Jielun’ CASES-99 based Analysis

In this documentation, we will list out the progress being done for the analysis and the findings of such.

0. Getting Started

The current study is aiming at finding if our SAVANT field data has similar turbulence effect happened under Stable Boundary Layer.

As for `CASES-99` :

> The Cooperative Atmospheric Surface Exchange Study October 1999 (CASES-99) field observational program represents the second study to investigate linkages between the atmosphere and the Earth's surface. This study is designed to examine events in the nighttime boundary layer, and to investigate the physical processes associated with evening and morning transition regimes. The overall effort encompasses observation, data analyses and numerical modeling to achieve an understanding of episodic events that populate the nighttime stable boundary layer.
> — NCAR

1. Data Description

The following types of data being collected during the experiment period are put into analysis.

Device Type	Resolution [MM:SS]	Description
Sonic Sensor	05:00	The climate monitoring sonic sensors which were installed on 4 primary multi-level flux profile towers. For more information, please visit **Data Report.**
Dusttrak	00:01	The Aerosol Monitor provides real-time aerosol mass readings with gravimetric sampling. For more information, please visit **Product Page.**
Optical Particle Sizer	00:01	The OPS measures particles from 0.3 to 10 µm in 16 user adjustable size channels. For more information, please visit **Product Page.**

1.1 Flux Tower Location

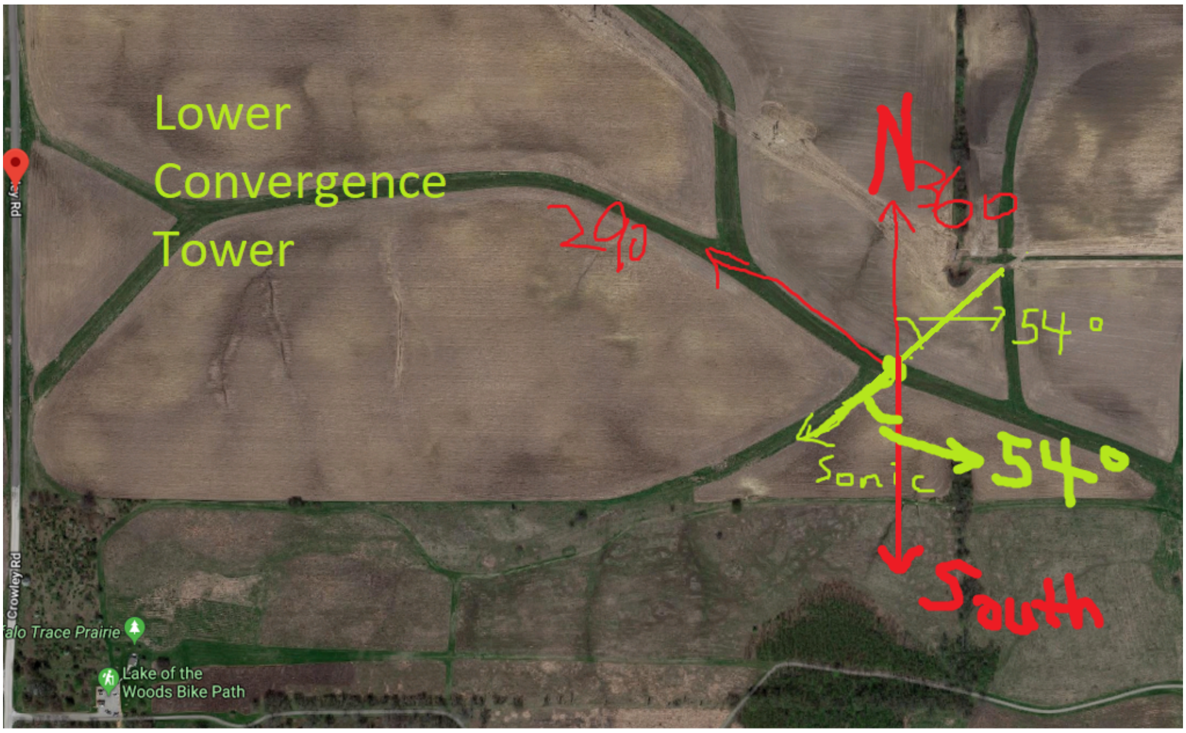
The experiment location is located at `Crowley Rd Mahomet Township, IL 61853.`

Flux Tower Name	Geo-location
Initiation Tower [Init]	40°12'41.46"N, 88°24'37.99"W
Release Tower [Rel]	40°12'42.04"N, 88°24'25.52"W
Upper Convergence Tower [Uconv]	40°12'39.78"N, 88°24'19.61"W
Lower Convergence Tower {Lconv}	40°12'36.91"N, 88°24'13.26"W

1.2 Sonic Sensor Boom Direction

Location	Angle	Type
Init	38°	M (Magnetic)
Rel	108°	M
Uconv	132°	M
Lconv	54°	M

The angle represents the degree in between the direction where the sensor arm is pointing at, and the direction of geological South. For example, at lower convergence tower:



1.3 Aerosol Monitor Device Mapping

Dustrak8530, 8520, OPC Setup Map (10/11/2018-10/12/2018)

Height	Initiation Tower	Release Tower	Upper Convergence Tower	Lower Convergence Tower
6.0 m				DT9 8530
3.0 m	DT5 – 8530 (see section 7 for instrument descriptions)	OPC1	DT8 -8530	OPC2
1.5 m		DT7 –8530		DT10 – 8530
0.5 m				
0.0 m		DT6 8530 DT3 8520		DT2 8520 (no data recorded)

Dustrak8530, 8520, OPC Setup Map (10/15/2018-10/16/2018)

Height	Initiation Tower	Release Tower	Upper Convergence Tower	Lower Convergence Tower
6.0 m				DT9 8530
3.0 m	DT5 – 8530	OPC1	DT8 -8530	OPC2

Height	Initiation Tower	Release Tower	Upper Convergence Tower	Lower Convergence Tower
1.5 m		DT7 -8530		DT10 - 8530
0.5 m				
0.0 m		DT6 8530	DT3 8520	DT2 8520

Dustrak8530, 8520, OPC Setup Map (10/17/2018-10/18/2018)

Height	Initiation Tower	Release Tower	Upper Convergence Tower	Lower Convergence Tower
6.0 m				DT9- 8530(no data recorded)
3.0 m	DT5 – 8530	OPC1	DT8 -8530	OPC2
1.5 m		DT7 –8530		DT10 – 8530
0.5 m				
0.0 m		DT6 8530 at 0.4 m Smoker	DT2-8520	DT3-8520

Dustrak8530, 8520, OPC Setup Map (10/23/2018-10/24/2018, 10/27/2018, 10/29/2018-10/30/2018,)

Height	Initiation Tower	Release Tower	Upper Convergence Tower	Lower Convergence Tower
6.0 m				DT9- 8530
3.0 m	DT5 – 8530	OPC1	DT8 -8530	OPC2
1.5 m		DT7 –8530		DT10 – 8530
0.5 m				
0.0 m		DT6 8530 at 0.4 m Smoker	DT2-8520	DT3-8520

Dustrak8530, 8520, OPC Setup Map (11/2/2018-11/3/2018, 11/7/2018-11/8/2018, 11/10/2018, 11/11/2018-11/12/2018, 11/13/2018-11/14/2018)

Height	Initiation Tower	Release Tower	Upper Convergence Tower	Lower Convergence Tower
6.0 m				DT9- 8530
3.0 m	DT5 – 8530	OPC2?	DT8 -8530	
1.5 m		DT7 –8530		DT10 – 8530

Height	Initiation Tower	Release Tower	Upper Convergence Tower	Lower Convergence Tower
0.5 m				
0.0 m		DT6- 8530	DT2-8520	DT3-8520

2. Data Extraction

2.1 Sonic Sensor Data

The sonic sensor data was extracted by using `NCToolkit`, for more information, please visit `NCToolkit` Manual.

Do notice that:

The filename follows:

```
<MMDD>_<DataCategory>.csv
```

For example, `1018_3DWind.csv` refers to `19:00` on `October 17` to `18:59` on `October 18`. This is because the original data was stored in `UTC` time zone. The current data extraction tool has converted the time into `CDT` time zone.

2.2 Dusttrak Data

The Dusttrak data was extracted by using `DusttrakGrouperTool`, for more information, please visit `DusttrakGrouperTool` Manual. Similarly, the data has been aligned in the same style as sonic sensor data. Therefore, the time range correction is the same as stated above.

3. Data Filtering

Based on Jielun's CASE-99 analysis, in order to perform numerical analysis for turbulence regimes and turbulence intermittency in the stable boundary layers, the ideal weather condition should be stable and dry. Hence, we filter the experimental data based on the following criteria.

After reviewing Jielun's analysis performed on CASE-99, which were published in 2002, 2003, 2012, and 2016, I was not able to find any comments on data selection. According to weather history, there were dates during the data collection period for CASE-99 where extreme weather conditions occurred.

In addition, after examining the publications listed under CASE-99 Publications page, only vague descriptions were given on the data qualification. After discussion with Dr. Junming Wang and Dr. David Kristovich, the following approaches were taken based on difference criteria to select qualified data.

3.1 Corrupted Datasets

During the data collection period, sensors can be offline, or malfunction during operation. Under some occasions, we witness that on the same tower, sensors at certain height can have missing data samples. For example:

In order to maintain the data integrity, at the time when one or more sensor at a given tower is missing, all data samples being collected at the time will be removed.

This filter is being applied to all the flux tower datasets.

3.2 Sonic Sensor Boom Angle

According to Jielun's study:

> Since the sonic anemometers were all mounted on booms pointing eastward, turbulent fluxes associated with winds from 270° ± 60° could be distorted by the 60-m tower; therefore, all the flux data from this sector were eliminated from this analysis.
>
> — **Turbulence Regimes and Turbulence Intermittency in the Stable Boundary Layer during CASES-99**

Based on the installation information mentioned in **Section 1.2**, if wind direction falls from the following range will be removed:

Tower ID	Starting Angle	End Angle
Init	338°(-22°)	98°
Rel	48°	168°
Uconv	72°	192°
Lconv	354°(-6°)	114°

This filter is only applied to wind speed and wind direction datasets, temperature datasets were excluded from this filter.

3.3 Weather Conditions

The following rules are being applied to separate the observation datasets into different groups.

3.3.1 Precipitation

Precipitation brings high humidity condition during the experiments. The precipitation will lead to high thermal exchange post the precipitation period. This can cause instability environmental condition which is not suitable for our study. Hence, the following condition is being used in order to filter out instability period. `Precip.` is the variable of measured precipitation represented in the hourly climate data.

```
Precip. > 0.00 in
```

3.3.2 Weather Condition

Since the precipitation resolution is only `0.01 in` collected from the hourly weather station. Sometimes, light rain or short storm was not able to be properly reflected on hourly precipitation collection. Therefore, regular expression method is being used in order to sort out these un-measurable sampling periods. In the hourly climate data, variable `Condition` is used for observers to record current weather condition at the given time. Hence, the following condition is being used in order to filter out instability period.

```
Condition == 'Rain'|'Wintry Mix'|'Storm'|'Snow'
```

Note that, for `Condition == 'Rain`, `Light Rain`, `Heavy Rain` are all included since these condition all contains the token `Rain`.

