Wind resource assessment uncertainty for a TLP-based met mast

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Why a TLP Met Mast ?

- Cost effective solution for deep waters
- Stable platform – mature TLP technology
- Re-deployable
- Multiple uses (radar, scanning lidar)

- Established configuration for WRA (non hub height met mast + lidar)
- Continuous verification of wind data (cups/sonic vs lidar)
- Smaller structure than Hub-Height masts (no flow blockage)
- High data availability
- Relatively protected equipment

NSRF 2007-2013 programme for development

European Commission
Horizon 2020
European Union funding
for Research & Innovation

SEAL OF EXCELLENCE

H2020 SME Instrument Phase 2

About the campaign

- Offshore Site location
  - Aegean Sea, NE of Makronissos island
  - 65m depth
- FloatMast TLP Met Mast
  - Platform height: 10m a.s.l.
  - 30m Carl-C self-supported met mast
  - Primary anemometer at 44m a.s.l.
- Instrumentation (WRA related)
  - ZephIR 300M lidar
  - 1 x Thies 3D Ultrasonic anemometer
  - 4 x Thies Clima First Class Advanced-X cups
  - 2 x Thies Clima First Class wind vanes
  - Thermo-hygrometer, barometer, sea temperature

Instrumentation

- Wave radar
  - max. & significant wave height, wave period (MIROS SM-140)
- Motion sensors (IMUs)
  - primary at 40m a.s.l. (Xsens Mti-G-710)
  - platform level
- ‘Blue’ sensors
  - salinity, dissolved O_2 , chlorophyll-A
- Platform dynamics
  - 4 x tension leg forces
  - central pylon bending moments & torsion
  - tank water level & pressure
- Dedicated DAQ system
  - 2 x CompactRIOs, 113 signals, online monitoring
  - Synchronization at FPGA level (µsec accuracy)
- Power Autonomy
  - Solar panels, wind turbines, fuel-cell, batteries


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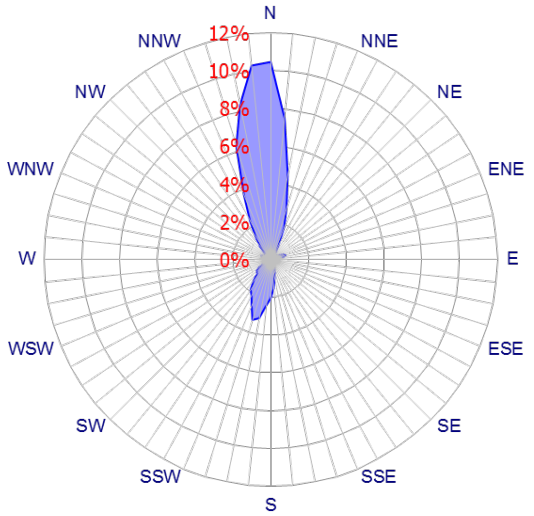
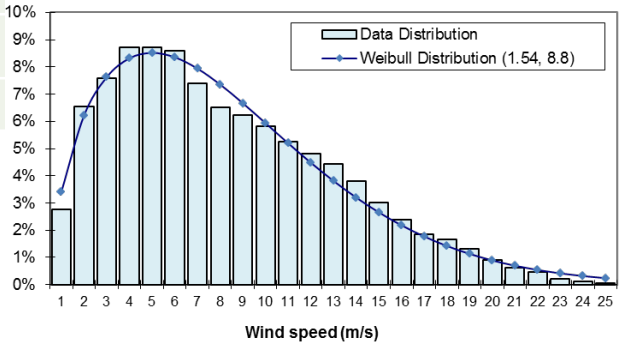
IP PTZ Camera

