

Grade Level:
6-12

Lesson Time:
45 minutes

Required Materials:

- Air temperature graph
- Relative humidity graph
- Wind speed graph
- Wind direction graph
- Computer access
- Internet access
- Student worksheet

Delaware Science Content Standards

Grades 6-8		Grades 9-12
1.1.A	5.2.H	1.1.A
1.1.C	5.2.I	1.1.D
1.2.A	5.2.J	1.2.A
2.1.E	5.3.A	8.3.B
5.1.B	8.3.A	8.3.C
5.2.F	8.3.C	

Related Topics

Density, heat capacity, land use, sustainable development, near-shore wind energy

written by Christopher Petrone,
Delaware Sea Grant, University of
Delaware College of Earth, Ocean, and
Environment

in cooperation with Dr. Dana Veron and
Christopher Hughes, University of
Delaware College of Earth, Ocean, and
Environment

Summary

Sea breezes can provide a welcome break from summertime temperatures and spark afternoon thunderstorms; however, their formation and strength are greatly affected by changes in land-use. Students will examine environmental observing system data and a radar loop to identify sea breeze fronts and discuss the implications of ongoing sea breeze research.

Activity Use

This activity can be used as part of a:

- Meteorology unit in earth science
- Human impact unit in ecology or environmental science
- Density unit

Objectives

After completing this activity, students will be able to:

- Describe the formation of sea breeze and land breeze and their effects
- Analyze line graphs of air temperature, humidity, wind speed, and wind direction
- Identify sea breeze fronts via line graph and radar loop
- Discuss the impacts of urbanization/land-use change on sea breeze

Vocabulary

Sea breeze, land breeze, land use, urbanization, differential heating, gradient, frontogenesis, front

Invitation

It's a toasty July day. You've just finished riding some great waves at one of Delaware's [award-winning beaches](http://www.nrdc.org/water/oceans/ttw/200beaches.asp) (<http://www.nrdc.org/water/oceans/ttw/200beaches.asp>) and you're now enjoying an early afternoon snack. All of a sudden you realize that the air temperature has dropped, the humidity seems to be increasing, and the wind is now not only stronger than it was, but now it's coming off the water. So you sit back and enjoy the cool breeze.

Later in the afternoon, just when you are ready to pack up your things and leave this epic beach day behind, you notice that the wind has shifted again, and though it is a little less humid, the temperature has climbed back up, leaving you wishing for another quick swim in the surf.

What in the world is happening? And how could you investigate what is happening?



Introduction

Sea Breeze

Water has a higher [heat capacity](http://www2.vims.edu/bridge/DATA.cfm?Bridge_Location=archive0909.html) (www2.vims.edu/bridge/DATA.cfm?Bridge_Location=archive0909.html) than land, meaning it takes more energy to raise the temperature of water than it does to raise the temperature of land. On hot summer days along the Delaware coast, the land heats up much faster than the waters of the Delaware Bay and Atlantic Ocean, which, for the most part, stay the same temperature throughout the day.

Because the air is in direct contact with these two surfaces, the land and the water, it also heats up at different rates. The air over water will heat and cool slower than the air over land. This is known as **differential heating** and results in a [pressure and density gradient](http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/fw/sea/crc.xml) (<http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/fw/sea/crc.xml>). This pressure gradient allows for **frontogenesis**, or the formation of a **front**. As the air over land heats, it rises into the atmosphere and is replaced at the surface by cooler air that moves in from over the cooler water. The leading edge of this moving air mass is known as a [sea breeze front](http://oceanservice.noaa.gov/education/yos/resource/JetStream/ocean/sb_circ.htm) (http://oceanservice.noaa.gov/education/yos/resource/JetStream/ocean/sb_circ.htm) and the cooler, moister air that we feel is known as, you guessed it, the sea breeze.

That rising warm air from the land spreads out in the atmosphere and eventually moves out over the water, where it cools and sinks back towards the surface completing the [circulation pattern](http://i.usatoday.net/weather/photos/breez2.jpg) (<http://i.usatoday.net/weather/photos/breez2.jpg>).

The sea breeze brings cooler air temperatures inland, which drop air temperatures anywhere from 5-20°F, and also raises the relative humidity because the air mass is moving in from over water. Sea breeze can last anywhere from an hour to several hours, and will add an easterly component to the wind direction, changing the direction to northeasterly, easterly, or southeasterly. (*Remember that winds are named by the direction from which they originate, so an easterly wind is moving from the east to the west.) In southern Delaware, sea breezes occur 63 percent of the time in the summer along the coast, and only 20% of the time inland. A stronger Delaware sea breeze can penetrate inland to about 30-40 miles.


Sea breeze is important to coastal communities because it relieves hot summertime temperatures, and under certain circumstances, can also provide crucial rain to Delaware's coastal farms during dry summer seasons. As the warm air over land rises, it can spark brief, strong thunderstorms capable of producing heavy rain. The daily afternoon thunderstorms experienced in [Florida](#) are an example of storms caused by sea breeze fronts.

On the other side of the sea breeze coin, coastal Delaware can also experience land breezes. These typically occur after sunset, when the land cools faster than the water and the warmer air over the water rises and is [replaced by cooler air from land](http://bentsci.edublogs.org/files/2009/11/sea-land-breeze.gif) (<http://bentsci.edublogs.org/files/2009/11/sea-land-breeze.gif>). In over-developed coastal areas, where the sea breeze helps to dissipate smog and other airborne contaminants, the land breeze can help move pollutants out to sea.

Land Use

Delaware's landscape has undergone many changes throughout its long history—it has transitioned from forests to farms, back to forests, and then in many cases, particularly in the northern and southeastern portions of the





state, from forests to residential and even urban areas. From 1992 to 1997 developed land (residential, commercial, transportation, etc.) in Sussex County, Del. increased by over 46 percent, while agricultural and forested land decreased by over 9 percent (Delaware Office of State Planning Coordination 1999).

Changes in [land use](http://www.eoearth.org/article/Land-use_and_land-cover_change) (http://www.eoearth.org/article/Land-use_and_land-cover_change) can have a profound effect on the soil, water, animals, and certainly the air.

With urbanization comes an increase in impervious surfaces such as roads, driveways, building roofs, and parking lots. These surfaces, which are often dark in color, trap heat and contribute to a [heat island effect](http://www.epa.gov/heatisld/) (<http://www.epa.gov/heatisld/>), in which the developed region becomes much warmer than the surrounding area.

There are many negative effects of heat islands, including increased energy consumption and air pollution, but near the coast, this increase in heat also has an effect on the sea breeze. Instead of moving through an area, the sea breeze front can be slowed or even held in place by the heat island effect. This can cause pollutants to become more concentrated in the urban area and prevent the formation of afternoon thunderstorms.

Current Sea Breeze Research

Tourism is a major component of southern Delaware's economy. As mentioned above, the number of seasonal and permanent residents is growing at an escalating rate in eastern Sussex County. This rapid growth, and the increased infrastructure needed to support it, is drastically changing local land use, which will have an impact on the coastal system, including the very important sea breeze.

