Lab Activity No. 4: Dispersion and forecast of air pollutants

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1 General and Specific Objectives

1.1 General Objective

- To determine the possible dispersion trajectories of urban air pollutants using the HYSPLIT air dispersion model

1.2 Specific Objectives

- To perform air dispersion modeling of air parcels using the Lagrangian approach implemented by the HYSPLIT Model

- To trace how far an air parcel travels by dispersion from the point source in 24 hours

- To observe any diurnal variations in air trajectories, and investigate their causes

2 Description of Site/Sampling Area

Just like our first lab activity, the sample site is located in the Quezon Memorial Center (QMC), Quezon City, Metro Manila, Philippines (14.65^oN, 121.05^oE). The QMC is a public park located in the middle of a highly urbanized city, surrounded by business hubs, malls, restaurants, transportation terminals, public schools and universities. Thus, despite being designated as a *green space*, QMC is surrounded by heavy vehicle and foot traffic. Sampling was done hourly from 00:00 August 2, 2015 to 23:00 August 2, 2015 (Philippine time). The sampling data contains the following: date and time, PM2.5 concentrations ($\mu g/m^2$), air temperature (^oC), relative humidity, pressure (mb), wind speed (m/s), wind direction (in degrees), latitude (^oN), and longitude (^oE). The link to the data set is included in the Appendix.

3 Review of Related Literature

In this lab activity, we investigate the diurnal behavior of a dispersing air parcel originating from an urban source. Our sampling site is located near a coastal area during the summer monsoon (Habagat) season. Thus, the following wind systems may affect the dispersal of the air parcel: land and sea breeze, monsoon winds, and the west Pacific subtropical high pressure system (WPHS).

The uneven heating rates of land and water causes two types of mesoscale thermal circulations: sea breeze and land breeze [1]. Land possesses a lower heating capacity than water, so land heats faster during the day (when temperatures are higher), while adjacent bodies of water remain cooler. The warm land surface produces a shallow thermal low, while the cool water surface produces a shallow thermal high. Thus, the wind, known

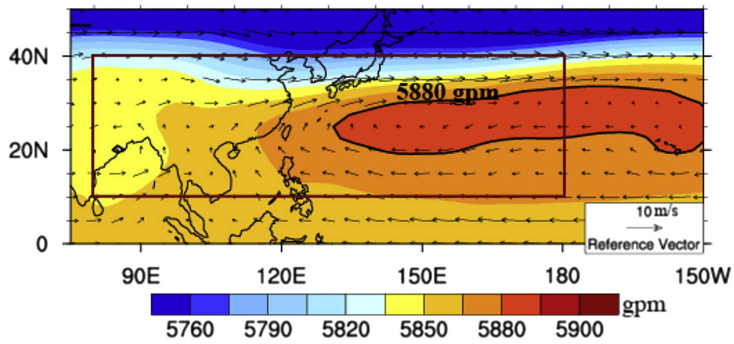


Figure 1: Climatological position of the west Pacific subtropical high during the summer and its characteristic winds. Figure from [6]

as a sea breeze, follows a general direction blowing from the water (thermal high) to the land (thermal low).

The opposite occurs during the night: the land cools faster than bodies of water [1]. Now, since the land is cooler, a thermal high forms over the land surface, while a thermal low forms over the water surface. The wind blows in an opposite direction—from the land to water—and is now known as the land breeze. The temperature difference between land and water is typically smaller, so the land breeze tends to be weaker than the sea breeze.

Previous studies have shown that the land and sea breeze influence the diurnal wind variation in coastal areas [2, 3]. Since Manila Bay, a coastal area, is located to the west of QMC, we expect the air parcel to posses an eastward component during the day (sea breeze), and a westward component during the evening (land breeze).

