Linking near surface remote sensing of plant phenology to ecosystem functioning: current state and perspectives from PhenoCam networks

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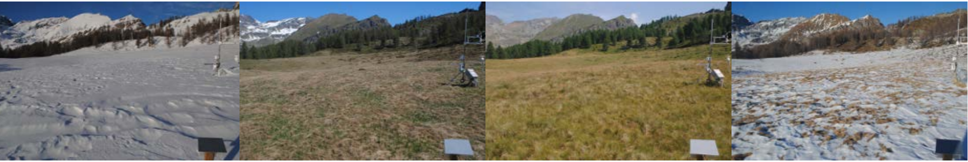
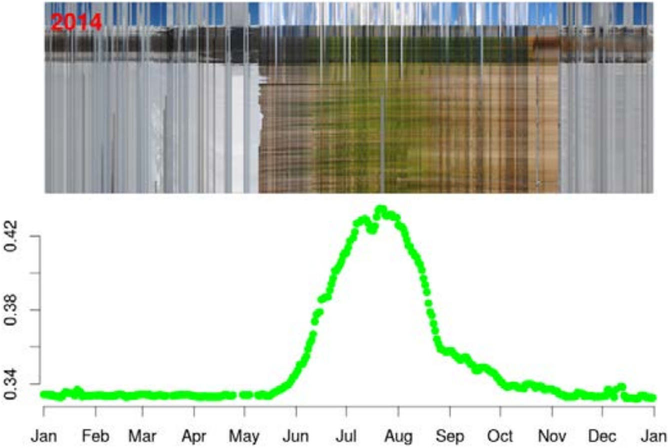


Optimise Final Conference - 21 Feb 2018

Background

- ✓ Use of digital camera to track **canopy phenology**
- ✓ Phenology is a key regulator of ecosystem processes and biosphere feedbacks to climate
- ✓ First applications date back to 2007 (Richardson *et al.* Oecologia, 2007)

Background


2014
0.34
0.38
0.42
Jan
Feb
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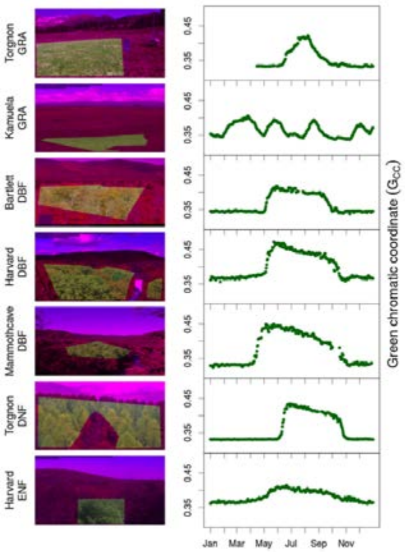
what we have learned so far

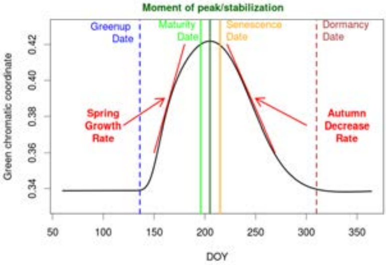


- ✓ **Greenness Index** (GCC=G/(R+G+B)): has proven to be an effective index over a wide range of ecosystems
- ✓ **setup**: camera model and installation instructions
- ✓ **processing**: tested filtering, fitting and phenophases estimation procedures
- ✓ **typical applications**: comparison with ground observations, evaluation of remote sensing phenology products, productivity, canopy properties, ...

