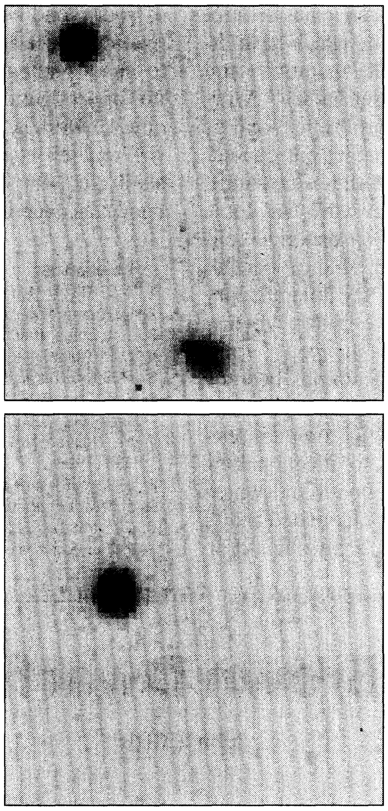
dwarf systems but many close doubles (see the figure) (*6*). Additional brown dwarf doubles are likely to be too close to be resolved.

The fraction of brown dwarfs found in multiple systems and the distribution of orbital separations are not identical with those of solar mass stars, but the observations are consistent with an extension of the properties of the lowest mass stars. Some widely separated brown dwarf companions to main sequence stars have also been detected. Furthermore, like stars, many very young brown dwarfs show evidence of disks (*7*, *8*). Whether these disks result in planetary systems is as yet unknown.



Hubble Space Telescope images of double brown dwarfs (*6*).

The basic structure and evolution of brown dwarfs are well understood, but many questions remain. First, characterization of the magnetic fields and magnetic activity of brown dwarfs is preliminary. Second, the x-ray coronae and Hα chromospheres so common among low-mass stars weaken and disappear around the hydrogen burning limit, but flares continue, at least in late-M spectral classes (*9*–*11*). Third, the properties of cool atmospheres are very difficult to calculate. Theoretical models predict dust formation in the atmosphere, and preliminary indications of weather variability due to dust clouds have been observed (*12*).

Studies of star-forming regions in Orion indicate that the brown dwarf sequence extends smoothly down to at least 5 to 8 M_J and possibly to lower masses (*13*, *14*). Extrasolar planetary systems with more massive ($>7\ M_J$) components have been detected (*15*), indicating that the upper tail of planet formation and the lower tail of star formation overlap in mass. This overlap has created a dilemma in naming conventions, particularly because the origin of a given object cannot usually be determined. The proposal to rename the lowest mass brown dwarfs "isolated planets" only confuses the problem of understanding the origin and properties of objects in the overlapping mass region.

The deuterium burning limit (13 M_J) has been proposed as a nomenclature cutoff, but this limit has no long-term evolutionary effects, nor (based on the observed mass distributions) does it have much to do with the formation of brown dwarfs or planets. If two classes of objects overlap in mass space, these classes of "brown dwarfs" and "planets" will likely have different statistical properties that will allow them to be distinguished.

The similarity of the observed properties of more massive brown dwarfs to stars has linked them to star formation. Extension of the studies of the initial mass function, binary frequency, disk frequency, magnetic fields, rotation, composition, and other parameters to lighter objects ($<20\ M_J$) now promises to reveal important insights into the differences between brown dwarfs and giant planets.

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PERSPECTIVES: CLIMATE CHANGE

How Fast Are Sea Levels Rising?

John A. Church

Sea levels are expected to rise as a result of global warming, with adverse effects on many people living in coastal areas. Accurate projections of sea level rise are therefore important for guiding policy. However, the most recent Intergovernmental Panel on Climate Change (IPCC) assessment of sea level rise (*1*) shows that the average of model estimates of 20th century sea level rise is low compared to the observations and there is a large range (1 to 2 mm/year) of observational estimates.