[Dr. Dana Veron](http://www.ceoe.udel.edu/people/profile.aspx?dveron) (<http://www.ceoe.udel.edu/people/profile.aspx?dveron>) of the University of Delaware College of Earth, Ocean, and Environment, and her graduate student Christopher Hughes, are working to better understand sea and bay breezes in Delaware. They are also working to identify the physical changes to the landscape that most affect sea breeze, predict how land use will change over the next 30 years, and use models to predict how the changing land use and population growth will impact the sea and bay breezes and Delaware's climate.

The results of their work will help inform local decision makers about some of the impacts of continued development in the fragile coastal zone. The project is three years in length and funded by [Delaware Sea Grant](http://www.deseagrant.org/seagrant/research/development/ETE-16) (<http://www.deseagrant.org/seagrant/research/development/ETE-16>).

Data Analysis: Identifying a Sea Breeze Front

Data for this activity came from the Delaware Environmental Observing System (DEOS). DEOS provides real-time and archived data from 48 stations located throughout Delaware and southeastern Pennsylvania, available 24 hours a day at www.deos.udel.edu.

Applying the information you have learned above, you will now explore real data recorded by two DEOS stations, one coastal and one further inland, from August 21, 2009. The coastal station, DBBB, is found on the Bethany Beach Boardwalk, roughly 200 feet from the Atlantic Ocean. The inland station, DLAU, is located at the airport in Laurel, Del., and is approximately 29 miles from the coast.



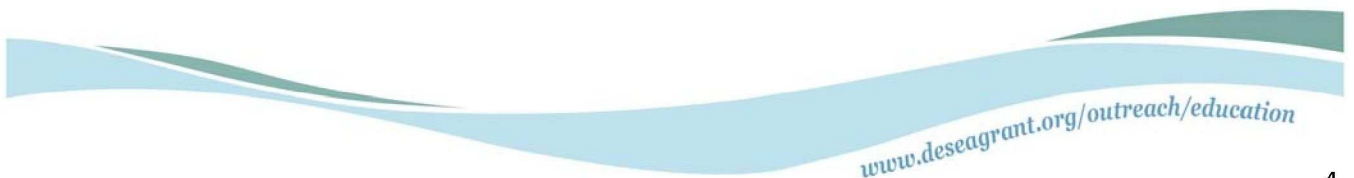
You will use several forms of archived data to identify sea breeze fronts. Then, you will explore real time data to determine if a sea breeze front has occurred within the last 24 hours.

Note: If students need additional work creating their own graphs, either by hand or using graphing software, please see Table 1 for all of the data.

- A. Knowing the effects of a sea breeze front on air temperature, relative humidity, wind speed, and wind direction, fill in the missing portions (10AM-3PM) of Figures 1 through 4—line graphs of these parameters. The coastal station, DBBB, is in blue, and the inland station, DLAU, is in green.

*Note: Part A can also be used as an Invitation/Engagement activity prior to receiving any introductory material.

- B. Using Figures 5 and 6, answer the following questions.
1. What differences do you notice between the two profiles?
 2. When did the sea breeze front begin?
 3. How long did the front have an effect?
 4. How much did air temperature change during this time?
 - a. At DBBB
 - b. At DLAU
 5. How much did the relative humidity change?
 - a. At DBBB
 - b. At DLAU
- C. A sea breeze front is also characterized by an increase in wind speed and a shift in wind direction to include an easterly component. Using Figures 7 and 8—line graphs of wind speed and direction—answer the following questions.
6. Based on your observation in Part A, locate the wind speed and wind direction data during the period of sea breeze:
 - i. By approximately how much did the wind speed increase at DBBB?
 - ii. From what direction did the wind shift?
 - iii. To what direction did the wind shift?
 - iv. How long did the increased wind speed and direction shift last?
 7. Were there any other drastic shifts in wind direction during the 24 hour period?
 8. Based on the data from Figures 1-4, did the DLAU station experience the sea breeze? Provide evidence for your answer.
- D. We are very familiar with radar maps shown by our local weather personalities. In precipitation mode, the radar produces visualizations which show precipitation that has been recorded through the use of electromagnetic waves being broadcast and returned via antennas. In clear-air mode, the radar is able to detect much smaller objects like dust and particulate matter.





View the clear-air mode radar loop from September 4, 2008 from Dover Air Force Base. The sea breeze front is shown as a line of red/purple moving east to west extending from the top of the state to the bottom.

9. Does the front cross the entire state of Delaware?
 10. Using the time stamps in the upper right corner, determine how long it takes for the front to move from the coast to the furthest point inland. (*Note: The time stamp is in GMT, or Greenwich Mean Time, which is 5 hours ahead of Eastern Standard Time and 4 hours ahead of Eastern Daylight Time. So 16:00 GMT = 4:00PM GMT = 12:00PM EDT = 11:00AM EST)
- E. You will now evaluate real-time data from several DEOS stations to determine if a sea breeze front has occurred in the last 24 hours.

Visit www.deos.udel.edu and click on the DOES GeoBrowser. A second window will open. Mouse over the southern-most coastal station, which should be the Bethany Beach Boardwalk station, DBBB, and click on it. A dialogue balloon will open with the most recent observations. Record the following:

11. The date and time of the current observations
12. Current air temperature
13. Current relative humidity
14. Current wind speed
15. Current wind direction

Now click on the View Last 24 Hours link. Another new window will open.

16. By looking at the plots of air temperature and relative humidity, is there evidence of a sea breeze front taking place in the last 24 hours?

Now view the 24 hour record of two other DEOS stations.

17. Is there evidence of a sea breeze front in other areas? Describe the evidence for or against the presence of a sea breeze front.

Discussion Questions

1. How might the following affect the formation and characteristics of a sea breeze front?
 - a. A cloudy day
 - b. A brief, but strong thunderstorm moving west to east over the area
 - c. A northeaster
 - d. An intense heat wave, with temperatures exceeding 100°F, for a week straight
 - e. Increased development of the coastal area, including wider road, more impervious surface, and large skyscraper hotels.
2. The radar loop definitively shows the movement of the sea breeze front. If you were a meteorologist on the news, what would be the advantages and disadvantages of showing a modeled or predicted loop as opposed to an actual radar loop?





3. In the radar loop, we can see what appears to be a slow moving sea breeze moving northeast from Delaware Bay into New Jersey. Why do you think there is not a sea breeze front moving west to east from Chesapeake Bay onto Maryland's Eastern Shore?
 - a. If there was a Chesapeake Bay sea breeze front, what would be the result of the two fronts converging?
4. Discuss the advantages and disadvantages of environmental observing system data.
5. If you were city manager, how could you use the data and models presented in this activity to guide future development in your city?
6. Describe other methods of determining the impact of urbanization on sea breeze fronts.

