

# Měření úhlové distribuce listů v listnatých porostech za použití UAV

**Jan Pisek**

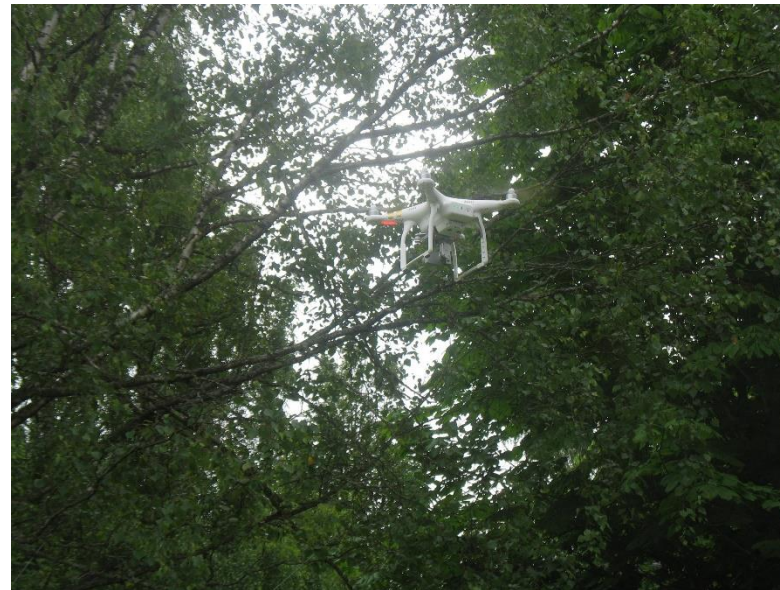


TARTU OBSERVATORY  
space research centre

**Brenden McNeil**



**Harald Lepisk**



## Vzdělání

- 2004 Mgr. Kartografie a geoinformatika; Masarykova Univerzita, Brno, ČR  
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- 2014 - Senior Research Scientist, Tartu Observatory, Estonia

**Zkoumání struktury vegetace pomocí in situ měření a DPZ  
(zaměření na využití víceúhlových měření)**

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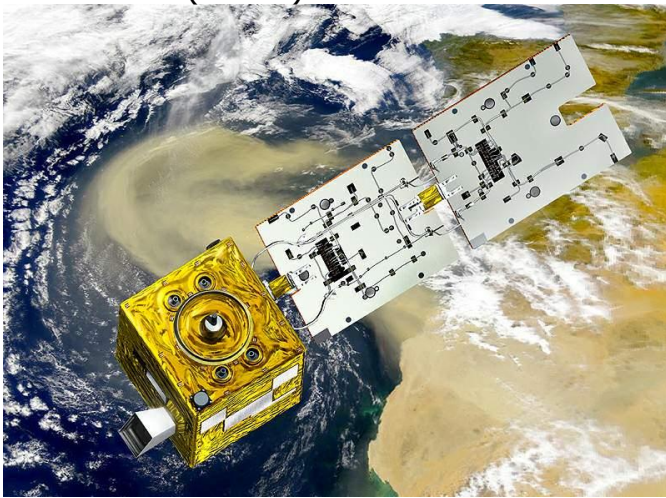
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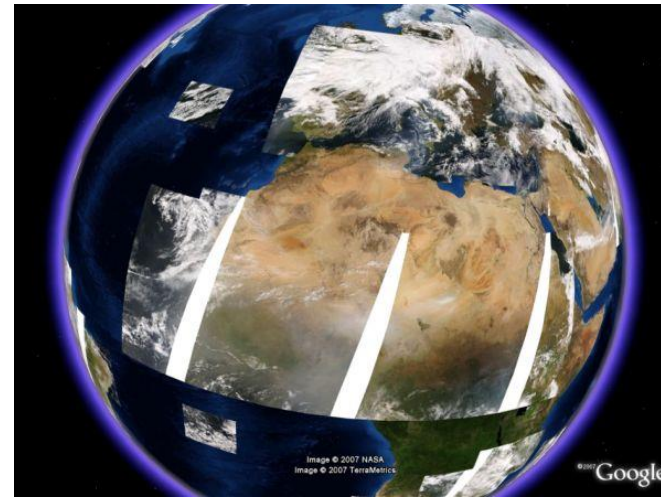
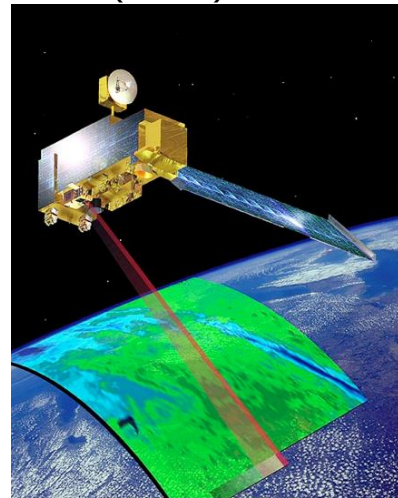
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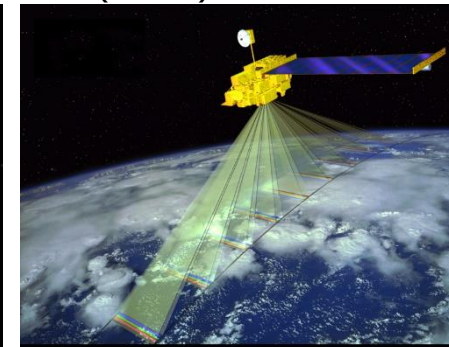
POLDER 1-3 (~6 km)



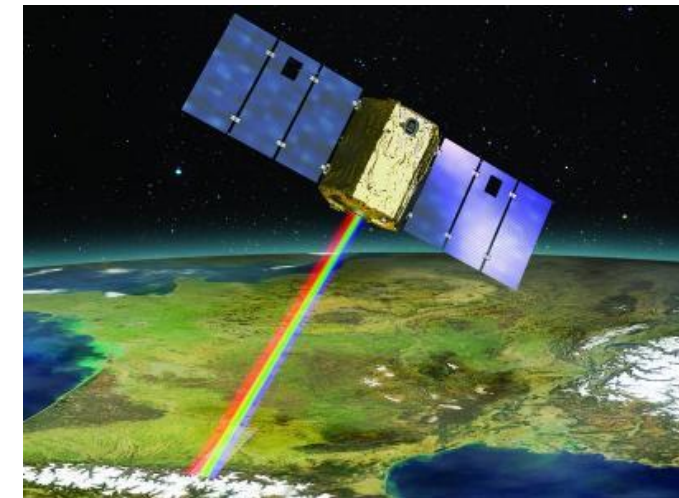
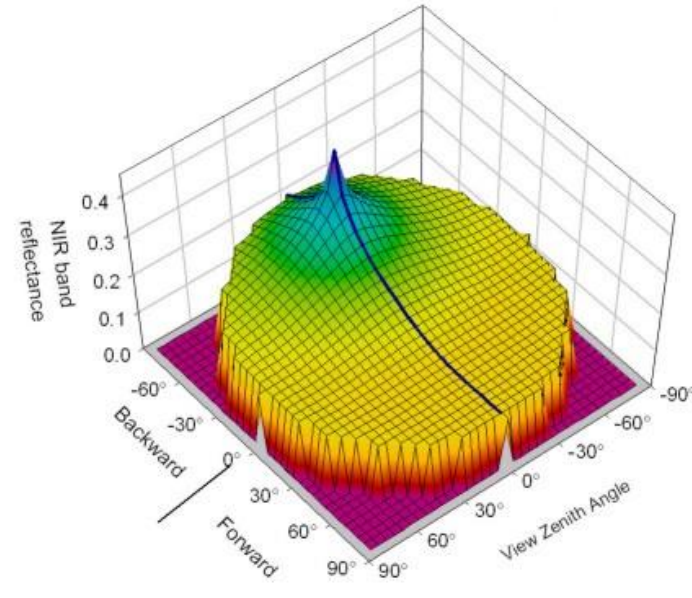
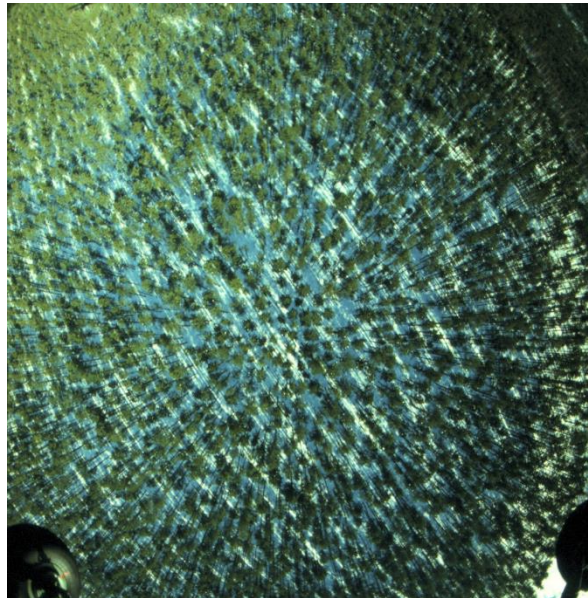
MODIS (500 m)



MISR (275 m)



MISR (Multi-angle Imaging Spectro-Radiometer) instrument on Terra satellite. MISR has nine cameras, each aimed at a different angle to get stereo information for every point on Earth.



