Prediction of Wind Fields using Weather Pattern Recognition: Analysis of Sailing Strategy and Real Weather Data in Tokyo 2020 Olympics

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Prediction of Wind Fields using Weather Pattern Recognition: Analysis of Sailing Strategy and Real Weather Data in Tokyo 2020 Olympics

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Abstract. The Tokyo 2020 Olympic Sailing Competitions were held in Enoshima Bay between the 25th of July and the 4th of August 2021. The climatological and the strategical analysis of the race area for the Swedish Sailing Team was developed in the three years prior to the Olympics (Masino et al., 2021). The result of the three years' research was a tool named "Call Book" that provides strategical rules for sailors and coaches both in terms of expected ranges of wind speed and direction and also in terms of trends with explanations for each identified weather pattern. The support team was working not only on the forecast but also on the specific analysis of the weather data in the race areas as measured on the water by the Olympics organising authorities and monitored through the SAP Analytics website (SAP Sailing Analytics, 2021). Two race areas are herein taken into consideration, namely Enoshima and Zushi, where the Swedish Team athletes sailed most of the races. A statistical meta-analysis on the comparison between the forecast issued using the "Call Book" and measured data on the race areas is carried out, investigating the specific outcome of the strategy of the races with the forecasted meteorological data.

Keywords: Meteorology; Meta-Analysis; Sailing; Olympics.

1 INTRODUCTION

Olympic sailing is a complex sport that comprises numerous performance parameters such as the ability to understand and predict weather conditions, the assessment and choice of technical gear (i.e. sails and equipment), tactical understanding and the mastering of strategy and boat handling (Bojsen-Moller et al., 2015). Weather modelling for specific sailing race areas has been developed over the past 30 years for Olympic venues (Giannaros et al., 2018; Li, 2008; Ma et al., 2013; Spark & Conno, 2004). Knowledge of local wind characteristics is used in sailing to determine a racing strategy (Messager et al., 2020; Pezzoli & Bellasio, 2014; Tagliaferri & Viola, 2017) and studying weather patterns is an essential part of preparation for a race. It is also necessary to build confidence in the forecast in the years and months prior to the races. As well demonstrated by (Masino et al., 2021), the complicated topography around Enoshima Bay plays an important role in the strength and direction of wind changes or variations, especially when the wind is blowing from onshore. The position of the race areas as well as some coastal features can be seen in Figure 1. The investigated race areas of Enoshima and Zushi are two of the more inland areas where local wind changes can largely affect the strategy of a race.

In Olympic sailing the ranking of each race will count towards the medal award. In general sailing research, the performance is assessed using a velocity prediction program (VPP) that predicts maximum boat speeds able to be reached for a range of wind speeds and angles. The resultant predicted race time is derived by balancing the resistive and propulsive forces acting on the vessel at different points of sail, or true wind angles, to determine the maximum Velocity Made Good (VMG) around the course. For this method to accurately predict course times, sophisticated force modelling is required. This must include the predominant sail and hydrodynamic forces but also the effect of perturbations caused by the naturally varying wind and wave environment as well as the motions of the sailor. For the purpose of this research, the race strategy and ranking are related to the forecasted and measured weather data without the addition of a VPP, as it was possible to retrieve boat speed and heading data from the tracking used during each race.

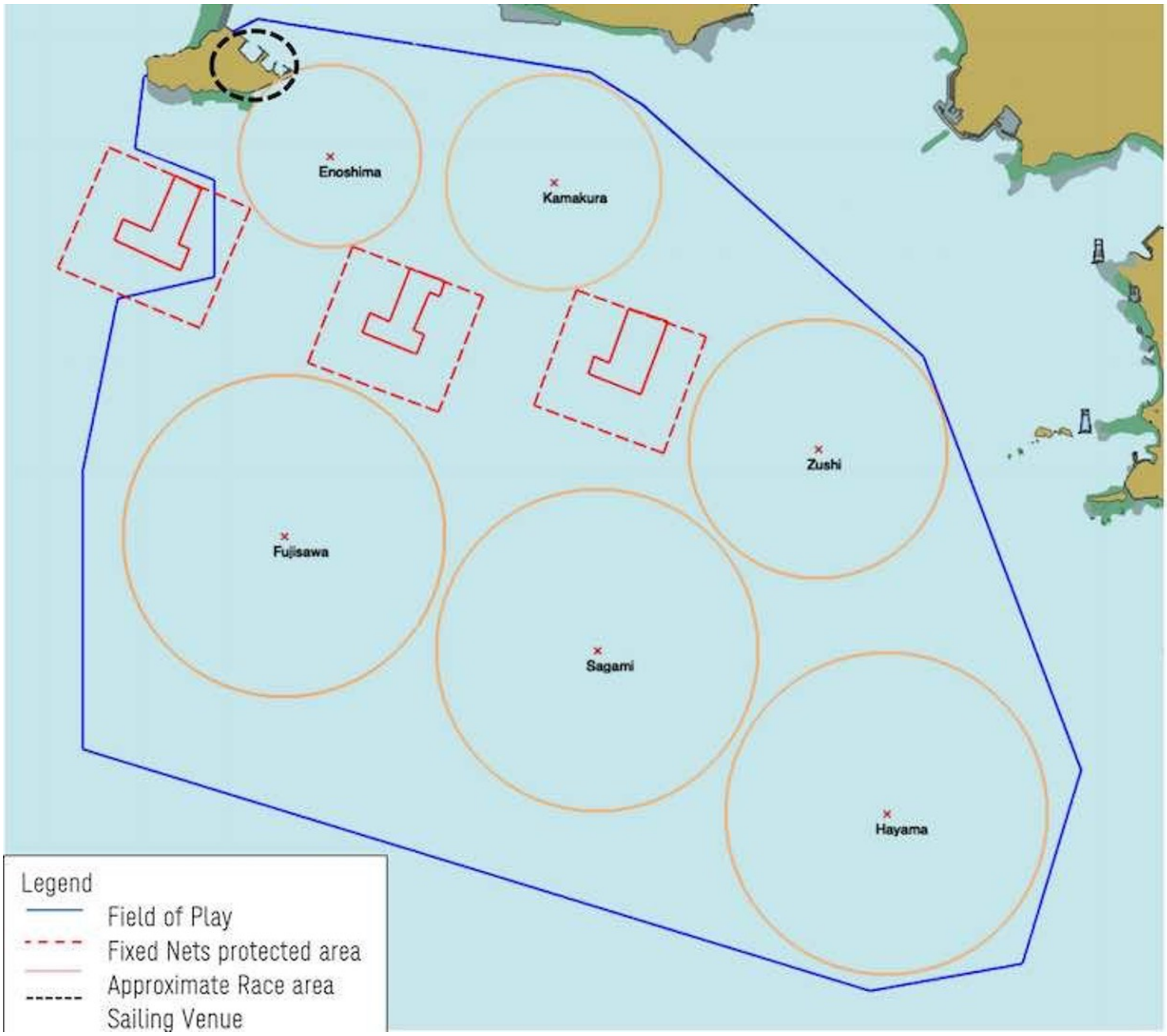

Figure 1. Competition area Tokyo 2020 Olympics race area identification location (World Sailing, 2021).

