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Science for Better Livelihoods in Dry Areas

Satellite-based modelling and monitoring of grasslands, croplands and land degradation

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CGIAR RESEARCH PROGRAM ON Dryland Systems

ELD CA 1st Inception
Antalya, 23-25, 2015

Multi-sensor and multi-scale observations of carbon, water, energy and greenhouse gases fluxes at farmscape to landscape scales

to address issues related to

Productivity of Croplands, Grasslands and Livestock and Tree based systems

Land Degradation and Desertification

Key Questions

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1. What and Where are those degraded lands?

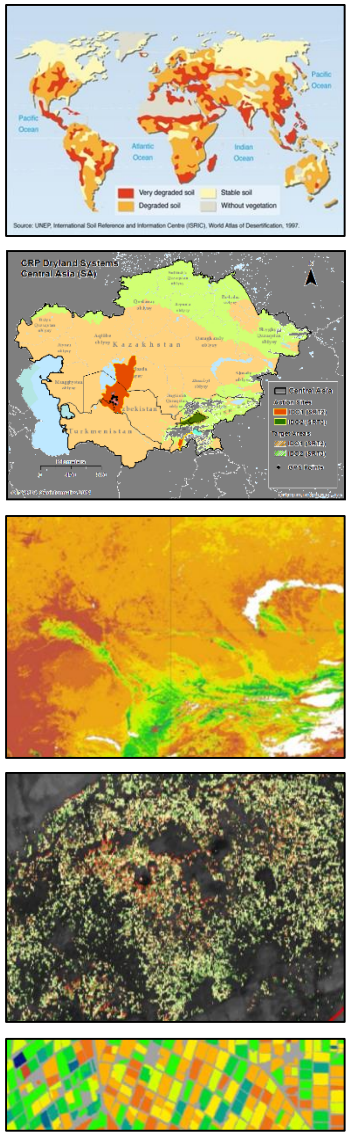
- ✓ How much, where, and what magnitude?
- ✓ What is dominant patterns, trends, and scale?
- ✓ How to prioritize and delineate hot spots?

2. What is the economic cost in loss and recovery?

- ✓ How much are we loosing? What is the cost of reclaiming? How to reduce the assumptive estimates?
- ✓ How to assess impact of program failures/success?
- ✓ What are key drivers, shocks and ecosystem services?

3. Where are the positive and negative dynamics?

- ✓ Where are the low hanging and not reachable fruits?
- ✓ What we can achieve in short/medium/long term?
- ✓ What agricultural livelihoods systems (ALS)?



Dryland Systems

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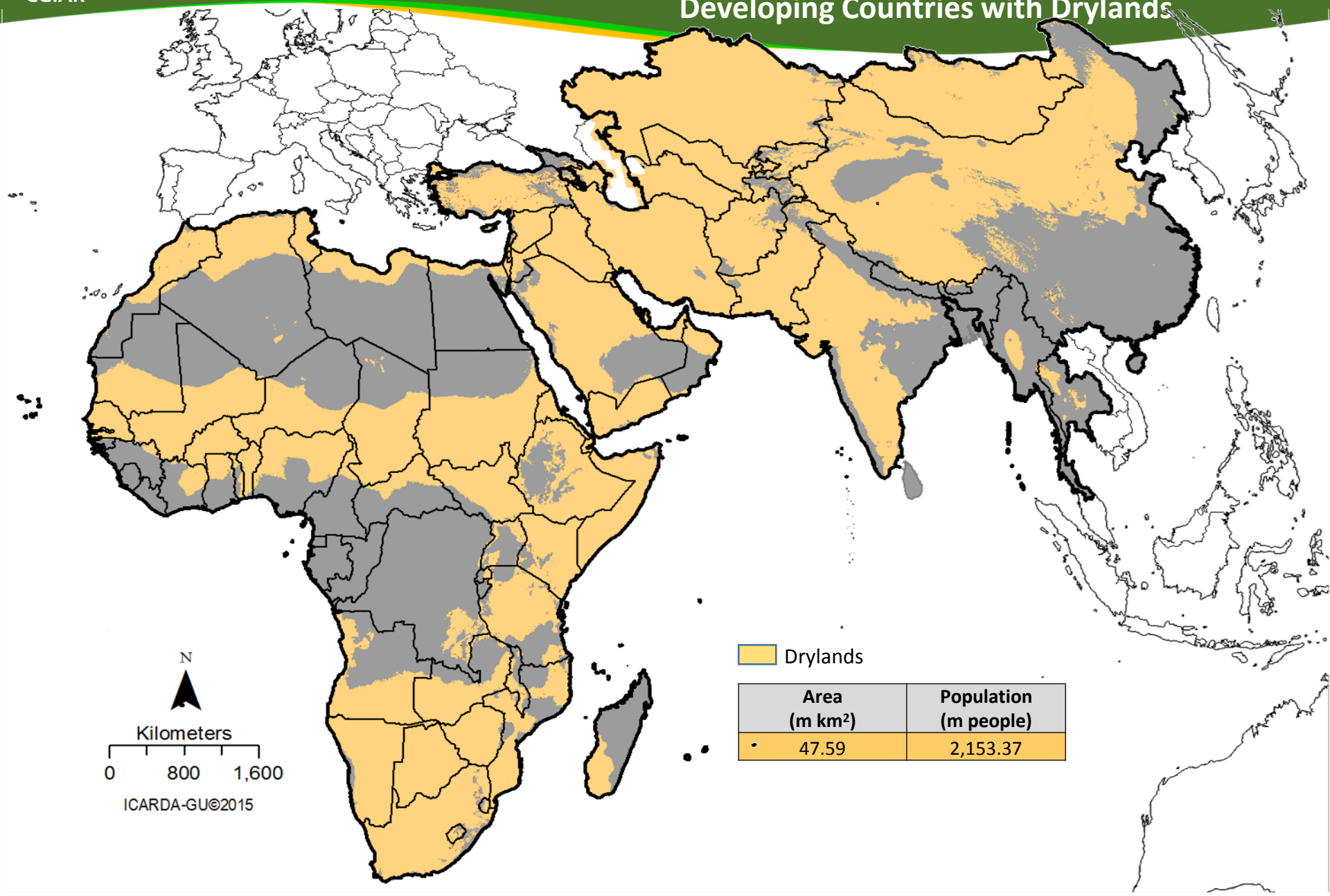
Developing Countries with Drylands



Area (m km²)	Population (m people)
47.59	2,153.37

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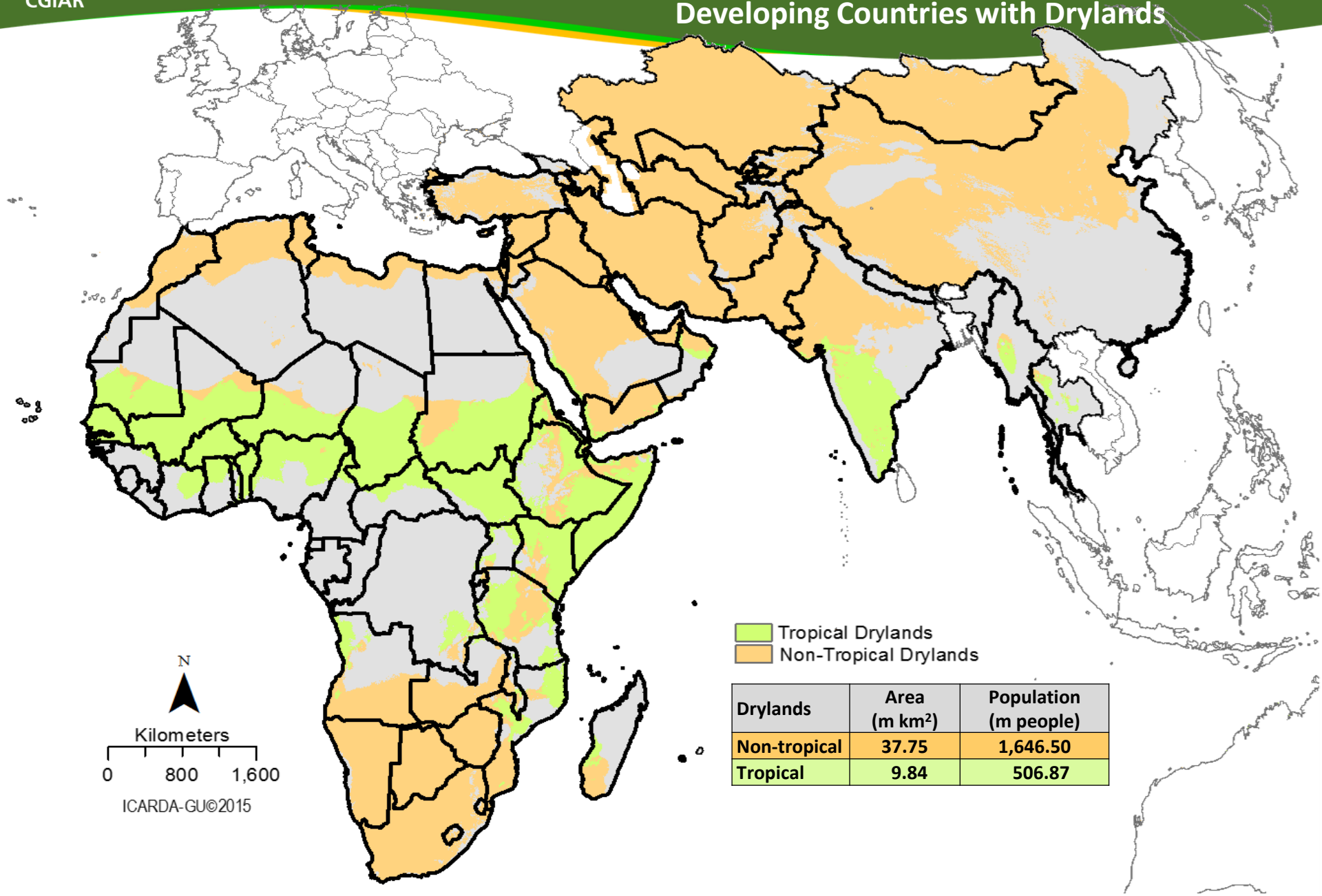

Drylands	Area (m km²)	Population (m people)
Non-tropical	37.75	1,646.50
Tropical	9.84	506.87

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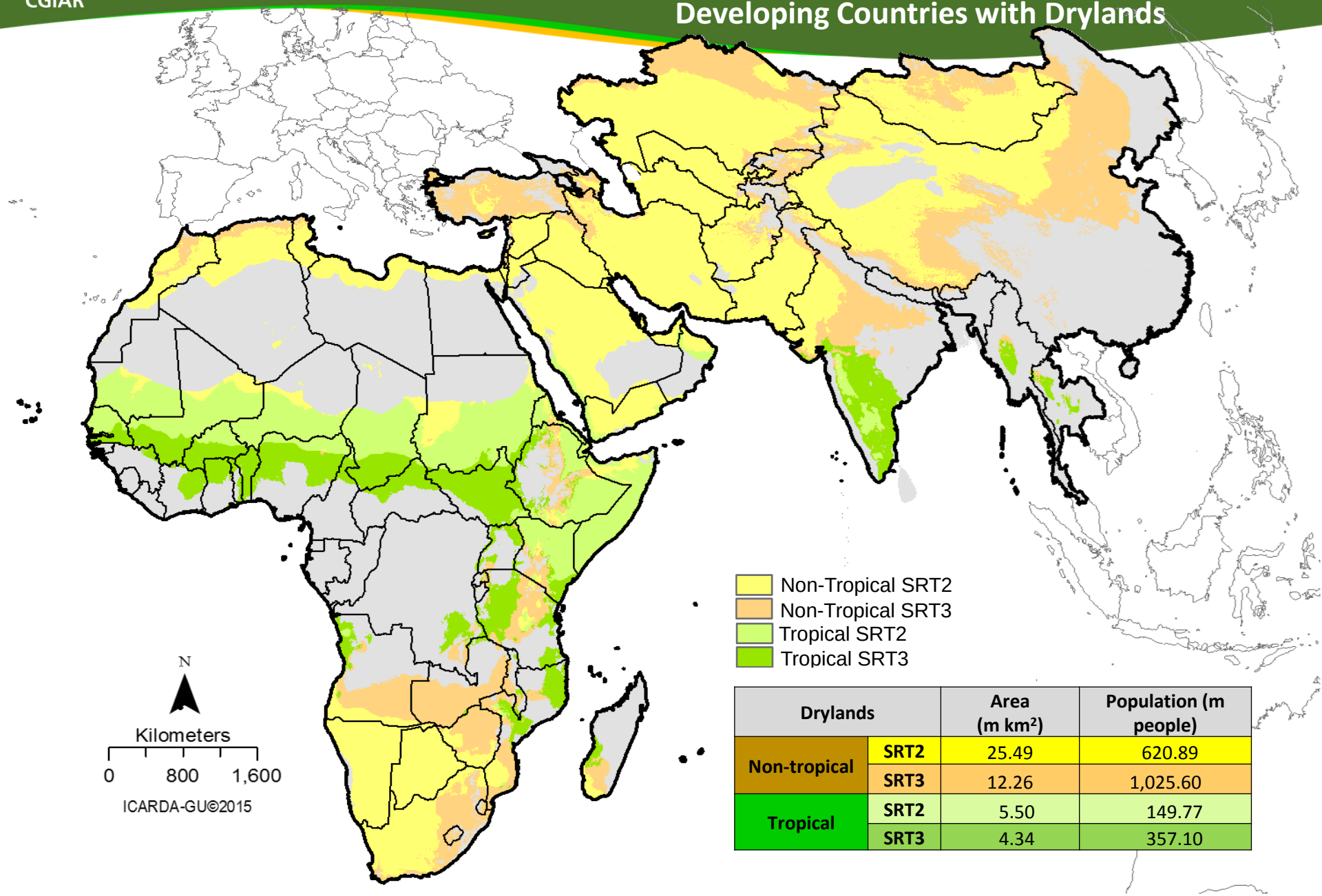

Drylands		Area (m km²)	Population (m people)
Non-tropical	SRT2	25.49	620.89
	SRT3	12.26	1,025.60
Tropical	SRT2	5.50	149.77
	SRT3	4.34	357.10

Dryland Systems

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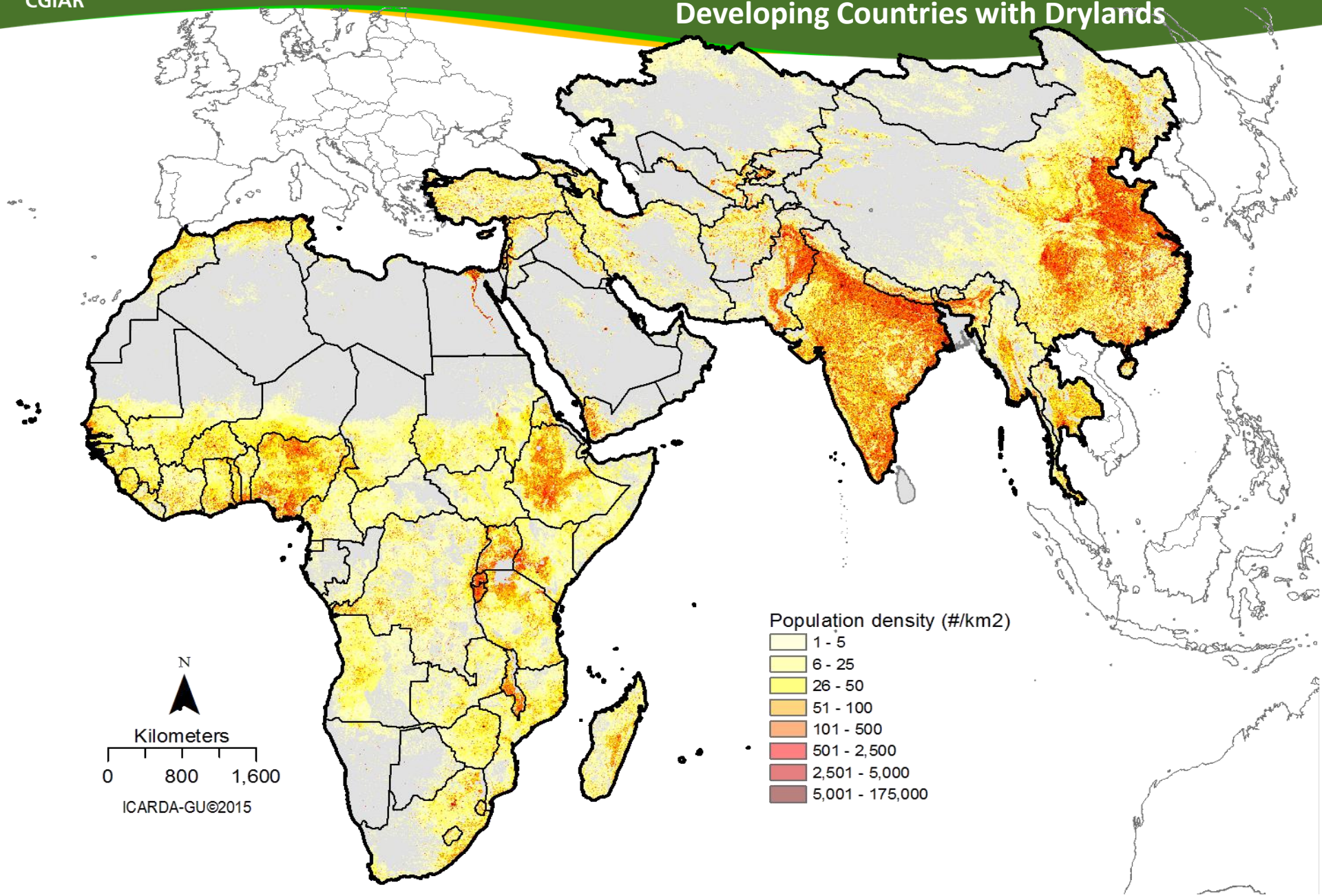