3.3.3 Related Thermal Instable Period

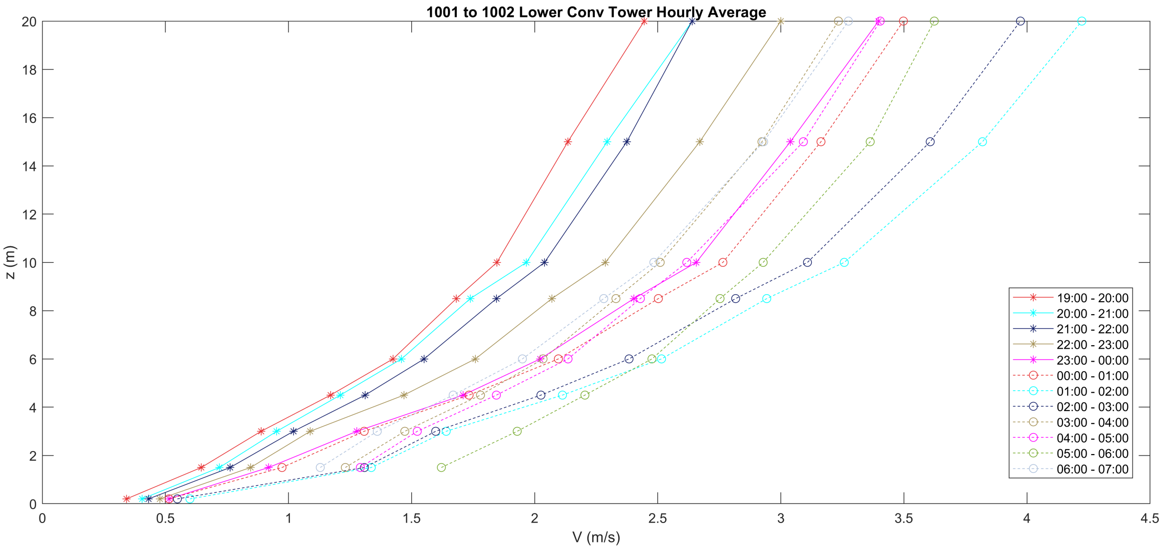
Post precipitation period, as the sensors are covered with moisture, according to technicians, 2 hours are usually needed for the surface of the sensors to dry out. During the drying period, the accuracy of the data may be affected due to local thermal exchange. Therefore, in order to avoid potential data corruptions, data from the hour before the starting of precipitation, along with 2 hours post the precipitation periods are being removed.

4. Data Visualization

The following data visualizations were practiced.

You can download a copy of the visualization images via **here**.

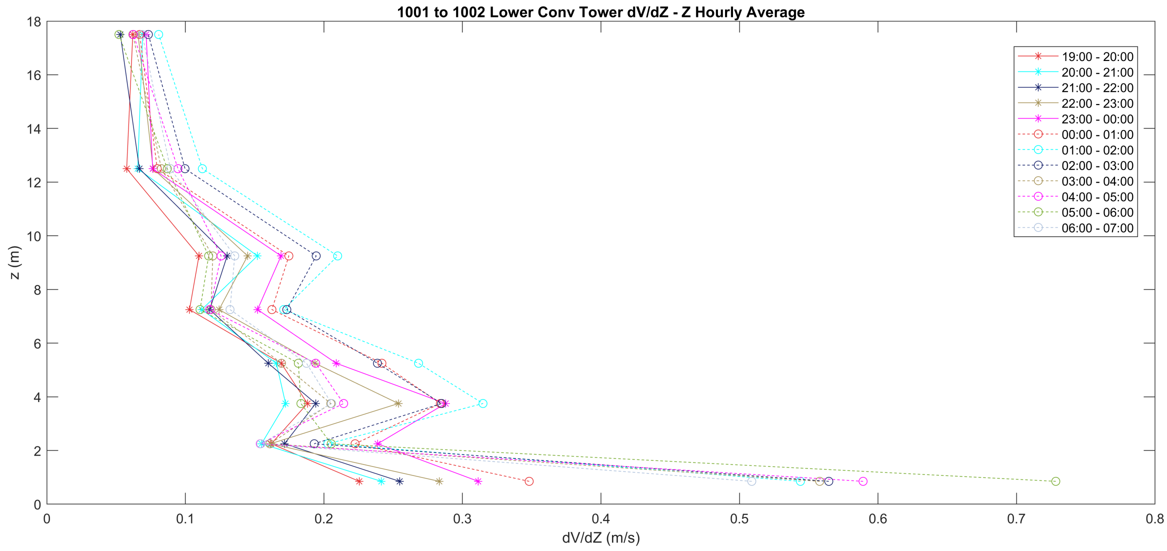
4.1 Wind Speed Hourly Average



The horizontal axis represents the wind velocity with a unit of meters per second denoted as `V`. As for the vertical axis, it represents the height denoted as `z` with a unit of meter. And as for each plotted lines, each marker on the line represents an average value of wind velocity at the respective height based on a period of 1 hour of 5-min sampled data samples. If a marker is missing at a certain height at a given hour, there are following possibilities which resulted in the issue:

1. Sonic sensor was not operating at the given time;
2. The wind direction falls into the interfering range noted in **Section 3.2**.

4.2 Wind Shear Hourly Average



The horizontal axis represents the wind shear with a unit of meters per second denoted as `dV/dZ`. It is calculated based on the following equation:

$$\frac{dV}{dZ} = \frac{V_{HigherHeight} - V_{LowerHeight}}{Z_{HigherHeight} - Z_{LowerHeight}}$$

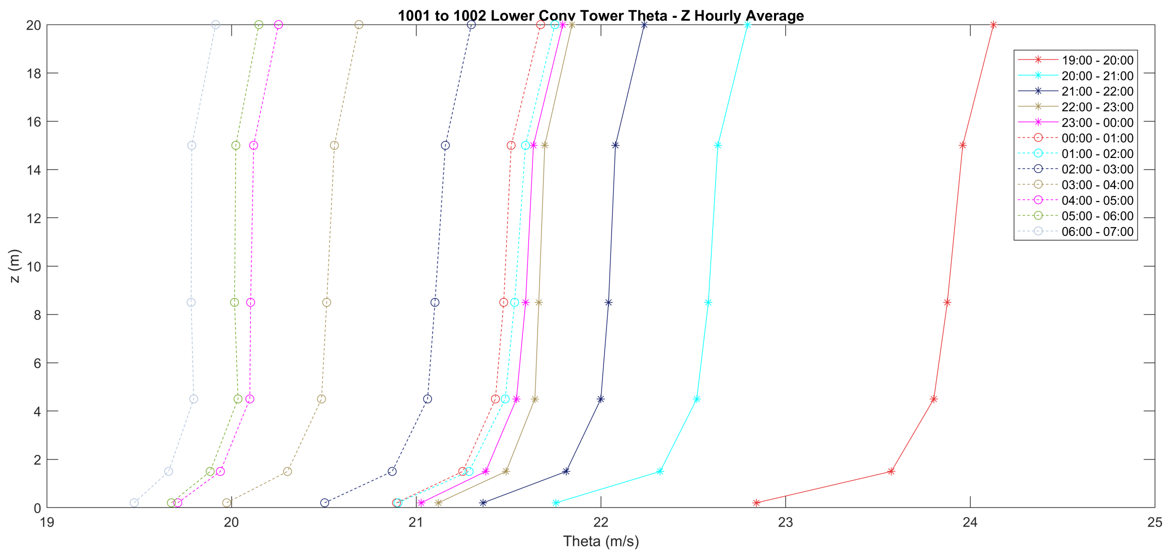
As for the vertical axis, it represents the height denoted as `z` with a unit of meter. The height is being assigned as:

$$z = \frac{1}{2} * (Z_{LowerHeight} + Z_{HigherHeight})$$

And as for each plotted lines, each marker on the line represents an average value of wind shear at the respective height based on a period of 1 hour of 5-min sampled data samples. If a marker is missing at a certain height at a given hour, there are following possibilities which resulted in the issue:

1. Either/Both given height(s) were not recording sampling data;
2. Either/Both given height(s) has direction fall into the interfering range noted in **Section 3.2**.

4.3 Potential Temperature Hourly Average



The horizontal axis represents the potential temperature with a unit of meters per second denoted as `Theta(θ)`. It is calculated based on the following equation:

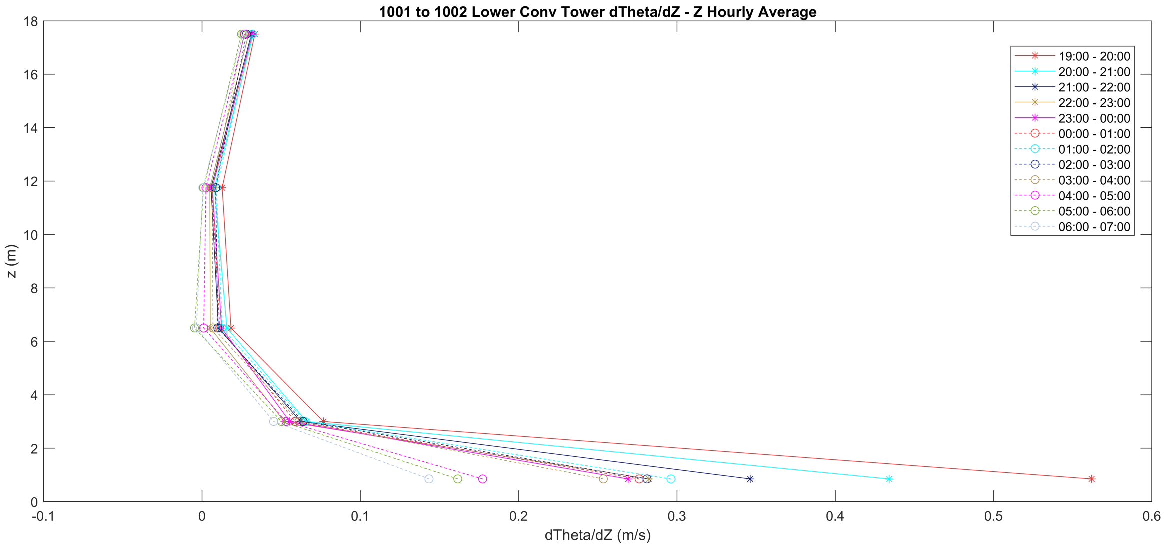
$$Potential\ Temperature(\theta) = T * (\frac{P_0}{P})^k$$

where as the Poisson Constant $k = \frac{2}{7}$, and $P_0 = 100\ kPa = 1000\ Millibar$, P is set to the atmospheric pressure at `1.5 m` at the nearest tower location.

As for the vertical axis, it represents the height denoted as `z` with a unit of meter. And as for each plotted lines, each marker on the line represents an average value of potential temperature at the respective height based on a period of 1 hour of 5-min sampled data samples. If a marker is missing at a certain height at a given hour, there are following possibilities which resulted in the issue:

1. Sonic sensor was not operating at the given time.

4.4 Vertical Temperature Gradient Hourly Average



The horizontal axis represents the potential temperature gradient with a unit of meters per second denoted as `dTheta(θ)/dZ`. It is calculated based on the following equation:

$$\frac{d\theta}{dZ} = \frac{\theta_{HeigherHeight} - \theta LowerHeight}{Z_{HigherHeight} - Z_{LowerHeight}}$$

As for the vertical axis, it represents the height denoted as `z` with a unit of meter. And as for each plotted lines, each marker on the line represents an average value of potential temperature gradient at the respective height based on a period of 1 hour of 5-min sampled data samples. If a marker is missing at a certain height at a given hour, there are following possibilities which resulted in the issue:

1. Sonic sensor was not operating at the given time.

4.5 DustTrak Real-Time

Under Construction

5. Initial Calculation and Filtering

In order to find out the stability of the boundary layers, the following calculations were performed during the initial stage of analsis.

5.1. Bulk Richardson Number

The **Bulk Richardson Number** is defined as:

below R_T before KH waves can form. Laboratory and theoretical work have shown that the criterion for KH wave formation is $Ri < R_c$. This leads to the apparent hysteresis, because the Richardson number of nonturbulent flow must be lowered to R_c before turbulence will start, but once turbulent, the turbulence can continue until the Richardson number is raised above R_T.

