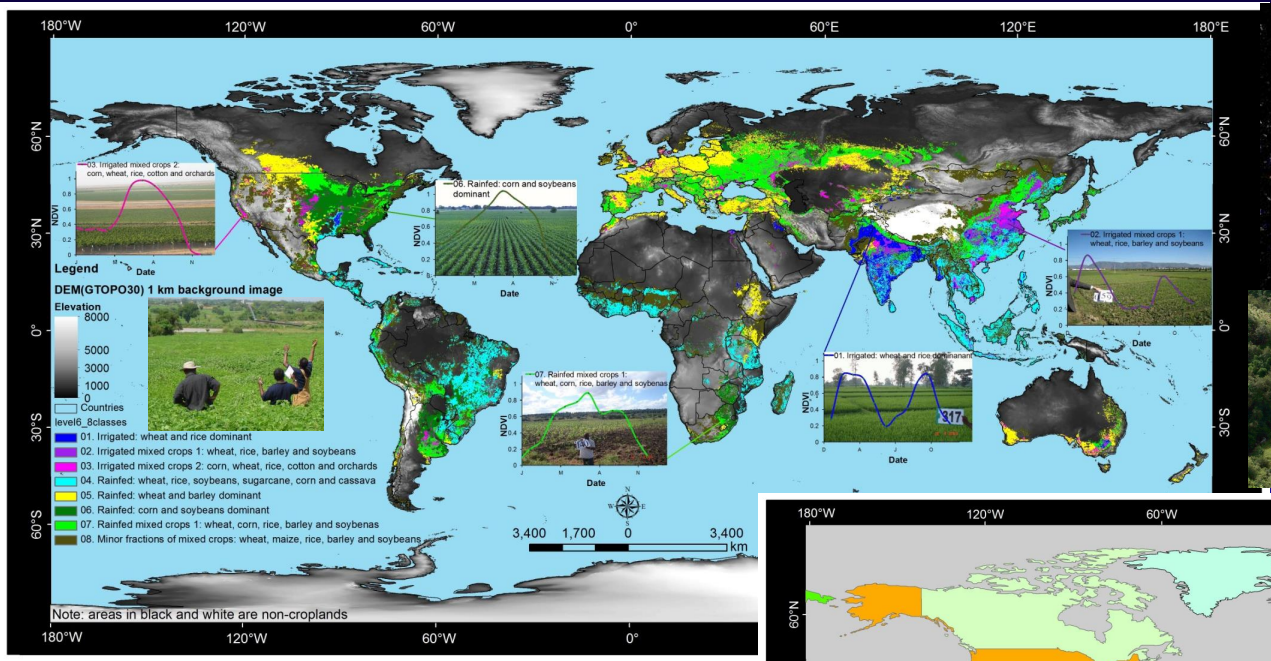
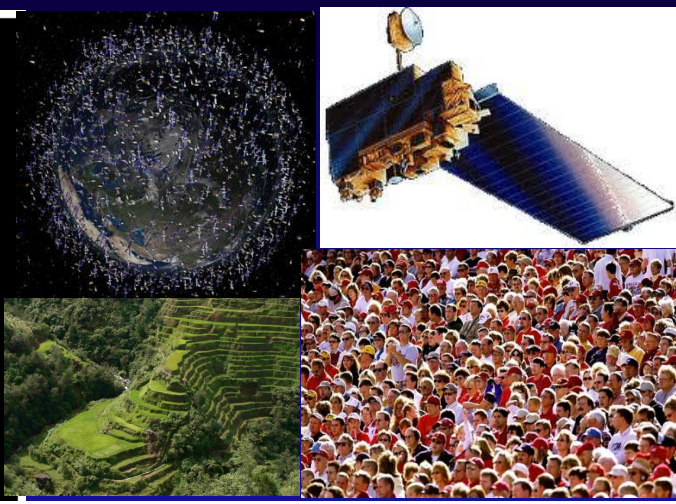
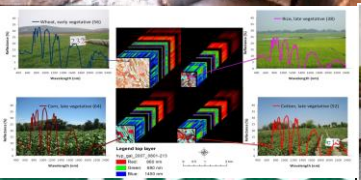
Remote Sensing of Global Croplands for Food Security







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Prasad S. Thenkabail (pthenkabail@usgs.gov)
Research Geographer, U.S. Geological Survey (USGS), USA

Colloquium presentation, University of North Dakota, April 22, 2015

Overview of
Today's Public Lecture

U.S. Geological Survey
U.S. Department of Interior

Overview of Today's Lecture

1. Context

2. Looking Back: How did we manage all these years?

3. Looking ahead: Big issues of Food Security in the 21st Century

4. Why "Business as Usual" is not a solution anymore

5. Setting the Stage: New paradigm for ensuring global food security
   - 5.1 Role of Global Croplands and Earth Observation (EO) Data
   - 5.2 Role of Global Cropland Water Use and EO Data

6. Solutions and Way Forward

7. References

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Context

Addressing the Global Food Security Challenge

U.S. Geological Survey
U.S. Department of Interior

Context: Big Picture

Key components, issues, and questions pertaining to Global Food Security

In a World of limited resources pertaining to

- Cropland Areas: 12% croplands; 24% grazing lands;
- Water Resources: 92% water use for agriculture;

And a World of ballooning

- Populations: 9.4 billion by 2050;

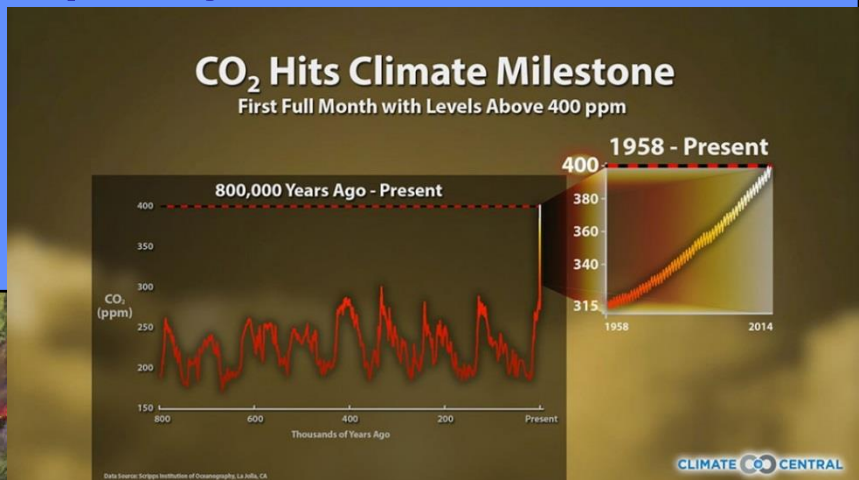
And a World where there is an urgent need to preserve

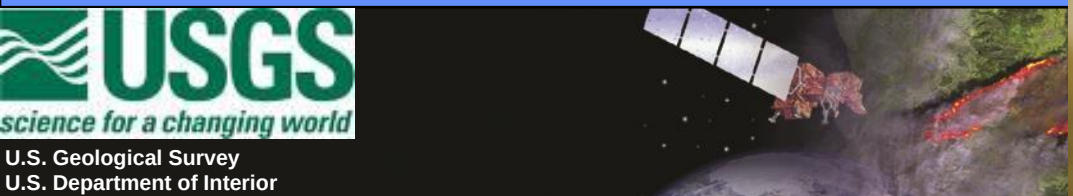
- Environments: ~400 ppmv in 2014;
- Flora/Fauna or Biodiversity: fast dwindling;

And a World where resource demands for other needs increase

- Urbanization
- Industry, Trade, and the complexity of a virtual world
- Environmental flows
- Health and recreation

……we will look at these issues from Earth Observation (EO) data from satellites and other Spatial Data





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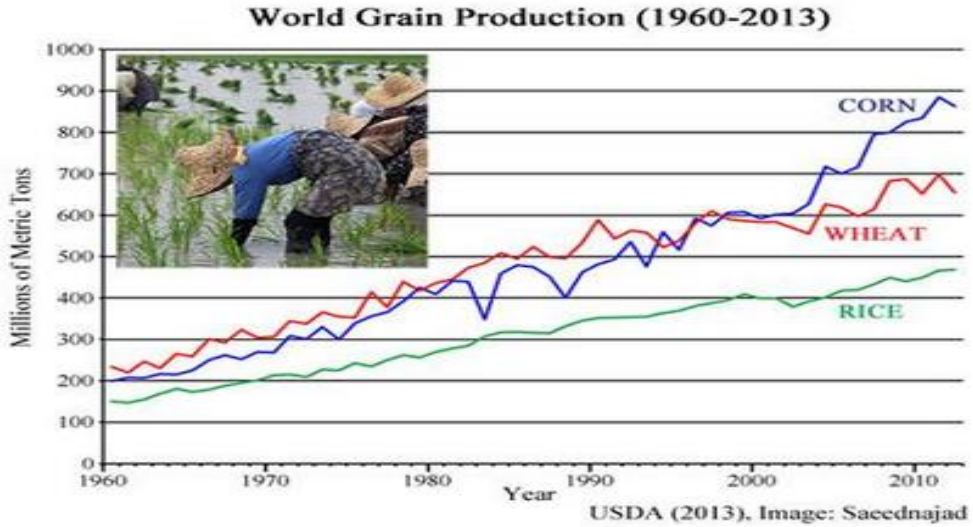
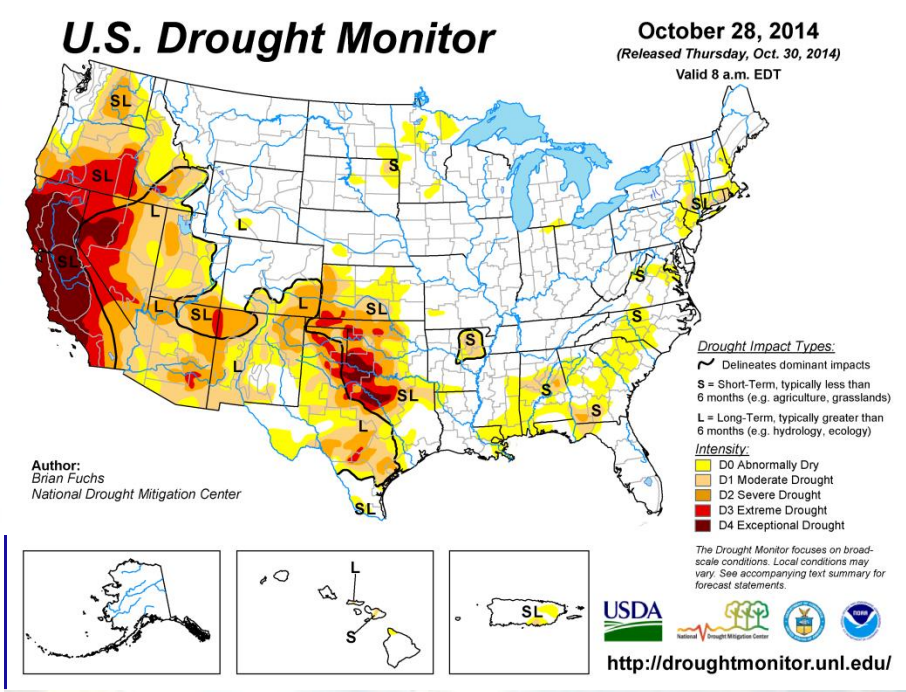
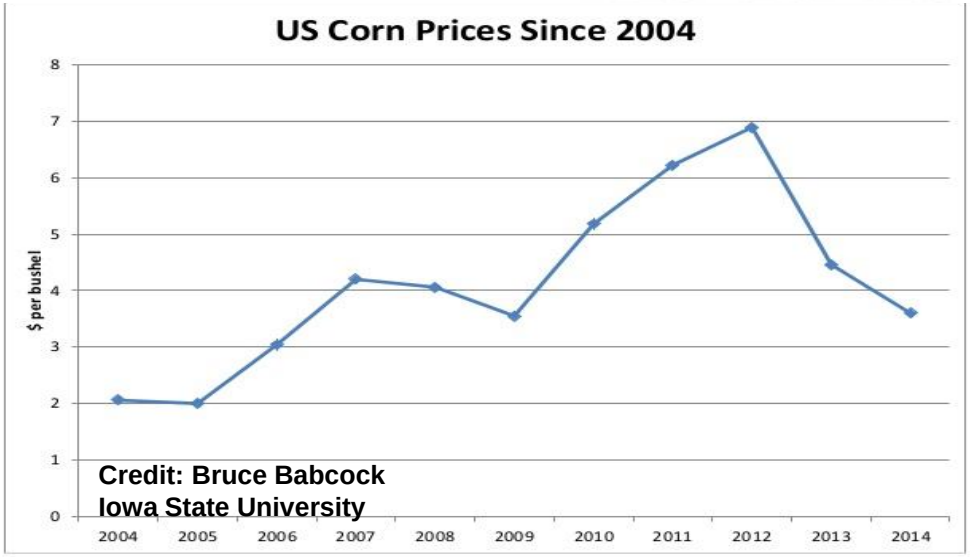
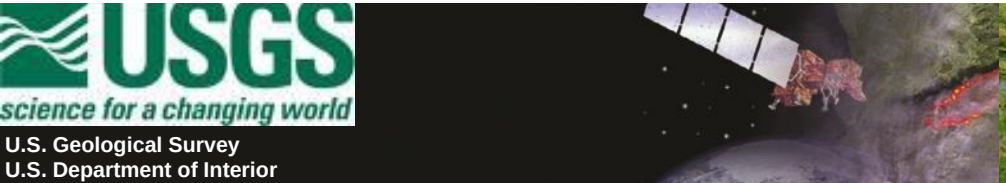
Context: Current Picture (e.g., 2012 Drought\Climate Variability)



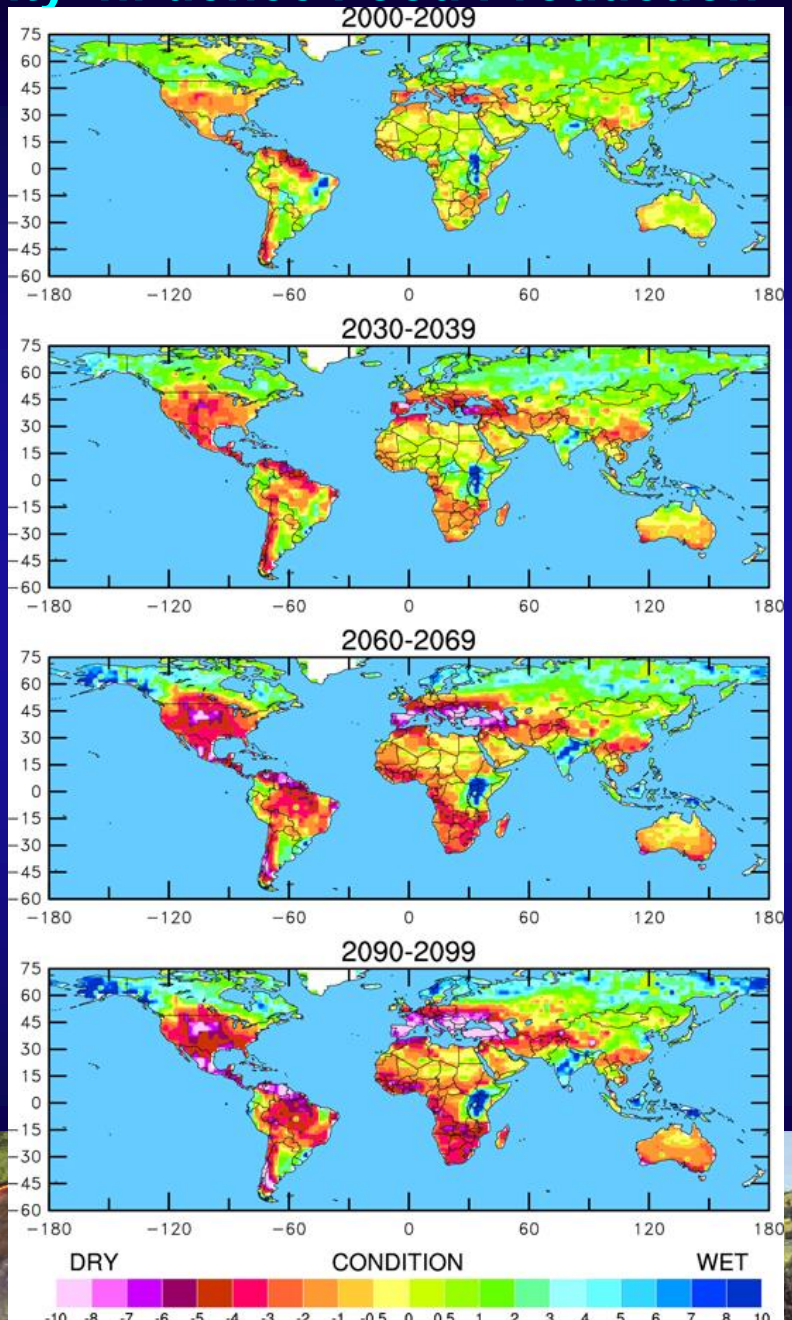






Context: How Does Climate Variability Influence Food Production

1. Will there be enough water to grow food?;
2. Will the water be available when it is needed (e.g., during the growing period)?;
3. What happens if the fertile croplands are taken for urban development?
4. Can we grow enough food by addressing environmental\health concerns?



Source: Future drought conditions, courtesy of Aiguo Dai/Wiley Interdisciplinary Reviews.

Global Food Security

How did we Manage all these Years?

....especially when population grew from 3 to 7 billion in last 50 years

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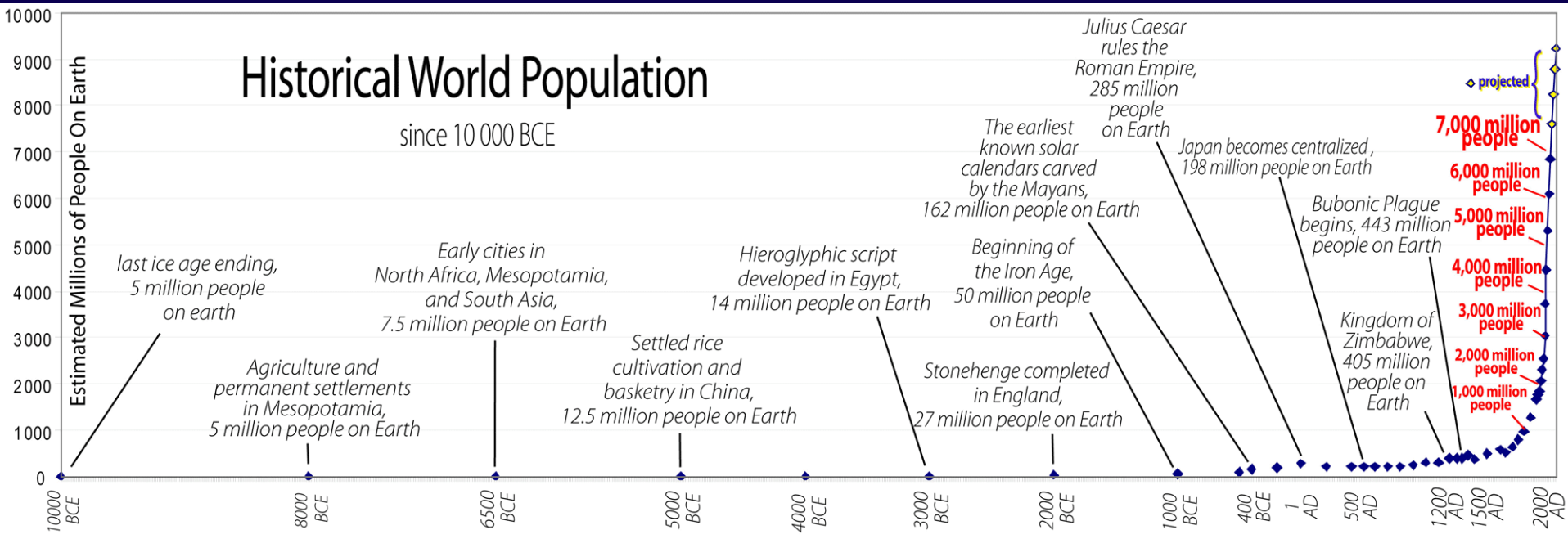
Global Population Growth: 10,000 Years+



Population increased from 3 billion in 1960 to 7.3 billion in 2014….How did we manage?

Source: UNEP-GRID, Sioux Falls, SD. Data from SEDAC

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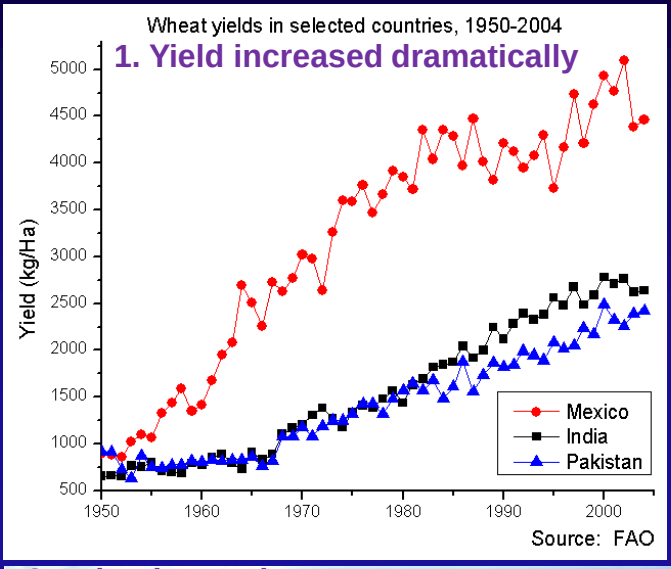
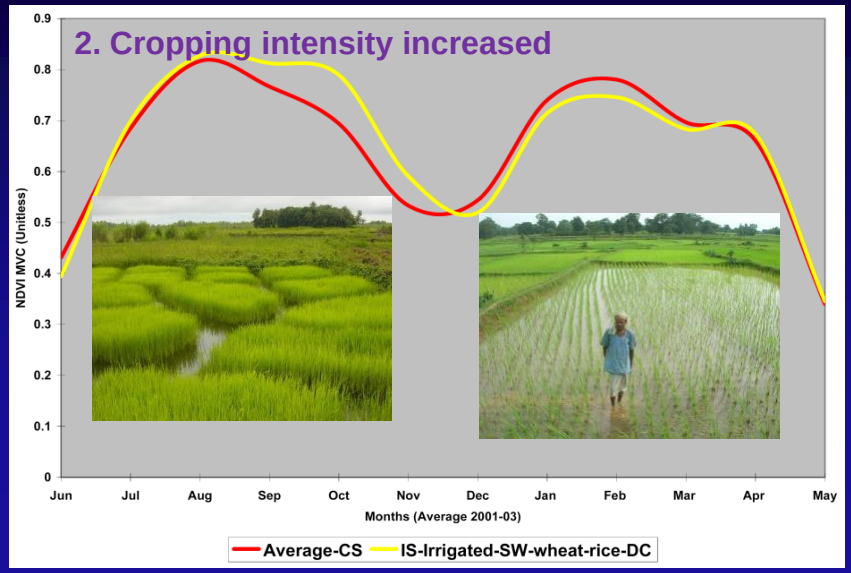
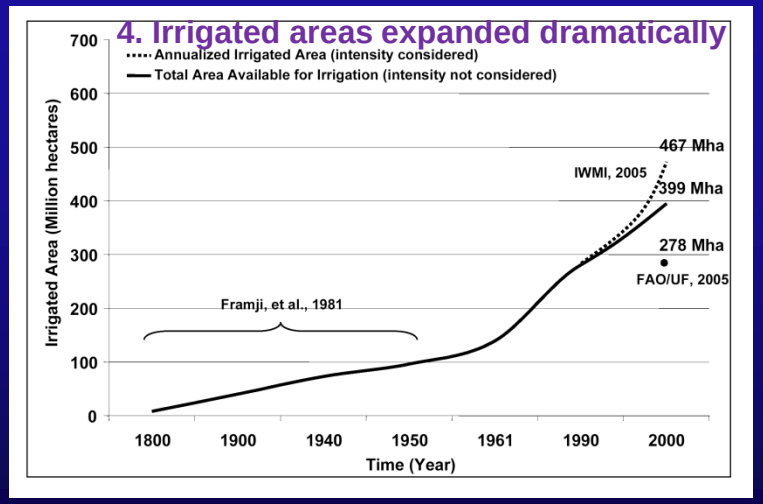
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

How Did we Feed the World between 1960-present: Green Revolution was Key

….when world added an additional 4 billion people in just 50 years!







….also cropland management involving herbicides, pesticides, fertilizers, drainage……. combination of these factors lead to green revolution

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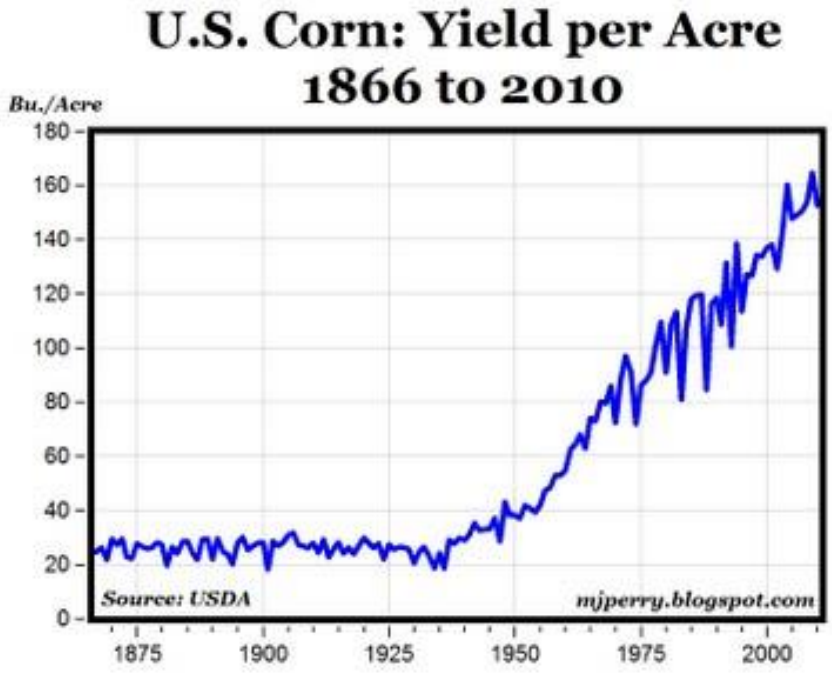
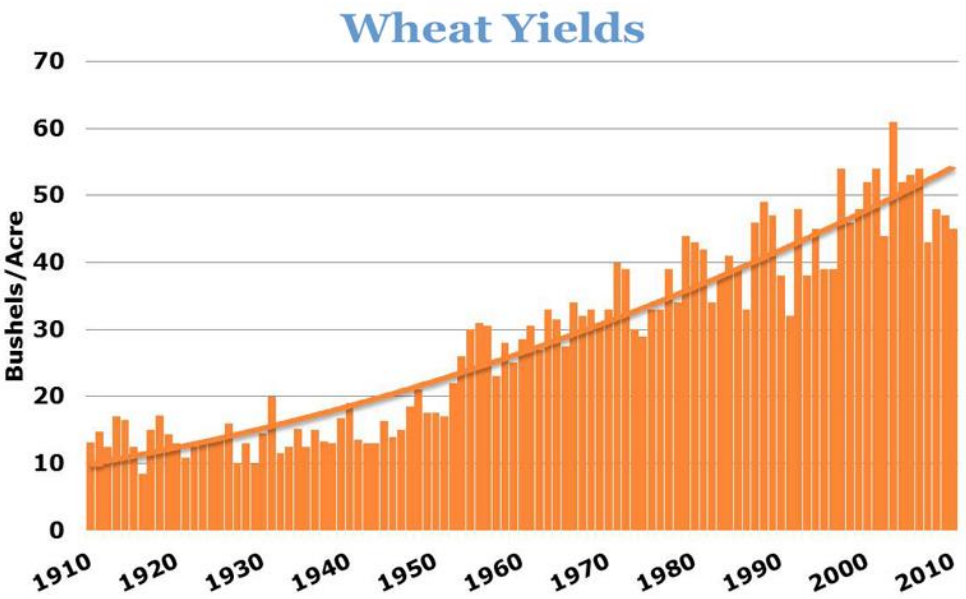
Global Food Production During the Green Revolution Era



Global grain production and consumption in billion metric tons

In the United States, for Example, Key Crop Yields increased by 300 to 400% during Green Revolution Era



Source: USDA NASS

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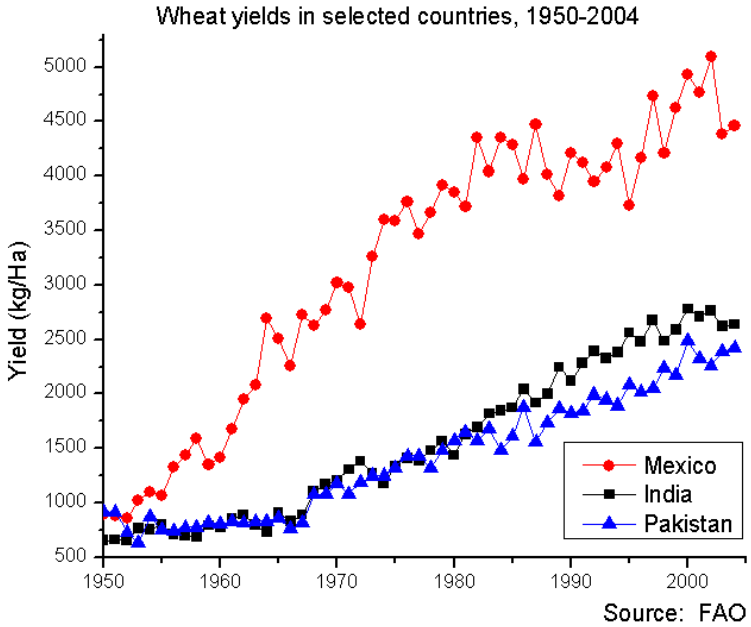
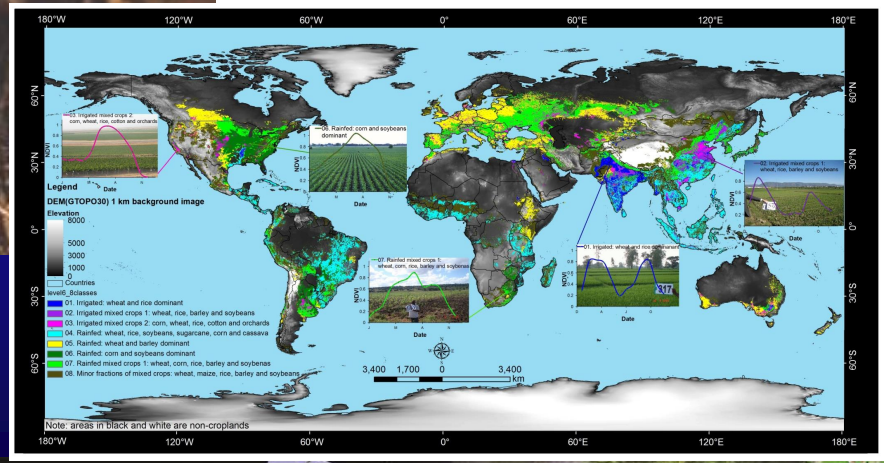
Green Revolution: Increases in Productivity per Unit of Land between 1950-2010

Norman Borlaug, Nobel laureate, World Food Prize and father of Green Revolution



Green Revolution Mantra:

1. High yielding varieties;
2. Cropland intensification;
3. Cropland expansion;
4. Irrigation expansion;
5. Management (e.g., herbicides, pesticides, drainage)



Norman Borlaug and M.S. Swaminathan, two pillars of Green Revolution. Photo credit: M.S. Swaminathan Foundation

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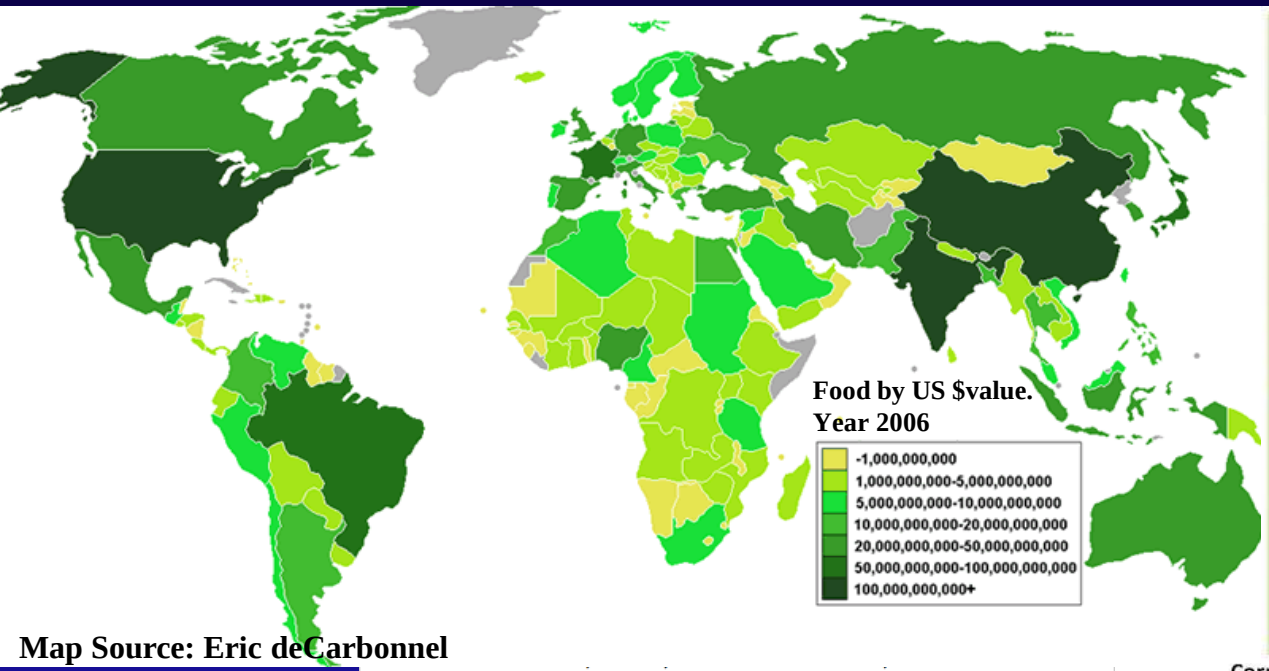
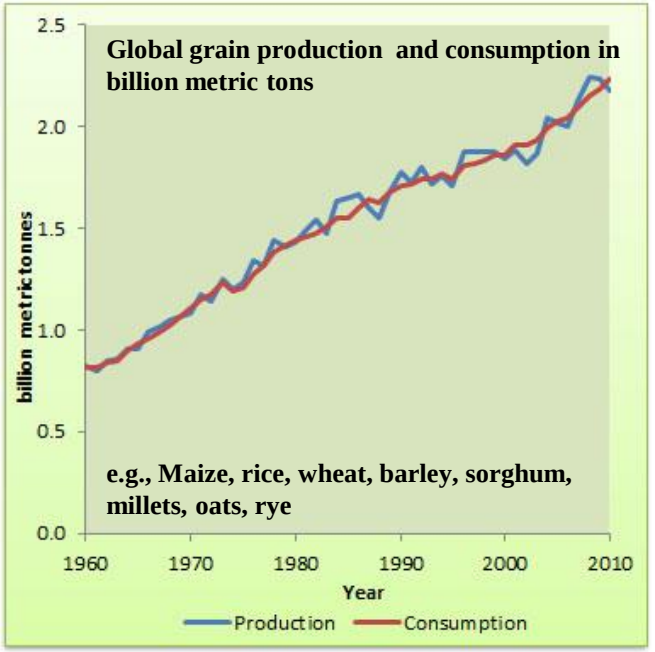
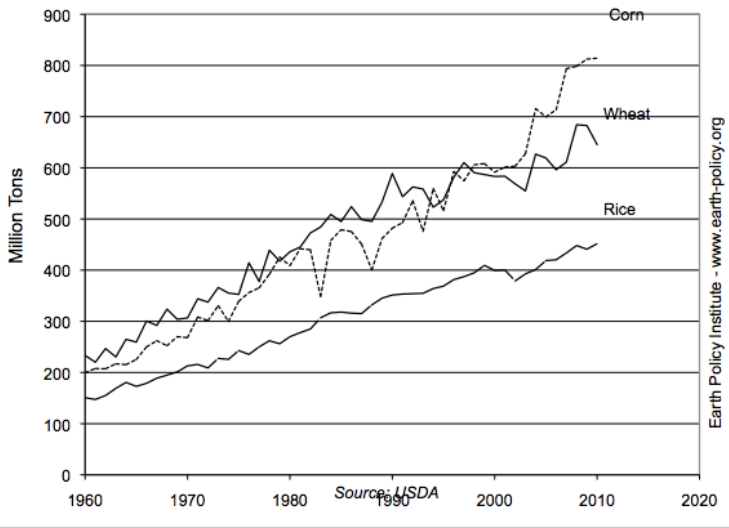
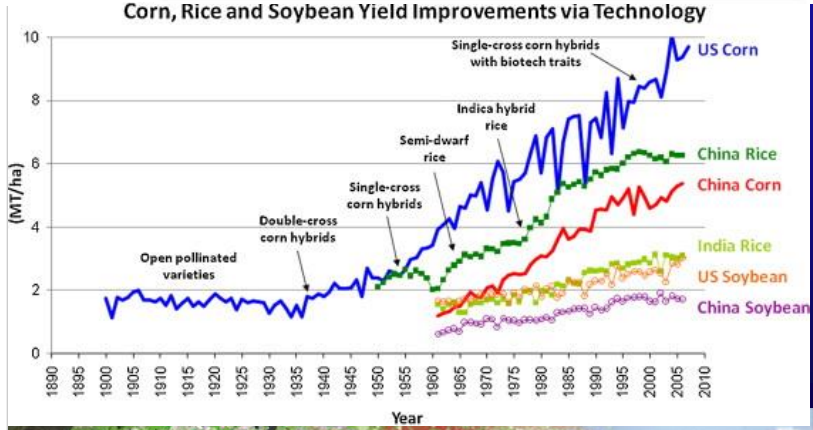
Global Food Production During the Green Revolution Era



Map Source: Eric deCarbonnel







Sources: USDA, IFRPI, FAO

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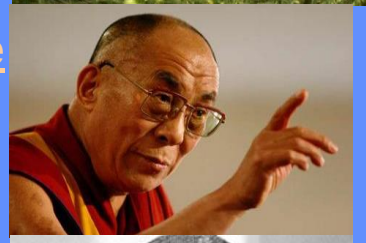
Global Food Security during the Green Revolution Era (~1960-2010)

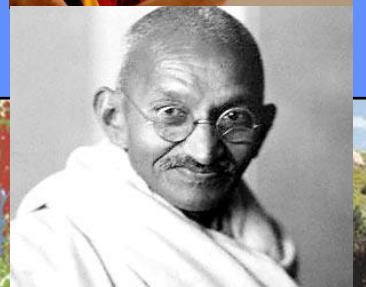
In the last 50 years population which grew from 3 billion in year 1960 to 7.3 billion in year 2014. The food demands of this ballooning population was met by:

Green Revolution

"Almost certainly, however, the first essential component of social justice is adequate food for all mankind" - **Norman Borlaug, Nobel laureate and Father of Green Revolution**



"Peace can only last where human rights are respected, where the people are fed, and where individuals and nations are free." **The 14th Dalai Lama**



"Food security is fundamental for human welfare, human advancement, and human dignity" **Mahatma Gandhi**

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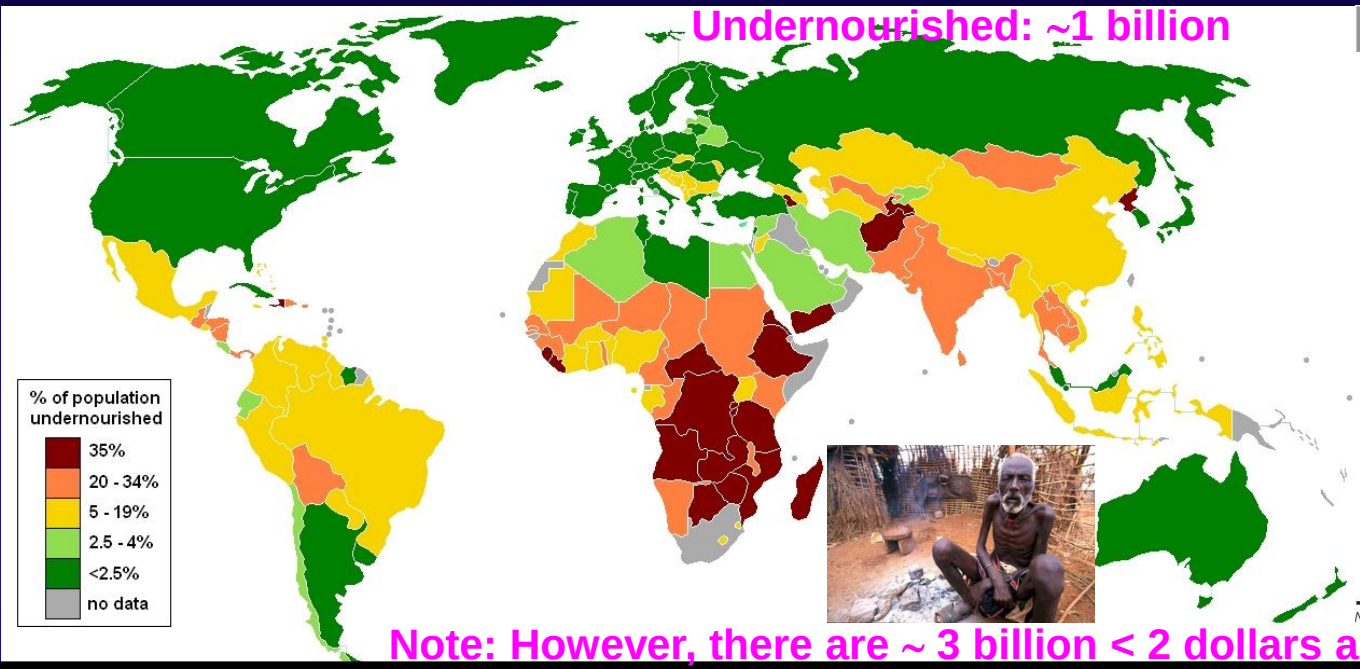
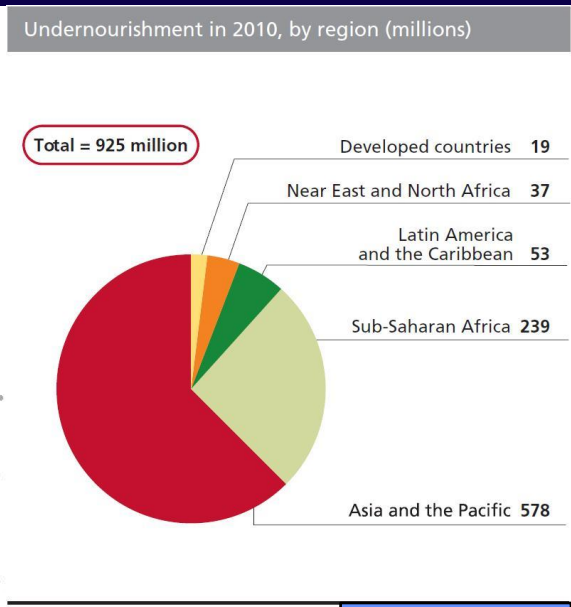
Undernourished *versus* Overnourished

Undernourished: ~1 billion

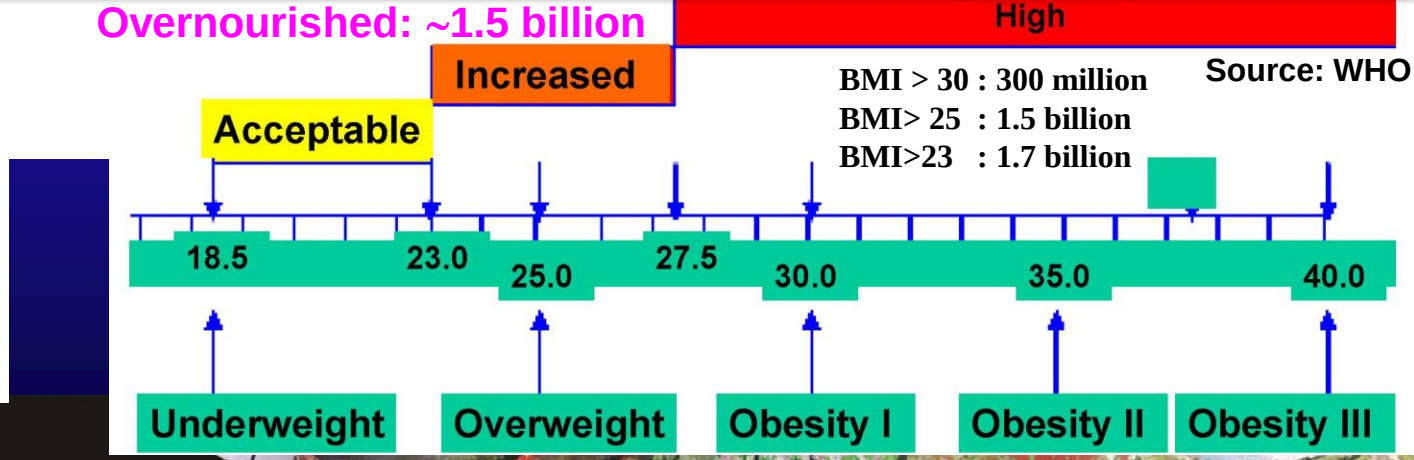




Source: FAO

Note: However, there are ~ 3 billion < 2 dollars a day

Overnourished: ~1.5 billion



Source: WHO

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Global Food Security

So What are the Big Issues in Years ahead?

