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## Slowing of the ocean's deep breath

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# 1 OCEANOGRAPHY

## 2 Slowing of the ocean's deep breath

3 *The deepest reaches of the ocean are ventilated by sinking of cold and relatively saline*  
4 *seawater around Antarctica. Observations from the Australian sector of the Southern Ocean*  
5 *reveal a decline in sinking and abyssal ventilation, linked to dropping ocean salinity on the*  
6 *Antarctic shelf.*

7

8 The deeper half of the World Ocean, below 2 km depth, is renewed by sinking of cold and  
9 dense waters in localized gravitational plumes around Antarctica and the North Atlantic<sup>1</sup>.  
10 Antarctic sinking plumes carry the densest waters, and constitute the primary ventilation  
11 pathway—or “respiratory route”—connecting the abyssal ocean (deeper than 3 km) to the  
12 atmosphere<sup>2</sup>. By transferring mass, oxygen, nutrients and carbon from the surface to large  
13 depths, this pathway influences major ocean circulation cells<sup>2,3</sup>, Antarctic glaciers<sup>4</sup>, marine  
14 ecosystems and global climate<sup>5</sup>. An ongoing slowdown of this ventilation pathway has been  
15 suspected based on observed widespread warming of bottom waters<sup>6</sup>. However, trends in  
16 Antarctic sinking and causes of abyssal warming have remained elusive due to a lack of  
17 direct observations of ocean flows. Writing in *Nature Climate Change*, [Kathryn](#) Gunn et al.<sup>7</sup>  
18 show observational evidence that transport of bottom waters in two important plumes  
19 feeding the abyssal Australian Antarctic basin has dwindled since the early 1990s. The  
20 transport trends mirror trends in the salinity of source waters on the Antarctic shelf,  
21 suggesting that projected mass losses of Antarctic ice<sup>8</sup> may further stifle abyssal ventilation  
22 by freshening and lightening shelf waters.

23 Observing mass transports in the deep ocean is challenging, because water velocity  
24 measurements rely on costly moored arrays of acoustic current profilers. Such moorings  
25 provide information about ocean velocities at a single location and typically for only a year  
26 or two between deployment and recovery. Basin-scale flow rates, let alone multidecadal  
27 trends in flow rates, are therefore extremely difficult to measure. Moreover, inverse  
28 methods that infer flow rates from more common hydrographic measurements, such as  
29 temperature and salinity, usually reconstruct only a time-mean ocean circulation state<sup>9</sup>.  
30 Fundamental observational constraints thus explain why long-term changes in deep ocean  
31 circulation, and a fortiori changes in downwelling around the remote Antarctic continent,  
32 remain hardly known.

33 Gunn et al.<sup>7</sup> circumvent these constraints by making three astute choices. First, they restrict  
34 their focus to three main gateways to the deep Australian Antarctic basin, which borders  
35 the white continent between 80°E and 150°E and extends to about 50°S. Second, they use  
36 one-year-long mooring measurements at these gateways to derive a relationship between  
37 density and speed in the near-bottom layer. By combining this relationship with repeated  
38 measurements of temperature, salinity and pressure (which together determine density) at  
39 the same locations over recent decades, they obtain temporal changes in the speed of  
40 sampled bottom-water plumes. Third, they employ a realistic, high-resolution model  
41 simulation to convert local speeds into total mass transports within the near-bottom layer.

42 It is this combination of moored velocity measurements, repeated hydrographic  
43 measurements and information from a model simulation that allows the reconstruction of  
44 evolving flow rates into this abyssal basin between 1994 and 2017. This reconstruction  
45 indicates a decline of net bottom-water transport into the Australian Antarctic basin by  
46 about 30% over this time period.

