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Relevance of Geothermal Sources and Ocean Circulation in the Reduction of the West Antarctica Sea Ice Sheet

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Abstract

A recent article by Schroeder et al. [1] suggests that geothermal heat may be the trigger of the reducing West Antarctica mostly marine ice sheet. I propose that the geothermal contribution is only a small part of a complex situation that also involves effects of ocean and air temperatures, glacial history, ice thickness, mass balance and sub-glacial elevations that unfortunately are not monitored as they should. Consideration of the simultaneous influences of all these factors are required to come to a meaningful conclusion about the West Antarctic (or the Arctic) ice sheet. A complex puzzle is not solved by a single piece, in this case a geothermal source, in the case of the IPCC [2] proxy data of surface air temperature.

Keywords

Geothermal Sources, West Antarctica, Antarctic, Sea Ice, Lower Troposphere Temperature

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1. The West Antarctica Ice Sheet

The Western Antarctic ice sheet is mostly marine-based. Also the bed of the ice sheet on land is located below sea level and the edges stream into floating ice shelves. The West Antarctic ice sheet accounts for less than 10% of the total Antarctic ice sheet. The rocks underlying the ice cap on land are sinking because of the weight of the ice thus increasing the ocean exposure of the sheet. This downward movement caused by isostatic adjustment is therefore increasing the exposure of the global West Antarctic ice sheet to the water conditions.

2. Known Climate Patterns

We know that the near-surface air temperatures are characterised by annual, inter-annual and multi-decadal variability. Observational data indicate that changes in near-surface temperatures since the early 1900s are superimposed on a longer-term trend of warming [3-5]. There has been an increase in solar activity over the last 100 years, but during the last two decades, it has stabilized [6, 7]. Also, the presence of greenhouse gases in the atmosphere has increased over the last 100 years [2]. Instrumental evidences gathered in recent years indicate that while the Arctic sea ice has been shrinking considerably during the last few decades, the Antarctic sea ice has been growing, and the ice cover in West Antarctica is the only exception to this expanding trend [8, 9].

3. Satellite Lower Troposphere Temperature Results

The satellite monitoring of temperatures, for example the Remote Sensing Systems (RSS) global monthly average Lower Troposphere Temperature (LTT) [10], is proposed by many authors, as for example [9]. The reader may consider the LTT anomaly since 1979 global and for the northern (60 to 82.5) and southern (-70 to -60) Polar Regions of [9]. The

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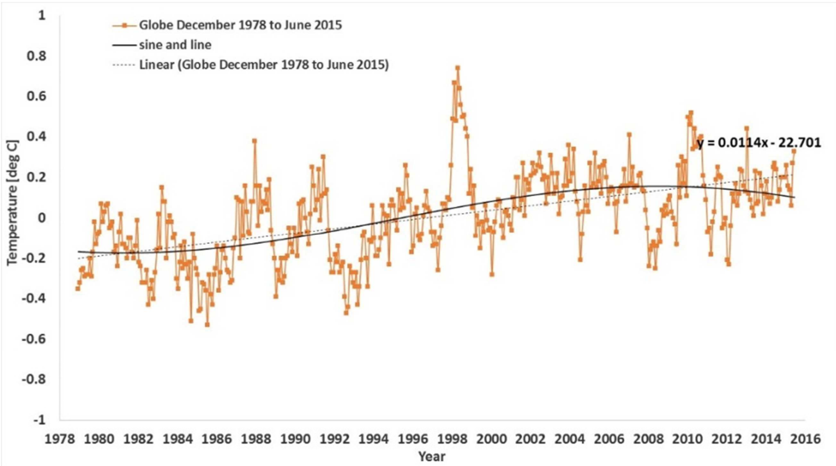
global (from -70 to +82.5 degrees of latitude) temperatures have been increasing since 1979 at a rate of +0.121°C/decade. However, the temperatures for the North Polar Region (from +60 to +82.5 degrees of latitude) have been increasing at a much higher rate of 0.322°C/decade, while the temperatures for the South Polar region (from -70 to -60 degrees of latitude) have been decreasing at a rate of -0.018°C/decade. It seems reasonable to conclude that while the near-surface air temperatures are increasing globally, the Arctic warming is much larger and the Antarctic temperatures are stable. The error in the estimation of the LTT is very difficult to assess, however this satellite monitoring is certainly the best data set we do have for global temperatures.



