CORRELATION WIND LIDAR WITH PMT DETECTOR ARRAY & PHOTON-COUNTING: TEST BED RESULTS

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TITLE: TALK OUTLINE

BACKGROUND

> Atmospheric Winds: very important parameter for many applications: Meteorology, Climatology, Atmospheric research, Navigation, …

> Wind measurement techniques:

DWL: Detect Frequency change of Doppler shift (as in Aeolus Satellite, ESA since 2018 …)

PBL winds via Auto-Correlation of Aerosol inhomogeneities with (ground)scanning Elastic lidar (Eloranta, University Wisconsin, 1977)

Cloud image correlation : first Wind measurements with correlation from satellites (NOAA, 1970)

BACKGROUND #2

DWL Technique (Aladin Instrument on Aeolus Satellite) is the best in terms of altitude range (0- 30 km), resolutions, accuracy but:

> DWL Tx requirements: very demanding in terms of wavelength, spectral purity, stability & energy

> DWL Rx requirements: high frequency accuracy/stability of filtering, very complex focal plane detection & processing

>>**This work: Simpler system based vector-wind determination by X-correlation of Matrices of Elastic-Lidar-generated Point Clouds (0-10 km**) + proposal x combination of Passive **O2 Doppler Interferometer** in Limb Sounding, for Molecular winds (10-30 km)

THE LIDAR CONCEPT

§ **Tx lidar based on:**

High-repetition rate (KHz), IR/Vis low energy , multi-beam laser

>> Vastly simplified laser technology & relaxed requirements than for DWL

§ **Rx lidar based on:**

Single Photon Detection/Counting with multi-channel PMT array

Cross-correlation of Point-Cloud Images of Tropospheric aerosols

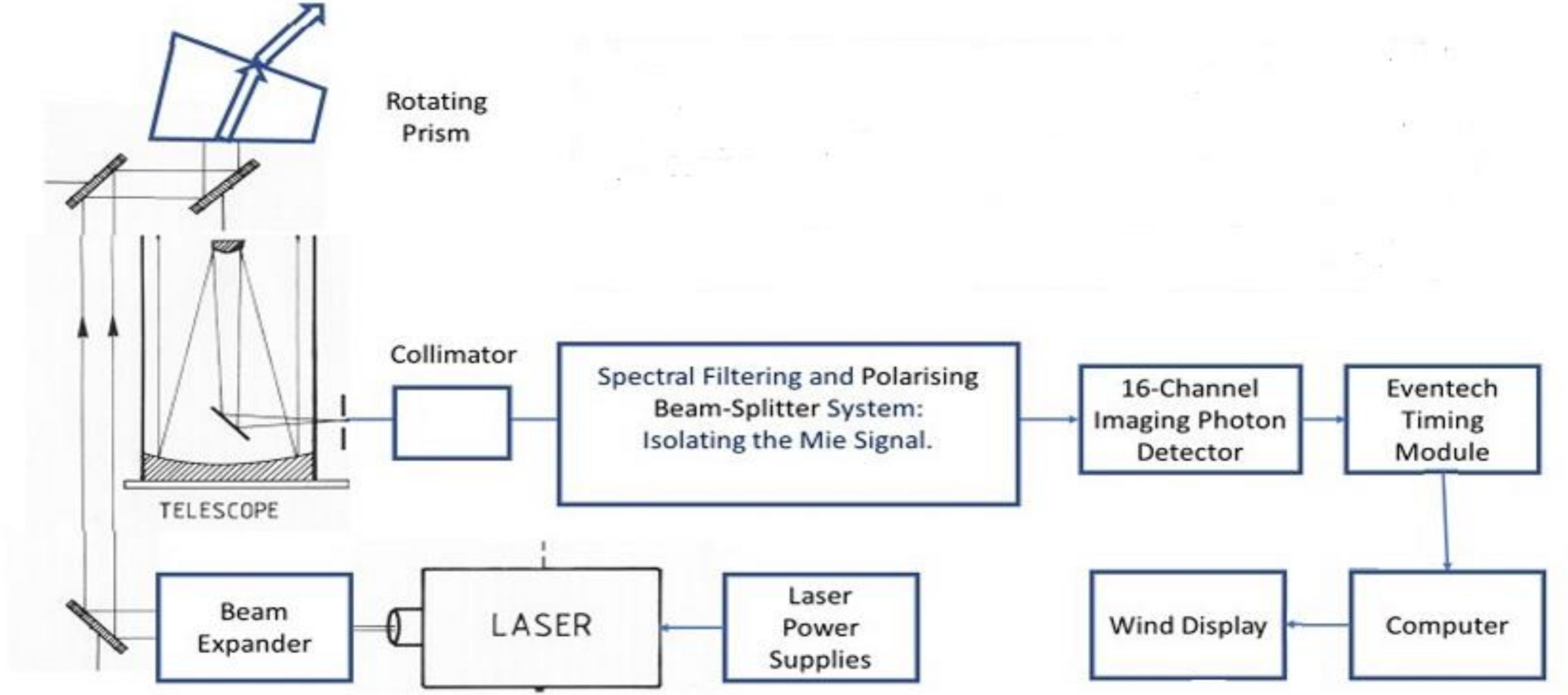
>> Vastly simplified Rx requirements than for DWL

§ **Multi-functional idar concept:**

High on Processing & Computer Power, apt for Sensor Data Fusion

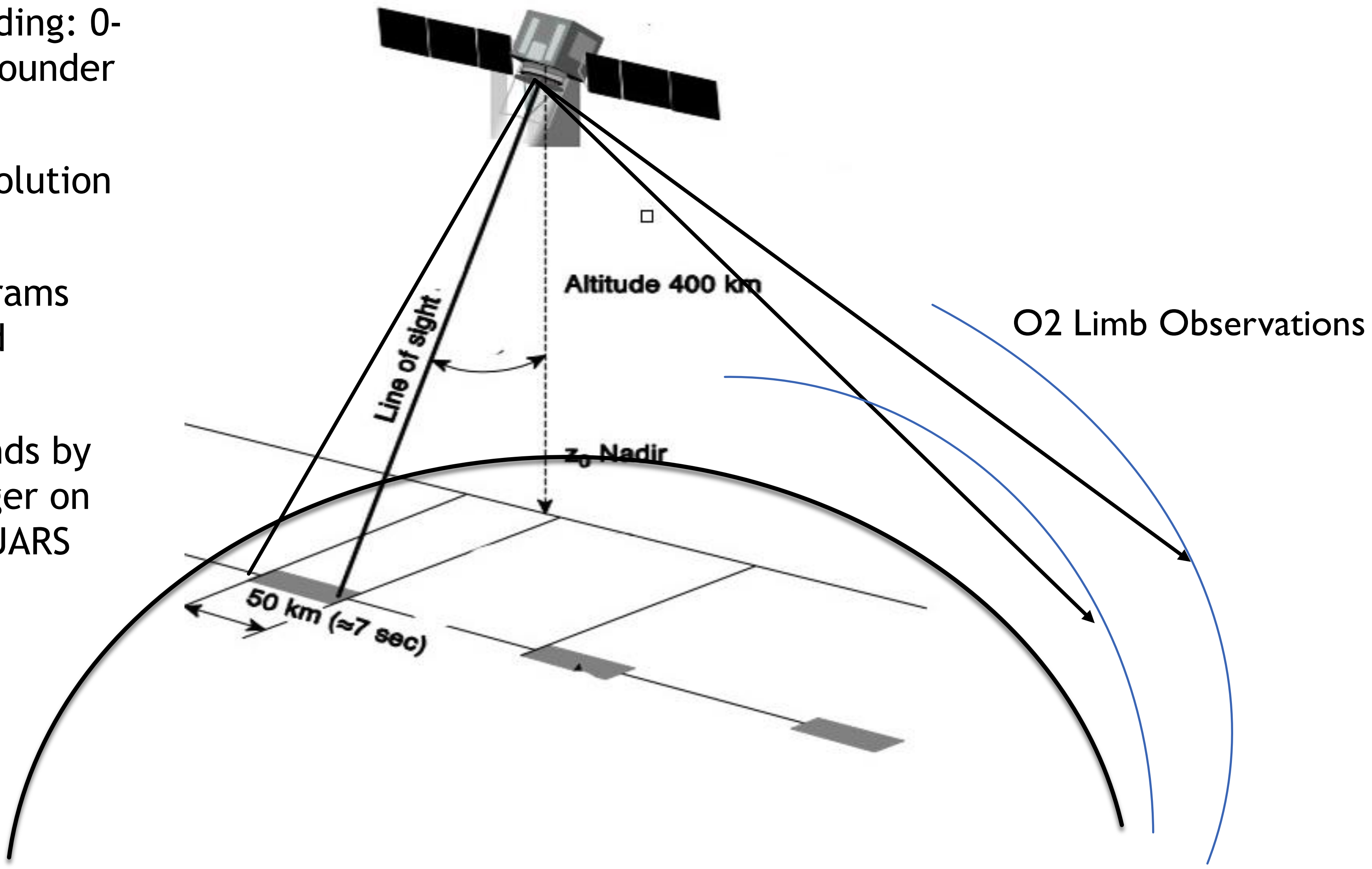
Ground Validation Test Bed

CORRELATION WIND LIDAR CONFIGURATION



WIND SATELLITE SPACE CONCEPT

- Combo-Instrument Satellite: CWL + Doppler Imager in Limb Sounding: 0-10 km CWL, 10-30 km Limb Sounder
- CWL emits 2 beams spatially separated by dx < spatial resolution (50 km), at an angle: δφ
- CWL: 0-10 Km aerosol histograms correlation provides 2-D wind components
- Limb Sounder: 10-30 Km: winds by High Resolution Doppler Imager on O2 lines (already proven on UARS HRDI)

