RESPONSE TO KURBATOV (Referee 2):

Comment: "The data presented in Table 1 make it impossible to evaluate the precision and accuracy of the analyses conducted on tephra particles extracted from ice cores. In general, high silica, high alkali glass are quite unstable under the electron beam. If this is the case, several potential volcanic regions with relatively poor historical records from the Azores (eg. Ablay et al., 1998) to Iceland or Iranian volcanoes (Davidson et al., 2004) are possible candidates based on geochemical fingerprint and measurement errors"

Response: We agree with the necessary of presenting the precision and accuracy of the analyses. We have incorporated a paragraph detailing the Philips XL30 and EDAX DX4 settings, the precision and accuracy as outlined in other publications, and Table 1 now includes our sanidine fragment analyses as well as information regarding the standard reference materials. Please see our response to Reviewer 1 for the full explanation of these changes. We have created a few figure (Figure 4) to better demonstrate why other relatively coeval volcanoes are not likely candidates as source volcanoes. As the reviewer mentions, high silica, high alkali glass is often unstable under the electron beam. Therefore our analyses are likely underestimations of the silica and alkali content. If this is the case, and the tephra actually have either higher silica and/or alkali content, the only two source options are Vesuvius or (if higher silica) the A.D. 90 ± 100 Sete Cidades Azores eruption. We are very interested in comparing the geochemical composition of the GRIP tephra to the Sete Cidades tephra in biplots similar to Figure 5. However, to the best of our knowledge, no such detailed information about the geochemical composition of the Sete Cidades A.D.90 eruption exists. Such a comparison would certainly be an interesting future study. We include the following new paragraph to address these points:

When compared against the total range of possible geochemical classifications, the six GRIP tephra fragments all fall within the phonolitic classification (Figure 4). However, when comparing the tephra fragments with whole-rock and individual pumice samples from the Pompeii A.D. 70 Vesuvius eruption, the GRIP particles appear relatively heterogenous (Figure 5; Santacroce et al., 2008; Balcone-Boissard et al., 2009). The GRIP tephra all contain high alkali (K_2O and Na_2O) concentrations and biplots demonstrate that for these elements all GRIP particles are consistent with previously determined Vesuvius chemistry (Figure 5). This high alkali concentration is important as, when comparing the Vesuvius eruption to coeval (A.D. 50-100) eruptions, only Vesuvius and eruptions from the Azores have high alkali concentrations (Figure 4; Table 4). The GRIP tephra differ from the Vesuvius values in FeO and TiO_2 versus CaO biplots (Figure 5), yet the range of Fe and Ti weight percentages remain within or close to those of Vesuvius (Figures 5 and 6). It is difficult to compare the GRIP FeO and TiO_2 values to other sources as using SEM-EDS to determine these oxides results in a high percentage of standard deviation even when analyzing standard reference materials (Table 1). Particles 1 and 2 contain higher SiO_2 values than the other tephra and plot near the phonolite-trachyte boundary (Table 1; Figure 4), suggesting that the Sete Cidades (A.D. 90 ± 100) eruption could be a source of these two particles. Comparing the geochemical composition of particles 1 and 2 to ejecta from the Sete Cidades eruption could illuminate if these particles are from the Azores, but to the best of our knowledge, no detailed geochemical analysis of the A.D. 90 Sete Cidades tephra exists. As particles 1 and 2 remain within the phonolitic chemical characterization (Figure 4) and as they are similar to other GRIP and Vesuvius products (Figure 5), we assume that they are from the same source as the other GRIP tephra. ……..

Of the coeval eruptions, only Sete Cidades and Furnas also have high alkali contents, although their geochemical classification (resulting either from higher SiO_2 contents and/or lower K_2O+Na_2O contents) differs from that of Vesuvius (Table 2; Figure 4). The consistently high K_2O and Na_2O weight percentages of all analyzed GRIP tephra makes it likely that the GRIP tephra are from any known coeval volcano other than Vesuvius, Sete Cidades or Furnas (Figures 4 and 5). The high GRIP K_2O and Na_2O values and their

correspondence with multiple measurements of Vesuvius pumice, strongly suggest that Vesuvius is the source of these tephra.

