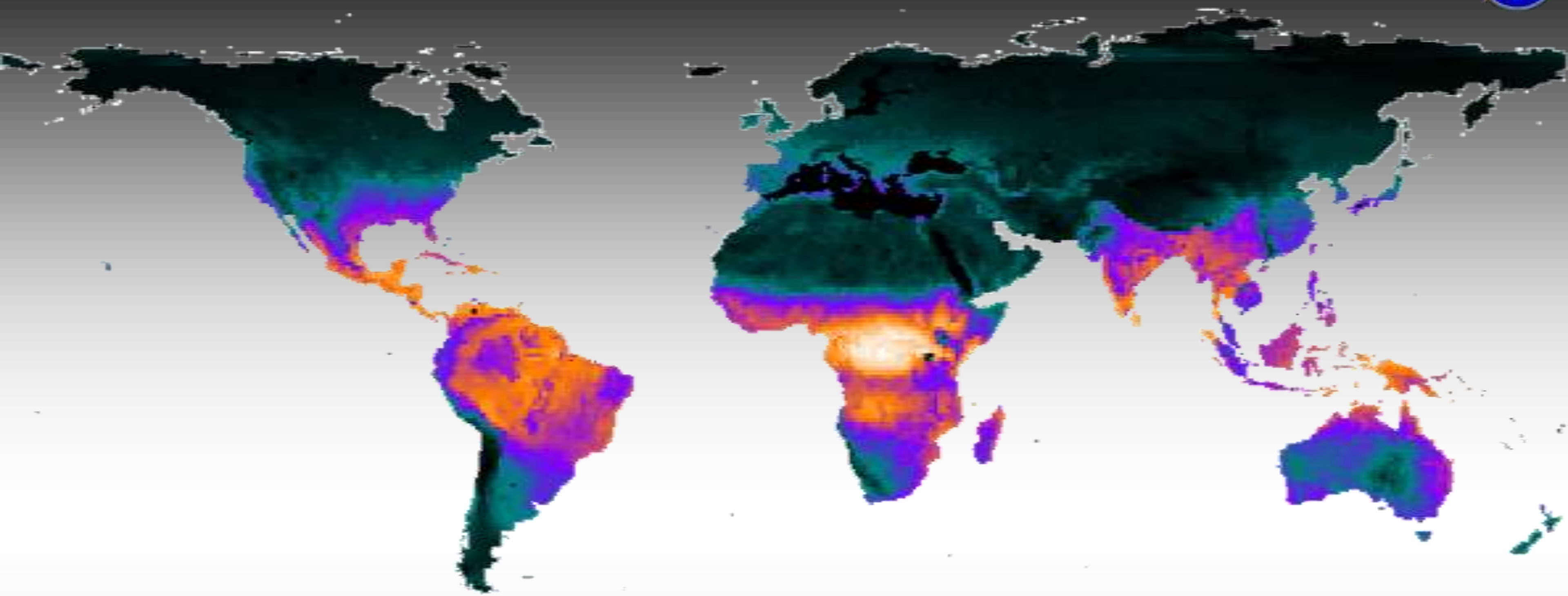

NASA JPL CALTECH

REMOTE SENSING OF THE HYDROLOGICAL CYCLE

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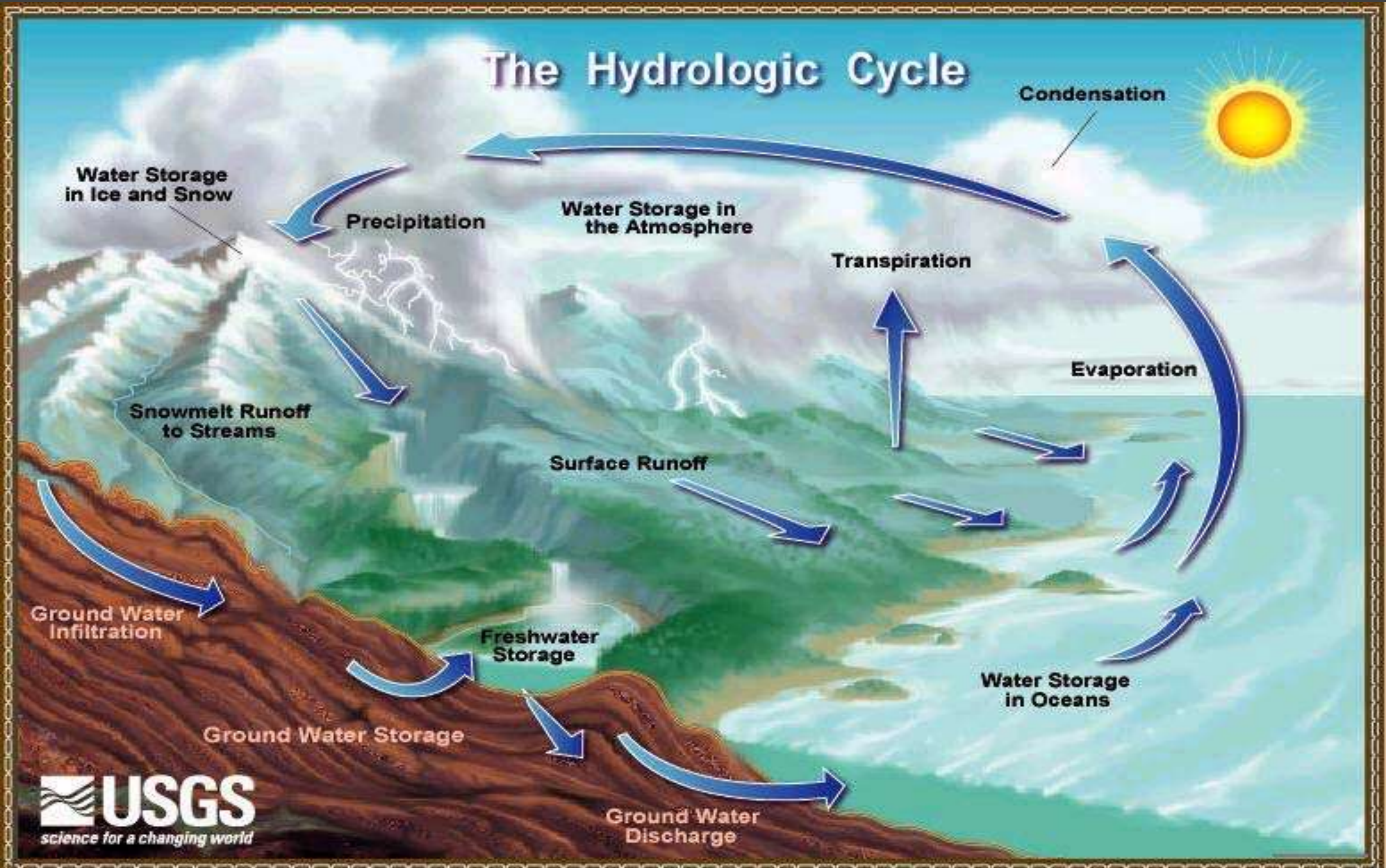
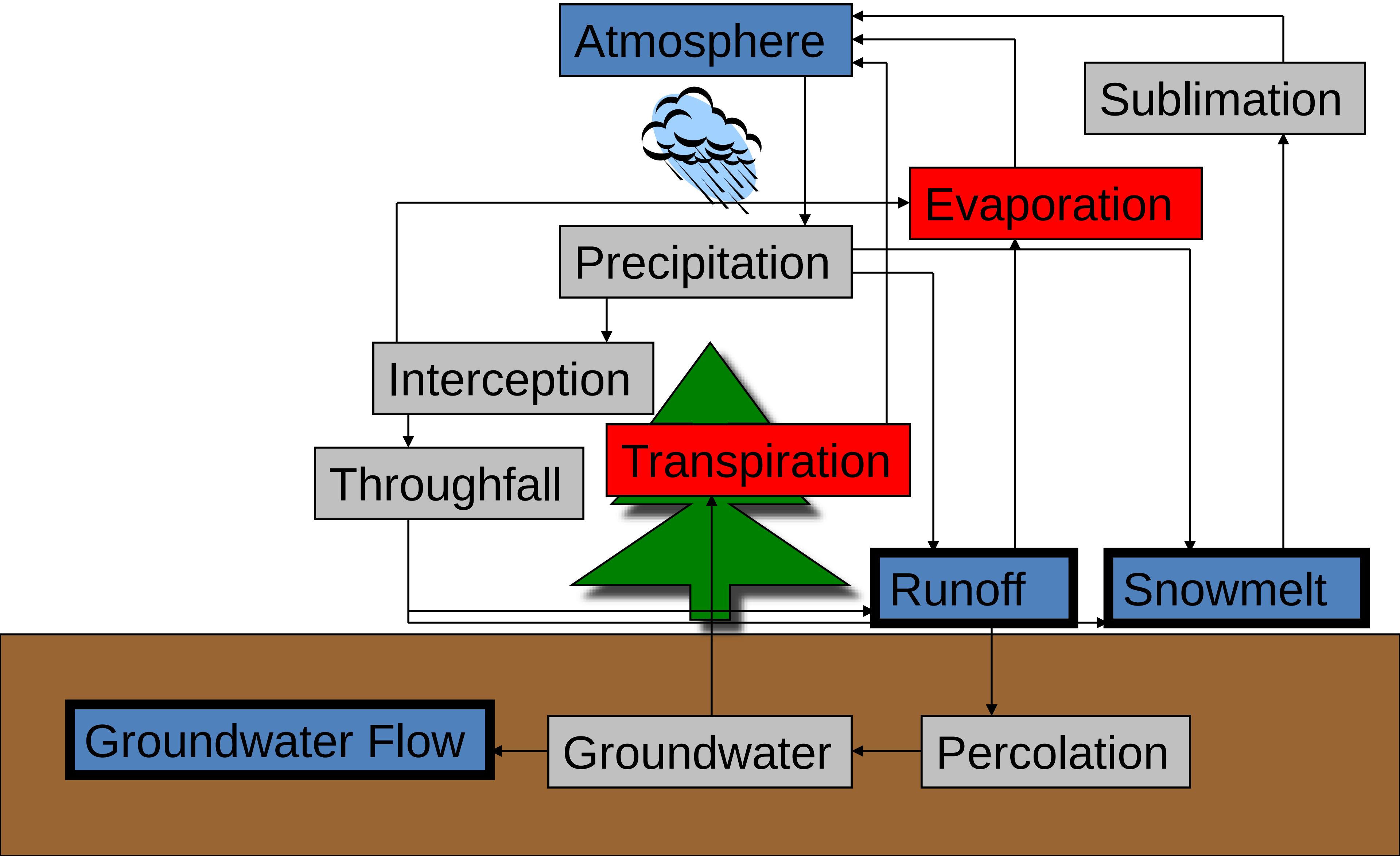
WATER BALANCE



