Food Security in a Changing Climate

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NASA/Goddard Earth Sciences Division

Food Security in a Changing Climate

Why NASA?

How is Earth's climate changing?

Why is Earth's climate changing?

How are humans affecting Earth's climate?

How is this affecting the availability of food?

What is the outlook for the future?

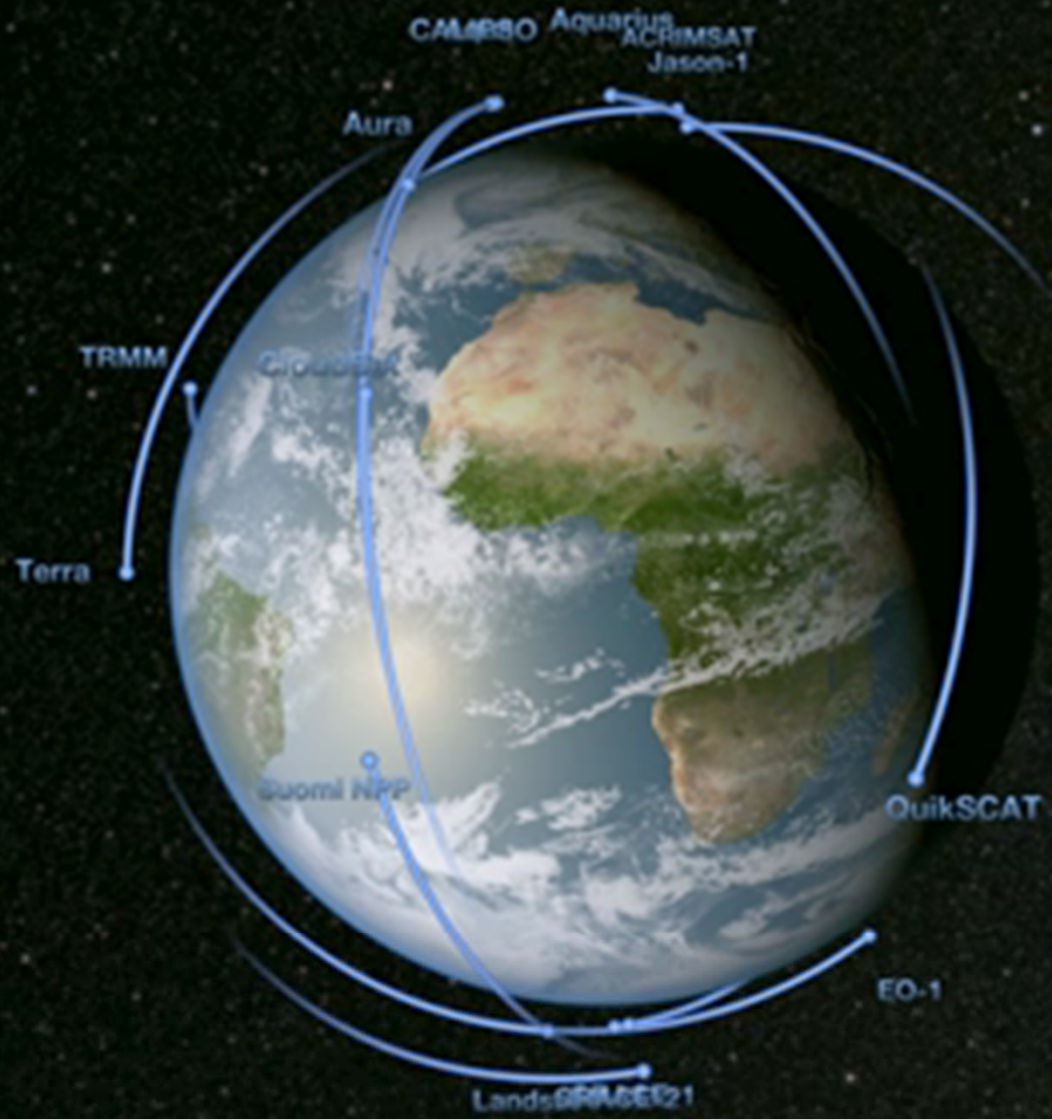
What about differences of opinion concerning climate ?

Why NASA?
The Need for Satellite Observations

- Ground-based measurements of climate:
  - are insufficient and declining
    - particularly outside N. America and Europe
  - lack the uniform calibration needed to assess climate variability and change

- Satellite-based observations of Earth's global climate:
  - provide uniform global coverage
  - can be calibrated against validating measurements
    - Ground and airborne
  - explain climate change forcing:
    - Radiation, Aerosols, Atmospheric chemistry, Global ocean circulation, Clouds explain climate change impacts:
    - Sea level rise, Ozone depletion, Sea ice depletion, Ice sheet melt, Mountain glacier melt, Air quality, Polar bear habitat, Longer growing season in high latitudes and on high mountains

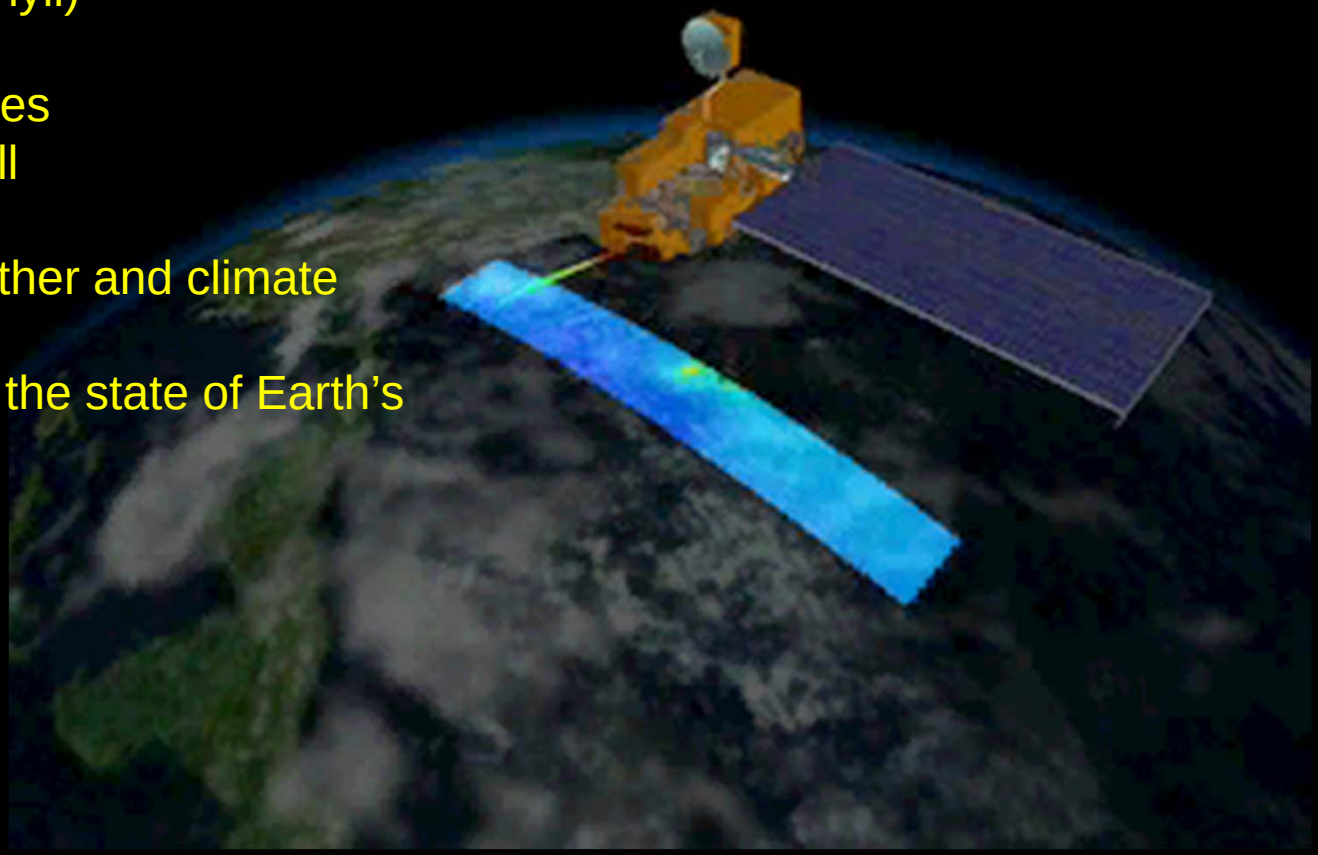
Satellite measurement of Earth properties



Multiple satellites measure a wide variety of earth processes:
winds, temperatures, clouds, pollution, ocean, and land surface
Data are used for weather and climate predictions

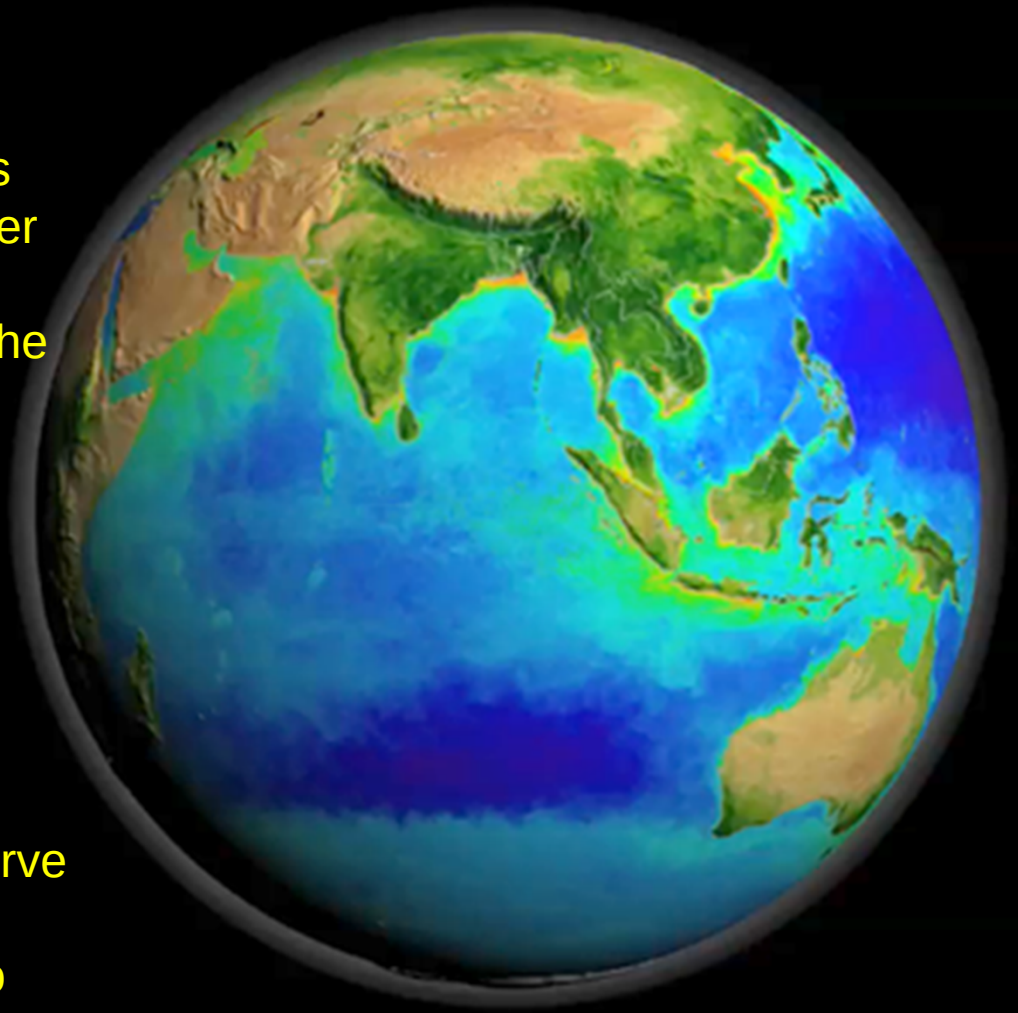
Satellite measurement of Earth properties

- Cross-track scanners measure:
  - Surface temperature (land and sea)
  - Atmospheric temperature and humidity
  - Plant life (chlorophyll)
  - Ocean winds
  - Atmospheric gasses
  - Clouds and rainfall
  - … and lots more
- Data are used for weather and climate predictions
- and for understanding the state of Earth's biosphere



Satellite measurement of Earth properties

Data from satellites are stitched together in a computer to make a picture of the whole Earth.

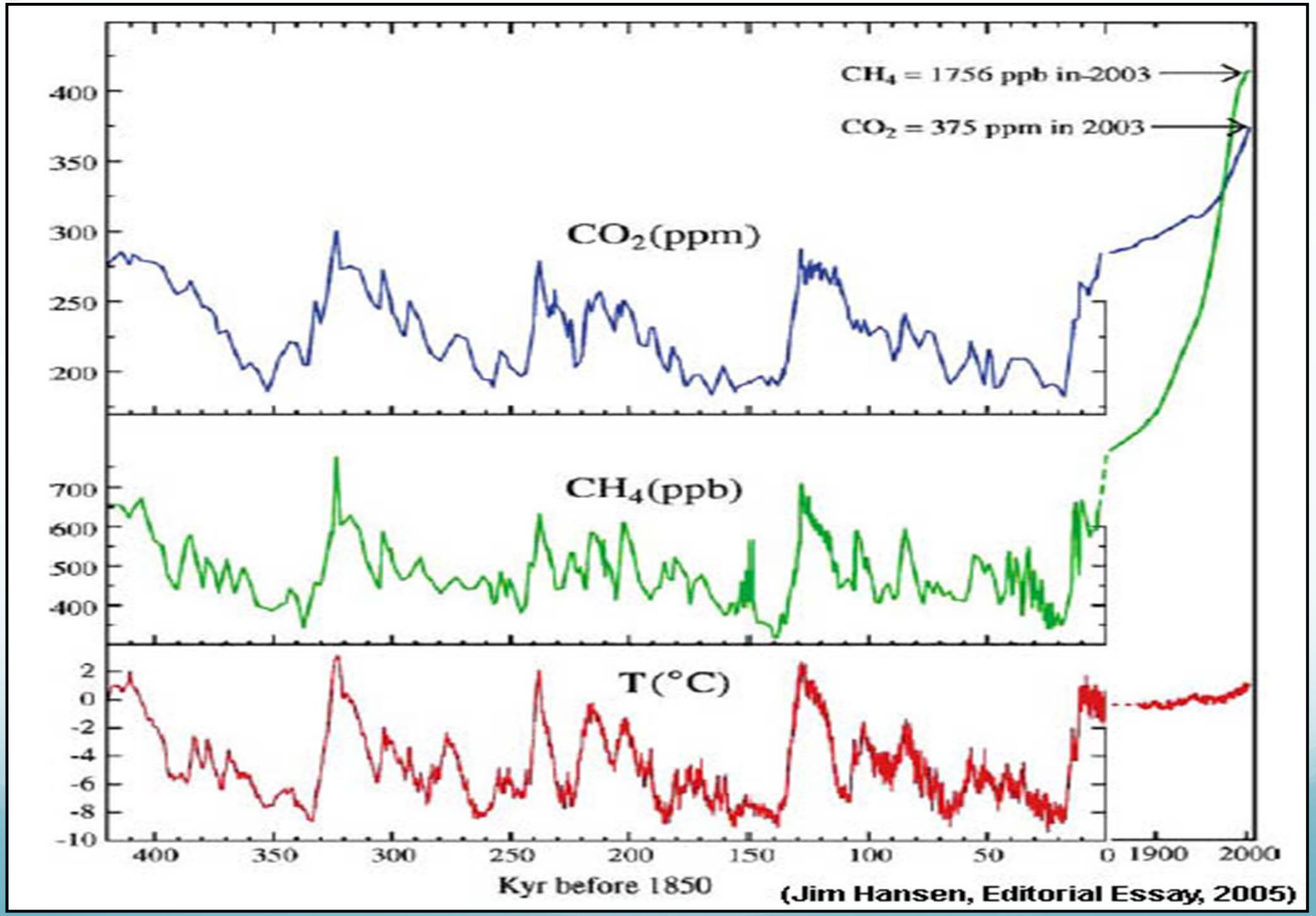


NASA satellite data are used worldwide to better understand the Earth and how it operates.

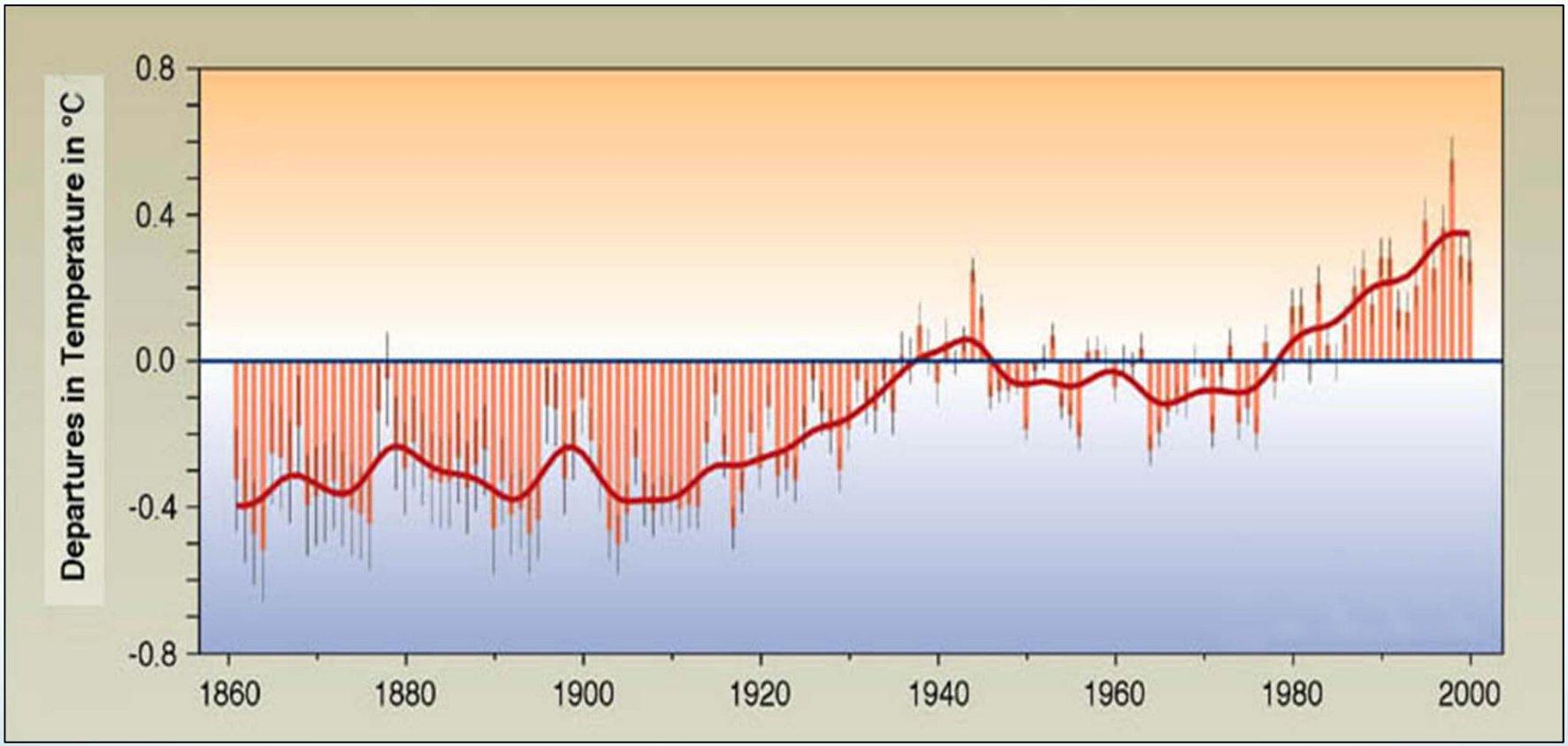
The satellites observe the full Earth more than once a day so we can measure night and day-time events.

We support the NOAA weather service and many other Agencies with our Earth observations.

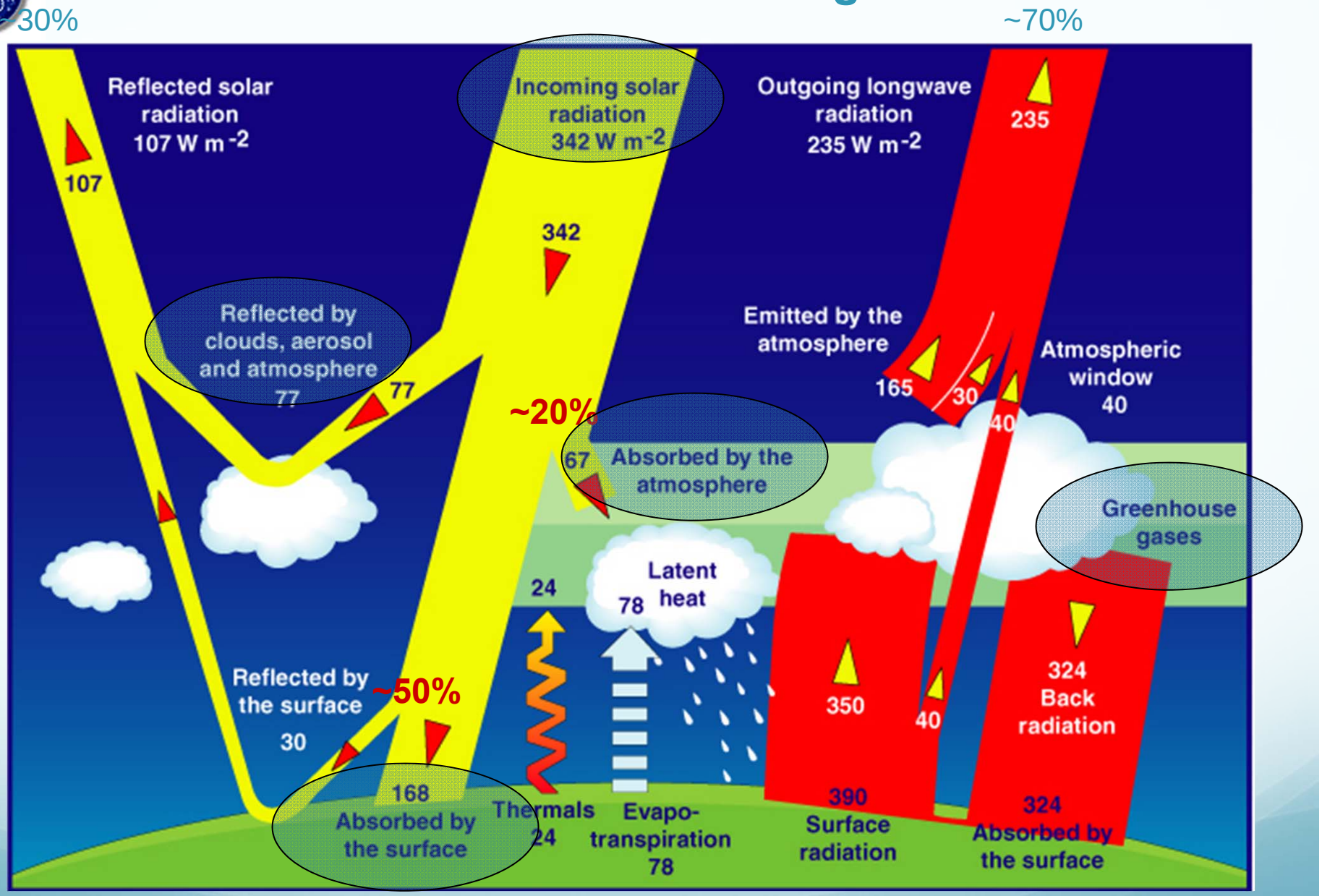
Global Climate and Climate Change



Global Climate and Climate Change

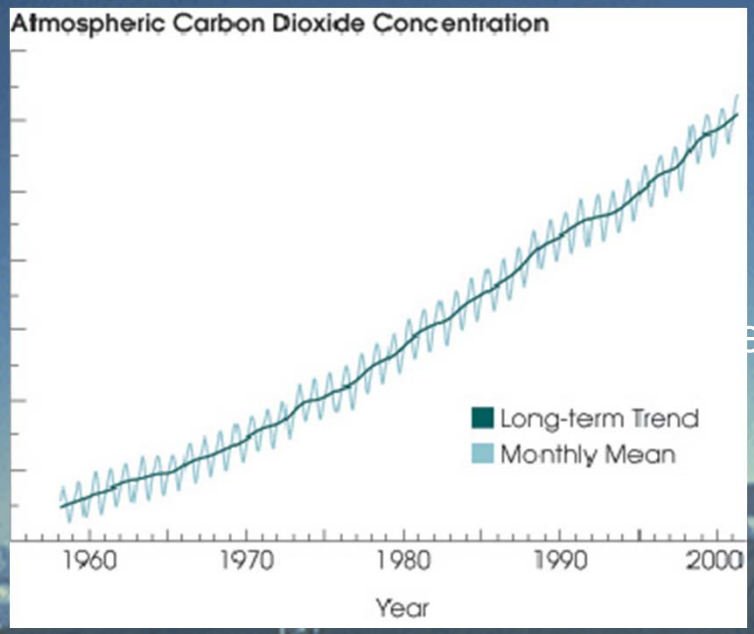


The Earth's Radiation Budget



(adapted from Kiehl and Trenberth, 1997, by the CERES Science Team)

Greenhouse Gases?