Assessment

Performance: Did student actively participate in the discussion portions of the activity? Was student engaged during activity?

Product: Did student answer the data analysis questions coherently and provide evidence for their answer?

Extensions

- Discuss the role of the Coriolis effect on the direction the sea breeze blows.
- View archived and real-time data from other DEOS and NOAA [National Data Buoy Center](http://www.ndbc.noaa.gov) (<http://www.ndbc.noaa.gov>) stations and determine the frequency, strength, and duration of sea breeze fronts from other sites in Delaware, the East Coast, the Gulf of Mexico, West Coast, and the Great Lakes
- Use Google Earth to explore the areas where DEOS sensors are found. Identify the land use (agricultural, residential, highway, etc.) and formulate a hypothesis about how the land use might affect the data measurements.
- If your school or home is located near the coast (less than 50 miles) measure air temperature, wind speed and direction, and humidity, to explore if you experience sea breezes. You can make several of the instruments needed to measure these parameters from items around the house.

Additional Resources

- Coastal Carolina University data activity *Coastal Weather and Sea Breezes* - <http://kingfish.coastal.edu/marine/risingtide/breeze/classroom.html>
- University of California data activity - http://earthguide.ucsd.edu/weather/teachers/teachers_wind.html
- Rutgers University sea breeze tutorial - <http://marine.rutgers.edu/cool/seabreeze/tutorial.html>
- NOAA National Ocean Service sea breeze tutorial - http://oceanservice.noaa.gov/education/pd/oceans_weather_climate/media/sea_and_land_breeze.swf
- Bridge DATA: Can't Take the Heat - http://www2.vims.edu/bridge/DATA.cfm?Bridge_Location=archive0909.html





References

- Delaware Office of State Planning Coordination. (1999). Gross Land Use Changes in Delaware 1992 to 1997. <http://www.stateplanning.delaware.gov/info/lulcdata/grsschng.pdf> . Accessed 5 October 2011.
- Hughes, Christopher. (2011). The Climatology of the Delaware Bay/Sea Breeze (Master's thesis, University of Delaware, 2011).
- Veron, Dana. (2009). Local Urban Growth and Climate Change Impacts on the Delaware Bay Sea Breeze. Delaware Sea Grant Research Proposal.





National Science Standards

Science as Inquiry

- Abilities necessary to do scientific inquiry (5-8, 9-12)
- Understanding about scientific inquiry (5-8, 9-12)

Earth and Space Science

- Structure of the earth system (5-8)
- Energy in the earth system (9-12)

Science & Technology

- Understandings about science and technology (5-8, 9-12)

Science in Personal and Social Perspectives

- Populations, resources, and environments (5-8)
- Natural and human-induced hazards (5-8, 9-12)
- Science, technology in society (5-8)
- Nature of science (5-8)

Ocean Literacy Principles

#3. The ocean is a major influence on weather and climate.

- a. The ocean controls weather and climate by dominating the Earth's energy, water and carbon systems.

#6. The oceans and human are inextricably interconnected.

- a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and over half of Earth's oxygen. It moderates the Earth's climate, influences our weather, and affects human health.
- d. Much of the world's population lives in coastal areas.
- e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

#7. The ocean is largely unexplored.

- b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.
- d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.
- e. Use of mathematical models is now an essential part of ocean sciences. Models help us understand the complexity of the ocean and of its interaction with Earth's climate. They process observations and help describe the interactions among systems.
- f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

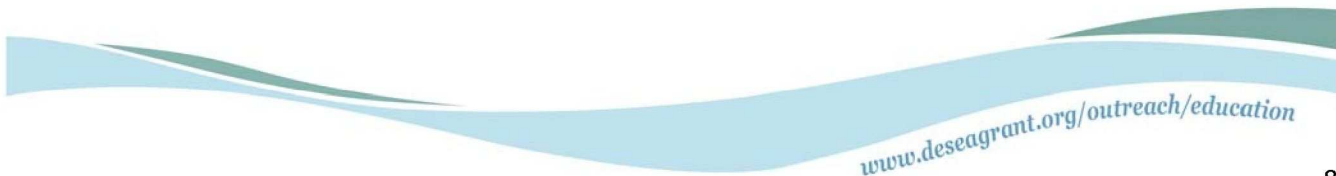


Figure 1. Air temperature data from DEOS stations DBBB and DLAU on 21 August 2009.