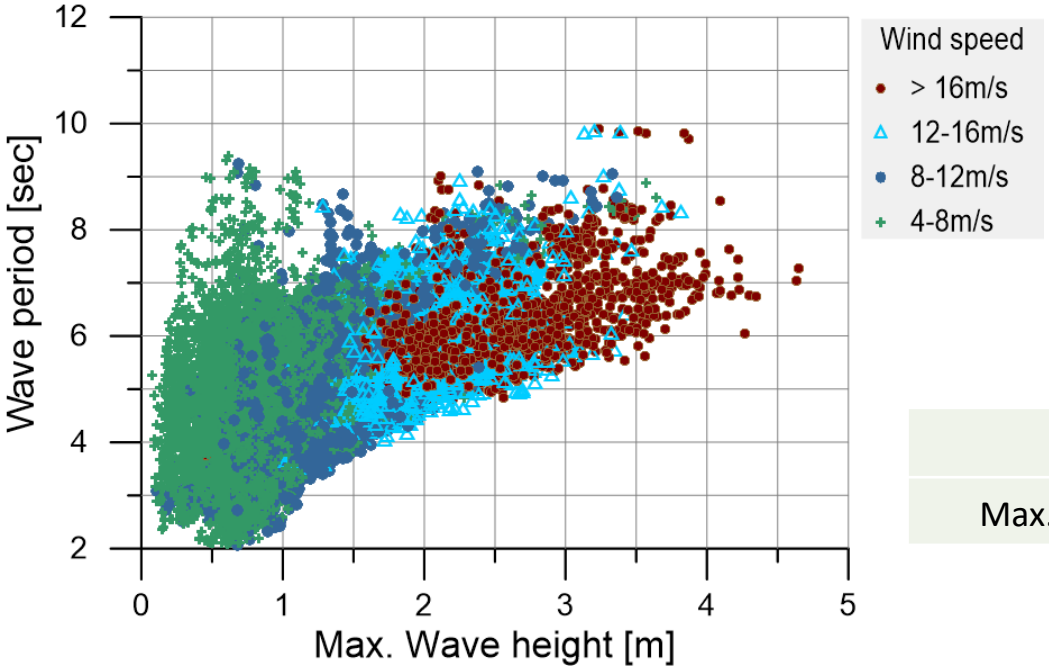
Wind regime

Measured quantity	Value	Height [m] asl
Mean 10min wind speed (cup anemometer)	7.9 m/s	44
Max. 10min wind speed (cup anemometer)	28.8 m/s	44
Max 1sec-gust wind speed (cup anemometer)	35.3 m/s	44
Uncertainty of mean wind speed (cup anemometer)	0.18 m/s	44
Mean turbulence intensity at 10m/s (cup anemometer)	8.3 %	44
Air temperature range	4.5 to 31.8 °C	38
Mean wind shear (lidar)	0.06	30-185
Availability of wind data (after filtering)	96.4 %	
Campaign duration	366 days	





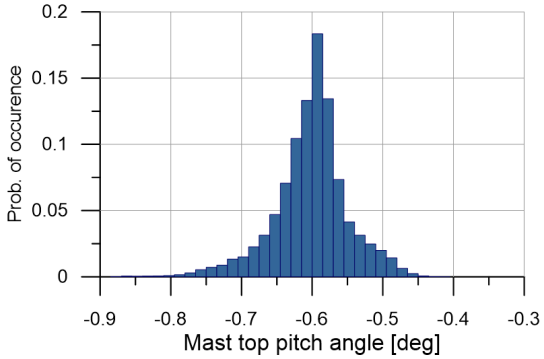
Wave regime

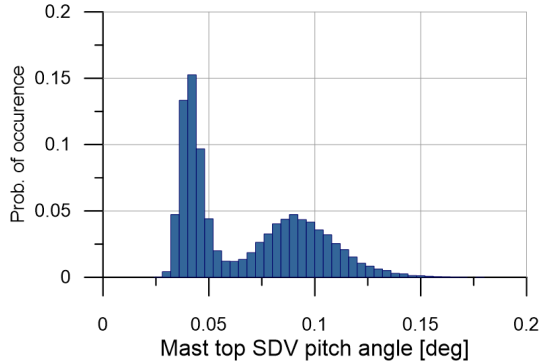


Maximum wave height	4.7 m
Max. significant wave height	3.03 m

TLP angular response

Pitch

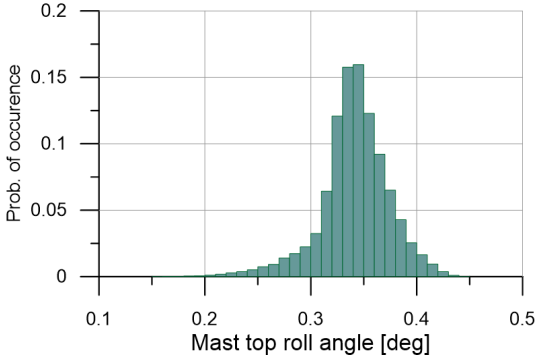


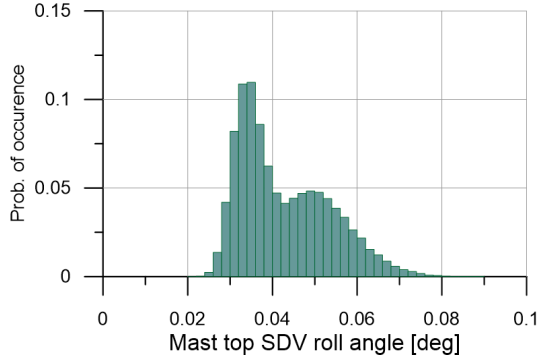


Max. inclination angle of met mast top (40m) < 1°.

Pitch angle average value is up to 0.5° over static value and its variation (σ) is limited to 0.15°.

