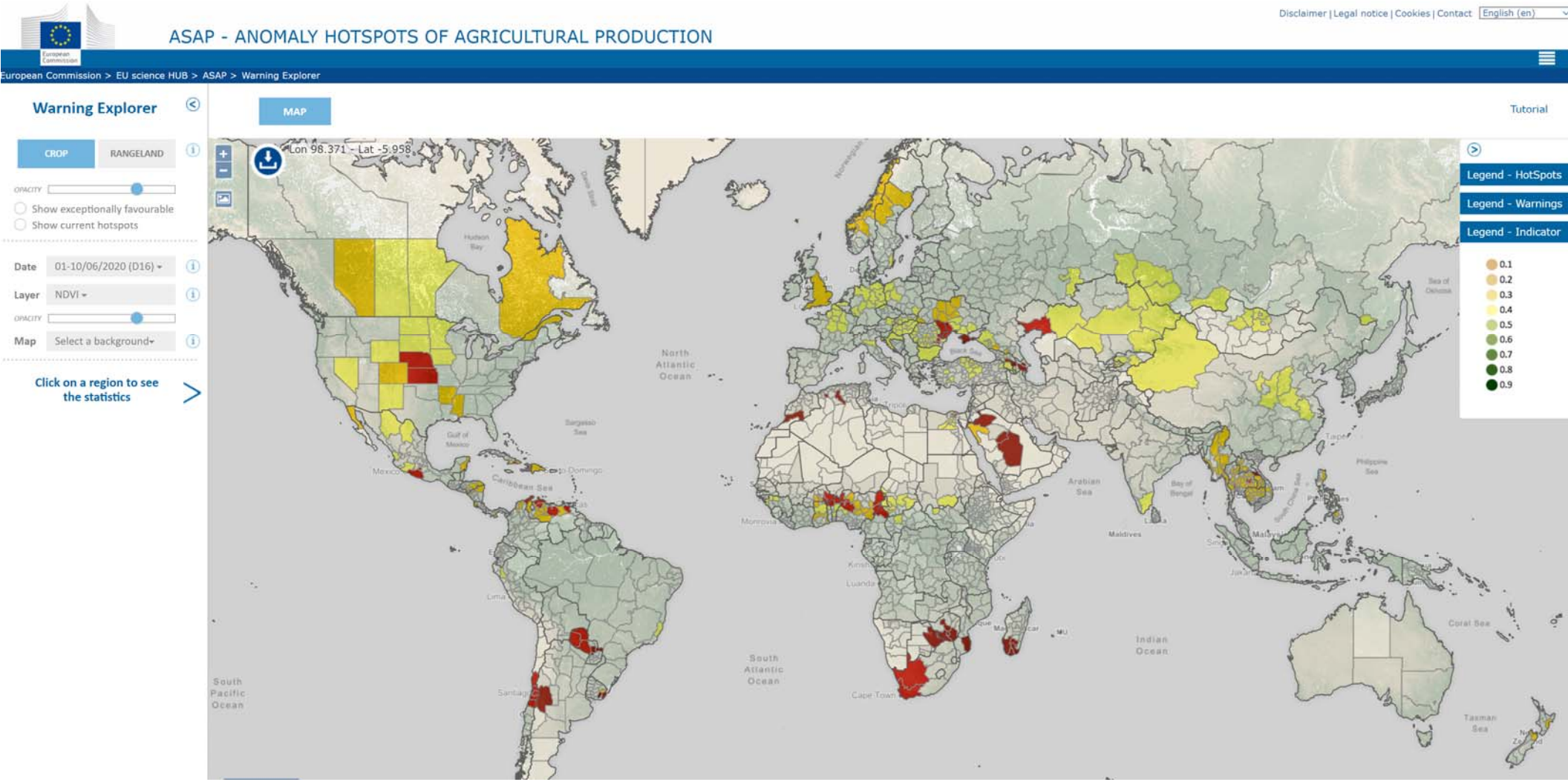
USGS science for a changing world

Date created: 14 May 2015
Map No. 20150514_RFSAN_MAP_REG_NDVIDiffMay_10-1_A3L
Data/Projection: UTM 37N
maps@rfsan.info

The Regional Food Security Analysis Network (RFSAN) is a joint initiative by FAO and iMMAP and is funded by the United States Agency for International Development (USAID)/ Food For Peace (FFP). The boundaries, names and designations used in this map do not imply official endorsement or acceptance by FAO, iMMAP or USAID.

