4th NECLIME Workshop on Digital Plant Distribution

Institut de Physique, Université de Liège

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Report

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The 4th NECLIME Workshop on Digital Plant Distribution was held in Liège, at the Institut de Physique, Université de Liège, from May 30–31, 2017, and was hosted by Louis François and Alexandra-Jane Henrot. Fourteen scientists from 5 countries attended this very productive workshop of the NECLIME working group on digital plant distribution. The workshop was organised in 4 sessions detailed below, each with introductory talks and round table discussions. Moreover, four presentations on various related topics were given (Marie Dury, Alexandra Henrot, Matthew Pound, Robert A. Spicer).

- Quantification of climate requirements of plant taxa using digital data on plant distribution – chorological resources and their quality (Bruch, Kern, Traiser)
- Sensitive climate variables in palaeoclimate reconstructions (Erdei, Utescher)
- Setting up a standard for the generation of climate data-sets based on digital resources – data handling and statistical procedures (Henrot, Pound)
- The role of CO_2 in triggering climatic requirements of plants (François, Konrad, Spicer)
- Presentations on related topics

We are very grateful to the Past Earth Network (PEN; http://www.pastearth.net) for the financial support allowing us to cover the expenses of six participants. We thank Edward Yorke (PEN) for his kind assistance.

Quantification of climate requirements of plant taxa using digital data on plant distribution – chorological resources and their quality

The first session on Quantification of climate requirements of plant taxa using digital data on plant distribution – chorological resources and their quality discussed possibilities/options to compile quantitative information on climate requirements of extant plant taxa as a prerequisite for NLR approaches to reconstruct past climate and vegetation. To obtain such data from digital sources climatological and plant distribution data need to be available.

- climatological data

With regard to climatological data NELCIME members agreed to rely primarily on the data sets provided by WorldClim. The highest available resolution of 30 arcsec would be the preferred option. However, other climate variables are worth considering (see below). Uncertainties and challenges that come with such data sets (interpolated from meteorological stations, especially with islands and high mountains) have already been addressed earlier by the group (Utescher et al. 2014).

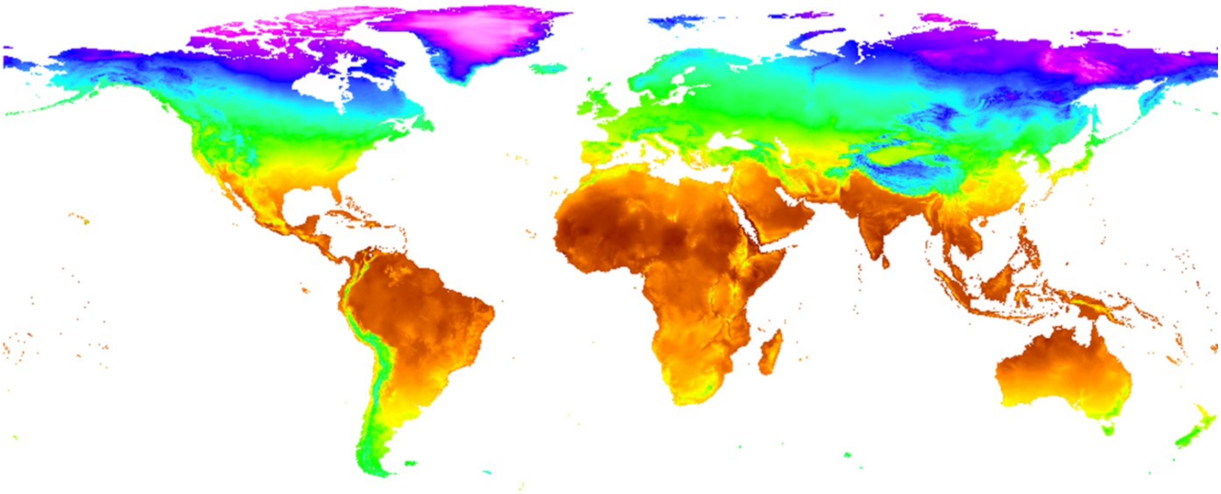

Figure 1: WORLDCLIM dataset providing 19 bioclimatic parameters and monthly data for Tmin, Tmax, and precipitation (55 parameters in total), in 10 arcmin, 2.5 arcmin, 30 arcsec resolution

- chorological data

Digital data on plant distribution are available from different sources that range from georeferenced shapefiles available for download, point data of plant occurrences with coordinates, digital maps (not georeferenced) to simple scans of analogue copies.