WATER BALANCE

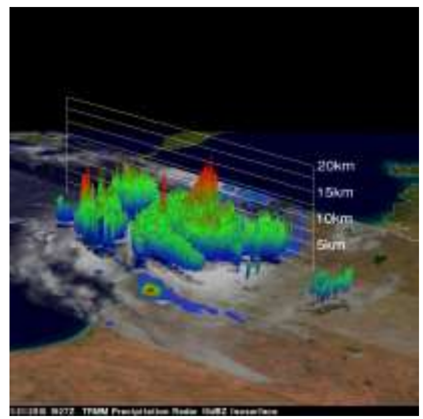


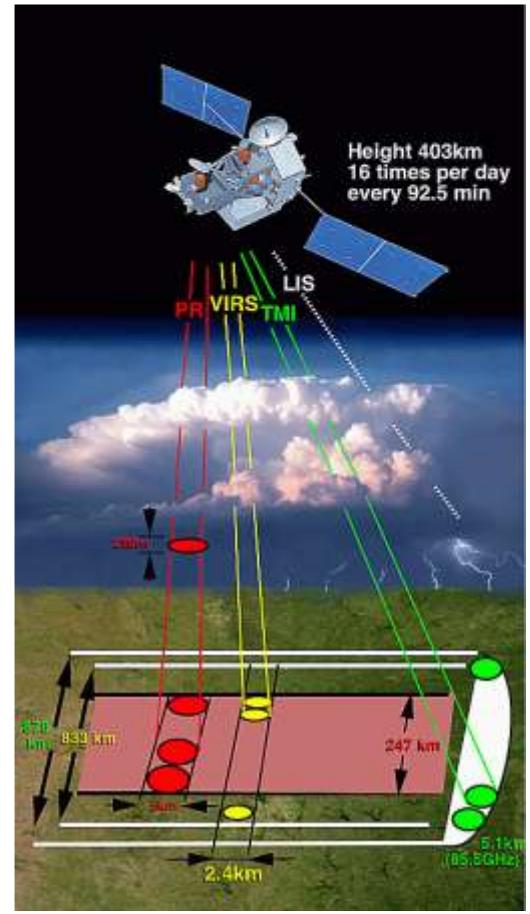
OUTLINE

- Precipitation
- Groundwater
- Soil moisture
- Snow
- Evapotranspiration
- Runoff
- Case study
  - *Drought Sensitivity of the Amazon*

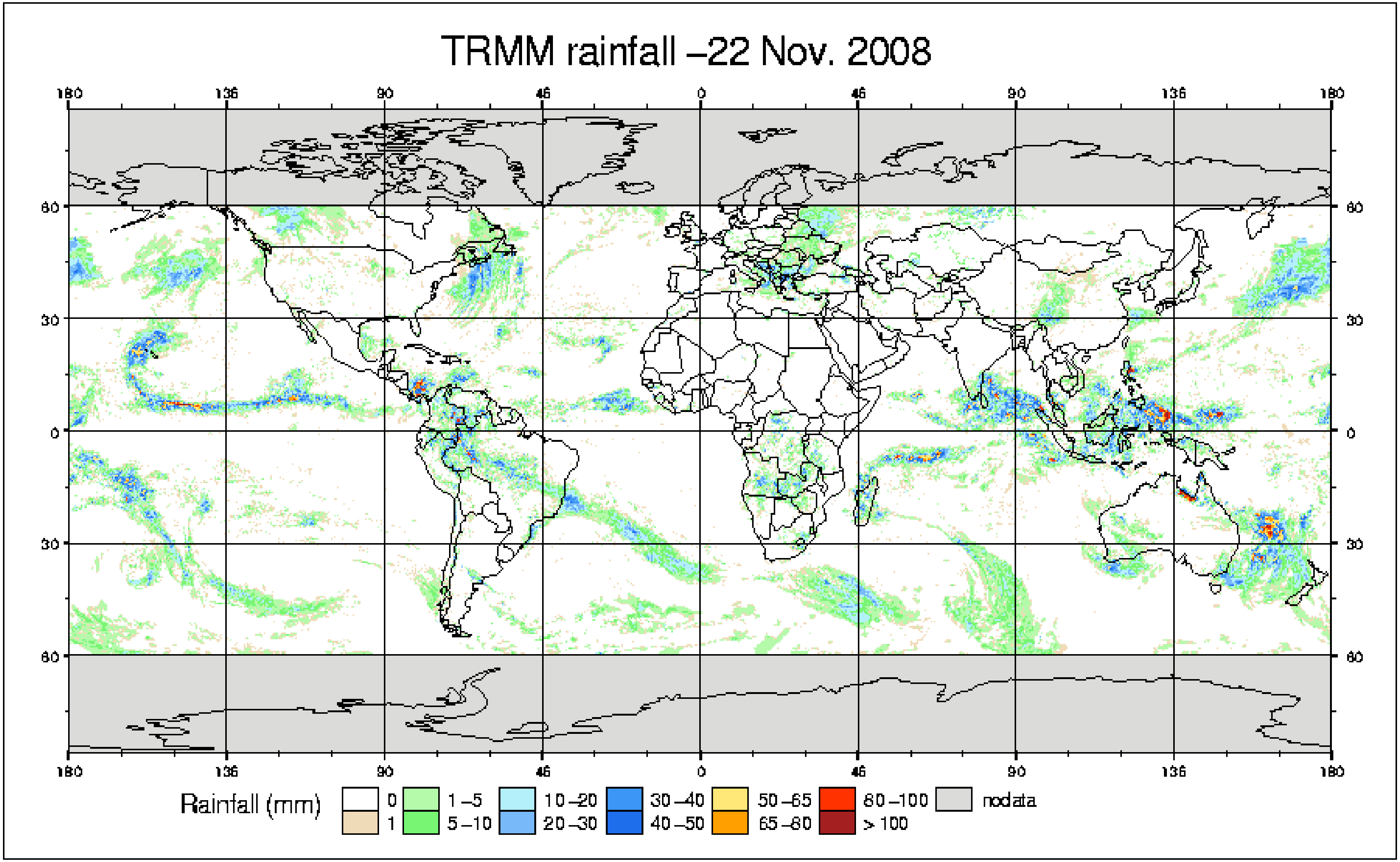
PRECIPITATION

- Tropical Rainfall Measuring Mission (TRMM)
  - Since 1997 (NASA & JAXA)
  - First satellite dedicated to precipitation
    - Built upon SSM/I
  - *Precipitation Radar*
    - Rain intensity
    - Rain distribution
    - Rain type
    - Snow → rain height
    - 3-D storm structure
    - Storm depth
  - *TRMM Microwave Imager*
    - Rain presence
    - Water vapor
    - Cloud water
  - *Lightning Imaging Sensor*
  - *Visible and Infrared Scanner*
  - *Clouds and the Earth's Radiant Energy System (CERES)*

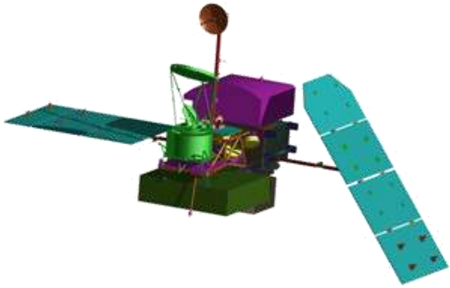




PRECIPITATION



PRECIPITATION

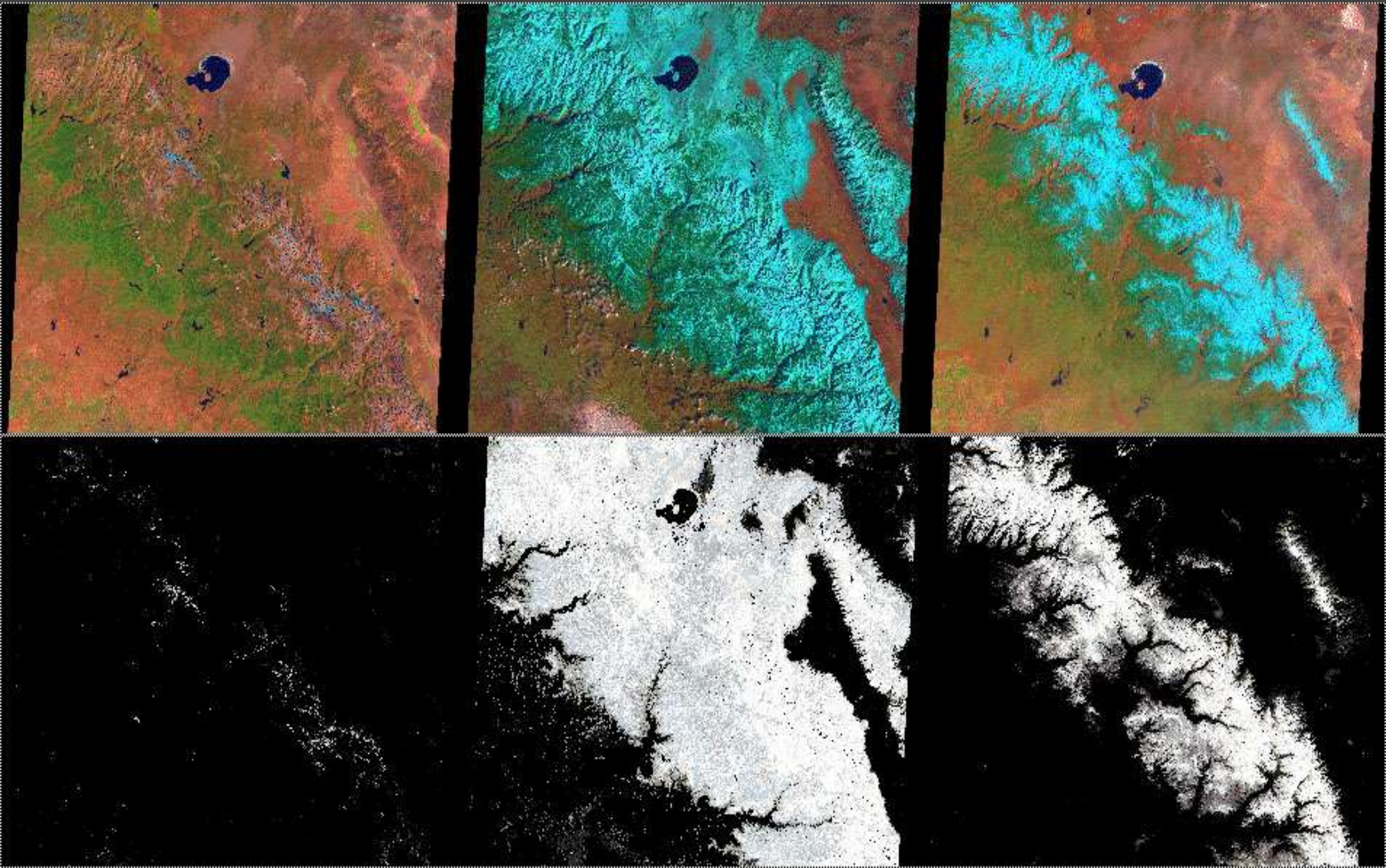


- Global Precipitation Mission (GPM)
  - To be launched: 2013 (NASA & JAXA)
  - Improve on TRMM
    - Coverage: global
    - Spatial resolution: 5 km, 0.25 km vertical
    - Temporal resolution: 3 hr
    - Accuracy: <25% error
  - Capable of measuring rainfall and snowfall rates of 0.01 – 4 inches/hr
  - Combined microwave radiometer (7 bands) and active radar (2 bands)
  - Network of satellites (5 – 8)
    - Prototype of Global Earth Observing System of Systems (GEOSS)

