Measurements on the ground are the key!
Remote sensing alone - will not do it!

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Outline

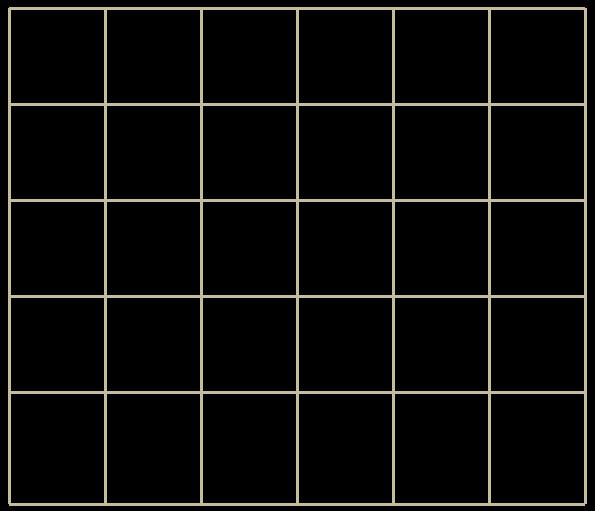
- Background
- Ground inventories
  - sampling for change in tropical forests
  - advantages/disadvantages of ground inventories
- Remote sensing-based inventories
  - GOFC-GOLD/IPCC GPG recommendations
  - sensor considerations
  - ground data considerations
  - bias and precision
  - advantages/disadvantages
- Summary and Conclusions

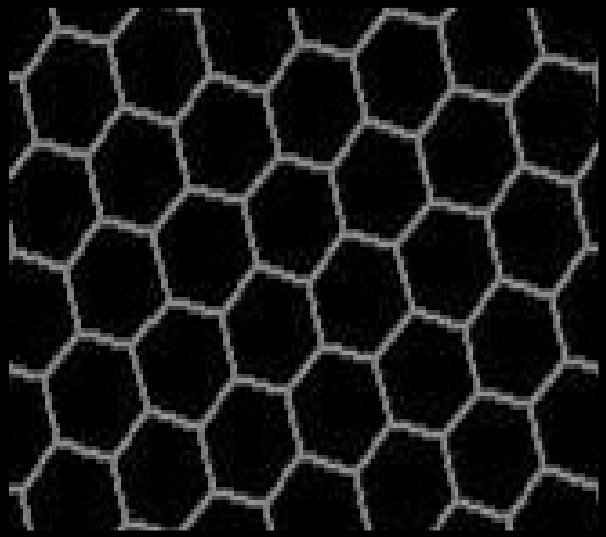
Background

- Definitions (GOFC-GOLD Sourcebook)
  - Deforestation:
    - *permanent conversion of land from forest to non-forest use*
    - *depends on definition of forest (area)*
  - Degradation:
    - *anthropogenic net emissions caused by a decrease in crown canopy cover/biomass*
    - *how much of a decrease?*

- **Ground sampling**
  - focus on:
    - tropical forests
    - change estimation (deforestation, degradation)
  - advantages/disadvantages

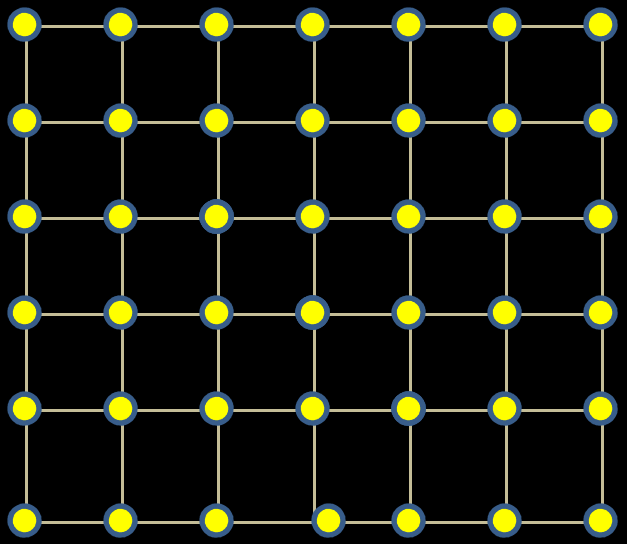
- **Sampling designs**
  - Spatial balance
    - grid-based or polygon-based

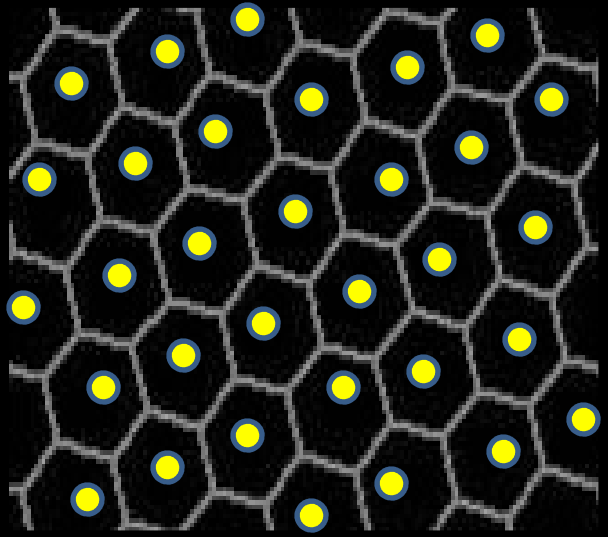




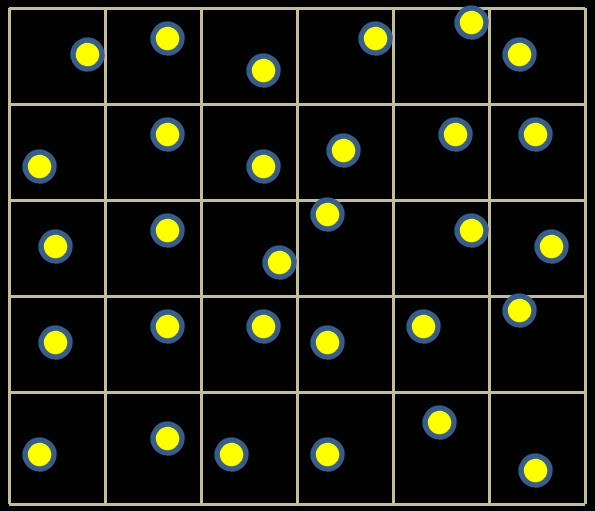
- **Sampling designs**
  - Spatial balance
    - grid-based or polygon-based
    - spatially aligned or unaligned