- Greenhouse gas concept known since 1820s:
  - Joseph Fourier (1824, 1827)
  - John Tyndall (1861)
  - Svante Arrhenius (1896)
- David Keeling measured CO_2 on top of Mauna Loa
  - CO_2 is increasing each year

  - High CO_2 values = northern winter
  - Low CO_2 values = northern summer, (when trees are growing)

Radiative Forcing of Climate Change

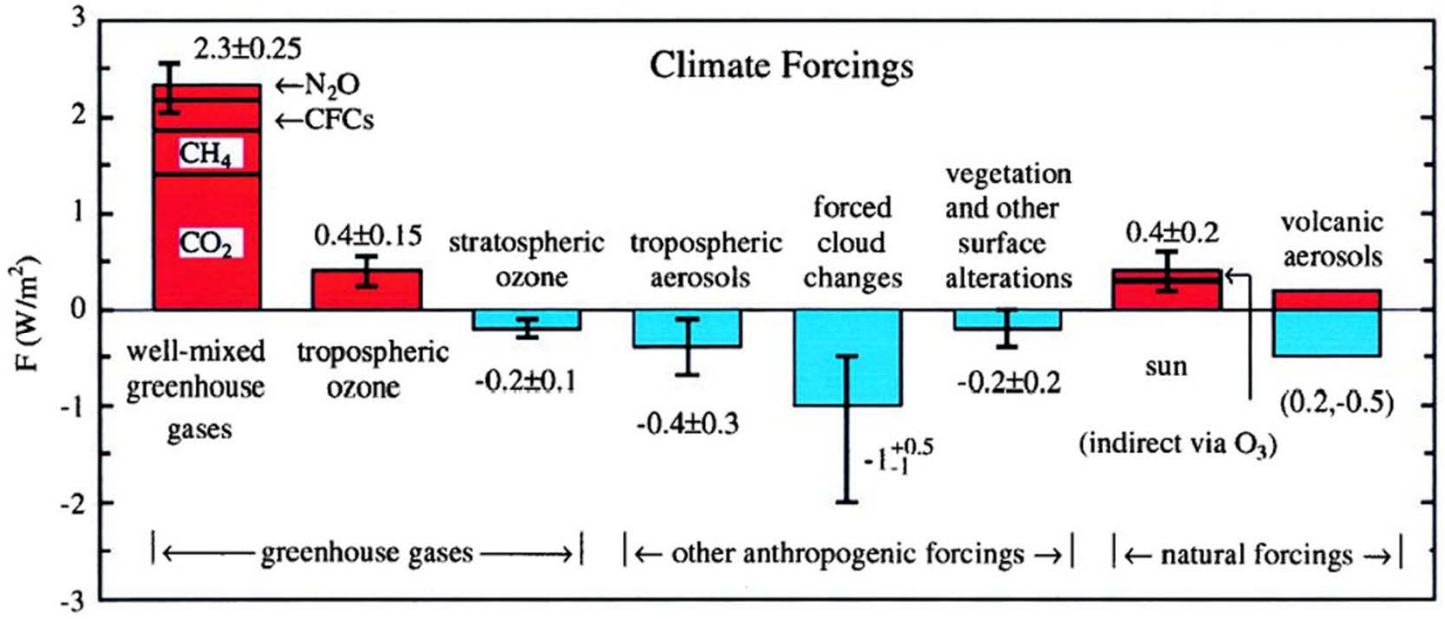


FIG. 2. Estimated radiative forcings between 1850 and the present.

Climate Change Forcing in the Industrial Era (1850-2000)

- ► CO_2 Is Largest Forcing
- ► Air Pollutants (O_3, CH_4, BC) Cause Large Forcing
- ► Aerosol Effects (direct + on clouds) Most Uncertain

Conclusion: CO_2 Largest Forcing, But Others Significant

References:

►**Trends of measured climate forcing agents**, *Proc.Natl.Acad.Sci.*, 98, 14778, 2001.

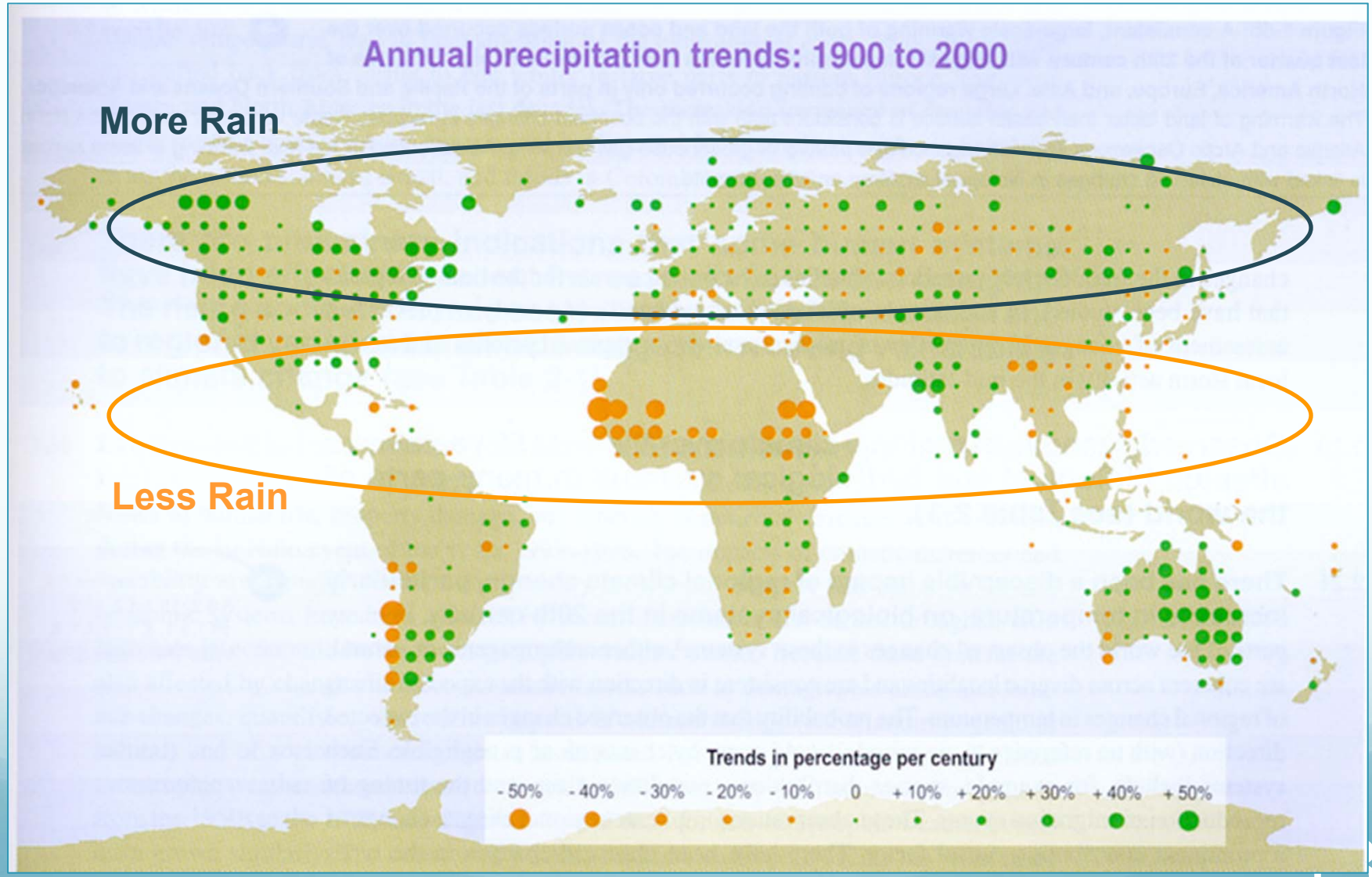
►**Efficacy of climate forcings**, *J. Geophys. Res.*, in press, 2005.

Source: NASA/GISS

With a hotter Earth, what has happened to water resources?

- Precipitation
- Storm intensity
- Snowfall
- Runoff
- Ice sheets and glaciers
- Sea level

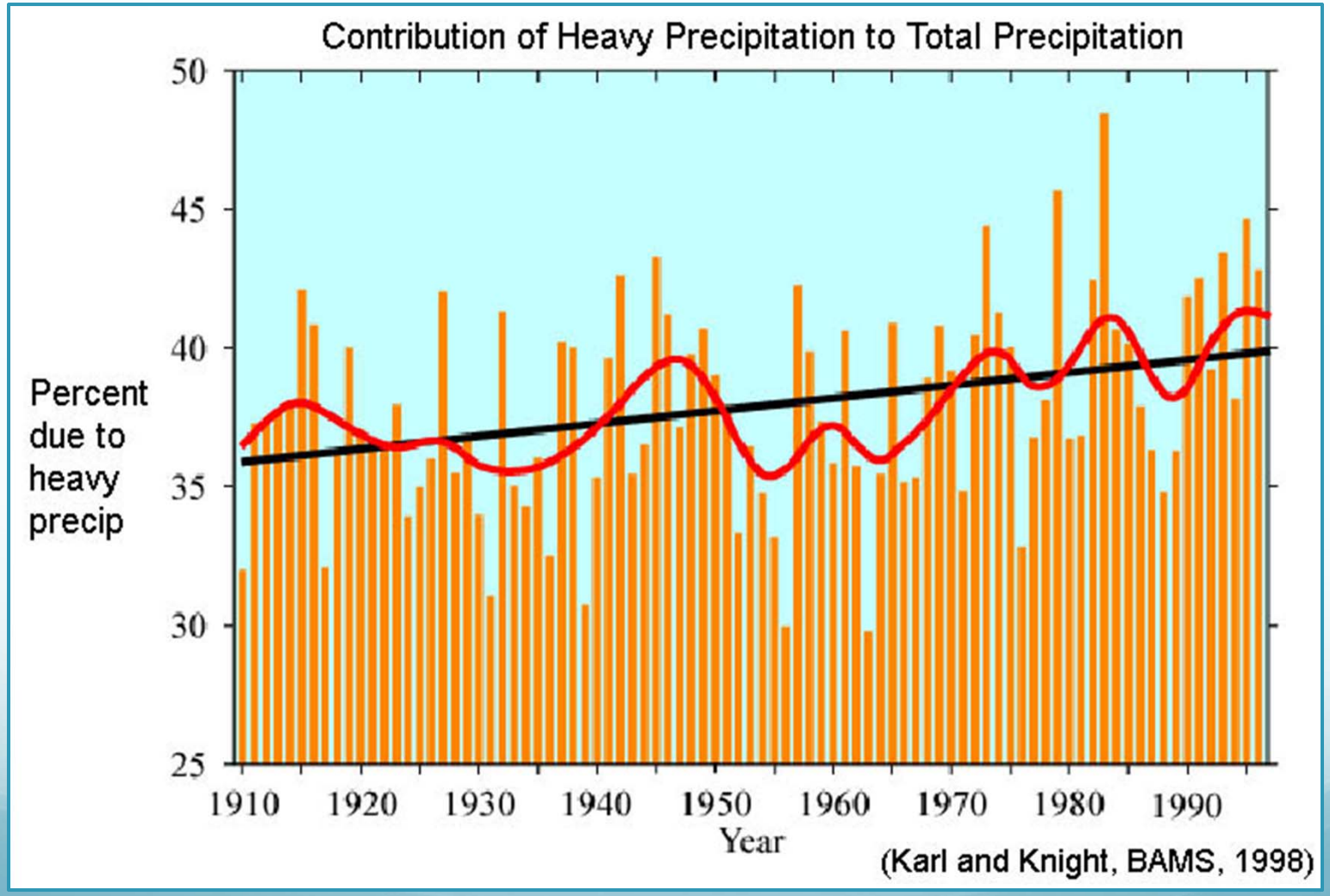
Changes in Precipitation



Source: IPCC

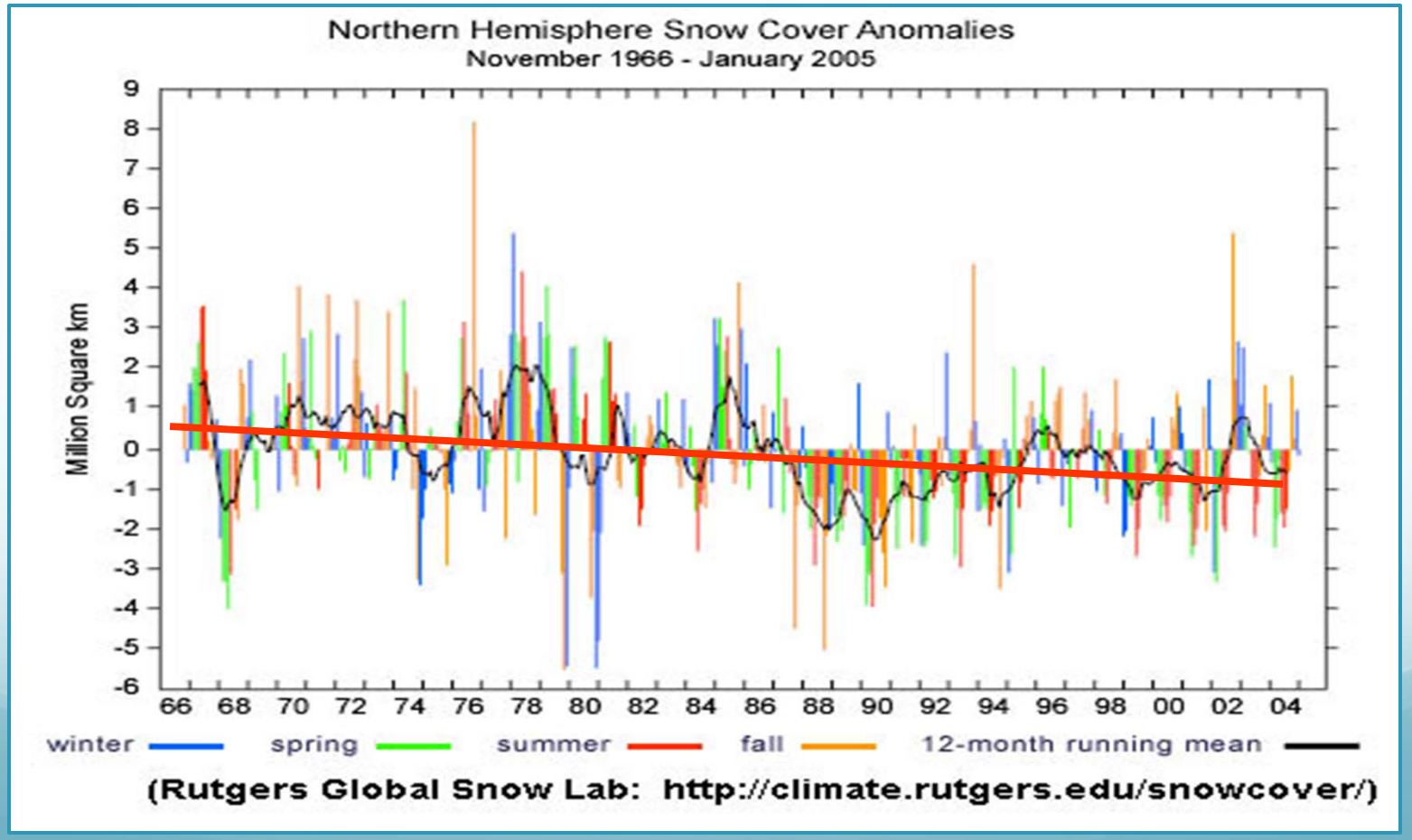
Rainfall Intensity Increases

- More days with rainfall
- Heavier rainfall
- Rainfall increases due to strong events

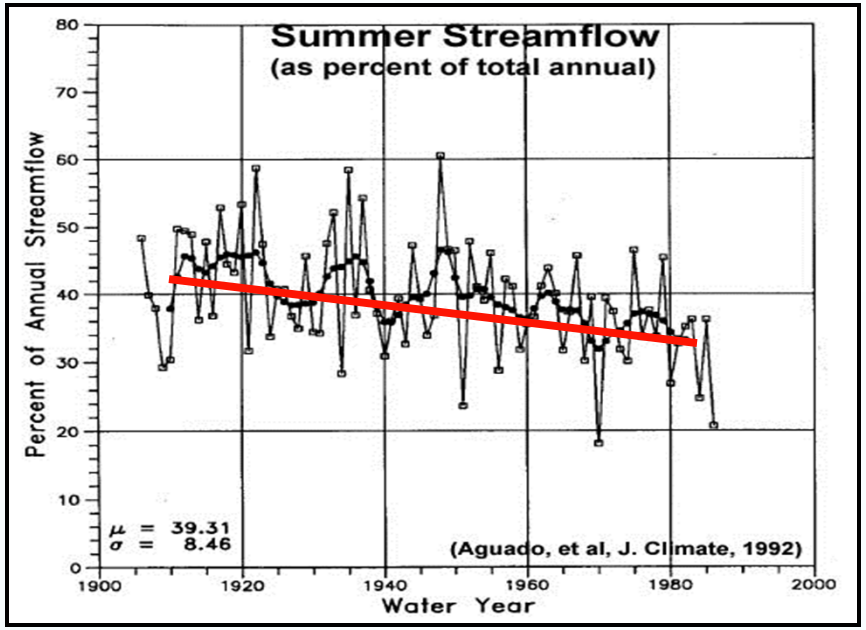


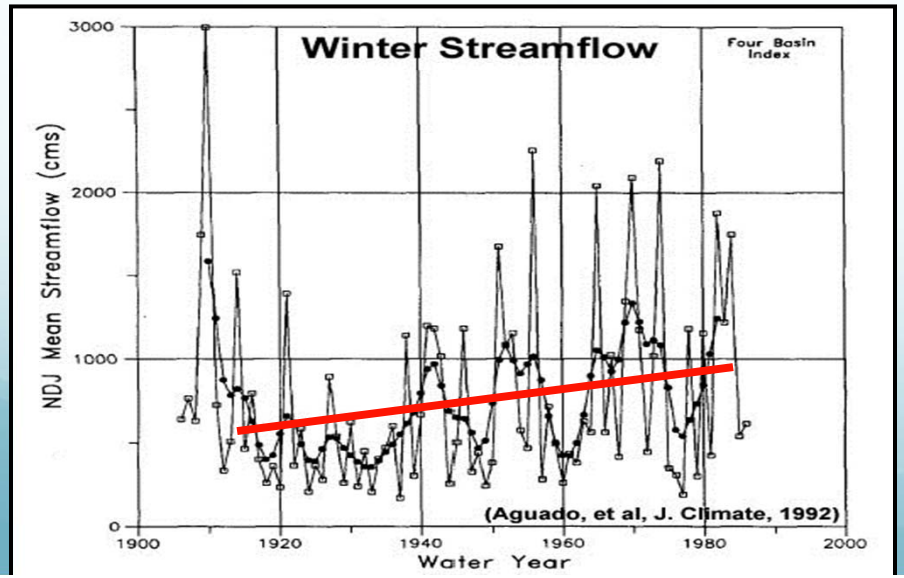
Decreased snow cover:

- Snow starts later in season
- Snow melts earlier
- Snow cover reduced 1-2 days/yr since early 1970's
- More precipitation is rain
- Water storage in snow pack is reduced



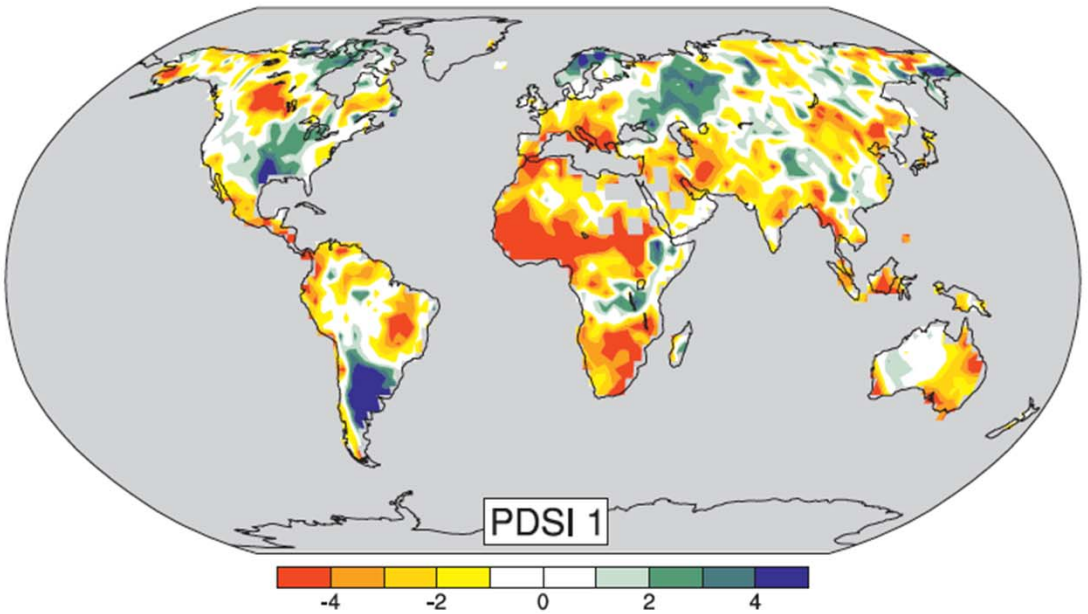
Runoff Changes in Spring and Fall

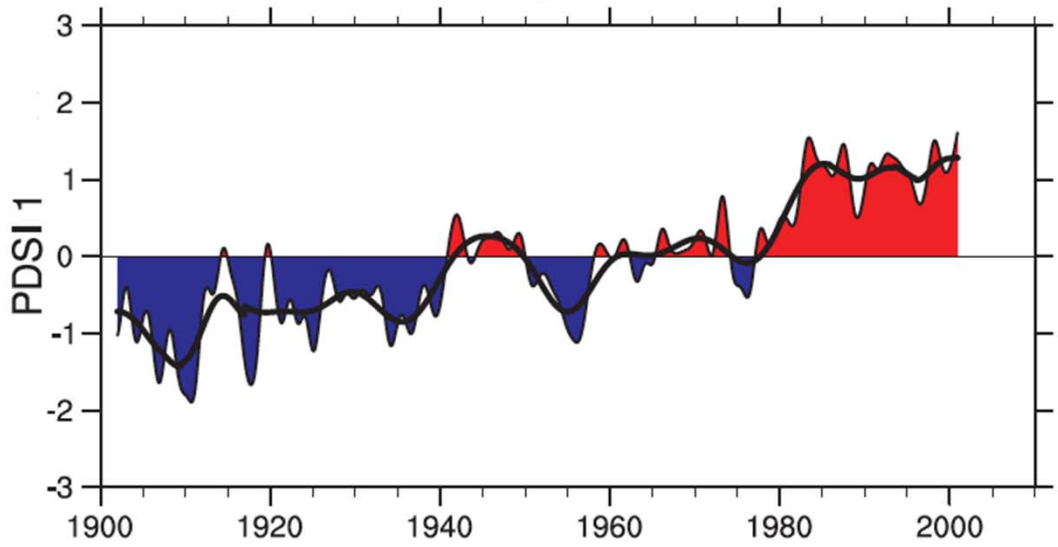




- As temperatures increase:
  - More precipitation falls as rain
  - Winter runoff is increased
  - Spring runoff pulse is earlier
  - Summer runoff is decreased