GPM Core

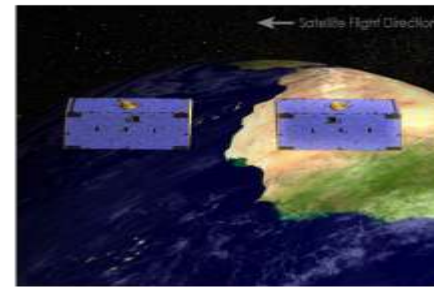
Core, DMSP-F18, DMSP-F19, GCOM-W, NASA-Constellation, EGPM, Megha-Tropiques, NPOESS

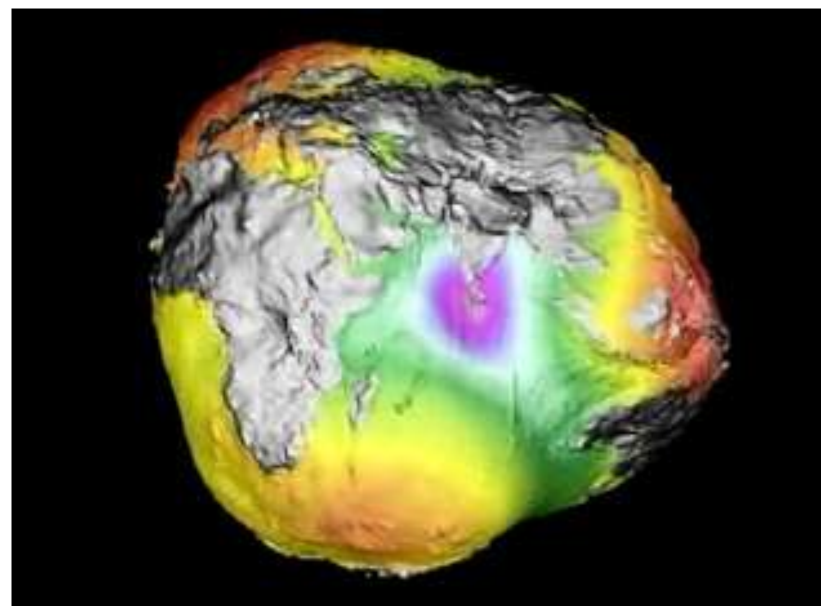
SNOW



GROUNDWATER

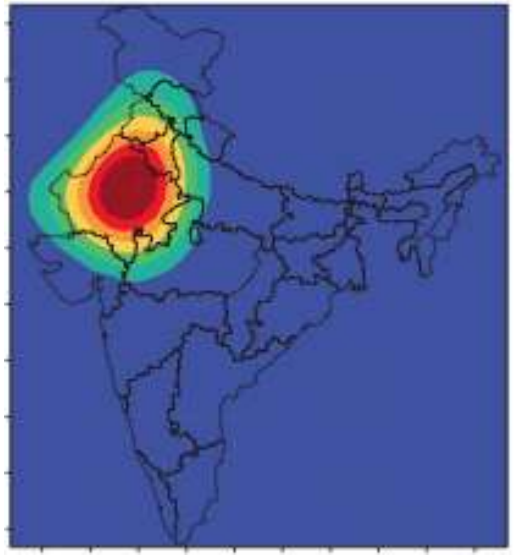
- Gravity Recovery And Climate Experiment (GRACE)
  - Since 2002
  - Variation in Earth's gravitational field
  - Caused by changes in:
    - Surface water
    - Groundwater
    - Deep ocean currents
    - Runoff
    - Glaciers
    - Ice sheets
    - Earth mass

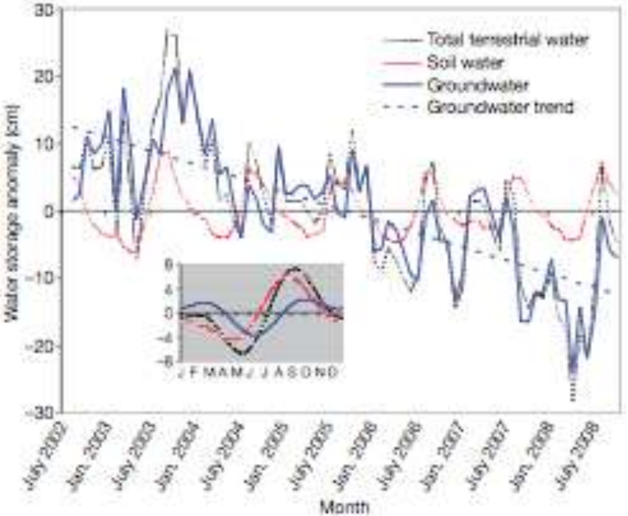




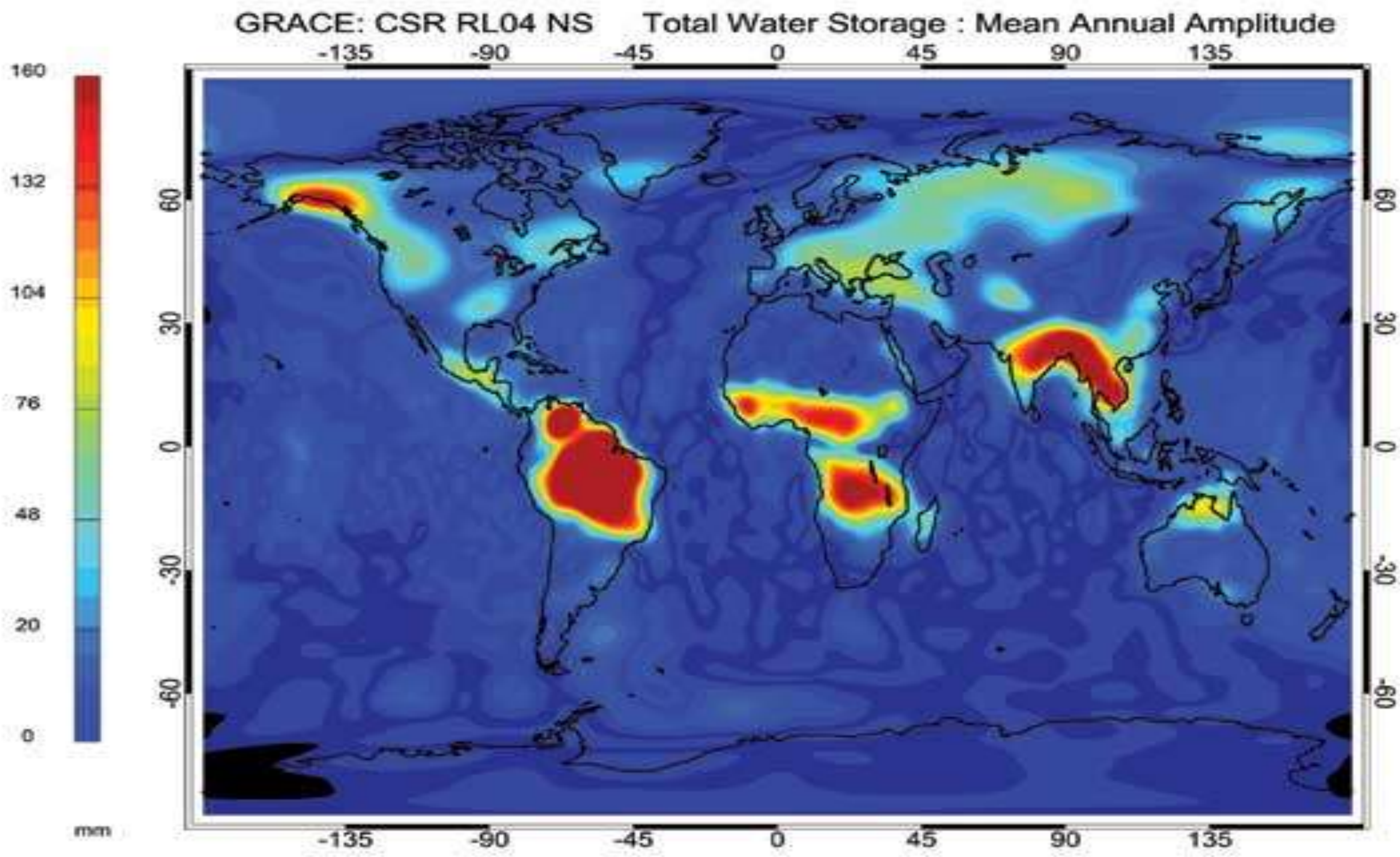
GROUNDWATER

- **Groundwater depletion in India**
  - Rodell et al. 2009: *Nature*
  - Precipitation minus depletion:
    - -4.0 ± 1.0 cm y^{-1}
  - Loss of 109 km^3 water from 2002-8
    - India's largest surface water reservoir: 55 km^3
  - Conclusion: groundwater is depleted at a rate that is unsustainable
    - Largely from the states bordering *Pakistan*



