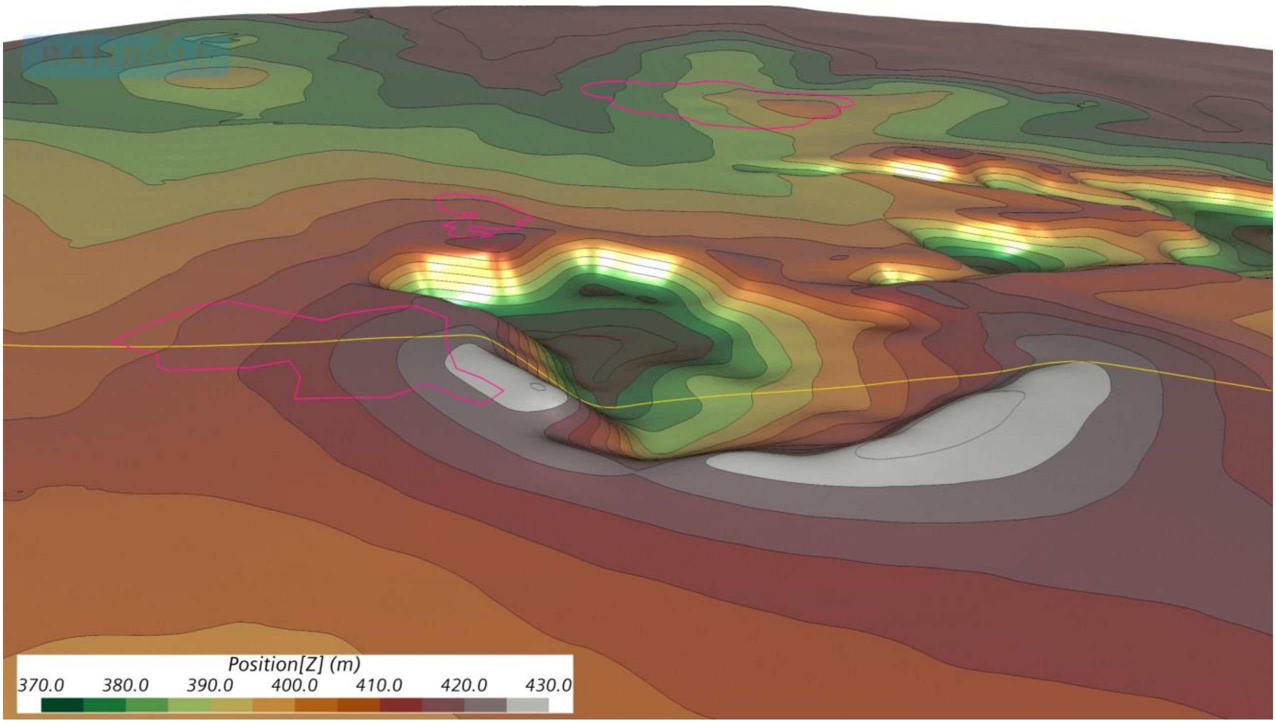
Intended for
Audalia Resources Ltd.

Document type
Report

Date
17 June, 2020

AUDALIA RESOURCES LIMITED MEDCALF PROJECT
CFD WIND STUDY



Bright ideas. Sustainable change.

AUDALIA RESOURCES LIMITED MEDCALF PROJECT
CFD WIND STUDY

Project name	**Audalia Resources Medcalf Project – CFD Wind Study**
Project no.	**318000777**
Recipient	**Audalia Resources**
Document type	**Report**
Version	**Revision 3**
Date	**17/06/2020**
Prepared by	**Søren Lovmand Hvid**
Checked by	**Stefano Capra**
Approved by	**Jens Chr. Bennetsen**

Ramboll
Lysholt Allé 11
DK-7100 Vejle
Denmark

T +45 5161 1000
F +45 5161 1001
https://ramboll.com

Rambøll Danmark A/S
DK reg.no. 35128417

Member of FRI

CONTENTS

TABLE OF FIGURES

APPENDICES

1. INTRODUCTION

1.1 Background

Audalia Resources Limited (Audalia) is proposing to develop the Medcalf Project, a vanadium, titanium and iron project located approximately 470 km south east of Perth near Lake Johnston, Western Australia. The Medcalf Project covers a total area of 38 km^2 (Figure 1).

The proposal includes the development of three open mine pits, beneficiation plant, tailings storage facility, waste rock landform, private haul road, road train transfer area and associated infrastructure such as laydown areas, borrow and gravel pits, borefield, workshops and accommodation camp.

Baseline environmental surveys have identified one flora species listed as Threatened under the *Biodiversity and Conservation Act 2016* (BC Act) within the Project site; *Marianthis aquilonaris*. In order to mitigate the potential impacts of mining operations on this species, Audalia propose to exclude all avoidable sub-populations of *M.aquilonaris* from the mine development envelope; and to implement a buffer zone (nominally 30 m) around all sub-populations found within close proximity of the proposed mining operations.

Audalia has requested that Ramboll Australia Pty Ltd (Ramboll) undertake computational fluid dynamic (CFD) wind modelling for the proposed Project site, to determine the potential changes in wind characteristics within and around the *M.aquilonaris* sub-populations.

1.2 Purpose of this report

This report presents the assessment of the potential changes in wind characteristics that may affect the growth conditions of the *M.aquilonaris* species. In the absence of more detailed knowledge of the plant's response to ambient conditions, the primary focus is on conditions that could potentially affect evaporation rates from the soil, these being the velocity gradient at ground level and turbulence levels ("buffeting").

As the *M.aquilonaris* sub-populations are located west and north of the mine deposit areas, it has been assumed that any changes in growth conditions will only be relevant with the wind blowing from east and south. To ensure that no relevant wind directions are excluded from the evaluation, wind directions from directly east (90 degrees) to directly west (270 degrees) are included, with a resolution of ten degrees.

The present revision of the report reflects updated population boundaries for the *M.aquilonaris* species and the impact this has on assessment of predicted changes to wind environment within the zones. CFD simulation of changes to wind conditions as a result of mining operations is still based on the original planned development envelope, mine crest locations etc. The effect of modifications to the mining extent is treated in an addendum to the report (section 7). The changes to mine site development extent and revised extent of *M.aquilonaris* population zones after completion of simulations are depicted on Figure 2.

Figure 1. Medcalf Project Proposed Development Envelope.

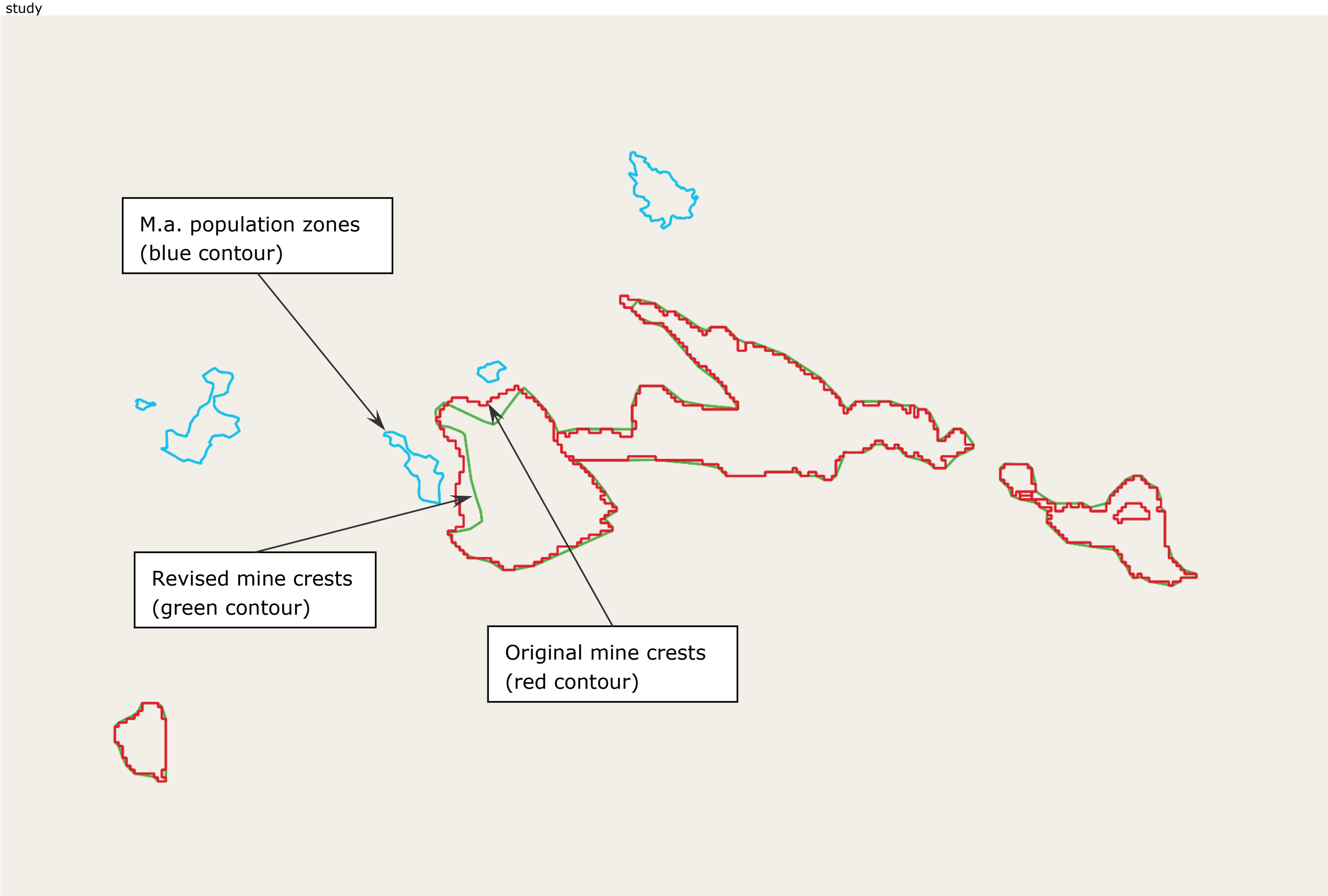


Figure 2. Revised shape of mine site and M.aquilonaris population areas.

2. TOPOGRAPHY AND WIND CLIMATE

2.1 Topography

The proposed Medcalf Project involves shallow (above the groundwater table) open pit mining for three separate open pits; the Vesuvius, Fuji and Egmont deposits. The surrounding terrain is relatively flat with elevation differences of approximately 100 m within a 2 km radius of the site, see Figure 4, with land gradually sloping away to the north, east and south of the deposits while maintaining elevation to the west. The *M.aquilonaris* sub-population areas are located west and north of the mine deposits.

The vegetation around the mine deposits is characterized as being relatively open shrubby to wooded, without densely forested areas.

The projected excavation will attain depths of up to about 50 m below the existing terrain elevation, as shown in Figure 3 below.

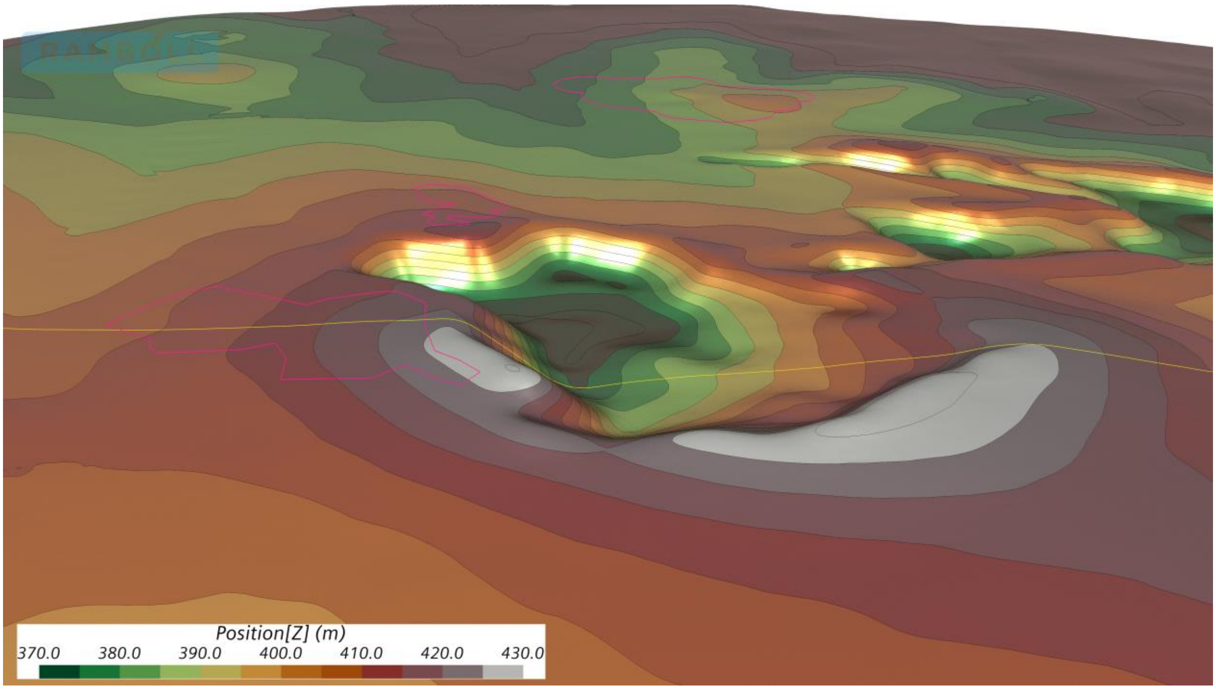


Figure 3. 3D impression of terrain elevations around the Vesuvius (centre) and Fuji (rear right) pits after excavation. The *M.aquilonaris* population areas are shown with the original extent.

The *M.aquilonaris* sub-population area immediately west of the Vesuvius pit is denoted "Population 1c" ("PoP 1c") and the sub-population area to the north of the pit "Population 1b" (PoP 1b"). These two population areas are the primary focus of the study due to their proximity to the mining pits.

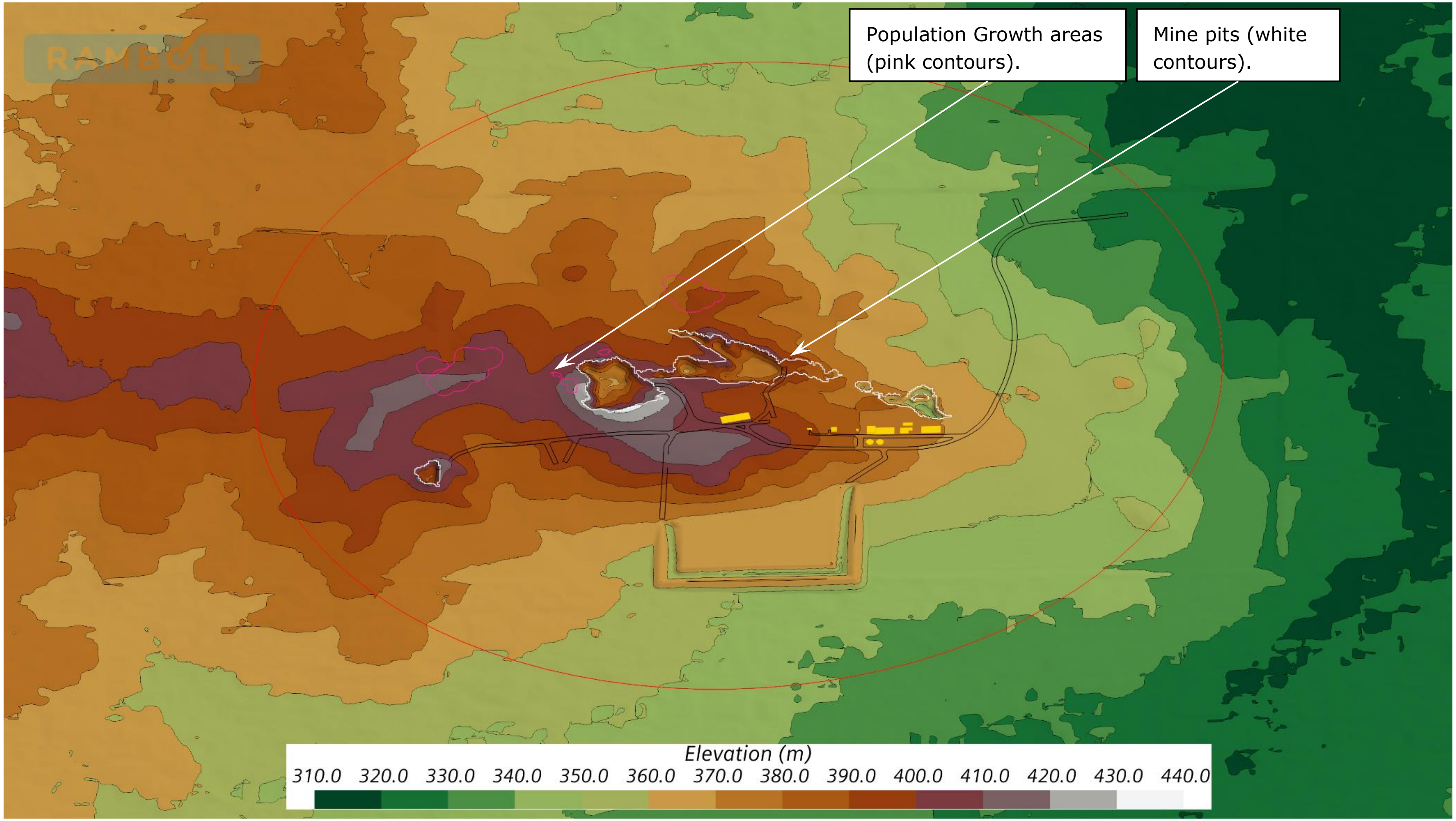


Figure 4. Medcalf project terrain elevation map showing projected mine pits (white contours), buildings (yellow), roads and M.aquilonaris population areas (pink contours). The outer red circle has a radius of 2 km. The project site shows the original, un-revised lay-out.

2.2 Wind climate

An annual wind rose for the Medcalf project site excluding wind speeds below 2 m/s is shown in Figure 5. It is noted that, although there are some directional differences in frequency, with higher frequencies from south-east and westerly wind directions, the wind rose is not generally directionally biased. It is similarly noted that, higher wind speeds tend to be from westerly directions.

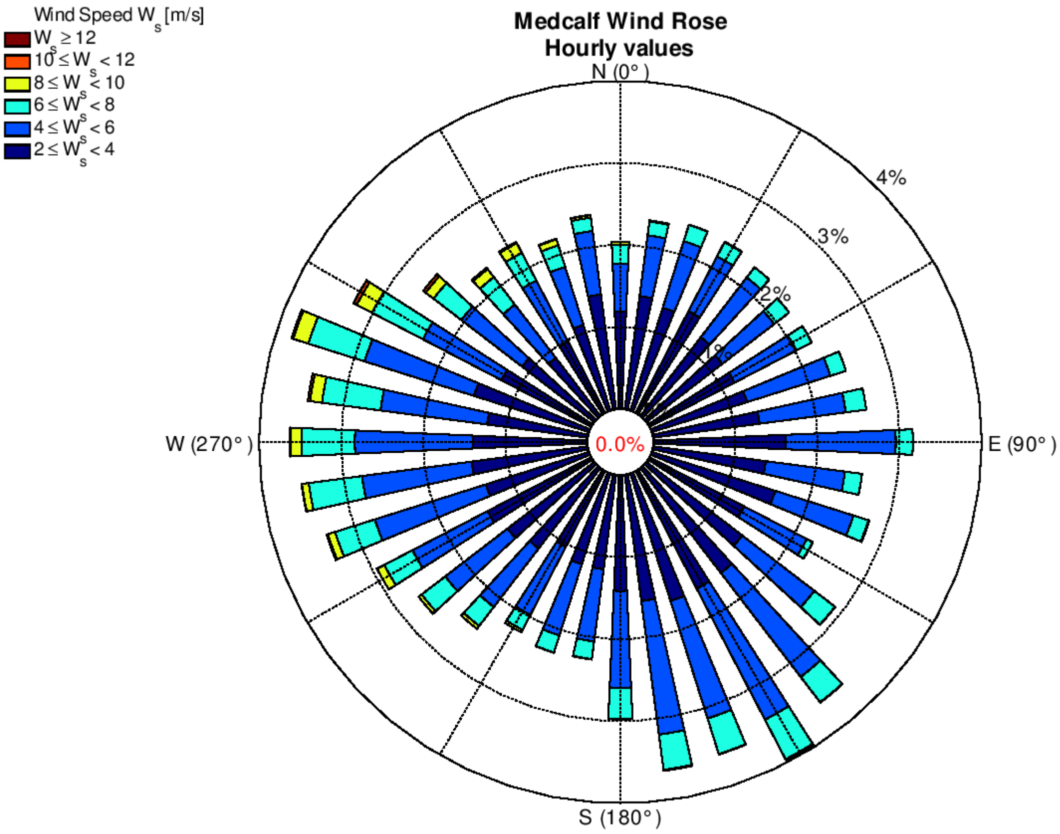


Figure 5. Detailed Wind Rose for the Medcalf project based on values of wind speeds above 2 m/s.

The wind rose shown above is used to produce wind frequency weighted results based on the CFD analysis data for each wind direction. This is further detailed in section 4.

3. CFD METHODOLOGY

CFD-analysis is routinely used to investigate flow around structures and in terrain. The methodology is based on a digital representation of the geometry (the "flow domain"), in which the governing equations for fluid flow are solved numerically. The geometry for the CFD analysis used to investigate changes in flow conditions as a result of excavations is based on elevation contour maps of the area. CAD models are prepared for the existing terrain as well as for the projected post-excavation site, including buildings and ore deposit area. The flow domain consists of a circular volume with a diameter of 5.4 km and extends to a height of 800 m above sea level, resulting in a height above ground level varying between approximately 350-500 m.

The flow domain is discretized using approximately 125 million computational cells concentrated in the lower portion of the domain close to the ground and in the central part of the domain where the mining pits and *M.aquilonaris* population areas are located. The average size of the individual computational cell in this region is 4m x 4m horizontally and 2 m in height, although the height of the cells close to the ground become progressively smaller.

