Turbulence measurements in a wind park with the Micro-RPAS SUMO

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Outline

- introduction
- presentation of the SUMO system
- description of the measurement site and campaign
- first results
- pitfalls and lessons learned
- outlook

Background

the structure of and the processes in the lowest few hundreds of meters in the marine atmospheric boundary layer (MABL) are poorly understood

- average wind profile
- wind shear
- turbulence intensity
- atmospheric stability
- non-stationary lower boundary layer (waves)

established measurement methods (masts, lidars, sodar, sodar RASS) are infrastructural demanding, expensive and rather inflexible

developments in microelectronics and miniaturiazition of sensors and components allows now for the implementation of flow and turbulence measurements also on very small and lightweight micro-UAS (Unmanned Aircraft System)

SUMO (Small Unmanned Meteorological Observer)

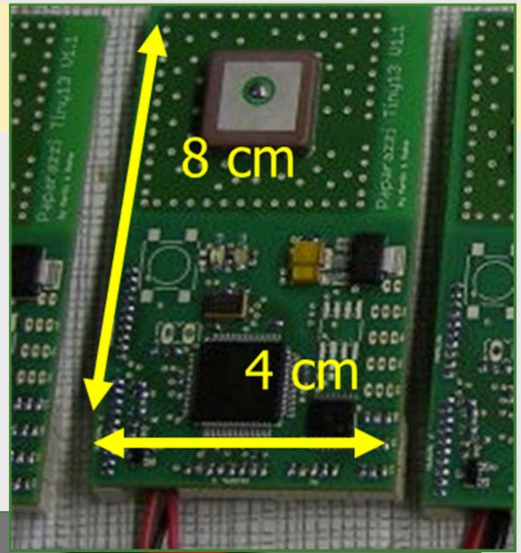
vehicle type	fixed wing UAS
DIMENSIONS	
wingspan	0.80 m
length	0.75 m
height	0.23 m
propeller diameter	227 mm (9"x6")
take-off weight	600 g
PROPULSION	
motor	electric brushless
motor type	AXI2212/26
motor power	120 W
battery type	lithium-polymer (3 cells)
battery capacity	2.4 Ah/11.1 V
SPEED AND ENDURANCE	
minimum speed	8 m/s
maximum speed	42 m/s
cruise speed	15 m/s
horizontal range	< 10 km
vertical range	> 4 km
flight duration	< 40 min

SUMO operation – ground control station (GCS)

EGU General assembly, 24.04.2012, Vienna

Geofysisk institutt
Universitetet i Bergen

SUMO sensors



- **autonomous navigation**:
  Paparazzi, an open source auto pilot system (including GPS and IMU)

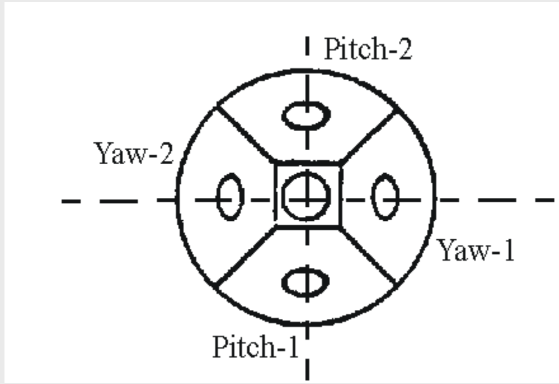
- **temperature sensor**:
  SHT75 by Sensirion (± 0.5 K)
- **humidity sensor**:
  SHT75 Sensirion (± 1.8 %)
- **temperature sensor**:
  Pt1000 (± 0.3 K)
- **pressure sensor**:
  SCP 1000 by VTI Technologies
- **IR thermopile**:
  surface temperature monitoring
- **5-hole probe:**
  for 100 Hz measurement of the 3D wind vector