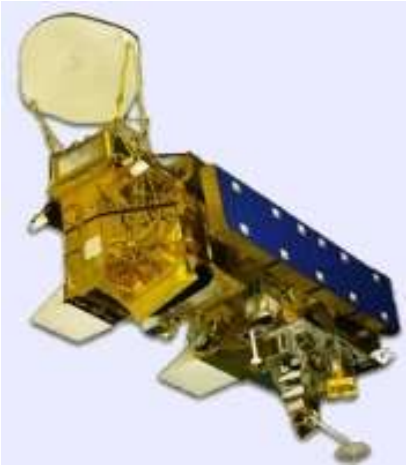


GROUNDWATER

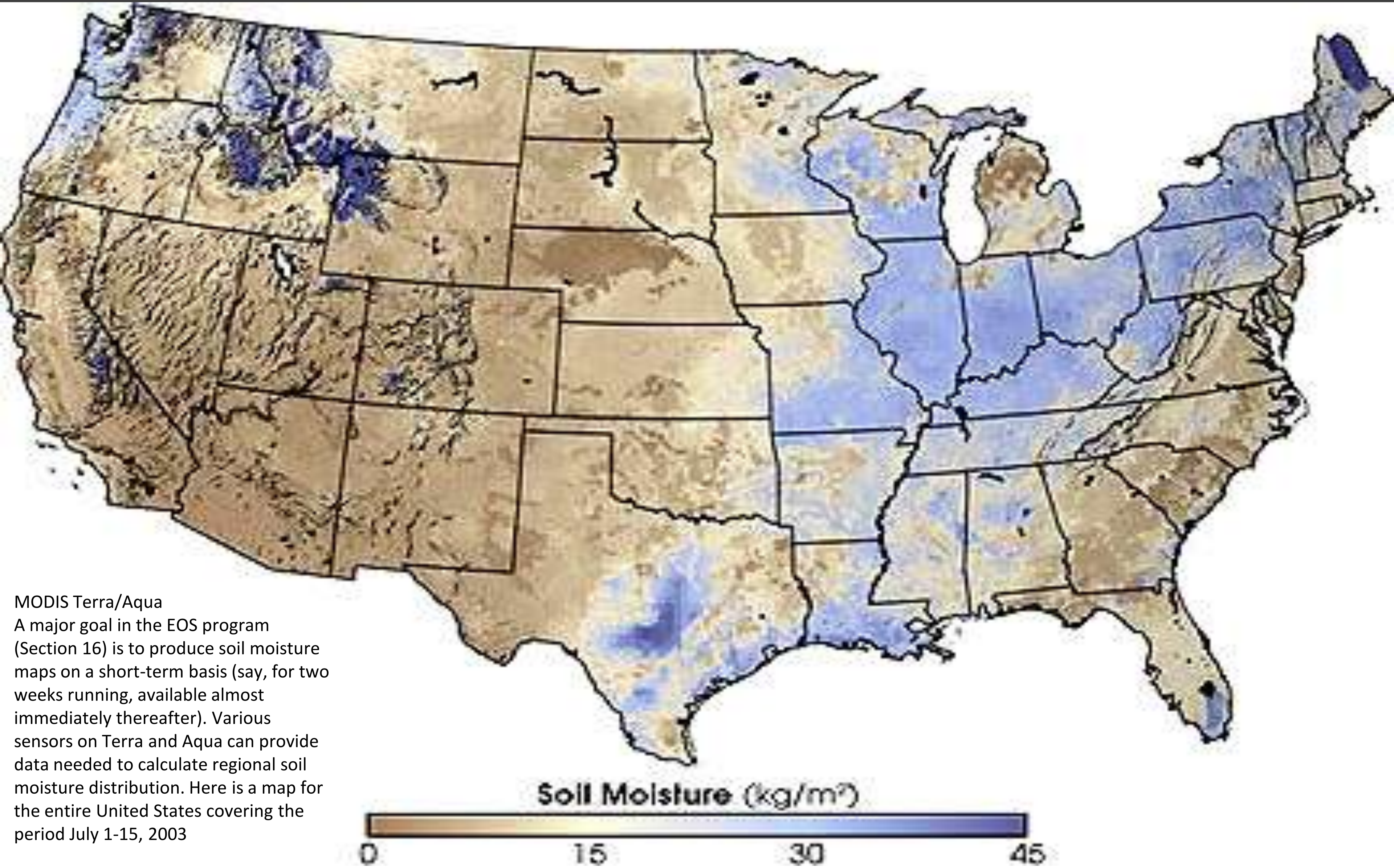


SOIL MOISTURE

- Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E)
  - Since 2002 (NASA & JAXA)
  - Passive microwave radiometer, 12 channels, 20 – 60 km^2, 20 d
  - Land, atmosphere, ocean, ice
  - Surface wetness, precipitation, water vapor, snow water equivalent, cloud water, ice concentration, sea surface temperature, wind speed



SOIL MOISTURE



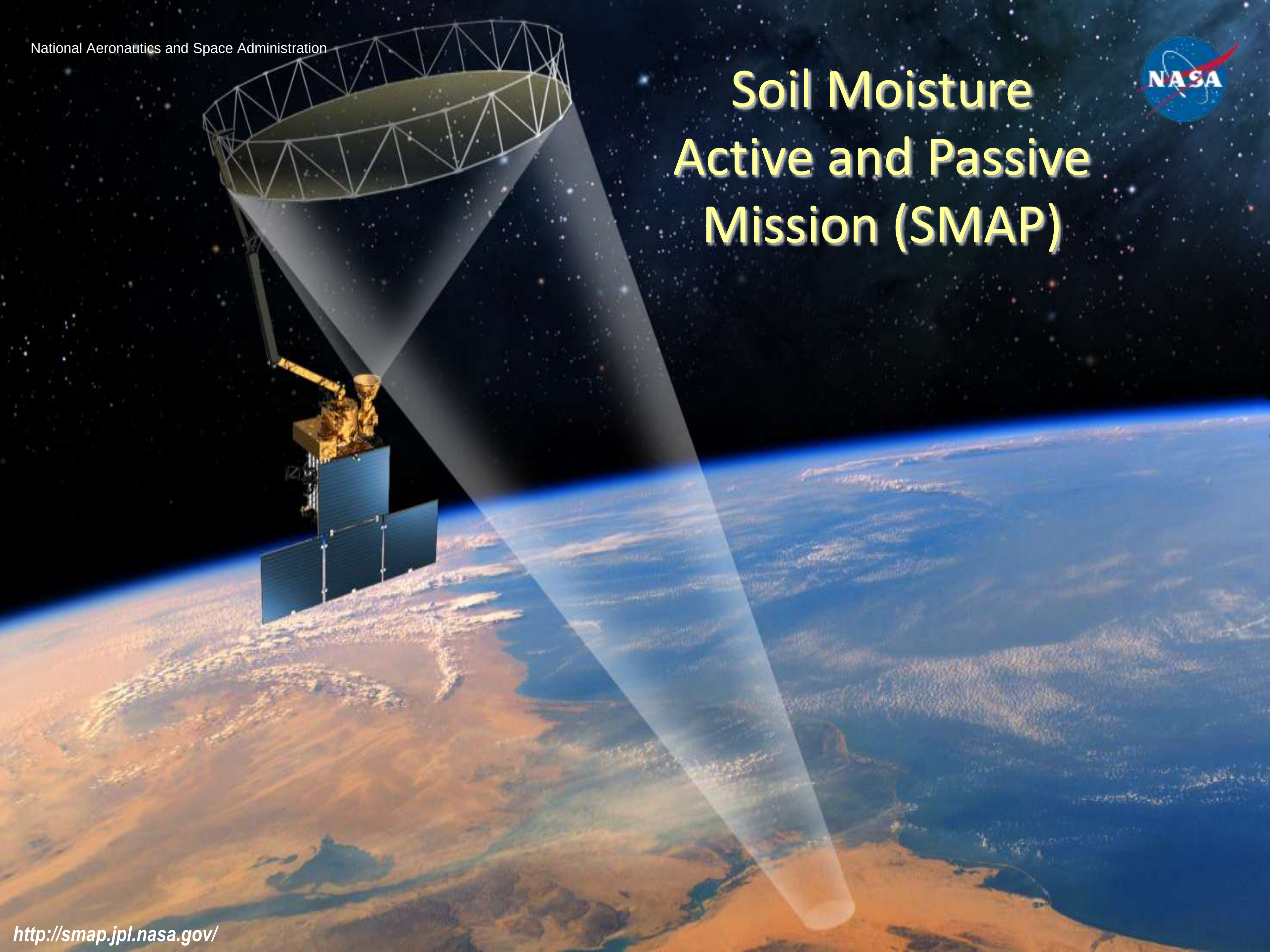
MODIS Terra/Aqua
A major goal in the EOS program (Section 16) is to produce soil moisture maps on a short-term basis (say, for two weeks running, available almost immediately thereafter). Various sensors on Terra and Aqua can provide data needed to calculate regional soil moisture distribution. Here is a map for the entire United States covering the period July 1-15, 2003

SOIL MOISTURE

- Soil Moisture & Ocean Salinity (SMOS)
  - Since 7 months ago (Nov 2009): ESA
  - Passive L-band (1.4 GHz), 35 – 50 km^2, 1 – 3 day
  - 4% accuracy volumetric soil moisture

National Aeronautics and Space Administration

Soil Moisture Active and Passive Mission (SMAP)

