



# CONTINUUM TOWN HALL

APRIL 23 2025 | 11am EST



- Continuum v1.3.2 Release
  - New features and improvements
- “Continuum Wind Flow Model Explained”
  - Part 2: Understanding Flow Types
- Open Q&A Forum
- Continuum Contributor Program



## CONTINUUM COMMUNITY HIGHLIGHT



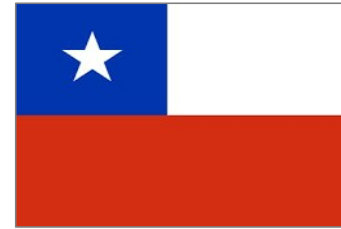
United States



India



Spain



Chile



Turkey



Canada



Vietnam



South Africa



Mexico



Lithuania



## CONTINUUM 1.3.2 Release Update

### Summary of New Features and Updates

- Land Cover key: “Missing” category
  - Ignored in surface roughness / displacement height calculation
- Max. Shadow Flicker Distance setting
- Updated ‘Time Series’ analysis tab
- New release alert
- Map generation using parallel threading
- LT Reference TAB file export
- USGS 10m data now available through ‘Download Topography’
- South Africa Land Cover Key
- ERA5 10m data download fix

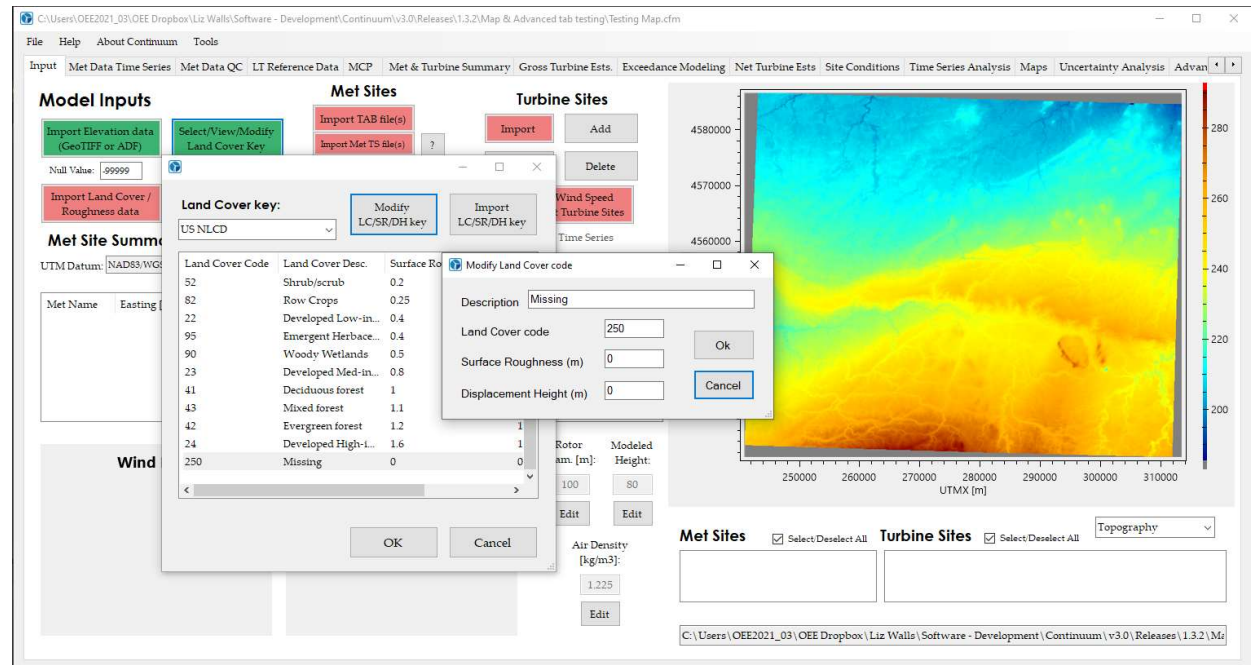
**AVAILABLE NOW  
SOON!**



## CONTINUUM 1.3.2 Release Update: “Missing” Land Cover Key

### Summary of New Features and Updates

- Added “Missing” land cover key
- Continuum ignores land cover with ‘Missing’ code when calculating surface roughness and displacement height





# NEW FEATURES

## CONTINUUM 1.3.2 Release Update: Max. Shadow Distance Setting

### Summary of New Features and Updates

- In Site Suitability, specify maximum shadow flicker distance between turbine and zone

The screenshot shows the Continuum software interface with the 'Run Shadow Flicker Model' dialog box open. The 'Max. Shadow Dist. [m]' field is highlighted with a red box and set to 2000. Other settings include '# Throws / Day: 300', '# Ice Days / Yr: 5', 'Hour: 7 pm', and 'Year: 1'. The 'Site Suitability Analyses' section shows a list of zones with their coordinates and lengths. The 'Shadow Flicker' section shows a heatmap titled 'Total Number of Shadow Flicker Hours' and a table for 'Hours of Shadow Flicker by Month / Hour'.

Zone	Total Hours
Z1	0
Z2	0
Z3	0
Z4	0
Z5	0
Z6	0
Z7	0
Z8	0
Z9	0
Z10	0

Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4 am	0	0	0	0	0	0	0	0	0	0	0	0
5 am	0	0	0	0	0	0	0	0	0	0	0	0
6 am	0	0	0	0	0	0	0	0	0	0	0	0
7 am	0	0	0	0	0	0	0	0	0	0	0	0
8 am	0	0	0	0	0	0	0	0	0	0	0	0
9 am	0	0	0	0	0	0	0	0	0	0	0	0
10 am	0	0	0	0	0	0	0	0	0	0	0	0
11 am	0	0	0	0	0	0	0	0	0	0	0	0
12 pm	0	0	0	0	0	0	0	0	0	0	0	0
1 pm	0	0	0	0	0	0	0	0	0	0	0	0
2 pm	0	0	0	0	0	0	0	0	0	0	0	0
3 pm	0	0	0	0	0	0	0	0	0	0	0	0



# NEW FEATURES

## UPDATED TIME SERIES TAB

View Hourly/Monthly/Yearly Time Series Estimates by changing 'Analysis' dropdown

File Help About Continuum Tools

Input: Met Data Time Series | Met Data QC | LT Reference Data | MCP | Met & Turbine Summary | Gross Turbine Ests. | Exceedance Modeling | Net Turbine Ests. | Site Conditions | Time Series Analysis | Maps | Uncertainty Analysis | Advanced | Site Sustainability

**Turbine Time Series Analysis** | Analysis: [Time Series - Hourly] | Power Curve: [Test\_Turbine] | Wake Model: [Eddy Visc. Test\_Turbine Exp: 3 degs, TI 10 %, WVEP] | From: [1/1/01 00:00] | To: [12/31/10 23:00] | [1] Days

All WTCs  
 Marion\_W1  
 Marion\_W2  
 Marion\_W3

Timestamp	Wind Farm Avg WS [m/s]	Wind Farm Gross AEP [DkWh]	Wind Farm Net AEP [DkWh]	Wind Farm Wake Loss [%]	Marion_W1 Avg WS [m/s]	Marion_W1 Gross AEP [DkWh]	Marion_W1 Net AEP [DkWh]	Marion_W1 Wake Loss [%]	Marion_W2 Avg WS [m/s]	Marion_W2 Gross AEP [DkWh]	Marion_W2 Net AEP [DkWh]	Marion_W2 Wake Loss [%]	Marion_W3 Avg WS [m/s]	Marion_W3 Gross AEP [DkWh]	Marion_W3 Net AEP [DkWh]	Marion_W3 Wake Loss [%]
2005-01-01 00:00	6.73	1302.2	1235.9	0	6.688	420.5	399.5	0	6.82	452.8	430.1	0	6.703	427.8	406.4	0
2005-01-01 01:00	6.154	971.9	923.2	0	6.199	331.8	315.2	0	6.18	328.4	311.9	0	6.083	311.7	296.1	0
2005-01-01 02:00	5.558	692.2	657.5	0	5.603	237	225.1	0	5.585	234.5	222.7	0	5.487	220.7	209.6	0
2005-01-01 03:00	5.196	590.1	522.5	0	5.162	217.2	206.3	0	5.182	184.4	180	0	5.149	164.5	156.2	0
2005-01-01 04:00	4.848	429	407.4	0	4.738	175.9	165.2	0	4.708	127.6	121.1	0	4.709	127.6	121.2	0
2005-01-01 05:00	5.031	489.9	465.4	0	5.311	197	187.1	0	4.891	148.4	139.1	0	4.892	146.5	139.2	0
2005-01-01 06:00	5.681	715.7	708.3	0	5.799	265.9	252.5	0	5.629	240.8	228.7	0	5.617	239	227	0
2005-01-01 07:00	5.71	758.4	720.3	0	5.827	270.3	256.7	0	5.807	240.9	232.7	0	5.445	243.1	231	0
2005-01-01 08:00	5.163	535	508.2	0	5.229	192.8	183.2	0	5.11	171.8	163.1	0	5.099	170.4	161.9	0
2005-01-01 09:00	5.09	508.2	482.7	0	5.137	175	166.3	0	5.093	160.7	161.2	0	5.041	163.5	153.3	0
2005-01-01 10:00	5.044	507.9	482	0	4.866	144.6	136.4	0	5.178	180.1	171.1	0	5.207	183.8	175.3	0
2005-01-01 11:00	5.013	482.4	458.2	0	4.794	136	129.2	0	5.107	171.4	162.8	0	5.137	175	166.2	0
2005-01-01 12:00	4.947	460.1	437.1	0	4.728	129.6	123.1	0	5.041	163.5	155.3	0	5.071	167.1	158.7	0
2005-01-01 13:00	4.911	448	423.5	0	4.692	125.9	119.5	0	5.005	160.8	151.3	0	5.035	160.8	154.4	0
2005-01-01 14:00	5.163	655.6	622.7	0	5.166	178.4	169.7	0	5.536	227.5	216.1	0	5.488	249.5	236.9	0
2005-01-01 15:00	6.241	1021	969.8	0	5.944	287.6	274.3	0	6.313	351.9	334.3	0	6.465	380.4	361.3	0
2005-01-01 16:00	7.07	1524.1	1446.6	0	6.773	442.8	420.6	0	7.142	524.1	497.8	0	7.294	592.6	551.2	0
2005-01-01 17:00	7.882	2133.9	2026.9	0	7.685	631.2	599.6	0	8.106	772.5	732.7	0	8.106	772.5	732.7	0
2005-01-01 18:00	8.059	2281.8	2167.4	0	7.763	678.2	644.2	0	8.131	792.7	740.6	0	8.283	823.9	782.4	0
2005-01-01 19:00	8.587	2738.9	2601.5	0	8.29	826	784.5	0	8.609	933.5	886.7	0	8.81	973.4	930.2	0
2005-01-01 20:00	8.5	2688.6	2509	17.4	8.234	806.6	733.5	17.9	8.603	917	871	0	8.774	967.7	914.4	0
2005-01-01 21:00	8.522	2680.9	2503.1	1.7	8.312	832.1	747.1	5.5	8.516	891.5	846.8	0	8.739	957.2	909.2	0
2005-01-01 22:00	8.172	2376.2	2257	0	7.962	732.2	695.5	0	8.165	789.3	749.7	0	8.389	854.6	811.8	0