Sources: FAO iMMAP

Early warning decision support system ASAP
(Anomaly hot Spots of Agricultural Production)



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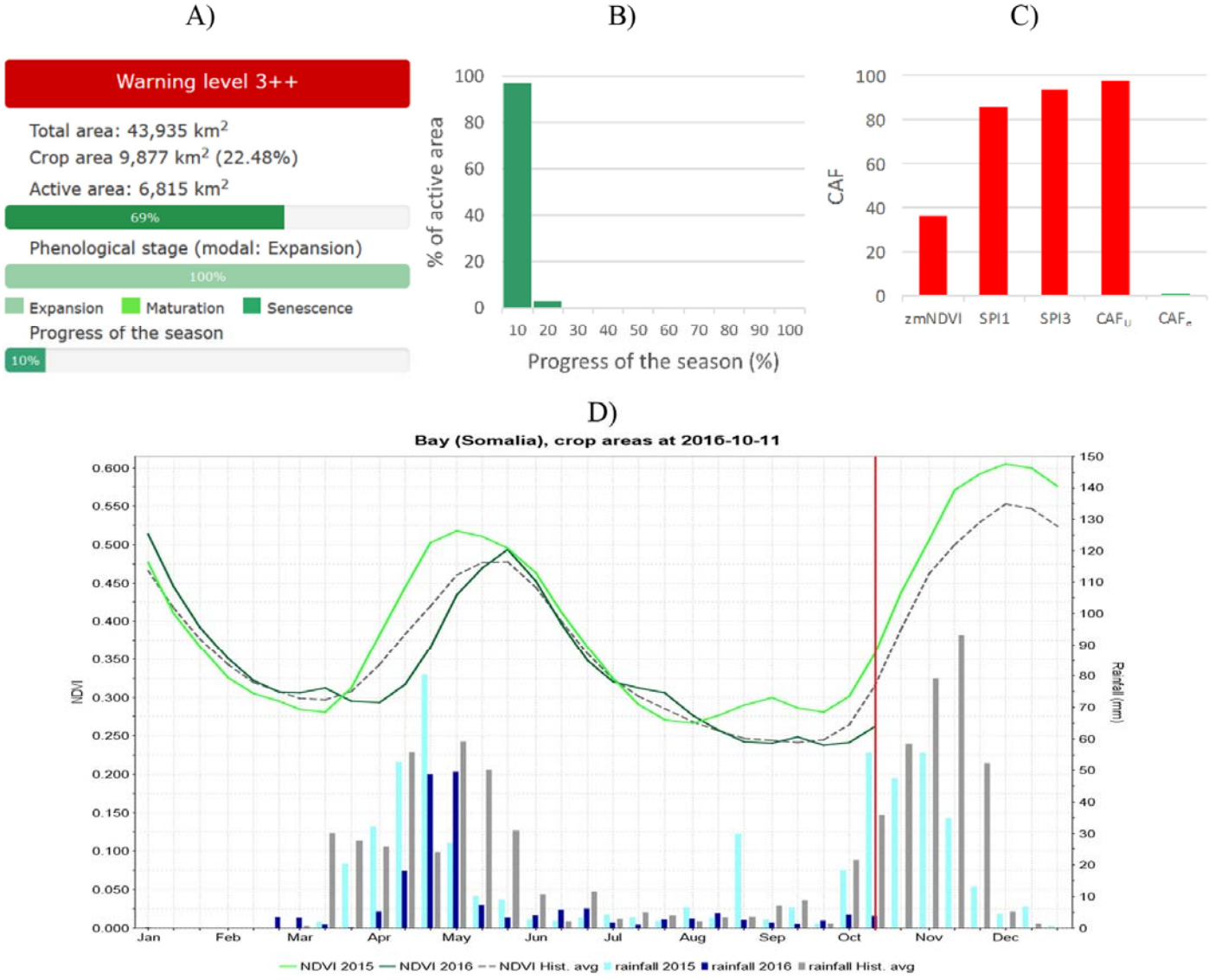
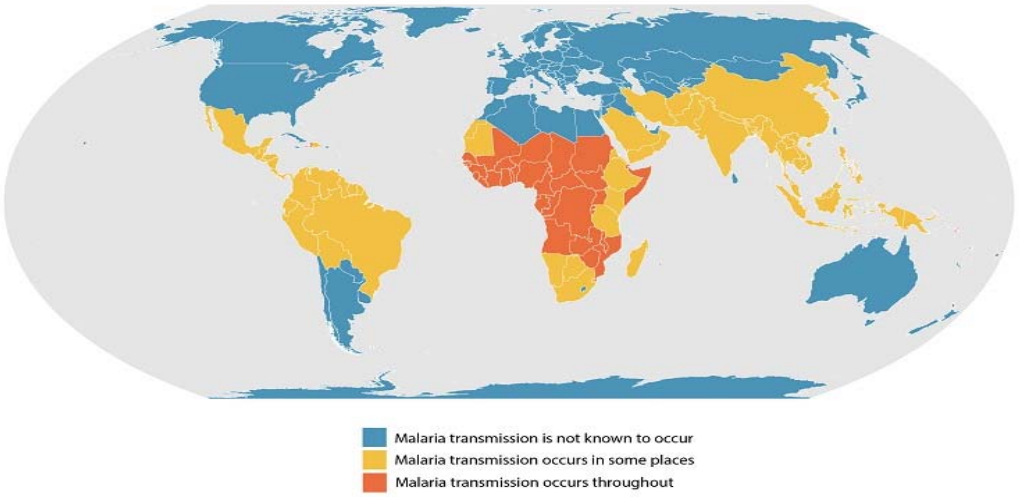


