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Wind turbine influence on surfers wind conditions at Hanstholm

Larsen, Torben J.; Andersen, Søren Juhl

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Torben J. Larsen, Søren J. Andersen

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Authors: Torben J. Larsen, Søren J. AndersenTorben J. Larsen, Søren J. Andersen

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In this report a consequence study regarding the surfers wind conditions east of the Hanstholm harbour area. Four existing turbines with a nominal power of 525kW is planned replaced with three new 4.3MW turbines near the beach are. It is investigated whether these wind turbines could potentially alter the wind conditions on the lee side, which is an important area for wind and kite surfers.

The Dynamic Wake Meander Model is used to investigate the wind conditions north east of the planned new turbines at Hanstholm covering a surf area from a location called “Fish Factory” to a location called “Hamborg”. This model, which predicts instationary wind conditions behind one or more wind turbines, has previously been used to predict the changed power and load conditions for wind turbines in wind farm conditions. Avery fine agreement to measurements is seen and the model is therefore considered sufficient for this particular study also. Furthermore a more advanced flow solver has been used to give a qualitative understanding of the flow conditions near the existing and new turbines.

In general the impact of the new windturbines are very limited and the same order of magnitude as the existing smaller turbines. The reason is that the new turbines mainly disturbs the wind conditions from 30m and upwards.

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Danmarks Tekniske Universitet
DTU Vindenergi
Nils Koppels Allé
Bygning 403
2800 Kgs. Lyngby
Phone

www.vindenergi.dtu.dk

Preface

This report includes a study of the influence three new planned turbines near Hansthold harbour have on the surf area east of the Hanstholm harbour. At present, there are four turbines located near the beach area with a nominal power of 525kW, a rotor diameter of 41m and a hubheight of 40m. These are planned decomissioned and replaced by four new 3.4MW turbine with a diameter of 126m and a hub height of 90m. The study is carried out using simulation models normally used for detailed consequence analysis of power and loading of wind turbines in wind turbine parks and is expected to be sufficient to quantify the effect in height of 10m above terrain, relavant for wind and kitesurfers.

This work is conducted based on request by Planenergi, Århus.

Roskilde, March 2017

Torben J. Larsen
Senior scientist

Content

Summary

In this report a consequence study regarding the surfers wind conditions east of the Hanstholm harbour area. Four existing turbines with a nominal power of 525kW is planned replaced with three new 4.3MW turbines near the beach are. It is investigated whether these wind turbines could potentially alter the wind conditions on the lee side, which is an important area for wind and kite surfers.

The Dynamic Wake Meander Model is used to investigate the wind conditions north east of the planned new turbines at Hanstholm covering a surf area from a location called “Fish Factory” to a location called “Hamborg”. This model, which predicts instationary wind conditions behind one or more wind turbines, has previously been used to predict the changed power and load conditions for wind turbines in wind farm conditions. Avery fine agreement to measurements is seen and the model is therefore considered sufficient for this particular study also. Furthermore, a more advanced flow solver has been used to give a qualitative understanding of the flow conditions near the existing and new turbines.

In general the impact of the new windturbines are very limited and the same order of magnitude as the existing smaller turbines. The reason is that the new turbines mainly disturbs the wind conditions from 30m and upwards

The largest impact is seen to be when the wind is directly from west causing a wind speed reduction of 0.5m/s and and increase in turbulence intensity from 6% to 9%. However, this is the same level of disturbance seen from the present turbines. The impact of the new turbines is therefore expected to be similar in magnitude to the existing turbines from 2-8m/s, but with a larger affected area.

For wind speeds above 8m/s the impact from the new wind turbines is less with the new turbines than for the old turbines. The reason is expected to be from the different control strategy of the old versus new wind turbines. The old turbine are based on a strategy called stall-control, whereas the new turbines uses pitch-control. With Pitch-control the relative thrust force of the rotor is smaller than for stall-control which leads to a smaller wind speed deficit, that again causes a smaller impact.

In short, the conclusion is:

- The impact on surf area from the wake of the new turbines is with respect to wind speed reduction and increased turbulence level similar to the impact from the existing turbines.
- The impacted area is larger for the new wind turbines than for the existing smaller turbines.
- The wake affected ares starts further away from the new turbines (+300m), whereas the impact from the old turbines was closer to the old turbine (+100m).
- At wind speed around 8m/s, measured at 8m height, the wind speed reduction is in the size of 0.5m/s and the turbulence intensity increase from 6% to 8%.
- At wind speeds above 8m/s, measured at 10m height, the turbines start to limit the power output as the wind speed at 90m height is above rated wind speed. This further minimizes the wake impact from the turbines. At these wind speed, the impact is smaller for the new turbines than for the existing turbines.

Konklusion

Denne rapport beskriver en undersøgelse af påvirkningen af vindmøller for et område øst for Hanstholm havn. Der er nu opstillet 4 møller med en nominal effekt på 525kW som planlægges erstattet med 3 nye 4.3MW møller tæt ved stranden. Denne undersøgelse går på om de nye vindmøller vil ændre på vind forholdene da området er unikt mht wind og kite surfing.

Til brug for undersøgelsen er anvendt en model med navn Dynamic Wake Meander (DWM). Denne model beskriver den instationære vindfelt bag en eller flere vindmøller og har tidligere været benyttet til at se på effekterne af vindmøllers effekt og lastniveauer i vindmølle parker. Grundet en meget overbevisende sammenhæng mellem beregninger og målinger er det antaget at modellerne også kan bruges til at give information omkring de vindforholdende i lavere højder som er relevant for vind og kite surfere. Derudover er en avanceret flow solver benyttet til at give en bedre forståelse af kompleksiteten nær de eksisterende og nye vindmøller.

Generelt er indflydelsen af de nye vindmøller ganske begrænset og i samme størrelsesorden som de eksisterende mindre møller. Årsagen er at de største ændringer i vindfeltet finder sted i højder over 30m.

Den største effekt ses ved vindretninger fra vest, hvor møllerne ved 8m/s giver en reduktion i området bag møllerne, på ca 0.5m/s. Derudover øges turbulensintensiteten fra 6% til 9%. Størrelsen af ændringer er ens for både de eksisterende samt nye møller, men det påvirkede område er større for de nye møller. Ved vindhastigheder over 8m/s målt i 10m højde, begynder de nye møller at begræns effekten idet vindhastighed er betydeligt højere i 90m højde. Dette begrænser påvirkningen af vinden. Ved disse højere vindhastigheder er wake effekten mindre for de nye møller end for de eksisterende.

I kort form kan der konkluderes:

- De nye møller vil påvirke det undersøgte surfer område mht reduktion af middelving samt forøget turbulens i samme størrelsesorden som de nuværende mindre møller.
- Det påvirkede område er større for de nye møller end for de eksisterende.
- Det påvirkede område starter længere væk fra de nye møller (+300m), hvor det for de eksisterende møller var tættere på møller og kyst (+100m).
- Ved vindhastigheder omkring 8/s, målt i 10m højde, er reduktionen i vindhastighed ca 0.5m/s og turbulens intensiteten øges fra 6% til 9%.
- Ved vindhastigheder over 8m/s, målt i 10m højde, vil de nye møller pga den højere vindhastighed højere oppe, starte med at begrænse den elektriske effekt. Det betyder at de bliver aerodynamisk mere transparente og dermed at påvirkningen af vindfeltet reduceres. Ved disse hastigheder er påvirkningen mindre for de nye møller end for de eksisterende.

1. Description of the turbine replacement

Presently, there are 4 turbines installed near the beach area East of Hanstholm harbour. Each turbine has a rotor diameter of 41m and a nominal power of 525kW. The tower height is 40m. The location of these turbines are shown in Figure 1. The plan is to take down these turbines and replace with 3 new 3.4MW turbines with a diameter of 126m and a tower height of 90m. The investigated area is also shown in Figure 1 with a red marked area and points numbered from 1 to 20. South of the surf area is a terrain consisting of a mixed area with houses and vegetation.

Figure 1 Visualization of the 4 existing turbines (marked with purple circles) and the 3 new turbines (marked with orange circles). Furthermore, the investigated surf area is shown.

2. Wind turbine wake effects

The energy conversion process by a wind turbine is basically caused by a reduction of the air flow momentum. Basically, the wind causes forces on the rotating turbine, which in contrast applies a counter pressure on the incoming flow. This counter pressure causes some of the air to pass around the turbine and some of it will pass through the rotor. Consequently there is a reduced wind speed in the area behind the wind turbine rotor. A wind turbine is (roughly speaking) designed to reduce the windspeed with 2/3 in the area immediately behind the rotor. This reduction in wind speed of 2/3 is kept constant until rated wind speed, which is normally around 12-13m/s (at hub height). For higher wind speeds, the turbine is controlled to operate at a constant power level, normally by changing the blade pitch angles. The wind speed reduction drops rapidly for increasing wind speeds since only a very small part of the energy content need to be converted in this region. For wind speeds higher than cut-out at 25m/s the turbine is fully stopped and the flow impact is negligible. The wind speed region of highest wind speed reduction is from 5-10m/s, whereas at 16m/s (at hub height) the impact is expected to be minimal.

