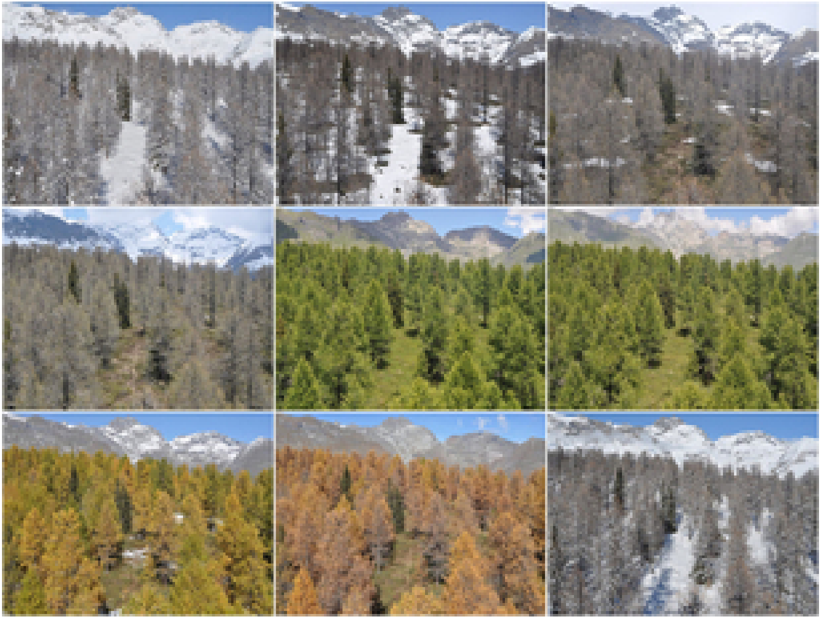
Alpine phenology from sensor networks: new insights from optical and snow depth sensors

E. Cremonese [1] G. Filippa [1] M. Galvagno [1]
U. Morra di Cella [1] C. Rixen [2]

[1]Environmental Protection Agency of Aosta Valley - ARPA VdA - Italy
[2]Swiss Federal Institute for Forest, Snow and Landscape Research, WSL

Fribourg 22 November 2014

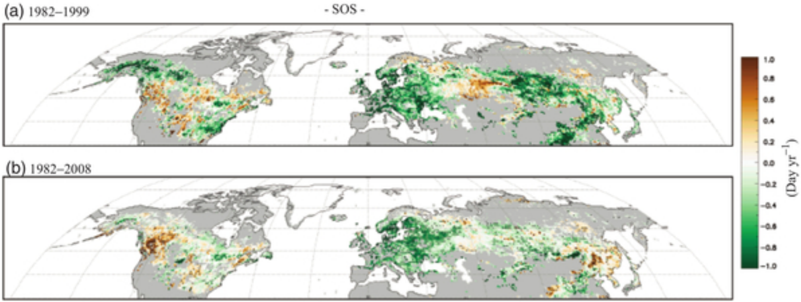
SGM 2014-Session 18: Earth System Science related Earth Observation



Phenology

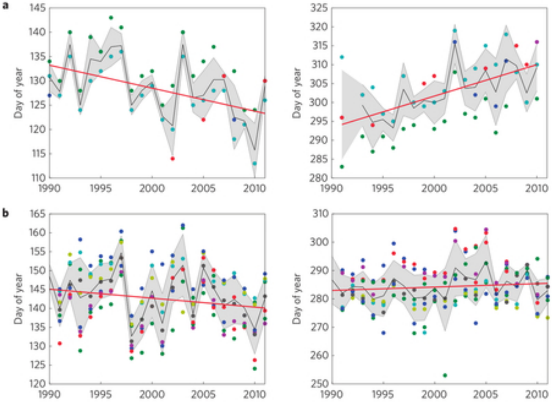
- The rhythm of the seasons (Morisette et al 2009, Front. Ecol. Env.)
- It responds fast to weather and climate changes
- It is easy to measure
- Phenology is the simplest process in which to track changes in the ecology of species in response to climate change (IPCC, 2007)

Phenology and Climate Change



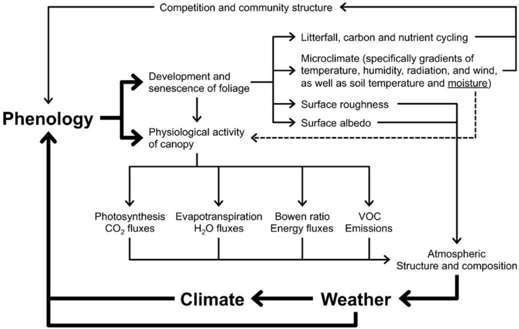
Shifts in phenology are observed worldwide (Jeong et al 2011, Glob. Ch. Biol.)

