Hyperspectral data based monitoring of Norway spruce forest conditions in a historically heavily polluted mountainous region of Czech Republic affected by long-term acidic deposition.

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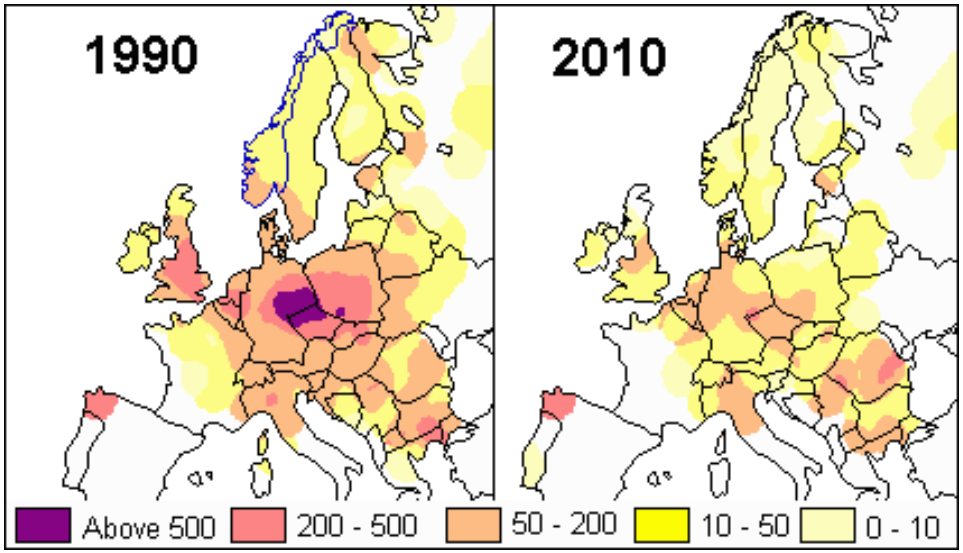
Climate change interacts with anthropogenic pollution

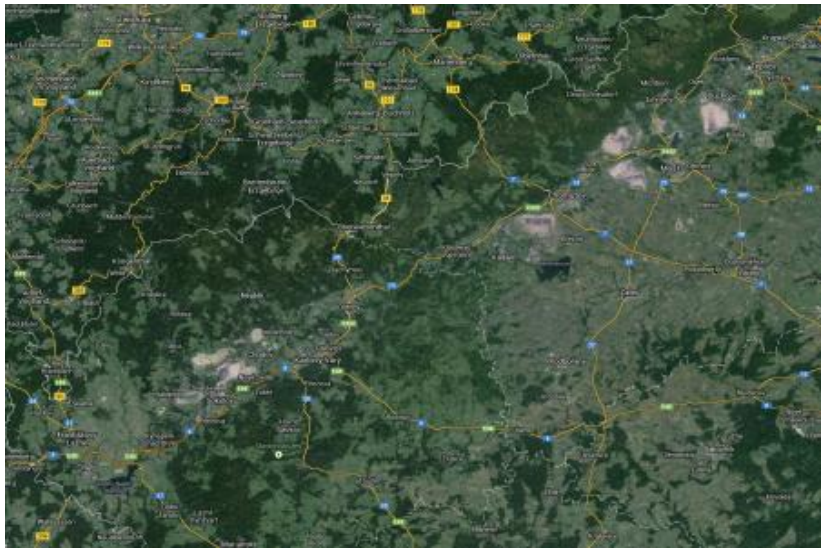
Monitoring forest health in heavily polluted North Czech Republic