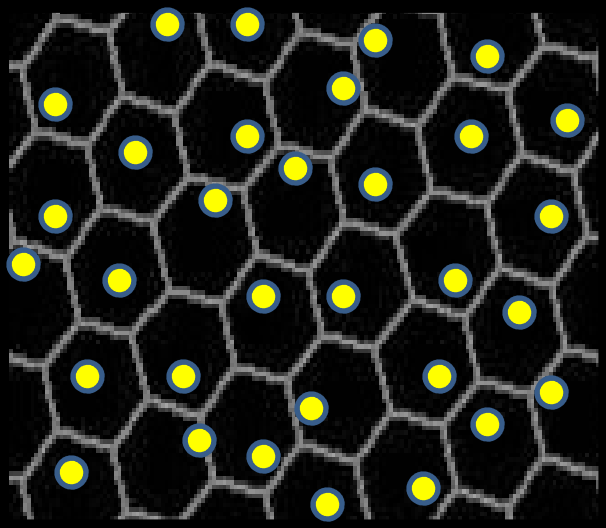
Spatially aligned





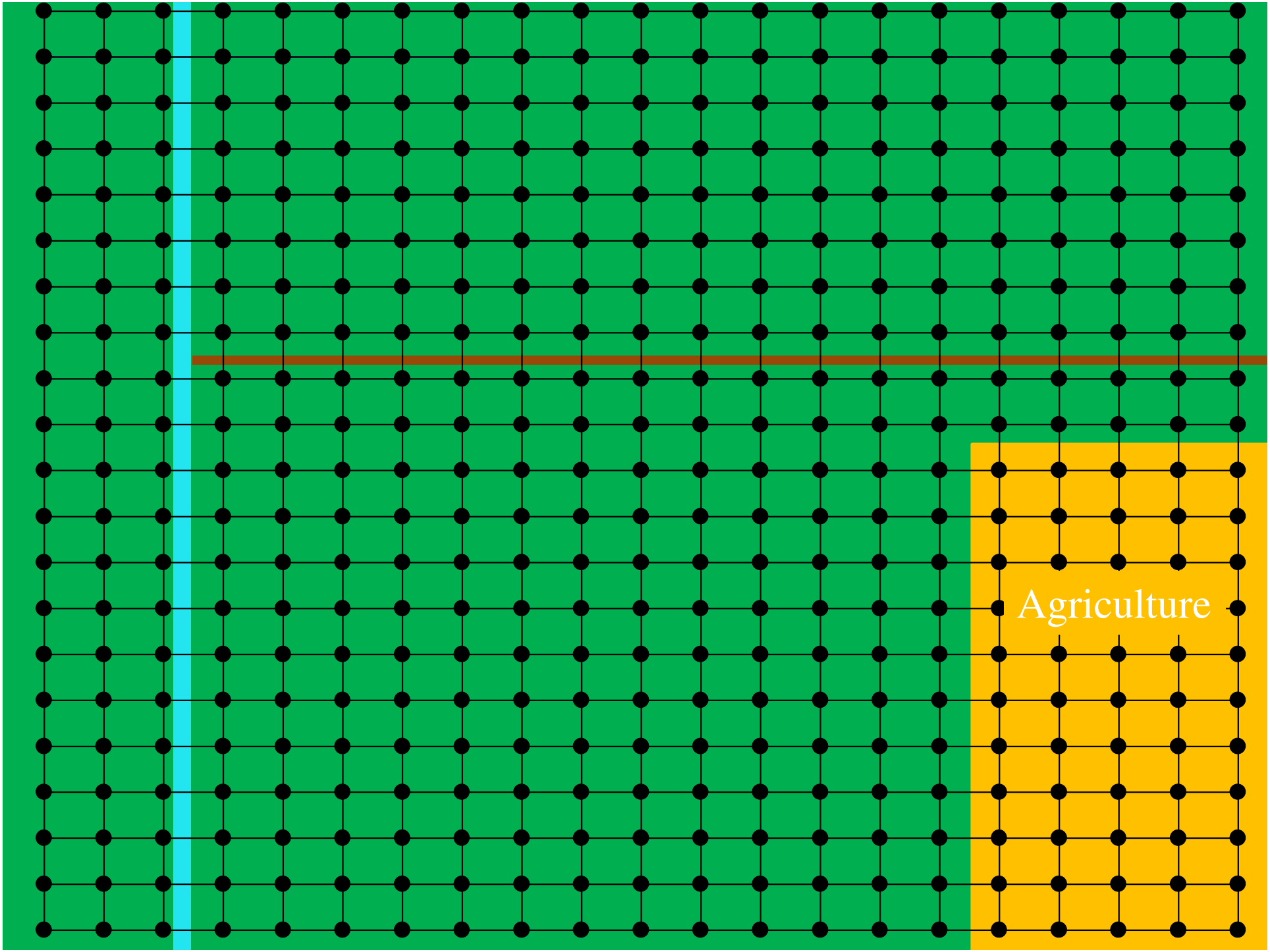
Spatially unaligned

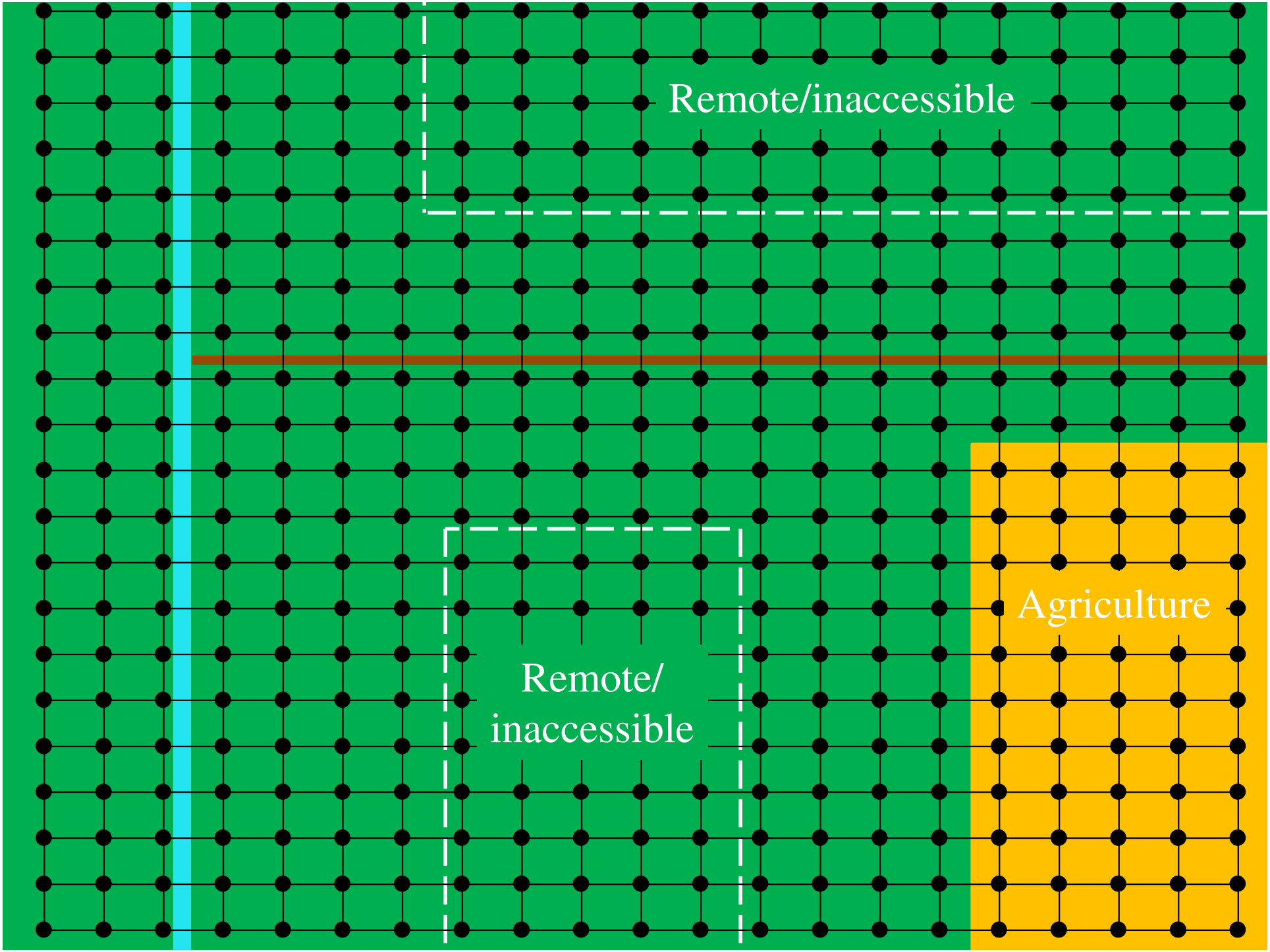