5.6.3 Bulk Richardson Number

The theoretical work yielding $R_c \cong 0.25$ is based on local measurements of the wind shear and temperature gradient. Meteorologists rarely know the actual local gradients, but can approximate the gradients using observations made at a series of discrete height intervals. If we approximate $\partial\overline{\theta_v}/\partial z$ by $\Delta\overline{\theta_v}/\Delta z$, and approximate $\partial\overline{U}/\partial z$ and $\partial\overline{V}/\partial z$ by $\Delta\overline{U}/\Delta z$ and $\Delta\overline{V}/\Delta z$ respectively, then we can define a new ratio known as the ***bulk Richardson number***, R_B :

$$R_B = \frac{g \, \Delta\overline{\theta_v} \, \Delta z}{\overline{\theta_v} \left[(\Delta\overline{U})^2 + (\Delta\overline{V})^2 \right]} \qquad (5.6.3)$$

It is this form of the Richardson number that is used most frequently in meteorology, because rawinsonde data and numerical weather forecasts supply wind and temperature measurements at discrete points in space. The sign of the finite differences are defined, for example, by $\Delta\overline{U} = \overline{U}(z_{top}) - \overline{U}(z_{bottom})$.

Unfortunately, the critical value of 0.25 applies only for local gradients, not for finite differences across thick layers. In fact, the thicker the layer is, the more likely we are to average out large gradients that occur within small subregions of the layer of interest. The net result is (1) we introduce uncertainty into our prediction of the occurrence of

In the `.csv` files, it is noted as `R_bulk`.

5.2. Obukhov Length

The **Obukhov Length** is calculated based on:

Each of these terms is now dimensionless. The last term, a dimensionless dissipation rate, will not be pursued further here.

The ***von Karman constant***, k, is a dimensionless number included by tradition. Its importance in the log wind profile in the surface layer is discussed in the next section. Investigators have yet to pin down its precise value, although preliminary experiments suggest that it is between about 0.35 and 0.42. We will use a value of 0.4 in most of this book, although some of the figures adopted from the literature are based on k=0.35.

Term III is usually assigned the symbol, ζ, and is further defined as $\zeta \equiv z/L$, where L is the ***Obukhov length***. Thus,

$$\zeta = \frac{z}{L} = \frac{-k \, z \, g \, (\overline{w'\theta_v'})_s}{\overline{\theta_v} \, u_*^3} \qquad (5.7b)$$

The Obukhov length is given by:

$$L = \frac{-\overline{\theta_v} \, u_*^3}{k \, g \, (\overline{w'\theta_v'})_s} \qquad (5.7c)$$

And the L for lower surface of the layer is denoted as `L_low`, and the upper surface is denoted as `L_high`. Note that, the value for $\frac{z}{L}$, is calculated and noted as `Term_3` in the picture above. The lower surface value is denoted as `Term_3_low` and upper surface value is denoted as `Term_3_high`.

6. Initial Findings

This is the first stage analysis with the reference to CASES-99 study.

6.1 Data Filtering

After constructing the base of analysis, additional filtering rules been applied to the datasets. As Jielun's Cases-99 were conducted in `September` , which is over a course of `30` days. All `October` datasets were set as target, to minimize the variation of climate thermal condition.

6.1.1 Temperature Filtering

By theory, under stable condition, the temperature should increase while height increases. Hence, the following Boolean rule has been applied:

`Initiation Tower / Upper Convergence Tower` :

$T_{0.2m} <= T_{1.5m} <= T_{3.0m} <= T_{4.5m} <= T_{6.0m} <= T_{10.0m}$

`Release Tower / Lower Convergence Tower` :

$T_{0.2m} <= T_{1.5m} <= T_{3.0m} <= T_{4.5m} <= T_{6.0m} <= T_{8.5m} <= T_{10.0m} <= T_{15.0m} <= T_{20.0m}$

6.1.2 Wind Speed Filtering

By theory, under stable condition, the wind speed should increase while height increases. Hence, the following Boolean rule has been applied:

`Initiation Tower / Upper Convergence Tower` :

$V_{0.2m} <= V_{1.5m} <= V_{3.0m} <= V_{4.5m} <= V_{6.0m} <= V_{10.0m}$

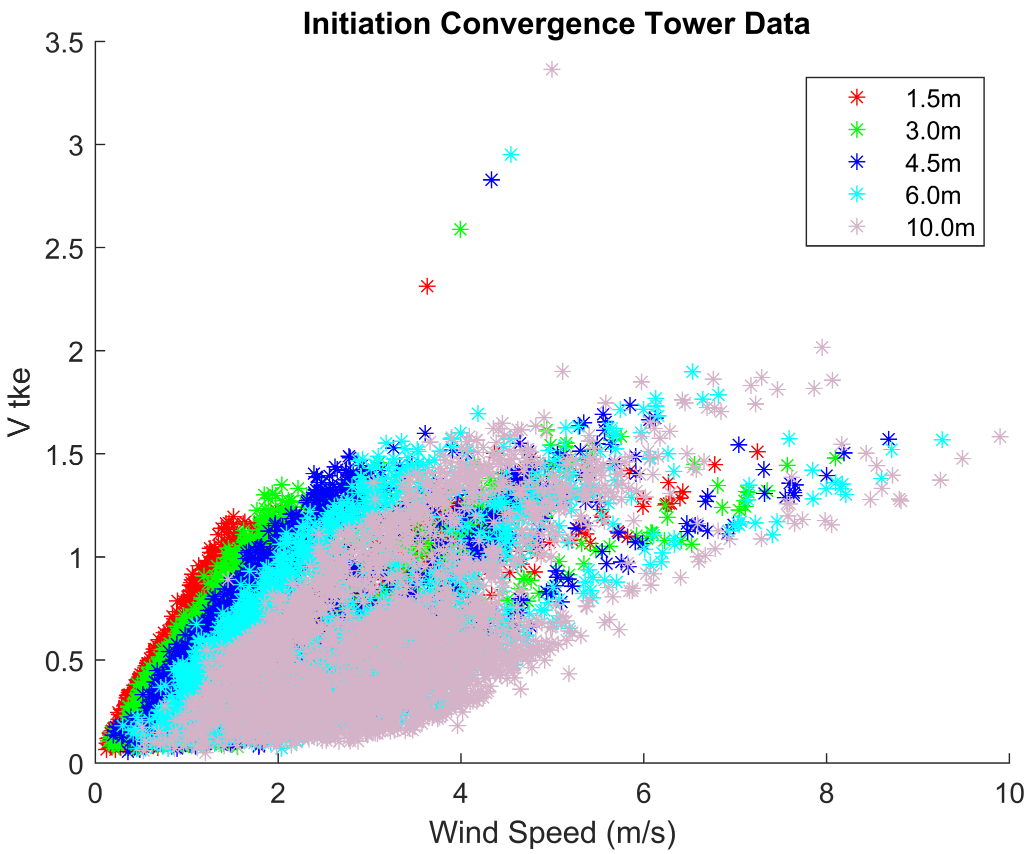
`Release Tower / Lower Convergence Tower` :

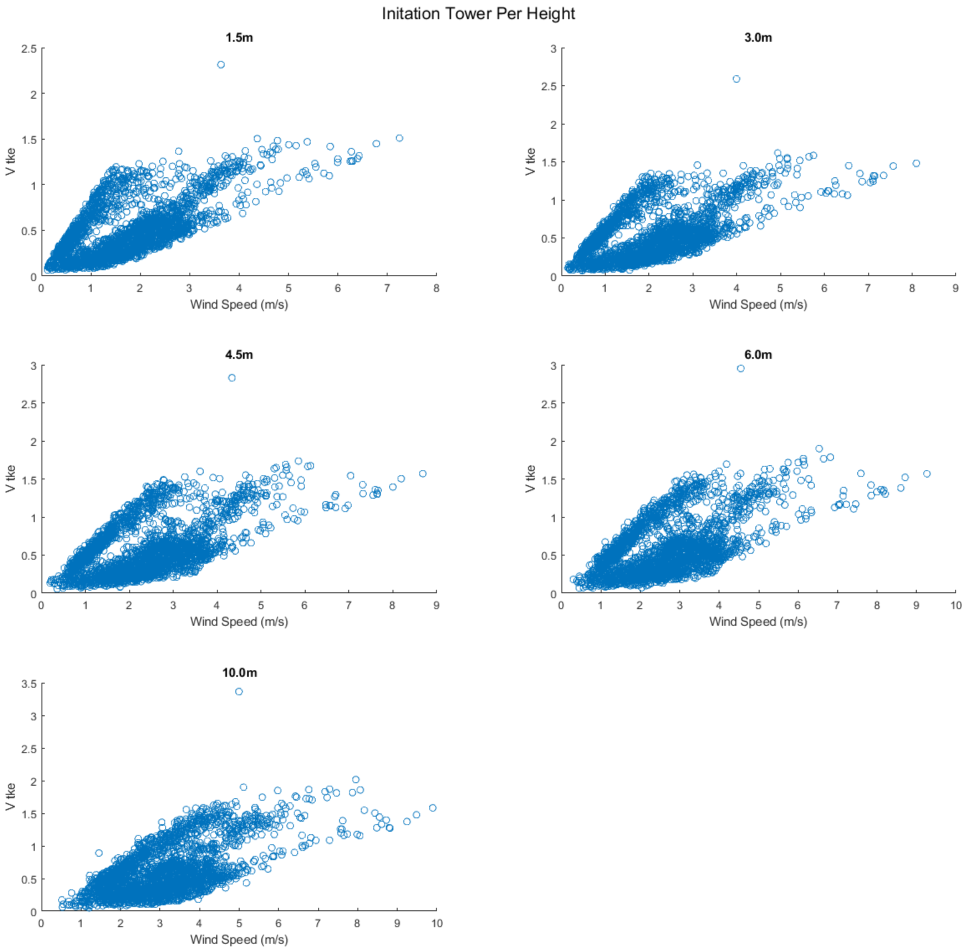
$V_{0.2m} <= V_{1.5m} <= V_{3.0m} <= V_{4.5m} <= V_{6.0m} <= V_{8.5m} <= V_{10.0m} <= V_{15.0m} <= V_{20.0m}$

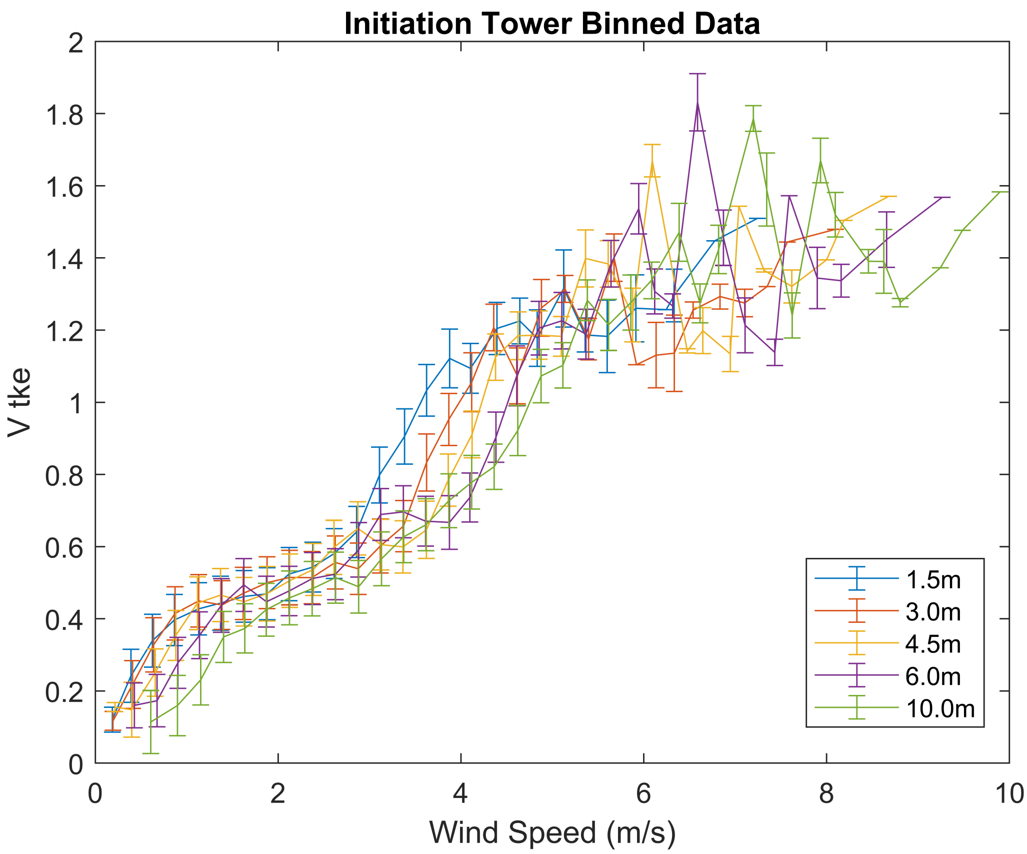
6.2 Scattered Visualization

The figures below are visualizing the valid data samples in scatter and binned mode.

