COMMONWEALTH OF MASSACHUSETTS
APPEALS COURT

Harvard Climate Justice Coalition, and others v. President and Fellows of Harvard College (Harvard Corporation"), and others	Appeals Court No. 2015-P-0905 (Suffolk Superior Court SUCV2014-03620-H)

MOTION BY DR. JAMES E. HANSEN TO APPEAR AS *AMICUS CURIAE* IN SUPPORT OF APPELLANTS, FOR LEAVE TO ENLARGE THE TIME FOR FILING AMICUS BRIEF, AND FOR LEAVE TO FILE SUPPORTING MATERIAL

Pursuant to MRAP 17, Dr. James E. Hansen seeks leave to appear as amicus curiae in support of Appellants Harvard Climate Justice Coalition, the individual Coalition member filers, and Future Generations (hereinafter, "the Coalition"). In addition, pursuant to MRAP 15, Amicus Hansen seeks leave to include, in an Appendix to his brief, excerpts from and internet references to two scientific papers, along with four maps.

Amicus Hansen has requested the position of the Appellees as to his motion to appear as an Amicus in support of the Coalition. Appellee Attorney General

takes no position with respect to Amicus Hansen's motion,[1] while the other Appellees have not responded.

Amicus Hansen's interest in this matter derives from his understanding that Earth's energy imbalance—caused principally by the burning of fossil fuels—is now disrupting the climate system to which humans and the balance of nature as we know it has adapted, and that this imbalance increasingly threatens the lives and prospects of both extant and future generation appellants.

Unabated emissions present a particularly dire threat to the population in low-lying coastal regions, placing in jeopardy the functionality of thousands of cities and the persistence of institutions of special interest to Coalition members. This includes physical structures of the Harvard Campus that lie within or near the reach of the rising seas.

Here, Amicus Hansen seeks to provide information and argument relevant to the Court's review of the issues of law that are likely to be dispositive to this Appeal.

---

[1] The Attorney General's Office conditioned its "no position" stance with the proviso that it receive a full and fair opportunity to respond to Amicus Hansen's amicus brief. Amicus Hansen will take no position with respect to a subsequent motion from the Attorney General seeking leave to respond to Amicus Hansen's brief.

On October 8, on Amicus Hansen's request, the Coalition filed a motion seeking leave for Amicus Hansen to file his Amicus Brief within two weeks of the Coalition's filing of its opening brief in this matter. The purpose was to enable Amicus Hansen to consider the Coalition's argument in its just-filed opening brief. On October 15, the Court denied the Coalition's motion "without prejudice to renewal as a motion by Dr. James E. Hansen." Here, Amicus Hansen files his own motion for leave to file an Amicus Brief. That brief is provided as Attachment A to this Motion, pursuant to MRAP 17 ("The brief may be conditionally filed with the motion for leave").[2]

In support of Amicus Hansen's arguments, we also attach to the brief excerpts from two recent scientific papers, of which Amicus Hansen is lead author, and several maps depicting a critical climate-related risk to the Harvard Campus. *See* App. to Hansen Amicus Brief.

LEGAL ARGUMENT

I. The Court Should Grant Amicus Hansen's Motion to File an Amicus Curiae Brief

[2] By this motion, Amicus Hansen seeks leave only to file an amicus brief, but not to appear, at this juncture, for oral argument on review of the lower court's grant of the motion to dismiss.

Amicus Hansen is qualified, in terms of experience and knowledge, to provide information to the Court about climate change, earth's energy imbalance and tipping points in the climate system—including disintegration of earth's major ice sheets, consequential sea level rise, and associated risks to cities, humanity, nature and Appellants. He is qualified, as well, on the question of the necessary pathway to energy balance and a stabilized climate system.

Amicus Hansen is the former Director of the NASA Goddard Institute for Space Studies. He is presently an Adjunct Professor at Columbia University's Earth Institute and Director of its program in Climate Science, Awareness, and Solutions.

Amicus Hansen trained in physics and astronomy in the space science program of Dr. James Van Allen at the University of Iowa, receiving a bachelor's degree with highest distinction in physics and mathematics, a master's degree in astronomy, and a Ph.D. in physics in 1967. In his early research, Amicus Hansen used telescopic observations of Venus to extract detailed information on the physical properties of the cloud and haze particles that veil Venus. Since the mid-

1970s, Amicus Hansen has focused on studies and computer simulations of the Earth's climate, for the purpose of understanding the human impact on global climate. His testimony on climate change to Congress in the 1980s helped raise broad awareness of the global warming issue.

In recent years, Amicus Hansen has drawn attention to the danger of passing climatic tipping points, including the melting of Earth's major ice sheets[3] that would yield irreversible climate impacts and a far different planet from the one that enabled civilization to develop. Amicus Hansen has also outlined steps that are needed to stabilize Earth's climate system and protect young people, future generations and nature.[4]

The direct implications of Amicus Hansen's work therefore may be taken as an essential context in which this Court may evaluate the Coalition's appeal. In particular, Amicus Hansen seeks to argue that the

---

[3] *See* Ice Melt, Sea Level Rise and Superstorms: Evidence from Paleoclimate Data, Climate Modeling, and Modern Observations that 2°C Global Warming is Highly Dangerous (July 2015), excerpted in the Appendix to proposed Amicus Brief at 6-14.

[4] *See id.* and Assessing ''Dangerous Climate Change'': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature, published by PLOS One (Dec. 3, 2013), excerpted in the Appendix to proposed Amicus Brief at 1-5.

urgent nature of the climate crisis and the correlative need for immediate effective action present an important context for the Court to evaluate two sets of arguments that the Coalition has presented: (1) that its Members have a personal interest in Harvard's fossil fuel investments—such that they have standing to seek injunctive relief to compel divestment, and (2) that Harvard's fossil fuel investments should be deemed an abnormally dangerous activity threatening the lives and fundamental interests of Appellant Future Generations.

II. The Court Should Grant Amicus Hansen's Request for Leave to File His Amicus Brief

Amicus Hansen seeks here to provide argument in support of the Coalition's most critical points that appear to have eluded, or else were simply not addressed by, the lower court. In so doing, Amicus Hansen wishes to steer clear of issues that the Coalition may have elected to ignore. *See Lane v. First Nat'l Bank of Bos.*, 871 F.2d 166, 175 (1st Cir. 1989), cert. denied, 133 S. Ct. 589 (2012) ("We know of no authority which allows an amicus to interject into a case issues which the litigants, whatever their reasons might be, have chosen to ignore.").

III. The Court Should Grant Amicus Hansen's Request for Leave To File His Appendix In Conjunction With His Amicus Brief

Amicus Hansen's Amicus Brief, among other things, seeks to support the Coalition's argument that the Harvard Campus is placed at risk from climate-induced sea level rise to which, the Coalition's underlying Complaint avers, Harvard's fossil fuel investments contribute.

In support of his arguments, Amicus Hansen attaches an Appendix to his Amicus Brief that contains excerpts from two scientific papers, of which he served as lead author. Amicus Brief App. 1- and App. 6-15. These provide support for Amicus Hansen's arguments that unabated emissions place civilization on an untenable path and that an alternate plan is required, and still conceivable, so as to preserve the planet's signal natural functioning. To further illustrate his point as to the risk presented from climate change, Amicus Hansen attaches maps depicting the inundation risk to the Harvard Campus from sea level rise. Amicus Br. App. 15-18.

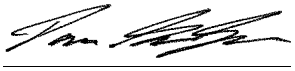
These documents were not before the Superior Court in its determination of the Motion to Dismiss. But here, on *de novo* review, *Aventine Renewable Energy*

Inc. v. Jp Morgan Sec. Inc., 458 Mass. 674, 676(2010)it is appropriate for the Court to consider Amicus Hansen's materials in support of his Amicus Brief arguments.

Accordingly, Amicus Hansen seeks leave to submit his attached Amicus Brief, along with its Appendix.

Respectfully submitted this 23d day of October, 2015.

Law Offices of Daniel M. Galpern



Daniel M. Galpern, Oregon State Bar #061950
1641 Oak Street
Eugene, OR 97401
dan.galpern@gmail.com
541.968.7164

Attorney for Amicus Dr. James E. Hansen

ATTACHMENT A

BRIEF OF AMICUS DR. JAMES E. HANSEN

COMMONWEALTH OF MASSACHUSETTS
APPEALS COURT
2015-P-0905

HARVARD CLIMATE JUSTICE COALITION and others

v.

PRESIDENT AND FELLOWS OF HARVARD COLLEGE
("HARVARD CORPORATION") and others

Appeal of the Suffolk County Superior Court's Order Granting Defendants-Respondents' Motion to Dismiss

---

BRIEF OF AMICUS DR. JAMES E. HANSEN

DANIEL M. GALPERN
Law Offices of Daniel M. Galpern
1641 Oak Street
Eugene, Oregon 97401
dan.galpern@gmail.com
541-968-7164

Attorney for Amicus Hansen

Table of Contents

I. Table of Authorities ii
II. Statement of the Issues 1
III. Statement of the Case 1
IV. Statement of Facts 2
V. Summary of the Argument 2
VI. Argument 3
A. The Superior Court Erred in Dismissing Count I 3
1. Standard of Review 3
2. The Superior Court In Error Ignored a Key Argument in Support of Count 1 4
B. The Tort Against Future Generations of Harvard's Intentional Investment in Abnormally Dangerous Activity Should be Recognized 7
1. The Coalition's Interest in the Harvard a Campus and Future Generations' Interest in a Viable Climate System Are At Risk 9
VII. Conclusion 18

I. Table of Authorities

Cases:

Aventine Renewable Energy Inc. v. Jp Morgan Sec. Inc., 458 Mass. 674, 676(2010) *10*

Commonwealth v. Camblin
(Mass., 2015) (Slip. Op.) 6

Kelsey Cascadia Rose Juliana, et. al. v. United States of America, et al.
No. 6:15-cv-01517-TC (D. Or. Aug. 12, 2015) 9

Littles v. Commissioner of Correction
444 Mass. 871 (2005). 6

Marram v. Kobrick Offshore Fund, Ltd.
442 Mass. 43 (2004) 3-4

Warner-Lambert Co. v. Execuquest Corp.
427 Mass. 46 (1998) 10

Other Authorities:

Climate Central, *Surging Seas Mapping Choices* (2015)
. 15-17

Hansen, *et al., Assessing ''Dangerous Climate Change'': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*
PLOS (Public Library of Science) One (2013). 11

Hansen, *et al., Ice Melt, Sea Level Rise and Superstorms: Evidence from Paleoclimate Data, Climate Modeling, and Modern Observations that 2°C Global Warming is Highly Dangerous* Atmospheric Chemistry Physics Discussions
(2015) 12

Harvard University's Campus in Allston, Institutional Master Plan (2013) 13-14

Strauss et al, *Carbon Choices Determine US Cities Committed To Futures Below Sea Level*
Proceedings of the National Academy of Sciences (PNAS)
(2015) 15

II. Statement of Issues

The central issue in this matter is whether Harvard students, working together, may bring suit to challenge, on their own behalf and on behalf of future generations, those of Harvard Corporation's investments that threaten their fundamental life prospects — particularly in the circumstance wherein such investments contravene the Harvard Charter but the State Attorney General, who is expressly authorized by law to enforce the obligations of a state charity, has functionally declined to act.

