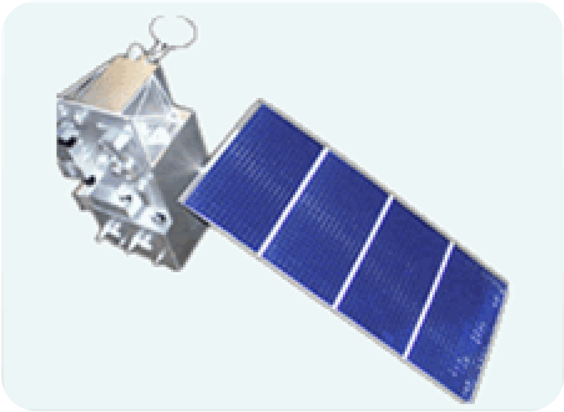
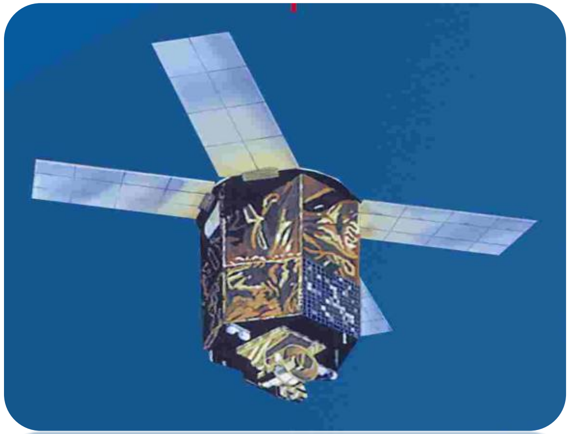
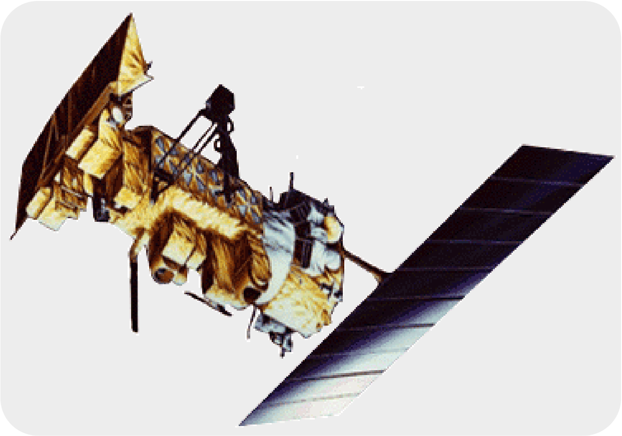
Frontier of Earth System Science Seminar No.1
Fall 2013

