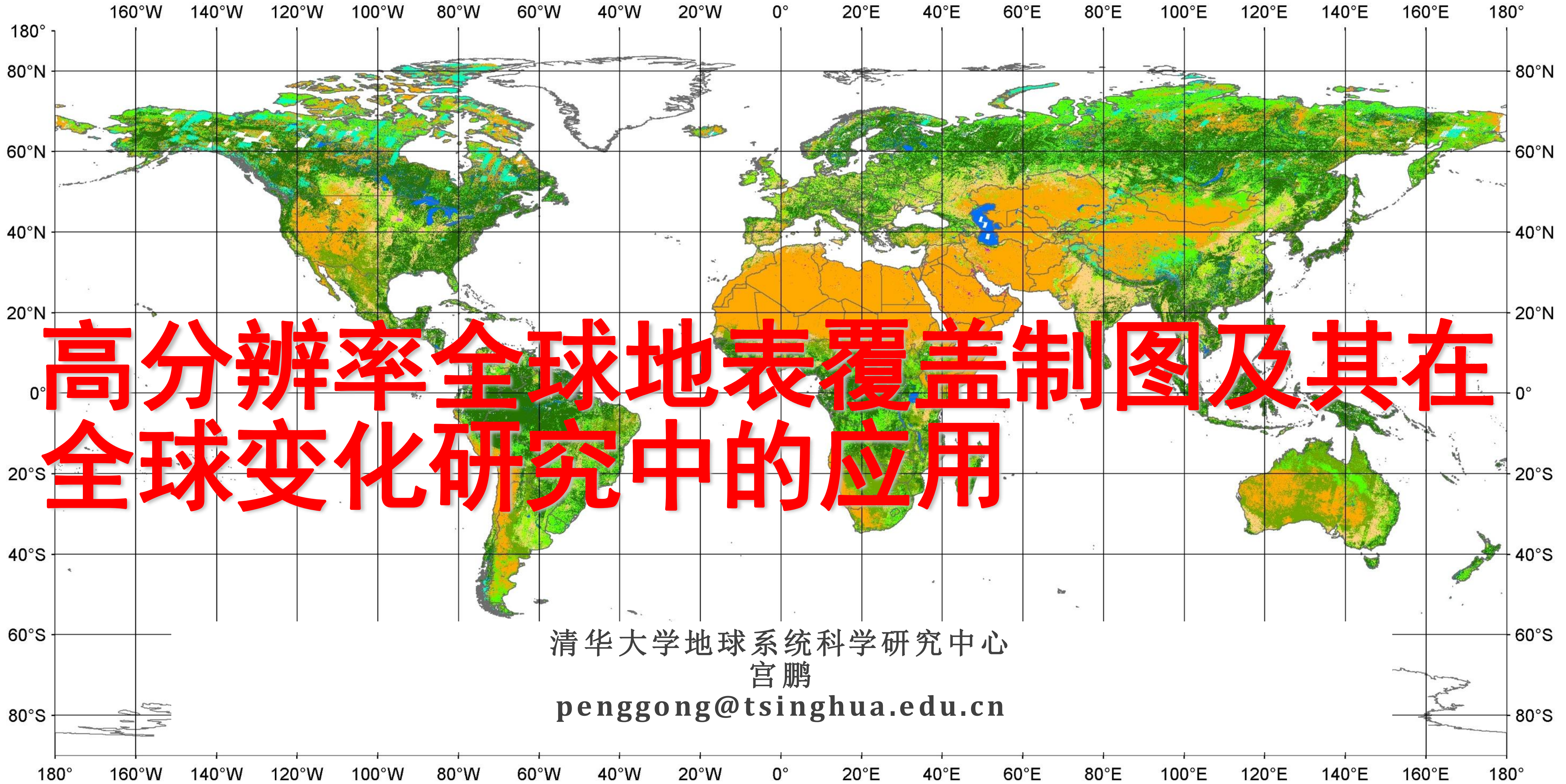

高分辨率全球地表覆盖制图及其在全球变化研究中的应用

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宫鹏
penggong@tsinghua.edu.cn

林则徐 （1785—1851） 师夷制夷，放眼看世界第一人

对英国侵略者的战争的困难是看不到对手，不知道前沿在哪里….

160多年后的今天我们知道前沿在哪里吗？

Land cover and land use

Land cover is the physical evidence on the earth surface

It is spectrally unique and thus easier to be automatically identified from remotely sensed imagery

Land cover and land use

Land use is the human activity on land – it is radiometrically heterogeneous and thus harder for automatic recognition

Each has different use

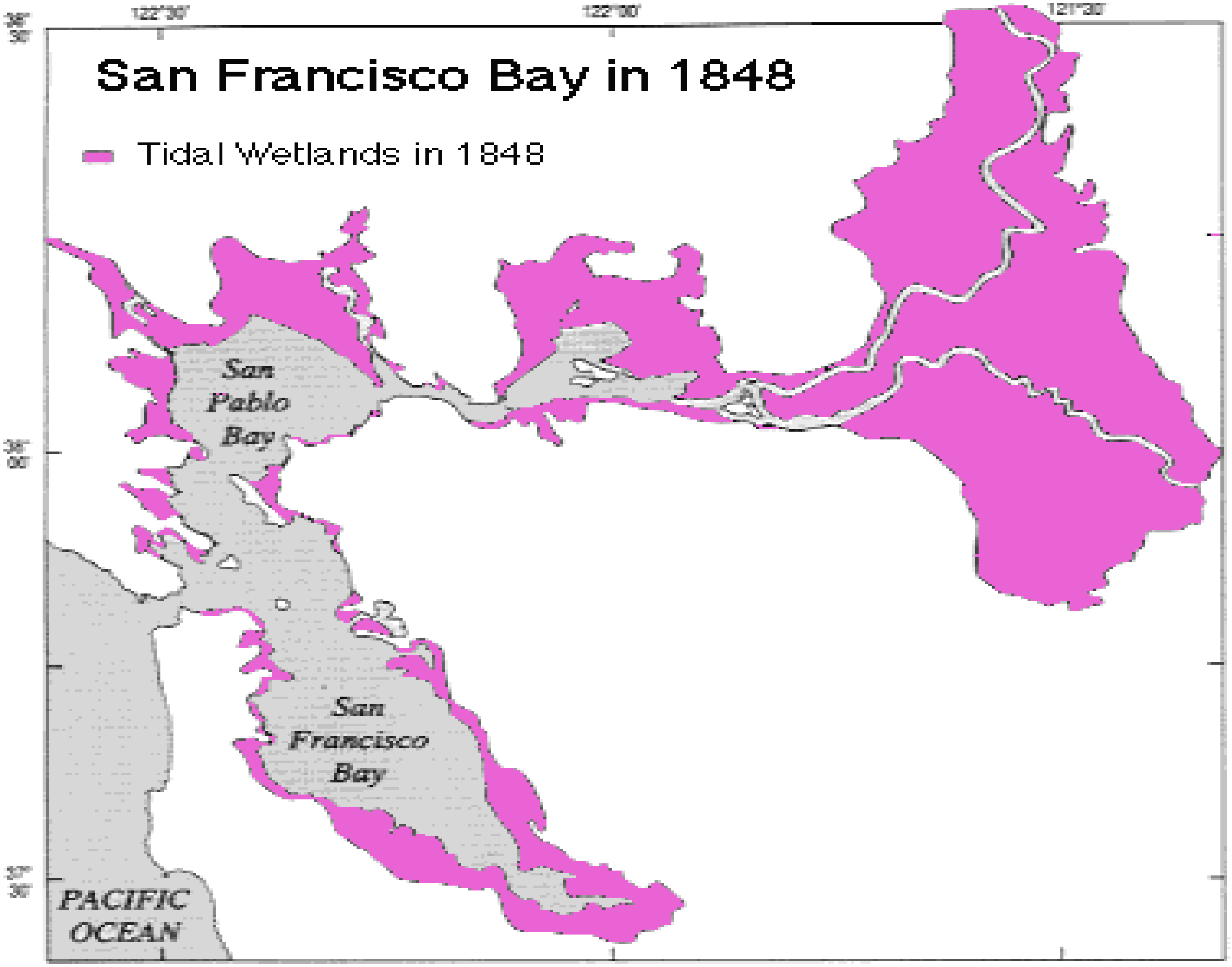
- Land use – reflects the social functions of land such as living, production, recreation, … is therefore related to economy, politics, culture…

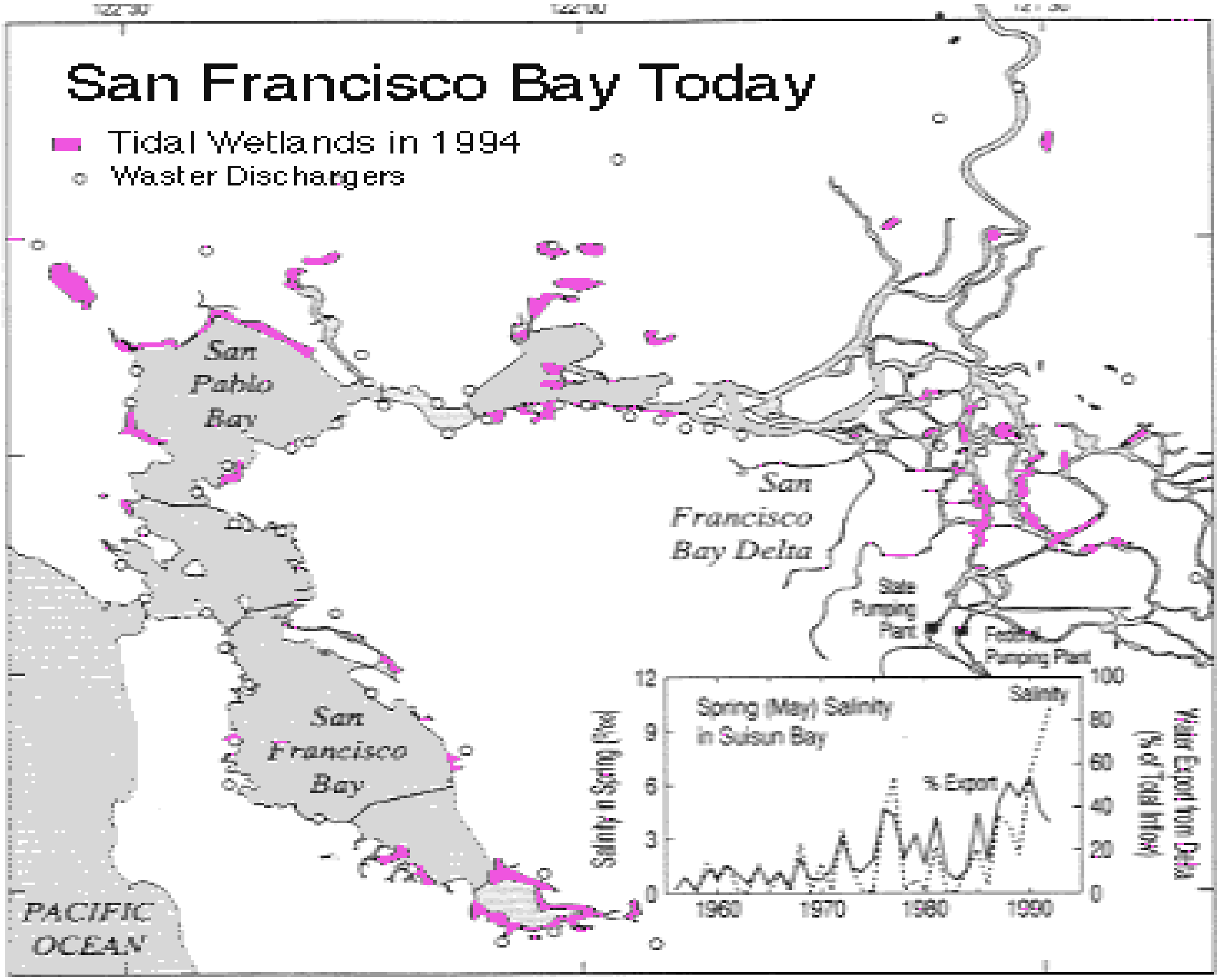
Land cover – determines surface radiation, runoff, matter mobility including liquid water, permeability… therefore is related to meteorology, hydrology, climatology, soil erosion, pollution dispersion ….

Importance of global land cover mapping

- Essential variable in earth observation
- Climate change and atmospheric science
- Carbon cycling
- Hydrological modeling
- Ecosystem services
- Habitat studies
- Biodiversity

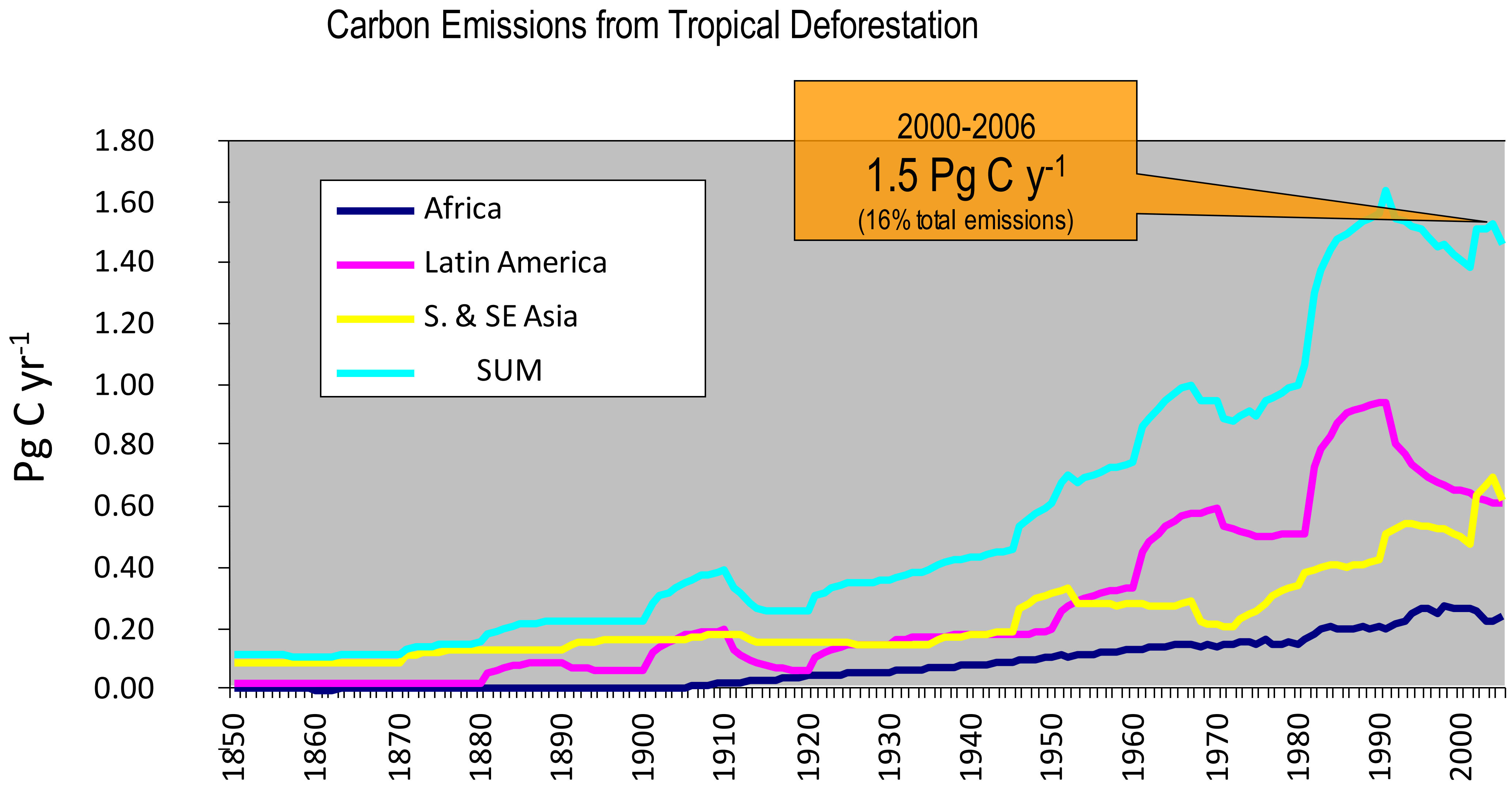
小尺度的森林砍伐、湿地损失、和城市化改变全球气候系统





旧金山海湾湿地在150年中的减少和破碎化

人类土地利用变化造成的碳排放



Houghton, unpublished

热带雨林减少：亚玛逊流域的情况

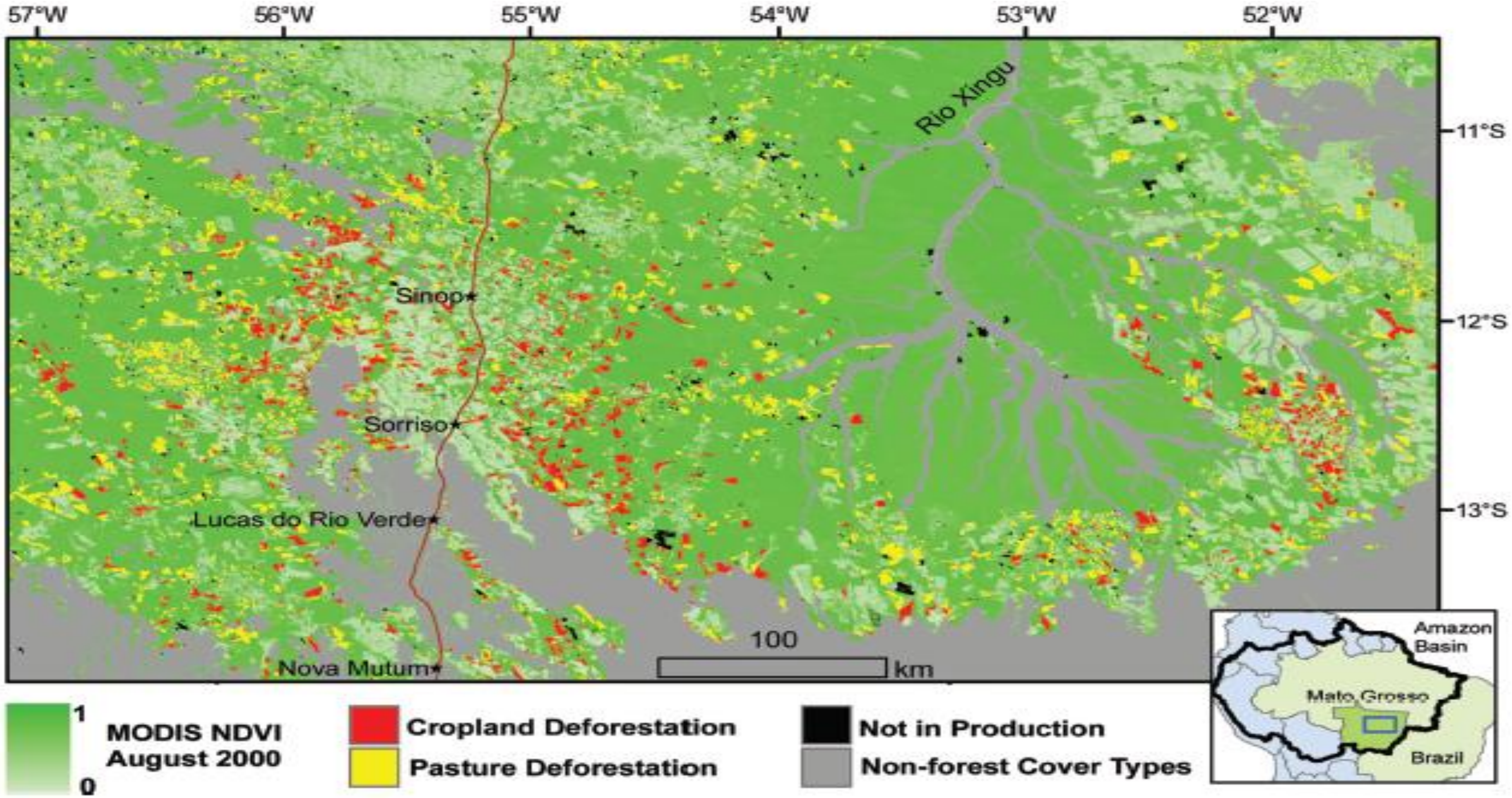


Fig. 1. Tropical deforestation for cropland agriculture in Mato Grosso state (2001–2004) is concentrated along the existing agricultural frontier. (*Inset*) Location of the study area subset within Mato Grosso state and the Amazon Basin.

