



# Communication Ecology and Climate of the Earth—The Same Biogeophysical System

Roger A. Pielke, Sr. <sup>1</sup>, Debra P. C. Peters <sup>2</sup> and Dev Niyogi <sup>3,\*</sup>

- <sup>1</sup> Cooperative Institute for Research in Environmental Sciences Boulder, University of Colorado at Boulder, Boulder, CO 80309, USA; pielkesr@gmail.com
- <sup>2</sup> United States Department of Agriculture, Agricultural Research Service, Beltsville, MD 20705, USA; deb.peters@usda.gov
- <sup>3</sup> Department of Geological Sciences, Jackson School of Geosciences, and Department of Civil, Architectural, and Environmental Engineering, Cockrell School of Engineering, University of Texas at Austin, Austin, TX 78712, USA
- \* Correspondence: happy1@utexas.edu

Abstract: Ecology and the climate provide two perspectives of the same biogeophysical system at all spatiotemporal scales More effectively embracing this congruence is an opportunity to improve scientific understanding and predictions as well as for a more effective policy that integrates both the bottom-up community, business-driven framework, and the popular, top-down impact assessment framework. The objective of this paper is, therefore, to more closely integrate the diverse spectrum of scientists, engineers and policymakers into finding optimal solutions to reduce the risk to environmental and social threats by considering the ecology and climate as an integrated system. Assessments such as performed towards the 2030 Plan for Sustainable Development, with its 17 Sustainable Development Goals and its Goal 13 in particular, can achieve more progress by accounting for the intimate connection of all aspects of the Earth's biogeophysical system.

Keywords: climate system; ecological system; climate impacts

# 1. Introduction—Definitions of the Earth's Climate and Ecology by Discipline,

**Professional Organizations** Clear and consistent definitions of scientific terminology are important, particularly when these definitions affect how information is communicated to the public, decisionmakers, and the scientific community. One example is the term "evapotranspiration" that combines two processes: losses of water to the atmosphere from evaporation, such as from the surface of a pond or bare soil, and transpiration losses from plants through plants stomata on their leaves and stems. The meaning of evapotranspiration, however, is often used differently even by scientists between and outside of multiple disciplines (e.g., [1]). It can, as one example, result in a misleading or confusing portrayal of the status of the

water cycle during drought. 'Ecology' and 'climate' are two terms with even more serious consequences if consistent definitions are not used. Effective communication for public outreach, to advance scientific understanding, and to develop policy and make decisions have been hampered when it is assumed either that climate is an external forcing function outside ecological systems (Figure 1) or that climate refers to a coupled geophysical Earth system without explicit consideration of the biota (Figure 2).

The article aims to communicate that the Earth system is, in reality, an intimately coupled physical-chemical-biological system. When scientists focus on the physics of the Earth system, it has traditionally been called climate. In contrast, when scientists focus on the biological aspect of the Earth system, it is called ecology. However, using two terms to refer to the same Earth system obscures the fact that multiple components interact across spatial and temporal scales within the same biogeochemical Earth system and that these



Citation: Pielke, R.A., Sr.; Peters, D.P.C.; Niyogi, D. Ecology and Climate of the Earth—The Same Biogeophysical System. *Climate* **2022**, *10*, 25. https:// doi.org/10.3390/cli10020025

Academic Editors: Matteo Convertino and Christine Fürst

Received: 24 December 2021 Accepted: 9 February 2022 Published: 14 February 2022

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/).



components cannot be viewed separately if an accurate understanding and predictions of the coupled system are to be achieved.

Figure 1. Ecology framing of the Earth.



**Figure 2.** Climate science framing of the Earth system (IPCC 2013—The Physical component of the Earth System focus. https://www.ipcc.ch/report/ar3/wg1/chapter-1-the-climate-system-an-overview/ accessed on 23 December 2021.

While there has been a movement towards coupling of the biota within a climate system, such as the incorporation of the carbon and nitrogen cycles in the Intergovernmental Panel on Climate Change assessments, there is still a general assumption by many that the physical components of the Earth system (e.g., carbon dioxide, precipitation, temperature, soil) drive the ecological components (e.g., primary production, plant and animal biodiversity, biogeochemical cycling). Figure 3, for example, shows forcings separated into climate and non-climate at the top and bottom of the figure as external drivers. Indeed, studies such as [2] have shown that the 'offline' versus 'coupled' meteorology and land surface ecosystem feedback can yield divergent outcomes for climate assessments.