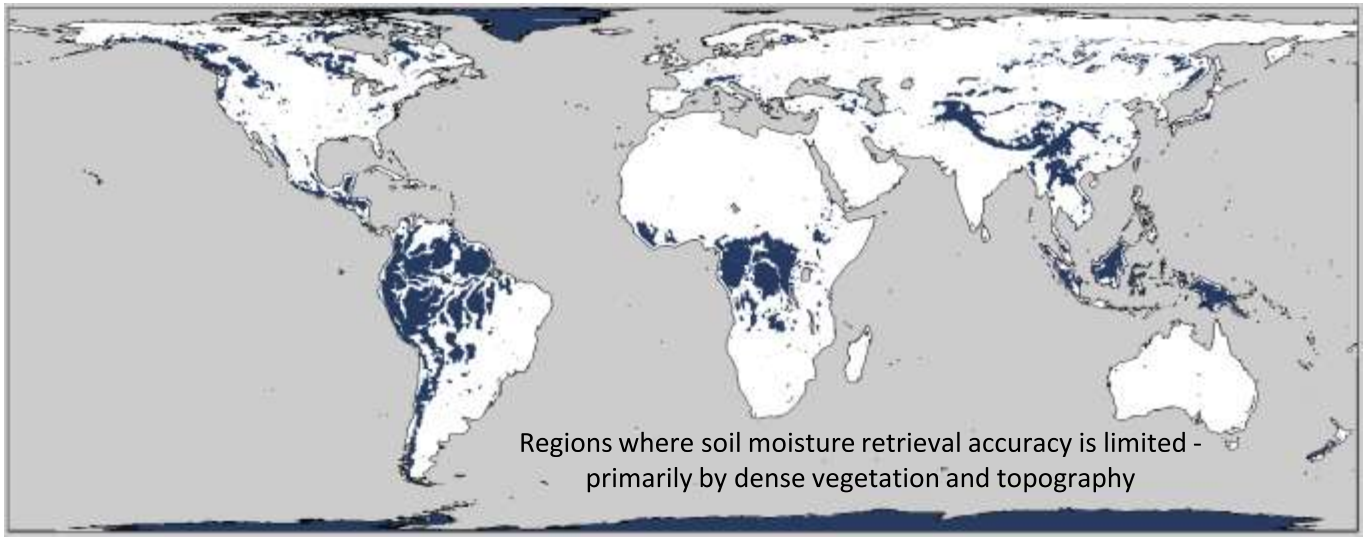


http://smap.jpl.nasa.gov/

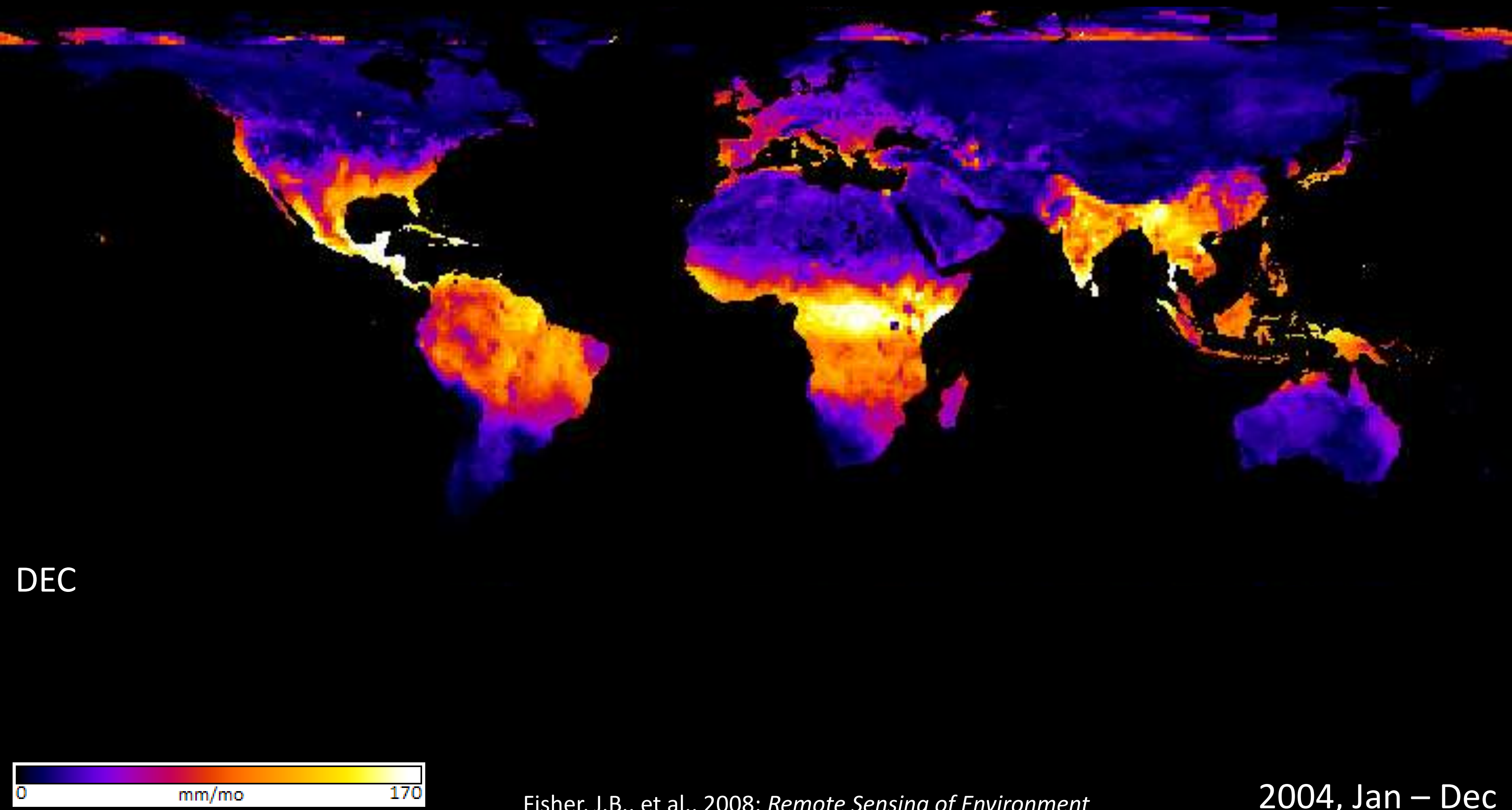
SOIL MOISTURE

- Soil Moisture Active & Passive (SMAP)
  - To be launched: 2015
  - 10 km, 3 (2x) day, 4% accuracy
  - Combined radiometer and radar
    - Radiometer (1.4 GHz): high accuracy (less influenced by roughness and vegetation) but coarse spatial resolution (40 km)
    - Radar (1.26 GHz): high spatial resolution (1 – 3 km) but more sensitive to roughness & vegetation
    - Combination algorithm: high resolution, high accuracy

SOIL MOISTURE



EVAPOTRANSPIRATION



Fisher, J.B., et al., 2008: *Remote Sensing of Environment*

2004, Jan – Dec

EVAPOTRANSPIRATION

- LAI
- Albedo
- Humidity
- Wind speed
- Precipitation
- Net radiation
- Soil moisture
- Soil resistance
- Air temperature
- Stomatal resistance
- Vapor pressure deficit
- Aerodynamic resistances
- Boundary layer resistance
- …

EVAPOTRANSPIRATION

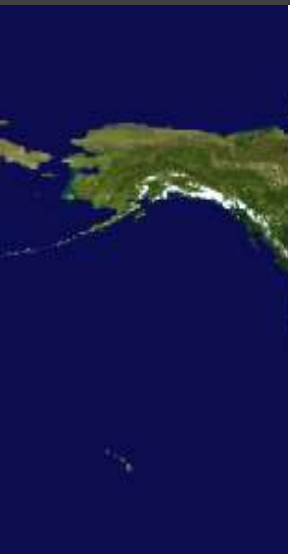
- Su (2002)
- Turc (1961)
- Liang (1994)
- Bowen (1926)
- Hamon (1963)
- Linacre (1977)
- Mu et al (2007)
- Bouchet (1963)
- Makkink (1957)
- Penman (1948)
- Sun et al (2009)
- Hargreaves (1974)
- Cleugh et al (2007)
- Nishida et al (2003)
- Thornthwaite (1948)
- Jackson et al (1977)
- Bartholic et al (1970)
- Jensen & Haise (1963)
- Blaney & Criddle (1950)
- Priestley &Taylor (1972)
- Penman-Monteith (1965)
- Doorenbos & Pruitt (1977)
- McNaughton & Black (1973)
- Shuttleworth & Wallace (1985)
- Choudhury & DiGirolamo (1998)
- …