Yield Gap in the Drylands

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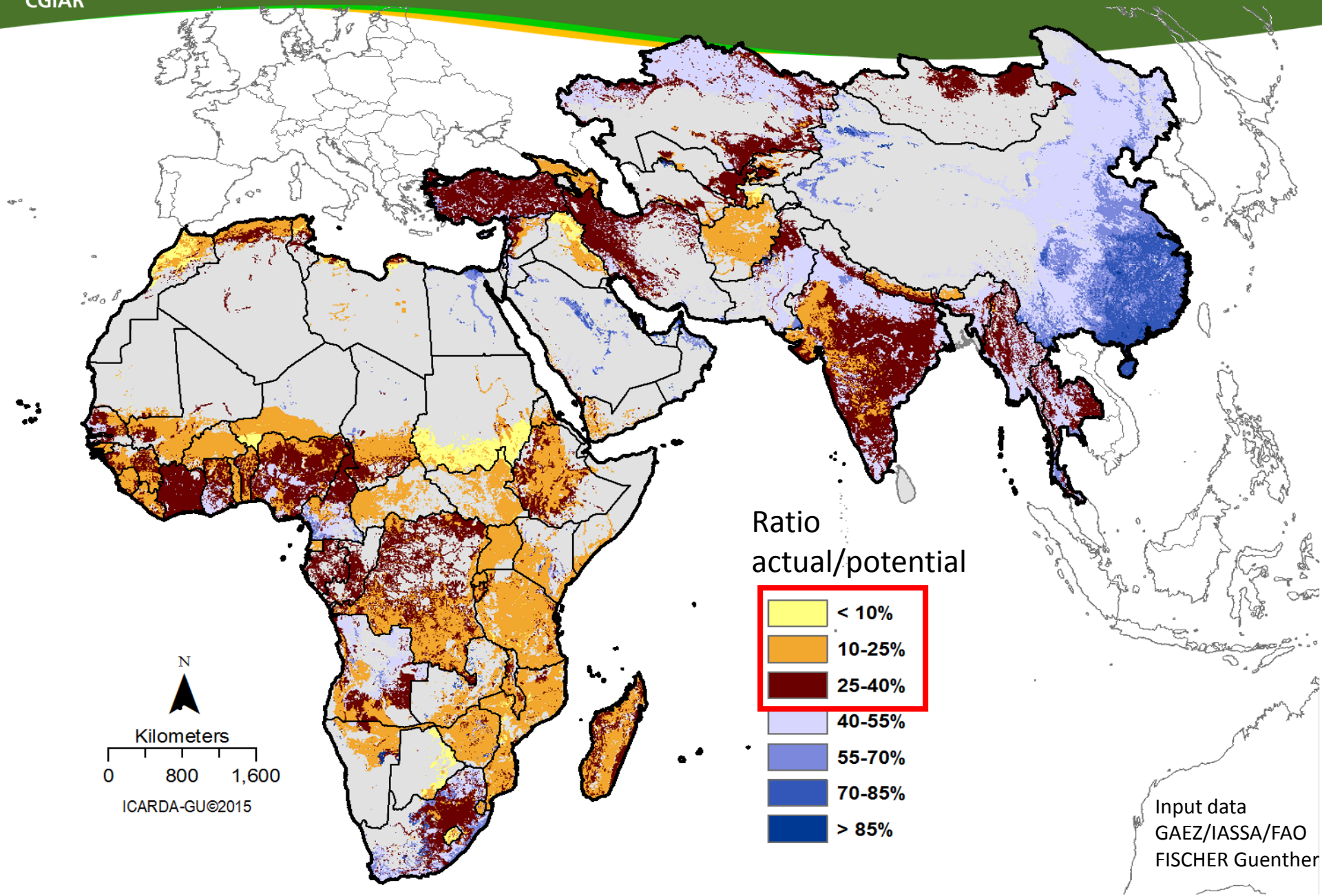

Yield Potential in Marginal Drylands

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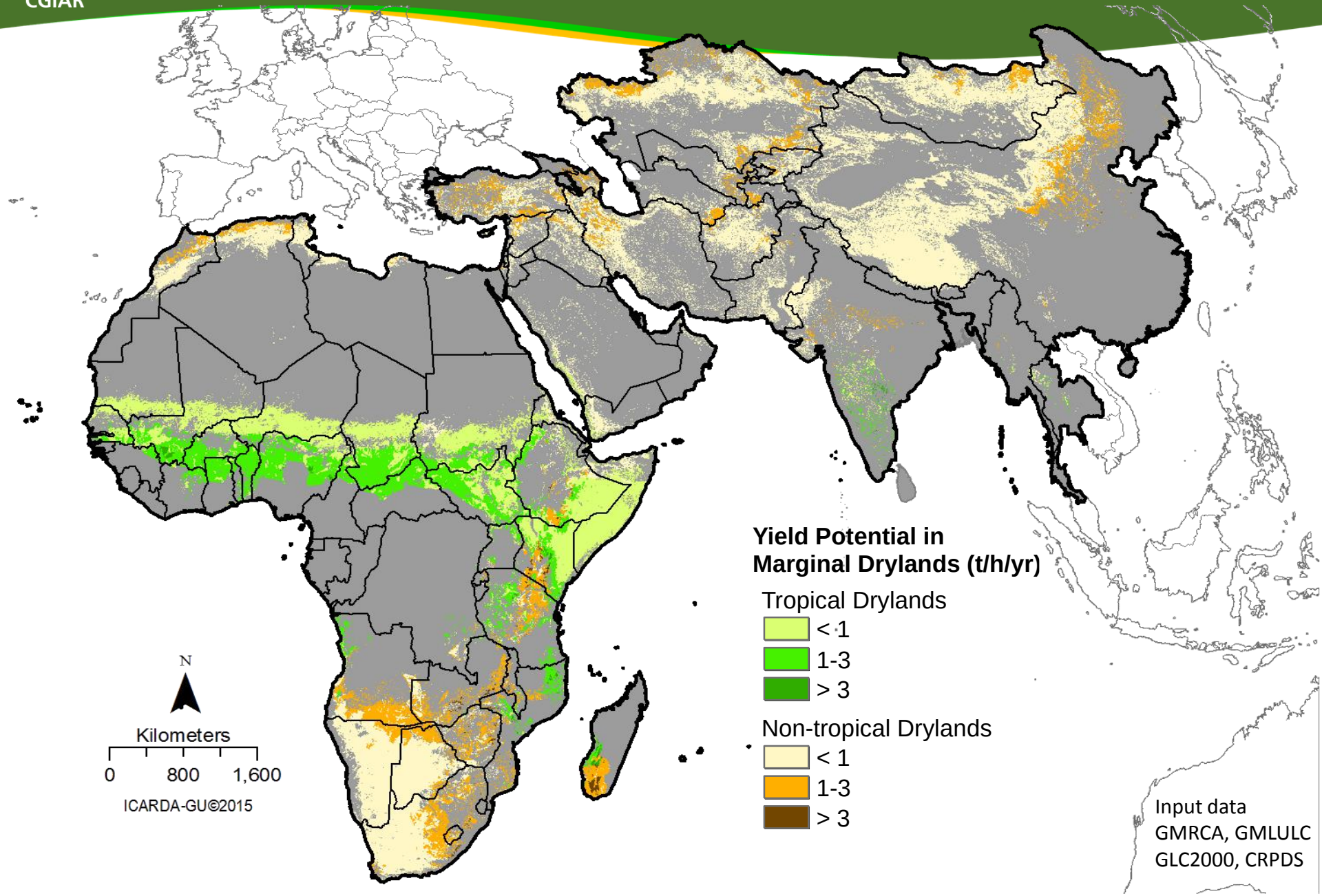
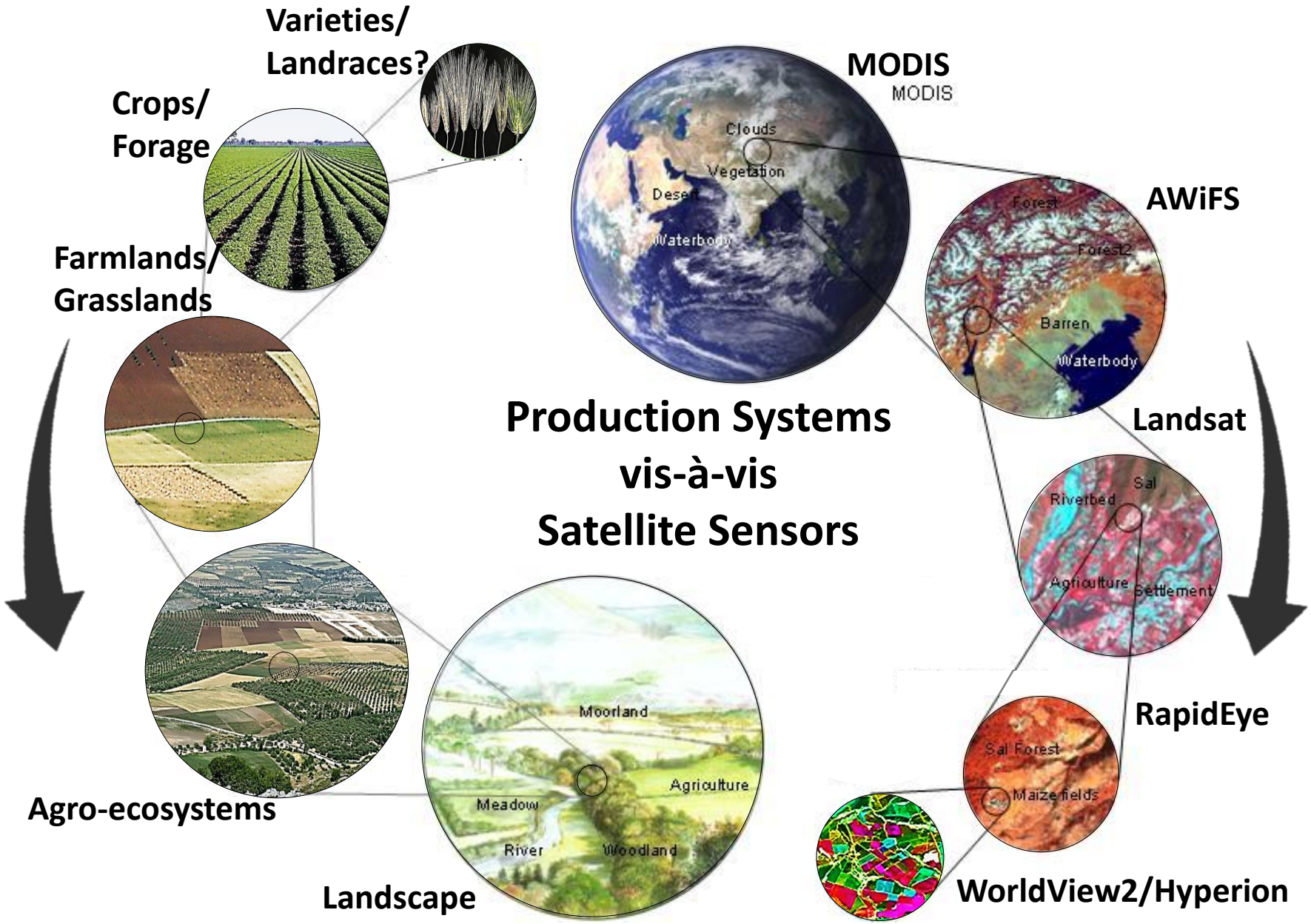
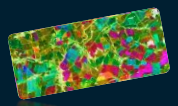
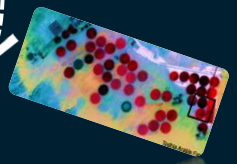


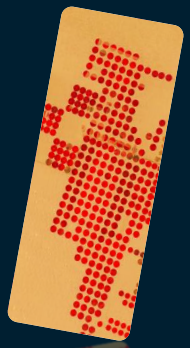

Varieties/
Landraces?
Crops/
Forage
Farmlands/
Grasslands
Agro-ecosystems
Landscape
MODIS
MODIS
Clouds
Vegetation
Desert
Waterbody
AWiFS
Forest
Forest2
Barren
Waterbody
Landsat
Riverbed
Sal
Agriculture
Settlement
RapidEye
Sal Forest
Maizefields
WorldView2/Hyperion
Production Systems
vis-à-vis
Satellite Sensors
Moorland
Agriculture
Meadow
River
Woodland

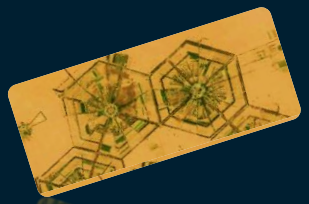
Earth Observation Systems for Agro-Ecosystem Research

SATELLITE AND SENSORS CHARACTERSTICS









Very High Resolution (Up to - 1 m)

Satellite Sensors	Resolution			Swath (km)
	Spatial (m)*	Temporal (days)	Spectral (Bands)	
GEOEYE-1	1.65 (0.41)	1	B, G, R, IR, P	15.2
IKONOS	3.2 (0.82)	14	B, G, R, IR, P	11.3
PLEIADES-1A	2 (0.5)	1	B, G, R, IR, P	20
PLEIADES-1B	3 (0.5)	1	B, G, R, IR, P	20
Quick Bird	2.4 (0.6)	3.5	B, G, R, IR, P	16.5
WorldView-1	(0.4)	1.2	P	17.6
WorldView-2	1.8 (0.4)	1.2	P, C, B, G, Y, R, RE, IR (2)	16.4
CARTOSAT-2	1	5	P	9.6
CARTOSAT-2a	<1	4	P	9.6
CARTOSAT-2B	<1	4	P	9.6
SKYSAT-1	2 (0.9)	<1 (hourly)	B, G, R, IR, P	8
KOMPSAT-3	2.8 (0.7)	14	B, G, R, IR, P	16.8
KOMPSAT-2	4 (1)	14	B, G, R, IR, P	15
OrbView-3	4 (1)	3	B, G, R, IR, P	14

High Resolution (1 to 5 m)

