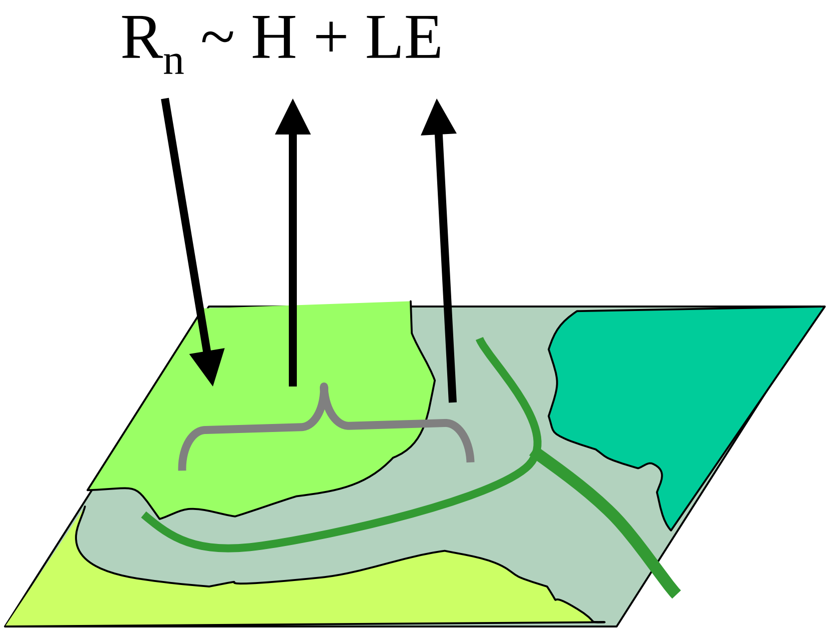
Surface water/energy budget coupling over heterogeneous terrain



$LE = f_{veg} \, LE_{veg} + (1 - f_{veg}) \, LE_{soil}$

$LE = f(R_n, T, g_c, g_a, g_{soil}, VPD)$

$g_a = f(\text{canopy structure, wind, ...})$

$g_c = f(\text{soil water, VPD, PAR, T, LAI})$

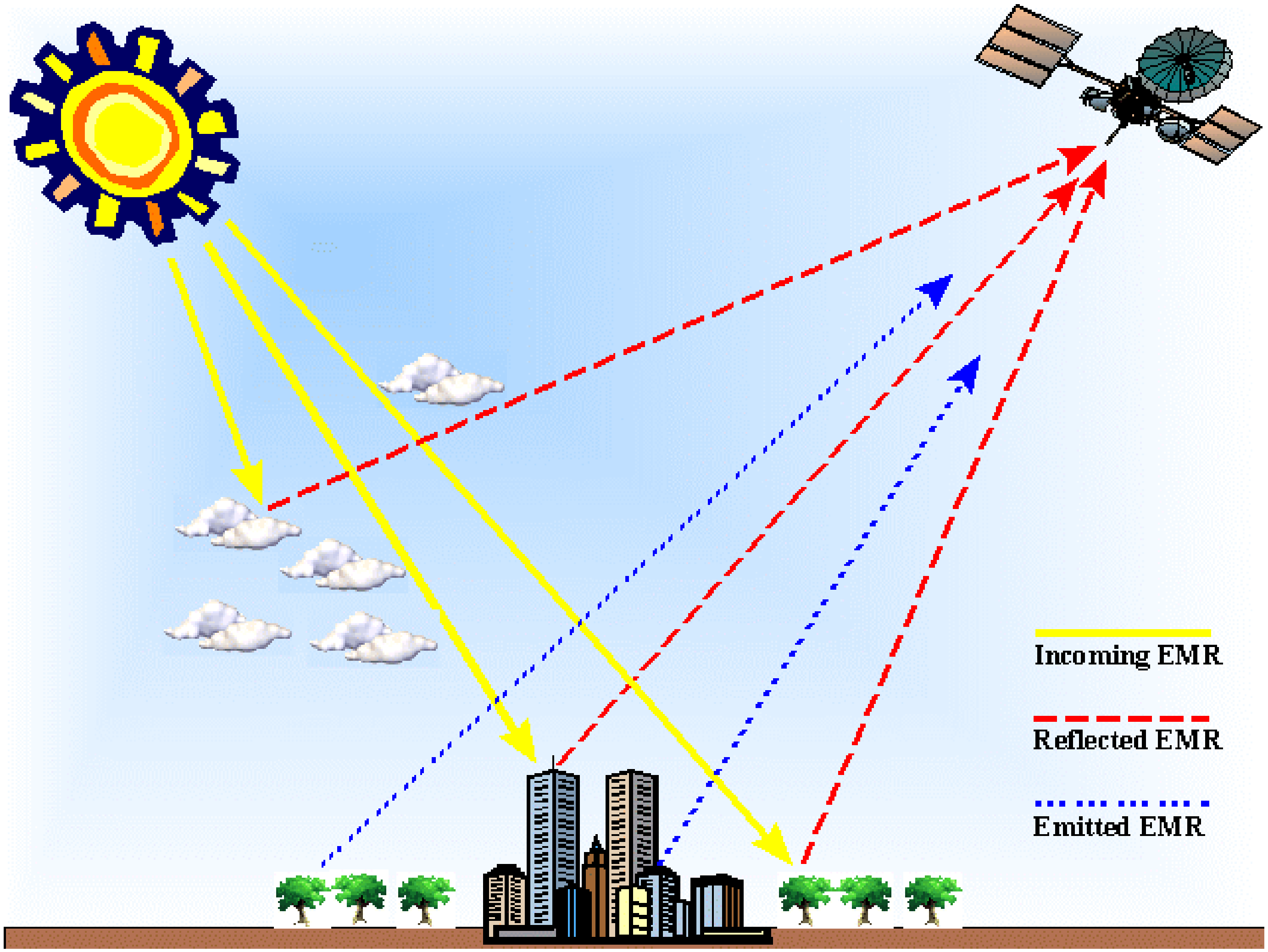
$g_{soil} = f(\text{soil water, ...})$

T_s lower with greater LE (evaporative cooling) as a function of soil water (other factors), greater canopy cover (higher NDVI)

