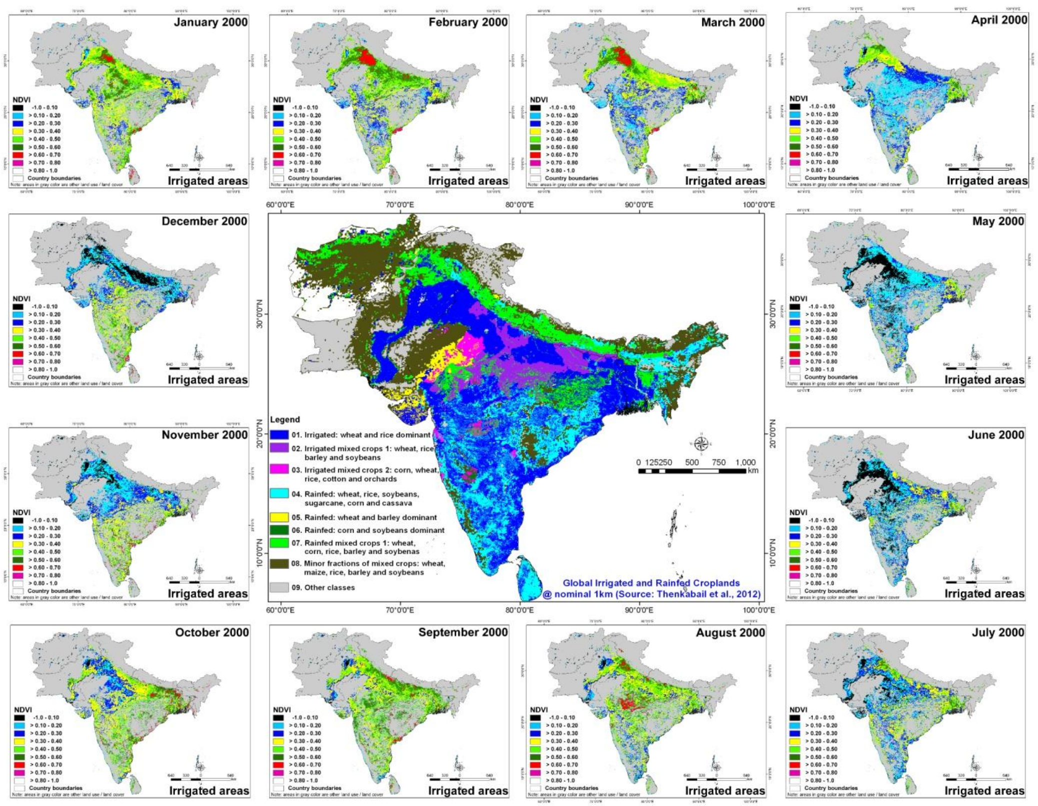
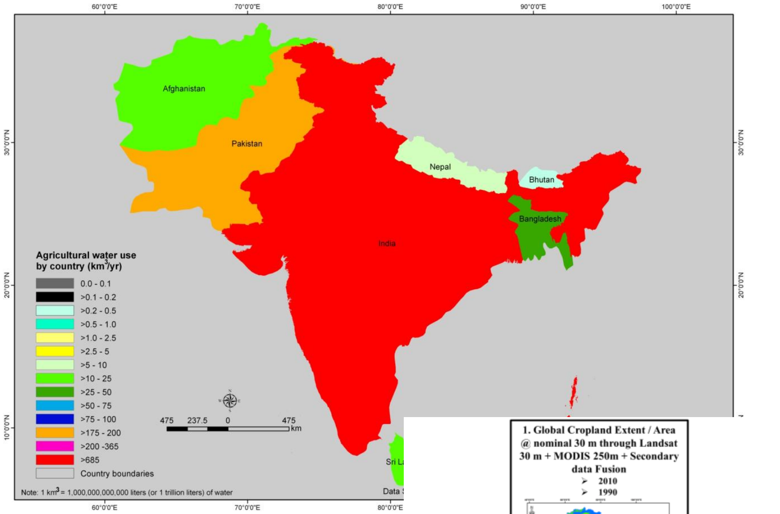
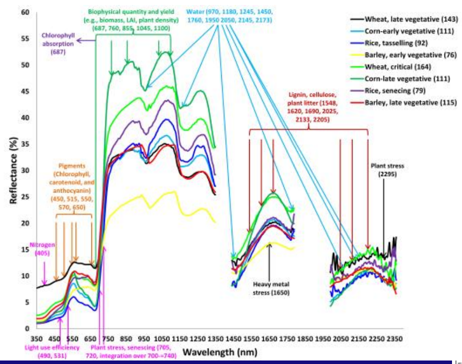
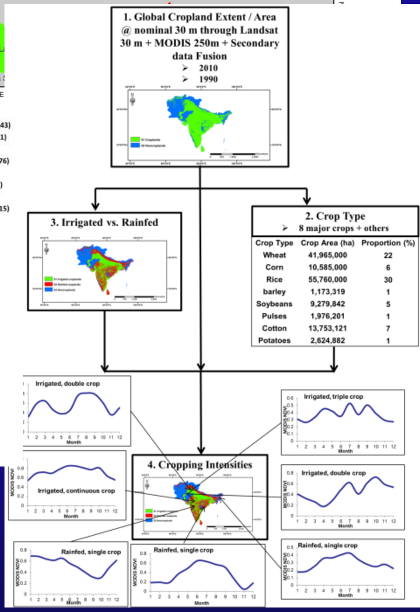
Cropland Mapping in South Asia

Advances in Earth Observation Data, Methods, and Approaches







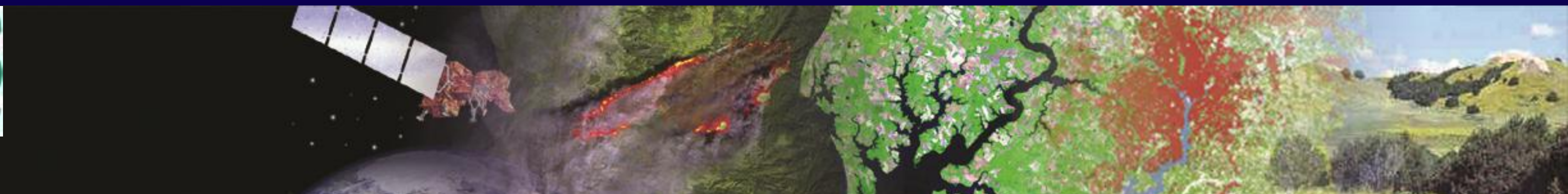


Crop Type	Crop Area (ha)	Proportion (%)
Wheat	41,965,000	22
Corn	10,585,000	6
Rice	55,760,000	30
barley	1,173,319	1
Soybeans	9,279,842	5
Pulses	1,976,201	1
Cotton	13,753,121	7
Potatoes	2,624,882	1

Prasad S. Thenkabail[1]

1 = U.S. Geological Survey (USGS), USA

January 10-14, 2013. NASA LCLUC Meeting @ the Karunya University, Coimbatore, Tamil Nadu, India.



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Importance, Context, Need

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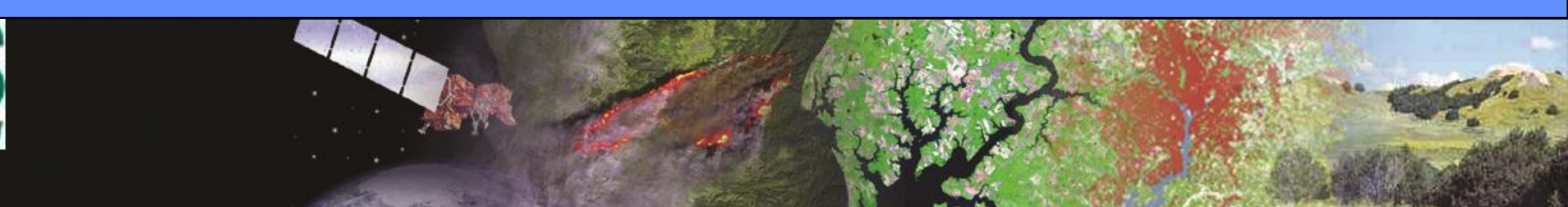
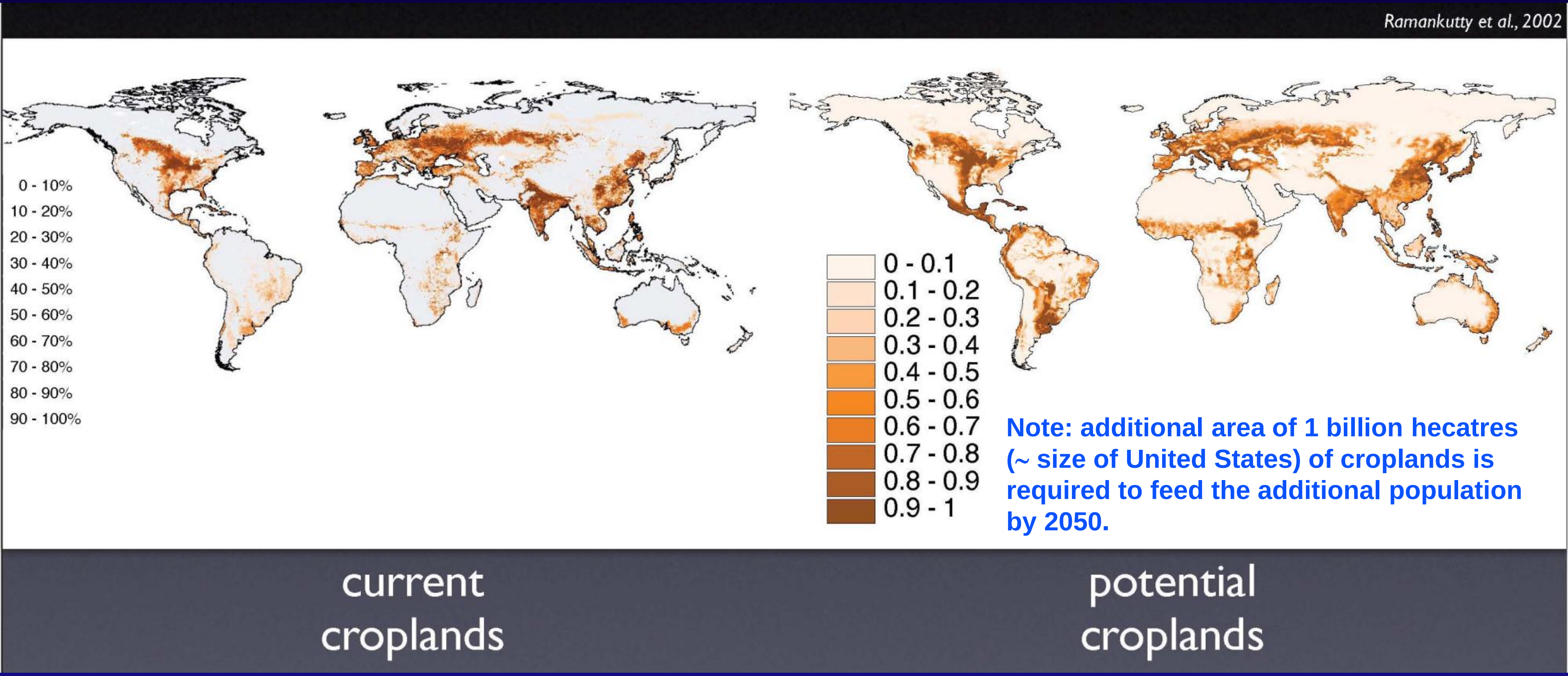
Addressing the Global Food Security Challenge

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. 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)**



Increasing Cropland Areas Difficult



..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

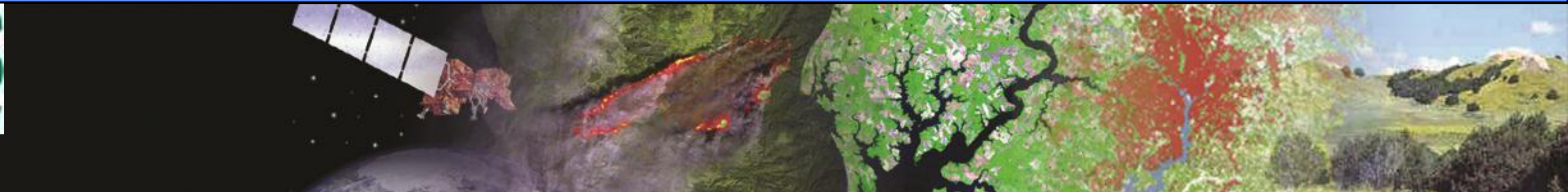
Addressing the Global Food Security Challenge

A critical and <u>urgent question</u> 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;**

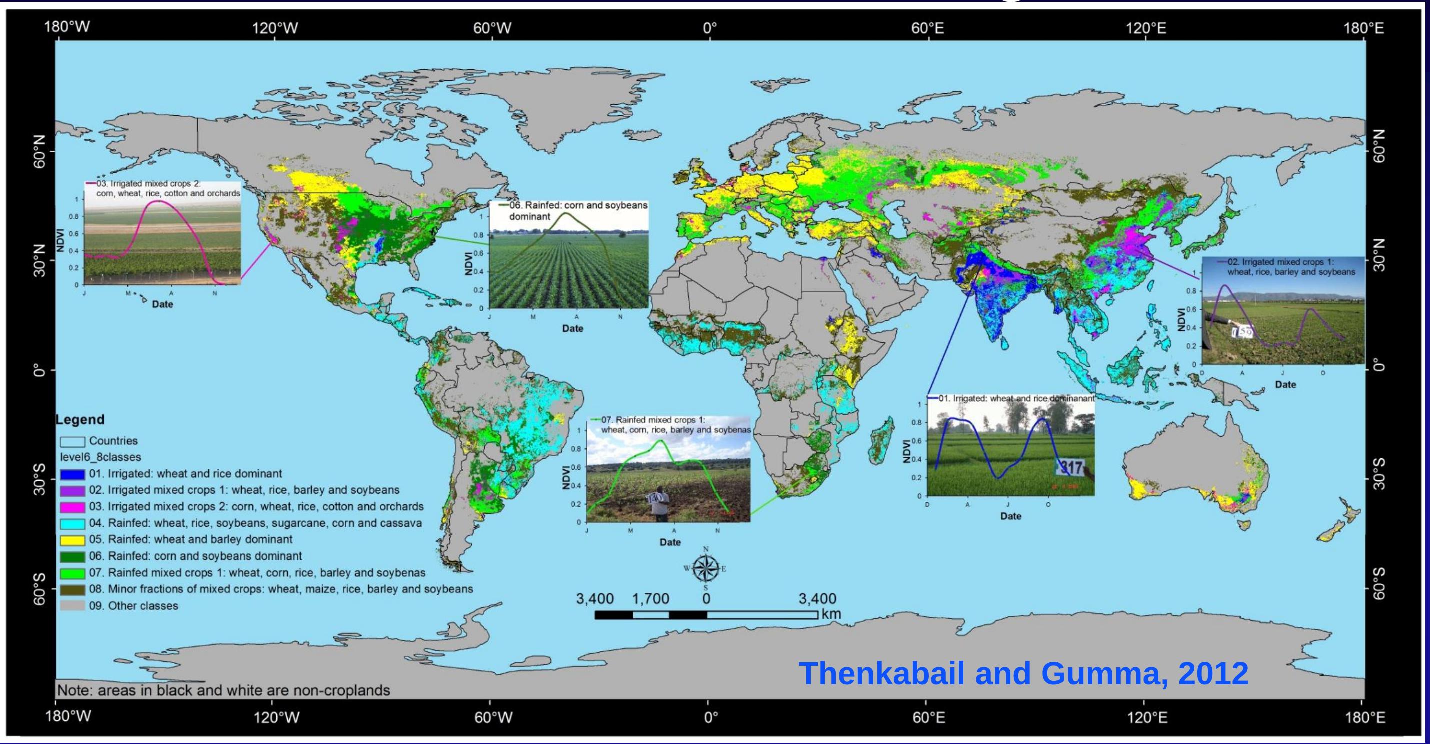
Indeed, an <u>even better question</u> to ask is how can we continue to feed the World's ballooning populations in the twenty-first century by

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)**



Global Cropland Area Database @ 30m (GCAD30)

Need for Multi-sensor High-resolution EO Data



The listed limitations are a major hindrance in accurate/reliable global, regional, and country by country water use assessments that in turn support crop productivity (productivity per unit of land; kg\m^2) studies, water productivity (productivity per unit of water; kg\m^3) studies, and food security analyses. The higher degrees of uncertainty in coarser resolution data are a result of an inability to capture fragmented, smaller patches of croplands accurately, and the homogenization of both crop and non-crop land within areas of patchy land cover distribution. In either case, there is a strong need for finer spatial resolution to resolve the confusion.

The coarse resolution cropland maps have many limitations:

- Absence of precise spatial location of the cropland areas;
- Uncertainties in differentiating irrigated areas from rainfed areas;
- Absence of crop types and cropping intensities;
- Inability to generate cropland maps and statistics, routinely; and
- Absence of dedicated web\data portal for dissemination cropland products.

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Croplands: Seven Key Products for Global Food Security Studies

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Global Cropland Area Database (GCAD30)

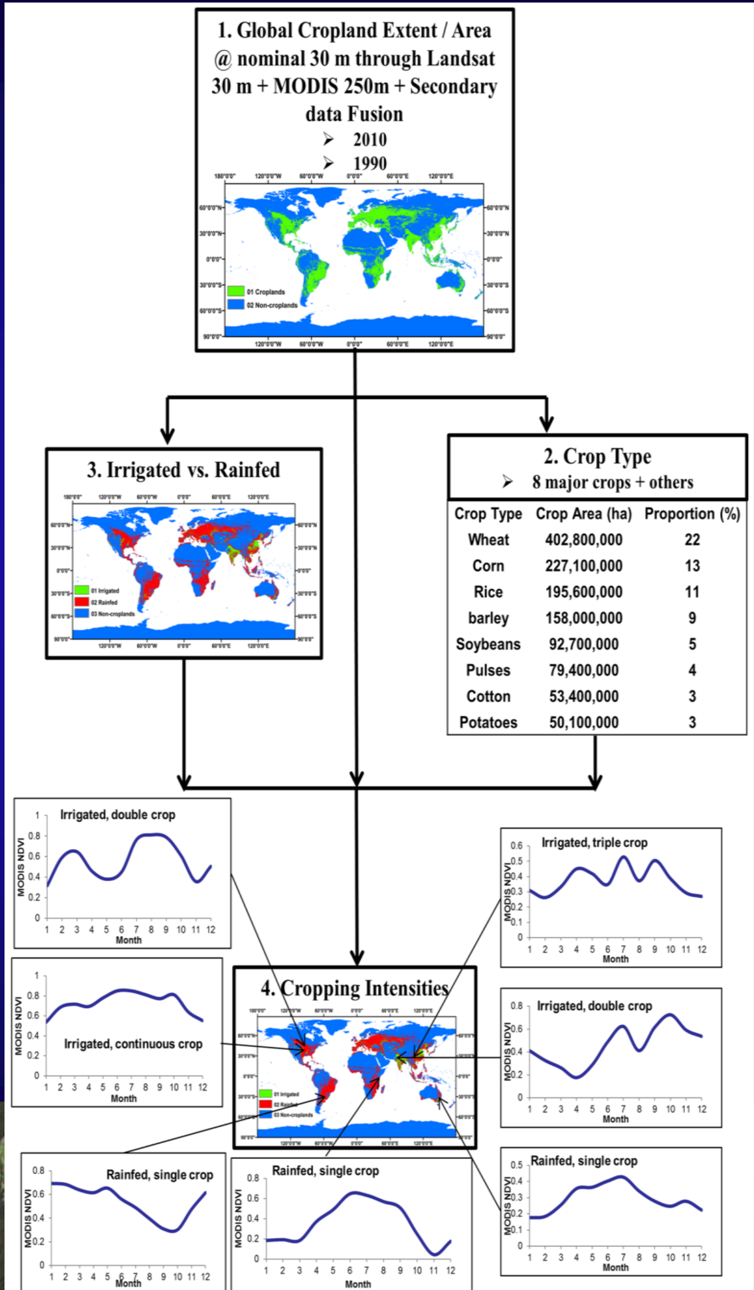
Seven Key Products from Earth Observation data: World

Five main products and 2 derived products most essential for global food security studies

1. Cropland extent\area;
2. Crop types (8 major crops + others);
3. Irrigated *versus* rainfed;
4. Cropping intensities (e.g., single, double, triple, and continuous cropping; and
5. Cropland change over space and time;

Once we have the above,

6. Crop productivity: productivity per unit of land; kg\m²,
7. water productivity: productivity per unit of water or “crop per drop”; kg\m³



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

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Global Cropland Area Database (GCAD30)

Seven Key Products from Earth Observation data: South Asia

Five main products and 2 derived products most essential for global food security studies

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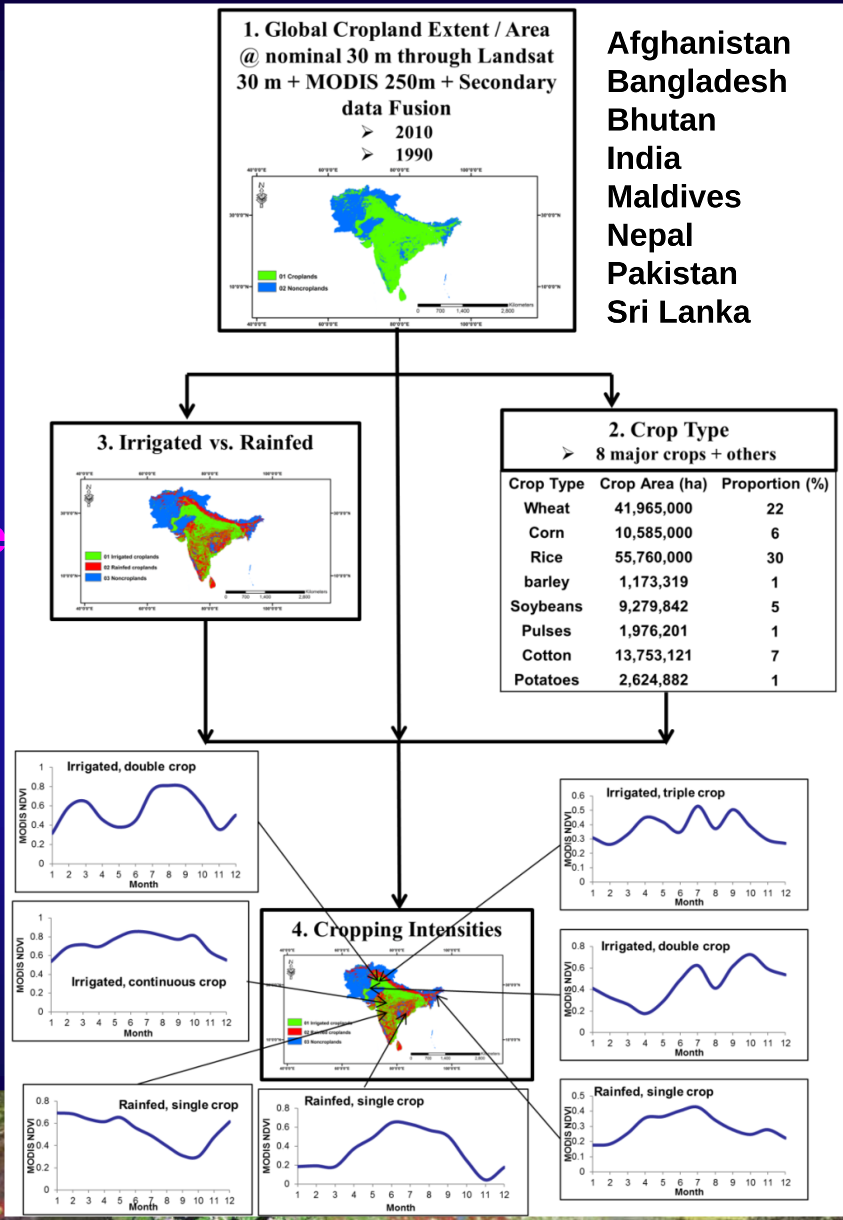
Afghanistan
Bangladesh
Bhutan
India
Maldives
Nepal
Pakistan
Sri Lanka



