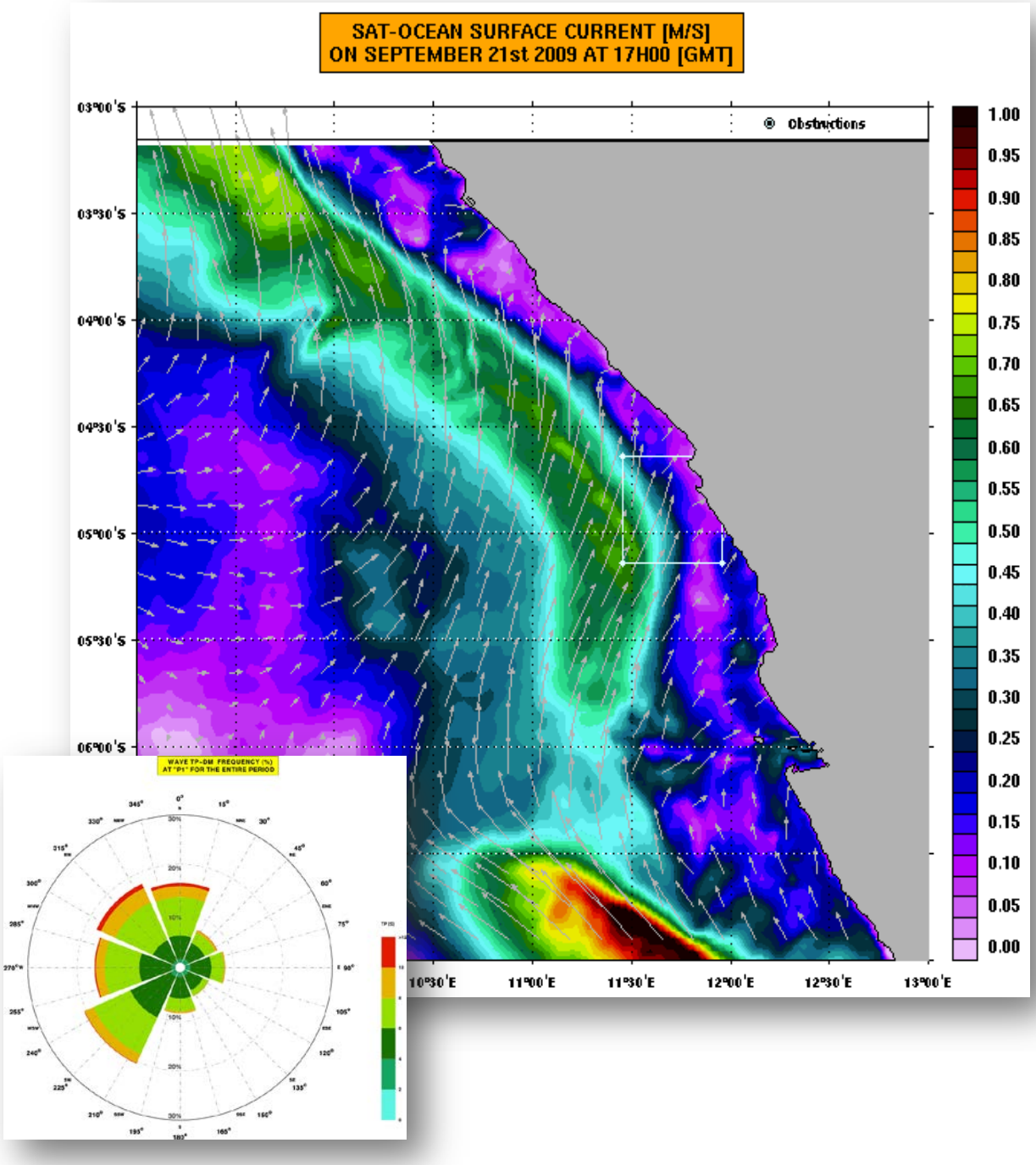
SCOPE OF WORK
CURRENT, WIND & WAVES HISTORICAL STUDIES



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1 Executive summary

SAT-OCEAN, using its experience in satellite data analysis and numerical modeling, provides historical statistical analysis (hindcast) of ocean currents (surface and sub-surface direction and magnitude), wind and waves.

SAT-OCEAN products include both 3D currents, winds and waves information, based on the last 2 to 10 years. It enables operators and contractors to gain an understanding of the Metocean conditions, especially regarding 3D currents, at the areas of interest for their operations.

Typical applications of such studies include operation planning, riser design analysis, field development studies, downtime analysis etc…

2 SAT-OCEAN service

2.1 Ocean current hindcasting

SAT-OCEAN ocean current modeling is based on HYCOM (Hybrid Coordinate Ocean Model - Bleck, 2001). HYCOM is a generalized hybrid vertical coordinate model widely recognized as a powerful and efficient tool for ocean modeling. To this state of the art model, SAT-OCEAN brings a significant methodology innovation in using it in an inverse way: the “data” drives the model and we fit the dynamics onto it to yield 3D absolute ocean currents.

From our merged sensor data sets, we produce sea surface temperature cloud-free fields with a very high spatial and temporal resolution and a 0.2°C rms error compared to simultaneous on site measurements, worldwide. From there, we have developed a method - based on regression coefficient calculation derived from simultaneous altimetric fields and historical temperature / salinity (T/S) profiles - that yields 3D temperature and salinity, daily: the obtained 3D T/S is called SAT-OCEAN dynamic climatology and represents as closely as possible the 3D state of the ocean over a given region, every day of concern for our model runs.

The 3D T/S data is then strongly being assimilated in our HYCOM/SAT-OCEAN model, strongly in the sense that we give very little freedom to our model, and are very close to performing an inversion of our forcing data, for the ocean circulation (except in the mix layer which is highly driven by the forcing wind stress). Another way to present this is to say that we fit ocean currents to high quality 3D satellite data, rather than obtaining current "data" from a model.

A baseline (1/8°) global model is being run and covers the entire ocean domain. Then, a fine resolution (1/64°equivalent to 1.7 km) configuration of the model is run to cover target areas. The runs encompass 34 layers, with an about 10-layer sampling of the thermocline with a 1-hour output time step. The values obtained represent the currents down to the smallest time scales encompassed in the forcing and assimilated data, from 1 to 6 hours.

2.2 Accuracy of current methodology

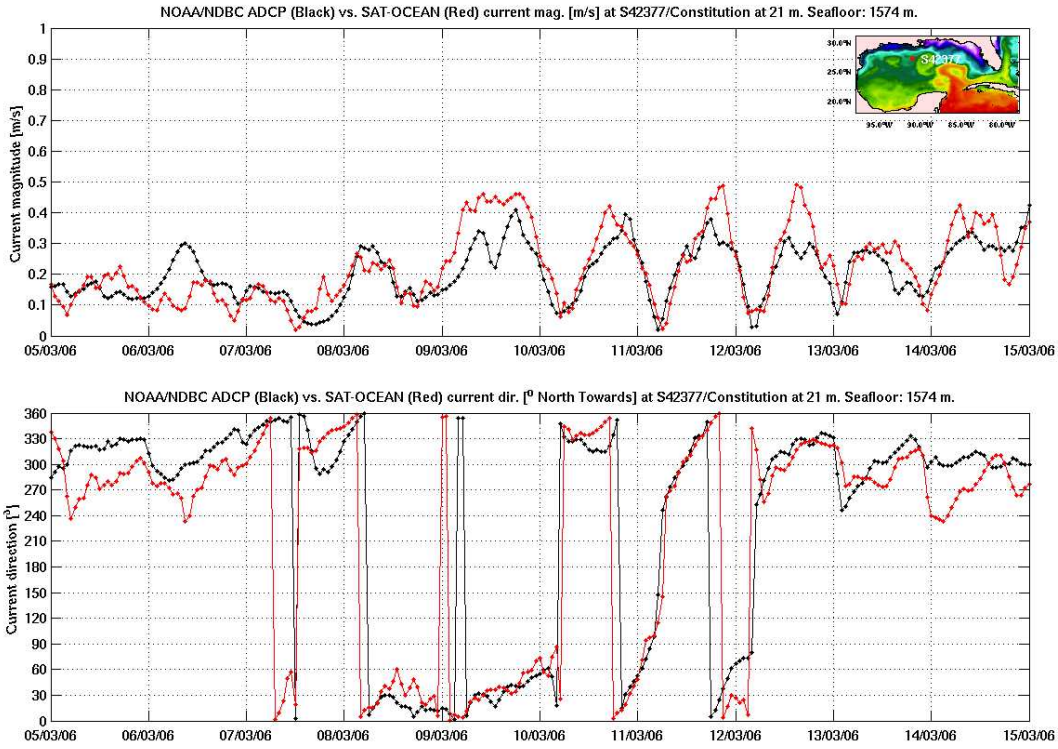


Figure 1 : SAT-OCEAN data vs measured data from NOAA/NDBC buoys (GoM)

2.3 Ocean waves hindcasting

SAT-OCEAN's wave hindcasting system is based on the combination of altimetry satellite data and the Wavewatch III numerical model. The altimetry satellite data is assimilated into the numerical model to improve the results.