Venus microsatellite, 12 spectral bands, 5-10 m every 2 days



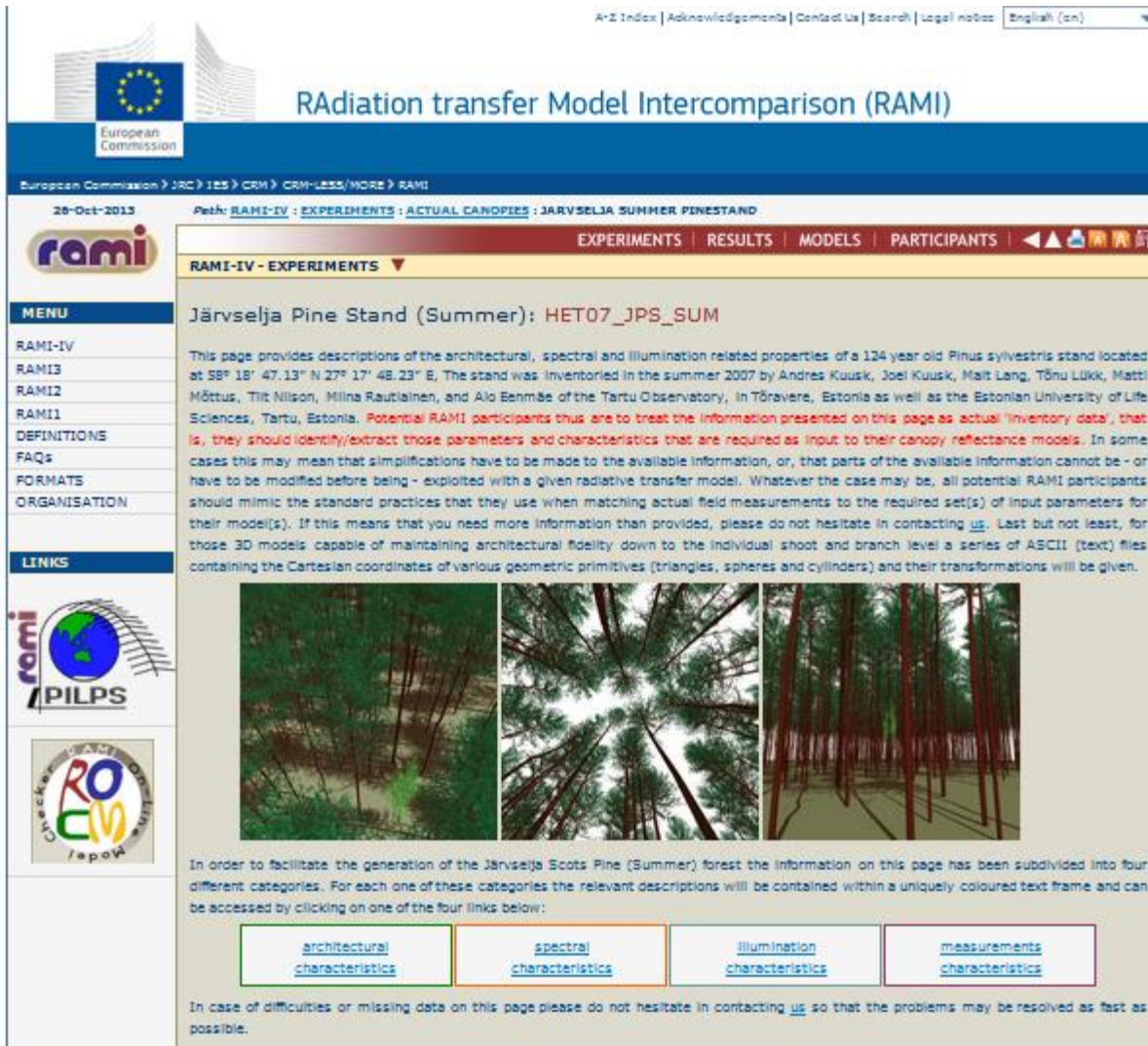




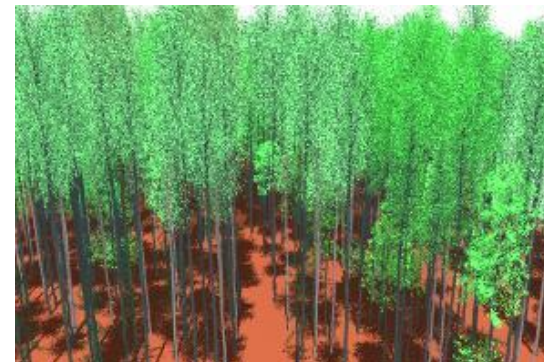
# Järvselja RAMI testovací plochy

## Bříza

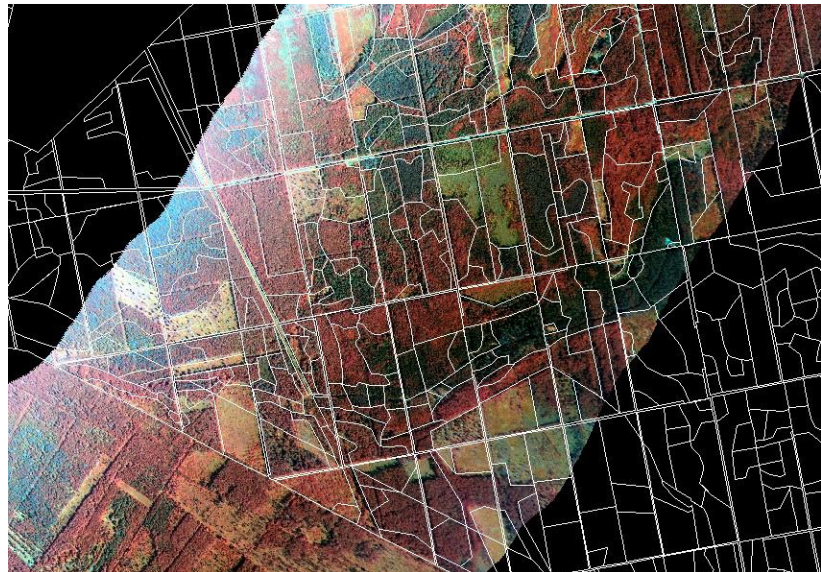
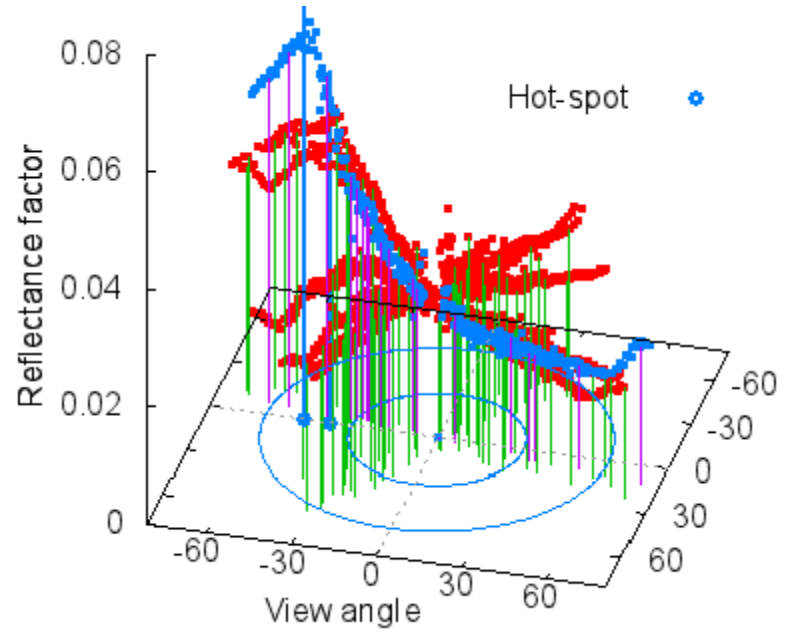
## Borovice



The screenshot shows the RAMI website interface. At the top, there is a navigation bar with links for 'Index', 'Acknowledgements', 'Contact Us', 'Search', and 'Legal notice'. The main header features the European Commission logo and the title 'RAAdiation transfer Model Intercomparison (RAMI)'. Below this, a breadcrumb trail reads 'European Commission > JRC > IES > CRM > CRM-LESS/MORE > RAMI'. The date '28-Oct-2013' and the path 'Path: RAMI-IV > EXPERIMENTS > ACTUAL CANOPIES > JÄRVSELJA SUMMER PINESTAND' are displayed. A navigation menu includes 'EXPERIMENTS', 'RESULTS', 'MODELS', and 'PARTICIPANTS'. The main content area is titled 'RAMI-IV - EXPERIMENTS' and 'Järvselja Pine Stand (Summer): HET07\_JPS\_SUM'. It provides a detailed description of the stand, including its location (59° 18' 47.13" N, 27° 17' 48.23" E) and the names of the researchers involved. A note states that potential participants should treat the information as actual 'inventory data'. Below the text, there are three small images: a photograph of the forest, a low-angle shot of tree trunks, and a 3D model of the forest. At the bottom, there are four colored buttons for 'architectural characteristics', 'spectral characteristics', 'illumination characteristics', and 'measurements characteristics'. A footer note encourages contacting the site if there are difficulties or missing data.











