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Scientific Internship/Forschungspraxis
Comparison of windsond measurement data and the mesoscale weather forecast model NAM12

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Contents

1 Introduction

This report summarizes a nine-week long research project that was done for Harvard University in the United States. It counts for the Forschungspraxis (science internship) that is part of the master's degree program of Electrical Engineering and Information Technology at the Technical University of Munich. The aimed target is a determination of accuracy for the mesoscale weather forecast model NAM12 (available in the Unites States). The NAM12 archive data is provided by the Air Resources Laboratory (ARL) of the National Oceanic and Atmospheric Administration (NOAA, U.S. Department of Commerce) [ARL, 2017]. This archive allows to view weather profiles for more than 250 000 grid points (12 km lambert conformal grid) located all over the U.S. with a time delta of three hours since May 2007 [ARL, 2013]. A first analysis is done with windsond data that was taken earlier during a measurement campaign in Indianapolis. Part of the project is also the start and operation of additional windsonds during the San Francisco bay area measurement campaign. The main goals of this project are (1) the design and implementation of an algorithm for the comparison of the NAM12 profiles to the windsond data and (2) the analysis of the resulting height profiles.

2 NAM12 Archive

The NAM12 archive is accessible online via a FTP server [ARL, 2017] or via the software Hysplit4. Archive files are generated daily with the labeling YYYYMMDD_nam12 and come in a binary format. We recommend installing Hysplit on your system as we later make use of an executable located in the Hysplit program folder. To download a NAM12 archive file with Hysplit navigate in the menu [Meteorology/ARL Data FTP/Archive] and fill the pop up window. The usual file size is 445,8 mb. After gathering this file, [Meteorology/Display Data/Text Profile] allows the generation of a vertical 17 level (1000-50 hPa, Δ 50 hPa) weather profile for a specific time (0-21 h UTC, Δ 3 h) and a specific geographical location (latitude and longitude). The profile of the closest grid point will be pulled in accordance with the given geographical coordinates. For each level the profile provides a simulated value for the windspeed (u-, v-component [m/s]), wind direction (u-, v-component [m/s]), altitude [m], temperature [°C], relative humidity [%] and other parameters labeled WWND in [mb/h], TKEN in [Joul] and TPOT in [°K]. There is also an array of ground level parameters available in the file.
This weather profiles represent the basic input for the later described algorithm. Note that this profiles can also be generated via the command prompt of the corresponding executable [profile] in ".../Hysplit4/exec". This method will later be used for an automated profile generation.

Figure 1: On the right side of the product banner is the windsond version S1B and on the left side of the figure the helium balloon that is used to generate updraft for the windsond. [Sparv, 2017]

3 Windsonds

The windsonds (Figure 1, right side) have the size of a coffee cup and their boxing are made of styrofoam. In this report, we will only name the most important technical details. For more information use the product catalog [Sparv Products, 2017] available on the windsonds website. The windsonds are connected to a base station that is set up on a laptop. The base station itself consists of an antenna and software, that allows to receive and process the windsond data. The windsonds are attached to a helium balloon (Figure 1, left side). For the project, we aimed for a rising speed of 1 m/s. For Indianapolis, the S1H2 sond was used (has an additional capacitive relative humidity sensor). In San Francisco, we used the base version S1B. The temperature sensor in the S1H2 is from type band gap (accuracy 0.3 °C, resolution 0.001 °C), while the S1B uses a thermistor (accuracy 0.3-0.7 °C, resolution 0.1-0.35 °C). In both versions, there are sensors for air pressure (accuracy 1.0 hPa, resolution 0.02 hPa), wind speed (accuracy approx. 5% [m/s], resolution 0.1 m/s) and wind direction (accuracy depends on GPS conditions, resolution 0.1 degrees). For the project the windsonds are expected to reach an altitude of 5000 m AGL. After a successful windsond flight two files are of importance for the later comparison: A *.KML file that holds the GPS information of the traveled path and height measurements along the path and a summary *.TXT file that offers values for launch time, ground height, rising speed, highest altitude, peak time and a smoothed height profile (Δ 100 m) with the parameters temperature, wind direction, wind speed and humidity (not in the base version) for each level.

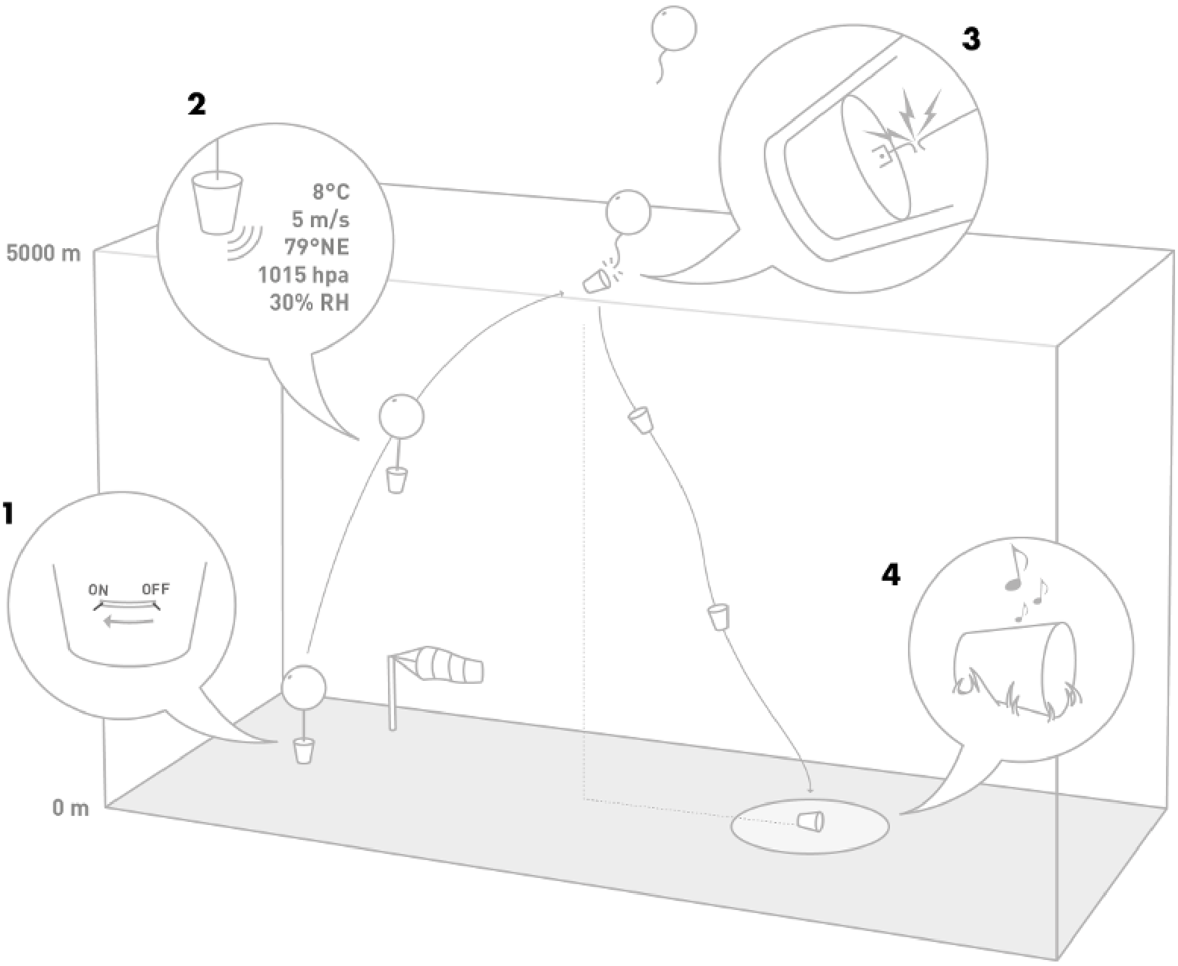

Figure 2: The figure shows the basic principle for windsond measurements. In step 1 the windsond is turned on and connected to the base station. In step 2 the windsond is rising and moves in wind direction. Meanwhile it is sending the measured data to the base station. In the third step the windsond is cut at the selected height (here 5000 m) with a current. After that it will fall and in the last step flash and make noice until the battery is consumed. [Sparv, 2017]

4 Algorithm for the Comparison

4.1 Working Principle

Before diving into the working principle of the developed algorithm, we want to give a short graphical introduction of the analyzing process. In Figure 3 the information stored in the *.KML file is shown. Opening the file with Google Earth Pro gives us a 3-dimensional trajectory. Opening it as plain text enables us to read latitude, longitude and altitude information. To match the resolution of the windsond summary *.TXT file, we decided to filter this data for one value for every additional 100 m in height. The resulting array of 3-tuples (altitude, longitude, latitude) is the input for the later interpolation of the mesoscale weather forecast model (NAM12) node profiles. For every three hours of a day and for each single node a vertical profile is available holding different physical weather parameters. Figure 4 shows the filtered 2-dimensional windsond trajectory (red points) surrounded by the locations of the NAM12 grid points (blue). As the windsond travels it is carried away by the wind and therefore passes different nodes during its flight.

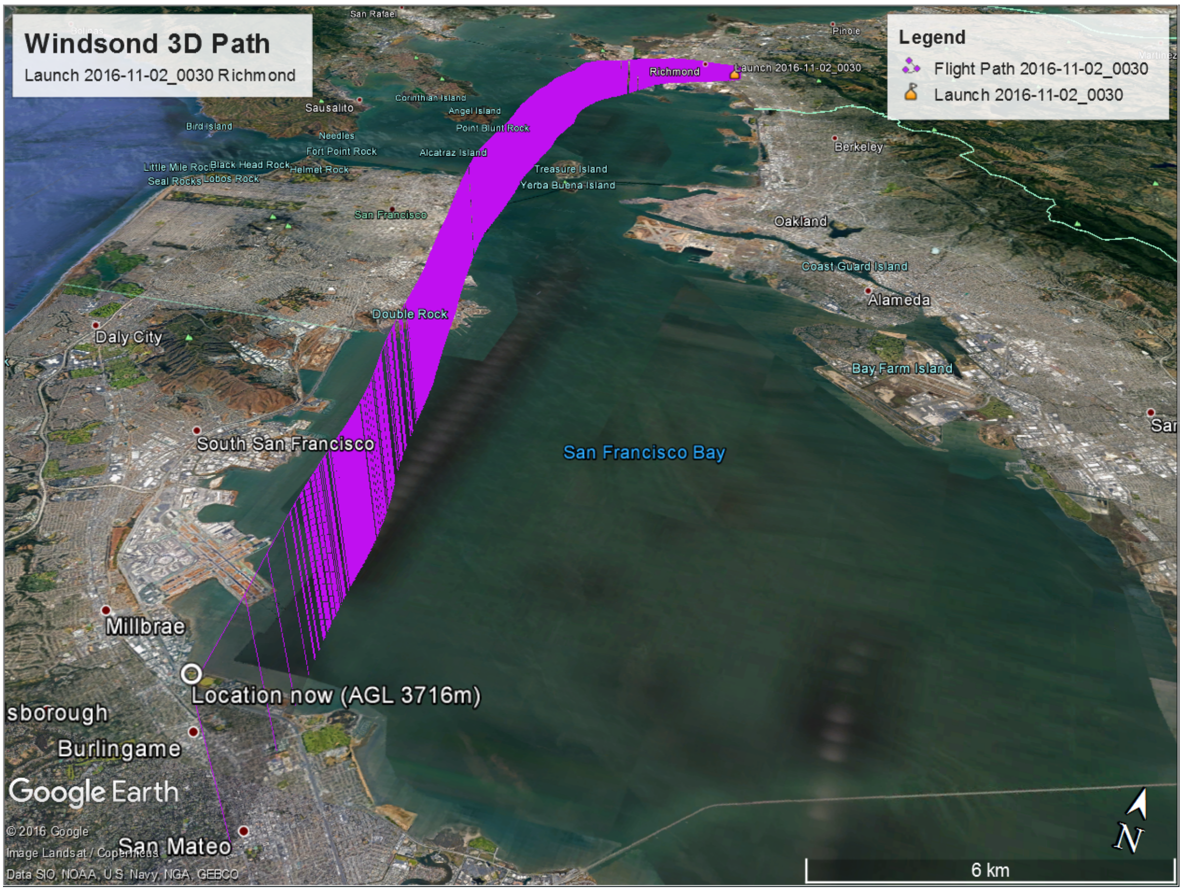

Figure 3: Google Earth export for a 3-D trajectory of a windsond. While rising, the sond is carried away by northeasterly/northerly wind. The map shows the San Francisco Bay Area.

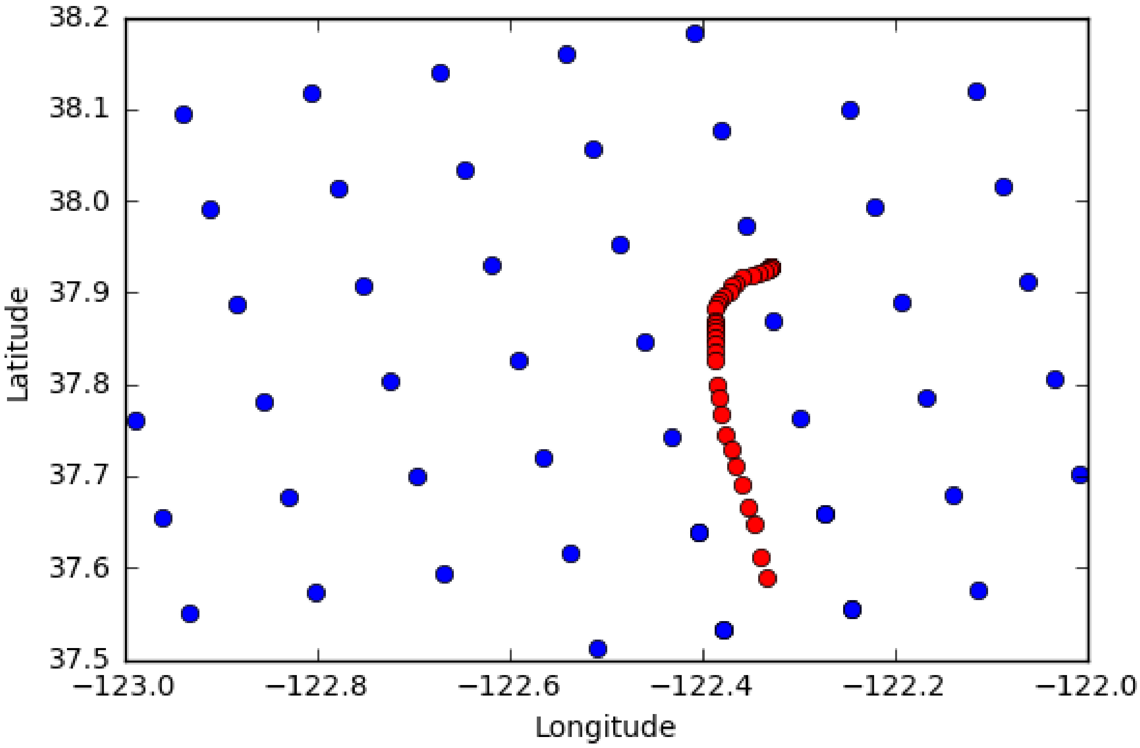

Figure 4: Filtered (Δ 100m altitude) 2-d projection (red) of the in Figure 3 shown windsond trajectory. The blue dots represent the grid points of the mesoscale weather forecast model NAM12.

For the proposed interpolation (16-points, Figure 5 the four surrounding grid point profiles need to be pulled for every red dot, while keeping track of the changing nodes and the distance to each surrounding grid point. In Figure 5 one of the points (red) of the windsond path (shown in Figure 4) is taken out to demonstrate the process that is supposed to enable the comparison between the windsond data to the NAM12 data. As the NAM12 node profiles carries vertical information each data point in the 3-tuple array will be between two levels of the four surrounding profiles (see Figure 5 [A]). To obtain a value that matches the geographical information of the connected windsond trajectory a trilinear interpolation must be done (see Figure 5 [B]). To further match the windsond snapshot in time another interpolation is required to factor in the 3-hour resolution of the profiles (see Figure 5 [C]). This process has to be repeated for every physical parameter (temperature, wind speed, wind-direction and humidity) of interest. The result is a 16-point interpolation for every physical parameter at all windsond locations of the filtered trajectory.
The height profile in Figure 6 serves as example of a successful run for the described algorithm. It shows the 3D-GPS-matched NAM12 profile (blue) paired with the measurement data of the windsond (red) for the parameter wind-direction.

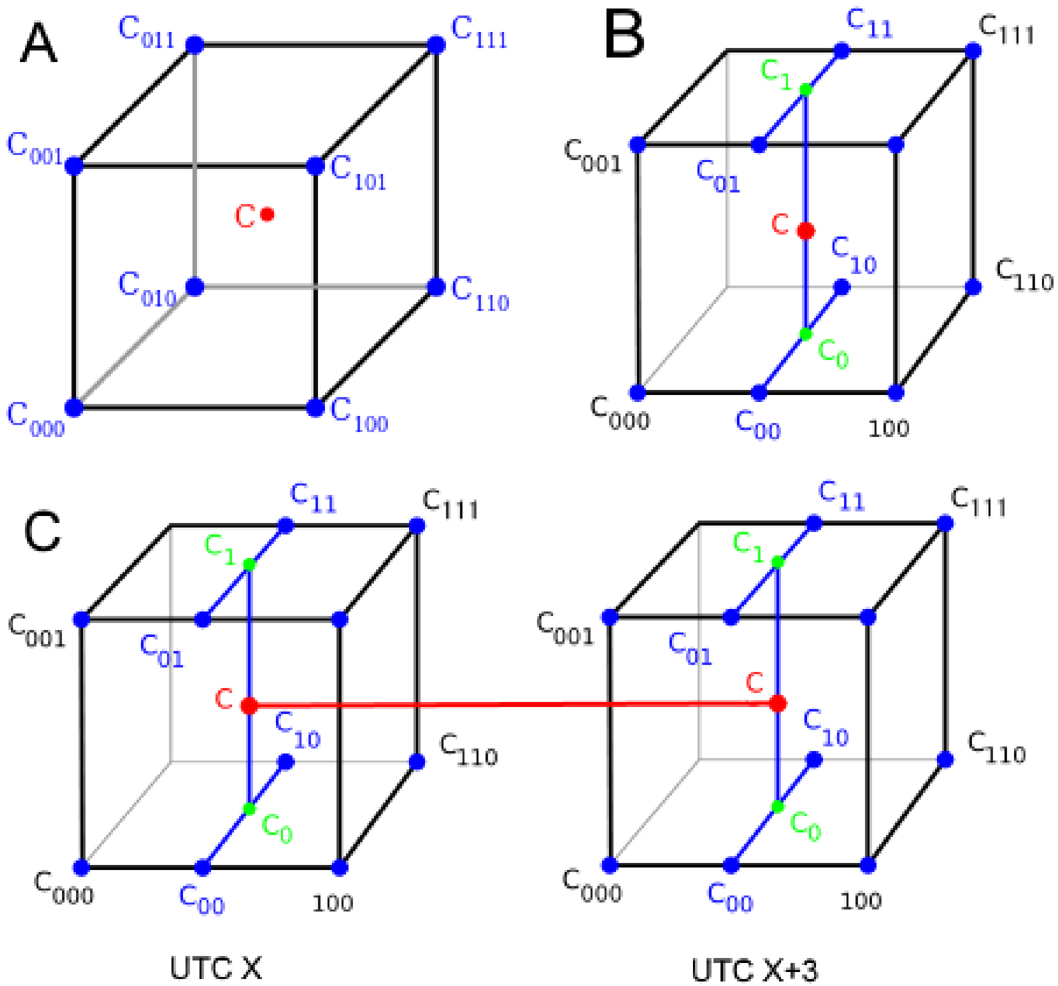

Figure 5: Basic principle of the intended 16-point interpolation. (A) shows four surrounding NAM12 nodes in two different height levels. (B) shows a trilinear interpolation for the red point C and (C) shows an interpolation in time (Δ 3h for NAM12 profiles) of two eight point models shown in (B). Base picture was taken from [Wikipedia, 2017]

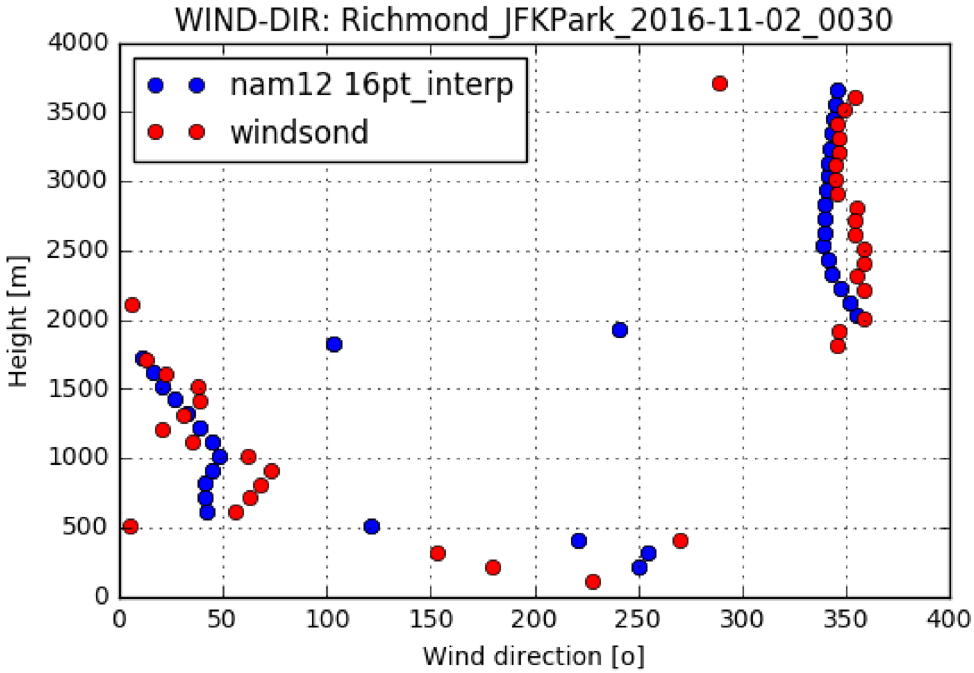

Figure 6: Exemplary height profiles for a comparison (NAM12 to windsond data) for the weather parameter wind-direction. The windsond was started in Richmond (JFK-Park) on November 2nd 2016 at 00:30 UTC.