SUMO turbulence sensor

miniaturized 5-hole probe from Aeroprobe Inc., USA (3 mm diameter)

differential pressure measurements (static-dynamic, left right, up-down)

provides flow velocity and angles of sideslip and attack with 100 Hz resolution



SUMO campaigns

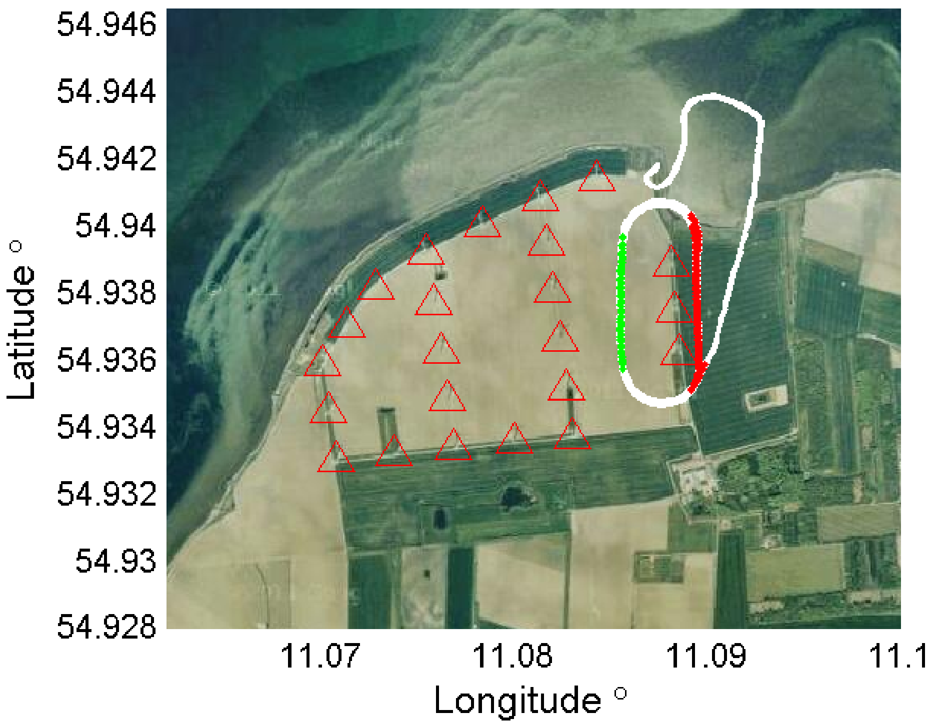
campaign/region	scientific topics	# of flights	max. alt. a.g.l.	time
FLOHOF, Hofsjökull, Central Iceland	instationary gravity waves, evaluation of ABL schemes in WRF	30	3580 m	summer 2007
Svalbard	system test polar region	44	1470 m	winter 2008
Coburg, Germany	nocturnal BL	25	2450 m	summer 2008
FLUXPAT III, Jülich, Germany	BL and inhomogeneous surfaces	34	800 m	summer 2008
Svalbard	polar BL; simultaneous flights; evaluation of ABL schemes in WRF	85	1500 m	spring 2009
MOSO, Iceland	orographic flow modification; land-sea breeze	68	2990 m	summer 2009
Andfjorden, Northern Norway	characterization of MBL; search and rescue	4	1600 m	fall 2009
Lolland Denmark	turbulence in a wind park	70	100 m	spring 2011
BLLAST, France	convective boundary layer transition	299	1600 m	summer 2011