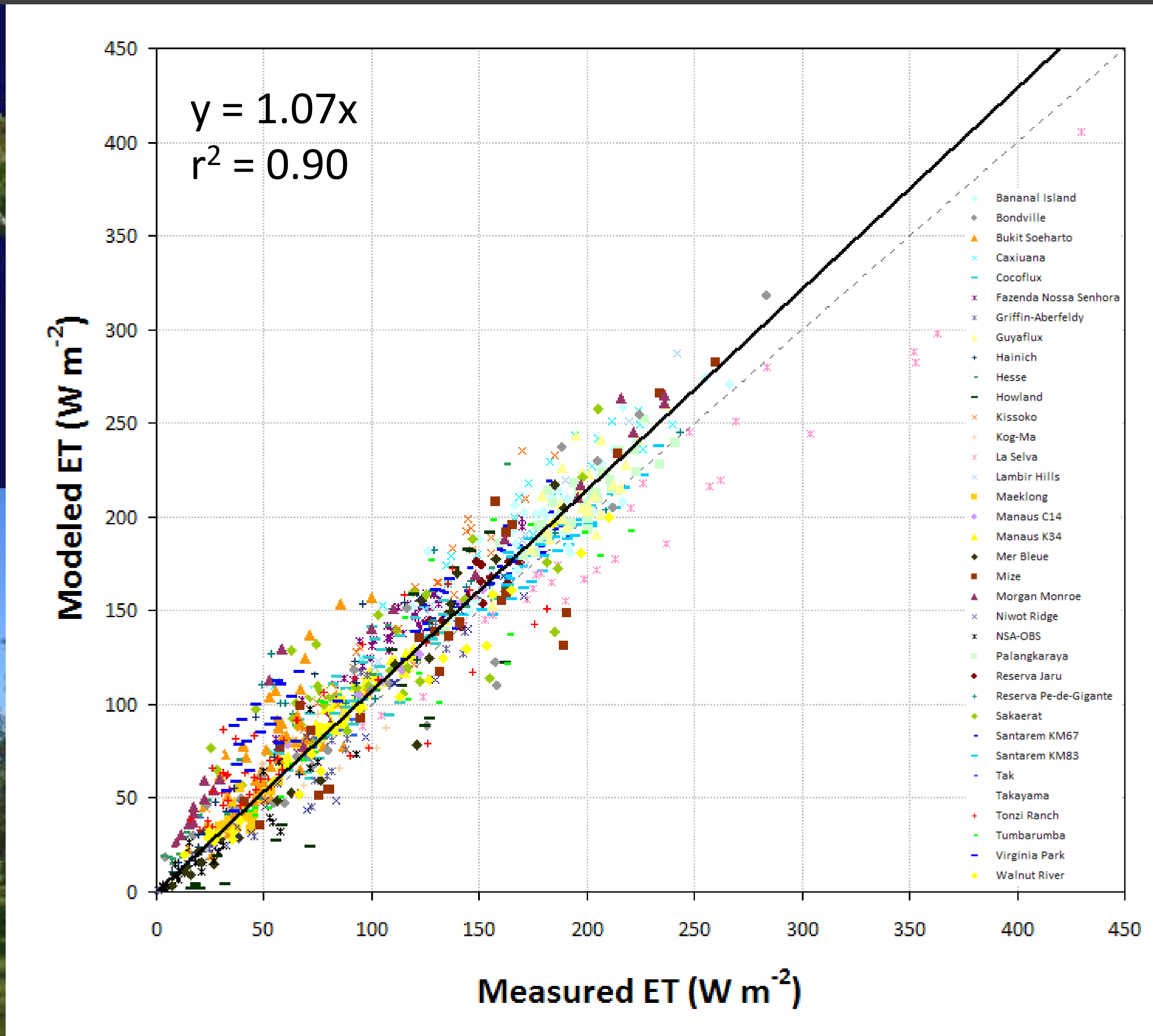
EVAPOTRANSPIRATION

$$LE = LE_s + LE_c + LE_i$$

R_n	SRB
T_a	AIRS
e_a [*RH*, *VPD*]	AIRS
Vegetation fraction	MODIS

EVAPOTRANSPIRATION

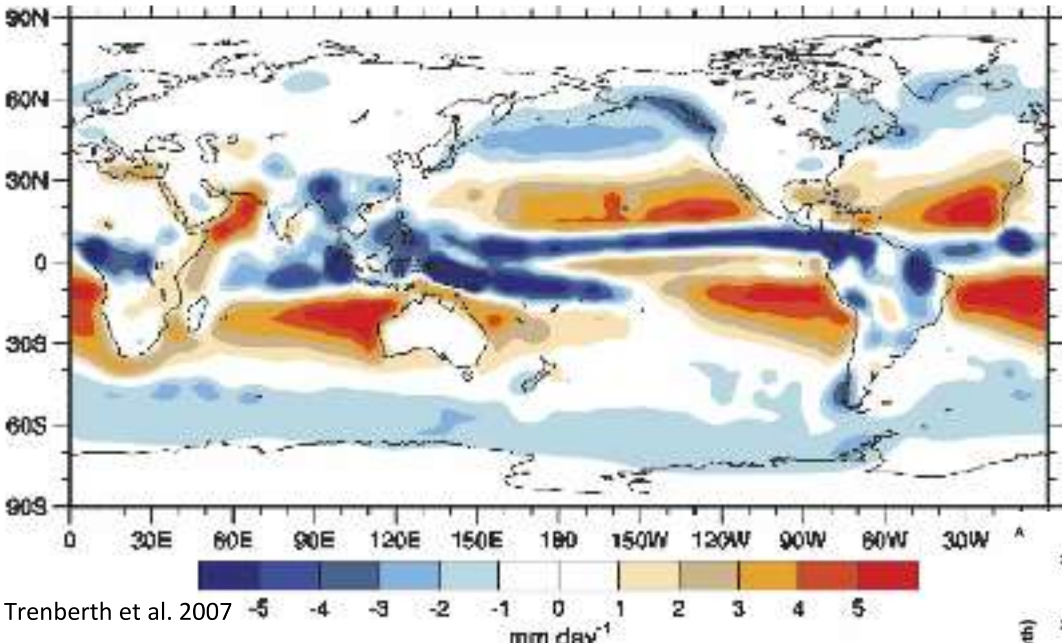




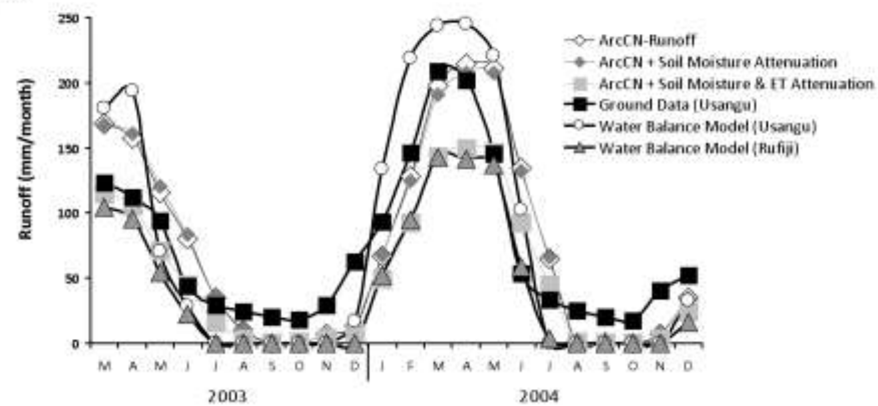
RUNOFF

$$Q = P - \Delta S - ET$$

ERA-40 Mean E-P (1979-2001) from moisture budget



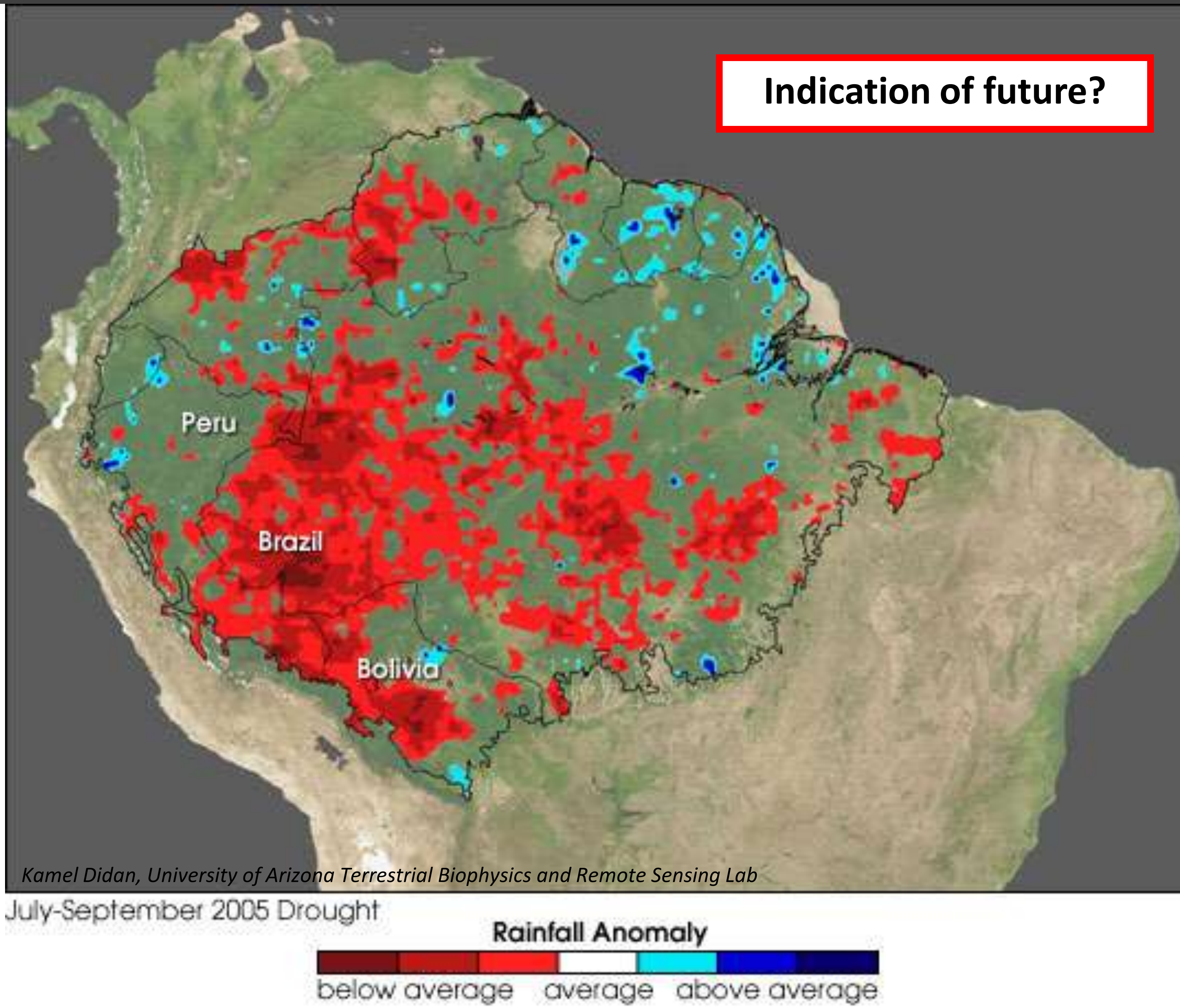
Trenberth et al. 2007



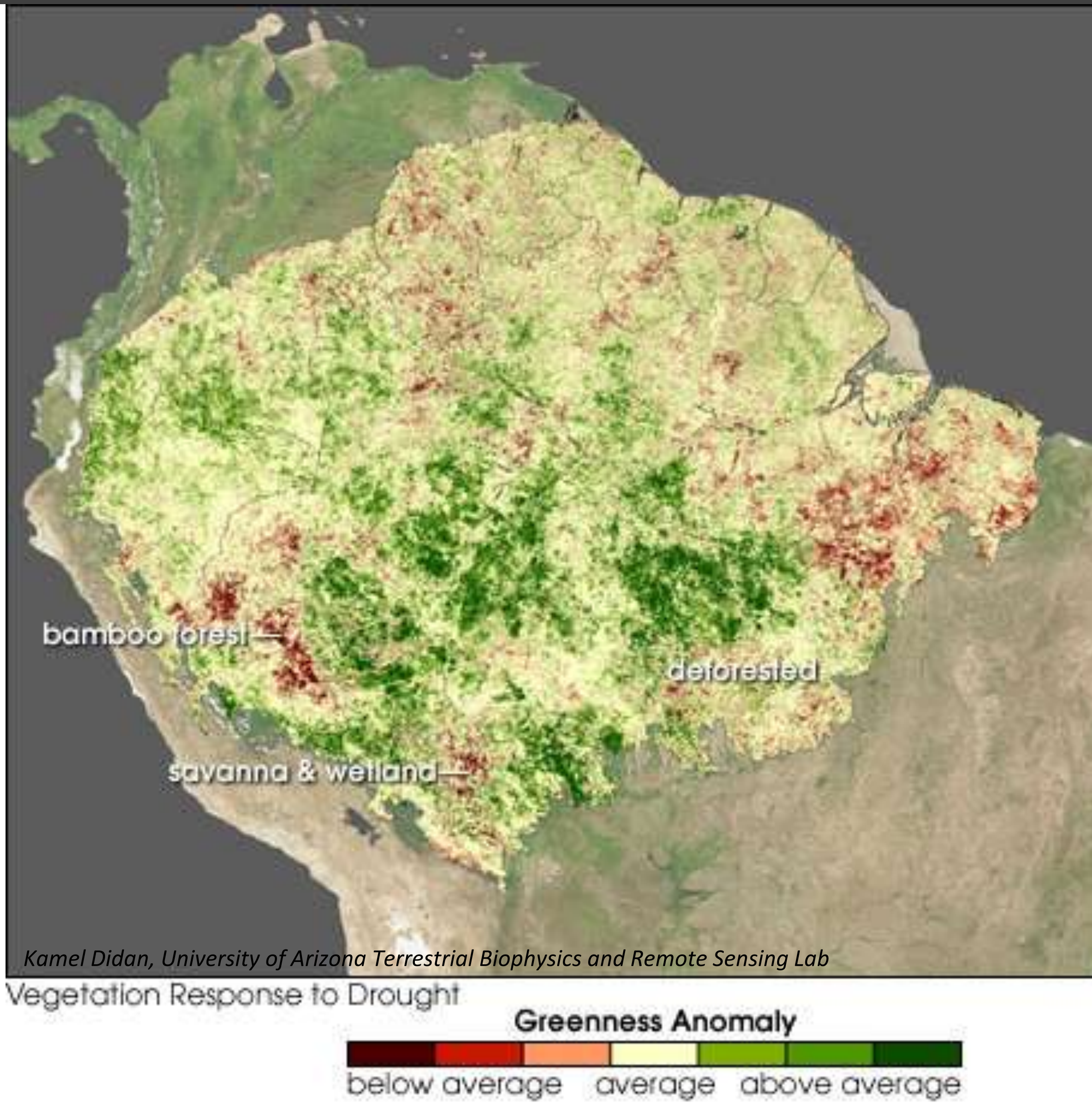
OUTLINE

- Precipitation
- Groundwater
- Soil moisture
- Snow
- Evapotranspiration
- Runoff
- Case study
  - *Drought Sensitivity of the Amazon*

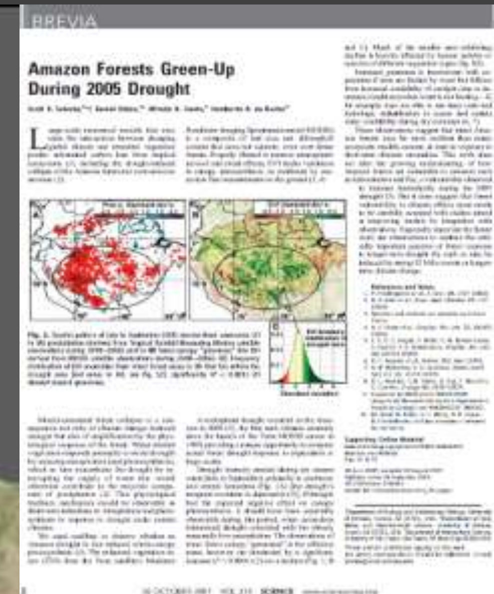
2005 DROUGHT



AMAZON GREEN-UP?