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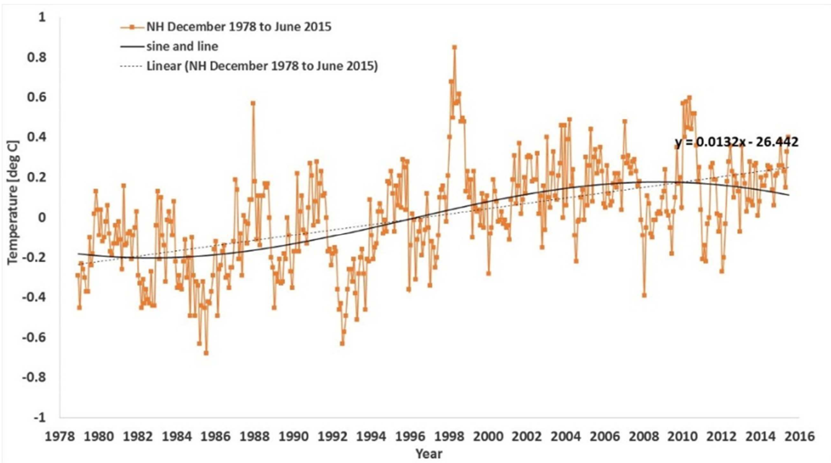

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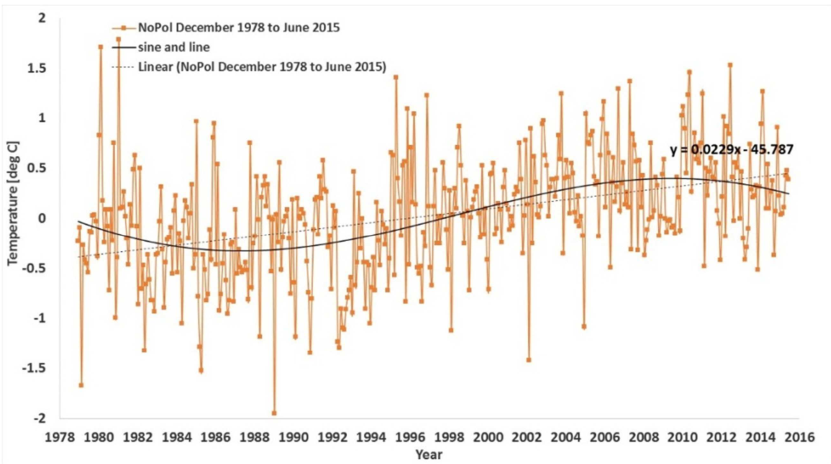

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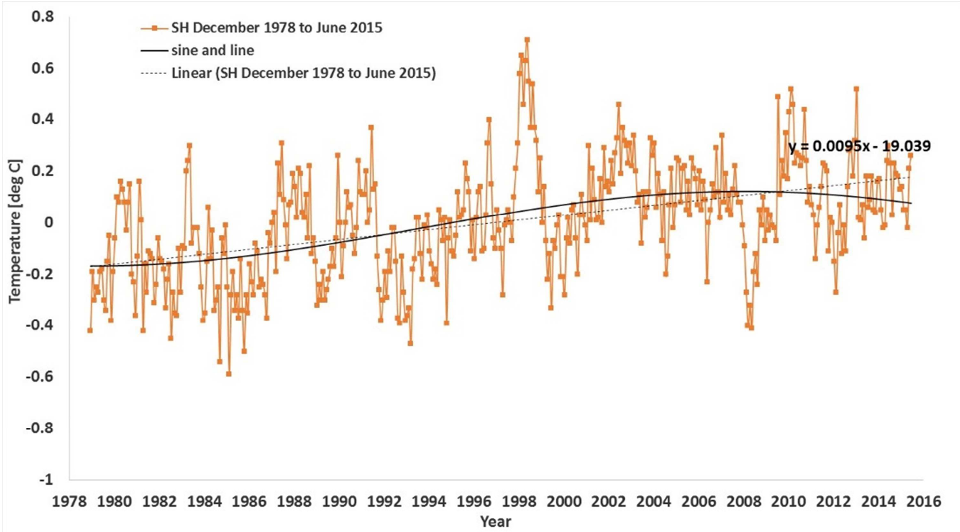