Phenology and Climate Change



Early spring onset and delayed autumn senescence (Keenan et al 2014, Nature)

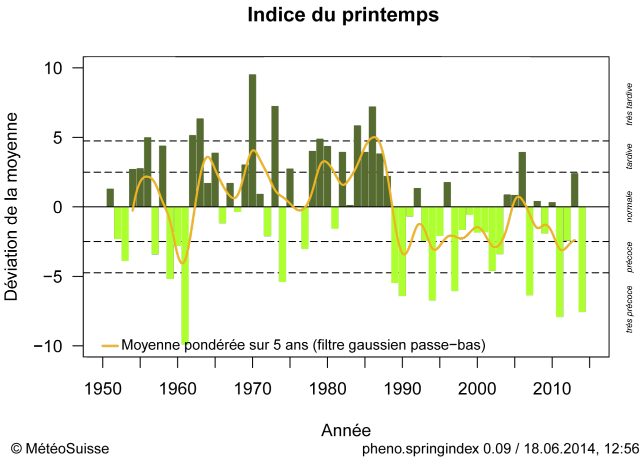
Phenology and its feedbacks



Richardson et al 2012, Agric. and For. Meteorol.

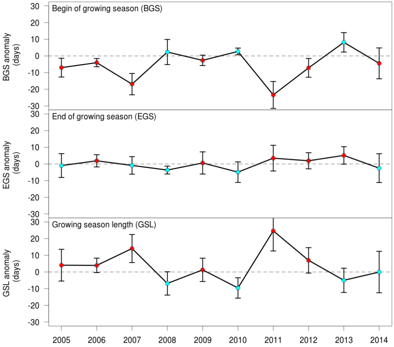
- weather and climate control phenology
- phenology feedbacks on carbon and water cycle
- phenology feedbacks on atmosphere and climate system
- shifts in phenology act on community structure, hence biodiversity

Phenology in the Alps (Meteo Suisse)



Phenology in the Alps (Aosta Valley - IT)

Larch phenology in the last 10 years in Aosta Valley

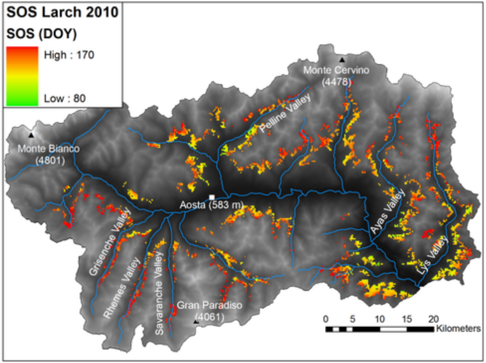


Impact of long term warming and climate extremes:
early snow melt, winter warm spells, ...

Phenology in the Alps (Aosta Valley - IT)

Phenology in the mountains is highly variable:

e.g. leaf emergence of larch in Aosta Valley can vary by some 90 days in a single year



Elevation, Continentality, Aspect, Precipitation, Snow, etc.

Keep an eye on Phenology

But from how far?

- Field observation: precise, single or few individuals, specific phases (i.e. not continuous), expensive
- Remote sensing: spatially integrated, no observer bias, geometric and temporal resolution
- sensor networks: spatially integrated (2-100 m), high temporal resolution, cheap, need of some infrastructure

Keep an eye on Phenology

But from how far?

- Field observation: precise, single or few individuals, specific phases (i.e. not continuous), expensive
- Remote sensing: spatially integrated, no observer bias, geometric and temporal resolution
- sensor networks: spatially integrated (2-100 m), high temporal resolution, cheap, need of some infrastructure

Keep an eye on Phenology

But from how far?