4.2 Implementation

In this section, we will talk about the realization of the previous described working principle. The programming is done in Python and Jupyter Notebook and the modules pandas, numpy and matplotlib.pyplot. Additionally, the modules datetime, subprocess and time find usage.
As first step the *.KML file is read as plain text and a 3-tuple of latitude, longitude and altitude is extracted. The included filter ignores values of altitude that are not at least 99 m bigger than the last saved value. In the second step the windsond *.TXT file is modified to a readable CSV format. As a last preparation step the NAM12 grid information [ARL, 2017] is read in.
Based on the earlier extracted array of 3-tuples, the algorithm then identifies for each point the four surrounding NAM12 grid points. To do this a simple distance calculation for every node is done and the resulting list is then sorted for the minimum entry. After that the x and y component of that grid point (i.e. 412/208) are modified to compare 411/208 + 413/208 and 412/207 and 412/209 in distance. After choosing the closer point of each set the algorithm autodetects the fourth. The result is the closest surrounding rectangle formed by the grid. Figure 7 (A) shows the filtered 2-D windsond trajectory (red) and the existing NAM12 nodes (blue) for the Bay Area. In Figure 7 (B-D) an exemplary detection for the four surrounding nodes (green) of the trajectory array n = 1, 15, 23 (red) is shown. The resulting information is saved into a pandas table.
To avoid pulling multiple identical profiles from the NAM12 archive file the table is sorted for unique grid points. Then the Hysplit executable [profile -d%s -f%s -y%s -x%s -o%s -p%s

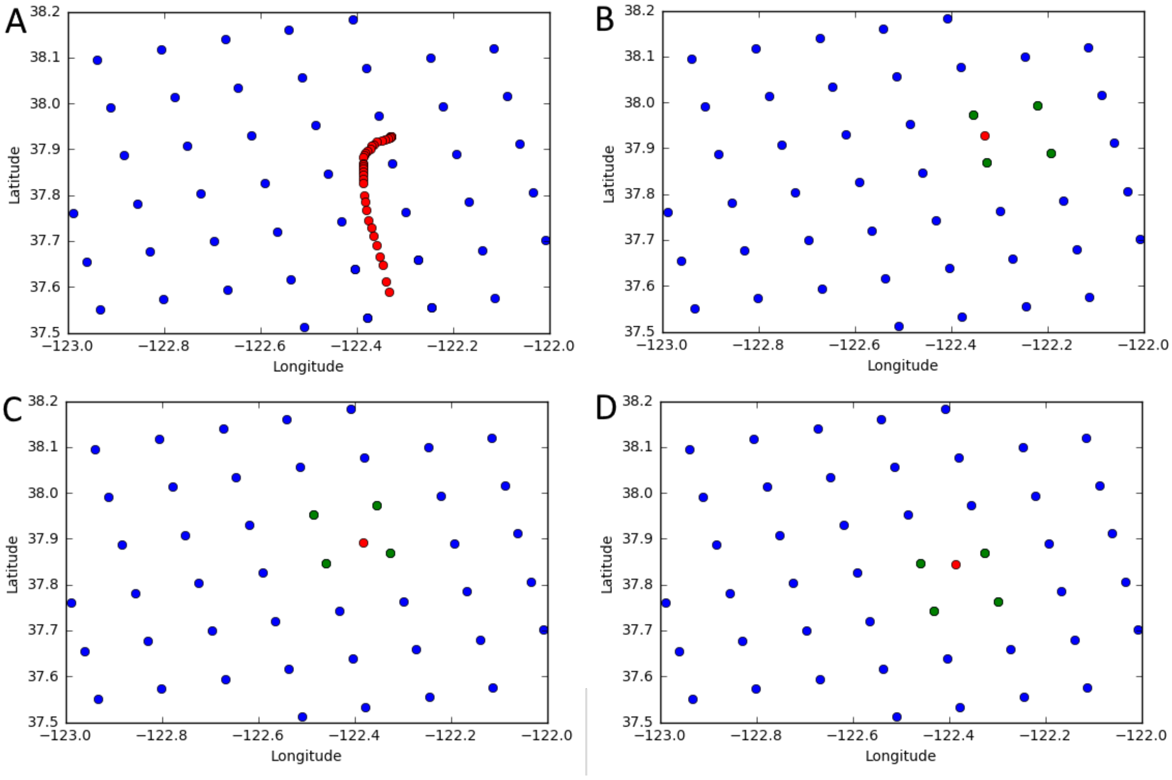

Figure 7: Filtered (Δ100 m in altitude) 2-D projection of a windsond surrounded by NAM12 grid points (blue) in the latitude and longitude region of the San Francisco Bay Area. (B-D) show the detected four surrounding NAM12 grid points (green) for different points taken out of (A) n = 1, 15, 23.

%(nam12 file pad, nam12 file name, lat, lon, time, suffix)] is dynamically called by the Python module subprocess. Note that each profile needs to be pulled twice for different time stamps. In the next step the 16-interpolation (see Figure 5) is prepared. Therefore, eight profiles (four for each time stamp) are read in and the components wind speed (u-, v-component [m/s]), wind direction (u-, v-component [m/s]), temperature [°C], relative humidity [%] are collected for the two enclosing levels. As soon as the 40 (48 with relative humidity) values are available, the algorithm then follows the method shown in Figure 5. The results are 3 (4 with relative humidity) NAM12 profiles along the windsond trajectory.

In the last step, the height profiles read from the *.TXT windsond file and the NAM12 profile are plotted into the same graph sorted by parameter (see Figure 6).

5 Results

In this section we will analyze the height profiles of our 10 winsond starts. The graphs can be found in Appendix A: Height profiles - Indianapolis and Appendix B: Height profiles - San Francisco Bay Area. For the analysis we will shortly dive into boundary layer meteorology [Stull, 1988] and explain the incurrence and influence of turbulences (eddies). After that we will briefly discuss our expectations for both Indianapolis and the San Francisco Bay Area and then analyze the final results. Last we will give an evaluation of the NAM12 performance overall.

5.1 Introduction into boundary layer meteorology

The observed atmosphere by the windsonds (<5000m) is the troposphere <7-20 km. The troposphere can be split into the boundary layer (100-3000 m) and the free atmosphere above [Stull, 1988]. According to [Stull, 1988] "the boundary layer [...] is directly influenced by the presence of the earth's surface and responds to surface forcing with a timescale of about an hour or less." The ground (absorbs 90% of solar radiation) shows diurnal variation connected to temperature, while in a higher altitude (free atmosphere) there is little to no diurnal variation [Stull, 1988]. The boundary layer is influenced by so called transport processes. One of the most important transport process is turbulence, which is generated by forcing from the ground (warming and cooling in response to radiation) [Stull, 1988]. "Turbulence [...] can be visualized as consisting of irregular swirls of motion called eddies" (diameter: 100-3000 m), which have a "relatively high frequency of occurrence [...] near the ground" [Stull, 1988]. Above the boundary layer there is a frequent lack of turbulence [Stull, 1988]. In boundary-layer studies fair weather cumulus clouds and stratocumulus clouds are also often included [Stull, 1988]. Winds inside of the boundary layer range between 2-10 m/s in speed, while at the surface level are overall slower [Stull, 1988].
The surface for Indianapolis is flat, which in our expectations should lead to easy conditions for the weather simulations and therefore to a good performance of the NAM12 model. For the San Francisco Bay Area the surface is rather challenging. The territory consists of a large water surface in the center surrounded by hills, mountains and valleys, which represent a huge factor for winds inside of that area. Accounting the rather difficult surface conditions we are expecting a worse performance than observed in Indianapolis.

5.2 Analysis for Indianapolis

For Indianapolis the S1H2 windsond version (band gap temperature sensor, additional humidity sensor) is used. Launches were performed by undergrads of the local university. Pre-launch preparations have not been documented. Note that you can find all discussed height profiles in Appendix A.
The Temperature profiles in Indianapolis show a consistent discrepancy of +2°C in all three height profiles. The typical inversion of the temperature can be easily detected for the windsond graphs and are in correspondence to the humidity and wind speed measurements. For the model the inversions is also apparent, but in a lower extend. For the windspeed above the boundary layer we can identify a steady increase and a maximum discrepancy of 1m/s. The model and the windsond graphs match for that region. Below the boundary layer the existance of local eddies is apparent. The discrepancy is around 2-3 m/s with a one time

observed maximum of 4 m/s. A similar trend is obvious. Note that the NAM12 base file shows a three hour time window, which lowers the impact of local eddies and smooths the graph overall. The humidity sensor performance varies by 10-20%, but shows a similar trend. A boundary layer detection is given for the model, but can't be as clearly seen as in the windsond measurements. We suspect the error to be connected to the windsond's humidity sensor. Based on this, we decided to go for the more cost effective windsond version S1B for the San Francisco Bay Area campaign. The global trend of the NAM12 graph for the wind-direction is consistent with the windsond data. There are some variations of around 50°, which (due to locally changing events in a smaller time scale) are to be expected. Again the boundary layer can be easily read (rapid change of the main wind-direction) in both the NAM12 and the windsond profiles.

5.3 Analysis for the San Francisco Bay Area

For the San Francisco Bay Area campaign we have 7 successful windsond launches of the version S1B and sufficient documentation. The sonds come without a humidity sensor. As the surface condition vary over the different launching spots it is useful to analyze each of the seven sets (temperature, wind speed and wind-direction) separately. For each set we at first analyze the windsonds graphs to determine the boundary layers and compare that information to the NAM12 model data. Note that you can find all discussed height profiles in Appendix B.

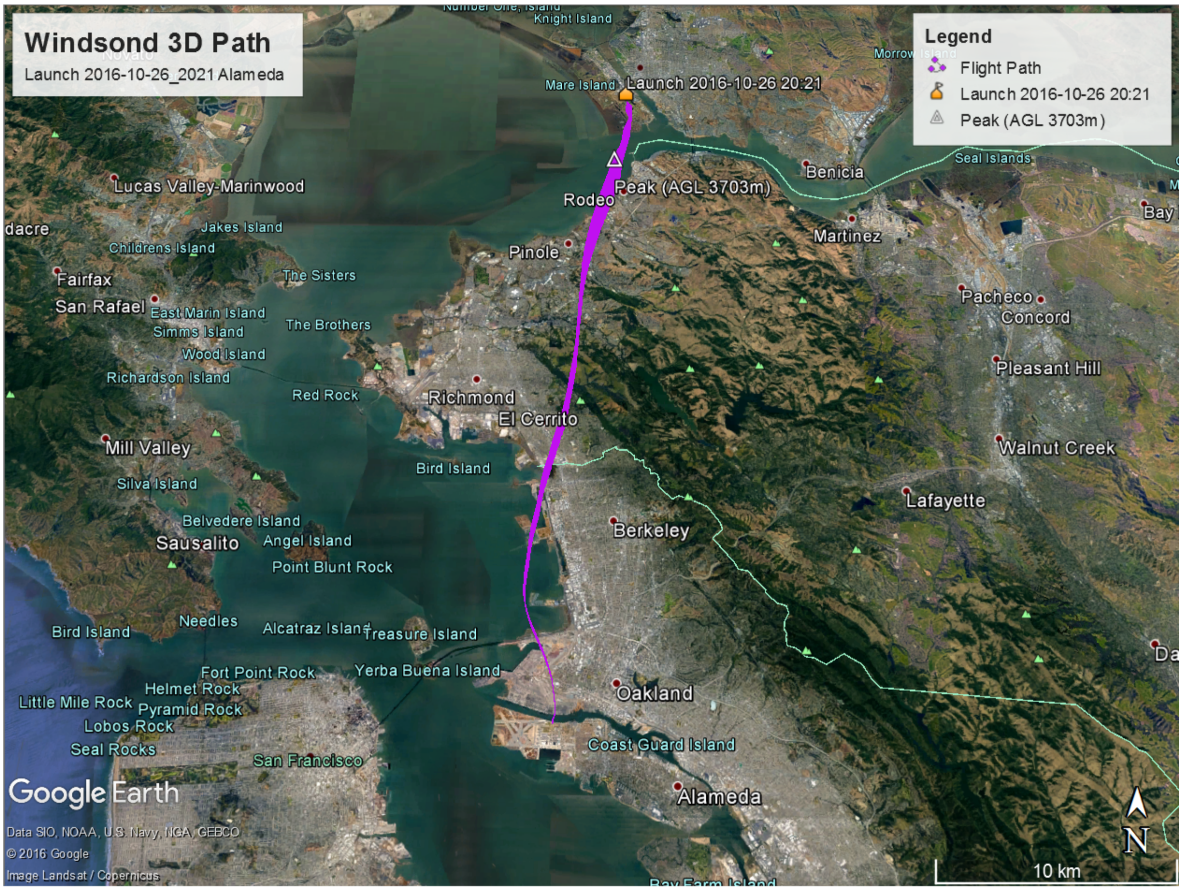

Figure 8

First launch: Alameda. The temperature curve of the windsond shows two different temperature inversions. This is at first unexpected, but with deeper analysis of the windsond path evident. The first inversion at 1500m can also be clearly read out of the wind-direction (windsond) profile. Between 2000-2500 meters the sond passes a short mountainous section that creates a locally separating barrier. The second inversion could show signs of another boundary layer (3000m), which presumably is affected by different local conditions. At the altitude of the second inversion rapid changes in the in the wind-direction (windsond) profile are visible, but do not give a clear information as for the first inversion. The model wind-direction graph does not show signs of another boundary layer above 2500 meter. The agreement of the temperature curves is good. The temperature graph of interpolated NAM 12 model does not show a good detection of the first boundary layer, but for the second inversion. For the wind speed the model is in line with the measurements within an error of 1 m/s below 2500m. The influence of eddies can be seen. Beyond 2500m a bigger influence of eddies is apparent (4-5 m/s variance). This could be subject to alternating ridges and valleys in that area. Another interesting observation is that the discrepancy in wind direction of the model and the windsond measurements is at maximum $<10°$. The windsond was started late in the day, therefore the boundary layer should already have reached its maximum height.

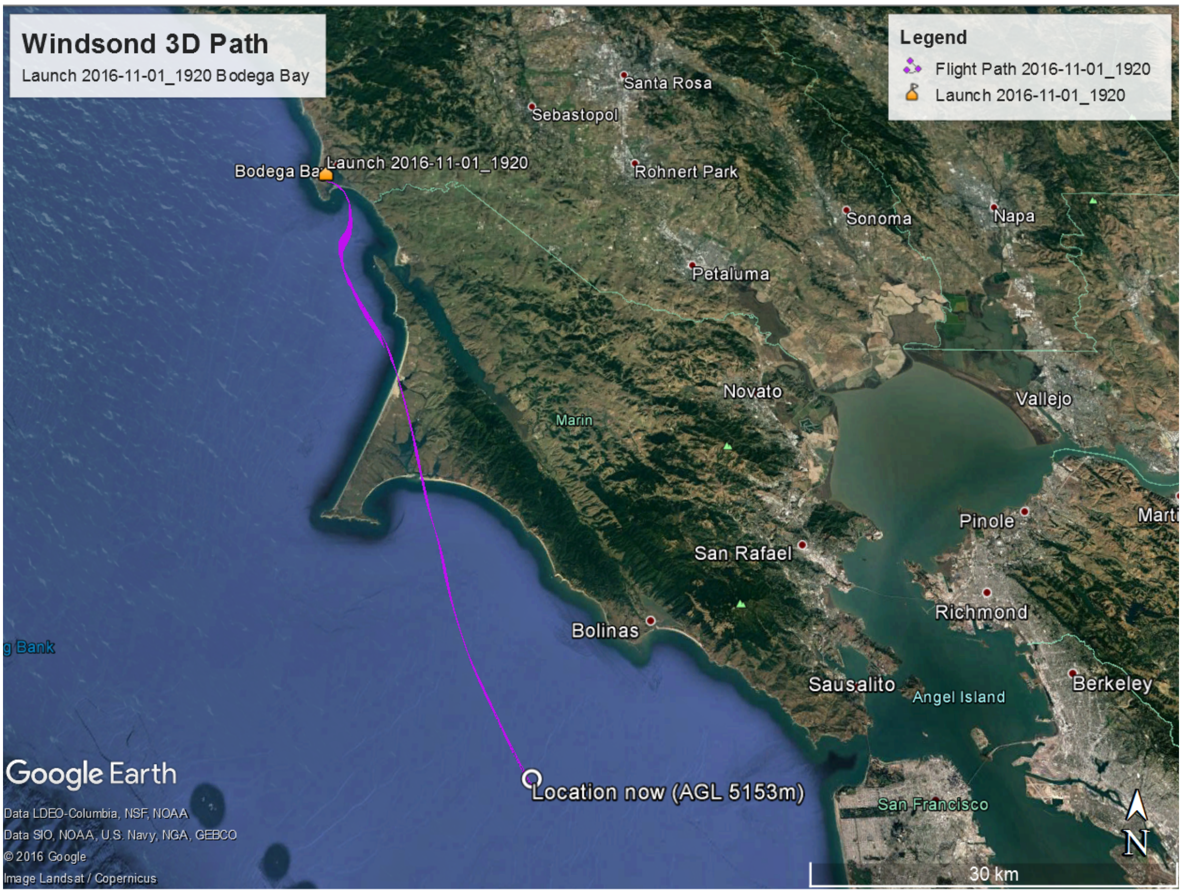

Figure 9

Second Launch: Bodega Bay. This launch is interesting, because it is the only sond data over the pacific ocean. The windsond travels over the ocean along the shoreline and passes between 2500-3000 meter height a peninsula. After the landmass it moves away from the shore and rises further over the pacific. For the measured temperature curve there exists a good agreement until 3000 meters, however after that a discrepancy of around 3°C can be seen. Indications for the boundary layer are shown in both windsond temperature and wind-speed between 2000-2500 meters. The wind-direction curve (windsond) does not give hints. Below 2500 meter the existence of local eddies is visible. We think that the windsond data shows the boundary layer at 2500 meter for the landmass, while the the windsond temperature curve shows another inversion at 3700 meter over the pacific ocean. According to [Stull, 1988] boundary layers over oceans vary slow in space and time, as "the sea surface temperature changes little over a diurnal cycle". We also learned that boundary layers heights are usually between 100-3000 meter. As the distance is still <20 km to the shore it is unlikely that the inversions shows indications for a second boundary layer. Additionally the temperature curve for the NAM12 model shows no clear inversion for 3700 meter. The model wind speed agrees with a boundary layer at around 2500 meter. The model wind direction shows a strong trend that is not matched with the windsond data. As the discrepancy is around 50° and the windsond data is a measurement at a single time point near the shoreline, it does not indicate a significant model failure.

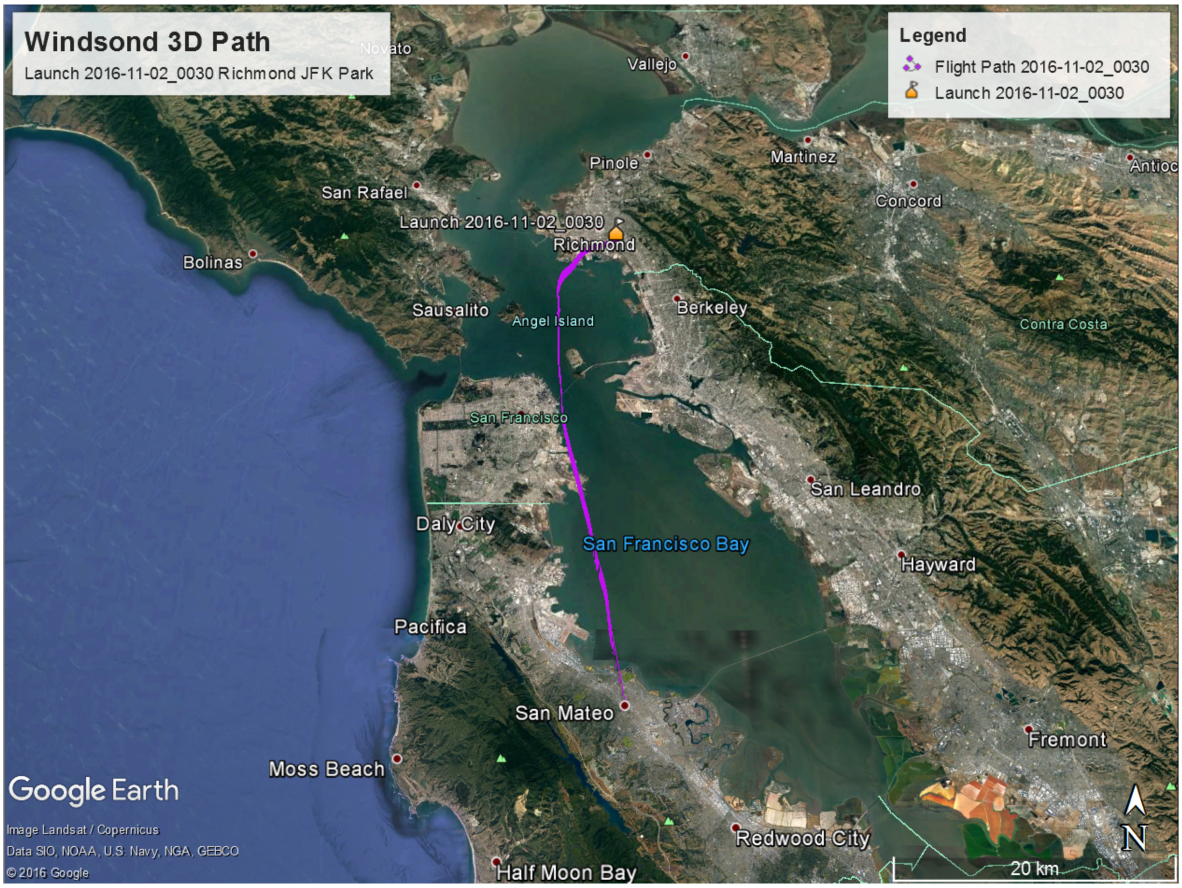

Figure 10

Third Launch: Richmond JFK Park. The temperature and wind-direction (windsond) show clear signs of a boundary layer at 1700 meter. While the windsond wind speed measurements are not very significant for boundary layer detection, the trend of the model windspeed profile is similar. Additionally the wind speed (windsond profile) shows the influence of eddies up to 3000 meters. Reasons for that could be the unprotected influence of oceanic west-winds, that are also visible on the 3D pathing of the windsond. After a south-westerly start the windsond changes its path in a more southerly direction. The windsond temperature curve agrees with activity beyond the boundary layer. The sond traveled a distance of over 40 km and may see local changes in boundary layer height. The NAM12 model profiles agree with a boundary layer at 1700 meter and also show slight tendencies at 2500 meter. As the sond arrives in a territory protected through westerly formation (Mount San Bruno Mountain) the windsond temperature profile shows an untypical behavior. Unfortunately at 3500 meter the connection to the windsond was lost, due to the long distance.

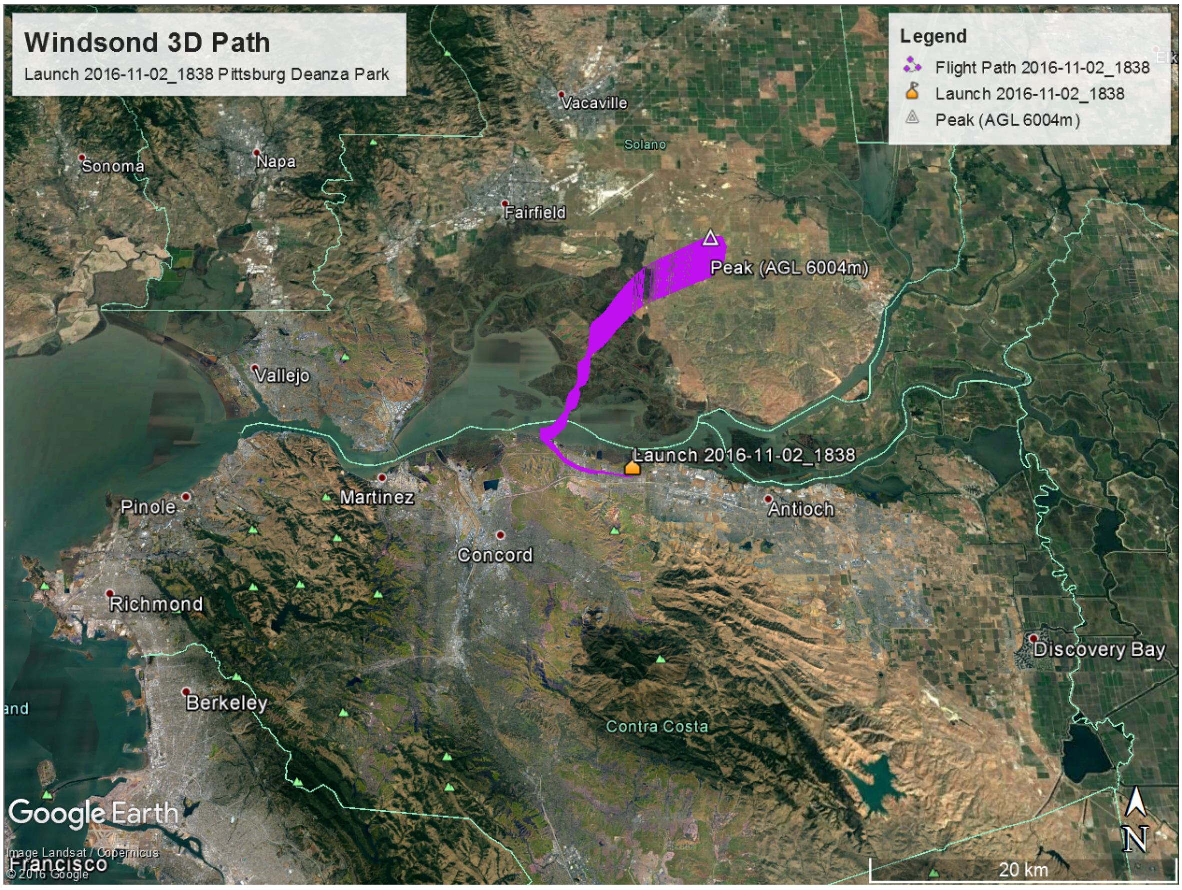

Figure 11

Fourth Launch: Pittsburg Deanza Park. The windsond's temperature profile shows an inversion at 2400 meter that indicates the boundary layer height. Above that the temperature curves of the model and the windsond agree, while below that altitude a shift of 2.5°C is apparent. The wind speed and wind-direction profiles of the windsond have no clear prediction for the boundary layer. Both profiles show a lot of movement. The wind speed shows a similar trend and a maximal discrepancy of 3-5 m/s between the two graphs. The wind-direction shows a maximum difference of 50°, but has difficulties with matching the rapid changes of the windsond profile. Overall we argue that the trend shows similarities. After the assumption of a boundary layer height of 2400 meter we calculated a mean value "by eye" and recognize a known pattern, that agrees with the message of the temperature profile. To understand the forces that affected the windsond during its flight we looked at the geographical profile. After the start in a westerly direction (easterly winds) the windsond direction was strongly changed by a force from the south. It stands to reason that the valley south of Concord channels southerly winds. Additionally the region around Vallejo functions as exit for westerly-winds apparent in the bay area. The combination and the interplay of these forces could explain the trends shown in the wind speed and wind-direction profiles.

