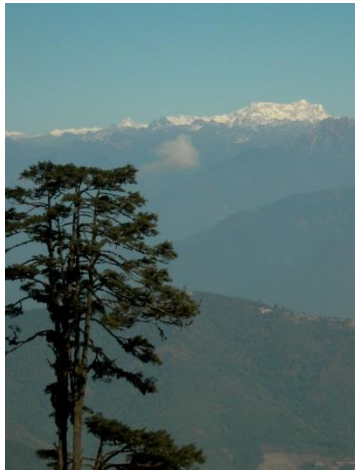
REMOTE SENSING OF THE FOREST TRANSITION AND ITS ECOSYSTEM IMPACTS IN MOUNTAIN ENVIRONMENTS

Bruggeman D., Balthazar V., Griffiths P., Hall J., Hostert P., Lambin E., Molina A., Vanacker V., Vanonckelen S., Van Rompaey A.

(FOMO)

Bhutan: national scale forest policies and the reported forest transition



Research Programme **STEREO II – BELSPO**

Context

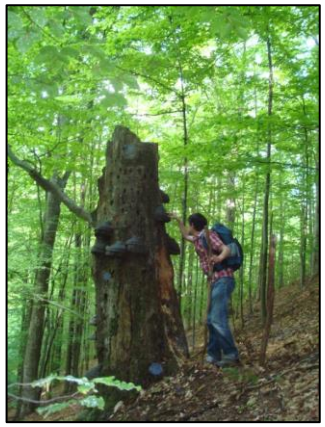
- **Forest transitions:**

- Forest recovery often on **marginal lands (<u>mountains)</u>**

- Remote sensing in mountain environments: a **privileged tool but…**

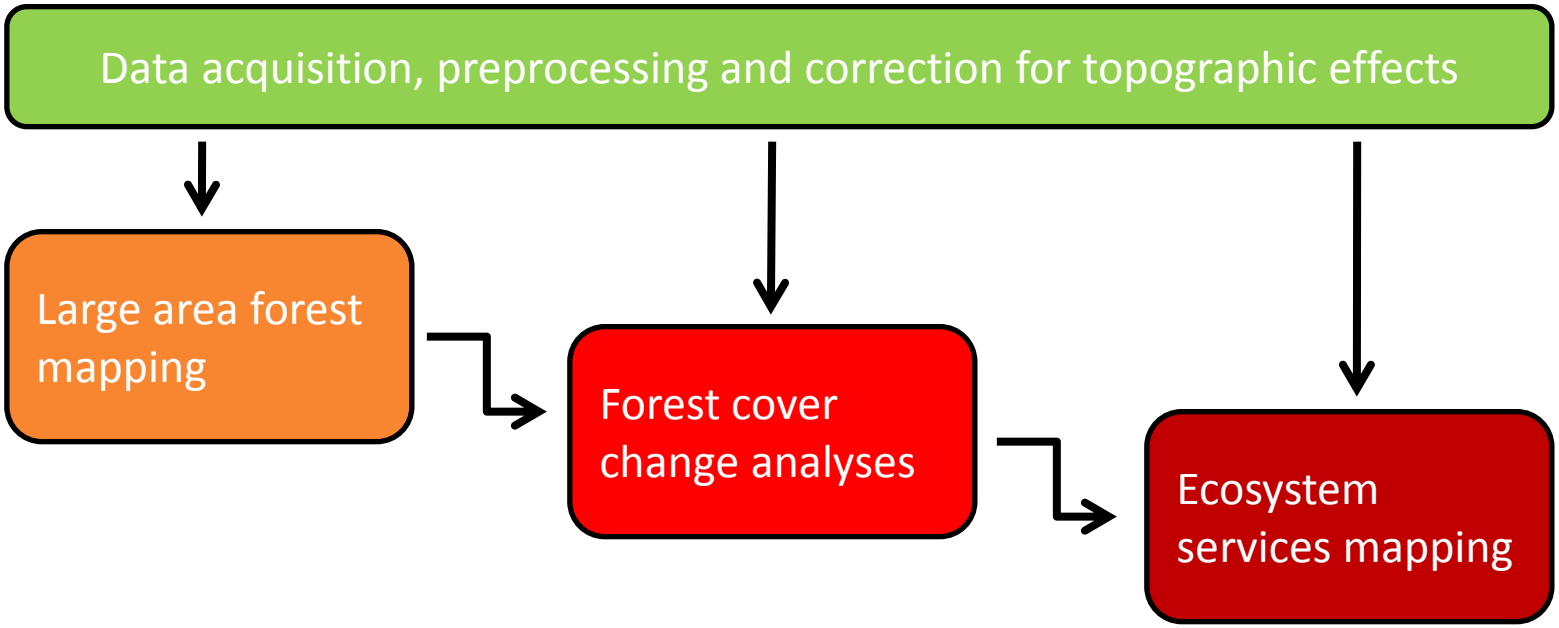
➔ Need for accurate & reliable **monitoring systems**

Objectives



- To make accurate, spatially-explicit and timely estimates of **forest-cover changes**
- To estimate their impacts on **ecosystems services**
- **Over large areas** (semi-automated methods)