The Chorotree website by Christopher Traiser (http://www.chorotree.de; linked on the NECLIME web pages) provides another compilation of digital chorological resources, offering taxa search functions and downloadable, lower-resolving overview maps. GIS-compliant data-sets (shape files) are available on request in higher resolution. Moreover, it was decided to provide an additional list containing web links to digital chorological resources on the NECLIME website.

Data resource	region	Web address
Chorotree	global	http://www.chorotree.de
Tropicos	global	tropicos.org
G-Bif	global	gbif.org
Atlas of Relations Between Climatic Parameters and Distributions of Important Trees and Shrubs in North America; Thompson et al.	USA	https://pubs.usgs.gov/pp/p1650-b/
BIEN	mainly Americas	http://bien.nceas.ucsb.edu/bien/ http://bien.nceas.ucsb.edu/bien/biendata/bien-3/
RAINFOR	tropics	rainfor.org

Atlas Florae Europaeae (AFE)	Europe	http://www.luomus.fi/en/atlas-florae-europaeae-afe-distribution-vascular-plants-europe
EUFORGEN	Europe	http://www.euforgen.org/species/
European Atlas of Forest Tree Species	Europe	http://forest.jrc.ec.europa.eu/european-atlas-of-forest-tree-species/
Vergleichende Chorologie der zentraleuropäischen Flora	Europe	http://www2.biologie.uni-halle.de/bot/ag_chorologie/
African Plant Database	Africa	http://www.ville-ge.ch/musinfo/bd/cjb/africa
Plants of southern Africa	Africa	newposa.sanbi.org

Table 1: Web-sites providing digital chorological information

It is generally advised to rely only on one data source to minimise inconsistencies. However, for most of the analyses in the frame of NECLIME this may not be sufficient.

During the meeting the various advantages and shortcomings of these different types of were discussed. It was generally concluded that point data would be preferred over polygon data.