Processing

Typical processing workflow

e.g. phenopix R package (Filippa *et al.* 2016)

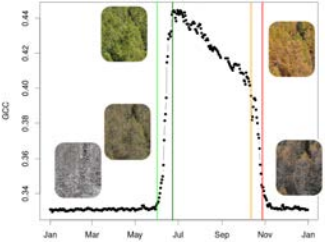


- ✓ ROI definition
- ✓ RGB data extraction and VIs (*e.g.* GCC, GEI, RCC, ..) computation
- ✓ filtering
- ✓ curve fitting
- ✓ estimation of phenological phases dates

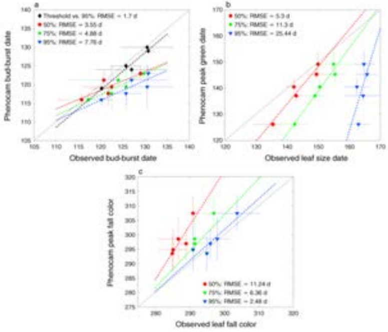
Phenocam vs. field observations

phenocam *vs.* ground observations

- ✓ spring RMSE: 1-8 days
- ✓ autumn phases RMSE: 4-16 days



Larch forest in the Alps

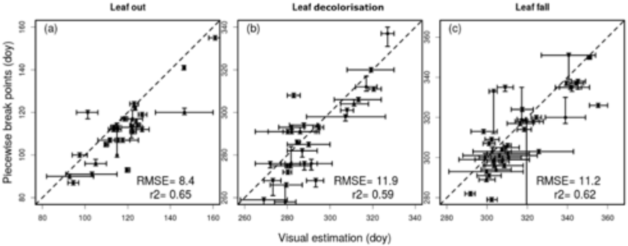


Keenan *et al.* 2014

Phenocam vs. field observations

✓ phenocam *vs.* visual image inspection

✓ **good accuracy** for spring phases and **lower accuracy** for autumn phases

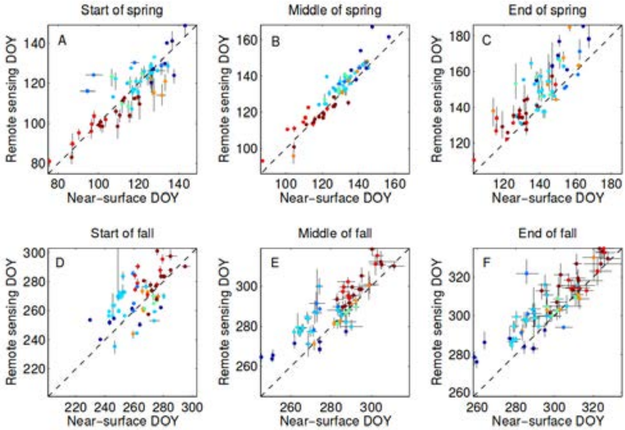


Wingate *et al.* 2015

Evaluation of remote sensing phenology products

✓ phenocam dates *vs.* RS dates: MODIS and AVHRR

✓ EVI has smaller uncertainties than NDVI + higher accuracy for spring phases + differences decrease with fractional forest cover



Klosterman *et al.* 2014

Evaluation of remote sensing phenology products

- ✓ phenocam dates *vs.* Landsat phenology algorithm (LPA)
- ✓ better agreement for spring phases than for autumn phases

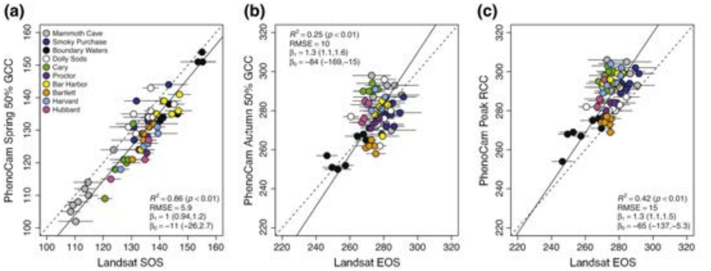


Fig. 4. Relationships between Landsat- and PhenoCam-derived SOS (a) and EOS (b and c) dates across PhenoCam sites. Dashed lines are 1:1 and solid lines are reduced major axis (RMA) regression models where between-site correlations are statistically significant ($p < 0.01$). RMA slope ($β_1$) and intercept ($β_0$) coefficients are provided with 95% confidence intervals. Horizontal bars indicate one standard deviation in SOS or EOS during each site year across a 500 m radius centered on each camera location.