The flow field behind an operating rotor is quite complex, first there is the reduced wind speed area, which gradually recovers further downstream. Here it is important to notice that this region of reduced wind speed does not necessarily follow a straight line downstream of the rotor center, but depends heavily on the structure of the ambient athmospheric turbulence. In a very popular way, it can be said that the deficit is transported in the direction of the wind, but the wind direction is continuously changing due to the turbulence.The movement both occurs in the horizontal as well as the vertical plane. Furthermore, there is the self generated vortex system from the rotor itself consisting manly of three tipvortexes and a root vortex, which is transported dowstream together with the deficit. These vortices tend to dissolve a few rotor diameters downstream under normal ambient turbulent conditions. The impact further downstream is mainly a slightly increased amount of high frequent turbulence compared to normal ambient turbulence

In general the wake effect will decrease faster under high ambient turbulence conditions and vice versa for low ambient turbulence. This study is performed or a turbulence level measured as a turbulence intensity (standard deviation / mean wind speed) of 6% corresponding to average offshore conditions.

3. Models used

Two different models have been used for this study. One is a based on a CFD actuator line method [1], and consist of a detailed 3D flow solution of the Navier-Stokes equations. The method combines a three-dimensional Navier-Stokes solver with a so-called actuator line technique in which body forces are distributed radially along lines representing the blades of the wind turbine. The model resolves the large eddies using a special Detached Eddy Simulation (DES) technique and is considered state-of-the-art within flow modelling of wind turbine wakes. It is however highly computationally costly, where 10min in realtime takes approximately 5 days of calculation time on a parallelized high performance computer. This model has been used to illustrate the complex flow behind a single wind turbine in section 4.

The second model used is known as the Dynamic Wake Meander (DWM) model [2],[3],[4],[5]. This model is considered a highly accurate engineering model including the important parts for handling fully instationary wind turbine wakes. The fundamental assumption is that there is a velocity deficit behains a wind turbine rotor, that depends on the loading of the rotor. This deficit is transported downstream in a meandering way fully determined by the flow structure of large and lowfrequent vortices in the ambient turbulent wind. The model has been compared to both full scale wind measurement as well as indirect measures of load impact on downstream placed turbines with a very convincing result, and is therefore also considered sufficient for this particular study.

Near terrain surface effects has not been included in any of the models, but his is not expected to have any significant influence on the results.

4. Detailed single wake analysis

This study is for a expected worst case scenario where the wind direction if from south causing the wake to impact the surf area directly. Furthermore the wind speed at 10m hug height is 8m/s, where the turbines have maximum impact on the wind for both the old and new turbines. A higher wind speed, the new turbines will have less impact as they reduce the blocking when reaching rated power level.

The study here is using an ambient turbulence level of 6% corresponding to offshore conditions. One could argue that for the interesting wind direction from south the ambient turbulence is higher, but as this will lead to a significantly faster wake recovery it is expected to be conservative for this study.

In Figure 2 a snapshot of the results of a CFD LES simulation is shown. It can be seen that just behind the rotor, a region with significantly reduced wind speed is present. This area is of same size as the rotor area (0-2D) and has very limited impact on wind conditions near the terrain surface. Further downstream (2-10D), a mixing occurs where it can be seen that in both situation, the wind speed near the surface is affected to some degree. Far down stream (>10D) the wake is more or less fully resolved causing minimal impact. It is important to be aware that the wake affected region is approximately the same in the horizontal direction as in the vertical direction.

When comparing the impact from the new versus the old turbine it can be seen that the affected region is closer to the turbine for the old turbines (from 100-500m), whereas the impact from the new turbines is from 300-900m. The impact is however on the same level of magnitude.

In Figure 3 the average wind speed is plotted. For the old turbine, the wind reduction are below the plotting threshold of 1m/s, whereas for the new turbine the wind speed reductions are just above the 1m/s threshold for downstream distances of 300-700m

In Figure 4, the average longitudinal wind speed is shown for a height of 10m. Here it can also be seen that a reduction of approximately 1m/s can be expected in the wake region.

In Figure 5 the impact on turbulence level is shown (however based on a coordinate system with origo at the individual hub heights). At a corresponding height of 10m the turbulence disturbance is of the same size. The old turbines have a impacted regions o f100-500m downstream, whereas the new turbines have an impact from 200-800m

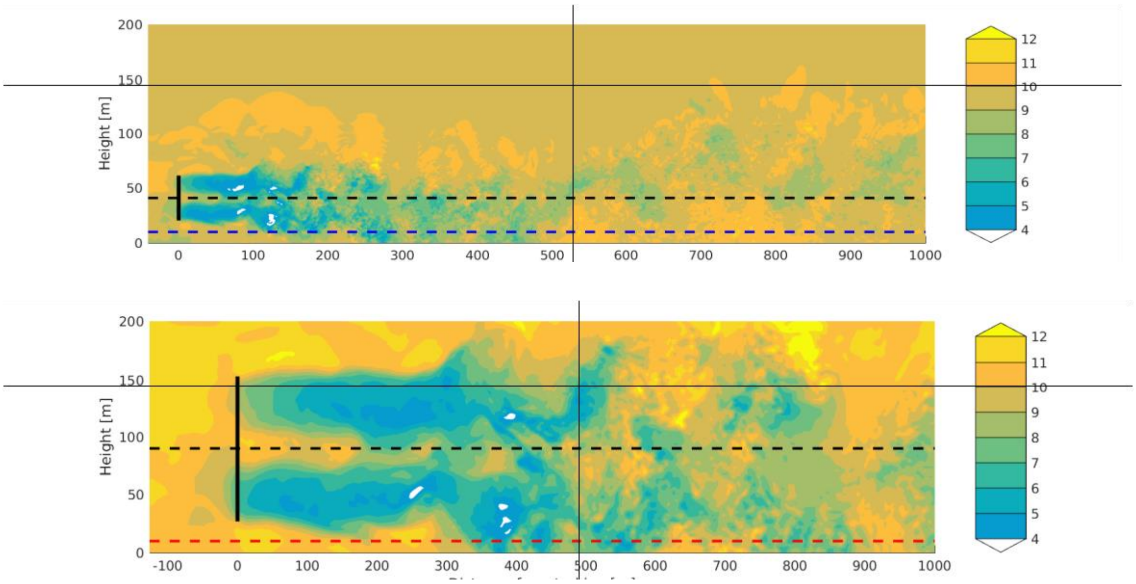

Figure 2 Detailed CFD LES flow simulation around rotors with different height. A snapshot of the instantaneous longitudinal wind speed is plotted. The upper rotor, correspons to the old turbines and the lower rotor corresponds to the new rotor with a diameter of 126m and a hub height of 90m. The ambient wind speed is 8m/s at 10m heght. A dotted line is included for the hugh height and for the height at 10m for the two cases

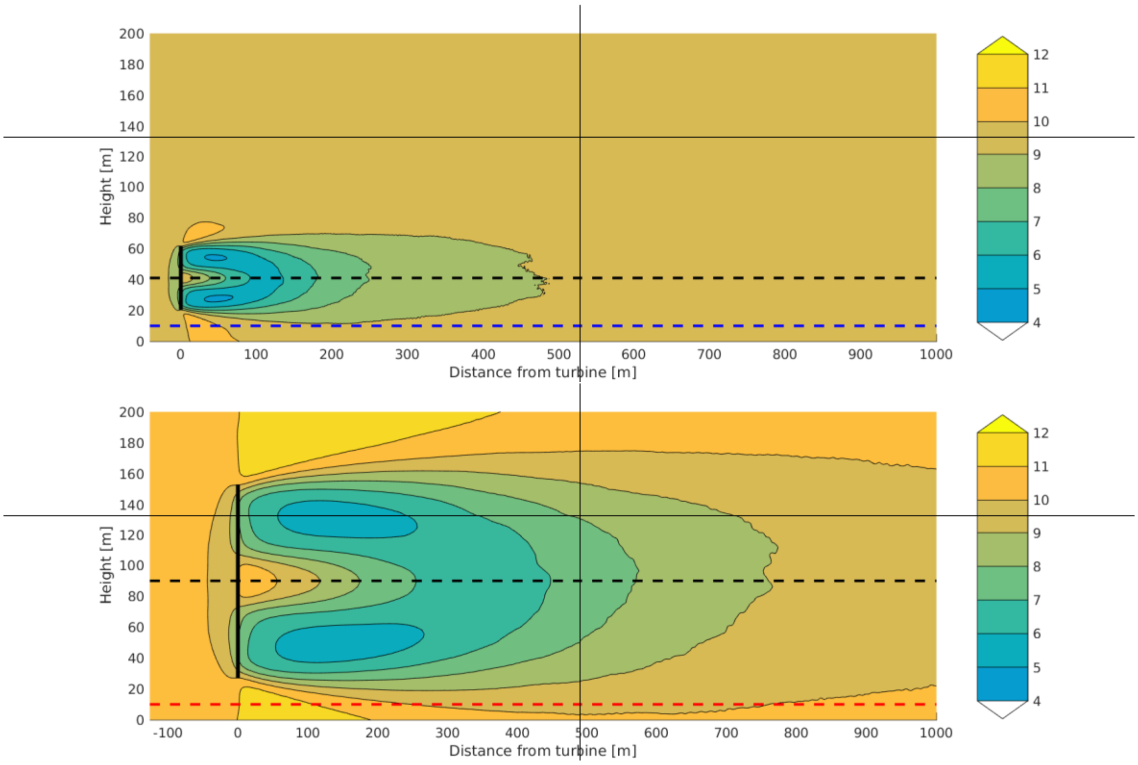

Figure 3 Detailed CFD LES flow simulation around rotors with different height. Averaged longitudinal wind speed is plotted for the two rotors

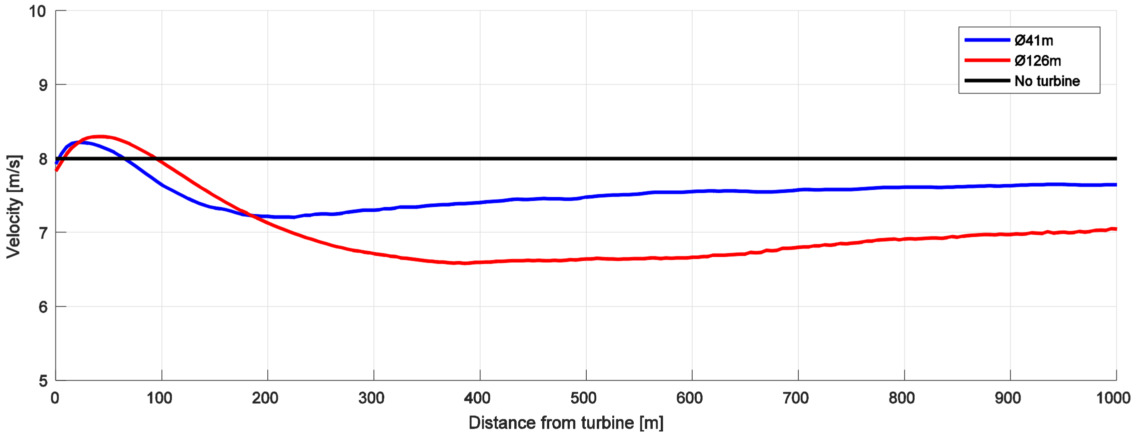

Figure 4 Average wind speed at 10m height for the new versus the old turbines for an ambient wind speed of 8m/s.