Gradient in air pollution based on direction of prevailing winds

Black Triangle in Europe

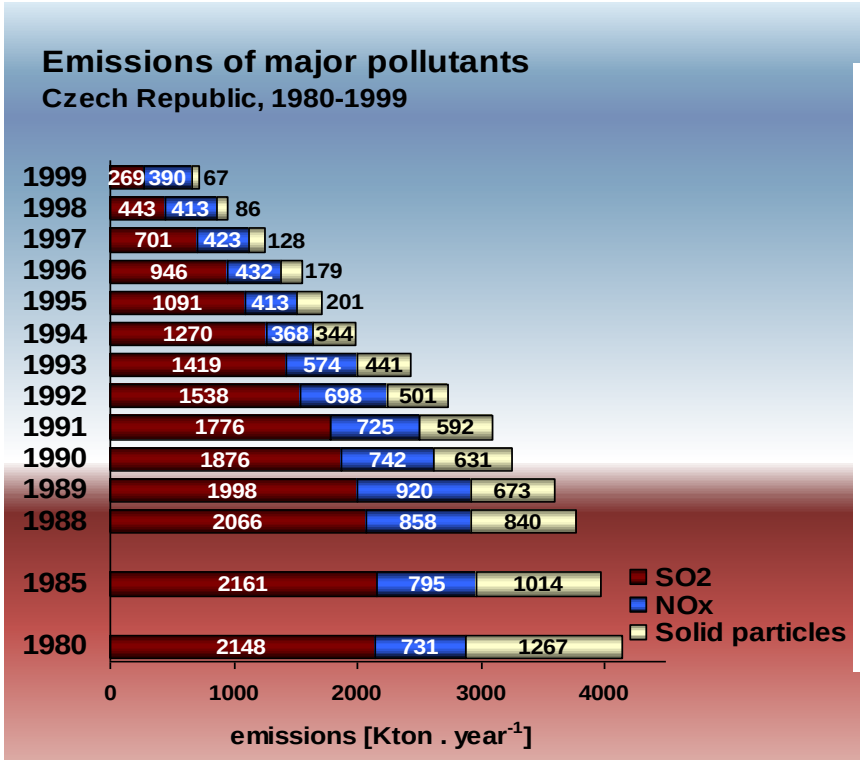
SO_2 in Europe (Tons per km2)

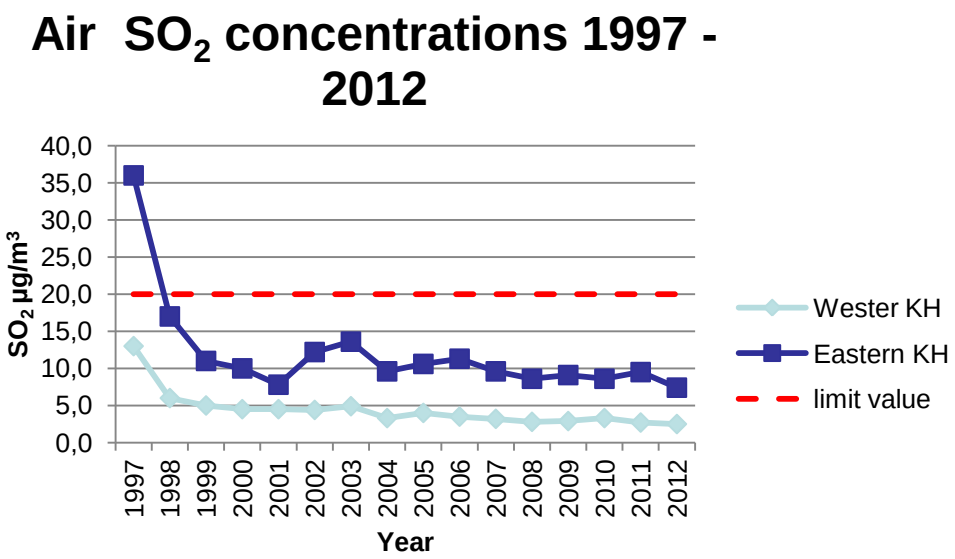




http://wgbis.ces.iisc.ernet.in/energy/HC270799/SOE/nor/soeno97/acidrain/state.htm