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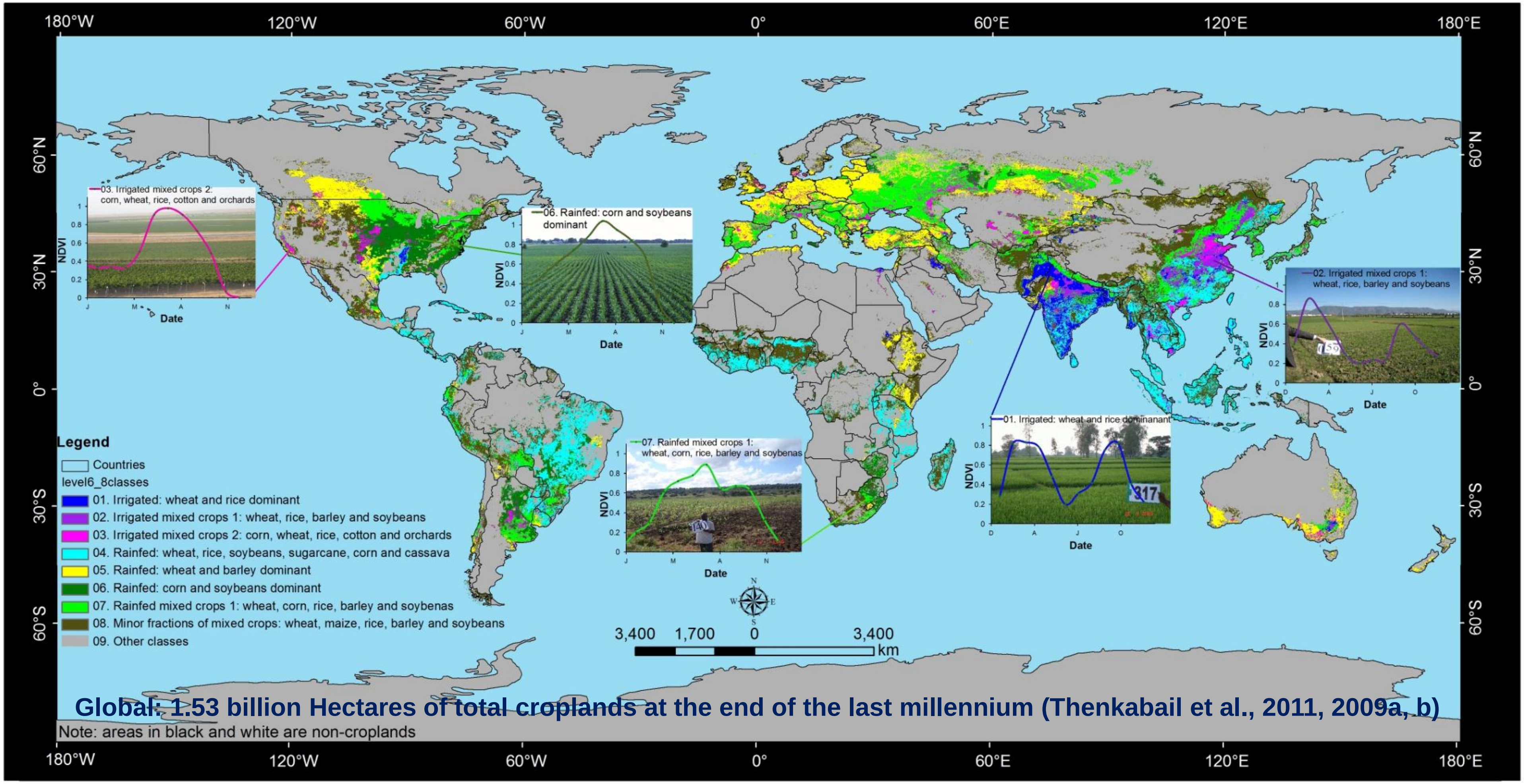
Croplands: Extent, Area

Global *versus* South Asia

Global Cropland Area Database (GCAD30)
Cropland Extent and Areas: World



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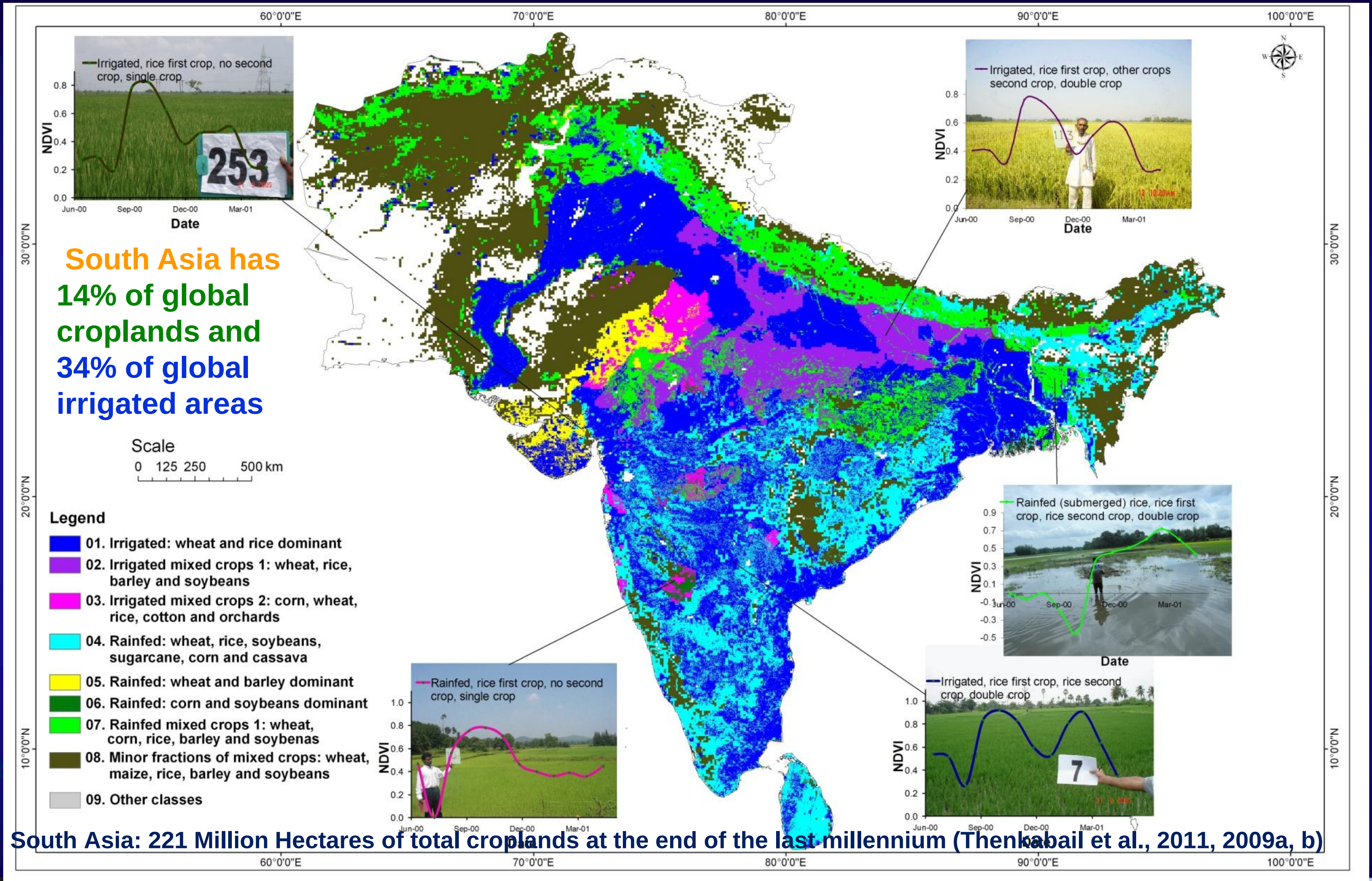
Global Cropland Area Database (GCAD30)

Cropland Extent and Areas: South Asia



South Asia: 221 Million Hectares of total croplands at the end of the last millennium (Thenkabail et al., 2011, 2009a, b)

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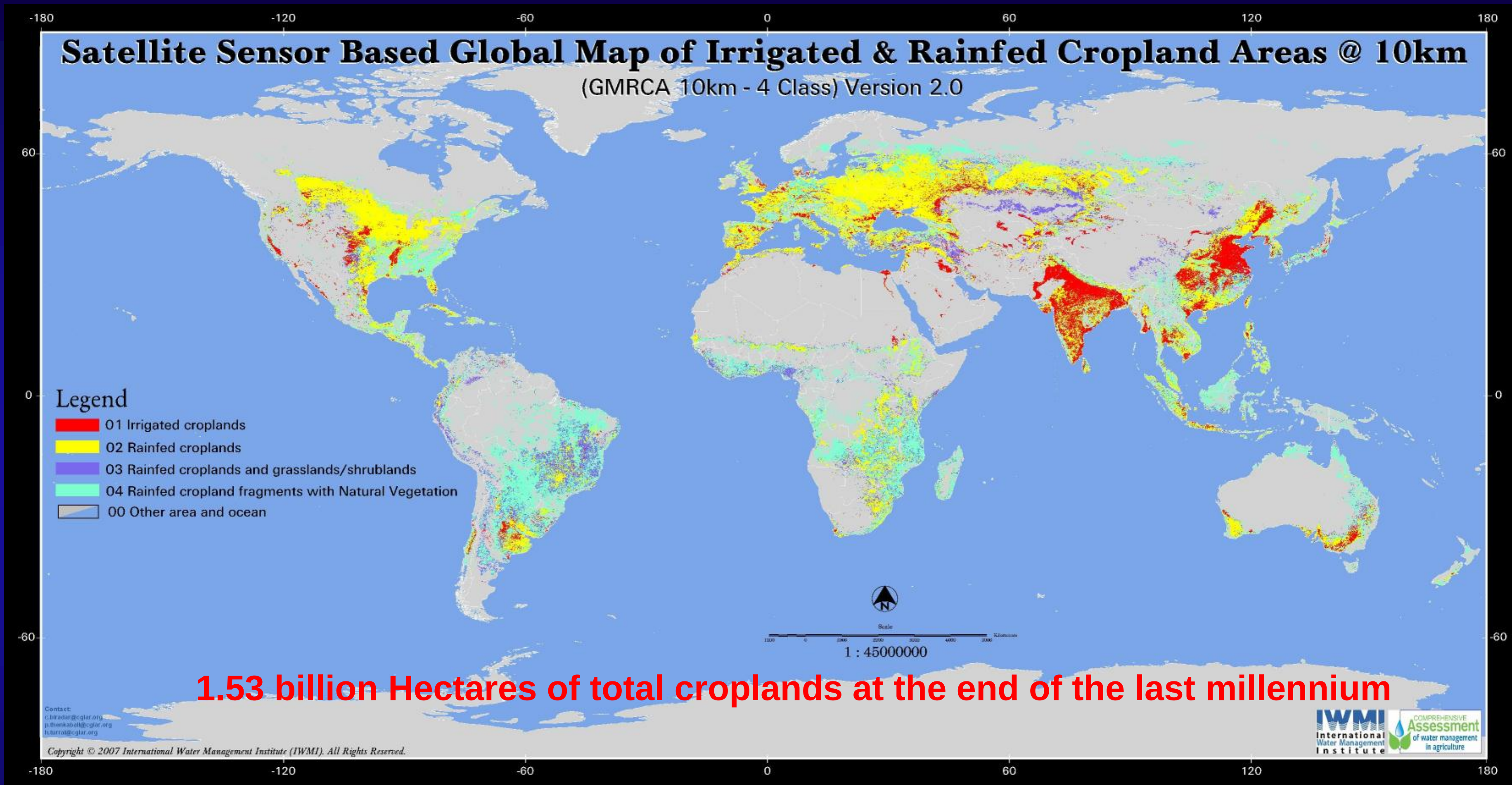
Croplands: Irrigated vs. Rainfed

Global *versus* South Asia

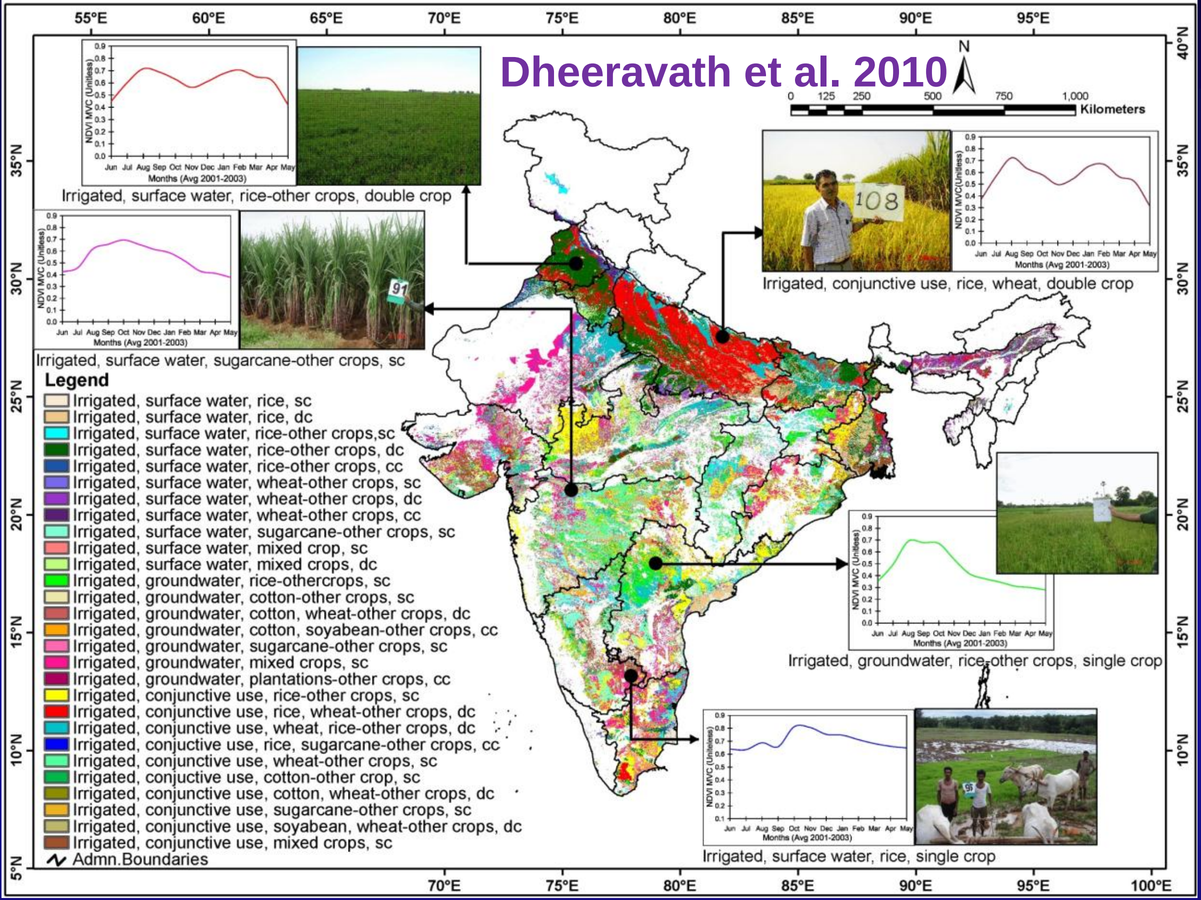
Global Cropland Area Database (GCAD30)

Irrigated *versus* Rainfed Croplands, Spatial Distribution: World



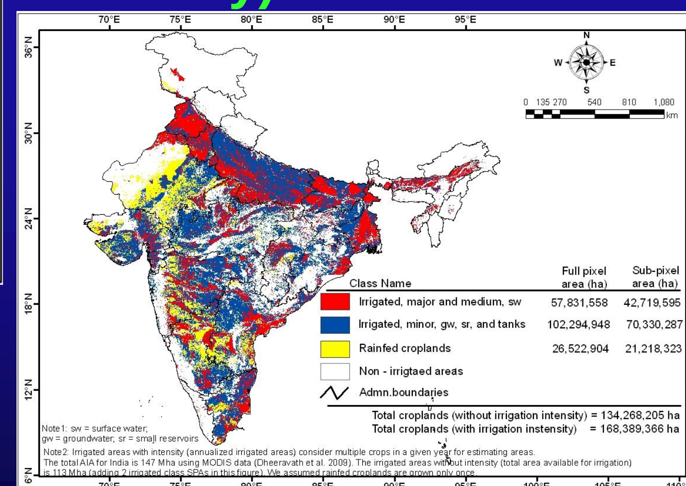
India's Irrigated Croplands @ Finer Resolution

Using MODIS 500m time-series for 2001-2003

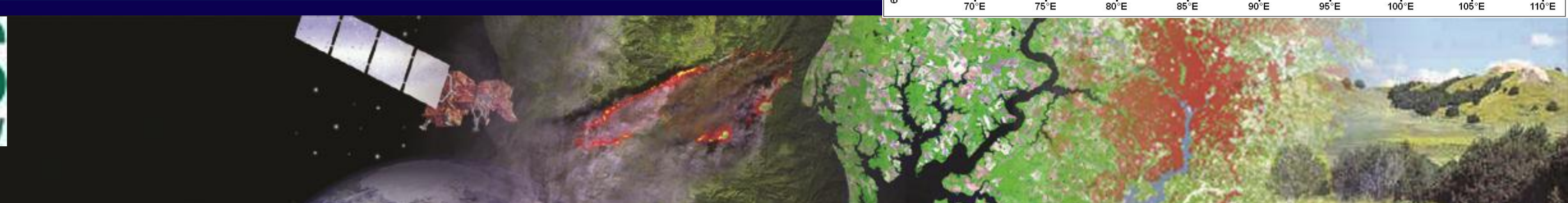


Irrigated Croplands of India = 113 Mha (annualized: season 1 + season 2 + continuous)

Croplands (irrigated + rainfed) of India = 170 Mha (includes irrigation intensity)



Dheeravath, V., Thenkabail, P.S., Chandrakantha, G, Noojipady, P., Biradar, C.B., Turral. H., Gumma, M.[1], Reddy, G.P.O., Velpuri, M. 2009. Irrigated areas of India derived using MODIS 500m data for years 2001-2003. ISPRS Journal of Photogrammetry and Remote Sensing. http://dx.doi.org/10.1016/j.isprsjprs.2009.08.004. in press. Corrected proof available online 22 September, 2009.



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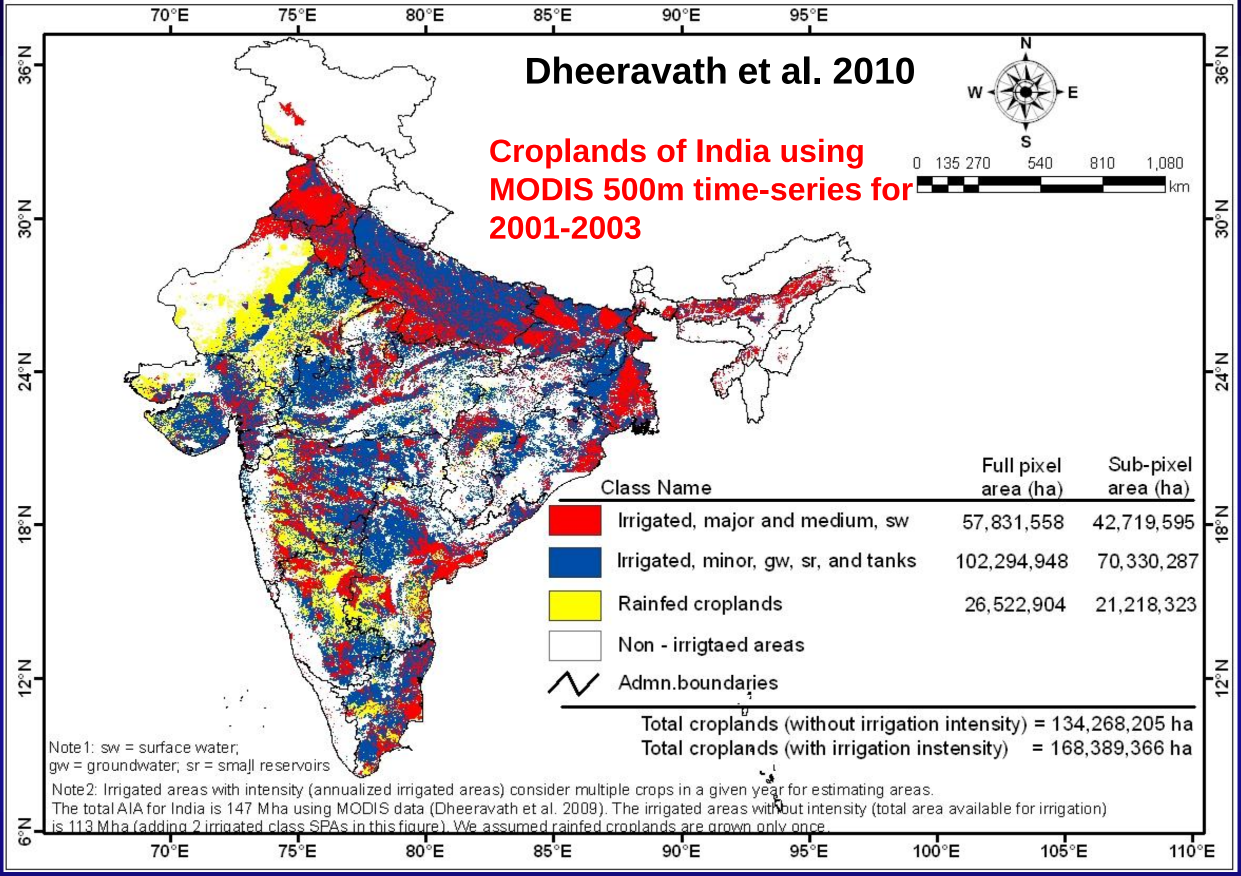
India's Croplands (irrigated + rainfed + permanent crops) @ Finer Resolution

Using MODIS 500m time-series for 2001-2003



Generally, most studies agree that about 52% (about 170 Mha) of India's geographic area (328.7 Mha) are croplands around year 2000.

But most studies disagree on the proportion of Irrigated versus rainfed

Dheeravath, V., Thenkabail, P.S., Chandrakantha, G, Noojipady, P., Biradar, C.B., Turral. H., Gumma, M.[1], Reddy, G.P.O., Velpuri, M. 2010. Irrigated areas of India derived using MODIS 500m data for years 2001-2003. ISPRS Journal of Photogrammetry and Remote Sensing. http://dx.doi.org/10.1016/j.isprsjprs.2009.08.004. 65(1): 42-59

Uncertainties in areas can still exist even with higher resolution due to: (a) definition, (b) methods, (c) need for even finer resolution.

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Global Cropland Area Database (GCAD30)

Irrigated *versus* Rainfed Croplands, Spatial Distribution: India

Sno	States/UTs	GIAM 10km Areas AIA	GIAM 500m Areas AIA	MoWR IPU Areas Major	MoWR IPU Areas Minor	MoWR IPU Areas IPU (Major+Minor)
		X 1000 ha	X 1000 ha	X 1000 ha	X 1000 ha	X 1000 ha
1	Andhra Pradesh	12874	13378	3052	3380	6432
2	Arunachal Pradesh	20	151	0	46	46
3	Assam	538	4103	174	245	419
4	Bihar	8433	9680	1715	2886	4601
5	Chhattisgarh	3193	3602	761	412	1173
6	Gujarat	8470	7858	1301	2762	4063
7	Haryana	3731	4959	1850	2275	4125
8	Himachal Pradesh	181	120	8	179	187
9	Jammu & Kashmir	503	485	169	340	509
10	Jharkhand	2242	2681	230	291	521
11	Karnataka	6394	7663	1845	1787	3632
12	Kerala	332	152	559	411	970
13	Madhya Pradesh	16121	15390	876	3500	4376
14	Maharashtra	12756	13020	2147	3955	6102
15	Manipur	38	51	111	27	138
16	Meghalaya	19	106	0	70	70
17	Orissa	4254	4943	1794	622	2416
18	Punjab	5129	6375	2486	5764	8250
19	Rajasthan	9649	10391	2314	3925	6239
20	Tamil Nadu	7339	6738	1549	2385	3934
21	Uttar Pradesh	22578	26780	6334	14075	20409
22	Uttaranchal	404	375	185	481	666
23	West Bengal	6833	7381	1527	1946	3473
	Total	**132,029**	**146,815**	**31,010**	**51,970**	**82,977**

Note: AIA = Annualized Irrigated Area; IPU = Irrigation Potential Utilized;
MOWR = Ministry of Water Resources

Table 1. Irrigated areas of major states of India compared between remote sensing derived approaches and national statistics (Dheeravath et al., 2010).

