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CLIMATE OF ANTARCTICA

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ABSTRACT

Anthropogenic warming of near-surface atmosphere in the last 50 years is dominant over the west Antarctic Peninsula. Ozone depletion has led to partly cooling of the stratosphere. The positive polarity of the Southern Hemisphere Annular Mode (SAM) index and its enhancement over the past 50 years have intensified the westerlies over the Southern Ocean, and induced warming of Antarctic Peninsula. This increase has strong regional and seasonal signatures. Models incorporating doubling of present day CO_2 predict warming of the Ant- arctic sea ice zone, a reduction in sea ice cover, and warming of the Antarctic Plateau, accompanied by increased snowfall.

Keywords: Component Antarctic Climate; Sea Ice; Glaciers; Southern Hemisphere Annular Mode; Antarctic Warming

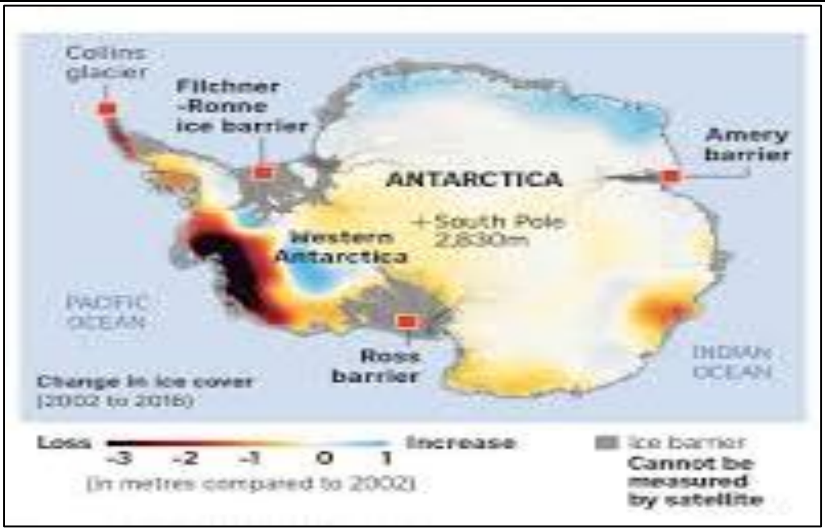
INTRODUCTION

Antarctica was discovered by James Cook who crossed the Antarctic Circle and circumnavigated the continent in 1773. The first landing on the continent was accomplished by the Norwegian whaling ship Antarctic in 1895, while the British were the first to spend a winter on Antarctica in 1899. . Airplanes first landed on Antarctica when Australian Hubert Wilkins flew 2092 km over the Antarctic Peninsula in the 1920s.A new mountain range discovered n 1929.by Rockefeller. Byrd. This is the coldest windiest & driest continent with a repository of more than 70% of the Earth's fresh- water as ice.

Antarctica hosts numerous fresh water and saline lakes in the ice-free oases on the edge of the continent such as the Vestfold Hills, Larsemann Hills and McMurdo Dry Valleys, which colonized by various organisms. The size of the lakes ranges from small to big. The continent is surrounded by sea ice which range from about two million square kilometres in January/ February (austral summer) to thirteen million square kilo- meters in September. In some regions, enhanced northward winds cause the sea ice to spread outwards from the continent. The sea ice extent peaked at 19.44 million $km^{2.}$

Antarctica, as it appears today exists for the past 60 million years, but it has not always been located where it is now, nor has it always been so cold. Antarctic history dates back to giant Southern Hemisphere land-mass known as Gondwanaland, which existed from 500 to 160 million years ago. At this time the eastern part of Antarctica formed the core of this super continent which also included Africa, South America, India, Australia and New Zealand. Evidence for this link up can be found in the similar geological features of the southern parts of these continents, which led Alfred Wegner to propose his theory of Continental Drift in 1912 that set the foundation to the development of theory of plate tectonics. It suggests that the continents move about on convection currents in the earth's molten interior. The supercontinent began splitting about 183 million years ago, during the Jurassic period. The violent volcanic eruptions swept past the land and ocean beds and caused extinction of many species including dinosaurs. Indian plate separated from that of Antarctic about 100 million years ago, Australia about 40 million years ago and South America was the last to separate at around 23 million years before present. This opened the sea route 'the Drake Passage' between South America and Antarctica about 28 million years from present, isolating the latter from the warmer world and ushering the formation of ice sheet on Antarctica.