T_s and NDVI estimated by a set of operational remote sensors

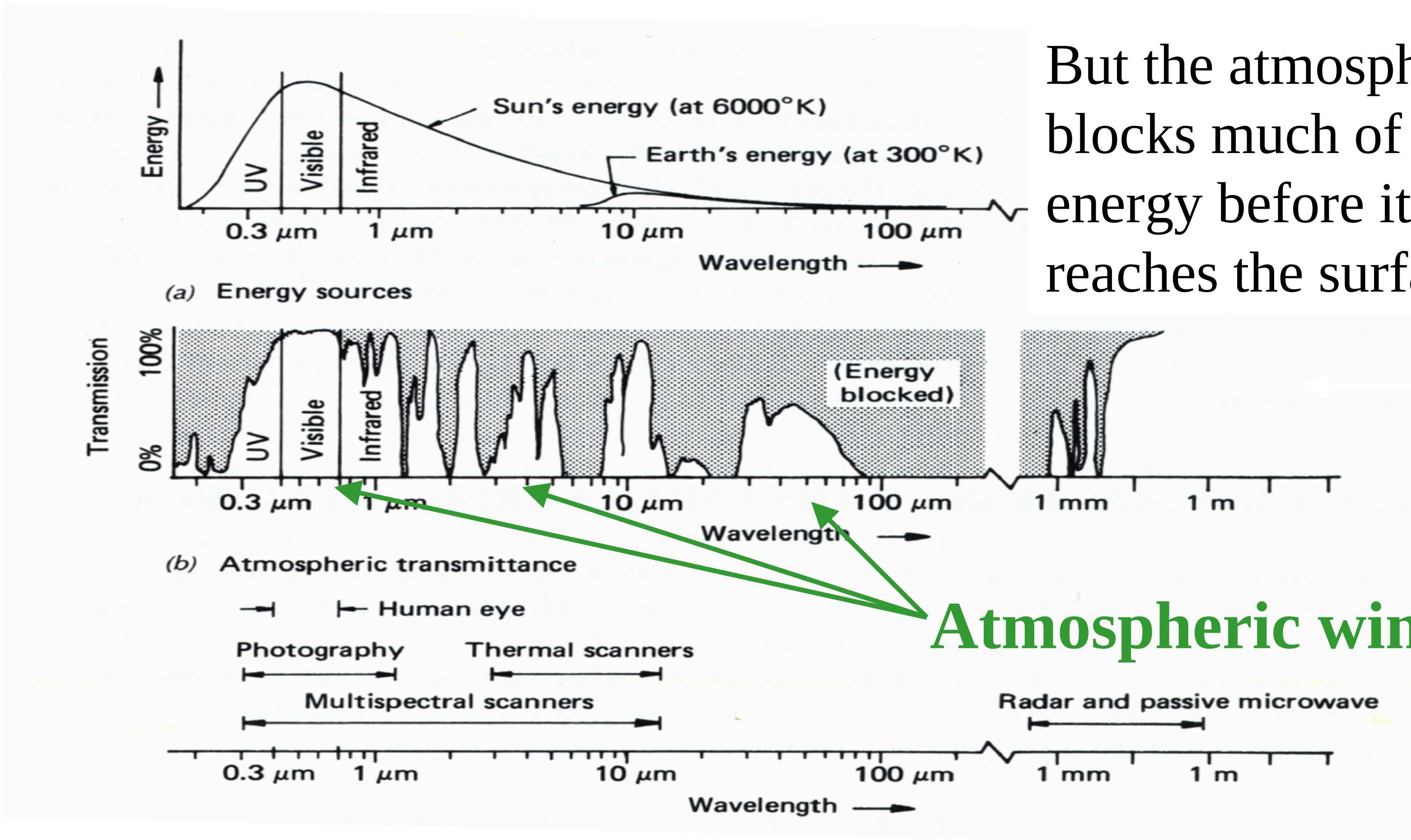
Satellite Imagery - Sensing EMR

- Digital data obtained by sensors on satellite platforms



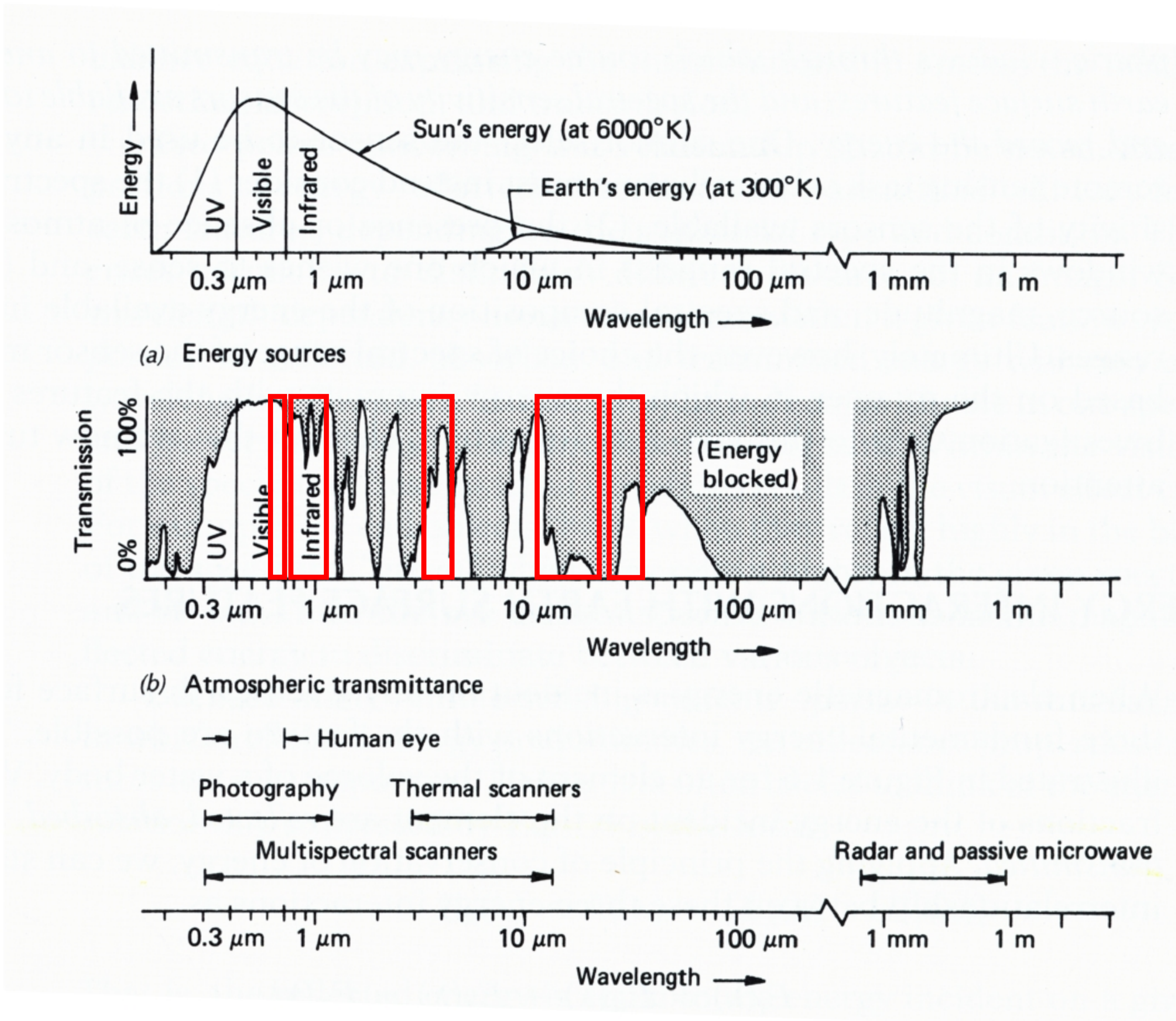
Solar Electromagnetic Radiation

- The sun emits EMR across a **broad spectrum** of wavelengths:



But the atmosphere blocks much of the energy before it reaches the surface

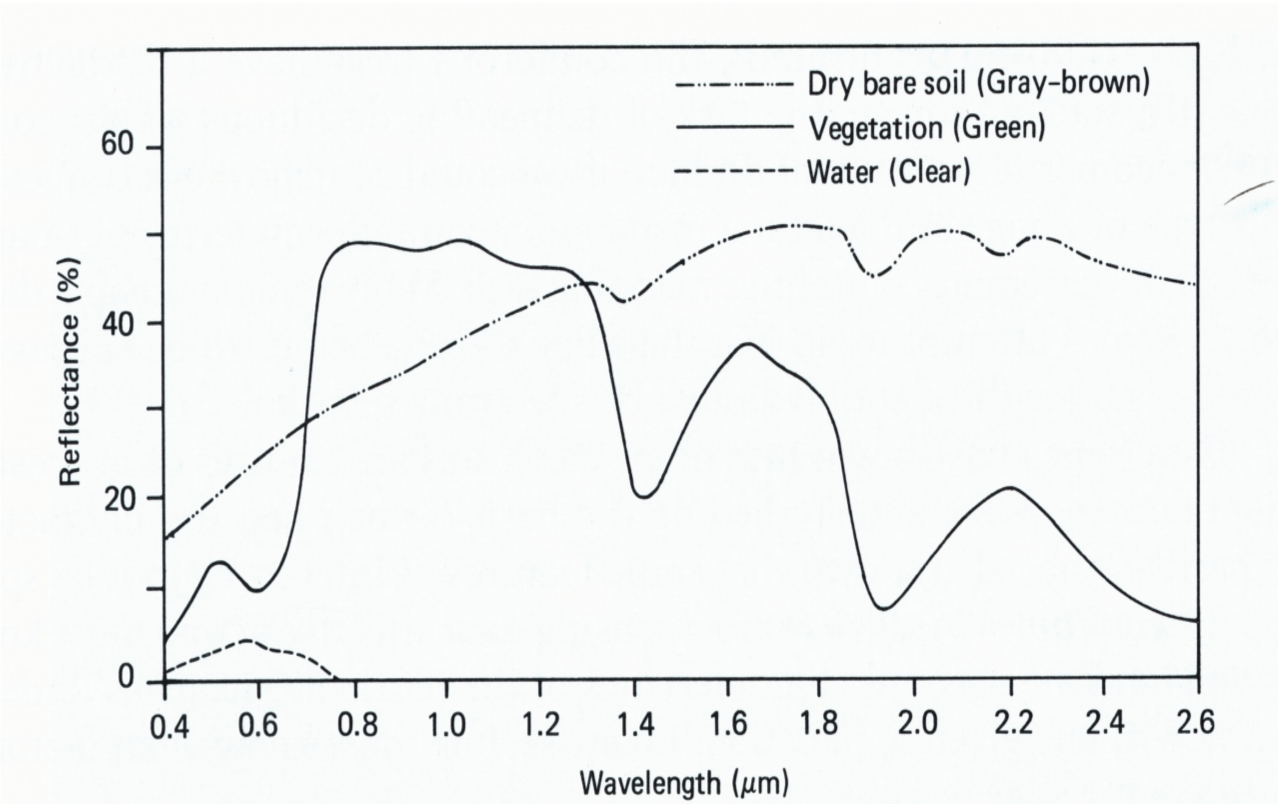
AVHRR Bands


Energy
UV
Visible
Infrared
Sun's energy (at 6000°K)
Earth's energy (at 300°K)
0.3 μm
1 μm
10 μm
100 μm
1 mm
1 m
Wavelength
(a) Energy sources
Transmission
100%
0%
(Energy blocked)
(b) Atmospheric transmittance
Human eye
Photography
Thermal scanners
Multispectral scanners
Radar and passive microwave

Sensing Vegetation and Temperature

- Can take ratios or other **combinations of multiple input bands** to produce indices, e.g.:
- **Normalized Difference Vegetation Index (NDVI)**
  – Designed to contrast heavily-vegetated areas with areas containing little vegetation, by taking advantage of vegetation's strong absorption of red and reflection of near infrared:
  – NDVI = (NIR-R) / (NIR + R)
- **Surface temperature (T_s)** from IR bands using Price (1984):
  – T_S = TIR1 + 3.33 (TIR1 – TIR2)
    - Wavelengths: TIR1 = 10.8 μm, TIR2 = 11.9 μm