Morton DC et al., 2006, PNAS

全球变暖对海岸带的潜在危害

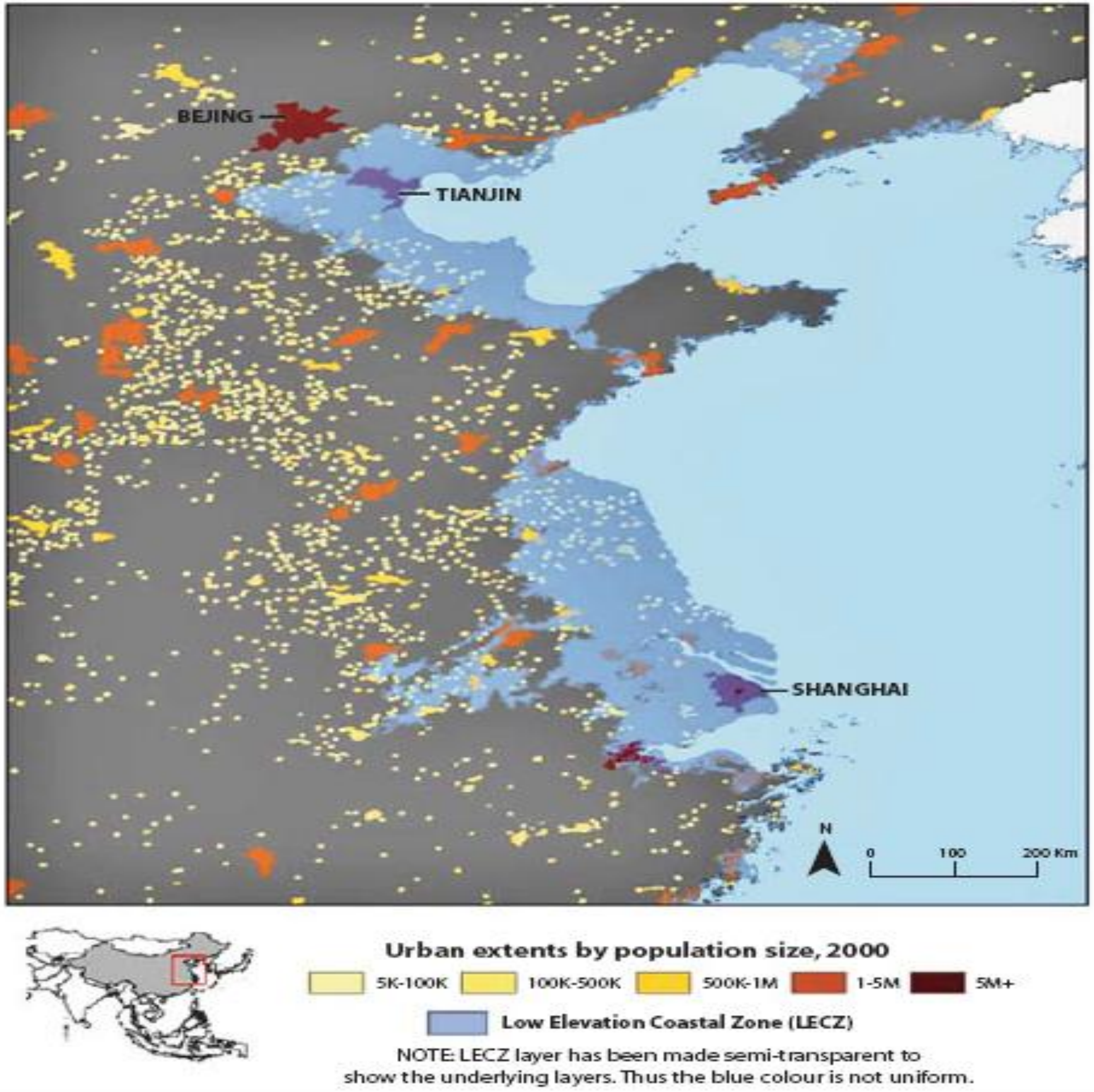
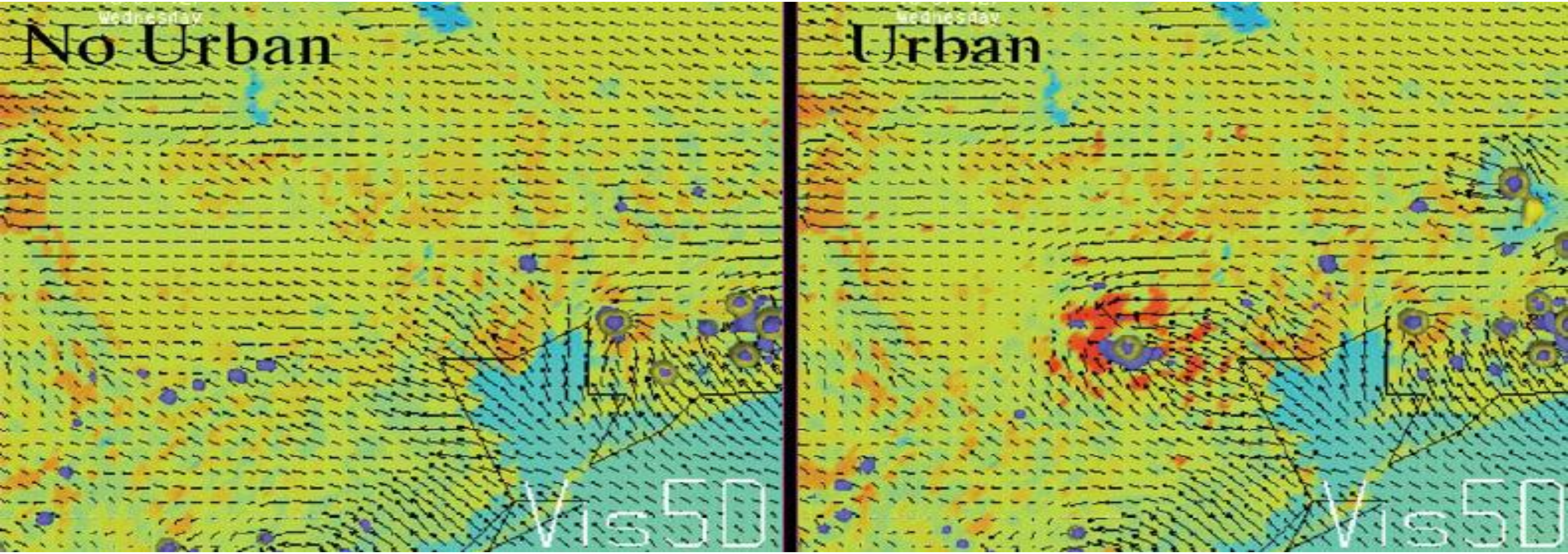


FIGURE 1
Yellow Sea coastal region

The rising sea level poses risk to the most densely populated region in China. The blue color represents the low elevation coastal zones (LECZ)

-*Source: Mcgranahan et al. 2007*

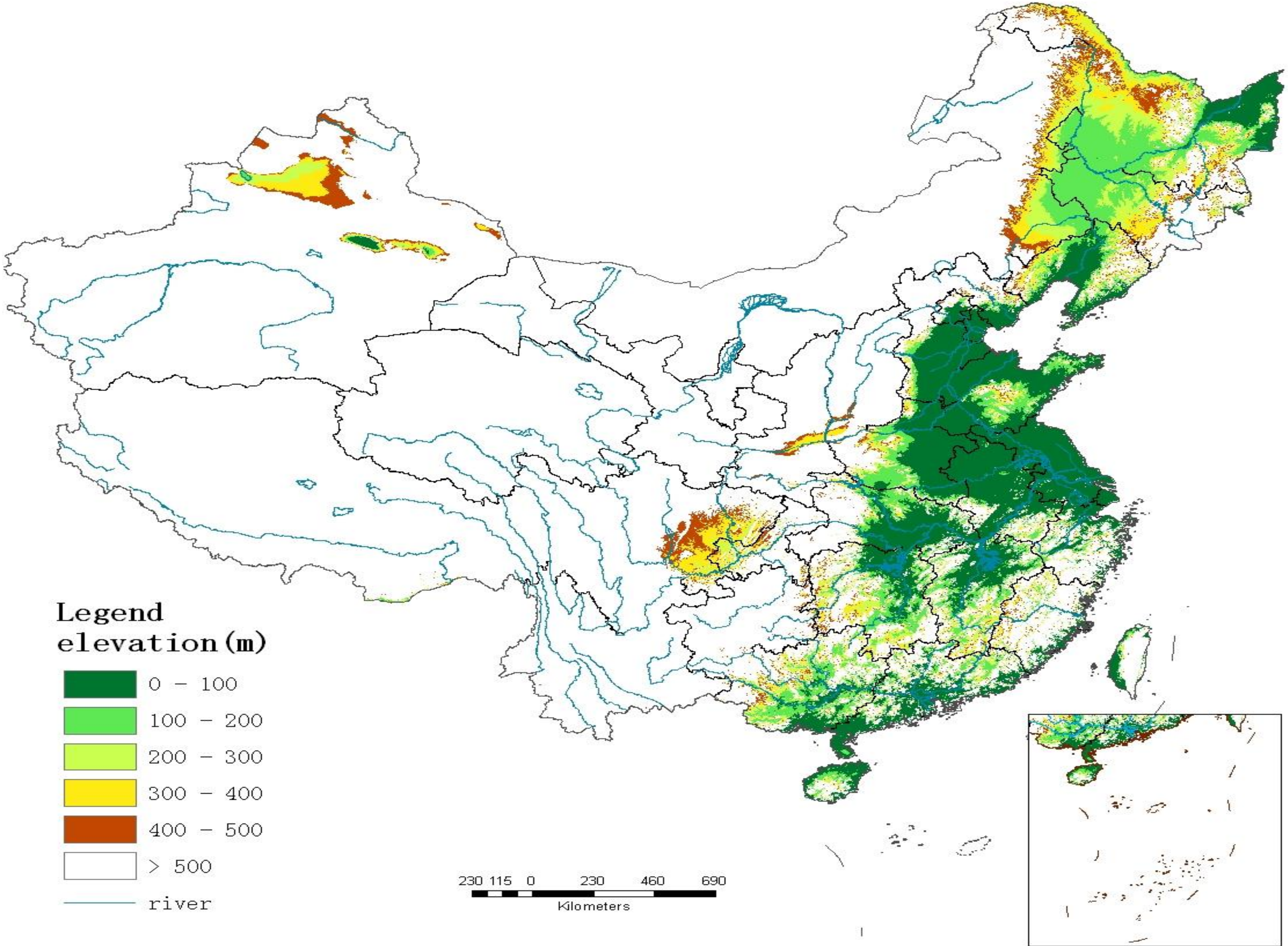
居住区特别是城市化发展改变气候

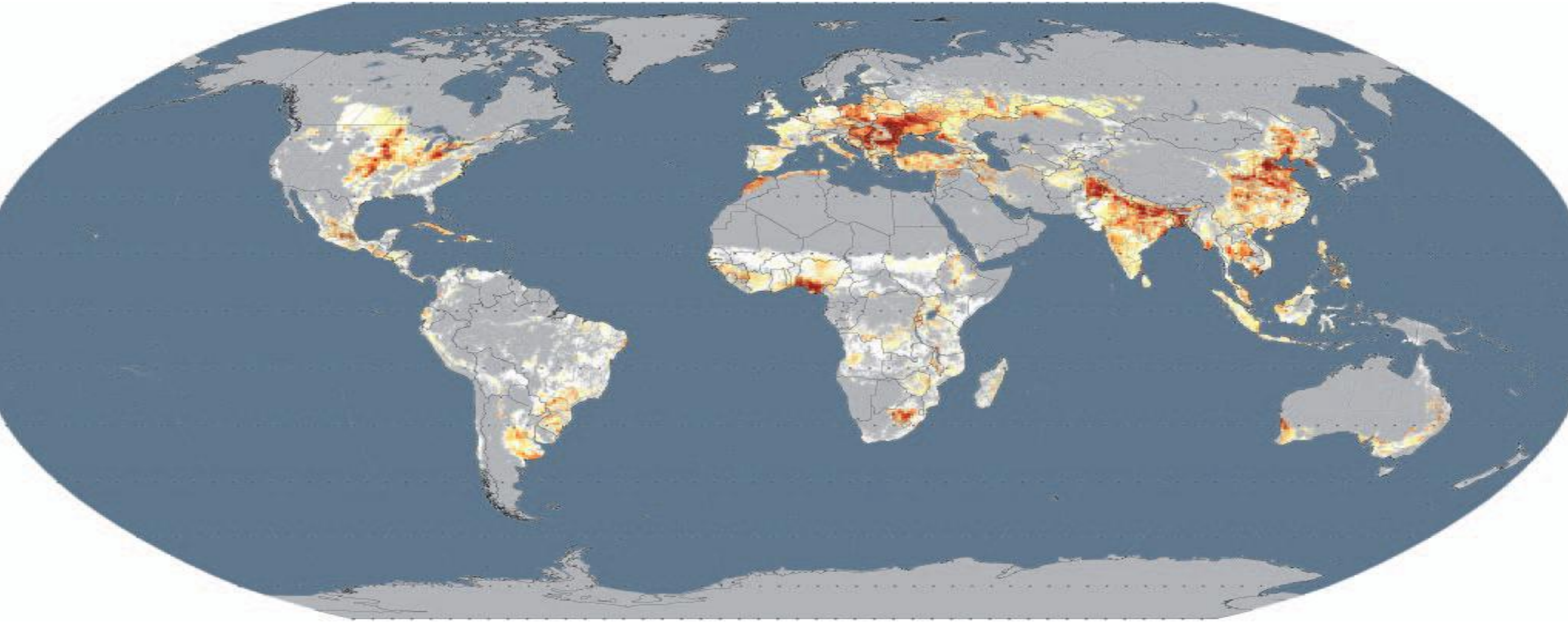


Jin、Dickinson、等的研究

Plain area occupies approx. 10% of China's total terrestrial area

More than 80% of China's population live on the plains





Warming effect on runoff, wildfire, forest change

Scholze et al 2006, PNAS

Lund-Potsdam -Jena GVM

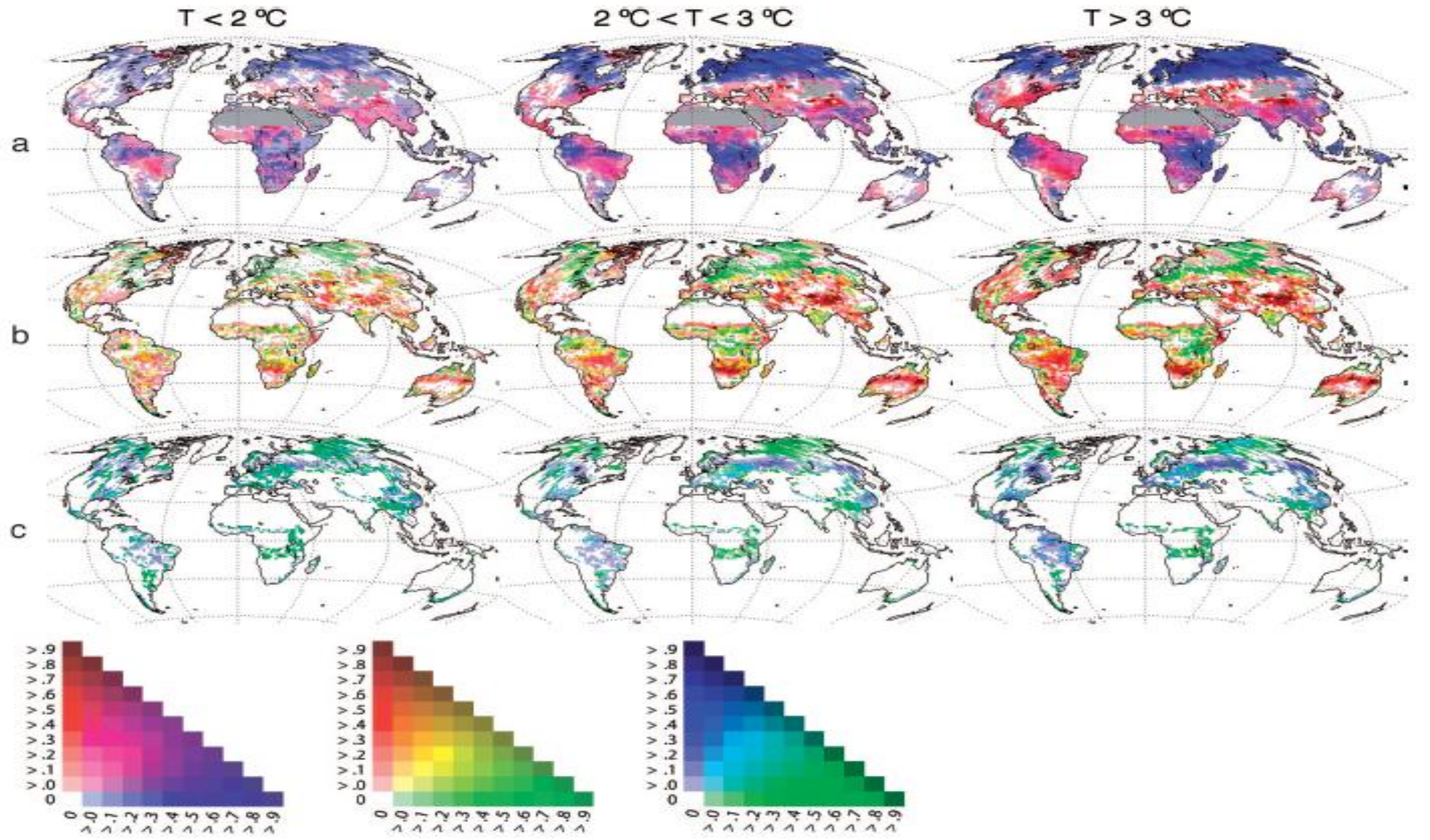


Fig. 2. Probability of exceeding critical levels of change between 1961–1990 and 2071–2100 for three levels of global warming. For quantitative variables (freshwater runoff and wildfire frequency), critical change is defined where the change in the mean of 2071–2100 exceeds $\pm 1\sigma$ of the observed (1961–1990) interannual variability. (*a*) Freshwater runoff (blue for increase, red for decrease; mixed colors show cases where different runs produce changes in opposite directions, i.e., there are runs of both exceeding the critical level by $+1\sigma$ as well as by -1σ). Gray areas denote grid cells with ≤ 10 mm·yr^{-1} mean runoff for 1961–1990. (*b*) Wildfire frequency (red, increase; green, decrease). (*c*) Biome change from forest to nonforest (blue) or vice versa (green). For wildfire frequency and biome change, colors are shown only for grid cells with <75% cultivated and managed areas.

What causes the increase in global river runoff?

The significant worldwide increase in observed river runoff has been tentatively attributed to the stomatal "antitranspirant" response of plants to rising atmospheric CO2 [Gedney N, 2006*Nature* 439:835–838].

When allowing for the increase in foliage area that results from increasing atmospheric CO2 levels in a global vegetation model, we find a decrease in global runoff from 1901 to 1999.

The elevated atmospheric CO2 concentration does not explain the estimated increase in global runoff over the last century.

Changes in mean climate, as well as its variability, do contribute to the global runoff increase.

Landuse change plays an additional important role in controlling regional runoff values, particularly in the tropics.

In tropical regions, the contribution of land use change is substantially larger than that of climate change.

Piao et al., 2007, PNAS ORCHIDEE model

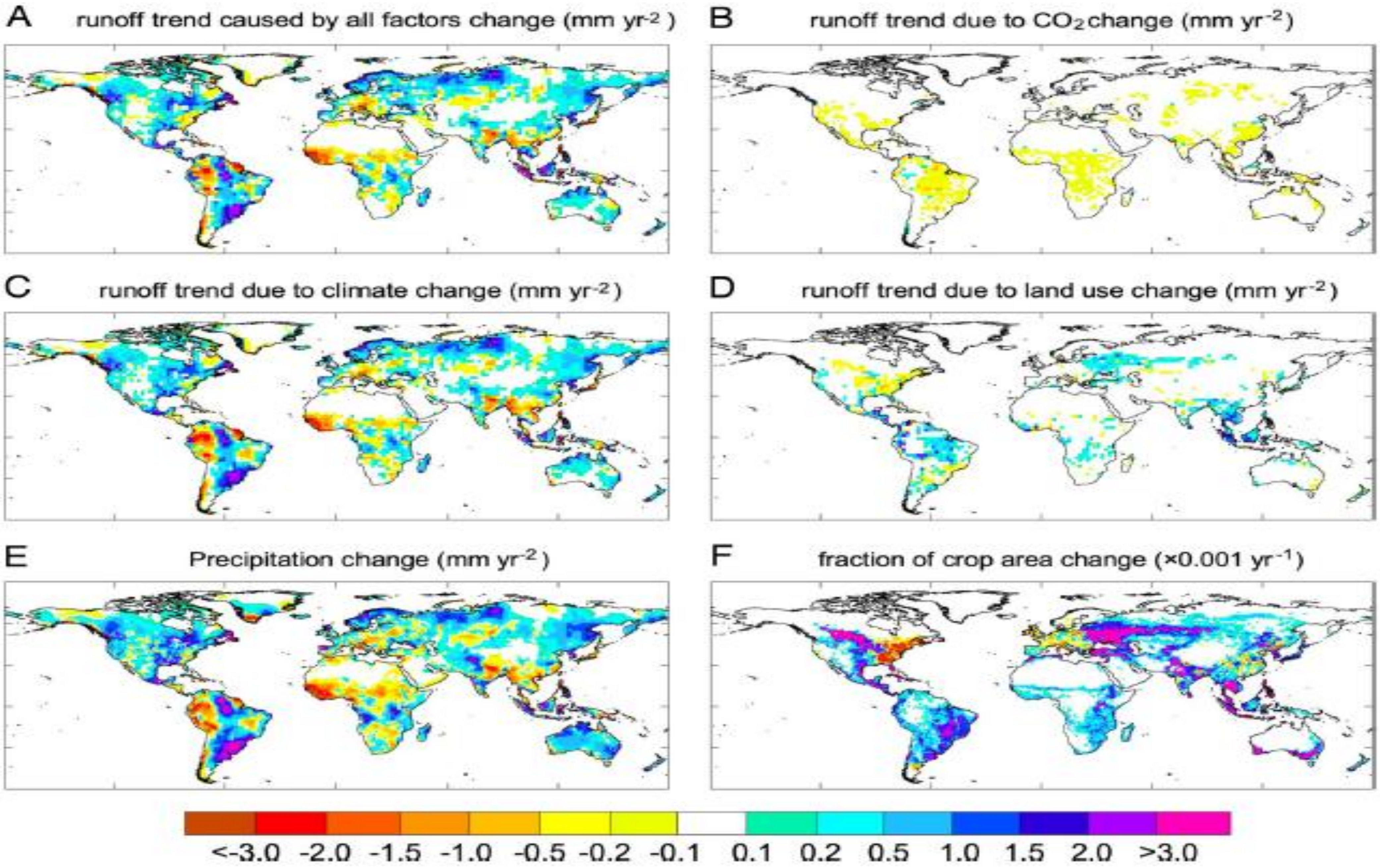


Fig. 3. Spatial distribution of the trend in modeled runoff (*A–D*), precipitation (*E*), and fraction of agriculture area (*F*) over the last century. (*A–D*) Runoff trend because of the combined effects of climate, land use, and atmospheric CO_2 (simulation E3) (*A*); increase in atmospheric CO_2 (allowing LAI changes) (simulation E1) (*B*); climate change (simulations E2–E1) (*C*); and land use change (simulation E3-E2) (*D*).

What causes the increase in global river runoff?

Previous reconstruction of global runoff data suggests that global river runoff increased significantly during the 20th century.

However, it is difficult to estimate whether this trend in runoff is caused by natural or anthropogenic factors, because the characteristics and dynamic properties of the hydrological cycle depend on many interrelated links among climate, atmosphere, soil, and vegetation dynamics.

Long-term changes in runoff depend on the balance of precipitation and evapotranspiration.

What about the role of impervious surface?

Projected impact of climate and land-use change on global bird diversity

Over the past few decades, land-use and climate change have led to substantial range contractions and species extinctions. Even more dramatic changes to global land cover are projected for this century.

Millennium Ecosystem Assessment scenarios used to evaluate the exposure of all 8,750 land bird species to projected land-cover changes due to climate and land-use change.

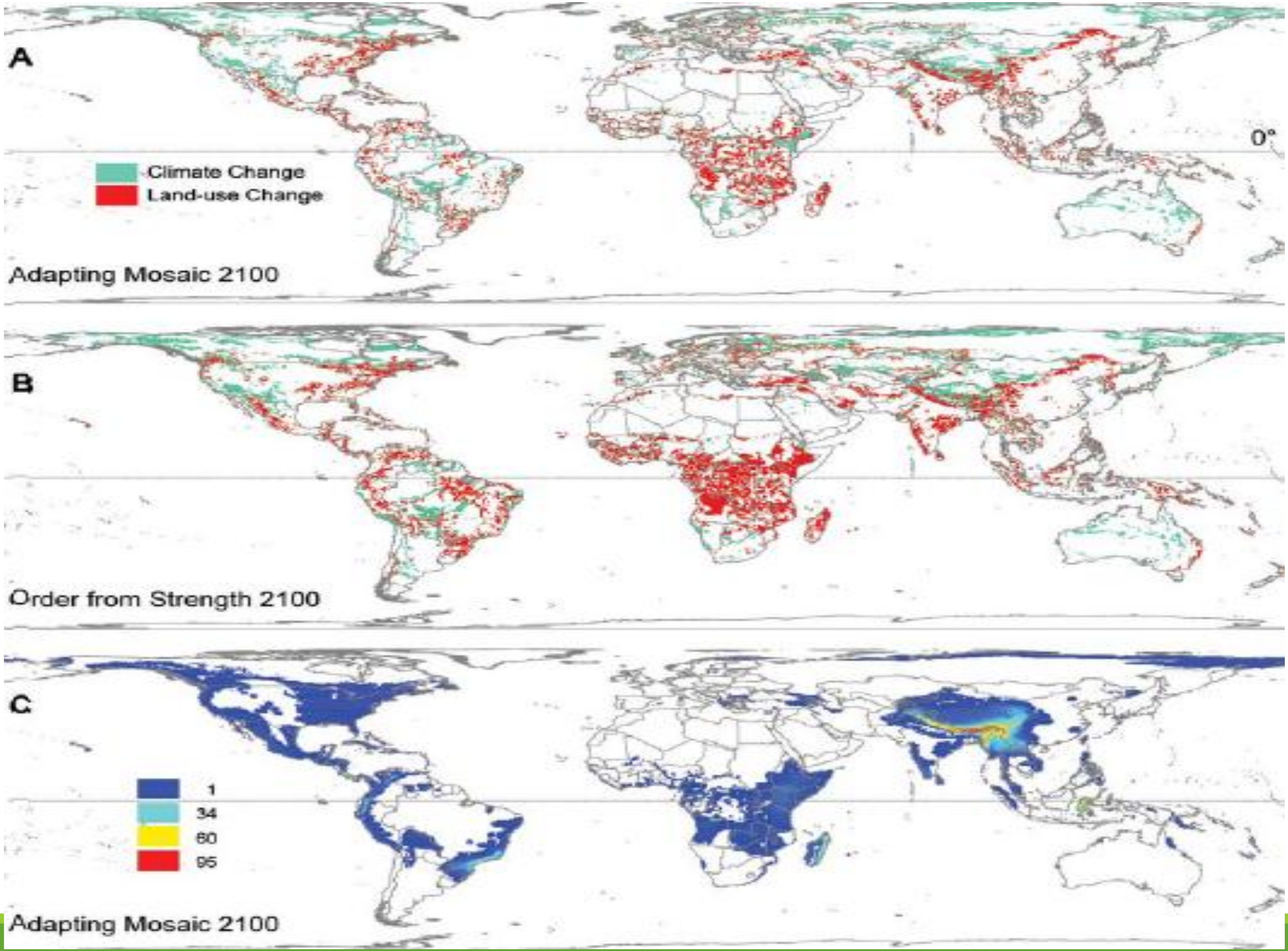
For this first baseline assessment, stationary geographic ranges were assumed that may overestimate actual losses in geographic range.