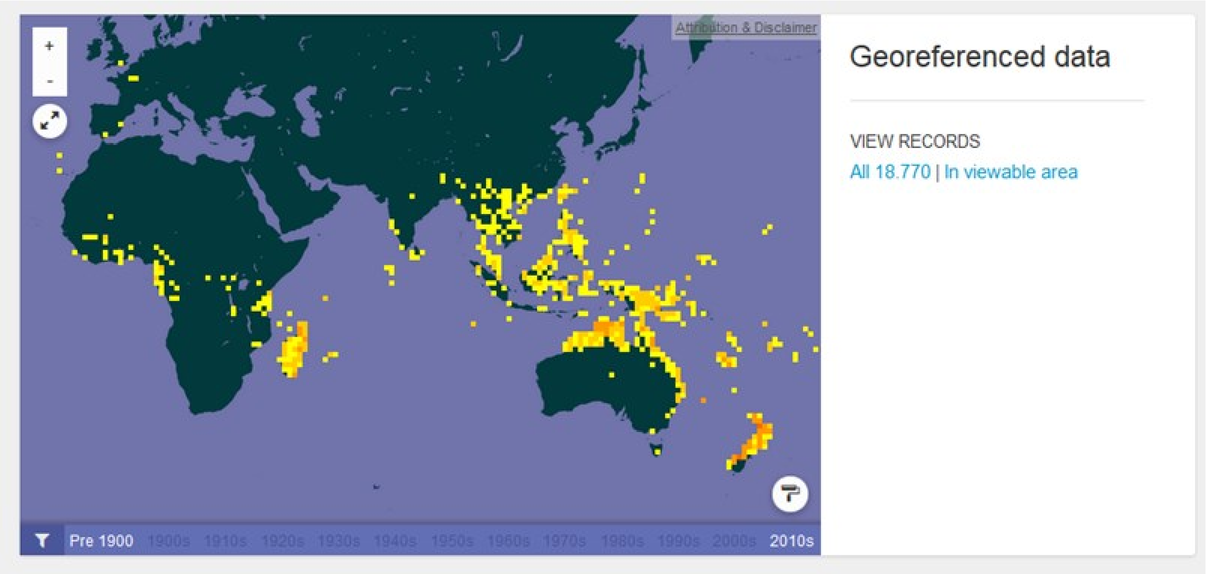

Figure 2: G-Bif point data as e.g. returned for Pandanaceae R. Br. may include, for example, fossil records and garden collections, and therefore require careful filtering before they can be used to extract climatic requirements of plant taxa.

Point data refer to observations or herbarium collections and may have a spatial resolution from a few meters (GPS) to several kilometres. This resolution can be taken into account by using adequate buffers in the analysis of these maps. Although potentially providing the most precise information on plant occurrences point data often do not provide a complete data cover over the entire potential distribution area of a plant taxon, and therefore their usefulness in identifying a density function of plant occurrences with respect to a given climate variable is limited.

The usefulness of raster data such as provided by the Atlas Florae Europaeae depends on the resolution of the grid. The quality of polygon data strongly depends on how they were generated and on the spatial resolution of any primary analogue chorological map on which they are based. Thus, the quality of polygon data is almost impossible to quantify. Nevertheless, they are often the only source of information available.

