R at ARPA VdA, multiple approaches for monitoring plant phenology

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ARPA VdA: Climate Change Area

Monitoring climate change effects on natural systems in Aosta Valley

ARPA VdA: Climate Change Area

Glaciers mass balance,
Phenology ...
R user (coming soon!)

Snow modeling
and data management ...
R user

Permafrost dynamics ...
R user

Phenology, carbon
fluxes,
Snow modeling ...
R user

Carbon dynamics in terrestrial
ecosystems and phenology ...
R user

Soil processes and
snow chemical properties ...
R user

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ARPA VdA: Climate Change Area

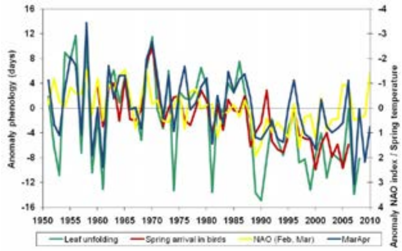
We use **R on Linux (Ubuntu)** operating system in:

- data management and processing
- data evaluation and check through automatic plots generation
- data analysis
- data modeling
- R - Grass for spatial data analysis

Focusing on Vegetation phenology

Phenology is the study of **recurring biological events** in plants life cycle and the causes of their timing e.g. bud burst, leaf flushing, flowering, leaf yellowing...

Phenology is a clear and useful **indicator of climate change** → long-term data, easy to communicate, comprises different methods..(Menzel, 2002)



Walther et al., 2002, Nature

How we can **monitor** shifts in vegetation phenology?

1. Field observations
2. Phenology of ecosystem processes
3. Remote sensing

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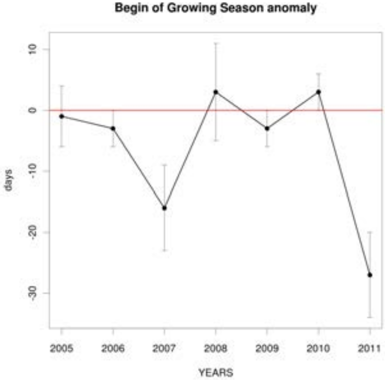
Method: Observing phenological phases in the field



How we can **monitor** shifts in vegetation phenology?

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Method: CO_2 flux measurements

At ARPA VdA the relationship between vegetation phenology and the ecosystem processes was monitored since 2008 by evaluating the **vegetation-atmosphere exchange of CO_2** at two alpine ecosystems

Method: CO_2 flux measurements

Gross Primary Production (GPP): the gross uptake of carbon by photosynthesis;

Ecosystem Respiration (Reco): the combined autotrophic and heterotrophic respiration;

Net Ecosystem Exchange (NEE): the net exchange of CO_2 between the ecosystem and the atmosphere, it is the balance between assimilatory and respiratory processes.

Method: CO_2 flux measurements

Eddy covariance → direct measure of Net Ecosystem CO_2 Exchange **(NEE)** between the ecosystem and the atmosphere thus allowing the evaluation of the relationship between carbon and water cycle and environmental conditions.

- Sampling frequency **10 Hz**
  - Averaging time **30 min**

Assumptions

$$\Downarrow$$

$$F = \overline{\rho_a{}'}\ \overline{w'c'}$$

Method: CO_2 flux measurements

Eddy covariance technique allows measurements of CO_2 flux at the ecosystem scale

Global network of micrometeorological flux measurement sites, **FLUXNET**, has been formed in order to meet the emerging need for long-term studies of the biosphere-atmosphere exchange of CO_2

http://www.fluxnet.ornl.gov/

Data management: R code workflow

eddy covariance → 48 hh x 365 days = 17520 measurements/year The method

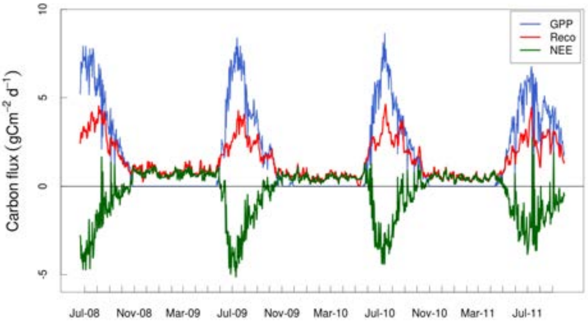
requires:

- data quality evaluation
- corrections
- filtering procedures
- data gap-filling
- ...