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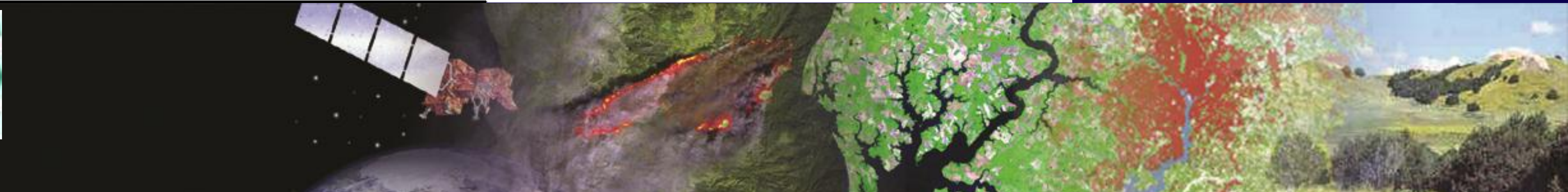

Croplands: Intensity

Global *versus* South Asia

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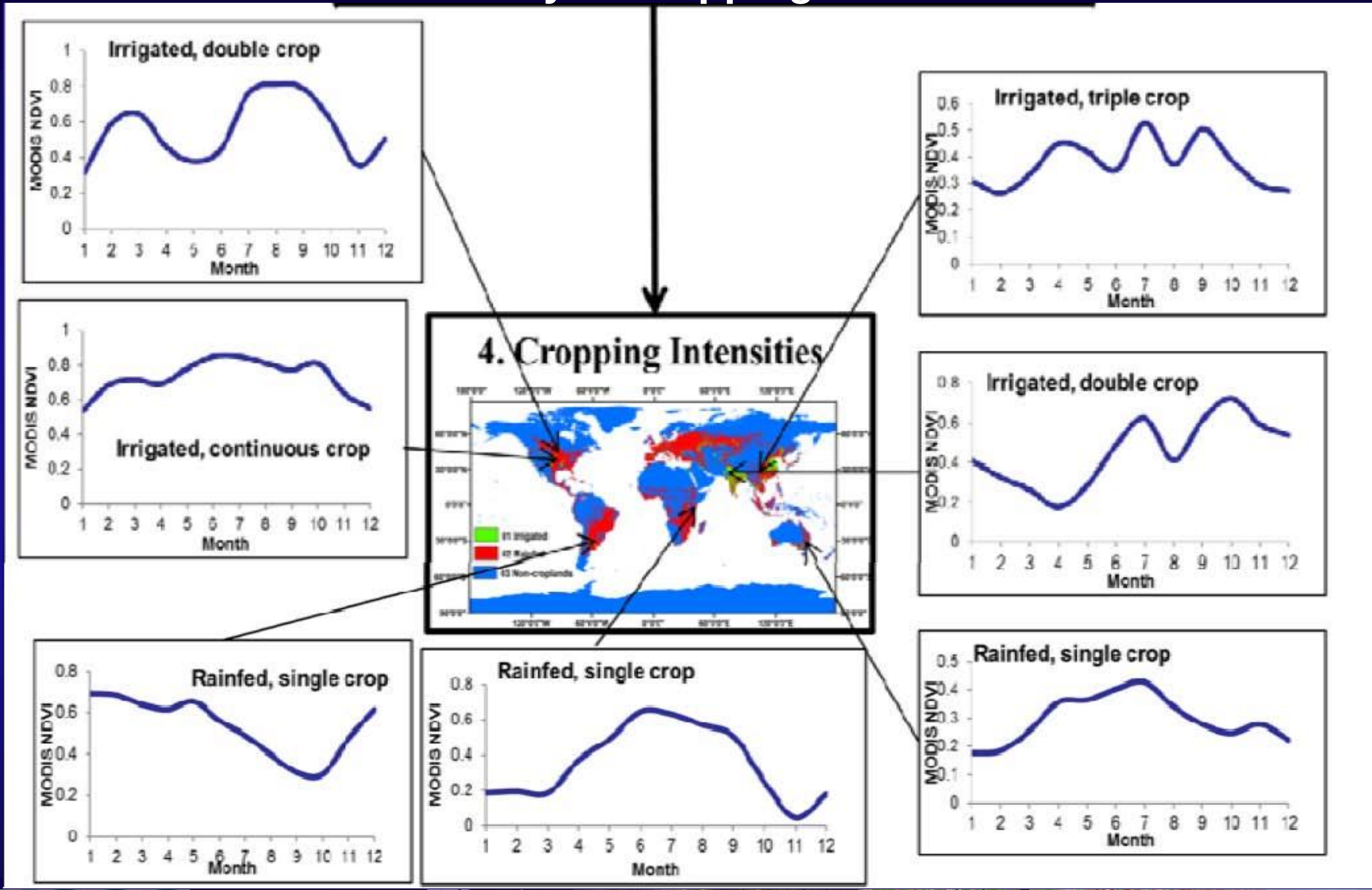
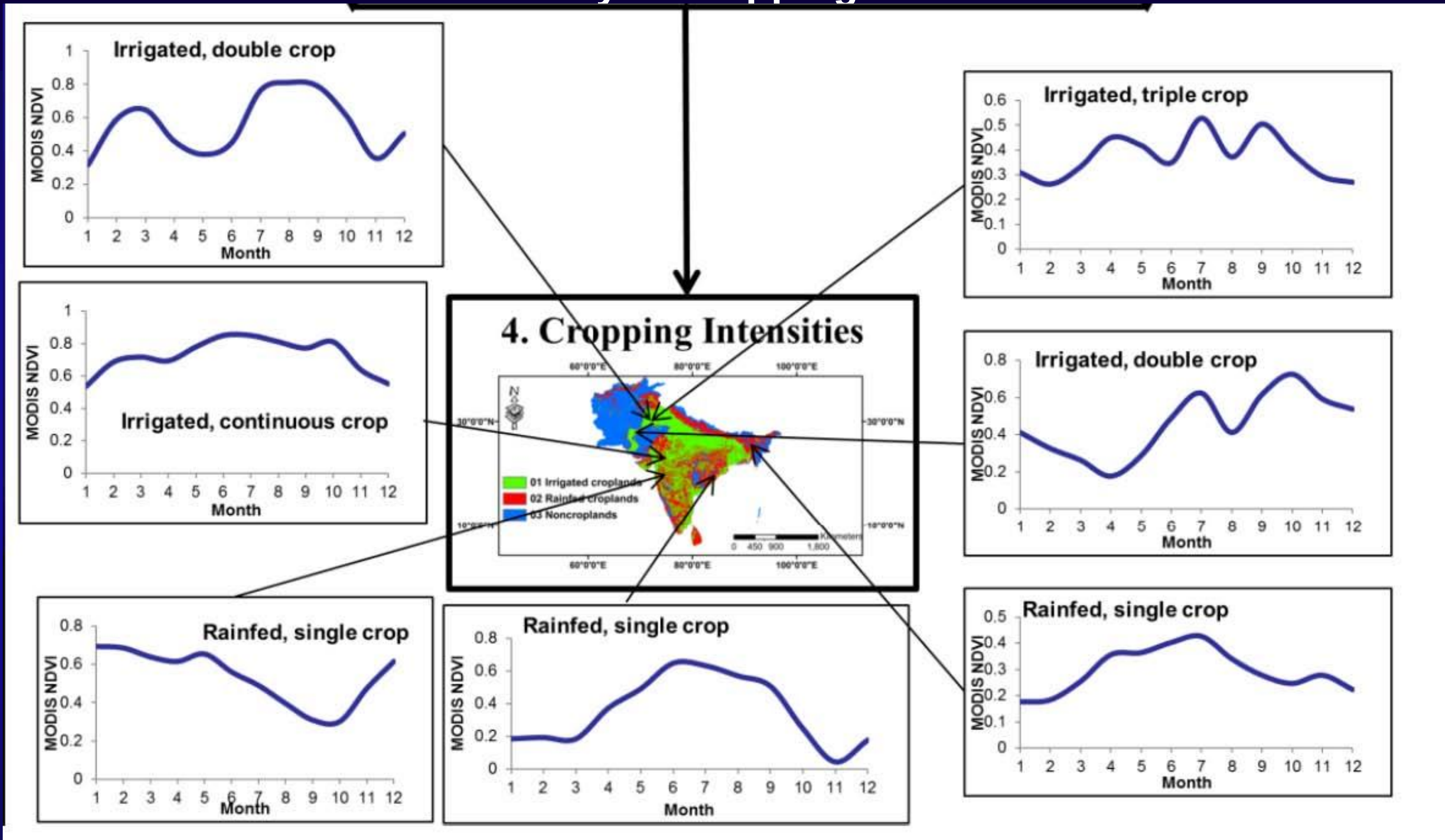
Global Cropland Area Database (GCAD30)

Intensity of cropping: World



Global Cropland Area Database (GCAD30)

Intensity of cropping: World

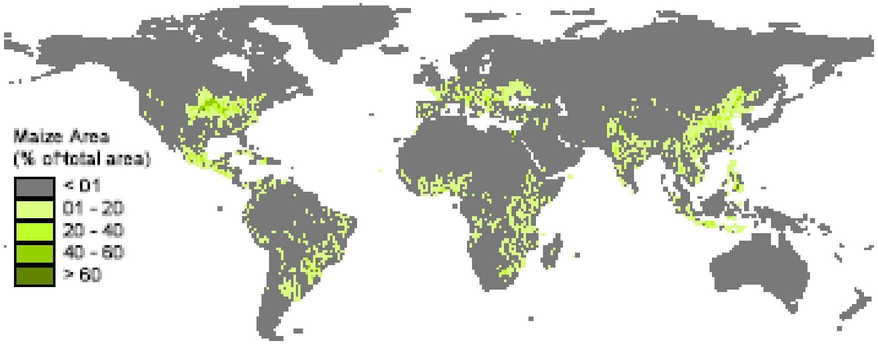


Croplands: Crop Type

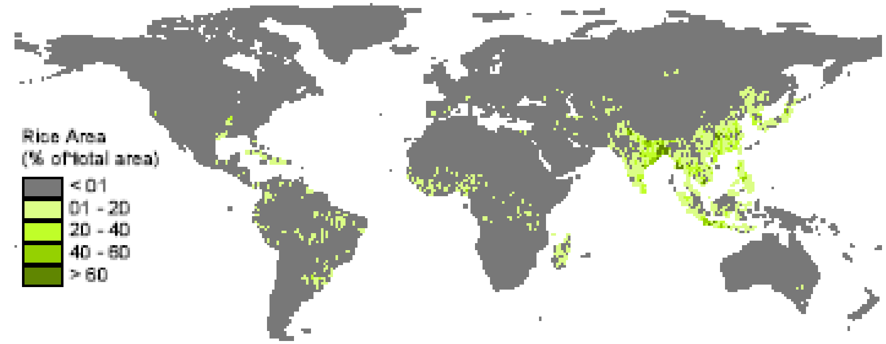
Global *versus* South Asia

Global Cropland Area Database (GCAD30)

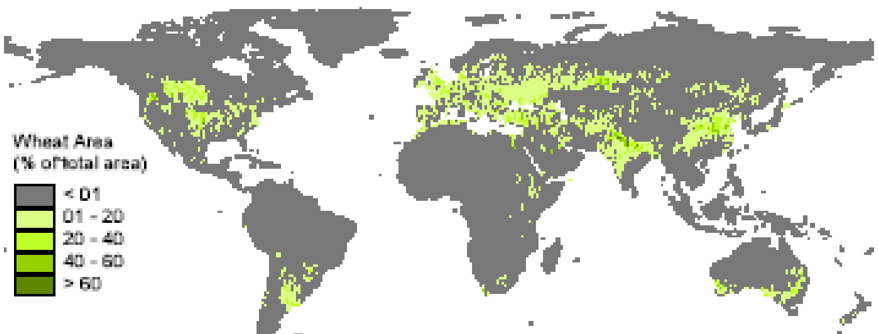
Crop Type Distribution: 4 Major crops that occupy ~55% of Total global Cropland Area (1.5 billion ha.)



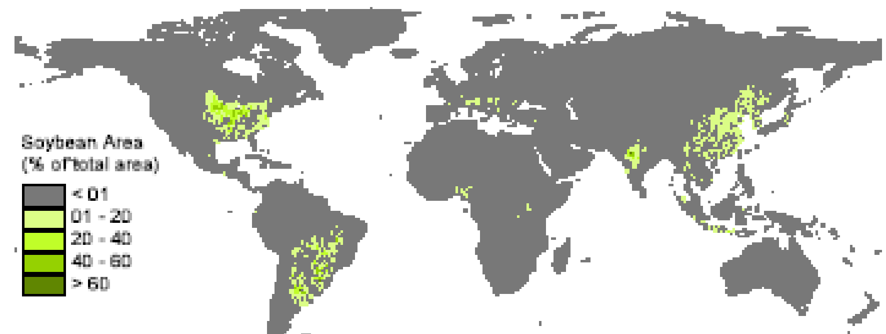
13% of total global cropland area



11% of total global cropland area



22% of total global cropland area



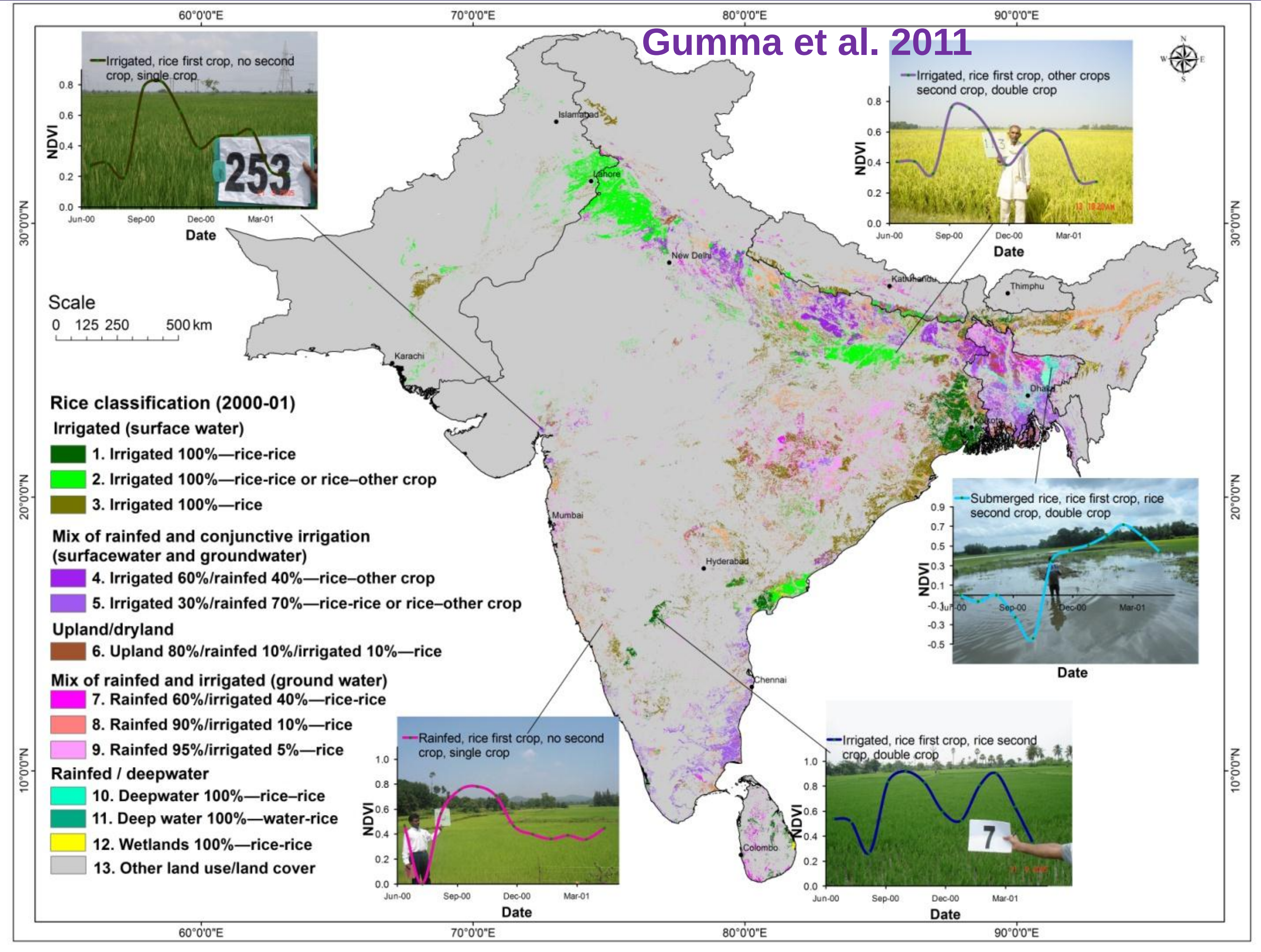
5% of total global cropland area

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 Cropland Area Database (GCAD30)

Crop Type Distribution: Rice Crop in South Asian Countries



How much water do crops use?….specificity of crops and their geographic location key.

Murali Krishna Gumma, Andrew Nelson, Prasad S. Thenkabail and Amrendra N. Singh, "Mapping rice areas of South Asia using MODIS multitemporal data", J. Appl. Remote Sens. 5, 053547 (Sep 01, 2011); doi:10.1117/1.3619838.

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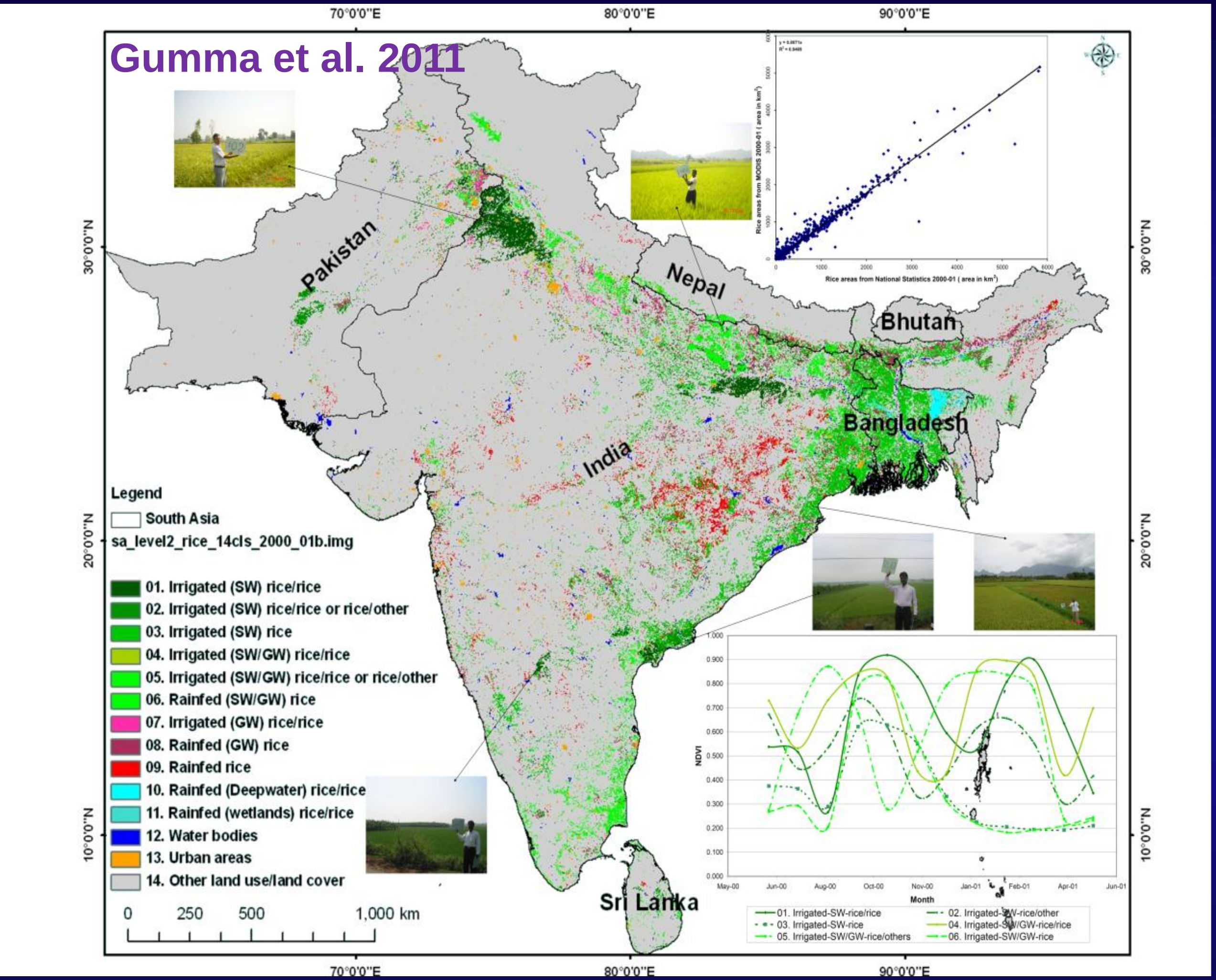
Crop phenologies and intensities studied using time-series remotely sensed data illustrated for rice crop in South Asia. A clear and deep understanding of phenologies and intensities will require us to develop a temporal (e.g., this figure) and spectral (e.g., Figure 5) knowledge base of each crop in different agroecosystems of the world leading to mapping distinct classes within a crop, which in turn will lead to accurate assessments of green water use (rainfed croplands) and blue water use (irrigated croplands). [adopted from Gumma, Nelson, Thenkabail., *2011*].

Global Cropland Area Database (GCAD30)

Crop Type Distribution: Rice Crop in South Asian Countries



Rice map of India and neighboring countries (Gumma et al., 2011). The map shows 11 classes of rice cultivation covering 50.6 million Hectares [This is the harvested wet-season area only. The harvested rice area across all seasons where there is more than one rice crop (*kharif* and *rabi* in India; *aman*, *boro*, and *aus* in Bangladesh; and *maha* and *yala* in Sri Lanka) is almost 60 million hectares].The two major types are irrigated and rainfed. The irrigated classes account for 24.2 million hectares and are further described by their irrigation type, such as surfacewater irrigation (from tanks, rivers, or reservoirs), groundwater irrigation (from wells or springs), and the cropping system, such as single rice, rice-rice, or rice–other crop systems. The rainfed classes account for 26.4 million hectares and include areas that have some occasional supplemental irrigation from groundwater sources as well as upland/ dryland rice and deepwater rice areas as found in eastern Bangladesh.