# Lightweight unmanned aerial vehicles will revolutionize spatial ecology

Karen Anderson\* and Kevin J Gaston

Ecologists require spatially explicit data to relate structure to function. To date, heavy reliance has been placed on obtaining such data from remote-sensing instruments mounted on spacecraft or manned aircraft, although the spatial and temporal resolutions of the data are often not suited to local-scale ecological investigations. Recent technological innovations have led to an upsurge in the availability of unmanned aerial vehicles (UAVs) – aircraft remotely operated from the ground – and there are now many lightweight UAVs on offer at reasonable costs. Flying low and slow, UAVs offer ecologists new opportunities for scale-appropriate measurements of ecological phenomena. Equipped with capable sensors, UAVs can deliver fine spatial resolution data at temporal resolutions defined by the end user. Recent innovations in UAV platform design have been accompanied by improvements in navigation and the miniaturization of measurement technologies, allowing the study of individual organisms and their spatiotemporal dynamics at close range.

*Front Ecol Environ* 2013; 11(3): 138–146, doi:10.1890/120150 (published online 18 Mar 2013)

Remote-sensing techniques have transformed ecological research by providing both spatial and temporal perspectives on ecological phenomena that would otherwise be difficult to study (eg Kerr and Ostrovsky 2003; Running *et al.* 2004; Vierling *et al.* 2008). In particular, a strong focus has been placed on the use of data obtained from spaceborne remote-sensing instruments because these provide regional- to global-scale observations and repeat time-series sampling of ecological indicators (eg Gould 2000). The main limitation of most of the research-focused satellite missions is the mismatch between the pixel resolution of many regional-extent sensors (eg Landsat [spatial resolution of ~30 m] to the Moderate Resolution Imaging Spectro-

range of new (largely commercially operated) satellite sensors have become operational over the past decade, offering data at finer than 10-m spatial resolution with more responsive capabilities (eg Quickbird, IKONOS, GeoEye-1, OrbView-3, WorldView-2). Such data are useful for ecological studies (Fretwell *et al.* 2012), but there remain three operational constraints: (1) a high cost per scene; (2) suitable repeat times are often only possible if oblique view angles are used, distorting geometric and radiometric pixel properties; and (3) cloud contamination, which can obscure features of interest (Loarie *et al.* 2007). Imaging sensors on board civilian aircraft platforms may also be used; these can provide more scale-appropriate data for

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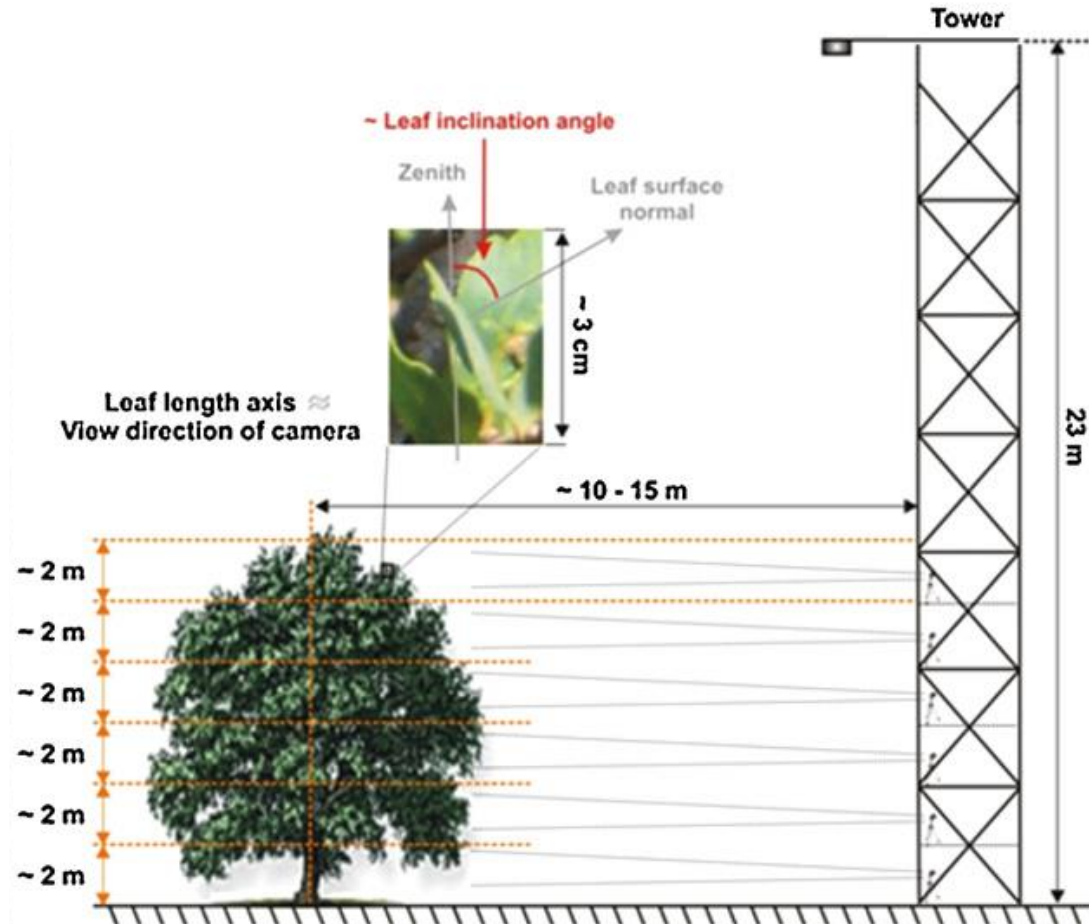


# Listy

- rozdělení úhlů listoví (the leaf angle distribution - LAD)** je jedním z hlavních parametrů ovlivňujících spektrální odrazivost a charakter šíření světla/záření skrz vegetaci
- navzdory svému významu ale zůstává jedním z **nejméně prostudovaných parametrů**/vstupů v modelech spektrální odrazivosti díky relativní obtížnosti měření úhlů listoví v terénu – obzvláště pak stromů

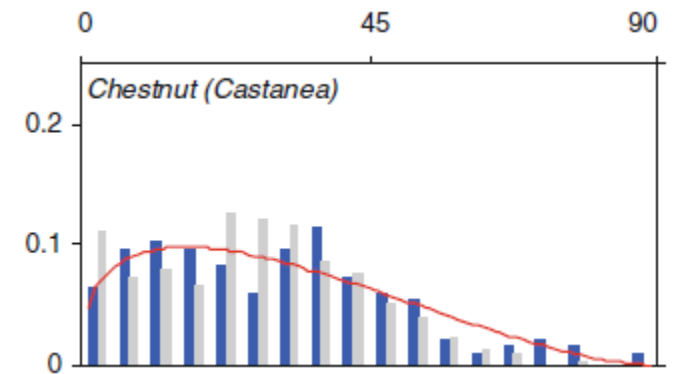
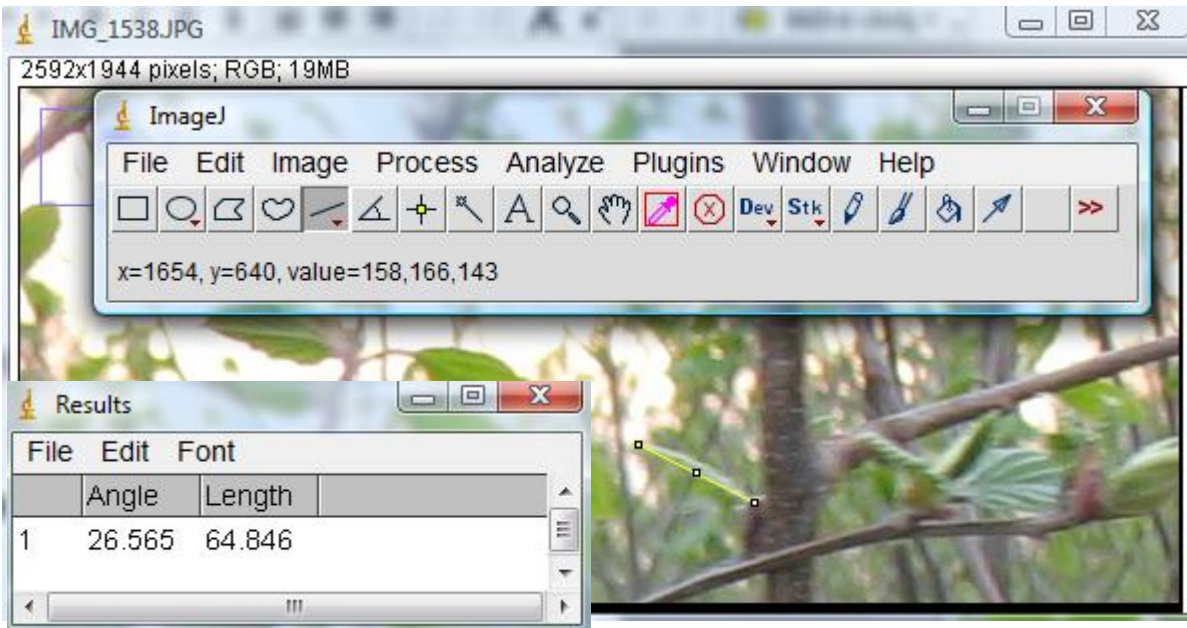
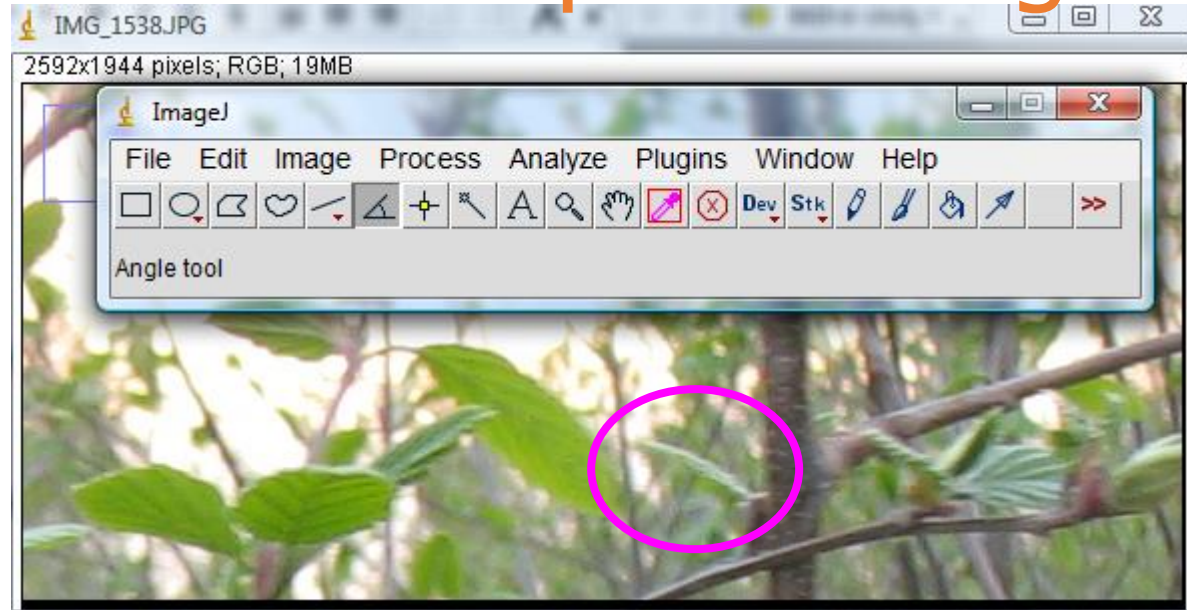