Normalized Difference Vegetation Index

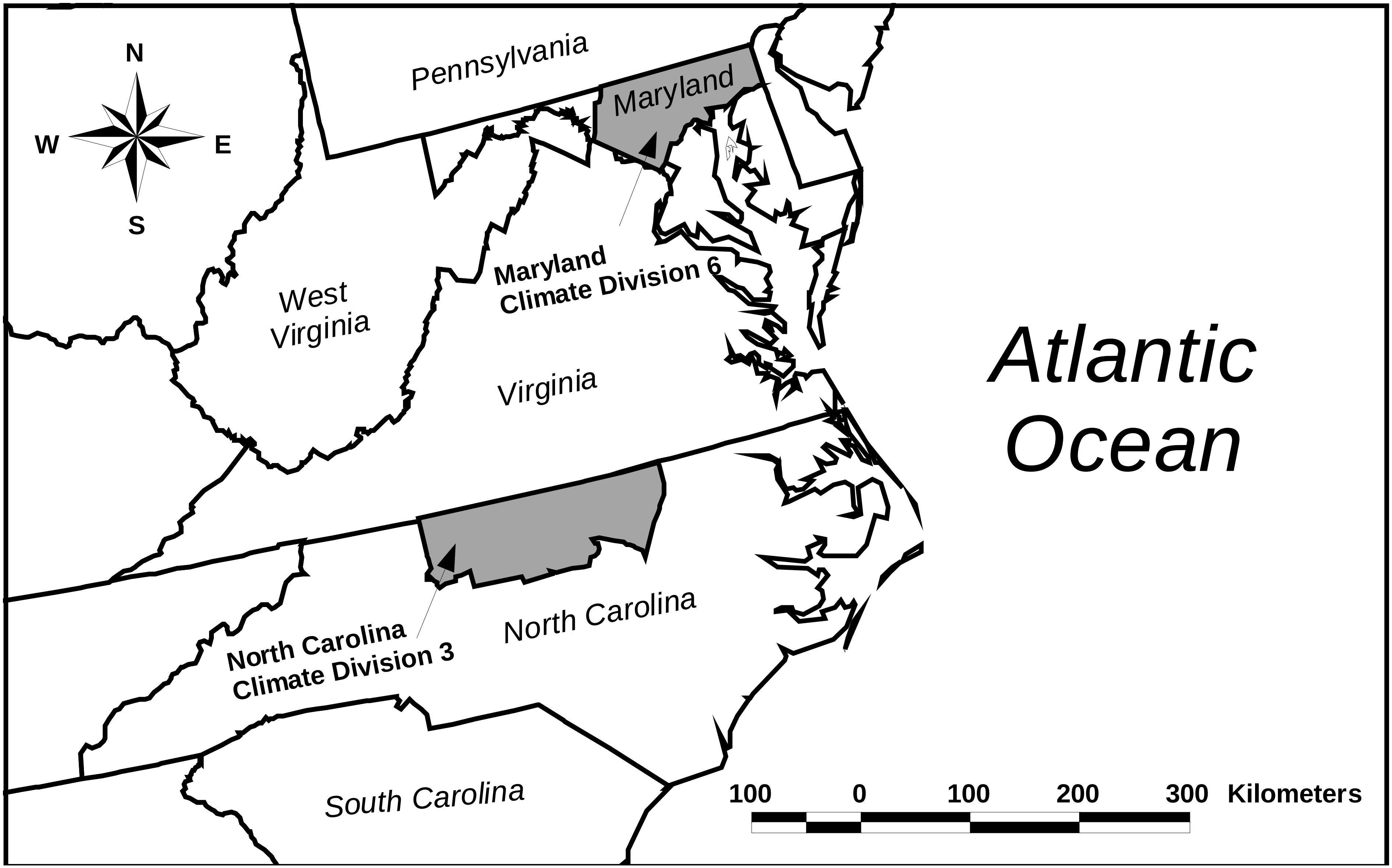


$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

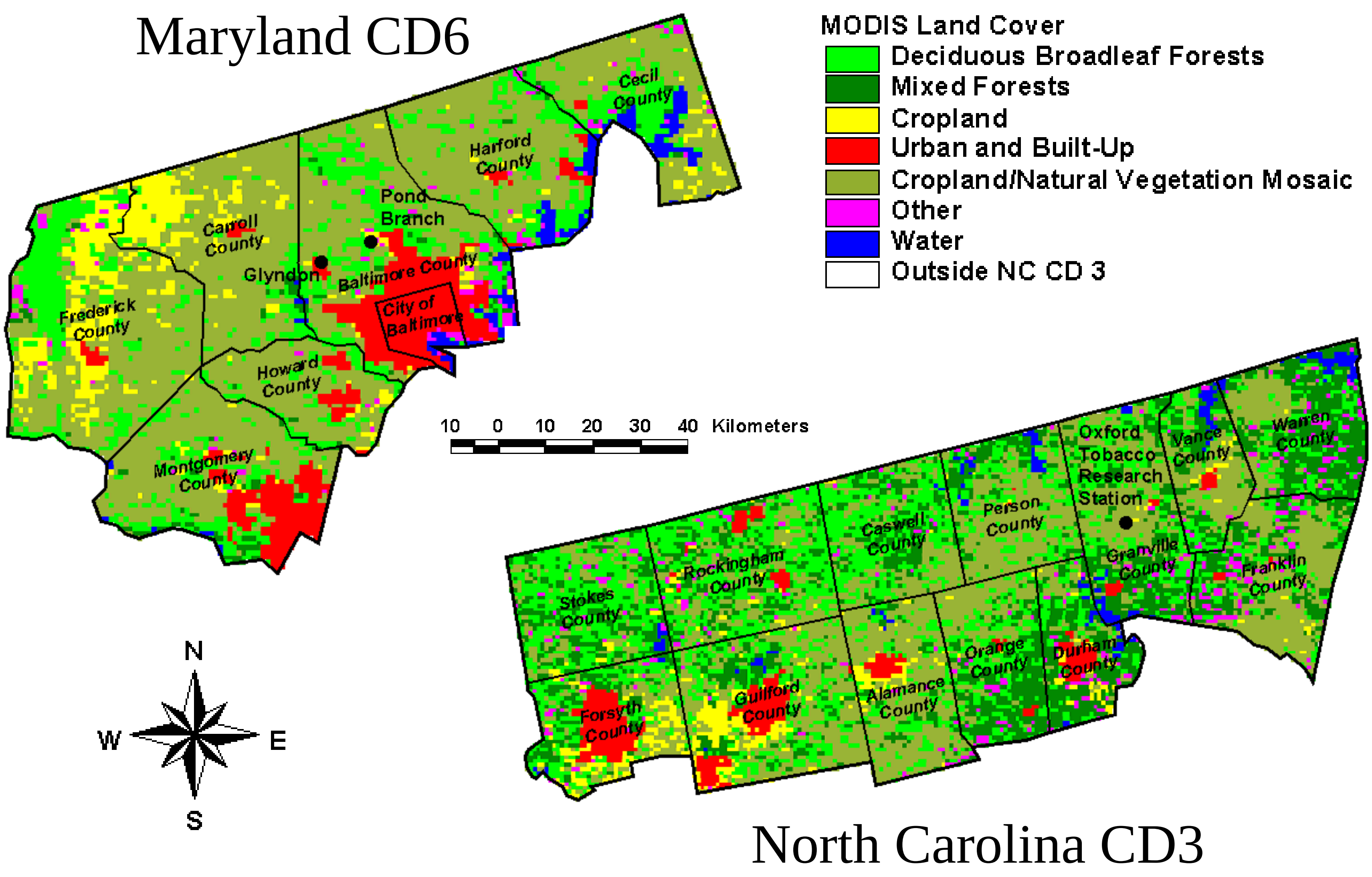
NDVI [-1,1]

•Vegetation has a **strong contrast in reflectance** between red and near infrared EMR, and NDVI takes advantage of this to **sense the presence/density of vegetation**

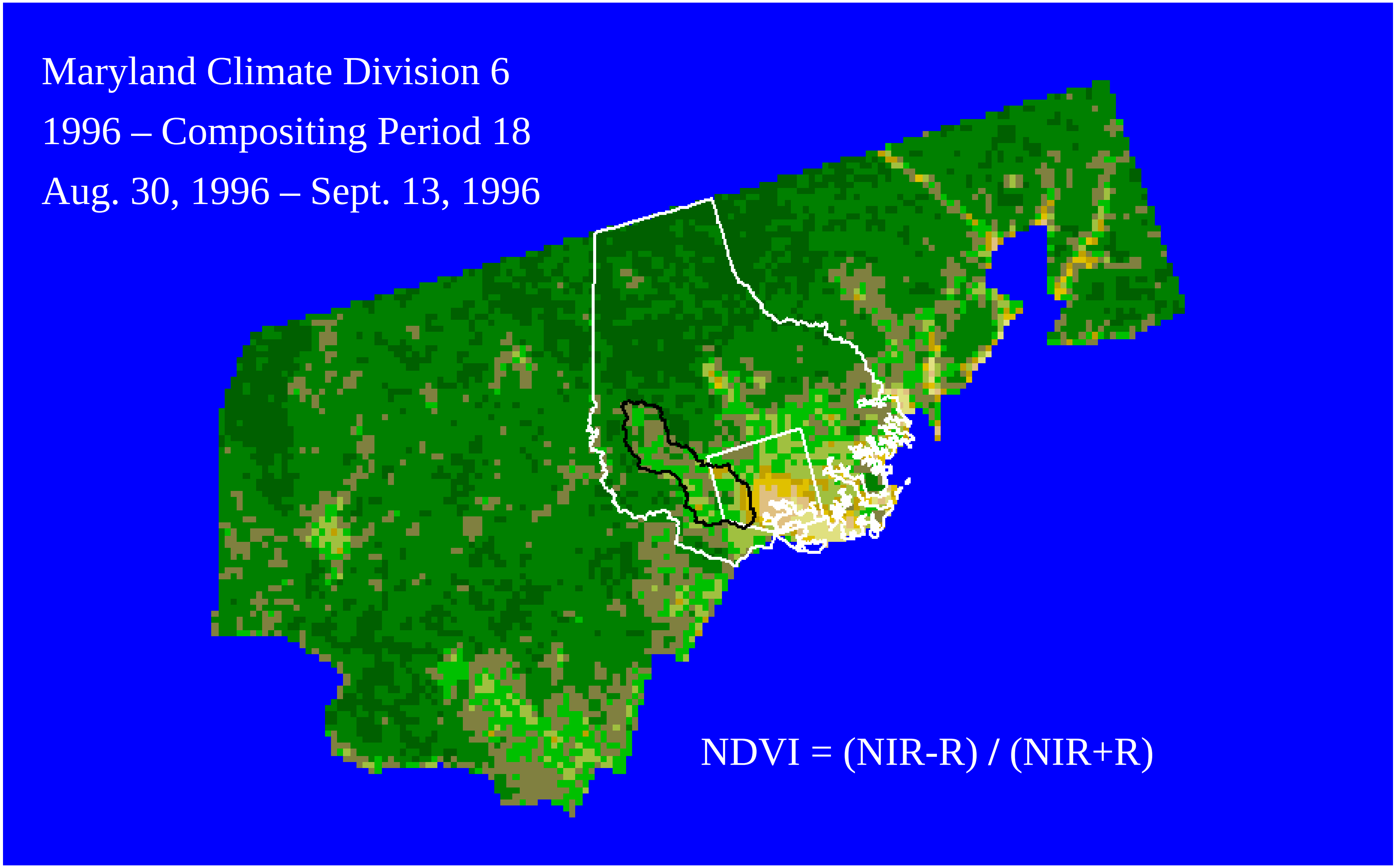
Study Climate Divisions



MODIS LULC In Climate Divisions



AVHRR Satellite Imagery - NDVI

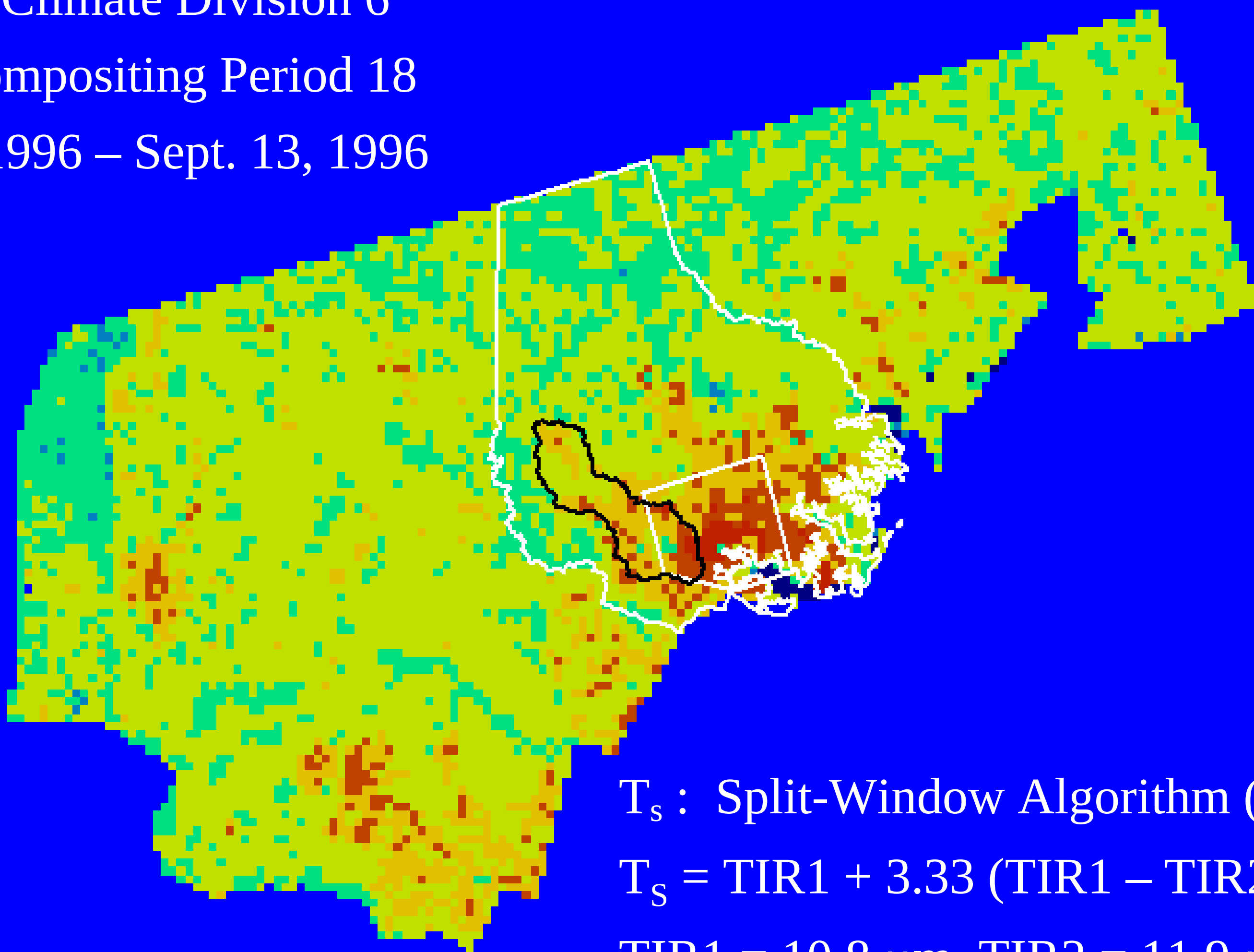


AVHRR Satellite Imagery - T_s

Maryland Climate Division 6

1996 – Compositing Period 18

Aug. 30, 1996 – Sept. 13, 1996

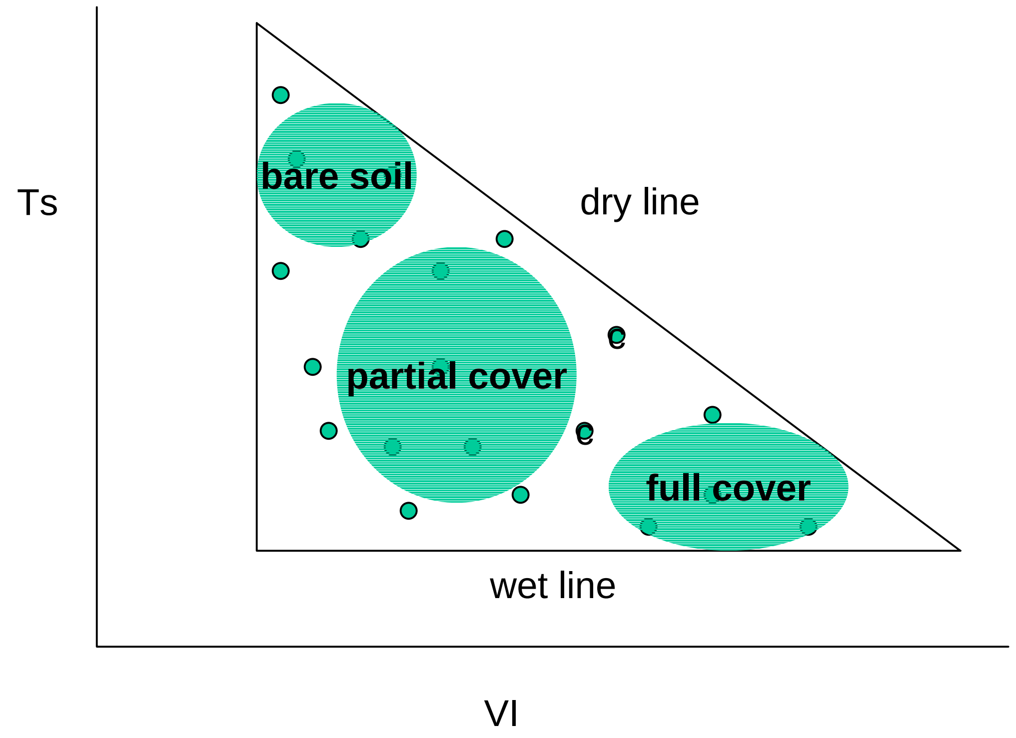


T_s : Split-Window Algorithm (Price 1984)