In the CFD-analysis an atmospheric boundary layer (ABL) wind profile is prescribed at the outer boundary of the flow domain upstream of the mining area, while a zero-gradient flow condition is used for the downstream boundaries. The terrain (and buildings) inside the flow domain will determine the flow characteristics around the mine deposits and *M.aquilonaris* population areas.

The ABL wind profile assumed is a conventional logarithmic profile, ref. (1):

$$U(z) = U(z_{ref})\frac{\log\left(\frac{z+z_0}{z_0}\right)}{\log\left(\frac{z_{ref}+z_0}{z_0}\right)},$$

where $U(z_{ref})$ is the wind speed at the reference elevation z_{ref} and z_0 is the aerodynamic roughness length of the terrain. The analysis is performed for a reference wind speed of 10 m/s at 10 m reference height. As analysis of data will be relative by comparing future and existing flow characteristics, the actual absolute value of the selected reference wind speed is of no importance, the only requirement being that the wind speed is sufficiently high to ensure similitude, i.e. a high Reynolds number. In sparsely vegetated terrain the aerodynamic roughness length typically varies between 0.1 m to 1 m, ref. (2). For the present study the lower value of 0.1 m has been selected, corresponding to a physical roughness height of approximately 2 m. As the analysis focuses on changes in wind characteristics rather than absolute values, the significance of the selected absolute value of the roughness parameter is negligible. With the selected values the wind profile becomes as illustrated on Figure 6 (for heights up to 100 m above ground level):

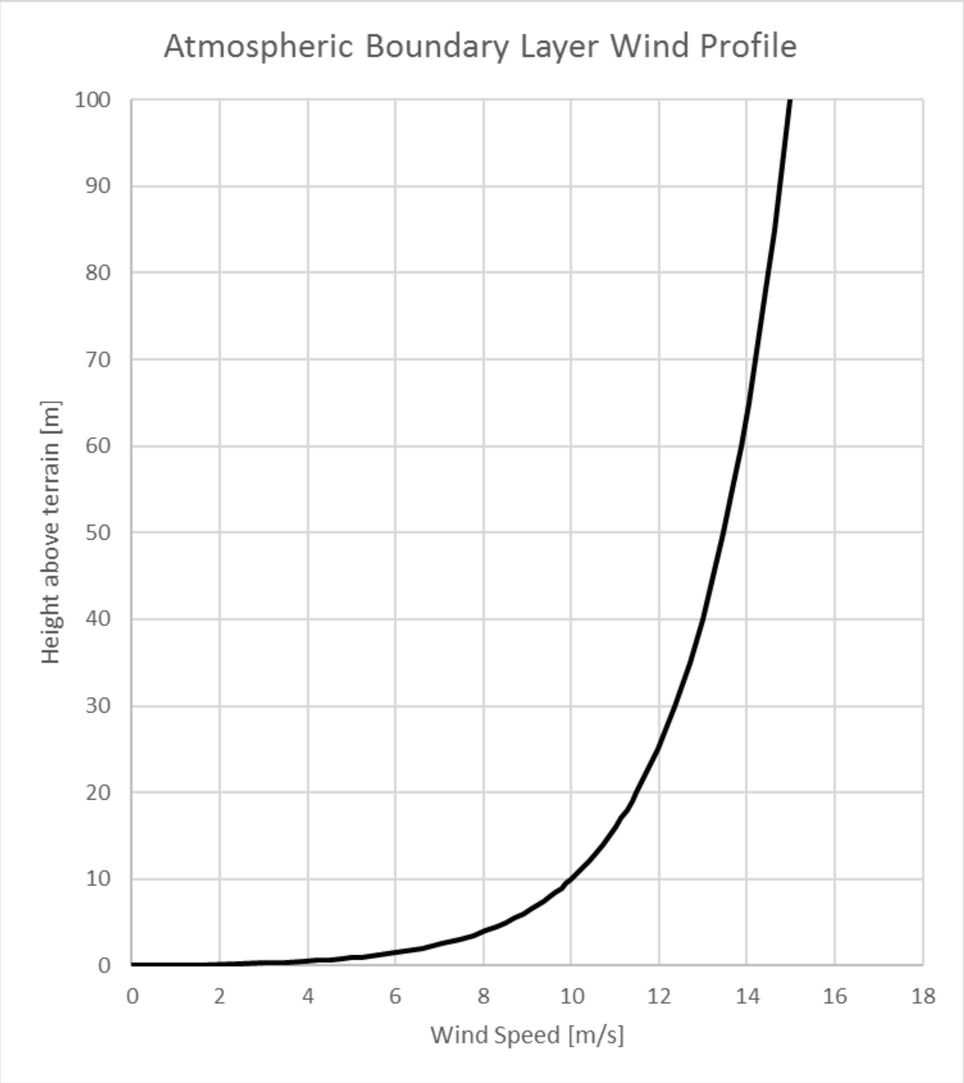


Figure 6. Atmospheric boundary layer wind profile applied on in-flow boundaries.

Turbulence in the stationary flow solution is based on the two-equation realizable k-ε model. The turbulent kinetic energy (TKE) is given by:

$$TKE = k \equiv ½\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right),$$

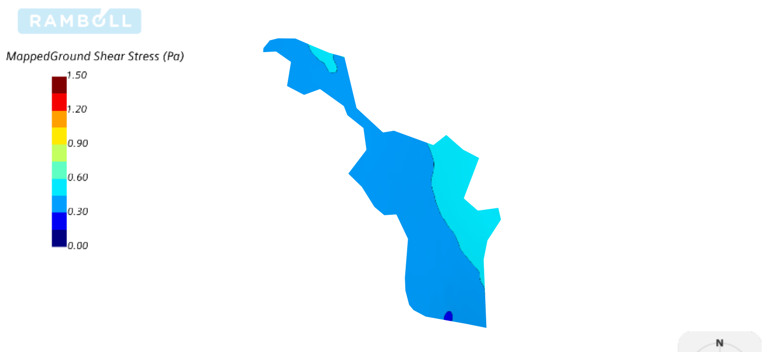
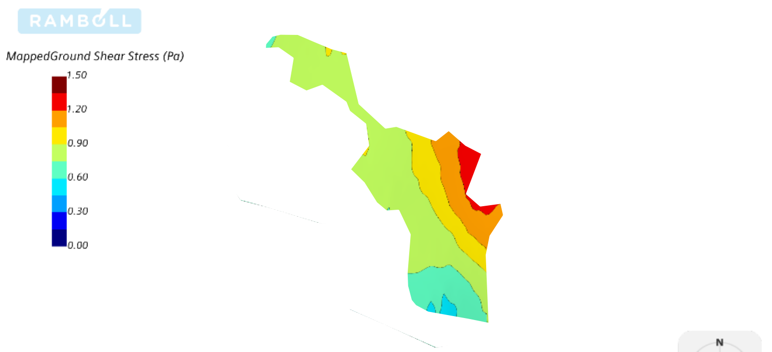
where $\overline{u'^2}$, $\overline{v'^2}$ and $\overline{w'^2}$ are the variances of velocity fluctuations in the three directions x, y and z. *TKE* is an expression for the mean absolute value of kinetic energy contained in deviations from the mean velocity (per unit mass), and may as such be perceived as a measure of gust factor or buffeting. By extracting the square root of TKE one obtains a measure of buffeting, or "turbulent velocity" with units of m/s. This has been used as the definition of "Gust Factor". As mentioned previously, result analysis will be relative, so the exact definition of the "gust factor" is of little importance. In an isotropic turbulence field, where $\overline{u'^2} = \overline{v'^2} = \overline{w'^2}$, the magnitude of each of these three components is therefore $\overline{u'^2} = \frac{2}{3}k$, so $\sqrt{\frac{2}{3}k}$ would have been an equally valid measure of the gust factor.

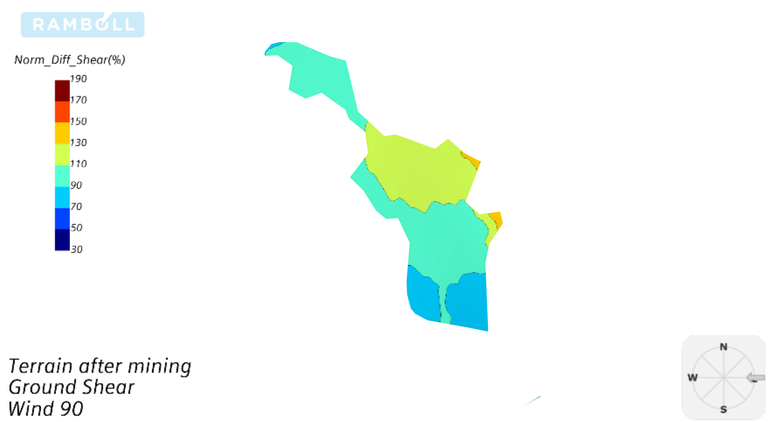
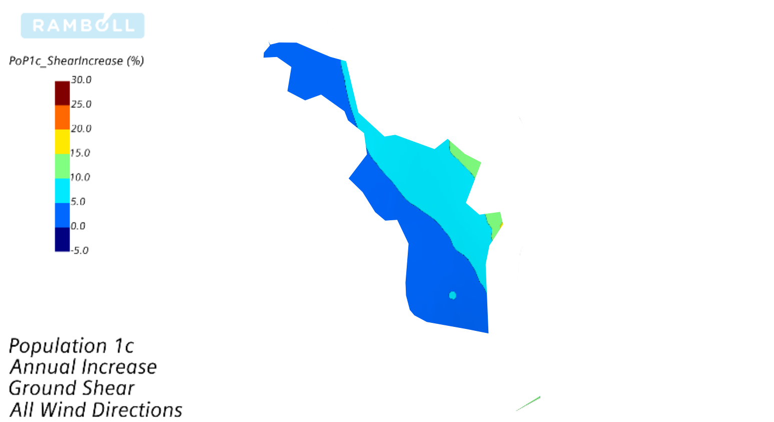
4. RESULTS

For each wind direction, the CFD results contain complete velocity and turbulence fields in the entire flow domain. The primary interest is on factors that affect evaporation rates in the *M.aquilonaris* sub-population areas, these being the "Ground Shear Stress" and the "Gust Factor" at 2 m height above ground level (AGL)". Complete maps of the variation of these two parameters for the existing terrain and future "mined terrain" are included in Appendix A. These maps are further supplemented by maps of the absolute velocity magnitude at 2 m height AGL, which yields a general impression of flow variations in the domain.

Absolute values of the relevant parameters are of little value unless they may be functionally correlated to detailed knowledge of their influence on growth conditions for the threatened species. Ramboll understand such knowledge is at present not available. The approach adopted in this study is therefore to obtain a "reference situation" for the existing terrain and subsequently characterize the influence of mining operations by the relative change of the parameters in the affected population areas.

Heat maps showing the relative change on an annual basis are produced by the following procedure, partially illustrated for the Ground Shear Stress for population area PoP1c (original contour) using results for wind from the east (90 degrees):

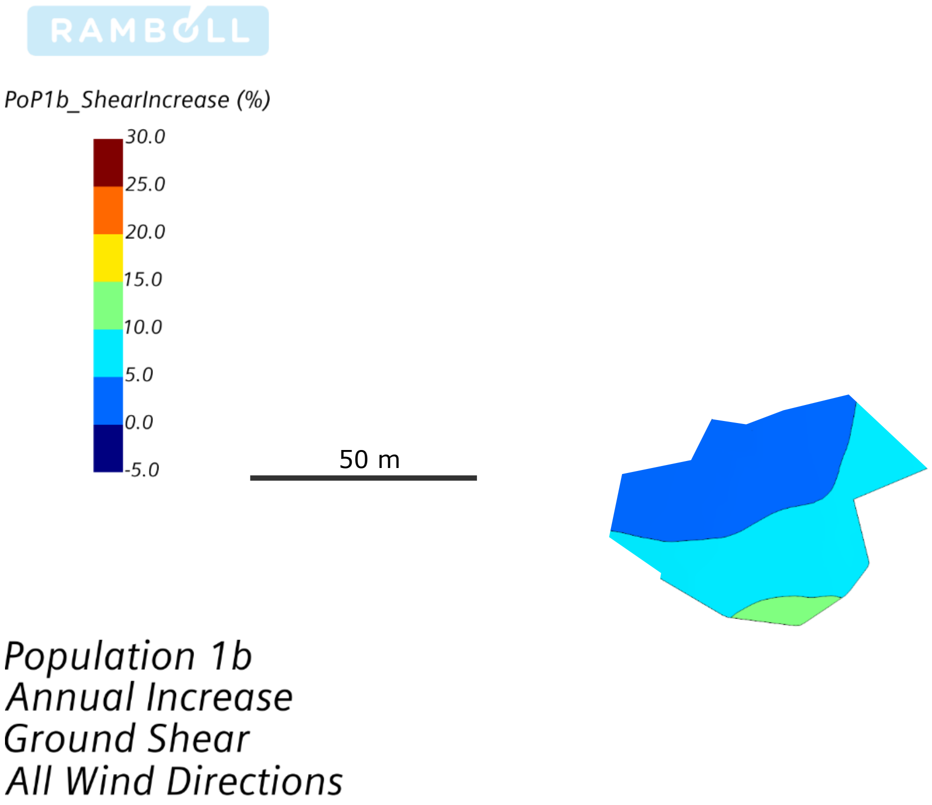
1.	Establish a reference for the existing terrain.	 *Terrain before mining* *Ground Shear* *Wind 90*
2.	Determine future values for the "as mined terrain".	 *Terrain after mining* *Ground Shear* *Wind 90*

3.	Compute the relative change (*RC*) as: $RC = \frac{Future - Existing}{Existing}$	
4.	Compute the annual contribution by multiplying the Relative Change with the frequency of winds above 2 m/s for the relevant wind direction (map not shown, as it is simply a scaled version of the one above).	
5.	Sum up contributions for all wind directions to produce an annual "heat map" of relative change.	

This approach yields the heat maps shown in Figure 7 for PoP1b located immediately north of the Vesuvius pit. The heat map contains values for the full extent of the original population zone. The areas no longer considered relevant have been greyed out, leaving only the revised population zone brightly coloured. As illustrated in Figure 7 the southernmost part of the population area is primarily affected by the changes in landscape, with the degree of change gradually decreasing with increasing distance from the pit. Ground shear is predicted to increase up to 15% on an annual basis within a distance of 5-10 m from the southernmost edge of the population area, which translates to approximately 40 m from the edge of the Vesuvius pit.[1] At distances above 55 m from the edge of the Vesuvius pit, the predicted increase is negligible (less than 5% on an annual basis). For the gust factor, the predicted annualised percentage increase is up to 25% within 45 m of the edge of the pit.

The heat maps for PoP1c located immediately west of the Vesuvius pit, Figure 8, reveal that the influence of landscape changes are restricted to the eastern and north-eastern parts of the area. An annualised percentage increase in ground shear exceeding 10% is predicted to be restricted to a narrow zone within 60 m from the edge of the pit, while the increase becomes negligible at distances above 100 m. For the gust factor, annualised relative changes of 5-10% are confined to within approx. 90 m of the edge of the pit, while changes also become negligible at distances above 100 m. The remaining sub-population areas are outside the sphere of influence of flow changes related to the landscape changes due to mining operations.

[1] The edge of the Vesuvius pit is located about 30 m from the edge of the defined population areas.



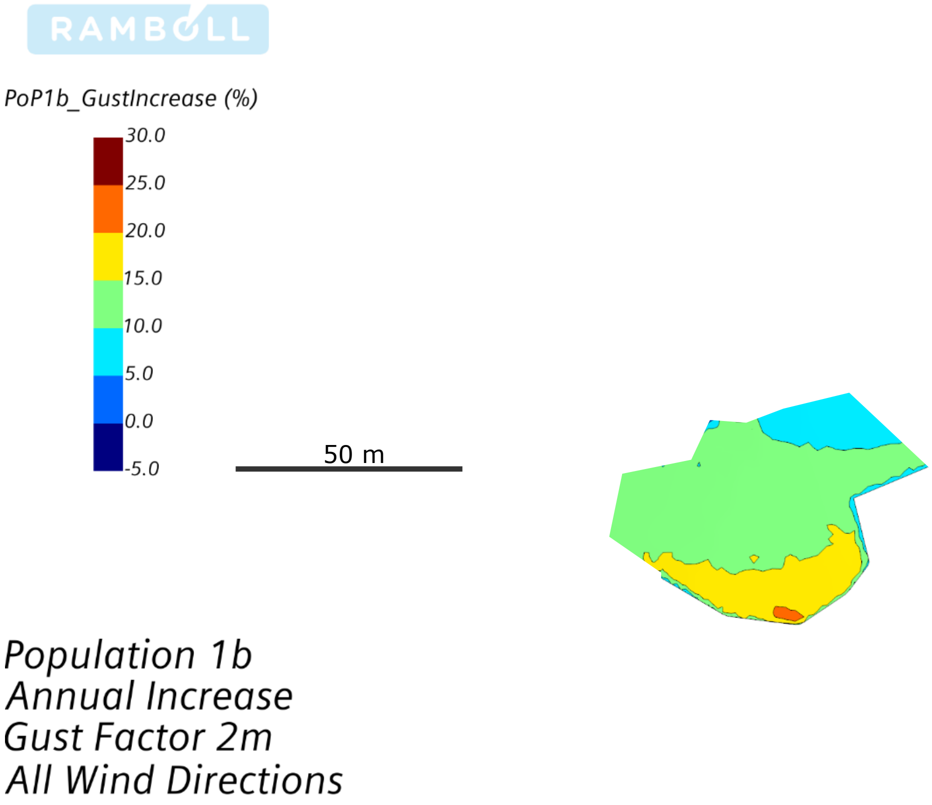
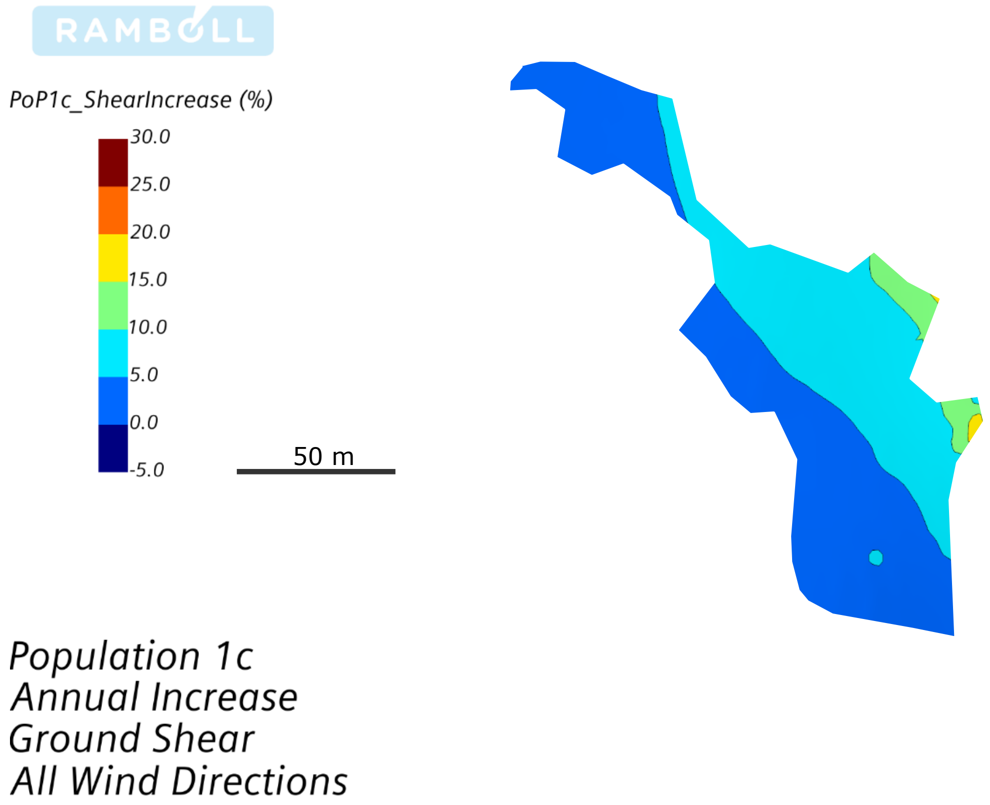


Figure 7. Annual increase in ground shear (top) and gust factor (bottom) for PoP1b, located immediately north of the Vesuvius pit.



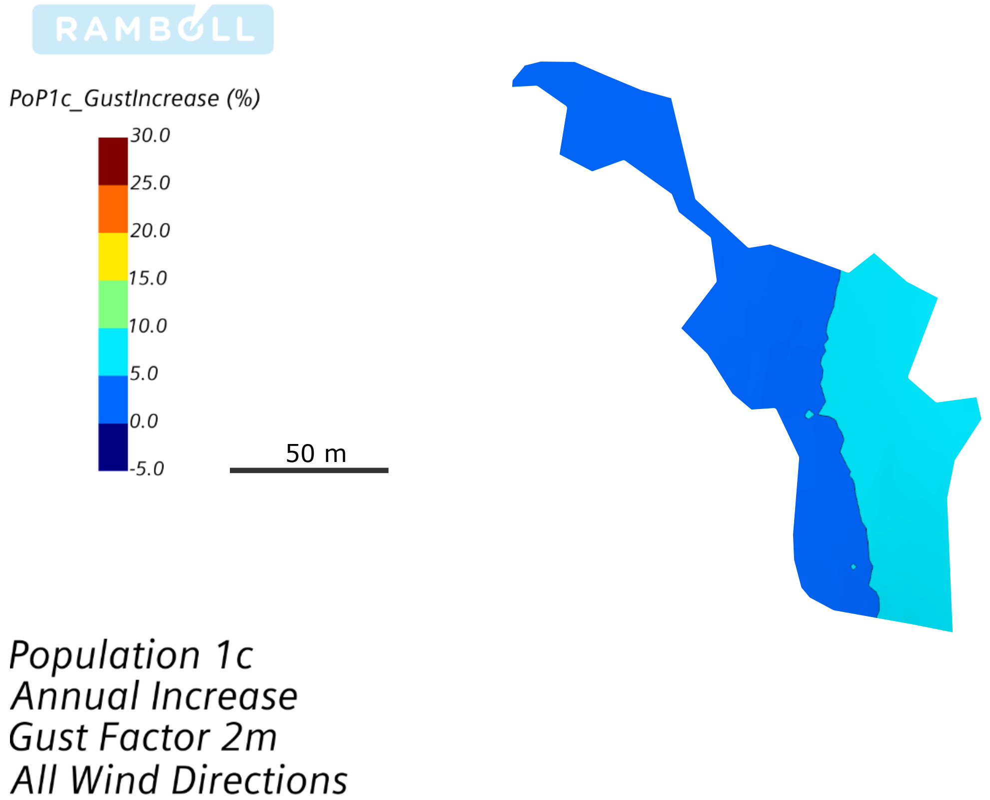


Figure 8. Annual increase in ground shear (top) and gust factor (bottom) for PoP1c, located immediately west of the Vesuvius pit.