Black Triangle in CZ: mountains, strip mines, reclamation sites

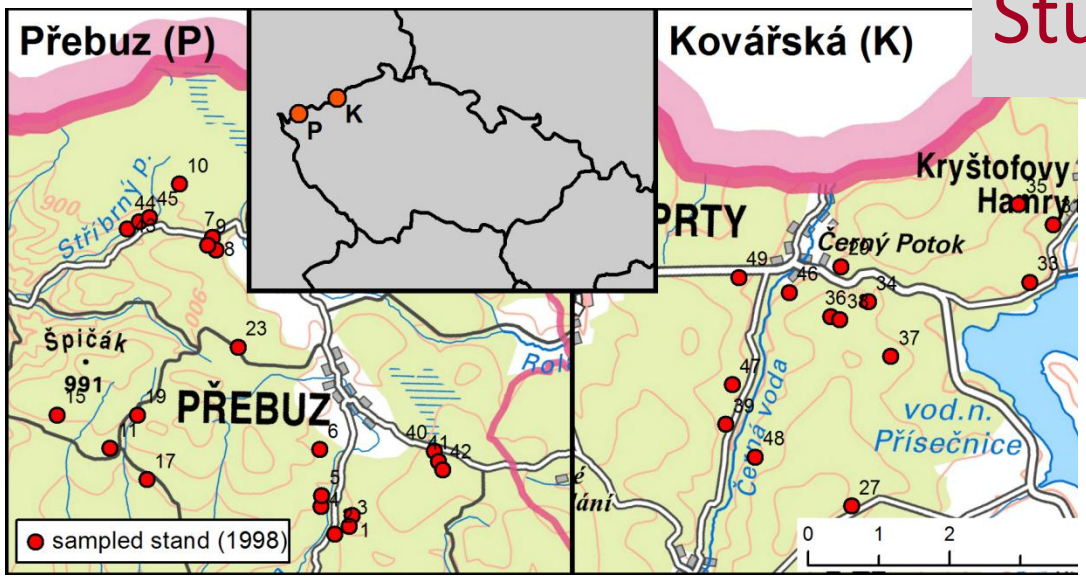


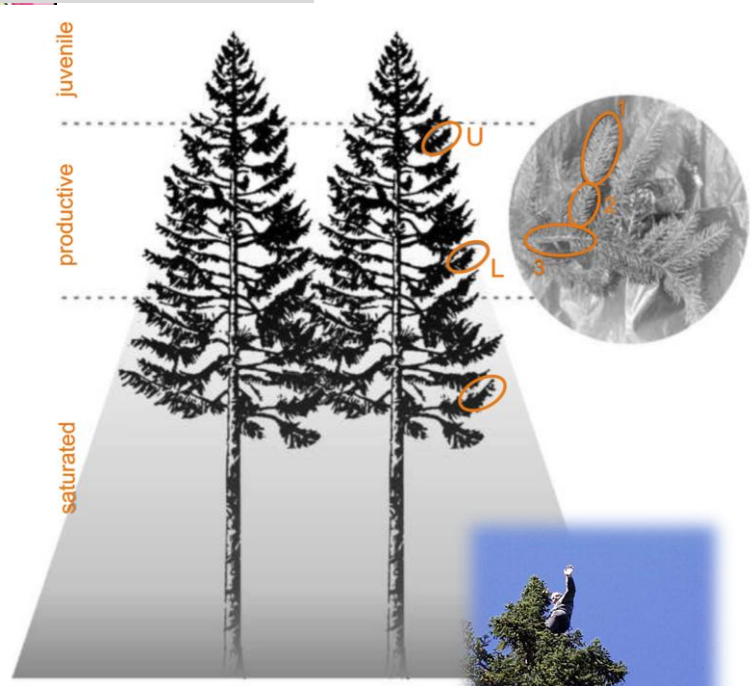


The 1970-1990´s:
dead forests in the Krusne hory Mts.

2 hyperspectral projects in the Krušné hory Mts

Study area





- **Two different localities** in the Krušné Hory Mts. about 50 km apart
- **Přebuz** - the western part -healthy or slightly damaged
- **Kovářská** - the central part - heavy acidic load, high visible damage
- Even-aged forest **stands older than 60 years** (15 sites at Kovářská and 22 sites at Přebuz in **1998**) and **older than 80 years** (5 sites at Kovářská and 6 sites at Přebuz in **2013**) were selected.