Remote sensing of the terrestrial ecosystem for climate change studies

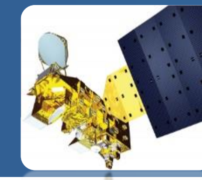






Jun Yang
Center for Earth System Science
Tsinghua University

Outline



1 Introduction

2 Observation of the terrestrial ecosystem

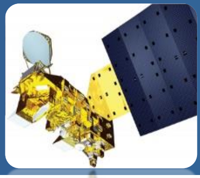
3 Integration with climate models

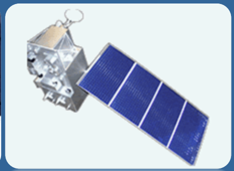
4 Limitations

5 Prospects

1 INTRODUCTION

1 Introduction



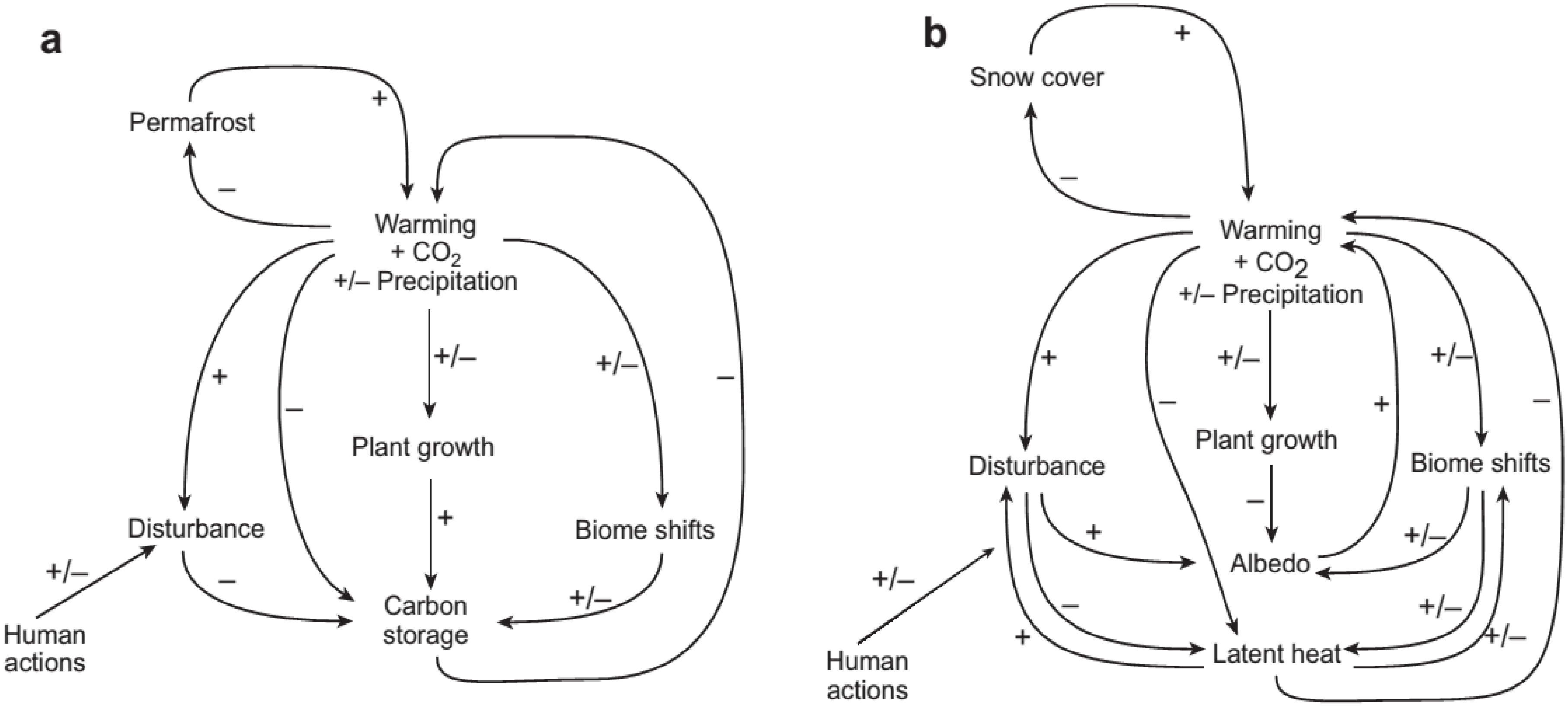


Terrestrial ecosystem-Impacts

- Species
- Biomes
- Phenology
- Disturbances
- Global biogeochemistry

1 Introduction

Terrestrial ecosystem-Feedbacks

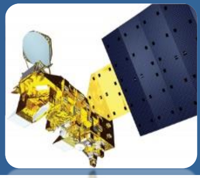


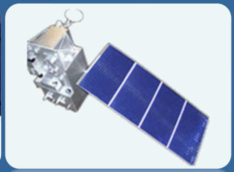
C feedbacks

Physical feedbacks

(Field et al., Annu. Rev. Environ. Resour. 2007）

1 Introduction

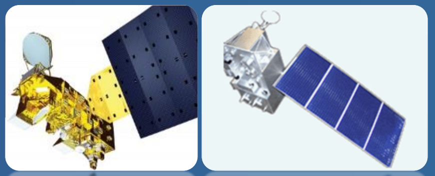


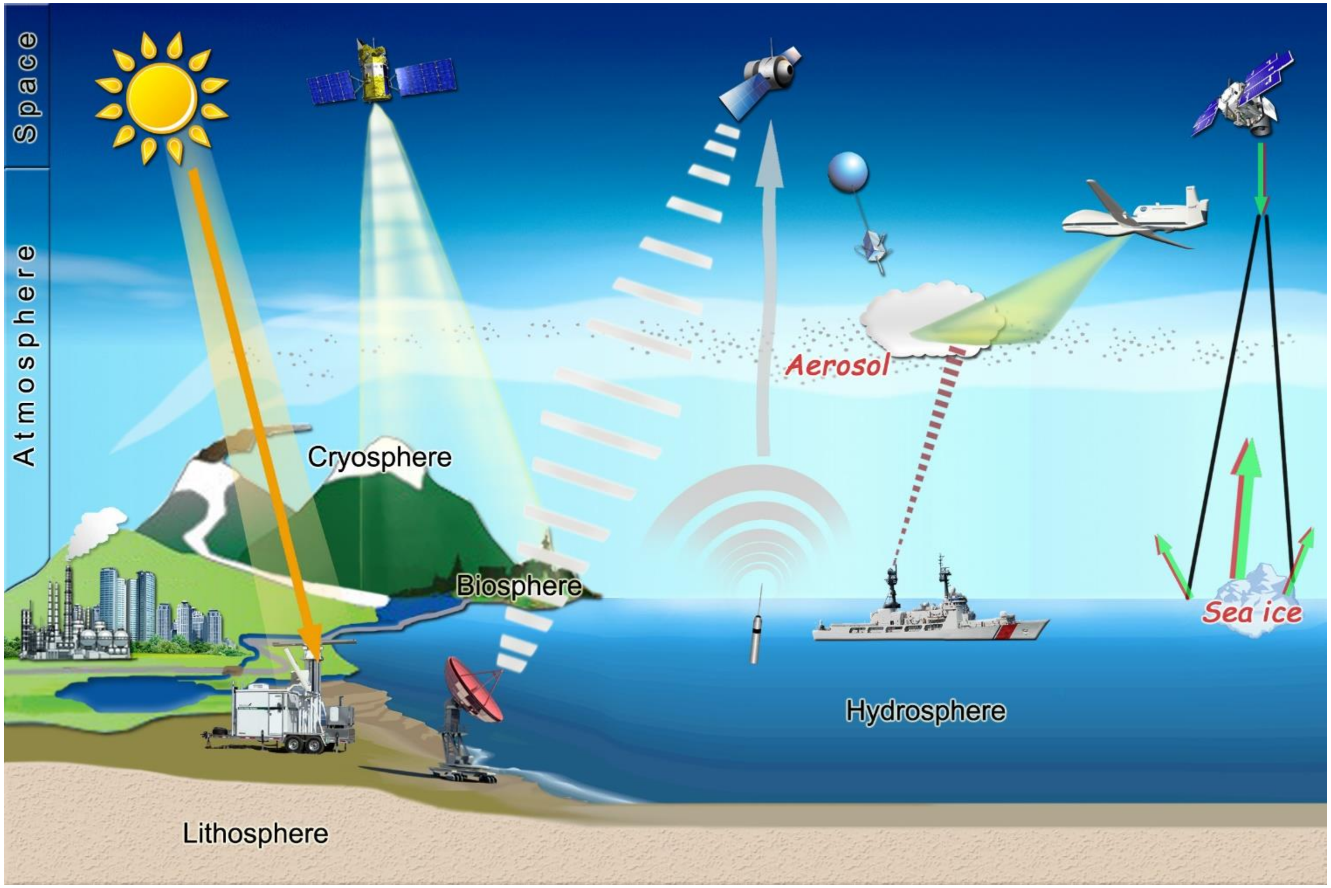


Why remote sensing?

1. Global coverage and high frequency
2. You have no other options

1 Introduction



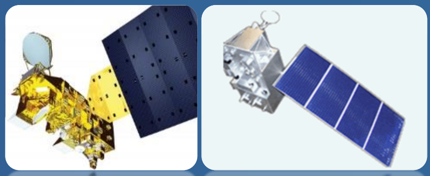


(Source: Yang et al. 2013)

Climate observation

-the foundation of our understanding of the climate system (*Overpeck*, 2011, *Science*)

1 Introduction



❖ Global coverage and frequency

- Essential climate variables (ECVs)

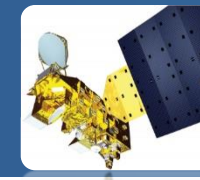
Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	Surface wind speed and direction; precipitation; upper-air temperature; upper-air wind speed and direction; water vapour; cloud properties; Earth radiation budget (including solar irradiance); carbon dioxide; methane and other long-lived greenhouse gases; and ozone and aerosol properties, supported by their precursors.
Oceanic	Sea-surface temperature; sea-surface salinity; sea level; sea state; sea ice; ocean colour.
Terrestrial	Lakes; snow cover; glaciers and ice caps;, ice sheets; albedo; land cover (including vegetation type); fraction of Absorbed Photosynthetically Active Radiation (FAPAR); Leaf Area Index (LAI); above-ground biomass; fire disturbance; soil moisture.

(*GCOS*, 2010)

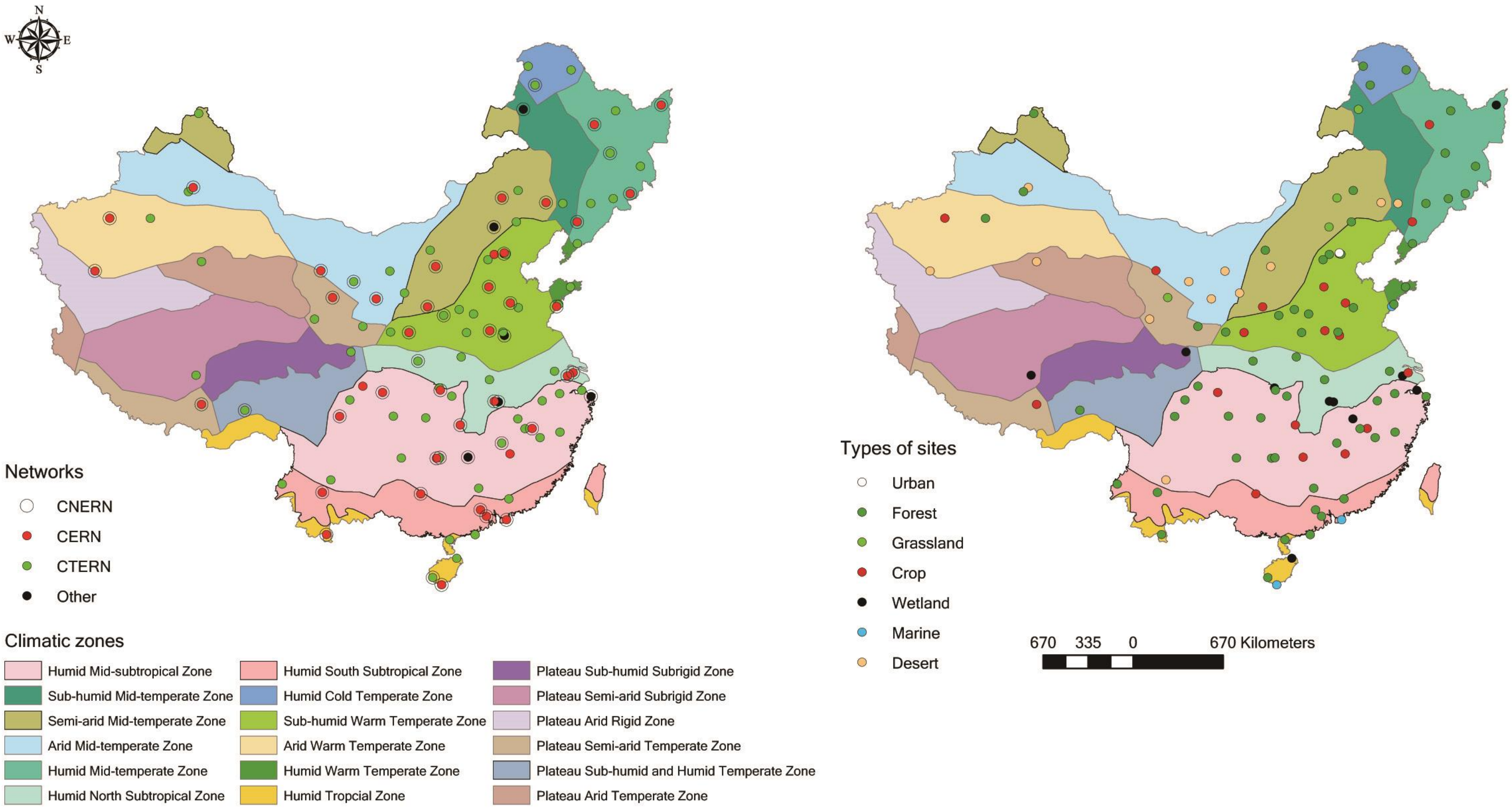
Table 4: Overview of Products – Terrestrial

ECVs / Global Products requiring Satellite Observations	Fundamental Climate Data Records required for Product Generation (from past, current and future missions)
Lakes For lakes in the Global Terrestrial Network for Lakes: Maps of lakes; Lake levels; Surface temperatures of lakes	VIS/NIR imagery, and radar imagery; Altimetry; High-resolution IR imagery
Glaciers and Ice Caps Maps of the areas covered by glaciers other than ice sheets; Ice-sheet elevation changes for mass-balance determination	High-resolution VIS/NIR/SWIR optical imagery; Altimetry
Snow Cover Snow areal extent	Moderate-resolution VIS/NIR/IR and passive microwave imagery
Albedo Directional-hemispherical (black sky) albedo	Multispectral and broadband imagery
Land Cover Moderate-resolution maps of land-cover type; High-resolution maps of land-cover type, for the detection of land-cover change	Moderate-resolution multispectral VIS/NIR imagery; High-resolution multispectral VIS/NIR imagery
fAPAR Maps of fAPAR	VIS/NIR imagery
LAI Maps of LAI	VIS/NIR imagery
Biomass Research towards global, above-ground forest biomass and forest-biomass change	L band / P band SAR; Laser altimetry
Fire Disturbance Burnt area, supplemented by active-fire maps and fire-radiated power	VIS/NIR/SWIR/TIR moderate-resolution multispectral imagery
Soil Moisture[4] Research towards global near-surface soil-moisture map (up to 10cm soil depth)	Active and passive microwave

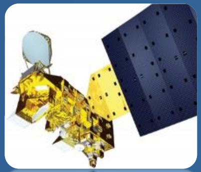
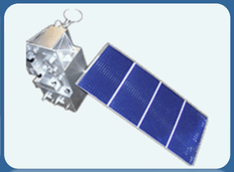
1 Introduction



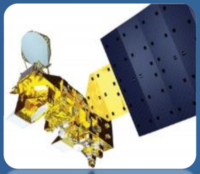
❖ You have no other options!!!