The Philippine summer monsoon (Habagat) winds carry wet warm air from southwest of the Philippines northward toward East Asia. Habagat season usually begins during May or June and ends by September [4]. Since Habagat is already active during the focus date, we expect the trajectories to have a northward component. The westward shift of the west Pacific subtropical high pressure system (WPSH) accompanies the onset of the summer monsoon [5, 6]. The position of the WPSH during the summer monsoon (shown in Fig. 1) induces easterlies to southeasterlies in the Philippines. Thus, we also expect an easterly component in our trajectories.

4 Methods Framework

To perform air dispersion modelling using the Lagrangian approach, I used the Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT). The model parameters I used are shown in Fig. 2. The model outputs the hourly forward trajectories of an air parcel from the point source (QMC) from 00:00 August 2, 2015 to 23:00 August 2, 2015 (Philippine time). The trajectories follow the air parcel as it travels for 24 hours from the point source.

To observe the relationship of wind dispersion and other meteorological parameters to air pollution concentrations, I also plotted the hourly measured temperature, relative humidity, wind speed and direction, and PM2.5 concentrations in August 2, 2015.

I also noted the coordinates of the final points in the modelled trajectories from the model's *.txt* file. Then, to obtain the final displacements of an air parcel after 24 hours, I calculated the distance between the source and the air parcel's final trajectories. I used the following website to perform calculations: https://www.nhc.noaa.gov/gccalc.shtml.

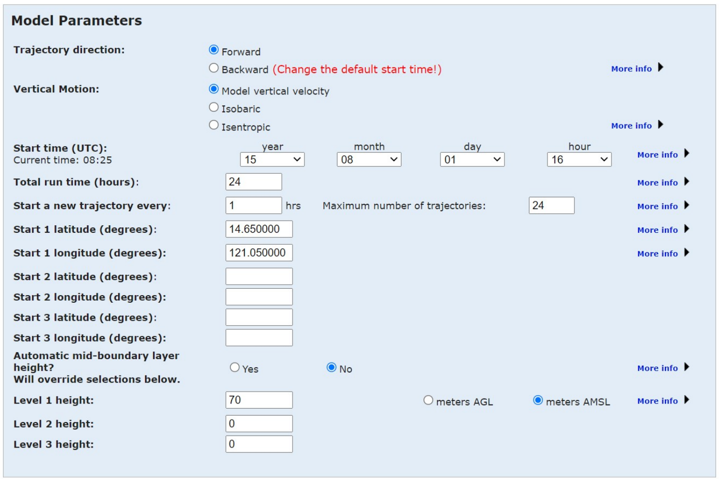


Figure 2: Model parameters for the HYSPLIT model

5 Results and Discussion

Similar to the average measurements of the meteorological parameters I presented in the first lab activity, the temperature & relative humidity, and PM2.5 concentrations & wind speed follow inverse relationships (shown in Fig. 3). At low wind speeds, PM2.5 concentrations tend to accumulate near the surface, but the accumulated PM2.5 scatters as winds strengthen.

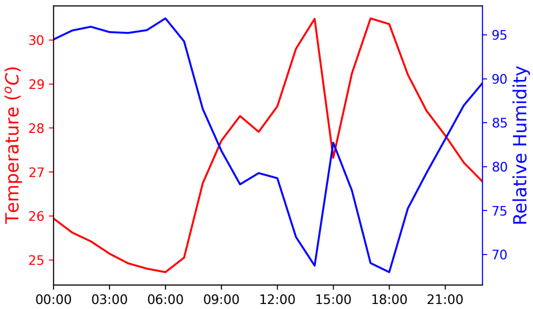
Based on the HYSPLIT model the hourly trajectories of the air parcel sweeps a half circle starting south of the source at midnight, moving clockwise until northwest of the source at late evening (shown in Fig. 4). During the early morning, the air parcel travels the shortest distance towards south Metro Manila. During the day, the air parcel travels the farthest displacement towards Bataan, crossing Manila Bay in the process. Lastly, during the evenings, the air parcel travels the longest distance covered towards Bataan, then curving upwards to Pampanga.

We can observe that the air parcel tends to follow a westward movement in a day. The strong westward winds could possibly be caused by the WPHS. The curving upward once the air parcel reaches the Western Philippine Sea could possibly be caused by the stronger influence of Habagat, which is active during August.