Even under environmentally benign scenarios, at least 400 species are projected to suffer. 50% range reductions by the year 2050 (over 900 by the year 2100).

Expected climate change effects at high latitudes are significant, species most at risk are predominantly narrow-ranged and endemic to the tropics, where projected range contractions are driven by anthropogenic land conversions.

Whereas climate change will severely affect biodiversity, in the near future, land-use change in tropical countries may lead to yet greater species loss.

A vastly expanded reserve network in the tropics, coupled with more ambitious goals to reduce climate change, will be needed to minimize global extinctions.



Jetz, et al., 2007
PLOS Biology

Changes in bird abundance in Eastern North America

The abundance of birds recorded in the North American Breeding Bird Survey decreased by up to 18 percent between 1966 and 2005.

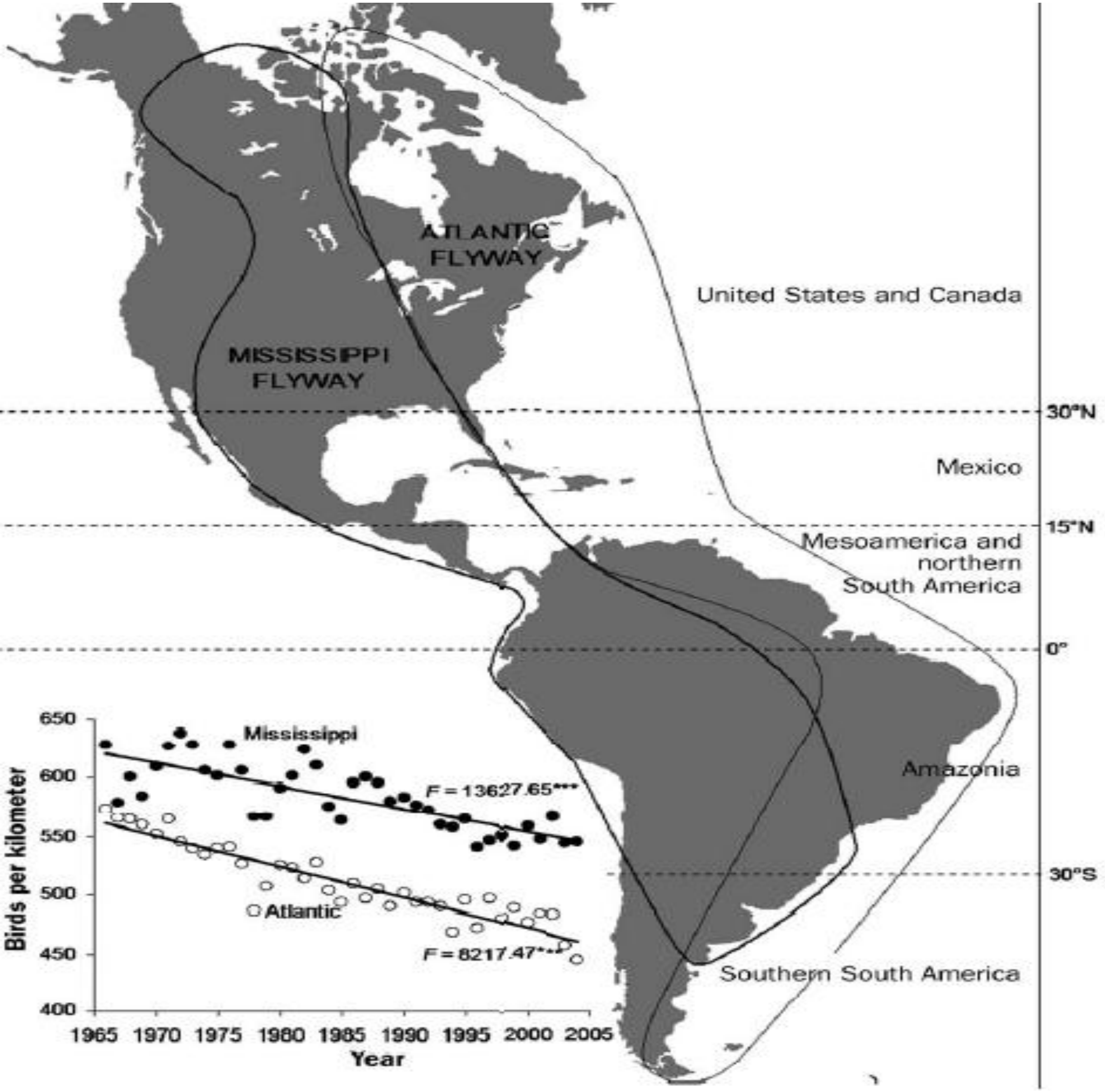
The abundance of US and Canadian resident species decreased by 30 percent, and that of migrants within the United States and Canada decreased by 19 percent.

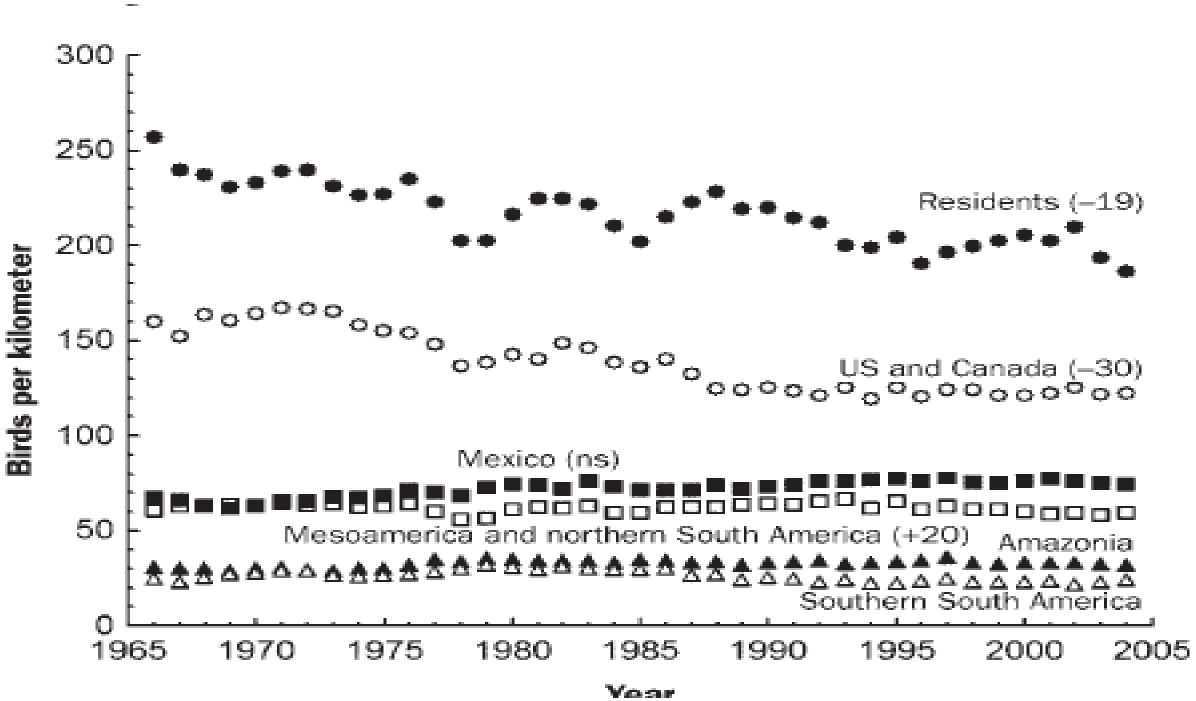
Land-cover changes in northern latitudes therefore seem more consequential for bird

populations than those occurring in Neotropical habitats. Lower abundances were most marked for resident breeding birds that used open, edge, and wetland habitats, the environments most affected by human disturbances—particularly urban sprawl—in northern latitudes.

The abundance of resident and migrant forest-dwelling birds increased with the increases seeming to follow the 20th-century expansion of forest area in northern latitudes, rather than the loss of Neotropical forests.

The geographic footprint of changes in bird abundance linked to habitat changes in North America may thus be extending southward, with negative effects on birds that use open habitats and positive effects on forest birds.



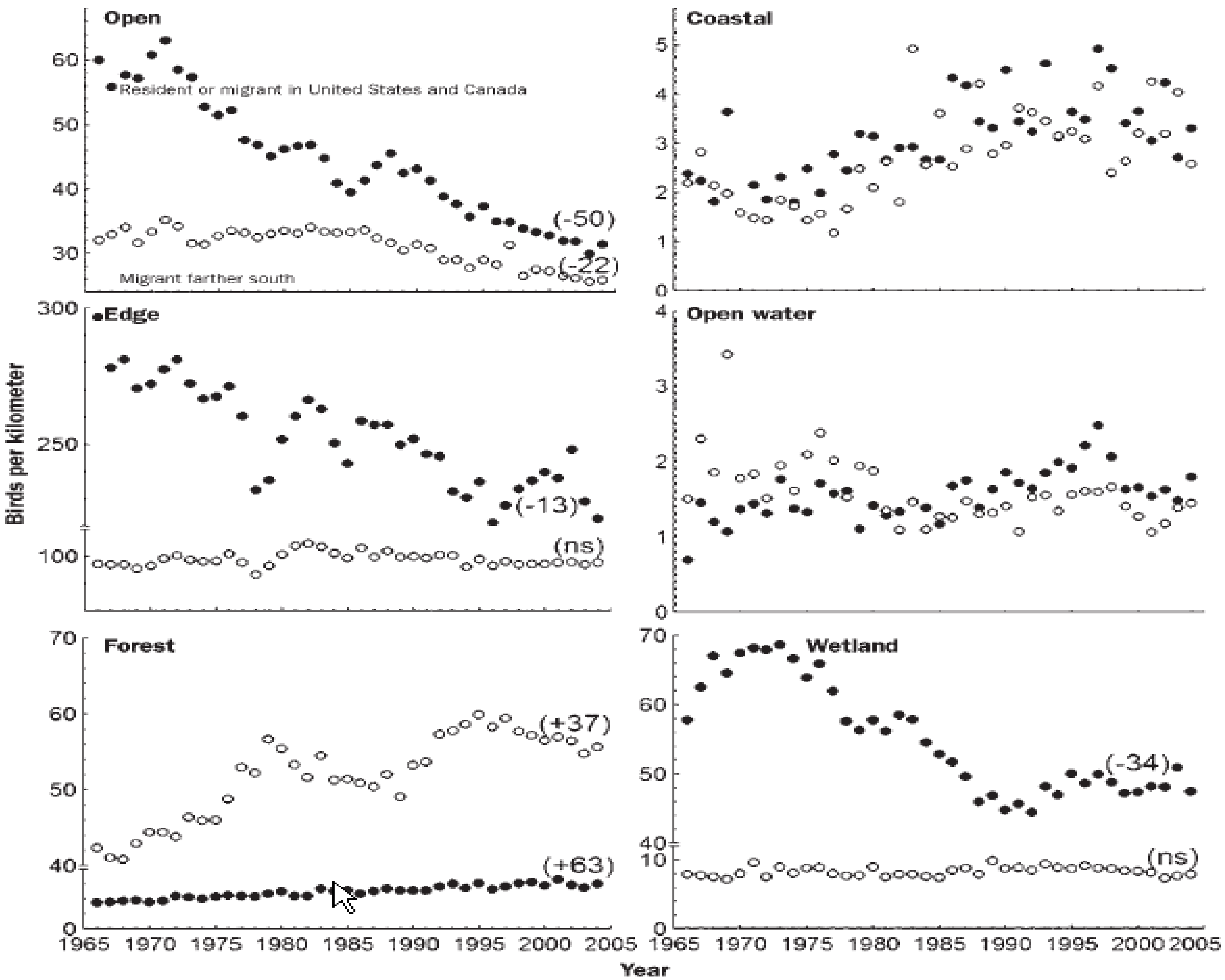


Valiela and Martinetto, 2007, Bioscience

Land use change

UWI

Forest increase



Wetland decrease

Current status (Foley, 2011, Nature)

According to FAO, croplands cover 1.53 billion hectares (about 12% of Earth's ice-free land), while pastures cover another 3.38 billion hectares (about 26% of Earth's ice-free land)

Between 1985 and 2005 the world's croplands and pastures expanded by 154 million hectares (about 3%). But this slow net increase includes significant expansion in some areas (the tropics),

Yield growth is slowing down

28% gain in production occurred as cropland area increased by only 2.4%, suggesting a 25%increase in yield.However, cropland area that was harvested increased by about 7% between 1985 and 2005

Using the same methods as for the 20%result, we note that yields increased by 56%between 1965 and 1985,

cereal crops decreased in harvested area by 3.6% between 1985 and 2005, yet their total production increased by 29%, reflecting a 34% increase in yields per hectare.

Oil crops increases in both harvested area (43%) and yield (57%), resulting in a 125% increase in total production

Fodder crop decreased

Crop use

Globally, only 62% of crop production (on a mass basis) is allocated to human food, versus 35% to animal feed (which produces human food indirectly, and much less efficiently, as meat and dairy products) and3% for bioenergy, seed and other industrial products.

we find the land devoted to raising animals totals 3.73 billion hectares—an astonishing ,75% of the world’s agricultural land.

土地变化科学的基本内容

土地变化科学将土地覆盖和土地利用的动态做为一个耦合的人—环境系统来理解。其主要内容是改善我们对土地利用和土地覆盖动态认识及其对地球系统结构和功能的影响

与研究气候变化科学、水科学一样，土地变化科学是一门基础科学

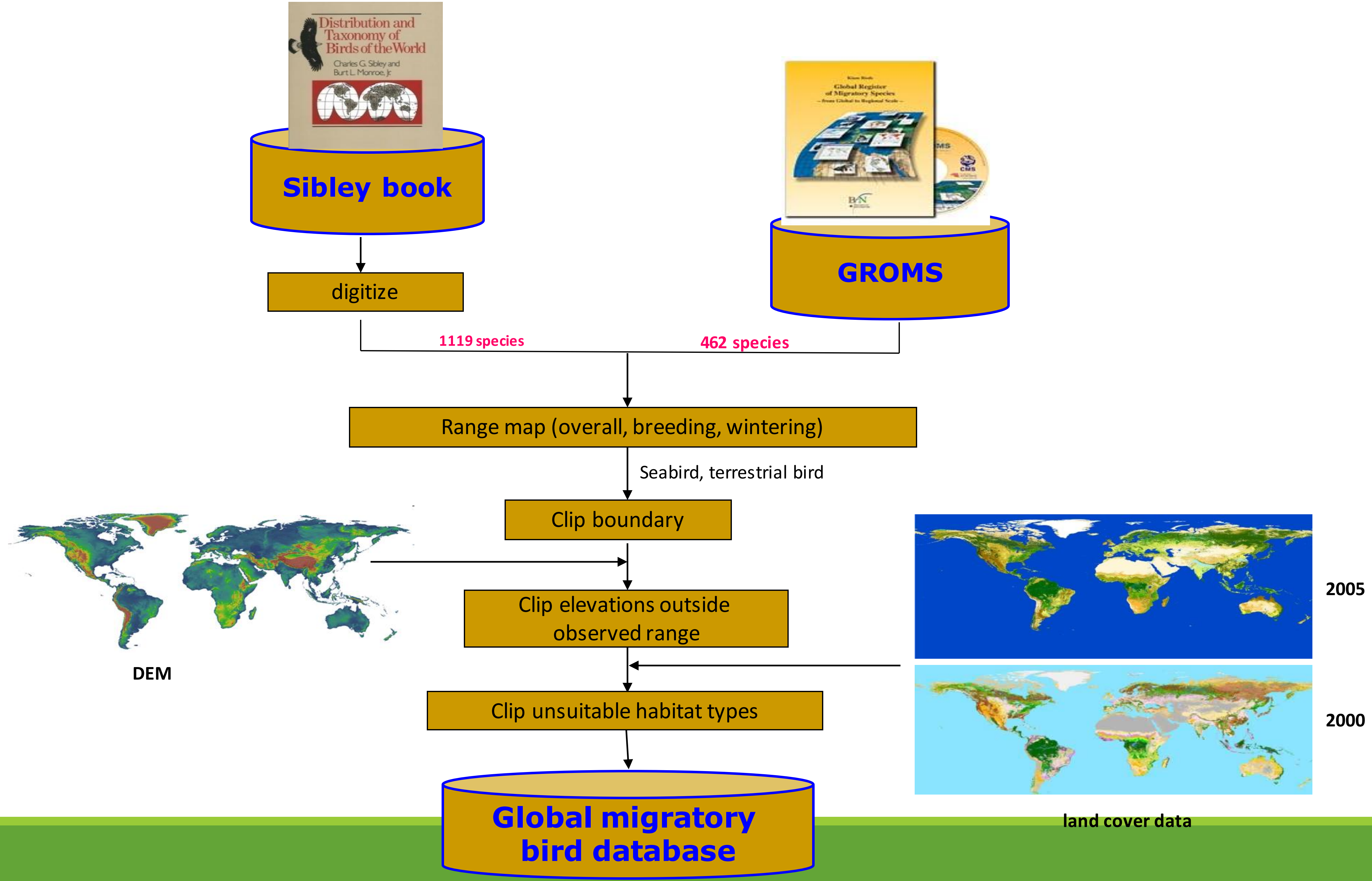
土地变化的驱动力是多种多样的—需要经济、政治、社会、科学与工程各个学科的交叉来加强驱动过程的理解

土地变化数据和测度

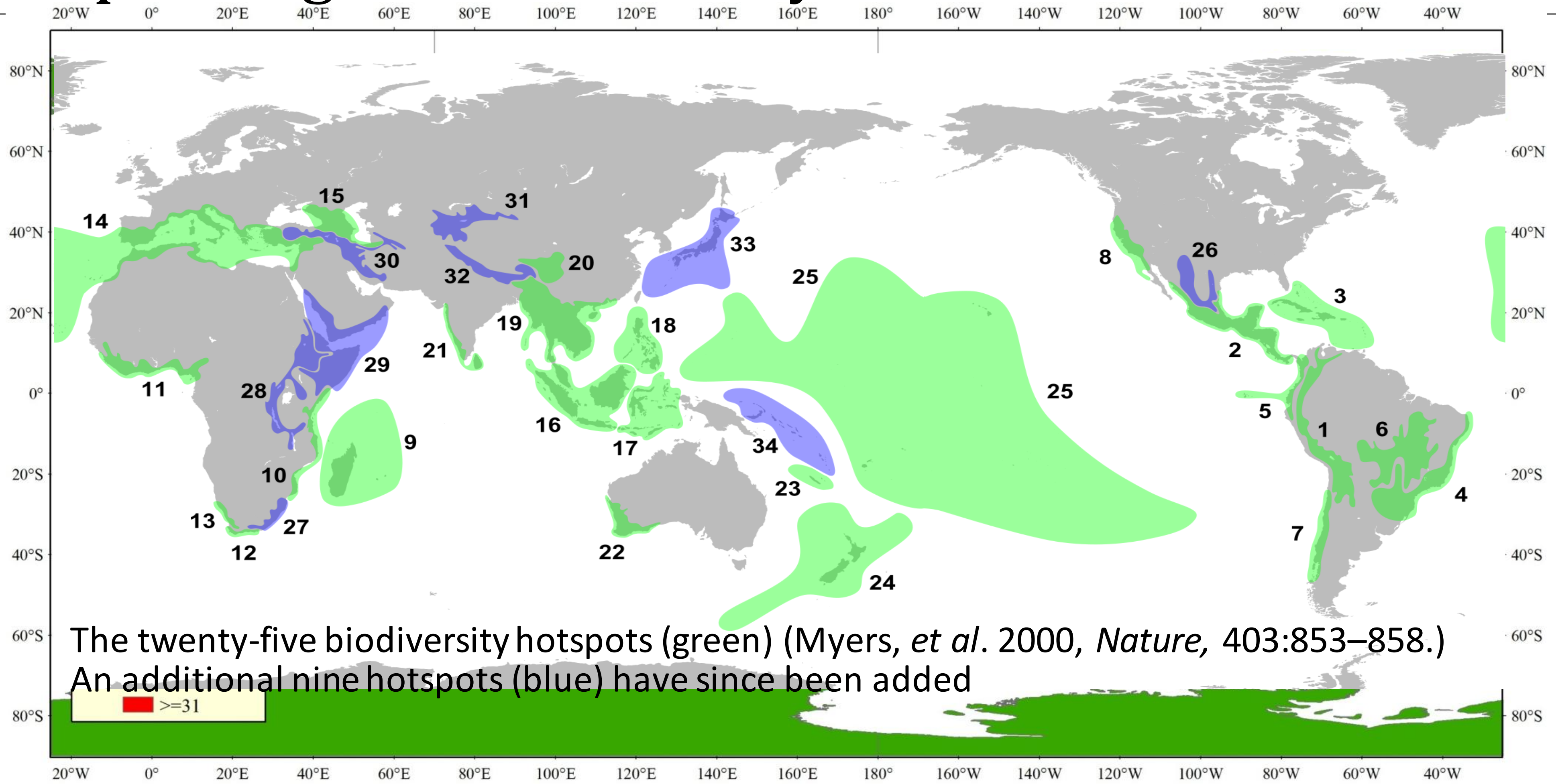
土地变化分析技术

土地变化模型与预测

The mismatch of research hotspots and mapping hotspots


Distribution and Taxonomy of Birds of the World
Charles G. Sibley and Burt L. Monroe, Jr.
Sibley book
digitize
GROMS
1119 species
462 species
Range map (overall, breeding, wintering)
Seabird, terrestrial bird
Clip boundary
Clip elevations outside observed range
Clip unsuitable habitat types
DEM
2005
2000
land cover data
Global migratory bird database

