CHAPTER 9

HOW TO USE THESE RESULTS TO PROJECT LOCAL SEA LEVEL

The results presented in Chapter 7, like those from previous sea level assessments, only account for the global rise in sea level resulting from global climate change. They include neither the change in global sea level resulting from other factors[1] nor changes in local sea level resulting from land subsidence, compaction, and other factors.

The Approach Employed by Previous Studies

Previous EPA studies on the impacts of sea level rise have assumed that the nonclimate contributors to sea level will remain constant.[2] Based on the assumption that global sea level rose 12 cm over the last century, these studies assumed that the net subsidence at particular locations was 1.2 mm/yr less than the observed rate of relative sea level rise measured by tidal gauges. With that assumption, estimates of local sea level rise were calculated as follows:

$$\text{local}(t) = \text{global}(t) + (\text{trend} - 0.12)\,(t - 1990),$$

where **local(t)** is the rise in sea level by year **t** at a particular location, measured in centimeters; **global(t)** is the global rise in sea level projected by a particular scenario; and **trend** is the current rate of relative sea level rise at the particular location. Because more recent estimates suggest that global sea level may be rising 1.8 mm/yr, some studies have replaced the coefficient 0.12 with 0.18.

Implicit in this procedure was the assumption that in the next century global warming will be the only net contributor to global sea level. Some impact researchers, by contrast, have developed local scenarios simply by adding local trends to the projections of global sea level rise.[3] Implicit in that procedure is the assumption that *none* of the historic sea level rise was caused by global warming. As long as people were investigating the implications of a 1 to 2 m rise in sea level, there was little practical distinction between these two approaches. But with sea level projections on the order of 50 cm, this 12 cm discrepancy is worth resolving.

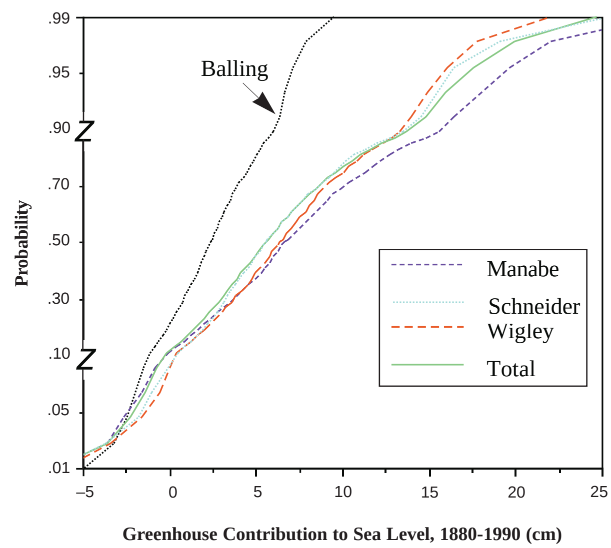

Figure 9-1. Historic Greenhouse Contribution to Sea Level, 1880–1990. The median estimate of the greenhouse contribution (0.5 mm/yr) implied by the reviewer assumptions is well below prevailing estimates of global sea level rise (1 to 2.5 mm/yr). Unless the nongreenhouse contributors are likely to change, it is reasonable to assume that global sea level rise in the next century will also be 0.5 to 2 mm/yr greater than the greenhouse contribution.

Which of these assumptions are correct? Probably neither. As Figure 9-1 shows, the reviewer assumptions with which we project future sea level rise imply that sea level rose about 0.5 mm/yr over the last century. This estimate is well below the

[1] *E.g.*, very long-term (glacial/interglacial) changes in climate, and nonclimatic factors such as groundwater depletion and changes in land use. Although nonclimatic sources have added at most a few centimeters to sea level in the last century (Sahagian et al. 1994), no one has thoroughly assessed the likely future contribution.

[2] This convention started with EPA's first sea level impacts assessment (Barth & Titus 1984) and continued through EPA's final assessment of U.S. impacts (Titus et al. 1991). The approach was endorsed by the National Academy of Engineering (Dean et al. 1987). More recent assessments have subtracted out a slightly higher estimate of global sea level trends.