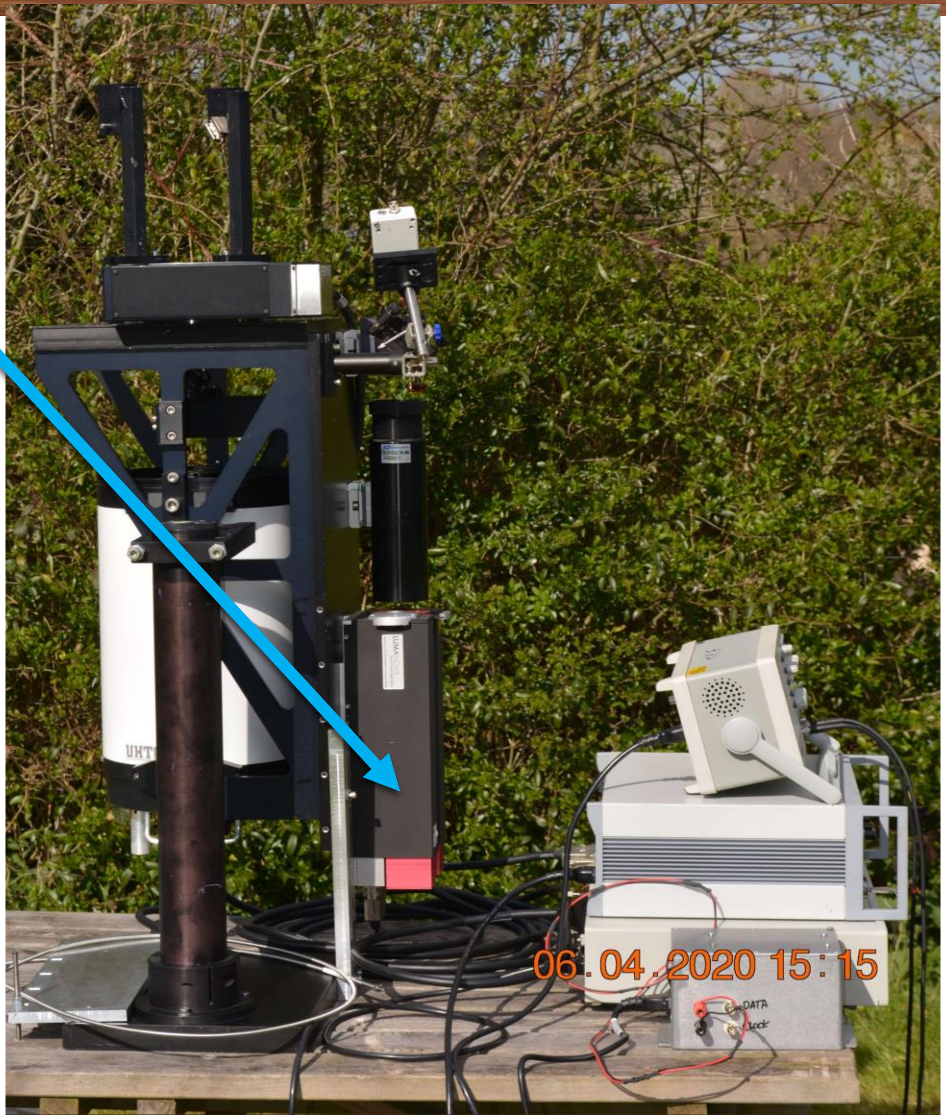


The CWL Engine

Left View:

Tx Laser (TEEM multi-mode, Un-stabilized, ~20 μJ*, 1 KHz, 20 mW, @ 355 nm), beam-expander, Newport Scanner & scan mirror mount.

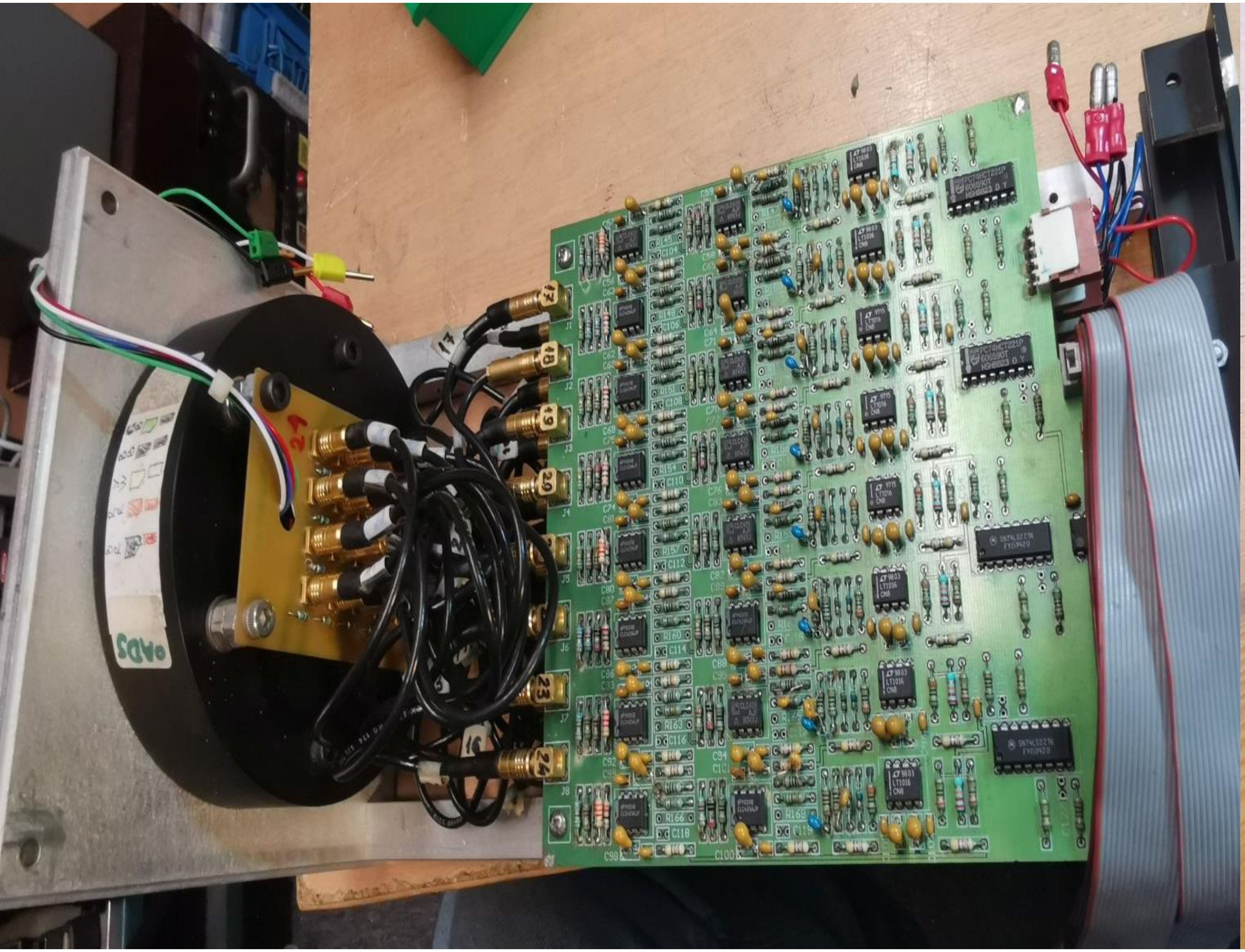
(*) before degradation of 2nd & 3rd harmonic filters to below 10 μJ



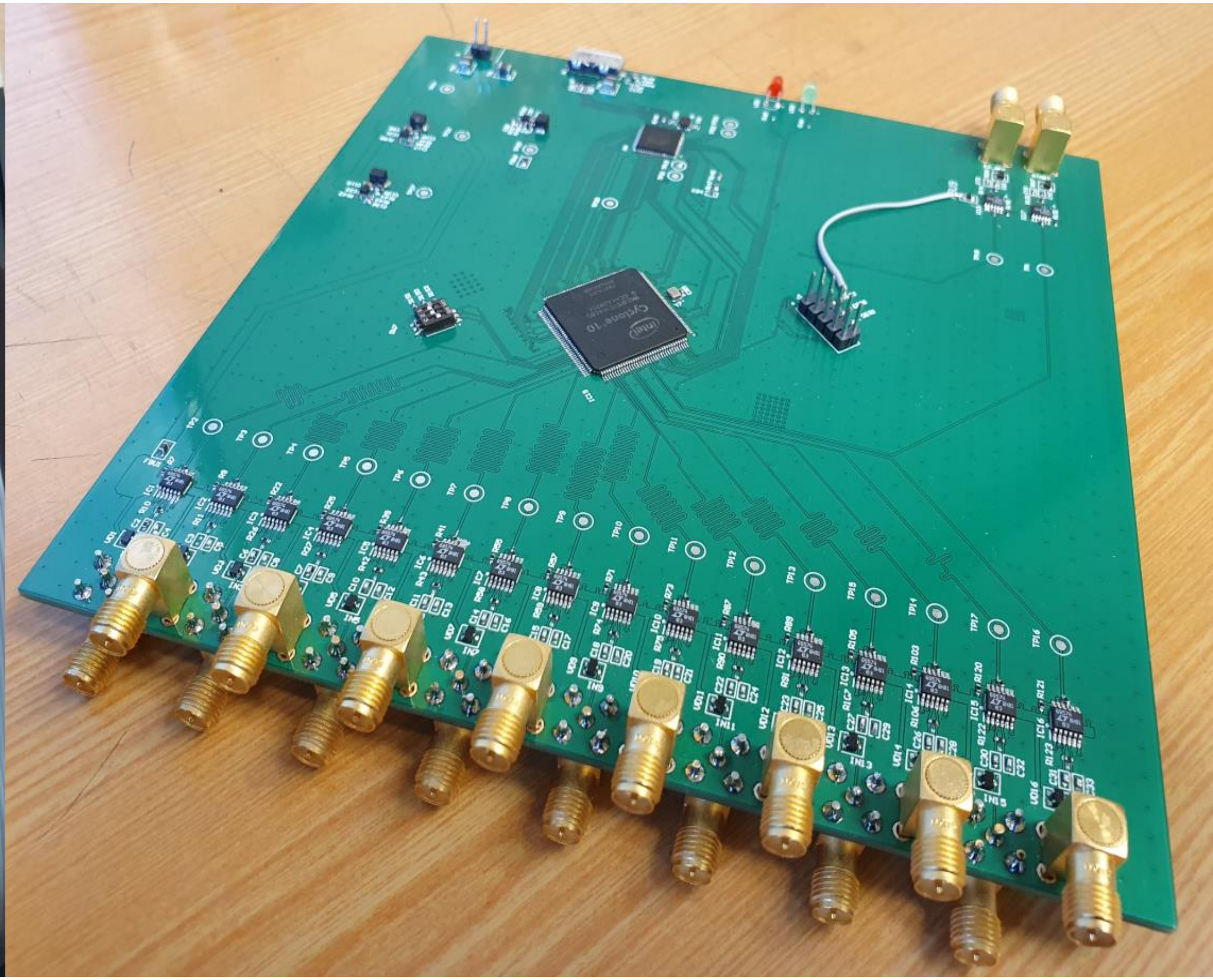
Right View:

