Response to anonymous referee :

We thank the reviewer for their comments. We address each point below. For clarity, reviewer's comments are in italics, our response is in plain text, additions or changes to the paper are in bold.

1) p. 3412 par. 2 Note also Garrett et al., 2012, Tellus, which extended analysis to Alert and to soot.

Assuming the reviewer is referring to 'The role of scavenging in the seasonal transport of black carbon and sulphate to the Arctic', Garrett et al. (2011), Geophysical Research Letters, a reference has been added.

2) p. 3412, par. 3 Note also Hirdman et al., 2010, ACP 9351-9368.

Reference has been added

3) p. 3419 "The two data sets differ substantially, however the MODIS fields are used north of 60 because they agree much better with surface observations of cloud cover (Curry et al., 1996; Curtis et al., 5 1998)". A remarkably prescient analysis by Curry and Curtis? Perhaps this sentence can be written so that it doesn't seem to imply that MODIS analyses were being done in the mid-90s.

Re-worded page 3419, line 2 as: **MODIS has been shown to retrieve Arctic cloud fraction with greater accuracy (compared to surface climatologies) than other instruments (Liu et al., 2004). This substitution is discussed further in section 4.**

4) p. 3419. MODIS should be spelled out where it is introduced first.

Text has been changed

5) p. 3421 "Aerosol lifetimes with respect to wet scavenging in warm (liquid-phase) clouds are of the order of 1 h even at light precipitation rates of 1mm/d (Curry et al., 1996)." This perpetuates a wide spread confusion about wet scavenging where it is presumed that clouds are somehow separate from the air around them. Because air is cycled through clouds, wet scavenging by clouds affects the entire mixed-layer in which they lie. Of course the Arctic tends to be fairly stable, but not so much so that clouds don't influence a layer deeper than their depth. Also, it might be worth mentioning here why scavenging times are so short independent of precipitation rate. The precipitation rate scales roughly as the liquid water path as in Eq. 2.

Here we mean that the in-cloud lifetime (that is the lifetime of aerosol in air parcels moving through the cloud) is of the order 1h. The text has now been altered to differentiate between the in-cloud CCN lifetime and the grid-box CCN lifetime (lifetime of all CCN in one grid-box). This paragraph has also been re-written so as to discuss the independence of the CCN in-cloud lifetime from the precipitation rate (i.e. why CCN in clouds with light precipitation rates still have short lifetimes).

First paragraph of section 5.1 now reads: I**n-cloud aerosol lifetimes with respect to wet scavenging in liquid-phase clouds are of the order 1h (Curry et al. 1996). In addition, in-cloud CCN lifetimes in liquid-phase clouds are generally independent of the cloud precipitation rate as liquid water path scales to the precipitation rate, leading to cancellation in Eq. 2 (Wood, 2006). However, scavenging processes in ice-phase clouds are much less efficient and in-cloud CCN lifetime can extend to 1 month if ice-nucleation is the predominant scavenging process (Davidson et al., 1987, Vinogradova and Ponomareva, 2000).**

6) Please double check throughout that the references chosen actually apply to the text to which they are affixed. Did Davidson really discuss scavenging by droplets in their study of the Greenland ice sheet?

This has been corrected. All other references have been checked.

7) p. 3421 "Conversely ice crystals tend to form via the nucleation of ice onto individual particles and grow by vapour deposition rather than collision and coalescence". Anywhere that ice crystals form from a liquid cloud, riming is almost inevitable, and so collision-coalescence is an important process in cold clouds too. It needs to be clarified how riming is represented in the model simulations. Note that in the Arctic, liquid can be present at temperatures that are even colder than -15ºC (e.g. Hobbs and Rangno, 1998).

As discussed in the previous response to Dr Flanner the inclusion of a separate mixed-phase scavenging scheme is not possible in GLOMAP. The neglect of riming processes in the model could lead to an overestimation of scavenging above -15ºC (where we assume all clouds are liquid) or an underestimate below -15ºC (where we assume all clouds are ice). However, the neglect of riming scavenging processes is likely to have little effect in winter when clouds are predominantly ice-phase or summer when liquid-phase clouds dominate.

In spring, when mixed-phase clouds are common in the Arctic boundary layer (Hobbs and Rangno, 1998), neglect of riming scavenging could alter the timing of the transition from the Arctic haze period to the `clean` summer. However, evidence of this effect is not obvious in the model-observation comparison in Fig 7. The exclusion of riming in the GLOMAP wet deposition scheme is discussed further in referee response 1 and is now also included in the paper (on page 3422 and 3435).