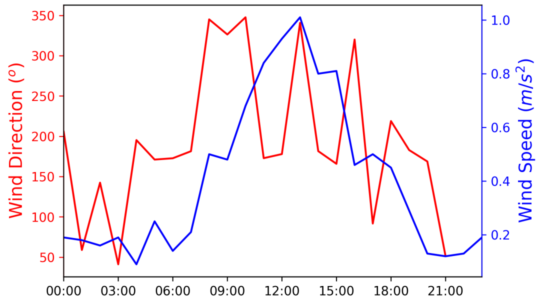
Since the land and sea breeze are smaller scale thermal convections than monsoons and the WPSH, they produce weaker effects on the overall trajectories of air parcels as they travel over land and water. Thus, we don't observe their diurnal variation in the model. The model outputs synoptic wind dispersion predictions, which cannot fully capture the dynamics of urban air dispersion, a mesoscale convection. The model cannot fully capture the effects of mesoscale phenomena in urban areas such as urban canyons and the effects of variations in the urban canopy layer.

However, if we look at the measured wind directions (shown in Fig. 3d), we see that during the day, the winds tend to alternate between westerlies and easterlies. The westerlies could possibly be caused by the day sea breeze. On the other hand, during the evenings and early morning, the winds tend to alternate between westerlies and northeasterlies. We only observe northeasterlies during the evening and early morning possibly because the night land breeze is weaker than the day sea breeze. Remember that since the Manila Bay is west of QMC, we expect a westerly component during the day, and an easterly component during the night. The measurements reflect these expectations.

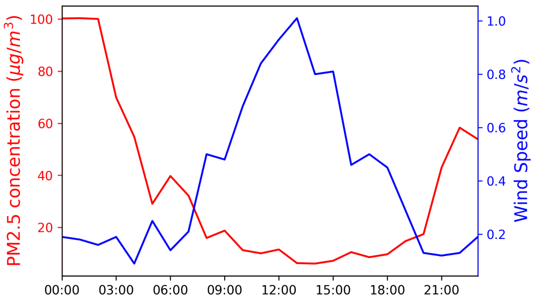
From Fig. 5, we see that the stronger the wind, the farther the air parcel disperses from



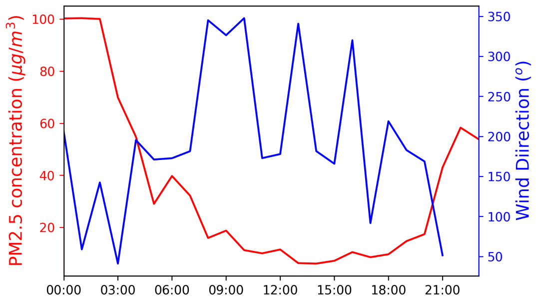
(a) Temperature and Relative Humidity



(b) Wind Direction and Speed



(c) PM2.5 Concentrations and Wind Speed



(d) PM2.5 Concentrations and Wind Direction

Figure 3: Superimposed hourly measures of sampling parameters.

