Personal Statement, K. Kochanski

Human societies are deeply shaped by the landscapes around them. Colorado's roads, for example, follow river-carved valleys through the Rockies. Those same rivers send water and soil down to the fertile Midwestern Plains. In turn, those farmlands rely on the snowfields of the Antarctic that, far away and untouched by humans until 1895, reflect solar radiation and keep our climate mild.

I became a geomorphologist to study natural processes like these. My first goal is to protect our society by increasing the scope and accuracy with which we can predict environmental change. My second is to create and share a truly global Earth Science across all cultural barriers.

1 Discovering Geology

Earth Science crossed my intellectual horizons in my second year at MIT. I was then majoring in Physics and working in an astrophysics lab, where I **calibrated a prototype x-ray polarimeter**. I enjoyed working with optics, and successfully tripled the machine's throughput, but I had started to lead hikes with the MIT Outing Club and wanted to learn what was under my feet. I took Introductory Geology and have been captivated by geoscience ever since.

My first geoscience research project began immediately afterwards, in January 2013 . Under Prof. Leigh Royden. I **built a 3D model to predict the flow of material under the Tibetan Plateau**. We estimated that modern topography could only be formed if the lower-crustal viscosity was less than $10^{17}\mathrm{Pa}\cdot\mathrm{s}$. This project introduced me to fluid dynamics simulations and to Matlab.

That summer I **worked as a field assistant in the western Himalaya** under Prof. Oliver Jagoutz and his student Ben Klein, with funding from the MIT-India program. We surveyed the Khardung volcanics for sample sites for a paleomagnetic study. We took cores from three sites [1]. The results have now been used to constrain the rate of the Indo-Asian collision [2]. My notebook from that trip is full of lines like "Why are the granite slopes so steep here?" or, "How do streambeds form in these mountains of colluvium?". Geology gave my questions a language.

In the fall I **declared a double major in Earth Science and Physics**. I chose electives that would help me analyze the natural world: Statistical Mechanics, Classical Mechanics through non-linear dynamics, and Experimental Physics. Alongside my core classes I took Prof. Taylor Perron's Geomorphology course, seeking answers to my questions about weathering, streambeds, and glacial valleys. His descriptions still snap into my mind when I encounter a new landscape.

In January 2014 I **mapped the Piute Mountains** with five other students for a field course. The area, a part of the Mojave Desert, has a deformed metamorphic core complex which had never been mapped in detail. Grappling with it taught me to visualize complex 3D structures and to communicate them to my partners, but what most interested me was the effect the deep structures had on the surface. Early in our course, Prof. Jagoutz and I followed a fault to a high ridge. We spent our lunch break analyzing the curvatures of the hillslopes below, and trying to differentiate quartzite colluvium from finer-grained schist debris by slope angles alone.

In the winters I slowly fell for the delicate beauty of ice, which clings like crystal chandeliers to the frozen streams and branches of New England. I grew more involved with the MIT Outing Club and volunteered to lead regular hikes and maintain the club's gear. These hikes let me show beginners how to dress warmly and travel on snow-shoes so that they too could find joy in the cold.

2 Published Research Projects

2.1 Floating objects in Smoothed Particle Hydrodynamics (SPH)

My junior summer I took a fluid-dynamics focused internship at Shell's Technology Center in Bangalore. The summer had a difficult start. Visa problems forced me to fly back to the US after three days in India. To prepare for my project while waiting for paperwork, I learned C#.

At Shell I **developed a SPH code** to simulate the movement of floating objects in free-surface flows. Our test case was the impact of high waves on an offshore oil tanker. My task was to generalize Shell's in-house C# code to model multiple floating objects. During this process I discovered a problem with our boundary conditions during collisions, and modified the solver's search algorithm to prevent non-physical behavior.

