REFLECTANCE VARIATION AND ANISOTROPY OF FOREST TREES IN RADIOMETRICALLY CALIBRATED AIRBORNE LINE-SENSOR (ADS40) IMAGES – IMPLICATIONS FOR SPECIES CLASSIFICATION

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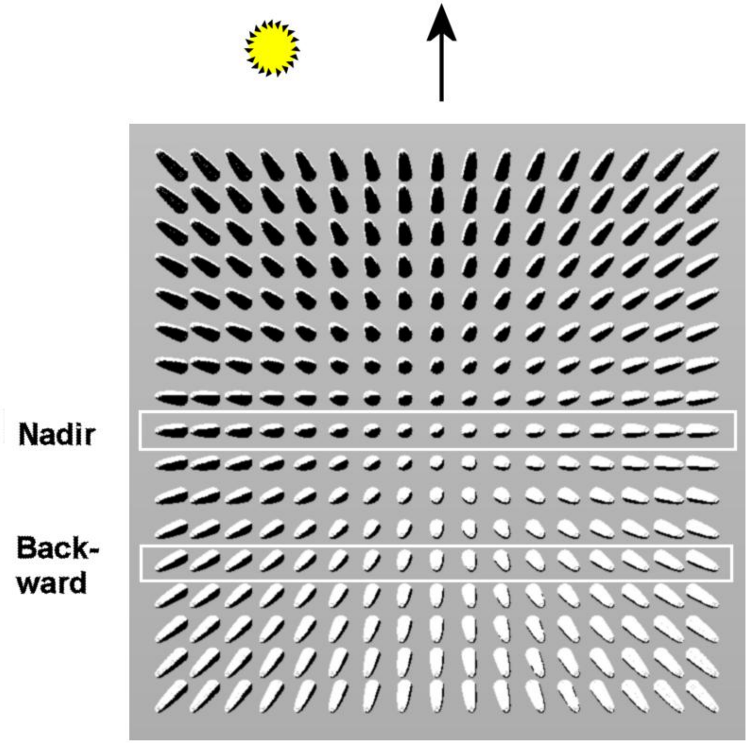
Rationales and Objectives

- LiDAR-based forest inventories in Scandinavia, Species identification = bottleneck

- Aerial images needed to complete LiDAR?

- Economical altitudes > 3 km ⇒ texture features out-of-reach ⇒ radiometric features (and deal with anisotropy)

- € is the consultant!



Rationales and Objectives

Options: Use anisotropy in multiple views, or,
use a line sensor to restrict the anisotropy.

Recent radiometric advances unexplored

We looked at the option of using absolutely calibrated MS airborne reflectance images.
(Available currently in ADS40+XPro, … DMC 2 coming?).