T_S = TIR1 + 3.33 (TIR1 – TIR2)

TIR1 = 10.8 µm, TIR2 = 11.9 µm

Interpretation of the VI-T_s Space

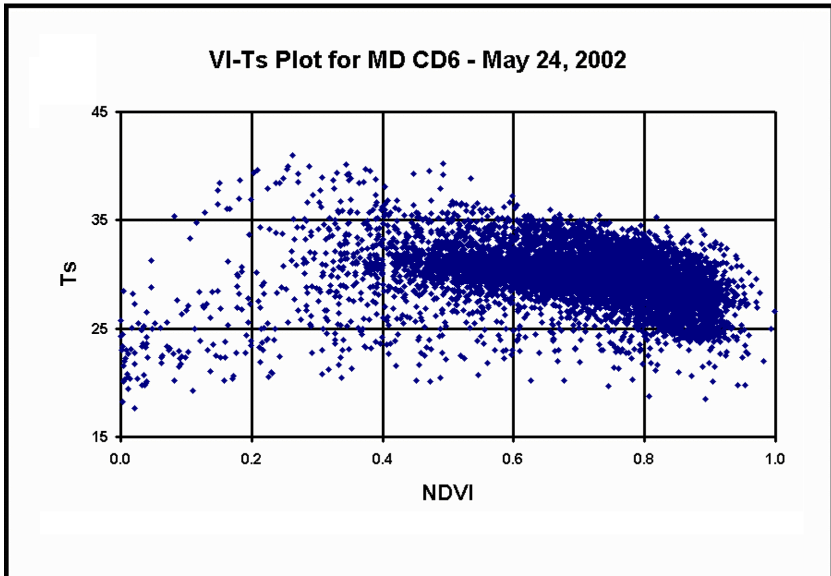


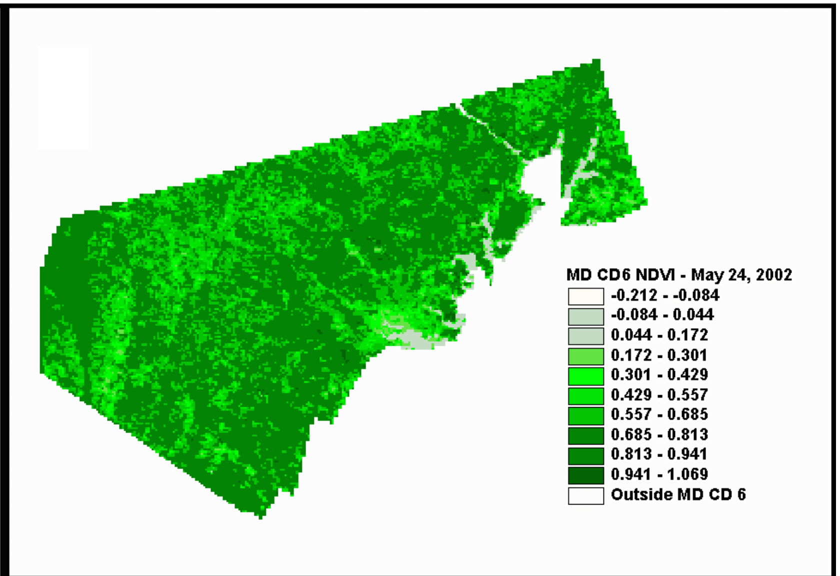
Adapted from Sandholt et al. 2002

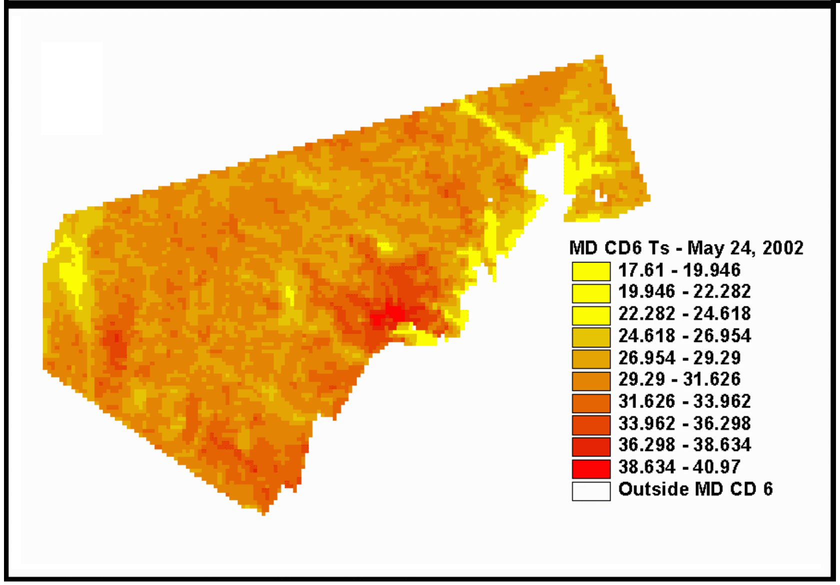
Dry Line Slope – Sigma (σ)

- Nemani and Running (1989) suggested, and later Nemani, Pierce, Running, and Goward (1993) demonstrated, that **the slope of the dry line** (symbolized using σ) is a good overall indicator of the **surface moisture condition** of a region (where the T_s and VI pixels that are drawn from to form the 2-D T_s-VI distribution) on the occasion when the imagery was collected
  - **Steeper, more negative** slopes represent **drier conditions** (where T_s disparities are greater)
- So **how** do we form the 2-D T_s-VI distribution and find the slope of the dry line?

Finding the Dry Line (σ) Slope





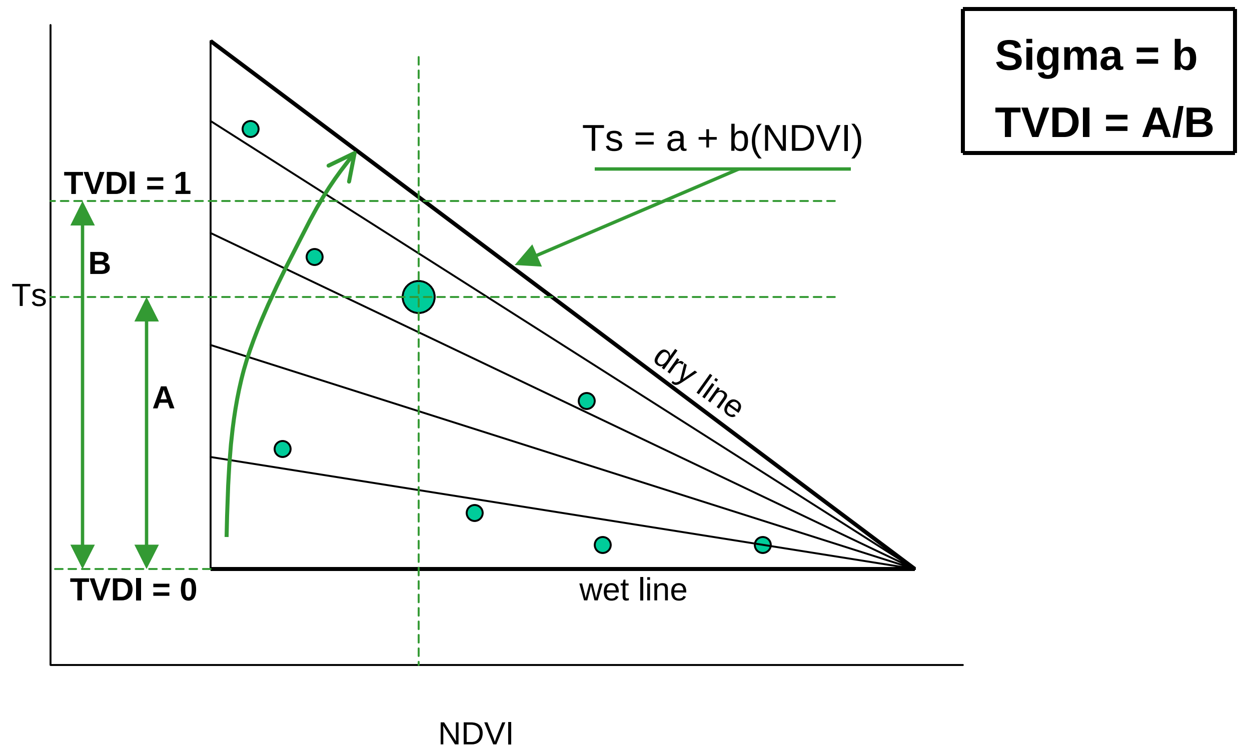


- We begin with **T_s and VI data**, ideally collected using the **same sensor at the same time** (e.g. from AVHRR bands 1, 2, 4, & 5)
- We then translate the values for each pixel into a **2-D parameter space**, the VI on the x-axis and the T_s on the y-axis

Obtaining Per Pixel Dryness Info

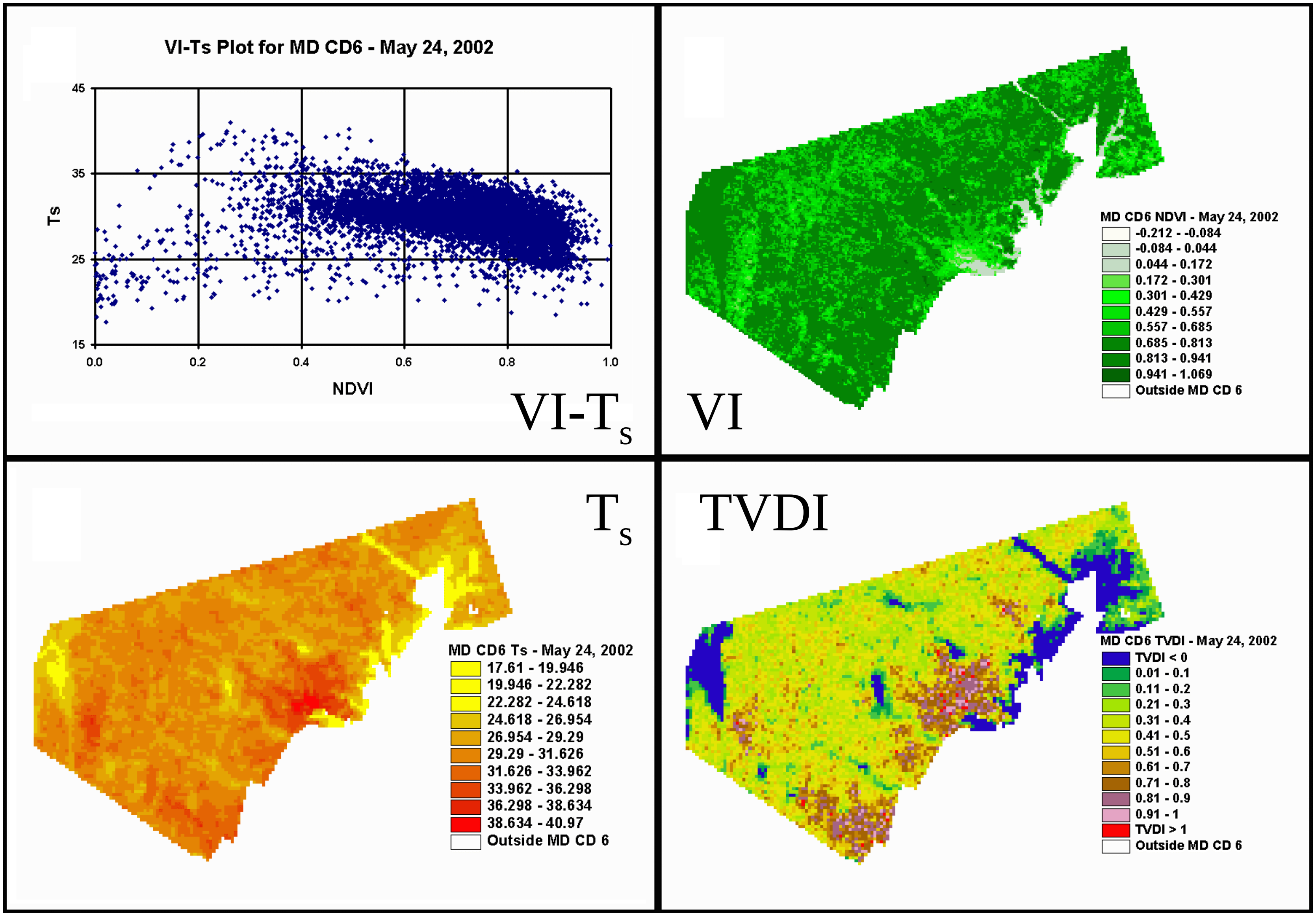
- **The slope of the dry line** (symbolized using σ) is a good overall indicator of the **surface moisture condition of a region** (where the T_s and VI pixels that are drawn from to form the 2-D T_s-VI distribution)
  - But it is just that, **a single number** that is a **regional descriptor** of the **surface moisture condition** of the **overall aggregate set of pixels**
- What if we want to know something about the **surface moisture condition of individual pixels**? How can we do this?
  - One way is to take an approach that **describes each pixel's position** in the distribution