2 hyperspectral projects in the Krušné hory Mts

- 1. NASA (1997-2000)
- 2. INMON (2012-2014)

2. INMON: Hyperspectral Krušné hory Mts. (2012-2015)

- Field campaign 2013

Data and methods:

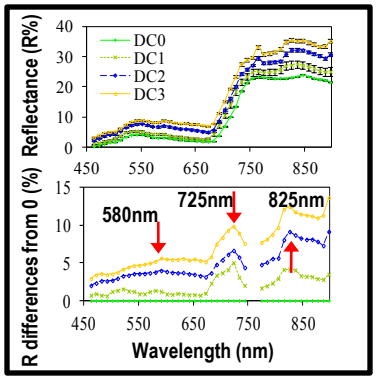
- Field measurements and sampling
  - **Foliar chemicals** (chlorophyll, carotenoids, lignin, cellulose, water etc.)
  - **Soil samples** (pH, heavy metals, bazic cations, trace elements, DOC, DON)
  - **LAI measurements** (hemispherical photography)
  - **Crown Defoliation and status assessment**
  - **Spectral properties of needles** (ASD Fieldspec-4 + integration sphere)
- Airborne hyperspectral imagery
  - Apex: (2013)

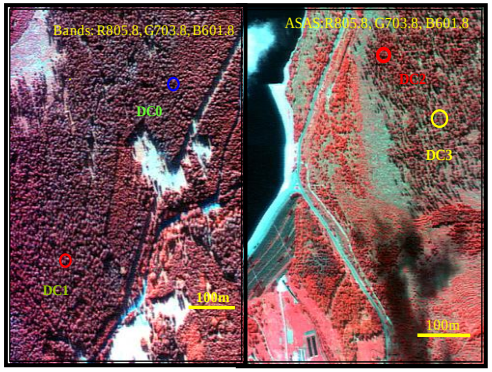
1. NASA - Hyperspectral Krusne hory Mts. (1997- 2000)

NASA project „Forest recovery in the Czech Republic“ NAG5-5192 (CFDA #43.002), **(1997-2000),** UNH, Complex Research Systems Centre, USA,

PI: Barrett N. Rock, UNH
Petya Campbell

Co-I : Jana Albrechtová

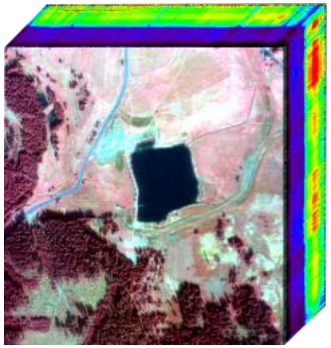




ASAS'98 images and spectra of healthy (DC0) and damaged (DC 1-4) canopies (Entcheva et al. 2004)

ASAS: Airborne Solid-state Array Spectroradiometer (ASAS) NASA Goddard Space Flight Center, USA.

ASAS 1998



•*Campbell, PKE, Rock, BN, Martin, ME, Neefus, CD, Irons, JR, Middleton, EM, Albrechtová, J. Detection of initial damage in Norway spruce canopies using hyperspectral airborne data. In: International Journal of Remote Sensing, 2004, 25, 24, s. 5557-5583*

•*Albrechtová J, Rock BN, Soukupová J, Entcheva P, Šolcová B, Polák T. Biochemical, histochemical, structural and reflectance markers of damage in Norway spruce from the Krušné hory used for interpretation of remote sensing data. Journal of Forest Science, 2001, 47, (Special issue), p. 26-33*

2. INMON: Hyperspectral Krušné hory Mts. (2012-2015)

Inovation of methods for monitoring of health status of Norway spruce stands in the Krusne hory Mts. with the use of hyperspectral data

The main goal: assessment of the temporal changes in the physiological status of Norway spruce forests in the Krušné Hory Mts. using two hyperspectral data sets acquired in 1998 and 2013.