At this stage of judicial review, the central issue is whether, in its analysis of the Harvard Climate Justice Coalition's standing and of the cognizability of its claims, the Superior Court abused its discretion by refusing to consider the severe and particularized climate-rated harms to which, as alleged in Complaint, Harvard's fossil fuel investments contribute.

III. Statement of the Case

Amicus Hansen herein adopts the statement of the case of Appellant Harvard Climate Justice Coalition (hereinafter, "the Coalition").

IV. Statement of Facts

Amicus Hansen herein adopts the statement of facts of the Coalition.

V. Summary of the Argument

In dismissing Count I, the Superior Court entirely failed to address the Coalition's argument that, in patent contravention of the Harvard Corporation's Charter, its fossil fuel investments jeopardize the Harvard campus in which Coalition members (among others) retain a significant interest. Moreover, none of the Superior Court's discussion of the Coalition's other arguments purporting to support Count 1 apply to the Coalition's physical-integrity-of-the campus argument. Amicus Hansen's brief, including supporting material that it incorporates by reference, establishes that the threat of sea level rise to coastal communities, including to the Harvard campus, is significant and, indeed, must be deemed an overriding consideration.

In dismissing Count II, the Superior Court determined that the Coalition's lawsuit was of the "sort" that allowed for no limits as to subject matter and scope, even though the Coalition's pleadings retained effective limitations that the Court could

have recognized, had it properly drawn inferences from the Complaint in the Coalition's favor. In brief, that limiting principle was that the activity at the heart of alleged tort must, among other things, threaten the physical environment upon which future generations of necessity will depend. But instead of fairly examining that limitation, the Superior Court over-generalized and trivialized the Coalition's position. Largely on that basis, the lower court cut short the Coalition's opportunity to discover and establish why the Harvard Corporation has ignored the foreseeable risks of unabated climate change through its continuing financial and infrastructure investments.

VI. Argument

A. The Superior Court Erred in Dismissing Count I

1. Standard of Review

Amicus Hansen herein adopts the Coalition's statement as to the proper standard of review with the proviso that, at this stage, the Coalition merits the benefit of reasonable doubt, if any, as to the applicability of alleged facts to legal standards at issue in its claims. *Marram v. Kobrick Offshore Fund*, Ltd., 442 Mass. 43, 45 (2004) ("Although errors of law

based on the facts alleged will not surmount a rule 12 (b) (6) challenge, the plaintiff's burden is "relatively light".")(Internal citation omitted).

2. The Superior Court In Error Ignored a Key Argument in Support of Count 1

The Coalition offered two categories of argument under Count 1 (Mismanagement of Charitable Funds) corresponding with obligations imposed on the Harvard Corporation by its Charter. These include, (1) Harvard's duty to promote the advancement and education of its students, and (2) Harvard's duty to maintain its physical campus for the well-being of its students. *See* Complaint at par. 42, App. Br., App. 10.

In its opinion dismissing Count 1, however, the Superior Court addressed only the first category of argument. In particular, after consideration, the Superior Court determined that the Coalition had not established that distortions of science by fossil fuel companies had harmed its members in a cognizably particularized way, App. Br., App. 34-35, and that the academic freedom of its members was not undermined sufficiently to ground their standing to bring the mismanagement claim. App. Br., App. 36-37.

But the Superior Court entirely failed to consider the Coalition's second and independent

category of argument, namely that its members retain a special interest in the physical integrity of the campus such that they retain standing to challenge Harvard's fossil fuel investments.

To be clear, the Superior Court, in its overview of the case, observed:

> The Complaint also notes that the Charter obligates the University's President and Fellows to maintain the University's physical campus. Harvard's investment in fossil fuel companies is at odds with that obligation, because even under optimistic scenarios, the Complaint alleges, parts of the Harvard campus near the Charles River will be flooded every two to three years by 2050 as a result of climate change.

Memorandum Order at 3-4 (App. Br., App. 27-28).

But the Superior Court did not proceed to evaluate or discuss, even, the Coalition's physical integrity of the campus argument – although that argument was a central component of the Coalition's claim that Harvard's continuing investment in fossil fuels violates its Charter.[1] *See* Complaint at pars. 29,

[1] Concerns that the Superior Court raised with respect to the Coalition's other arguments in support of Count I do not appear to apply to the Coalition's physical integrity argument. For instance, the Superior Court's expressed concern for "breaks in the chain of caustion" leading to the "'diminishment of Plaintiffs' educations" (sic), Memorandum Order at 12, App. Br., App. 36. But that chain does not apply to the separate set of causation links postulated in the Complaint with respect to the physical integrity of

34, 42, 47, 49, 53, and 56, App. Br., App. 8-12. This failure amounted to plain error. *Commonwealth v. Camblin* (Mass., 2015) (Slip. Op. at 9) (court's failure to consider defendant's specific challenges on their merits deemed error); *Littles v. Commissioner of Correction*, 444 Mass. 871 (2005) (lower court's implicit denial of Appellants' claims deemed "sufficient to confer appellate jurisdiction").

Although the Superior Court failed to address the Coalition's physical integrity argument, based on other parts of that court's Memorandum Decision it appears that the court regarded the climate risk alleged by the Coalition to be trivial, one sounding in subjective taste or mere opinion – and, perhaps, on par with some hypothetical interest in the

---

the campus question. *That* chain proceeds from the allegation that Harvard's fossil fuel investments increase emissions that, in turn, exacerbate climate change, such that, in turn, the Harvard campus is placed at increased risk. Assuming, as is required here (on review of the Superior Court's dismissal for lack of standing or failure to state a claim), that the allegations of the Complaint are true and all inferences must be drawn in the Coalition's favor, the chain of reasoning giving rise to concern over the risk to the campus must be deemed reasonable.

preservation of campus green space. Memorandum Order at 16, App. Br., App. 40.[2]

However, in Amicus Hansen's expert opinion, the threat of climate change-induced sea level rise is significant; indeed, it is overriding. In fact, climate-change-induced sea level rise presents a disruptive and lethal risk of unprecedented proportion to low-lying coastal communities, including much of Harvard. Amicus Hansen discusses that risk further in subsection B, below. Based on that discussion, Amicus Hansen urges this Court to recognize that the Superior Court erred in failing to consider the Coalition's physical integrity argument in support of Count 1.

B. The Tort Against Future Generations of Harvard's Intentional Investment in Abnormally Dangerous Activity Should be Recognized

The Superior Court declined to recognize the Coalition's admittedly novel tort residing at the heart of Count II. The "overarching problem," according to the court, was "the absence of any limits on the subject matter and scope of lawsuits of this sort." *Id.* But in its discussion, as noted above,

[2] At another point, the Superior Court allowed that the Coalition "perhaps" may be right "that climate change is the most serious threat facing the world," but then pivoted to say "[b]ut other students believe just as fervently in other causes." *Id.* at 17.

the Superior Court ignored the limiting principle inherent in the Coalition's physical integrity argument.

The postulated tort, in brief, would allow that where a defendant's investment activity exacerbates climate change such that persons (here, with respect to Court II, Plaintiff Future Generations) thereby will be harmed, then such potentially harmed persons — or those afforded the right to speak on their behalf — may seek an injunction of that tortious activity. The limiting principle is that the activity complained of must threaten the physical environment upon which future generations of necessity will depend.

But instead of fairly examining that limitation, the Superior Court pilloried the Coalition's position by overly-generalizing it and positing a simplistic *reductio ad absurdum*:

> [P]erhaps today's Plaintiffs, whose Complaint makes clear that they believe that fossil fuel companies are promoting "scientific falsehoods ... [that] distort[] academic research" at Harvard, Complaint ¶ 57, will petition the court to ban such "falsehoods" from the Harvard curriculum so that Future Generations of Harvard students will not have their academic research distorted.

App. Br., App.40.[3]

But again, climate change exacerbated by the continued burning of fossil fuels in fact presents a severe threat – not only to present Coalition members, but also to future generations (including future Harvard students). This, too, is discussed in below, and in materials therein incorporated by reference.

As for the Superior Court's observation that procedure is lacking to enable the Coalition to have petitioned for guardian ad litem status so as to represent Plaintiff Future Generations, *id.*, Amicus Hansen observes that he now serves in that capacity for a minor plaintiff, Sophie K., as well as for Plaintiff Future Generations, in a recently filed federal climate change-related case. *Kelsey Cascadia Rose Juliana, et. al. v. United States of America, et al.*, No. 6:15-cv-01517-TC (D. Or. Aug. 12, 2015).

Accordingly, in light of the importance of the instant case, and at the discretion of the Court, Amicus Hansen stands ready to assume a similar guardian role here upon remand and fuller consideration of the alleged tort in this matter.

[3] Here the Superior Court appeared unwilling even to presume that Coalition members retained an elementary familiarity with the First Amendment.

1. The Coalition's Interest in the Harvard Campus and Future Generations' Interest in a Viable Climate System Are At Risk

The relevant scientific community has established for some time that high CO_2 emissions from fossil fuel burning have disrupted Earth's climate system and that, unless we fundamentally alter business as usual, the build up of atmospheric CO_2 will impose profound and mounting risks of ecological, economic and social collapse.

The fundamental metric is Earth's present and growing energy imbalance. There remains a real, but time-limited, opportunity to commence a phase-down of CO_2 and other GHG (greenhouse gas) emissions so as to restore energy balance, and stabilize the climate system. But increased exploitation of fossil fuel reserves cuts sharply in the wrong direction.

Here, on de novo review, *Aventine Renewable Energy Inc. v. Jp Morgan Sec. Inc.*, 458 Mass. 674, 676(2010), the Coalition's factual allegations must be credited as true, with all plausible inferences drawn in its favor. *Warner-Lambert Co. v. Execuquest Corp.*, 427 Mass. 46, 47 (1998) ("the allegations of the complaint, as well as such inferences as may be drawn

therefrom in the plaintiff's favor, are to be taken as true.") (internal citation omitted).

The Coalition's Complaint reasonably alleges, among other things, that Harvard's investments in fossil fuel corporations, at least in part, cause an increase in CO_2 emissions, which in turn increases the risk of climate system disruption.

In conjunction with a number of colleagues, Amicus Hansen has written about the urgent need to reduce the atmospheric CO_2 concentration to no more than 350ppm so as to restore Earth's energy balance. Amicus Hansen has also written about the real risk to our nation and coastal cities throughout the world of multi-meter sea level rise that will occur if we fail to phase out emissions and restore energy balance over the coming decades.

In the Appendix to this brief, App. 1-5,[4] we provide the Court with excerpts of a study by Amicus Hansen and 17 colleagues that establishes that continued fossil fuel burning up to even 2°C above the

[4] Hansen, et. al, *Assessing ''Dangerous Climate Change'': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*, PLOS One (Dec. 3, 2013), available, as well, at: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0081648.

preindustrial level[5] likely would cause large climate change with disastrous and irreversible consequences. Accordingly, actions to rapidly phase out CO_2 emissions, along with efforts to increase the sequestration of carbon, are urgently required so as to reduce the atmospheric CO_2 concentration to no more than 350ppm and restore Earth's energy balance.

Also in the Appendix to this brief, App. 6-18,[6] we provide the Court with excerpts of Amicus Hansen's recent study establishing that, in the event of continuing high CO_2 emissions – so that additional energy is continuously pumped at a high rate into the ocean – the melting of the planet's major ice sheets with consequential multi-meter sea level rise will become practically unavoidable. This may well threaten the very fabric of civilization, including

---

[5] We are already 0.9°C above the preindustrial temperature. Indeed, in 2015 global temperature is reaching a level ~1°C above the preindustrial level, but the high 2015 level is partly a temporary effect of a strong El Nino, a natural oscillation of tropical Pacific Ocean temperature.