The courses at the Olympics varied in length and in number of laps, but they all had some common features, such as the start and at least two upwind and two downwind legs. The upwind point of sail is determined as the tack close to the wind direction. The closest angle to the wind of each class varies, but all classes feature a series of tacking manoeuvres to reach the first windward mark in a zig-zag-like fashion. The downwind point of sail is orientated away from the wind direction, with angles off the wind of approximately 120 to 180 degrees. The strategy of the race can be well set-up during the pre-start time and the first upwind leg, when the top sailors will place themselves ahead of the rest of the fleet. Depending on the class and boats speed and the skills of the sailors, some overtakes can happen during the downwind legs and the second upwind.

To have a better strategical analysis, that it is strongly affected by the weather situation, a Decision Support System (DSS), based on the climatic analysis of the race areas, was developed in the years 2017-2020 (Masino et al., 2021). The DSS is an innovative system that can confer a valuable advantage to the sailors who use it for two main reasons. Firstly, the use of a limited scale meteorological model in hindcasting compensates for the lack of continuous measurements at sea, providing a distributed analysis of wind fields (Pezzoli & Bellasio, 2014). Secondly, this system is capable of machine learning from errors, and it can easily be amended and updated as new measurements are made. In this paper a deeper reanalysis of the DSS during the sailing races of the Tokyo 2020 Olympic Games is developed considering both the methodology to develop this tool, based on weather pattern recognition's method, and the results obtained as described by Masino et al. (2021). It is important to note that the DSS was effectively used to forecast the weather conditions in the Enoshima Bay and to analyse the different strategical plans that the sailors could use during the race, with particular focus on the first upwind strategy.

2 MATERIAL AND METHODS: THE DECISION SUPPORT SYSTEM, A TOOL FOR THE WEATHER AND STRATEGIC FORECAST

Olympic sailing consists of ten classes, comprising a total of 15 sailor positions/functions of which 5 involve helming and hiking, 3 involve helming and trapezing, 5 involve crewing and trapezing and 2 involve board sailors. The classes are divided in traditional boats, i.e. Laser, Laser Radial, 470 Men, 470 Women, Finn, and high-performance boats or boards, i.e. NACRA 17, 49er, 49er FX, RS:X Men and RS:X Women. The traditional boats during Tokyo 2020 have raced 10 races plus the double-point "medal race" and the high-performance ones have raced 12 races plus a double-point "medal race". During the Olympics the races are all considered "fleet races" with the medal race only containing the top 10 placed boats after the qualifying series.

The main component of the DSS is the "call book", a simple and effective guide designed to help athletes and coaches in the preparation of race strategies. The guide summarizes the meteorological data of the six race fields in tables, plots, and cartographic representations with brief descriptions to be easily understood and quickly consulted both inshore in the months prior to the Olympics and at the venue when training or between races. These kind of communication tools have been developed by Houghton and Campbell (2006). The guide includes the wind-roses produced on the competition fields by means of Windrose PRO3 software and reports all the wind patterns identified during the analysis. For each race area, a typical day between the 24th of July and the 9th of August, was reconstructed with hourly data from 09:00LT to 18:00LT, a typical time interval in which the competitions take place, and represented by the wind maps employing QGIS software. It was then possible to identify the six main weather patterns (Table 1), recognized and identified by the gradient wind measured in the race area by the Wind Profiler system provided by the Japan Meteorological Agency (2021). From Table 1 it is possible to see that sea breeze weather pattern (WP1) could occur both as a fully developed sea breeze, when the gradient wind is light to medium in strength, and as a non fully developed sea breeze, either when the gradient wind is extremely light, in a range of 0-4 knots, or when the gradient wind is of medium strength, in a range of 9-12 knots. Overall the sea breeze weather pattern comprises of the highest frequency (40.6%) comparing the historical data, however, it was only present twice in the Olympic period, as later shown in Table 5.

Table 1. Weather patterns that characterise Enoshima Bay.

Weather Pattern	Name	Gradient wind direction	Gradient wind speed [kts]	Wind direction local shift (9-12-15-18) [°]	Wind speed range [kts]	Air pressure [hPa]	Air temperature [C°]	Frequency	Date
1A-1B-1C	Pure sea breeze fully developed	NW-E	3-9	$80 \rightarrow 165 \rightarrow 185 \rightarrow 170$	3-10	$1005 \rightarrow\leftarrow$	26-30	40.6%	07/08/13
	Pure sea breeze **not** fully developed		0-4 9-12						09/08/12 24/07/18
2	S-SW light with sea breeze effect	S-SW	1-9	$225 \rightarrow 185 \rightarrow 195 \rightarrow 200$	5-15	1008↓	26-30	31.8%	27/07/16
3	SW moderate with sea rotation to N	SW	9-14	$200 \rightarrow 180 \rightarrow 200 \rightarrow 360$	3-12	$1010 \rightarrow\leftarrow$	26-30	5.6%	25/07/10
4	E-NE moderate	E-NE	12-18	$40 \rightarrow 55 \rightarrow 80 \rightarrow 90$	7-10	$1005 \rightarrow\leftarrow\downarrow$	24-32	8.2%	31/07/11
5	SW moderate	S-SW	10-15	$225 \rightarrow 195 \rightarrow 200 \rightarrow 205$	10-20	1012→1008	26-32	10.2%	28/07/10
	SW strong		16-25						
6	S very strong	S-SSW	26-38	$210 \rightarrow 195 \rightarrow 200 \rightarrow 180$	10-25	1005↓	24-28	0.6%	29/07/10

Finally, for each weather pattern, a table containing the main meteorological and strategical characteristics was prepared and provided to coaches and athletes to be used during the Tokyo 2020 races. An example of this table is provided for the “Weather Pattern 1C – Sea Breeze with E gradient wind” (Table 2), “Weather Pattern 2 – S-SW light gradient wind with sea breeze effect” (Table 3) and “Weather Pattern 4 – NE-E moderate gradient wind” (Table 4).

The analysis of the weather data recorded during the races, runs along the whole race time, considering all the legs and comparing the results with the forecasted solutions. The wind data available from the SAP Sailing Analytics (2021) was measured every second.

Table 2. Description of the meteorological and strategical rules for the “Weather Pattern 1C – Sea Breeze with E gradient wind”.