A baseline (1^{o}) global model is being run to cover the entire ocean domain, and a first nesting procedure is applied to a higher-resolution area ($1/4^{o}$). Then a second nesting is applied down to $1/16^{th}$ of a degree spanning the target area embedded in the 1/4 ° run.

The governing equations of the Wavewatch III wave model include refraction and straining of the wave field due to temporal and spatial variations of the mean water depth and of the mean current (tides, surges etc.), when applicable.

Parameterizations of physical processes (source terms) include wave growth and decay due to the actions of wind, nonlinear resonant interactions, dissipation (whitecapping) and bottom friction.

Wave propagation is considered to be linear. Relevant nonlinear effects such as resonant interactions are, therefore, included in the source terms (physics).

2.4 Accuracy of Waves methodology

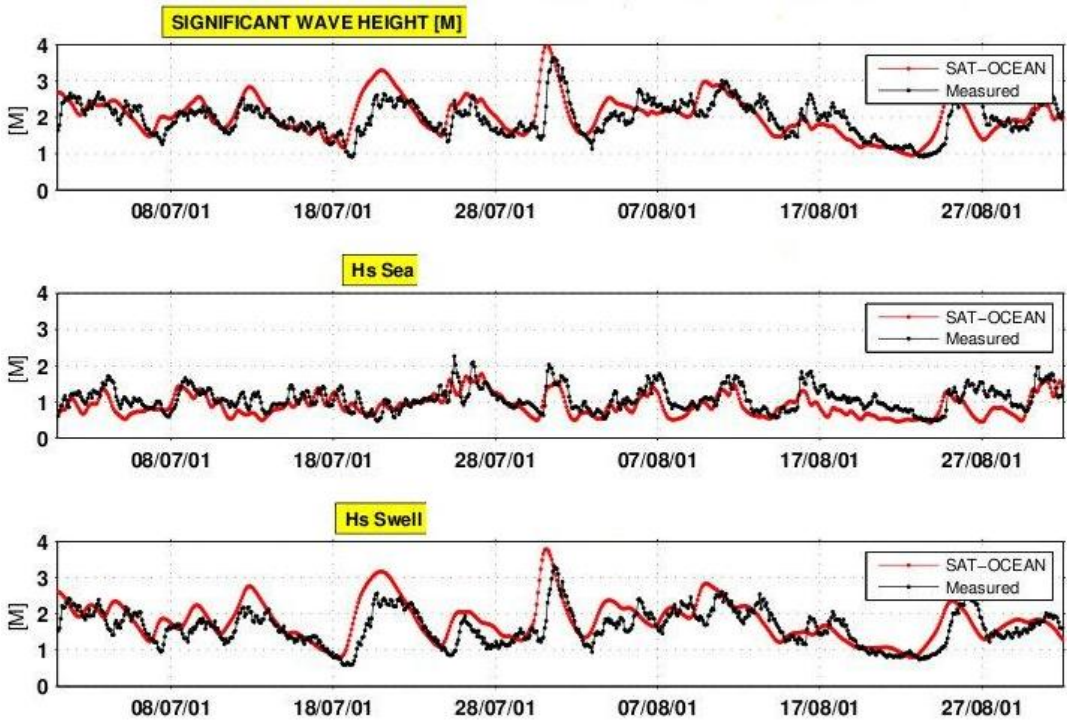


Figure 2 : SAT-OCEAN data vs measured data offshore Australia

2.5 Wind hindcasting

SAT-OCEAN provides high quality analyzed satellite wind data for up to 20 years long. We can provide longer time series by combining these data with lower resolution dataset based on all the historical data available worldwide and meteorological numerical models.

Our winds are based on NCEP 1/2° global winds and Wave Watch 3 improved winds. We then calibrate the global winds with satellites scatterometers to improve the accuracy. Our winds are accurate to within 90-95% depending on the region and period of time.

2.6 Accuracy of wind methodology

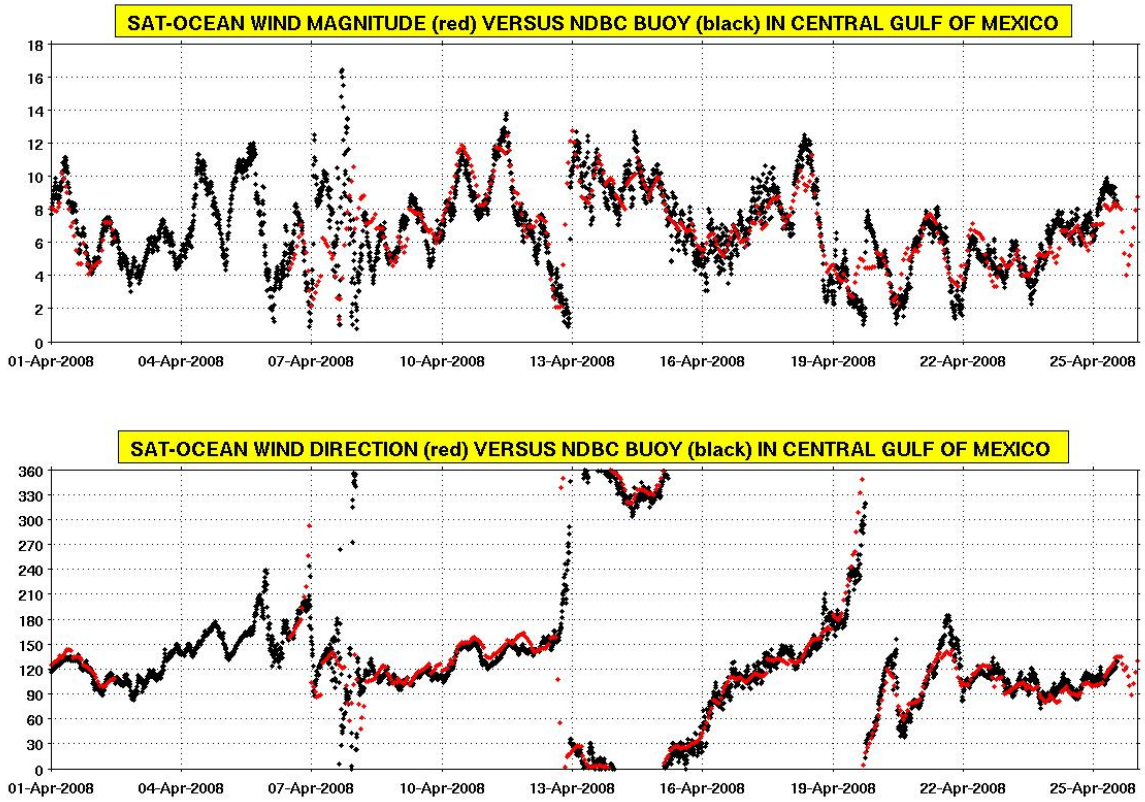


Figure 3 : SAT-OCEAN data vs measured data in the Gulf of Mexico

3 Product deliverables

3.1 Reports

Full reports are provided for 3D current, wind and waves. The latter include all statistics mentioned in the list below and are provided in PDF electronic format.

Statistical data are also provided in Excel format.

3.2 Ocean current deliverables

SAT-OCEAN deliver the following absolute 2D or 3D ocean current statistics:

- Current compass plots
- Multidirectional extreme current derivation at 1, 10 and 100 year-return (others on request)
- Joint distributions of the current magnitude vs direction
- Statistics table for current
- Maps presenting the 2-dimensional average and standard deviation of surface current