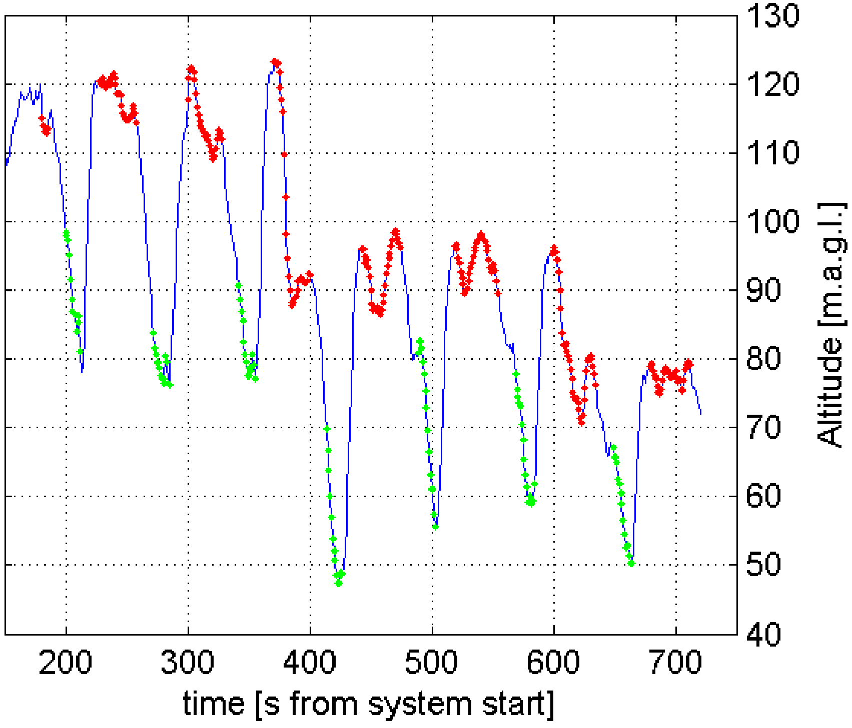
Measurement campaign Lolland, Denmark

- 5 days, May 9-13, 2011
- funded by the Danish (energinet.dk) ForskEL project "Autonomous Aerial Sensors for Wind Power Meteorology (project number 10268)

  (DTU Risø, University of Bergen, Aalborg University, University of Braunschweig, University of Tübingen)
- Nøjsomheds Odde wind farm owned and operated by Dong Energy
- 21 Bonus 1000 turbines (1 MW, hub height 55 m, diameter 52 m)
- a total of 70 flights, 20 with the advanced 5-hole probe turbulence system