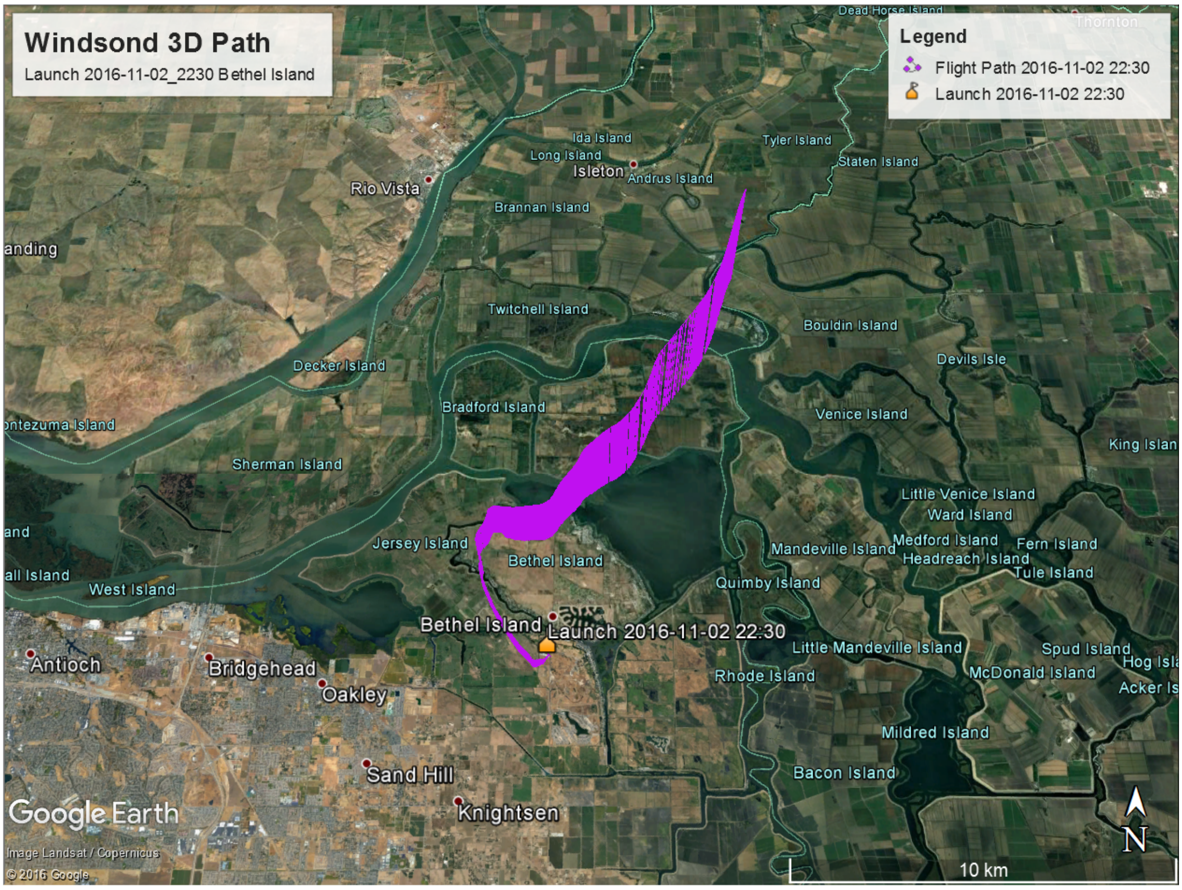

Figure 12

Fifth Launch: Bethel Island. To understand the curves we want to first describe the windsond path. After a south-westerly start the sond does a 270° turn. This indicates strong changing influences. Between 2200-2500 meters the sond switches the curvature and rotates back for 90°. After that it stays semi-stable in a north-easterly direction. The stabilization at around 2500 meter indicates the transition from the boundary layer into the free atmosphere. The windsond's temperature curve also shows an inversion at 2500 meters. Unfortunately there is also an inversions at around 3600 and between 800-1800 meters. As the sond was started late in the day (the boundary layer should have reached its maximum height) the inversions below 2500 meter can be linked to the strong conditions inside of the boundary layer. We learned that the boundary layer usually forms at a maximum of 3000 meter. The NAM12 model predictions of the temperature and wind-direction also agree with a boundary layer at 2500 meter. For the wind speed the model and the windsond data show good agreement within an error of 1 m/s, except one local eddy with a discrepancy of 4 m/s. The wind-direction comparison shows troubles below 1000 meter, that make sense comparing it to the windsond 3D path. Above 1000 meter a similar trend is shown. Overall the steps of the NAM12 interpolated profile indicates larger differences of the surrounding profiles.

Figure 13

Sixth Launch: Berkley. The wind speed and wind-direction profiles (windsond) indicate a boundary layer close to 2000 meter. The temperature curve (windsond) on the other hand does not cleary confirm that observation, but agrees with a boundary layer below the 2000 meter line. The temperature curve shows an untypical behavior below 1000 meter. Alle three model profiles show an identical trend as the profile described before. The maximum discrepancy in temperature is 2°C, 1 m/s in wind speed (with one exception at 4500 meter that can be lead back to mountain surface conditions) and 50° in wind-direction. Overall the Berkley windsond launch shows clear statements, a good agreement between measurements and the model and also functions as a good example for visualization of the boundary layer through the windsond 3D path.

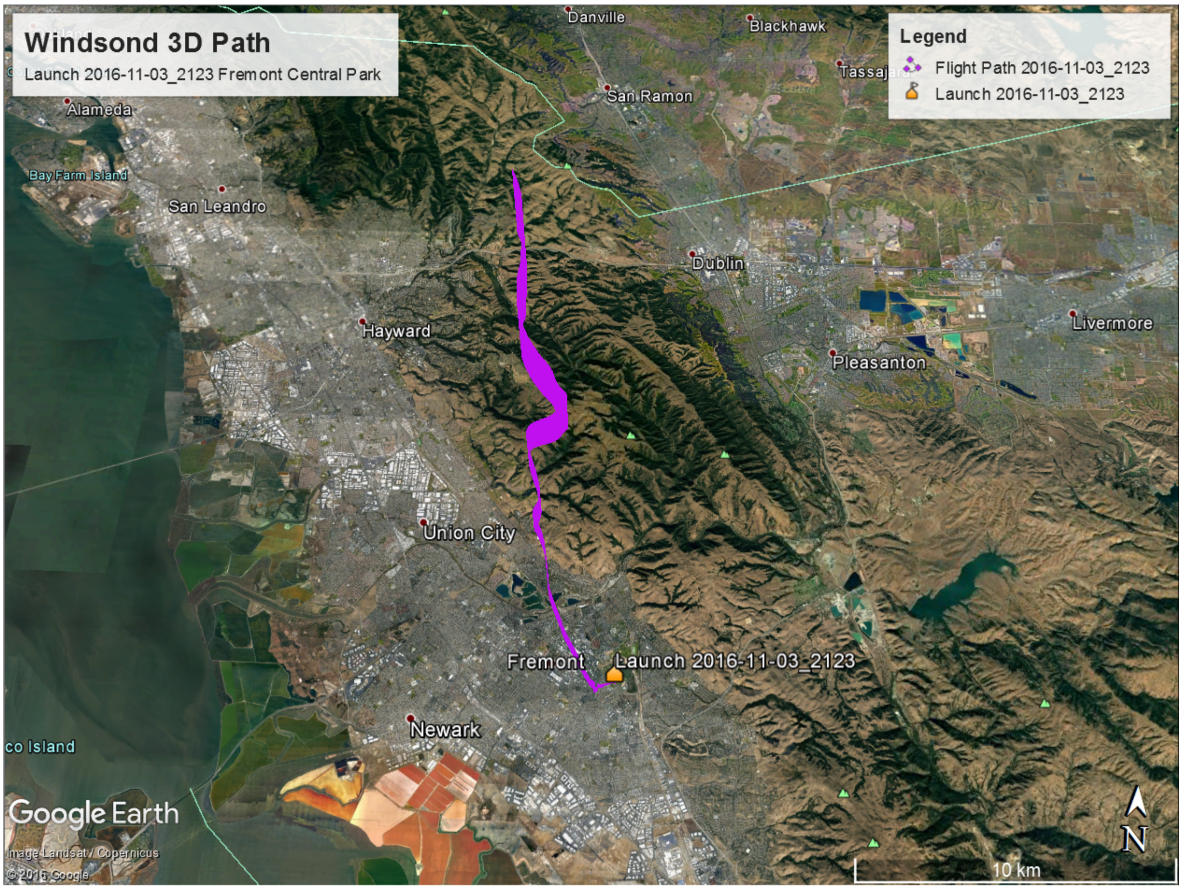

Figure 14

Seventh Launch: Fremont Central Park. As in the last example the temperature profiles show a similar trend. Below 1000 meter the windsond's graph shows a small discrepancy and above that threshold both curves align. The wind speed curves also show matching trends with a maximum of 1m/s and an exception around 1000 m. The model wind-direction graph shows - between 2000-2500 meter - one of the biggest differences of about 100° in all comparisons. A reason for that could be a local influence of the mountainous surface. On basis of the strong inversion at around 1000 meter, one could read and argue about a boundary layer height of 1000 meter. But it stands to reason, that with a launch late in the day the boundary layer should be higher. Both the profiles and the 3D path do not support a clear identification. We estimate the boundary layer height to be between 2000-2500 meter. Reasons for this is a small inversion visible in the temperature curve, a trend of growing wind speed at around that level and indications in the wind-direction profile. It seems as if the boundary layer wind-direction matches the wind-direction over the mountain ridge, while the altitude of the surface slowly rises.

6 Conclusion

In this last section we want evaluate the results shown in this report. The overall performance of NAM12 exceeded our expectations. There was no case where the model was completely off. Even for difficult surface conditions and for the rather challenging San Francisco Bay Area the model agreed within an expected error margin. In most cases the model could predict the boundary layer precisely, but signs were not always distinctive. As anticipated the model did not predict local eddies. For the temperature curve we often observed either an total offset of around 2°C or only for some parts of the profile. It is hard to say, if the model or the measurement failed. Certainly there exists a need for further research. For the wind speed the error margin was usually within 1-2 m/s, which is completely satisfying. Also the wind-direction profiles do not differ for more than 50°. For both the wind speed and the wind-direction profile it is a snapshot of slightly changing wind conditions. All in all we can recommend the usage of the mesoscale weather forecast model NAM12 as an input source for calculations.

Appendix A: Height profiles - Indianapolis

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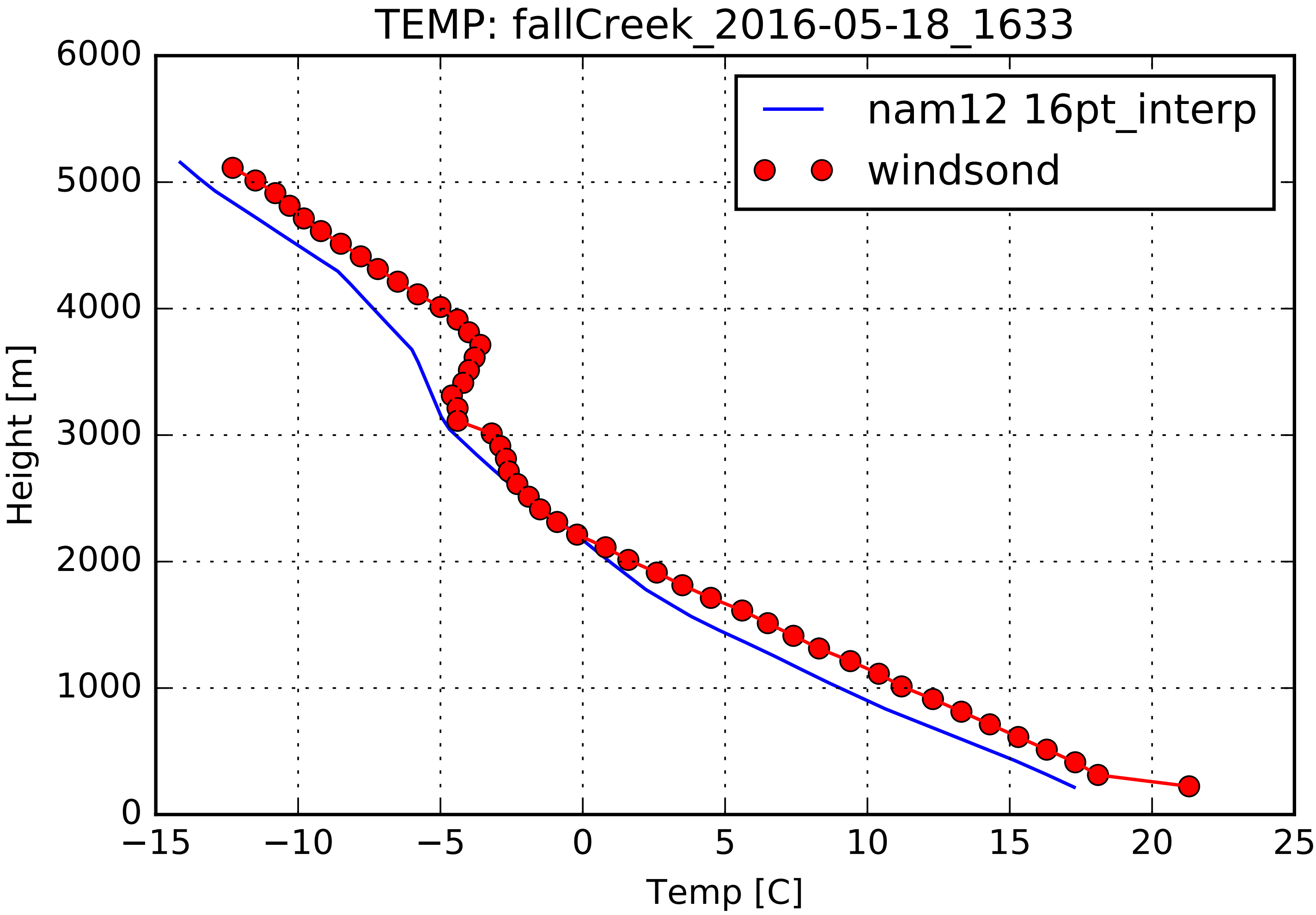
2016-05-19_1459
2016-05-19_1637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15
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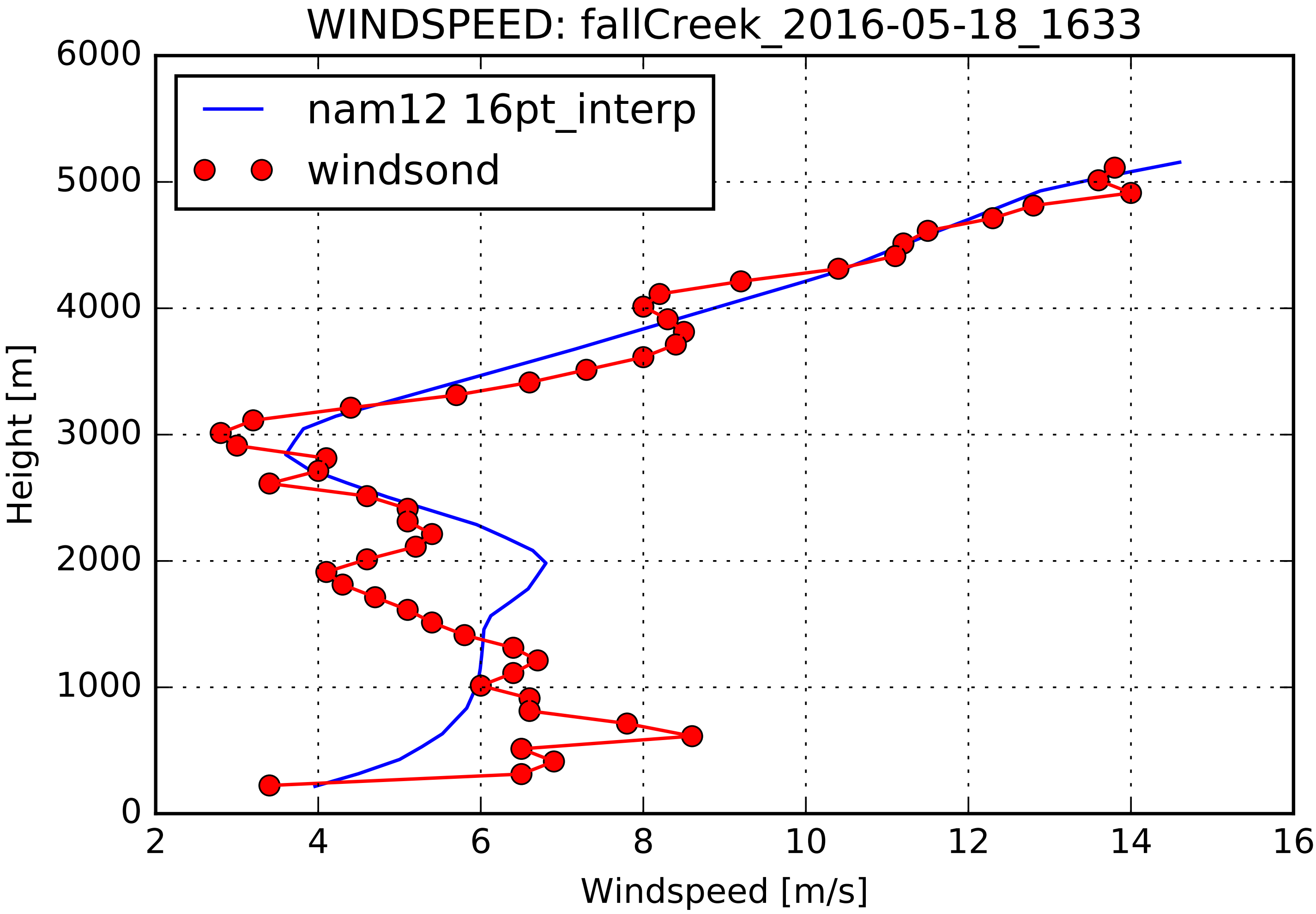
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nam12 16pt_interp
windsond
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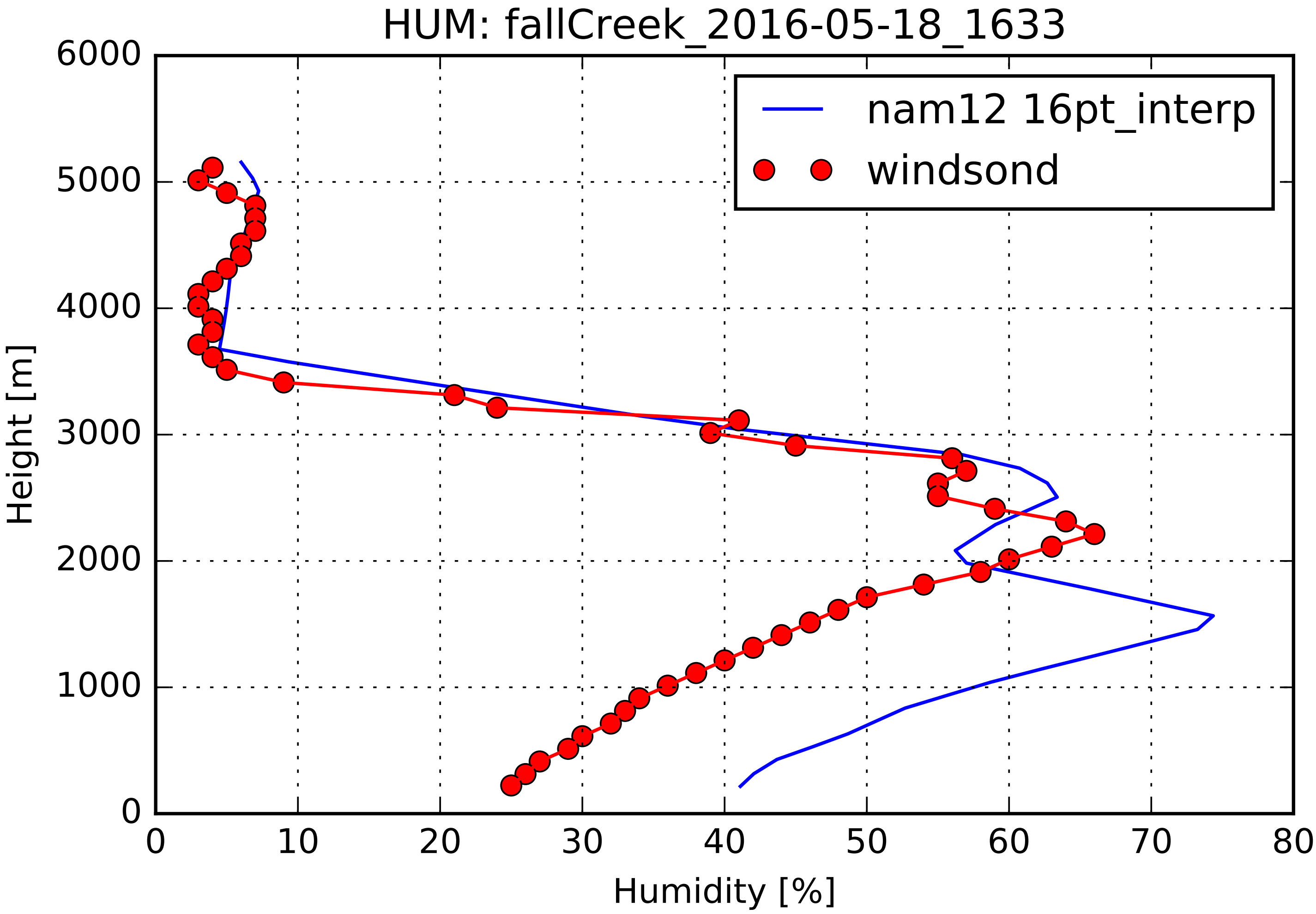

