

The influence of sea breeze on mold spore dispersion

Leonard Bielory, M.D.,¹ Louis Bowers, Ph.D.,³ Rivka Marcus,² and Rich Dunk, Ph.D.^{3,4}

ABSTRACT

Background: Many allergists consider the ocean breeze to be free of allergens and recommend visits to the coast for relief; however, the coast may perpetuate an allergenic environment.

Objective: This study investigated the sea breeze's impact on spore dispersion between coastal and inland sites, and the potential implications of sea breeze on human health and coastal resources.

Methods: Spore sampling occurred during 2006 by using pollen samplers. Samplers were located at the Rutgers University Institute of Marine and Coastal Sciences Marine Field Station and the Rutgers University Pinelands Field Station. Statistical analysis was performed on the spore data to compare concentrations from the various locations. The effect of sea breeze circulation on particulate matter was analyzed from meteorological data collected in 2006. Sea breeze data were collected from simulations, Doppler radar, and meteorological towers at varying heights.

Results: There was no significant difference between the total spore concentration at the New Jersey coast and the New Jersey Pinelands canopy.

Conclusion: Sea breeze has been shown to favor aerobiologic transfers from coastal seawater to land, but the immediate environment (floor) still remains a primary determinant of affecting an individual's allergic airway disease. Results of some studies have shown that coastal environments may favor the onset allergic airway, but in our study this seemed to be equivalent to the floor (or immediate locale) of an individual affected with allergy. However, the sea breeze effect seemed to have the ability to impact allergic airway disease (AAD) populations not only living along the coasts but of those living up to 130 km inland and potentially those living in the Philadelphia metropolitan area.

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The dispersal and transport of allergenic material (*i.e.*, pollen, pollutants, and mold) from numerous taxa are influenced by several meteorological factors, such as wind, rainfall, air temperature, and relative humidity.¹ Wind, in particular, is a major factor that affects pollen circulation and has been associated with cases of conjunctivitis and asthma.² Its impact on air-borne pollen and mold spore concentration, however, has not been thoroughly studied. Sea breeze is a common phenomenon of the sudden reversal of winds from an offshore wind to an onshore wind that occurs during the spring and summer months along the New Jersey coastline and almost daily in more tropical locations. It is formed through a complex ocean-atmosphere interaction, wherein the differential heating of the land and sea results in pressure and density

gradients; this permits a “front” to occur right along the shoreline similar to a small-scale localized cold front. Because the temperature of the ocean off the coast is still rather cold compared with the land and because of the high heat capacity of the ocean, it will take much longer for the ocean to warm in relation to the land.

On warm spring and summer days, the land is heated by incoming solar radiation, which in turn heats up parcels of air by convection that rise until the air reaches a stable layer of the atmosphere, a few thousand feet in altitude. Because the rising air cannot continue rising and cannot sink, to maintain mass continuity, it must spread outward, or diverge. When the warm divergent air moves over the cooler air that resides over the ocean, it sinks back down to the surface of the ocean.³ The rising motion of the air over the land results in the formation of a weak thermal low-pressure area. In contrast, the sinking motion of the air over the water results in the formation of a weak high-pressure area, which causes a pressure gradient and, ultimately, a sea breeze. The strength of the sea breeze is directly proportional to the temperature difference between the land and the sea. The depth of this breeze flow is not locally restricted and has been shown to reach 100–130 km inland.⁴

The significance of this sea-land breeze or, in particular, the sea breeze front, is that there is considerable vertical wind shear within the sea breeze cell that

From the ¹Medicine and Ophthalmology, Hackensack Meridian School of Medicine, Nutley, New Jersey; Rutgers University, Center for Environmental Prediction, New Brunswick, New Jersey; Kean University, New Jersey Center for Science, Technology and Mathematics, Union, New Jersey, USA; ²Starx Allergy and Asthma Center, LLC – Springfield, New Jersey, USA; ³Rutgers University, Center for Ocean Observation Leadership, New Brunswick and Little Egg Harbor, New Jersey, USA; and ⁴AquaWind, LLC, West Tuckerton, New Jersey, USA

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Address correspondence to Leonard Bielory, M.D., Rutgers University, 400 Mountain Ave., Springfield, NJ, 07081