https://mars.jrc.ec.europa.eu/asap/

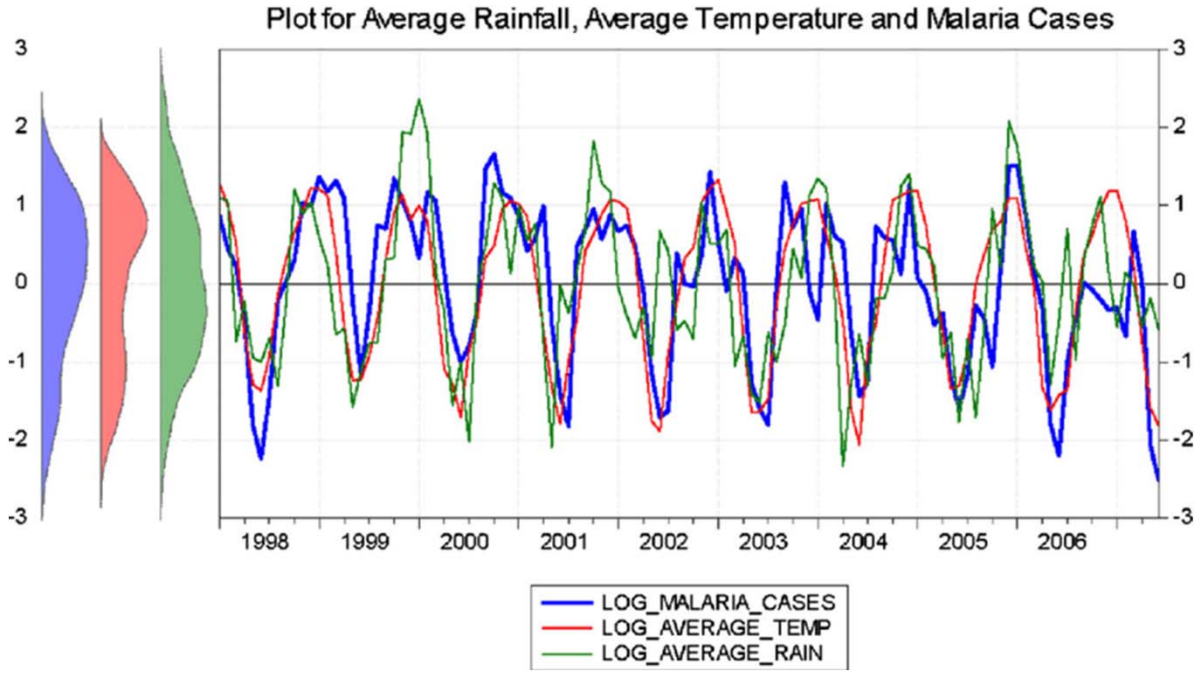
Vegetation and Malaria

Malaria Facts

- Malaria affects 150- 300 million people annually
- 1.5-3 million malaria-caused deaths