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Croplands: Change over space, time
Global *versus* South Asia

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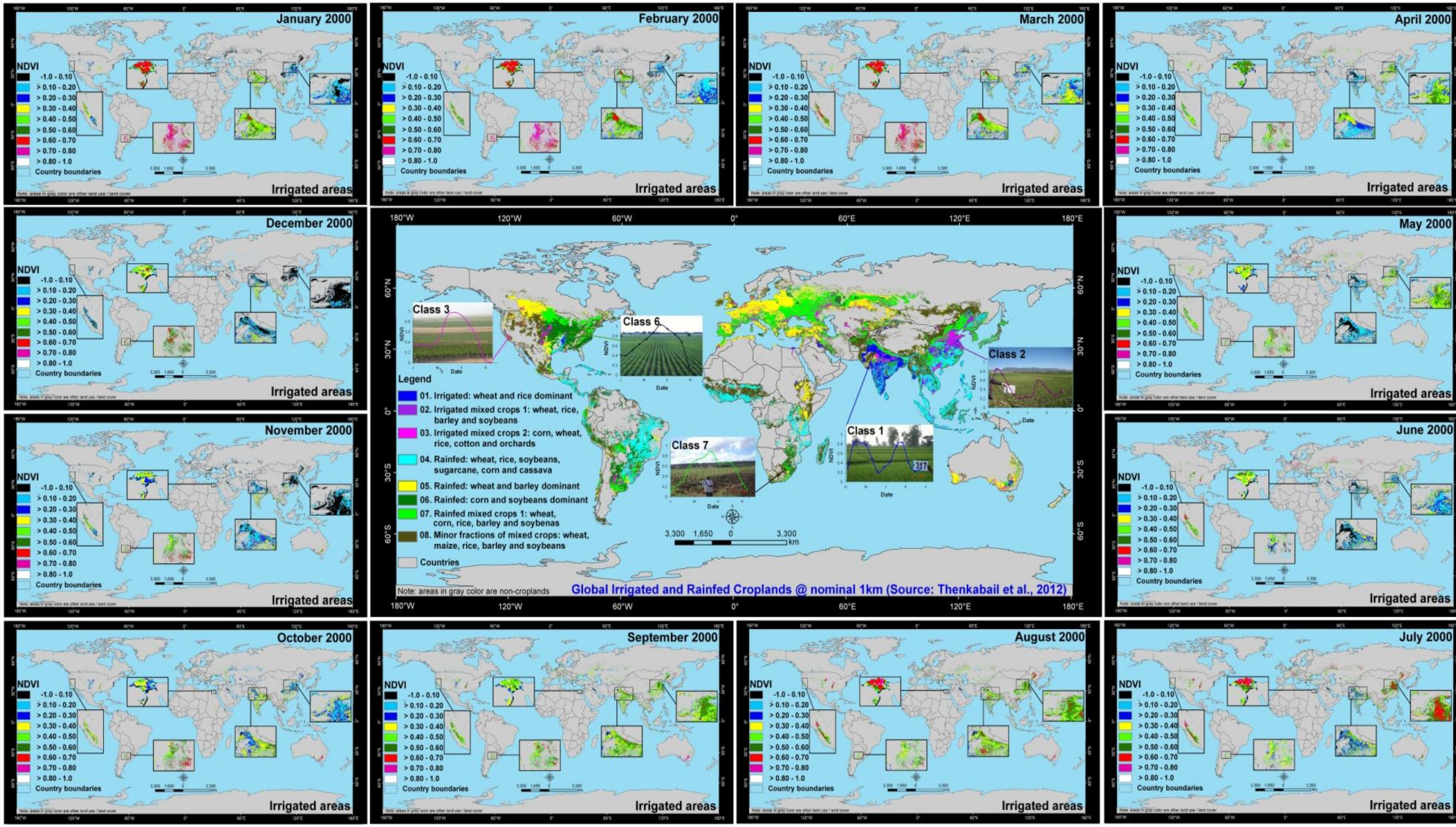
Global Cropland Area Database (GCAD30)

Monitoring Spatial Changes in Irrigated Areas over time: World



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Center image of global cropland (irrigated and rainfed) areas @ 1 km for year 2000 produced by overlying the remote sensing derived product of the International Water Management Institute (IWMI; Thenkabail et al., 2012, 2011, 2009a, 2009b; http://www.iwmigiam.org) over 5 dominant crops (wheat, rice, maize, barley and soybeans) of the world produced by Ramankutty et al. (2008). The 5 crops constitute about 60% of all global cropland areas. The IWMI remote sensing product is derived using remotely sensed data fusion (e.g., NOAA AVHRR, SPOT VGT, JERS SAR), secondary data (e.g., elevation, temperature, and precipitation), and *in-situ* data. Total area of croplands is 1.53 billion hectares of which 399 million hectares is total area available for irrigation (without considering cropping intensity) and 467 million hectares is annualized irrigated areas (considering cropping intensity). **Surrounding NDVI images of irrigated areas:** The January to December irrigated area NDVI dynamics is produced using NOAA AVHRR NDVI. The irrigated areas were determined by Thenkabail et al. (2011, 2009a, b).

Global Cropland Area Database (GCAD30)

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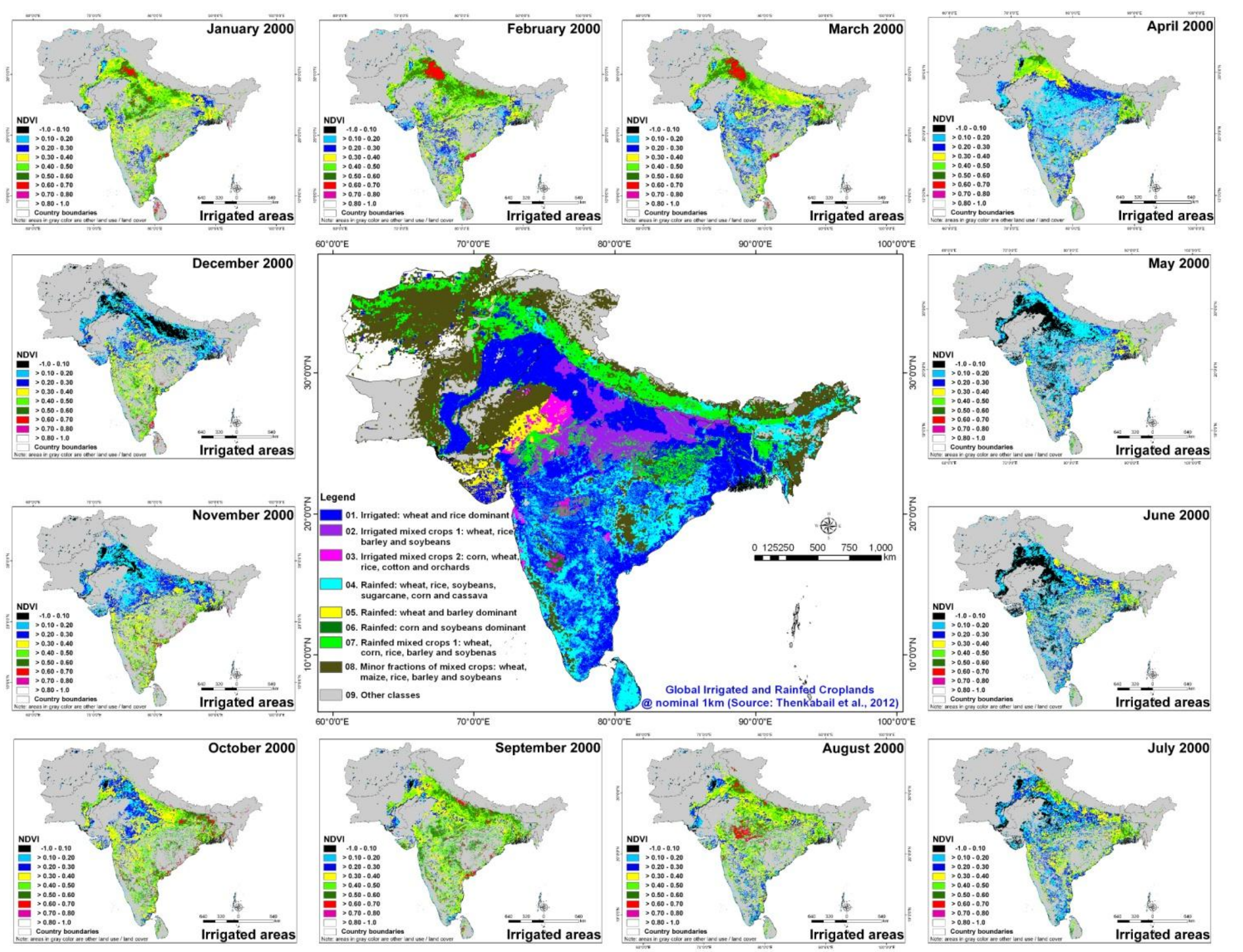

South Asia has 34% (~160 Mha) of global irrigated areas…….you see the dynamics of irrigated areas of South Asia for one year, month by month.

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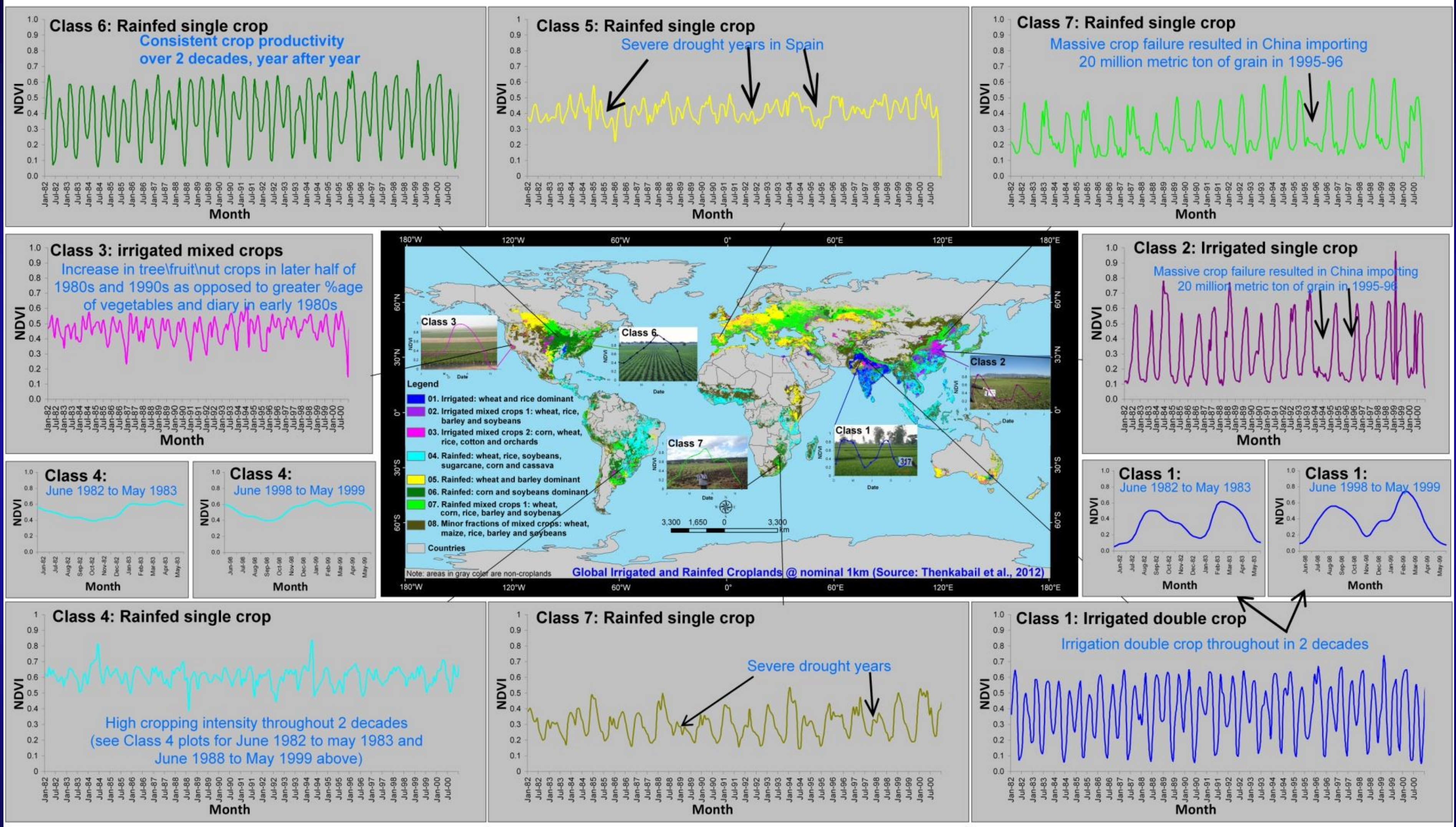
Center image of global cropland (irrigated and rainfed) areas @ 1 km for year 2000 produced by overlying the remote sensing derived product of the International Water Management Institute (IWMI; Thenkabail et al., 2012, 2011, 2009a, 2009b; http://www.iwmigiam.org) over 5 dominant crops (wheat, rice, maize, barley and soybeans) of the world produced by Ramankutty et al. (2008). The 5 crops constitute about 60% of all global cropland areas. The IWMI remote sensing product is derived using remotely sensed data fusion (e.g., NOAA AVHRR, SPOT VGT, JERS SAR), secondary data (e.g., elevation, temperature, and precipitation), and *in-situ* data. Total area of croplands is 221 Mha of which 160 million hectares is total area available for irrigation (without considering cropping intensity) and 467 million hectares is annualized irrigated areas (considering cropping intensity). **Surrounding NDVI images of irrigated areas:** The January to December irrigated area NDVI dynamics is produced using NOAA AVHRR NDVI. The irrigated areas were determined by Thenkabail et al. (2011, 2009a, b).

Global Cropland Area Database (GCAD30)

Change of Time and Space over Long Time-periods: World



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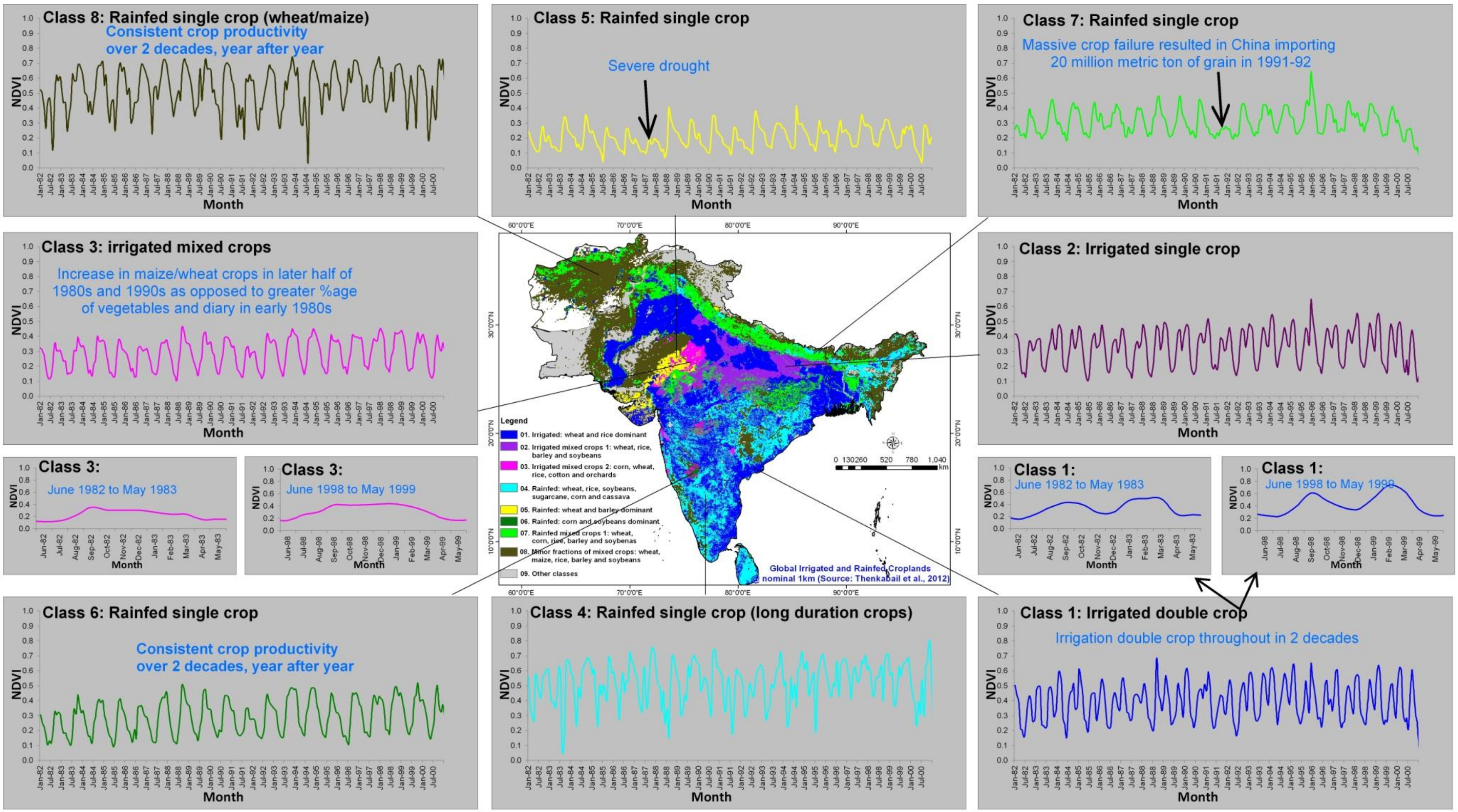
Global agricultural dynamics over 2 decades illustrated here for some of the most significant agricultural areas of the World. Once we establish GCAD2010 and GCAD1990 at nominal 30 m resolution for the entire world, we will use AVHRR-MODIS monthly MVC NDVI time-series from 1982 to 2017 to provide a continuous time history of global irrigated and rainfed croplands, establish their spatial and temporal changes, and highlight the hot spots of change. The GCAD2010, GCAD1990, and GCAD four decade's data will be made available on USGS global cropland data portal (currently under construction): http://powellcenter.usgs.gov/current_projects.php#GlobalCroplandsAbstract.

Global Cropland Area Database (GCAD30)

Change of Time and Space over Long Time-periods: South Asia



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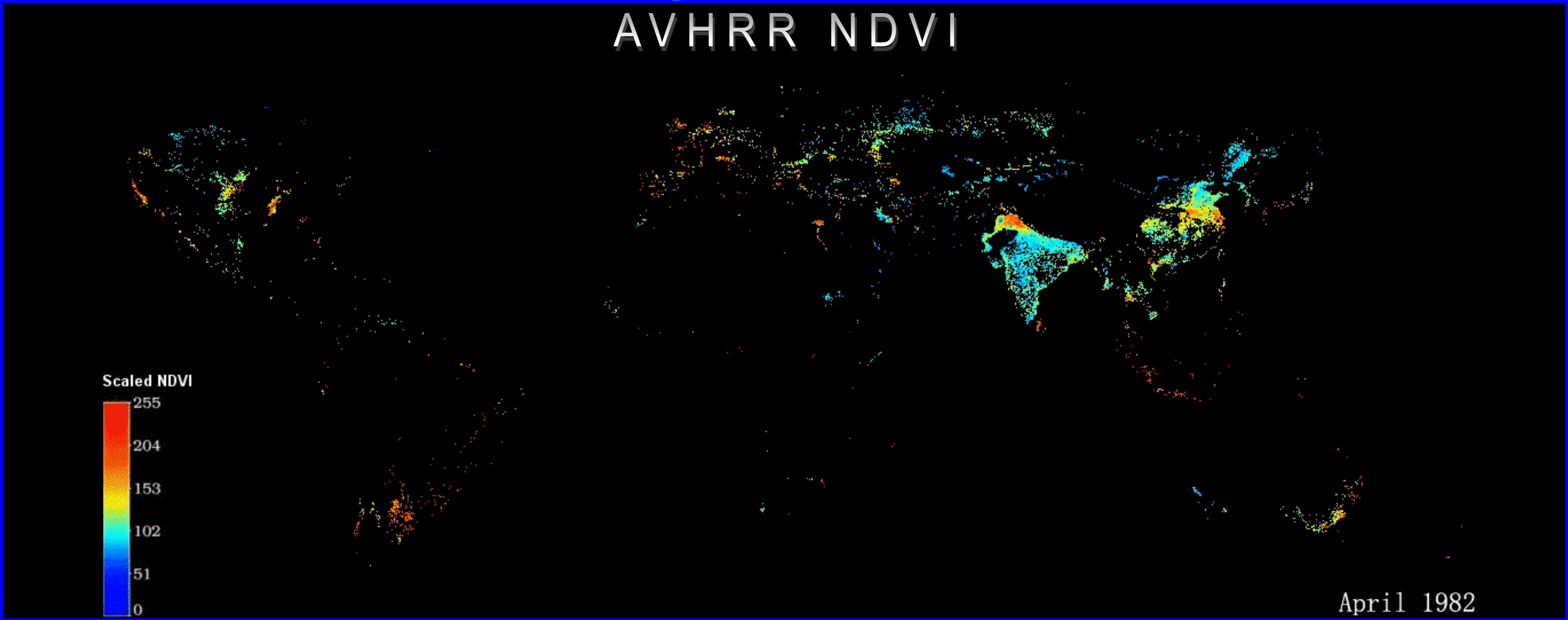
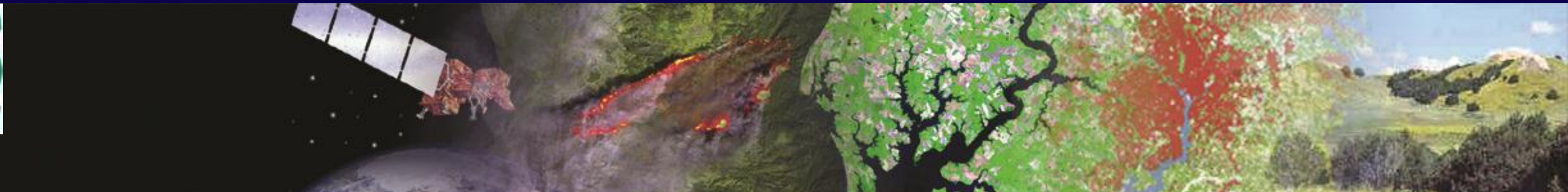
Global agricultural dynamics over 2 decades illustrated here for some of the most significant agricultural areas of the World. Once we establish GCAD2010 and GCAD1990 at nominal 30 m resolution for the entire world, we will use AVHRR-MODIS monthly MVC NDVI time-series from 1982 to 2017 to provide a continuous time history of global irrigated and rainfed croplands, establish their spatial and temporal changes, and highlight the hot spots of change. The GCAD2010, GCAD1990, and GCAD four decade's data will be made available on USGS global cropland data portal (currently under construction): http://powellcenter.usgs.gov/current_projects.php#GlobalCroplandsAbstract.