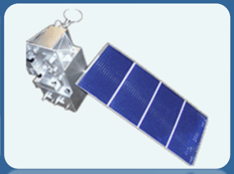


Ecological monitoring stations in China

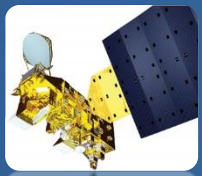
2 Observation of the terrestrial ecosystem

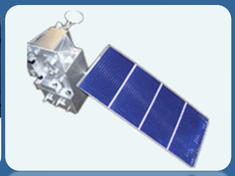




Land use/land cover change

- Impacts of the climate change
  - Snow and ice cover melt
  - Land degradation
- Feedbacks to climate
  - Surface albedo
  - Surface fluxes of mass and energy
    - CO_2
    - Water vapor
    - Aerosols
    - Momentum





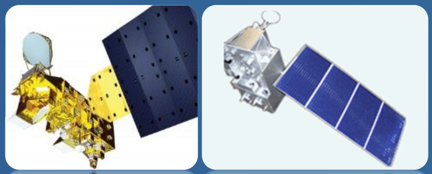
Land use/land cover change

- Remote sensing methodology

Method	Data	Samples	Time	Resolution
Classification Visual ISODATA MLC SVM	AVHRR	GLCC2.0	1992	1km
	ENVISAT	GlobCover	2006,2009	300m
	MODIS	MCD12Q1	Yearly	500m
	Landsat	FROM-GLC	2000,2010	30m,250m

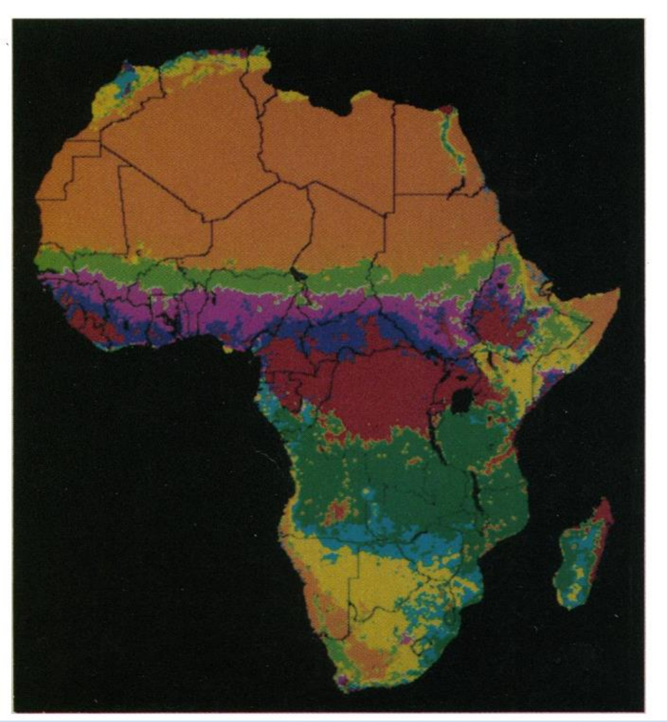
The most *efficient* approaches to monitor land cover and its changes in time over a variety of spatial scales.

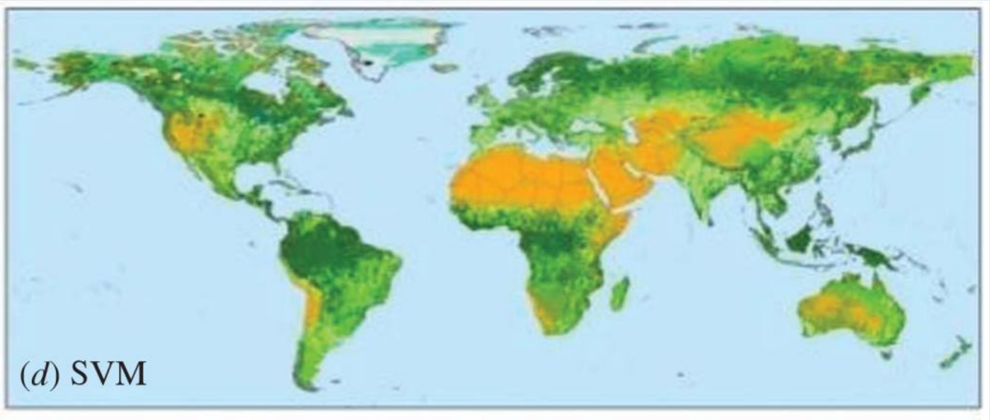
(*Bontemps et al*., 2011, *Biogeosciences Discuss*)



Land use/Land cover change

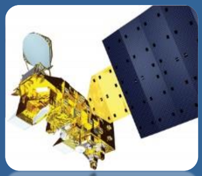
(GlobCover, 2009, ESA)

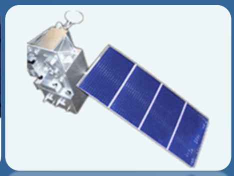




(Tucker et al., 1985, *Science)*

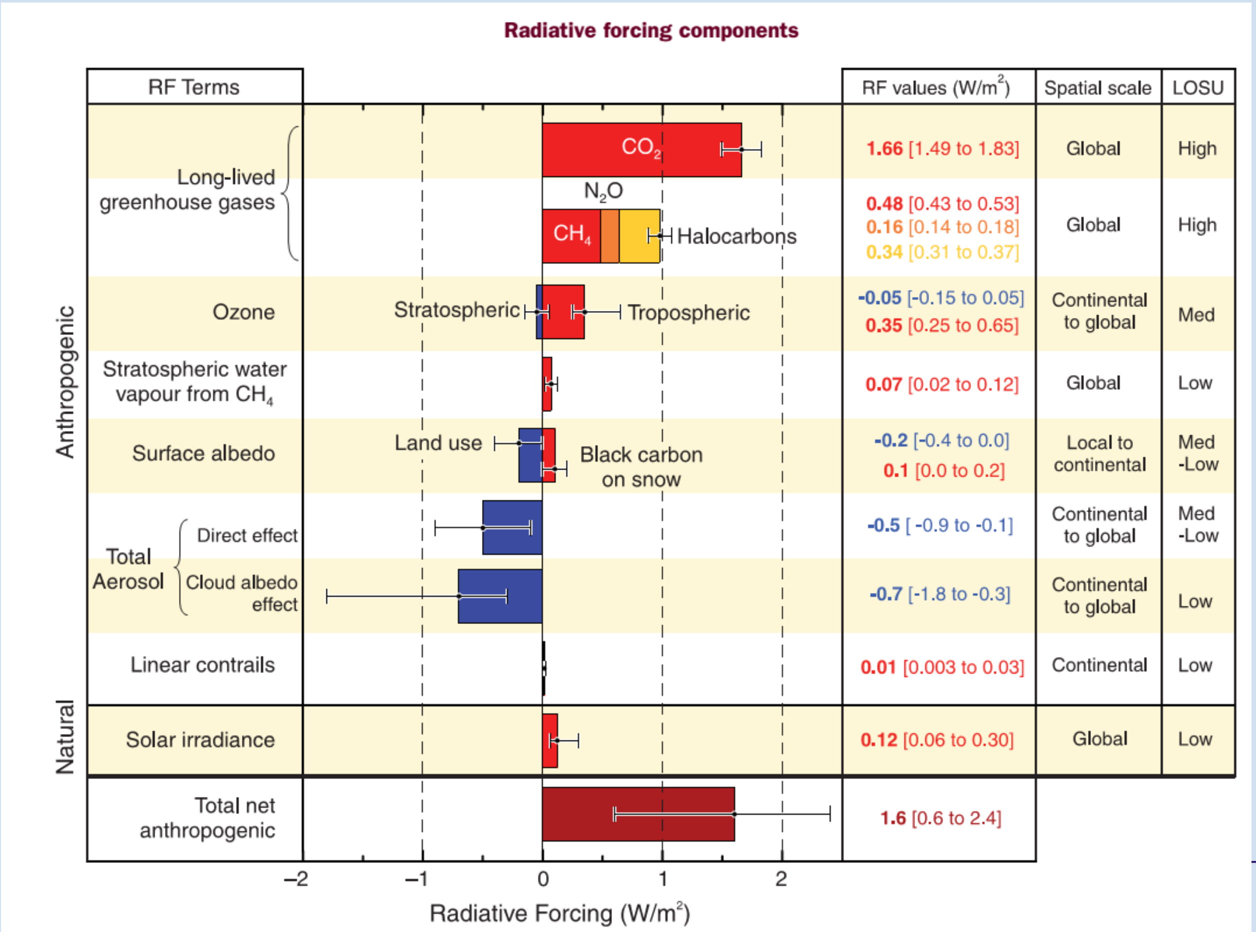
(FROM-GLC, 2010, Gong et al., 2012)





❖ Land use/land cover change

- Major discoveries



(IPCC AR4, 2007)

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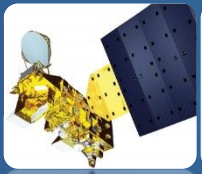
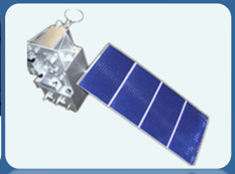
2 Observation of the terrestrial ecosystem

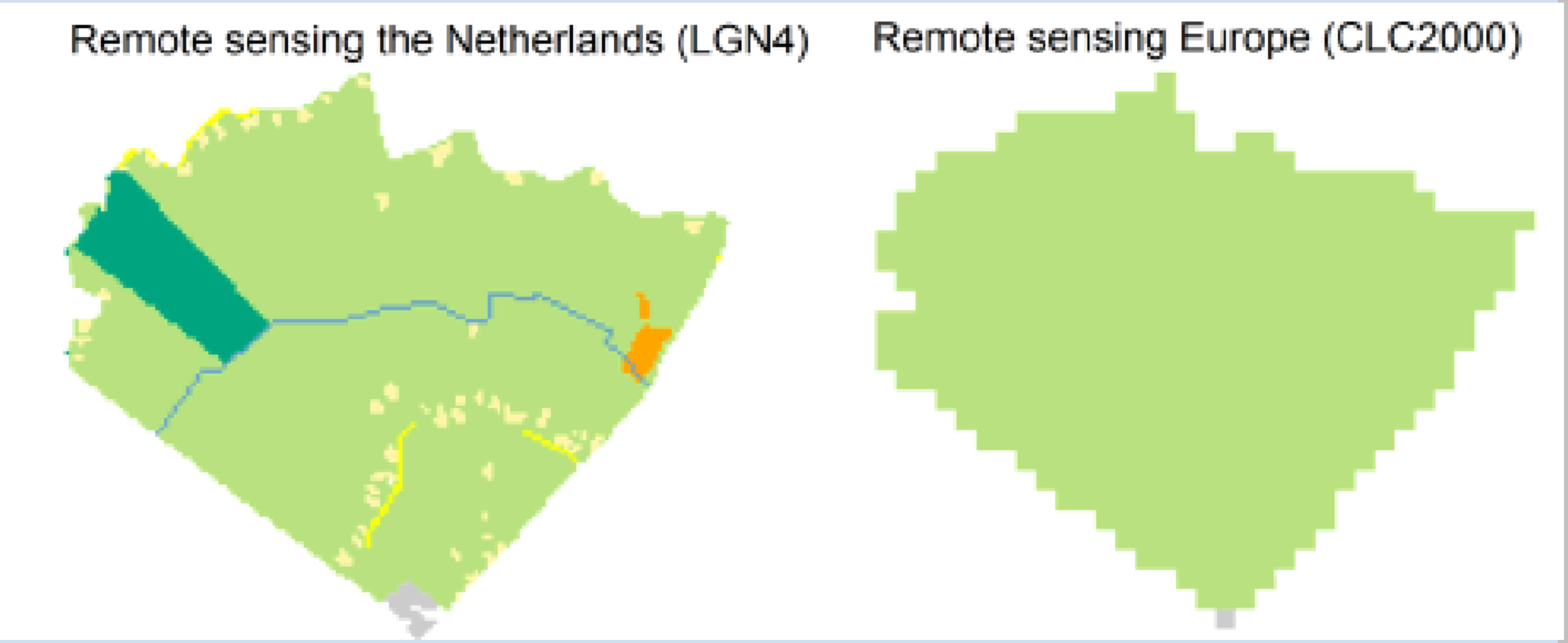
❖ Land use/land cover change

- Existing problems
  - Data inventory and aggregation methods
  - Disagreements in heterogeneous landscapes or transition zones
  - Accuracy <70%
  - Hard to differentiating the stable and the dynamic components of the land cover