Frequency of drought increases



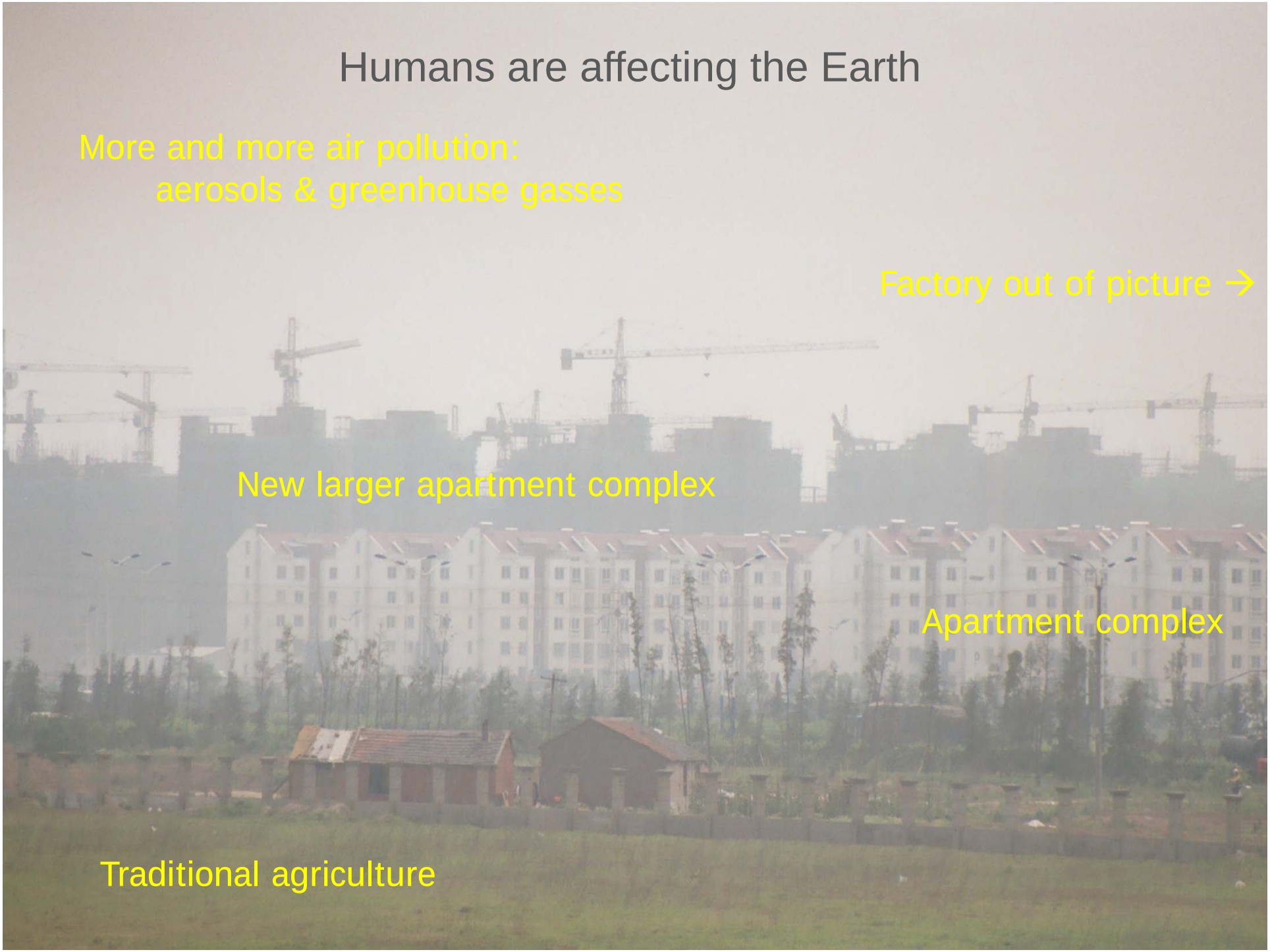


Source: IPCC

With a hotter Earth, what has happened to water resources?

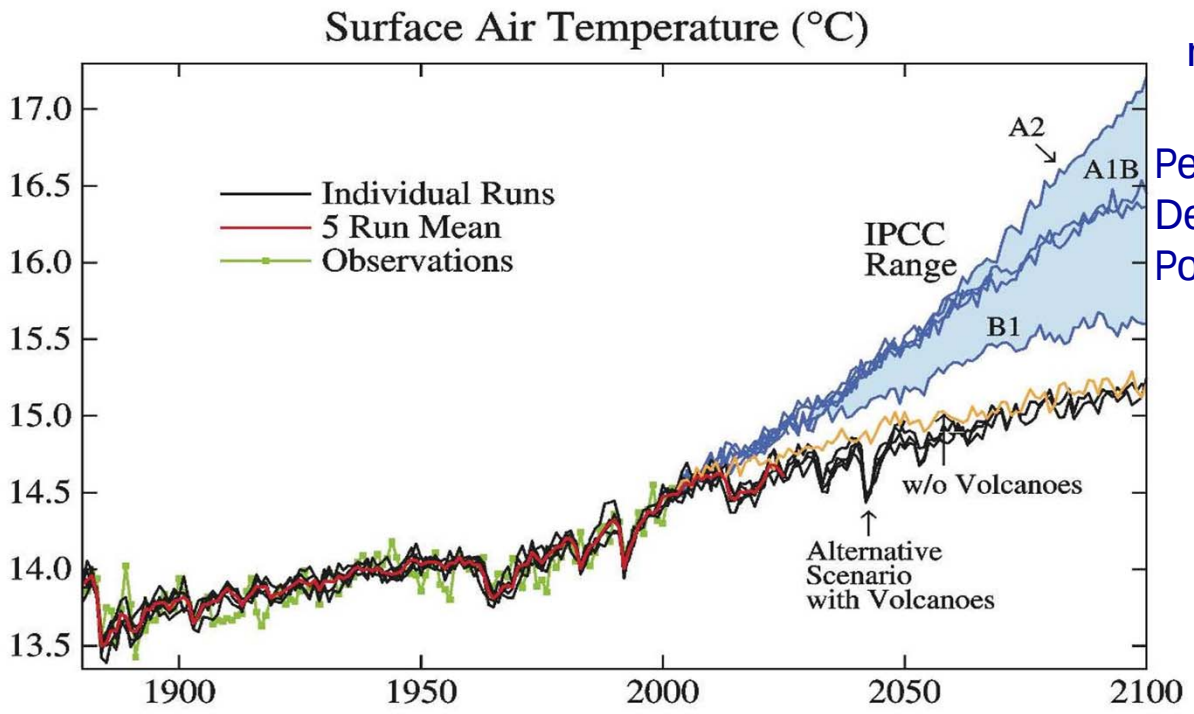
- Precipitation:
  - More & Heavier events
- Storm intensity
  - Stronger large scale weather patterns:
  - More intense storms
  - More droughts
- Snowfall decrease
  - Later freeze, earlier thaw
  - More precipitation as rain
- Earlier runoff
- Melting of ice sheets and glaciers
- Sea level rise

Humans are affecting the Earth



Climate Forecasting

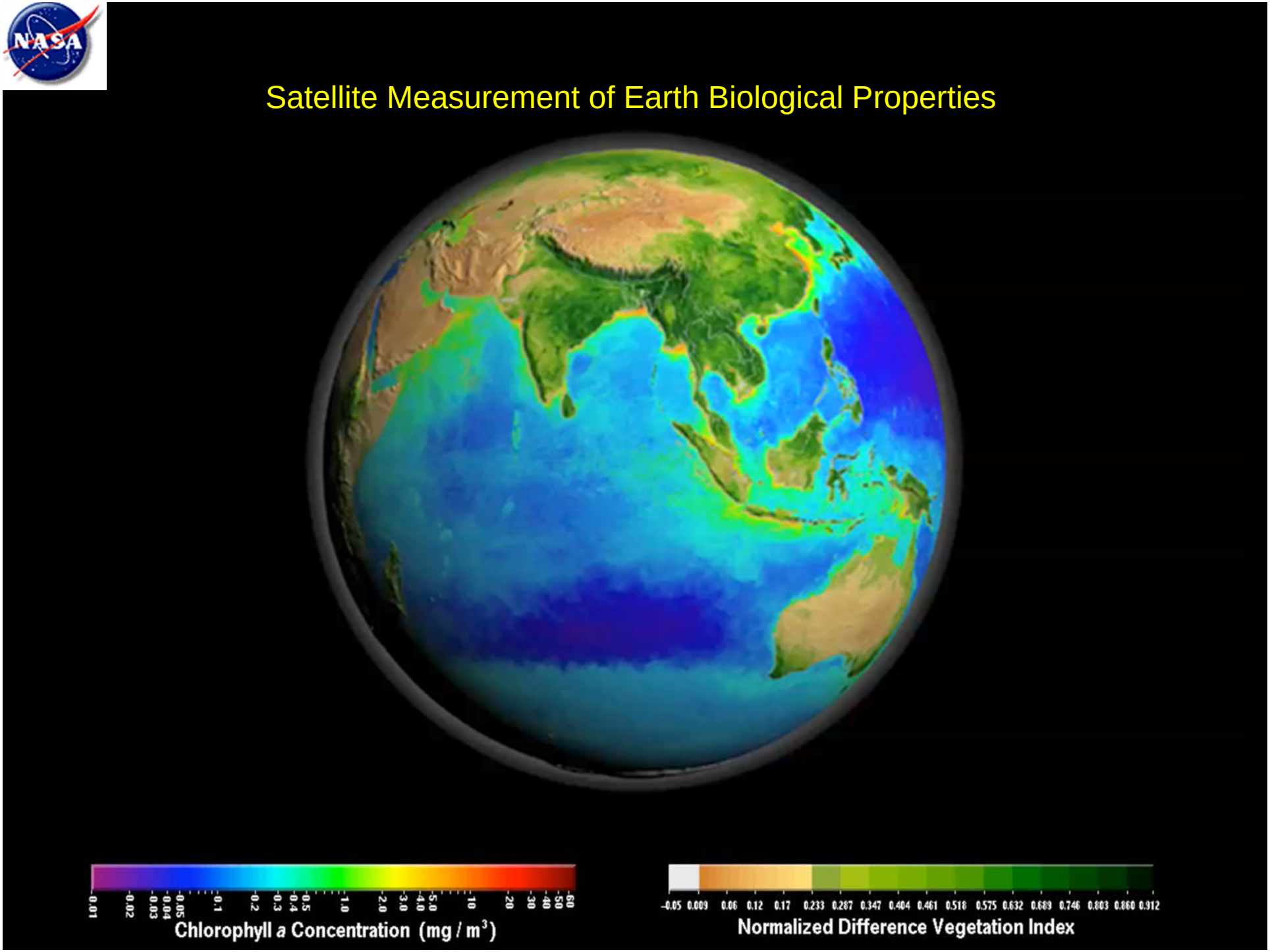
Global Climate Simulations



Climate Simulations for IPCC 2007 Report

- GISS Model Fits Observations Well for 1880-2003
  (but trade-off between sensitivity & forcing)
- Future Global Warming Depends Strongly on GHG Scenarios
  (but also depends on uncertain aerosol forcing)

Satellite Measurement of Earth Biological Properties



NASA Land Information System (LIS)

LIS Development:

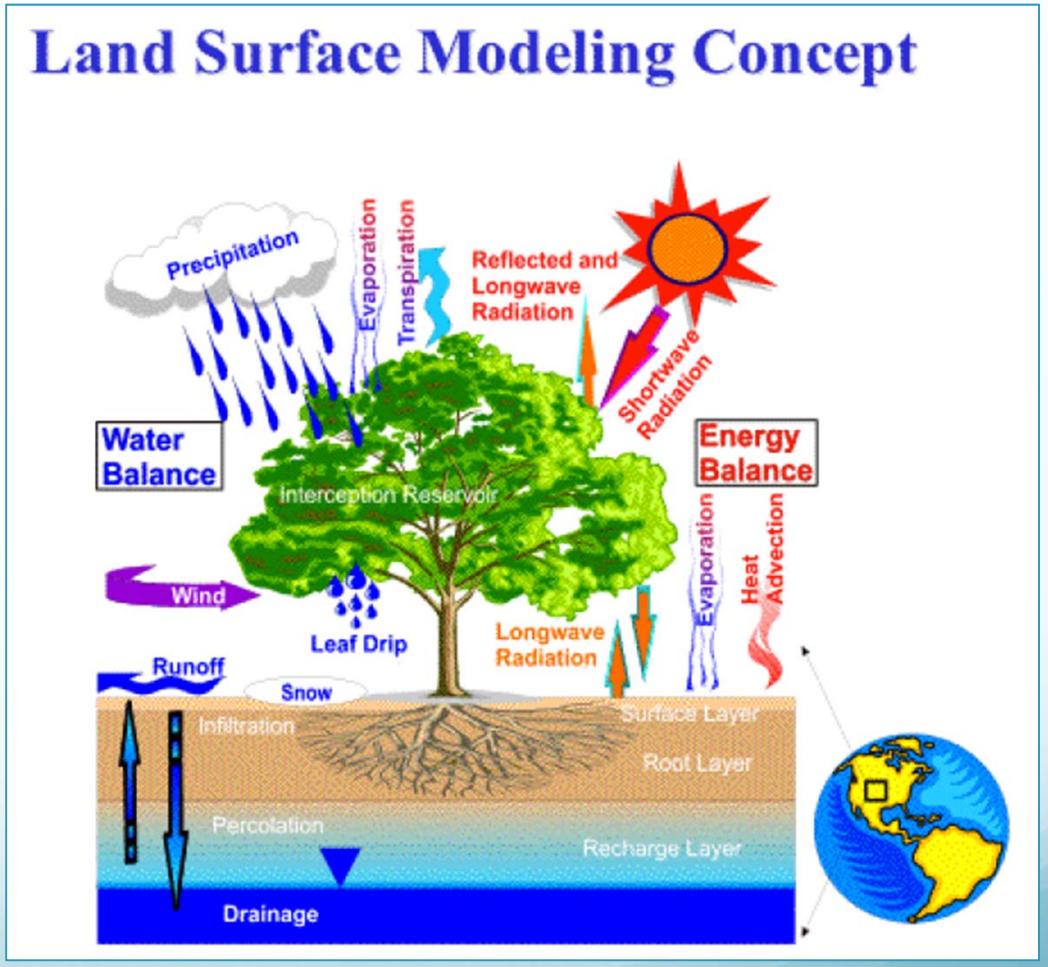
- Developed by Hydrological Sciences Lab

LIS Capabilities:

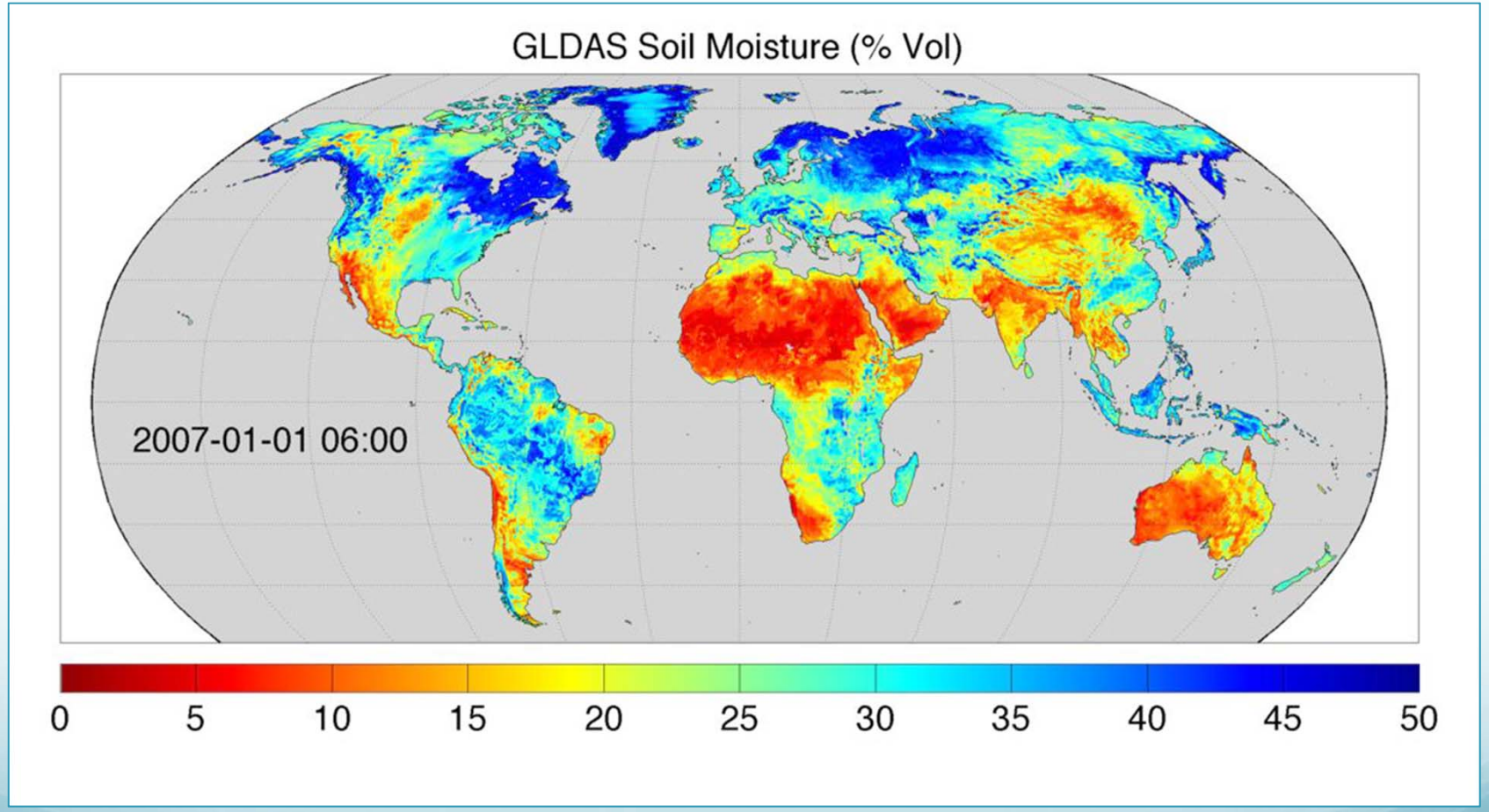
- High performance land surface modeling
- Land surface data assimilation
- Allows customized data assimilation for partiicular applications using standardized interfaces

LIS Operational Application:

- Operational weather forecasts by NOAA/NCEP, AFWA , NASA/GSFC

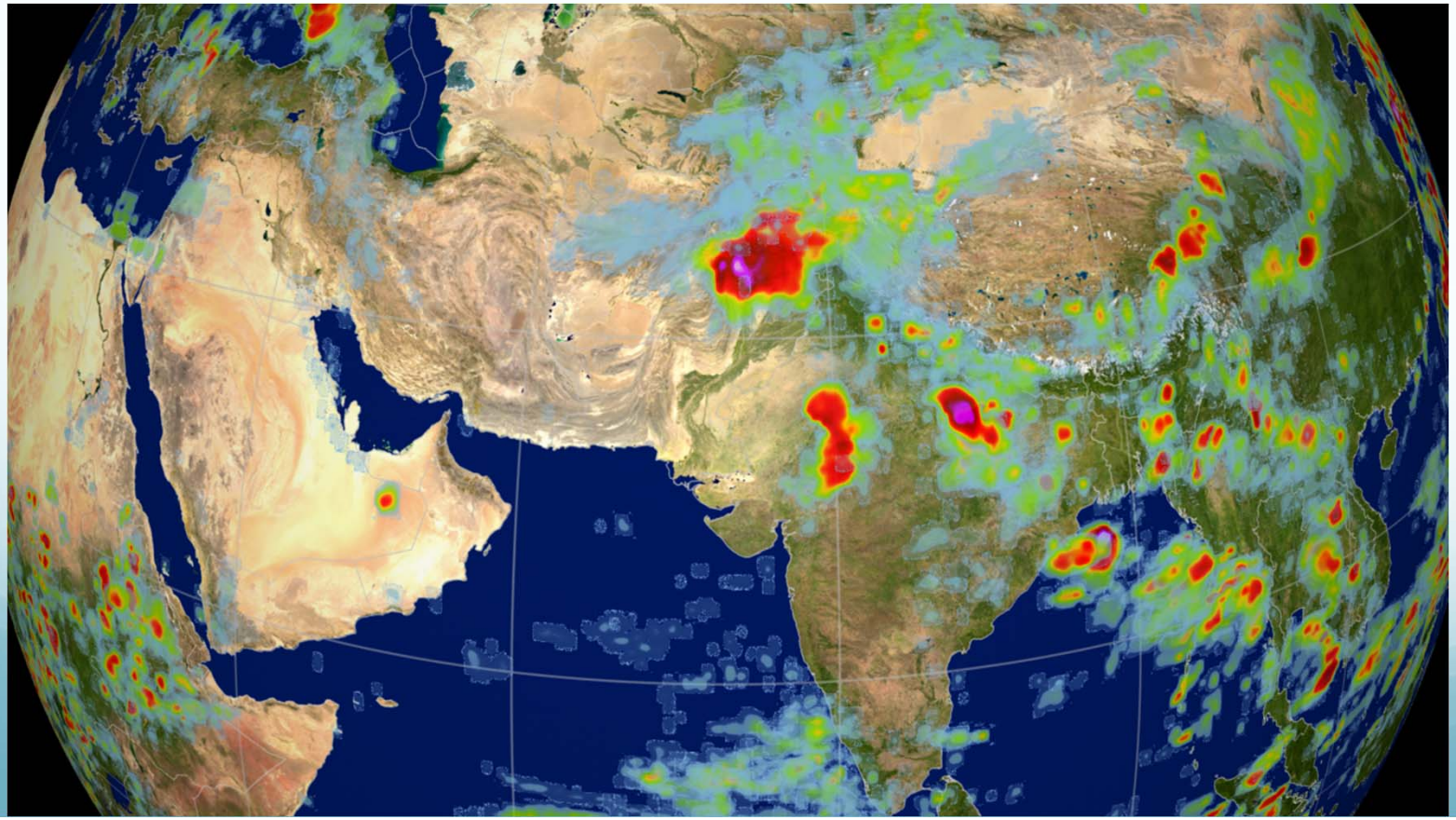


Soil Moisture products



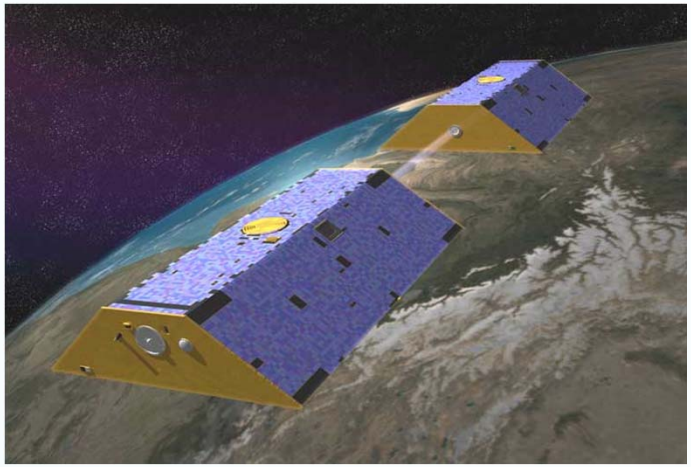
Rainfall data from satellites

Real-time rainfall data are being used for flood forecasting, but in many developing countries rain gauging stations are either not available or are to sparsely available to develop representative aerial samples. Satellite-derived rainfall products are useful for flood forecasting.