My group **published our work** at an international SPH workshop in June 2015. Shell will use the results to **improve rig safety** and **reduce the risk of oil spills**. This experience with simulated floating particles will be very useful for my future research. Suspended sediment is an important part of many natural systems, including wind-blown snow. That summer I also met colleagues from across India, and learned how to wear an elegant dupatta and to brew spicy chai.

2.2 Ice Accumulation on GPS stations in Alaska

For my senior thesis, supervised by Prof. Thomas Herring, I aimed to use geodetic data to **analyze how 2015's warm winter affected Alaskan hydrology**. Warm rainfall runs off the land faster than snow, depriving spring vegetation of water, and increasing weathering rates and groundwater acidity. GPS stations can measure hydrology because the weight of water depresses the ground by 5-10mm seasonally. Stations in southern Alaska reliably oscillate in phase with snowfall [3]. I looked for recent changes in the movement of fifty GPS stations across the state.

Instead, in Northwest Alaska I **found that six stations move out of phase with snowfall** by over two months, with vertical amplitudes from 4-15mm. In winter these six stations move discontinuously, jumping over 10mm/day, and they have unusually asymmetric time-series. I formed several hypotheses for these discrepancies, including pressure fluctuations, thermal expansion, or localized loading by lakes or sea birds. However, the stations' horizontal movements were inconsistent with these hypotheses. Finally, I discovered that three of these stations are on high points on Alaska's west coast. They suffer high winds and humidity, and should accumulate thick rime.

Prof. Herring and I **demonstrated that horizontal rime causes GPS stations to appear to move vertically** by simulating signal delay in icy rime feathers using Matlab. Using multipath data, I confirmed that the signals were more scattered in winter than in summer, and verified our results by using wind speed directions to predict rime orientation at each station, confirming that these stations' apparent winter motion is indeed caused by signal delay in ice.

This project let me apply my statistics and data analysis skills to a research problem of my own. The results will **improve geodetic and hydrologic measurements** in cold climates. I will **present them at the AGU 2015 Fall Meeting** and am **preparing them for publication**.

3 Sharing science

I believe that my first responsibility as a scientist is to **communicate rigorous science**. At MIT I refined my communication skills with a Writing concentration. In addition, for three semesters I taught twice-weekly recitations for a writing-intensive philosophy class. The first semester, some students wrote incoherent midterms. To improve the class the next year, I designed three academic writing workshops, after which all my students wrote clear and effective essays.

To share my research with the public, I **give frequent public outreach lectures**, and maintain a non-technical geology blog [tinyurl.com/blog-geo]. I love to show people the world from a new perspective. My favorite lecture starts with a photo of a marine fossil from the high Himalaya, one thousand miles from the sea, then explains how it got up there. In 2015 I **received MIT's Suzanne Berger Award for Future Global Leaders** for my success in India, with both fieldwork and computational research, and for the enthusiasm with which I shared my experiences at home.

Last year I **attended the American Geophysical Union's Fall Meeting**. Presenters demonstrated an amazing array of tools, from Lidar to image-processing, which they had applied to study the Earth. I look forward to presenting my thesis there this fall.

4 Inspiring future scientists

Last summer I **taught real research skills to high school students** by working with six MIT students to organize the first Chilean Young Physicists' Tournament (YPT) at two public schools in Santiago [iyptchile.wordpress.com]. Teams of students investigated simple, unsolved problems. To progress, they reviewed literature, designed experiments, and presented their findings. My role was to design our curriculum and to mentor a team.

The local teachers were on strike when we arrived in Santiago, and the school was occupied by protesting students. I immediately **negotiated to secure lab space**. As normal classes were cancelled we arranged to teach for four hours each day for seven weeks, working in Spanish.

My students were eleven young women who had never had a hands-on class before. Our first project was to mix salt and sugar water. At first, students mixed the liquids arbitrarily, but eventually they designed a series of experiments in which they varied saltwater densities to investigate double-diffusive convection. I began to overhear, "wait, which hypothesis does that test?" and realized that they had begun to internalize the scientific process.