Melaas *et al.* 2016

Seasonality of canopy photosynthesis

- ✓ canopy greenness is often in close agreement with photosynthesis (e.g. Toomey *et al.* 2015)
- ✓ several examples of productivity modelling: Hufkens *et al.* 2016, Migliavacca *et al.* 2011, Knocks *et al.* 2017, ...

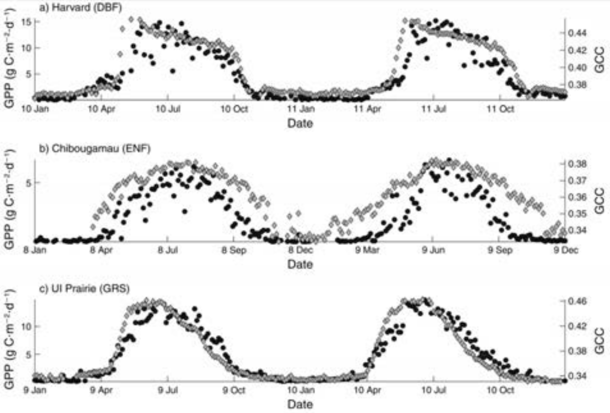
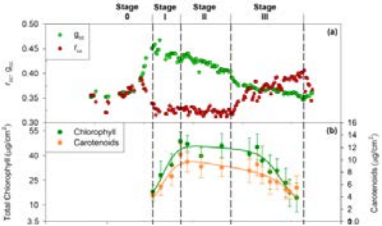


FIG. 2. Time series of daily GPP (black circles, g $C \cdot m^{-2} \cdot d^{-1}$) and GCC (green chromatic coordinate, gray diamonds) for (a) deciduous broadleaf forest (DBF); (b) evergreen needleleaf forest (ENF); and (c) grassland/crops (GRS). Two characteristic years of data are featured in each subplot. See *Methods* for acronyms.

Toomey *et al.* 2015

Canopy properties



Yang *et al.* 2014

✓ few studies evaluated the relation between GCC and canopy physiological, biochemical, structural properties (e.g. Yang *et al.* 2014, Keenan *et al.* 2014, Wingate *et al.* 2015, Luo *et al.* 2018 submitted)

✓ combined effect of leaves color and canopy structure (i.e. LAI) and the colour of the background

✓ GCC insensitive to LAI changes above 2-2.5 → temporal mismatch or nonlinear relationship

✓ ... further studies needed

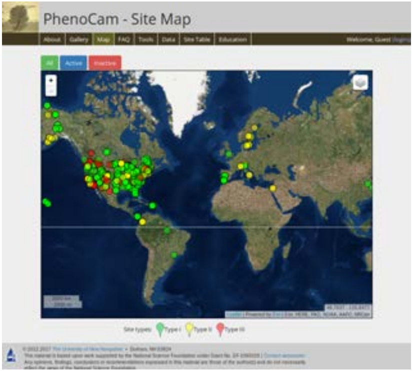
Phenocam networks and dataset availability

Great opportunities thanks to the increasing number of observation sites, networks and datasets (Brown *et al.* 2016)

- ✓ **Phenocam USA**
- ✓ **ICOS ecosystem stations**
- ✓ **other EU networks**
- ✓ **Australian phenocam network**
- ✓ **Phenological Eyes Network (PEN)**