Roll

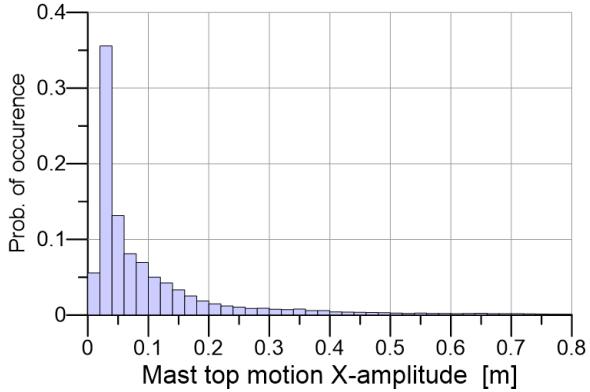


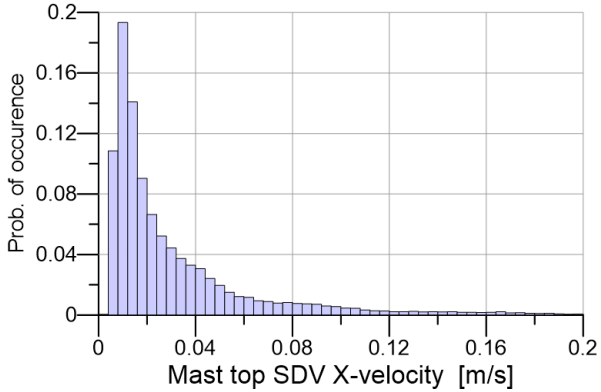


Roll angle average value is up to 0.3° over static value and its variation (σ) is limited to 0.1°.

TLP translational response

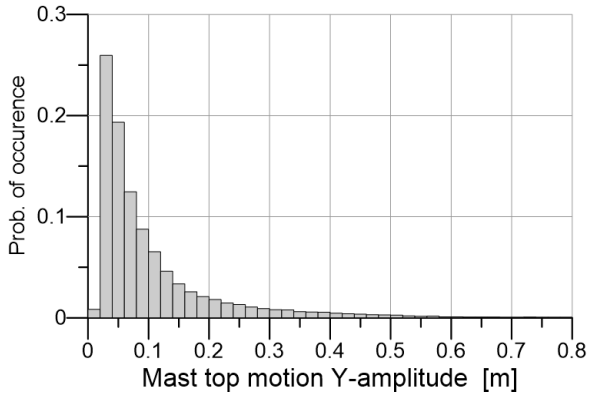
X-axis

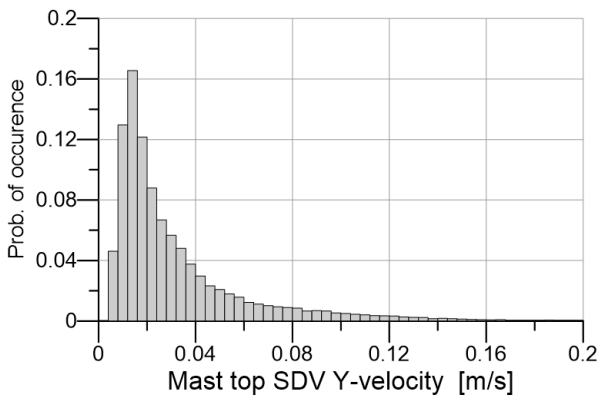




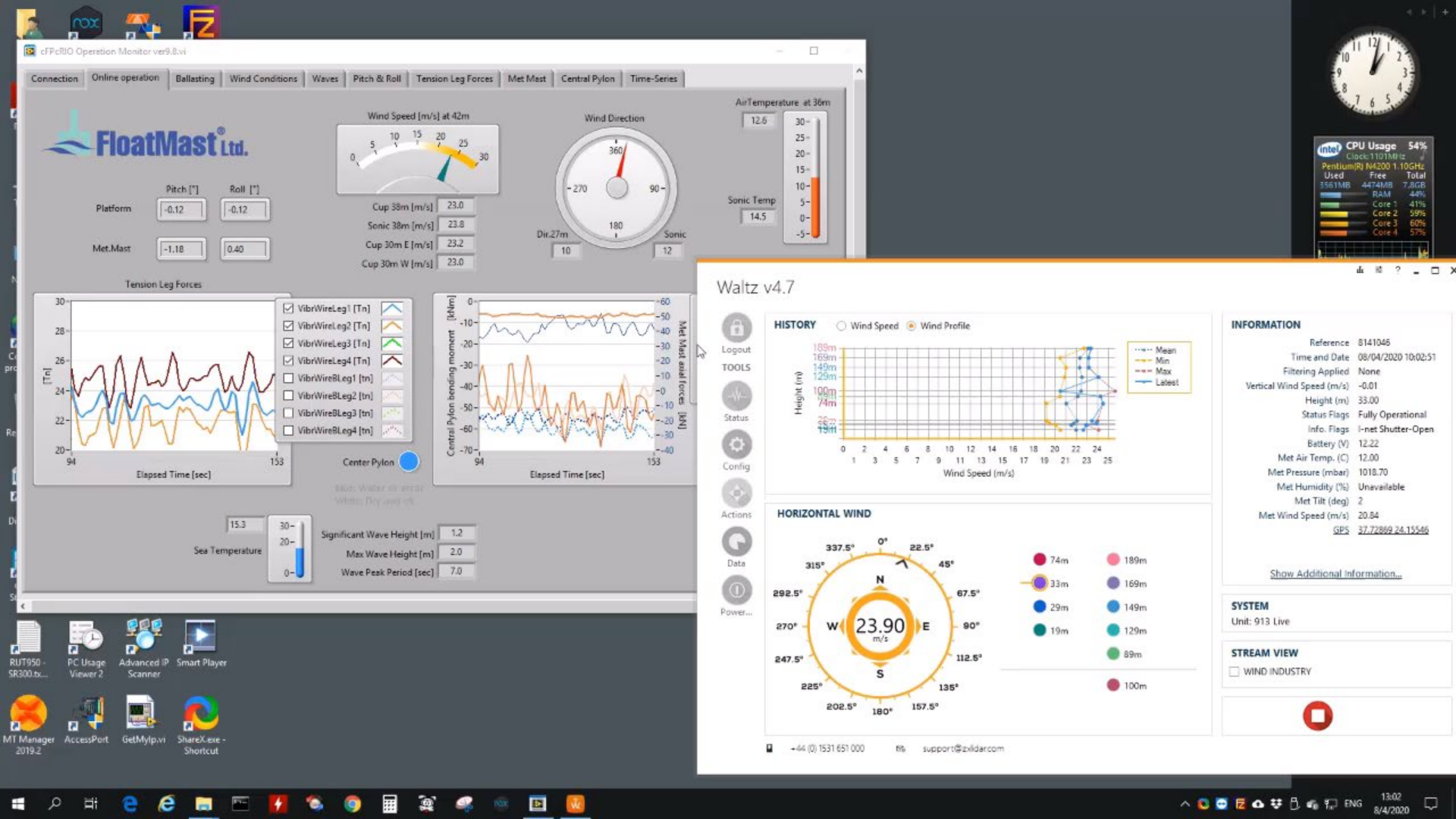
Motion max. amplitude remains < 1m up to 16m/s.
At higher winds exceeds 2m in rare cases.