# Měření pomocí dig. fotoaparátu (leveled digital camera approach)

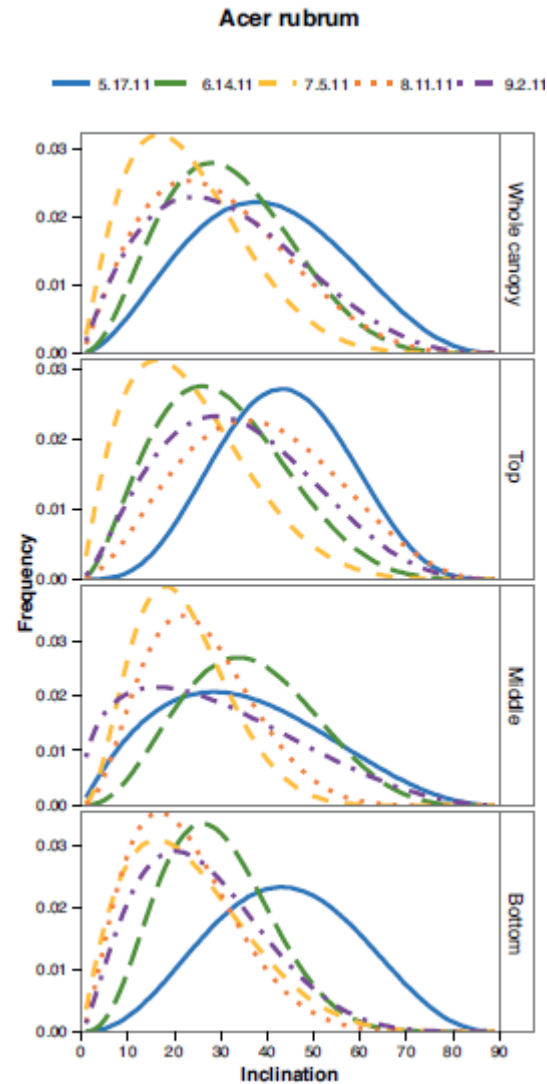




# Měření pomocí dig. fotoaparátu



# Je možné měřit úhly listoví kdykoliv/kdekoliv?



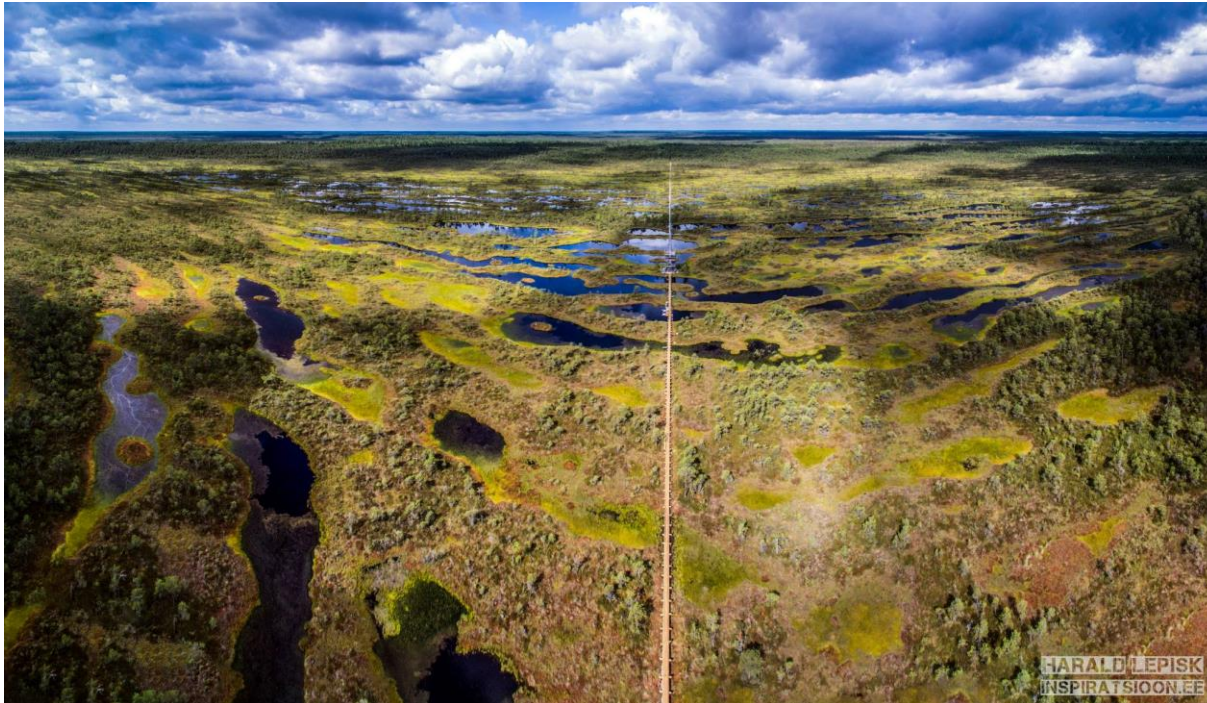
# Je možné měřit úhly listoví kdykoliv/kdekoliv?



DJI Phantom 3 Professional  
4K camera with 3-axis gimbal  
94 deg. recti-linear lens



# Je možné měřit úhly listoví kdykoliv/kdekoliv?





30. června, 2015, Toravere,  
Estonsko  
Betula pendula, Alnus incana,  
Aesculus hippocastanum