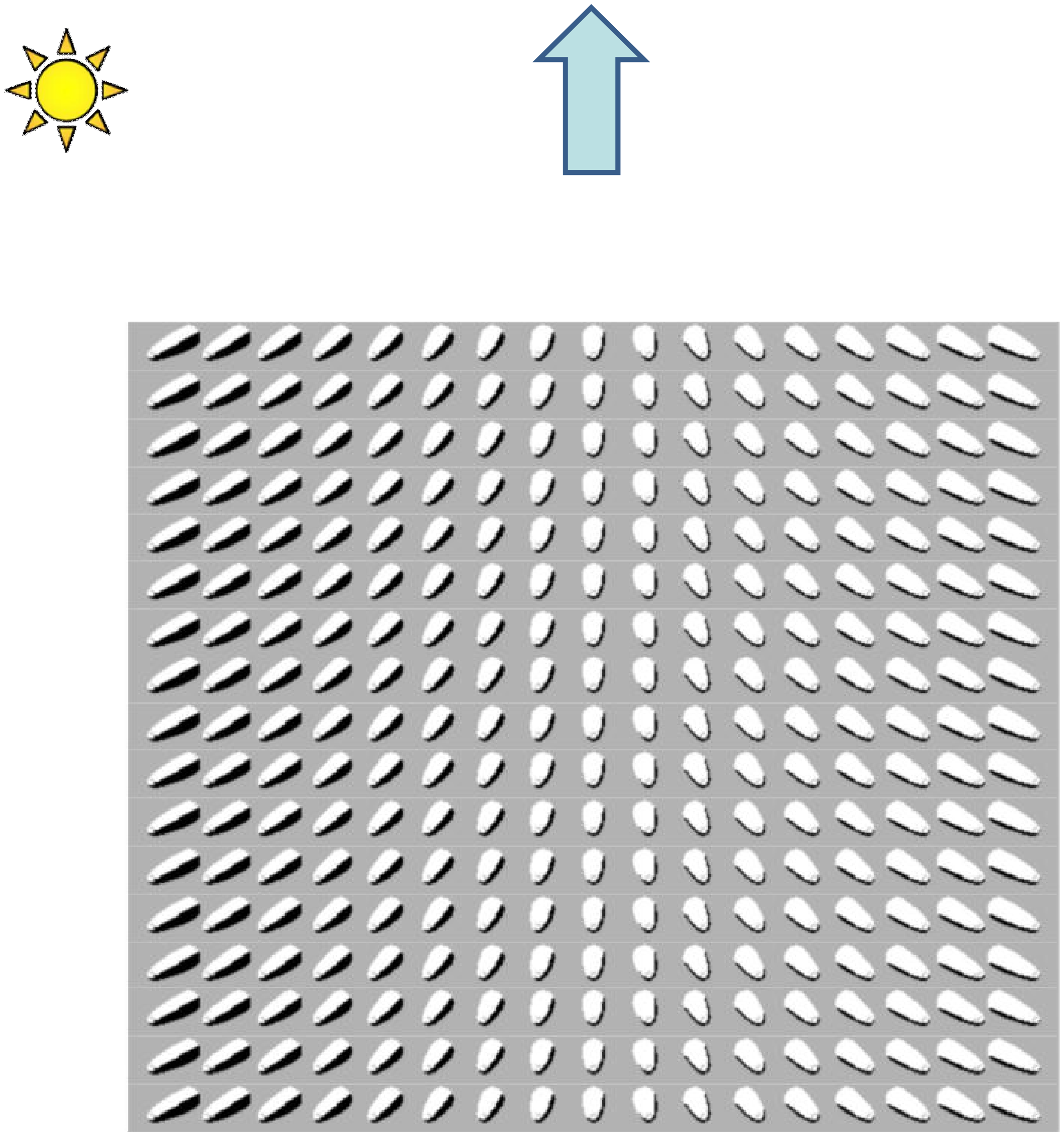
Objectives

1. Implement an ADS40 sensor model (technical)

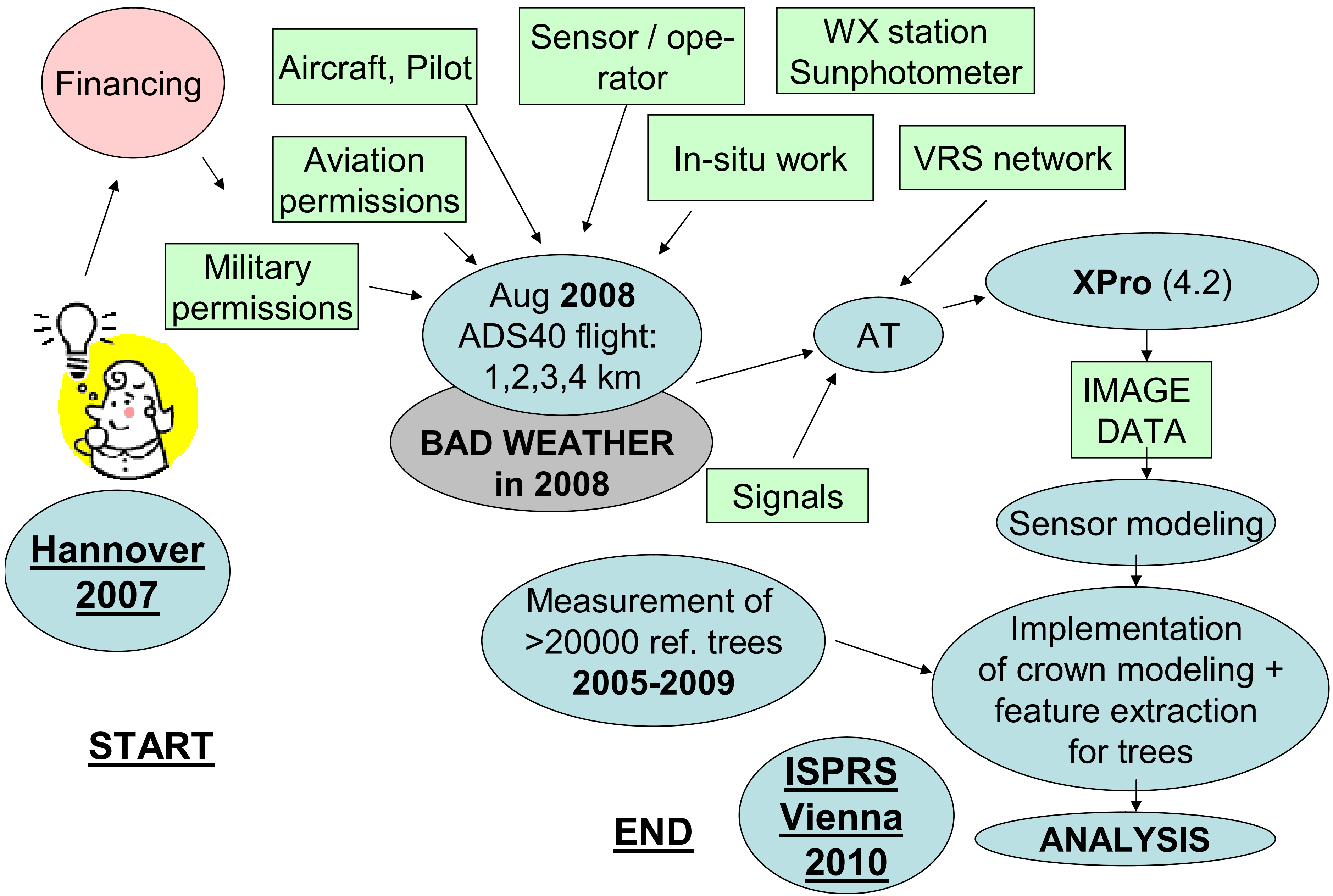
2. Crown partitioning into illumination classes

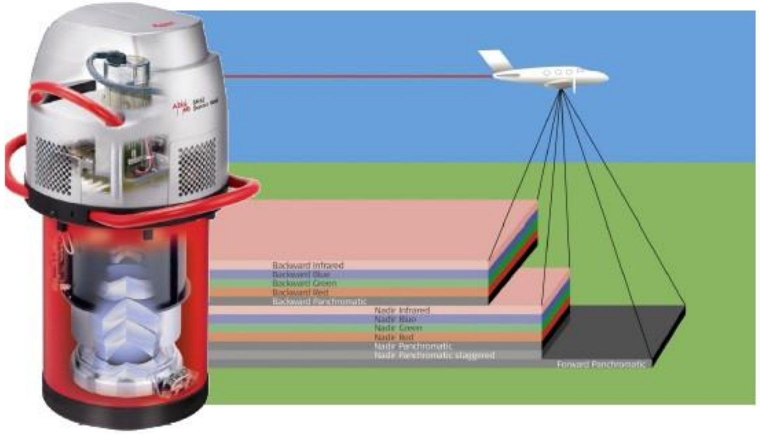
3. Study reflectance variation and anisotropy for spp. classification
(i.e. the basics of spectral tree spp. classification in passive optical data)