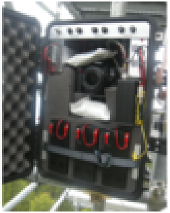
- Field observation: precise, single or few individuals, specific phases (i.e. not continuous), expensive
- Remote sensing: spatially integrated, no observer bias, geometric and temporal resolution
- sensor networks: spatially integrated (2-100 m), high temporal resolution, cheap, need of some infrastructure

Which sensors?

- optical sensors
  - Digital cameras or webcams
  - NDVI
- snow depth sensors

Digital cameras

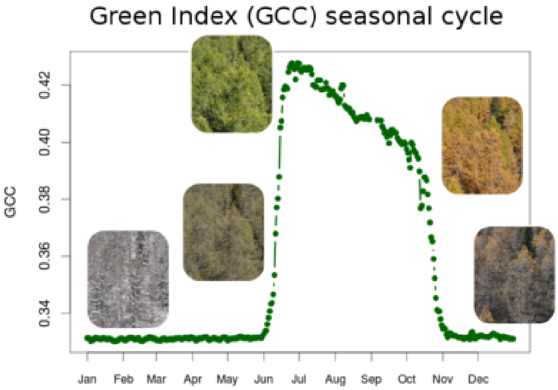
Digital camera images can be analysed and used to obtain quantitative data on the seasonal patterns of development and senescence of vegetation (Richardson et al 2012, Agric and For Meteorology)



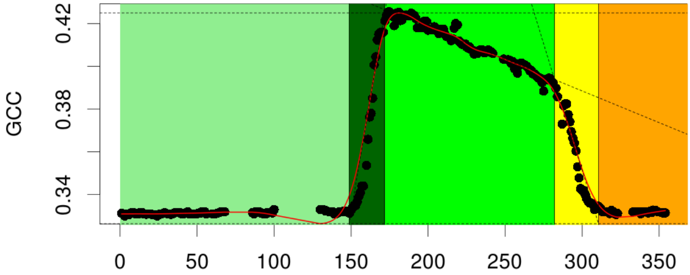
Digital cameras

GCC seasonal trajectory

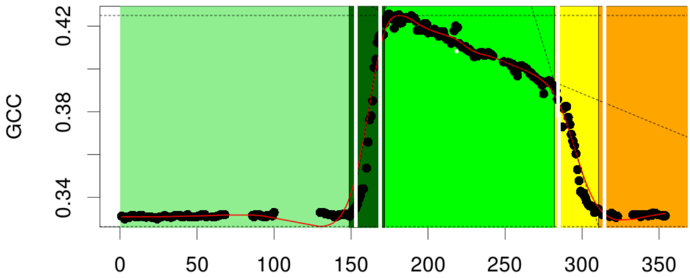
From the red, green and blue (RGB) channels of the images, the green chromatic coordinate ($GCC = \frac{green}{red+green+blue}$) can be computed. GCC represents the amount of green contained in the images and thus it's related to vegetation development



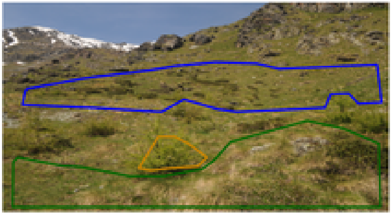
- larch forest: phenophases extraction and comparison with field observations