**Figure 3.** Illustration of common consideration that physical component of climate system is external to biological components of the Earth system (Fourth National Climate Assessment Chapter 7: Ecosystems, Ecosystem Services, and Biodiversity, https://nca2018.globalchange.gov/ accessed on 23 December 2021).

There is urgency in developing a consistent terminology for the Earth system as the climate continues to change with consequences for the ecological and societal components that feedback to the climate. The subject of climate change has become of preeminent national and international importance. The Paris Climate Agreement of 2015 has become the international policy directive that aims to limit increases in the global average surface air temperature to 1.5 degrees Celsius, but certainly less than 2.0 degrees Celsius. The framework postulates that emissions from fossil fuel combustion are driving this increase with resultant damaging effects to the environment and society due to this global warming. Thus, to the public and policymakers, the term "global warming" has become synonymous with the term "climate change" [3].

The International Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). It was later endorsed by the United Nations General Assembly. The IPCC is the United Nations body for assessing the science related to climate change. Its mission is *"to provide a comprehensive summary to policymakers of what is known about the drivers of climate change, its impacts and future risks, and how adaptation and mitigation can reduce those risks"*. Figure 2 illustrates the framing of the climate system by the IPCC (2013). This continues with the latest 2021 report [4] which is titled *"Climate Change 2021 The Physical Science Basis"*.

The United Nations Framework Convention on Climate Change (UNFCCC) was subsequently established in 1992 by 154 nation states with the mission to stabilize greenhouse gas concentrations at a level that would prevent dangerous anthropogenic (human-induced) interference with the climate system. It states that "such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner". It is important to note that the mission of the UNFCCC with a focus on stabilizing greenhouse gas concentrations and identifying ecosystem impacts is narrower and than the broader goals of the IPCC [5].

The climate assessments and the available models have been used to study the physical component of the climate system as the driver of impacts on ecosystems. Indeed, the Working Group (WG) 1 reports of the IPCC (are titled "Working Group I—The Physical Science Basis". In these reports, the UNFCCC focus on stabilizing greenhouse gas emissions is emphasized. This WG1 report further guides the assessment reports, which are titled "Climate Change 2014: Impacts. Adaptation, and Vulnerability"), which includes forcings on ecosystems, and Climate Change 2014: Mitigation of Climate Change which includes the goal to reduce greenhouse gas emissions, such as through management of agricultural land and forests. As indicated by the IPCC reports and summarized by [6] and based on work by Mike Hulme, "the hugely complex challenges posed by anthropogenic climate change are boiled down to a single indicator for risk, namely, rising concentrations of a single gas: carbon dioxide (CO2)". This is practically powerful to help develop assessments, implementation policies and develop impact assessments but could also lead to a simplistic view of the climate system.

Also included in the latest IPCC WG1 report (2021) [4] of the assessment is the implicit recognition that the climate and ecological systems are two terms for the same Earth System. The report provides an important highlight:

"In summary, there is abundant evidence that changes in land use and land cover alter the water cycle globally, regionally and locally, by changing precipitation, evaporation, flooding, ground water, and the availability of fresh water for a variety of uses. Since all the components of the water cycle are connected (and linked to the carbon cycle), changes in land use trickle down to many other components of the water cycle and climate system".

The report also highlights:

"FAQ 8.1, Figure 1: Land-use changes and their consequences on the water cycle. As all the components or the water cycle are tightly connected, changes in one aspect of the cycle affects almost all the cycle".

Nonetheless, the major thrust of the climate community and the understanding of what the climate community studies have been centered on rising concentrations of CO2 and global warming to climate change and led to a 'mitigation'-centric focus for climate solutions [7]. This is reaffirmed to many in the scientific community of the dominance of climate with respect to ecological dynamics. In the scientific community, there has long been the presumption that climate governs vegetation. One example is the Köppen climate classification which is an empirical climate classification system developed by botanist-climatologist Wladimir Köppen [8]. This classification divides climate into classes based on seasonal precipitation and temperature patterns and uses this to determine the resulting expected natural vegetation landscape types. Similarly, the Clementsian succession model in the early 1900s assumed vegetation is in equilibrium with climate and soils, and following disturbance will return to that steady-state vegetation. This model was used to justify the cultivation and overgrazing throughout the central Great Plains of the US in the 1900s. Many of the current vegetation maps continue to use the concept of potential natural vegetation and climate-soil-vegetation associations to map baseline vegetation in the US and globally.