View geometry ADS40 (Nadir + Backwards 16°)



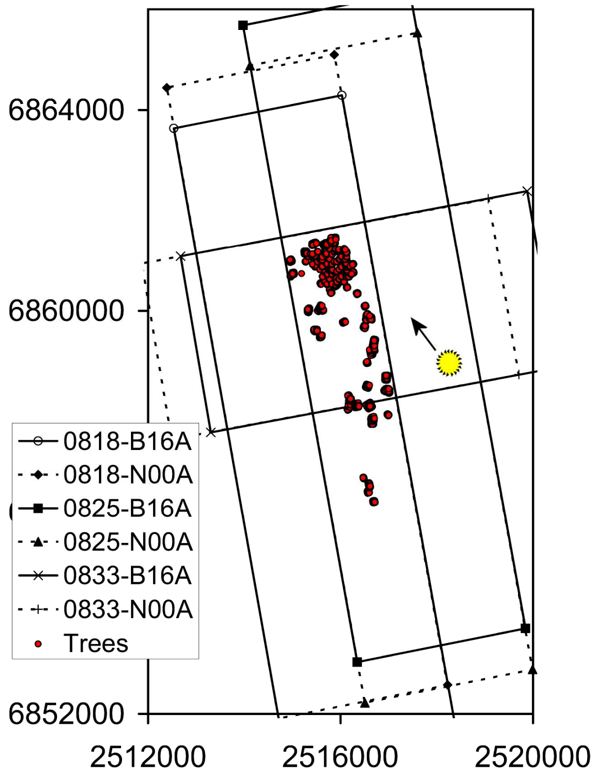
Workflow of the study (Acknowledgements)

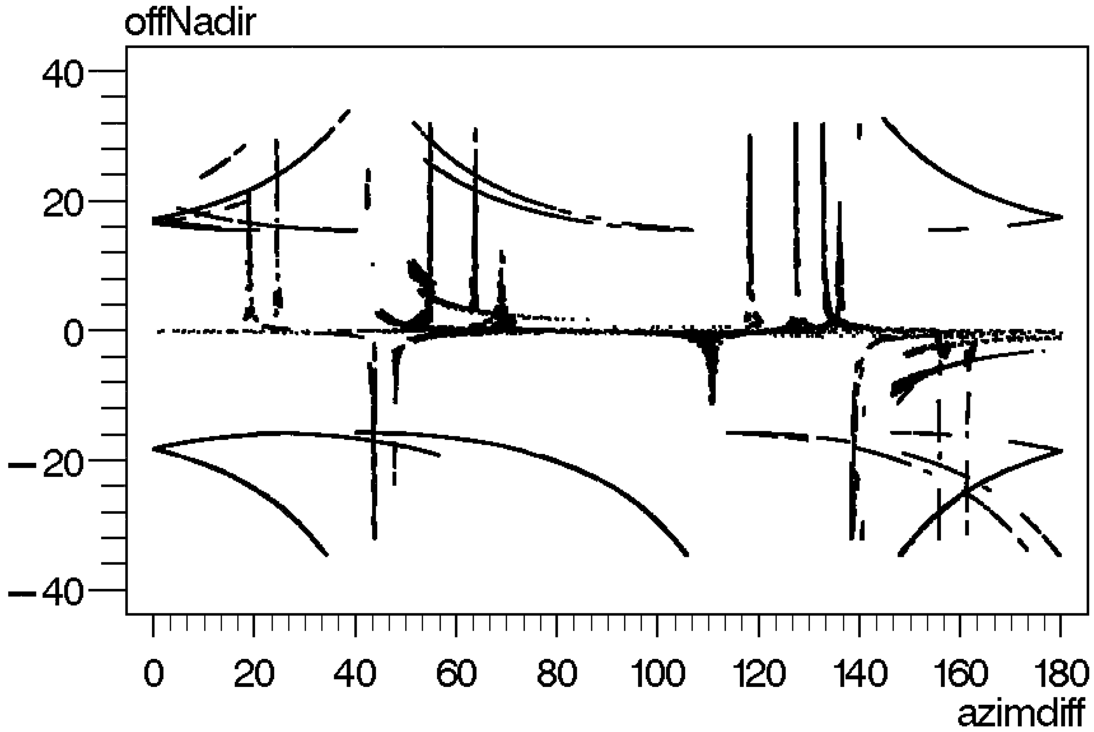


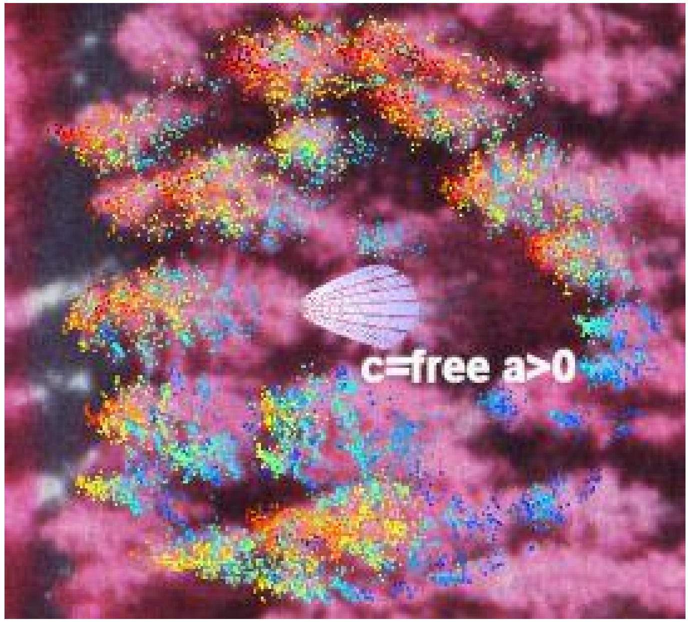


Experiment in Finland

- ADS40 (BLU, GRN, RED, NIR) × 2
  1-4 km, 10–40 cm GSD.
- Solar elevation 27°– 37°
- Trees ($N_{visible}$=15687), LiDAR



