# Parameterization and Projection of Sea Breezes in New York City


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## Abstract


This project examines occurrences of sea breezes on hot days in New York City [NYC] from a climatological perspective. Sea breezes are identified from station data in the recent observational record (1981-2015) and large-scale predictors developed that are able to parameterize sea-breeze occurrence. These predictors, in turn, can be applied to CMIP5 models, enabling projections that sea breezes may somewhat increase in frequency under anthropogenic climate change. While still in progress and subject to revision, this work represents a first effort to parameterize this important process and to obtain estimates of changes in sea-breeze occurrence in a computationally efficient way.


## Background and Purpose

Extreme heat is expected to increase substantially over the 21st century [*Horton et al.,* 2016]. Sea breezes in the NYC area can penetrate far inland [*Orton et al.*, 2010; *Thompson et al*., 2007; *Novak and Colle,* 2006], thus making them potentially efficient at cooling the substantial urban heat island that frequently develops and is accentuated at times of extreme regional heat [*Gutierrez et al.*, 2015]. In the Northeast US, due to the geography of the coastline and the ridges to the south that usually cause extreme heat, low-level winds during hot days are often from the SW [*Meir et al.*, 2013; *Gedzelman et al.*, 2003]. Sea breezes in the NYC area are typically from the SSE, however, meaning that the directional difference between the hot synoptic flow and the cool marine flow is fairly subtle [*Meir et al*., 2013], and the temperature signature of sea breezes is a more-reliable though imperfect indicator. These complexities have made systematic investigation of sea breezes and especially their connection to larger time and space scales almost non-existent, at least to the author's knowledge.

## Data

- Observations:
  - Temperature, moisture, and surface-wind data at hourly resolution at JFK and EWR airports from the NCDC Integrated Station Database, available on Github at http://github.com/cr2630/finalhourlystationdataset
- Reanalysis:
  - Geopotential height, winds, temperature, and specific humidity at 3-hourly, 32-km resolution from the North American Regional Reanalysis [NARR]
- Model output:
  - 500-hPa geopotential height and 700-hPa winds at daily, 0.5-2.0º-resolution from the CNRM-CM5, IPSL-CM5-AR, MIROC5, and NorESM1-M models for 1980-2005 (historical runs) and 2006-2100 (future runs).

## References


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## Sea-breeze identification

We define sea breezes using station data at JFK and synoptic winds at 700 hPa from NARR. We focus on hot days (those with daily $T_{max}$ above the 95th percentile for that month, over the extended summer period of MJJAS) as this is when the impacts of heat are largest and the ameliorating effect of sea breezes most pronounced.

**A sea-breeze day must meet the following criteria:**

-700-hPa wind speed over NYC must shift less than 12 m/s from 01:00 LST to 13:00 LST

-air temperature must be greater than water temperature by >=3º C

-the surface-wind direction must shift by at least 60º from 06:00 LST to sometime within 13:00-19:00 LST

-the surface-wind direction must shift by at least 30º sometime within 13:00-19:00 LST, and then must have a mean hourly change of no more than 1/3 of this value for 3 hours thereafter

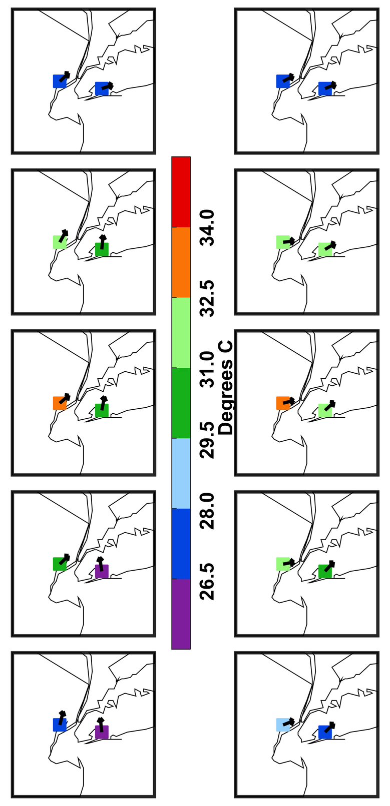
-the surface-wind direction immediately following the maximum wind shift must be <90º from the vector perpendicular to the local coastline

