Cleaning of the air by convective clouds.

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Abstract

In this project ORAC processed SEVIRI data over Europe was analysed to quantify the effects of convective clouds on aerosols in the atmosphere. Algorithms for identifying the tropopause and convective clouds were developed and validated qualitatively. Aerosol retrieval from ORAC was then filtered, averaged and then used to produce a comparison between the aerosol optical thickness before and after the identification of a convective cloud. An analysis was carried out for 15 minutely data from the 19th of August 2015 and a drop of 0.13 in aerosol optical thickness was observed.

1 Introduction and Theory

The goal of this project was to quantify the effect of convective clouds on aerosols in the atmosphere. This was done by analysing the aerosol optical thickness(AOT) of ORAC (Optimal Retrieval of Aerosol and Cloud) processed SEVIRI(Spinning Enhanced Visible and Infrared Imager) data over Europe. Algorithms for identifying the tropopause and convective clouds were also developed.

The optimal retrieval of aerosol and cloud, ORAC, is an optimal esitmation scheme that determines aerosol and cloud properties from multispectral imagery [6]. ORAC was used to process satellite data from SEVIRI, a geostationary satellite, inorder to obtain the required quantities for the analysis. Satellite data over Europe with a temporal resolution of 15 minutes across 24 hours was used. Due to a high degree of unreliablitiy in aerosol retrival over land only data over the sea was considered for the analysis.

Convective clouds are large clouds that span the troposphere. They are formed from water vapour that has been carried by powerful upward air currents that are often a result of instability in the atmosphere. This can be caused by the heating of the ground or the bottom layers of the troposphere/boundary layer or by the lifting or saturation of a potentially unstable layer [1]. The main focus of the project was convective clouds of the genus Cumulonimbus, particularly Cumulonimbus incus, more commonly known as anvil clouds. This is mainly due to a relative ease in detecting them as they have a cloud top height at the tropopause.

As convective clouds are very large and form a towering column that spans the entire troposphere, they contain vast amounts of water vapour. Our hypothesis therefore is that as they pass through the atmosphere aerosols in the air should act as nucleation points about which the water vapour can coalesce and form water droplets, which will in turn be carried by the convective cloud until they fall out as precipitation. This should cause a measurable drop in aerosol optical thickness, which is what we set out to quantify.

Detailed predictions by climate models are unreliable, one of the reasons for this being a poor resolution of the physical processes governing aerosol-cloud interactions. A motivation for this project was to quantify the change in AOT associated with the described 'cleaning' effect to help constrain aerosol-cloud interactions and enable more precise detailed predictions by climate models. A further analyses could be carried out in order to determine this phenomena's contribution to the Earth's radiation budget and thus its influence on the climate.

As a part of identifying these convective clouds the tropopause had to be located. The tropopause is the boundary layer between the troposphere and the stratosphere and was defined by the World Meteorological Organization in 1957 as follow: "the lowest level at which the lapse-rate decreases to 2 K/km or less, provided that the average lapse-rate between this level and all higher levels within 2 km does not exceed 2 K/km" [3], with the latter condition preventing the false identification of areas of local stability.

2 Method

First a method for identifying convective clouds in the data was established. The approach that was first considered was the filtering of clouds by cloud optical thickness as convective clouds have an optical thickness measurably higher than most other clouds. This however was not implemented as establishing a threshold optical thickness above which clouds were convective as a sole parameter was time consuming. Another issue this approach encountered was a difficultiy in solely flagging convective clouds at the lower thresholds and missing a large proportion of clouds at higher thresholds.

The approach that was carried out was the identification mainly based on emmisivity and cloud top temperature relative to the tropopause. Inorder to do this an algorithm for identifying the tropopause was first created. The algorithm used ECMWF temperature profiles and applied the WMO definition of the tropopause in order to locate it. In addition to the aforementioned definition an additional criterion was added whereas to start the search from an altitude of 5km in order to prevent false flags caused by surface inversions. The search was also stops at 25km and outputs a fill value if unsuccessful, in order to prevent unrealistic flags.