Verburg, 2011, Global Change Biology

❖ Land use/land cover change

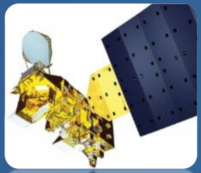
- Existing problems

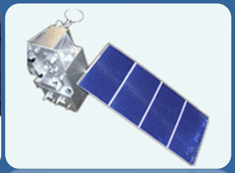


Verburg, 2011, Global Change Biology

Degree confluence project, combined with high-resolution images; Plant functional types

2 Observation of the terrestrial ecosystem





Land use/land cover change

- Future research
  - Data integration
  - Improve validation techniques
  - Harmonization of classification systems
  - Select data to fit the specific applications
  - Incorporate uncertainties in land cover into future assessments
  - Answer the question of global-scale teleconnections

Pielke et al., 2011, WIRES Clim Change

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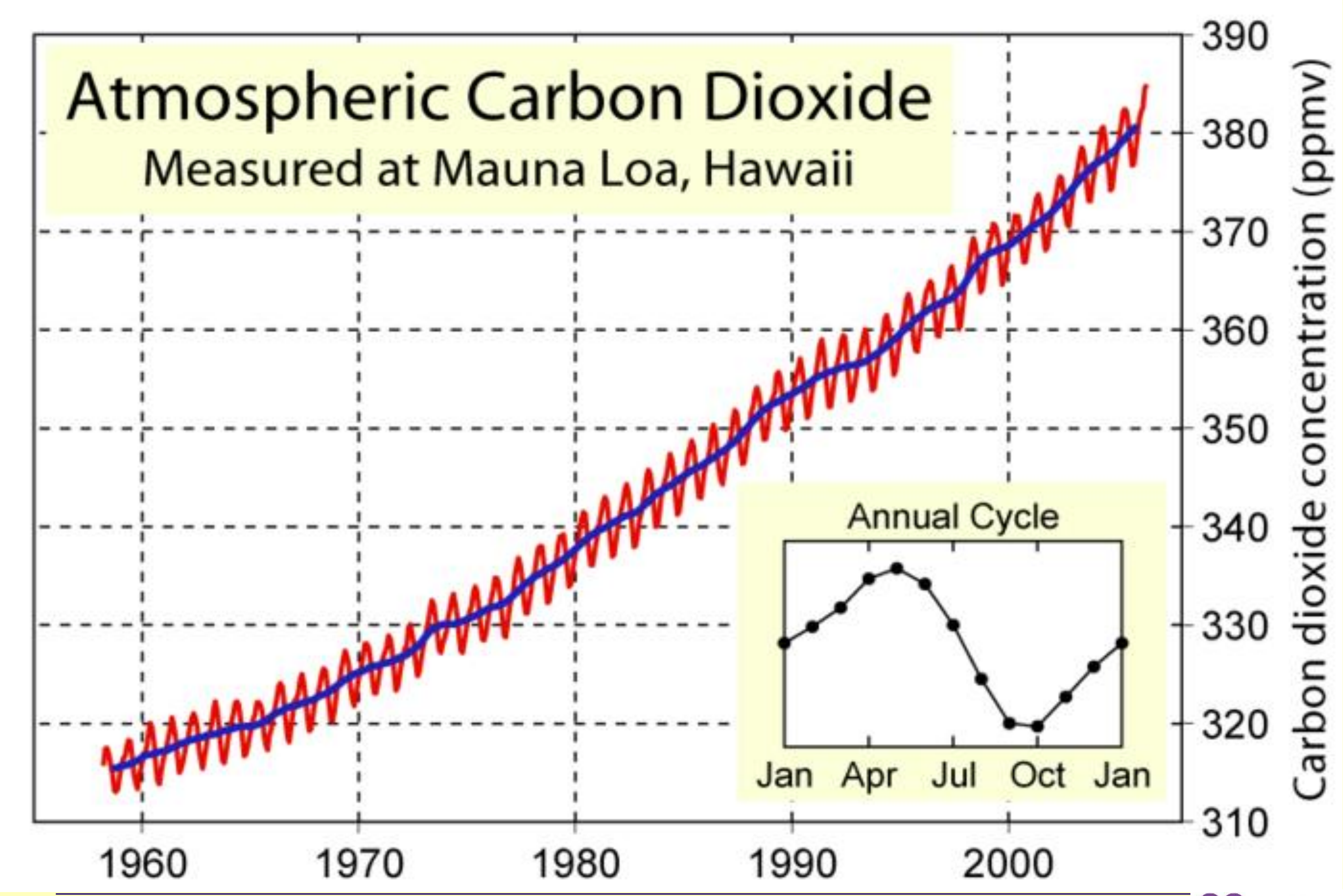
2 Observation of the terrestrial ecosystem

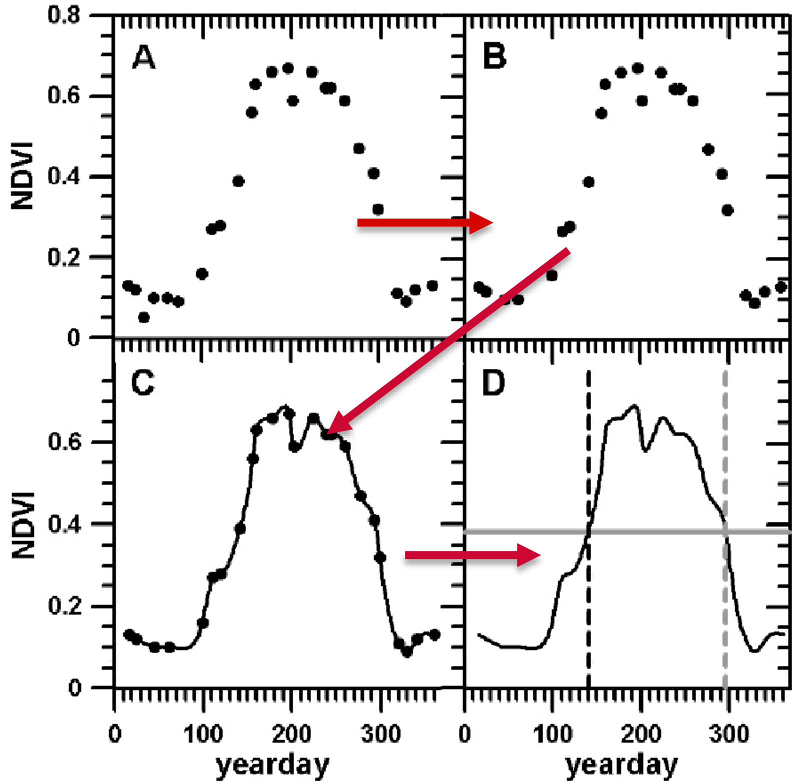


Phenological shifts

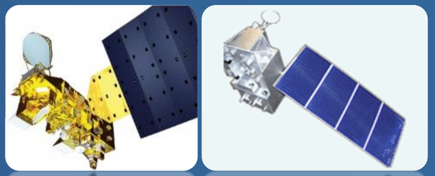
- Remote sensing methodology
  - AVHRR and MODIS data, also Landsat
  - Start of season (SOS) method
    - Find time breaks on Normalized difference vegetation index(NDVI) or Enhanced vegetation index(EVI) curves: first upturn and midpoint
    - Representing the vegetation indices(VI) curves: actual data and curve fitting