[6] Hansen, et. al., *Ice Melt, Sea Level Rise and Superstorms: Evidence from Paleoclimate Data, Climate Modeling, and Modern Observations that 2°C Global Warming is Highly Dangerous* (2015), also available at: http://www.atmos-chem-phys-discuss.net/15/20059/2015/acpd-15-20059-2015.pdf

the life prospects of young persons and future generations.

Amicus Hansen hereby incorporates by reference the analyses and conclusions of the aforementioned studies into this brief.

The Appellant's Brief to this Court postulates that discovery in this matter, if this Court allows it to proceed on remand, "will reveal evidence substantiating [the Coalition's] claims [including] evidence of the harms to Harvard's physical campus, perhaps in the form of internal risk assessments regarding the impacts of climate change on the University."

In Amicus Hansen's view, such discovery may be important for a closely related reason, namely to discern the Harvard Corporation's state of knowledge (*vel non*) as to the risks imposed by sea level rise to the campus. In particular, to judge from Harvard's Master Plan for its Allston Campus (hereinafter, "Master Plan"),[7] at least as of October 2013 — the date of the revised plan — it appears highly plausible that

---

[7] The full report, *Harvard University's Campus in Allston, Institutional Master Plan*, from which Ex. L to the Complaint, is excerpted, is available at http://home.hppm.harvard.edu/files/hppm/files/harvard_imp_2013_0.pdf.

the Harvard Corporation grossly and erroneously discounted that risk. In particular, the referenced Harvard report states, among other things, that:

> Sea level rise is caused by local coastal subsidence, plus the expansion of water with increased temperatures and the melting of land ice in places such as Greenland and Antarctica. Of concern to the Allston campus are the impacts from sea level rise, coupled with waves from an on-sort storm occurring at high tide (storm surge). The Allston campus is behind the Charles River Dam, owned by the Massachusetts Department of Conservation and Recreation (DCR). However, DCR has yet to study the effectiveness of the dam in a severe storm event, to take into account sea level rise, and more intense storms. *If the dam was overtopped or not effective, there is a possibility of flooding in the Allston campus*.

Master Plan at 235. [Emphasis added.]

That same plan notes that the Charles River Dam would be overtopped whenever flood elevation reaches 7.5 feet above the mean high water mark (the 100 year flood scenario of the report), *id*. at 232 and 233 (Charles River Dam Breached), and that a 100-year flood is anticipated in Allston "every two or three years by 2050, and every year to two years by 2100." *Id*. at 235. The plan proceeds, among other things, to promise that Harvard "will plan for the key impacts . . . especially flooding events, power loss, and extreme heat."

If the cited Master Plan represents the extent of the Harvard Corporation's projections, then Harvard, in Amicus Hansen's view, has vastly underappreciated the relevant risks. Significant other work was and remains available to Harvard, as to the public, establishing that anticipated sea level rise presents a severe risk to coastal communities and institutions. Amicus Hansen's own recent work, denoted *supra*, studies and data cited therein, along with other research, establish those risks. Most recently, research by Climate Central allows for an accessible graphical inspection of the impacts of the rising seas.

Based on the latter work, Amicus Hansen provides to the Court, in App. 148-151, maps illustrating the risk of inundation to Harvard. Graphic 1, App. 15, is the university's own campus map, provided here to allow comparison and ready location of structures.[8] Graphics 2-4, App. 16-18, depict inundation of the area utilizing Climate Central's publicly available tools.[9]

---

[8] Harvard campus map also publicly available from https://map.harvard.edu/pdf/8.5x11%20Campus%20Map.pdf.

[9] Available at sealevel.climatecentral.org (visited Oct. 13, 2015). Amicus Hansen served as editor of the theoretical work on which the latest Climate Central tool was based. *See* Strauss et al, *Carbon Choices*

Graphic 2 shows a portion of Cambridge and environs without additional sea level rise: the Charles River is shown within its regular banks and the Allston neighborhood, Soldiers Field, Kennedy School and Logan International are dry.

Graphic 3 depicts the region when sea level has risen 10 feet. As noted, *supra*, the Charles River Dam at its present level would be overtopped. In addition, areas including Soldiers Field and surrounding Harvard Stadium would be inundated, while much of Logan International also would be submerged.

Graphic 4, depicting the region including Harvard under 23 feet of water (the anticipated range is 14 to 33 feet) illustrates the reach of the sea at equilibrium as estimated, eventually, to result from the essentially unchecked pollution pathway that we have been following. Under it, most of Harvard — including Harvard Law, the Kennedy School, the Business School, and much of the Allston neighborhood — will also be submerged. A narrow, lonely strip would remain above water, forming a small island.

Determine US Cities Committed To Futures Below Sea Level (Proceedings of the National Academy of Sciences: Sept. 18, 2015; edited by James Hansen) available at http://www.pnas.org/content/early/2015/10/07/1511186112.abstract?tab=author-info.

Graphic 4 also enables comparison with projections of sea level rise anticipated even in the event of serious climate action – with concerted national and international efforts stemming CO_2 emissions growth by 2020 and phasing it out fully out by 2080. Under that scenario, much of the campus north of the Charles River would be preserved.

But with respect to the right side, Graphic 4 makes clear that much of the Harvard Allston campus will under water come what may, as equilibrium will not be achieved even under the rigorous carbon reduction scenario before sea level rises an estimated 7.9 feet. That estimate *exceeds* the sea level rise considered by Harvard in its October 2013 Revised Master Plan for its Allston campus. Master Plan at 232 (sea level rise assumed at 7.5 feet). Accordingly, the maximum sea level rise assessed by Harvard appears to have been *lower* than that estimated to result from the most *optimistic* emissions scenario considered by the Intergovernmental Panel on Climate Change in its most recent assessment report.[10] It appears, then, that

[10] *See* Climate Central, *Surging Seas Mapping Choices: Which sea leavel will we lock in?* at http://choices.climatecentral.org/#when and Information on Representative Concentration Pathways – in particular, RCP 2.6 – at

Harvard may have seriously underestimated the risk to the Harvard campus, the Harvard community and, of course, to future generations.

In the light of the above, it appears likely that Harvard Corporation's failure to undertake rational action in light of climate change – including not only divestment from fossil fuel corporations, but also reconsideration of its expansion plans for areas of the city that foreseeably will be submerged – stems from a simple failure prudently to consider highly foreseeable risks of sea level rise.[11] Because the implications of Harvard's potential mistaken comprehension of that risk are central to the Coalition's case, the Coalition should be allowed to pursue discovery on the topic, among others.

---

http://tntcat.iiasa.ac.at:8787/RcpDb/dsd?Action=htmlpage&page=about#intro.

[11] Likewise it is plausible that the Attorney General's inaction to date, App. Br. 33, may be a function of her failure to consider the extent of risk imposed on the Harvard community and upon the public from unabated CO_2 emissions stemming, in part, as the Coalition alleges, from Harvard's intentional investment in what it knows, or should know, to be abnormally dangerous activity.

VII. Conclusion

Based on the foregoing argument and in light of the appropriate standard of review Amicus Hansen urges this Court to find error in the Superior Court's dismissal of Counts I and II. The matter should be remanded to the Superior Court for further proceedings.

_____

Respectfully submitted this 23d day of October, 2015.

Law Offices of Daniel M. Galpern

Daniel M. Galpern, Oregon State Bar #061950
1641 Oak Street
Eugene, OR 97401
dan.galpern@gmail.com
541.968.7164

Attorney for Amicus Dr. James E. Hansen

APPENDIX TO DR. JAMES E. HANSEN AMICUS BRIEF

Appendix to Dr. James E. Hansen Amicus Brief

Table of Contents

Appendix Pages	Document
1-5	Excerpts from Hansen, et al., *Assessing ''Dangerous Climate Change'': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature*, published by PLOS One (Dec. 3, 2013). [Full study available at: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0081648].
6-14	Excerpts from Hansen, et al., *Ice Melt, Sea Level Rise and Superstorms: Evidence from Paleoclimate Data, Climate Modeling, and Modern Observations that 2°C Global Warming is Highly Dangerous* (July 2015). [Full study available at: www.atmos-chem-phys-discuss.net/15/20059/2015/acpd-15-20059-2015.pdf.]
15	Graphic 1: Map of Harvard Campus.
16	Graphic 2: Map of Harvard and environs with today's sea level.
17	Graphic 3: Map of Harvard and environs with a 10 foot sea level rise.
18	Graphic 4: Map of Harvard and environs with a 23-foot sea level rise.

OPEN ACCESS Freely available online

PLOS ONE

Review

Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature

James Hansen[1]*, Pushker Kharecha[1,2], Makiko Sato[1], Valerie Masson-Delmotte[3], Frank Ackerman[4], David J. Beerling[5], Paul J. Hearty[6], Ove Hoegh-Guldberg[7], Shi-Ling Hsu[8], Camille Parmesan[9,10], Johan Rockstrom[11], Eelco J. Rohling[12,13], Jeffrey Sachs[1], Pete Smith[14], Konrad Steffen[15], Lise Van Susteren[16], Karina von Schuckmann[17], James C. Zachos[18]

1 Earth Institute, Columbia University, New York, New York, United States of America, **2** Goddard Institute for Space Studies, NASA, New York, New York, United States of America, **3** Institut Pierre Simon Laplace, Laboratoire des Sciences du Climat et de l'Environnement (CEA-CNRS-UVSQ), Gif-sur-Yvette, France, **4** Synapse Energy Economics, Cambridge, Massachusetts, United States of America, **5** Department of Animal and Plant Sciences, University of Sheffield, Sheffield, South Yorkshire, United Kingdom, **6** Department of Environmental Studies, University of North Carolina, Wilmington, North Carolina, United States of America, **7** Global Change Institute, University of Queensland, St. Lucia, Queensland, Australia, **8** College of Law, Florida State University, Tallahassee, Florida, United States of America, **9** Marine Institute, Plymouth University, Plymouth, Devon, United Kingdom, **10** Integrative Biology, University of Texas, Austin, Texas, United States of America, **11** Stockholm Resilience Center, Stockholm University, Stockholm, Sweden, **12** School of Ocean and Earth Science, University of Southampton, Southampton, Hampshire, United Kingdom, **13** Research School of Earth Sciences, Australian National University, Canberra, ACT, Australia, **14** University of Aberdeen, Aberdeen, Scotland, United Kingdom, **15** Swiss Federal Institute of Technology, Swiss Federal Research Institute WSL, Zurich, Switzerland, **16** Center for Health and the Global Environment, Advisory Board, Harvard School of Public Health, Boston, Massachusetts, United States of America, **17** L'Institut Francais de Recherche pour l'Exploitation de la Mer, Ifremer, Toulon, France, **18** Earth and Planetary Science, University of California, Santa Cruz, CA, United States of America

Abstract: We assess climate impacts of global warming using ongoing observations and paleoclimate data. We use Earth's measured energy imbalance, paleoclimate data, and simple representations of the global carbon cycle and temperature to define emission reductions needed to stabilize climate and avoid potentially disastrous impacts on today's young people, future generations, and nature. A cumulative industrial-era limit of ~500 GtC fossil fuel emissions and 100 GtC storage in the biosphere and soil would keep climate close to the Holocene range to which humanity and other species are adapted. Cumulative emissions of ~1000 GtC, sometimes associated with 2°C global warming, would spur "slow" feedbacks and eventual warming of 3–4°C with disastrous consequences. Rapid emissions reduction is required to restore Earth's energy balance and avoid ocean heat uptake that would practically guarantee irreversible effects. Continuation of high fossil fuel emissions, given current knowledge of the consequences, would be an act of extraordinary witting intergenerational injustice. Responsible policymaking requires a rising price on carbon emissions that would preclude emissions from most remaining coal and unconventional fossil fuels and phase down emissions from conventional fossil fuels.