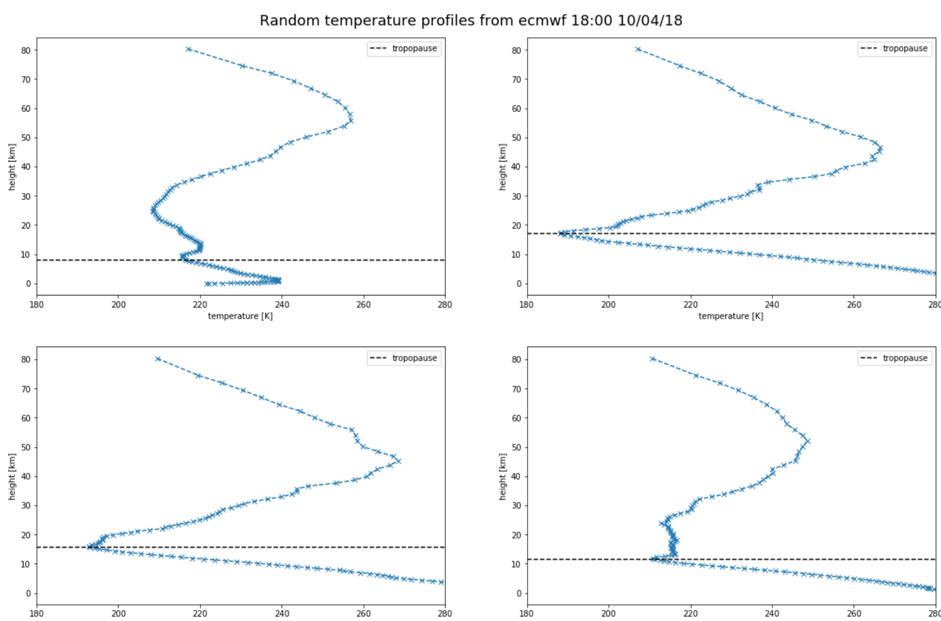

Figure 1: 4 Random ECMWF temperature profiles along with their located tropopause.

Once the tropopause was located it was used to identify convective clouds. This was done using the fact that they had a cloud top height around the tropopause height. First the calculated tropopause data was interpolated with the SEVIRI output from ORAC, this was done because the ECMWF data was of a lower resolution than SEVIRI. Next all cloud pixels with a cloud top height that was more than 2km below the tropopause were discarded.

The clouds were then filtered by their emissivity; pixels with a cloud emissivity of below 0.8 being discarded. This was to eliminate cirrus clouds that also tend to be very close to the tropopause but have a lower emissivity than the much larger convective clouds.

The remaining cloud pixels were then filtered by cloud top temperature (CTT). First all pixels that had a CTT that was within 3 K of the tropopause were flagged as being convective. Next all pixels with a CTT within 5 K of the tropopause were flagged if they had one of the previously flagged convective pixels (the ones within 3K) in the 1 lat x 1 lon box centred about it. This was to ensure that once a convective cloud was located the majority of pixels in the cloud are flagged as convective.

Below is an example of the cloud optical thickness of an example cloud field and of the convective clouds detected by the algorithm in that cloud field.

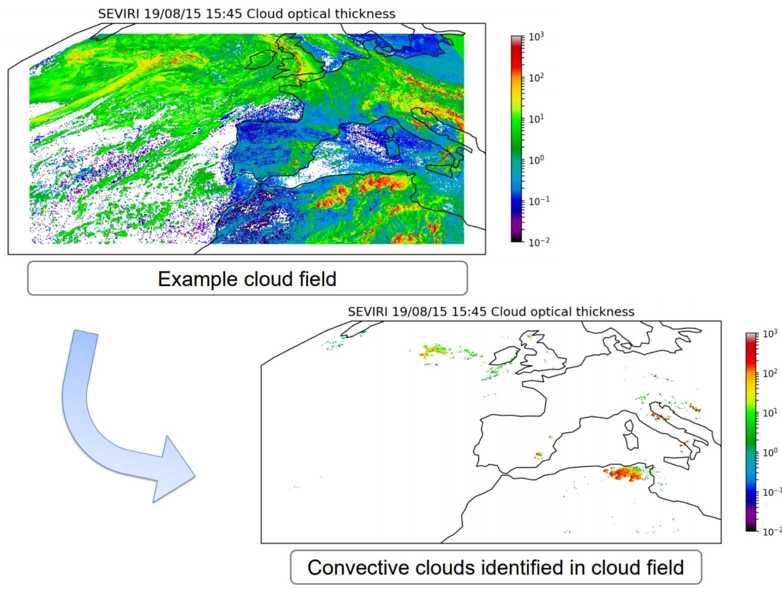

Figure 2: 4 Random ECMWF temperature profiles along with their located tropopause.