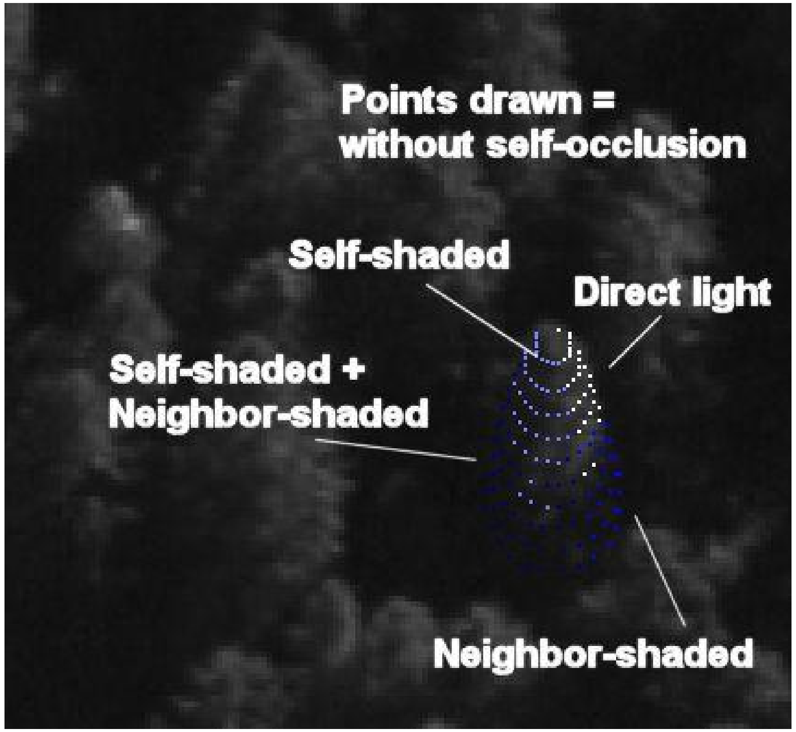


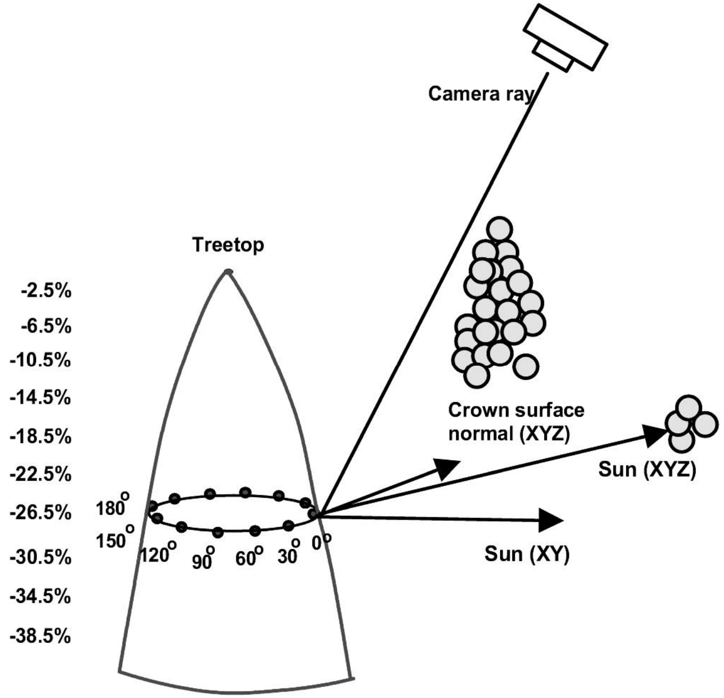


Crown modeling in LiDAR

- Crown sampled in 1 + 10 × 12 points
- illumination class assigned to each point

Camera-visibility and shading determined using ray-tracing.