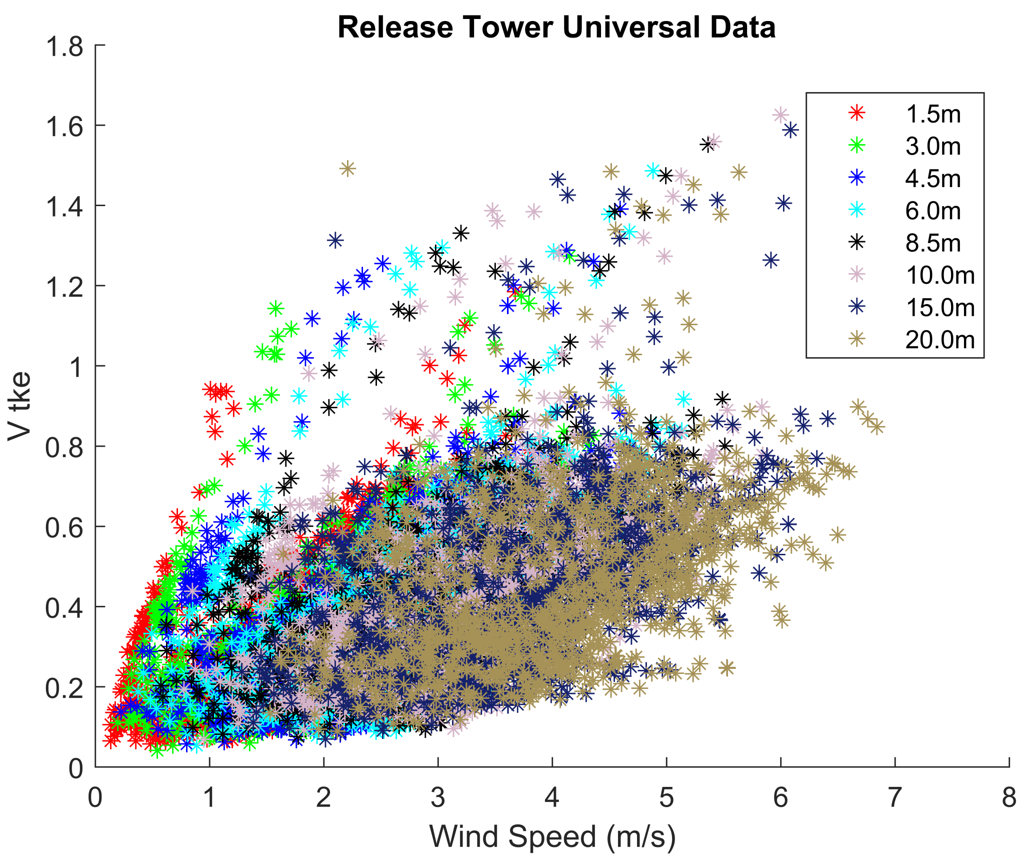
6.2.1 Initiation Tower

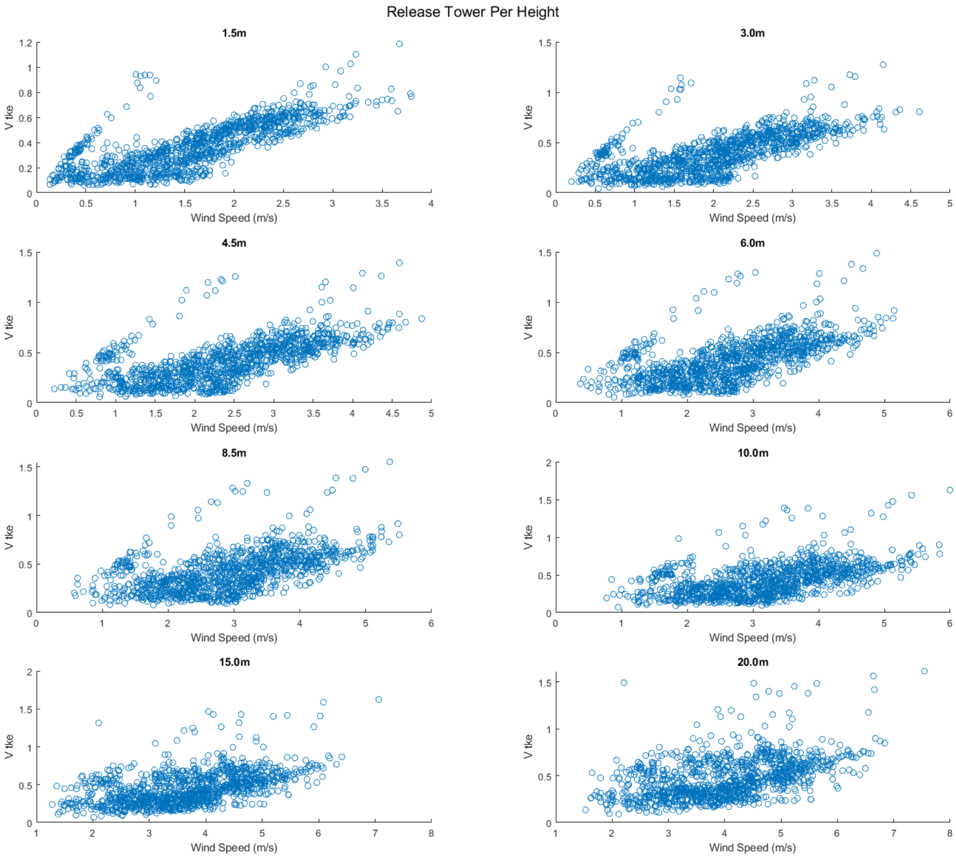

Initiation Convergence Tower Data
V tke
Wind Speed (m/s)
1.5m
3.0m
4.5m
6.0m
10.0m

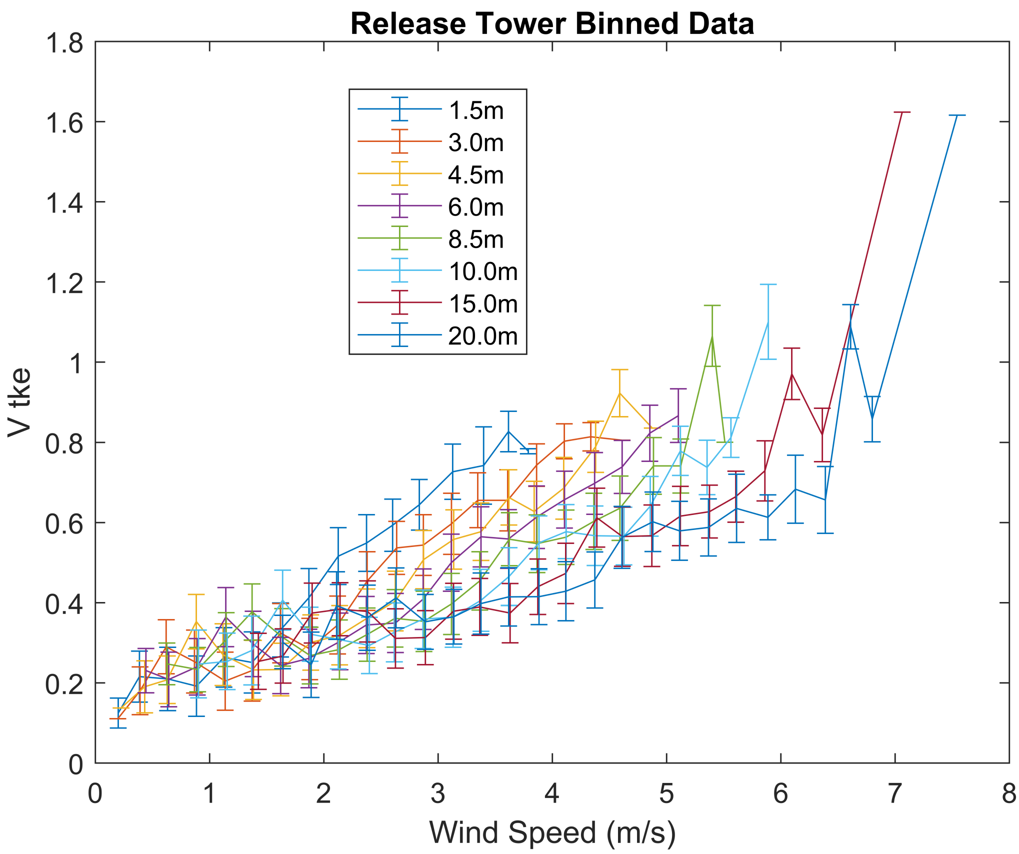

Initation Tower Per Height
1.5m
3.0m
4.5m
6.0m
10.0m
V tke
Wind Speed (m/s)