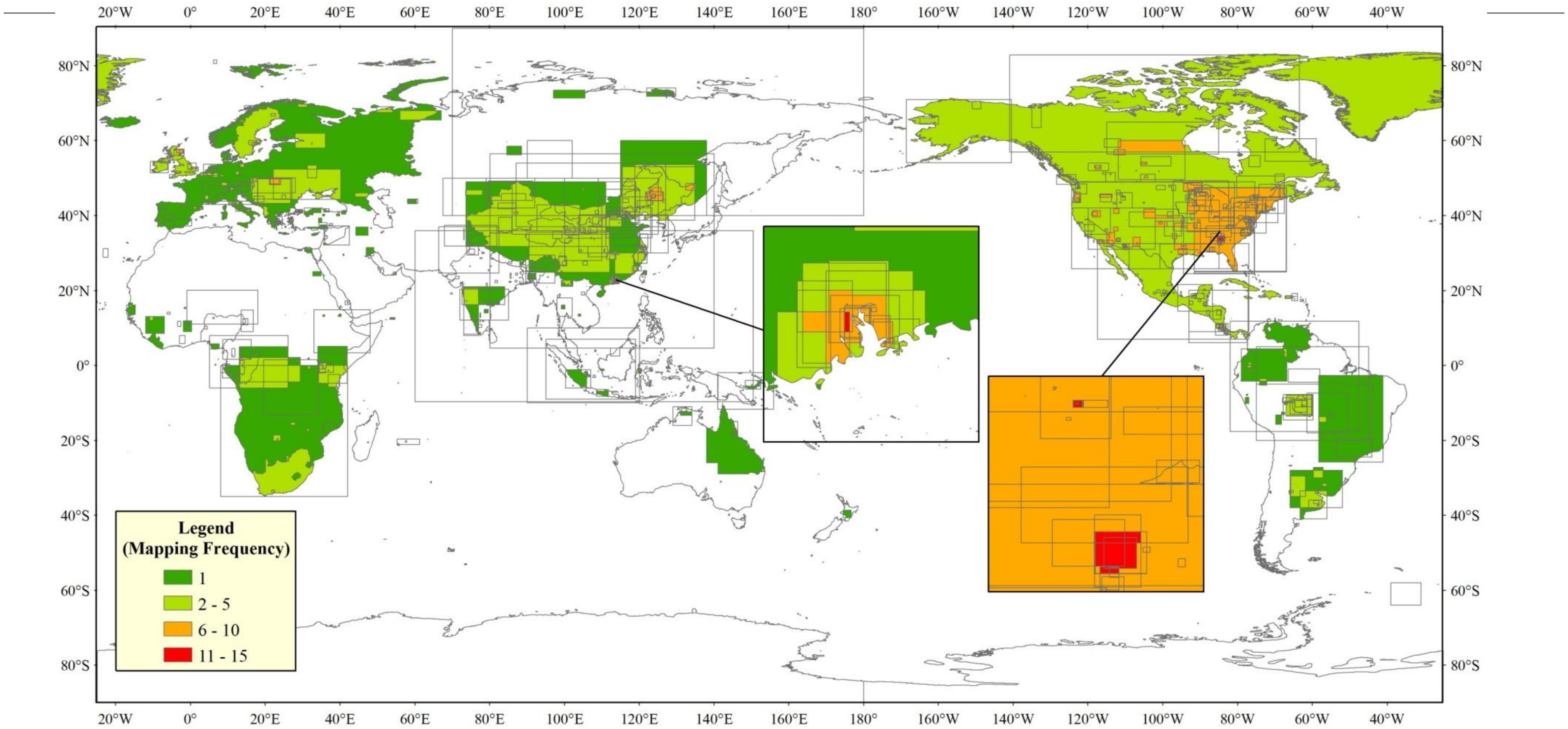
Hot spots of global biodiversity



The twenty-five biodiversity hotspots (green) (Myers, *et al*. 2000, *Nature,* 403:853–858.)
An additional nine hotspots (blue) have since been added

Yu et al., in preparation

Hot spots of using 30 meter TM/ETM+



Yu et al., in preparation

Initial objectives of China's global land cover mapping

To support earth system modeling

Requires substantial change in land cover classification system – they are composites

Requires processing, informing, a large number of images taken at different time and location

OUR MISSION

Pure cover – cross-walkable to previous classification systems

Images chosen from the greenest season – so limited number of spectral channels

Large quantities of training and testing samples

Multiple – classifier comparison

30 m global land cover map of the land areas except for Greenland and Antarctica in 2000, 2010

Results so far and soon to be available

Global Analyst, Global Mapper software – based on Google Earth and ENVI

Over 90,000 training samples

Over 38,000 validation samples – aiming at a global standard – already produced insightful results

30 m global land cover map in circa 2010 – 66% overall accuracy; although accuracies low better than any existing land cover products

250 m global land cover maps 2001, 2010 from MODIS time series data > 74% overall accuracy

Soon to be available – land cover proportion maps in 1 km (2010), 10 km (2001,2010), 25 km (2001,2010), 1 degree (2001,2010) – for ESM

Eastern Africa Climate Modeling Using RAMS

Ge et al., 2007

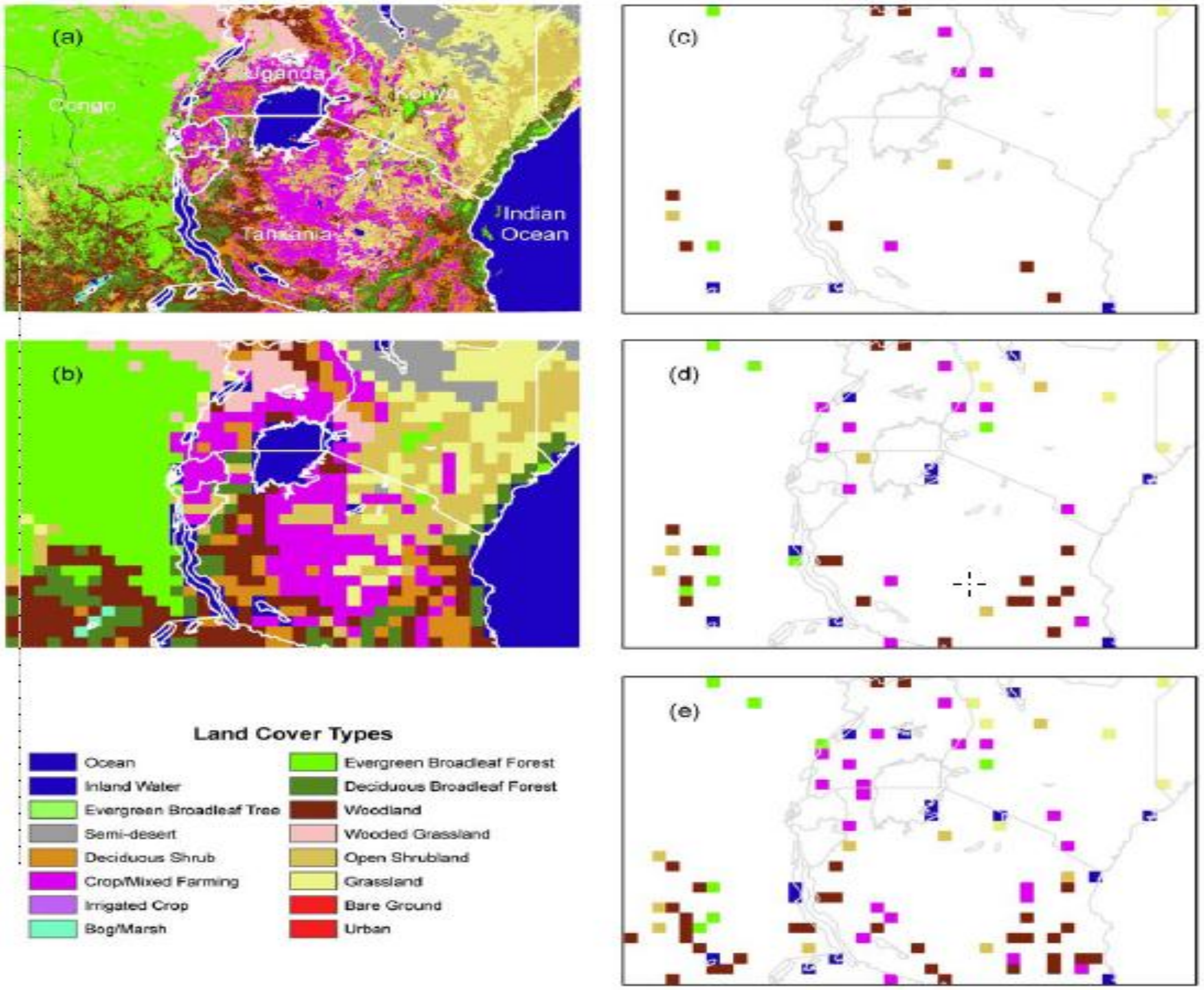
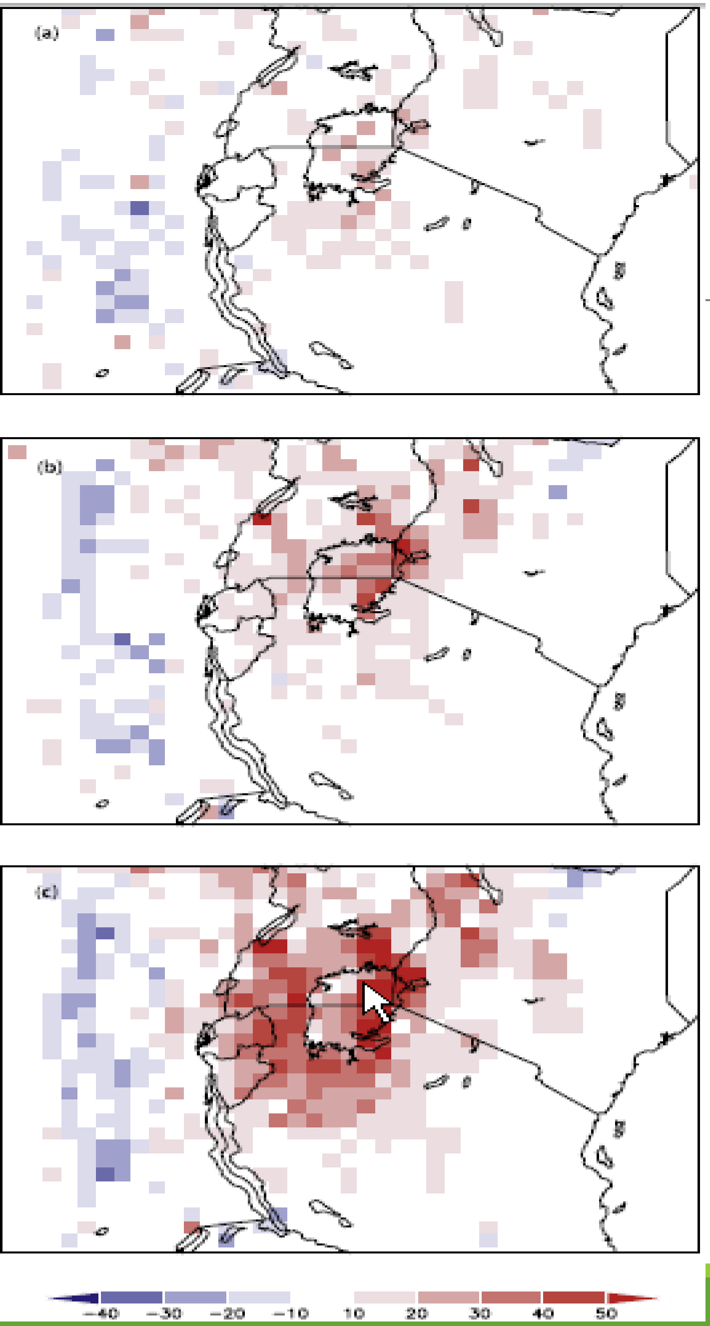
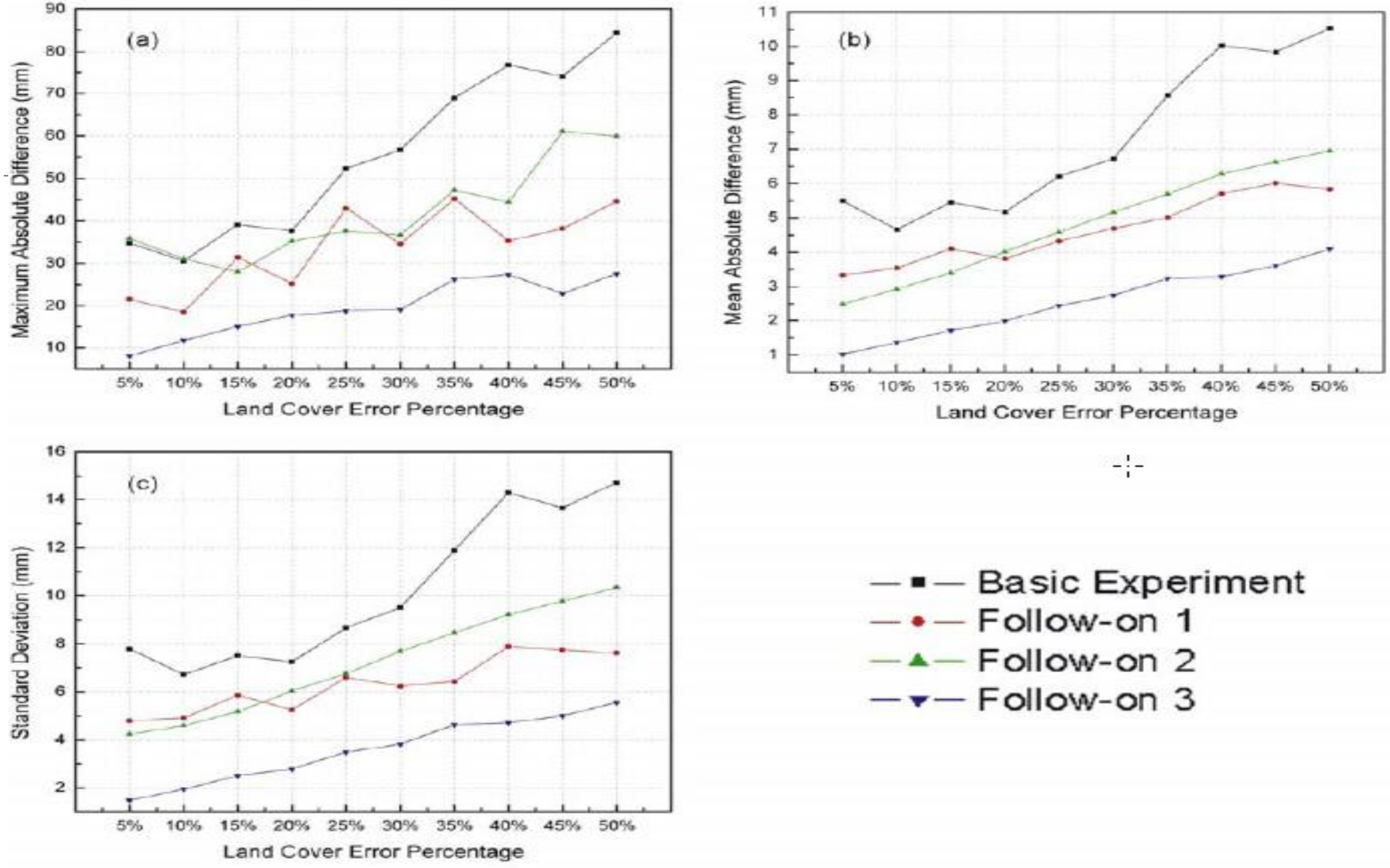


Figure 2. Cross-referenced GLC2000 with (a) 1 km resolution and (b) 50 km resolution, and simulated land cover classification errors: (c) 10%, (d) 30%, and (e) 50%. Land cover types in Figures 2b, 2c, 2d, and 2e only represent the biggest patches in grid cells. See texts for more details.


(a)
(b)
(c)
−40 −30 −20 −10 10 20 30 40 50


(a)
Maximum Absolute Difference (mm)
90 80 70 60 50 40 30 20 10
5% 10% 15% 20% 25% 30% 35% 40% 45% 50%
Land Cover Error Percentage
(b)
Mean Absolute Difference (mm)
11 10 9 8 7 6 5 4 3 2 1
5% 10% 15% 20% 25% 30% 35% 40% 45% 50%
Land Cover Error Percentage
(c)
Standard Deviation (mm)
16 14 12 10 8 6 4 2
5% 10% 15% 20% 25% 30% 35% 40% 45% 50%
Land Cover Error Percentage
Basic Experiment
Follow-on 1
Follow-on 2
Follow-on 3

A new classification scheme

Satisfying needs in earth system modeling

Earth system models needs plant growing forms, woody plant seasonality, leaf forms, non-woody vegetation photosynthesis types (C3、C4) and age, disturbance type and intensity

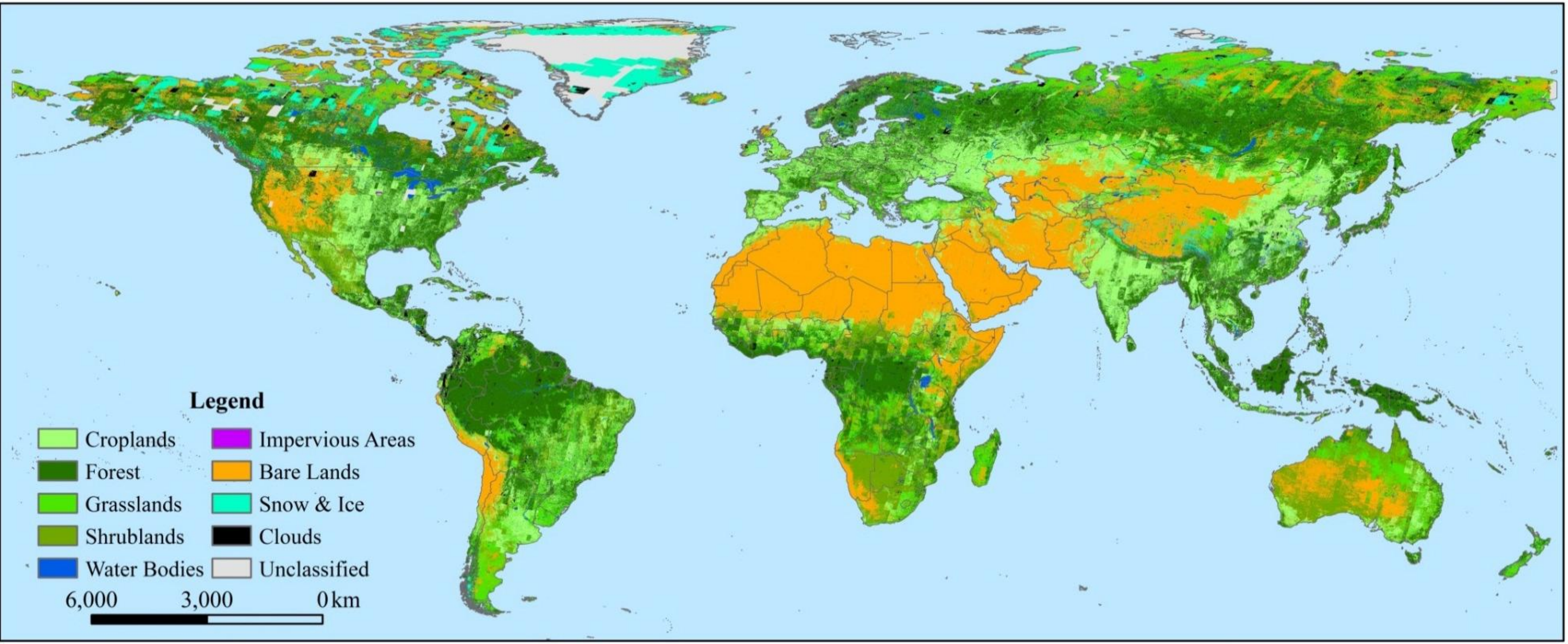
Rough parameterization based on those global land cover types when applied in models

UNLCCS	Def	Land cover type	Form	PFT	Closure	Hgt	Remark
11	Post flooding or irrigated cr	Cropland (1)		C3/C4			Corn/Wheat
14	Rainfed croplands	Cropland		C3/C4			Corn/Wheat
20	Mosaic cropland/vege	Crop/Vege		C3/C4	50-70%		
30	Mosaic vege/cropland	Crop/Vege		C3/C4	50-70%		
40	>15%-BL-EG/Semi D Fo>5m	Forest (2)	BL EG/Dec (1)		>15%	>5m	
50	>40% BL D Fo>5m	Forest	BL D (2)		>40%	>5m	
60	15—40% BL D Fo>5m	Forest	BL D		15-40%	>5m	
70	>40% NL EG Fo>5m	Forest	NL EG (3)		>40%	>5m	
90	15-40% NL D EG Fo>5m	Forest	BL D/EG		15-40%	>5m	
100	>15% ML Fo > 5m	Forest	BL/NL		>15%	>5m	
110	MoFo/Sh (50-70%)/G(20-50)	Fo/Shrub/Gras		C3/C4	50-70%		
120	MoG(50-70)/F/Sh(20-50)	Fo/Shr/Grass		C3/C4	50-70%		
130	>15% Sh(<5m)	Shr (3)		C3/C4	>15%	<5m	
140	>15% G	Grassland (4)		C3/C4	>15%		Tall/S/Tundra
150	<15% Vege	Vege		C3/C4	<15%		
160	>40% BL Fo Reg Fl Fresh	Inland fo wetl	BL		>40%		
170	>40% Semi BL EG reg Fl Sal	Coastal fo wetl	BL Semi D/EG		>40%		
180	>15% vege on reg Fl or w log	Marshland (5)	Watered veg (4)	C3/C4	>15%		Inund/Floa
190	Artificial (urban > 50%)	Urban (6)			>50%		Imp/Perv/Roof/
200	Bare	Bare (7)	Wd/Wt form				R/G/Sd/St
210	Water	Water (8)					L/Rv/Riv
220	Permanent Snow/Ice	Snow/Ice (9)					

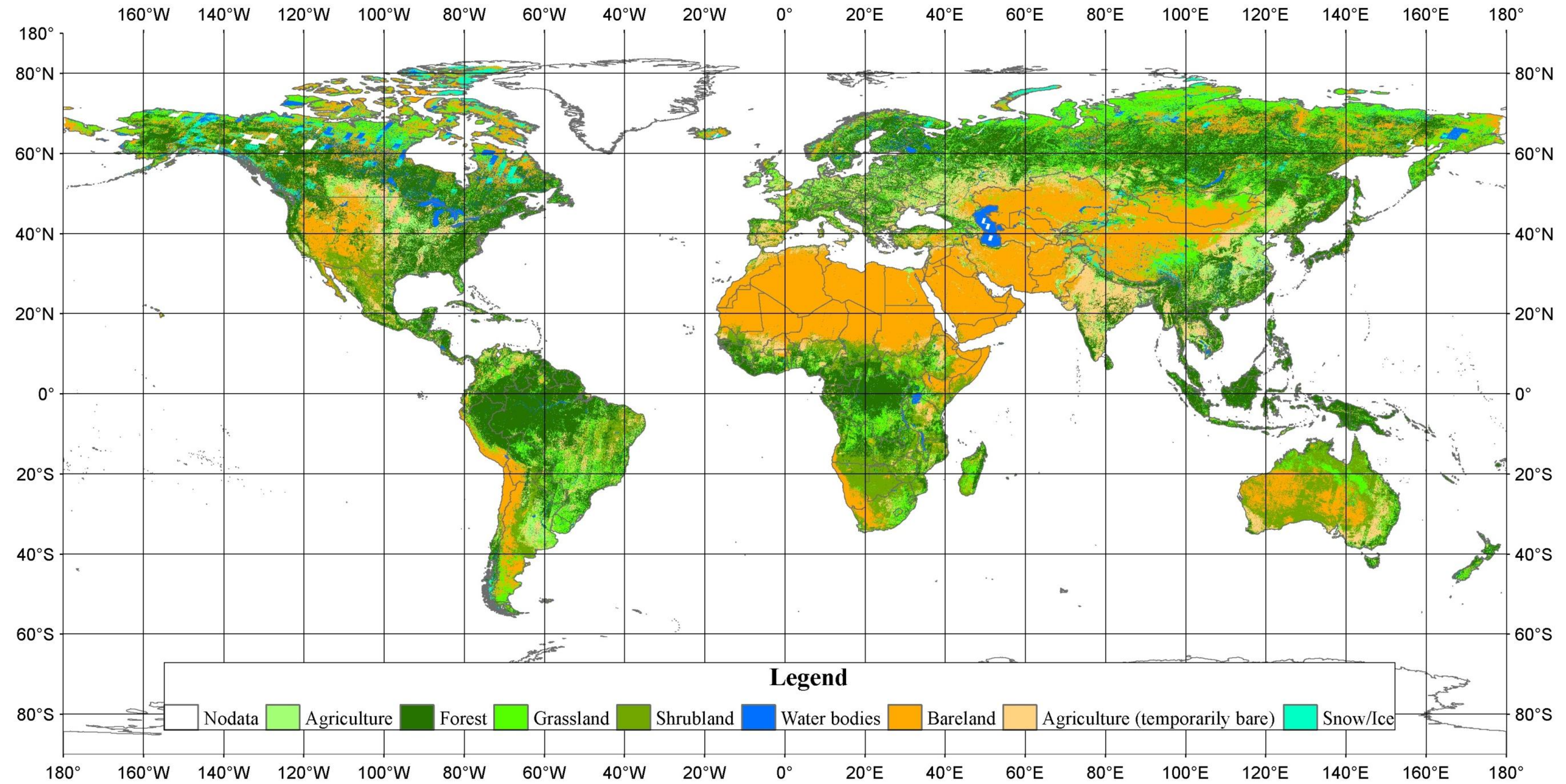
10 classes

Existing opportunities

FROM-GLC (Accuracy: 63.72%)