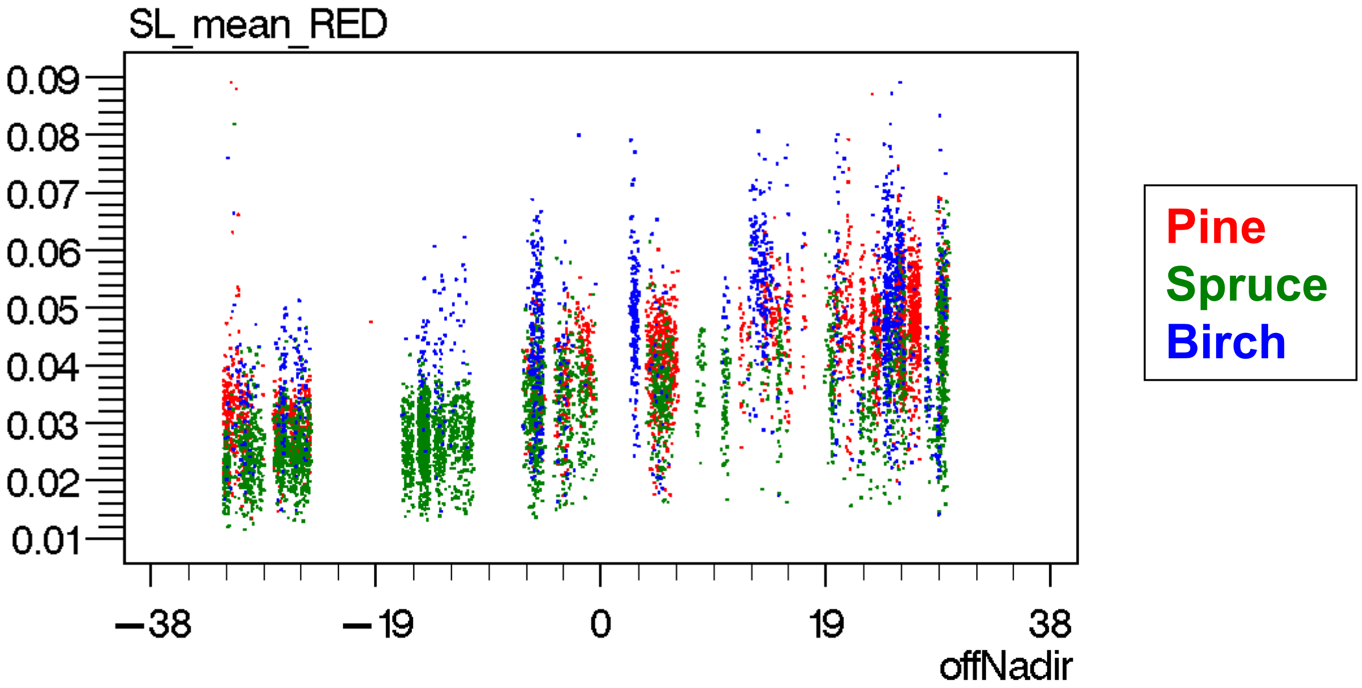

PINE
SPRUCE
BIRCH


Results: Basic refl. observations

Reflectance data had a <u>precision</u> of ~5%, in well-defined, non-tree targets (~system precision + experiment effects).

Anisotropy of reflectance in trees was up to ±40% when the instrument was flown almost perpendicular to Sun.

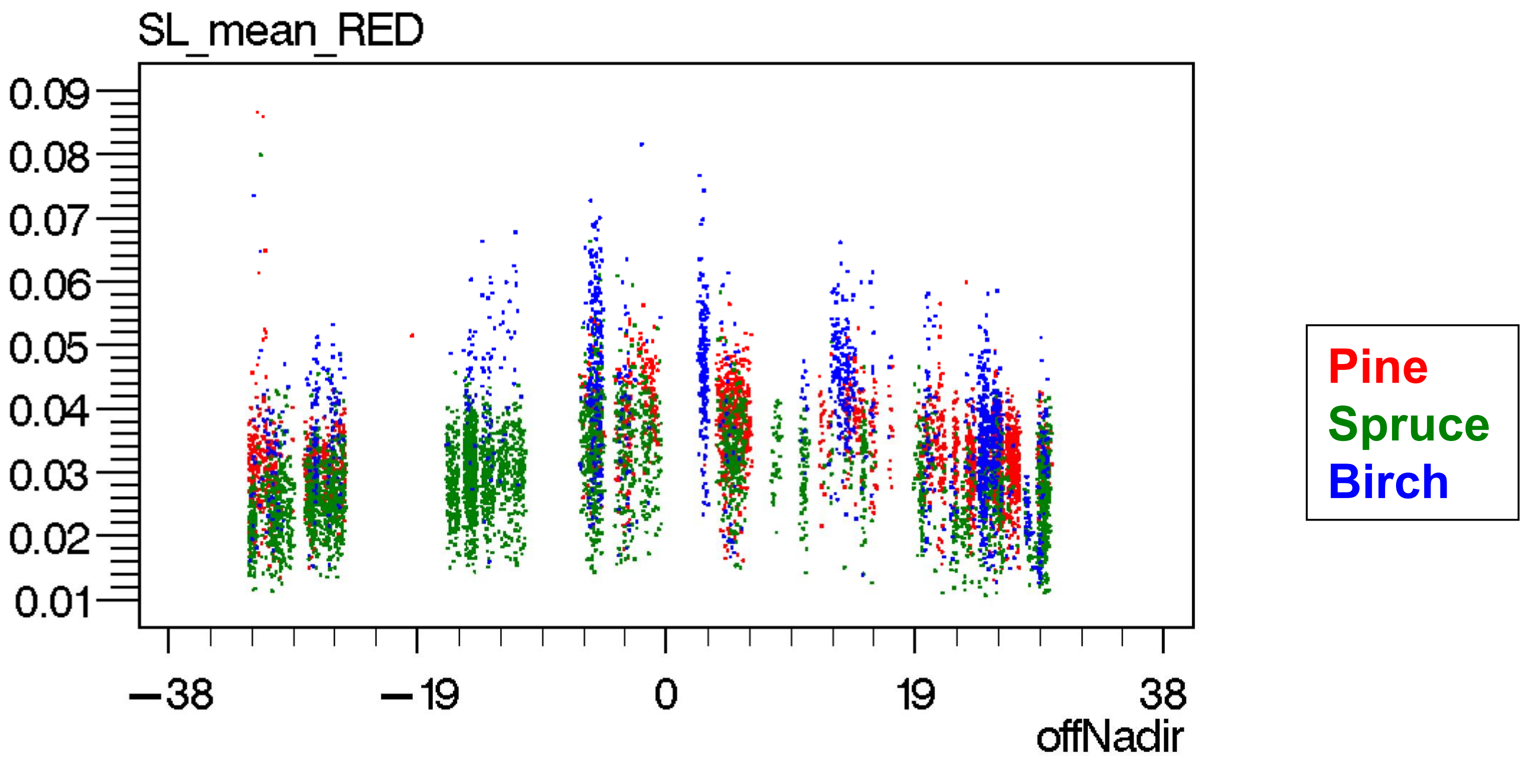
High intraspecies variation, small interspecies differences.