Introduction

Humans are now the main cause of changes of Earth's atmospheric composition and thus the drive for future climate change [1]. The principal climate forcing, defined as an imposed change of planetary energy balance [1–2], is increasing carbon dioxide (CO_2) from fossil fuel emissions, much of which will remain in the atmosphere for millennia [1,3]. The climate response to this forcing and society's response to climate change are complicated by the system's inertia, mainly due to the ocean and the ice sheets on Greenland and Antarctica together with the long residence time of fossil fuel carbon in the climate system. The inertia causes climate to appear to respond slowly to this human-made forcing, but further long-lasting responses can be locked in.

More than 170 nations have agreed on the need to limit fossil fuel emissions to avoid dangerous human-made climate change, as formalized in the 1992 Framework Convention on Climate Change [6]. However, the stark reality is that global emissions have accelerated (Fig. 1) and new efforts are underway to massively expand fossil fuel extraction [7–9] by drilling to increasing ocean depths and into the Arctic, squeezing oil from tar sands and tar shale, hydro-fracking to expand extraction of natural gas, developing exploitation of methane hydrates, and mining of coal via mountaintop removal and mechanized long-wall mining. The growth rate of fossil fuel emissions increased from 1.5%/year during 1980–2000 to 3%/year in 2000–2012, mainly because of increased coal use [4–5].

The Framework Convention [6] does not define a dangerous level for global warming or an emissions limit for fossil fuels. The

Citation: Hansen J, Kharecha P, Sato M, Masson-Delmotte V, Ackerman F, et al. (2013) Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature. PLoS ONE 8(12): e81648. doi:10.1371/journal.pone.0081648

Editor: Juan A. Añel, University of Oxford, United Kingdom

Published December 3, 2013

Funding: Funding came from: NASA Climate Research Funding, Gifts to Columbia University from H.F. ("Gerry") Lenfest, private philanthropist (no web site, but see http://en.wikipedia.org/wiki/H._F._Lenfest), Jim Miller, Lee Wasserman (Rockefeller Family Fund) (http://www.rffund.org/), Flora Family Foundation (http://www.florafamily.org/), Jeremy Grantham, ClimateWorks and the Energy Foundation provided support for Hansen's Climate Science, Awareness and Solutions program at Columbia University to complete this research and publication. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

* E-mail: jimehansen@gmail.com

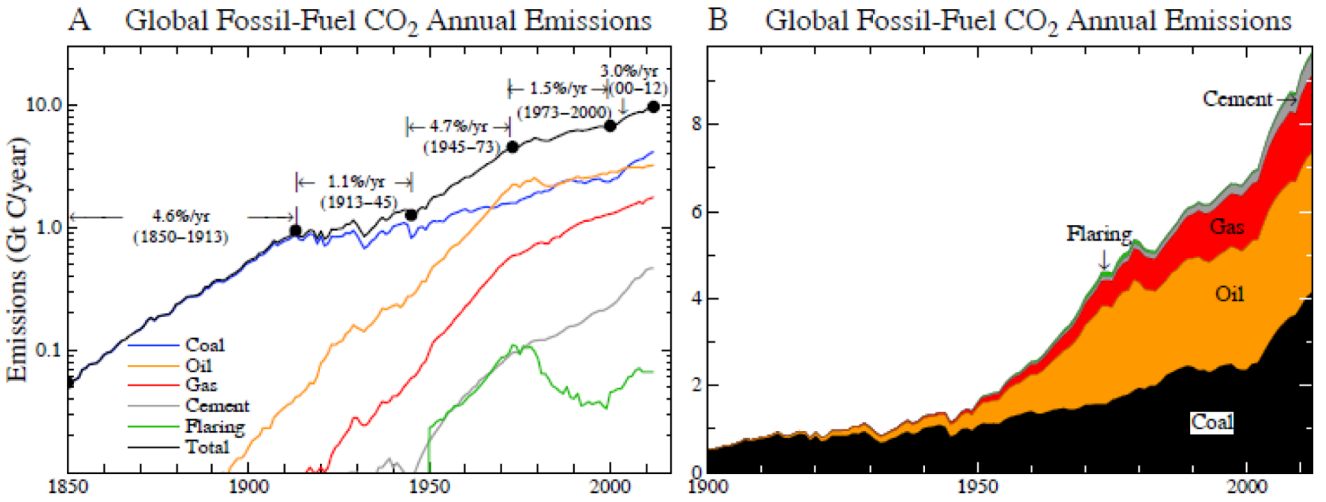


Figure 1. CO_2 annual emissions from fossil fuel use and cement manufacture, based on data of British Petroleum [4] concatenated with data of Boden et al. [5]. (A) is log scale and (B) is linear.
doi:10.1371/journal.pone.0081648.g001

European Union in 1996 proposed to limit global warming to 2°C relative to pre-industrial times [10], based partly on evidence that many ecosystems are at risk with larger climate change. The 2°C target was reaffirmed in the 2009 "Copenhagen Accord" emerging from the 15th Conference of the Parties of the Framework Convention [11], with specific language "We agree that deep cuts in global emissions are required according to science, as documented in the IPCC Fourth Assessment Report with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius…".

A global warming target is converted to a fossil fuel emissions target with the help of global climate-carbon-cycle models, which reveal that eventual warming depends on cumulative carbon emissions, not on the temporal history of emissions [12]. The emission limit depends on climate sensitivity, but central estimates [12–13], including those in the upcoming Fifth Assessment of the Intergovernmental Panel on Climate Change [14], are that a 2°C global warming limit implies a cumulative carbon emissions limit of the order of 1000 GtC. In comparing carbon emissions, note that some authors emphasize the sum of fossil fuel and deforestation carbon. We bookkeep fossil fuel and deforestation carbon separately, because the larger fossil fuel term is known more accurately and this carbon stays in the climate system for hundreds of thousands of years. Thus fossil fuel carbon is the crucial human input that must be limited. Deforestation carbon is more uncertain and potentially can be offset on the century time scale by storage in the biosphere, including the soil, via reforestation and improved agricultural and forestry practices.

There are sufficient fossil fuel resources to readily supply 1000 GtC, as fossil fuel emissions to date (370 GtC) are only a small fraction of potential emissions from known reserves and potentially recoverable resources (Fig. 2). Although there are uncertainties in reserves and resources, ongoing fossil fuel subsidies and continuing technological advances ensure that more and more of these fuels will be economically recoverable. As we will show, Earth's paleoclimate record makes it clear that the CO_2 produced by burning all or most of these fossil fuels would lead to a very different planet than the one that humanity knows.

Our evaluation of a fossil fuel emissions limit is not based on climate models but rather on observational evidence of global climate change as a function of global temperature and on the fact that climate stabilization requires long-term planetary energy balance. We use measured global temperature and Earth's measured energy imbalance to determine the atmospheric CO_2 level required to stabilize climate at today's global temperature, which is near the upper end of the global temperature range in the current interglacial period (the Holocene). We then examine climate impacts during the past few decades of global warming and in paleoclimate records including the Eemian period, concluding that there are already clear indications of undesirable impacts at the current level of warming and that 2°C warming would have major deleterious consequences. We use simple representations of the carbon cycle and global temperature, consistent with observations, to simulate transient global temperature and assess carbon emission scenarios that could keep global climate near the Holocene range. Finally, we discuss likely overshooting of target emissions, the potential for carbon extraction from the atmosphere, and implications for energy and economic policies, as well as intergenerational justice.

Global Temperature and Earth's Energy Balance

Global temperature and Earth's energy imbalance provide our most useful measuring sticks for quantifying global climate change and the changes of global climate forcings that would be required to stabilize global climate. Thus we must first quantify knowledge of these quantities.

Temperature

Temperature change in the past century (Fig. 3; update of figures in [16]) includes unforced variability and forced climate change. The long-term global warming trend is predominantly a forced climate change caused by increased human-made atmospheric gases, mainly CO_2 [1]. Increase of "greenhouse" gases such as CO_2 has little effect on incoming sunlight but makes the atmosphere more opaque at infrared wavelengths, causing infrared (heat) radiation to space to emerge from higher, colder levels, which thus reduces infrared radiation to space. The resulting planetary energy imbalance, absorbed solar energy exceeding heat emitted to space, causes Earth to warm. Observations, discussed below, confirm that Earth is now substantially out of energy balance, so the long-term warming will continue.

control, but not of their doing. The possibility of such intergenerational injustice is not remote – it is at our doorstep now. We have a planetary climate crisis that requires urgent change to our energy and carbon pathway to avoid dangerous consequences for young people and other life on Earth.

Yet governments and industry are rushing into expanded use of fossil fuels, including unconventional fossil fuels such as tar sands, tar shale, shale gas extracted by hydrofracking, and methane hydrates. How can this course be unfolding despite knowledge of climate consequences and evidence that a rising carbon price would be economically efficient and reduce demand for fossil fuels? A case has been made that the absence of effective governmental leadership is related to the effect of special interests on policy, as well as to public relations efforts by organizations that profit from the public's addiction to fossil fuels [237,250].

The judicial branch of governments may be less subject to pressures from special financial interests than the executive and legislative branches, and the courts are expected to protect the rights of all people, including the less powerful. The concept that the atmosphere is a public trust [251], that today's adults must deliver to their children and future generations an atmosphere as beneficial as the one they received, is the basis for a lawsuit [252] in which it is argued that the U.S. government is obligated to protect the atmosphere from harmful greenhouse gases.

Independent of this specific lawsuit, we suggest that intergenerational justice in this matter derives from fundamental rights of equality and justice. The Universal Declaration of Human Rights [253] declares "All are equal before the law and are entitled without any discrimination to equal protection of the law." Further, to consider a specific example, the United States Constitution provides all citizens "equal protection of the laws" and states that no person can be deprived of "life, liberty or property without due process of law". These fundamental rights are a basis for young people to expect fairness and justice in a matter as essential as the condition of the planet they will inhabit. We do not prescribe the legal arguments by which these rights can be achieved, but we maintain that failure of governments to effectively address climate change infringes on fundamental rights of young people.

Ultimately, however, human-made climate change is more a matter of morality than a legal issue. Broad public support is probably needed to achieve the changes needed to phase out fossil fuel emissions. As with the issue of slavery and civil rights, public recognition of the moral dimensions of human-made climate change may be needed to stir the public's conscience to the point of action.

A scenario is conceivable in which growing evidence of climate change and recognition of implications for young people lead to massive public support for action. Influential industry leaders, aware of the moral issue, may join the campaign to phase out emissions, with more business leaders becoming supportive as they recognize the merits of a rising price on carbon. Given the relative ease with which a flat carbon price can be made international [236], a rapid global emissions phasedown is feasible. As fossil fuels are made to pay their costs to society, energy efficiency and clean energies may reach tipping points and begin to be rapidly adopted.

Our analysis shows that a set of actions exists with a good chance of averting "dangerous" climate change, if the actions begin now. However, we also show that time is running out. Unless a human "tipping point" is reached soon, with implementation of effective policy actions, large irreversible climate changes will become unavoidable. Our parent's generation did not know that their energy use would harm future generations and other life on the planet. If we do not change our course, we can only pretend that we did not know.