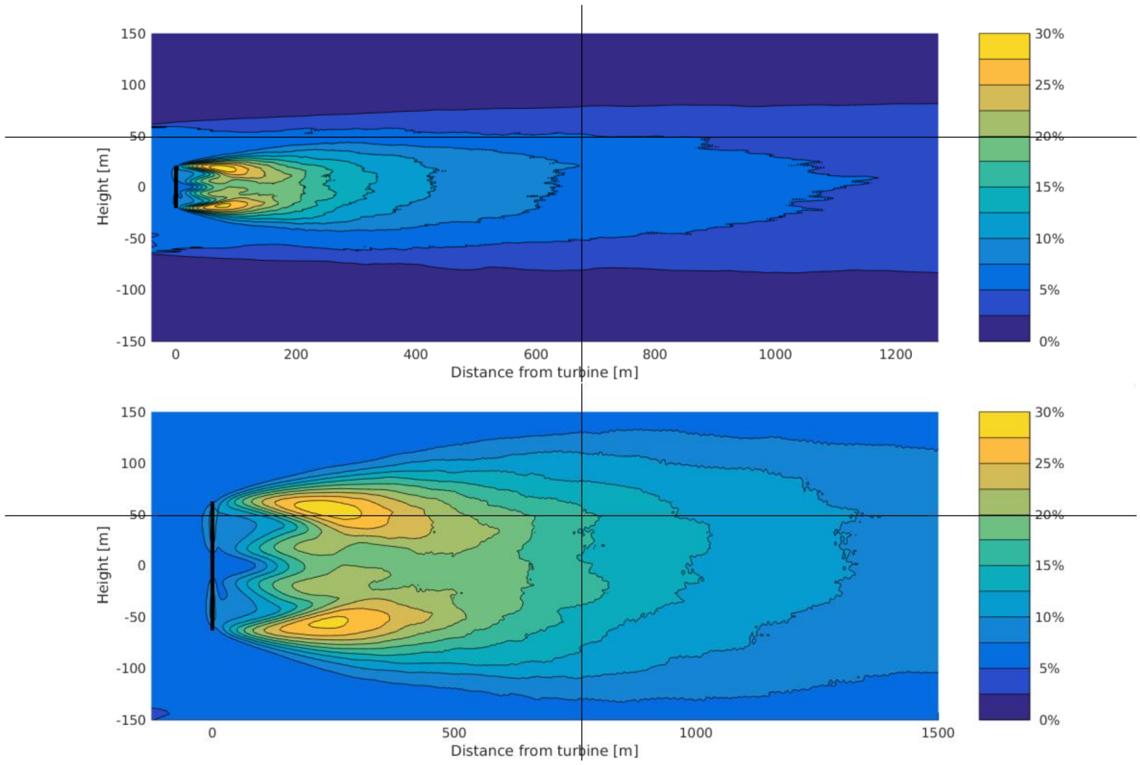

Figure 5 Turbulence intensity near the rotors. The impact on the turbulence level at a height above terrain of 10m is similar for the two turbines.

5. Analysis of all turbines

In order to investigate the effects for the surf area between “Fish factory” and “Hamborg”, the dynamic wake meander model is used. 20 positions area used as reference points in the surf area, however a fines grid of 120points is used for the actual simulations results used for the vizualisation.

In the following pages results of the impact in the surf area is seen for different wind directions ranging from 150deg south-east to 270deg West. Wind directions from Northern directions have not been included as these does not cause any wake effects in the surf area. What is interesting to pay attention to is the difference between the maximum and minimum value of either mean wind speed (top), turbulence level (Middle) and turbulence intensity level (bottom) as this express the variation between non-affected are and wake affected area.

Only a minimal impact is seen for direction 150-180deg as the wakes does not really hit any of the locations observed. At 210deg the wake is down the second row of observation points. Here the new turbines can be seen to decrease the wind speed from 8m/s with 0.3m/s and increase the turbulence intensity from 6% to 9%.

The largest impact is seen to be when the wind is directly from west causing a wind speed reduction of 0.5m/s and and increase in turbulence intensity from 6% to 9%. However, this is the same level of disturbance seen from the present turbines. The impact of the new turbines is therefore expected to be similar in magnitude to the existing turbines, but with a larger affected area.

In the figures 14-18, the worst case wind direction from 270deg west are shown. It can be seen that for wind speeds above 8m/s the impact from the new wind turbines is less with the new turbines than for the old turbines. The reason is expected to be from the different control strategy of the old versus new wind turbines. The old turbine are based on a strategy called stall-control, whereas the new turbines uses pitch-control. With pitch-control the relative thrust force of the rotor is smaller than for stall-control which leads to a smaller wind speed deficit, that again causes a smaller impact.

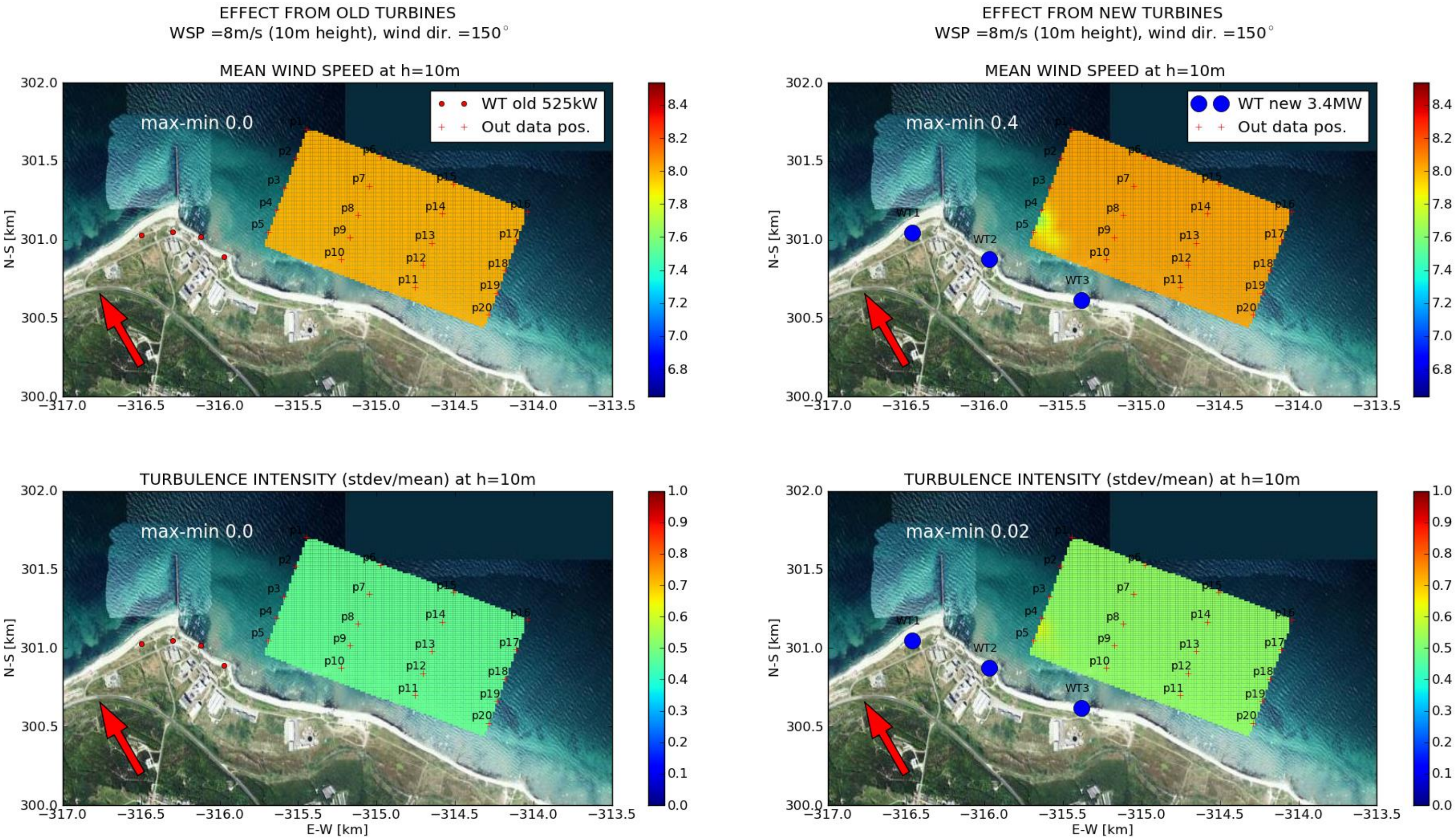

Figure 6 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 150deg South-East. The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

