toward defining human needs: how does the atmosphere hurt us?

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Abstract

In an attempt to define human needs toward which resources in the atmospheric sciences ought to be directed, a compilation is made of a recent seven-year total of deaths, injuries, and damages attributed in ESSA's *Storm Data* to various categories of element and classes of storm. It is found that in the United States cumulus convective storms kill many more people than do extratropical storms and tropical cyclones. Dollar damages from convective and from tropical storms are comparable.

Estimated costs of damage due to air pollution are an order of magnitude larger than direct damage due to all other atmospheric sources combined, but are regarded as indirect costs, for which no counterpart due to other sources is available.

An improved capability for safeguarding society from convective storms and a study of the ways in which atmospheric science can benefit society through the abatement and control of air pollution are seen as urgent needs which require augmented allocation of resources.

1. Introduction

In these days of rapid change and widespread questioning of the traditional bases of institutions and of social processes, it is not surprising that the goals of atmospheric science are being reexamined. An emerging point of view has been well expressed by Hilst (1970): "[Previously, National Academy of Sciences] studies and recommendations were geared entirely to the welfare and advancement of the science. It was assumed that these advances would be useful and valuable. Now our approach is to start with defined *needs* for knowledge and information about the atmosphere, now and in the future, and then assess what must be done in the atmospheric sciences to meet these needs."

In any list of such human needs, preservation of life and property must be at the top. Among the various threats which the atmosphere poses, the clear and present dangers, such as death from tornado, must be considered together with the more remote and problematical ones, such as ecological disruption from global effects of deteriorating air quality. Rational establishment of priorities is extremely difficult because of the uncertainties in the estimation of future threats, and of the indirect costs of present threats. *De facto* priorities will be assigned, nevertheless, by the diffuse and partly political process of assignment of resources to one or another part of atmospheric science. It behooves us, therefore, to try to contribute to this process. This small study represents such an attempt.

2. Categories of loss

We have undertaken to assess the extent of death, injury, and damage produced directly by various atmospheric phenomena, as reported in the monthly ESSA publication *Storm Data* for the 7-year period July 1963 through June 1970. This publication lists, in varying degrees of detail and specificity, accounts of damaging events in the 50 states, Puerto Rico, the Virgin Islands, and the Pacific Islands administered by this nation. The

TABLE 1. List of categories.

1. Fog
2. Rain (plus any phenomenon except wind, ice, or snow)
3. Rain and wind (plus any phenomenon except snow)
4. Rain and ice (plus any phenomenon except snow)
5. Ice (plus any phenomenon except rain, snow, or wind)
6. Rain and snow (plus any phenomenon)
7. Snow and ice (plus any phenomenon except rain, wind, or cold)
8. Snow and wind (plus any phenomenon except rain, wind, or cold)
9. Snow (plus any phenomenon except wind, ice, rain, or cold)
10. Snow and cold (plus any phenomenon except rain)
11. Blizzard
12. Avalanche
13. Cold
14. Flood
15. Sea or surf
16. Drought
17. Wind (plus any phenomenon except rain, snow, or ice)
18. Wind and ice
19. Turbulence aloft
20. Tornado
21. Hail (plus lightning)
22. Lightning
23. Tropical storm
24. Heat

Note: The elements within parenthesis are those whose appearance in the characterization did not preclude the assignment of the event to the category indicated by the primary element. The characterizations "glaze" and "freezing" [Precipitation]" are included in the category of "ice."

accounts include the number of deaths and injuries directly attributable to atmospheric phenomena, together with code numbers representing to the nearest power of ten the associated dollar damage to property and to crops. The meteorological character of each event is denoted sometimes as a structure (e.g., thunderstorm or nor' easter) and sometimes as a constituent element (e.g., high wind or heavy rain). We classified all such characterizations into an exhaustive and mutually exclusive set of 24 categories, representing mainly (but not entirely) constituent elements. The list is given in Table 1. The appearance of "blizzard," "tornado," or "tropical storm" in the characterization of an event was considered preemptive, and all the death, injury, and damage associated with such event was attributed to category 11, 20, or 23, respectively, because we did not have the patience to make an apportionment to the elements represented (nor was it always possible to do so on the basis of the information provided). Neither was such apportionment made in the other compound categories. Sea and surf, avalanche, and flood, though not atmospheric phenomena, were included because they are a direct consequence of atmospheric events.