Antarctic continent is divided into East Antarctica and West Antarctica, which are quite different geologically from each other. East Antarctica consists of a stable shield of pre-Cambrian rocks older than 570 million years and mostly above sealevel. West Antarctica would be simply a string of islands, if the ice cover were removed. The two regions are separated by the Trans Antarctic Mountains extending from the tip of the Antarctic Peninsula to Cape Adare, spanning a distance of about 3500 km. East Antarctica is colder than its western counterpart. In most places, about 2% - 4% of the area are exposed which consists of isolated tips of mountains (nunataks), the edges of the continent where the ice sheet leaves exposed rock and oases that have been exposed both through postglacial retreat of the ice cap and isostatic rebound of the Earth's crust following the most recent deglaciation. The largest oases are found near the coast of the Ross Sea, and are known as the McMurdo Dry Valleys. Other large oases are found in eastern Antarctica including the Vestfold Hills, Larsemann Hills, Bunger Hills, Schirmacher Oasis, Syowa Oasis, and on the Antarctic Peninsula at Ablation Point on the east coast of Alexander Island. The coast of Antarctica is more densely populated with ice shelves, and nearly half the coastline consists of floating ice. The present climate over the Antarctica is a result of interaction of the cryosphere ocean atmosphere and can be briefly summarized as follows. With a decline in CO_2 level and air temperature at above 4˚C than the present, ice sheets were formed around 34 Ma ago. The ice sheets spanned all over the Antarctic continent, although they were warmer and thinner than present. With a gradual decrease in global CO_2 levels, thick ice sheets covered Antarctica about 14 Ma ago. Ice core records from East Antarctica reveal an early Holocene climatic optimum from 11.5 to 9 ka ago, followed by a cold event about 8 ka ago, then a return to mid Holocene warm conditions, and followed by a slow cooling that ended with the rise in CO_2 post-1850.



ANTARCTIC ATMOSPHERIC CHEMISTRY

The Antarctic air, snow, and ice bears the testimony of anthropogenic chemicals which have accumulated over time scales ranging from storm events to hundreds of thousands of years. Over Antarctica springtime depletion of stratospheric ozone 10% below normal of January levels was detected in 1984, The destruction takes place in the austral spring (August - October), when the sun begins to rise, heating the stratosphere and supplying UV rays that convert chlorine gas to the chlorine atoms that attack ozone molecules. This chemical reaction is facilitated because the Antarctic stratosphere cools down to below −78˚C. That coldness is sustained by strong stratospheric winds that blow clockwise around the continent during austral winter to form a wall of moving air called the polar vortex.

The Polar Regions are known for spectacular natural light display in the sky resulting from emissions of pho- tons in the Earth's thermosphere from ionized atoms re- turning from an excited state to ground state. They are ionized or excited by the collision of solar wind and magnetospheric particles being funnelled down and accelerated along the Earth's magnetic field lines. Collisions between these ions and atmospheric atoms and molecules cause energy releases in the form of aurora appearing in large circles around the poles. Aurorae marked by different colors appear depending on the amount of energy absorbed and the state of the atom: if the atom regains an electron after it has been ionized, or if returning to ground state from an excited state. Green and red aurora results from atomic oxygen, light blue from ionic nitrogen, red and purple with ripple edges from neutral nitrogen. Auroras are more frequent and brighter during the intense phase of the solar cycle when coronal mass ejections increase the intensity of the solar wind. On average, 50 auroras have been recorded in Schirmacher Oasis by Indian scientists in an austral season.

ANTARCTIC WARMING AND SURFACE MASS BALANCE

During the last 50 years, Antarctica has undergone a complex temperature changes. Analysis of Antarctic radiosonde temperature profiles indicates that there has been a warming of the winter troposphere and cooling of the stratosphere (3˚C - 4˚C/decade) during late winter/springtime over the last 30 years. The regional midtropospheric temperatures around the 500 hPa level have risen by 0.5˚C - 0.7˚C/decade. On the other hand, the lower part of the stratosphere cooled by 10˚C during 1985 to 2002, and the time of decay of the polar vortex has shifted from early November during the 1970s to late December in the 1990s. In the lower stratosphere, cooling trends appear to be primarily driven by ozone depletion, whereas in the upper stratosphere they are the consequence of both ozone changes and in- creasing greenhouse gas concentrations.

