DETECTION AND ATTRIBUTION OF ANTARCTIC CLIMATE CHANGE

DETECCIÓN Y ATRIBUCIÓN DEL CAMBIO CLIMÁTICO EN LA ANTÁRTIDA

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RESUMEN

El conocimiento actual de los cambios climáticos que han ocurrido en los últimos 50 años sobre la Antártica se presenta con un enfoque sobre: (i) un calentamiento de verano de la región oriental de la Península Antártica, lo que provocó el colapso de la plataforma de hielo Larsen B, (ii) la observación del importante aumento de la extensión total del hielo marino y (iii) una huella antropogénica en el patrón de cambio de temperatura en toda la Antártica. Las implicaciones de esto para las predicciones del futuro se discuten.

Palabras clave: Detección y atribución, la Antártica, el clima, el agujero de ozono, el hielo marino.

ABSTRACT

The current understanding of climate changes that have occurred in the last 50 years over Antarctica is presented with a focus on: (i) a summer warming of the eastern Antarctic Peninsula, which caused the collapse of the Larsen B ice shelf, (ii) the observed significant increase of total sea ice extent and (iii) an anthropogenic 'fingerprint' in the Antarctic-wide temperature change pattern. The implications of this for predictions of the future are discussed.

Key words: Detection and attribution, Antarctic, climate, ozone hole, sea ice.

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INTRODUCTION

Prediction of future climate change is intimately linked with understanding past changes. The Antarctic is a continent of contrasts in terms of temperature change, with one of the most rapidly warming places on the surface of the planet over the Peninsula region and large areas with no detectable change elsewhere. Here we will summarise changes that have occurred over the last 50 years where evidence has been found of a human contribution. These are: (i) a summer warming of the eastern Peninsula, which caused the collapse of the Larsen B ice shelf, (ii) the observed significant increase of total sea ice extent and (iii) an anthropogenic 'fingerprint' in the Antarctic-wide temperature change pattern. The implications of this for predictions of the future will be discussed.

The phrase 'detection and attribution' describes two stages in assessing changes in climate. The detection stage is the task of determining whether an observed change (usually a linear trend) is significant according to some statistical test. The attribution stage is the more complex task of determining what has caused the significant change. One must consider known important climate drivers, both natural and anthropogenic, and the contribution from unforced natural variations of the atmosphere and ocean. A human influence can be said to be detected if (i) the change is consistent with the response to anthropogenic drivers and (ii) the change cannot be explained by natural drivers or internal variability. Here recent findings on the anthropogenic influence on Antarctic climate are summarised.

The ozone hole has contributed to the collapse of the Larsen B ice shelf

The rapid loss of stratospheric ozone over the last few decades (the ozone hole) has, by cooling the stratosphere, resulted in an increase of the surface westerly winds that blow around the Antarctic (Fig. 1). This effect is strongest at the surface in the summer months (December through February). The increased summer westerlies have forced more warm air over the Antarctic Peninsula and increased the summer melt, which contributed to the loss of the Larsen B ice shelf (*Marshall et al.* 2006).

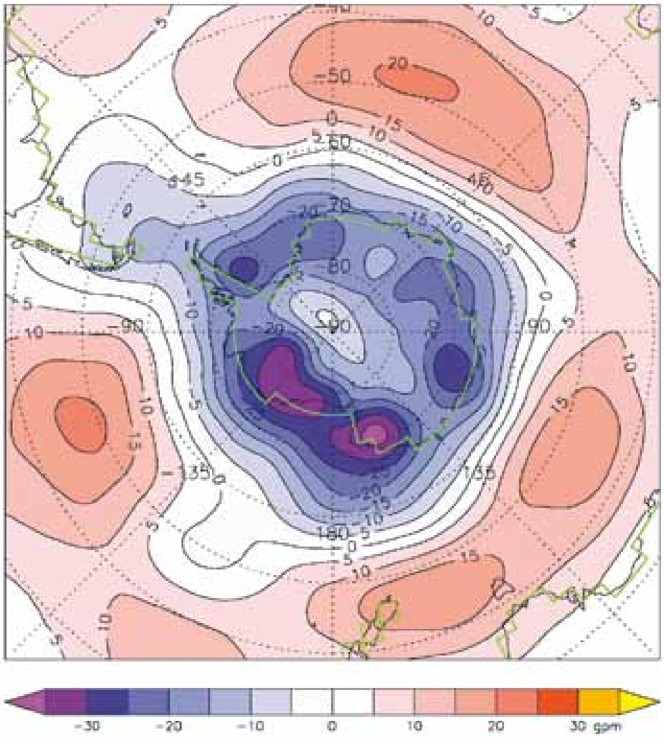

Fig. 1. Linear trend in summer (DJF) 500 hPa geopotential height for 1979-2002 in units of meters/decade. The dataset used here is the NASA Modern Era Retrospective Analysis for Research and Applications (MERRA) dataset.

