Remote Sensing of Global Croplands for Food Security
Overview of Today’s Public Lecture
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
Context

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

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

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

India got 48 year record unseasonal rains in March, 2015 resulting in crop damage of about 200 million US dollars.
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

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.
How did we Manage all these Years?

....especially when population grew from 3 to 7 billion in last 50 years
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

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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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!

1. Yield increased dramatically

2. Cropping intensity increased

3. Irrigation took over

4. Irrigated areas expanded dramatically

….also cropland management involving herbicides, pesticides, fertilizers, drainage......

combination of these factors lead to green revolution
Global Croplands and their Water Use for Food Security in the 21st Century

Global Food Production During the Green Revolution Era

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

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

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

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, Nobel laureate, World Food Prize and father of Green Revolution.

Norman Borlaug and M.S. Swaminathan, two pillars of Green Revolution. Photo credit: M.S. Swaminathan Foundation
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Global Food Production During the Green Revolution Era

Map Source: Eric deCarbonnel

Sources: USDA, IFRPI, FAO
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

BMI > 30 : 300 million
BMI > 25 : 1.5 billion
BMI > 23 : 1.7 billion

Source: WHO

Overnourished: ~1.5 billion

BMI > 30 : 300 million
BMI > 25 : 1.5 billion
BMI > 23 : 1.7 billion

Source: WHO

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

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

Current Global Population Density (people/km$^2$)

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

At present, 134 million come in per year and 56 million go out.
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Global Population Growth Simulation: 1950 through 2100

World Population 1950

World Population Animation created by Benjamin D. Hennig, University of Sheffield
Data Source: UN World Population Prospects 2010
www.viewsoftheworld.net
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Population Dynamics Scenario: 1950-2300

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

** = Not in top 19 countries in the year

Source: CIA factbook, 2006
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Daily Calories: A Global Picture

- **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

Source: FAO, 2010

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.

UN recommends 2350 calories per day.
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
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Increasing Cropland Areas Difficult

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

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

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

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)

Rainfed Areas: green water use

“Irregular Areas: blue water use” (water in river, lakes, reservoirs, and aquifer ground water). 470 million hectares (when you consider intensity) of irrigated areas uses the rest 30% of agricultural water use.

“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.

..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....
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Global Greenhouse Gas (GHG) Emissions will only Increase

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

36.9 billion Metric Tons (Gt) of CO₂ in 2014

CO₂ emissions:
Coal: 43%
Oil: 33%
Gas: 18%
Cement: 5.5%
Gas flaring 0.6%

Also, Methane is 22 times and N₂O 300 times more potent in trapping GHGs

...economic growth must pay for environmental/ecological damages
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

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

Environmental/Ecological Damage Can be Irreversible

...sustainable development for healthy livelihoods
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
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
History and 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…”.

Settled agriculture = 23,000 years
Irrigated agriculture = 10,000 years
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

History and Current State of Global Croplands

4000 years
3000 BC to 1000 AD

Past 500 years
1500 AD to 2000 AD

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

Goldewijk et al., 2011

~1.5 to 1.7 billion ha. (~10.3 to 12% of total land area)
Global Food Security-support Data @ 30 m (GFSAD30) Project
GCE 1km Multi-study Crop Mask (aka GCE V1.0)


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.

Global Food Security-support Data @ 30 m (GFSAD30) Project
GCE 1km Multi-study Crop Mask (aka GCE V1.0)


~2.3 billion hectares full pixel area (FPAs) with 34% irrigated and 66% rainfed.
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