E-mail address: drlbielory@gmail.com

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could potentially cause a portion of airborne material to be transported to the south of the source location material. The sea breeze front also could potentially cause air contaminants to be recirculated within the sea breeze cell, which results in a cumulative increase in adverse ambient air concentrations over the spatial area affected by the sea breeze circulation. Furthermore, it has been shown that, with the sea breeze, airborne particulate matter inland air, such as pollen and mold, are conveyed over the coastal area to the sea at night while the land-atmosphere is refreshed by fresh marine air during the daytime.⁵ In this study, we investigated the impact of the sea breeze on aerobiologic particulate matter transport and dispersion between coastal and inland sites, and its potential implications on human health and coastal resources.

METHODS

Location

The New Jersey Pine Barrens, or Pinelands, lies in the most densely populated state, New Jersey, and spans ~1 million acres. It is the largest area of contiguous, undeveloped forest and wetland on the Atlantic Coastal Plain of the Mid-Atlantic region and supports a unique and diverse spectrum of plant life. Tuckerton, New Jersey, is a coastal city (39°36'5''N, 74°20'17''W) that borders the New Jersey Pinelands and has a population of ~3500 inhabitants. The vegetation at Tuckerton is significantly less than that of the New Jersey Pinelands and does not accommodate the same pollen and spore-producing plants.

Sea Breeze Modeling and Monitoring

Rutgers Institute of Marine and Coastal Sciences, Coastal Laboratory for Applied Meteorology, along with guidance from the New Jersey Department of Environmental Protection, Bureau of Air Quality Planning, and Bureau of Air Quality Monitoring collaborated to analyze the 2006 monitoring and modeling results relative to pollen and mold concentrations at both coastal and inland locations. The effect of sea breeze circulation over particulate matter was analyzed from hourly meteorological data registered during 2006. Sea breeze data were collected from computer simulations, remote sensing by using Doppler radar, and meteorological towers at 10 m, 46 m, and 116 m. Wind data from each level were acquired from predominantly sea breeze events. Previous Rutgers University-Weather Research Forecast model simulations were selected to represent a typical sea breeze circulation with onshore winds that occur within the surface boundary layer at 100 meter, and 500 meter winds (from the northeasterly sector) above the thermal internal boundary layer, and the prevailing offshore (westerly)

synoptic flow that occurs at the upper boundary (1000 m) of the sea breeze cell.

Air Quality Monitoring

Pollen and mold spore sampling occurred during the 2006 season when using RotoRod pollen sampler: Minnetonka, Minnesota located at the Rutgers Institute of Marine and Coastal Sciences Marine Field Station in Tuckerton, NJ (coastal site), and at the Rutgers Pinelands Field Station (inland spore source location). Samples were collected concurrently at the 2-m level at both the Marine Field Station and the Pinelands Field Station as well as at the top of the forest canopy at the Pinelands Fields Station. Pollen and mold spore sampling with sea breeze occurrence were performed during well-developed sea breeze events (higher temperatures and humidity values that occur as a result of weak synoptic flow and a large temperature gradient between air over the ocean and air over the land). These sea breeze events occurred during the latter part of the 2006 season. Statistical analysis was performed on pollen and mold spore data by using paired *t*-tests to compare concentrations at the coast, forest base, and forest canopy.

RESULTS

Wind Data

As the Atlantic sea breeze propagates inland, the sea breeze will be opposed by the prevailing synoptic flow, which causes the speed of inland penetration to lessen and eventually be curtailed, which is defined by the sea breeze "front." Winds converge with a significant vertical velocity component. The sea breeze front is readily observed by Doppler radar, as shown in Fig. 1.