Meade Telescope; 45 degree mirror, monostatic configuration; elliptical scan mirror mount. Not showing: 355nm bandpass & Rayleigh Filter

Photek Detector Array & Eventech Photon Counter: The Brain of the Lidar



16 Channel PMT-MCP Photek Detector Array

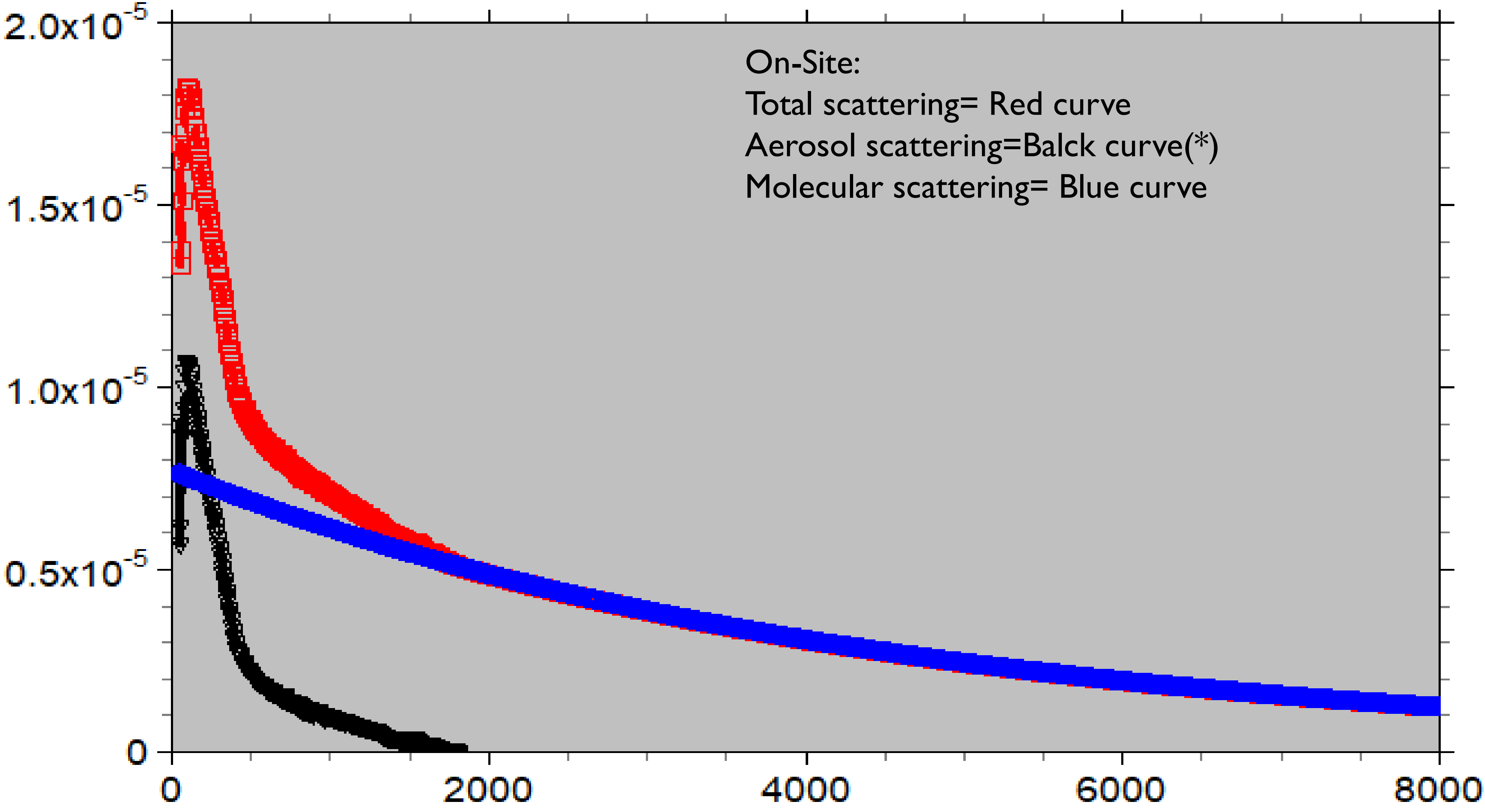


16 Channel Eventech Photon Counter Board

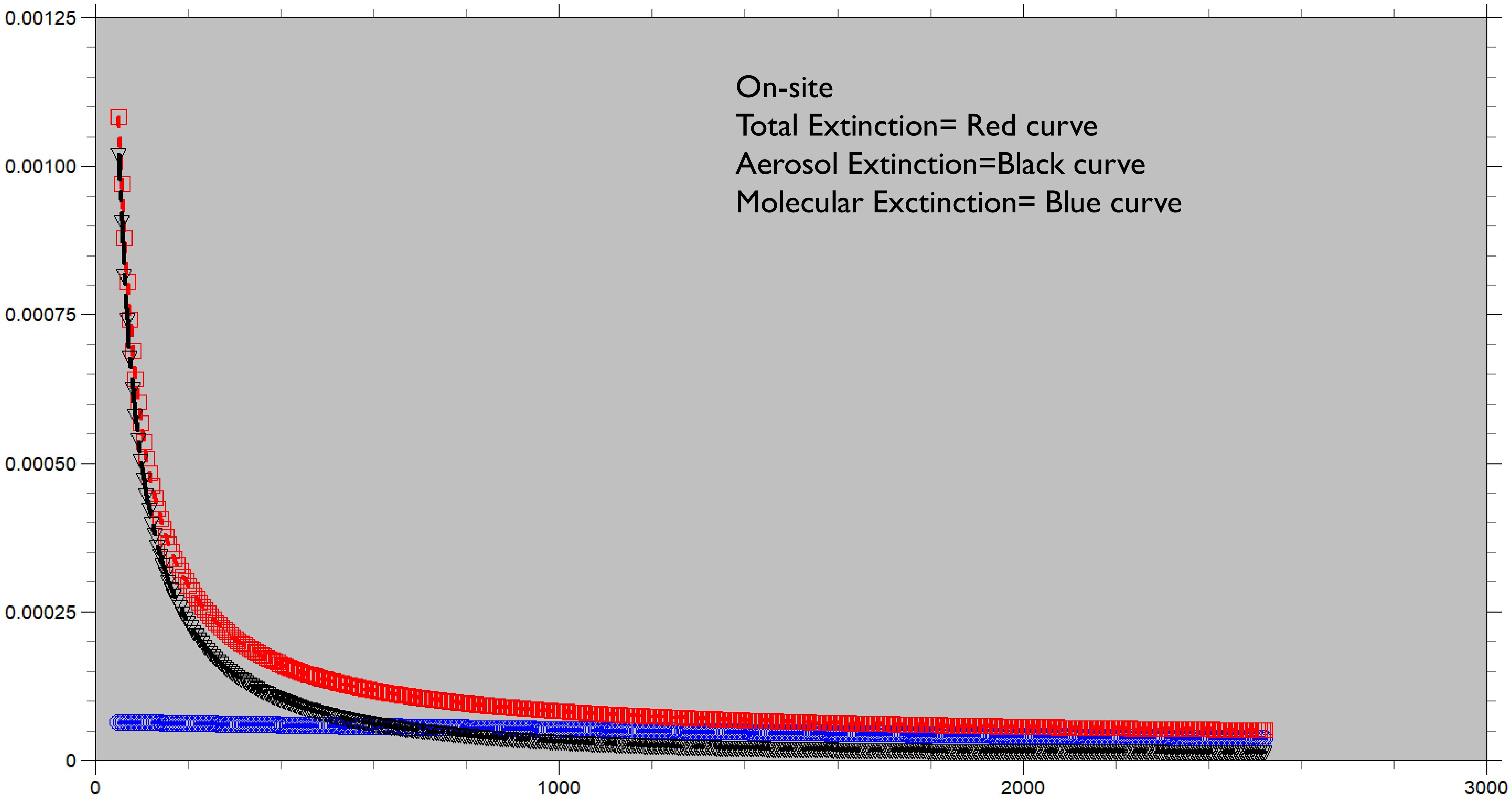
DATA SET OUTPUT & PROCESSING STEPS

1.Multi-channel Detector output: atmospheric signal intensity profiles vs height (Point Clouds: x, t, S or x, φ, S)
2. Pre-processing of data: averaging, R^2, background subtraction, normalization & outputted as Excel file (TPF software)
3. Processing Wind of data: Cross-Correlation-Algorithm (CCA) of (Excel) data sets from subsequent scanned Images. CCA part of MATLAB DSP package