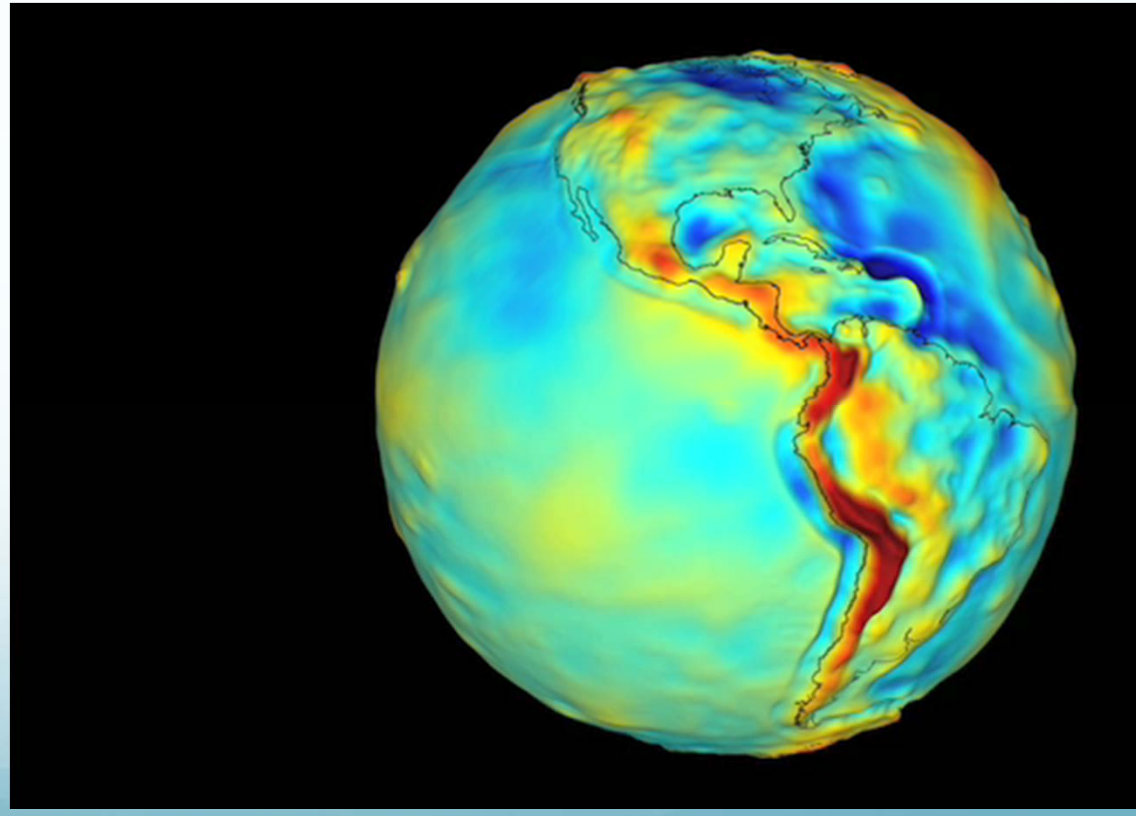


Flooding event in Pakistan and India, 2004

NASA GRACE*
Gravity Recovery and Climate Experiment



The Gravity Recovery and Climate Experiment measures the Earth gravity field using a pair of satellites.

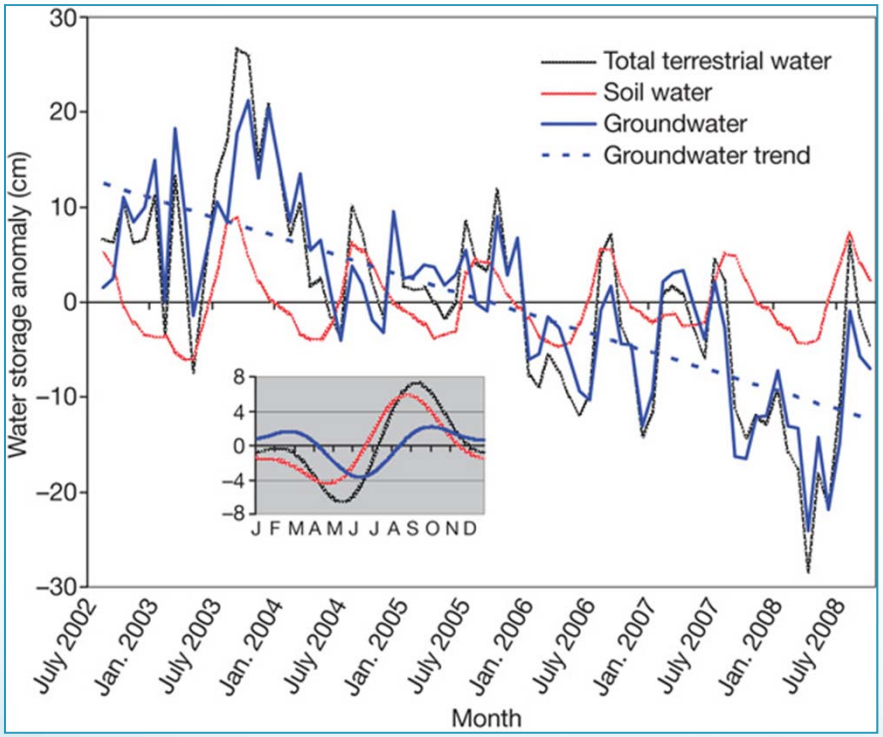


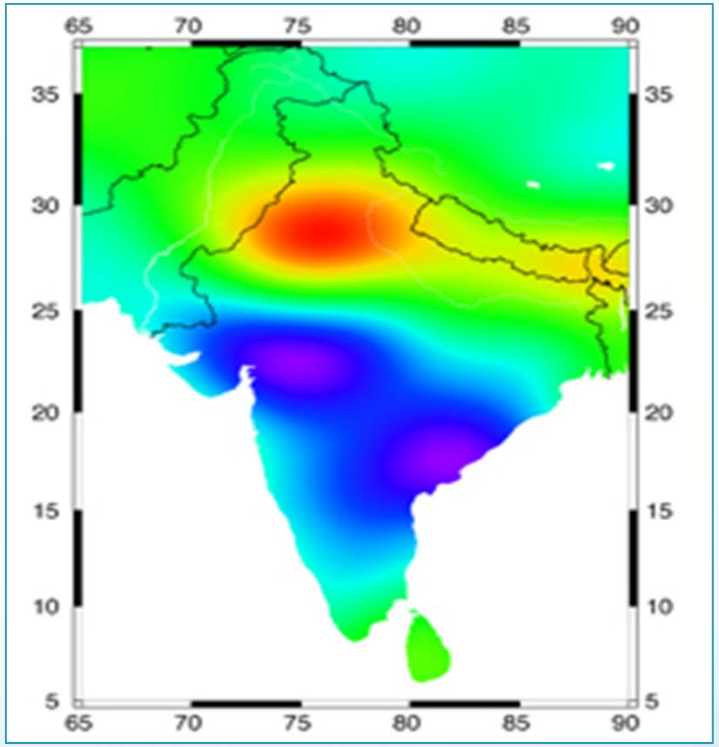
Earth's gravity field = geology + oceans + ice sheets + soil moisture + snow + ground water + ...

* GRACE is a joint partnership between NASA and DLR in Germany.

NASA GRACE*
Gravity Recovery and Climate Experiment

India's Disappearing Groundwater: observations by GRACE show regions that are losing centimeters of groundwater each year.





Monthly time series of anomalies of GRACE-derived total TWS, modeled soil-water storage and estimated groundwater storage, averaged over Rajasthan, Punjab and Haryana, plotted as equivalent heights of water in centimeters. Also shown is the best-fit linear groundwater trend. Inset, mean seasonal cycle of each variable. Credit: M. Rodell et al., Satellite-Based Estimates of Groundwater Depletion in India, Nature 460, August 2009

*Joint with DLR, Germany

NASA Land Surface Modeling

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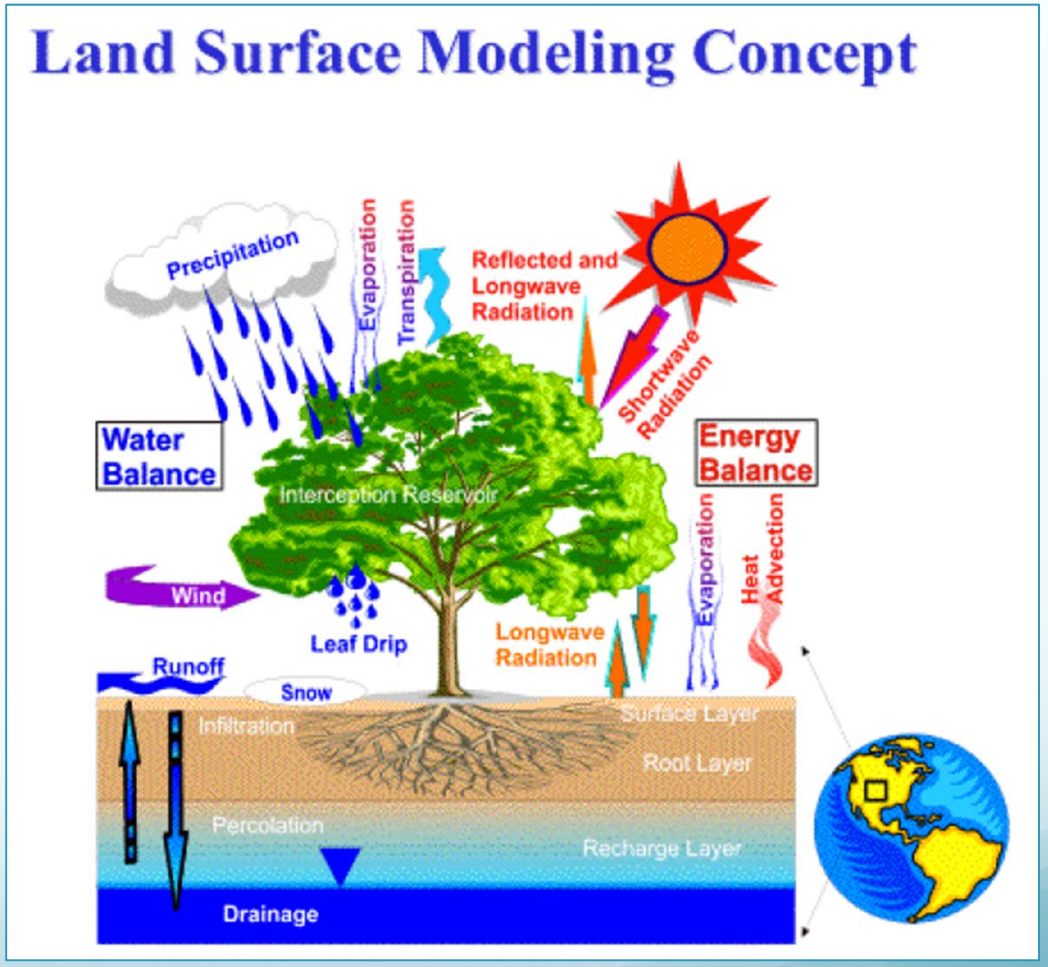
LIS Couples with Biospheric Data and Models to:

- Evaluate state of biosphere
- Forecast future changes



Why does NASA do research on food security?

- In 2012, over 40 companies sold the US Government 1.8 million tons and nearly $1b worth of food for use in its overseas programs
- US food was shipped to at least 48 countries
- NASA can help USAID to better target that assistance, and ensure that the food goes where it is needed, and not where it isn't
- Understanding the impact of drought and floods on food production requires high quality, global data

The Environment matters…

- Climate variability reduces predictability and increases the likelihood of extreme events
  - Risk of weather-related agricultural impacts growing
  - The need for information that is comparable, timely and global is increasing
- Satellite remote sensing is a starting point for information systems that can warn of abrupt changes to ecosystems
- Global food system is changing
  - Stronger links between food and fuel
  - Changing agriculture policies
  - Increasing use of commodities in investment portfolios
- External shocks from commodity prices, extreme events can have significant negative impact on agriculture and societal well being

Food Security

Food security is the ability of all people to attain and use sufficient food for an active and healthy life.

Individual: *Prevalent diseases, malnutrition, care of infants, feeding and food preparation practices, presence of health & sanitation facilities, water supply characteristics, etc...*

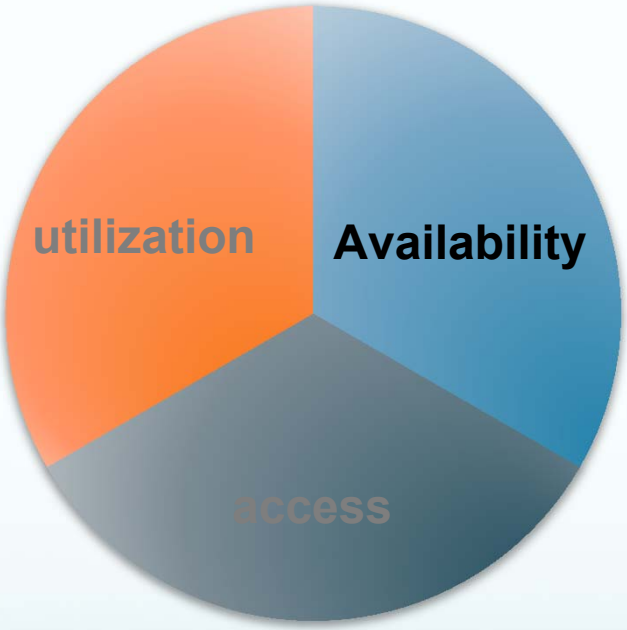
Availability: *Crop planting date, vegetation or crop condition, amount & timing of rain, drought, market availability of food, public stocks, household stocks, wild food availability, etc...*

Household/community: *Local household food crop & animal production, household sales of goods & services, food prices, imports, exports, conditions of other income sources, labor wage rates, food aid, assets, etc...*

From Gary Eilerts, USAID

Food Availability

Individual: *Prevalent diseases, malnutrition, care of infants, feeding and food preparation practices, presence of health & sanitation facilities, water supply characteristics, etc...*



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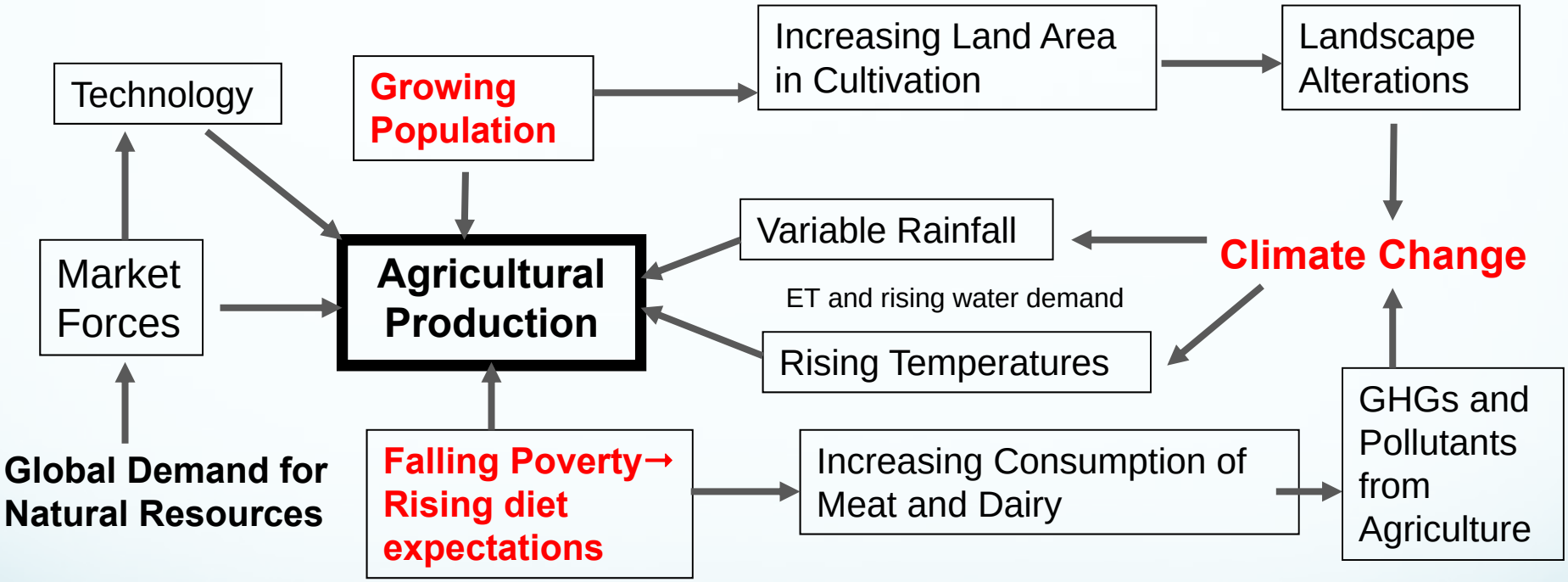
Availability of Food: *The Challenges*

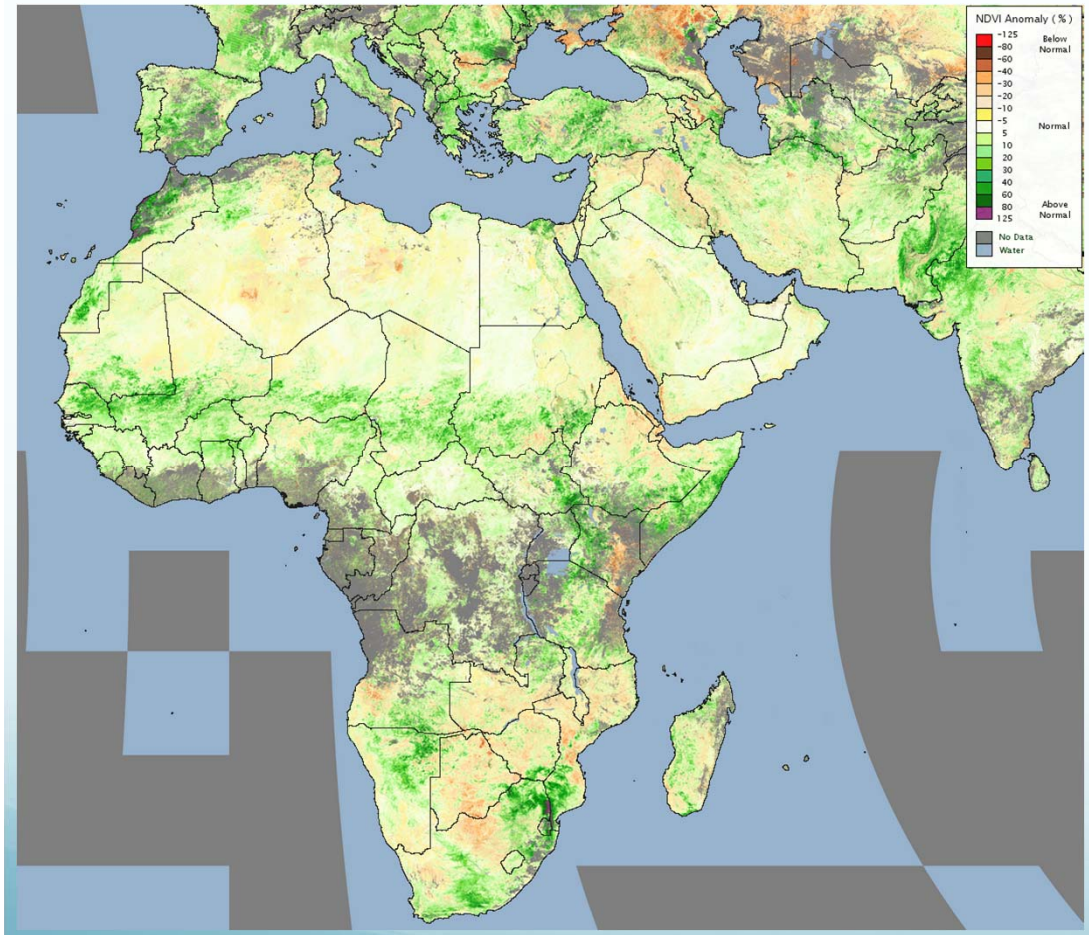


Advancements in technology are needed to counter the effects of climate change and the demands of growing population and diet expectations.

Availability of Food: *Increased World Food Demand*

- World food demand could double in first half of 21st century:
  - 50% increase from world population growth – from 6 to 9 billion – most in least developed countries
  - 50% increase from broad-based economic growth in low income countries
    - *The World Bank has estimated the number of people in developing countries in households with incomes >$16,000/year will rise from 352 million in 2000 to 2.1 billion by 2030.*
- How many presently low income consumers escape from poverty is the *most important* determinant of future global demand for food.

Availability of Food:
Satellite data measure food production and climate



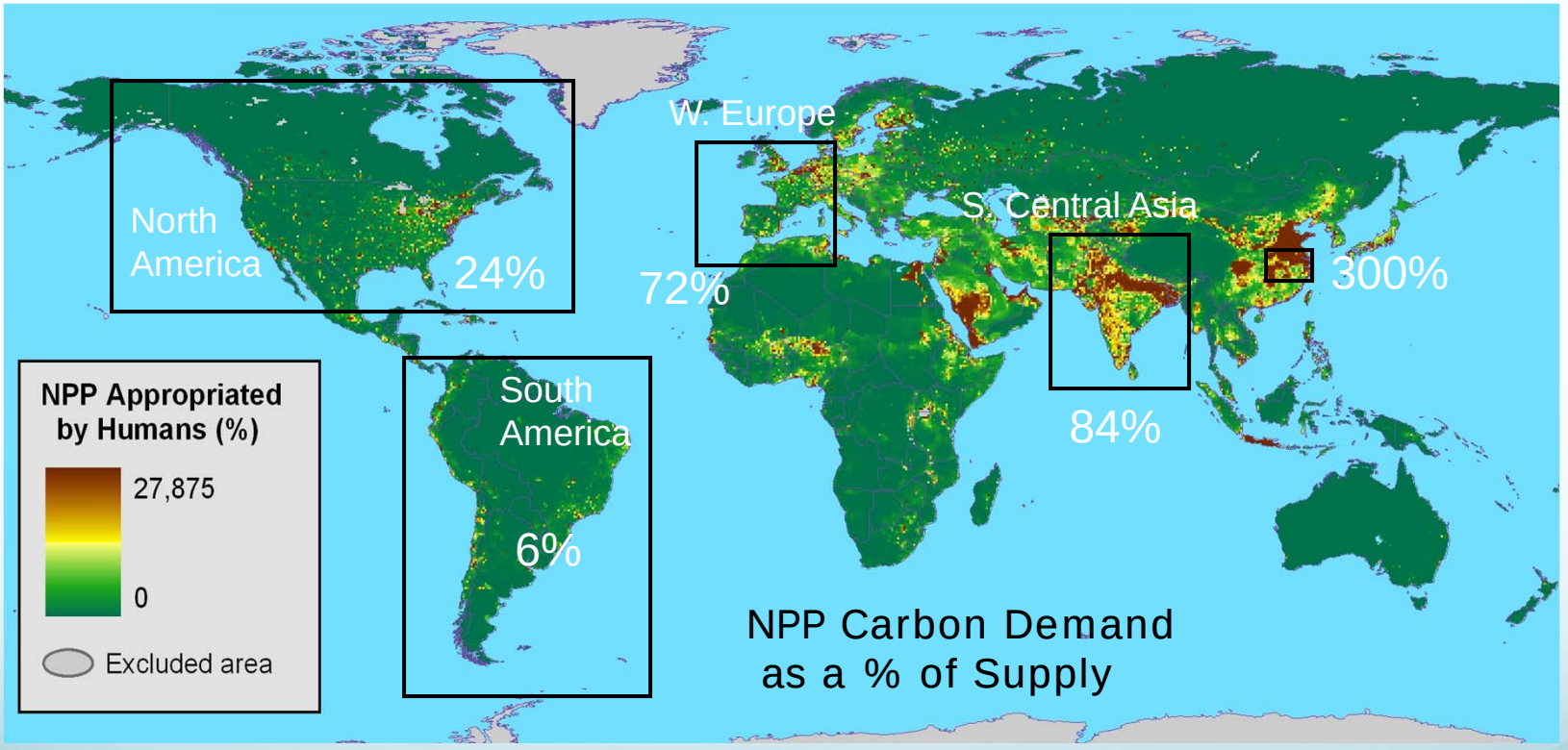
- Assess food production
- Understand the impact of changes in production on local food prices
- To estimate health outcomes
- To understand what the US Government should do during a crisis