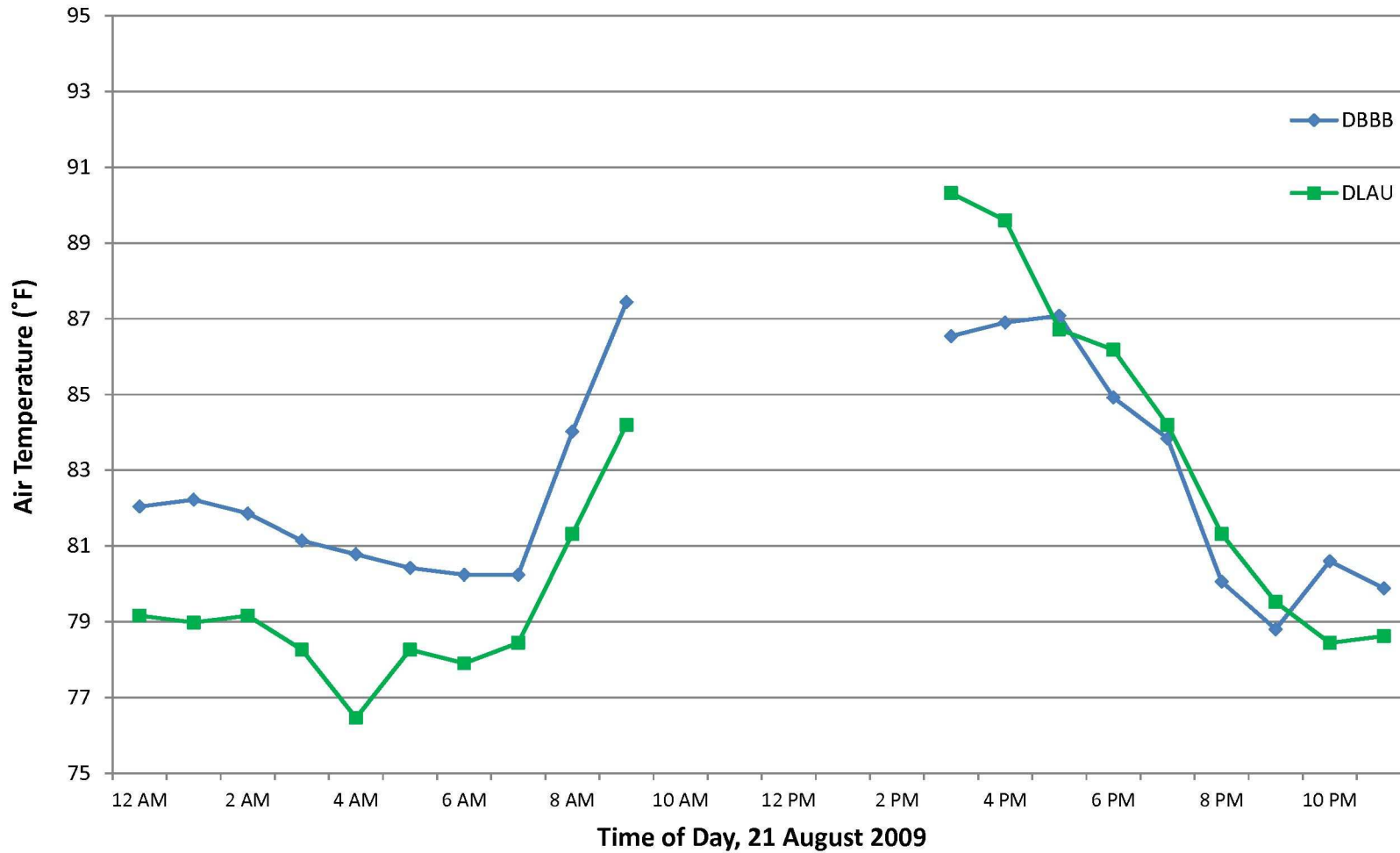


Figure 2. Relative humidity data from DEOS stations DBBB and DLAU on 21 August 2009.

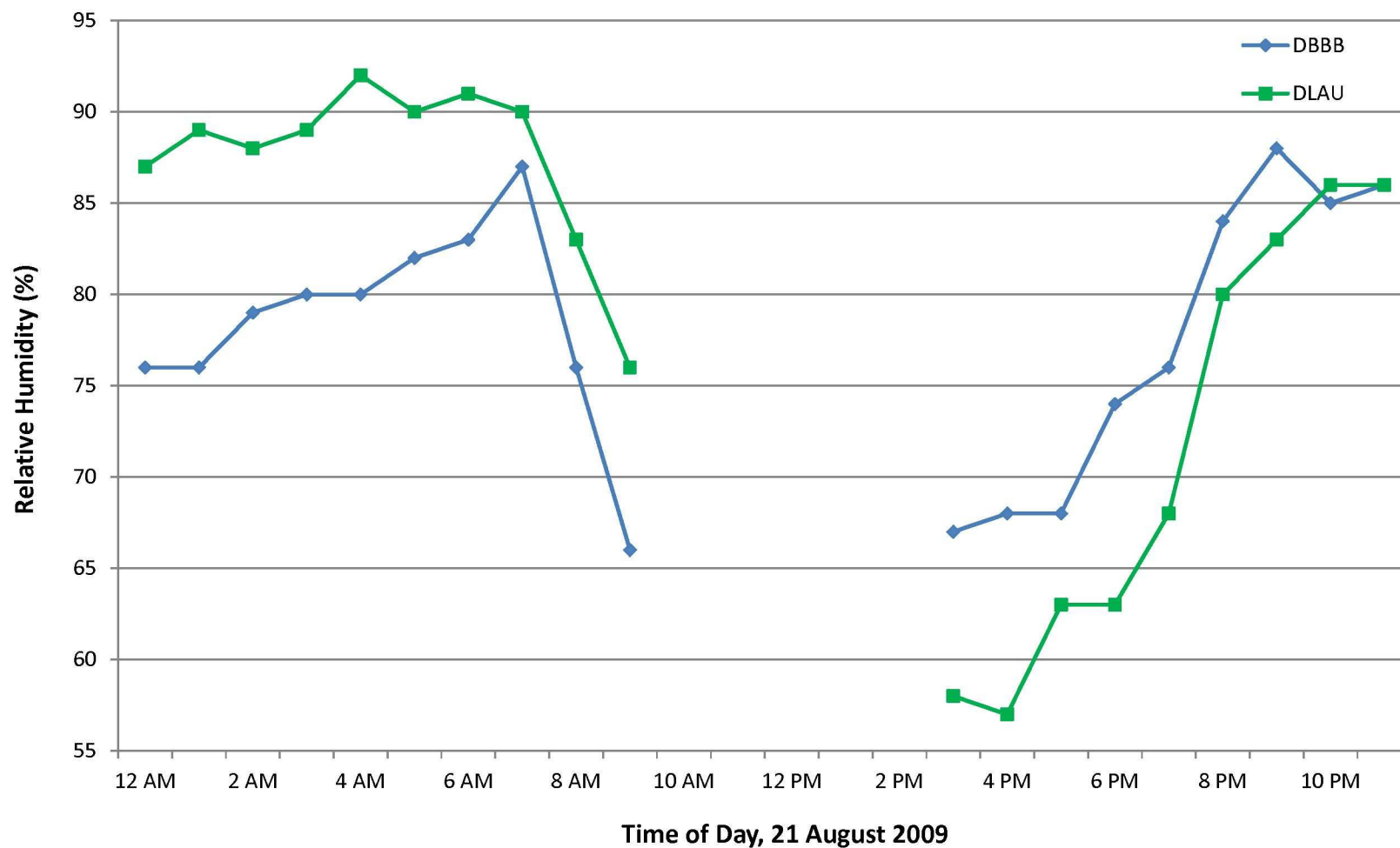


Figure 3. Wind speed data from DEOS stations DBBB and DLAU on 21 August 2009.