→ **R script** to load and manage huge datasets and convert them into **.Rdata** files = considerably **light**, easy to manage and treat by **every R user**

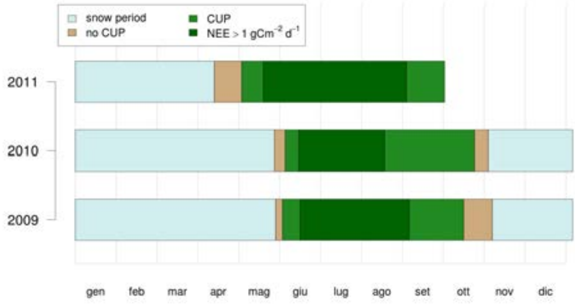
Data analysis: time-courses

Grassland: time-courses of carbon flux components



Data analysis: phenological indicators

Grassland: phenological indicators of the beginning, the length and the end of season



`rect(xleft, ybottom, xright, ytop, col = 'colorname'...)`

Data analysis: Wavelet coherence analysis

- Ecosystem processes are influenced by weather variables at **multiple temporal scales**
- Simple relationships between meteorological variables and fluxes often weakly reveal the underlying controls

Temperature
Light (PAR)
Water
Phenology
Snow

⇒ ⇐

Daily
Weekly
Seasonal
Yearly

⇒ ⇐

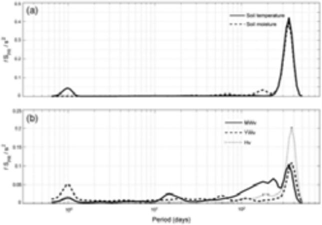
Ecosystem processes

Data analysis: Wavelet coherence analysis

Analysis in the time-frequency domain identify **periodicities** in a signal and can reveal when different variables are relevant for driving processes

→ **Wavelet coherence analysis**:

correlation between the periodicities of environmental factors time-series and those of carbon cycle processes (*Vargas et al., 2011*)



Data analysis: Wavelet coherence analysis

Wavelet coherence analysis is applied to investigate coherencies between GPP from eddy covariance and: air temperature, soil temperature, SWC, and PAR

→ **Function** `wco()` from the package **Sowas** (SOftware for Wavelet analysis and Synthesis):
http://tocsy.agnld.uni-potsdam.de/wavelets/

→ **input data**: half-hourly time-series of GPP and meteorological variables
→ **graphical output**: temporal localisation of correlations between GPP and the meteorological factor considered

Wavelet coherence analysis

Example: Function `wco()`

```
#load required package:
library(Sowas)
GPP_wco <- wco(ts1, ts2, s0=1,sw=0.4,tw=1.2,noctave=8,
nvoice=16,siglevel = 0.95)
```

ts1 = first time series object to be transformed

ts2 = second time series object to be transformed

s0 = lowest calculated scale in units of the time series

noctave = number of octaves

nvoice = number of voices per octave

sw= length of smoothing window in scale direction is 2*sw*nvoice+1

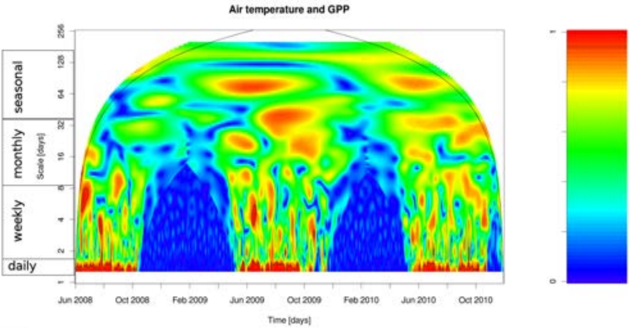
tw = length of smoothing window in time direction is 2*s*tw+1

...