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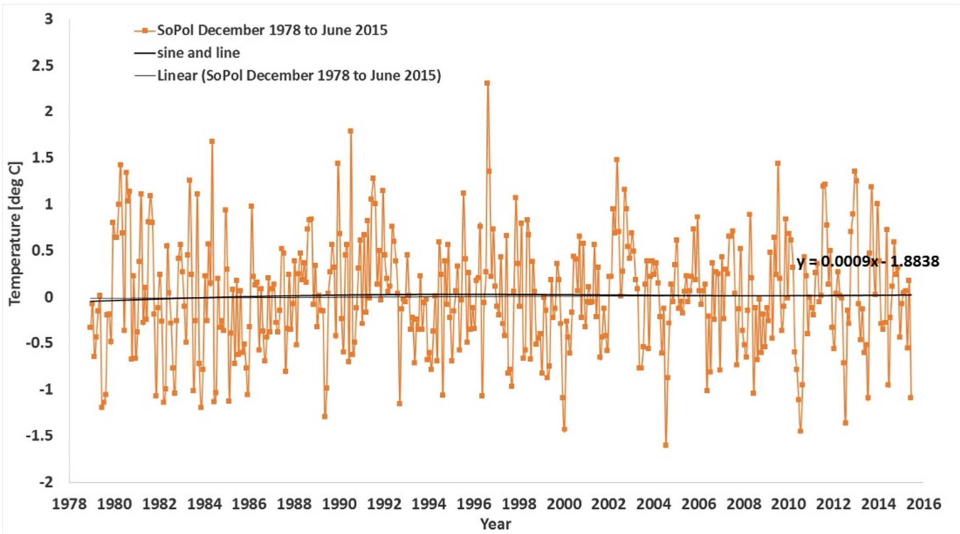

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Figure 1. Satellite lower troposphere temperature (LTT) from NSSTC [32]. a) Globe. b) Northern Emisphere. c) North Pole. d) Southern Emisphere. e) South Pole.

My contribution to the discussion, Figure 1 presents the satellite lower troposphere temperature (LTT) from NSSTC [32]. a) Globe. b) Northern Emisphere. b) North Pole. c) Southern Emisphere. d) South Pole. The amplitude of the natural oscillations increases approaching the North Pole and reduces approaching the South Pole. The data available do not permit to clarify the multi-decadal variability evidenced by scattered ground thermometers measurements.

As the temperatures are very well known to oscillate with many periodicities up to a strong quasi-60 years very well evidenced in the recorded data [3,4,5], the fitting with a line of the data collected starting from a valley of the multi decadal peaks & valleys oscillation certainly overrates the warming trend. I propose to better use a fitting with a line and a sine. This approach returns much smaller warming rates as the quasi-60 years oscillation turned from positive (warming phase) to negative (cooling phase) about the year 2000. With the linear fitting, the warming rate Globe is 1.14 C/century, the warming rate of the North Emisphere is a larger 1.32 C/century and in the North Pole, the linear fitting return an even larger warming rate at 2.29 C/century. In the South Emisphere, the warming rate from the linear fitting reduces to 0.95 C/century. With the fitting with a line and a sine of periodicity 60 years, the warming rate drastically reduces in all these case. The amplitude of the quasi-60 years oscillation reduces from the North Pole moving southwards. In the South Pole, the warming is basically zero and the quasi-60 years oscillation has a very small amplitude. The figure clearly shows the multi decadal variability is very likely substantial (the data collected are not enough), and the warming is everything but dramatic. The quasi-60 years pulsation seems to be a global phenomenon amplified in the Arctic and damped in the Antarctica. The pulsation is not limited to the temperatures but involves all the climate parameters from sea levels to rainfall.