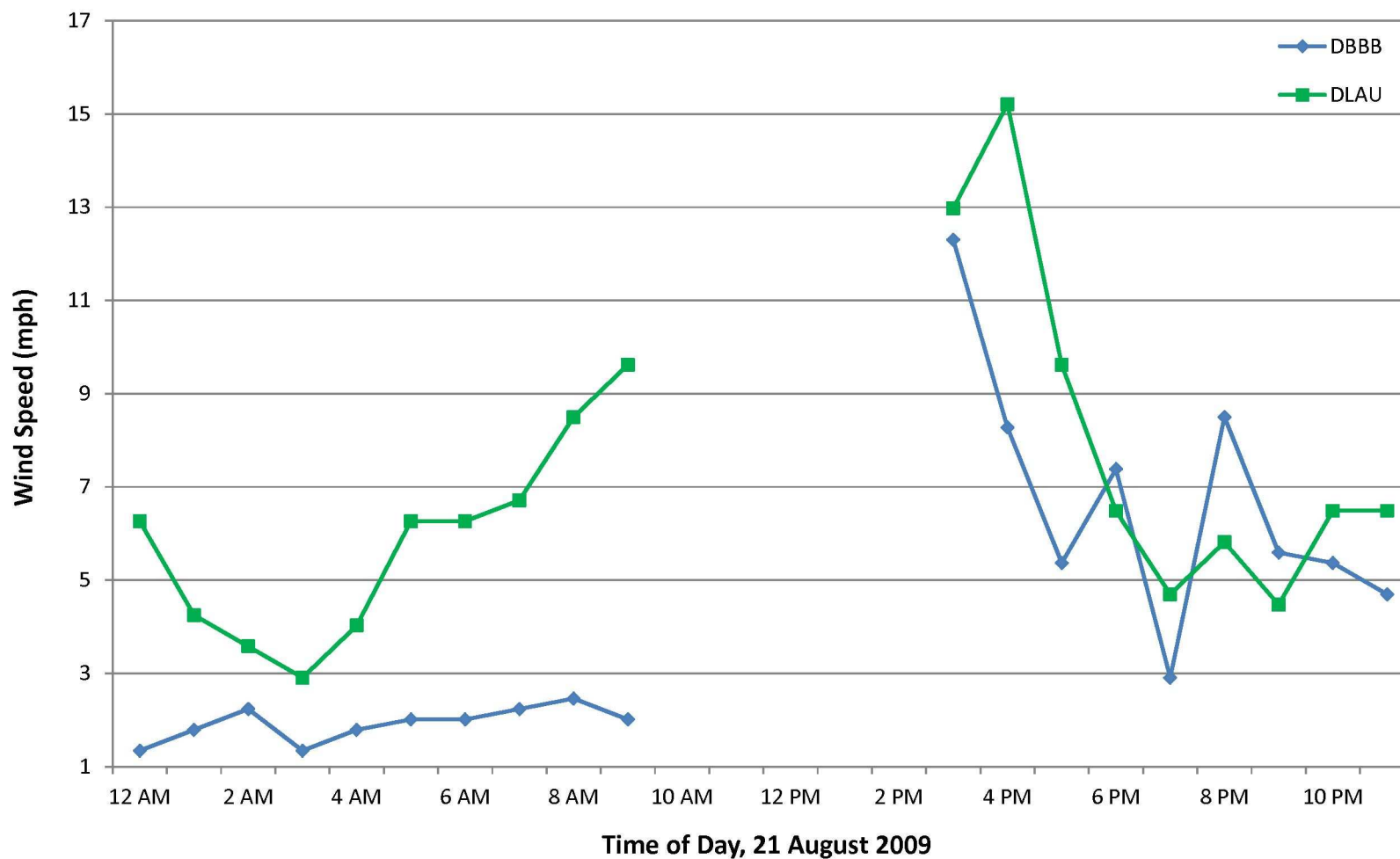


Figure 4. Wind direction data from DEOS stations DBBB and DLAU on 21 August 2009.

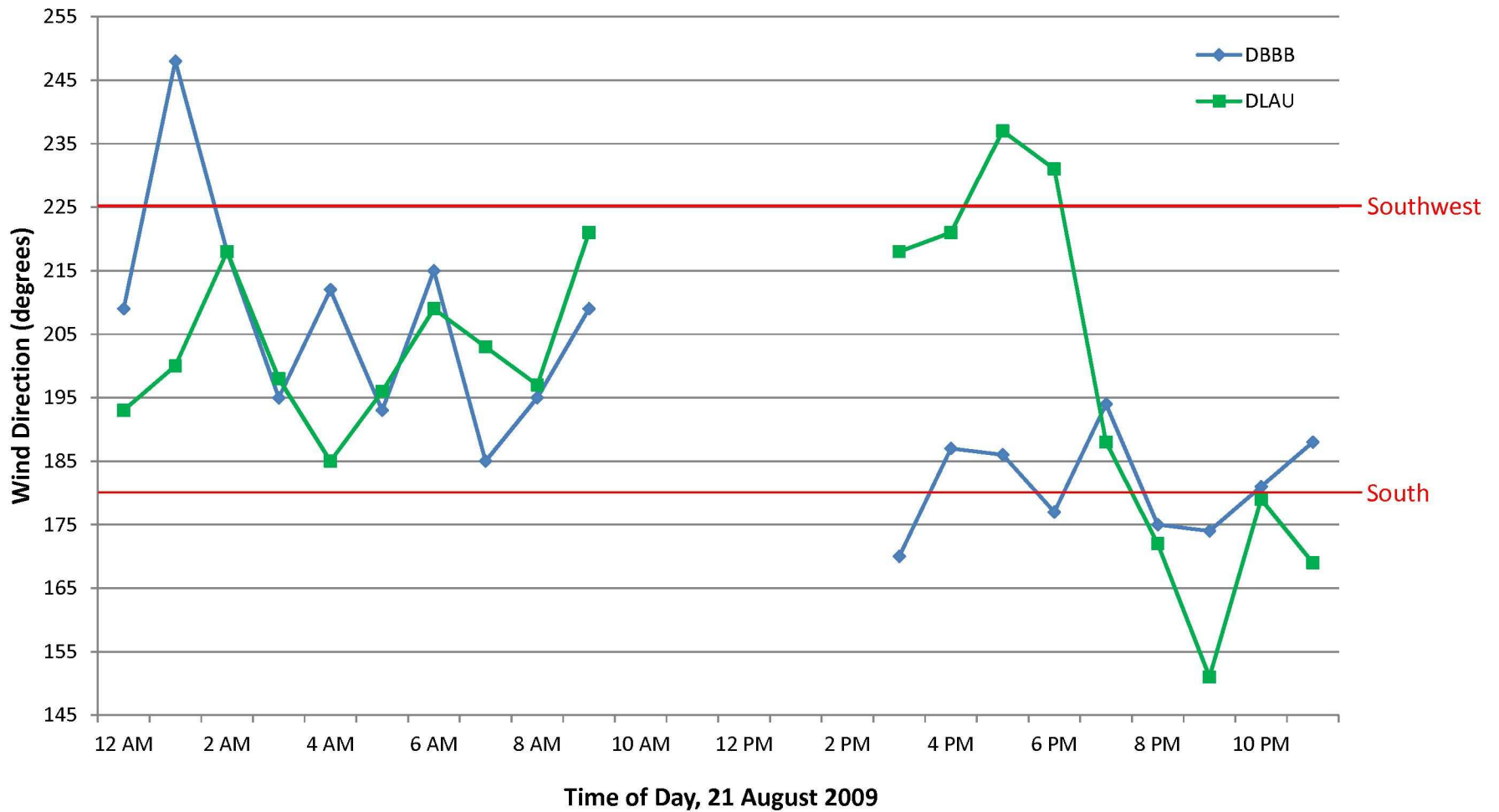


Figure 5. Air temperature data from DEOS stations DBBB and DLAU on 21 August 2009.