Y-axis

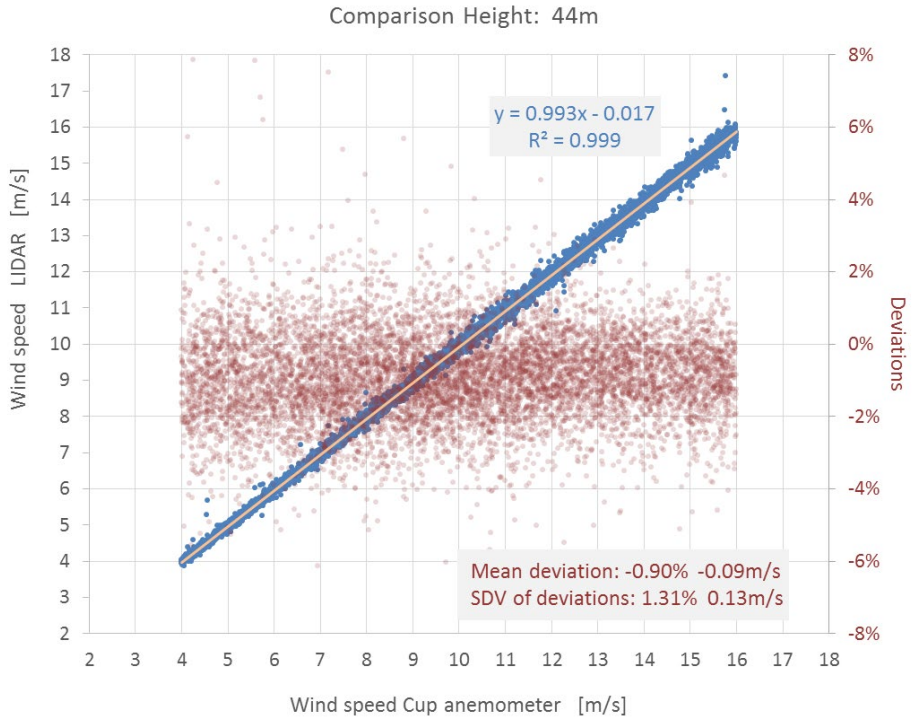


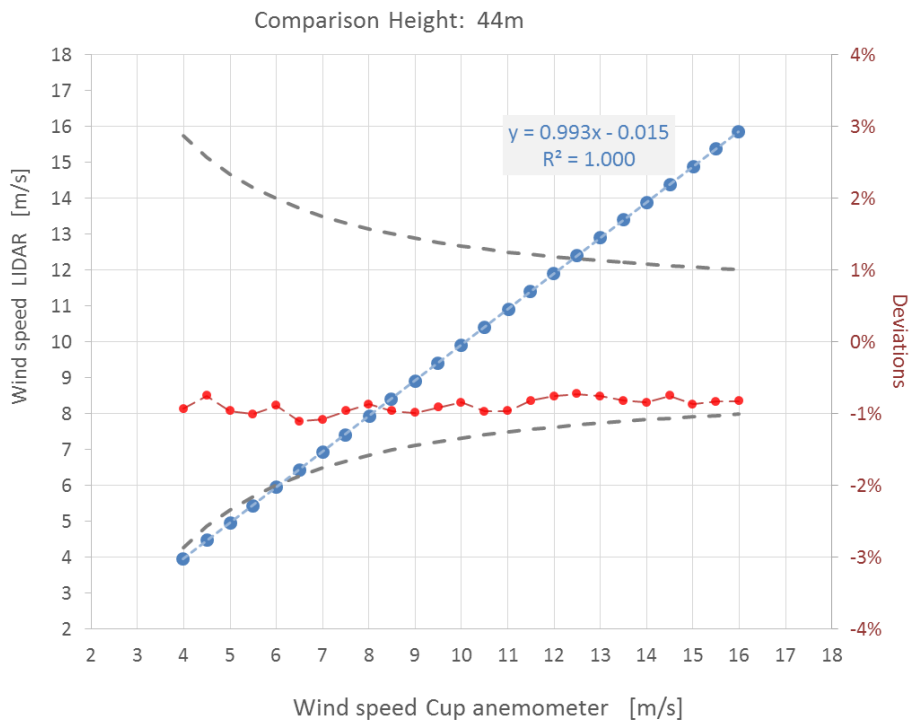


Motion's velocity variation (σ) remains < 0.2m/s up to 16m/s in either directions.
At higher winds exceeds 0.3m/s in rare cases.


cFPcRIO Operation Monitor ver9.8.vi
Connection
Online operation
Ballasting
Wind Conditions
Waves
Pitch & Roll
Tension Leg Forces
Met Mast
Central Pylon
Time-Series
FloatMast Ltd.
Wind Speed [m/s] at 42m
Wind Direction
AirTemperature at 36m
Pitch [°]
Roll [°]
Platform
-0.12
-0.12
Met.Mast
-1.18
0.40
Cup 38m [m/s] 23.0
Sonic 38m [m/s] 23.8
Cup 30m E [m/s] 23.2
Cup 30m W [m/s] 23.0
Dir.27m 10
Sonic 12
12.6
Sonic Temp 14.5
Tension Leg Forces
[Tn]
Elapsed Time [sec]
VibriWireLeg1 [Tn]
VibriWireLeg2 [Tn]
VibriWireLeg3 [Tn]
VibriWireLeg4 [Tn]
VibriWireBLeg1 [tn]
VibriWireBLeg2 [tn]
VibriWireBLeg3 [tn]
VibriWireBLeg4 [tn]
Center Pylon
Central Pylon bending moment [kNm]
Met Mast axial forces [kN]
Sea Temperature 15.3
Significant Wave Height [m] 1.2
Max Wave Height [m] 2.0
Wave Peak Period [sec] 7.0
Waltz v4.7
Logout
TOOLS
Status
Config
Actions
Data
Power...
HISTORY
Wind Speed
Wind Profile
Height (m)
Wind Speed (m/s)
Mean
Min
Max
Latest
HORIZONTAL WIND