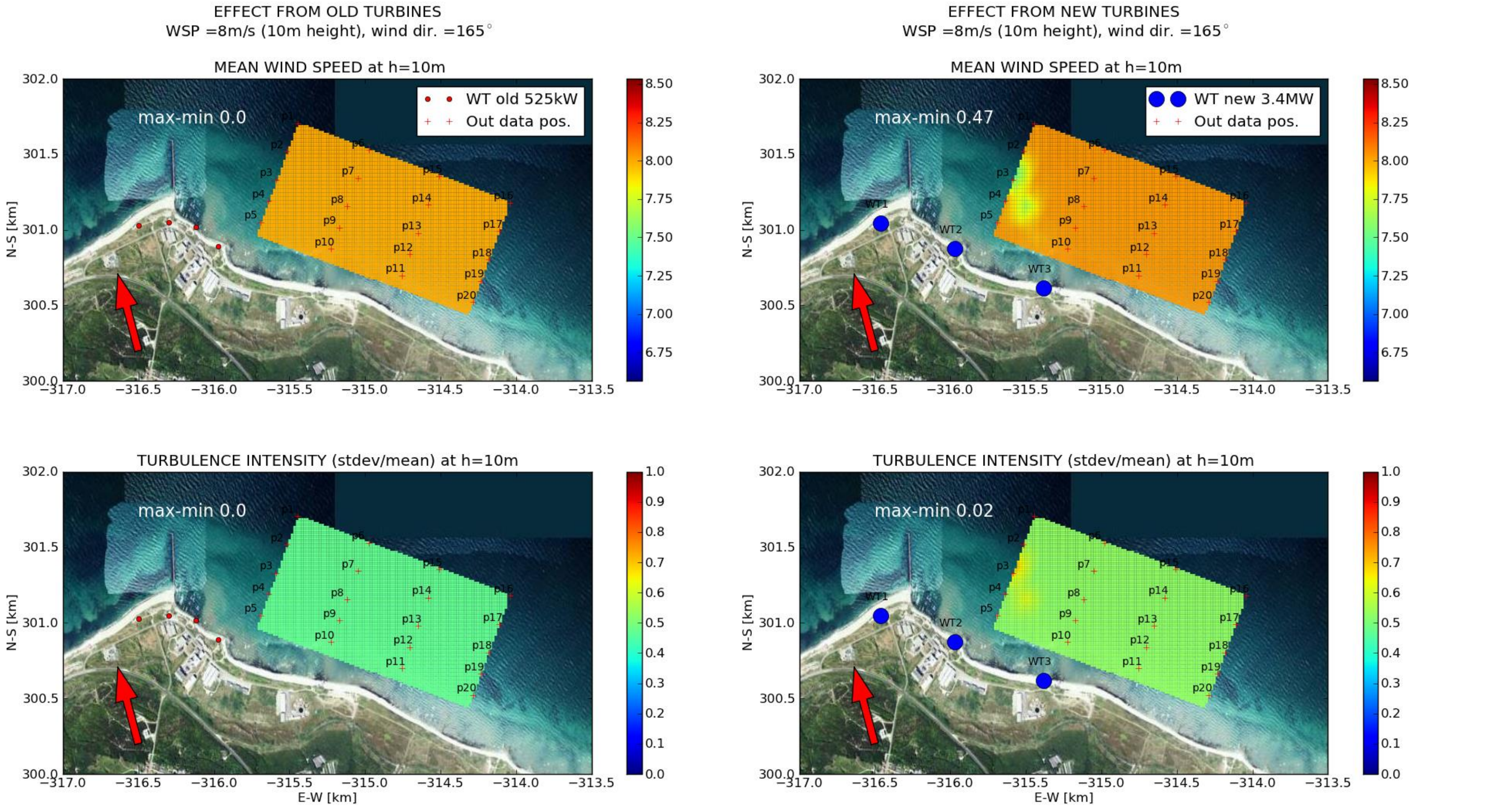

Figure 7 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 165deg South. The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

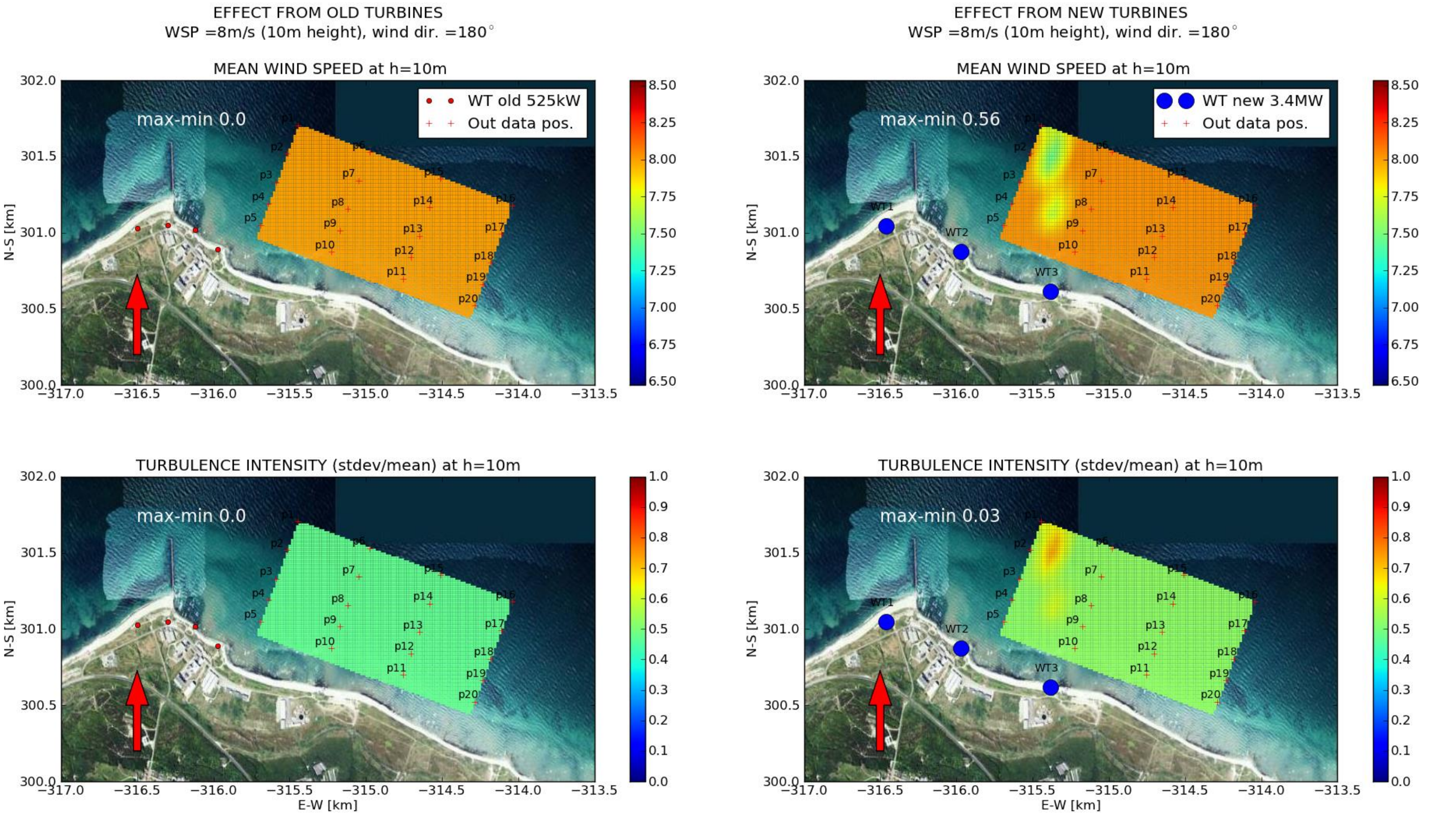

Figure 8 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 180deg South. The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