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nam12 16pt_interp
windsond
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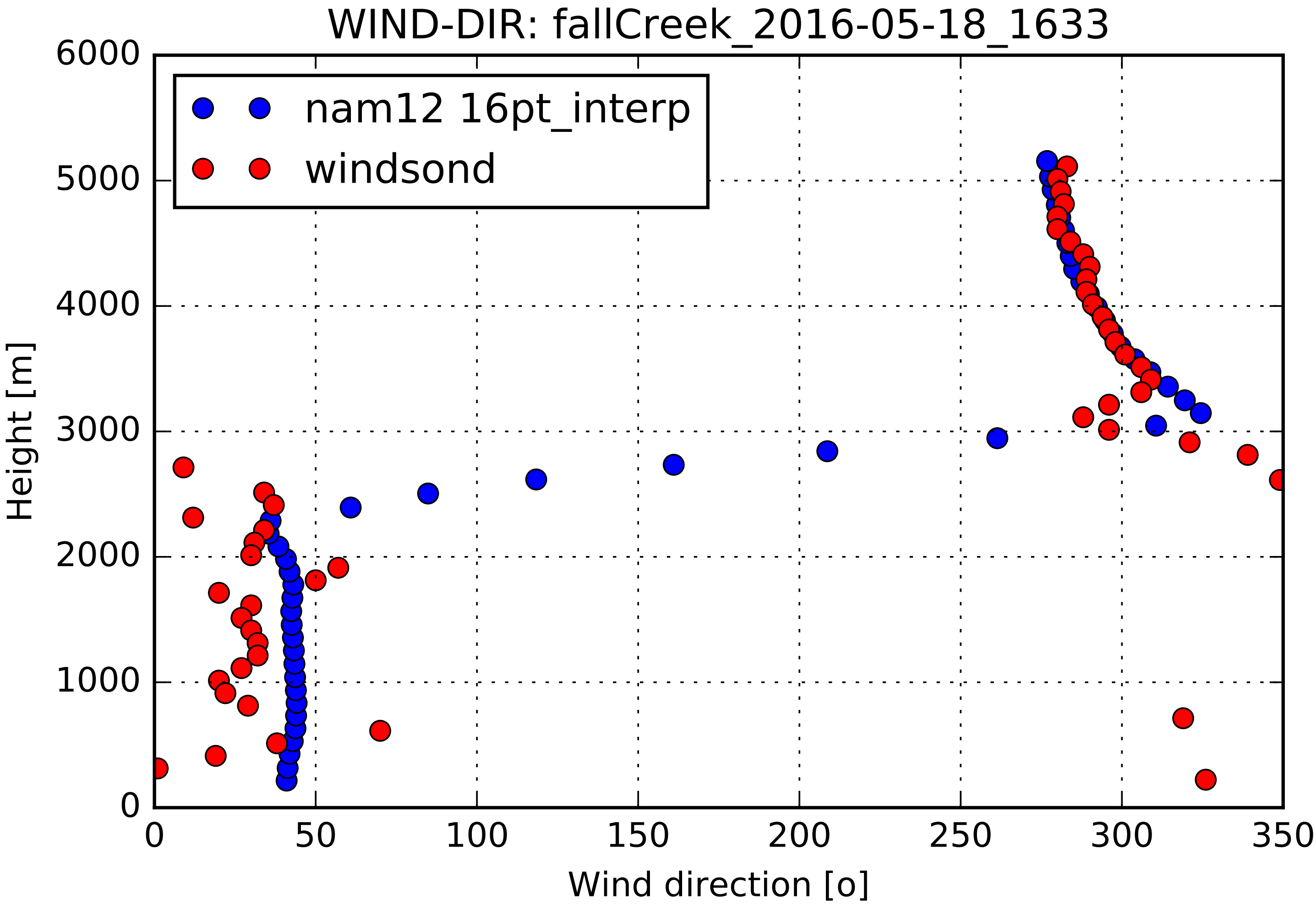
80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nam12 16pt_interp
windsond
Height [m]
Wind direction [o]
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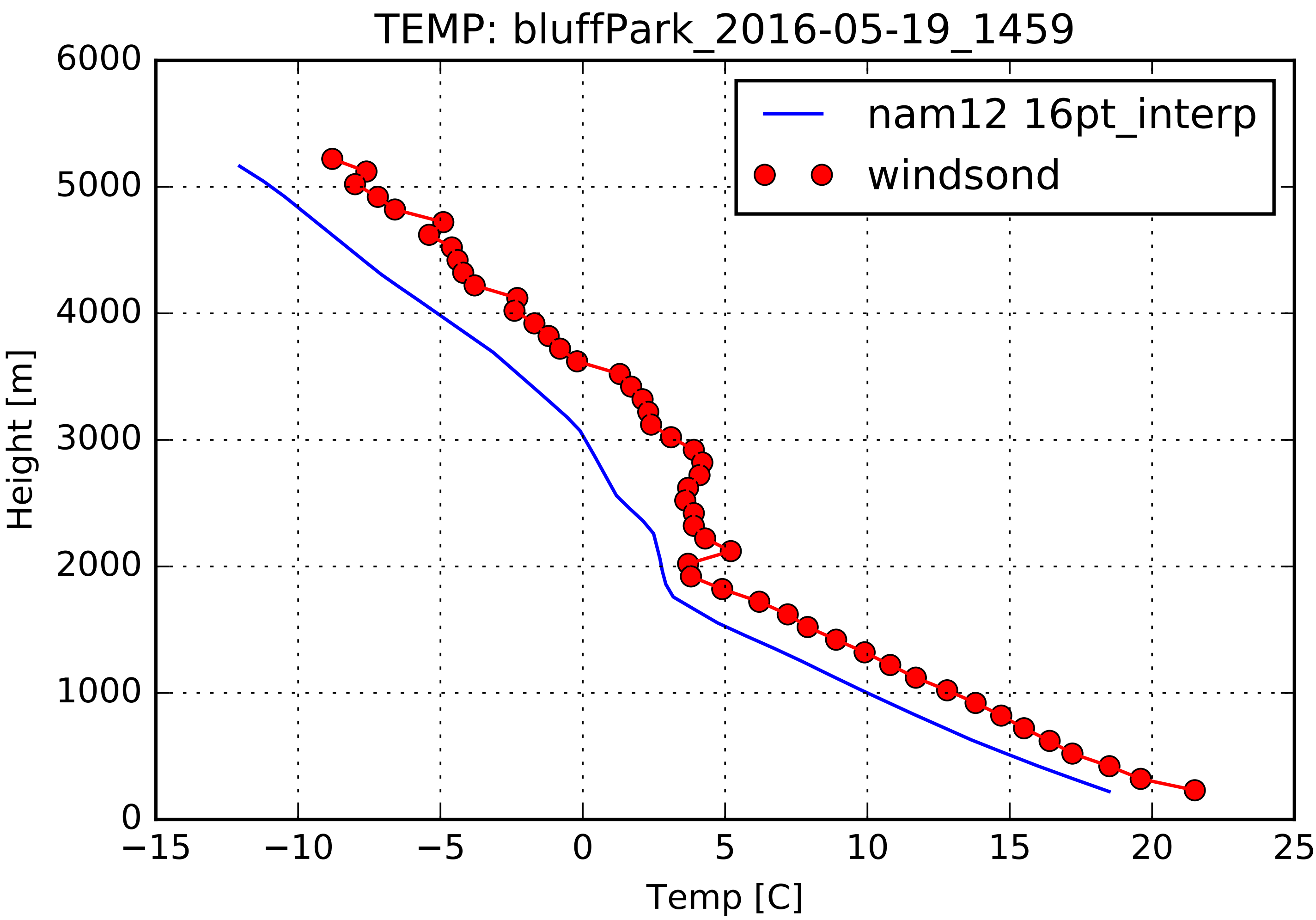
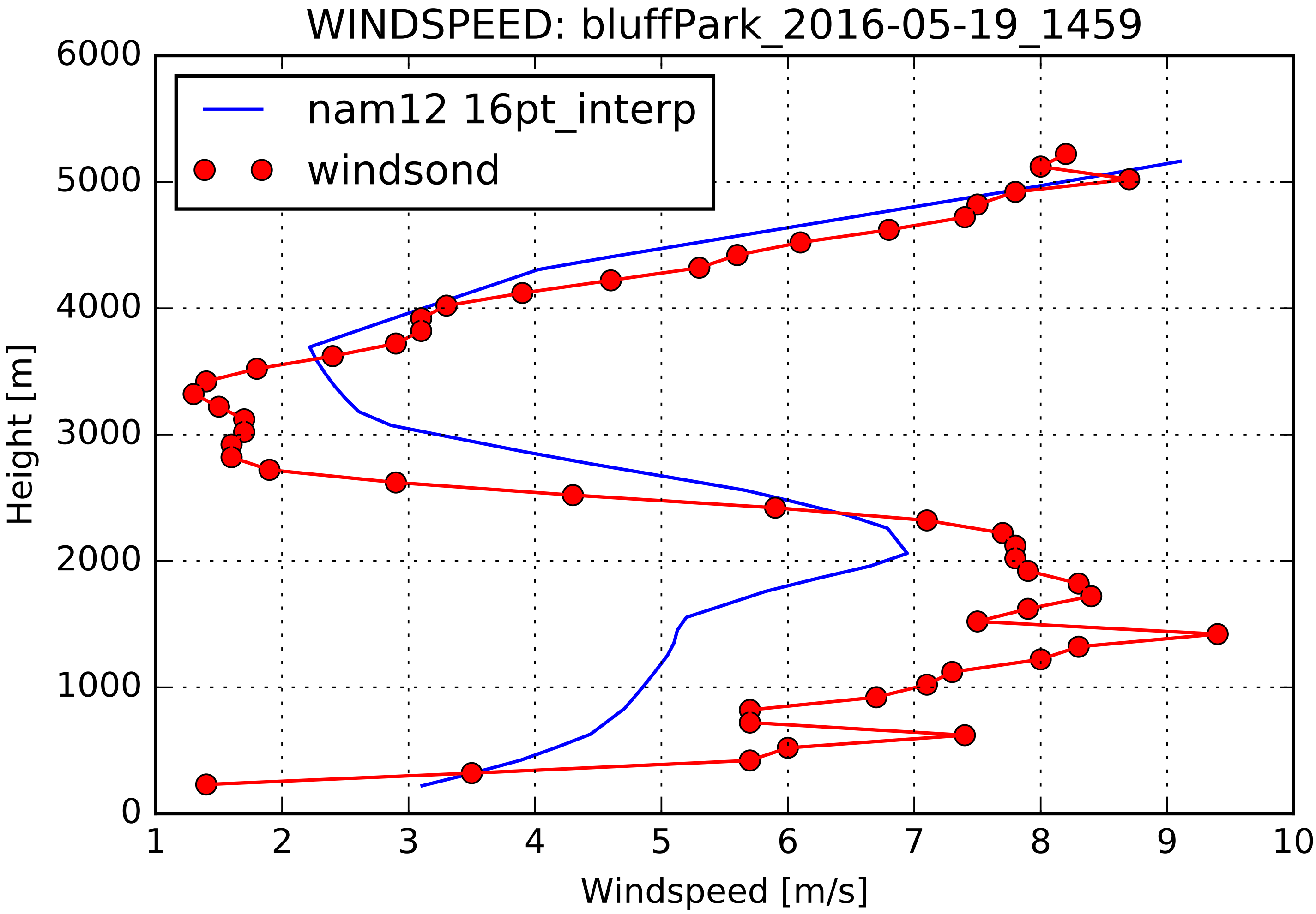
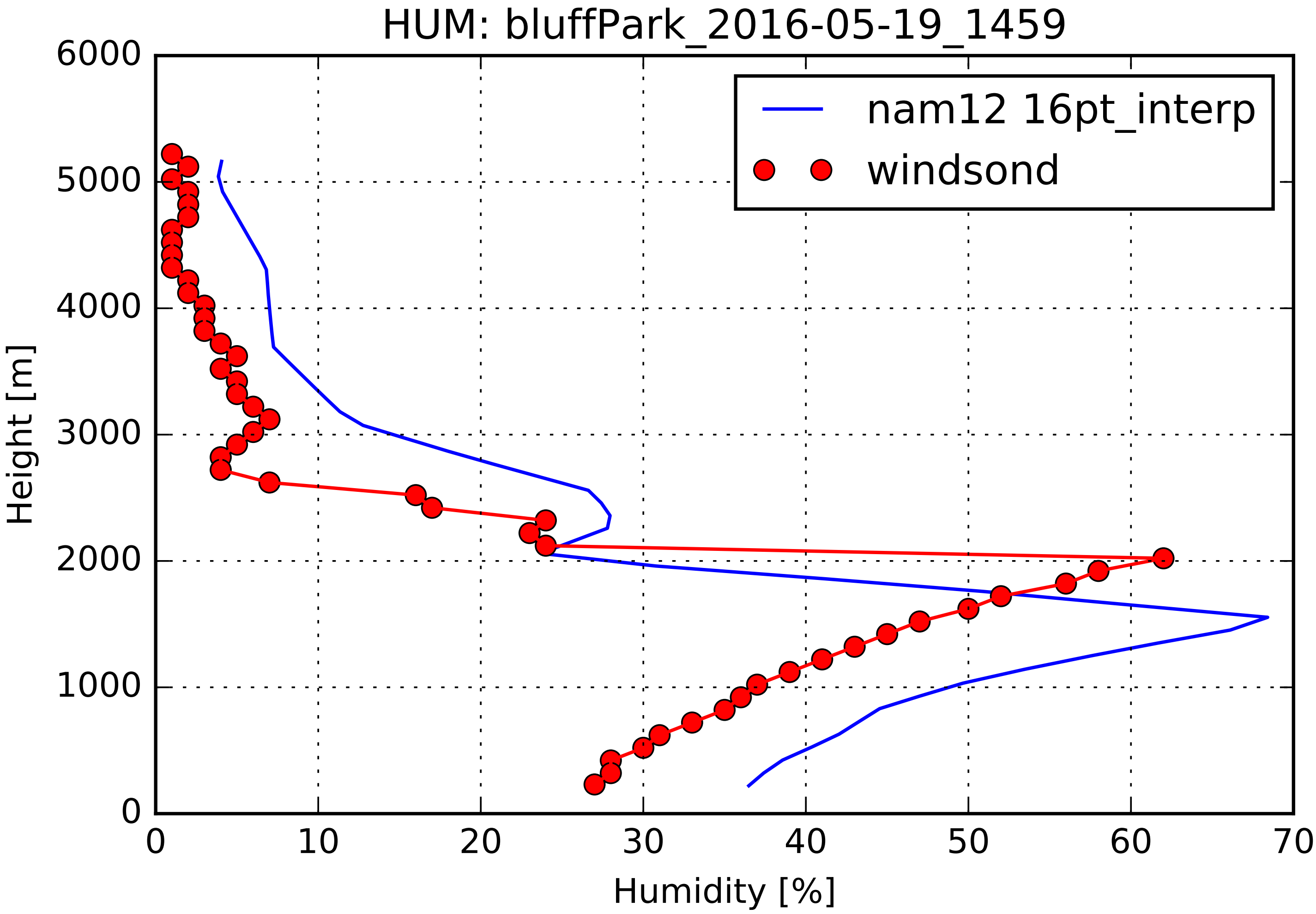
50
100
150
200
250
300
350

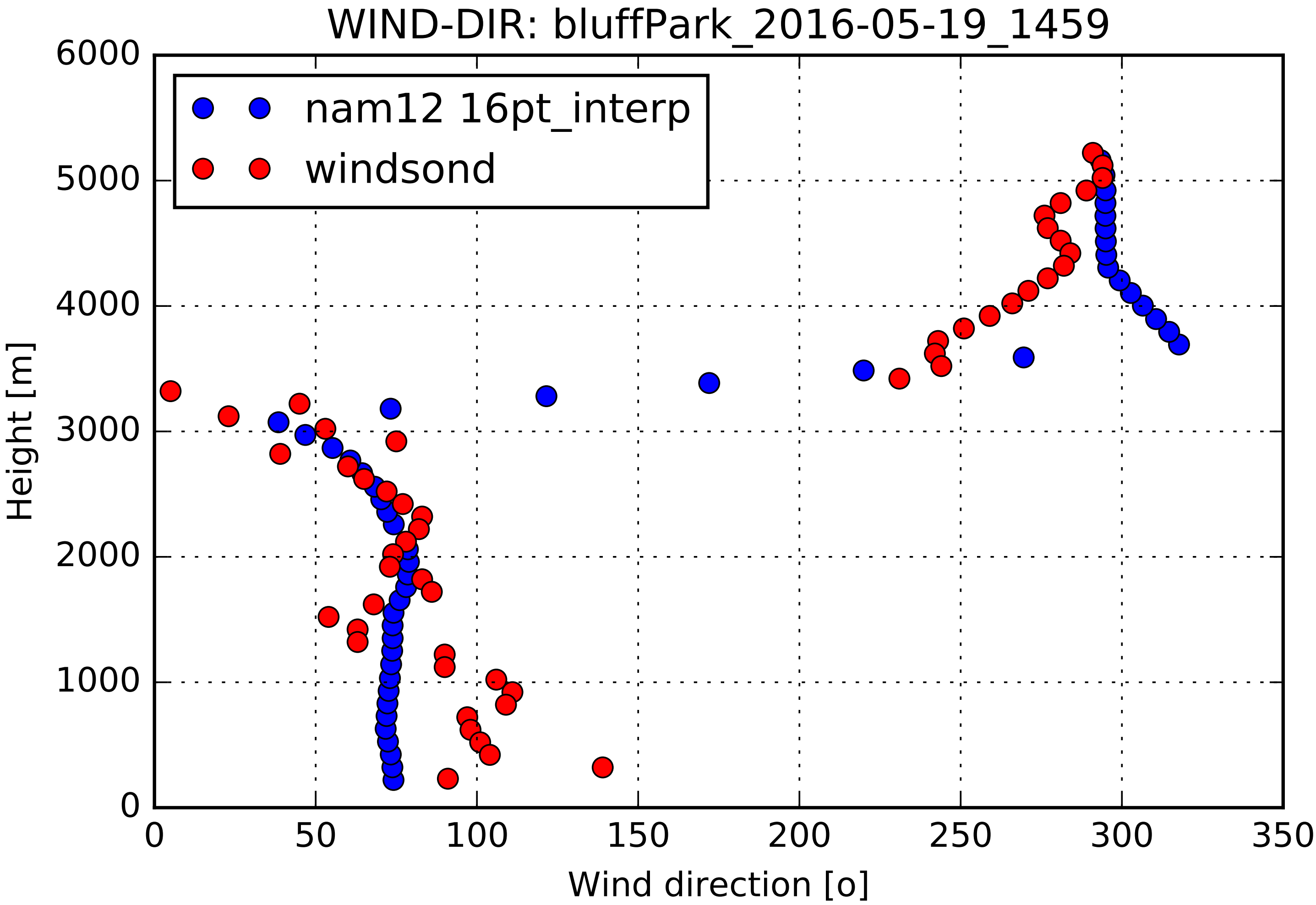

TEMP: bluffPark_2016-05-19_1459
nam12 16pt_interp
windsond
Height [m]
Temp [C]
0
1000
2000
3000
4000
5000
6000
−15
−10
−5
0
5
10
15
20
25



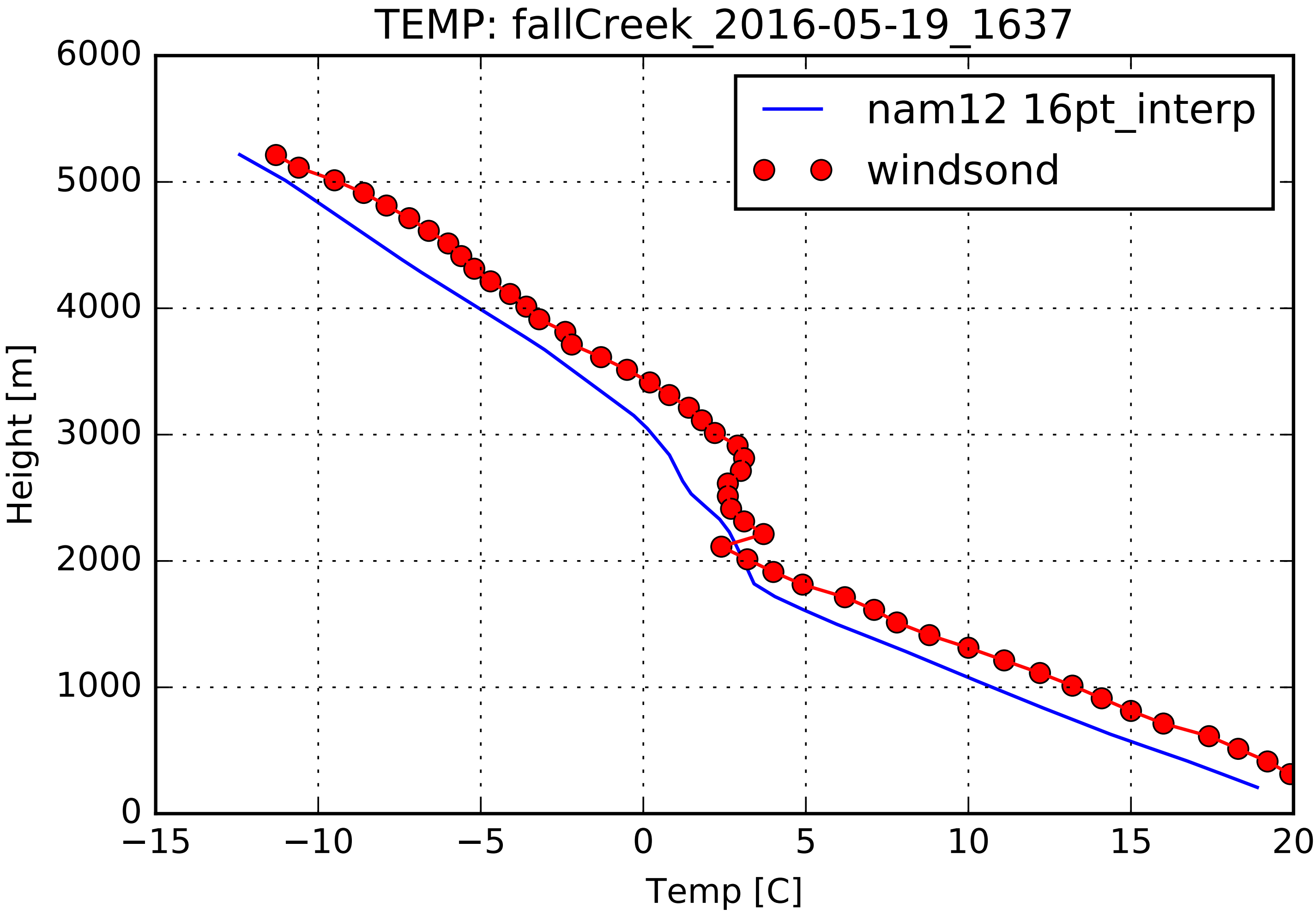
WINDSPEED: bluffPark_2016-05-19_1459
nam12 16pt_interp
windsond
Height [m]
Windspeed [m/s]
0
1000
2000
3000
4000
5000
6000
1
2
3
4
5
6
7
8
9
10