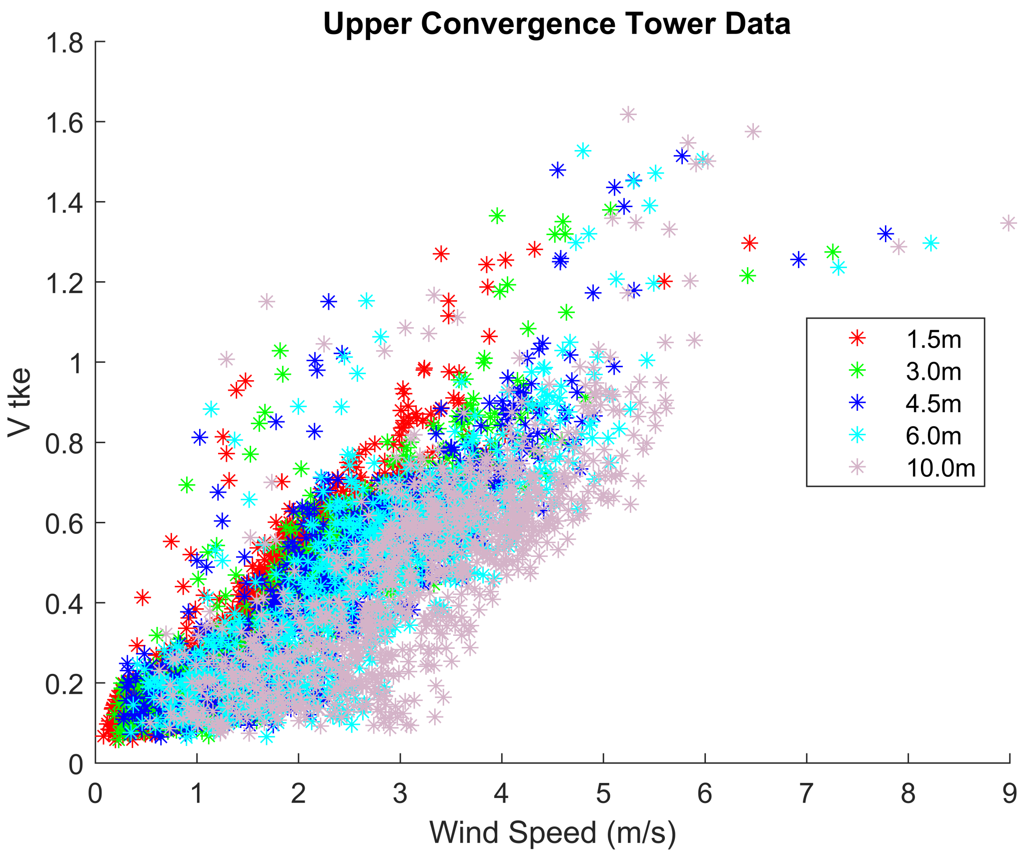
6.2.2 Release Tower

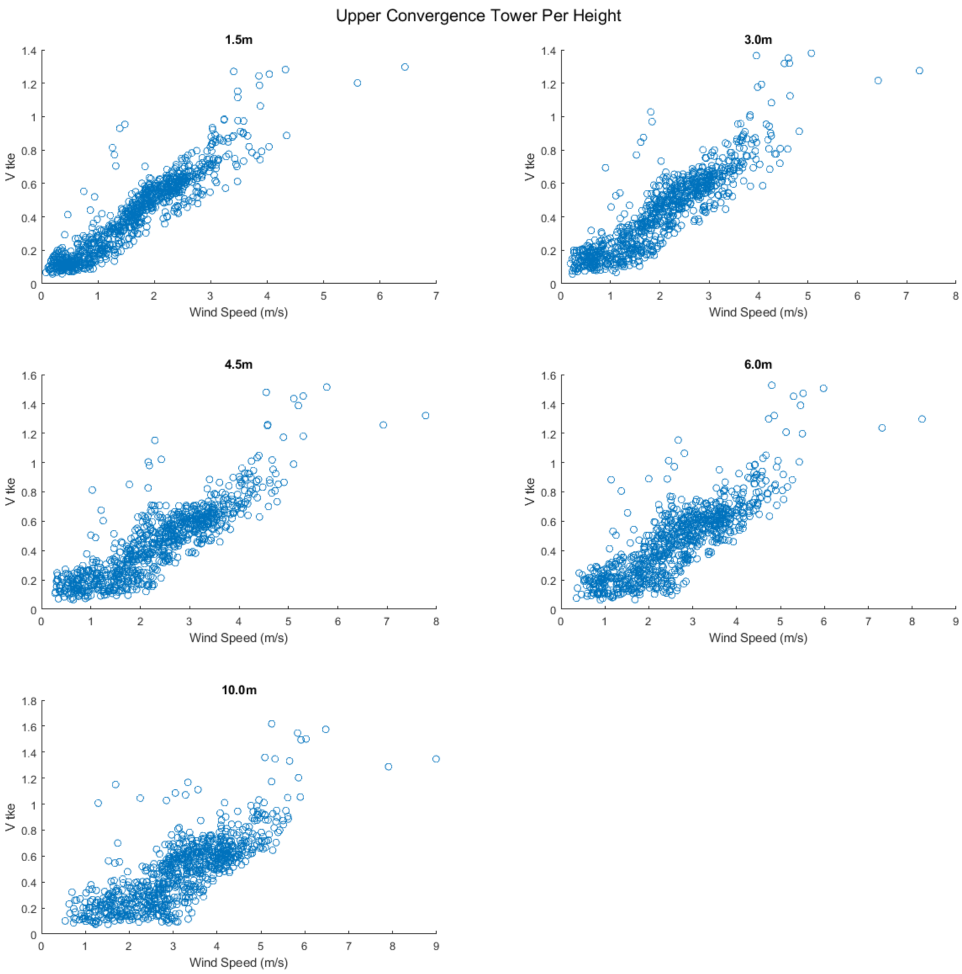


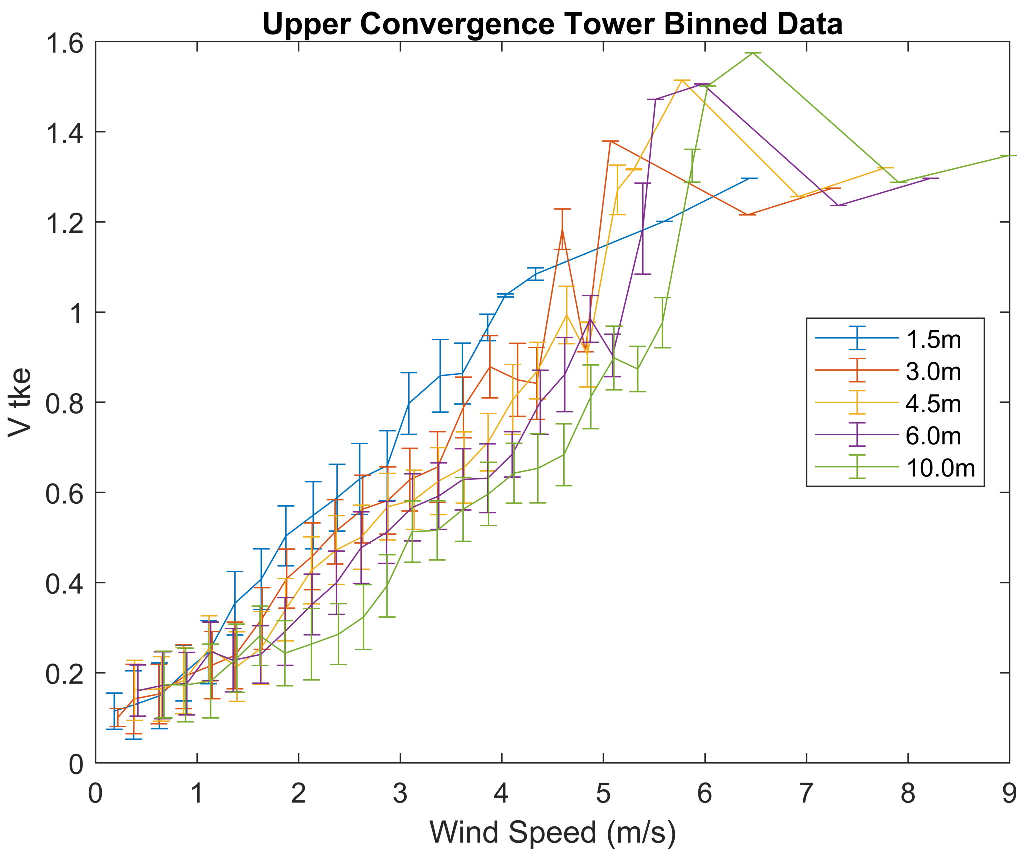




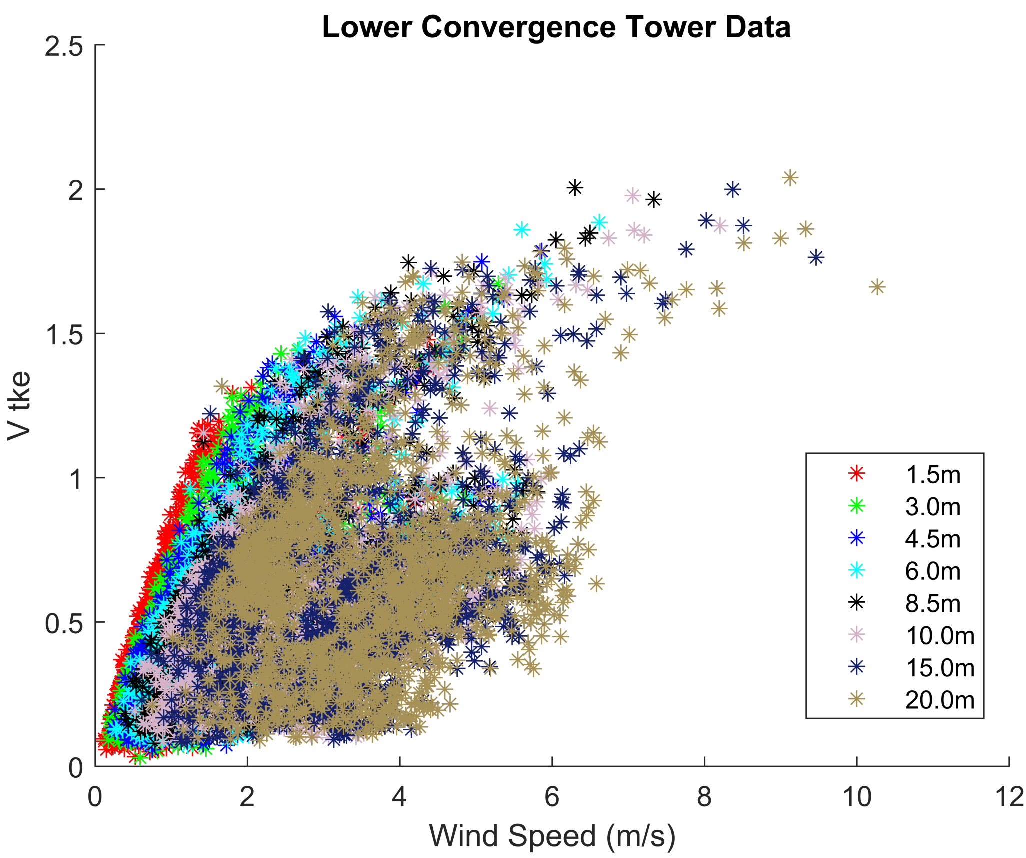
6.2.3 Upper Convergence Tower

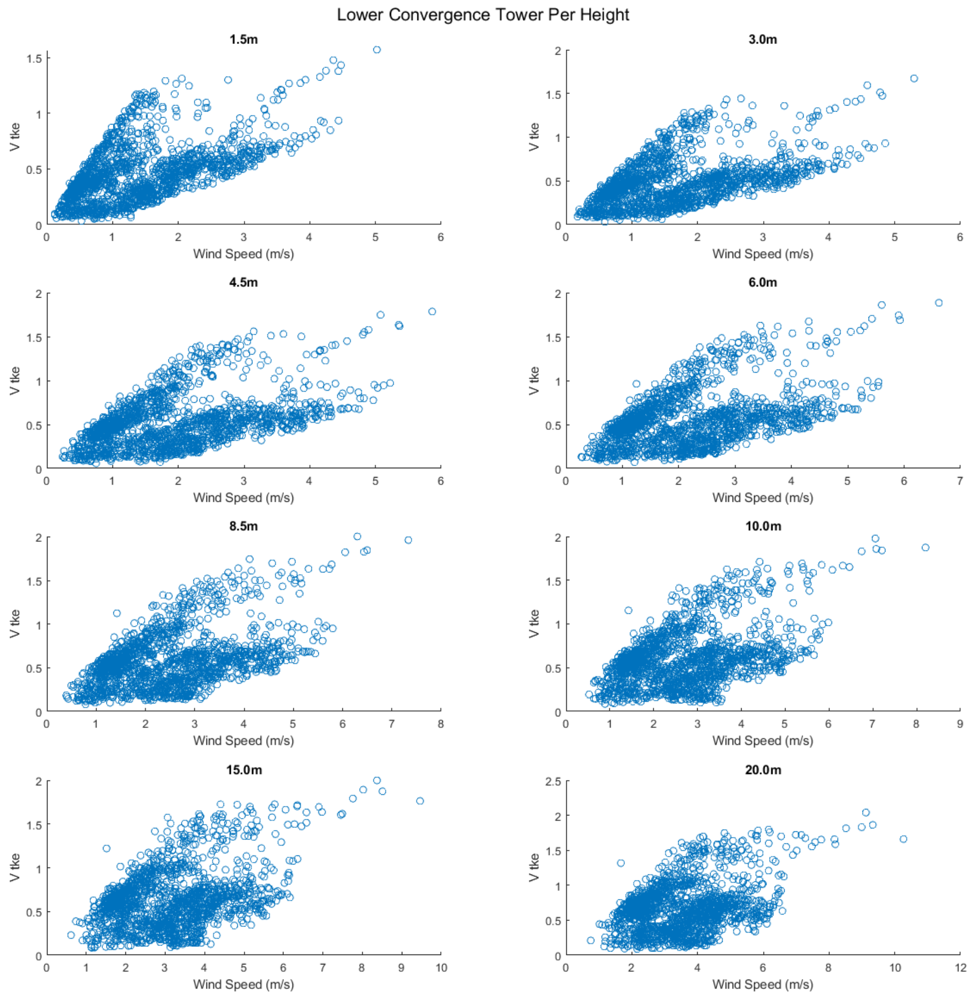

Upper Convergence Tower Data
V tke
Wind Speed (m/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
1
2
3
4
5
6
7
8
9
1.5m
3.0m
4.5m
6.0m
10.0m