Global Patterns in Human Consumption of Net Primary Production (NPP)

Global NPP Demand is 11.5 Pg C per year (20% of Supply)

There are large regional and local variations

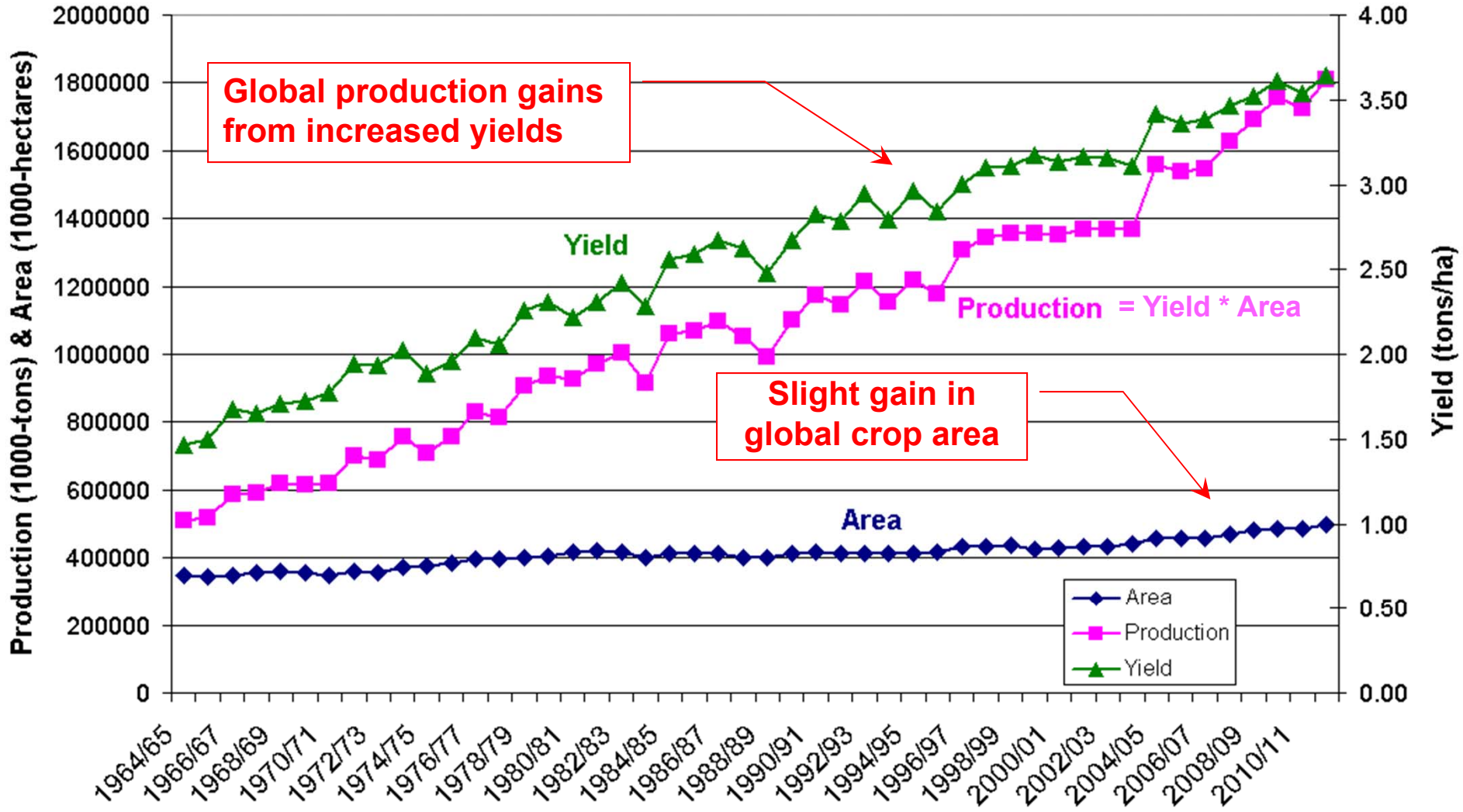
6% (South America) to over 70% (Europe and Asia), and from near 0% (Central Australia) to over 30,000% (New York City, Bejing).



The rate at which humans consume NPP-C is a powerful aggregate measure of human impact on biosphere function.

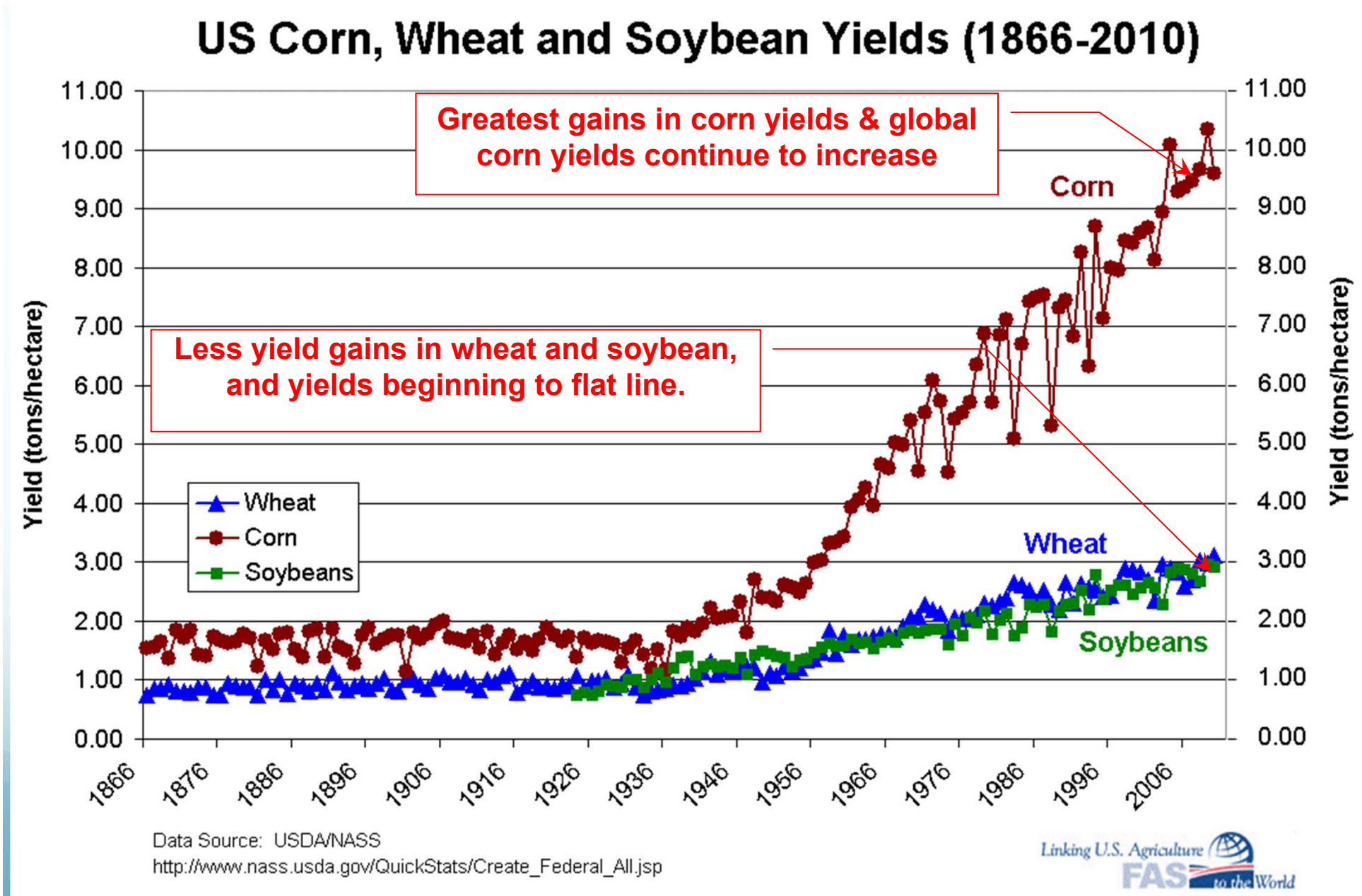
M. L. Imhoff, et al. Nature, 2004

Global Production, Area and Yield (PAY) (1964-2011) for Wheat, Soybeans & Corn

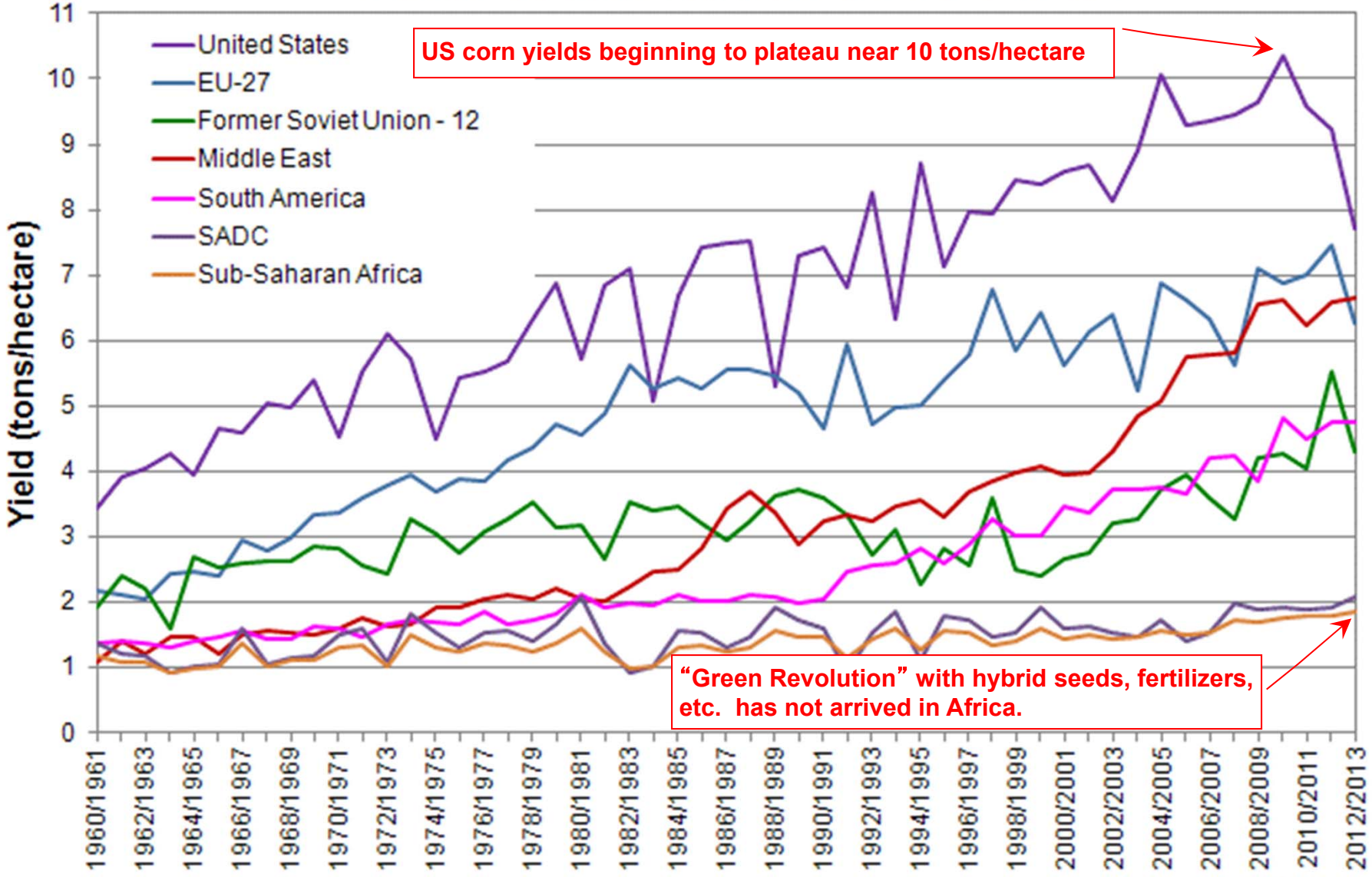


Source: PSD (May 10, 2011)

Linking U.S. Agriculture FAS to the World


US Corn, Wheat and Soybean Yields (1866-2010)
Greatest gains in corn yields & global corn yields continue to increase
Less yield gains in wheat and soybean, and yields beginning to flat line.
Corn
Wheat
Soybeans
Wheat
Corn
Soybeans
Yield (tons/hectare)
Yield (tons/hectare)
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1866
1876
1886
1896
1906
1916
1926
1936
1946
1956
1966
1976
1986
1996
2006
Data Source: USDA/NASS
http://www.nass.usda.gov/QuickStats/Create_Federal_All.jsp
Linking U.S. Agriculture
FAS to the World

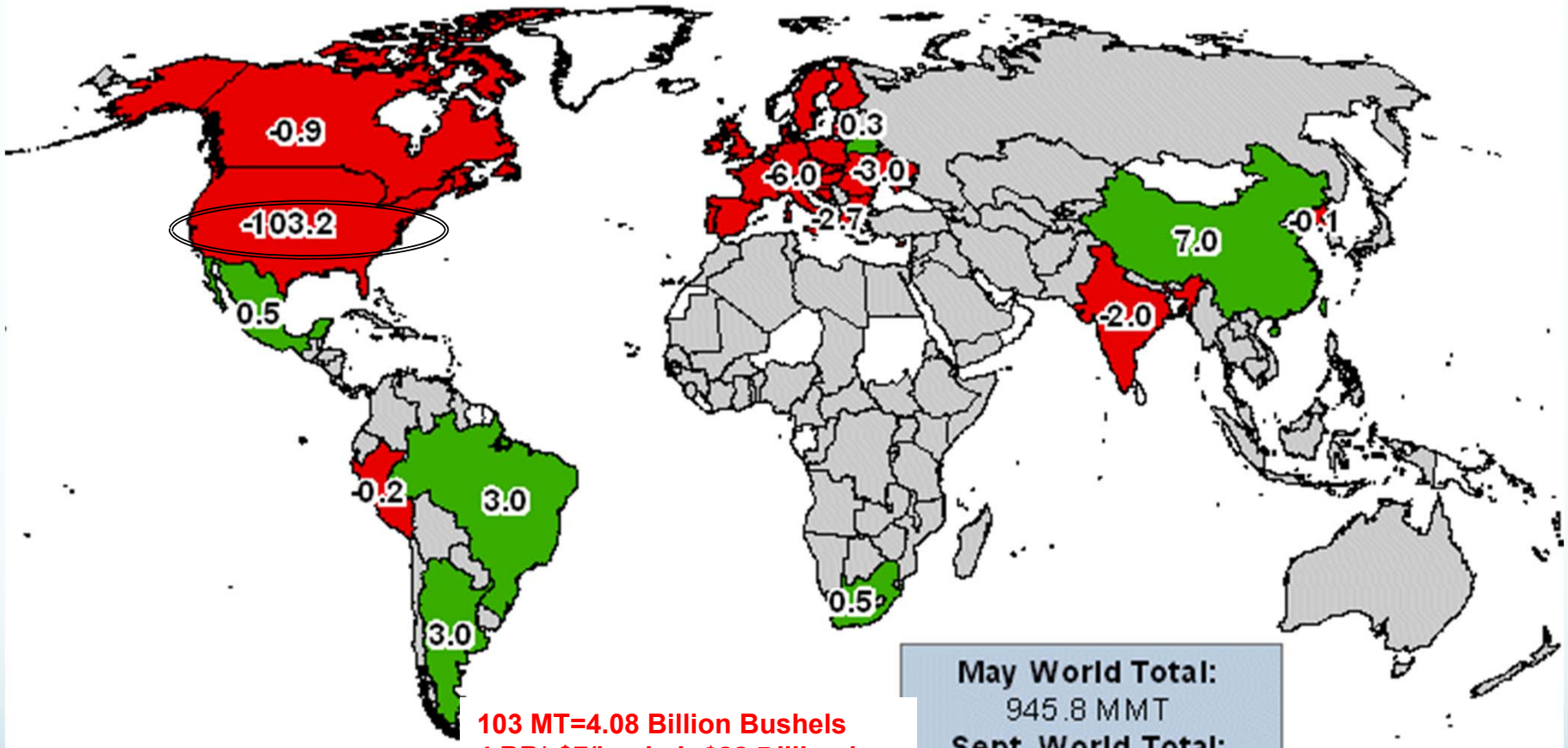
Corn Yields from 1960-2012



Source: USDA's Production, Supply and Distribution (PSD) Database
http://www.fas.usda.gov/psdonline/

Linking U.S. Agriculture FAS to the World

May to Sept 2012 Corn Production Difference (MMT)



103 MT=4.08 Billion Bushels
4 BB* $7/bushel=*$28 Billion lost*

May World Total:
945.8 MMT
Sept. World Total:
841.1 MMT
World Difference Total:
-104.7 MMT

May to Sept. 2012 Production Difference (MMT)

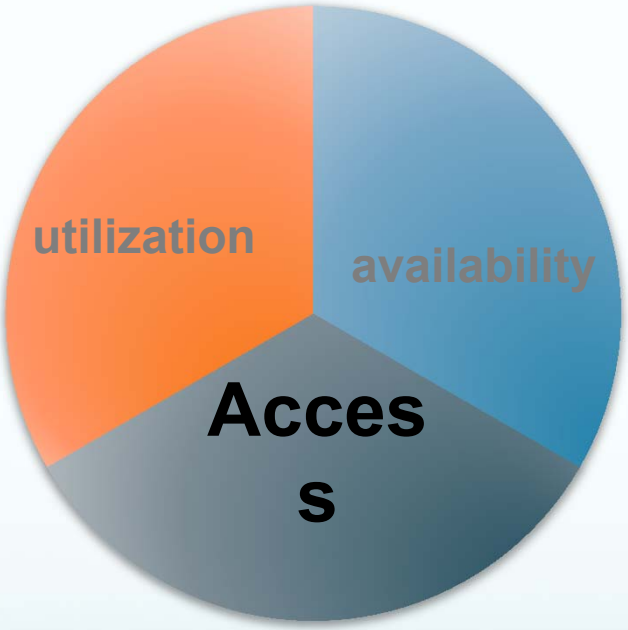
- Negative
- None
- Positive

Source: PSD Online (Updated: 9/12/2012)
(http://www.fas.usda.gov/psdonline)

Linking U.S. Agriculture FAS to the World

Food Access

Individual: *Prevalent diseases, malnutrition, care of infants, feeding and food preparation practices, presence of health & sanitation facilities, water supply characteristics, etc...*



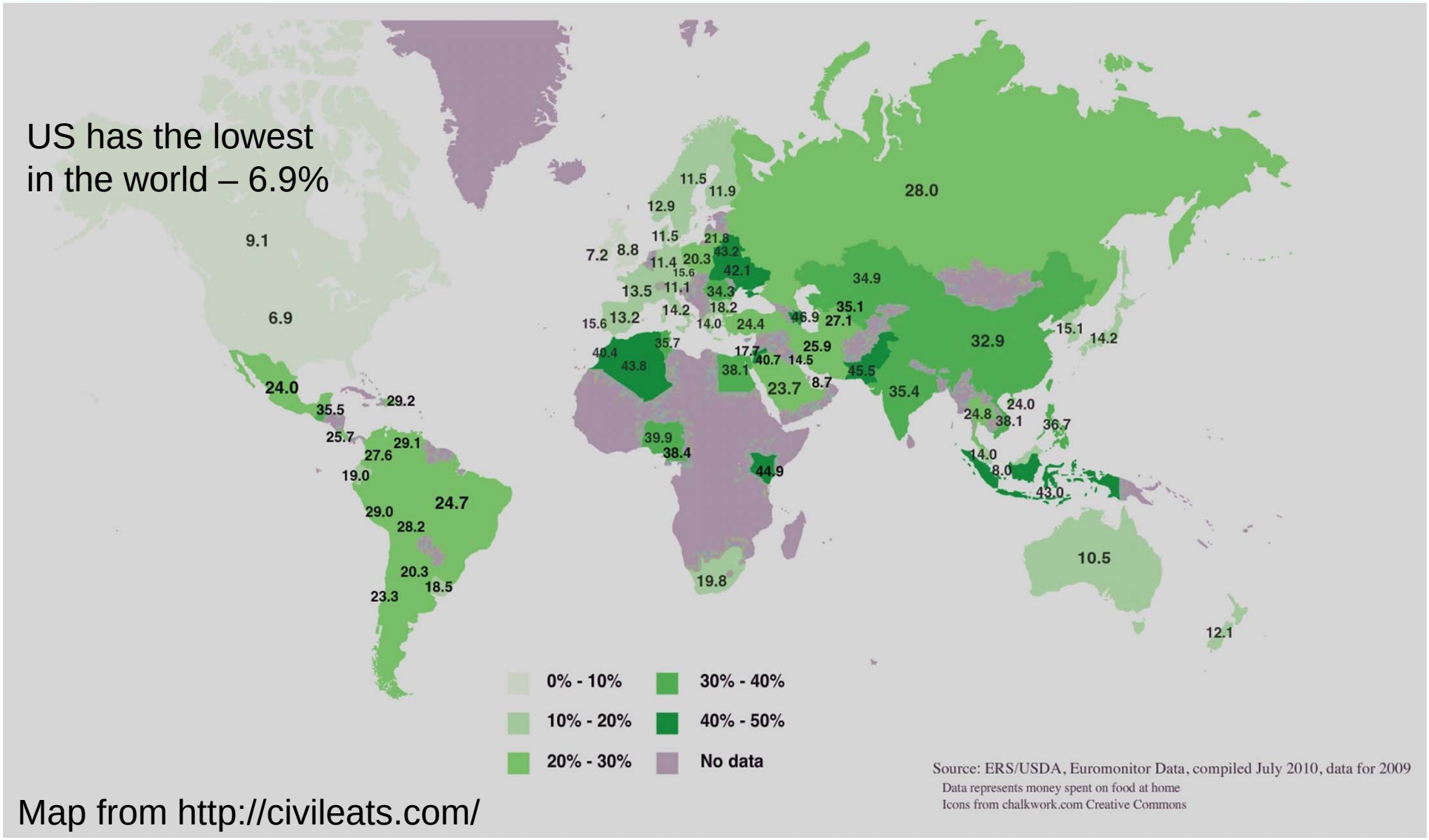
Availability: *Crop planting date, vegetation or crop condition, amount & timing of rain, drought, market availability of food, imports, exports, public stocks, household stocks, wild food availability, etc...*

Household/community: *Local household food crop & animal production, household sales of goods & services, food prices, conditions of other income sources, labor wage rates, food aid, assets, etc...*

From Gary Eilerts, USAID

How much of family's income is spent on food?