SUPPORTING MEASUREMENTS: ATMOSPHERIC SCATTERING



SUPPORTING MEASUREMENTS: ATMOSPHERIC EXTINCTION



Example of CWL data file

The Paradigm Factor Ltd																															
Date anc	22092020-050434																														
Number (	1																														
Number (	4096																														
Sync Moc	Single																														
Trigger P	Leading Edge (Positive)																														
Integrati	1000																														
Bin Widt	66																														
Threshol	1.5																														
Fire Dela	0																														
Sync Dela	0																														
22.443	22.47	22.452	22.671	22.876	22.494	22.901	22.876	22.981	22.95	22.859	23.245	23.08	23.051	23.3	23.638	23.799	24.087	24.339	24.831	24.691	24.987	25.164	25.337	25.066	24.864	24.942	24.734	24.588	24.564	24.717	24.511
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel
2466	2503	2521	2543	2566	2577	2576	2557	2477	2495	2510	2537	2504	2484	2508	2431	2449	2492	2438	2431	2398	2375	2468	2430	2389	2184	2445	2514	2540	2528	2557	2438
2466	2503	2521	2543	2566	2577	2576	2557	2477	2495	2510	2537	2504	2484	2508	2431	2449	2492	2438	2431	2398	2375	2468	2430	2389	2184	2445	2514	2540	2528	2557	2438
2125	2122	2098	2092	2103	2051	2036	2056	2074	2089	2039	2100	2112	2102	2101	2115	2115	2109	2119	2076	2128	2089	2085	2119	2111	1915	2083	2132	2135	2136	2169	2140
2200	2208	2222	2180	2174	2177	2161	2112	2103	2048	2035	2089	2108	2141	2174	2094	2133	2110	2093	2131	2057	2081	2084	2130	2141	1925	2111	2212	2209	2213	2215	2245
2249	2282	2291	2322	2293	2284	2327	2281	2228	2171	2189	2247	2279	2297	2237	2180	2117	2163	2078	2039	2076	2192	2209	2221	2183	2036	2248	2184	2252	2237	2265	2263
2198	2190	2194	2206	2178	2178	2182	2228	2266	2277	2291	2312	2316	2288	2272	2329	2274	2239	2209	2201	2235	2212	2207	2240	2216	2083	2205	2256	2286	2278	2320	2233
2012	1965	1980	1936	1895	1902	1898	1856	1914	1971	2118	2127	2249	2220	2229	2285	2295	2255	2271	2250	2185	2157	2218	2244	2149	1966	2063	2170	2175	2112	2043	2013
1723	1659	1647	1660	1582	1553	1531	1585	1556	1630	1652	1719	1805	1838	1798	1884	1992	2002	2127	2052	1943	1671	1748	1875	1779	1631	1862	1870	1828	1822	1799	1735
1253	1206	1235	1226	1213	1180	1172	1124	1189	1187	1214	1241	1232	1323	1403	1448	1424	1467	1528	1566	1478	1303	1303	1362	1343	1239	1354	1514	1507	1437	1405	1341
980	940	1029	1027	1009	951	1001	919	928	902	970	1003	1028	1121	1093	1154	1119	1122	1149	1117	1097	1026	1015	1046	1010	900	991	1022	1089	1065	1033	996
837	827	866	850	842	848	831	806	789	834	778	881	848	907	965	1001	970	954	945	944	865	847	870	857	843	736	804	829	861	842	902	886
730	734	758	791	708	759	693	711	670	653	667	725	721	751	807	842	833	839	820	776	770	742	783	726	684	624	729	765	791	779	775	745
622	612	629	637	635	600	614	569	603	566	570	594	615	664	746	734	732	694	693	683	650	650	645	652	609	543	631	665	683	656	661	690
540	526	547	549	498	509	533	498	521	500	515	508	506	579	621	622	623	605	653	547	581	520	573	572	521	475	577	574	568	612	586	583
503	482	484	507	456	477	448	410	419	418	432	489	452	493	573	575	563	506	521	522	465	463	462	466	442	367	492	485	453	484	491	486
398	454	451	442	423	441	435	405	390	388	404	392	422	473	483	494	486	503	442	435	428	392	394	414	383	386	418	419	447	441	464	415
358	330	341	375	381	343	328	349	335	318	329	359	392	399	445	451	418	426	419	392	399	374	421	380	371	337	333	354	379	390	399	379
319	322	344	356	346	336	342	308	327	314	293	296	364	379	383	355	417	384	323	334	346	323	333	348	279	283	294	324	318	347	334	327
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219	202	228	209	234	241	218	209	187	224	201	190	238	263	286	249	267	251	245	264	237	196	228	221	216	191	206	218	237	249	227	237
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150	147	170	161	176	167	159	170	149	155	163	143	184	204	174	184	203	209	197	181	163	170	169	168	173	151	148	177	183	178	156	169
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153	127	141	144	152	169	131	121	104	131	141	113	126	176	132	128	170	160	161	150	163	131	141	161	143	123	122	162	157	146	148	149
122	131	115	131	121	131	121	116	111	133	123	130	110	147	144	134	149	161	141	123	129	143	117	146	134	124	125	153	149	125	134	139
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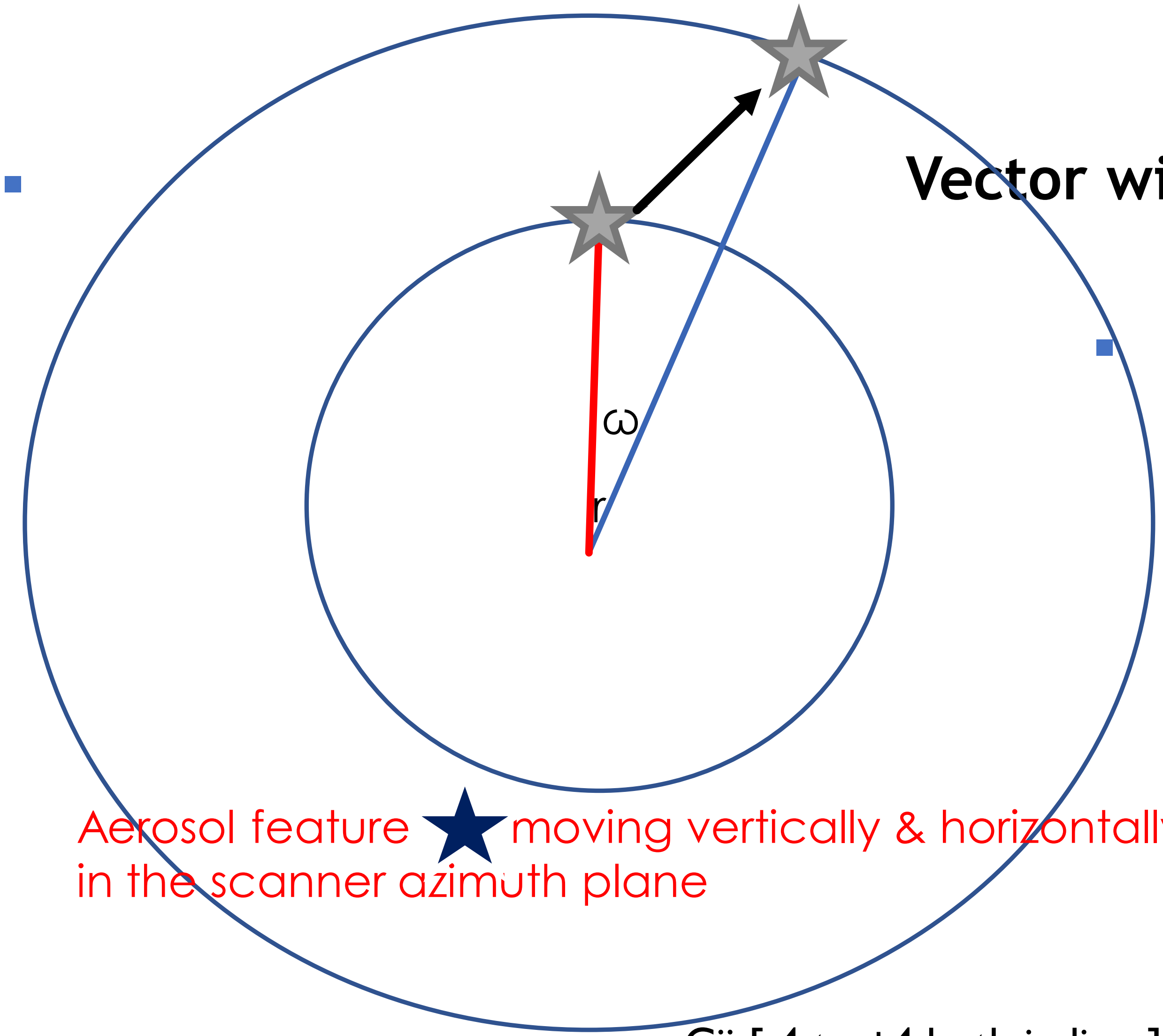
93	106	125	110	116	124	117	95	100	102	105	108	126	141	130	141	142	114	114	110	129	111	128	117	116	98	107	112	115	135	104	120

MergedResults-33334-33783 | Sheet2 | Sheet1 | Inverted Range

Pictorial view of wind calculation (Polar)



Vector wind : U= (R+/-dr)*sin(360+/-ω)/(T+/-dt)

0.0655	-0.5478	-0.5947	-0.6683	-0.6225	-0.6186	-0.6118	-0.7753	-0.2270
-0.1214	-0.5272	-0.6850	-0.6222	-0.6542	-0.6666	-0.6861	-0.5482	-0.1604
0.0312	-0.0769	0.3308	0.5059	0.3948	-0.4927	0.3931	-0.0237	0.0742
0.0334	-0.0749	0.0337	0.1667	-0.6462	-0.2703	-0.1159	-0.0469	0.0681
0.0309	-0.0228	0.2143	0.0564	0.0731	0.3814	-0.0807	0.0453	0.1068
0.0435	-0.0027	0.8473	0.0106	0.6889	0.5994	0.8003	0.0225	0.0976
0.0492	-0.0668	0.3444	0.5648	0.6754	0.5418	0.4620	0.0031	0.0693
-0.0305	0.3914	0.6053	0.6700	0.6375	0.6403	0.6286	0.6227	0.2646
0.2128	0.5466	0.6758	0.6874	0.6764	0.6863	0.6811	0.6167	0.3239