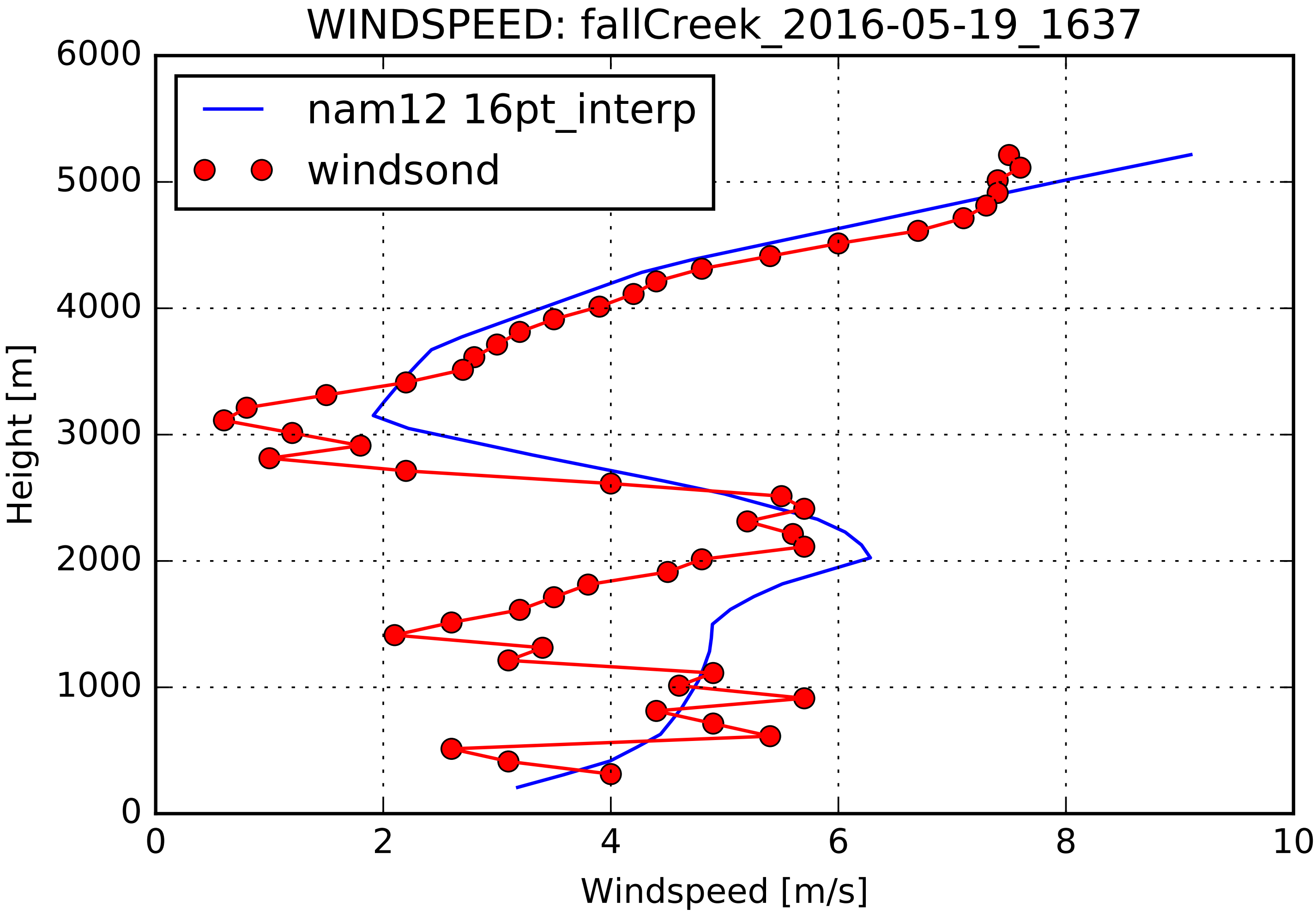


HUM: bluffPark_2016-05-19_1459
nam12 16pt_interp
windsond
Height [m]
Humidity [%]
0
1000
2000
3000
4000
5000
6000
0
10
20
30
40
50
60
70

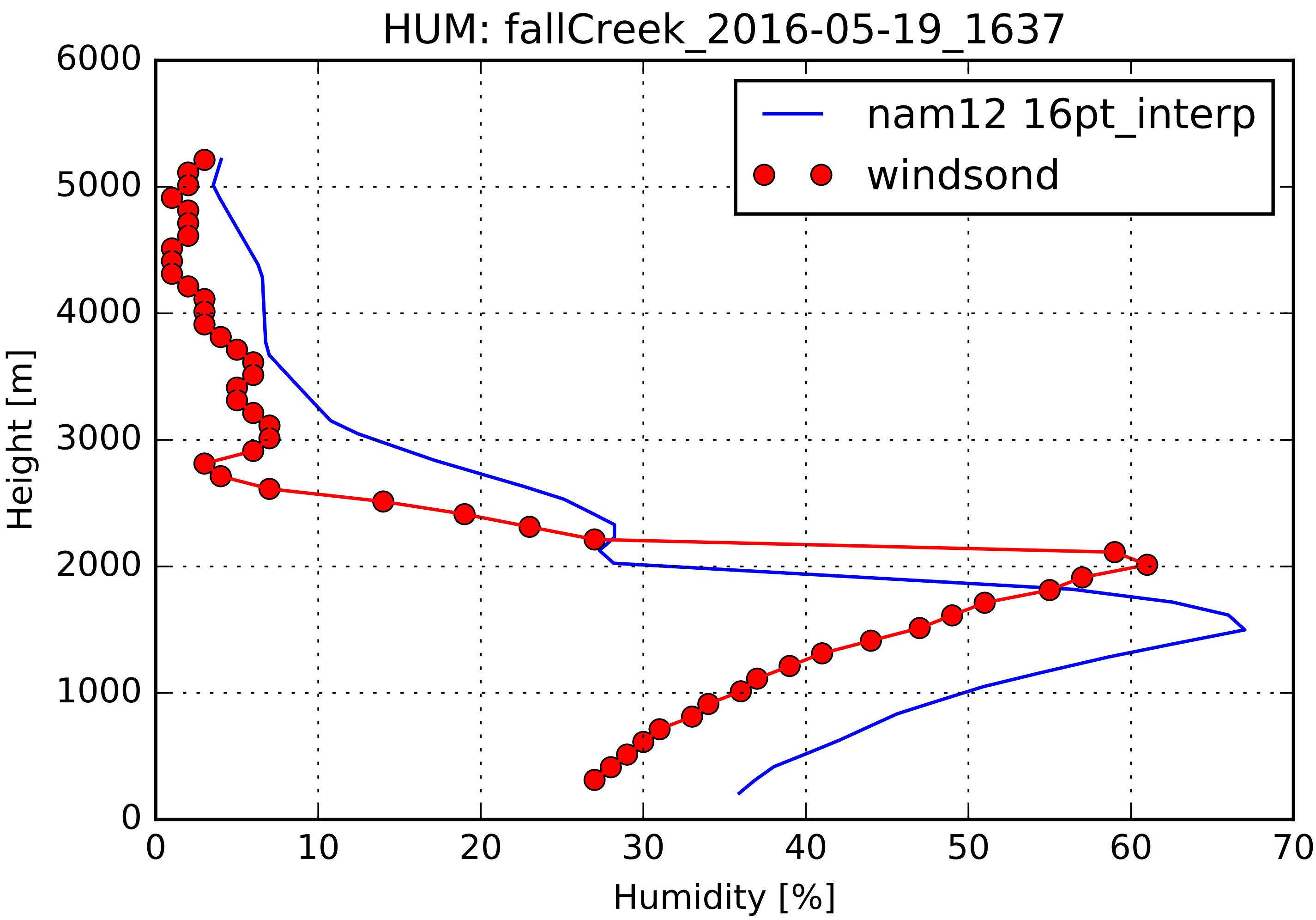


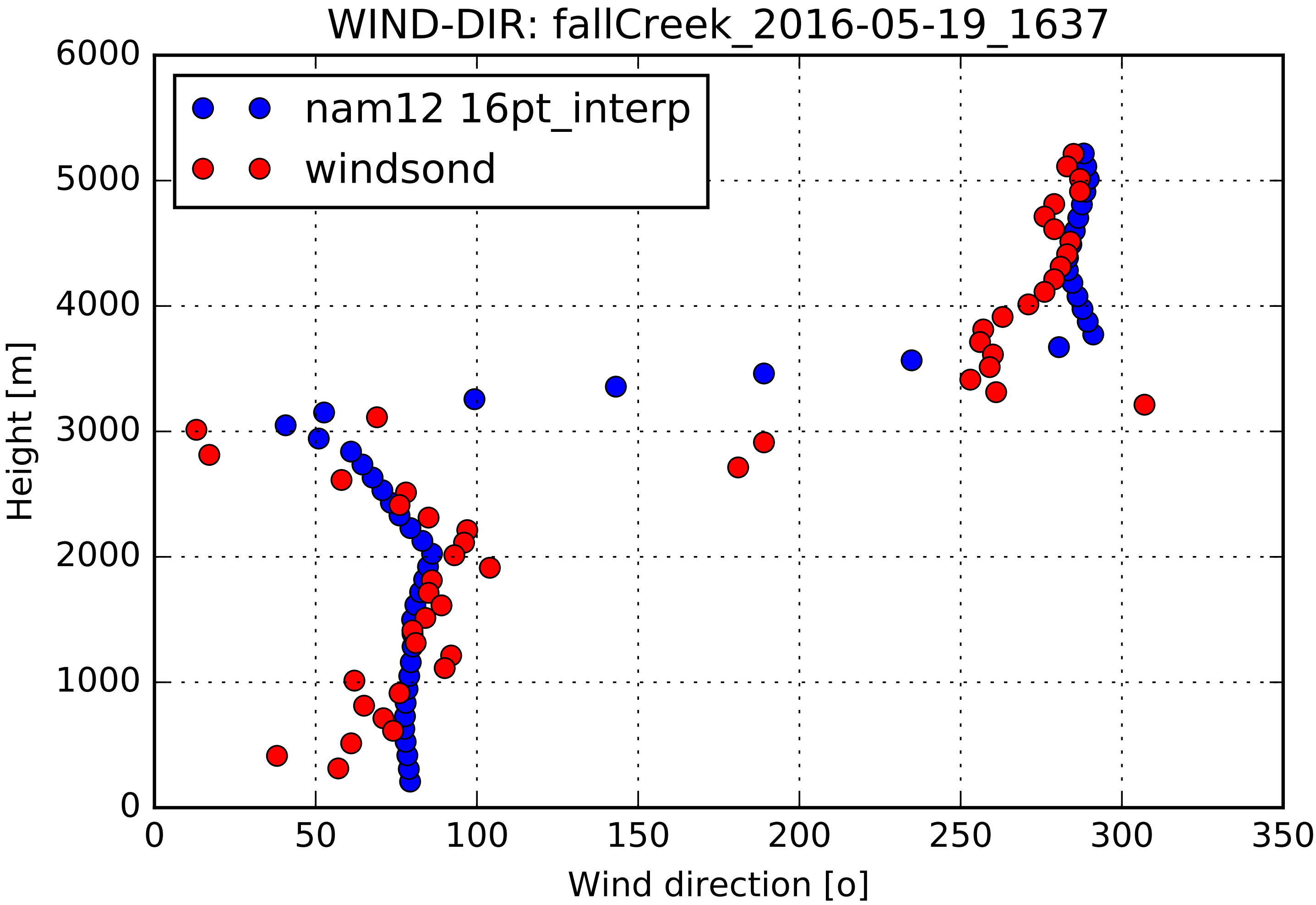
WIND-DIR: bluffPark_2016-05-19_1459
nam12 16pt_interp
windsond
Height [m]
Wind direction [o]
0
1000
2000
3000
4000
5000
6000
0
50
100
150
200
250
300
350


TEMP: fallCreek_2016-05-19_1637
nam12 16pt_interp
windsond
Height [m]
Temp [C]
6000
5000
4000
3000
2000
1000
0
−15
−10
−5
0
5
10
15
20



WINDSPEED: fallCreek_2016-05-19_1637
nam12 16pt_interp
windsond
Height [m]
Windspeed [m/s]
0
1000
2000
3000
4000
5000
6000
0
2
4
6
8
10

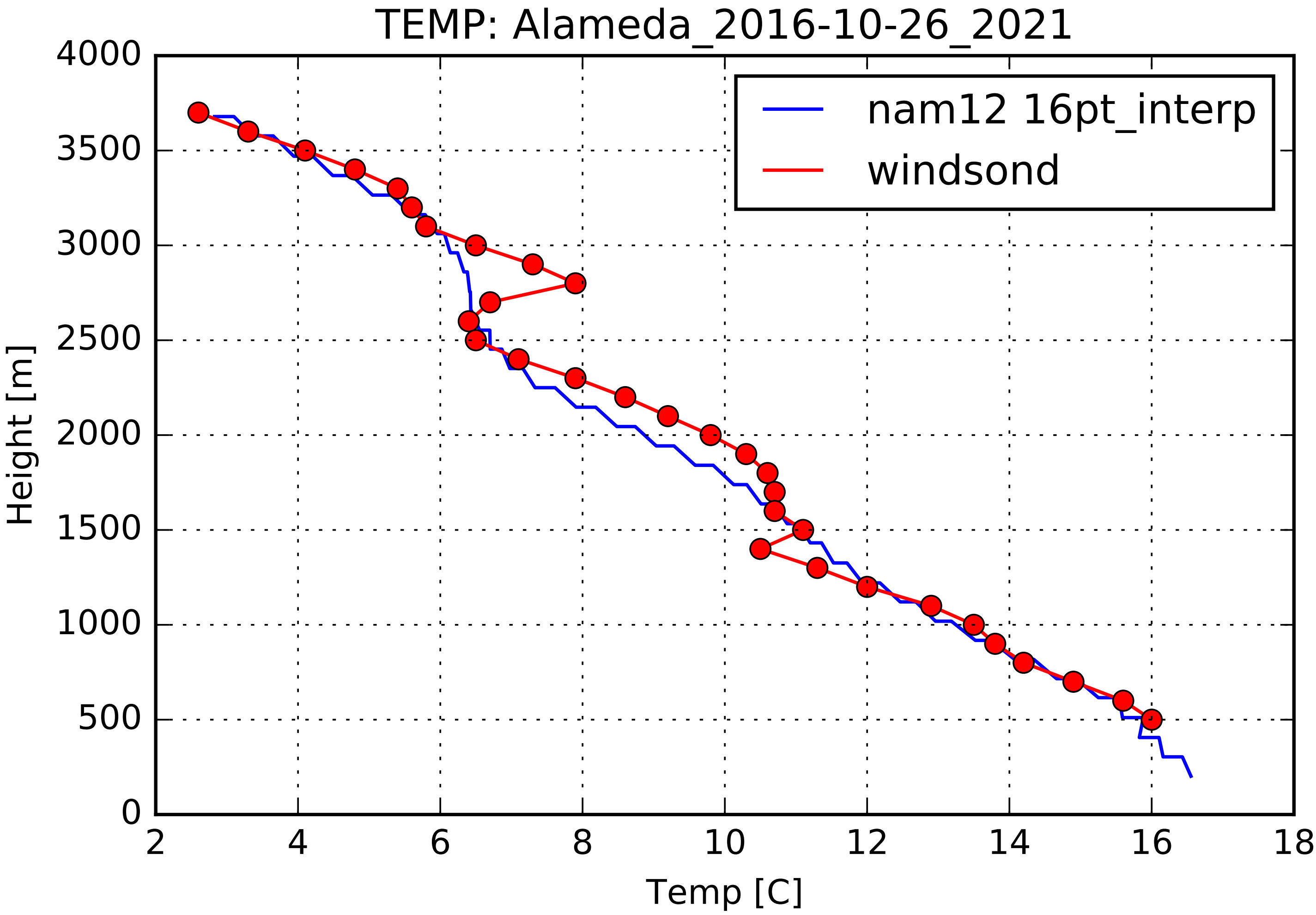

HUM: fallCreek_2016-05-19_1637
nam12 16pt_interp
windsond
Height [m]
Humidity [%]
0
1000
2000
3000
4000
5000
6000
0
10
20
30
40
50
60
70

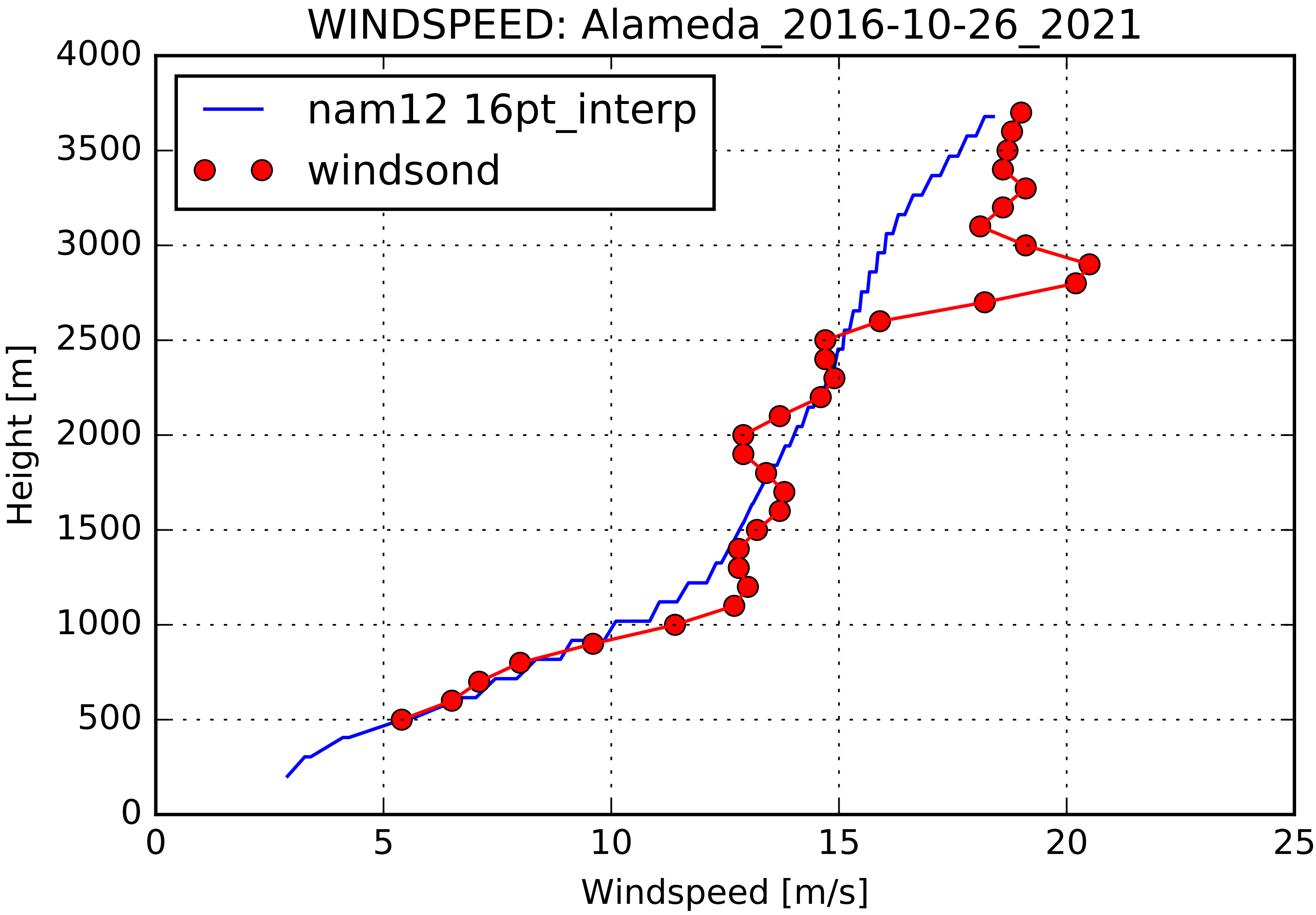


WIND-DIR: fallCreek_2016-05-19_1637
nam12 16pt_interp
windsond
Height [m]
Wind direction [o]
0
1000
2000
3000
4000
5000
6000
0
50
100
150
200
250
300
350

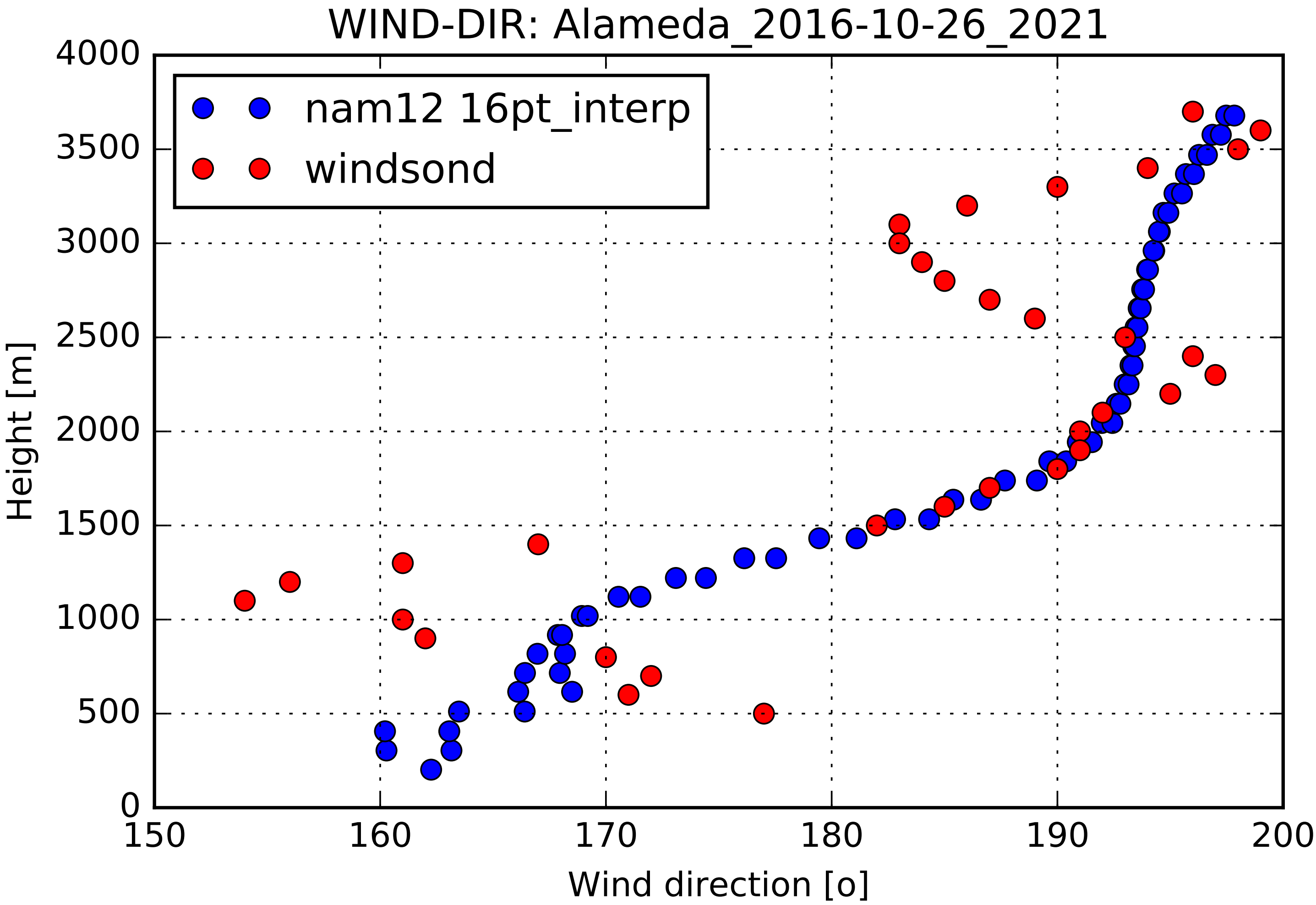
Appendix B: Height profiles - San Francisco Bay Area

Content
2016-10-26_2021
2016-11-01_1920
2016-11-02_0030
2016-11-02_1838
2016-11-02_2230
2016-11-03_1730
2016-11-02_2123