Data analysis: Wavelet coherence analysis

Example:

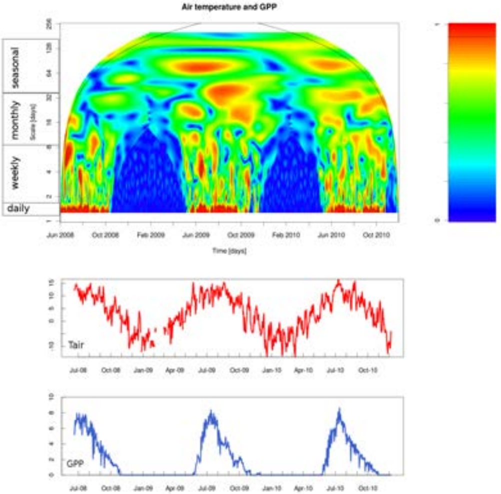
Air temperature and GPP



Example:

Air temperature and GPP

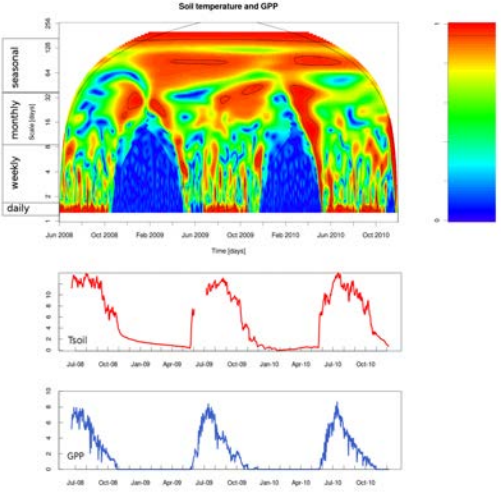
Small scale coherence
(daily cycle)



Example:

Soil temperature and GPP

Small scale coherence
(daily cycle)
Big scale coherence
(seasonal cycle)
Rise after snow melt



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Method: digital repeat photography


Campbell Scientific, Inc

webcam, model CC640 (Campbell Scientific, Inc.), to remotely track changes in grassland phenology, from **June 2009**

Method: digital repeat photography

- **custom R** to process digital images.
- analysis on one specific **ROI**

$$TotalDN = R_{DN} + G_{DN} + B_{DN}$$

$$\boxed{GI = \frac{G_{DN}}{TotalDN}}$$

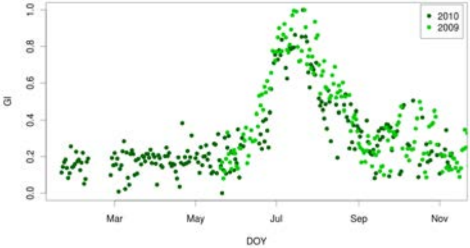
Data analysis: RGB values extraction

Example: Function `read.jpeg ()`

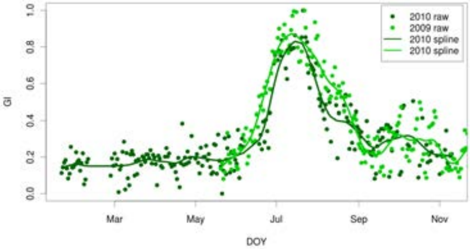
```
#load required packages:
library(rimage)
library(Hmisc)
library(gtools)
img <- read.jpeg(imagefile.jpg)
locator() = Reads the position of the graphics cursor when the
(first) mouse button is pressed.

ROI <-img[(coordinates),]
R <- mean(img[ROI,1])
G <- mean(img[ROI,2])
B <- mean(img[ROI,3])
```

Data analysis: RGB values extraction



Data analysis: fill data gap



```
spline_data<-smooth.spline(time,data,df=df)
```

- Integrating the approaches...

