EOS

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 86 NUMBER 22

31 MAY 2005

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Hydrothermal and Volcanic Activity Found on the Southern Mid-Atlantic Ridge

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The process of plate accretion at mid-ocean ridges, once thought to occur in a relatively simple, magmatic system, has been shown in recent years to possess unexpected layers of complexity [e.g., *Cannat*, 1996; *Escartín and Lin*, 1998; *Jokat et al.*, 2003; *Michael et al.*, 2003]. Particularly at lower spreading rates, the magma supply to some or all of the ridge decreases, with the plate spreading motion being taken up instead on faults.

The balance between these magmatic and tectonic processes governs such features as the topography, seismic activity, location of hydrothermal vents, and degree of chemical exchange between crust and ocean at spreading axes. It therefore has important implications for the hydrothermal marine biosphere and global chemical budgets.

With increasing tectonism at lower spreading rates comes increasing heterogeneity in the accretion process. This means that ridge crest surveys need to be correspondingly lengthened in order to make meaningful and statistically significant statements about the role of these ridges in global lithospheric and oceanographic processes. Unfortunately, it is exactly the slow spreading ridges which, up to present, have been the least studied globally, with only ~10% of their total length having been surveyed to date for hydrothermal activity, for example [*Baker and German*, 2004].

Six-Year Effort on the Mid-Atlantic Ridge

To address this need, the German Science Foundation (DFG) initiated in October 2003 a six-year multi-cruise study of a 450-km-long stretch of slow spreading axis in the South Atlantic between 7° and 11°S near the Island of Ascension. Previous studies [*Bruguier et al.*, 2003; *Minshull et al.*, 1998] had divided this area into four major segments, A1–A4 (see Figure 1). The widely varying topography and crustal thicknesses suggested that rates of magma supply differ greatly from one segment to another.

Some of the aims of the DFG study are to establish the characteristic spacing between hydrothermal vents in the area and the magmatic/tectonic features which control their location; to determine the total hydrothermal heat, water, and chemical fluxes from the vents; and to examine how the fauna associated with the vents relates to those known from other vent areas around the globe.

The first cruise in the series (with the German research vessel *Meteor*, cruise number M62/5) returned to port at the end of December 2004 with new insights into the volcanology and tectonics of the southern Mid-Atlantic Ridge (MAR), and the first detailed mapping of a hydrothermal plume south of the equator in the Atlantic.

Varying Volcanology and Tectonics Along Axis

During a 12-day deployment of the British deep-towed side-scan sonar system TOBI (Towed Ocean Bottom Instrument), 6000 km^2 of the spreading zone between the Ascension and Bode Verde Fracture Zones (Figure 1) were imaged for the first time, yielding evidence for both magmatically and tectonically dominated spreading.

Segment A1 appears to have a low magma supply—the axial valley is deep, volcanism is concentrated on small within-axis volcanic ridges, and these ridges are sometimes topped by discrete small volcanoes with well developed calderas. Optical backscatter information from miniature autonomous plume recorders (MAPRs) attached to the TOBI vehicle and its tow wire showed several signs of turbid hydrothermal plumes within the water column, in some cases confirming previous indications from a conductivity-temperature-depth (CTD) profile in the area [*German et al.*, 2002].

Segment A2 showed some of the youngest-looking flows (Figure 1b and c). Both off-axis (Figure 1b) and on-axis (Figure 1c) flows are seen to blanket axial fault scarps. The on-axis flow (Figure 1c) does not appear to have been fractured by any fault planes large enough to be visible at the resolution of the TOBI images (6 m mean pixel resolution).

Segment A3 is the shallowest segment, with crustal thicknesses up to 11 km [*Bruguier et al.*, 2003]. The axial region is characterized by extensive sheet flows and the virtual absence of "hummocky terrain," which is the surface expression of pillow volcanoes and a typical feature of slow spreading ridges.

The jump to segment A4 is accompanied by a large increase in axial depth and a return to volcanic features similar to those seen on segment A1. Despite the fact that A4 is labeled as one segment, the side-scan data show several individual volcanic segments, separated from one another by nontransform displacements of up to 8 km, within the axial valley.