- It is spread by mosquito which need warm and humid conditions to breed

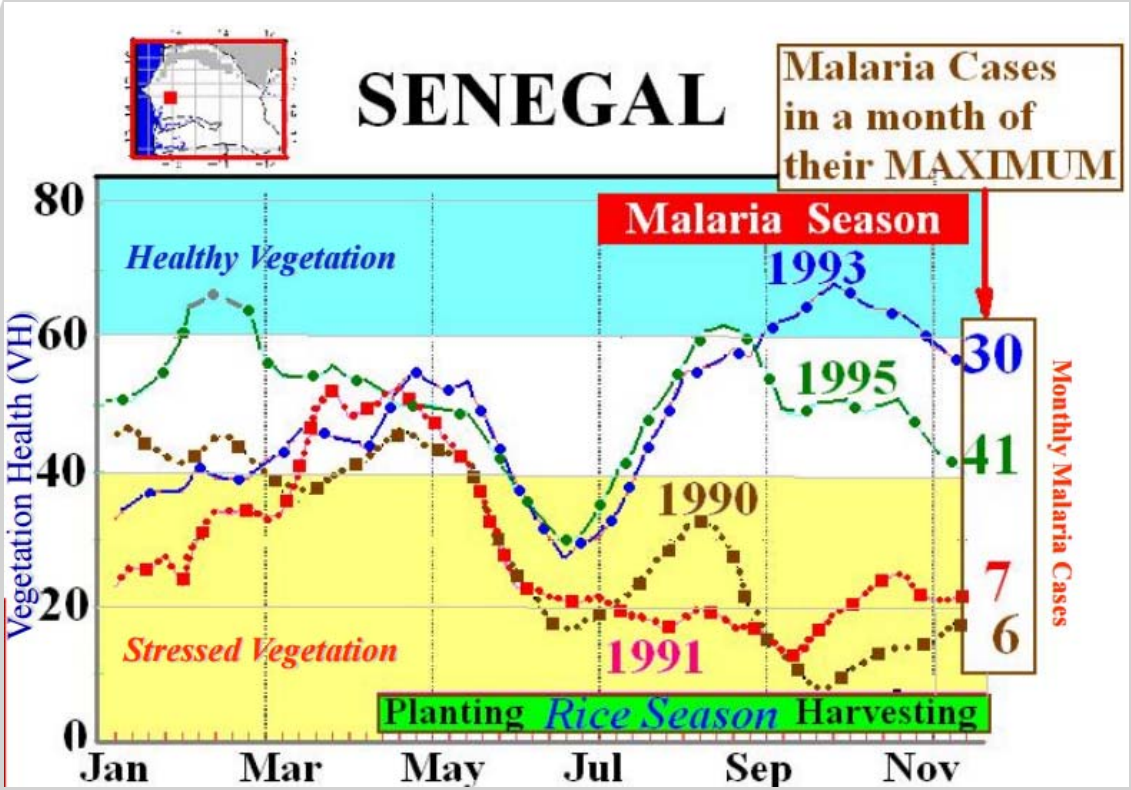


There is an obvious correlation between malaria and weather : More malaria cases in more humid and warm weather.



