



Global Land Cover Changes under Changing Climate and Socioeconomic Conditions from 2001 to 2020

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1. Introduction

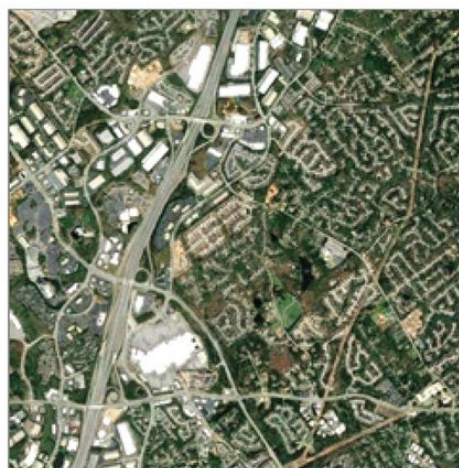
Global land cover has significantly changed during the past decades across space and time.



Deforestation



Cropland Expansion



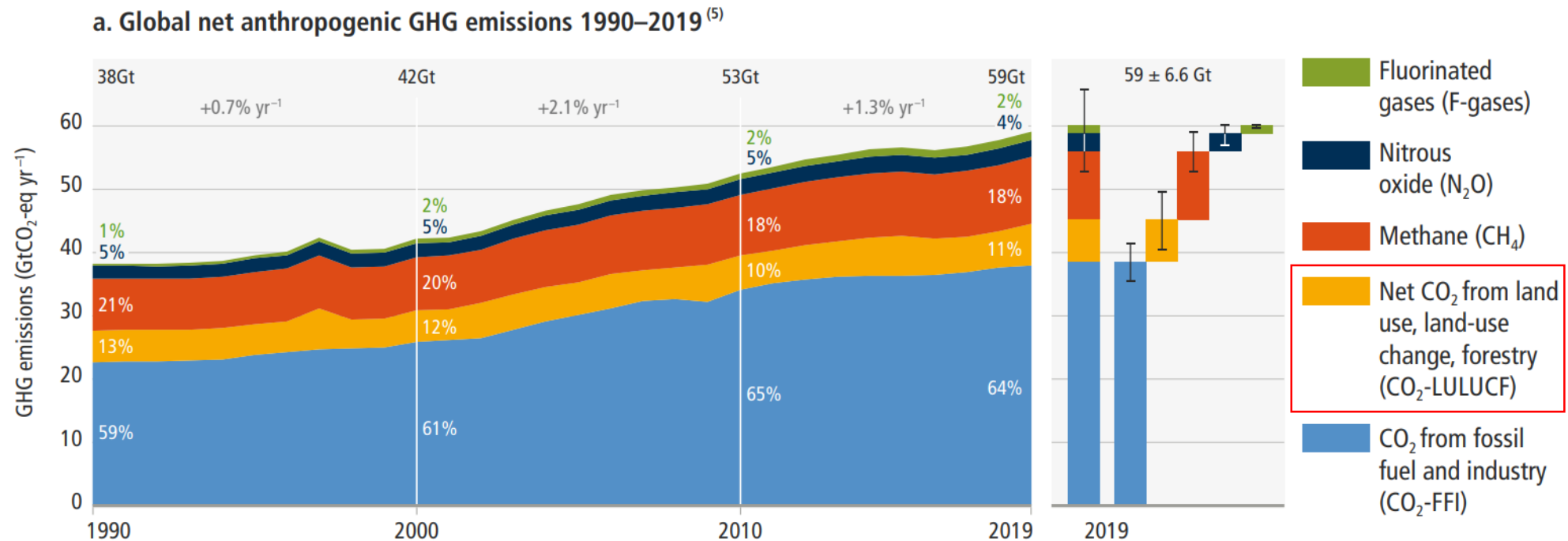
Urbanization



Shrubland Expansion

1. Introduction

The land cover change has strongly influenced biogeochemical cycles and further raised a series of issues on climate change and terrestrial ecosystems



1. Introduction

There is a pressing need for comprehensively understanding global land cover dynamics to develop a new benchmark land use database for the GTAP-BIO model to evaluate the consequences of land cover change.

In this study, we first quantified the annual net land cover change at the global scale from 2001 to 2020. Then we further separated intermittent land cover change and long-term conversion. Lastly, we examined the source and fate of converted land cover.

This research aims to address the following questions:

- Which land cover types and which regions have undergone the greatest changes from 2001 to 2020?
- What were the source and fate of converted land cover from 2001 to 2020?

2. Data and method

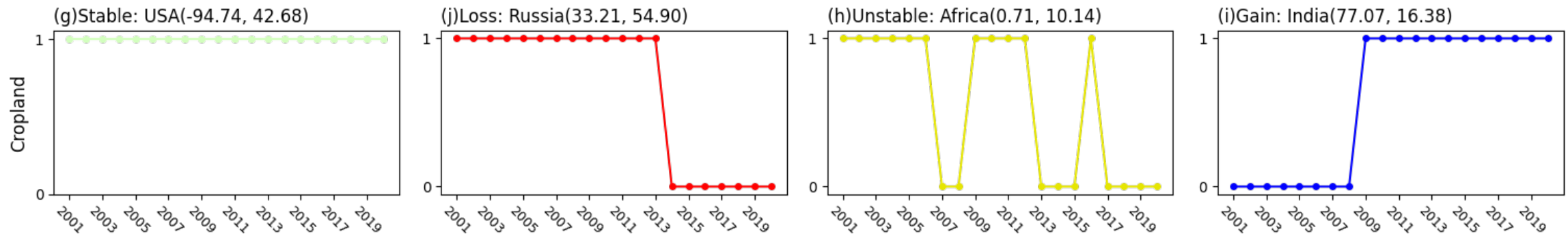
- **MODIS Land Cover Types product (MCD12Q1)**
 - Annual
 - 500m
 - 2001 to 2020