….especially when population will grow from 7 to 9 or 10 billion in next 50 years

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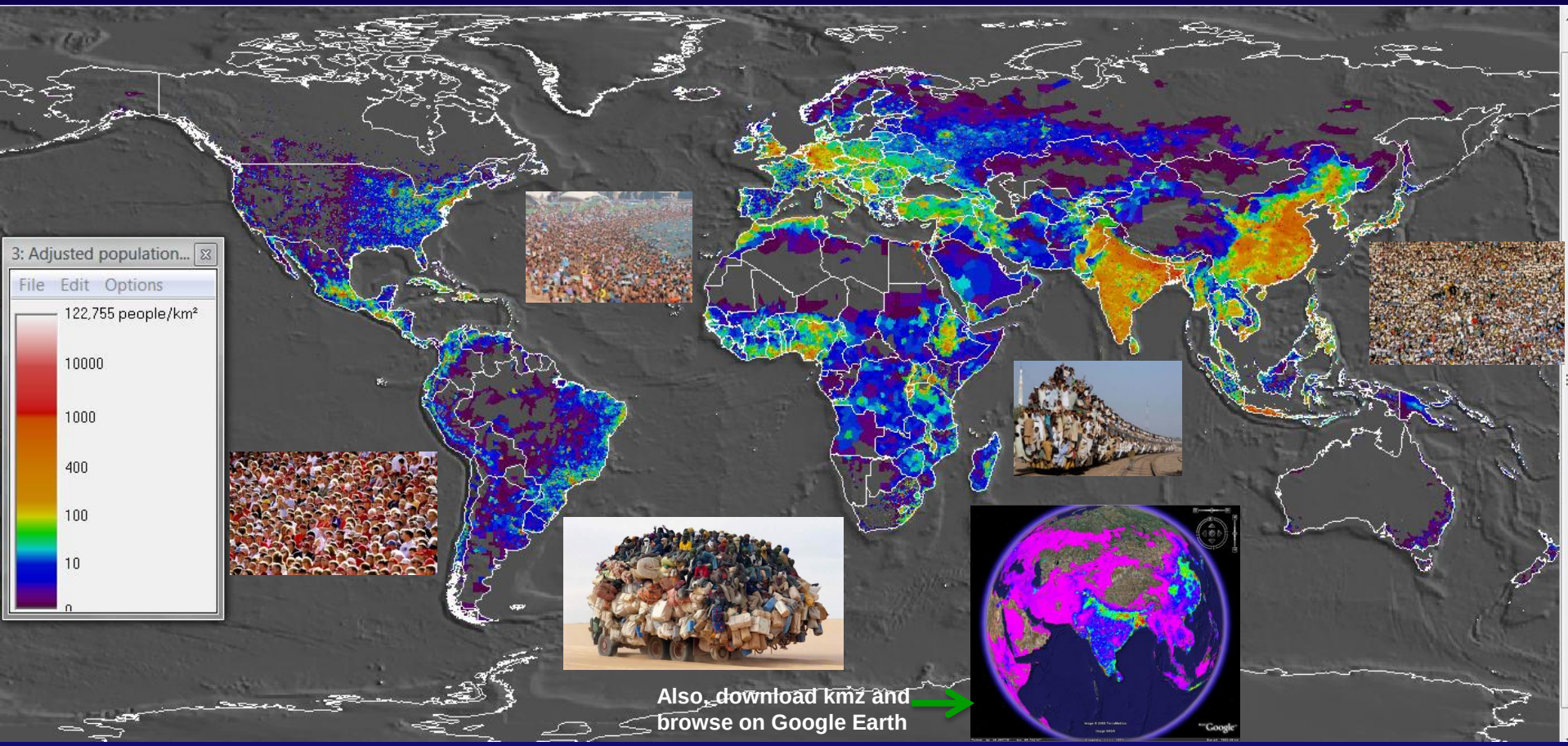
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Current Global Population Density (people/km²)



Source: LandScan 2007 from Oak Ridge National Laboratory and Gridded Population of the World v 3.0 from the NASA-funded Socioeconomic Data and Applications Center at the Center for International Earth Science Information Network.

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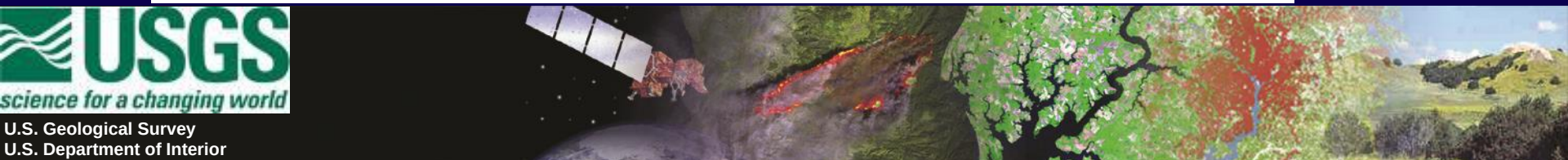
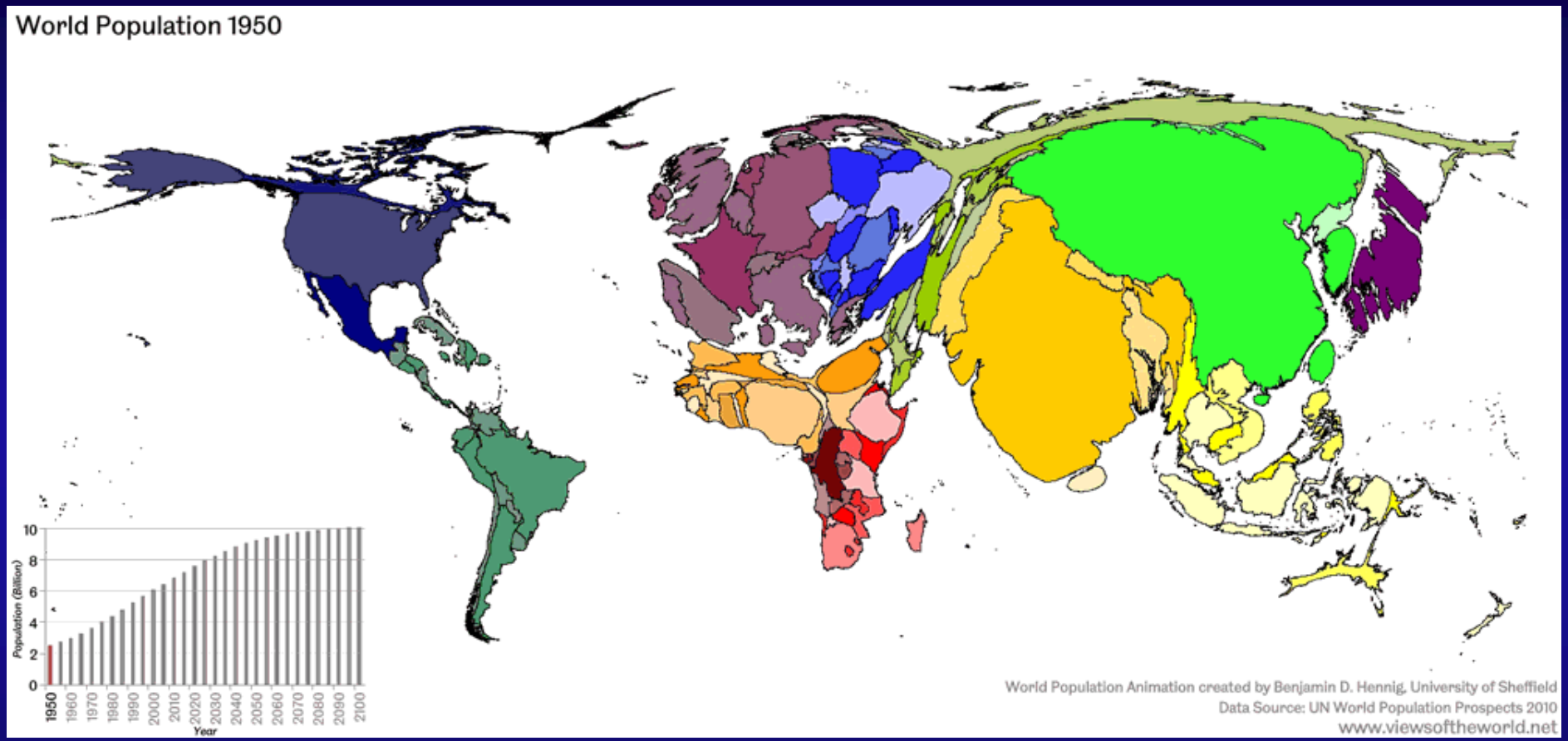
Projected Global Population Scenarios: Variants

Source: World Population to 2300, United Nations, 2004

Figure 6. Estimated world population: 1950-2000, and projections: 2000-2300



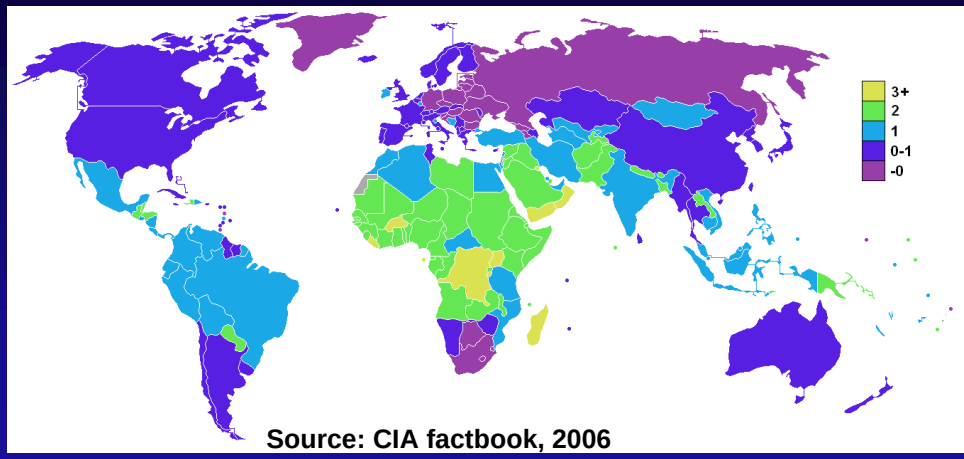
Global Population Growth Simulation: 1950 through 2100



Population Dynamics Scenario: 1950-2300

	Year	Year	Year	Year	Year
	1950	2000	2050	2100	2300
	Millions	Millions	Millions	Millions	Millions
Japan	84	127	109	**	**
Germany	68	82	**	**	**
United Kir	50	**	**	**	**
Russia	102	145	101	**	**
USA	157	285	408	437	493
Brazil	54	172	233	212	222
Mexico	28	99	140	128	127
Nigeria	30	114	258	302	282
Ethiopia	**	66	171	222	206
Congo DR	**	**	151	203	183
Uganda	**	**	103	167	155
Egypt	22	68	127	132	125
Yemen	**	**	84	144	130
Iran	**	66	105	98	101

** = Not in top 19 countries in the year



Source: CIA factbook, 2006

	Year	Year	Year	Year	Year
	1950	2000	2050	2100	2300
	Millions	Millions	Millions	Millions	Millions
China	554	1275	1395	1181	1285
India	357	1016	1531	1458	1371
Bangladesh	42	138	254	260	242
Pakistan	40	142	349	408	359
Indonesia	79.5	211	293	272	276
Africa	221	795	1803	2254	2112
Asia	1398	3679	5222	5019	4943
Latin America and Carribean	167	520	767	732	722
Oceania	12.8	31	45.8	46.1	48.4
North America	171	315	447	473	534
Europe	547	728	631	538	611
Total	2516.8	6068	8915.8	9062.1	8970.4

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Daily Calories: A Global Picture














Daily Calorie Intake Per Capita

- Less than 1,890
- 1,890 – 2,170
- 2,170 – 2,390
- 2,390 – 2,620
- 2,620 – 2,850
- 2,850 – 3,050
- 3,050 – 3,270
- 3,270 – 3,480
- 3,480 – 3,770
- No data

in kcal/person/day

World: 2780 kcal/person/day
Developed countries: 3420 kcal/person/day
Developing World: 2630 kcal/person/day
Sub-Saharan Africa: 2240 kcal/person/day
Central Africa: 1820 kcal/person/day

UN recommends 2350 calories per day.

Source: FAO, 2010

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Kilocalorie: A unit of measurement of dietary energy. One kcal equals 1,000 calories and one kJ equals 1,000 joules. In the International System of Units (ISU), the universal unit of dietary energy is the joule (J). One kcal = 4.184 kJ.

Addressing the Global Food Security Challenge

Next 50 years World needs to meet the food demand of a population which will grow from 7 billion in year 2011 to 9 or 10 billion by 2050. Three factors need to be noted:

1. Population growth (e.g., additional 2 to 3 billion);
2. Increasing nutritional demand (e.g., more meat);
3. Change in demographics (e.g., swift rise in population in Africa)

Global Food Security

Why "business as usual" is not a solution

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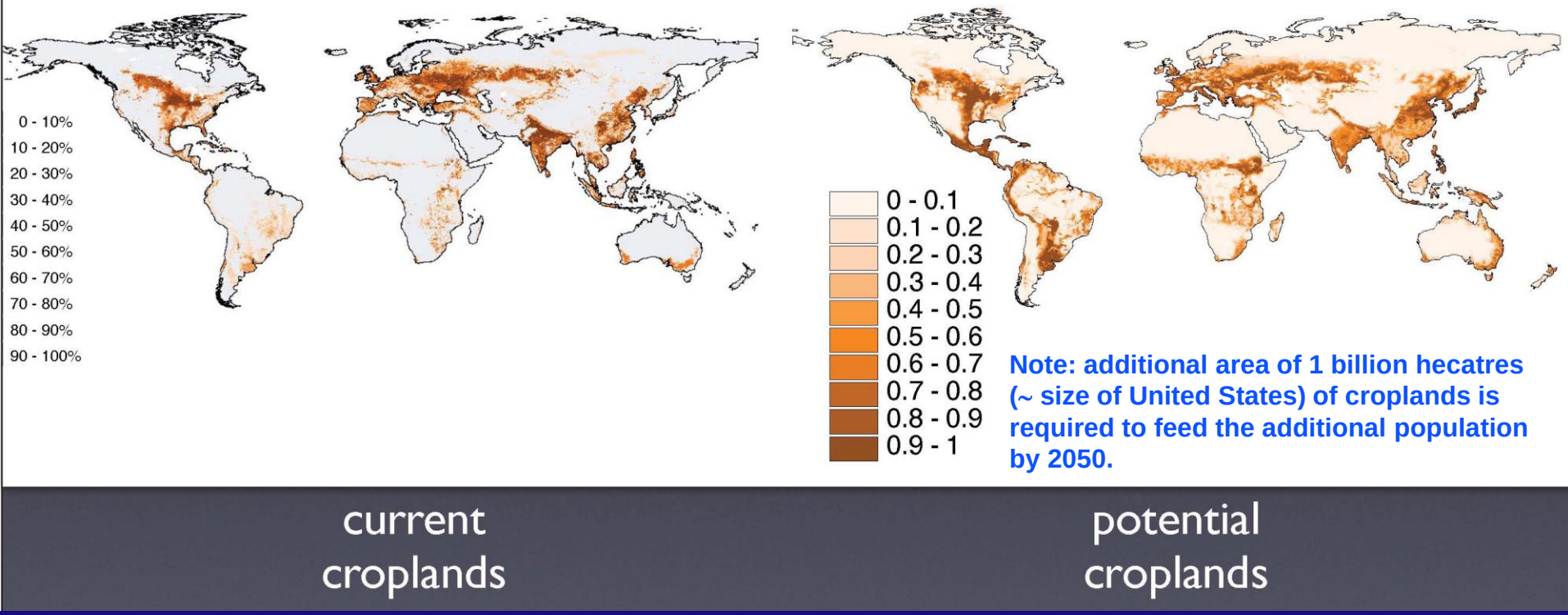
Increasing Cropland Areas Difficult

Ramankutty et al., 2002



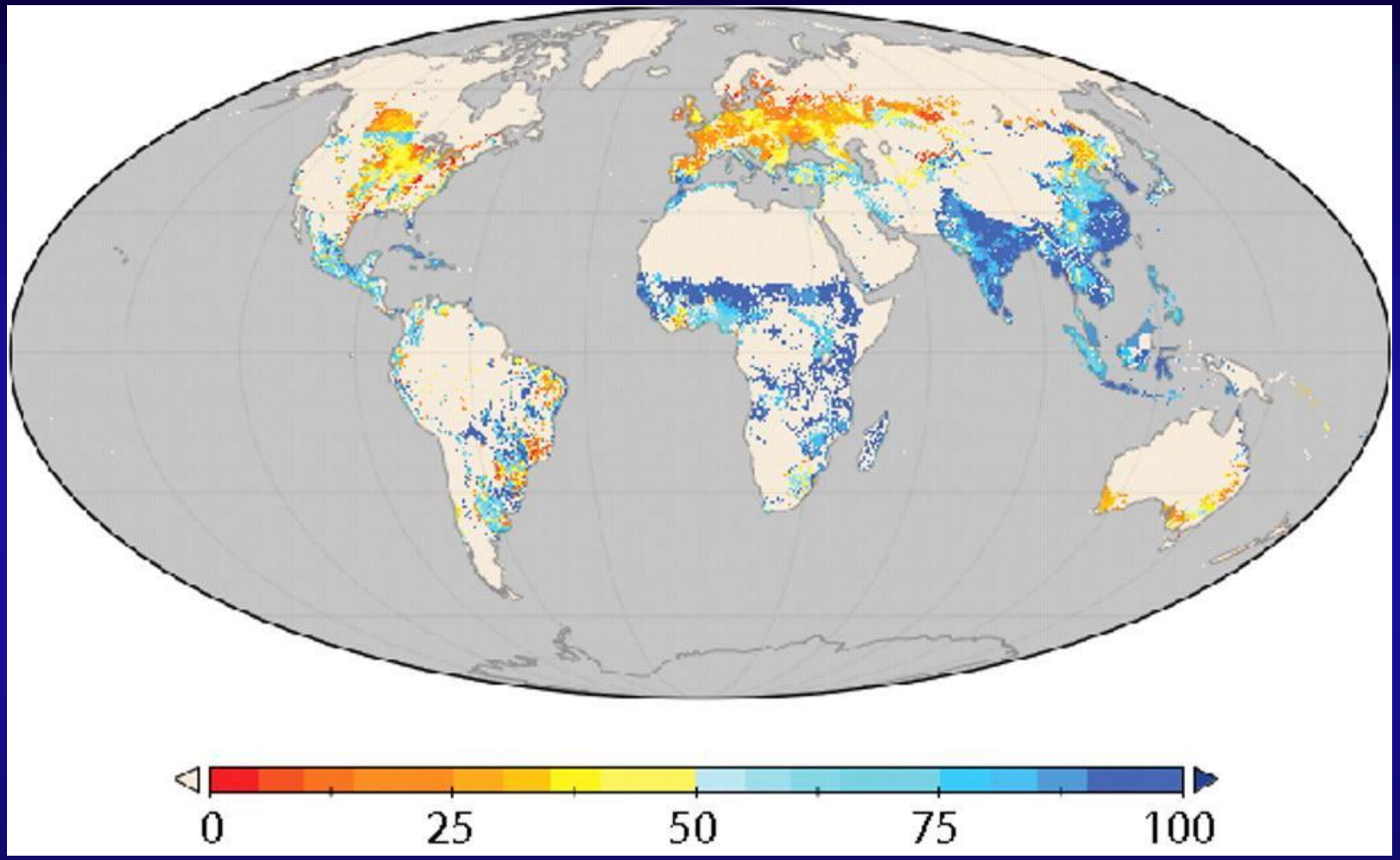
Note: additional area of 1 billion hecatres (~ size of United States) of croplands is required to feed the additional population by 2050.

..only @ Very High environmental/ecological costs….further high demand for land for alternatives uses (e.g., industry, urban, bio-fuel)

Source: Ramankutty et al., 2002; Foley, 2011

Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Croplands and Pasture lands already cover 1/3rd of the Ice Free Planet



Source: Monfreda, C., N. Ramankutty, and J. A. Foley (In Press), Farming the Planet. 2: The Geographic Distribution of Crop Areas, Yields, Physiological Types, and NPP in the Year 2000, Global Biogeochemical Cycles, doi:10.1029/2007GB002947.

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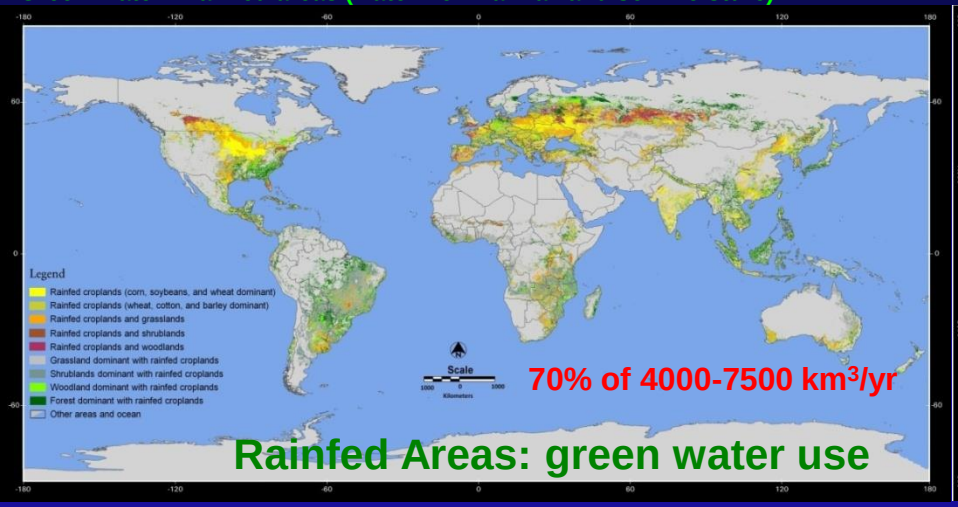
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

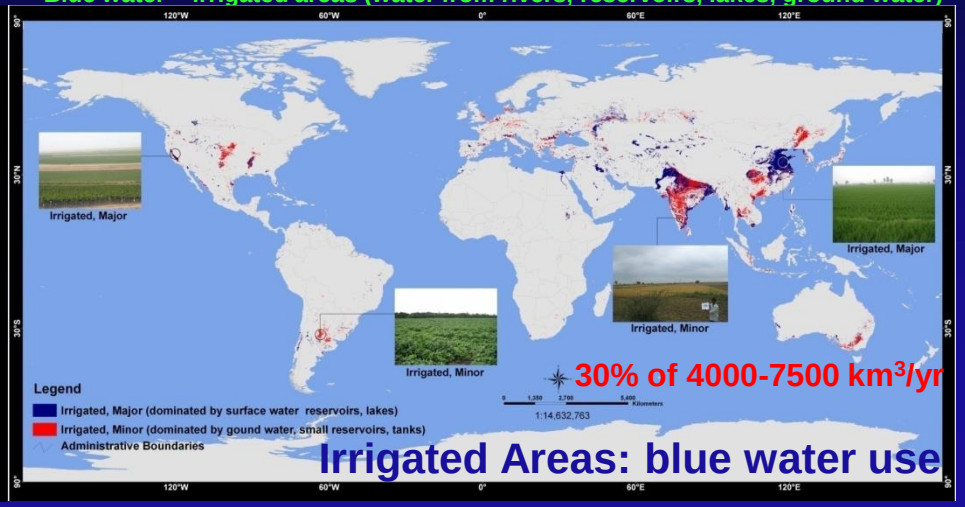
Increase Water Allocations for Agriculture Difficult

Agriculture already uses 92% of all Human Water Use (PNAS, Hoekstra et al., 2012)

Green Water = rainfed areas (water from rainfall and soil moisture)



Blue water = irrigated areas (water from rivers, reservoirs, lakes, ground water)



"green water use" (water from rain and soil moisture from unsaturated zone). 1.1 billion hectares of rainfed areas use 70% of agricultural water use.

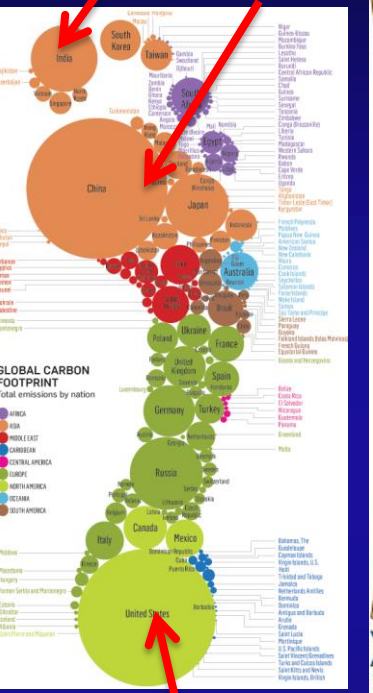
"blue water use" (water in river, lakes, reservoirs, and acquifer ground water). 470 million hectares (when you consider intensity) of irrigated areas uses the rest 30% of agricultural water use.

..already agriculture takes up overwhelming amount of human water use and alternative uses of water always increasing…..so, it is obvious food production requires a new paradigm….

Global Greenhouse Gas (GHG) Emissions will only Increase

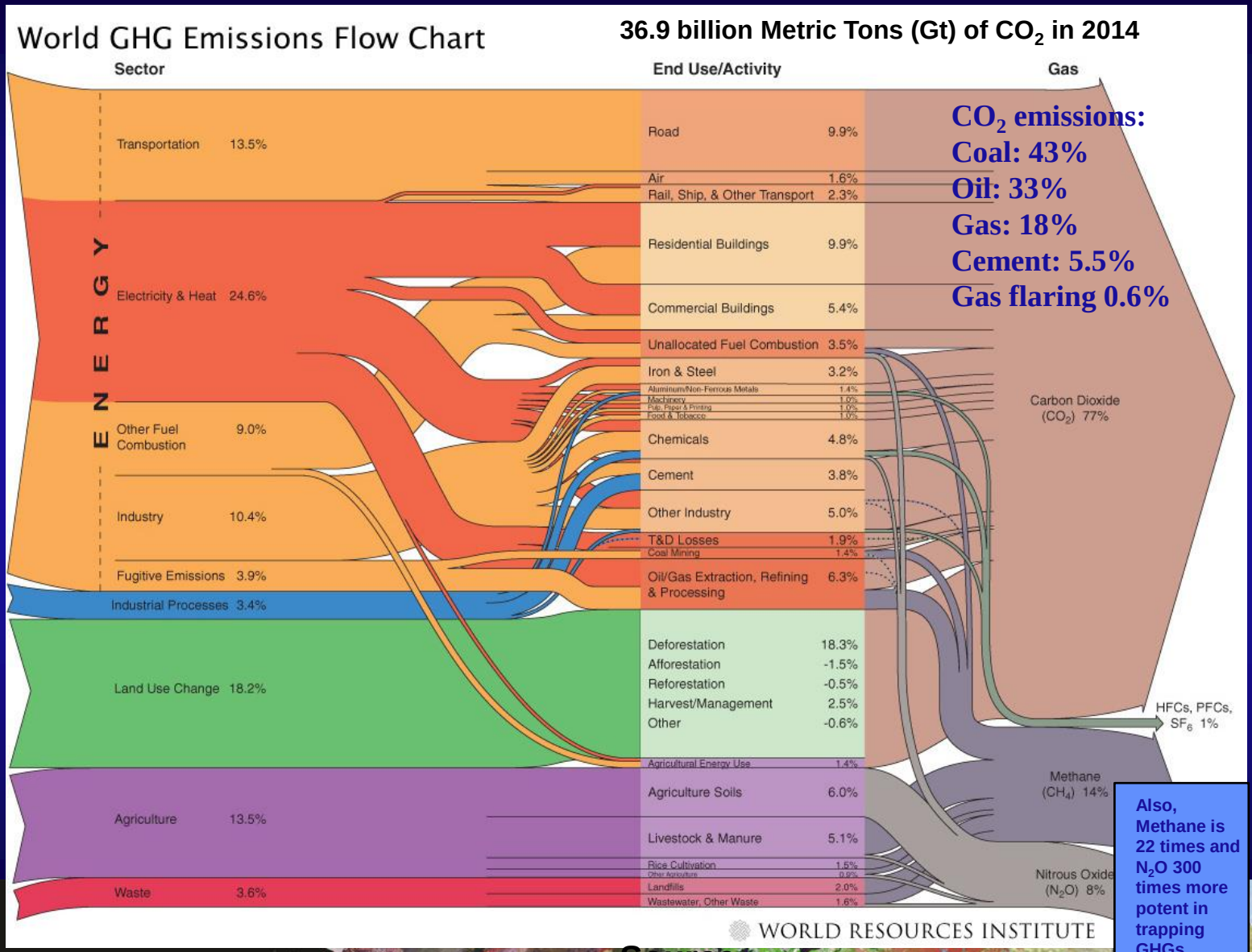
India

China



USA

China: 28%
USA: 14%
EU: 10%
India: 7%



CO_2 emissions:
Coal: 43%
Oil: 33%
Gas: 18%
Cement: 5.5%
Gas flaring 0.6%

Also, Methane is 22 times and N_2O 300 times more potent in trapping GHGs

Source:

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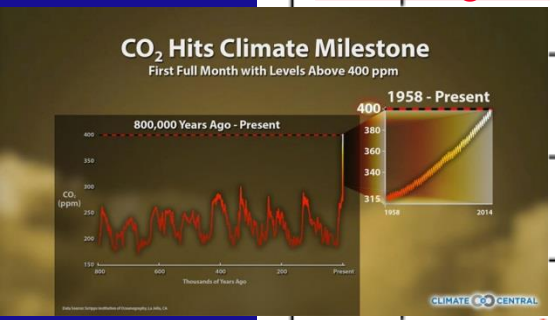
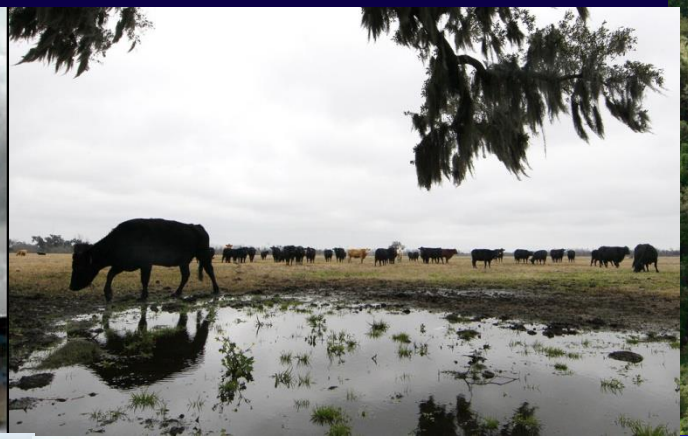
…economic growth must pay for environmental/ecological damages

Global Greenhouse Gas (GHG) Emissions will only Increase



Agriculture contributes to ~14% of 31.6 billion Metric Tons (Gt) of CO_2 in 2011. However, note the "breathing cycle" of the planet wherein summer months in Northern Hemisphere where plant activity is highest helps suck in the CO2 in atmosphere.

Environmental/Ecological Damage Can be Irreversible



…sustainable development for healthy livelihoods

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Addressing the Global Food Security Challenge

Next 50 years World needs to meet the food demand of a population which will grow from 7 billion in year 2011 to 9 or 10 billion by 2050.

There is a consensus view that:

1. **Increasing cropland areas is NOT a solution;**
2. **Increasing water allocations (e.g., more irrigation) is NOT a solution.**

…….So a New paradigm to increase food production that is ecologically, environmentally friendly with: (a) less croplands, and (b) less water allocations for croplands

Global Food Security

Setting a Stage for A New Paradigm

U.S. Geological Survey
U.S. Department of Interior

Addressing the Global Food Security Challenge

A critical and urgent question facing humanity in the twenty-first century is, how can we continue to feed the World's ballooning populations in the twenty-first century:

1. **Without increasing cropland areas;**
2. **Without increasing allocations for cropland water use;**

Indeed, an even better question to ask is how can we continue to feed the World's ballooning populations in the twenty-first century by

1. **Reducing the existing cropland areas for food production? (e.g., taken away for bio-fuels, urbanization), and\or**
2. **Reducing the existing water allocations for food production? (e.g., water needed to produce unit of grain in increasing as a result of increasing temperature in a changing climate)**

Role of Global Croplands in Ensuring Global Food Security

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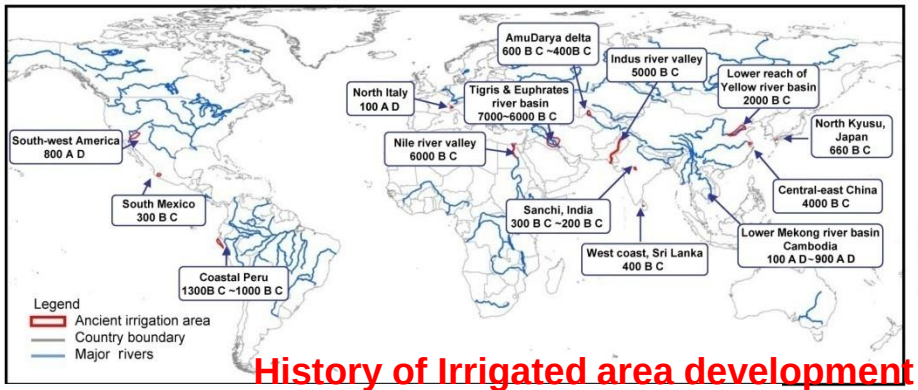
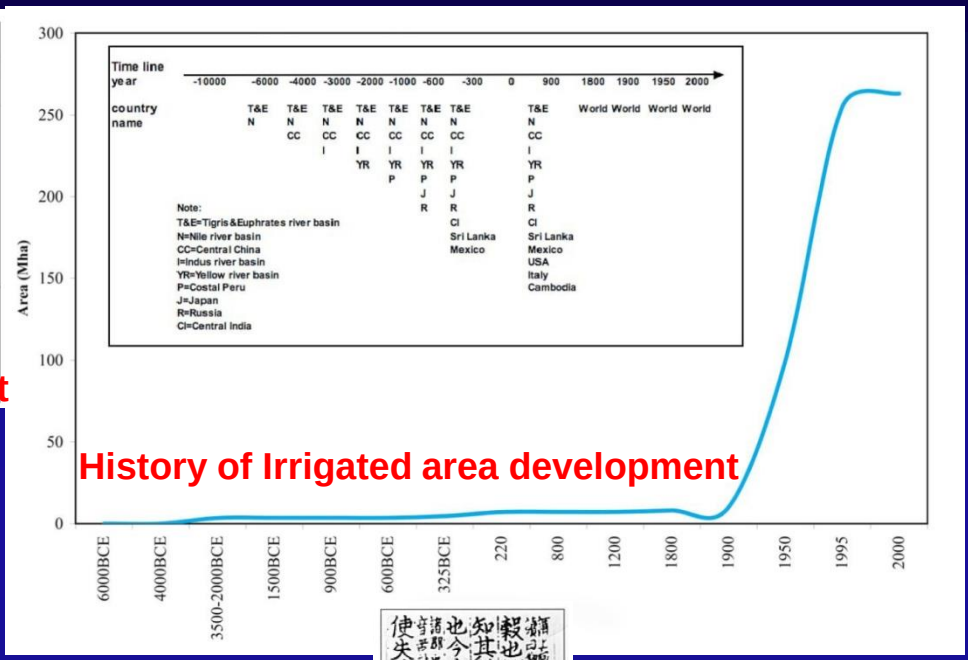
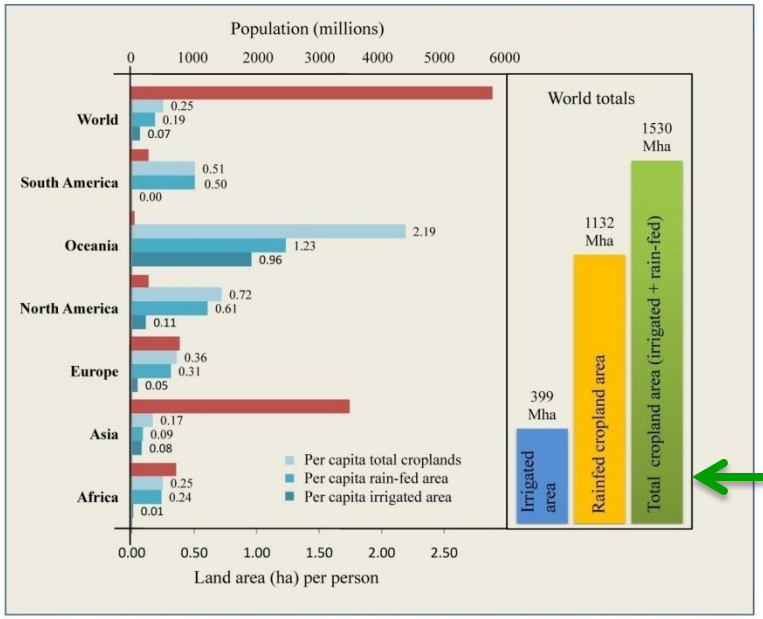
History and Current State of Global Croplands



History of Irrigated area development



History of Irrigated area development



Settled agriculture = 23,000 years
Irrigated agriculture = 10,000 years

Current state of Global Croplands

Early recorded irrigation history of China. This is one of the oldest history books called the 'Han Book' published during the reign of King Han Wu (155 BC to 74 BC). The words written there are "Agriculture is the foundation of a country while irrigation is the spirit of agriculture…".