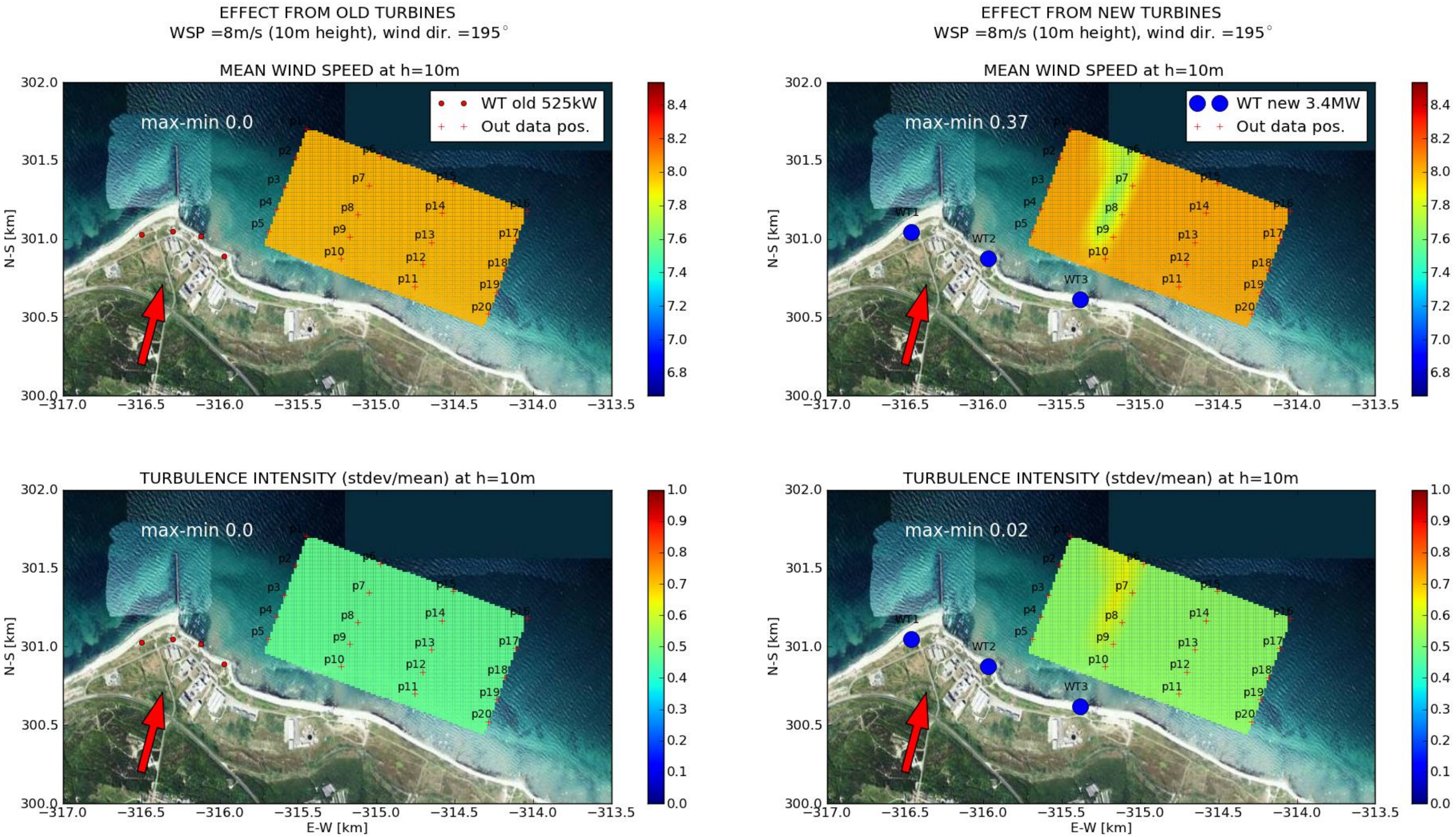

Figure 9 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 195deg South. The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

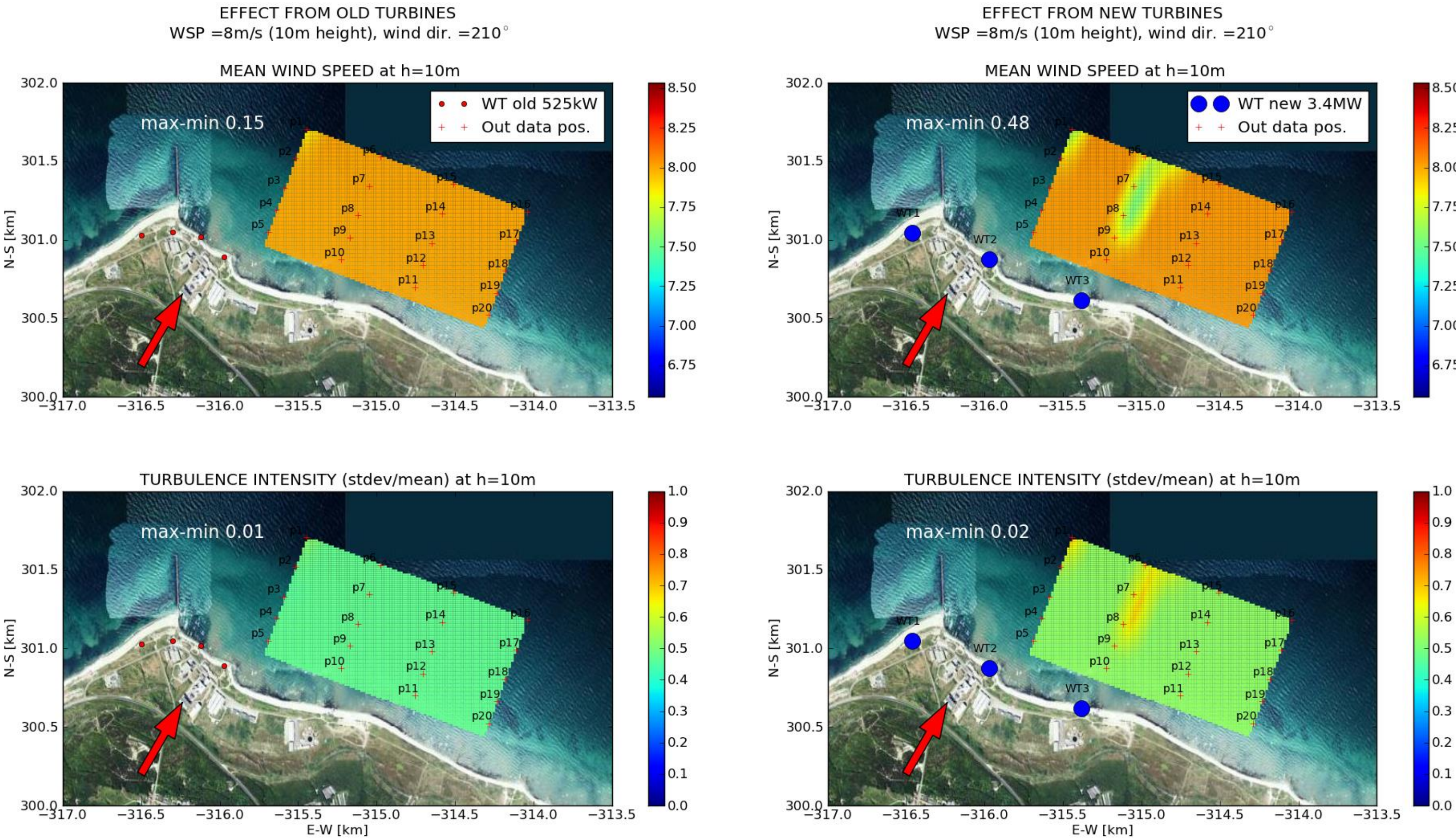

Figure 10 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 210deg South-West. The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

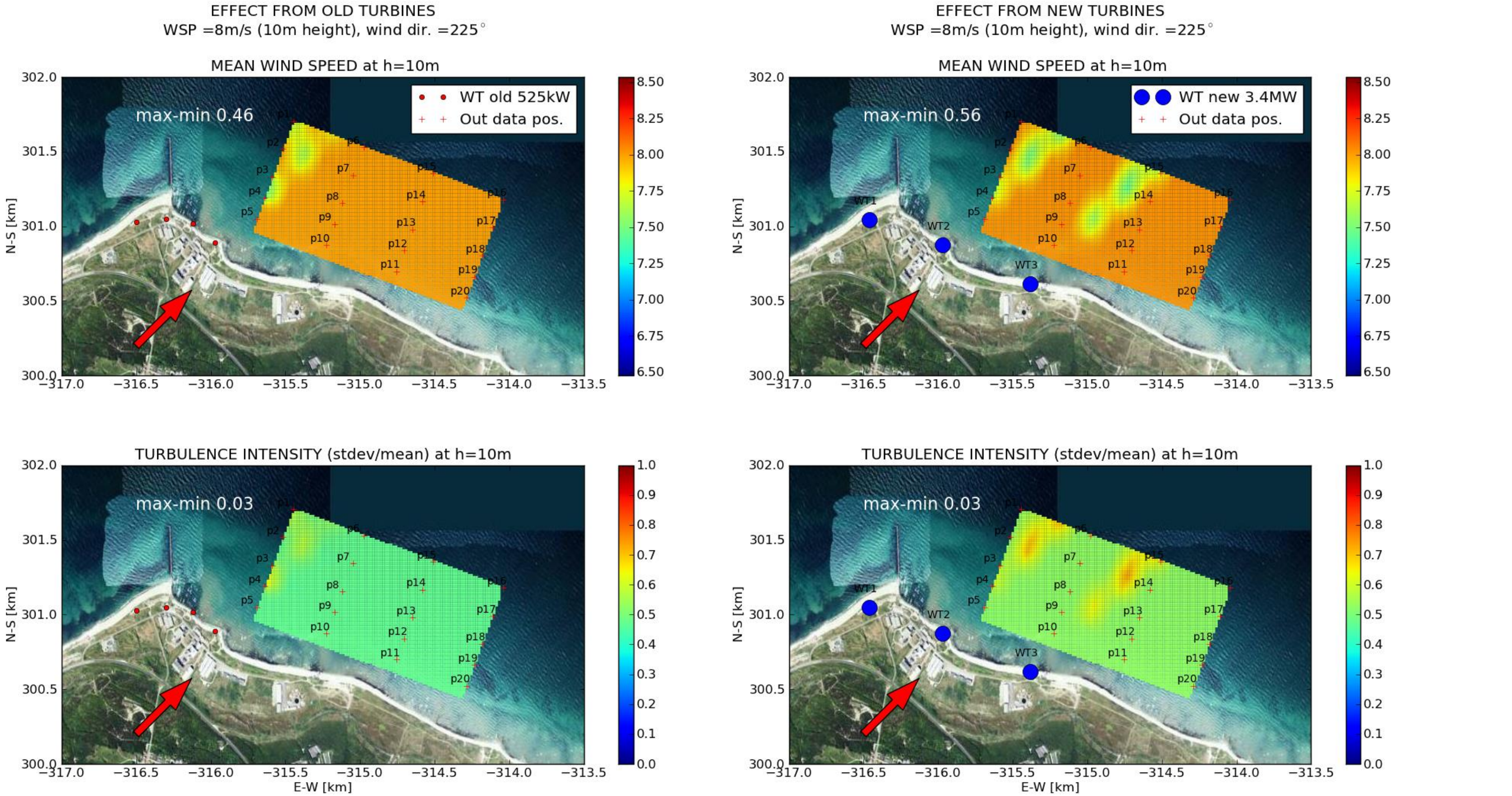

Figure 11 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 225deg South-West. The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