2.1 Land cover mapping and classifications

Acronym	Landcover Type	FAOSTAT land cover classification*
Forest	Tree-covered areas	$\text{Class10} + \text{Class20} + 0.40 * \text{Class25}$
Grasslands	Grasslands	$\text{Class30} + 0.20 * \text{Class35}$
Shrubland	Shrub-covered areas	$\text{Class40} + 0.20 * \text{Class35}$
Cropland	Herbaceous crops	$\text{Class36} + 0.60 * (\text{Class25} + \text{Class35})$
Barren	Terrestrial barren land	Class1
Water	Inland water bodies	Class3
Ice	Permanent snow and glaciers	Class2
Urban	Artificial surfaces	Class9

*Note: the same classification as FAOSTAT

2.2 Identification of lost, gained, stable, and unstable land cover



3.1 Characteristics of global land cover changes from 2001 to 2020.

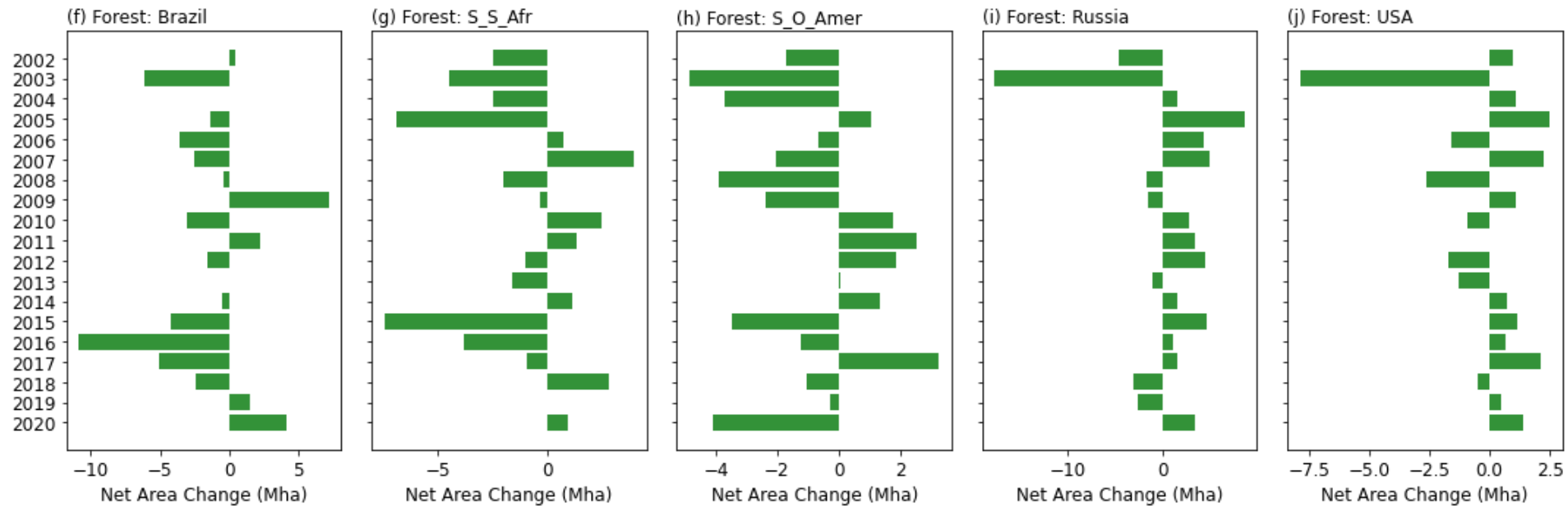
Globally, forest, shrubland, barren land areas and snow-covered areas decreased while grassland, cropland, water and urban area increased from 2001 to 2020

Region	Forest	Grassland	Shrubland	Cropland	Barren	Water	Ice	Urban
USA	-108.2	688.5	-191.7	161.7	-443.5	-7.8	-124.6	23.9
EU27	29.7	31.1	-17.3	-41.8	-2.1	-7.3	0.0	7.8
Brazil	-1372.6	895.1	-180.7	651.1	-4.5	10.1	0.0	1.8
Canada	247.8	8.9	-593.6	491.0	-4.7	-5.7	-146.7	2.7
Japan	-30.0	31.5	1.4	-4.3	-0.2	0.0	0.0	1.6
China	614.6	212.6	-217.9	184.8	-956.9	25.5	10.0	126.1
India	244.9	-930.8	-196.0	880.7	-41.4	17.6	17.4	7.6
Central America	226.8	324.0	-151.3	-185.9	-302.5	61.6	32.7	5.1
South America	-928.4	689.0	218.5	264.8	-140.1	-13.0	41.2	3.0
East Asia	62.8	409.3	-6.8	-25.1	-439.1	-2.9	-0.1	1.9
Malaysia-Indonesia	91.4	53.3	-1.7	-154.6	-1.0	1.8	0.0	11.1
South East Asia	-176.8	115.6	-8.8	62.7	-1.8	0.6	-0.7	9.7
Rest of South Asia	96.7	155.0	256.4	111.9	-656.7	2.7	34.3	1.7
Russia	514.1	316.6	-720.2	-19.4	-63.4	0.7	-32.2	4.3
E. Europe-USSR	59.2	901.3	-52.1	-50.9	-910.2	11.9	48.5	4.2
Other Europe	-116.6	85.2	34.2	1.8	-2.3	2.8	-5.3	0.2
Middle East-N. Afr.	46.2	123.2	574.1	191.6	-933.9	0.0	0.0	5.4
Sub Saharan Africa	-1045.7	3281.1	-1024.1	-1087.8	-94.7	-8.3	0.0	22.6
Oceania	-151.0	-1299.7	1433.9	82.0	-38.5	-26.4	-2.1	2.6
Total	-1695.1	6090.8	-843.7	1514.3	-5037.5	63.9	-127.6	243.3

*Note: These results match with FAOSTAT records.