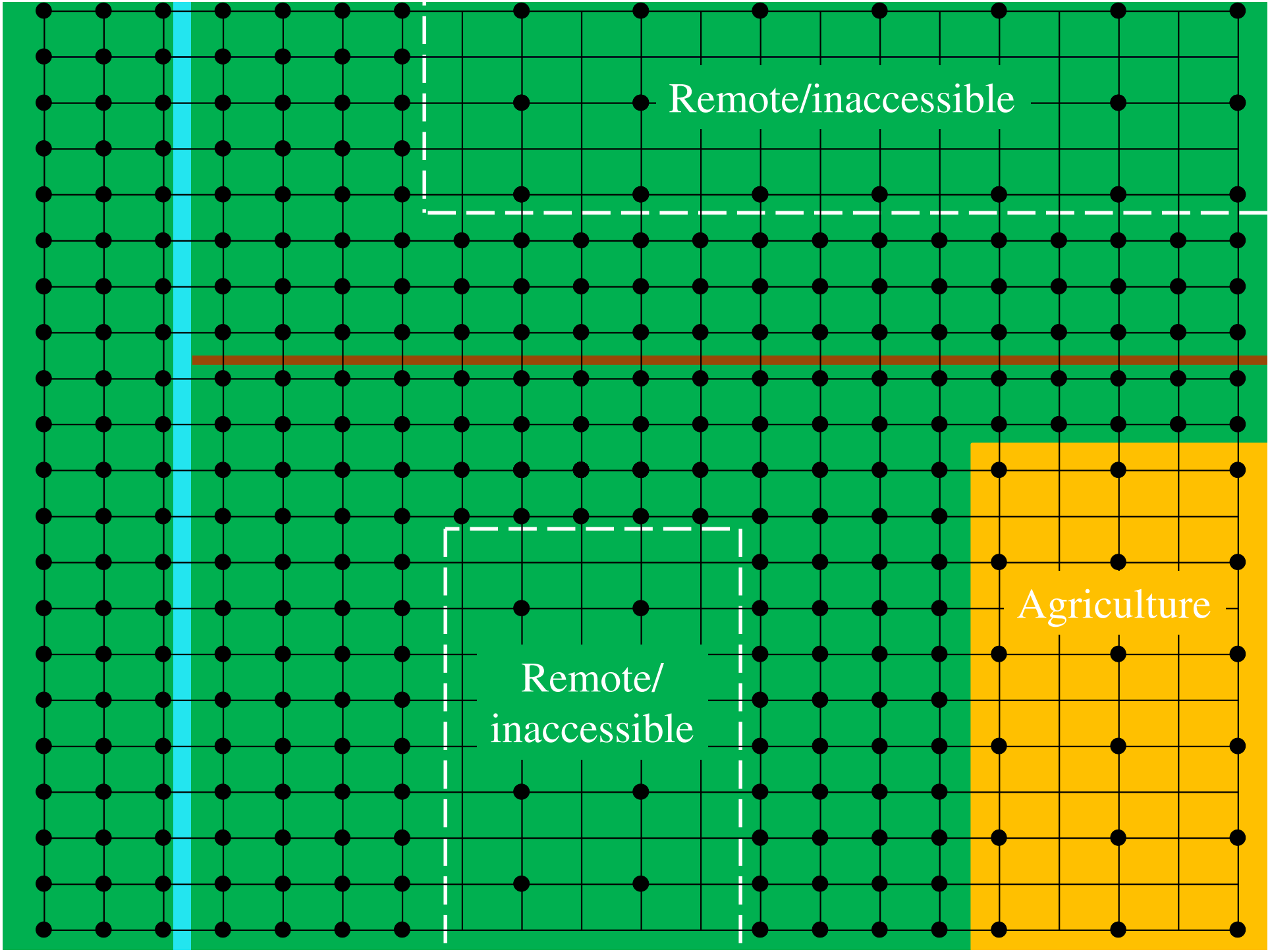


- **Sampling designs**
  - Spatial balance
    - grid-based or polygon-based
    - spatially aligned or unaligned