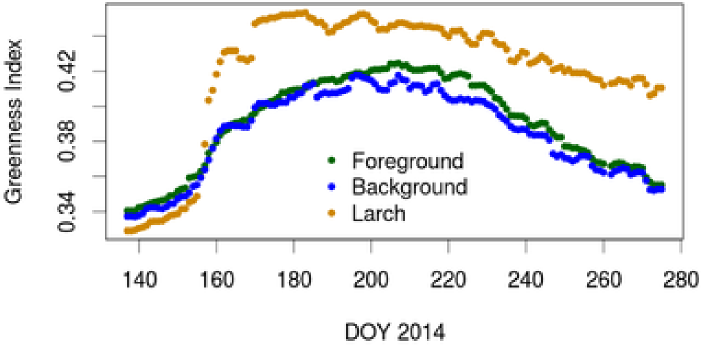


- larch forest: phenophases extraction and comparison with field observations



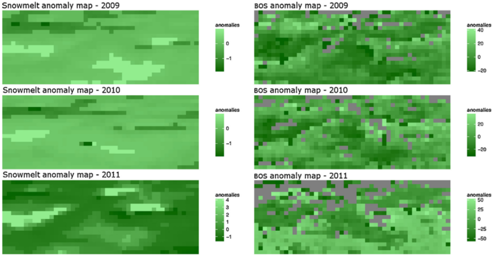
- phenology at different spatial levels: from ecosystem (grassland) to species or individuals
- camera quality and setup limits elaboration capabilities

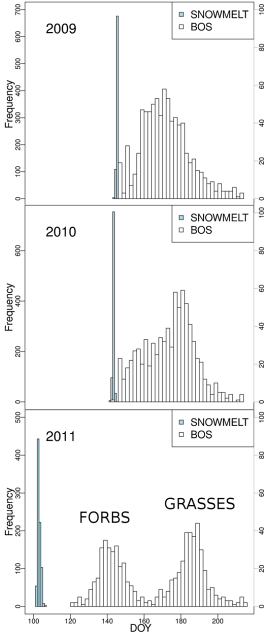



Greenness Index
0.34
0.38
0.42
140
160
180
200
220
240
260
280
DOY 2014
Foreground
Background
Larch

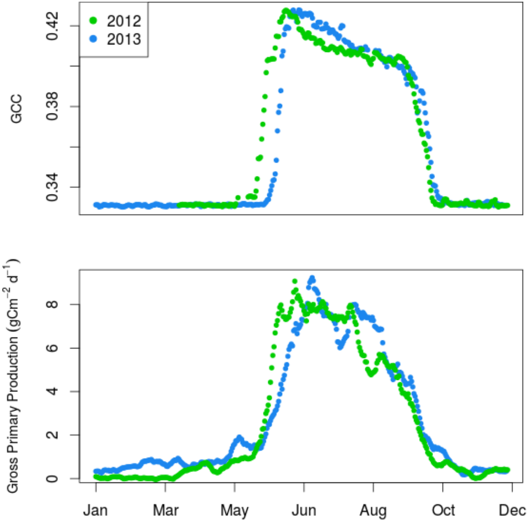
- grid based analysis (Julitta et al, 2014, AFM)

- relation snowmelt-phenology (Julitta et al, 2014, AFM)





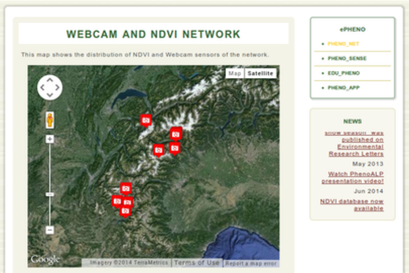
- GCC to track photosynthesis phenology: GCC and GPP (larch forest)



- Phenopix R package for image processing, fitting and phenophase extraction (available @ https://r-forge.r-project.org/projects/phenopix/)
- Phenological models optimisation (Migliavacca et al, 2012)
- Light use efficiency models (Rossini et al, 2012, 2013)
- Grassland phenology observation methods and ecological drivers (Filippa et al, in prep)

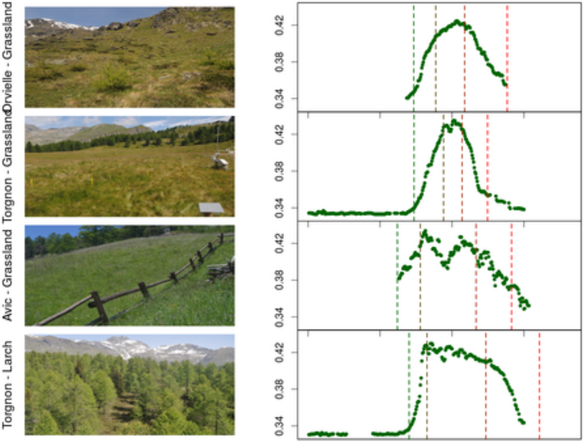
NW Alps camera network

- PhenoAlp (2009-2011) and e-pheno (2012-2014) projects (phenoalp.eu)
- 10 sites (5IT, 5FR) most sites installed since 2012
- ecosystems: grasslands (1800-2100 m asl) and subalpine ($<$ 2100 m asl) larch forests
- common setup protocol and processing



NW Alps camera network

- 2014 phenology in Aosta Valley sites
- impact of species composition, land use, ...