The next step was to validate the algorithm created. The first procedure attempted once again involved using cloud optical thickeness to gauge whether the clouds that were flagged were indeed convective, this however once again ran into to a similar issue as before as the convective clouds had a varied range of optical thicknesses. This validation technique, though unsuccessful, revealed that the convective cloud detection algorithm often flagged frontal clouds as being convective, however as these pixels constituted a low proportion of flaged pixels this was ignored.

The validation was then carried out in two ways, though both were only done qualitatively. The first technique was to use ENTLN lightning data. Lightning strikes recorded at the same time as the SEVIRI measurements were superimposed on an image of the convective clouds flagged by the algorithm. It was found that though the algorithm was reliable at identifying convective clouds, several convective clouds remained undetected by the algorithm.

This observation was confirmed by the second validation method. The second method involved creating RGB images from the a set of channel differences recommended by the EUMETSAT for the identification of convection [4]. The channels used consisted of the difference between 2 water vapour channels (WV6.2-WV7.3) for red, 2 infra-red channels (IR3.9-IR10.8) for green and a visible and near infra-red channel (NIR1.6-VIS0.6) for blue.

On these images (once normalised according to [5]) "severe convection" appeared as being yellow. However the normalisation process was carried out differently and severe convection thus appears bright white in the images below. These images were then compared to the algorithm's output and were used to once again asses its effectiveness.

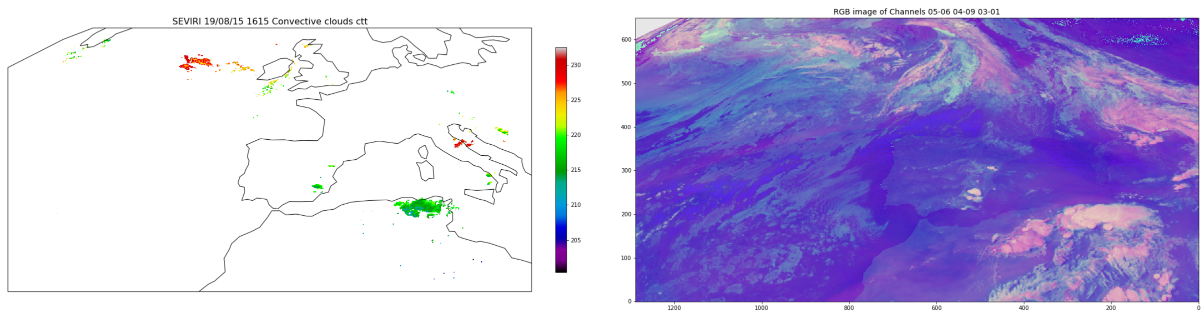

Figure 3: CTT of convective pixels flagged along with RGB image of channel differences for 16:15 on 19/08/2015

Once the algorithm for identifying convective clouds was validated their effect on aerosols was quantified. This was done by comparing the median aerosol optical thickness (AOT) of a given pixel (i.e a set location) in the 6 hours before and after it was flagged as being convective. This was then repeated over all convective pixel flags, for all time stamps.

The comparison was carried out by first filtering out AOT distributions that were very noisy. This was done by looking at the interquartile range of the AOT distributions in the 6 hour time window before and after the pixel flag, if the interquartile range was greater than 0.75 then the pixel flag was discarded, this seemed to remove a large proportion of distributions with low quality aerosol retrieval. Next data points above the 3rd quartile were discarded, mainly to remove data points associated with falsely deeming a pixel to be aerosol when it was in fact cloud, thus yielding a very large optical thickness.

Below is a graph of the temporal distribution of AOT for a random pixel that illustrates the filtering that was carried out. The dotted black line denotes at what time the pixel was flagged as being convective and the data points with a blue marker are those that got filtered out. The median AOT was then taken for the red data points.