Methodology

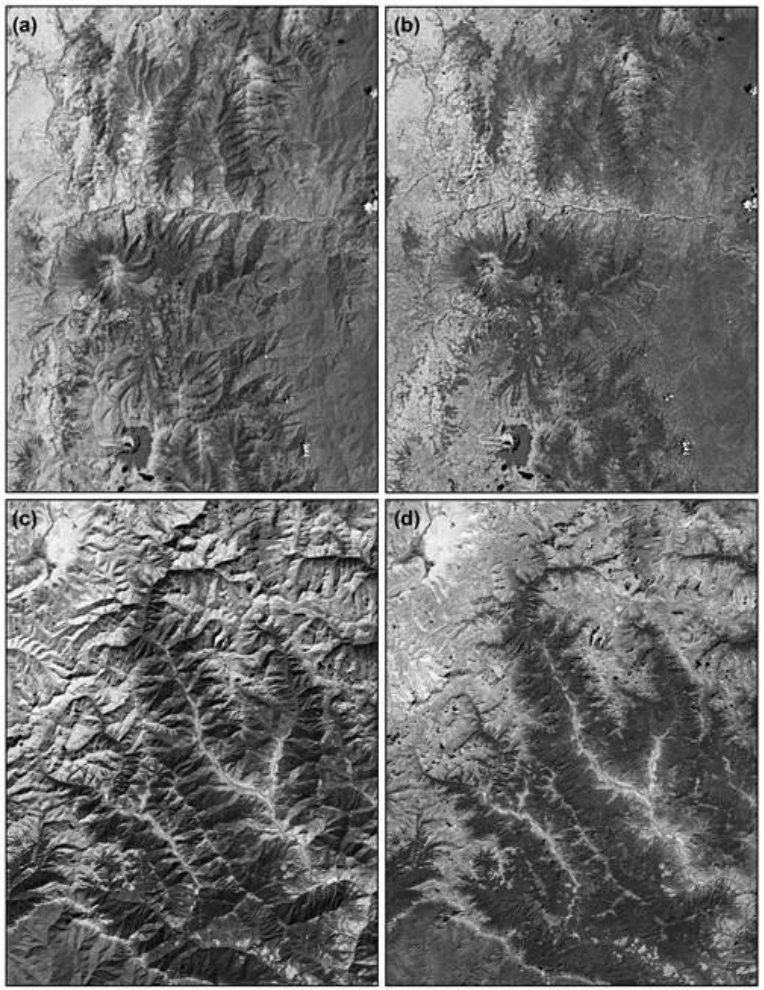


Test sites

Himalaya (Bhutan) - **Carpathians** (Central Europe) – **Northern Andes** (Ecuador)

Data acquisition, pre-processing and correction for topographic effects

Publications	4
Conferences	5
Partners involved	6/9
Successful PhD	2
Sites	3/3
External researchers	3

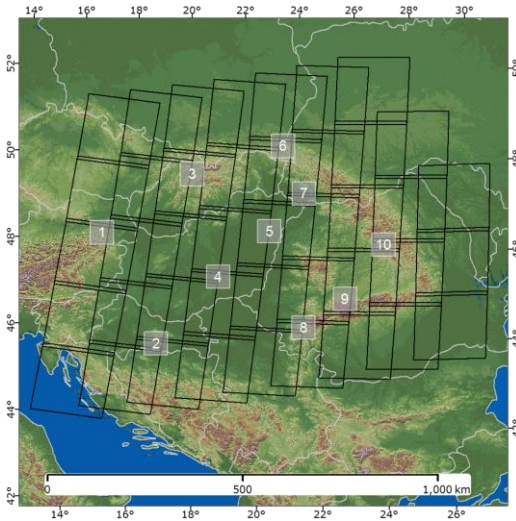


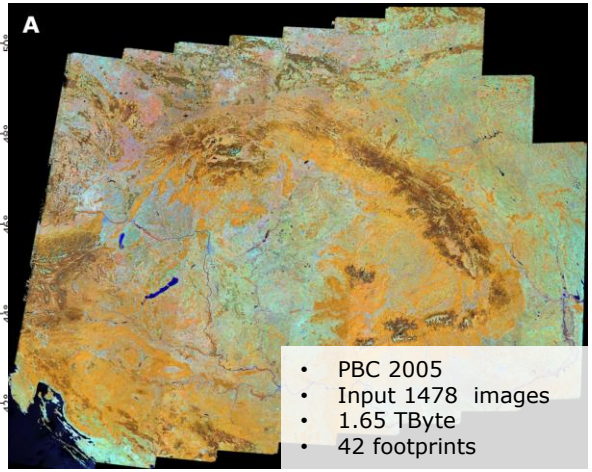
Balthazar et al., 2012 (International Journal of Applied Earth Observation and Geoinformation)

- Use, test, and **comparison of multiple TC algorithms**
  - **Combination of** AC and TC
  - Refinement of existing method (**ATCOR3**)
  - **Quantitative** assessments
- **Input** for other WPs

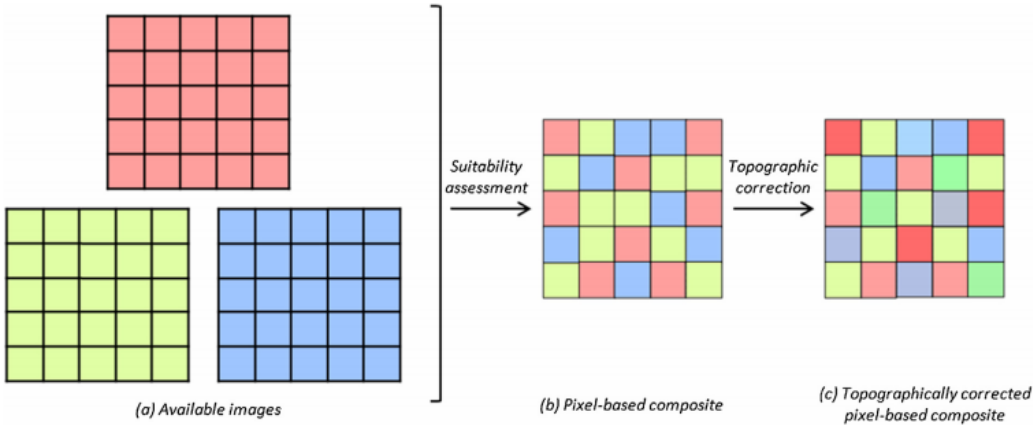
Large area forest mapping

Publications	3
Conferences	5
Partners involved	4/9
Successful PhD	1
Sites	3/3
External researchers	4