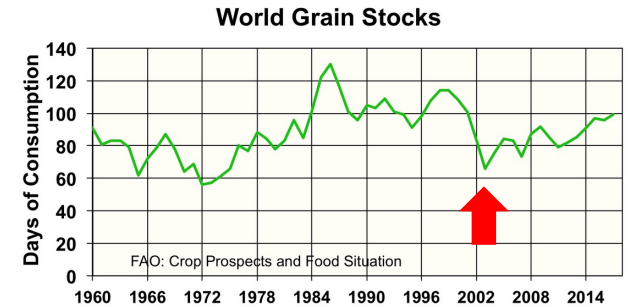
3.1 Characteristics of global land cover changes from 2001 to 2020.

- Brazil, Sub-Saharan Africa, and South America had negative net forest area changes in most years (Figures f, g, and h). Brazil had the largest negative net forest area change in 2016.
- Russia and the USA, mainly located in temperate regions, had positive net forest area change in most of the years (Figure i and j).

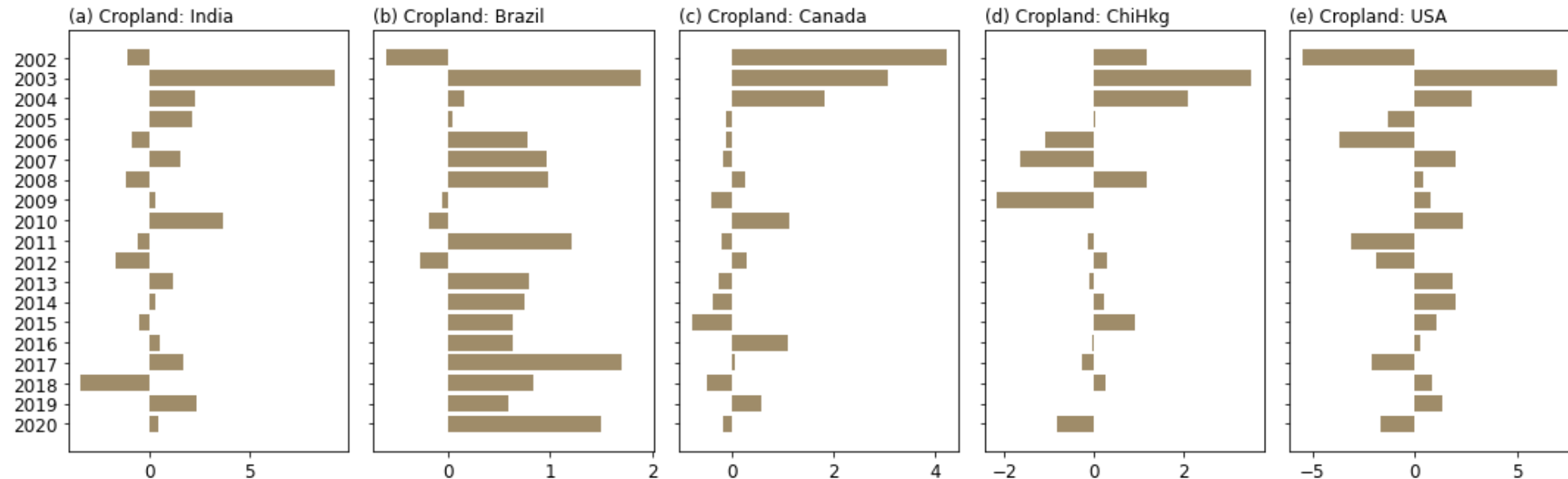


3.1 Characteristics of global land cover changes from 2001 to 2020.

- All selected regions had a peak of positive net cropland area change in 2003.
 - Grain stocks are at historic lows in 2003
 - Global crude oil prices began to break away from the low of US\$30/barrel and continued to rise, breaking through the US\$60/barrel mark by mid-2005.

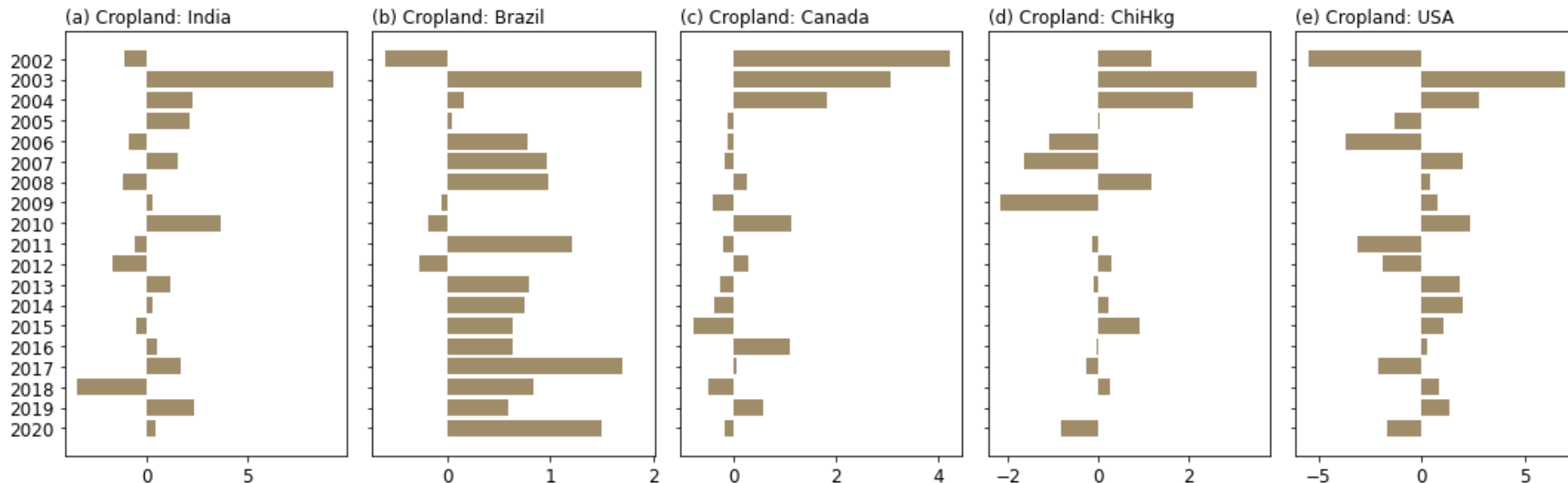


- **India** had a large positive net cropland change in 2003, and then the cropland area fluctuated between positive and negative in the following years (Figure a).
- **Brazil** had positive net cropland area changes in most years, with peaks in 2003, 2017, and 2020.
 - 2017 and 2020: soybean import, rising trade tensions between the United States and China since 2017



