Rating: Very Good

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

+ The group intends to create LEAPangeo, and open cloud-based resource, that will be valuable to ML and geoscience researchers.
+ They plan to develop and refine ML algorithms to improve climate models.
+ They will identify and collect new data and evaluation techniques.
+ Plan to create connections worldwide among academic, industrial and public institutions to tackle climate change.
+ LEAP consists and a highly interdisciplinary and accomplished group of scientists that as a group bring the skills and experience necessary to achieve their goals.
- Can they organize themselves to be an effective coalition of researchers,
+ Organized to address different data domains from rich to moderate to poor with different strategies for making progress.
- Integration is potentially the weakest aspect of LEAP

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

+ Successful research outcomes in LEAP will contribute to health, the economy, safety, general well-being, etc.
+ LEAP will be positioned to train the next generation of climate scientists
+ Their connection to six of NSF's Big Ideas will impact research and society
+ They have good connections with to organizations that can affect public policy.
+ The focus on new programs, recruiting, and exe3cutive training are promising if not truly novel.

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

1. Rationale for an STC:
Does it Suggest and explore creative, original, or potentially transformative concepts
LEAP will examine how to improve climate model precision, scale, and data utilization by applying machine learning (ML) and transferring to public policy. They make a strong case to justify the large-scale investment in the center. A STC may be the appropriate vehicle, but some concern about the size and distribution of researchers. If successful, the anticipated scientific and societal legacies substantive and transformative in addressing this important issue.
Intellectual Merit (Rationale)
The group intends to create LEAPangeo, and open cloud-based resource, that will be valuable to ML and geoscience researchers.
They plan to develop and refine ML algorithms to improve climate models.
They will identify and collect new data and evaluation techniques.
Broader Impacts (Rationale)
Successful research outcomes in LEAP will contribute to health, the economy, safety, general well-being, etc.
LEAP will be positioned to train the next generation of climate scientists

2. Research plan
Again, LEAP has the potential to achieve significant strategic outcomes. The note that their research plan addresses six of NSF's Big Ideas: harnessing the data revolution; creating mid-scale infrastructure; growing convergence research; addressing the future of work (in the climate domain); addressing Artic issues; and creating a diverse workforce. Th proposal attempts to make a case for the feasibility of significant progress over the next five years with a concern of how to organize such a large and distributed

group into a cohesive research team.

Intellectual Merit (Research Plan)
Plan to create connections worldwide among academic, industrial and public institutions to tackle climate change.
Broader Impacts (Research Plan)
Their connection to six of NSF's Big Ideas will impact research and society

3. Partnerships and Participants
The team consists of six academic, 2 national lab, and five administrative partner organizations and 48 researchers. If managed appropriately, this highly qualified team can be successful in achieving their proposed outcomes. They note that LEAP will be different but complimentary to other efforts such as CLIMA, VULCAN, etc. and that LEAP team members are involved in many of these activities.

Intellectual Merit (Partnerships)
LEAP consists and a highly interdisciplinary and accomplished group of scientists that as a group bring the skills and experience necessary to achieve their goals.
Can they organize themselves to be an effective coalition of researchers,
Organized to address different data domains from rich to moderate to poor with different strategies for making progress.
Broader Impacts (Partnerships)
They have good connections with to organizations that can affect public policy.

4. Integration Strategies
The big challenge will be to promote a center culture among 48 researchers spread across more than a dozen institutions, Not clear that Gentine has the experience and skills to manage a Center of this scale. The management team includes first rate scientists, but center management is a significant challenge. It is not clear that the proposed Center management have the experience and capacity to "manage a complex, multi¬faceted, and innovative enterprise that integrates research, education, broadening participation, and knowledge transfer." The overlapping team structure seems promising, but there are a lot of committees. Is it a center that is more than just the sum of the parts?

As to the proposed education programs, these seem to be relatively standard approaches with a focus on recruiting. The partnership will support knowledge transfer. Again, their broadening participation strategy focuses on recruiting. The management team is gender balanced, but lacking of POC except in the "equity officer" role. I do believe that the research, education, knowledge transfer, and broadening participation are embedded and integrated in the proposed Center, There are adequate proposed resources.

Intellectual Merit (Integration)
Integration is potentially the weakest aspect of LEAP
Broader Impacts (Integration)
The focus on new programs, recruiting, and exe3cutive training are promising if not truly novel.

Summary Statement

This addresses an important area, has assembled a stellar team, and has a good plan of action and desired outcomes. The primary question is whether they are appropriately structured and led to achieve their goals.

Rating: Very Good

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

The LEAP proposal focuses on what it calls the ``parameterization deadlock''. Earth System Models (ESMs) will likely never be able to resolve all the processes involved in setting the climate response to changes in external forcing, e.g human emissions of greenhouse gases, or changes in land use. At the spatial resolutions likely achievable over the next decade we will be parameterizing key processes in the atmosphere, ocean, and land surface. LEAP will use machine learning (ML) techniques to derive parameterizations of these processes leveraging new observational data and high resolution models. Even after extensive observational and theoretical effort at the process level, there remains structural and parametric error in the models, which are not removed even after an extensive tuning procedure. This is the ``deadlock''. (B1).

LEAP will endeavor to bring ML techniques to bear on the deadlock. It will apply different methodologies to classes of problems ranging from ``data-rich'' domains, where parameterizations can be directly derived from data and high resolution simulations, to ``data poor'' areas where LEAP will apply theory in the absence of extensive data. ``Hybrid'' methods will be used in moderate data domains in between. (B3).

From process level improvement they will proceed to uncertainty quantification and Bayesian parameter estimation across the full coupled system (B4.4).

This is an emergent approach to ESMs that is rapidly becoming widespread across the field. What differentiates LEAP from its rivals is that unlike Clima, which is beginning a de novo modeling effort, this effort is tightly integrated with established modeling groups at NCAR and GISS. Vulcan, also mentioned, is focused only on atmospheric convection, while LEAP is looking to apply this approach broadly across the entire ESM (A5).

LEAP's goal is to improve climate projections relevant for policy makers over many decades (Fig 1).

The project is ambitious and based on a rapidly growing emerging area of research, which the proposal calls ``climate data science''. There are many efforts in this area, clearly: there multiple workshops and conferences devoted to this area every year, as well as becoming a dominant theme at AGU, AMS, and so on. The proposal shows some difficulty stating exactly what sets it apart from other efforts in the area. If we focus on what sets it apart from Clima, I would have liked to see a statement of what specific classes of simulations at NCAR and GISS would be run with the new ML-inspired components, to differentiate it from the previous generation of models.