- Project team:
  - **Faculty of Science, Charles University in Prague**

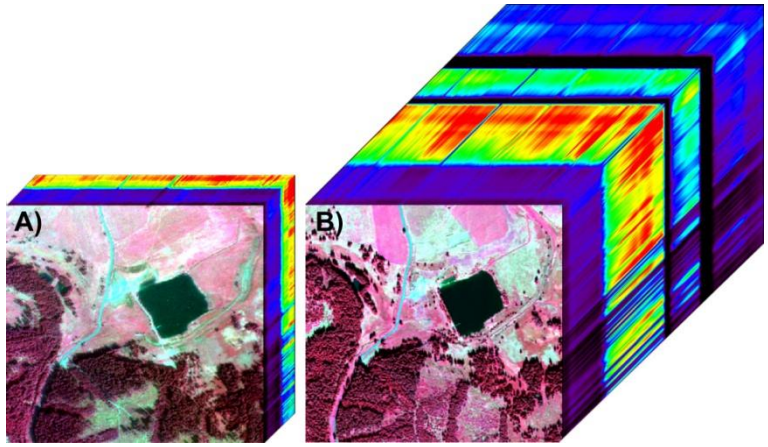
    PI: Dr. Jana Albrechtová, Dr. Zuzana Lhotáková, Dr. Lucie Kupková, Dr. Markéta Potůčková, Mgr. Lucie Červená, Mgr. Monika Kovářová
  - **Czech Geological Survey**

    Mgr. Veronika Kopačková, Mgr. Jan Mišurec
  - **University of Maryland BC, NASA GSFC**

    Dr. Petya Entcheva-Campbell

APEX 2013

ASAS 1998



2. INMON: Hyperspectral Krušné hory Mts. (2012-2015)

Image hyperspectral data

1998 ASAS sensor

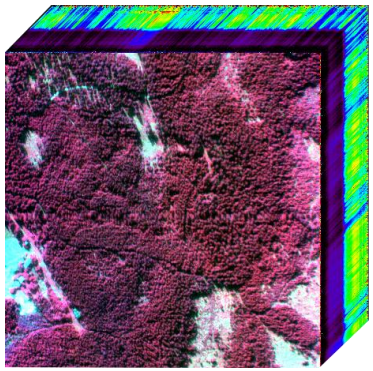
Advanced Solid-state Array Spectrometer

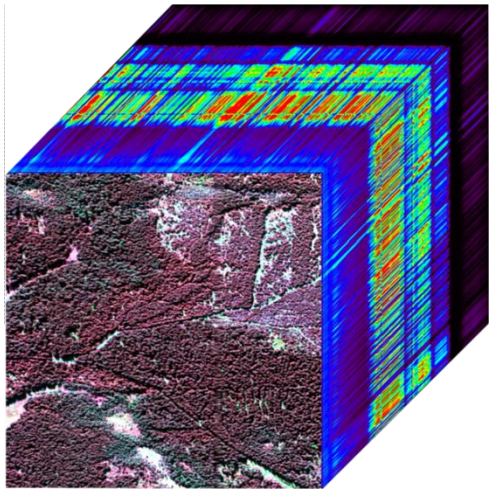
Spectral coverage: 410 – 1032 nm
Number of bands: 62
FWHM: 9,5 – 11,5 nm
Radiometric resolution: 16-bit
Spatial resolution: 1,5 x 2,0 m
flight elevation: 2500 m
flight line width: (m): 820 m
flight line width:(pix): 512 pix

2013 APEX sensor

Airborne Prism EXperiment

Spectral coverage: 380 – 2500 nm
Number of bands: 313
FWHM: 6 nm (VNIR), 10 nm (SWIR)
Radiometric resolution: 14-bit (VNIR), 13-bit (SWIR)
Spatial resolution: 1.5 m
flight elevation: 4300 m
flight line width: 1500 m
flight line width:(pix): 1000 pix





INDICES, predictive models

- Total chlorophyll:
  - $NDVI_{705}$, $mNDVI_{705}$, MCARI, TCARI, TCARI/OSAVI, TVI, $ANMB_{650-725}$
- Total carotenoids
  - CRI_{550}, CRI_{700}, $RNIR*CRI_{550}$, $RNIR*CRI_{700}$
- Relative Water Content
  - WI, NDWI
- Statistical models
  - Simple Linear Regressions (indices)
  - Partial Least Square Regression (PLSR)
    - 450 – 2,500 nm, region 350 – 450 nm excluded from the analyses due to the noise in the measured spectra
    - Reflectance spectra, continuum removed reflectance spectra
  - Coefficient of Determination (R^2), p-values, Root Mean Square Error (RMSE)

2. INMON: Hyperspectral Krušné hory Mts. (2012-2015)

Results – indices, predictive models

- The best results were achieved by TCARI/OSAVI index (for photosynthetic pigments), WI (for water content) and PLSR.