Between classes, the students helped me. I **learned scientific Spanish**, and how to find meeting space in Santiago when floods closed the school. Four students have now entered a chemistry competition with a plan to combat Santiago's smog. Their schools are under-funded and unreliable, but they are fighting for their educations, and I am more than proud to have helped them.

5 Future goals

CU-Boulder's Department of Geological Sciences is home to exceptionally lively geomorphology and Arctic research communities. Here, I have support to develop both my quantitative skills and my understanding of the Earth. My peers share my love for the science of the natural world and encourage me to pass that love on to younger students.

To use my Spanish teaching experience and **engage with Hispanic students**, I have volunteered to be a science fair judge for the Bryant-Webster Dual Language ECE-8 School.

My main outreach project is to **create a local Young Physicists' Tournament**. To begin, I will design and teach a weekly YPT course this winter. Teams of 3-5 students will undertake open-ended science projects, such as to pull a horizontal frisbee out of a water trough and investigate the vortices beneath it. I have discussed this plan extensively with CU's Science Discovery, who are excited to host a new hands-on course. We are aiming the class at home-schooled students, who typically have few opportunities for team work.

The International YPT draws teams from 30+ countries, but the USA has participated only once since 2006. I have talked with two other fledgling US YPT groups. We hope to collectively field an international team in 2017 to **develop the next generation of globally engaged scientists**.

My two major career goals are to improve our scientific and public understanding of our environment, and to inspire younger scientists who will develop that understanding even further. I am pursuing those goals with every resource available to me through CU. An NSF GRF would give me financial freedom to focus on my work until I attain them.

[**1**] Bailey, E. & Weiss, B. B.Sc. thesis, MIT, 2014. [**2**] Jagoutz, O., Royden, L., Holt, A.F. & Becker, T.W. *Nature Geoscience*, **8**, 2015. [**3**] Fu, Y., Freymueller, J.T. & Jensen, T. *Geo. Res. Letters*, **39**, 2012.

The geometry and evolution of aeolian snow bedforms

Looking upwind at sastrugi. R. Anderson, Niwot Ridge, CO.

When the wind picks up snow, it whirls through the sky - except in Terre Adélie, Antarctica, where freezing air falls 3200m from the Antarctic Plateau to the Dumont D'Urville Sea. The katabatic winds that result are the strongest and most persistent on Earth, with average windspeeds of 19.5m/s[1]. If you placed a metre-stick on that ground, over 10^6kg of snow would blow across it in one year [2].

Blowing snow moves by the same processes as aeolian, or wind-blown, sand: saltation, suspension, and creep. Like sand, snow deposits form ripples and dart-like barchan dunes. But unlike sand, little attention - from numerical, laboratory or field workers - has been given to snow. Yet snowy landscapes are beautifully self-organized and possess unique physical properties. Given time, snow grains sinter and solidify. They form hard surfaces which the wind scallops and abrades into orderly, elongate sastrugi [3]. These features often form in the course of a single storm, so we can easily watch them evolve.

Places with katabatic winds, like Terre Adélie and certain parts of the North American Rockies, are natural laboratories for aeolian snow transport. Moreover, snow surfaces influence the climate of Antarctica, as I explain below. This landscape is a crucial testing ground for aeolian geomorphology.

1 Simulation of snow bedform evolution

I propose build a model that will characterise the roughness and geometry of snow bedforms.

Research aim — to lead us towards a process-based understanding of snow surfaces, to characterise the geometry of snow bedforms, and to improve the accuracy of polar climate models.

Software — I will build the simulation with LIGGGHTS [4], which is a community-standard computational fluid dynamics (CFD) package. The software is suitable because it can simulate turbulent air; track suspended snow grains; and detach particles from a solid bed. It is open-source, so I can edit it with C++. I will modify one of the program's built in cohesion functions to make snow grains sinter. My second choice software is called OpenFOAM.