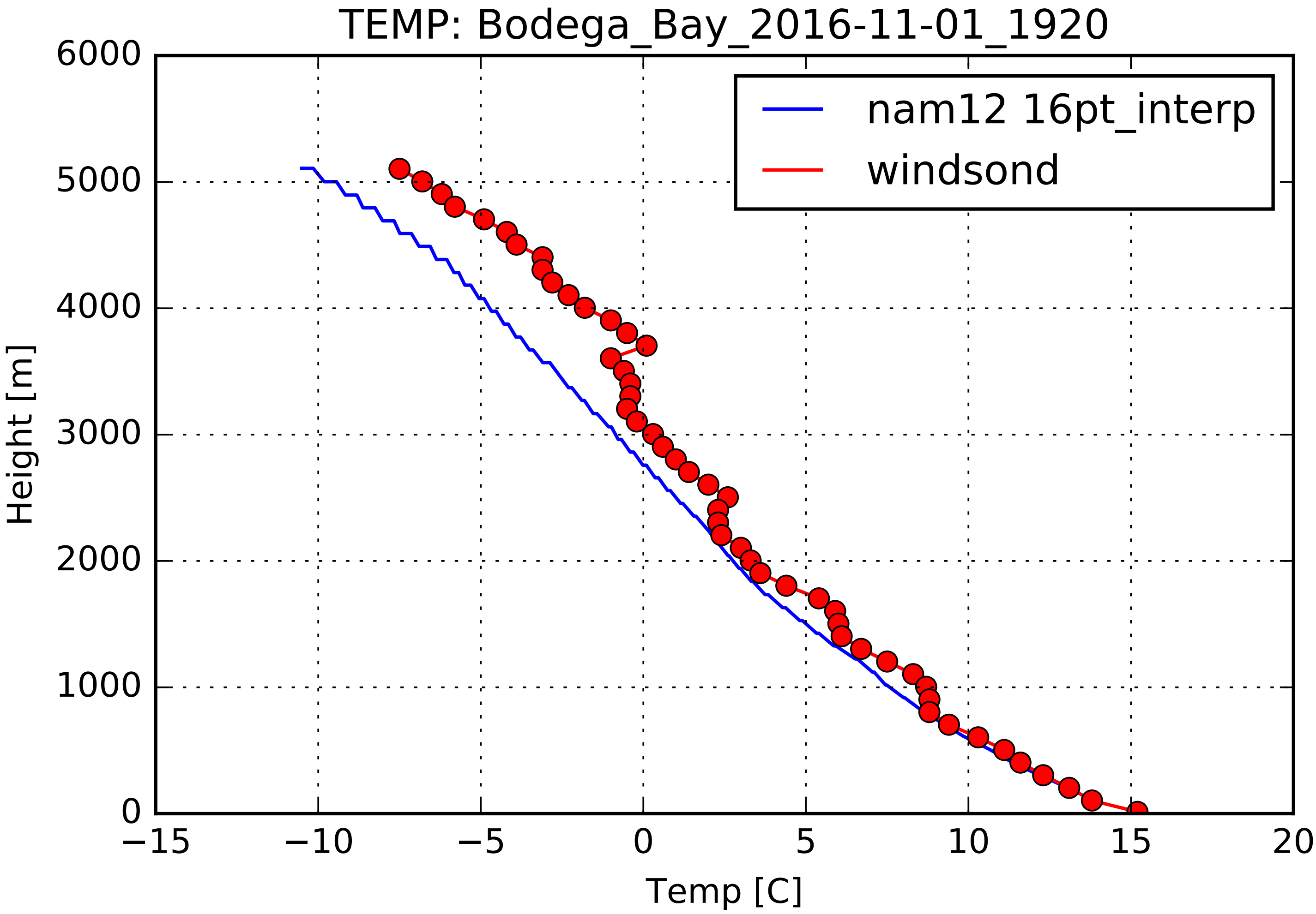

TEMP: Alameda_2016-10-26_2021
nam12 16pt_interp
windsond
Height [m]
Temp [C]
0
500
1000
1500
2000
2500
3000
3500
4000
2
4
6
8
10
12
14
16
18

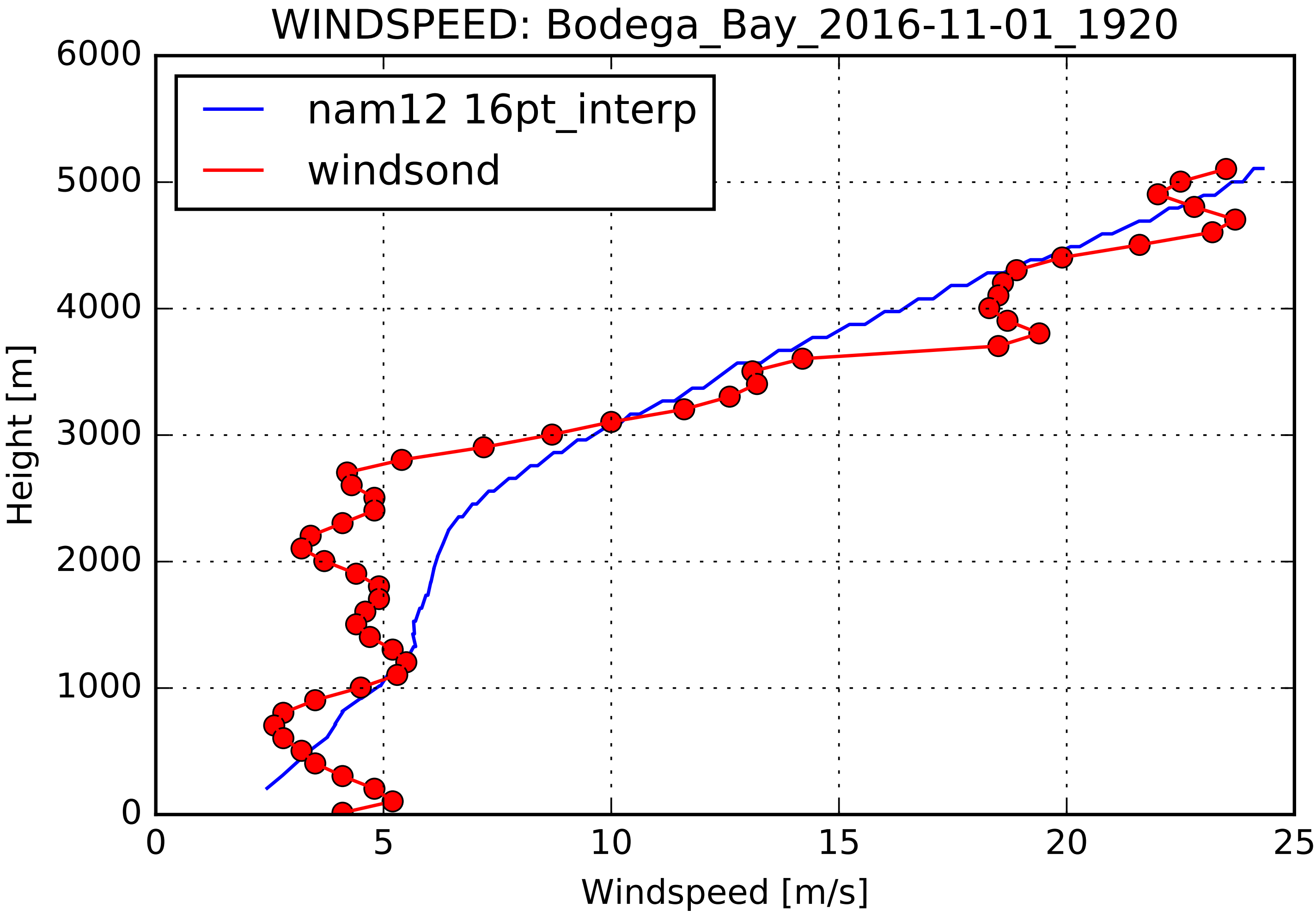


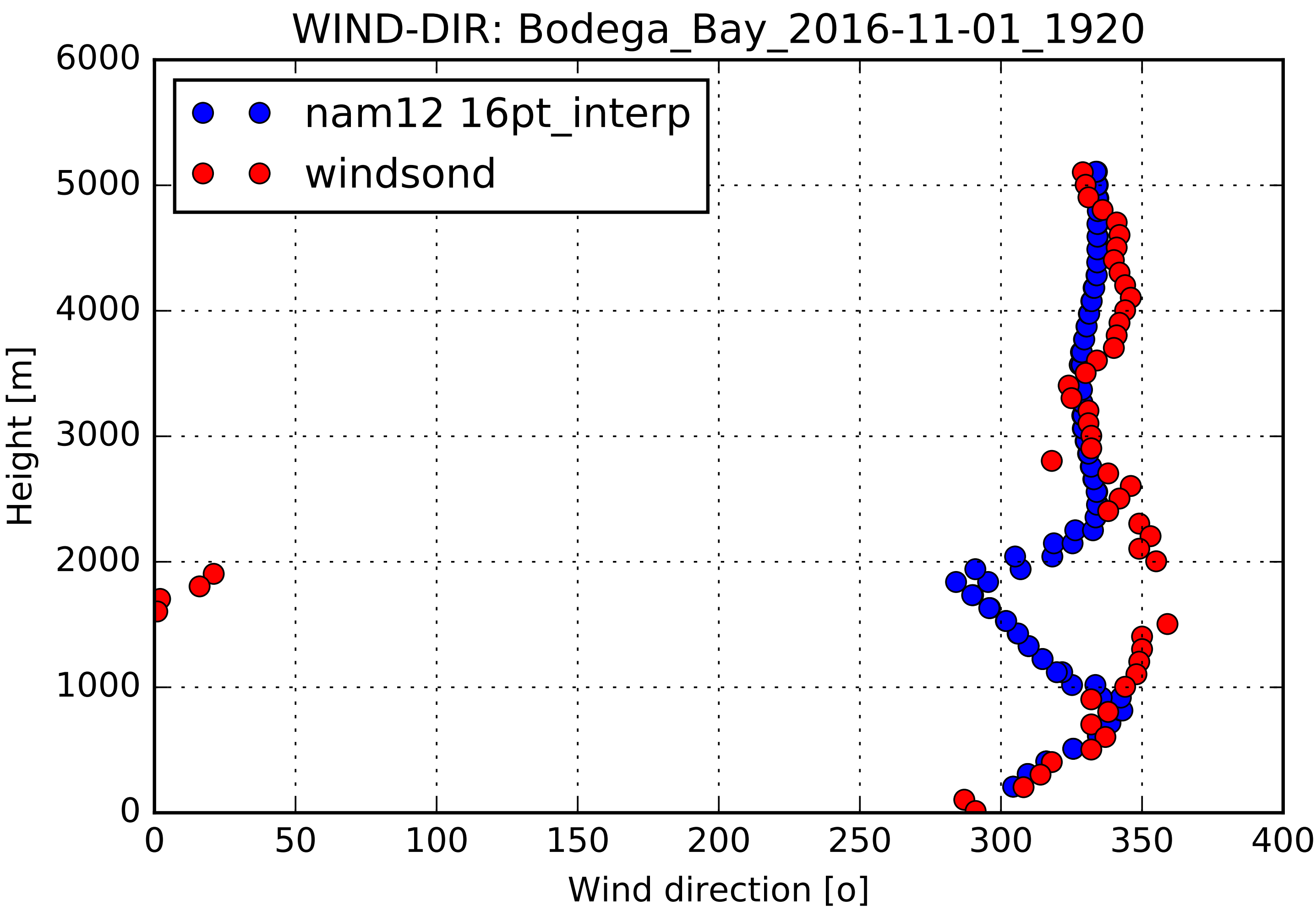
WINDSPEED: Alameda_2016-10-26_2021
nam12 16pt_interp
windsond
Height [m]
Windspeed [m/s]
0
500
1000
1500
2000
2500
3000
3500
4000
0
5
10
15
20
25



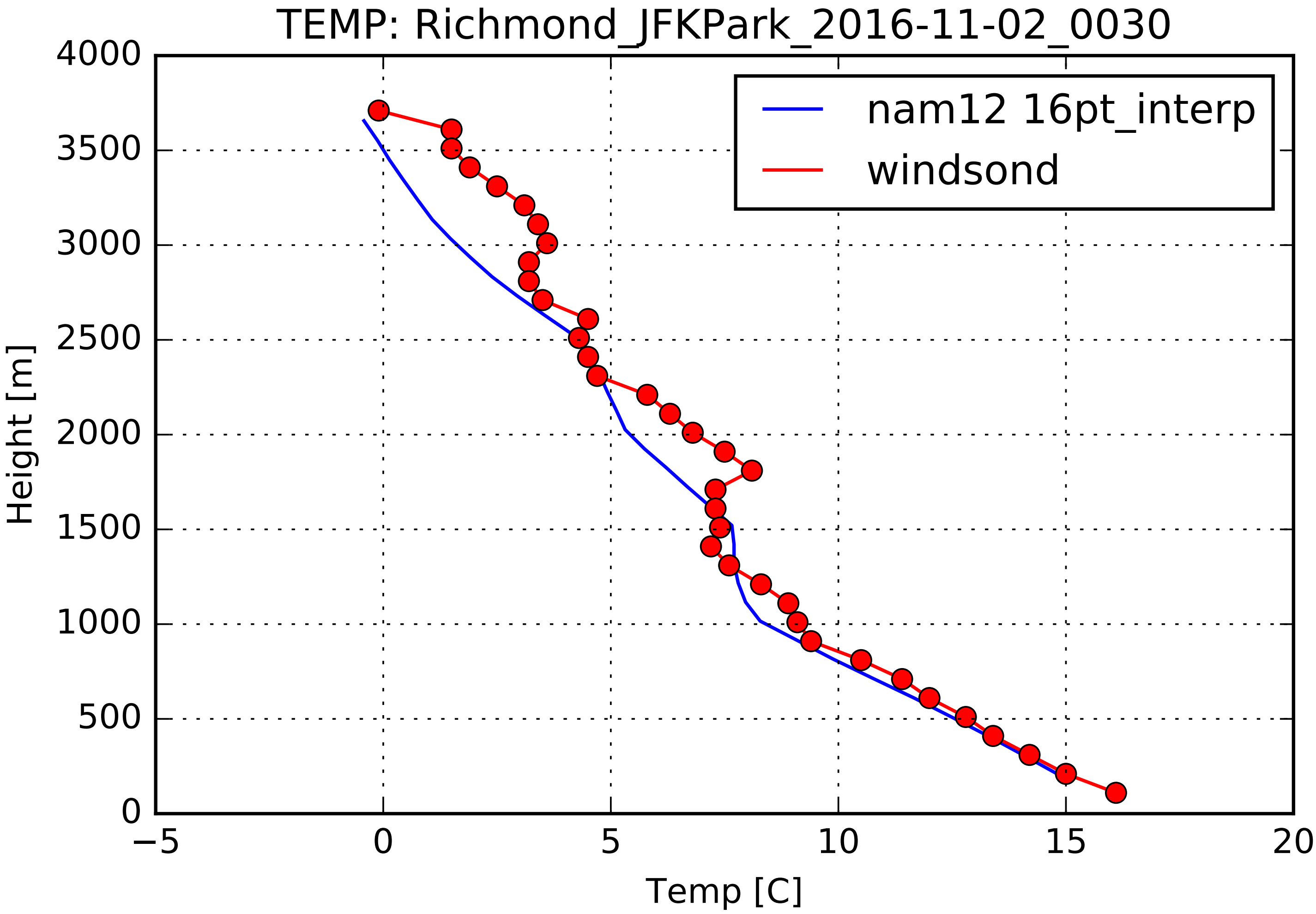
WIND-DIR: Alameda_2016-10-26_2021
nam12 16pt_interp
windsond
Height [m]
Wind direction [o]
0
500
1000
1500
2000
2500
3000
3500
4000
150
160
170
180
190
200


TEMP: Bodega_Bay_2016-11-01_1920
nam12 16pt_interp
windsond
Height [m]
Temp [C]
6000
5000
4000
3000
2000
1000
0
−15
−10
−5
0
5
10
15
20

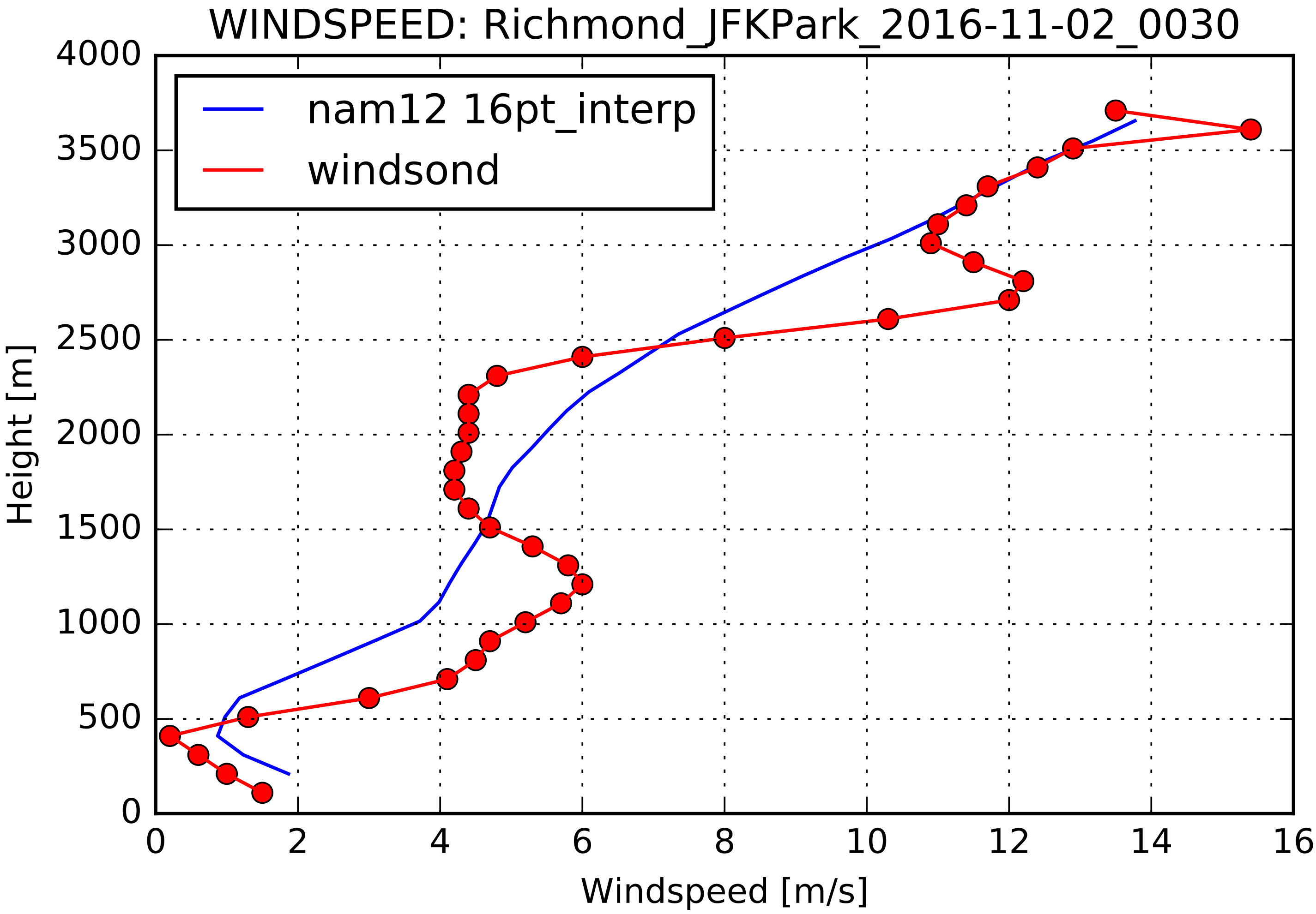

WINDSPEED: Bodega_Bay_2016-11-01_1920
nam12 16pt_interp
windsond
Height [m]
Windspeed [m/s]
0
1000
2000
3000
4000
5000
6000
0
5
10
15
20
25



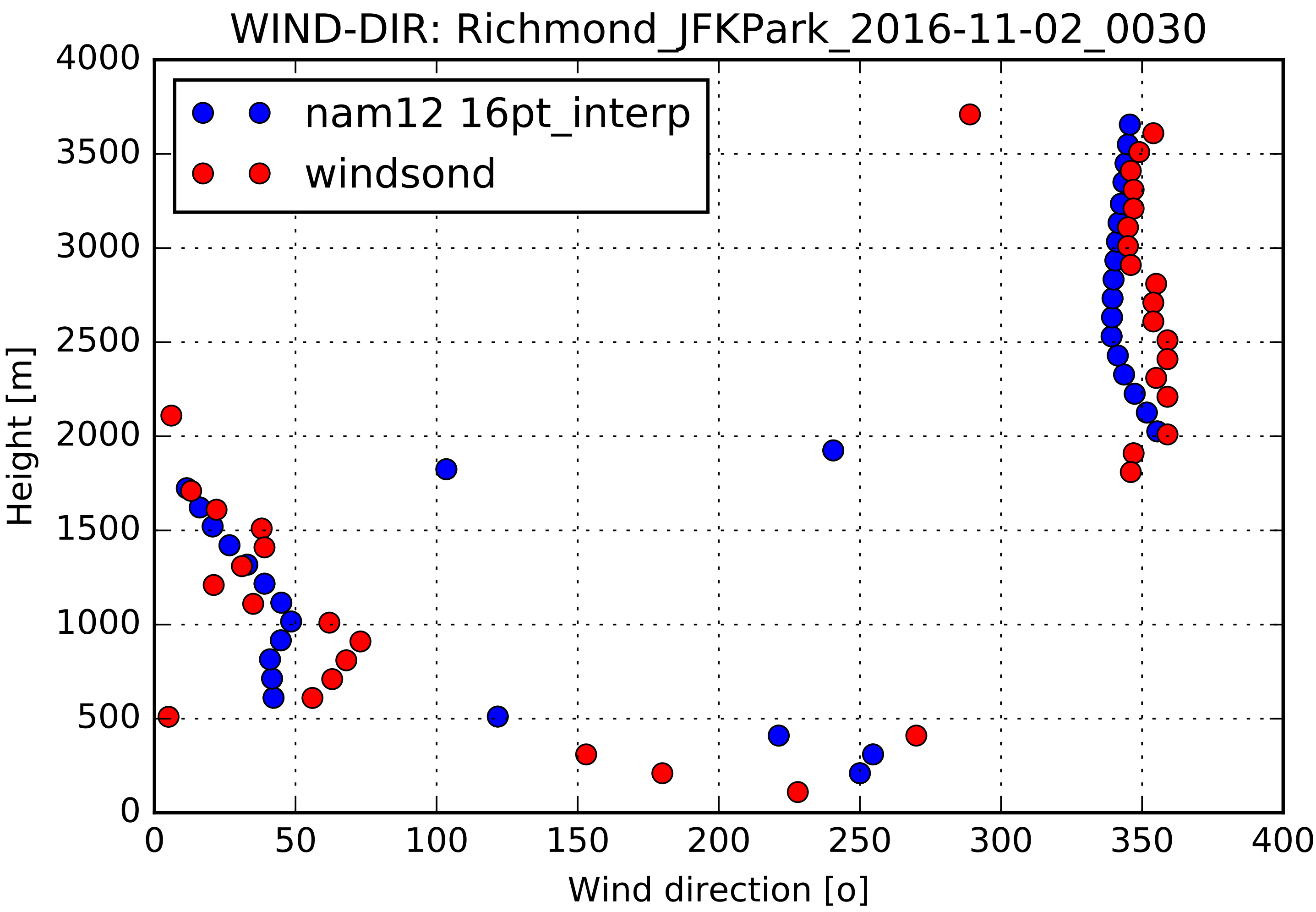
WIND-DIR: Bodega_Bay_2016-11-01_1920
nam12 16pt_interp
windsond
Height [m]
Wind direction [o]
0
1000
2000
3000
4000
5000
6000
0
50
100
150
200
250
300
350
400