5. CONCLUSIONS

Audalia is proposing to develop the Medcalf Project located approximately 470 km south east of Perth near Lake Johnston, Western Australia. The proposal includes the development of three open mine pits, beneficiation plant, tailings storage facility, waste rock landform, private haul road, road train transfer area and associated infrastructure such as laydown areas, borrow and gravel pits, borefield, workshops and accommodation camp.

Baseline environmental surveys have identified one flora species listed as Threatened under the BC Act within the Project site; *M. aquilonaris*. In order to mitigate the potential impacts of mining operations on this species, Audalia propose to exclude all avoidable sub-populations of *M.aquilonaris* from the mine development envelope; and to implement a buffer zone (nominally 30 m) around the sub-populations found within close proximity of the proposed mining operations.

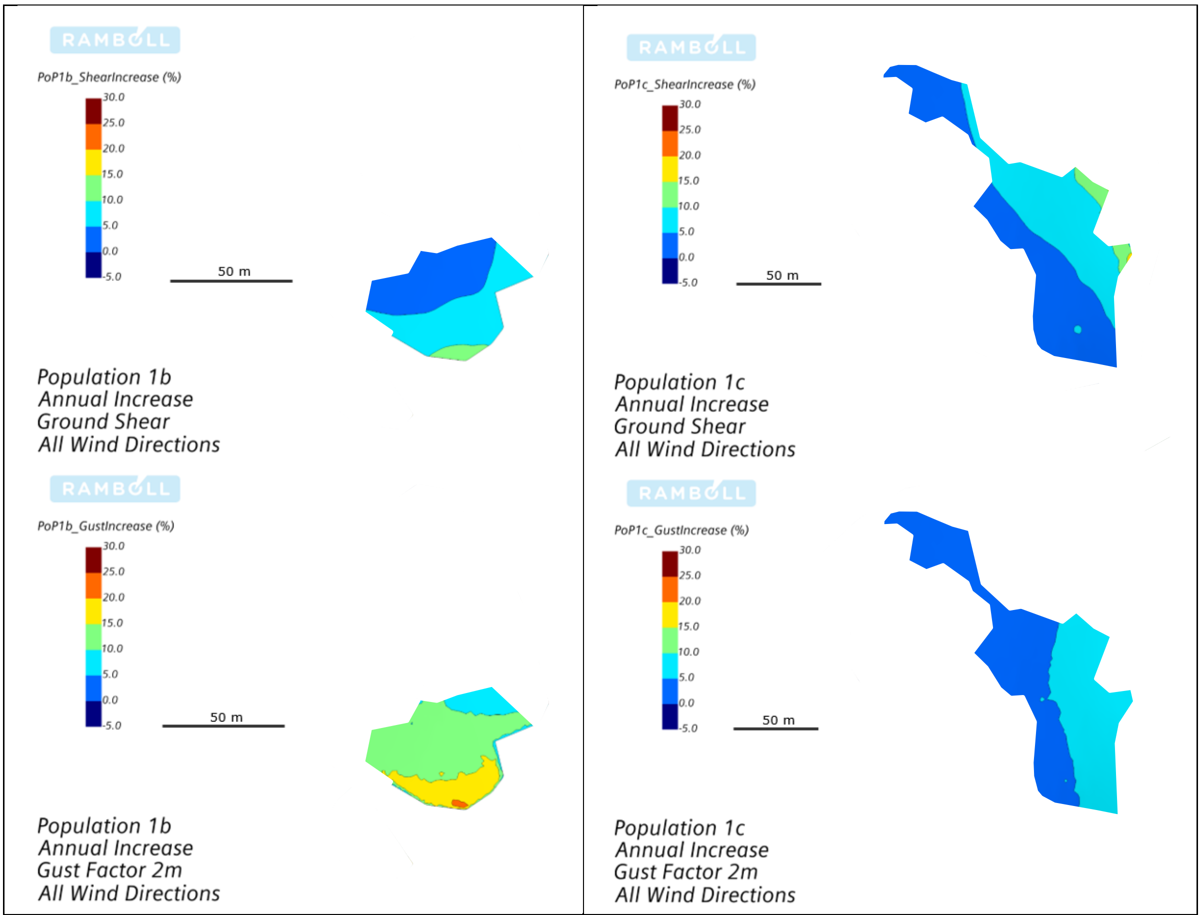
Review of the proposed mine site layout indicates the western and northern boundaries of the Vesuvius pit are within closest proximity to any of the identified *M.aquilonaris* sub-populations. The landscape changes due to the proposed mining operations have been detailed, and contour maps of both the existing and post-mining terrain have been prepared.

CFD flow modelling has been undertaken, to determine the potential impact on wind conditions likely to influence growth conditions for the *M.aquilonaris* sub-populations. In the absence of specific assessment guidelines for impacts on vegetation from wind conditions, it is difficult to quantitatively assess the potential impact on the *M.aquilonaris* sub-populations, however it is assumed that an important factor is the evaporation rate. Evaporation rates depend on velocity gradients close to the ground and on mixing rates in the boundary layer above it, and these two factors have therefore been selected as descriptive of the potential impacts from mining operations.

To provide an overview of the potential changes in wind conditions, annual "heat maps" of relative increase (change) have been prepared, where the wind statistics have been embedded. As wind dependent evaporation rates increase as wind speed increases, only winds above 2 m/s have been included in the underlying statistics when generating the maps. As winds below 2 m/s have a frequency of 16.4% on annual basis, the maps provided are believed to be conservative.

For population area 1b located north of the Vesuvius pit ground shear is predicted to increase up to 10% on an annual basis within a distance of 40 m from the edge of the Vesuvius pit. At distances above 55 m from the pit, the predicted increase is negligible (less than 5% on an annual basis). For the gust factor, the predicted annualised percentage increase is up to 20% within 40 m of the edge of the pit, while at distances above 100 m the increase is negligible.

The heat maps for population area 1c located immediately west of the Vesuvius pit, an annualised percentage increase in ground shear exceeding 10% is predicted to be restricted to within 60 m from the edge of the pit, while the increase becomes negligible at distances above 100 m. For the gust factor, an annualised increase of 5-10% is confined to within 90 m of the edge of the pit, with changes also becoming negligible at distances above 100 m.



Heat maps for population area 1b	Heat maps for population area 1c

Figure 9. Annual increase in ground shear (top) and gust factor (bottom) for population areas 1b and 1c.

6. REFERENCES

1. *Appropriate boundary conditions for computational wind engineering models using the k-e turbulence model.* **Richards, P. J. and Hoxey, R. P.** 1993, Journal of Wind Engineering and Industrial Aerodynamics, Vol. 46, pp. 145-153.
2. *Updating the Davenport roughness classification.* **Wieringa, J.** 1992, Journal of Wind Engineering and Industrial Aerodynamics, Vols. 41(1-3), pp. 357-368.
3. **Ramboll.** *Audalia Resources Limited Medcalf Project - Dust Deposition Study.* Perth, Australia : s.n., 2019.

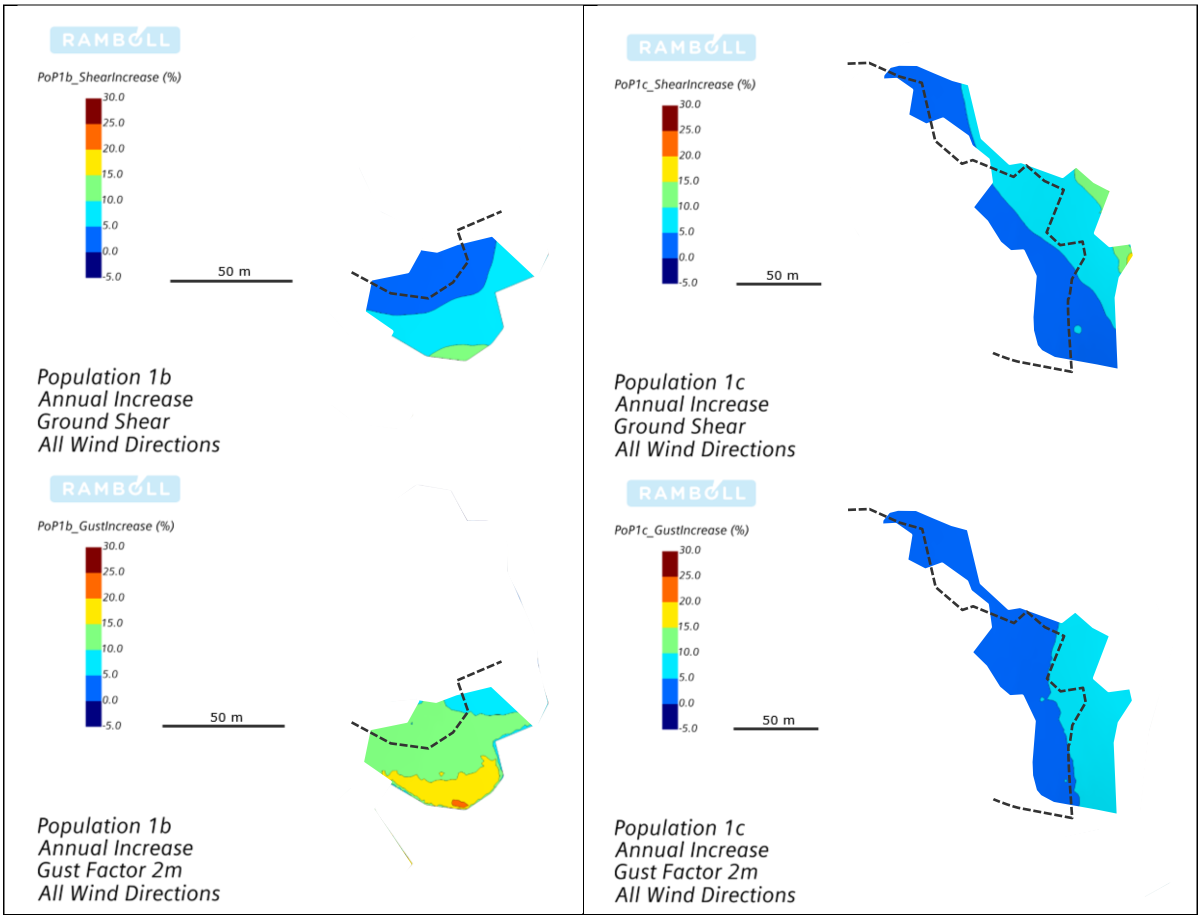
7. ADDENDUM

Ramboll understand since completion of the CFD wind assessment, the footprint of the Vesuvius pit has been revised and the distance between the proposed pit crest and sub-populations 1b and 1c has increased. The revised pit boundary is set back an additional 30 to 50 m from the sub-population 1b buffer zone; and between 15 to 50 m further back from the sub-population 1c buffer zone (Figure 11). In effect, the minimum distance between the pit crest and sub-population 1b has increased from 30 m to 60 m, and the minimum distance between the pit crest and sub-population 1c has increased from 30 m to 45 m.

Assuming a similarly shaped pit, the effect of this revision is not likely to have significant impact on computed wind characteristics, apart from a corresponding shift of the location of wind shear and gust factors, generated by the terrain features. The findings of the CFD wind assessment, the predicted annual increase in ground shear and gust factor at sub-population 1b and 1c are likely to be significantly lower than those presented in Figure 7 and Figure 8, given that modelling results indicate a rapid decrease in relative change in these gradients with increasing distance from the modelled pit crest. Assuming that wind gradients produced by the pit crest of the revised Vesuvius pit footprint is similar to those predicted for the original pit footprint (based on similarly shaped pits as noted), an indication of the likely effect of increasing the distance between the pit crest and *M.aquilonaris* sub-populations can be inferred from the dotted contours illustrated on Figure 10.

As indicated in the illustration, the predicted maximum increase in ground shear for population area 1b located north of the Vesuvius pit would likely decrease from 10-15% to less than 5% on an annual basis. For the gust factor, the corresponding annualised percentage increase would likely decrease from a maximum of 20% to a maximum of 15%. The total affected area of the population would also decrease significantly in both cases.

For population area 1c located immediately west of the Vesuvius pit, the annualised percentage increase in ground shear would likewise decrease from a maximum around 15% to a maximum of around 10%. For the gust factor, a maximum annualised increase of up to 10% would decrease to a maximum increase of up to just above 5%. Similarly, the total affected area of the population would decrease significantly.



Heat maps for population area 1b	Heat maps for population area 1c

Figure 10. Expected annual increase in ground shear (top) and gust factor (bottom) for population areas 1b and 1c, with a 30 m increase in distance from the Vesuvius pit crest. The relevant portions of the heat map following the revised mine site footprint is above and to the left of the dotted lines.

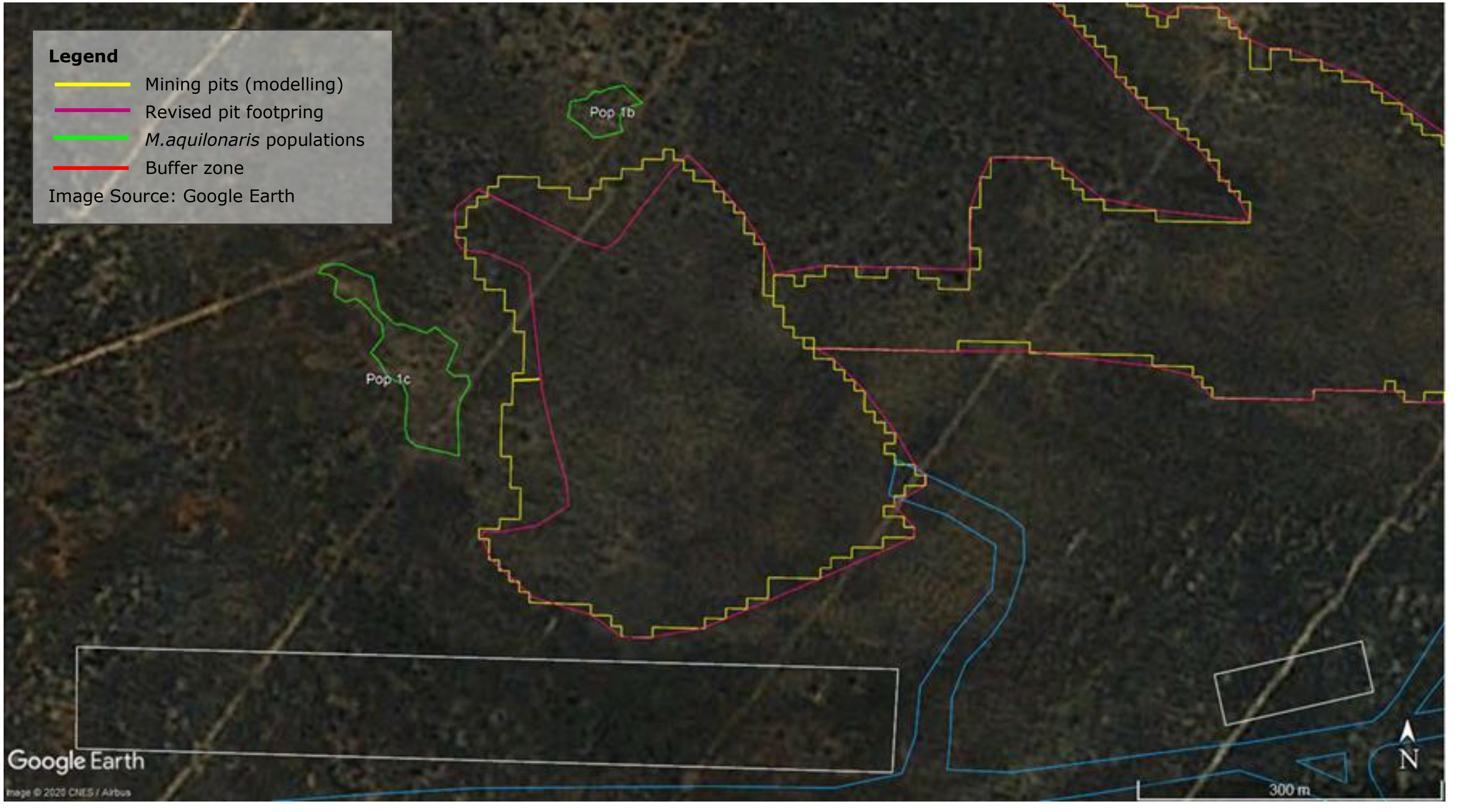


Figure 11: Proposed Revision of Vesuvius Pit Boundary.

APPENDIX 1
RESULT MAPS FOR ALL WIND DIRECTIONS (ORIGINAL M.AQUILONARIS POPULATION CONTOURS)

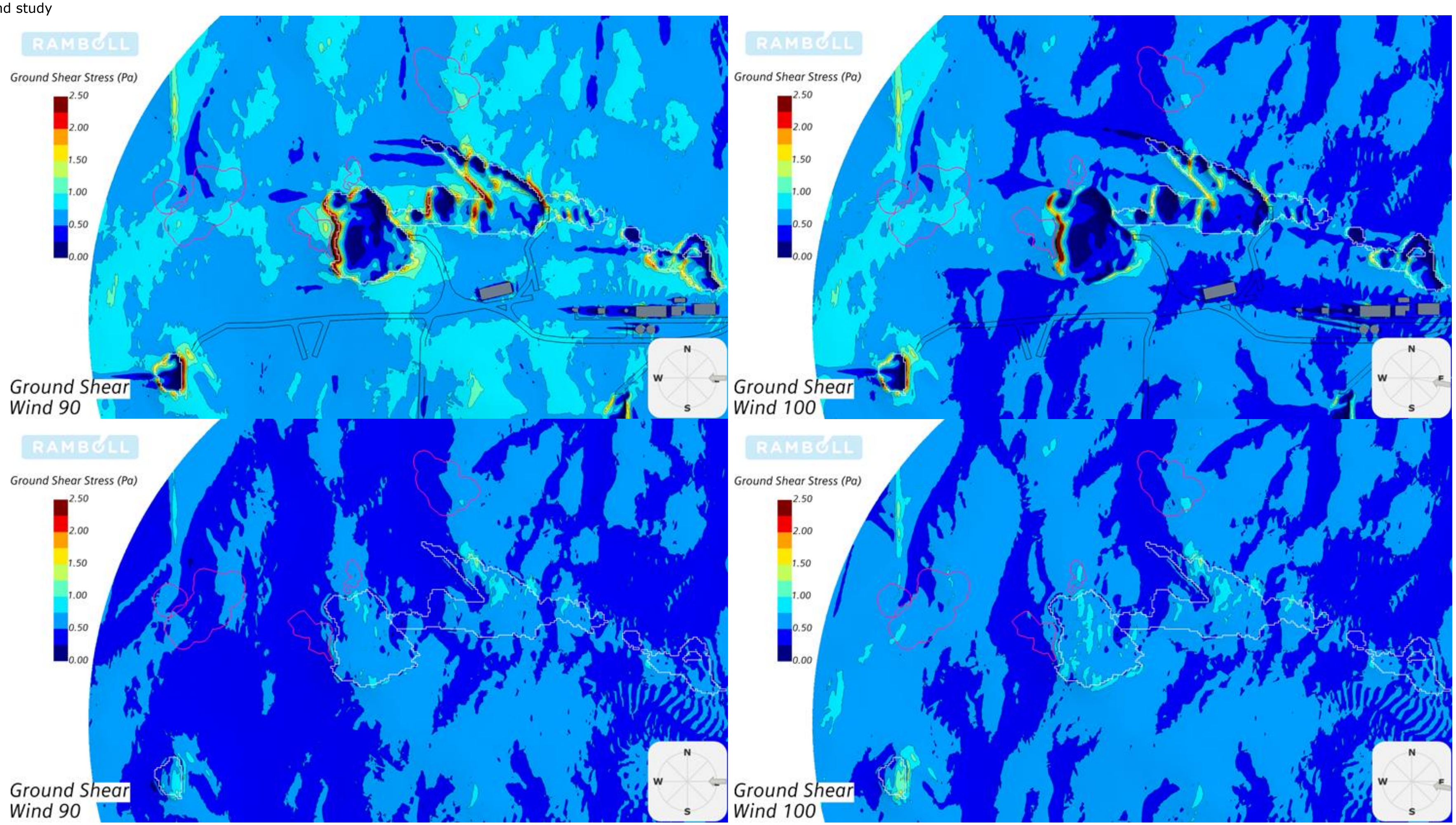


Figure A. 1. Ground Shear Stress for 90 and 100 degrees. Mined terrain (top) and existing Terrain (bottom).

