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Coupled Climate Models Reveal an Atmospheric Shield Stabilizing the East Antarctic Ice Sheet

East Antarctic Ice Sheet * Climate Modeling * Glaciology

Holding enough frozen water to raise global mean sea level by roughly 52 meters if completely melted, the East Antarctic Ice Sheet (EAIS) is the largest single reservoir of freshwater on Earth. For decades, long-term projections of how the continent's ice will respond to sustained greenhouse warming have relied heavily on "offline" or uncoupled modeling -- where output from an atmospheric simulation is fed one-way into a standalone ice-sheet model. A new study published in Nature Climate Change by Axel Timmermann and colleagues at the Institute for Basic Science (IBS) Center for Climate Physics at Pusan National University demonstrates that leaving out two-way atmospheric feedbacks dramatically overestimates interior East Antarctic collapse.

By running fully coupled climate-ice-sheet simulations that allow the evolving topography, reflectivity (albedo), cloud cover, and wind patterns of Antarctica to interact continuously over multi-millennial timescales, the team identified a powerful stabilizing mechanism: an atmospheric shield of enhanced snowfall and solar-blocking cloud decks that preserves roughly 80% of the East Antarctic Ice Sheet's volume even under extreme warming scenarios exceeding +10 deg C above pre-industrial levels.

Uncoupled vs. Fully Coupled Ice-Sheet Physics

In traditional offline ice-sheet modeling, researchers prescribe surface air temperature and precipitation changes using simplified scaling rules: as global temperatures climb, local air temperatures over the ice sheet are raised proportionally, driving runaway surface melt across the continental margins and gradually drawing down the interior ice dome. When the IBS Center for Climate Physics team ran control simulations that excluded dynamic atmospheric adjustments in clouds and precipitation, extreme long-term warming triggered catastrophic ablation -- eroding approximately 70% of the Antarctic Ice Sheet's total volume .

However, when the researchers enabled full two-way coupling between the atmospheric general circulation model and the dynamic ice sheet, projected total ice volume loss dropped by more than two-thirds -- to roughly 20% . Rather than passively melting under a warmer sky, the high-elevation plateau of East Antarctica actively reshaped regional atmospheric circulation , hydrological transport, and surface radiation budgets.

The Two Pillars of the East Antarctic Atmospheric Shield

Why does the interior of East Antarctica resist melting so much more strongly in a fully coupled atmosphere? The study traces the stabilization to two physically linked negative feedback loops operating above the continent's high interior plateau (where surface elevations exceed 3,000 to 4,000 meters above sea level):

* Clausius-Clapeyron Snowfall Amplification: Under the thermodynamic Clausius-Clapeyron relation , the atmosphere's water-vapor holding capacity increases by approximately 7% for every 1 deg C (1 K) of warming . Because the high-altitude interior of East Antarctica starts at an annual mean surface temperature between 30 deg C and 55 deg C, even substantial global warming leaves the central plateau well below the freezing point (0 deg C). Consequently, warmer, moisture-laden air masses sweeping poleward from the Southern Ocean dump their extra water vapor not as rain, but as heavy interior snowfall -- thickening the central ice dome and dynamically replenishing mass lost along the coastal margins.

* Shortwave Cloud Radiative Shielding: The same surge in poleward moisture transport fuels thicker, more persistent cloud cover across the East Antarctic plateau during the austral summer (December-February), when 24-hour sunlight would otherwise drive surface melting. These optically dense cloud decks reflect incoming shortwave solar radiation back to space -- a negative cloud-albedo feedback that acts as a planetary sunshade over the ice sheet's interior and suppresses summer surface meltwater ponding.

| Model Configuration / Cryospheric Sector | | Atmospheric Feedback Coupling | | Hydrological & Radiative Regime | | Modeled Volume Loss (Extreme Warming) | | Primary Physical Driver |

| Antarctic Ice Sheet (Uncoupled / Offline Control) | | Prescribed temperature forcing; fixed cloud/precipitation scaling | | Unshielded shortwave insolation; runaway surface ablation | | ~70% volume loss (~30% retained) | | Positive melt-elevation feedback without cloud or snowfall compensation |

| Antarctic Ice Sheet (Fully Coupled Climate-Ice Model) | | Two-way dynamic atmosphere, cloud, wind, and ice-topography coupling | | Enhanced poleward moisture transport + summer cloud shortwave shading | | ~20% volume loss (~80% retained) | | Clausius-Clapeyron snowfall gain + optically thick cloud albedo shield |

| East Antarctic Interior Plateau (EAIS) | | High-altitude bedrock (>3,000 m elevation; sub-zero year-round) | | Net positive surface mass balance (SMB > 0) across central dome | | <15% - 20% interior loss (highly stabilized) | | Sub-freezing accumulation zone converts excess moisture into snow mass |

| West Antarctic Ice Sheet (WAIS) & Coastal Basins | | Marine-based ice grounded on retrograde bedrock below sea level | | Warm Circumpolar Deep Water basal intrusion + coastal surface melt | | High vulnerability at +2 deg C (partial to near-complete collapse) | | Marine Ice Sheet Instability (MISI) and grounding-line retreat |

Orographic Winds and the Melt-Elevation Tug-of-War

In glaciology , ice sheets are classically governed by a dangerous positive feedback known as the melt-elevation feedback : as an ice sheet thins, its surface drops into lower, warmer layers of the troposphere , accelerating melting further. In East Antarctica, the coupled simulations show that katabatic (downslope) winds and steep coastal escarpments help confine surface melting to a narrow coastal fringe.

As the coastal margins steepen slightly under warming, moist Southern Ocean air masses are forced upward more abruptly along the ice-sheet slopes (orographic lifting), wringing out snow over the outer plateau while dense cloud cover caps the

amount of solar energy absorbed by the snowpack. Together, the snowfall mass gain and cloud shading prevent the coastal melt zone from migrating inward across the continental divide.

A Sharp Regional Divide: East Antarctic Stability vs. West Antarctic Vulnerability

Crucially, the authors caution that atmospheric stabilization of the East Antarctic interior does not mean global coastlines are safe from Antarctic sea-level rise. The continent is divided by the Transantarctic Mountains into two fundamentally different geological regimes:

* Continental East Antarctica: Most of the East Antarctic Ice Sheet rests on continental bedrock above sea level, allowing high-altitude atmospheric physics -- snowfall and cloud reflection -- to govern its long-term survival.

* Marine-Based West Antarctica: By contrast, the West Antarctic Ice Sheet (WAIS) -- along with low-lying East Antarctic marine subglacial basins such as the Wilkes and Aurora basins -- sits on bedrock up to 2,000 meters below sea level that slopes downward toward the interior. Because these glaciers are attacked from underneath by warming ocean currents (Circumpolar Deep Water) melting their floating ice shelves and grounding lines, atmospheric cloud shading cannot rescue them.

Even in the fully coupled simulations, the West Antarctic Ice Sheet remains highly susceptible to irreversible retreat under warming thresholds as low as +2 deg C above pre-industrial levels , carrying 3.3 to 5 meters of potential global sea-level rise on its own. By separating the ocean-driven vulnerability of West Antarctica from the atmospherically shielded interior of East Antarctica, the study provides climate modelers with a sharper physical benchmark for projecting multi-century sea-level commitments and paleoclimate ice-sheet hysteresis.

References & Primary Sources

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