Phenological shifts

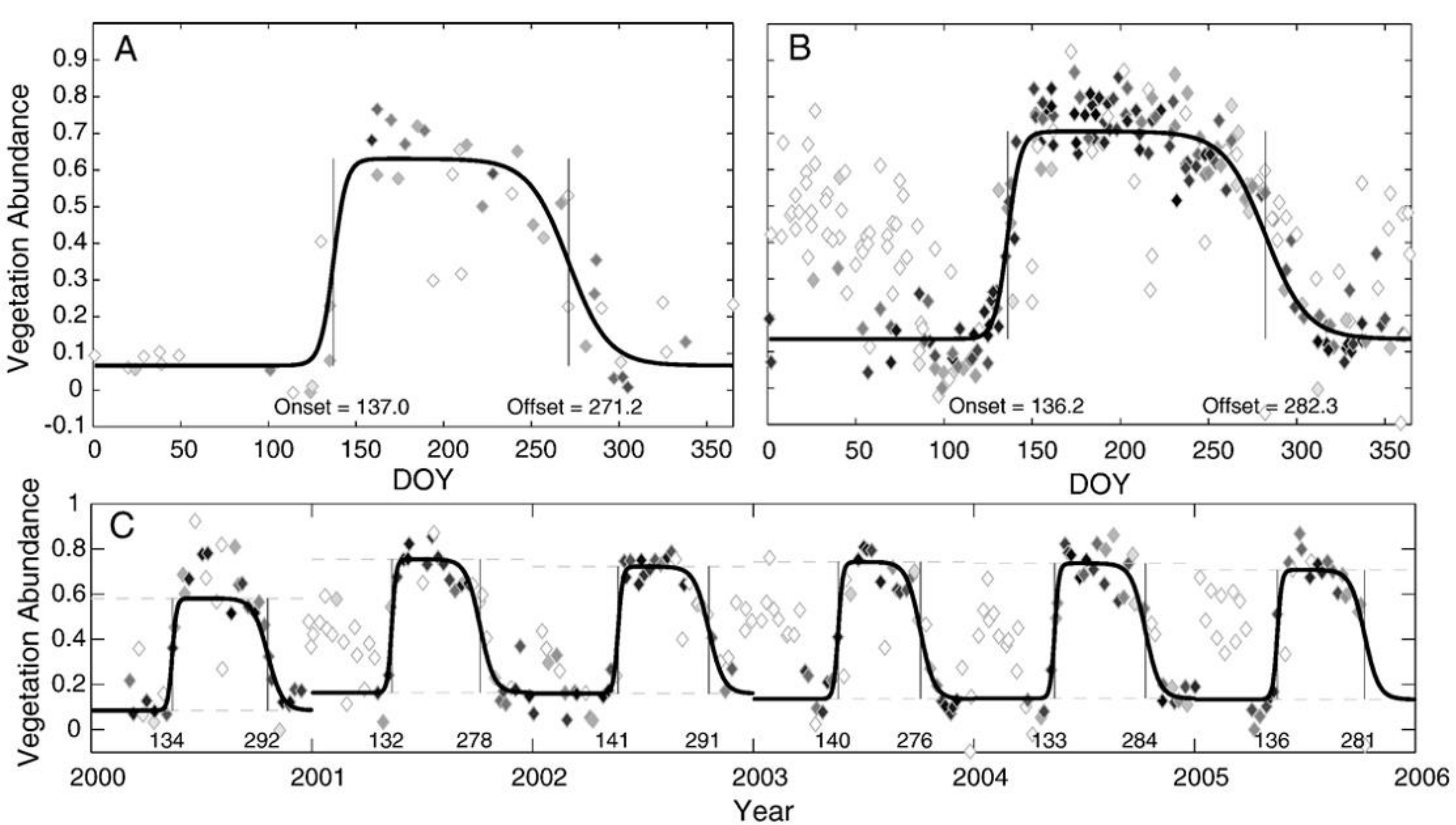
- Remote sensing methodology



Seasonal midpoint NDVI (SMN)
(White et al., 2001 Ecosystems)



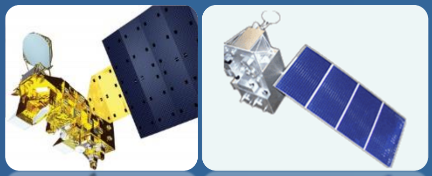
Phenological shifts



Curve fitting method

(Fisher and Mustard, 2007, RSE)

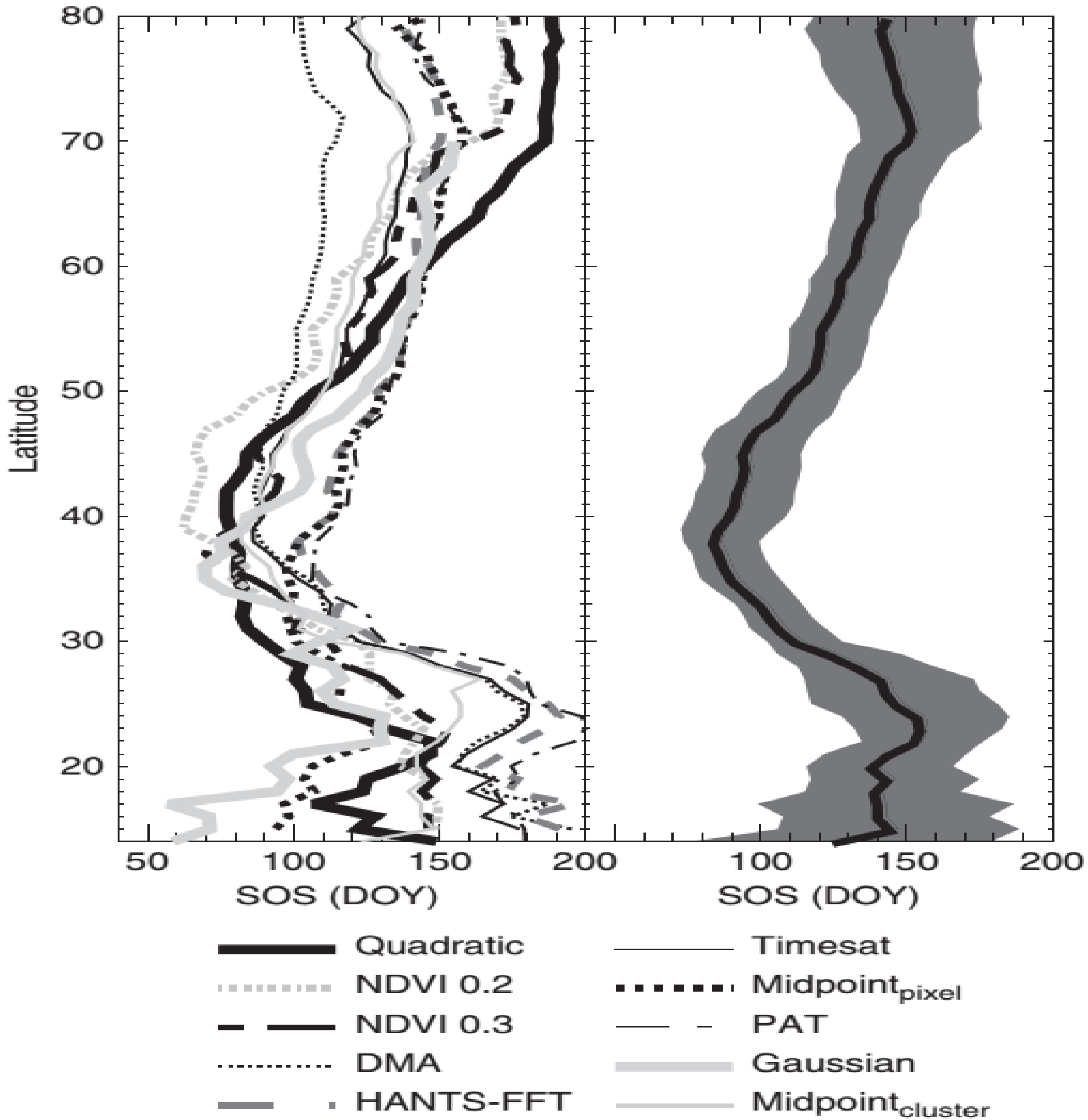
2 Observation of the terrestrial ecosystem

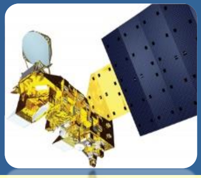


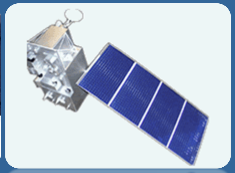
❖ Phenological shifts

- Major discoveries
  - Wall-to-wall coverage of global vegetation since 1982
  - Shift towards earlier spring greening in many region

2 Observation of the terrestrial ecosystem

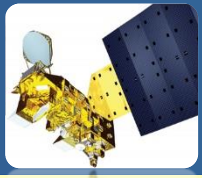


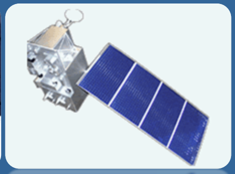




❖ Phenological shifts

- Existing problems
  - Possible reasons:
    - – Lost of fine-grain distinction
    - – Difference in retrieval methods
    - – Implementation procedure

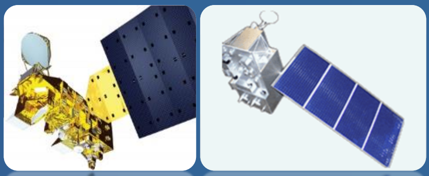




Phenological shifts

- Future research
  - Intercomparison study
  - Validation with ground measurements
  - Complement the VIR/IR data using microwave data

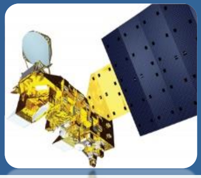
2 Observation of the terrestrial ecosystem

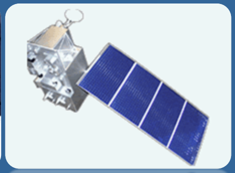


Productivity

- The productivities of the global ecosystem
  - GPP, NPP, NEP
- Impact: variations of productivities
- Feedbacks: global C cycle

2. Observation of the terrestrial ecosystem





❖ Productivity

- Remote sensing methodology

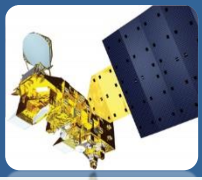
$$GPP = \varepsilon \times FPAR \times PAR \approx \varepsilon \times NDVI \times PAR$$

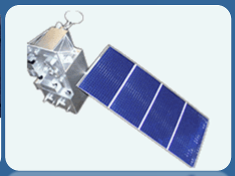
$$NPP = \sum(PSN_{net}) - R_g - R_m$$

$$PSN_{net} = GPP - R_{lr}$$

FPAR, Fraction of photosynthetically active radiation	*PAR*, radiation in photosynthetic wavelengths
PSN_{net}, daily net photosynthesis	R_g, annual growth respiration
R_{lr}, daily maintenance respiration of leaves and the fine roots	R_m, maintenance respiration of live cells in woody tissues
ε, conversion efficiency or light use efficiency；normally annual plant, 2gC/MJ, woody, 0.2-1.5 gC/MJ	

(Running et al., 2004, Bioscience)