Griffiths et al., 2013 (*EEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing.*)



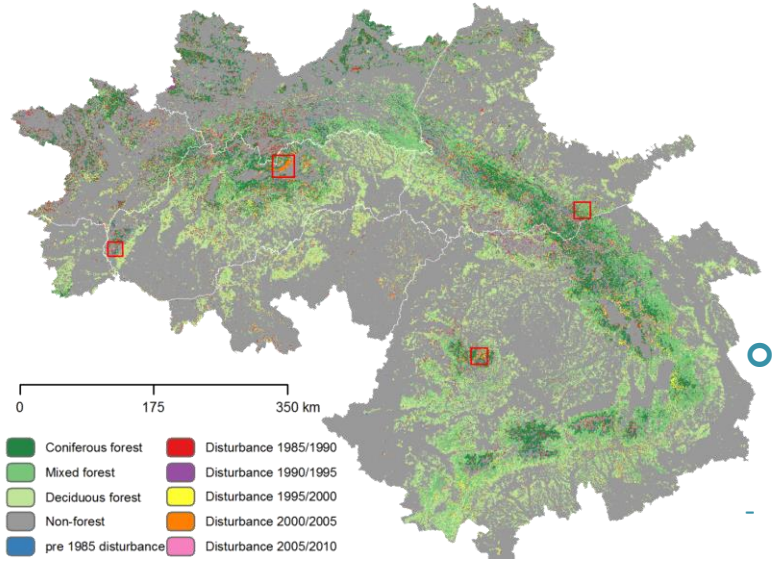
Vanonckelen et al., 2015 (International Journal of Applied Earth Observation and Geoinformation)

- **Temporal compositing** with **Landsat data**
- **Automatic** creation of **composite datasets**
- **High annual, seasonal and radiometric consistency**
- **Integration of TC algorithm in the compositing workflow**

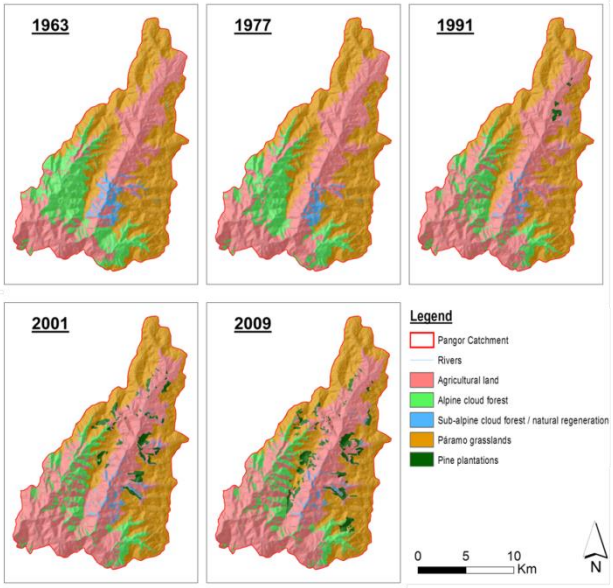
Forest cover change analyses

Publications	4
Conferences	6
Partners involved	9/9
Successful PhD	/
Sites	3/3
External researchers	4

Griffiths et al., 2013 (Remote Sensing of Environment)



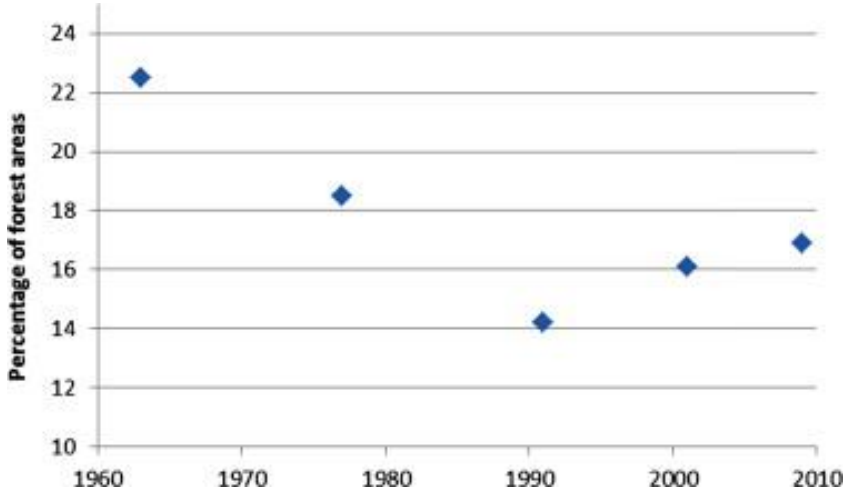
Balthazar et al., 2015 (Ecological Indicators)



- **Spatio-temporal patterns** of **forest cover dynamics in:**
  - the Carpathians (**1985-2010**)
  - the Ecuadorian Andes (**1963-2009**)
  - the Bhutanese Himalayas (**1990 -2011**)
- Highlight of **disturbance, deforestation, afforestation, reforestation**

Ecosystem services mapping

Publications	6
Conferences	8
Partners involved	5/9
Successful PhD	1
Sites	1/3
External researchers	3



- **Most relevant ES in mountains**:
  - Natural hazard regulation
  - Water and erosion regulation
  - Biodiversity and carbon storage

Balthazar et al., 2015 (Ecological Indicators)

- **Forest transition** at the catchment scale triggered by **pine plantation**
- **No direct improvement in ecological conditions**