The largest annual warming trend of 0.56˚C/decade during 1951-2000 has been reported for the western and northern parts of the Antarctic Peninsula. The largest warming of 5˚C over 50 years has been reported at Vernadksy station (former Faraday) (65˚15'S, 64˚16'W) during winter season due to a decrease in winter sea ice over Amundsen-Bellingshausen Sea and increase in ocean-to-atmosphere heat fluxes in the winter .The West Antarctic warming has been attributed in part to warming in the tropical Pacific Ocean and associated tele connections .which are discussed in the next section. The greatest warming during austral summer has occurred on the eastern Peninsula, which is thought to be associated with the enhancement of the circumpolar westerlies over the Southern Ocean (SO), with the Southern Hemisphere Annular Mode (SAM) switching over to its positive phase since the mid-1970. Stronger winds have facilitated relatively warm, maritime air masses crossing the Peninsula and reaching the low-lying ice shelves on the eastern Peninsula, as well as the adiabatic descent and warming of these winds crossing the Antarctic Peninsula topography .There have been few statistically significant changes in surface air temperature over the last 50 years around the coastal Antarctica. However, a statistically significant cooling in recent decades has been reported for Amundsen-Scott Station (90˚S, 0˚) which is thought to be a result of fewer maritime air masses penetrating into the interior of the continent. Reconstruction of temperatures over the past 200 years, based on eight records distributed over the ice sheet, reveal a warming of 0.2˚C for the past century with no discernible trend. cracks in the ice shelf, it deepens and erodes, and expands the cracks as it refreezes during the winter. In a separate process, especially in the East Antarctica, warmer ocean water melts the ice shelf from below, thinning it and making it more vulnerable to cracking. Other than these two processes, waning sea ice surrounding the Antarctic Peninsula has also contributed to the recent collapses. Sea ice provides a layer of protection between an ice shelf and the surrounding ocean, muting the power of large waves and storms. As sea ice decreases, more waves buffet the ice shelves. The largest waves can buckle and bend an ice shelf, increasing instability and possibly contributing to its collapse. A decrease in the sea ice also facilitates heat flow from atmosphere to open water thereby, accelerating the thinning of ice sheet from below.

The breakup of other shelves in the Antarctic could have a major effect on the rate of ice flow off the continent. Ice shelves act as braking system for glaciers. Further, the shelves keep warmer marine air at a distance from the glaciers; therefore, they moderate the amount of melting that occurs on the glaciers' surfaces. Once their ice shelves are removed, the glaciers increase in speed due to melt water percolation and/or a reduction of braking forces, and they may begin to dump more ice into the ocean than they gather as snow in their catchments. Glacier ice speed increases are already observed in peninsular areas where ice shelves disintegrated in prior years.

Annual-mean time series of ozone hole area and column ozone observed by Total Ozone Mapping Spectrometer (1978-2005) and Ozone Monitoring Instrument (OMI) (2005 onwards) processed with the Version 8 algorithm that has been developed by NASA Goddard's Ozone Processing Team.

FUTURE CLIMATE SCENARIO

The coupled atmosphere-ocean climate models are main tools to predict the scenario for the Antarctic region in particular and the Earth in general for the next 100 years. Great efforts are required to implement key physics related to sea ice, cryosphere-ocean-atmosphere interaction and polar stratospheric cloud forcing in the current climate models. The model projections of Antarctic climate over the 21st century reported in the Ref. can be summarized below. The models were run with CO_2 double that of the present atmosphere over the next century (up to 2100). The variation expected of the key climate parameters over Antarctica are as follows. Surface temperature would increase by 0.24˚C ± 0.10˚C per decade in the sea ice zone. An overall decrease in sea ice area would be expected (33% ± 9%). An increase in the air temperature by 0.34˚C ± 0.10˚C per decade over the interior of Antarctica and weakening of katabatic winds, particularly during the austral summer season.