**Původní RAW**

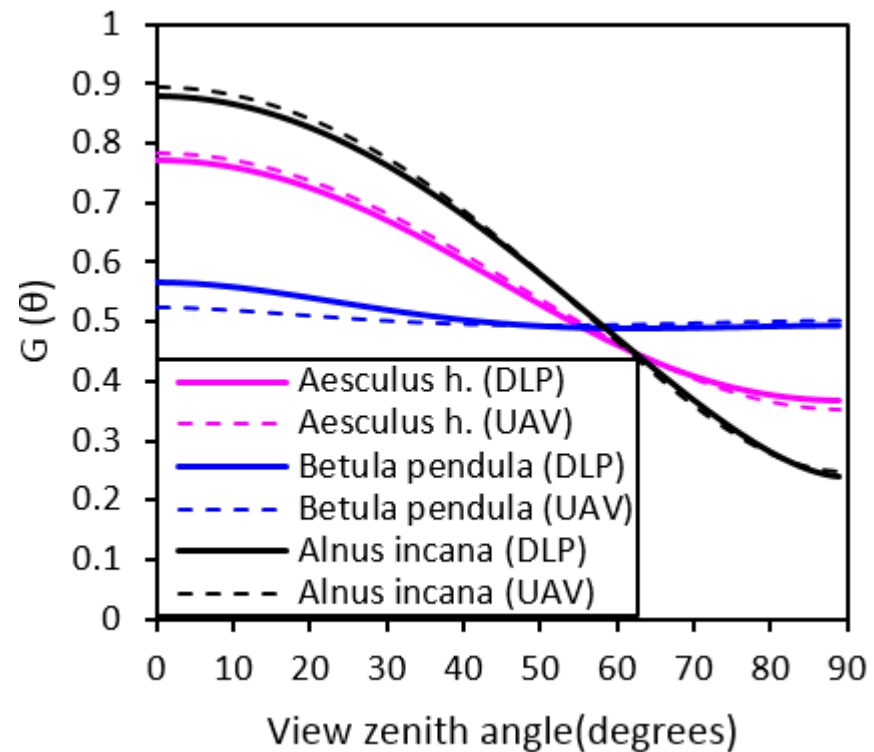
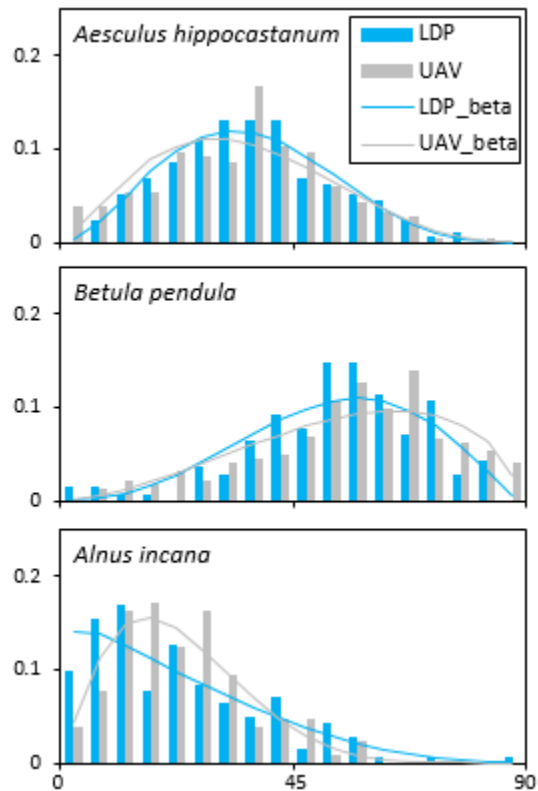


**Opravený JPEG (opravené prostorové zkreslení)**



# Výsledky

species	n	control			UAV			deWit
		mean	standev	deWit	n	mean	standev	
<i>Aesculus hippocastanum</i>	175	36.91	15.22	plagiophile	186	35.28	16.34	plagiophile
<i>Betula pendula</i>	141	53.81	16.47	spherical	244	56.26	18.63	spherical
<i>Alnus incana</i>	142	22.98	17.04	planophile	128	23.48	12.67	planophile





13. srpna, 2015, Monongahela National Forest, Central Appalachian Mountains, West Virginia, USA  
Acer rubrum, Quercus rubra



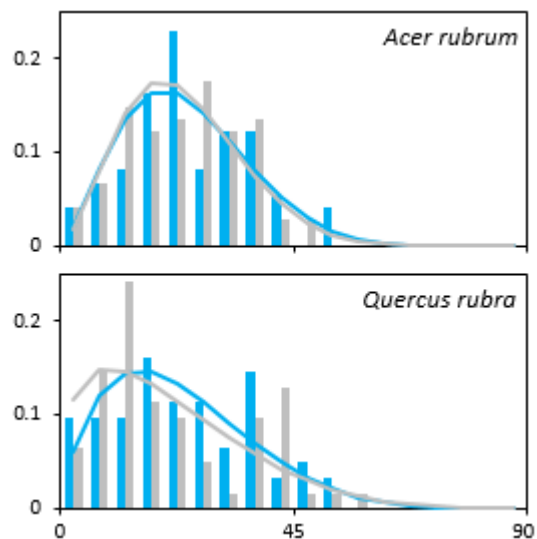
3DRobotics Y6 hexacopter outfitted with a gimbal-mounted Canon Powershot S110 compact camera





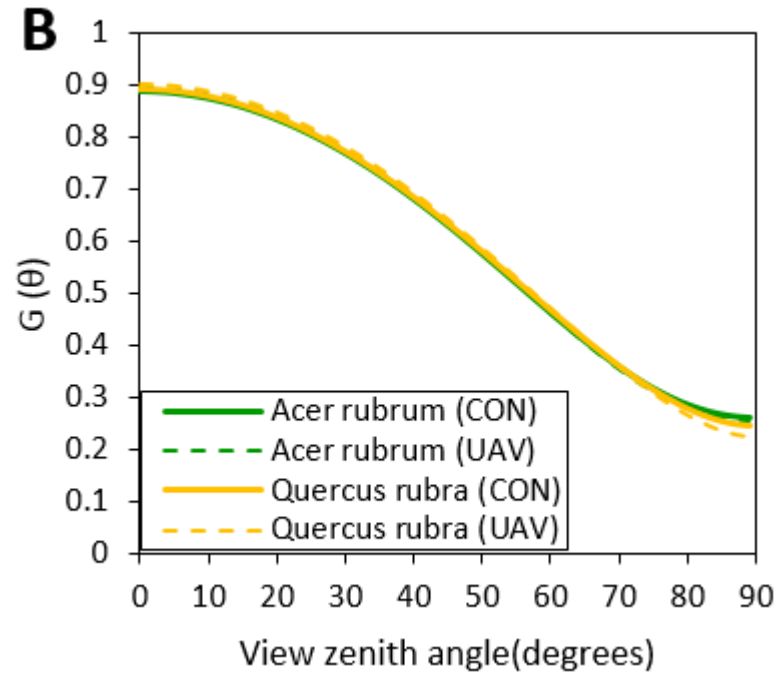
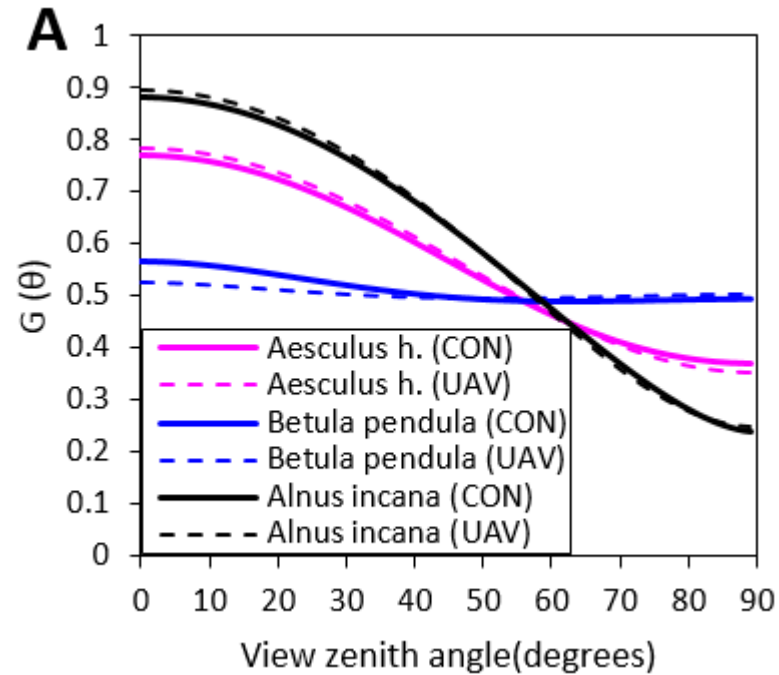
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<i>Acer rubrum</i>	74	24.81	11.76	planophile	74	24.15	11.06	planophile
<i>Quercus rubra</i>	62	23.56	13.66	planophile	62	21.87	14.45	planophile