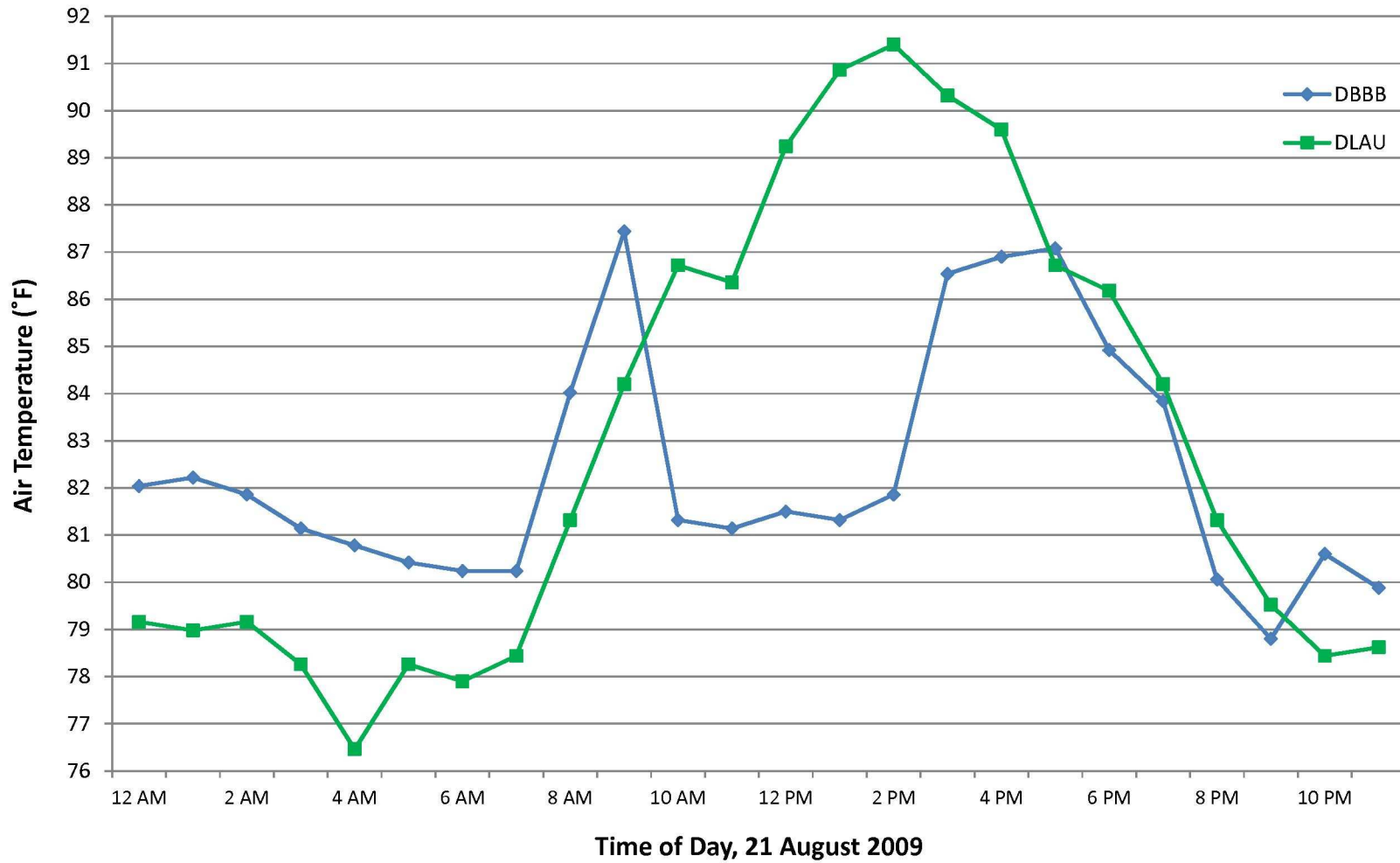


Figure 6. Relative humidity data from DEOS stations DBBB and DLAU on 21 August 2009.

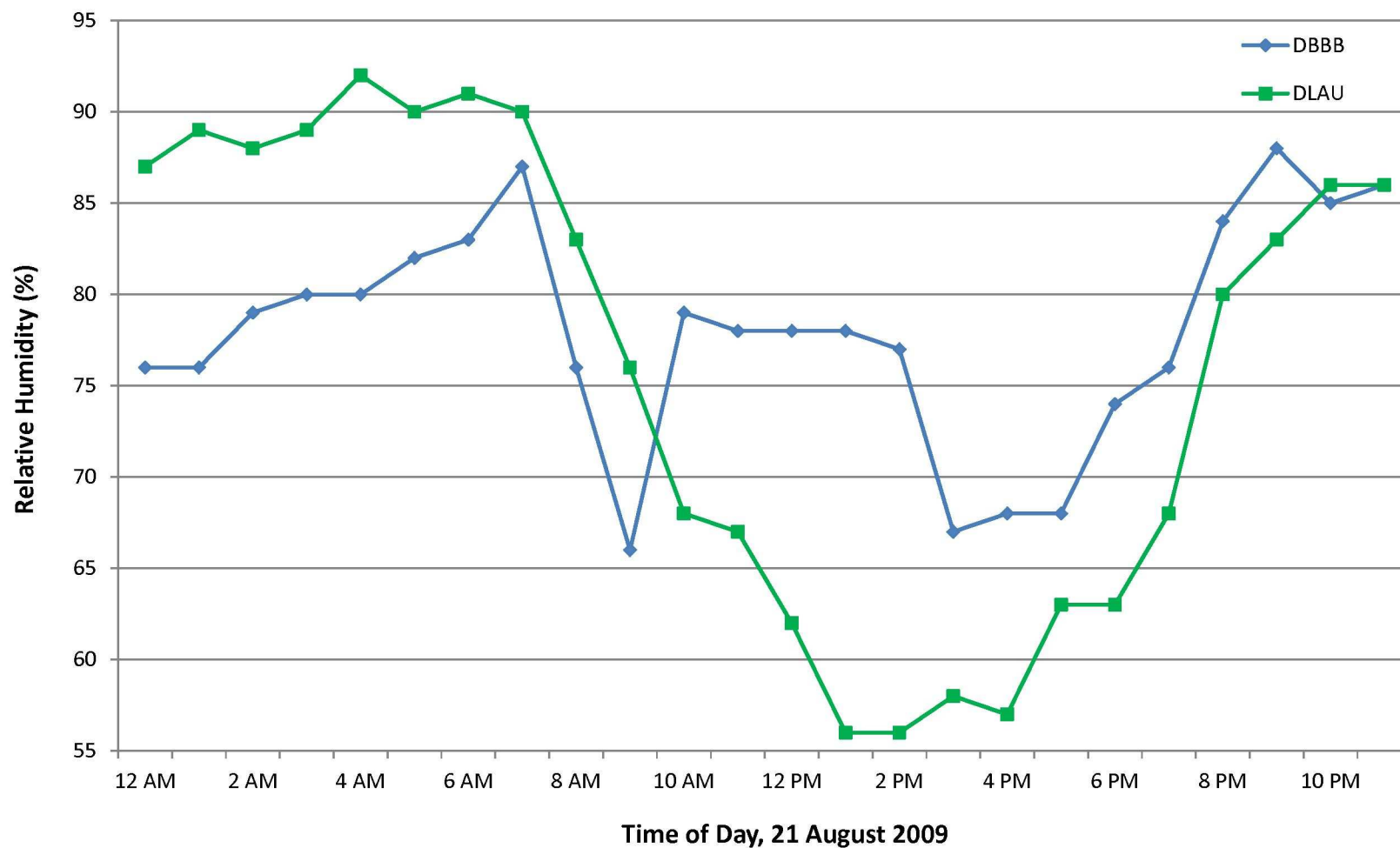


Figure 7. Wind speed data from DEOS stations DBBB and DLAU on 21 August 2009.