Evidence for Multiple Hydrothermal Sites

Although there is evidence for as many as 24 venting sites between 15°N and 38°N on the northern MAR [*Baker and German*, 2004], information on the locations of active hydrothermalism on the southern MAR is virtually nil, with the exception of some total dissolved manganese (TDMn) anomalies in the water column found by *German et al.* [2002].

During the *Meteor* cruise, strong evidence was found for hydrothermal activity on a topographic high that rises to 2900 m depth from the rift valley floor at 3500 m depth between 8°17'S and 8°19'S to the east of the tip of segment A2 (see star in Figure 1). High methane concentrations (up to 115 nanomoles per litre, or nmol/L) together with layers of increased light scattering peaking at 2700 m depth in the vicinity of 8°18'S, 13°31'W (Figure 2), indicate the presence of venting in this area.

Although black smokers have not yet been directly observed, manganese concentrations of up to 25 nmol/L, coincident with the peak in methane concentration and light scattering (Figure 3), confirm the hydrothermal nature of this water anomaly. Additionally, a temperature anomaly of 0.14°C 2 m above the seafloor, found during a remotely operated vehicle (ROV) dive at the western flank of the area, is probably related to heat transfer from a hydrothermal system below the surface. This higher temperature has caused pervasive local alteration of rocks and sediments. This region has been named the "Nibelungen Field," after an ancient German myth of subterranean dwarves (Nibelungen) hoarding riches.