Temperature Vegetation Dryness Index



Adapted from Sandholt et al. 2002

Generating TVDI Values

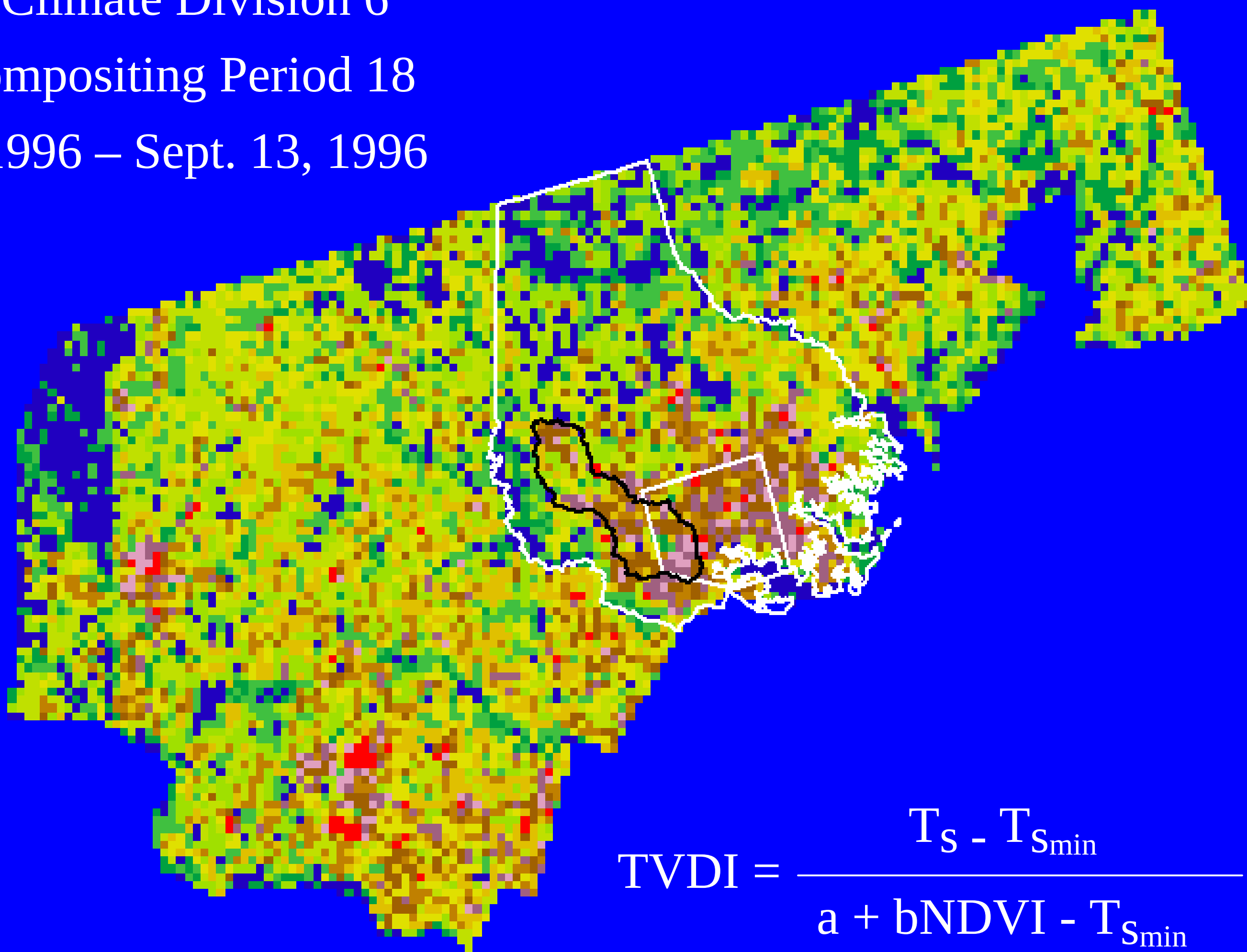


AVHRR Satellite Imagery - TVDI

Maryland Climate Division 6

1996 – Compositing Period 18

Aug. 30, 1996 – Sept. 13, 1996



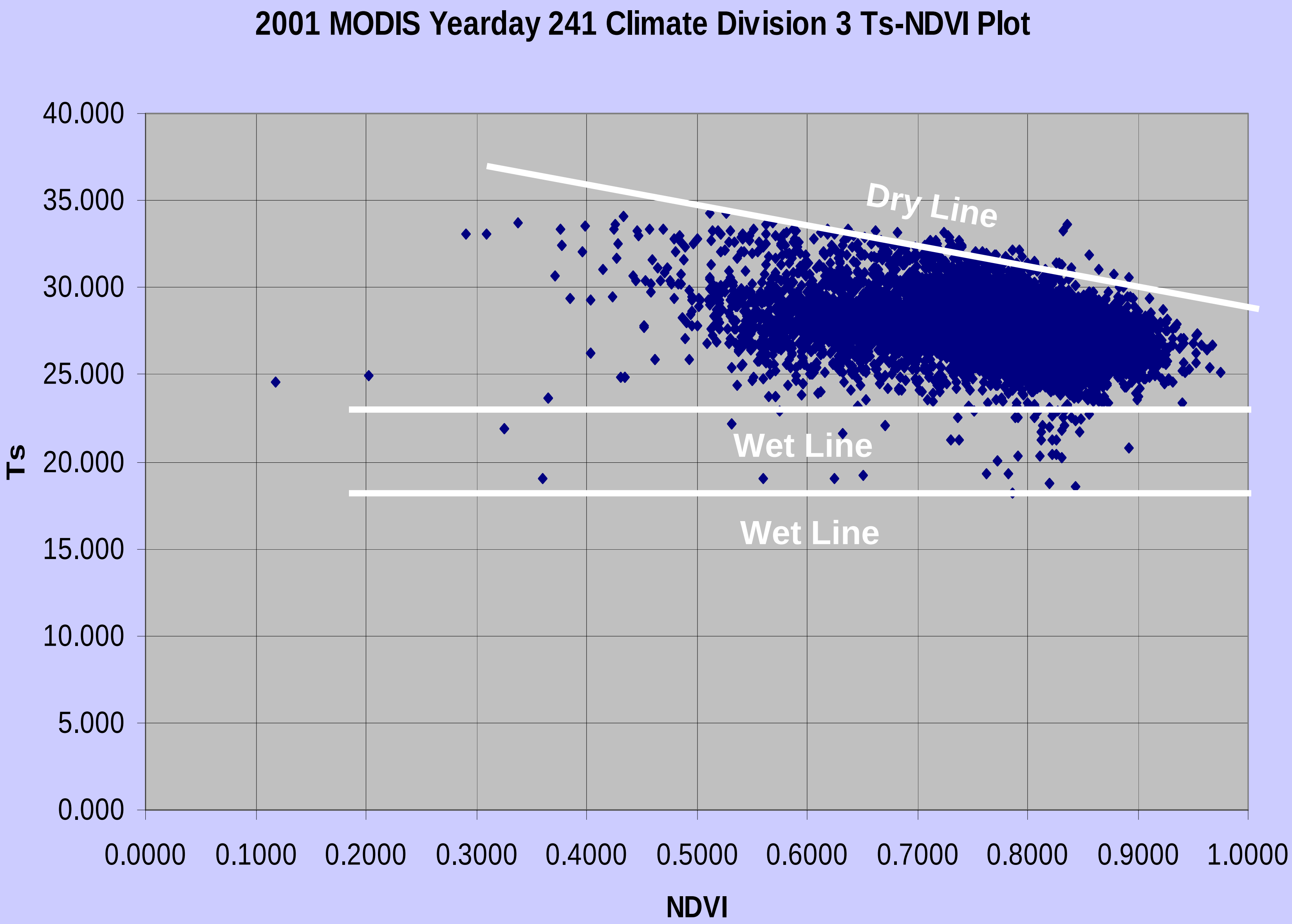
$$TVDI = \frac{T_S - T_{S_{min}}}{a + bNDVI - T_{S_{min}}}$$

Temperature Vegetation Dryness Index

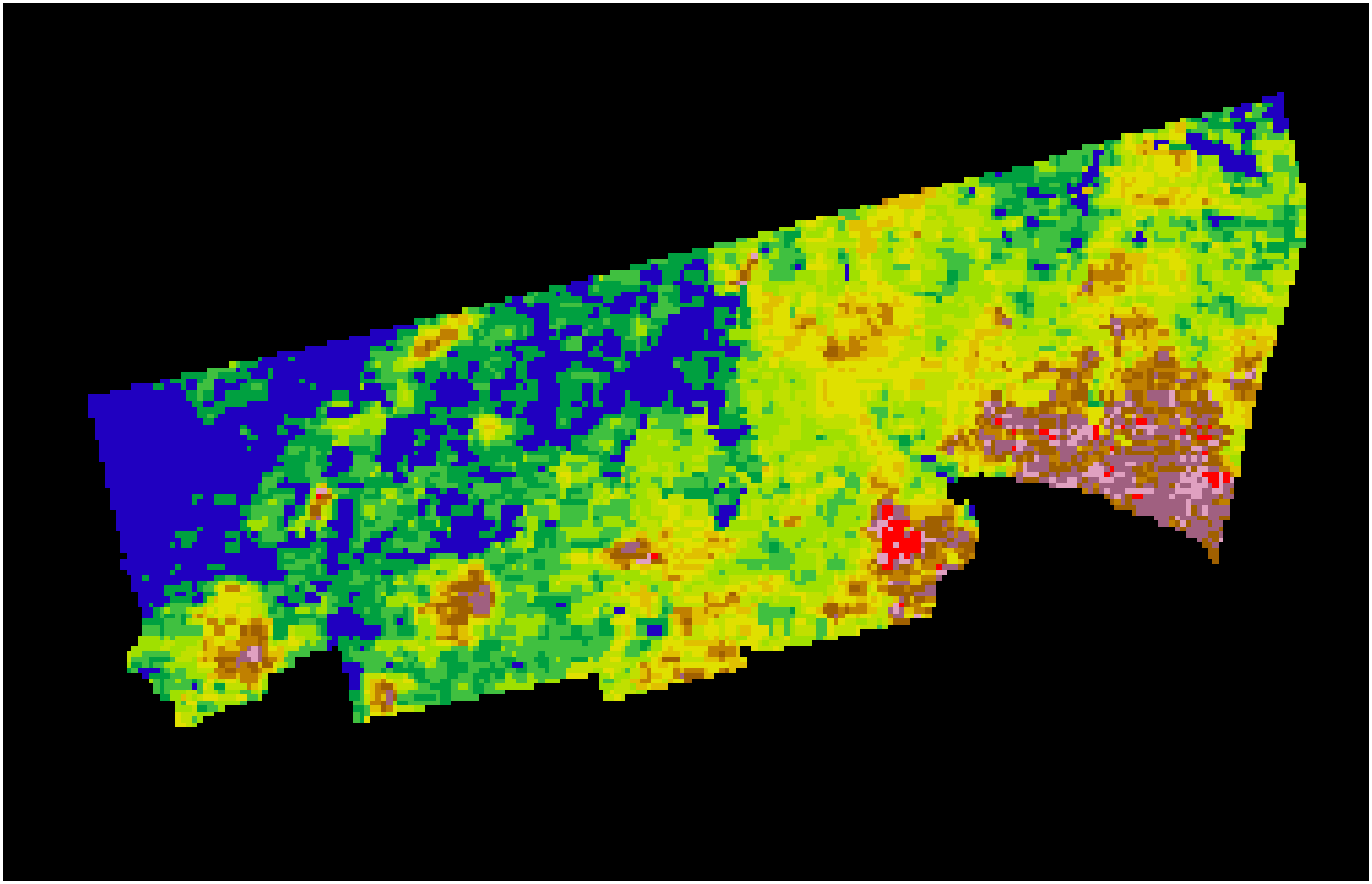
- The **procedure for creating TVDI** initially requires all the steps required to obtain σ :
  1. Form the 2-D T_s – VI distribution
  2. Calculate/find σ