**Time Series - Hourly**

File Help About Continuum Tools

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 Marion\_W3

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2005-01	6.227	10914	9276	2.4	6.179	325.4	305.4	2.1	6.278	332	305.5	3.8	6.285	340	315.7	1.3
2005-02	5.637	684.7	668.2	6.5	5.606	222.7	204.5	3.3	5.446	227.2	204.5	9.8	5.718	234.8	209.1	6.2
2005-03	6.156	1039.1	950.4	3.2	6.123	340.9	320.8	0.9	6.107	346.1	322.5	4.9	6.216	352.2	322.1	3.7
2005-04	7.132	1373.9	1233.6	3.8	7.072	447.1	413.9	2.5	7.131	454.4	409.5	5.9	7.234	466.5	430.1	2.9
2005-05	5.562	789.7	676.3	6.3	5.484	244.6	228.1	2.7	5.359	253.3	227.8	9.5	5.534	261.7	232.5	6.5
2005-06	5.41	617.5	555.9	5.2	5.344	196.8	183.2	2	5.435	205.4	179.7	7.9	5.539	215.3	182.9	5.7
2005-07	4.737	440.4	390.8	6.1	4.631	138.1	123.7	5.8	4.713	148.9	123.7	9.8	4.807	155.3	143.3	2.9
2005-08	4.655	430.4	380.8	6.9	4.569	136.9	124.8	4	4.649	143.1	121.2	10.9	4.747	150.4	134.7	5.7
2005-09	5.236	562.9	522.8	3.2	5.154	179.6	168.1	1.5	5.224	187	171.3	3.5	5.229	196.3	181.4	1.6
2005-10	5.473	653.6	614.4	1	5.456	227.1	205.1	0.5	5.445	224.7	206.6	1.7	5.218	221.8	208.8	0.9
2005-11	7.348	1404.3	1294.6	2.9	7.265	457.6	431.3	0.8	7.347	467.8	434.6	4.4	7.431	478.9	438.8	3.5
2005-12	5.922	843.7	791.4	6.2	5.847	274.2	259.1	0.5	5.912	280.2	241.2	9.4	5.987	289.4	251.1	8.6
2006-01	6.678	1253.3	1109.3	2.4	6.614	417.8	394.6	0.6	6.646	425.7	390	3.5	6.596	438.8	404.7	2.9
2006-02	6.324	985.6	905.1	3.3	6.297	324.8	307.5	0.3	6.315	328	295.6	5.1	6.362	332.8	302	4.5
2006-03	6.693	1084.8	996.7	2.2	6.627	352.6	309.9	1.9	6.666	354.3	306.4	3.5	6.139	341.7	320.5	1.2
2006-04	6.48	1094.4	994	5.6	6.388	362.1	309.5	4.7	6.486	359.9	308.5	8.8	6.505	360.4	336	3.4
2006-05	5.122	688.9	647.6	1	5.398	223.5	212.2	0	5.437	228.6	213.7	1.6	5.521	236.7	221.6	1.4
2006-06	4.498	393	359.1	1.8	4.577	114.7	107.8	1.1	4.589	116.4	107.3	2.9	4.457	121.9	114	1.5
2006-07	4.991	469.8	436.8	2.1	4.924	150.3	141	1.2	4.983	155.6	142.8	3.4	5.068	164	153.1	1.8
2006-08	5.02	530.9	491.2	2.6	4.934	168.6	155.9	2.9	5.02	177.3	161.4	4.2	5.107	180	174.2	0.8
2006-09	5.24	567.9	520.8	3.4	5.182	181.4	170	1.4	5.231	189.5	170.7	5.1	5.305	197	180.2	3.7
2006-10	6.331	1007.2	912.9	1.6	6.239	326.9	307.7	0.9	6.334	335.9	296.7	7	6.402	344.4	308.1	1.6
2006-11	5.385	672.3	595.7	3.9	5.337	213.1	200.8	0.8	5.362	214.8	192	5.9	5.456	224.4	202.9	4.8

**Time Series - Yearly**

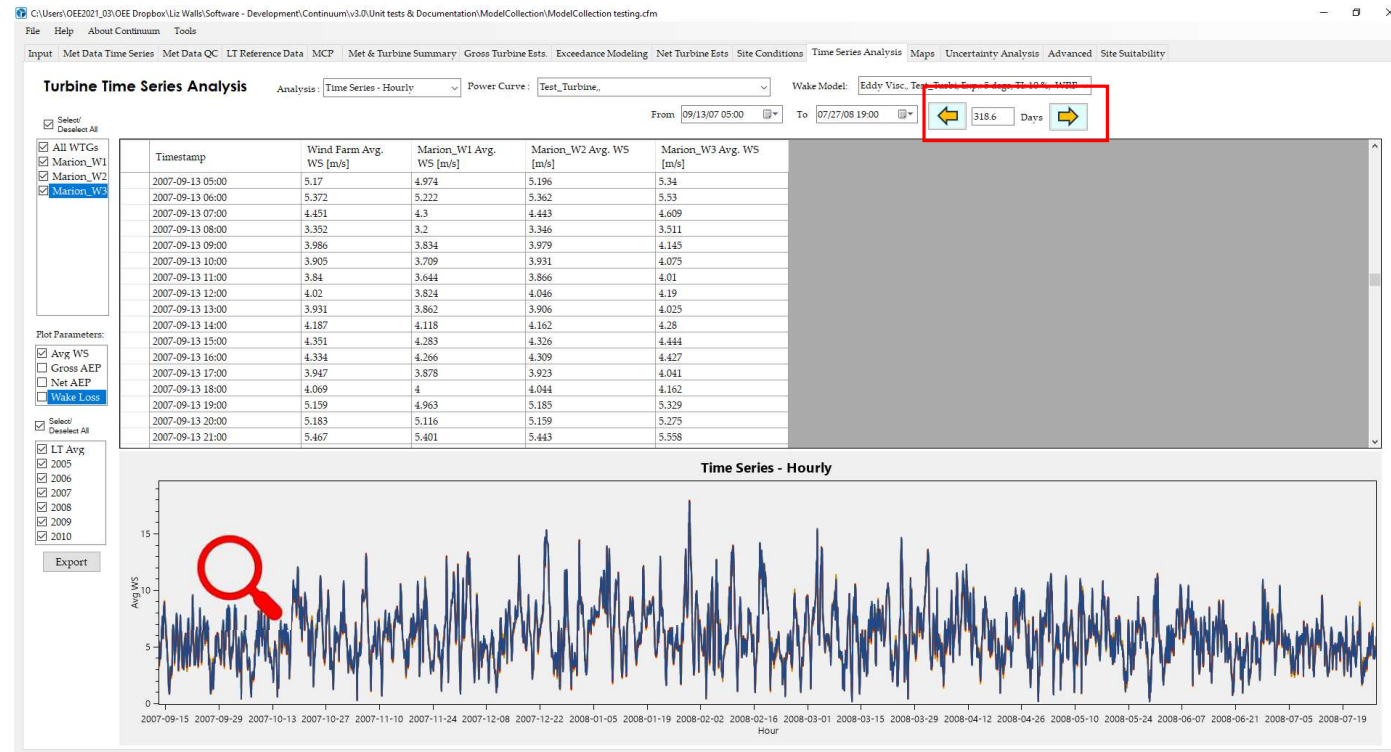


# NEW FEATURES

## UPDATED TIME SERIES TAB

Zoom in to view time series data

- Hover over plot and use mouse wheel to zoom in/out
- Table scrolls to same time period
- Use left/right arrows to step through data

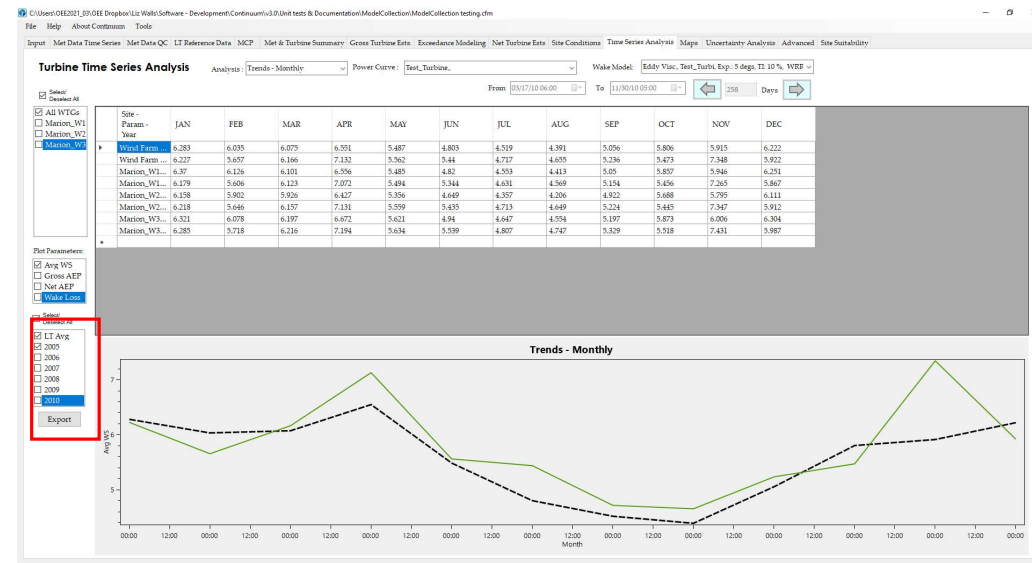
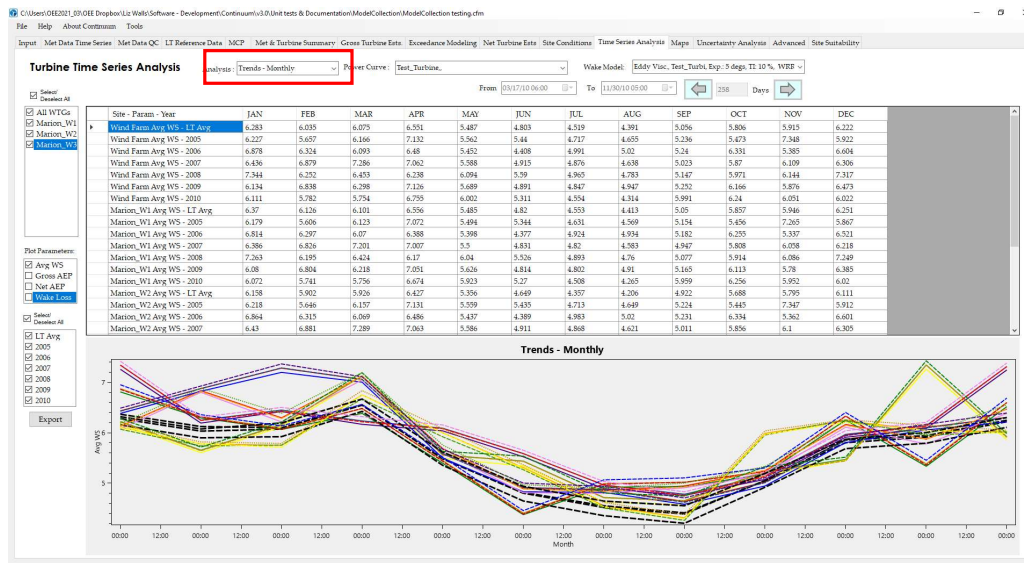