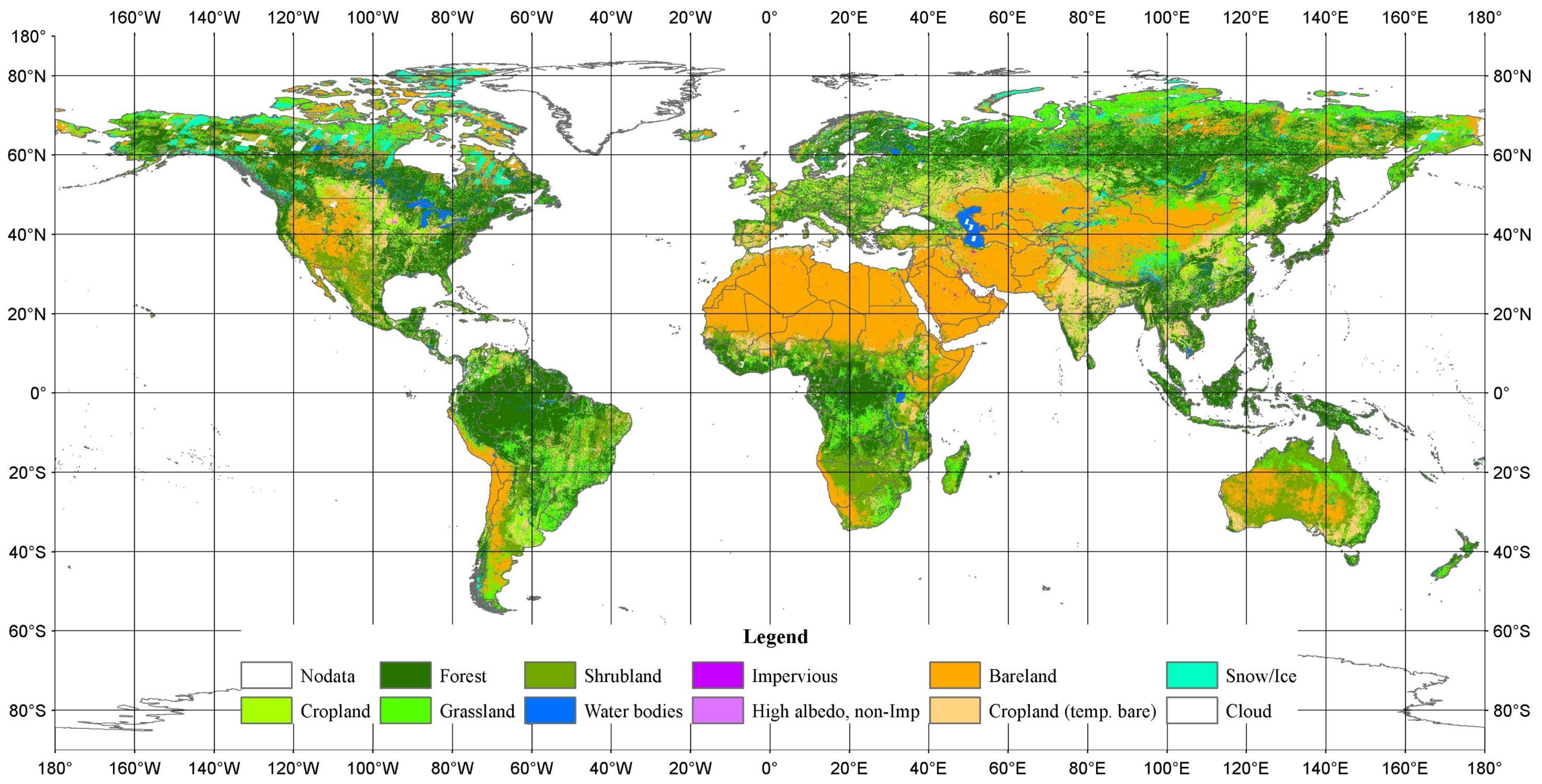


Gong et al., 2013



FROM-GLC-seg (Accuracy: 64.63%)

Yu et al., in review



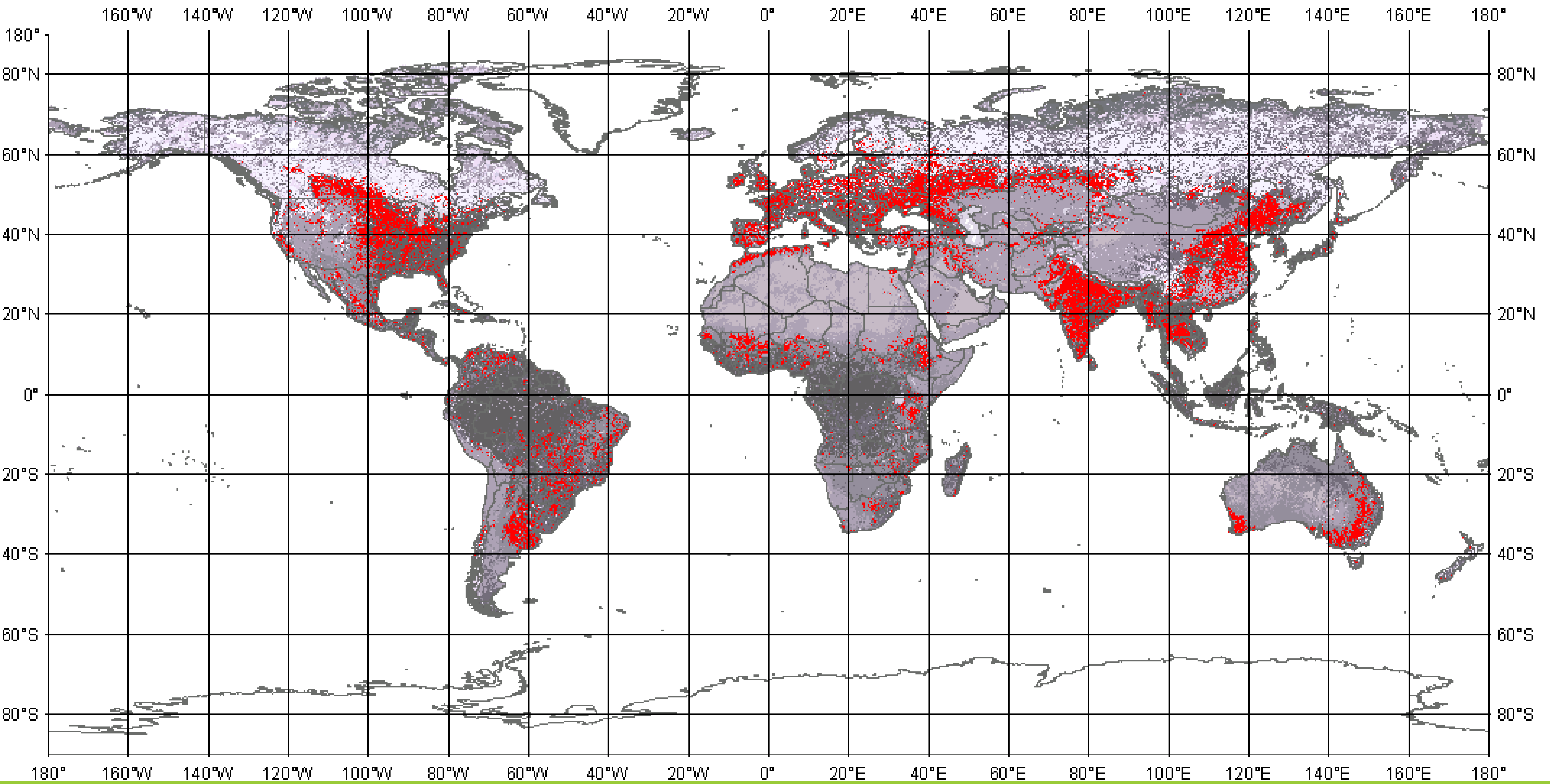
FROM-GLC-agg (Accuracy: 66.00%)

Yu et al, submitted

Accuracy comparison

	FROM-GLC (63.72%/51.68%)		FROM-GLC-seg (64.63%/52.41%)		FROM-GLC-agg (66.00%/53.70%)	
	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)
Cropland	37.59	43.24	**61.56**	59.81	60.76	**62.68**
Forest	77.10	80.16	**79.30**	79.72	78.15	**80.89**
Grasslands	34.16	**53.66**	**36.03**	43.93	35.61	44.50
Shrublands	34.73	49.11	**38.30**	50.48	38.19	**50.60**
Water Bodies	88.41	**82.88**	88.01	69.09	**91.71**	69.45
Impervious	10.53	34.88	-	-	**19.62**	**35.14**
Bare Lands	**93.45**	56.38	89.37	62.71	88.36	**64.08**
Snow & Ice	**85.89**	**96.77**	63.20	80.35	81.40	92.53
Cloud	**83.55**	65.24	-	-	76.01	**68.70**

Yu et al., submitted



Global Cropland Distribution

Proportions of land cover types on land

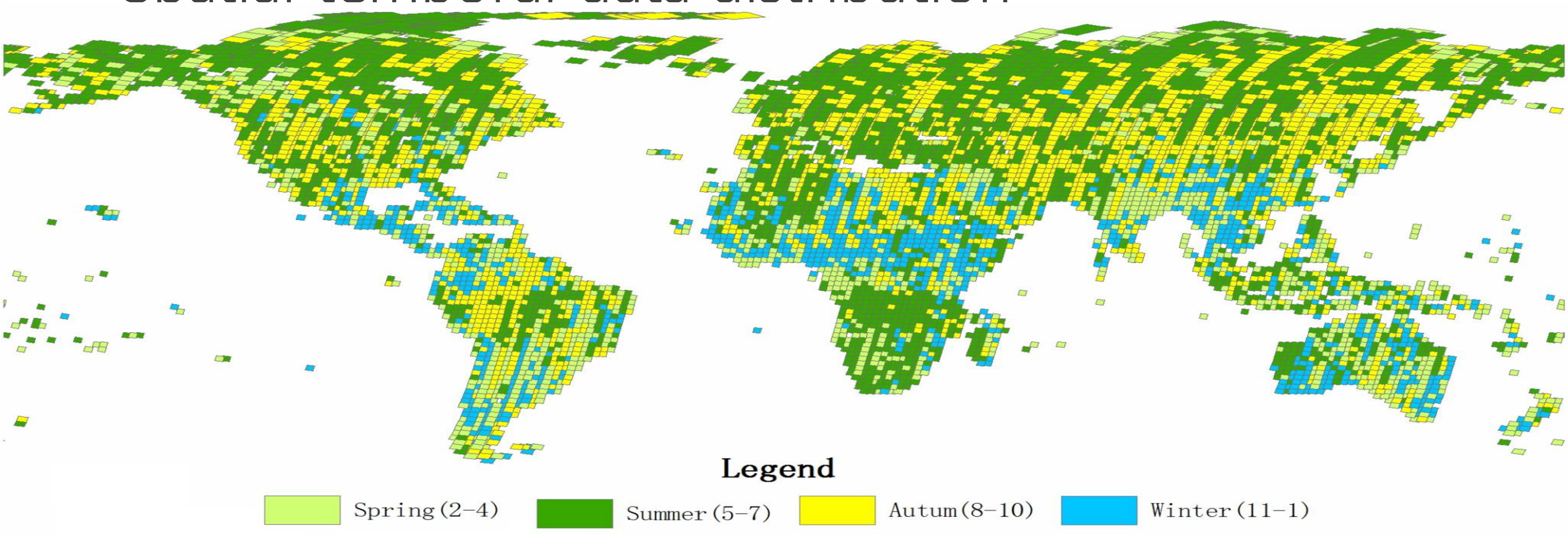
Land cover	Percentage (%)		Adjusted percentage (%)		Area (10^4 km^2)	
	Estimated value	Range	Estimated value	Range	Estimated value	Range
Croplands	8.0	4.8 – 9.9	7.1	4.3 – 8.9	1058.79	642.79 – 1319.74
Forests	32.1	28.1 – 35.9	28.6	25.1 – 32.0	4259.33	3737.80 – 4766.66
Grasslands	20.8	8.6 – 23.9	18.6	7.7 – 21.3	2765.36	1145.90 – 3170.99
Shrublands	12.7	6.6 – 16.7	11.3	5.9 – 14.9	1683.93	878.04 – 2216.59
Waterbodies	2.6	2.4 – 2.7	2.3	2.1 – 2.4	338.86	320.05 – 362.65
Impervious	0.8	0.6 – 0.9	0.7	0.5 – 0.8	102.46	78.67 – 123.95
Barren	21.0	20.1 – 34.3	18.7	17.9 – 30.6	2787.23	2670.19 – 4559.05
Snow and ice	2.2	2.1 – 2.2	1.9	1.9 – 2.0	287.43	276.31 – 297.41

Initial results appeared in IJRS

- Support from the Ministry of Science and Technology, and Tsinghua University of China
- Peng Gong, Jie Wang, Le Yu, Yongchao Zhao, Yuanyuan Zhao, Lu Liang, Zhenguo Niu, Xiaomeng Huang, Haohuan Fu, Shuang Liu, Congcong Li, Xueyan Li, Wei Fu, Caixia Liu, Yue Xu, Xiaoyi Wang, Qu Cheng, Luanyun Hu, Wenbo Yao, Han Zhang, Peng Zhu, Ziying Zhao, Haiying Zhang, Yaomin Zheng, Luyan Ji, Yawen Zhang, Han Chen, An Yan, Jianhong Guo, Liang Yu, Lei Wang, Xiaojun Liu, Tingting Shi, Menghua Zhu, Yanlei Chen, Guangwen Yang, Ping Tang, Bing Xu, Chandra Giri, Nicholas Clinton, Zhiliang Zhu, Jin Chen, Jun Chen, 2013. **Finer resolution observation and monitoring of global land cover: first mapping results from Landsat TM and ETM+ data**. *International Journal of Remote Sensing*. 34(7):2604-2657.

A bit of details

Spatial-temporal data distribution



Training and test sampling

Training sample requirement

Homogeneous

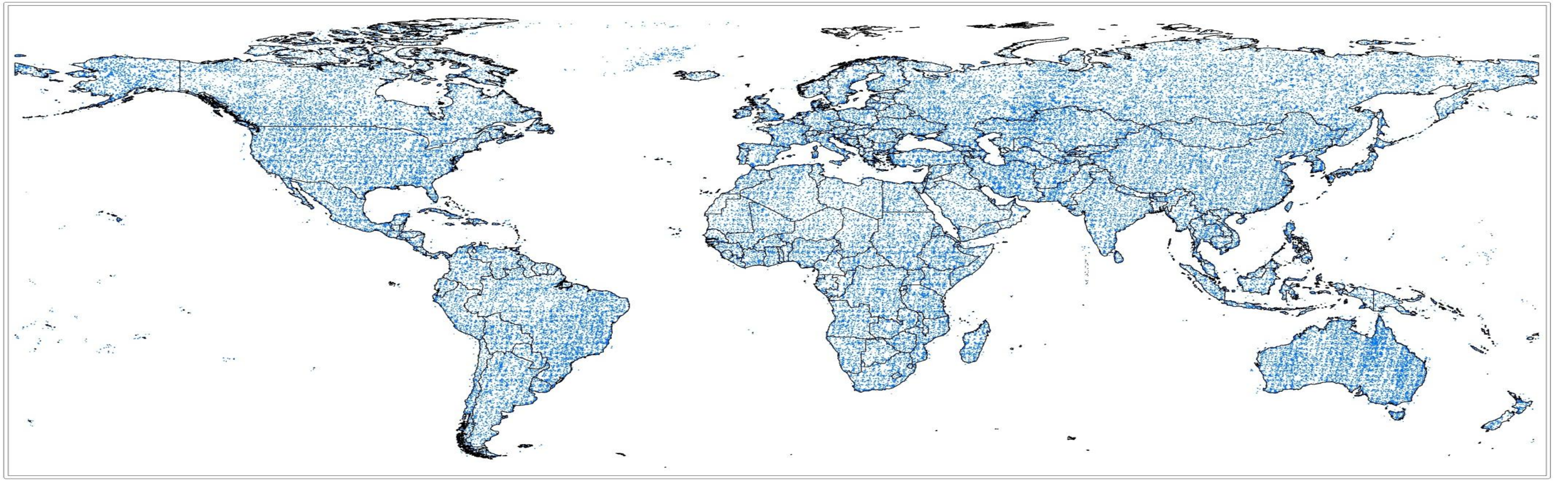
Evenly distributed

Minimum 8 by 8 pixels in size

10-20 per scene

Not fewer than 3 in a category

ID	Img-Name	Type Code	Large Sample	High Resolution	Confi-dence	Cross -Check	Quality control	Comment	Notes



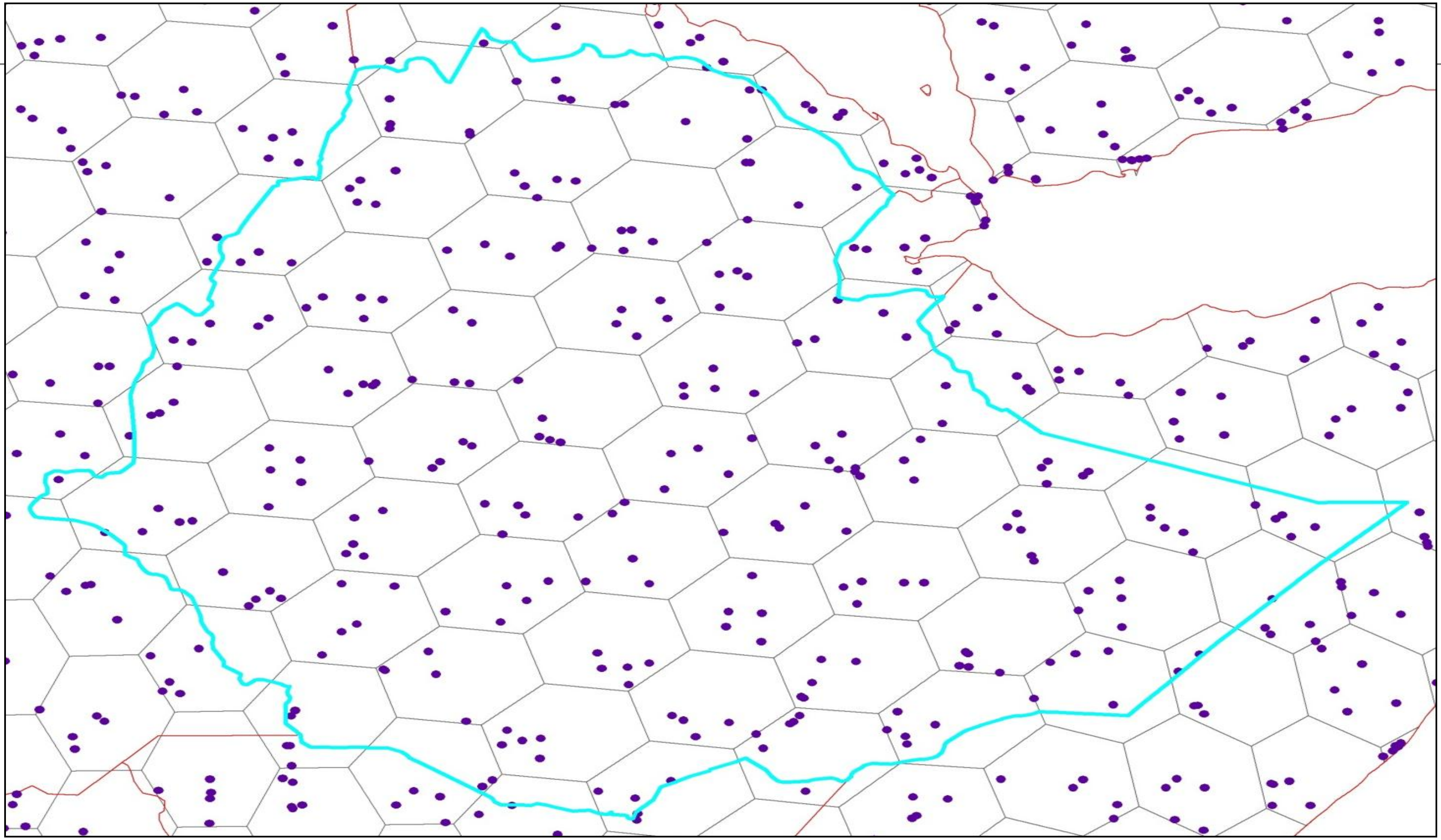
Training samples

Large Sample – homogeneous area greater than 500 m X 500 m	77.20%(70718/91600)
High Resolution images available in Google Earth	75.18%(68868/91600)
Confidence-sure	95.72%(87675/91600)
Confidence-not sure	4.16%(3810/91600)
Confidence-highly uncertain	0.13%(115/91600)

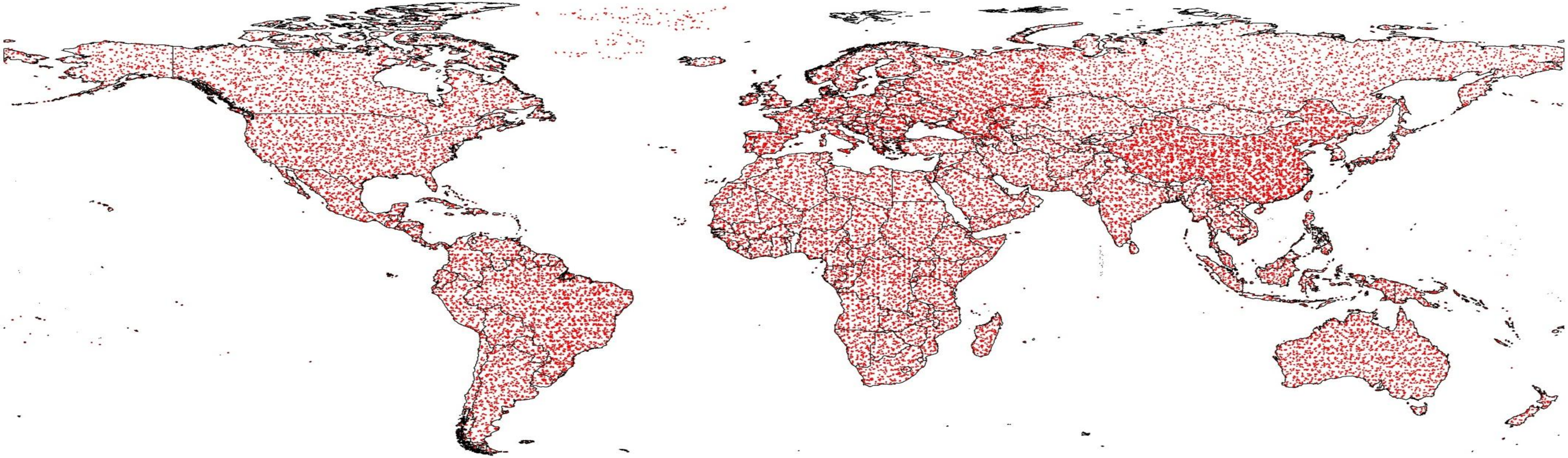
Test samples

Sample types and quality	Percent of total
Large Sample – homogeneous area greater than 500 m X 500 m	36.85%(16366/44411)
High Resolution images available in Google Earth	60.42%(26835/44411)
Confidence class - sure	79.98%(35518/44411)
Confidence class - not sure	12.91%(5735/44411)
Confidence class - highly uncertain	7.11%(3158/44411)
Pure Pixel	61.70%(27400/44411)