Discussion

We conclude that an appropriate target is to keep global temperature within or close to the temperature range in the Holocene, the interglacial period in which civilization developed. With warming of 0.8°C in the past century, Earth is just emerging from that range, implying that we need to restore the planet's energy balance and curb further warming. A limit of approximately 500 GtC on cumulative fossil fuel emissions, accompanied by a net storage of 100 GtC in the biosphere and soil, could keep global temperature close to the Holocene range, assuming that the net future forcing change from other factors is small. The longevity of global warming (Fig. 9) and the implausibility of removing the warming if it is once allowed to penetrate the deep ocean emphasize the urgency of slowing emissions so as to stay close to the 500 GtC target.

Fossil fuel emissions of 1000 GtC, sometimes associated with a 2°C global warming target, would be expected to cause large climate change with disastrous consequences. The eventual warming from 1000 GtC fossil fuel emissions likely would reach well over 2°C, for several reasons. With such emissions and temperature tendency, other trace greenhouse gases including methane and nitrous oxide would be expected to increase, adding to the effect of CO_2. The global warming and shifting climate zones would make it less likely that a substantial increase in forest and soil carbon could be achieved. Paleoclimate data indicate that slow feedbacks would substantially amplify the 2°C global warming. It is clear that pushing global climate far outside the Holocene range is inherently dangerous and foolhardy.

The fifth IPCC assessment Summary for Policymakers [14] concludes that to achieve a 50% chance of keeping global warming below 2°C equivalent CO_2 emissions should not exceed 1210 GtC, and after accounting for non-CO_2 climate forcings this limit on CO_2 emissions becomes 840 GtC. The existing drafts of the fifth IPCC assessment are not yet approved for comparison and citation, but the IPCC assessment is consistent with studies of Meinshausen et al. [254] and Allen et al. [13], hereafter M2009 and A2009, with which we can make comparisons. We will also compare our conclusions with those of McKibben [255]. M2009 and A2009 appear together in the same journal with the two lead authors on each paper being co-authors on the other paper. McKibben [255], published in a popular magazine, uses quantitative results of M2009 to conclude that most remaining fossil fuel reserves must be left in the ground, if global warming this century is to be kept below 2°C. McKibben [255] has been very successful in drawing public attention to the urgency of rapidly phasing down fossil fuel emissions.

M2009 use a simplified carbon cycle and climate model to make a large ensemble of simulations in which principal uncertainties in the carbon cycle, radiative forcings, and climate response are allowed to vary, thus yielding a probability distribution for global warming as a function of time throughout the 21st century. M2009 use this distribution to infer a limit on total (fossil fuel+net land use) carbon emissions in the period 2000–2049 if global warming in the 21st century is to be kept below 2°C at some specified probability. For example, they conclude that the limit on total 2000–2049 carbon emissions is 1440 $GtCO_2$ (393 GtC) to achieve a 50% chance that 21st century global warming will not exceed 2°C.

A2009 also use a large ensemble of model runs, varying uncertain parameters, and conclude that total (fossil fuel+net land use) carbon emissions of 1000 GtC would most likely yield a peak

CO_2-induced warming of 2°C, with 90% confidence that the peak warming would be in the range 1.3–3.9°C. They note that their results are consistent with those of M2009, as the A2009 scenarios that yield 2°C warming have 400–500 GtC emissions during 2000–2049; M2009 find 393 GtC emissions for 2°C warming, but M2009 included a net warming effect of non-CO_2 forcings, while A2009 neglected non-CO_2 forcings.

McKibben [255] uses results of M2009 to infer allowable fossil fuel emissions up to 2050 if there is to be an 80% chance that maximum warming in the 21st century will not exceed 2°C above the pre-industrial level. M2009 conclude that staying under this 2°C limit with 80% probability requires that 2000–2049 emissions must be limited to 656 $GtCO_2$ (179 GtC) for 2007–2049. McKibben [255] used this M2009 result to determine a remaining carbon budget (at a time not specified exactly) of 565 $GtCO_2$ (154 GtC) if warming is to stay under 2°C. Let us update this analysis to the present: fossil fuel emissions in 2007–2012 were 51 GtC [5], so, assuming no net emissions from land use in these few years, the M2009 study implies that the remaining budget at the beginning of 2013 was 128 GtC.

Thus, coincidentally, the McKibben [255] approach via M2009 yields almost exactly the same remaining carbon budget (128 GtC) as our analysis (130 GtC). However, our budget is that required to limit warming to about 1°C (there is a temporary maximum during this century at about 1.1–1.2°C, Fig. 9), while McKibben [255] is allowing global warming to reach 2°C, which we have concluded would be a disaster scenario! This apparently vast difference arises from three major factors.

First, we assumed that reforestation and improved agricultural and forestry practices can suck up the net land use carbon of the past. We estimate net land use emissions as 100 GtC, while M2009 have land use emissions almost twice that large (~180 GtC). We argue elsewhere (see section 14 in Supporting Information of [54]) that the commonly employed net land use estimates [256] are about a factor of two larger than the net land use carbon that is most consistent with observed CO_2 history. However, we need not resolve that long-standing controversy here. The point is that, to make the M2009 study equivalent to ours, negative land use emissions must be included in the 21st century equal to earlier positive land use emissions.

Second, we have assumed that future net change of non-CO_2 forcings will be zero, while M2009 have included significant non-CO_2 forcings. In recent years non-CO_2 GHGs have provided about 20% of the increase of total GHG climate forcing.

Third, our calculations are for a single fast-feedback equilibrium climate sensitivity, 3°C for doubled CO_2, which we infer from paleoclimate data. M2009 use a range of climate sensitivities to compute a probability distribution function for expected warming, and then McKibben [255] selects the carbon emission limit that keeps 80% of the probability distribution below 2°C.

The third factor is a matter of methodology, but one to be borne in mind. Regarding the first two factors, it may be argued that our scenario is optimistic. That is true, but both goals, extracting 100 GtC from the atmosphere via improved forestry and agricultural practices (with possibly some assistance from CCS technology) and limiting additional net change of non-CO_2 forcings to zero, are feasible and probably much easier than the principal task of limiting additional fossil fuel emissions to 130 GtC.

We noted above that reforestation and improving agricultural and forestry practices that store more carbon in the soil make sense for other reasons. Also that task is made easier by the excess CO_2 in the air today, which causes vegetation to take up CO_2 more efficiently. Indeed, this may be the reason that net land use emissions seem to be less than is often assumed.

As for the non-CO_2 forcings, it is noteworthy that greenhouse gases controlled by the Montreal Protocol are now decreasing, and recent agreement has been achieved to use the Montreal Protocol to phase out production of some additional greenhouse gases even though those gases do not affect the ozone layer. The most important non-CO_2 forcing is methane, whose increases in turn cause tropospheric ozone and stratospheric water vapor to increase. Fossil fuel use is probably the largest source of methane [1], so if fossil fuel use begins to be phased down, there is good basis to anticipate that all three of these greenhouse gases could decrease, because of the approximate 10-year lifetime of methane.

As for fossil fuel CO_2 emissions, considering the large, long-lived fossil fuel infrastructure in place, the science is telling us that policy should be set to reduce emissions as rapidly as possible. The most fundamental implication is the need for an across-the-board rising fee on fossil fuel emissions in order to allow true free market competition from non-fossil energy sources. We note that biospheric storage should not be allowed to offset further fossil fuel emissions. Most fossil fuel carbon will remain in the climate system more than 100,000 years, so it is essential to limit the emission of fossil fuel carbon. It will be necessary to have incentives to restore biospheric carbon, but these must be accompanied by decreased fossil fuel emissions.

A crucial point to note is that the three tasks [limiting fossil fuel CO_2 emissions, limiting (and reversing) land use emissions, limiting (and reversing) growth of non-CO_2 forcings] are interactive and reinforcing. In mathematical terms, the problem is non-linear. As one of these climate forcings increases, it increases the others. The good news is that, as one of them decreases, it tends to decrease the others. In order to bestow upon future generations a planet like the one we received, we need to win on all three counts, and by far the most important is rapid phasedown of fossil fuel emissions.

It is distressing that, despite the clarity and imminence of the danger of continued high fossil fuel emissions, governments continue to allow and even encourage pursuit of ever more fossil fuels. Recognition of this reality and perceptions of what is "politically feasible" may partially account for acceptance of targets for global warming and carbon emissions that are well into the range of "dangerous human-made interference" with climate. Although there is merit in simply chronicling what is happening, there is still opportunity for humanity to exercise free will. Thus our objective is to define what the science indicates is needed, not to assess political feasibility. Further, it is not obvious to us that there are physical or economic limitations that prohibit fossil fuel emission targets far lower than 1000 GtC, even targets closer to 500 GtC. Indeed, we suggest that rapid transition off fossil fuels would have numerous near-term and long-term social benefits, including improved human health and outstanding potential for job creation.

A world summit on climate change will be held at United Nations Headquarters in September 2014 as a preliminary to negotiation of a new climate treaty in Paris in late 2015. If this treaty is analogous to the 1997 Kyoto Protocol [257], based on national targets for emission reductions and cap-and-trade-with-offsets emissions trading mechanisms, climate deterioration and gross intergenerational injustice will be practically guaranteed. The palpable danger that such an approach is conceivable is suggested by examination of proposed climate policies of even the most forward-looking of nations. Norway, which along with the other Scandinavian countries has been among the most ambitious and successful of all nations in reducing its emissions, nevertheless approves expanded oil drilling in the Arctic and development of tar sands as a majority owner of Statoil [258–259]. Emissions

foreseen by the Energy Perspectives of Statoil [259], if they occur, would approach or exceed 1000 GtC and cause dramatic climate change that would run out of control of future generations. If, in contrast, leading nations agree in 2015 to have internal rising fees on carbon with border duties on products from nations without a carbon fee, a foundation would be established for phaseover to carbon free energies and stable climate.

Supporting Information

Table S1
(ODS)

Table S2
(ODS)

Table S3
(ODS)

Text S1
(DOC)

Acknowledgments

We greatly appreciate the assistance of editor Juan A. Añel in achieving requisite form and clarity for publication. The paper is dedicated to Paul Epstein, a fervent defender of the health of humans and the environment, who graciously provided important inputs to this paper while battling late stages of non-Hodgkin's lymphoma. We thank David Archer, Inez Fung, Charles Komanoff and two anonymous referees for perceptive helpful reviews and Mark Chandler, Bishop Dansby, Ian Dunlop, Dian Gaffen Seidel, Edward Greisch, Fred Hendrick, Tim Mock, Ana Prados, Stefan Rahmstorf, Rob Socolow and George Stanford for helpful suggestions on a draft of the paper.

Author Contributions

Conceived and designed the experiments: JH PK MS. Performed the experiments: MS PK. Wrote the paper: JH. Wrote the first draft: JH. All authors made numerous critiques and suggested specific wording and references: JH PK MS VM-D FA DJB PJH OHG SLH CP JR EJR JS PS KS LVS KvS JCZ. Especially: PK MS VM-D.