Skills — I am proficient in Python, Matlab and C#. In 2014 I worked on a similar project at Shell, where I modified CFD software to model floating bodies in water. My advisor, Robert Anderson, has worked extensively on both aeolian transport and polar landscapes.

Computing — I have access to CU's Community Surface Dynamics Modeling System (CSDMS) 704-core high performance computing cluster 'beach'. If this is insufficient, I can gain access to CU's NSF-supported 16,416-core supercomputer 'Janus'. An NSF GRF would provide access to XSEDE and further expand my computational resources.

2 Validation case studies

Terre Adélie, Antarctica — [2] took extensive measurements of aeolian snow transport in Terre Adélie. They provide good lower-bounds for snow mass flux at various wind speeds, and estimate the shear stress exerted on snow beds by the wind. I will use this data to verify that my model is robust in extreme wind and cold, and therefore useful for polar climate models.

Barker Reservoir, CO — This reservoir, whose frozen surface is host to barchan snow dunes every winter, is only 15 miles from the University of Colorado (CU). With an undergraduate field assistant, I will monitor weather data and aeolian snow fluxes on the reservoir next winter. At every visit we will measure the positions and sizes of the dunes. My model must produce dunes within the natural variability. This will be the first data set to document the evolution of snow bedforms.

3 Applications of the model : Intellectual merit

Hypothesis 1: Bedforms control the characteristic roughness length of snow surfaces
Surface roughness, which controls near-surface wind speeds and turbulence, is a major source of uncertainty in polar climate models [5]. I will have the first simulation that can resolve boundary-layer turbulence around snow bedforms, which are the dominant roughness feature on many ice shelves and plateaus. Modellers will be able to use my results to estimate the size of bedforms in their region and thereby choose a realistic roughness length and turbulence model. This will improve the accuracy of aeolian snow flux and climate models of the polar regions.

Hypothesis 2: Wind speed and direction can predict the reflectance of snow surfaces
The shadows of linear sastrugi cause the reflectance of snow fields to vary by 10% as a function of the azimuthal angle between the sastrugi and the sun [6]. Using the best current observations, this bias still skews radiation-balance calculations by -5 to $7\mathrm{Wm}^{-2}$ [7]. This is approximately 2% of Antarctica's net summer radiation. I will combine my field measurements with simulation results to create a database of sastrugi orientations and geometries. This will allow me to model the of sunlight scattered from the bedforms and to provide climate modellers with a full picture of the reflectance of snowy surfaces.

Hypothesis 3: Snow dunes increase the fraction of sea ice covered by spring melt ponds
Snow insulates sea ice from warm air and delays melting. In spring, melt ponds form on sea ice in the bare spaces between snow dunes [8]. Ponds have a lower albedo than the ice and accelerate melting. I predict that high wind speeds will consolidate snow, expose more underlying ice, and increase the area of the ponds. The variability of snow cover may be as important to sea ice preservation as the snow depth. My results will quantify that variability.

4 Broader impact strategy

This research plan targets three major sources of uncertainty in polar climate models. Improving the accuracy of these models will help us to **anticipate the effects of our changing climate**. Moreover, predicting sea ice melt rates is important for Arctic transport, shipping and drilling.

To **communicate my results**, I will publish in journals and at conferences, and will give regular talks to local polar researchers at INSTAAR and the National Snow and Ice Data Center.

The Colorado Front Range experiences katabatic winds when cold air flows down from the Rockies. I will **engage local teachers** by explaining this local weather on CU's Portal to the Public, and **make my work publicly accessible** by showcasing Barker Reservoir on my blog [tinyurl.com/blog-geo] and uploading photos and animations to [tinyurl.com/csdms-edu].

Finally, as detailed in my personal statement, I am offering a new hands-on course through CU's Science Discovery Program. The course is modelled after a 6-week program I organized and taught last summer, and is designed to **teach research skills to high-school students**.