Results: Atmospheric + BRDF correction

BRDF-corrected (FULL) reflectance data suitable for mosaicking,

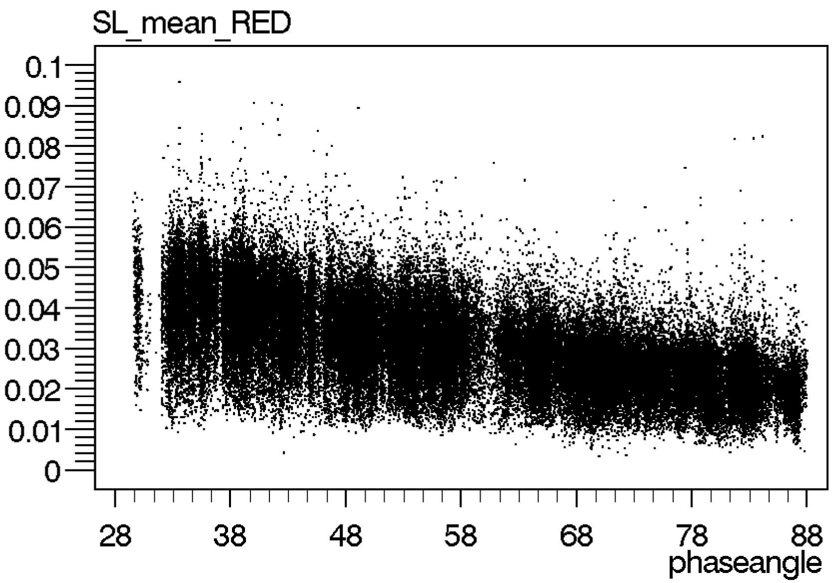
A single BRDF-correction will fail for Finnish tree spp.



Results: Illumination

Anisotropy for targets in direct and diffuse light differed.

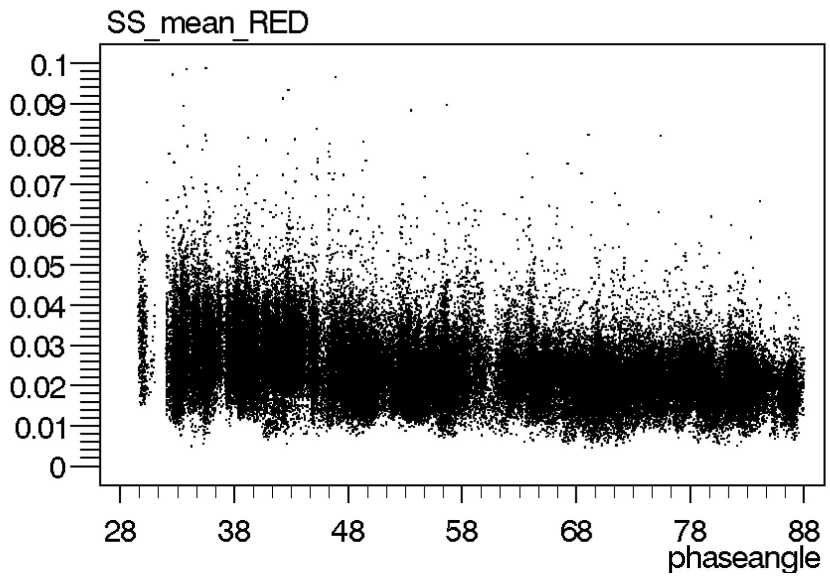
Sun-lit, spruce



Front-lit trees

Back-lit trees

Shaded, spruce



Front-lit trees

Back-lit trees

Results: anisotropy & variation sources

- 62% of the Sun-lit reflectance variation in BLU was explained by phase-angle and azimuth-difference, while only 15% in NIR (ANCOVA)

Some sources of high intraspecies reflectance variation:

1) Proximity effects by neighboring trees

Proximity effects (in mean per-tree refl.) up to 33% in NIR, and <15% in visible bands.

2) Effects by age and site fertility

Both explained (ΔR^2)1-5% of NIR, NDVI, and RED variation

3) Overall stand-level effects (site-to-site variance component)

Explained 1-19%, being strongest in NIR

Results: Intracrown trends

Pine	Sunlit [o]							Shaded				
	-90	-60	-30	0	30	60	90	-120	-150	180	150	120
RED	0.955	1.048	1.155	1.240	1.242	1.137	0.983	1.029	1.035	1.024	1.022	1.002
Height ↓	0.971	1.066	1.168	1.252	1.262	1.162	1.008	1.019	0.993	0.956	0.976	0.992
	0.989	1.076	1.171	1.249	1.259	1.170	1.028	1.003	0.950	0.897	0.927	0.975
	1.008	1.094	1.176	1.251	1.263	1.180	1.050	0.981	0.907	0.849	0.879	0.949
	1.018	1.105	1.177	1.256	1.272	1.172	1.062	0.956	0.876	0.814	0.835	0.926
	1.028	1.113	1.185	1.264	1.274	1.160	1.061	0.931	0.845	0.781	0.808	0.898
	1.047	1.114	1.174	1.258	1.256	1.148	1.059	0.909	0.823	0.760	0.774	0.873
	1.048	1.113	1.154	1.250	1.247	1.121	1.050	0.879	0.804	0.742	0.755	0.851
	1.028	1.090	1.127	1.228	1.233	1.075	1.037	0.858	0.783	0.720	0.740	0.811
	0.987	1.071	1.035	1.067	1.154	1.025	0.983	0.806	0.777	0.701	0.724	0.808

