

**Case No. 18-36082**

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**IN THE UNITED STATES COURT OF APPEALS  
FOR THE NINTH CIRCUIT**

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KELSEY CASCADIA ROSE JULIANA, *et al.*,  
Plaintiffs-Appellees,

v.

UNITED STATES OF AMERICA, *et al.*,  
Defendants-Appellants.

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On Interlocutory Appeal Pursuant to 28 U.S.C. § 1292(b)

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**DECLARATION OF ERIC RIGNOT, PH.D, IN SUPPORT OF  
PLAINTIFFS' URGENT MOTION UNDER CIRCUIT RULE 27-3(b)  
FOR PRELIMINARY INJUNCTION**

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*Attorneys for Plaintiffs-Appellees*

I, Dr. Eric Rignot, hereby declare and if called upon would testify as follows:

1. I have been researching and studying ice sheets and climate change for nearly 30 years. I have spent decades on the ice sheets of Greenland and Antarctica, watching them transform and decay into rivers. I submit this declaration in support of Plaintiffs' Motion for Preliminary Injunction because we have already lost too much of our ice sheets to unstoppable collapse and if the United States does not shift course, we will lose even more.
2. I am currently a Professor of Earth system science at the University of California, Irvine, and the principal scientist for the Radar Science and Engineering Section at NASA's Jet Propulsion Laboratory. The opinions expressed in this declaration are my own, and are not submitted on behalf of, nor intended to reflect the opinion of, any organization with which I am affiliated.
3. I have been retained as an expert on behalf of Plaintiffs in this litigation before the United States District Court for the District of Oregon ("District Court"). I have prepared an expert report for this litigation in my personal capacity, not on behalf of any institution with which I am affiliated ("Expert Report"), which forms part of the record in the District Court (D. Ct. Doc. 267-1). On October 18, 2018, Plaintiffs' counsel served on counsel for Defendants a

corrected version of my Expert Report. A true and correct copy of my Corrected Expert Report is attached hereto as **Exhibit 1**.

#### **Expert Qualifications and Experience**

4. I have authored over 385 publications in the area of glaciology and climate science and given dozens of talks on the subject. My research is highly-cited in the geosciences, with my work being cited over 3,100 times in 2018. I have extensively investigated the interactions of ice and climate, in particular to determine how the ice sheets in Antarctica and Greenland will respond to climate change in the coming century and how they will affect global sea level, using satellite remote sensing techniques (imaging radar, laser altimetry, radio echo sounding), airborne geophysical surveys (icebridge), field surveys (radar, GPS, bathymetry, CTD), and numerical modeling (ice sheet motion, ocean circulation near glaciers, coupled ocean/ice sheet models). I have particular expertise in glaciology, climate change, understanding the interactions of ice and climate, ice sheet mass balance, how ice sheets in Antarctica and Greenland will respond to climate change, satellite remote sensing, ice-ocean interactions, and current/future contributions of ice sheets to sea level change. I have served on many national and international committees, including National Research Council/National Academy of Science committees, panels and/or boards.

5. I have been extensively involved in the Intergovernmental Panel on Climate Change (“IPCC”) scientific assessment activity, with a particular emphasis on cryosphere science. I was a Contributing Author of Chapter 4 and Expert Reviewer of Chapters 5 and 10, WG1, IPCC Fourth Assessment Report, which was attributed the Nobel Peace Prize in 2007. I was a Lead Author of Chapter 4, Cryosphere, IPCC Fifth Assessment Report in 2013. I am currently the Lead Author of the IPCC “Special Report on Ocean and Cryosphere,” Chapter 3. In 2018, I was elected a Member of the National Academy of Sciences. In 2016, I was awarded the Louis Agassiz Medal for the Cryosphere Division of the European Geosciences Union. I was also elected a Fellow of the American Geophysical Union in 2013 and awarded NASA’s Outstanding Leadership Medal in 2012. A true and correct copy of my curriculum vitae is attached hereto at **Exhibit B** to **Exhibit 1**.

**Ice Sheets are Dangerously Disintegrating Due to Fossil Fuel Burning**

6. Ice melt from pole to pole is rising because of past and ongoing human-caused greenhouse gas emissions, which warm the air and the oceans and affect the wind regimes, storm tracks, and ocean circulation around the planet. The increasing surface temperatures melt the ice from above and the warming seas melt the ice from below, where the glaciers touch the sea. Sea levels are rising because of the increasing ice melt on land that discharges into the sea,

primarily from Alaska, Canada, Greenland and Antarctica, but increasingly – and already dominantly - from Greenland and Antarctica.

7. One critical aspect of the process of ice sheet melt is its irreversible character. Irreversible means that it would take centuries to reverse the process and restore the system back to its initial state. We are in a situation where the extra heat from accumulated carbon dioxide (“CO<sub>2</sub>”) concentrations has created a ticking time bomb for the planet’s ice sheets. Some of our ice sheets are already in an unstoppable melt and disintegration. For example, two of Greenland’s largest glaciers are in an irreversible melt. We are currently on a pathway that will almost certainly lead to 3 m sea level rise from Greenland if climate warming continues on its present path. The West Antarctic ice sheet is already in a state of collapse, committing us to 1 m sea level rise from the Amundsen Sea Embayment and possibly 3 m from the rest of the marine based sector of West Antarctica. Thus, between the irreversible melting of portions of Greenland’s and Antarctica’s ice sheets, humanity has already committed itself to a 3-6 m rise in sea level.
8. Enormous irreparable damage has already been done, but there is even greater damage that is still preventable if we act swiftly. The only way to prevent additional ice sheet disintegration is to prevent further buildup of human-caused CO<sub>2</sub> and other greenhouse gases in the atmosphere, and ultimately to

facilitate the drawdown through land-based sequestration of the overaccumulation of CO<sub>2</sub> that is heating the planet. There is only one effective way to stop future planetary heating, and to do it quickly. It is to swiftly transition away from burning fossil fuels and not invest in or continue to support development of these energy sources that are melting our planet's ice.

9. What we do *today* will influence the stability of ice sheets for the next 30-40 years with enormous consequences for the nation's shorelines and marine resources. Presently, we are on course to launch the ice sheets of Greenland and Antarctica into multi-meter sea level rise. While we have passed the point of return for some of these ice sheets, we cannot afford for others, like the East Antarctic Ice Sheet, to follow the same fate. Every month of growing CO<sub>2</sub> accumulation in the atmosphere does more damage to the cryosphere and leads to more sea level rise and more commitment to raise sea level rapidly in decades to come.
10. In a new paper just published in the National Academy of Sciences studying the rate of ice loss from Antarctica's ice sheet, my colleagues and I show that the rate of loss of ice today is six times the rate of loss in the 1980s.<sup>1</sup> There is also evidence today that indicates the East Antarctic Ice Sheet might also be

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<sup>1</sup> E. Rignot, et al. (2019) Four decades of Antarctic Ice Sheet mass balance from 1979-2017, *Proc. Nat. Acad. Sci.* 116(4) 1095-1103, doi: 10.1073/pnas.1812883116.

at risk of destabilization. It was 1998 when we first saw the significant evidence of ice loss in West Antarctica. All the scientific data that we have collected in the past 20 years in this region keeps confirming that the worst scenario of disintegration is taking place before our very eyes. Many international programs are solely focused on this most sensitive part of Antarctica because the international community as a whole has understood the major significance of the evolution of this part of our planet. Our study reveals that East Antarctica ice and its multi-meter sea level rise potential is getting ready to be added to the growing list of collapsing ice sheets if we allow it to unravel by further delaying the necessary transition off of fossil fuels.

11. Perspective is important. When we are measuring changes on the ice sheets from week to week or even year to year, the changes might not seem as profound, but looking at the transition of these giant ice sheets since the 1980s is overwhelming from both a scientific and human perspective. It is like a doctor watching a patient over a period of time and seeing them gradually dying. It is also akin to a parent watching their children grow up. If you watch them every day, you may not see the changes, but the growth is profound in a single decade from birth to ten.
12. The challenge for the human mind is to accept that what we do at this moment will have enormous consequences for decades to come, and well into the latter

part of the century due to the long life of CO<sub>2</sub> and the longevity of heat in the vast oceans. I cannot say with scientific certainty that we can stop multi-meter sea level rise over the course of the century because we have already dangerously pushed some of the ice shelves over the edge and they will unequivocally melt. However, I can say with certainty that if emissions do not steeply decline forthwith, we will lose the opportunity to protect even more of these giant ice sheets from collapse. We are running out of time. There is no other way to express this.

13. In order to protect children from losing their sea level homes, and from living with the fear of that coming tragedy, and to protect entire coastal regions of the United States from becoming part of the sea, we need to bring our ice sheets back to the way they were in the 1980s or before. We must cool back the planet and our oceans.
14. I also wish to correct a misunderstanding that the international community created in adopting the Paris agreement. That agreement yielded an idea that we could allow our planet to warm by up to 1.5 degrees Celsius and that would be acceptable. We cannot protect the integrity of the ice sheets and stop multi-meter sea level rise if we allow continued warming above present levels. Already, at just over 1 degree Celsius of warming, we are losing massive amounts of the planet's cryosphere. And yet, it is as if there is a fire burning



in a room of the house, and rather than getting a fire hose to put out the fire, tinder is being added to stoke the fire, until the house, the village, and the surrounding cities burn.

15. From the time scientists diagnosed that CFCs were damaging the ozone layer and scientists verified the ozone hole through observations and measurements, it took approximately twelve years from the scientific discovery to implement the solution to stop ozone destruction. Through model simulations today, NASA has shown that if governments had not responded to the threat of CFCs, by the year 2050, the world could have become unlivable in a safe condition for humans because of the expansion of the ozone hole, which would have led to a pandemic of skin cancer. At the time of the ozone hole threat, there were not yet measurable impacts on humans, but people paid attention to the science of a long-term threat posing enormous human health risks that needed to be promptly addressed. We are well beyond that point with climate change. The diagnosable problem occurred over 100 years ago, verified again and again by scientists and governments around the world. By 1965, the scientific evidence warranted an entire chapter in a White House report on CO<sub>2</sub> pollution.<sup>2</sup> Today, humans, including these plaintiffs, are experiencing the

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<sup>2</sup> The White House, Restoring the Quality of Our Environment: Report of the Environmental Pollution Panel of the President's Science Advisory Committee, November 1965.

harsh effects of climate change and we are on course for catastrophic sea level rise, among other environmental catastrophes that include widespread forest dieback, extreme drought and heat waves, stronger hurricanes, more frequent and severe wildfires, enhanced air pollution, extreme floods and massive loss of biodiversity, and yet we keep stoking that fire and not heeding the overwhelming amount of science that has said for almost a century that we are on a deadly course for humanity and for life as we know it on the planet.

16. A short injunction on new fossil fuel extraction and infrastructure to allow this case to be heard is minimally necessary to give these plaintiffs a chance to seek their remedy in this case without locking in even more ice melt.

I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct. Executed on February 6, 2019.

Respectfully submitted,



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Eric Rignot, Ph.D

# **Exhibit 1**

**CORRECTED EXPERT REPORT  
OF  
ERIC RIGNOT, Ph.D.**

Kelsey Cascadia Rose Juliana; Xiuhtezcatl Tonatiuh M.,  
through his Guardian Tamara Roske-Martinez; et al.,  
Plaintiffs,

v.

The United States of America; Donald Trump,  
in his official capacity as President of the United States; et al.,  
Defendants.

IN THE UNITED STATES DISTRICT COURT  
DISTRICT OF OREGON

(Case No.: 6:15-cv-01517-TC)

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## **TABLE OF CONTENTS**

Table of Contents.....	ii
Table of Acronyms and Abbreviations.....	iii
Introduction .....	1
Executive Summary .....	1
Qualifications and Compensation.....	2
Expert Opinion .....	3
A. The Interactions Between Climate and Ice .....	3
B. Greenland Ice Sheet Loss and Contribution to Sea Level Rise.....	5
C. Antarctica Ice Sheet Loss and Contribution to Sea Level Rise.....	8
D. Alaska and Canada Glaciers.....	11
E. Iceland Glaciers .....	12
F. Patagonia Glaciers .....	12
G. Glacier National Park.....	13
H. Sea Ice.....	14
I. Points of No Return .....	15
J. What must be done to protect our climate and our ice?.....	16
Conclusion and Recommendations.....	18

**TABLE OF ACRONYMS AND ABBREVIATIONS**

BAU:	business as usual
C:	Celsius
CARB:	California Air Resources Board
CDW:	circumpolar deep water
CO <sub>2</sub> :	carbon dioxide
EIS:	Extreme Ice Survey
GHG:	greenhouse gas
GPR:	ground penetrating radar
GPS:	global positioning system
IPCC:	Intergovernmental Panel on Climate Change
IPCC AR4:	Intergovernmental Panel on Climate Change Fourth Assessment Report
IPCC AR5:	Intergovernmental Panel on Climate Change Fifth Assessment Report
JKS:	Jakobshavn Glacier
JPL/UCI:	Jet Propulsion Laboratory/University of California, Irvine
NASA:	National Aeronautics and Space Administration
NO <sub>2</sub> :	nitrogen dioxide
ppm:	parts per million
SLR:	sea level rise
USGS:	United States Geological Survey

## **INTRODUCTION**

I, Eric Rignot, have been retained by Plaintiffs in the above-captioned matter to provide expert testimony regarding how human-caused CO<sub>2</sub> emissions are affecting the interactions between climate and ice, which are causing some of the injuries and constitutional violations alleged in the Complaint in this case. I discuss how human-caused CO<sub>2</sub> emissions, and other greenhouse gas emissions, are warming both the surface temperature of the earth and the oceans and causing dangerous ice melt. The planet's major ice sheets and glaciers around the world are in significant decline, sending significant amounts of water into our oceans, thereby causing the seas to rise. I discuss the status of several important glaciers and give my opinion on the kind of collapse of our ice sheets and glaciers we can expect in the future and what must be done to slow it and eventually stop it.

## **EXECUTIVE SUMMARY**

Ice melt from pole to pole is rising because of past and ongoing human-caused greenhouse gas emissions, which warm the air and the oceans.

The increasing surface temperatures melt the ice from above and the warming seas melt the ice from below, where the glaciers touch the sea. Sea levels are rising because of the increasing ice melt on land that discharges to the sea, primarily from Alaska, Canada, Greenland and Antarctica, but increasingly – and already dominantly – from Greenland and Antarctica.

Glaciers that do not drain to the sea are also diminishing globally, which impacts freshwater security, ecosystems and iconic landscapes in places like Alaska and Glacier National Park.

Already, we are seeing dangerous levels of ice melt and the resulting sea level rise is larger, more rapid, and taking place sooner than expected by climate models.

One critical aspect of the process of ice sheet melt is its irreversible character. Irreversible means that it would take centuries to reverse the process and restore the system back to its initial state.

Projections for sea level rise are 1-2 meters by the end of the century. Regardless of which projections turn out to be correct, all projections have catastrophic consequences.

Two of Greenland's largest glaciers are in an irreversible melt. We are currently on a pathway that will almost certainly lead to 3 m sea level rise from Greenland if climate warming continues.

Numerous scientists also agree that the West Antarctic ice sheet is already in a state of collapse, committing us to 1 m sea level rise from the Amundsen Sea Embayment and possibly 3 m from the rest of the marine based sector of West Antarctica. Thus, between the irreversible melting of portions of Greenland's and Antarctica's ice sheets, humanity has already committed itself to a 3-6 m rise in sea level.

It is not clear how much of this sea level rise can be avoided by slowing down climate warming or even cooling the planet again. However, it is clear that unabated climate warming will melt the ice faster than humanity can handle.

Some of the most adverse effects of land ice melt and sea level rise may be avoided by swift action and a transition to declining GHG concentrations, with the effect that a return to a colder climate will slow down glacier and ice sheet disintegration and save them for the benefit and security of young people living today and future generations.

In my opinion, any additional climate pollution and warming in the system, which will further increase temperatures from what they are today, is catastrophic.

Because warming is not equally distributed across the globe, a 2 degree C average warming across the globe implies a 4 to 6 degrees C warming in the Arctic. This means seasonal sea ice cover will be gone, Greenland ice sheet will melt almost completely and all Antarctic ice shelves will break up and disappear, entraining rapid speed up of the glaciers and multiple meter of sea level rise per century.

We need to drop carbon concentration in the atmosphere back to the pre-industrial era level of ~280 ppm to slow down the retreat and decay of ice sheets. Ice sheets in Antarctica and Greenland were stable in that climate. As an interim step to returning to preindustrial CO<sub>2</sub> concentrations, we should at minimum aim to return to no more than 350 ppm by 2100 (Hansen 2013).

### **QUALIFICATIONS AND COMPENSATION**

The opinions expressed in this report are my own, and do not reflect the opinion of any organization I am affiliated with. All opinions expressed herein are based on the data and facts available to me at the time of writing and available publicly. All opinions expressed herein are to a reasonable degree of scientific certainty, unless otherwise specifically stated. Should additional relevant or pertinent information become available, I reserve the right to supplement the discussion and findings in this expert report in this action.

A statement of my qualifications is contained in **Exhibit A** to my expert report in this action. My full CV is attached as **Exhibit B** to my report. A list of publications I authored within the last ten years is attached as **Exhibit C** to my expert report. My report contains a list of citations to the documents that I have used or considered in forming my opinions, listed in **Exhibit D**. I also attach visual and video exhibits to be used in summary of, in support of, or to visually illustrate my opinions with this report, as **Exhibits E-Q**. **Exhibit R** is a spreadsheet providing the precise data and information about each of the **Exhibits E-Q**.