3.3 Examples of current deliverables

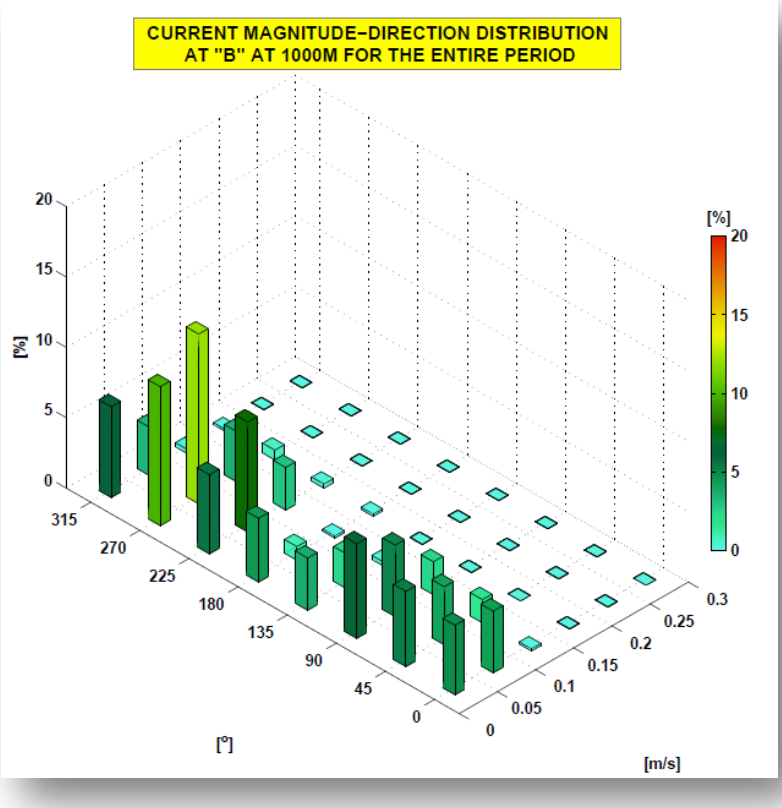


Figure 4 : Example of current magnitude/direction distribution at 1000m depth

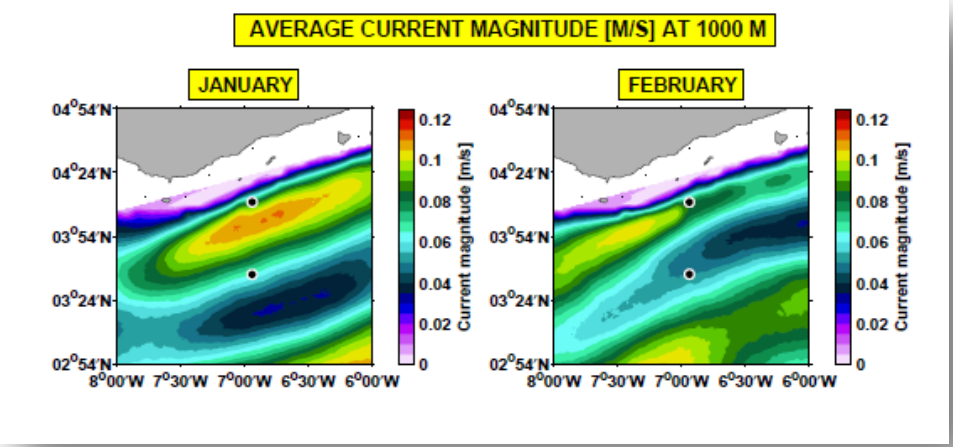


Figure 5 : Example of monthly average current magnitude at 1000m

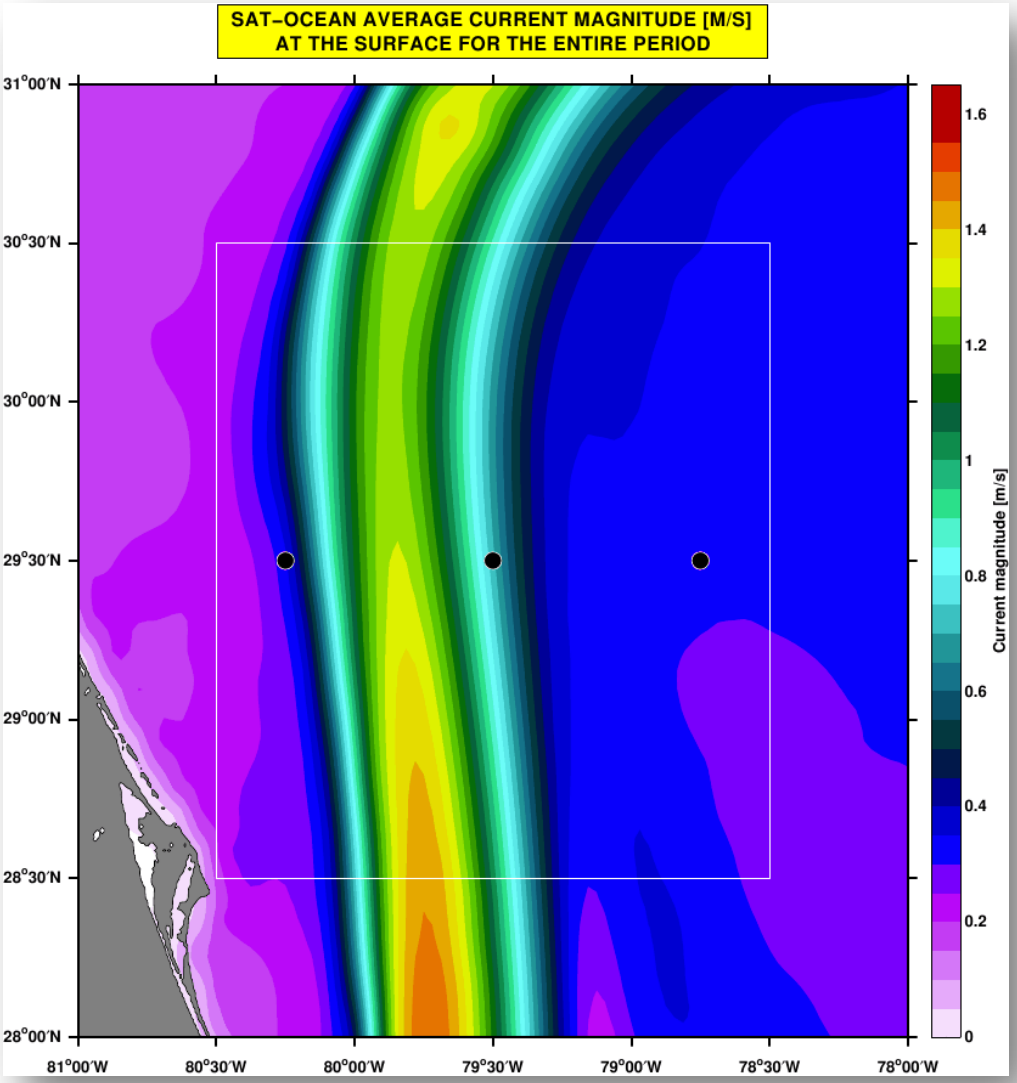


Figure 6 : current average speed surface map

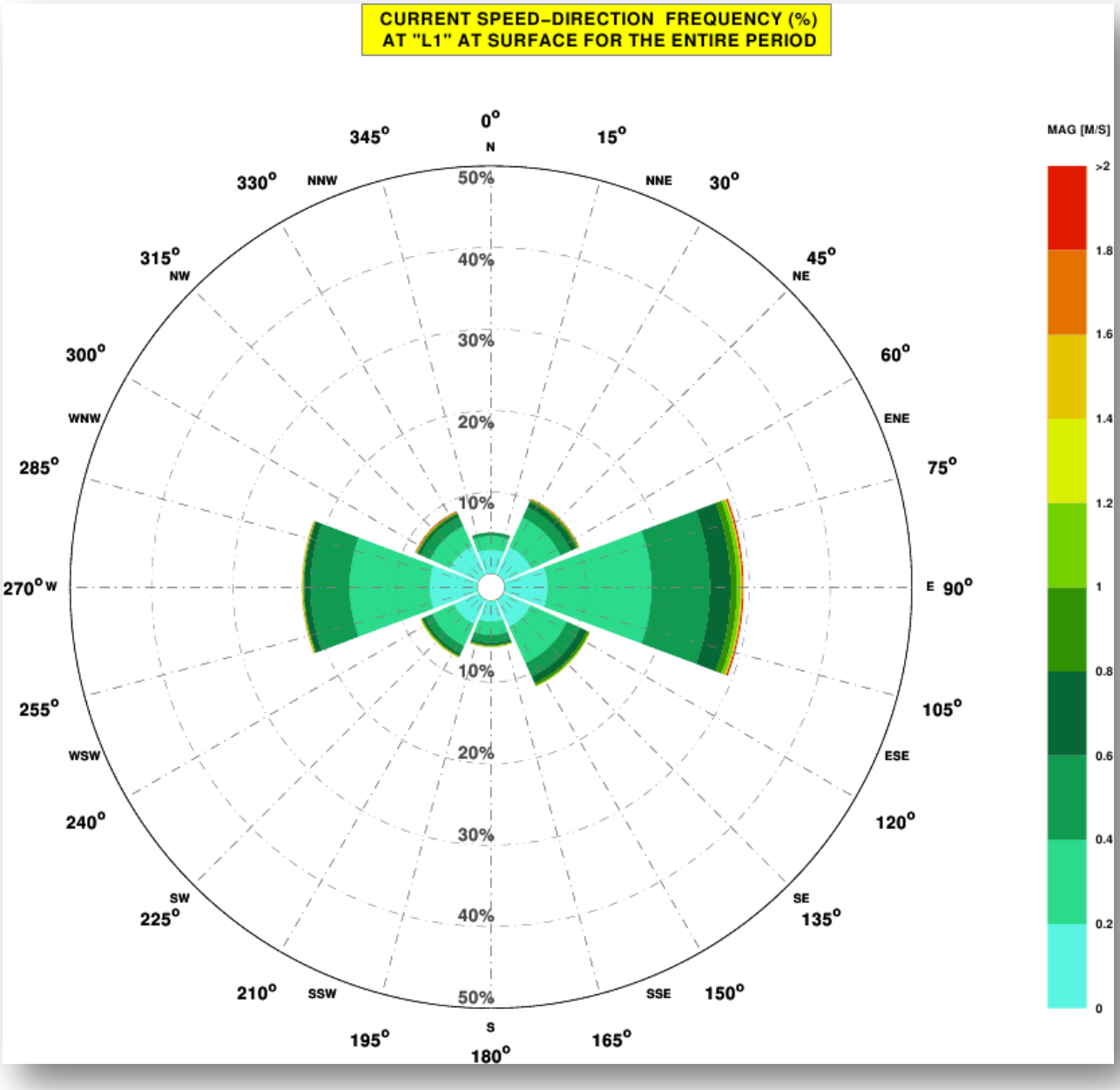


Figure 7 : Current compass diagram indicating direction occurrence and directional speed occurrence