Global Cropland Area Database (GCAD30)

AVHRR Monthly Time-series Data and their Characteristics

Month of April from 1981-2001



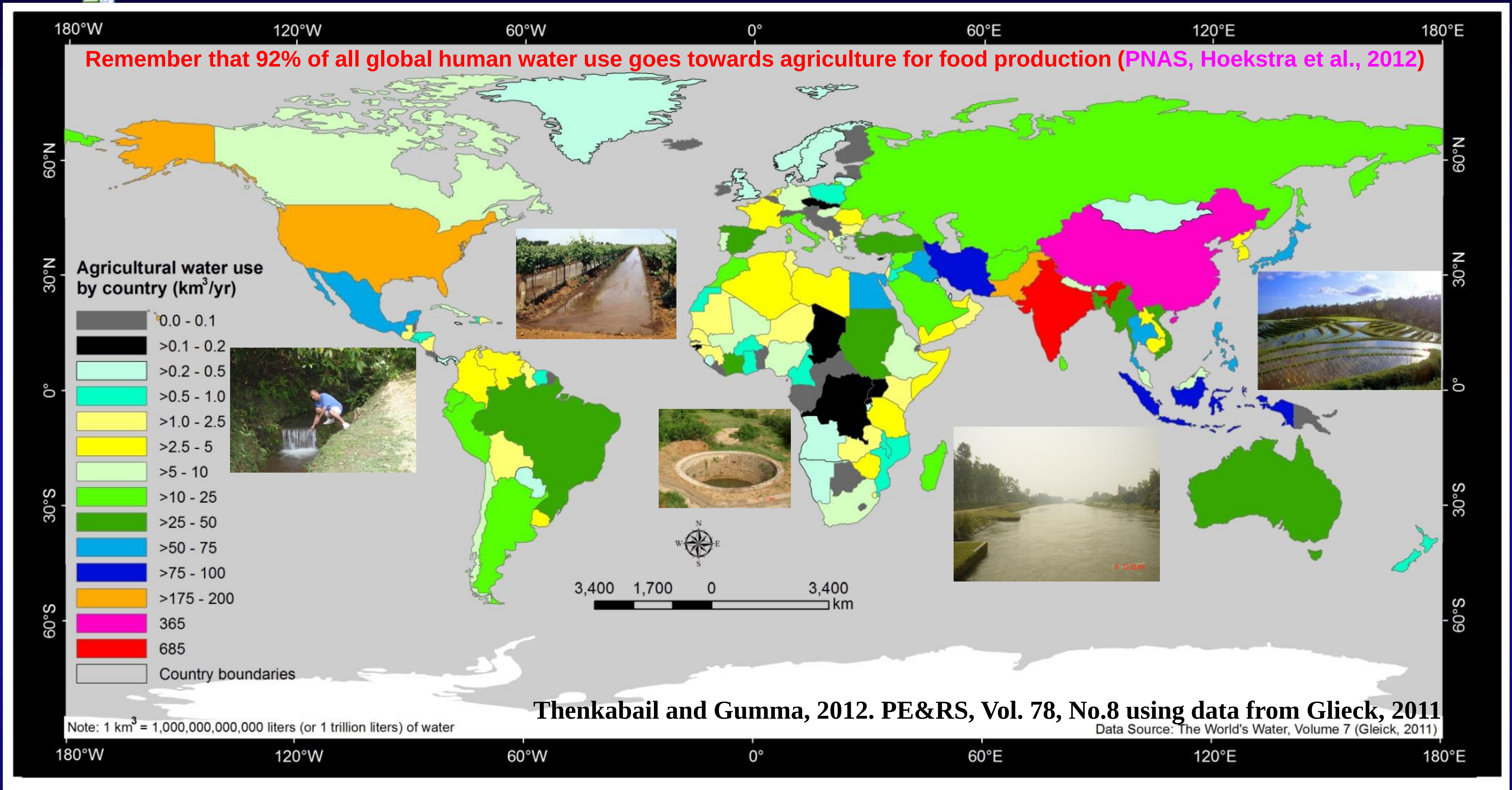


Croplands: Water Use

Global *versus* South Asia

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

Global Cropland Area Database (GCAD30)
Cropland Water Use for Food Production by Country: World



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: ~2500 m^3\yr\person whereas in India ~1000 m^3\yr\person and China ~700 m^3\yr\person

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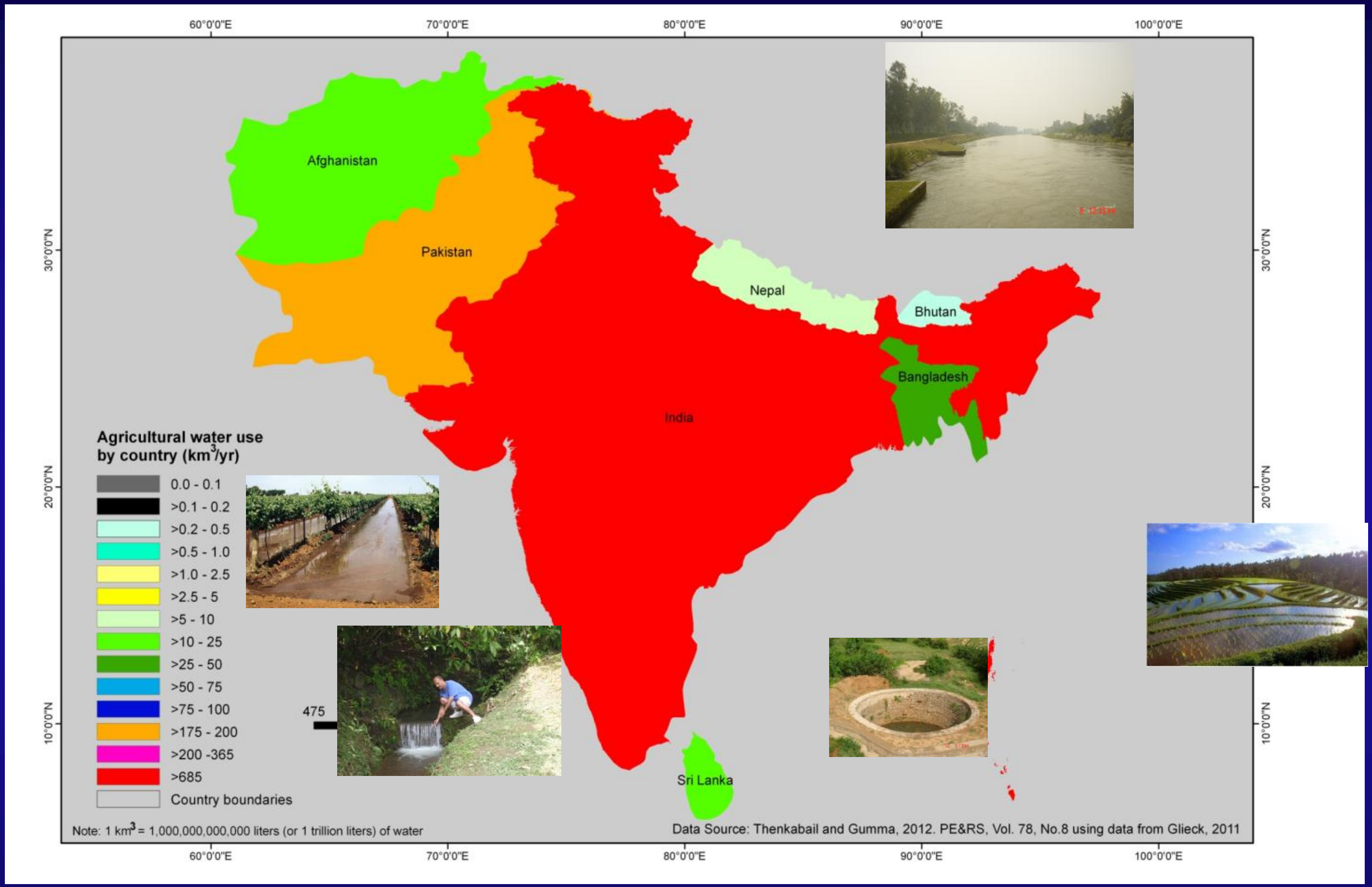
Global Cropland Area Database (GCAD30)

Cropland Water Use for Food Production by Country: South Asia

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



Thenkabail and Gumma, 2012. PE&RS, Vol. 78, No.8 using data from Glieck, 2011

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.

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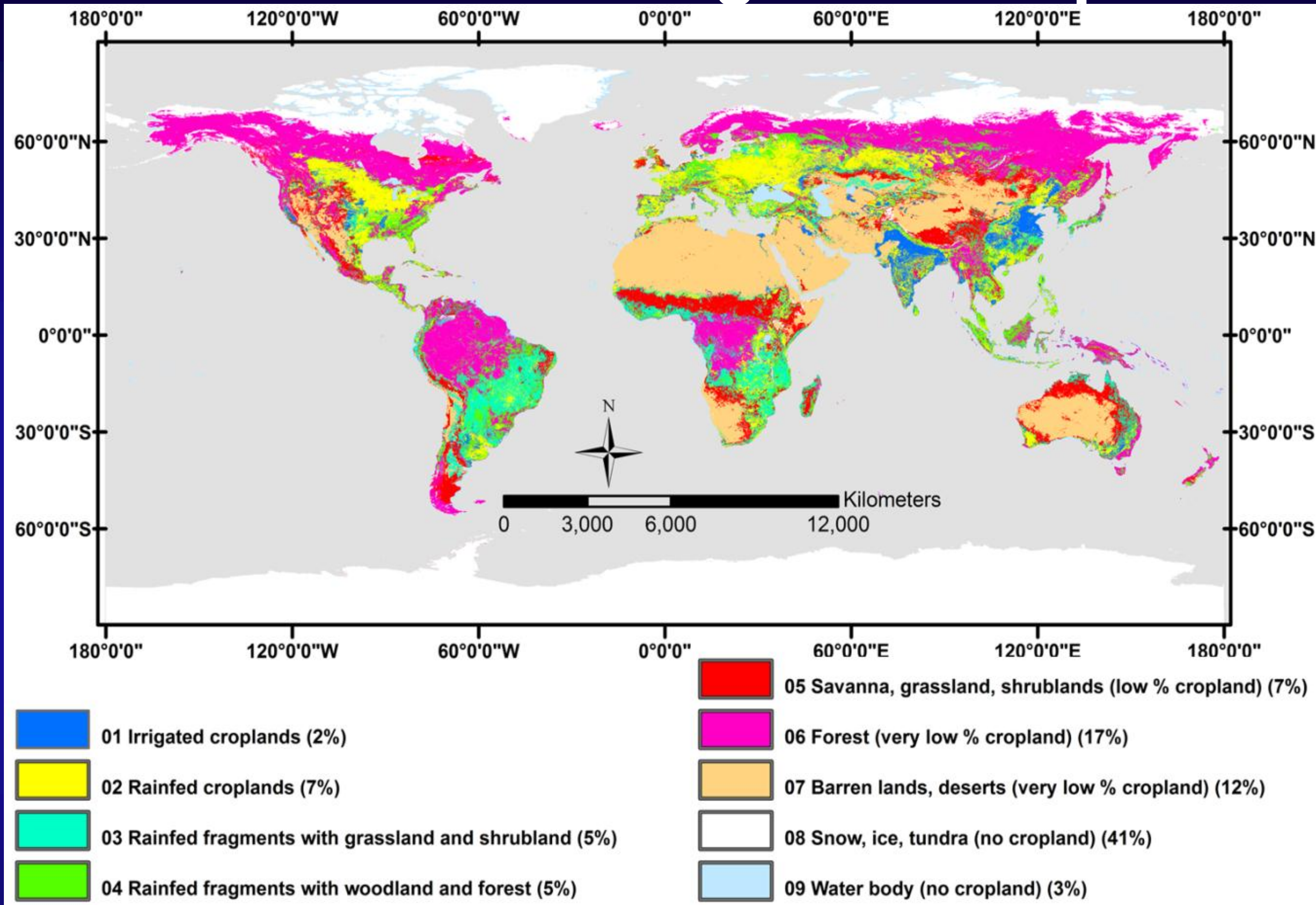
Cropland Mapping Over Large Areas
Strengths and Challenges for
Earth Observation Data

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

Global Cropland Area Database (GCAD30)

Remote Sensing Data Requirements:World



Masking and segmenting global terrestrial land to: (a) eliminate areas of zero croplands (classes 8 and 9) that occupy 44% (4200 Landsat scenes out of 9550) of the total terrestrial land from analysis, (b) discern highly fragmented croplands in forests (class 6 with 17% terrestrial area) and deserts (class 7 with 12% terrestrial area), where ~5% of global croplands exist, and (c) prioritize areas of classes 1 to 5 (26% of the terrestrial area) where 95% of all global croplands exists with first 3 classes having ~75% and the next 3 ~20%.

~10 to 12% (1.5 to 1.7 billion hectares) out of the total terrestrial land area (14.894 billion hectares) is currently cultivated. This is where we should focus of getting the EO data.

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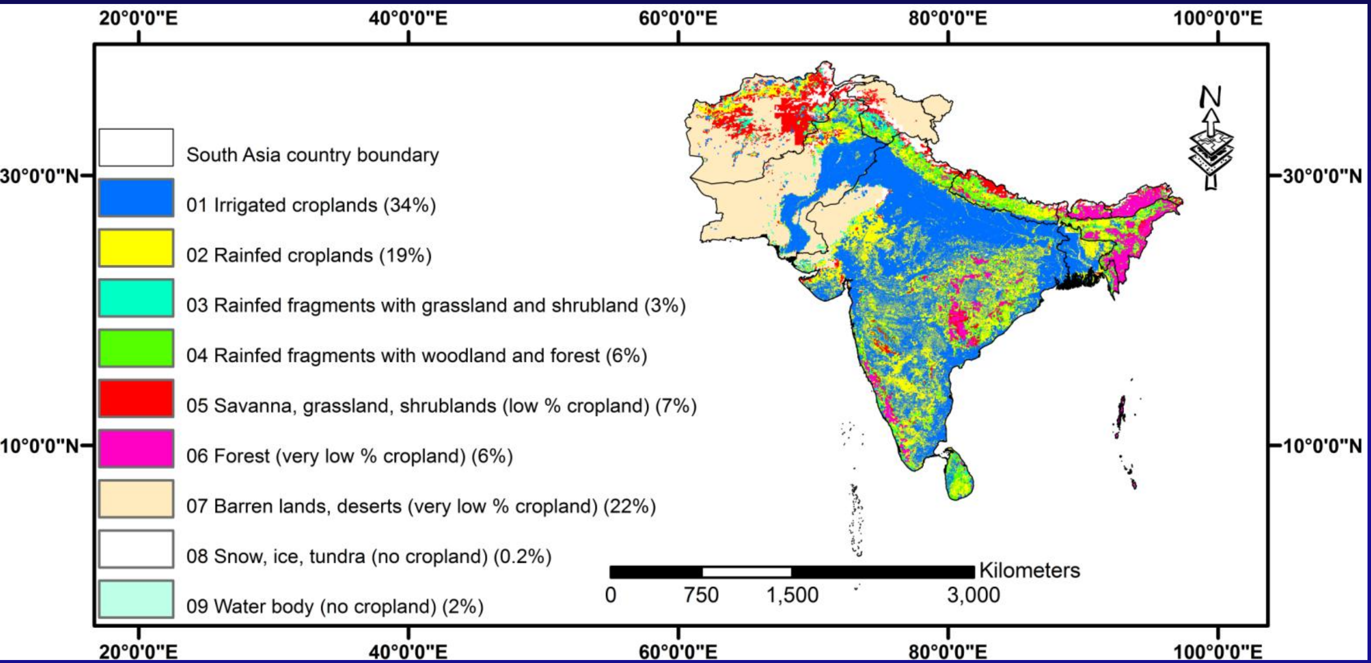
Global Cropland Area Database (GCAD30)

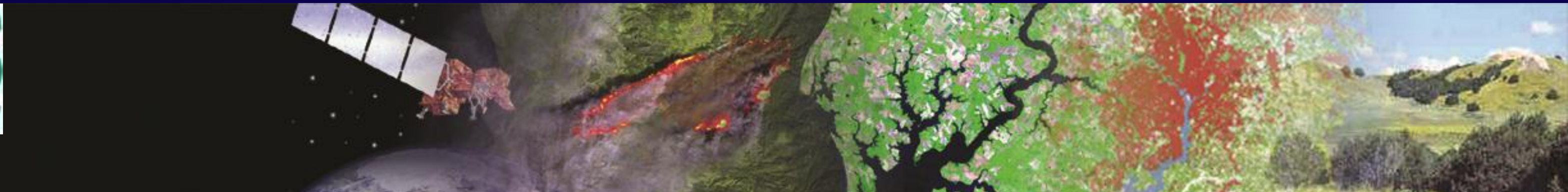
Remote Sensing Data Requirements: World



Masking and segmenting global terrestrial land to: (a) eliminate areas of zero croplands (classes 8 and 9) that occupy just 2.2% (just 4 Landsat scenes out of 167) of the total terrestrial land from analysis, (b) discern highly fragmented croplands in forests (class 6 with 6% terrestrial area) and deserts (class 7 with 22% terrestrial area), where ~5% of global croplands exist, and (c) prioritize areas of classes 1 to 5 (69% of the terrestrial area) where 95% of all South Asian croplands exists with first 3 classes having ~56% and the next 3 ~13%.

167 Landsat images cover the 520 Mha area

~43% (221 million hectares) out of the total terrestrial land area (520 million hectares) is currently cultivated. This is where we should focus of getting the EO data.



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Cropland Monitoring

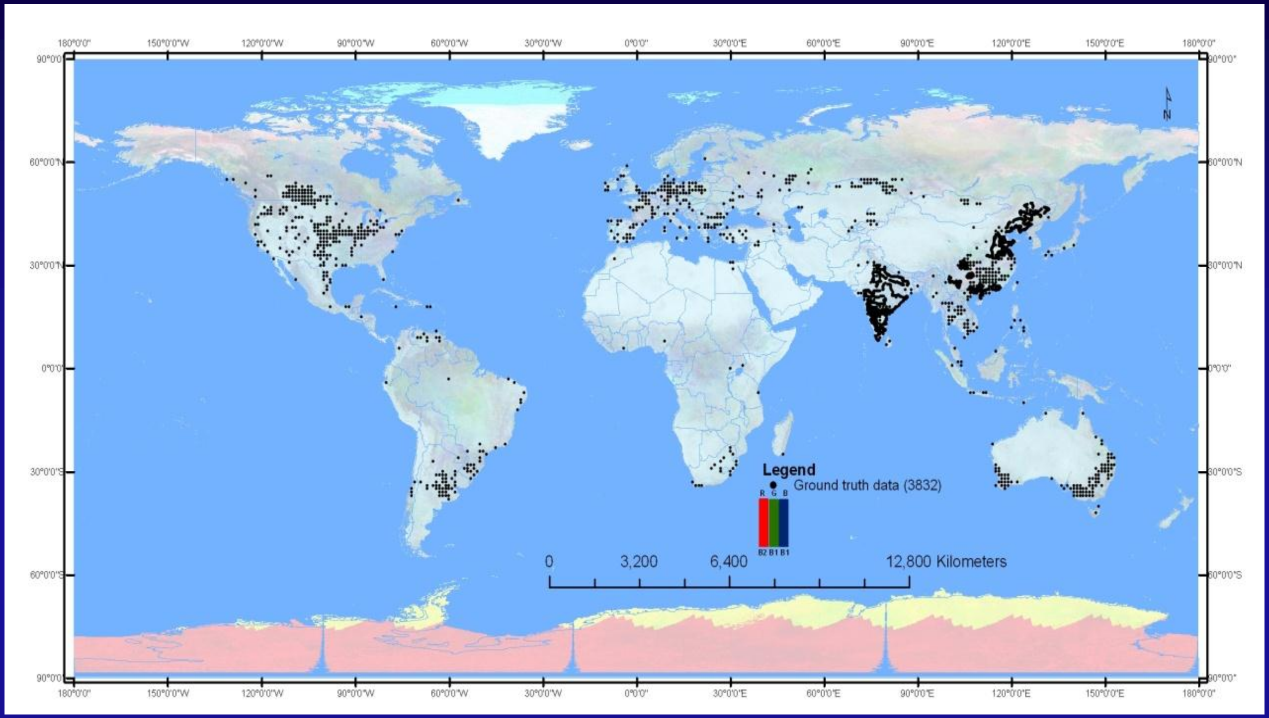
Type of EO Data and their Characteristics, Some Examples

Joint Experiment for Crop Area Monitoring (JECAM)

Mission	Agency	Launch	Instrument	Bands	Swath (km)	Resolution (m)
Current Missions (in orbit)						
Optical Instrumentation						
Landsat-5	USGS, NASA	1984	TM	VIS, NIR, SWIR, TIR	185	30
SPOT-4	CNES	1998	HRVIR, Vegetation	VIS, NIR, SWIR	117,2200	10-20,1.15
Landsat-7	USGS, NASA	1999	ETM+	VIS, NIR, SWIR, TIR	185	30
Terra	NASA	1999	ASTER	VIS, NIR, SWIR, TIR	60	15
NMP EO-1	NASA	2000	Hyperion, ALI	VIS, NIR, SWIR	8,37	10,30
SPOT-5	CNES	2002	HRG, Vegetation	VIS, NIR, SWIR	117	5-10,1.15
ALOS	JAXA	2006	AVNIR-2	VIS, NIR	70	10
RapidEye	DLR	2008	MSI	VIS, NIR	78	6.5
ResourceSat-2	ISRO	2010	LISS-3, LISS-4	VIS, NIR, SWIR(3)	141,70	23.5,5.8
Radar Instrumentation						
RADARSAT-1	CSA	1995	SAR	C-Band	500	8
ERS-2	ESA	1995	AMI/SAR	C-Band	100	30
Aqua	NASA	2002	AMSR-E	C-Band, X-Band	1445	5-50
Envisat	ESA	2002	ASAR	C-Band	400	30
ALOS	JAXA	2006	PALSAR	L-Band	360	7
RADARSAT-2	CSA, MDA	2007	SAR	C-Band	500	2
COSMO-SkyMed 1	ASI, MiD	2007	SAR	X-Band	200	1
COSMO-SkyMed 2	ASI, MiD	2007	SAR	X-Band	200	1
TerraSAR-X	DLR	2007	SAR	X-Band	100	4
COSMO-SkyMed 3	ASI, MiD	2008	SAR	X-Band	200	1
RISAT-2	ISRO	2009	SAR-X	X-Band	650	3
COSMO-SkyMed 4	ASI, MiD	2010	SAR	X-Band	200	1
Future Missions (planned)						
Optical Instrumentation						
CBERS-3	INPE, CRESDA	2011	PAN, WFI-2	VIS, NIR	60,866	5,64
LDCM	NASA, USGS	2012	OLI, TIRS	VIS,NIR,SWIR; TIR	185	15,100
AWiFSSAT	ISRO	2012	AWiFS	VIS, NIR, SWIR	730	55
Sentinel-2A	ESA, EC	2013	MSI	VIS, SWIR	290	10
CBERS-4	INPE, CRESDA	2014	PAN, WFI-2	VIS, NIR	60,866	5,64
Sentinel-2B	ESA, EC	2014	MSI	VIS, SWIR	290	10
Radar Instrumentation						
KOMPSAT-5	KARI	2011	COSI	X-Band	100	1
RISAT-1	ISRO	2011	SAR	C-Band	240	3
Sentinel-1A	ESA, EC	2012	SAR	C-Band	400	9
RISAT-1F	ISRO	2012	SAR-L	L-Band		
HY-3A	NSOAS, CAST	2012	WSAR	X-Band	150	1
ALOS-2	JAXA, METI	2013	SAR	L-Band	360	1
TerraSAR-X2	DLR	2013	SAR	X-Band	100	4
RISAT-2F	ISRO	2013	SAR-X	X-Band	650	3
Sentinel-1B	ESA, EC	2014	SAR	C-Band	400	9
RISAT-3L	ISRO	2014	SAR-L	L-Band		
SMAP	NASA	2014	L-Band Radar	L-Band		

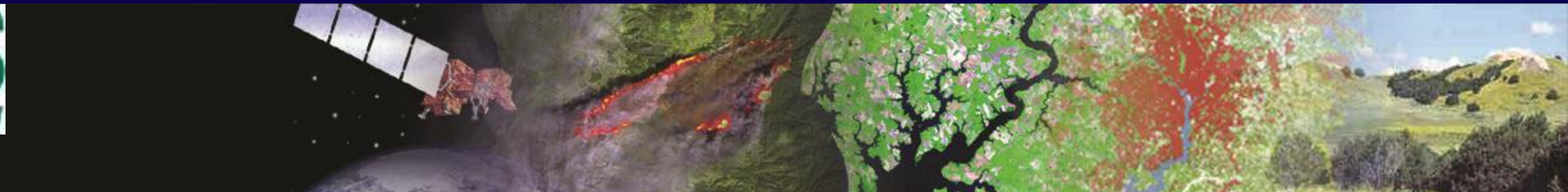
Cropland Monitoring

Need of Very High Spatial Resolution (≤ 5 meter) EO data for Accuracy Assessments



Uncertainties, Errors, and Accuracies: A complete error analysis and validation is necessary in order to evaluate the sources of error, control them, and make effective use of the global cropland maps and statistics created. It is achieved through: (a) error matrix analysis, and (b) regression analysis. An error matrix (overall, producers, and user's accuracies).

Data used for accuracy assessments include: (i) 25% of the ~20,000 ground data points, (ii) thousand+ globally well distributed very high resolution (sub-meter to 5 meter) Commercial Imagery Derived Requirement (CIDR) Database of USGS, available free of cost to the project through the National Geospatial Intelligence Agency (https://warp.nga.mil/), (iii) our ongoing collaborative work over large areas (e.g., rice map of Asia; Figure 7), (iv) maps from national systems (e.g., USDA cropland data layer; see letters of support from global partners; also e.g., MoWR, 2011, MOA, 2010), and (b) 500, 5 x 5 kilometer samples used in global land cover products (Olofsson et al., 2011, Stehman et al., 2011).



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Cropland Mapping Over Large Areas
Advances in Methods and Approaches using
Earth Observation Data

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

Cropland Classification Algorithms

Existing and Evolving Methods

Known methods of crop classification techniques using time-series data:

A. Fourier harmonic analysis, fast Fourier transformation (FFT);
B. wavelet techniques (e.g., Jakubauskas et al. 2002, Olsson and Eklundh, 1994);
C. principal component analysis, change detection analysis (Jensen, 2000);
D. Artificial neural networks and decision trees (Defries et al., 1998, Mather, 2003);
E. Decision Trees;

Evolving Automated Cropland Classification Methods:

1. Spectral matching techniques (SMTs);
2. Automated Cropland Classification Algorithms (ACCA); and
3. Ensemble of Machine learning algorithm (EMLAs) (e.g., decision trees, neural network); and
4. Classification and Regression Tree (CART).