In preparing my expert report and testifying at trial, I am not receiving any compensation and am providing my expertise pro bono to the Plaintiffs.



## **EXPERT OPINION**

### **A. The Interactions Between Climate and Ice**

Human-caused CO<sub>2</sub> emissions, and other greenhouse gas emissions, are affecting the interactions between climate and ice, which are causing some of the injuries and constitutional violations alleged in the First Amended Complaint in this case.

Based on simple physics, ice sheet disintegration is a signature harm of CO<sub>2</sub> emissions and global surface and ocean warming (IPCC AR5, 2013). Air temperature is rising primarily as a result of historic and ongoing fossil fuel emissions, and from other sources of human-caused greenhouse gas emissions, such as deforestation and animal agriculture, which amplify the natural greenhouse effect. Ocean temperature is also rising as a result of these emissions because over 90 percent of the extra heat in the atmosphere is absorbed by the ocean. Ice melt is increasing because the sources of greenhouse gas emissions continue to grow and warm the air and the oceans. Sea level rise is increasing because of the increasing land ice melt. The underlying physics to explain this cycle of greenhouse gas emissions causing warming, ice melt, and sea level rise goes back to scientist Svante Arrhenius' work in the late 1800s (Baum and Rudy, 2016), which established the greenhouse effect, and is scientifically undisputable (IPCC AR5, 2013).

The ice sheets and glaciers in Greenland and Antarctica, along with the glaciers and ice caps around the world, are melting away into the oceans faster than they did throughout the Holocene before the industrial revolution, hence contributing to rising sea level worldwide at 3 mm/yr now versus 1.8 mm/yr at the beginning of the century (Church and White, 2011). The ice sheets melt from the top and from below. At the top, ice sheets melt at the surface from warmer air temperature, a decreasing surface albedo (melted white snow is replaced by darker ice, ice absorbs 3-4 times more solar radiation than snow, and melts faster), and a decreasing elevation (as ice melts its surface elevation drops, exposing it to warmer temperatures, which further accelerates melting) (IPCC AR5, 2013). At the base, the ice sheets and glaciers meet with the ocean waters along the margin, melt vigorously into the salty, warm ocean waters, and this melting increases as the oceans get warmer. The ocean circulation at the ice front (where the ice and ocean waters meet), which is responsible for ice melt, is also enhanced by more melt water production from the ice sheet surface, which fuels a more vigorous circulation of waters along the calving faces of glaciers, further exacerbating the melting of the calving faces into the ocean (Xu et al., 2013; Straneo and Heimbach, 2014).

The effect of fossil fuel and other greenhouse gas emissions is exacerbated in the Arctic because the reduction in sea ice cover, which amounts to 3% in surface area per decade, enables the ocean to absorb more heat from the atmosphere (decrease in albedo) and reduces seasonal snow cover on land that increases the absorption of atmospheric heat by land. The Arctic is therefore warming at 2-3 times the global average, as predicted by climate models (IPCC AR5 2013).

In the Antarctic, the albedo effect does not operate the same way because the snow cover has not been changing at a significant level and the sea ice cover has not been decreasing. However, the combination of ozone depletion (which cools the stratosphere) and the rapid warming of the rest

of the world from greenhouse gas emissions has resulted in stronger westerly winds around Antarctica. The stronger westerly winds contract toward the south pole (Mayewski et al., 2013; Spence et al., 2014; Abram et al., 2014)), pushing the surface waters to the north (this is called “Ekman transport”) and compensation for that surface motion tends to push warmer, saltier subsurface waters toward the Antarctic continent. The warm, salty subsurface waters (which are commonly referred to as “circumpolar deep water (CDW)” or modified CDW) melt the glaciers from below, at rates several orders of magnitude greater than the exchange of mass at the surface with the atmosphere (accumulation of snowfall), de-stabilizing the glaciers, allowing them to speed up their melting into the ocean and thereby raising sea level (Rignot et al., 2013; Alley et al., 2015).

The contribution of ice sheets to sea level rise is larger, more rapid, and taking place sooner than expected by climate models, including those used by the Intergovernmental Panel on Climate Change (IPCC AR5 2013), in part because the coupling between the different components of the climate system (ocean, land, atmosphere and cryosphere) involves positive feedbacks that enhance ice-climate interaction, and in part because the rate of climate warming is unprecedented in the last 10,000 years. At the current rate of melt and annual increase in melt based on business as usual projected emissions, the ice sheets will raise sea level by more than one meter - or three feet - by the end of the century. Most likely, however, this amount of sea level rise is a minimum (best case scenario under business as usual emission projections) because as climate warming continues unabated, the response of ice sheets to climate forcing will become stronger with time based on the physics of ice flow and ice fracturing (DeConto and Pollard, 2016). Some studies have placed an upper bound for sea level rise by the end of the century at two meters or six feet based on the maximum rate of increase in ice flow of the glaciers over a period of a few decades (Pfeffer et al. 2008; De Conto and Pollard, 2016), with most of that sea level rise taking place in the second part of the century. Other studies show that, based on the paleoclimate record, an exponential melting response could raise sea level several meters within 50, 100, or 200 years depending upon how fast the doubling time is (Hansen et al. 2016). We can say with certainty that under any business as usual scenario, the outcome will be catastrophic for coastal cities and people around the world. The only variance in projections is how quickly the catastrophic sea level rise occurs, not whether it occurs.

The melting of ice sheets as a result of human-induced climate warming is not a projection or a future scenario, it is happening today, at rates that exceed all prior expectations, because the planet is warming rapidly and because both the atmosphere and the ocean contribute to the melting of land ice. New scientific research and understanding shows us that the role of the oceans in causing ice sheet disintegration has been underestimated by scientists and by prior IPCC assessments (IPCC AR5 2013). It is important to also understand that one reason the IPCC assessments underestimate projected impacts is that the reports are a consensus summary of scientific understanding in existence approximately two years prior to the assessments being released. Thus, by the time the IPCC assessments are publicly released, they are already out of date on many climate science issues.

One critical aspect of the process of ice sheet melt is its irreversible character. Irreversible means that it would take centuries to reverse the process and restore the system back to its initial state, e.g. the state of the climate at the beginning of the industrial age. Glaciers that have been de-

stabilized and started to retreat on a reverse bed, i.e. a bed that is getting deeper inland, undergo an unstoppable retreat. Once the retreat is complete and assuming that the climate is able to return to colder conditions, it would take centuries for the glaciers to slowly re-advance to their former positions. The marine-instability theory dates from the 1970s. It predicts that glaciers retreating on reverse slope cannot be stopped unless the glacier fronts reach a new, stabilizing bump in bed topography upstream; if there is no stabilizing bump, they melt completely and rapidly (Weertman, 1974; Thomas and Bentley, 1978). This theory has been verified with the rapid retreat of tidewater glaciers in the state of Alaska (Post et al., 2011) and confirmed with the rapid retreat of glaciers in Greenland and West Antarctica (Rignot et al., 2014; Joughin et al 2014; Favier et al. 2014). There is no exception to this rule.

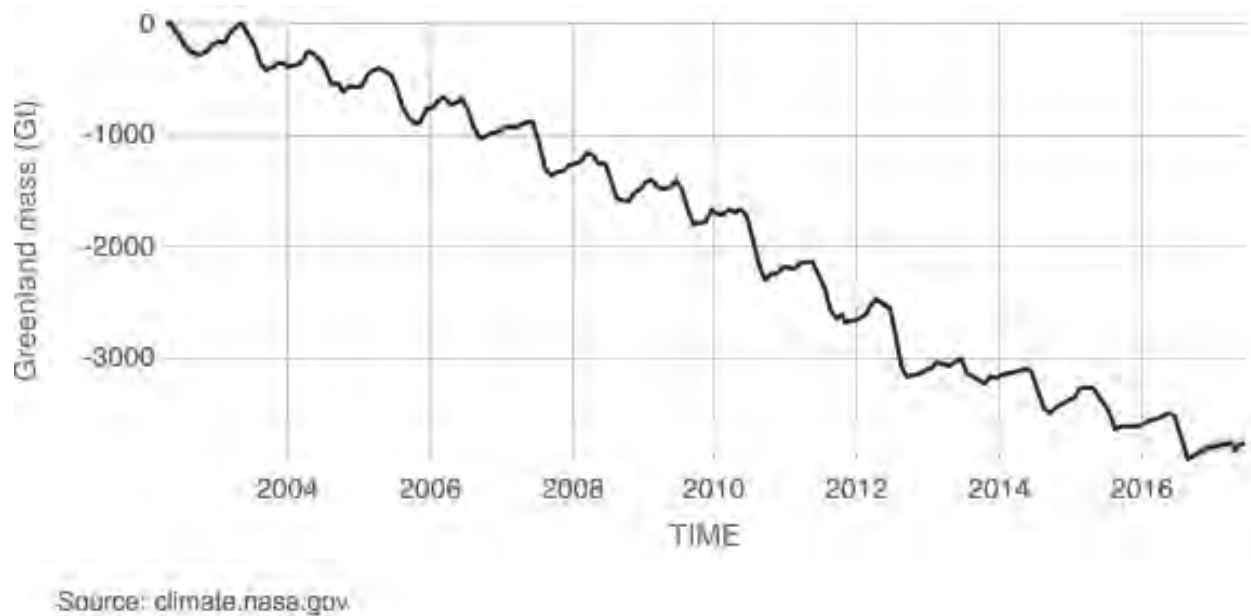
However, there is some positive news. As glaciers retreat through series of reverse (rapid retreat) and normal (slowed retreat) bed topography, recent research has shown that the speed of retreat is modulated by the temperature of the ocean (Dutrieux et al., 2014). A warmer ocean speeds up the retreat; a colder ocean slows it down. At present, the ocean is warming up. A return to colder ocean conditions could, in principle, slow down glacial retreat, which means that some of the most devastating effects of land ice melt and sea level rise could be mitigated if proper action is taken.

Thus, the ice sheet losses I discuss below should be considered irreversible if emissions of GHG continue and if we are not able to sequester enough atmospheric carbon back into the ground. Some of the most adverse effects of land ice melt and sea level rise may be avoided by swift action and a transition to declining GHG concentrations, with the effect that a return to a colder climate will slow down glacier and ice sheet disintegration and save them for the benefit and security of young people living today and future generations.

## **B. Greenland Ice Sheet Loss and Contribution to Sea Level Rise**

At present, the Greenland ice sheet is melting two times faster than it should to maintain its total mass in a state of equilibrium (Rignot et al., 2011). Overall, the mass loss is small compared to the total storage of ice in Greenland. On a human scale, however, the ice sheet is losing the equivalent of the annual consumption of water from 300 cities like Los Angeles to the ocean every year. The mass loss is therefore considerable and affects the entire coastline of Greenland.

The mass loss has been markedly increasing with time since the early 1990s. Greenland experienced a period of loss in the 1930-1940s as well (Bjork et al. 2012), but the melting signal recorded since the 1990s is unprecedented in the last few centuries. Two-thirds of the mass loss of Greenland's ice sheet is caused by increased surface melt from warmer air temperature; one-third is caused by the acceleration of its glaciers that have been de-stabilized by the presence of warmer-than-average ocean waters along the margins (van den Broeke et al., 2009). Over the past 36 years, the mass loss of the Greenland ice sheet has been increasing almost linearly with time and there is no statistically significant indication that this trend will stop or slow in the future. If anything, its mass loss is more likely to increase than decrease, meaning we expect the mass loss to progress exponentially (Hansen et al., 2016; Christoffersen et al., 2018).



**Figure 1:** Data collected by NASA satellites show the steady decline in Greenland ice mass since 2002

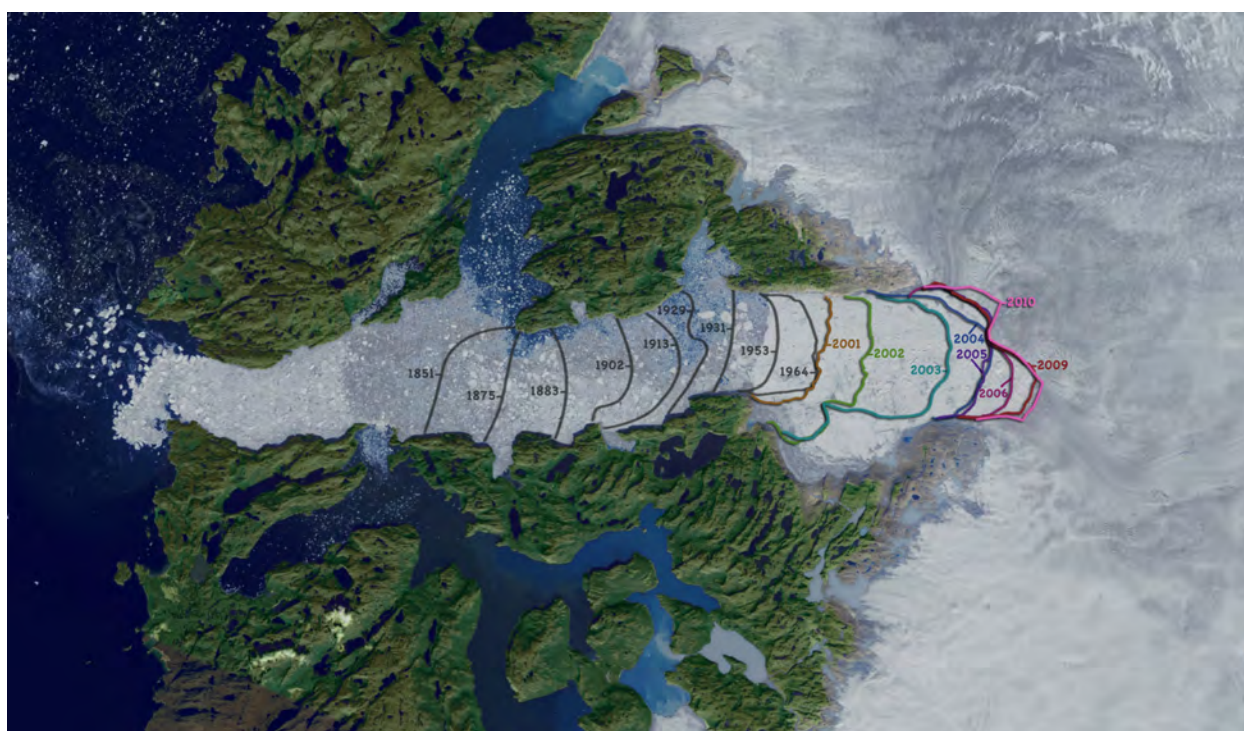
2017 was second only to 2016 in terms of elevated surface temperature in the latitudes north of 60° N since records began in 1900 (Richter-Menge et al., 2017). As climate continues to warm up the Arctic, snow/ice melt will increase because of the albedo feedback (replacing white snow with dark ice and snow-covered sea ice with dark ocean waters) and the drop in elevation of the ice surface (hence exposing it to higher air temperature). Records from the Eemian period, 25,000 years ago, when the Earth was about one to two degrees Celsius above pre-industrial levels, indicate that sea level was six to nine meters above present. A large fraction of Greenland melted away (Dutton et al., 2015).

Observational evidence is unequivocal that climate warming has had a devastating impact on the ice sheets in the polar regions (IPCC AR5 2013). The effect is already felt across the entire Greenland Ice Sheet, including its far north corners where ice shelves (floating extensions of glaciers into the ocean waters) are retreating at an alarming rate (0.5 to 1 km/yr) (Mouginot et al., 2015). Greenland currently holds an ice volume equivalent to seven meters of sea level rise. The most vulnerable sectors of Greenland, which are marine based, i.e. ice is resting on a bed below sea level so the glaciers will remain in contact with the ocean waters for the entire duration of their retreat, hold a sea level equivalent of three meters. We are currently on a pathway that will almost certainly lead to 3 m sea level rise from Greenland if climate warming continues BAU.

We have a very detailed understanding and observational record of the glaciers for the past 40 years and beyond. We have detailed and precise reconstructions of the accumulation of snowfall and the melting of snow/ice from the top dating back to 1958 and beyond. We have a detailed understanding of the glaciers at risk, i.e. glaciers that are grounded below sea level and which drain a basin that is mostly below sea level.



Not all ice will melt easily, but many Greenland glaciers have already been significantly affected by climate warming. At present, about 2/3 of the loss is caused by melting snow/ice from the top; and 1/3 is from melting of ice in contact with the ocean or breaking up into the ocean. Ice resting on land above sea level will take longer to melt because it will only be affected by air temperature. Ice resting on a bed below sea level will melt from both the top and below (by the ocean) and break up into the ocean to form icebergs (no iceberg forms on land terminating glaciers). Thus, ice resting on a bed below sea level will melt considerably faster than ice resting on land. Ice resting on a marine bed could be responsible for a three-meter global sea level rise from Greenland. The three-meter sea level rise is controlled by three major glacier systems named: Petermann, Zachariae and Jakobshavn (also called Ilulissat). At present, two of these glaciers have been de-stabilized by climate warming and are raising sea level; the third one has lost 1/3 of its floating ice shelf for the first time since 1900 (Mouginot et al., 2015).