Phenocam USA

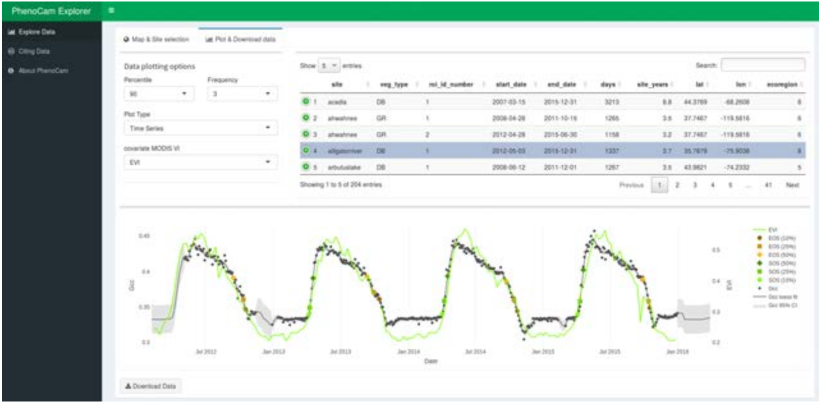
phenocam.sr.unh.edu



- ✓ > 450 sites
- ✓ data set: **PhenoCam Dataset v 1.0** under release: explore.phenocam.us
- ✓ > 750 site-years from different vegetation zones (392 DBF, 121 GRA, 80 ENF)
- ✓ quality-controled
- ✓ seasonal greennees trajectories and phenophases dates
- ✓ Richardson *et al.*, Tracking vegetation phenology across diverse North American biomes using PhenoCam imagery. Scientific Data, in press

Phenocam USA

explore.phenocam.us



contact Andrew Richardson or Koen Hufkens for details

ICOS ecosystem stations

www.icos-etc.eu/icos

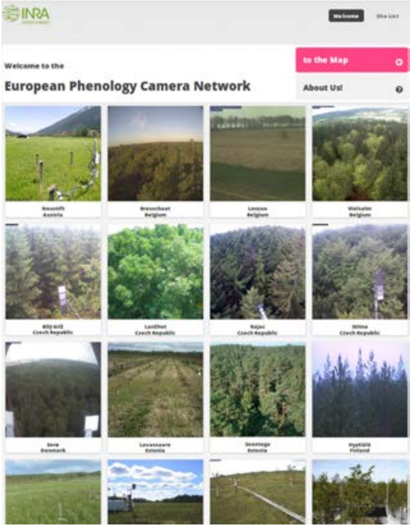
- ✓ network under deployment
- ✓ station labelling phase
- ✓ phenocam protocol and instructions nearly ready
- ✓ camera model: NetCam SC 5MP IR, StarDot Technologies
- ✓ centralized processing and data distribution @ETC

European Phenology camera network

> 70 sites

european-webcam-network.net

Wingate *et al.* 2015

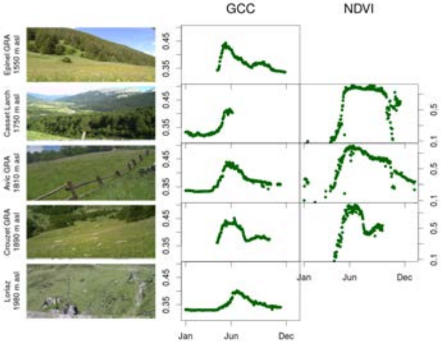


Other EU networks

✓ Alpine network (IT-FR)

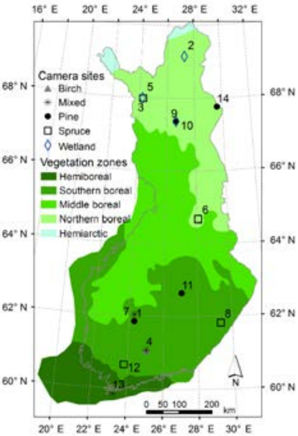
✓ 15-20 active sites

✓ coupled phenocam and field NDVI sensors



Other EU networks

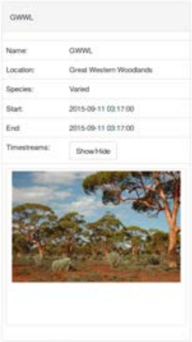
- ✓ Finland network: 31 sites
  - ✓ Peltoniemi et al. 2018



- ✓ SITES spectral network: Swedish Infrastructure for Ecosystem Science
  - ✓ www.fieldsites.se