Without this institutional heft the project is likely to remain an academic proof of concept along the lines of the ones in (B2).

It is also not completely clear what the ``cost function'' being optimized is: many aspects and ESM deficiencies are mentioned, including model biases, extremes, etc. Some of these may require trading off one against the other. The strategy was not obvious to me how tradeoffs will be evaluated. Again, a certain set of target simulations using an ESM could clarify these goals.

The idea of blending physical knowledge and machine learning in ESMs now has a healthy literature,

especially in the last 3 years, not least from scientists participating in the LEAP proposal. It is potentially transformative, although everything said in this pro- posal has been stated in other proposals and other review papers going back at least 2-3 years, so it isn't completely original.

The plan is well-organized. Fig 5 is a sound basis for deciding which strategy to pursue in any given instance. Project organiza- tion is clear (Fig 9). Education plan also (Fig 6). As noted above, the participation of 2 modeling groups is a strength of the pro- posal. However, while multiple individual CVs are included from NCAR and GISS (all generously donating their time), their par- ticipation seems rather limited (highlighted at the top of p24). I think it will need more engagement than that. Model integration is not a lightweight activity.

4. How well qualified is the individual, team, or organization to conduct the proposed activities?
Very well qualified.
5. Are there adequate resources available to the PI (either at the home organization or through collaborations) to carry out the proposed activities?
There are a number of aspects of the proposal critically dependent on expensive computations (see e.g p10). Some of this will likely involve new large computations (for instance I would be cautious about using data from an obsolete model (POP) with well-known deficiencies as training data.). Similarly the idea of constraining microphysics using the Bayesian framework will be computation- ally expensive. I find the cloud-first strategy (p8) somewhat risky for the computational part (though it is quite reasonable for the data analysis, ML training, and outreach activities). While there is mention that NCAR's computational platform may be avail- able for this project (p8), the computational requirement may be quite high (100M CPU-h may be the order of magnitude), so it will be worthwhile securing an explicit commitment from NCAR and GISS to make computational resources available for this project as cost-share.

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

LEAP has a very admirable and ambitious set of goals to broaden the participation of underserved minorities in science, taking full advantage of the lead institution's New York City (NYC) loca- tion. This includes doctoral fellowships (C2), project based learn- ing and certification (C3, C1) at the college and post-graduate level, faculty level training (C5), NYC high schools (C6-8). NCAR's existing programs are also leveraged to good effect. There are substantial efforts to engage the general public and climate jus- tice activists. The broader impacts are an outstanding part of the proposal. A lot of partnerships with external organizations require investment by the outside parties. NSF should require more metrics of suc- cess: including measures of participation from the core science team (rather than just the outreach team), and actual impact (sustained activities by community organizations once engage- ment with LEAP is terminated). Some of the targets of outreach (from "investors" to "activists", see E2) may themselves have con- flicting goals, and LEAP may be in the crosshairs. Also, I wonder why Columbia's CIESIN or NYU's CUSP are not involved? They have substantial experience navigating this terrain.

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

Solicitation Specific Review Criteria Rationale for an STC, including questions: Is the vision for the project com- pelling enough to justify the large-scale focus of resources? If so, is an STC the appropriate vehicle? Why is an STC investment warranted at this time? Are the anticipated scientific and societal legacies substantive and transfor- mative?

The proposal contains both science and technology elements, with both scientific and societal impact potential, justifying an STC level investment.

Research plan, including questions: Are the plans for research and holistic in- tegration appropriately ambitious, leading to significant strategic outcomes? Does the proposal address potential bottlenecks and technical challenges? Does the proposal make a case for the feasibility of significant progress over the next five years?

Could use more SWOT analysis of the science plan: the outreach plan does a good job.

Partnerships and Participants, including questions: Is the team of partner organizations and personnel assembled for the proposed Center appropriate and essential? Is the role of each participant clear? Does the team have unique strengths relative to the other groups working in related fields?

The project places a lot of the onus and responsibility at Columbia. In the view of this reviewer, the modeling centers' role could be more substantive, as noted above.

Integration Strategies, including questions: Are the leadership and man- agement strategies promoting a center culture and are the foci of education, knowledge transfer and broadening participation strategically supporting the goals of the center?

The risk is that the science and outreach activities get decoupled: while the organization structure in Fig 9 is supposed to prevent this, it would be good to have clearer metrics of success in this regard.

Are the research, education, knowledge transfer, and broadening participation efforts strategically embedded and integrated in the proposed Center?

The risk is that the science and outreach activities get decoupled: while the organization structure in Fig 9 is supposed to prevent this, it would be good to have clearer metrics of success in this regard.

Are the partner organizations and participants meaningfully integrated into a diverse Center that is more than just the sum of the parts?
Yes, I hope so.

Does the proposal include a vision and plan for leadership in broadening the participation of underrepresented groups and does it articulate a credible commitment to broadening participation as a means of achieving its overall goals?Yes. The proposal does a great job in this regard.

Are the educational activities innovative and do they contribute to the unifying mission of the proposed Center?
Yes. The educational aspects may well feed back on aspects of the science plan, e.g the design of LEAPangeo.

Does the proposal include a promising plan to promote the transfer of knowledge through the meaningful exchange of scientific and technical information with external stakeholders such as industrial partners, public policy-makers, or international oganizations?

Not much international participation that I could discern, other- wise fine.
Does the proposed Center management have the vision, experience, and capacity to manage a complex, multifaceted, and innovative enterprise that integrates research, education, broadening participation, and knowledge transfer?
Yes.

Are the institutional and other commitments appropriate to carry out the proposed research?
Sufficient at the university sites, insufficient at the big labs.

Summary Statement

Very good proposal, transformative with some changes as outlined above.

Rating: Excellent

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

This STC would focus on earth system models, climate change and big data science Together, these themes can reshape and hopefully greatly enhance climate modeling to the benefit of society. Many new and diverse high resolution data sets of high temporal frequency are being generated that have yet to be mined by the earth system modeling community. Doing so is computationally challenging. The purpose of LEAP (Learning the Earth with Artificial Intelligence and Physics) is to integrate physical and biological knowledge with machine learning to transform Earth system modeling. One important aspect of this research agenda is to create advances in Machine Learning that can more capably use climate data to advance climate model projections.