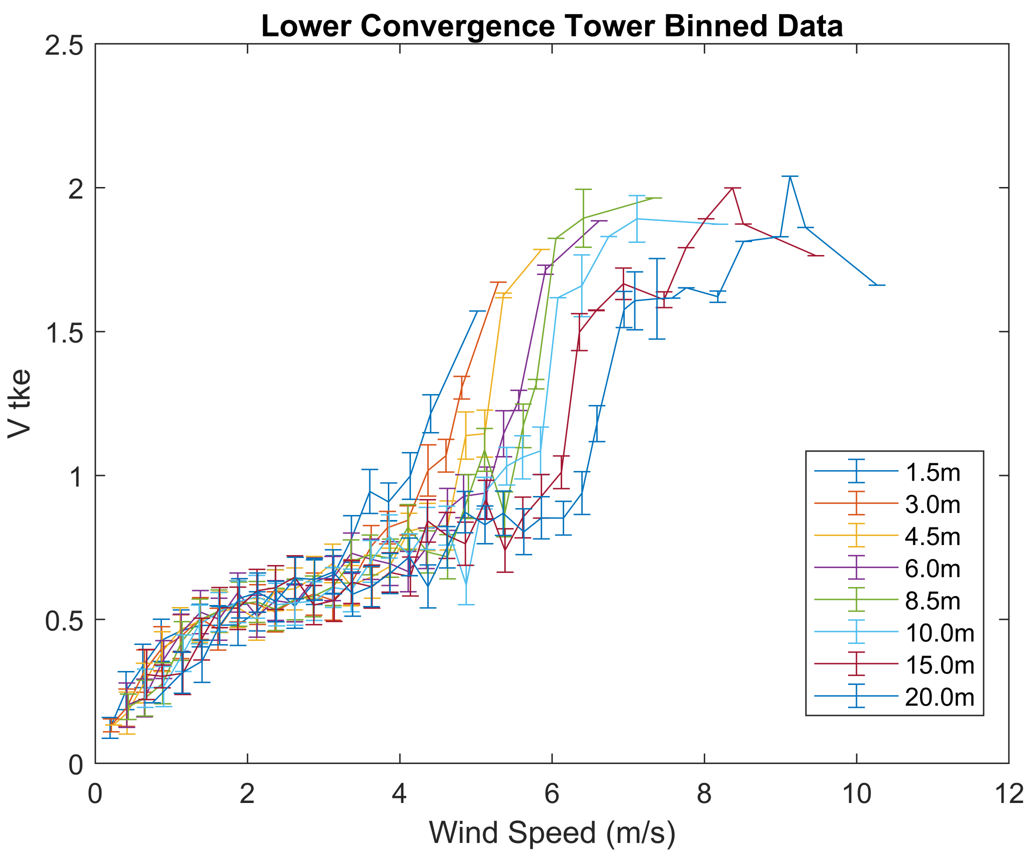

Upper Convergence Tower Per Height
1.5m
3.0m
4.5m
6.0m
10.0m
V tke
Wind Speed (m/s)



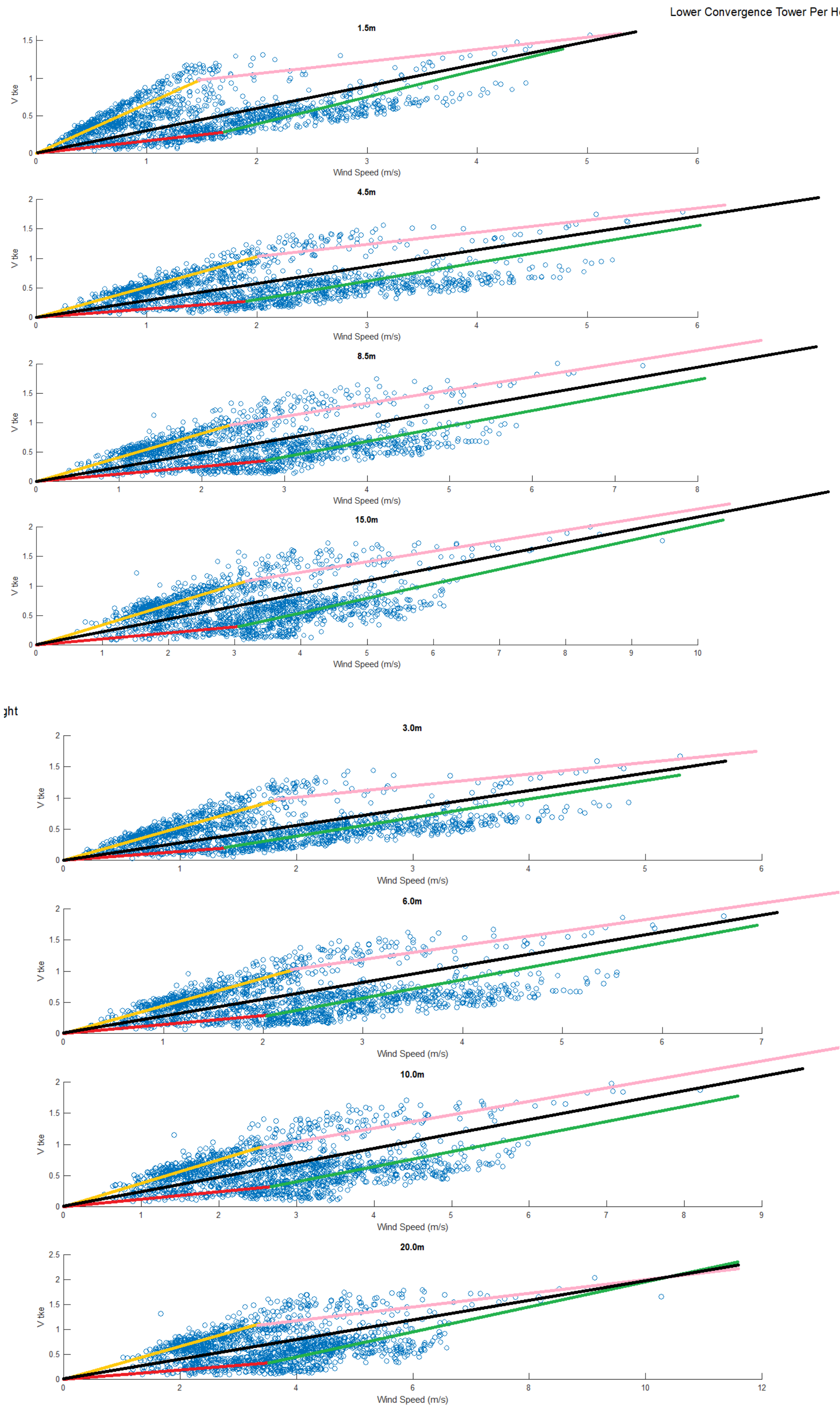
6.2.4 Lower Convergence Tower




Lower Convergence Tower Per Height
1.5m
3.0m
4.5m
6.0m
8.5m
10.0m
15.0m
20.0m
V tke
Wind Speed (m/s)


Lower Convergence Tower Binned Data
V tke
Wind Speed (m/s)
1.5m
3.0m
4.5m
6.0m
8.5m
10.0m
15.0m
20.0m

However, if we look at the Lower Convergence Tower scattered plot, we can see some clustering effect as:



Also, the horizontal axis is the `Horizontal Wind Speed`, and the vertical axis is the V_{TKE}. I believe that further filtering is required in order to bring down the data samples which surrounds the yellow and pink linear fitting zone.

6.3 Valid Sample Rate

The table down below reveals how many samples are valid post the filtering process. And `Universal` refers to how many overall data samples are presented in the October time domain.

Overall valid data counts:

For initiation tower:

Speed	Temperature	Direction	Total Count	Universal
22902	14640	20112	57654	71424

For release tower:

Speed	Temperature	Direction	Total Count	Universal
29691	13308	24156	67155	107136

For upper convergence tower:

Speed	Temperature	Direction	Total Count	Universal
20586	10096	14628	45310	71424

For lower convergence tower:

Speed	Temperature	Direction	Total Count	Universal
29079	16602	26577	72258	107136

Do notice that, the wind direction of 0.2 meter are not being filtered, due to the fact it is way too close to the ground, and it is highly possible that the wind direction at 0.2 meter can be different that other heights, which falls into the range mentioned in `Section 3.2`.