**Figure 2:** *Glacial retreat of Jakobshavn Glacier in Greenland. Photo credit: NASA*

Ilulissat Glacier, or Jakobshavn Glacier (JKS), in central West Greenland is the largest discharger of ice in Greenland. JKS controls about 6 percent of the total ice volume in Greenland. If all ice from that glacier were to melt away, it would raise sea level by 0.6 m (An et al., 2017). This glacier is also the fastest moving glacier on the face of the earth, reaching peak speeds of 18 km/yr in 2012 during a particularly warm summer, or 50 m/d or 164 feet per day. The calving front moves at 13 km/yr. The glacier is retreating at 0.5 km/yr into one of the deepest fjords in Greenland, more than 1,600 m below sea level. The glacier is discharging 44 billion tons of water into the ocean every year. The glacier used to develop a floating ice tongue that had been slowly retreating the end of the little ice age in 1850. Since about the year 2000, the retreat accelerated considerably, and the floating ice tongue collapsed in 2002, triggering a tripling of the glacier speed (Joughin et al., 2014). For a while, the glacier thinned at a record rate

of 50 m/yr. Since then, however, it has been noted that the glacier retreat rate has remained steady at 0.5 km/yr. The glacier calves giant icebergs (more than 800 m in height, several km in width and 1-2 km in length) that send tremors or icequakes that can be recorded on the four corners of the world. The bergs get stranded in the fjord because of a shallow shoal at the fjord entrance, making the fjord impossible to navigate. In the time-lapse series of **Exhibit H**, we witness the tremendous size of the glacier (the height of the cliff is nearly 100 m above the sea in some places; the glacier is 20 km wide), its speed (a river of ice), the rapidly retreating front which required the camera to be adjusted every few years, and its retreat pathway down a deep canyon (visible as an over-deepening of the glacier surface).

**Exhibit N** is a time-lapse series by NASA showing the seasonal melting that is occurring on Greenland's glaciers by aerial imaging. The Zachariae Isstrom Glacier, depicted in the video, began undergoing fast changes in the early 1990s, but the changes accelerated rapidly in the past five years. It broke free from its stable glacial position in 2012 and has been on an accelerating retreat. It drains about 5 percent of Greenland's Ice Sheet. The blue pockets of color within the white are the melt ponds that form during the melt season. As they grow, they can cause further ice sheet disintegration by opening cracks in the underlying ice, which drain to the base, and by lubricating the glacier's flow. **Exhibit Q** is a video clip from the film "Before the Flood," which illustrates the scale of the melting that is occurring in Greenland, and the rivers that have formed in the glaciers.

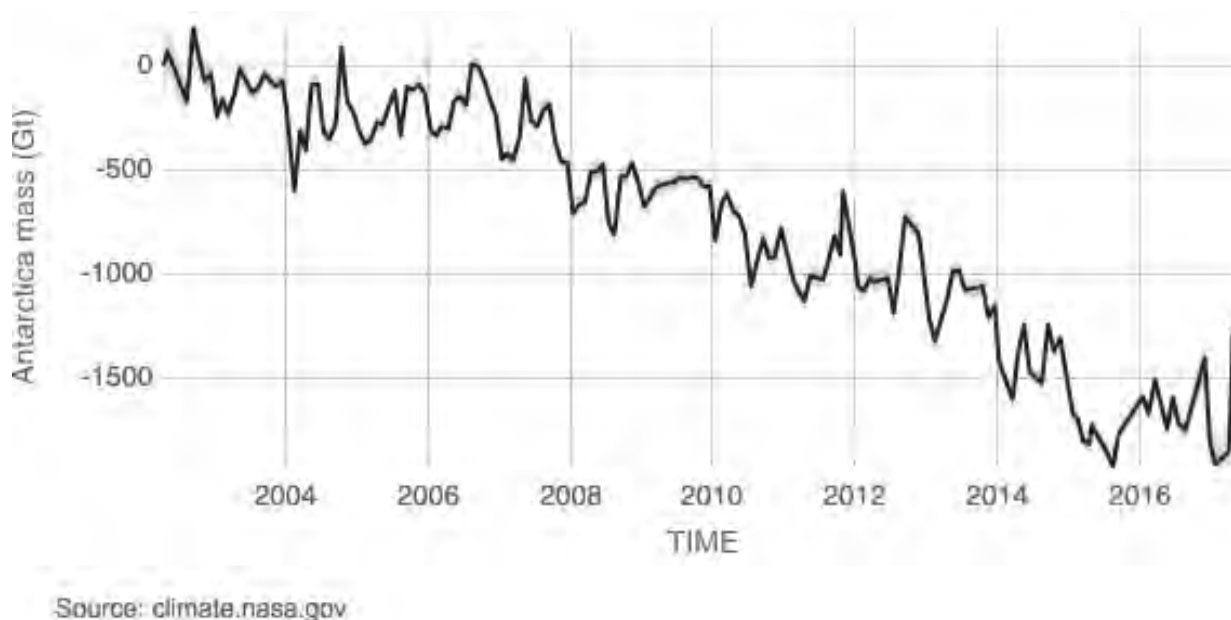
We do not know how to stop the process of decay. We do know that unabated climate warming will accelerate the collapse of these glaciers.

### **C. Antarctica Ice Sheet Loss and Contribution to Sea Level Rise**

In Antarctica, compared to Greenland ice sheets, the mass loss is a smaller fraction of the annual turnover of mass of the continent, but because the continent is seven times larger than Greenland, its net contribution to sea level rise is almost as large as Greenland's. Surface melt is limited at present in Antarctica to the melting of relatively small areas of blue ice (Kingslake et al., 2016). Thus, nearly all the mass loss is caused by the acceleration of glaciers that have been destabilized by the presence of warm, salty waters along the ice sheet margins. In select regions, such as the Antarctic Peninsula and West Antarctica, warmer air temperatures have contributed to the collapse of ice shelves, or floating extensions of glaciers into the sea. The loss of ice shelves, analog to the loss of a plug in front of the glaciers, reduces resistance to flow of the glaciers and enables the acceleration of their disintegration and thus the discharge of larger quantities of ice into the Southern Ocean than in the past, hence raising sea levels. The collapse of ice shelves in the Antarctic Peninsula in the 1990s and 2000s has shown examples of glacier speeding up by a factor three to eight (Wuite et al., 2015).

In Antarctica, the ice sheets have an ice volume equivalent to a 57 m sea level rise. Portions of the Antarctic ice sheets are grounded below sea level and are more likely to break up and melt away easily. These regions hold a sea level rise equivalent of 19 m (Fretwell et al., 2013). Out of these, 3 m would come from West Antarctica, which is low lying and exposed to warmer, saltier waters; and 16 m would come from East Antarctica which rests on higher ground and is less exposed to warm waters. In West Antarctica, modern, detailed observations going back more

than 40 years suggest that the glaciers draining into the Amundsen Sea Embayment have been de-stabilized by warm, salty ocean waters pushed by stronger winds. These glaciers are retreating at the fastest rates recorded on the planet (even faster than glaciers of Greenland or Alaska) and hold a sea level equivalent of one meter. How fast sea level will rise by one meter is not known with certainty at present, but the time scales are measured in less than two centuries. One numerical model has suggested that the one-meter rise in sea level from melting Amundsen Sea Embayment glaciers alone could occur within the next one-hundred years (De Conto and Pollard, 2016).



**Figure 3:** Data collected by NASA satellites show the steady decline in Antarctic ice mass since 2002

One example of the irreversible character of ice sheet melt is the collapse of ice shelves in the Antarctic Peninsula. Larsen B ice shelf collapsed in 2002 following years of slow retreat and thinning. If we were to re-create the ice shelf by stabilizing atmospheric CO<sub>2</sub> concentrations and global temperatures at preindustrial levels, allowing glacier ice to float again in the ocean and slowly spread out, it would take approximately 500 years to re-form that ice shelf. This ice shelf had been stable for at least 10,000 years. Its recent collapse is unique in human history. The glaciers that were buttressed by this ice shelf sped up after the collapse, similar to a water bottle being uncorked. The glaciers sped up by a factor 3 to 8, one order of magnitude, and they were still flowing 2 to 5 times faster in 2017 than in the 1990s. If all the glaciers around Antarctica were to speed up by a factor 7, we would raise sea level 4 m per century. A rate of sea level rise of 4 m per century would have catastrophic consequences for coastal populations worldwide and redefine the world geography as we know it. This rate of global sea level rise happened about 14,000 years ago, when the large ice sheets in the northern hemisphere and parts of Antarctica melted rapidly. This rate of sea level rise has been imprinted in coral reef records around the world and is undisputable (Cronin, 2012). The differences between 14,000 years ago and today are the human causes of the melting and the short time frame in which humans have heated the planet.

The glaciers upstream of Larsen B only hold a 4 mm global sea level rise. Larsen C Ice Shelf farther south is slowly collapsing as well, as publicized in the spring of 2017 with the calving of the largest iceberg on record (5,500 square km or the size of the state of Rhode Island). Larsen C holds a 1 cm global sea level rise. A 4 mm or 1 cm rise in sea level is impactful to some coastal communities, but does not pose the same level of danger that the combined melting of the world's ice sheets does. These events illustrate what will happen as climate warming hits ice shelves and glaciers farther south. The collapse of ice shelves will unleash bigger and bigger glaciers holding larger and larger contributions to sea level. For instance, the George VI Ice Shelf, in the Antarctic Peninsula, which will be the next one to go, holds glaciers with a 28-cm sea level rise equivalent. Farther south, ice shelves hold glaciers with meter to multiple meter sea level rise equivalent. Even a one meter sea level rise will have devastating consequence on coastal populations, with the worst consequences to poor regions and on islands, places where there is nowhere else to go and where humans cannot easily adapt to changing coastlines and submerged islands.

Newly published research (2018) provides more detailed analysis of the thinning and disintegration of Antarctica's ice shelves, which cause upstream acceleration of grounded ice, thereby raising sea levels. The research shows that localized ice-shelf thinning from warm ocean water intrusion reaches across ice shelves and accelerates the glacier flow (Reese, et al. 2018). Recent calculations from satellite altimeter observations show that the grounding lines of Antarctic glaciers are retreating due to warmer ocean water, with a loss of 1,463 square km of grounded-ice area between 2010 and 2016 (Konrad, et al. 2018). The grounding zone is where ice transitions from ice over ground to freely floating ice shelves. As the grounding line moves, exposing more ice to warm ocean waters, ice sheet disintegration accelerates.<sup>1</sup> The rapidity with which ice sheet disintegration could occur from these processes is measured in centuries or less, consistent with the paleorecord of sea level rising in pulses (Dominguez and Wanless, 1991; Gelsanliter, 1996; Gelsanliter and Wanless, 1995). The changes we see now in parts of Antarctica are several times higher than the historical average (Konrad, et al. 2018).

Observational evidence is unequivocal that climate warming has had a devastating impact on the ice sheets in the polar regions, particularly the most vulnerable parts of West Antarctica. As climate warming continues unabated, larger sectors of Antarctica will be affected, unleashing larger amounts of ice into the ocean, and increasing sea level rise at ever increasing rates. It has been well established that floating ice shelves reach a limit of viability above a certain air temperature (Morris and Vaughan, 2013). In Antarctica, if climate warming exceeds 4 to 5 degrees C, all ice shelves will disappear and the world will be in a situation where sea level could rise as fast as 4 m per century if the glaciers speed up by a factor 7 as in the Antarctic Peninsula. Even with lower levels of climate warming, disasters are becoming harder to avoid. At present, numerous scientists agree that the West Antarctic ice sheet is already in a state of collapse, committing ourselves to 1 m sea level rise from the Amundsen Sea Embayment and possibly 3 m from the rest of the marine based sector of West Antarctica. I am one of the

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<sup>1</sup> The animation in this video from Konrad, et al. 2018 depicts this process.  
[https://www.youtube.com/watch?v=R4U\\_fetxb6A&feature=youtu.be](https://www.youtube.com/watch?v=R4U_fetxb6A&feature=youtu.be)



scientists who came to this conclusion, after 20 years of research in that part of Antarctica and made it public in May 2014 in a NASA press conference. It is uncertain whether a quick pathway to decarbonization of the energy system and additional carbon sequestration could stop this collapse, which under present circumstances appears irreversible.

**Exhibit M** is a video animation explaining the changes occurring on the West Antarctic Ice Sheet that flows into the Amundsen Sea Embayment, which I prepared, and narrated, for NASA. **Exhibit O** shows changes in the ice sheet positions in Wordie Bay, Antarctica between 1989 and 2009. **Exhibit P** is a video animation prepared by NASA showing changes in the Antarctic ice sheet between 2002 and 2016 as measured by NASA Goddard Space Flight Center's GRACE Observations. NASA measured that Antarctica shed approximately 125 gigatons of ice per year, causing global sea level to rise by 0.35 millimeters per year.

#### **D. Alaska and Canada Glaciers**

Just as the ice sheets and glaciers of Antarctica and Greenland are raising the seas, the melting glaciers in Alaska and Canada are major contributors to sea level rise. This melting is a direct result of warming surface temperatures. Glaciers ending on land are affected by air temperatures while glaciers ending in the ocean are affected by both air and ocean temperatures. Alaska (Larsen et al., 2015) and Canada (Millan et al. 2017) illustrate what Greenland and Antarctica will look like in a warmer world. Few of these glaciers reach the ocean at present, but most are melting at rapid rates.

The melting of all mountain glaciers and ice caps worldwide would raise sea level by about 0.5 m or 2 feet (IPCC AR5 2013). These glaciers are an important participant to present-day sea level rise. Their contribution to sea level rise today is almost as large as that of Greenland and Antarctic combined. However, in the future, we expect the ice sheets to be the largest contributors. A 0.5 m SLR is already a major contribution to SLR. The melting of glaciers and ice caps will have other direct consequences on human systems as well. Many of these glaciers regulate freshwater supply to local populations. A change in the water supply from glaciers and the eventual disappearance of these glaciers is a great source of concern for these populations. If BAU continues, these populations will have less time to adapt to this situation.

Glaciers in Alaska are retreating at an alarming rate, losing mass at a rate of 58 billion tons per year since 2002 and the mass loss increases every year by 9 billion tons (Ciraci et al., 2017). For comparison, the glaciers in Patagonia have been losing 33 billion tons per year since 2002. Every year the mass loss increases by 8 billion tons per year. In the Canadian Archipelago, the mass loss averages 73 billion tons per year and increases by another 9 billion tons per year every year. In High Mountain Asia, the mass loss averages 17 billion tons per year and increases by 9 billion tons per year every year (Ciraci et al., 2017).

Mendenhall Glacier in southeast Alaska, near Juneau, retreated more than 1,830 feet – or a third of a mile – in eight years. The glacier went from flowing across Mendenhall Lake to edging it on one side. The glacier is visited by 500,000 people per year. They now have to travel farther to see the glacier. They also have to face the dangers of the lake level rising above the dam, creating burst floods that inundate the nearby areas and cause tremors equivalent to an

earthquake. **Exhibit F** is an accurate time-lapse series of the retreat of the Mendenhall Glacier from 2008 to 2016, prepared from the Extreme Ice Survey time series photographs. This melting trend is ongoing.

One of the few remaining tidewater glaciers (ending in the ocean) in Alaska is Columbia glacier, in south central Alaska, which started an unstoppable retreat in the 1980s as warm, salty, ocean waters eroded its ice front, dislodging the glacier front from a sill that stabilized it for at least two centuries (Vancouver, 1798) and triggering a retreat on a reverse bed (Meier et al., 1994). The glacier has been retreating at 0.5 km/yr, increased its ice front speed four fold, retreating 12 km in 25 years, and thinning at a rate of 20 m/yr near the ice front. Columbia Glacier is projected to continue retreating for decades to come along the marine-based portion of its drainage basin, for at least another 50 km. In the EIS time-lapse series in **Exhibit G**, we see that the retreat of Columbia Glacier is so rapid that the camera position was adjusted over the time of the photo series in order to keep track of the retreating ice front. **Exhibit I** shows the still image of the Columbia Glacier's retreat from 2009 to 2015. This retreat caused enough ocean turmoil in Alaska to disturb maritime traffic and initiate an observation program by the USGS to understand the evolution of the glacier.

Elsewhere in Alaska, ice melt is dominated by surface processes, i.e. the melting of ice from warmer air temperature. The same process now dominates the melting of the Canadian ice caps. The rate of surface melt of these glaciers is one order of magnitude larger than that experienced by the ice sheets. Albedo feedback and elevation feedback (discussed above) make it impossible for these glaciers to survive into the future unless we bring the climate system ultimately back to pre-industrial levels of stability, CO<sub>2</sub> concentrations of 280 ppm, with a return of CO<sub>2</sub> levels to under 350 ppm by century's end.

## **E. Iceland Glaciers**

The glaciers in Iceland are losing mass at a rate of 11 billion tons per year since 2002, with an acceleration of 4 billion tons per year every year (Ciraci et al., 2017). One billion tons of water per year is the annual consumption of water by a large city like Los Angeles or New York City. **Exhibit E** shows a spectacular time-lapse sequence over a famous land-terminating glacier in Iceland, Solheimajokull glacier, which illustrates the speed at which a glacier can melt away over time. Solheim has been retreating at a rate of one Olympic pool-length per year for the past two decades, leaving nothing in its path but gravel and melt water. The video reveals the stark appearance of the glacier surface, the ice front retreat, and the shrinkage of the glacier margins over time, illustrating that the glacier is not just getting shorter, it is shrinking in ice volume.

