New developments for improved carbon flux estimation by remote sensing

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Contents

- Spatial heteorgeneity and carbon modeling
- New vegetation index: Plant Phenology Index (PPI)
- Data modeling by spatio-temporal filtering

COST OPTIMISE Workshop, Madrid, 30 Mar.-1 Apr. 2015

Managing the gap between flux towers and global modeling

Flux tower infrastructure

Fluxnet, ICOS, etc.

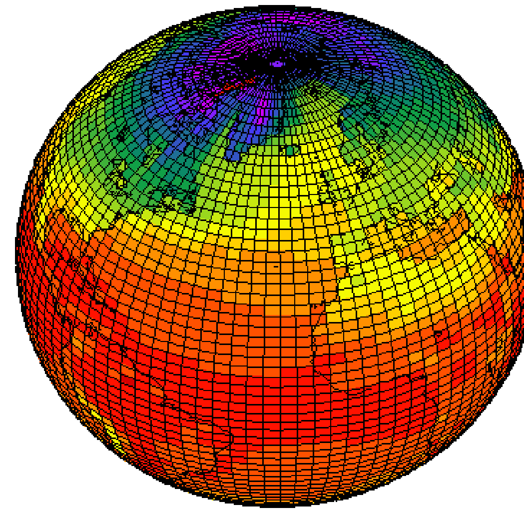
Norunda ICOS flux tower

Source: www.necc.nu

Bridge the gap

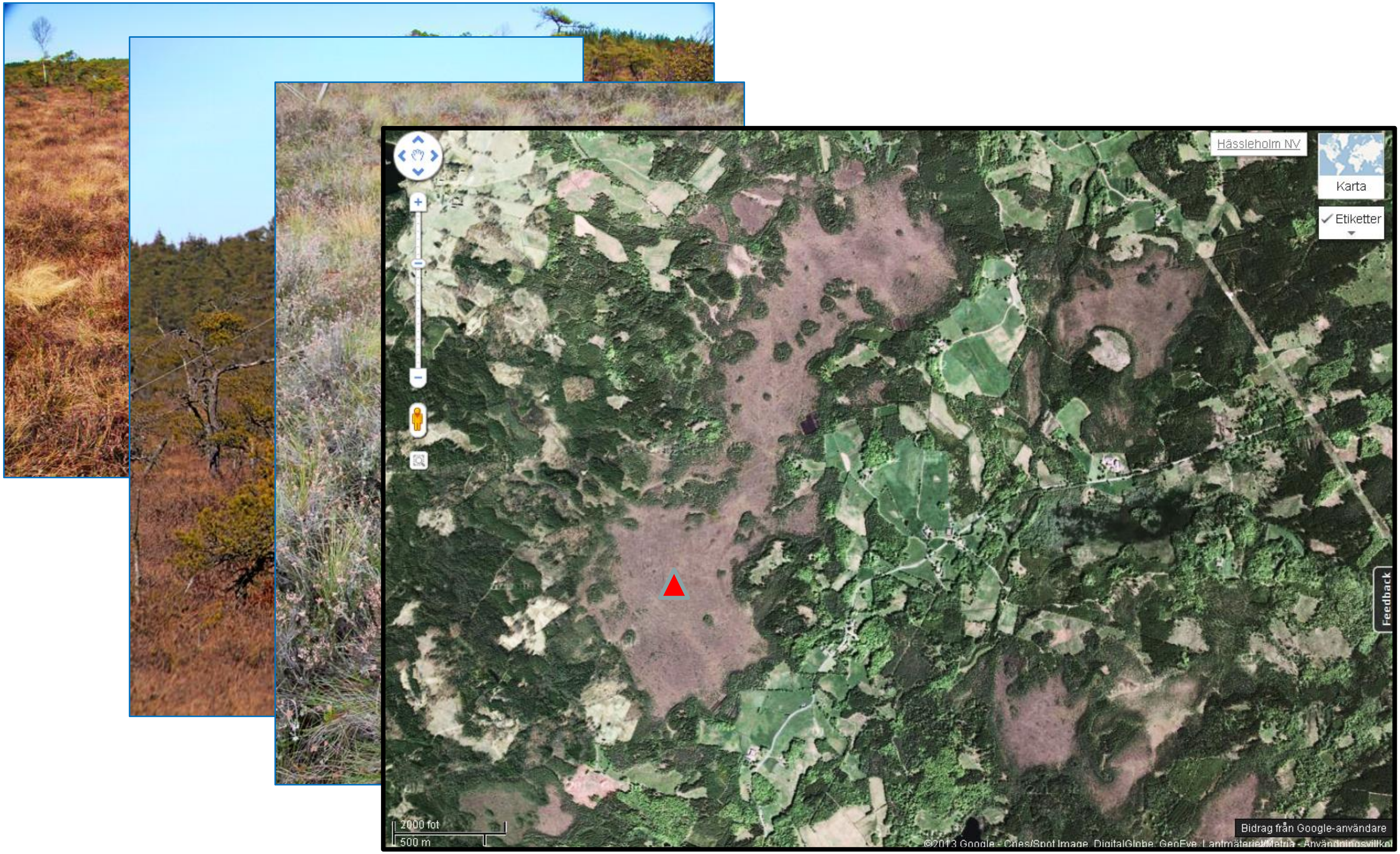
SPOT satellite image 2010-06-28. Source: Lantmäteriet / Saccess

Carbon Cycle Data Assimilation Models (CCDAS)



Source: http://www.geos.ed.ac.uk

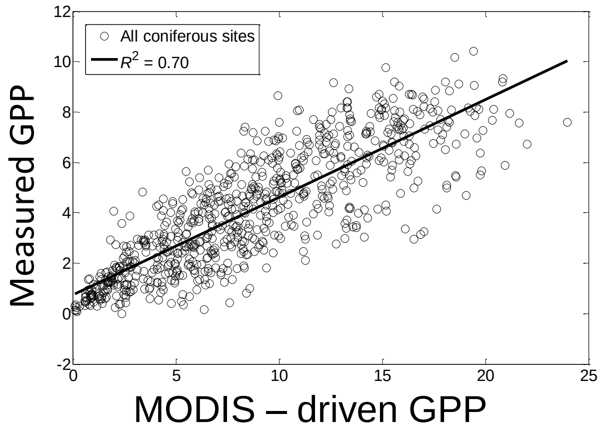
From the tower to global carbon modeling



Area represents < 3 % of a 0.25° x 0.25° modeling grid cell

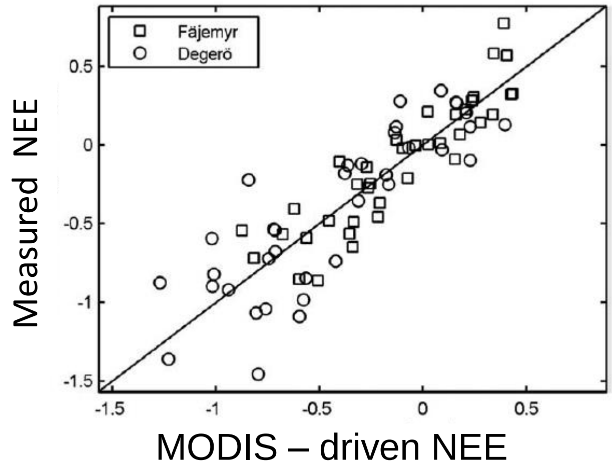
Temporal satellite data can mimick carbon variations

GPP of boreal forest stands



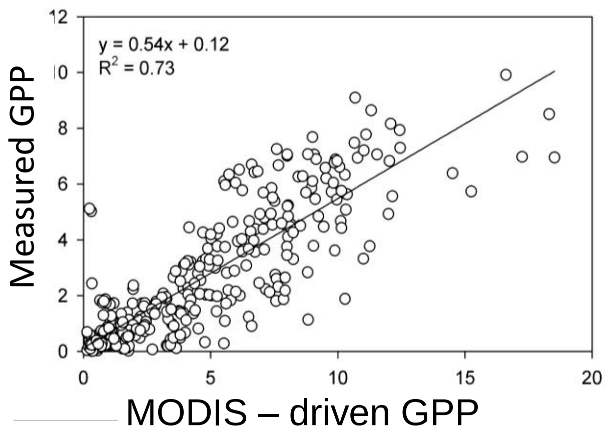
Schubert et al. , 2012, *Rem Sens Env., 126.*

NEE of two peatlands



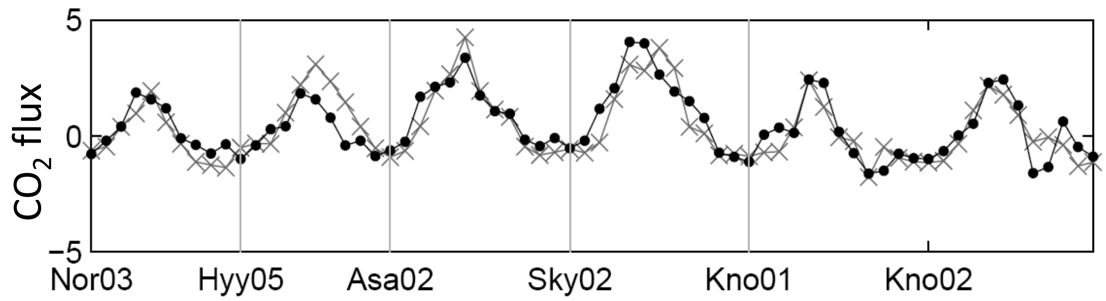
Schubert et al. , 2010, *Rem. Sens. Env.*, 114.

GPP of African drylands



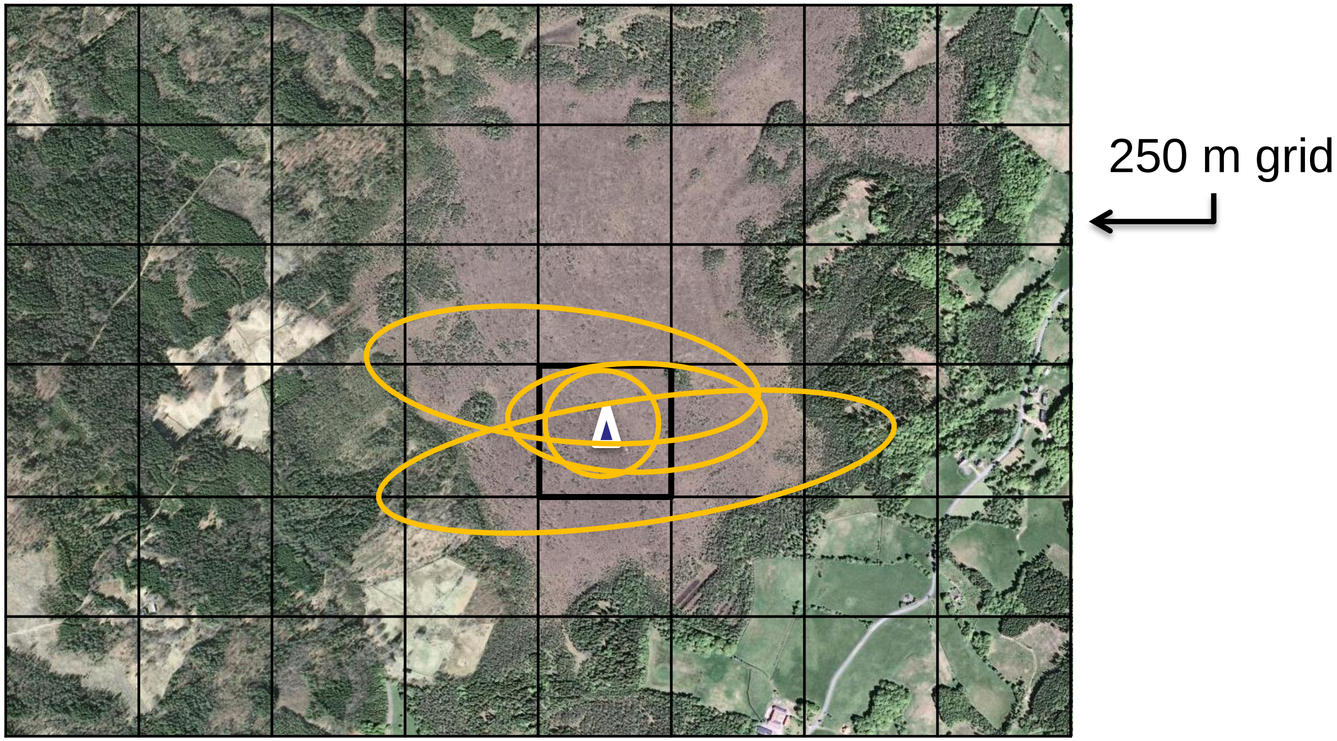
Sjöström et al., 2009, *Biogeosciences*, 6.
Sjöström et al., 2011, *Rem Sens Env*, 115.