Comment: The reviewer requests the following information:

- SEM images
- Total number of particles and grain size analyses suing SEM images
- Philips XL30 and EDAX DX4 settings, including geometry of EDS detector(s)
- Results of EDC measurements of Vesuvius white pumice of the same size on the same instrument under the same operating conditions and with the same tools and supplies
- Monte Carlo simulation of grain size dependence on tephra particle analysis that could predict possible changes in measured composition

Response: We agree with the reviewer that this information helps strengthen the paper. We have included information regarding the Philips XL30 and EDAX DX4 settings, and the geometry of the EDS detector in the methods section. We include the total number of particles, standard reference materials, and results of sanidine particles in Table 1. Please see our response to Reviewer 1 for the detailed changes that we have made to the manuscript to incorporate these points. Unfortunately, our SEM image quality is quite poor and we are not including these in the manuscript. We have included sentences (changes in italics below) regarding the fact that we only have six tephra particles, yet this low number of particles is within the range of published values. As we only have six particles, these are too few to allow Monte Carlo simulations of grain size to provide meaningful predictions of composition.

"These six tephra particles extracted from the GRIP ice core comprise a limited data set, but are consistent with numbers of volcanic tephra found in Greenland ice cores (Narcisi et al., 2010 and references within). Previous analyses of volcanic glasses in Greenland ice cores indicate that the concentration of volcanic shards in ice may vary by orders of magnitude and can range from visible ash layers to as few as < 10 particles per kg of ice (Davies et al., 2010 and references within). *The presence of tephra in ice core records has only one possible source, and is a clear indication of past volcanic activity*."

Comment: "My last major point is related to the comment made my Dr. Baillie about potential "circularity" in loading for the A.D. 79 Vesuvius Eruption, estimated from ice core records (see page 5438, Line 25). The majority of ice core researchers are well aware that the atmospheric loading calculation for this eruption is based on magnitudes of sulfate spikes in Dye 3, GRIP and GISP 2 ice cores. It is also known that in the GISP2 annual counted chronology the only available acidity peak was about ten years off from the A.D. 79 date (see Zeilinski, 1995, page 20,940), thus providing a possibility for "another volcanic event". I agree with Dr. Baillie's concern that large sulfate spike attribution to A.D. 79 eruption could mislead the estimation of the total sulfate eruption burden if no other independent methods for the estimate of sulfate emissions from this eruption are used. The authors could clarify their position in the next revision."

Response: We do not attempt to estimate or influence the magnitude of the total sulfate eruption burden. In order to minimize any confusion regarding this point, we have eliminated the entire paragraph from p. 5439 line 20 to p. 5439 line 5 (below). We do argue that a large acidity spike occurs in the GRIP ice core at 429.1 m depth. Acidity spikes can be caused by multiple factors, but a

concurrent SO_4^{2-} peak demonstrates that this acidity spike reflects a volcanic event. No other major ions peak during this period (Figure 3) providing further proof of the volcanic origin. We have extracted tephra from the microparticle peak at 429.3 meters depth. Tephra only have a volcanic source. The literature supports such offsets between tephra and SO_4^{2-}deposition of volcanic emissions on ice sheets. Therefore, the main question becomes determining if our chemical analyses of the tephra are sufficient to determine a Vesuvius source. In order to better address this point, we have created two new figures (Figures 4 and 5) that compare the GRIP tephra with the geochemical characteristics of other relatively coeval volcanoes (Figure 4) and biplots that compare the chemical composition of the GRIP tephra with known Vesuvius A.D. 79 pumice and whole-rock analyses.

The GRIP sulfuric acid flux between 428.8 to 429.0 m is consistent both with elevated sulfuric acid concentrations in the DYE-3 ice core for strata dated within the same range and with the quantity of sulfuric acid ejected by the 79 A.D. Vesuvius eruption (Clausen et al., 1997). The estimated amount of sulfuric acid released into the atmosphere from this volcanic event ranges between 38 to 52 Mton (Zielinski, 1995; Clausen et al., 1997). A similar estimate from the same volcanic signal in the DYE-3 ice core (from an annual layer dated to A.D. 80) suggests ~ 47 Mton of sulfuric acid was injected into the atmosphere by Vesuvius (Clausen et al., 1997). The variability between sites may be due to wind erosion or the spatial distribution of deposition (Clausen and Hammer, 1988; Zielinski, 1995). These estimates of the ejected sulfuric acid are up to four times greater than the present average global annual flux of 13 Mton SO_2 emissions from explosive and non-explosive volcanism (Bluth et al., 1993), demonstrating the likelihood that Vesuvius eruption products would have been sufficient to change hemispheric concentrations of sulfuric acid.

We have also changed the caption for Figure 1 to address this point. The new figure caption is now:

"Acid concentrations in the GRIP ice core determined by high-resolution electrical conductivity measurements (ECM) over 425-435 m. The acid spike is attributed to the AD 79 eruption in the GICC05 chronology (Vinther et al., 2006)."