Arblaster and Meehl (2006) showed that, according to the NCAR-PCM1 climate model, changes in stratospheric ozone are the most important single factor in forcing summer and autumn trends of sea level pressure. These changes act to increase the near-surface westerly winds that are semi-permanent around the whole continent. A weather pattern that is linked to the westerlies, known as the Southern Annular Mode (SAM), shows increases corresponding to the increased westerly winds (*Marshall* 2003). In recent years this increase has levelled off, but remains high compared to early years in the record.

The Antarctic Peninsula protrudes northward into the region of westerlies affected by the ozone hole. Most of the time the Peninsula acts as a barrier to near-surface westerly winds and deflects flow southward. In these situations the relatively warm and moist air does not affect the eastern side of the Peninsula. However, on occasions when the wind is strong enough the westerly air can flow over the Peninsula to the east and bring anomalously warm air to the surface (*Orr et al.* 2004). In the summer such events promote melting at the surface (*Marshall et al.* 2006). The implication is that the ozone hole is, through its influence on the winds, the cause of the breakup of the Larsen B ice shelf.

The human influence on Antarctic sea ice extent

In the period since the introduction of satellite-derived measurements of sea ice in 1979 there has been a small, but statistically significant, increase in the total southern hemisphere sea ice extent. This contrasts with the large decreases that have occurred over the Arctic. The ozone hole has again been implicated in causing this observed change (*Turner et al.* 2003). However, for at least two reasons the link is less robust than for the Larsen B ice shelf breakup. Firstly the increase in sea ice extent is not significantly larger than what would be expected without any human influences on climate. Secondly, climate models have difficulty in simulating both current sea ice and its response to the ozone hole. In this section we outline the evidence and priorities for improving understanding.

The overall increases around Antarctica incorporate regional increases and decreases (Fig. 2a). There are increases over the central and north western Ross Sea, the eastern Weddell Sea and around East Antarctica. In contrast there are decreases over the Amundsen/Bellingshausen Sea and north western Weddell Sea. This pattern of change is consistent with both the observed atmospheric

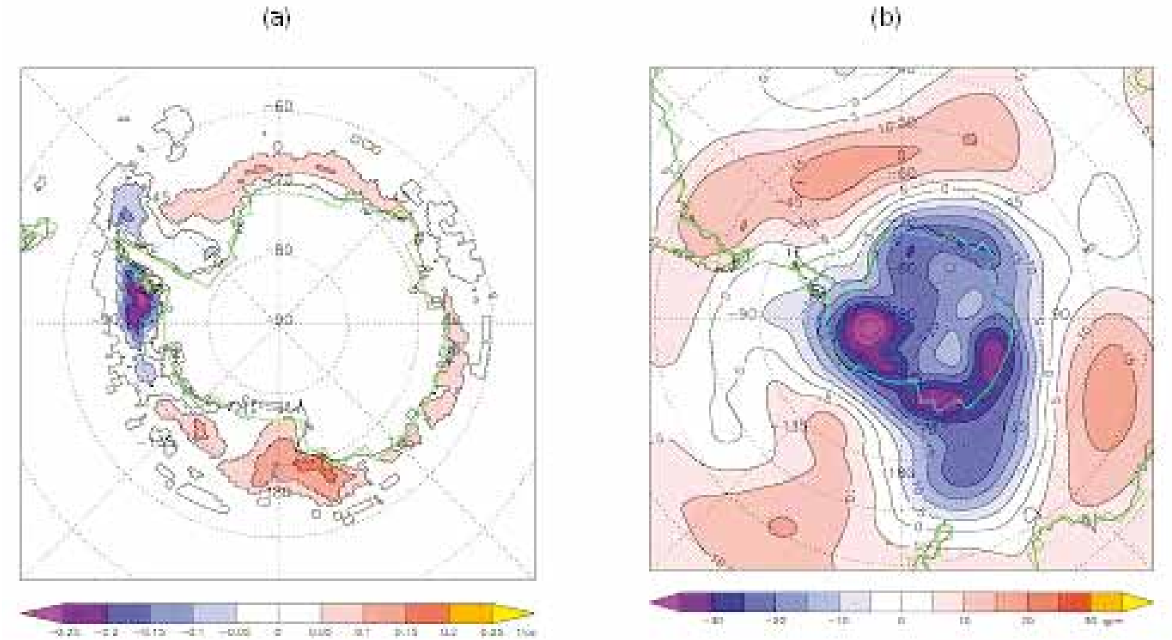

Fig. 2. (a) Spatial pattern of linear sea ice concentration trends for autumn between 1979 and 2002 in units of fraction per decade. (b) Spatial pattern of linear 500 hPa geopotential height trends between 1979 and 2002 in meters per decade. The sea ice dataset used is satellite observations from *Comiso* (1999) using the bootstrap method. As in Fig. 1 MERRA is used for the atmospheric data.