Gradient wind (1000m)	NE-E/3-4kts
Wind direction (maximum left)	160-170 (in the end of the day)
Wind direction (maximum right)	185-195 (around 13.00LT)
Wind speed (minimum) [kts]	5-6 (around 12.00LT)
Wind speed (maximum)[kts]	11-12 (end of the day around 17.00-18.00LT)
Shift	Excluded for Hayama, after the FIRST SHIFT (BACKING if the wind direction will be more right than the 180-190 or VEERING if the wind direction will be more left than 180-190), expected around 12.00LT, the wind will VEERING to reach the maximum right (expected around 13.00LT) then it will BACKING. In Hayama the wind will BACKING for all day. OBSERVATION 1: during the VEERING and the BACKING the wind will be OSCILLATING (in the start period of the sea breeze around 12.00LT: period around 5’-10’ with angle between 002°-005° ; after that the wind speed will be above 7-8kts: the oscillations will be bigger in period, 10’-15’, and in angle around 005°-008°, max. 010°) OBSERVATION 2: the only way to understand when the wind will BACKING, it is to see when you reach the maximum right. At this time you have to stay careful to the possible BACKING. This it is because, in the afternoon, during the increasing of the wind speed you will have the VEERING but,also during the BACKING you have increasing of the wind speed.
Wind’s pressure	Always from left
Wave - Swell	SSW wind-wave and SW swell
Air temperature (Ta) & Sea Temperature (Ts)	Ta=26 $\doteq$ 30°C (increasing) Ts=25 $\doteq$ 26°C (min. 23°C ; max. 28°C)
Atmospheric pressure	Steady pressure
Sky and Clouds	Clear with bad visibility in the morning then Cu steady inland
Occurrence’s frequencies	40,6% (together with WP1$_A$ and WP1$_B$)

Table 3. Description of the meteorological and strategical rules for the “Weather Pattern 2 – S-SW light gradient wind with sea breeze effect”.

Gradient wind (1000m)	S-SW/1-9kts
Wind direction (maximum left)	160-170 (with lowest wind speed included between 5-7kts) 170-180 (with lowest wind speed included between 7-9kts)
Wind direction (maximum right)	220-230
Wind speed (minimum) [kts]	5-6 (around 12.00LT) A significant measure of the lowest wind speed will be around 12.00LT
Wind speed (maximum)[kts]	11-13
Shift	LEFT trend until 12.00 - 13.00LT then RIGHT trend in OSCILLATING wind (long oscillations, more or less 10’-20’ as the persistent shifts, with big angle included between 020°-040°. It will be very difficult to found an average direction due to the long period of the oscillations). OBSERVATION for the OSCILLATIONS: Danger!!! It is very difficult to know the period of the oscillations, so it is very difficult to be well positioned in function of the oscillations. We don’t have any “secondary” OSCILLATIONS that they can help us to return if we stay in the wrong side.
Wind’s pressure	Zushi better pressure in left hand side; Sagami possible better in left hand side (it depends of the strength of the wind speed); in other race area better in middle right but, sometimes, the pressure follow the shift.
Wave - Swell	SW
Air temperature (Ta) & Sea Temperature (Ts)	Ta=26 $\doteq$ 30°C (increasing) Ts=25 $\doteq$ 26°C (min. 23°C ; max. 28°C)
Atmospheric pressure	Decreasing
Sky and Clouds	Partially cloudy with milky sky and bad visibility, Sc and Cu clouds in race area.
Occurrence’s frequencies	31.8%

Table 4. Description of the meteorological and strategical rules for the “Weather Pattern 4 – NE-E moderate gradient wind”.

Gradient wind (1000m)	SE-NE/12-18kts
Wind direction (maximum left)	5-15
Wind direction (maximum right)	80-90
Wind speed (minimum) [kts]	6-7
Wind speed (maximum)[kts]	12-13
Shift	OSCILLATING wind (in the early morning: random “main” OSCILLATIONS included between 15’-30’ for 020°-040° superimposed a the “secondary” OSCILLATIONS included between 2’-3’ for 005°-010°; in late morning – early afternoon: long oscillations, more or less 15’-30’ as the persistent shifts, with big angle included between 020°-040°. It will be very difficult to found an average direction due to the long period of the oscillations) with some TRENDS. Rule for TRENDS: **Early morning when Ta < Ts** Increasing wind speed = left trend Decreasing wind speed = right trend Decreasing wind speed = right trend **Late morning – early afternoon when Ta > Ts** Increasing wind speed = right trend Decreasing wind speed = left trend
Wind’s pressure	Topographically affected. Off-shore race area: play with the shift of the oscillations (in 80% of the time, the wind’s pressure follows the shift). In-shore race area: wind’s pressure will prevail on the shift of the oscillations. The good side is also affected by the swell and rip currents in case of swell!
Wave - Swell	Wind-wave from NE, possible swell from SW
Air temperature (Ta) & Sea Temperature (Ts)	Ta=24 ≐ 32°C (increasing) Ts=25 ≐ 26°C (min. 23°C ; max. 28°C)
Atmospheric pressure	Decreasing (tropical depression located in the Pacific Ocean, close and East of the centre of Japan or TS-TY moving to the South of Japan close to Sagami Bay). Steady-Increasing (low pressure positioned in the centre of Pacific Ocean moving towards East)
Sky and Clouds	Partially cloudy possible Ac moving from NE to SW and St steady.
Occurrence’s frequencies	8.2%

The SAP on-the-water measured data during the Olympics races was used to reanalyse the DSS (“Call Book”) (SAP Sailing Analytics, 2021). An example of weather data as measured by SAP Sailing Analytics can be seen in Figure 2. From to the wind measurements shown, it is possible to see a shift of wind direction in the second upwind section of the race. Thoroughly analysing the datapoints is therefore possible to link the top boats’ strategy with the wind shifts in direction and in intensity.

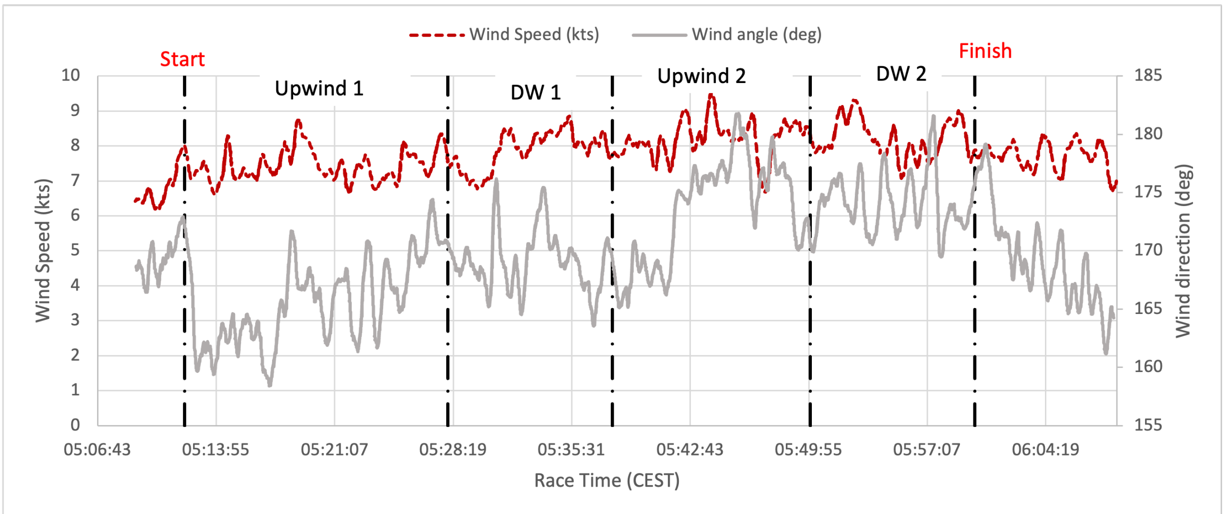

Figure 2. Race 9 Laser Radial example of wind speed and direction as measured on the race area.