  - Stratification
    - vary sampling intensities


Agriculture


Agriculture


Remote/inaccessible
Agriculture
Remote/
inaccessible


Remote/inaccessible
Agriculture
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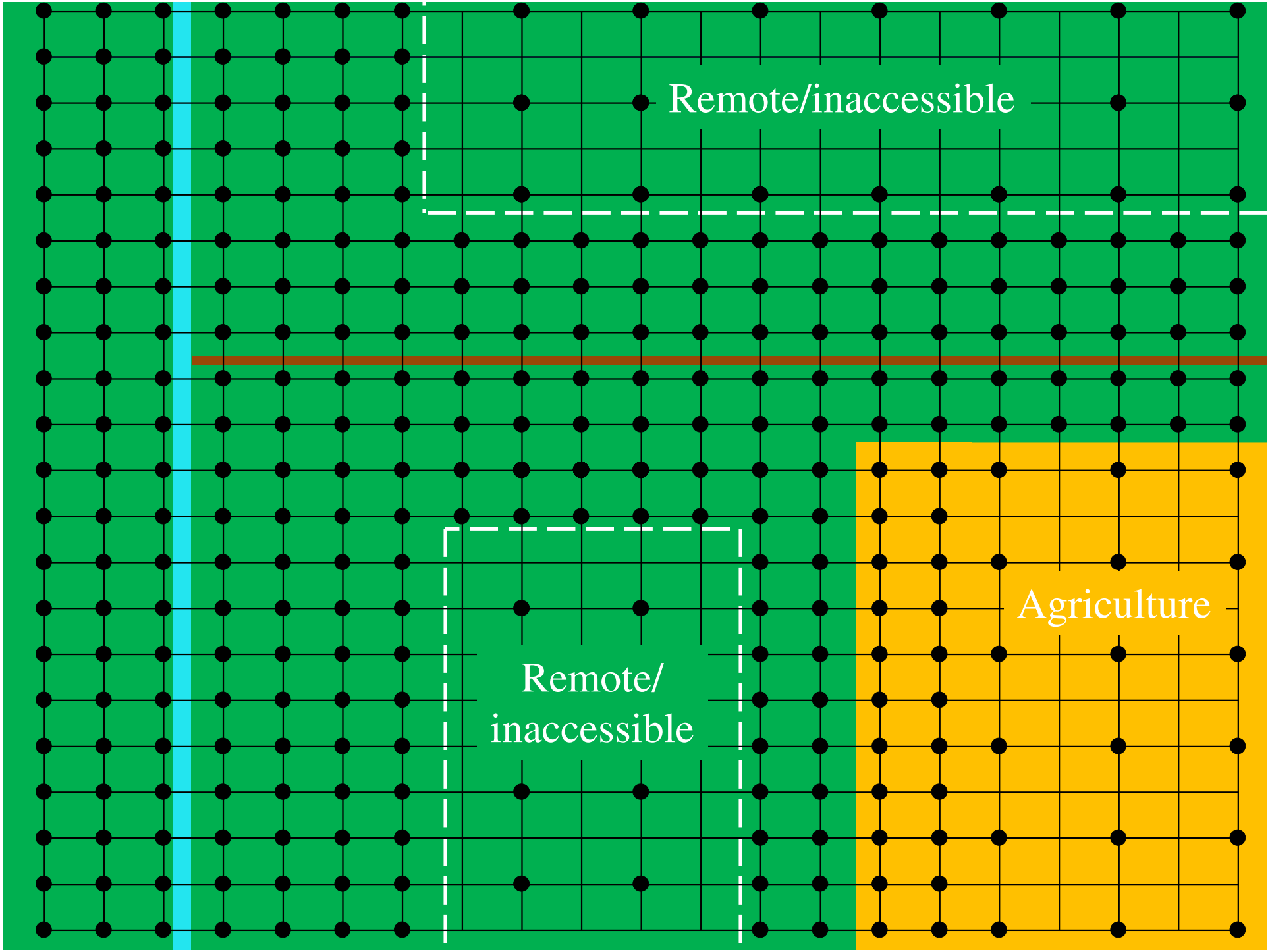
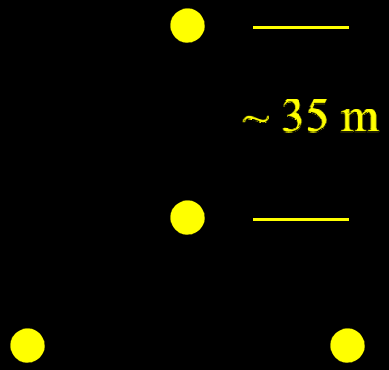
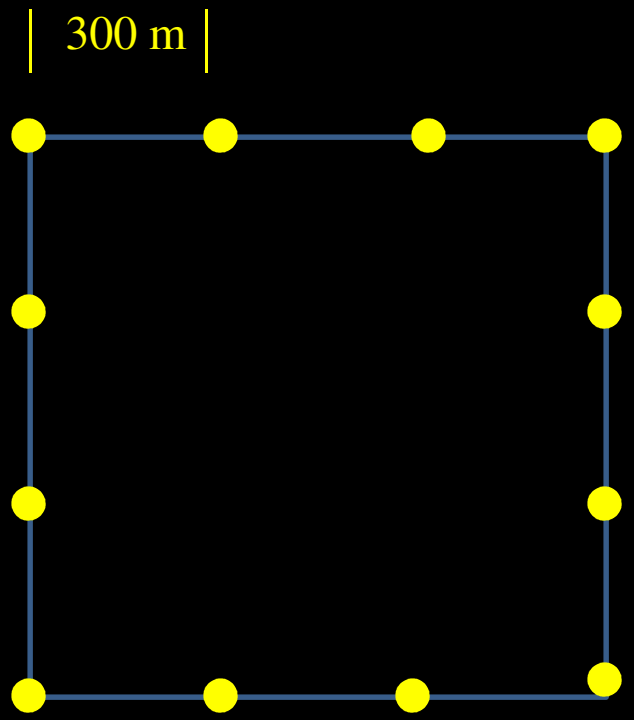