Remote Sensing of The Forest Transition And Its Ecosystem impacts In Mountain Environments (FOMO)

Bhutan: national scale forest policies and the reported forest transition

Forest cover change maps of Bhutan (1990-2011)

Derek Bruggeman, Eric Lambin

CONTEXT

- Mountainous country (38 000 km²) with a low population density (16 pop./km² in 2005)

CIA World Factbook, 2012

- Forest conservation policies:
  - 1969: Bhutan Forest Act
    - **Nationalization** of forests
  - 1974: National Forest Policy
    - **60%** of national territory cover by **forestlands**
  - 1995: Bhutan Forest and Nature Conservation Act
    - **Ban of shifting agriculture**
    - **Decentralization** of forest management (CF)
  - Protected Areas
    - 1966: First national park
    - 2008: PAs cover **40%** of the national **territory**
  - Forestry sector and trade:
    - 1979: Logging operations **nationalized**
    - 1995: Legal frame for **rules regarding management** (FMUs, PAs, CFs)
    - 1999: Partial **ban** on timber **export**
    - 2011: Notification on timber **import**

→ Mostly covered by forestlands

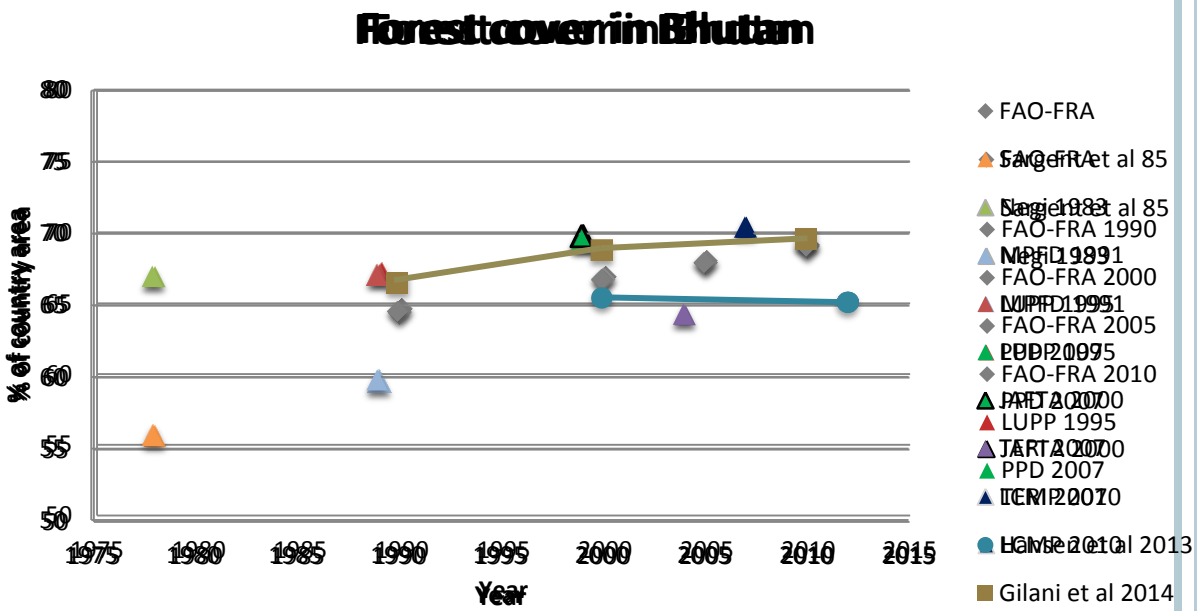
Jadin et al., under revision
(Regional Environmental Change)

Forest cover

- Reported increase in forest areas (FAO-FRA)

Land Cover Data

- LUPP (1995)
- PPD (2007)
- Sargent et al (1985)
- Negi (1983)
- MPFD (1991)
- JAFTA (2000)
- TERI (2007)
- LCMP (2010)



Forest Change Data

- Hansen et al (2013)
- Gilani et al (2014)

	1990-2000 (Gilani et al. 2014)	2000-2010 (Gilani et al. 2014)	2000-2012 (Hansen et al., 2013)
Forest loss	167km²	0km²	129km²
Forest gain	1055km²	285km²	23km²