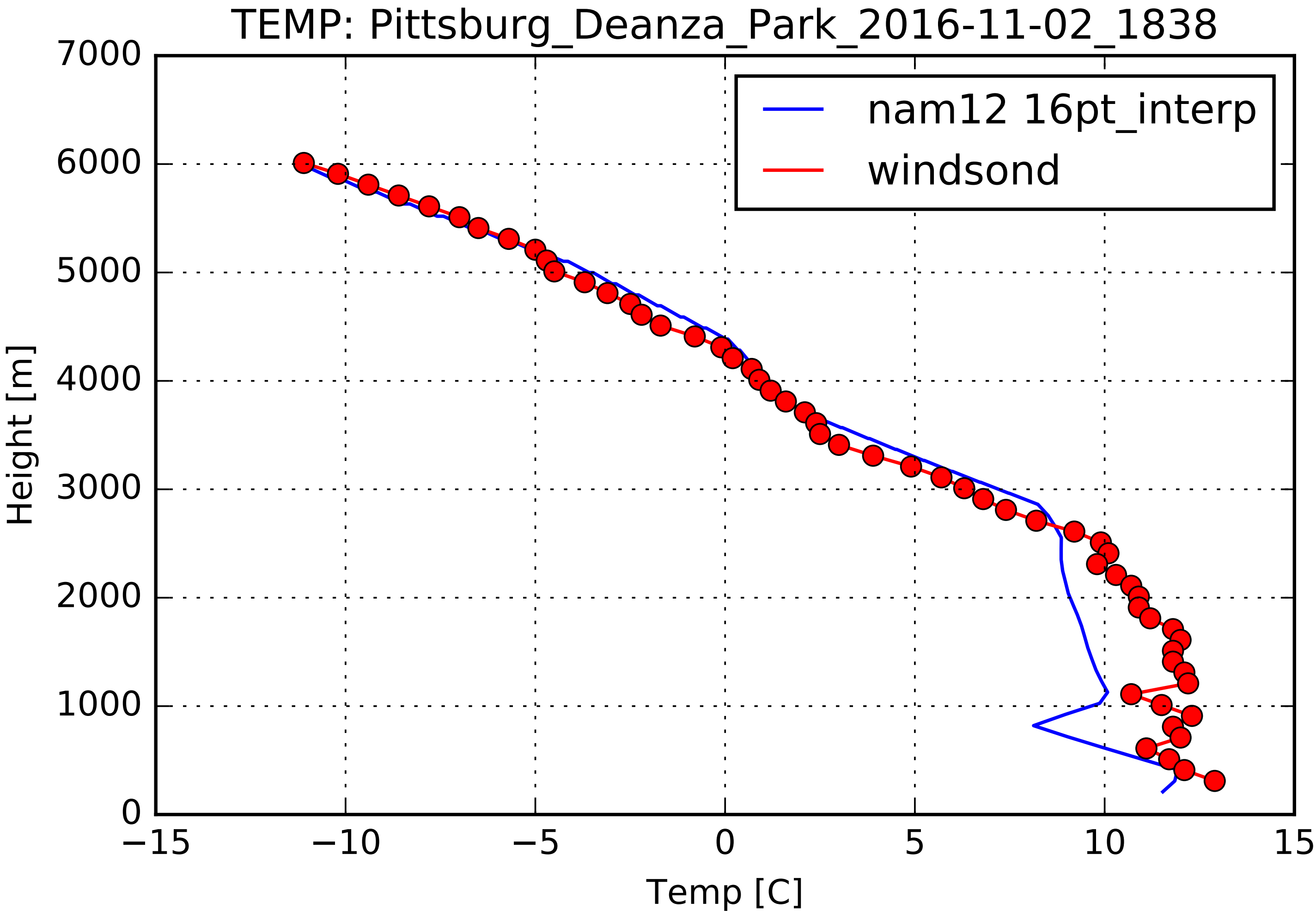


TEMP: Richmond_JFKPark_2016-11-02_0030
nam12 16pt_interp
windsond
Height [m]
Temp [C]
4000
3500
3000
2500
2000
1500
1000
500
0
−5
0
5
10
15
20

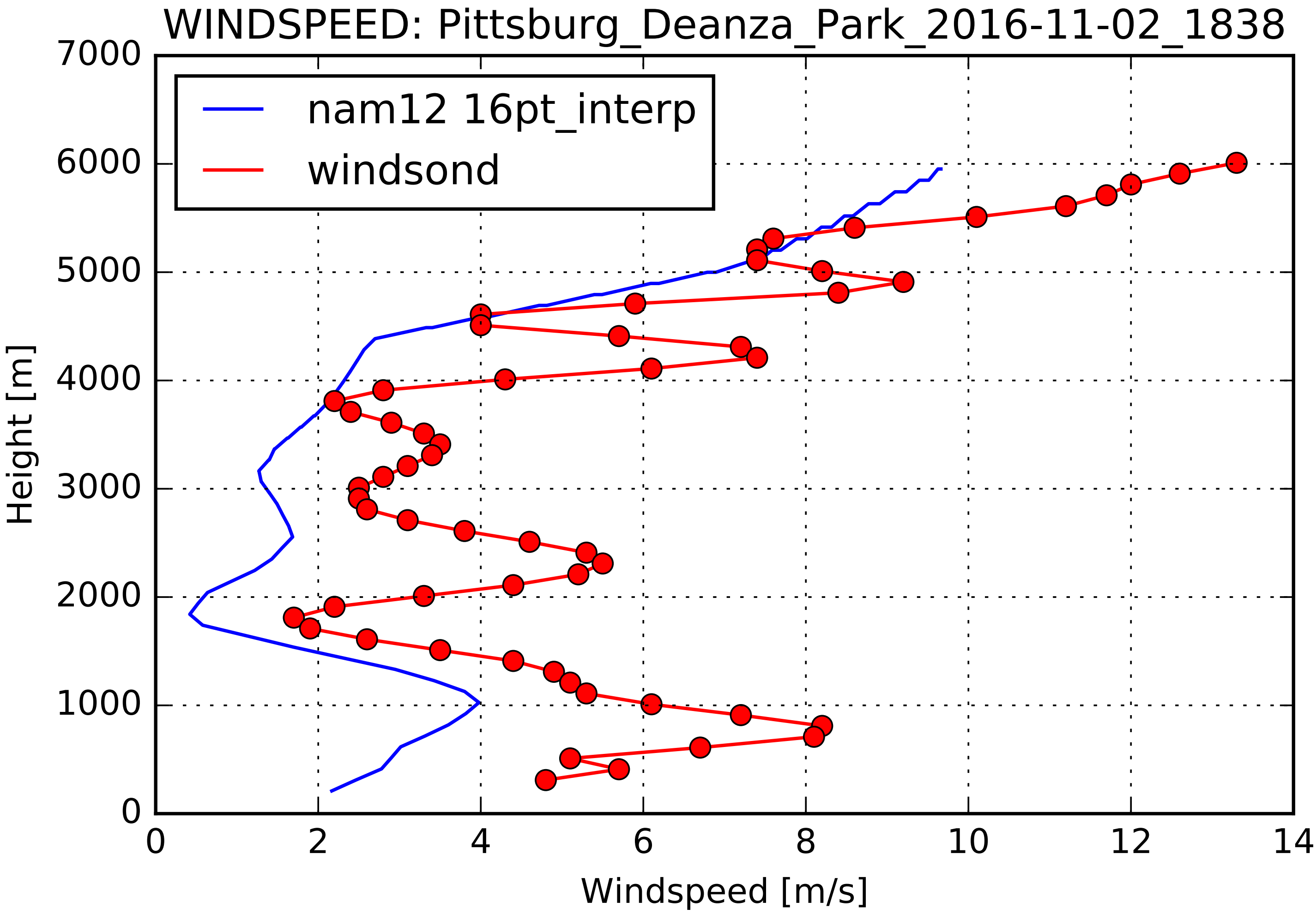


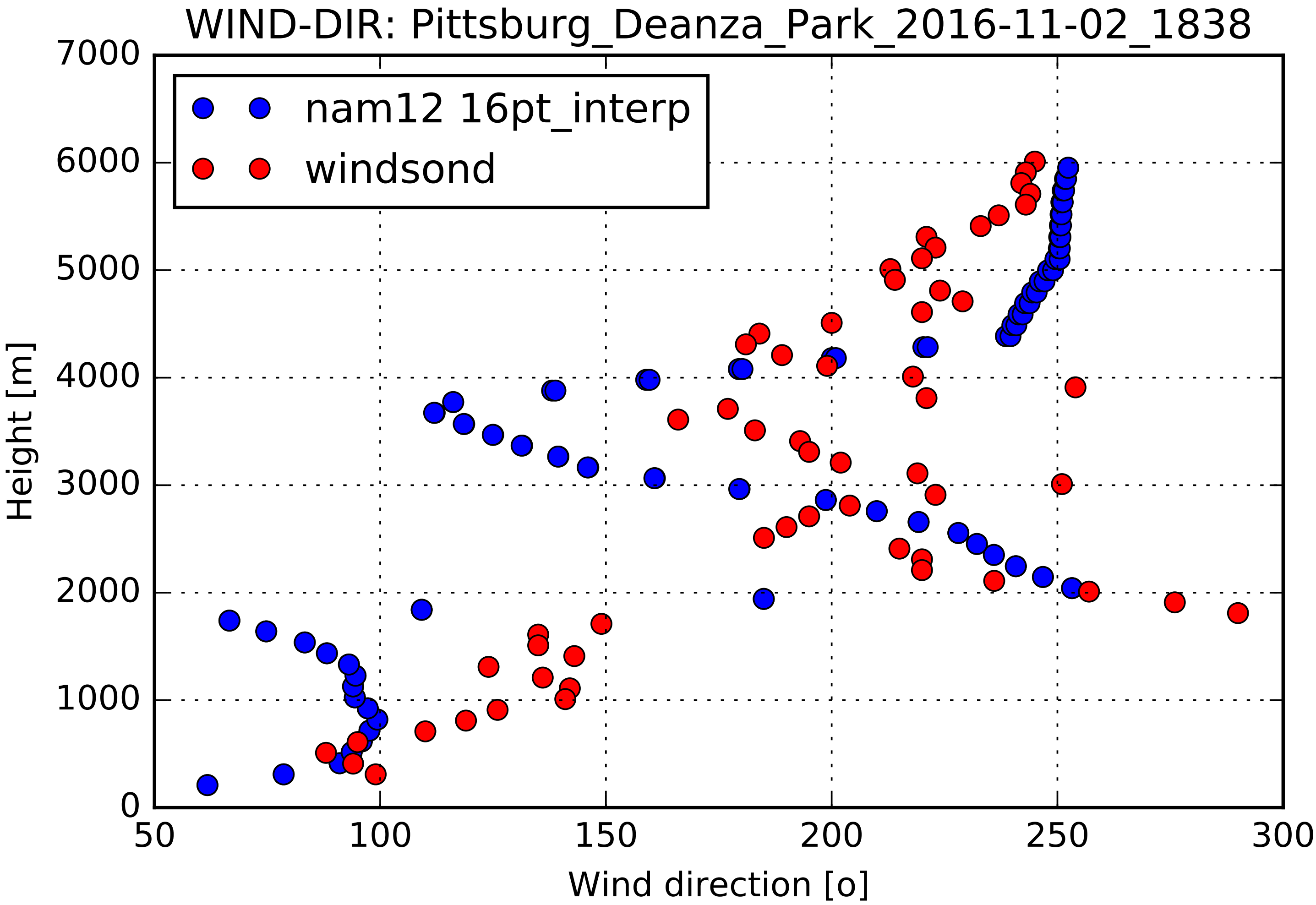
WINDSPEED: Richmond_JFKPark_2016-11-02_0030
nam12 16pt_interp
windsond
Height [m]
Windspeed [m/s]
0
500
1000
1500
2000
2500
3000
3500
4000
0
2
4
6
8
10
12
14
16

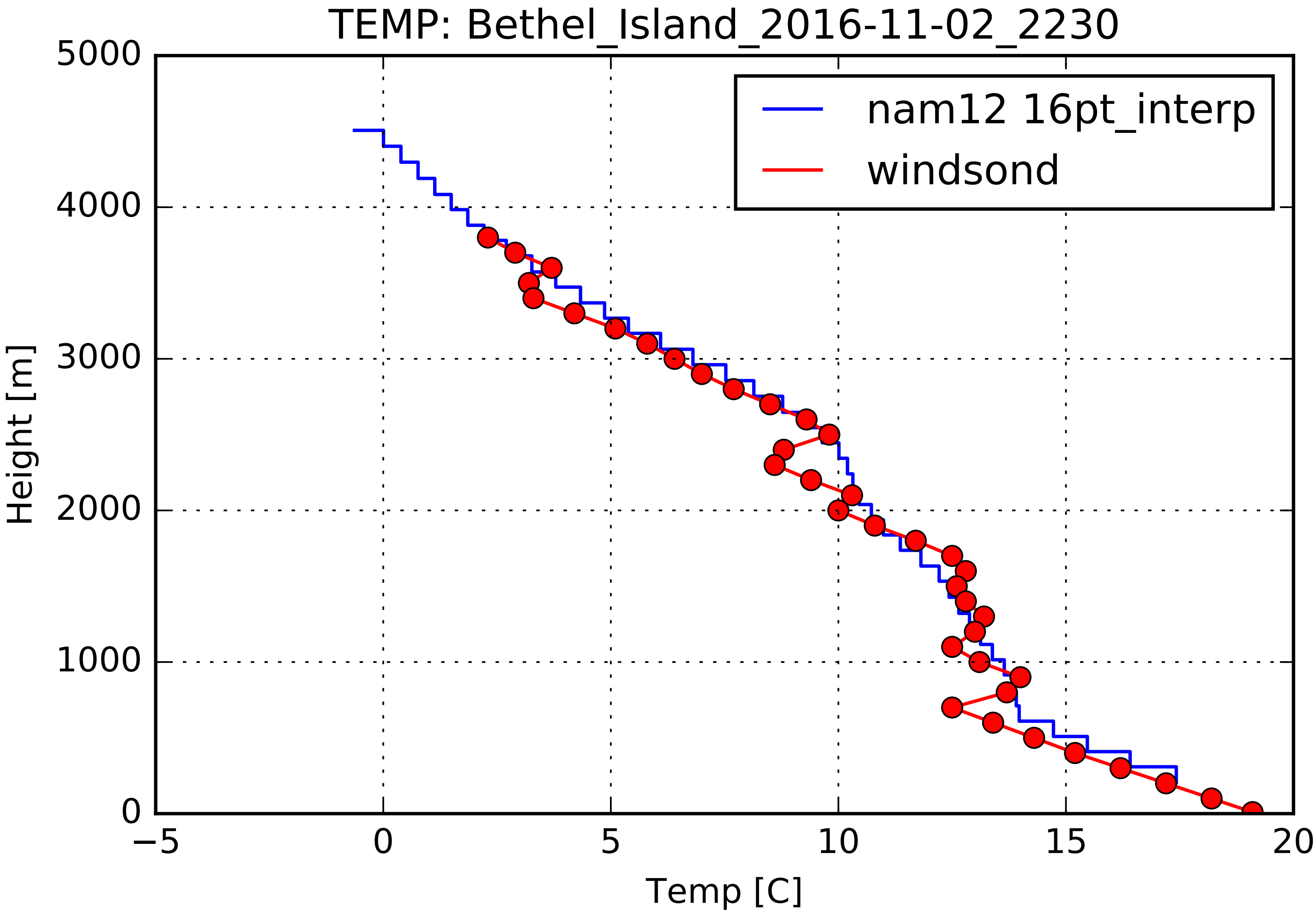

WIND-DIR: Richmond_JFKPark_2016-11-02_0030
nam12 16pt_interp
windsond
Height [m]
Wind direction [o]
0
500
1000
1500
2000
2500
3000
3500
4000
0
50
100
150
200
250
300
350
400

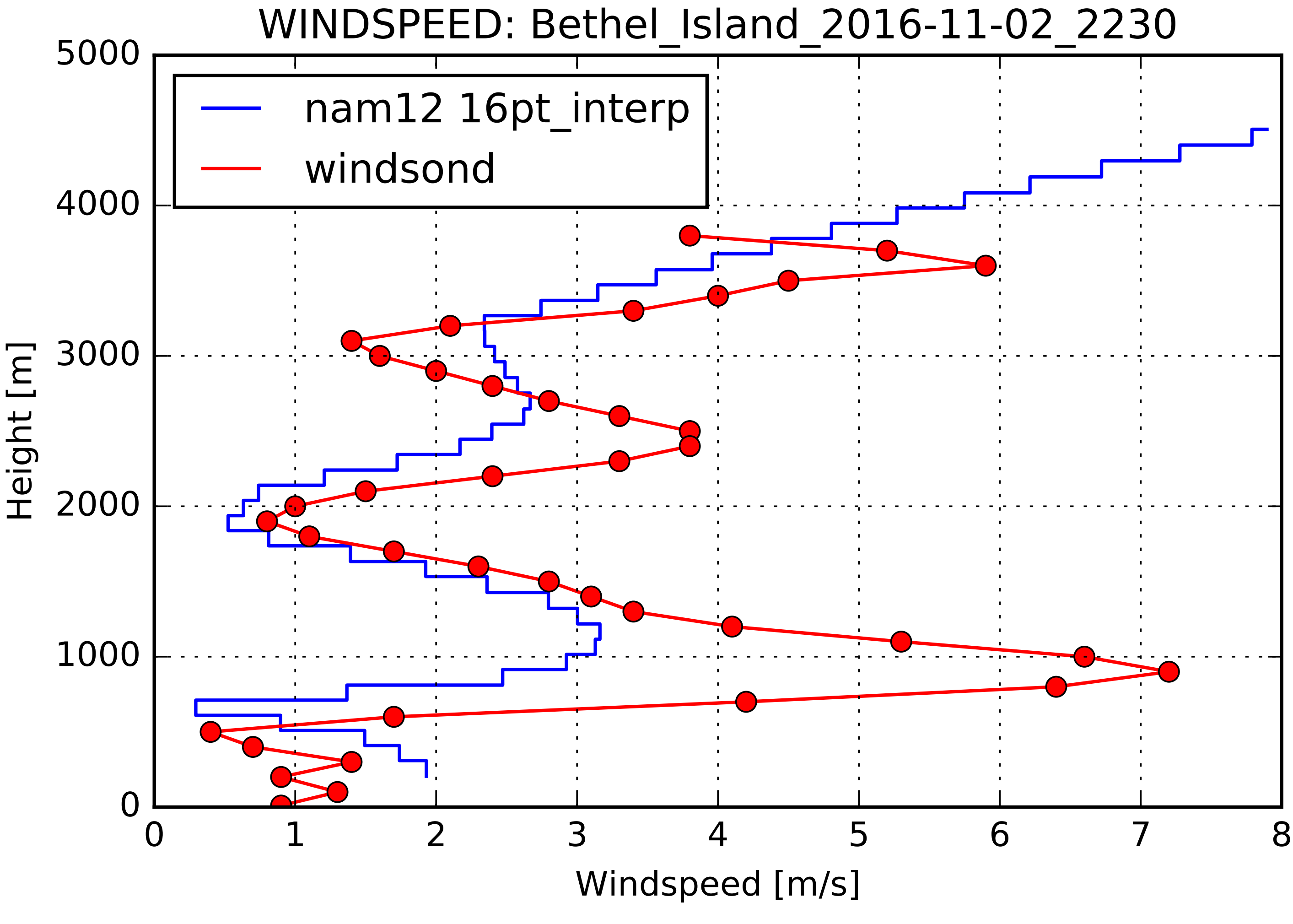


TEMP: Pittsburg_Deanza_Park_2016-11-02_1838
Height [m]
Temp [C]
nam12 16pt_interp
windsond
0
1000
2000
3000
4000
5000
6000
7000
−15
−10
−5
0
5
10
15

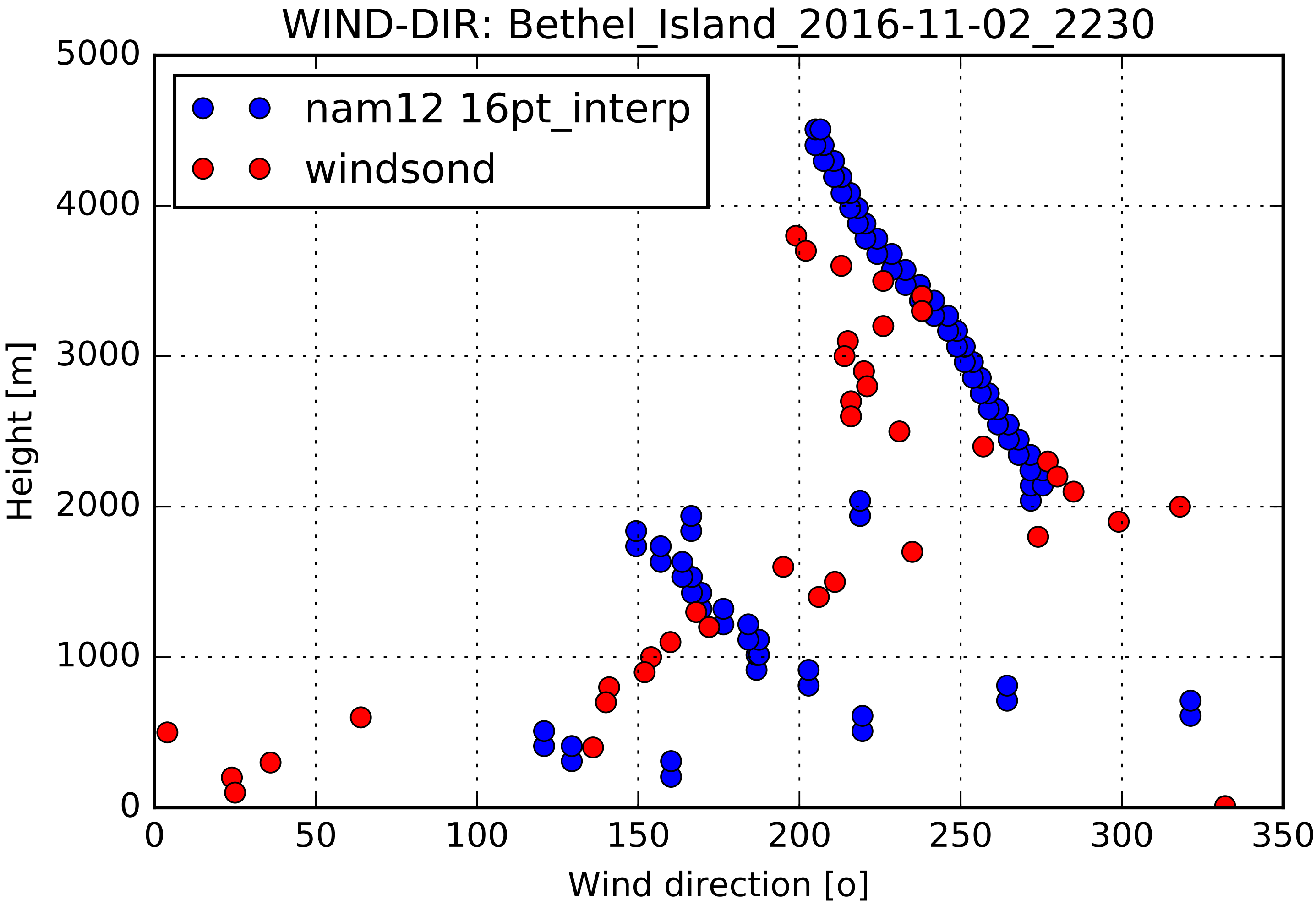

WINDSPEED: Pittsburg_Deanza_Park_2016-11-02_1838
nam12 16pt_interp
windsond
Height [m]
Windspeed [m/s]
0
1000
2000
3000
4000
5000
6000
7000
0
2
4
6
8
10
12
14