Remote/inaccessible
Agriculture
Remote/
inaccessible

- **Plot configurations**
  - Clustering
    - greatest cost of measuring a plot is travel

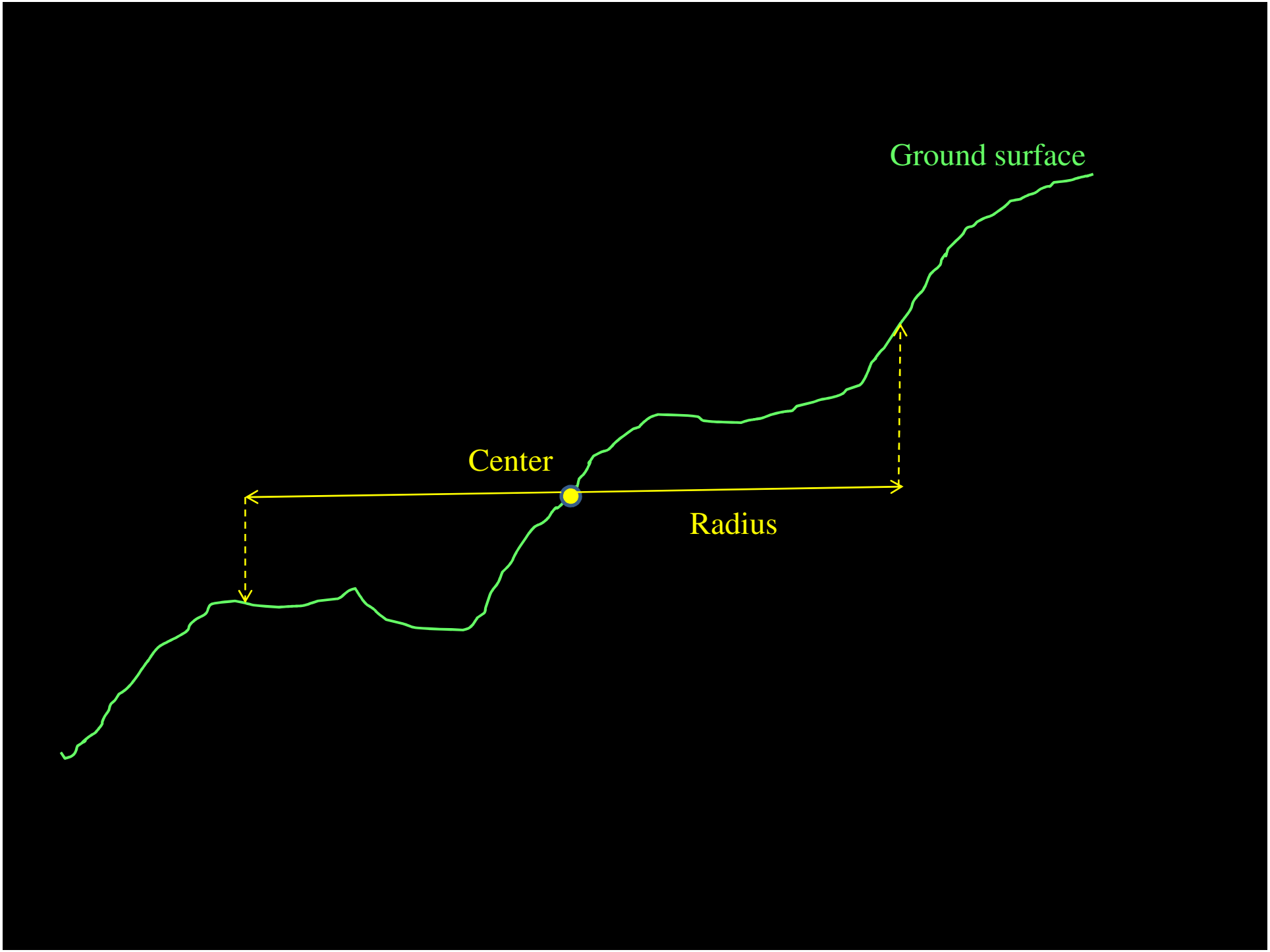


American subplots

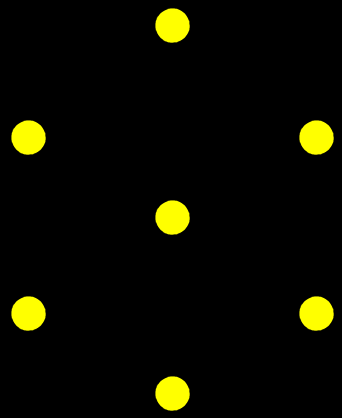


Finnish plot cluster

- **Plot configurations**
  - Clustering
    - greatest cost of measuring a plot is travel
  - Size
    - topography → smaller


Ground surface
Center
Radius

- **Plot characteristics**
  - Clustering
    - greatest cost of measuring a plot is travel
  - Size
    - topography → smaller
    - tree density → smaller
    - diversity → larger cluster area
      smaller plots & more plots per cluster?



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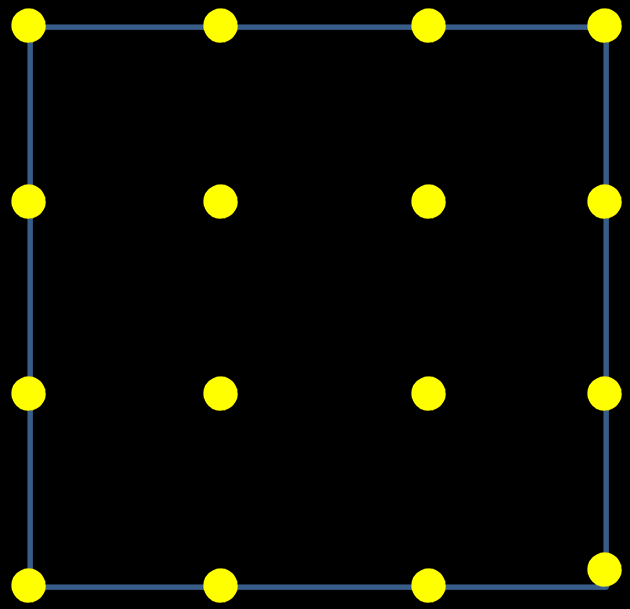


Finnish plot cluster

- **Plot characteristics**
  - Clustering
    - greatest cost of measuring a plot is travel
  - Size
    - topography → smaller
    - tree density → smaller
    - diversity → larger
  - Change
    - large proportion of permanent plots

Ground sampling design and plot configuration recommendations

- Spatial balance → systematic component
- Stratification
  - allocation to vary sampling intensities
- Plot configuration
  - cluster sampling
  - relatively small, nested plots
  - large proportion of permanent plots

Ground inventories

- Advantages
  - We know how to do it !!!
- Disadvantages
  - Small sample sizes for remote, inaccessible regions
  - No maps

- **Remote sensing-based inventories**
  - GOFC-GOLD/IPCC GPG recommendations
  - sensor considerations
  - bias and precision
  - advantages/disadvantages