## **F. Patagonia Glaciers**

The glaciers in Patagonia are the southern hemisphere equivalent to the glaciers in Alaska. Many of the Patagonia glaciers are terminating in the ocean on the west coast and in glacial lakes on the east coast. Almost all of the glaciers except one – Moreno glacier - are retreating, but Moreno is a special case of a glacier abutting a mountain at its terminus and undergoing regular oscillations in terminus position, analogous to Hubbard Glacier in Alaska. The melting of Patagonia glaciers is similarly a direct result of warming surface temperatures from GHG

emissions. Some glaciers in Patagonia have experienced catastrophic levels of retreat. For instance, Glaciar Jorge Montt thinned at rates of 50 m/yr for several years; HPS 15 retreated so rapidly that it left trees stranded on cliffs along its former margins (Mouginot and Rignot, 2015). The retreat of Glaciar Jorge Montt from its original preindustrial extent through 2014 is illustrated by the overlaid image in **Exhibit L**. Along with the increase in ice melt, more proglacial lakes have broken through their natural dams and generated destructive floods that endangered populations unaware of such changes. Glaciar Upsala has retreated more than 30 km since the 1970s.

The melting of mountain glaciers affects water resources and local populations; it can also destabilize mountain slopes and create landslides and tsunamis (from land slide or iceberg breakup). Argentinians are concerned about the future evolution of glacial lakes at the margin of the icefields. Farther north, smaller glaciers in the Andes that hold smaller ice volumes play a critical role in providing freshwater supply year round to populations. These glaciers are disappearing, some of them have already disappeared, with major impacts on freshwater supply. The impact of melting glaciers on fresh water supply is prevalent in the Andes of South America as well as for the heavily populated regions of India, Pakistan, Bangladesh, who rely on High Mountain Asia glaciers for a fraction of their freshwater supply (Lutz et al. 2014). The situation will worsen in the future and local governments are trying to find solutions to slow down the process, even using extreme solutions such as covering glaciers with rocks.

## **G. Glacier National Park**

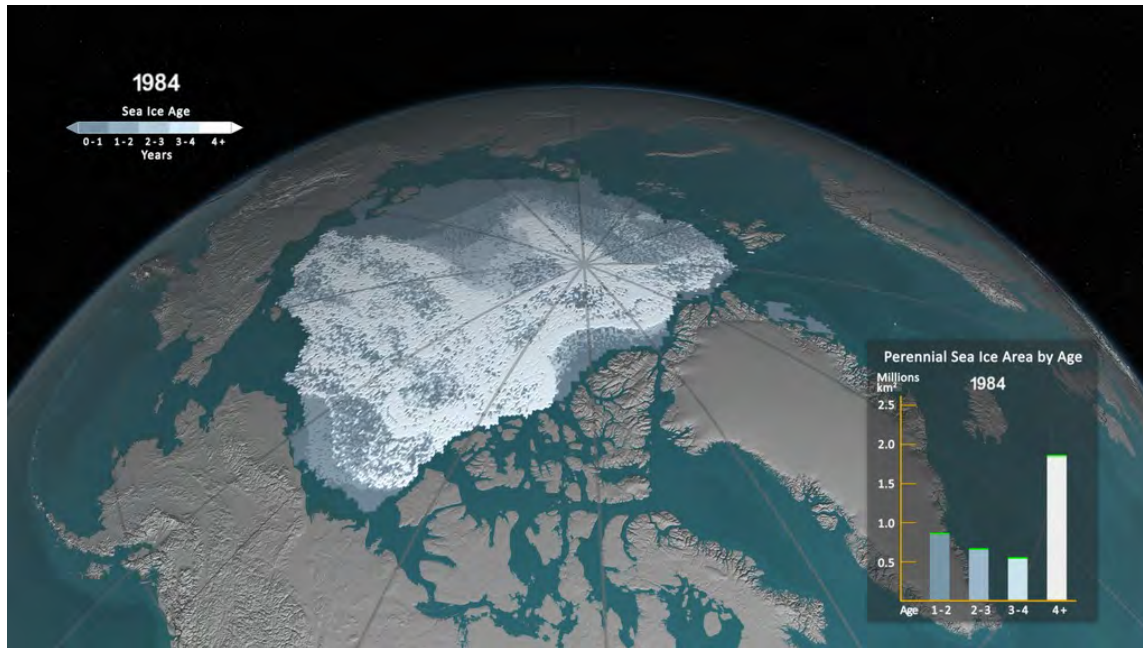
Glaciers in the continental U.S. are not important vectors of sea level rise, nor do they have a critical impact on freshwater supply (albeit reduced overall snowpack does have a critical impact), but they are the direct signature of climate change that any American can see with their own eyes even without a background in science. The loss of continental glaciers impacts the ecology, scenery, and experience of mountains like those in Glacier National Park. Glacier National Park will soon have no glaciers left (USGS 2015). Most of the glaciers in that park no longer qualify as glaciers per my definition of what a glacier is, which is an entity of ice thick enough to deform under its own weight, which requires ice to be at least 100 m thick. Such glaciers no longer exist in Glacier National Park, where we now see only remnant slabs of ice doomed to melt slowly and unstoppably. Children today, like these Plaintiffs, as well as future generations will never see glaciers in Glacier National Park, as we and our ancestors did throughout human history. However, if we stabilize the climate system and eventually return to atmospheric CO<sub>2</sub> of less than 350 ppm and ultimately return to pre-industrial levels, these Plaintiffs' grandchildren may in their lifetimes be able once again to see glaciers in the continental U.S.

The destruction of glaciers in Glacier National Park is a direct result of the warming surface temperatures caused by human climate pollution. There is no other explanation.

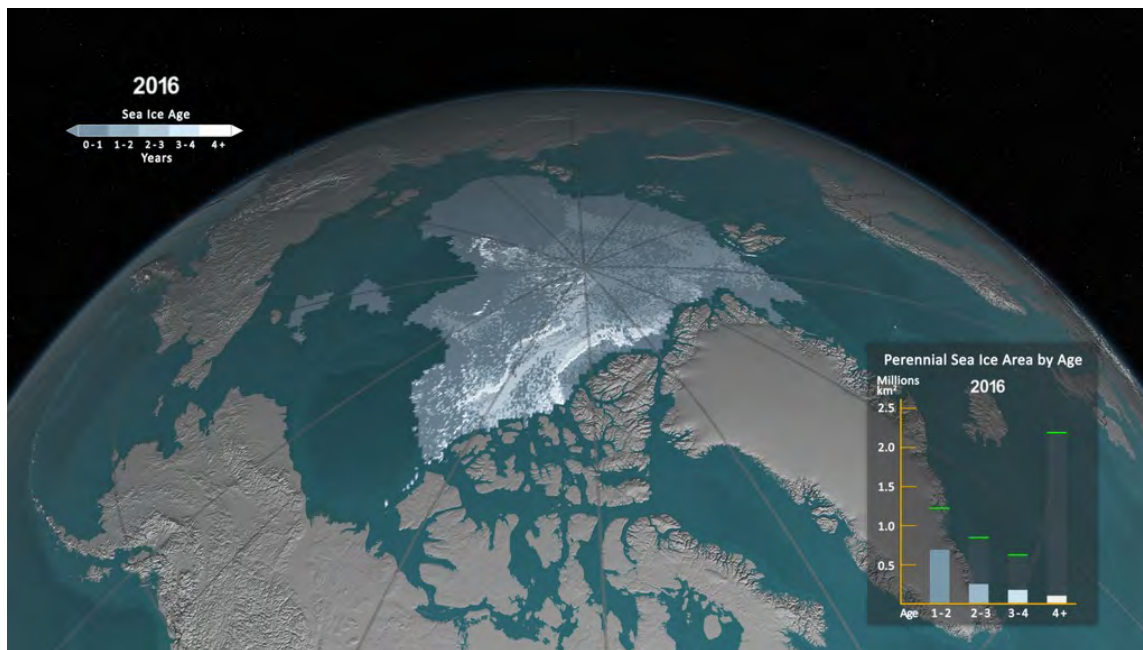
**Exhibit J** shows USGS time comparison images of the disappearing Chaney Glacier in Glacier National Park and **Exhibit K** shows the diminishment of the Blackfoot-Jackson Glacier over the course of nearly a century.

## H. Sea Ice

Arctic Ocean sea ice extent has been declining since satellite observations began in 1979. In addition to reductions in Arctic Ocean sea ice extent, the Arctic sea ice is not as long lived today as it was in 1984 when the majority of Arctic ice was 4 years old or older (**Figure 4**). In 2016, the majority of Arctic sea ice is only one or two years old (**Figure 5**). This younger ice is thinner and melts more rapidly than the older, thicker ice that covered most of the Arctic Ocean just a few decades ago.



**Figure 4:** Minimum sea ice extent 1984 with chart of age of ice. Source NASA <https://svs.gsfc.nasa.gov/4489>



**Figure 5:** Minimum sea ice extent in 2016 with chart of age of ice. Source NASA. <https://svs.gsfc.nasa.gov/4489>



While not a contributor to sea level rise, Arctic sea ice is an important indicator of global temperatures. The reduction in Arctic sea ice is a result of warmer ocean temperatures, warmer air temperatures, and changes in wind. In summer, warmer temperatures cause sea ice to retreat further each year, and warmer winter temperatures prevent sea ice from extending as far.

Importantly, as the amount of water surface covered by sea ice shrinks, the highly reflective ice surface that once reflected solar energy back into space gets replaced by dark blue ocean that absorbs the solar energy converting it into heat that further increases the rate of warming. This is a classic climate feedback loop that is visible today. This retreat of sea ice combines with the decrease in snow cover in the northern hemisphere since the 1980s, which also reduces the albedo on land and increases absorption of solar energy by the ground, another positive feedback contributing to the rapid warming of the Arctic (IPCC AR5 2013).

Finally, as sea ice retreats, the impacts on human populations become visible. Coastlines once protected from ocean waves by seasonal winter ice have become susceptible to erosion from wave action driven by winter storms. What was once extensive sea ice that enabled subsistence hunters to travel and access marine prey, has now become open ocean. This shrinking sea ice has also enabled more shipping traffic in Arctic waters and will enable increased fossil fuel extraction in areas previously inaccessible to the fossil fuel industry.

## **I. Points of No Return**

There is ongoing scientific debate about whether we have already reached the point of no return in melting parts of the planet's ice sheets, or when that point of no return might be reached, meaning the point at which nothing will stop the disintegration and loss of a portion of an ice sheet or a glacier. There is no legitimate ongoing scientific debate about the fact that dangerous melting of the planet's ice sheets and glaciers is occurring, is happening faster than we (and the IPCC) previously predicted, and that it is a signature result of human-caused climate change.

It is my opinion that we already passed the point of no return for two of the major glaciers in Greenland, Jakobshavn and Zachariae Isstrom, and that it is only a matter of time (years, or decades) before the third one follows suit, particularly if business as usual climate pollution and warming continues. These glaciers hold a sea level equivalent of 3 m. The glaciers are retreating along a reverse bed, i.e. the retreat is irreversible.

Recent observations suggest that the retreat is proceeding at a constant speed (about 0.5 km/yr), meaning that some physical processes act to maximize the rate of retreat. Also, observations of seasonal to inter-annual fluctuations suggest that a return to colder ocean conditions could slow down the retreat, perhaps even slowing it down to a halt. However, governments, like the U.S., are not pursuing a route toward a colder ocean at present; instead governments, like the U.S., continue pursuing a route of fossil fuel burning that will continue to make the ocean warmer with time, which means the ice sheet and glacier retreat will be fueled by warmer and warmer waters.

We already passed a point of no return in West Antarctica as well. In May 2014, we publicized at NASA that we had learned enough about the Amundsen Sea Embayment of West Antarctica to conclude that we passed the point of no return. We made this determination from a detailed

mapping of the bed topography beneath the glaciers that suggested that there were no large bumps that could prevent the glaciers retreat all the way to their ice divides. At the current rate of retreat, a large fraction of these glaciers will be gone in the next 100 years. As it continues, the retreat will entrain the collapse of the rest of West Antarctica, for a total 3 m sea level rise.

In East Antarctica, some of the most vulnerable sectors are changing. Totten Glacier holds a sea level equivalent of 3.9 m, more than all of West Antarctica. The glacier is thinning, retreating at 0.2 km/yr but detailed mapping of its bed topography reveals a normal bed, i.e., the glacier retreat is protected by a topographic barrier extending 50 km inland that will take centuries to take over. Another glacier, Denman, which holds a 1.6 m sea level equivalent is also changing. The glacier is perched on a high ground with a reverse bed upstream dropping by 1.5 km over the next 50 km. This glacier could be a giant source of sea level rise in the future. A recent hydrographic survey reveals the presence of warm, salty water of circumpolar current origin at the mouth of Totten Glacier. We suspect that a similar situation exists on Denman but no ship has been able to collect data in that sector. We know this because the rate of ice shelf melt in front of Denman is unusually large and can only be explained by the presence of warm waters. An increasing rate of ocean heat transport from the westerlies toward these glaciers could precipitate their demise. I consider Denman Glacier to be a high-risk glacier for rapid sea level rise from East Antarctica.

It is not clear how much of this sea level rise can be avoided by slowing down climate warming or even cooling the planet again. It is clear that unabated climate warming will melt the ice faster than humanity can handle, i.e. on the time scale of the next century, for which we are not ready. The cost of adaptation of society will be enormous and measured in trillions of dollars, but ultimately the losses are incalculable. Reduced warming will slow the melting and reduce the economic impacts, and perhaps preserve the opportunity for the seas to cool enough to preserve some of these ancient ice sheets and glaciers, and thus our shorelines.

## **J. What must be done to protect our climate and our ice?**

In order to prevent the most serious and calamitous sea level rise, states need to implement measures to curb our fossil fuel emissions immediately. Some climate models indicate that it will take about 30-40 years for any marked change in fossil fuel emissions to have a measurable impact on air temperature, so what states do today in 2018 will have a profound impact on the climate system mid-century. Climate models project that under business as usual scenarios we will have exceeded 1.5 degrees C above pre-industrial temperatures and probably 2 degrees C above pre-industrial temperatures, which would commit the world to multiple-meter sea level rise (6- 9m according to paleoclimate records). Delaying the transition off of fossil fuels would be disastrous. A recent study computes that every 5-year delay in the global peak of CO<sub>2</sub> emissions results in 0.2 m (and up to 1 m at the high end) of increased sea level rise by 2300 (Mengel 2018). Because sea level does not always rise linearly, but exponentially and in pulses, even those estimates may be conservative.

In 2016, climate warming almost reached 1.5 degrees C above preindustrial temperatures already at the poles. A world 2 degrees C above preindustrial temperatures is not sustainable in terms of sea level rise. Because warming is not equally distributed across the globe, a 2 degrees C world

average implies a 4 to 6 degrees C above preindustrial warming in the Arctic. This means seasonal sea ice cover will be gone, Greenland ice sheet is doomed to melt almost completely and if the same warming is applied to Antarctica (which requires 4-5 degrees C to melt at the surface), this would mean that all ice shelves will break up and disappear, entraining rapid speed up of the glaciers and multiple meter of sea level rise per century from Antarctica.

Even with 1 degree C of warming above preindustrial temperatures, as we have today, there is unstoppable melting of certain glaciers, and it has already led to the elimination of glaciers in Glacier National Park. In my opinion, any additional climate pollution and warming in the system, which will further increase temperatures from what they are today is, catastrophic.

I recommend states take immediate action on short-term greenhouse gases such as methane and NO<sub>2</sub> because these GHGs are short lived compared to CO<sub>2</sub> and will help slow down the rate of warming (CARB 2017). Comprehensive, multifaceted strategies have been developed describing the technologies and policies that would limit the speed and extent of warming to avoid the worst impacts of climate change (Ramanathan 2017). I recommend we follow these roadmaps to slow the melt and, to the extent possible, preserve our global glaciers and ice sheets.

I recommend states maximize the biotic carbon sequestration potential of soils, wetlands, and forests, through improved practices in agriculture and forestry management.

I recommend states move to a cleaner world in terms of energy production as soon as possible and states consider developing technologies to sequester more carbon back into the ground, to reduce GHG concentration and cool back the planet. States should move quickly to achieve a 100% fossil free energy system for all sectors by 2050, at minimum, as many energy experts believe is feasible technologically and economically. We need to drop carbon concentration in the atmosphere back to the level where they were in the pre-industrial era (280 ppm) to slow down the retreat and decay of ice sheets.<sup>2</sup> Ice sheets in Antarctica and Greenland were stable in that climate. While this may not stop the collapse of marine-based parts of the ice sheets, it will likely slow down the retreat considerably. As an interim step to returning to preindustrial CO<sub>2</sub> concentrations, we should at minimum aim to return to no more than 350 ppm by 2100 (Hansen 2013).

The most important discovery of the last 20 years is that the ice sheets, which seem so remote and eternal from a vantage point, have reacted almost immediately to climate warming. The reason, in retrospect, is simple: while the vast majority of the ice sheets reside in the coldest part of the planet, often at high elevation above the ground (Greenland tops at 3,000 m above sea level, Antarctica's south pole towers at 4,000 m), the periphery of the ice sheets is at sea level, surrounded by a warm, salty ocean that holds a tremendous amount of heat. Any change in

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<sup>2</sup> It is worth noting that the Federal Defendants state in their Answer to Plaintiffs' First Amended Complaint that "atmospheric CO<sub>2</sub> concentrations over 280 ppm have led to an energy imbalance compared to the pre-industrial era." Dkt. 98, ¶ 203. Most of that energy imbalance is being taken up by the oceans, causing the ice melt described herein. This is consistent with my expert opinion that to preserve our ice and our coastlines over the long term, we need to return CO<sub>2</sub> levels to 280 ppm.

temperature of the ocean carries a large amount of heat, which can melt vast quantities of ice immediately and trigger glacier retreat. Similarly, melting of the ice surface during a warm summer has immediate consequences for sea level. Melting at the periphery of Greenland and even Antarctica is common, but a small change in temperature propagates the effect at large distances inland because most glacier landscapes have shallow slopes (less than 1%) so any change in temperature migrates over 10 km's to 100 km's inland and affects vast areas. Finally, the rate of sea level rise that we are facing today, which is a multi-meter sea level rise, is not unprecedented; it took place 14,000 years ago during rapid episodes of deglaciation and was caused by ice sheet collapse. This is based on our observational record of the Earth system by scientists with training in physics, mathematics, and engineering whose agenda is to help us understand our planet, learn how to live on it with other humans, in harmony with our environment.