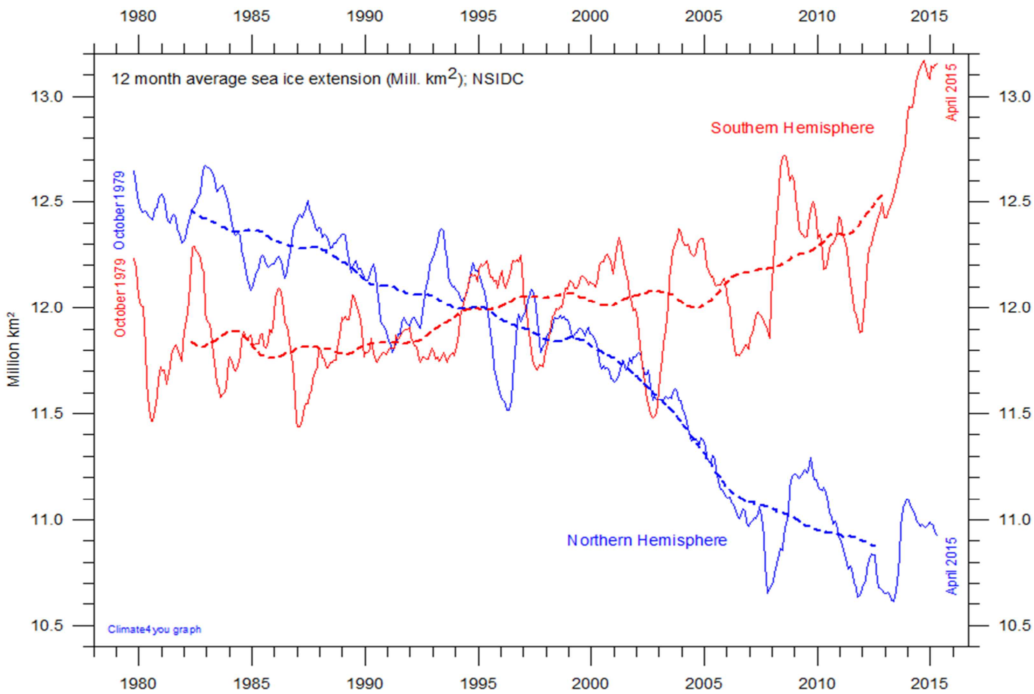


Figure 2. 12 month running average of NSDIC sea ice extension in both hemispheres since 1979. The stippled lines represent a 61-month average. Data is from [8]. The Arctic sea ice is shrinking but it is now turning stable, while the Antarctic sea ice is expanding. Image is from [9].