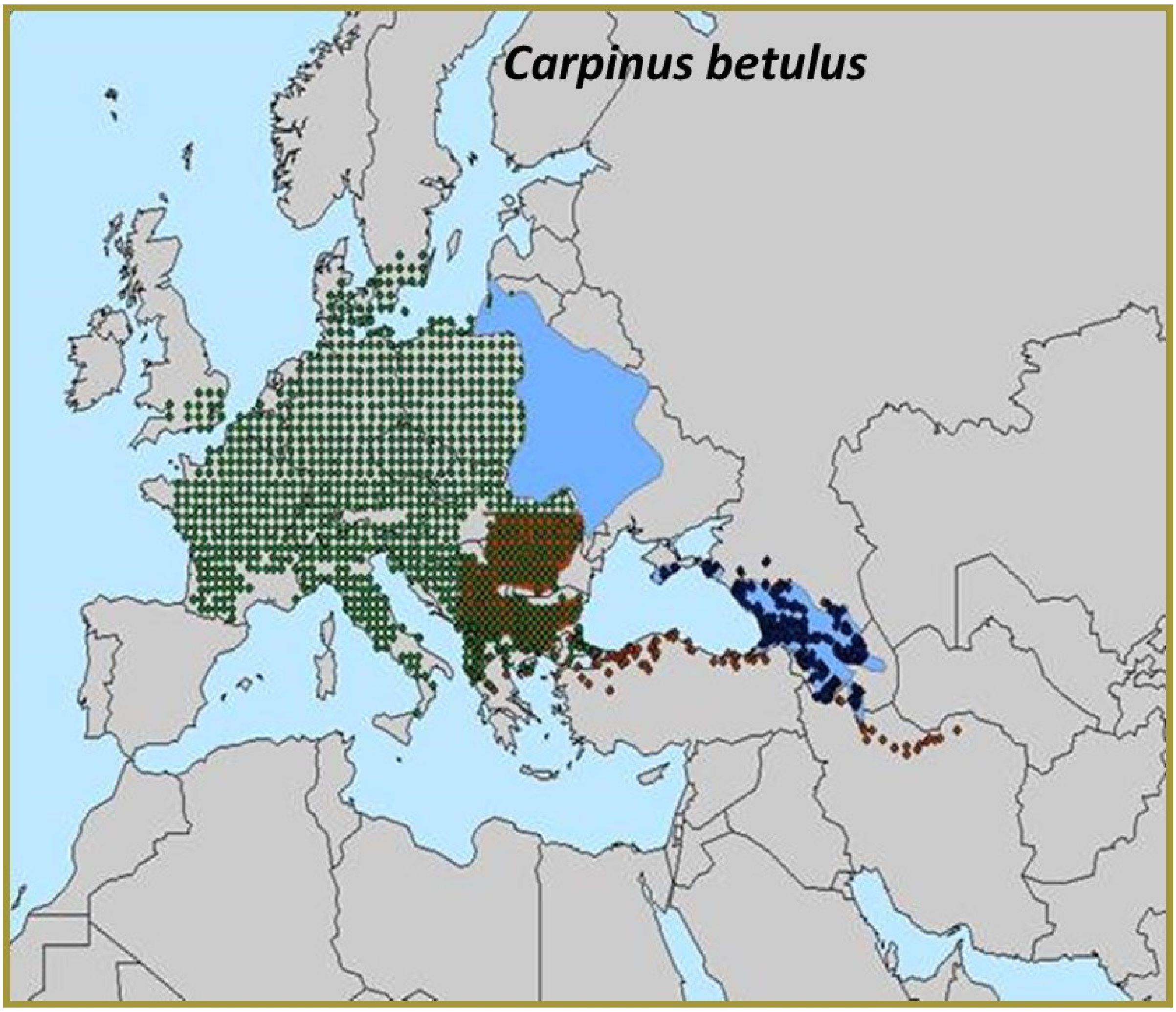

Figure 3: Raster and polygon data for *Carpinus betulus* compiled from various sources.

A description and ranking of the quality of the different sources is recommended. Therefore, quality criteria have to be collected, including point/polygon, resolution, spatial coverage, etc. allowing the reliability of the extracted climate data to be judged. Climate data should furthermore be extracted from each source in single steps to avoid increasing errors.

Considerations on the reliability of raster and polygon data involve their attention to detail in regions with steep gradients (regarding terrain and climatology). In most of the cases, the available data sources do not provide sufficient spatial resolution to adequately resolve plant distribution in regions where there is a steep relief complicated by microclimatic conditions involving, for example, slope, aspect and local snow depth in the cold season. Therefore, suitable filtering with respect to elevation is required when extracting climate data from raster and polygon data sources.

Despite these issues regarding resolution and precision, raster and polygon data provide complete coverage of the distribution area of a given taxon. Thus, data extraction for the climate variables of interest provides frequency distributions (climatic value vs. number of grid points) that can be analysed statistically. Using quantiles, long tails of these distributions can be cut off where they occur. As already detailed in Utescher et al. (2014) plant occurrences in a very minor part of the distribution area grid cells with extreme values may account for a considerable extension of the climatic range of a plant. These occurrences on the one hand refer to small, isolated relic stands, not necessarily in equilibrium with the actual climate, and to occurrences in mountainous regions involving microclimates that are not resolved in any standard climatology. Thus, the use of quantiles is highly recommended when identifying the climatic range for a plant with respect to a given climate parameter within which it may be encountered, with an adequate probability, also in any fossil record.

Sensitive climate variables in palaeoclimate reconstructions

The second session focused on the question of which climatic variables are most important to consider with respect to climate and vegetation reconstructions, especially in view of model-proxy or multi-proxy comparisons. To keep such comparisons as significant as possible the same parameters need to be collected. Moreover, globally, different climatic variables are more important in different regions and therefore have (or have not) to be considered accordingly (Nemani et al. 2003, Seddon et al. 2016).