Mold Data

The New Jersey Pineland canopy (NJP-C) height was approximately 50 ft (15.24m). New Jersey Pineland base (NJP-B) distance from the New Jersey coast (NJC) was approximately 40 miles (64.37km). As shown in Table 1, the composite (average) results of mold spore concentration from several sampling periods. Spore concentration at the NJP-C was 5500 spores/m³ and was similar to the concentration at the NJC (5100 spores/m³). There was no statistically significant difference between the total spore concentration at the NJC and the NJP-C (*p*=0.56), as shown in Fig. 2 The total spore concentration at the NJP-B was 9172 spores/m³ and was 1.66 times greater than the spore concentration at the NJP-C, which was statistically significant (*p*=0.04). The dominant spore concentrations at the NJP-C were the same as the NJC: *Cladosporium*, ascospore, and basidiospore. Together, there was no statistically significant difference in concentration between the NJC and NJP-C (*p*=0.17). Although

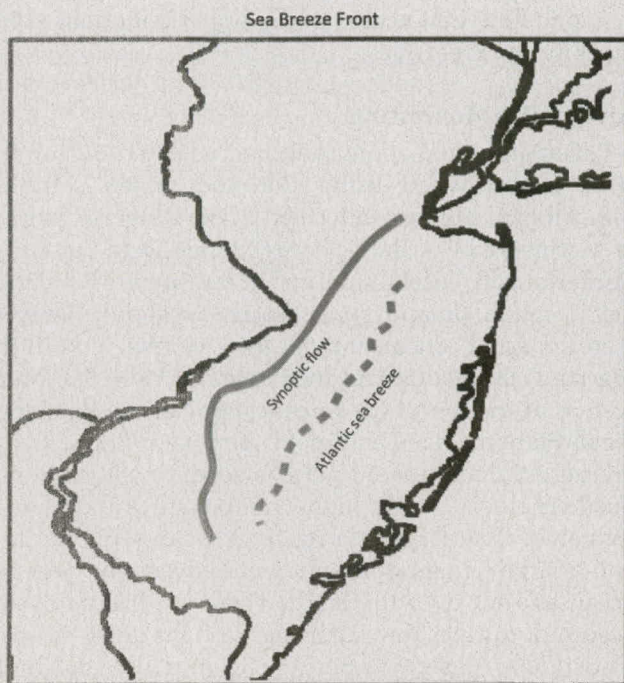


Fig. 1. The dashed line represents the front of the sea breeze as it moves away from the coast further inland. The extent of the sea breeze's movement before it is curtailed by synoptic winds is represented by the solid gray line.

torula, smuts, and *Dreschslera* had greater spore concentrations on the NJP-C than on the NJC, there was no statistically significant difference. Rusts and *Pithomyces* were the only mold spores not found at the NJP-B but both were found at the NJP-C and NJC, with NJP-C concentrations of 79 spores/m³ and 13 spores/m³ respectively.

DISCUSSION

Pollen and Mold

Atmospheric aerobiologic particulate matter concentrations fluctuate within the same day, from day to day, and are clearly influenced by temperature, relative humidity, and wind. Wind is the chief agent that causes fluctuations in mold catch because it is the sole dispersal agent and also regulates the rate of deposition for most of the aeroallergens. It has been shown that different pollens and molds have different patterns of diurnal periodicity, likely related to microclimatic factors.⁶ It is generally accepted that the majority of mold trapped comes from local sources. Nevertheless, mold from taxa not representative of the local or regional vegetation is also recorded, which implies long-range transport. The distance mold travels, once released into the air is closely related to the wind as a vectorial quantity. Furthermore, there have been reports for mold transfer of wind-pollinated taxa into the sea or among

continents, which cover distances up to hundreds or thousands of kilometers away from the source.⁷⁻⁹ Despite long travel, the grains of aerobiologic particulate matter are shown to be in good condition, with unbroken walls and intact cytoplasm; however, some allergenic material travels better than others. Pine pollen has been shown to cross great distances, whereas spruce pollen does not travel as readily given its larger size.⁹

Daily variations in weather conditions will influence pollen and/or mold release, particularly those areas with a dry, warm climate with a steady wind. Areas at sea level with low mean pressure systems can generate strong, dry wind gradients that have been associated with high pollen and/or mold concentration.¹⁰ High counts of airborne particles also strongly and positively correlate with air temperature and sunshine, whereas an increase in relative humidity or rainfall often results in a decrease of airborne particle counts.^{2,11} However, the exact numbers of pollen or mold grains that are going to be dispersed in the atmosphere in a specific region depend on the presence of rain and its duration, and the relative air humidity during the flowering season.¹ In general, pollen and/or mold grains follow a pattern that coincides with the diurnal maximum temperatures and sunshine hours, with the highest concentrations during midday and minimums during the early morning. Fungal spores also follow a similar diurnal pattern; however, spore peaks occur during the late afternoon.¹²

