The Relationship Between Atmospheric Boundary Layer Structure, Brown Haze, and Air Pollution in Auckland, New Zealand

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Background

A local-scale brown air pollution haze that forms over some international cities during the winter has been found to be associated with negative health outcomes and high surface air pollution levels. Previous research has demonstrated a well-established link between the structure of the atmospheric boundary layer (ABL) and surface air quality; however, the degree to which the structure of the ABL influences the formation of local-scale brown haze (BH) is unknown.

Using continuous ceilometer data covering seven consecutive winters, we investigate the influence of the structure of the ABL in relation to surface air pollution and brown haze formation over an urban area of complex coastal terrain in the Southern Hemisphere city of Auckland, New Zealand (Fig. 1).

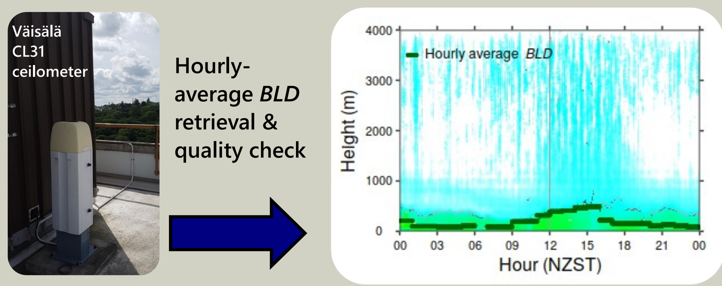
Fig. 1. Map showing the location of Auckland, New Zealand. Also shown are the locations of the ceilometer instrument, the brown haze camera (white lines show angle of the camera), the surface air quality (AQ) monitoring sites, and the meteorological station used in this study, in relation to Auckland's central business district (CBD). The satellite imagery and the New Zealand coastline map were sourced from LINZ Data Service (2014, 2019) and licensed for re-use under the Creative Commons Attribution 4.0 International License.

Research Question

How is the depth and structure of the atmospheric boundary layer related to the occurrence of local-scale winter brown haze?

Methods

- Retrieval of hourly-average boundary-layer depth (*BLD*) estimates from ceilometer data covering seven consecutive winters (May-August of 2013-2019)

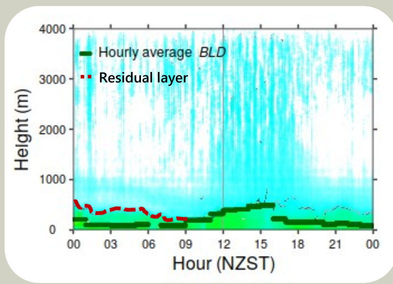


- Calculation of morning transition (MT) growth rates and identification of residual layers (indicating the presence of particulate matter within this layer)

$$\text{MT growth rate} = \frac{\Delta h}{\text{MT duration}}$$

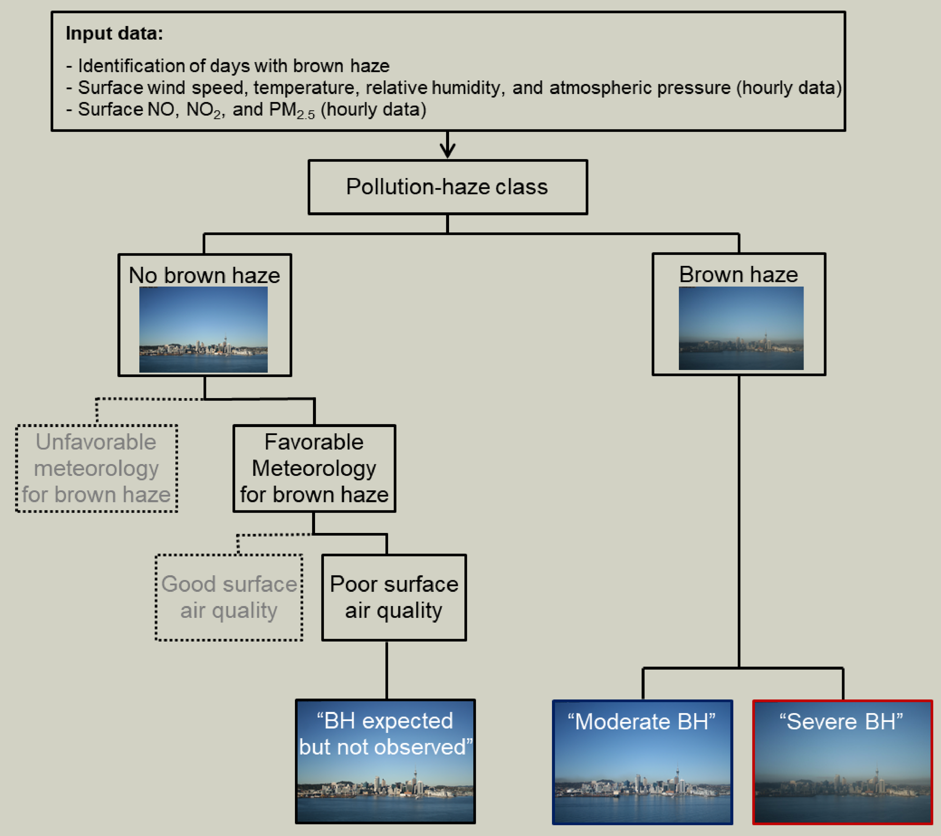
(where Δh is the change in ABL height (m) between the MT start time and the MT end time)