LEAP is built around five "Convergence Stategies". First, they will launch LEAPangeo, an open cloud computing platform to engage the broader community working at the intersection of geosciences and machine learning. Second, they will develop next-generation machine learning algorithms, using physics and causal mechanisms to improve near-term climate projections. Third, they plan to harness new machine learning methods to improve the Community Earth System Model by using newly generated data to advance model process representation, develop new data products and novel model evaluation metrics. Fourth, they will exploit these studies to train the next generation of climate data science scholars. Finally, they will establish a communication network between academia, industry, and the public, forging mutual engagement in the science and utility of climate projection.

LEAP will unite 48 researchers, five executive administrators, six academic institutions, two federal research labs, and 27 institutional partners. Teams within the center will work on 23 knowledge-data science research problems. This seems rather wide ranging and ambitious. Resources are being widely distributed on many subprojects which may dilute their effectiveness. Also, such a distribution of resources and fragmentation of research questions might make it hard to develop cohort coherence and integration.

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

As part of their education plan, they will develop a certificate program in climate data science available to partner institutions and the consortium of NYC universities. The certificate program includes four graduate level courses that will be freely available to 5 Society of Black Engineers students per year. Grad students can apply for fellowships (renewable) after completing the overarching Challenges course. Seminars appear to be very advanced and inclusive in format. Postdocs will visit partner institutions and PhD students will work across institutions, visit NCAR. As part of the mentoring plan undergraduate students and faculty teams will write proposals for summer research support. High school students will be involved through a Science Honors Program for STEM enrichment that meets on Saturdays. The plan to have graduate and undergraduate students in charge of this effort. Some PI commitment to this effort would be valuable.

The plan to host "train the trainer" faculty workshops to engage partner faculty in a two day workshop using LEAP datasets. They will organize mini-hackathons on algorithm develop, and to consider and address questions related to climate projections. Lab to school summer institute and parent training. Engage NYC High School teachers through Summer Institute Climate Data Science via Teacher's College and Center for Sustainable Futures. This center is connected to NYC Dept of Ed. which hosts a parents conference where summer institute participants can present research findings. Finally, they will partner with AMNH through existing programs that attract thousands of 8th graders annually. Create exhibits in the museum. In other words lots of thoughtful efforts at outreach and engagement at all levels and targeted towards the public.

One aspect of graduate training is a Design Studio for students to develop case studies and formal curricula. All materials generated with be shared openly. All education activities will be assessed by an outside evaluator.

Diversity, Equity and Inclusion strategy – They admit that the geosciences is woefully lacking in members of underrepresented groups and they take this challenge to heart. The plan three annual workshops and assess recruitment strategies and how candidates at all levels are evaluated. They recruitment evaluation as a research opportunity. They will support three Bridge Scholars per year to enhance their qualifications for grad school (this appears to be modeled on PREP, perhaps?). They will partner with the UCAR SOARS program a minority enhancement program in climate science by supporting some SOARS students in their second year in that program.

Knowledge Transfer Objectives are built around a two way exchange of information and ideas. Of course,

they want their information to get out to stakeholders and be applied, but they also recognize that they need to learn what information users, such as corporations, need.
To address this, they will fund an Executives in Residence program to teach a new graduate course, co-advise students and participate in outreach. This is an interesting idea, but how many executives have the time, energy, interest or ability to skip work for this? They will also host convergence luncheons with lightning talks and participate in "Ask Me Anything" on Reddit and Twitter, Instagram.

A novel aspect to the center is the Story Tellers in Residence Program in which they will engage artists from Harlem to translate findings to non-science audiences. The artists will be in residence and offer other kinds of sessions and training on scientific translation. They will host four public "conversations" per year. They also plan to translate their NSF annual report into a "graphics heavy" public report, which would be nice given that those reports are essentially buried at NSF.

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

I like the titles of the various Directors. Chief Convergence Officer and Education Director, Center Director and Diversity co-Director, Equity Officer and Knowledge Transfer Director, Corporate Engagement, Public Engagement, etc.

External Advisory Committee 6 people non affiliated executives meets annually. Diverse backgrounds. Directors Council 6-8 people from LEAP core institutions (Deans and Institute Directors), Executive Committee Director and other Directors, Convergence Subcommittee meets monthly to evaluate progress on all tasks, plan luncheons, award small grants, Knowledge Transfer Committee will oversee storytellers, DEI efforts, hackathon, corprorate and public engagement, Climate Justice Leadership Board Grad fellows to partner with NYC climate organizations, target vulnerable populations, broaden participation.

I found the data management plan to be a bit cryptic. There isn't a clear plan for open access to data products although they do encourage release of code, perhaps with publications. I see no one designated for data management which means a free-for-all approach. Columbia U will take over managing the web site when the funding ends. Their ethics plan is adequate.

Summary Statement

Overall, this was the most creative proposal for management and integration. Leaders cross over to other committees and convergence leads the organization. The research itself is cutting edge and fundamentally important. The center would blend the emerging field of Machine Language with the enormous challenges of climate projections using massive data sets. The outreach efforts are novel and interesting, the team is highly qualified to conduct the research and organize the center.

Rating: Very Good

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

This proposal is an exciting merger between data sciences and geosciences, planning to address many of the key issues in climate sciences with data sciences approaches proven in other fields.

The potential for the proposed activity is high to advance knowledge and understanding, especially in a transdisciplinary communication sense. Climate modeling will be improved, especially the NSF-sponsored CESM. I think it is unlikely that all of the proposed topics will be affected in a transformative way, but the project highlights many of the most important issues in climate modeling and making progress on even a few would represent a major step forward.

The proposal is not creative or novel in the sense that no one has ever thought, "wouldn't it be interesting to try ML on climate models?". However, it is creative and novel in that it takes advantage of outstanding

young scientists, proven communicators, the existing NSF/NCAR/CESM infrastructure, and the progress over the past decades in identifying key problems to address in climate modeling I was not impressed that any one geosciences topic received particularly novel approaches, but I was very impressed that each received a thoughtful treatment that lies within the combined skill sets of the combined geosciences and data sciences team.