Synoptic scale analysis of IPCC model results reveal an increased cyclone activity and stronger zonal winds due to enhanced positive SAM index during the 21st century in Antarctica. With the higher moisture- holding capacity of the warmer atmosphere projected for the 21st century, the models predicted an increase of Ant- arctic precipitation that averages 0.42 ± 0.01 mm/yr. The increased snowfall on the floating ice shelves would weighs them down, making them sink more heavily in the water, while the snowfall on the landmass of Antarctica would increase the elevation toward the interior of the continent. This would result in a steep slope from interior to the coast, thereby enhancing the speed of ice flow up to three times from continent toward the sea, raising the sea-level by 1.25 m in the year 2500, envisaging a warmest scenario .

In the scenario of stronger and positive SAM index, enhancement of westerly winds over the SO is expected to isolate Antarctica thereby, preventing penetration of warm maritime air masses in the interior; so lesser warming in the interior of Antarctica is predicted. The extent and thickness of Antarctic ice sheets are expected to implore massive responses, similar to the retreat of Northern Hemisphere ice sheets. Potential impacts of threshold effects on the ice sheet and sea ice extent could result in massive restructuring of the cryosphere-ocean-atmosphere system, triggering rapid climate change events, similar to those experienced during last glacial and current inter- glacial period.

Paleolimnological studies are also focused on changes in lake salinity from which the atmospheric moisture budget can be inferred and compared with the evidence from Antarctic ice cores. Other studies are required to track the origin and development of the lake biota and, from this, inferences about the nature and direction of environmental change could be inferred. Despite clear signs of marked recent environmental changes over the continent, we have only a limited perspective on how Antarctic climate and environmental conditions have varied in the past. As long-term monitoring programs in high-latitude regions have only been established for the past several decades, paleolimnological methods will continue in developing our understanding of the past environmental changes that will help us anticipate the magnitude, nature, and direction of future change.

INDIA'S CONTRIBUTION TO ANTARCTIC RESEARCH

India landed on Antarctica on 9th January 1982 and established a base camp on the ice-shelf. In 1983-84, a permanent station Dakshin Gangotri (70˚5'37"S, 12˚E) was established and commissioned on the ice shelf, off the Princess Astrid coast in Central Dronning Maud Land.

India built a second permanent station Maitri (70˚45'57"S, 11˚44'09"E; 117 m above mean sea level) on Schirmacher Oasis situated on Queen Maud Land, East Antarctica, during 1988-89, as the first research station got buried under ice. The Ministry of Earth Sciences (former Department of Ocean Development), Government of India, established on the 25th May 1998, the National Centre for Antarctic and Ocean Research (NCAOR) to handle polar research and logistic activities (http://www.ncaor.gov.in). A third state-of-art Bharti station (69˚24'28'S, 76˚11'14"E; 43 m above mean sea level) was raised during 2011-12 at unnamed promontory between Stornes and Broknes Peninsula in the Larsemann Hills. It is about 3000 km from Schirmacher Oasis where station Maitri stands.

The Indian Antarctic program involves multiinstitutions and multidisciplinary researchers with broad themes focused on the following topical areas: Meteorology and Atmospheric Sciences, Earth Sciences and Glaciology, Environment and Biological Sciences, Engineering and Communication, Human Physiology and Medicine, and Southern Ocean Oceanography. The Indian Meteorological Department has established an uninterrupted data set spanning more than three decades. The air temperature during 1991-2010 indicated a cooling trend of −0.4˚C/ decade. During the same period wind speed showed an increasing trend of 0.27 kt/decade, with a decreasing trend of −0.43 kt/decade during 2001-2010; the latter is as a result of less cyclonic disturbances affecting Maitri [106]. It has been shown that negative SAM index leads warmer surface temperature in the central Dronning Maud Land [106]. Measurements of ozone concentration using Brewer Ozone Spectrophotometer showed that it varied by 4% in during 2005-06 and 2006-07 summer period.