Where at least two layers exist during the night time in the ceilometer profiles, the residual layer was identified as the layer above the nocturnal boundary layer.



Residual layer present

- Characterization of 'pollution-haze class'



- **Brown haze identification:** occurrence and severity of brown haze was identified from photographs of the atmosphere over the Auckland CBD, following the methods used by Salmond et al. (2016), Dirks et al. (2017), and Griffiths et al. (2019).
- **Thresholds for favorable meteorology for brown haze:** 0900 NZST wind speed ≤ 2 m s^{-1}, 0900 NZST temperature ≤ 14.8 ℃, 0900 NZST relative humidity ≥ 69%, diurnal temperature range ≥ 7.1 ℃, midnight atmospheric pressure ≥ 1006 hPa, midday atmospheric pressure ≥ 1009 hPa.
- **Thresholds for poor surface air quality:** regional 0800-1100 NZST mean concentration for NO, NO_2, and/or $PM_{2.5}$ > 85th percentile for the given pollutant.

Results

When days with severe brown haze are compared with those when brown haze is expected but not observed (based on favorable meteorology and high surface air pollution levels), days with severe brown haze are found to coincide with a significantly shallower daytime convective boundary layer (~ 48% lower, $p < 0.05$), and the nights preceding brown haze formation are found to have significantly shallower nocturnal boundary layers (~ 28% lower, $p < 0.05$) (Fig. 2).

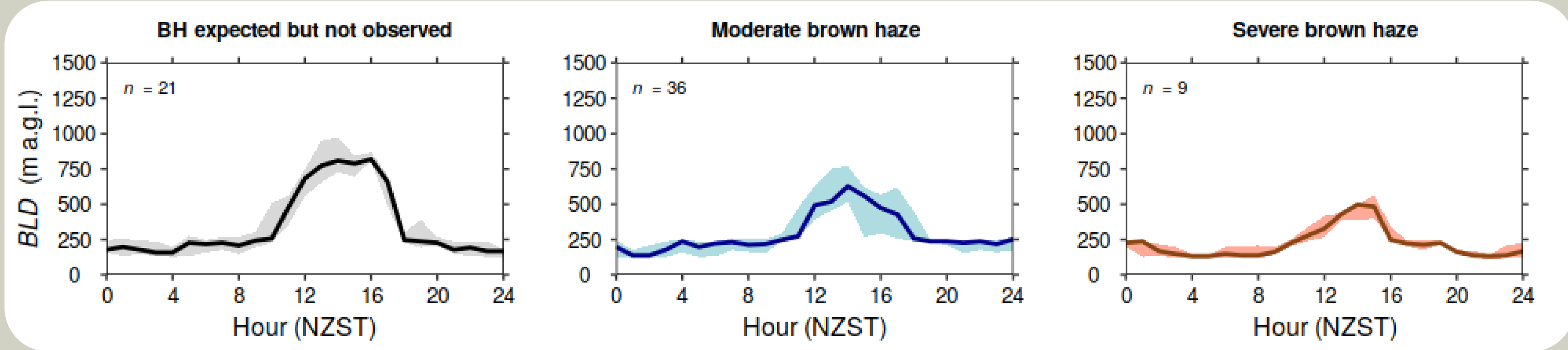


Fig. 2. Diurnal boundary-layer depth (*BLD*) profiles for the winter months (May to August) of 2013 to 2019 for the pollution-haze classes. The dark line represents the median and the shading represents the interquartile range (25th and 75th percentiles). Noted on each plot are the number of days sampled in each pollution-haze classes (*n*). NZST = New Zealand standard time (UTC + 12 h).