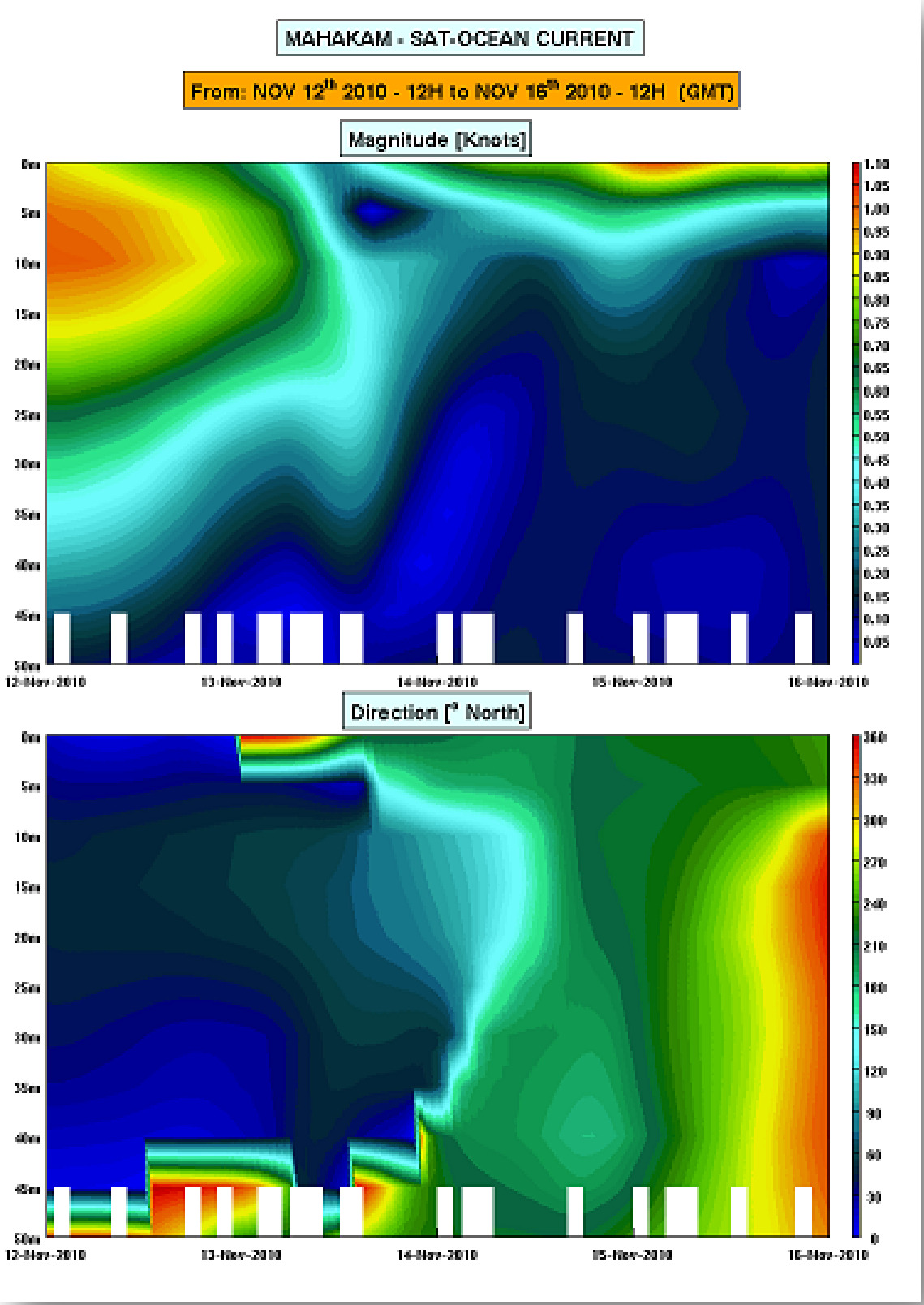


Figure 8: Time/Depth plot of ocean current magnitude and direction

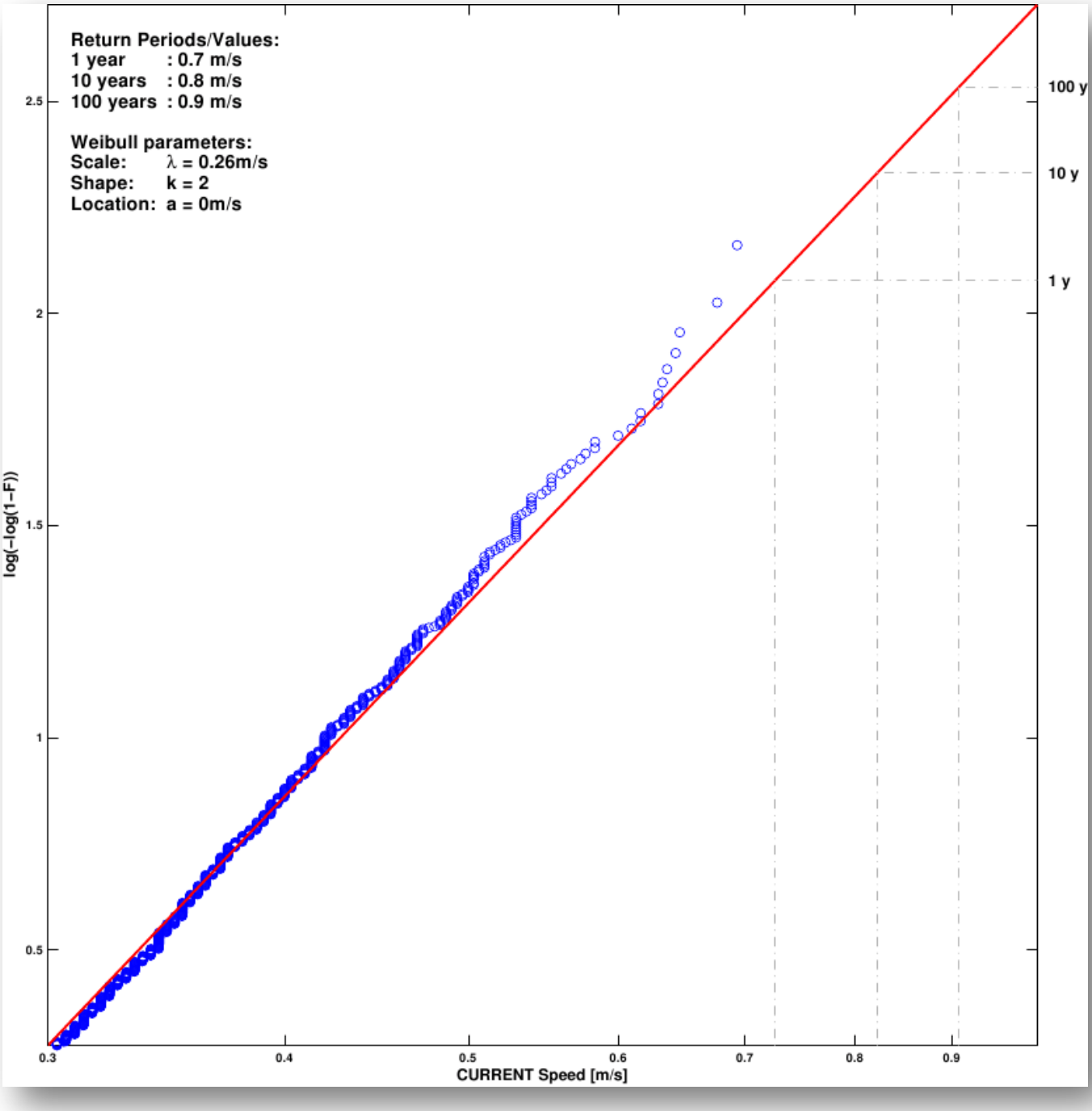


Figure 9 : Current return period derivation plot

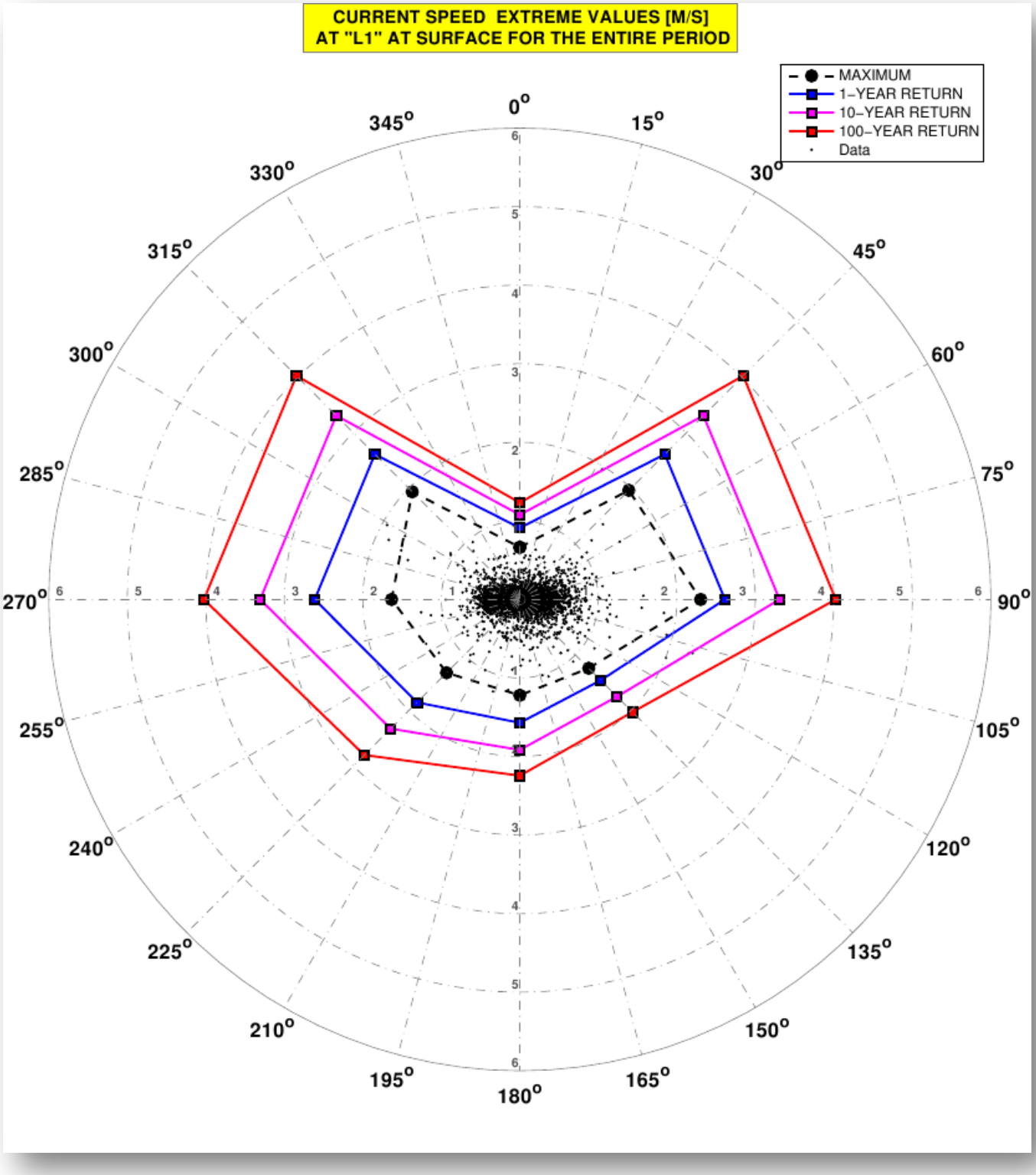


Figure 10 : Directional extreme value diagram of the current speed indicating speed maximum, 1-year, 10-year and 100-year return values

CURRENT MONTHLY STATISTICS AT "A" AT SURFACE

MONTH	MEAN MAGNITUDE [M/S]	MAGNITUDE STANDARD DEVIATION [M/S]	MEDIAN MAGNITUDE [M/S]	MINIMUM MAGNITUDE [M/S]	MAXIMUM MAGNITUDE [M/S]	MAGNITUDE EXCEEDANCE PROBA ≤ 99%, 95% 90%, 50% 10%, 5% 1% [M/S]	MOST FREQUENT DIRECTION (TOWARD)	MOST FREQUENT DIRECTION OF STRONGEST CURRENT (TOWARD)
JANUARY	0.58	0.29	0.65	0.02	1.1	0.031, 0.052 0.14, 0.64 0.97, 0.98 1	E	E
FEBRUARY	0.54	0.33	0.62	0.02	1.1	0.029, 0.061 0.12, 0.6 0.94, 0.97 1	E	E
MARCH	0.91	0.22	0.88	0.36	1.5	0.37, 0.51 0.64, 0.87 1.2, 1.2 1.4	E	E
APRIL	0.93	0.17	0.93	0.57	1.3	0.58, 0.64 0.67, 0.93 1.1, 1.2 1.3	N – E	E
MAY	0.6	0.26	0.66	0.11	1.1	0.11, 0.18 0.21, 0.65 0.91, 1 1	N – E	N – E
JUNE	0.49	0.24	0.46	0.14	1.1	0.15, 0.19 0.2, 0.45 0.84, 0.87 1	N – E	N – E
JULY	1	0.2	1	0.64	1.5	0.65, 0.75 0.81, 0.98 1.3, 1.4 1.4	E	E
AUGUST	0.95	0.26	0.94	0.49	1.5	0.5, 0.57 0.6, 0.94 1.3, 1.4 1.5	E	E
SEPTEMBER	0.7	0.36	0.65	0.08	1.4	0.091, 0.16 0.19, 0.65 1.2, 1.2 1.3	E	E
OCTOBER	0.43	0.25	0.37	0.05	1.1	0.059, 0.14 0.16, 0.37 0.85, 0.95 1	E	E
NOVEMBER	0.28	0.17	0.23	0.03	0.77	0.039, 0.059 0.089, 0.23 0.52, 0.54 0.77	E	E