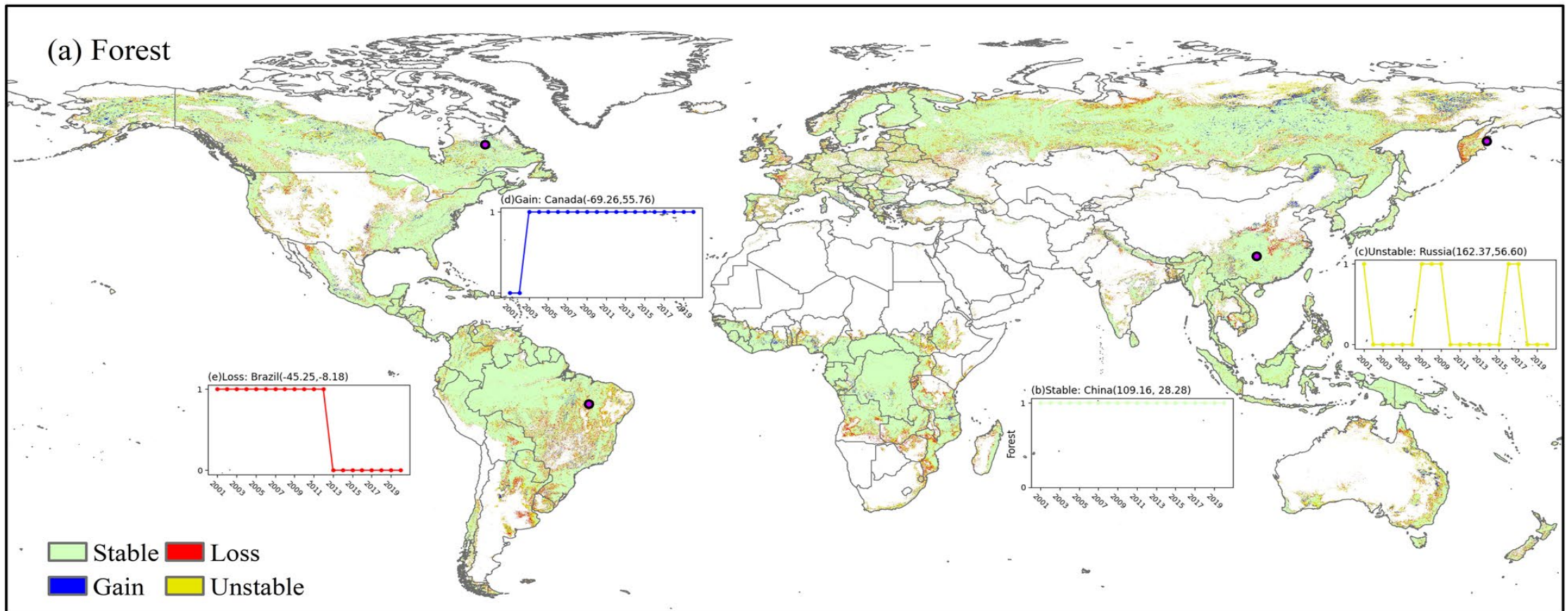
3.1 Characteristics of global land cover changes from 2001 to 2020.

- **Canada** had a larger positive net cropland area change from 2002 to 2004, then subsequent fluctuations were minimal (Figure c).
 - 2002 to 2004: biofuel, crude oil prices ↑; after 2004: Species at Risk Act (SARA): Enacted in 2002 and coming into force in 2003, habitat protection
- **China** had large positive net cropland area changes from 2002 to 2004 while large negative net cropland area changes in 2006, 2007, and 2009 (Figure d).
 - Farmland protection policy: Dynamic Balance of Total Farmland Area (DBTFA) policy released in 1998
 - Forest protection policy: Returning Farmland to Forest Program