From the same race shown in Figure 2, it is possible to see the first upwind strategy of some highlighted boats in Figure 3.

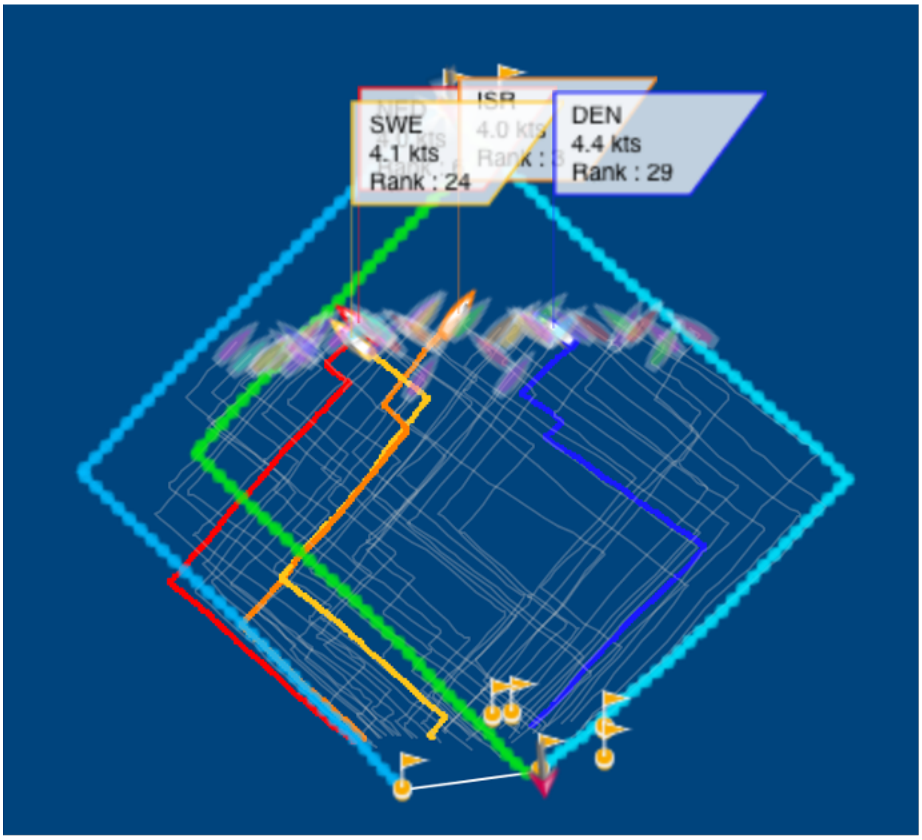

Figure 3. Race 9 Laser Radial example of strategy for the target boats. The first upwind track is shown, with the target selected boats being NED in red, SWE in yellow, DEN in blue and ISR in orange. The green track shown represents the ideal strategy with the wind rotating left from an average of $162°$ at the start of the race toward $170°$ in the latter part of the first upwind. The cyan and azure dotted lines represent the two corners of the upwind race area if a boat was to sail all the way to each side of the course and perform only one tack to get to the first windward mark.

Considering that the strategy on a race course is normally set for the first upwind and the second upwind can rely more on tactical decisions and positioning compared to other boats, let us analyse more in detail the first upwind wind direction encountered during Race 3 of the Laser Radial on the 26^{th} of July, present also in the re-analysis Section 3.1.

From SAP Analytics, a range of different wind sensors are used on each race area. Selecting and analysing different wind sensor locations around the race area, it is possible to investigate phase shifts and local oscillations. In Figure 4 a wind sensor at the windward mark and one further to windward of the windward mark are selected. From the Figure, it is possible to see how the oscillations are trending toward the same wind direction and don't present a phase shift between them.

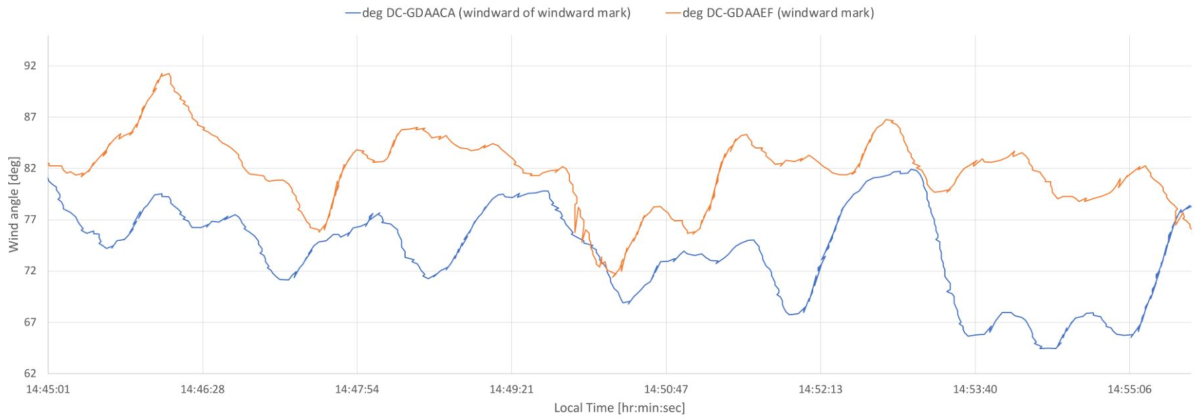

Figure 4. Race 3 Laser Radial wind sensors recorded direction at the windward mark and to windward of the windward mark.

Furthermore, between 14:49:30 and 14:52:30 Local Time, there is a clear right shift up to 5 degrees, with a shift back to the left around 14:53:00. This is reflected in the first upwind strategy of the top boats, see Figure 5. Considering a short lag of wind pattern between when recorded at the windward mark and when flowing through the race area, it is clear that the three selected boats are sailing a right shift when the SWE boat tacked and NOR and ITA are lifted into a better angle to the wind, all three boats then tack back onto port, when the wind shifts left again closer to the windward mark.