  followed by **a few further steps**:

  3. Define the wet line along the bottom the triangle (which can usually be safely done in a fairly unsophisticated fashion)
  4. Calculate TVDI as described (where is the point/pixel of interest positioned between the dry and wet lines at the given NDVI)
  5. Take the resulting values and map them back to their respective pixels


2001 MODIS Yearday 241 Climate Division 3 Ts-NDVI Plot
40.000
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Ts
0.0000
0.1000
0.2000
0.3000
0.4000
0.5000
0.6000
0.7000
0.8000
0.9000
1.0000
NDVI
Dry Line
Wet Line
Wet Line

TVDI Composites – NC CD3
Nov. 2000 -Sept. 2001



MODIS

- AVHRR has been superceded by **MODIS (Moderate Resolution Imaging Spectrometer)** which is a project being run by NASA, in partnership with the USGS (US Geological Survey)
- The MODIS sensors are the ‘centerpiece’ sensors on two new satellites that have been called Earth Observing Systems (EOS-AM and EOS-PM), codenamed **Terra and Aqua**
- **Terra** was designed to focus on land-based applications and has an equatorial **overpass time of about 10:30 AM**, while **Aqua** was designed for more sea-oriented applications and has an equatorial **overpass time of about 2:30 PM**, and the MODIS sensors on them are known as MODIS-AM and MODIS-PM

MODIS Characteristics

Orbit: 705 km,

Time to cross equator: 10:30 a.m. descending node (Terra), 2:30 pm descending node (Aqua)

sun-synchronous, near-polar, circular

Sensor Systems: Across Track Scanning (‘Wiskbroom’)

Radiometric resolution: 12 bits

Temporal resolution: 1-2 days

Spatial Resolution:

250 m (bands 1-2)

500 m (bands 3-7)

1000 m (bands 8-36)

Design Life: 6 years

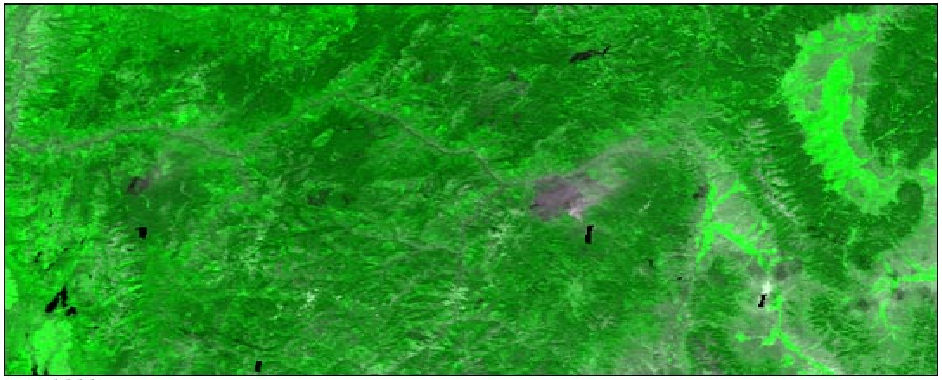
MODIS Bands

TABLE 6.14 MODIS Spectral Bands

Primary Use	Band	Bandwidth	Resolution (m)
Land/cloud boundaries	1	620–670 nm	250
	2	841–876 nm	250
Land/cloud properties	3	459–479 nm	500
	4	545–565 nm	500
	5	1230–1250 nm	500
	6	1628–1652 nm	500
	7	2105–2155 nm	500
Ocean color/ phytoplankton/ biogeochemistry	8	405–420 nm	1000
	9	438–448 nm	1000
	10	483–493 nm	1000
	11	526–536 nm	1000
	12	546–556 nm	1000
	13	662–672 nm	1000
	14	673–683 nm	1000
	15	743–753 nm	1000
	16	862–877 nm	1000
Atmospheric water vapor	17	890–920 nm	1000
	18	931–941 nm	1000
	19	915–965 nm	1000
Surface/cloud temperature	20	3.660–3.840 μm	1000
	21[a]	3.929–3.989 μm	1000
	22	3.929–3.989 μm	1000
	23	4.020–4.080 μm	1000
Atmospheric temperature	24	4.433–4.498 μm	1000
	25	4.482–4.549 μm	1000
Cirrus clouds	26[b]	1.360–1.390 μm	1000
Water vapor	27	6.538–6.895 μm	1000
	28	7.175–7.475 μm	1000
	29	8.400–8.700 μm	1000
Ozone	30	9.580–9.880 μm	1000
Surface/cloud temperature	31	10.780–11.280 μm	1000
	32	11.770–12.270 μm	1000
Cloud top altitude	33	13.185–13.485 μm	1000
	34	13.485–13.758 μm	1000
	35	13.785–14.085 μm	1000
	36	14.085–14.385 μm	1000

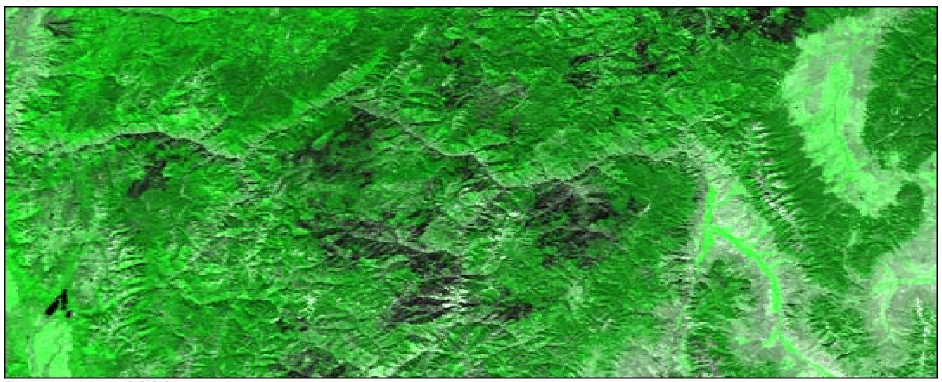
[a]Band 21 and 22 are similar, but band 21 saturates at 500 K versus 328 K.
[b]Wavelength out of sequence due to change in sensor design.