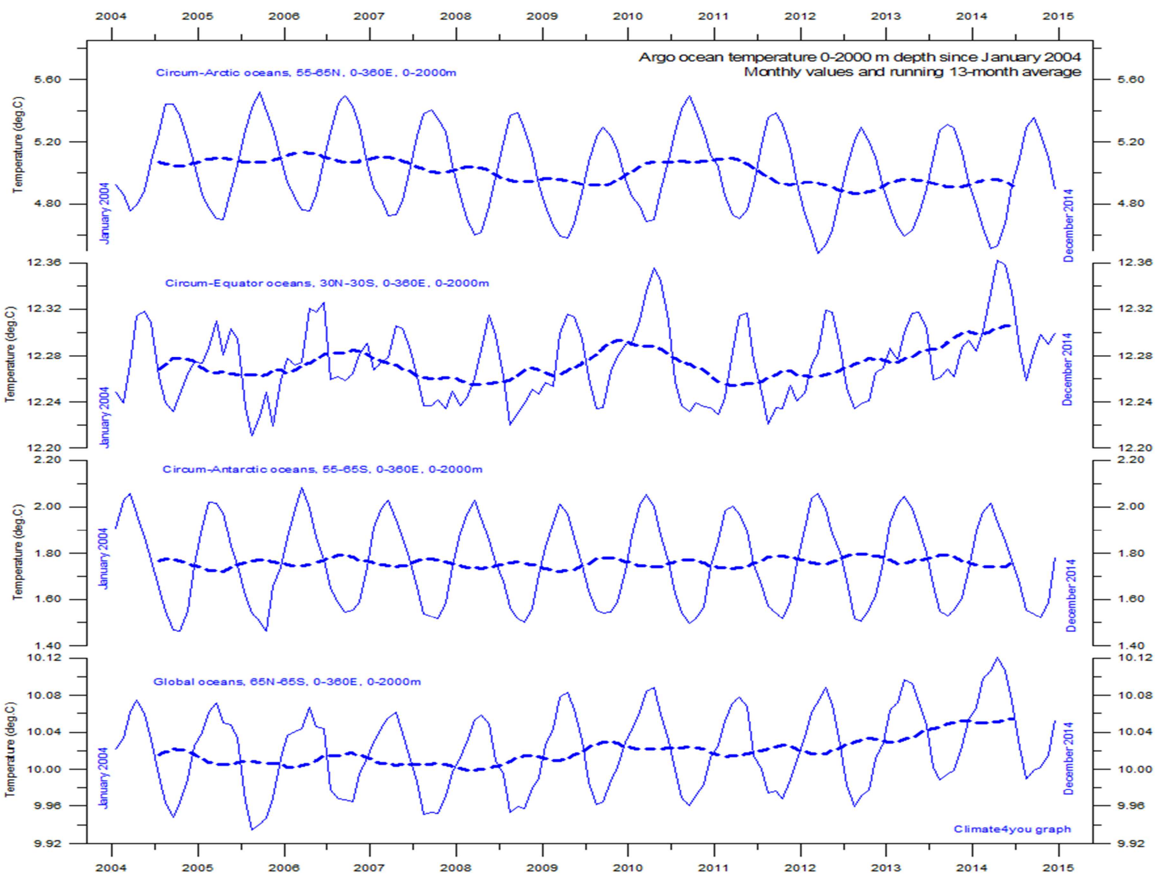


Figure 3. Diagram showing ARGO average 0-2000m depth ocean temperatures in selected latitudinal bands, using Argo-data. The thin line shows monthly values and the thick line shows the running 13-month average. Source of data [11]. The global oceans are marginally warming. The circum-Antarctic oceans have stable temperatures. The circum-Arctic oceans have marginally reducing temperatures. Image is from [9].

4. Satellite Sea Ice Extension Results

Similar satellite monitoring of the ice extension, for example the National Snow & Ice Data Centre (NSIDC) Sea Ice Index [8], is proposed by many authors, as again [9], and it is presented in Figure 2. The Arctic and Antarctic wide changes in sea ice extension in the online summary report of [9], with the 12 month running average of NSDIC sea ice extension in both hemispheres since 1979, indicate the sea ice extension of the Arctic has been regionally shrinking; however the sea ice extension for the Antarctic has been regionally expanding. Yet again, the error in the estimation of the sea ice extension is very difficult to assess, but this satellite information is certainly the best data set we do have for the global sea ice.

5. Ocean Buoys Temperature Results

Monitoring of ocean temperatures in the upper 2000 metres from the ARGO measurements [11] has shown that the circum-Arctic and the circum-Antarctic oceans haven't changed too much their temperatures over the last decade, even though the world oceans have warmed marginally. This is clear from the diagram showing the average 0-2000m depth ocean temperatures in selected latitudinal bands, using Argo-data, of [9], reproposed in Figure 3. As this marginal warming originates from removal of "*cold*" outliers (measurements from thermometers returning temperatures much colder than expected) but not of "*hot*" outliers (measurements from thermometers returning temperatures much warmer than the expected), very likely the world ocean temperatures haven't warmed at all over the last decade [12]. The global oceans are marginally warming. The circum-Antarctic oceans have stable temperatures. The circum-Arctic oceans have marginally reducing temperatures. Once again, the error in the estimation of the ocean temperature is very difficult to assess, but this result from a consistent float of buoys is definitely the best data set we do have for the ocean heat content.

6. Discussion of Arctic and Antarctic Different Patterns

The satellite monitoring of temperatures and sea ice extent and the ARGO monitoring of ocean temperatures are a necessary introduction to any study of the Antarctic or the Arctic changes in the climate.

The different behaviours of the Arctic and the Antarctic regions have puzzled the scientific community for many years, since a satisfactory explanation has not been found so far. Similarly, the fact that the Antarctic ice sheet is expanding while the West Antarctica ice sheet is shrinking lacks an explanation.

While the Antarctic is mostly land surrounded by water, the Arctic is water surrounded by land. The Antarctic is a relatively stable environment, where perturbations produce effects very likely damped. Conversely, the Arctic is a relatively unstable environment, where perturbations may produce non-damped but amplifying effects [13]. The Arctic amplification [13] is a mechanism where temperature, water vapour, clouds and surface albedo feedbacks contribute to amplify the warming effects that have been proposed to explain the rapidly shrinking and warming Arctic. This feedback mechanism does not fully explain the Arctic pattern, and certainly does not explain why West Antarctica ice sheet is shrinking while the overall temperatures are stable and the sea ice is expanding elsewhere in Antarctica.