US has the lowest in the world – 6.9%



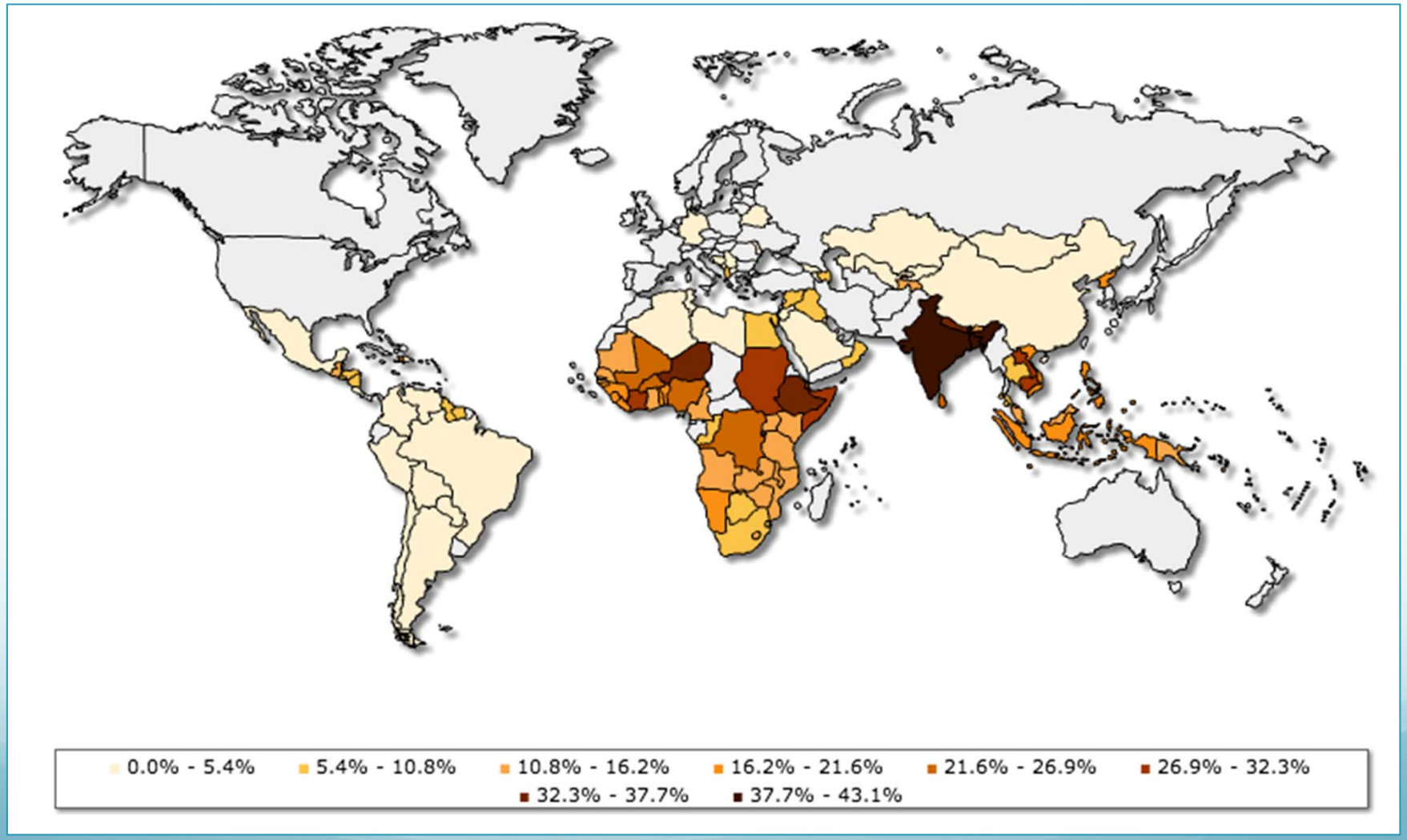
Source: ERS/USDA, Euromonitor Data, compiled July 2010, data for 2009
Data represents money spent on food at home
Icons from chalkwork.com Creative Commons

Map from http://civileats.com/

Poverty Is the Root of Household Food Insecurity and Hunger

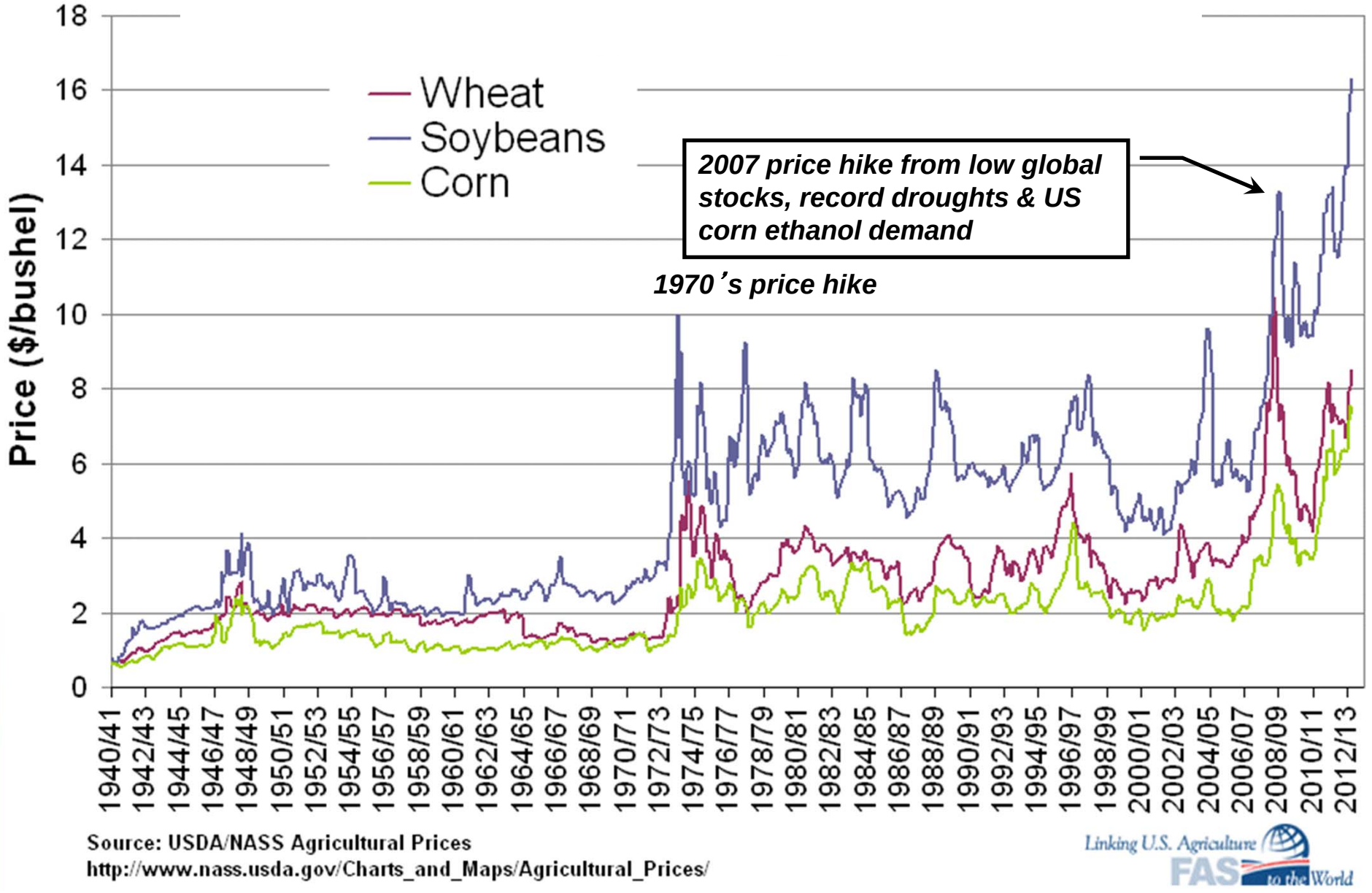
- 925 million people suffer under-nutrition or hunger.
- 1.4 billion people live on less than $1.25 per day; 70% of them are rural, and most of these depend on farming for their meager incomes
- Hunger is due mainly to poverty except in times of war, natural disaster or politically-imposed famine.
- The rich in no country go hungry.
- To solve the world's hunger problem, the world poverty problem must be solved.

Percent of Malnutrition in Children– poverty metric



Map from GlobalHealthFacts.org, data from UN World Health Organization

High US Producer Prices…
Record soybean($17.89/bu) & corn prices ($8.49/bu)



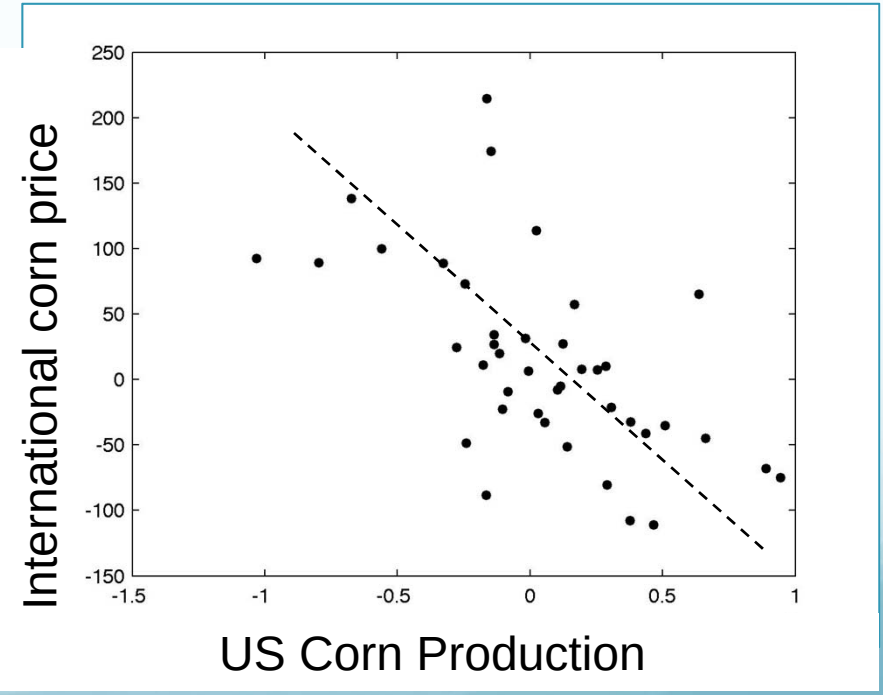
Source: USDA/NASS Agricultural Prices
http://www.nass.usda.gov/Charts_and_Maps/Agricultural_Prices/

Linking U.S. Agriculture FAS to the World

US Corn production and International corn prices

- US corn production accounts for 30% of the variance of the corn futures, due to the US's extremely large contribution to the world export market.

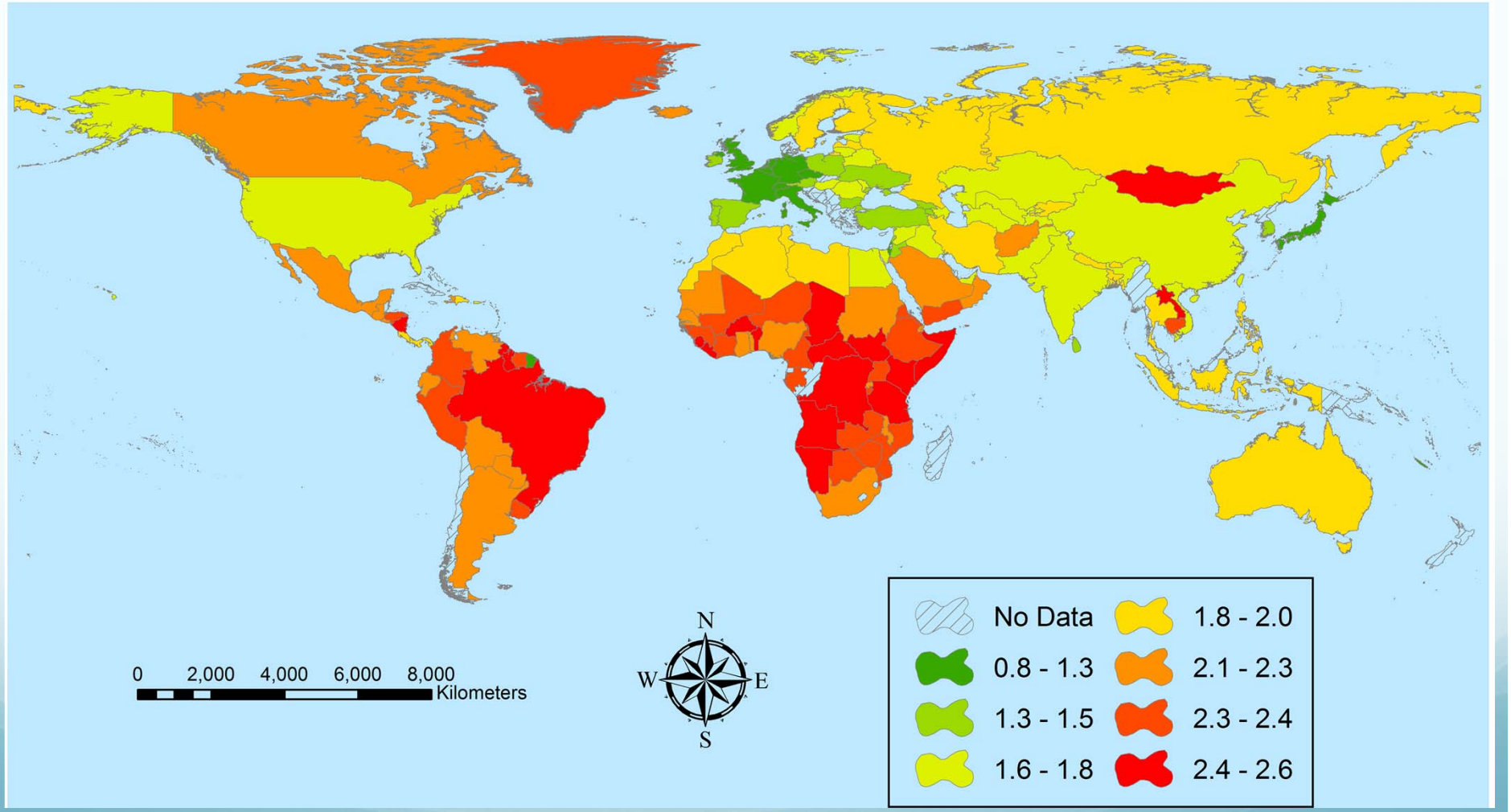
Maize Production		
Rank	Country	MT
1	United States	314
2	China	193
3	Brazil	70
4	EU-27	65
5	Ukraine	23
	World	874



High costs to move goods in regions with poor infrastructure

Port of Lagos

Country Isolation metric



Brown et al Applied Geography 2013

Infrastructure that connects this farm to a market determines its profitability

Poor infrastructure contributes to food market isolation

Mapping food price ‘pressure points’

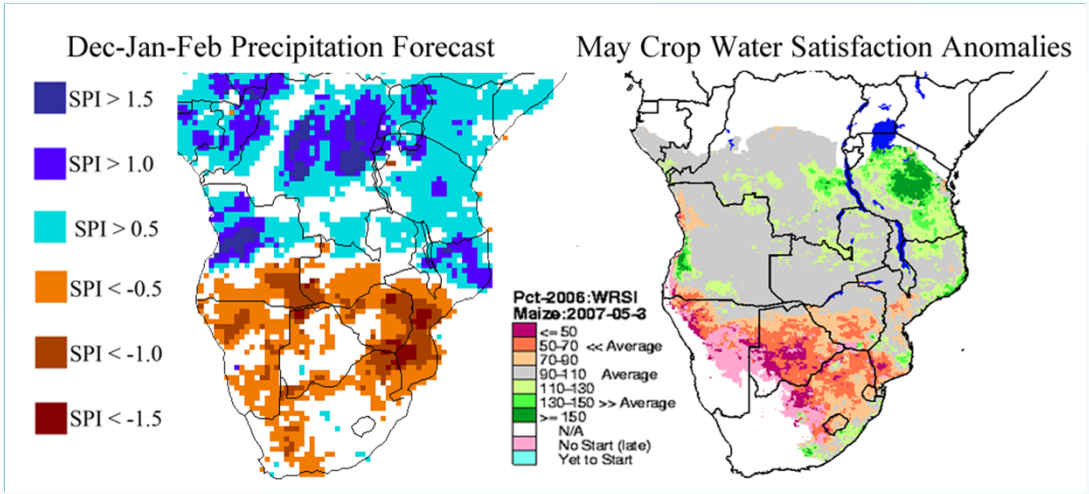
This map needs more quantitative analysis!

Oxfam International

Famine Early Warning System: Remote Sensing + Models

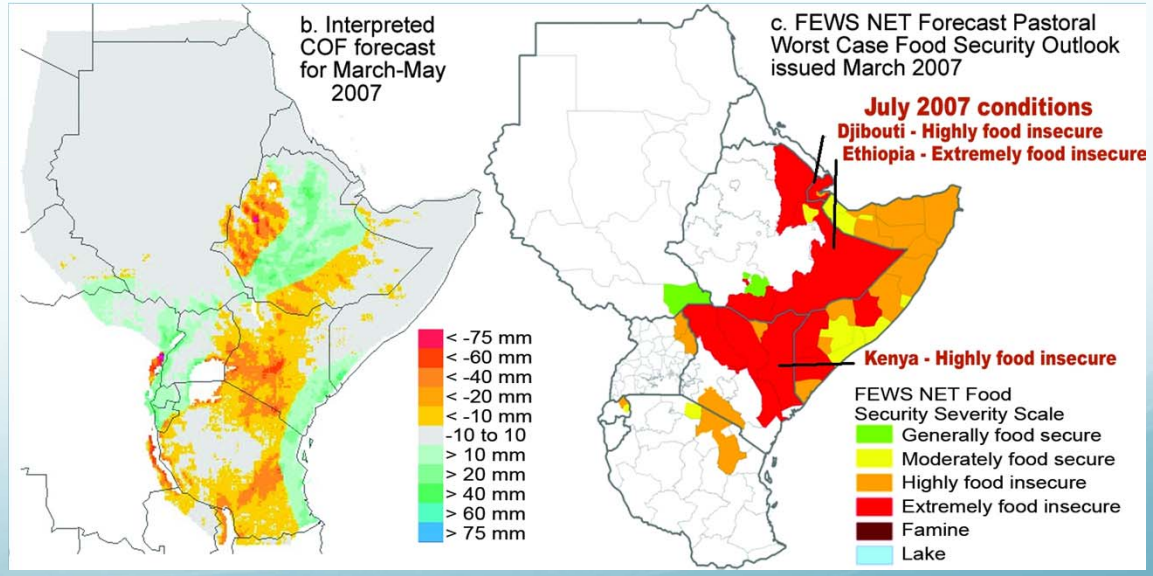
Famine Early Warning System*

- biophysical satellite remote sensing
- coupled with models of climate, ecosystem, crop and economic models
- *enables movement of emergency food supplies prior to famine outbreak*



Global climate model:

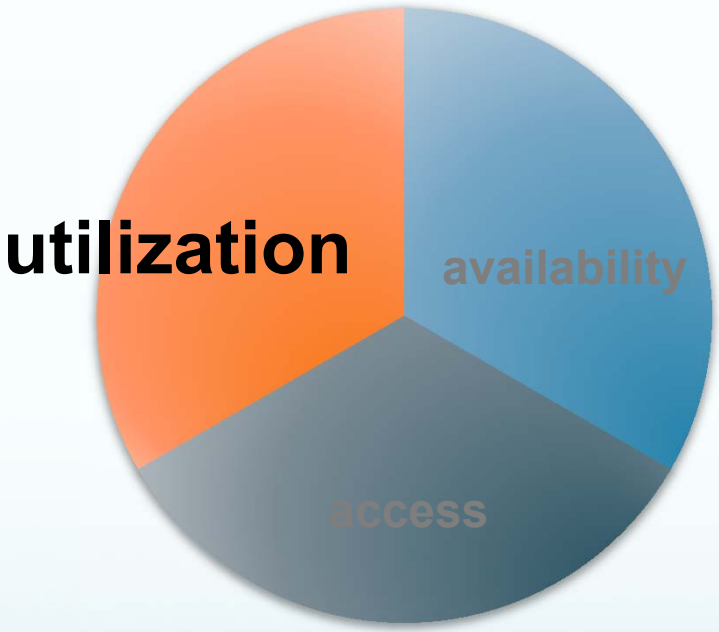
- predicts future crop production
- integrate with socio-economic information
- enables estimates of future changes in food security for response planning



* USAID, see http://www.fews.net/ M. Brown/GSFC

Food utilization

Individual: *Prevalent diseases, malnutrition, care of infants, feeding and food preparation practices, presence of health & sanitation facilities, water supply characteristics, etc...*



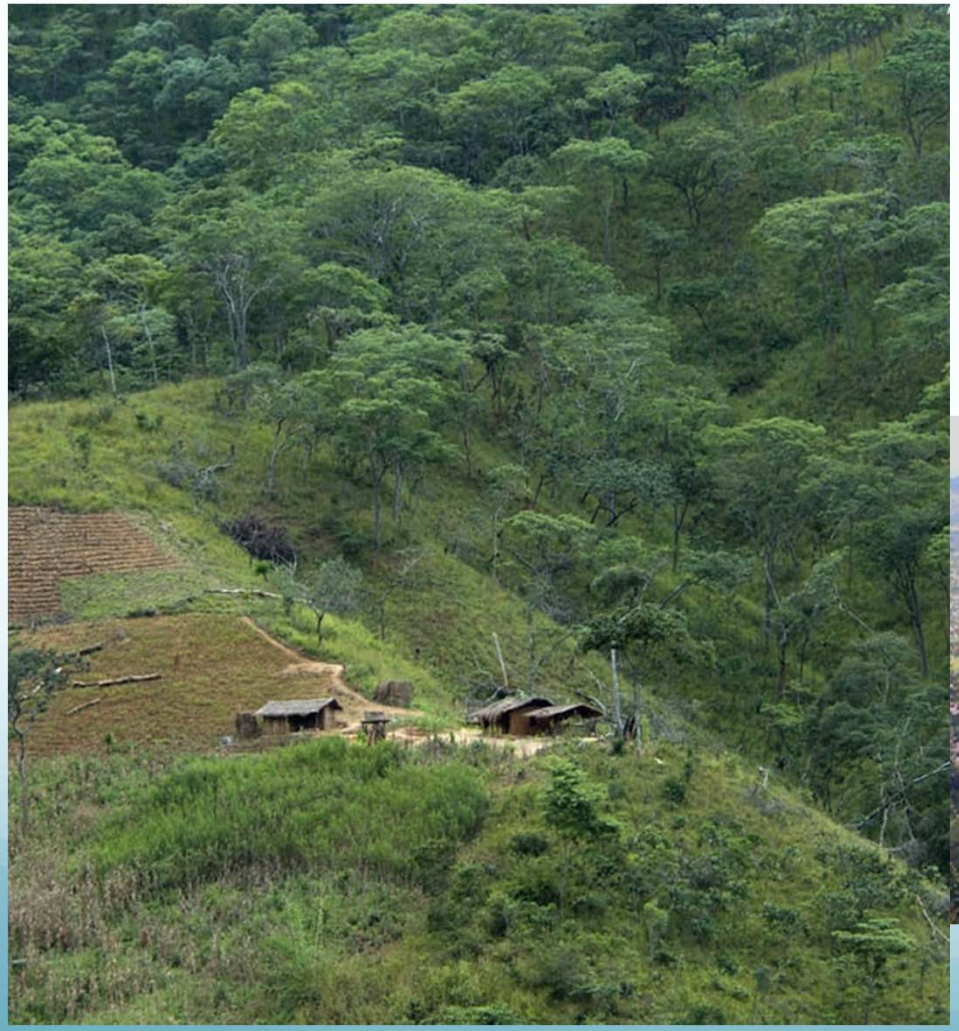
An area: *Crop planting date, vegetation or crop condition, amount & timing of rain, drought, market availability of food, food prices, imports, exports, public stocks, household stocks, wild food availability, etc...*

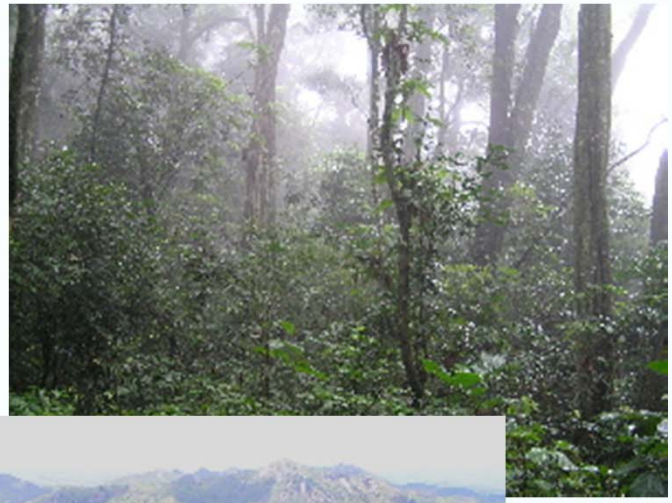
Household/community: *Local household food crop & animal production, household sales of goods & services, conditions of other income sources, labor wage rates, food aid, assets, etc...*