References

1. Intergovernmental Panel on Climate Change (2007) Climate Change 2007: Physical Science Basis, Solomon, S, Dahe, Q, Manning M, Chen Z, Marquis M, et al., editors. Cambridge Univ. Press: New York 2007; 996 pp.
2. Hansen J, Sato M, Ruedy R, Nazarenko L, Lacis A, et al. (2005) Efficacy of climate forcings. J Geophys Res 110, D18104, doi:10.1029/2005JD005776.
3. Archer D (2005) Fate of fossil fuel CO_2 in geologic time. J Geophys Res 110: C09S05.
4. BP Statistical Review of World Energy 2012 (http://www.bp.com/sectionbodycopy.do?categoryId = 7500&contentId = 7068481).
5. Boden TA, Marland G, Andres RJ (2012) Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2012.
6. United Nations Framework Convention on Climate Change (1992) Available: http://www.unfccc.int.
7. Energy Information Administration (EIA) (2011) International Energy Outlook Available: http://www.eia.gov/forecasts/ieo/pdf/0484.Pdf accessed Sept 2011.
8. German Advisory Council on Global Change (GAC)(2011) World in Transition - A Social Contract for Sustainability. Available: http://www.wbgu.de/en/flagship-reports/fr-2011-a-social-contract/. Accessed Oct 2011.
9. Global Energy Assessment (GEA) (2012) Toward a Sustainable Future. Johanson TB, Patwardhan E, Nakićenović N, editors. Cambridge: Cambridge University Press.
10. Randalls S (2010) History of the 2°C climate target. WIREs Clim Change 1, 598–605.
11. Copenhagen Accord (2009) United Nations Framework Convention on Climate Change, Draft decision −/CP.15 FCCC/CP/2009/L.7 18 December 2009.
12. Matthews HD, Gillett NP, Stott PA, Zickfeld K (2009) The proportionality of global warming to cumulative carbon emissions. Nature 459: 829–832.
13. Allen MR, Frame DJ, Huntingford C, Jones CD, Lowe JA, et al. (2009) Warming caused by cumulative carbon emissions towards the trillionth tonne. Nature 458, 1163–1166.
14. Intergovernmental Panel on Climate Change (2013) Approved Summary for Policymakers of full draft report of Climate Change 2013: Physical Science Basis, Stocker T, Dahe Q, Plattner G-K, coordinating lead authors, available: http://www.ipcc.ch/report/ar5/wg1/#.UlCweRCvHMM.
15. Intergovernmental Panel on Climate Change (2007) Climate Change 2007: Mitigation of Climate Change. Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, editors. Cambridge: Cambridge University Press.
16. Hansen J, Ruedy R, Sato M, Lo K (2010) Global Surface Temperature Change. Rev Geophys 48: RG4004.
17. Meehl GA, Arblaster JM, Marsh DR (2013) Could a future "Grand Solar Minimum" like the Maunder Minimum stop global warming? Geophys Res Lett 40, 1789–1793.
18. Kosaka Y, Xie SP (2013) Recent global-warming hiatus tied to equatorial Pacific surface cooling. Nature published online 28 August doi:10.1038/nature12534.
19. Intergovernmental Panel on Climate Change (2001) Climate Change 2001: The Scientific Basis. Houghton JT, MacCarthy JJ, Metz M, editors. Cambridge: Cambridge University Press.
20. Schneider SH, Mastrandrea MD (2005) Probabilistic assessment "dangerous" climate change and emissions pathways. Proc Natl Acad Sci USA 102: 15728–15735.
21. Stroeve JC, Kattsov V, Barrett A, Serreze M, Pavlova T, et al. (2012) Trends in Arctic sea ice extent from CMIP5, CMIP3 and observations. Geophys Res Lett 39: L16502.
22. Rampal P, Weiss J, Dubois C, Campin JM (2011) IPCC climate models do not capture Arctic sea ice drift acceleration: Consequences in terms of projected sea ice thinning and decline. J Geophys Res 116: C00D07.
23. Shepherd A, Ivins ER, Geruo A, Barletta VR, Bentley MJ, et al. (2012) A reconciled estimate of ice-sheet mass balance. Science 338: 1183–1189.
24. Rignot E, Velicogna I, van den Broeke MR, Monaghan A, Lenaerts J (2011) Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. Geophys Res Lett 38: L05503–L05508.
25. Hanna E, Navarro FJ, Pattyn F,Domingues CM, Fettweis X, et al. (2013) Ice-sheet mass balance and climate change. Nature 498: 51–59.
26. Intergovernmental Panel on Climate Change (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability. Parry, ML, Canziani O, Palutikof J, van der Linden P, Hanson C, editors. Cambridge: Cambridge University Press.
27. Rabatel A, Francou B, Soruco A, Gomez J, Caceres B, et al. (2013) Current state of glaciers in the tropical Andes: a multi-century perspective on glacier evolution and climate change. The Cryosphere 7: 81–102.
28. Sorg A, Bolch T, Stoffel M, Solomina O, Beniston M (2012) Climate change impacts on glaciers and runoff in Tien Shan (Central Asia). Nature Clim Change 2, 725–731.
29. Yao T, Thompson L, Yang W, Yu W, Gao Y, et al. (2012) Different glacier status with atmospheric circulations in Tibetan Plateau and surroundings. Nature Clim Change 2, 663–667.
30. Barnett TP, Pierce DW, Hidalgo HG, Bonfils C, Santer BD, et al. (2008) Human-induced changes in the hydrology of the western United States. Science 319: 1080–1083.
31. Kaser G, Grosshauser M, Marzeion B (2010) Contribution potential of glaciers to water availability in different climate regimes. Proc Natl Acad Sci USA 107: 20223–20227.
32. Vergara W, Deeb AM, Valencia AM, Bradley RS, Francou B, et al. (2007) Economic impacts of rapid glacier retreat in the Andes. EOS Trans Amer. Geophys Union 88: 261–268.
33. Held IM, Soden BJ (2006) Robust responses of the hydrological cycle to global warming. J Clim 19: 5686–5699.
34. Seidel DJ, Fu Q, Randel WJ, Reichler TJ (2008) Widening of the tropical belt in a changing climate. Nat Geosci 1: 21–24.
35. Davis SM, Rosenlof KH (2011) A multi-diagnostic intercomparison of tropical width time series using reanalyses and satellite observations. J Clim doi: 10.1175/JCLI-D-1111–00127.00121.
36. Liu J, Song M, Hu Y, Ren X (2012) Changes in the strength and width of the Hadley circulation since 1871. Clim Past 8: 1169–1175.
37. Dai A (2013) Increasing drought under global warming in observations and models. Nature Clim Change 3, 52–58.
38. Westerling AL, Hidalgo HG, Cayan DR, Swetnam TW (2006) Warming and earlier spring increase western US forest wildfire activity. Science 313: 940–943.
39. Bruno JF, Selig ER (2007) Regional decline of coral cover in the Indo-Pacific: timing, extent, and subregional comparisons. Plos One 2: e711.
40. Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, et al. (2007) Coral reefs under rapid climate change and ocean acidification. Science 318: 1737–1742.
41. Veron JE, Hoegh-Guldberg O, Lenton TM, Lough JM, Obura DO, et al. (2009) The coral reef crisis: The critical importance of <350 ppm CO2. Mar Pollut Bull 58: 1428–1436.

Atmos. Chem. Phys. Discuss., 15, 20059–20179, 2015
www.atmos-chem-phys-discuss.net/15/20059/2015/
doi:10.5194/acpd-15-20059-2015

Atmospheric Chemistry and Physics Discussions

Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming is highly dangerous

J. Hansen[1], M. Sato[1], P. Hearty[2], R. Ruedy[3,4], M. Kelley[3,4], V. Masson-Delmotte[5], G. Russell[4], G. Tselioudis[4], J. Cao[6], E. Rignot[7,8], I. Velicogna[8,7], E. Kandiano[9], K. von Schuckmann[10], P. Kharecha[1,4], A. N. Legrande[4], M. Bauer[11], and K.-W. Lo[3,4]

[1]Climate Science, Awareness and Solutions, Columbia University Earth Institute, New York, NY 10115, USA
[2]Department of Environmental Studies, University of North Carolina at Wilmington, North Carolina 28403, USA
[3]Trinnovium LLC, New York, NY 10025, USA
[4]NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA
[5]Institut Pierre Simon Laplace, Laboratoire des Sciences du Climat et de l'Environnement (CEA-CNRS-UVSQ), Gif-sur-Yvette, France

[6]Key Lab of Aerosol Chemistry & Physics, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710075, China
[7]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, 91109, USA
[8]Department of Earth System Science, University of California, Irvine, California, 92697, USA
[9]GEOMAR, Helmholtz Centre for Ocean Research, Wischhofstrasse 1–3, Kiel 24148, Germany
[10]Mediterranean Institute of Oceanography, University of Toulon, La Garde, France
[11]Department of Applied Physics and Applied Mathematics, Columbia University, New York, NY, 10027, USA

Received: 11 June 2015 – Accepted: 9 July 2015 – Published: 23 July 2015

Correspondence to: J. Hansen (jeh1@columbia.edu)

Published by Copernicus Publications on behalf of the European Geosciences Union.

ACPD
15, 20059–20179, 2015

Abstract

There is evidence of ice melt, sea level rise to +5–9 m, and extreme storms in the prior interglacial period that was less than 1 °C warmer than today. Human-made climate forcing is stronger and more rapid than paleo forcings, but much can be learned by combining insights from paleoclimate, climate modeling, and on-going observations. We argue that ice sheets in contact with the ocean are vulnerable to non-linear disintegration in response to ocean warming, and we posit that ice sheet mass loss can be approximated by a doubling time up to sea level rise of at least several meters. Doubling times of 10, 20 or 40 years yield sea level rise of several meters in 50, 100 or 200 years. Paleoclimate data reveal that subsurface ocean warming causes ice shelf melt and ice sheet discharge. Our climate model exposes amplifying feedbacks in the Southern Ocean that slow Antarctic bottom water formation and increase ocean temperature near ice shelf grounding lines, while cooling the surface ocean and increasing sea ice cover and water column stability. Ocean surface cooling, in the North Atlantic as well as the Southern Ocean, increases tropospheric horizontal temperature gradients, eddy kinetic energy and baroclinicity, which drive more powerful storms. We focus attention on the Southern Ocean's role in affecting atmospheric CO_2 amount, which in turn is a tight control knob on global climate. The millennial (500–2000 year) time scale of deep ocean ventilation affects the time scale for natural CO_2 change, thus the time scale for paleo global climate, ice sheet and sea level changes. This millennial carbon cycle time scale should not be misinterpreted as the ice sheet time scale for response to a rapid human-made climate forcing. Recent ice sheet melt rates have a doubling time near the lower end of the 10–40 year range. We conclude that 2 °C global warming above the preindustrial level, which would spur more ice shelf melt, is highly dangerous. Earth's energy imbalance, which must be eliminated to stabilize climate, provides a crucial metric.

ACPD
15, 20059–20179, 2015

1 Introduction

Humanity is rapidly extracting and burning fossil fuels without full understanding of the consequences. Current assessments place emphasis on practical effects such as increasing extremes of heat waves, droughts, heavy rainfall, floods, and encroaching seas (IPCC, 2014; USNCA, 2014). These assessments and our recent study (Hansen et al., 2013a) conclude that there is an urgency to slow carbon dioxide (CO_2) emissions, because the longevity of the carbon in the climate system (Archer, 2005) and persistence of the induced warming (Solomon et al., 2010) may lock in unavoidable highly undesirable consequences.

Despite these warnings, global CO_2 emissions continue to increase as fossil fuels remain the primary energy source. The argument is made that it is economically and morally responsible to continue fossil fuel use for the sake of raising living standards, with expectation that humanity can adapt to climate change and find ways to minimize effects via advanced technologies.