7. Geothermal Sources for the Arctic and the Antarctic

The authors of [1] have recently shown that the Thwaites Glacier, the large, rapidly changing outlet of the West Antarctic ice sheet, is being eroded by the ocean but also being melted from below by geothermal heat. Radar techniques were used to map the water flows under the ice sheets and determine the ice melting rates. The results were interpreted as indicative of significant sources of geothermal heat under the Thwaites Glacier. They proposed that movement of magma and associated volcanic activity arising from the rifting of the Earth's crust beneath the West Antarctic ice sheet leads to enhanced heat flux beneath the glacier. As significant underwater cold seeps, hydrothermal vents, and more general volcanic and geothermal activity have been recently detected for the Arctic [14-23], the geothermal contribution to the melting of the Arctic and of the West Antarctica ice sheets may be larger than previously thought, even if only one part of a complex puzzle.

Because the Antarctic is much less covered by scientific studies than the Arctic, further geothermal information for the Arctic may certainly be of interest. However, it must be noted that the comparison of Arctic and Antarctic has its limitations, as for example the age of northern Ice Age is essentially quaternary, going back about 3 million years, while the Antarctic ice sheet has been around for over 33 million years.

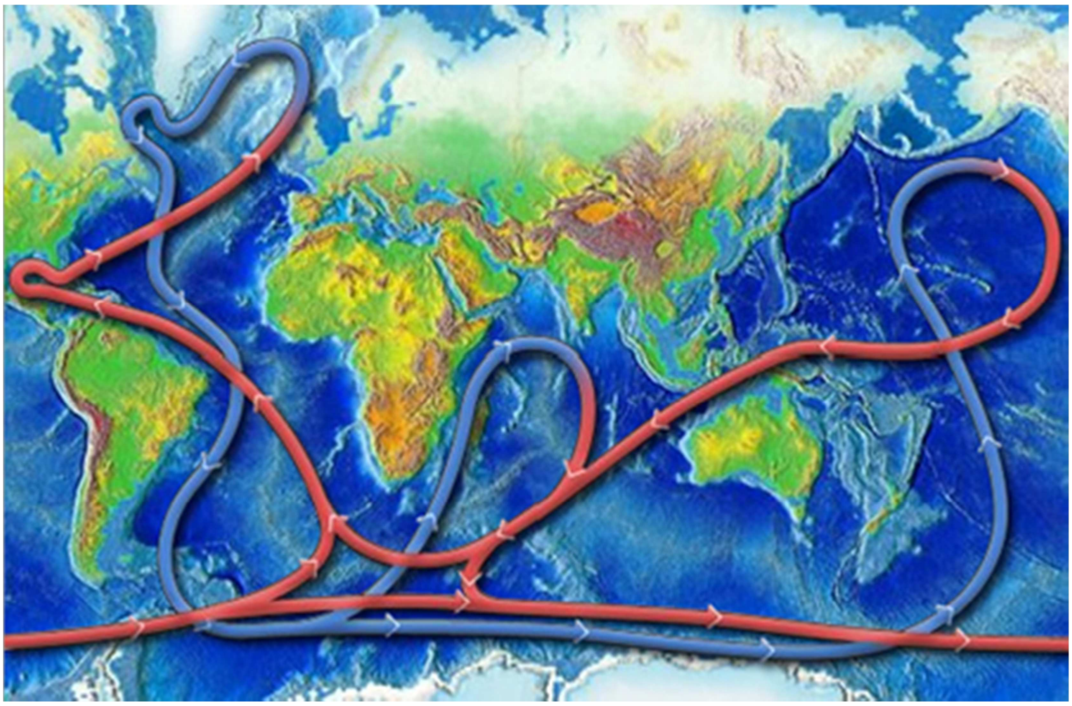
Methane expulsion from the ocean floor is a broadly observed phenomenon. The authors of [14] found a seepage in the Arctic west of Svalbard at 200 to 400 m water depth. The seepage is explained by ocean temperature controlled gas hydrate instabilities at the shelf break. The work [14] discusses the influence of tectonic stress on seepage evolution along the ~ 100 km long hydrate bearing Vestnesa Ridge in the Fram Strait reporting multiple seepage events coinciding with glacial intensification and active faulting for at least the last ~ 2.7 million years. The mud and methane emission of the Håkon Mosby Mud Volcano in the Arctic has been shown in [15] to be characterised by unsteady conditions of vigorous mud movement revealed by variations in fluid flow, seabed temperature and seafloor bathymetry. The work [15] documents multiple pulses of hot subsurface fluids, accompanied by eruptions that changed the landscape of the mud volcano. Four major recent events triggered rapid sediment uplift, substantial lateral flow and significant emissions of methane and CO_2 from the seafloor. Few years ago, the volcanic and geothermal activity in the Gakkel Ridge in the Arctic was the subject of many works [16-23]. The Gakkel Ridge, 1,800 km long and stretching across the Arctic from Greenland to Siberia, is one of the slow-spreading ridges where molten rock rises up from inside the earth creating new crust. The works reported widespread and ongoing gas and molten lava being blasted out of the Arctic seabed. The exploding mixtures of lava and gas flowing out of the volcanoes were forming huge clouds.