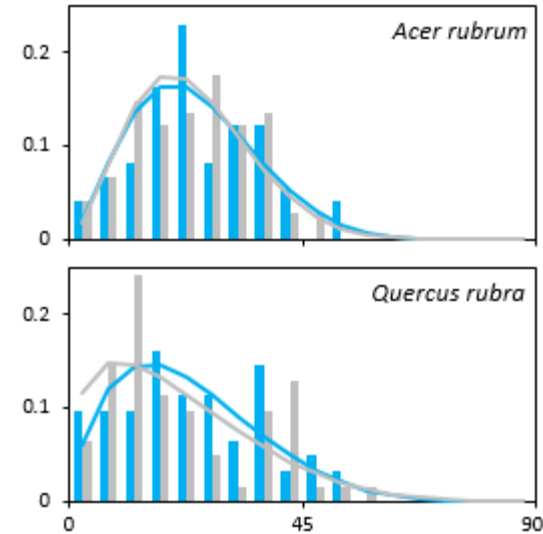
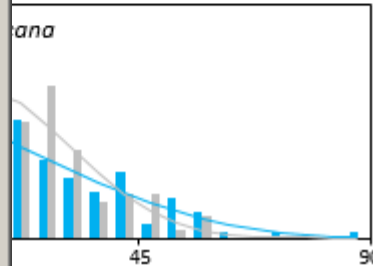
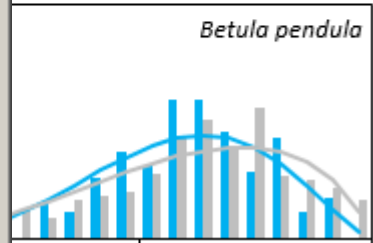
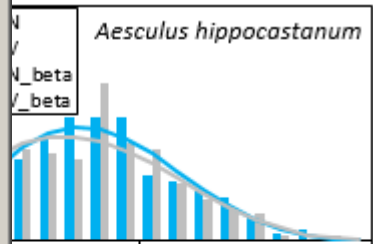
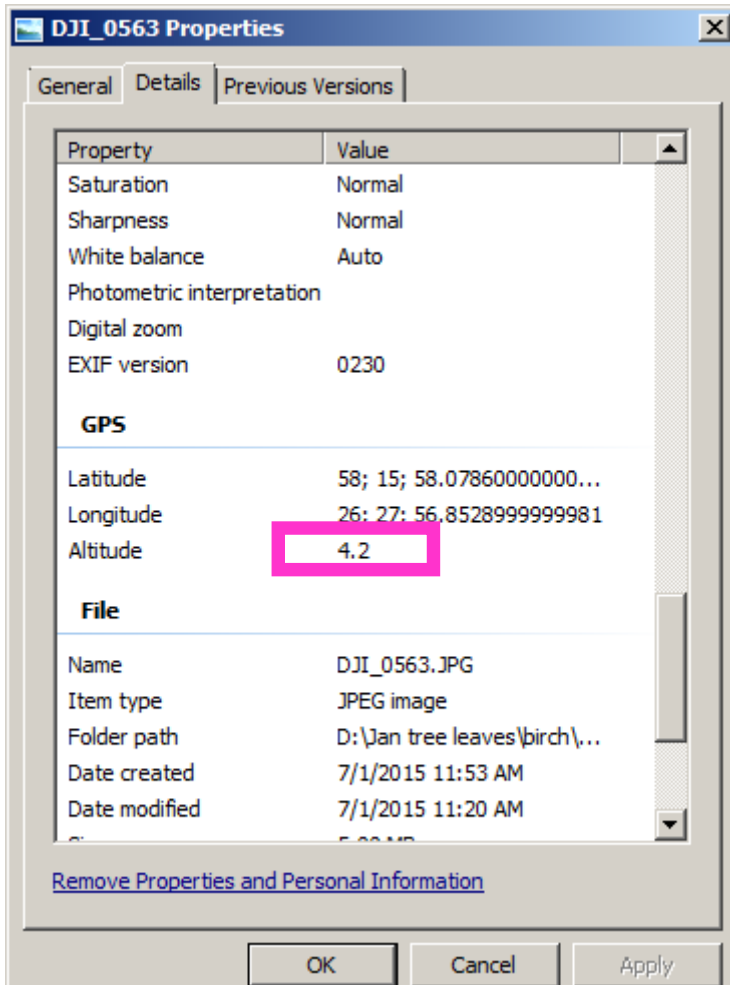
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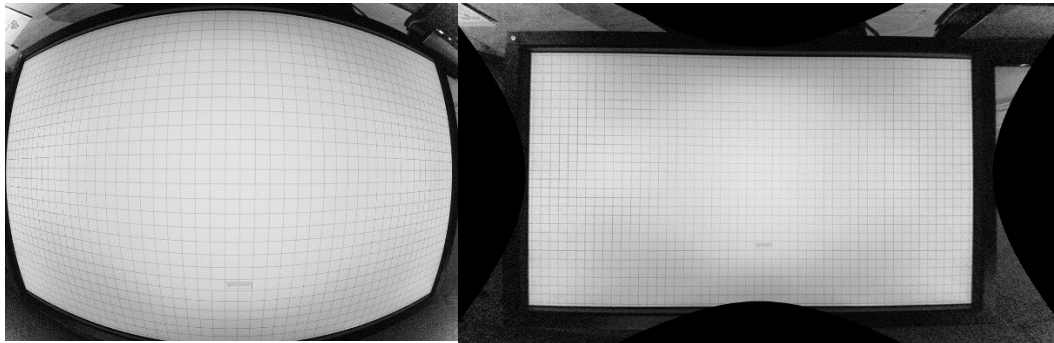


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# Na co dávat pozor?



Kamera z GoPro Hero 2 UAV (zde nepoužita!)



Canon PowerShot A610 (použitý foťák pro ověření výsledků)





Short communication

## Measuring leaf angle distribution in broadleaf canopies using UAVs

Brenden E. McNeil<sup>a,\*</sup>, Jan Pisek<sup>b,1</sup>, Harald Lepiec<sup>c</sup>, Evelin A. Flamenco<sup>a</sup><sup>a</sup> Department of Geology & Geography, West Virginia University, Morgantown, WV 26506, USA<sup>b</sup> Faculty of Forestry, University of Agriculture in Turin, 20090 Turin, Italy<sup>c</sup> Victory Technology, Qixi 1.2 N/A, Tartanmas, Ontario

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## ABSTRACT

Leaf angle distribution (LAD) is an important parameter affecting the biophysical interaction of sunlight and forest canopies. But, difficulty in measuring LAD has limited exploration of its species-specific phenology and variation across environmental gradients. To evaluate whether digital photographs from unpiloted aerial vehicles (UAVs) could be used to measure LAD, we directly compared UAV-based measurements of leaf angle against those made from conventional leveled digital photographs taken from towers, ladders, buildings, or poles. We used two different UAV and camera systems, and found that both systems provided statistically similar results to the conventional measurements of LAD on five common broadleaf tree species of Europe and North America. In addition to overcoming challenges of UAV airspace regulation and piloting UAVs within complex forest canopies, we recommend potential users of this method should identify, minimize, and correct for any image distortion effects created by their UAV and camera system. With these considerations in mind, our results indicate that UAVs can be used to measure LAD in virtually any broadleaf forest environment, which opens the new possibility for obtaining accurate, species-specific information on the variability of LAD through time and along broad environmental gradients.

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# Jak dál?



## 1. Introduction

The leaf angle distribution (LAD) is a key parameter in models useful for understanding the forest canopy processes of photosynthesis, evapotranspiration, radiation transmission, and spectral reflectance (Warren Wilson, 1959; Lemström and Blad, 1974; Myrnes et al., 1989; Asner, 1998). Yet, despite the strong sensitivity of many of these models to variability in LAD, the difficulty in measuring LAD often causes it to be one of the most poorly constrained model parameters (see e.g. Öllinger, 2011). Improving methodologies for measuring LAD is thus essential for advancing ecological understanding of its role within the biophysical interaction of sunlight and the forest canopy.

Recently, Ryu et al. (2010) introduced a robust and affordable method that allows reproducible measurements of leaf inclination angles based on digital photography. The method has shown potential to overcome many of the shortcomings of other LAD measurement techniques (Pisek et al., 2011; Zou et al., 2014). However, since only a small fraction of the ecological variability in forests can

be measured from towers, poles, ladders, and other conventional platforms, the remaining challenge is how to collect these photographic leaf angle measurements for the remaining tall, or remote forest canopies.

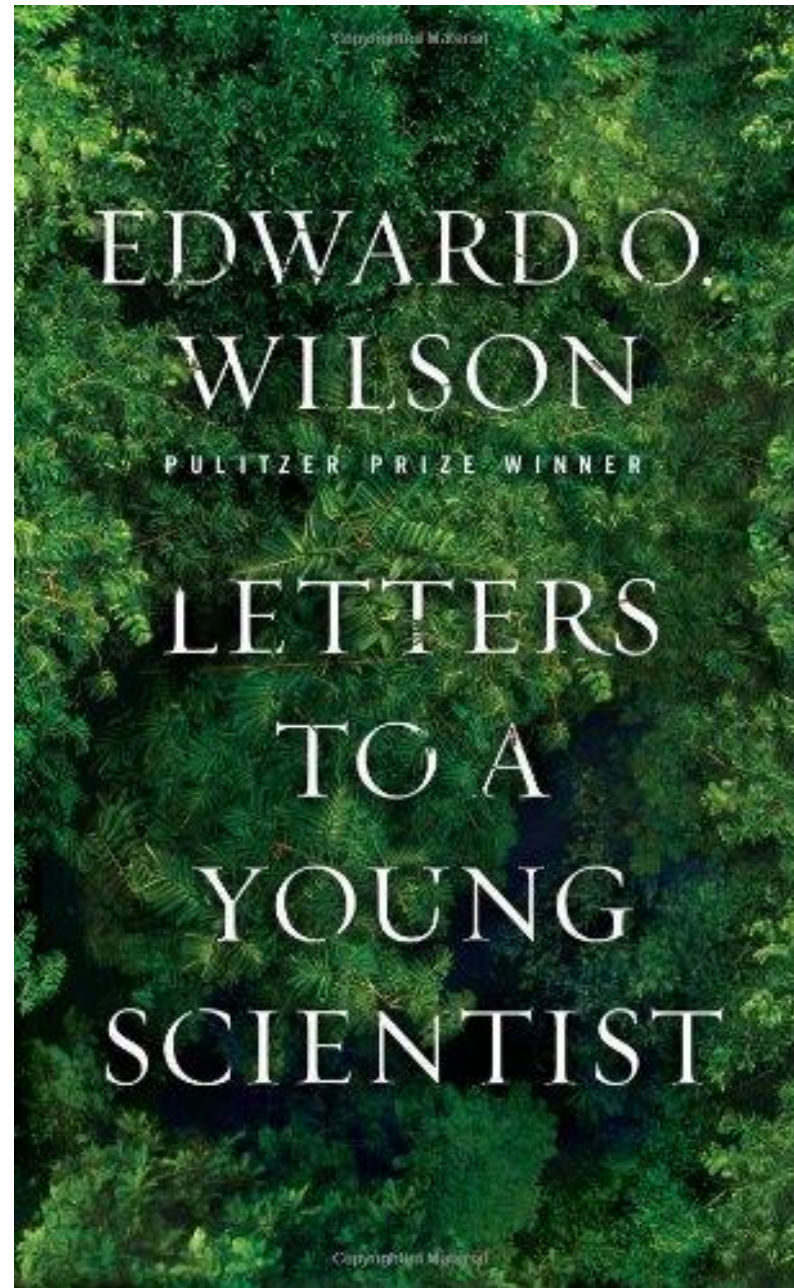
Recent technological innovations have led to an upsurge in the availability of unpiloted aerial vehicles (UAVs) – aircraft remotely operated from the ground – and there are now many lightweight UAVs available at reasonable costs. Specifically for small, multi-rotor UAVs, recent innovations in power systems, self-leveling gimbal designs, stabilized flight, and lightweight cameras now allow for the study of individual organisms and their spatiotemporal dynamics at close range (Anderson and Gaston, 2013). Crucially for forest canopy research, these small multi-rotor UAVs could serve as portable canopy research towers; they are potentially small and nimble enough to pilot throughout a complex three-dimensional forest canopy environment, all while taking high-resolution, and level photographs of individual tree crowns.