Kamel Didan, University of Arizona Terrestrial Biophysics and Remote Sensing Lab

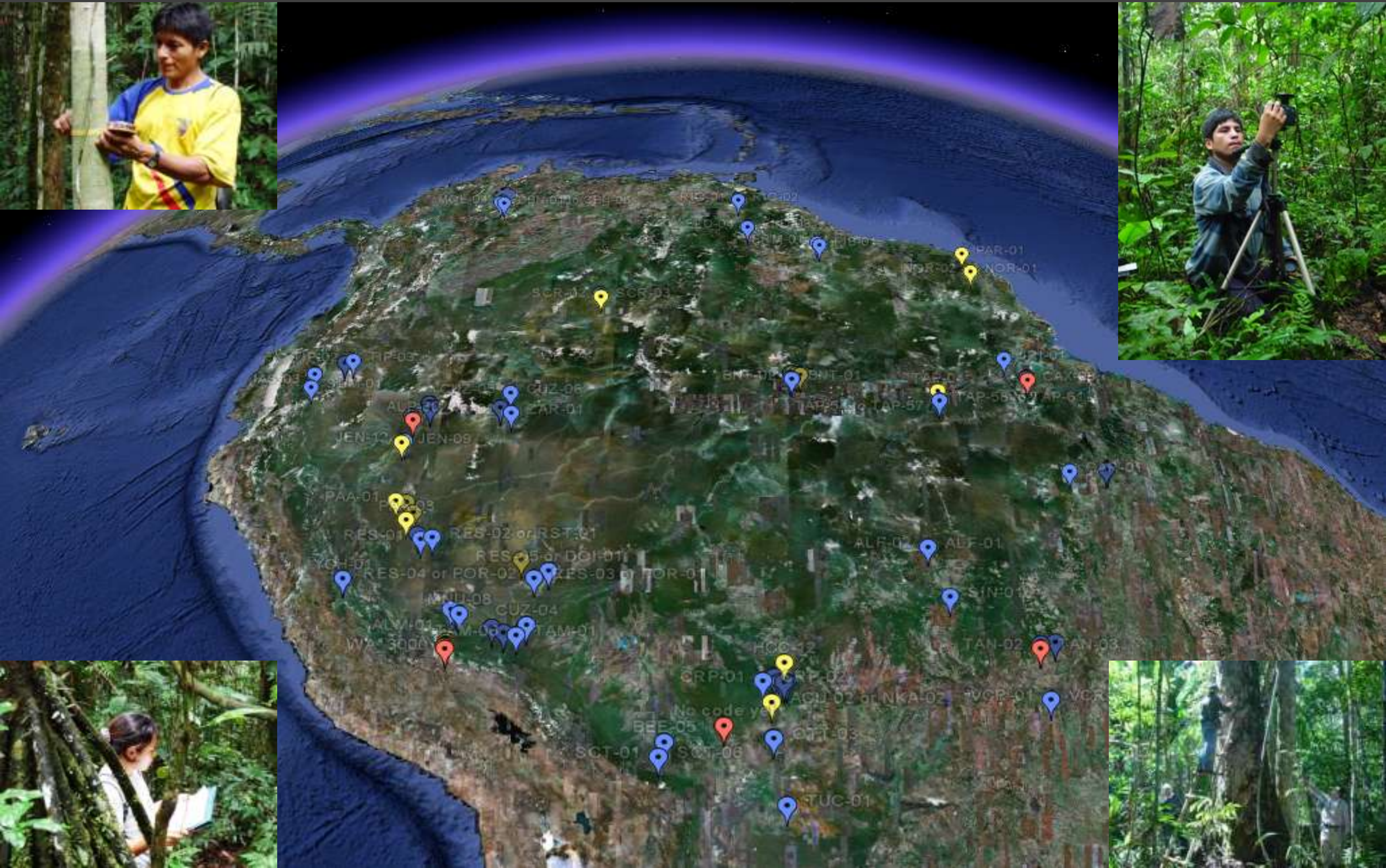


BREVIA

Amazon Forests Green-Up During 2005 Drought

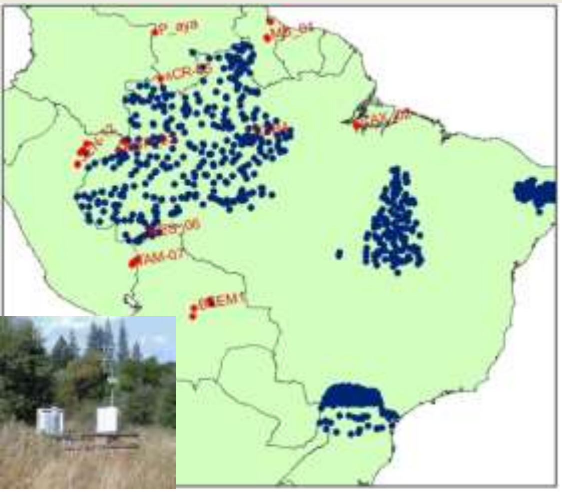
Amazon rainforests green-up with sunlight in dry season

RAINFOR



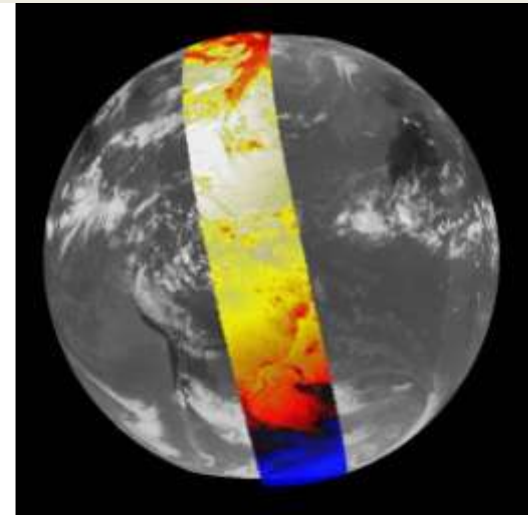
PAR-01
NOR-01
TAP-55
TAP-57
ALF-02
ALF-01
SIN-01
TAN-02
TAN-03
JEN-12
JEN-09
PAA-01
RES-01
RES-02 or RST-01
RES-05 or DOI-01
RES-04 or POR-02
RES-03 or TOR-01
CUZ-04
TAM-01
CRP-01
ACU-02 or NKA-02
BEE-05
SCT-01
SCT-06
OTR-03
TUC-01

DROUGHT SENSITIVITY



$$P = Q + ET + \Delta S$$

$$\Delta S = P - ET - Q$$



Clouds & the Earth's Radiant Energy System (CERES)

$f\{$

$R_n,$

$T_a,$

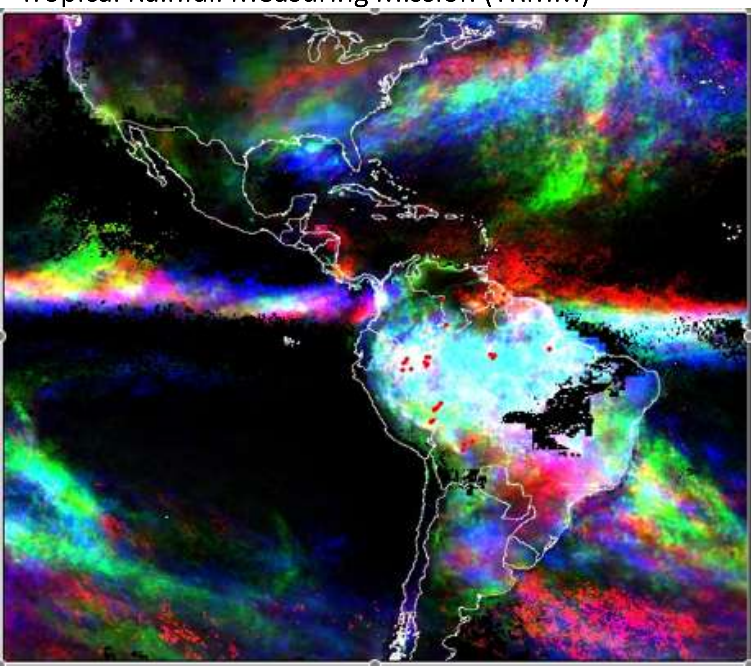
$RH/VPD,$

$NDVI/SAVI/EVI,$

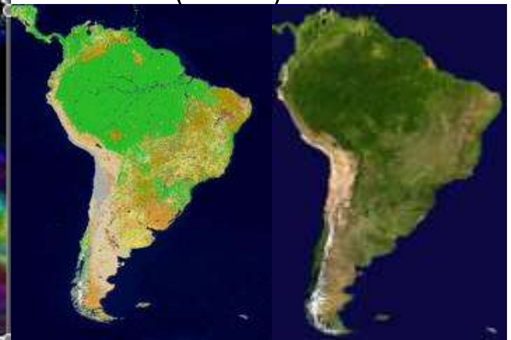
$\}$

Centro de Previsão de Tempo e Estudos Climáticos (CPTEC) w/ Geostationary Operational Environmental Satellites (GOES)