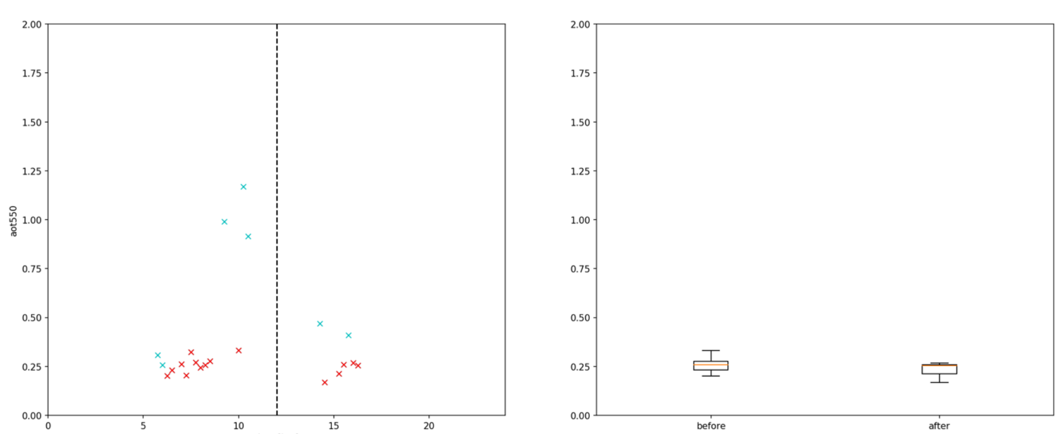

Figure 4: Illustration of the filtering of the AOT temporal distribution.

After the data had been filtered the median AOT before and after were obtained and compared.

3 Results

An analysis of 15 minutely data from 19th of August 2015 was carried out and the results are analysed in this section, aerosol retrieval over land was not carried out due to its unreliability. The comparison between AOT before and after convective clouds yielded a measurable drop. Below are histograms of the distribution of AOT values before and after convective cloud.

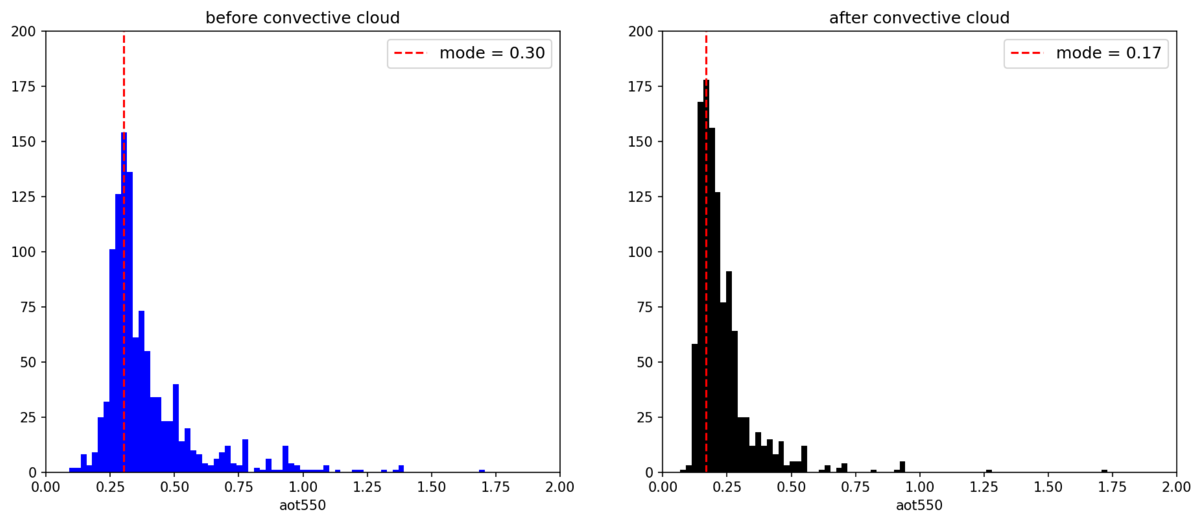

Figure 5: AOT distributions before and after a convective cloud for the 19th of August 2015

Both of the histograms above contain the same number of points (just over 1000) and are from the results post filtering. The histograms show a drop in the peak value of 0.13 as well as an increase in the localisation of the distributions about the peak value. This increased localisation, i.e. lower proportion of high AOT and higher proportion of lower AOT, is to be expected as the 'cleaning' effect should be more effective in air that is more optically thick.

Next the distribution of change in AOT between before and after a pixel was flagged as convective was conducted. This once again yielded a peak drop of 0.13, with a mean difference of -0.16 and median of -0.14. The distribution appeared to be Gaussian with a standard deviation of 0.22.