In this short communication, we seek to test the potential of small multi-rotor UAVs to serve as a platform for measuring leaf angles using the leveled digital photography method. Specifically, we use two different UAV and camera systems to measure leaf angles, as well as estimate the LAD and G-function of five broadleaf tree species common to Europe and North America. After discussing some important considerations for minimizing errors caused by

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-automatizace identifikace listů a měření úhlů  
-jehličnany?



# Vedoucí práce



# Hlavní je zápal/nadšení, až pak je kvalifikace/intelligence

Too many Ph.D.s are creatively stillborn, with their personal research ending more or less with their doctoral dissertations.

Very often ambition and entrepreneurial drive, in combination, beat brilliance.

# Zkoušejte stále něco nového

Disturb Nature and see if she reveals a secret.

Almost anything, no matter how unsophisticated, can yield discoveries publishable in scientific journals.

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Short communication

**Measuring leaf angle distribution in broadleaf canopies using UAVs**

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**ABSTRACT**

Leaf angle distribution (LAD) is an important parameter affecting the biophysical interaction of sunlight and forest canopies. But, difficulty in measuring LAD has limited exploration of its species-specific phenology and variation across environmental gradients. To evaluate whether digital photographs from unpersoned aerial vehicles (UAVs) could be used to measure LAD, we directly compared UAV-based measurements of leaf angle against those made from conventional leveled digital photographs taken from towers, ladders, buildings, or poles. We used two different UAV and camera systems, and found that both systems provided statistically similar results to the conventional measurements of LAD on five common broadleaf tree species of Europe and North America. In addition to overcoming challenges of UAV airspace regulation and piloting UAVs within complex forest canopies, we recommend potential users of this method should identify, minimize, and correct for any image distortion effects created by their UAV and camera systems. With these considerations in mind, our results indicate that UAVs can be used to measure LAD in virtually any broadleaf forest environment, which opens the new possibility for obtaining accurate, species-specific information on the variability of LAD through time and along broad environmental gradients.

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**1. Introduction**

The leaf angle distribution (LAD) is a key parameter in models useful for understanding the forest canopy processes of photosynthesis, evapotranspiration, radiation transmission, and spectral reflectance (Warren Wilson, 1959; Lemeur and Blad, 1974; Myneni et al., 1989; Asner, 1998). Yet, despite the strong sensitivity of many of these models to variability in LAD, the difficulty in measuring LAD often causes it to be one of the most poorly constrained model parameters (see e.g. Ollinger, 2011). Improving methodologies for measuring LAD is thus essential for advancing ecological understanding of its role within the biophysical interaction of sunlight and the forest canopy.

Recently, Ryu et al. (2010) introduced a robust and affordable method that allows reproducible measurements of leaf inclination angles based on digital photography. The method has shown potential to overcome many of the shortcomings of other LAD measurement techniques (Pisek et al., 2011; Zou et al., 2014). However, since only a small fraction of the ecological variability in forests can be measured from towers, poles, ladders, and other conventional platforms, the remaining challenge is how to collect these photographic leaf angle measurements for the remaining tall, or remote forest canopies.

Recent technological innovations have led to an upsurge in the availability of unpersoned aerial vehicles (UAVs) – aircraft remotely operated from the ground – and there are now many lightweight UAVs available at reasonable costs. Specifically for small, multi-rotor UAVs, recent innovations in power systems, self-leveling gimbal designs, stabilized flight, and lightweight cameras now allow for the study of individual organisms and their spatiotemporal dynamics at close range (Anderson and Gaston, 2013). Crucially for forest canopy research, these small multi-rotor UAVs could serve as portable canopy research towers; they are potentially small and nimble enough to pilot throughout a complex three-dimensional forest canopy environment, all while taking high-resolution, and level photographs of individual tree crowns.

In this short communication, we seek to test the potential of small multi-rotor UAVs to serve as a platform for measuring leaf angles using the leveled digital photography method. Specifically, we use two different UAV and camera systems to measure leaf angles, as well as estimate the LAD and G-fractions of five broadleaf tree species common to Europe and North America. After discussing some important considerations for minimizing errors caused by

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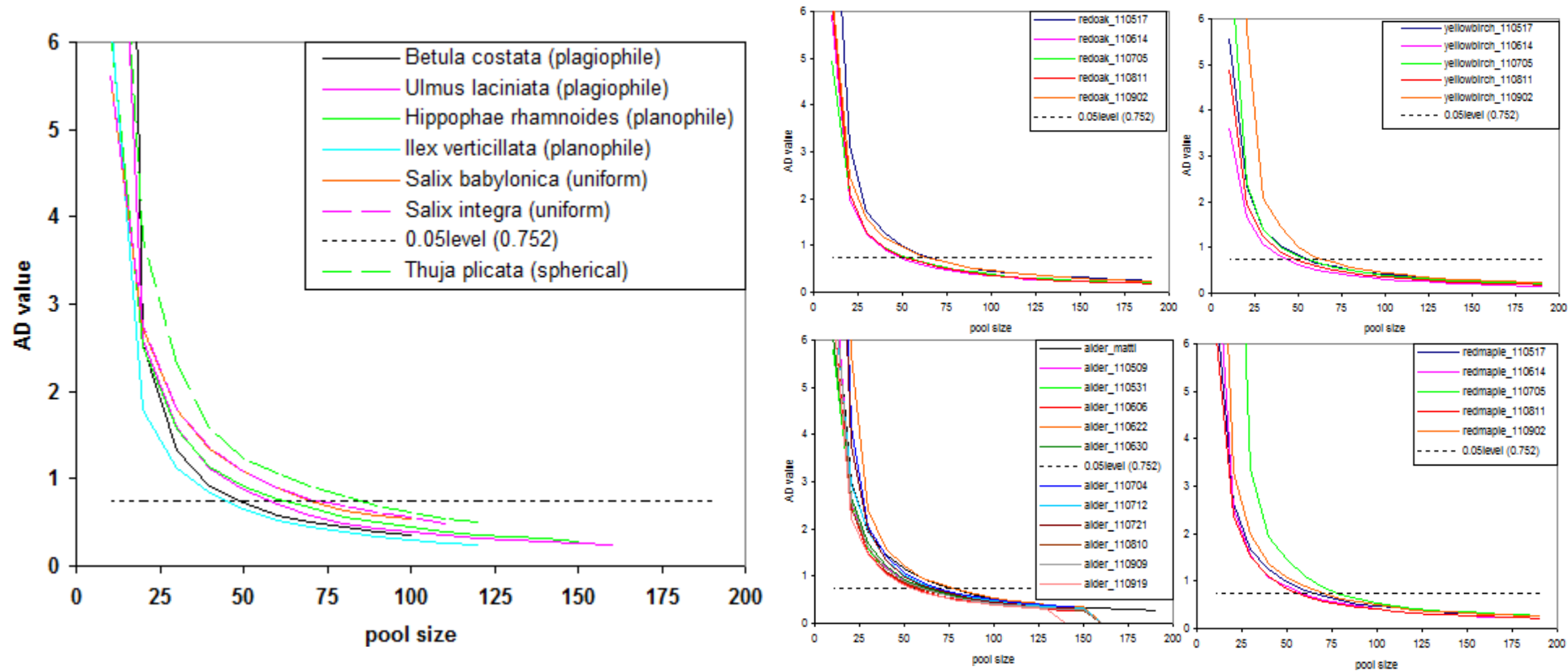
# Mějte za kamaráda/kamarádku matematika/statistika

It is far easier for scientists to acquire needed collaboration from mathematicians and statisticians than it is for mathematicians and statisticians to find scientists able to make use of their equations.

For every scientist, whether researcher, technologist, or teacher, of whatever competence in mathematics, there exists a discipline in science for which that level of mathematical competence is enough to achieve excellence.



# How many leaves are enough?



## Anderson-Darling test (Anderson and Darling, 1952)

- test statistic of the sum of squares of the differences between the distribution of sample and a given probability distribution function, with a weight function that emphasizes discrepancies in both tails

# Poznejte svůj obor/téma do poslední mrtě

Fortune favours only the prepared mind. Louis  
Pasteur, 1854

Na konci své dizertace by jste o daném tématu měli  
vědět více, než Váš vedoucí práce.