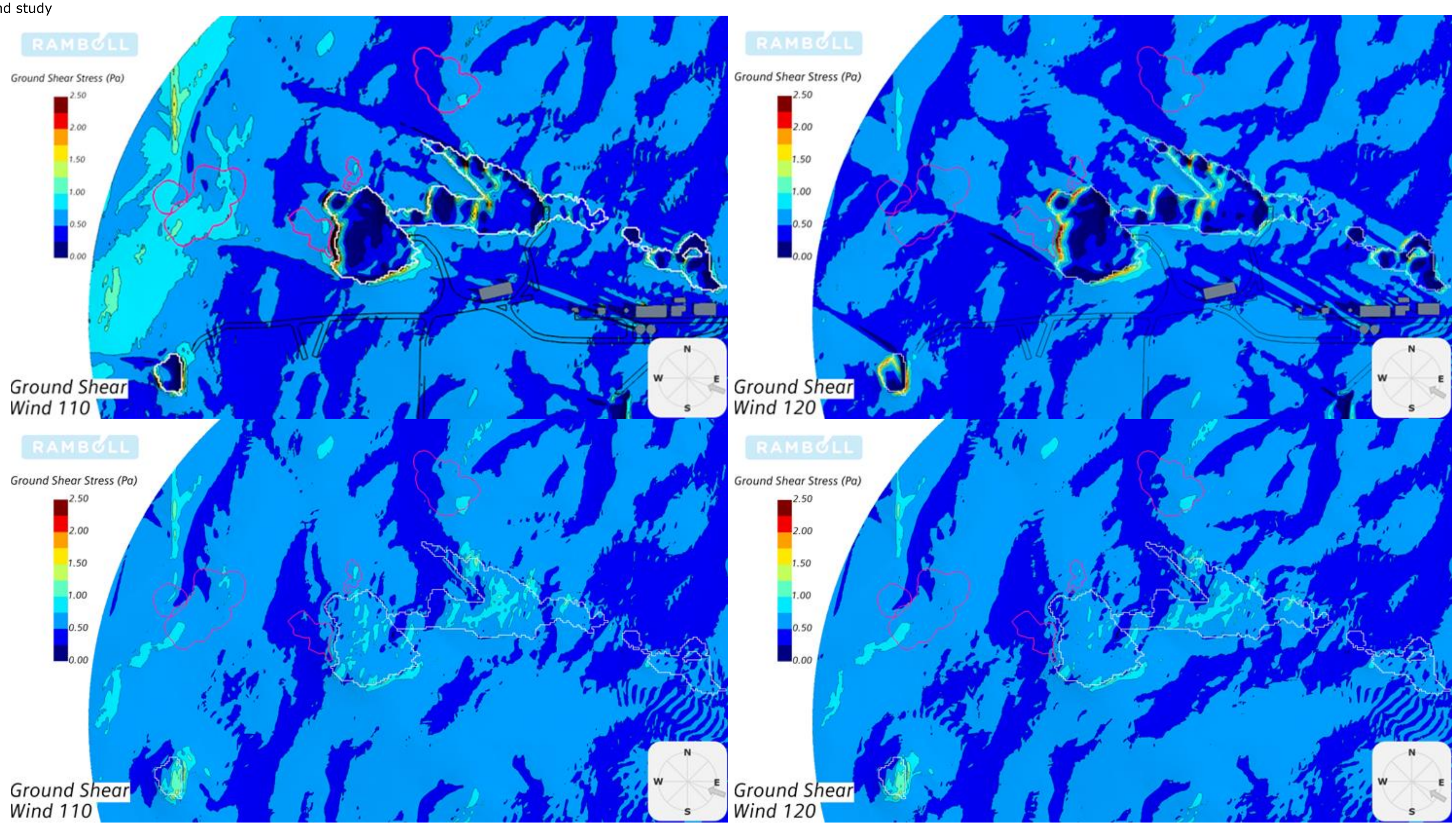


Figure A. 2. Ground Shear Stress for 110 and 120 degrees. Mined terrain (top) and existing Terrain (bottom).

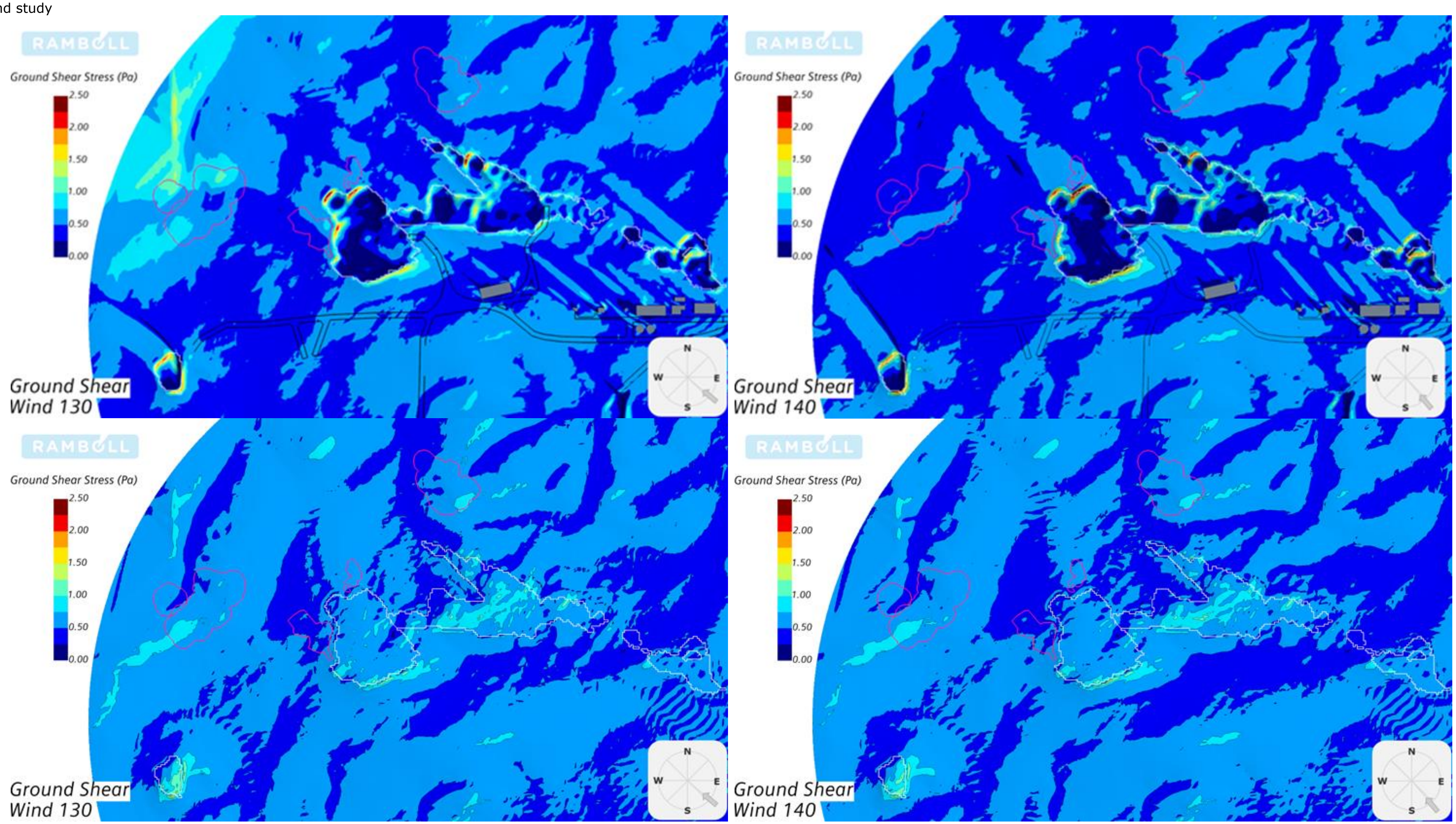


Figure A. 3. Ground Shear Stress for 130 and 140 degrees. Mined terrain (top) and existing Terrain (bottom).

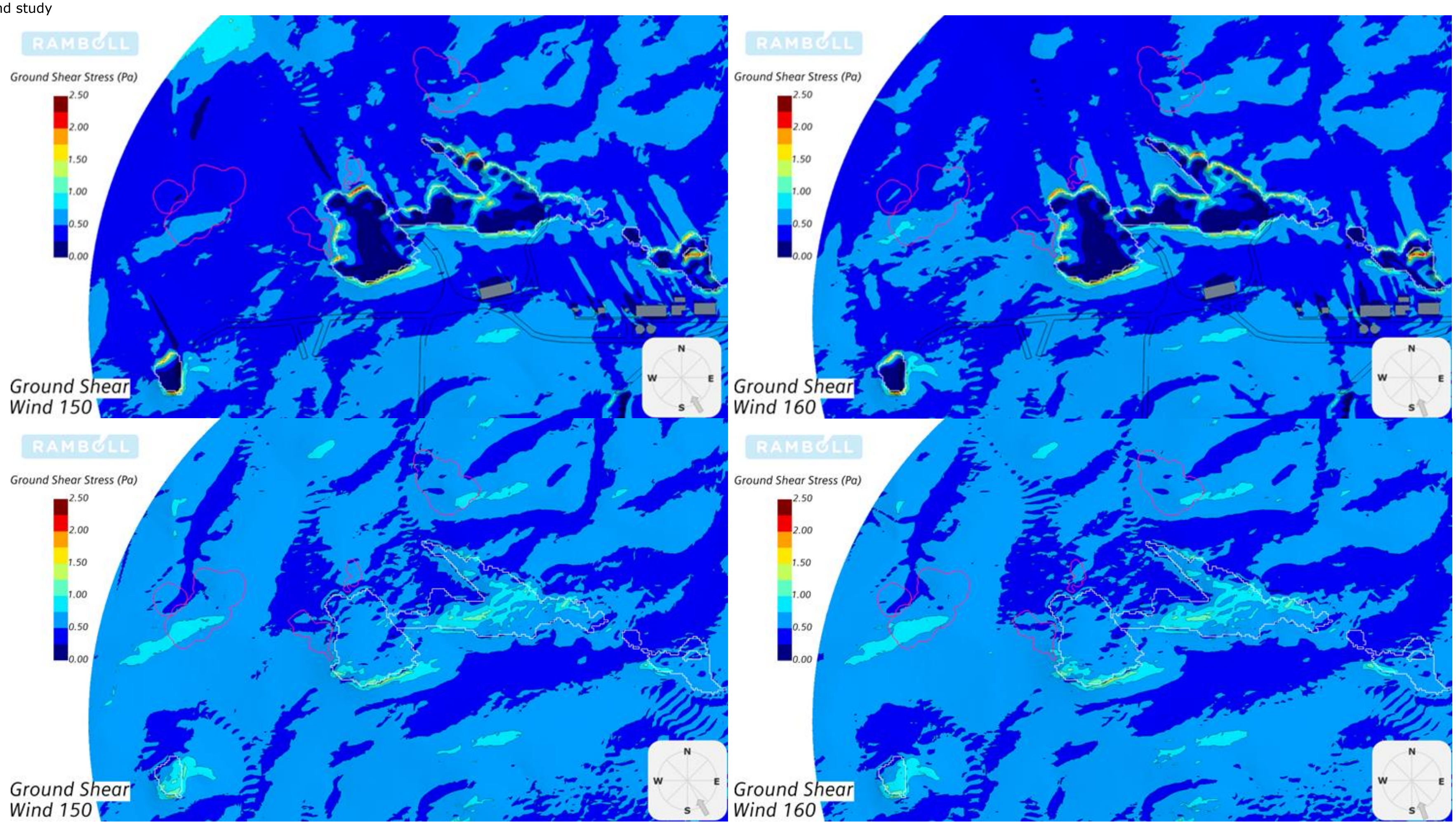


Figure A. 4. Ground Shear Stress for 150 and 160 degrees. Mined terrain (top) and existing Terrain (bottom).

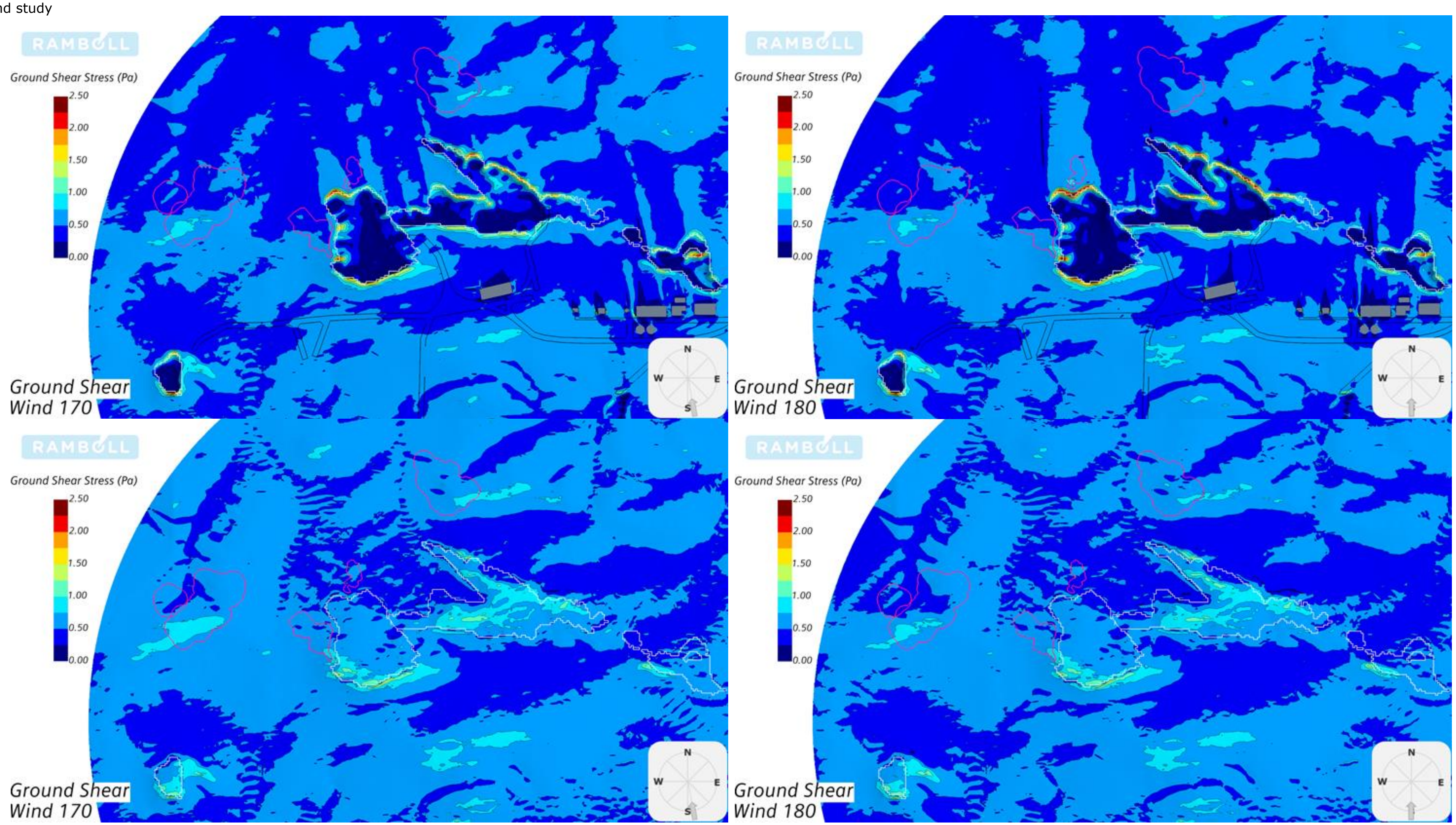


Figure A. 5. Ground Shear Stress for 170 and 180 degrees. Mined terrain (top) and existing Terrain (bottom).

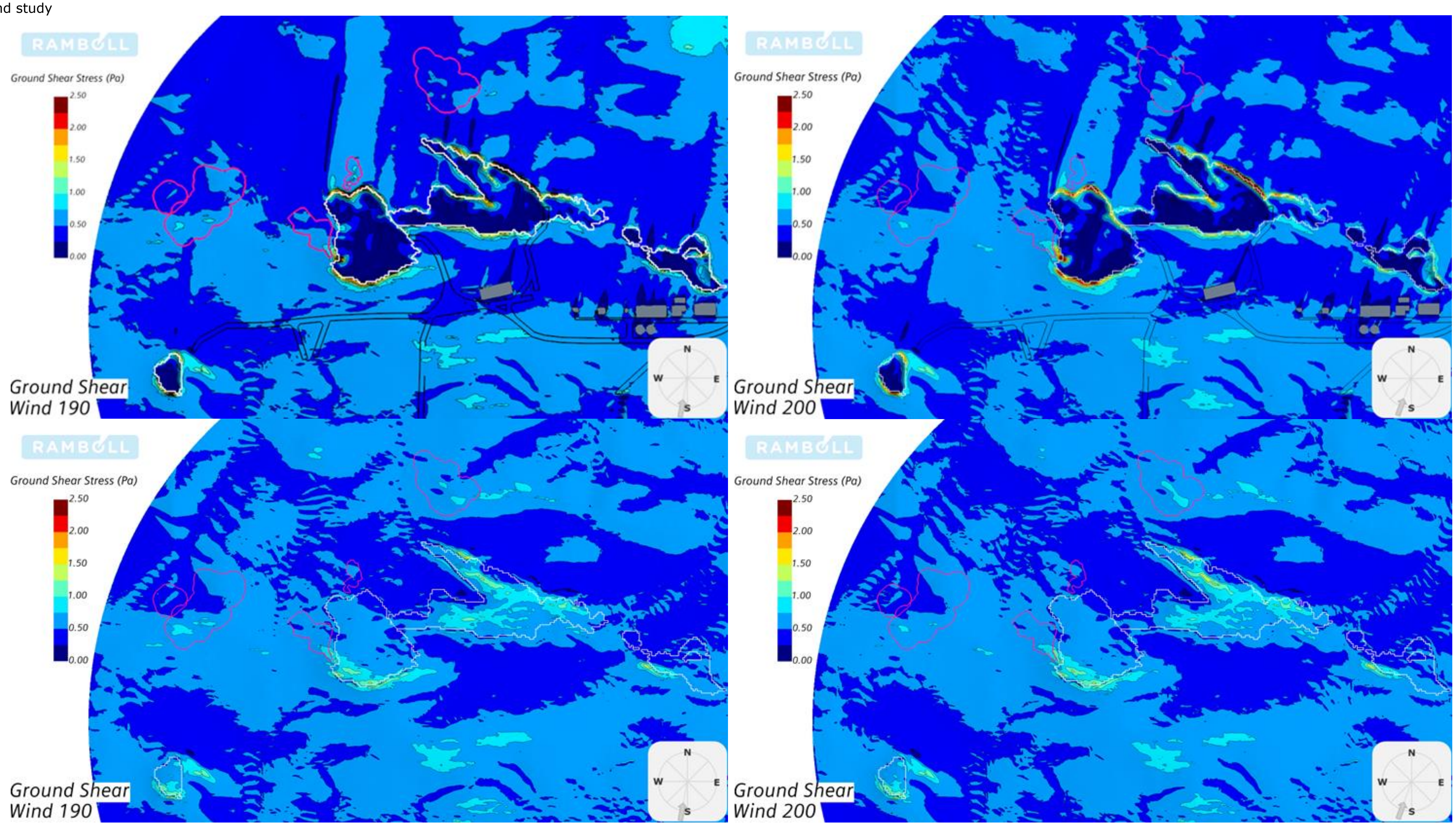


Figure A. 6. Ground Shear Stress for 190 and 200 degrees. Mined terrain (top) and existing Terrain (bottom).

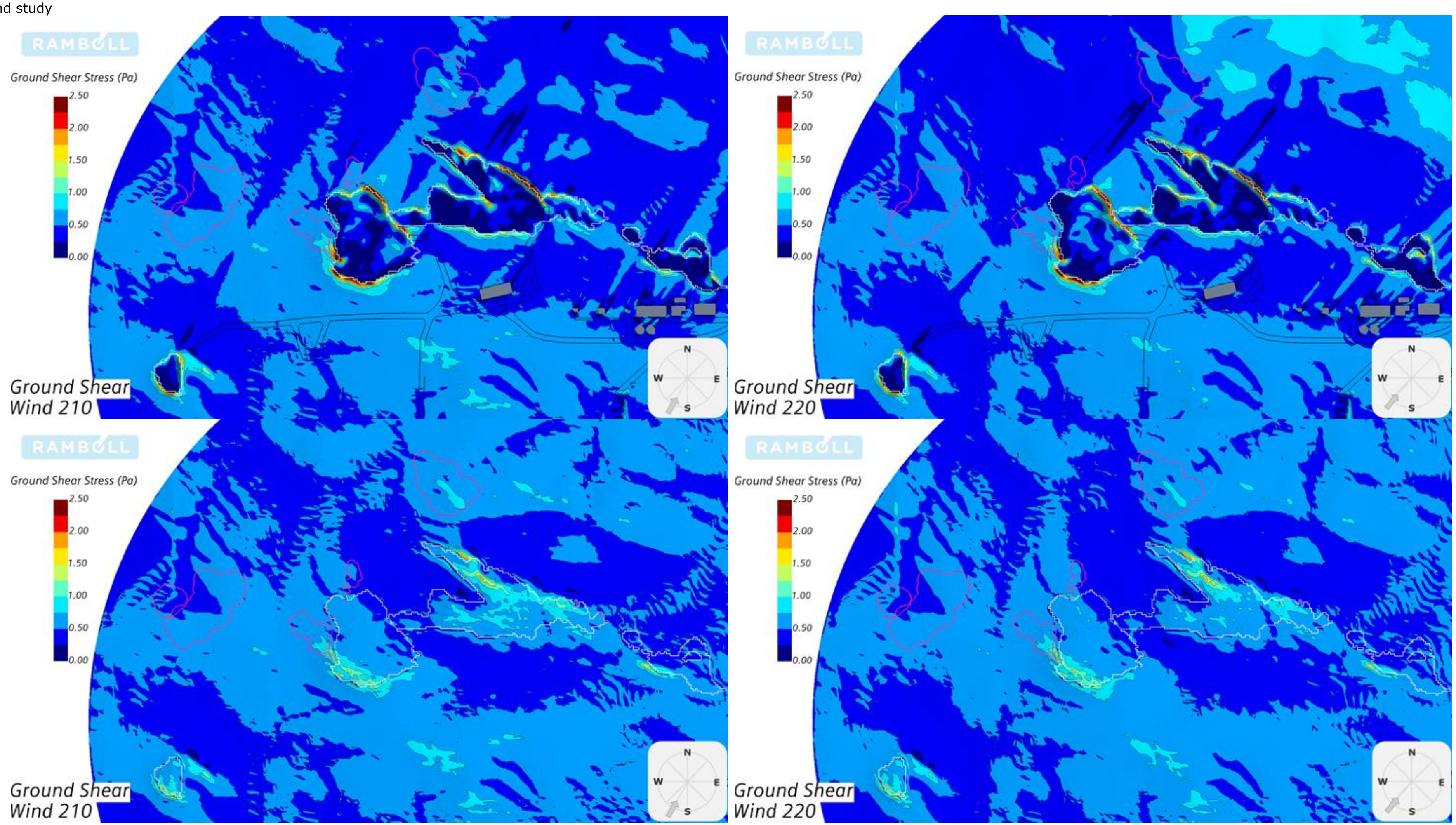


Figure A. 7. Ground Shear Stress for 210 and 220 degrees. Mined terrain (top) and existing Terrain (bottom).