# NEW FEATURES

## UPDATED TIME SERIES TAB

View Monthly Trends including long-term monthly estimates

Focus in on specific years to view deviations from long-term trend





## CONTINUUM EXPLAINED: WIND FLOW MODEL LECTURE SERIES

$\Delta WS =$

$$\underbrace{m_{UW} \Delta Exp_{UW} + m_{DW} \Delta Exp_{DW}} + \underbrace{\left[ \frac{WS_1 \left( \ln \left( \frac{z - d_{2UW}}{z_{02UW}} \right) + \psi_{2UW} \right)}{\ln \left( \frac{z - d_{1UW}}{z_{01UW}} \right) + \psi_{1UW}} - WS_1 \right] + \left[ \frac{WS_1 \left( \ln \left( \frac{z - d_{2DW}}{z_{02DW}} \right) + \psi_{2DW} \right)}{\ln \left( \frac{z - d_{1DW}}{z_{01DW}} \right) + \psi_{1DW}} - WS_1 \right]} + \underbrace{m_{Elev} \Delta Elev + m_{valley} \Delta (Exp_{UW} + Exp_{DW})}$$

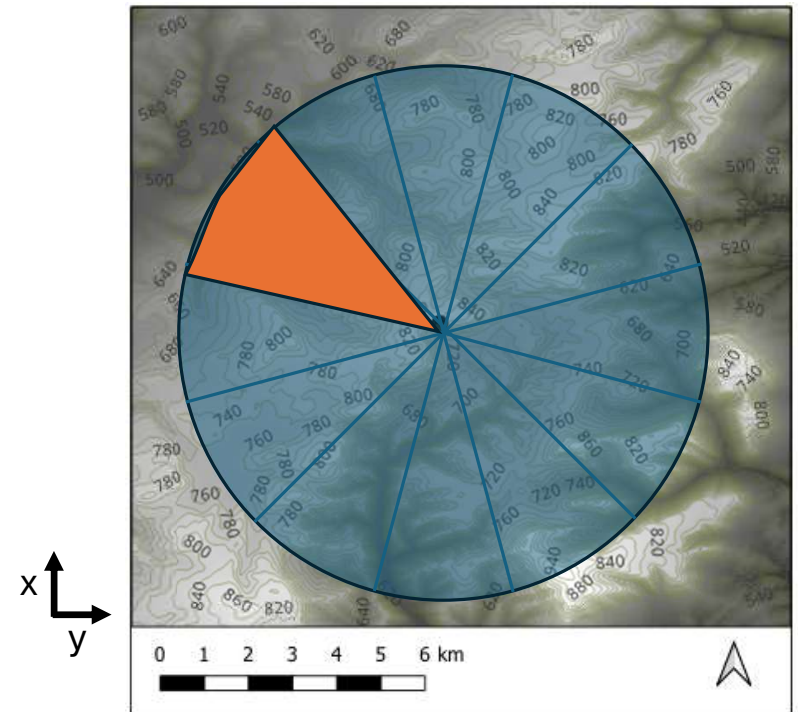
- SESSION 1&2:** Understanding the UW and DW exposure components, flow types
- SESSION 3:** Understanding the UW and DW SR/DH components
- SESSION 4:** Understanding the elevation and valley components
- SESSION 5:** Understanding terrain complexity and model coefficient definitions
- SESSION 6:** Understanding machine learning model coefficient determination



## What is Terrain Exposure?

**Exposure** = Average elevation difference between a site and the surrounding terrain (within a specified R) weighted by inverse distance.

$$Exposure_{\theta} = \frac{\left( \sum_{i=0}^N \frac{Z_o - Z_i}{(d_{z_o-z_i})^{\beta}} \right)}{\left( \sum_{i=0}^N \frac{1}{(d_{z_o-z_i})^{\beta}} \right)}$$



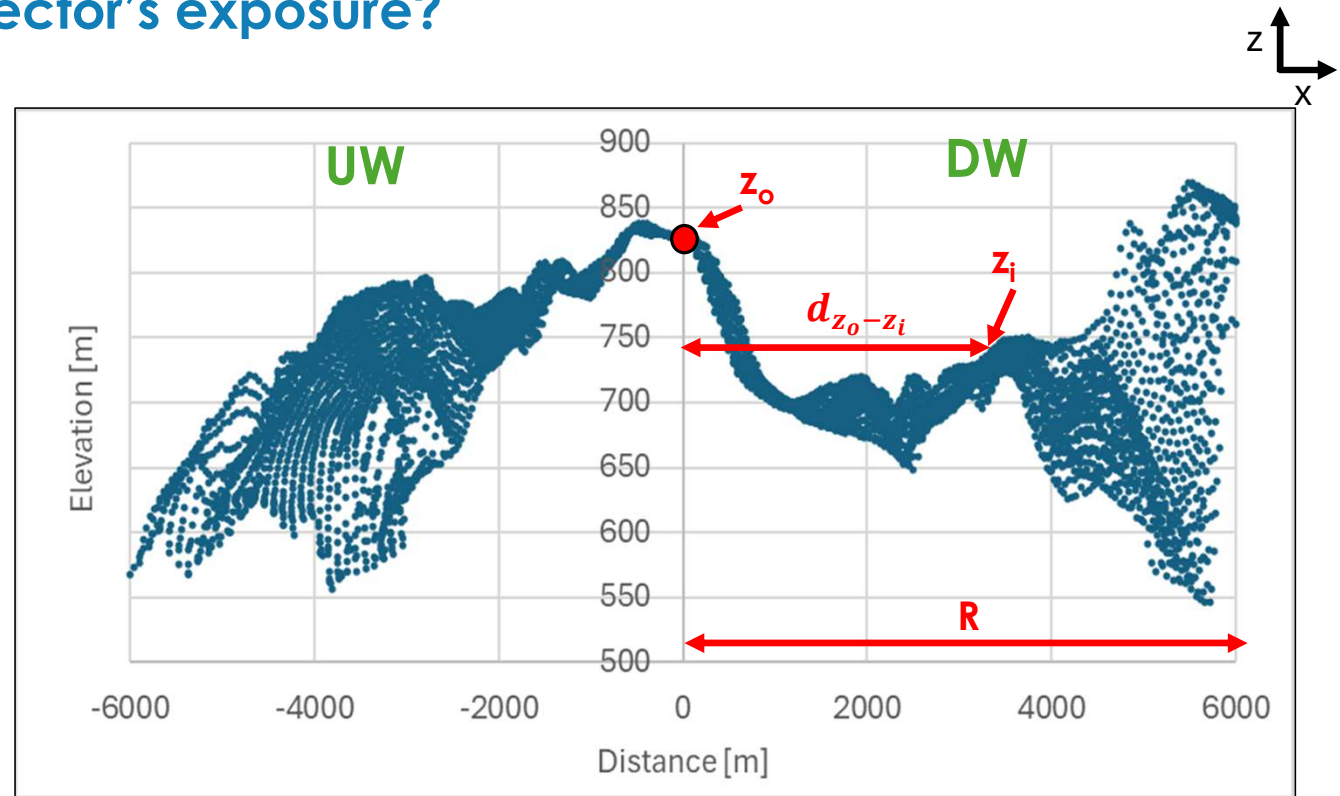


# CONTINUUM EXPLAINED

How do we calculate a sector's exposure?

$$Exposure_{\theta} = \frac{\left( \sum_{i=0}^N \frac{Z_o - Z_i}{(d_{z_o-z_i})^{\beta}} \right)}{\left( \sum_{i=0}^N \frac{1}{(d_{z_o-z_i})^{\beta}} \right)}$$

$N$ : all elevation datapoints within the directional sector





## Exposure vs. Wind Speed Relationship

- Observed in nature
  - Linear relationship between UW exposure, DW exposure, elevation and WS
  - RAMWind model based on correlation/regression relationship

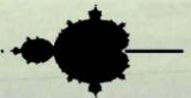
But **WHY** is there a relationship?

### Previous Studies Involving Exposure-based modeling

- [A New and Objective Empirical Model of Wind Flow Over Terrain](#)
  - AWEA Wind Resource & Project Assessment Workshop 2007, Portland, OR
  - Presented by: Jack Kline, RAM Associates
  - First introduction of exposure-based modeling to the wind industry. The linear relationship that exists between wind speed and exposure was demonstrated.
- [Wind Flow Modeling Software Comparison](#)
  - AWEA Wind Resource Assessment Workshop 2009, Minneapolis, MN
  - Presented by: John Vanden Bosche, Chinook Wind
  - Wind flow model results were compared at two project sites with moderately complex terrain. The models included WAsP, CFD models and RAMWind (exposure) model. The RAMWind model produced the most accurate results.
- [Comparison of WAsP, MS-Micro/3, CFD, MWP, and Analytical Methods for Estimating Site-Wide Wind Speeds](#)
  - AWEA Wind Resource and Project Energy Assessment Workshop 2009, Minneapolis, MN
  - Presented by: David VanLuvanee, GEC-DNV
  - Wind flow model results were compared at four project sites with moderately complex terrain. The models included WAsP, CFD models and RAMWind (exposure) model. At three out of four sites, the RAMWind model produced the most accurate results.