By C. W. Devey, K. S. Lackschewitz, and E. Baker

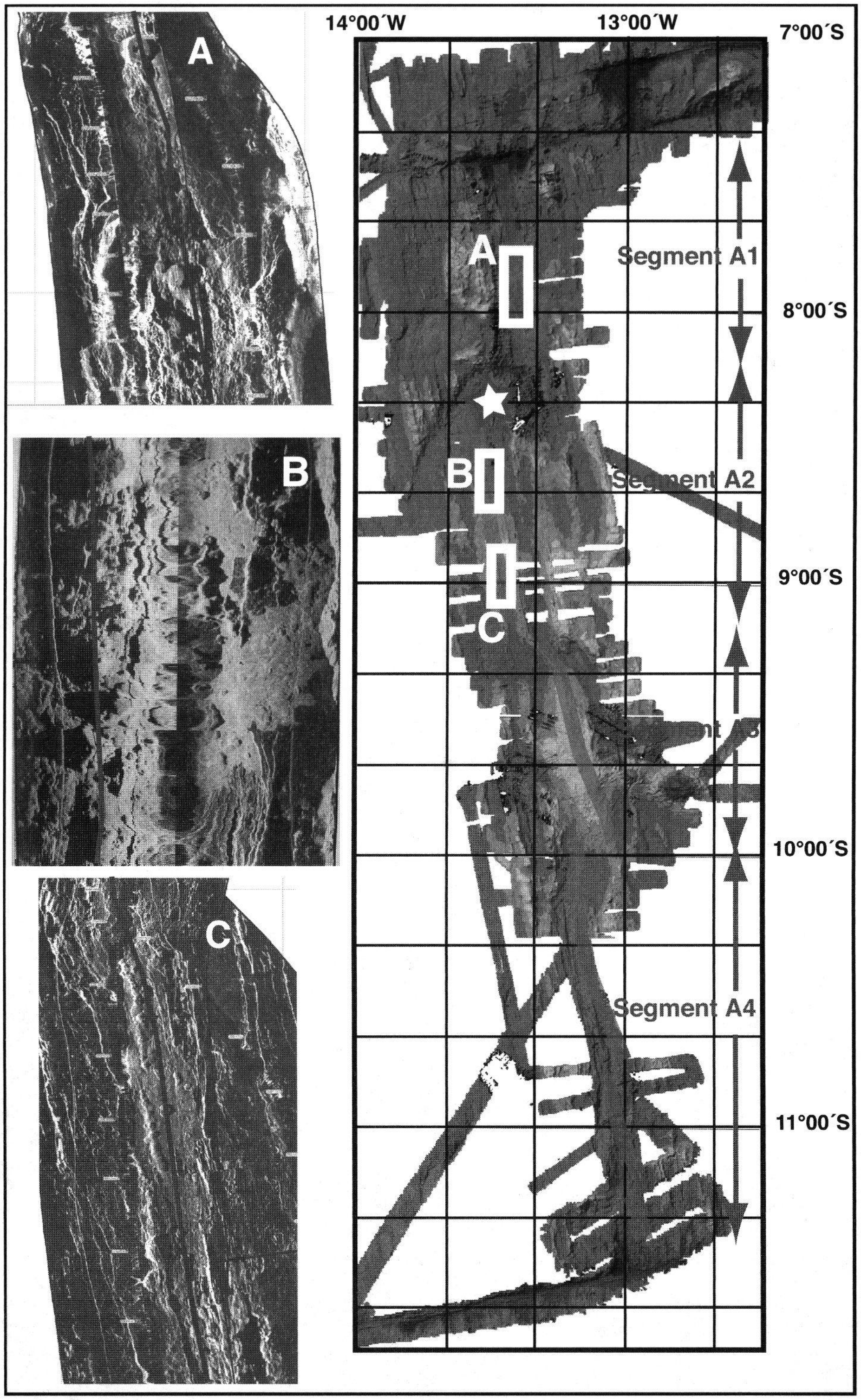

Fig. 1. Bathymetry and selected side-scan images of the axial region near Ascension Island. Red lines on side-scan images and grey lines on the bathymetric map mark the approximate trace of the plate boundary. Lighter shades on the side-scan images denote areas of high sonar reflectivity (hard, unsedimented seafloor or fault scarp). (a) Isolated volcanic cones in segment A1 seen on a postprocessed image made by combining two towed ocean bottom instrument (TOBI) passes. The image width is ~10 km. (b) Young, off-axis lava flows on the eastern flank of segment A2, which cover some prominent faults and appear to pond against the large fault scarp on the right edge of the picture. The unprocessed image is direct from the TOBI recorder. The image width is ~6 km. (c) Postprocessed image of a large (~10 km²) lava flow in the axial valley of segment A2. Note the apparent chain of volcanic mounds just left of the plate boundary trace in the middle of the picture. The image width is ~10 km. Original color image appears at the back of this volume.

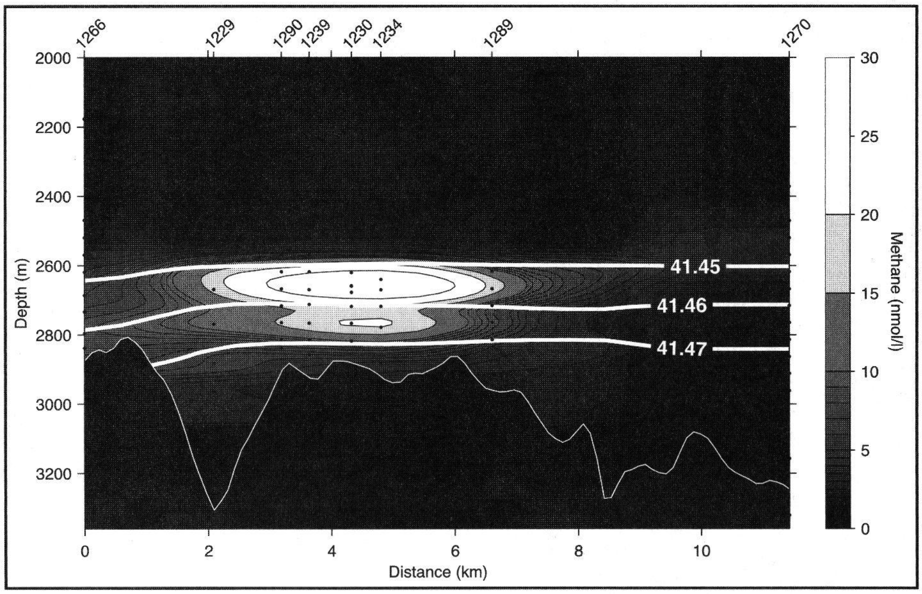

Fig. 2. Methane data from the "Nibelungen Field" area, along a south-north transect from 8°20' to 8°15'S at ~13°30'W. Black dots indicate water samples used to construct the Figure. Methane values are presented as nmol/L; white lines denote surfaces of constant density (isopycnals) in sigma units (kg/m^3 in excess of the density of pure water). Original color image appears at the back of this volume.