The team is in many ways the best qualified in the world. Gentine & Pritchard's work on ML in cloud superparameterization stands out to me as the best application of ML to date in geosciences. Abernathey's role in Pangeo is critical and ground-breaking--he is regularly providing cloud-based tools that make everyone else's efforts look preliminary. McKinley is clearly a leader in BGC modeling--especially in process impacts. Zanna is one of the most creative producers of ideas in oceanography, with excellent follow-through in actually getting things done and published. Schmidt & Revkin are spectacular communicators, etc., etc. The only potential weaknesses I see are on the project management side, just because I do not know the (it seems like from the budgets) 3 individuals selected and that is critical for the overall success, and on the ego balancing side. Will so many successful scientists be able to work together?

The collaborations and resources of the institutes, together with this large sum of money, will be able to make great successes on this front and build a world center that extends far beyond this project.

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

The project has an exceptionally ambitious outreach, education, and diversity component. Key aspects of these proposed activities touch on all of the "right" points, from K-12 to museums to graduate training in teaching. Partners are among the best known institutions in the most cosmopolitan city in the US. Schmidt and Revkin are perhaps the best known communicators of climate science anywhere. So, on potential and ambition, I give this proposal very high marks.

However, I am a bit concerned about the management aspects of all of this. While a clear governance structure for the overall project is made, the outreach and education goals rival that of an entire high school, with a staff of 40 graduate students and a large number of undergraduates. The governance structure is run by scientists, which is natural from the perspective of the also ambitious research goals, but the education, diversity and engagement branches have a large responsibility. This concern is not a prediction of failure to deliver exactly, but just a cause for concern. Cogburn's and Zheng's roles are critical. However, where possible partners with strong legacies (NCAR, AMNH, NYoM, SOARS, Teachers College) are included and that should help in pulling off some of these more complex efforts.

One other worry for me is where the group will find 40 graduate students and 16 postdocs ready to work on this project. 40 graduate students, seemingly all in the same recruitment year, in perhaps 3 fields with lots of overlap in applicants, and two rounds of 8 postdocs, will be a double-digit percentage increase of the students & nearly that of postdocs at LDEO/NYU. I see the efforts to recruit a diverse set are meaningfully planned, but do LDEO/NYU really get this many candidates that are ready to go on such a specific project? I imagine that many existing students may transfer over and no-cost extensions, etc., leading to perhaps 3 years of recruitment or so, but this is still a massive crop of students to find at one time.

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

Summary Statement

Overall, this is a needed step in climate modeling, and this is probably the best team to try under this framing of scope. I have no doubts that excellent science will be done and this will boost all of the participating institutions' capabilities. Whether all of the truly ambitious goals proposed or just a decent subset are carried out, it will be a transformative center for US research.

Rating: Excellent

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

Overview: improved precision in projections for climate change, making use of new data sources and algorithmic approaches for extrapolation

Intellectual Merits
+Cloud computing platform for climate modeling
+Application of data-driven techniques to improve climate science
+Development of physics-based algorithms to improve extrapolation for climate

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

+Training of interdisciplinary climate scientists
+New community links for climate among public, academia, industry, and NYC mayor's office
+Well laid out set of educational activities from high school (Saturday program) to graduate studies (seminars, courses); teacher training and training of faculty researcher also included
-REU planned but no indication of number of new funded positions
+Bridge program for scholars may have significant impact given low base numbers

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

Rationale for STC: vision, timeliness, transformational
+Good comparison to other large scale efforts shows differences in focus
+Plausible scientific agenda that could lead to improvement in models with profound societal consequences; strong emphasis on public outreach together with linkage to national labs will increase chances of influencing decisions.

Research: ambition, integration, feasibility
+Present models deal with data at coarse scales due to computational issues (overcome with parameterization using physical models to fill in) and lack of fine-grained data. Argues that parameterization errors are main source of uncertainty: structural errors (scientific uncertainty) and model parameter errors (tuning not accurate). Center aims to address problem at multiple levels
+Research thrusts build on prior work of investigators in use of ML for climate modeling
+Investigation of continuum of data rich/model poor to sparse data/strong models in instance of climate potentially applies to many other application domains; good discussion of the set of approaches
+Timeline for research looks plausible with clear path to integration
+Seminars for "convergent" research to link research streams

Partnerships: comprehensive, qualifications, clarity of roles
+Linked to NCAR and GISS, national labs in climate science
+Team has considerable prior experience
+Management plan is clear and adequate

Integration Strategies: research/education/diversity mutual support, team vs. individual effort, knowledge transfer, institutional commitments
+Open source for data, models, and algorithms
+Workshops for journalists on climate science
+Study of message effectiveness within corporations to improve narrative presentation
+Broad set of public outreach activities designed to gain community participation

Summary Statement

Strong across all the elements

Rating: Very Good

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

Strengths - excellent science, novel approach to climate data, progress will redound to both the climate modeling/ESM community as well as to ML. I especially like the problem taxonomy and the sliding scale of data/model dependence. ML in climate has great potential to be transformative. Excellent team.

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

Strengths: Many excellent partners. The storytellers-in-residence program and "translate-o-thons" are terrific and potentially transformative.

Weaknesses: BI does not feel as well thought out as the science. Examples include Research Seed Funding (how would a graduate student and faculty member not the adviser create a new team to investigate a project?); What happens to a LEAP Fellow who is not renewed? AMNH collaboration not really spelled out; "Lab-to-School" program is interesting. Connections to high school could be better. The diversity recruitment plan is not innovative - weakest part of proposal - but the commitment to the Bridge-to-PhD program is laudable, would be stronger if accompanied by explicit access/connection to partners, especially NCAR/UCAR. Connection to SOARS program is very good. Embedding journalism/storytelling in the STC is an interesting idea. The BI efforts are linked largely to climate modeling generally and not specific to the STC rationale. That said, the outreach partnerships are strong and BI on climate science and climate impacts generally is still important.

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

STC rationale seems a little above borderline. With so many climate scientists and data scientists already in place at Columbia, unclear as to why the STC is needed to make the collaboration happen. With many moving parts and affiliated faculty and organizations this seems difficult to manage effectively. What kind of CEO is meant to be on the Exec Committee? The Climate Justice Leadership Board seems like another program as opposed to a management structure.