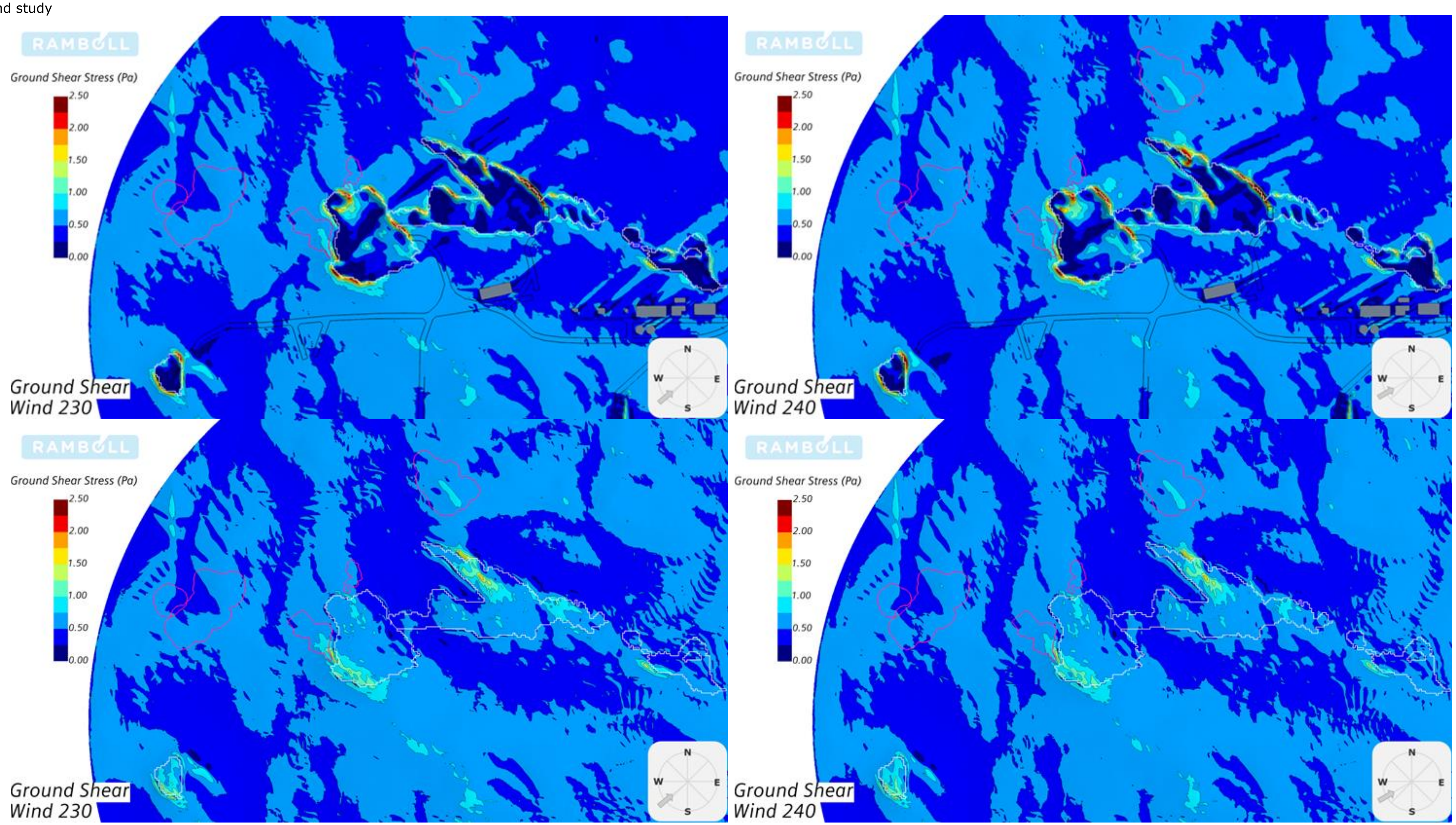


Figure A. 8. Ground Shear Stress for 230 and 240 degrees. Mined terrain (top) and existing Terrain (bottom).

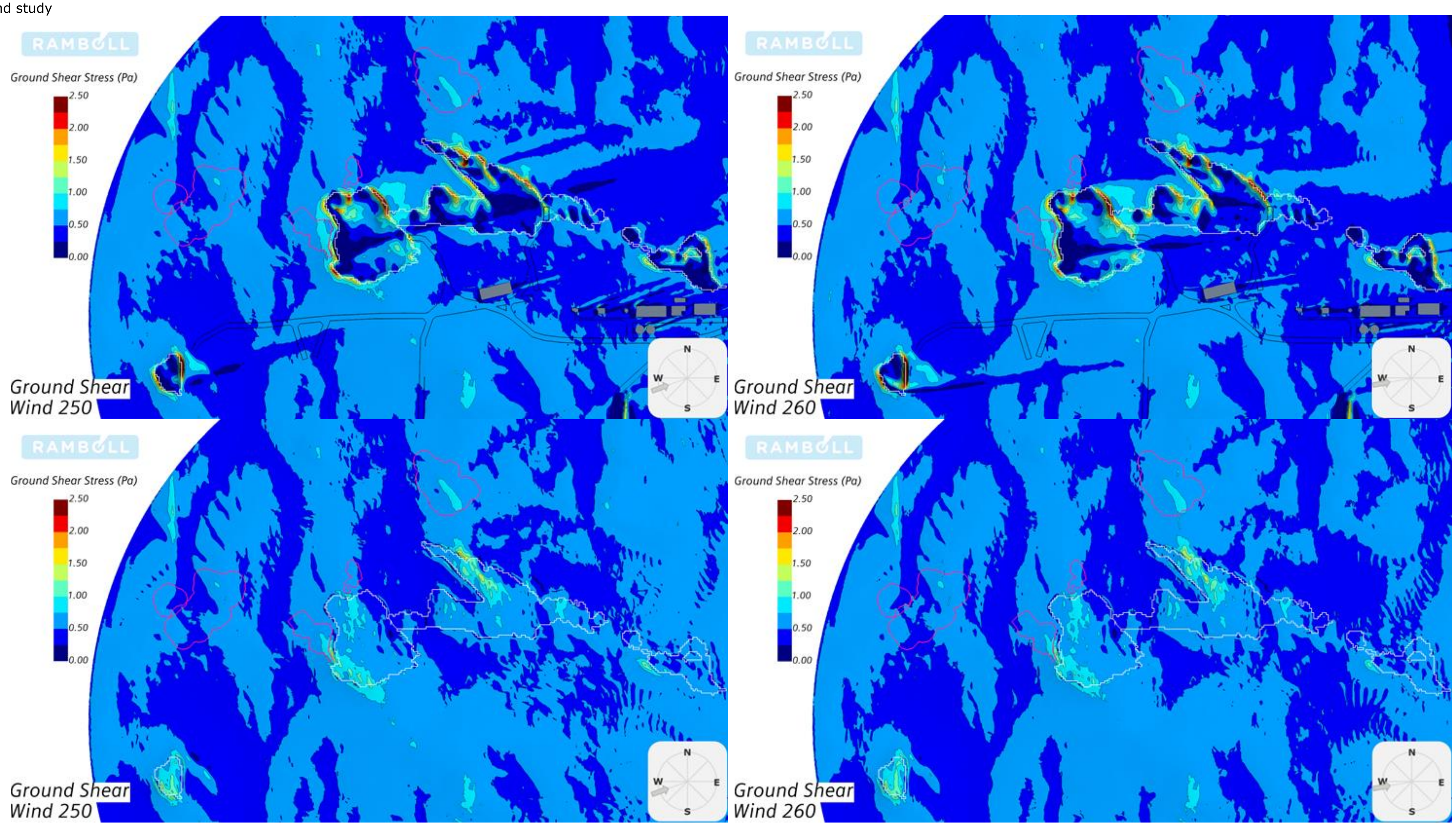


Figure A. 9. Ground Shear Stress for 250 and 260 degrees. Mined terrain (top) and existing Terrain (bottom).

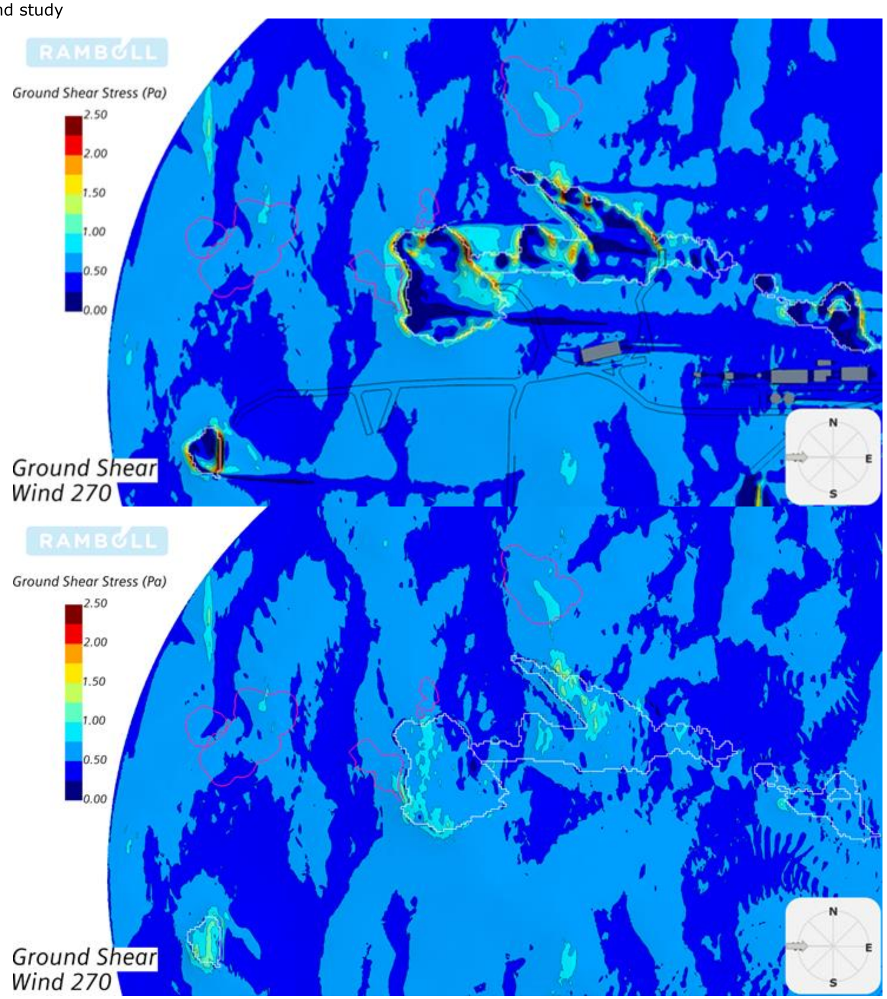


Figure A. 10. Ground Shear Stress for 270 degrees. Mined terrain (top) and existing Terrain (bottom).

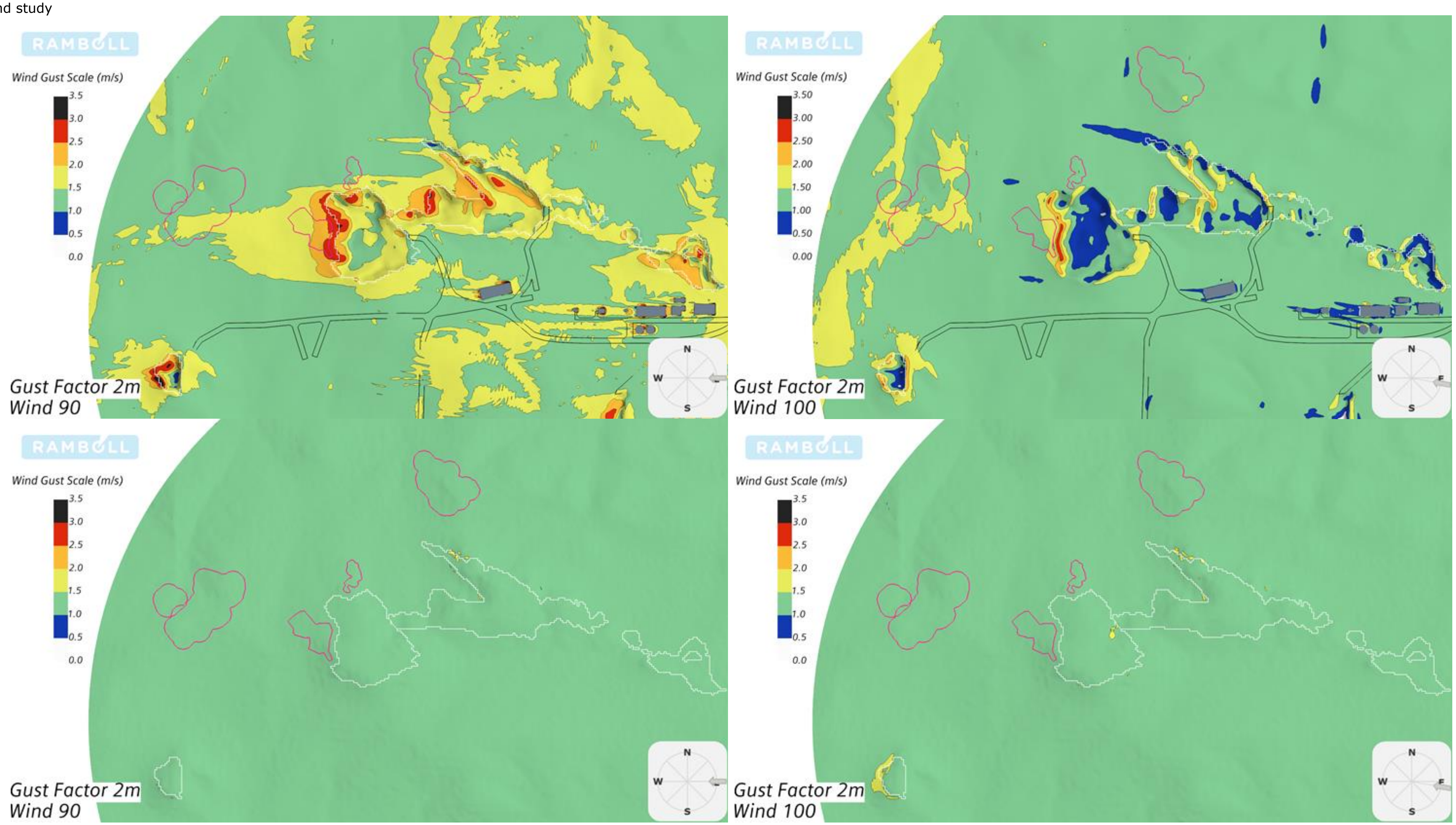


Figure A. 11. Gust Factor 2 m AGL for 90 and 100 degrees. Mined terrain (top) and existing Terrain (bottom).

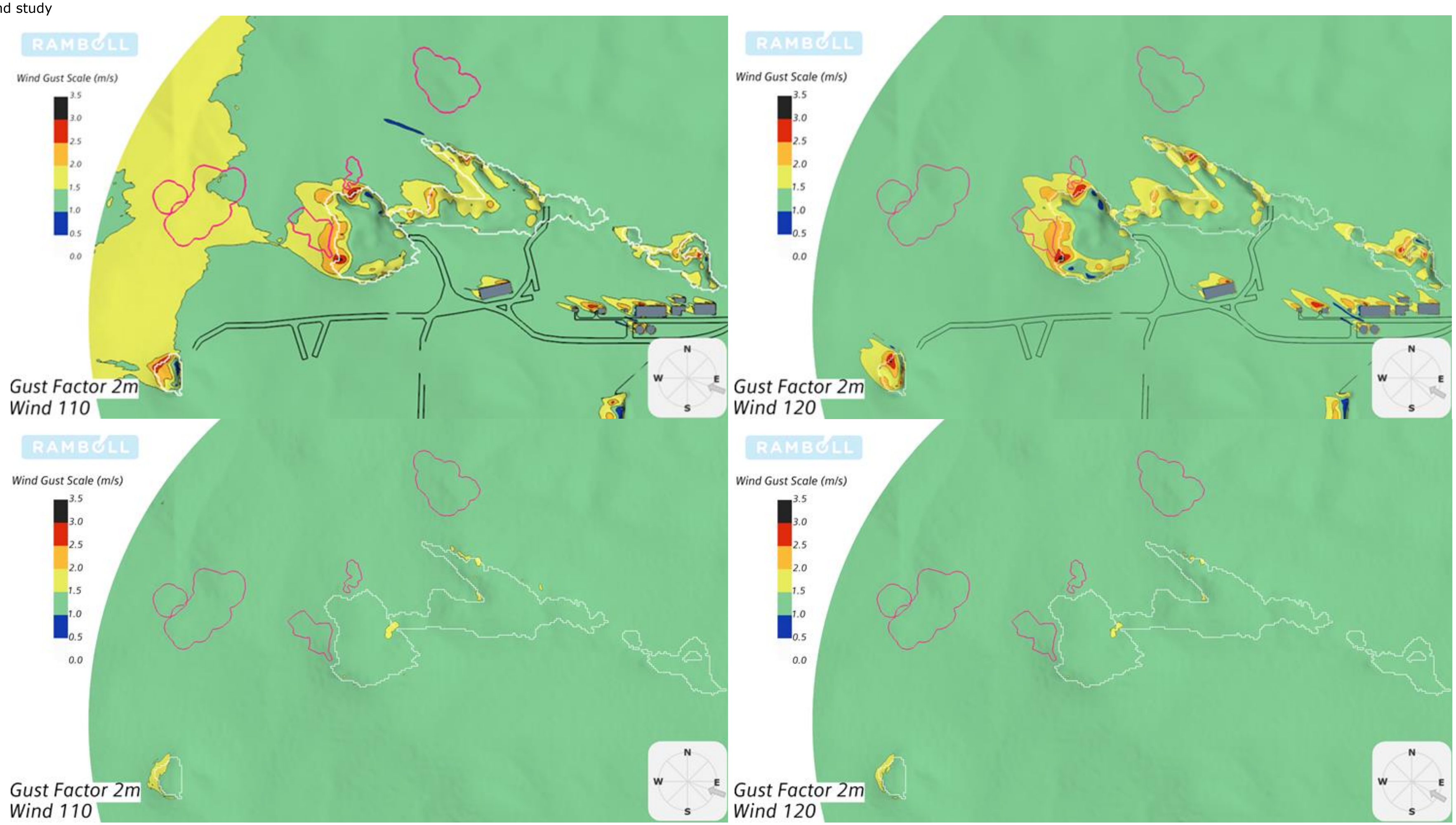


Figure A. 12. Gust Factor 2 m AGL for 110 and 120 degrees. Mined terrain (top) and existing Terrain (bottom).

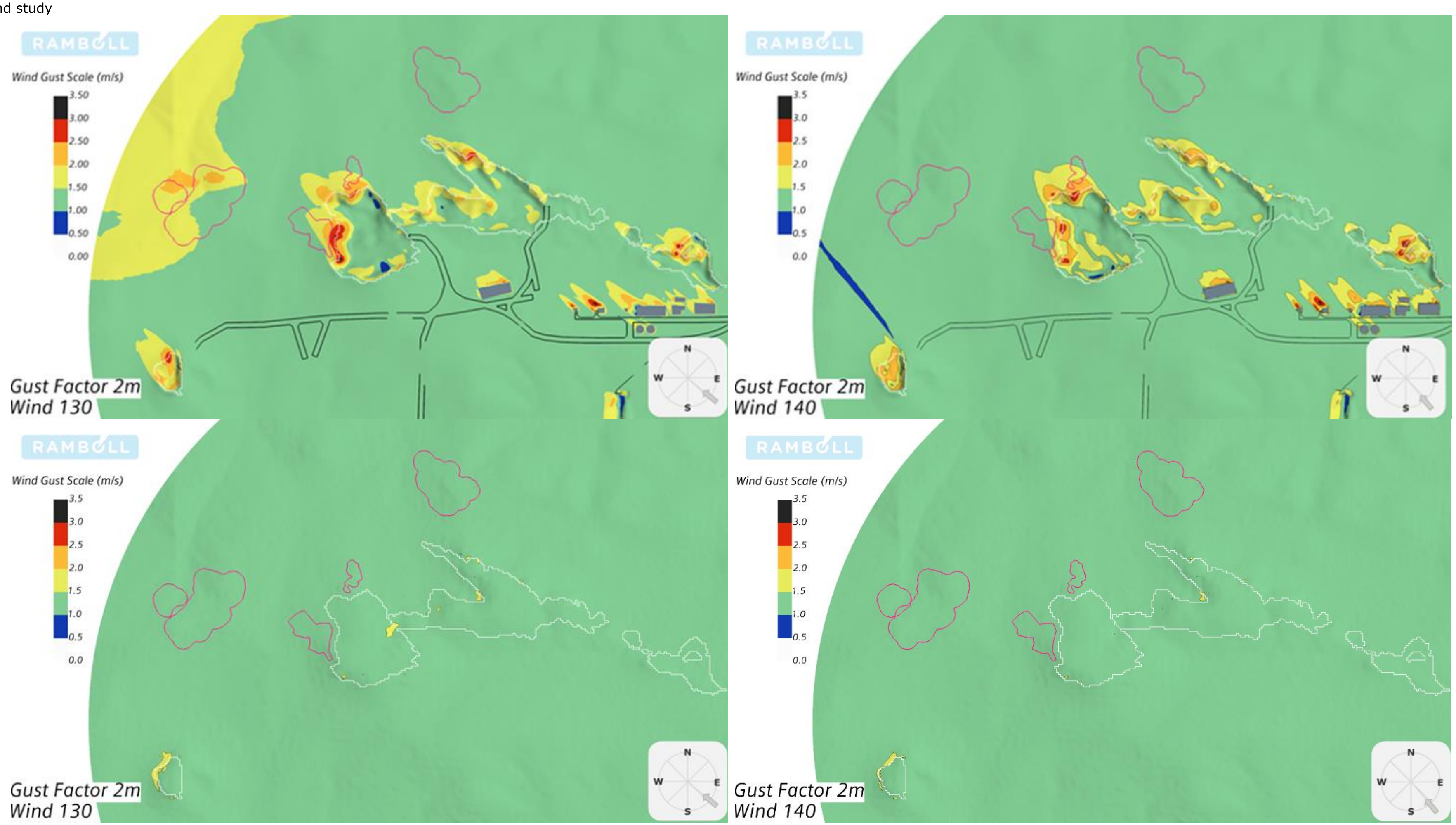


Figure A. 13. Gust Factor 2 m AGL for 130 and 140 degrees. Mined terrain (top) and existing Terrain (bottom).