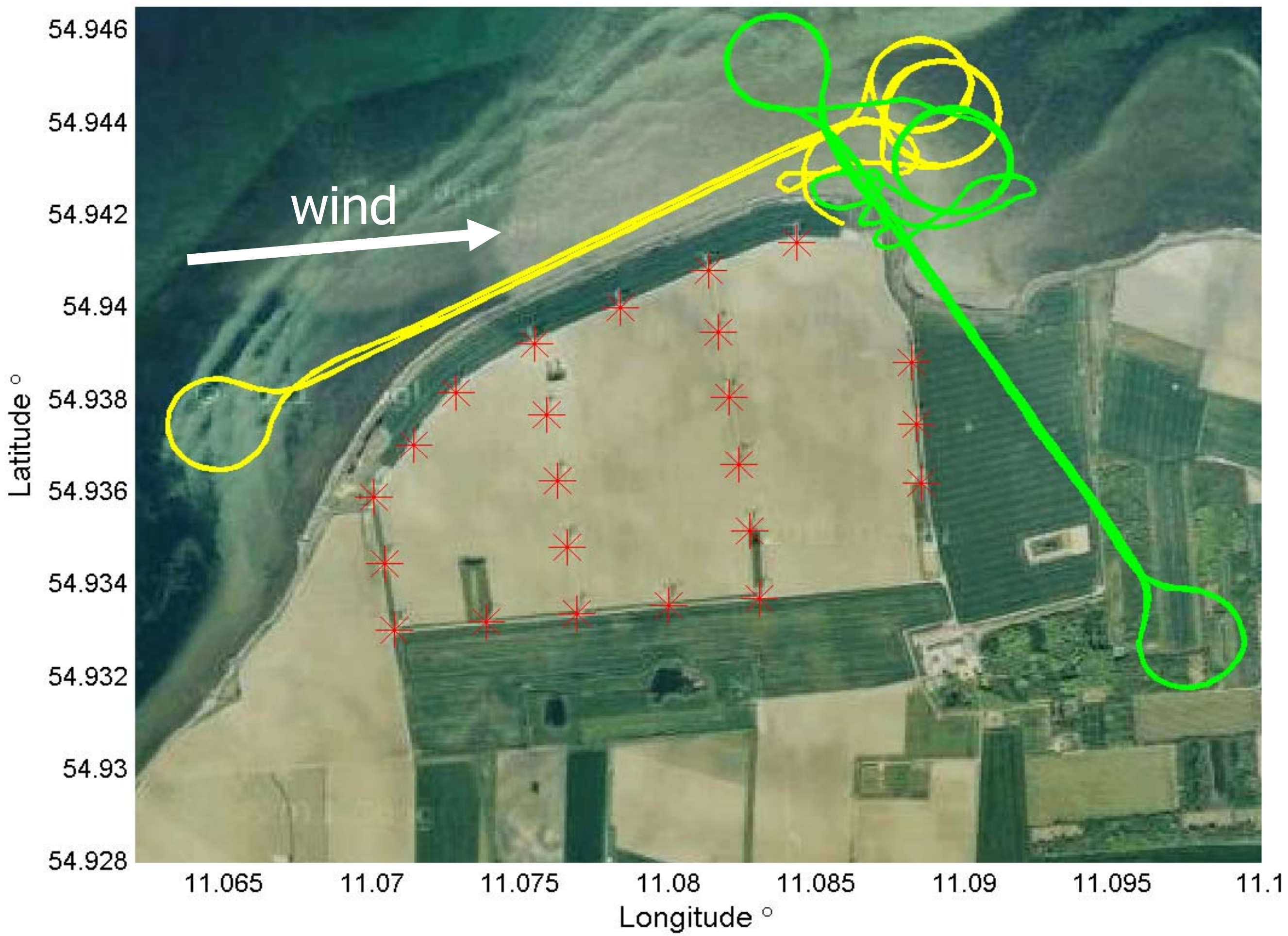
turbulence measurements



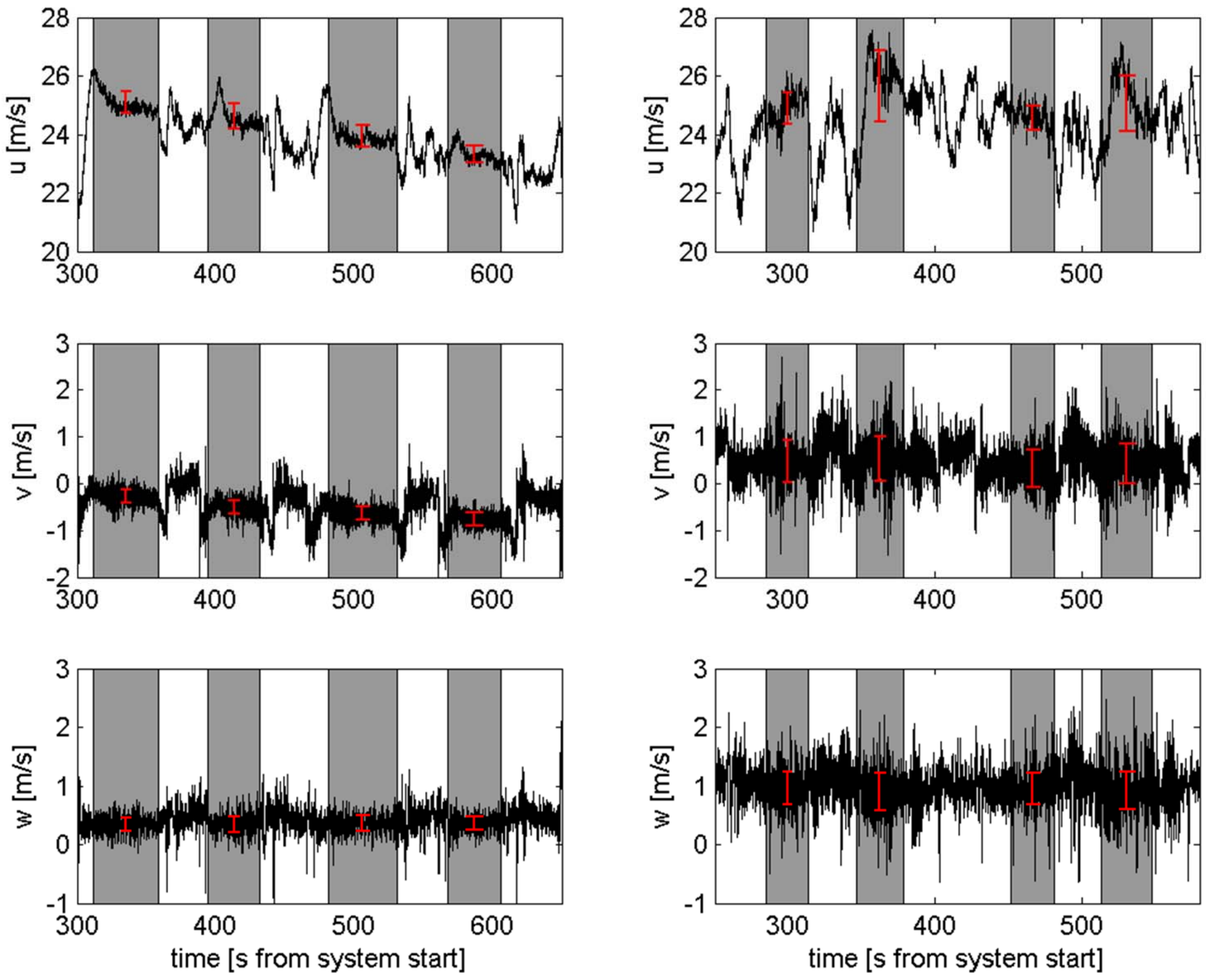


- insufficient altitude control of the autopilot (incomplete fine-tuning of the control parameters after change of attitude control by IMU instead of IR horizon)
- difficult to correct turbulence measurements for aircraft movement (2 unsynchronized data loggers with different measurement frequencies; turbulence probe 100 Hz, autopilots attitude 10 Hz)