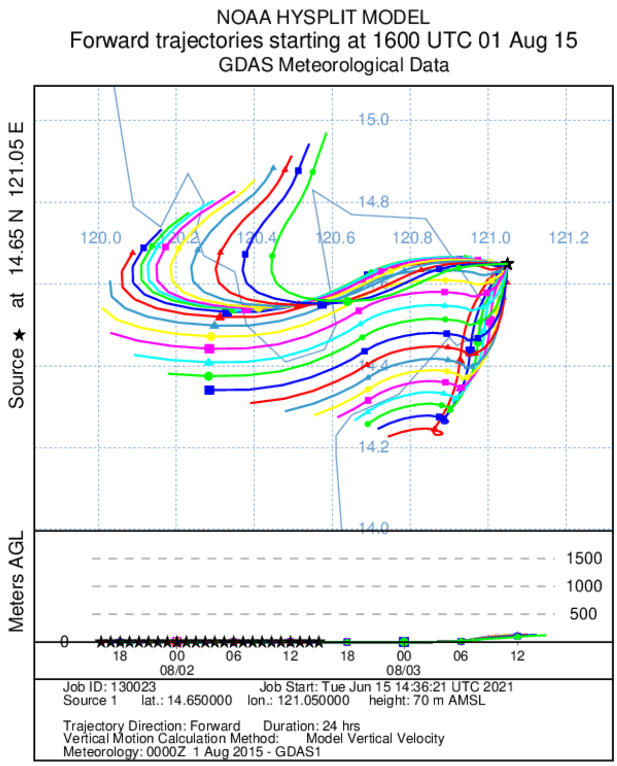
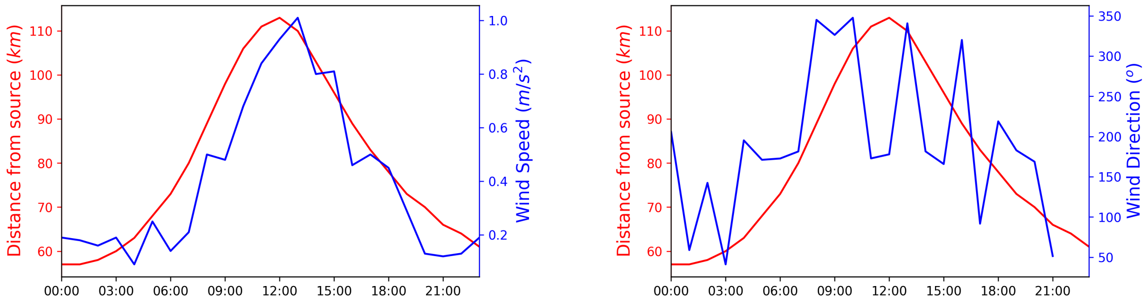


Figure 4: Forward trajectories of an air parcel originating from Quezon Memorial Center obtained using the HYSPLIT Model.



(a) Farthest Distance and Wind Speed

(b) Farthest Distance and Wind Direction

Figure 5: Superimposed hourly measures of wind speed and direction, and the final displacement traveled by the air parcel based on the output of the HYSPLIT model.

the source (QMC). We could also note from Figs. 3c and 5a that some of the accumulated PM2.5 during the evening gets blown away by the strong winds during the day to farther places such as Bataan and Pampanga. We can say that Bataan and Pampanga could be at risk of urban air pollution (not just PM2.5) originating from Metro Manila. Comparing Fig. 5b to Fig. 4, we see that the model and measurements agree that primarily strong easterlies prevail during the day, while weaker northerlies prevail during the early morning. However, during the evenings, the measurements indicate weak westerly-northwesterlies, while the model indicates strong easterlies.

References

[1] C. D. Ahrens, *Third Edition Essentials of Meteorology* (2000), ISBN 9780123736154.

[2] R. Yu, J. Li, and H. Chen, Diurnal variation of surface wind over central eastern China, *Climate Dynamics* **33**, 1089 (2008), ISSN 1432-0894.

[3] P. G. Remya and R. Kumar, Impact of Diurnal Variation of Winds on Coastal Waves off South East Coast of India, *The International Journal of Ocean and Climate Systems* **4**, 171 (2013), ISSN 1759-3131.

[4] G. Bagtasa, Enhancement of Summer Monsoon Rainfall by Tropical Cyclones in Northwestern Philippines, *. 2* **advpub** (2019).

[5] R. Lu and B. Dong, Westward Extension of North Pacific Subtropical High in Summer, *. 2* **79**, 1229 (2001).

[6] Z. Zhao and Y. Wang, Influence of the West Pacific subtropical high on surface ozone daily variability in summertime over eastern China, *Atmospheric Environment* **170**, 197 (2017), ISSN 1352-2310.

Appendix

The data set can be found in:
https://drive.google.com/file/d/1zXPyVpaQFAbbR4ybwI0nQY1zkhremsd0/view?usp=sharing.