Summary Statement

This is a proposal to create an STC - LEAP (Center for Learning the Earth with Artificial Intelligence) - focused on the integration of machine learning into climate science, specifically to create enhanced Earth Systems Models (coupled climate models that include carbon dynamics). The scientific justification for a full-on STC is a bit above borderline. The proposers argue that more use of the petabytes of data relevant to Earth Systems Modeling is - arugably - underused and ML techniques, especially new work related to physics modeling is an interesting approach to doing so. The utility of deep learning in the numerical analysis/PDEs world is still in its infancy. The integration of these techniques into the production of ESMs provides an important context for further investigation of this idea, so that progress in this regard should both redound to a better understanding of deep learning as well as better ESMs. The concomitant piece of societal impacts relative to investigating climate, and anticipated reach of the work help to bolster the argument for an STC as would well-integrated educational and workforce-related programming. That said, it is not so clear that an STC is needed to make this happen. While the science is strong - and the partners are strong, as is the local (Columbia U. scientific resources in climate) environment, the human resources development piece and broader impacts feel weaker and underplanned or at least under-explained. The effort as explained to increase minority representation in the climate data science is not innovative. The

prospect of providing and packaging climate data for investment companies and reinsurance giants feels troubling. The partnership with Google is not explained. The large number of partners seems both an opportunity as well as a management challenge.

Rating: Excellent

Review:

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to intellectual merit.

1. What is the potential for the proposed activity to
a. advance knowledge and understanding within its own field or across different fields (Intellectual Merit)

The Intellectual Merit of this project is the use of a "Knowledge-Data Continuum" framework within which to advance the development, application, and incorporation of Machine Learning (ML) techniques around and into earth system models (ESMs). Research activities incorporate development of ML techniques (B4), application of various techniques to different Earth System components (B5), and incorporation of new ML parameterizations into ESMs (B6). Within each of these efforts a wide range of activities are proposed.

One of the important contributions from LEAP is the co-development of ML techniques with applications that are relevant to ESMs. This distinguishes this effort in that a need for co-development of techniques and applications is very clear. For data-rich fields, the use of physical constraints and alternate loss functions in ML techniques is interesting and important. There seems to be a lot of utility in developing techniques that apply structure or determine structure of relationships between variables, such as the description of Equation discovery, and transfer learning. Some of these efforts seem like they might be overly ambitious, but I suspect even if these fail a lot will be learned.

There is a wide range of applications proposed in the project, spanning from improving and replacing physical parameterizations in climate models, to data extrapolation, interpolation, and uncertainty propagation. These activities provide opportunities – which are discussed in the proposal – for learning more about the system as well. Techniques such as equation learning, transfer learning, and physics-guided ML seem very promising in blending mechanistic models with sparse or non-sparse data to provide insight into physical processes, or advance understanding of climate processes and variability despite sparse data. Mechanistically, the use of neural networks to improve and accelerate model tuning seems very important as well. I do have some concerns about how ambitious the proposed work seems, in particular the extent of what is being promised. For example, it's not clear to me that equation discovery will translate to more complicated systems, or that use of ML will be able to improve estimates of basal shear stress. Use of high resolution models do not necessarily address the issue as functional form of basal shear is not well known in the first place. This is one example of a potential problem with the direct simulation methods described, where ML is applied to output of a high resolution model, especially for poorly constrained physical processes such as those associated with soil carbon, basal and marginal ice sheet flow, and deep convection in regions where convection is not well sampled.

One of the concerns I have about the research relates to the use of deterministic (one-to-one) relationships between "inputs" and "outputs". It seems to me that ML could be used to generate conditioned probability distributions for outputs that could be drawn upon for stochastic parameterization, which has shown some promise. I'm not sure how this will be addressed in the project, but the potential for stochastic parameterization should be considered.

The incorporation of ML parameterizations in to ESMs, CESM in particular, is a critically important part of this project, and I think is an important vision for the future of climate modeling. It is critical that this kind of work take place in parallel with standard efforts at improving ESMs, which are happening elsewhere. I do see this as extremely high risk, as it is entirely possible that the result of new ML-based parameterizations will amount to a new form of tuning in these models. However, that may not be the case and as such the reward could be immense. Either way, the advancement of both ML techniques and understanding of Earth System Sciences is a major benefit of the project.

2. To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?

The proposed activities are extremely creative, original, and potentially transformative. A key reality upon which the proposed STC is based is that the application of ML to Earth System Sciences involves a unique set of constraints that do not affect ML in other fields. As such, ML techniques need to be developed in collaboration with Earth System Science applications, which is how the STC is structured. As such, the development and application of these techniques are creative, original and extremely potentially transformative.

In addition to development of ML techniques, the potential to reconsider how ESM's are designed could be immensely transformative as well. The use of neural networks as model simulators, the development of new tuning methodologies, and the use of ML-based parameterizations in existing ESMs are all potential game-changers in development of the next generation of ESMs. Again, this is high-risk, but the potentially transformative nature of this work is very high.

3. Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to assess success?

The project includes a variety of mechanisms by which to evaluate success. The use of a "Convergence Subcommittee" that evaluates progress and identifies new needed work is an important and creative evaluative component. The External Advisory Board is an important component as well, though I might suggest additional expertise in Geoscience and in Data Science in advising the overall effort. I expect some of that would come with the annual NSF site visit as well.

Metrics for success in evaluating the incorporation of ML Parameterizations into CESM are appropriate, and development of new metrics is going to be very important. It's clear that LEAP recognizes that the existing set of evaluation metrics for climate model performance are somewhat limited – which is to be expected of any complex system.

4. How well qualified is the individual, team, or institution to conduct the proposed activities?

The team is exceptionally well qualified to carry out the proposed activities. Connections between Data Sciences and Earth System Sciences are strong in the proposed STC, and I expect that even for individual project failures, there will be much to learn in the interactions.

The development of LEAPangeo is an important step toward server-side analytics that will be important for future Earth System Science analysis ("Future of Work"), and is to be commended. It's clear that the team is qualified and up for that task as well, given past experience with Pangeo.

5. Are there adequate resources available to the PI (either at the home institution or through collaborations) to carry out the proposed activities?

The resources allocated appear to be appropriate for the center. The participating institutions have strong connections with external stakeholders and other groups. The connections with Google and Microsoft are also important, and provide an opportunity (provided that data / methods / etc. remain open access) for transforming the "future of work".

In the context of the five review elements, please
evaluate the strengths and weaknesses of the proposal with respect to broader impacts.

1. What is the potential for the proposed activity to
a. benefit society or advance desired societal outcomes (Broader Impacts)?