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History and Current State of Global Croplands

Global Ecology and Biogeography, 20, 73–86, © 2010 Blackwell Publishing Ltd

4000 years
3000 BC to 1000 AD

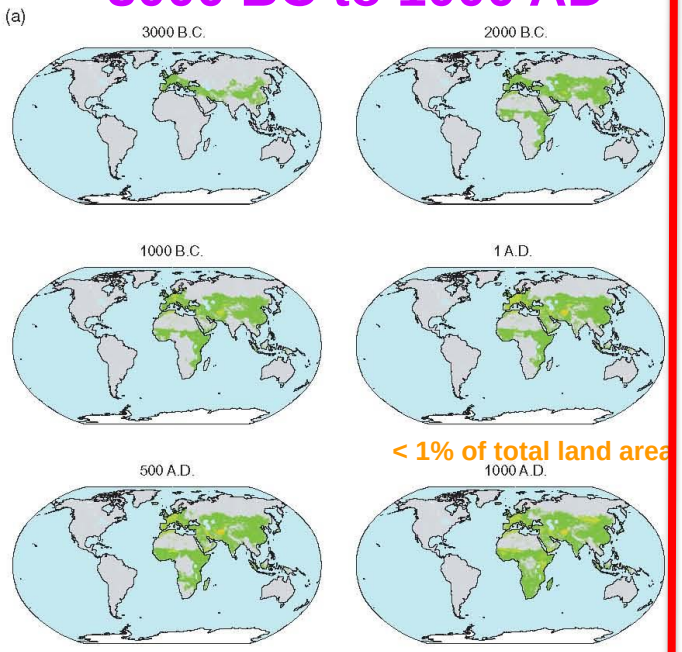
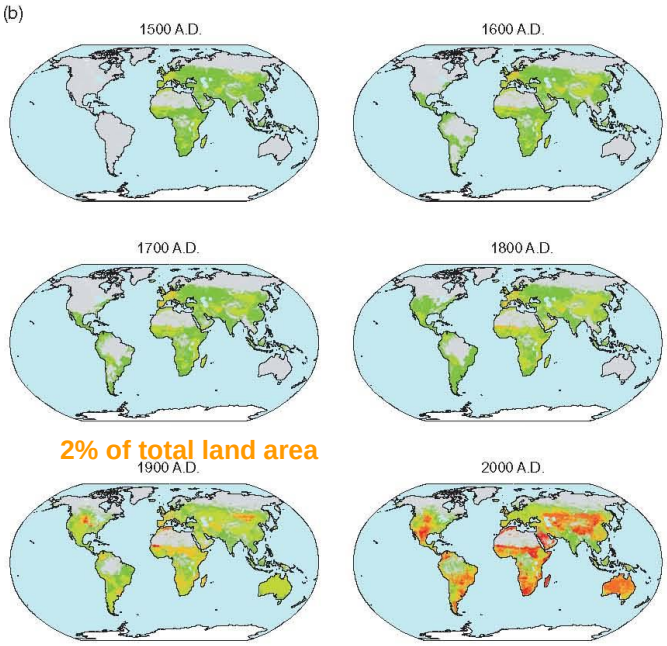


Figure 2 Historical pasture area (a) 3000 BC to AD 1000 and (b) AD 1500–2000.

< 1% of total land area

Past 500 years
1500 AD to 2000 AD



2% of total land area

~1.5 to 1.7 billion ha. (~10.3 to 12% of total land area)

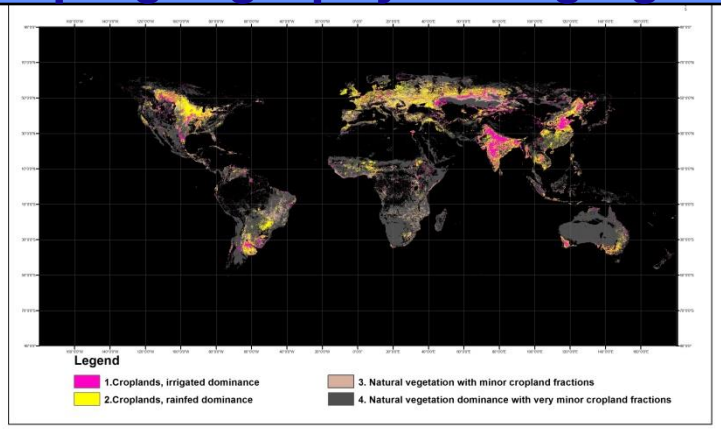
HYDE 3.1 Holocene land use

Goldewijk et al., 2011

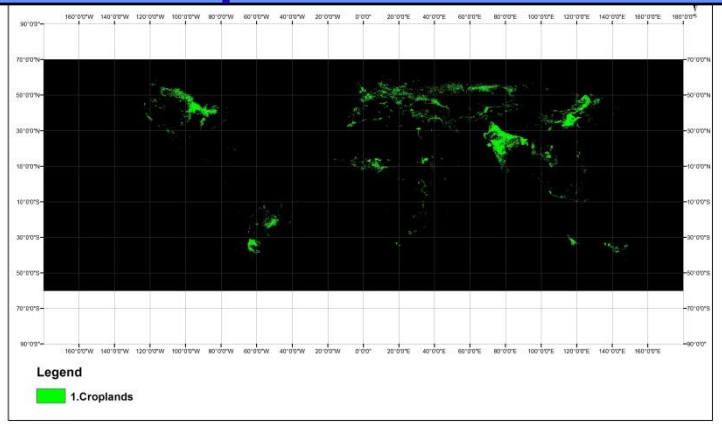
Global Food Security-support Data @ 30 m (GFSAD30) Project

GCE 1km Multi-study Crop Mask (aka GCE V1.0)

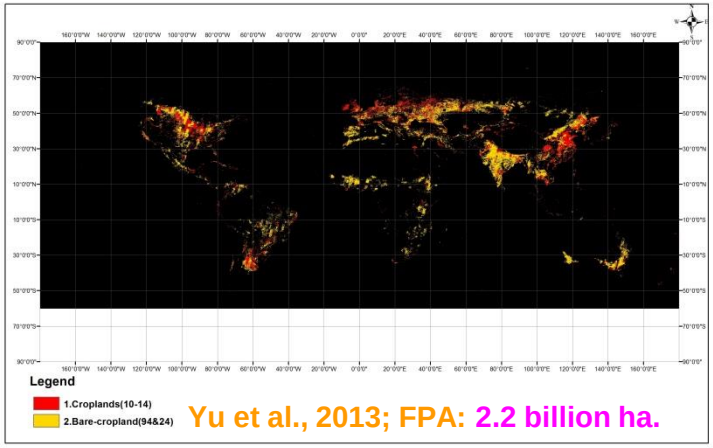
http://geography.wr.usgs.gov/science/croplands/index.html



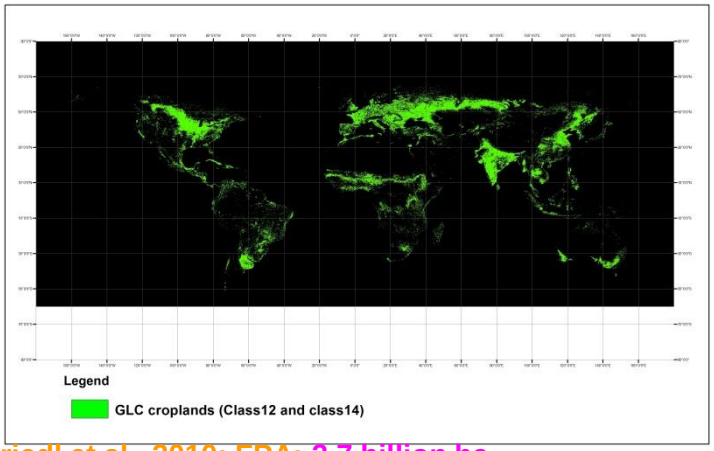
Thenkabail et al., 2011, 2009a,b; FPA: 2.3 billion ha.



Pittman et al., 2010; FPA: 0.9 billion ha.



Yu et al., 2013; FPA: 2.2 billion ha.



Friedl et al., 2010; FPA: 2.7 billion ha.

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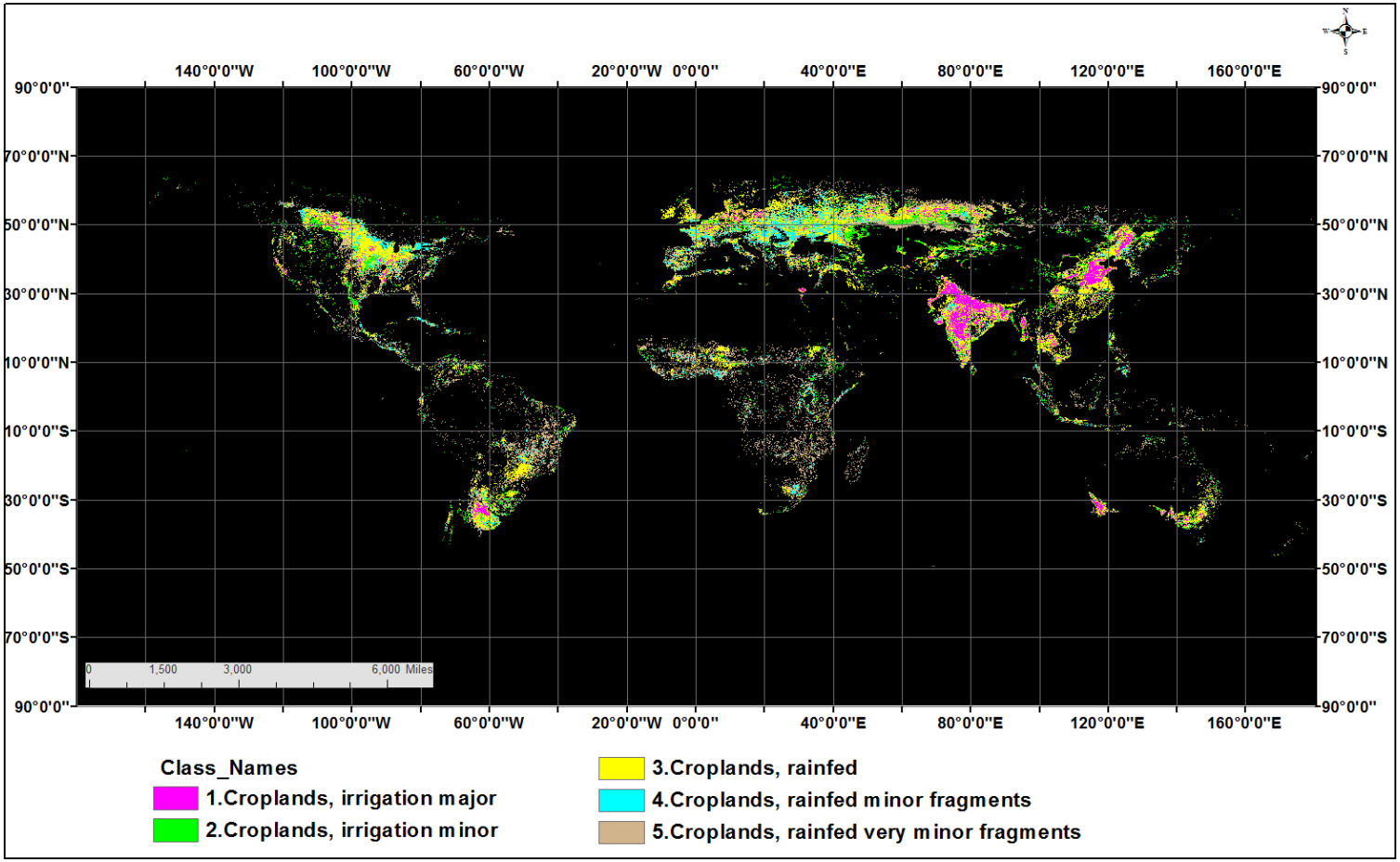
Teluguntla, P., Thenkabail, P.S., Xiong, J., Gumma, M.K., Giri, C., Milesi, C., Ozdogan, M., Congalton, R., Tilton, J., Sankey, T.R., Massey, R., Phalke, A., and Yadav, K. 2015. Global Cropland Area Database (GCAD) derived from Remote Sensing in Support of Food Security in the Twenty-first Century: Current Achievements and Future Possibilities. Chapter 7, Vol. II. Land Resources: Monitoring, Modelling, and Mapping, Remote Sensing Handbook edited by Prasad S. Thenkabail. Accepted. http://geography.wr.usgs.gov/science/croplands/pubs2014.html

Global Food Security-support Data @ 30 m (GFSAD30) Project

GCE 1km Multi-study Crop Mask (aka GCE V1.0)

http://geography.wr.usgs.gov/science/croplands/index.html



~2.3 billion hectares full pixel area (FPAs) with 34% irrigated and 66% rainfed.

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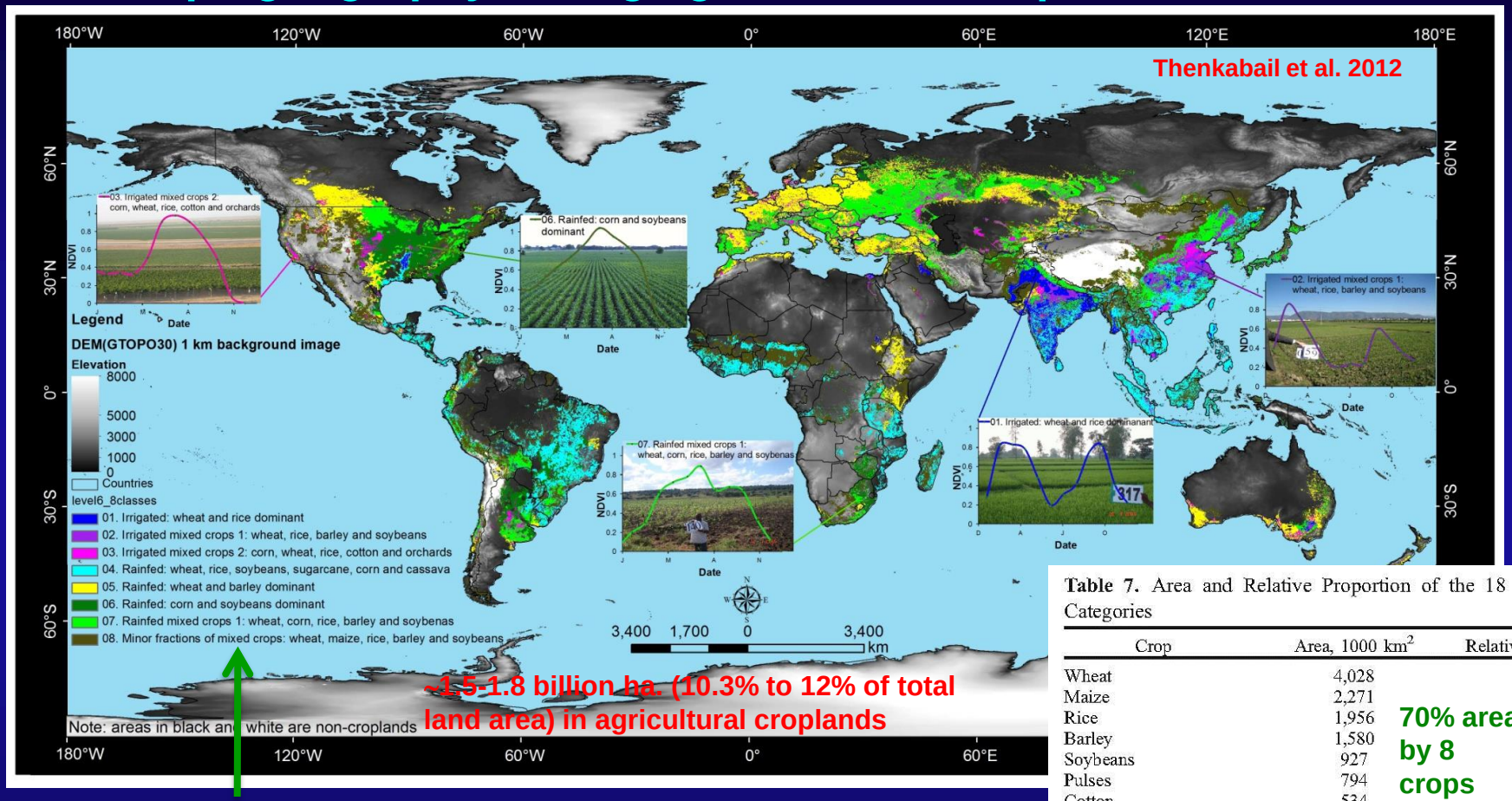
Teluguntla, P., Thenkabail, P.S., Xiong, J., Gumma, M.K., Giri, C., Milesi, C., Ozdogan, M., Congalton, R., Tilton, J., Sankey, T.R., Massey, R., Phalke, A., and Yadav, K. 2015. Global Cropland Area Database (GCAD) derived from Remote Sensing in Support of Food Security in the Twenty-first Century: Current Achievements and Future Possibilities. Chapter 7, Vol. II. Land Resources: Monitoring, Modelling, and Mapping, Remote Sensing Handbook edited by Prasad S. Thenkabail. Accepted. http://geography.wr.usgs.gov/science/croplands/pubs2014.html

Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Global Agricultural Cropland Monitoring System

http://geography.wr.usgs.gov/science/croplands/index.html



~1.5-1.8 billion ha. (10.3% to 12% of total land area) in agricultural croplands

1. Focus on global mapping irrigated and rainfed croplands and computing their blue water and green water use

2. Focus on 18 crops occupy 85% of all global cropland areas…..so, we can focus on them

Table 7. Area and Relative Proportion of the 18 Major Crop Categories

Crop	Area, 1000 km^2	Relative Fraction, %
Wheat	4,028	22
Maize	2,271	13
Rice	1,956	11
Barley	1,580	9
Soybeans	927	5
Pulses	794	4
Cotton	534	3
Potatoes	501	3
Sorghum	501	3
Millet	331	2
Sunflower	290	2
Rye	288	2
Rapeseed/canola	283	2
Sugar cane	265	1
Groundnuts/peanuts	247	1
Cassava	235	1
Sugar beets	154	1
Oil palm fruit	72	<1
Total of major 18 crops	*15,256*	*85*
Others	2664	15
Total cropland	*17,920*	*100*

70% area by 8 crops

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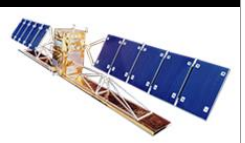
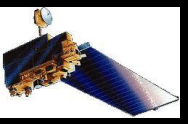
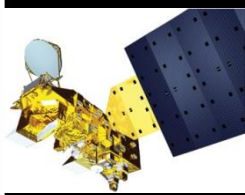
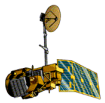
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Earth Observation Based Global Agricultural Cropland Monitoring System



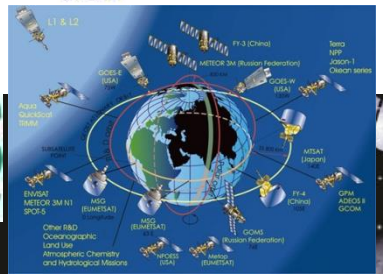
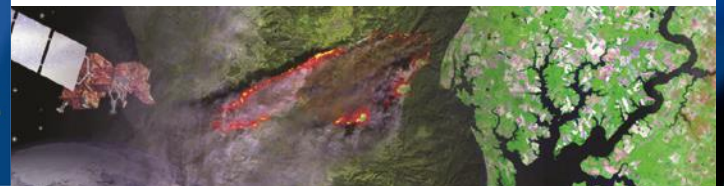



GROUP ON EARTH OBSERVATIONS

http://wgiss.ceos.org/lsip/satellites_midres1.shtml
http://www.ceos-cove.org/index.php

SORCE
Envisat
Aura/Aqua/Terra
QuikScat
Sage
IKONOS
CBERS
SeaWiFS
SPOT 4, 5
SPIN-2
SeaWinds
Orbview 2, 3
TRMM
DMC
SAC-D/Aquarius
ACRIMSAT
ERBS
EROS A1
Radarsat
ALOS
QuickBird
Toms-EP
Grace
Landsat 7
UARS
Jason
SAC-C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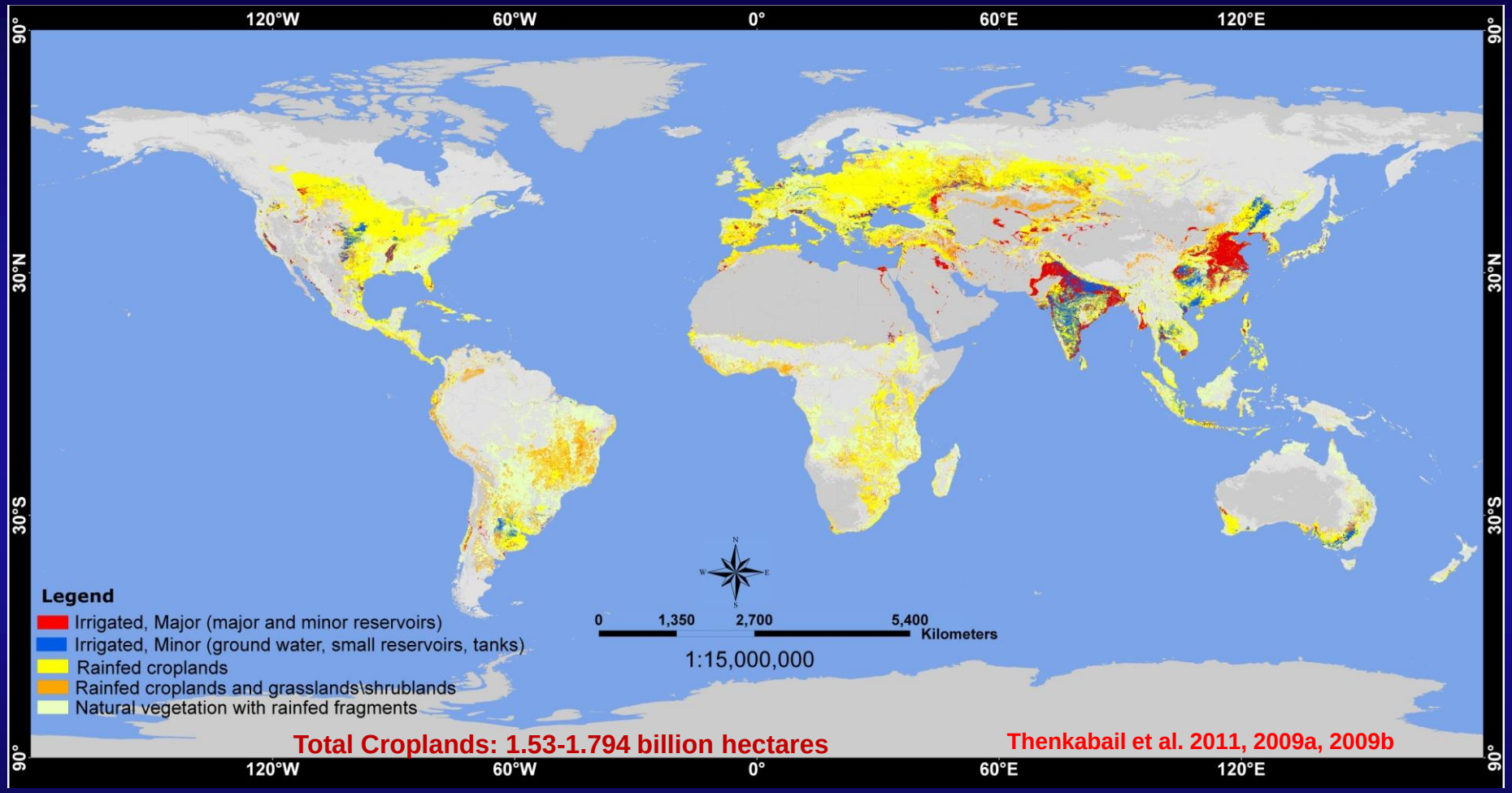
Global Croplands (irrigated + rainfed + permanent crops)

Source: AVHRR, SPOT VGT, Secondary (e.g., precipitation, elevation), groundtruth (Primarily remote sensing)

Earth Observation (EO) Data for Cropland Monitoring



Total Croplands: 1.53-1.794 billion hectares

Thenkabail et al. 2011, 2009a, 2009b

Note: total land area= 14.894 billion hectares (148,940,000 km²). Total cropland area is 10.3-12% in year 2000

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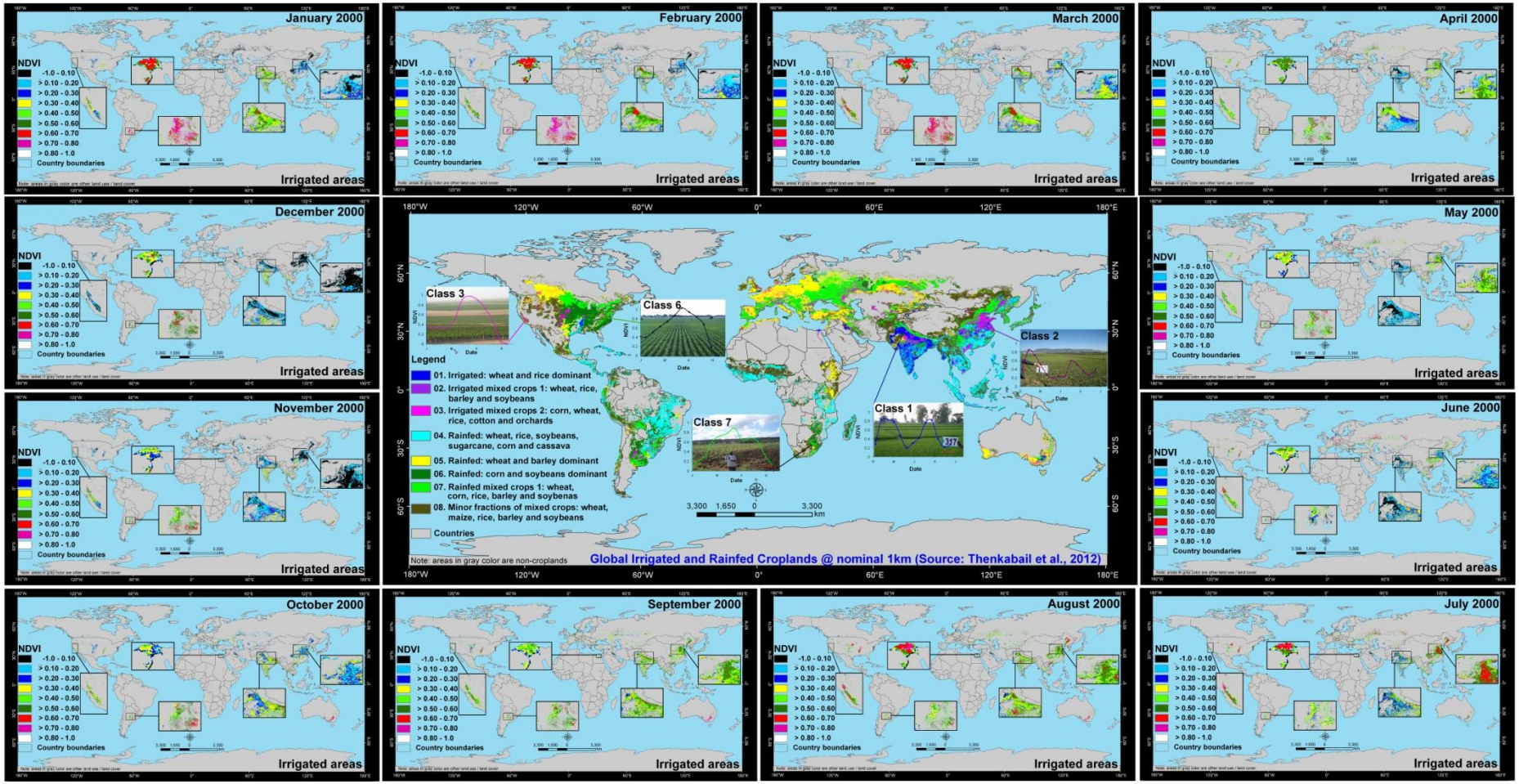
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Global Agricultural Cropland Monitoring System using EO Data

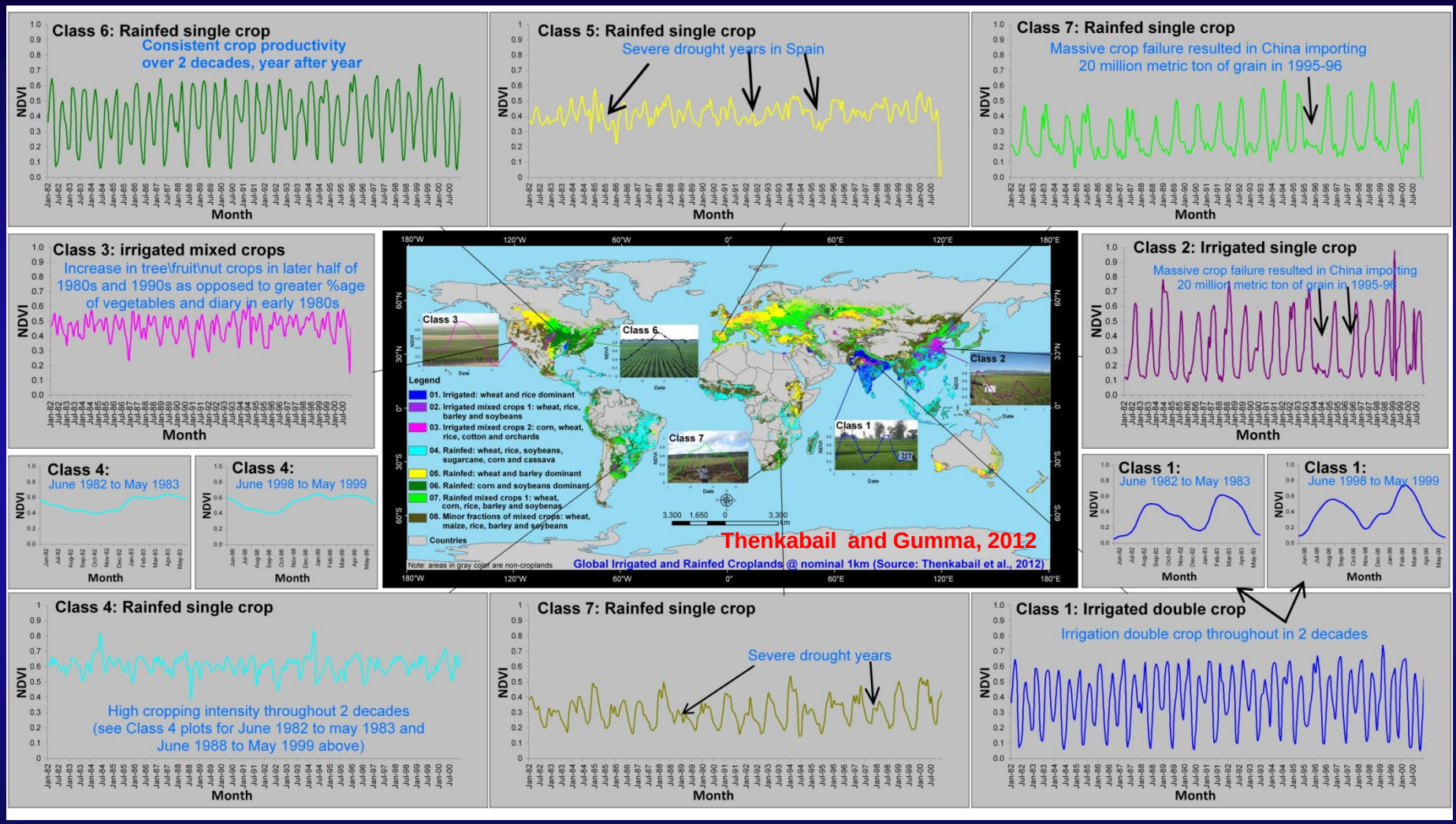
Thenkabail and Gumma, 2012



Month by month NDVI dynamics of global croplands. Year 2000.

Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Global Agricultural Cropland Monitoring System using EO Data



Month by Month NDVI dynamics of global croplands. Years 1982-2000

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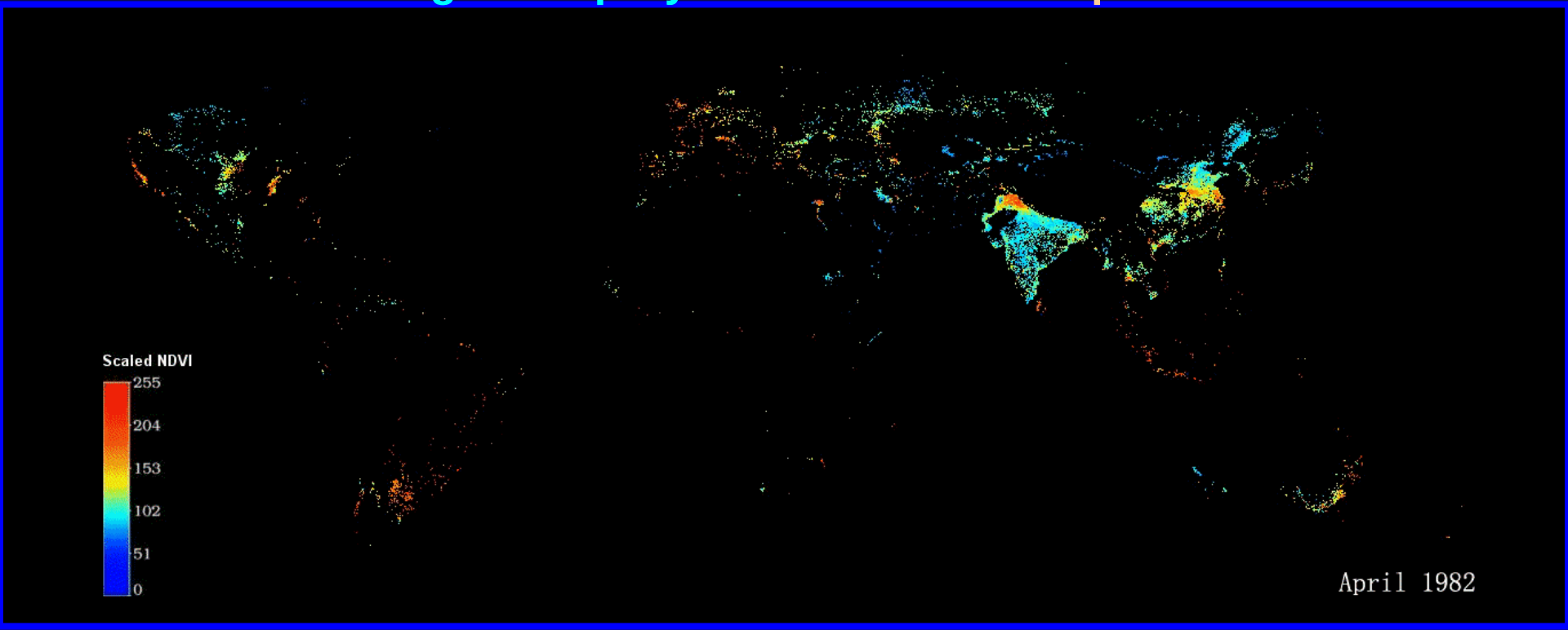
Opportunities and Challenges for

Advancing Accurate Cropland Maps and Statistics: Need for Time-series data

EO Data Looking at Crop Dynamics: Month of April from 1981-2001



….current GIMMS (Global Inventory Modeling and Mapping Studies) bi-monthly global data: 1982-2011, followed by MODIS (Moderate Resolution Imaging Spectroradiometer) terra\aqua from 2000-present, then onto NPP (NPOESS Preparatory Project) 2011-, and NPOESS (National Polar-orbiting Operational Environmental Satellite System) upcoming.

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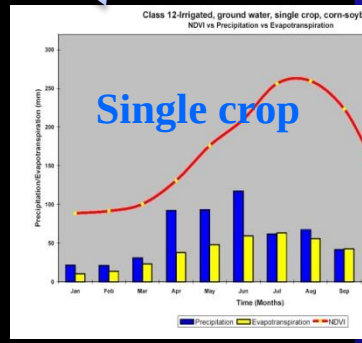
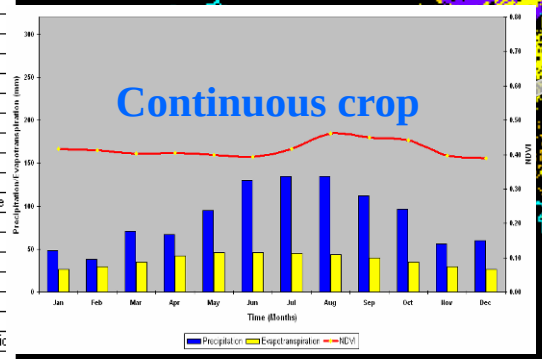
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Mapping Croplands (irrigated + rainfed+permanent crops) of China using Satellite Data

Multi-sensor imagery from NOAA AVHRR+SPOT VGT + secondary data (e.g., precip., temp, elev.) + ground data

Annualized Irrigated Areas (AIAs) = 152 Mha





- 01 Irrigated, surface water, single crop, wheat-cron-cotton
- 02 Irrigated, surface water, single crop, cotton-rice-wheat
- 03 Irrigated, surface water, single crop, mixed-crops
- 04 Irrigated, surface water, double crop, rice-wheat-cotton
- 05 Irrigated, surface water, double crop, rice-wheat-cotton-corn
- 06 Irrigated, surface water, double crop, rice-wheat-plantations
- 07 Irrigated, surface water, double crop, sugarcane
- 08 Irrigated, surface water, double crop, mixed-crops
- 09 Irrigated, surface water, continuous crop, sugarcane
- 10 Irrigated, surface water, continuous crop, plantations
- 11 Irrigated, ground water, single crop, rice-sugarcane
- 12 Irrigated, ground water, single crop, corn-soybean
- 13 Irrigated, ground water, single crop,rice and other crops
- 14 Irrigated, ground water, single crop, mixed-crops
- 15 Irrigated, ground water, double crop, rice and other crops
- 16 Irrigated, conjunctive use, single crop, wheat-corn-soybean-rice
- 17 Irrigated, conjunctive use, single crop, wheat-corn-orchards-rice
- 18 Irrigated, conjunctive use, single crop, corn-soybeans-othercrops
- 19 Irrigated, conjunctive use, single crop, pastures
- 20 Irrigated, conjunctive use, single crop, pasture, wheat, sugarcane
- 21 Irrigated, conjunctive use, single crop, mixed-crops
- 22 Irrigated, conjunctive use, double crop, rice-wheat-sugacane
- 23 Irrigated, conjunctive use, double crop, sugarcane-other crops
- 24 Irrigated, conjunctive use, double crop, mixed-crops
- 25 Irrigated, conjunctive use, continuous crop, rice-wheat
- 26 Irrigated, conjunctive use, continuous crop, rice-wheat-corn
- 27 Irrigated, conjunctive use, continuous crop, sugacane-orchards-ric
- 28 Irrigated, conjunctive use, continuous crop, mixed-crops

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U.S. Department of Interior

Global Food Security-support Analysis Data @ 30 m (GFSAD30) Project

Overarching Goal

Monitoring global croplands (GCs) is imperative for ensuring sustainable water and food security to the people of the world in the Twenty-first Century. However, the currently available cropland products suffer from major limitations such as: (1) Absence of precise spatial location of the cropped areas; (b) Coarse resolution nature of the map products with significant uncertainties in areas, locations, and detail; (b) Uncertainties in differentiating irrigated areas from rainfed areas; (c) Absence of crop types and cropping intensities; and (e) Absence of a dedicated web\data portal for the dissemination of cropland products.