It is important that the observational and model estimates are reconciled. If the 20th century model estimates are low, then projections for the 21st century may also be underestimated. Alternatively, the observational estimates of 20th century sea level rise may be too high. This is the conclusion reached by Cabanes *et al.* on page 840 of this issue (*2*). The authors examine global altimeter and ocean temperature observations and arrive at observational estimates of sea level rise that are closer to the model estimates.

Several factors contribute to sea level change. The most important contribution to 20th and 21st century sea level rise is likely to be thermal expansion of the ocean as it warms. Other contributions include the melting of glaciers, changes in the mass of the Antarctic and Greenland ice sheets, and (highly uncertain) changes in the terrestrial storage of water.

Observational estimates of sea level change are based on the short (less than 10 years) satellite record of sea level height and the longer but geographically uneven and sparse tide-gauge network. The latter has few gauges with long records in the ocean-dominated Southern Hemisphere and few gauges at mid-ocean locations. Other difficulties in determining the rate of 20th century sea level change include the need to allow for land motions (both post-glacial rebound and tectonic motions) and for regional differences in sea level rise.

Regional differences in the rate of sea level rise should leave a mark in the pattern

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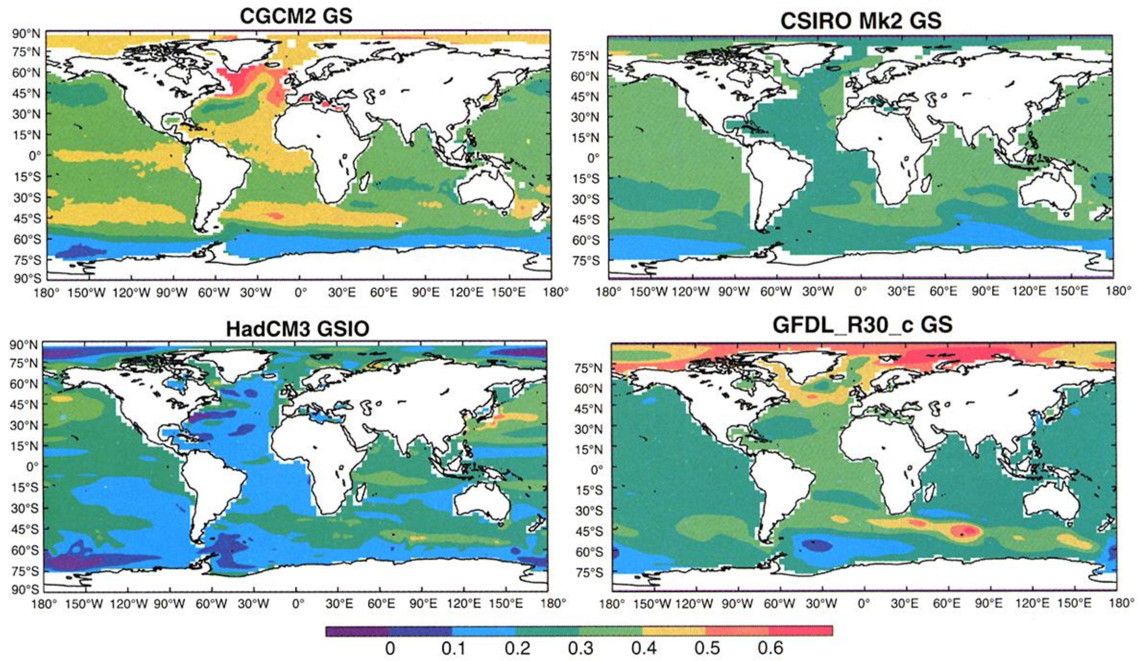
of sea level rise revealed by satellite altimeters and in observations of ocean thermal expansion from historical (subsurface) ocean-temperature observations (*3*). For 1993–98, Cabanes *et al.* find that the global average sea level rise of 3.2 ± 0.2 mm/year calculated from satellite altimeter data is almost equal to the thermal expansion (3.1 ± 0.4 mm/year) computed from temperatures of the upper 500 m of the ocean (*3*). The authors infer that the net contribution of the other components to sea level rise is small. They also find that the pattern of sea level rise from the two data sets is qualitatively similar.