23.90
m/s
74m
33m
29m
19m
189m
169m
149m
129m
89m
100m
INFORMATION
Reference 8141046
Time and Date 08/04/2020 10:02:51
Filtering Applied None
Vertical Wind Speed (m/s) -0.01
Height (m) 33.00
Status Flags Fully Operational
Info. Flags I-net Shutter-Open
Battery (V) 12.22
Met Air Temp. (C) 12.00
Met Pressure (mbar) 1018.70
Met Humidity (%) Unavailable
Met Tilt (deg) 2
Met Wind Speed (m/s) 20.84
GPS 37.72869 24.15546
Show Additional Information...
SYSTEM
Unit: 913 Live
STREAM VIEW
WIND INDUSTRY
+44 (0) 1531 651 000
support@zxlidar.com
RUT950 - SR300.tx...
PC Usage Viewer 2
Advanced IP Scanner
Smart Player
MT Manager 2019.2
AccessPort
GetMyIp.vi
ShareX.exe - Shortcut
CPU Usage 54%
Pentium(R) N4200 1.10GHz
RAM 44%
Core 1 41%
Core 2 59%
Core 3 60%
Core 4 57%
ENG
13:02
8/4/2020

TLP’s anemometers verification : top cup vs onboard lidar





Total RSD wind speed uncertainty = 1.68% (as per Annex-L.3 of IEC-61400-12-1 Ed.2017)

Uncertainty assessment due to TLP motion

- Comparisons between TLP-onboard and onshore lidar
  - Initial ZX300M performance verification
  - Side-by-side operation before deployment
  - Uncertainty assessed by inter-comparisons on site