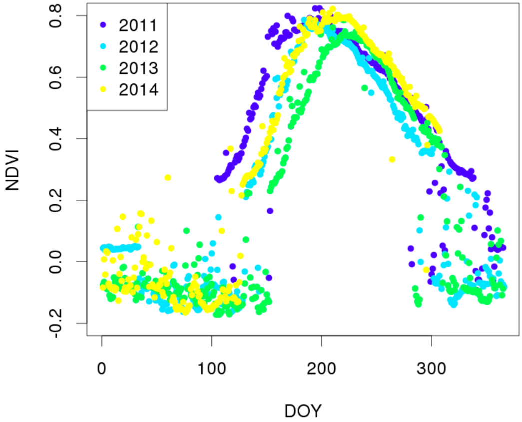


NDVI: Rationale

- Upward e downward sensors measuring reflectance in NIR and RED bands
- $NDVI = \frac{NIR-R}{NIR+R}$
- NDVI is related to vegetation biomass
- long tradition in remote sensing community, more recently used in field campaign or monitoring

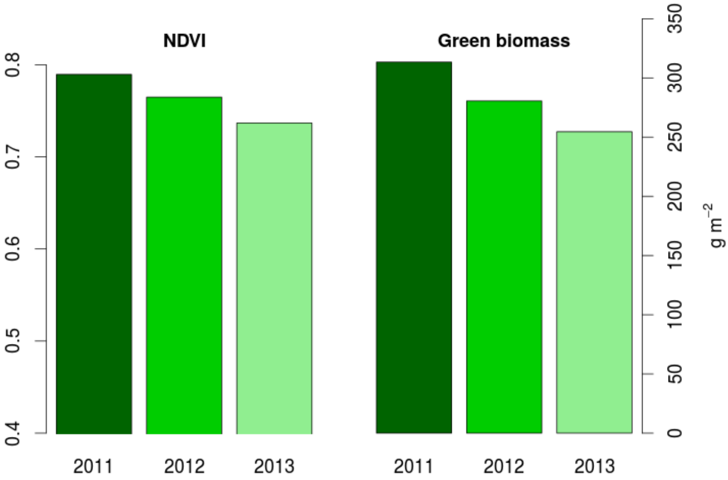
Continuous NDVI field measures result in seasonal trajectories depending on plant development and, thereby phenology.

NDVI interannual variability (IAV) in grassland



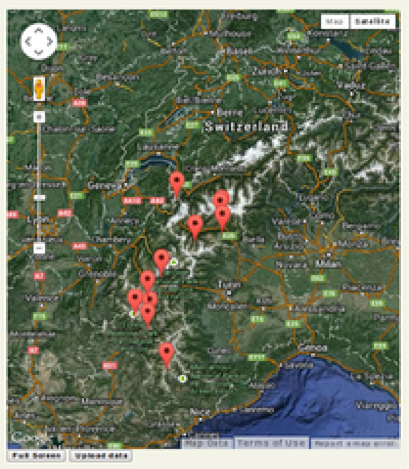
- tracking of IAV during spring and senescence development
- noise during snow period
- IAV at max summer values (no saturation)

NDVI and biomass at max summer values

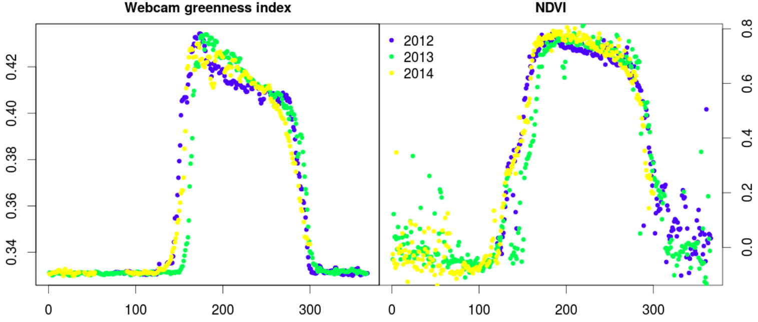


NW Alps NDVI network

- PhenoAlp (2009-2011) and e-pheno (2012-2014) projects (phenoalp.eu)
- 13 sites (4IT, 9FR) most sites installed since 2012
- ecosystems: grasslands (1800-2100 m asl) and subalpine ($<$ 2100 m asl) larch forests
- common setup protocol but different sensors