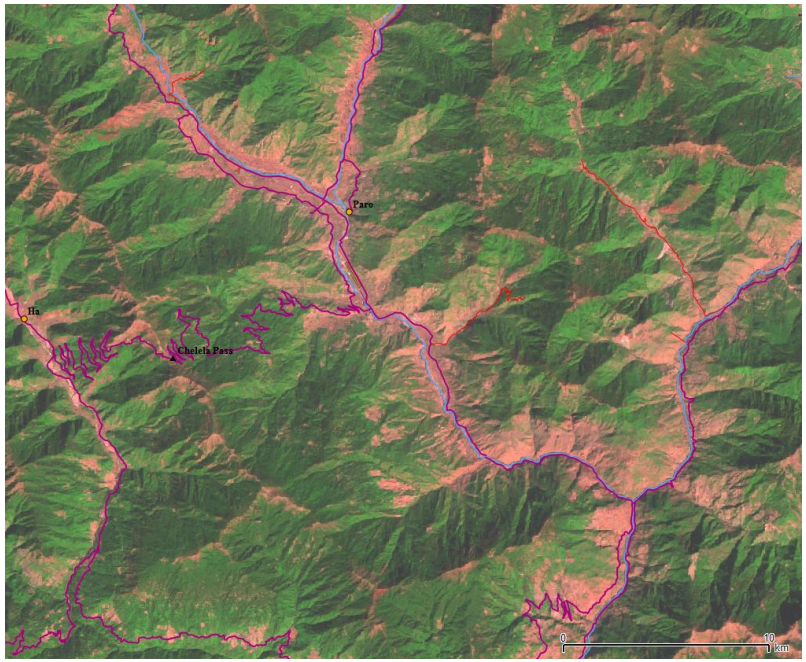
Need for consistency and reliability

METHODOLOGY

Data acquisition and preprocessing

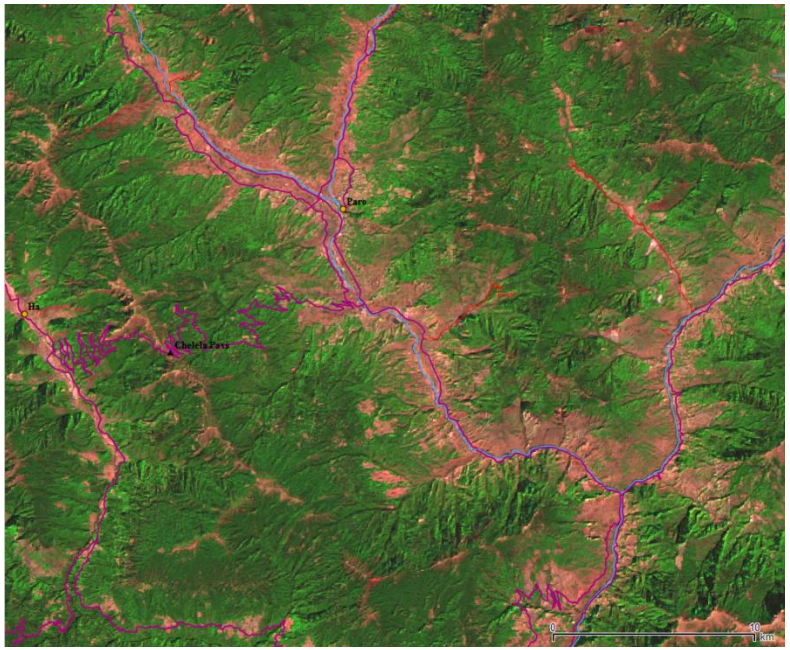
- 6 **Landsat images** taken at **close dates** (<12 days) to cover **2 time periods:**

1990 ⟶ 2001/2 ⟶ 2011



Landsat TM 743 color composite

ATCOR3



Landsat TM 743 color composite

- **Masks** application (shaded slopes, snow, clouds, SLC-off)