The overarching goal of this project is to produce consistent and unbiased estimates of global agricultural cropland areas, crop types, crop watering method, and cropping intensities using Multi-sensor, Multi-date Remote Sensing and mature cropland mapping algorithms (CMAs).

USGS science for a changing world

http://geography.wr.usgs.gov/science/croplands/index.html

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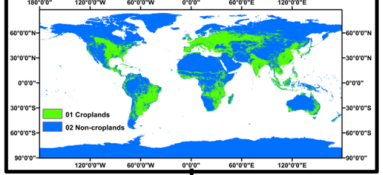
GFSAD30: NASA MEaSUREs Project on Global Food Security

Key Products for the Entire World @ 30m (Landsat + MODIS + secondary)

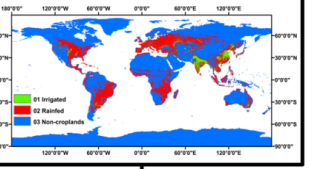
http://geography.wr.usgs.gov/science/croplands/index.html

1. Global Cropland Extent / Area @ nominal 30 m through Landsat 30 m + MODIS 250m + Secondary data Fusion

- 2010
- 1990



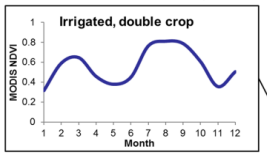
3. Irrigated vs. Rainfed

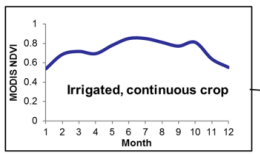


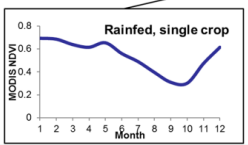
2. Crop Type

- 8 major crops + others

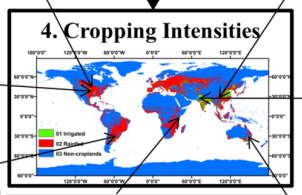
Crop Type	Crop Area (ha)	Proportion (%)
Wheat	402,800,000	22
Corn	227,100,000	13
Rice	195,600,000	11
barley	158,000,000	9
Soybeans	92,700,000	5
Pulses	79,400,000	4
Cotton	53,400,000	3
Potatoes	50,100,000	3

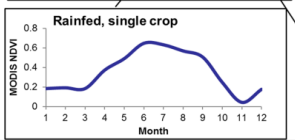


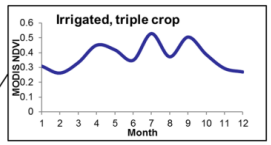


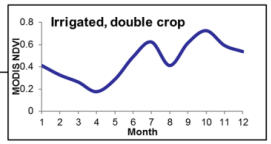


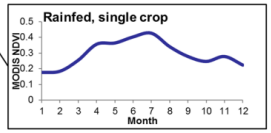
4. Cropping Intensities

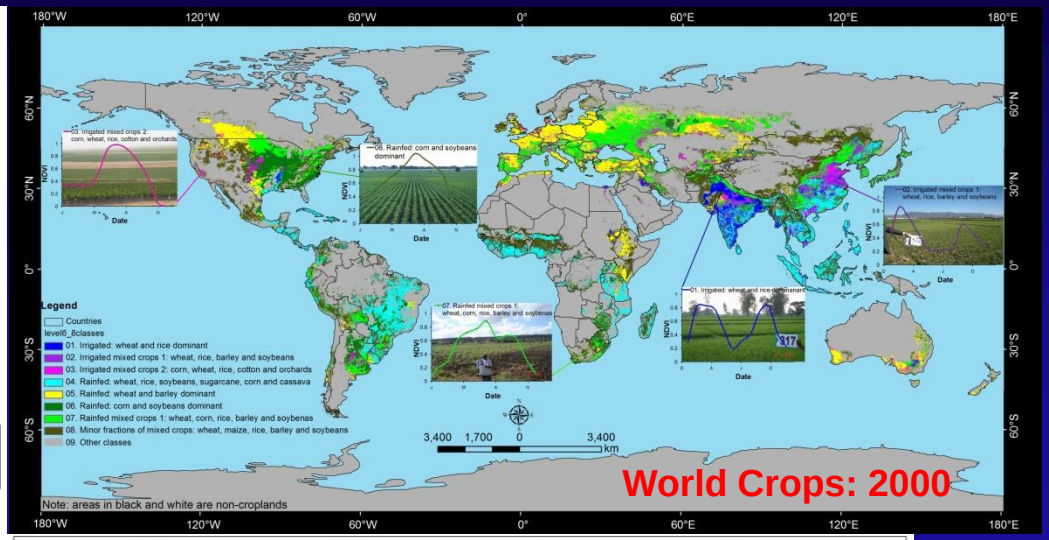




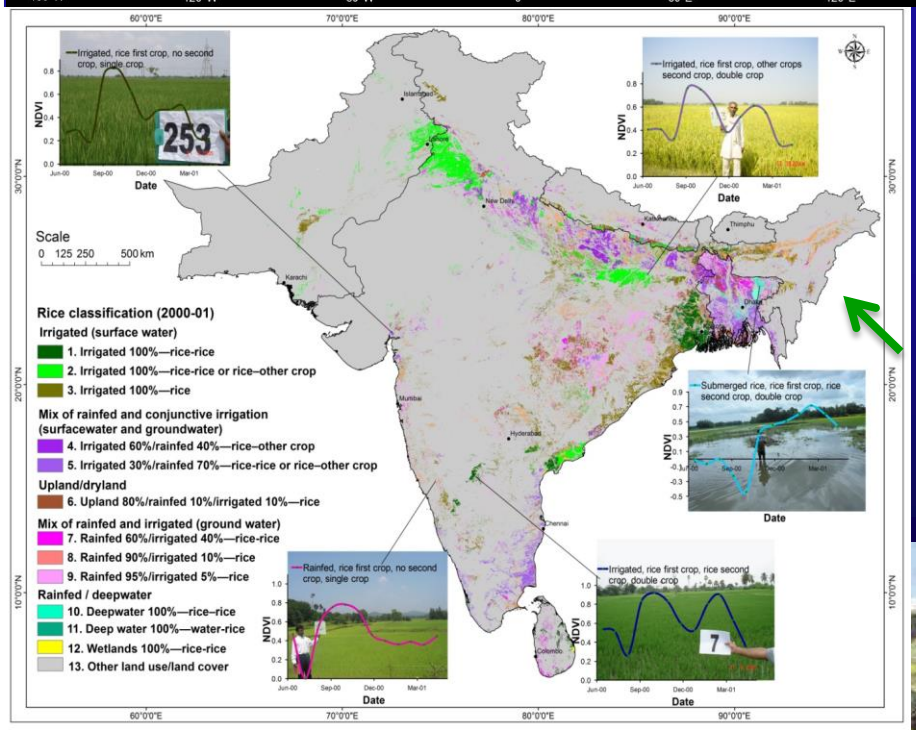








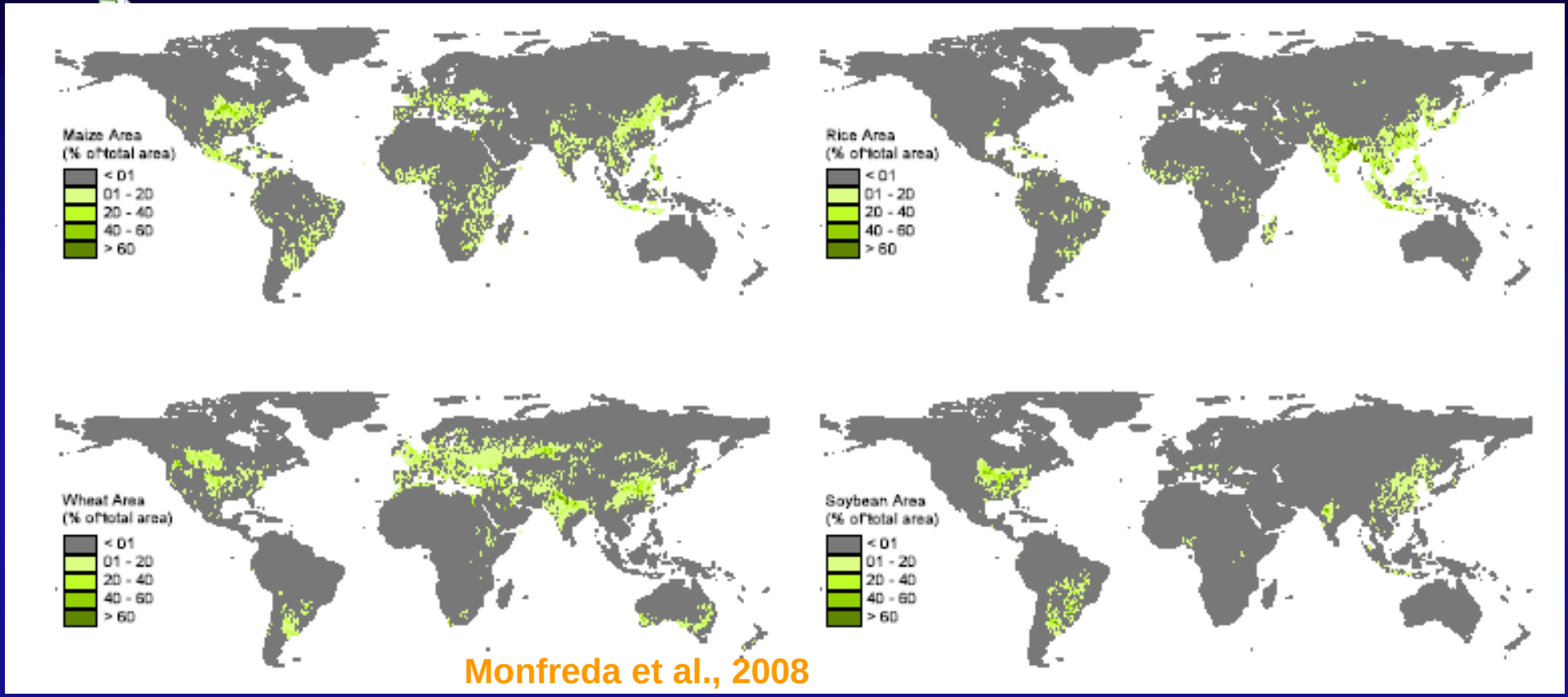
World Crops: 2000



Rice crop in India: Year 2000

Global Agricultural Monitoring System

Crop Type Distribution: 4 Major crops that occupy ~55% of Total global Cropland Area (1.5 billion ha.)



Monfreda et al., 2008

….focus on these crops to increase crop productivity ("crop per unit of land") and water productivity ("crop per unit of water")

Global Food Security-support Analysis Data @ 30 m (GFSAD30) Project

Cropland Products @ Different Resolutions

1A. GCE 1km Crop Dominance (aka GCE V0.0)
- Cropland extent and areas;
- Cropland watering method: irrigation versus rainfed

To a lesser extent
- Crop dominance (not type)

1B. GCE 1km Multi-study Crop Mask (aka GCE V1.0)
- Cropland extent and areas;
- Cropland watering method: irrigation versus rainfed

1 km

2. GCE 250m Crop Dominance (aka GCE V2.0)
- Cropland extent and areas;
- Cropland watering method: irrigation versus rainfed;
- Cropping intensity;

To a lesser extent
- Crop type and\or dominance

250 m

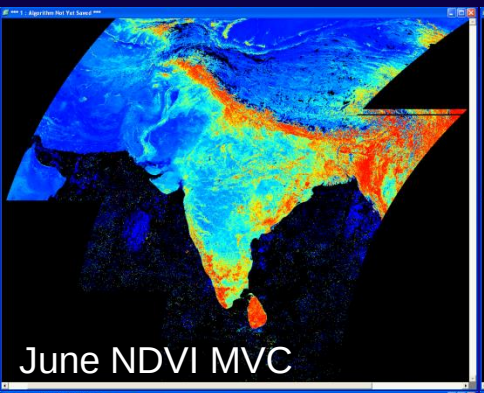
3. GCE 30m Crop Dominance (aka GCE V3.0)
- Cropland extent and areas;
- Cropland watering method: irrigation versus rainfed;
- Cropping intensity;
- Crop type and\or dominance

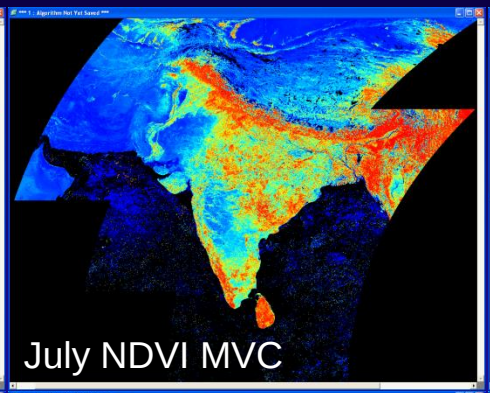
30 m

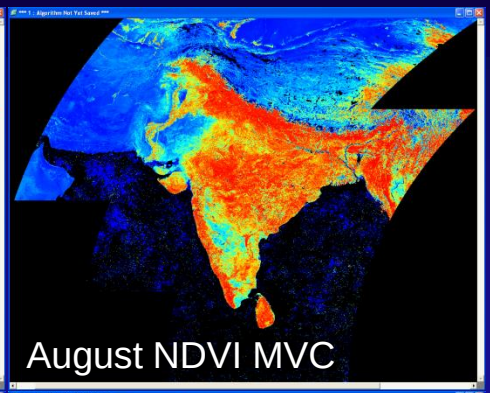
http://geography.wr.usgs.gov/science/croplands/index.html

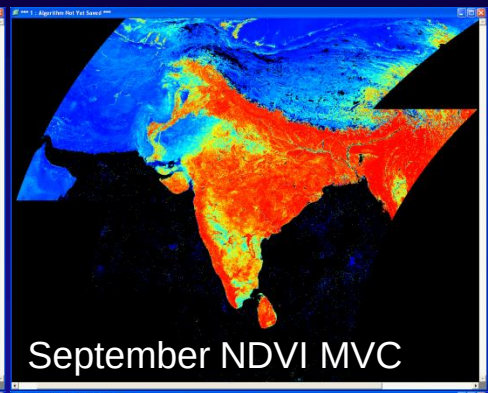
Opportunities and Challenges for

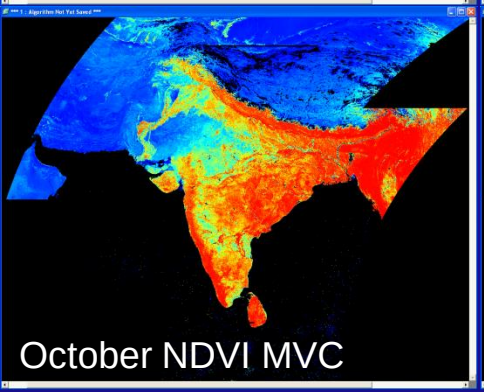
Advancing Accurate Cropland Maps and Statistics: Need for Time-series Data

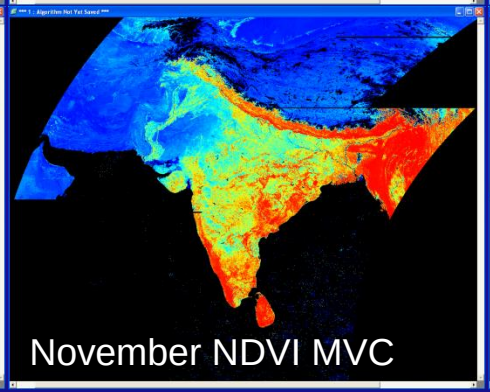


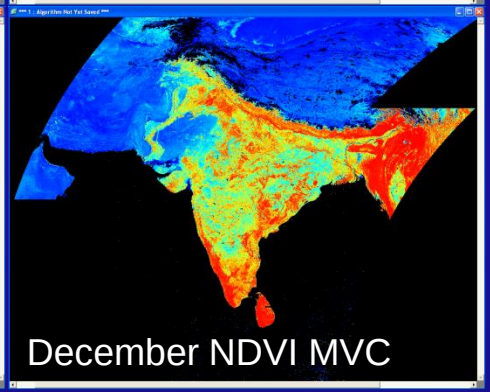


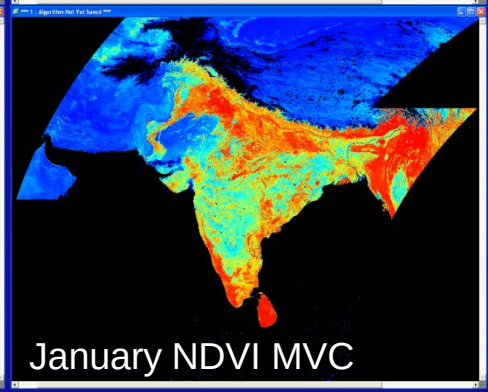


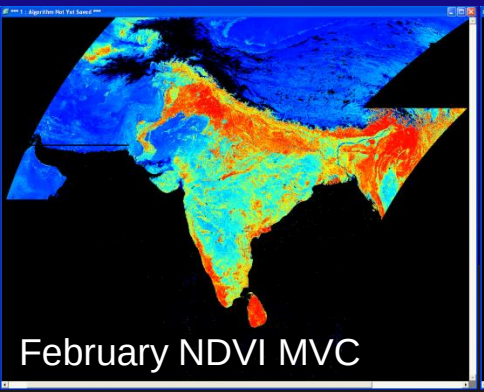


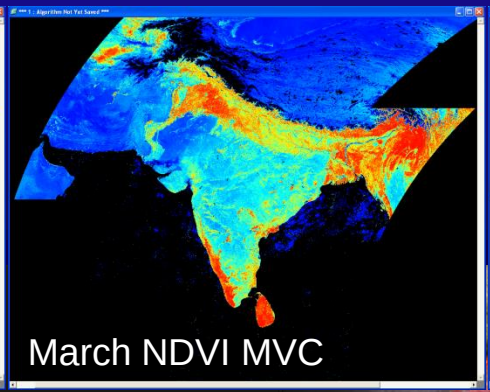


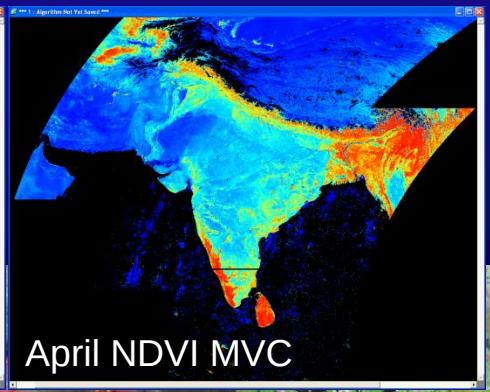


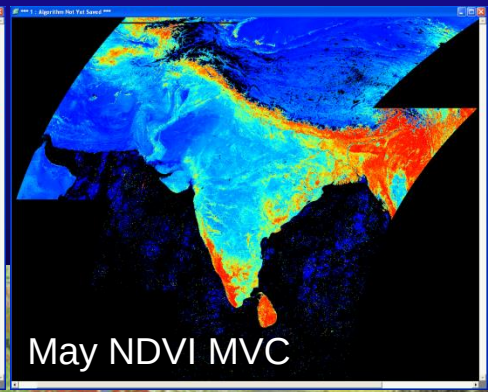






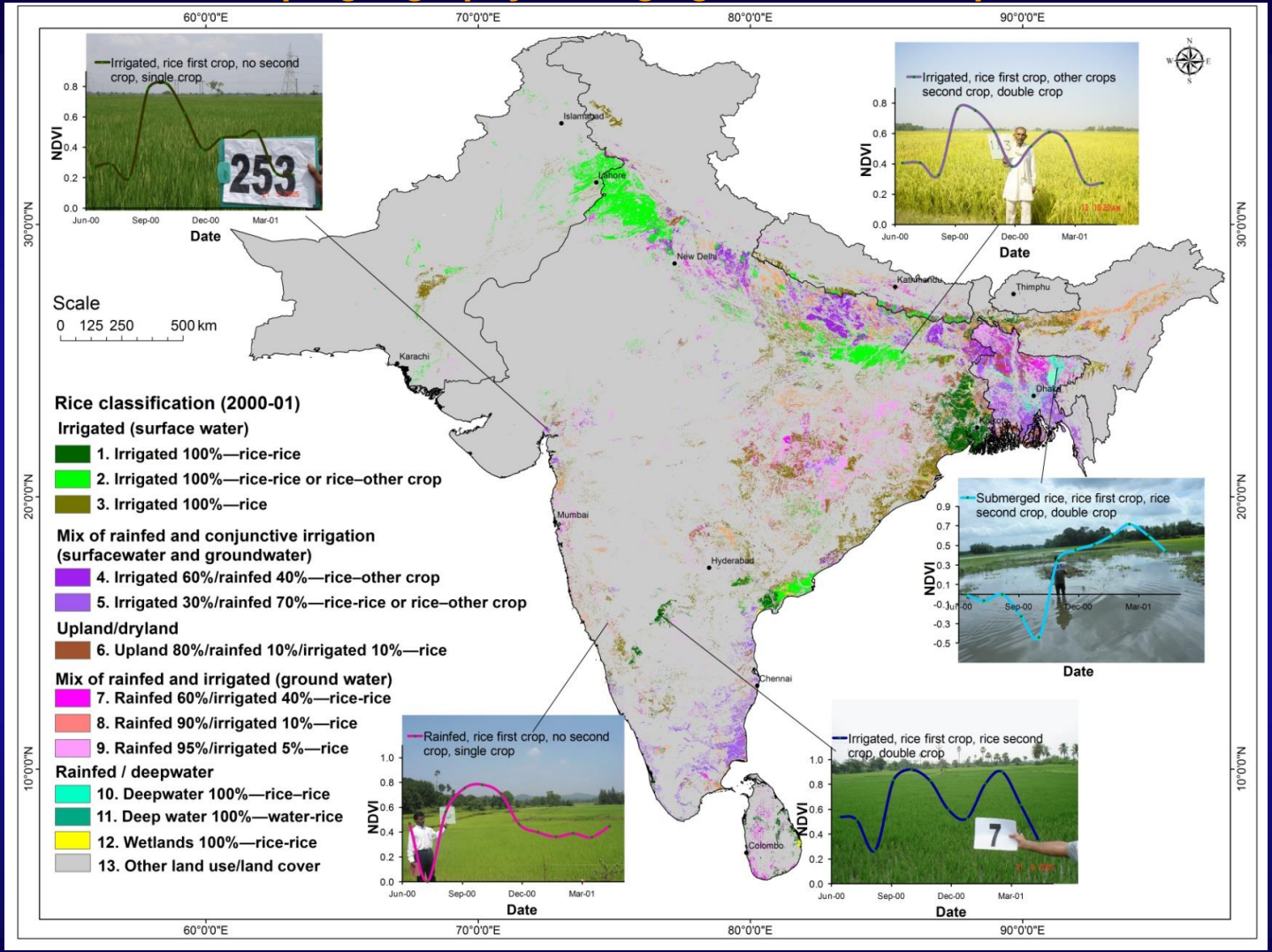






Mapping Crop Types of South Asia using EO Data

http://geography.wr.usgs.gov/science/croplands/index.html



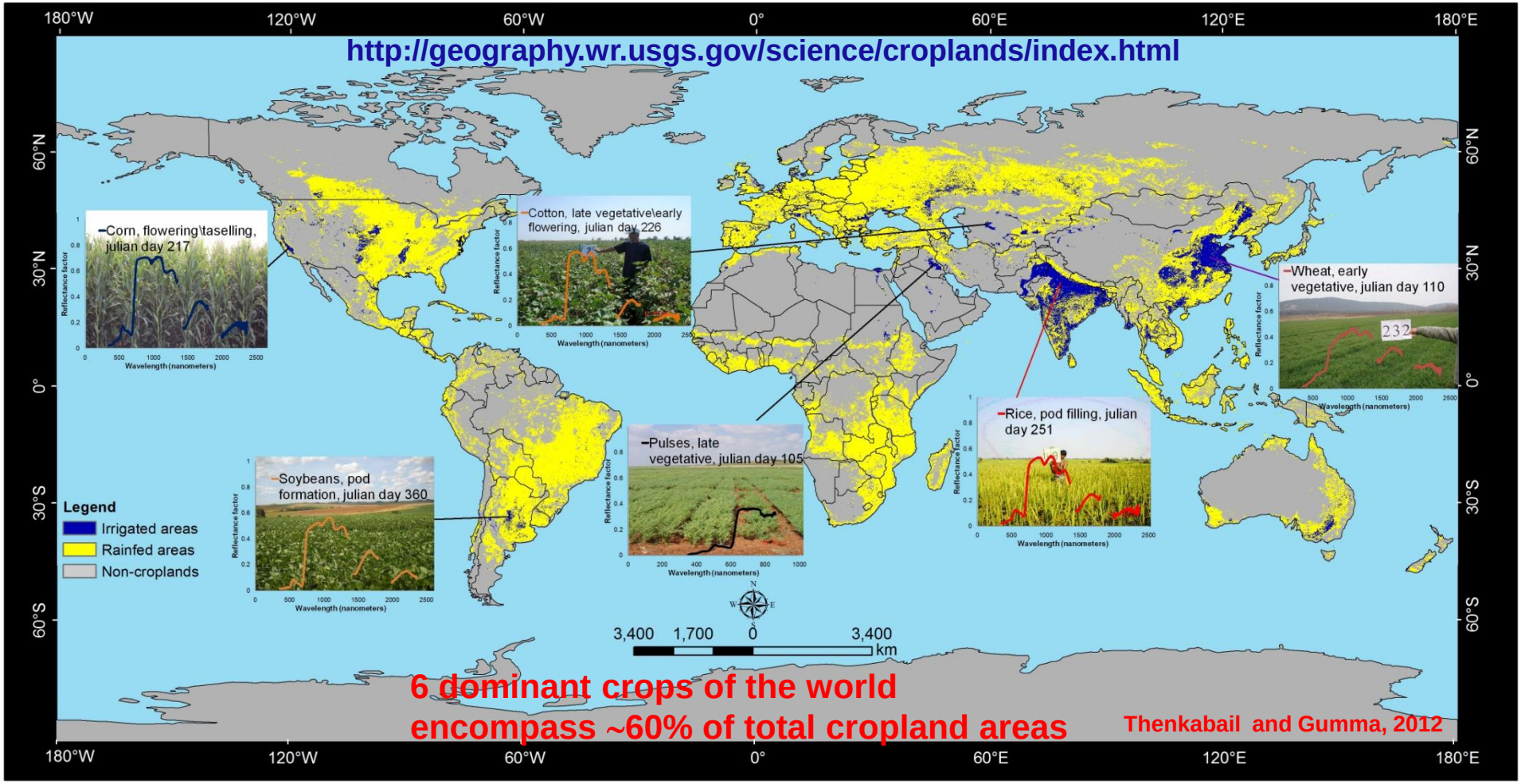
Rice map of South Asia for year 2010-11 using MODIS 250 m time-series Satellite Imagery

Gumma, Thenkabail and others 2011

Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Global Agricultural Cropland Monitoring System using EO Data

Future EO data (e.g., Hyperspectral) will allow us to Capture crop biophysical and biochemical properties with ever greater precision



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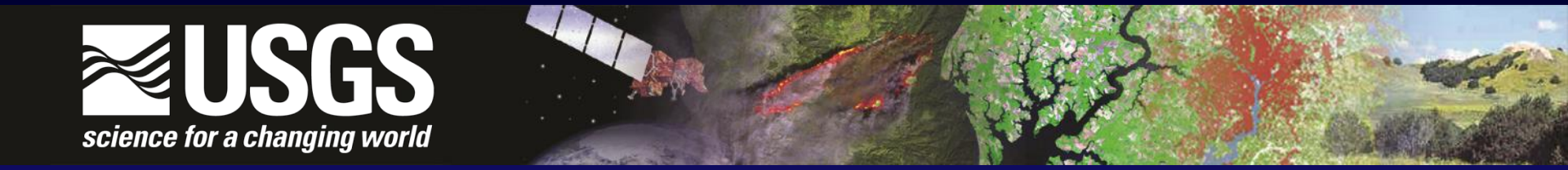
U.S. Geological Survey
U.S. Department of Interior



GFSAD30

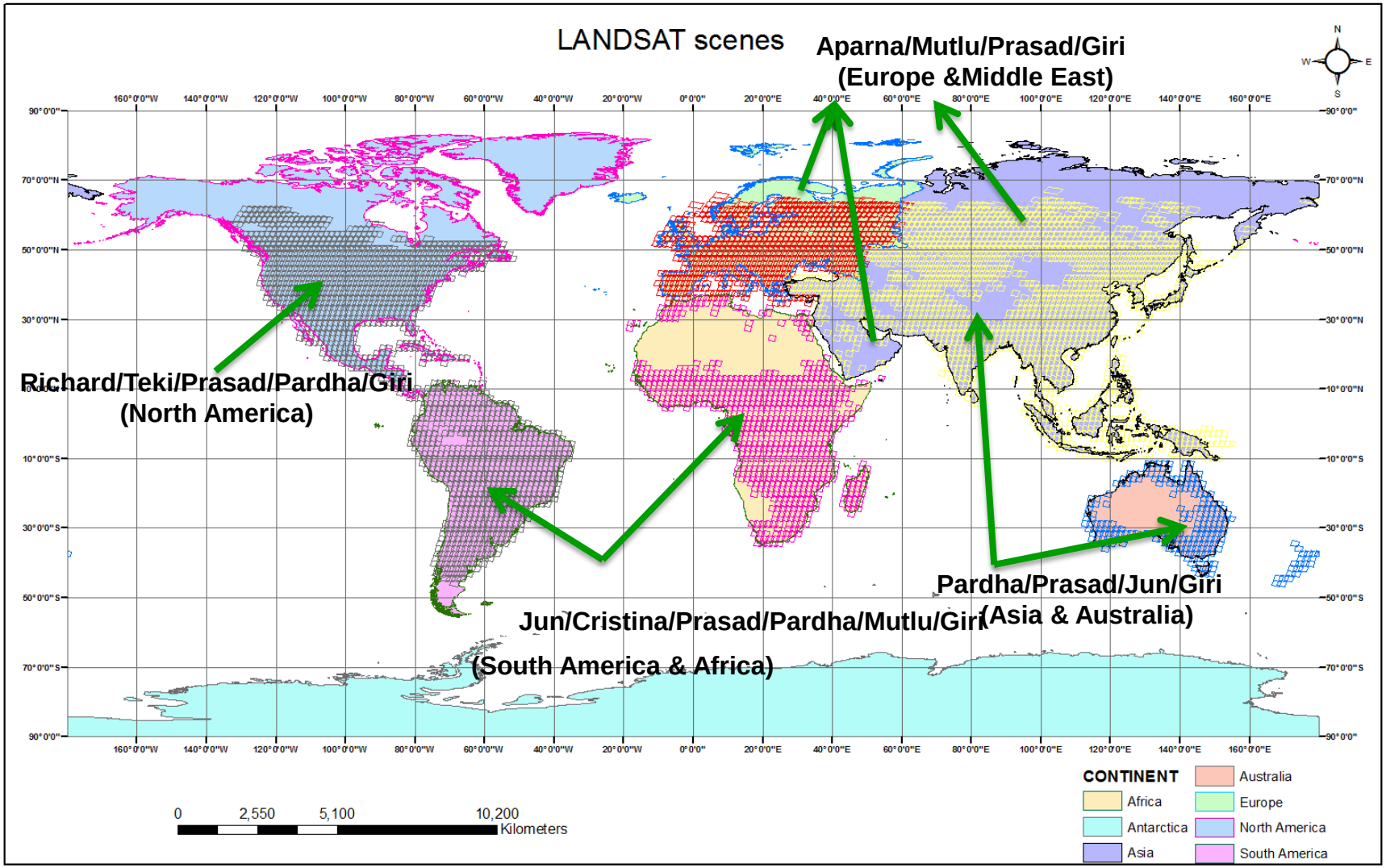
GCE 30m Crop Dominance (aka GCE V3.0)

http://geography.wr.usgs.gov/science/croplands/index.html

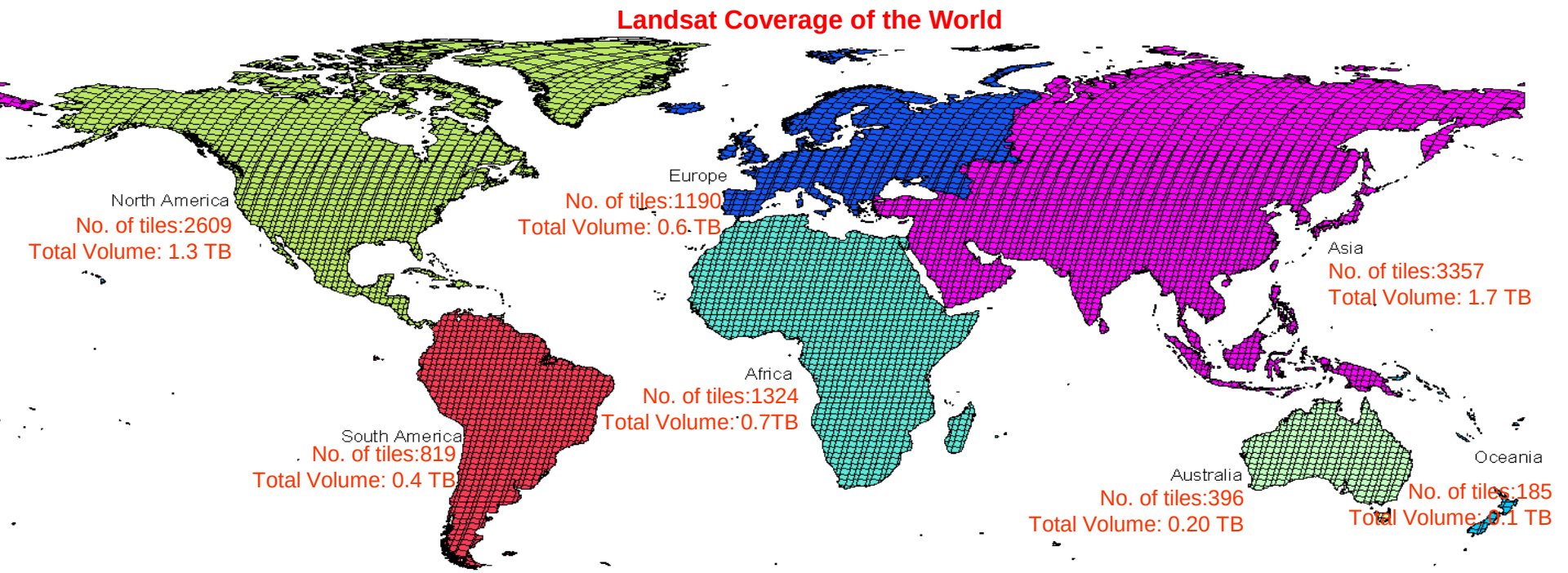
U.S. Department of the Interior
U.S. Geological Survey

GCE 30m Crop Dominance (aka GCE V3.0) @ nominal 30m

Study Areas Splitting the World with sub-Teams



GCE 30m Crop Dominance (aka GCE V3.0) @ nominal 30m
Landsat Data of the World



Total no of tiles needed: 9,770 (Digital number files)
Average size of single tile: 500 Mb (excluding thermal and panchromatic bands)
Total volume for the Globe*: ~ 4.8 TB (DN Images)
Total volume for the Globe: ~20.0 TB (Reflectance Images) #

…….further drastic reduction is possible if we consider only areas mapped as irrigated and rainfed in GIAM and GMRCA.

* For all the landmass, except Antarctica continent.