Template A= 3x3
Image B= 7x7

Correlation Matrix
Dimensions : 3 + 7 - 1

Cij [-4 to +4 both indices]
i: scan in range, j: scan in azimuth/time

EXAMPLE OF IMAGE(B: 5X5)& TEMPLATE(A: 3X3) MATRICES FROM CONTIGUOUS SCANS TO MATLAB

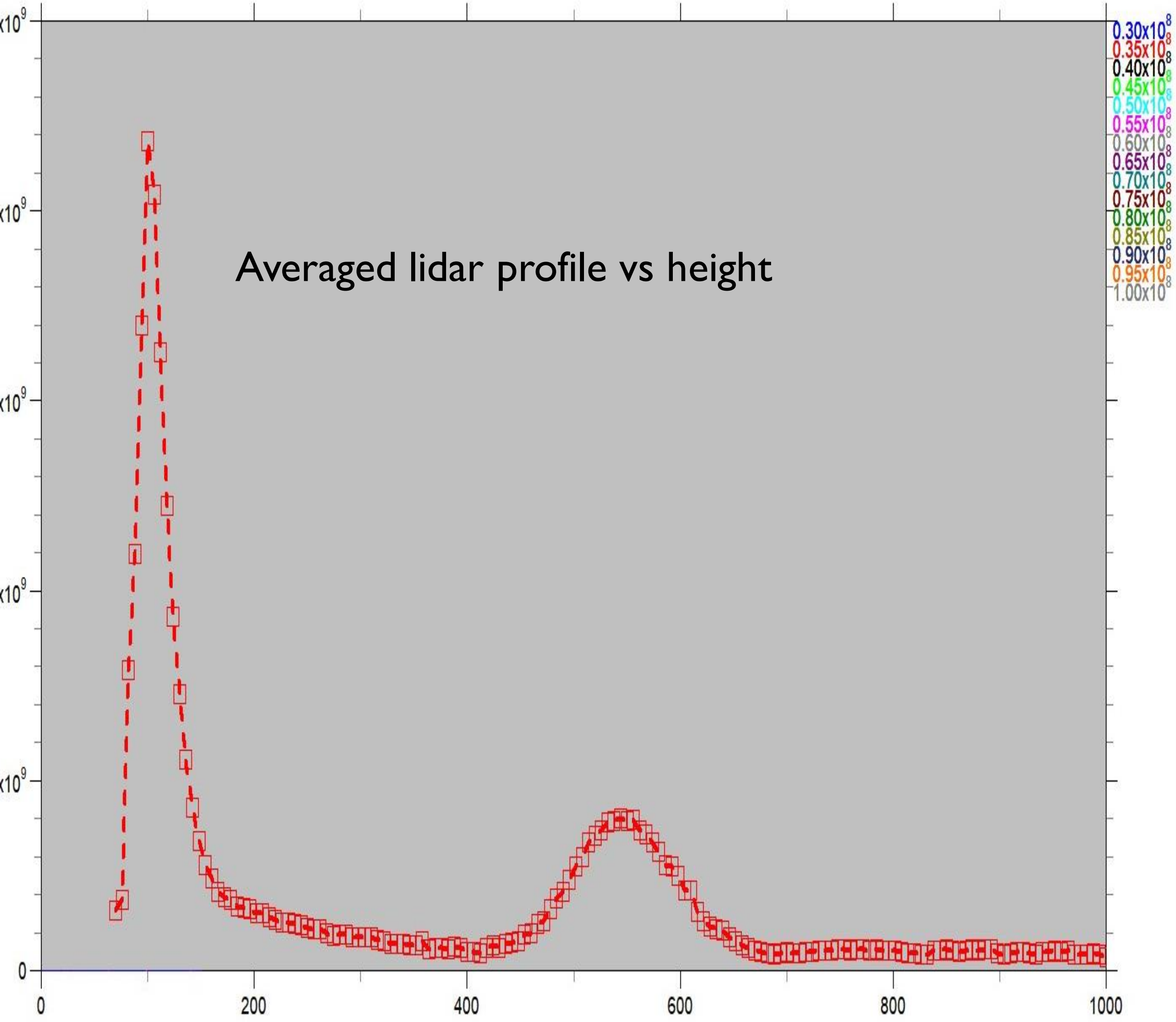
8766	8846	8739	5006	7075	8834	8138	8670
8973	8971	8789	5061	7001	8736	8402	9065
8336	8822	8462	4865	6566	7913	8041	8220
7311	8117	7850	4577	6188	7259	7168	7469
6632	7053	6987	4116	5395	6399	6117	6452
5759	6388	6215	3616	4620	5422	5184	5648
4842	5498	5475	3183	4064	4714	4377	4856
4504	4999	4921	2837	3670	4299	3720	4217
3753	4555	4571	2634	3267	3792	3384	3723
3538	4082	4112	2379	3011	3399	3037	3411
3250	3547	3631	2159	2699	3212	2681	3225
2990	3390	3417	2128	2486	2818	2634	2877
2769	3165	3225	1984	2358	2627	2369	2589

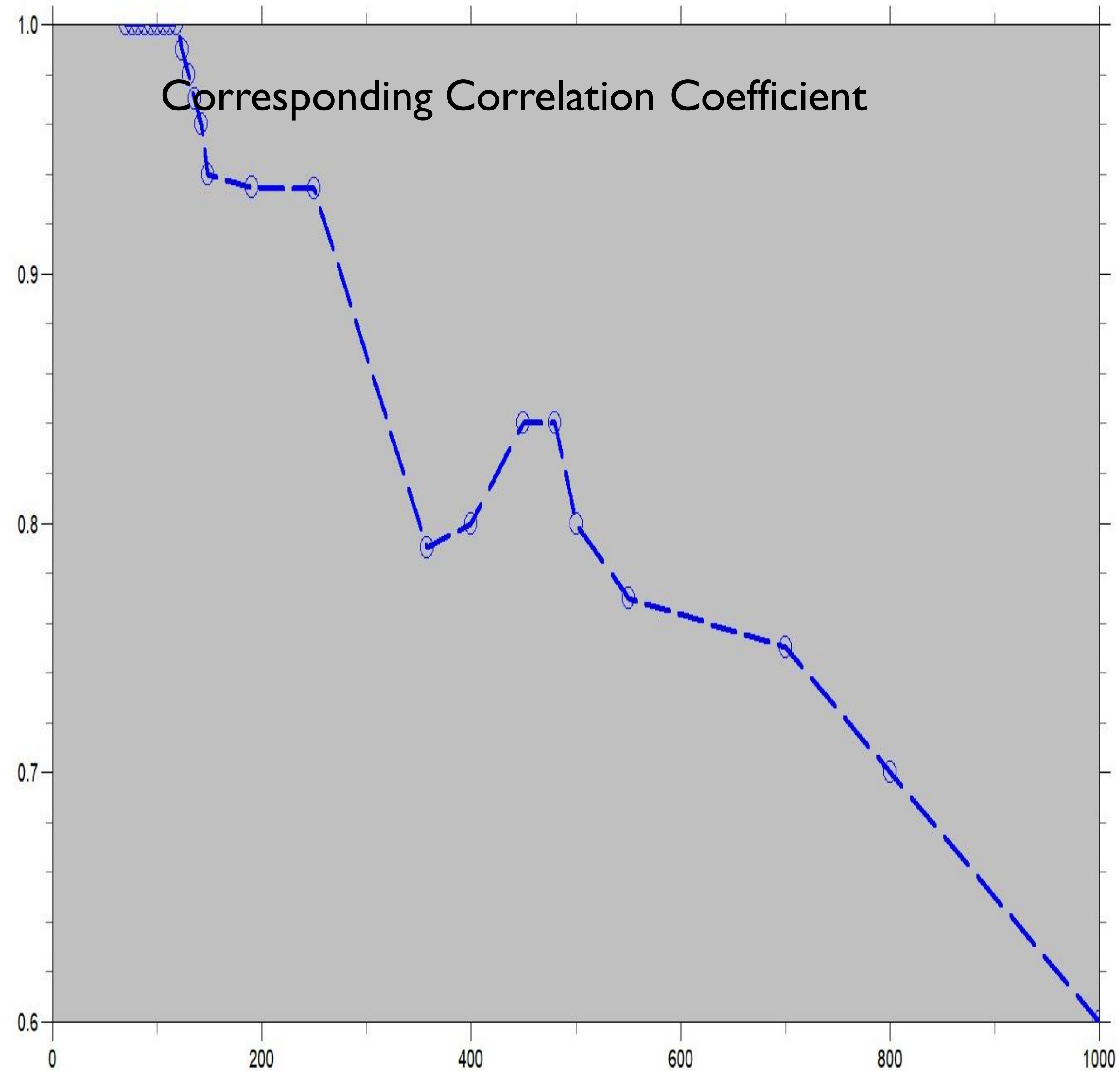
A

8655	9047	8927	3740	8503	8945	8416	8692	8717	8876	7481
9043	9096	9111	3794	8082	8973	8420	8771	9240	8857	7489
8372	8752	8673	3752	7581	8351	7985	8203	8702	8704	7140
7785	8279	7912	3590	7002	7517	7196	7344	7970	7956	6635
6820	7305	7001	3111	5927	6552	6094	6587	7170	7149	5738
5759	6441	6302	2784	5294	5708	5242	5617	6237	6409	5044
5154	5710	5614	2424	4545	4887	4531	4962	5500	5603	4484
4425	5097	4935	2265	4116	4386	3954	4296	4988	5091	4058
4061	4536	4359	2001	3621	3703	3407	3793	4329	4494	3517
3655	4111	3917	1795	3450	3463	2983	3433	3869	3983	3238
3320	3645	3691	1713	3084	3103	2787	3004	3455	3658	2985
3014	3421	3297	1652	2863	2835	2586	2958	3266	3462	2789
2828	3168	3168	1588	2620	2615	2419	2648	2975	3239	2540