Geomagnetospheric measurements consisting of atmospheric electricity parameters and their response to the global thunderstorm activity and space weather events have been carried at Maitri station. Though Maitri is at the equatorial peripheral of the Auroral electrojet, during the geomagnetic storm the station comes under the influence of the auroral electro jet which enables the field line currents to influence the upper space environment. Suggests the existence of correlation between the atmospheric electrical parameters and geo- magnetic activity. Indian geologists have mapped about 20,000 sq km of the area in central Dronning Maud land on a 1:50,000 scale. Three geological maps of Schirmacher Oasis, Wohlthat and Orvin Mountains and a geo- morphological map of Schirmacher Oasis are published (www.portal.gsi.gov.in). Monitoring of glacier snout and the continental ice margin adjoining India Bay in Princess Astrid Coast, on a regular basis has revealed significant retreat of the ice margin in the last two decades.

CONCLUSIONS

Antarctica is a barometer of the Earth's climate system which records signatures of global climate change induced by local (anthropogenic) and remote forcing. Ant- arctic modern climate evolves through an interaction of cryosphere ocean-atmosphere system in response to past and present climate forcing. Superimposed on the long- term trend of post-glacial warming are millennial and finer scale oscillations, for example, those associated with the 11-year sunspot cycle.

In the last 50 years, the near-surface air temperature has risen over the west of the Antarctic Peninsula, concomitant with an increase in sea surface temperature, retreat of glaciers and the collapse of ice shelves around the Antarctic Peninsula. The SAM index has switched over to positive mode in the last five decades leading to the intensification and southward shift of the westerlies over the SO, and warming of the west Antarctica, mostly the Antarctic Peninsula. On the other hand, cooling of the stratosphere over Antarctica has enhanced the development of polar stratospheric clouds thereby, intensifying the ozone depletion. As for the ice loss, East Antarctica is stable compared to the Antarctic Peninsula and West Antarctica. The in homogeneity of Antarctic climate in space and time implies that recent Antarctic climate changes are due on the one hand to a combination of strong multidecadal variability and anthropogenic effects and, as demonstrated by the paleoclimate record, on the other hand to multidecadal to millennial scale and longer natural variability forced through changes in orbital insulation, greenhouse gases, solar variability, ice dynamoics, and aerosols.

The scenario of Antarctic climate changes in the 21st century projects warming of the sea ice zone, reduction in sea ice extent, warming of the Antarctic Plateau, and increased precipitation in snow form. Climate models needs to incorporate better atmospheric physics and glacier dynamics to forecast the change at the regional level. The retreat of the Antarctic ice sheet since the Last Glacial Maximum could be significantly accelerated by global warming. Ice sheet models are inadequately represented with the mechanisms related to the effect of warming on ice melt and subsequent sea level rise. Threshold effects may have a significant impact on the ice sheet and sea ice extent. During the last glacial and current interglacial, such effects resulted in massive reorganizations of the cryosphere-ocean-atmosphere system, leading to rapid climate change events. Comprehensive satellite data reinforced by ground truth, and modelling of the ocean- ice-atmosphere system are needed to forecast and quantify climate change with confidence on regional and global scales.

Some recommendations for future studies are as follows: 1) Observational program for Antarctica should be taken on a larger scale. A high accurate meteorological, glaciological and environmental chemistry data are needed for determining the trends and their statistical significance. Automatic Weather Stations should be installed in remote locations, especially in the Antarctic Plateau. 2) With the available and now assemblage of time series from several sources, it is necessary to maintain an appropriate data archive, such that all of the existing data (plus future data) can be easily accessed and utilized by individual researchers and institutions. Provisions should also be made so that data available in the future from newer instrumentation and/or observing platforms can be added to the archive with relative ease. 3) The variability on different scales, ranging from monthly to seasonal to annual to interannual to decadal, and spatial scales ranging from individual locations to regional areas to zonal belts to planetary dimensions, needs to be fully documented. In this regard, further work is needed on under- standing and modelling the effects of variations due to solar irradiance changes, volcanic eruptions, Indian Ocean Dipole, ENSO, quasi-biennial zonal wind oscillation in order to improve upon the estimates of natural variability, such that trends detection and in particular their attribution to anthropogenic causes.

REFERENCES

[1] P. Uotila, A. H. Lynch, J. J. Cassano and R. I. Cullather, “Changes in Antarctic Net Precipitation in the 21st Cen- tury Based on Intergovernmental Panel on Climate Change (IPCC) Model Scenarios,” Journal of Geophysi- cal Research, Vol. 112, No. D10, 2007, Article ID: D10107. doi:10.1029/2006JD007482

[2] P. R. Holland and R. Kwok, “Wind-Driven Trends in Antarctic Sea-Ice Drift,”Nature Geoscience, Vol. 5, No. 12, 2012, pp. 872-875.