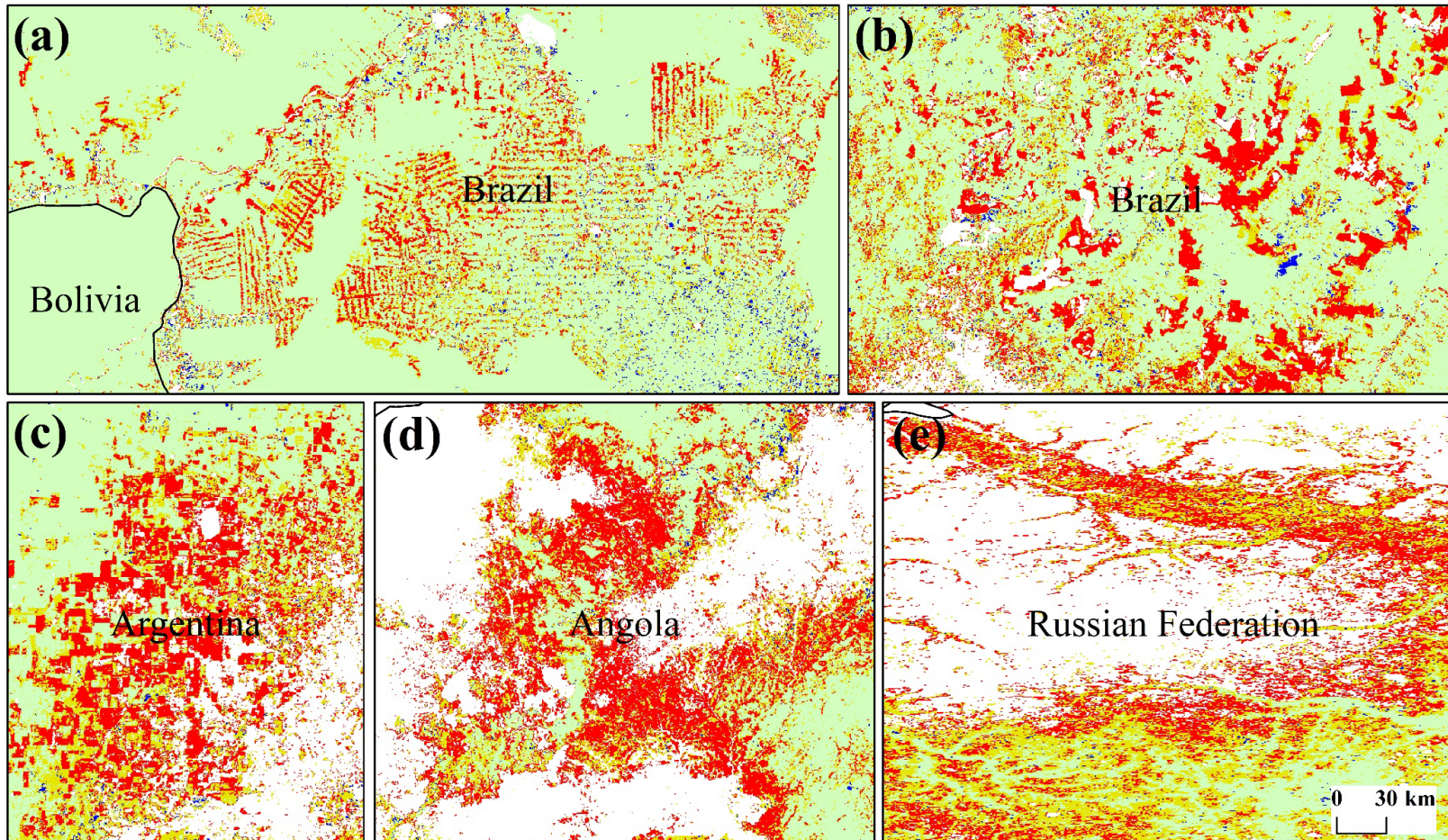
3.2. Location and area of land cover conversions

- Of the global forest area, 74.9% was always forest from 2001 to 2020 (stable), 4.4% was converted from other land cover types (gain), 4.9% changed to other land cover types (loss), and 15.7% was intermittent (unstable).
- The hotspots of deforestation include Brazil, South America, Sub-Saharan Africa, and Russia.



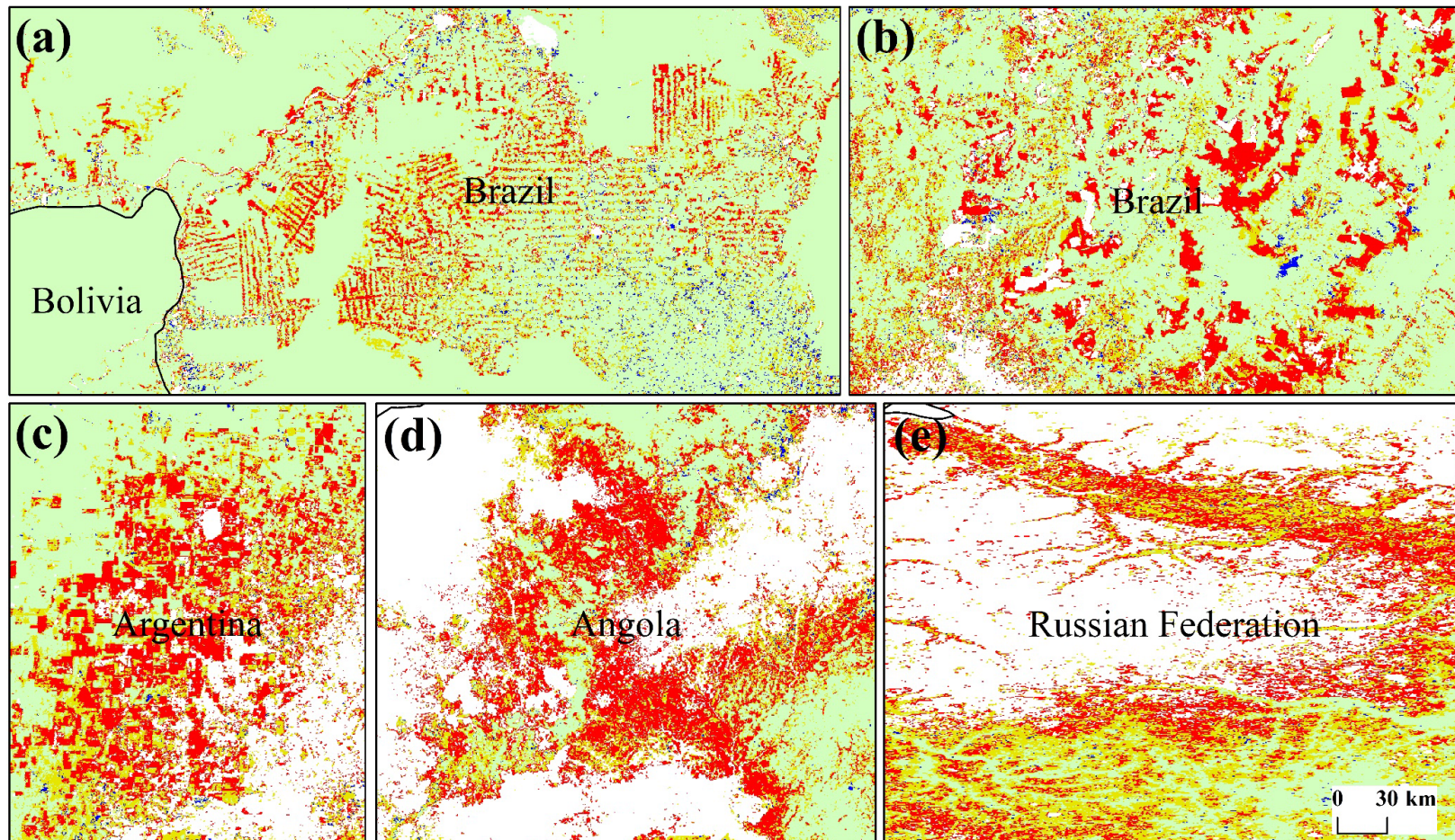
3.2. Location and area of land cover conversions

- In the **Brazilian Amazon**, “herring bone” deforestation pattern cut through the rainforest (Figure a).
- Small clearings could be also found in the **Cerrado areas** (Figure b).