B

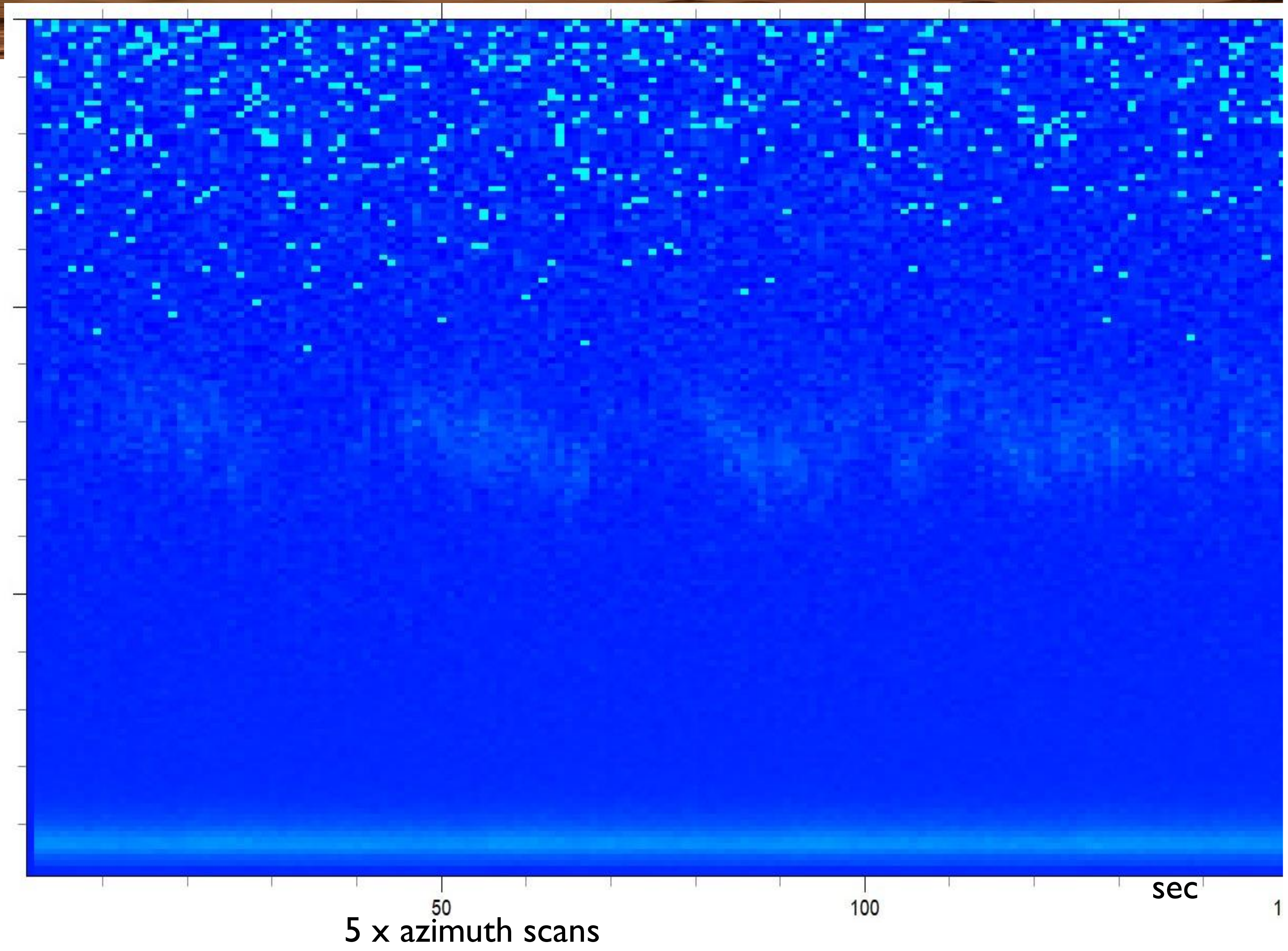
Examples of Winds: case 1

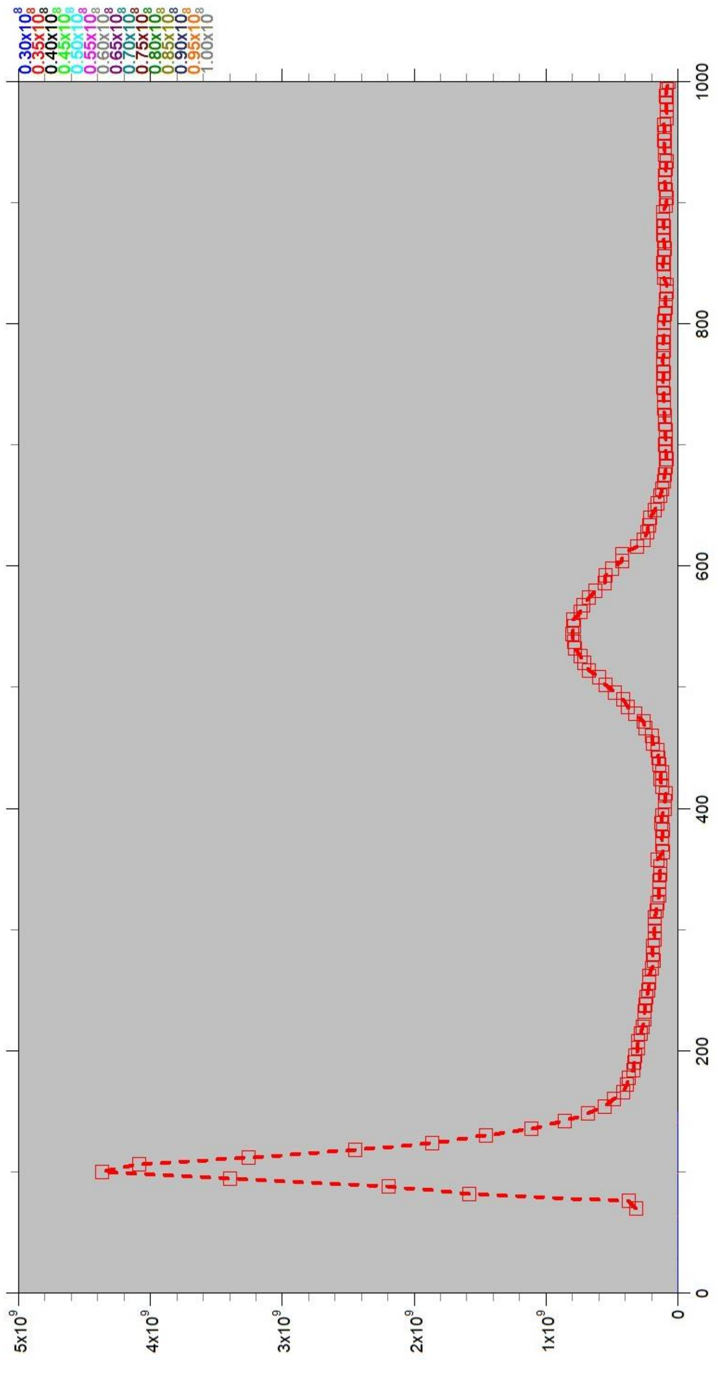




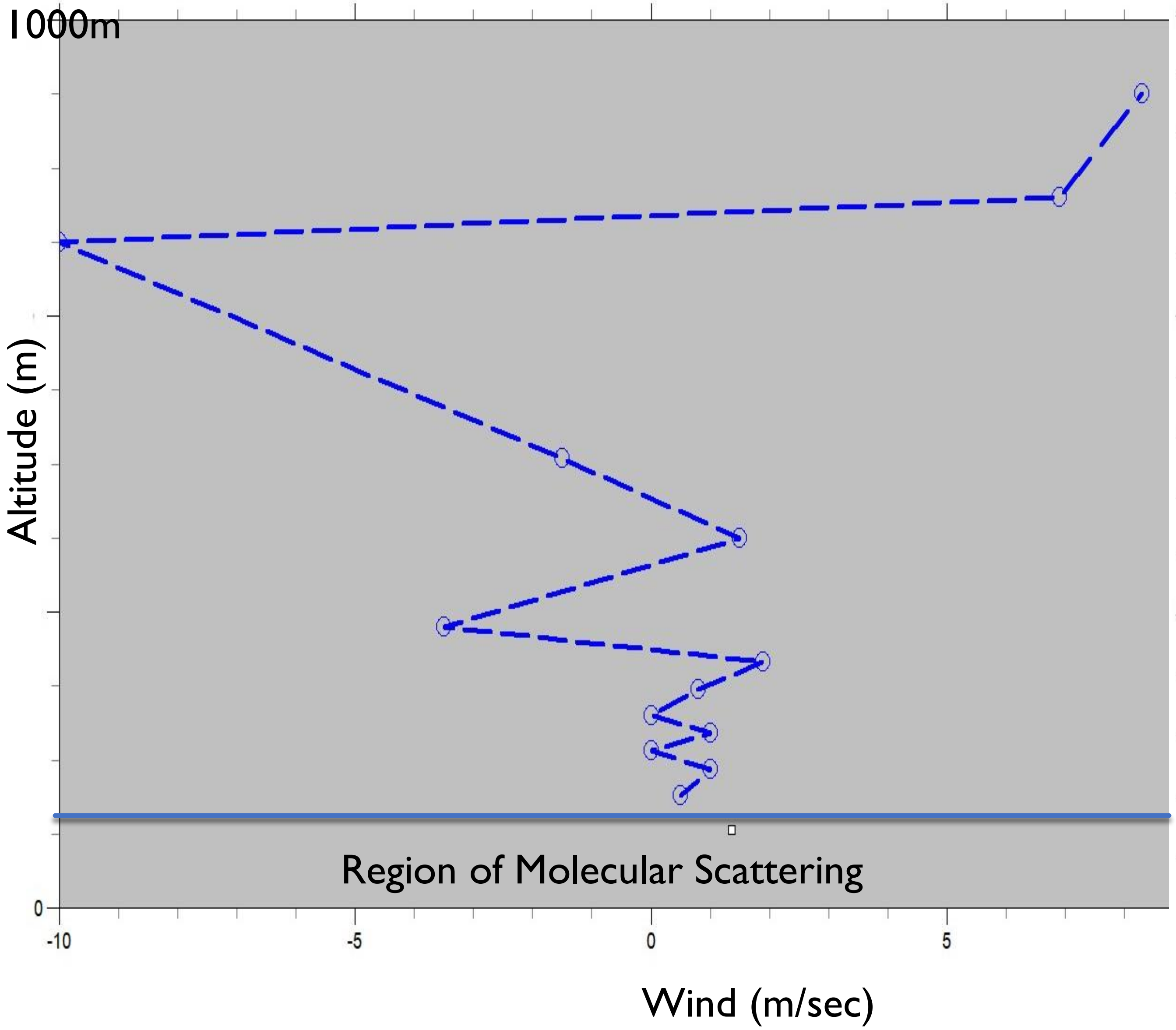
Show case 1: July 2020; location: West Sussex; country, low aerosol load, quiet & clear summer night