Seasonal forest NEE



Olofsson et al., 2008, *Biogeosciences*, 5.

Coarse resolution satellite geometric uncertainty



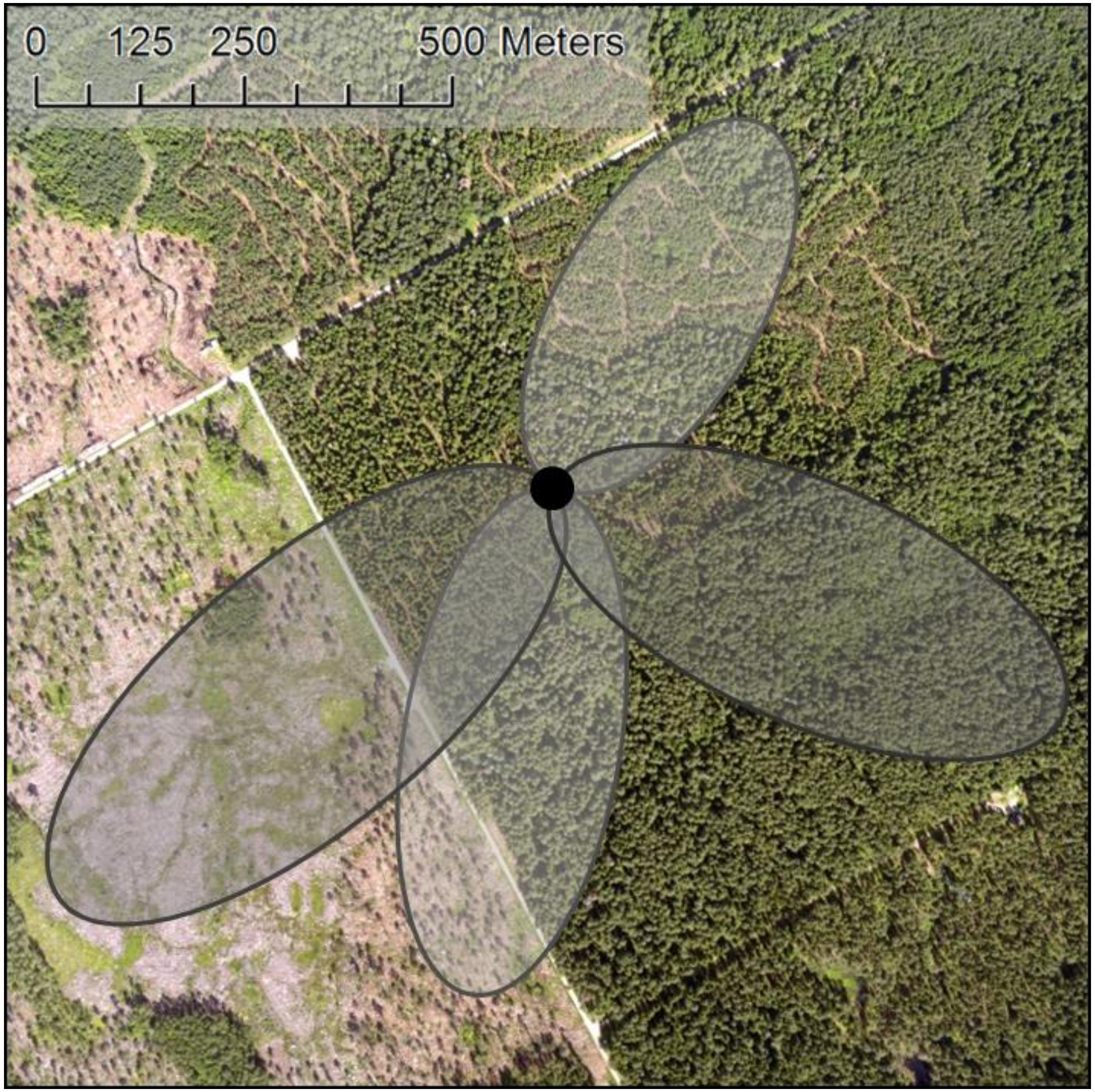
(Note: simulated data…)

Map: hitta.se

Most important other problems:

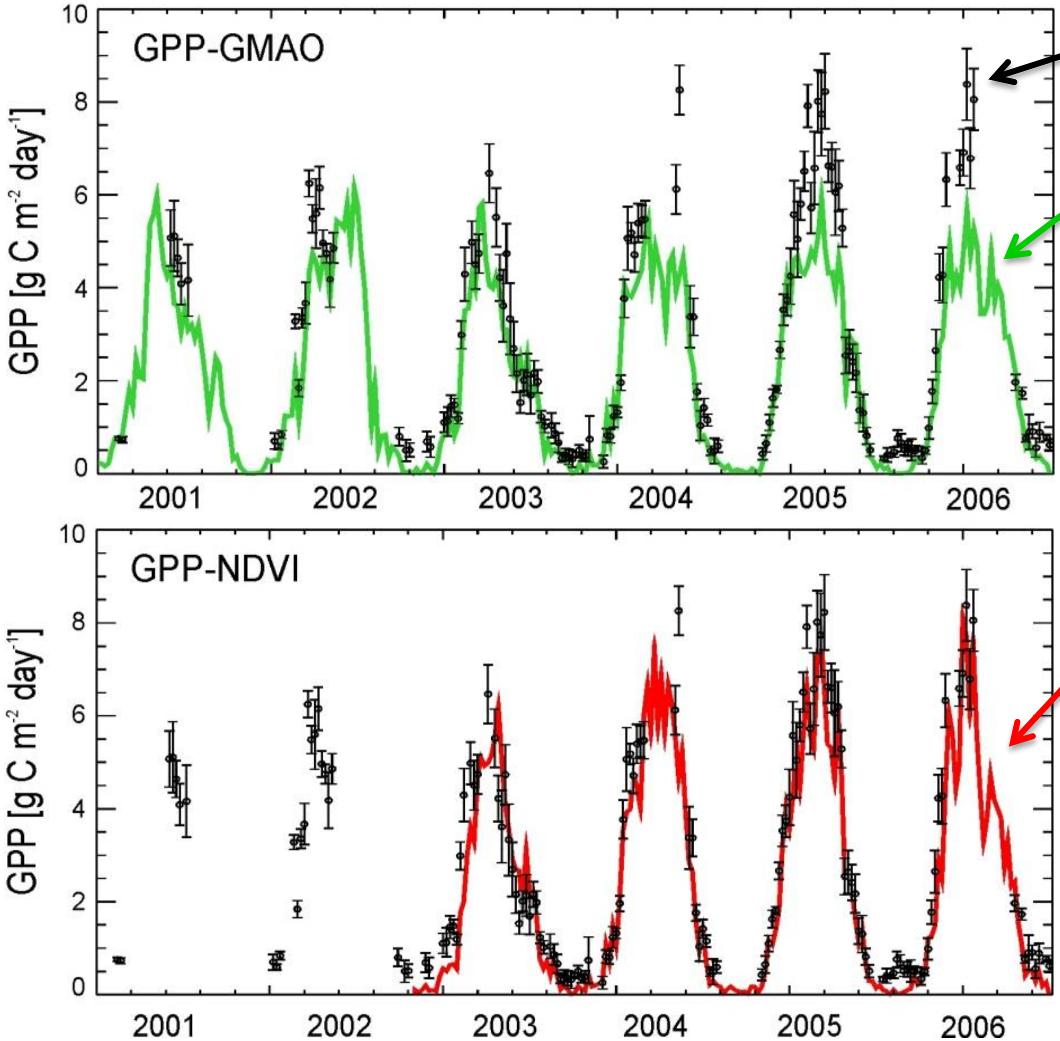
- Clouds
- Atmospheric disturbances
- Angular effects
- Uncertainty of target processes

Flux footprint variations



Half-hour flux footprints from the ICOS Norunda mast (black dot)
Credit: Natascha Kljun

Matching tall tower GPP with footprint-derived NDVI



Tower GPP

MODIS GPP global standard product, 1 km resolution, RMSE = 1.13

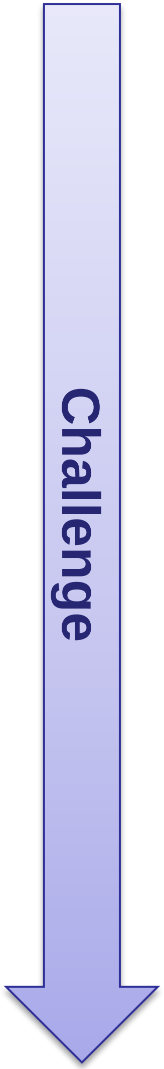
GPP from MODIS NDVI and footprint weighting, 250 m resolution, RMSE = 0.82