DECEMBER	0.59	0.27	0.64	0.09	1.1	0.091, 0.14 0.2, 0.63 0.91, 0.99 1.1	E	E

Figure 11 : Monthly current statistics

CURRENT SPEED–DIRECTION DISTRIBUTION [%] AT "L1" AT SURFACE FOR THE ENTIRE PERIOD

DIR / SPEED [M/S]	N	NE	E	SE	S	SW	W	NW	TOTAL	% EXCEED
TOTAL	5.07	10.23	29.35	11.71	5.67	7.85	21.54	8.55	100.00	
> 1.4	0	0.1	0.31	0	0	0	0.07	0.1	0.58	0.58
1.2 – 1.4	0	0	0.07	0.03	0.03	0.07	0.03	0.03	0.26	0.86
1 – 1.2	0	0.07	0.45	0.1	0.1	0.07	0.07	0.07	0.93	1.78
0.8 – 1	0	0.27	0.75	0.31	0.1	0.14	0.1	0.17	1.84	3.63
0.6 – 0.8	0.03	0.68	2.57	0.89	0.27	0.31	0.75	0.34	5.84	9.49
0.4 – 0.6	0.41	1.4	7.16	1.82	0.96	0.99	4.83	1.3	18.87	28.36
0.2 – 0.4	1.68	3.94	12.77	4.86	1.64	2.95	9.83	2.67	40.34	68.7
0 – 0.2	2.95	3.77	5.27	3.7	2.57	3.32	5.86	3.87	31.31	100

Figure 12 : Joint distribution table of current speed and direction

CURRENT–SPEED PERSISTENCE AT "L1" AT SURFACE FOR THE ENTIRE PERIOD

ENTIRE SERIES	LESS/MORE THAN 0.2M/S	LESS/MORE THAN 0.4M/S	LESS/MORE THAN 0.6M/S	LESS/MORE THAN 0.8M/S	LESS/MORE THAN 1M/S
BETWEEN 3 – 6 HRS	3.2% 35%	45% 7.4%	81% 2.4%	93% 1%	96% 0.4%
BETWEEN 6 – 9 HRS	1.1% 27%	36% 5.3%	78% 1.5%	91% 0.7%	96% 0.2%
BETWEEN 9 – 12 HRS	0.7% 22%	32% 4.2%	75% 1.1%	90% 0.4%	95% 0.2%
BETWEEN 12 HRS – 1 DAY	0.2% 14%	25% 2.2%	70% 0.6%	87% 0.2%	93% 0%
BETWEEN 1 – 1.5 DAYS	0% 7.4%	18% 0.8%	63% 0.2%	84% 0%	91% 0%
BETWEEN 1.5 – 2 DAYS	0% 4.3%	13% 0.2%	58% 0%	80% 0%	88% 0%
BETWEEN 2 – 2.5 DAYS	0% 2.3%	9.7% 0%	52% 0%	77% 0%	86% 0%
BETWEEN 2.5 – 3 DAYS	0% 0.9%	7.5% 0%	48% 0%	74% 0%	84% 0%
BETWEEN 3 – 4 DAYS	0% 0.2%	5.1% 0%	41% 0%	70% 0%	81% 0%