-the temperature must fall immediately following the maximum wind shift

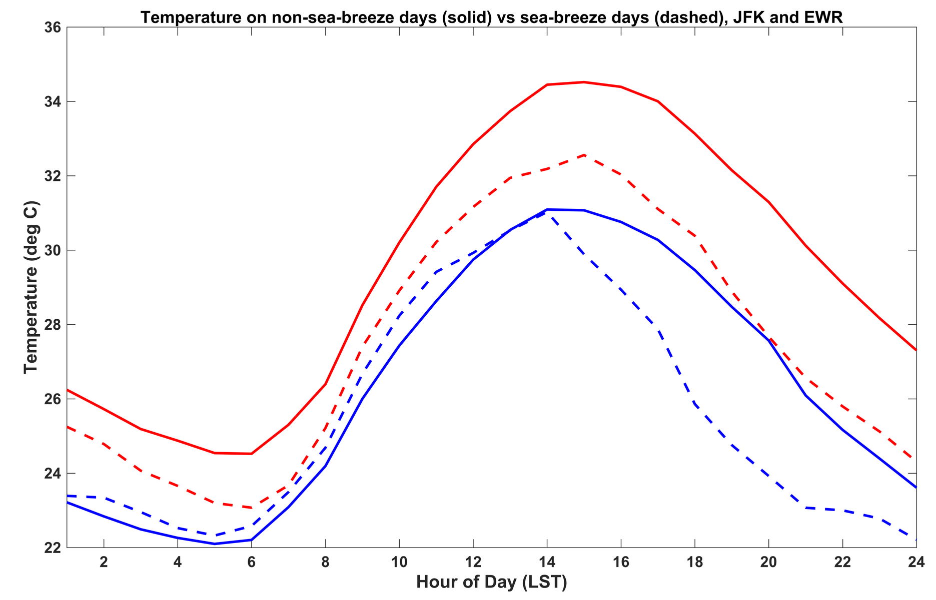
-there must be a temperature drop at the coast between 14:00 and 20:00 LST of at least 1º C more than would be expected from the diurnal cycle

## Sea-breeze characteristics

Applying the above definition to all 276 hot days, we obtain $n$=37 sea-breeze days over the 1981-2010 period. Compositing over these sea-breeze days, and comparing to the non-sea-breeze days, we find the canonical systematic differences that we broadly expected: namely, an onset at JFK around 14:00 LST, where winds become southerly and temperatures drop considerably. Temperatures are also lower at EWR on these days as well, though without the time shift in $T_{max}$ or the wind shift. Further examination of possible differences in synoptic or local meteorological conditions will be one of the next subjects of study in this project.



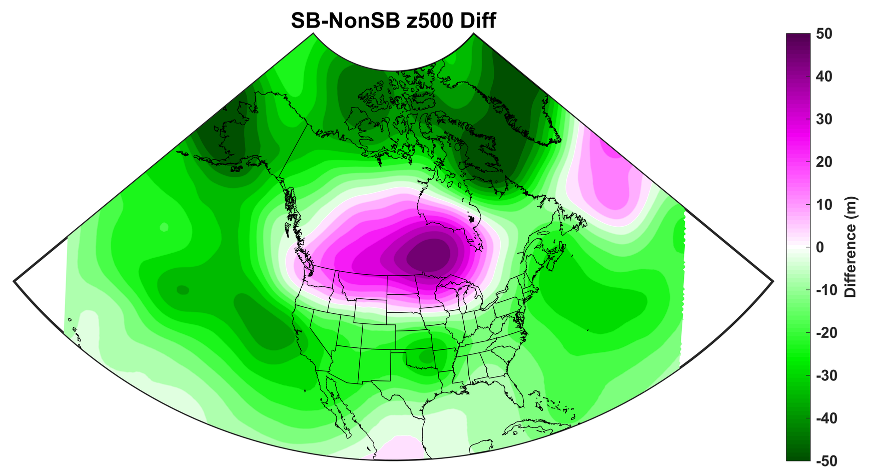

*The daily evolution of temperature (shading) and wind (vectors) on hot sea-breeze days (left) and hot non-sea-breeze days (right) for JFK and EWR.*




*Another visualization of the difference in temperature between sea-breeze and non-sea-breeze days for JFK (blue) and EWR (red).*