2004-2006 wetter and cooler

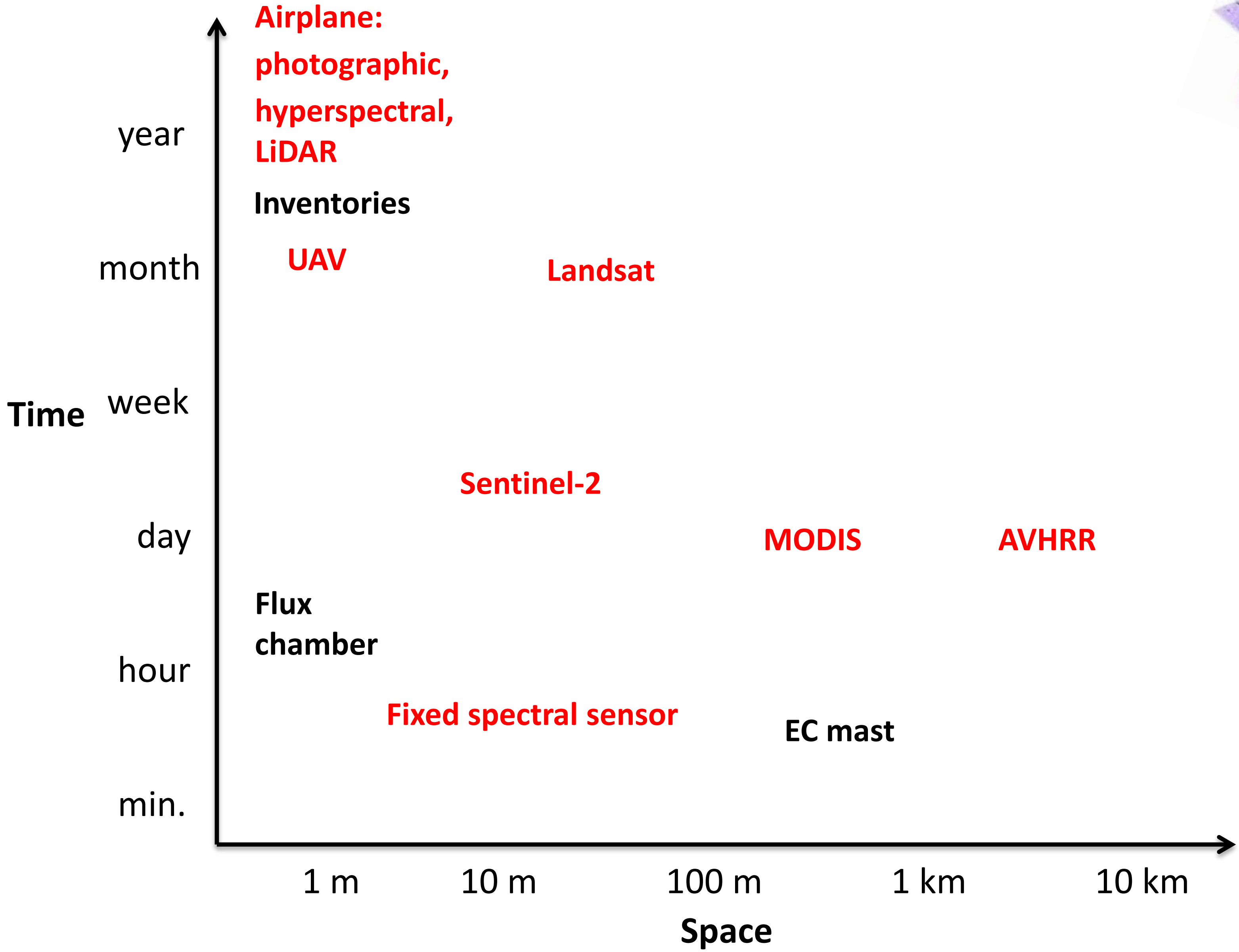
Gelybo, Barcza, Kern, Kljun, 2013, AFM 174-175, 43-53

Some vegetation parameters for upscaling

- Phenology, interannual foliage variations
- fAPAR (radiation absorption)
- Leaf area index
- Canopy light response
- Canopy height
- Vegetation structure
- Chlorophyll concentration
- Canopy moisture
- Canopy surface temperature
- Biomass, forest volume
- Light use efficiency
- Soil moisture
- Chlorophyll fluorescence
- Vegetation nutrient level
- Species

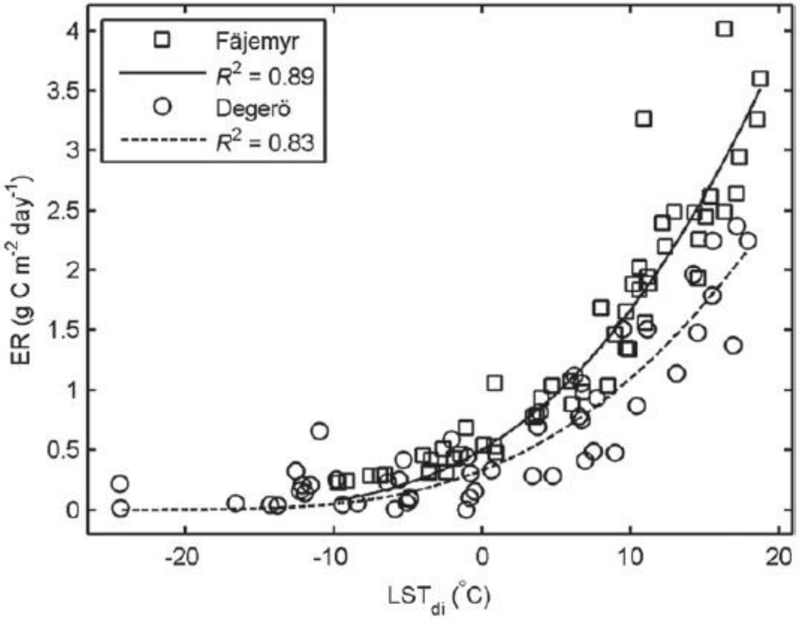


Time-space graph of measurements



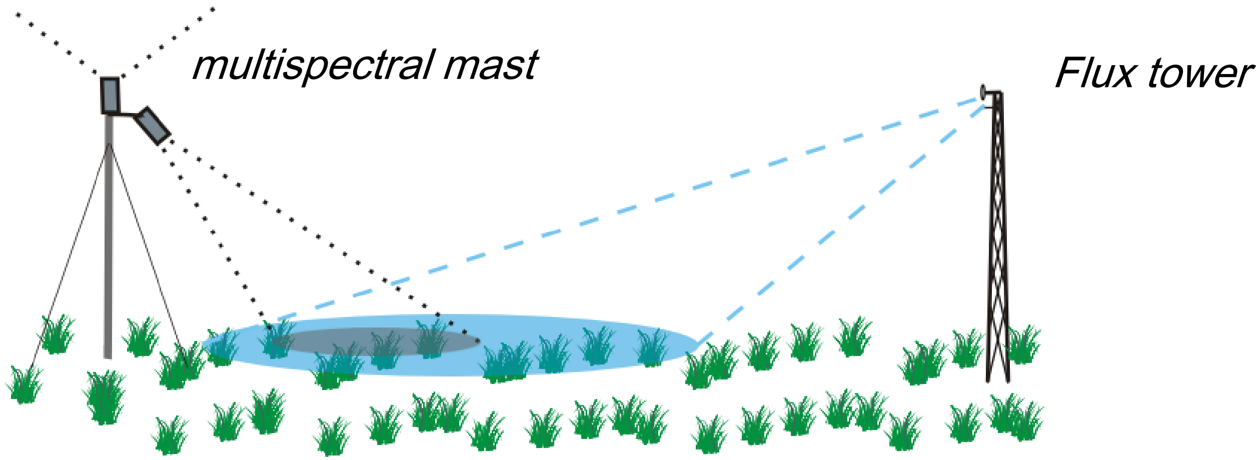
Some necessary advances for improved process understanding and upscaling

- Improved sampling at different spatial scales
  - Fixed sensors
  - UAV
  - New satellite data: Sentinel-2
- Better understanding of spectral data and vegetation indices
  - PRI: photochemical reflectance index vs. light use efficiency
  - SWIR radiation: canopy moisture
  - Land surface temperature
  - PPI – plant phenology index
- Better data processing methods for handling noise and missing data
  - Bayesian methods for data integration
  - Spatio-temporal data modeling



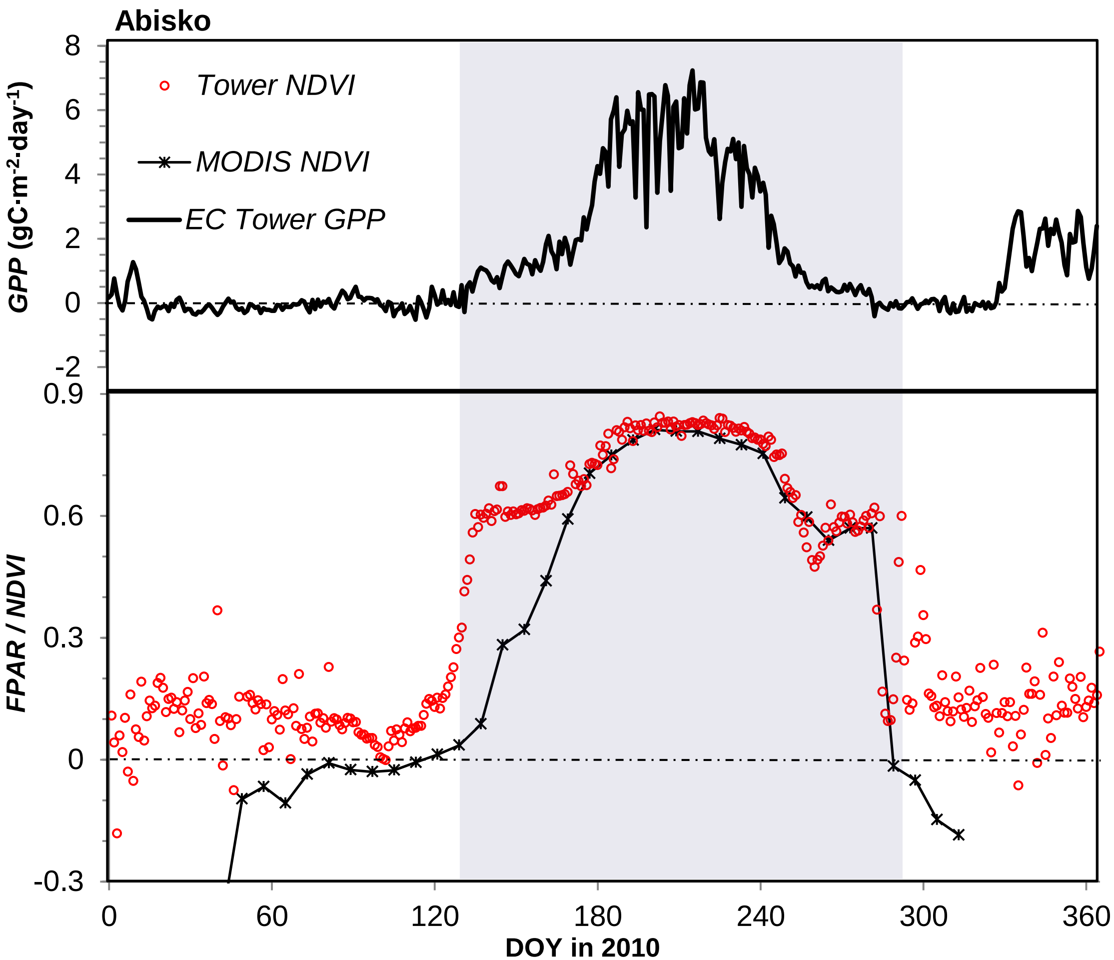
Ecosystem respiration estimated from MODIS land surface temperature. Schubert et al. (2010) Rem. Sens. Env, 114.