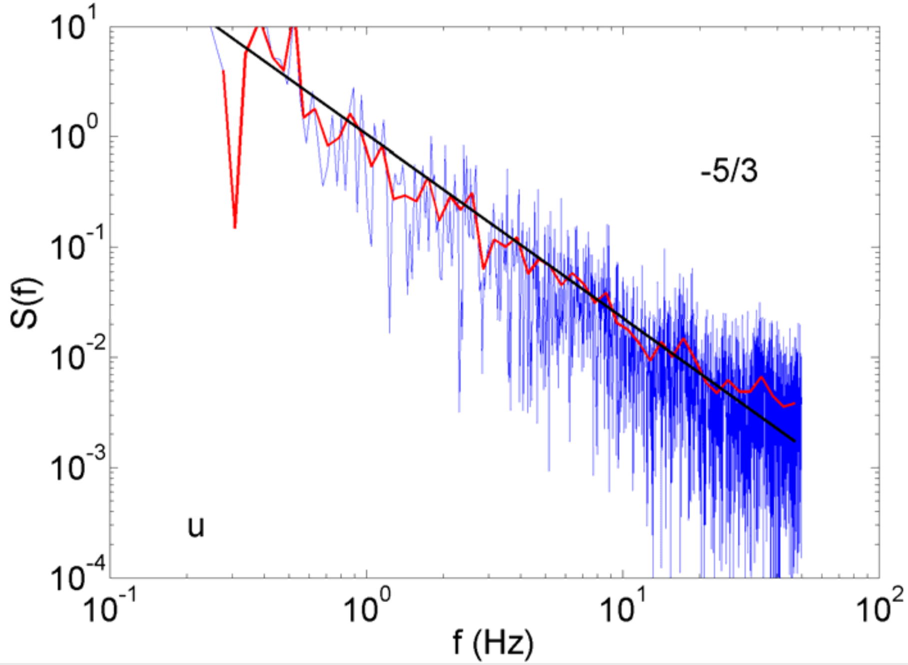
turbulence measurements

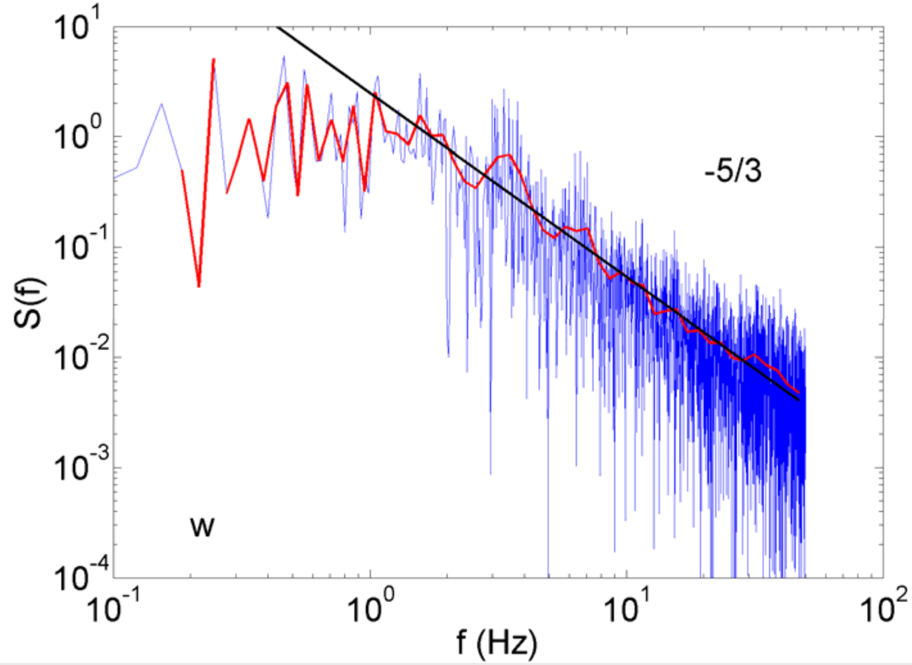


turbulence measurements



turbulence measurements





turbulence measurements

alt. [m]	head. [dir]	u [m/s]	v [m/s]	w [m/s]	std(u) [m/s]	std(v) [m/s]	std(w) [m/s]
upwind					**0.35**	**0.15**	**0.14**
81.6	241.7	25.0	-0.28	0.34	0.24	0.15	0.12
79.8	62.1	24.5	-0.52	0.35	0.42	0.17	0.17
79.2	241.9	24.0	-0.62	0.35	0.46	0.15	0.13
78.4	62	23.3	-0.77	0.37	0.29	0.14	0.13
downwind					**1.05**	**0.43**	**0.31**
80.0	327.5	23.2	0.57	1.08	0.99	0.38	0.27
87.3	147.8	24.5	0.58	1.02	1.69	0.47	0.33
79.9	327.5	24.7	0.49	0.98	0.85	0.40	0.25
85.2	123.4	24.0	0.71	1.08	0.66	0.45	0.37

Summary and outlook

measurements of the turbulent flow vector are becoming feasible even with platforms in the micro-RPAS class below 1 kg take-off weight

crucial to implement a common data logging system with identical data acquisition rates for the turbulence measurements and the aircraft attitude

the issue of insufficient altitude stability has been solved in the meanwhile

master project on further evaluation of existing measurements and future improvements of the system has recently been started

micro-RPAS will in the future provide complementary measurements to the established measurement methods, in particular for the investigation of the wake effect of a single wind turbine or of a limited number of wind turbines inside a wind park

larger RPAS with longer endurance will be capable of longer flights around larger wind farms, e.g. for the investigation of the far field wake of a park

Thanks for your attention !!!

and do not forget:
Next time you hear SUMO…

…you should think about flying !!!