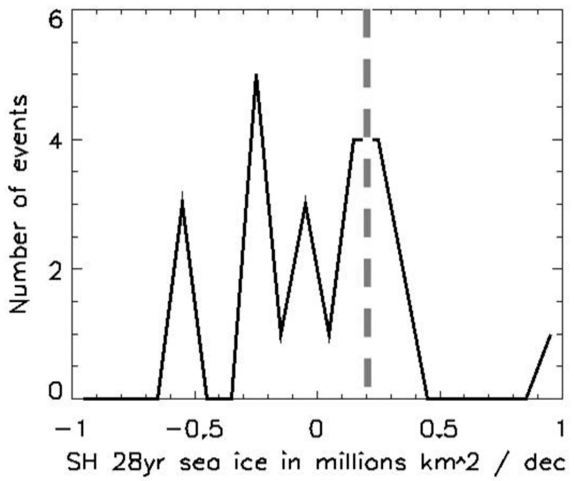

Fig. 3. Histogram of trends in autumn total Antarctic sea ice extent in a 340-year control run of HadCM3. The blue dashed line shows the observed value.

pressure changes and those seen in climate model experiments of the effects of the ozone hole.

An observationally constrained reconstruction of the atmosphere (the NASA Modern Era Retrospective Analysis for Research and Applications (MERRA) - *Rienecker et al.* 2008) was used to show how atmospheric pressure patterns have changed since 1979.The changes can be seen in autumn 500 hPa geopotential height for 1979–2002 (Fig. 2b). The trend towards generally lower (higher) atmospheric pressures/heights across the Antarctic (Southern Ocean) at this time of year can be seen. There has been a deepening of the climatological trough over the Amundsen Sea and West Antarctica resulting in greater flow off the Ross Ice Shelf and west of the Antarctic Peninsula. This is consistent with the spatial pattern of sea ice trends in the Amundsen, Weddell and the Ross Seas (cf. Fig. 2b).

A climate model experiment using the UK Met Office HadCM3 model showed a pattern of pressure changes that is also consistent with the observed sea ice changes (Turner *et al.* 2009). Two sets of experiments were run. In one set stratospheric ozone amounts were kept constant while in the other set the observed decrease was imposed on the model. This indicates that the ozone hole is a possible reason explanation for the changes in sea ice concentration.

Although the above results are consistent with human influence in the observed sea ice increases, it was not possible to clearly discount internal (unforced) climate variability as the cause. A 340-year run of a coupled ocean-atmosphere version of HadCM3 which had no changes in external forcing ($CO2$, solar etc) was assessed. Model diagnostics of sea ice extent trend in 22 29-year 50% overlapping periods are shown in Fig. 3. This showed five periods when the Antarctic sea ice extent increased by at least as much as was observed in recent decades. In other words, the HadCM3 control run suggests that there is a high probability that this trend in sea ice could have occurred in the absence of human influence.

Observational constraints on projected temperature change

The results in Section 2 only conclusively show a human influence in the summer warming of the eastern Peninsula. In other regions and for continent-wide averages it has not been possible to robustly detect a signal of human-induced local change when compared to background internal variability. However, a powerful technique that takes into account the spatial pattern of temperature changes has been used to detect a human 'fingerprint' of temperature change over the continent as a whole (*Gillett et al.* 2008). This 'optimal fingerprinting' can provide information on the whether a given climate model over or under-estimates externally forced changes. This information can then scale future projections if one assumes that a model will similarly over or under-estimate future change (*Stott et al.* 2006) (Fig. 4).

A challenge over the Antarctic is that both greenhouse gases (GHGs) and stratospheric ozone changes appear to have a significant effect on surface climate. Since stratospheric ozone amounts are predicted to recover in the future the scaling of projections requires separate scaling factors for the effects of GHGs and ozone to be determined. This is still an unresolved problem that remains for future work.