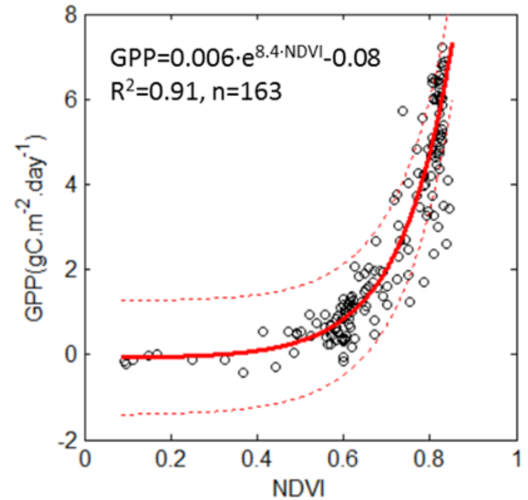
Point measurements for high-frequency and long-term data sampling



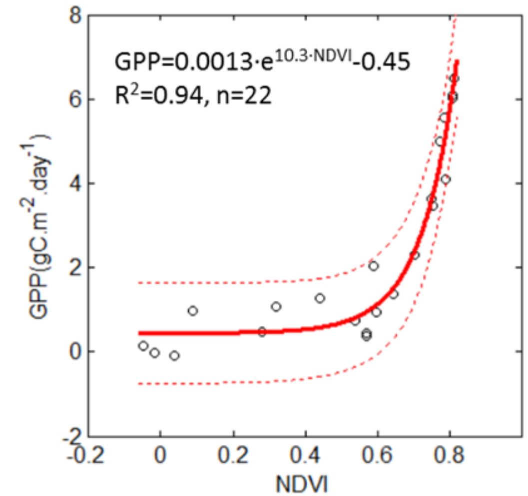
Seasonal GPP and NDVI from mast

Abisko birch forest 2010





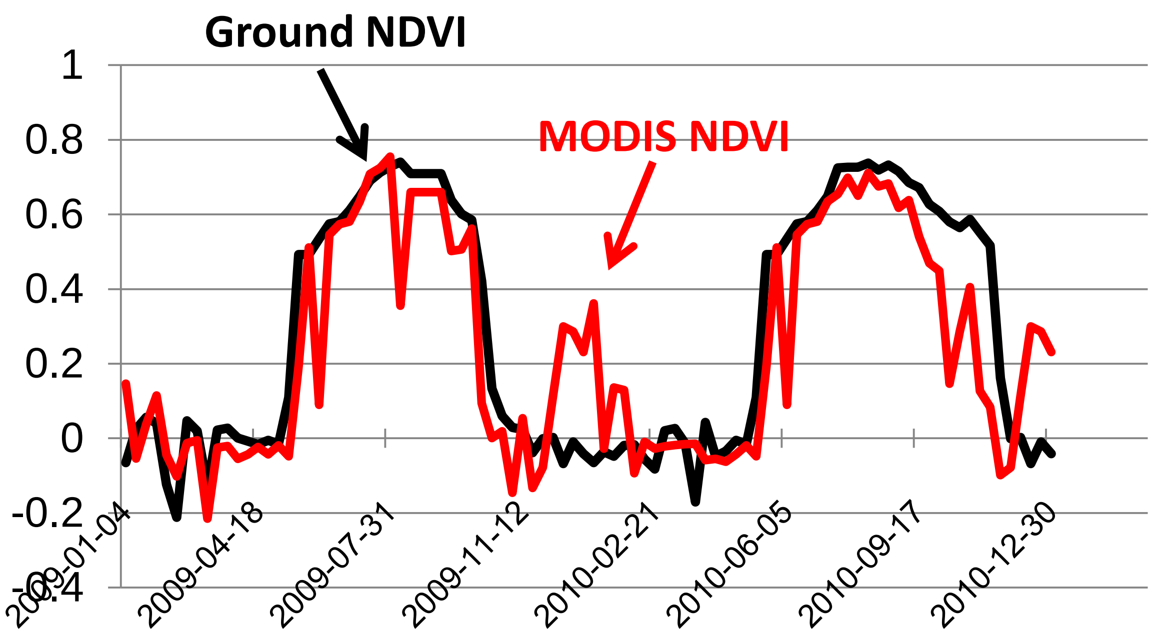
Ground NDVI



MODIS MOD43A2 NBAR NDVI

Modified from Eklundh et al. (2011)

Reference data for validating satellite data



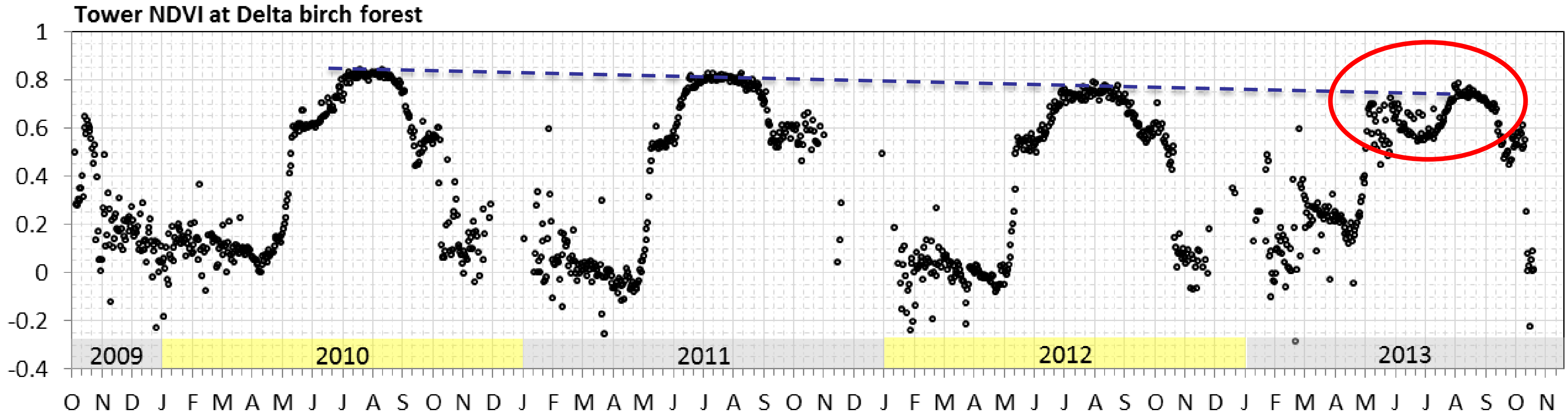
Changes in RMSE between in-situ and **TIMESAT** processed data.

Shows decreasing error with spike removal + envelope iterations.

Best method: Savitzky-Golay (note: example!)

Method	Raw MODIS	Ass. Gauss	Sav. Gol.	Doub. log.
Default TIMESAT	0.1724	0.1399	0.1377	0.1437
Spike removal	0.1724	0.1285	0.1232	0.1289
Envelope iterations	0.1724	0.1148	**0.1059**	0.1165

Slow and sudden environmental impacts



1. Tendency for NDVI to decrease 2010 – 2013
2. 2013 season strongly affected by insect attack

New satellites

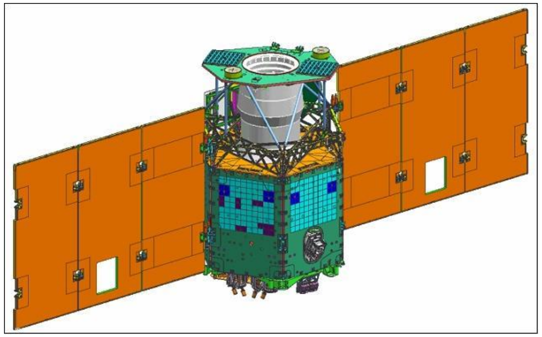
Sentinel-2

- Launch June 2015
- 13 spectral bands (Vis-NIR-TIR)
- 10-60 m ground resolution
- 3-5 days temporal resolution

http://spacefellowship.com

Venμs

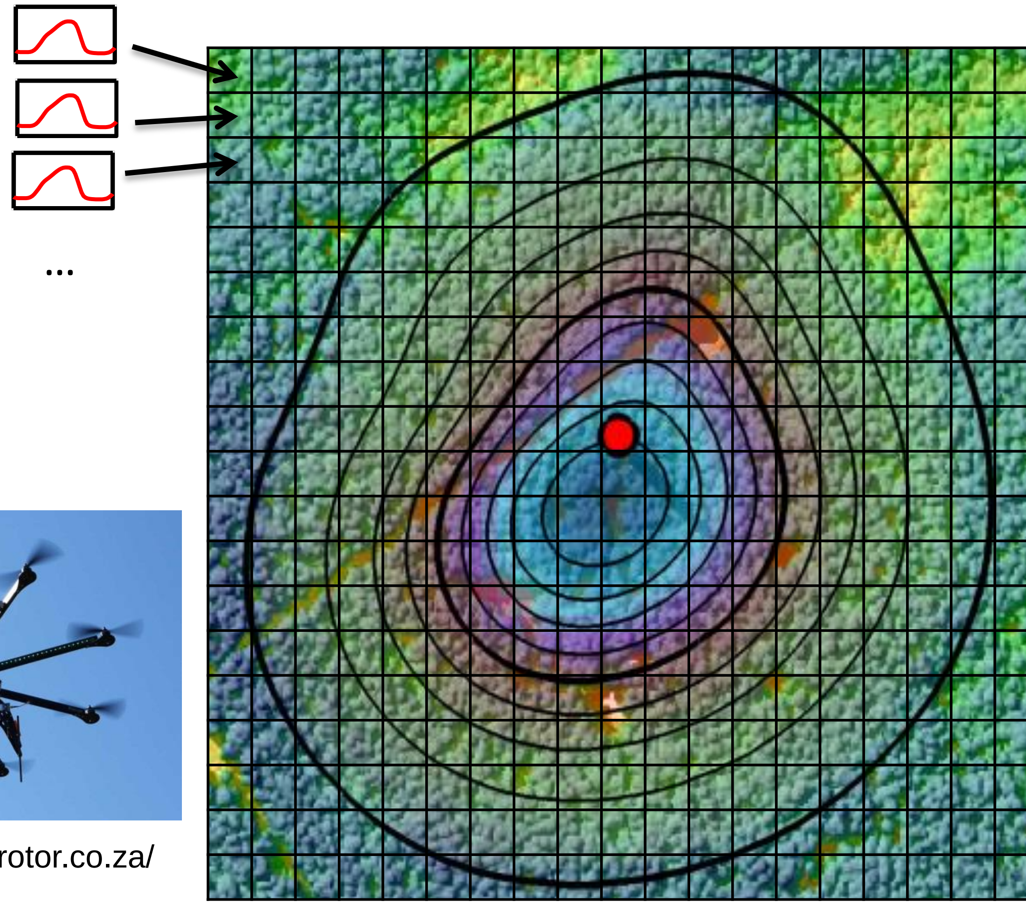
- Launch 2016
- 12 spectral bands (Vis-NIR)
- 10 m ground resolution
- 2 days temporal resolution
- Experimental – only 100 selected sites globally
- Lifetime 2.5 years



https://directory.eoportal.org/

Scaling within flux footprints: high-resolution dynamic data for weighting pixel contribution

Use fixed sensors, UAV, and new satellite data for creating better representation of the flux footprint variation



Source: http://www.pro-lite.co.uk/

Source: http://multirotor.co.za/

PPI – Plant Phenology Index

Remote Sensing of Environment 152 (2014) 512–525

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

A physically based vegetation index for improved monitoring of plant phenology

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Department of Physical Geography and Ecosystem Science, Lund University, Sölvegatan 12, SE-223 62 Lund, Sweden