[3] This procedure is consistent with the approach used by Roger Revelle in NAS (1983). Revelle explicitly added the historic trend of 12 cm to his estimates of thermal expansion, Greenland, and small glacier contributions to sea level.

1.8 mm/yr estimate of total global sea level rise. Thus, it would appear that other factors are adding to sea level. Possible explanations include groundwater depletion (Sahagian et al. 1994), a delayed response to the warming that has taken place since the last ice age, and shifts in ocean basins. It is also possible that tidal gauges cannot measure true global sea level rise because coasts are generally subsiding.[4]

Until we know precisely why our models underpredict historic sea level rise, it seems most reasonable to assume that those factors that we have not modeled will continue. *Because this assessment (like previous IPCC assessments) only examines the sea level rise induced by climate change, the results presented in Chapter 7 should be interpreted as estimating the extent to which climate change will accelerate the rate of sea level rise, compared with what otherwise would occur.*

Recommended Procedure

The most realistic procedure, in our view, is to extrapolate all trends other than those due to global warming. Simply adding historic trends to published projections of sea level rise doublecounts whatever portion of the historic local trend was caused by global warming. We remove this doublecounting by developing a set of normalized projections in which the historic component of the greenhouse contribution has been removed.[5] *The normalized projections estimate the extent to which future sea level rise will exceed what would have happened if current trends simply continued*. Table 9-1 summarizes our normalized results.

Those who require an estimate of sea level rise at a particular location can simply add the normalized projection to the current rate of sea level rise[6]:

$$\text{local}(t) = \text{normalized}(t) + (t - 1990) \times \text{trend}.$$

For example, according to Table 9-2, sea level at New York City has been rising 2.7 mm/yr.[7] This rate is typical of the U.S. Atlantic and Gulf Coasts (Lyles et al. 1988). For the year 2100, the median and 1%-high normalized projections are 25 and 92 cm for the year 2100. Because even current trends would result in a 30 cm rise, the total rise is most likely to be 55 cm (about 2 feet); but it also has a 1 percent chance of exceeding 122 cm (about 4 feet). Similarly, if one assumes that average worldwide sea level has been rising 1.8 mm/yr, then global sea level has a 50 percent chance of rising 45 cm, and a 1 percent chance of rising 112 cm, by the year 2100. (See Figure 9–2.)

Caveats

Scenarios of sea level rise can be put to a variety of uses. In general, individual users know—far better than we—the most appropriate uses for these scenarios. All we can do is convey what we know about their limitations.

Most importantly, our *probability estimates are not based on statistics*. Our estimates simply convey what the probability of various rates of sea level rise would be *if* one is willing to assume that the experts we polled are each equally wise and that their collective

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[4]For example, due to the additional mass placed on the continental shelves from previous sea level rise.

[5]Each normalized projection was calculated as follows:

$$\text{Normalized}_i(t) = \text{global}_i(t) - [\text{model}_i(1990) - \text{model}_i(1880)]\ \frac{t-1990}{110},$$

where $\mathbf{global_i(t)}$ is the greenhouse (and sulfate) contribution to sea level (*i.e.*, the result reported in Chapter 7) between 1990 and the year **t** for the i^{th} simulation; and $\mathbf{model_i}$ represents the historic greenhouse contribution to sea level estimated by the i^{th} simulation between 1765 and a particular year. Thus, the i^{th} normalized projection represents the extent to which the greenhouse contribution by a particular year exceeds the contribution that would be expected by merely extrapolating the estimated historic greenhouse contribution. Assuming that the nongreenhouse contributors remain constant, the normalized projection also represents the extent to which sea level rise will exceed the rise that would be expected from extrapolating the historic rate of rise.

[6]This procedure is not the same as simply adding a historic trend to every element of the probability distribution, since $\mathbf{Model_i}$ will be different for different simulations (*see* Note 5, *supra*). The overall tendency will be for the normalized distribution to have a smaller variance than the greenhouse contribution; for example, a high temperature sensitivity implies that historic thermal expansion was greater than the mean estimate, and hence that the historic nongreenhouse contribution was less than the mean estimate, for a given estimate of total historic sea level rise.