Global Agricultural Cropland Monitoring System

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

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

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

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area, 1000 km²</th>
<th>Relative Fraction, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>4,028</td>
<td>22</td>
</tr>
<tr>
<td>Maize</td>
<td>2,271</td>
<td>13</td>
</tr>
<tr>
<td>Rice</td>
<td>1,956</td>
<td>11</td>
</tr>
<tr>
<td>Barley</td>
<td>1,580</td>
<td>9</td>
</tr>
<tr>
<td>Soybeans</td>
<td>927</td>
<td>5</td>
</tr>
<tr>
<td>Pulses</td>
<td>794</td>
<td>4</td>
</tr>
<tr>
<td>Cotton</td>
<td>534</td>
<td>3</td>
</tr>
<tr>
<td>Potatoes</td>
<td>501</td>
<td>3</td>
</tr>
<tr>
<td>Sorghum</td>
<td>501</td>
<td>3</td>
</tr>
<tr>
<td>Millet</td>
<td>331</td>
<td>2</td>
</tr>
<tr>
<td>Sunflower</td>
<td>290</td>
<td>2</td>
</tr>
<tr>
<td>Rye</td>
<td>288</td>
<td>2</td>
</tr>
<tr>
<td>Rapeseed/canola</td>
<td>283</td>
<td>2</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>265</td>
<td>1</td>
</tr>
<tr>
<td>Groundnuts/peanuts</td>
<td>247</td>
<td>1</td>
</tr>
<tr>
<td>Cassava</td>
<td>235</td>
<td>1</td>
</tr>
<tr>
<td>Sugar beets</td>
<td>154</td>
<td>1</td>
</tr>
<tr>
<td>Oil palm fruit</td>
<td>72</td>
<td>&lt;1</td>
</tr>
<tr>
<td><strong>Total of major 18 crops</strong></td>
<td><strong>15,256</strong></td>
<td><strong>85</strong></td>
</tr>
<tr>
<td><strong>Others</strong></td>
<td>2664</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total cropland</strong></td>
<td>17,920</td>
<td>100</td>
</tr>
</tbody>
</table>

70% area by 8 crops

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

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

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

Legend
- Irrigated, Major (major and minor reservoirs)
- Irrigated, Minor (ground water, small reservoirs, tanks)
- Rainfed croplands
- Rainfed croplands and grasslands/shrublands
- Natural vegetation with rainfed fragments

Total Croplands: 1.53-1.794 billion hectares

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

Thenkabail et al. 2011, 2009a, 2009b
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. Year 2000.

Thenkabail and Gumma, 2012
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

Thenkabail and Gumma, 2012

Thenkabail and Gumma, 2012
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.
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

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

Rice crop in India: Year 2000

GFSAD30: NASA MEaSUREs Project on Global Food Security
Key Products for the Entire World @ 30m (Landsat + MODIS + secondary)
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”)

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

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

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

Opportunities and Challenges for 
Advancing Accurate Cropland Maps and Statistics: Need for Time-series Data
Rice map of South Asia for year 2010-11 using MODIS 250 m time-series Satellite Imagery

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

Mapping Crop Types of South Asia using EO Data


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.


6 dominant crops of the world encompass ~60% of total cropland areas

Thenkabail and Gumma, 2012
GCE 30m Crop Dominance (aka GCE V3.0) @ nominal 30m
Study Areas Splitting the World with sub-Teams

LANDSAT scenes

Richard/Teki/Prasad/Pardha/Giri (North America)

Aparna/Mutlu/Prasad/Giri (Europe & Middle East)

Pardha/Prasad/Jun/Giri (Asia & Australia)

Jun/Cristina/Prasad/Pardha/Mutlu/Giri (South America & Africa)
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) #

* For all the landmass, except Antarctica continent
# Further drastic reduction is possible if we consider only areas mapped as irrigated and rainfed in GIAM and GMRCA

Each reflectance image is 4 times by volume of a DN image
Web-enabled (free) Landsat Data and Rapid Generation Products via Supercomputers
NASA AMES NEX supercomputer and Google Earth Engine to Enable Computing Power

~ 4900 Landsat image tiles where croplands exists to some degree, at times a small patch

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...)

Multiple bands displayed in FCC

NDVI
GFSAD30
GCE 250m Crop Dominance (aka GCE V2.0) for Africa

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.
Parallel K-means Clustering Algorithm

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

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

\[
\text{kmeans_clustering}() \\
\begin{align*}
1 & \text{while } \delta/N > \text{threshold} \\
2 & \delta \leftarrow 0 \\
3 & \text{for } i \leftarrow 0 \text{ to } N-1 \\
4 & \quad \text{for } j \leftarrow 0 \text{ to } K-1 \\
5 & \quad \quad \text{distance} \leftarrow \| \text{objects}[i] - \text{clusters}[j] \| \\
6 & \quad \quad \text{if } \text{distance} < d_{\text{min}} \\
7 & \quad \quad \quad d_{\text{min}} \leftarrow \text{distance} \\
8 & \quad \quad n \leftarrow j \\
9 & \quad \quad \text{if } \text{membership}[i] \neq n \\
10 & \quad \quad \delta \leftarrow \delta + 1 \\
11 & \quad \quad \text{membership}[i] \leftarrow n \\
12 & \quad \quad \text{new_clusters}[n] \leftarrow \text{new_clusters}[n] + \text{objects}[i] \\
13 & \quad \quad \text{new_cluster_size}[n] \leftarrow \text{new_cluster_size}[n] + 1 \\
14 & \quad \text{for } j \leftarrow 0 \text{ to } K-1 \\
15 & \quad \quad \text{clusters}[j][*] \leftarrow \text{new_clusters}[j][*] / \text{new_cluster_size}[j] \\
16 & \quad \quad \text{new_clusters}[j][*] \leftarrow 0 \\
17 & \quad \quad \text{new_cluster_size}[j] \leftarrow 0 \\
\end{align*}
\]