We suggest that this viewpoint fails to appreciate the nature of the threat posed by ice sheet instability and sea level rise. If the ocean continues to accumulate heat and increase melting of marine-terminating ice shelves of Antarctica and Greenland, a point will be reached at which it is impossible to avoid large scale ice sheet disintegration with sea level rise of at least several meters. The economic and social cost of losing functionality of all coastal cities is practically incalculable. We suggest that a strategic approach relying on adaptation to such consequences is unacceptable to most of humanity, so it is important to understand this threat as soon as possible.

We examine events late in the last interglacial period warmer than today, called Marine Isotope Stage (MIS) 5e in studies of ocean sediment cores, Eemian in European climate studies, and sometimes Sangamonian in American literature (see Sect. 5 for timescale diagram of Marine Isotope Stages). Accurately known changes of Earth's astronomical configuration altered the seasonal and geographical distribution of incoming radiation during the Eemian. Resulting global warming was due to feedbacks that am-

ACPD
15, 20059–20179, 2015

plified the orbital forcing. While the Eemian is not an analog of future warming, it is useful for investigating climate feedbacks, the response of polar ice sheets to polar warming, and the interplay between ocean circulation and ice sheet melt.

Our study relies on a large body of research by the scientific community. After introducing evidence concerning late Eemian climate change, we analyze relevant climate processes in three stages. First we carry our IPCC-like climate simulations, but with growing freshwater sources in the North Atlantic and Southern Oceans. Second we use paleoclimate data to extract information on key processes identified by the modeling. Third we use modern data to show that these processes are already spurring climate change today.

2 Evidence concerning Eemian climate

We first discuss geologic evidence of late-Eemian sea level rise and storms. We then discuss ocean core data that help define a rapid cooling event in the North Atlantic that marks the initial descent from interglacial conditions toward global ice age conditions. This rapid end-Eemian cooling occurs at ~ 118 ky b2k in ocean cores with uncertainty ~ 2 ky, and is identified by Chapman and Shackleton (1999) as cold event C26.

C26 is the cold phase of Dansgaard–Oeschger climate oscillation D–O 26 in the NGRIP (North Greenland Ice Core Project) ice core (NGRIP, 2004). C26 begins with a sharp cooling at 119.14 ky b2k on the GICC05modelext time scale (Rasmussen et al., 2014). The GICC05 time scale is based on annual layer counting in Greenland ice cores for the last 60 ky and on an ice flow-model extension for earlier times. An alternative time scale is provided by Antarctic ice core chronology AICC2012 (Bazin et al., 2013; Veres et al., 2013) on which Greenland ice core records have been synchronized via global markers such as oscillations of atmospheric CH_4 amount. C26 on Greenland is at 116.72 ky b2k on the AICC2012 time scale. Figure S1 in the Supplement shows the difference between GICC05 and AICC2012 times scales versus time.

ACPD
15, 20059–20179, 2015

Our analysis paints a different picture than IPCC (2013) for how this Hyper-Anthropocene phase is likely to proceed if GHG emissions grow at a rate that continues to pump energy at a high rate into the ocean. We conclude that multi-meter sea level rise would become practically unavoidable. Social disruption and economic consequences of such large sea level rise could be devastating. It is not difficult to imagine that conflicts arising from forced migrations and economic collapse might make the planet ungovernable, threatening the fabric of civilization.

This image of our planet with accelerating meltwater includes growing climate chaos and storminess, as meltwater causes cooling around Antarctica and in the North Atlantic while the tropics and subtropics continue to warm. Rising seas and more powerful storms together are especially threatening, providing strong incentive to phase down CO_2 emissions rapidly.

8 Summary implications

Humanity faces near certainty of eventual sea level rise of at least Eemian proportions, 5–9 m, if fossil fuel emissions continue on a business-as-usual course, e.g., IPCC scenario A1B that has CO_2 ~ 700 ppm in 2100 (Fig. S21). It is unlikely that coastal cities or low-lying areas such as Bangladesh, European lowlands, and large portions of the United States eastern coast and northeast China plains (Fig. S22) could be protected against such large sea level rise.

Rapid large sea level rise may begin sooner than generally assumed. Amplifying feedbacks, including slowdown of SMOC and cooling of the near-Antarctic ocean surface with increasing sea ice, may spur nonlinear growth of Antarctic ice sheet mass loss. Deep submarine valleys in West Antarctica and the Wilkes Basin of East Antarctica, each with access to ice amounting to several meters of sea level, provide gateways to the ocean. If the Southern Ocean forcing (subsurface warming) of the Antarctic ice sheets continues to grow, it likely will become impossible to avoid sea level rise of several meters, with the largest uncertainty being how rapidly it will occur.

ACPD
15, 20059–20179, 2015

The Greenland ice sheet does not have as much ice subject to rapid nonlinear disintegration, so the speed at which it adds to 21st century sea level rise may be limited. However, even a slower Greenland ice sheet response is expected to be faster than carbon cycle or ocean thermal recovery times. Therefore, if climate forcing continues to grow rapidly, amplifying feedbacks will assure large eventual mass loss. Also with present growth of freshwater injection from Greenland, in combination with increasing North Atlantic precipitation, we already may be on the verge of substantial North Atlantic climate disruption.

Storms conjoin with sea level rise to cause the most devastating coastal damage. End-Eemian and projected 21st century conditions are similar in having warm tropics and increased freshwater injection. Our simulations imply increasing storm strengths for such situations, as a stronger temperature gradient caused by ice melt increases baroclinicity and provides energy for more severe weather events. A strengthened Bermuda High in the warm season increases prevailing northeasterlies that can help account for stronger end-Eemian storms. Weakened cold season sea level pressure south of Greenland favors occurrence of atmospheric blocking that can increase wintertime Arctic cold air intrusions into northern midlatitudes.

Effects of freshwater injection and resulting ocean stratification are occurring sooner in the real world than in our model. We suggest that this is an effect of excessive small scale mixing in our model that limits stratification, a problem that may exist in other models (Hansen et al., 2011). We encourage similar simulations with other models, with special attention to the model's ability to maintain realistic stratification and perturbations. This issue may be addressed in our model with increased vertical resolution, more accurate finite differencing method in ocean dynamics that reduces noise, and use of a smaller background diffusivity.

There are many other practical impacts of continued high fossil fuel emissions via climate change and ocean acidification, including irreplaceable loss of many species, as reviewed elsewhere (IPCC, 2013, 2014; Hansen et al., 2013a). However, sea level rise sets the lowest limit on allowable human-made climate forcing and CO_2, because of the

ACPD
15, 20059–20179, 2015

extreme sensitivity of sea level to ocean warming and the devastating economic and humanitarian impacts of a multi-meter sea level rise. Ice sheet response time is shorter than the time for natural geologic processes to remove CO_2 from the climate system, so there is no morally defensible excuse to delay phase-out of fossil fuel emissions as rapidly as possible.

We conclude that the 2 °C global warming "guardrail", affirmed in the Copenhagen Accord (2009), does not provide safety, as such warming would likely yield sea level rise of several meters along with numerous other severely disruptive consequences for human society and ecosystems. The Eemian, less than 2 °C warmer than pre-industrial Earth, itself provides a clear indication of the danger, even though the orbital drive for Eemian warming differed from today's human-made climate forcing. Ongoing changes in the Southern Ocean, while global warming is less than 1 °C, provide a strong warning, as observed changes tend to confirm the mechanisms amplifying change. Predicted effects, such as cooling of the surface ocean around Antarctica, are occurring even faster than modeled.

Our finding of global cooling from ice melt calls into question whether global temperature is the most fundamental metric for global climate in the 21st century. The first order requirement to stabilize climate is to remove Earth's energy imbalance, which is now about $+0.6\,W\,m^{-2}$, more energy coming in than going out. If other forcings are unchanged, removing this imbalance requires reducing atmospheric CO_2 from ~400 to ~350 ppm (Hansen et al., 2008, 2013a).

The message that the climate science delivers to policymakers, instead of defining a safe "guardrail", is that fossil fuel CO_2 emissions must be reduced as rapidly as practical. Hansen et al. (2013a) conclude that this implies a need for a rising carbon fee or tax, an approach that has the potential to be near-global, as opposed to national caps or goals for emission reductions. Although a carbon fee is the sine qua non for phasing out emissions, the urgency of slowing emissions also implies other needs including widespread technical cooperation in clean energy technologies (Hansen et al., 2013a).