Figure 13 : Current speed persistence table with double "Less/More" entries

3.4 Ocean waves deliverables

SAT-OCEAN will deliver the following wave statistics :

- Wave Hs-Dp compass plot
- Wave Tp-Dp compass plot
- Wave Hs-Dp joint distribution
- Wave Hs-Tp joint distribution
- Wave Tp-Dp joint distribution
- Wave Hs occurrence
- Wave Tp occurrence
- Wave Dp occurrence
- Extreme 1, 10 and 100 year wave Hs return periods (others on request)

- Statistics table for Hs, Tp, and Dp :
    - Mean, max, standard dev.
    - Occurrence
    - Persistence
    - Exceedance
    - Return periods

3.5 Examples of waves deliverables

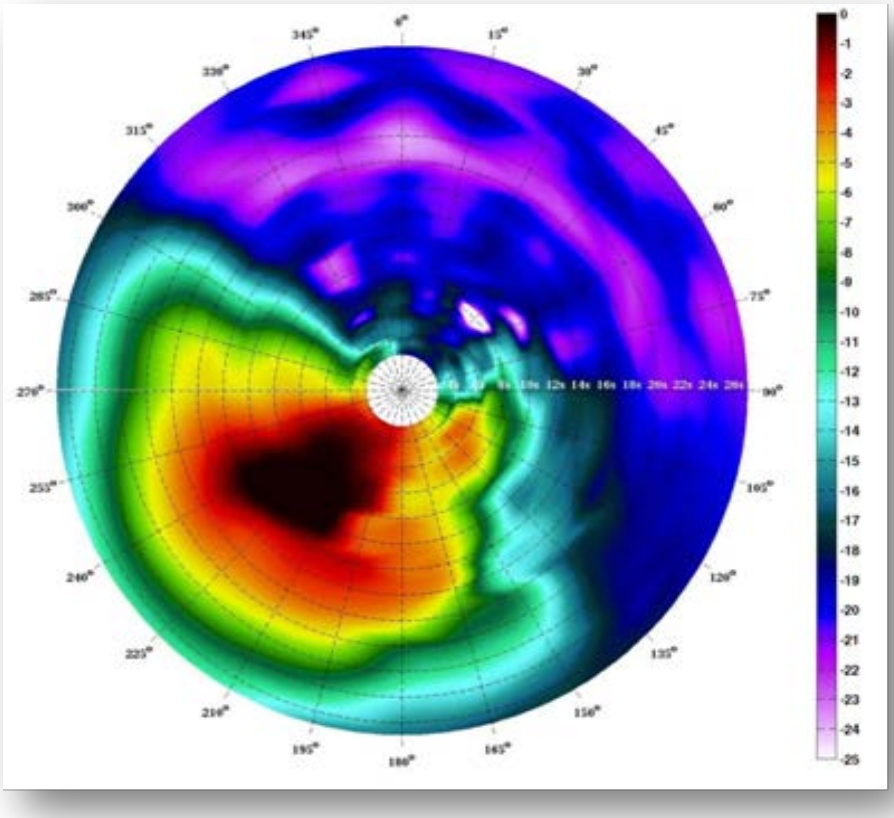


Figure 14 : Frequency – direction spectrum at drilling location

WAVE HS / TP RETURN VALUES AT "P1"

	3–hr HS [M] / TP[S] 1–YR	3–hr HS [M] / TP[S] 10–YR	3–hr HS [M] / TP[S] 100–YR
ENTIRE TIME SERIES	7.9 / 14	9.7 / 16	11.4 / 18
JANUARY	7.9 / 14	9.4 / 15	10.6 / 17
FEBRUARY	7.7 / 13	9 / 15	10.2 / 16
MARCH	5.8 / 11	6.6 / 12	7.3 / 13
APRIL	5.1 / 10	5.9 / 11	6.6 / 12
MAY	3.7 / 9	4.3 / 9	4.7 / 10
JUNE	4.6 / 10	5.5 / 11	6.3 / 12
JULY	4 / 9	4.7 / 10	5.4 / 10
AUGUST	4.5 / 9	5.3 / 10	6 / 11
SEPTEMBER	5.5 / 11	6.4 / 12	7.1 / 13
OCTOBER	7.3 / 13	8.7 / 14	10 / 16
NOVEMBER	7.9 / 14	9.7 / 16	11.3 / 18
DECEMBER	7.9 / 14	9.7 / 16	11.4 / 18

Figure 15 : Waves HS period monthly extremes table

WAVE PERIOD–DIRECTION DISTRIBUTION [%] AT "P1" FOR THE ENTIRE PERIOD

DM / TP [S]	N	NE	E	SE	S	SW	W	NW	TOTAL	% EXCEED
TOTAL	16.17	7.35	8.22	5.38	8.29	20.49	16.42	17.71	100.00	
> 10	0.62	0.07	0.02	0.02	0.02	0.1	0.24	0.94	2.03	2.03
8 – 10	2.28	0.43	0.27	0.03	0.36	1.96	1.81	3.22	10.36	12.37
6 – 8	7.78	2.35	2.53	1.22	2.61	8.26	7.03	8.43	40.21	52.59
4 – 6	4.74	3.51	4.37	3.23	4.38	9.06	6.54	4.6	40.43	93
2 – 4	0.7	0.97	1.02	0.88	0.91	1.07	0.76	0.5	6.81	99.81
< 2	0.05	0.02	0.01	0	0.01	0.04	0.04	0.02	0.19	100

Figure 16 : Waves joint distribution period direction table

WAVE HEIGHT–DIRECTION STATISTICS AT "P1"

HS [M]	ALL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
QTLE 99%	4.9	5.9	5.7	4.5	4.2	2.9	3.1	3	3.5	4.6	5.2	5.2	5.6
95%	3.6	4.4	4.3	3.7	2.9	2.3	2.4	2.2	2.6	3.3	3.8	3.9	4.3
90%	3	3.8	3.6	3.1	2.4	2.1	1.9	1.8	2.2	2.7	3.2	3.5	3.8
10%	0.6	0.9	0.8	0.7	0.5	0.5	0.5	0.4	0.4	0.6	0.8	0.9	0.8
5%	0.4	0.7	0.7	0.5	0.4	0.4	0.3	0.3	0.3	0.5	0.6	0.7	0.6
1%	0.2	0.5	0.5	0.4	0.2	0.2	0.2	0.1	0.1	0.3	0.4	0.5	0.4
MEAN	1.6	2.2	2	1.8	1.4	1.2	1.1	1	1.2	1.5	1.9	2.1	2.1
STD	1	1.2	1.1	0.9	0.8	0.6	0.6	0.6	0.7	0.9	1	1	1.2
MED	1.4	2	1.8	1.6	1.2	1.1	1	0.9	1	1.3	1.7	1.9	2
MIN	0	0.2	0.3	0.1	0	0	0	0	0	0.1	0.2	0.2	0.2
MAX	10.6	8.5	8	6.2	5.4	4	4.9	4.3	4.7	5.8	7.6	10.6	10.1
MOST FREQUENT DIRECTION (FROM)	SW	SW	SW	SW	N	N	N	NW	NW	NW	SW	SW	SW
MOST FREQUENT DIRECTION OF HIGHEST WAVE (FROM)	SW	SW	W	NW	NW	N	NW	NW	NW	NW	SW	NW	SW

Figure 17 : Waves HS directions statistics table

WAVE HEIGHT–PERIOD DISTRIBUTION [%] AT "P1" FOR THE ENTIRE PERIOD

TP [S] / HS [M]	< 2	2 – 4	4 – 6	6 – 8	8 – 10	10 <	TOTAL
TOTAL	0.19	6.81	40.42	40.22	10.35	2.01	100.00
> 5	0	0	0	0	0.29	0.58	0.87
4 – 5	0	0	0	0.01	1.96	0.24	2.21
3 – 4	0	0	0	2.58	4.37	0.06	7.01
2 – 3	0	0	0.27	16.5	1.52	0.19	18.48
1 – 2	0	0.12	21.2	17.77	1.18	0.51	40.78
0 – 1	0.19	6.69	18.95	3.36	1.03	0.43	30.65

Figure 18 : Waves joint distribution

3.6 Wind deliverables

SAT-OCEAN will deliver the following wind data statistics:

- 10-meter wind compass plots
- Extreme wind derivation at 1, 10 and 100 year return periods (others on request)
- Joint distributions of wind magnitude vs direction
- Statistics table for wind