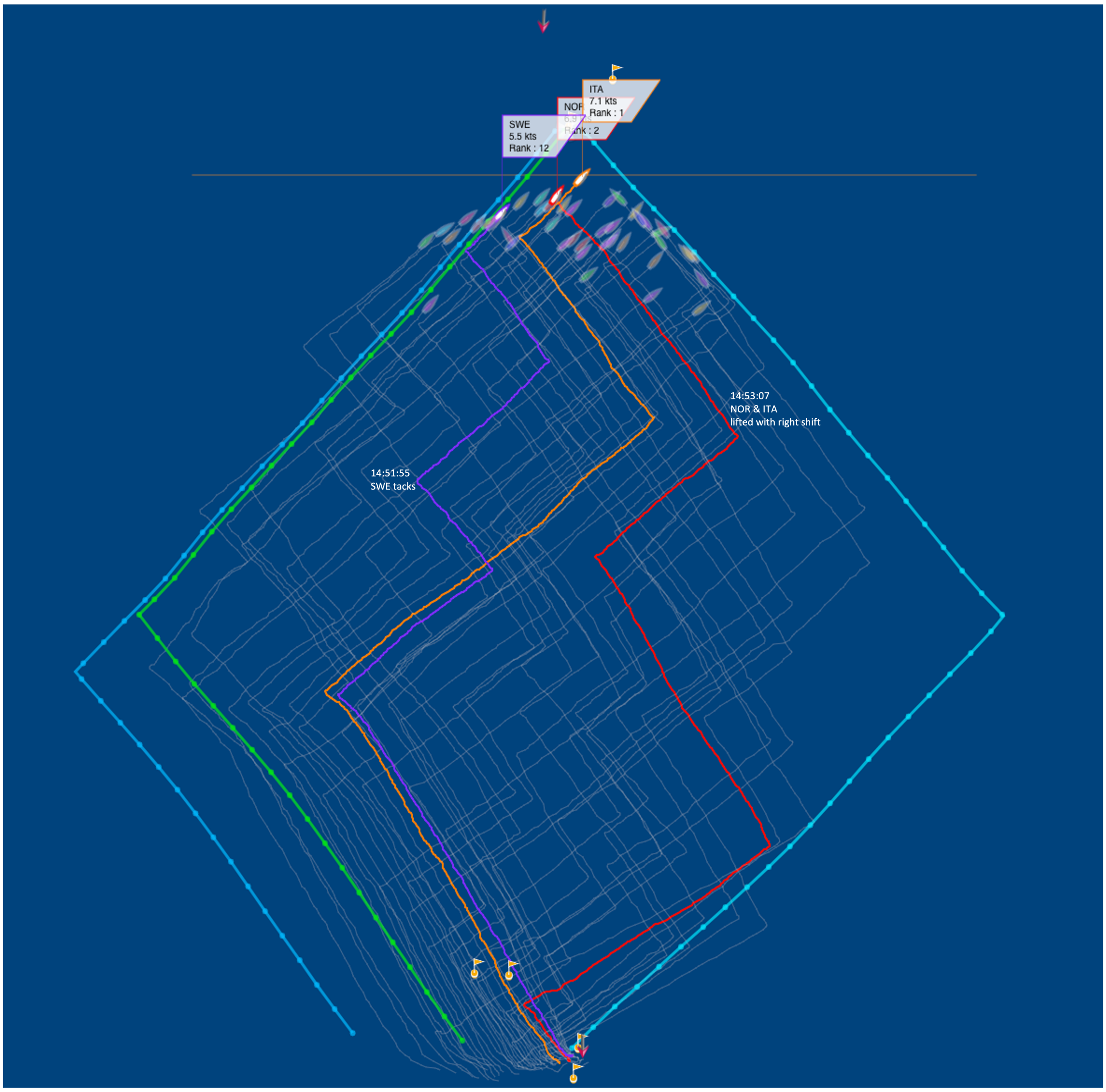

Figure 5. First upwind Race 3 Laser Radial, strategy of three selected boats.

3 RESULTS AND DISCUSSION: STATISTICAL ANALYSIS OF RACE AREAS

During the Olympic period among the two investigated courses, a range between 4 and 12 wind stations were used to record the wind speed and direction in each course and race. The ”Call Book” as well as the daily forecast are taken into consideration for the statistical analysis. The daily forecast would be based on the ”Call Book” with further daily refinements, and two types of forecast will be given with a different confidence level and probability of occurrence. Figure 6 and Figure 7 are created with data collected from (SAP Sailing Analytics, 2021) and compared to the daily forecast. The figures present polar plots of occurrence frequency for the two investigated race areas. For the analysed races, a total of 6169 measurement points were used for the Enoshima polar plot and 6468 measurement points for the Zushi plot. Both figures take into consideration the number of data points that are matching with any of the forecast alternatives for a day of racing during the Olympic period, for instance in the Enoshima race area, only 2537 measurement points were matching with the forecast direction comprised between $0°$ and $360°$. The frequency, shown as a heat map, represents the number of measurement points that match with a forecasted angle, for example in Enoshima we see that there are 85 matches at $80°$. The probability of occurrence instead, shown in the radial direction, represents the number of points matching with a forecast over the number of measured points. During the Olympic period, it is possible to see that the prevailing wind direction in Zushi ranges between south-east and south-west showing most of the occurrence happening between 150 and 200 degrees. This is well represented in Enoshima race area too, where some matching data are also found from the westerly wind direction, showing a large influence of the Enoshima peninsula, just west of the race area.