**RAM Associates**

Resource Assessment & Micrositing





## CONTINUUM MODEL PREMISE

- Continuum is a wind flow model derived from [Navier-Stokes / conservation of momentum theory](#)
- Conservation of momentum theory:
  - Change in momentum of moving fluid (flow) is equal to the sum of the forces acting on the fluid
  - Acceleration of a fluid is directly proportional to the net force acting on the fluid and is inversely proportional to mass

$$F = ma \quad \longrightarrow \quad \rho \left( \frac{\partial v}{\partial t} + v \cdot \nabla v \right) = -\nabla P + \nabla T + F$$

accel = pressure + shear + gravity



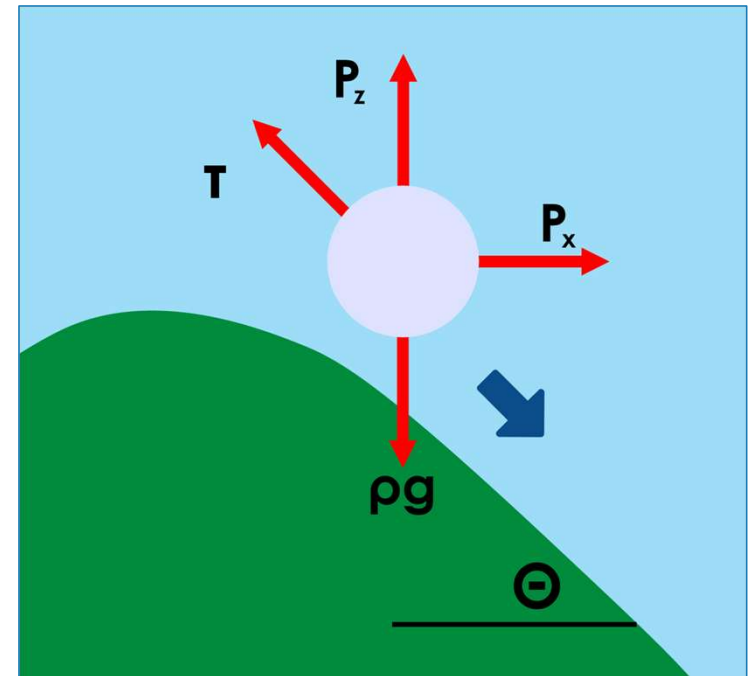
## DOWNHILL FLOW: THEORY

Use 'Control Volume' approach

- Define imaginary surface that encompasses a volume of fluid analyzed (parcel)
- Treat parcel as a free-body diagram and examine forces on it
- Sum of the forces acting on parcel determines acceleration

The **acceleration** in the wind flowing **downhill** is equal to the sum of the forces acting on the wind. Those forces are:

- $P_x$  = Horizontal Pressure Gradient Force (HPGF)
- $P_z$  = Vertical Pressure Gradient Force (VPGF)
- $T$  = Shear Force
- $g$  = Force of gravity



$$\rho \left( \frac{\partial v}{\partial t} + v \cdot \nabla v \right) = -\nabla P + \nabla T + F \longrightarrow \rho a = P_x \cos \theta - P_z \sin \theta - \tau + \rho g \sin \theta$$



## DOWNHILL FLOW: THEORY DERIVATION EXAMPLE

Say there are two sites both with **positive downwind exposure**, but steeper terrain at Site 2:

- $Exp_2 > Exp_1$

The **acceleration** in WS at the two sites due to the **downhill flow**:

$$\text{Site 1 accel: } \rho_1 a_1 = P_{x1} \cos \theta_1 - P_{z1} \sin \theta_1 - \tau_1 + \rho g \sin \theta_1$$

$$\text{Site 2 accel: } \rho_2 a_2 = P_{x2} \cos \theta_2 - P_{z2} \sin \theta_2 - \tau_2 + \rho g \sin \theta_2$$

Apply conservation of momentum theory between the two sites:

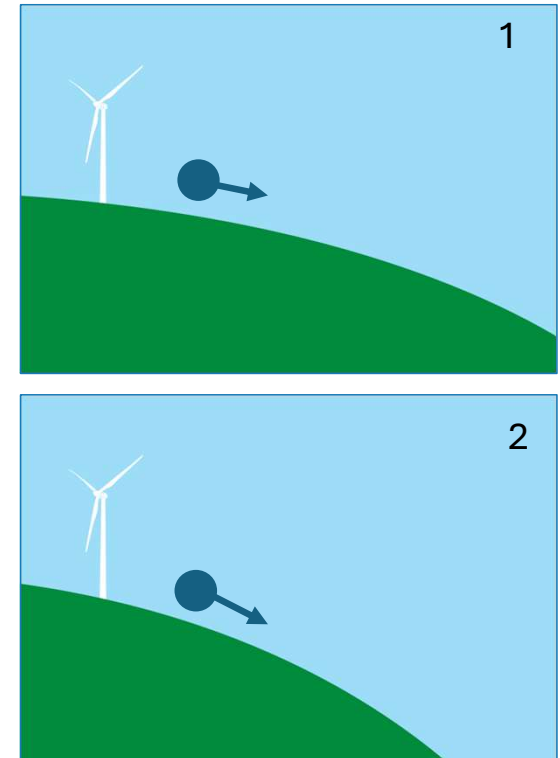
$$\text{Site 2 accel} - \text{Site 1 accel} = 0$$

$$(\rho_2 a_2 - P_{x2} \cos \theta_2 + P_{z2} \sin \theta_2 + \tau_2 - \rho g \sin \theta_2) - (\rho_1 a_1 - P_{x1} \cos \theta_1 + P_{z1} \sin \theta_1 + \tau_1 - \rho g \sin \theta_1) = 0$$

$$\rho_2 a_2 - \rho_1 a_1 - P_{x2} \cos \theta_2 + P_{x1} \cos \theta_1 + P_{z2} \sin \theta_2 - P_{z1} \sin \theta_1 + \tau_2 - \tau_1 - \rho g \sin \theta_2 + \rho g \sin \theta_1 = 0$$

$$a_2 - a_1 = \frac{P_x}{\rho} \Delta \cos \theta - \frac{P_z}{\rho} \Delta \sin \theta + g \Delta \sin \theta$$

Since  $\Delta \cos \theta \ll \Delta \sin \theta$ :  $a_2 - a_1 = \left( g - \frac{P_z}{\rho} \right) \Delta \sin \theta$



Assume similar conditions at the two sites:

- Density:  $\rho_1 = \rho_2$
- VPGF:  $P_{z1} = P_{z2}$
- HPGF:  $P_{x1} = P_{x2}$
- Surface roughness:  $\tau_1 = \tau_2$



## DOWNHILL FLOW: THEORY DERIVATION EXAMPLE

Acceleration can be defined using the material derivative,  $\frac{Dv}{Dt}$

$$a_2 - a_1 = \frac{Dv_2}{Dt} - \frac{Dv_1}{Dt} = \left( \frac{\partial v_2}{\partial t} + v_2 \left( \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} \right) \right) - \left( \frac{\partial v_1}{\partial t} + v_1 \left( \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} \right) \right)$$

But remember,  $a_2 - a_1 = \left( g - \frac{P_z}{\rho} \right) \Delta \sin \theta$

$$\left( \cancel{\frac{\partial v_2}{\partial t}} + v_2 \left( \cancel{\frac{\partial v_x}{\partial x}} + \cancel{\frac{\partial v_y}{\partial y}} + \cancel{\frac{\partial v_z}{\partial z}} \right) \right) - \left( \cancel{\frac{\partial v_1}{\partial t}} + v_1 \left( \cancel{\frac{\partial v_x}{\partial x}} + \cancel{\frac{\partial v_y}{\partial y}} + \cancel{\frac{\partial v_z}{\partial z}} \right) \right) = \left( g - \frac{P_z}{\rho} \right) \Delta \sin \theta$$

Assume:

- Steady-state conditions ( $\frac{\partial v_2}{\partial t} = 0$ )
- 2D flow ( $\frac{\partial v_y}{\partial y} = 0$ )
- $\frac{\partial v_x}{\partial x}$  and  $\frac{\partial v_z}{\partial z}$  are equal at Sites 1 and 2.

$$v_2 = v_1 + \frac{\left( g - \frac{P_z}{\rho} \right) \Delta \sin \theta}{\left( \frac{\partial v_x}{\partial x} + \frac{\partial v_z}{\partial z} \right)}$$

Since  $\sin \theta \propto \text{Exposure/Radius}$ :

$$v_2 = v_1 + \frac{\left( g - \frac{P_z}{\rho} \right) \Delta \text{Exp}}{\left( \frac{\partial v_x}{\partial x} + \frac{\partial v_z}{\partial z} \right) R} = v_1 + m \Delta \text{Exp}$$

Coeff: Function of atmospheric stability

Coeff: Function of terrain complexity



## UPHILL FLOW: THEORY

The **acceleration** in the wind flowing **uphill** is equal to the sum of the forces acting on the wind. Those forces are:

- $P_x$  = Horizontal Pressure Gradient Force (HPGF)
- $P_z$  = Vertical Pressure Gradient Force (VPGF)
- $T$  = Shear Force
- $g$  = Force of gravity

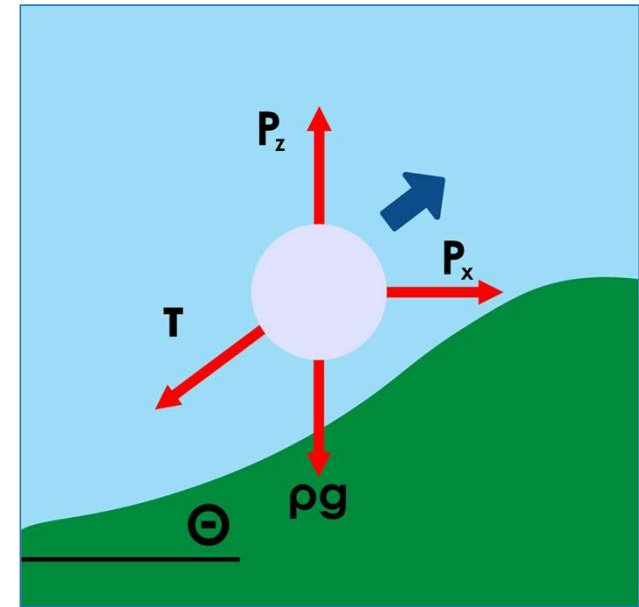
$$\rho \left( \frac{\partial v}{\partial t} + v \cdot \nabla v \right) = -\nabla P + \nabla T + F$$



$$\rho a = P_x \cos \theta + P_z \sin \theta - \tau - \rho g \sin \theta$$

Pressure gradient forces  
acting **WITH** flow

Gravity acting  
**AGAINST** flow





## UPHILL FLOW: THEORY DERIVATION EXAMPLE

Say there are two sites both with **positive upwind exposure**, but steeper terrain at Site 2:

- $Exp_2 > Exp_1$

The **acceleration** in WS at the two sites due to the **uphill flow**:

$$\text{Site 1 accel: } \rho_1 a_1 = P_{x1} \cos \theta_1 + P_{z1} \sin \theta_1 - \tau_1 - \rho g \sin \theta_1$$

$$\text{Site 2 accel: } \rho_2 a_2 = P_{x2} \cos \theta_2 + P_{z2} \sin \theta_2 - \tau_2 - \rho g \sin \theta_2$$

Apply conservation of momentum theory between the two sites:

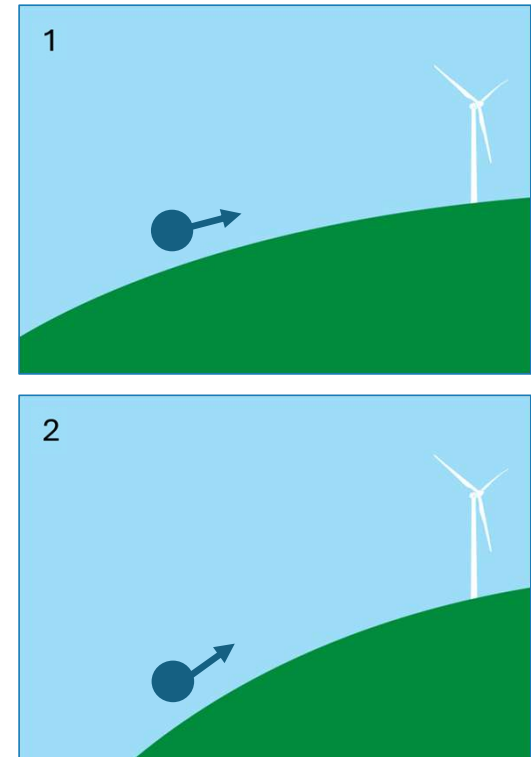
$$\text{Site 2 accel} - \text{Site 1 accel} = 0$$

$$(\rho_2 a_2 - P_{x2} \cos \theta_2 - P_{z2} \sin \theta_2 + \tau_2 + \rho g \sin \theta_2) - (\rho_1 a_1 - P_{x1} \cos \theta_1 - P_{z1} \sin \theta_1 + \tau_1 + \rho g \sin \theta_1) = 0$$

$$\rho_2 a_2 - \rho_1 a_1 - P_{x2} \cos \theta_2 + P_{x1} \cos \theta_1 - P_{z2} \sin \theta_2 + P_{z1} \sin \theta_1 + \tau_2 - \tau_1 + \rho g \sin \theta_2 - \rho g \sin \theta_1 = 0$$

$$a_2 - a_1 = \frac{P_x}{\rho} \Delta \cos \theta + \frac{P_z}{\rho} \Delta \sin \theta - g \Delta \sin \theta$$

Since  $\Delta \cos \theta \ll \Delta \sin \theta$ :  $a_2 - a_1 = \left( \frac{P_z}{\rho} - g \right) \Delta \sin \theta$



Assume similar conditions at the two sites:

- Density:  $\rho_1 = \rho_2$
- VPGF:  $P_{z1} = P_{z2}$
- HPGF:  $P_{x1} = P_{x2}$
- Surface roughness:  $\tau_1 = \tau_2$



# CONTINUUM EXPLAINED

## UPHILL FLOW: THEORY DERIVATION EXAMPLE

Acceleration can be defined using the material derivative,  $\frac{Dv}{Dt}$

$$a_2 - a_1 = \frac{Dv_2}{Dt} - \frac{Dv_1}{Dt} = \left( \frac{\partial v_2}{\partial t} + v_2 \left( \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} \right) \right) - \left( \frac{\partial v_1}{\partial t} + v_1 \left( \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} \right) \right)$$

But remember,  $a_2 - a_1 = \underbrace{\left( \frac{P_z}{\rho} - g \right) \Delta \sin \theta}$

$$\left( \cancel{\frac{\partial v_2}{\partial t}} + v_2 \left( \cancel{\frac{\partial v_x}{\partial x}} + \cancel{\frac{\partial v_y}{\partial y}} + \cancel{\frac{\partial v_z}{\partial z}} \right) \right) - \left( \cancel{\frac{\partial v_1}{\partial t}} + v_1 \left( \cancel{\frac{\partial v_x}{\partial x}} + \cancel{\frac{\partial v_y}{\partial y}} + \cancel{\frac{\partial v_z}{\partial z}} \right) \right) = \left( \frac{P_z}{\rho} - g \right) \Delta \sin \theta$$

Assume:

- Steady-state conditions ( $\frac{\partial v_2}{\partial t} = 0$ )
- 2D flow ( $\frac{\partial v_y}{\partial y} = 0$ )
- $\frac{\partial v_x}{\partial x}$  and  $\frac{\partial v_z}{\partial z}$  are equal at Sites 1 and 2.

$$v_2 = v_1 + \frac{\left( \frac{P_z}{\rho} - g \right) \Delta \sin \theta}{\left( \frac{\partial v_x}{\partial x} + \frac{\partial v_z}{\partial z} \right)}$$

Since  $\sin \theta \propto \text{Exposure/Radius}$ :

$$v_2 = v_1 + \frac{\left( \frac{P_z}{\rho} - g \right) \Delta \text{Exp}}{\left( \frac{\partial v_x}{\partial x} + \frac{\partial v_z}{\partial z} \right) R} = v_1 + m \Delta \text{Exp}$$

Coeff: Function of atmospheric stability

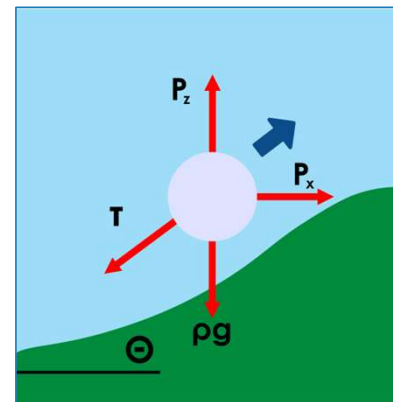
Coeff: Function of terrain complexity



# CONTINUUM EXPLAINED

## UPHILL FLOW: INDUCED SPEED-UP, CRITICAL EXPOSURE (UW sector only)

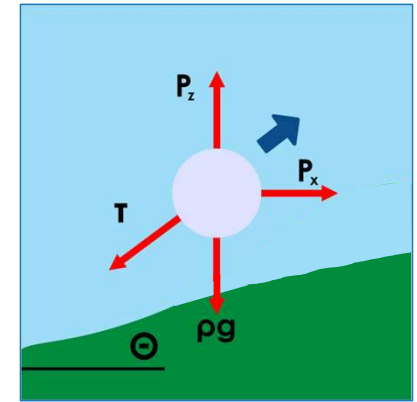
- When wind travels over a hill, there is pressure build-up on the upwind side which may cause an induced acceleration
- At the same time, gravity and shear forces decelerate the wind
- The pressure gradient forces act against the shear and gravity forces
- Point when pressure gradient forces are equal and opposite to shear and gravity forces defined as the 'critical upwind exposure',  $Exp_{UW,critical}$
- If  $Exp_{UW} > Exp_{UW,critical}$ , then the wind decelerates as it travels uphill
- If  $Exp_{UW} < Exp_{UW,critical}$ , the wind accelerates over the hill



$$Exp_{UW} > Exp_{UW,critical}$$

$$g > \frac{P_z}{\rho}$$

Uphill Flow: **Decelerates**



$$Exp_{UW} < Exp_{UW,critical}$$

$$\frac{P_z}{\rho} > g$$

Induced Speed Up: **Accelerates**

Typical critical UW Exposure value is ~20 m

*Model-specific and determined within the model algorithm*



## COMBINING UW & DW SECTORS

- Momentum of wind may change due to variations in **BOTH** UW and DW directions
- Total WS change effect of UW and DW terrain are simply summed

**DW:**  $v_2 = v_1 + m_{DW}\Delta Exp_{DW}$

Downhill (DH)



$$\Delta v_{DW} = m_{DH}\Delta Exp_{DW}$$

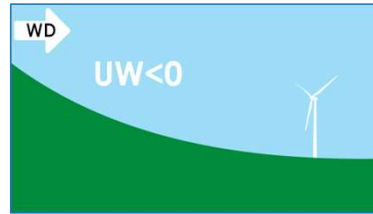
Uphill (UH)



$$\Delta v_{DW} = m_{UH}\Delta Exp_{DW}$$

**UW:**  $v_2 = v_1 + m_{UW}\Delta Exp_{UW}$

Downhill (DH)



$$\Delta v_{UW} = -m_{DH}\Delta Exp_{UW}$$

Speed-Up (SU)



$$\Delta v_{UW} = m_{SU}\Delta Exp_{UW}$$

Uphill (UH)



$$\Delta v_{UW} = -m_{UH}\Delta Exp_{UW}$$

**Total WS change:**  $\Delta v = \Delta v_{UW} + \Delta v_{DW}$

$$\Delta v = m_{UW}\Delta Exp_{UW} + m_{DW}\Delta Exp_{DW}$$

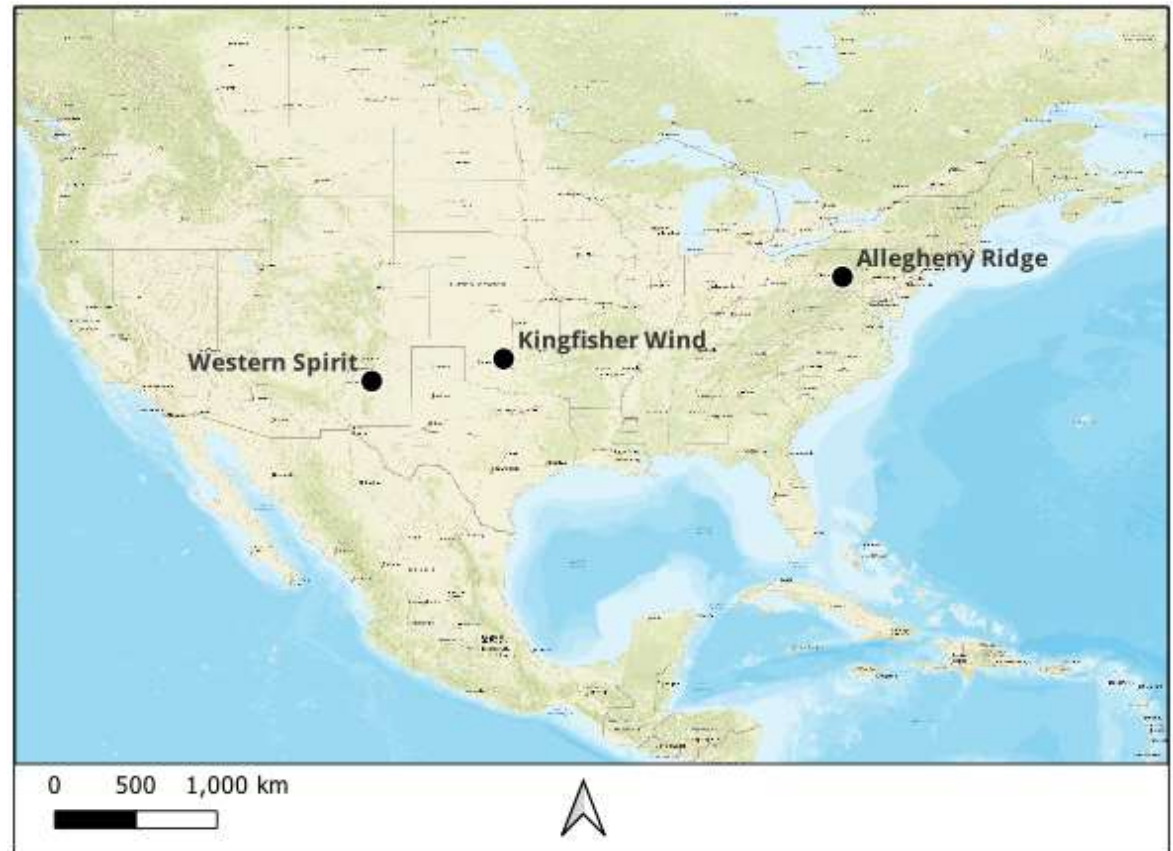


# CONTINUUM EXPLAINED

## Wind Farms for Examples

Three wind farms selected with low, moderate, and high levels of complexity

- **Kingfisher Wind (low)**
- **Western Spirit (moderate)**
- **Allegheny Ridge (high)**