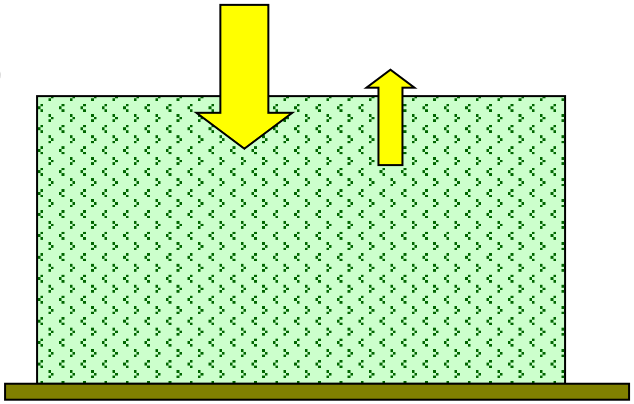
- Uses red and NIR reflectance
- Diffusive reflectance theory by Hapke (1993)

$$\rho_C \approx \rho_V + (\rho_S - \rho_V) \cdot e^{-k \cdot L},$$

Canopy reflectance

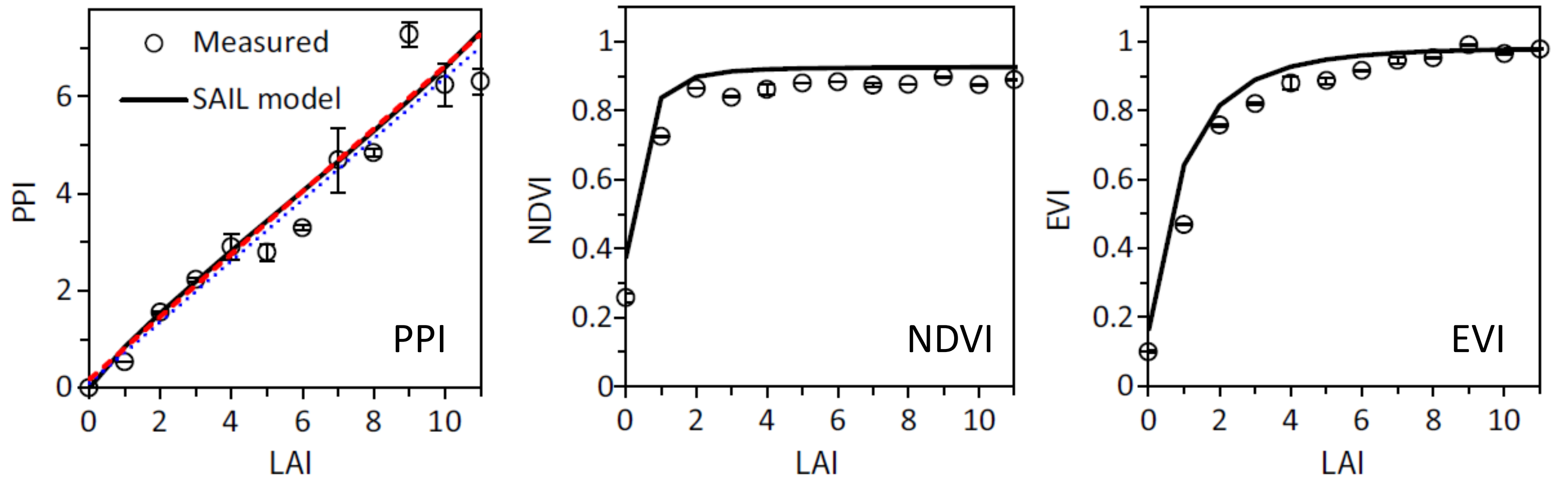
Soil vs. veg. refl.

LAI

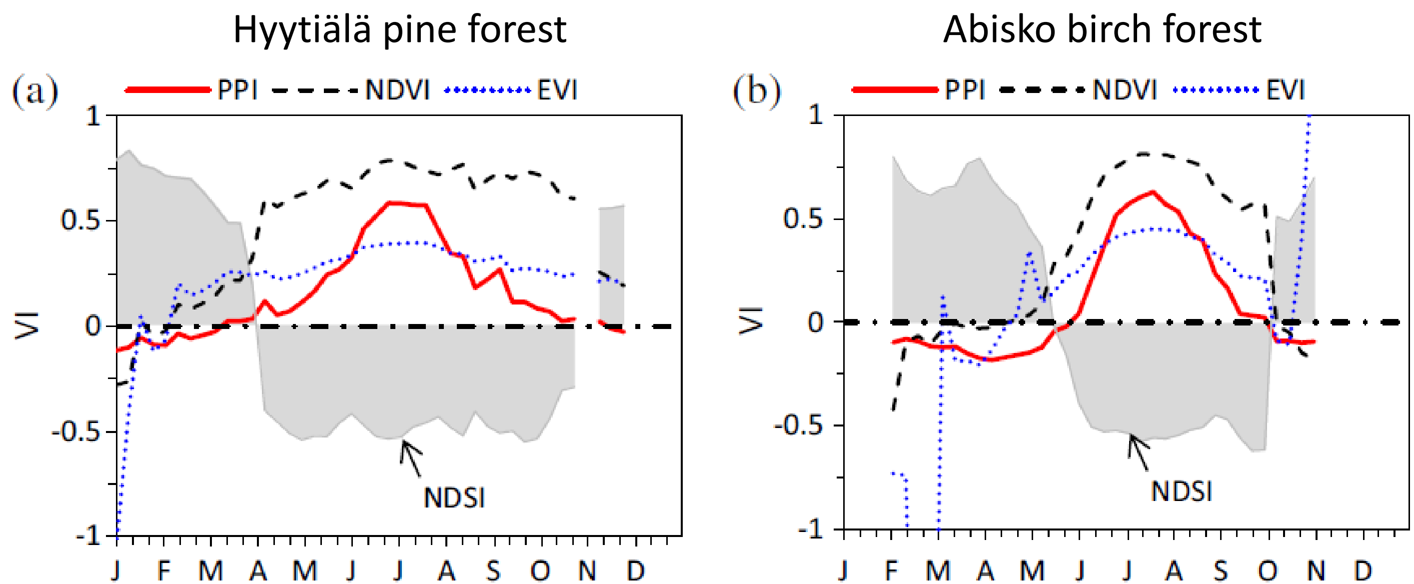


PPI – properties

Linear with green LAI

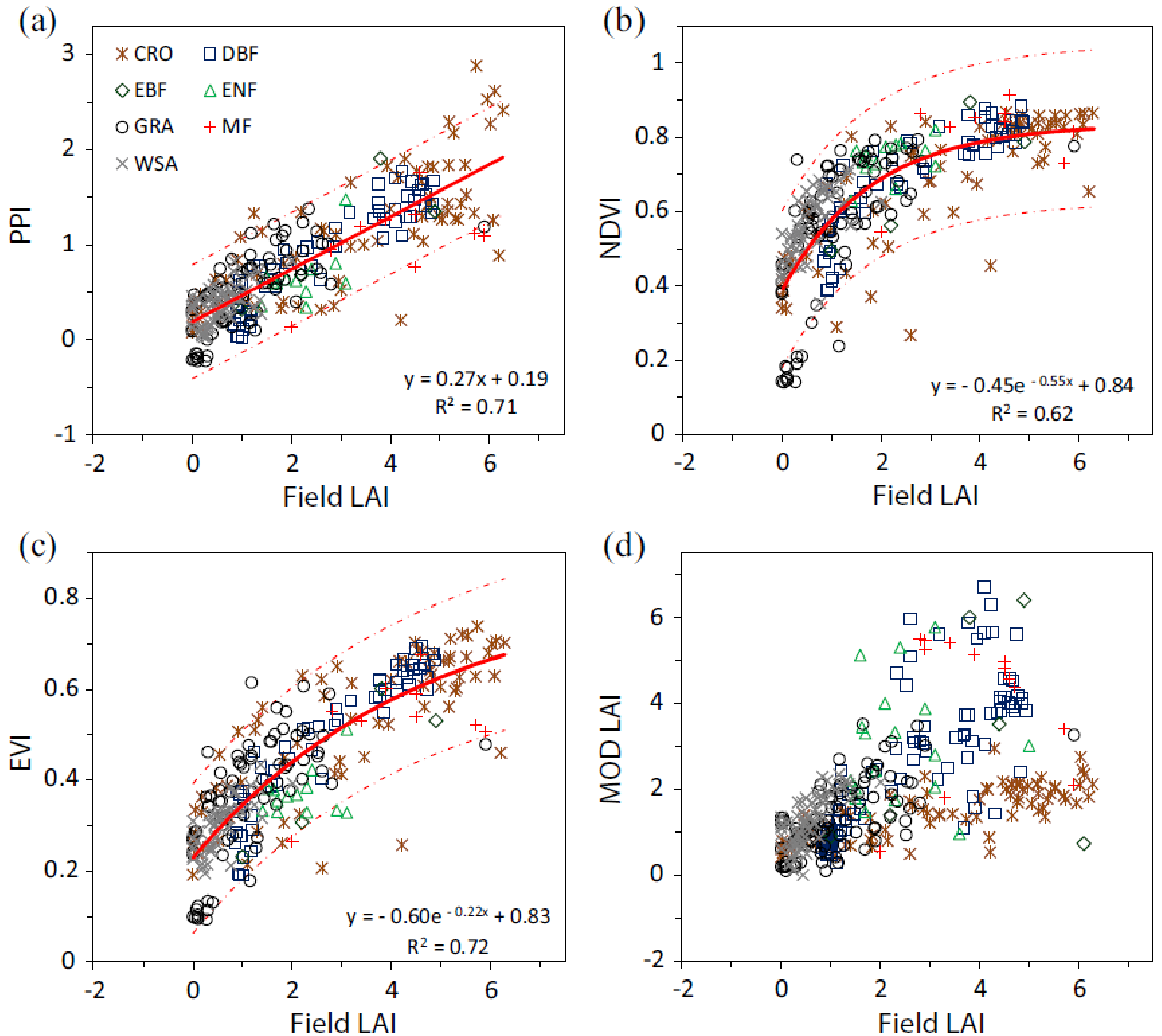


Insensitive to snow



Validation against field LAI data

LAI data from 46 global validation sites (BELMANIP, Fluxnet, etc.)