[**1**] Parish, T. & Bromwich, D. *Nature*, **328**, 1987. [**2**] Trouvilliez et al. *Cold Regions Sci. and Tech.*, **108**, 125-138, 2014. [**3**] Filhol, S. & Sturm, M. *J. Geo. Res. Earth Surf.*, **120**, 2015. [**4**] Christoph, K., et al. *Progress in CFD, An Int. J.*, **12**(2/3), 140-152, 2012. [**5**] Amory, C. et al. *The Cryosphere*, **9**, 1373-1383, 2015. [**6**] Warren, S. & Brandt, R. *J. Geo. Res.*, **103**(E11), 25789-25807, 1998. [**7**] Corbett, J. & Su, W. *Atm. Meas. Tech.*, **8**(8), 3163-3175, 2015. [**8**] Petrich, C. et al. *J. Geo. Res.*, **107**(C09029), 2012.

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit

Excellent

Explanation to Applicant

The applicant has strong research experience and numerous accomplishments. The applicant seeks to build a model that will characterize the roughness and geometry of snow surfaces. Applicant also has extensive modeling experience and seeks to take advantage of the additional computational resources that a GRF would provide access to.

Broader Impacts Criterion

Overall Assessment of Broader Impacts

Excellent

Explanation to Applicant

Broader impacts are excellent and include improve the accuracy of polar climate models, communicate results to National Snow and Ice Data Center, engage local teachers, make work publicly available on a blog, and a hands-on course through CU's Science Discovery Program.

Summary Comments

The applicant has strong qualifications and reference letters. The student is well qualified to conduct the proposed research and both statements are well written and clear.

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit

Excellent

Explanation to Applicant

Kelly Kochanski's proposed project is on the geometry and evolution of eolian snow bedforms, such as sastrugi, in the Antarctic. The project combines a software model for bedform evolution with empirical field data from the Antarctic and a local site in Colorado. I expect the model to be sophisticated and of the highest quality; Ms. Kochanski has a undergraduate double major in physics and geology from MIT and has extensive experience in modeling and programming. She has also had direct field experience and data gathering in the Himalayas, Alaska, and the Mohave, so she combine superb technical skills with empirical knowledge. She has presented her Alaska research at AGU. I am confident the current project will present high quality results of broad interest.

Broader Impacts Criterion

Overall Assessment of Broader Impacts

Excellent

Explanation to Applicant

The applicant has an exemplary record in outreach. She went ot Santiago, Chile to work with students in two public schools and is planning to use this as the basis for a new hands on course for students near rhe University of Colorado. She has also given outreach lectures and maintains a very attractive blog.

Summary Comments

Ms. Kochanski is a superb candidate for the GRFP. She excels in both of the main criteria.

Intellectual Merit Criterion

Overall Assessment of Intellectual Merit

Excellent

Explanation to Applicant

This applicant proposes to build a model to characterize the roughness, geometry and evolutions of Aeolian snow bedform. The proposal will use direct observations from two test sites, one in Antarctica and another one in Corolado, to test several hypotheses related to snow bedforms. The proposal is very well organized, with research aim, testable hypotheses and needed resources clearly articulated. The applicant has a strong academic background with nearly perfect GPAs from MIT, and has gained several research and field experience in the past. In addition, the recommendation letters were also very strong.

Broader Impacts Criterion

Overall Assessment of Broader Impacts

Excellent

Explanation to Applicant

The proposed work would help to reduce uncertainties in polar climate models, and hence could help to better predict the effects of climate changes on sea ice melts. The applicant plans to find multiple ways to make the work publically available via online blog and local teachers. Finally, the applicant plans to teach research skills to high-school teachers. All these activities help to promote science to general public, as well as helping training teachers for bringing STEM to future generations.

Summary Comments

This is a very strong proposal that deserves the highest priority of support. The applicant has ample research experience in the past, strong academic background, and support from the university and advisors to assure success in the proposed work.