Each reflectance image is 4 times by volume of a DN image

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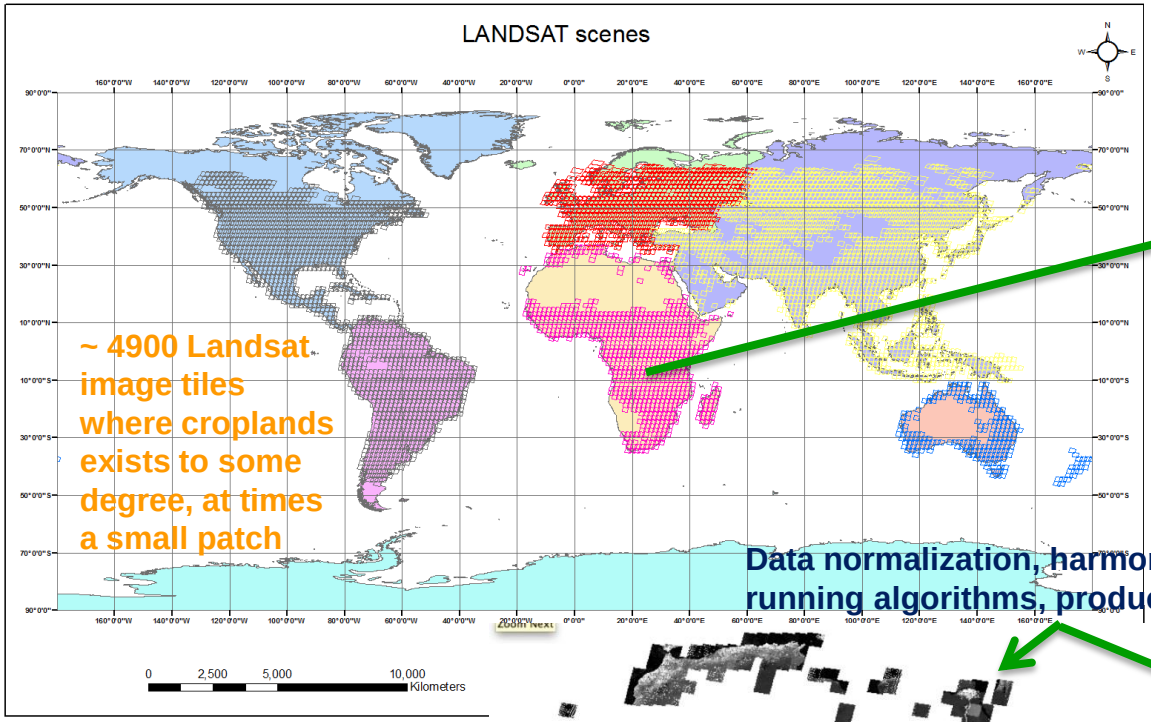
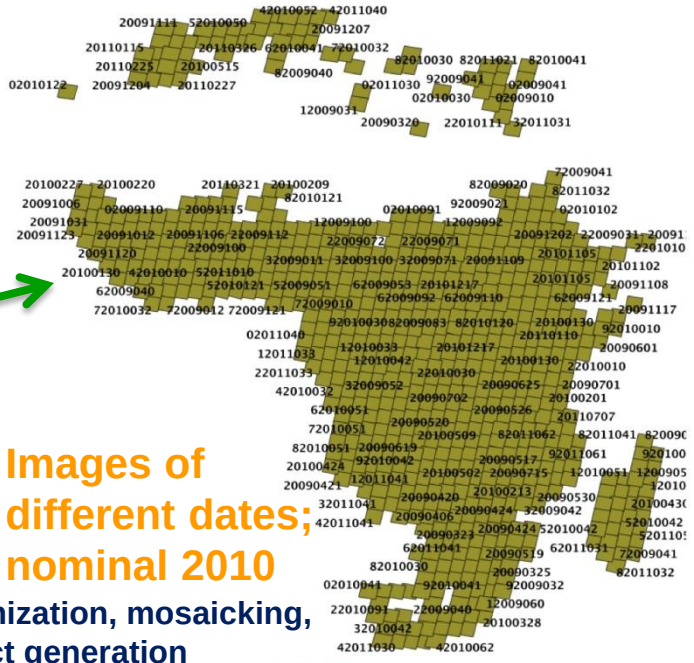
Web-enabled (free) Landsat Data and Rapid Generation Products via Supercomputers
NASA AMES NEX supercomputer and Google Earth Engine to Enable Computing Power

http://earthexplorer.usgs.gov; http://glovis.usgs.gov/



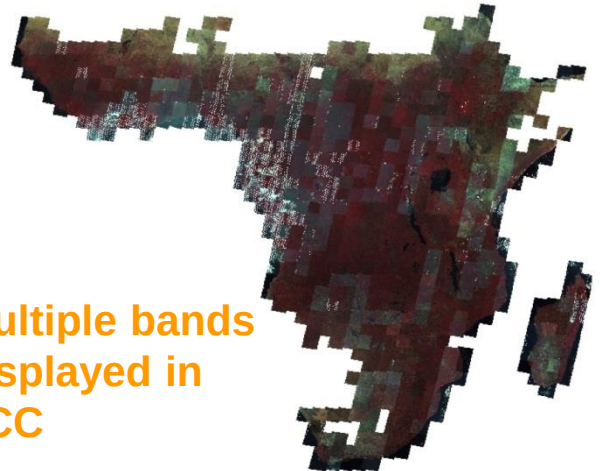


Images of different dates; nominal 2010

Data normalization, harmonization, mosaicking, running algorithms, product generation

Ability to mosaic, run algorithms, and generate global products within few hours to few days…..challenge is to go from products like NDVI to Cropland Products (e.g., crop types, crop stress\drought, crop productivity, water productivity……)

NDVI



Multiple bands displayed in FCC

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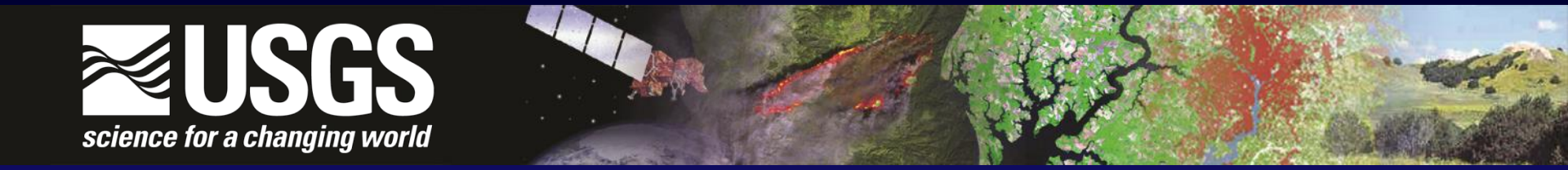
U.S. Department of Interior



GFSAD30

GCE 250m Crop Dominance (aka GCE V2.0) for Africa

http://geography.wr.usgs.gov/science/croplands/index.html

U.S. Department of the Interior
U.S. Geological Survey

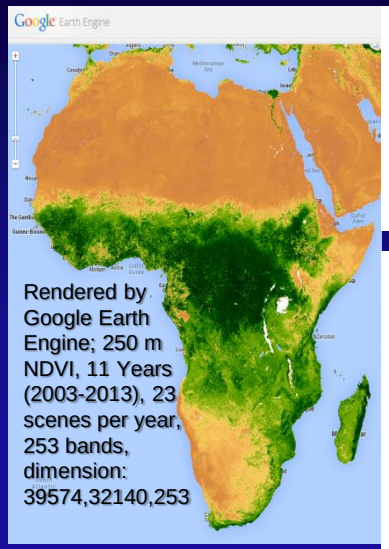
GCE 250m Crop Dominance (aka GCE V2.0) @ nominal 250 m for Africa

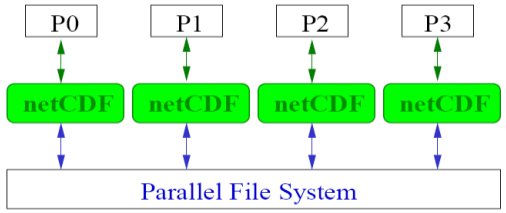
Africa is Growing at Rapid Phase and So is Agriculture

1. African population is expected to grow from little over 1 billion now to 4 billion by 2100;
2. Africa has hitherto been mostly limited to smallholder agriculture;
3. But, large farms are emerging, eventhough consequences of that is up for debate.

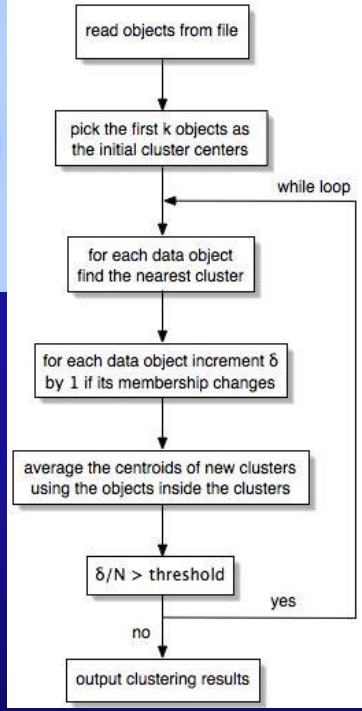
GCE 250m Crop Dominance (aka GCE V2.0) @ nominal 250 m for Africa

Parallel K-means Clustering Algorithm





- Multiple file pieces
- Breaks the netCDF dataset
- Independent Access



N: *number of data objects*
K: *number of clusters*

objects[N]: *array of data objects*
clusters[K]: *array of cluster centers*
membership[N]: *array of object memberships*

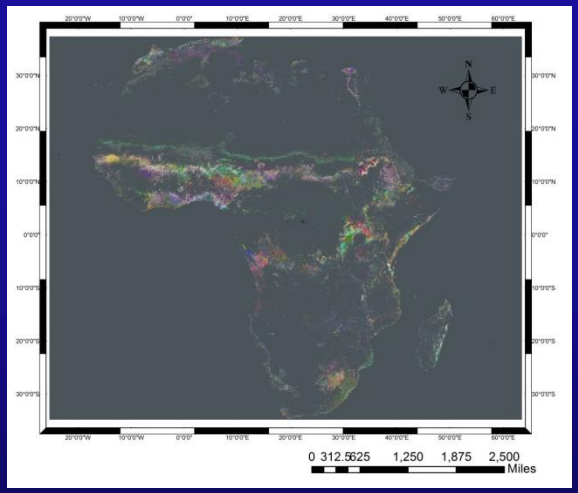
```
kmeans_clustering( )
1   while δ/N > threshold
2      δ ← 0
3      for i ← 0 to N-1
4         for j ← 0 to K-1
5            distance ← | objects[i] - clusters[j] |
6            if distance < dmin
7               dmin ← distance
8               n ← j
9         if membership[i] ≠ n
10           δ ← δ + 1
11           membership[i] ← n
12        new_clusters[n] ← new_clusters[n] + objects[i]
13        new_cluster_size[n] ← new_cluster_size[n] + 1
14     for j ← 0 to K-1
15        clusters[j][*] ← new_clusters[j][*] / new_cluster_size[j]
16        new_clusters[j][*] ← 0
17        new_cluster_size[j] ← 0
```

The Parallel K-means Clustering Algorithm

- Clustering Algorithm (written in C)
- IO powered by Parallel-netcdf (input file > 2TB)
- > 2000 CPUs hosted by NASA Ames Research Center
- MPI libraries and schedule system on NEX (Nasa Earth Exchange)

Steps:

1. Stacking and Clustering 253-band MODIS 250m NDVI Time-series Megacube;
2. Building standard reference signatures dataset from all-level relevant sources;
3. Identification of generic clusters with signatures using semi-automatical algorithm; and
4. Accuracy Assessment of GCEV2 product



Dataset dimension: (39574, 32140, 23), 60GB; Generic Clusters: 500; Platform: NASA NEX; nCPUS used:1000;Time:26 mins

http://geography.wr.usgs.gov/science/croplands/index.html

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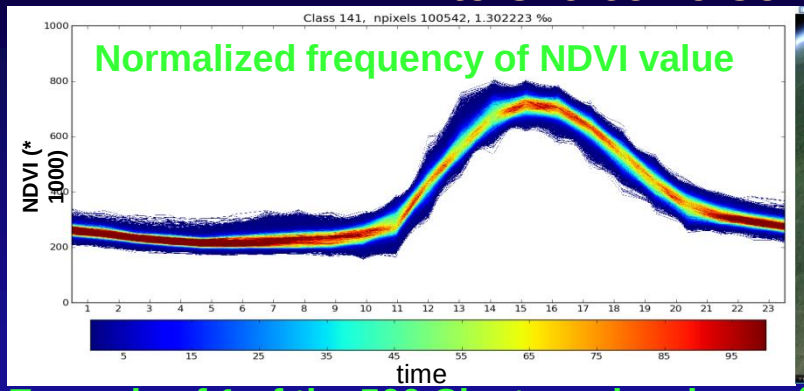
U.S. Department of Interior

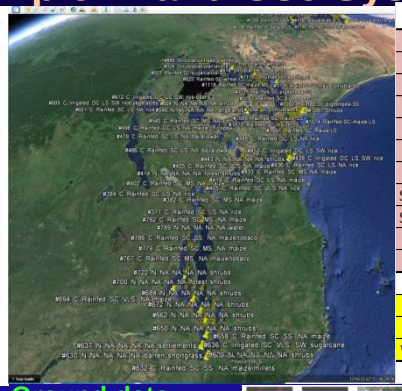
Credits: Jun Xiong et al.

GCE 250m Crop Dominance (aka GCE V2.0) @ nominal 250 m for Africa

Creating an Holistic System for Multi-Source Ground Knowledge to Overcome Complex Land Use Systems of Africa



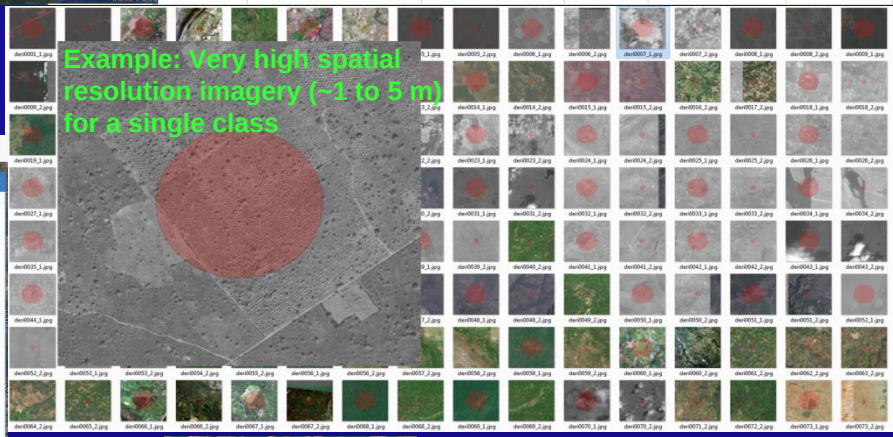
Example of 1 of the 500 Clusters showing 11 year MODIS NDVI Times series in Africa



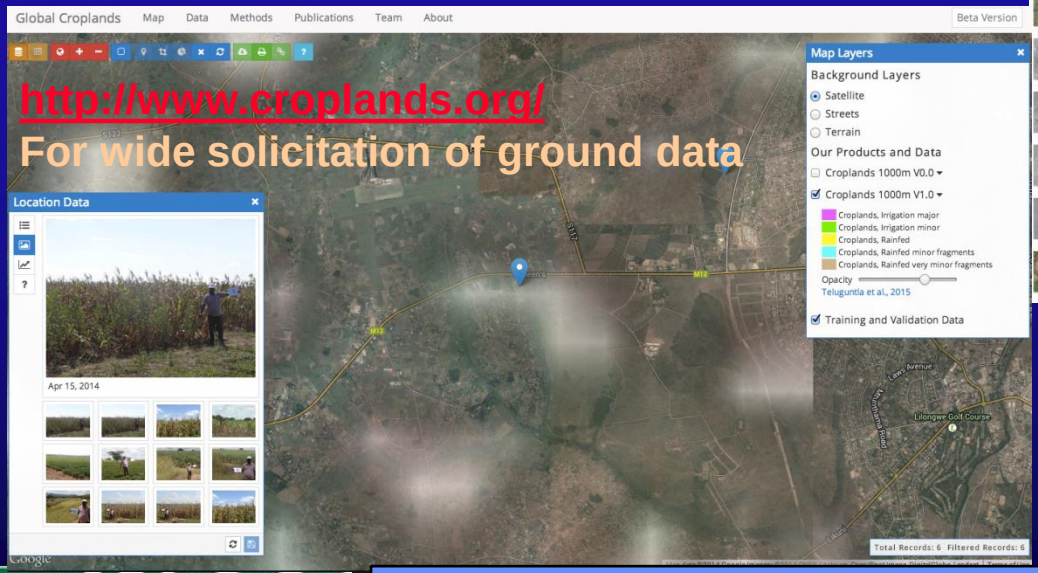
Ground data collected by team for all classes

Ground data collected by team for all classes

Zone	Number of Samples	Provider	Date	Type	Field
Rwanda	60	Murali	Nov-07	Field Work	Full
Tanzania	199	Murali	May-13	Field Work	Full
Ghana	365	Murali	Jun-08	Field Work	Full
Malawi	164	Murali	May-14	Field Work	Full
Malawi	700	Murali	May-14	Field Work	Crop Types
Kenya	338	Murali	Jun-14	Field Work	Full
Ghana	328	University of Ghana	Dec-12	GIS polygons	Crop Types
South Africa	n/a	AGIS	n/a	GIS	Crop Types
South Africa	618	Google StreetView		Ground Photos	Date, Location
Egypt	126	Shalaby	Jun-05	Landsat Class Map	LU
Egypt	131	Ayad	2005	Landsat Class Map	LU
Sum	3029				
Africa	3639	Geo Wiki	n/a	user-submit	LU
Africa	28	Degree_Confluence	n/a	user-submit	LU
West Africa	874	Thenkabail	before 2000	Field Work	Full
Total	7570				

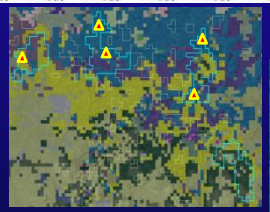


Example: Very high spatial resolution imagery (~1 to 5 m) for a single class



http://www.croplands.org/

For wide solicitation of ground data



Example: gathering data from homogeneous pixels for cropland classes using secondary products and VHRI

http://geography.wr.usgs.gov/science/croplands/index.html

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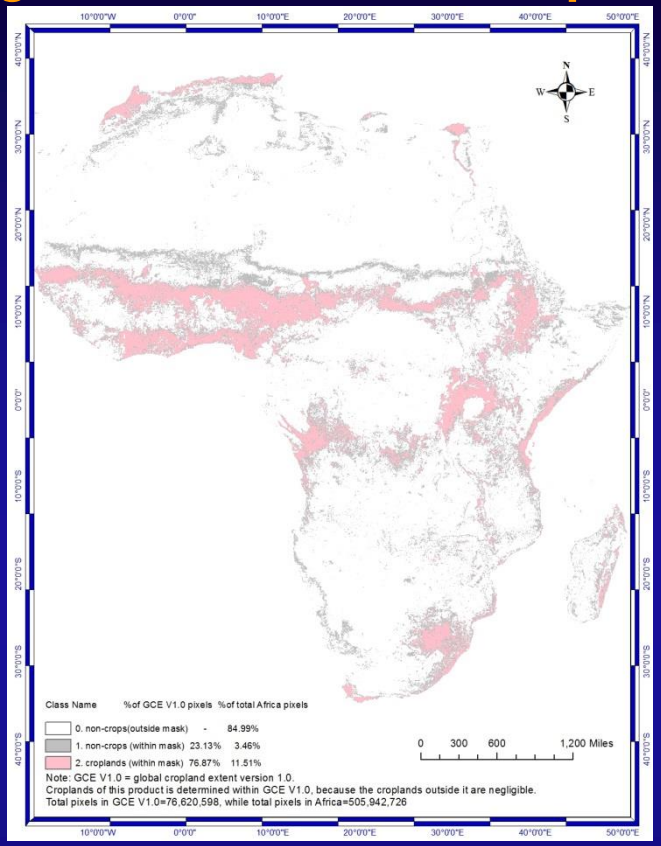
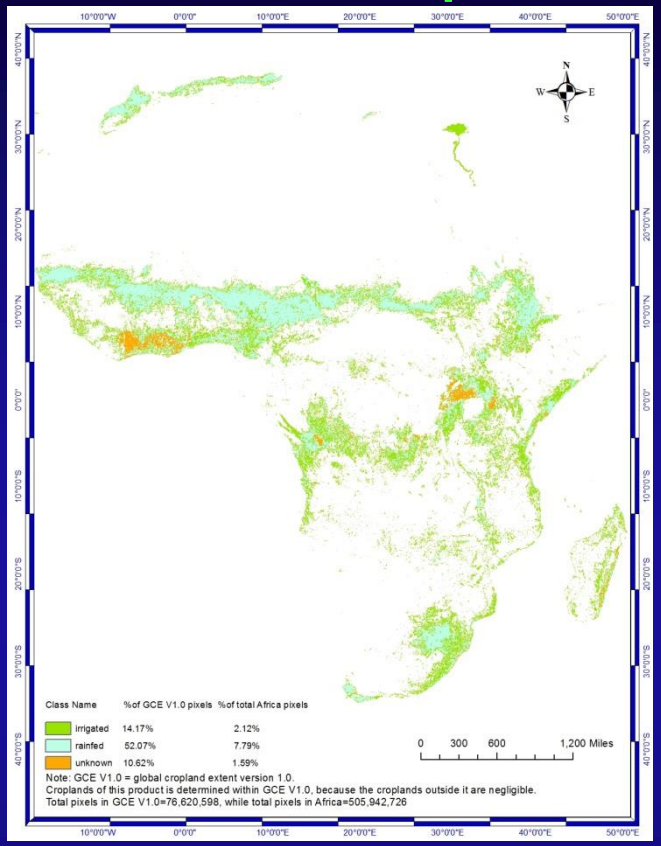
U.S. Department of Interior

Credits: Jun Xiong et al.

GCE 250m Crop Dominance (aka GCE V2.0) @ nominal 250 m for Africa

Irrigated and Rainfed Croplands of Africa: Composite 2003-2013





GCE 250m Crop Dominance (aka GCE V2.0) @ nominal 250 m for Africa provides

1. Croplands vs. non croplands;
2. Irrigation vs. rainfed;
3. Cropping intensity (single, double, continuous);
4. Crop type and\or dominance

http://geography.wr.usgs.gov/science/croplands/index.html

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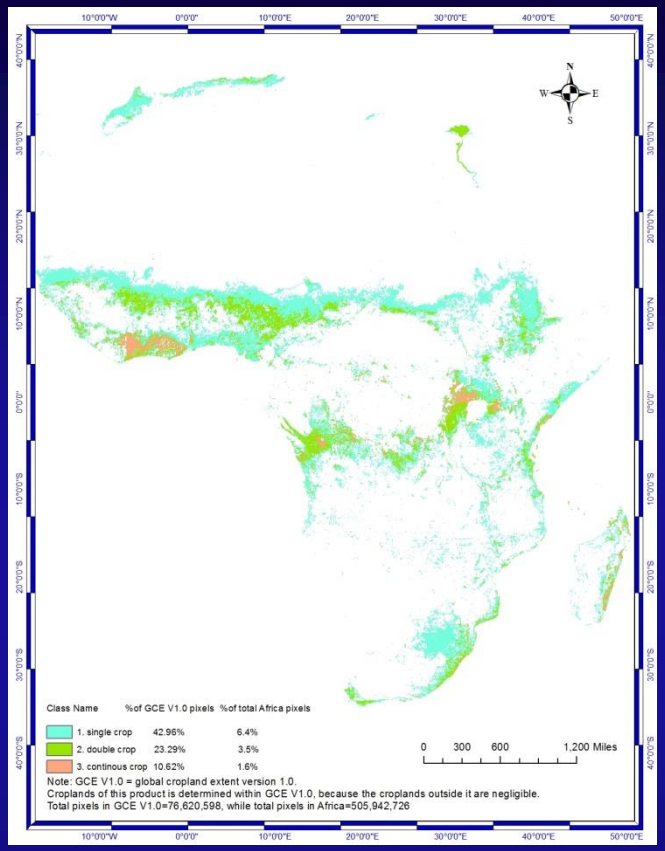
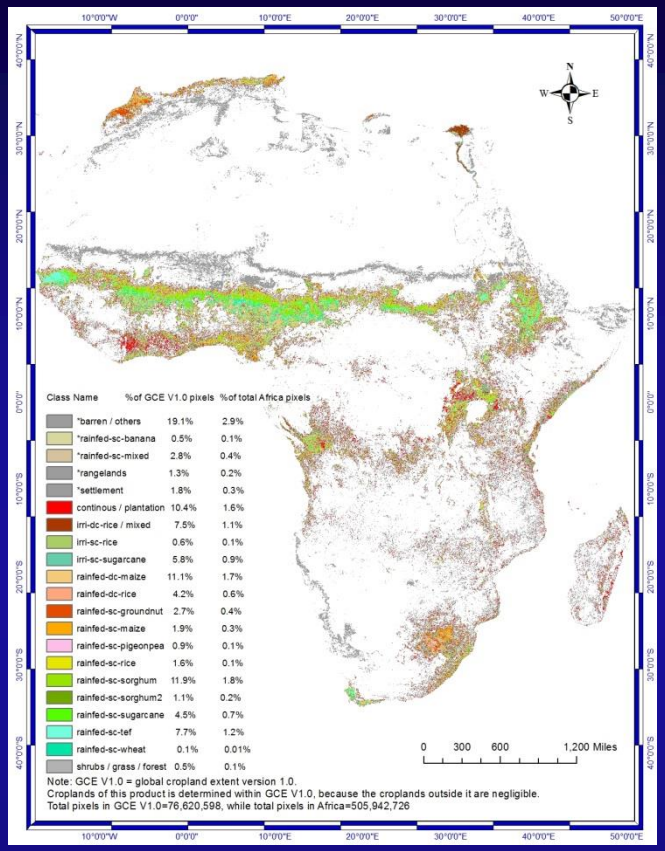
Irrigated and Rainfed Croplands of Africa: Composite 2003-2013





GCE 250m Crop Dominance (aka GCE V2.0) @ nominal 250 m for Africa provides

1. Croplands vs. non croplands;
2. Irrigation vs. rainfed;
3. Cropping intensity (single, double, continuous);
4. Crop type and\or dominance

http://geography.wr.usgs.gov/science/croplands/index.html

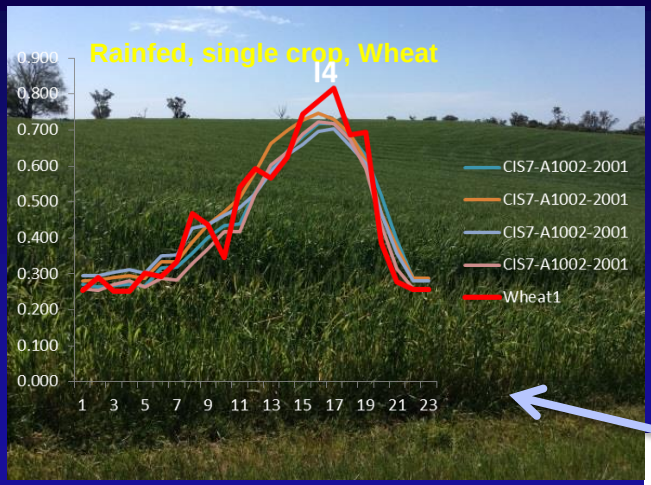
USGS science for a changing world

U.S. Geological Survey
U.S. Department of Interior

Credits: Jun Xiong et al.

GCE 250m Crop Dominance (aka GCE V2.0) @ nominal 250 m for Australia

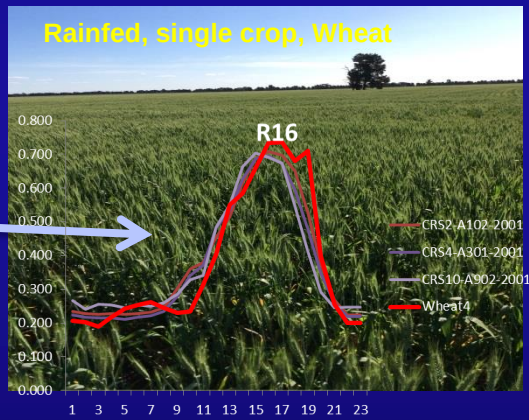
Matching Class Spectra with Ideal Spectra



Ideal Spectra (deep red) matched with class spectra (all others)

We can develop ideal spectra of classes and match them with Class spectra using quantitative spectral matching techniques

Example shown here for wheat crop in Australia for year 2014



Ideal Spectra (deep red) matched with class spectra (all others)

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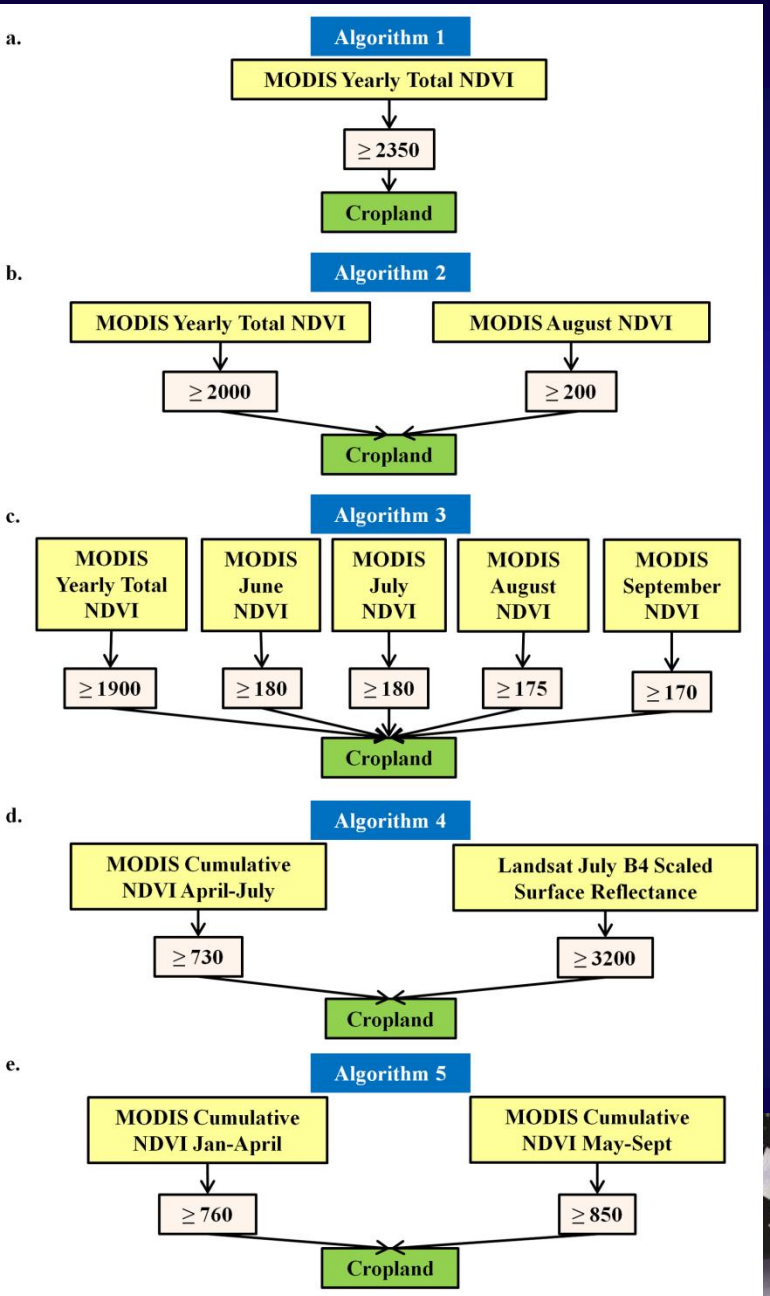
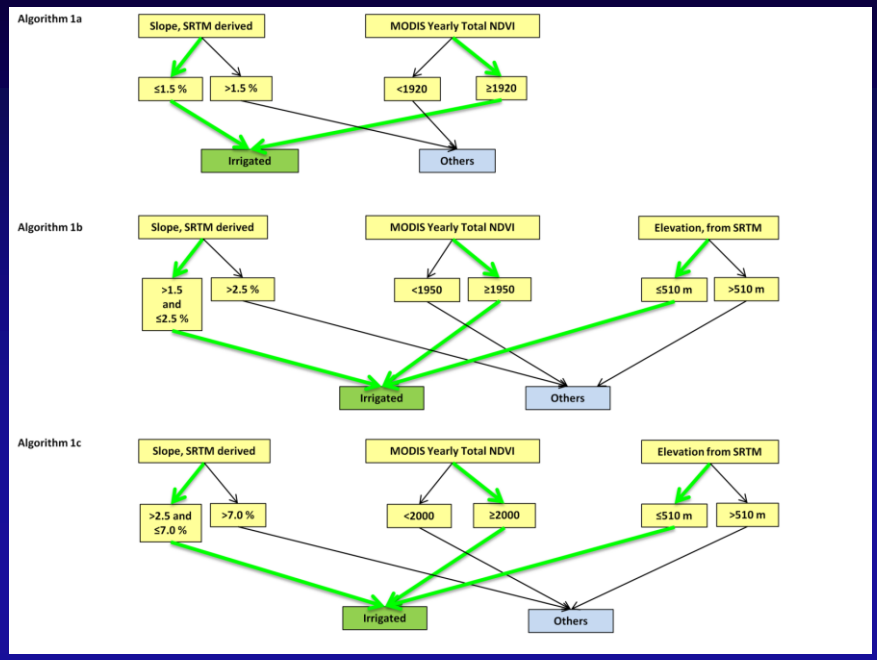
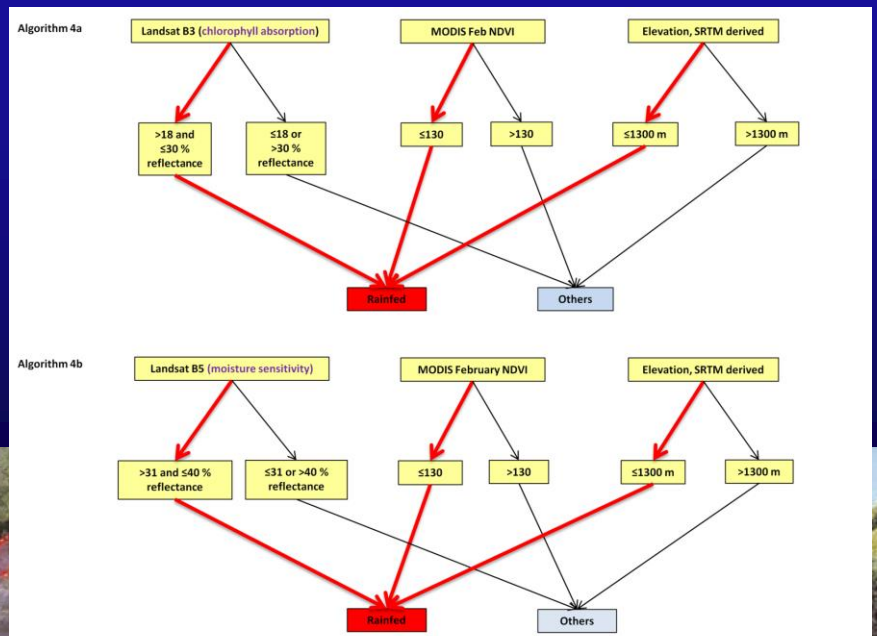
Credits: Pardha Teluguntla et al.

Automated Cropland Classification Algorithm (ACCA) for Croplands, Irrigated, Rainfed

Algorithm Development based on MODIS, Landsat, and Secondary Data



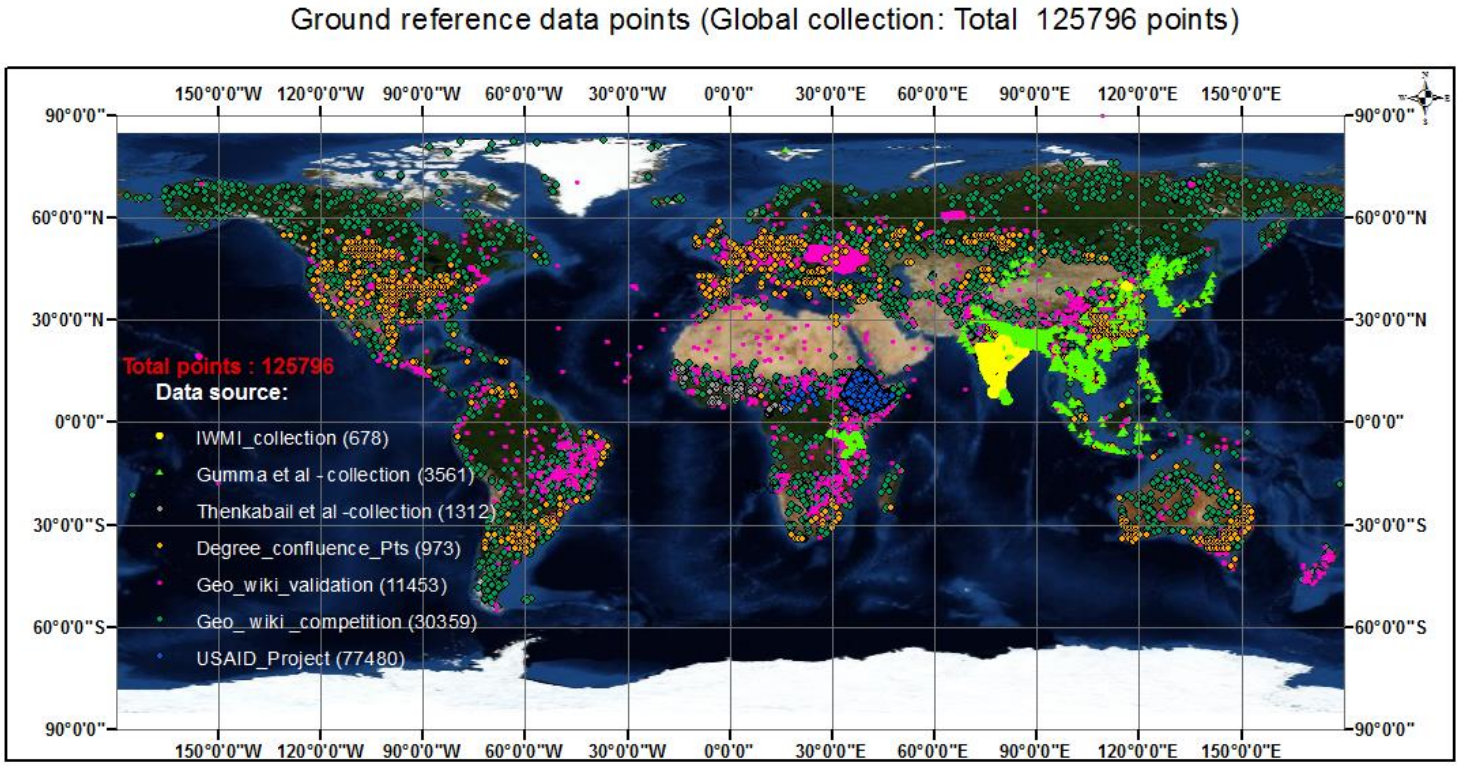




Global Food Security-support Analysis Data @ 30 m (GFSAD30) Project

Ground Data from Numerous Sources

1. Existing ground data has been harmonized;
2. New ground data is being collected;
3. uploading ground data on GEE for sysnthesis and generating cropland signatures;
4. Development of a ground data App in progress



http://www.croplands.org/

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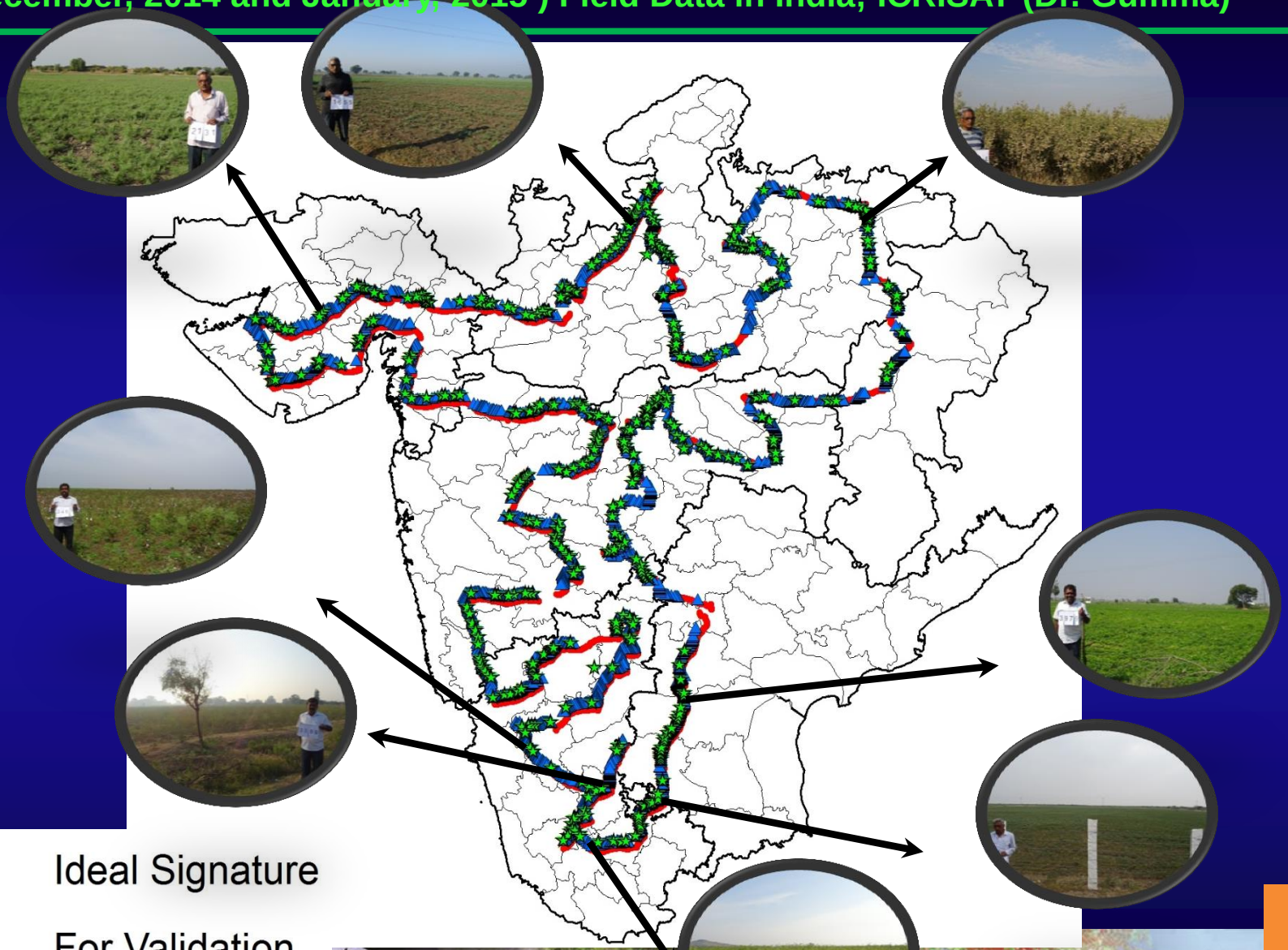
Credits: Justin Poehnelt, Mutlu Ozdogan et al

Collaborations for Validation and Feedback Recent

Recent (December, 2014 and January, 2015) Field Data in India; ICRISAT (Dr. Gumma)