Systematic unaligned test sampling

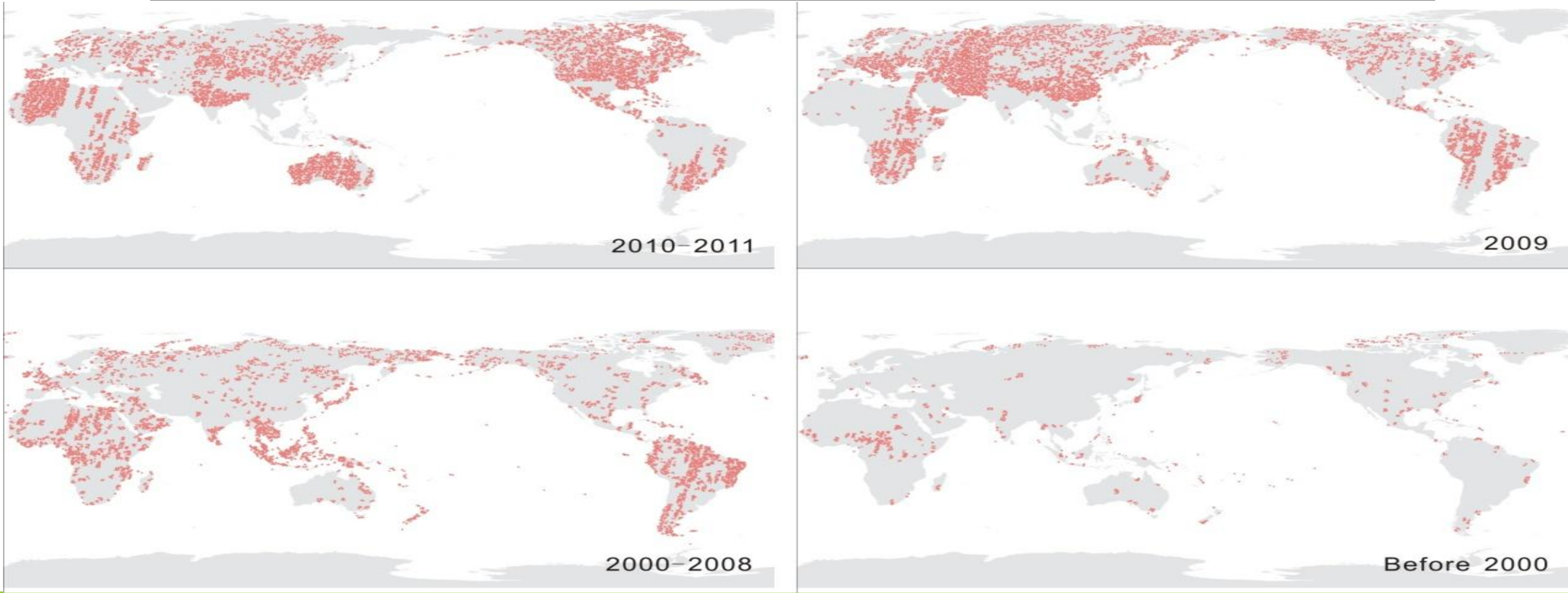


Test sample distribution

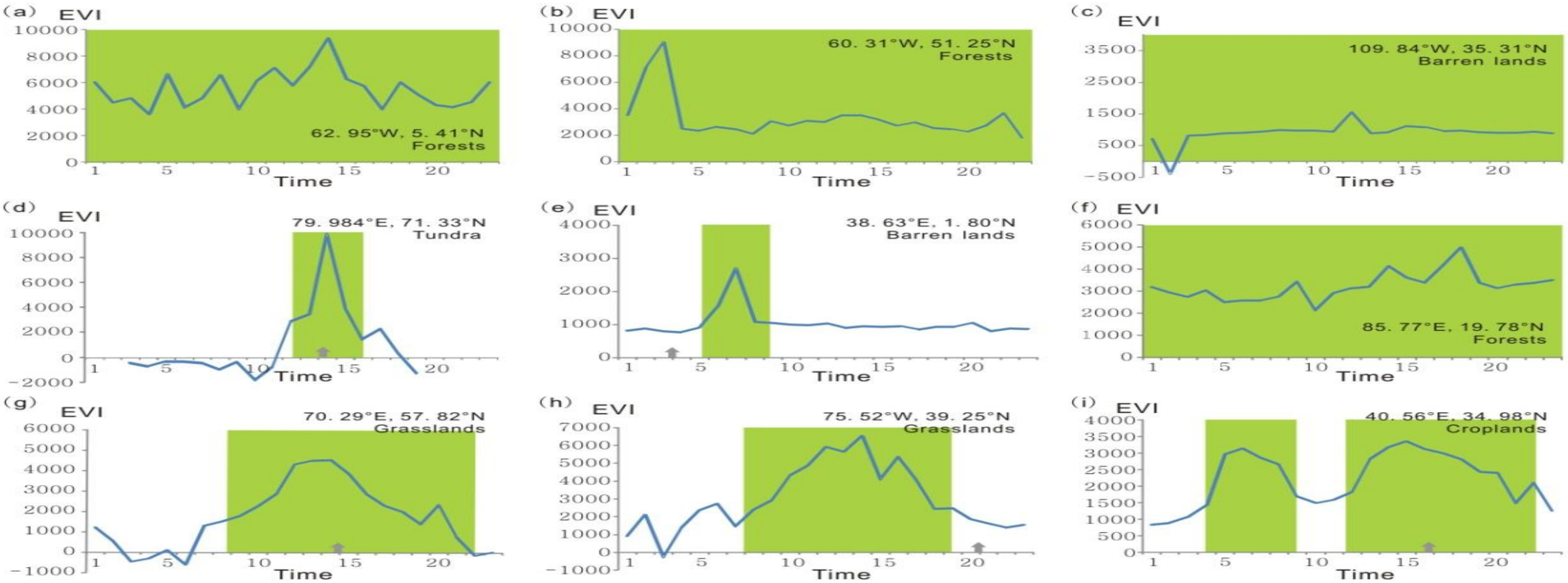


Recent additional work – revealed new challenges

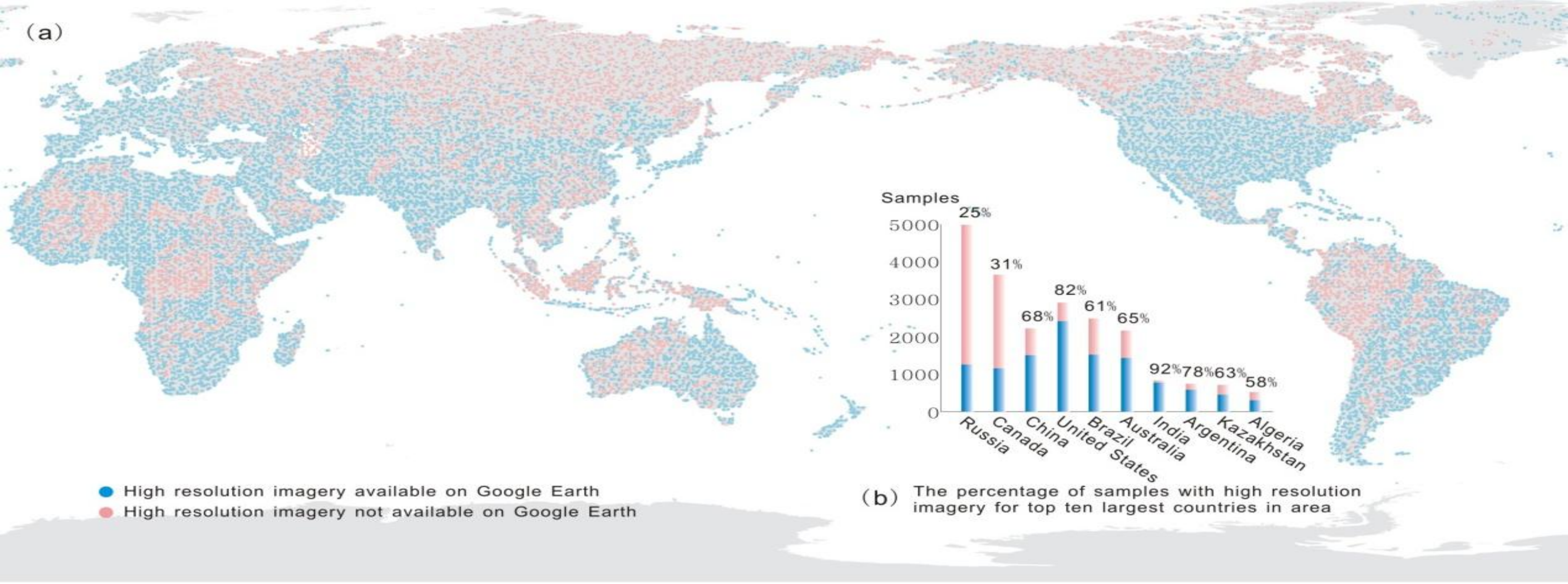
Challenges – samples coming from different times



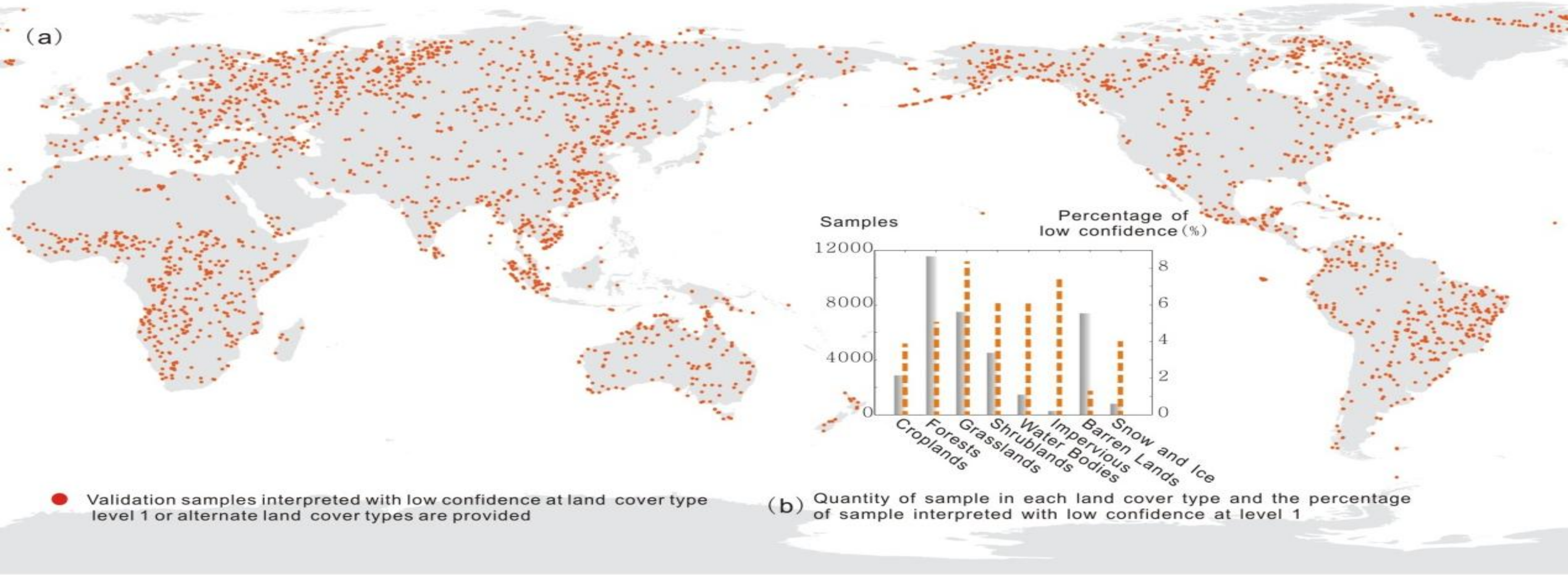
Challenges – not all samples are from the greenest season



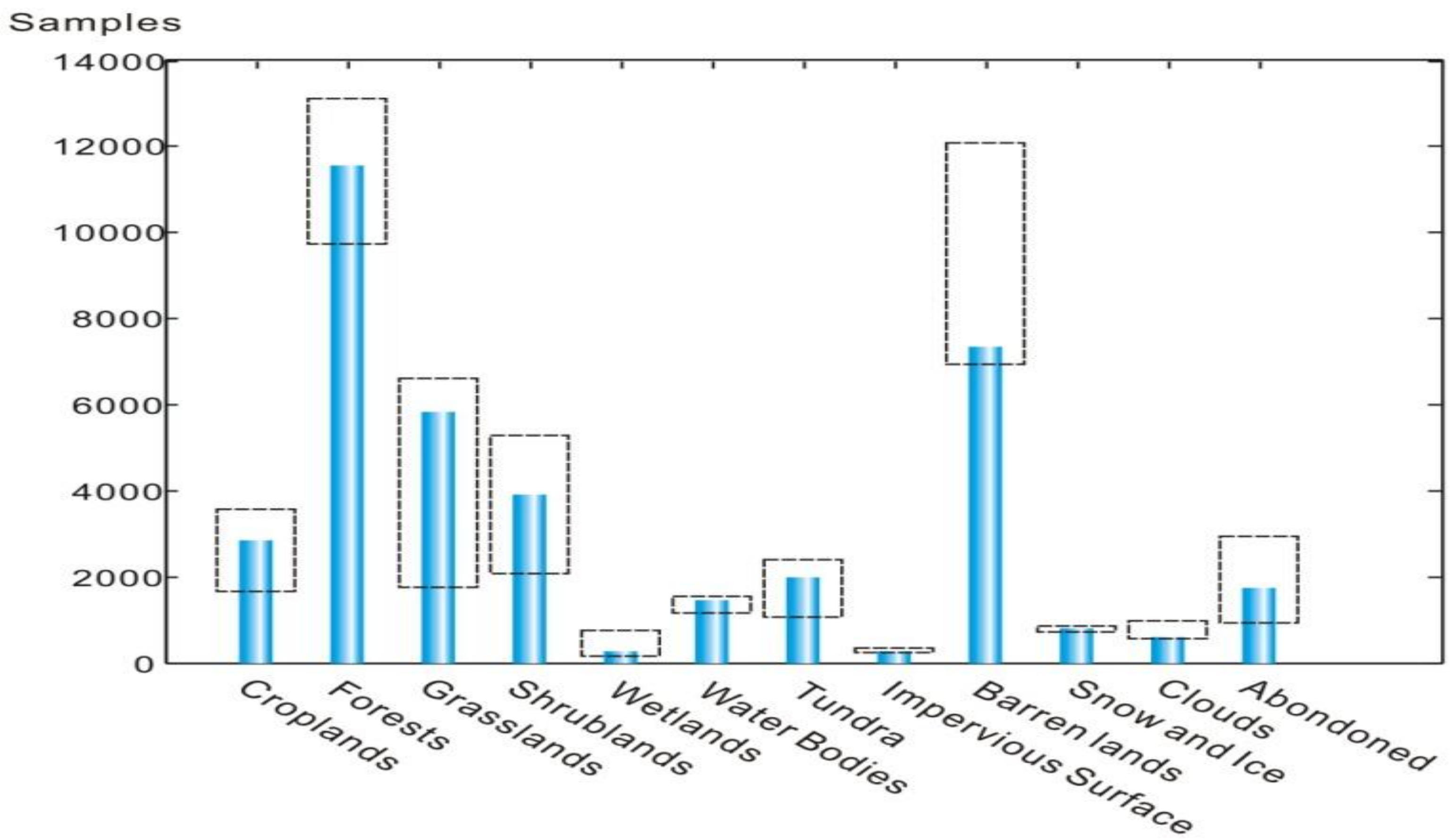
Challenges – not all samples are supported by high resolution images



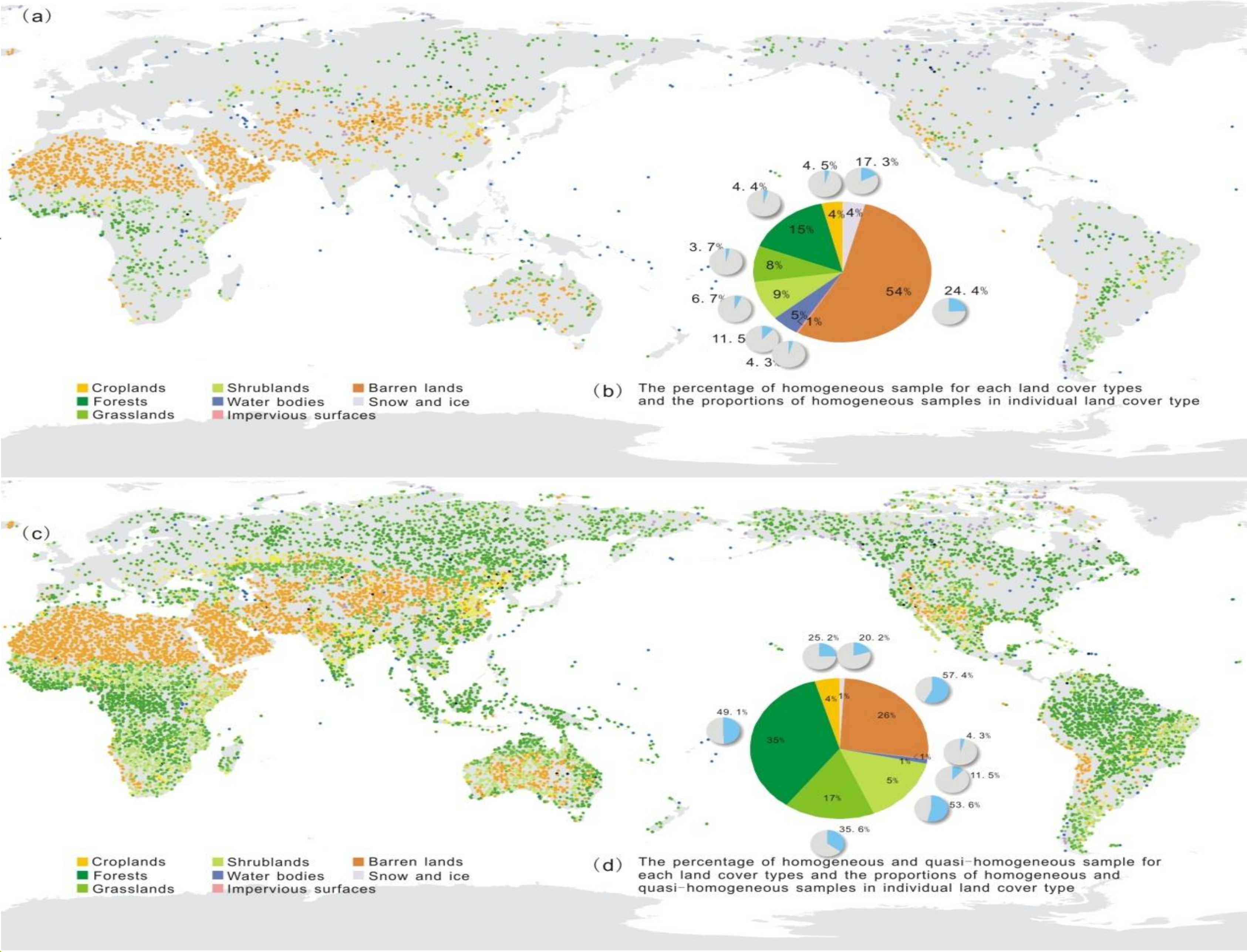
Challenges – some test samples are uncertain



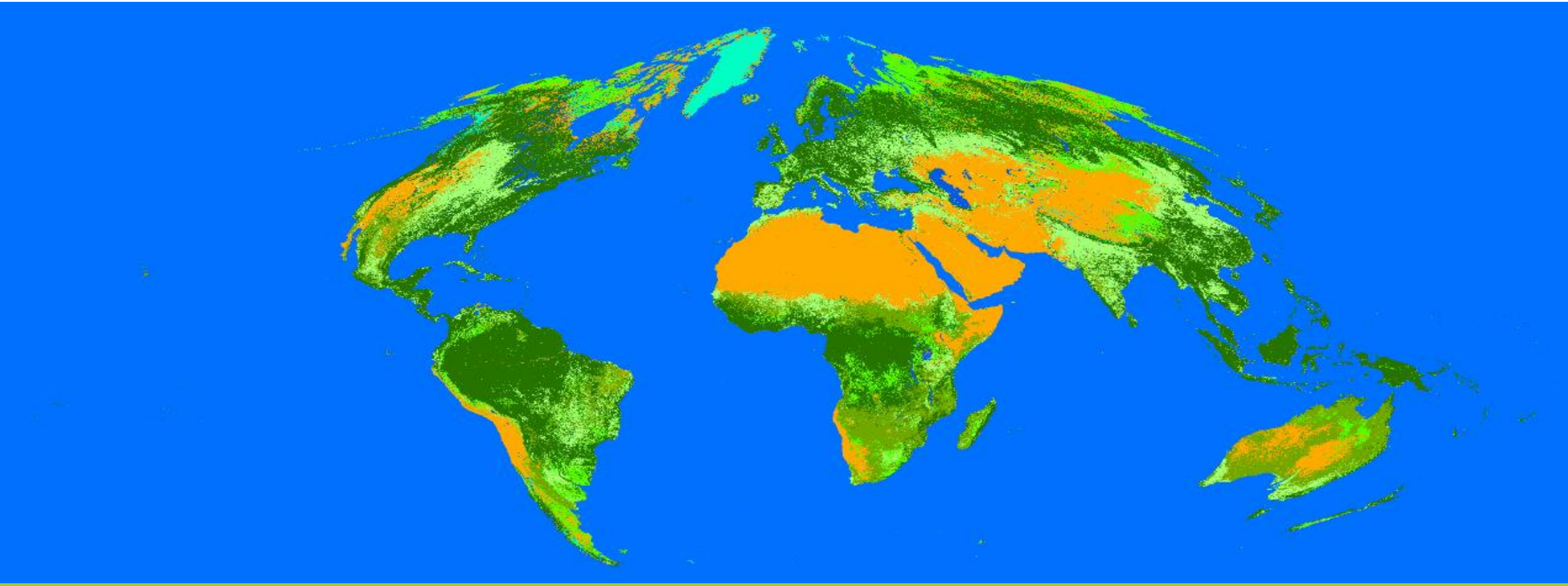
Challenges – different interpreters disagree with each other