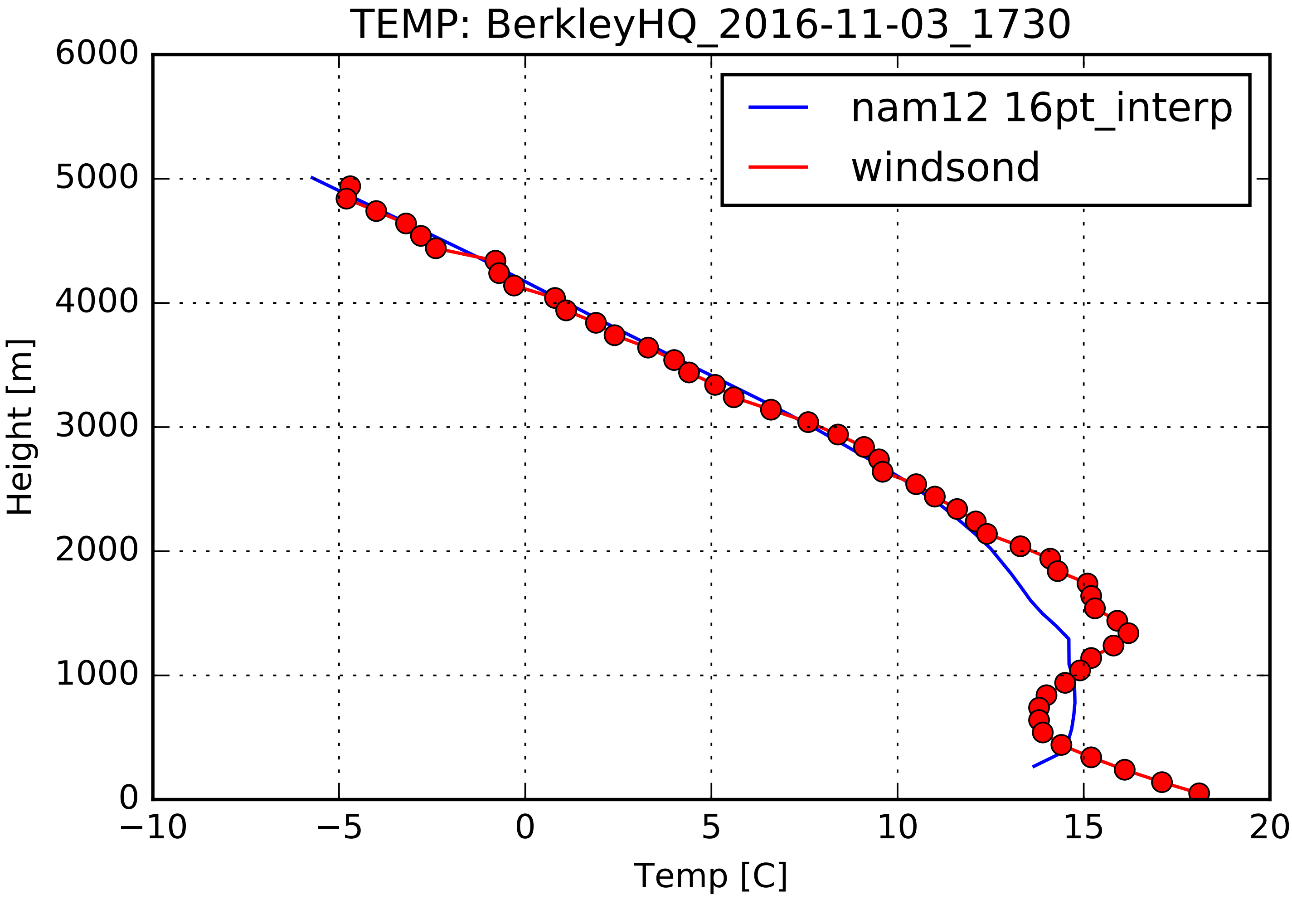

WIND-DIR: Pittsburg_Deanza_Park_2016-11-02_1838
nam12 16pt_interp
windsond
Height [m]
Wind direction [o]
0
1000
2000
3000
4000
5000
6000
7000
50
100
150
200
250
300

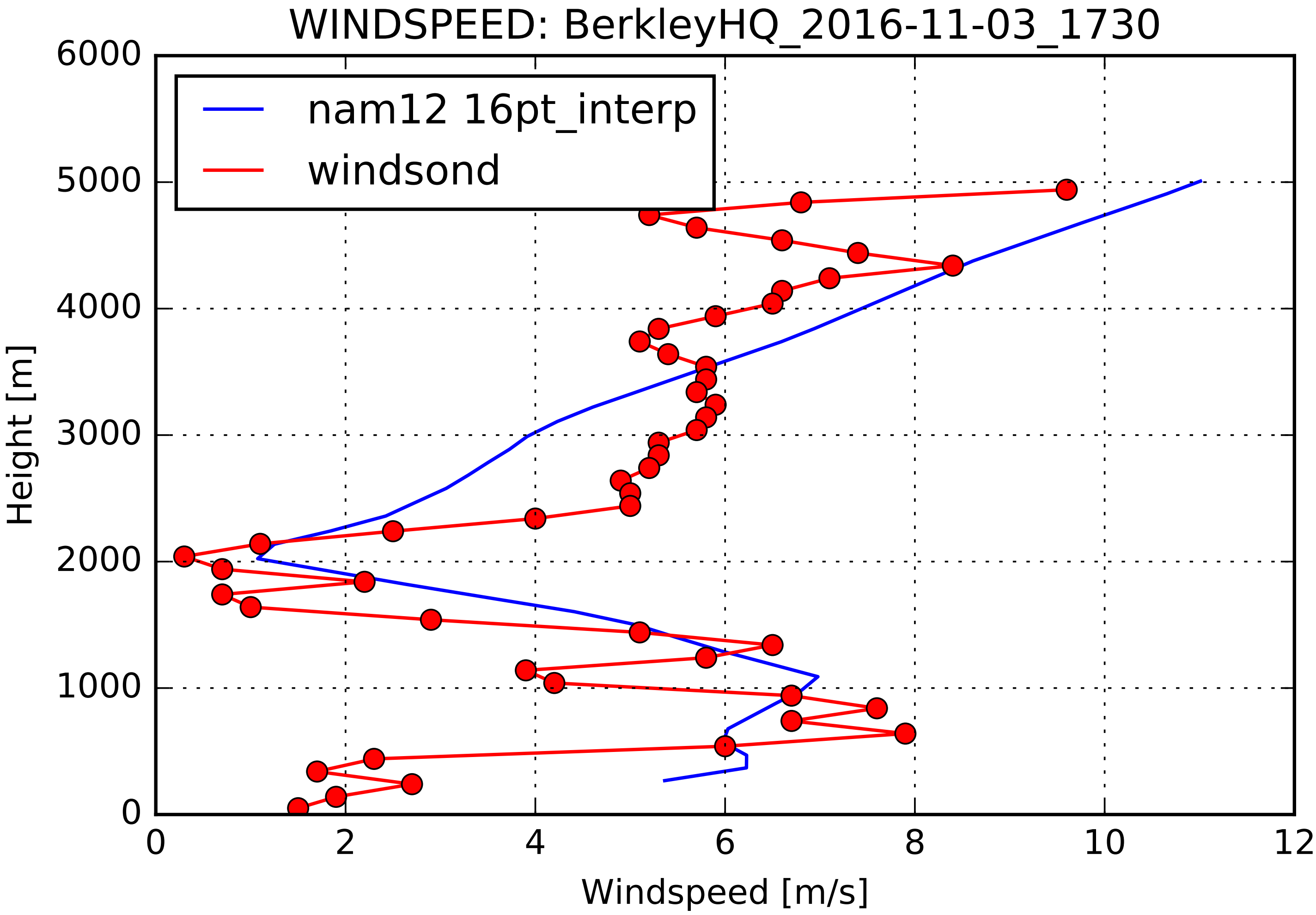

TEMP: Bethel_Island_2016-11-02_2230
nam12 16pt_interp
windsond
Height [m]
Temp [C]
5000
4000
3000
2000
1000
0
−5
0
5
10
15
20



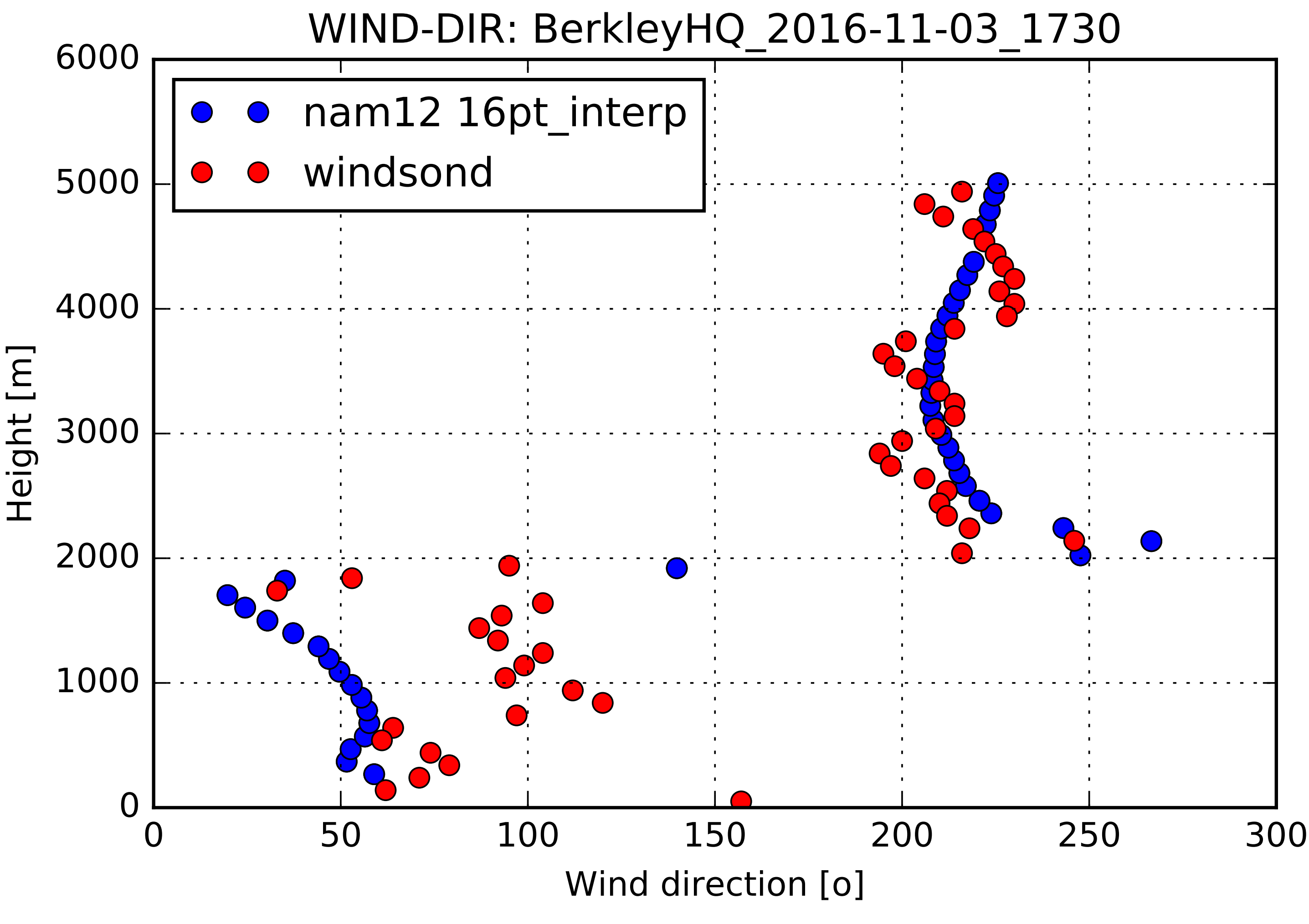
WINDSPEED: Bethel_Island_2016-11-02_2230
nam12 16pt_interp
windsond
Height [m]
Windspeed [m/s]
0
1000
2000
3000
4000
5000
0
1
2
3
4
5
6
7
8

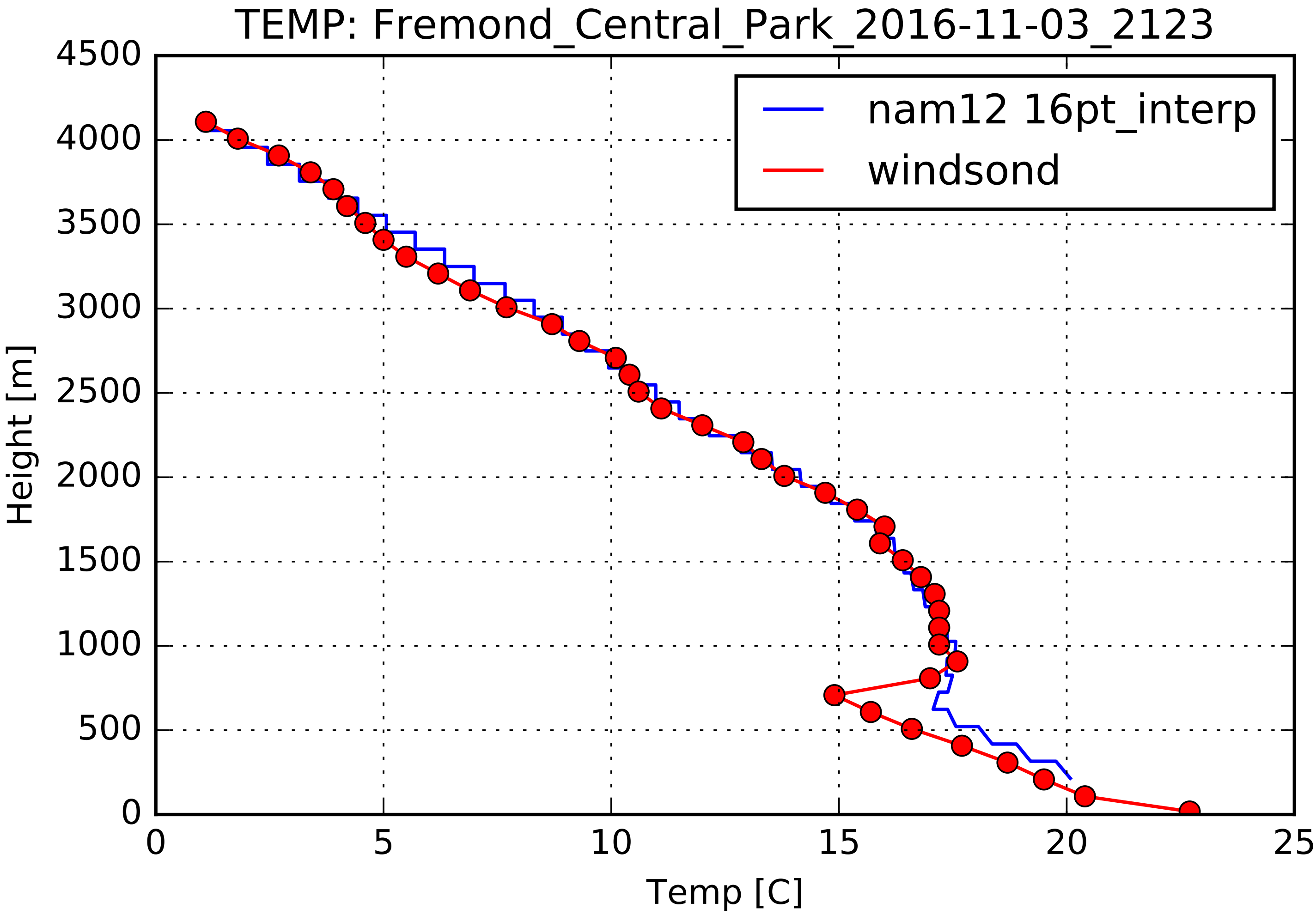

WIND-DIR: Bethel_Island_2016-11-02_2230
nam12 16pt_interp
windsond
Height [m]
Wind direction [o]
0
1000
2000
3000
4000
5000
0
50
100
150
200
250
300
350

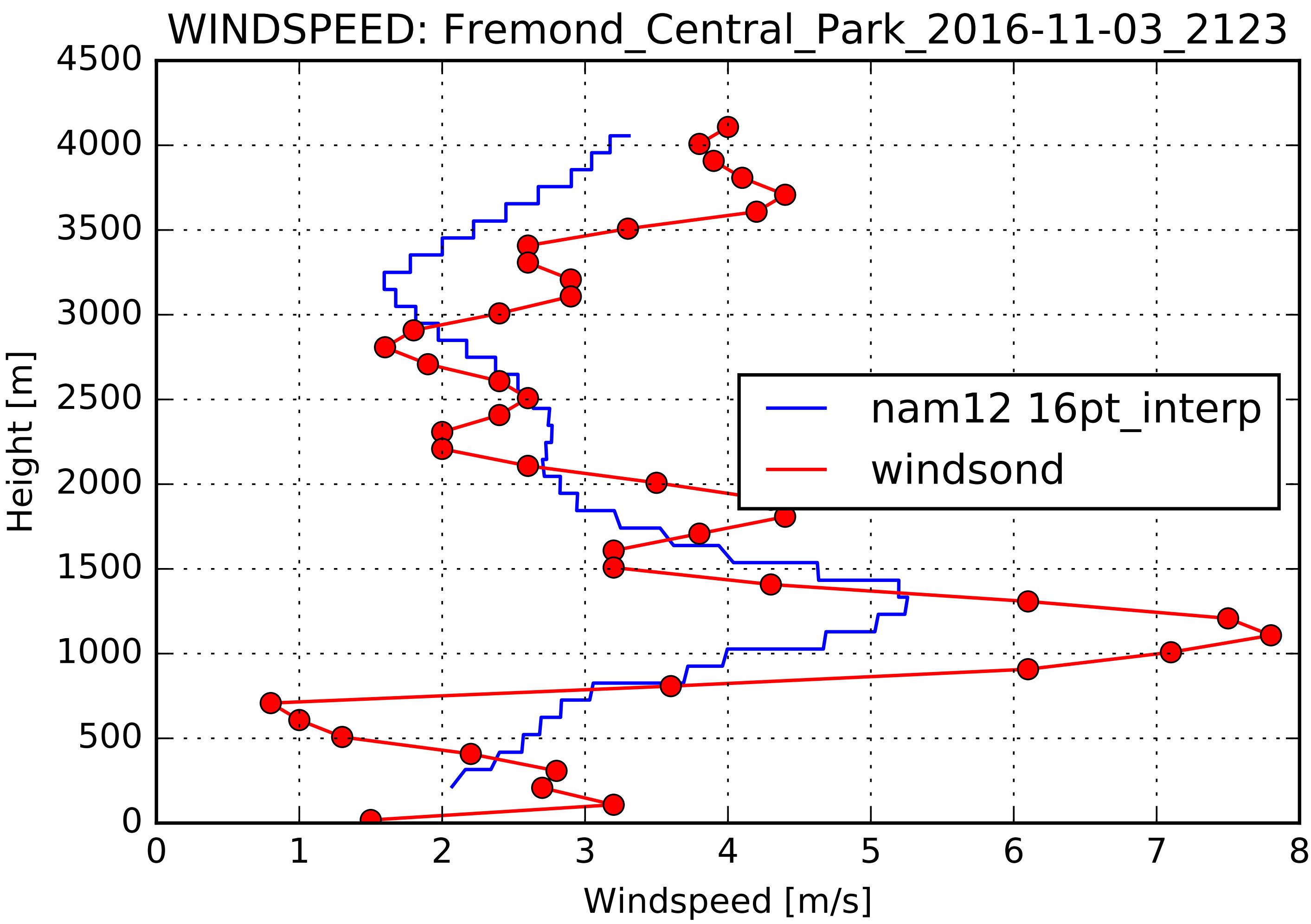

TEMP: BerkleyHQ_2016-11-03_1730
nam12 16pt_interp
windsond
Height [m]
Temp [C]
0
1000
2000
3000
4000
5000
6000
−10
−5
0
5
10
15
20

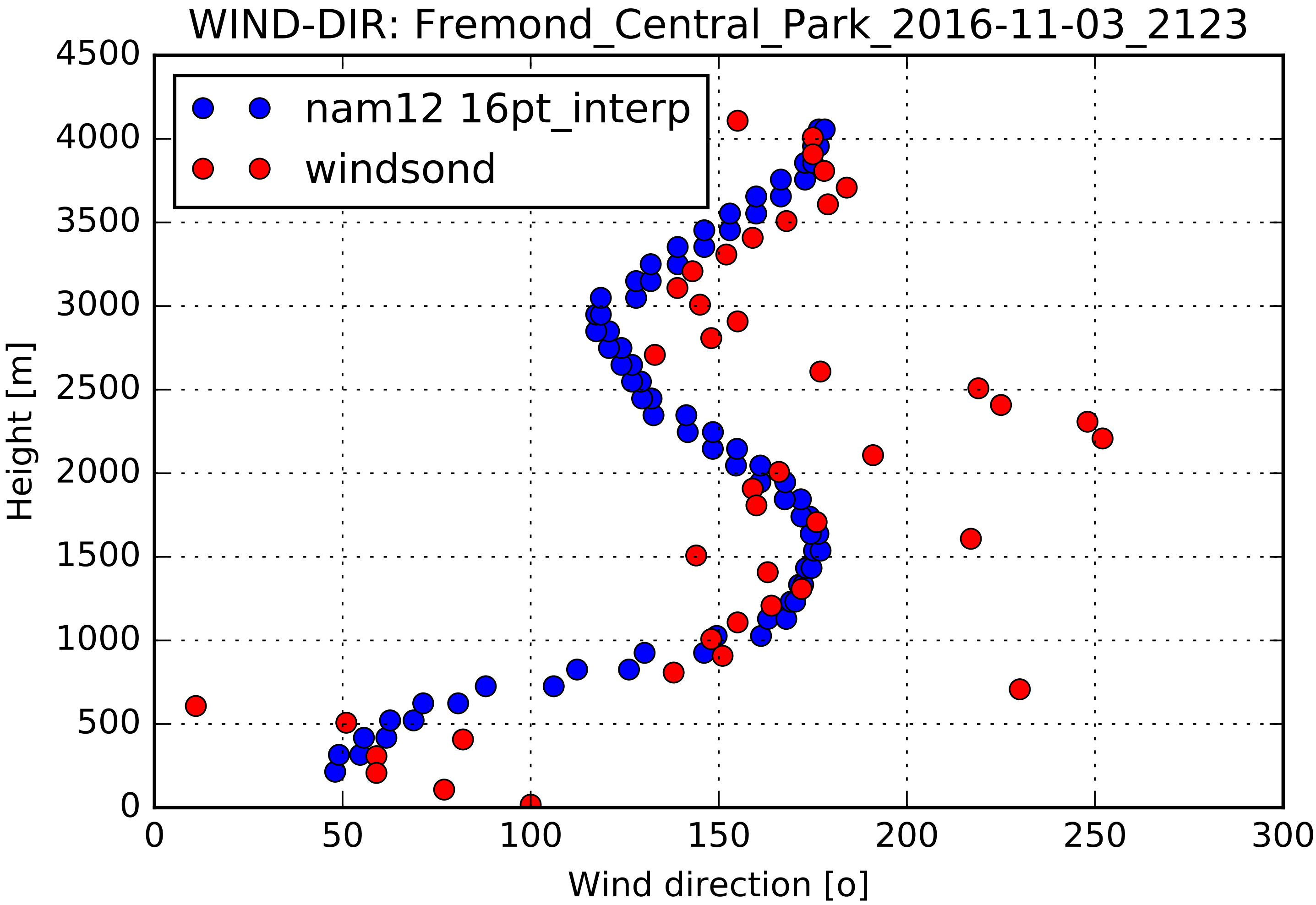


WINDSPEED: BerkleyHQ_2016-11-03_1730
nam12 16pt_interp
windsond
Height [m]
Windspeed [m/s]
0
1000
2000
3000
4000
5000
6000
0
2
4
6
8
10
12


WIND-DIR: BerkleyHQ_2016-11-03_1730
nam12 16pt_interp
windsond
Height [m]
Wind direction [o]
0
1000
2000
3000
4000
5000
6000
0
50
100
150
200
250
300


TEMP: Fremond_Central_Park_2016-11-03_2123
Height [m]
Temp [C]
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
5
10
15
20
25
nam12 16pt_interp
windsond


WINDSPEED: Fremond_Central_Park_2016-11-03_2123
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Height [m]
0
1
2
3
4
5
6
7
8
Windspeed [m/s]
nam12 16pt_interp
windsond


WIND-DIR: Fremond_Central_Park_2016-11-03_2123
nam12 16pt_interp
windsond
Height [m]
Wind direction [o]
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
50
100
150
200
250
300

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