Australian phenocam network and TERN SuperSites

Brown *et al.* 2016, Moore *et al.* 2016

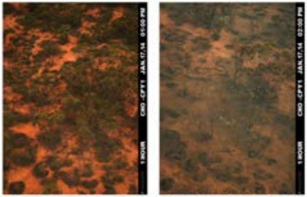


TERN SuperSites Ecosystem Change Observatory

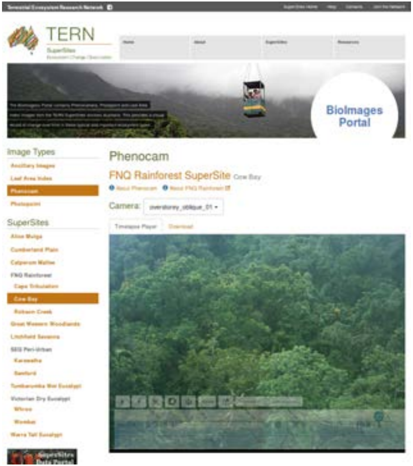
phenocam.org.au

- ✓ intensive field station in typical Australian biomes
- ✓ field and sensor monitoring
- ✓ plant physiological measurements, OzFlux system

Australian phenocam network and TERN SuperSites



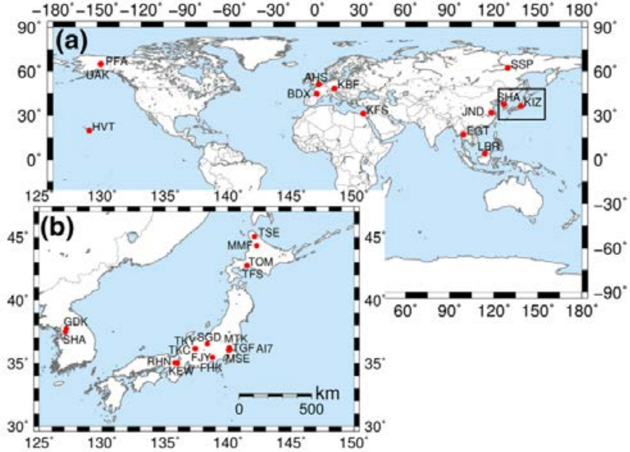
Phenocam images from the Calperum Mallee SuperSite just prior to and just after the fire, Jan 2014



- ✓ Phenocams deployed on OzFlux towers and sub-canopy
- ✓ Sentinal Camera: Raspberry PI based with USB camera, site conditions and low power use
- ✓ Image repository: bioimages portal **bioimages.tern.org.au**
- ✓ LAI, photogrammetry with drones, ...
- ✓ more info @ Tim Brown and Michael Liddell

Phenological Eyes Network (PEN)

Nasahara *et al.* 2015

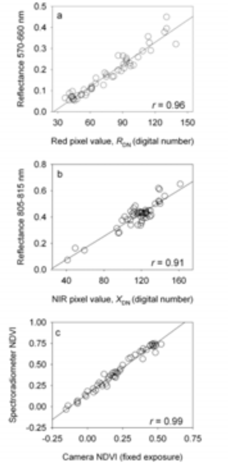


www.pheno-eye.org

New applications and perspectives

- ✓ use of NIR-enabled cameras to compute camera NDVI (CamNDVI)
- ✓ GPP phenology with GCC, CamNDVI or new phenocam-base indices (e.g. NIR_v)
- ✓ spatial analysis
- ✓ impact of climate extremes
- ✓ UAV

Camera NDVI



Petach *et al*, 2014

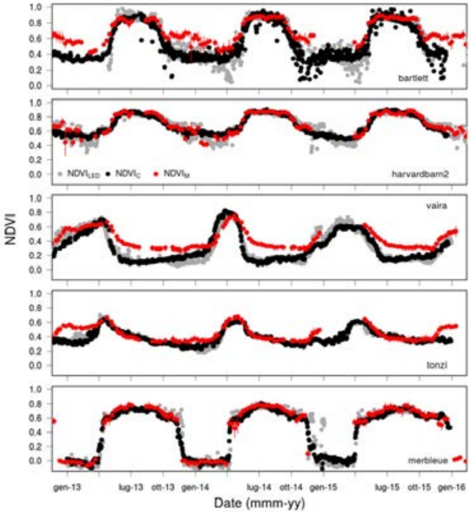
✓ near-infrared enabled cameras (e.g. StarDot NetCam SC 5MP IR camera)