Interestingly, recently the Nature Portfolio is a forum for research papers on climatechange ecology, and described as, *"the study of the effects of anthropogenic climate change on any*  aspect of ecology (https://www.nature.com/subjects/climate-change-ecology (accessed on 23 December 2021)). This discipline [considers] the effects of altered temperature and precipitation on the distribution, abundance, behavior and physiology of populations and communities". In other words, the climate is assumed to drive the ecological response. There are many such instances where it is apparent that climate is considered as an extension of meteorology and as an external forcing that can dominate other Earth system components, including ecological processes. In contrast to the view that the physical part of the Earth system dominates the biology, there is evidence that broadens this view. For instance, it has been shown that the location of the boreal forest-tundra boundary significantly influences the position of the polar front over northern hemisphere land in the summer [9].

Another example is the Dust Bowl of the 1930s. It is not possible to explain regional patterns in corn yield using and soil properties and weather patterns alone from the 1920s to the 1940s. The Missouri River, as a barrier, for example, overwhelmed the local influence of precipitation, temperature, and soils to protect Iowa cornfields from the dune fields of Nebraska [10]). Climate doesn't always explain ecosystem patterns.

However, for both climate scientists and ecologists, there are parallels in how they view the world that can be used in a complementary approach if consistent terminology can be developed.

For climate scientists, the climate system is defined as a complex set of interactions and responses to external forces that include the atmosphere, hydrosphere, lithosphere, cryosphere, and biosphere (definition of climate from The American Meteorological Society; ref [11]). This definition of the climate system, where the natural and human-caused variability is inherent in some components (e.g., the biosphere), needs to be included to focus on details of the physical and chemical components.

Climate processes, as segmented by physical scientists, can be distinguished by spatial scales: global climate, regional climate, local (mesoscale) climate, and microclimate that can have temporal frequencies from long to short.

Similarly, ecology is defined as "the study of the interrelationships between and among living organisms, including humans, and their physical environment" (Figure 1; definition from the Ecological Society of America). Ecological patterns are observable within spatial extents from fine (patches, landscapes) to broad (regions, continents, Earth) with corresponding temporal frequencies (fast to slow). Processes occur within multiple levels of an organization (e.g., from individuals to populations, species, communities, ecosystems, and macrosystems). Climate is most often viewed as a forcing function or driver external to the system, although there are examples where feedback from the vegetation to the climate has been considered [10].

The parallelism is unmistakable. In the real world, there is no "*physical*" climate system on Earth. There is only a physical component of the Earth system. Even in Antarctica, one of the harshest climates on Earth, all five components interact to result in the Earth system. In contrast, on the moon, there is no climate-relevant biology. Thus, the Moon system is likely close to being only a physical system (atmosphere and geosphere). With respect to Mars, dust storms are a major factor in its climate, and they propagate across the planet in a few weeks because there is no vegetation to limit their spread. Mars is a physical system only. That is, there is no need to consider biology to predict the spread of dust storms. However, understanding dust storms on Earth intimately involves biology and other land surface properties.

The similarity in the perspectives of climate and ecology scientists with respect to the Earth indicates that they are examining the same Earth system but from two different perspectives with the physical science community (climate) dominating the development of global policy.

### 2. Why Does It Matter?

The New York Times had an article on 10 June 2021, titled "Our Response to Climate Change Is Missing Something Big, Scientists Say". The article, based on a report of The

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and Co-Sponsored Workshop Report on Biodiversity and Climate Change, states, "the world needs to treat warming and biodiversity loss as two parts of the same problem". Such explicit recognition that climate and ecology study the same system would make effective policy decisions more likely.

There have been attempts in the past. For example, the International-Geosphere-Biosphere Programme (IGBP) was launched in 1987 to coordinate international research on global-scale and regional-scale interactions between Earth's biological, chemical and physical processes and their interactions with human systems. However, The IGBP, although ideally suited to advance the understanding of the climate as an ecological system, ended in 2015. One of the reports [12] is titled "*Vegetation, water, humans and the climate: A new perspective on an interactive system*".

A National Research Report in 2005, "Radiative forcing of climate change: Expanding the concept and addressing uncertainties", helped broaden the perspective of the climate community beyond the focus on the physical subset. One of the recommendations, for example, was that "continued conversion of landscapes by human activity, particularly in the humid tropics, has complex and possibly important consequences for regional and global climate change as a result of changes in the surface energy budget".