[3] A. Wegner, “The Origin of Continents and Oceans,” Methuen and Co. Ltd., London, 1924.

[4] R. M. DeConto and D. Pollard, “Rapid Cenozoic Glaci- ations of Antarctica Induced by Declining Atmospheric CO2,” Nature, Vol. 421, No. 6920, 2003, pp. 245-249.

[5] M. Pagani, J. Zachos, K. H. Freeman, B. Tipple and S. M. Boharty, “Marked Decline in Atmospheric Carbon Dio- xide Concentrations during the Paleogene,” Science, Vol. 309, No. 5734, 2005, pp. 600-603.

[6] J. C. Zachos, J. R. Breza and S. W. Wise, “Early Oligo- cene Ice Sheet Expansion on Antarctica, Sedimentologi- cal and Isotopic Evidence from the Kergulen Plateau,” Geology, Vol. 20, No. 6, 1992, pp. 569-573.

[7] B. P. Flower and J. P. Kennett, “The Middle Miocene Climatic Transition: East Antarctic Ice Sheet Develop- ment, Deep Ocean Circulation and Global Carbon Cy- cling,” Palaeogeography, Palaeoclimatology, Palaeo- ecology, Vol. 108, No. 3-4, 1994, pp. 537-555.

[8] J. C. Farman, B. G. Gardiner and J. D. Shanklin, “Large Losses of Total Ozone in Antarctica Reveal Seasonal ClOx/NOx Interaction,” Nature, Vol. 315, 1985, pp. 207- 210. doi:10.1038/315207a0

[9] P. Hamill and O. B. Toon, “Polar Stratospheric Clouds and the Ozone Depletion,” Physics Today, Vol. 44, No. 12, 1991, pp. 34-42. doi:10.1063/1.881277

[10] World Meteorological Organization Global Ozone Re- search and Monitoring Project, “Scientific Assessment of Ozone Depletion: 2006,” Report 50, World Meteorologi- cal Organization, Geneva, 2007.

[11] D. W. J. Thompson and S. Solomon, “Interpretation of recent Southern Hemisphere Climate Change,” Science, Vol. 296, No. 5569, 2002, pp. 895-899. doi:10.1126/science.1069270

[12] G. J. M. Velders, S. O. Andersen, J. S. Daniel, D. W. Fahey and M. McFarland, “The Importance of the Mont- real Protocol in Protecting Climate,” Proceedings of the National Academy of Sciences of the United States of America, Vol. 104, No. 12, 2007, pp. 4814-4819.

[13] M. J. Newchurch, E.-S. Yang, D. M. Cunnold, G. C. Reinsel, J. M. Zawodny and J. M. Russell III, “Evidence for Slowdown in Stratospheric Ozone Loss: First Stage of Ozone Recovery,” Journal of Geophysical Research, Vol.

108, No. D16, 2003, Article ID: 4507.doi:10.1029/2003JD003471

[14] United Nations Framework Convention on Climate Change, “Kyoto Protocol to the United Nations Frame- work Convention on Climate Change,” 1997.

[15] S. Hong, Y. Kim, C. F. Boutron, C. P. Ferrari, J. R. Petit, C. Barbante, K. Rosman and Y. Lipenkov, “Climate Re- lated Variations in Lead Concentration and Sources in Vostok Antarctic Ice from 65,000 to 240,000 Years BP,” Geophysical Research Letters, Vol. 30, No. 22, 2003, Ar- ticle ID: 2138. doi:10.1029/2003GL018411

[16] C. F. Boutron and C. C. Patterson, “The Occurrence of Lead in Antarctic Recent Snow, Firn Deposited over the Last Two Centuries and Prehistoric Ice,” Geochimica et Cosmochimica Acta, Vol. 47, No. 8, 1983, pp. 1355- 1368.