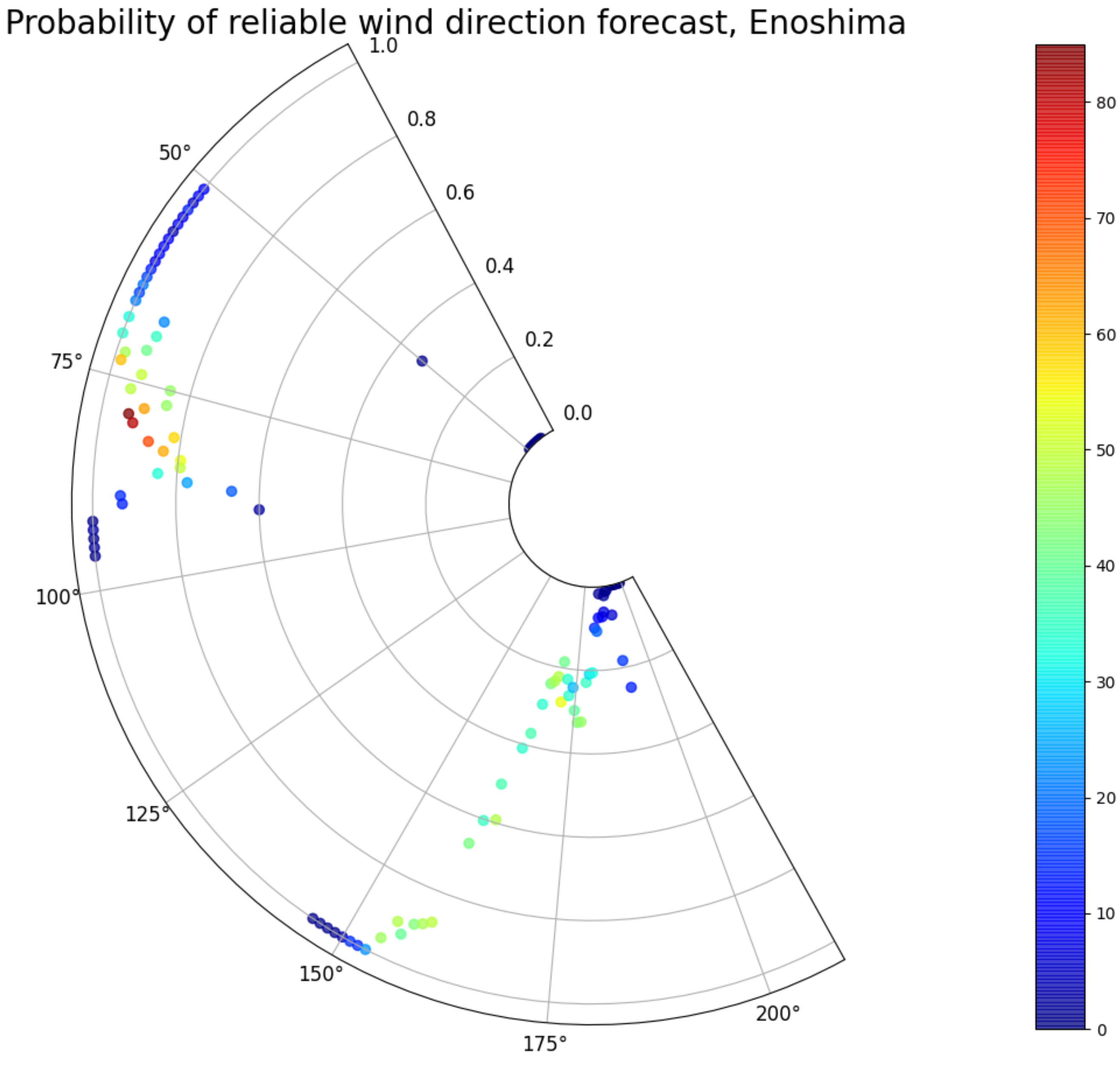

Figure 6. Enoshima race area occurrence frequency polar plot. The maximum probability of occurrence is in the radial and the wind direction is plotted in the polar diagram. The frequency of occurrence is shown as heat map.

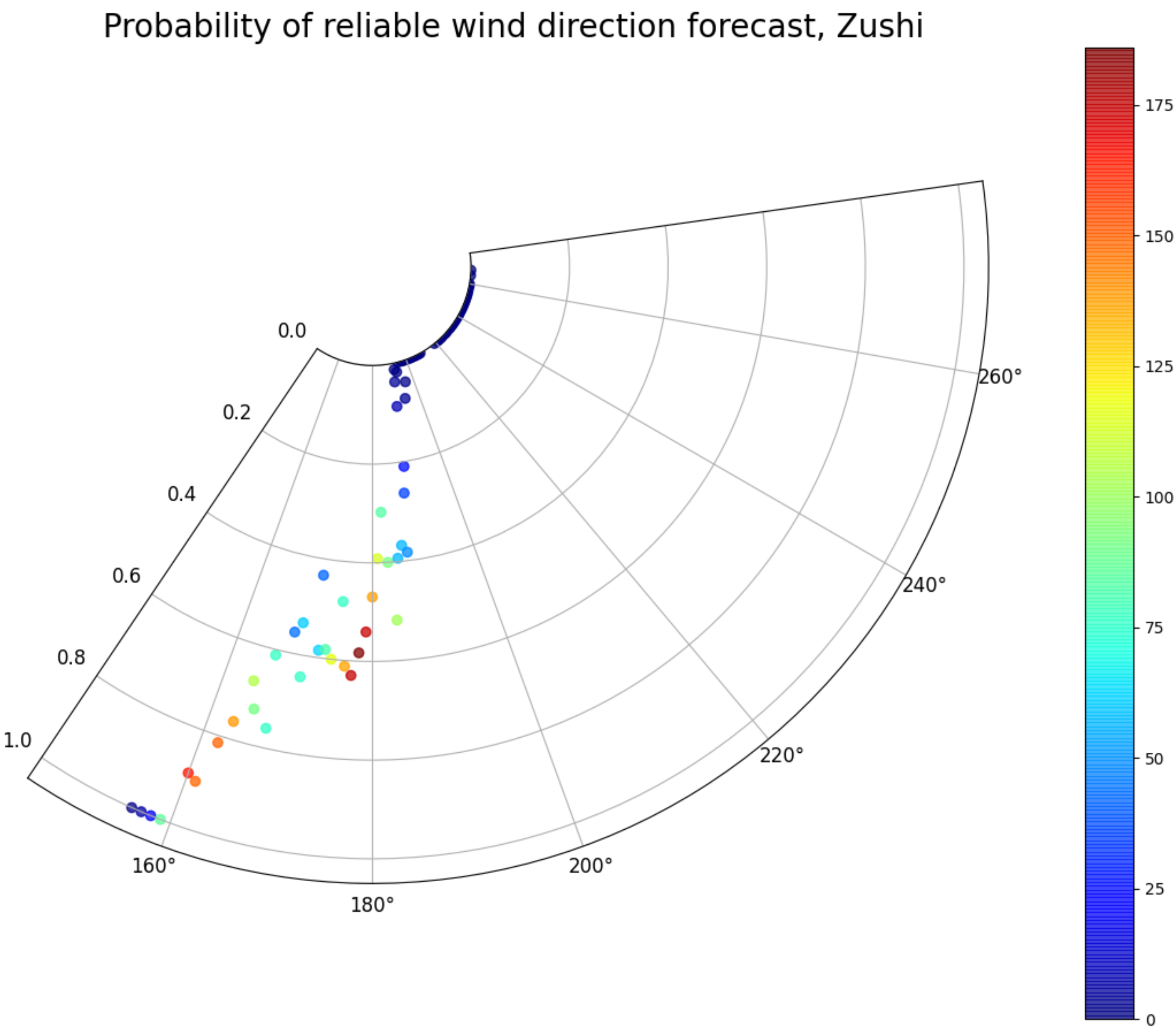

Figure 7. Zushi race area occurrence frequency polar plot. The maximum probability of occurrence is in the radial direction and the wind direction is plotted in the polar diagram. The frequency of occurrence is shown as heat map.

From this analysis it was confirmed that the prevailing Weather Patterns were WP1C, WP2 and WP5 (see Table 1). This is highlighted a posteriori in Table 5 where, for each Olympic day, the Weather Pattern that occurred was identified by the measured gradient wind from the Wind Profile system of the Japan Meteorological Agency. In the presented research, the DSS ("Call Book") was analysed and compared to the information provided to the coaches and athletes with the measured data from the SAP system. This comparison was developed using a meta-communication comparison where the strategical information summarized in Table 2, Table 3 and Table 4 (i.e.: shift and wind pressure) was compared with the real situation that occurred during the races and therefore the best strategy to follow to win the races.