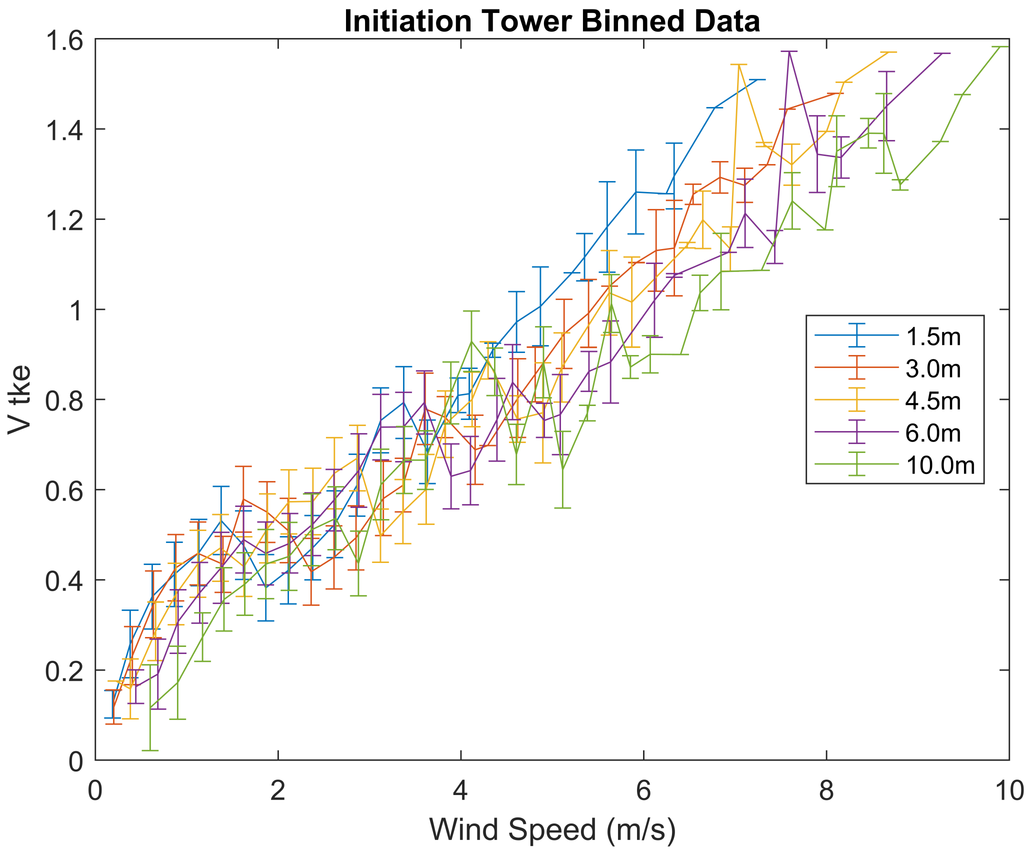
1	CDT_time	bar_fence	dir_0_2m_	dir_1_5m_	dir_3m_in	dir_4_5m_	dir_6m_in	dir_10m_i	bar_fence	c
2	19:02:30	|	85.70762	254.1179	254.9864	253.3238	255.6018	261.6891	|	
3	19:07:30	|	82.37345	256.5462	259.0426	259.374	261.6779	267.6556	|	
4	19:12:30	|	83.35069	258.2654	261.6403	262.2093	264.3275	269.0941	|	
5	19:17:30	|	81.57107	256.4594	261.1581	259.9644	261.8058	266.9083	|	
6	19:22:30	|	85.31113	260.4436	265.2862	262.8221	264.6827	268.6537	|	
7	19:27:30	|	92.90716	267.1595	267.9006	266.7885	267.855	271.054	|	
8	19:32:30	|	83.00816	262.42	265.5573	266.7185	269.3281	271.9616	|	
9	19:37:30	|	90.16147	269.7145	272.0547	271.2636	272.018	273.0664	|	
10	19:42:30	|	92.15915	269.4885	271.0569	269.0024	269.4949	271.6956	|	
11	19:47:30	|	73.77975	256.7838	261.2857	261.9168	264.0069	268.7328	|	
12	19:52:30	|	74.04988	257.6515	261.9816	263.9331	267.0035	271.9838	|	
13	19:57:30	|	78.92814	263.1642	268.32	268.5911	270.3091	273.8125	|	
14	20:02:30	|	80.68176	263.8802	267.495	267.139	268.0737	270.7853	|	
15	20:07:30	|	87.04723	268.2211	271.1018	271.0839	272.8393	275.3816	|	
16	20:12:30	|	91.97872	268.3779	270.6049	269.613	270.6855	273.8943	|	
17	20:17:30	|	90.40736	267.9553	270.1344	269.5003	270.3369	272.6865	|	
18	20:22:30	|	96.03874	274.6117	276.2364	276.1027	277.3183	279.9893	|	

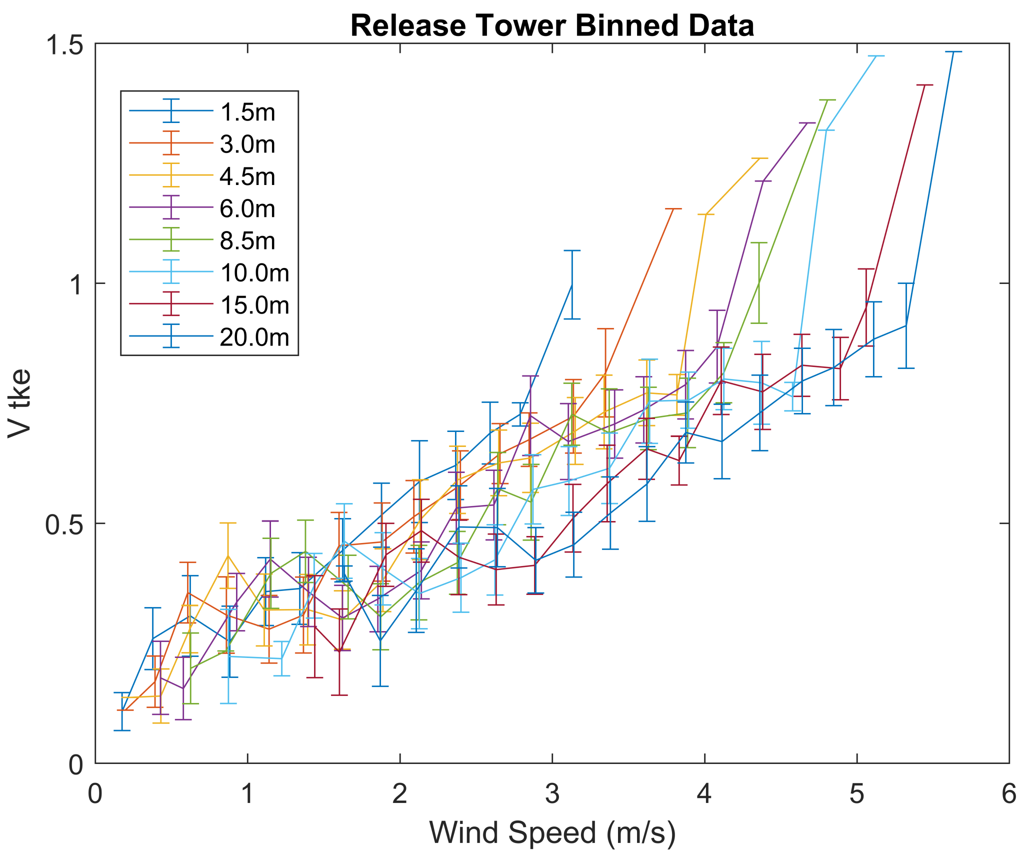
As shown in the red circled area above, it is a usual phenonium where wind direction at 0.2 meter at each tower can be different / in 90 degrees different than the direction at any other height, whereas the direction at any other heights are virtually the same.

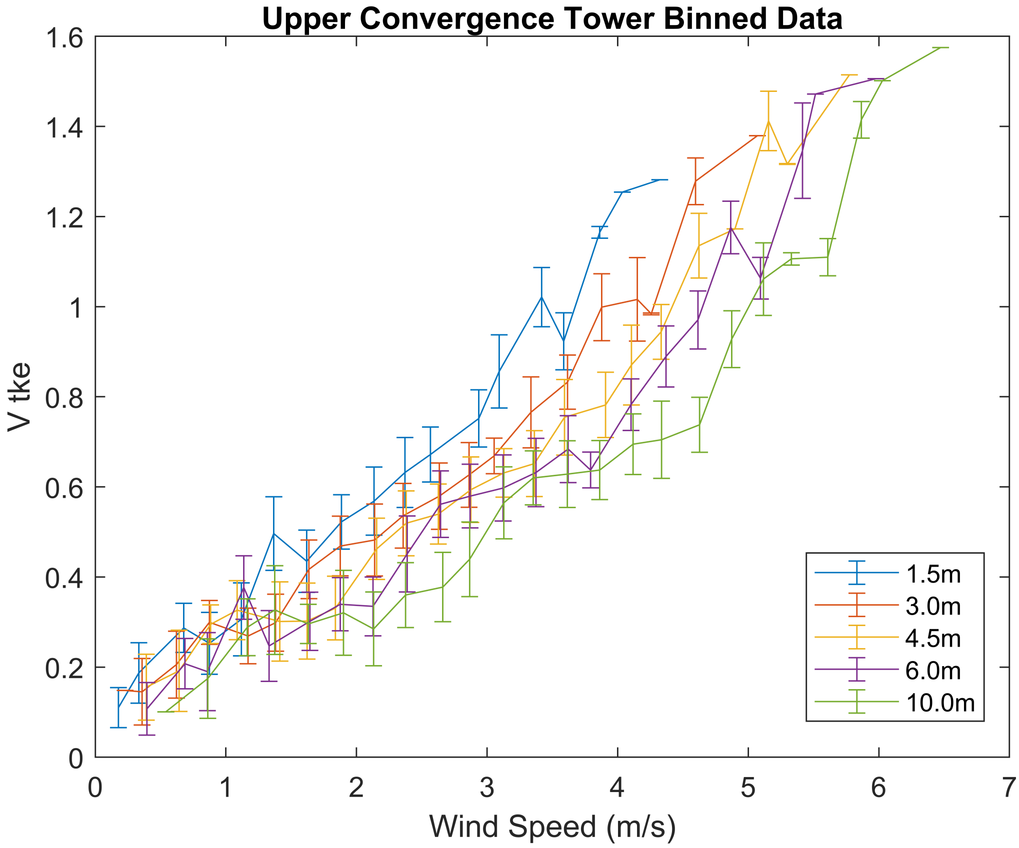
If we `DO` filter the wind direction at 0.2 meter, which will bring down the valid samples to:

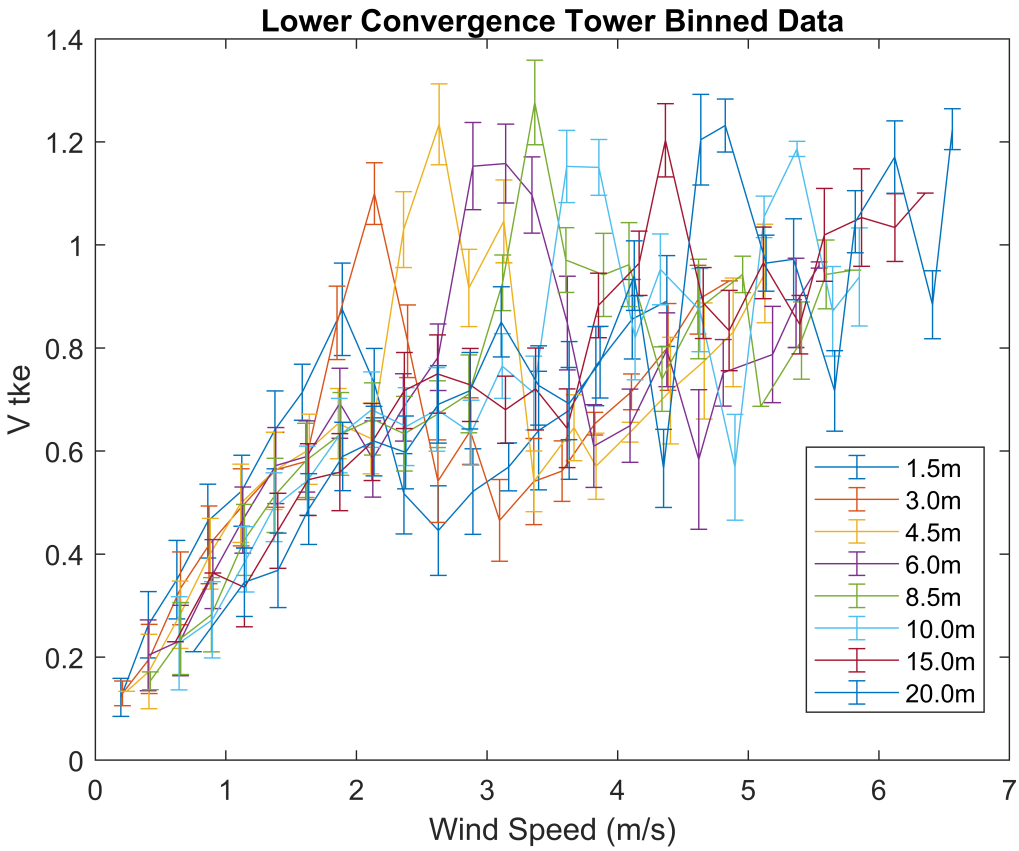
```
==========================================================================

Overall valid data counts:

For initiation tower:
-------------------------------------------------------------------------
|    Speed     | Temperature |  Direction   | Total Count |  Universal   |
-------------------------------------------------------------------------
|    22902     |    14640    |     7632     |    45174    |    71424     |
-------------------------------------------------------------------------

For release tower:
-------------------------------------------------------------------------
|    Speed     | Temperature |  Direction   | Total Count |  Universal   |
-------------------------------------------------------------------------
|    29691     |    13308    |     5742     |    48741    |    107136    |
-------------------------------------------------------------------------

For upper convergence tower:
-------------------------------------------------------------------------
|    Speed     | Temperature |  Direction   | Total Count |  Universal   |
-------------------------------------------------------------------------
|    20586     |    10096    |     5370     |    36052    |    71424     |
-------------------------------------------------------------------------

For lower convergence tower:
-------------------------------------------------------------------------
|    Speed     | Temperature |  Direction   | Total Count |  Universal   |
-------------------------------------------------------------------------
|    29079     |    16602    |    14931     |    60612    |    107136    |
-------------------------------------------------------------------------
==========================================================================
```