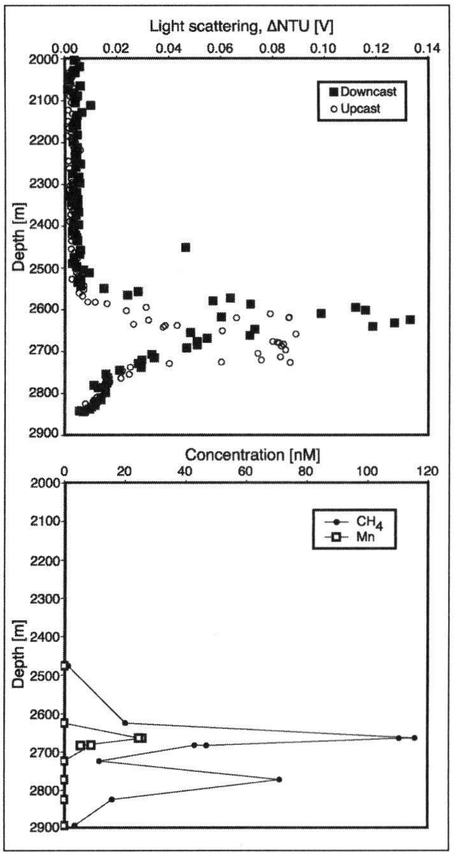

Fig. 3. Light scattering sensor, methane, and total dissolved manganese (TDMn) data from water sampling station 1230 at 8°18.00'S and 13°31.00'W.

Two other hydrothermal plumes were also detected. Along an east-west CTD transect at 8°10'S (north of the Nibelungen Field) a clearly defined plume in methane concentration (up to 9.7 nmol/L) was identified at 2000 m water depth at 13°28'W, suggesting a hydrothermal source probably located at the western slope of the rift valley. Farther north, the TOBI/MAPR survey identified a 100-m-thick plume layer centered at 2600 m depth, extending from 7°58' to 8°02'S near 13°26.5'W. While the depth range of this plume overlaps the "Nibelungen" plumes, its location in a different segment suggests it arises from a separate source.

The initial surveys on this ~450-km-long ridge section identify a minimum of three vent sites, or 0.7 sites per 100 km, which is consistent with previous estimates of site frequency along the northern MAR. Excessive along-axis relief (Figure 1), combined with a typical TOBI towing altitude of 400–800 m above bottom, could have hidden some plumes from the survey, which would make this estimate conservative.

This study is one of the most detailed yet undertaken along the southern MAR, and illustrates the efficiency of melding geophysical and water column surveys into a single operation. Applying this technique to other segments would allow more robust estimates of the importance of Atlantic hydrothermal circulation at a global scale to be made, and the importance of these sites as biological stepping-stones that link the North Atlantic to the other major ocean basins to be determined.

Acknowledgments

We thank Captain N. Jakobi and crew for the excellent support during *Meteor* cruise M62/5. The cruise and postcruise scientific work was supported by the German Science Foundation (DFG). The scientific party includes B. Bannert, O. Bislich, G. Engemann, L. Fowler, P. Günnewig, D. Hüttig, Y.-G. Kim, A. Klügel, A. Knee, A. Koschinsky, A. Ksienzyk, B. Kührig, T. Kuhn, D. Matthew, C. Mertens, T. Mosch, B. Murton, N. Nowald, H. Paulick, V. Ratmeyer, M. Reuter, I. Rousse, O. Schmale, W. Schmidt, F. Schubotz, M. Schröder, C. Seiter, K. Stange, J. Stecher, U. Stöber, S. Storm, J. Sültenfuss, T. Teichgräber, P. O. Thierer, S. Tille, S. Tyler, W. Walter, P. Wefers, and F. Zielinski.