Table 5. Description of the Weather Patterns characterising each day of Olympic sailing Races. Green highlights the days where the DSS were re-analysed and the measured data from the SAP system were compared with the "Call Book".

Day	Weather pattern
25/07/2021	WP4 shift to WP1C
26/07/2021	WP4
27/07/2021	WP3 reverse shift
28/07/2021	WP5
29/07/2021	WP5
30/07/2021	WP2
31/07/2021	WP1C
01/08/2021	WP2
02/08/2021	WP1 sea breeze not fully developed
03/08/2021	WP2
04/08/2021	WP2

3.1 Reanalysis of Weather Pattern 4 (26/07/2021)

Early in the Olympic series, the second and third races of the Laser Standard class as well as the third race of the Laser Radial were picked for reanalysis. Those races were sailed on the Enoshima race area. Table 6 shows the characteristics of the weather pattern described in the "Call Book", compared to the SAP measurement data. There were three strategic key factors in these four races: the main oscillation, the secondary oscillation and the left trend in the decreasing wind speed that happened later in the day when the RSX men were racing. A fleet race in the Laser Radial and Laser Standard classes, as well as other traditional boats like the 470 and Finn, has a target time of approximately 50 minutes to 1 hour, giving more time for the oscillations to play a larger role in the race strategy. The main oscillation was 30 minutes long, which means the time between the maximum left and the maximum right shift is 15 minutes, where an upwind leg in the Laser Class is approximately 12 minutes long. A wind shift through the main oscillation occurs very suddenly, and then stays at that direction for half the period. This means that if the main oscillation shifts just before the leg starts, the secondary oscillation, which is significantly shorter, is the key factor in the next leg of the course. If the main oscillation doesn't occur just before the next leg starts, the side of the race area to which the next shift of the main oscillation is expected would be favorable.

During the day a right trend was forecast in increasing breeze. As seen in Figure 8 it is possible to see that there is a right trend throughout the day, with a wind increase between 12:00 and 15:00. The average wind direction corresponds to $75.2°$, $72.1°$ and $81.3°$ for the three first upwind legs of the three investigated races respectively.

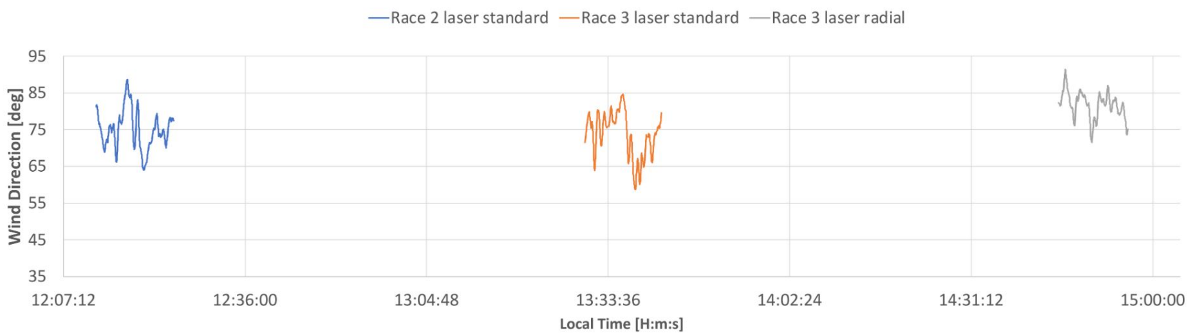

Figure 8. First upwind wind direction for Race 1, Race 2 of Laser Standard and Race 3 of Laser Radial classes.

The third key factor was the left trend with the decreasing wind speed as an indicator. In that case the left side of the race area was favorable, and indeed an average wind direction in the RSX men first upwind of race 5 is recorded as $47°$.

Table 6. Comparison between "Call Book" and data measured by SAP system.

Parameter	Call Book	SAP Data
Wind direction	5°-90°	76°-78° → left trend in the afternoon 65°-55°
Wind speed	6-13kn	11-17kn → decreasing to 6-13kn in the afternoon.
Main Oscillation	15-30 minute period with and angle of 20°-40°	30 minute period with an angle of 10°-20°
Secondary Oscillation	2-3 minutes period with an angle of 5°-10°	2-5 minutes period with an angle of 3°-10°
Trend	**Early morning:** Increasing with speed → left trend Decreasing with speed → right trend **Early afternoon:** Increasing wind speed → right trend Decreasing wind speed → left trend	Left trend with the decreasing wind speed.

As highlighted in Section 3, the daily forecast provided to the coaches and athletes is presented with an associated qualitative confidence level and is divided in two parts with a different percentage of confidence. Commonly, especially if the gradient wind is prevailing, one of the two forecast will result in a higher confidence. In the case of the 26th of July 2022, the forecast had a preferred option.

Figure 9 shows visually the differences between the forecast that had a 70% confidence, shown with a blue range, the secondary forecast, shown with a orange range, as well as the measured data from the Laser Radial race 3 with wind measured data presented as the combination of all wind sensors across the race area, shown in green. Most measured data lie within the preferred forecast; however, it is possible to see how some gusts with higher wind speeds are not captured by the forecast model, which was predicting for lower wind speed. A possible reason of the underestimation of the weather forecast in the wind speed range can be linked with the thermal enhancement found during the races in the early afternoon of the 26th of July.