Brief illustrations of these today

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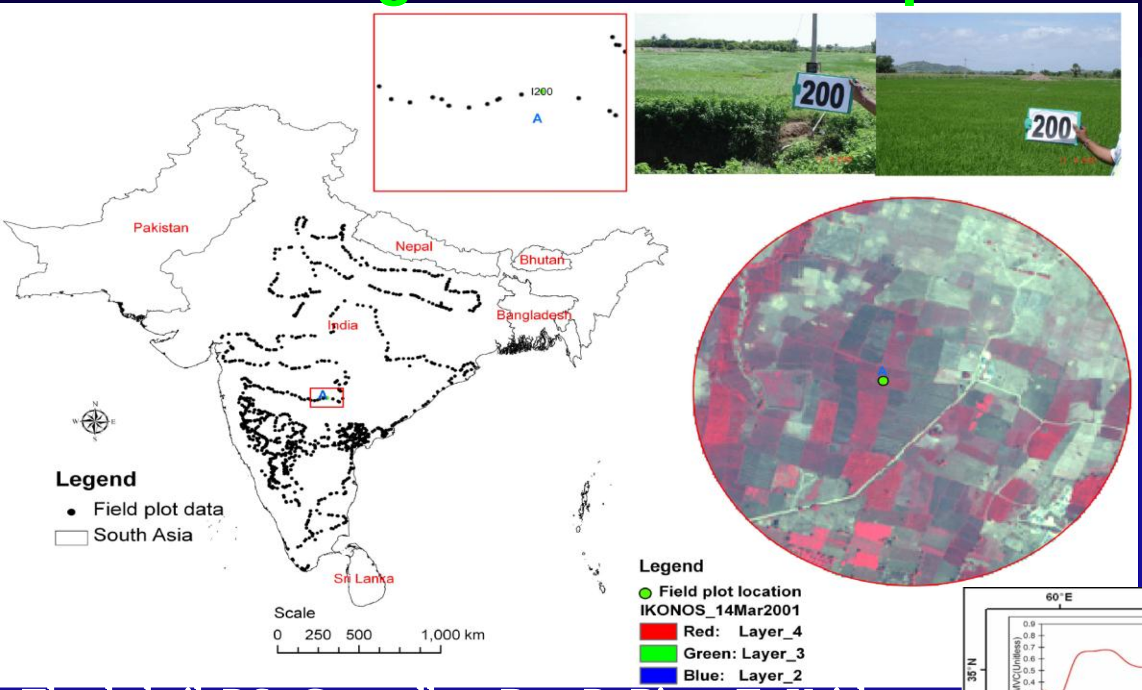
Cropland Mapping Over Large Areas

Spectral Matching Techniques (SMTs)

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

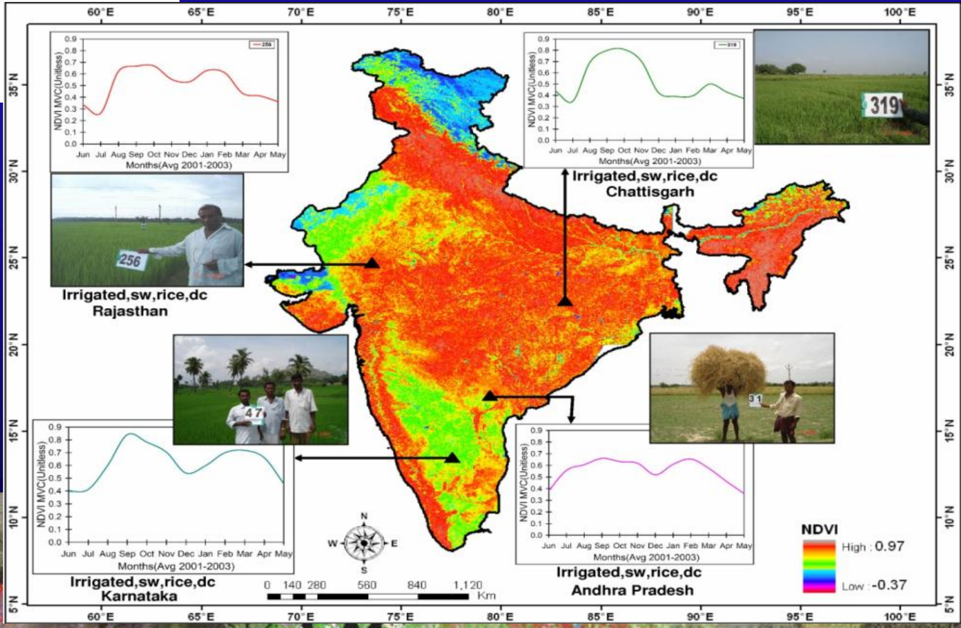
Spectral matching Techniques (SMTs)

Gathering Field Data for Spectral Matching Techniques



Field-plot data points of India. The data collected in these plots include crop types, cropping intensity (e.g., single crop, double crop), watering source (irrigated vs rainfed), and a number of other parameters (e.g., digital photos) were also collected.

Thenkabail, P.S., GangadharaRao, P., Biggs, T., Krishna, M., and Turral, H., 2007. Spectral Matching Techniques to Determine Historical Land use/Land cover (LULC) and Irrigated Areas using Time-series AVHRR Pathfinder Datasets in the Krishna River Basin, India. Photogrammetric Engineering and Remote Sensing. 73(9): 1029-1040. (Second Place Recipients of the 2008 John I. Davidson ASPRS President's Award for Practical papers).



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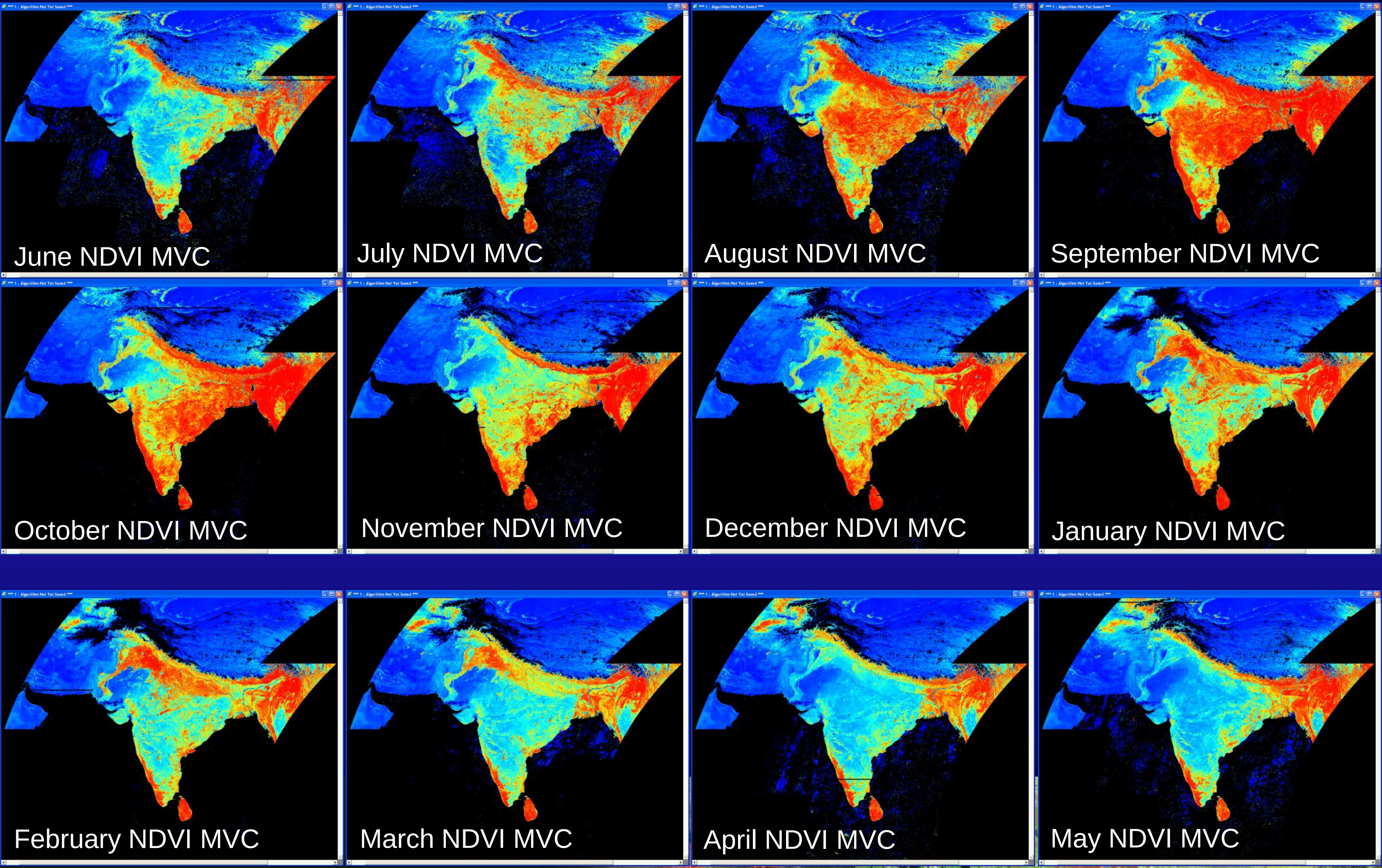
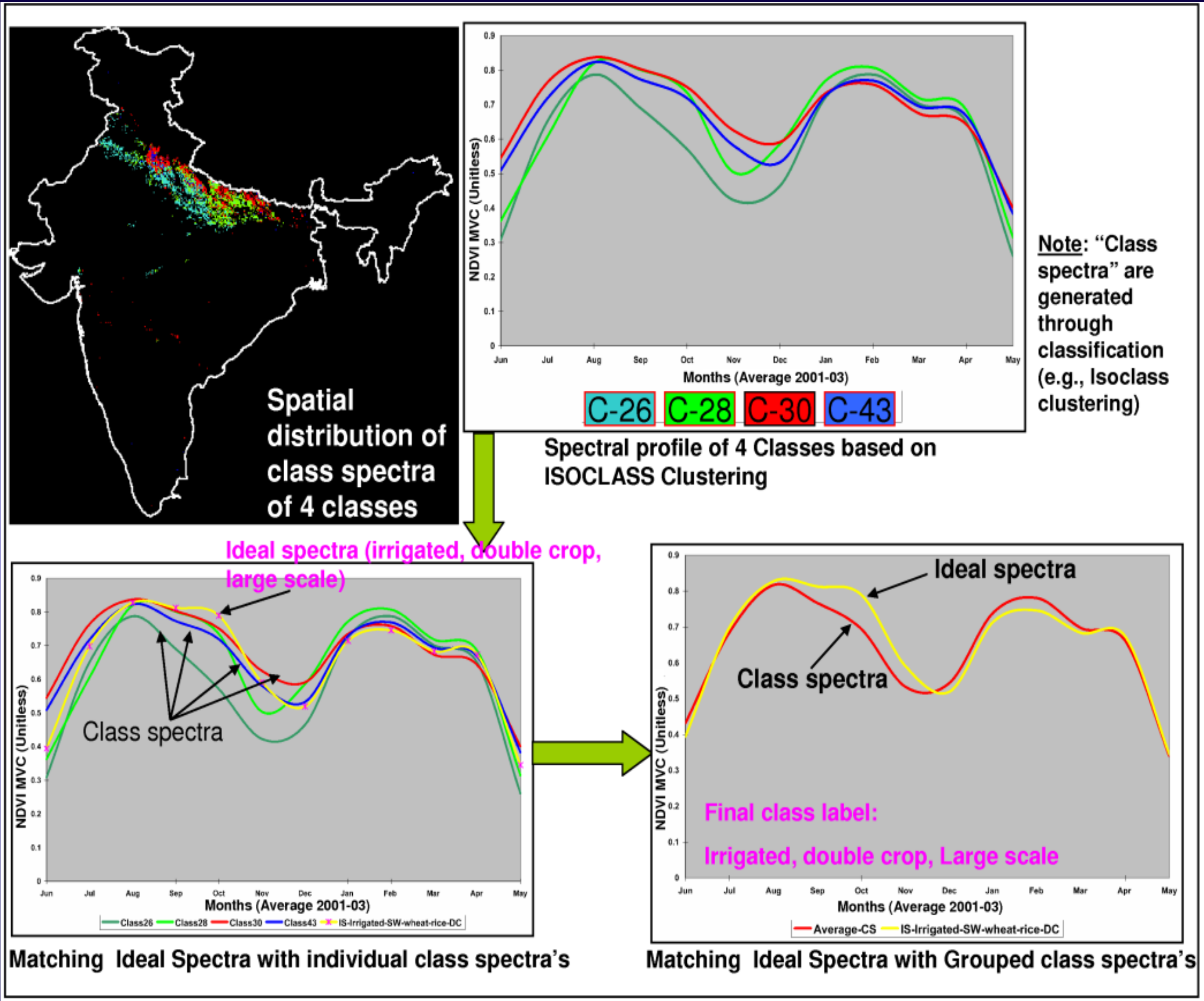
Spectral Matching Techniques (SMTs)

Generate time-series Imagery (e.g., MODIS monthly NDVI MVC)



Spectral matching Techniques (SMTs)

Creating Ideal\target Spectra, Class Spectra and Matching the Them



Pheno-spectral Matching Technique (SMTs). Illustration of double-crop (DC) irrigation. The NDVI spectra of the 4 classes (C-26, C-28, C-30, and C-43) of DC irrigation are "matched" with ideal spectra (shown in yellow) for the same. Using MODIS 250 m time-series along with Landsat 30m data it is possible to create cropping intensities and crop calendars.

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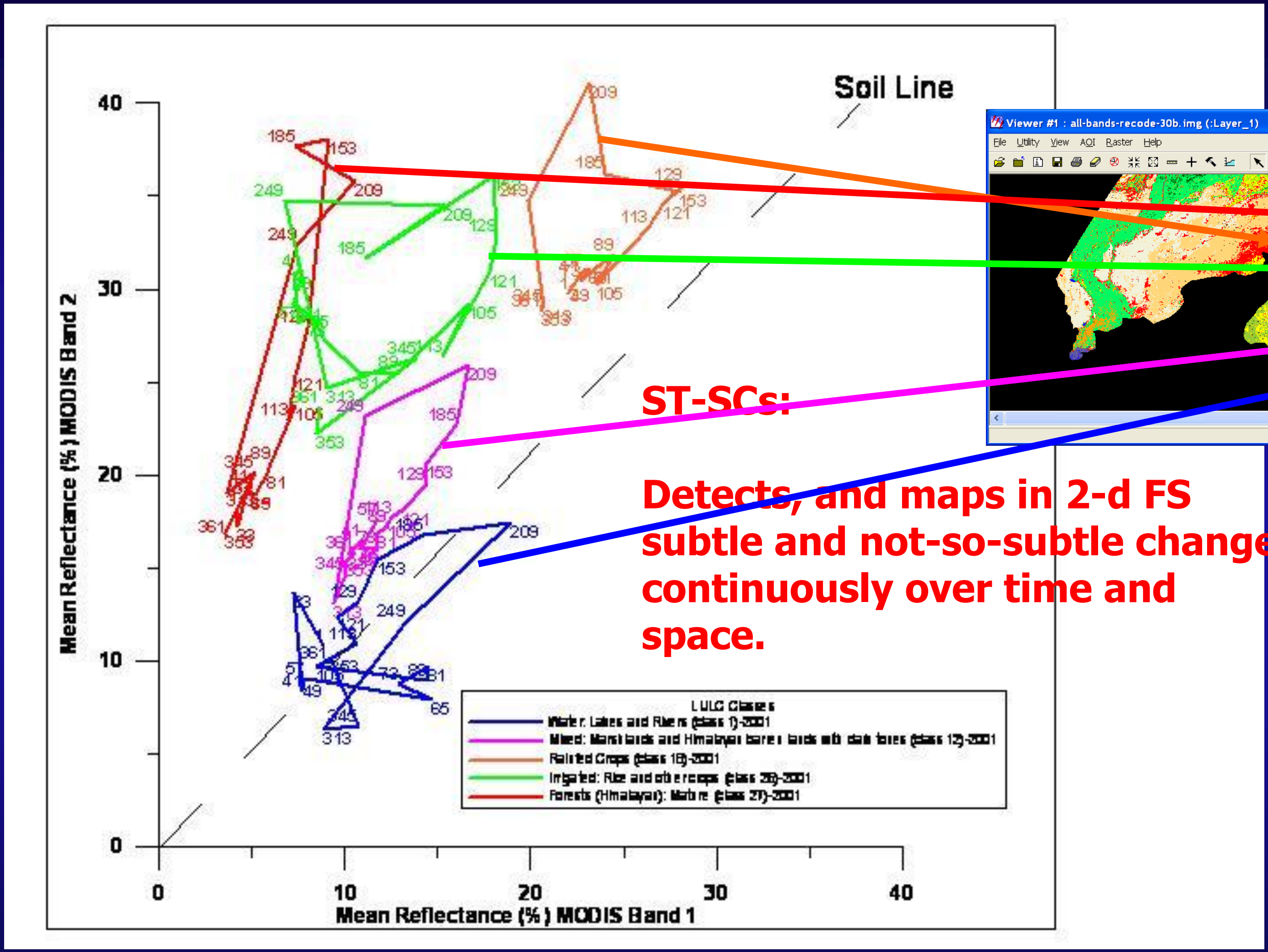
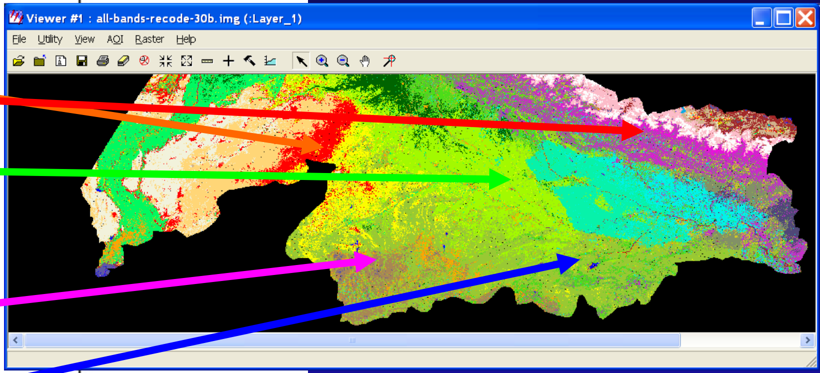
Other Methods: Space-time Spiral Curves (ST SCs)

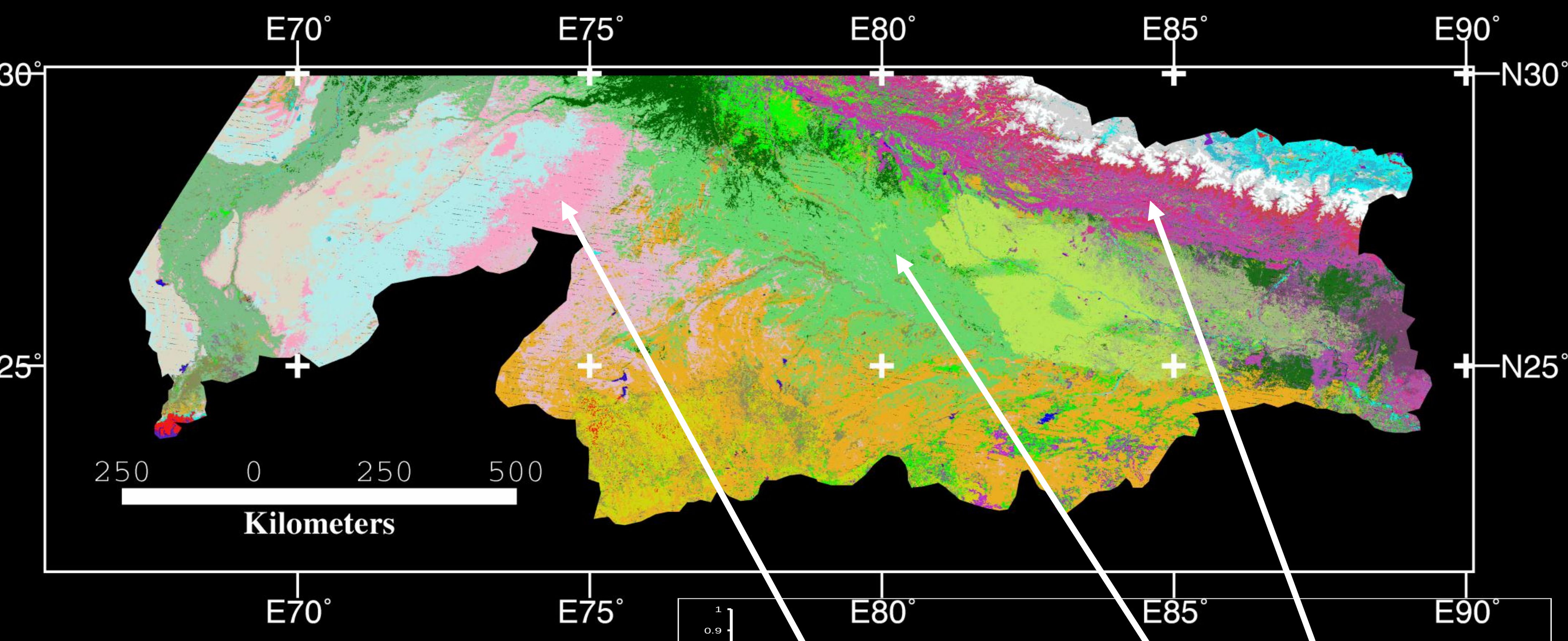
Class Identification and Labeling Process



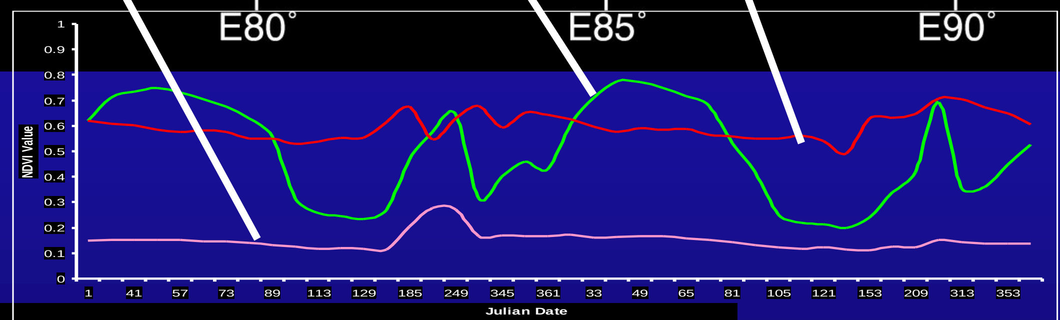


ST-SCs:

Detects, and maps in 2-d FS subtle and not-so-subtle changes continuously over time and space.



Unique class signatures, based on CS-NDVI and their intra- and inter-seasonal and intra- and inter-year characteristics.