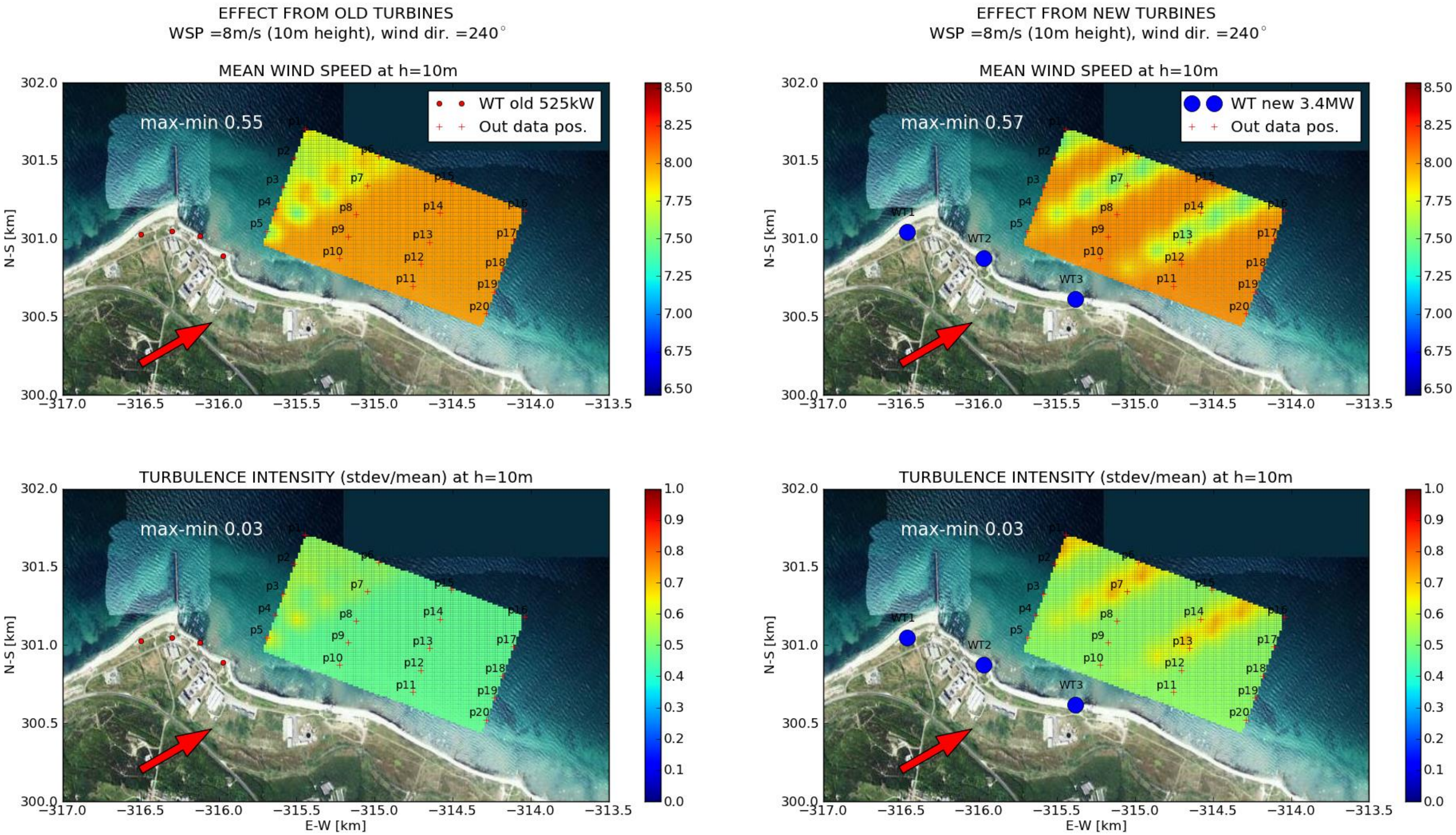

Figure 12 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 240deg South-West. The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

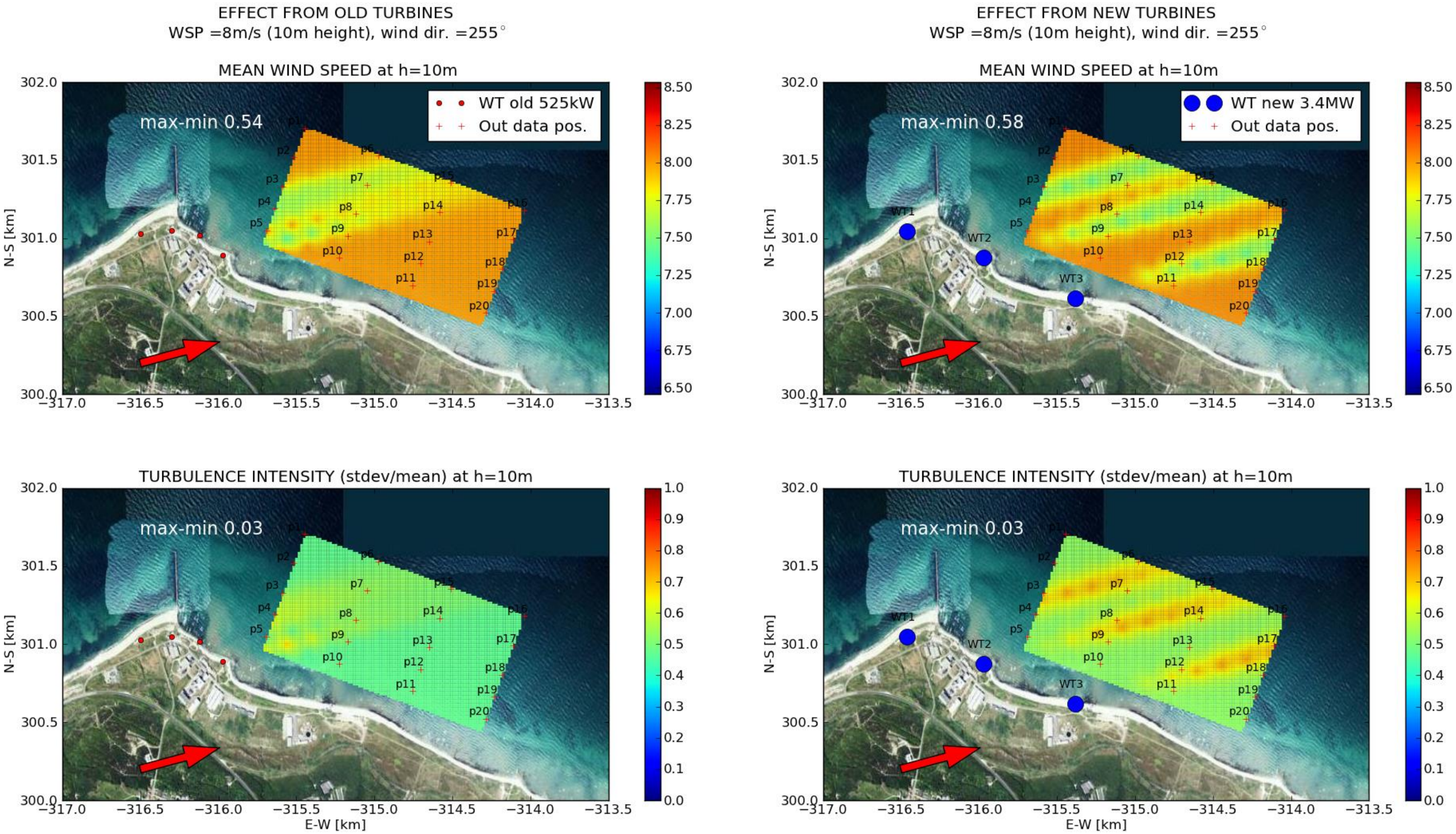

Figure 13 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 255deg South-West. The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