Satellite Sensors	Resolution			Swath (km)
	Spatial (m)*	Temporal (days)	Spectral (Bands)	
CARTOSAT-1	(2.5)	5	P	30
FORMOSAT-2	8 (2)	1	B, G, R , IR, P	24
SPOT-5	5, 20 (2.5, 5)	2-3	G, R, IR, SW, P	60 to 80
SPOT-6 (1.5)	6 (1.5)	2-3	B, G, R , IR, P	60
RapidEye	5	1	B, G, R, RE, IR	77
RESOURCESAT-1	5.8	5	G, R, IR	23, 70
GOKTURK-2	10, 20 (2.5)	2.5	B, G, R, IR, SW, P	20
TH-2	10 (2)		B, G, R, IR,P	60
EROS-A	(1.8)	2.1	P	14
Theos	15 (2)	3	B, G, R, IR	96
BEIJING-1	32 (4)	1	R G, IR	600
PROBA/HRC	18, 34 (5)	7	18	15

Medium resolution (5 - 30 m)

Satellite	Multispectral resolution (m)	B, s	Swath width (km)
ASTER (15m)			
VNIR (Visible Near Infrared)	15	VIR (4)	60
SWIR (Shortwave Infrared)	30	SW (6)	60
TIR (Thermal Infrared)	60	TIR (5)	60
CBERS - 2			
WFI	260	R, IR	890
CCD	20	B, G, R, IR	113
IRMSS	(2.7)	P-	27
LANDSAT 5TM -7ETM	30 (14.8)	B, G, R, IR, SW1, TIR, SW2, P	185
Nigeriasat-X	22	G, R, IR	-
Resourcesat-2/Liss-III	23.5	R, G, IR, SW	141
Deimos-1	22	G, R, IR	600
UK-DMC-2/SLIM6	22	G, R, IR	638
BILSAT-1	26 (12)	R, B, G, IR, P	640
Nigeriasat-1	32	G, R, IR	640
ALSAT-1	32	G, R, IR	640
UK-DMC/EC (DMC)	32	G, R, IR	600
EO-1/ALI-MS	30	B (2), G, R, IR (3), SW (2), P	37
EO-1/ Hyperion	30	220 bands	7,7
ASTER (15m)	15, 30, 90	G, R, IR (2) SW(6), TIR (4)	60
LANDSAT 7ETM+	30m (14.5)	B, G, R, IR, SW (2), TIR, P	185
SPOT-4	20 (10)	G, R, IR, SW, P	60
SPOT-3	20 (10)	G, R, IR+P	60
JERS-1	24 (18)	G, R, IR, IR	75
SPOT-2	20 (10)	G, R, IR	60
SPOT-1	20 (10)	G, R, IR	60
Landsat 5/MSS	80	G, R, IR, IR	185
Landsat 5/TM	30, 120	B, G, R, IR, SW, SW, TIR	185
RESURS-01-1	45	G, R, IR	600

Low or Medium resolution

Satellite	Multispectral resolution (m)	B, s	Swath width (km)
Landsat 8	30 (14.8)	P, C, B, G, R, IR, SW (3)	185
VIIRS	375, 750	22b, s	3000
ASAR	(12.5)	VV 1	5 - 406
MERIS	300	15 b, s	1150
Metosat MSG			
GERB	40000	7	-
SEVIRI	1000, 3000	12	-
SPOT5/VEGETATION 2	1000	B, R, IR, SW (4)	2250
MODIS	250, 500, 1000	36	2330
SPOT4/VEGETATION 1	1000	B, R, IR, SW (4)	60
IRS-1D/ WiFS	188	R, IR (2)	774
Orbview-2/ SeaWiFS	1130	B(2), G (3), IR (8)	2800
IRS-1C/ WiFS	188	R, IR (2)	810
RESURS-01-1/ MSU-S	240	G, R, IR (3)	600
RESURS-01-1/ MSU-SK	170, 600	R, G, IR(2), TIR	600
ResourceSat/AWiFS	56	R, G, IR, SW	740
Landsat 2/ MSS	80	G, R, IR, IR	183
Landsat 2/ RBV	80	G, R, IR	183
Landsat 1/ MSS	80	G, R, IR, IR	183
Landsat 1/ RBV	80	G, R, IR	183

Radar Satellites

Satellite	Bands	Band (Polarity)	Swath width (km)
Sentinel-1			10, 40, 30, 100,
COSMO-SKYMED 4	1, 5, 15, 30, 100	X-B (HH, VV, HV, VH)	200
TanDEM-X	1, 3, 16	X-B (HH, VV, HV, VH)	1500
COSMO_SKYMED 2	1, 5, 15, 30, 100	X-B (HH, VV, HV, VH)	10, 40, 30, 100, 200
RADARSAT 2	3, 8, 12, 18, 25, 30, 40, 50, 100	C-B (HH, HV, VH, VV)	5 - 500
COSMO-SKYMED 1	1, 5, 15, 30, 100	X-B (HH, VV, HV, VH)	10, 40, 30, 100, 200
Terra SAR-X	1, 3, 16	X-B (HH, VV, HV, VH)	1500
ALOS (PALSAR)	10, 20, 30, 100	L-B (HH, VV, HH, HV, VH)	70
ENVISAT (ASAR)	12.5	C-B (VV)	5 - 406
RADARSAT 1 (SAR)	8,25, 30, 35, 50, 100	C-B (HH)	50 - 500
ERS 2 (AMI)	25	C-B (VV)	100
ERS 1 (AMI)	25	C-B (VV)	100

*=Resolution in parenthesis is panchromatic
+=Bands: B-Blue, G-Green, R-Red, IR-Infra Red, C-Coastal blue, Y-Yellow, SW-Shortwave Infrared, M-Mid infrared, P-Panchromatic, H-Horizonal, V-vertcial

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Remote Sensing Matrix for Agro-ecosystems

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Quantification and Characterization

Example of One Sensor in each Platform

	Platforms	Ground/*in-situ*		Airborne		Spaceborne				
	Mode	Hyperspectral	Multispectral	Optical	LiDAR	Optical			LiDAR	SAR
RS data characteristics	Sensor	ASD FieldSpec	M× Camera	APs/UAVs	Lidar	WorldView-2	Landsat	MODIS	ICESat*	PALSAR
	Spectral	350-2500nm	4 bands	3-4 bands	1264nm	8 bands	7 bands	7/36 bands*	1264 & 532nm	L band
	Spatial resolution	0.1-1.5m	0.1-0.2m	1-m	20 - 80cm	0.46m Pan; 1.84m MS	15m Pan; 30m MS	250m, 500m, 1000m MS	70m	10m, 20m, 100m
	Swath	1-4m	2-10m	--	1-2km	16.4km	185km	2330km		35-250km
	Revisit	--	--	3-year	--	1.1 days	16 days	1 day	91 days	46 days
Biophysical	Plant biomass	×	×		×	×	×	×		×
	Plant height				×				×	×
	LAI, fPAR, LST	×	×			×	×	×		
	NDVI, EVI, LSWI	×	×	×		×	×	×		
Biochemical	Erosion, Salinity	×	×	×	×	×	×	×		
	Soil moisture	×	×	×		×	×			×
	Chlolophyll	×	×	×		×	x	×		
	Nitrogen	×	×	×		×	×			
	Phosphorous	×	×			×				
	Plant water	×	×			×		×		
Production	GPP	×	×	×		×		×		
	NPP	×				×	×	×		
LULC	land cover/use	×	×	×		×	×	×		×
	phenology	×	×				x	×		×
	Irrigation	×	×	×		×	×	×		×
Terrain	DEM		×	×	×	×			×	×
	Derivatives		×	×	×				×	×
Scale	Tier 1 AOIs	×	×	×	×	×	×	×	×	×
	Tier 2 action sites	×	×	×			×	×	×	×
	Tier 3 AEZs	×	×	×				×	×	×
	Tier 4 Target			×				×		×

Satellite-based Production Efficiency Models (PEMs)

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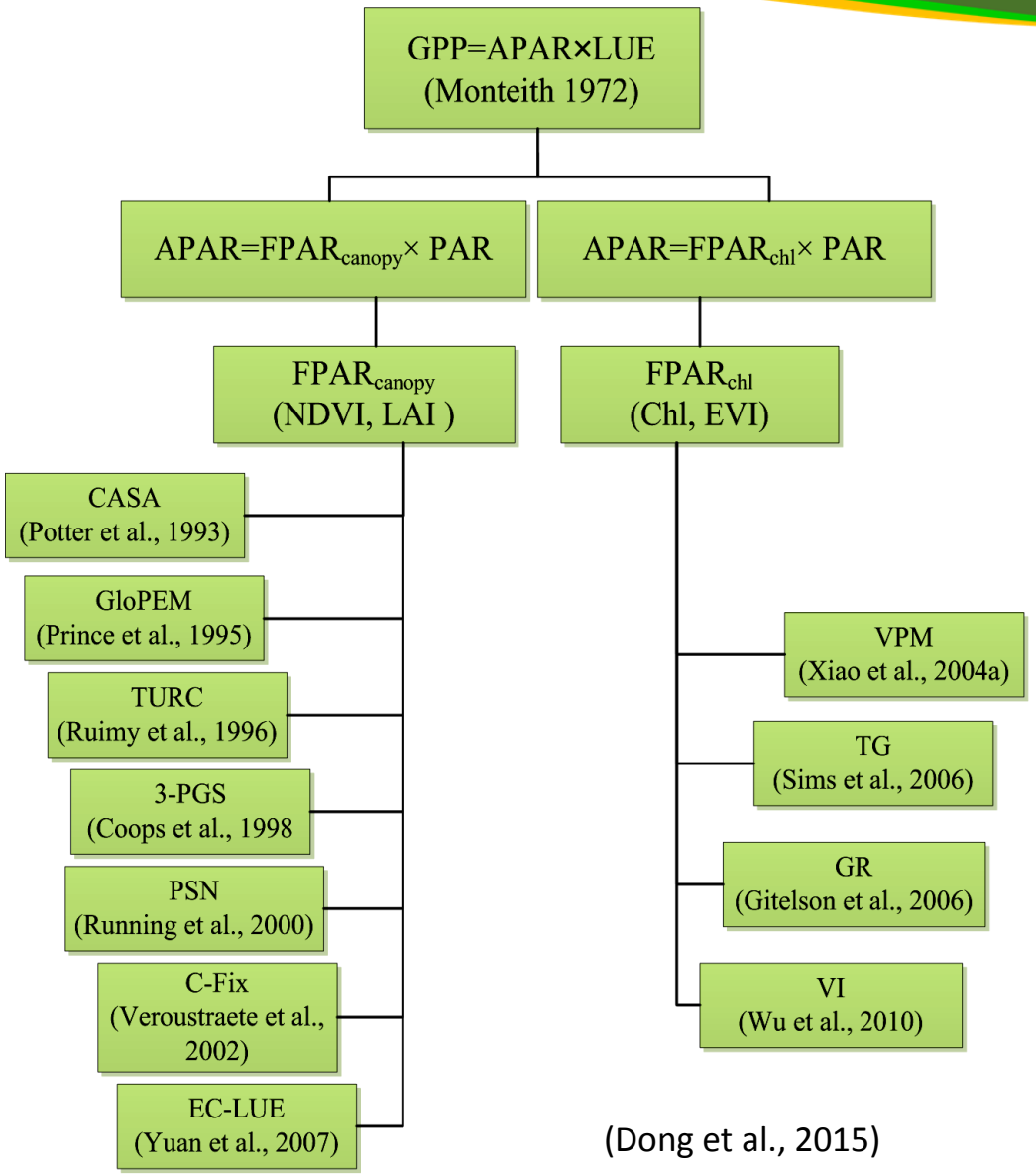
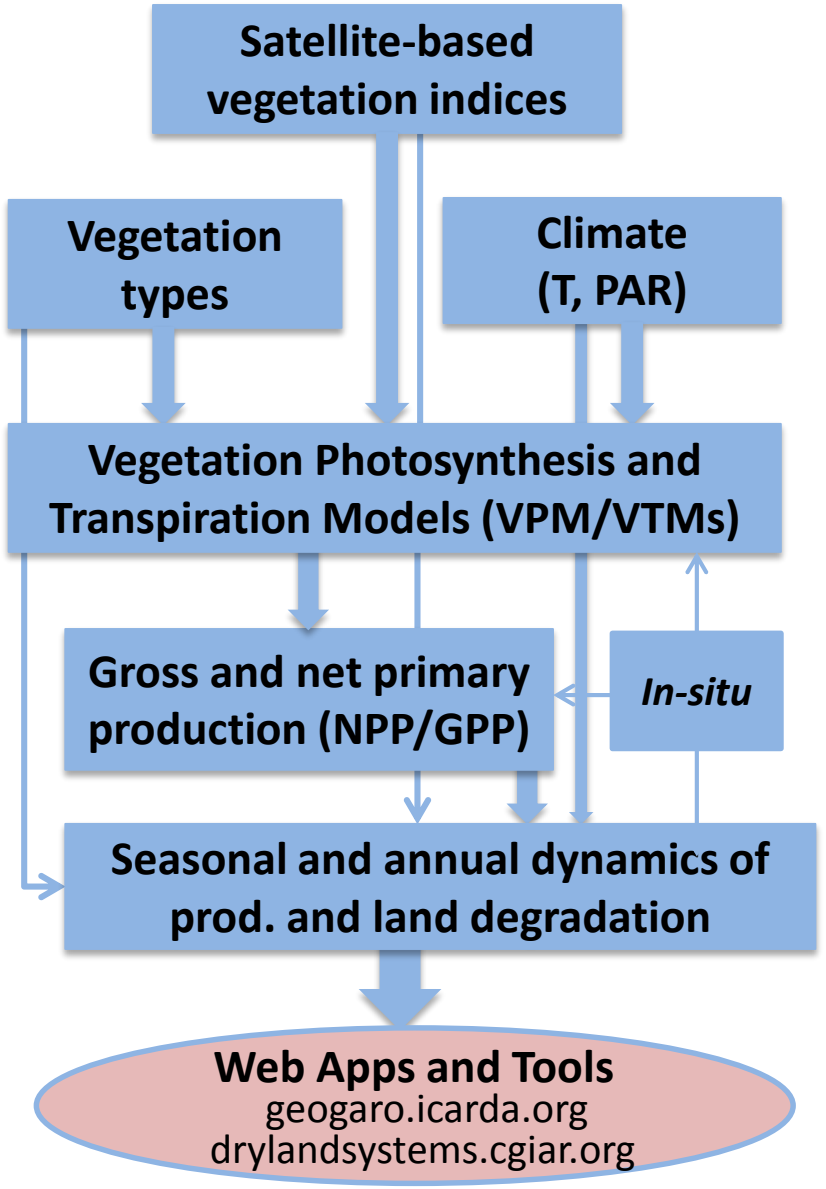


(Dong et al., 2015)



Structural perspective --- canopy cover and leaf area index

Normalized Difference Vegetation Index (NDVI)

$$NDVI = \frac{\rho_{\text{nir}} - \rho_{\text{red}}}{\rho_{\text{nir}} + \rho_{\text{red}}}$$

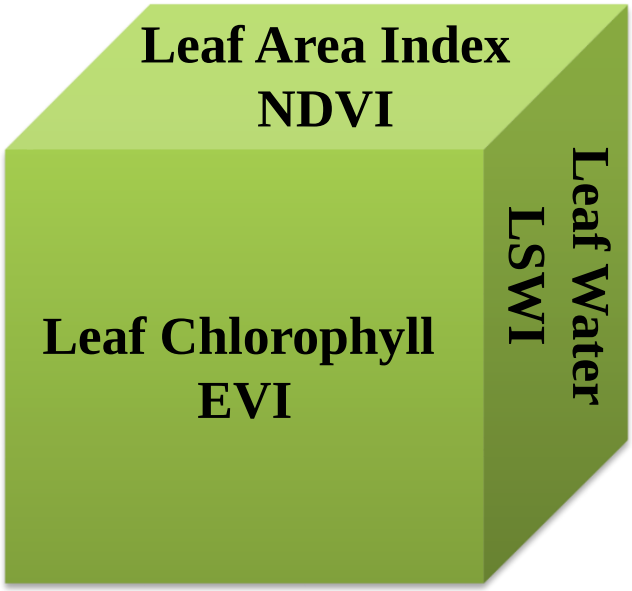
Biochemical perspective --- chlorophyll & water