Productivity

- Remote sensing methodology

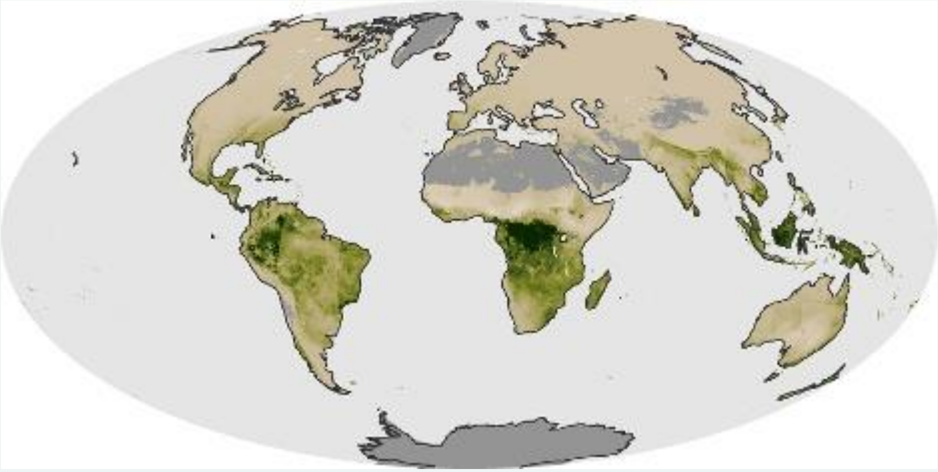
Model	Remote sensing based parameters
CASA	Vegetation Distribution, *fPAR*
GLO-PEM	*fPAR*, Solar radiation,Temperature, Vapour Pressure Deficit, Soil water
TURC	Vegetation Distribution, *fPAR*
SDBM	*fPAR*
VPM	Vegetation Distribution, *fPAR*

Table 1. Remote sensing based parameters in PEMs

(Liu et al., 2010, IGRASS)

Productivity

- Major discoveries



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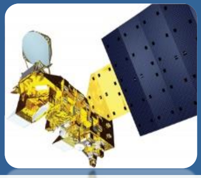
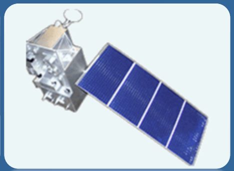
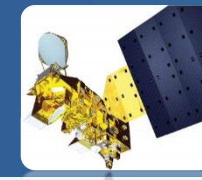




❖ Productivity

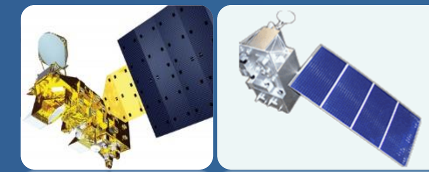
- Major discoveries
  - Overall increase of global NPP
  - NPP/GPP ratio varied with climate and geography
  - Total terrestrial NPP
    - 56.4±7.9 Pg C yr^{-1} averaged from 46 RS studies
    - 56.2±14.3 Pg C yr^{-1} averaged from 251 inventory and model studies



Productivity

- Existing problems
  - Overestimation at low-productivity sites and underestimation at high-productivity sites
  - Low quality of meteorological inputs (PAR, Temperature, Vapor pressure deficit)
  - Assumption of a constant light use efficiency is not true
  - Inadequate environmental constrains (VPD, soil water, nutrient availability)

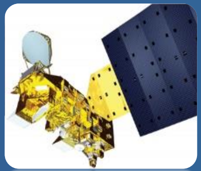
2 Observation of the terrestrial ecosystem

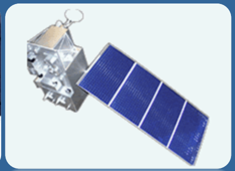


Productivity

- Future research
  - Use photochemical reflectance index (PRI) as a surrogate of light use efficiency
  - More realistic representation of environmental constraints
  - Better estimation of respiration components

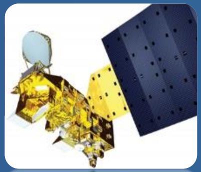
2. Observation of the terrestrial ecosystem

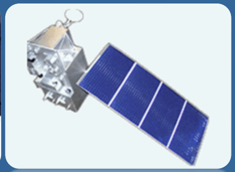




Species and biomes

- Impacts
  - Ecology
  - Evolution





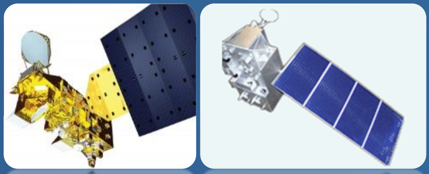
Species and biomes

- Remote sensing methodology
  - Biophysical characteristics of habitats
  - Spatial variability in species richness
  - Natural and anthropogenic changes

Species and biomes

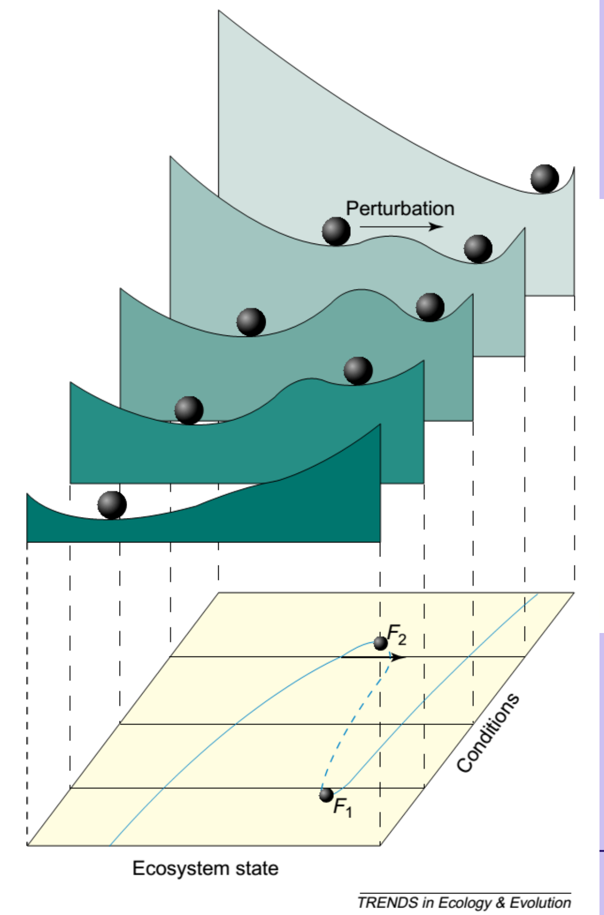
- Regime shift
  - Aptly sudden shifts in ecosystems
  - E.g.
    - The formation of Sahara desert
    - Shift in Caribbean coral reefs

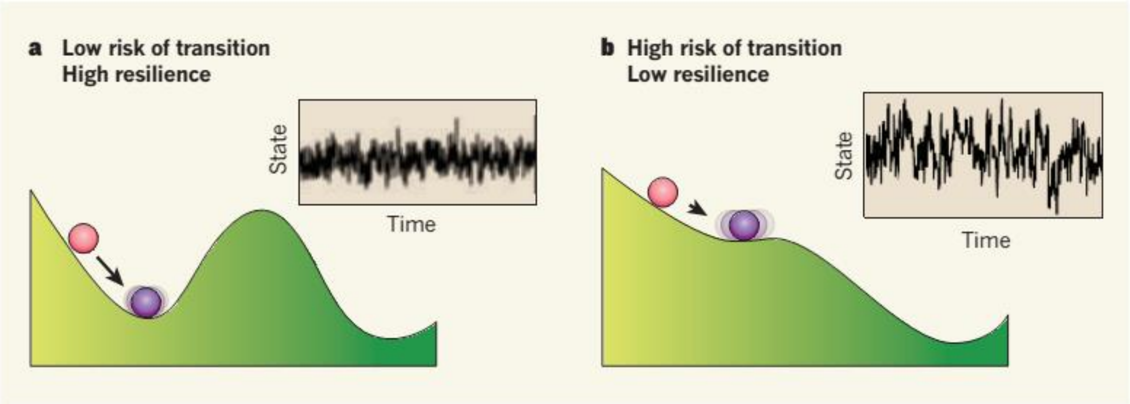
(Scheffer and Carpenter, 2003, TREE)



Species and biomes

- Stable states and Regime shift

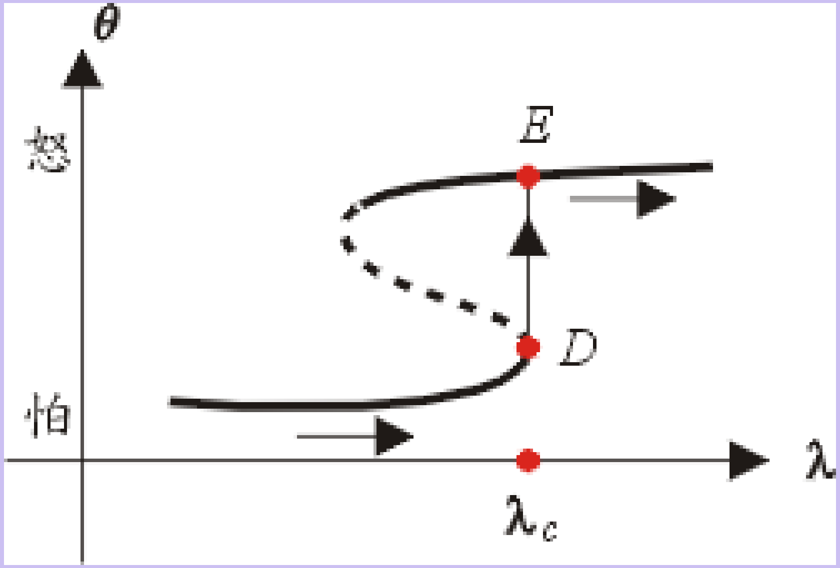




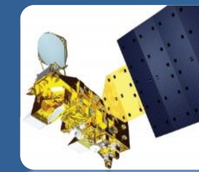
(Scheffer 2010, Nature)

Species and biomes

- Regime shift



(Lin Songshan 2013)