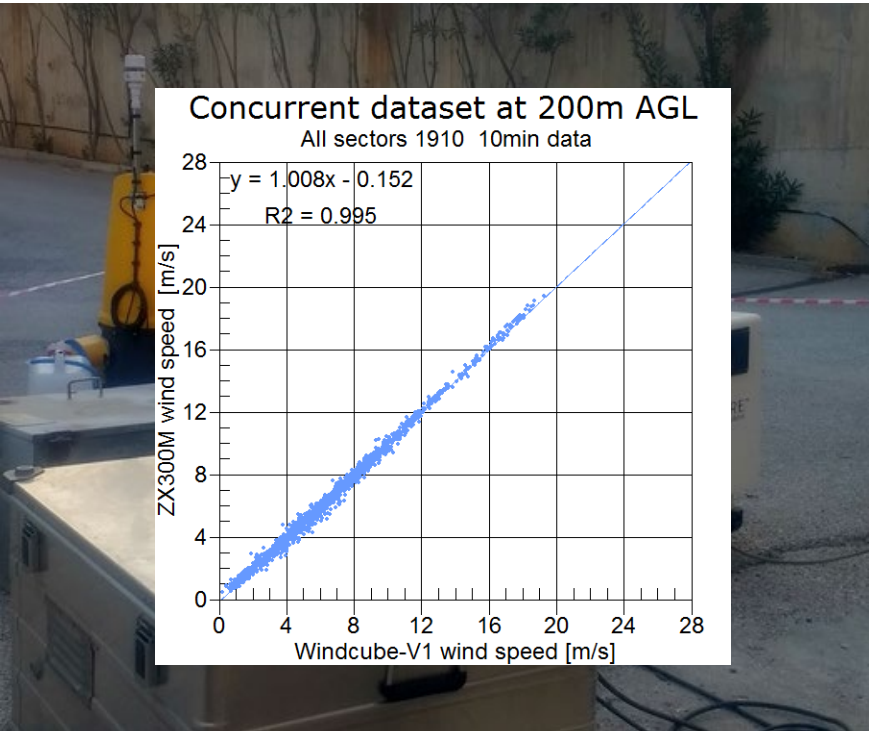
- Wind Tunnel Experiments
  - Cup/sonic/vane submitted in various motion cases
  - Establish uncertainty values

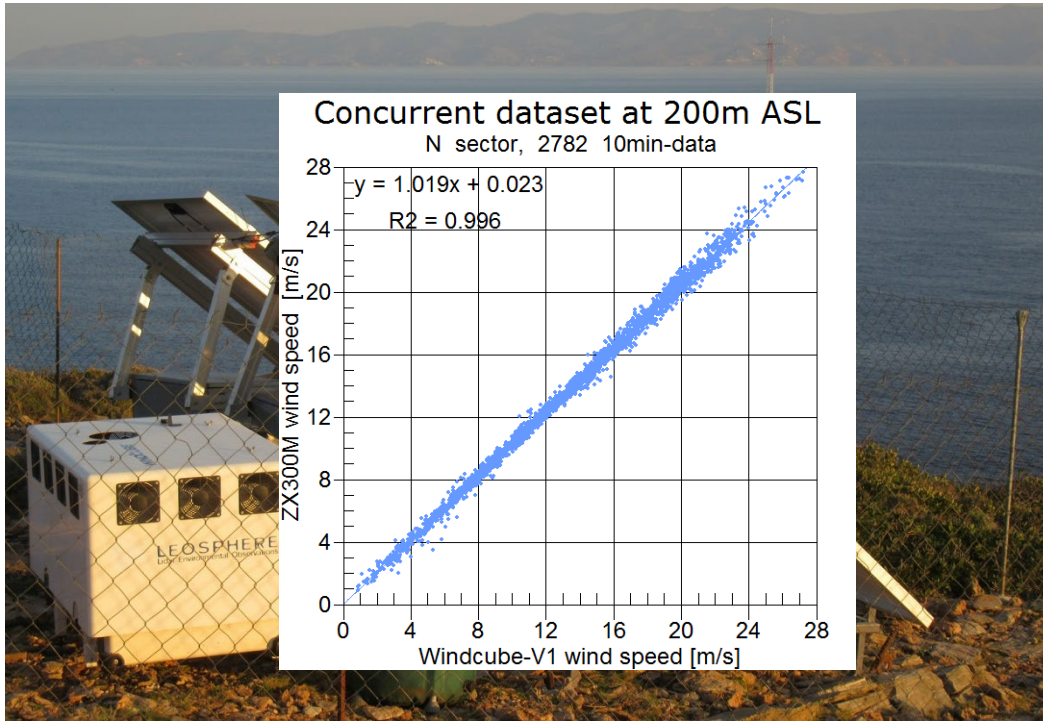
Initial side-by-side correlations before deployment