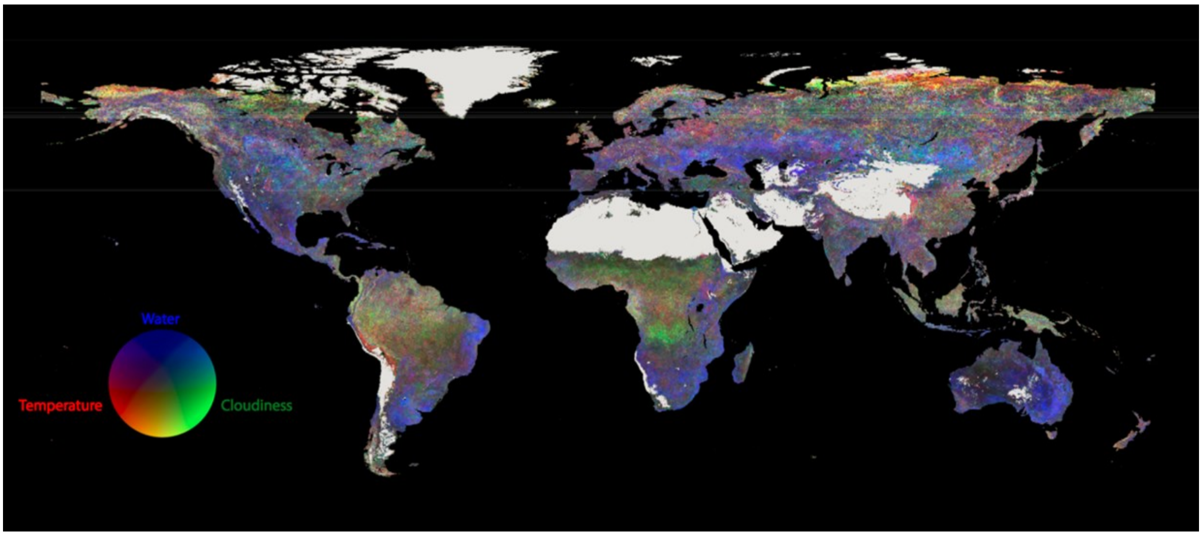

Figure 4: Global contribution of three climate variables to the vegetation sensitivity index (temperature, red; water availability, blue; and cloudiness, green) (from Seddon et al., 2016).

While bioclimatic variables such as daily temperature extremes, temperature for germination, seasonality of climate, and soil water are crucial for the distribution of plants standard variables such as MAT and MAP are essential for data-model inter-comparison. Withal the importance of bioclimatic variables their coupling with the plant distribution is often still unknown/unresolved and more studies in modern ecology are required. Moreover, not all these variables can be calculated from the WorldClim dataset but require data modelling.

			currently used for		
	Climatic variable	unit	climate	vegetation	available from WORLDCLIM
Temperature variables					
	Mean Annual Temperature (MAT)	°C	CA, CLAMP	PFT	x
	Maximum Temperature of Warmest Month	°C			x
	Minimum Temperature of Coldest Month	°C			x
	Mean Temperature of the Coldest Month (CMMT)	°C	CA, CLAMP	PFT	NO
	Mean Temperature of the Warmest Month (WMMT)	°C	CA, CLAMP	PFT	NO
	Mean Temperature of Wettest Quarter	°C			x
	Mean Temperature of Driest Quarter	°C			x
	Mean Temperature of Warmest Quarter	°C			x
	Mean Temperature of Coldest Quarter	°C			x
	Tmin – daily minimum temperature	°C		biome mod.	NO
	Tmax – daily maximum temperature	°C		biome mod.	NO
Precipitaion variables					
	Annual Precipitation	mm	CA		x
	Precipitation of the Wettest Month	mm	CA		x
	Precipitain of the Driest Month	mm	CA		x
	Precipitation of the Warmest Month	mm	CA		NO
	Precipitation of Wettest Quarter (3-WET)	mm	CLAMP		x
	Precipitation of Driest Quarter (3-DRY)	mm	CLAMP		x
	Precipitation of Warmest Quarter	mm			x
	Precipitation of Coldest Quarter	mm			x
Seasonality of Temperature					
	Mean Diurnal Range (Mean of monthly (max temp - min temp))				x
	Isothermality (P2/P7) (* 100)				x
	Temperature Seasonality (standard deviation *100)				x
	Temperature Annual Range (Tmax-Tmin)	°C			x
Seasonality of Precipitation					
	Precipitation Seasonality (Coefficient of Variation)				x
Other parameters important for plant distribution					
	GDD_5	°C		biome mod.	not yet avaliable
	GDD_0	°C			not yet avaliable
	Moisture Availability				not yet avalaible
	Water Stress				not yet avalaible
	Soil water			biome mod.	NO
	Tmax_germ - Maximum temperature for germination	°C		biome mod.	NO
	SWmax_germ – Maximum soil water for germination			biome mod.	NO
	Lenght of the Dry Season	months	CA		NO
	Length of Growing Season (GROWSEAS)	months	CLAMP		NO
	Growing Season Precipitation (GSP)	mm	CLAMP		NO
	Mean monthly GSP (MMGSP)	mm	CLAMP		NO
	Relative Humidity (RH)	%	CA, CLAMP		NO
	Specifi humidity (SH)	(g/kg)	CLAMP		NO
	Enthalpy	0.1*(kJ/kg)	CLAMP		NO

Table 2: Climatic variables relevant in proxy-based palaeoclimate and palaeovegetation reconstructions and in the establishment of PFTs in biome modelling.