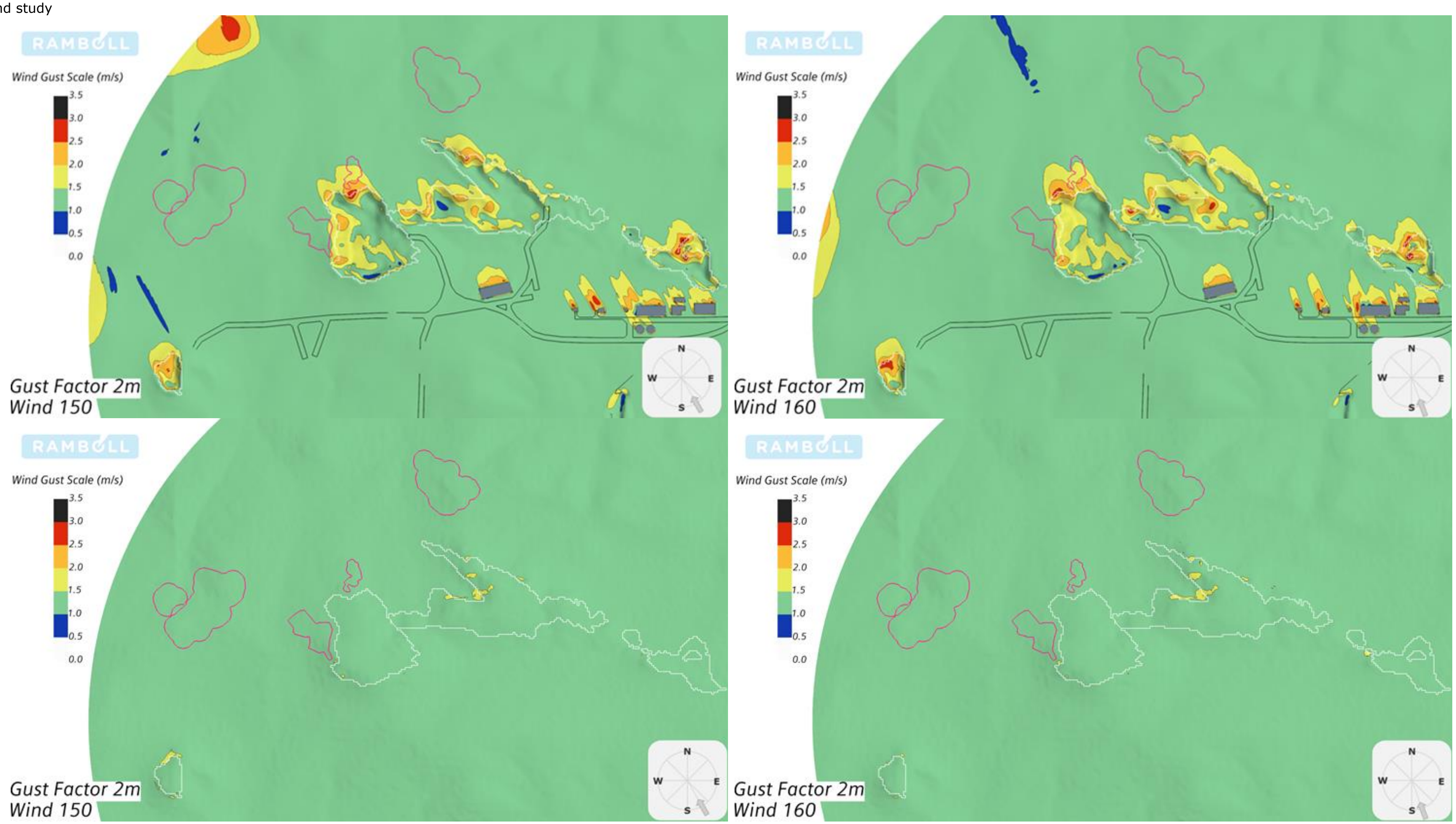


Figure A. 14. Gust Factor 2 m AGL for 150 and 160 degrees. Mined terrain (top) and existing Terrain (bottom).

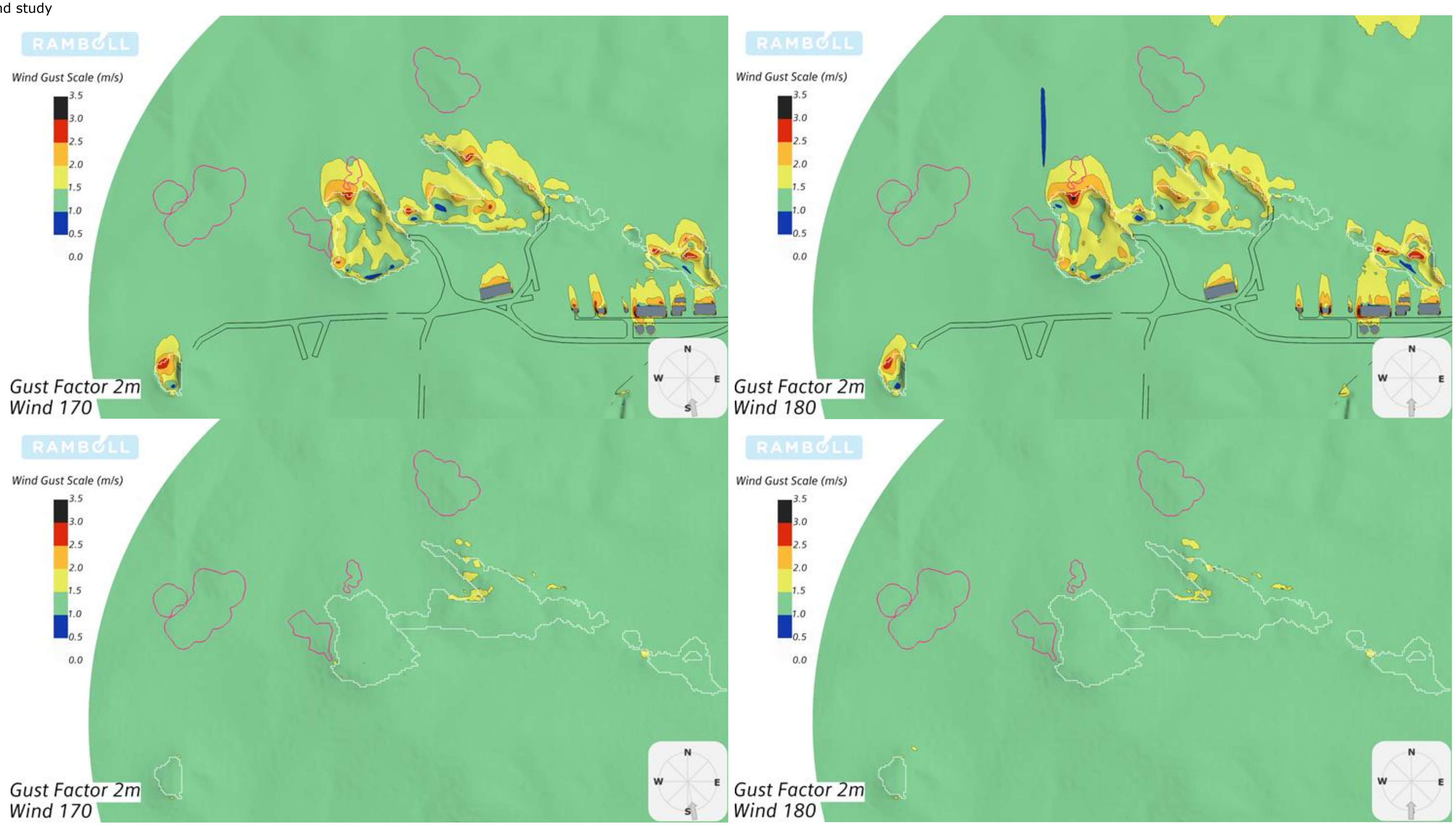


Figure A. 15. Gust Factor 2 m AGL for 170 and 180 degrees. Mined terrain (top) and existing Terrain (bottom).

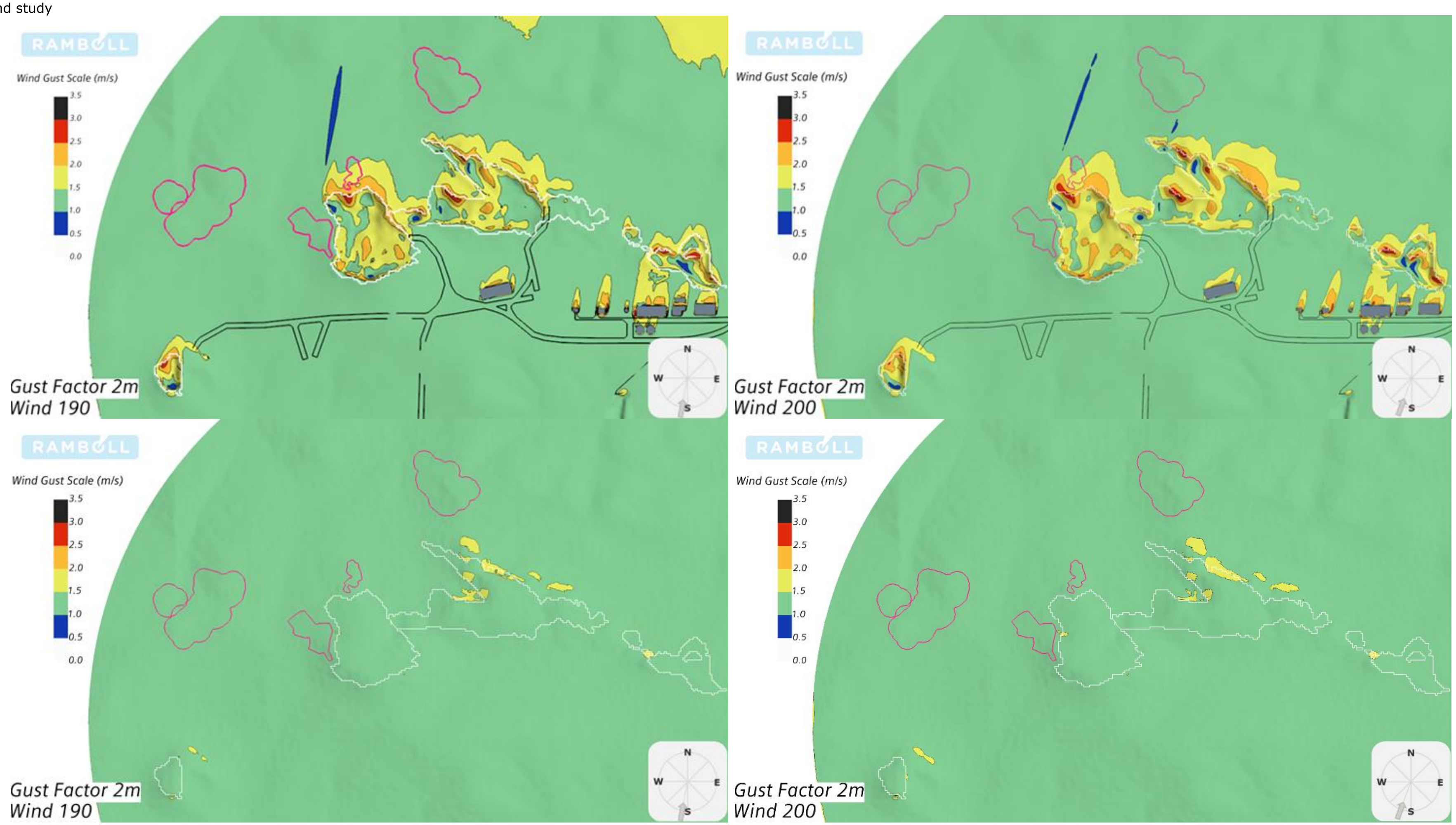


Figure A. 16. Gust Factor 2 m AGL for 190 and 200 degrees. Mined terrain (top) and existing Terrain (bottom).

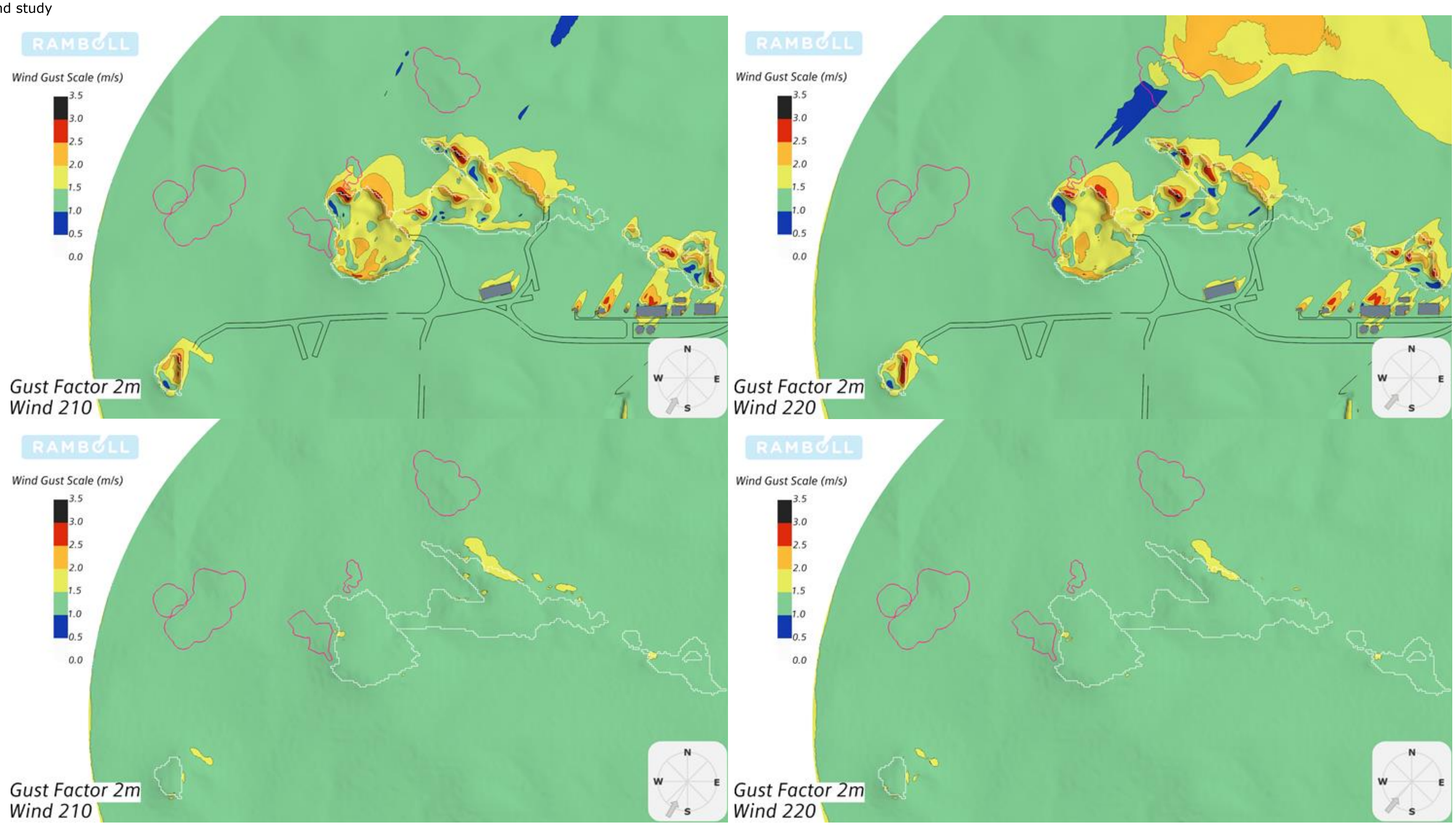


Figure A. 17. Gust Factor 2 m AGL for 210 and 220 degrees. Mined terrain (top) and existing Terrain (bottom).

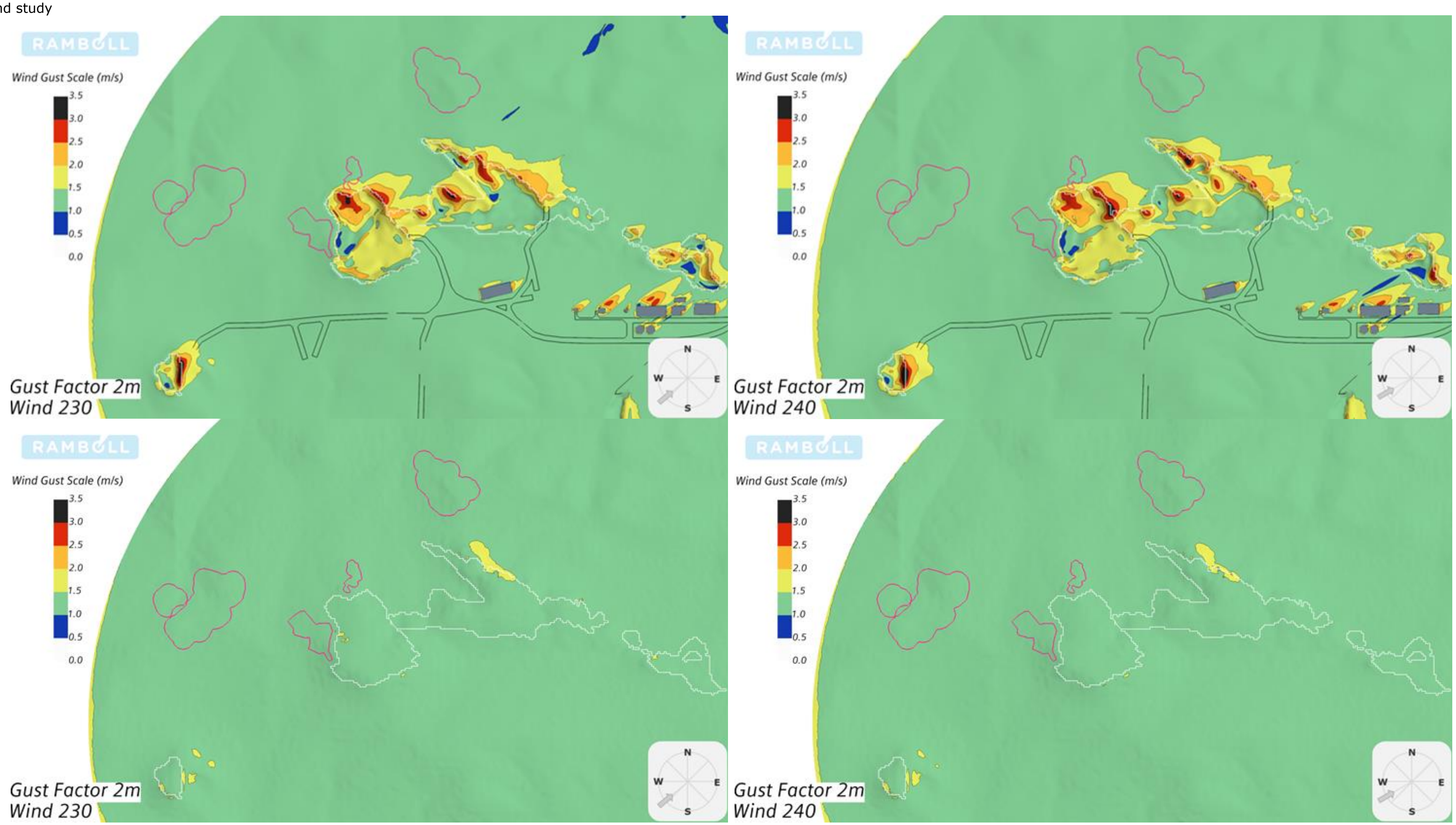


Figure A. 18. Gust Factor 2 m AGL for 230 and 240 degrees. Mined terrain (top) and existing Terrain (bottom).