4,5 months of common operation


Windcube V1
350m
FloatMast
Image © 2019 TerraMetrics
Google Earth

Lidar wind speed comparisons

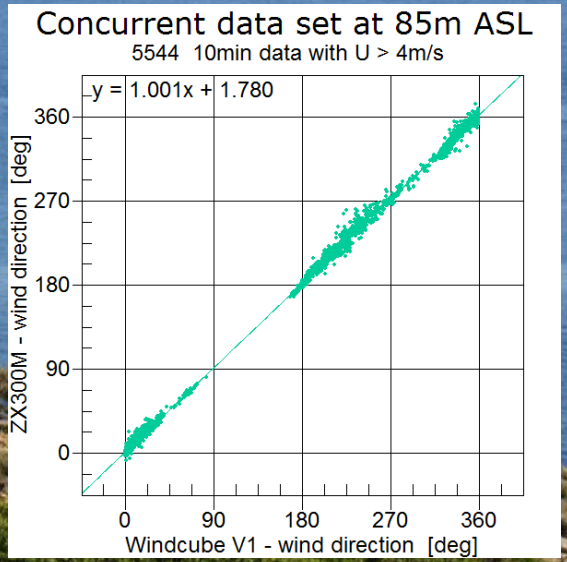


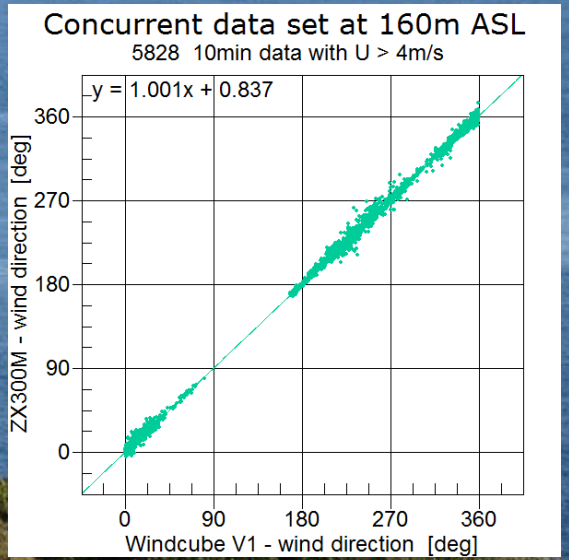


ZX300M's uncertainty increases by ~ 1% (Ref. lidar onshore: Windcube)

Best results at higher heights (topography effects vanish, approaching measuring volumes)

Lidar wind direction comparisons





FloatMast RSD accuracy assessment by KPIs*

		Acceptance criteria		
KPI	**Definition**	**Stage2**	**Stage3**	**FloatMast's RSD**
Xmws	Mean Wind Speed – Slope	0.97-1.03	0.98 – 1.02	1.02
R2mws	Mean Wind Speed – R^2	> 0.97	> 0.98	0.996
Mmwd	Mean Wind Direction – Slope	0.95 – 1.05	0.97 – 1.03	1.00
OFFmwd	Mean Wind Direction – Offset	< 10°	< 5°	2°
R2mwd	Mean Wind Direction – R^2	> 0.95	> 0.97	0.99
OSA_{CA}	Overall System Availability – Campaign Average	> 95%	> 97 %	98.4 %
$OPDA_{CA}$	Overall Post-processed Data Availability	> 85%	> 90 %	90 %

* Carbon Trust Offshore Wind Accelerator "Roadmap for Commercial Acceptance of Floating Lidars, Version2.0, October 2018

Wind Tunnel experiments

Static calibrations compared to oscillating sensors.

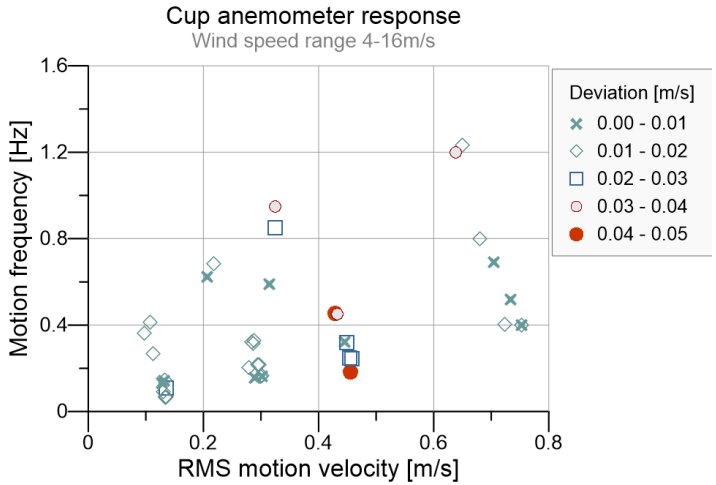
Oscillation parameters :

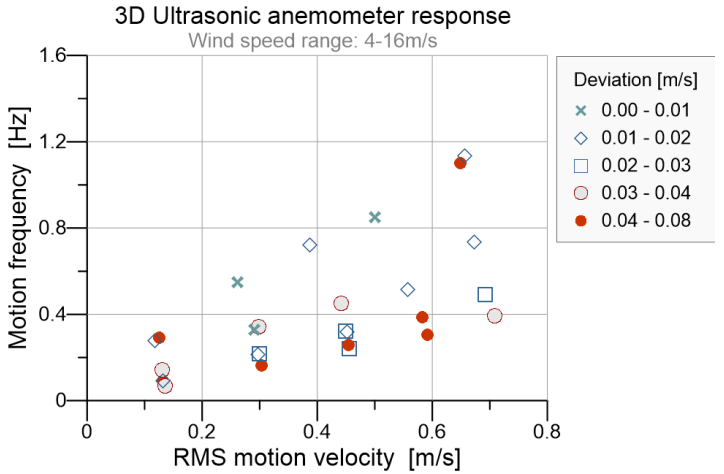
Velocity variation (σ_U)	0.1 - 0.8	[m/s]
Period (T)	0.8 - 15.0	[sec]
Max. displacement	0.95	[m]