Although it is not quite clear yet which variables reflect plant distribution most sensitively, and a strong regional dependency is suggested, GIS functionality and available scripts allow for the extraction of a comprehensive set of variables as far as these are contained in the climatology. Possibilities for making available global data-sets for parameters not available in the open access

WorldClim dataset still need to be discussed within the working group. Twentieth century daily data recalculated can be used to calculate variables not provided by WorldClim.

Setting up a standard of climate data-sets based on digital resources – data handling and statistical procedures

It was decided to make available a NECLIME standard protocol on the NECLIME website. A first draft of this protocol is outlined in the following

- climatological data

For data extraction the use of the open access WorldClim dataset is recommended. We are planning to make available additional datasets for parameters not provided by WorldClim.

- digital chorological resources

As by far not all necessary data are available online our own efforts to geo-reference analogue maps will continue. The Chorotree website compiles this information and will provide shape files to NECLIME members upon request.

- data extraction

For each type of chorological source separate data extraction is recommended because the quality of the results strongly depends on the resolution of the primary data. For point data provided in G-Bif adequate filtering has to be employed. When handling low-resolution raster and polygon data an adequate treatment of areas with steep gradients (altitudinal/hydrological) is crucial, e.g. by using polygons to cut off areas. In the case of detailed information on the region-specific altitudinal range of a plant taxon high-resolving digital elevation models may be useful, however, slope and orientation should be considered as well.

Data extraction should not only include the identification of ranges but should include data on number of grid cells over parameter values. These allow the application of statistical procedures such as the identification of quantiles that can be used to quantify the errors that are related to the different qualities of the maps/extracted climate data. Statistical analyses of the obtained distributions allow us to estimate uncertainties of climatic ranges of plant taxa. These should be provided as a qualifier, together with the climate data-set reconstructed for a plant.

- sharing policy

Analogous to the Palaeoflora data base (www.palaeoflora.de) and with the same data sharing policy, the extracted climate data will be compiled in a joint data-base. In the short-term we will make available first data-sets.

The role of CO_2 in triggering climatic requirements of plants

The increase in CO_2 stimulates the photosynthesis of C3 plants, a process known as CO_2 fertilisation. This stimulation is clear over the short-term, but does it persist over longer time periods? This leads to the question whether climatic (T, P) ranges of species are impacted by CO_2 fertilisation.

- Impacts on stomata (stomatal conductance, stomatal density/ index)

  Ball-Berry relationship: $g = g0 + g1 . An . hs / c_a$

- Stimulation of carboxylation through increase of intercellular (c_i) /chloroplast (c_c) CO2

  Farquhar model:

$$A_1 = \frac{J(I_{APAR}, J_{\max})}{4} \cdot \frac{c_i - \Gamma_*}{c_i + 2\Gamma_*} \qquad A_2 = V_{c,\max} \cdot \frac{c_i - \Gamma_*}{c_i + K_c(1 + \frac{O_2}{K_o})}$$

$$A = \min(A_1, A_2)$$

- Reduction of photorespiration due to the reduction of the O_2/ CO_2 ratio

Figure 5: Mechanisms of CO_2 fertilisation

The effect of CO_2 fertilisation is downregulated by various factors such as acclimation of the plant, biochemical feedbacks and adaption (Smith and Dukes, 2013). FACE experiments (Free Air Carbon Dioxide Enrichment) show response of stomatal conductance to elevated CO_2 and downregulation processes (Ainsworth and Rogers, 2007). Based on studies by Hasper et al. (2017), it can be concluded that the stomatal responsiveness appears to be related to leaf area-specific plant hydraulic conductance. Also photosynthetic capacity appears to be related to the proportion of leaf nitrogen allocated to photosynthesis, rather than to total leaf nitrogen.