We readily admit that the list of categories seems less than completely satisfactory, but it is the best we could do before the fact in dealing with the great variety and inconsistency in the characterizations in *Storm Data*. Even after the fact it is not clear how we might have done substantially better. We might wish for a more rigorously organized and systematic presentation of information in this publication, but we realize that we would doubtless thereby lose the colorfulness of many of the individual accounts, the perverse enjoyment of which made the tedium of tabulation bearable.

TABLE 2. Losses July 1963–June 1970.

Category	Killed	Injured	Total damage (millions $)	Death rank	Damage rank
1	12	94	1		
2	424	332	1183	4	3
3	198	1196	673	6	5
4	1	18	12		
5	37	1727	63		
6	41	43	205		9
7	33	10	223		8
8	98	162	71	10	
9	122	217	37	9	
10	19	2	159		10
11	162	105	35	8	
12	2	6	0		
13	33	3	96		
14	180	915	753	7	4
15	14	65	2		
16	0	0	18		
17	383	2961	646	5	6
18	5	6	2		
19	0	5	<1		
20	868	13954	1494	1	2
21	22	128	330		7
22	659	1337	96	2	
23	467	28282	3724	3	1
24	3	0	0		
Total	3783	51568	9824		

The 7-year total of deaths, injuries, and damage attributable to each of the categories appears in Table 2. In arriving at the damage totals we attributed a nominal value to each *Storm Data* code number, representing the approximate geometric mean of the range represented by that number. Thus, for example, code 4 ($5000–50,000) was considered to represent $15,000. An exception to this practice was the use of the dollar value quoted in the account, when provided for damage code 6 ($500,000–5,000,000) and higher. In Table 2 we have not attempted to separate crop and other property damages, because in the original accounts they were often combined.

An examination of the data in Table 2 prompts a number of comments. At our most cynically callous, we note that the "body count" seems relatively small: the 7-year total is more than an order of magnitude smaller than the total automobile fatalities for a single year. This state of affairs is, of course, a credit to the accuracy of the warnings of the National Weather Service and to the effectiveness of community response to them. One need only ponder, for example, the loss of hundreds of thousands of lives in the East Pakistan tropical storm catastrophe of 1970, and the evacuation of roughly 100,000 persons from the Gulf Coast path of Hurricane Beulah in 1967 to appreciate the destructive potential of these storms and the importance of an effective system of response to threat.

We had hoped that loss of life and dollar damage would be highly correlated among the various categories, so that in the process of assigning priorities we would not have to jeopardize our souls by establishing an equivalence between them. Alas, the correlation is far from perfect, as can be seen from a comparison of the death and damage ranks in Table 2. Thus, for example, if we valued life infinitely highly, lightning from otherwise innocuous thunderstorms (category 22) would receive great attention, while if we had a relatively high regard for property we would be inclined to direct increased resources toward tropical storms (category 23). Let us pursue this distressing line no further.

We wonder whether the losses are fairly stated, or more precisely whether they are stated consistently from one category to another. In *Storm Data*, for example, only three deaths were attributed to heat; yet we reflect that a metropolitan newspaper seems to cite that many fatalities on any single day when the temperature exceeds 90F. By way of contrast, it is likely that every death attributable to a tornado finds its way into *Storm Data*, if for no other reason than the spectacular nature of the event. The difficulty of coping with this state of affairs is compounded by a consideration of what is meant by "directly attributable" to the atmosphere.

Consider, for example, the unfortunate woman found on a winter morning by her husband outside her home, dead from exposure and full of alcohol. Should this death be attributed to cold (we in fact placed it in category 13), a craving for the bottle, or homicide prompted by a suspicion of marital infidelity?