### **CONCLUSION AND RECOMMENDATIONS**

Based on my 28 years of research on the interaction of ice and climate, 200 peer-reviewed publications and information publicly available, it is my expert opinion that young people today, including the youth Plaintiffs in this case, have already suffered tremendous harm to the temperature of the surface of the Earth and the oceans and consequently the ice sheets, glaciers and ice caps that are melting, some in irreversible decline. The melting is resulting from the excess heat caused by fossil fuel pollution and other human-caused greenhouse gas emissions. The U.S. is responsible for a large share of those global emissions. The planetary warming has already caused dangerous amounts of ice melt around the globe, which is happening faster than we have predicted and is raising sea level and threatening water sources, communities, ecosystems and landscapes.

It is my expert opinion that two of the melting glaciers in Greenland (and soon another large glacier) as well as the Amundsen Sea Embayment in West Antarctica are irreversibly disintegrating and may cause the seas to rise as much as 3-6 m. Other glaciers and portions of ice sheets are poised to follow course. This century alone, we are very likely to see more than one meter in sea level rise, as a conservative estimate. It is particularly revealing that as time goes, the projections for future sea level rise become larger, i.e. models tend to underestimate the magnitude of the changes, not overestimate them. The reason is simple. The scientific community has been overly conservative in projecting sea level rise from melting ice sheets because we did not know well how fast glaciers could collapse. We have never witnessed something like this in the past. But now, after 40 years of detailed scientific observations, especially the last 25 years, we know that these rates of collapse exceed all of our expectations (IPCC AR5 2013).

Antarctica's ice sheets have an ice volume equivalent to a 57 m sea level rise. Under certain scenarios of emissions and melting, we could see a 4 m rise in sea level each century from Antarctica. In the future, the seas will continue to dangerously rise from the already too warm oceans and surface temperature. However, unless states reverse course by reducing greenhouse gas emissions, sequestering more carbon from the atmosphere and returning atmospheric CO<sub>2</sub> levels to 350 ppm by centuries end, and eventually back to ~280 ppm, young people will grow



up with rising seas that threaten every coastal area and island on the planet, submerging lands indiscriminately across the globe. The amount of sea level rise we presently face and will increasingly face from Antarctica and Greenland melting ice sheets are unfathomable to most people, but it is in fact a real possibility unless governments drastically and quickly shift course toward a clean energy system and address other sources of greenhouse gas pollution. Any children living in a coastal area in Florida, Louisiana, Alaska, Hawaii, New York City or the Pacific Northwest, as are some of these youth Plaintiffs, are at risk from the rising seas. What states do today with emissions will have direct consequences to these youth Plaintiffs during their middle-age, when they may be having their own children.

Less important for future sea level rise, but still vital for people's experience of the landscapes of the U.S., and for ecosystem and freshwater resources are the disappearing and melting glaciers of Glacier National Park and Alaska. In my opinion, these young Plaintiffs will never see a true glacier in Glacier National Park because they have melted to nothing or slabs of ice, not glaciers. In Alaska, the glaciers are dramatically melting and changing landscapes and ecosystems. These are real losses visible to the human eye.

These youth Plaintiffs and future generations will live with rising seas, but we have an opportunity to reduce the amount by which the seas rise, and how quickly. We have a chance to leave an opportunity for the seas to once again cool and allow for the re-propagation of ice in the next seven generations. The task before this court is a grave one, for so much life and the stability of our planet is at stake.

In order to protect these youth Plaintiffs, other children, and future generations from the above-described harms that are occurring from greenhouse gas pollution, I recommend that states swiftly decarbonize and drastically reduce greenhouse gas pollution, as well as take strong steps to increase the U.S. capacity for carbon sequestration. The prescription set forth by Hansen, et al. in 2013 and 2016 is the minimum course that should be followed for CO<sub>2</sub>.

Signed this 11th day of April, 2018 in Irvine, California.

Corrected report signed this 28th day in October, 2018 in Irvine, California.

A handwritten signature in black ink, appearing to read 'Eric Rignot', with a stylized, flowing script.

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Eric Rignot, Ph.D.

## **EXHIBIT A: STATEMENT OF QUALIFICATIONS**

My expertise stems from 28 years of research in situ observations, ice sheet numerical models, and training in physics, mathematics and engineering. My work has been conducted in teams of researchers, from multiple disciplines, following standard scientific practices of making our data available to the public and other scientists, make our results transparent to others and available in peer-reviewed publications so that other research teams can learn from our work, confirm our results, and develop the next steps of study and understanding of the Earth system.

Our modern observational record for the ice sheets extends 40 years with the first satellites and the first international geophysical year. Historical data collected by humans in Greenland go back to the early part of the 20<sup>th</sup> century and to the 1940s for Antarctica. We exploit that as well. By including the climatic records extracted from ice core samples in Greenland and Antarctica by our colleagues, we have knowledge and observational understanding of the climate system over the past 500,000 years with amazing details. This is known as the paleoclimate record. Ice-coring yields accurate data going back 800,000 years. Air bubbles trapped in ice gives accurate measurements of the composition of the air and GHG concentrations at the time the ice was formed and the seasonal layering of ice over ranges of time give an accurate chronology of ancient climates. Ice-coring also provides us with related information about precipitation and temperature patterns, ocean surface temperature, salinity levels, pollen counts and the presence or lack thereof of volcanic ash, all of which are used to inform our understanding of the climate system and the relationship between climate and ice and therefore sea levels.

While scientists' understanding of the basic physics of climate change has been known for centuries, we have made tremendous progress in the last 20 years as a result of satellite techniques, a new generation of climate models enabled by powerful computers, and enhanced numerical techniques of analysis to improve our more precise understanding of the Earth system and the evolution of polar regions in a warmer world on the time scale of human lives. These enhanced techniques allow us to measure the amount of melting occurring with greater precision, measure sea level rise with greater precision and make better predictions about the future rate of ice melt. For example, our research group specializes in remote sensing techniques, mostly imaging radar to measure ice motion from space at a level of precision (millimeter), over the entire ice sheets, that would be impossible to match in quality and extent by ground surveys. We employ airborne radar sounders developed and flown by NASA to probe ice thickness. We collaborate with teams of experts that developed numerical climate models to reconstruct snowfall and ice/snow melt at the ice sheet surface, the same class of models that are used for weather predictions on a daily basis. We collaborate with colleagues that employ time series of time-variable gravity from space to measure mass changes. We work with colleagues using time series of surface elevation from laser and radar altimeters from space and airborne platform to document volume changes. All these lines of evidence from multiple techniques are used synergistically to help us understand the Earth system and the evolution of polar regions and strengthen our conclusions with multiple lines of evidence and a clear understanding of the physical processes at play. Among them, observations are fundamental. In our group, we conduct field surveys (GPR, GPS, shipborne mapping of bathymetry) in complement to remote sensing data. We are also engaged in advanced numerical ice sheet models and the coupling of ice sheet

models and ocean models (the MITgcm ocean model). Our team of 20 researchers mixes expertise in physics, mathematics, programming, signal processing, oceanography, glaciology, and climate change. We are in constant contact with hundreds of other scientists worldwide and write joint scientific publications together on a monthly basis. A large part of our work is to keep abreast on the latest development in Earth science and technology applicable to Earth science.

International teams of experts using various instruments have been assembled by international space agencies to collate our results and provide multiple lines of evidence to support our assessments and conclusions on the state of mass balance of ice sheets. These committees employ scientists who volunteer their time to do this. I served in the IPCC for the past ten years, I never got paid one dollar to do this; we do this as a public and scientific service. The scientific community thanked us by attributing the Nobel Peace Prize to the lead authors, authors and co-authors of the IPCC AR4 report in 2007. The evidence for climate warming, ice sheet melting, and sea level rise has become so strong in the last decade, especially in the Arctic, that it is overwhelming and unequivocal.

**EXHIBIT B: CURRICULUM VITAE**

**Donald Bren and Chancellor's Professor of Earth System Science, Eric RIGNOT**

Chair, Department of Earth System Science

University of California Irvine

Croul Hall, Irvine California 92697

ph. 949 824 3739, email: erignot@uci.edu

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Faculty Part Time and Senior Research Scientist

Caltech's Jet Propulsion Laboratory

Pasadena, California 91109.

**Education:** Ph.D., Electrical Engineering, 1991, University of Southern California, CA.

M.Sc., Aerospace Engineering, 1988, University of Southern California, CA.

M.Sc., Electrical Engineering, 1987, University of Southern California, CA.

M.Sc., Astronomy, 1986, University of Paris VI Pierre et Marie Curie, Paris, France.

Engineer Degree, 1985, Ecole Centrale des Arts et Manufactures, Paris, France.

**Professional Experience:**

Chair, Department of Earth System Science, University of California Irvine, 2017-present.

Donald Bren Professor, Earth System Science, University of California Irvine, 2016-present.

Chancellor's Professor, Earth System Science, University of California Irvine, 2015-2016.

Vice Chair Graduate Studies, Earth System Science, University of California Irvine, 2013-2015.

Full Professor, Earth System Science, University of California Irvine, 2007-present.

Joint Faculty Appointee, JPL Office of the Chief Scientist, 2007-present.

Senior Research Scientist, JPL, 2006-present.

Principal Scientist, Radar Science and Engineering Section, JPL, 2003-present.

Member of Technical Staff, JPL, 1988-2002.

Research Assistant, University of Southern California, 1986-1988.

**Membership and Honors:**

Member of the National Academy of Sciences, May 2018.

James Arnold Lecture, UC San Diego, January 2018.

Thomson Reuters Highly Cited Researcher, Geosciences, 2017.

NASA Group Achievement Award, Oceans Melting Greenland Team, 2017.

Louis Agassiz Medal for the Cryosphere Division of the European Geosciences Union, 2016.

Thomson Reuters Highly Cited Researcher, Geosciences, 2016.

Seng T. Lee Lecture in Antarctic Studies, Wellington, New Zealand, 2016.

John F. Nye Lecture, American Geophysical Union, 2015.

Thomson Reuters Highly Cited Researcher, Geosciences, 2015.

Thomson Reuters Highly Cited Researcher, Geosciences, 2014.

Fellow American Geophysical Union, 2013.

NASA Group Achievement Award, Ice Mass Balance Intercomparison Exercise Team, 2013.

NASA Outstanding Leadership Medal, 2012.

Exceptional Impact on UC Irvine ESS Honor Student, 2012.  
NASA Group Achievement Award, IceBridge Mission, 2011.  
NASA Group Achievement Award, Ice Sheet System Model, 2011.  
NASA Group Achievement Award, Warm Ice Sounding Explorer Team, 2010.  
National Science Foundation's Antarctic Service Medal, 2009.  
William Bowie Lecture, American Geophysical Union, 2008.  
NASA Exceptional Scientific Achievement Medal, 2007.  
Contributing Author IPCC AR4 which was attributed Nobel Peace Prize 2007.  
JPL Edward Stone Award for Outstanding Research Publication, 2005.  
NASA Exceptional Scientific Achievement Medal, 2003.  
Nomination of "Rignot Glacier, Antarctica" by U. S. Board Geographic Names, 2003.  
JPL Edward Stone Award for Outstanding Research Publication, 2003.  
JPL Director Lew Allen Award for Excellence, 1998.  
IEEE Geos. Rem. Sens. Soc. Award for Best Journal Paper, 1994.  
IEEE Geos. Rem. Sens. Soc. Award for Best Oral Paper, 1990.  
12 NASA Certificates of Recognition since 1988.  
Member of International Glaciological Society, AAAS, IEEE.

#### **Education and Outreach:**

Interviews with national (NY Times, San Francisco Chronicle, LA Times, Washington Post, etc.) and international (Argentina's Clarin, France's Figaro, France's Le Monde, England's Times, etc.) newspapers, magazines (National Geographic, Scientific American, etc.) national (Richard Harris' NPR, etc.) and international programs (Radio Canada, TV5), national (CNN, ABC, National Geographics, Discovery Channel, NBC, NOVA, etc.) and international television channels (BBC, Arte, Reuters) on glaciological changes in Antarctica, Greenland and Patagonia. HBO special on Antarctica with digital news media VICE.com in 2014 with major documentary awards, interview with Skeptical Science at AGU Fall 2014, and special professional article in New York Times magazine in November 2015. Worked with PBS/NOVA on Virtual Reality documentary/application for NASA's mission Ocean Melting Greenland in 2016-2017. Worked with VP Al Gore on "Inconvenient Sequel: from Truth to Power" in Greenland in summer 2016, distributed Worldwide by Paramount Studios.

Seminars at Caltech, University of Southern California, University of California Los Angeles, Irvine and Santa Cruz, Stanford University, New York University, Royal Society of London, British Antarctic Survey, Laboratory of Glaciology in Grenoble, Centro de Estudios Cientificos, Climate Change Institute in Washington DC, Oxford University, Vice President Al Gore's Climate Reality Project, UCI Research Council.

#### **Student Mentoring and Advising**

PhD student main advisor: Marjorie Schmeltz (2002) now High School Teacher, France; Eric Larour (2005) now Research Scientist, Div. 32 at JPL; Helene Seroussi (2011) now Research Scientist JPL; Mathieu Morlighem (Dec. 2011) now Assistant Professor UCI; Yun Xu (June 2014) now researcher at Berkeley National Lab.; Xin Li (January 2016) now Team Leader, Orbital Insight

Inc., San Francisco; An Lu (Oct. 2017) now postdoc UCI; Cilan Cai (exp. 05/2018); Hongju Yu (exp. 05/2018); Romain Millan (exp. 04/2018); Michael Wood (exp. 05/2019); Emily Kane (exp. 05/2020); Shivani Ehrenfeucht (exp. 05/2021); Toufik Chouki (exp. 05/2021).

PhD committee/external advisor: Dan McGrath, University of Colorado Boulder 2008-2013; Karli Ouellette, UCI ESS 2010-2014; Daniel Seneca Lindsey, UCI ESS 2009-2015; Collin Lawrence, UCI ESS 2011-2014; Tyler Sutterley, UCI ESS 2012-2015; Wenshan Wang, UCI ESS 2014-2017; Chia-Wei Hsu, UCI ESS-2012-present; Enciro Ciraci, UCI ESS 2014-present; Yara Mohajerani, UCI ESS 2015-present.

Master student advisor: Arnaud Buzzi, Ecole Centrale Paris (6 mo. 2014); Pierre Gourlet Ecole Centrale Paris (6 mo. 2015); Vincent Bernier Ecole Centrale Paris (6 mo. 2016); Valentin Martineau (6 mo. 2017); Arnaud Charolais (6 mo. 2017); Mohamed Gharbi Ecole Centrale Paris (6 mo. 2018), Toufik Chtouki, Universite de Strasbourg (6 mo. 2018).

Post-doctoral fellow advisor: Ala Khazendar NASA Postdoctoral Program (NPP) administered by ORAU (NPP/ORAU) postdoc 2008, now Research Scientist, Div. 33 at JPL; Chris Borstadt NPP/ORAU JPL postdoc 2011-2014, now Assistant Professor, University Centre, Svalbard; Behnaz Khabak, JPL postdoc 2011-2012; Feras Habbal UCI postdoc, 2011-2013, now Researcher UTIG, Texas; Ian Fenty NPP/ORAU JPL postdoc, 2011, now Research Scientist, Div. 32 at JPL; Jeremie Mouginot, UCI postdoc 2009-2010, now Associate Researcher UCI and Researcher at CNRS, Grenoble, France; Basile de Fleurian, UCI postdoc 2013-2015, now Research Assistant University of Bergen; Yoshihiro Nakayama, UCI postdoc 2015-2016, now NPP/URSA JPL postdoc; Pietro Millilo, NPP/URSA JPL postdoc 2015-present, now Research Scientist, Div. 33 at JPL; Anders Bjork, UCI postdoc 2016-present; Virginia Brancano, NPP/URSA JPL/Agencia Spaziale Italian, 2018-present.

Project Scientist supervisor: Bernd Scheuchl; Jeremie Mouginot (now Associate Researcher UCI); Mathieu Morlighem (now Assistant Professor UCI ESS).

### **Field experience:**

Deputy Lead, Earth Venture Suborbital-2 NASA Mission "Ocean Melting Greenland", 2015-present, \$30 M budget over 5 years.

Science Lead, NASA's Operation IceBridge (OIB) Mission to Greenland and Antarctica to bridge the gap between ICESat-1 and ICESat-2, 2009 to 2020, \$19M/yr budget.