✓ sequential capture of **visible-only (RGB)** and combined **visible+NIR** images

✓ calculate camera-based NDVI (CamNDVI) (Petach *et al.* 2014)

Camera NDVI

NDVI derived from near-infrared-enabled digital cameras: Applicability across different plant functional types, Filippa *et al.* 2017



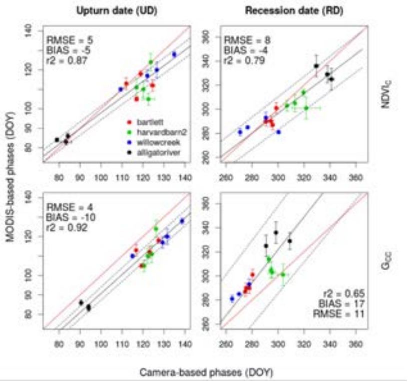
- compare CamNDVI to MODIS NDVI and ground NDVI measures

⇓

✓ CamNDVI is an accurate estimate of NDVI

Camera NDVI

Filippa *et al.* 2017

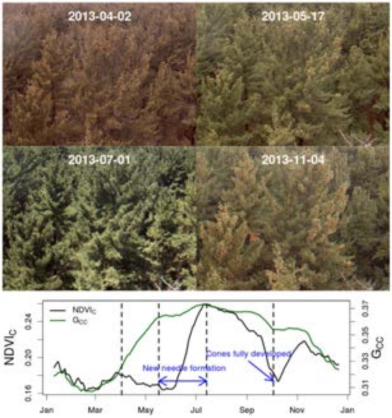


- camera-derived phenological transition dates *vs.* MODIS Land Cover Dynamics Product (MCD12Q2)

✓ higher accuracy CamNDVI-MCD12Q2 in autumn phases

Camera NDVI

Filippa *et al.* 2017



- compare CamNDVI and GCC seasonal trajectories

✓ GCC is more sensitive to changes in leaf color and CamNDVI is more sensitive to changes in leaf area/canopy structure

✓ CamNDVI and GCC provide complementary informations in particular in ENF sites (*P. strobus*)

GPP phenology with NIR_v


SCIENCE ADVANCES | RESEARCH ARTICLE

ENVIRONMENTAL SCIENCE

Canopy near-infrared reflectance and terrestrial photosynthesis

Grayson Badgley,[1,2]* Christopher B. Field,[1,2] Joseph A. Berry[1]

Global estimates of terrestrial gross primary production (GPP) remain highly uncertain, despite decades of satellite measurements and intensive in situ monitoring. We report a new approach for quantifying the near-infrared reflectance of terrestrial vegetation (NIR_v). NIR_v provides a foundation for a new approach to estimate GPP that consistently untangles the confounding effects of background brightness, leaf area, and the distribution of photosynthetic capacity with depth in canopies using existing moderate spatial and spectral resolution satellite sensors. NIR_v is strongly correlated with solar-induced chlorophyll fluorescence, a direct index of photons intercepted by chlorophyll, and with site-level and globally gridded estimates of GPP. NIR_v makes it possible to use existing and future reflectance data as a starting point for accurately estimating GPP.

