EARTH AND SPACE SCIENCE **Autumn 2019**
505 *THE CRYOSPHERE* 4 Credits, SLN 15015

ESS 505 The Cryosphere – Term Project and Paper

For ESS 505, 10% of your final grade is comprised of a term paper and presentation. The objective of this project is to allow graduate students to further explore a cryospheric topic of interest and gain experience in preparing research for presentation and publication. Projects may review a current research field, summarize the historical development of an important idea, continue dissertation (or degree) research, or develop new ideas for research in the cryosphere. The exact choice of topic is free to the student in consultation with the course instructor.

Term Paper Format: The final paper should be the format, style, and length equivalent of a publication in *Geophysical Research Letters* or *Geology*. Both journals aim to rapidly publish short-format, high-impact research of interdisciplinary interest. Paper length should be approximately 2000 to 2500 words (~4 formatted pages), including the abstract (250 words or less), but excluding figure/table captions, citations, and references. Approximately four display items (figures or tables) can be included. No more than 30 references should be cited. If data and/or new computational methods are presented in the paper, information on data/computational code availability should be given. Supplements/appendices can be used to further explain mathematical or other background information and allow presentation of additional data, but the paper should be written such that this information is truly supplemental and is not essential to understand the main conclusions. Both *Geology* and *Geophysical Research Letters* provide manuscript templates to aid in formatting.

Oral Presentation Format: You will also give a (12-minute) oral presentation in the final discussion section of the course. The format should be similar to that of a talk given at the American Geophysical Union (AGU) fall meeting, Geological Society of America (GSA) annual meeting, or another international conference. The presentation should be accessible to anyone with an undergraduate degree in geology or a related field, but also present information of interest to specialists. Generally, the presenter spends 2 to 3 minutes introducing the topic, 8 minutes discussing the study and its results, and 2 to 3 minutes summarizing the study (with emphasis on the impact of the results). If there is sufficient time, a few questions are permitted. In our case, we will allow 3 to 5 minutes of questions. Tentatively, presentations are planned for the final lab section (Friday December 6th 2019).

Topic Selection and Work During the Semester: Please select a topic by the discussion section on Friday October 11th. Turn in half a page with cryospheric topic of interest, an idea or question to investigate, and a few bullets detailing your general approach. We will meet approximately once a week (after Friday lab or at another scheduled time) to discuss progress and/or issues. You are free to change topics as your work progresses.

Example Topics:

1. **Arctic vs. Antarctic sea ice extent.** During the last forty years, Arctic sea-ice extent has dramatically declined (roughly 3 to 4% per decade) while Antarctic sea-ice extent has slightly expanded (roughly 1% per decade). What are the reasons for this disparity? How do you expect sea-ice concentration and extent to change in the next century? What impacts will these changes have on regional and global climate?

2. **Extent of the Greenland ice sheet during the Eemian.** During the last interglacial period (the Eemian; 130-115 kyr before present), global sea level was likely >6 m higher than it is today. A reduced Greenland ice sheet could have contributed to this past sea-level high stand, but current estimates of past Greenland ice-sheet size vary widely. Is contribution from Greenland alone sufficient to explain the sea-level high stand? If not, what sources are implicated to supply the additional water? What does this imply about ice-sheet behavior in the coming centuries?

3. **Incorporation of calving processes into ice-sheet models.** A general calving law that can be easily implemented in ice-sheet models remains elusive. Recently, several parameterizations have been introduced into ice-sheet models that greatly effect ice-sheet evolution simulations on multiple timescales. Discuss the strengths and weaknesses of calving parameterizations. Introduce your own?

4. **Glacier response to anthropogenic climate change.** Glaciers are often cited as the bellwether of anthropogenic climate change. However, glacier response occurs on multiple time scales and there is significant internal variability in glacier systems. Is an unambiguous anthropogenic signal detectable in recent glacier behavior (regionally or globally)? If not, when might we expect one?

5. **Glacier basal rheology.** Basal shear stress (resistance to flow at the base of a glacier or ice sheet) is often represented as a power law rheology. Explain the strengths and weaknesses of this model. How does a more-linear (lower exponent) or more-plastic (higher exponent) basal flow law affect ice-sheet stability?

6. **Ice/water interactions in icy planets (moons).** What phases of ice are expected? How do we detect them? What are their implications for existence of oceans and/or tectonic processes?

7. **Clathrates under Antarctica.** What are possible rates of methanogenesis in sub-Antarctic marine sediments? At what depths do pressure/temperature conditions favor methane hydrate formation in East and West Antarctica? How large are (sub)Antarctic hydrate accumulations and how do they compare to recent estimates made for Arctic permafrost? What is the prognosis for methane release during ice-sheet wastage and is there evidence of past positive feedback on climate warming when the ice sheet was smaller?

8. **Orbital vs. greenhouse gas forcing.** During the past 3 million years, climate has been dominated by ice-age cycles with periodicities generally predicted by Milankovitch (orbital forcing). How large was the impact of orbital forcing prior to the onset of Greenlandic (~3 Myr before present) and Antarctic (~35 Myr before present) glaciation? Can orbital forcing trigger other large, rapid climate changes that are not associated with ice sheets? What elements of the cryosphere would this involve, has it happened in the past, and what does it imply for the future?

9. **Retreat of the West Antarctic ice sheet since the Last Glacial Maximum.** The grounding line of the West Antarctic ice sheet extended nearly 1300 km farther seaward at the Last Glacial Maximum (about 20 kyr before present) than today. Some have posited that grounding-line retreat in the Ross Embayment followed a swinging-door pattern, with much greater retreat occurring along the Trans-Antarctic Mountains (the western boundary of the Ross ice shelf) than the eastern boundary of the ice shelf. Others dispute this hypothesis by claiming it is biased by limited, sparse data. What data would you collect to help resolve this disagreement? Where would you collect it?

10. **Radar interferometry studies of local glaciers.** The department has recently purchased a terrestrial radar interferometer. Propose a plan to deploy this instrument to study glaciers in the US Pacific Northwest. What processes would you propose to study? How might these data benefit satellite interferometry studies of glaciers and ice sheets elsewhere?

11. **Future snow droughts?** In 2015, snowfall (water equivalent) was only about 5% of the 1971 to 2000 average. Was this year truly anomalous or is it a harbinger of winters to come? How would you advise Seattle water managers concerning long-term adaptation scenarios?

12. **Avalanches and glacier mass balance.** Avalanches impact glacier mass balance through significant mass addition. Where might this be an especially important factor? What other effects on glacier mass balance do avalanches have besides direct mass input?