Are therefore significant underwater cold seeps, hydrothermal vents, and more general volcanic and geothermal activity playing a role for the Antarctic? Unfortunately, apart from recent works as [1], there is no evidence to support or negate this opportunity.

8. Ocean Circulation for the Arctic and the Antarctic

In addition to localised events such as the geothermal source mentioned in [1], there may certainly be the opportunity of a much broader range of underwater events occurring even far from the selected location that the complex ocean circulation could make relevant.

The melting of the West Antarctic ice sheet in otherwise stable temperature conditions may also be due to a warming from beneath due to changes in the ocean waters circulation. The path of the global "*conveyer belt*" may be found in many online sources as for example [24]. Strongest currents translate in more heat being conveyed, however with significant differences between Antarctica and the Atlantic and Pacific Arctic. A weakening or strengthening of the oceanic currents may certainly also affect the sea ice extension of West Antarctica. However, detailed measurements of the velocities and temperatures of the current are still presently unavailable and the qualitative image of [24] reproduced in Figure 4a only serves to understand the fact that any change in the amount of heat conveyed by the oceanic currents may have a dramatic impact on the climate in general and to the polar ice sheets in particular.



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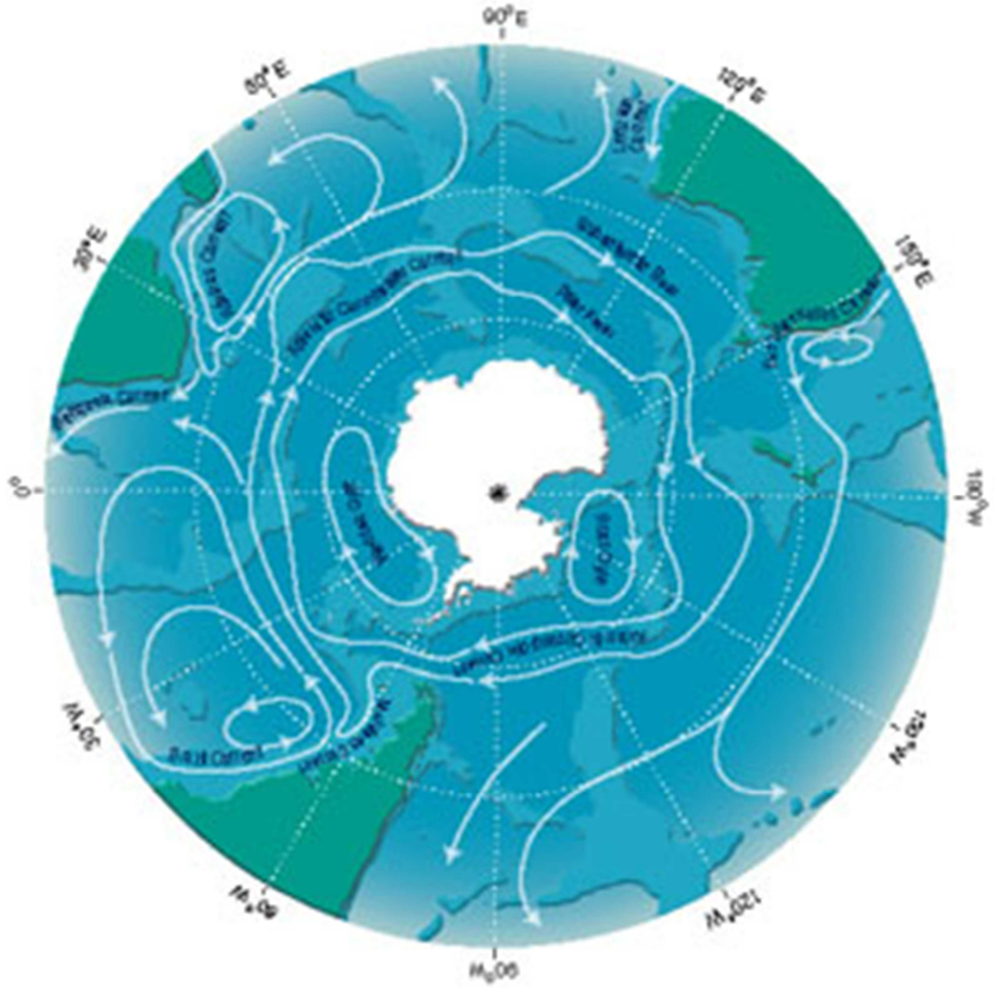