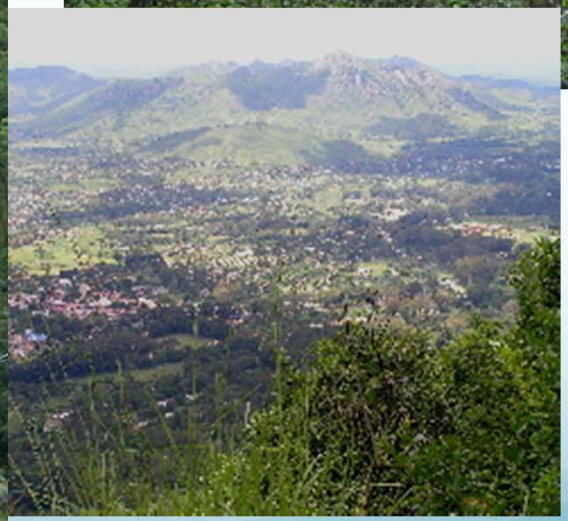
From Gary Eilerts, USAID

Poor sanitation and disease vectors that increase malnutrition are ecologically coupled

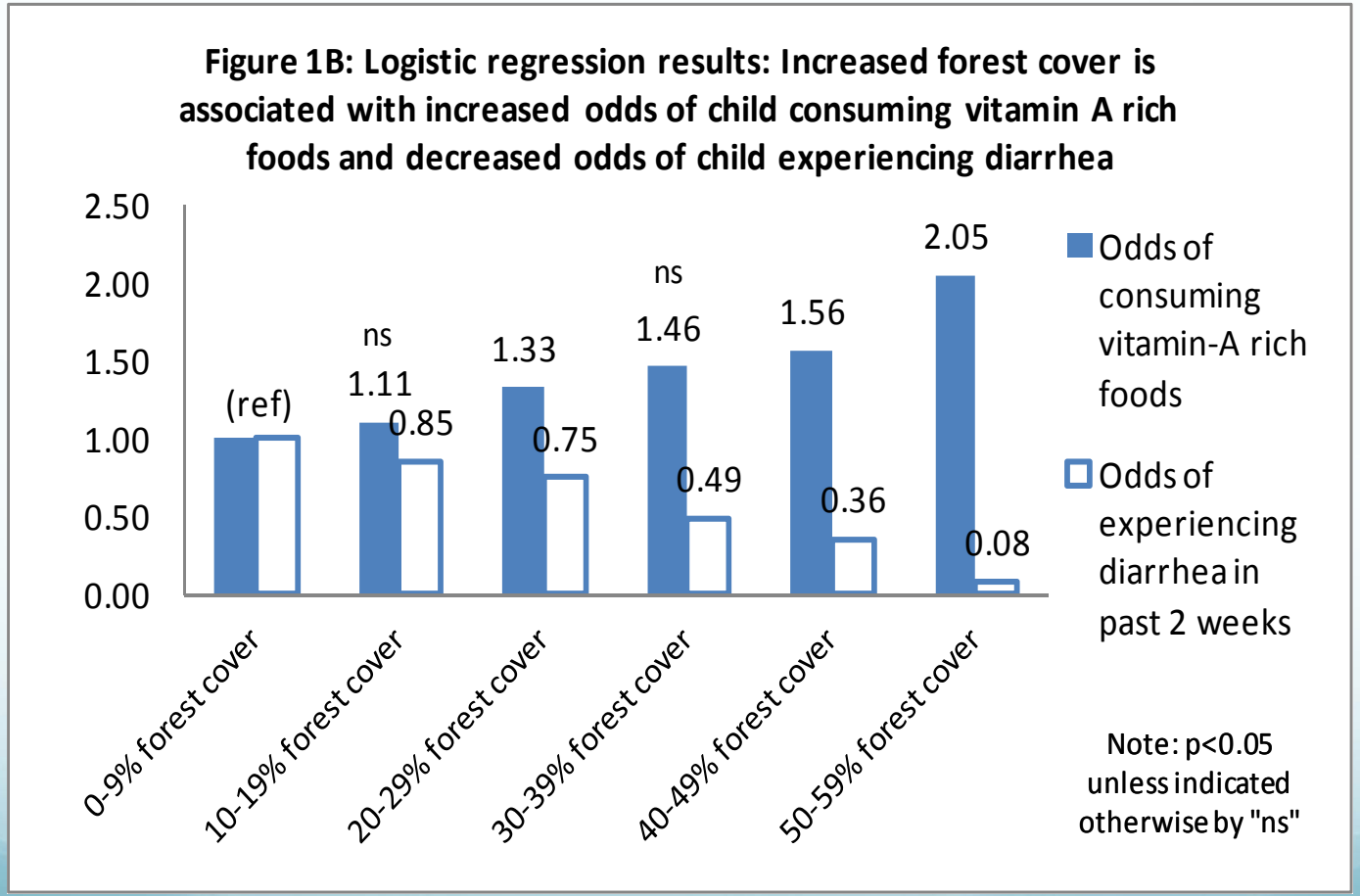
Malawi forest cover and health outcomes





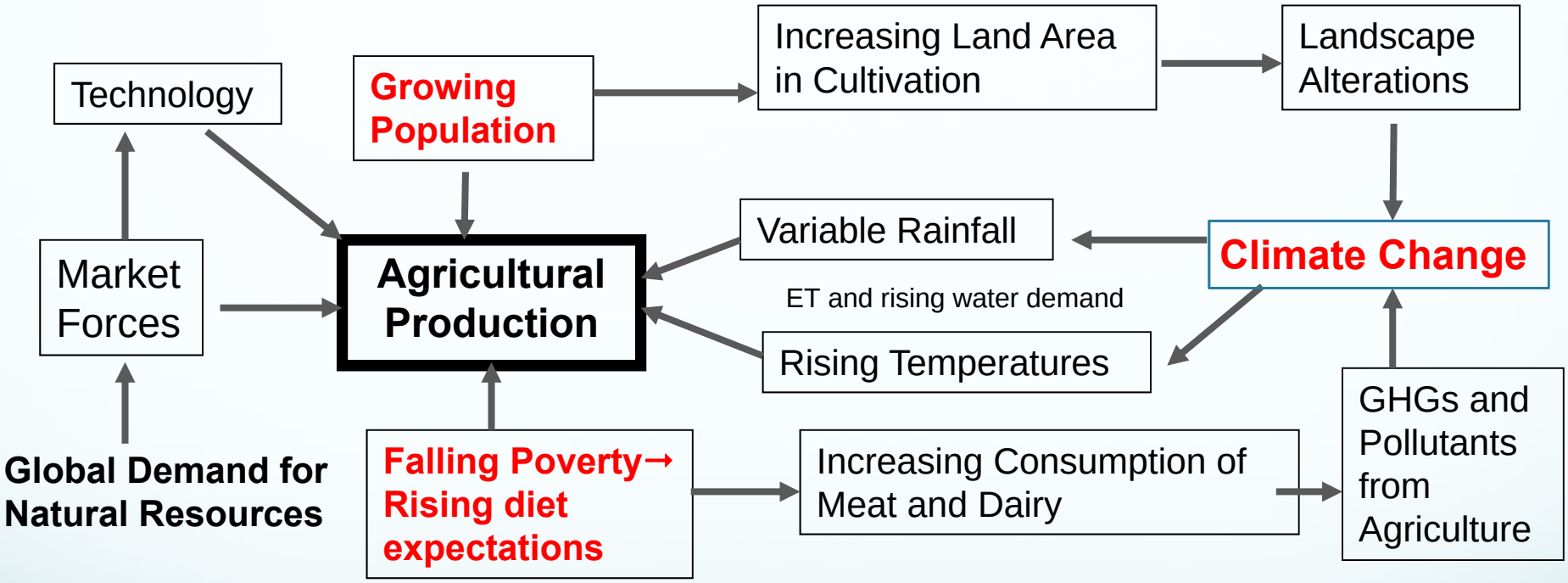


Links between forest cover and food diversity, illness



Johnson, Jacobs and Brown 2013

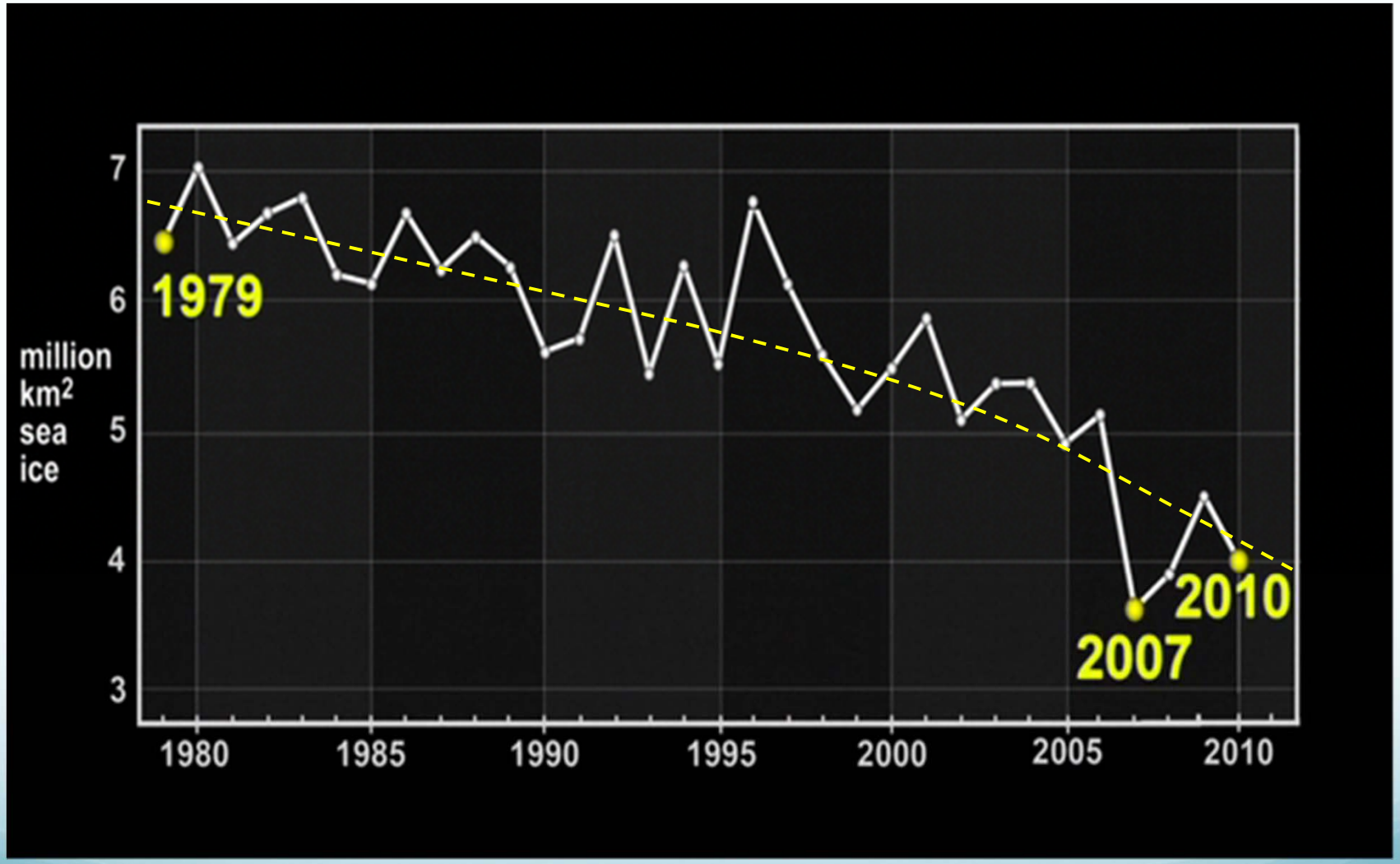
Availability of Food: *The Challenges*



Advancements in technology are needed to counter the effects of climate change and the demands of growing population and diet expectations.

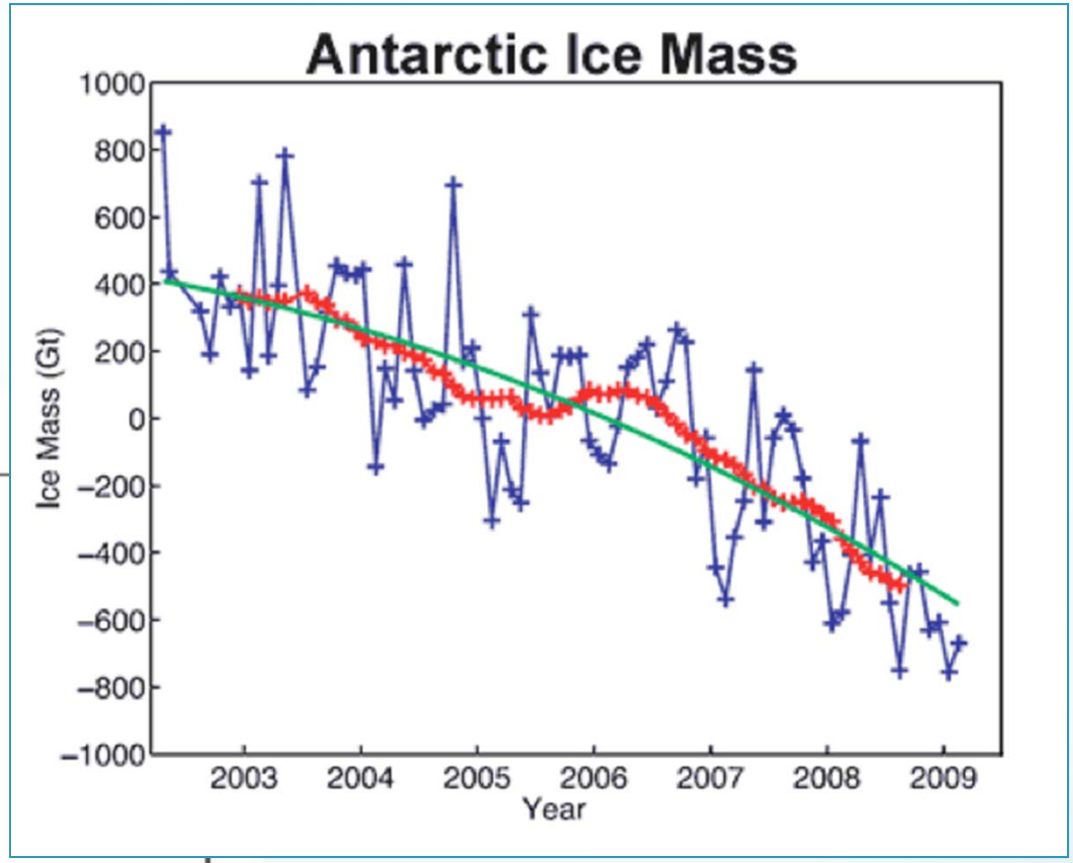
Thank you!!