Output clustering results


Credits: Jun Xiong et al.
Example of 1 of the 500 Clusters showing 11 year MODIS NDVI Times series in Africa

Normalized frequency of NDVI value

Ground data collected by team for all classes

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

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

http://www.croplands.org/

For wide solicitation of ground data


Credits: Jun Xiong et al.
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


Credits: Jun Xiong et al.
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


Credits: Jun Xiong et al.
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.

Credits: Pardha Teluguntla et al.
Automated Cropland Classification Algorithm (ACCA) for Croplands, Irrigated, Rainfed

Algorithm Development based on MODIS, Landsat, and Secondary Data
1. Existing ground data has been harmonized;
2. New ground data is being collected;
3. Uploading ground data on GEE for synthesis and generating cropland signatures;
4. Development of a ground data App in progress

http://www.croplands.org/

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
Recent (December, 2014 and January, 2015) Field Data in India; ICRISAT (Dr. Gumma)
Role of Global Cropland Water Use in Ensuring Global Food Security
Just 4 countries use 52% of cropland water use: India: 684 km$^3$/yr, China: 364 km$^3$/yr, USA: 197 km$^3$/yr, and Pakistan: 172 km$^3$/yr. However, per capita water use in USA is: $\sim 2500$ m$^3$/yr/person whereas in India $\sim 1000$ m$^3$/yr/person and China $\sim 700$ m$^3$/yr/person.

Remember that 92% of all global human water use goes towards agriculture for food production (PNAS, Hoekstra et al., 2012).
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 aquifer 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 the end of the last millennium.

<table>
<thead>
<tr>
<th>Blue water use by Irrigated crops km/yr</th>
<th>Green water use by irrigated crops km/yr</th>
<th>Green water use by Rainfed crops km/yr</th>
<th>Total water use by irrigated and rainfed crops km/yr</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1180</td>
<td>919</td>
<td>4586</td>
<td>6685</td>
<td>Siebert and Döll (2009)</td>
</tr>
<tr>
<td>1800</td>
<td>-</td>
<td>5000</td>
<td>6800</td>
<td>Falkenmark and Rockström (2006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7500</td>
<td>Postel (1998)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Blue water use</th>
<th>Green water use by irrigated crops</th>
<th>Green water use by rainfed crops</th>
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<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated crops km/yr</td>
<td>km/yr</td>
<td>km/yr</td>
<td>km/yr</td>
<td></td>
</tr>
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</table>

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

4586 to 5000 km³/yr water used for agriculture (irrigated+rainfed)
Table 2. Global blue water and green water use by agricultural crops for roughly at end of last millennium.

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<thead>
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<th>Blue water use by Irrigated crops km/yr</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>7500</td>
<td>Postel (1998)</td>
</tr>
</tbody>
</table>
Landsat Data for Mapping
Irrigated Areas + Rainfed Areas

Landsat Data highlighting minor irrigation from small tanks in India
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

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

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

~20% of world’s water use is virtual


Red: water importers; Green: water Exporters.

Note: 1 Gm³/yr (billion cubic meter per year)
Global Croplands and their Water Use for Food Security in the 21st Century

SOLUTIONS and WAY FORWARD
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 \( \text{N}_2\text{O} \) and 50% of \( \text{CH}_4 \)

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

...so, certainly NOT a solution.
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;

Many countries and regions are already water stressed

Source: IWMI

Proportion of water used for agriculture is already very high in many Countries

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

Blue Revolution: Single Biggest Opportunity

Green revolution has virtually ended: the focus was on increasing productivity per unit of land (kg/m²).