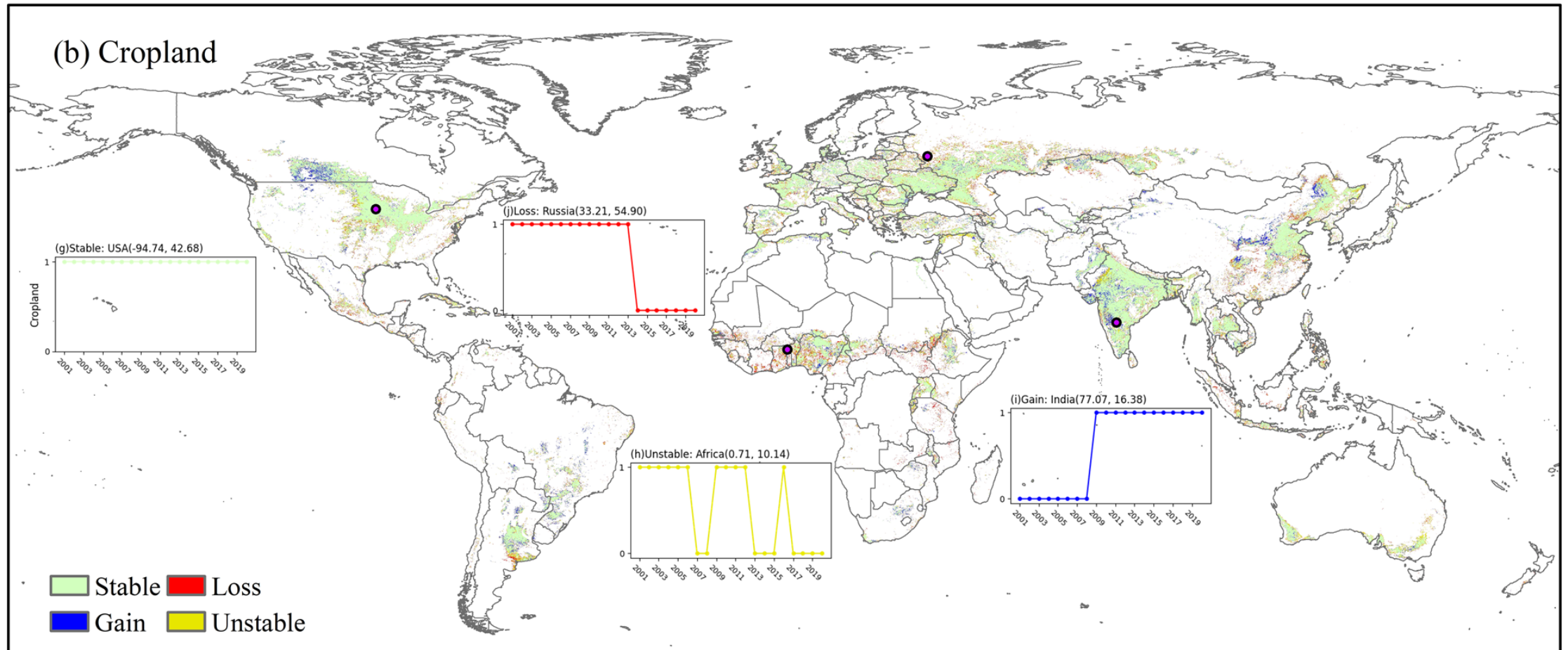
3.2. Location and area of land cover conversions

- **South America:** Deforestation with regular boundaries (Figure c).
- **Sub-Saharan Africa:** Deforestation was pervasive across the frontier of the **Miombo woodlands** (Figure d)
- The forests in **Russia** experienced a high disturbance in Yamalo-Nenets Autonomous Okrug (YNAO) and Kamchatka Peninsula (Figure e).