Enhanced Vegetation Index (EVI)

$$EVI = G \times \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + C_1 \times \rho_{red} - C_2 \times \rho_{blue} + L}$$

Land Surface Water Index (LSWI)

$$LSWI = \frac{\rho_{\text{nir}} - \rho_{\text{swir}}}{\rho_{\text{nir}} + \rho_{swir}}$$



Time-series Spectral Profiles of Dryland Ecosystems

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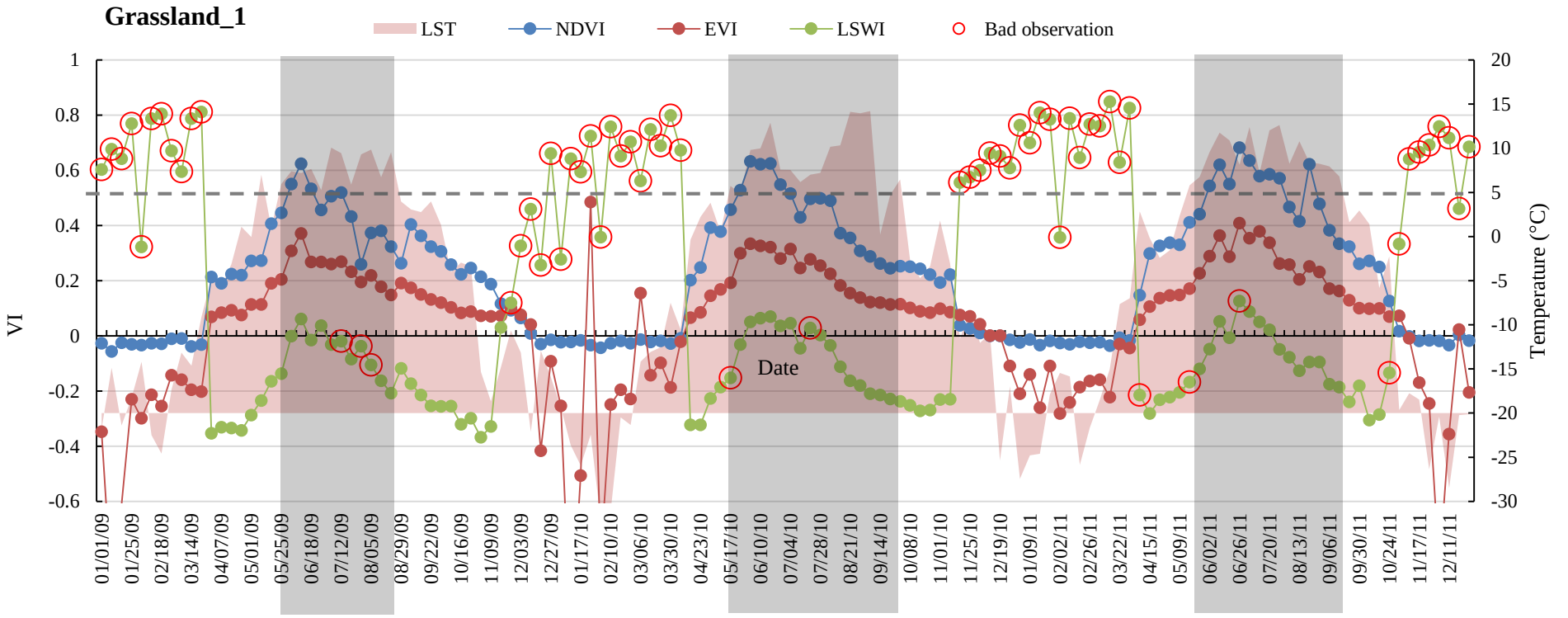
Seasonal and Annual Dynamics

Grassland Site1

More Productive

49.345293 N
73.305316 E



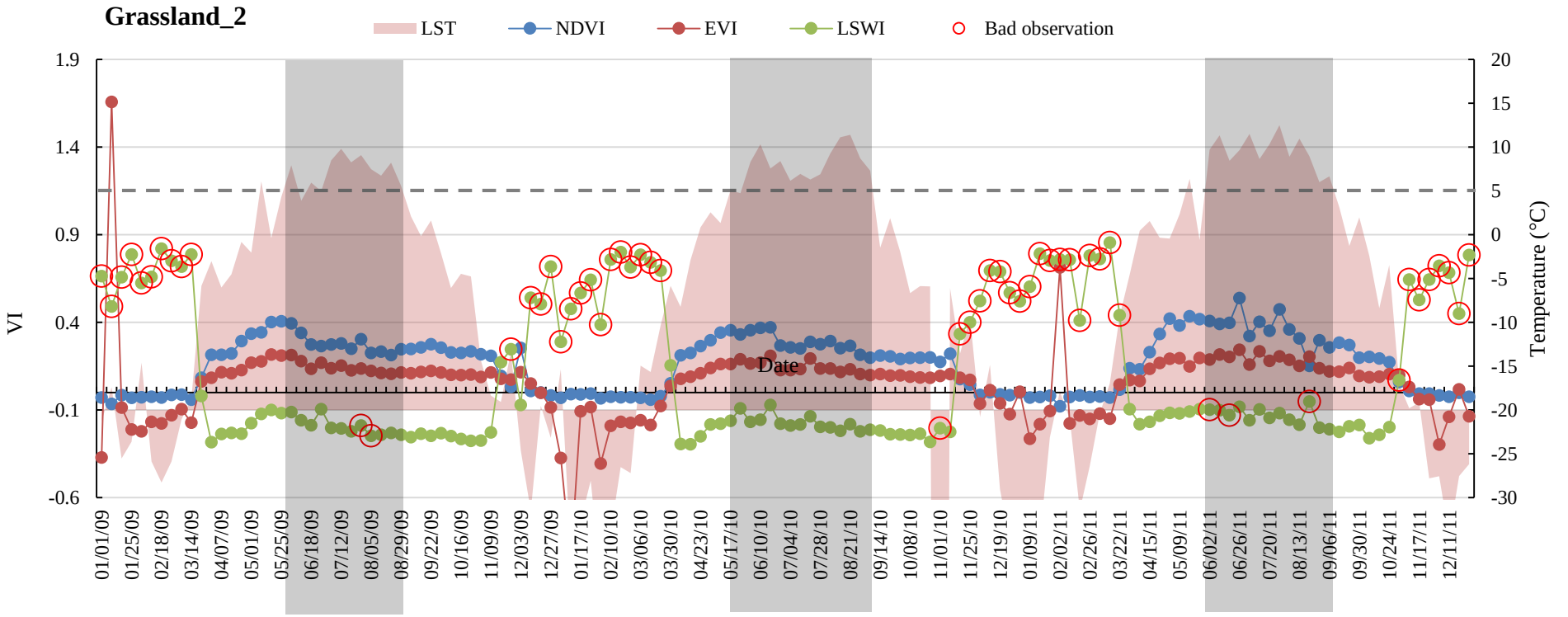
Time-series Spectral Profiles of Dryland Ecosystems

Seasonal and Annual Dynamics

Grassland Site2

Less Productive

49.321334 N,
72.948339 E



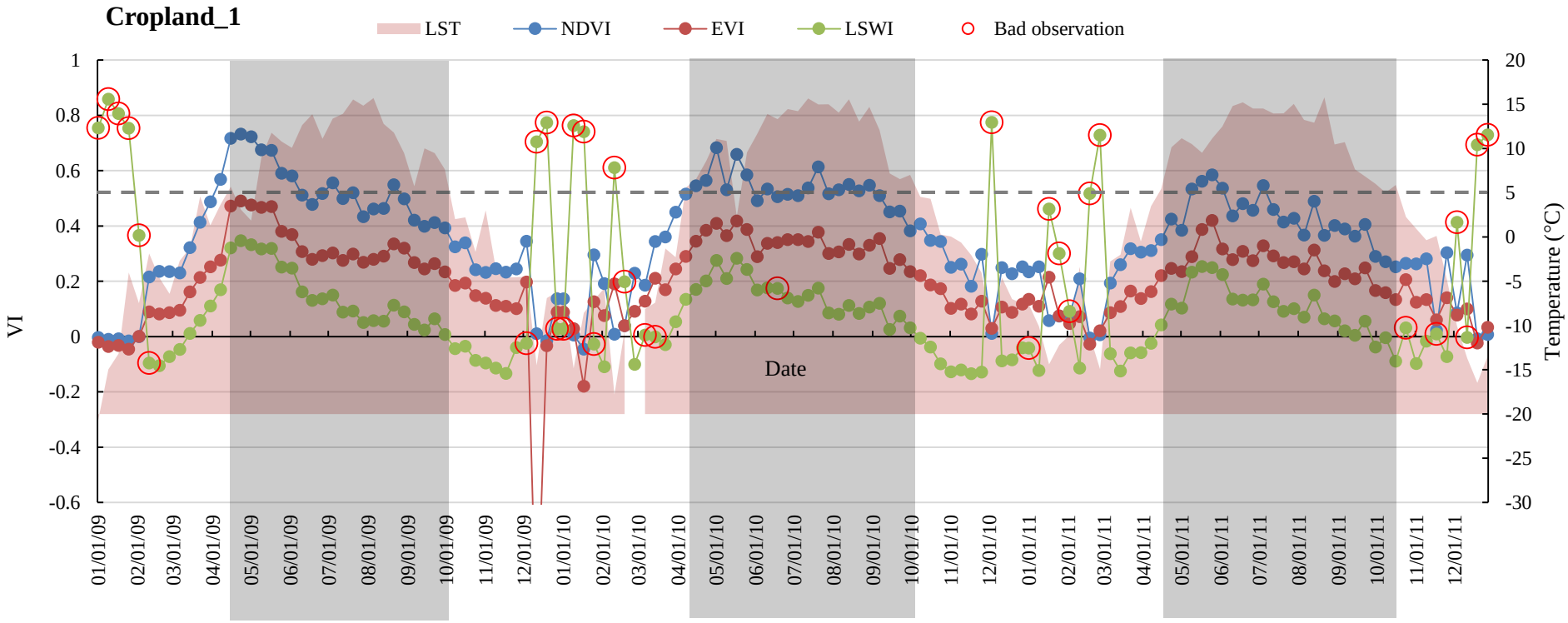
Time-series Spectral Profiles of Dryland Ecosystems

Seasonal and Annual Dynamics

Cropland Site1

Irrigated

40.738691 N
73.234460 E



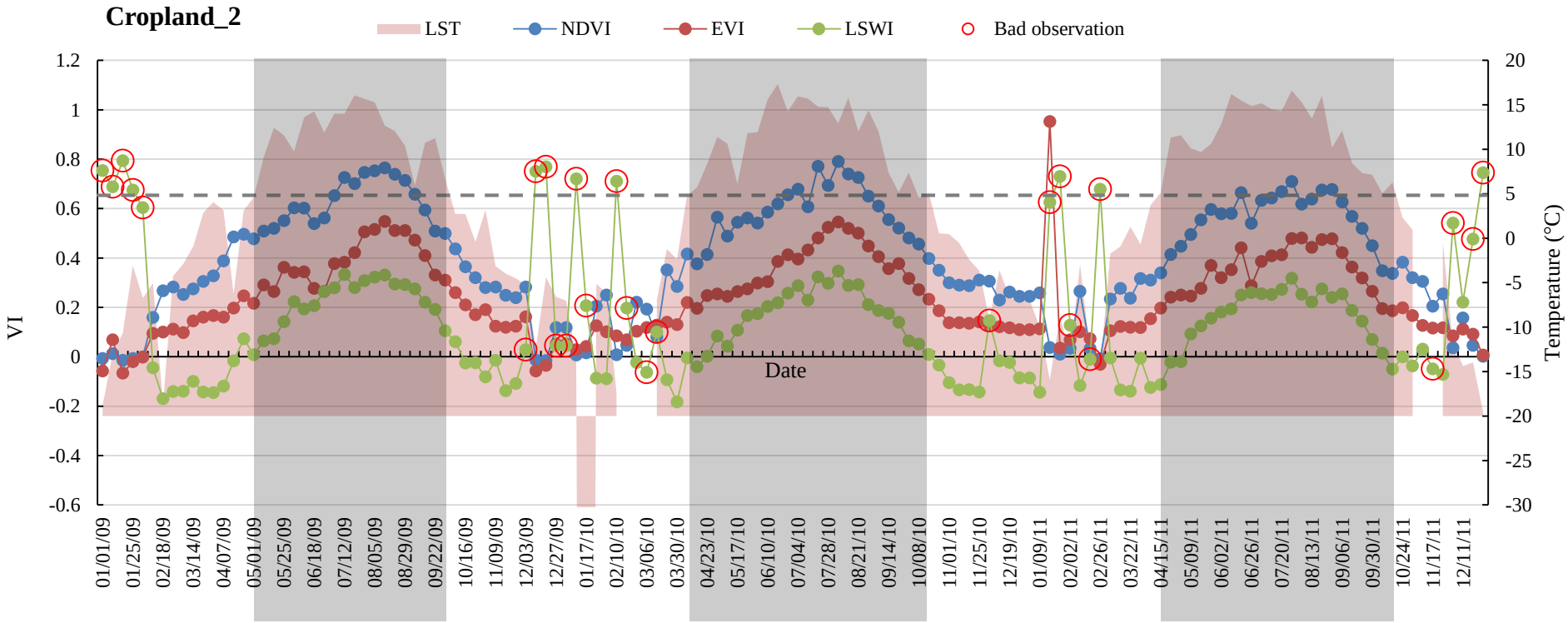
Time-series Spectral Profiles of Dryland Ecosystems

Seasonal and Annual Dynamics

Cropland Site2

Rainfed

40.826791 N
73.268077 E



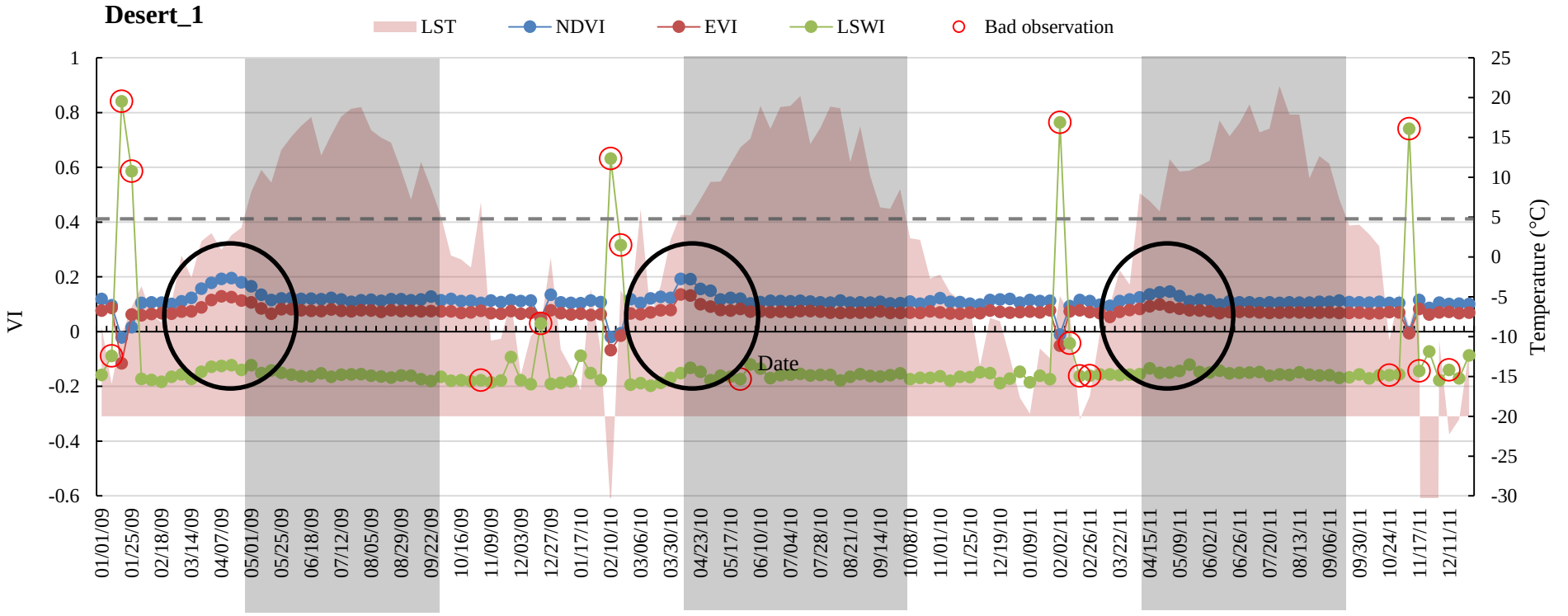
Time-series Spectral Profiles of Dryland Ecosystems

Seasonal and Annual Dynamics

Desert Site 1

Sparsely veg.