The United Nations 2030 Agenda (https://sdgs.un.org/2030agenda accessed on 23 December 2021) and the 17 Sustainable Development Goals (https://sdgs.un.org/goals accessed on 23 December 2021) are moving towards a broader perspective. Yet, the physical (atmospheric) component of the biogeochemical system, as represented by emissions of carbon dioxide into the atmosphere, is still treated as an external forcing (Goal 13).

#### 3. Convergent Definitions

The convergence between climate and ecology should be recognized. There is already movement in that direction [13] an illustrate examples of the complementary approaches in the climate and ecology communities.

On the microscale, ecologists and climate scientists both measure fluxes between the land, ice, and atmosphere of heat, moisture, carbon, nitrogen and other trace gases and aerosols. While they often consider themselves micrometeorologists, hydrologists, soil scientists, and so forth, they focus on a component of the biogeophysical Earth system. Fluxnet, for example, is a global network that includes more than 800 active and historic flux measurement sites, dispersed across most of the world's representative biomes (https://fluxnet.org/about/ accessed on 23 December 2021). Turbulence measurements of carbon dioxide and water vapor exchange fluxes are being made routinely on all continents, that combined with microscale measurements can be used to extrapolate to larger (biome/regional) scales. Air temperature and humidity are measured together with energy and carbon fluxes in the boundary layer above the vegetation canopy at half-hourly time-steps. As one example, Fluxnet sites have shown the contrasting behavior of forest and grassland sites in terms of radiative, sensible and latent energy fluxes during heat waves [14].

At the landscape scale, the Long Term Ecological Research (LTER) is a network of sites (https://lternet.edu/ accessed on 23 December 2021) designed to conduct research to understand and predict ecological system dynamics over decadal time frames. LTER research integrates disciplines to understand ecological processes as they play out across spatial scales at individual sites. Synthetic cross-site studies reveal broader principles that operate at regional to global scales [15]. In addition, the USA National Phenology Network was designed to monitor the impacts of seasonal weather patterns over multi-decadal periods on plants and animals across large spatial extents of regions to continents and the globe (https://www.usanpn.org/usa-national-phenology-network accessed on 23 December 2021).

Meteorologists have similar observational sites, such as the U.S. Climate Reference Network, which measure temperature, precipitation, wind speed, and soil conditions (https://www.ncdc.noaa.gov/crn/ accessed on 23 December 2021). The national weather services worldwide routinely measure temperature, humidity, and winds at the surface and aloft to create weather forecasts. The U.S. Historical Climatology Network (USHCN) temperature data are used to quantify multi-decadal national- and regional-scale surface air temperature changes in the contiguous United States (CONUS). Temperature measurements from the USHCN are integral to monitoring the 1.5C and 2.0C Paris climate agreement. The absence of an analogous biological metric as part of that agreement is notable—and should be addressed.

On the mesoscale and regional scales, shorter-term field campaigns such as the Great Plains Irrigation Experiment in southeast Nebraska in [16]. examined how the onset of irrigation affects weather. In addition, in a combined atmosphere-vegetation dynamics study, aerosols have been shown to significantly impact net carbon dioxide exchange from vegetation, and their effect is broadly relevant for the climate system [17].

In the oceans, research has shown that phytoplankton growth in the Arctic Ocean can amplify warming in that region by 20% [18]. This is because chlorophyll and the related pigments in phytoplankton absorb solar radiation and then change sea surface temperature.

Mammals and insect dynamics also are interactive components of the Earth system. For example, the slaughter of millions of bison in the Great Plains of the USA in the late 1800s altered the short grass prairie from what it had been and, thus, likely changed surface fluxes exchanges with the atmosphere [19]. Drought can also significantly alter these fluxes and even result in dust storms, as occurred in the 1930s Dust Bowl. Likewise, the still unexplained sudden extinction of the estimated over 12.5 trillion Rocky Mountain locusts in the late 1800s [20] undoubtedly altered vegetation (and thus surface heat and moisture and trace gas and aerosol fluxes) in the western USA and Canada, and thus changed regional weather patterns.