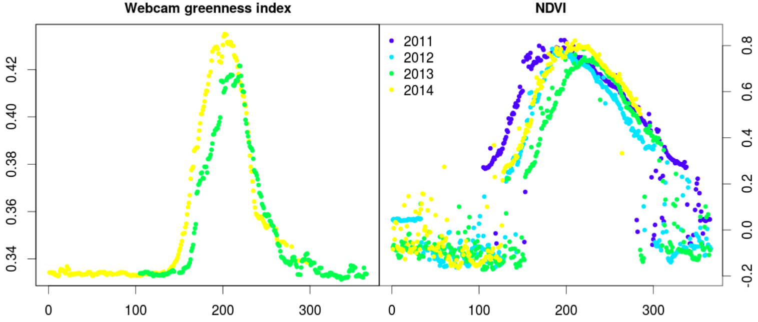


Coupling cameras and NDVI: larch



- coherent patterns of spring development and autumn senescence
- different shapes: gcc tracks chlorophylls and NDVI tracks biomass (Petach et al 2014, Keenan et al 2014, Wingate et al in prep)

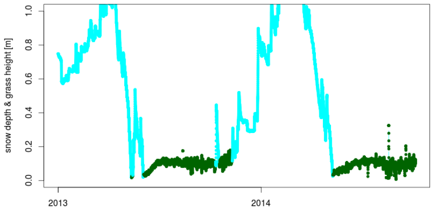
Coupling cameras and NDVI: grassland



- coherent patterns of spring development and autumn senescence and differences in max summer values
- different shapes: gcc tracks chlorophylls and NDVI tracks biomass (Petach et al 2014, Keenan et al 2014, Wingate et al in prep)

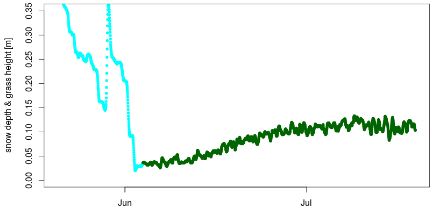
Snow depth sensors

- Snow depth is measured using ultrasonic snow depth sensors. After snow melt, these sensors can also track grass growth
- previous papers: Jonas, Rixen et al., 2008, JGR and Rammig et al, 2010 Biogeoscience
- Further step: enlarge analysis dataset to IMIS network: 133 sites (data from 1995, thus 1520 site-years), 1500-3000 m asl elevation range, snow depth, soil and air temp



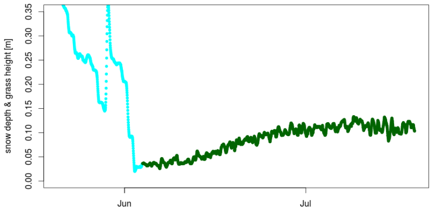
Snow depth sensors

- Snow depth is measured using ultrasonic snow depth sensors. After snow melt, these sensors can also track grass growth
- previous papers: Jonas, Rixen et al., 2008, JGR and Rammig et al, 2010 Biogeoscience
- Further step: enlarge analysis dataset to IMIS network: 133 sites (data from 1995, thus 1520 site-years), 1500-3000 m asl elevation range, snow depth, soil and air temp



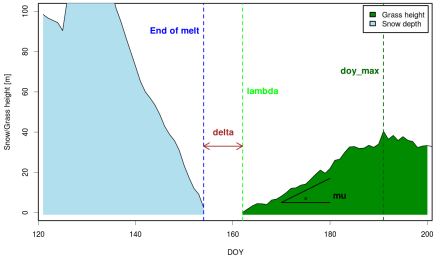
Snow depth sensors

- Snow depth is measured using ultrasonic snow depth sensors. After snow melt, these sensors can also track grass growth
- previous papers: Jonas, Rixen et al., 2008, JGR and Rammig et al, 2010 Biogeoscience
- Further step: enlarge analysis dataset to IMIS network: 133 sites (data from 1995, thus 1520 site-years), 1500-3000 m asl elevation range, snow depth, soil and air temp