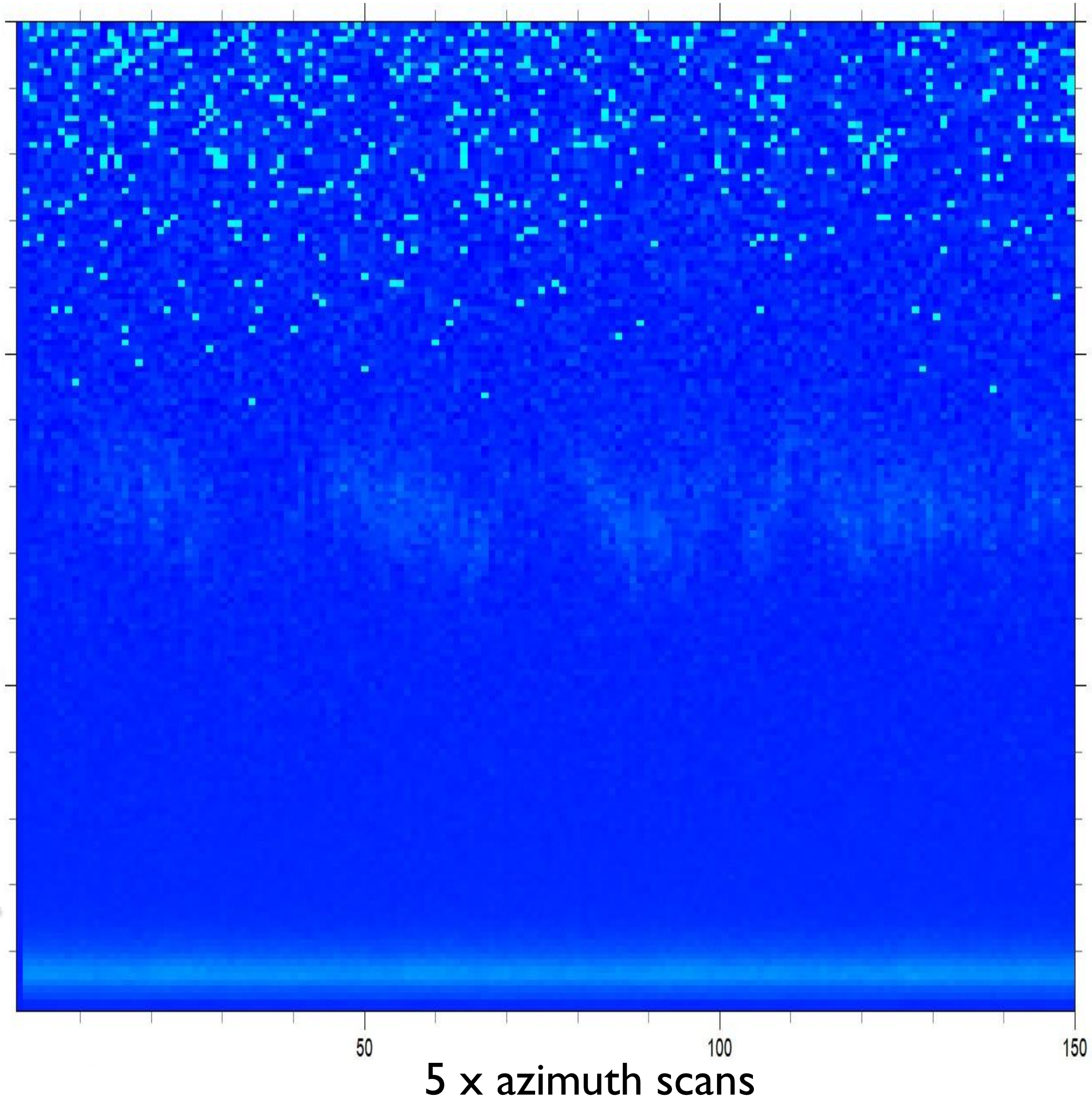
Winds: case 1


50
100
1
sec
5 x azimuth scans

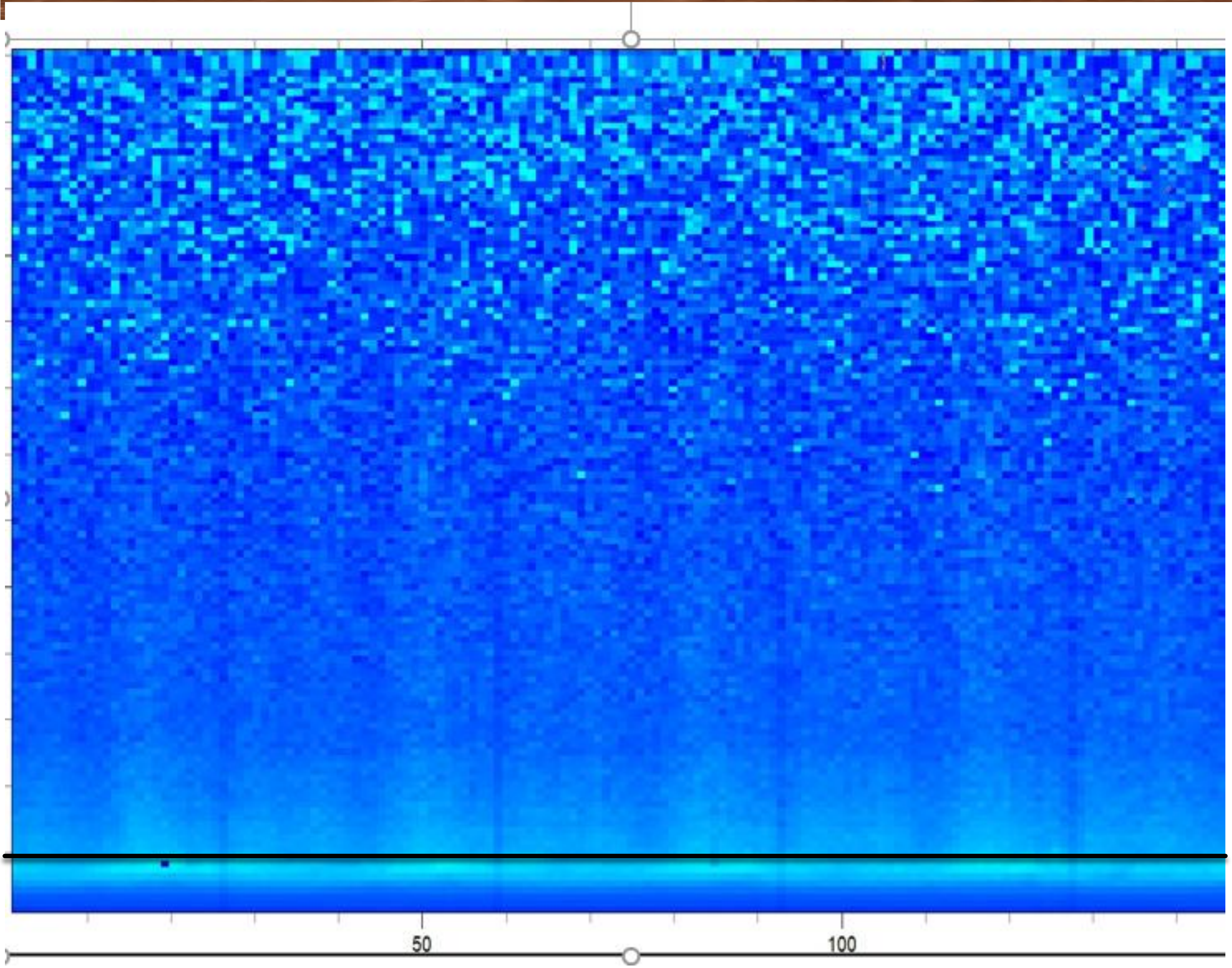

1000
800
600
400
200
0
5x10^9
4x10^9
3x10^9
2x10^9
1x10^9
0

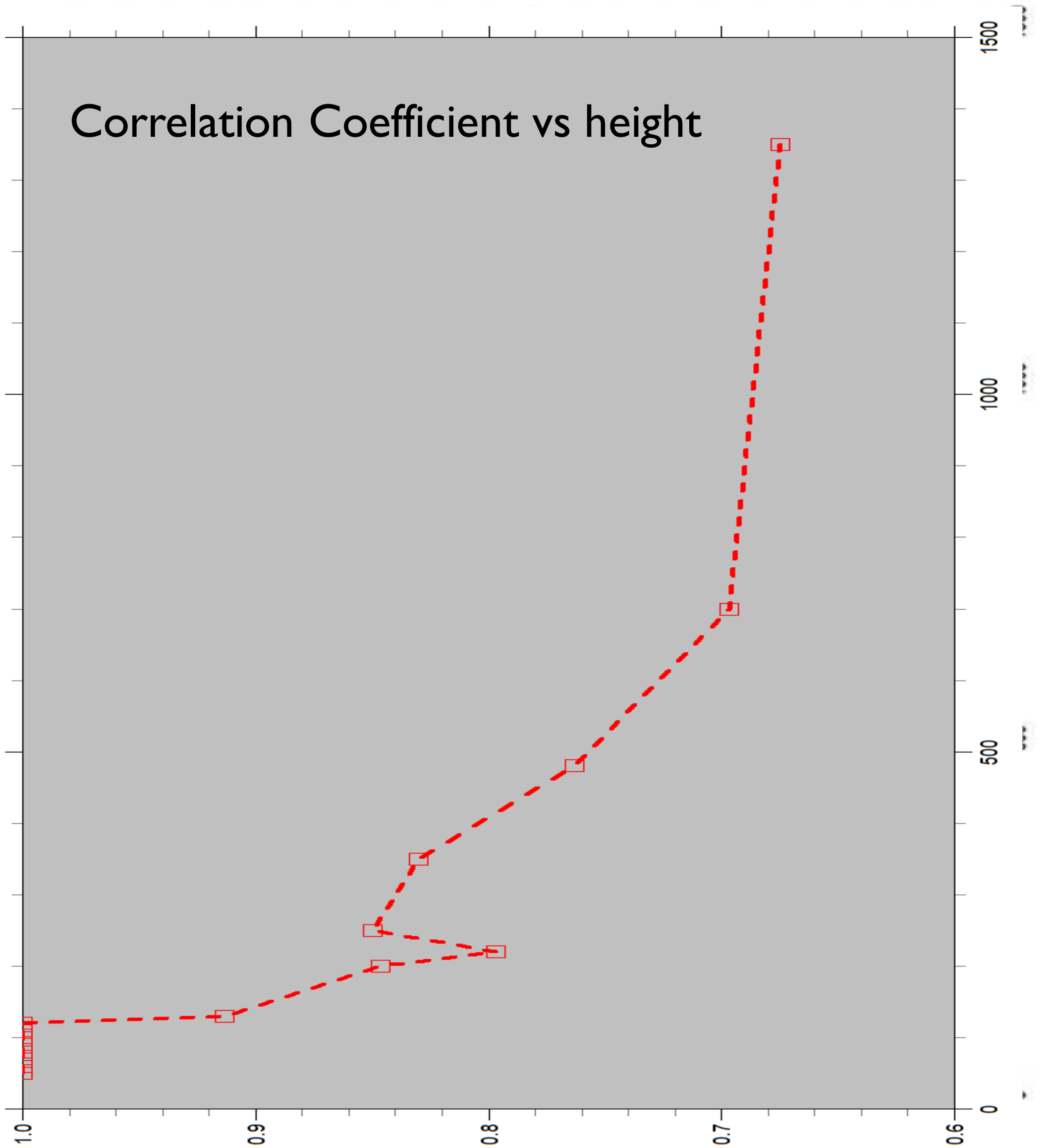
Winds: case 1


1000m
Altitude (m)
0
-10
-5
0
5
Region of Molecular Scattering
Wind (m/sec)