Lead three airborne radar sounder/imager deployments in Antarctica (JPL/UCI/University of Iowa Warm Ice Sounding Explorer (WISE) radar in East Antarctica Jan. 2009 and Dec. 2009, AIRSAR/TOPSAR in Antarctic Peninsula March 2004), two in Patagonia (WISE in March 2007 and Oct. 2014), three in Alaska (WISE in March 2006, Oct. 2008, March 2011), and four in Greenland (AIRSAR/TOPSAR May 1995, JPL/WISE in April 2008, JPL/WISE in April 2009, JPL/WISE in March 2010, NASA/OIB July 2016).

Lead three helicopter-borne gravity, radar sounding and laser surveys for the Gordon and Betty Moore Foundation in Patagonia April 2012, West Greenland Aug. 2012 and Patagonia Oct. 2012 and July 2016.

Lead six oceanographic surveys of West Greenland glaciers in Aug. 2008, 2010, 2012, 2013, 2014, 2016 and 2017 using CTD, multi beam echo sounding and ADCP to study ice-ocean interactions in glacial fjords.

Automatic weather station maintenance in Greenland (May 2005, 2006 and 2007), airborne deployments of the NASA P3 in Greenland (5 times between May 1998 and 2006) and Antarctica (November 2002, 2004, and 2008 in collaboration with CECS, Chile).

Co-lead field glacier survey in Patagonia (Tyndall Glacier, March 1999, 2002 and 2003; San Rafael Glacier, November 1995 and March 2005), Greenland (NSF project on Petermann Glacier, April 2002-2004, with University of Colorado in Boulder and the British Antarctic Survey (BAS)), and Antarctica (NSF IPY project on Larsen C ice shelf, Antarctic Peninsula with Univ. Colorado, Univ. Utrecht and BAS, 2008-2011).

#### **National and International Committee Memberships:**

2017-present: Member of the Space Studies Board, "Committee on Earth Science and Applications from Space" (CESAS) (14 members in the US from all disciplines of Earth Science) to support scientific progress in Earth system science and applications, with an emphasis on research requiring global data that are best acquired from space and to assist the federal government in planning programs in these fields by providing advice on the implementation of decadal survey recommendations. Appointed by the President of the National Academies of Sciences, Engineering, and Medicine.

2017-present: Lead Author of the Intergovernmental Panel on Climate Change (IPCC) "Special Report on Ocean and Cryosphere" (SROCC), Chapter 3, due 2019.

2016-2018: Panel Member, "Climate Variability and Change: Seasonal to Centennial", National Academies of Sciences, Engineering, and Medicine's 2017-2027 Decadal Survey for Earth Science and Applications from Space (ESAS). Appointed by the President of the National Academies of Sciences, Engineering, and Medicine.

2014-2017: National Earth Observation Assessment (EOA 2016) Climate Social Benefit Areas, lead by the White House Office of Science and Technology Policy (OSTP) and organized by the U.S. Group on Earth Observations (USGEO), Team Lead for Cryosphere.

2013-2015: National Research Council Committee Member on "Committee on a Framework for Analyzing the Needs for Continuity of NASA-Sustained Remote Sensing Observations of the Earth from Space" appointed by the President of the National Academy of Sciences.

2013-present: Science Lead of NASA Mission Operation IceBridge to bridge the gap between



ICESat-1 and ICESat-2 in Greenland and Antarctica. Budget of \$19M/yr with multiple airborne deployments in Greenland and Antarctica.

2012-present: Member of the Science Team of NASA Indian Space Research Organization (ISRO) NISAR radar mission, Cryosphere (2012-Present). A \$1.2B mission to be launched in 2020.

2011-present: Member of US CLIVAR Working Group on Greenland Ice Sheet.

2010-2013: Lead Author Chapter 4, Cryosphere, Intergovernmental Panel on Climate Change (IPCC), Fifth Assessment Report (AR5).

2009-2013: Science Team Member, NASA Operation IceBridge (OIB) Mission in Greenland and Antarctica.

2009: Invited expert at the IPCC AR5 Scoping Meeting, Venice Italy July 2009, WG1.

2008-present: Member of the National Science Foundation (NSF)'s SEARCH Committee (Study of Environmental Arctic Environmental Change), Observing change panel member.

2006-2013: Editor Geophysical Research Letters.

2004-present: Adjunct Researcher, Centro de Estudios Cientificos (CECS), Valdivia, Chile.

2004-present: Visiting Scientist, CIRES, University of Colorado, Boulder, CO.

2004-present: Science Team Member, TanDEM-X TerraSAR-X satellite mission.

2002-2007: Member of the Jet Propulsion Laboratory Science Advisory Group (SAG) to the JPL Chief Scientist.

2005-2007: Member of NSF's Science and Technology Center, CReSis, University of Kansas, Lawrence, KS, to understand the contribution to sea level rise of polar ice sheets. Lead remote sensing branch.

2004-2007: Contributing Author Chapter 4 WG1 IPCC AR4, Expert Reviewer WG1 Chapter 5 and 10.

2001, 2011: Editor Annals of Glaciology, International Glaciological Society.

2001-2004: Science Team Member on NASA's Earth Science Pathfinder mission "Earth Change and Hazard Observatory" (ECHO).

2001-2003: Member of NASA's Earth Science Vision Working Group.

2000-2003: Member of NASA's Solid Earth Science Working Group.

1999-2011: Member of the Alaska SAR Facility User Working Group.

1998-2000: Science Team Member of the Earth Science Information Partner "Tropical RainForest Information Center", Basic Remote Sensing, Michigan State University.

**Funded Research Proposals at UC Irvine 2008-2016: \$18.1M total funding (\$7.5M in last 4 years)**

NASA ROSES 2005. Cryosphere Science Program. "A Revised Estimate of the Ice Mass Budget of Antarctica from Icesat and Radarsat-1 Data Combined", E. Rignot PI (JPL). \$472K in 3 yr at JPL. 3rd yr transferred to UCI, \$160K.

NASA ROSES 2006. MEaSURES. "Ice Velocity Mapping of the Great Ice Sheets: Antarctica", E. Rignot PI (UCI). \$2.45M in 5 yr.

NASA ROSES 2007. Cryosphere Science Program. "Diagnosis and Prognosis of a Greenland Outlet Glacier: Inverse and Forward Modeling Constrained by Remote Sensing", T. Dupont PI, E. Rignot co-I, \$446K in 3 yr; co-I portion \$150K.

NASA ROSES 2008. Modeling, Analysis and Prediction (MAP) Program. "A three-dimensional, high-resolution, higher-order flow model of the Greenland ice sheet: validation and prediction." \$962K. E. Rignot PI (JPL).

JPL DRDF 2009. "Observation and Modeling of Antarctic Ice Sheet and Ocean Circulation Interactions". E. Larour PI JPL \$200K. E. Rignot co-I (JPL), \$65.5K for 1 yr. JPL Grant 1402082.

NASA ROSES 2009. Cryosphere Science Program. Ice Bridge Science Team, "A glacier dynamics and ice-ocean interactions perspective for IceBridge Science". E. Rignot PI (UCI). \$260K in 3 yr. Grant NNX10AV16G.

NASA ROSES 2009. Cryosphere Science Program. "University of Alaska LiDAR combined with JPL WISE Radar Sounder". C. Larsen (UAF) PI, E. Rignot co-I, Y. Gim (JPL) co-I. \$60K at JPL in 2 yr.

NASA ROSES 2009. Interdisciplinary Science Program. "Regional pattern of sea level change from the melting of the Greenland, Antarctic and Patagonia ice sheets derived from combined InSAR ice motion, reconstructed surface mass balance and GRACE time-variable gravity." E. Rignot PI (UCI), I. Velicogna (UCI) co-PI, J. Wahr (Univ. Colorado) co-PI. \$1.25 M at UC Irvine in 3 yr. Grant NNX10AR66G.

NASA ROSES 2010. Modeling, Analysis and Prediction (MAP) Program. "Estimating the Circulation and Climate of the Ocean, Phase III (ECCO3): Improved Representation of Ocean-Ice Interactions in Earth System Models". D. Menemenlis PI (JPL), E. Rignot co-I (UCI), P. Heimbach co-I (MIT). \$350K at UC Irvine in 5 yr. JPL Grant 1434991.

JPL DRDF 2010 joint research activities on ice-ocean interactions JPL/UC Irvine. "Observation and Modeling of Antarctic Ice Sheet and Ocean Circulation Interactions", FY 2010 E. Larour PI (JPL), D. Menemenlis co-I (JPL), T. Dupont co-I (UCI), E. Rignot co-I (JPL). \$117K at UC Irvine in 1 year. Selected 2010. Grant 1402082.

NASA ROSES 2010. Science Definition Team for the DESDynI-Radar mission. "Inputs to the definition of the DESDynI-R mission requirements from 19 yr. of InSAR analysis of ice sheet and glacier motion, E. Rignot PI (UCI), \$225K at UC Irvine in 3 yr. Grant NNX12AO21G

NSF OPP EAGER 2011. Office of Polar Science. "Three-dimensional Stokes grounding line dynamics with the open community JPL/UCI Ice Sheet System Model (ISSM)". E. Rignot PI (UCI), \$275K at UC Irvine in 2 yr. Grant ANT-1155885.

GORDON BETTY MOORE FOUNDATION (GBMF) 2011. "High-resolution Airborne Gravity-Radar Observations of Glaciers in Patagonia and West Greenland". E. Rignot PI (UCI). \$2.2M at UC Irvine in 3 yr. Grant 3280.

NASA/JPL Climate Center Graduate Fellowship at UC Irvine, Department of Earth System Science starting Oct. 1, 2011 for 3 yr. awarded to Ms. Xin Li, PhD candidate ESS. JPL Grant.

NASA ROSES 2011. Cryosphere Science Program. "Improved Mapping of Glacier Thickness Using Icebridge Data Combined with Radar Interferometry Data", E. Rignot PI (UCI). \$329K at UC Irvine in 3 yr. Grant NNX12AB86G.

NASA ROSES 2011. Interdisciplinary Science Program. "Ice shelf melting in Antarctica and impact on glacier dynamics" E. Rignot PI (UCI), D. Menemenlis, E. Larour, A. Khazendar (JPL co-Is), C. Hill (MIT co-I) \$1.1 M at UC Irvine in 3 yr. Grant NNX13AN46G.

NASA ROSES 2012. Making Earth System Data Records (ESDRs) for use in Research Environments, "Ice velocity mapping of the Antarctic Ice Sheet". E. Rignot, PI (UCI), \$2.6 M at UC Irvine in 5 yr. Grant NNX13A184A.

NASA ROSES 2013. NNH13ZDA001N-ICEBST Operation IceBridge. "Coastal land ice dynamics with OIB data". E. Rignot, PI (UCI), Science Lead, \$240K in 3 yr. Grant NNX14AB93G.

NASA ROSES 2013 ROSES 2013. NNH13ZDA001N-CRYO. "Greenland bed mapping using mass conservation, IceBridge and InSAR data, M. Morlighem PI (UCI), E. Rignot (co-I), \$304 K at UC Irvine.

NASA ROSES 2014. NNH13ZDA001N-SLR: Sea Level Rise, "Mass balance and bed topography datasets of ice sheets for sea level studies". E. Rignot, PI (UCI), \$1.3 M at UC Irvine in 3 yr. Grant NNX14AN03G

JPL DRDF 2014-2017. "Downscaling Global Ocean State Estimates for Understanding Past and Projecting Future Sea Level Rise", I. Fenty PI (JPL), I. Fukumori co-I (JPL), E. Rignot co-I (JPL),

E. Larour co-I (JPL). \$180 K/yr in 3 yr. JPL Grant.

NASA ROSES 2014. EARTH VENTURE SUBORBITAL-3 2014, NNH13ZDA001N-EVS2, "Oceans melting Greenland: OMG", EVS-2 Proposal, \$30 million in 5 yr. J. Willis PI (JPL). E. Rignot, Deputy PI, \$966 K in 5 yr at UC Irvine.

NASA ROSES 2014. NNH14ZDA001N-ICEBR, "Reducing uncertainties in Greenland surface mass balance using IceBridge altimetry, GRACE data and regional atmospheric climate model outputs.", I. Velicogna PI (UCI), E. Rignot co-I, \$ 310K at UC Irvine. Funded. Collaborator.

NASA ROSES 2014. NNH14ZDA001N-ICEBR, "Assimilation of altimetry data in North-East Greenland using ISSM.", E. Larour PI (JPL), E. Rignot (co-I), \$157K at UC Irvine. Funded. Collaborator.

GORDON BETTY MOORE FOUNDATION (GBMF) 2015. "High-resolution Airborne Gravity-Radar Observations of Glaciers in Patagonia and West Greenland". E. Rignot PI (UCI). Extension \$220K in 1 yr. Grant 3280.

NASA ROSES 2015. NNH15ZDA001N-ICEB, "Gravity Sounding of Southern Greenland Glaciers.", E. Rignot, PI (UCI), \$941K. Funded.

NASA ROSES 2015. NNH15ZDA001N-NSDT. "NISAR Mission Science Definition Team: Mission Products for Ice Sheet and Glacier Studies." E. Rignot, PI (UCI), \$348K. Funded.

NASA ROSES 2016. NNH16ZDA001N-ICEBST, "Land ice dynamics and ice sheet mass balance with Operation IceBridge and other data", E. Rignot, PI (UCI), \$538K. Funded.

NASA ROSES 2017. NNH17ZDA001N-MEASURES, "Earth System Data Record of Ice Motion and Bed Topography in Antarctica", E. Rignot, PI (UCI), \$2.3M, Funded.

NASA ROSES 2017. EARTH VENTURE SUBORBITAL-3 2018, NNH17ZDA001N-EVS3, "Southern Ocean Melting Antarctica: SOMA", E. Rignot, PI (UCI), \$30M. Pending.

**Peer-Reviewed Publications (Web of Sci. 233 papers, h-index 58; Google Scholar h-index 76; 2,800 citations per year)**

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- 2018 Y. Mohajearni, I. Velicogna, E. Rignot, Mass loss of Totten and Moscow University glaciers, East Antarctica, using regionally-optimized GRACE mascons, *Geophys. Res. Lett.*, 45 (14), 7010-7018.
- 2018 H Liao, FJ Meyer, B Scheuchl, J Mouginot, I Joughin, E Rignot, Ionospheric correction of InSAR data for accurate ice velocity measurement at polar regions, *Remote Sensing of Environment* 209, 166-180.
- 2018 T. Sutterley, I. Velicogna, M. van den Broeke, X. Fettweis, E. Rignot, Evaluation of ice sheet surface mass balance models in the ablation zone using ICESat and Operation IceBridge laser altimeter data, *Geophys. Res. Lett.*, 45, 8324-8333..
- 2018 M. Wood, E. Rignot, I. Fenty, D. Menemenlis, R. Millan, M. Morlighem, J. Mouginot, H. Seroussi, Ocean-induced melt triggers glacier retreat in northwest Greenland, *Geophys. Res. Lett.*, 45, 8334-8342.
- 2018 A. Cazenave et al., Global Sea Level Budget 1993-Present, *Earth System Science Data*, 10 (3), 1551-1590.
- 2018 E. Rignot, J. Mouginot, B. Scheuchl, M. van den Broeke, J. Wessem, Forty years of Antarctic Ice Sheet Mass Balance: 1979-2017, *Proc. Nat. Acad. Sci.*, in press.
- 2018 P. Milillo, E. Rignot, P. Rizzoli, B. Scheuchl, J. Mouginot, J. Bueso-Bello, P. Prats-Iraola, Heterogeneous retreat and ice melt of Thwaites Glacier, West Antarctica, *Science Advance*, in press.
- 2018 G. Collao-Barrios, F. Gillet-Chaulet, V. Favier, G. Casassa, E. Berthier, I. Dussaillant, J. Mouginot, E. Rignot, M. Schaeffer, Ice-flow modelling to constrain the surface mass balance and ice discharge of San Rafael Glacier, Northern Patagonia Icefield, *J. Glaciol.*, 64 (246), 568-582.
- 2018 J. Merryman Boncori et al., Intercomparison and validation of SAR-based ice velocity measurement techniques within the Greenland Ice Sheet CCI project, *Remote Sensing*, 10 (6), 929.