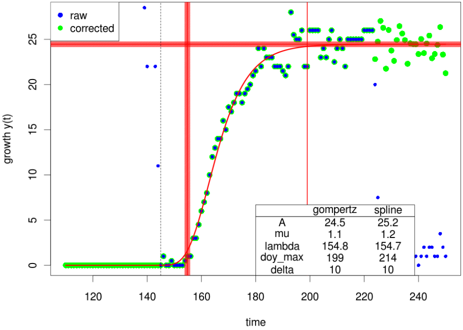
Automatic processing

- Snow melt detection based on a bayesian breakpoint procedure
- fit grass growth data
- extract phenological metrics with associated uncertainty



A fitting example

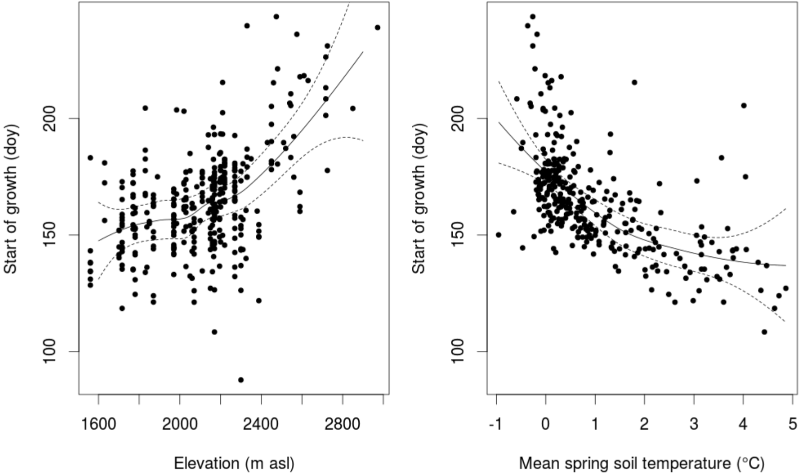
- A is the maximum grass height (cm)
- mu is the maximum growth rate (cm/day)
- lambda is the start of growth (doy)
- delta between snow melt and start of growth (days)
- doy_max is the day of peak (doy)



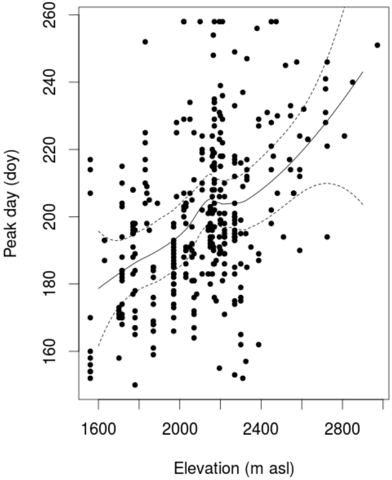
First analysis

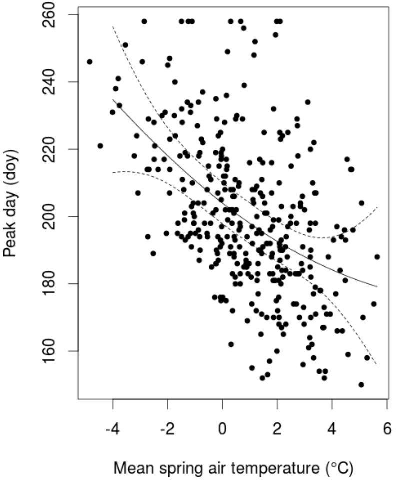
- Relationship with meteorological and topographical drivers
- Trend Analysis