Shoot development and GPP in spruce and pine forests

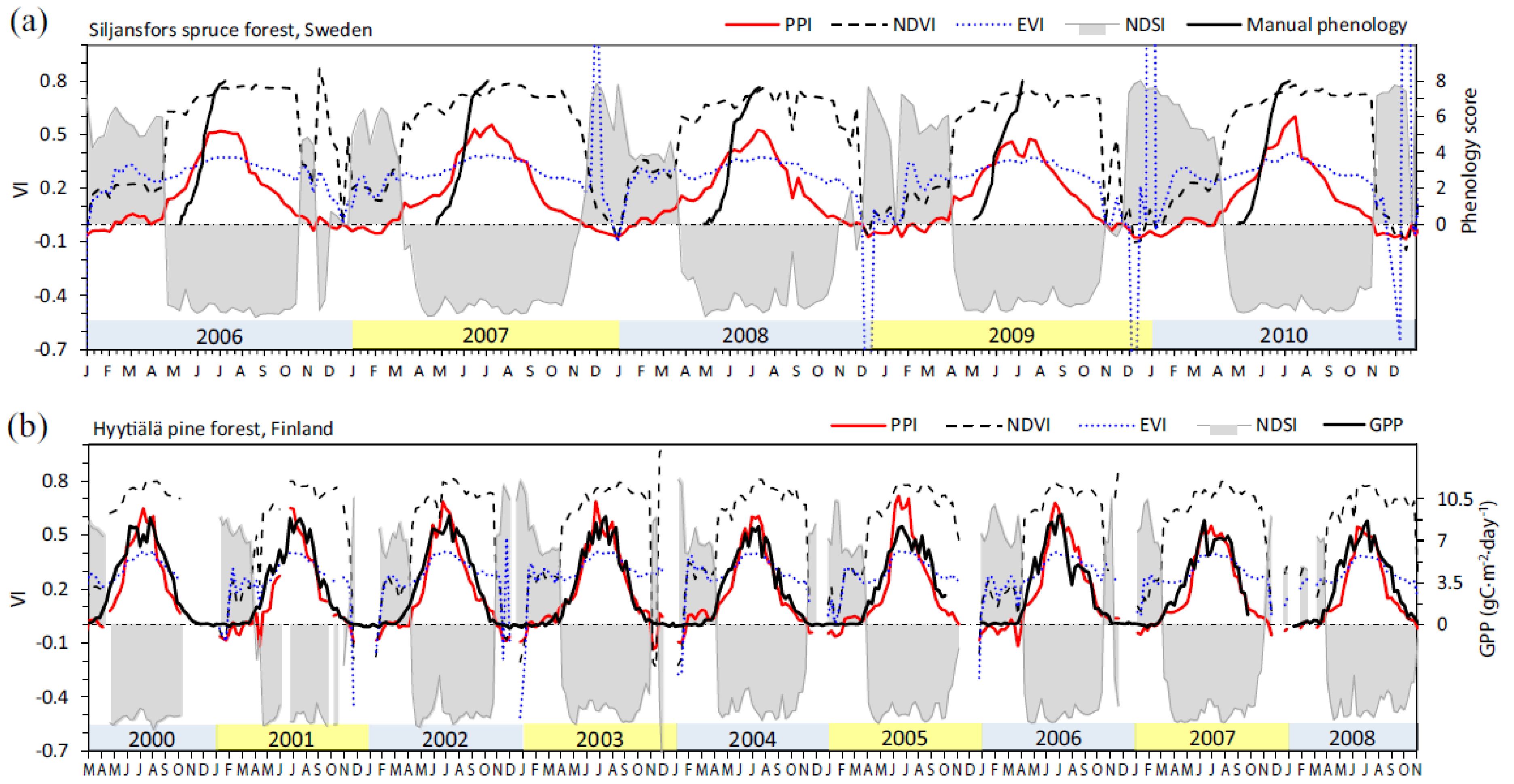
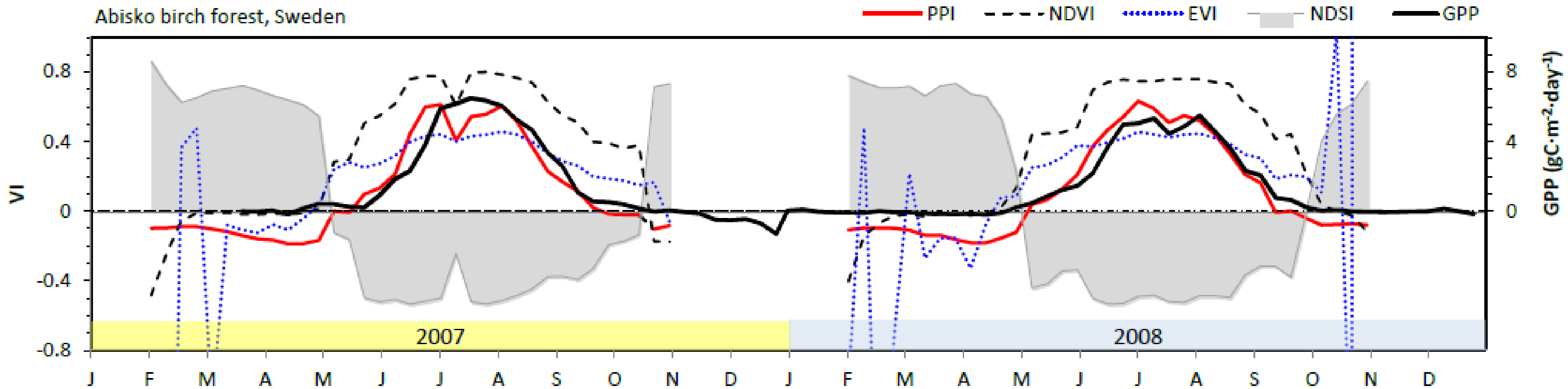
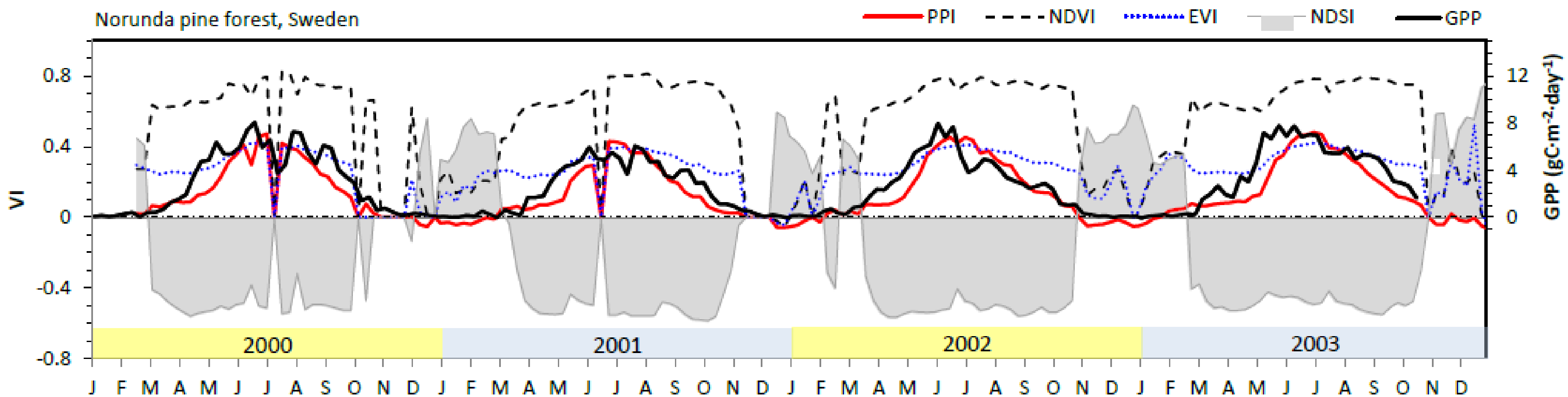


Fig. 11. Comparison of VI time series with ground observed vegetation dynamics: (a) manually observed spring phenology scores at Siljansfors spruce forest, middle Sweden; and (b) EC tower measured GPP at Hyytiälä pine forest, Finland. Shaded areas show snow activity indicated by the NDSI.

GPP: broadleaf and mixed coniferous sites



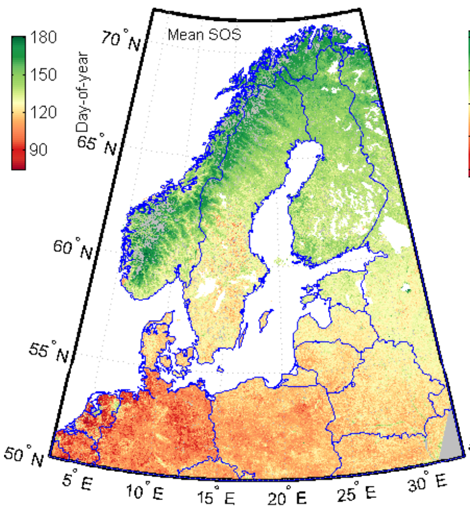


Correlations

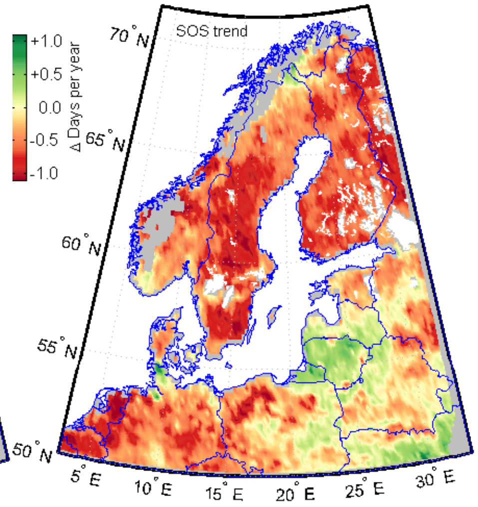
	Index		
Ground obs.	PPI	NDVI	EVI
Phenology score			
Siljansfors spruce forest (2006–2010) (60.88°N, 14.40°E, 240 m a.s.l.)	0.93	0.81	0.94
Vindeln spruce forest (2006–2010) (64.23°N, 19.77°E, 180 m a.s.l.)	0.92	0.69	0.89
GPP			
Hyytiälä pine forest (2000–2008) (61.85°N, 24.29°E, 170 m a.s.l.)	0.93	0.73	0.61
Norunda pine forest (2000–2003) (60.09°N, 17.48°E, 70 m a.s.l.)	0.89	0.73	0.76
Abisko birch forest (2008–2009) (68.36°N, 18.80°E, 350 m a.s.l.)	0.93	0.79	0.77