- Statistics table for wind magnitude and direction :

  - Mean, max, standard dev.
  - Occurrence
  - Persistence
  - Exceedance
  - Return periods

3.7 Examples of wind deliverables

WIND SPEED–DIRECTION STATISTICS AT "P1" AT 10M

SPEED [M/S]	ALL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
QTLE 99%	17	20	18	16	15	12	13	13	14	16	18	18	19
95%	14	17	16	14	12	11	11	10	11	13	15	15	16
90%	13	15	14	13	11	10	10	9	10	12	14	14	15
10%	3	5	4	4	3	3	3	2	3	4	5	5	4
5%	3	4	4	3	2	2	2	2	2	3	4	4	4
1%	1	2	2	2	1	1	1	1	1	2	2	3	2
MEAN	8	10	9	8	7	6	6	6	6	7	9	9	9
STD	4	4	4	3	3	3	3	3	3	3	3	4	4
MED	7	9	9	8	7	6	6	6	6	7	9	9	9
MIN	0	0	1	0	0	0	0	0	0	0	1	1	1
MAX	26	26	23	23	19	18	17	16	19	19	25	26	25
MOST FREQUENT DIRECTION (FROM)	SW	SW	SW	SW	SW	SW	SW	W	SW	SW	SW	SW	SW
MOST FREQUENT DIRECTION OF STRONGEST WIND (FROM)	SW	SW	W	W	SW	N	NW	NW	NW	W	SW	SW	SW

Figure 19 : Wind occurrence speed table

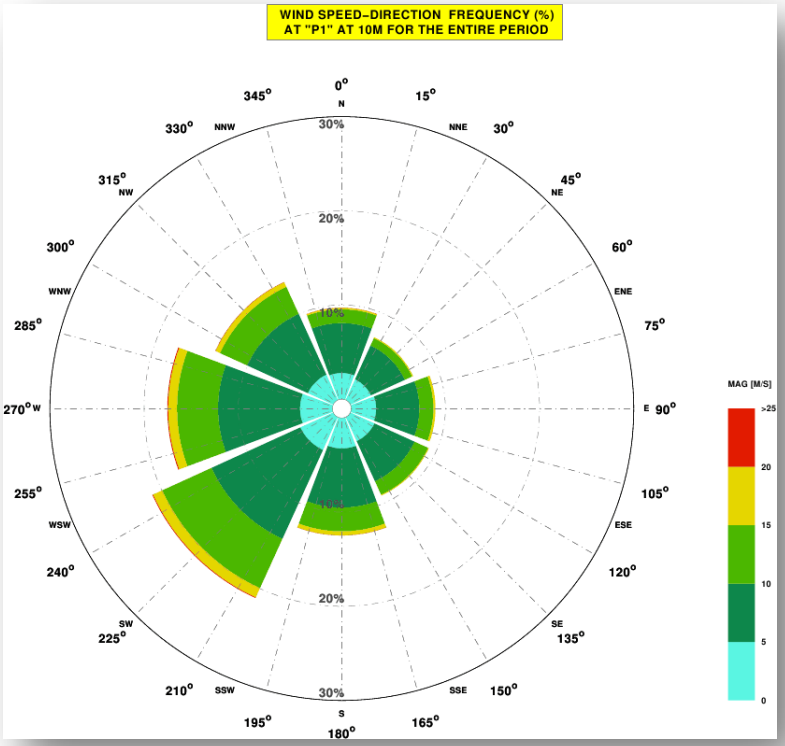


Figure 20 : Wind speed compass plot

WIND-SPEED PERSISTENCE AT "P1" AT 10M FOR THE ENTIRE PERIOD

ENTIRE SERIES	LESS/MORE THAN 2.5M/S	LESS/MORE THAN 5M/S	LESS/MORE THAN 7.5M/S	LESS/MORE THAN 10M/S	LESS/MORE THAN 12.5M/S	LESS/MORE THAN 15M/S	LESS/MORE THAN 17.5M/S
BETWEEN 3 – 6 HRS	2% 93%	17% 69%	44% 40%	69% 19%	86% 7.2%	94% 2.1%	98% 0.4%
BETWEEN 6 – 9 HRS	1.4% 92%	15% 66%	40% 37%	66% 17%	84% 5.9%	93% 1.6%	98% 0.3%
BETWEEN 9 – 12 HRS	1.1% 91%	13% 63%	38% 34%	64% 15%	82% 4.9%	93% 1.2%	98% 0.2%
BETWEEN 12 HRS – 1 DAY	0.6% 89%	9.1% 57%	32% 28%	59% 11%	79% 3.2%	91% 0.7%	97% 0.1%
BETWEEN 1 – 1.5 DAYS	0.2% 85%	5.3% 49%	25% 21%	52% 7.1%	75% 1.6%	88% 0.2%	96% 0%
BETWEEN 1.5 – 2 DAYS	0.1% 82%	3.2% 42%	20% 16%	46% 4.7%	71% 0.8%	86% 0.1%	95% 0%
BETWEEN 2 – 2.5 DAYS	0% 79%	2.1% 37%	16% 13%	42% 3.2%	67% 0.5%	83% 0%	94% 0%
BETWEEN 2.5 – 3 DAYS	0% 76%	1.4% 32%	13% 10%	38% 2.2%	64% 0.3%	81% 0%	94% 0%
BETWEEN 3 – 4 DAYS	0% 72%	0.8% 26%	10% 7.2%	33% 1.3%	60% 0.1%	79% 0%	92% 0%