[17] E. W. Wolff and E. D. Suttie, “Antarctic Snow Record of Southern Hemisphere Lead Pollution,” Geophysical Re- search Letters, Vol. 21, No. 9, 1994, pp. 781-784. doi:10.1029/94GL00656

[18] E. W. Wolff, E. D. Suttie and D. A. Peel, “Antarctic Snow Record of Cadmium, Copper and Zinc Content dur- ing the Twentieth Century,” Atmospheric Environment, Vol. 33, No. 10, 1999, pp. 1535-1541.

[19] F. A. M. Planchon, C. F. Boutron, C. Barbante, G. Cozzi, V. Gaspari, E. W. Wolff, C. P. Ferrari and P. Cescon, “Changes in Heavy Metals in Antarctic Snow from Coats Land since the Mid-19th to the Late-20th Century,” Earth and Planetary Science Letters, Vol. 200, No. 1-2, 2002, pp. 207-222.

[20] P.Vallelonga, K. van de Velde, J. P. Candelone, I. Mor- gan, C. F. Boutron and K. J. R. Rosman, “The Lead Pol- lution History of Law Dome, Antarctica, from Isotopic Measurements on Ice Cores: 1500 AD to 1989 AD,” Earth and Planetary Science Letters, Vol. 204, No. 1-2, 2002, pp. 291-306.

[21] K. van de Velde, P. Vallelonga, J. P. Candelone, K. J. R. Rosman, V. Gaspari, G. Cozzi, C. Barbante, R. Udisti, P. Cescon and C. Boutron, “Pb Isotope Record over One Century in Snow from Victoria Land, Antarctica,” Earth and Planetary Science Letters, Vol. 232, No. 1-2, 2005, pp. 95-108. doi:10.1016/j.epsl.2005.01.007

[22] R.Fuoco, M. P. Colombini, A. Ceccarini and C. Abete, “Polychlorobiphenyls in Antarctica,” Microchemical Jour- nal, Vol. 54, No. 4, 1996, pp. 384-390. doi:10.1006/mchj.1996.0115

[23] S. Corsolini, T. Romeo, N. Ademollo, S. Greco and S. Focardi, “POPs in Key Species of Marine Antarctic Eco- system,” Microchemical Journal, Vol. 73, No. 1-2, 2002, pp. 187-193.

[24] K. Weber and H. Goerke, “Persistent Organic Pollutants (POPs) in Antarctic Fish: Levels, Patterns, and Changes,” Chemosphere, Vol. 53, No. 6, 2003, pp. 667-678.

[25] R. C. Montone, S. Taniguchi and R. R. Weber, “PCBs in the Atmosphere of King George Island, Antarctica,” The Science of the Total Environment, Vol. 308, No. 1-3,

2003, pp. 167-173.

[26] J. Dibb, P. A. Mayewski, C. F. Buck and S. M. Drummey, “Beta Radiation from Snow,” Nature, Vol. 345, No. 6270, 1990, p. 25.

[27] A. M. Rankin, V. Auld and E. W. Wolff, “Frost Flowers as a Source of Fractionated Sea Salt Aerosol in the Polar Regions,” Geophysical Research Letters, Vol. 27, No. 21,

2000, pp. 3469-3472. doi:10.1029/2000GL011771

[28] A. M. Rankin, E. W. Wolff and S. Martin, “Frost Flowers: Implications for Tropospheric Chemistry and Ice Core Interpretation,” Journal of Geophysical Research, Vol. 107, No. D23, 2002, p. 4683. doi:10.1029/2002JD002492

[29] P. A. Mayewski, M. P. Meredith, C. P. Summerhayes, J. Turner, A. Worby, P. J. Barrett, G. Casassa, N. A. N. Bertler, T. Bracegirdle, A. C. N. Garabato, D. Bromwich, H. Campbell, G. S. Hamilton, W. B. Lyons, K. A. Maasch, S. Aoki, C. Xiao and T. van Ommen, “State of the Antarctic and Southern Ocean Climate System,” Re- views of Geophysics, Vol. 47, No. 1, 2009, Article ID: RG1003. doi:10.1029/2007RG000231

[30] M. Thamban, C. M. Laluraj, S. S. Naik and A. Chaturvedi, “Reconstruction of Antarctic Climate Change Using Ice Core Proxy Records from the Coastal Dronning Maud Land, East Antarctica,” Journal of the Geological Society of India, Vol. 78, No. 1, 2011, pp. 19-29.