- Class-11 Desert lands: Higher NDVI
- Class-10 Desert lands: Lower NDVI
- Class-9 Barren lands: Himalayas with bright tones
- Class-8 Barren lands: Himalayas with bright tones, river beds and built-up
- Class-7 Snow: Year Round
- Class-6 Snow: Seasonal
- Class-5 Wetlands: Agriculture
- Class-4 Wetlands: Natural Vegetation
- Class-3 Water: Glacial Lakes
- Class-2 Water: Marshland or Estuary
- Class-1 Water: Lakes and Rivers
- Class-22 Irrigated: Rice, sugarcane, agroforests, other crops
- Class-21 Irrigated: Rice, sugarcane, other crops
- Class-20 Forests (open): mix with rice and natural vegetation
- Class-19 Forests (open): mix with rice and other crops
- Class-18 Rainfed Crops
- Class-17 Rainfed Crops and Rangelands
- Class-16 Mixed: Shrublands, fallow lands, built-up, and others
- Class-15 Mixed : Rangelands, open areas, rainfed crops, and sub-urban built-up
- Class-14 Mixed : Rice, other crops, shrubs, and young secondary forest
- Class-13 Mixed: Rice, other crops, and wetlands
- Class-12 Mixed: Marshlands and Himalayan barren lands with dark tones
- Class-29 Forests (Himalayan): Young
- Class-28 Forests (Himalayan): Young and Wetlands
- Class-27 Forests (Himalayan): Mature
- Class-26 Irrigated: Rice and other crops
- Class-25 Irrigated: Rice with wetlands
- Class-24 Irrigated: Water logged crops (Indus), rice, shrubs
- Class-23 Irrigated: Other crops, fallow farms, rice

Class Identification and Labeling Process

Time-series NDVI Data

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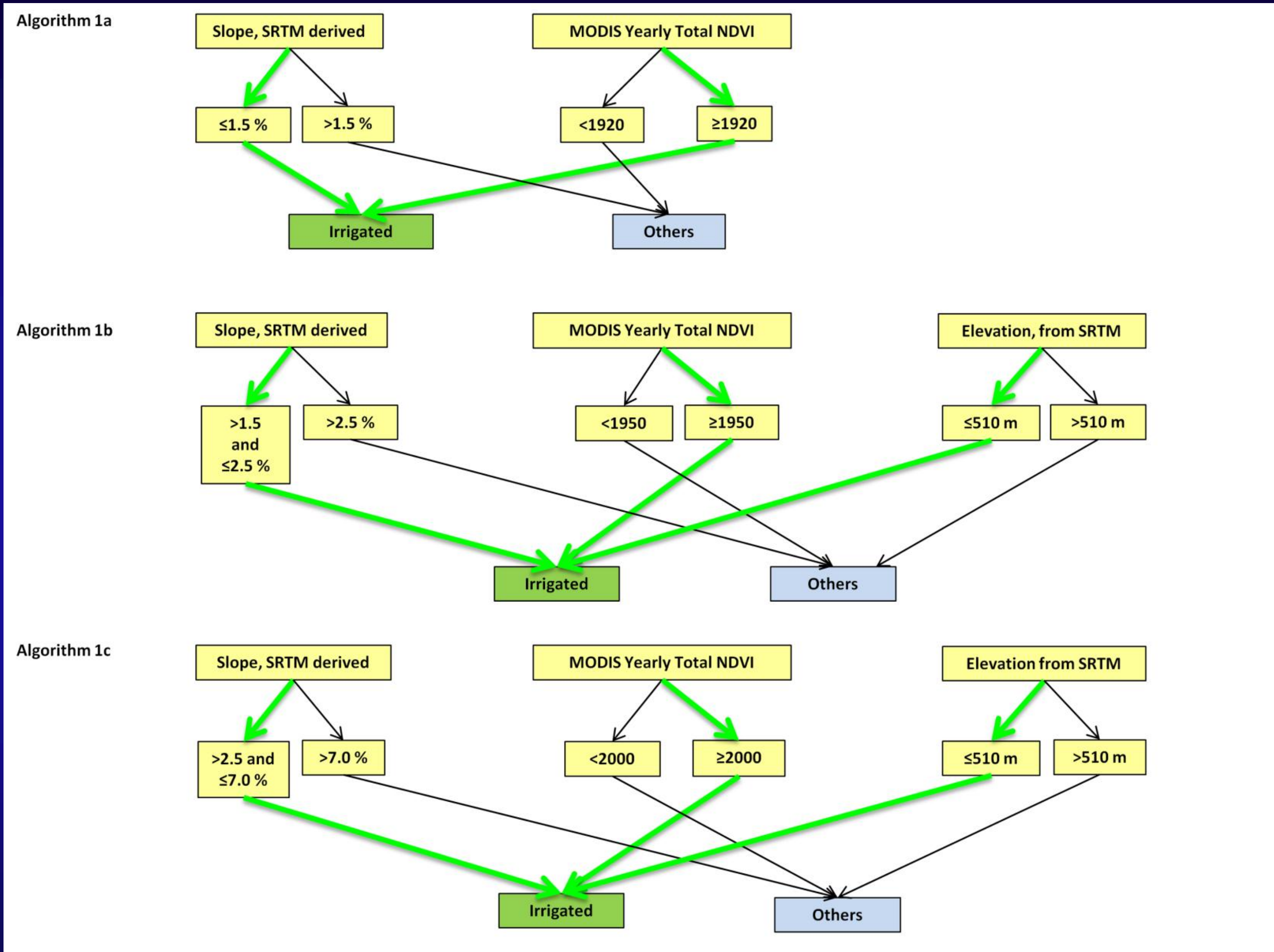
Cropland Mapping Over Large Areas

Automated Cropland Classification Algorithm (ACCA)

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

Automated Cropland\Fallowland Classification Algorithm (ACCA)

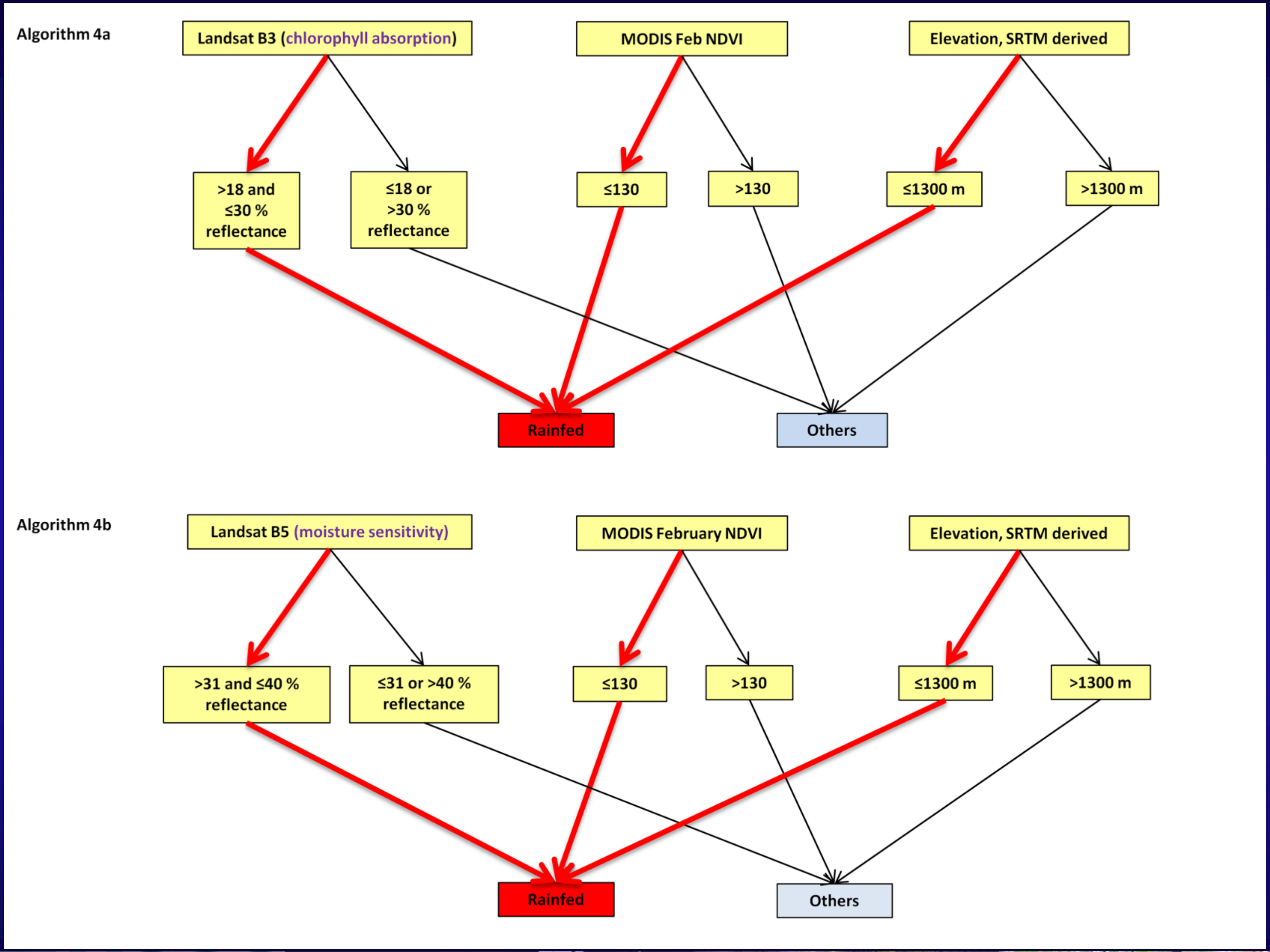
Algorithm Development based on MODIS, Landsat, and Secondary Data



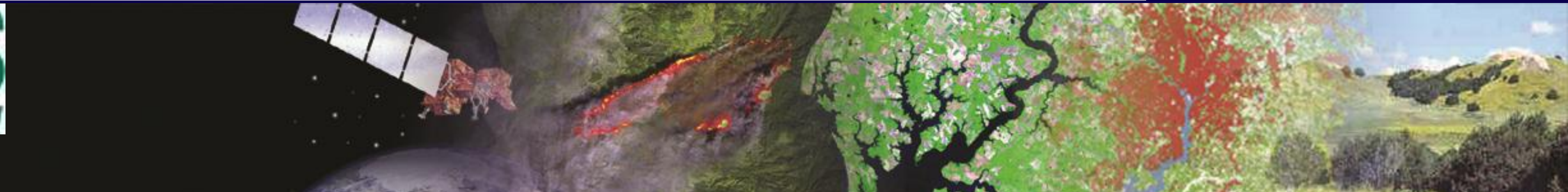
Delineating irrigated from others

Automated Cropland\Fallowland Classification Algorithm (ACCA)

Algorithm Development based on MODIS, Landsat, and Secondary Data



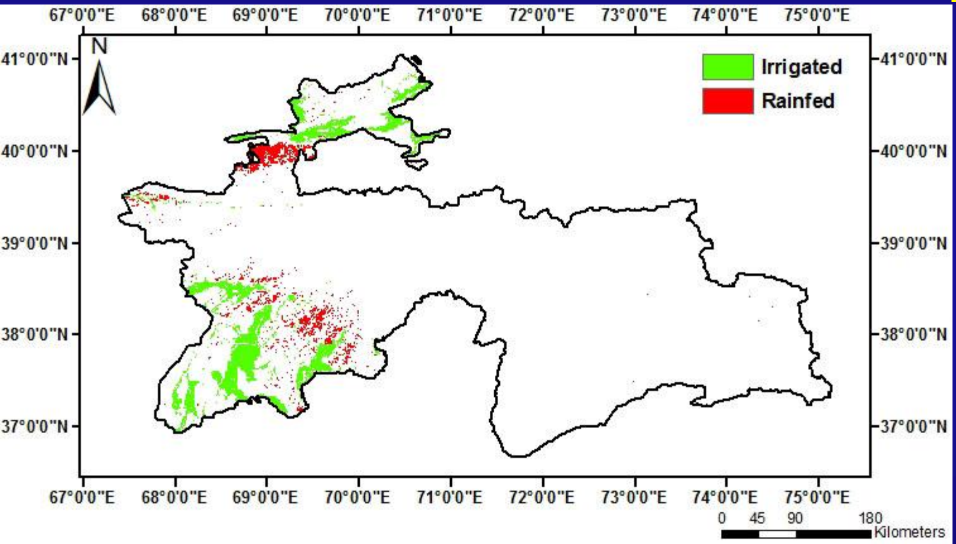
Delineating rainfed from others



Irrigated + Rainfed Areas of Tajikistan: Full Country View
Comparison: Truth Layer vs. Algorithm Derived Layer

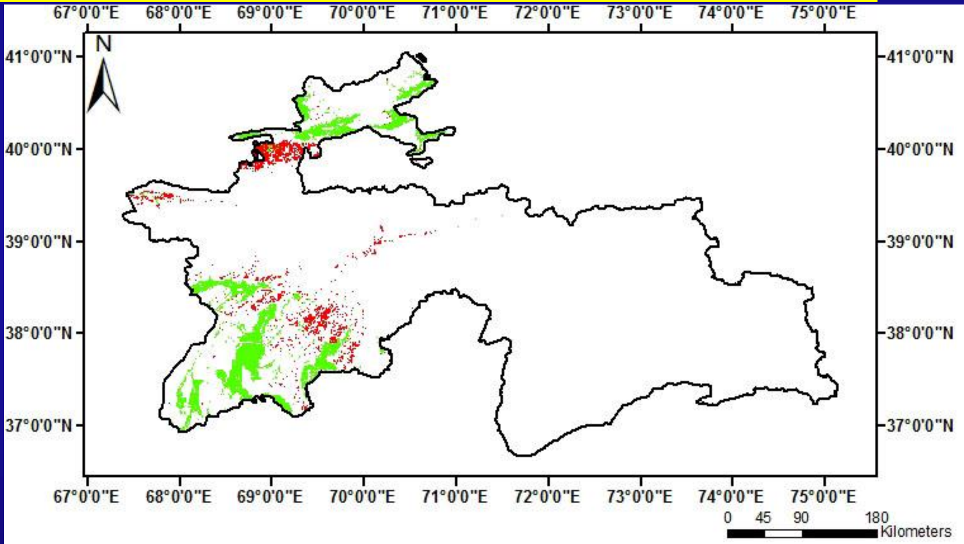
Thenkabail, P.S.; Wu, Z. An Automated Cropland Classification Algorithm (ACCA) for Tajikistan by Combining Landsat, MODIS, and Secondary Data. *Remote Sens.* 2012, *4*, 2890-2918.

Truth Layer (truth) for year 2005



30 m spatial resolution

Algorithm derived layer also for year 2005

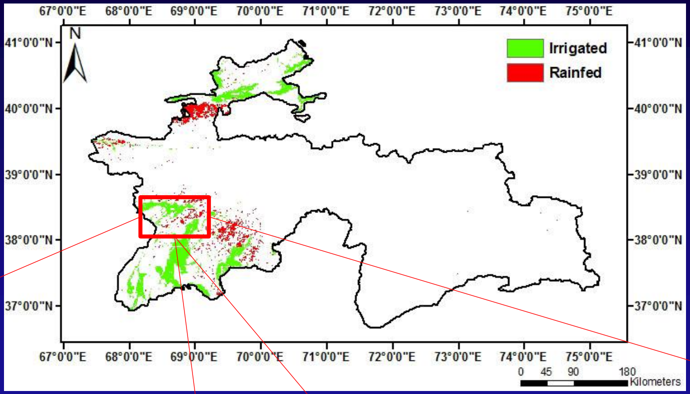


30 m spatial resolution

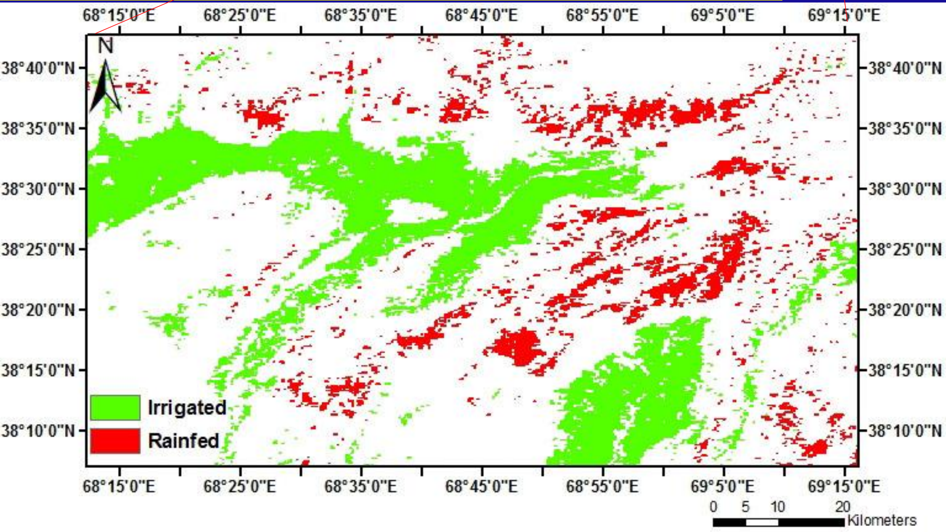
Note: Once you have the algorithm, it takes only a few minutes to derive irrigated and rainfed areas.

Irrigated + Rainfed Areas of Tajikistan: Zoom in View

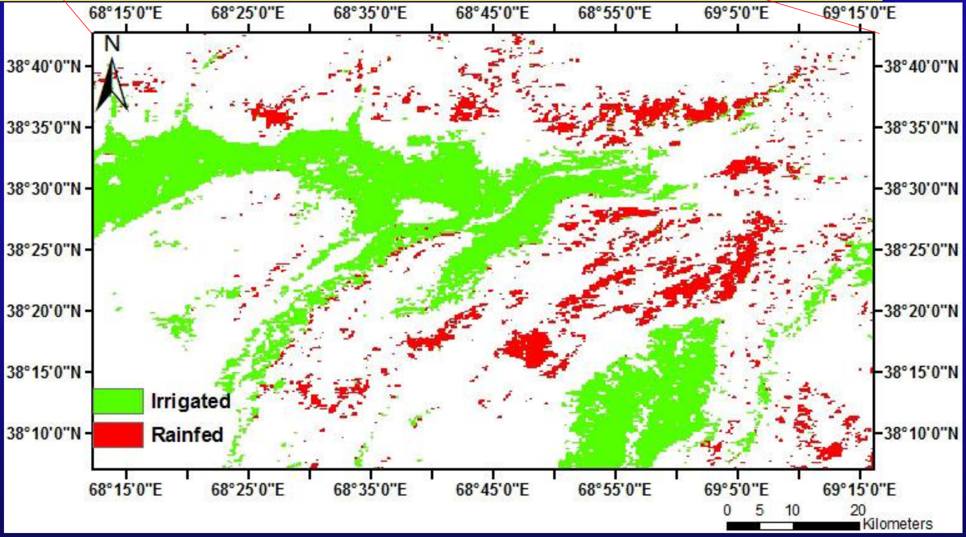
Comparison: Truth Layer vs. Algorithm Derived Layer



Truth Layer (truth) for year 2005



Algorithm derived layer also for year 2005

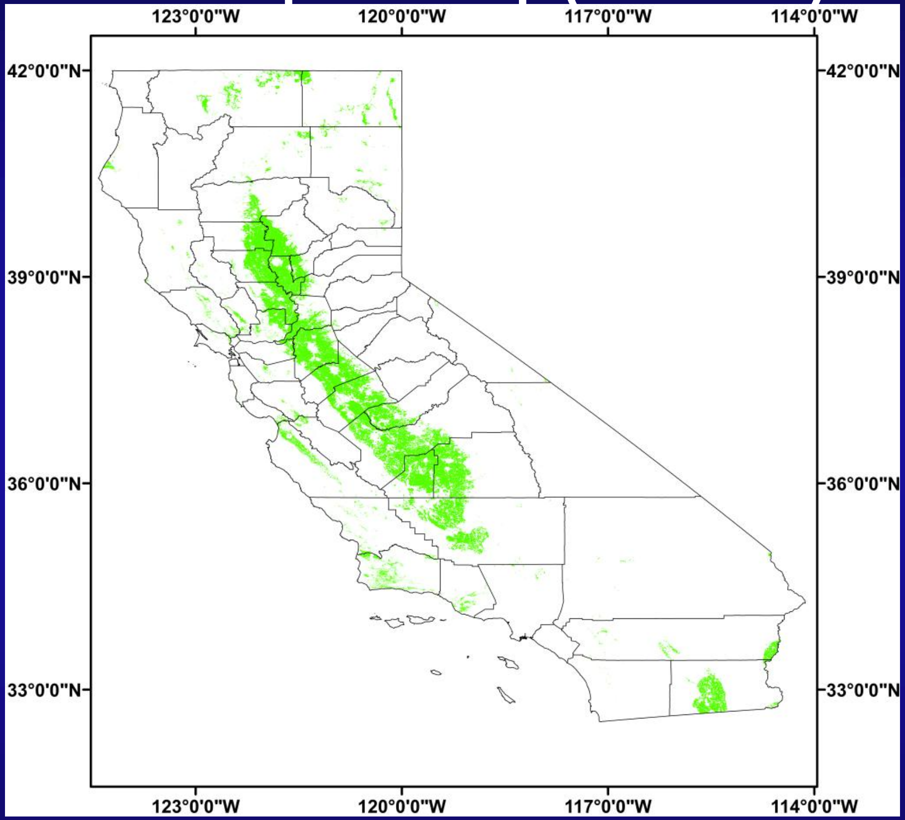


Note: Once you have the algorithm, it takes only a few minutes to derive irrigated and rainfed areas.

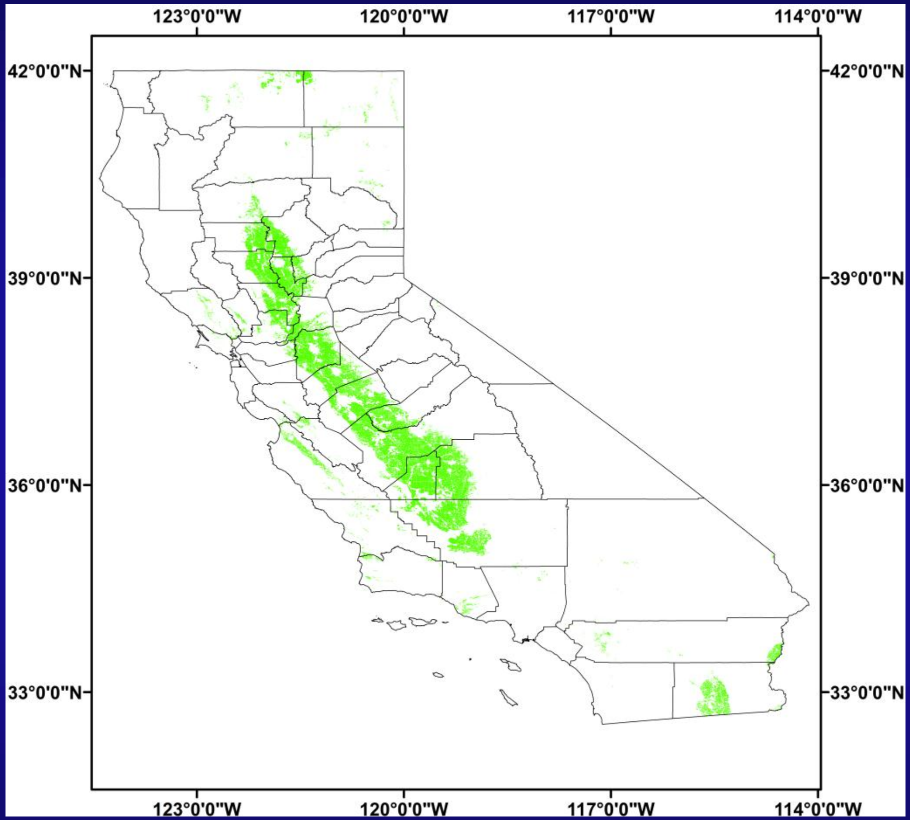
Automated Cropland\Fallowland Classification Algorithm (ACCA)

ACL2007 (algorithm) versus CTL2007 (USDA CDL)

ACCA applied for year 2007: cropland map (ACL2007)



USDA CDL 2007: Cropland map (CTL2007)



Note: once the data layer is ready, this layer was generated automatically by ACCA in about ~60 minutes on DELL Precision T7400 desktop

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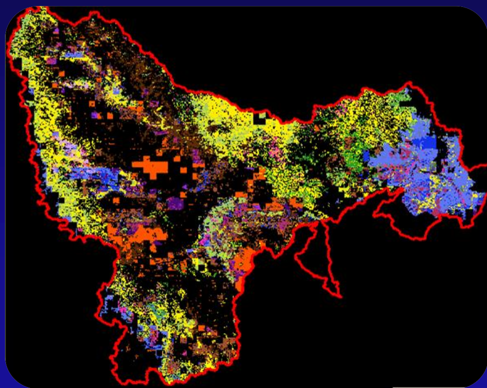
Cropland Mapping Over Large Areas

Uncertainties and Overcoming Uncertainties using Earth Observation Data @ Various Resolutions

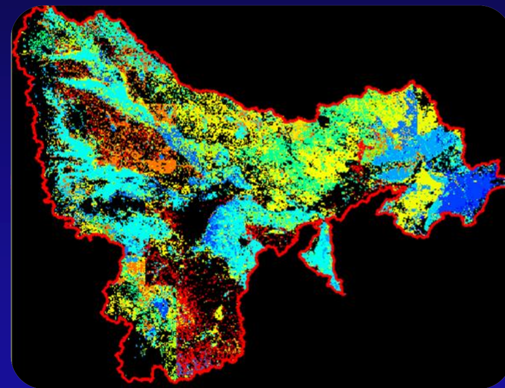
Uncertainties in Cropland Area Locations and Areas

Use of Finer Spatial resolution Data to Reduce Uncertainty

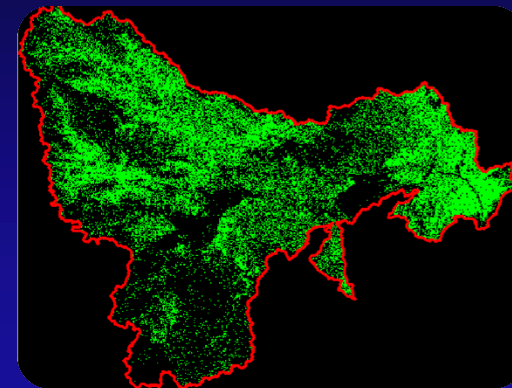
Spatial Distribution of irrigated areas in different resolutions (Velpuri et al., 2009)



AVHRR 10 km



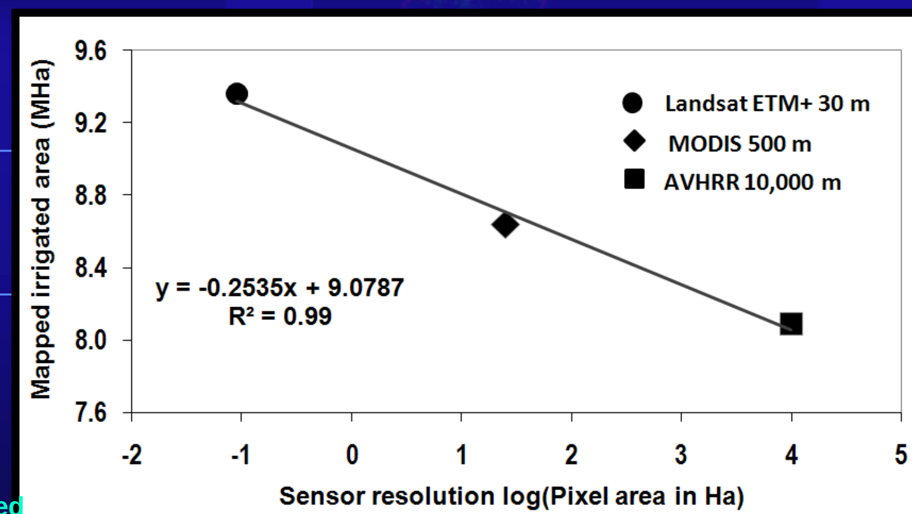
MODIS 500 M



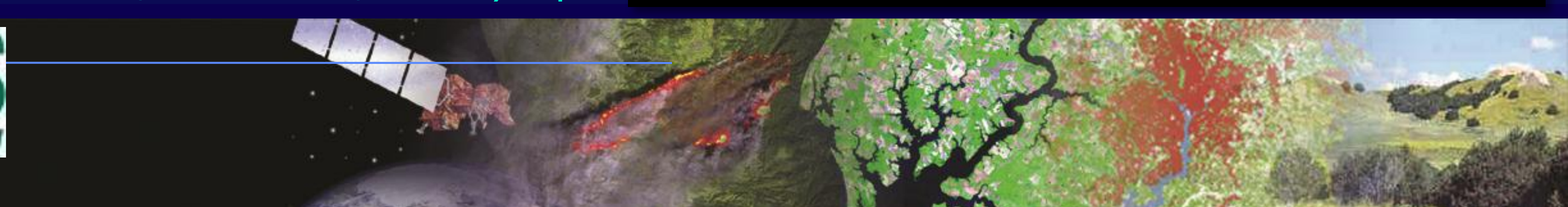
LANDSAT 30 M

Irrigated areas in different resolutions

Resolution of data (in meters)	Area (M ha)
NOAA AVHRR10 km	**8.09**
TERRA MODIS 500 m	**8.64**
LANDSAT ETM+ 30 m	**9.36**



Finer the spatial resolution greater is the area….since at finer resolution fragmented areas (from ground water, small reservoirs, and tanks) are picked better.