The global scale Earth system, of course, integrates all the regional and local effects. On the global scale, satellite observations show a clear response of vegetation greenness to increased atmospheric carbon dioxide concentrations [21] A quarter to half of Earth's vegetated lands have shown significant greening over the last 35 years, largely due to rising atmospheric carbon dioxide levels [22] and illustrated in Figure 4. The increase in photosynthesis from the more prominent green biomass significantly alters the surface fluxes of heat, moisture, momentum, trace gases and aerosols, which then affects other components of the Earth system. For example, India monsoon precipitation is altered in response to changes in the surface fluxes from urbanization and, to some extent, the change of prevalent mixed forest into deciduous needle/leaf forest in Kerala [23]. As another example, there has been documentation of tropospheric cooling in northeast Asia due to cropland expansion [24].



Figure 4. Change in leaf area between 2015 and 1982 presented as 1982 minus 2015 (from [22]).

#### 4. Implications for Policy

These examples illustrate that ecologists and climate scientists are studying the same biogeophysical Earth system. The climate community, has been influential in defining the scientific assessment framework for policymakers, as shown in the IPCC reports and US National Assessments. To develop effective policy to minimize threats to key environmental and social resources, the development and implementation of the assessment findings will need to help foster a partnership of the physical science and biological communities, along with the input and expertise of the social science community.

The intimate interleaving of physical and biological processes is clear, as exemplified in the paper with the title "Cross-scale interactions, nonlinearities, and forecasting catastrophic events" by [25]. It is thus noted that interactions and feedbacks between the physical and the biological components of the Earth's biogeochemical system are a fundamental aspect of the real-world functioning of this system. We can study components of the system by prescribing other components as fixed, but the understanding that this is a limitation on the realism of the results needs to be emphasized.

The requirement to consider the multifaceted, multidisciplinary interactions across space and time in the Earth's biogeochemical system also needs to be communicated to educators, policymakers and the public. Broadening the assessments beyond greenhouse emissions and feedback amongst the different climate components will likely help prioritize adaptation and mitigation with respect to the variety of natural and human risks to the environment and society. The reduction of vulnerability of water, food, and energy resources, and human, plant and animal health require assessing all social and environmental risks. After these threats are identified for each resource, the relative risks can be compared to adopt optimal preferred mitigation/adaptation strategies [21].

Several papers advance this approach, including [26–29]. Also, the 2030 Agenda (https://sdgs.un.org/2030agenda accessed on 23 December 2021) and the 17 Sustainable Development Goals (https://sdgs.un.org/goals accessed on 23 December 2021) provide a movement towards a more integrated approach.

However, as mentioned earlier, and illustrated by Goal 13 (https://sdgs.un.org/goals/ goal13 accessed on 23 December 2021), this UN initiative highlights the physical component of the climate system as an external driver than an integral interactive part of the Earth's biogeophysical system. This goal, which states "*take urgent action to combat climate change and its impacts*" focuses on rising atmospheric greenhouse gases, treating this as an external forcing. However, forcings that significantly affect the weather also include aerosols and land use change/land management [30,31]. Nonlinear feedbacks between components within the system also need to be considered [32].

# As Written in the National Research Council Report

"Several types of forcings—most notably aerosols, land-use and landcover change, and modifications to biogeochemistry—impact the climate system in nonradiative ways, in particular by modifying the hydrological cycle and vegetation dynamics. Aerosols exert a forcing on the hydrological cycle by modifying cloud condensation nuclei, ice nuclei, precipitation efficiency, and the ratio between solar direct and diffuse radiation received. Other nonradiative forcings modify the biological components of the climate system by changing the fluxes of trace gases and heat between vegetation, soils, and the atmosphere and by modifying the amount and types of vegetation. No metrics for quantifying such nonradiative forcings have been accepted".

Thus, we recommend that when accounting for contributions towards Goal 13, studies that characterize the risks to the weather and other environmental components of the biogeophysical system all be considered.

## 5. Conclusions and the Path Ahead

Ecology and the climate of the Earth provide two views of the same biogeophysical system on different spatial and time scales. This congruence of perspectives is not yet gen-

erally adopted. Recognizing this congruence will help develop additional opportunities for more effective policy including a bottom-up, community and businesses-driven framework to minimize damage to society and the environment. There is a clear need to understand and foster research for these linkages among the different components of the Earth System to anticipate the impacts of a changing environment on these coupled systems and provide timely, science-based information to the public and decision-makers.