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/m³) 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.
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

Current waste due to low WP

Grow more food

From less water

Create “new water” banks

Feed populations

Sustain ecosystems

Sustain fish and wildlife

84% of California’s human water use goes for 10 million acres of irrigation

Uzbekistan: ~80% of the area is low or very low crop water productivity.
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

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

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

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area, 1000 km²</th>
<th>Relative Fraction, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>4,028</td>
<td>22</td>
</tr>
<tr>
<td>Maize</td>
<td>2,271</td>
<td>13</td>
</tr>
<tr>
<td>Rice</td>
<td>1,956</td>
<td>11</td>
</tr>
<tr>
<td>Barley</td>
<td>1,580</td>
<td>9</td>
</tr>
<tr>
<td>Soybeans</td>
<td>927</td>
<td>5</td>
</tr>
<tr>
<td>Pulses</td>
<td>794</td>
<td>4</td>
</tr>
<tr>
<td>Cotton</td>
<td>534</td>
<td>3</td>
</tr>
<tr>
<td>Potatoes</td>
<td>501</td>
<td>3</td>
</tr>
<tr>
<td>Sorghum</td>
<td>501</td>
<td>3</td>
</tr>
<tr>
<td>Millet</td>
<td>331</td>
<td>2</td>
</tr>
<tr>
<td>Sunflower</td>
<td>290</td>
<td>2</td>
</tr>
<tr>
<td>Rye</td>
<td>288</td>
<td>2</td>
</tr>
<tr>
<td>Rapeseed/canola</td>
<td>283</td>
<td>2</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>265</td>
<td>1</td>
</tr>
<tr>
<td>Groundnuts/peanuts</td>
<td>247</td>
<td>1</td>
</tr>
<tr>
<td>Cassava</td>
<td>235</td>
<td>1</td>
</tr>
<tr>
<td>Sugar beets</td>
<td>154</td>
<td>1</td>
</tr>
<tr>
<td>Oil palm fruit</td>
<td>72</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Total of major 18 crops</td>
<td>15,336</td>
<td>85</td>
</tr>
<tr>
<td>Others</td>
<td>2,066</td>
<td>15</td>
</tr>
<tr>
<td>Total cropland</td>
<td>17,402</td>
<td>100</td>
</tr>
</tbody>
</table>
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.

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

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)

But, will that result in marginalizing the subsistence farmer?
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
Africa is Growing @ Rapid Phase and so is its Agriculture

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

Source: “African Agriculture Goes Global”, National Geographic; July 2014
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

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

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

![Chart of Global Food Production](chart)

**Global Food Production:** ~ 4 billion tons/yr

**Global Food Waste:** ~ 1.3 billion tons/yr

Solutions to Overcome Waste

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

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

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-Saharan Africa and South/Southeast Asia, 460 kg/year.
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

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

African Wetlands: Potential Source of Agricultural Development

However, we need to determine wetlands: (a) best suited for cultivation, and (b) prioritized for conservation.
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).
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security
Other measures: Reduce individual and National Waterfootprint

<table>
<thead>
<tr>
<th>A. Vegetarian</th>
<th>litres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat 1 kg</td>
<td>900</td>
</tr>
<tr>
<td>Rice 1 kg</td>
<td>1912</td>
</tr>
<tr>
<td>Barley 1 kg</td>
<td>1300</td>
</tr>
<tr>
<td>Potato 1 kg</td>
<td>900</td>
</tr>
<tr>
<td>Corn 1 kg</td>
<td>900</td>
</tr>
<tr>
<td>Bread 1 slice</td>
<td>40</td>
</tr>
<tr>
<td>Apple 1 apple</td>
<td>70</td>
</tr>
<tr>
<td>Cheese 1 kg</td>
<td>5000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Non-Vegetarian</th>
<th>litres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef 1 kg</td>
<td>15500</td>
</tr>
<tr>
<td>Goat meat 1 kg</td>
<td>4000</td>
</tr>
<tr>
<td>Chicken 1</td>
<td>3900</td>
</tr>
<tr>
<td>Egg 1 egg</td>
<td>200</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C. Beverage</th>
<th>litres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coffee 1 cup</td>
<td>140</td>
</tr>
<tr>
<td>Tea 1</td>
<td>30</td>
</tr>
<tr>
<td>Wine 1 glass</td>
<td>120</td>
</tr>
<tr>
<td>Beer 1 glass</td>
<td>75</td>
</tr>
</tbody>
</table>

Water footprint (individual)

Global = 1240 m³ yr⁻¹ person
USA = 2480 m³ yr⁻¹ person
China = 700 m³ yr⁻¹ person
India = 980 m³ yr⁻¹ 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 footprint 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](http://www.waterfootprint.com)
Global Food Security in the 21st Century: Increasing Need of Cropland Areas and Agriculture Water for Food Security

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
State-of-Art of Global Croplands and their Water Use: Inter-linkages between Croplands, their Water use, and Food Security


Publications
Guest Edit a Special Issue on “Global Croplands” for Journal Remote Sensing
http://www.mdpi.com/journal/remotesensing/special_issues/croplands

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


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

3. LP DAAC data and products on global croplands

4. Google Earth Engine (GEE) global croplands