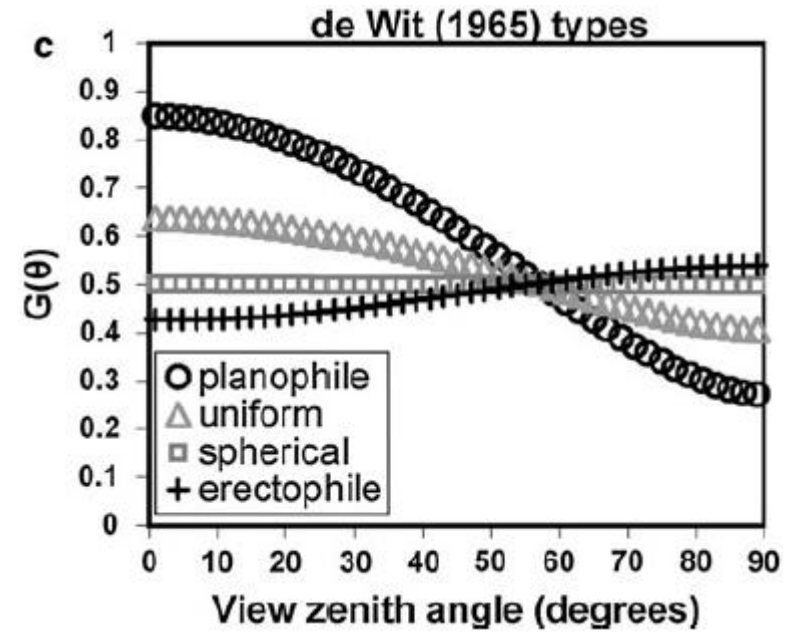
Využijte čas, dokud nemáte děti... ;)



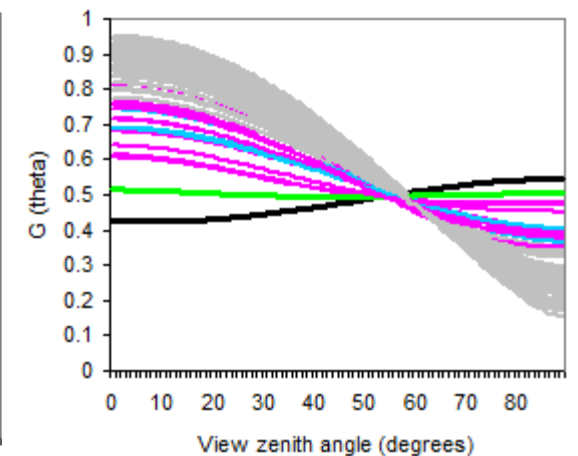
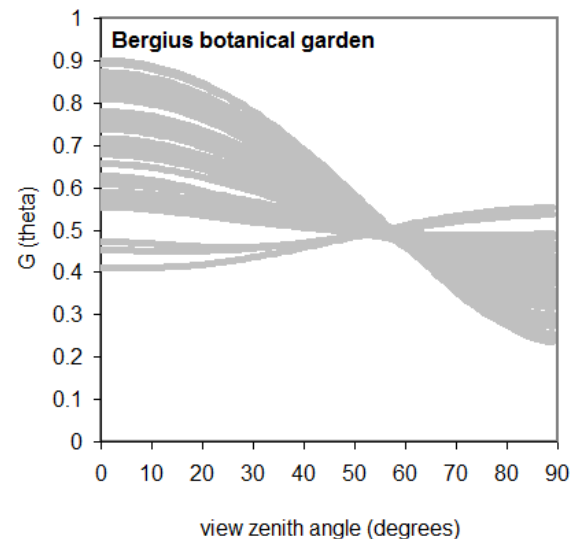
# Zajímejte se o to, co zrovna není populární

March away from the sound of the guns. Observe the fray from the distance, and while you are at it, consider making your own fray.

In the search for scientific discoveries, every problem is an opportunity. The more difficult the problem, the greater the likely importance of its solution.



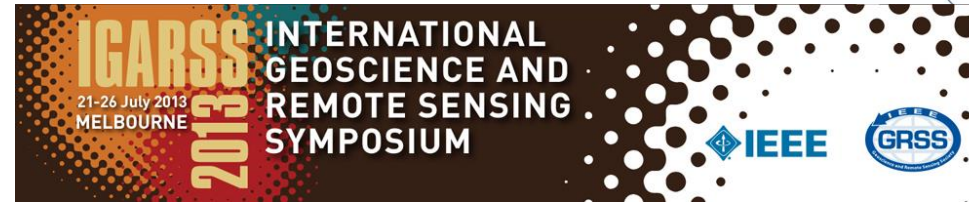
$$P(\theta) = e^{-G(\theta)L\Omega/\cos\theta}$$



# Nikdy si neberte “dovolenou”

Real scientist takes field trips or temporary research fellowships at other institutions.

Avoid department-level administration and duties as much as possible.



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Intercomparison of clumping index estimates from POLDER, MODIS, and MISR satellite data over reference sites

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**ABSTRACT**

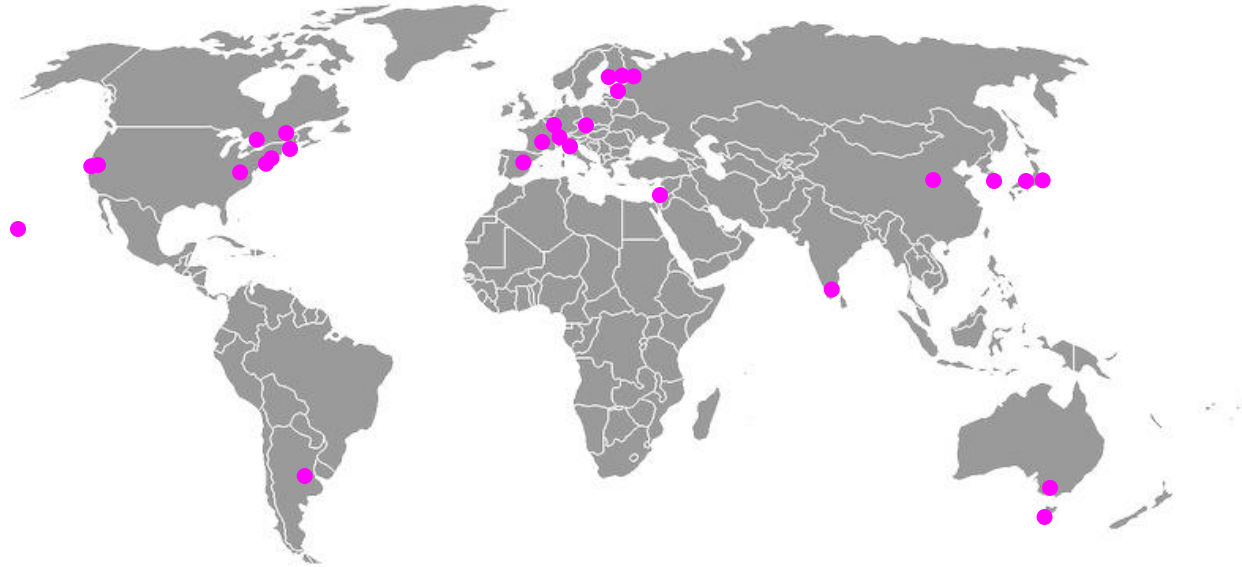
Clumping index is the measure of foliage grouping relative to a random distribution of leaves in space. It is a key structural parameter of plant canopies that influences canopy radiation regimes and canopy photosynthesis and other land-atmosphere interactions. The Normalized Difference between Hotspot and Darkspot (NDHD) index has been previously used to retrieve global clumping index from Polarization and Directionality of the Earth's Reflectances (POLDER) data at ~6 km resolution and the Bidirectional Reflectance Distribution Function (BRDF) product from Moderate Resolution Imaging Spectroradiometer (MODIS) at 500 m resolution. Most recently the algorithm was also applied with Multi-angle Imaging SpectroRadiometer (MISR) data at 275 m resolution over selected areas. In this study for the first time we characterized and compared the three products over a set of sites representing diverse biomes and different canopy structures. The products were also directly validated with in-situ vertical profiles and available seasonal trajectories of clumping index over several sites. We demonstrated that the vertical distribution of foliage and especially the effect of understory need to be taken into account while validating foliage clumping products from remote sensing products with values measured in the field. Satellite measurements responded to the structural effects near the top of canopy while ground measurements may be biased by the lower vegetation layers. Additionally, caution should be taken regarding the misclassification in land cover maps as their errors can propagate into the foliage clumping maps. Our results indicate that MODIS data and MISR data, with 275 m in particular, can provide good quality clumping index estimates at spatial scales pertinent for modeling local carbon energy fluxes.

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**Keywords:**  
Multi-angle remote sensing  
MISR  
MODIS  
POLDER  
Vegetation clumping index  
Hotspot



# Asistujte, spolupracujte, tvořte, inovujte



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Forestry Tasmania, Australia



# Závist a nejistota patří mezi hlavní motory vědeckého pokroku

It won't hurt if you have a dose of them also.

# Etika ve vědě

Čím více budete citovat jiné, tím větší je šance, že někdo bude citovat také Vás.