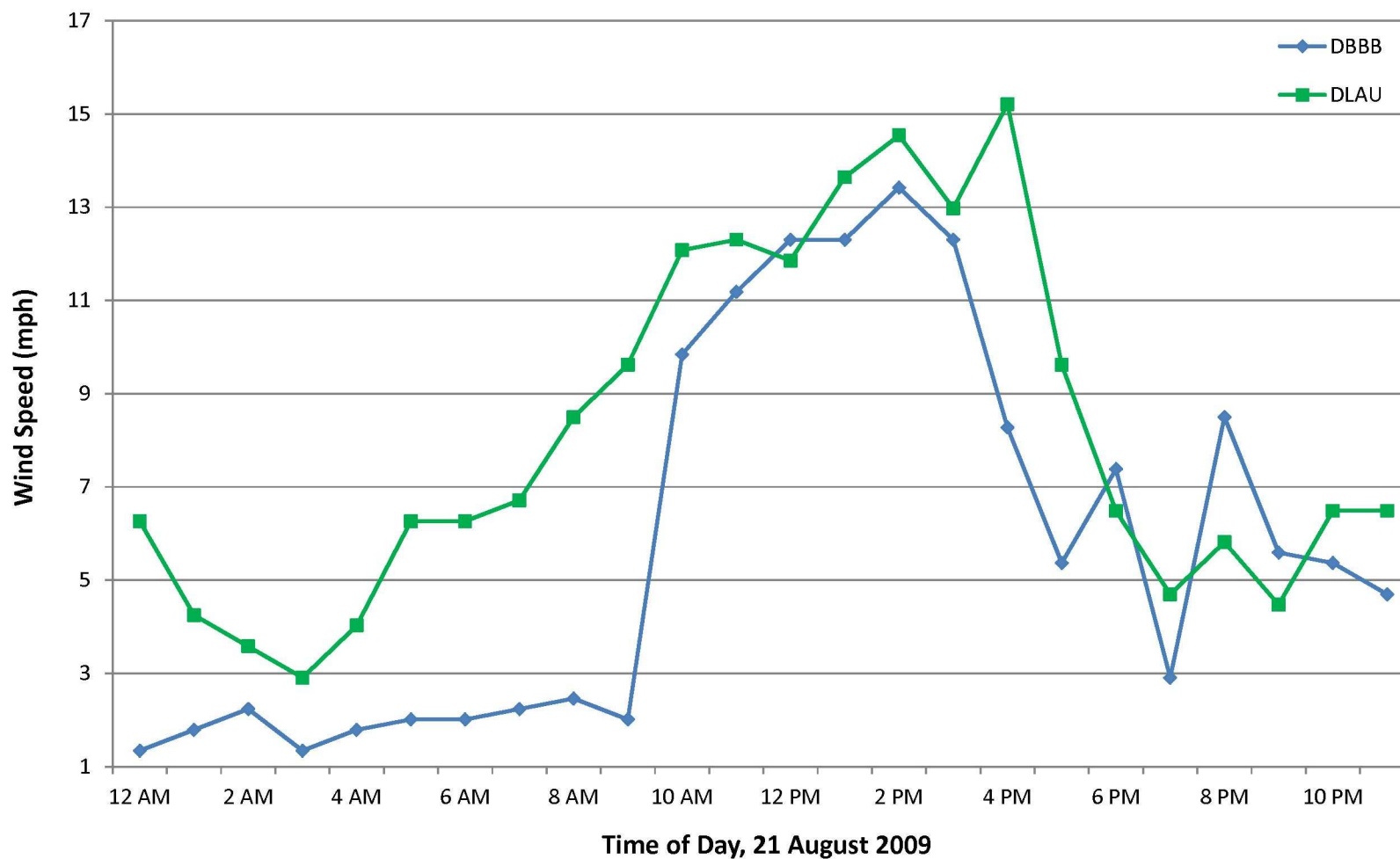
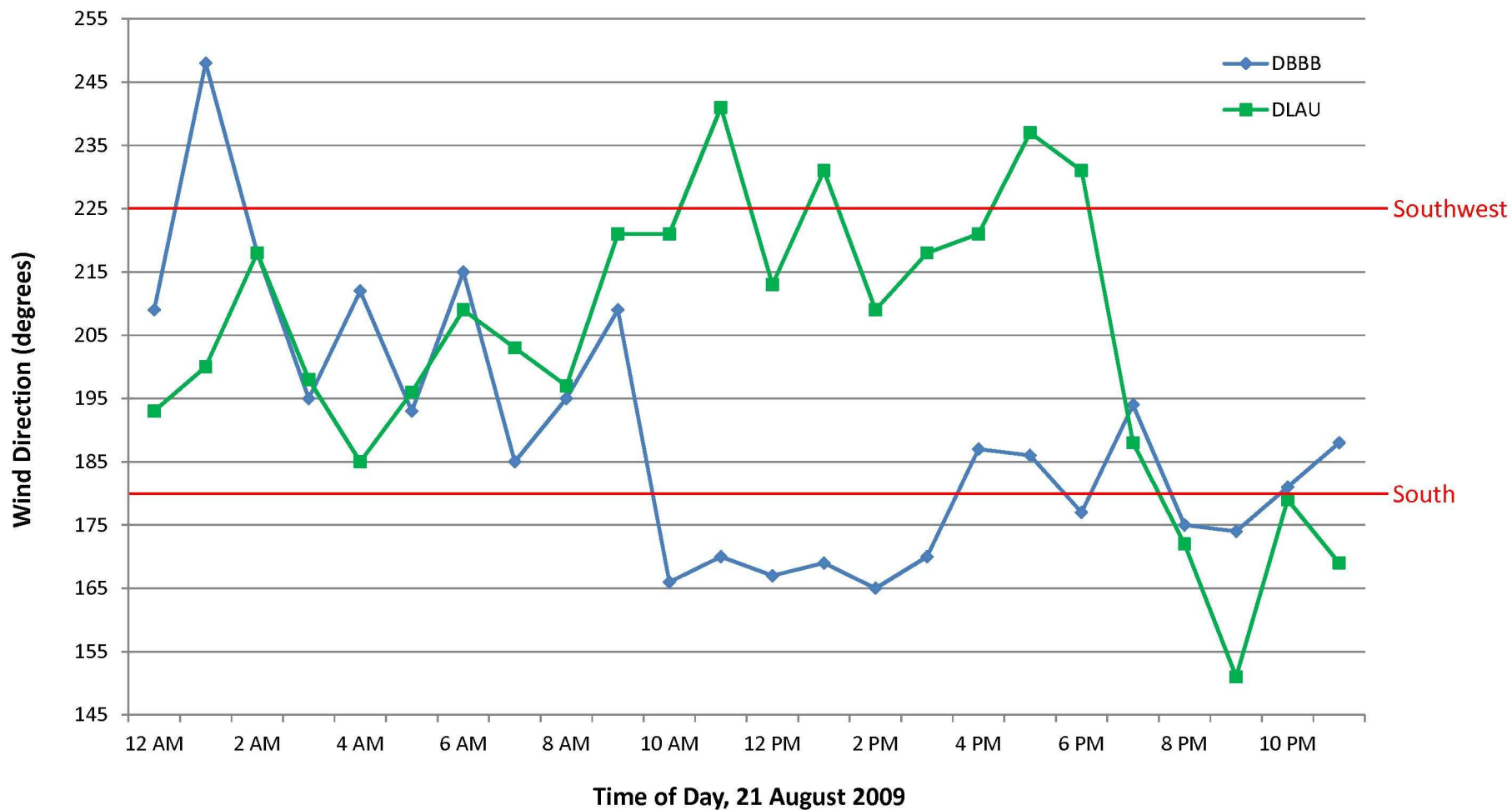