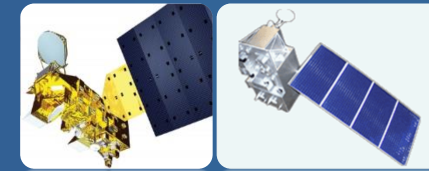



Species and biomes

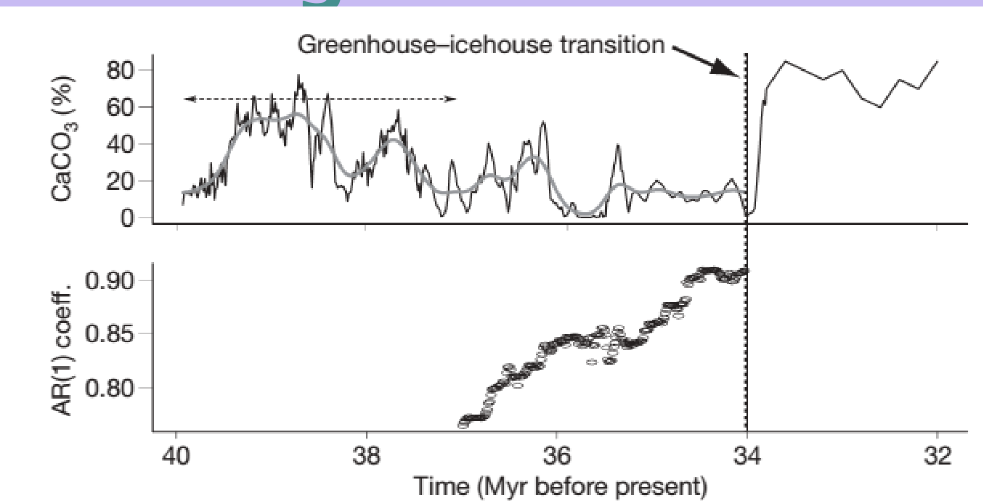
- Regime shift

Early warming indicators

Phenomenon	Method	Signal	References
Critical slowing down	Autocorrelation; Return time	↑	Carpenter et al. 2011
Increased variability	Variance; σ	↑	Drake and Griffen 2010
Skewed responses	Skewness	↑	Biggs et al., 2009
More extremes	Kurtosis	↑	Biggs et al. 2009
Spatial pattern	Qualitative change	regular	Bailey 2011

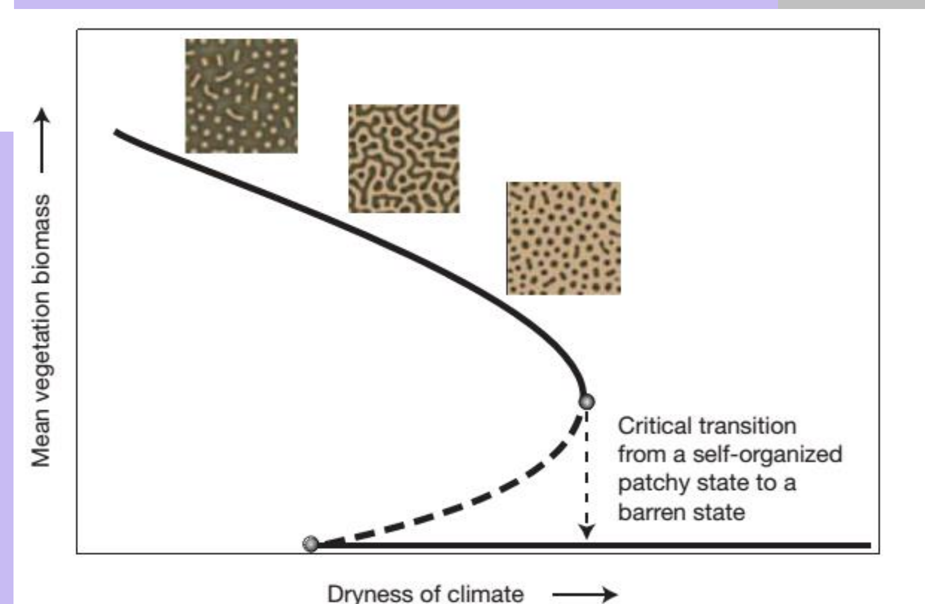


❖ Regime shifts

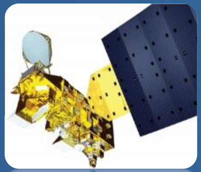


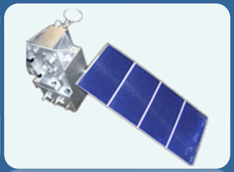
Critical slowing down

Self-organized spatial pattern



(Scheffer et al., 2009, Nature)

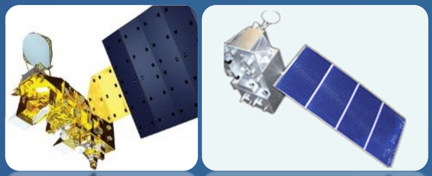




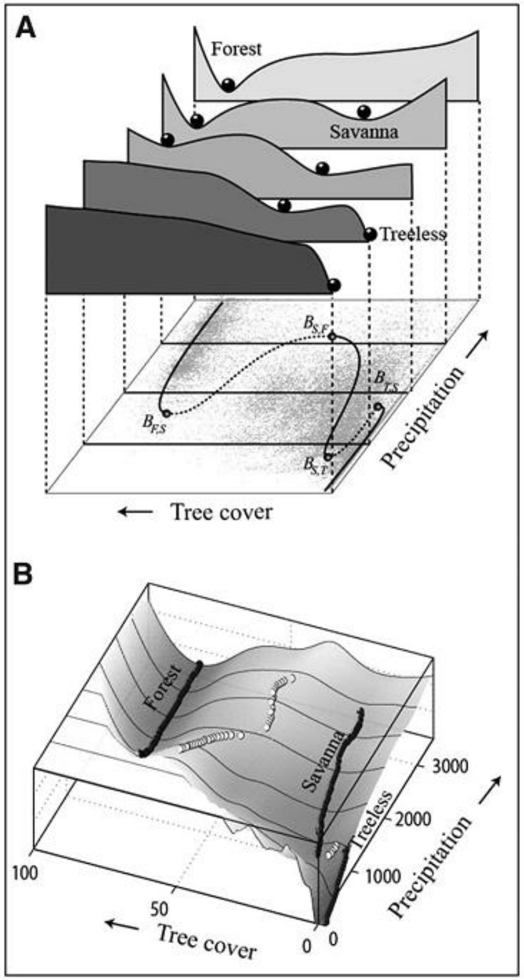
2. Observation of the terrestrial ecosystem

Regime shifts

- Remote sensing approach
  - Prove the existence of early warning signals
  - Prove the existence of the “tipping point”
  - Prove the existence of alternative states



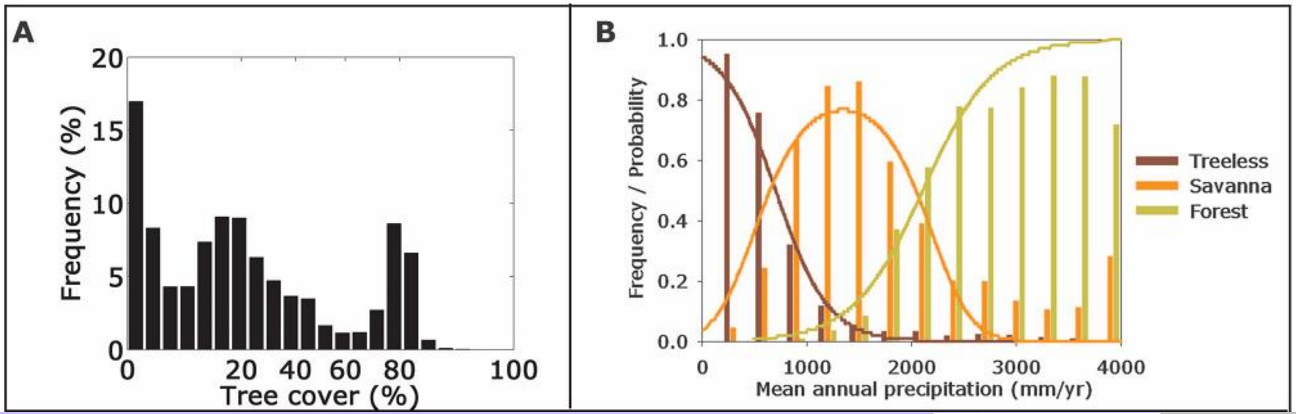
❖ Regime shifts

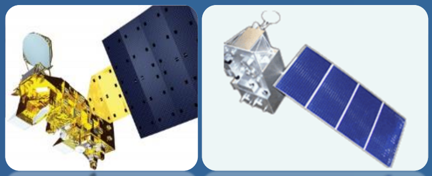


Transition between tropical forest and Savana

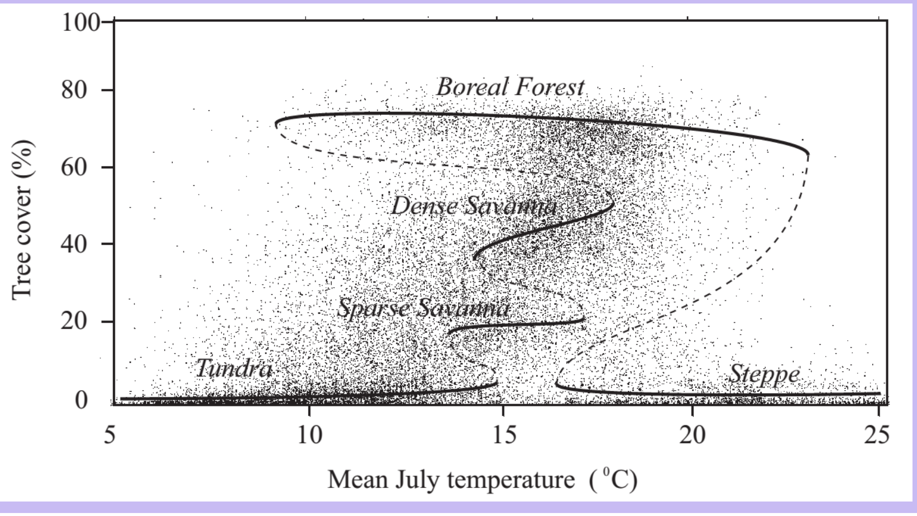
1. Tropical forest and savanna represent alternative stable states
2. Threshold 5%, 60% tree cover
3. Driven by precipitation