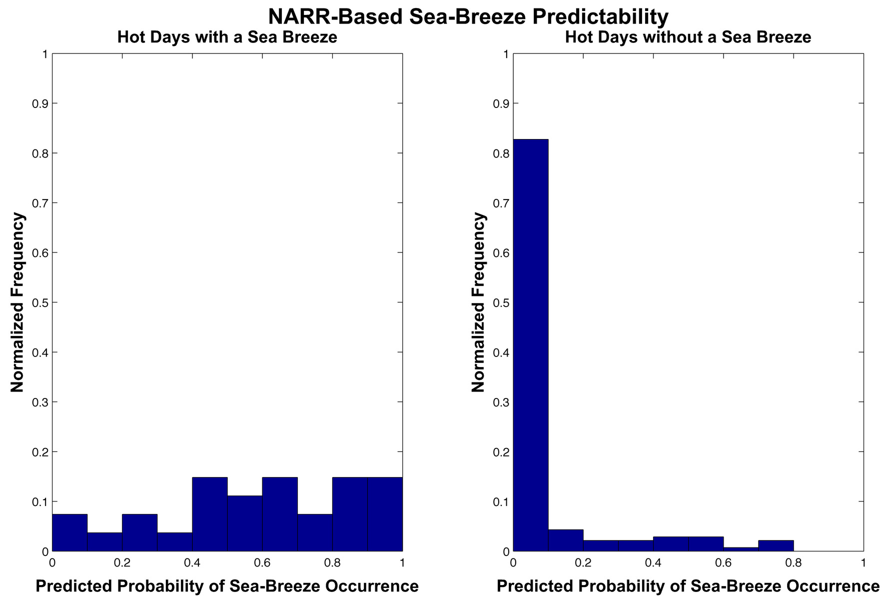
## Determination of large-scale predictors

To determine which variables regularly available from gridded data best predict the occurrence of sea breezes, a multinomial regression model was used (the Matlab function *mnrfit*). The variables 700-hPa zonal wind, 1000-hPa temperature, 500-hPa geopotential height, 850-hPa temperature, and 850-hPa specific humidity were tested, each one at every NARR gridpoint within 3000 km of NYC. As can be inferred from the below figure, the most important feature, and the only one significant over a large contiguous area at the 95th percentile, is the higher geopotential heights over south-central Canada. This height pattern is linked to a geostrophic flow on hot sea-breeze days with a more northeasterly component than on hot non-sea-breeze days.




*Difference in 500-hPa geopotential height between sea-breeze and non-sea-breeze days at NYC.*

As a verification of the ability of the large-scale predictors to differentiate between sea-breeze and non-sea-breeze days, we test how well our multinomial regression model can predict sea-breeze occurrence for 2011-15. We simultaneously run the station-based identification algorithm as cross-validation. The below histograms indicate that the large-scale predictors, while not perfect, are reasonably skillful, especially if predictions are binned into >50% and <50% probability categories.

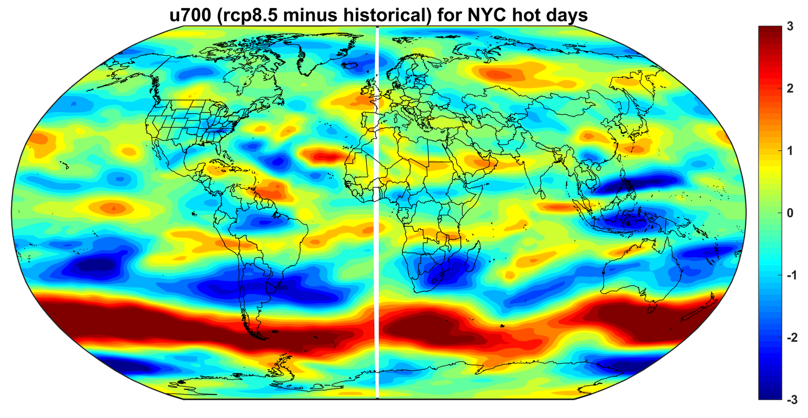



*The histogram of predicted sea-breeze probability from only the NARR large-scale predictors, for days identified from the station data as sea-breeze (left) or non-sea-breeze (right) days.*