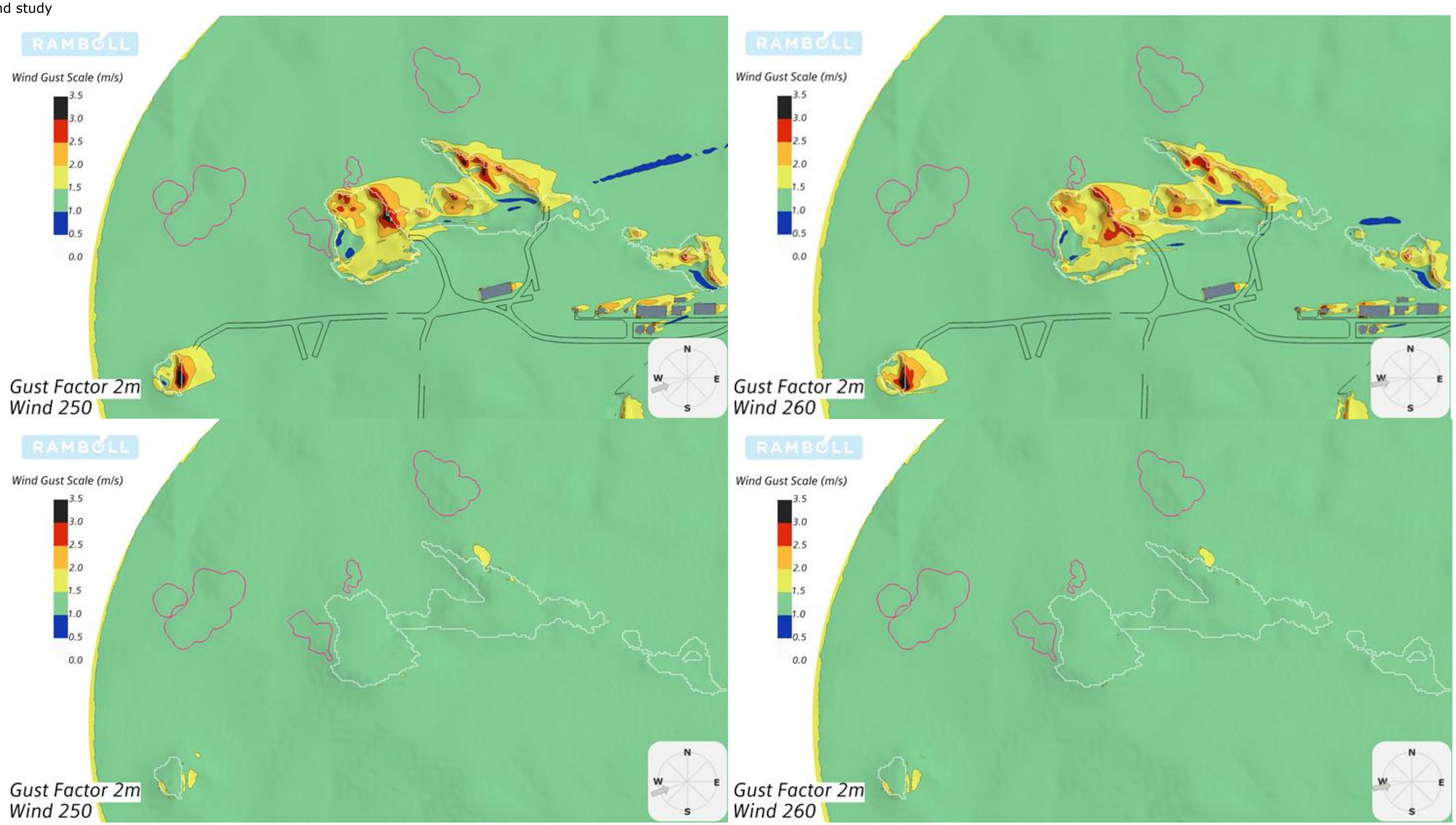


Figure A. 19. Gust Factor 2 m AGL for 250 and 260 degrees. Mined terrain (top) and existing Terrain (bottom).

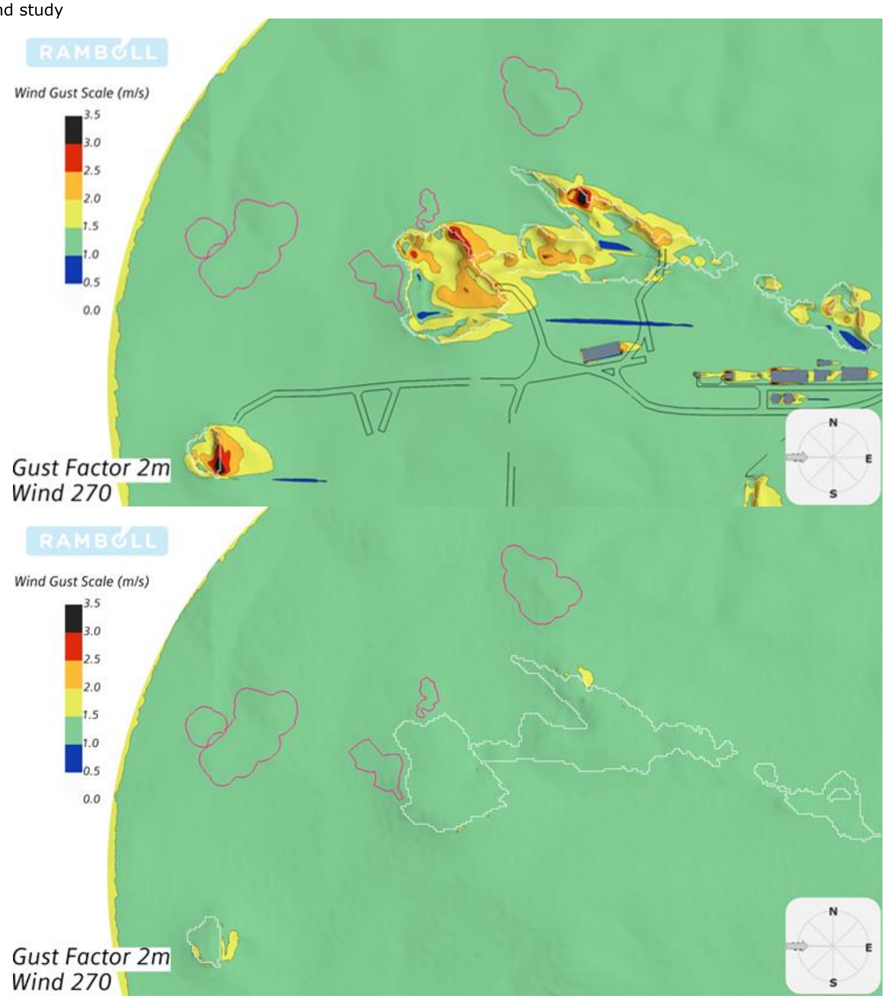


Figure A. 20. Gust Factor 2 m AGL for 270 degrees. Mined terrain (top) and existing Terrain (bottom).

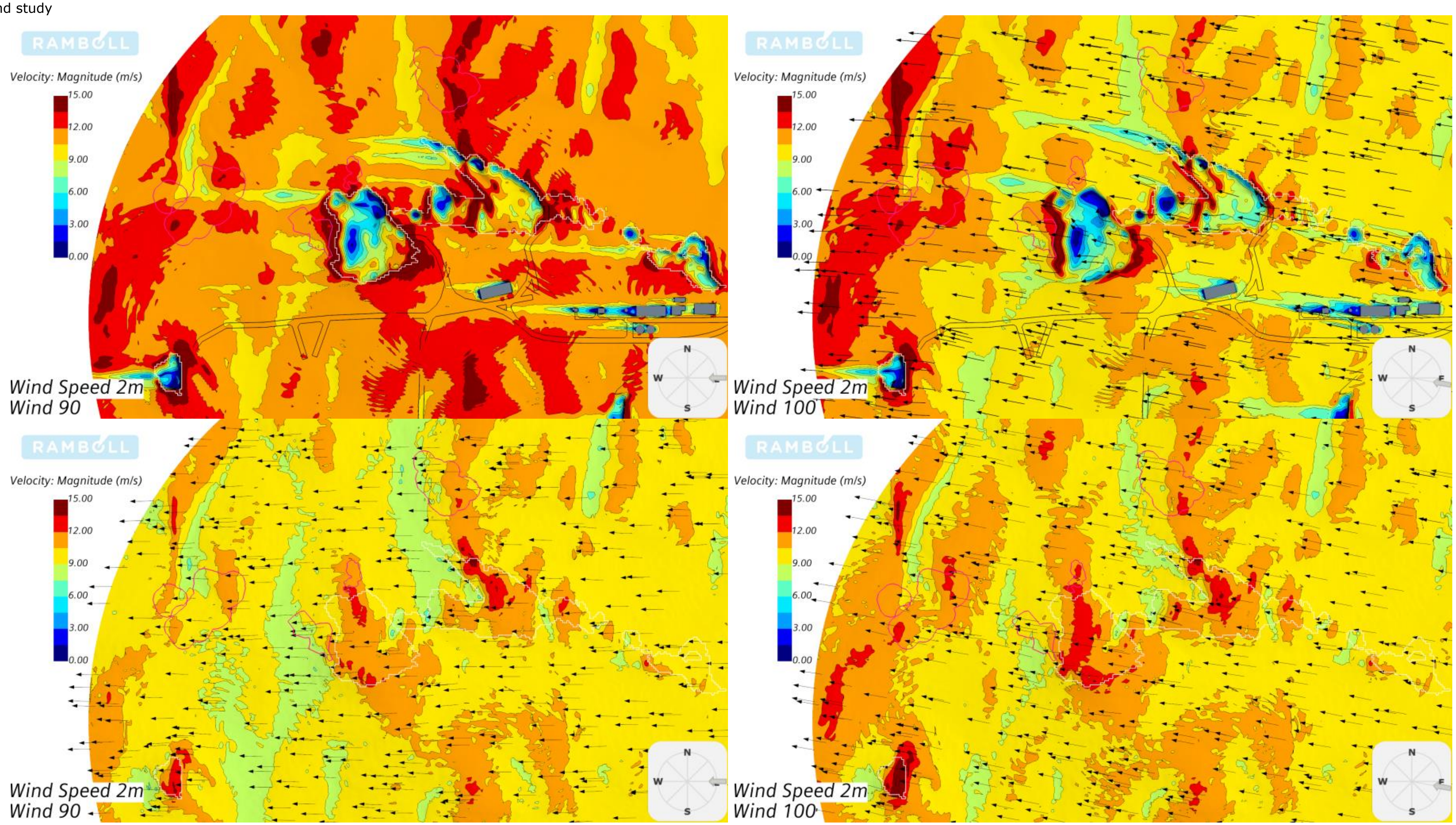


Figure A. 21. Wind Speed 2 m AGL for 90 and 100 degrees. Mined terrain (top) and existing Terrain (bottom).

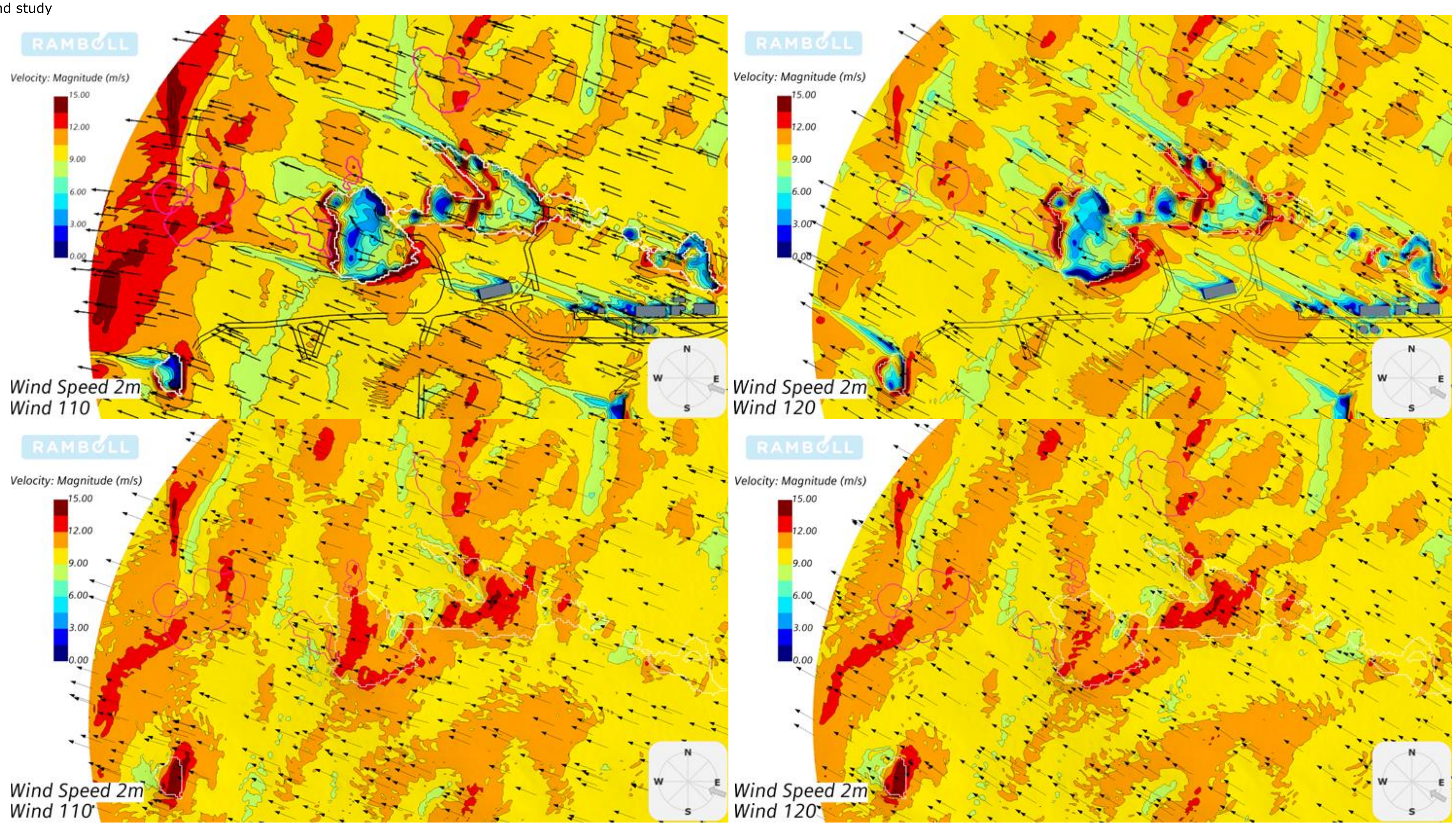


Figure A. 22. Wind Speed 2 m AGL for 110 and 120 degrees. Mined terrain (top) and existing Terrain (bottom).

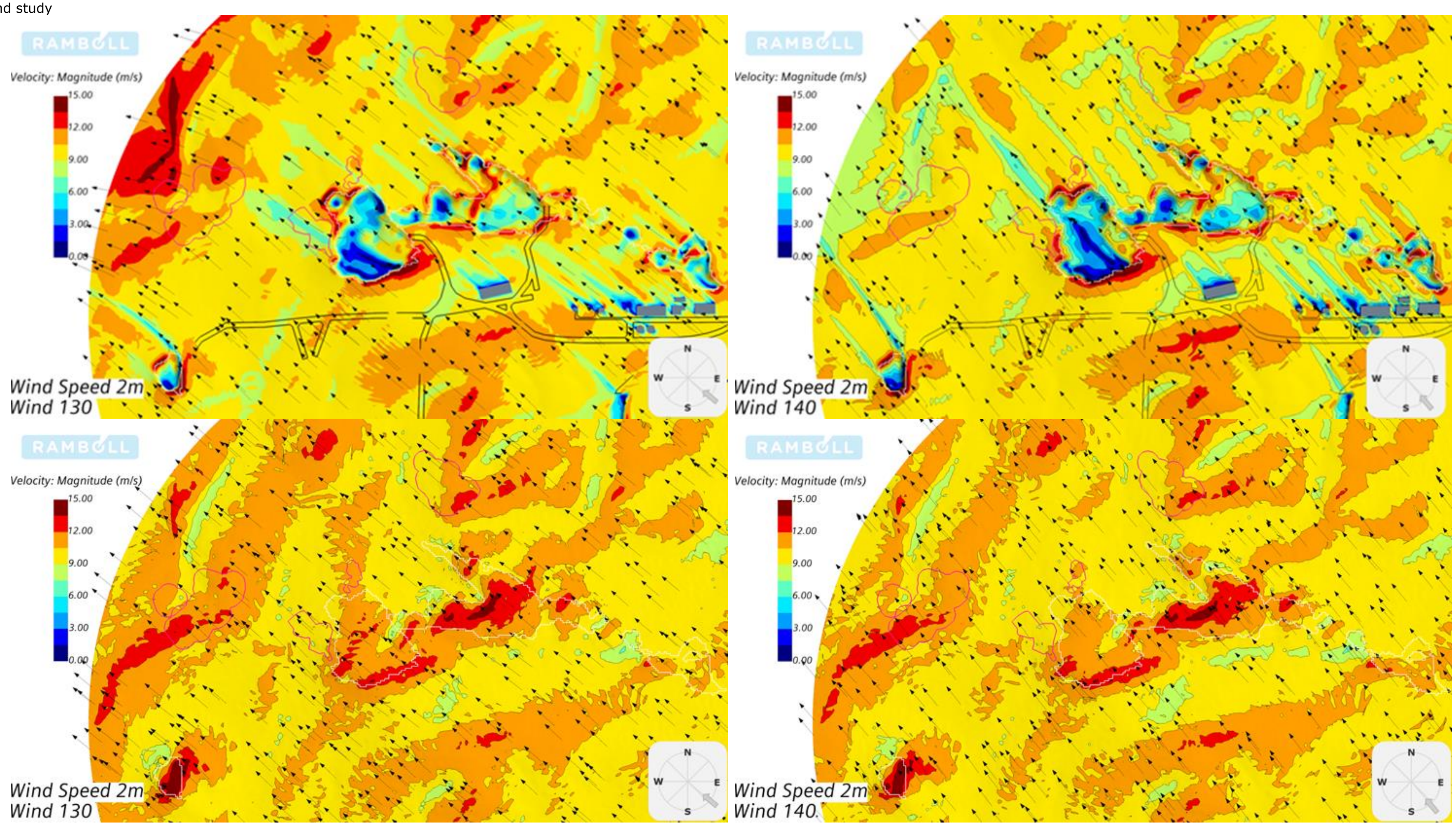


Figure A. 23. Wind Speed 2 m AGL for 130 and 140 degrees. Mined terrain (top) and existing Terrain (bottom).

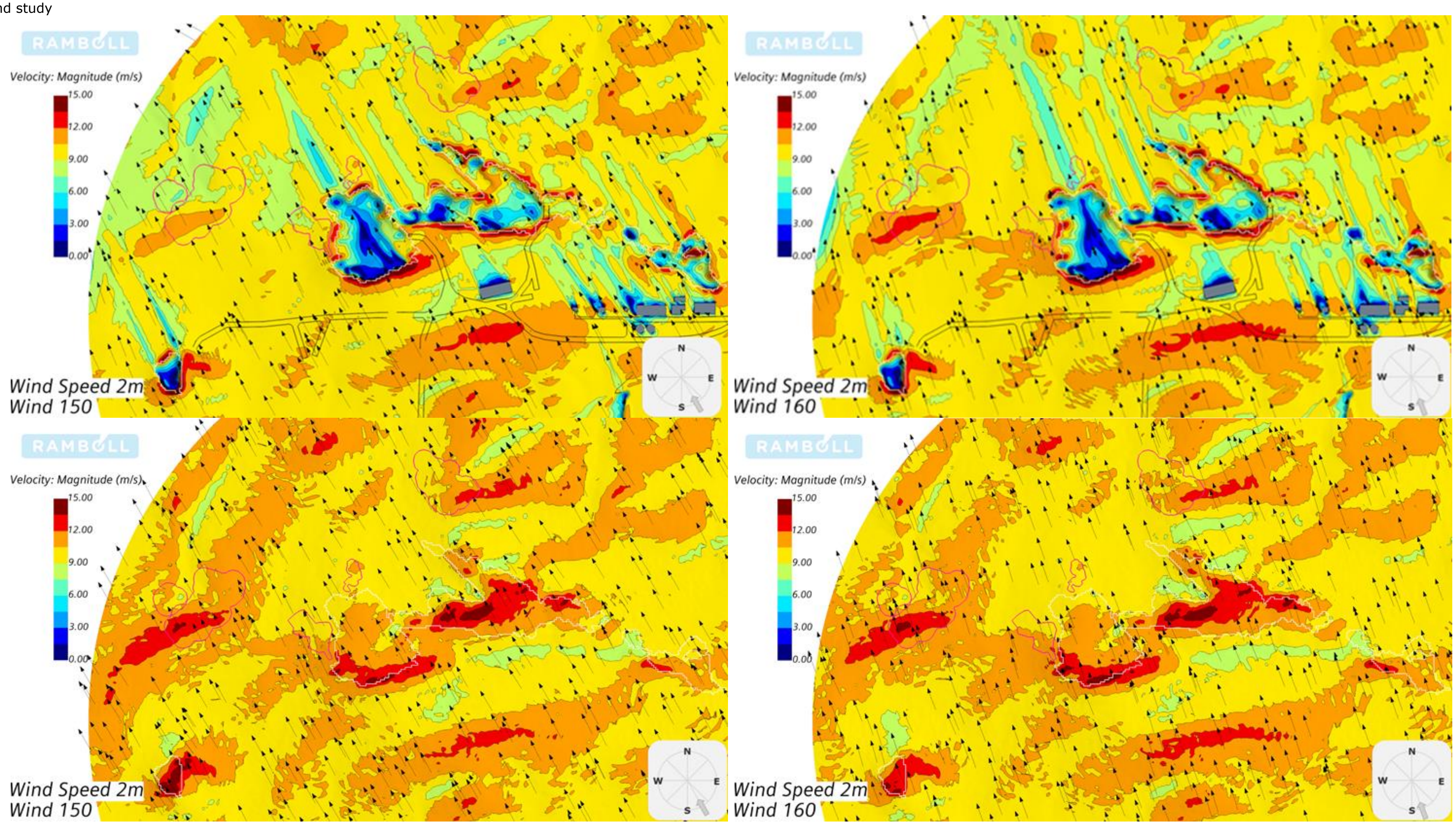


Figure A. 24. Wind Speed 2 m AGL for 150 and 160 degrees. Mined terrain (top) and existing Terrain (bottom).