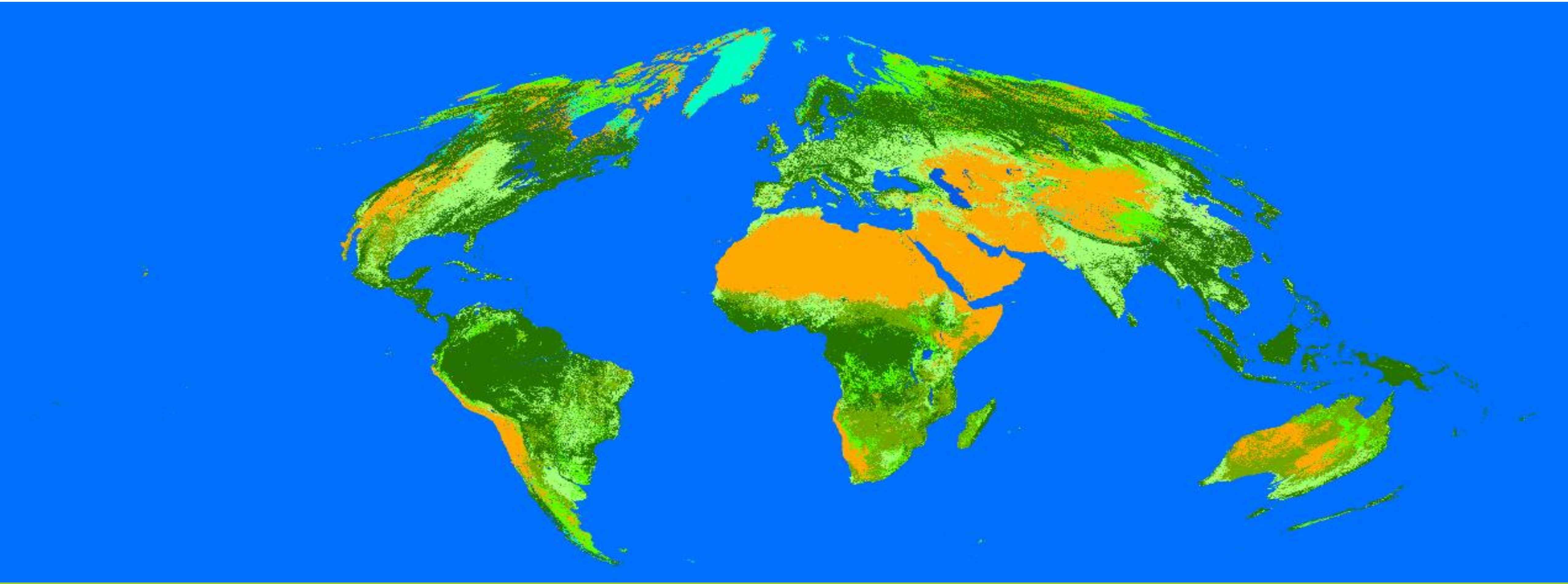
Challenges – large samples are not evenly distributed



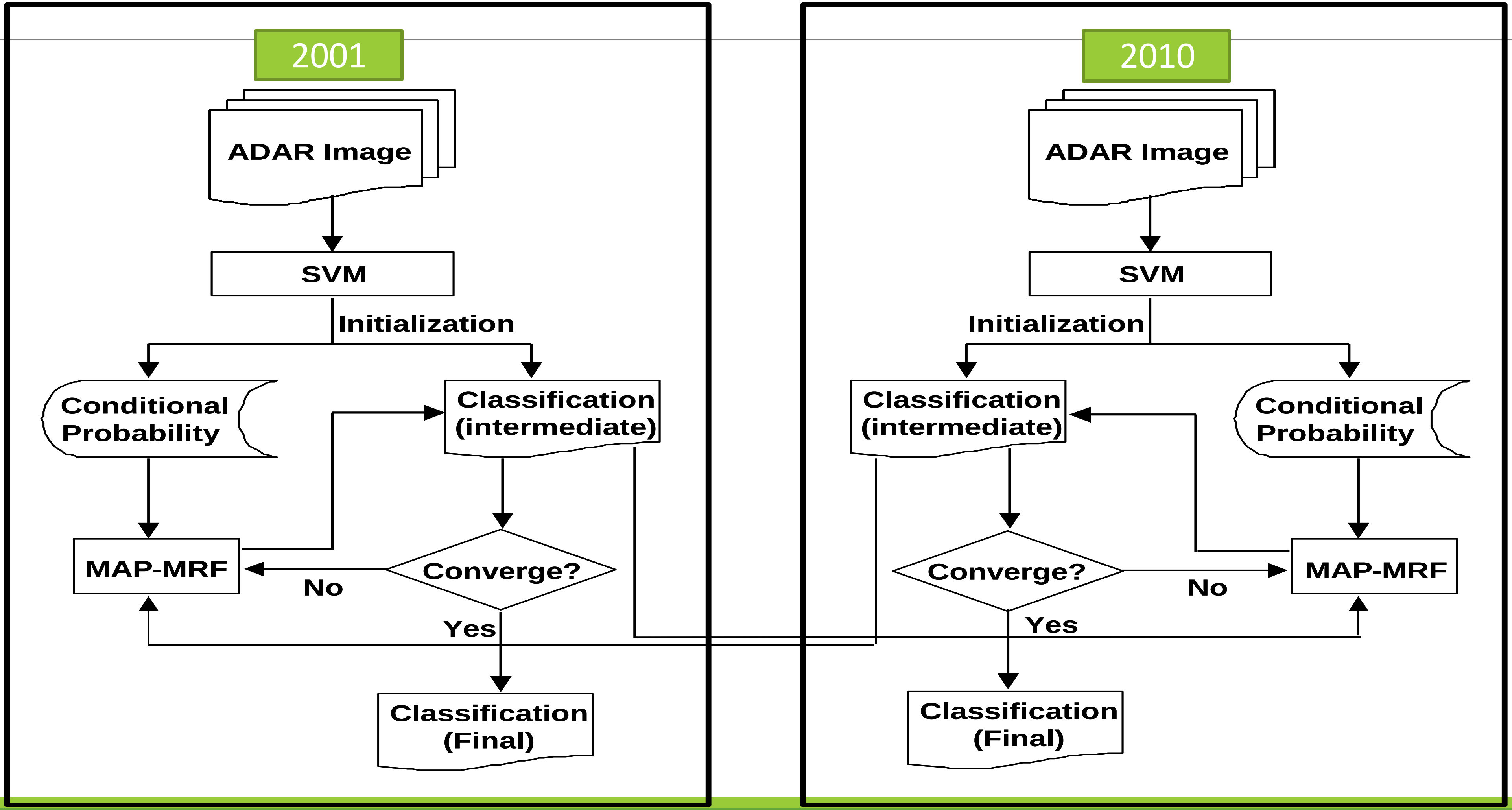
250 m global land cover maps (2001)



250 m global land cover maps (2010)

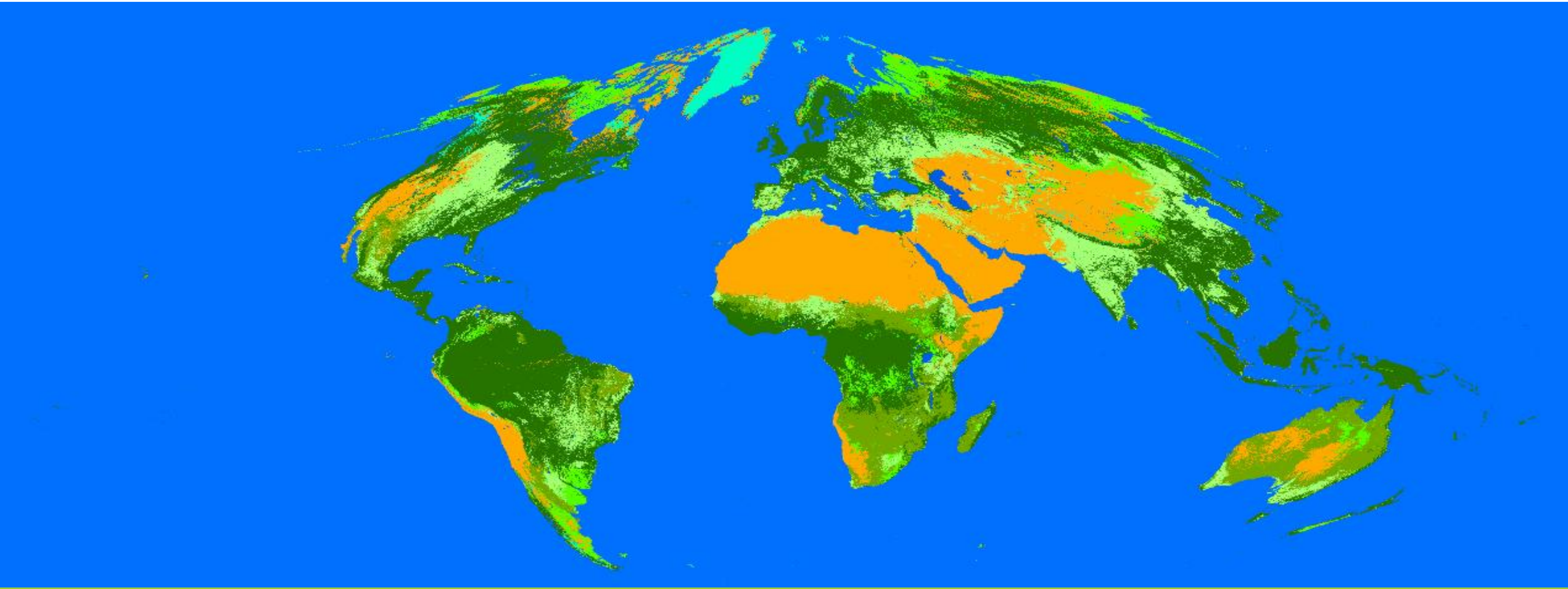


Spatial temporal contextual classification

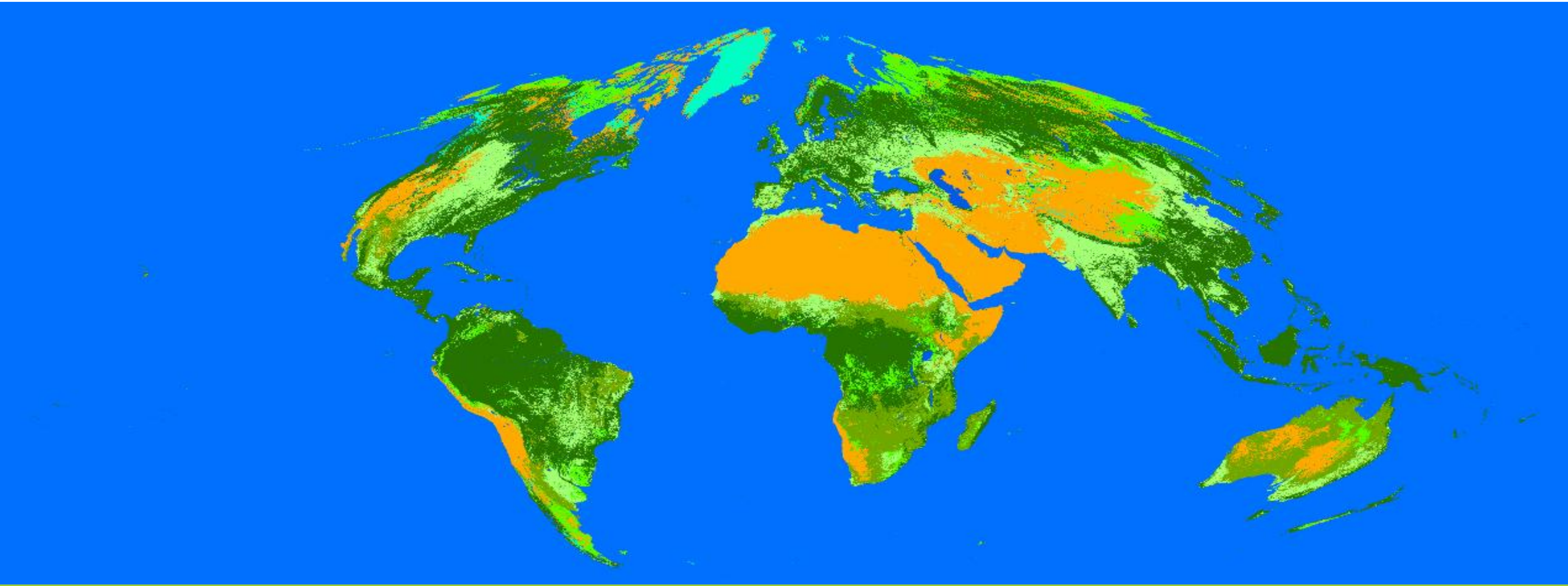


Adapted from Liu et al, 2006, RSE

Spatial-temporal contextural 250 m global land cover maps (2001)

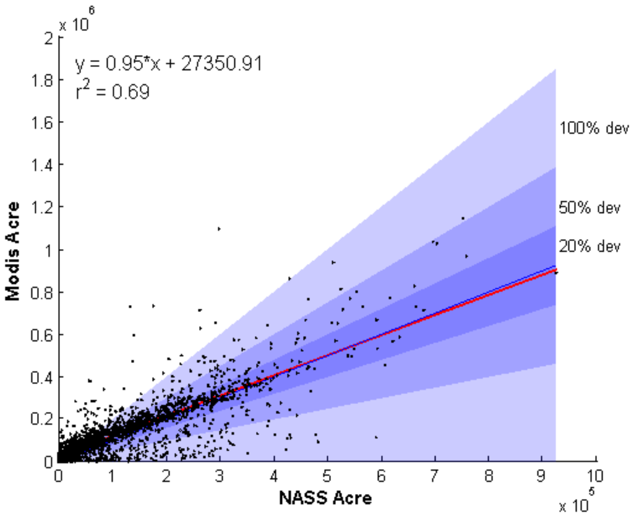


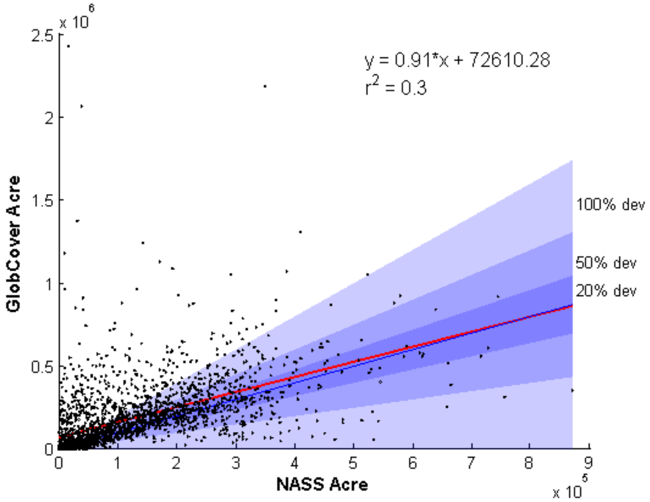
Spatial-temporal contextural 250 m global land cover maps (2010)

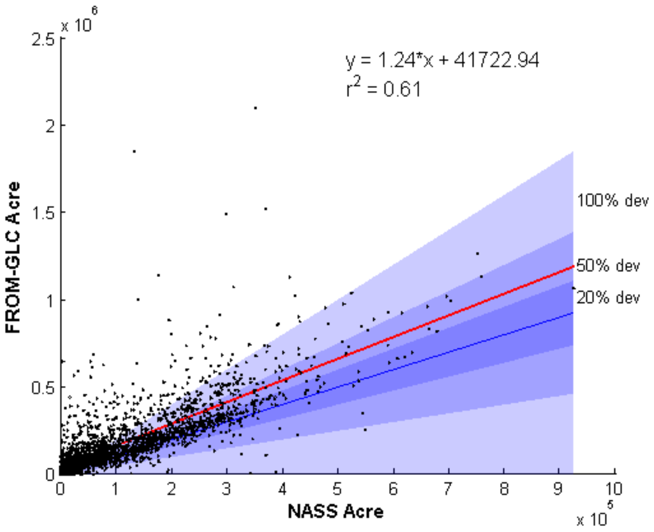


Our near-term activities

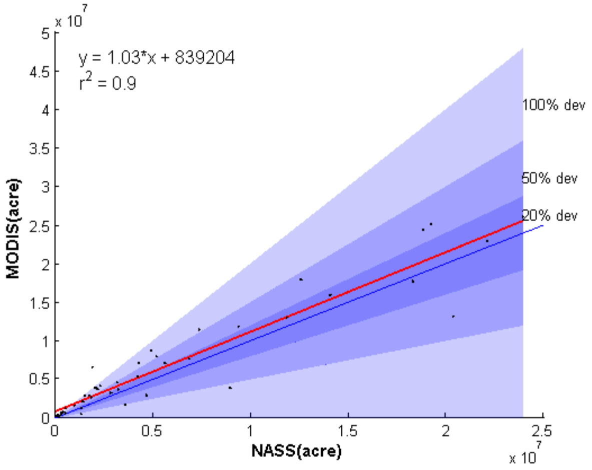
Statistical evaluation – USDA crop land area at the county level

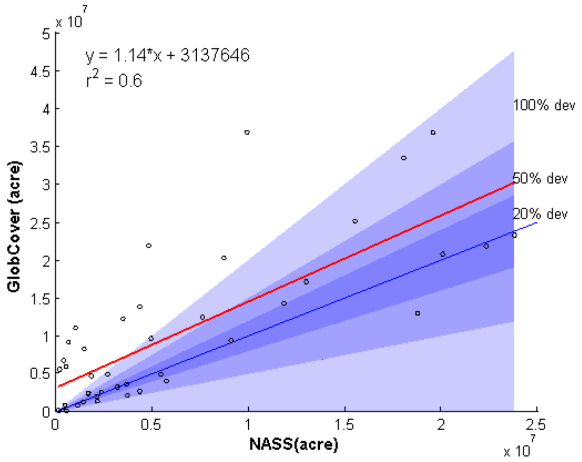


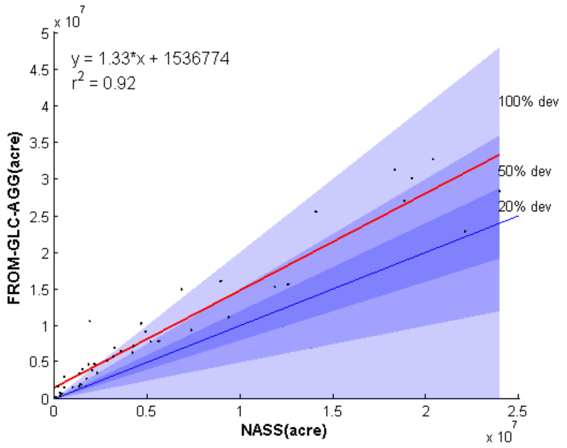


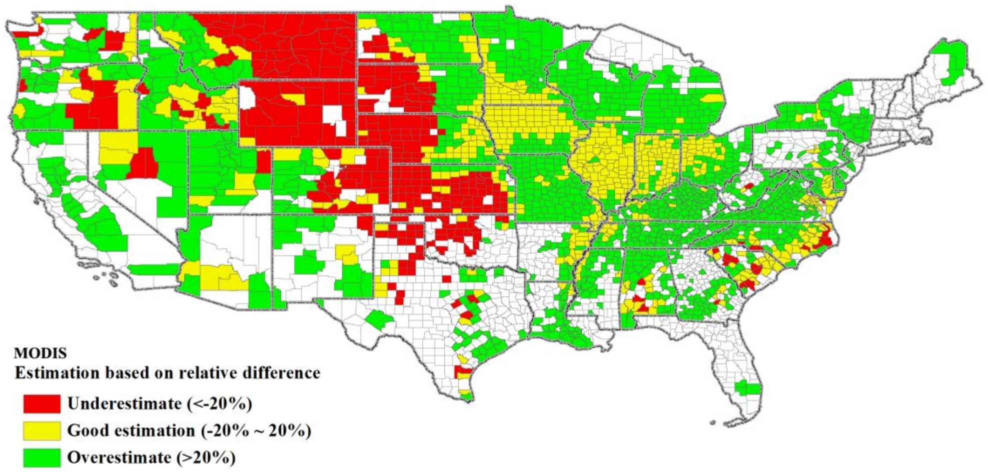


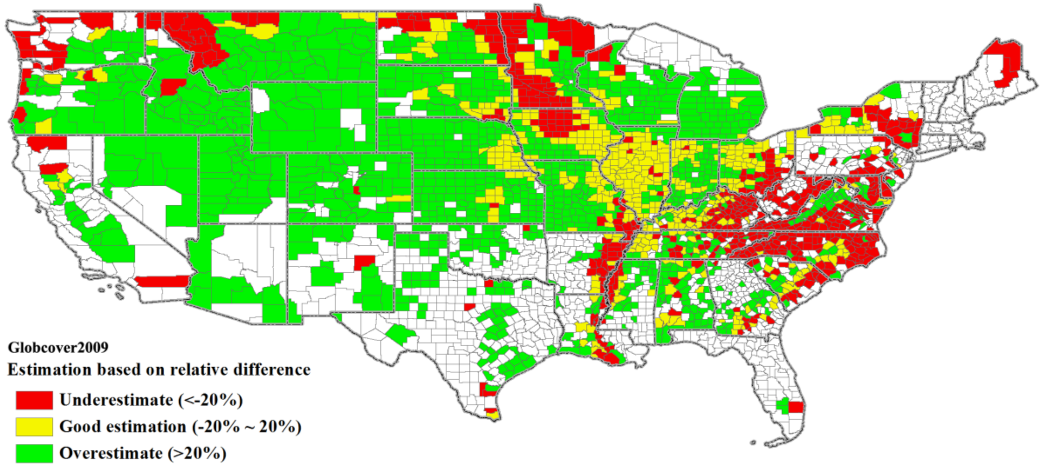
Statistical evaluation – USDA crop land area at the state level