Pine

	SL -90	SL -60	SL -30	SL 0	SL 30	SL 60	SL 90	SS -120	SS -150	SS 180	SS 150	SS 120
RED	0.955	1.048	1.155	1.240	1.242	1.137	0.983	1.029	1.035	1.024	1.022	1.002
	0.971	1.066	1.168	1.252	1.262	1.162	1.008	1.019	0.993	0.956	0.976	0.992
	0.989	1.076	1.171	1.249	1.259	1.170	1.028	1.003	0.950	0.897	0.927	0.975
	1.008	1.094	1.176	1.251	1.263	1.180	1.050	0.981	0.907	0.849	0.879	0.949
	1.018	1.105	1.177	1.256	1.272	1.172	1.062	0.956	0.876	0.814	0.835	0.926
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	0.987	1.071	1.035	1.067	1.154	1.025	0.983	0.806	0.777	0.701	0.724	0.808
GRN	0.948	1.043	1.152	1.226	1.222	1.134	0.989	1.006	0.986	0.968	0.983	0.978
	0.959	1.061	1.158	1.220	1.223	1.149	1.013	0.978	0.917	0.878	0.919	0.953
	0.980	1.068	1.151	1.204	1.204	1.146	1.027	0.946	0.859	0.810	0.859	0.923
	0.997	1.077	1.145	1.193	1.191	1.138	1.038	0.908	0.808	0.757	0.805	0.887
	1.002	1.079	1.132	1.181	1.180	1.119	1.034	0.873	0.771	0.717	0.757	0.856
	1.005	1.076	1.126	1.165	1.156	1.094	1.027	0.840	0.735	0.683	0.725	0.821
	1.019	1.071	1.104	1.143	1.125	1.063	1.013	0.812	0.712	0.661	0.693	0.792
	1.007	1.057	1.072	1.115	1.094	1.030	0.991	0.777	0.691	0.644	0.675	0.768
	0.990	1.031	1.032	1.080	1.067	0.983	0.968	0.757	0.675	0.631	0.659	0.731
	0.947	1.006	0.955	0.945	0.987	0.935	0.927	0.716	0.674	0.618	0.645	0.719
BLU	0.992	1.022	1.053	1.076	1.074	1.043	1.000	1.007	1.010	1.007	1.005	1.001
	0.995	1.027	1.058	1.081	1.082	1.052	1.008	1.000	0.994	0.984	0.986	0.991
	0.994	1.028	1.055	1.076	1.078	1.052	1.013	0.991	0.978	0.962	0.967	0.980
	0.996	1.029	1.051	1.071	1.074	1.051	1.017	0.981	0.961	0.943	0.947	0.967
	0.995	1.026	1.044	1.068	1.071	1.045	1.016	0.971	0.948	0.928	0.931	0.958
	0.992	1.025	1.043	1.062	1.064	1.037	1.014	0.962	0.935	0.915	0.920	0.945
	0.995	1.023	1.033	1.055	1.053	1.030	1.008	0.954	0.927	0.906	0.904	0.935
	0.990	1.016	1.022	1.047	1.042	1.016	1.002	0.945	0.918	0.897	0.897	0.927
	0.980	1.007	1.011	1.032	1.033	0.997	0.996	0.938	0.905	0.888	0.892	0.911
	0.961	0.995	0.982	0.985	1.004	0.982	0.976	0.917	0.902	0.876	0.887	0.905
NIR	0.961	1.069	1.188	1.268	1.263	1.166	1.001	1.023	0.978	0.942	0.950	0.946
	0.985	1.088	1.205	1.278	1.276	1.189	1.030	0.968	0.867	0.819	0.862	0.901
	1.018	1.099	1.198	1.256	1.243	1.175	1.046	0.905	0.777	0.722	0.779	0.854
	1.040	1.101	1.183	1.226	1.207	1.147	1.049	0.838	0.698	0.642	0.703	0.803
	1.045	1.096	1.154	1.192	1.166	1.103	1.032	0.775	0.636	0.579	0.635	0.752
	1.047	1.086	1.127	1.143	1.114	1.053	1.011	0.718	0.581	0.526	0.585	0.702
	1.045	1.056	1.078	1.085	1.047	0.996	0.969	0.669	0.538	0.486	0.536	0.657
	1.037	1.022	1.017	1.029	0.988	0.942	0.936	0.618	0.507	0.461	0.504	0.616
	0.999	0.984	0.954	0.954	0.954	0.883	0.889	0.588	0.481	0.439	0.479	0.579
	0.946	0.935	0.869	0.816	0.841	0.828	0.835	0.546	0.486	0.428	0.459	0.547