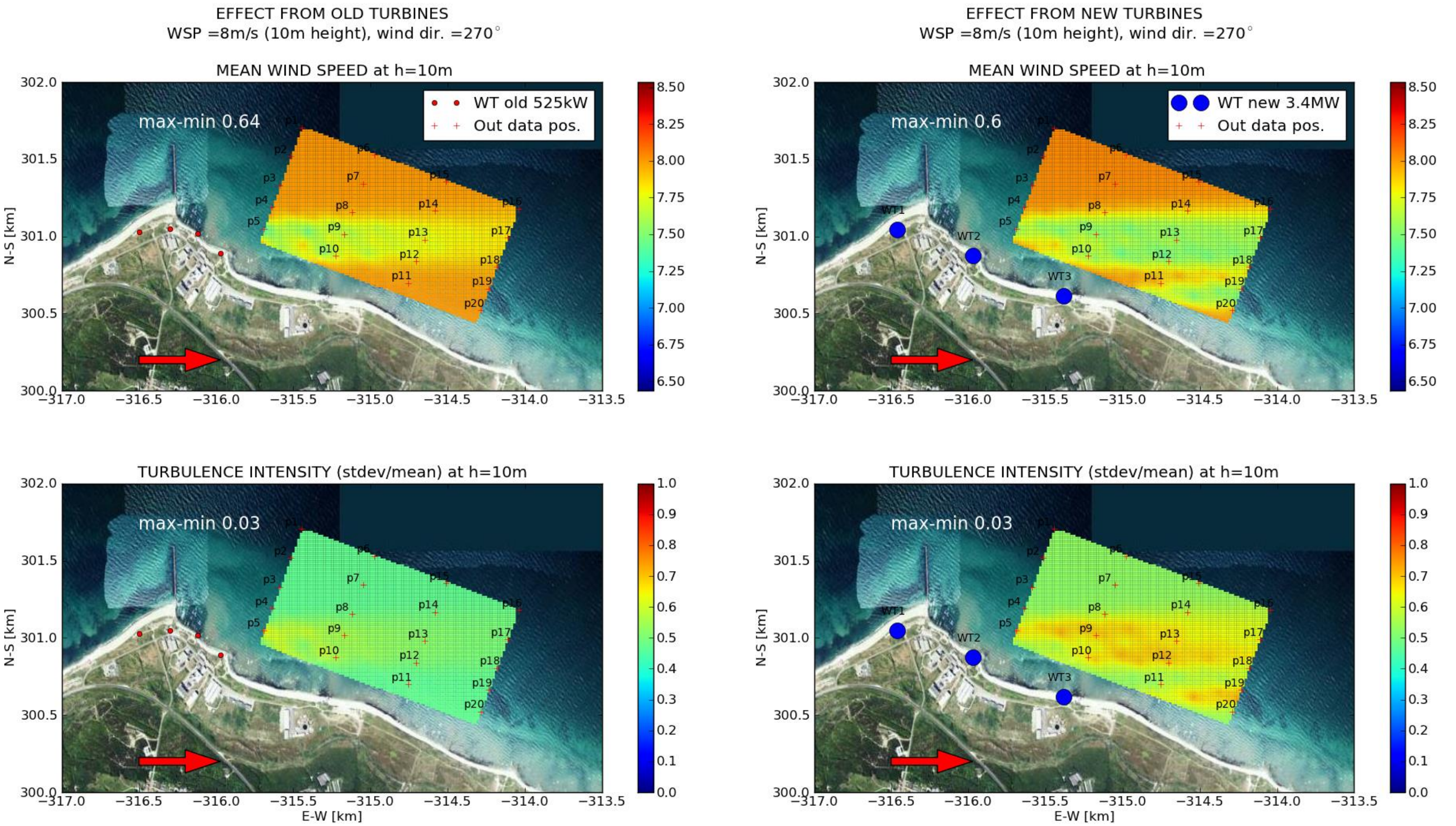

Figure 14 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 270deg West. The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

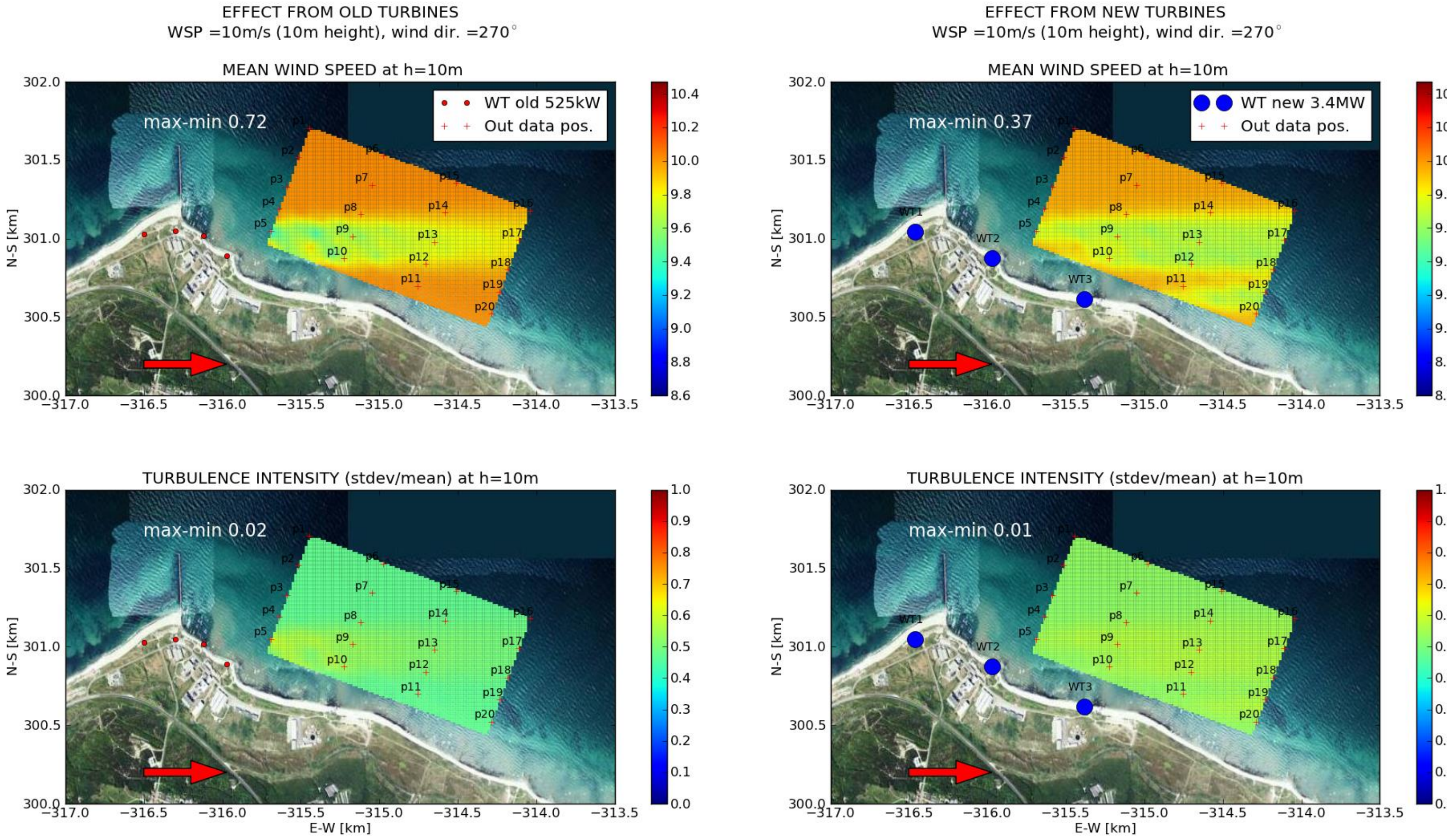

Figure 15 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 270deg West at 10m/s (10m height). The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

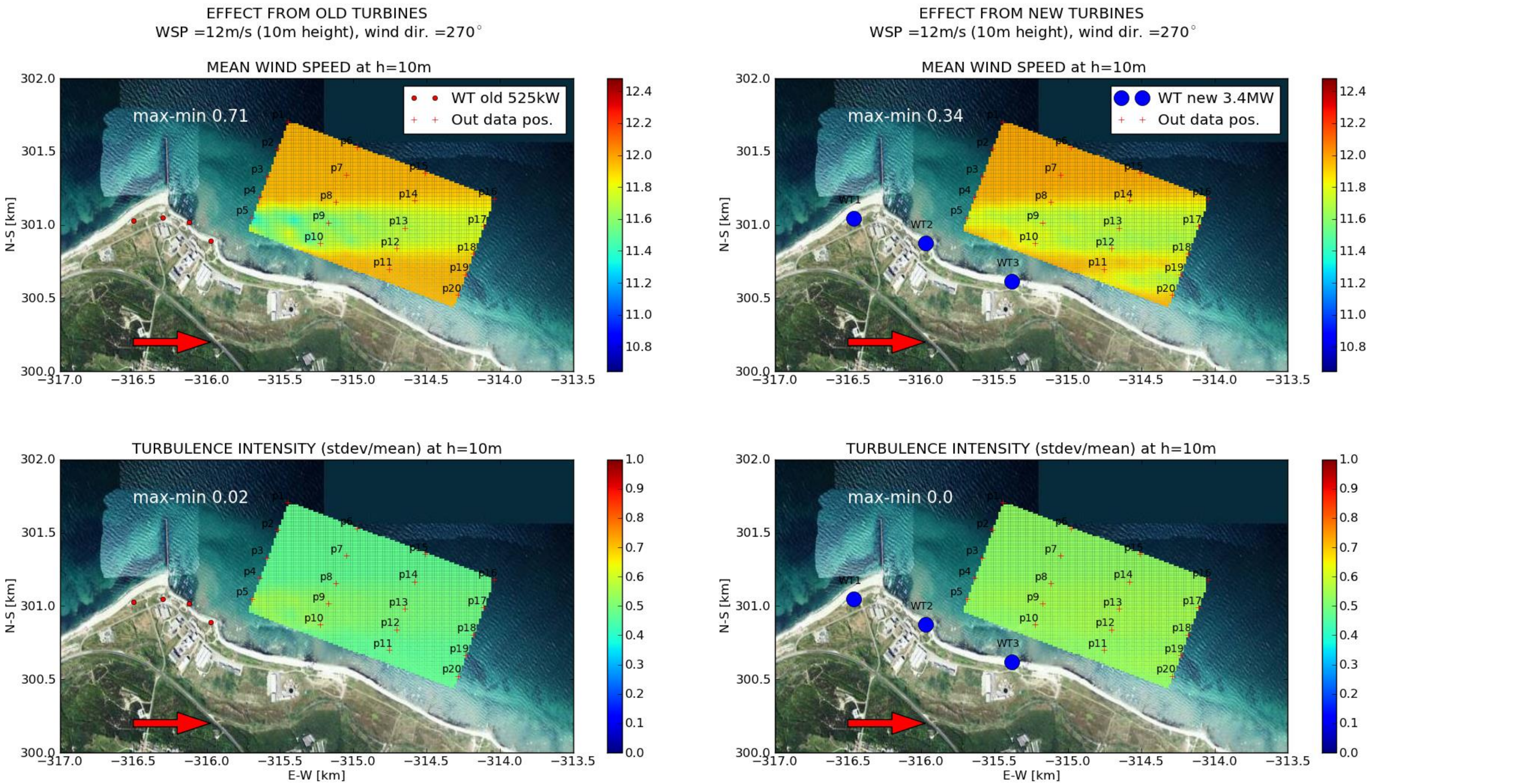

Figure 16 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 270deg West at 12m/s (10m height). The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