Internal variability of the climate system

In addition to the relatively steady background changes forced by greenhouse gases and stratospheric ozone, internal variability of the atmosphere

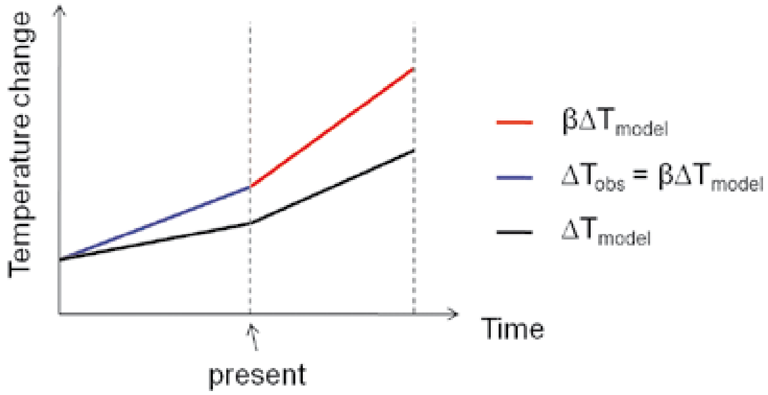

Fig. 4. Schematic of the scaling of climate projections using observations. This shows a model that under-estimates warming by β and a projection of future change scaled by β. β generally has a large uncertainty (*Stott et al.*, 2006).

and ocean can be large on decadal timescales. An important example of this is the Antarctic Peninsula, for which the extent to which natural fluctuations have contributed to the large trends observed in recent decades is difficult to determine. This is very important for estimating the uncertainty in the projected changes of climate in the Peninsula over the coming decades. Could natural variations lead to a short-term cooling in the coming decade before the influence of greenhouse gases becomes larger? A priority of future work will be to assess how accurately climate models can replicate the local internal climate variability at the Peninsula. This may require the use of regional climate models that include more accurate representations of key features of the Antarctic Peninsula such as the steep mountains.

LITERATURE CITED

Arblaster, J.M., & G. A. Meehl 2006. Contributions of external forcings to southern annular mode trends, *Journal of Climate*, 19(12): 2896-2905

Comiso, J. C. 2000. Variability and trends in Antarctic surface temperatures from in situ and satellite infrared measurements, *Journal of Climate*, 13: 1674-1696

Gillett, N.P., D. A. Stone, P.A. Stott, T. Nozawa, A.Y. Karpechko, G.C. Hegerl, M.F. Wehner & P.D. Jones 2008. Attribution of polar warming to human influence, *Nature Geoscience*, 1(11): 750-754

Gillett, N.P., D.A. Stone, P.A. Stott, T. Nozawa, A.Y. Karpechko, G.C. Hegerl, M.F. Wehner & P.D. Jones 2008. Attribution of polar warming to human influence, *Nature Geoscience*, *1*(11): 750-754

Marshall, G.J. 2003. Trends in the Southern Annular Mode from observations and reanalyses, *Journal of Climate*, 16: 4134-4143

Marshall, G.J., A. Orr, N.P.M. van Lipzig & J.C. King 2006. The impact of a changing Southern Hemisphere Annular Mode on Antarctic Peninsula summer temperatures, *Journal of Climate*, 19(20): 5388-5404

Marshall, G. J., A. Orr, N. P. M. van Lipzig & J.C. King 2006. The impact of a changing Southern Hemisphere Annular Mode on Antarctic Peninsula summer temperatures, *Journal of Climate*, 19(20): 5388-5404

Orr, A., D. Cresswell, G. J. Marshall, J. C. R. Hunt, J. Sommeria, C. G. Wang & M. Light 2004. A 'low-level' explanation for the recent large warming trend over the western Antarctic Peninsula involving blocked winds and changes in zonal circulation, *Geophysical research letters,* 31: L06204-L06206doi.

Rienecker, M. M., M.J. Suarez, R. Todling, J. Bacmeister, L. Takacs, H.-C. Liu, W. Gu, M. Sienkiewicz, R.D. Koster, R. Gelaro, I. Stajner & J.E. Nielsen 2008. The GEOS-5 Data Assimilation System - Documentation of Versions 5.0.1, 5.1.0, and 5.2.0Rep. vol.27, NASA-GMAO, NASA-GMAO, Goddard Space Flight Center, USA.

Stott, P.A., J.A. Kettleborough & M.R. Allen 2006. Uncertainty in continental-scale temperature predictions, *Geophysical research letters,* 33(2). L02708.

Turner, J., J.C. Comiso, G.J. Marshall, T.A. Lachlan-Cope, T. J. Bracegirdle, T. Maksym, M. P. Meredith, Z. Wang & A. Orr 2009. Non-annular atmospheric circulation change induced by stratospheric ozone depletion and its role in the recent increase of Antarctic sea ice extent, *Geophysical research letters,* 36: L08502, doi: 10.1029/2009GL037524.