MODIS Applications - Fire Damage



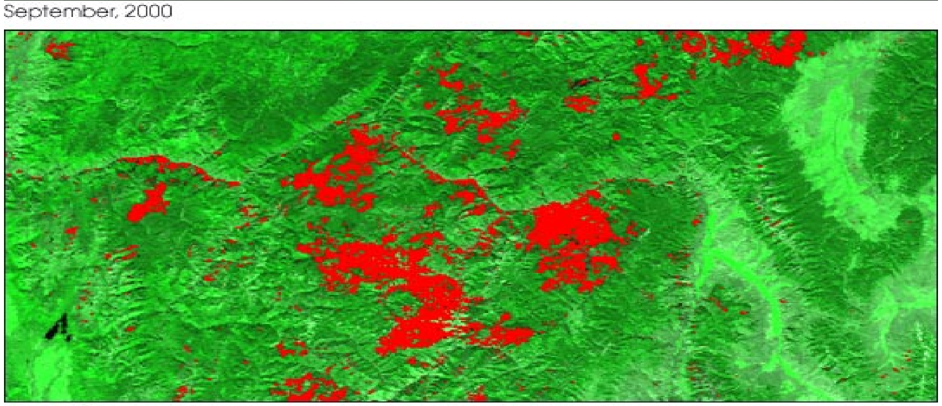
July, 2000

Pre-forest fire



September, 2000

Post-forest fire

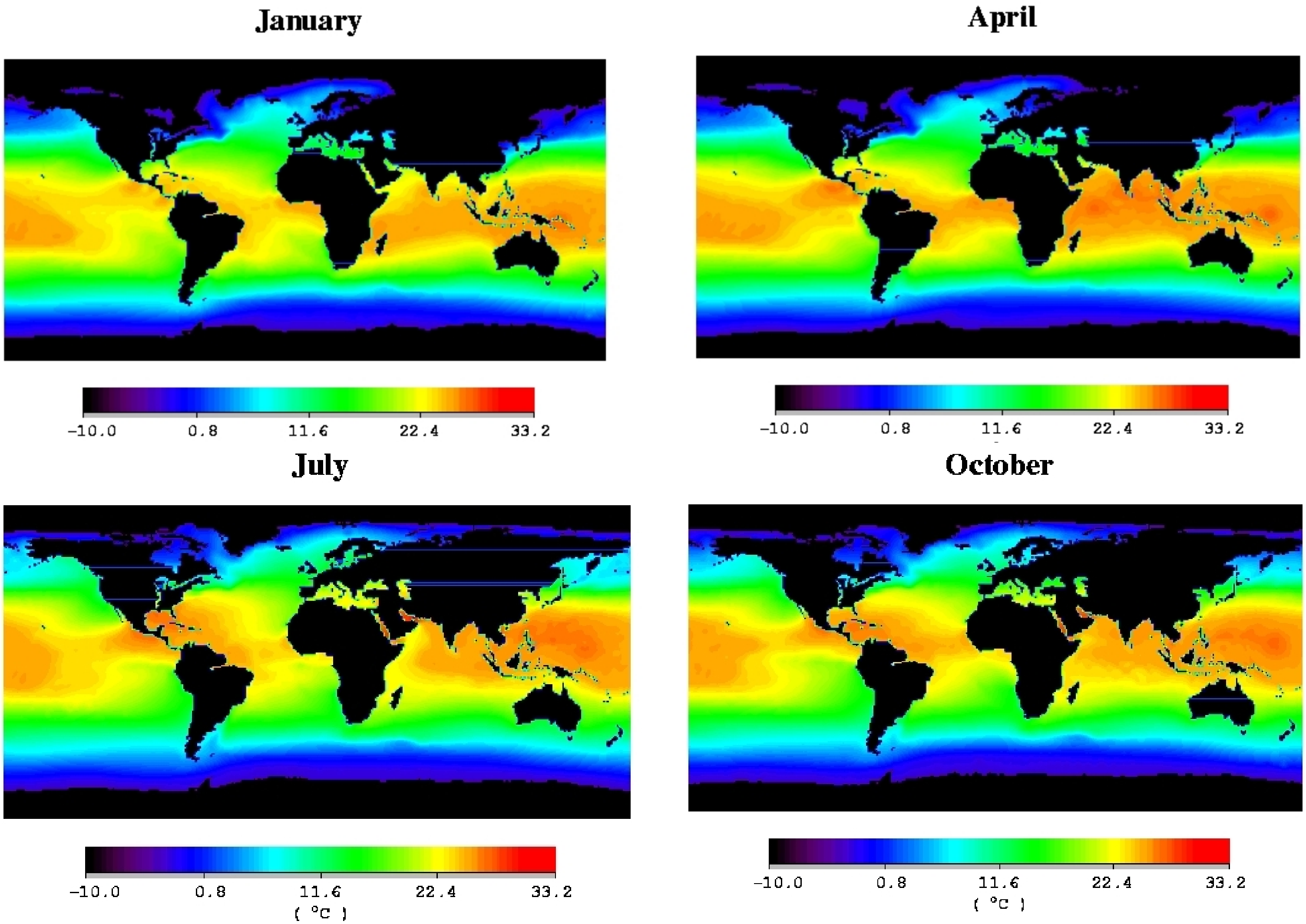


Burned Area

Burnt area identified from space

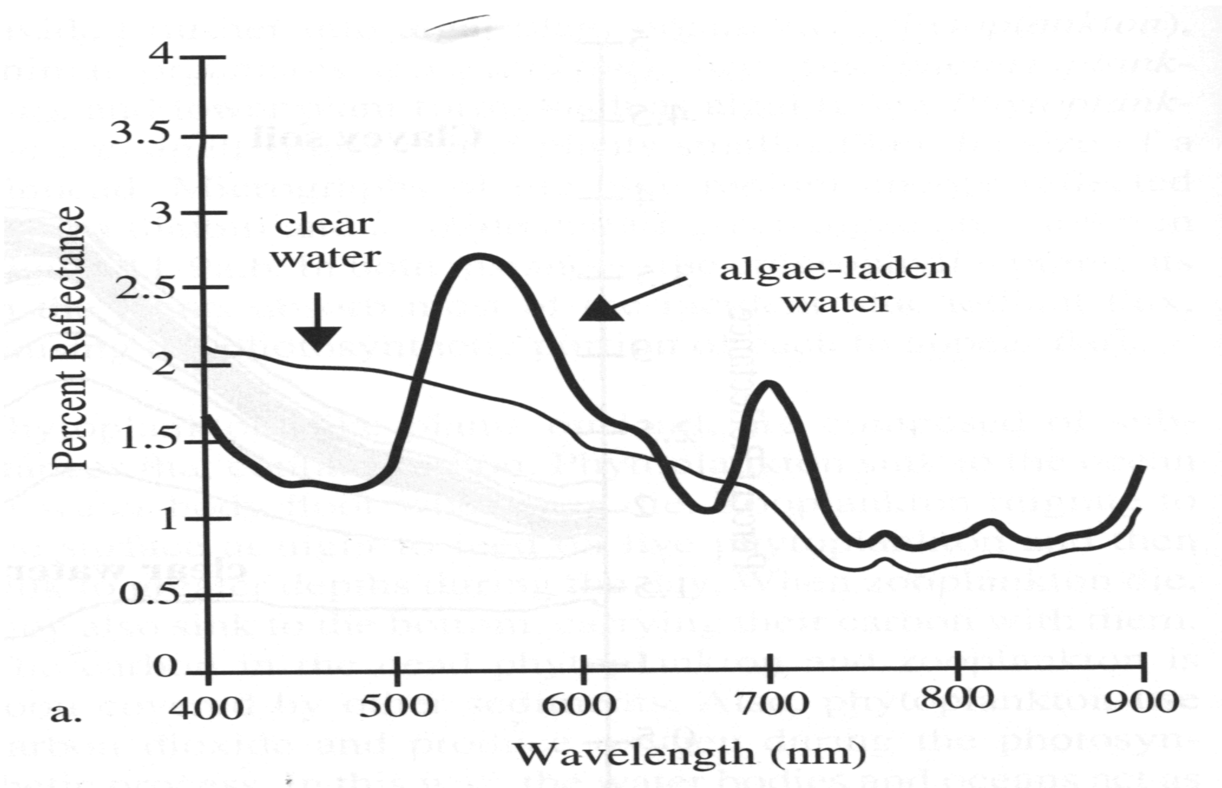
Scale (km)
0 25

MODIS Applications - SST



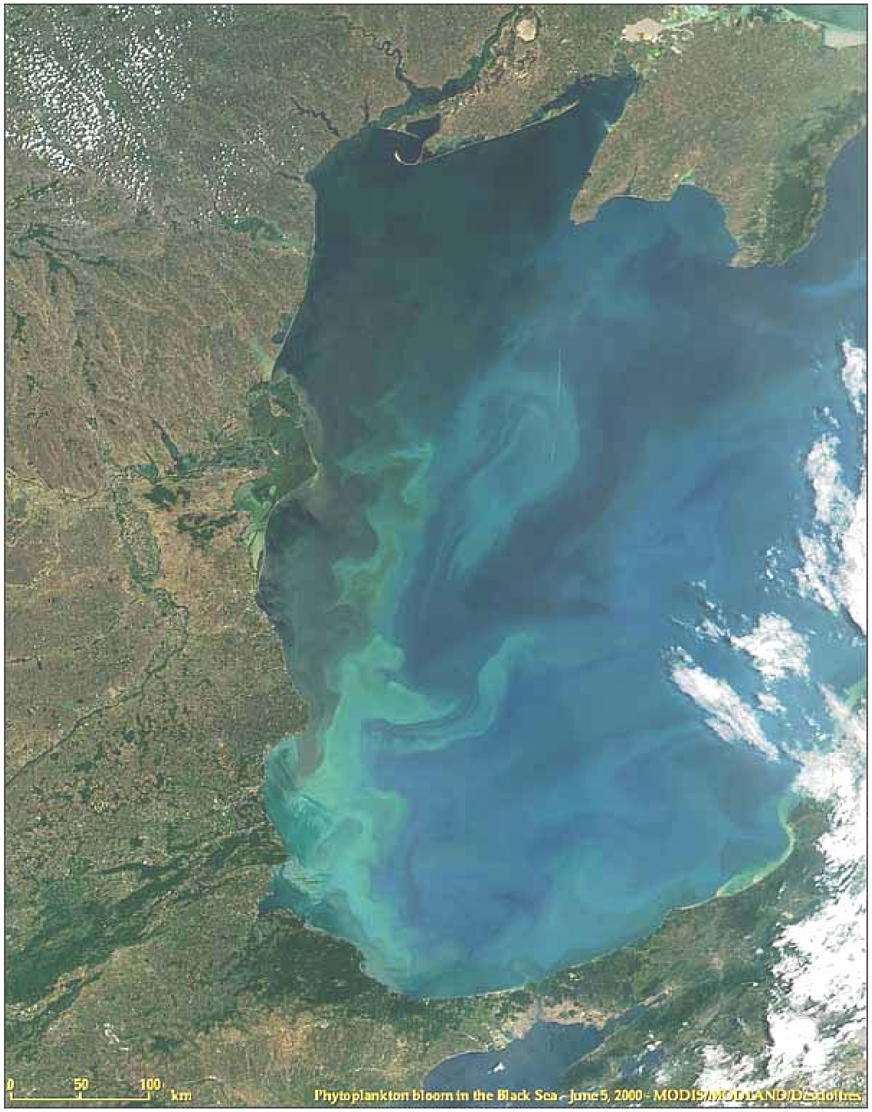
MODIS Applications - Algae

Spectral Properties of Water with Algae

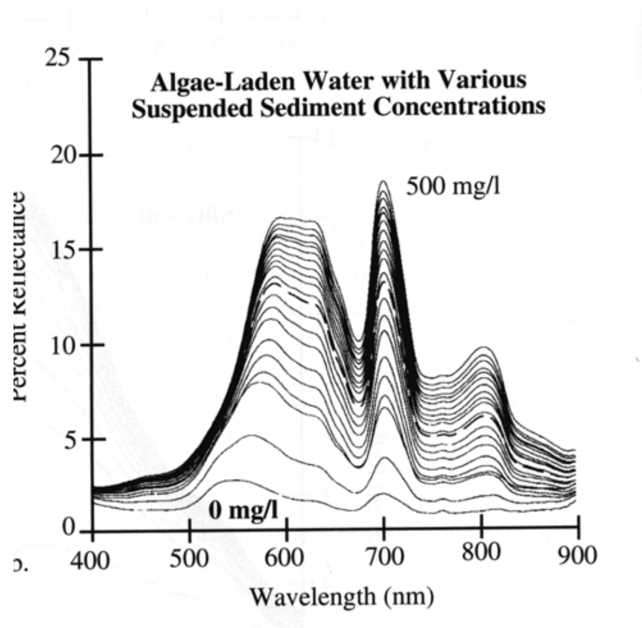


Algae **absorbs** a significant amount of **CO_2**, and its presence / absence / abundance is important to understanding the ocean. It is useful to track the spatial and temporal dynamics of algae blooms

MODIS Applications - Algae

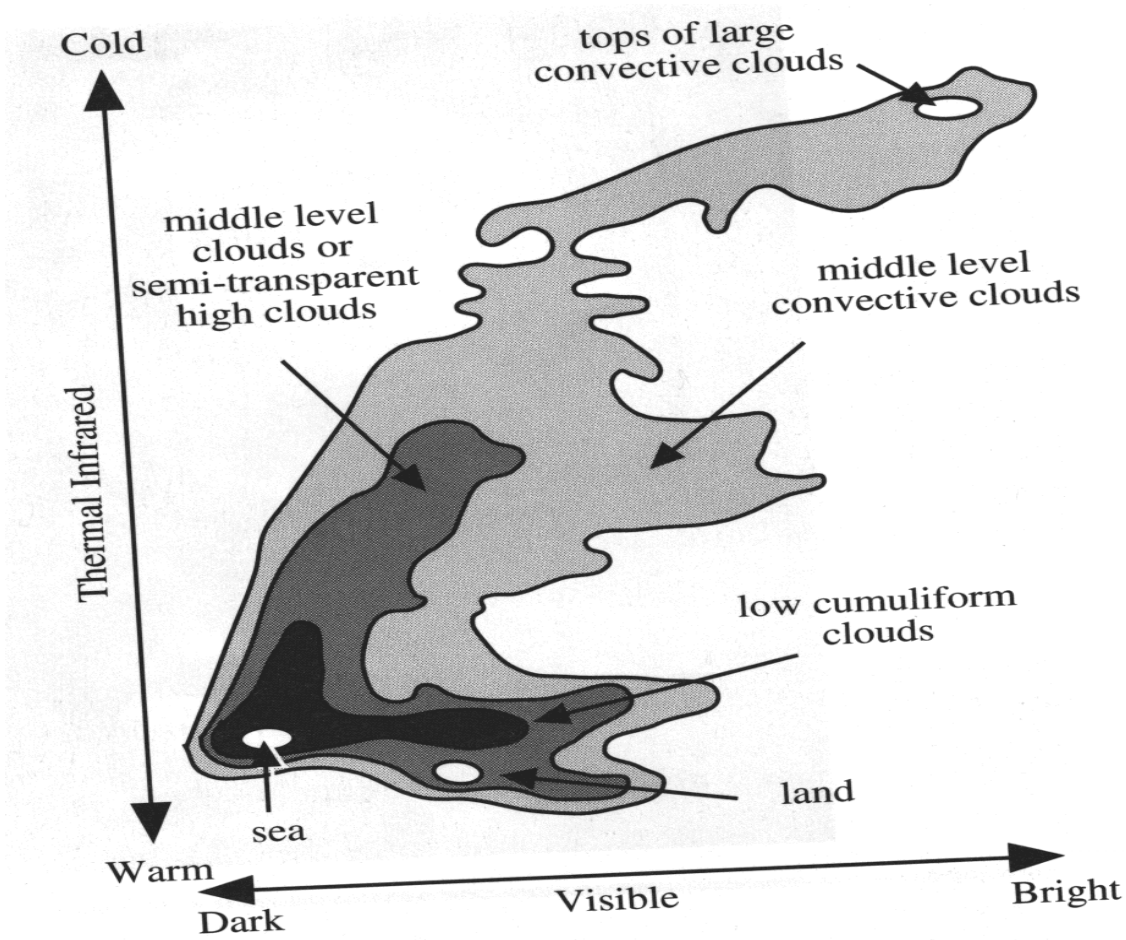


Phytoplankton bloom in the Black Sea. MODIS band 1 (red), 4 (green) and 3 (blue)