⟶

<u>**Period 1** (1990-2001/2)</u>: **84%** of land < 4400m

<u>**Period 2** (2001/2-2011)</u>: **80%** of land < 4400m

Classifications

Non-forest

- Non-vegetated
  - **Bare soil**
  - **Burned areas**
  - **Water**

- Vegetated
  - **Irrigated paddy fields**

  - **Shrubs/rain-fed agriculture/ grasslands**

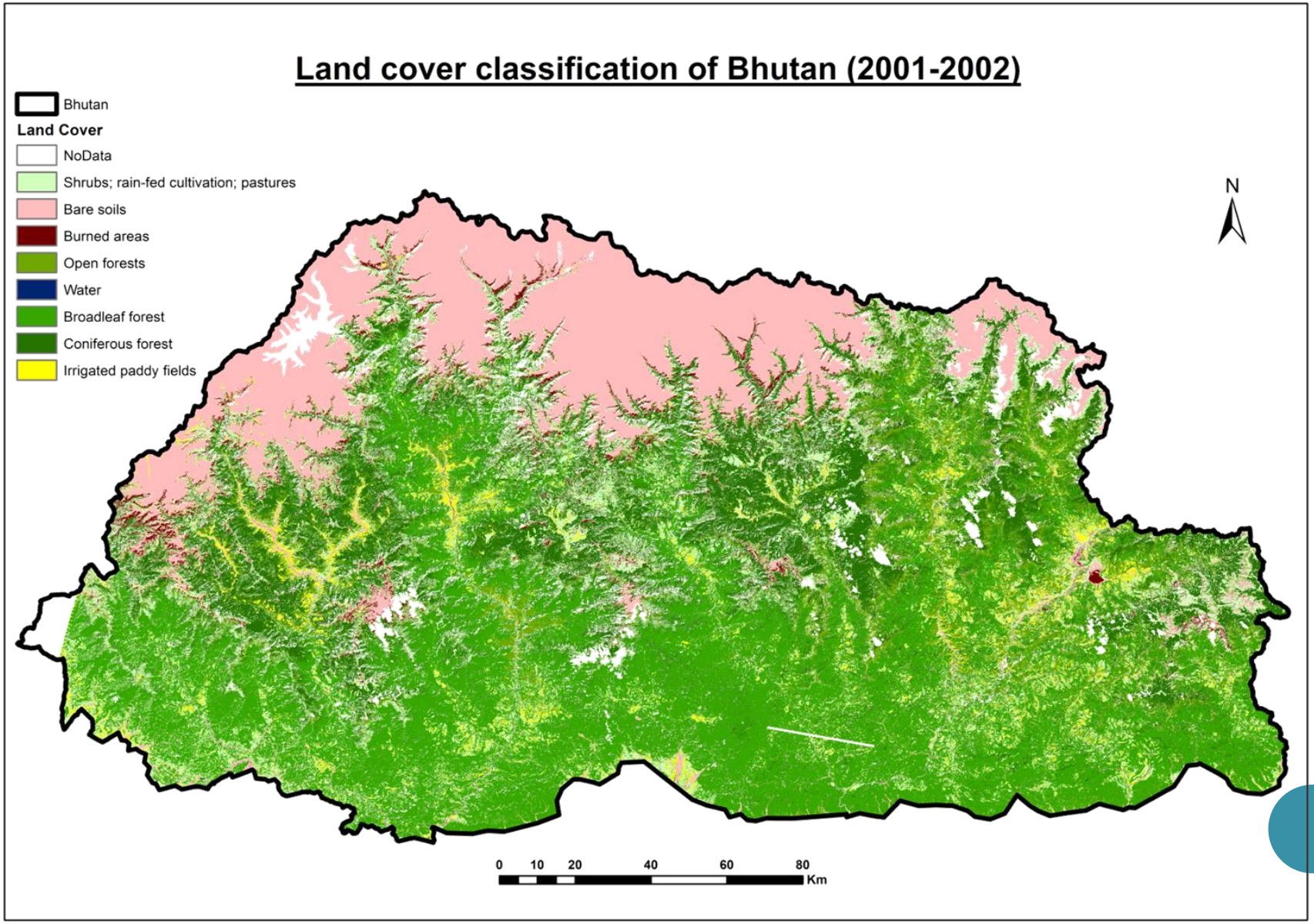
Forest

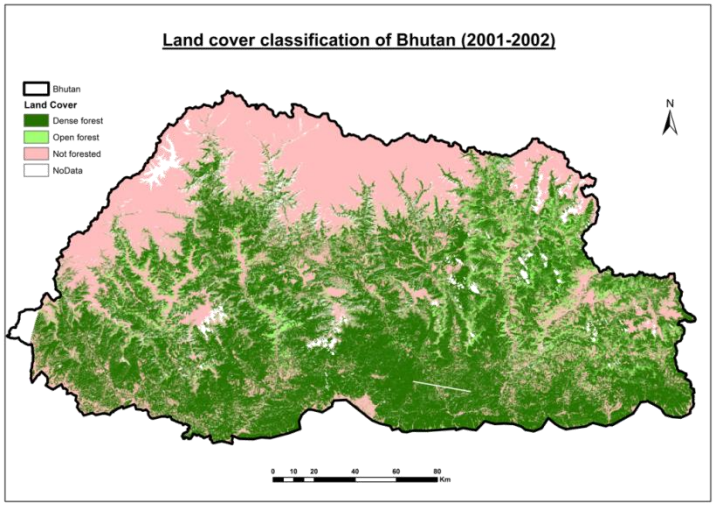
- **Open forest**

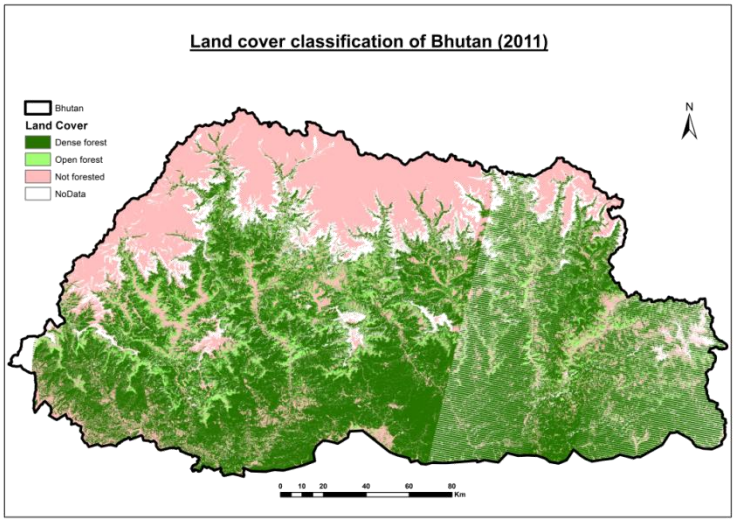
Erhard, 2010

- Dense forest
  - **Broadleaf forest**

  - **Coniferous forest**


Land cover classification of Bhutan (2001-2002)
Bhutan
Land Cover
NoData
Shrubs; rain-fed cultivation; pastures
Bare soils
Burned areas
Open forests
Water
Broadleaf forest
Coniferous forest
Irrigated paddy fields
N
0 10 20 40 60 80
Km