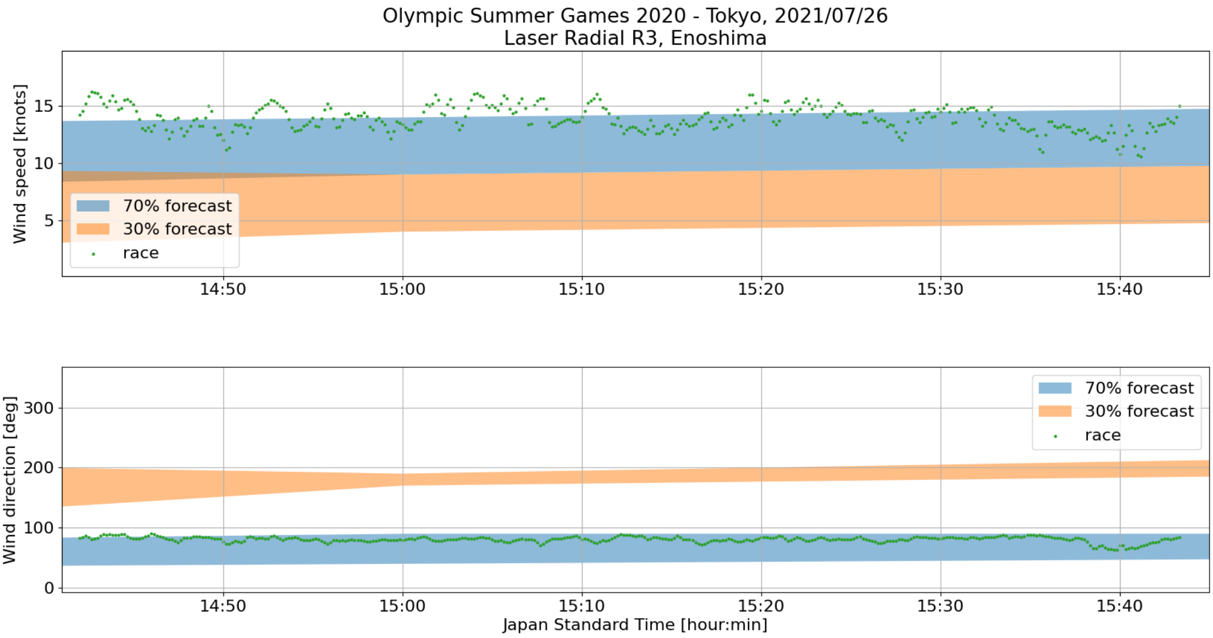

Figure 9. Visual comparison of predicted wind speed and direction with primary forecast with 70% confidence in blue and secondary forecast with 30% confidence in orange compared to measured data - green markers – for race 3 of the Laser Radial class. The measured data are averaged over 10 seconds and represent all the wind sensors present in the race area.

3.2 Reanalysis of Weather Pattern 1C (31/07/2021)

The RSX Women and Men Medal Races were selected for the reanalysis of Weather Pattern 1C. These races were sailed on the Enoshima race area. Table 7 shows the characteristics of the weather pattern described in the call book (see Table 2), compared with the SAP measurement data collected during the Medal races of RSX Women and Men:

Table 7. Comparison between "Call Book" and data measured by SAP system.

Parameter	Call Book	SAP Data
Wind direction	160°-195°	232° trending to the left 197°
Wind speed	5-12kn	5-7kn increasing to 8-10kn
Main Oscillation	In the developing Phase of the Sea Breeze: 5-10 minute period with an angle of 2°-5° When the wind speed will be above 7-8kn: 10-15 minute period with an angle of 5°-8°	2-5 minutes period with an angle of 3°-5°
Secondary Oscillation	No secondary oscillation	No secondary oscillation
Trend	**Left trend** if the wind directions is further right then 180°-190°, **right trend** if the wind directions is further left then 180°-190°.	After the maximum right of 238° was reached there was a left trend for the rest of the day.

From a strategic point of view, it is possible to note that the upwind leg in the RSX is only 6 minutes long and the downwind leg only 3 minutes, which means even though the oscillation has a very short period, only 1-3 small shifts per leg are possible. The top five ranked boards in both races had very different strategies, leading to the conclusion that the shifts per leg were too small to gain a real strategic advantage. During the RSX Men Medal Race a series of unforced errors from the start, with three top ranked teams being called over the line "On Course Side" (OCS), also affected the overall classification, making the reanalysis difficult when compared to the final ranking.

3.3 Reanalysis Weather Pattern 2 (01/08/2021)

On the 1st of August, the reanalysis of the Races 10, 11 and 12 of the NACRA 17 class were chosen, as well as the Medal Races of the Laser Radial and Laser Standard classes. All races were sailed on the Enoshima race area. Table 8 shows the characteristics of the weather pattern described in the call book, compared with the SAP measurement data:

Table 8. Comparison between "Call Book" and data measured by SAP system.

Parameter	Call Book	SAP Data
Wind direction	170°-230°	152°-178°
Wind speed	5-13kn	9-11kn
Main Oscillation	10-20 minutes period with an angle included between 20°-40°	random and small in the first part of the day Increases throughout the day 1 hour period with an angle of 10°-20°.
Secondary Oscillation	No secondary oscillation	No secondary oscillation
Trend	**Left trend** until 12:00-13:00, after that there will be a right trend.	Left trend at the beginning of the day. Right trend starts at 14:00.

A common factor in all the races is that there was one significant shift per race from which the sailors could gain a strategic advantage. In the NACRA 17 Class, where the first race started at 12:05, this significant shift was caused by a left trend as predicted in the call book. In the second and third races of the NACRA 17 Class, a small oscillation over a 30-minute period and 5° angle was measured. Normally a race in the NACRA 17 class has a target time of approximately 30 minutes. Having such a short target time, in a scenario as the one presented by WP2 where the main oscillations have long periods, only one significant shift would happen per race. When just a 5° angle change is measured over the entire race time, the sailors are not able to gain much advantage from the oscillation due to its slow development and small range.

In the afternoon the Laser Radial and Laser Standard classes sailed their Medal Races. In both races there was one significant oscillation to the right caused by an oscillation that took twice as long as the Medal Race, set with a target time of 20 minutes. It is interesting to note how, in terms of Velocity Made Good (VMG), the oscillations can have the effect of "persistent shift" for long races with a target time of 50 minutes to 1 hour, such as fleet racing for the Laser and Laser Radial classes, or can be negligible for the shorter races, such as Medal Races or RSX and NACRA fleet races. In a weather pattern similar to WP2, the tactical aspect of sail racing will emerge more compared to the strategical approach, especially for the high performance classes with short target times.

4 CONCLUSIONS

There are four factors that a sailor must consider during a race to win: the strategy, the tactics, the boat speed and boat handling which can be weighted differently in each weather pattern. The current research investigated the impact of weather forecast and a priori knowledge on the race strategy, with focus on the first upwind legs. As investigated in the reanalysis, the length and magnitude of oscillations in wind direction and wind strength, will vary accordingly to which type of class and target race time is sailed. If a sailor knows the weather pattern of the race day beforehand, it will count as an advantage to their pre-race strategy. This advantage gives the sailor a clear focus on one the of the key factors of any race day so that they have a better understanding on how to approach the race course and more specifically the first upwind leg. In case where there is no strategic advantage to be gained, the sailor can focus more on the tactics, boat speed and boat handling. As the build up of the "Call Book" was developed along three years, and in this span of time a similar reanalysis of weather patterns could be performed against data measured during races that occurred on the Olympic venue (e.g. World Cup Enoshima, Olympic Test Event, etc.), it was possible to establish a level of confidence both quantitatively on the DSS, and also on perceived knowledge gained by the athletes and coaches. Associating the daily forecast to the "Call Book" and stating the different confidence levels, allows the sailors and their coaches to better prepare for different types of race day. The local geological features, sea and land temperature, location of specific race areas, tides and currents all play a role in the winning strategy of a sailing race. The collaboration within the Swedish Sailing Team allowed the constant update and analysis of the forecasted models to learn for the race areas where most likely the medals were played. Using the Decision Support System in conjunction with the available SAP measures allowed a thorough investigation of each race in the Olympic period. Finally, this research confirmed how the data analysis and a methodology based on the "recognition pattern" (Nayak & Ghosh, 2013; Vaghefi et al., 2017), used for the first time in the application for the Sailing Sports (Masino et al., 2021) can be an added values for the Sailing Team.

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