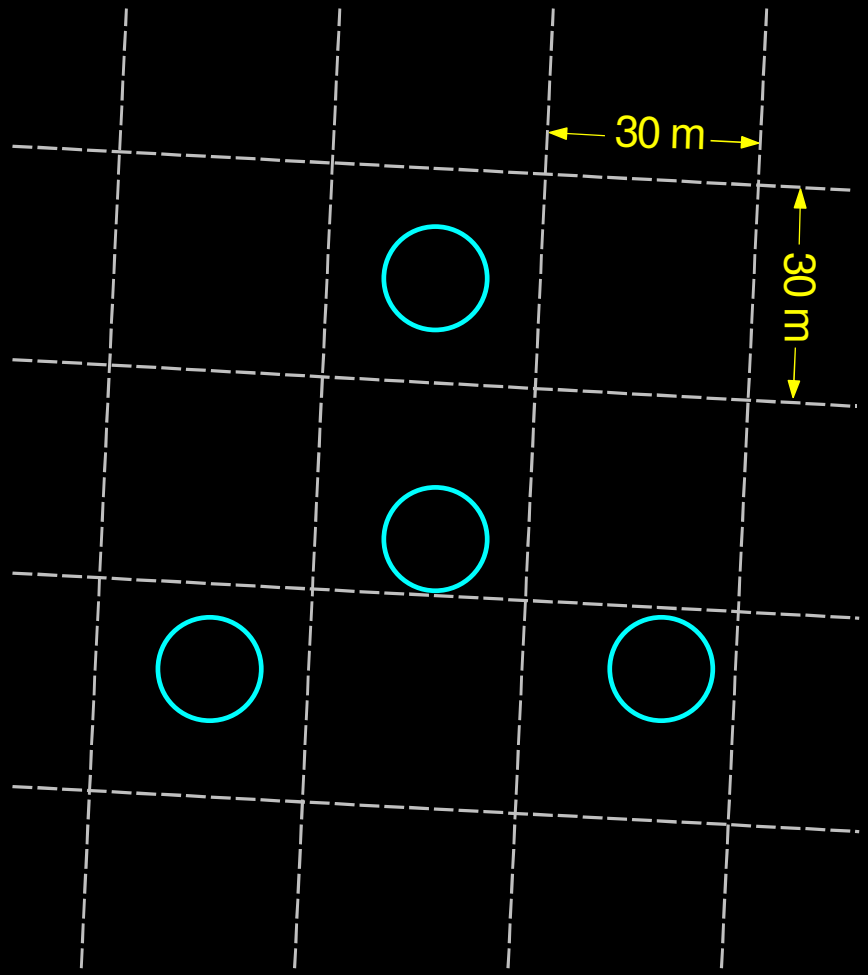
GOFC/GOLD & IPCC GPG recommendations

- Use Landsat
  - cloud cover ???
- Supervised classification
  - requires reference data !!!
- Automated classification
  - promotes consistency
- Supported by ground observations
  - suggests integrated approach

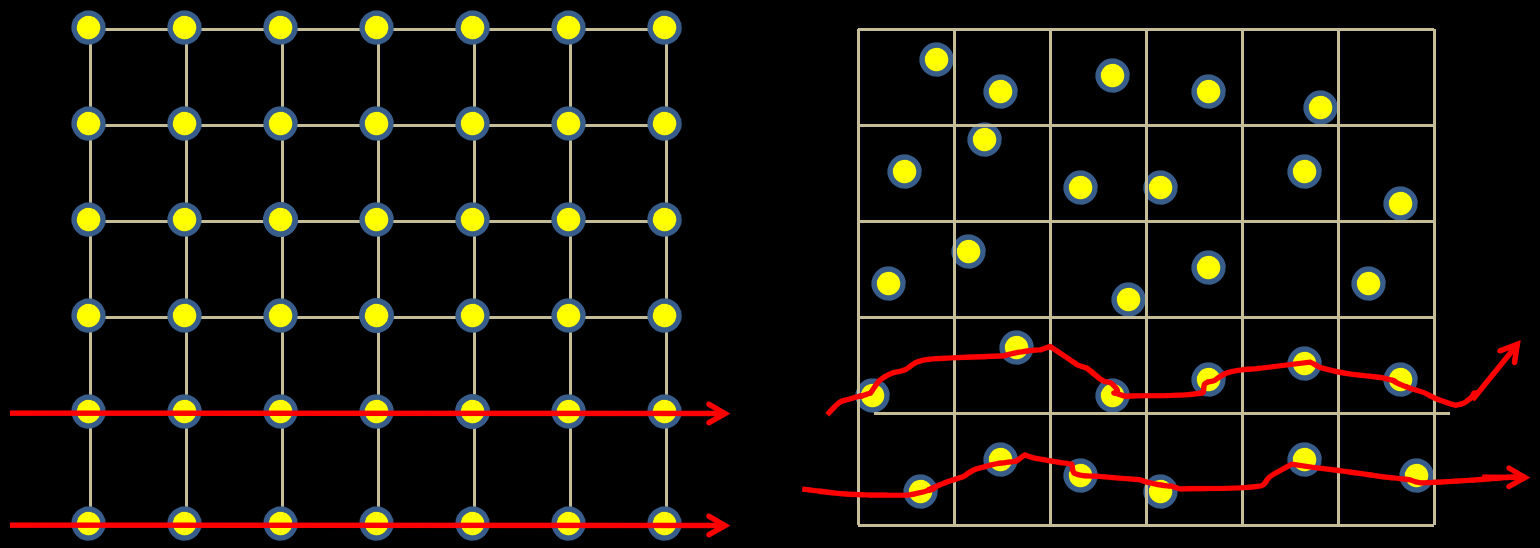
Integrating ground and remote sensing inventories

Landsat TM pixels and American inventory plot configuration

Are subplots adequate samples of pixels?



Integrating ground and remote sensing inventories



Spatially aligned

Spatially unaligned

Which alignment facilitates acquisition
of lidar data from an airborne platform?

GOFC/GOLD & IPCC GPG recommendations

- Use Landsat
  - cloud cover ???
- Supervised classification
  - requires reference data !!!
- Automated classification
  - promotes consistency
- Supported by ground observations
  - suggests integrated approach

- Remote sensing
  - GOFC-GOLD/IPCC GPG recommendations
  - sensor considerations

- **Sensor considerations**
  - cloud cover
    - short repeat cycle length
    - cloud penetration
  - change estimation
    - resolution comparable to deforestation size
    - canopy penetration for degradation
  - inexpensive

Sensor considerations

Optical (passive) sensors

Sensor	Resolution	Repeat cycle	Cost
SPOT	8-m x 8-m	2-3 days	High
Landsat	30-m x 30-m	16 days	Free
MODIS	250-m x 250-m	1-2 days	Free

Active sensors

Scanning lidar:

- active component: laser (light)
- airborne platforms
- minimal cloud penetration
- penetrates forest canopy
- costly