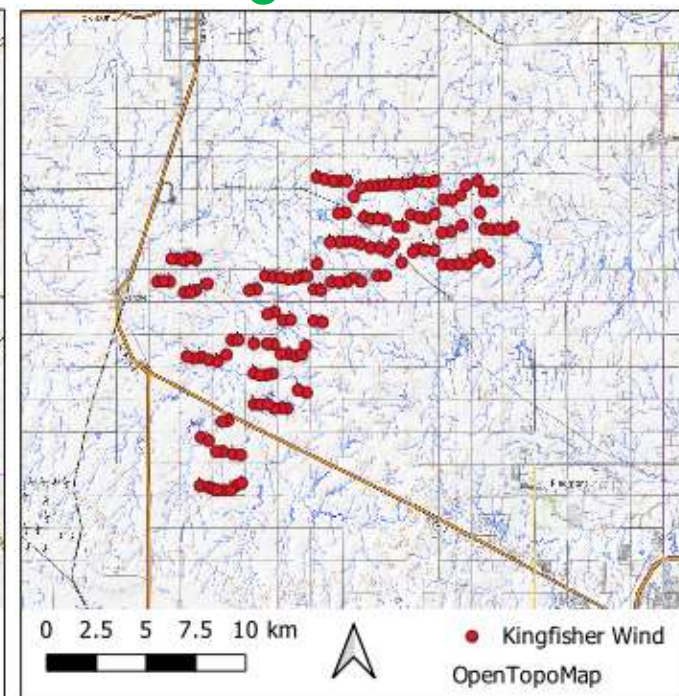
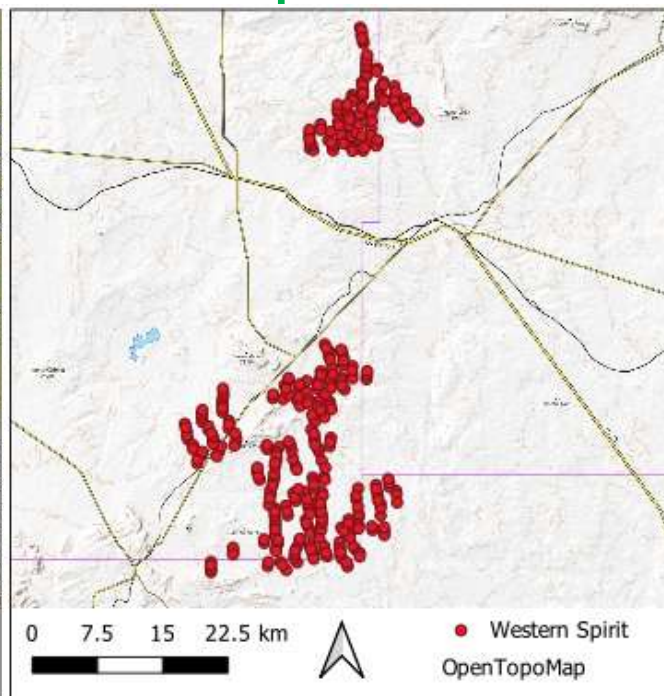
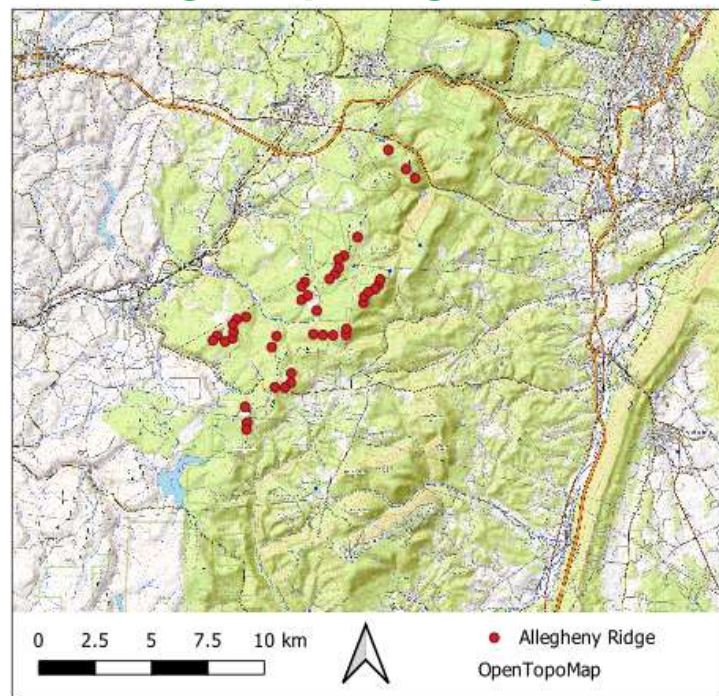
# CONTINUUM EXPLAINED

## Wind Farms for Examples

### Allegheny Ridge - High

### Western Spirit - Moderate

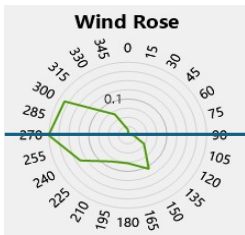
### Kingfisher - Low





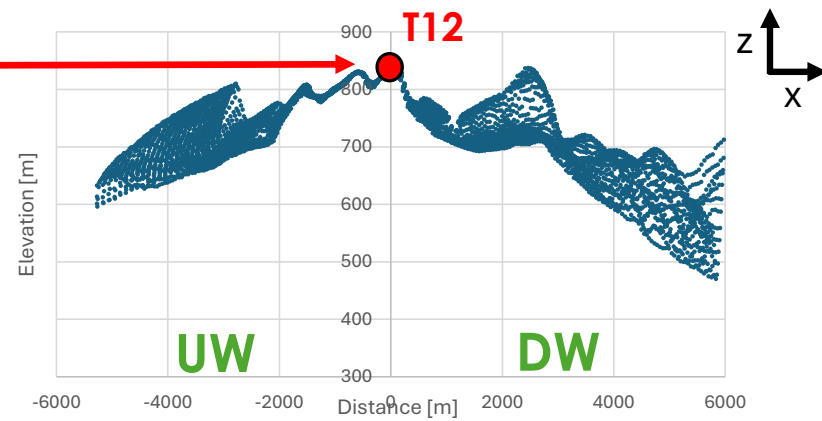
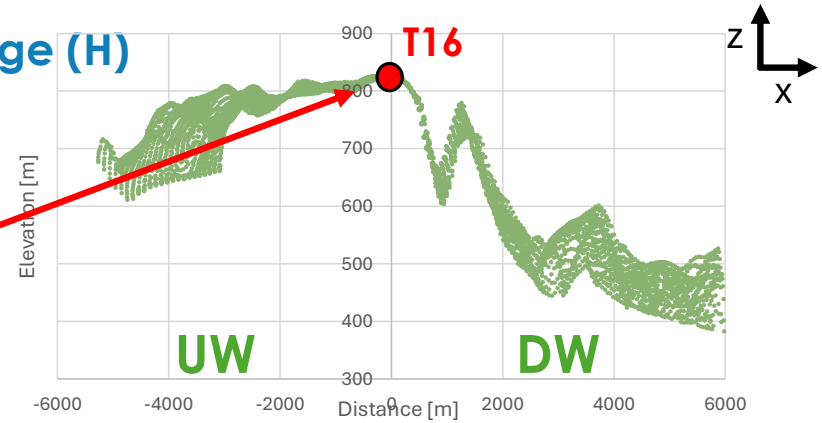
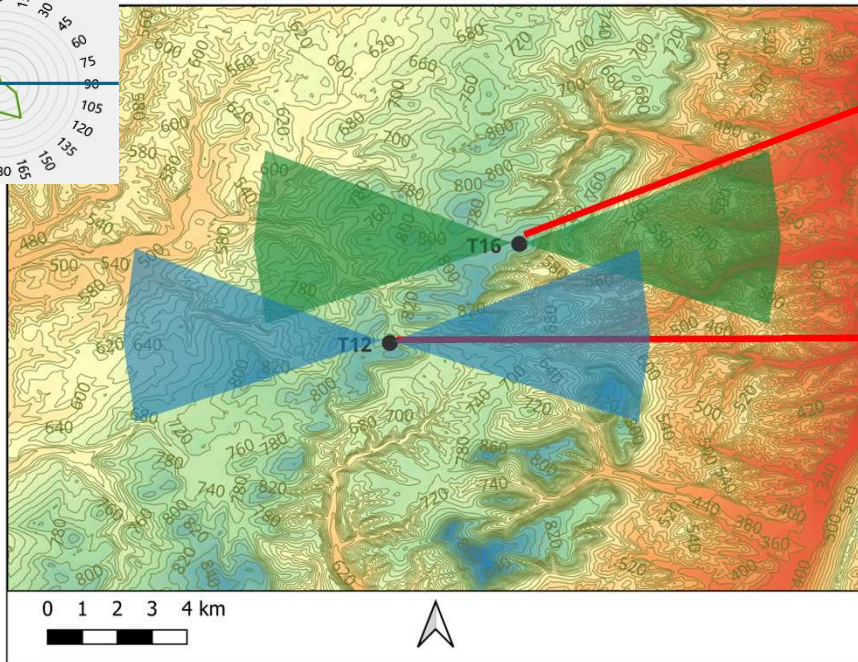
# CONTINUUM EXPLAINED

## UW Uphill / DW Downhill Flow WS Example: Allegheny Ridge (H)



UW sector: 270

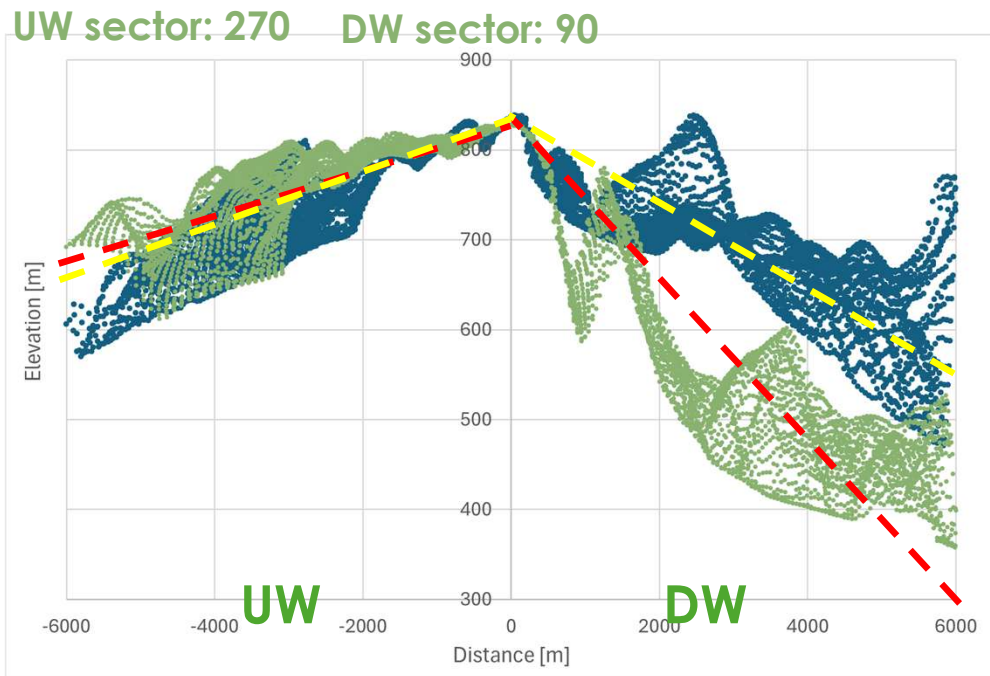
DW sector: 90





# CONTINUUM EXPLAINED

## UW Uphill / DW Downhill Flow WS Example: Allegheny Ridge (H)



T12    T16

What can we say about the signs of the UW and DW exposure for each site?