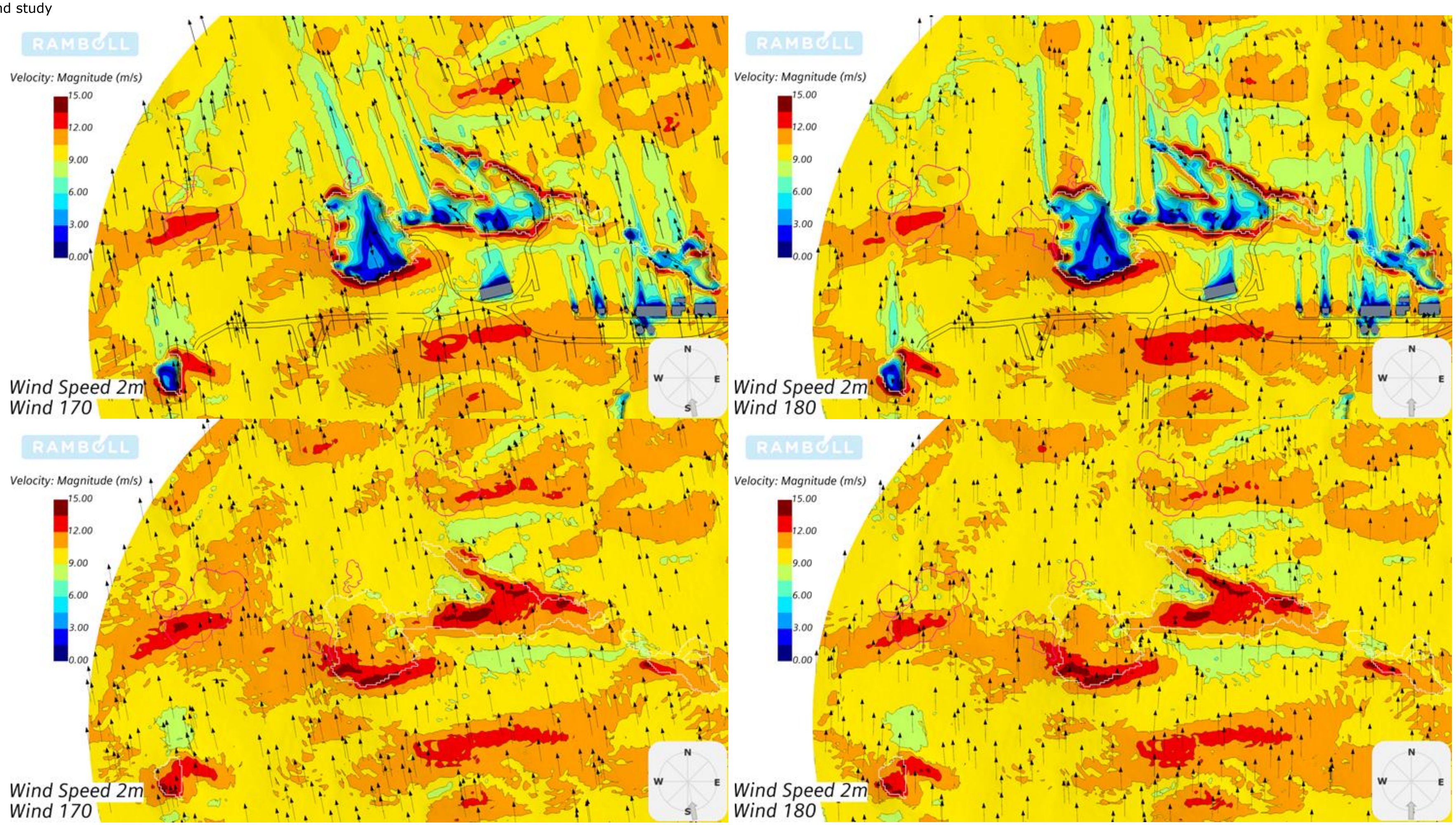


Figure A. 25. Wind Speed 2 m AGL for 170 and 180 degrees. Mined terrain (top) and existing Terrain (bottom).

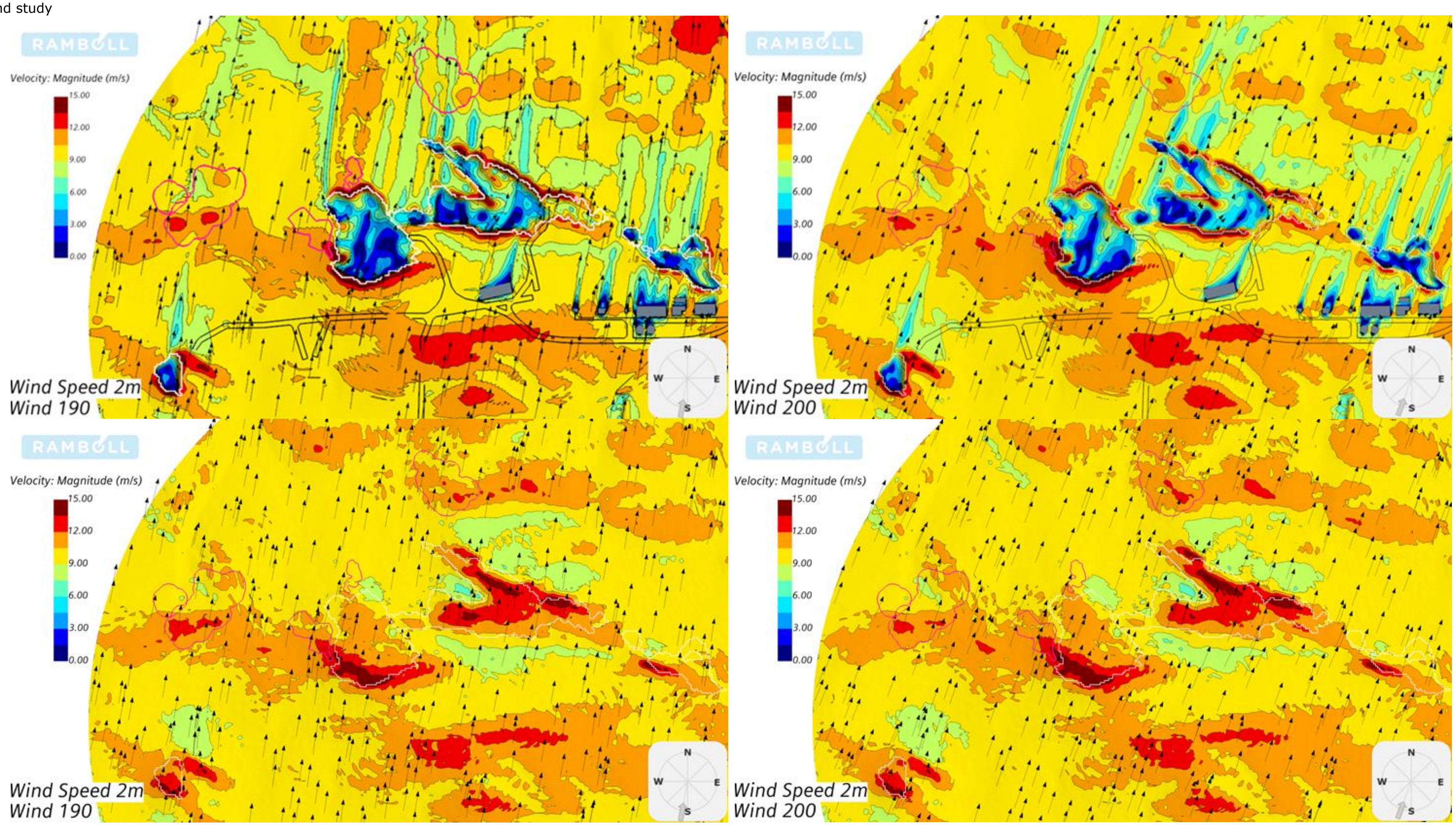


Figure A. 26. Wind Speed 2 m AGL for 190 and 200 degrees. Mined terrain (top) and existing Terrain (bottom).

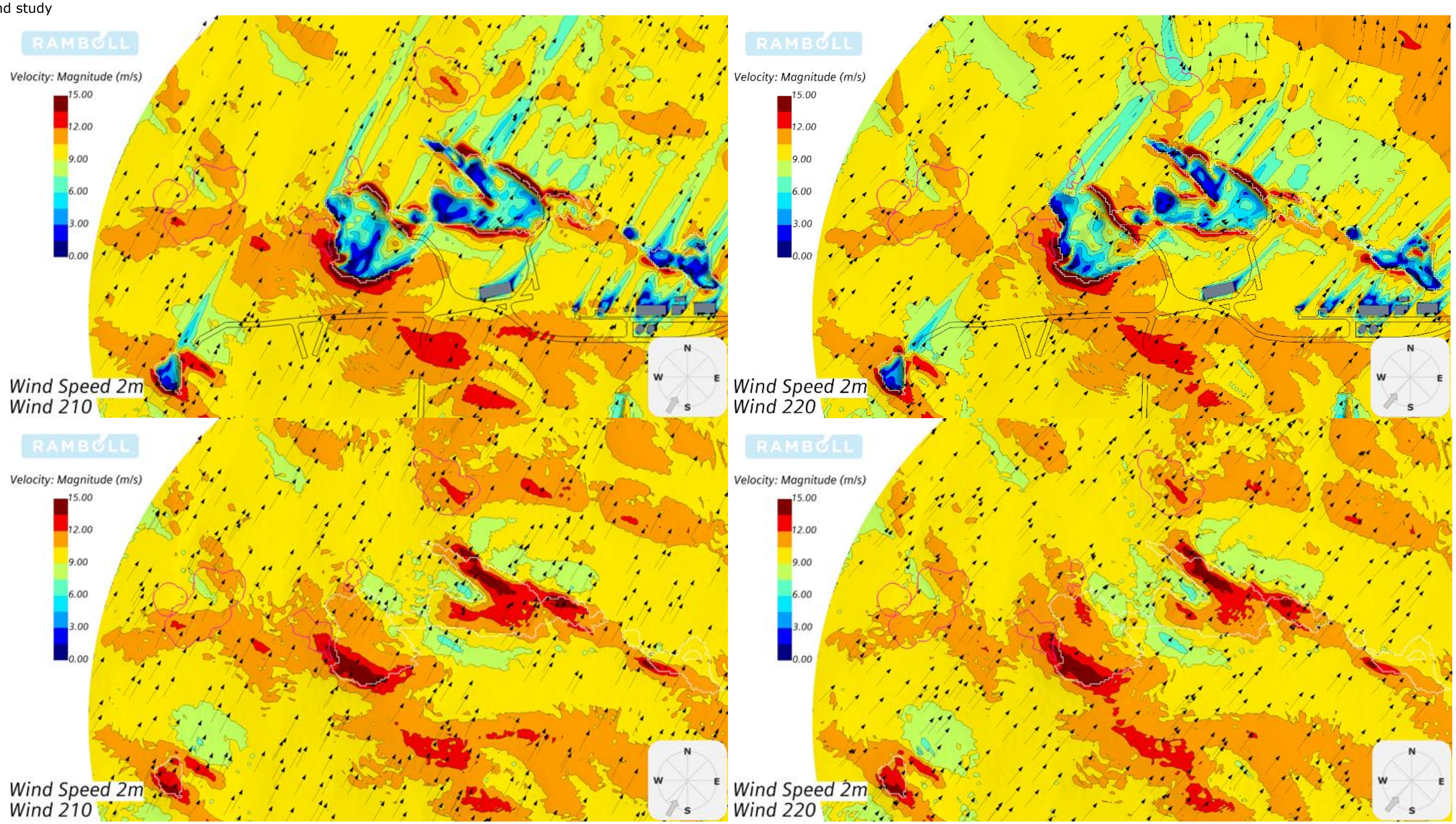


Figure A. 27. Wind Speed 2 m AGL for 210 and 220 degrees. Mined terrain (top) and existing Terrain (bottom).

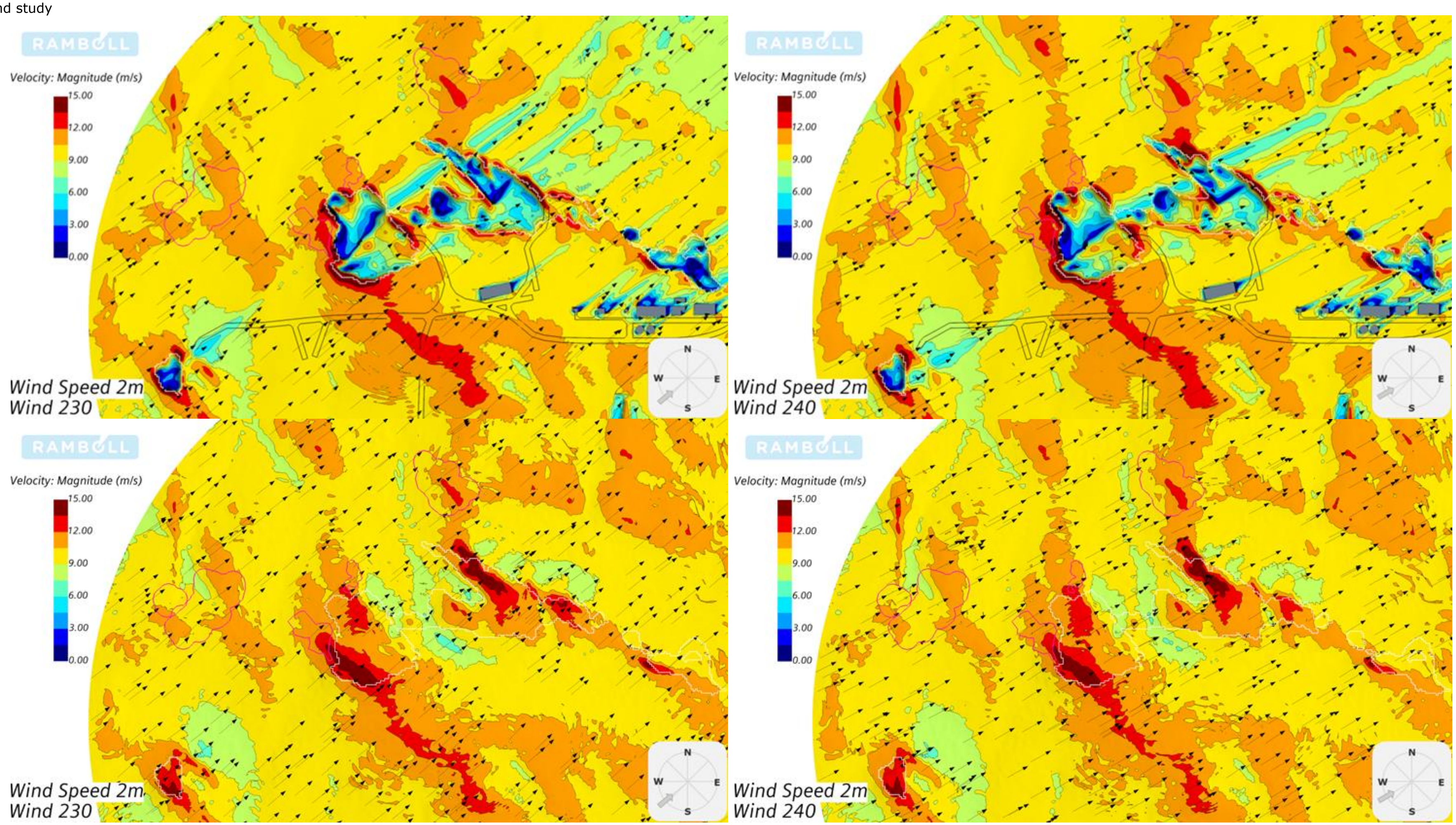


Figure A. 28. Wind Speed 2 m AGL for 230 and 240 degrees. Mined terrain (top) and existing Terrain (bottom).

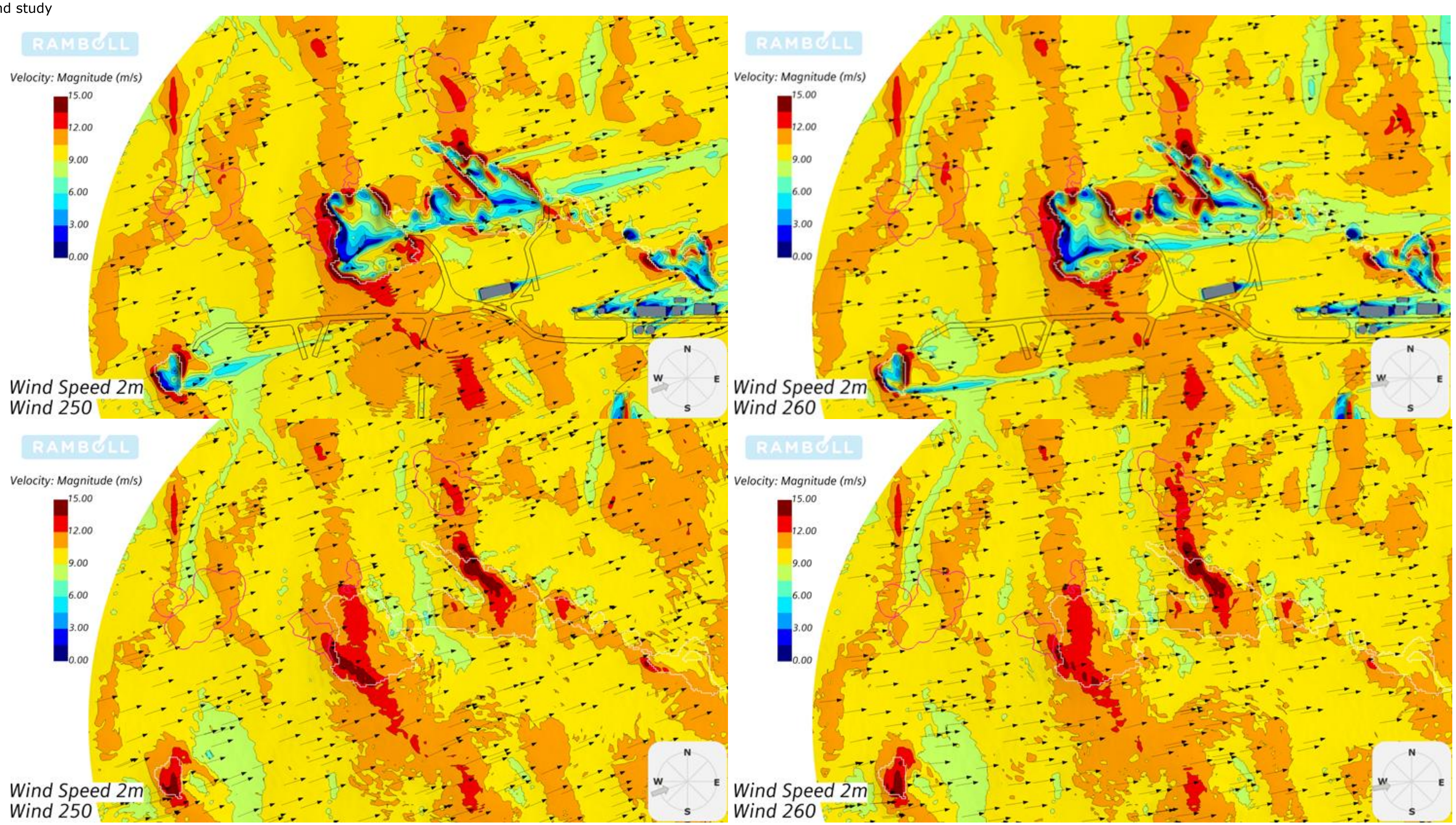


Figure A. 29. Wind Speed 2 m AGL for 250 and 260 degrees. Mined terrain (top) and existing Terrain (bottom).

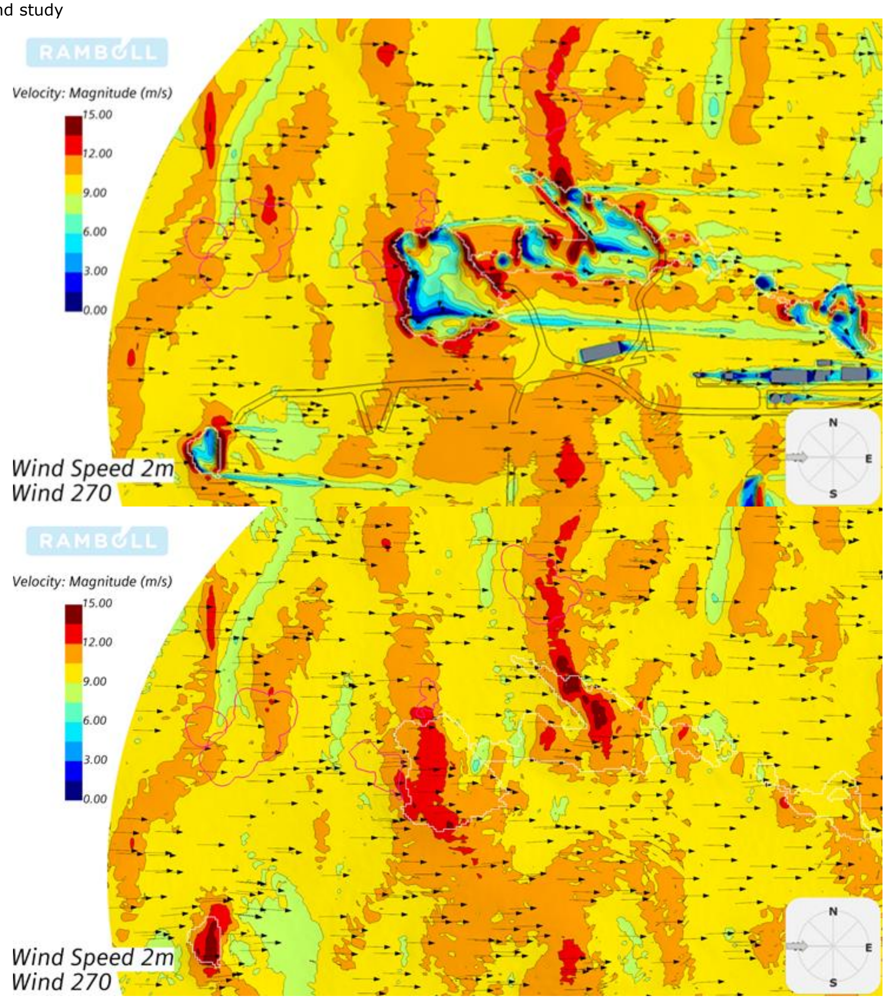


Figure A. 30. Wind Speed 2 m AGL for 270 degrees. Mined terrain (top) and existing Terrain (bottom).