There are numerous broader impacts that LEAP will provide in the benefit of society. The project includes an integrated educational activities for a wide range of learning levels (from high-school to post-doctoral) and includes training LEAP fellows in developing and implementing educational activities. The effort includes a sound plan for enhancing Diversity, Equity and Inclusion (DEI), and formalizes the importance of DEI through annual evaluations and in director positions. The LEAP team itself is considerably more diverse than Geosciences in general (although this is a VERY low bar). Finally, there are clear efforts at Knowledge Transfer through various media efforts.

The ML and ESM research will provide a critical service to society in providing new climate model simulations, including the potential for large ensembles of model simulations, that can be used to better

understand future climate impacts. That being said, it is clear that "better climate models" is not what is limiting societal willingness to adapt or mitigate future climatic changes (the opening of the proposal). The use of media outlets to advance public understanding is important here, together with interactive communication efforts (such as the teaching opportunities, public speaking, museum collaborations, hack-a-thons, etc.) that increase engagement of scientists and stakeholders. Further, LEAP includes efforts to enhance diversity in Geosciences and Data Sciences, and targets traditionally underrepresented populations through partnerships and shared activities.

2. To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?

The propsed STC includes extensive efforts to enhance the broader impacts of the project. It is clear that the LEAP team has thought broadly about broader impacts, from expanding the learning opportunities of individual LEAP fellows by engaging in Design Studio educational efforts, advancing media communication through a Climate Journalism Fellow, incorporating business executives in training opportunities, and partnering with the National Society for Black Engineers to increase DEI opportunities (to name just a few). If carried out, the full suite of proposed broader impacts (in sections C, D, and E) amount to a very impressive and extensive landscape of Broader Impacts efforts.

3. Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to assess success?

The plan for carrying out the proposed suite of broader impacts in sections C, D, and E is very well reasoned, well organized, and in the case of DEI especially addresses some critical issues. The educational plan includes a well thought-out curriculum that includes opportunities for students to develop their own educational "stories" (enhancing climate communication). This pairs well with a number of the Knowledge Transfer activities as well. The synergy between the education and knowledge transfer is clear. The center structure is also set up to ensure synergy between the various components of the project, including DEI at the highest level.

One limitation I saw to the proposal is that the discussion of two-way knowledge transfer is somewhat limited to the broader impacts side of the proposal only. The Data Science and Earth System research does not appear to be strongly influenced by what happens on the broader impacts side of the STC. While I may have missed it, it is worth incorporating projects that study and publish findings – perhaps in non education-specific journals such as Nature, Science, or BAMS – on the Education, DEI and Knowledge Transfer findings from the STC. Some mention is made in the proposal of such efforts, but I think it would be a benefit to the community to have LEAP share it's successes and failures.

4. How well qualified is the individual, team, or institution to conduct the proposed activities?

Like the Data and Earth System science side of the proposal, the team is exceptionally well qualified to carry out the proposed activities. Much of the proposed work is well beyond a concept stage, for example the use of the Design Studio for developing educational material. The individual investigators all have extensive experience in advancing broader impacts of their work, and the STC includes expertise in implementing and evaluating the educational, DEI, and knowledge transfer efforts.

5. Are there adequate resources available to the PI (either at the home institution or through collaborations) to carry out the proposed activities?

The various institutions and partnerships demonstrate adequate resources for carrying out the broader impacts proposed by LEAP.

Please evaluate the strengths and
weaknesses of the proposal with respect to any additional solicitation-specific review criteria, if applicable

1. Solicitation Specific Review Criterea:

o Rationale for an STC, including questions: Is the vision for the project compelling enough to justify the large-scale focus of resources? If so, is an STC the appropriate vehicle? Why is an STC investment warranted at this time? Are the anticipated scientific and societal legacies substantive and transformative?

This project is exceptionally well suited for an STC. The unique challenges in implementing machine learning techniques into Earth System Sciences applications necessitates a co-evolution between the two fields, which is the intent of this STC. The vision for this STC is very broad, from developing new ML techniques, to advancing understanding in Earth System Models (ESMs), to advancing technical aspects of ESM development. The vision also includes a broad set of educational outcomes; a focus on Diversity, Equity and Inclusion; and an impressive knowledge transfer effort.

o Research plan, including questions: Are the plans for research and holistic integration appropriately ambitious, leading to significant strategic outcomes? Does the proposal address potential bottlenecks and technical challenges? Does the proposal make a case for the feasibility of significant progress over the next five years?

The research plans are certainly ambitious. The proposed work would certainly take at least five years, though I do expect that by the end of the five year project, it will be successful in developing ML-based parameterizations into climate models. Further, I expect the work – even in its failures – will inform and expand our understanding of the context within which ML techniques can and should be applied to Earth System applications.

The proposal is somewhat limited in addressing one of the big technical challenges in implementing LEAPangeo, but the PIs have experience in similar projects so I expect this will be implemented. One thought that the PIs should consider is developing a crash course in using GitHub and LEAPangeo for incoming Fellows that could be taken in the first or second week of the fellows' tenure. Equivalently, it's worth considering ongoing monitoring and training in ML techniques and open source work flow. This could go a long way toward ensuring consistent open source protocol, and a unified work flow.

o Partnerships and Participants, including questions: Is the team of partner organizations and personnel assembled for the proposed Center appropriate and essential? Is the role of each participant clear? Does the team have unique strengths relative to the other groups working in related fields?

The team appears to be appropriate and essential. Team members span a large range of disciplines and include leadership at NCAR that will facilitate development of ML parameterizations into CESM. Partnerships with other institutions and organizations are well outlined.

Partner organizations have clear roles, though it would have been nice to have seen more information about Google and Microsoft's role in the STC (I do see that Lucas Joppa is listed as a collaborator and will serve as the first Executive in Residence). I did not see letters of support from Google or Microsoft, which I may have missed in the long document.

o Integration Strategies, including questions: Are the leadership and management strategies promoting a center culture and are the foci of education, knowledge transfer and broadening participation strategically supporting the goals of the center?

This was a strength of the proposal, I thought. Yes, leadership and management strategies are clearly integrating the education, knowledge transfer, and broadening participation efforts of the center. The integration of fellows into these activities is especially important, and ensures more of a holistic development of individual trainees. The leadership structure and evaluation techniques explicitly address issues of DEI, which is an important characteristic of LEAP.

o Are the research, education, knowledge transfer, and broadening participation efforts strategically embedded and integrated in the proposed Center?