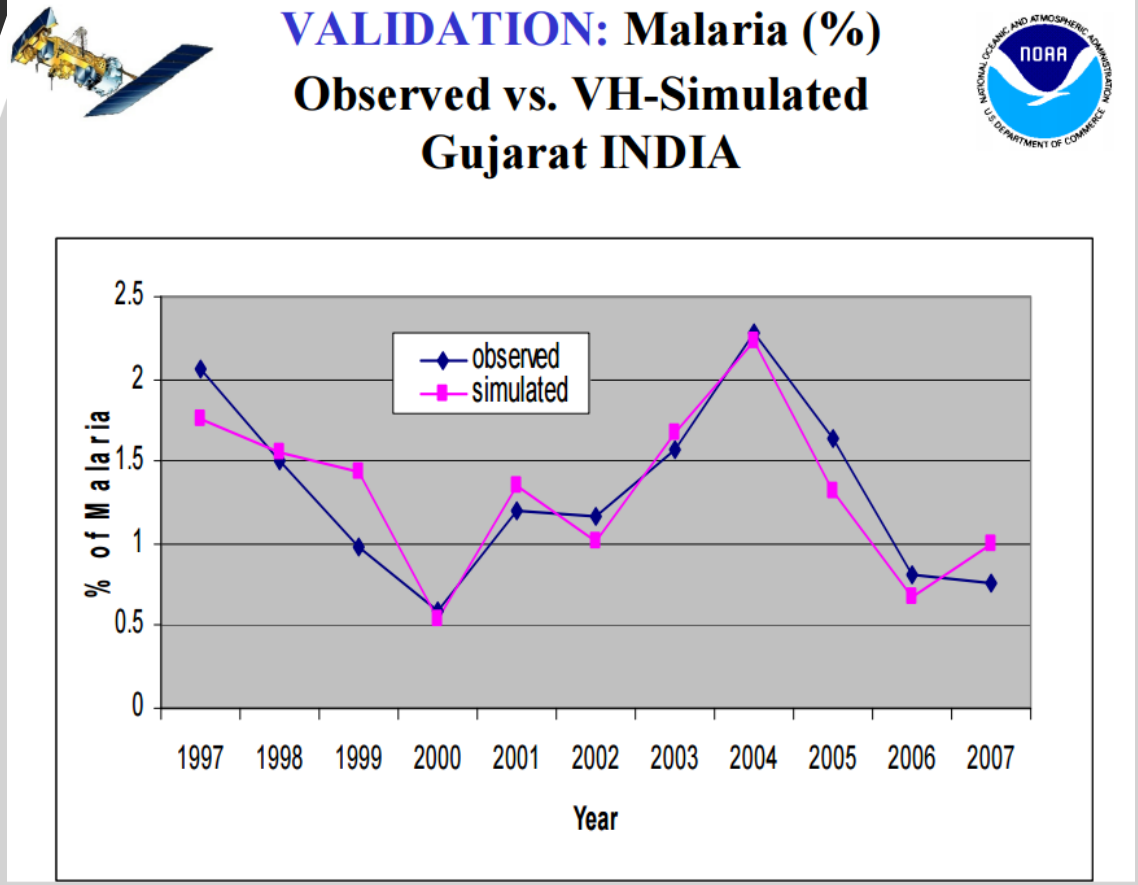
Vegetation Health and Malaria in Senegal

Satellite-based vegetation health Index has shown to have a robust statistical relationship with the number of malaria cases: More malaria cases when vegetation condition is much better than normal