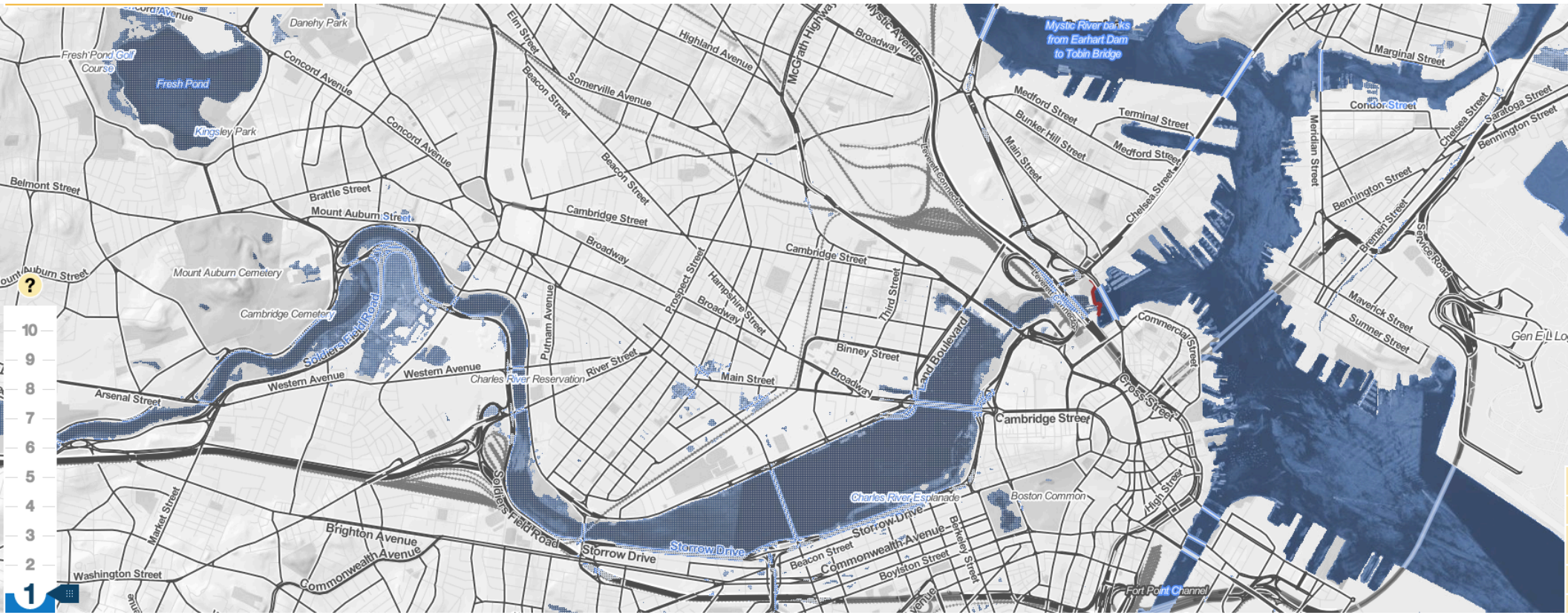
ACPD
15, 20059–20179, 2015

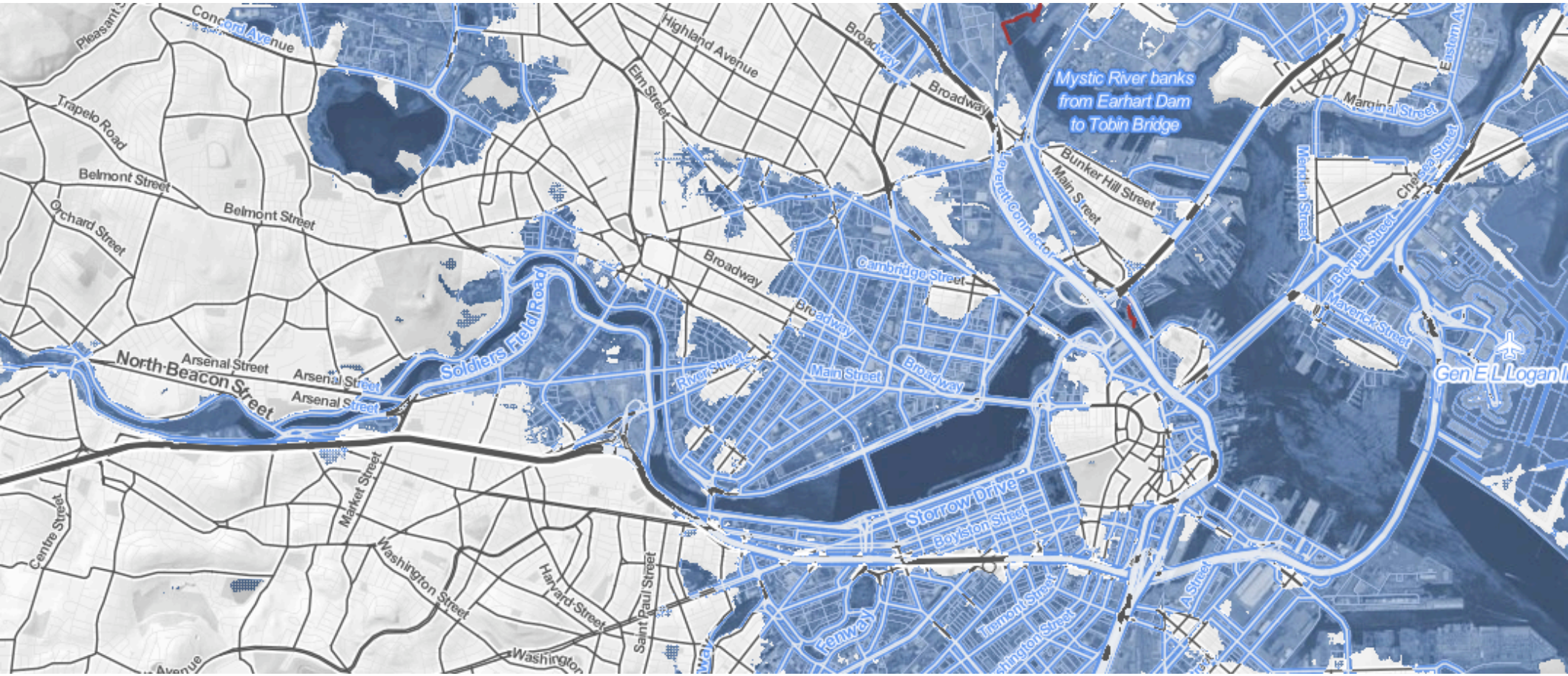
The task of achieving a reduction of atmospheric CO_2 is formidable, but not impossible. Rapid transition to abundant affordable carbon-free electricity is the core requirement, as that would also permit production of net-zero-carbon liquid fuels from electricity. The rate at which CO_2 emissions must be reduced is about 6 % yr^{-1} to reach 350 ppm atmospheric CO_2 by about 2100, under the assumption that improved agricultural and forestry practices could sequester 100 GtC (Hansen et al., 2013a). The amount of CO_2 fossil fuel emissions taken up by the ocean, soil and biosphere has continued to increase (Fig. S23), thus providing hope that it may be possible to sequester more than 100 GtC. Improved understanding of the carbon cycle and non-CO_2 forcings are needed, but it is clear that the essential requirement is to begin to phase down fossil fuel CO_2 emissions rapidly. It is also clear that continued high emissions are likely to lock-in continued global energy imbalance, ocean warming, ice sheet disintegration, and large sea level rise, which young people and future generations would not be able to avoid. Given the inertia of the climate and energy systems, and the grave threat posed by continued high emissions, the matter is urgent and calls for emergency cooperation among nations.

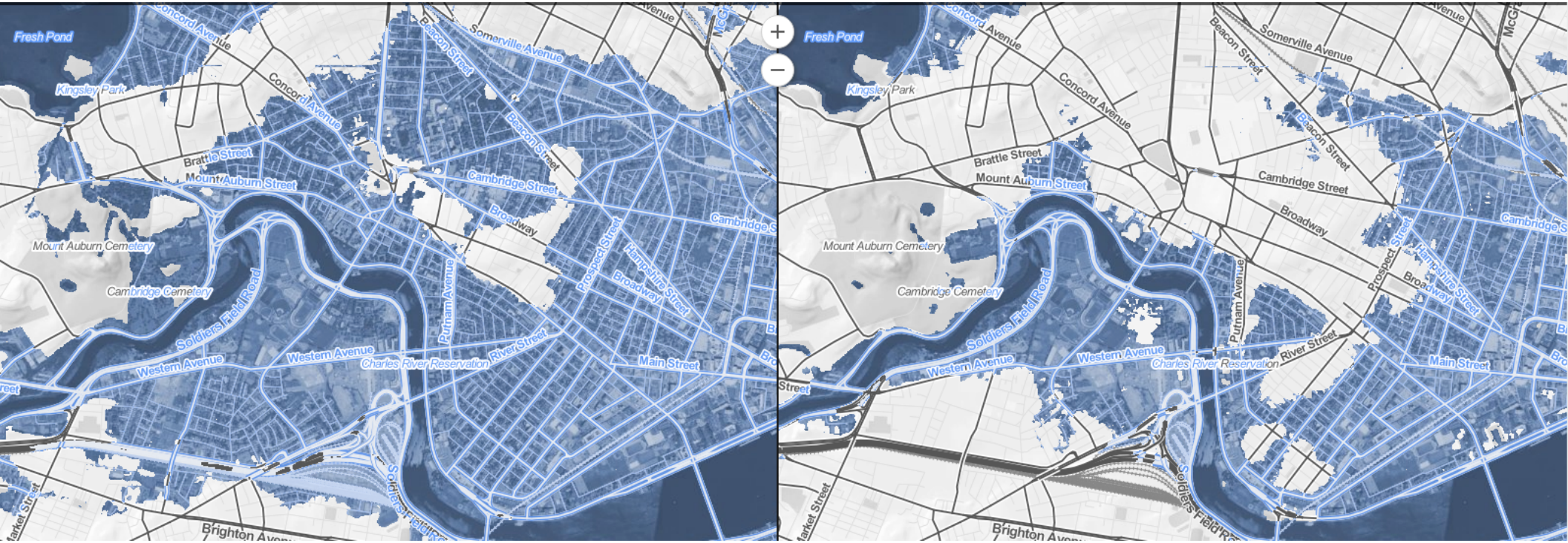
The Supplement related to this article is available online at doi:10.5194/acpd-15-20059-2015-supplement.

Acknowledgements. Completion of this study was made possible by a generous gift from The Durst Family to the Climate Science, Awareness and Solutions program at the Columbia University Earth Institute. That program was initiated in 2013 primarily via support from the Grantham Foundation for Protection of the Environment, Jim and Krisann Miller, and Gerry Lenfest and sustained via their continuing support. Other substantial support has been provided by the Flora Family Foundation, Dennis Pence, the Skoll Global Threats Fund, Alexander Totic and Hugh Perrine. We thank Anders Carlson, Elsa Cortijo, Nil Irvali, Kurt Lambeck, Scott Lehman, and Ulysses Ninnemann for their kind provision of data and related information. Support for climate simulations was provided by the NASA High-End Computing (HEC) Program through the NASA Center for Climate Simulation (NCCS) at Goddard Space Flight Center.


Pforzheimer House
Currier House
RADCLIFFE QUADRANGLE
Cabot House
Bunting Quadrangle
RADCLIFFE INSTITUTE
Radcliffe Yard
GR. SCHOOL OF EDUCATION
HARVARD LAW SCHOOL
HARVARD JOHN A. PAULSON SCHOOL OF ENGINEERING AND APPLIED SCIENCES
HARVARD DIVINITY SCHOOL
GR. SCHOOL OF DESIGN
Old Yard
Tercentenary Theatre
HARVARD YARD
HARVARD KENNEDY SCHOOL
Kirkland House
Lowell House
Eliot House
Winthrop House
Leverett House
Quincy House
Adams House
Dunster House
Mather House
SOLDIERS FIELD ATHLETIC AREA
HARVARD BUSINESS SCHOOL
ALLSTON LANDING NORTH
Charles River
Buildings
Harvard Institutional
Harvard Non-Institutional
Non-Harvard (Leased Space)
Harvard Underground
Non-Harvard
Green
Harvard
Public/Other
0 95 190 380 570 760 Feet


Mystic River banks from Earhart Dam to Tobin Bridge
Fresh Pond
Fresh Pond Golf Course
Kingsley Park
Danehy Park
Mount Auburn Cemetery
Cambridge Cemetery
Charles River Reservation
Charles River Esplanade
Boston Common
Fort Point Channel
Concord Avenue
Belmont Street
Brattle Street
Mount Auburn Street
Cambridge Street
Broadway
Beacon Street
Somerville Avenue
Highland Avenue
McGrath Highway
Mystic Avenue
Medford Street
Terminal Street
Bunker Hill Street
Main Street
Chelsea Street
Marginal Street
Condor Street
Meridian Street
Bennington Street
Saratoga Street
Chelsea Street
Bremen Street
Service Road
Maverick Street
Sumner Street
Commercial Street
Prospect Street
Hampshire Street
Third Street
Putnam Avenue
River Street
Western Avenue
Arsenal Street
Soldiers Field Road
Binney Street
Land Boulevard
Cross Street
High Street
Storrow Drive
Commonwealth Avenue
Boylston Street
Berkeley Street
Market Street
Brighton Avenue
Washington Street
10
9
8
7
6
5
4
3
2
1


Mystic River banks
from Earhart Dam
to Tobin Bridge
Concord Avenue
Highland Avenue
Broadway
Trapelo Road
Belmont Street
Orchard Street
Elm Street
Bunker Hill Street
Main Street
Marginal Street
Chelsea Street
Meridian Street
Everett Connector
Cambridge Street
Soldiers Field Road
North Beacon Street
Arsenal Street
River Street
Storrow Drive
Boylston Street
Market Street
Washington Street
Harvard Street
Saint Paul Street
Centre Street
Fenway
Trimont Street
Gen E L Logan


Fresh Pond
Kingsley Park
Concord Avenue
Beacon Street
Somerville Avenue
Brattle Street
Mount Auburn Street
Cambridge Street
Broadway
Mount Auburn Cemetery
Cambridge Cemetery
Soldiers Field Road
Western Avenue
Charles River Reservation
River Street
Putnam Avenue
Prospect Street
Hampshire Street
Main Street
Brighton Avenue