Figure 21 : Wind persistence speed table

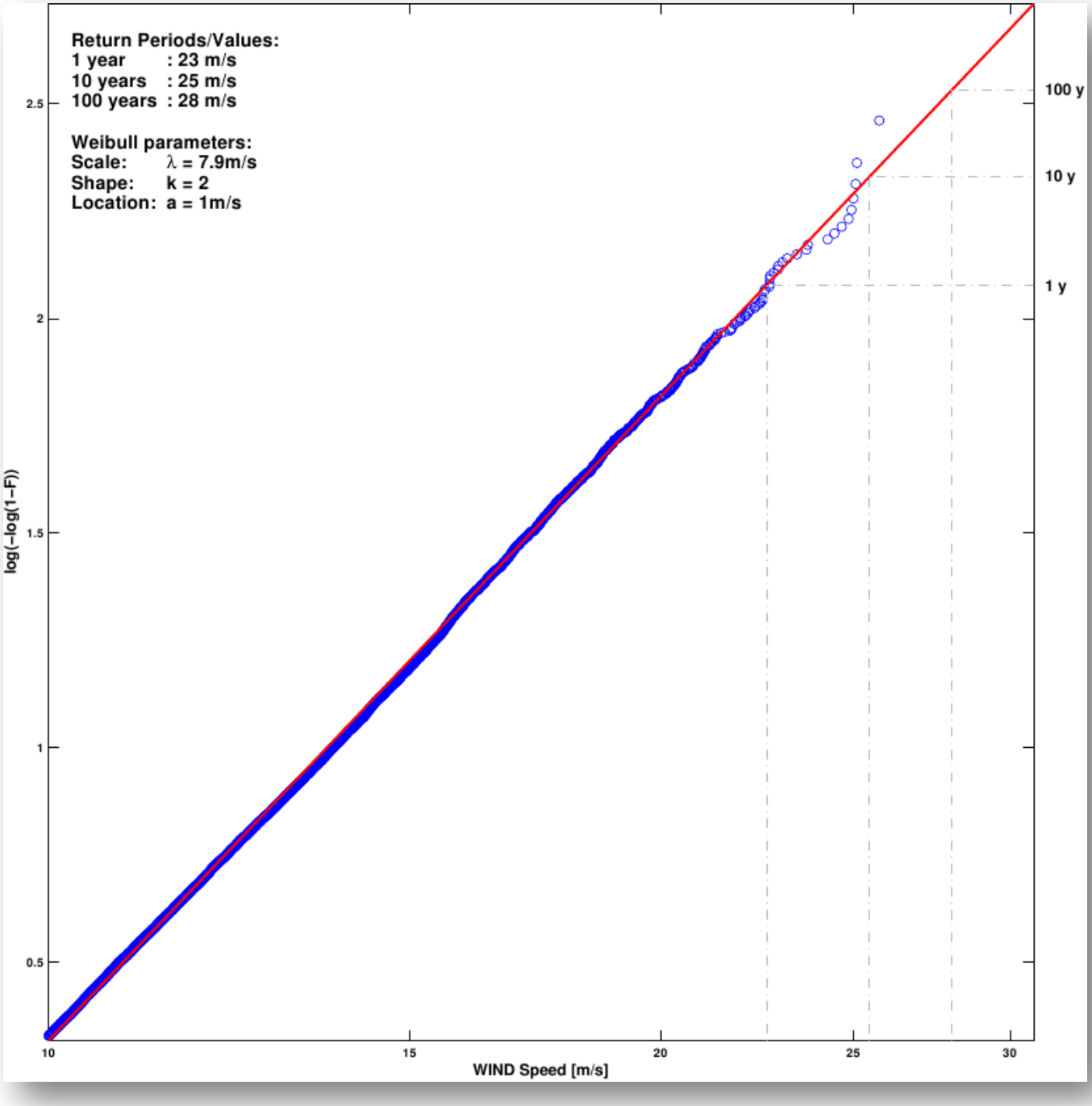


Figure 22 : Wind return period derivation plot

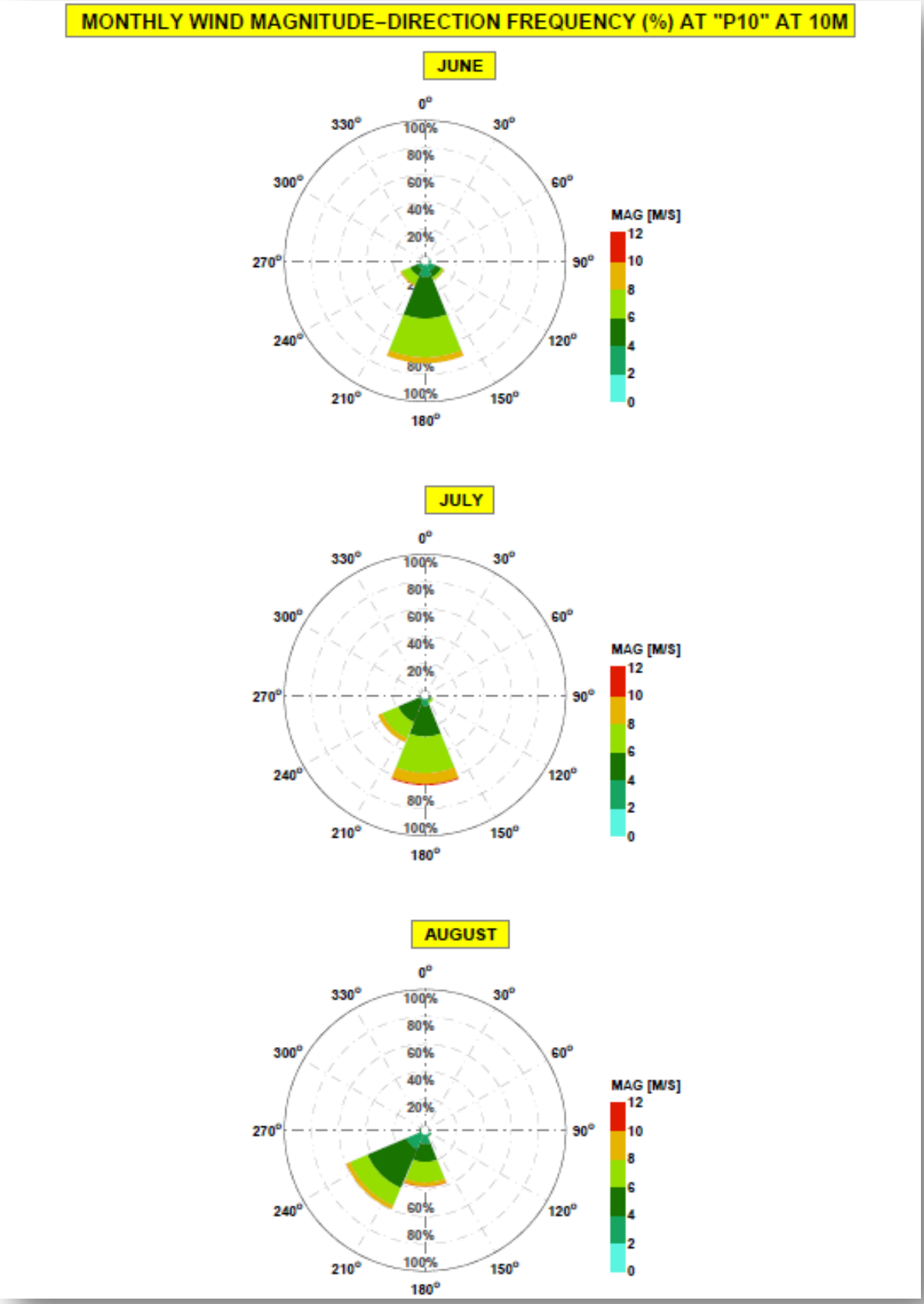


Figure 23 : Examples of Frequency of wind magnitude and direction

APPENDIX: PERENCO CASE STUDY

Perenco presence in Congo

Perenco operates the offshore fields of Yombo and Emeraude in the Republic of Congo. The Emeraude field is a major accumulation lying offshore Pointe Noire at 60m water-depth.

After several years of pre project and reservoir simulations, Perenco / CONGOREP initiated in 2006 an important project to confirm the economic viability of an extensive development at the Emeraude field. The project consists in the deployment of an offshore steam injection plant on a new built drilling, process and production platform.

New platform installation challenges

The construction, transportation and installation are part of the new program. The platform has a 40 x 30m deck and weights 4.000T. After a one-month transit from Morocco, it is to be anchored on the 55m deep seabed.

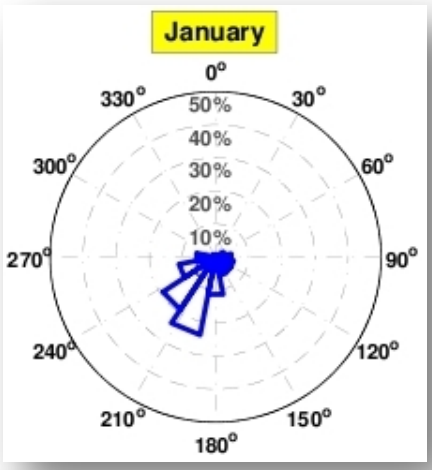
Changing environmental conditions presented a significant risk for installation operations. The region offshore Pointe Noire is indeed under the influence of the Congo River plume which regularly diverts northwards and disturbs greatly the coastal ocean circulation.

As a result, high magnitude surface currents occur in association with a very strong variability over time. The signal is confined in the very upper layer, which depth varies typically between 3 to 8 meters, and a strong vertical stratification tends to occur. These sudden changes in surface & near-surface currents direction were a major issue for the barge float off planned by Perenco.

Planning phase

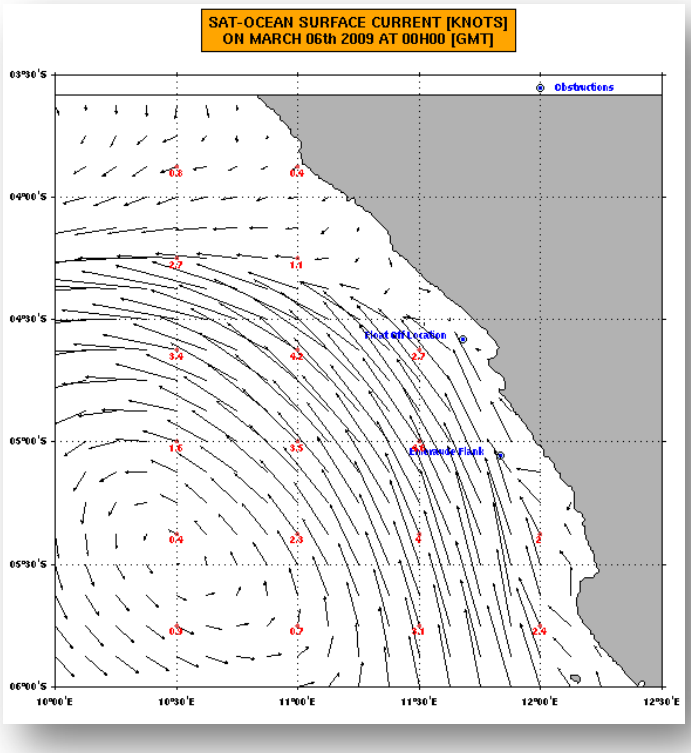
Perenco completed a careful design of the operations through a thorough wind, waves and current persistence analysis. SAT-OCEAN was involved at that early stage and delivered a study of local conditions.

This data set was used in the initial planning of the float off to ensure that the structural integrity of both vessel and platform would not be put at risk. It also enabled to define the most appropriate installation window and select between 2 and 4 point anchoring for the project.



Real-time assistance to float off operations

For the 15-day duration of the platform installation, Perenco also received real-time forecasts from SAT-OCEAN. One of the phenomena Perenco wanted to monitor was abrupt shifts in current direction, which had already been witnessed in several occasions. To that end, SAT-OCEAN provided daily Metocean reports with 48-hour current forecast.



"***SAT-OCEAN has been of great help for the Emeraude Flank project***" says Louis Hannecart, Perenco Project Manager. "***Their currents forecasts matched well with our observations and contributed significantly to the safety & good planning of the barge float off***".