Collaborations for Validation and Feedback Recent

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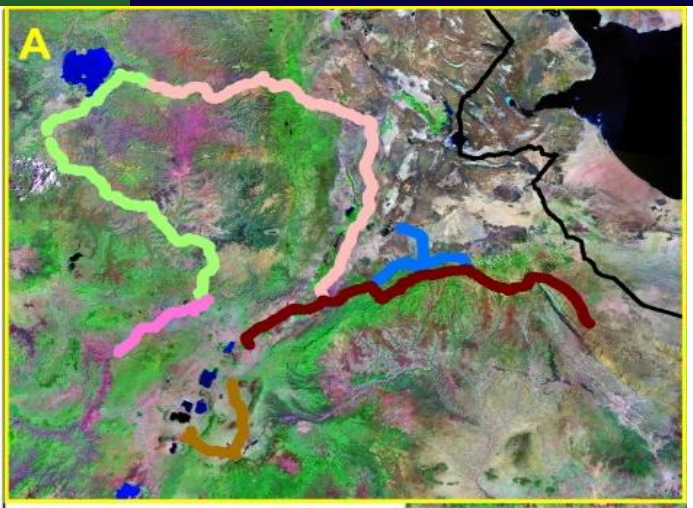


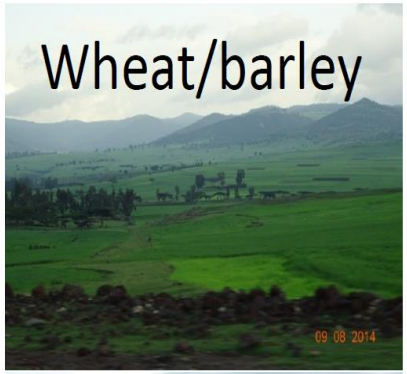
Legend

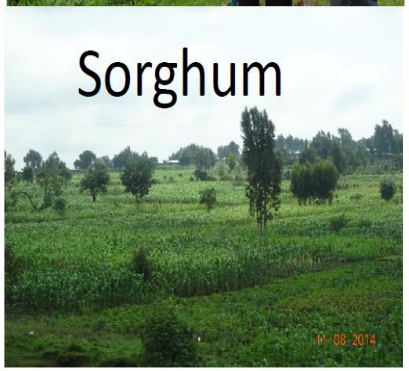
Route (day-wise)

- 09-08-2014
- 10-08-2014
- 11-08-2014
- 12-08-2014
- 13-08-2014
- 14-08-2014

RGB

- Red: Band_1
- Green: Band_2
- Blue: Band_3
- Ground data_8-16Aug2014_accuracy
- Ground data_8-16Aug2014_classification





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Role of Global Cropland Water Use in Ensuring Global Food Security

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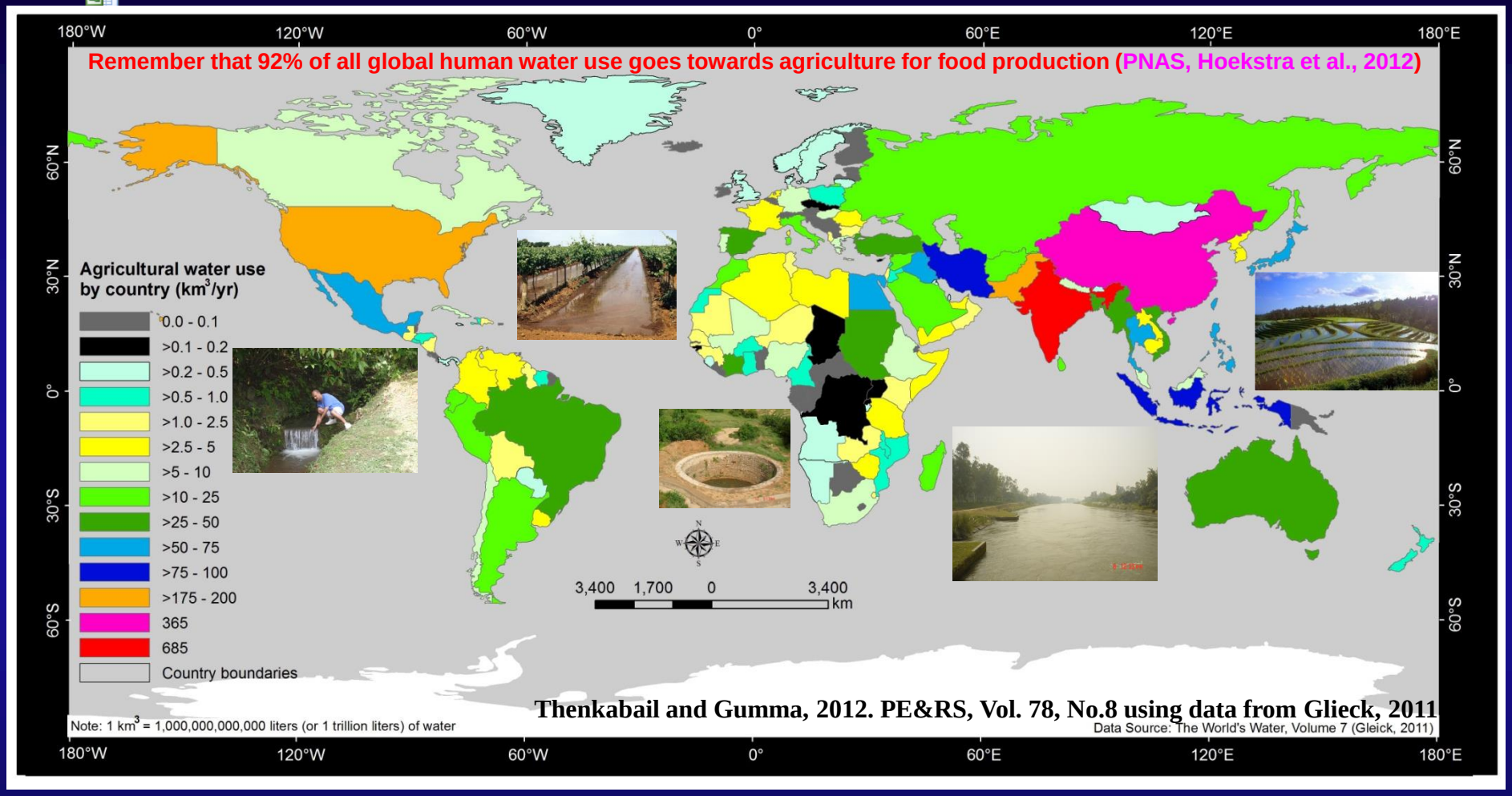
Global Cropland Water Use for Food Production by Country



Just 4 countries use 52% of cropland water use: India: 684 km³\yr, China: 364 km³\yr, USA: 197 km³\yr, and Pakistan: 172 km³\yr. However, per capita water use in USA is: ~2500 m³\yr\person whereas in India ~1000 m³\yr\person and China ~700 m³\yr\person

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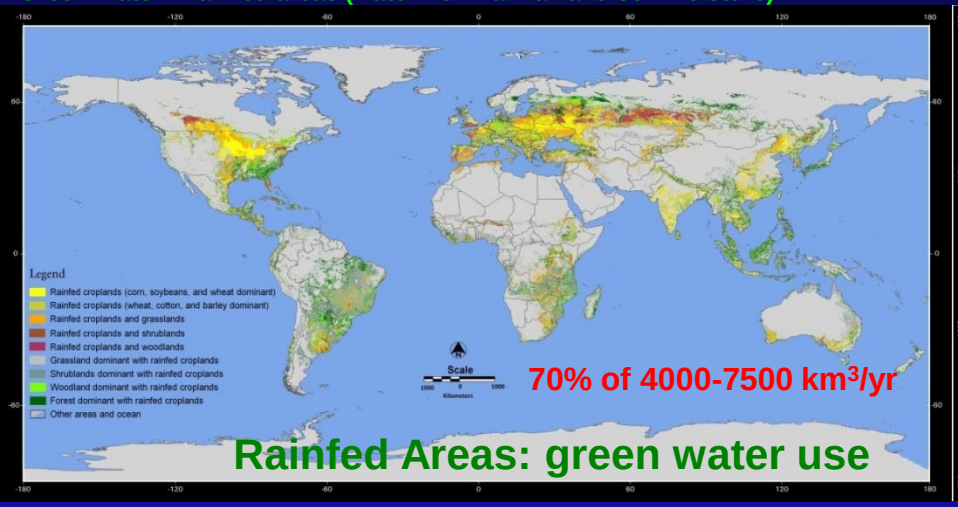
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

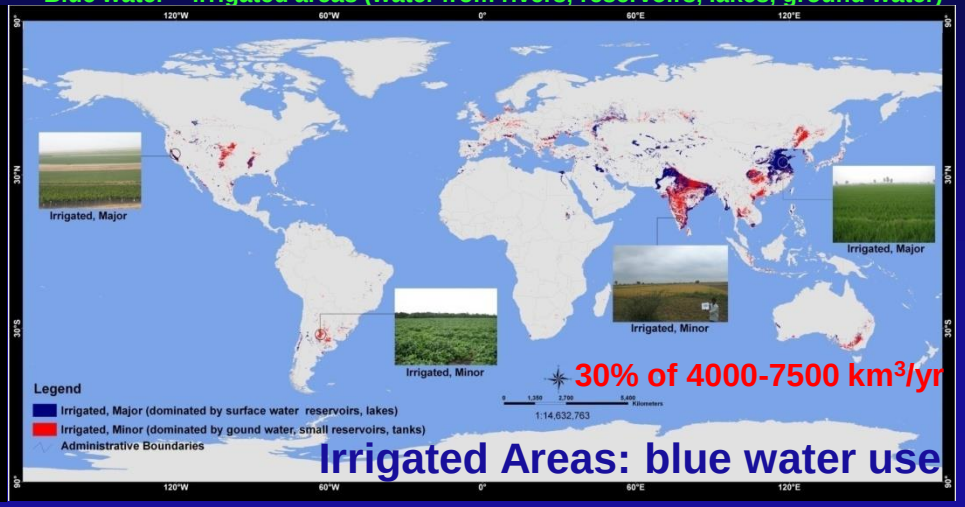
Increase Water Allocations for Agriculture Difficult

Agriculture already uses 92% of all Human Water Use (PNAS, Hoekstra et al., 2012)

Green Water = rainfed areas (water from rainfall and soil moisture)



Blue water = irrigated areas (water from rivers, reservoirs, lakes, ground water)



"green water use" (water from rain and soil moisture from unsaturated zone). 1.1 billion hectares of rainfed areas use 70% of agricultural water use.

"blue water use" (water in river, lakes, reservoirs, and acquifer ground water). 470 million hectares (when you consider intensity) of irrigated areas uses the rest 30% of agricultural water use.

..already agriculture takes up overwhelming amount of human water use and alternative uses of water always increasing…..so, it is obvious food production requires a new paradigm….

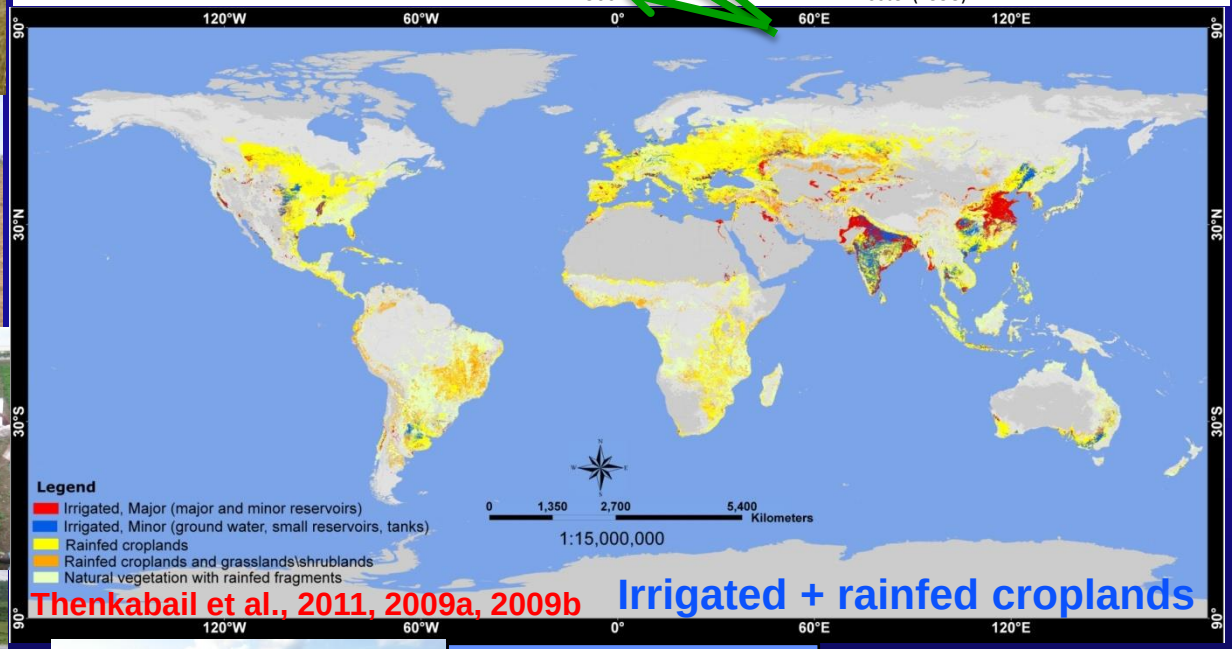
Total Global Water Used by All (irrigated + rainfed) Croplands

Blue water (from lakes, reservoirs, rivers, ground water) + Green Water (from soil moisture) use by croplands

Table 2. Global blue water and green water use by agricultural crops for roughly at end of the last millennium.

Blue water use By Irrigated crops km^3/yr	Green water use by irrigated crops km^3/yr	Green water use by Rainfed crops km^3/yr	Total water use by irrigated and rainfed crops km^3/yr	Reference
1180	919	4586	6685	Siebert and Döll (2009)
1800	-	5000	6800	Falkenmark and Rockström (2006)
			7500	Postel (1998)

global crop water model (GCWM)



Thenkabail et al., 2011, 2009a, 2009b

Irrigated + rainfed croplands

How much water does 1.53 billion hectares of total cropland areas use?

….but these estimates will change if we consider uncertainties in irrigated areas…….

4000 to 7500 km^3/yr water used for agriculture (irrigated+rainfed)

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Total Global Water Used by Rainfed Croplands

Green Water (from soil moisture in unsaturated zone + direct rainfall on rainfed croplands) use by croplands

Table 2. Global blue water and green water use by agricultural crops for roughly at end of the last millennium.

Blue water use By Irrigated crops km^3/yr	Green water use by irrigated crops km^3/yr	Green water use by Rainfed crops km^3/yr	Total water use by irrigated and rainfed crops km^3/yr	Reference
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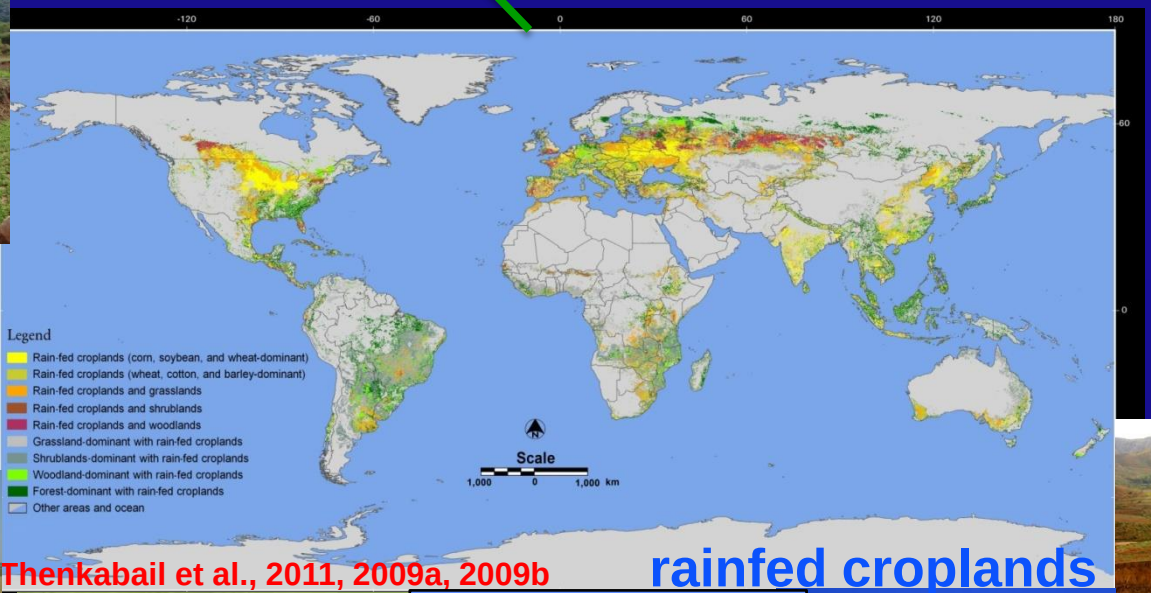

Thenkabail et al., 2011, 2009a, 2009b

rainfed croplands

How much water does 1.13 billion hectares of rainfed croplands use?

4586 to 5000 km^3/yr water used for agriculture (irrigated+rainfed)

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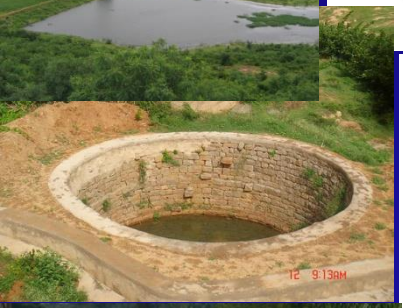
Total Global Water Used by Irrigated Croplands

Blue water (from lakes, rivers, reservoirs, ground water) + direct rainfall over irrigated croplands



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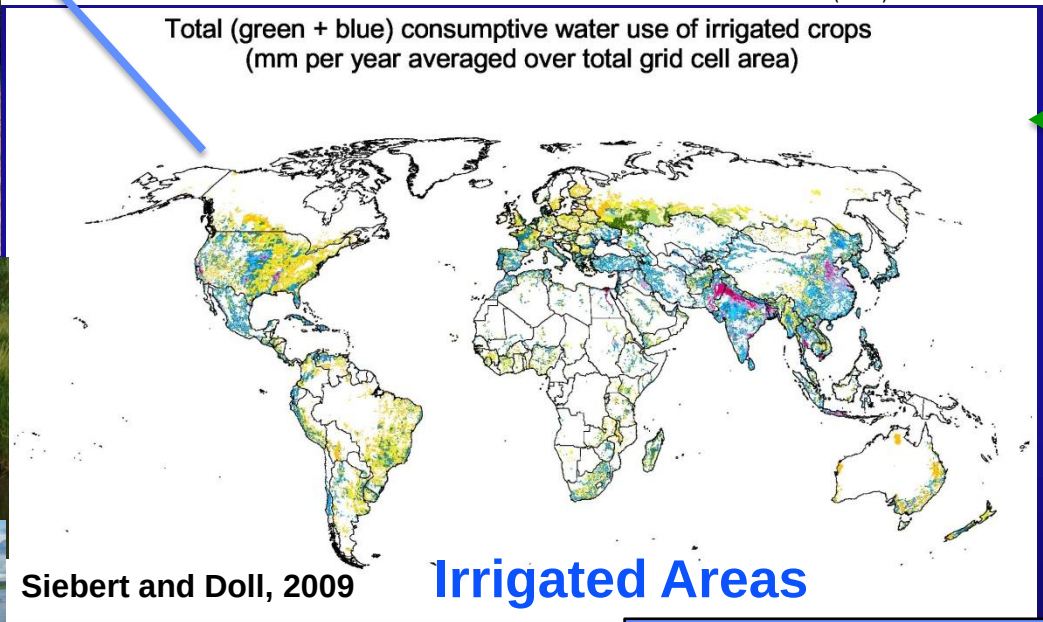
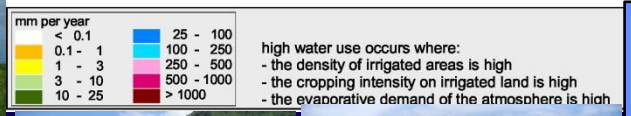
1800	-	5000	6800	Falkenmark and Rockström (2006)
			7500	Postel (1998)

Direct rainfall over irrigated areas

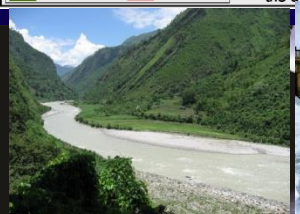


How much water does 278.4 Mha (Siebert et al., 2006) irrigated croplands use?

How much water does 399 Mha (or 467 Mha with intensity) (Thenkabail et al. (2011, 2009a, 2009b) of irrigated croplands use?



1180 to 1800 km^3/yr water used for agriculture (irrigated). Plus 919 km^3/yr of direct rainfall falling on irrigated areas



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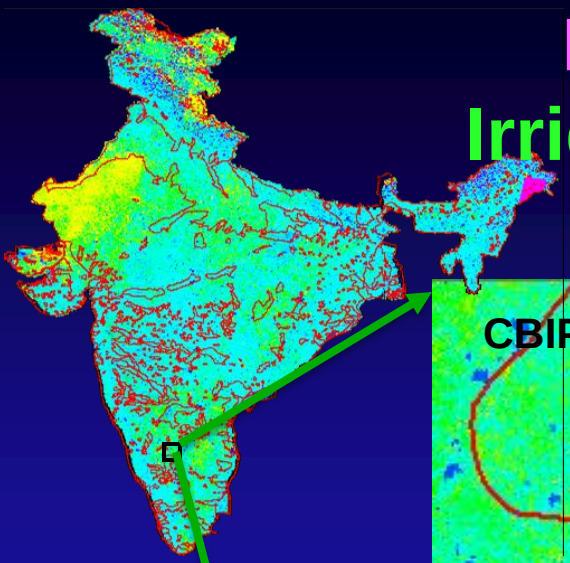
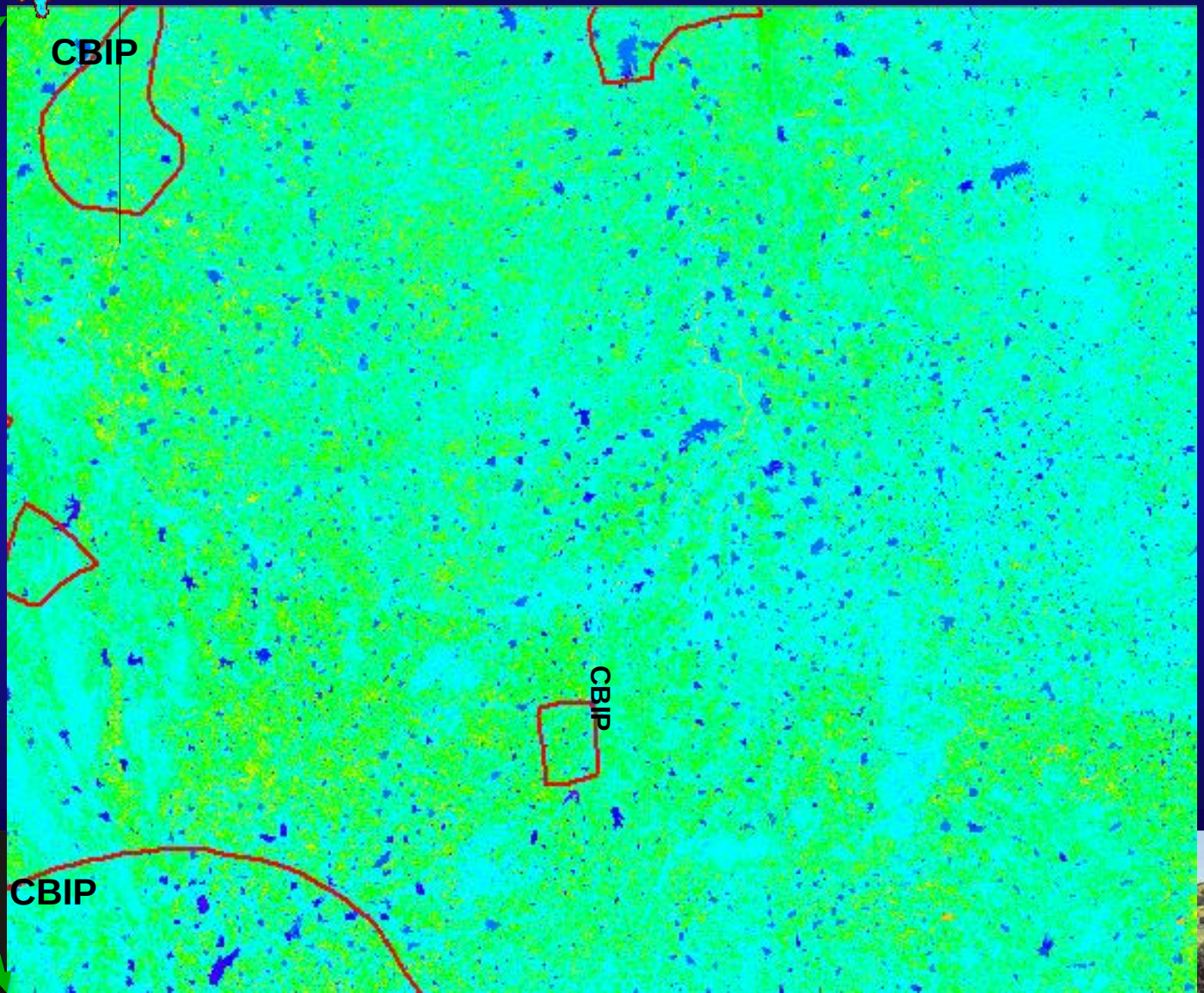
Landsat Data for Mapping Irrigated Areas + Rainfed Areas





Landsat Data highlighting minor irrigation from small tanks in India

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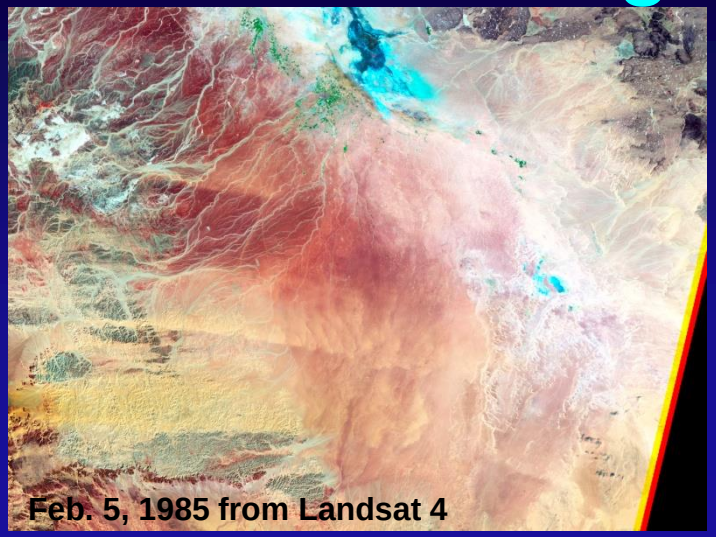
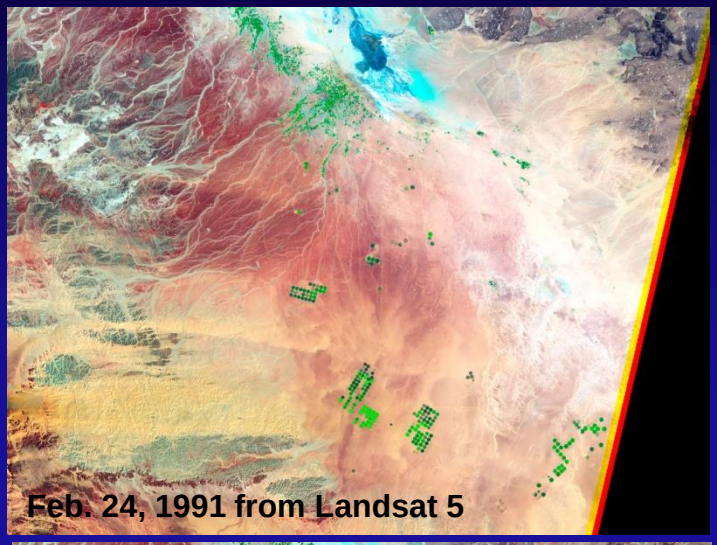
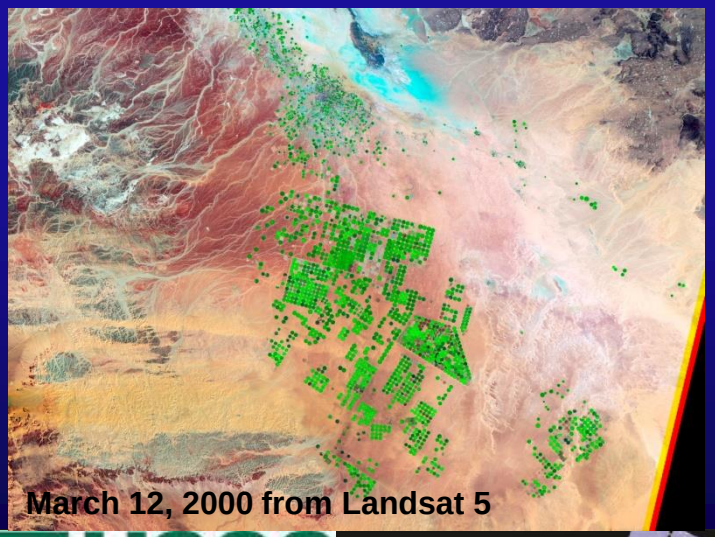
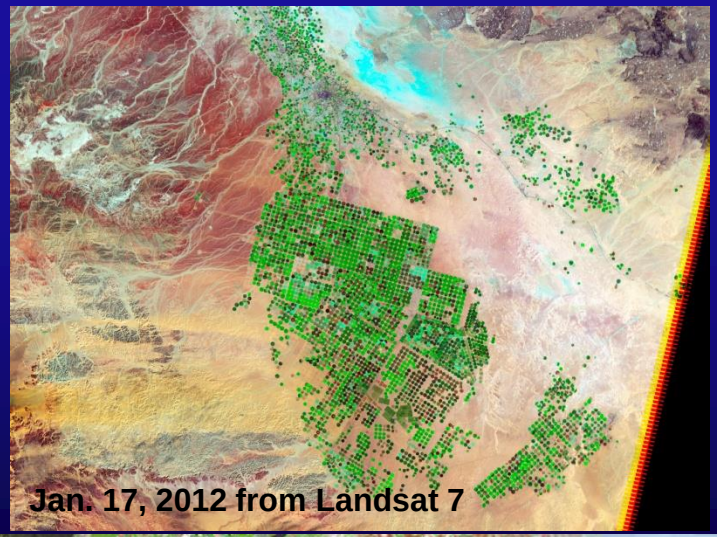
Desert Agriculture and Water Use





Each circle is 100 hectares of farmland. Uses ground water from 1-km deep wells. Desert agriculture water use in Saudi Arabia: 6.8 cubic kilometers in 1980 to 21 cubic kilometer in 2006. Rainfall just 100 to 200 mm per yr. Also, as per 2006 statistics of FAO, the Sudi Arabian Surface water resources was 2.4 cubic kilometers. However, annual water use was 23.7 cubic kilometers.





Source: Robert Simon and Jesse Allen. NASA Earth Observatory, CIA, and FAO.

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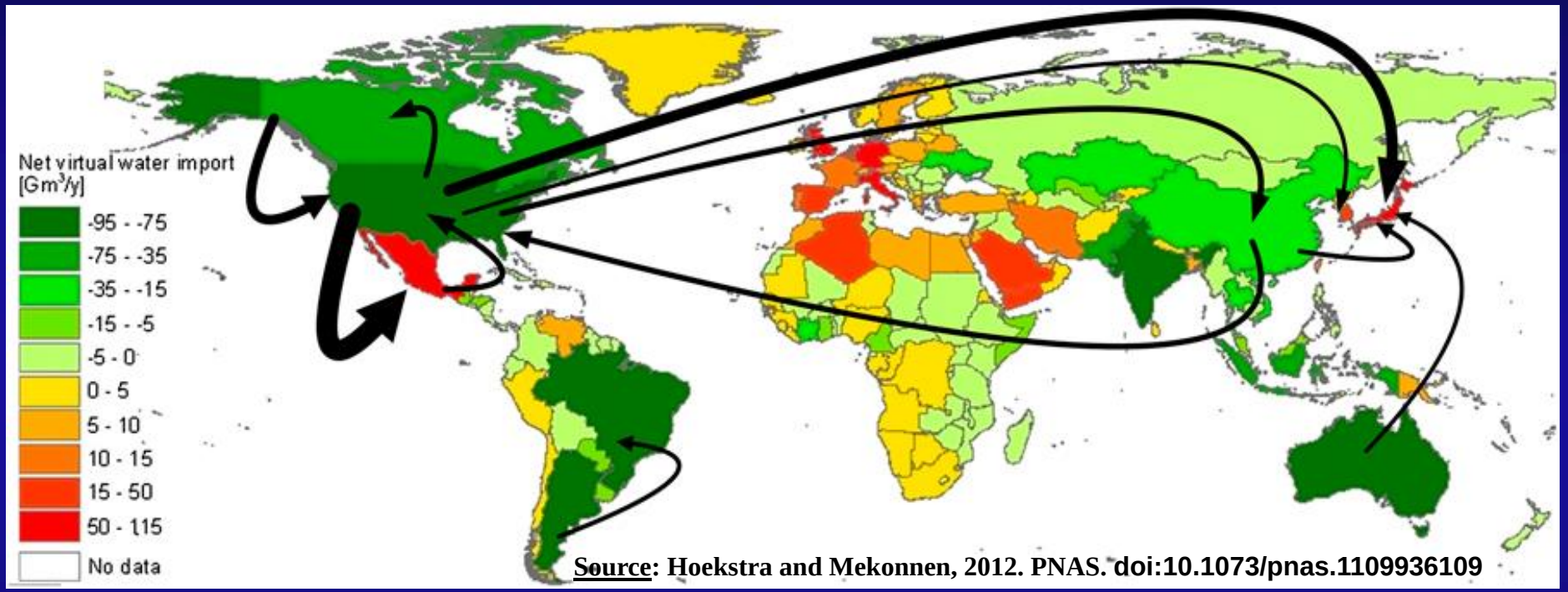
Virtual Water: Water Importers and Water Exporters in A Global Economy

Microsoft Excel Worksheet

~20% of world's water use is virtual



Source: Hoekstra and Mekonnen, 2012. PNAS. doi:10.1073/pnas.1109936109

Red: water importers; Green: water Exporters.

Note: 1 Gm^3/yr (billion cubic meter per year)

Global Croplands and their Water Use for Food Security in the 21st Century

SOLUTIONS and WAY FORWARD

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Further Expansion of Global Croplands is NOT a Solution

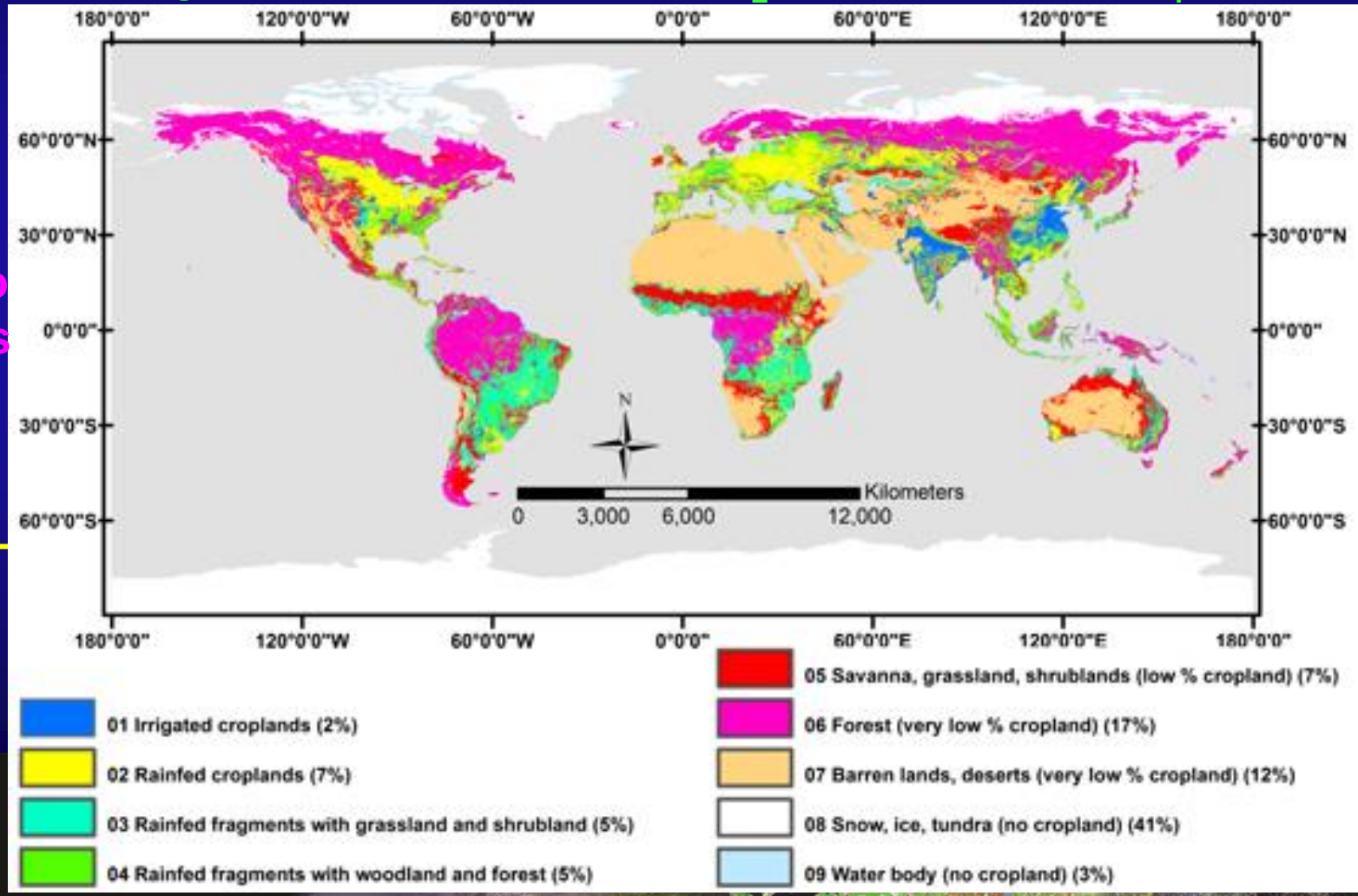
~12% of the Global Terrestrial Area in Croplands

~90% of all human water use goes for croplands to produce food

~14% of greenhouse gas emissions; 60% of ~N_2O and ~50% of CH_4

Further expansion of croplands at huge costs to environments, and loss of flora/fauna…

….so, certainly NOT a solution.