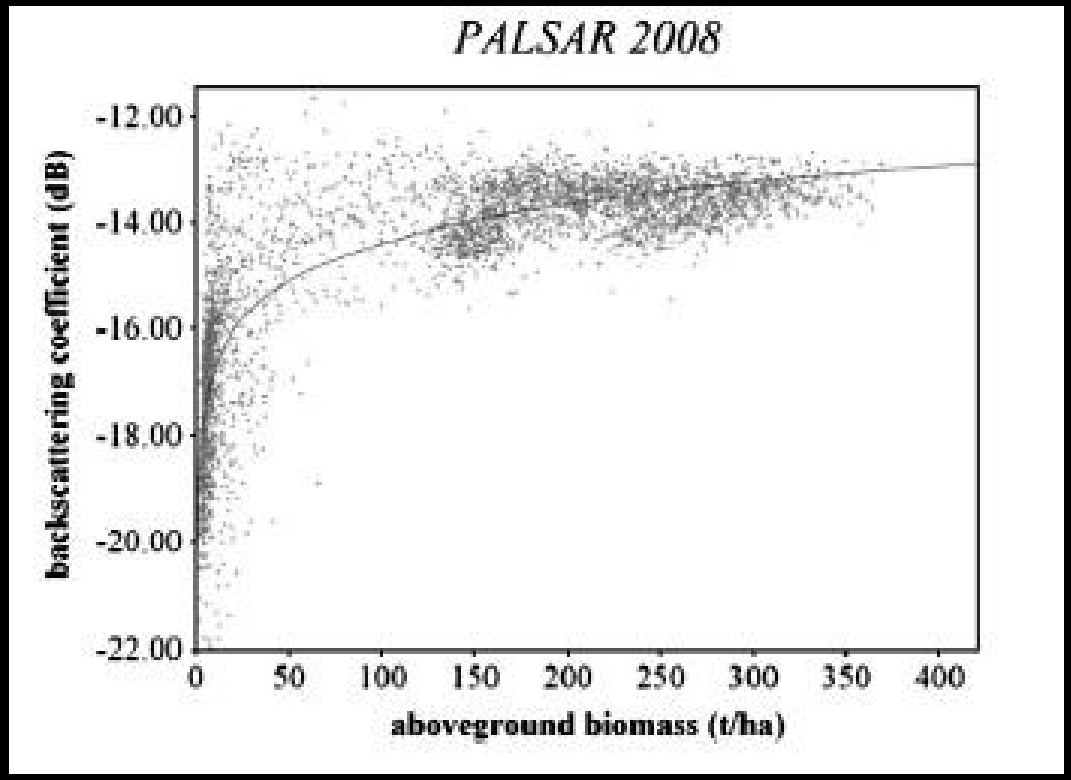
Synthetic aperture radar:

- active component: microwave
- airborne platforms
- all weather, all day/night
- penetrates forest canopy
- costly

- **Sensor considerations**
  - cloud cover
    - short repeat cycle length
    - cloud penetration
  - change estimation
    - resolution comparable to deforestation size
    - canopy penetration for degradation
  - inexpensive
  - saturation

Saturation:

To some degree, all remote sensors experience biomass saturation, i.e., biomass levels greater than some limit cannot be distinguished .



Englhart et al. 2011. Rem. Sens. Env.

- **Sensor considerations**
  - cloud cover
    - short repeat cycle length
    - cloud penetration
  - change estimation
    - resolution comparable to deforestation size
    - canopy penetration for degradation
  - inexpensive
  - saturation
  - combining plot and remotely sensed data

Co-registration:

When combining data from multiple sources such as ground plots and remote sensor, correct registration of the multiple coordinates systems to each other is crucial.

Requires high quality GPS receivers

- Remote sensing
  - GOFC-GOLD/IPCC GPG recommendations
  - sensor considerations
  - accuracy assessment: bias and precision

Error/Confusion Matrix

		Predicted class			Total	Producer's accuracy
		No chg	F→NF	NF→F		
Observed class	No chg	75	1	8	84	0.90
	F → N F	2	5	1	8	0.63
	NF→F	1	1	6	8	0.75
Total		78	7	15	100	
User's accuracy		0.96	0.71	0.40	OA=0.86	

Should the donor pay?

- Suppose:
  - Agreed limit is 5% deforestation
  - From classification, $\hat{p}_{F \rightarrow NF} = 0.045$
- However, from error matrix:
  - 7/100 predicted to be F→NF
  - 8/100 observed to be F→NF
  - bias estimate is -0.01 $\Rightarrow \hat{p}^{adj}_{F \rightarrow NF} = 0.045 + 0.01 = 0.055$
  - Is 0.055 statistically significantly greater than 0.05?
    Need a confidence interval and, in turn, a variance estimate
- Conclusions:
  - An error matrix by itself is not sufficient
  - **Need good accuracy assessment data!!**

- Remote sensing
  - GOFC-GOLD/IPCC GPG recommendations
  - sensor considerations
  - accuracy assessment: bias and precision
  - advantages/disadvantages

Remote sensing-based inventories

- Advantages
  - Spatial coverage
  - Maps
- Disadvantages
  - Data acquisition
    - clouds (Landsat/SPOT)
    - cost (lidar)

Remote sensing-based inventories

- Disadvantages (continued)

We do not have much experience!

  - Matching definitions of deforestation and degradation to sensor capabilities

  - Integrating ground and remotely sensed data acquisition
    - adequacy (pixel/plot sizes)
    - efficiency (flight lines),
    - training and accuracy assessment data

  - Bias and precision estimation

Why ground data are the key

- Selection of deforestation and degradation thresholds require ground data assessments to determine levels that remote sensing can detect
- Supervised classification requires training data
- Bias and precision estimation require accuracy assessment data

Summary/Conclusions

- Ground inventories
  - Can deal with any threshold for deforestation and degradation
  - We have considerable experience
  - Sample sizes will be too small for remote and inaccessible regions
- Remote sensing
  - Complete coverage
  - We can do it, but efficiency and precision are unknown
  - We have no other choice for remote and inaccessible regions
- Solutions
  - Learn fast!
  - Exploit what we know and can do well (ground inventories)