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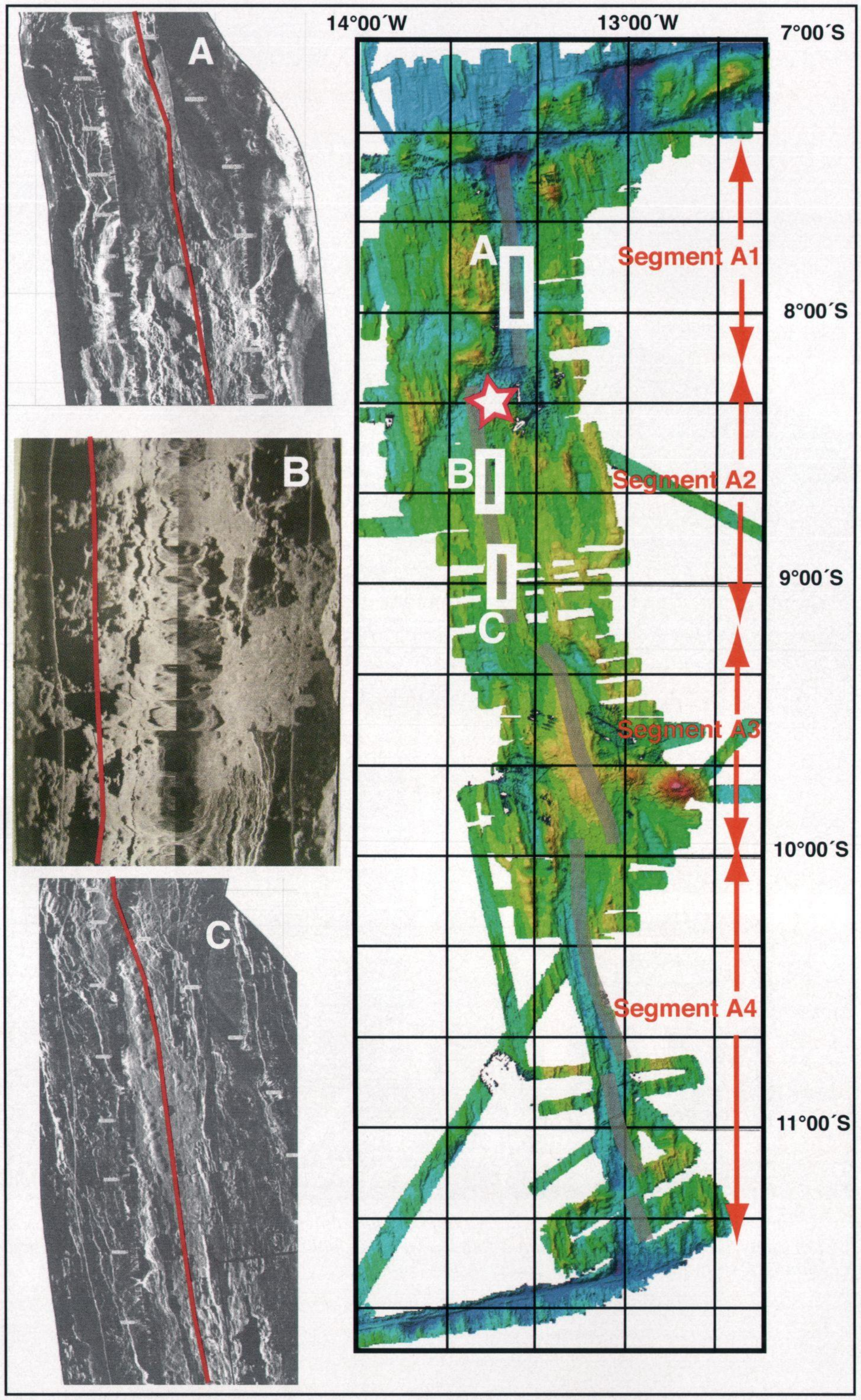