Ref. [33] in their review conclude that "biosphere is central to understanding why and how the Earth system is changing and to adapting to and mitigating future changes". Their review outlines three pathways that are needed. The first is at the core of this paper, where the congruence and confluence of the biosphere/ecology and the climate needs to be explicitly recognized. The second and third relates to the integration and synthesis of largescale with local vulnerability, impacts, and adaptation (VIA), as well as for improved predictability.

Specific to the recommendation related to the large and local VIA integration, a way forward is to address each Earth System concern with the following questions [34].

1. Why is this resource important? How is it used? To what stakeholders is it valuable?

For example, the resource considered could be green cover or reserve tree canopy in an urban neighborhood. The resource could be used as a basis for parks and recreation greenbelt requirements. It could also be used as a community playground and for flora and fauna management for a sensitive ecological locale. The value of this green cover is different for different constituents with impact ranging from a reduced heat island, to an improved ecological footprint, or erosion control, to give an example.

2. What are the key environmental and social variables that influence this resource?

The green cover, continuing on the above example, could be influenced by droughts, extreme heat or cold, as well as pests and invasive species that can cause damage to the foliage. The social variables would be community organizations highlighting the need for the green cover, parks for the neighborhood well being. Other factors could be city programs in response to council and community guidelines to help different community services.

3. What is the sensitivity of this resource to changes in each of these key variables? This includes, but is not limited to, the sensitivity of the resource to climate variations and change on short (e.g., days), medium (e.g., seasons), and long (e.g., multi-decadal) timescales.

The meteorological variables such as extreme cold or freeze could have a deleterious effect on the green cover in a matter of days—but the likelihood of that happening is related to the climatology of the region including the potential for a pest infestation or invasion of different ecosystems. There could be more stress from the longer-term climatic change but the most impactful sensitivity is to social drivers such as community migration, neighborhood development plans that can decide the fate of the green cover.

4. What changes (thresholds) in these key variables would have to occur to result in a negative (or positive) response to this resource?

The climatic forcing would need to be of an extreme nature to have an impact on the green cover; on the other hand, the green cover with sufficient spatial coverage can alter the regional meteorological, hydrological, biological and societal forcing.

5. What are the best estimates of the probabilities for these changes to occur? What tools are available to quantify the effect of these changes? Can these estimates be skillfully predicted?

These probabilities and outcome can either be quantified using long term weather observations or model projections or can be provided by experts as guesstimates. The impact of green cover change also can be estimated based on the pressure on landscape and the adaptive measurements underway. 6. What actions (adaptation/mitigation) can be undertaken in order to minimize or eliminate the negative consequences of these changes (or to optimize a positive response)?

Clearly an integrative set of actions related to the green spaces and, societal and environmental well being need to be developed.

7. What are specific recommendations for policymakers and other stakeholders?

The integration of the meteorology, hydrology, biology, and societal benefits as well as feedbacks will need to be considered. Note that in the questions posed above, the green cover and urban ecosystem are simply taken as an example to illustrate a point. More generically, it is highlighted that by framing the questions this way, the current perceived distinction between whether it is climate or ecology that is affected can be avoided.

The recognition that enhancing ecosystem services- from urban to forest to agricultural to aquatic and beyond- is part of bolstering climate services will add more effective strategies and resource identification for local and regional adaptation and mitigation approaches. Assessing the stresses and feedbacks between the ecological/ecosystem systems allows a better assessment of the broader climate system [32]. This recognition will also likely help communities and business enterprises to assess their efforts towards climate goals that are beyond the emission reduction targets and have conformance to the sustainability development goals (SDG2030). Achieving these goals within this decade would require such an integrated research agenda.

Author Contributions: Conceptualization R.A.P.S.; Writing—R.A.P.S., D.C.P., D.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

**Data Availability Statement:** Websites with urls are listed in the paper and that information including data is publically available.