A study of the accounts, however, gives a clear impression that fatalities are stated much more consistently than injuries. Of the total of 51,568 injuries, 17,500 were attributed without elaboration to Hurricane Betsy in Louisiana in September 1965. Despite reservations, however, we find from inspection of Table 2 that lightning, rain, snow, ice, and extreme cold are characterized by relatively large ratios of deaths to injuries, while relatively large numbers of injuries occur in categories in which wind plays a part. Evidently, in these instances people are injured but not killed by being thrown about or by being hit by wind-driven objects.

The damages are probably quite fairly stated as far as they go. (A striking omission is loss due to weather-related fire in the West.) There is generally no attempt in *Storm Data,* however, to estimate what we might call indirect, or secondary, costs. An example is the cost of protecting property against a hurricane, whether or not it arrives. This scenario would seem to constitute a direct loss of gross national product since the time and material, in the absence of the hurricane or the threat of it, might have been spent constructively. Another, somewhat different, example is the loss of a working day (without loss of pay to the employee, of course) for a metropolitan area throttled by a heavy snowstorm. It is reasonable to suppose that part of the time lost would be made up at the cost of additional wages, possibly at overtime rates for evening or weekend work, say. That part then would represent no real loss of gross national product but would represent an inflationary pressure on prices since the associated goods or services would have a higher labor cost and price, while the wage earner would have more money in his pocket. Our apologies to any economist who should happen to read this simplistic analysis. Our point is to illustrate the difficulty of dealing with secondary costs arising from atmospheric threats and events.

Finally, one might question the representativeness of our results. The activity in most categories can be described as slow but steady, so that the 7-year total can be accepted with confidence as a basis for short-range prediction. There can be no such confidence, however, with respect to hurricanes and tornadoes since an individual case can have a strong influence on the total. The great majority of loss due to tropical storms was produced by Hurricanes Betsy 1965, Beulah 1967, and Camille 1969. Tornado losses are not quite so concentrated but reflect strongly the contributions of the Palm Sunday storms in the lower Great Lakes on 11 April 1965, and the disasters at Topeka, Kans., on 8 June 1966, and at Lubbock, Tex., on 11 May 1970.

TABLE 3. Losses by class July 1963–June 1970.

Class	Categories	Total deaths	Total damages (millions $)
Extratropical cyclones and anticyclones	2, 3, 14, 17 (Oct–Mar) 4 8 5 9 6 10 7 11 18	858	1973
Cumulus convective storms	2, 3, 14, 17 (Apr–Sep) 20 21 22	2394	4010
Tropical storms	23	467	3724
Miscellaneous	1 16 12 19 13 24 15	64	117
Total		3783	9824

3. Classes of storms

With these many qualifications and sources of doubt before us, it seemed unwise to draw conclusions from a comparison of individual members of our 24-category set. Therefore, we tried to combine them into a small number of classes. Extratropical cyclones and anticyclones, cumulus convective storms, and tropical storms immediately suggested themselves, with a miscellaneous class for whatever didn't fit into one of the other three. There was a difficulty with categories 2, 3, 14 and 17 (representing rain, wind and flood), which might be produced by either cyclone-scale or convective storms. These were arbitrarily classed as convective during the months of April through September and as extratropical from October through March. This procedure is tantamount to assuming that the loss attributable to these elements in extratropical storms during the warm season is equal to the corresponding loss in convective storms during the cold season. The combination of categories into the four classes is shown in Table 3, with the resulting total deaths, injuries, and damage.

It is difficult to compare our results with other estimates because of differences of comprehensiveness, of categorization, and of periods of reference. Kessler (1970), however, has recently assembled an estimate of annual deaths and property damage due to tornadoes, lightning, hail, and hurricanes which can be quite readily compared with ours. His estimates for the total of the first three of these categories (which would be placed within cumulus convective class) may be projected to yield 7-year totals of 1925 deaths and property damage of $3213 million. These values are somewhat smaller than our comparable totals in Table 3, as they should be since they include no contribution from convective rain, nontornadic wind, and flood. Kessler's values for hurricanes would yield 7-year totals of 525 deaths and damages of $3500 million, reasonably near ours. Perhaps, then, our results as displayed in Table 3 can be accepted with some confidence.