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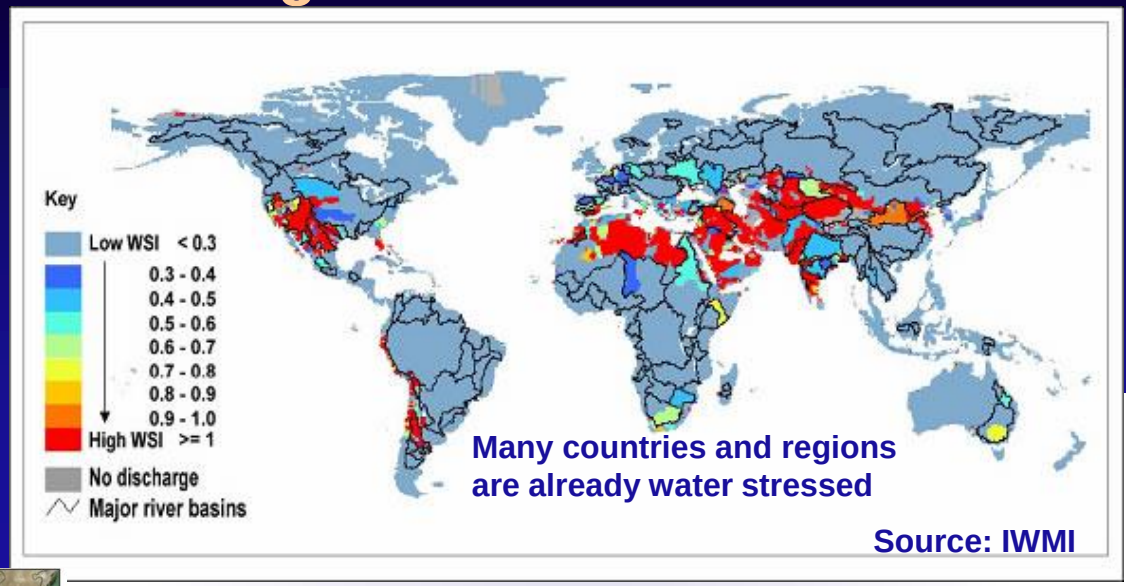
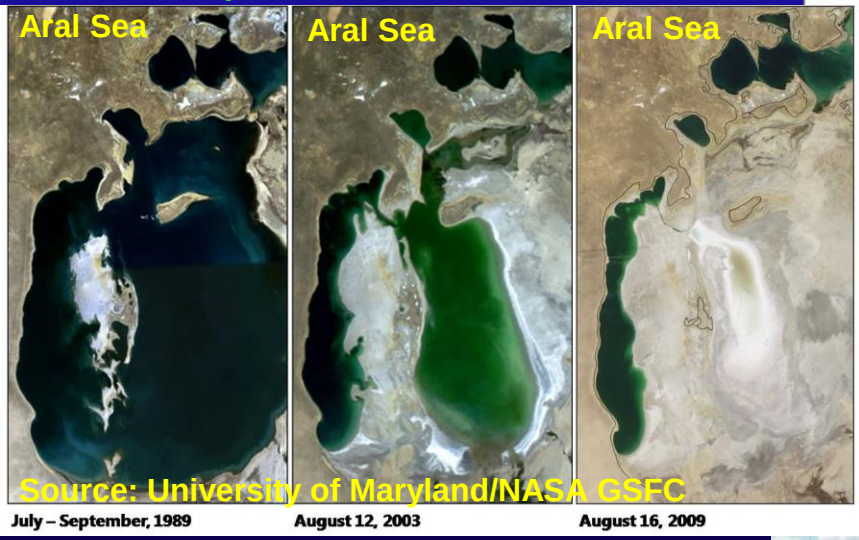
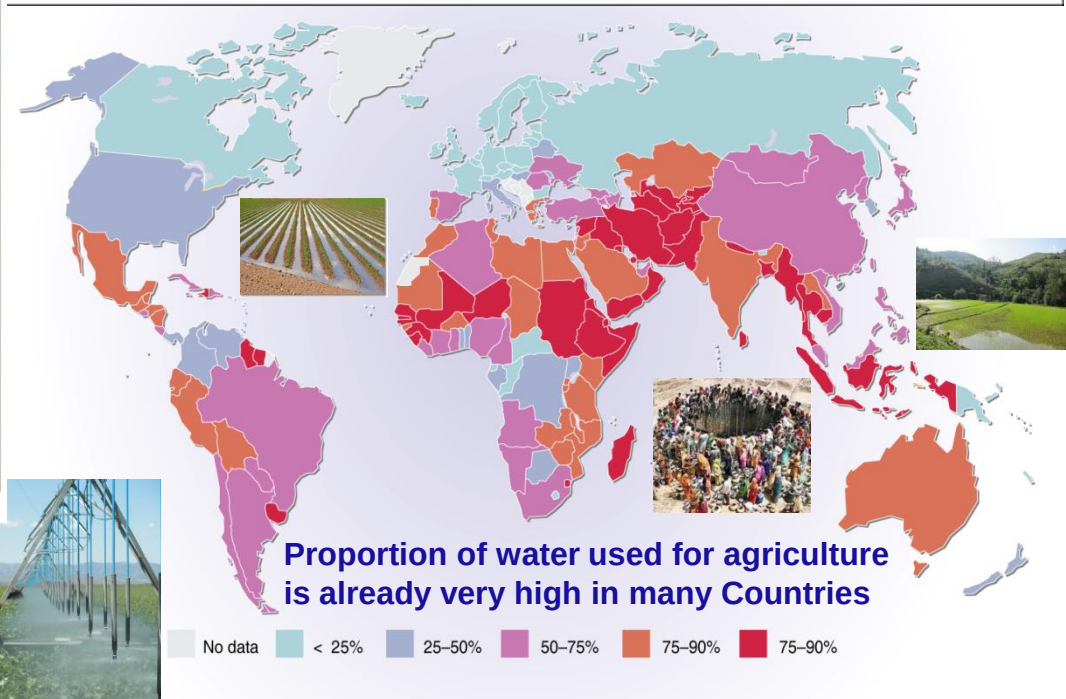
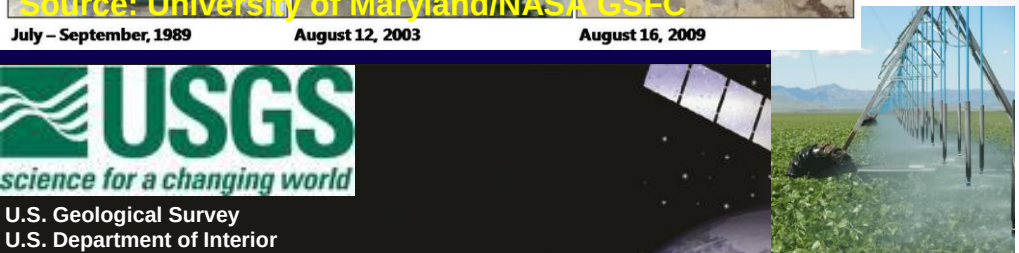
Further Allocation of Water for Agriculture is NOT feasible

~90% of all human water use already goes for agriculture to produce food;
~Alternative uses for water are already increasing;
~Climate change is making water availability highly variable;



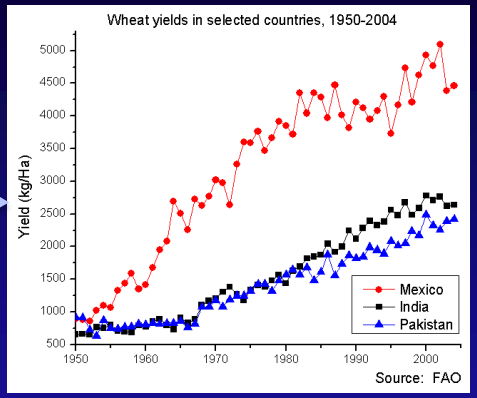






Blue Revolution: Single Biggest Opportunity

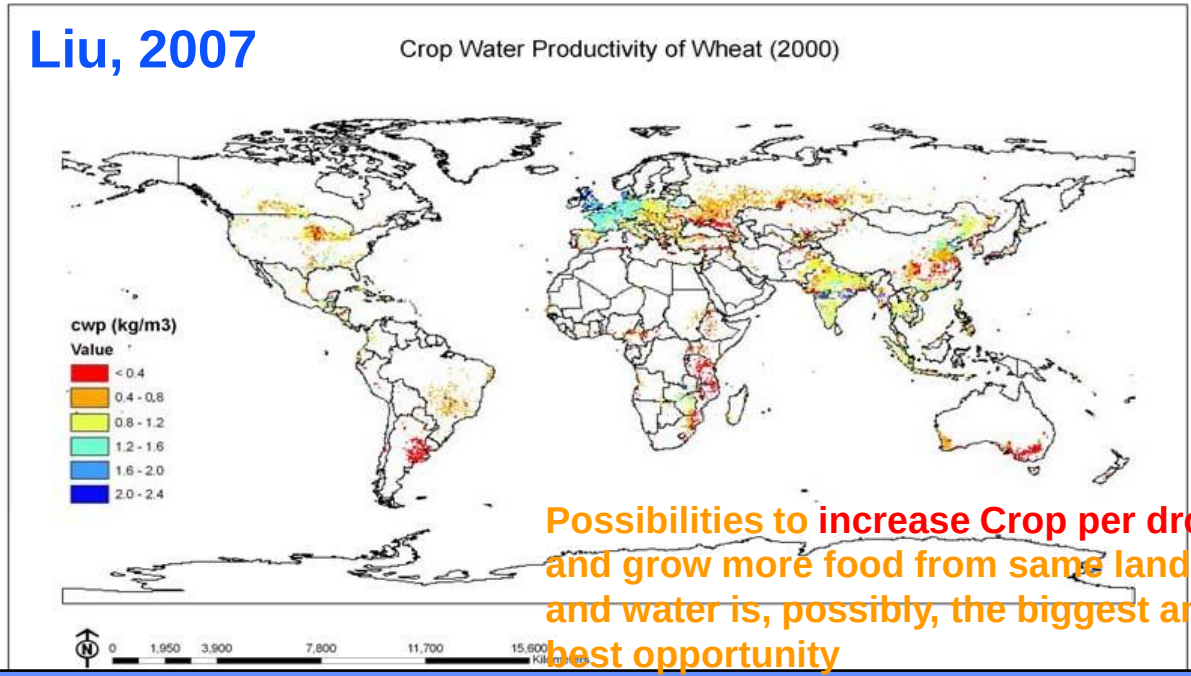
Green revolution has virtually ended: the focus was on increasing productivity per unit of land (kg\m^2)



e.g., Wheat yield no more increasing….similarly, crop yields of other crops have stagnated.

Similarly, 1. irrigated areas no more increasing; 2. croplands have stagnated; 3. increase in crop intensities have plateaued (also due to water limitations.

Blue revolution is in the nascent stage and offers the single biggest opportunity to grow more food from same land and water: the focus is on increasing productivity per unit of water (kg\m^3) or crop per drop.



Possibilities to increase Crop per drop and grow more food from same land and water is, possibly, the biggest and best opportunity

There is tremendous opportunity to increase water productivity of croplands in much of the World's croplands

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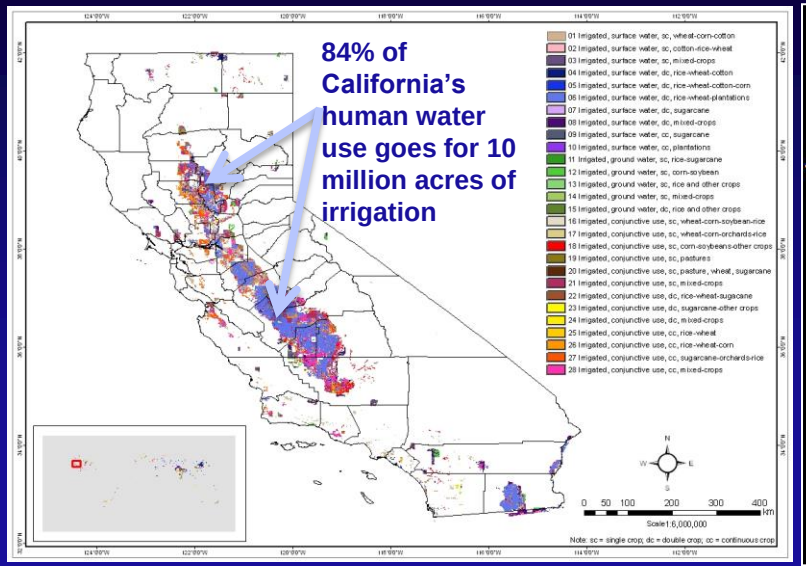
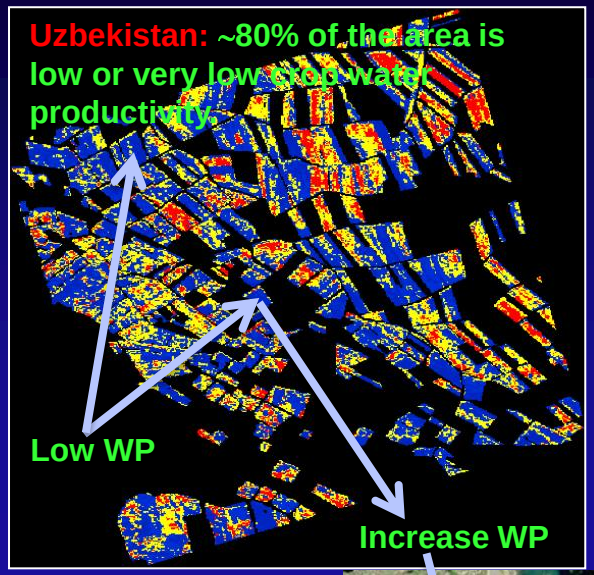
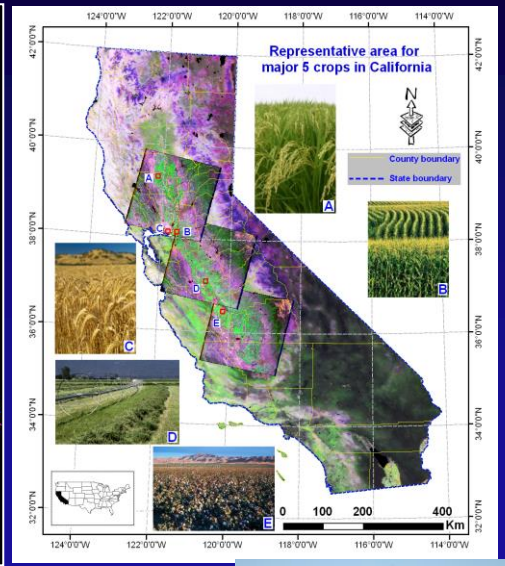
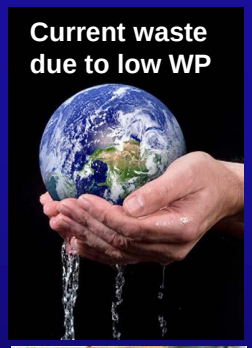
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Ongoing USGS Mendenhall Research in California









Overarching goal is to use spaceborne data to study and establish irrigated agriculture water productivity in California's Central Valley

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Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Focus on Key Crops for a Blue Revolution

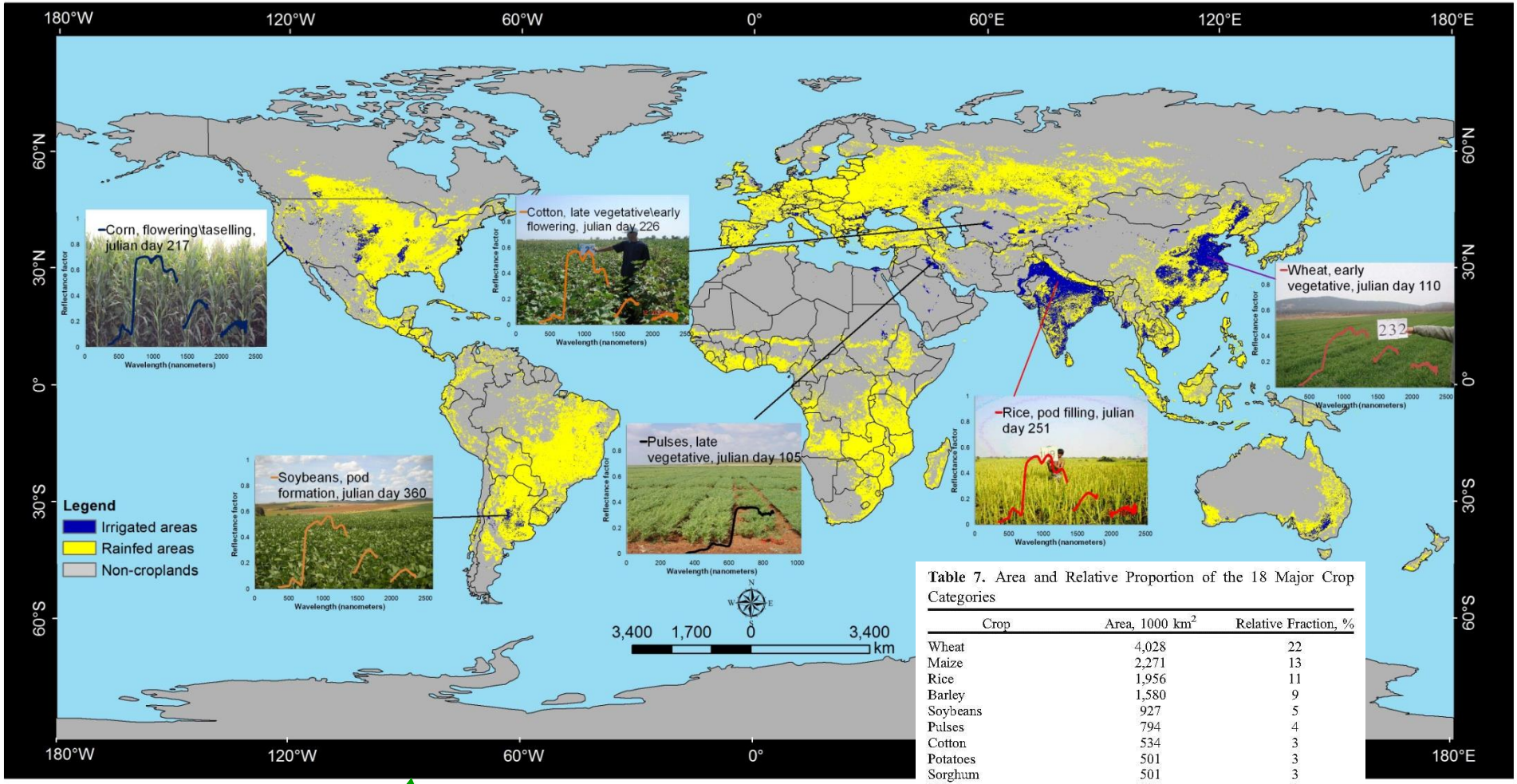

Table 7. Area and Relative Proportion of the 18 Major Crop Categories

Crop	Area, 1000 km^2	Relative Fraction, %
Wheat	4,028	22
Maize	2,271	13
Rice	1,956	11
Barley	1,580	9
Soybeans	927	5
Pulses	794	4
Cotton	534	3
Potatoes	501	3
Sorghum	501	3
Millet	331	2
Sunflower	290	2
Rye	288	2
Rapeseed/canola	283	2
Sugar cane	265	1
Groundnuts/peanuts	247	1
Cassava	235	1
Sugar beets	154	1
Oil palm fruit	72	<1
Total of major 18 crops	*15,256*	*85*
Others	2664	15
Total cropland	*17,920*	*100*

1. Have a Global Perspective…..so we can develop models that are applicable over space and time

2. Focus on 18 crops occupy 85% of all global cropland areas…..so, we can focus on them

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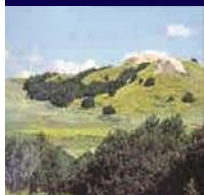
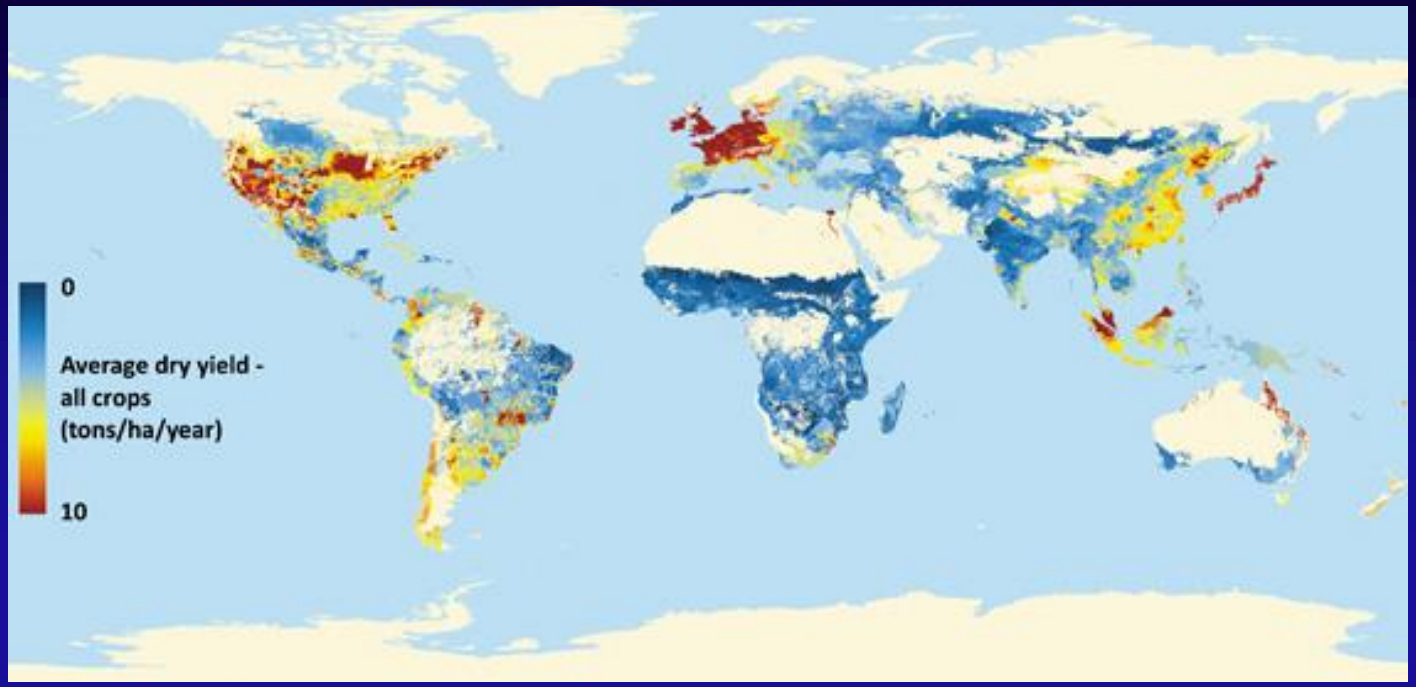


Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Continued Green Revolution: To Close the Yield Gap in Most of the Existing Croplands



However, watch out for detrimental application of herbicides, pesticides, Nitrogen…..that invariably lead to polluted aquifers, loss of biodiversity (e.g., fish life), and degradation of soils.

Image Source: Paul C. West, Holly K. Gibbs, Chad Monfreda, John Wagner, Carol C. Barford, Stephen R. Carpenter, and Jonathan A. Foley. Trading carbon for food: Global comparison of carbon stocks vs. crop yields on agricultural land. PNAS. DOI: 10.1073/pnas.1011078107.

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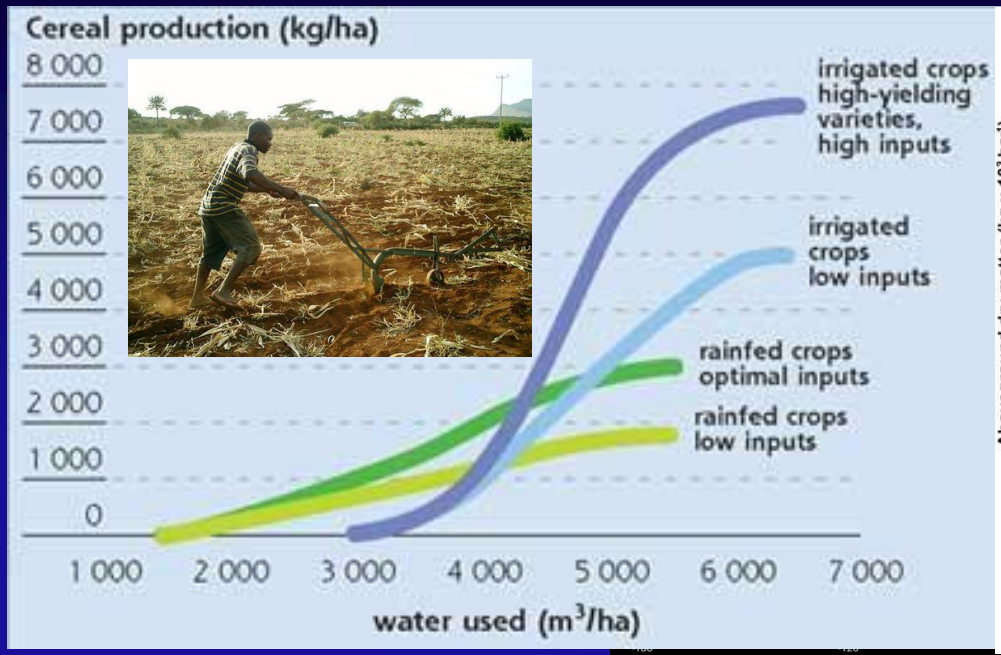
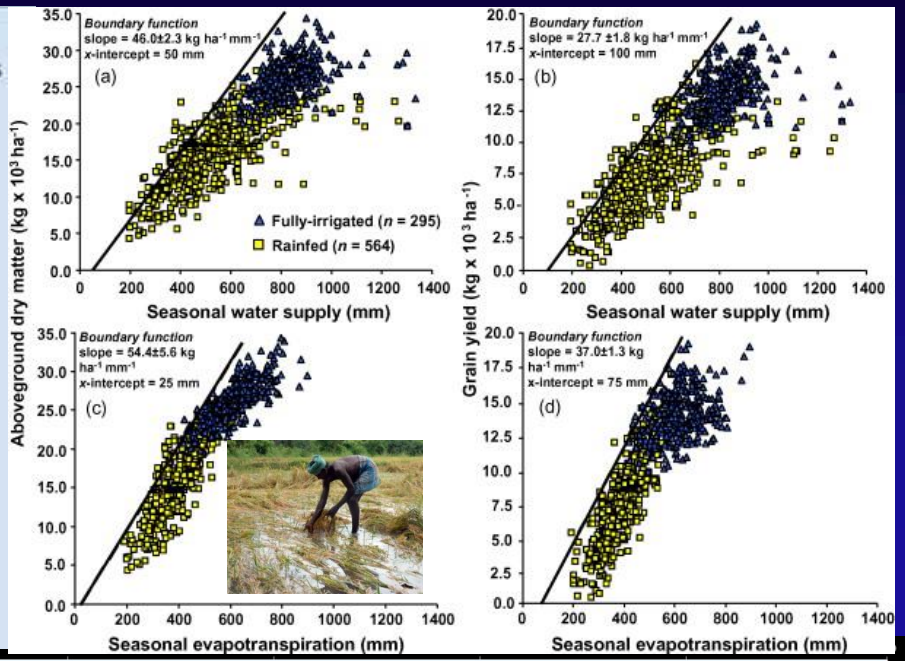
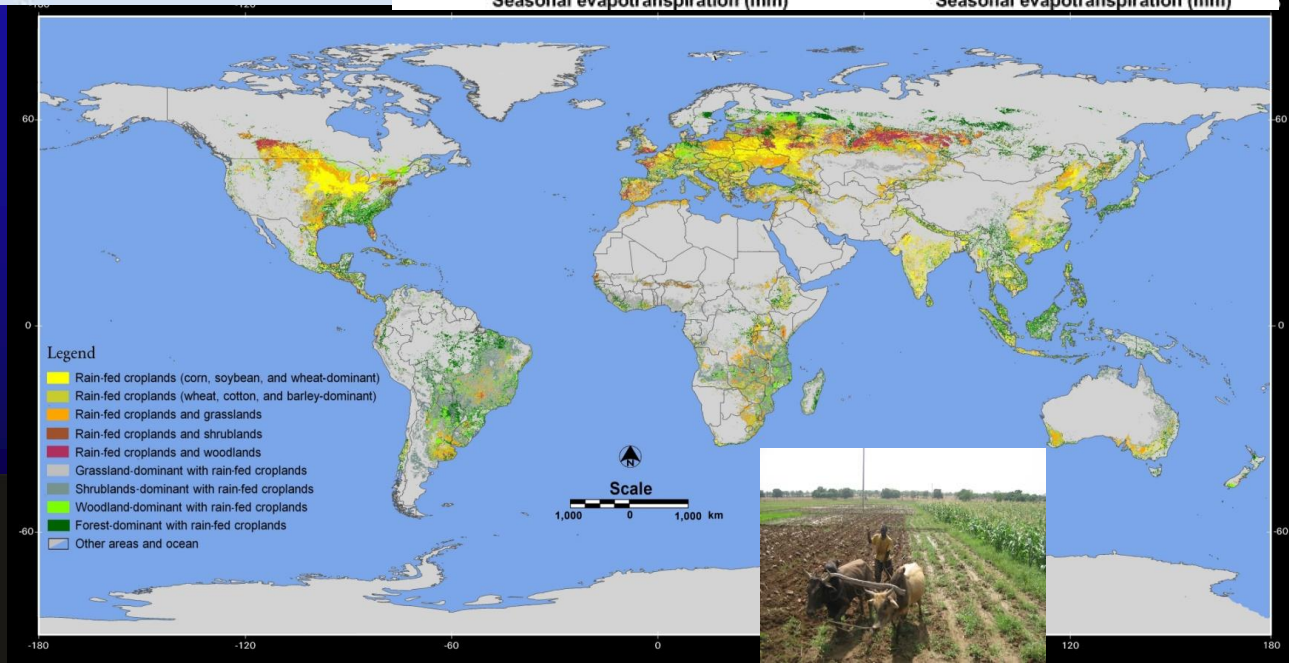
Rainfed Croplands: Great Opportunity for Production Increase in 1.1 billion hectares





Yield gap in rainfed croplands relative to irrigated croplands is great. Further, there is tremendous scope for increasing the crop productivity and water productivity of rainfed croplands of the world. With 1.1 billion hectares of rainfed croplands this is one great opportunity to increase food production.



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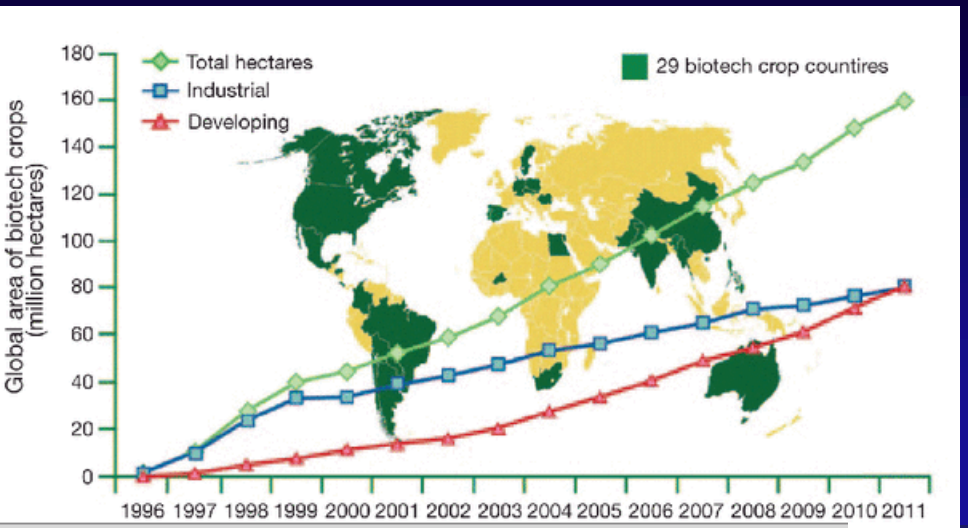
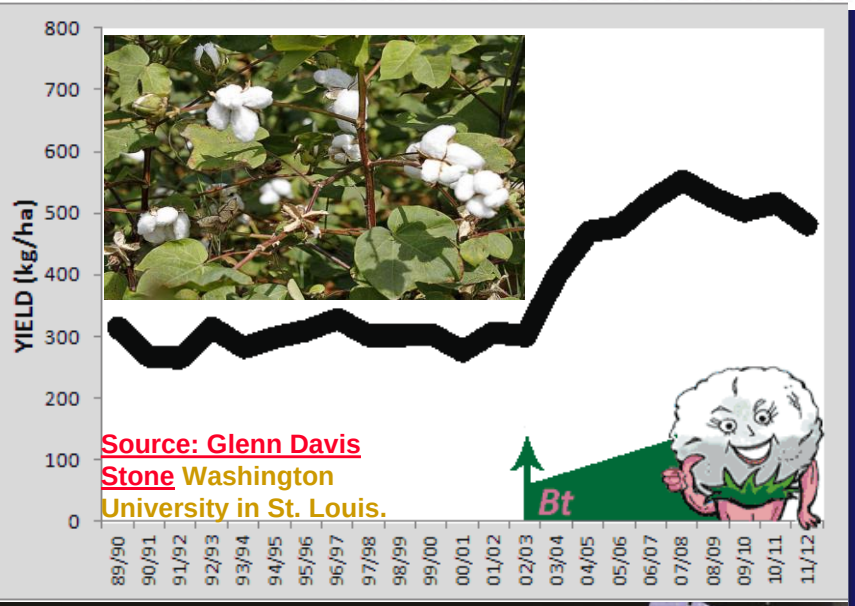
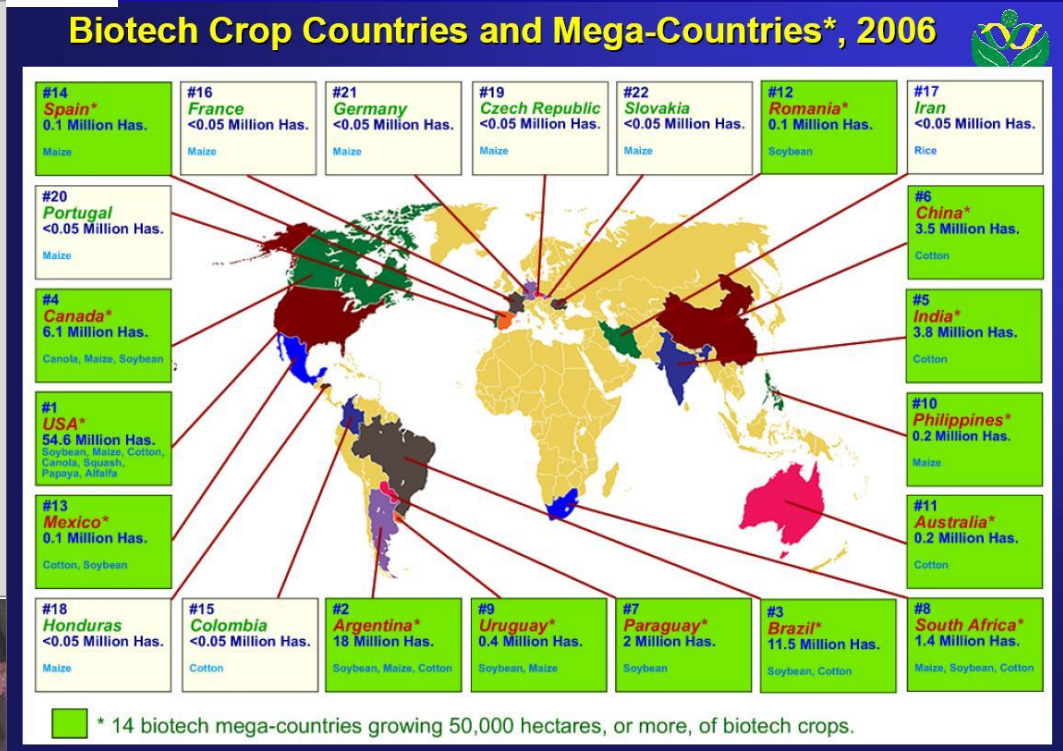
Biotech Crops: Great Opportunity for Global Expansion, but serious debates remain



BT crops are known to increase yields, decrease pest and disease and are currently only in about 10% of total global croplands. So, more widespread use of BT varieties will help increase yields……..however, there are serious issues debated on BT varieties and unless we understand all consequences and ensure safety there will be questions.





Source: Clive James, 2006

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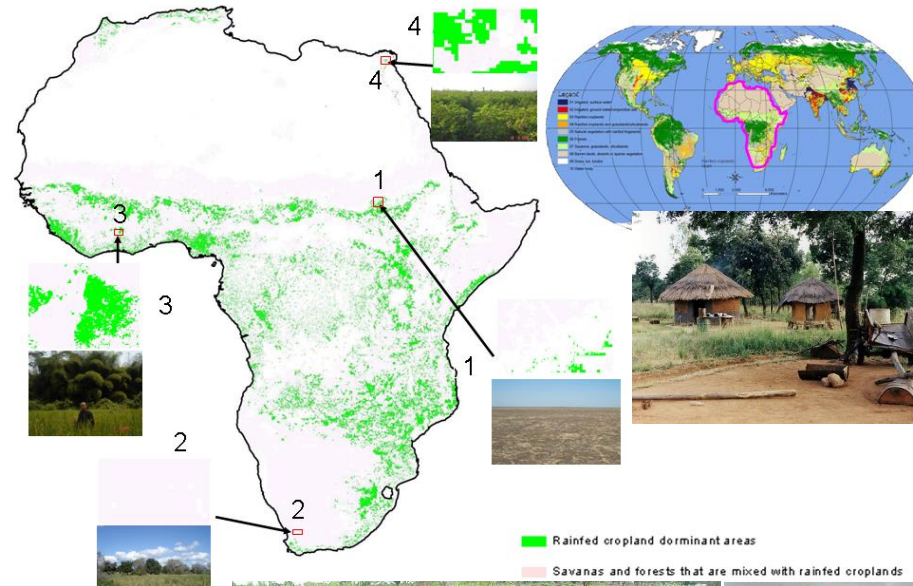
Untapped African Farming……but think of Subsistence Farmers!

Other Countries are Looking for Land in Africa to produce food for their Countries….virtual water use will increase in coming years

So, will Africa play a big role in addressing World Food Security?

Bill Gates In Nigeria (Photo credit: Bill and Melinda Gates Foundation)


Studying grain, Karsana, Nigeria



But, will that result in marginalizing the the subsistence farmer?

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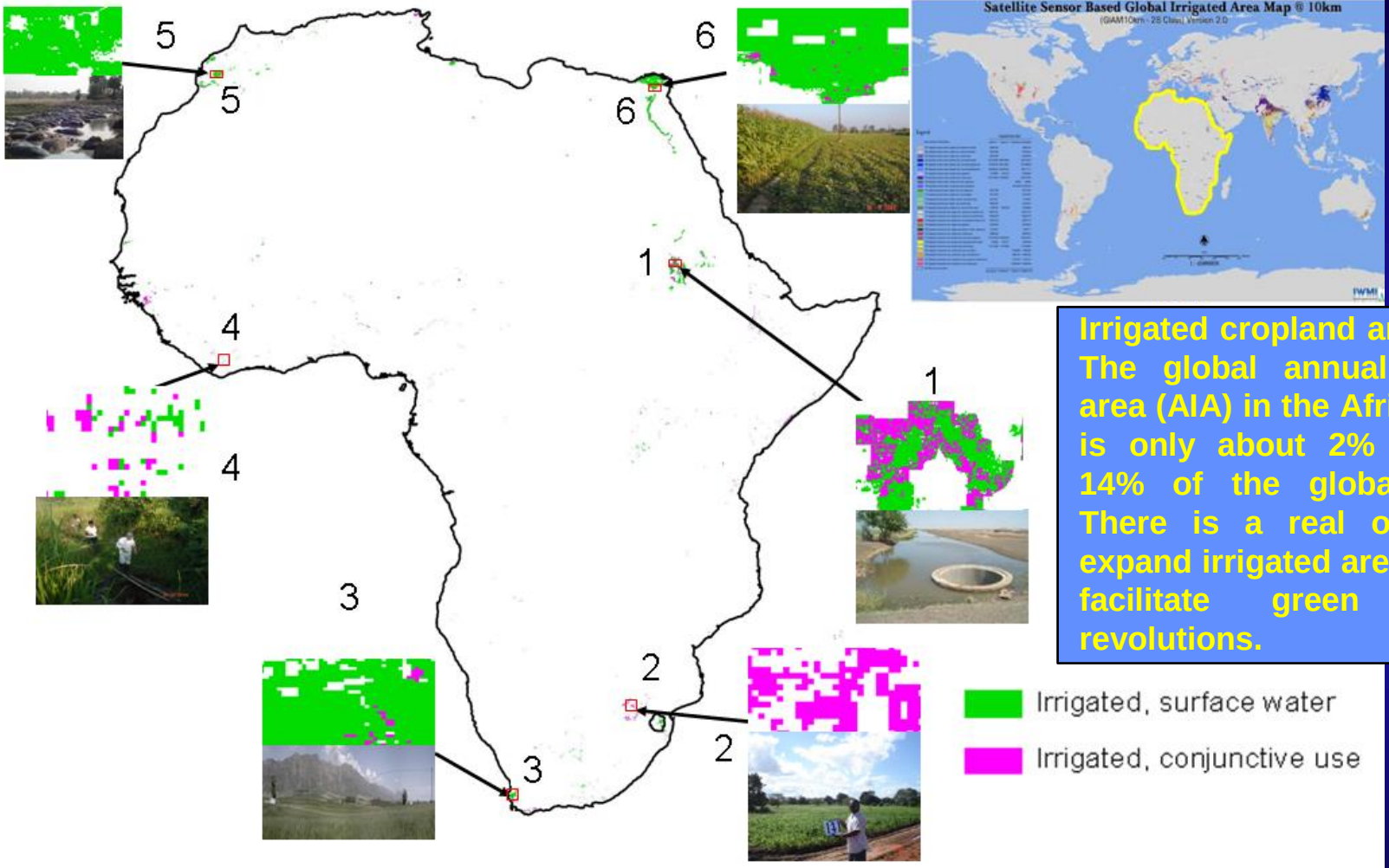
Irrigation expansion in Africa?: Contributing to Africa's/Global Food Security



Irrigated cropland areas of Africa. The global annualized irrigated area (AIA) in the African continent is only about 2% compared to 14% of the global population. There is a real opportunity to expand irrigated areas in Africa to facilitate green and blue revolutions.