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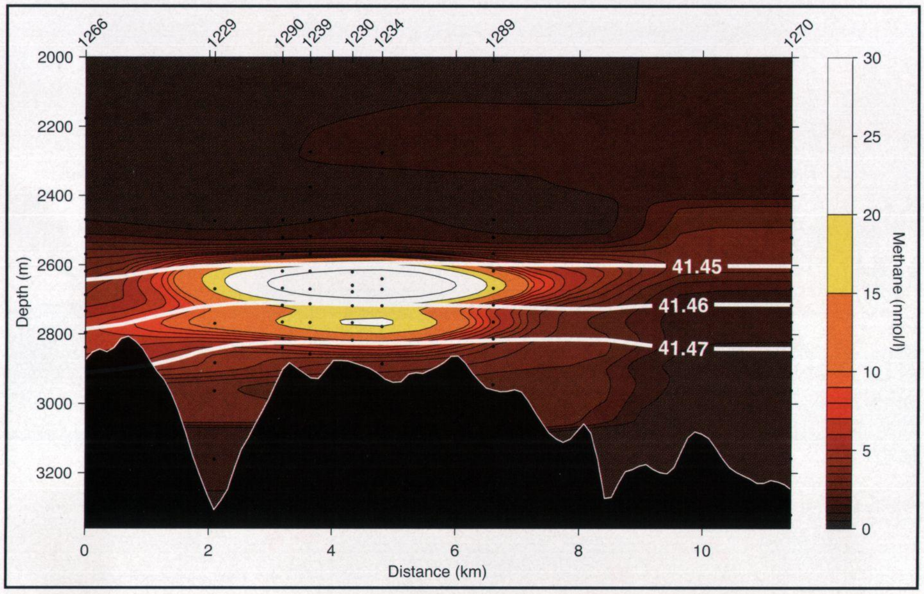

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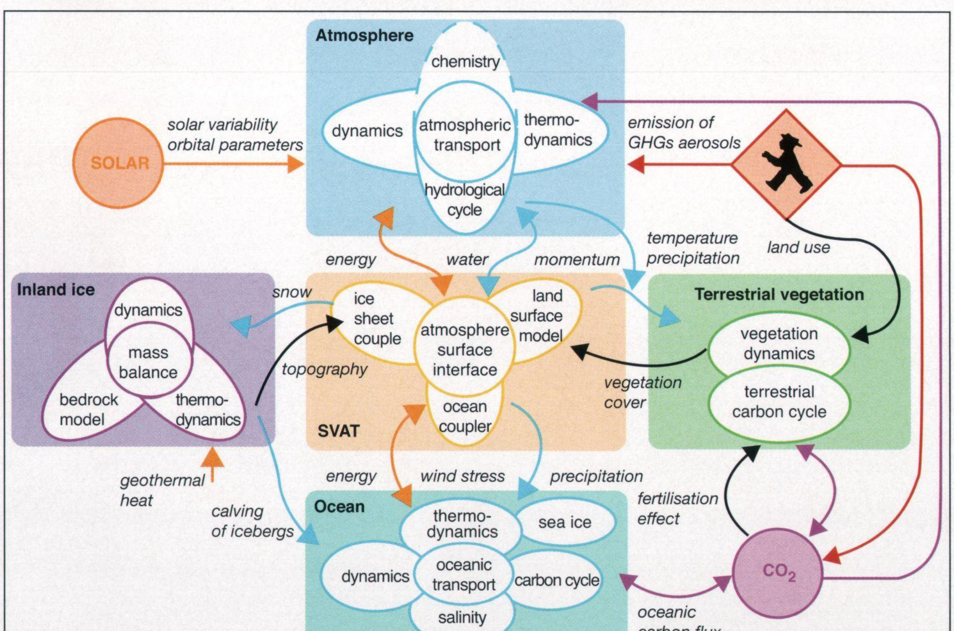

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Fig. 2. Schematic diagram of the climate and biosphere (CLIMBER) Earth system model of intermediate complexity (EMIC). EMICs are part of a hierarchy of Earth system modeling approaches to be considered in AIMES. Adapted from Petoukhov et al. *[2000].*