T12:  
Exp<sub>UW</sub> is positive  
Exp<sub>DW</sub> is positive

T16:  
Exp<sub>UW</sub> is positive  
Exp<sub>DW</sub> is positive

Both sites are **HIGHER** than the average elevation in the UW and DW sectors

UW **uphill** flow, DW **downhill** flow

	ExpUW [m]	ExpDW [m]
T12	127.2	173.1
T16	89.0	304.5



## UW Uphill / DW Downhill Flow WS Example: Allegheny Ridge (H)

	ExpUW [m]	ExpDW [m]	ExpUW Coeff	ExpDW Coeff
T12	127.2	173.1	-0.003	0.004
T16	89.0	304.5		

What's the WS difference going from T16 to T12 in the 270 sector?

$$\Delta WS = m_{UW} \Delta Exp_{UW} + m_{DW} \Delta Exp_{DW}$$

$$\Delta WS = m_{UW} (Exp_{UW,T16} - Exp_{UW,T12}) + m_{DW} (Exp_{DW,T16} - Exp_{DW,T12})$$

$$\Delta WS = -0.003(89.0 - 127.2) + 0.004(304.5 - 173.1)$$

$$\Delta WS = 0.11 + 0.53$$

$$\Delta WS = 0.64 \text{ m/s}$$

WS at T16 will be 0.64 m/s  
**HIGHER** than the WS at T12

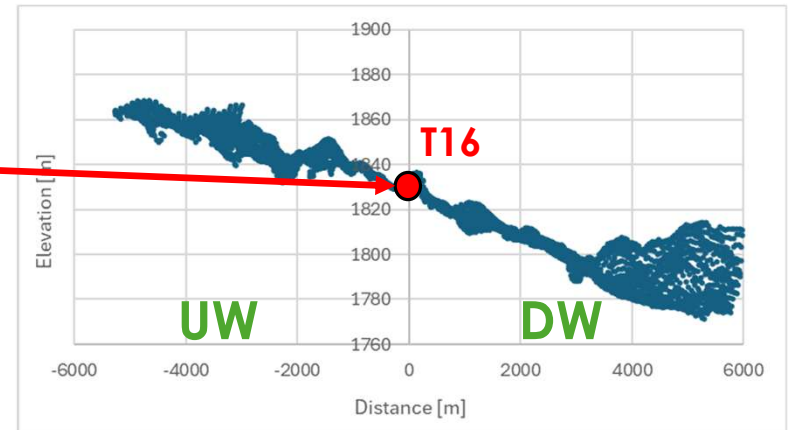
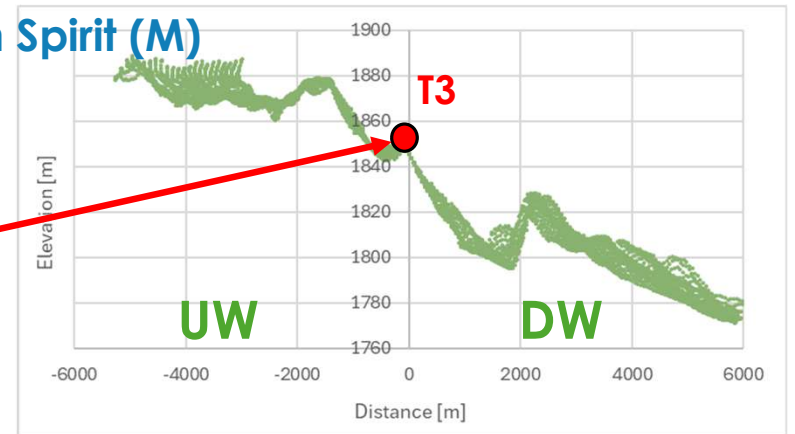
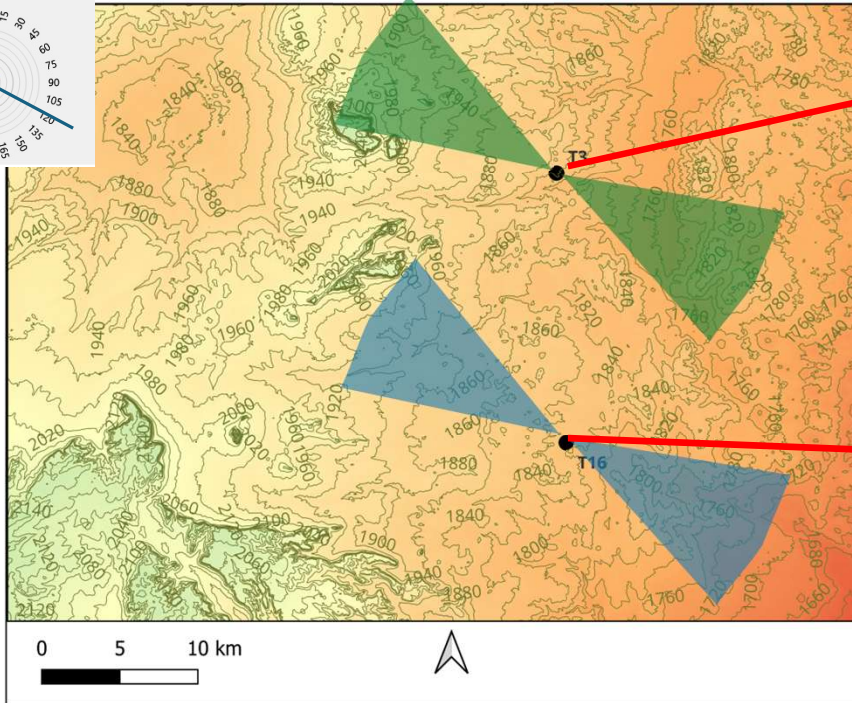
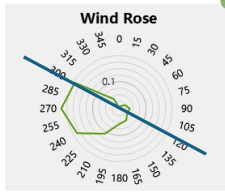


# CONTINUUM EXPLAINED

## UW Downhill / DW Downhill Flow WS Example: Western Spirit (M)

UW sector: 300

DW sector: 120



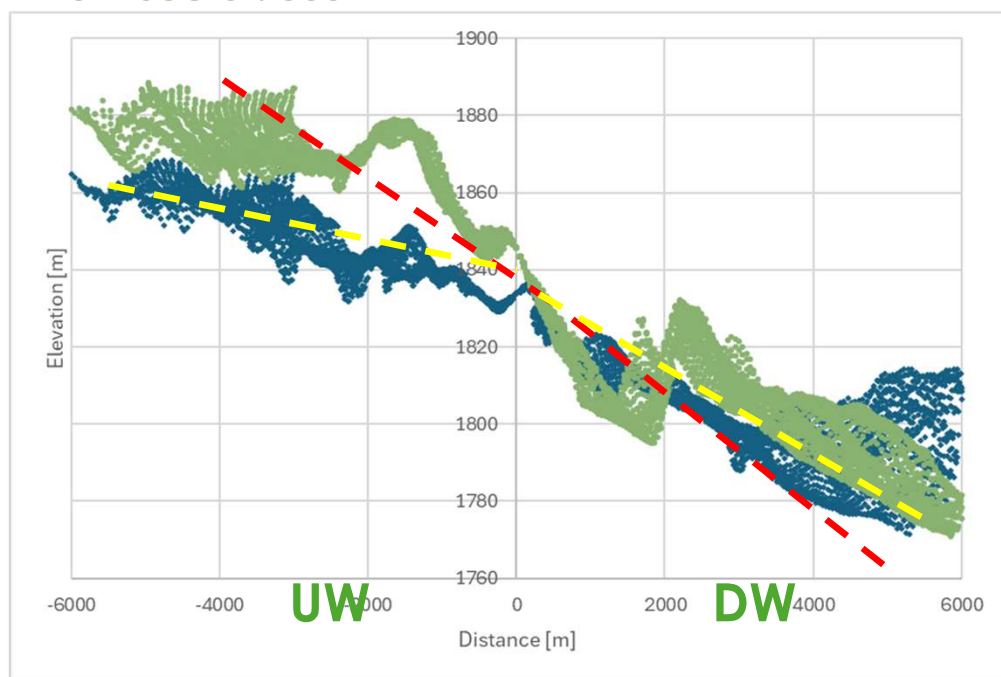


# CONTINUUM EXPLAINED

## UW Downhill / DW Downhill Flow WS Example: Western Spirit (M)

UW sector: 300

DW sector: 120



T16 T3

What can we say about the signs of the UW and DW exposure for each site?