#### **Book Chapters and Scientific Reports**



- 1993 M. R. Drinkwater, R. Kwok, E. Rignot, H. Israelsson, R. Onstott, and D. Winebrenner, Radar polarimetry of sea ice, Chapter 5.0 in *Microwave Remote Sensing of Sea Ice*, F. Carsey ed., Geophysical Monograph 68, (American Geophysical Union, Washington D.C. 1993), pp. 73-102, 1993.
- 2000 D.G. Vaughan, A.M. Smith, H. Corr, A. Jenkins, C.R. Bentley, M.D. Stenoien, S.S. Jacobs, T.B. Kellog, E. Rignot and B.K. Lucchitta, A review of ice-sheet dynamics in the Pine Island Glacier basin, West Antarctica: hypothesis of instability versus observations of change, in *The West Antarctic Ice Sheet: Behavior and Environment*, R. Alley and R. Bindshadler eds., Antarctic Research Series Vol. 77, (American Geophysical Union, Washington D.C. 2000), pp. 237-256, 2000.
- 2006 E. Rignot, Case Study: influence of ocean warming on glaciers and ice streams, in *Glacier Science and Environmental Change*, Peter Knight Ed., Blackwell Publishing, July 2006.
- 2007 E. Rignot, Pine Island and Thwaites Glaciers, West Antarctica, in *Encyclopedia of the Antarctic*, Ed. Beau Riffenburgh, 2-volume set, Routledge NY, Oct. 2006.
- 2007 E. Rignot and I. Joughin, Ice sheets on the move, in: King, M.D., C. L. Parkinson, K. C. Partington, and R. G. Williams (eds), *Our Changing Planet: The View from Space*, Cambridge University Press, Cambridge, UK, pp. 214-218.
- 2008 Steffen, K., P.U. Clark, J.G. Cogley, D. Holland, S. Marshall, E. Rignot, and R. Thomas, Chapter 2: Rapid changes in glaciers and ice sheets and their impacts on sea level, in *brupt climate change, Synthesis and Assessment Product 3.4, Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*, P.U. Clark, A.J. Weaver, eds., U.S. Geological Survey, Reston, VA, pp. 60-142.
- 2008 E. Rignot, Changes in the Greenland Ice Sheet and Implications for Global Sea Level Rise, in *Sudden and disruptive climate change: exploring the real risks and how we can avoid them*, M. MacCracken, F. Moore and J.C. Topping Jr., Eds., Earthscan Publications, London 2008 Publisher,
- 2009 Steffen, K., R. Thomas, E. Rignot, G. Cogley, M. Dyurgerov, S. Raper, and P. Huybrechts, 2007 : Cryospheric Contributions to Sea-level Rise and Variability, in *J. Church, P. Woodworth, T. Aarup, and S. Wilson (eds.): Understanding Sea-level Rise and Variability*, Blackwell Publishing, Inc. 2009.
- 2009 E. Rignot and A. Cazenave, Chapter 3: Ice sheets and sea-level rise feedbacks, in *Arctic and Climate Feedbacks: Global implications*, M. Sommerkorn and S. Joy Hassol, Eds., Published by WWF International Arctic Programme, Aug. 2009, ISBN: 978-2-88085-305-1.
- 2011 The Copenhagen Diagnosis, 2009: Updating the world on the Latest Climate Science. I. Allison, N. L. Bindoff, R.A. Bindshadler, P.M. Cox, N. de Noblet, M.H. England, J.E. Francis, N. Gruber, A.M. Haywood, D.J. Karoly, G. Kaser, C. Le Qur, T.M. Lenton, M.E. Mann, B.I. McNeil, A.J. Pitman, S. Rahmstorf, E. Rignot, H.J. Schellnhuber, S.H. Schneider, S.C. Sherwood, R.C.J. Somerville, K.Steffen, E.J. Steig, M. Visbeck, A.J. Weaver.



- The University of New South Wales Climate Change Research Centre (CCRC), Sydney, Australia, 60pp. Elsevier, ISBN: 978-0-12-386999-9.
- 2011 Fogt, R. L., Ed., 2011: Antarctica in "State of the Climate in 2010". Bull. Amer. Meteor. Soc., 92 (6), S161-171.
- 2011 E. Rignot, Ice sheet mass balance, Encyclopedia of Snow, ice and glaciers, V.P. Singh, P. Singh, U.K. Haritashya (Eds), Springer Verlag, ISBN 978-90-481-2641-5
- 2012 P. Heimbach et al., Understanding the Dynamic Response of Greenland's Marine Terminating Glaciers to Oceanic and Atmospheric Forcing: A White Paper by the U.S. CLIVAR Working Group on Greenland Ice Sheet - Ocean Interactions (GRISO), Report 2012-2, U.S. CLIVAR Office, Washington, DC 20006, 22pp.
- 2012 S. Rintoul *et al.* The Southern Ocean observing system: Initial science and implementation strategy, Ed. S. R. Rintoul *et al.*, Scientific Committee on Antarctic Research/Scientific Committee on Oceanic Research, 74 pp.
- 2014 D. Vaughan *et al.*, Chapter 4: Observations: Cryosphere, in *Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Basis*, Stocker et al. Eds., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- 2015 Collins, W.D., S.J. Davis, R. Bales, J. Burney, R. McCarthy, E. Rignot and D.G. Victor, 2016: Science and Pathways for Bending the Curve, Chapter 1, Bending the Curve: 10 Scalable Solutions for Carbon and Climate Neutrality, V. Ramanathan, D. Kammen and F. Forman, Eds., University of California Press, Oakland.
- 2015 Tapley B. *et al.*, Continuity of NASA Earth Observations from Space: A Value Framework, National Academies of Sciences, Engineering, and Medicine, Washington D.C.: The National Academies Press.
- 2015 V. Ramanathan *et al.* 2015: Executive Summary of the Report, Bending the Curve: 10 scalable solutions for carbon neutrality and climate stability. Published by the University of California, October 27, 2015.
- 2016 Collins, W D *et al.*, 2016 Chapter 3. Science and Pathways for Bending the Curve. *Collabra*, 2(1): 17, pp. 1?17.
- 2017 Ramanathan, V., Molina, M.J., Zaelke, D., Borgford-Parnell, N., Alex, K., Auffhammer, M., Bledsoe, P., Collins, W., Croes, B., Forman, F., Gustafsson, O, Haines, A., Harnish, R., Jacobson, M., Kang, S., Lawrence, M., Leloup, D., Lenton, T., Morehouse, T., Munk, W., Picolotti, R., Prather, K., Raga, G., Rignot, E., Shindell, D., Singh, AK, Steiner, A., Thiemens, M., Titley, D.W., Tucker, M.E., Tripathi, S., Victor, D. and Xu, Y., Under 2 Degrees Celsius: Fast Action Policies to Protect People and the Planet from Extreme Climate Changes, 2017.

## Professional Articles

Article in Science American, <https://www.scientificamerican.com/article/how-is-worldwide-sea-level-rise-driven-by-melting-arctic-ice/>

Article in the New York Times Magazine, Nov. 12, 2015, "The Secrets in Greenland's ice sheet", by Jon Gertner. [nytimes.com/2015/11/15/magazine/the-secrets-in-greenlands-ice-sheets](http://nytimes.com/2015/11/15/magazine/the-secrets-in-greenlands-ice-sheets)

Article in the Orange County Register, Dec. 20, 2015, as the Most Influential in 2015: Eric Rignot, by Aaron Orłowski. [ocregister.com/articles/rignot-696791-ice-melting.html](http://ocregister.com/articles/rignot-696791-ice-melting.html)

NASA Press Release: RELEASE 14-131, May 12, 2014. NASA-UCI Study Indicates Loss of West Antarctic Glaciers Appears Unstoppable

Article in Le Monde, Science et Technologie, 01.07.2014, "Portrait Eric Rignot, un Cassandre de la Glaciologie", [lemonde.fr/sciences/article/2014/07/01/portrait-eric-rignot-un-cassandre-de-la-glaciologie\\_4448790\\_1650684](http://lemonde.fr/sciences/article/2014/07/01/portrait-eric-rignot-un-cassandre-de-la-glaciologie_4448790_1650684).

NASA Press Release: NASA Science Zeros in on Ocean Rise: How Much? How Soon?

**List of active (last six months) scientific collaborators**

Pr. Julian Dowdeswell, Scott Polar Institute, Cambridge, UK.  
Dr. Ian Fenty, Jet Propulsion Laboratory, Pasadena CA.  
Dr. Xavier Fettweis, Department of Geography - University of Liege, Belgium.  
Dr. Yonggyu Gim, Jet Propulsion Laboratory, Pasadena CA.  
Pr. Bernard Hallet, University of Washington, Seattle, WA.  
Pr. David Holland, New York University, NY.  
Mr. Stanley Jacobs, Lamont Observatory, NY.  
Dr. Donald Kirchner, the University of Iowa, Iowa.  
Dr. Eric Larour, Jet Propulsion Laboratory, Pasadena CA.  
Dr. Ala Khazendar, Jet Propulsion Laboratory, Pasadena CA.  
Dr. Dimitris Menemenlis, Jet Propulsion Laboratory, Pasadena CA.  
Pr. Mathieu Morlighem University of California, Irvine CA.  
Dr. John Paden, Kansas University, Lawrence, Kansas.  
Dr. Andres Rivera, Centro de Estudios Cientificos, Valdivia, Chile.  
Dr. Michael Schodlok, Jet Propulsion Laboratory, Pasadena CA.  
Mr. John Sonntag, NASA Wallops, VA.  
Pr. Michiel van den Broeke, Utrecht University, Utrecht, The Netherlands  
Pr. Isabella Velicogna, University of California Irvine, Irvine, CA.  
Dr. Josh Willis, Jet Propulsion Laboratory, Pasadena CA.

**University Services.**

Dean's Leadership Council, w. Dean Ken Janda, School of Physical Sciences, Oct. 17, 2017; Dec. 7, 2016; June 8, 2016; Feb. 3, 2016; Dec. 2, 2015; Jun. 10, 2015; May 6, 2015; Mar. 30, 2015 for leadership discussions and presentations.

Member of Committee on Earth Science and Applications from Space (CESAS) by the President of the National Academy of Science, Medicine and Engineering, 2017-present.

Annual Retreat and Strategic Planning of the School of Engineering, University of California Irvine, by Dean Greg Washington, Sept. 27, 2016.

National Research Council Decadal Survey, Climate Panel, 2016-2017.

Letter of Recommendation for Prof. Wolfgang Rack for Associate Professor position, University of Canterbury, New Zealand, 2017.

Letter of Recommendation for Prof. Andy Aschwangen to Associate Professor position, University of Alaska, Fairbanks, 2017.

Letter of Recommendation for Dr. Motyka as AGU Fellow. March 2017.

Letter of Recommendation for Prof. W. Abdalati as AGU Medalist, March 2017.

Letter of Recommendation for Dr. Konrad Steffen for nomination to the Alfred Wegener Medal and Honorary Membership of the European Geophysical Union, July 2016 and 2017;

Letter of Recommendation for Dr. Beata Csatho for Associate Professor position in Geophysics at Arizona State Univ., Dec. 2015;

Letter of Recommendation for Dr. Helene Seroussi for Assistant Professor position in Polar Science at SIO, November, 2015;

Letter of Recommendation for Dr. Konrad Steffen for nomination to the Alfred Wegener Medal and Honorary Membership of the European Geophysical Union, July 2015;

Letter of Recommendation for Prof. Prasad Gogineni for the Tyler Prize 2014, January, 2014;

Letter of Recommendation for Prof. Jeremy Bassis for promotion to Associate Professor, University of Michigan, January, 2014;

Letter of Recommendation for Dr. Christopher Borstad for Assistant Professor position at Svalbard University, February, 2014;

Letter of Recommendation for Dr. Michiel van den Broeke for Full Professor position in Utrecht University, July 2013;

NRC Decadal Survey in Earth Science and Applications from Space White Paper 2017-2027, Advancing Sea Level Science, R. S. Nerem, A. A. Arendt, B. D. Beckley, G. Blewitt, C. Boening, D. P. Chambers, J. L. Davis, G. Forget, H. A. Fricker, I. Fukumori, A. S. Gardner, B. D. Hamlington, P. Heimbach, D. Hill, E. R. Ivins, F. W. Landerer, R. R. Leben, F. G. Lemoine, E. W. Leuliette, S. B. Luthcke, M. A. Merrifield, G. T. Mitchum, S. Nowicki, S. O'Neel, R. M. Ponte, R. D. Ray, J. T. Reager, E. Rignot, N. Vinogradova, J. K. Willis.

NRC Decadal Survey in Earth Science and Applications from Space White Paper 2017-2027, Understanding and Quantifying Glacier Ice Dynamics for Improved Sea Level Projections, Eric Rignot, Ian Joughin, Mark Fahnestock.

NRC Decadal Survey in Earth Science and Applications from Space White Paper 2017-2027, The Lack of a Climate Observing System, Bruce A. Wielicki, Betsy Weatherhead, William Collins, V. Ramaswamy, Dennis Hartmann, Brian Soden, Tom Ackerman, Tom Karl, Kevin Trenberth, Byron Tapley, Eric Rignot, Chelle Gettleman, Michael Prather, Mark Abbott, John Bates, Robert Dick-

enson, Randall Friedl, Lee-Lueng Fu, Kathryn Kelly, Compton Tucker, Graeme Stephens, David Winker, Norman Loeb, Judith Lean, Steve Ackerman, Michael King, Joyce Penner, Robert Pincus, Greg Kopp, Peter Pilewskie, Hank Revercomb, Martin Mlynchak, David Johnson, Constantine Lukashin, William Smith, Sr., Xianglei Huang

Al Gore: <http://www.nature.com/nature/journal/v547/n7664/full/547400a.html?foxtrotcallback=true>

<https://www.nytimes.com/2017/07/28/movies/an-inconvenient-truth-al-gore-documentary-sequels.html?mcubz=3>

<http://www.elle.com/culture/career-politics/a46288/an-inconvenient-truth-sequel-feature/>

PBS/NOVA Emblematic 360 deg. Why Is Greenland Melting? FRONTLINE + NOVA + Emblematic Group <https://www.youtube.com/watch?v=YLZPZcuvsEQ> *feature =youtu.be:disable\_polymer = true*

Special Report Greenland: <https://specialreports.news.uci.edu/greenland/>

Most influential person in Orange County in 2015: <http://www.ocregister.com/2015/12/20/most-influential-2015-eric-rignot/>

GRACE <http://www.sciencemag.org/news/2017/09/satellites-measuring-earth-s-melting-ice-sheets-go-dark>

### **Invited lectures: 2007-2018**

Jan. 2018. Invited Speaker, James Arnold Lecture, University of California San Diego, CA.

Oct. 2017. Invited Panelist, Norma Kershaw Auditorium, Bowers Museum, Santa Ana, CA, "An Antarctic Panel" along with Ed. Larson, Prof. History and Law, Pepperdine Univ., hosted by Emily Mahon, Director of Education and Julia Lupton, Prof. English and Associate Dean for Research, School of Humanites, UCI, to celebrate the exposition "Endurance: Antarctic Legacy of Sir Ernest Shackleton and Frank Hurley".

Oct. 2017. Invited Speaker on Ice sheet melting and climate change, Long Beach Aquarium of the Pacific, Climate change series hosted by Jerry Schubel.

Apr. 2017. Invited Speaker, Louis Agassiz Cryosphere Medal of the European Geophysical Union, Vienna, Austria, April 27, 2017.

Nov. 2016. Invited Speaker, "Song T Lee Lecture", Antarctic Research Series, Wellington, New Zealand.

Dec. 2015. Fall American Geophysical Union (AGU) named Lecture in Cryosphere, "John Nye Lecture".

Nov. 2015. Invited Speaker at the College de France, Paris, by Edouard Bard under the leadership of French President Francois Hollande, in preparation for the United Nations (UN) Framework on Climate Change COP21 (Paris Agreement on Climate Change discussed and ratified by 190 countries) under the theme of "Climate, Society and Energy".

Feb. 2015. Invited Speaker, Oxford University, UK, Department of Earth Sciences.

Dec. 2014. Invited Speaker, Fall AGU Meeting, San Francisco, CA (IN34A-03, C51C-01)

Feb. 2014. Invited Speaker, Stanford University, Department of Physics and Earth Sciences, CA.

Sept. 2014. Invited Speaker, West Antarctic Ice Sheet meeting, Scripps, San Diego, California.

Jan. 2014. Invited Speaker, ICESat-2 Science Team Meeting, Scripps, San Diego, California.

Dec. 2013. Invited Speaker, Fall AGU Meeting, San Francisco, CA (C018).

Oct. 2013. Invited Speaker, California Institute of Technology, Sleeping Giants in Antarctica, KISS center.

Dec. 2011. Invited Speaker, Fall AGU Meeting, San Francisco, CA (C12A, PA23B).

Oct. 2011. Invited Speaker, UCI Newkirk Center, "Glacier Melt, Early Snowmelt, and Sea Level Rise: Toward a Sustainable 21st Century Series", Oct. 21.

Oct. 2011. Invited Speaker, JPL and Caltech Seminar Series, Sponsored by the JPL Office of the Chief Scientist and Chief Technologist.

Aug. 2011. Invited Speaker, JPL Climate Center Sea Level Workshop. Keynote Lecture on Ice Sheet Mass Balance.

Dec. 2010. Invited Speaker, Fall AGU Meeting, San Francisco, CA (C22B, C12B).

June 2010. Invited Speaker, IPCC Workshop on Sea Level Rise, Kuala Lumpur, Malaysia, T. Stocker, WG1 Chair.

Feb. 2010. Invited Speaker, Department Seminar, Department of Geosciences, Princeton, invited by Michael Bender.

Jan. 2010, Invited Speaker, Department of Earth Sciences, Rice University, invited by Jon Anderson.

Dec. 2009. Invited Speaker, Fall AGU Meeting, San Francisco, CA (G52A, C42A).

Aug. 2009. Changes of the Greenland Cryosphere, invited lecture by R. Forsberg, Nuuk, Greenland, Aug. 25-27. "Rapid submarine melting of the calving faces of Greenland tidewater glaciers."

Aug. 2009. Department lecture, University of Udine, Italy, Department of Physics, invited by Alessandro de Angelis. "Ice sheet melting and the future"

Aug. 2009. Invited seminar, Laboratoire de Glaciologie Grenoble (LGGE), invited by Emmanuel LeMeur. "Ice sheets and sea level rise".

Aug. 2009. Invited lecture on ice melting, Chambon sur Lignon, France, invited by Gerard Bollon. "Fonte des glaces: Quel futur".

Jul. 2009. IPCC AR5 Scoping Meeting, Invited Expert, invited by Thomas Stocker, Chair Group I. "Review of ice sheet melting and contribution to sea level change". Member of ice sheet instabilities and sea level change sub-committee (6 members).

Apr. 8th, 2009. Invited Lecture on ice sheets and sea level, Orange Coast College for OCC Environment Day, "Glaciers and Global Sea Level Rise", invited by Tom Garrison.