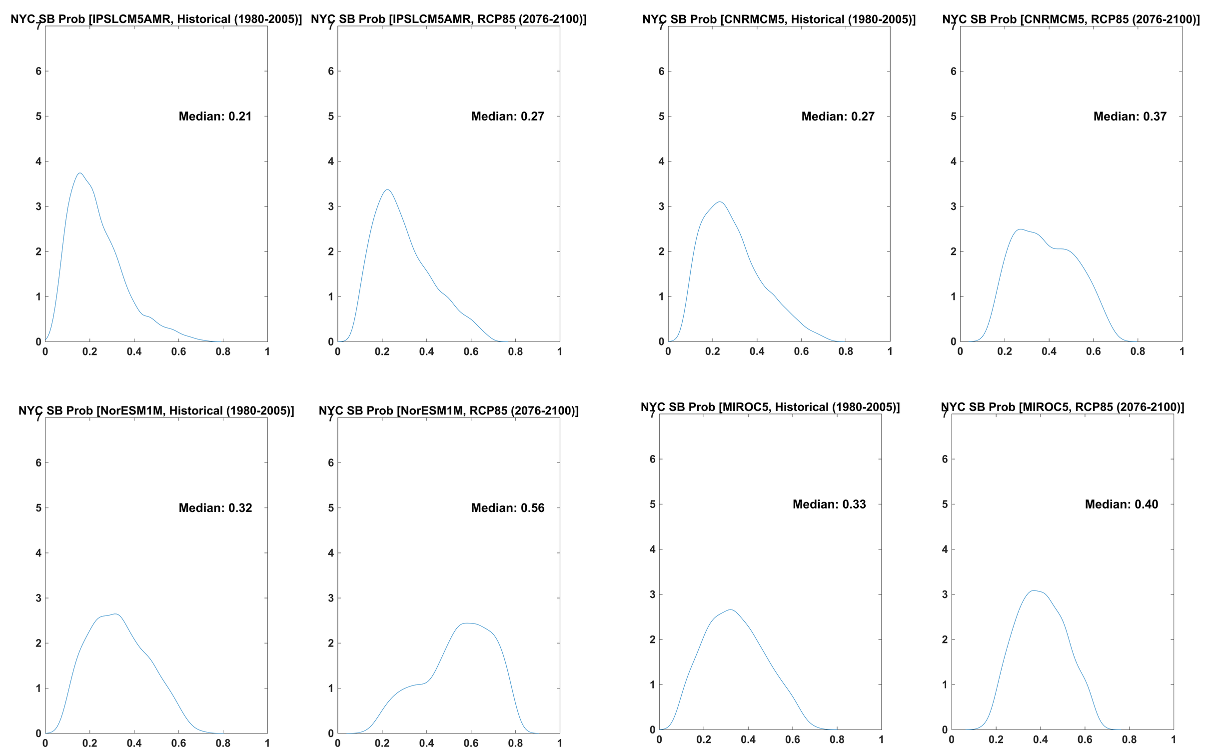
## Model projections

Sea-breeze probability estimates are obtained by applying the large-scale predictors to model data for four major CMIP5 models (with more planned). The resulting distribution of sea-breeze projections is based on the contemporaneous large-scale patterns that each model projects for hot days in NYC, meaning that the comparisons are internally consistent in model-space.

The projected decrease in zonal-wind speed near NYC during the hottest days of boreal summer is reproduced fairly well across models, with one example below. This implies a moderate increase in sea-breeze occurrence at NYC, with the substantial caveat that applying the predictors relies on the assumption that the circulation patterns associated with extreme heat in NYC will remain more or less the same under climate change.




*Projected change in 700-hPa zonal wind speed (m/s) on hot days at NYC from the 1980-2005 period to the 2076-2100 period, for the IPSL-CM5-AR model.*



*Sea-breeze probability estimates on the hottest 5% of days in MJJAS, using four CMIP5 models for 1980-2005 (left subplots) and 2076-2100 (right subplots).*

## Conclusions and Future Work

These preliminary findings show that it is possible to predict fine-scale features from coarse gridded data if the translation function is carefully defined. The other main result so far is that weaker westerly winds in the future may allow sea breezes to more frequently penetrate inland along the US East Coast during hot days.

The remainder of this project will comprise refining the predictor definition, expanding the number of models and improving the statistical analysis of their output, and perhaps calculating changes in particular SOM categories, rather than simply looking at mean changes. The role of differential land-sea temperature change also bears examination in a modeling context.