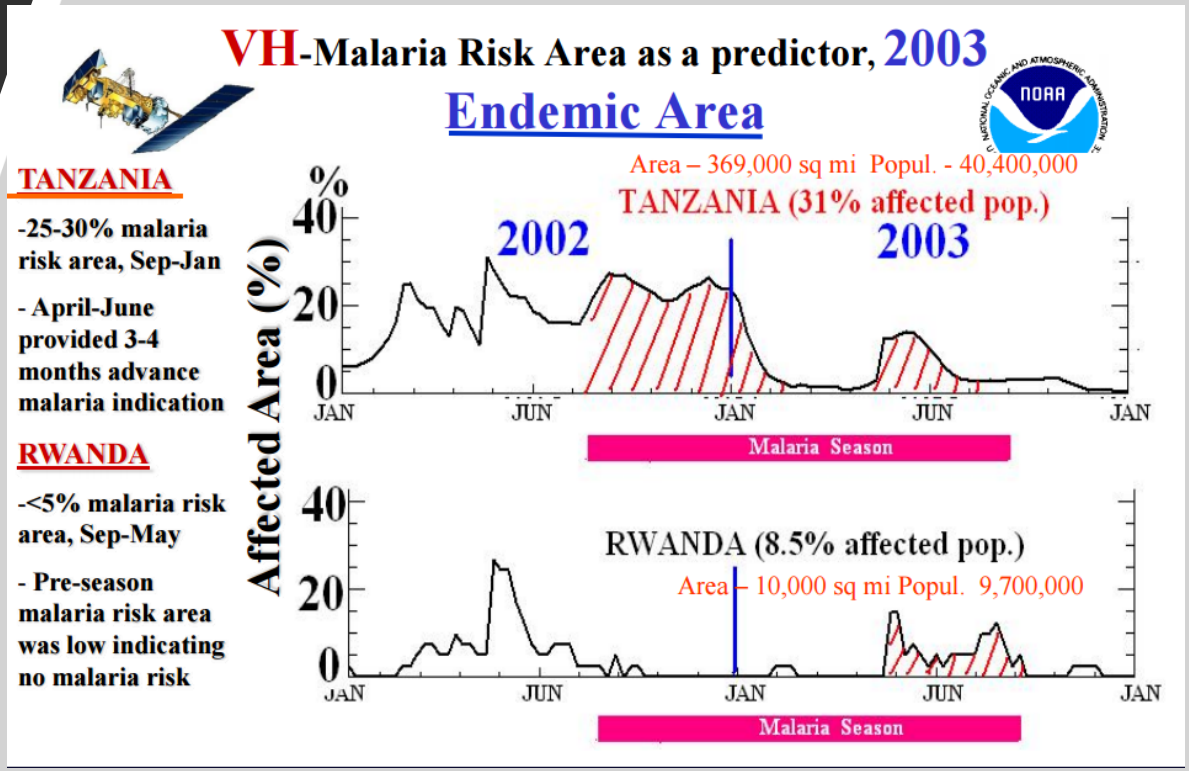
Vegetation and Malaria: Prediction

- The historical statistics of malaria cases combined with historical satellite records have been used to predict the potential spread of malaria using the Vegetation Health Index.
- This approach can be used to estimate whether malaria preventive measures taken by local governments become more efficient with time.



Vegetation and Malaria: Prediction

Correlation between Vegetation Health (VH) and malaria can be used to predict malaria, it also may be used to measure the progress in malaria treatment by local health institutions.



Limitations of NDVI

- NDVI is a radiance-based parameter, characterizes “greeness” of the scene, not physical properties of the vegetation
- Most current weather sensors provide observations in the visible and near infrared, however spectral bands used may be different. As a result, NDVI values from different sensors may not be comparable.
- NDVI value may change with changing illumination geometry.
- NDVI does not account for variations in the atmospheric properties, e.g., aerosols. MODIS provides atmospherically-corrected vegetation index which is better suited for time series analysis.

SUMMARY

- Meteorological satellites present an efficient tool to monitor global vegetation cover. This is done primarily through the use of NDVI.
- NDVI is a radiance-based parameter, characterizing “greeness” of the scene. It can be used to discriminate vegetated and non-vegetated land as well as to monitor seasonal dynamics of vegetation
- Available vegetation-related satellite-based products provide information on NDVI at 0.5-1 km spatial resolution on a daily-weekly and bi-weekly time period. Weekly and bi-weekly products present maximum NDVI composited values and reduced (or eliminated) cloud contamination of the image
- Satellite-based vegetation monitoring is actively employed in the agriculture. It can be used to examine the state of the crop , diaznose droughts and to predict the yield.
- In tropical areas vegetation cover can be used to predict malaria. More data on malaria cases are needed. They are very hard to get.

Reading…

- Remote Sensing Phenology page of United States Geological Survey (USGS)

http://phenology.cr.usgs.gov/

- NASA Remote Sensing Tutorial at Federation of America n Scientists web site. Section 3

http://fas.org/irp/imint/docs/rst/Sect3/Sect3_1.html

- EUMETSAT. Monitoring Vegetation from Space. Tutorial. (a bit disorganized)

http://www.eumetrain.org/data/3/36/print.htm