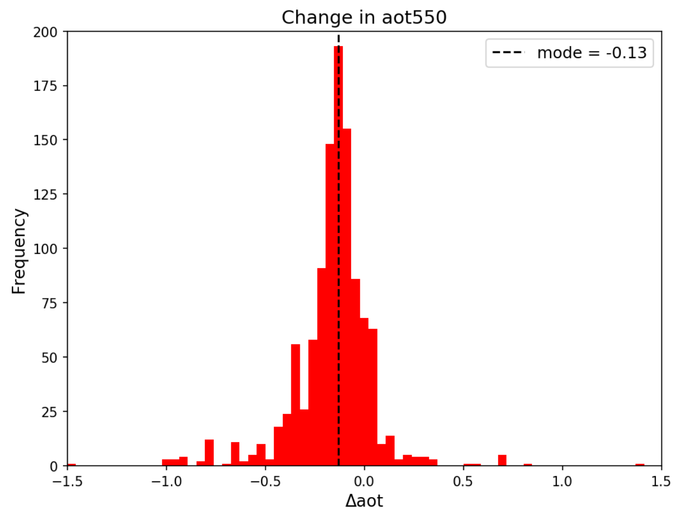

Figure 6: distribution of changes in AOT for filtered data from 19th of August 2015

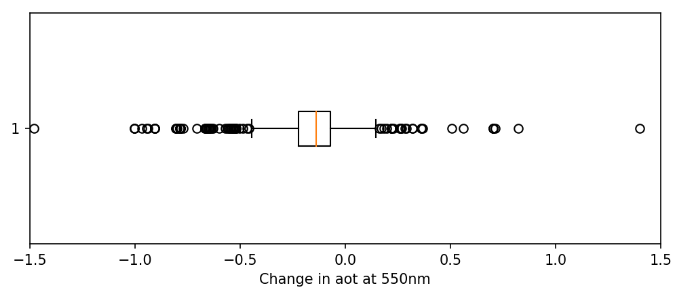

Figure 7: box plot of distribution of changes in AOT

This histogram once again shows a measurable drop in AOT. A similar comparison was done for pixels that were cloudy, but not necessarily convective and a similar distribution was observed, but with an average value at 0.

Considering the above distribution of change in AOT and one of the distribution prior to the filtering, shown below (with a mean of -0.17), highlights the lack of accuracy in the aerosol retrieval and how improved filtering techqinues could further improve the robustness of the result.

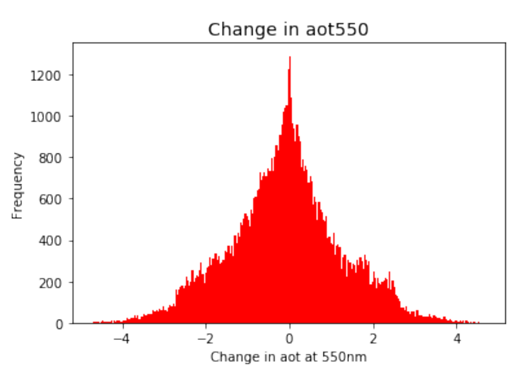

Figure 8: unfiltered distribution of changes in AOT

4 Conclusion

The effect predicted by the hypothesis was observed and roughly quantified. A drop of about 0.13 in aerosol optical thickness was measured. In addition to this, algorithms for locating the tropopause and convective clouds were also produced. The described analysis does however needs to be carried out for a larger data set with more rigorous filtering techniques before any robust, quantitative conclusions and can be derived from the results.

Effects other than the 'cleaning' by convective clouds may need to be accounted for before these results can be fully attributed to hypothesised phenomena, some of the alternative effects include; diurnal variations in aerosol optical depth[7], changes in aerosol optical thickness caused by an increased aerosol size (due to water coalescing about aerosols) though the aerosol may remain in the same place, aerosols dropping to a lower altitude (causing a decrease in AOT without necessarily cleaning that part of the troposphere) due to their increased mass yet remaining in the same area and hence not being cleaned out the troposphere exactly as hypothesised.

Further analyses could incorporate the vertical distribution of aerosol from lidar measurements to investigate possible changes in aerosol altitude and an analysis of the change in aerosol effective radius could be used to determine its contribution to the change AOT.

5 Acknowledgements

I'd like to thank Dr Adam Povey and all of the EODG group for the amazing oppurtunity. This project has been a great learning experience that has enabled me to get a feel for what academia is like and gain invaluable skills. Integration into the group through the groups meetings and weekly presentations provided great insight into the sorts of things people were working on in the field and provided a wider framework within which I could better understand the importance of what I was working on. The meetings also provided an enviorment where I could get advice from people with different specilaizations and differing approaches on how to best tackle any challenges I was facing.

References

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