GPP modeling

Integration of **eddy covariance data** and **webcam GI** to evaluate the use of optical indices in describing GPP dynamics

GPP modeling

A **LUE** modeling approach (*Monteith and Unsworth, 2008*) was used in order to estimate ecosystem productivity by **remote sensing** data.
The approach is based on the algorithm **MOD17** (*Heinsch et al., 2006*):

$$photosynthesis = plant\ light\ use\ efficiency \cdot light$$

$$GPP = \varepsilon \cdot fAPAR \cdot PAR$$

$\varepsilon \rightarrow$ estimated

fAPAR$\rightarrow$ estimated

PAR $\rightarrow$ measured

GPP modeling

$$GPP = \varepsilon \cdot \color{red}{fAPAR} \cdot PAR$$

GPP modeling

$$GPP = \varepsilon \cdot fAPAR \cdot PAR$$
$$GPP = \varepsilon \cdot (a_0 + a_1 \cdot GI) \cdot PAR$$

GPP modeling

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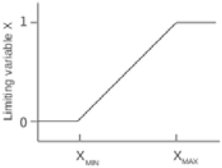
GPP modeling

$$GPP = \varepsilon \cdot fAPAR \cdot PAR$$

$$GPP = \varepsilon \cdot (a_0 + a_1 \cdot GI) \cdot PAR$$

$$GPP = \varepsilon_{max} \cdot f(Ta_{Min}) \cdot f(VPD) \cdot (a_0 + a_1 \cdot GI) \cdot PAR$$



GPP modeling

- **Optimization 2009** → model parameters estimated against observed EC daily GPP, by **simulated annealing** (300 loops), implemented in the R function `optim()` (R stats package)
  Best-fit model parameters selected on the basis of RMSE, EF and R^2
- **Simulation 2010** → 2009 optimized parameters to simulate GPP 2010

GPP modeling

Example: function `optim()`, Simulated Annealing

```
maxit=40000
temp=200
tmax=10
pcontrol=list(maxit=maxit, temp=temp, tmax=tmax)
theta<-c(-5.0, 12.02, 6.50, 35.00, 0.68, 0.8642, -0.0814)
res.GPP <- optim(theta, MOD17, meteo=meteo, obs=obs,
method=‘‘SANN’’, control=pcontrol)
```

GPP modeling

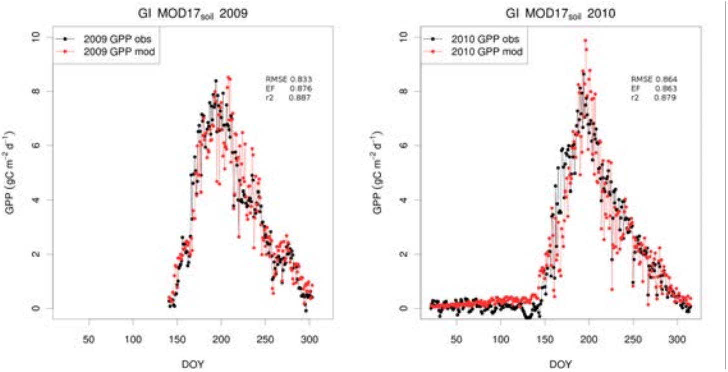
Example: generate functions: `function()`

```
MOD17 <- function(theta, PAR, GI, obs){
Tmmin <- theta[1]
Tmmax <- theta[2]
VPDmin <- theta[3]
VPDmax <- theta[4]
ε <- theta[5]
a <- theta[6]
b <- theta[7]
sim<-(ε*PAR*f(Ta)*f(VPD)*((a*GI)+b))
RMSE <- sqrt(sum((sim-obs)^2)/length(obs))
return(RMSE)
}
```

GPP modeling

VI: digital camera GI

Limiting factors: Tsoil, VPD



Conclusions

- The use of R in our activities allows to **optimize and speed up** long and complex data treatments
- The **total sharing** of R codes in the work group enhances each member knowledge on statistical solutions, available functions, graphical tricks...
- Open source software and operating system in a public agency = **saving money** (no software licences!)
- What we would like to implement in the future?
  → developing and sharing **R packages**

THANKS FOR YOUR ATTENTION

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http://www.phenoalp.eu/

http://www.arpa.vda.it/