[31] S. Benassai, S. Becagli, R. Gragnani, O. Magand, M. Proposito, I. Fattori, R. Traversi and R. Udisti, “Sea- Spray Deposition in Antarctic Coastal and Plateau Areas from ITASE Traverses,” Annals of Glaciology, Vol. 41, No. 1, 2005, pp. 32-40. doi:10.3189/172756405781813285

[32] R. Naveen, H. J. Lynch, S. Forrest, T. Mueller and M. Polito, “First Direct, Site-Wide Penguin Survey at Decep- tion Island, Antarctica, Suggests Significant Declines in Breeding Chinstrap Penguins,” Polar Biology, Vol. 35, No. 12, 2012, pp. 1879-1888.

[33] P. T. Fretwell, M. A. LaRue, P. Morin, G. L. Kooyman, B. Wienecke, N. Ratcliffe, A. J. Fox, A. H. Fleming, C. Por- ter and P. N. Trathan, “An Emperor Penguin Population Estimate: The First Global, Synoptic Survey of a Species from Space,” PLoS One, Vol. 7, No. 4, 2012, Article ID: e33751. doi:10.1371/journal.pone.0033751

[34] W. Z. Trivelpiece, J. T. Hinke, A. K. Miller, C. S. Reiss, S. G. Trivelpiece and G. M. Watters, “Variability in Krill Biomass Links Harvesting and Climate Warming to Pen- guin Population Changes in Antarctica,” Proceedings of the National Academy of Sciences of the United States of America, Vol. 108, No. 18, 2011, pp. 7625-7628. doi:10.1073/pnas.1016560108

[35] W. Z. Trivelpiece, S. G. Trivelpiece, G. R. Geupel, J. Kjelmyr and N. J. Volkman, “Antarctic Ecosystems-Eco- logical Change and Conservation,” Springer, Berlin, 1990.

[36] A. Atkinson, V. Siegel, E. Pakhomov and P. Rothery, “Long-Term Decline in Krill Stock and Increase in Salps within the Southern Ocean,” Nature, Vol. 432, No. 7013, 2004, pp. 100-103.

[37] IPCC, “Contribution of Work Groups I, II and III to the 4th Assessment Report of the Intergovernmental Panel on Climate Change,” Climate Change Synthesis Report, Ge- neva, 2007.

[38] A. Atkinson, V. Siegel, E. A. Pakhomov, P. Rothery, V. Loeb, R. M. Ross, L. B. Quetin, K. Schmidt, P. Fretwell, E. J. Murphy, G. A. Tarling and A. H. Fleming, “Oceanic Circumpolar Habitats of Antarctic Krill,” Marine Ecology Progress Series, Vol. 362, 2008, pp. 1-23. doi:10.3354/meps07498

[39] V. Loeb, V. Siegel, O. Holm-Hansen, R. Hewitt, W. Fra- serk, W. Trivelpiecek and S. Trivelpiecek, “Effects of Sea-Ice Extent and Krill or Salp Dominance on the Ant- arctic Food Web,” Nature, Vol. 387, No. 6636, 1997, pp. 897-900.

[40] D. G. Vaughan, G. J. Marshall, W. M. Connolley, C. Parkinson, R. Mulvaney, D. A. Hodgson, J. C. King, C. J. Pusdsey and J. Turner, "Recent Rapid Regional Climate Warming on the Antarctic Peninsula," Climatic Change, Vol. 60, No. 3, 2003, pp. 243-274. doi:10.1023/A:1026021217991

[41] M. P. Meredith and J. C. King, "Rapid Climate Change in the Ocean West of the Antarctic Peninsula during the Second Half of the 20th Century," Geophysical Research Letters, Vol. 32, No. 19, 2005, Article ID: L19604. doi:10.1029/2005GL024042

[42] F. A. O'Gorman, "Fur Seals Breeding in the Falkland Islands Dependencies," Nature, Vol. 192, 1961, pp. 914- 916. doi:10.1038/192914a0

[43] I. L. Boyd, "Pup Production and Distribution of Breeding Antarctic Fur Seals (Arctocephalus gazelle) at South Georgia," Antarctic Science, Vol. 5, No. 1, 1993, pp. 17- 24. doi:10.1017/S0954102093000045