Start of growth vs elevation and spring soil temperature

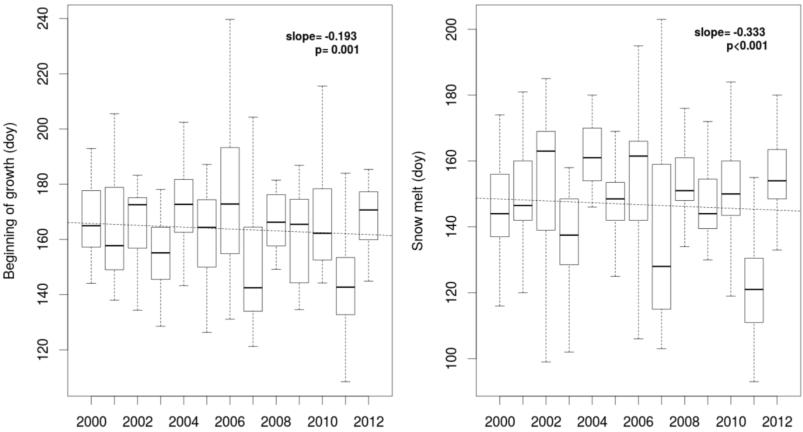


Day of max growth vs elevation and spring soil temperature





Trend analysis



Concluding

- Sensor based approach lies in between field observations and remote sensing data. Good spatial integration: from ecosystem to individuals
- Seasonal trajectories from spring development to autumn senescence at daily temporal resolution
- Provide quantitative data that can be linked to ecosystem variables and processes (e.g. GPP, biomass, grass height)
- Sensor network can be used to analyse different ecosystems and locations. Digital camera and NDVI networks need to be developed while the use of snow depth sensors relies on existing networks
- Data archiving and common processing techniques allow site intercomparison, upscaling, ...

Concluding

- Sensor based approach lies in between field observations and remote sensing data. Good spatial integration: from ecosystem to individuals
- Seasonal trajectories from spring development to autumn senescence at daily temporal resolution
- Provide quantitative data that can be linked to ecosystem variables and processes (e.g. GPP, biomass, grass height)
- Sensor network can be used to analyse different ecosystems and locations. Digital camera and NDVI networks need to be developed while the use of snow depth sensors relies on existing networks
- Data archiving and common processing techniques allow site intercomparison, upscaling, ...

Concluding

- Sensor based approach lies in between field observations and remote sensing data. Good spatial integration: from ecosystem to individuals
- Seasonal trajectories from spring development to autumn senescence at daily temporal resolution
- Provide quantitative data that can be linked to ecosystem variables and processes (e.g. GPP, biomass, grass height)
- Sensor network can be used to analyse different ecosystems and locations. Digital camera and NDVI networks need to be developed while the use of snow depth sensors relies on existing networks
- Data archiving and common processing techniques allow site intercomparison, upscaling, ...

Concluding

- Sensor based approach lies in between field observations and remote sensing data. Good spatial integration: from ecosystem to individuals
- Seasonal trajectories from spring development to autumn senescence at daily temporal resolution
- Provide quantitative data that can be linked to ecosystem variables and processes (e.g. GPP, biomass, grass height)
- Sensor network can be used to analyse different ecosystems and locations. Digital camera and NDVI networks need to be developed while the use of snow depth sensors relies on existing networks
- Data archiving and common processing techniques allow site intercomparison, upscaling, ...

Concluding

- Sensor based approach lies in between field observations and remote sensing data. Good spatial integration: from ecosystem to individuals
- Seasonal trajectories from spring development to autumn senescence at daily temporal resolution
- Provide quantitative data that can be linked to ecosystem variables and processes (e.g. GPP, biomass, grass height)
- Sensor network can be used to analyse different ecosystems and locations. Digital camera and NDVI networks need to be developed while the use of snow depth sensors relies on existing networks
- Data archiving and common processing techniques allow site intercomparison, upscaling, ...

Concluding

- Sensor based approach lies in between field observations and remote sensing data. Good spatial integration: from ecosystem to individuals
- Seasonal trajectories from spring development to autumn senescence at daily temporal resolution
- Provide quantitative data that can be linked to ecosystem variables and processes (e.g. GPP, biomass, grass height)
- Sensor network can be used to analyse different ecosystems and locations. Digital camera and NDVI networks need to be developed while the use of snow depth sensors relies on existing networks
- Data archiving and common processing techniques allow site intercomparison, upscaling, ...

Thanks for your attention

e.cremonese@arpa.vda.it

Questions?