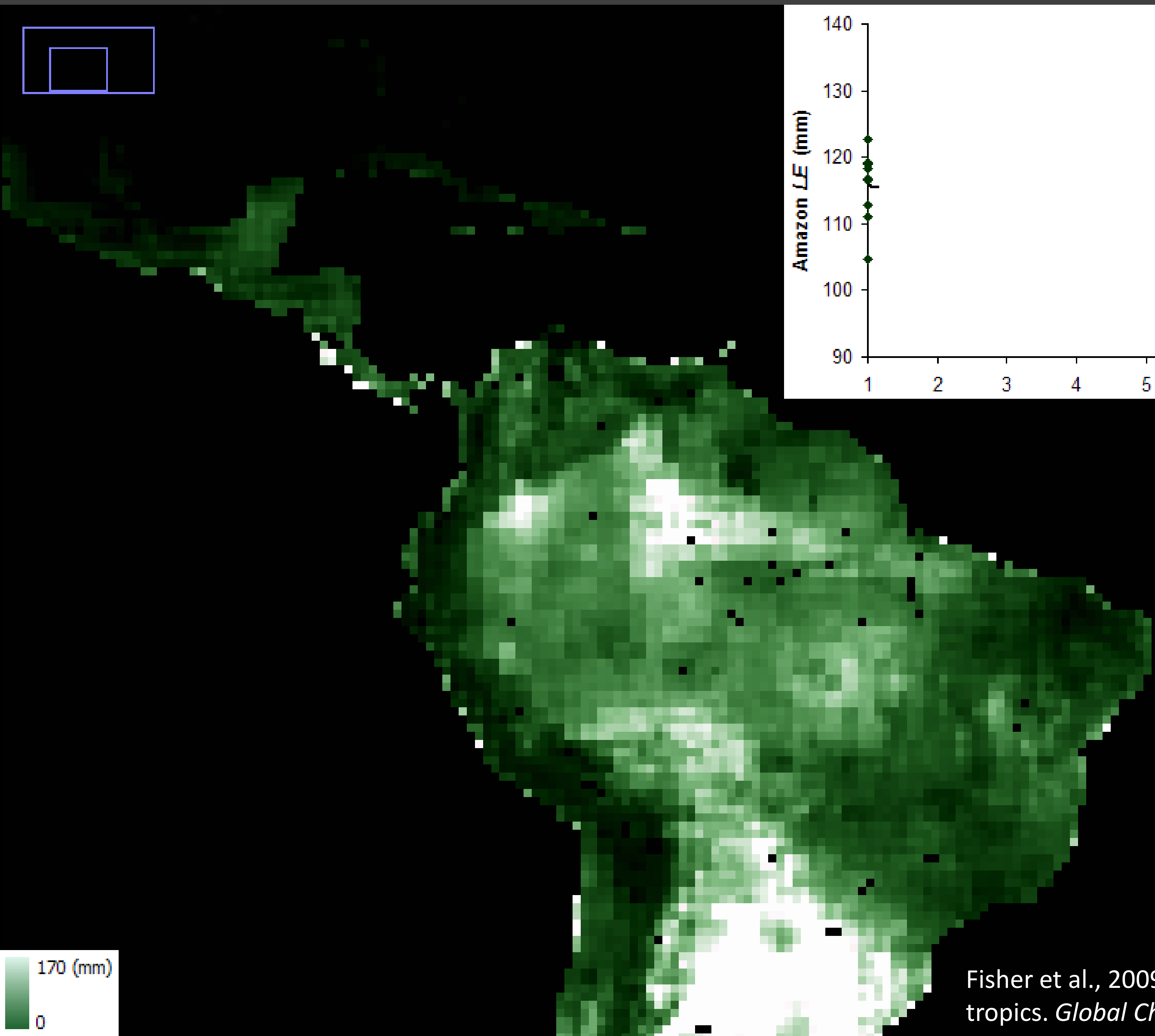
Tropical Rainfall Measuring Mission (TRMM)

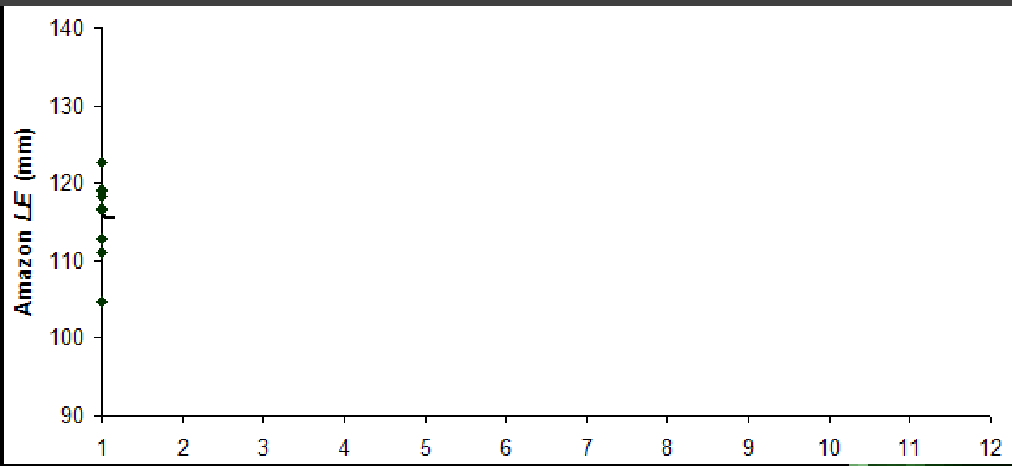


Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Very High Resolution Radiometer (AVHRR)



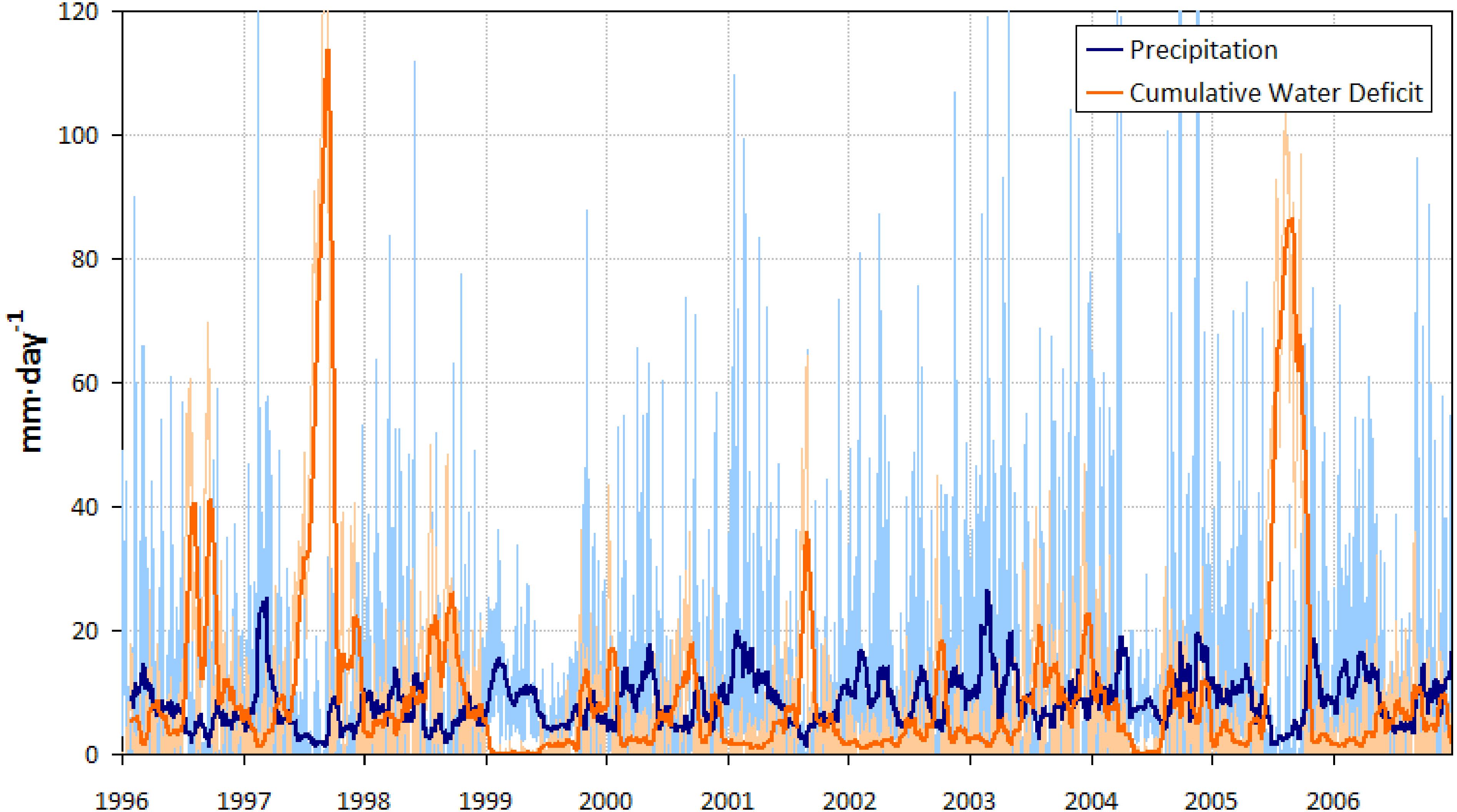
AMAZON ET





Fisher et al., 2009. The land-atmosphere water flux in the tropics. *Global Change Biology* 15: 2694-2714.

DROUGHT SENSITIVITY



DROUGHT SENSITIVITY

Drought Sensitivity of the Amazon Rainforest

Oliver L. Phillips,[1*] Luiz E. O. C. Aragão,[2] Simon L. Lewis,[1] Joshua B. Fisher,[2] Jon Lloyd,[1] Gabriela López-González,[1] Yadvinder Malhi,[2] Abel Monteagudo,[3] Julie Peacock,[1] Carlos A. Quesada,[1,4] Geertje van der Heijden,[1] Samuel Almeida,[5] Iêda Amaral,[4,6] Luzmila Arroyo,[7,8] Gerardo Aymard,[9] Tim R. Baker,[1] Olaf Bánki,[10] Lilian Blanc,[11] Damien Bonal,[12] Paulo Brando,[13,14] Jerome Chave,[15] Átila Cristina Alves de Oliveira,[4] Nallaret Dávila Cardozo,[16] Claudia I. Czimczik,[17] Ted R. Feldpausch,[1] Maria Aparecida Freitas,[5]

Amazon forests are a key but poorly understood component of the global carbon cycle. If, as anticipated, they dry this century, they might accelerate climate change through carbon losses and changed surface energy balances. We used records from multiple long-term monitoring plots across Amazonia to assess forest responses to the intense 2005 drought, a possible analog of future events. Affected forest lost biomass, reversing a large long-term carbon sink, with the greatest impacts observed where the dry season was unusually intense. Relative to pre-2005 conditions, forest subjected to a 100-millimeter increase in water deficit lost 5.3 megagrams of aboveground biomass of carbon per hectare. The drought had a total biomass carbon impact of 1.2 to 1.6 petagrams (1.2×10^{15} to 1.6×10^{15} grams). Amazon forests therefore appear vulnerable to increasing moisture stress, with the potential for large carbon losses to exert feedback on climate change.

Large-scale on-the-ground assessments of the ecological impacts of tropical droughts are completely lacking, precluding tests of these ideas.

In 2005, large areas of the Amazon Basin experienced one of the most intense droughts of the past 100 years (*18*), providing a unique opportunity to directly evaluate the large-scale sensitivity of tropical forest to water deficits. The 2005 event was driven not by El Niño, as is often the case for Amazonia, but by elevated tropical North Atlantic sea surface temperatures

OUTLINE

- Precipitation
- Groundwater
- Soil moisture
- Snow
- Evapotranspiration
- Runoff
- Case study
  - *Drought Sensitivity of the Amazon*