To further investigate the impact of CO_2 fertilisation on the climatic ranges of plant species available CARAIB model runs for the present and the future are used to model the distribution of *Fagus sylvatica* and *Olea europaea* (ARPEGE-CLIMATE; transient 1950–2100 with increase in CO_2; transient 1950–2100, with CO_2 kept to 330 ppmv in the vegetation model).

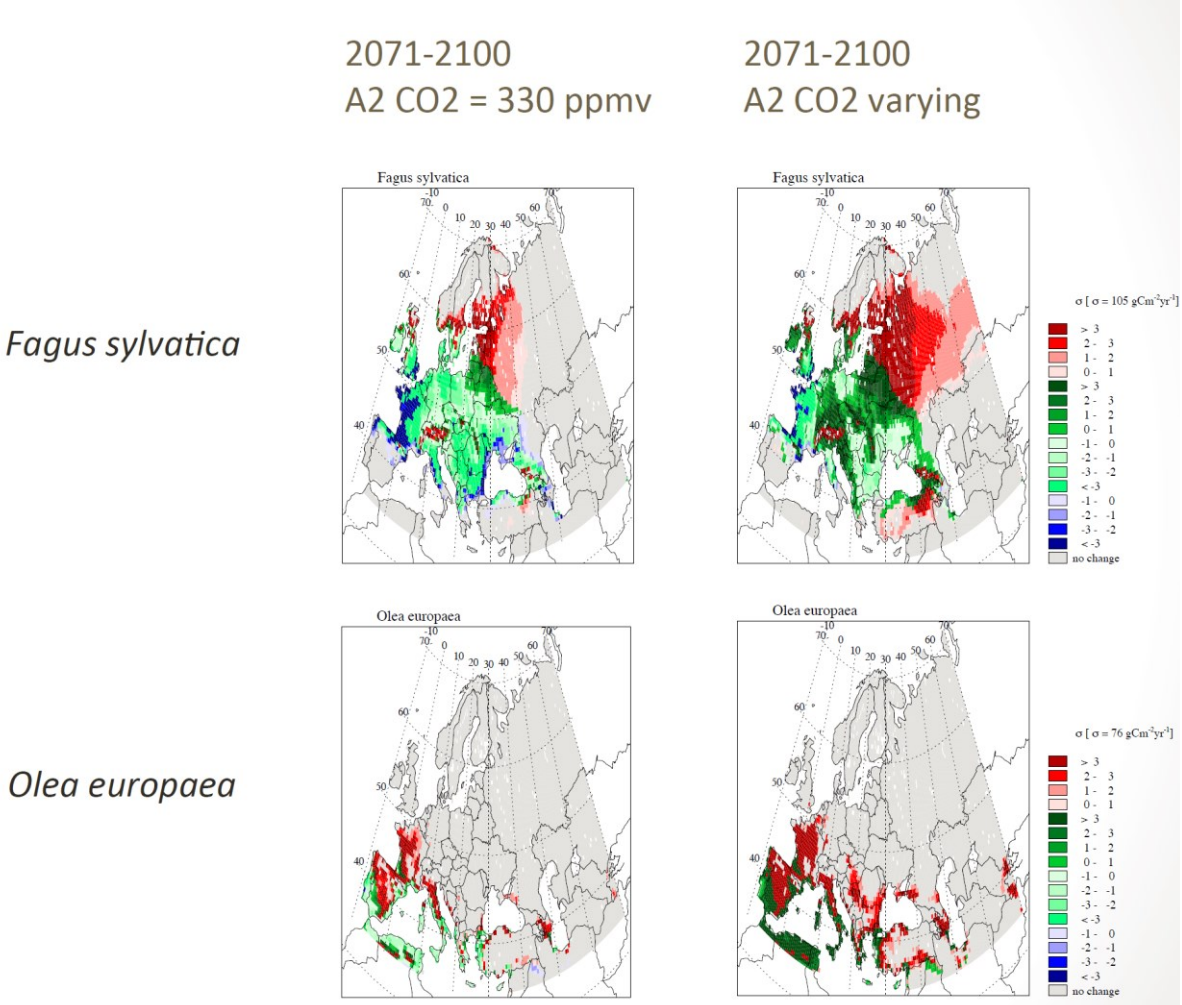

Figure 6: CARAIB simulations for *Fagus sylvatica* and *Olea europaea*

The CARAIB model predicts that CO_2 fertilisation may have an impact on the climatic range of a species. Model data indicate that the effect is very significant for cold month temperature (CMT) and less important for annual mean climatic variables such as MAT and MAP. However, it remains uncertain how real this effect is because acclimation to CO_2 is poorly represented in the model, and only a limited number of biochemical feedbacks have been considered. Also it is suggested that the results are species-dependent, and are also related to the prescribed NPP (Net Primary Production) threshold and the coupling of water and carbon cycles in the model.

CO_2 demand for assimilation ("hunger") and fear of perilously high transpiration ("thirst") are conflicting tasks for a plant. Collecting a given number of CO_2-molecules in a high CO_2 world requires less time than at the present CO_2-level. Hence it can be assumed that in a high CO_2 world, plant water consumption is reduced while in a low CO_2 world, plant water consumption is increased. Thus, under different atmospheric CO_2 conditions, a plant species may have thrived under humidity/soil water conditions which would be unsuitable at present. The CO_2/H_2O-coupling due to leaf anatomy can be quantified by mechanistic models (Konrad et al., 2017).

Atmospheric CO_2 is known from ice cores for the last 800,000 years. Together with data pertaining to (a) atmospheric temperature and humidity and (b) the anatomy of fossil leaves, gas exchange models allow us to calculate V_{cmax} (and its possible variations) as a function of environmental conditions:

$$V_{cmax} = \frac{\nu\eta C_a (1-\kappa)(\kappa C_a + K)}{(\kappa C_a - \Gamma)(\nu + \xi)}$$

Environment: C_a, T
Photosynthesis: q, Γ, K (depending on T)
Leaf anatomy: $\nu, \xi, \eta, \beta;\ \kappa = C_i/C_a$