Phenology variations 15 years from MODIS PPI

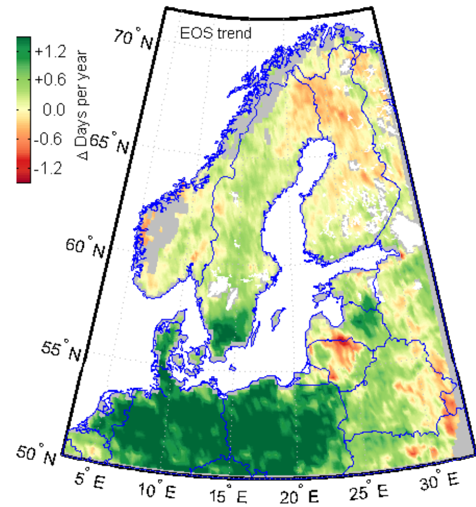
Mean SOS



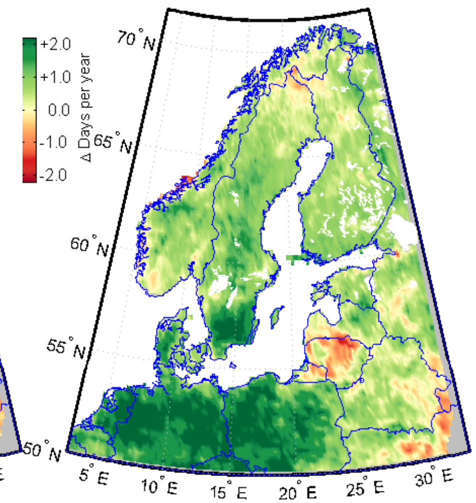
SOS trend



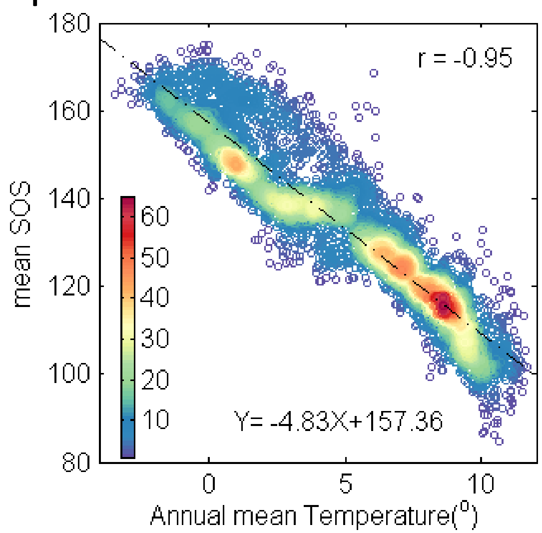
EOS trend



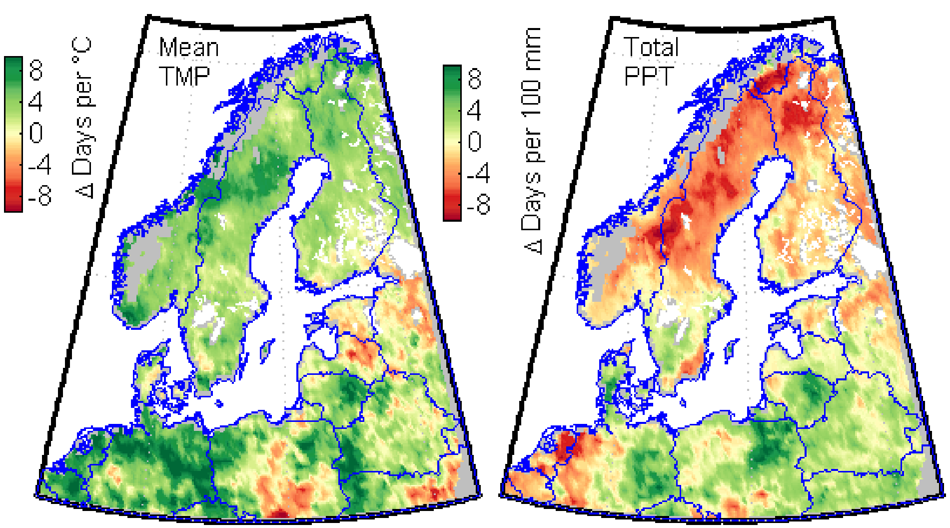
LOS trend



Spatial relation SOS – mean T

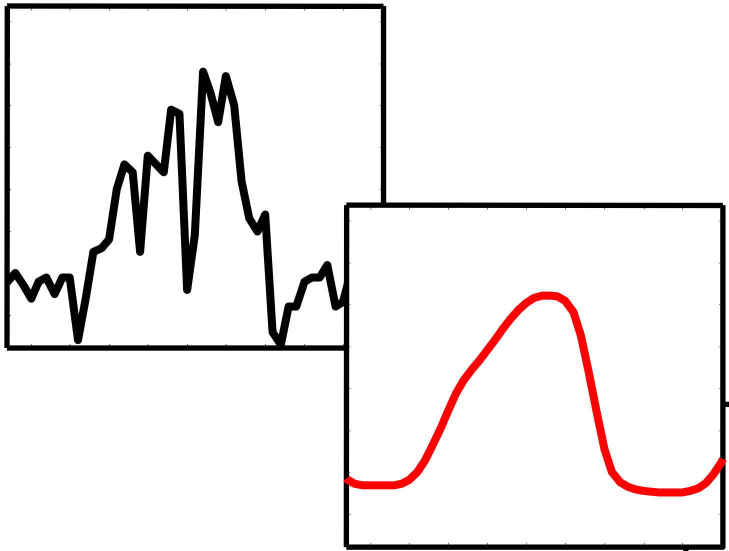


Sensitivity of LOS to temp and precip

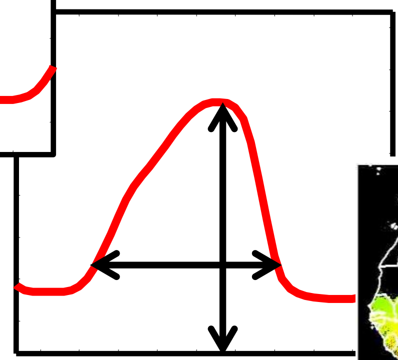


Hongxiao Jin et al. in prep.

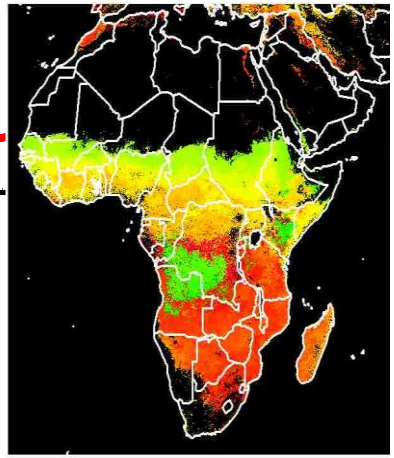
Modeling time-series data using TIMESAT



- Generate smooth model functions from noisy satellite sensor data



- Extract parameters that describe the seasons



- Map the seasonality parameters

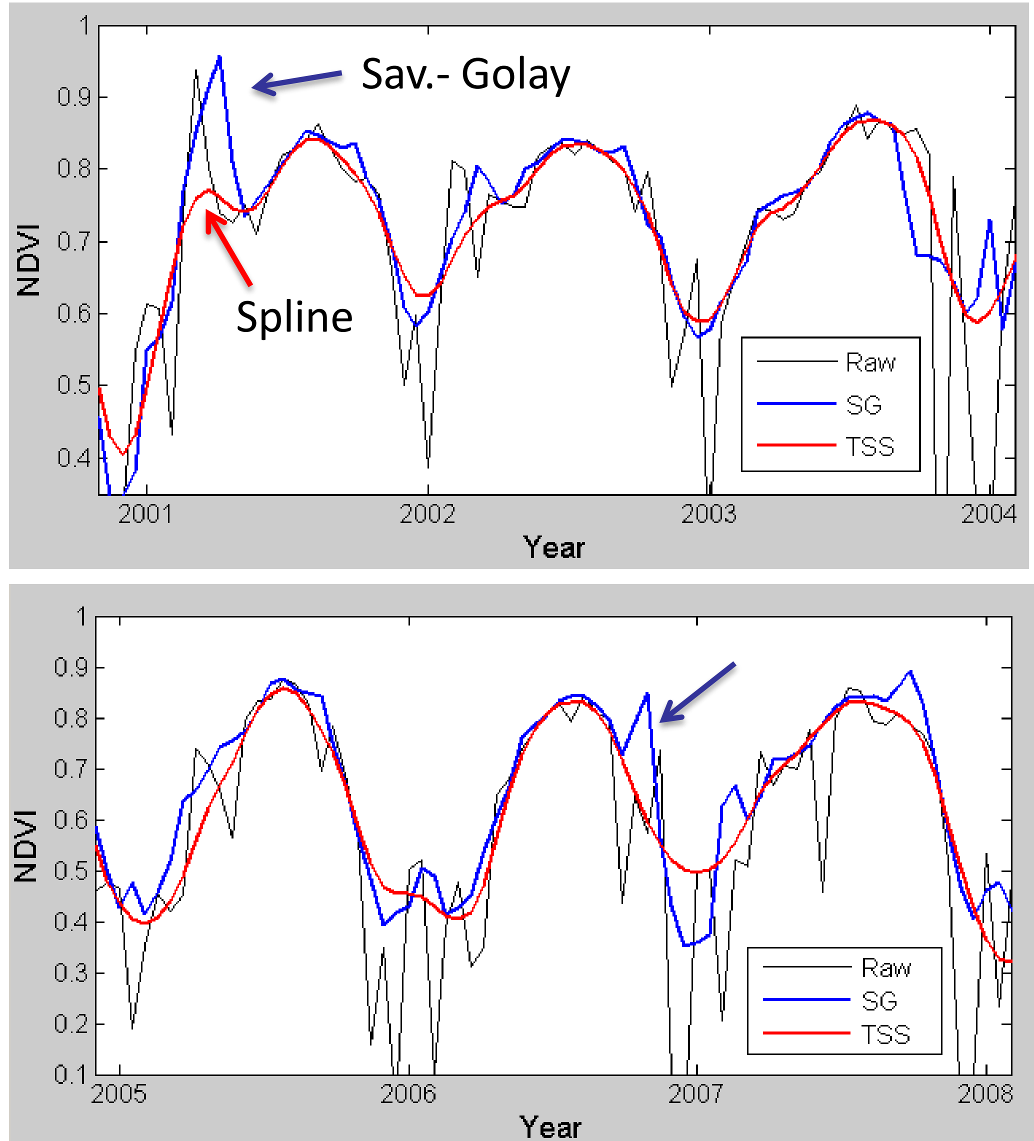
Jönsson & Eklundh 2002, *IEEE TGRS*, 40
Jönsson & Eklundh 2004, *Comp. Geosc.*, 30

http://www.nateko.lu.se/TIMESAT

Smoothing splines for local modeling

E.g. method by Garcia, 2010,
Comp. Stat. Data Anal,
54, 1167-1178

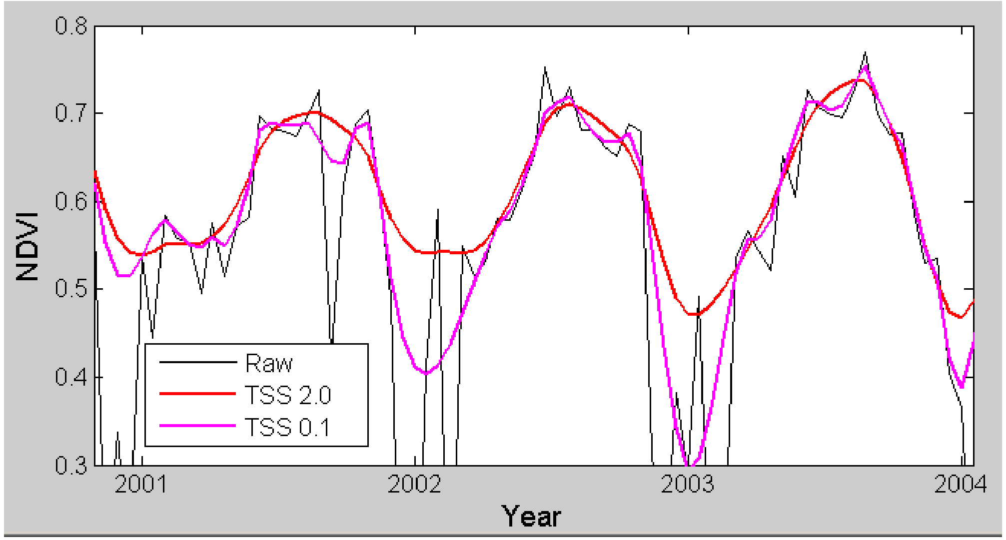
- Can work in one or several dimensions
- Is robust to outliers
- Allows for weighting the variables
- Can adapt to the upper data envelope
- Tolerates missing data