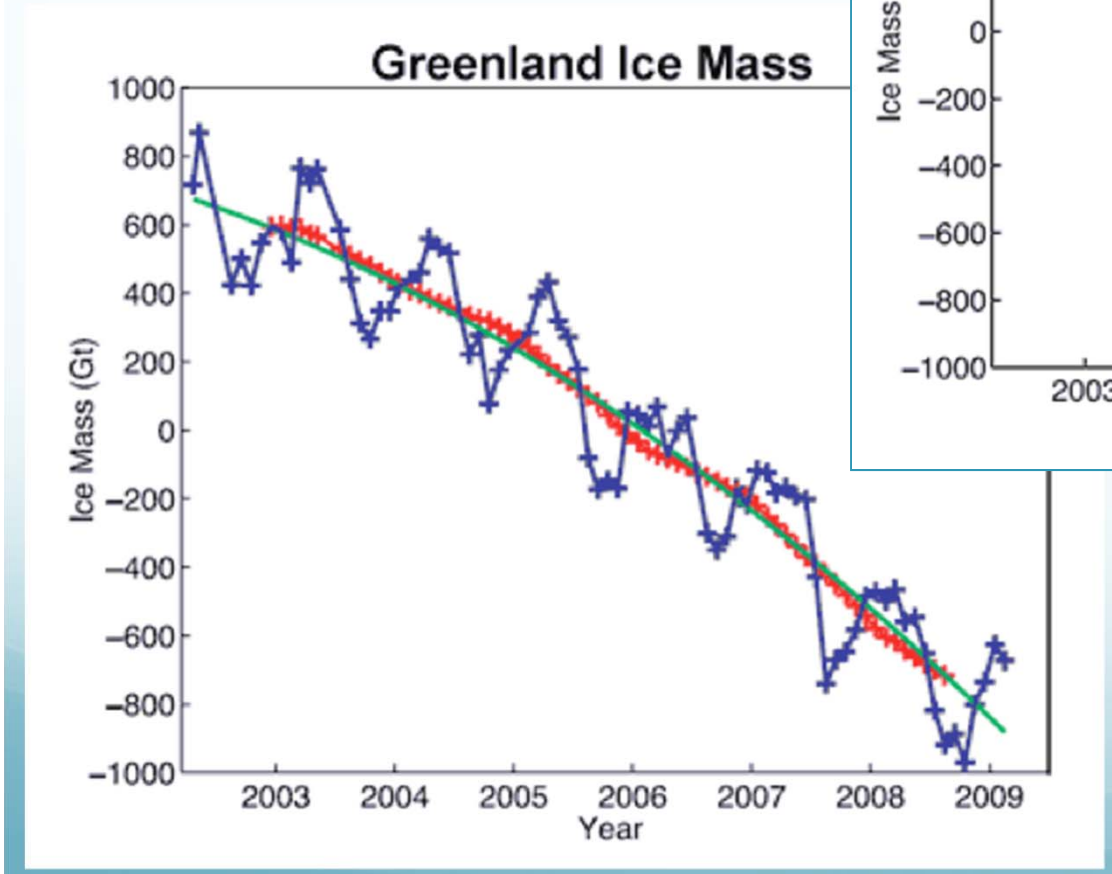
Arctic Sea Ice



Source: NASA/GSFC/SVS

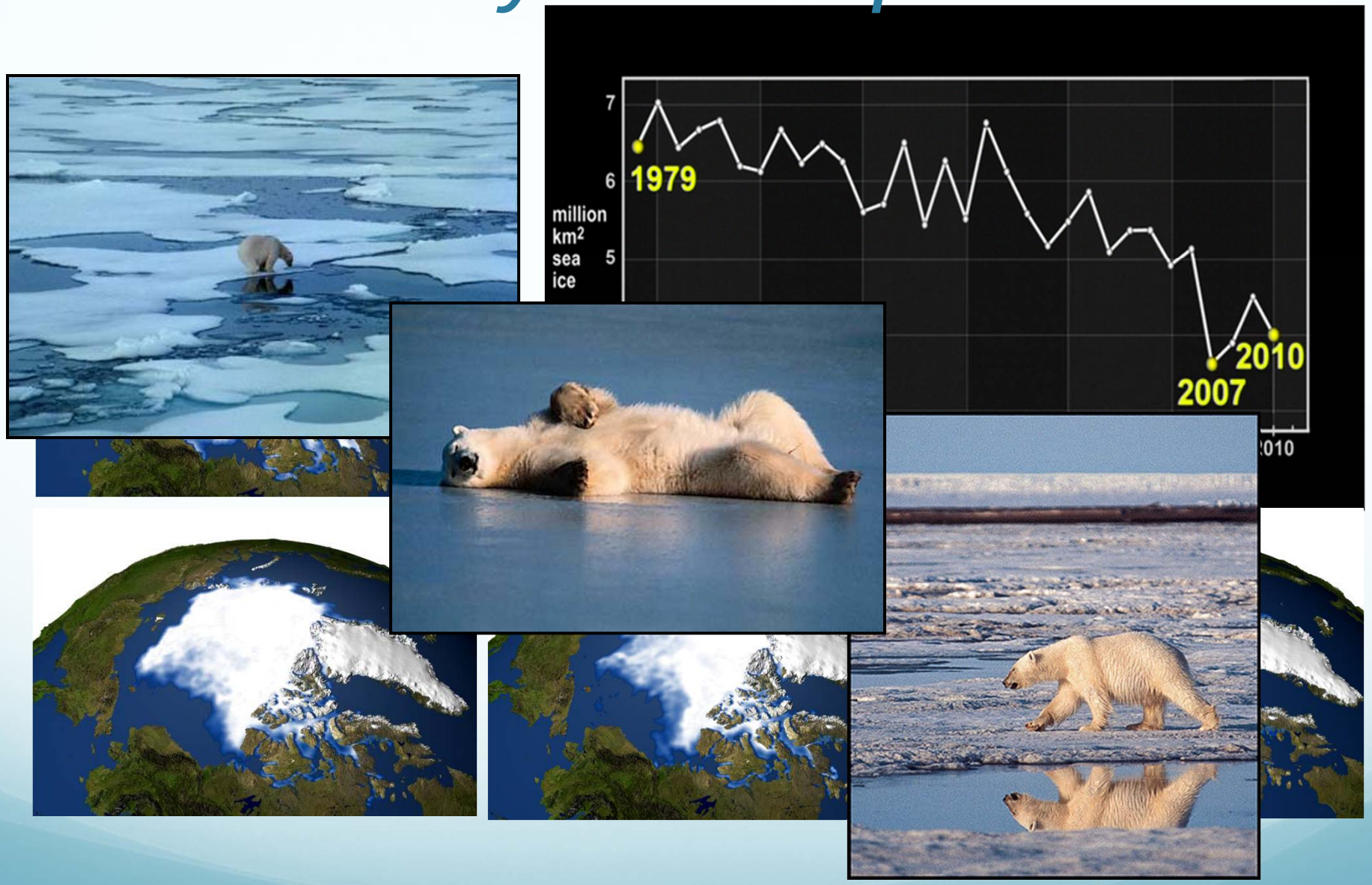
Ice loss from Greenland and Antarctica





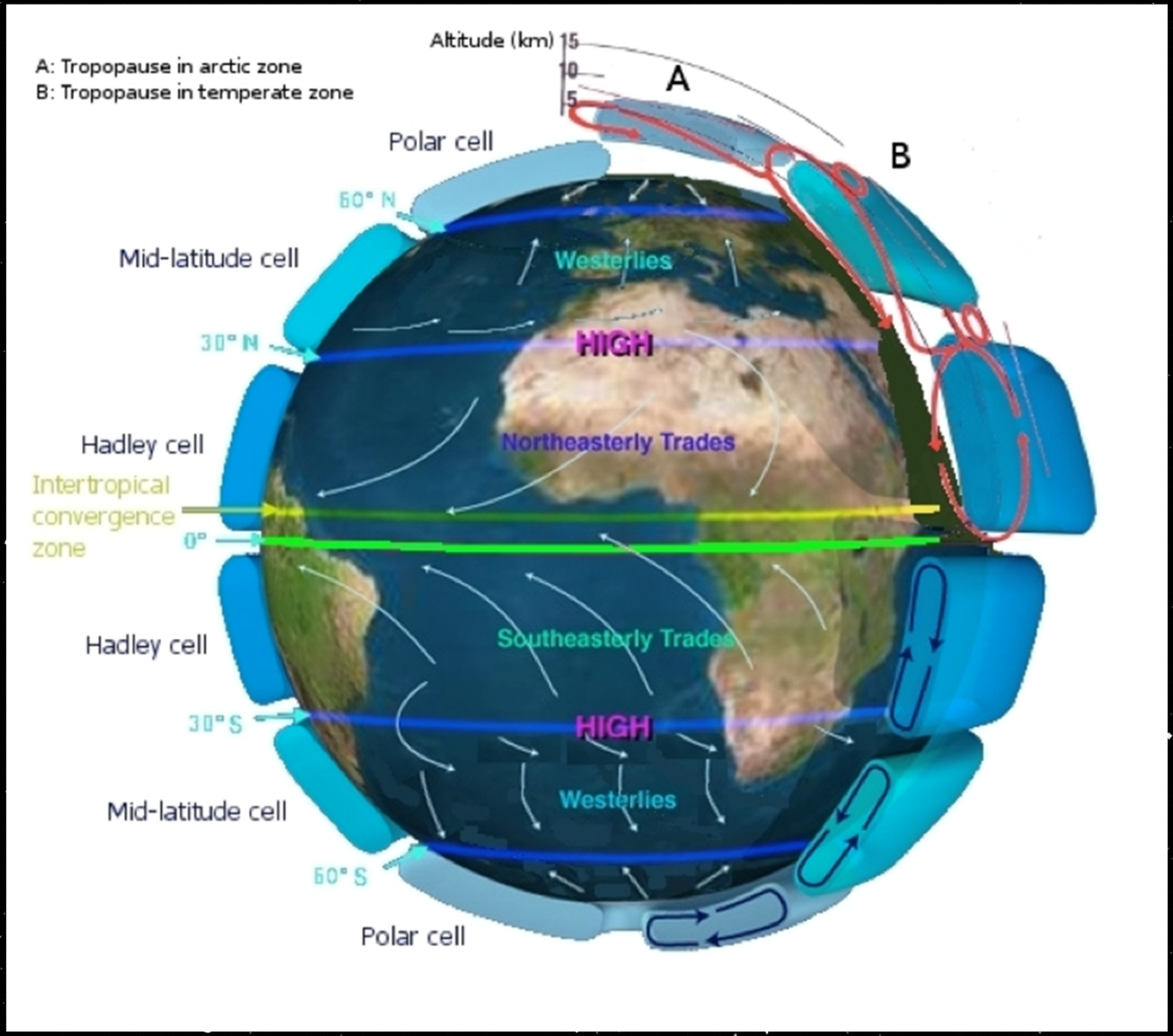
Source: NASA/GSFC/SVS

Ecosystem Impacts



Source: NASA/GSFC/SVS

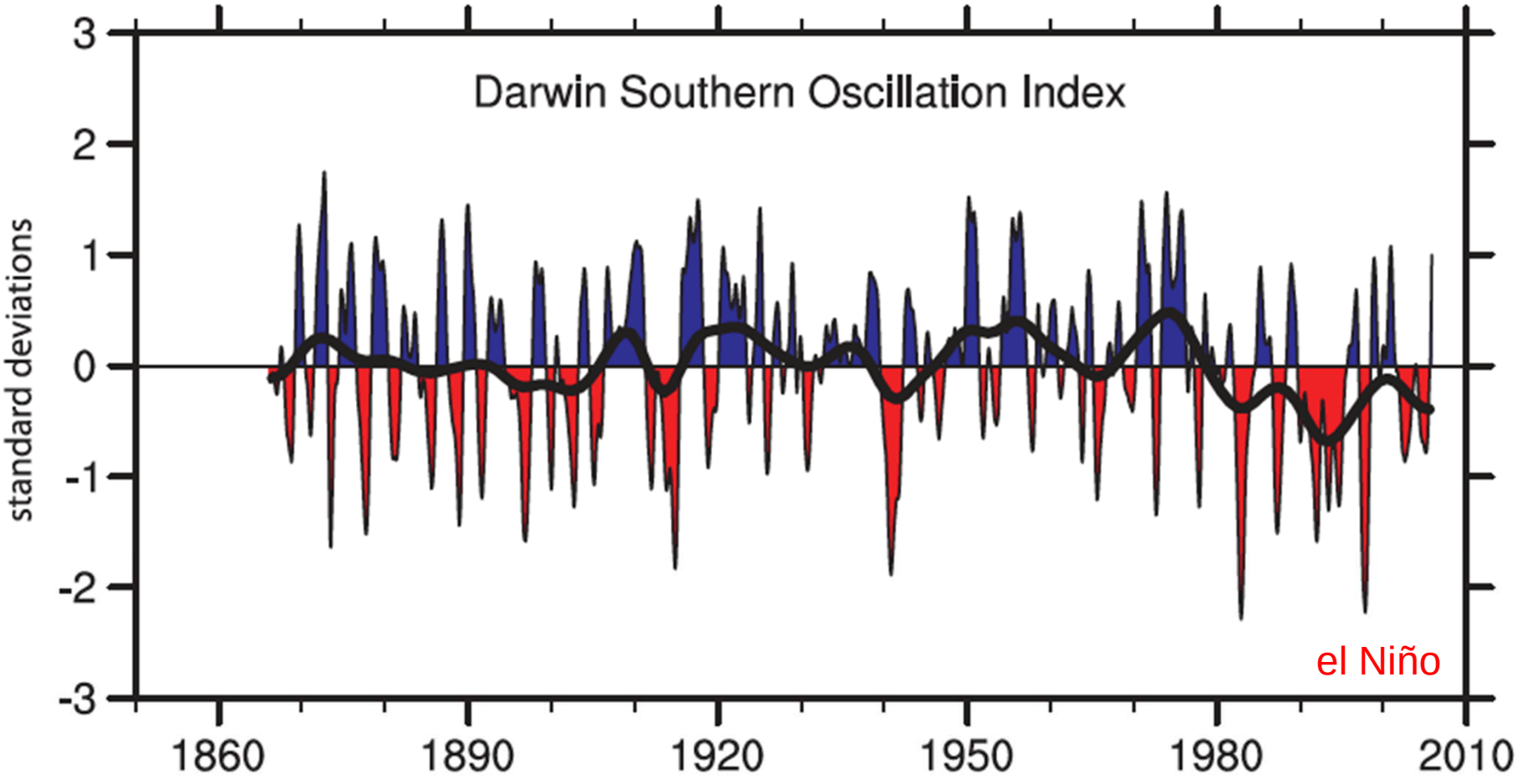
Changes in global circulations



Storm tracks move poleward

Source: NASA/GISS

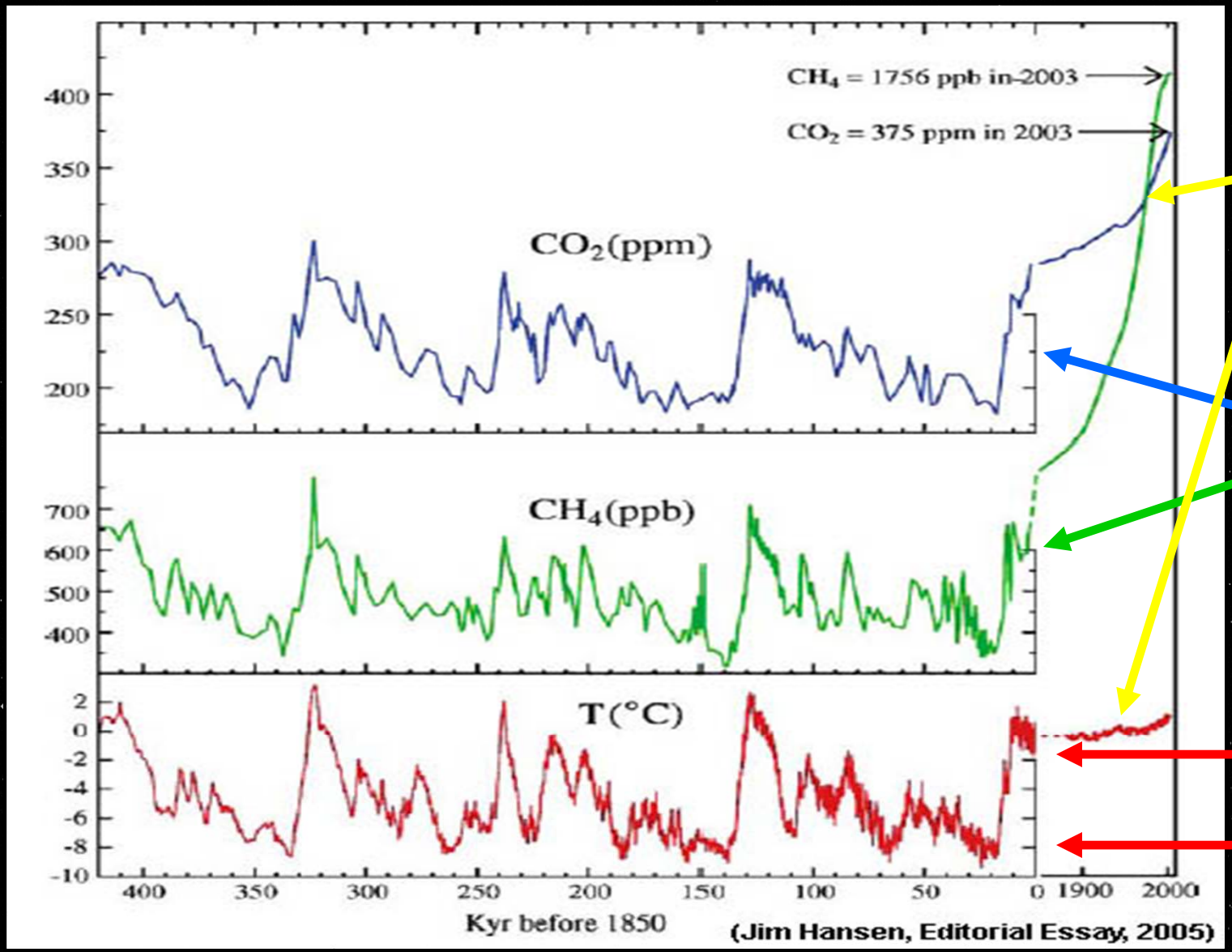
Changes in global circulations



Tendency towards persistent el Niño conditions

Source: NASA/GISS

Earth Tipping Point Example: *Ice Ages*

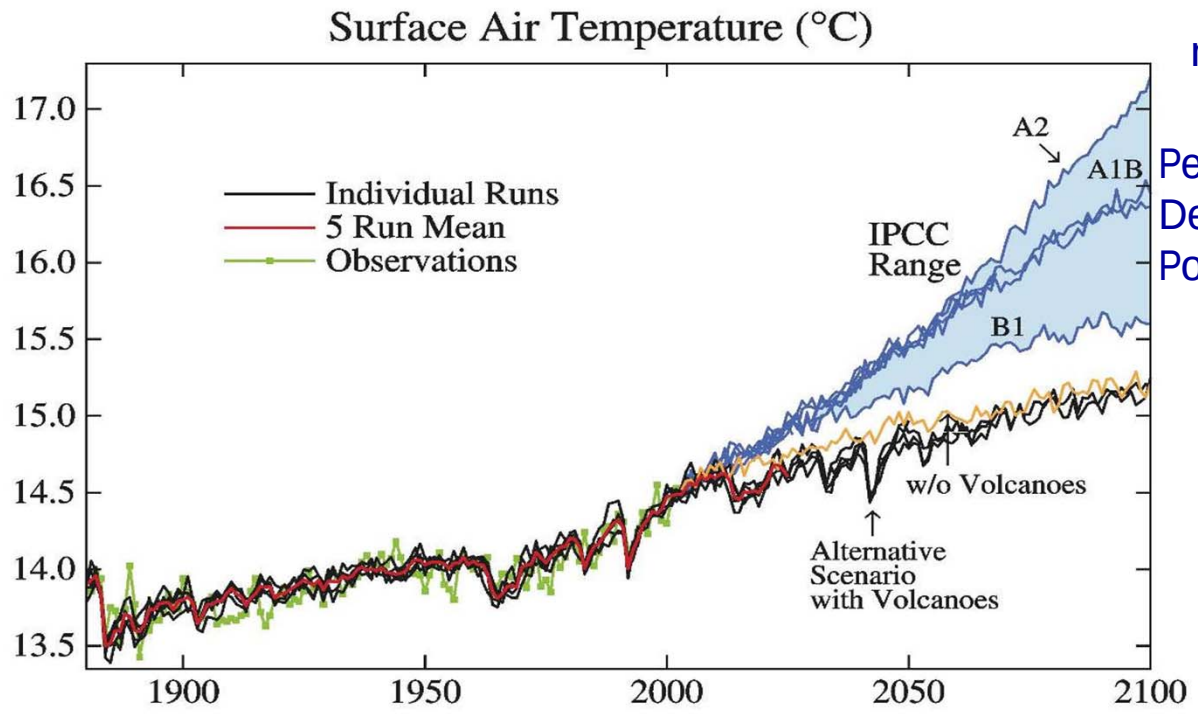


Last 150yrs: greenhouse gases *driving* temperature change

greenhouse gases change *in response to* climate change

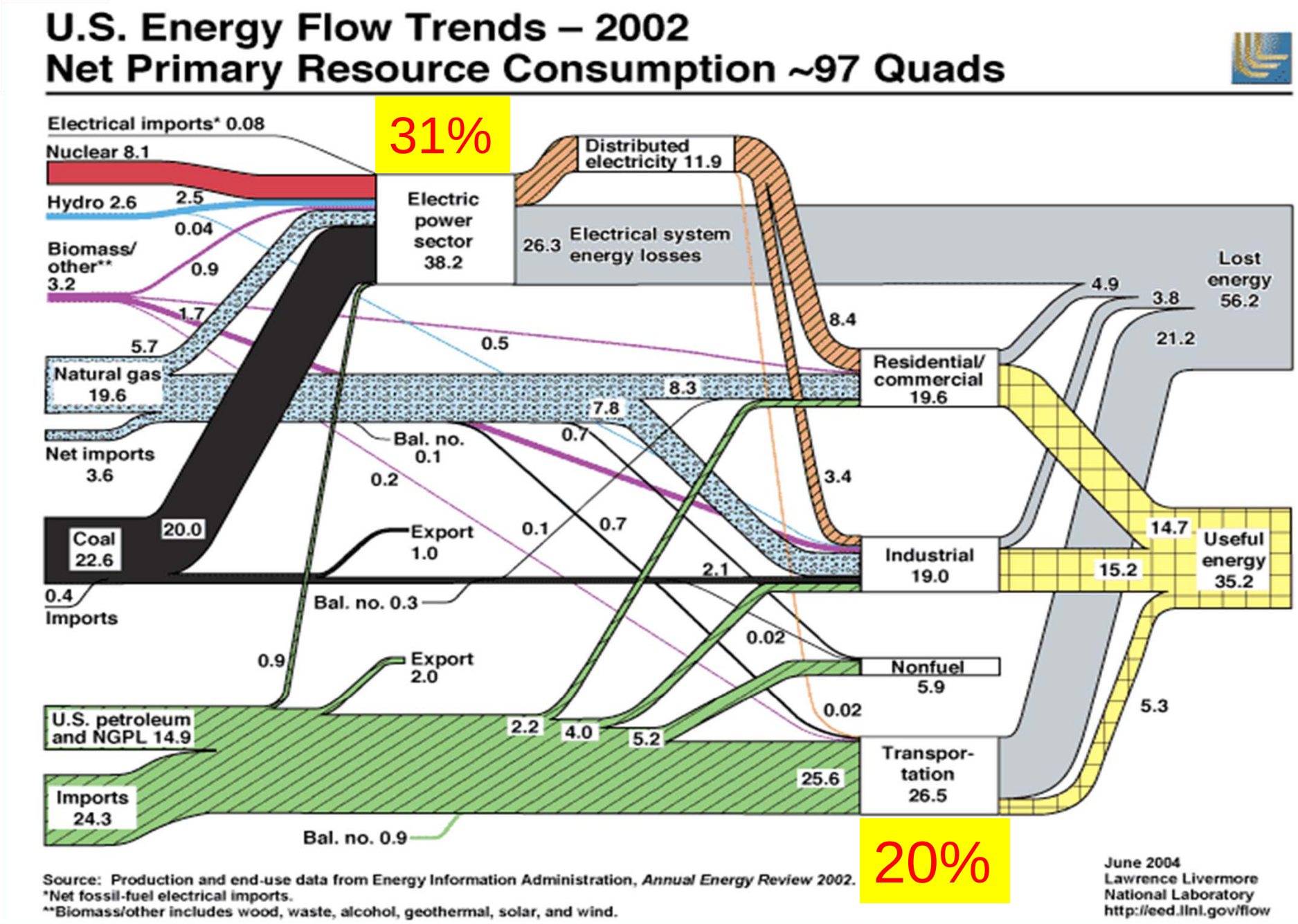
Climate Forecasting

Global Climate Simulations



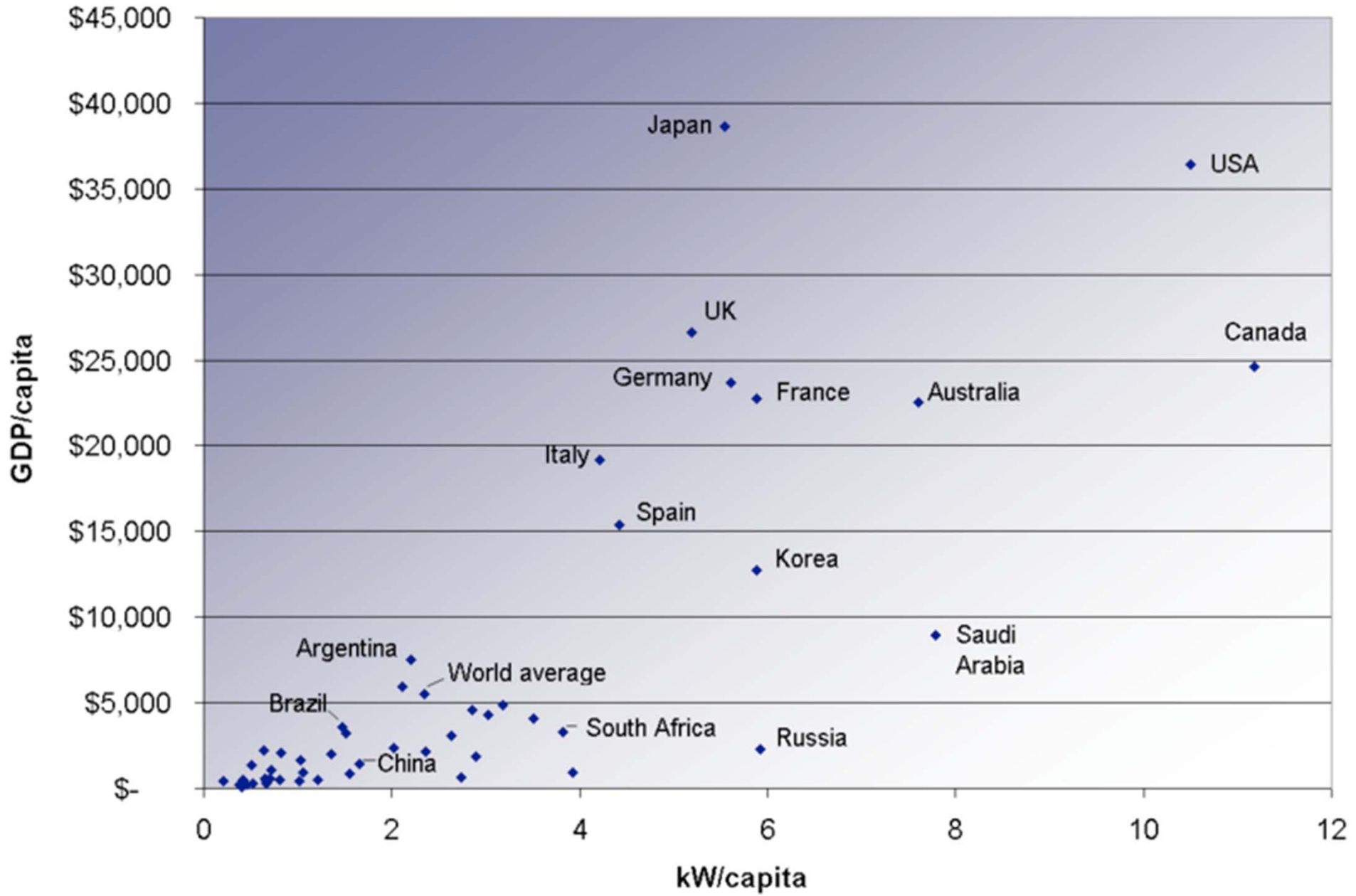
Climate Simulations for IPCC 2007 Report

- GISS Model Fits Observations Well for 1880-2003
  (but trade-off between sensitivity & forcing)
- Future Global Warming Depends Strongly on GHG Scenarios
  (but also depends on uncertain aerosol forcing)



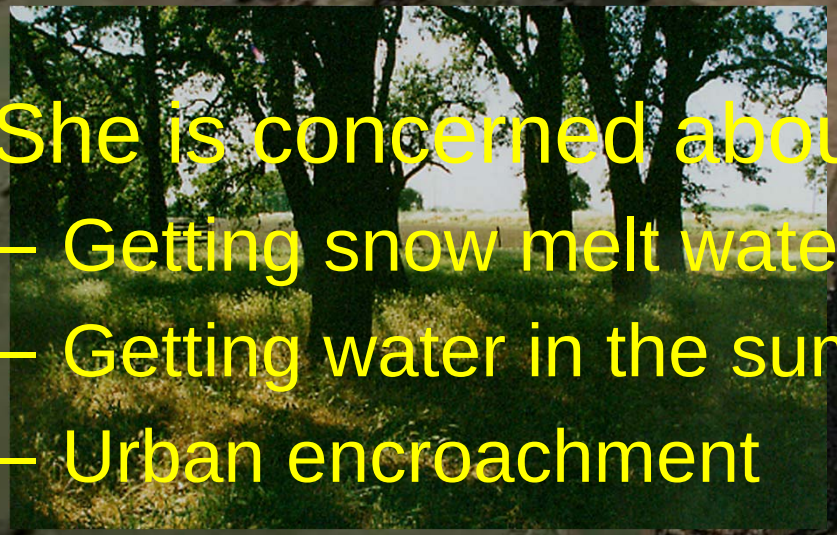
Source: Lawrence Livermore National Lab; https://eed.llnl.gov/flow/02flow.php

Energy Uses Around the World



Ecosystem Impacts:

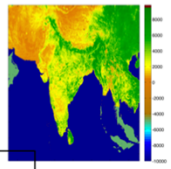
What does this mean for a farmer?



- She is concerned about climate change effects:
  - Getting snow melt water from the river for irrigation
  - Getting water in the summer
  - Urban encroachment

Evaluation of Land Use Productivity

AVHRR NDVI 8km



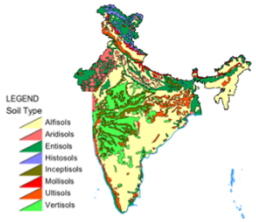
AVHRR, MODIS, VIIRS

Sum NDVI observations

AVHRR, TRMM, GPM

Rainfall observations

Ancillary Datasets (soil type, land use, elevation)

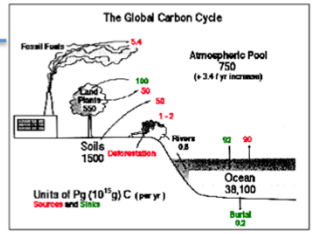


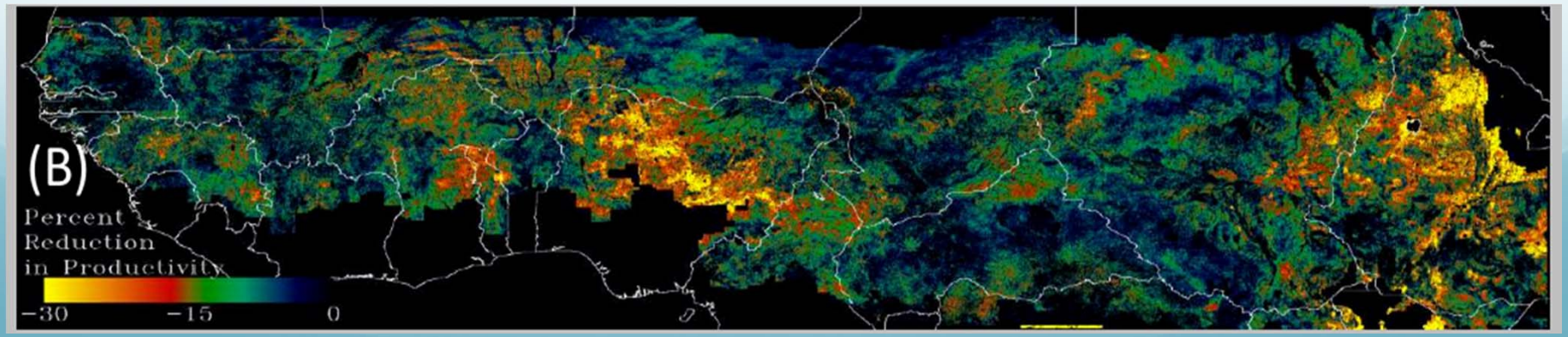
Integrated Earth Science Models (CASA)

Net Primary Productivity (NPP)

Rain Use Efficiency NPP/Rainfall

Observations of Soil Type and Quality



Maps of Land Degradation (Annual Timestep)

Causes of Land Degradation:
- Agricultural land management
- Wind and water erosion
- Deforestation
- Land use change