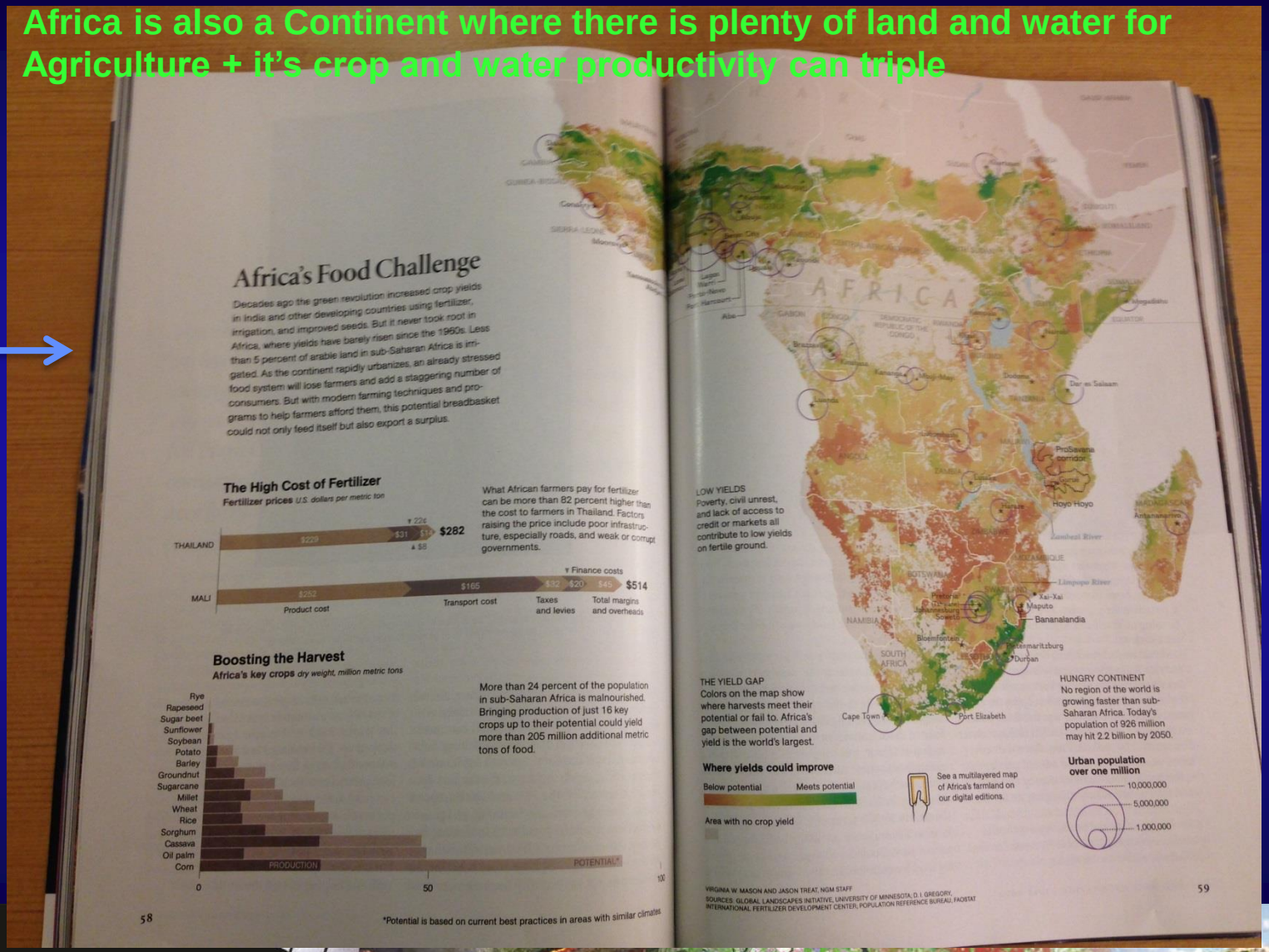
Thenkabail et al., 2009

Global Cropland Extent V2.0 (GCE V2.0) @ nominal 250 m for Africa

Africa is Growing @ Rapid Phase and so is its Agriculture

Source: "African Agriculture Goes Global", National Geographic ; July 2014

Africa is also a Continent where there is plenty of land and water for Agriculture + it's crop and water productivity can triple



Africa's Food Challenge

Decades ago the green revolution increased crop yields in India and other developing countries using fertilizer, irrigation, and improved seeds. But it never took root in Africa, where yields have barely risen since the 1960s. Less than 5 percent of arable land in sub-Saharan Africa is irrigated. As the continent rapidly urbanizes, an already stressed food system will lose farmers and add a staggering number of consumers. But with modern farming techniques and programs to help farmers afford them, this potential breadbasket could not only feed itself but also export a surplus.

The High Cost of Fertilizer

Fertilizer prices *U.S. dollars per metric ton*

THAILAND: $229 + $31 + $22 = $282

MALI: $252 + $165 + $32 + $20 + $45 = $514

Product cost · Transport cost · Taxes and levies · Total margins and overheads · Finance costs

What African farmers pay for fertilizer can be more than 82 percent higher than the cost to farmers in Thailand. Factors raising the price include poor infrastructure, especially roads, and weak or corrupt governments.

Boosting the Harvest

Africa's key crops *dry weight, million metric tons*

More than 24 percent of the population in sub-Saharan Africa is malnourished. Bringing production of just 16 key crops up to their potential could yield more than 205 million additional metric tons of food.

*Potential is based on current best practices in areas with similar climates

58

LOW YIELDS
Poverty, civil unrest, and lack of access to credit or markets all contribute to low yields on fertile ground.

THE YIELD GAP
Colors on the map show where harvests meet their potential or fail to. Africa's gap between potential and yield is the world's largest.

HUNGRY CONTINENT
No region of the world is growing faster than sub-Saharan Africa. Today's population of 926 million may hit 2.2 billion by 2050.

Where yields could improve

Below potential · Meets potential

Area with no crop yield

See a multilayered map of Africa's farmland on our digital editions.

Urban population over one million

10,000,000
5,000,000
1,000,000

VIRGINIA W. MASON AND JASON TREAT, NGM STAFF
SOURCES: GLOBAL LANDSCAPES INITIATIVE, UNIVERSITY OF MINNESOTA; D. I. GREGORY, INTERNATIONAL FERTILIZER DEVELOPMENT CENTER; POPULATION REFERENCE BUREAU; FAOSTAT

59

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Irrigation expansion in Africa?: Contributing to Africa's/Global Food Security

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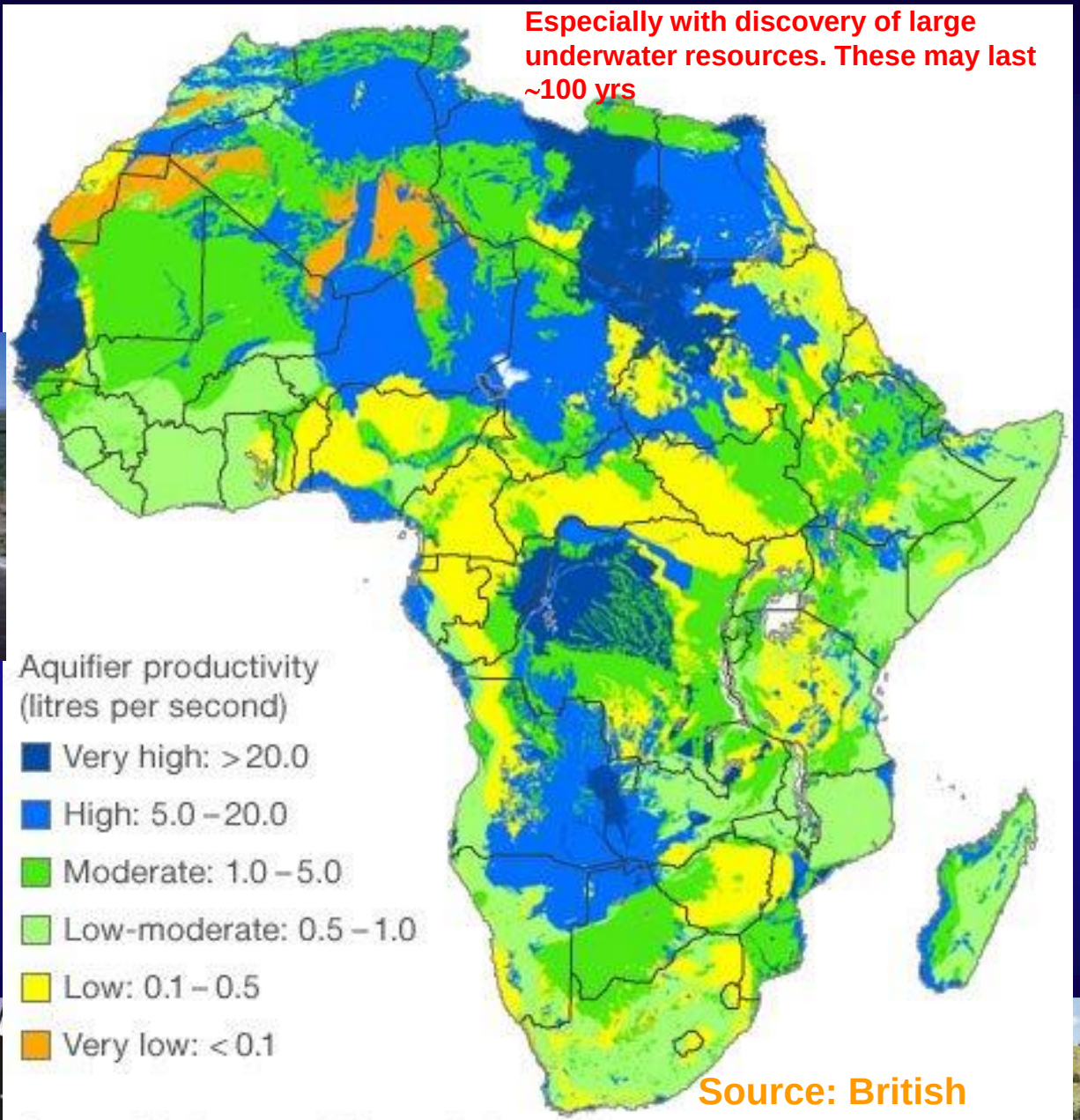
Especially with discovery of large underwater resources. These may last ~100 yrs

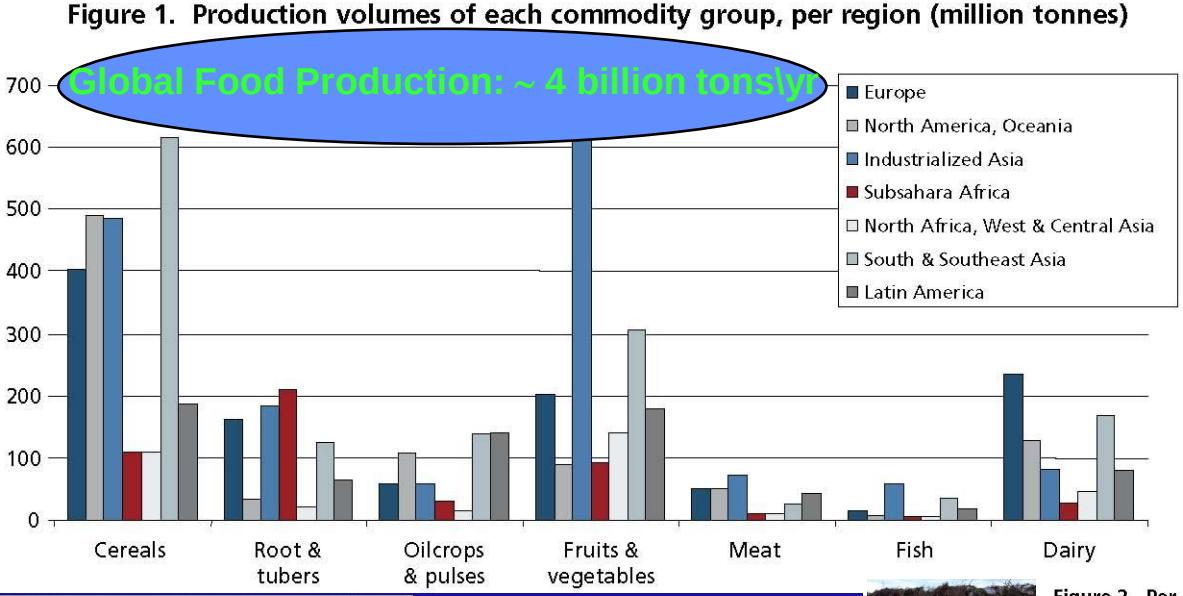


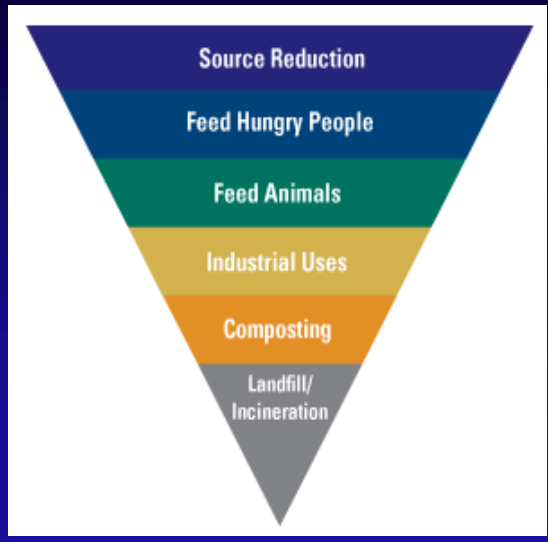
Source: Environmental Research Letters

Source: British Geological Survey

Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

About 30% (~1.3 billion tons\yr) of the Food Produced for Human Consumption Goes Waste

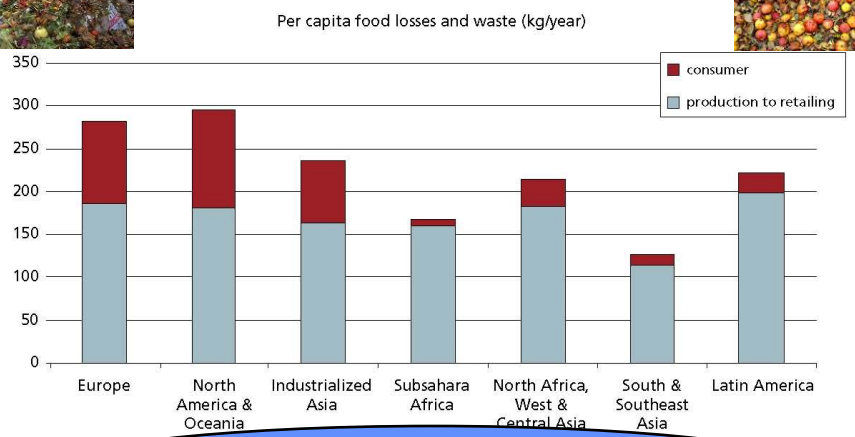




Solutions to Overcome Waste

Some estimates show that controlling food Waste alone could feed an additional 2 billion by 2050!

Figure 2. Per capita food losses and waste, at consumption and pre-consumptions stages, in different regions



Global Food Waste: ~ 1.3 billion tons\yr

Figure 2 shows that the per capita food loss in Europe and North-America is 280-300 kg/year. In Sub-Saharan Africa and South/Southeast Asia it is 120-170 kg/year. The total per capita production of edible parts of food for human consumption is, in Europe and North-America, about 900 kg/year and, in sub-

Source: Jenny Gustavsson et al. (Swedish Institute for Food and Biotechnology); Robert van Otterdijk et al. UN FAO, 2012

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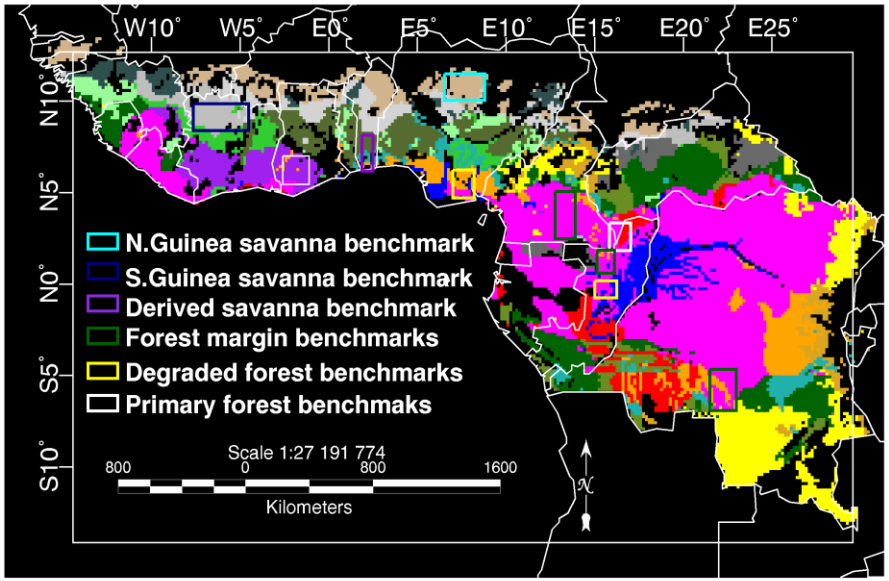
African Wetlands: Potential Source of Agricultural Development

The wetlands of Africa are increasingly considered "hotspots" for agricultural development and for expediting Africa's Green and Blue Revolution. Currently, these IV wetlands are un-utilized or highly under-utilized in WCA (Figure) in spite of their rich soils and abundant water availability as a result of:

(a) limited road access to these wetlands, and

(b) prevailing diseases such as *Malaria, Trypanosomiasis* (sleeping sickness) and *Onchocerciasis* (river blindness).

However, the utilization of IV wetlands for agriculture is becoming unavoidable in WCA countries due to increasing pressure for food from a ballooning human population and difficulty finding arable land with access to water resources.



Agroecological and Soil Zones (AESZ) in Humid-forests and savannas of West and Central Africa

- Derived savanna:Acrisols (11.7 Mha)
- Derived savanna:Lithosols (10.8 Mha)
- Humid forest:Ferralsols (150.1 Mha)
- Humid forest:Nitosols (27.2 Mha)
- Humid forest:Gleysols (19.2 Mha)
- Humid forest:Arenosols (18.9 Mha)
- Humid forest:Acrisols (18.0 Mha)
- Mid-alt. savanna:Ferralsols (45.4 Mha)
- Mid-alt. savanna:Nitosols (12.3 Mha)
- N.Guinea savanna:Luvisols (25.2Mha)
- S.Guinea savanna:Luvisols (18.4 Mha)
- S.Guinea savanna:Acrisols (12.4 Mha)
- S.Guinea savanna:Ferralsols (11.9 Mha)
- S.Guinea savanna:Lithosols (10.7 Mha)
- Derived savanna:Ferralsols (47.2 Mha)
- Derived savanna:Luvisols (24.9 Mha)
- Derived savanna:Nitosols (14.2 Mha)
- Derived savanna:Arenosols (14.0 Mha)

Classification Key

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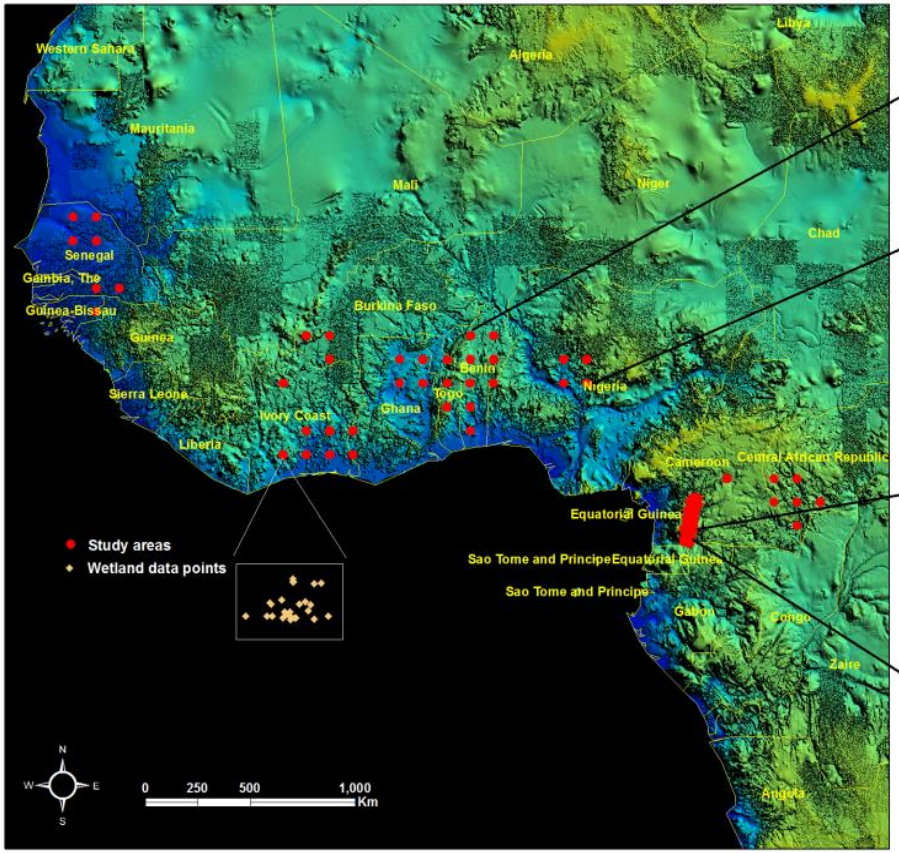
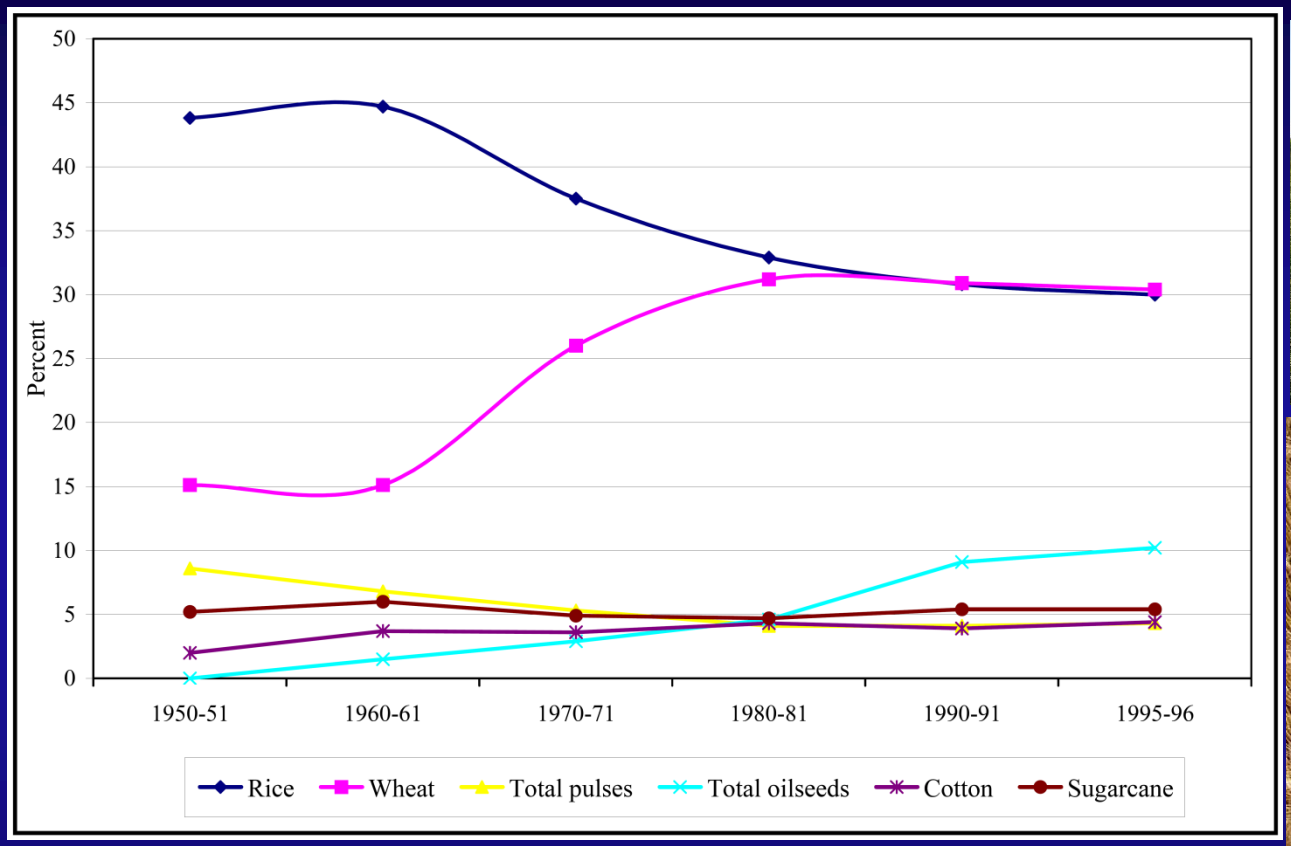
African Wetlands: Potential Source of Agricultural Development



However, we need to Determine Wetlands: (a) Best Suited for cultivation, and (b) Prioritized for Conservation

Grow Crops that Consume Less Water (e.g., More Wheat than Rice)



Currently, India produces about 93 million tonnes of rice per year requiring water of 178 km^3. If we convert 50% of rice area to wheat, we will save about 45 km^3 (45000000000000 liters or 45 trillion liters of water).

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Other measures: Reduce individual and National Waterfootprint

		litres
A. Vegetarian		
Wheat	1 kg	900
Rice	1 kg	1912
Barley	1 kg	1300
Potato	1 kg	900
Corn	1 kg	900
Bread	1 slice	40
Apple	1 apple	70
Cheese	1 kg	5000
B. Non-Vegetarian		
Beef	1 kg	15500
Goat meat	1 kg	4000
Chicken	1	3900
Egg	1 egg	200
C. Beverage		
Coffee	1 cup	140
Tea	1	30
Wine	1 glass	120
Beer	1 glass	75

Water footprint (individual)

Global = 1240 m^3\yr\person
USA = 2480 m^3\yr\person
China = 700 m^3\yr\person
India = 980 m^3\yr\person

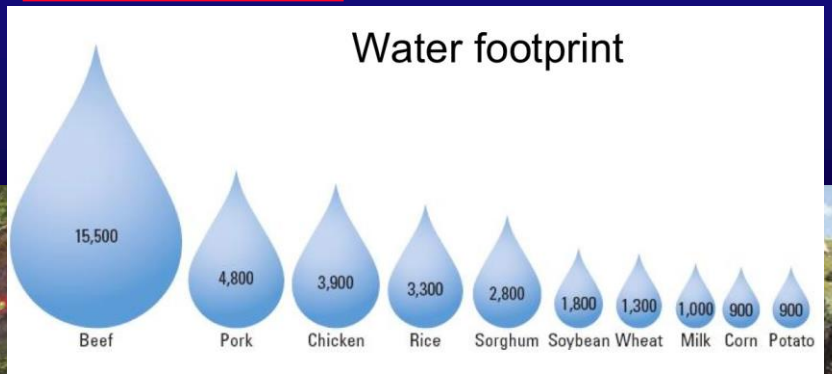
Countries with highest water footprint:

India = 987 trillion cubic meters per year
China = 883 trillion cubic meters per year
USA = 696 trillion cubic meters per year
Russia = 270 trillion cubic meters per year
Indonesia = 269 trillion cubic meters per year
Nigeria = 248 trillion cubic meters per year
Brazil = 233 trillion cubic meters per year

Note: Water foot print can depend on what you produce where (e.g., Virtual water content of cotton will be 5,404 m3/ton if produced in China but 21,563 m3/ton if produced in India.)

Source: http://www.waterfootprint.com

Hoekstra, A. Y and Chapagain, A. K., 2007. Water footprints of nations: Water use by people as a function of their consumption pattern. Water Resource Management, 21: 35-48.



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Many other Measures

1. **Reduce waste:** anywhere between 20-35% of all food is wasted;
2. **Desalination:** okay for urban water use, too costly for irrigation;
3. **Water re-use:** Reverse osmosis;
4. **Better management**: desalinization of croplands, precision farming, advanced water management techniques;

……..and many others.

Global Cropland Water Use

References

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State-of-Art of Global Croplands and their Water Use

Inter-linkages between Croplands, their Water use, and Food Security

American Society of Photogrammetry and Remote Sensing (ASPRS) PE&RS special issue on Global Croplands. August 2012, Vol. 78, No. 8. Guest editor: Thenkabail

Thenkabail P.S., Knox J.W., Ozdogan, M., Gumma, M.K., Congalton, R.G., Wu, Z., Milesi, C., Finkral, A., Marshall, M., Mariotto, I., You, S. Giri, C. and Nagler, P. 2012. Assessing future risks to agricultural productivity, water resources and food security: how can remote sensing help?. Photogrammetric Engineering and Remote Sensing, August 2012 Special Issue on Global Croplands: Highlight Article. Accepted. In press.

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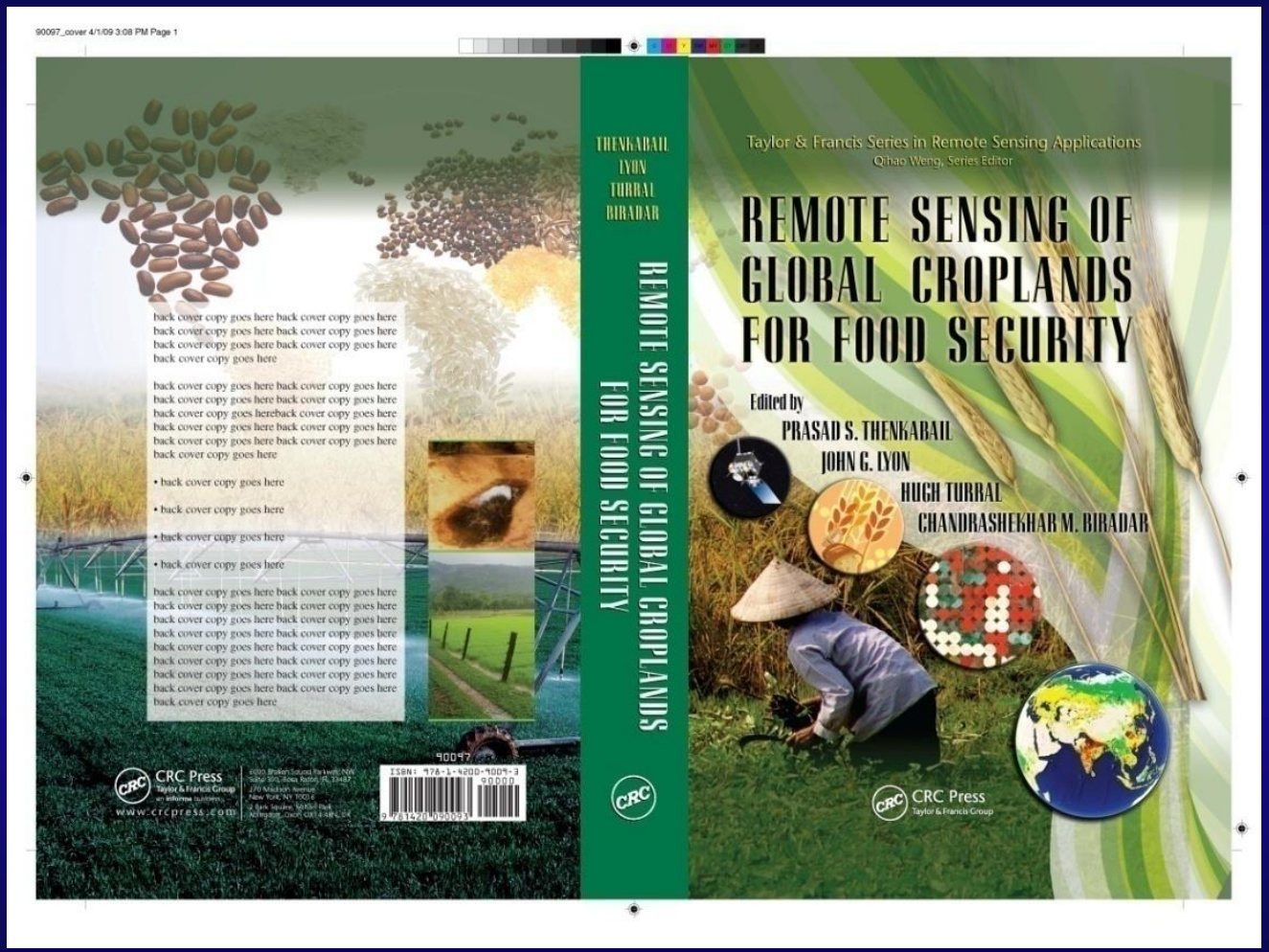
Publications

Book



Thenkabail. P., Lyon, G.J., Turral, H., and Biradar, C.M. 2009. Book entitled: "**Remote Sensing of Global Croplands for Food Security**" (CRC Press- Taylor and Francis group, Boca Raton, London, New York. Pp. 556 (48 pages in color). **Published in June, 2009.**

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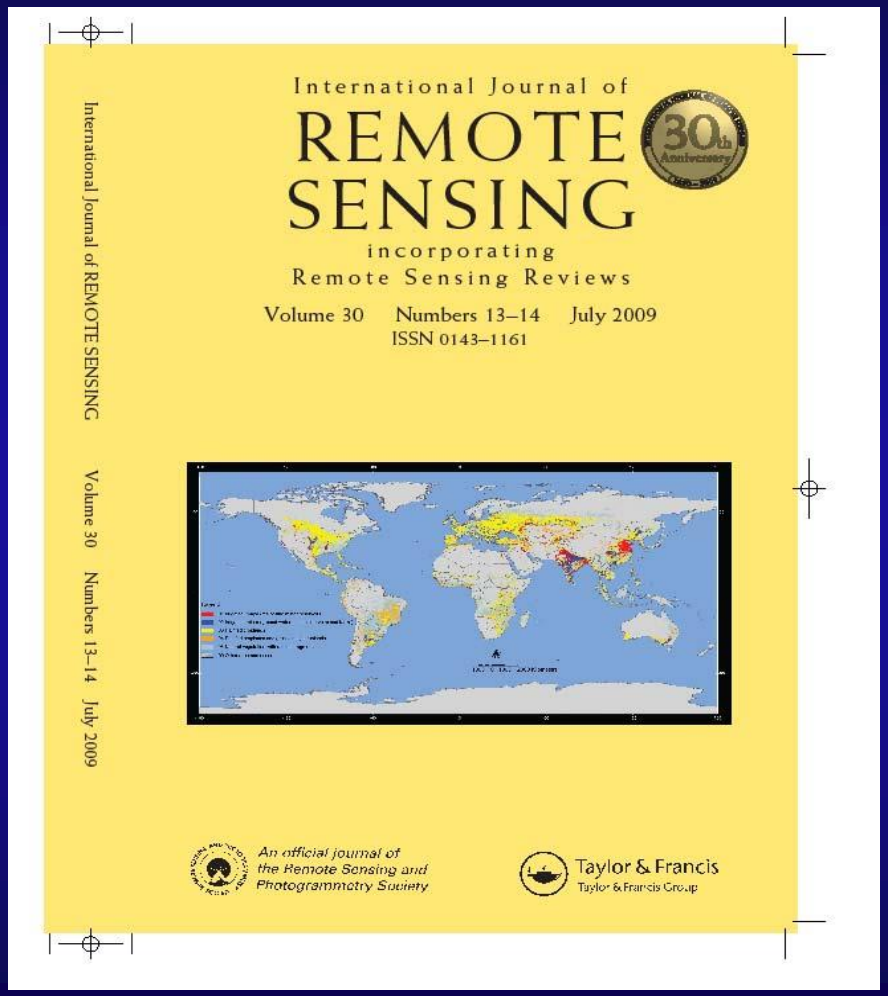
Publications

Peer review Journal Articles



Thenkabail, P.S., Biradar C.M., Noojipady, P., Dheeravath, V., Li, Y.J., Velpuri, M., Gumma, M., Reddy, G.P.O., Turral, H., Cai, X. L., Vithanage, J., Schull, M., and Dutta, R. 2009. **Global irrigated area map (GIAM), derived from remote sensing, for the end of the last millennium. International Journal of Remote Sensing**. 30(14): 3679-3733. July, 20, 2009.

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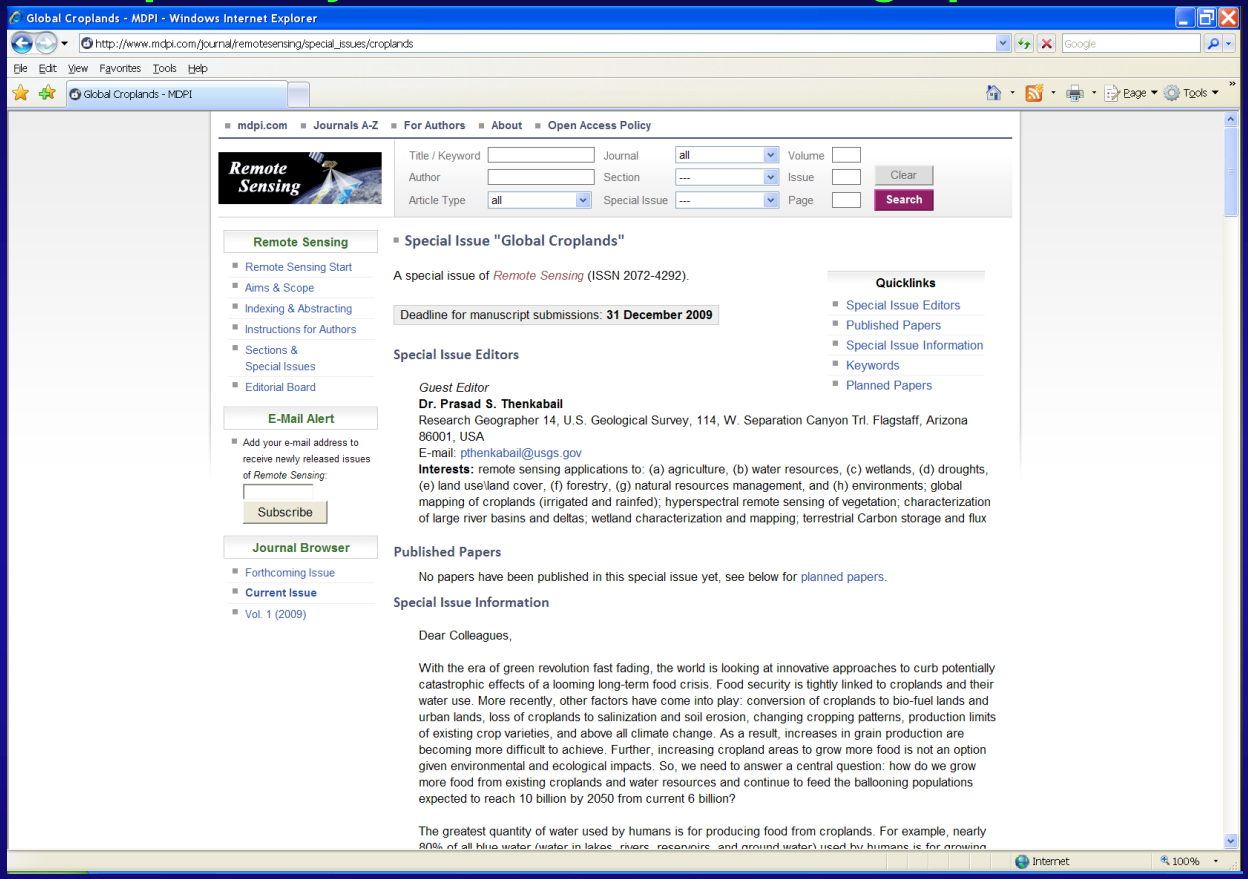
Publications

Guest Edit a Special Issue on “Global Croplands” for Journal Remote Sensing

http://www.mdpi.com/journal/remotesensing/special_issues/croplands



A comprehensive paper on the subject entitled: “*A Holistic View of Global Croplands and Their Water Use for Ensuring Global Food Security in the Twenty-First Century through Advance Remote Sensing and Non-Remote Sensing Approaches*” (in review)

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Remote Sensing of Global Croplands for Food Security

Data, Products, Algorithms, Documentations, Manuscripts

1. Global food security support-analysis data @ 30 m (GFSAD30) web site

http://geography.wr.usgs.gov/science/croplands/index.html

2. Croplands.org for data browsing
http://www.croplands.org/

3. LP DAAC data and products on global croplands
http://geography.wr.usgs.gov/science/croplands/products.html#LPDAAC

4. Google Earth Engine (GEE) global croplands
http://geography.wr.usgs.gov/science/croplands/products.html#LPDAAC