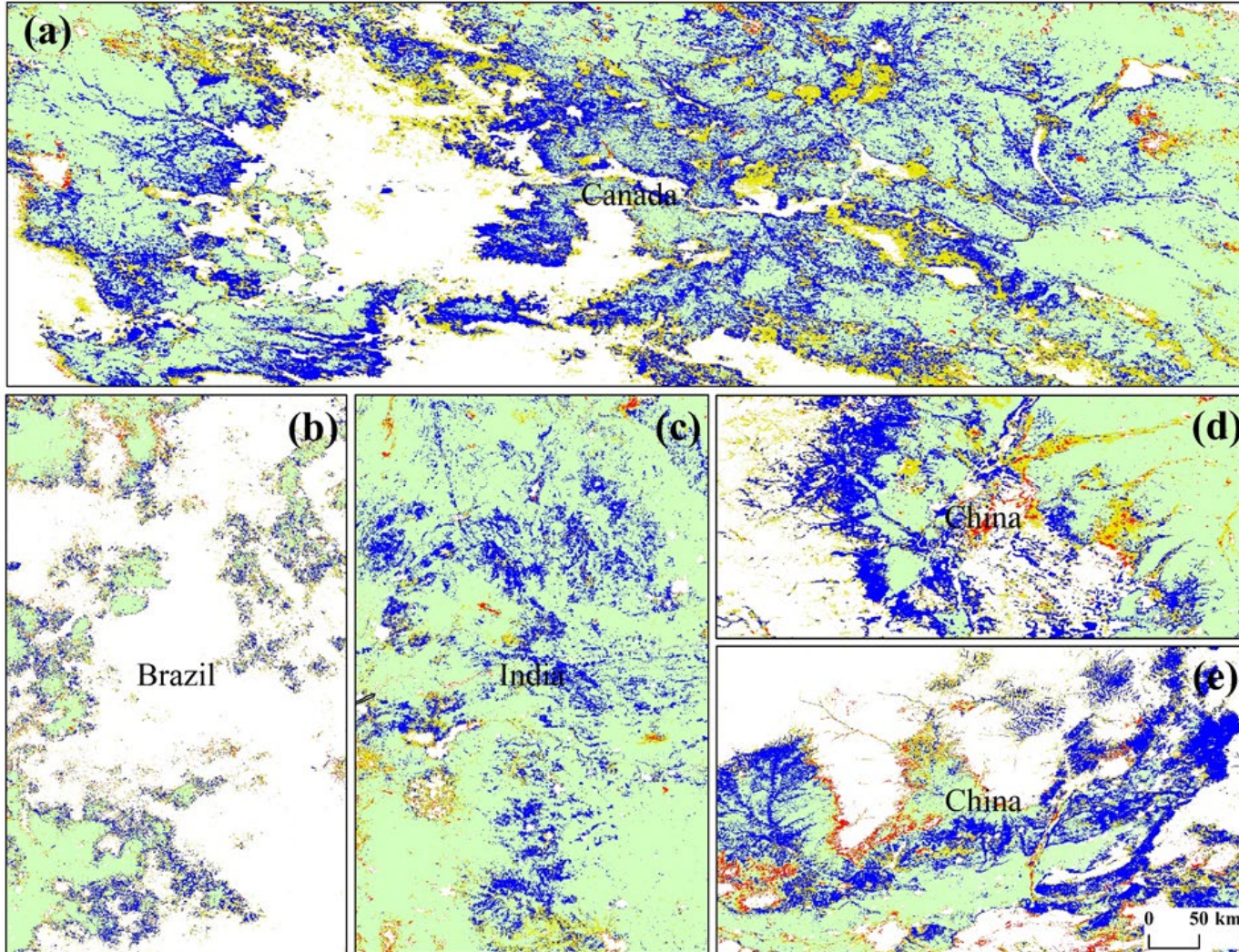


3.2. Location and area of land cover conversions

- Of the global cropland area, 74.9% was stable, 4.4% was gain, 4.9% was loss, and 15.7% was unstable.
- The global hotspots of cropland expansion include the Canadian Prairies, South America, India, Northwestern and Northeastern China.



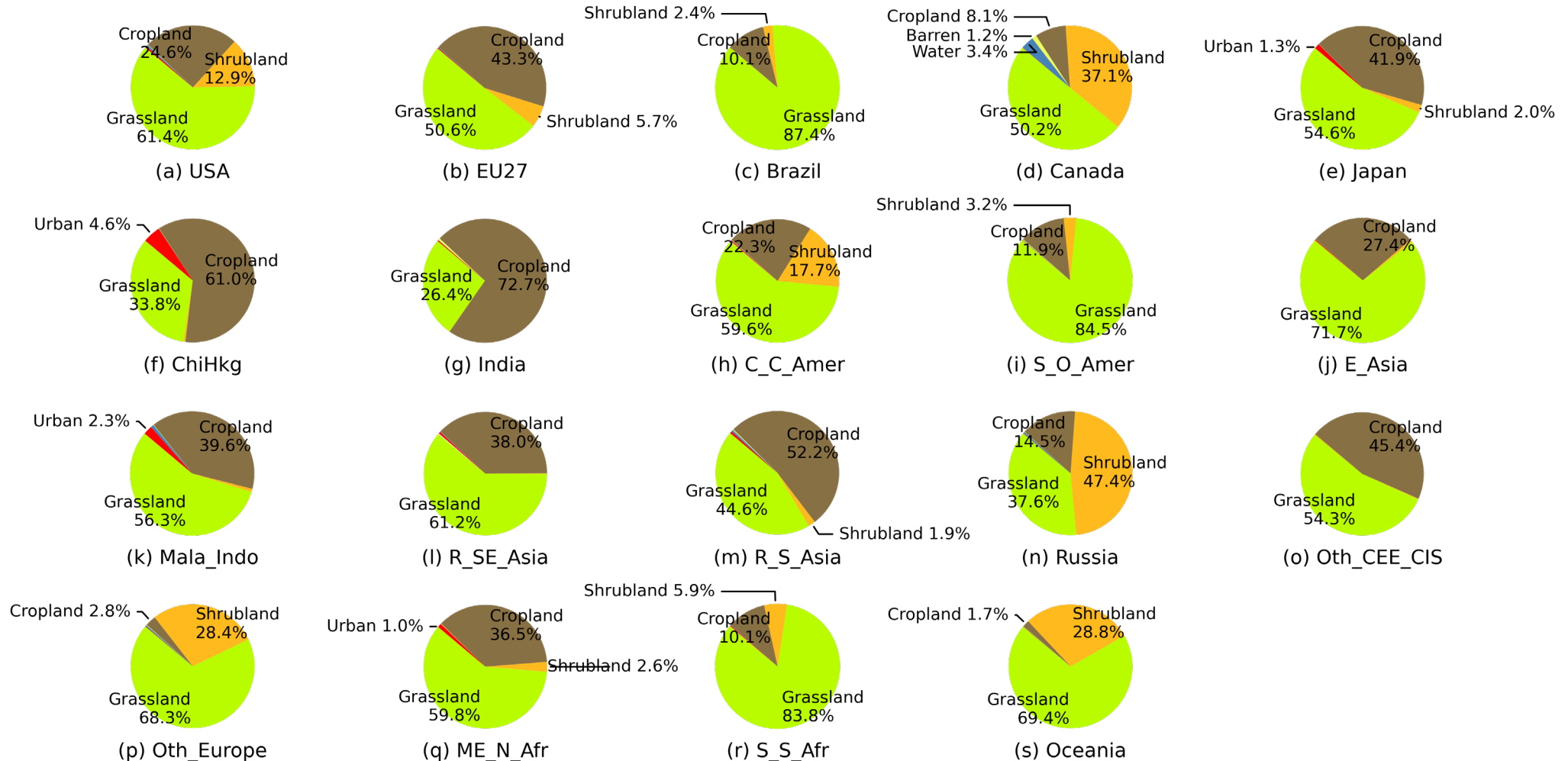
3.2. Location and area of land cover conversions