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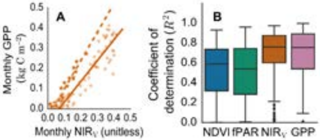


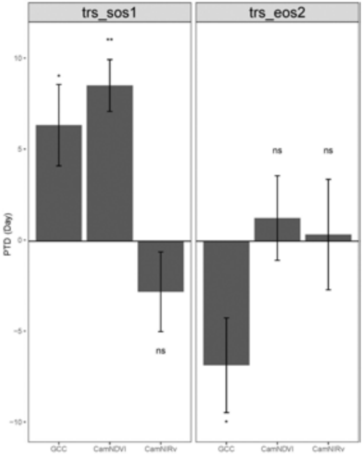
✓ NIR_v = NDVI x NIR reflectance

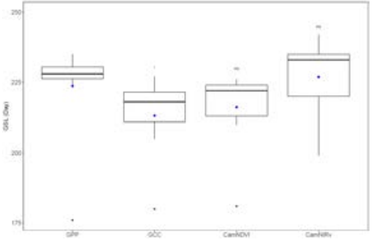
✓ Monthly MODIS NIR_v has a higher correlation with globally gridded GPP than GOME-2 SIF and MODIS NDVI (Fig.2 and Fig.3)

✓ NIR_v describes the relationship between canopy light capture and GPP

GPP phenology with NIR_v

GPP phenology using phenocam NIR_v: first results from Mediterranean tree-grass ecosystems (ES-Lm1, ES-Lm2, ES-Alb), Luo *et al.* in prep



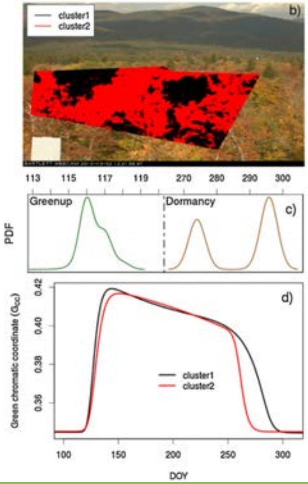


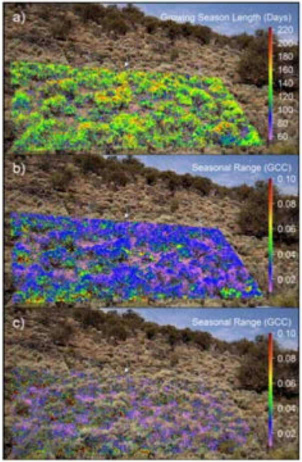
- ✓ NIR_v increases accuracy in the estimation of GPP phenology compared to GCC and CamNDVI
- ✓ expanding the analysis in Ameriflux sites using phenocam dataset
  - ✓ more info @ Mirco Migliavacca and Yunpeng Luo

Spatial analysis: potential to monitor biodiversity

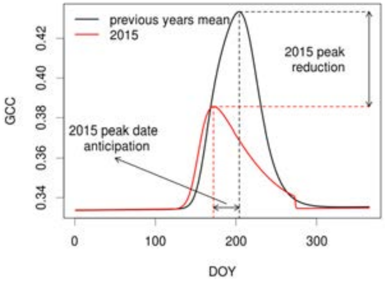
✓ clustering based on phenological diversity
Filippa *et al.* 2015

✓ phenological mapping
Snyder *et al.* 2017





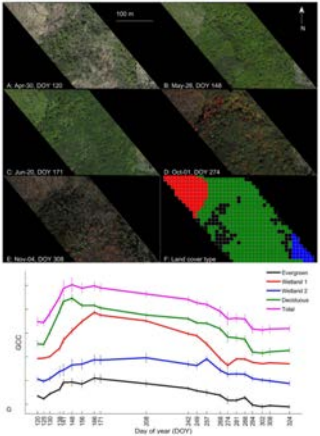
Impact of climate extremes



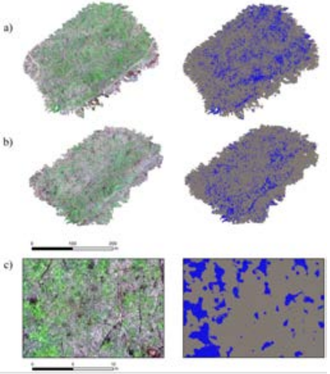
- ✓ **GCC anomalies** can be used to detect climate extreme impacts on functional or structural canopy properties
- ✓ e.g. summer heat wave in a mountain grassland. Impacts on canopy photosynthesis parameters (i.e. Amax) and strutural canopy properties (LAI and biomass), Cremonese *et al.* 2017
- ✓ examples of **late frost** impact: Menzel *et al.* 2015, Hufkens *et al.* 2012