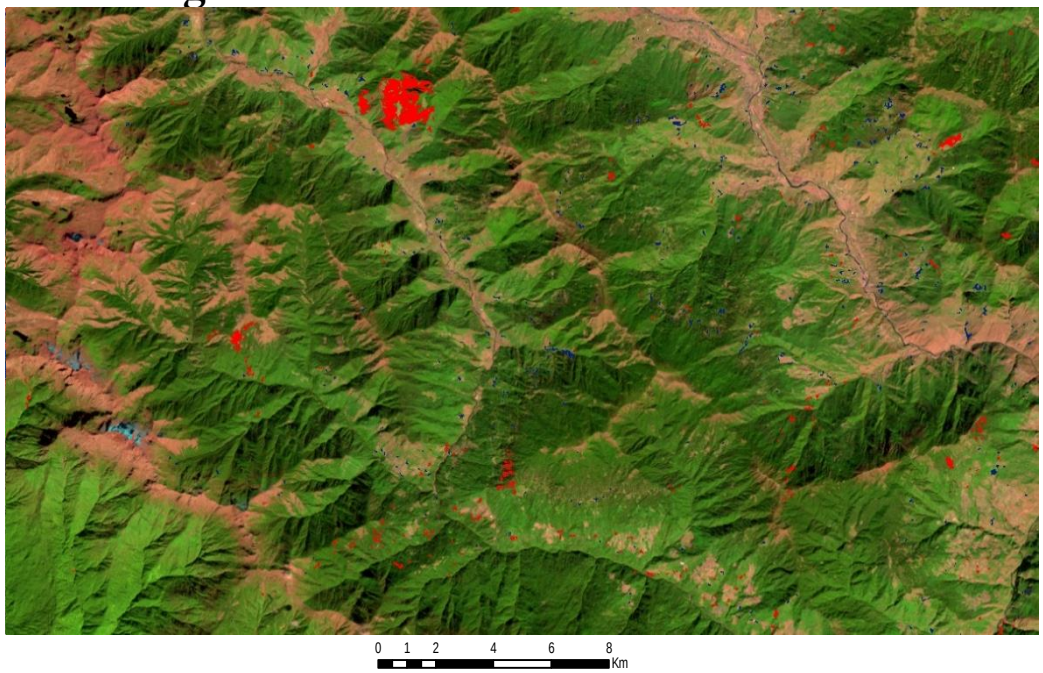




Date	Covered	Dense forest	Open forest	Forest	Not forested
1990	**88.3%**	52.3%	8.7%	**61.0%**	39.0%
2001/2002	**93.2%**	52.6%	7.4%	**60.0%**	40.0%
2011	**85.0%**	56.0%	9.3%	**65.3%**	34.7%

Change detection – Vegetation indices

Change detection between 2002 and 2011



Change detection

Vegetation indices decrease

Vegetation indices increase

Diff NDVI (NIR-RED)/(NIR+RED)

Diff NDMI (NIR-MIR)/(NIR+MIR)

Diff Greenness

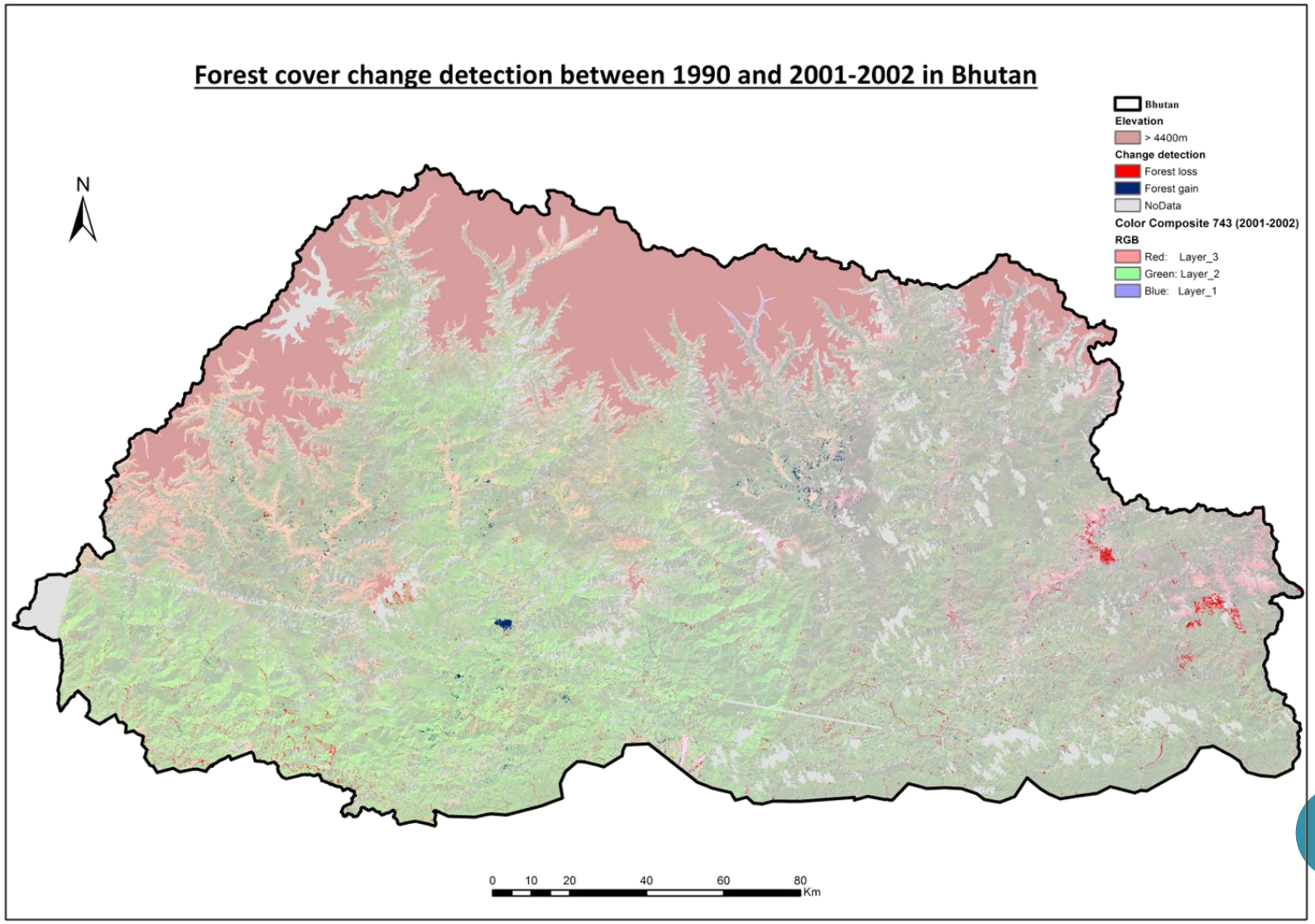
Diff Wetness

Band 2 (Green)

Change = detected as change by at least 2 methods **AND** by post classification comparison

RESULTS

Forest cover change maps



Validation

Land cover classifications

Reference

Classification	2001/2002	Forest	Not forested	
	Forest	459	30	
	Not forested	54	140	
				599
		Validation pts: 683		**87.7%**

Reference

Classification	2011	Forest	Not forested	
	Forest	461	22	
	Not forested	47	105	
				566
		Validation pts: 635		**89.1%**

- Random sampling based on **Google Earth** (not available for 1990)
- Underestimation of forest cover at **both dates**
- **No bias** towards deforestation or reforestation