	Total chlorophyll (mg/g d.m.)			Carotenoids (mg/g d.m.)			RWC (%)	
method	**R^2 ***	**RMSE**	**method**	**R^2 ***	**RMSE**	**method**	**R^2 ***	**RMSE**
MCARI	0.5221	0.4620	**x**	x	x	**WI**	0.5014	1.7461
TCARI/OSAVI	0.6476	0.3745	**x**	x	x	**NDWI**	0.4817	1.9763
TVI	0.4941	0.4889	**x**	x	x	**x**	x	x
PLSR	0.7763 (6 comp.)	0.3317	**PLSR**	0.7737 (6 comp.)	0.0380	**PLSR**	0.7831 (8 comp.)	1.4555

2. INMON: Hyperspectral Krušné hory Mts. (2012-2015)

Results – comparison of ASAS and APEX data

- Vegetation indices used for the spatio-temporal analysis of Norway spruce physiological status.

Table 2: Vegetation indices

$NDVI_{705}$ [12]	MCARI [19]
VOG_1 and VOG_2 [13]	TVI [20]
REP [14]	TCARI [21]
NDVI [15]	OSAVI [22]
RDVI [16]	TCARI/OSAVI [21]
MSR [17]	N_{704}, N_{714}, N_{724} [4]
MSAVI [18]	D_{714}/D704, D_{724}/D_{704} [4]

- Misurec et al., manuscript under preparation

2. INMON: Hyperspectral Krušné hory Mts. (2012-2015)

Results – comparison of ASAS and APEX data

- **Separability index** was calculated between the healthy and damaged forest stands for the all VIs to check their sensitivity on forest damage.

$$SI = \frac{|\mu_h - \mu_d|}{\sigma_h + \sigma_d}$$

- Separability scores (SI) of the five most sensitive indices for the original (2 m) and generalized (6 m) spatial resolution ASAS data.

data set	**ASAS (1998)**	
resolution	**2 m**	**6 m**
1.	VOG_1: 1.87	N_{714}: 1.92
2.	NDVI: 1.55	VOG_1: 1.88
3.	TCARI/OSAVI: 1.52	TCARI/OSAVI: 1.88
4.	MSR: 1.48	MSR: 1.85
5.	$NDVI_{705}$: 1.44	$NDVI_{705}$: 1.80

- Misurec et al., manuscript under preparation

2. INMON: Hyperspectral Krušné hory Mts. (2012-2015)

Results – comparison of ASAS and APEX data

- The original values of the given VIs obtained from the ASAS dataset are not directly comparable to the ones extracted from the APEX dataset. This is mainly due to technological differences between ASAS and APEX sensors, differences in atmospheric correction applied on the ASAS and APEX datasets etc. **The original VIs values were therefore normalized to allow their mutual comparability using the following formula**:

$$VI'_x = \frac{VI_x - VI_\mu}{VI_\sigma}$$

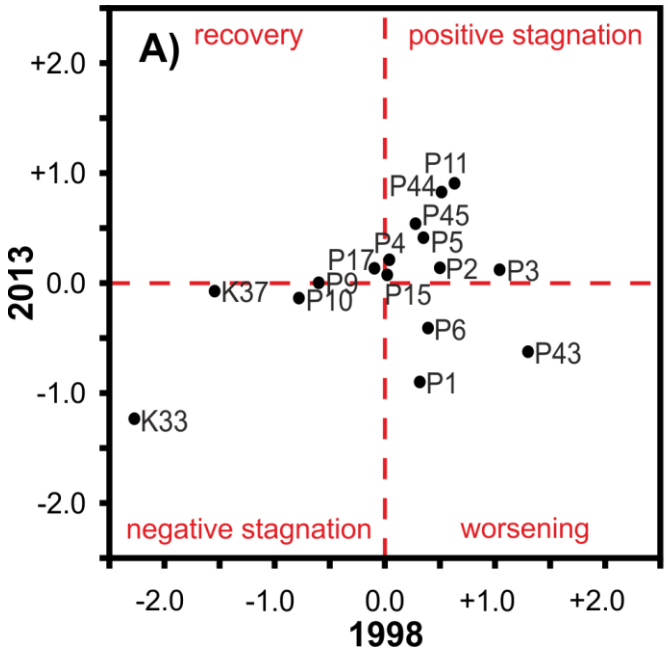
- where: VI'_x is the normalized value of vegetation index VI for pixel x; VI_x is the original value of vegetation index VI for pixel x; VI_μ and VI_σ are mean and standard deviation values of vegetation index VI calculated from the all pixels representing sunlit crowns within the all buffer areas representing the selected forest stands.