Yes – see answer to previous question. This is another strength of the proposal, in that research, education, knowledge transfer, and broadening participation efforts are strategically integrated into the Center operations. It is noteworthy that the research is not strongly motivated by the other efforts, but in the context of this center I think that's OK.

o Are the partner organizations and participants meaningfully integrated into a diverse Center that is more than just the sum of the parts?

The vast majority of the work will be done at Columbia University. However, it appears that the partner organizations are meaningfully integrated into the Center. A major strength here is the contribution from

NCAR and GISS, both of which will work to try to integrate some of the developed parameterizations into their respective climate modeling efforts. This will be critical for success, and a regular mechanism for interaction should be put in place, such as monthly videoconferences, or something. I did not see such a mechanism, but it's a HUGE proposal, so this is more something to recommend to the PIs if the project gets funded. I did see in the budget justification that funding is requested for housing for LEAP Fellows and postdocs travelling to NCAR in Boulder for semester-long residences – this is VERY useful for the fellows and post docs, and I strongly encourage this kind of interaction.

Integration from New York Teacher's College is through the evaluation and education components of the project, and it is good to see that Lang is involved in evaluation of numerous components of the educational and outreach components.

The ocean lead – Zanna – is at NYU and is embedded into leadership as the Geoscience Research Lead. I notice that she intends to draw 0.5mo funding with 2.5% increase each year, and one graduate student per year from the project. That does not seem like enough of a commitment for such a position, and considering that she will be leading the ocean physics parameterizations. I think that should be increased, even at the expense of funding for other individuals. I note that the Data Science Lead is taking 1.5 month of salary with 4% raises per year. This seems inequitable.

Integration with Google and Microsoft is certainly interesting, but I didn't see a lot of details aside from interactions with Lucas Joppa (including the Executive in Residence term). Again, it would be nice to see what kind of resources and commitment are expected.

o Does the proposal include a vision and plan for leadership in broadening the participation of underrepresented groups and does it articulate a credible commitment to broadening participation as a means of achieving its overall goals?

This is a strength of the proposal. The director also serves as Diversity Co-Director, and the gender balance of the leadership team is close to 50/50. In general, the team is more diverse than geosciences as a whole, which is good. The team also will integrate with the SOARS program, and includes regular training for fellows etc. Diversity, Equity, and Inclusion is also a criteria around which the program will be evaluated. The leadership has an impressive record of advancing DEI, so I expect this will be a priority.

o Are the educational activities innovative and do they contribute to the unifying mission of the proposed Center?

Yes – see above for some additional description. There are a wide range of educational and knowledge transfer efforts that are planned. Many of the educational efforts include the fellows themselves, either through the Design Studio, storytelling, etc. This ensures that the entire cohort of fellows will be gaining experience that is beyond the scope of their research.

o Does the proposal include a promising plan to promote the transfer of knowledge through the meaningful exchange of scientific and technical information with external stakeholders such as industrial partners, public policy-makers, or international organizations?

LEAP includes a variety of mechanisms for promoting knowledge transfer with private companies and local public entities. It includes a Staff Writer and Knowledge Transfer Program Manager in the Administrative Structure which is approporiate and needed in order to carry out the large number of planned activities in knowledge transfer.

o Does the proposed Center management have the vision, experience, and capacity to manage a complex, multi¬faceted, and innovative enterprise that integrates research, education, broadening participation, and knowledge transfer?

Yes. The proposed Center Director and Deputy Director have a long history in managing research, education, and outreach efforts. I have a lot of confidence that the project will be well administered. I am glad to see that the center will hire a Managing Director, and a suite of administrative individuals to assist with education, finances and operations, knowledge transfer, and writing. This demonstrates commitment to a wide range of activities that LEAP

o Are the institutional and other commitments appropriate to carry out the proposed research?

It appears that LEAP will be headquartered within a new Research and Education Cetner for Artificial Intelligence at Columbia University. That provides three offices and room for 10 students and post-docs – about half of what is expected per year. I note a statement that: "Allinstitutions are fully committed to this project, and will contribute to the following resources…". While this may be true, the vast majority of the budget goes to Columbia University (almost 90%), and I would hope Columbia is also contributing the vast majority of the additional contributions. I don't mean to make a stink of this, but I was surprised to see the disparity in funding for the Geosciences Director.

As mentioned earlier, it would be nice to know what kind of resources Google and Microsoft are contributing to the project.

Summary Statement

Summary Statement:

The Center for Learning the Earth with Artificial Intelligence and Physics (LEAP) proposes to advance (i) the development, use, and incorporation of Machine Learning (ML) techniques into Earth System Modeling (ESM); (ii) open data infrastructure; and (iii) transfer of climate data and information to public and private stakeholders through educational initiatives.

LEAP proposes a suite of ML / ESM activities that fall within a spectrum from Data Rich / Data-Driven interpolation, to Data Poor / Knowledge-driven extrapolation, with a variety of hybrid methods that fall somewhere along that continuum. The research activities span a large range of Earth System Sciences including small-scale atmospheric and oceanic processes (turbulence / convection parameterizations), land ice sheets, ocean biogeochemistry, and land processes. Activities incorporate development of ML techniques (B4), application of various techniques to different Earth System components (B5), and incorporation of new ML parameterizations into ESMs (B6). The research is supported by an impressive array of expertise, and is broad enough in scope that it warrants a highly interactive center approach. Many of the research projects seem promising; those that do not are still likely to be informative in that they drive knowledge discovery in both ML and ESM fields.

The education and human resource development objectives of the program are broad, and include development of undergraduate- and graduate-level curricula; provide research training experiences for a wide range of levels from high-school to post-doctoral; develop outreach training and engagement experiences for teachers and science museums; and structured opportunities for engaging LEAP trainees into outreach activities. These efforts are broad, and include mechanisms (such as the Design Studio training) for integrating research into outreach and educational activities. The incorporation of education / human resource development into the LEAP Fellows' curricula is important and commendable.

LEAP activities are grounded in efforts to broaden participation and enhance diversity, equity, and inclusion (DEI). Activities to promote DEI include annual DEI training workshops; use of DEI in trainee in recruitment, evaluation, and engagement activities; partnering with existing programs such as NCAR's SOARS and the National Society of Black Engineers; and continual assessment of DEI efforts. These efforts are targeted at all individuals at all levels of LEAP, from individual researchers to trainees, to administrators. DEI efforts appear to be well integrated into LEAP.