UAV

✓ plant communities high resolution phenology maps (Klosterman *et al.* 2018)



✓ understory invasive species detection based on GCC threshold (Leduc *et al.* 2018)



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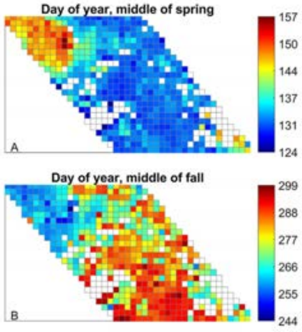

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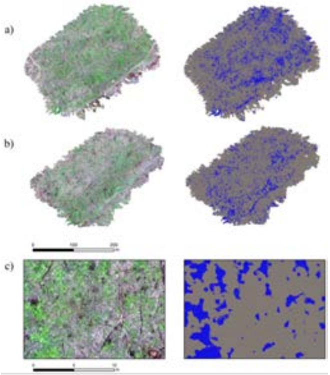


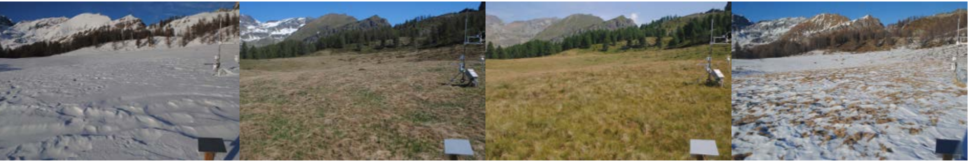
Conclusions

- ✓ GCC and CamNDVI provide complementary information to improve the understanding of phenological cycles, dynamics of ecosystem functions and their response to climate variability and extreme events
- ✓ potential to monitor biodiversity with phenocam spatial analysis and combined with drones, dynamics of photosynthesis and provide data for phenology models (e.g. Hufkens *et al.*, 2018, phenoR)
- ✓ direct link with structural and functional traits requires further attention
- ✓ great opportunities emerging from new sites deployment, network establishment, data archiving and data release (standard site set-up and processing allowing cross site comparison)
- ✓ EU initiatives could benefit from a trans-national coordination, beside ICOS sites. Opportunities for a new COST action?

Thank you for the attention

e.cremonese@arpa.vda.it

www.arpa.vda.it/climate-change-impacts

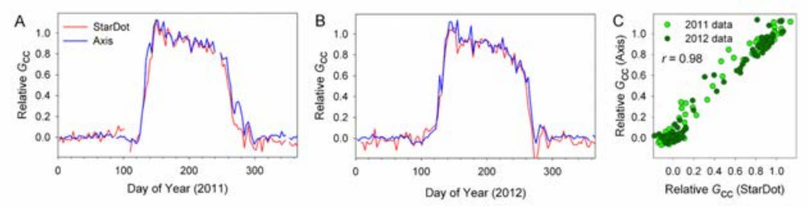


S1: camera model effect

✓ spring phases differences 0.4±1.4d

✓ autumn phases differences 1±0.7d

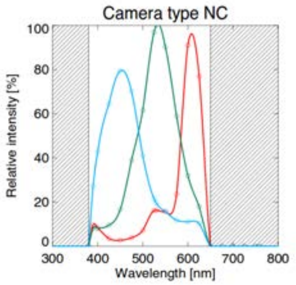
Richardson *et al*. Scientific Data, in press



S2: spectral sensitivity and sensor response

✓ B: 430-515 nm, G: 510-570 nm, R: 575-710 nm

Wingate *et al.* 2015, Petach *et al.* 2014



✓ Sensor response function for 10 StarDot cameras of different age and different field deployment time

Richardson *et al.* Scientific Data, in press