43.100062 N
64.643772 E



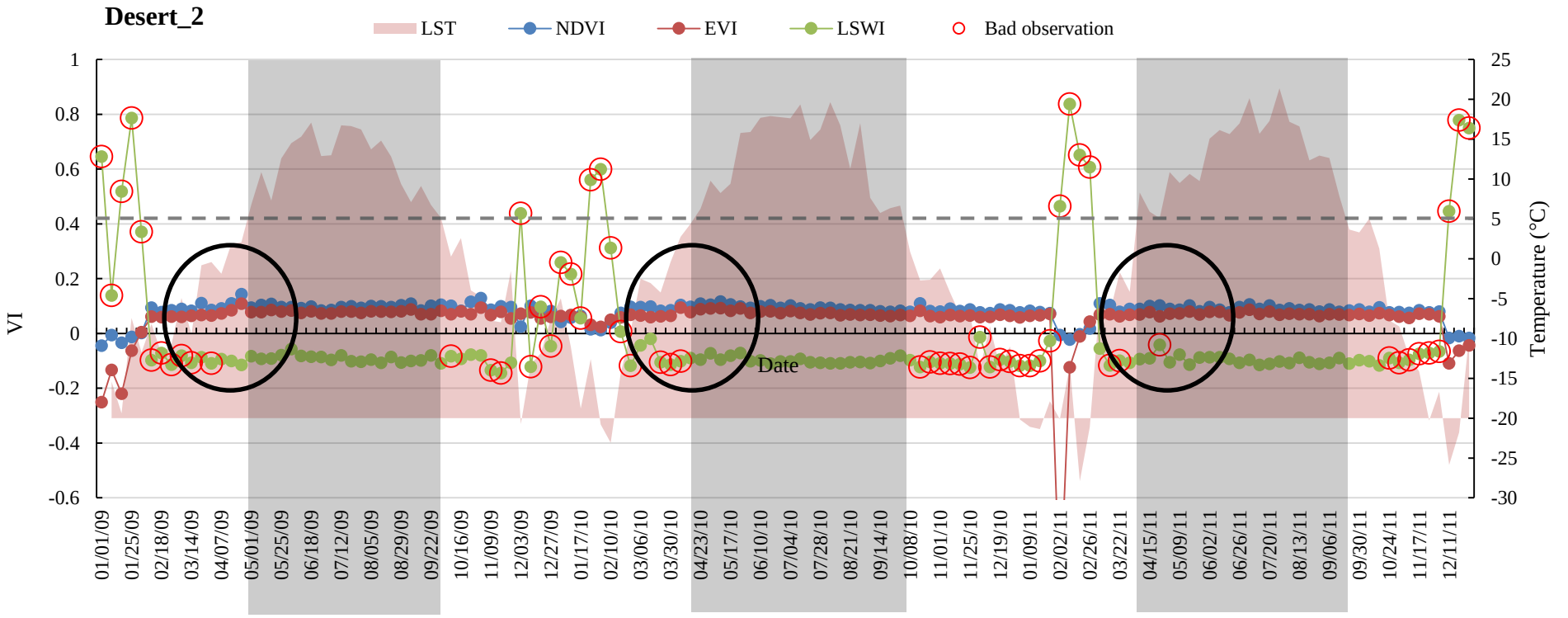
Time-series Spectral Profiles of Dryland Ecosystems

Seasonal and Annual Dynamics

Desert Site 2

Mostly Barren

45.441748 N
65.328133 E

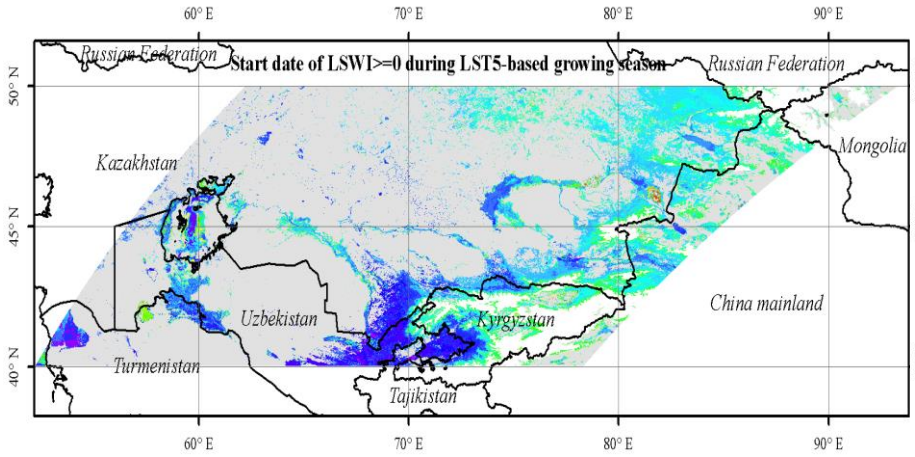


Ground truth data

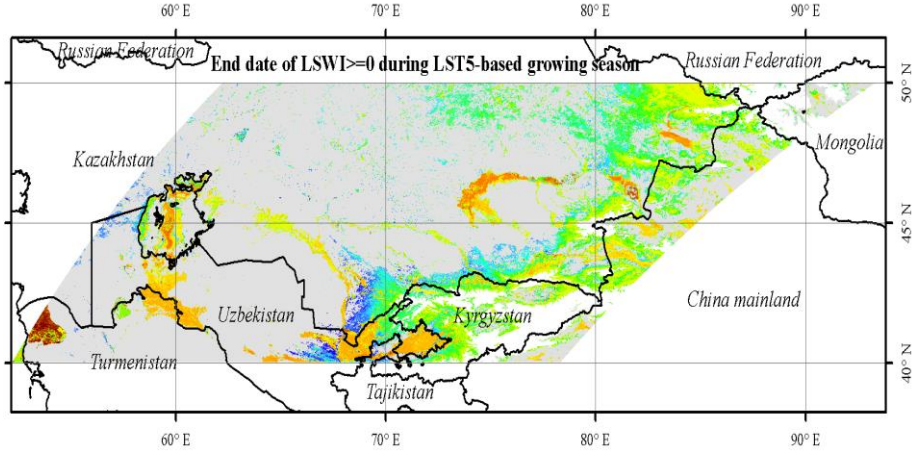
Spatial-pattern of Vegetation Phenology

LSWI

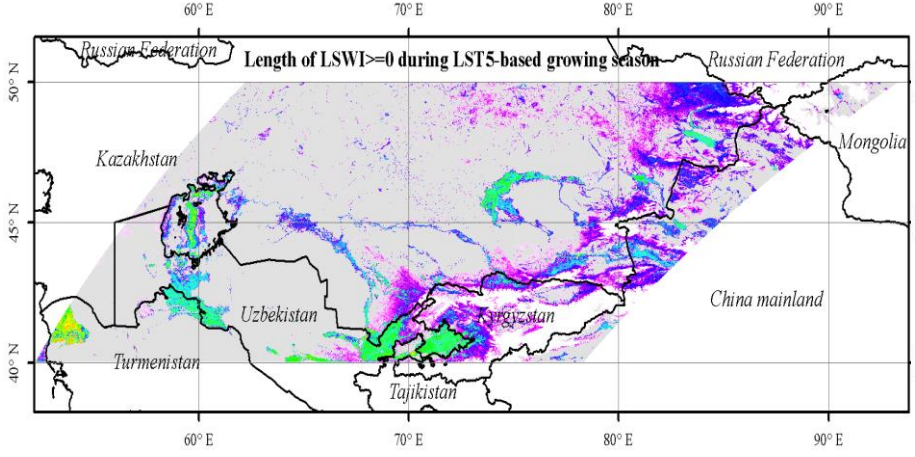
Start date of LSWI>=0 during LST-5 based growing season



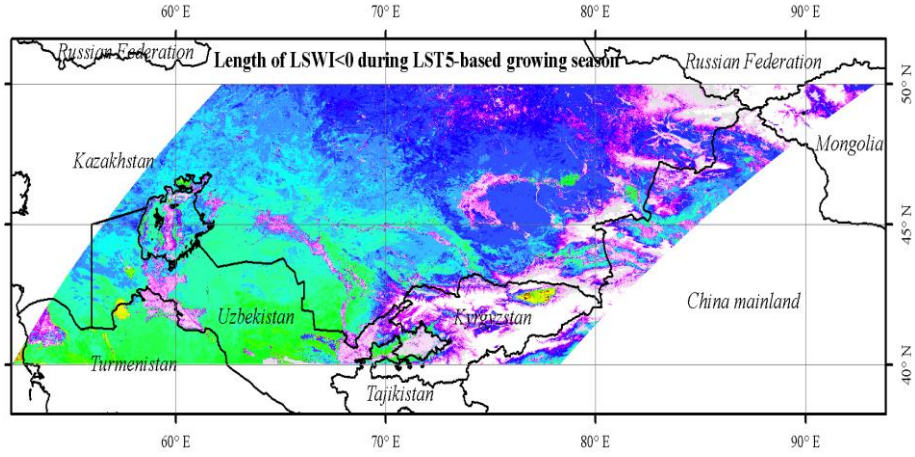
End date of LSWI>=0 during LST-5 based growing season



Length of LSWI>=0 during LST-5 based growing season



Length of LSWI<0 during LST-5 based growing season



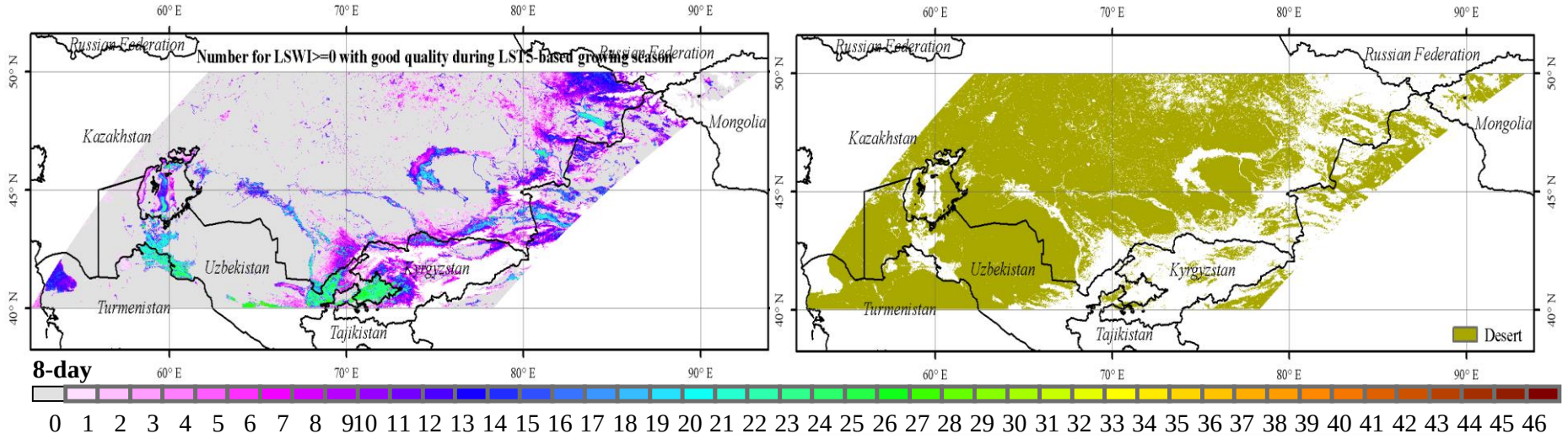
8-day

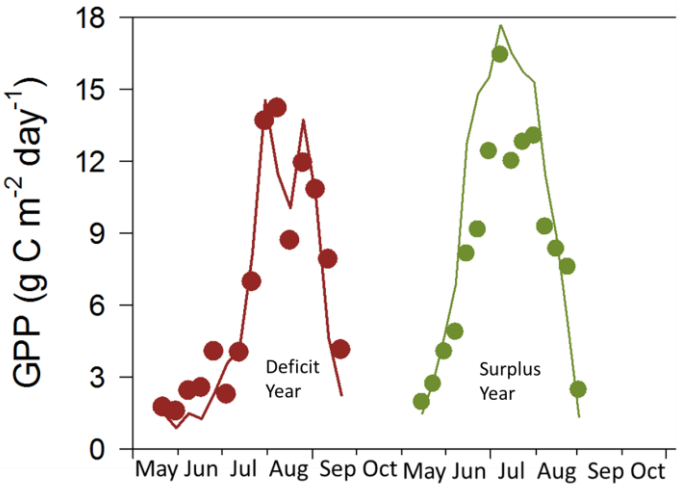
Spatial-pattern of Vegetation Phenology

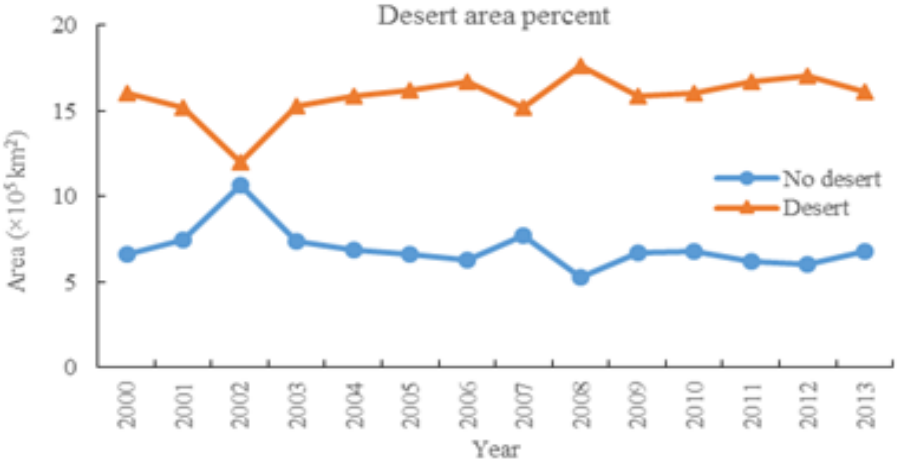
LSWI

LSWI>=0 with frequency of good quality during LST-5 based growing season

Desert (all LSWI <0 without the disturb of cloud during LST-5 based growing season)