Knowledge transfer objectives are primarily framed as a communication problem that aims to provide diverse ways of communicating climate research. This includes a wide range of activities, such as a Climate Journalism Fellowship, Executives in Residence program, annual workshops and conferences, informal communication (such as "Convergence Luncheons" and "Ask Me Anything" conversations on social media), a newsletter, and public engagement events. These activities describe a broad set of communication goals and activities aimed at a wide range of engagement levels from intense fellowship experiences, to casual interactions over social media. While the Knowledge Transfer objectives are laudable, this is still largely a one-way communication of climate information "from research to stakeholder" that is largely tangential to the broader research objectives of the project – i.e. the research does not appear to be strongly shaped in any way by interactions with stakeholders. This is not necessarily a problem for this STC (this would be more of an issue for a NOAA RISA, for example), but it does point out that Knowledge Transfer Objectives are primarily one-way. Statements such as "most … climate adaptation decisions are stalled or misguided because … climate forcing factors cannot be predicted … [or] climate models … are too imprecise" (Page 1, paragraph 1), which are incongruous even with the reference used to support it, demonstrate the problem. I don't think this is a major shortcoming for the project, as

the research and broader impacts are still excellent.

The organizational and management structure of the STC is well thought out and includes key advisory committees that one would hope for in such an effort. The attention to DEI in management activities and demographics is impressive.

From the perspective of the U.S. Research Community, I think it is critical that NSF maintain efforts to advance a Community Earth System Model (like CESM) in diverse ways. This includes incorporation of novel new methods into Community Earth System Modeling. The objectives of this STC, together with partnerships with NCAR and the CESM development team, are well aligned with that goal. I encourage the STC to consider ways to ensure even stronger connection with NCAR and CESM development. Further, the incorporation of data science methods into Earth System Modeling is lagging the data science community for a variety of reasons, one of which includes the constraints inherent to modeling geophysical systems using machine learning tools. The co-development of tools in geoscience and data science communities is critical for advancing this important area of research. The efforts at broadening participation and inclusion into the STC, as well as the suite of knowledge transfer mechanisms in this proposal, round out an important effort that should be funded by NSF.

Based on the extremely strong intellectual merit of this proposal, and the impressive suite of broader impacts that touch a wide range of audiences and objectives, I rank this proposal Excellent, and strongly encourage NSF to fund this STC.

Panel Summary:

Panel Summary

Summary of the proposal:

The purpose of LEAP (Learning the Earth with Artificial Intelligence and Physics) is to integrate physical and biological knowledge with machine learning to transform Earth System Modeling ESM). An important aspect of the research agenda is to create advances in Machine Learning (ML) that can more capably use climate data to advance climate model projections. With a focus on earth system models, climate change and big data, the team aspires to greatly enhance climate modeling for the benefit of society.

Intellectual Merit
Strengths: This is an ambitious proposal; the research is cutting-edge and fundamentally important. The timing is right for climate studies such as this and it presents the type of research that should be championed. Creating advances in ML that can more capably use climate data to advance climate model projections is potentially transformative for climate science and perhaps for machine learning.

This effort appropriately builds on prior work of the investigators, giving a clear view of the deficiencies of present climate models and what the team plans to do to address the deficiencies. Particularly appealing (compelling?) is the presentation of the continuum from models to data and the plausible paths to integration. This should yield outcomes with broad applicability. Thus, integration is a key strength.
The strength goes well beyond ML and builds chemistry and physics disciplines in the right contexts.

Weaknesses: One reviewer found the proposal to be overly focused on the application of tools, but others found this a needed element of the center. It was noted that team would look for where there were data gaps and that application of data models is needed.

Broader Impacts
Strengths: The scientific agenda is plausible and could lead to profound societal benefits. The anticipated climate model improvements are much needed. For example, video and integration are novel. It is anticipated that domain and disciplinary specifics will evolve from integration.

The integration of ML with traditionals and new forms of climate-related data has great potential for also helping to push forward the frontiers of machine learning, especially as relates to the tensions and trade-offs between models and data-driven (e.g., NNs) techniques.

Weaknesses: Aspects of the education and mentoring plan are not well laid-out and need to be strengthened. In addition, locating the needed graduate students and post-docs in the research area may be difficult, so particular attention should be given to recruiting strategies.

Reviewers questioned if there is a market for the Certificate Program; its target, and its rationale.

Solicitation Specific Review Criteria
Strengths: The proposers have given serious thought to both the education initiative and the management structure.

The partnerships are comprehensive and included linkages to NCAR and GISS, national labs in climate science. The partnership with NCAR will facilitate development of ML parameterizations in CESM. The tight integration with established modeling groups such as NCAR and GISS differentiates this effort from others in the field.
LEAP has an admirable and expressive set of goals to broaden participation of underserved groups in science, capitalizing on the lead institution's location in NYC.
This provides gateways for new community links for climate among public, academia, industrial and local governments (mayor's office).

Weaknesses: This is a large complex project that needs to be managed well to be exceptionally successful. The PIs appear not to have significant experience in managing large center-like projects, and this could present problems in fully promoting the center culture and coordinating all the moving parts.

Lamont is huge and this center is a fit for this project. However, reviewers questioned why this work on how data science relates to climate science is not already being pursued.

Reviewers commented that the outreach and science seemed decoupled and this aspect should be strengthened. Also, evaluation is presented as if simply handed-off to a contractor and this needs to be given more thought.
The connections to private sector organizations seems dubious (packaging climate data for companies; partnership with Google; its role is not clear) and are not well explained.The proposal would have benefited form a clarification of the private sector connections, especially with the re-insurance industry and financial institutions.

What is the rationale for including a "CEO" on the External Advisory Board. Also, the goal of the Executive in Residence Program is not clear.

Rationale for Recommendation:
The Center for Learning the Earth with Artificial Intelligence and Physics (LEAP) proposed to advance the development, use and incorporation of ML techniques in Earth Systems Modeling; open data infrastructure; and transfer climate data and information to public and private stakeholders through several initiatives.

Based on the extremely strong intellectual merit of this proposal and the impressive suite of broader impacts of significant societal impact and that reach a wide range of audiences, this proposal is recommended for a Site Visit.

Panel recommendation:

Site visit