Notwithstanding our concern in Chapter 3, Note 4, the normalized projections are probably improved somewhat by the fact that each model run included a historic simulation. If a particular set of parameters substantially overestimates the historic rate of sea level rise, for example, the net effect of our procedure is to adjust the future projection downward by the amount of the historical overestimate.

[7]The National Ocean Service periodically publishes estimates of the rate of sea level rise for several U.S. cities. As this report went to press, NOS was about to release its new estimates for sea level trends. The new report can be obtained from Steve Lyles, National Ocean Service, SSMC4, Station 7601, 1305 East-West Highway, Silver Spring, MD 20910-3233. Fax: 301-713-4435.

TABLE 9-1
ESTIMATING SEA LEVEL RISE AT A SPECIFIC LOCATION
Normalized Sea Level Projections, Compared with 1990 Levels (cm)

Cumulative Probability	Sea Level Projection by Year: 2025	2050	2075	2100	2150	2200
1	–10	–16	–21	–24	–32	–40
5	–3	–4	–5	–6	–7	–8
10	–1	–1	0	1	3	5
20	1	3	6	10	16	23
30	3	6	10	16	26	37
40	4	8	14	20	35	51
50	5	10	17	25	43	64
60	6	13	21	30	53	78
70	8	15	24	36	65	98
80	9	18	29	44	80	125
90	12	23	37	55	106	174
95	14	27	43	66	134	231
97.5	17	31	50	78	167	296
99	19	35	57	92	210	402
Mean	5	11	18	27	51	81
σ	6	10	15	23	47	81

NOTE: To estimate sea level at a particular location, add these estimates to the rise that would occur if current trends were to continue. See Table 9-2 for historic rates of sea level rise. For example, if sea level is currently rising 3 mm/yr, then under current trends, sea level will rise 26 cm between 1990 and 2075. Adding 26 cm to the normalized values in the Table, the median estimate for 2075 is 43 cm, with a 1 percent chance of an 83 cm rise.

TABLE 9-2
HISTORIC RATE OF SEA LEVEL RISE AT VARIOUS LOCATIONS IN THE UNITED STATES
(mm/yr)

Atlantic Coast					
Eastport, ME	2.7	Sandy Hook, NJ	4.1	Portsmouth, VA	3.7
Portland, ME	2.2	Atlantic City, NJ	3.9	Wilmington, NC	1.8
Boston, MA	2.9	Philadelphia, PA	2.6	Charleston, SC	3.4
Woods Hole, MA	2.7	Lewes, DE	3.1	Ft. Pulaski, GA	3.0
Newport, RI	2.7	Annapolis, MD	3.6	Fernandina, FL	1.9
New London, CT	2.1	Solomons, Is., MD	3.3	Mayport, FL	2.2
Montauk, NY	1.9	Washington, DC	3.2	Miami Beach, FL	2.3
New York, NY	2.7	Hampton Roads, VA	4.3		
Gulf Coast					
Key West	2.2	Grand Isle, LA	10.5	Galveston,TX	6.4
St. Petersburg, FL	2.3	Eugene Island, LA	9.7	Freeport, TX	14.0
Pensacola, FL	2.4	Sabine Pass, TX	13.2	Padre Island, TX	5.1
Pacific Coast					
Honolulu, HI	1.6	Los Angeles, CA	0.8	Astoria, OR	–0.3
Hilo, HI	3.6	Santa Monica, CA	1.8	Seattle, WA	2.0
San Diego, CA	2.1	San Francisco, CA	1.3	Neah Bay, WA	–1.1
La Jolla, CA	2.0	Alameda, CA	1.0	Sitka, AK	–2.2
Newport, CA	1.9	Crescent City, CA	–0.6	Juneau, AK	–12.4

wisdom reflects the best available knowledge. In a statistical model, we would conduct an experiment at least several dozen times and determine the variation of outcomes. But within the time horizon of this project, humanity can only conduct the experiment once, which we are doing; so statistical estimates of probability are impossible. Our projections are less like a statistical weather forecast and more like handicapping a horse race.