47 The calculated decline in transport includes a relatively large uncertainty range because it  
48 relies on temporally spaced hydrographic observations and imperfect mooring and model  
49 derived conversion functions. Even so, separate lines of evidence corroborate the  
50 downward trend in transport. In accord with previous work<sup>6</sup>, the authors find a descent of  
51 temperature and density surfaces in the considered abyssal basin, of about 60 m per decade.  
52 This downward shift of water bodies, observed over much of the water column, is  
53 consistent with a loss of the coldest and densest categories of bottom water. Importantly,  
54 the authors also report a loss of oxygen in the abyssal layer, which is a hallmark of reduced  
55 ventilation—that is, of reduced communication between the atmosphere and abyssal seas.  
56 The measured oxygen loss is attributed to slowing gravitational plumes rather than  
57 reduced oxygenation of source waters on the Antarctic margin (Fig.1).

58 Gunn and colleagues<sup>7</sup> link the slowdown of gravitational sinking to a decrease in the salinity,  
59 and therefore in the density, of the dense shelf waters that initiate the cascading down the  
60 continental slope of Antarctica. This mechanism is consistent with the model-based  
61 expectation that freshening of Antarctic coastal waters—as may result from losses of  
62 Antarctic ice—hinders gravitational sinking<sup>8</sup>. In addition, salinity observations on the Ross  
63 Sea continental shelf, a key source region for the deep Australian Antarctic basin, support a  
64 downward trend over the 1957-2020 period<sup>10</sup>. However, strong interannual to decadal  
65 variations are superimposed on this downward trend<sup>10</sup>, including a pronounced rebound of  
66 dense shelf water salinity during 2014-2018, which was linked to transient wind and sea-  
67 ice anomalies<sup>11</sup>. This rebound highlights the difficulty to predict long-term trends and the  
68 risk of aliasing short-term variability with temporally sparse measurements. Continuing  
69 observations in the major source regions and abyssal gateways are thus of utmost  
70 importance to reduce uncertainty in observed changes and their causes.

71 The Australian Antarctic basin occupies just one fifth of the latitude band encircling  
72 Antarctica, and its abyss is fed from source regions known to be influenced by increased  
73 meltwater release from the West Antarctic ice sheet<sup>8,10</sup>. Observational studies in other  
74 sectors of the Southern Ocean are in need to probe the circumpolar trend in Antarctic  
75 sinking, and to discriminate the relative roles of wind, sea-ice and glacier changes on global  
76 abyssal ventilation. Such efforts are likely to uncover previously unforeseen interactions  
77 between the ocean, atmosphere and cryosphere in this data sparse region.

78 Potential changes in North Atlantic dense water formation and sinking have received  
79 substantial attention for several decades. In comparison, changes in Antarctic sinking, and  
80 their repercussions on climate, sea level and marine ecosystems, are only emerging  
81 concerns. Gunn et al.<sup>7</sup> orient and impel this field of research by bringing to light the  
82 mechanism and magnitude of ongoing abyssal ventilation changes, in a basin that channels  
83 a sizeable proportion of bottom waters in transit from Antarctica to the global ocean abyss.

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## 103 **Competing interests**

104 The author declares no competing interests.

105

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## 111 **Figure legend**

112 **Fig. 1: Slowdown of Antarctic sinking drives deoxygenation of the deep ocean.** Shading  
113 shows observed dissolved oxygen concentrations, from the gridded product GLODAPv2 (ref.  
114 12), along a 140°E transect joining Antarctica and Australia. This transect cuts through the  
115 Australian Antarctic basin, which lies south of 53°S. Black contours mark two selected  
116 density surfaces (neutral density values of 27.5 and 28.1) that separate low-oxygen mid-  
117 depth waters from high-oxygen upper and abyssal waters. In the high-density abyssal  
118 volume, oxygen is supplied by sinking along the Antarctic continental slope. Gunn and co-  
119 authors<sup>7</sup> show that an ongoing decline in sinking (dashed red arrow) drives substantial  
120 oxygen loss in the deep ocean via contraction of the well-ventilated abyssal volume  
121 (downward red arrows).