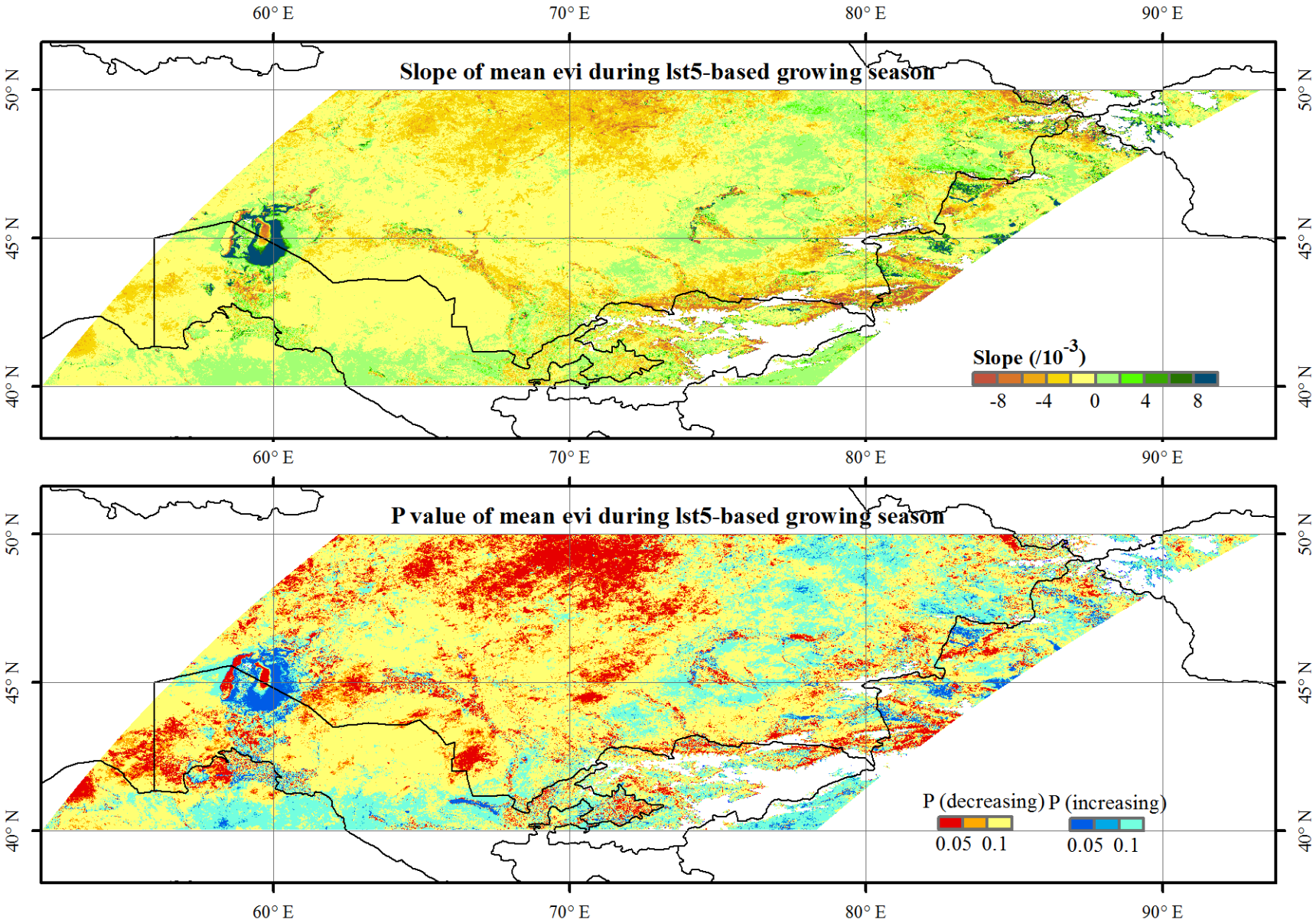




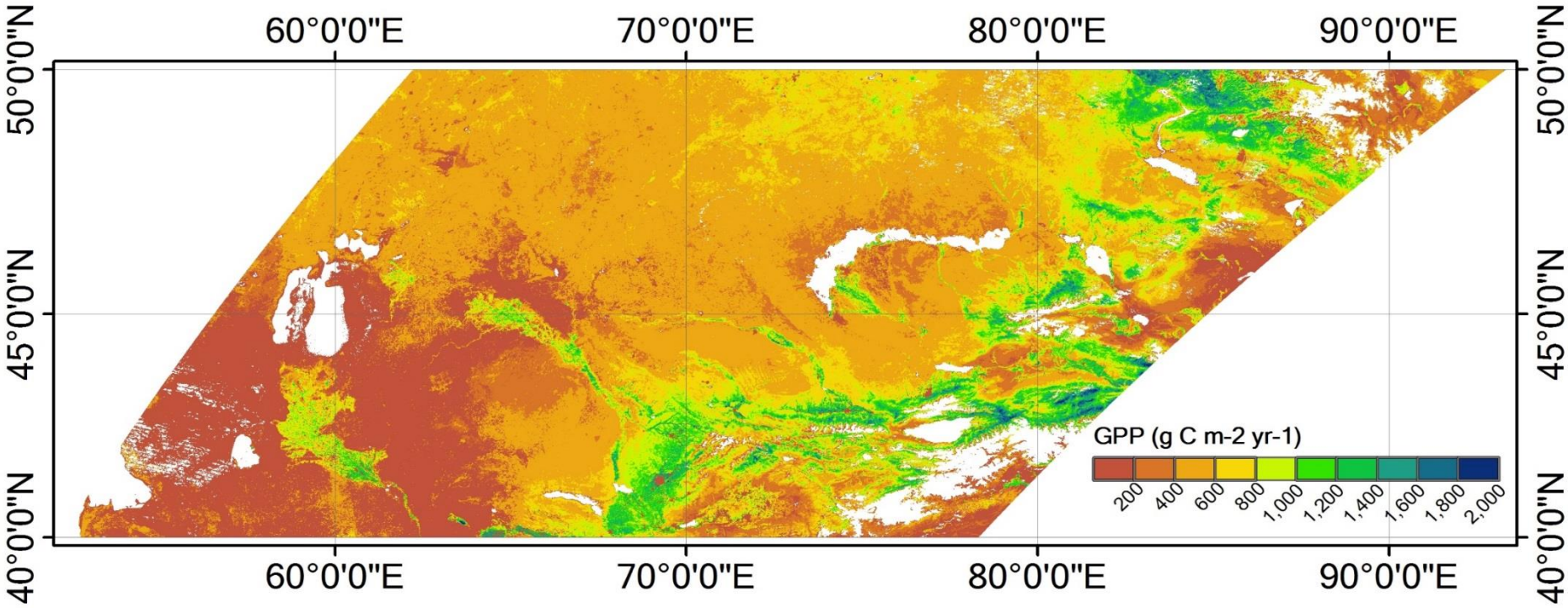
Changes in the total area of desert over 2000-2013

Trends of the vegetation dynamics

Hot spots of land degradation?



Gross Primary Production (GPP)



Spatial distribution of annual gross primary production (GPP) of vegetation in the study area in 2010, as predicted by the satellite-based Vegetation Photosynthesis Model (VPM) with MODIS and Climate Data 2010

Croplands vs Grasslands vs Deserts

Dynamics of Productivity Under Changing Climate

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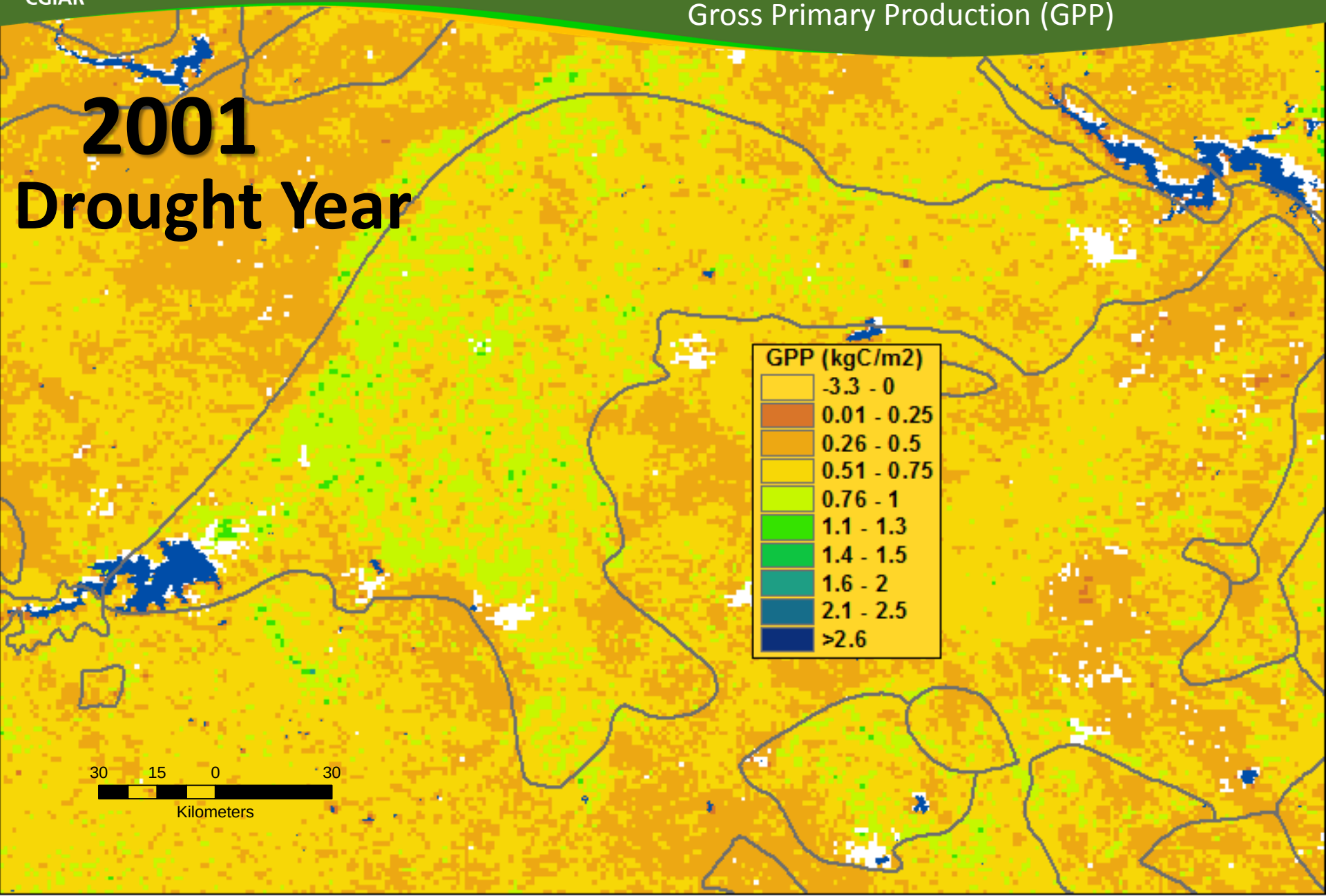
Gross Primary Production (GPP)



Dynamics of Productivity Under Changing Climate

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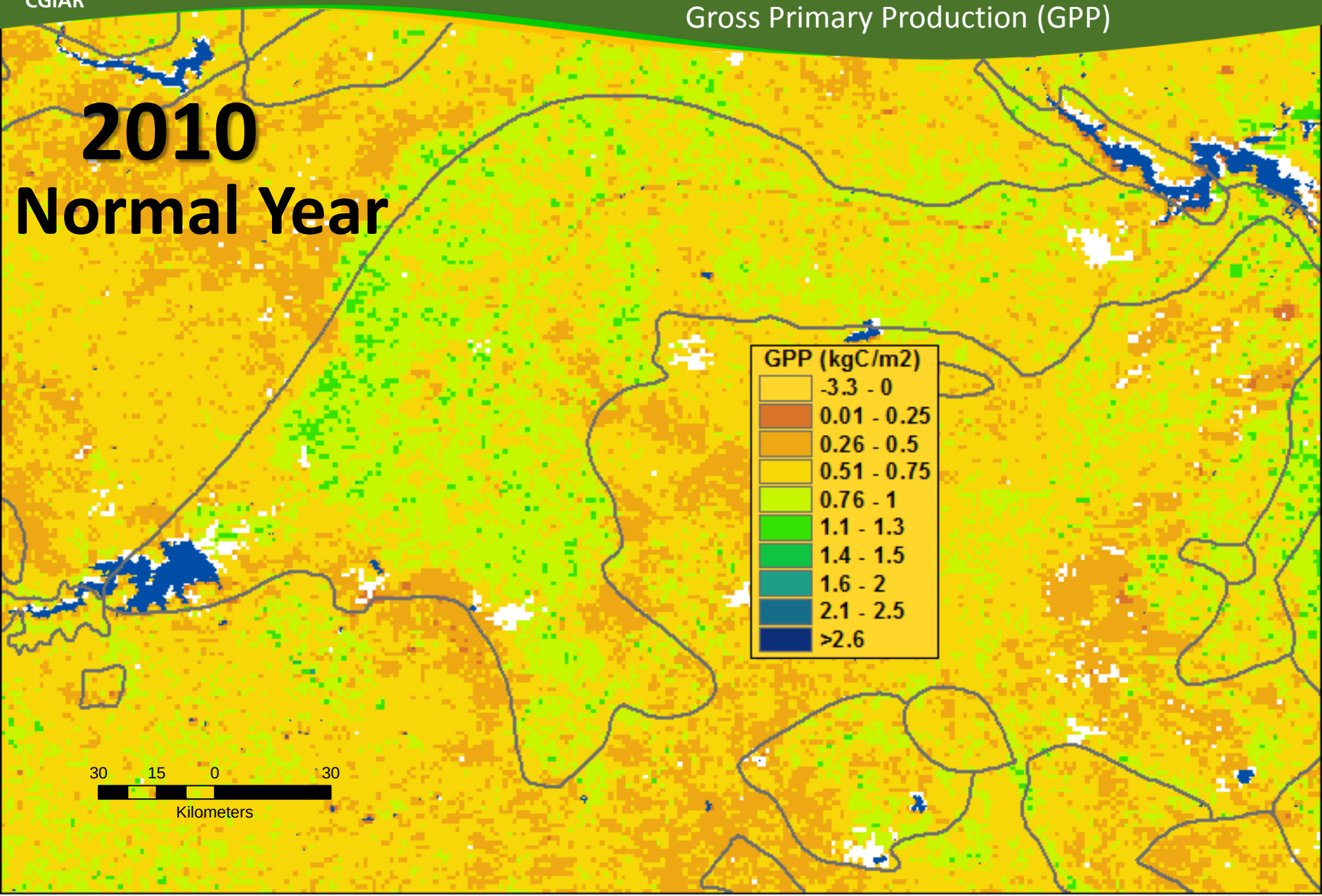
Gross Primary Production (GPP)