As shown above, we can see that the valid sample can reduce by 20-30% of the overall amount. This will change the binned plots to:

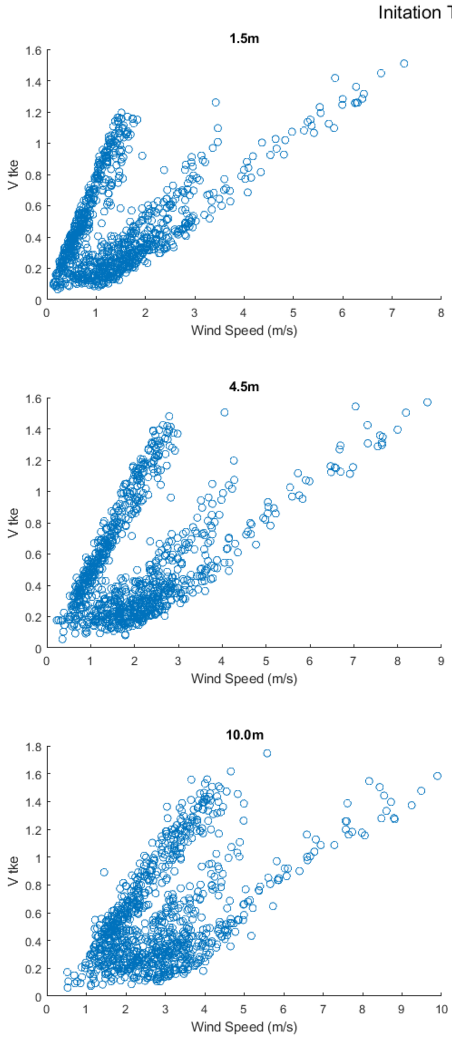




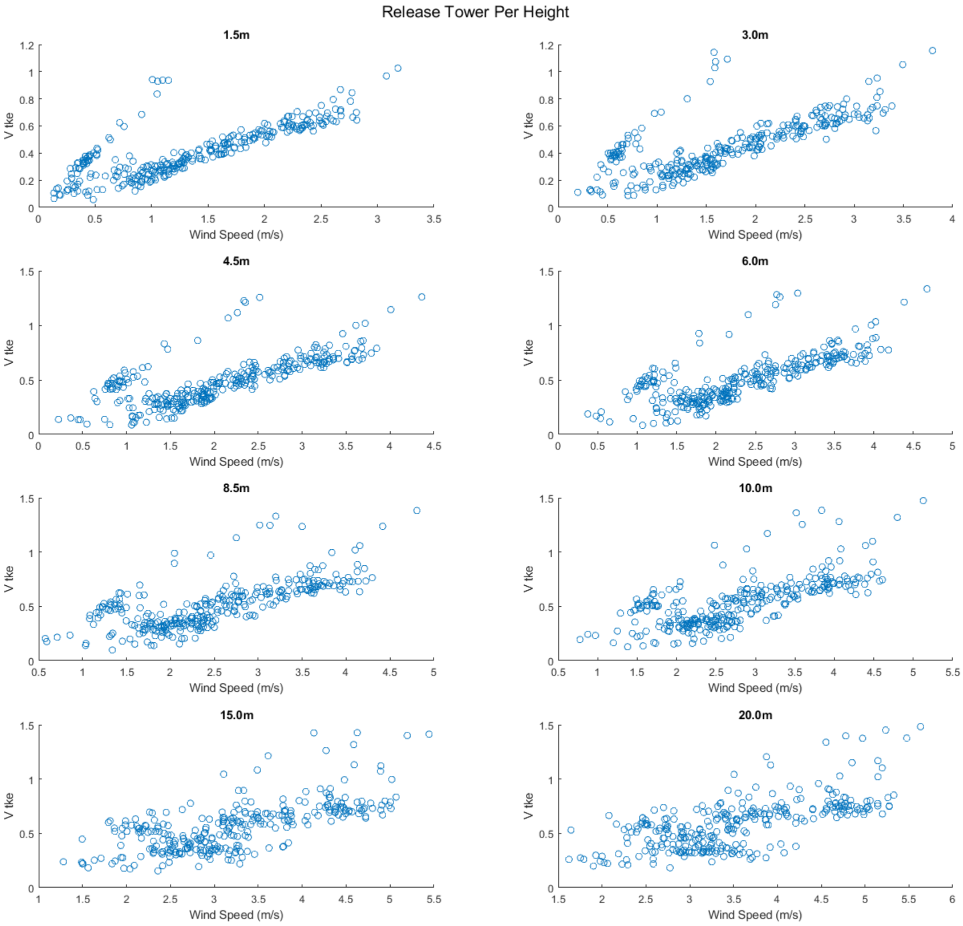




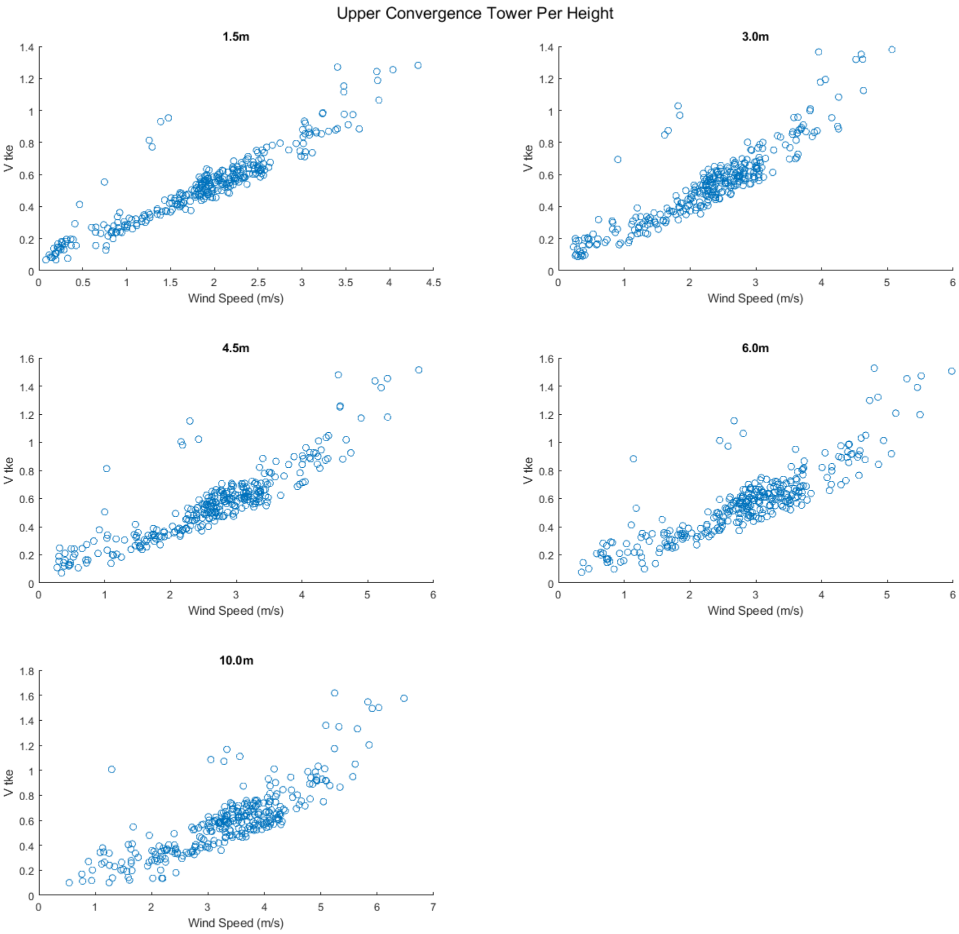
However, the overall scattered plot patterns will remain similar:

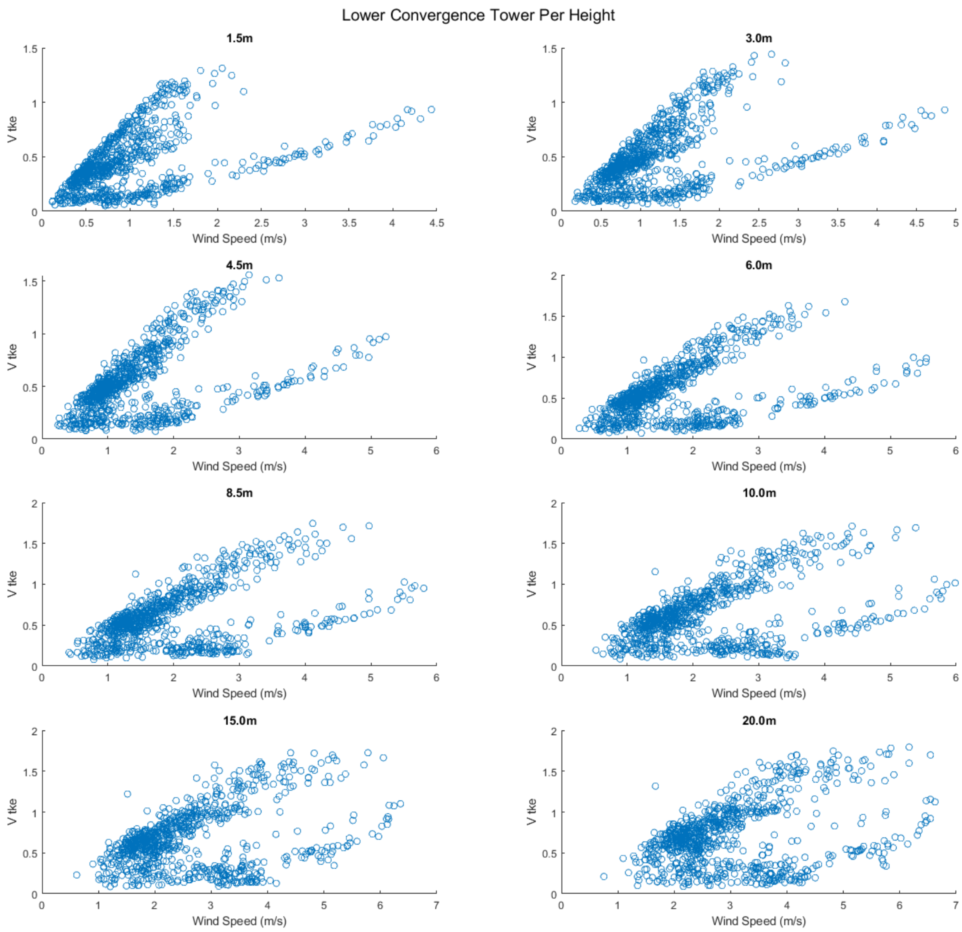


Initation Tower Per Height
1.5m
3.0m
4.5m
6.0m
10.0m
V tke
Wind Speed (m/s)



Release Tower Per Height
1.5m
3.0m
4.5m
6.0m
8.5m
10.0m
15.0m
20.0m
V tke
Wind Speed (m/s)


Upper Convergence Tower Per Height
1.5m
3.0m
4.5m
6.0m
10.0m
V tke
Wind Speed (m/s)



Lower Convergence Tower Per Height
1.5m
3.0m
4.5m
6.0m
8.5m
10.0m
15.0m
20.0m
V tke
Wind Speed (m/s)