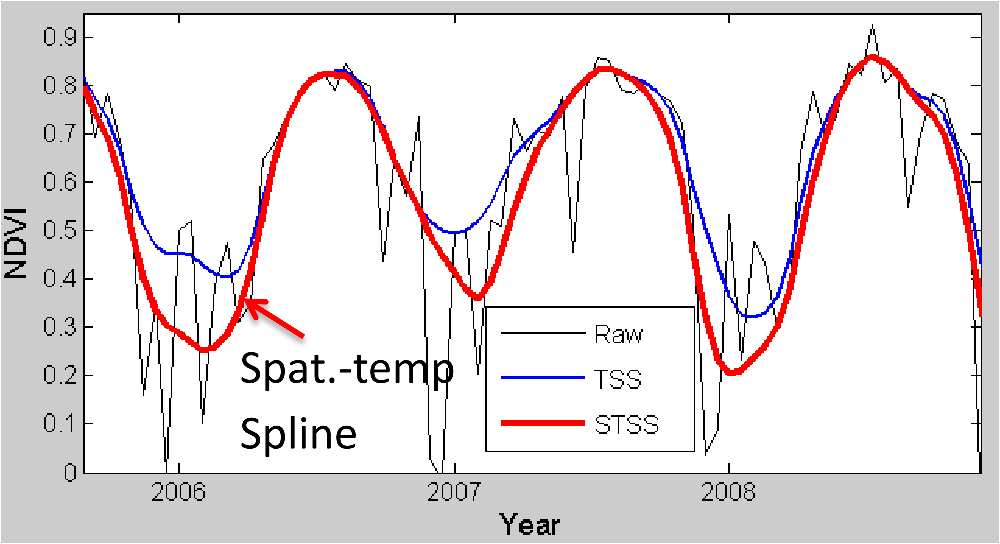
Eklundh et al. 2013, Proc. ISRSE

Modifying the spline smoothing

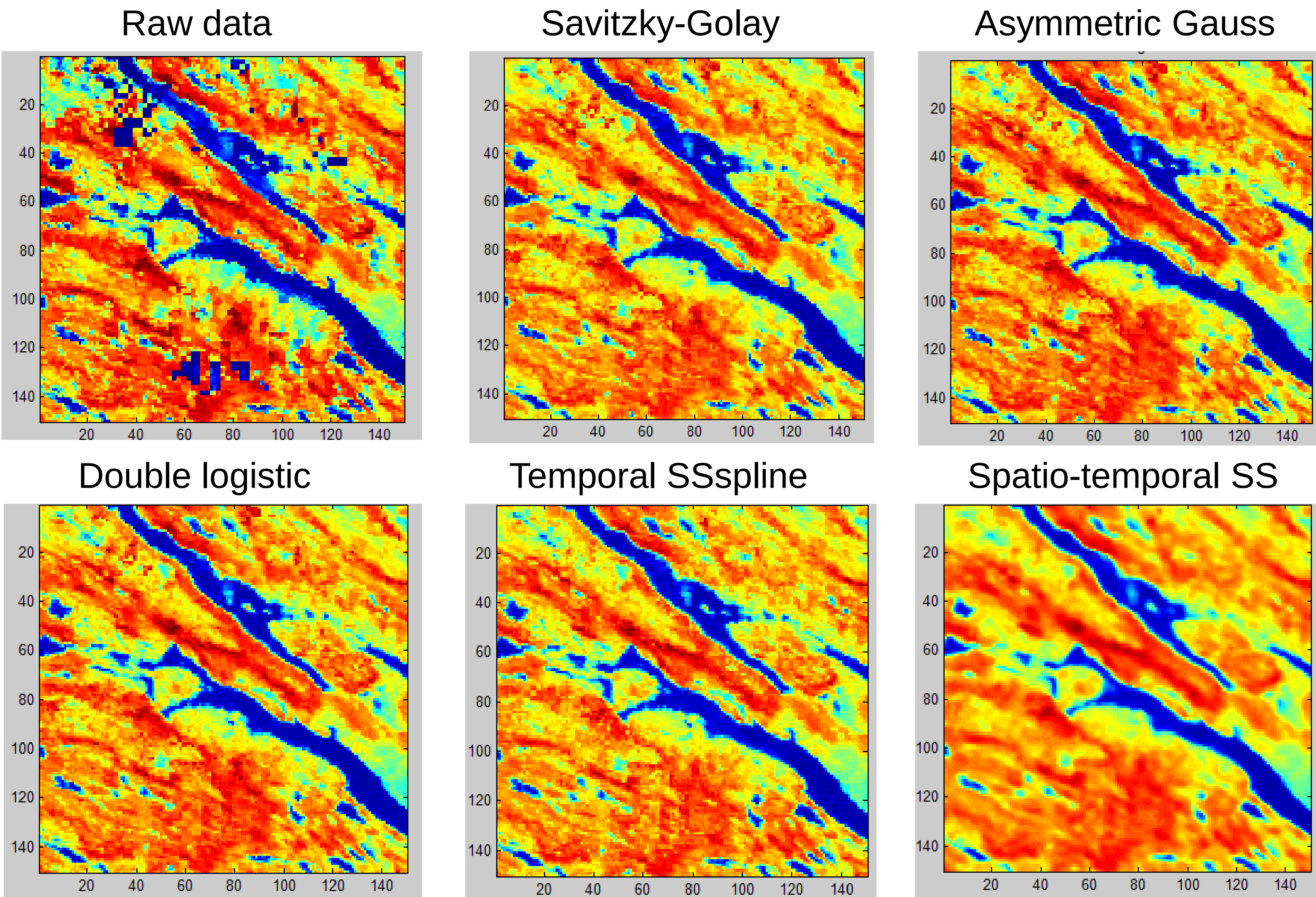
Modifying the degree of smoothing



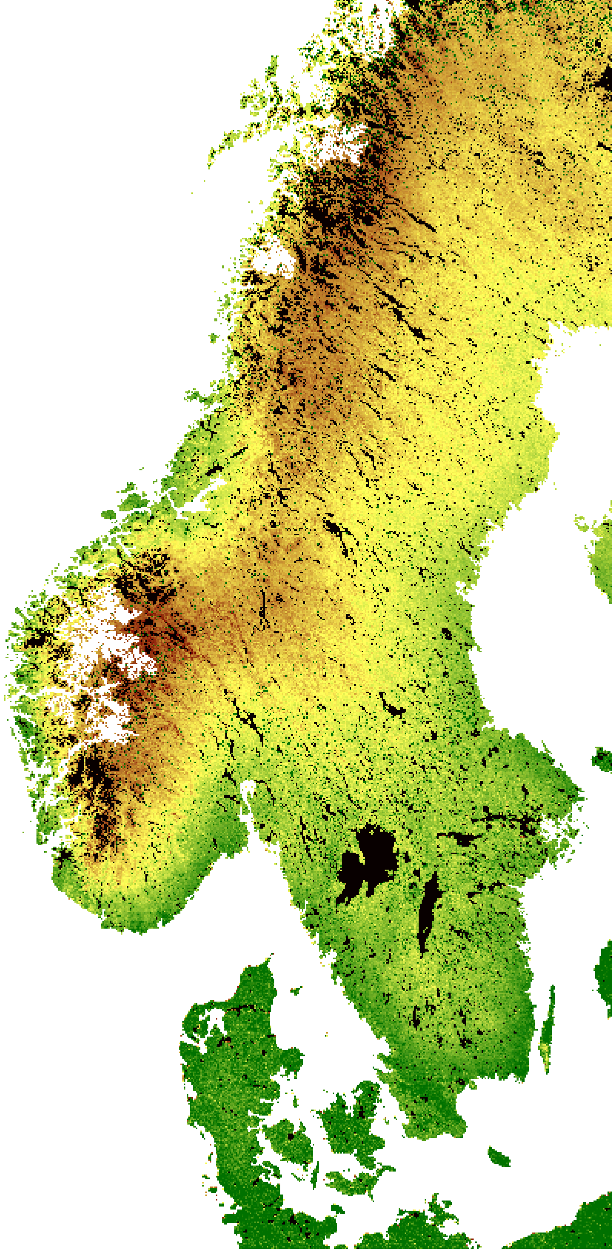
Smoothing over the spatio-temporal domain



MODIS EVI images



Summary

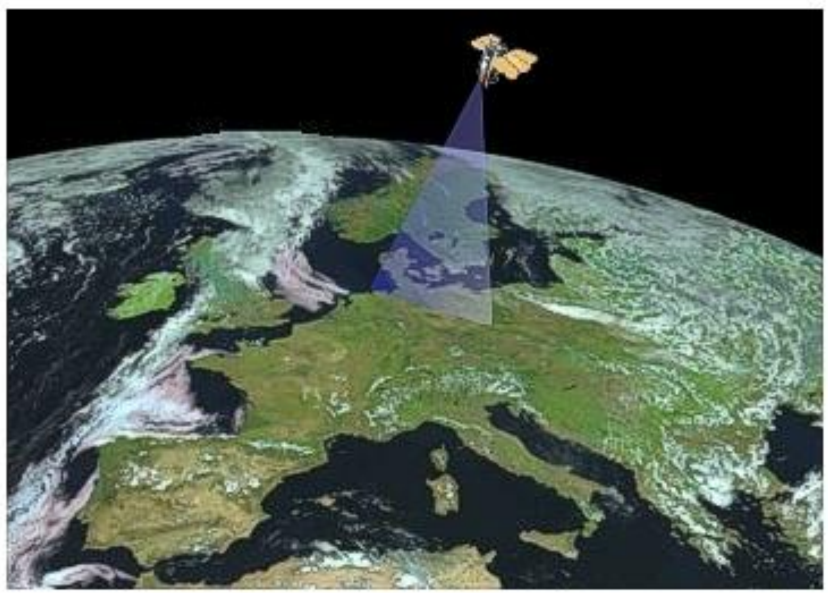


- New remote sensing techniques can fill the time-space data gaps and for improved understanding of general relationships
  - Fixed-sensor spectral measurements
  - UAVs
  - New satellites: Sentinel-2, Venμs
- Enable improved flux-footprint calculations
- PPI is a new vegetation index which responds to seasonal variations in LAI; shows excellent relationships with GPP and phenology
- New data modelling and integration methods, e.g. smoothing splines
- Success requires interdisciplinary collaboration between different science communities!

Thank you!

E-mail: lars.eklundh@nateko.lu.se

Web: http://www.nateko.lu.se/earth_observation



PPI formulation

$$PPI = -K \times \ln\left(\frac{M - DVI}{M - DVI_S}\right)$$

$$K = \frac{1}{4Q_E} \cdot \frac{1 + M}{1 - M} \cdot \frac{\varphi}{-\ln(1-\varphi)}$$

$$Q_E = d_c + (1 - d_c) \cdot \frac{G}{\cos(\theta_i)}$$

$$d_c = 0.0336 + 0.0477/\cos(\theta_i)$$

$$G = \frac{\sqrt{\chi^2 \cos^2(\theta_i) + \sin^2(\theta_i)}}{\chi + 1.774(\chi + 1.182)^{-0.733}},$$

DVI = difference VI

M = max of DVI over a time period

K = extinction coefficient

Q_E = canopy light extinction efficiency

d_c = diffuse fraction of solar radiation

G = leaf angular distribution function

Jin, H. and Eklundh, L. (2014), A physically based vegetation index for improved monitoring of plant phenology. *Remote Sensing of Environment* ,152:512-525.