8) p. 3422 It seems that black carbon is not scavenged in the model except at very cold temperatures. Aged aerosols that reach the Arctic are likely to be internally rather than externally mixed (e.g. Covert and Heintzenberg, 1993), in which case I would expect that black carbon and soluble aerosols will be removed with nearly equal efficiency. Shouldn't this be represented in the simulations?

Soluble BC is scavenged with the same efficiency as SO_4 at temperatures above -15ºC. Insoluble BC can be activated as IN (at temperatures below -15ºC) and deposited. However, this deposition process is negligible (see response 1). In winter and spring almost all modelled BC is soluble (between 80-90% of the total BC mass) and as shown in Figure 10 is affected by the suppression of ice-phase scavenging in the lower troposphere to the same degree as sulphate. However, in the late summer 70-90% of BC mass is insoluble so stratocumulus cloud scavenging of BC is less efficient than that of SO_4 (Fig 9). The high hydrophobic fraction in the late-summer modelled BC load likely results from our treatment of ageing in GLOMAP, which is sensitive to both SO_2 emissions and the H_2SO_4 condensation sink. The sensitivity of BC concentrations to the GLOMAP ageing scheme is now addressed in the paper (page 3436) and discussed further in reviewer response 1.

9) The point that Arctic rather than sub-Arctic precipitation seems most important to the precipitation is particularly interesting, and a bit counter-intuitive given that precipitation rates are so much higher at lower latitudes. The sensitivity studies are very nice, but a bit black box. Can more insight be provided on how aerosol make it to 60ºN without being scavenged? Is it that the plumes tend to be sub-saturated until they are cooled?

In summer, we suggest that extra-Arctic stratocumulus scavenging has a negligible effect on summertime Arctic aerosol concentrations (section 7.2.3), mainly because low-cloud coverage is relatively low compared to the Arctic. However, Arctic aerosol is sensitive to extra-Arctic scavenging in frontal and convective clouds throughout the year (Shindell et al., 2008; Korhonen et al., 2008). Comparison of the deposition rate between the CTRL and DRIZZ simulations suggests that stratocumulus cloud rapidly scavenges aerosol transported through the marginal Arctic troposphere (Fig. 9c). Essentially, drizzle scavenging becomes an important process when the transported aerosol encounters the region of persistent Arctic stratocumulus. Therefore, in GLOMAP, we can infer that the majority of aerosol plumes that reach 60ºN enter the Arctic through the lower troposphere. This result is consistent with the lagrangian study of Stohl, (2006).

10) The Arctic is drier in winter than in summer due to reduced sources of moisture and convection. Why is this alone not sufficient to account for the seasonal cycle in scavenging without invoking cloud microphysical effects? It is very interesting that microphysical effects seem to be important, but surely these aren't the first order control?

The most importance Arctic deposition process in GLOMAP is summertime stratocumulus cloud scavenging. Stratocumulus cloud is indeed formed in the summer due to the increase in Arctic humidity. The details of the precipitation formation processes (if these are the microphysical effects the reviewer refers too) are probably not the first order driver of the summertime scavenging. However, Arctic precipitation rates in the winter and early spring are appreciable. Our model suggests that suppression of scavenging rates in ice-phase high-level frontal clouds is needed to explain Arctic haze. Without this "microphysical effect", wintertime Arctic aerosol concentrations would be very low. Once the aerosol has been transported to the Arctic, the dry and stable atmospheric conditions enable the persistence of the Arctic haze. However, the haze is the result of long-range transport in the mid-upper troposphere (Stohl, 2006). From our analysis we suggest that cloud microphysical processes (precipitation formation) could be an important process controlling long-range transport efficiency into the Arctic and therefore the Arctic seasonal cycle in BC and sulphate concentrations.

Additional references

Garrett, T. J., S. Brattström, S. Sharma, D. E. J. Worthy and P. Novelli, The role of scavenging in the seasonal transport of black carbon and sulfate to the Arctic, 2011, *Geophys. Res. Lett.*, 38, L16805, doi:10.1029/2011GL048221

Hirdman, D., H. Sodemann, S. Eckhardt, J. F. Burkhart, A. Jefferson, T. Mefford, P. K. Quinn, S. Sharma, J. Ström and A. Stohl, Source identification of short-lived air pollutants in the Arctic using statistical analysis of measurement data and particle dispersion model output, 2010, *Atmos. Chem. Phys.*, 10, 2, 669-693,