- Misurec et al., manuscript under preparation

2. INMON: Hyperspectral Krušné hory Mts. (2012-2015)

Results – comparison of ASAS and APEX data

the relative distance of the particular stands (defined by local mean of the given VI) from the baselines (defined by the global mean of the given VI) in both time horizons.



•Visualization of Norway spruce health status temporal change between 1998 and 2013 at Přebuz (P) and Kovářská (K) sites using VOG_1 vegetation index

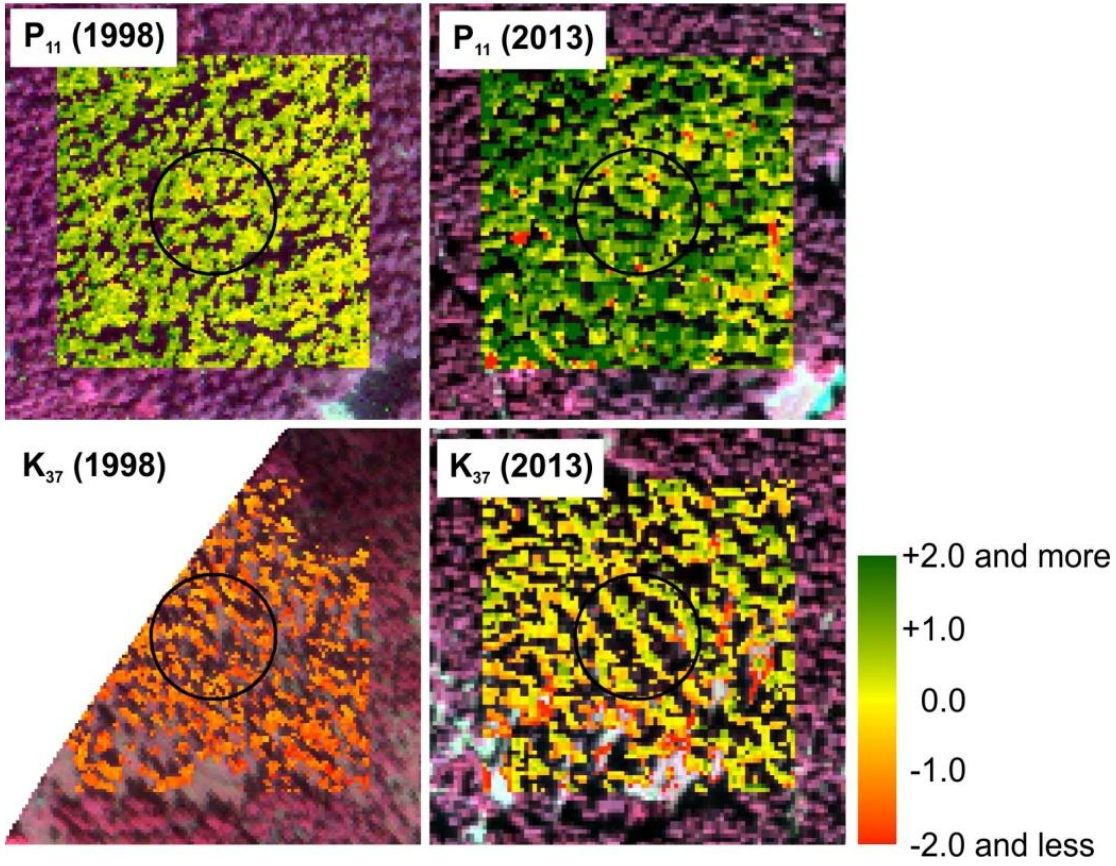
•Misurec et al., manuscript under preparation

Table 2: Separability scores (SI) of the five most sensitive indices for the original (2 m) and generalized (6 m) spatial resolution ASAS

2. INMON: Hyperspectral Krušné hory Mts. (2012-2015)

Results – comparison of ASAS and APEX data

- Relativized values of the VOG_1 vegetation index calculated from the ASAS (1998) and APEX (2013) hyperspectral image data in original 2 m spatial resolution for P_{11} and K_{37} stands.