- Large crop expansion is the dominant pattern in **Canada** and **India** (Figure a&c).
- Small concentrated patches of cropland expansion were scattered across **Brazil** (Figure d).
- In **China**: Locations of cropland expansion also had high levels of abandonment (Figure d&e).

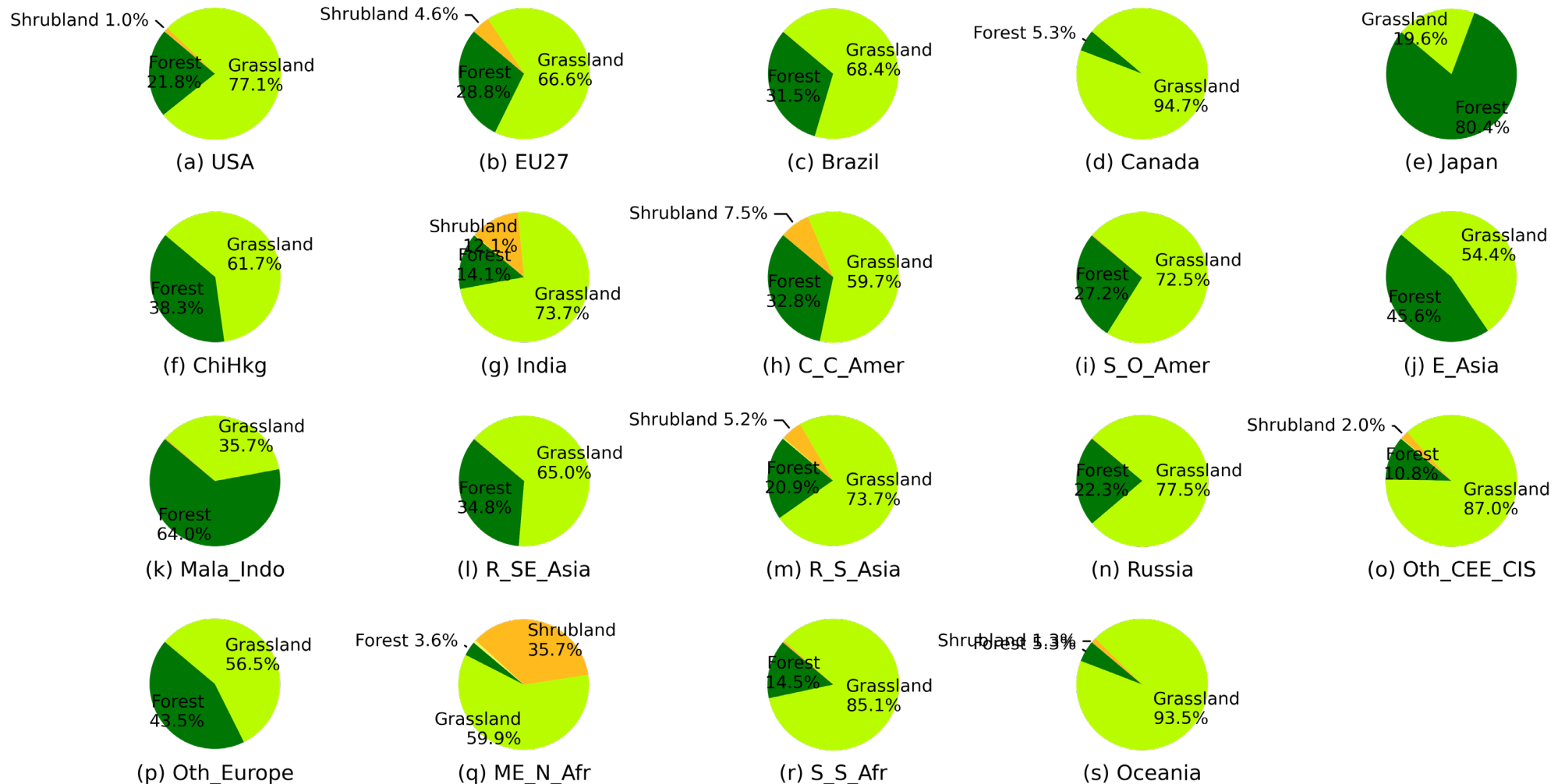
3.3. Identifying sources and fates of land cover change

- Forest -> grassland: dominant in most regions, like USA, Canada
- Forest -> cropland: India, ChiHkg, and the Rest of South Asia (R_S_Asia)
- Forest -> shrubland: Canada and Russia



3.3. Identifying sources and fates of land cover change

- Grassland -> cropland: dominant in most regions, especially Canada and Oceania
- Forest -> cropland: Japan and Mala_Indo (Malaysia and Indonesia)
- Shrubland -> cropland: ME_N_Afr (Middle Eastern and North Africa)



4. Summary

- Global forest, shrubland, barren land areas, and snow-covered areas decreased while grassland, cropland, water, and urban areas increased from 2001 to 2020.
- Brazil, South America Sub-Saharan Africa, and Russia are the hotspots of deforestation, with most of which converted to grassland.
- The global cropland expansion hotspots are the Canadian Prairies, India, and China, which were mainly converted from grassland.
- On the other hand, a large amount of shrubland converted to forest in the northern hemisphere's temperate regions.
- Barren areas in the USA, Kazakhstan, and China were converted to grassland, getting back to production.