T16:  
 $Exp_{UW}$  is negative  
 $Exp_{DW}$  is positive

T3:  
 $Exp_{UW}$  is negative  
 $Exp_{DW}$  is positive

Both sites are **LOWER** than the average elevation in the UW sector and **HIGHER** than the average elevation in the DW sector

UW downhill flow, DW downhill flow

	ExpUW [m]	ExpDW [m]
T16	-14.3	25.4
T3	-23.3	42.7



## UW Downhill / DW Downhill Flow WS Example: Western Spirit (M)

	ExpUW [m]	ExpDW [m]	ExpUW Coeff	ExpDW Coeff
T16	-14.3	25.4	-0.013	0.013
T3	-23.3	42.7		

What's the WS difference going from T16 to T3 in the 300 sector?

$$\Delta WS = m_{UW} \Delta Exp_{UW} + m_{DW} \Delta Exp_{DW}$$

$$\Delta WS = m_{UW} (Exp_{UW,T3} - Exp_{UW,T16}) + m_{DW} (Exp_{DW,T3} - Exp_{DW,T16})$$

$$\Delta WS = -0.013(-23.3 - (-14.3)) + 0.013(42.7 - 25.4)$$

$$\Delta WS = 0.12 + 0.23$$

$$\Delta WS = 0.34 \text{ m/s}$$

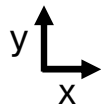
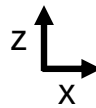
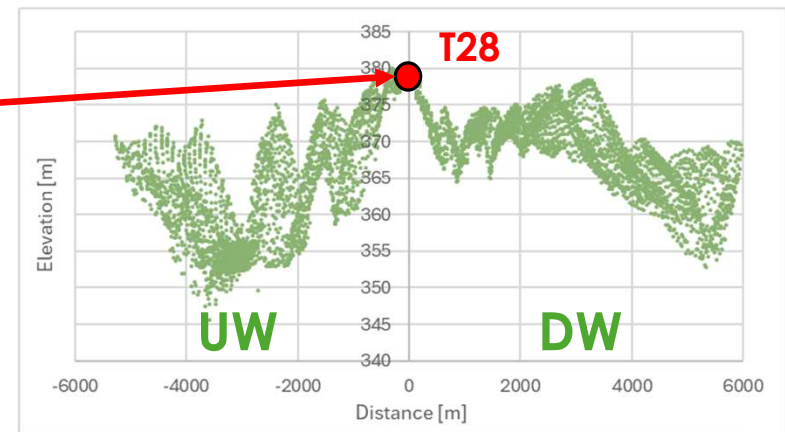
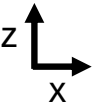
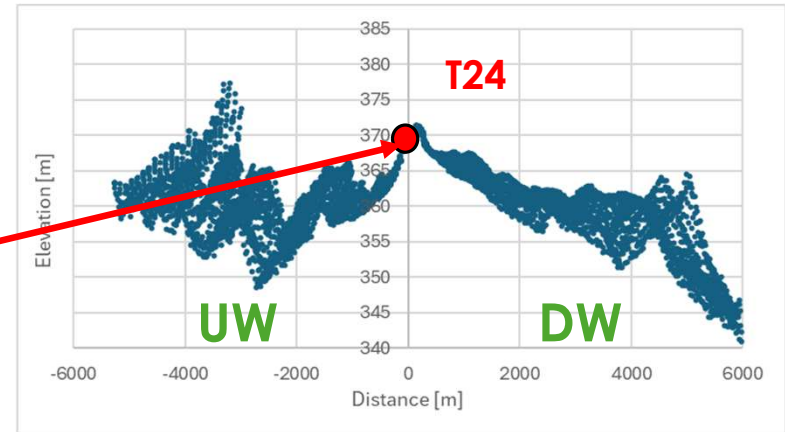
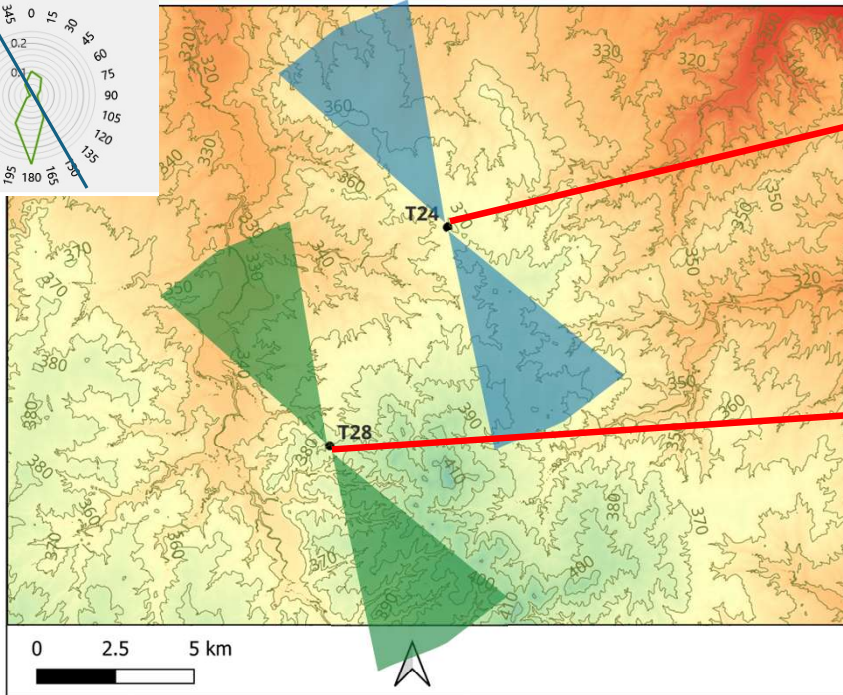
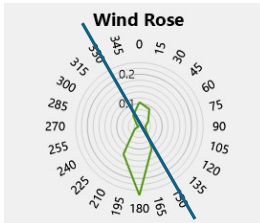
WS at T3 will be 0.34 m/s  
**HIGHER** than the WS at T16



# CONTINUUM EXPLAINED

## UW Speed-Up / DW Downhill Flow WS Example: Kingfisher Wind (L)

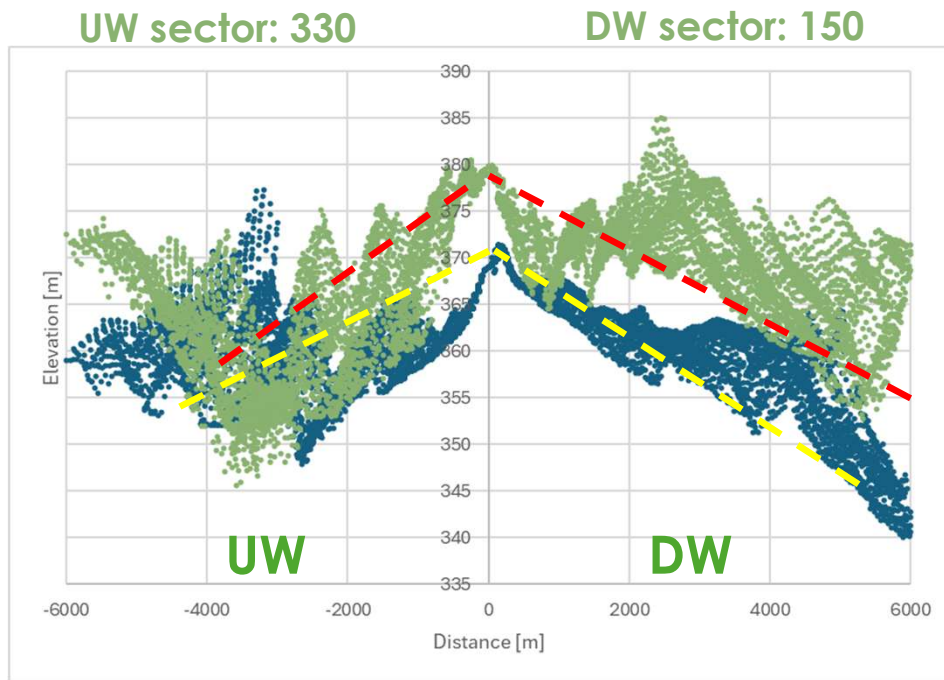
UW sector: 330    DW sector: 150





# CONTINUUM EXPLAINED

## UW Speed-Up / DW Downhill Flow WS Example: Kingfisher Wind (L)



What can we say about the signs of the UW and DW exposure for each site?

**T24:**  
 $Exp_{UW}$  is positive  
 $Exp_{DW}$  is positive

**T28:**  
 $Exp_{UW}$  is positive  
 $Exp_{DW}$  is positive

Both sites are **HIGHER** than the average elevation in the UW and DW sectors

**UW exposure at both sites are below UW critical**

UW **uphill induced speed-up** flow,  
 DW **downhill** flow

T24    T28

	ExpUW [m]	ExpDW [m]
T24	9.0	9.4
T28	16.0	9.6



## UW Speed-Up / DW Downhill Flow WS Example: Kingfisher Wind (L)

	ExpUW [m]	ExpDW [m]	ExpUW Coeff	ExpDW Coeff
T24	9.0	9.4	0.006	0.04
T28	16.0	9.6		

What's the WS difference going from T24 to T28 in the 330 sector?

$$\Delta WS = m_{UW} \Delta Exp_{UW} + m_{DW} \Delta Exp_{DW}$$

$$\Delta WS = m_{UW} (Exp_{UW, T24} - Exp_{UW, T28}) + m_{DW} (Exp_{DW, T24} - Exp_{DW, T28})$$

$$\Delta WS = 0.006(16.0 - 9.0) + 0.04(9.6 - 9.4)$$

$$\Delta WS = 0.04 + 0.01$$

$$\Delta WS = 0.05 \text{ m/s}$$

WS at T28 will be 0.05 m/s  
**HIGHER** than the WS at T24



# OPEN FORUM

**ANY QUESTIONS, COMMENTS, CONCERNS ON CONTINUUM?**



# BECOME A CONTRIBUTOR

**CONTINUUM CONTRIBUTOR:** Someone who actively participates to enhance the Continuum® wind energy software

Continuum's mission is to further the pre-construction wind energy industry through collaboration of wind professionals, researchers, and students

We have an extensive list of projects to incorporate into the software on the Continuum website, but are always open to additions from the community

Submit Continuum® Development Suggestions or R&D Project Ideas or Apply to be Contributor

Name\*

Work suggestion for future development  
Add to be Continuum Contributor  
Submit R&D request

Email\*

Message

Submit

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Continuum® Contributors Open Project List

Project Name	Module	Type ing/R&D/DEV	Details	Difficulty	Status
Performance Curves	Exceedance	Both	Currently, all exceedance performance curves, which define the loss and uncertainty of a given parameter, are specified by the user by setting mean and SD of a distribution or by importing a CSV containing the distribution. Utilize the generated time series data to auto-generate all possible performance curves.	Moderate	
IEC Uncertainty and Losses	Exceedance	Coding	A framework for estimating the loss and uncertainty of a pre-construction net energy estimate has been proposed in IEC 61400-15 ( <a href="https://www.nrel.gov/docs/2015/0031.pdf">https://www.nrel.gov/docs/2015/0031.pdf</a> ). While it may be argued that the exceedance performance curve approach is a better method, it would also be beneficial to show estimates generated using the more simplified approach.	Challenging	
OpenTopo API	Input	Coding	Connect to OpenTopography API and download elevation Geotiff data for project's turbine and met layout.	Easy	Complete
NREL Wind Data API	Input	Coding	Connect to NREL's API to download 20-year wind dataset to use as pseudo met towers.	Easy	
Met Data Reader Improvement	Input	Coding	Improve met data time series reader to be more flexible with headers.	Moderate	
LT Reference Datasets	LT Reference	Both	Incorporate other LT reference datasets (EPRI, Japan JRA, Australia BOM).	Challenging	
Machine	Input	Both			

Projects are broken into two categories: software development and R&D

## Software Development

- Getting into the code and making changes to existing framework
- Example: allow for manual filtering, incorporating other long-term reference datasets (non-US)

## R&D

- New method development and analysis
- Example: wake loss model parameter sensitivity analysis, new ice impact model algorithm

<https://www.continuumwind.com/contributors>



# THANKS FOR JOINING!

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**APRIL 23 2025**