50
100
150
5 x azimuth scans

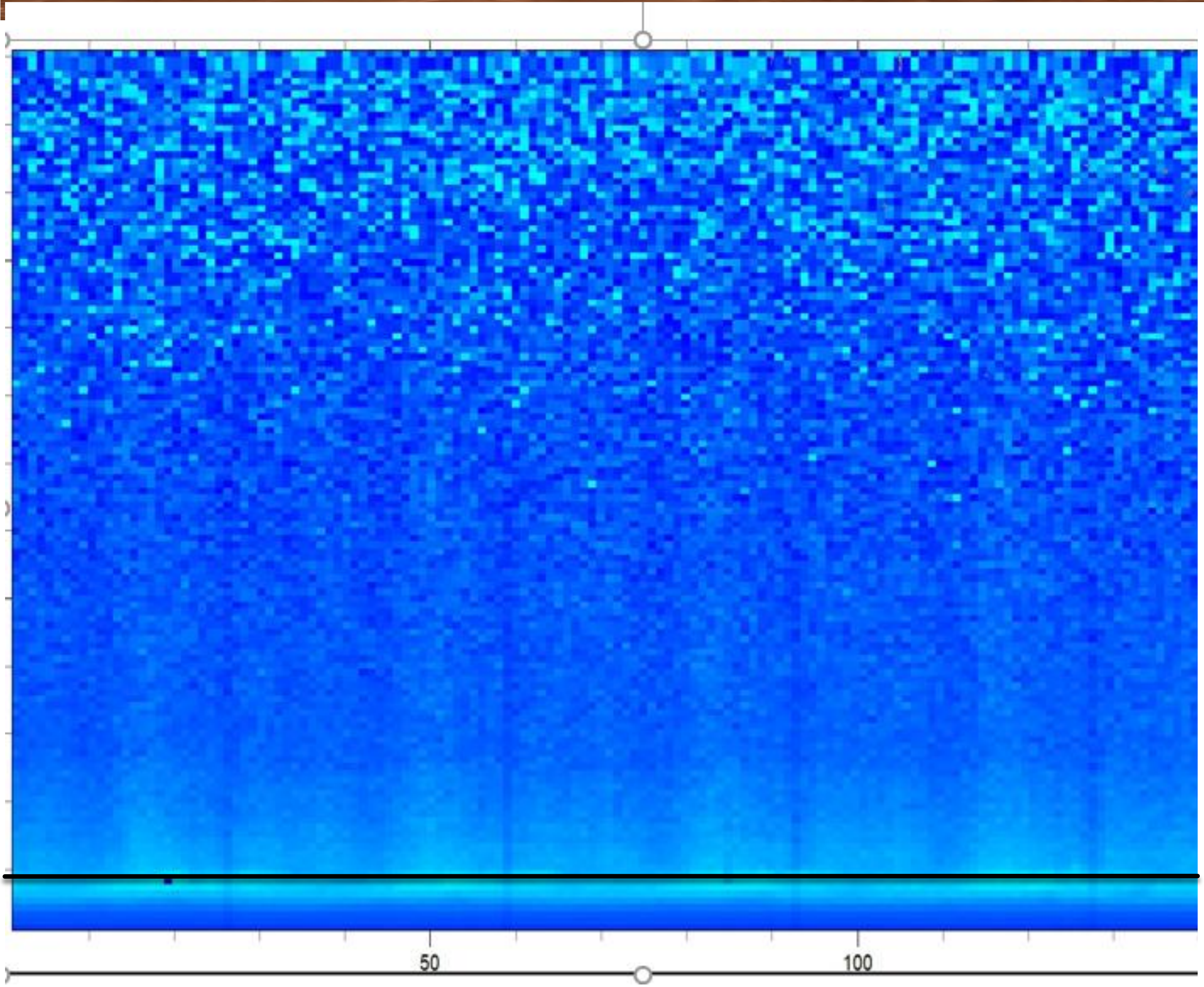
Winds: case 2



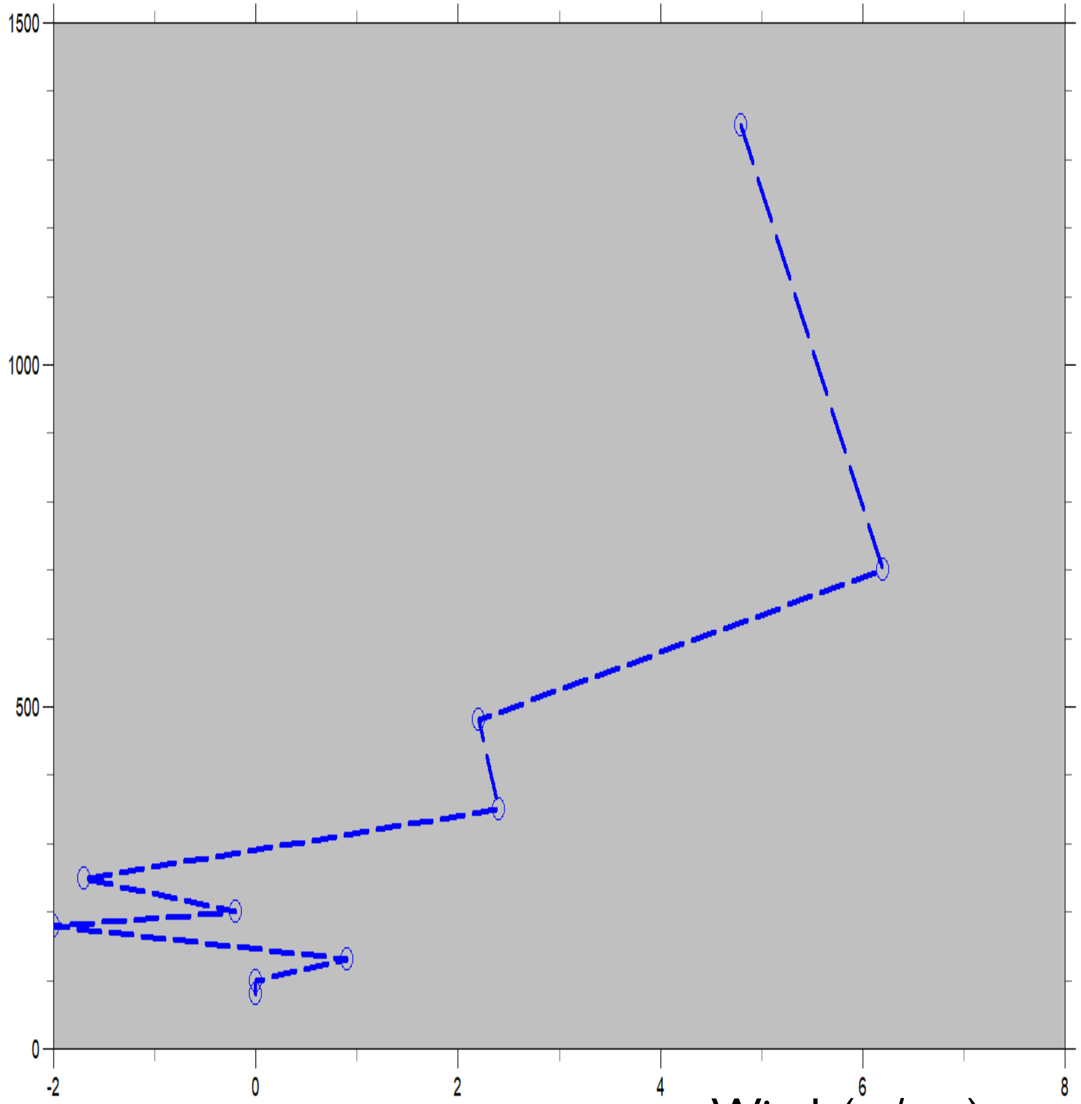


Show case2: September;2020 location:West Sussex; country, low aerosol load, quiet & clear summer night

Winds: case 2



5 x azimuth scans



Conclusions & Outlook

- The CWL lidar technique with DSP processing has demonstrates that it can provide atmospheric winds, offering significant system simplification in terms of H/W, S/W & Processing.
- The New Instrument Concept is multifunctional & can be applied to Altimetry & Imaging (already demonstrated)
- Tx complexity traded & replaced by Processing & on-board Computer Power
- Downscaling in Swap Technology possible & feasible for applications in Planetary & Earth Sciences
- A "PIC" down-scaled model under investigation with ESA
- Combination with Passive sensors (cameras) & Sensor fusions opens up the use in GNC & Landing for Planetary research (Mars, Moon , etc): initial steps being investigated with European Industrial Consortium

The CWL Team & Acknowledgment

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The Project Team comprises:

- E. Armandillo, Eventech Advisor: CWL overall system engineer & Wind Processing
- D. Rees, The Paradigm Factor (UK): CWL Lidar lead engineer, Assembly & Testing
- V. Kurtenoks & I. Pulkstenis (Eventech) : 16 Channel Timer & Single Photon Counter
- Photek Limited (UK): PMT Array Supplier

THANK YOU FOR YOUR ATTENTION !!!