Starting date of Growing Season

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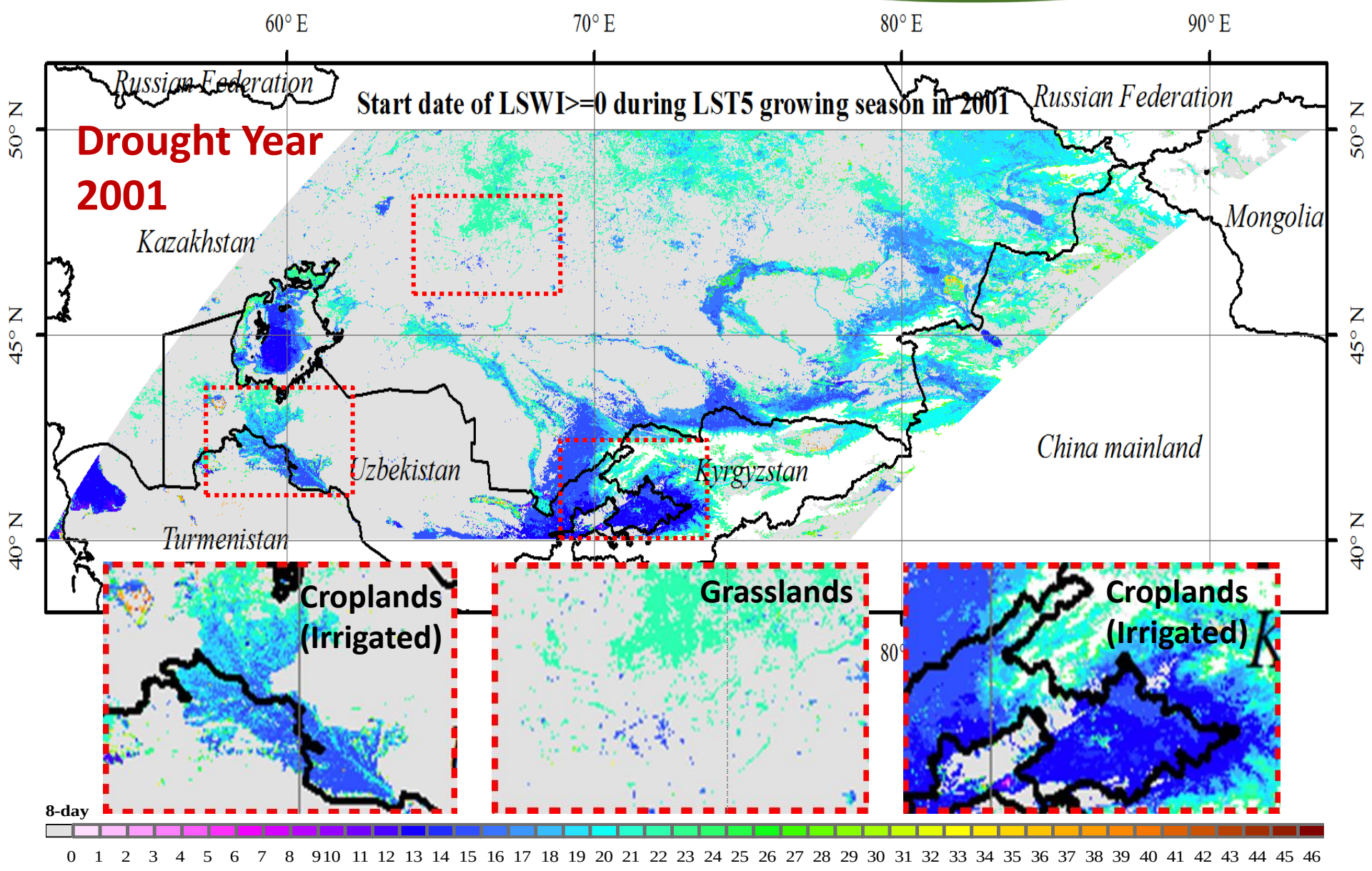
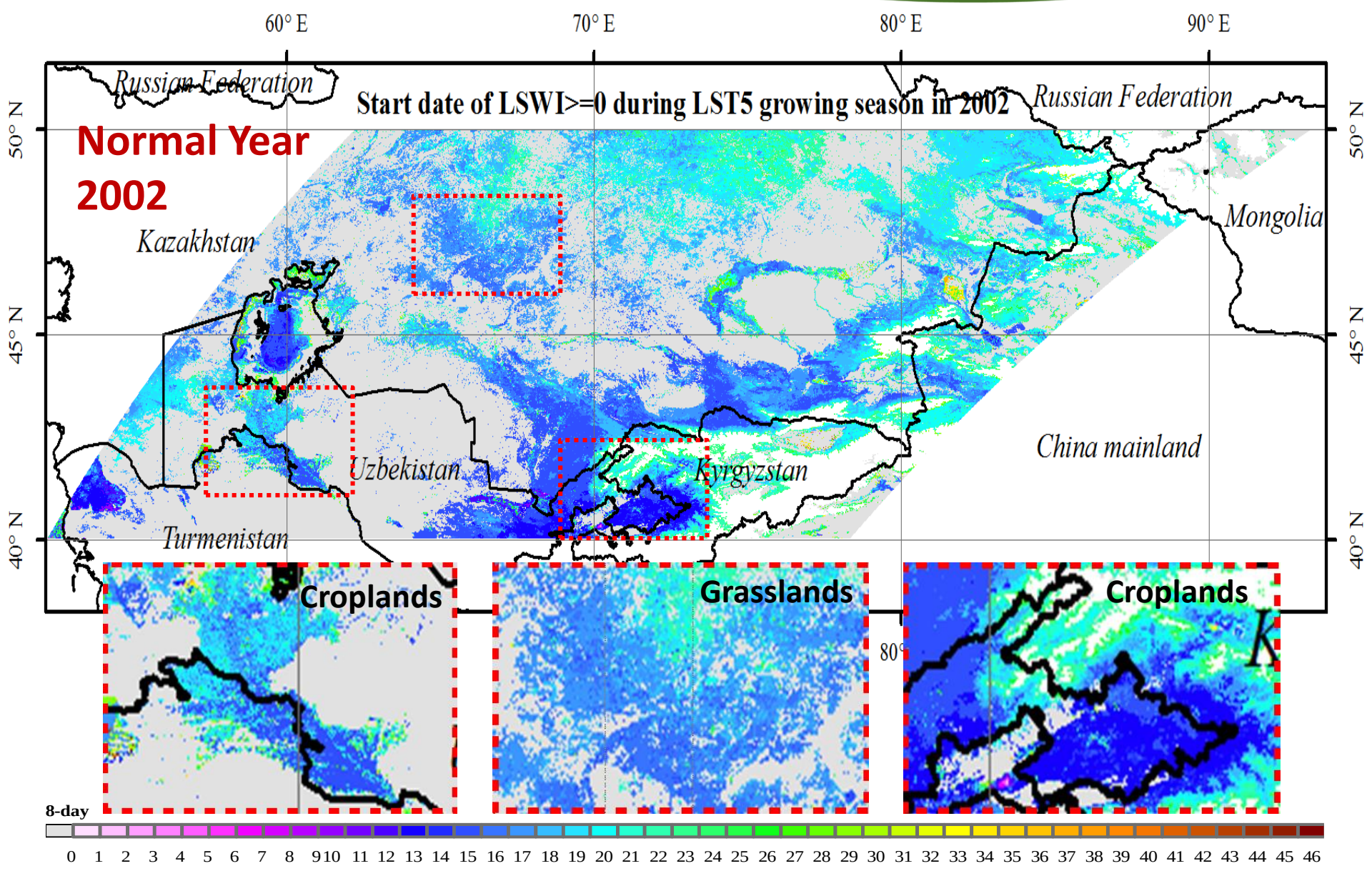
LSWI>0 with LST 5°C