Fungal spores are released from the spore-bearing cells either by active or passive mechanisms, in which active mechanisms depend on changes in moisture conditions. Ascospores and basidiospores are released as the spore-bearing cell absorbs water, either during rainfall or as humidity increases. Some dry-weather spores (e.g., *Cladosporium*) are shaken loose as the spore-bearing cell twists as it dries. In other cases, air movements alone are sufficient to cause the release of spores.¹³ Overall, as with pollen, the most accurate weather predictors for the appearance of spore plumes are temperature, air pressure, wind speed, and dew point.¹⁴

Airborne Pollutants

High pollution levels have been linked to accumulation and photochemical processing of air pollutants. Sea breeze may return polluted air masses that have been transported out to the sea earlier during the day. Pollutant levels vary highly within a sea breeze, but sea breeze events have been shown to carry both fresh and aged particles that have undergone several hours of photochemical processing in the atmosphere.^{8,15} Similar to pollen grains and mold spores, atmospheric particles such as halocarbons follow a diurnal cycle

Table 1 The composite results of mold spore concentration from several sampling periods

	Fungal Spore Count of Air					Comparison Ratio of Coast to Forest Canopy
	NJC Coast, spores/m ³	NJP-C Forest Canopy, spores/m ³	NJP-B Forest Base, spores/m ³	Change from Forest Base to Coast, %	Change from Forest Base to Canopy, %	
Ascospore	1611	1381	2032	21	32	1.16
Basidiospore	815	776	2025	60	62	1.05
Cladosporium	2032	1716	2821	28	39	1.18
Curvularia	7	53	72	90	26	7.57
Dreschslera	33	59	72	54	18	1.78
Epicoccum	39	138	171	77	19	3.54
Nigrospora	0	0	0	0	0	0
Periconia	99	33	256	61	87	3.00
Pithomyces	7	13	0			1.86
Rusts	53	79	0			1.49
Smuts	276	434	855	36	49	1.57
Torula	99	178	283	65	37	1.80
Unidentified	59	388	302	80	128	6.57
Total	5143	5510	9172	44	40	1.07
p Value	—	—	—	0.01	0.04	0.56

NJC = New Jersey coast; NJP-C = New Jersey Pineland canopy; NJP-B = New Jersey Pineland base; p value = probability.

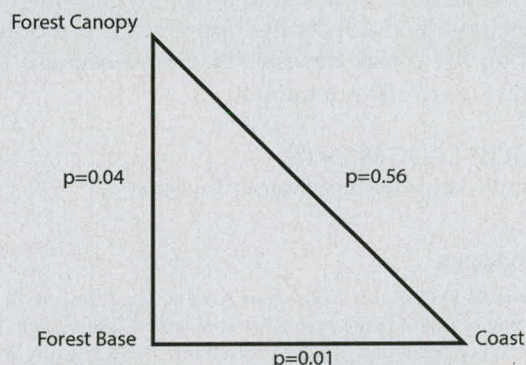


Fig. 2. There was no statistically significant difference between the total spore concentration at the New Jersey coast (NJC) and the New Jersey Pineland canopy (NJP-C) ($p = 0.56$).

driven by diurnal land-sea breezes. Halocarbon levels were highest at night and lowest during the daytime, likely attributed to weak nighttime land breezes and strong daytime sea breezes.¹⁶

Long-range transport of pollutants over hundreds of kilometers is also generally driven by sea breezes. A Japanese study found that seriously polluted areas could be found > 100 km inland from industrial and populated areas.¹⁷ Moreover, the sea breeze has been shown to favor the transfer of pollutants from coastal seawater to land, which thus returns to land previously deposited or spilled pollutants in the marine

environment. However, this tendency can be counteracted by the presumably higher polycyclic aromatic hydrocarbon concentrations in air masses coming from urban areas during the evening sea breeze period.¹⁸ Sea breeze also contributes to the formation and elevation of distinct layers of polluted air in a coastal region.¹⁹