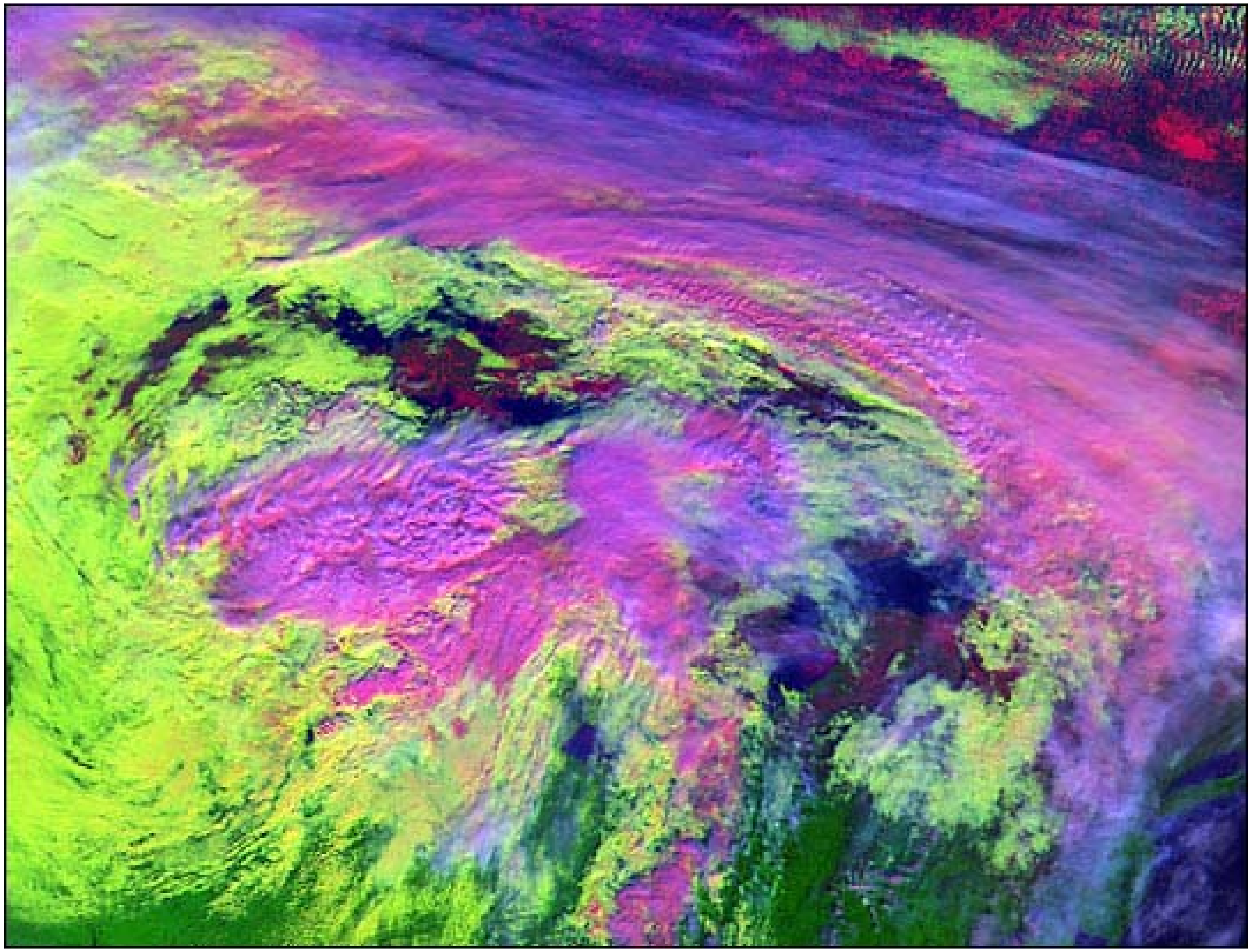


MODIS Applications - Clouds

Cloud Spectral Properties

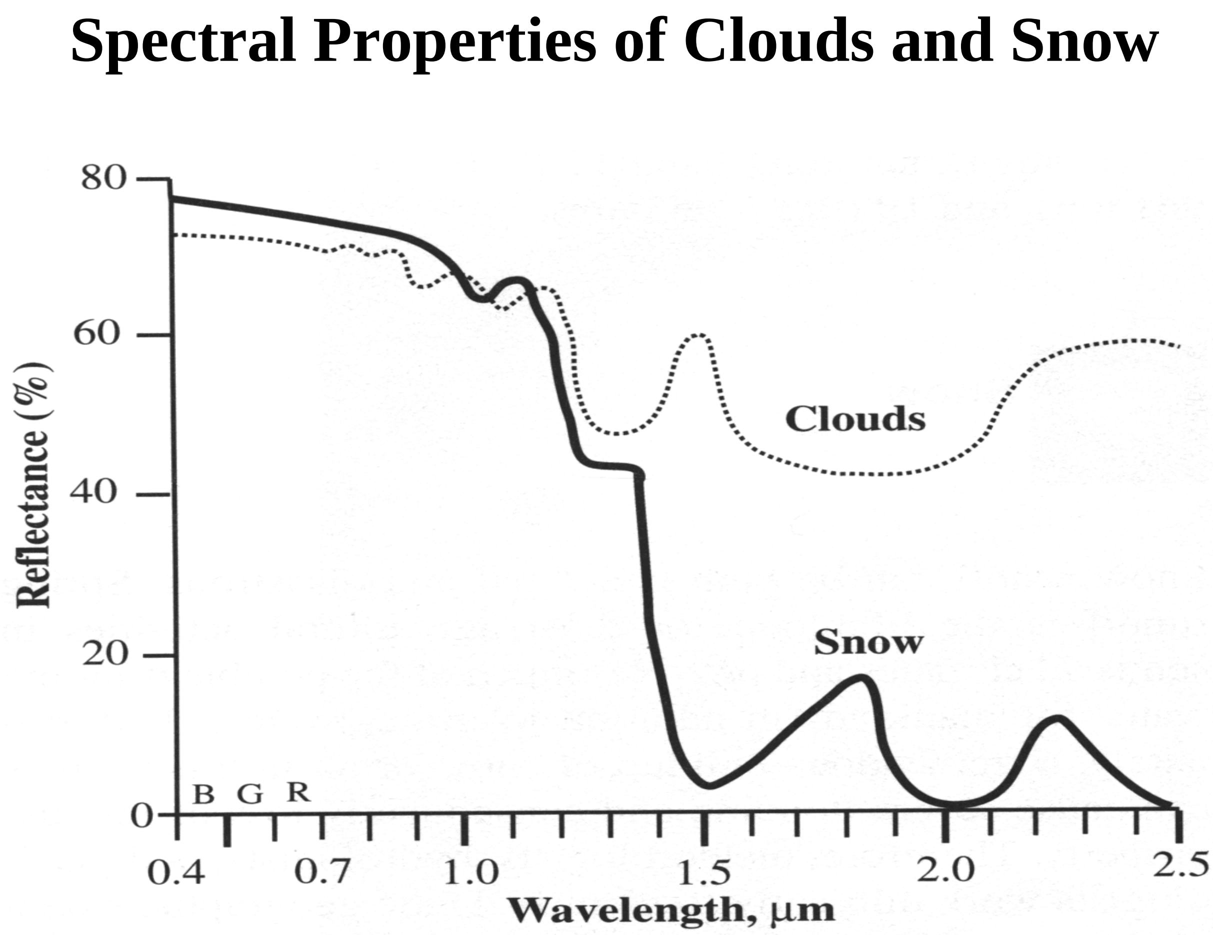


MODIS Applications - Clouds



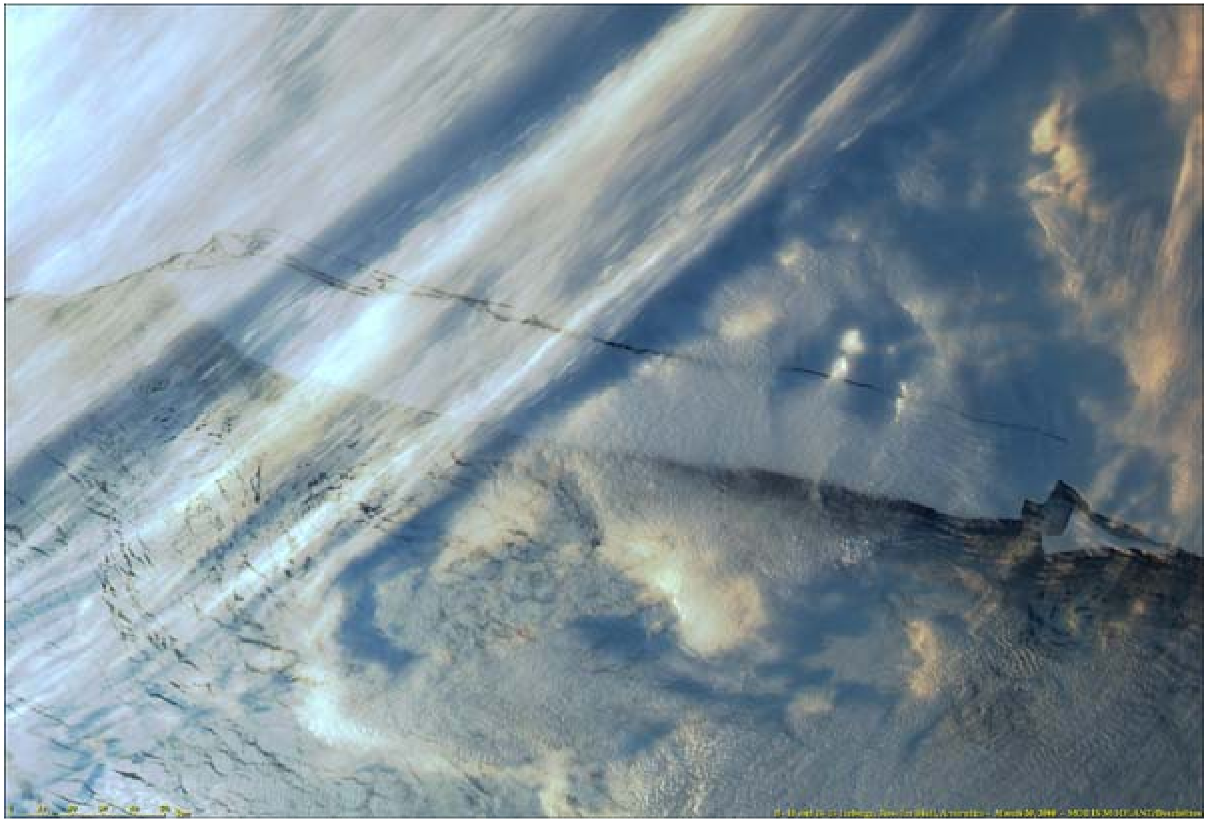
Cloud types from MODIS: pink - cold high level snow and ice clouds; neon green - low level water clouds. These two cloud types reflect and emit radiant energy differently

MODIS Applications - Snow



In the **visible spectrum** clouds and snow look **very similar**. Thus, it is difficult to separate them with human eyes. But they are **very different in the mid-infrared**

MODIS Applications - Snow



A **massive iceberg**, one of the largest ever observed, broke off the Ross Ice Shelf near Roosevelt Island in Antarctica in mid-March 2000. This iceberg is about 40 miles wide and 300 miles long. The breaking off of such a big iceberg may be related to global climate change