Following this approach, the question whether V_{cmax} is constant or adapts to variations in CO_2 could be resolved and the "driving forces" of an adaptation could be identified.

Hence, it is assumed that palaeoclimate reconstruction using modern plant distribution and climate requirements (as in the CA) are impacted by past CO_2 levels, however, the induced errors are hard quantify at the present time.

Presentations on various topics

Matthew Pound presented a study on vegetation changes across the Eocene–Oligocene transition in a global context. In this study, the hypotheses of a rapid temperature fall (CO_2 hypothesis) vs. long-term, gradual transition (gateway hypothesis) are tested. The studied records show a pointed regional heterogeneity and in parts almost no change over the time-span regarded, thus favoring the gateway hypothesis.

Robert A. Spicer presented an overview of latest research on Tibetan and Himalayan uplift, and revised dating of the palaeobotanical record in parts of Yunnan, China. Moreover, he introduced recent studies on CO_2 concentrations inside the canopy of forest vegetation of the lower latitudes.

Alexandra Henrot introduced the VULPES (vulnerability of populations under extreme scenarios) project. The project aims to study microrefugial areas of several mountain tree species using fossil records, DNA analysis and modeling, and to evaluate the impact of microrefugia on the persistence of the species through time. The example presented included a high-resolution simulation of the distribution of *Cedrus atlantica* in Morocco with the CARAIB dynamic vegetation model.

Modelling studies on past and present distribution of African biomes were presented by Marie Dury. In this project the distribution of about 80 tropical tree species is considered. Data on modern plant distribution are obtained from the RAINBIO database including records for ca. 25,000 vascular plant species.

With regards to palaeoclimate analyses using the Coexistence Approach (CA) Matthew Pound suggested the use of statistical procedures when analysing coexistence intervals in time series, by using the stack of climatic ranges underlying each Coexistence Interval (CI). A suitable approach would be useful to unravel probable signals of climate change in time series, even in the case of overlapping of CIs in a sample series. Further studies will be conducted (Pound/Utescher).

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