For the longer period of 1955–96, Cabanes *et al.* estimate a globally averaged value of thermal expansion for depths of 0 to 3000 m of 0.5 ± 0.05 mm/year. In contrast, the average sea level rise computed from thermal expansion at locations near tide gauges is 1.4 ± 0.1 mm/year, close to the corresponding tide-gauge estimate of sea level rise of 1.6 ± 0.15 mm/year. Subsampling of the global field thus appears to result in an overestimate of thermal expansion by about 0.9 mm/year.

If, as seems likely, much of the thermal expansion has occurred in the past few decades, the overestimate determined by Cabanes *et al.* may be too large to apply to estimates of globally averaged 20th century sea level rise. A more suitable value can be found by scaling the overestimate using the computed rate of thermal expansion from the IPCC Assessment (*1*). This gives about 0.6 mm/year. Using this value, the central IPCC estimate of 1.5 mm/year and the widely accepted estimate of Douglas (*4*) of 1.8 mm/year for 20th century sea level rise should be reduced to 0.9 and 1.2 mm/year, respectively. These estimates are closer to the IPCC estimates of the sum of contributions to sea level rise of 0.7 mm/year (or 1 mm/year if we ignore the poorly constrained terrestrial storage).

Gregory *et al.* (*5*) used model results to test the hypothesis that the locations of the tide gauges lead to a bias in global estimates of sea level rise. For 1910–90, they found differences of less than 20% (less than 0.2 mm/year) in most cases, much less than the differences found by Cabanes *et al.* For one model, averaging the rise at tide-gauge locations even resulted in an underestimate (rather than an overestimate as in Cabanes *et al.*) of the global average by almost 50%. However, different models produce very different patterns of sea level rise from each other (see the figure) and from the thermal expansion field estimated from observations. At present, we cannot tell which model, if any, is correct.



Projected sea level rise distributions. The IPCC Asssessment (*1*) included projections of sea level rise distributions for the 21st century from nine climate models run with the IS92a greenhouse gas scenario (including the direct effect of sulfate aerosol). Four of these projections are shown here (contour interval is 0.1 m). To date, we have little confidence in the distribution of sea level rise because the different models produce different patterns of sea level rise. Reproduced with permission of the IPCC.

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The central question is: How good is the spatial pattern of ocean thermal expansion? Even during the 1993-98 period, when altimeter data are available and in situ ocean data sets are relatively complete, Cabanes *et al.* point out that sea level trends from thermal expansion in the Southern Ocean (a region of sparse data) are noticeably smaller than the altimeter trends.

Most tide gauges used in historical analyses are in regions with relatively complete historical ocean observations. It may be that the thermal expansion trends for 1955 to 1996 are also biased low in data-poor regions, leading to a low bias in the global average. Qualitative support for this idea comes from repeated observations along particular ocean transects (*1*), which tend to indicate a sea level rise from thermal expansion closer to 1 mm/year (rather than 0.5 mm/year). However, the individual section comparisons are subject to decadal variability and there is incomplete global coverage.

Sea level rise is not likely to be uniform around the globe, and, as identified by Cabanes *et al.* (*2*) and the IPCC (*1*), there may be spatial biases in the historical estimates of sea level rise. To further reconcile models and observations, we need to continue to examine the historical data base, critically compare models with observations, continue model development, and continue to observe the global climate system. High-quality satellite altimeter missions and a global ocean program of profiling floats supported by repeat ship observations offer great promise for understanding regional sea level rise. This is crucial as the impacts of sea level rise depend on regional values and not the global average.

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