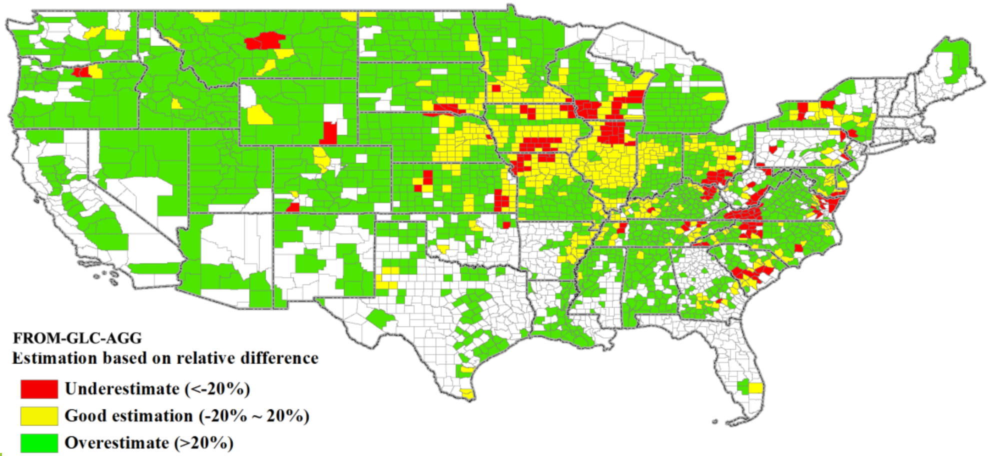




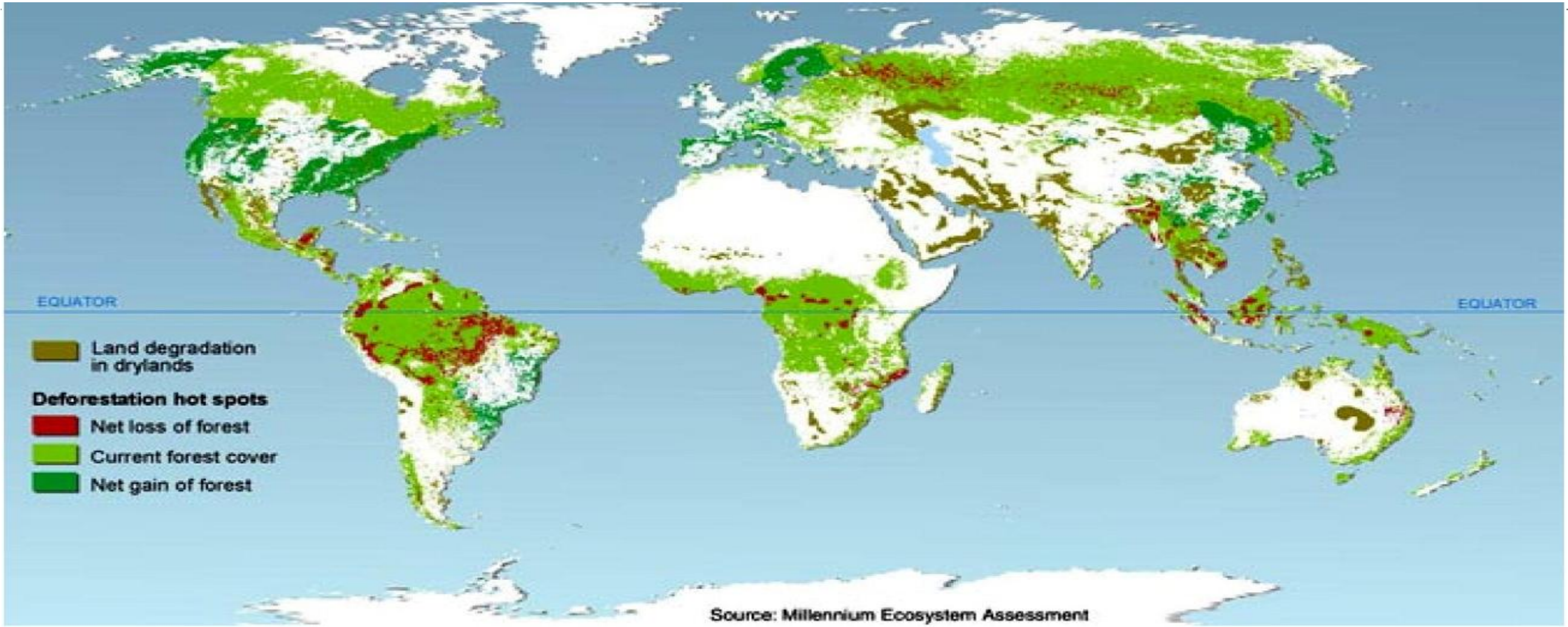



MODIS
Estimation based on relative difference
Underestimate (<-20%)
Good estimation (-20% ~ 20%)
Overestimate (>20%)


Globcover2009
Estimation based on relative difference
Underestimate (<-20%)
Good estimation (-20% ~ 20%)
Overestimate (>20%)

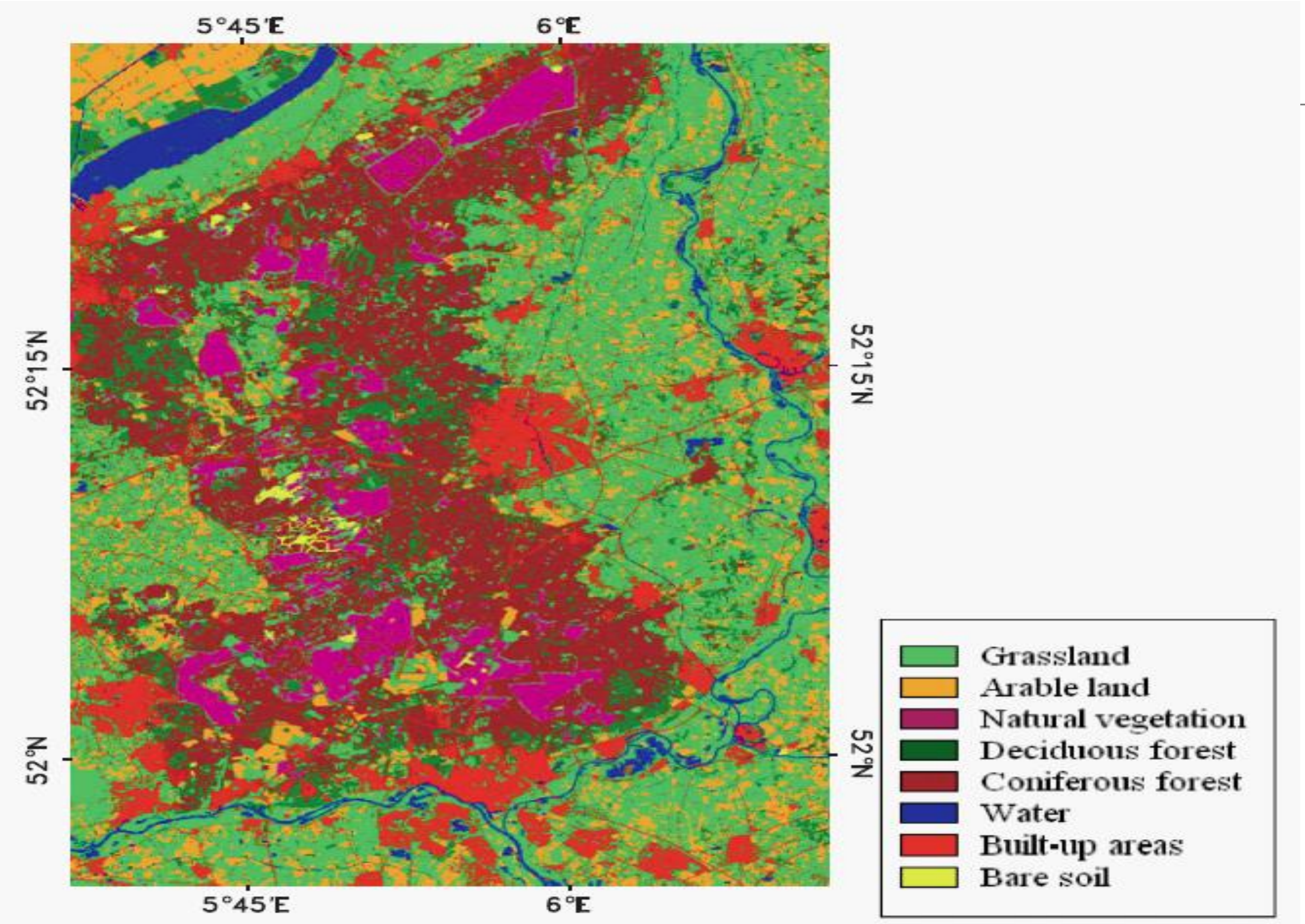

FROM-GLC-AGG
Estimation based on relative difference
Underestimate (<-20%)
Good estimation (-20% ~ 20%)
Overestimate (>20%)

Compare with other products in the world: e.g., World forest status



Hall et al., 2011, RSE

Additional sources of validation



Zurita-Milla et al, 2011,IJRS

What can we do together?

We need to collaborate within the center

Mid-latitude afforestation shifts general circulation and tropical precipitation

Abigail L. S. Swann[a,b,c,1], Inez Y. Fung[c], and John C. H. Chiang[d]

[a]Organismic and Evolutionary Biology Department, Harvard University, Cambridge, MA 02138; [b]Sustainability Science Program, Harvard University, Cambridge, MA 02138; [c]Department of Earth and Planetary Sciences, University of California, Berkeley, CA 94720; and [d]Department of Geography, University of California, Berkeley, CA 94720

Contributed by Inez Y. Fung, October 12, 2011 (sent for review June 7, 2011)

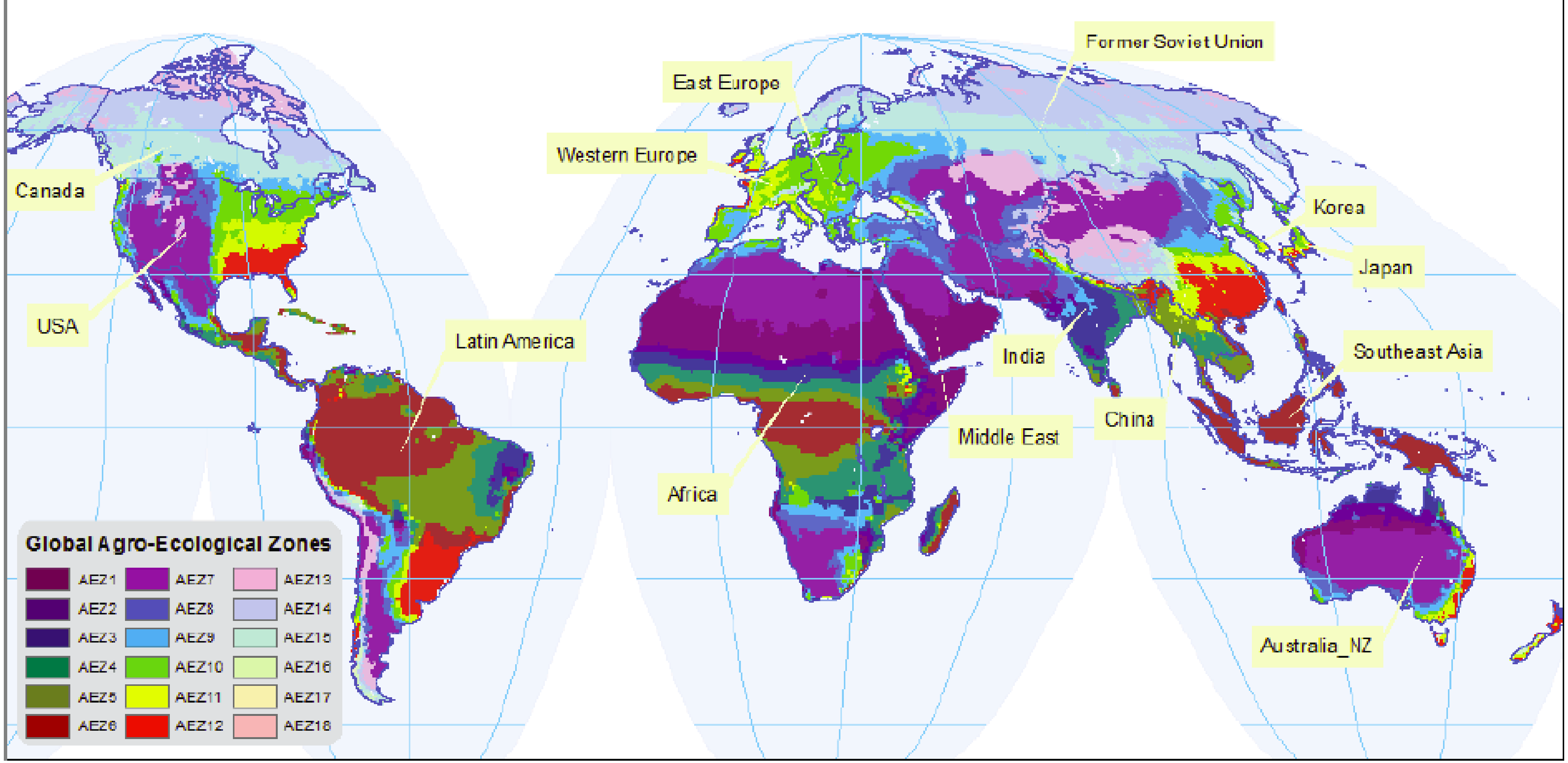
Changes in Arctic vegetation amplify high-latitude warming through the greenhouse effect

Abigail L. Swann[a,1], Inez Y. Fung[a], Samuel Levis[b], Gordon B. Bonan[b], and Scott C. Doney[c]

[a]Department of Earth & Planetary Science, University of California, Berkeley, CA 94720; [b]National Center for Atmospheric Research, Boulder, CO 80307; and [c]Department of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution, Woods Hole, MA 02543

Contributed by Inez Y. Fung, December 4, 2009 (sent for review October 20, 2009)

The GCAM 3.0 Agriculture and Land Use Regions

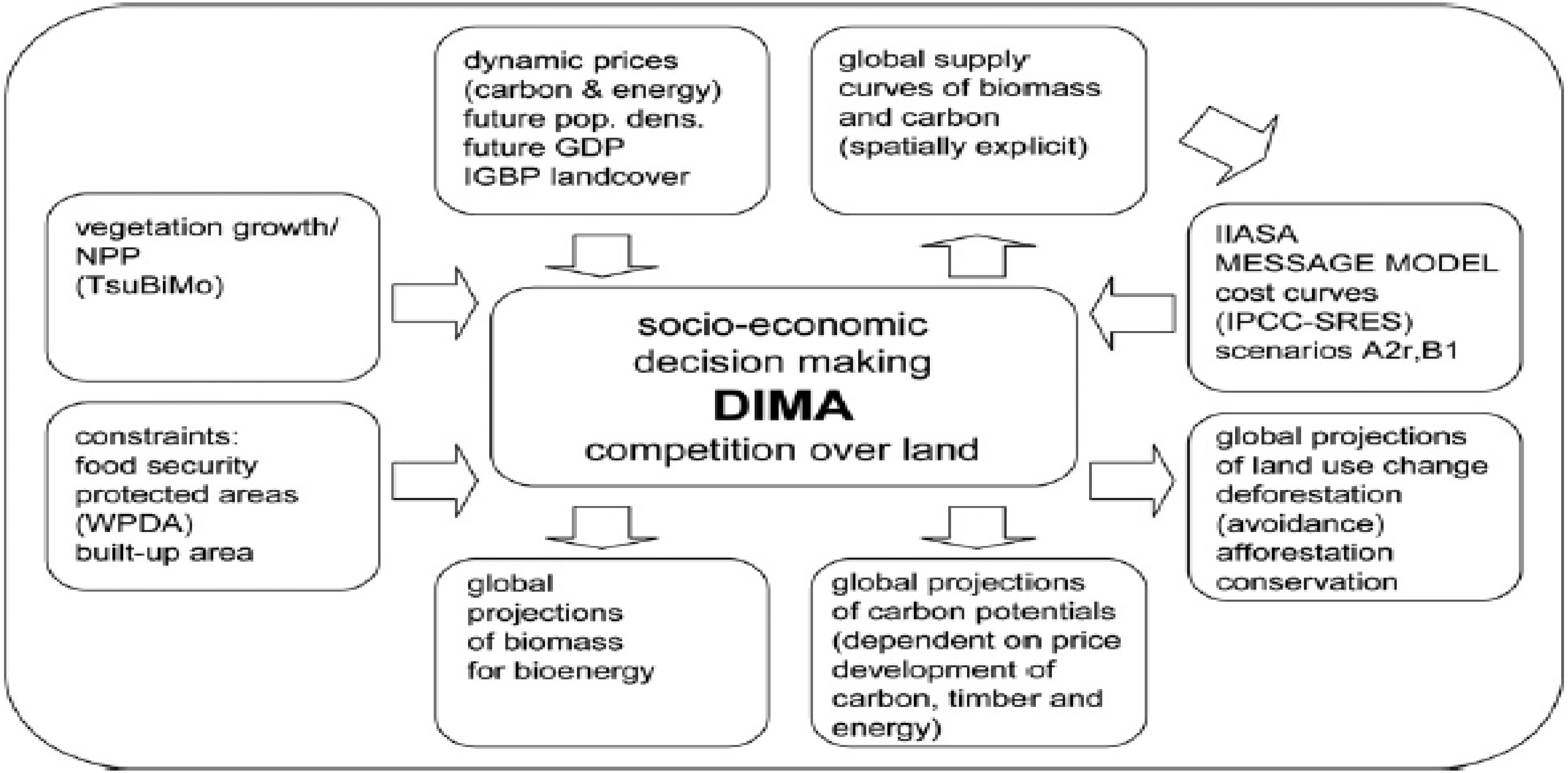


0 2,500 5,000 10,000
Kilometers

Projection: Goode Homolosine
Source for Agro-Ecological Zones (AEZs):
GTAP (Monfreda, Ramankutty, and Hertel, 2009)
Map built by JGCRI

Pacific Northwest National Laboratory

D. Rokityanskiy et al. / Technological Forecasting & Social Change 74 (2007) 1057–1082



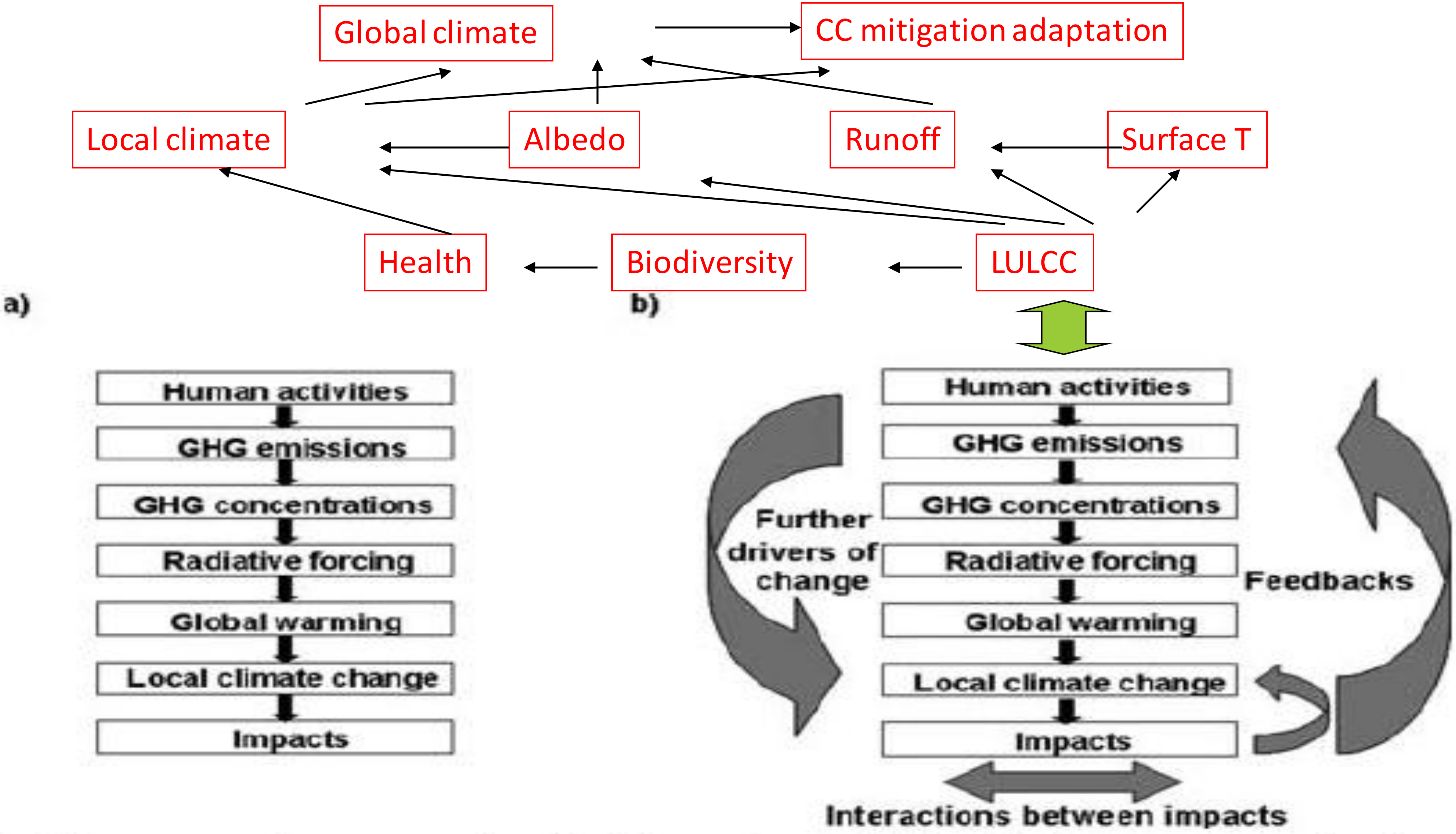
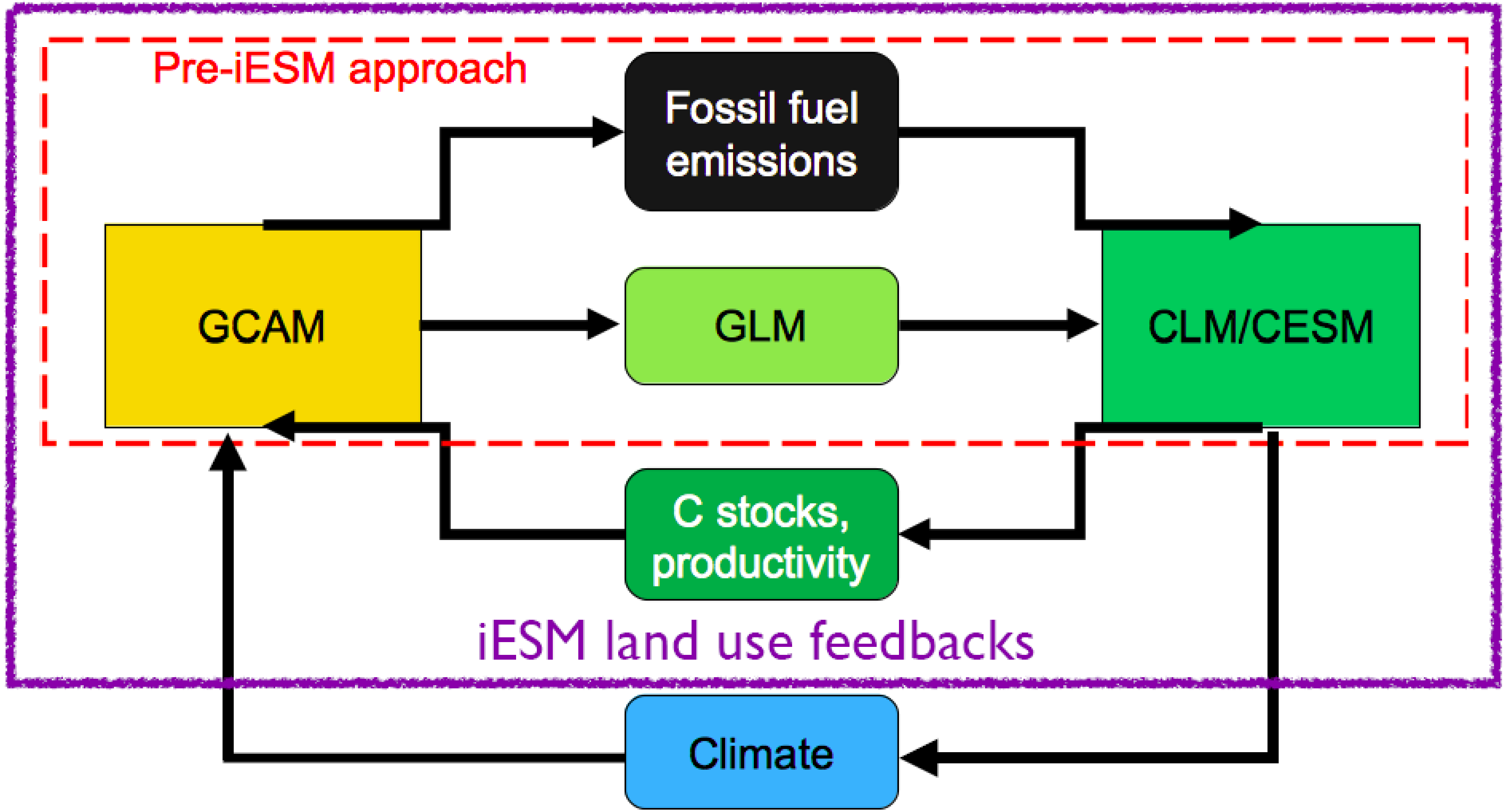


Fig. 1. (a) Conventional, linear, cause-effect conceptual model of climate change. (b) Roles of land ecosystem-atmosphere interactions

Betts, 2007, Tellus



Alan Di Vitorrio， personal comm

Thank you!