Specific comments Kurbatov:

Page 5430, line 25. Why do the authors reference Kelley et al., 2006 and ignore early work on this topic? Maybe add some specific details why his paper was important for understanding how "low-latitude explosive volcanoes…. Are capable of cooling the global climate for several years".

Response: In order to properly represent earlier work on this topic, but also remain within the publication criteria, we have changed the attribution to (Kelly et al., 1996 and references within).

Page 5431, line 10. Maybe replace the reference to Langway et al., 1998 with the paper by Rampino and Self (1982). Reword lines 10-13 so it is clear to the reader that SO2 injected into the stratosphere by large volcanic eruptions is more likely to be transported to polar regions once it is converted into H_2SO^4 based aerosols.

Response: We have incorporated these suggestions into the text in the following manner (changes in italics):

"Volcanoes release SO_2 into the atmosphere which oxidizes in the eruption plume to form H_2SO_4 (*Rampino and Self, 1982;* Langway et al., 1988). *The conversion of SO_2 into H_2SO_4 facilitates transport of volcanice emissions to the polar regions as* H_2SO_4 is able to reach the stratosphere. This atmospheric height means that even H_2SO_4 that forms in low-latitude volcanic clouds can eventually reach the polar regions (*Rampino and Self, 1982;* Langway et al., 1988)."

Page 5433, line 25. Need more explanation about why mass of material suggests that tephra reached Greenland.

Response: We have omitted the reference to the mass of material, and this sentence now reads, "The height of the convective columns *reaching the stratosphere* suggest that tephra and volcanic acids could reach the Greenland ice sheet surface."

Page 5435, line 7. "Are generally considered to signify volcanic eruptions in Greenland ice cores". I agree with Dr. Baillie that new data from a number of ice cores show complex relationships between acidity peaks, tephra layers and confirmed historical volcanic eruptions (see more in Davies et al., 2010: Coulter et al., 2012). The authors also say this on Page 5422, Line 12. Maybe remove the reference to Clausen et al., 1997 and just mention that there is an ECM peak at 429.1 m depth in the GRIP ice core?"

Response: We agree that the reference to Clausen et al., 1997 and Figure 1 cause confusion within the text. We have changed the caption to Figure 1 (as above) and have removed the reference to Clausen et al., 1997 as well as the phrase "*where ECM peaks > 4μeq/kg are generally considered to signify volcanic eruptions in Greenland ice cores (Clausen et al., 1997)"* These lines now read: "*The ECM data demonstrate only one major peak (429.1 m depth) between 60 to 90 A.D. (Figure 1)."*

Page 5441, line 6. "We demonstrate that the high acidity signal and SO2 spike found at 429.1 depth and the microparticle peak at 429.3 m in the GRIP ice core are caused by a major volcanic eruption. " Maybe remove this line or reword" This sentence is not really related to the goal of the paper.

Response: We agree with the reviewer and have eliminated this sentence.

Page 5441, line 14. "The low number of glass fragments in the ice is likely due to the relatively low height of the eruption column (26-32 km), and the SSE trajectory of the plinian phase of the eruption (Carey and Sigurdsson, 1987; Sigurdsson et al., 1990). This low number of volcanic glass fragments is consistent with quantities of volcanic ejecta in ice cores (Palais et al., 1992)." Transport of volcanic material to polar regions is still relatively poorly understood. References provided by the authors no not provide any quantitative information on how the number of volcanic particles in the Greenland ice core should be related to the magnitude of the volcanic events.

Response: We agree with the reviewer that "transport of volcanic material to polar regions is still relatively poorly understood". We acknowledge that we have only 6 tephra pieces, but this low number is similar to other studies. We omitted the sentence highlighted by the reviewer. We have changed the text to the following (changes in italics):

No volcanic glass particles were found in the 429.15-429.25 m microparticle peak, and all microparticles had elemental chemical composition typical of continental crust. This large microparticle peak does not influence any conclusions regarding volcanic activity. However, the microparticle concentration peak at 429.3 m contained six tephra particles with a K-phonolitic composition (Table 1; Figure 4). These six tephra particles extracted from the GRIP ice core comprise a limited data set, but are consistent with numbers of volcanic tephra found in Greenland ice cores (Narcisi et al., 2010 and references within). Previous analyses of volcanic glasses in Greenland ice cores indicate that the concentration of volcanic shards in ice may vary by orders of magnitude and can range from visible ash layers to as few as < 10 particles per kg of ice (Davies et al., 2010 and references within). *The presence of tephra in ice core records has only one possible source, and is a clear indication of past volcanic activity*.

Technical corrections: We have addressed and changed all requested technical corrections.