Figure 8. Wind direction data from DEOS stations DBBB and DLAU on 21 August 2009.





Sea Breeze



Table 1. Meteorological data from two Delaware Environmental Observing System (DEOS) stations from 8 August, 2009.

Year	Month	Day	Hour (EDT)	Station: DBBB				Station: DLAU			
				Air Temperature	Relative Humidity	Wind Speed	Wind Direction	Air Temperature	Relative Humidity	Wind Speed	Wind Direction
				(°F)	(%)	(mph)	(degrees)	(°F)	(%)	(mph)	(degrees)
2009	8	21	12:00 AM	82.04	76	1.3	209	79.16	87	6.3	193
2009	8	21	1:00 AM	82.22	76	1.8	248	78.98	89	4.3	200
2009	8	21	2:00 AM	81.86	79	2.2	218	79.16	88	3.6	218
2009	8	21	3:00 AM	81.14	80	1.3	195	78.26	89	2.9	198
2009	8	21	4:00 AM	80.78	80	1.8	212	76.46	92	4.0	185
2009	8	21	5:00 AM	80.42	82	2.0	193	78.26	90	6.3	196
2009	8	21	6:00 AM	80.24	83	2.0	215	77.9	91	6.3	209
2009	8	21	7:00 AM	80.24	87	2.2	185	78.44	90	6.7	203
2009	8	21	8:00 AM	84.02	76	2.5	195	81.32	83	8.5	197
2009	8	21	9:00 AM	87.44	66	2.0	209	84.2	76	9.6	221
2009	8	21	10:00 AM	81.32	79	9.8	166	86.72	68	12.1	221
2009	8	21	11:00 AM	81.14	78	11.2	170	86.36	67	12.3	241
2009	8	21	12:00 PM	81.5	78	12.3	167	89.24	62	11.9	213
2009	8	21	1:00 PM	81.32	78	12.3	169	90.86	56	13.6	231
2009	8	21	2:00 PM	81.86	77	13.4	165	91.4	56	14.5	209
2009	8	21	3:00 PM	86.54	67	12.3	170	90.32	58	13.0	218
2009	8	21	4:00 PM	86.9	68	8.3	187	89.6	57	15.2	221
2009	8	21	5:00 PM	87.08	68	5.4	186	86.72	63	9.6	237
2009	8	21	6:00 PM	84.92	74	7.4	177	86.18	63	6.5	231
2009	8	21	7:00 PM	83.84	76	2.9	194	84.2	68	4.7	188
2009	8	21	8:00 PM	80.06	84	8.5	175	81.32	80	5.8	172
2009	8	21	9:00 PM	78.8	88	5.6	174	79.52	83	4.5	151
2009	8	21	10:00 PM	80.6	85	5.4	181	78.44	86	6.5	179
2009	8	21	11:00 PM	79.88	86	4.7	188	78.62	86	6.5	169

Data Analysis: *Identifying a Sea Breeze Front*

- A. Complete this portion on the provided Figures 1-4.
- B. Using Figures 5 and 6:
1. What differences do you notice between the two profiles?
 2. When did the sea breeze front begin?
 3. How long did the front have an effect?
 4. How much did air temperature change during this time?
 - a. At DBBB: _____
 - b. At DLAU: _____
 5. How much did the relative humidity change?
 - a. At DBBB: _____
 - b. At DLAU: _____
- C. Using Figures 7 and 8:
6.
 - i. By approximately how much did the wind speed increase at DBBB? _____
 - ii. From what direction did the wind shift? _____
 - iii. To what direction did the wind shift? _____
 - iv. How long did the increased wind speed and direction shift last? _____
 7. Were there any other drastic shifts in wind direction during the 24 hour period?
 8. Based on the data from Figures 1-4, did the DLAU station experience the sea breeze? Provide evidence for your answer.
- D. Using the radar loop:
9. Does the front cross the entire state of Delaware? _____
 10. Using the time stamps in the upper right corner, determine how long it takes for the front to move from the coast to the furthest point inland. _____
- E. Using real-time data from DEOS (www.deos.udel.edu):
11. The date and time of the current observations: _____
 12. Current air temperature: _____
 13. Current relative humidity: _____
 14. Current wind speed: _____
 15. Current wind direction: _____

16. By looking at the plots of air temperature and relative humidity, is there evidence of a sea breeze front taking place in the last 24 hours?
17. Is there evidence of a sea breeze front in other areas? Describe the evidence for or against the presence of a sea breeze front.

Discussion Questions

1. How might the following affect the formation and characteristics of a sea breeze front?
 - a. A cloudy day
 - b. A brief, but strong thunderstorm moving west to east over the area
 - c. A northeaster
 - d. An intense heat wave, with temperatures exceeding 100°F, for a week straight
 - e. Increased development of the coastal area, including wider road, more impervious surface, and large skyscraper hotels.
2. The radar loop definitively shows the movement of the sea breeze front. If you were a meteorologist on the news, what would be the advantages and disadvantages of showing a modeled or predicted loop as opposed to an actual radar loop?
3. In the radar loop, we can see what appears to be a slow moving sea breeze moving northeast from Delaware Bay into New Jersey. Why do you think there is not a sea breeze front moving west to east from Chesapeake Bay onto Maryland's Eastern Shore?

- a. If there was a Chesapeake Bay sea breeze front, what would be the result of the two fronts converging?
4. Discuss the advantages and disadvantages of environmental observing system data.
5. If you were city manager, how could you use the data and models presented in this activity to guide future development in your city?
6. Describe other methods of determining the impact of urbanization on sea breeze fronts.