Forest change detection

Reference

Change detection	2001/2 - 2011	Non forest - stable	Forest - stable	Shift	Deforestation	Reforestation /Afforestation	Total
	Stable	95	288	0	3	2	388
	Deforestation	21	24	24	120	0	189
	Reforestation /Afforestation	44	19	22	0	106	191
	Total	160	331	46	123	108	768

- Stratified random sampling based on **Google Earth** (not available for 1990-2001/2)
- **User's accuracy** of 76% for deforestation and 67% for reforestation/afforestation

Statistics of change

Vegetation indices + post classification comparison

	1990-2001/2	%/yr	2001/2-2011	%/yr
Forest loss	265km²	0,11	134km²	0,07
Forest gain	174km²	0,07	187km²	0,10
Net forest change	- 91km²	-0,04	+ 53km²	+0,03

- **Few changes** but net deforestation followed by a net reforestation

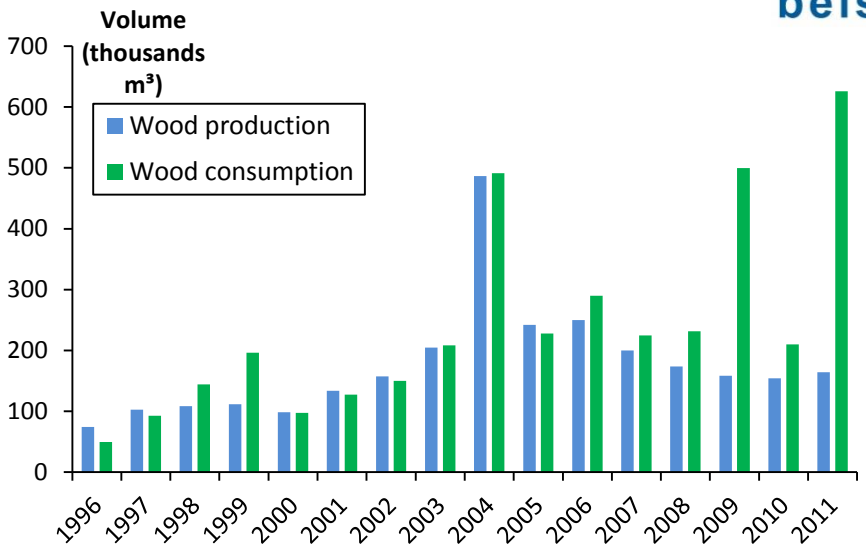
Comparison with similar studies

	1990-2000 (Gilani et al. 2014)	2000-2010 (Gilani et al. 2014)	2000-2012 (Hansen et al., 2013) – 2001/2-2011
Forest loss	167km²	0km²	129km² - 108km²
Forest gain	1055km²	285km²	23km²
Net forest change	+ 888km²	+ 285km²	- 106km²

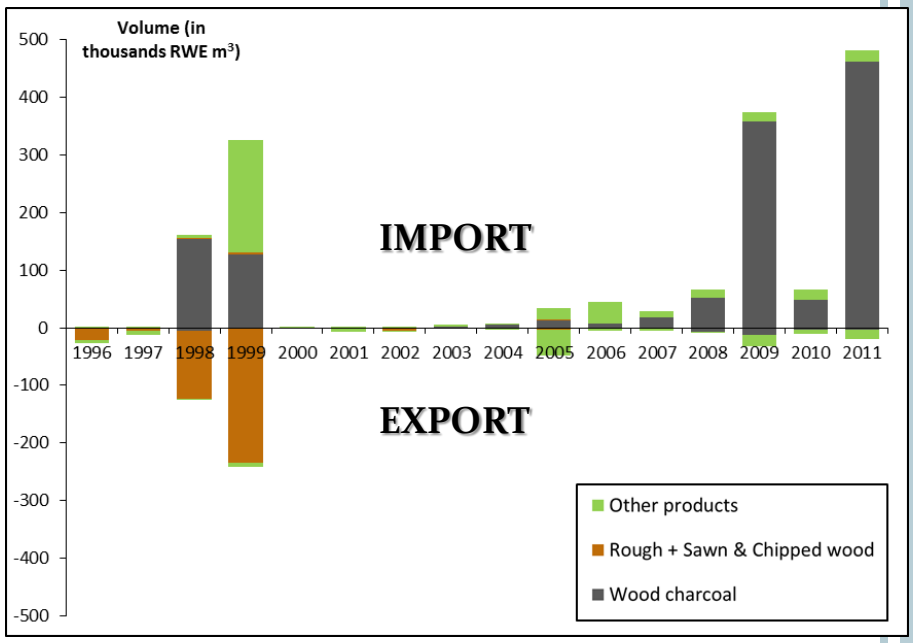
- Similar order of magnitude compared to Hansen's statistics (for deforestation)
- Totally divergent with Gilani et al., 2014

Land use displacement

- Reconstruction of domestic **production and consumption of wood products**
- Estimation of **land-use displacement** through **international trade of wood products**



- ~**40%** of the wood consumed in Bhutan **came from India** (1996-2011)
- **Wood imports** mainly in the form of **wood charcoal**
- **Wood export marginal in the 2000s**
- Net **positive displacement** since 2006



Government policies turn this forest-rich country into a **net wood importer**

Jadin et al., under revision
(Regional Environmental Change)

CONCLUSION

- Forest protection policies allow the conservation of >**60% of land under forest cover**
- **Topographic correction significantly improved** results

- **Fairly stable** forest cover
- Evidence of a **small increase in forest cover** (2001/2-2011)
- **Validation** highlighted challenging nature of large scale land-cover change analyses in mountains

- Trend in forest cover associated with **land use displacement via trade** of wood products

Thank you for your attention