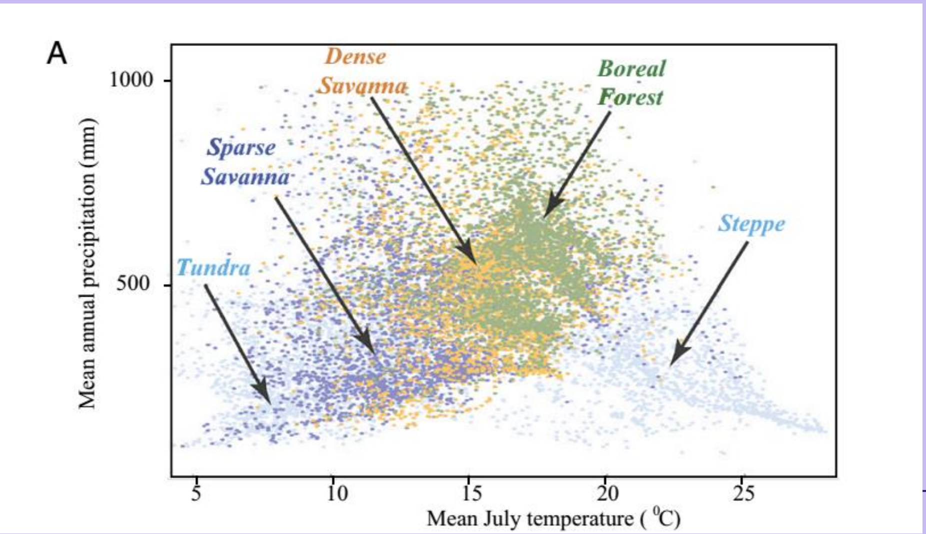
(Hirota et al., 2011, Science)





❖ Regime shifts



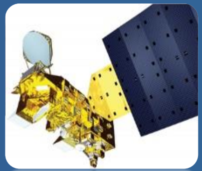


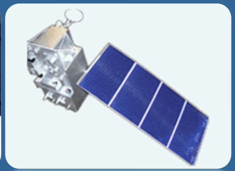
Thresholds for boreal biome transitions

1. Three states, treeless, savanna, and boreal forests
2. Thresholds: 20%, 40%, 75%
3. Driven by temperature and precipitation

(Scheffer et al., 2012, PNAS)

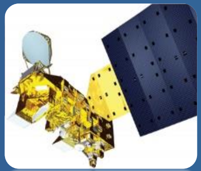
2 Observation of the terrestrial ecosystem

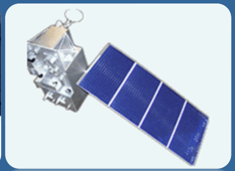




❖ Regime shifts

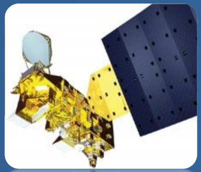
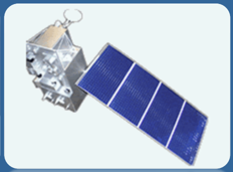
- Remote sensing approach
  - 1. Get MODIS tree canopy cover data (MOD44B)
  - 2. Extract a random samples of pixels
  - 3. Analysis of multimodality of the tree cover frequency distribution using latent class analysis
  - 4. Build the correlation with precipitation and/or temprature





Regime shifts

- Future research
  - Find the mechanisms that drive the changes
  - Identify the character and timing of the transition
  - Answer the question: whether the vegetation-climate system has alternative stable states?

3 Integration with climate models

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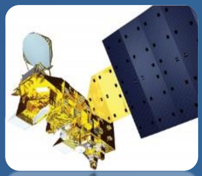
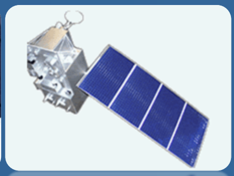




Input of climate models

- Provide boundary conditions
- Reinitialize models
- Update the state variables
- Provide constrains

3 Integration with climate models

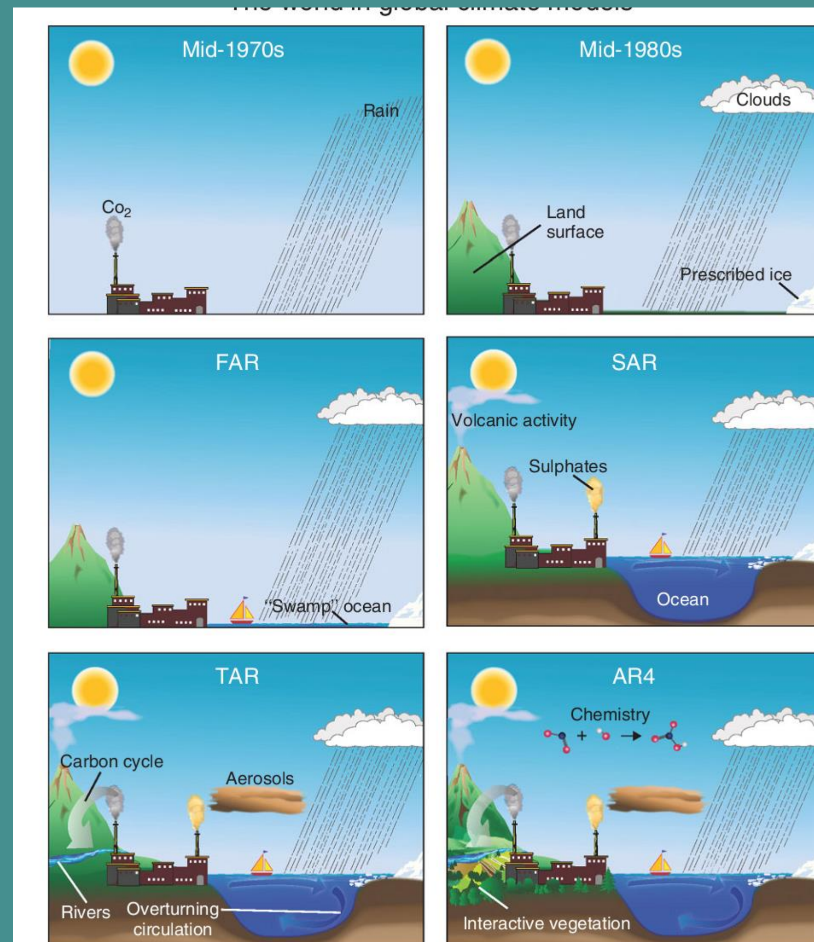
Homogeneous land cover

↓

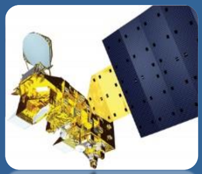
Dynamic vegetation model

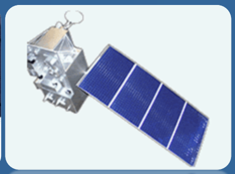
↓

Dynamic vegetation model with disturbances



3 Integration with climate models

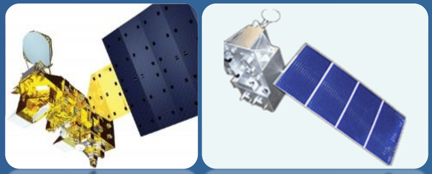




Improve climate models

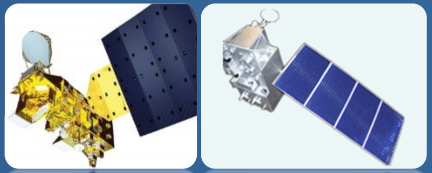
- Improve the accuracy of model predictions
    - Data assimilation: adjustment of the model state at observation times with measurements of a predictable uncertainties
    - Statistical linear estimation and ensemble assimilation
    - E.g., Land surface models+operational data assimilation schemes→ lowered RMSE (27.4-32.2%) *(Ghent et al., 2010, JGR-Atmosphere)*

3 Integration with climate models



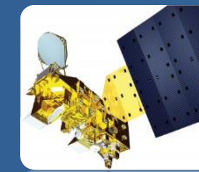
- **Validate/calibrate climate models**
  - Compared to the GCM’s outputs directly
  - Combine with in situ measurements

3. Integration with climate models



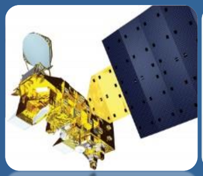
Problems

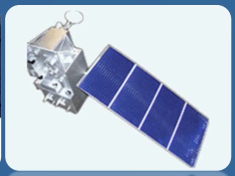
- Spatio-temporal mismatching
- Lack of interfaces in climate models
- Changing mix of observations over time



4 Limitations

4. Limitations





- Short data spans of satellite data
- Biases associated with instrument
- Uncertainties in retrieval algorithms

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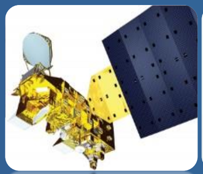
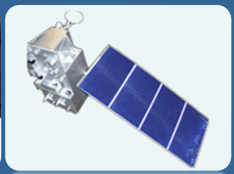
4 Limitations

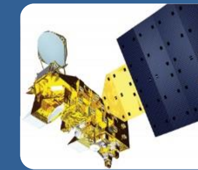
❖ Short data spans of satellite data

Time length of available observations

Time length (year)	Terrestrial ECV
0~9	Biomass, Glacier and ice caps
10~19	Land cover, Albedo, fAPAR, Fire disturbance
20~29	Lakes, LAI
30~39	Soil moisture
40~49	Snow cover

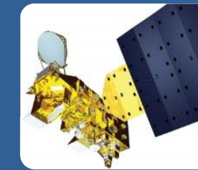
Yang et al. 2013, *Nature Climate Change*

4 Limitations




- **Biases associated with instrument**
  - Inadequate spatial resolution and temporal frequency
  - Poor calibrations
  - Merging data from different systems

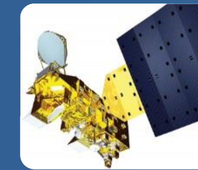
4 Limitations



- **Uncertainties in retrieval algorithms**
  - Radiative transfer models
  - Uncertainties in common inputs

5 Prospects

5 Prospects



Improvements in

- Future works
  - Intercomparison of data sets
  - Innovative use of existing data
  - Rigorous reanalysis
- Future systems
  - Dedicated satellite missions
  - Combine passive and active remote sensing
  - High-quality validation networks