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Figure 4. a) Path of the global conveyer belt. The blue arrows indicate the path of deep, cold, dense water currents. The red arrows indicate the path of warmer, less dense surface waters. Strongest currents translate in more heat being Strongest currents translate in more heat being conveyed, however with significant differences between Antarctica and the Atlantic and Pacific Arctic. Image is from [24]. b) Schematic and simplified ocean currents of Antarctica. Image is from [31].

Moving from global to local, the details of the major currents south of 20° south longitude as for example in [31] reproduced in Figure 4.b may better illustrate the nature of seawater circulation around the West Antarctic ice shelf area. Any perturbation in the velocity or temperature of the stream below and around West Antarctica may impact on the melting of the sea ice there. Unfortunately, we do not have any detailed measurement to understand the changes occurring in the relevant time frame.

The West Antarctica ice shelves are also warmed from below by the Circumpolar Deep Water [25]. System imbalances, more intense melting, glacier acceleration and drainage basin drawdown have been previously attributed to the Circumpolar Deep Water [26-28]. The global "*conveyor belt*" of thermo-haline circulation redistributes heat between the poles and the tropics. The influence of the oceanic currents on the Arctic and Antarctic marine ice sheets is certainly another topic that deserves further attention. Quantitative estimates of heat redistribution by ocean currents are unfortunately unavailable.

Changes in the global heat distribution by changing the speed of the oceanic currents may indeed largely affect the polar ice sheets. At present, there are very little data for determining the changing strength of the ocean currents about Antarctica. For example, the Atlantic Meridional Overturning Circulation (AMOC) has been the subject of many works showing either stability or increasing or reducing trends by using indices and approaches all having the limitations of the inaccuracy and/or the short time windows that make them unable to determine a reliable trend cleared out of the variability [29, 30].

The simplified AMOC [29] computed by using the de-trended relative sea level records of The Battery, NY and Brest has shown a slightly increasing circulation since the early 1900, but with much higher strengths over the period 1860 to 1900, and a drastically reducing AMOC over the last decade. Other indices offer different interpretations equally right or wrong. To address complex issues we must have a detailed description of all the parts of the puzzle. Without these details, we do only have the option of conjectures.

9. Conclusion

The paper [1] has shown that the geothermal contribution may be the trigger of the accelerating melting of the West Antarctica ice sheet. The complex ocean circulation may also make relevant other geothermal sources located far from the melting marine ice sheet. This argument may certainly apply to the Arctic and the West Antarctic ice sheets. However, the above considerations are only a small part of a complex situation that involves ocean and air temperatures, geothermal heat flow, glacial history, ice thickness, mass balance, sub-glacial elevations, and many other factors that are mostly not monitored. To come to a meaningful conclusion about the West Antarctic ice sheet (or the Arctic ice sheet) would certainly take a major effort beyond what has been done so far, as the evidence available is simply not enough. What has been done in [1] is to delineate a small piece of a much larger puzzle. It is certainly important to understand that the puzzle is not solved by using a single piece, not a single localised geothermal source, nor the proxy data of surface air temperature as claimed by the IPCC [2].

In the last 3 decades, most climate studies have been funded to prove the presence of an ongoing catastrophic global warming. As a result of the focus on a single piece of many complex puzzles we still lack a proper understanding of many climate patterns. With the data we do have, the West Antarctica puzzle is impossible to solve. The West Antarctica sea ice shrinking in otherwise regionally stable conditions is not fully explained by the Thwaites Glacier geothermal source of [1] or by the Circumpolar Deep Water of [25-28]. I suggest that changes in the heat flow beneath the West Antarctica sea ice due to geothermal sources that are made relevant because of the changes they bring to ocean circulation or the strength of the circulation may be a cause.

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