CRES Wind Tunnel for accredited anemometer calibrations

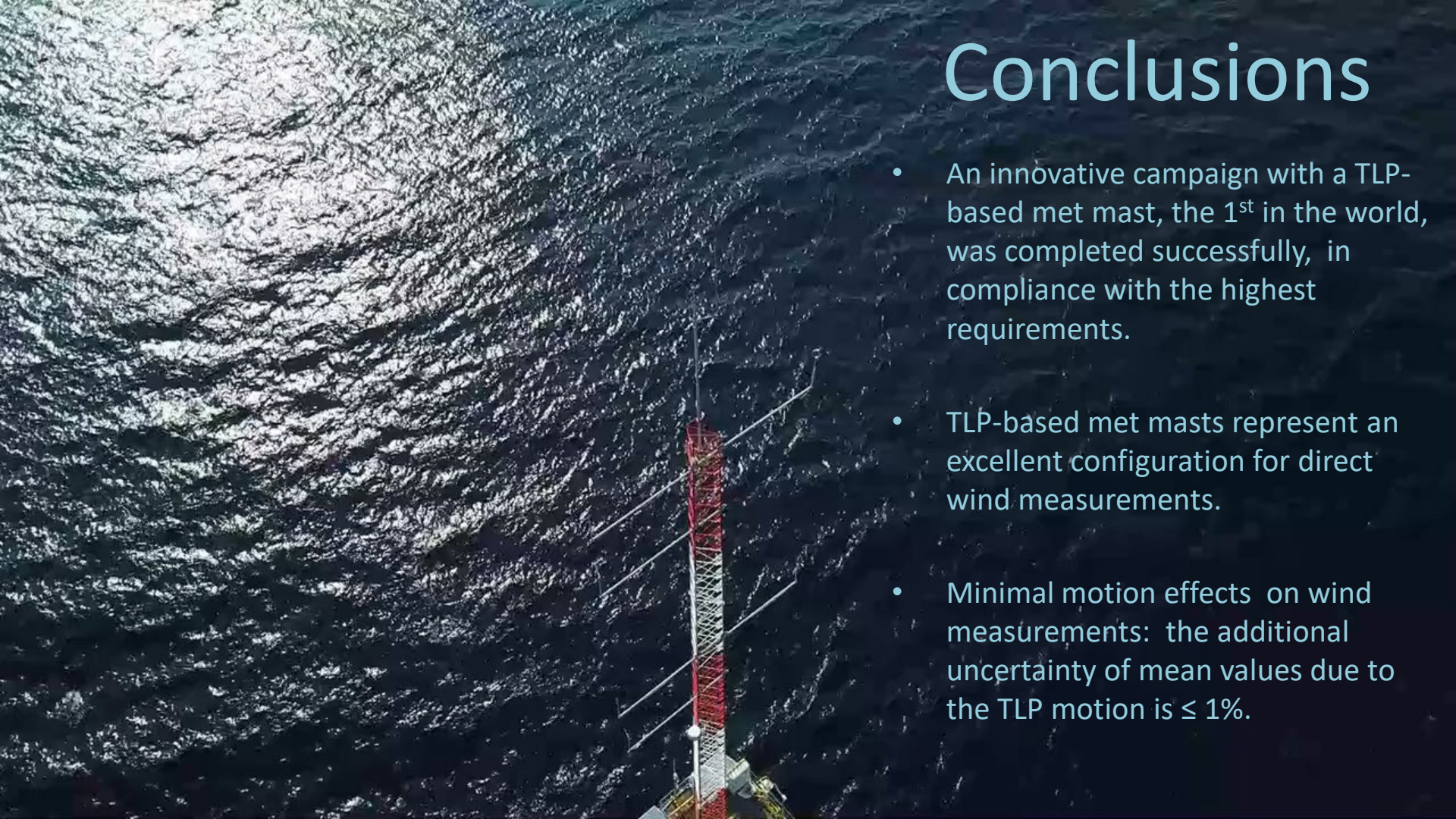
Wind Tunnel results

	Cup anemometer		Sonic anemometer		Vane	
Wind speed range [m/s]	Calibration Uncertainty [m/s]	Mean deviation due to motion [m/s]	Calibration uncertainty [m/s]	Mean deviation due to motion [m/s]	Calibration Uncertainty [deg]	Mean deviation due to motion [deg]
4-16	< 0.11	0.01 – 0.05	< 0.08	0.01 – 0.07	1	< 0.5





Assumed wind speed uncertainty for TLP met masts : $(0.08 + 0.005u) / \sqrt{3}$ [m/s]



Conclusions

- An innovative campaign with a TLP-based met mast, the 1st in the world, was completed successfully, in compliance with the highest requirements.
- TLP-based met masts represent an excellent configuration for direct wind measurements.
- Minimal motion effects on wind measurements: the additional uncertainty of mean values due to the TLP motion is ≤ 1%.