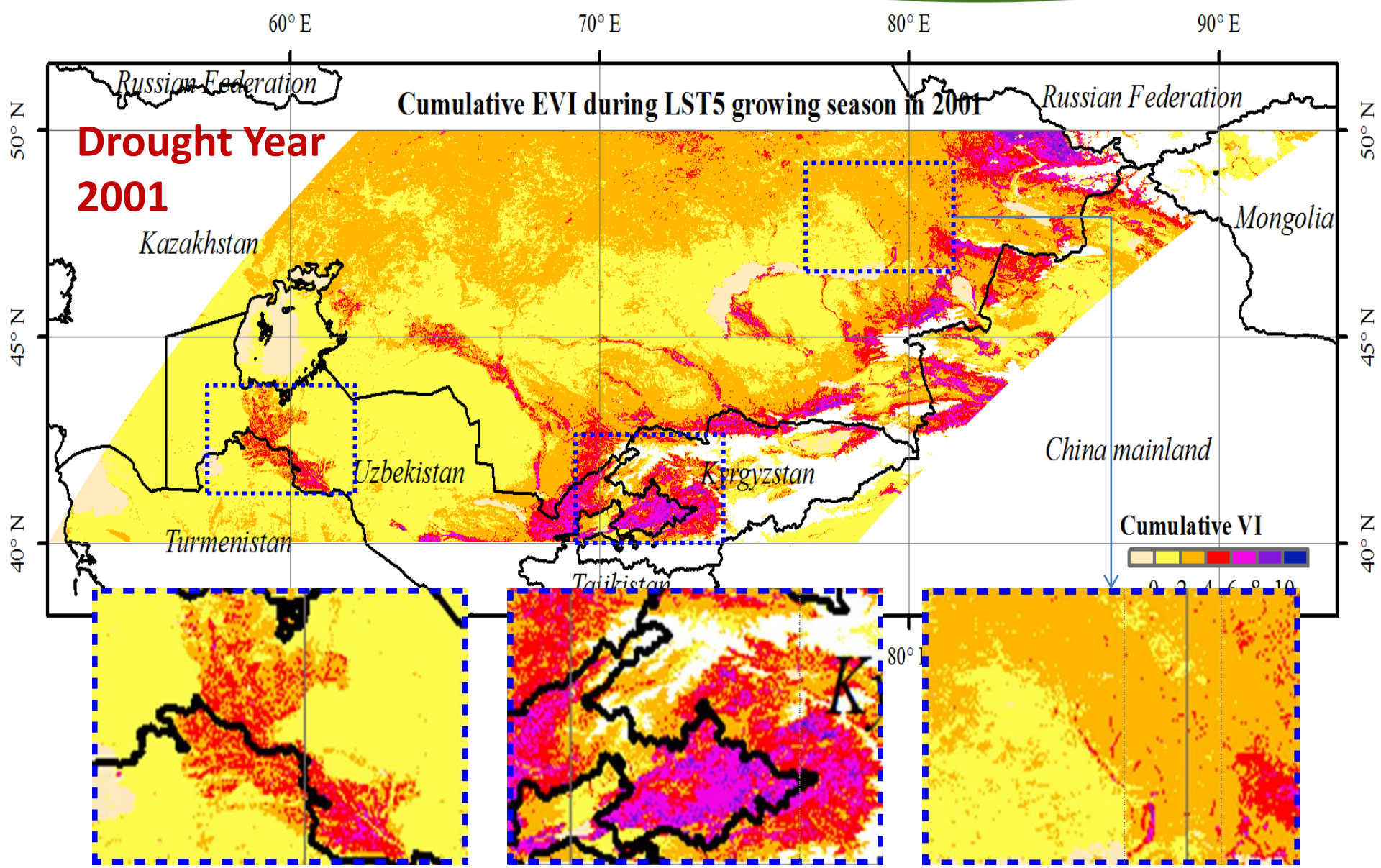
Starting date of Growing Season

LSWI>0 with LST 5°C



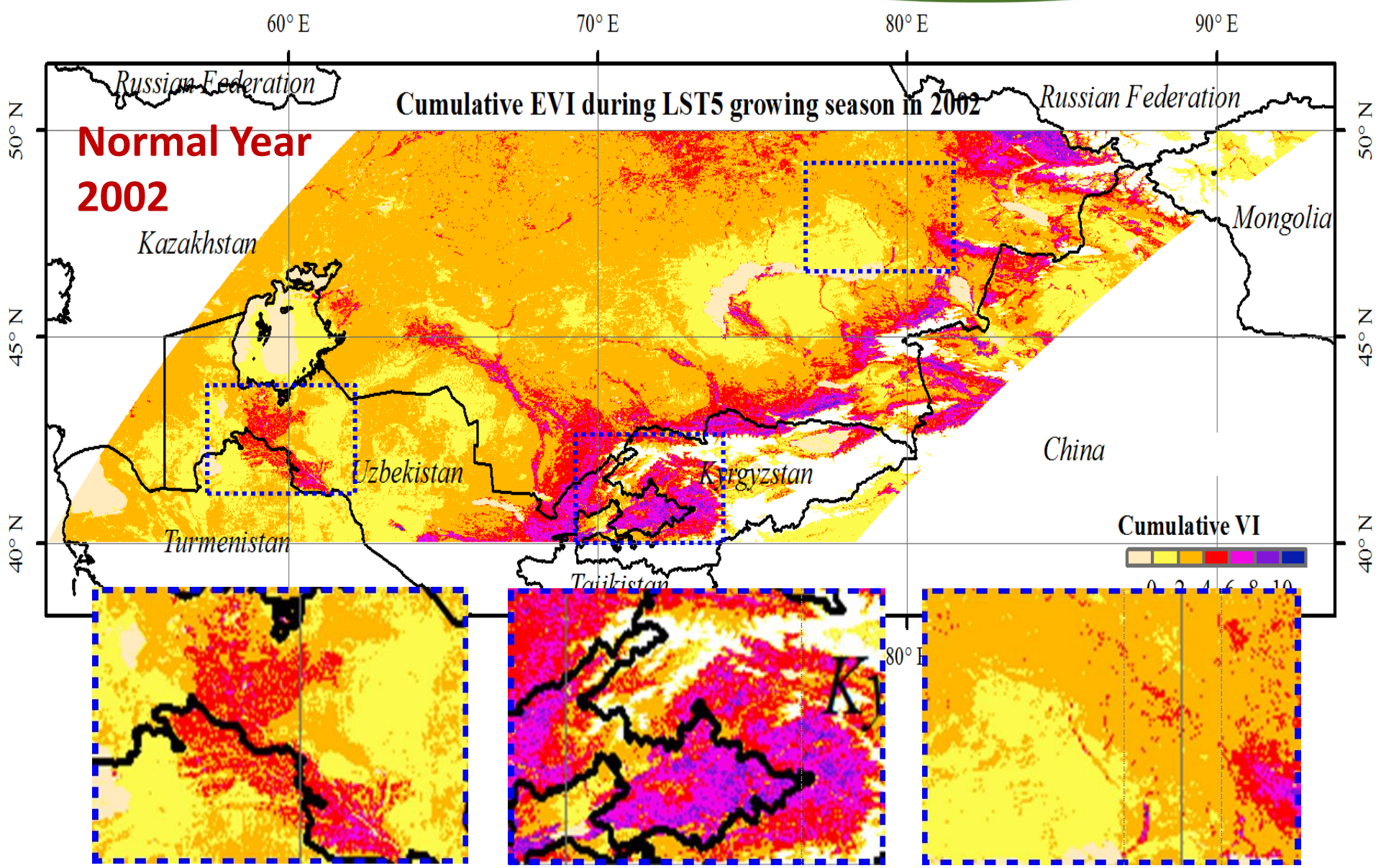
Annual Cumulative EVI

EVI with LST 5°C



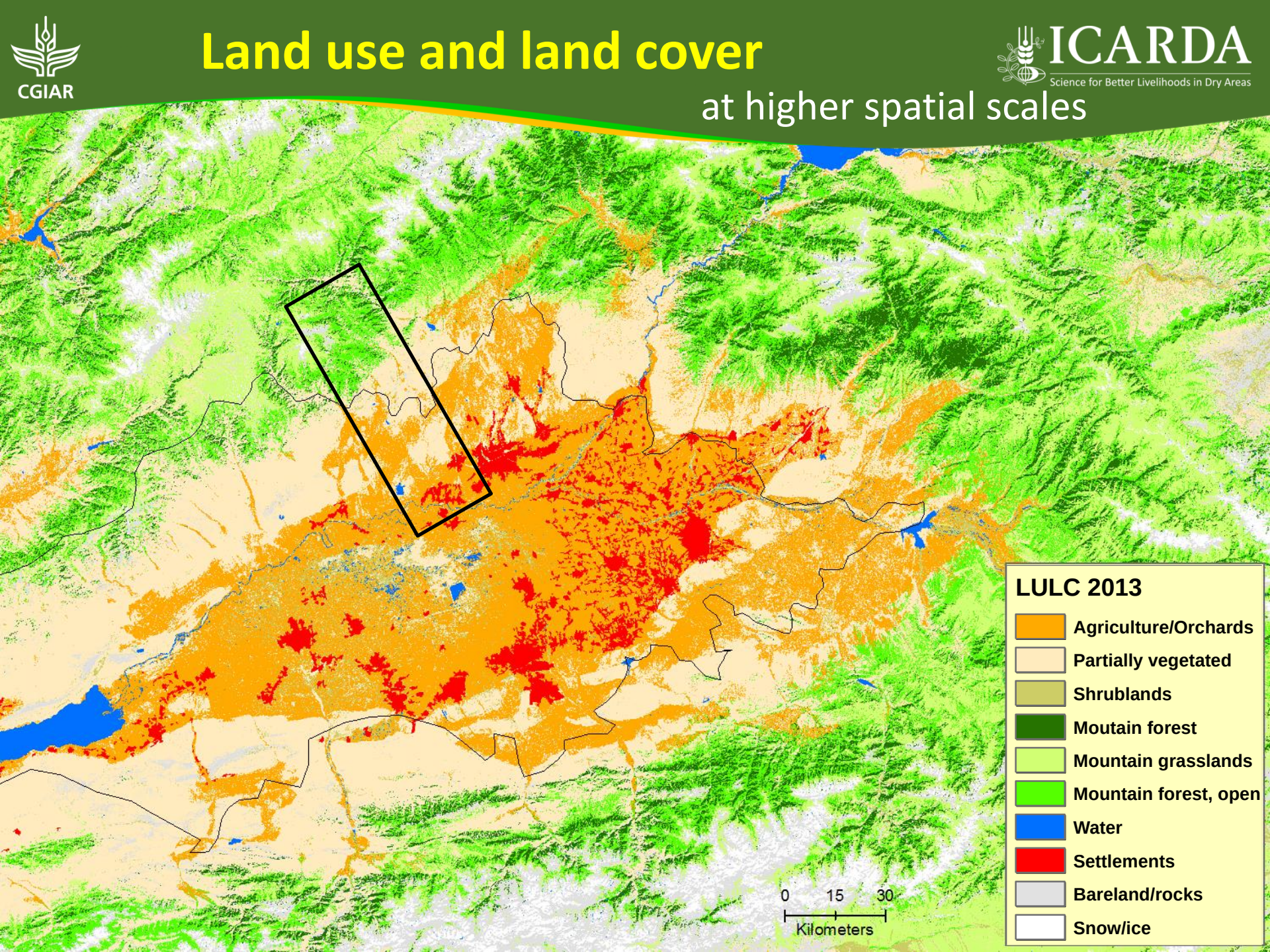
Annual Cumulative EVI

EVI with LST 5°C



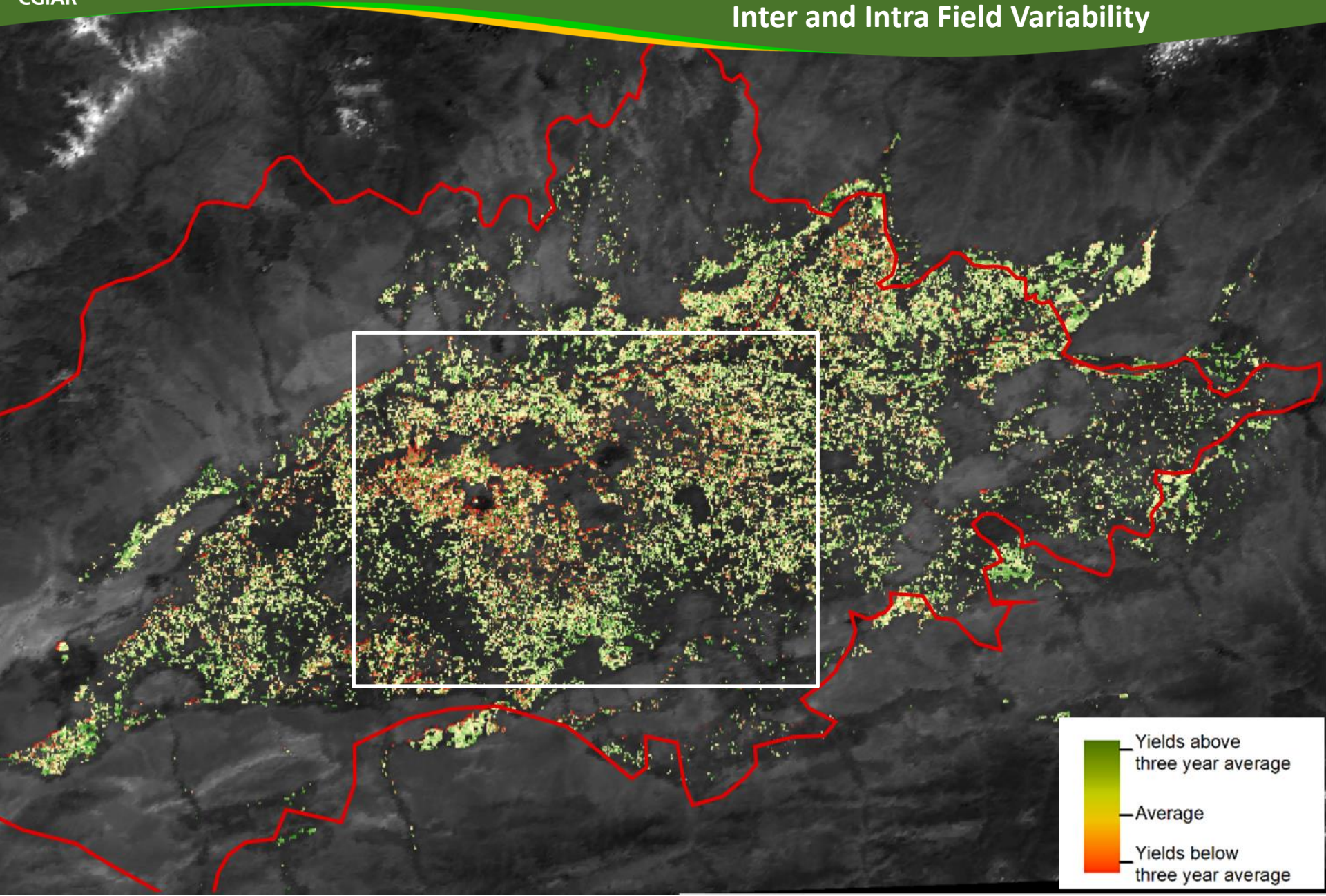
Land use and land cover

at higher spatial scales



Dynamics of Degradation?

Inter and Intra Field Variability



Productivity Gaps & Economic Impacts

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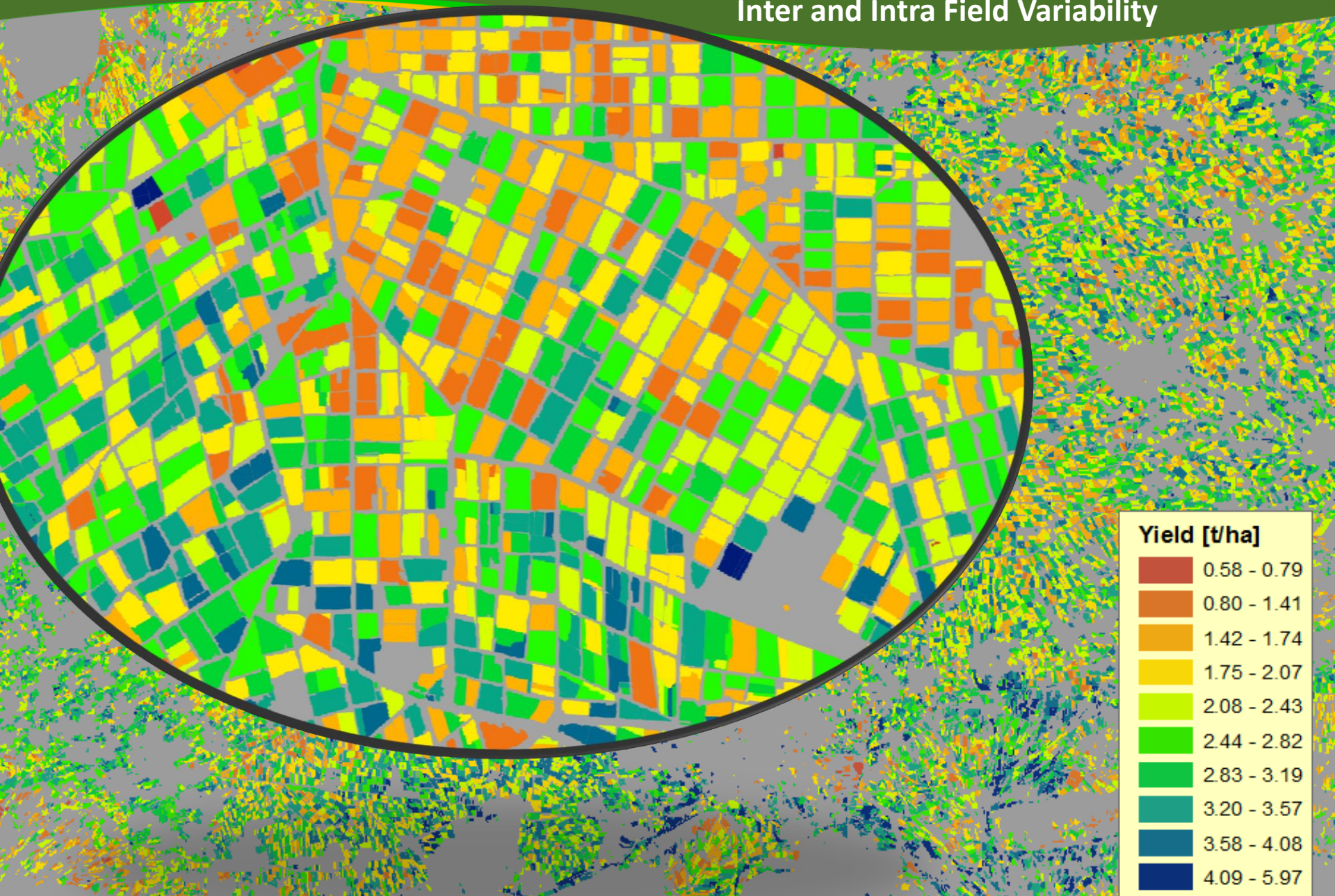
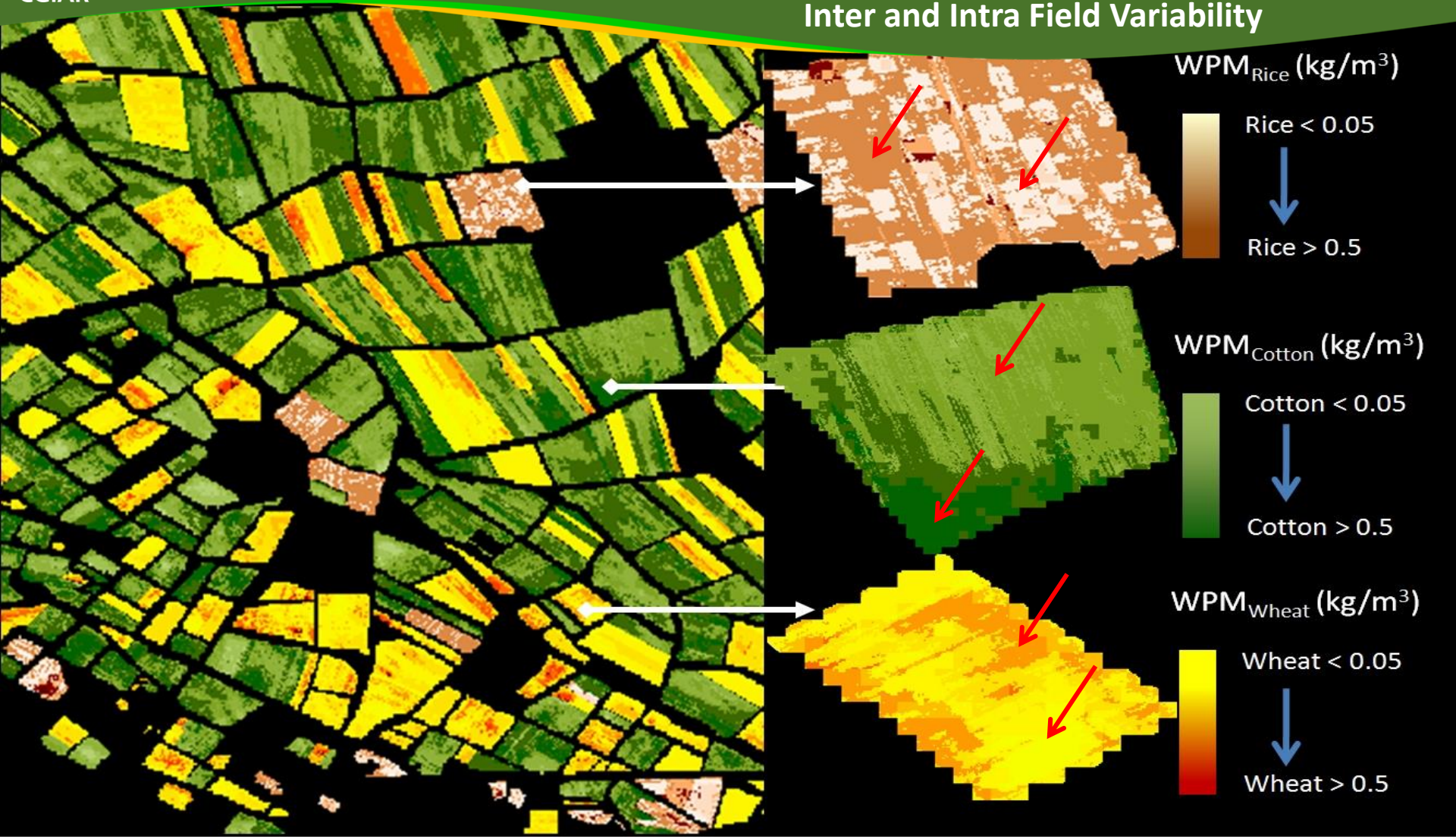
Inter and Intra Field Variability



Yield/Productivity Gaps

Inter and Intra Field Variability



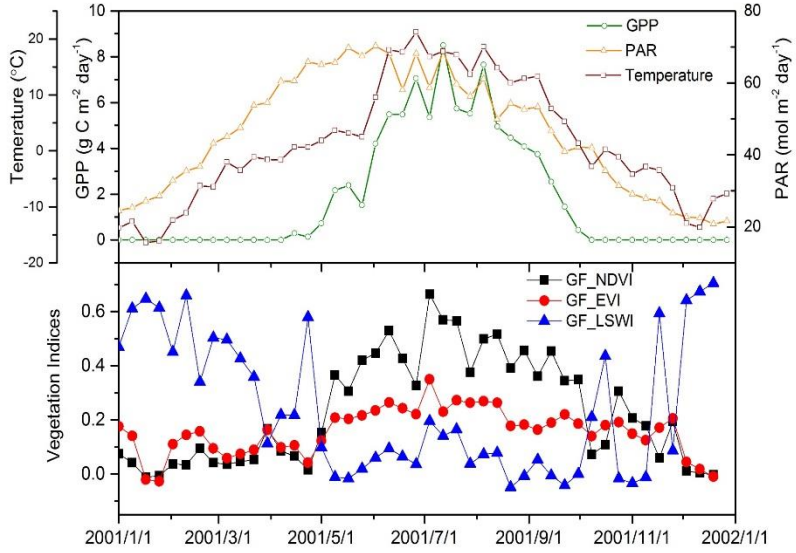
Water productivity (WP) is defined as the kg of yield produced/m^3 of water used or, alternatively, as value in $ of yield produced/m^3 of water used.

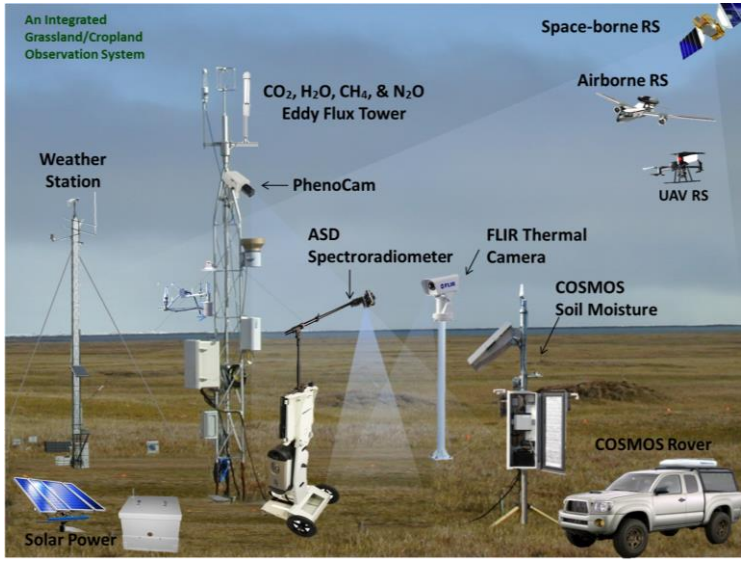
WP of Cotton	0.42 kg/m^3	0.50 USD/m^3
WP of Wheat	0.60 kg/m^3	0.33 USD/m^3
WP of Rice paddy	0.50 kg/m^3	0.10 USD/m^3

Remarks and Way forward

- EVI/CHL based approach
- Highly scalable (spatial and temporal)- up and out scaling
- Bottom up approach - grassroots
- Good validation source for the top to bottom schemes
- Better integration- system approach
- Inter and intra- seasonal flux
- Quantifiable- intervention impacts

- Its just beginning
- How this could link to ELD initiative?
- Improve simulation, validation and verification at farms/landscapes
- Lack of flux towers in the region
- Need refinement of LULC specific LUE





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Agricultural Livelihood Systems

Pastoral | Agropastoral | Rainfed | Tree-based | Irrigated

Thanks you

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CGIAR RESEARCH PROGRAM ON Dryland Systems