As with a horse race, our inaccuracy results more from our inability to quantify the relevant factors than from the random fluctuations within the processes whose uncertainties we have described. We have left out some factors; so our uncertainty is probably greater than we estimate it to be.

Finally, this particular exercise, like EPA's 1982–83 report projecting sea level rise (Hoffman et al. 1983), is limited by the fact that the authors are not experts about any of the particular processes that contribute to sea level. Just as the 1983 report was undertaken because no one else was estimating sea level rise for specific years, this report was undertaken because no one was estimating the probability of sea level rise or factoring in the small-but-important risk of a large Antarctic contribution. For the foreseeable future, coastal decisionmakers should view this prospect as a potentially important risk that is poorly understood. Although Antarctica will probably not contribute significantly to sea level in the next century, the glaciology reviewers of this report were unanimous that the research necessary to rule it out simply has not been undertaken. (*See also* Appendix 3.)

The reader should have no illusions about the adequacy of the models used in this or any report projecting future sea level rise. Because a reasonable person cannot confidently be certain that any particular group of experts knows the actual story, we have attempted to incorporate every view that we could obtain. We hope that these estimates of the probability of sea level rise help coastal engineers, planners, and legislators to determine whether and how to prepare for the consequences of a rising sea.

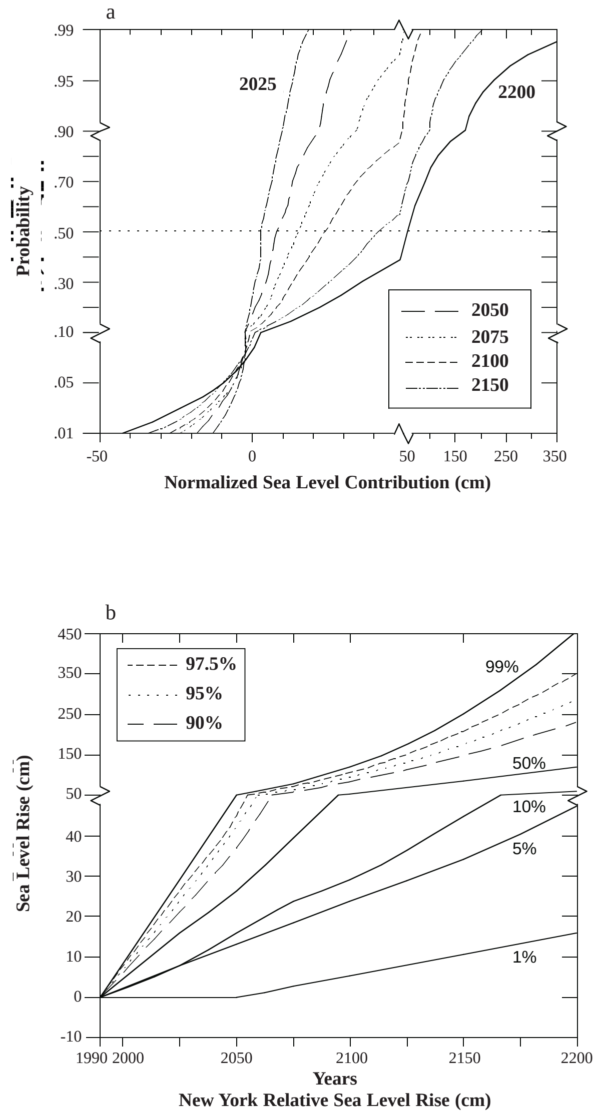

Figure 9-2. Normalized Contribution to Sea Level. By netting out the historic greenhouse contribution, the normalized estimates in (a) represent the projected *acceleration* in sea level compared with historic trends. One can estimate local or global sea level by adding these estimates to trends from tide guages. For example, in (b) these estimates are added to New York's historic trend of 2.7 mm/yr, which typifies the U.S. Atlantic

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