Cross-border air pollution has also been linked to sea breeze, particularly in the transport of particulate matter from nearby oil-combustion and coal-compression power plants.²⁰ Distribution of aerosols emitted from vehicular traffic and industrial activity is also significantly affected by wind-flow patterns under sea breeze conditions.²¹ Sea breeze has also been implicated in ozone transport inland, and ozone precursors emitted during the night from large point sources in industrial parks can remain inland overnight. These plumes that remain inland overnight may have resulted from atmospheric stagnation from light winds, which leaves a potential cause of serious air pollution.²²

Wind Transport

Airborne allergen-bearing particles follow the same physical rules as any particle of the same aerodynamic diameter. They are dispersed *via* air movements and settle and impact in relation to their aerodynamic diameter and available impaction surfaces.¹² The dispersal rate of the liberated and/or discharged pollen and/or mold grains in the ambient atmosphere depends on the extent of air movement and/or the magnitude of

atmospheric turbulence, which varies according to changes in air temperature throughout the day, the percentage of green area, and coastal closeness. Grains of aerobiologic particulate matter disperse if the prevailing winds are strong and sufficiently turbulent.²³

Local air-circulation patterns in the atmosphere also play an important role in modulating the atmospheric levels of airborne pollutants. For inland areas, transport of terrestrial airborne pollutants during the daytime is driven by air convection near the ground. As the ground is heated by solar radiation, the polluted air near the surface becomes warmer and more buoyant. Subsequently, the cooler and denser upper air over the ocean moves toward the land to replace buoyant air. Without the effective influence of lateral wind, airborne pollutants can build up in the near-ground atmosphere of the inland urban area at night due to a restricted vertical dissipation process, especially when the atmosphere is under a nocturnal temperature inversion.¹⁵

Wind-transported particles, *e.g.*, mold, become dispersed by turbulence into the thermal internal boundary layer (TIBL). For coastal cities, dispersion characteristics become more complex due to both the TIBL and sea-land breezes. As the sea breeze front arrives, there is significant vertical lifting where particles both within the coastal region and those beyond the region will accumulate during the morning hours and will advance inland.²⁴ At night the atmosphere is more stable, and the turbulence drops to levels at which the flow becomes sporadically laminar and the TIBL height reaches its lowest value. This reduces dispersion and diffusion of airborne particles, and results in a net transport of airborne particles emitted from other areas to coastal cities. Therefore, particle recirculation potential and entrainment from peripheral sources can be associated with sea breeze circulation associated with air pollution and air quality.^{25,26}

Asthma and Allergic Rhinitis

Environmental exposure to an allergen and its relation to asthma and allergy morbidity have been studied extensively and can clearly be related to the provocation of asthma attacks and asthma severity.²⁷ There, however, have been very few studies on the long-term effects of climate on the variability of asthma prevalence. Studies have shown a seasonal variation in asthma hospital admissions.^{28,29} There also is evidence that climatic changes and variations in airborne allergens may be responsible for fluctuations in asthma and allergy symptoms.³⁰ However, what is still not clear is whether climatic factors affect asthma exacerbations directly or indirectly through their effect on other environmental agents.³¹

CONCLUSION

Allergen exposure in individuals who are sensitized has been related to increased asthma severity.^{32,33} Ambient concentrations of total pollen grains have been associated with emergency hospital admission for respiratory disease.^{34–36} Positive correlations have also been found between pollen counts and symptom scores in children with pollen allergy.³⁷ Air pollutants are thought to exacerbate asthma through airway inflammation and may affect symptom severity as a function of acute and chronic airway obstruction.³⁸ In particular, photochemical pollutants such as SO₂, NO₂, CO₂, O₃, PM₁₀ (particulate matter 10 micrometers or less in diameter), and PM_{2.5} (particulate matter 2.5 micrometers or less in diameter) are associated with increased asthma-related hospital admissions.^{31,39–41}

With regard to climate change, cold air has been implicated in decreases in forced expiratory volume at 1 second (FEV1) of expiration,⁴² whereas strong winds have been associated with increasing asthma exacerbations in coastal and island areas.⁴³ Asthma epidemics have also been linked to a preceding passage of a cold front, followed by a high-pressure system, which results in stagnant and rain-free conditions that tend to retain airborne particles.⁴⁴ Furthermore, some studies have shown that coastal environments may favor the onset of asthma and asthma-like symptoms.⁴⁵ Sea breeze circulation affects the populations not only living along the coasts but further inland because it can penetrate up to 130 km inland.

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