These results speak for themselves. As killers, cumulus convective storms are in a class by themselves, while as damage producers they rate with tropical storms. There is a prime need, then, for an enhanced ability to protect the American citizenry from convective storms. The problem is formidable on the scientific side because this phenomenon is neither well observed nor well understood and on the technological side because the phenomenon is so shortlived and its destructiveness is so sporadic.

4. Costs of air pollution

Table 3 includes only those atmospheric threats which have been visible for a long time. How do these "classical" losses compare with losses due to the more or less immediate effects of urban air pollution, a problem which has received great attention only recently? In the matter of loss of life, urban air pollution doubtless contributes to fatality among the debilitated and especially among those suffering from cardiovascular or respiratory diseases, though no extensive numerical estimates for the United States seem to be available. As a measure of potential threat we might mention the attributing of 4000 deaths to the London smog of December 1952. In the matter of economic loss, an annual figure of $13.5 billion for the United States was quoted in *The New Republic,* October 31, 1970. Since this amount is an order of magnitude greater than the annual amount indicated in Table 3 for all other atmospheric sources of damage, pollution would appear to be of singular importance.

These air pollution damages, however, are estimates of the associated incremental costs of laundry, cleaning, painting, lighting, replacement of corroded materials, and similar items which in the context of the preceding discussion would be regarded as secondary costs. That is, the necessary cost of cleaning a building because of air pollution seems to resemble more nearly the necessary cost of heating it because of cold weather than the cost of replacing it because it was destroyed by a hurricane. Such secondary costs of the classical atmospheric vicissitudes are difficult to calculate, as we have said, but are doubtless large. We do not seriously consider abolishing cold weather, of course, because it appears scientifically and economically unfeasible to do so. On the other hand, limiting of pollutant concentrations to acceptable levels appears technically feasible and not prohibitively expensive, according to a recent report by the Secretary of Health, Education, and Welfare (1970).

When we consider the demands of air pollution and of other atmospheric threats upon the resources available to the atmospheric sciences, we must consider how application of meteorological knowledge can improve the lot of society. In the light of abundant experience we have little difficulty conceiving of storm warning systems and how they can contribute to reduction of death and damage. It is not so clear how a pollution warning service might work (though we understand that such services have begun in some communities), what decisions might be made on the basis of the warnings, and what benefits might result. The study of these questions would seem to be an urgent need.

We make no claim for profundity or for definitiveness. Rather, we suggest how we might begin to think about the interaction of atmospheric science and the rest of the human enterprise, and hope that others will come forward with better information and further thought. The difficulty of grappling with these considerations hardly relieves us of the obligation of trying.

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References

Hilst, G. R., 1970: Meteorology and the AMS: where to from here? *Bull. Amer. Meteor. Soc.,* **51**, 1049–1051.

Kessler, E., 1970: Tornadoes. *Bull. Amer. Meteor. Soc.,* **51**, 926–936.

Secretary of Health, Education, and Welfare, 1970: The cost of clean air. Senate Document No. 91-65, U. S. Government Printing Office.

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Computer predicts storm surge heights

A computer program for predicting the height of hurricane storm surges has been developed by the National Weather Service Techniques Development Laboratory. The inrushing torrent of wind-driven water is the hurricane's real killer. Until now, the forecaster has had to rely entirely on his own experience and judgment in predicting how high the devastating surges will rise.

The new system provides a valuable backstop for forecasters and should improve the accuracy of storm surge prediction. The model was tested in real time during the 1970 hurricane season with tropical storms Becky and Felice and hurricane Celia in the Gulf of Mexico. The computer predictions compared very favorably with the surges that actually occurred.

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