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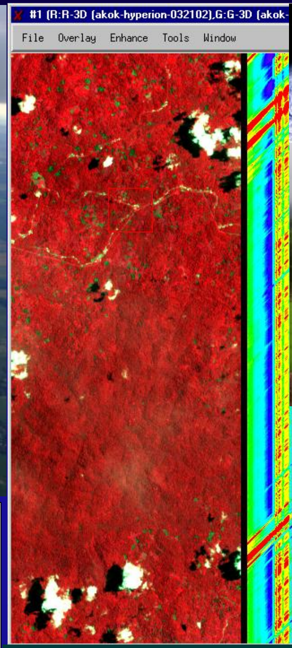
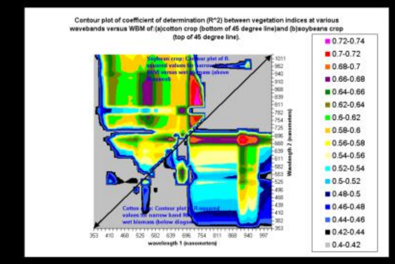
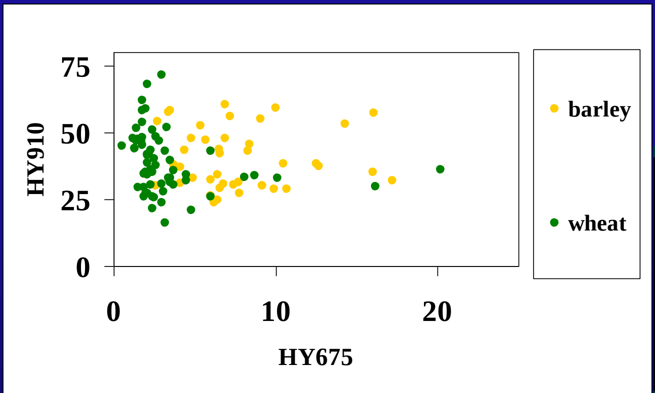
U.S. Department of Interior

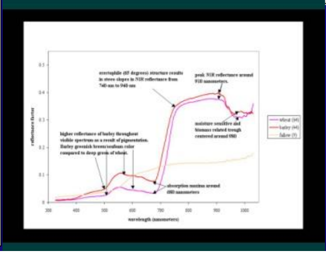
Uncertainties in Cropland Area Locations and Areas

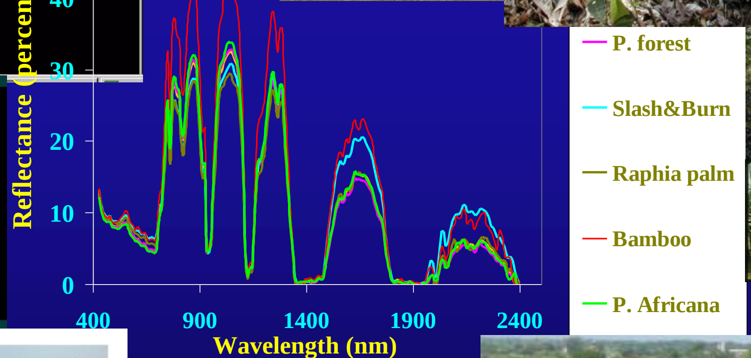
Use of Finer Spectral Resolution Data to Reduce Uncertainty

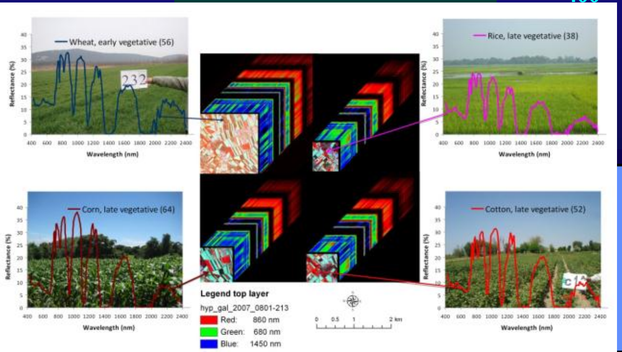












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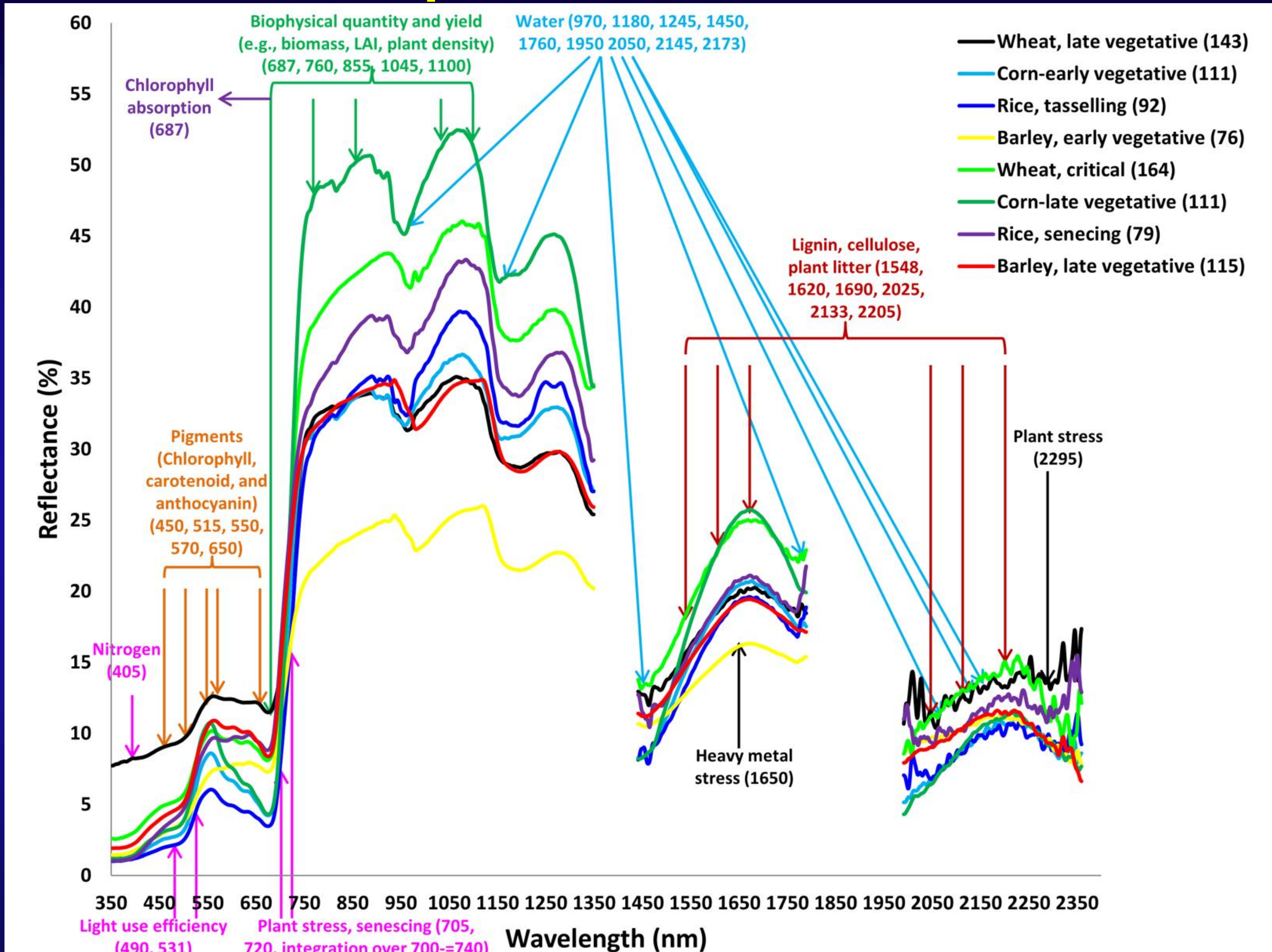
Uncertainties in Cropland Area Locations and Areas

Use of Finer Spectral Resolution Data to Reduce Uncertainty



Exploring Hyperspectral narrowbands (HNBs) and hyperspectral vegetation indices (HVIs) that specifically Target Specific Plant Biophysical and Biochemical Properties

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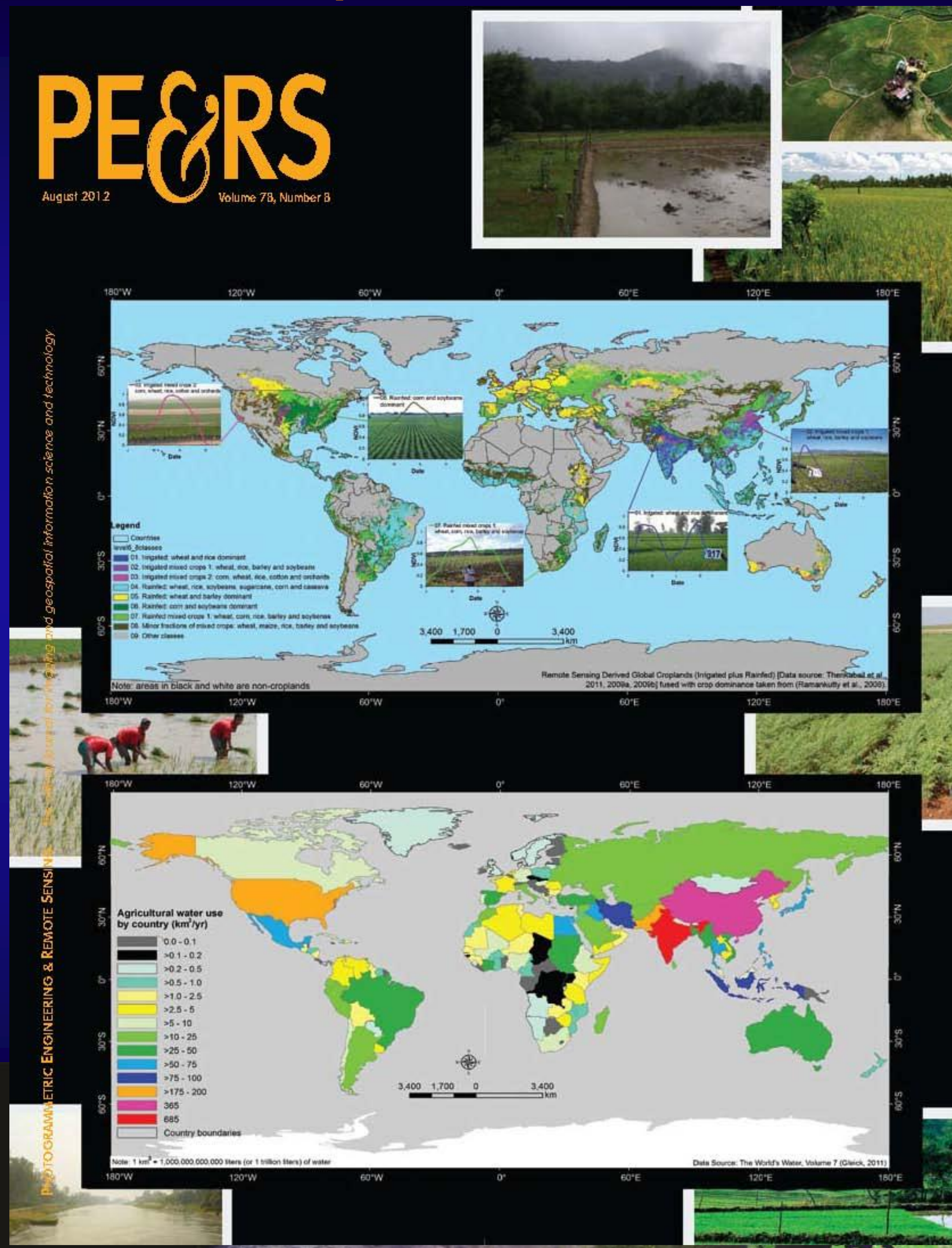
Publications

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

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



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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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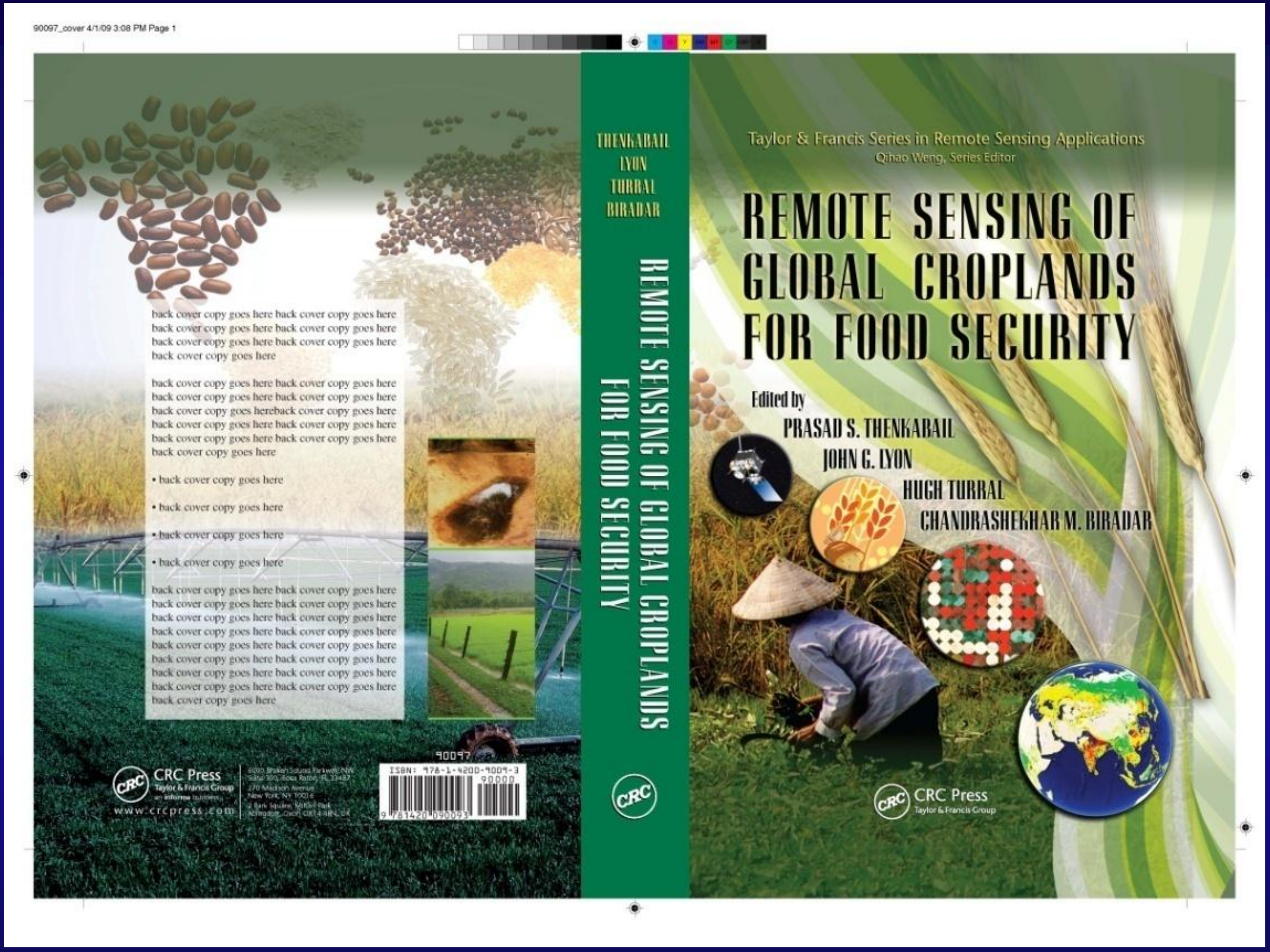
GIAM and GMRCA

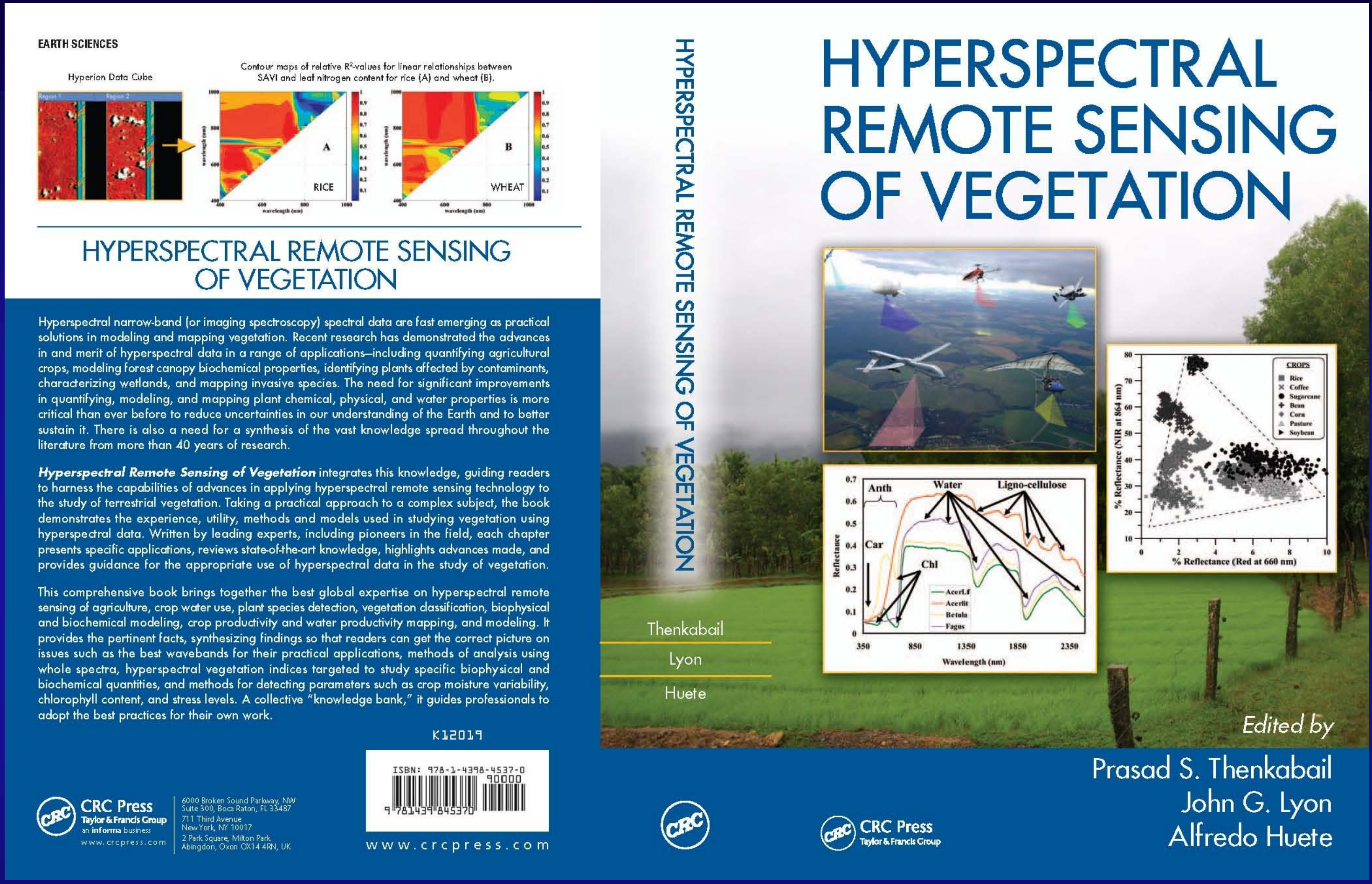
Peer-Review Publications: Book, Web Portal, Journal Articles



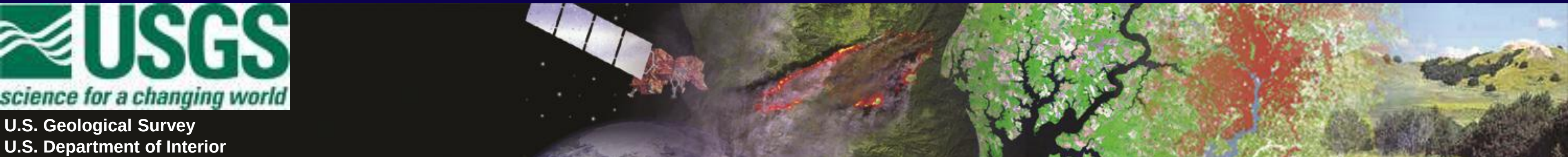
Thenkabail. P., Lyon, G.J., Turral, H., and Biradar, C.M. 2009a. Book entitled: "Remote Sensing of Global Croplands for Food Security" (CRC Press- Taylor and Francis group, Boca Raton, London, New York. Pp. 556 (48 pages in color). Published in June, 2009.

Hyperspectral Remote Sensing Vegetation

References Pertaining to this Presentation



Thenkabail, P.S., Lyon, G.J., and Huete, A. 2011. Book entitled: "Advanced Hyperspectral Remote Sensing of Terrestrial Environment". 28 Chapters. CRC Press- Taylor and Francis group, Boca Raton, London, New York. Pp. 781 (80+ pages in color).



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