Mar. 14, 2009. Invited lecture by Ann Henderson-Sellers, Session 9 "Detection and attribution: state of play in 2009", Climate change, Global risks, challenges and decisions, March 12-14 2009, Copenhagen, in preparation for COP15 Dec. 2009. "What are the large ice sheets in Greenland and Antarctica doing now".

Mar. 31, 2009. Lecture on ice sheets, UCI Breakfast Series, invited by Dean of Physical Sciences. "Measuring ice sheets".

Feb. 2, 2009. Lecture on ice sheets, Oregon State University, invited by P.U. Clark. "Evolution of ice sheets and glaciers in a warming climate". Colloquium Series on Global Climate Change.

Feb. 2009. Division Seminar, Caltech, invited by P. Wennberg and Le Kuai. "Evolution of ice sheets and glaciers in a warming climate: What is going on".

Dec. 2008. Fall AGU Meeting, San Francisco, CA. William Bowie Named Lecture, Geodesy Section.

Dec. 2008. Fall AGU Meeting, San Francisco, CA. Two invited lectures (CO4 and G23).

Apr. 2008. Invited Lecture, JASON Advisory Group to the U.S. Government, invited by P. Dimotakis. "Evolution of the Greenland and Antarctic ice sheets in a warming climate: Lullabies and reality."

Dec. 2007. Fall AGU Meeting, San Francisco, CA. Two invited lectures (G53A-05 and PP53B-01).

## **Teaching**

EarthSS60A: Earth and Environmental Studies (undergraduate)

EarthSS138: Remote sensing (undergraduate)

EarthSS238: Remote Sensing (graduate).

EarthSS202: Climate Change (graduate).

EarthSS215: Cryosphere (graduate).

EarthSS280: Cryosphere topics (graduate).

### **Other Services**

Chair, Department of Earth System Science, School of Physical Sciences, Oct. 1, 2017 - present.

Invited Speaker, NASA Student Airborne Research Program (SARP), UC Irvine, Jul. 2012, 2013, 2014, 2015, 2017. SARP invites highly motivated advanced undergraduates to participate in a summer NASA research program and fly on a NASA airborne mission. Dr. Emily Shaller, Manager.

Invited Scientist. White House Arctic Ministerial, Hosted by John Holdren, White House, Washington DC, Sept. 27, 2016.

Invited Speaker. Retreat of the School of Engineering, Sept 8, 2016, The Challenges of Climate Change.

Vice-Chair of Graduate Studies, Department of Earth System Sciences, UC Irvine, Sept. 2013- July 2015.

Graduate Student Admission Committee, Earth System Science, UC Irvine, 2012-present.

Chair Graduate Student Committee 2013-2015.

Member of Award Committee, Earth System Science, UC Irvine, 2012-2015.

Co-Director of the UC Irvine/Caltech's Jet Propulsion Laboratory's Ice Sheet System Model Center (<http://www.issm.jpl.nasa.gov>) funded by JPL Research and Technology Development, NASA's Cryospheric Science Program, NASA's Modeling Analysis and Prediction Program (MAP), and the National Science Foundation Office of Polar Program, in partnership with the "Estimating the Circulation and Climate of the Ocean, Phase II and III (ECCO2 and 3)" Project funded by NASA (<http://ecco2.jpl.nasa.gov>) and multiple universities (MIT, AWI, Harvard, UCLA, etc.).

Invited Speaker, Dean's Leadership Council, School of Physical Sciences, UC Irvine, May 2015.

Panel Member, Arctic Expedition Film Premiere, School of Physical Sciences and School of Biological Sciences, UC Irvine, Nov. 2014.



Invited Speaker, Governing Board of the National Academy of Sciences, Beckman Center of the National Academies, UC Irvine, Feb. 2014.

Invited Speaker, Aquarium of the Pacific's Aquatic Academy Course, Long Beach, CA, Feb. 2013.

Invited Speaker, Research and Distinguished Speakers, Pacific Club Luncheons, Apr. 2012.

Invited Speaker, Smart Energy and Sustainable Environment Luncheon, Beckman Center of the National Academies, UC Irvine, Feb. 2012.

**Workshop organizations. 2008-2017**

June 2017. Host 2nd Science Meeting of Earth Venture SubOrbital Mission (EVS-2) Ocean Melting Greenland (OMG), UC Irvine June 22-23.

Jun. 2012-2018. Mission Planning Meeting for NASA's Mission Operation IceBridge Science Team Meeting for Antarctica, UCI (7th Annual Meeting).

Dec. 2016. Fall American Geophysical Union (AGU) Meeting. Organized, Convened and Chaired one session; Held NASA/OIB Town Hall Meeting.

Dec. 2015. Fall AGU Meeting. Organized, Convener and Chair two sessions; Held NASA/OIB Town Hall Meeting.

Dec. 2014. Fall AGU Meeting. Organizer, Convener and Chair of sessions C21B, C23B, C24B, C34B, and OIB Town Hall Meeting TH13G.

Dec. 2012. JPL/UCI Ice Sheet System Model (ISSM) Open Source, Second International Workshop, hosted at UCI and co-sponsored by NASA, NSF OPP and CliC.

Dec. 2011. Fall AGU Meeting. Session Organizer, Convener and Chair of C18 and C24.

Dec. 2011. JPL/UCI Ice Sheet System Model (ISSM) Open Source First International Workshop, hosted at JPL.

Oct. 2011. Worked with John M. Whiteley to organize the program on Snowmelt and Glacier Melt with Implications for Human Security and Ecosystem Sustainability (Oct. 21, 2011) at Arnold and Mabel Beckman Center of the National Academies of Sciences and Engineering in Irvine, California

Aug. 2011. JPL Climate Center's Sea Level Workshop.

Jun. 2011. NASA IceBridge Mission Planning meeting at UC Irvine, CA.

Jan. 2011. NASA IceBridge Mission Planning meeting at NASA GSFC, MD.

Dec. 2010. Fall AGU Meeting. Session Organizer and Convener C14 and C21.

Dec. 2009. Fall AGU Meeting. Session Organizer and Convener C05 and G03.

Jul. 2009. Lead Convener IACS Symposium, MOCA, Montreal July 19-24 2009, Session J09, "The Contribution of Greenland and Antarctica to Fresh Water Input to the Ocean and Sea Level Change"

Dec. 2008. Fall AGU Meeting. Session Organized and Convener C31 and C43.

Jun. 2008. Antarctic Peninsula Climate Change 5th International Workshop (APCC5) hosted at University of California Irvine, ESS, June 24-27, 2009, and sponsored by NASA, NSF and IGPP.

**EXHIBIT C: LIST OF PUBLICATIONS (LAST TEN YEARS)****Peer-Reviewed journal publications**

- 2007 A. Khazendar, E. Rignot, E. Larour, Larsen B Ice Shelf rheology preceding its disintegration inferred by a control method, *Geophys. Res. Lett.*, **34**(19), L19503, doi:10.1029/2007GL030980.
- 2008 E. Rignot and K. Steffen, Channelized bottom melting and stability of a floating ice shelf in northwestern Greenland, *Geophys. Res. Lett.*, **35**, L02503, doi:10.1029/2007GL031765.
- 2008 E. Rignot, J. Bamber, M. van den Broeke, C. Davis, Y. Li, W. van de Berg, E. van Meijgaard, Recent mass loss of the Antarctic Ice Sheet from dynamic thinning, *Nature Geosc.* **1**, doi: 10.1038/ngeo102
- 2008 E. Rignot, Changes in West Antarctic ice stream dynamics observed with ALOS PALSAR data. *Geophys. Res. Lett.*, **35**, L12505, doi:10.1029/2008GL033365.
- 2008 E. Rignot, J. Box, E. Burgh, E. Hanna, Mass balance of Greenland glaciers from 1958 to 2007, *Geophys. Res. Lett.*, **35**, L20502, doi:10.1029/2008GL035417.
- 2009 H. Conway, B. Smith, P. Vaswani, K. Matsuoka, E. Rignot, P. Claus, A low-frequency ice-penetrating radar system adapted for use from an airplane: test results from Bering and Malaspina Glaciers, Alaska, *Ann. Glaciol.*, **51**, 93-97.
- 2009 G. Casassa, Krabill, W.; Rivera, A.; Wendt, J.; Wendt, A.; Lopez, P.; Bown, F.; Rignot, E.; Thomas, R.; Yungel, J.; Sonntag, J.; Frederick, E.; Russell, R.; Linkswiler, M.; Arendt, A.; Steffen, K., The Patagonian icefields: an updated assessment of sea level contribution, *IOP Conference Series: Earth and Environmental Science*, **6**, 012006.
- 2009 Van den Broeke, M. R., J. L. Bamber, J. Ettema, E. Rignot, E. J. O. Schrama, W. J. van de Berg, E. van Meijgaard, I. Velicogna and B. Wouters, 2009: Partitioning recent Greenland mass loss, *Science*, **326**(5955), 984-986.
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**EXHIBITS E–R: VIDEO EXHIBITS**

Exhibits E through Q are all video exhibits, attached hereto via Dropbox. Exhibit R is a spreadsheet providing the precise data and information about each of the Exhibits E-Q, and is also attached hereto via Dropbox.

## EXHIBIT I for Dr. Eric Rignot



## EXHIBIT J for Dr. Eric Rignot Chaney Glacier, Glacier National Park



**1911**

*M.R. Campbell photo*  
USGS



**2005**

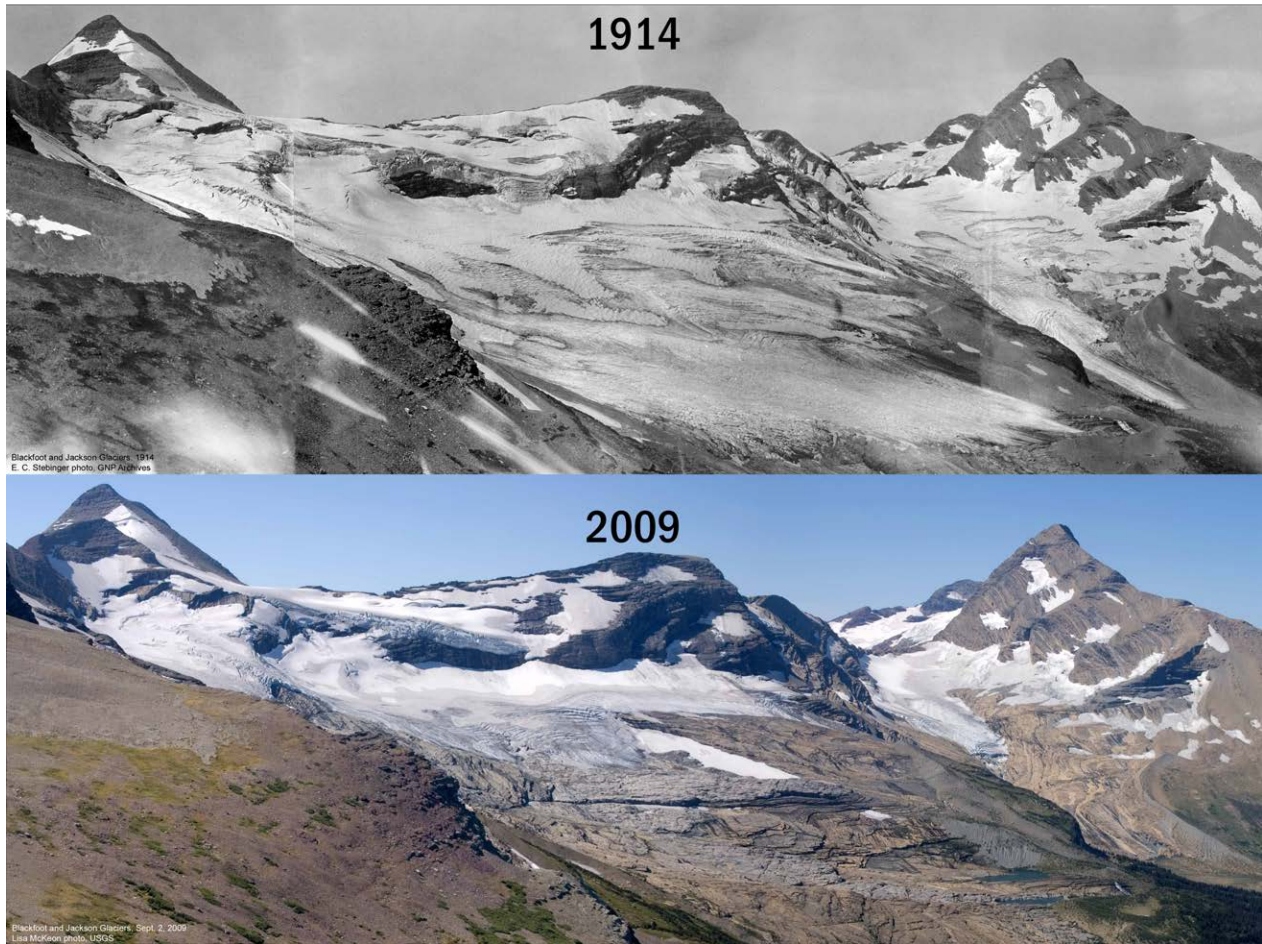
*Blase Reardon photo*  
USGS



USGS Repeat Photography Project  
<http://nrm-sc.usgs.gov/repeatphoto/>



**EXHIBIT K for Dr. Eric Rignot**  
**Blackfoot-Jackson Glacier, Glacier National Park (1914/2009)**

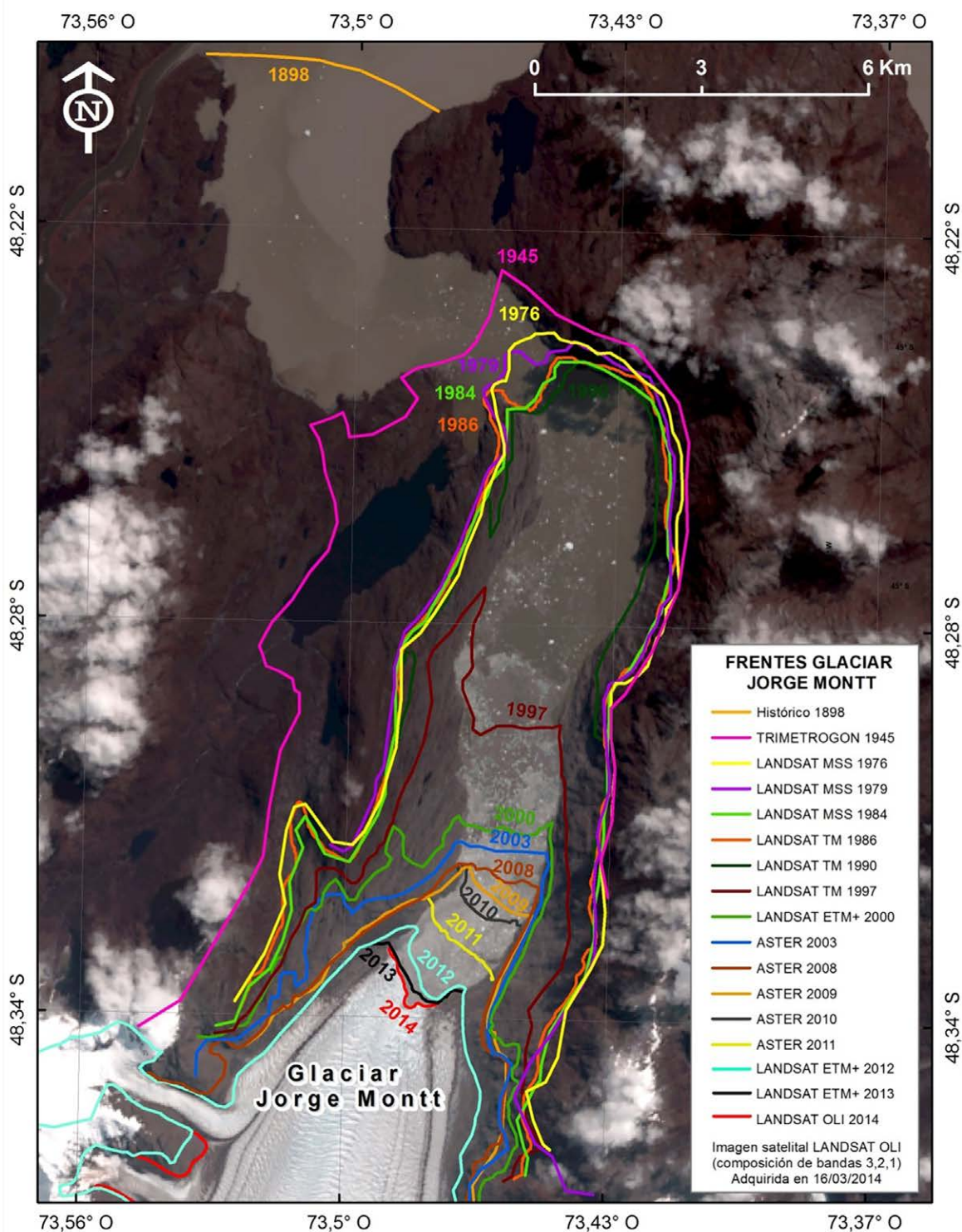




# EXHIBIT L for Dr. Eric Rignot

## Image overlay of glacial melt (1898-2014)

### Jorge Montt Glacier, Chile



## EXHIBIT O for Dr. Eric Rignot

### Wordie Bay Ice Sheet Changes 1989-2009