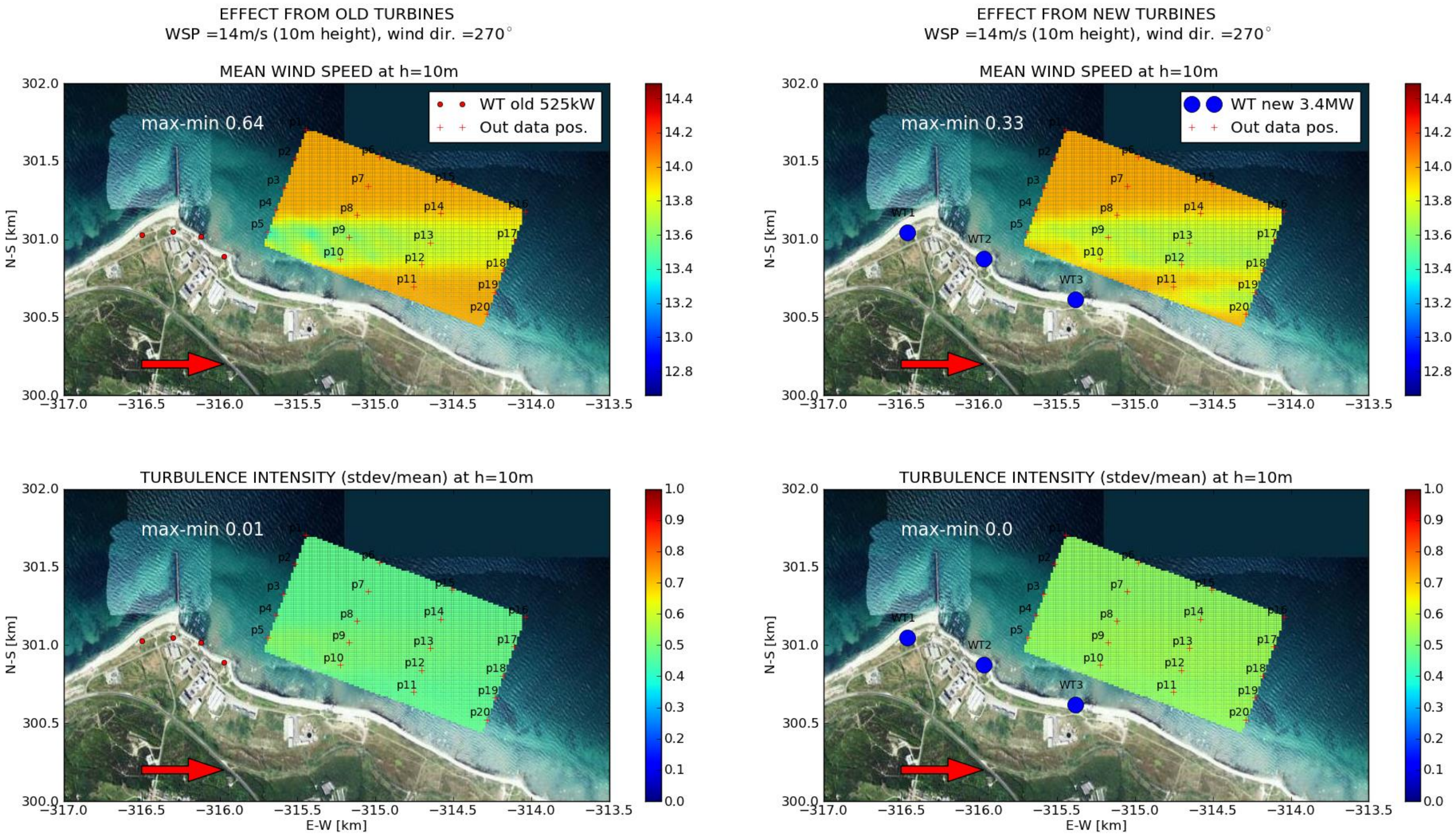

Figure 17 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 270deg West at 14m/s (10m height). The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

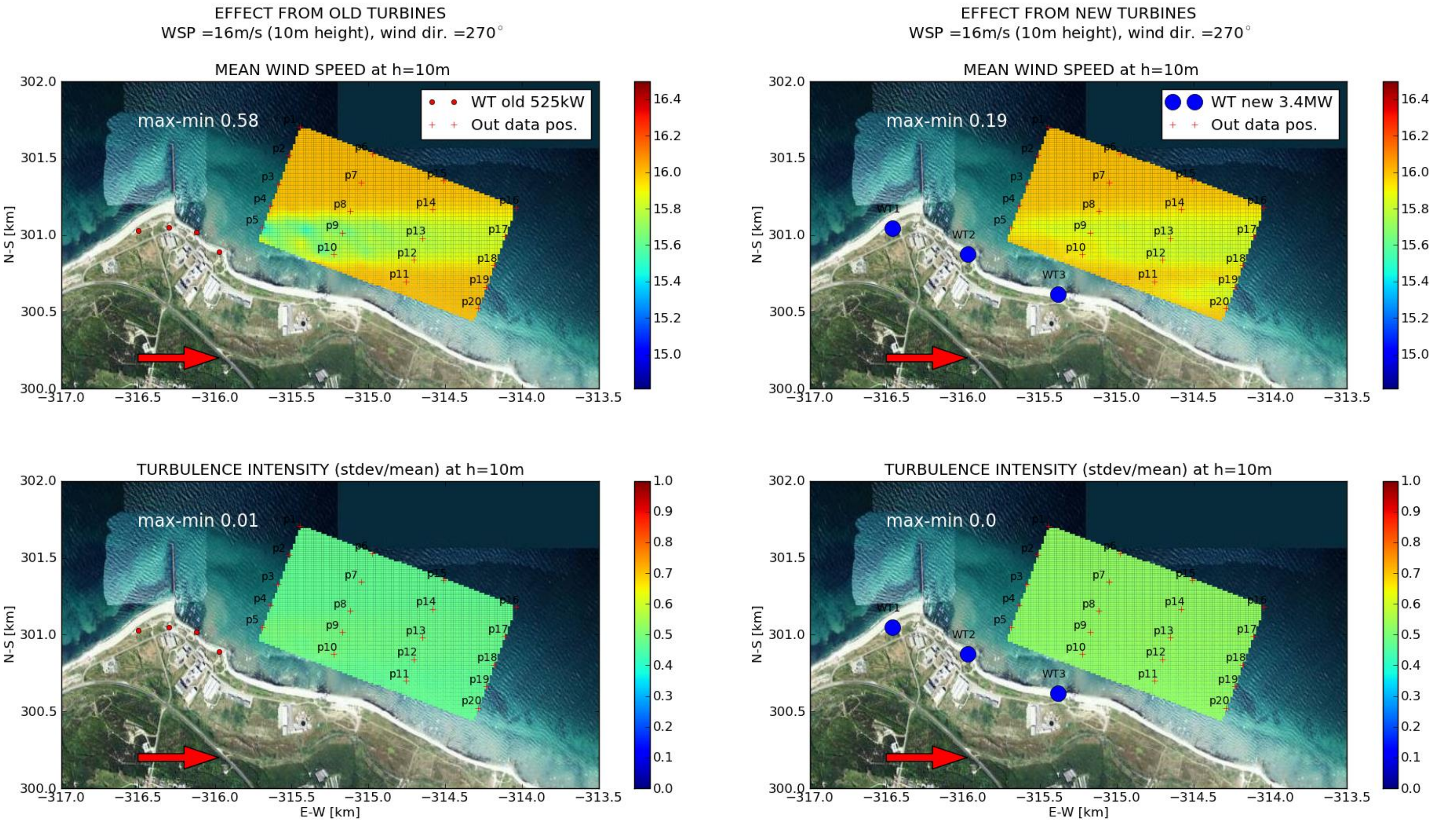

Figure 18 Influence of the existing (left) and new (right) turbines of the investigated surf area with a wind direction of 270deg West at 14m/s (10m height). The upper figures show the wind field mean wind speed, whereas the lower figures show the turbulence intensity.

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We have more than 240 staff members of which approximately 60 are PhD students. Research is conducted within nine research programmes organized into three main topics: Wind energy systems, Wind turbine technology and Basics for wind energy.

Danmarks Tekniske Universitet
DTU Vindenergi
Nils Koppels Allé
Bygning 403
2800 Kgs. Lyngby
Phone 45 25 25 25

info@vindenergi.dtu.dk
www.vindenergi.dtu.dk