- Misurec et al., manuscript under preparation

2. INMON: Hyperspectral Krušné hory Mts. (2012-2015)

Conclusions

HYPERSPECTRAL DATA FOR MONITORING SPRUCE FOREST HEALTH

- Several of the tested VIs proved to be **highly sensitive to vegetation health status and forest damage, particularly VOG_1, TCARI/OSAVI, MSR and $NDVI_{705}$.**

- **The VOG_1 index was showing high and stable sensitivity to forest damage**.

- **Selected sensitive VIs also demonstrated ability to detect** not only high level of forest damage, but also **slight differences in physiological status,** which do not have any visible symptoms (such as high defoliation level etc.).

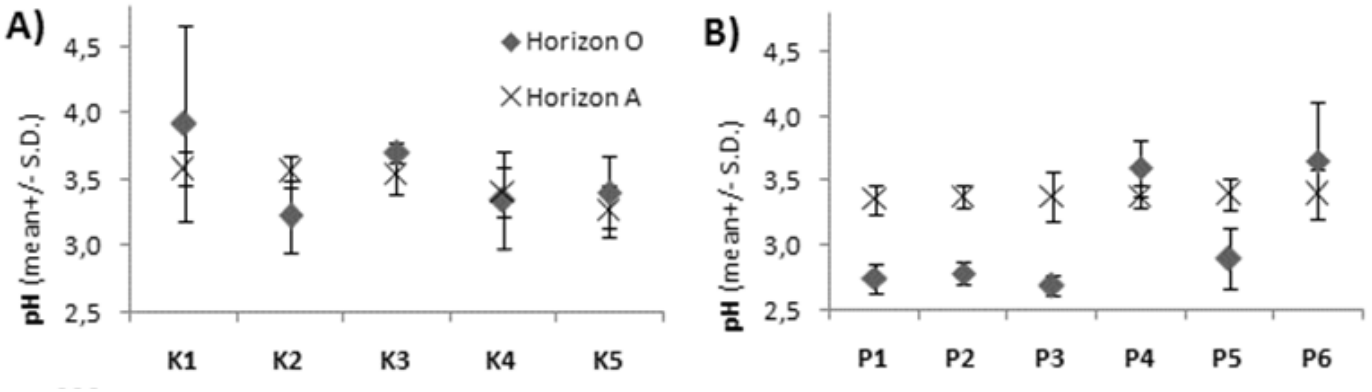
2. INMON: Hyperspectral Krušné hory Mts. (2012-2015)

Conclusions

SOIL POLLUTION is ONE OF THE MAIN DRIVING FACTORS:

- It appears that after removal of main acidic deposition sources in 1990´s, the soil acidification is now the main driving factor of Norway spruce physiological status in Krušné Hory Mts.

- CENTRAL



- The improvement of forest soils damaged by previous acidic deposition is a long-term process and only slight recovery was observed after a decade in other mountainous regions of the Czech Republic

2. INMON: Hyperspectral Krušné hory Mts. (2012-2015)

Conclusions

Forest recovery appeared in Ore Mts. during the observed period 1998 – 2013.

Regarding spatio-temporal changes in forest status, in 1998 significant differences were observed between damaged (central Ore Mts. – Kovářská) and undamaged (western Ore Mts. – Přebuz) stands, while in 2013 sort of “averaging” of the health status of Norway spruce stands has been observed: surviving trees in the central part improved their health status remarkably while originally undamaged stands in the western part showed symptoms of chronic damage.

Since adverse soil conditions are longer persisting and improving only slowly comparing to air conditions and pollution, forests in the Ore Mts. are still exposed to acid soil conditions.

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Magda Edwards- Jonášová[4], Pavel Cudlín[4]

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Thank you for your attention

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