On severe brown haze days the growth rate during the morning transition phase from a nocturnal boundary layer to a convective daytime boundary layer is found to be significantly reduced (70 m h-1), compared to days on which brown haze is expected but not observed (170 m h-1) ($p < 0.05$) (Fig. 3).

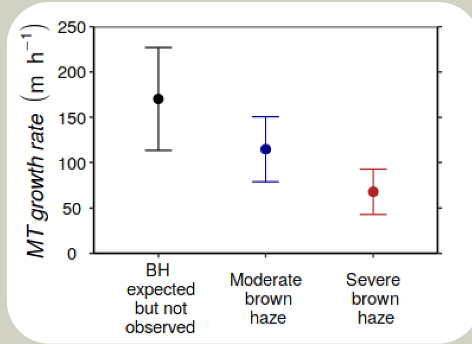


Fig. 3. Morning transition (*MT*) growth rates (m h^{-1}) for the pollution-haze classes. The dots represent the mean and the error bars represent the 95% confidence interval limits.

Severe brown haze days are found to be significantly more likely to have residual layers (indicating the presence of particulate matter within this layer) present in the ceilometer backscatter coefficient profiles (56% occurrence), compared with moderate brown haze days (19% occurrence) ($p < 0.05$) (Fig. 4).

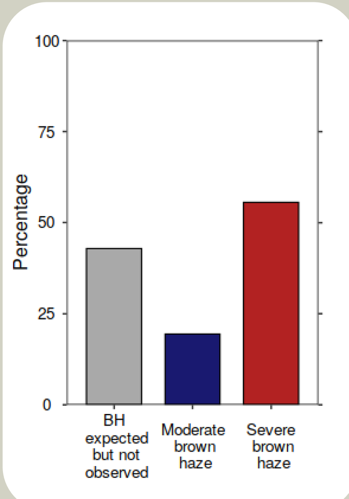


Fig. 4. Percentage of days in each pollution-haze class with a distinct residual layer present in the ceilometer backscatter coefficient profiles.

Despite this, the majority of brown haze days did not have a distinct residual layer present in the ceilometer backscatter coefficient profiles, as is shown in Fig. 5.

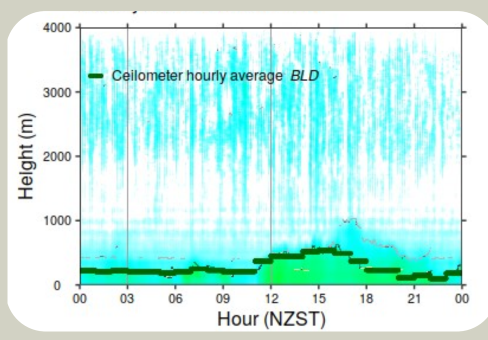


Fig. 5. Diurnal *BLD* profile for a BH day showing valid hourly-average *BLD* estimates in green. A residual layer is not present during the early morning hours.

Summary

- The findings presented above indicate that, on severe BH days, the combination of shallower nocturnal and convective boundary layer, and a weak morning transition growth rate, greatly inhibit the dilution and dispersal of pollutants, resulting in the observation of an intense and prolonged haze.
- Our results suggest that the presence of particulate matter in the residual layer is not necessary for the formation of BH, as a residual layer is only present on approximately 19% of moderate BH days. However, severe BH days were significantly more likely to have a residual layer compared with moderate BH days, indicating that the entrainment and mixing of residual layer particulate matter back down to the surface may contribute to the severity of the haze.
- On BH days it was more likely for a residual layer to be absent in the ceilometer backscatter coefficient profiles, indicating that the conditions conducive to brown haze formation occur inside the boundary layer.

Limitations:

- Pollution measurements were only available at near surface sites and were not available for upper levels.
- Auckland's BH blows around over the city when light winds are present and the haze doesn't always impact visibility. For these reasons we used the subjective method of BH identification from photographs. However, this method may not have identified BH over other parts of the city.

Future research avenues:

- The influence of flow regimes (e.g. sea-land breezes) on the transport and accumulation of pollutants leading up to BH days.
- The source and composition of residual layer pollutants and their contribution to the formation of BH.

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This poster is based on:

Marley, H.G., Dirks, K.N., Neverman, A.J., McKendry, I., & Salmond, J.A. (in press) The Relationship Between Brown Haze, Atmospheric Boundary Structure, and Air Pollution in an Urban Area of Complex Coastal Terrain. *Atmospheric Pollution Research.*

Acknowledgements

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