Birch

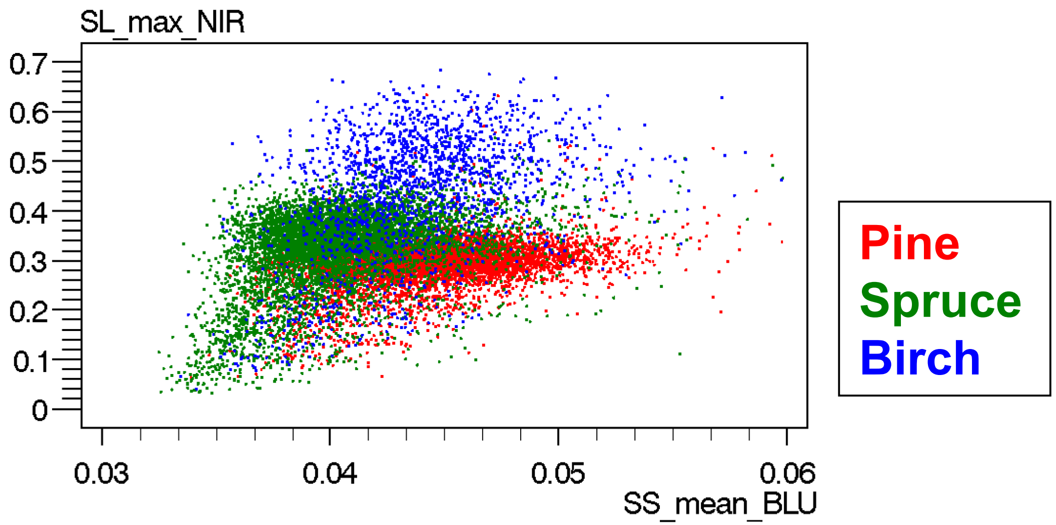
	-90	-60	-30	0	30	60	90	-120	-150	180	150	120
RED	0.950	1.131	1.320	1.424	1.383	1.233	1.022	0.948	0.859	0.820	0.853	0.881
	0.991	1.191	1.379	1.464	1.407	1.278	1.088	0.882	0.775	0.738	0.783	0.837
	1.025	1.238	1.399	1.453	1.399	1.283	1.120	0.834	0.730	0.693	0.741	0.801
	1.070	1.266	1.394	1.423	1.362	1.267	1.138	0.804	0.702	0.658	0.703	0.766
	1.092	1.265	1.369	1.391	1.329	1.230	1.134	0.778	0.671	0.629	0.670	0.744
	1.125	1.258	1.362	1.371	1.295	1.179	1.139	0.739	0.642	0.603	0.639	0.723
	1.116	1.235	1.284	1.357	1.257	1.138	1.118	0.720	0.628	0.590	0.618	0.696
	1.139	1.192	1.254	1.259	1.191	1.112	1.110	0.705	0.607	0.572	0.595	0.687
	1.109	1.160	1.169	1.167	1.104	1.082	1.088	0.680	0.602	0.554	0.585	0.654
	1.101	1.054	1.052	0.979	0.937	0.959	0.995	0.674	0.591	0.560	0.572	0.640
GRN	0.948	1.122	1.305	1.413	1.367	1.214	1.015	0.953	0.858	0.825	0.857	0.879
	0.979	1.181	1.361	1.432	1.388	1.256	1.074	0.891	0.782	0.745	0.790	0.834
	1.017	1.219	1.371	1.422	1.368	1.259	1.102	0.848	0.740	0.704	0.750	0.800
	1.052	1.240	1.369	1.403	1.342	1.247	1.126	0.813	0.712	0.671	0.713	0.774
	1.073	1.246	1.342	1.370	1.310	1.211	1.117	0.785	0.680	0.644	0.683	0.752
	1.109	1.242	1.332	1.343	1.261	1.170	1.120	0.749	0.653	0.614	0.651	0.728
	1.087	1.218	1.265	1.339	1.218	1.116	1.101	0.732	0.633	0.597	0.630	0.706
	1.108	1.191	1.244	1.239	1.160	1.106	1.103	0.720	0.616	0.581	0.611	0.692
	1.087	1.140	1.145	1.156	1.086	1.063	1.091	0.691	0.607	0.563	0.600	0.656
	1.085	1.047	1.028	0.964	0.917	0.958	0.980	0.681	0.594	0.569	0.590	0.647
BLU	0.994	1.048	1.100	1.126	1.108	1.061	1.003	0.981	0.961	0.949	0.955	0.963
	1.005	1.063	1.113	1.134	1.115	1.070	1.017	0.958	0.932	0.916	0.925	0.943
	1.016	1.072	1.111	1.126	1.105	1.067	1.023	0.940	0.914	0.896	0.904	0.926
	1.025	1.073	1.104	1.111	1.093	1.060	1.027	0.926	0.898	0.879	0.889	0.910
	1.030	1.068	1.091	1.097	1.075	1.045	1.025	0.912	0.881	0.866	0.872	0.899
	1.037	1.061	1.082	1.081	1.057	1.031	1.024	0.897	0.868	0.849	0.856	0.885
	1.028	1.053	1.052	1.074	1.037	1.006	1.020	0.885	0.858	0.842	0.841	0.872
	1.030	1.038	1.043	1.033	1.010	1.002	1.013	0.879	0.847	0.828	0.833	0.861
	1.014	1.009	1.010	1.002	0.983	0.977	1.001	0.865	0.836	0.821	0.822	0.847
	0.998	0.972	0.958	0.936	0.927	0.940	0.965	0.860	0.827	0.810	0.815	0.838
NIR	0.953	1.135	1.354	1.483	1.441	1.260	1.019	1.022	0.945	0.897	0.891	0.879
	0.995	1.196	1.419	1.531	1.478	1.310	1.084	0.953	0.856	0.810	0.826	0.836
	1.041	1.243	1.433	1.516	1.456	1.318	1.123	0.892	0.792	0.752	0.778	0.800
	1.078	1.257	1.431	1.477	1.406	1.289	1.137	0.842	0.738	0.702	0.730	0.771
	1.102	1.250	1.393	1.425	1.347	1.240	1.133	0.789	0.680	0.649	0.689	0.743
	1.133	1.238	1.361	1.378	1.285	1.197	1.119	0.734	0.627	0.597	0.634	0.703
	1.121	1.209	1.259	1.328	1.202	1.112	1.097	0.688	0.591	0.553	0.587	0.666
	1.126	1.162	1.207	1.176	1.081	1.077	1.083	0.657	0.545	0.515	0.551	0.629
	1.102	1.078	1.078	1.034	0.983	0.985	1.032	0.616	0.516	0.480	0.515	0.586
	1.041	0.950	0.902	0.816	0.794	0.855	0.901	0.591	0.499	0.465	0.495	0.554

Results: Monoscopic classification

Best-case monoscopic classification accuracy 80%,
Nadir images and 7 predictors. ASR data best.

Stereo data (Heikkinen et al. 88%).

Diffuse-light reflectances provided additional information to sun-lit reflectances, and BLU band was a good predictor.



Sun-lit maximum NIR and mean BLU of the shaded crown side

Conclusions

Pushbroom sensors (nadir) provide stable reflectance data, if the sensor is flown towards/away from Sun.

80% (88% Stereo) classification accuracy from 4 km flying altitude shows high performance in ADS40/XPro data.

Reflectance variation in (studied) trees is very high and species-specific differences are marginal and dependent on the view-illumination geometry.

Frame images that view the trees in 10-15 directions might enable measurement of the anisotropy, which should increase classification accuracy >85% but <90% because of the noise. Expensive.

Thank you!


PUMA


sn:o 316 Strip: 1
143
135/314°
134/286°
140/55°
141/79°
142/111°
144/209°
Sp: Pine
Height: 21.4 m
d13: 221 mm