**Conflicts of Interest:** The authors declare no conflict of interest.

# References

- Miralles, D.G.; Brutsaert, W.; Dolman, A.J.; Gash, J.H. On the Use of the Term "Evapotranspiration". Water Resour. Res. 2020, 56. [CrossRef] [PubMed]
- Cox, P.M.; Betts, R.A.; Jones, C.D.; Spall, S.A.; Totterdell, I.J. Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. *Nature* 2000, 408, 184–187. [CrossRef] [PubMed]
- 3. Shepardson, D.P.; Niyogi, D.; Roychoudhury, A.; Hirsch, A. Conceptualizing climate change in the context of a climate system: Implications for climate and environmental education. *Environ. Educ. Res.* **2012**, *18*, 323–352. [CrossRef]
- 4. IPCC. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., et al., Eds.; Cambridge University Press: Cambridge, UK, 2022; in press; Available online: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/ (accessed on 23 December 2021).
- 5. Pielke, R., Jr. Misdefining "climate change": Consequences for science and action. Environ. Sci. Policy 2005, 8, 548-561. [CrossRef]
- 6. Beck, S.; Oomenb, J. Imagining the corridor of climate mitigation—What is at stake in IPCC's politics of anticipation? *Environ. Sci. Policy* **2021**, *123*, 169–178. [CrossRef]
- Bierbaum, R.; Smith, J.B.; Lee, A.; Blair, M.; Carter, L.; Chapin, F.S., III; Fleming, P.; Ruffo, S.; Stults, M.; McNeeley, S.; et al. A comprehensive review of climate adaptation in the United States: More than before, but less than needed. *Mitig. Adapt. Strat. Glob. Chang.* 2013, *18*, 361–406. [CrossRef]
- Kottek, M.; Grieser, J.; Beck, C.; Rudolf, B.; Rubel, F. World Map of the Köppen-Geiger Climate Classification Updated. *Meteorol.* Z. 2006, 15, 259–263. [CrossRef]
- 9. Pielke, R.A., Sr.; Vidale, P.L. The boreal forest and the polar front. J. Geophys. Res. Earth Surf. 1995, 100, 25755–25758. [CrossRef]
- 10. Peters, D.P.; Burruss, N.D.; Okin, G.S.; Hatfield, J.L.; Scroggs, S.L.; Huang, H.; Brungard, C.W.; Yao, J. Deciphering the past to inform the future: Preparing for the next ("really big") extreme event. *Front. Ecol. Environ.* **2020**, *18*, 401–408. [CrossRef]
- Shepardson, D.P.; Niyogi, D.; Choi, S.; Charusombat, U. Students' conceptions about the greenhouse effect, global warming, and climate change. *Clim. Chang.* 2010, 104, 481–507. [CrossRef]

- Kabat, P.; Claussen, M.; Dirmeyer, P.A.; Gash, J.H.C.; de Guenni, L.B.; Meybeck, M., Sr.; Vorosmarty, C.J.; Hutjes, R.W.A.; Lutkemeier, S. (Eds.) Vegetation, Water, Humans and the Climate: A New Perspective on an Interactive System; Global Change— The IGBP Series; Springer: Berlin, Germany, 2004.
- Peters, D.P.; Groffman, P.M.; Nadelhoffer, K.; Grimm, N.B.; Collins, S.L.; Michener, W.K.; Huston, M.A. Living in an increasingly connected world: A framework for continental-scale environmental science. *Front. Ecol. Environ.* 2008, 6, 229–237. [CrossRef]
- Teuling, A.; Seneviratne, S.; Stöckli, R.; Reichstein, M.; Moors, E.; Ciais, P.; Luyssaert, S.; Hurk, B.V.D.; Ammann, C.; Bernhofer, C.; et al. Contrasting response of European forest and grassland energy exchange to heatwaves. *Nat. Geosci.* 2010, *3*, 722–727. [CrossRef]
- 15. Hudson, A.R.; Peters, D.P.C.; Blair, J.M.; Childers, D.L.; Doran, P.T.; Geil, K.; Goosef, M.; Gross, K.L.; Haddad, N.M.; Pastore, M.A.; et al. Cross-site comparisons of climate change on drylands in the US LTER Network. *Bioscience* 2022, *in press*.
- 16. Rappin, E.; Mahmood, R.; Nair, U.; Pielke, R.A., Sr.; Brown, W.; Oncley, S.; Wurman, J.; Kosiba, K.; Kaulfus, A.; Phillips, C.; et al. The Great Plains Irrigation Experiment (GRAINEX). *Bull. Am. Meteorol. Soc.September* **2021**, *102*, E1756–E1785. [CrossRef]
- Niyogi, D.; Chang, H.I.; Saxena, V.K.; Holt, T.; Alapaty, K.; Booker, F.; Chen, F.; Davis, K.J.; Holben, B.; Matsui, T.; et al. Direct observations of the effects of aerosol loading on net ecosystem CO<sub>2</sub> exchanges over different landscapes. *Geophys. Res. Lett.* 2004, 31, L20506. [CrossRef]
- Park, J.-Y.; Kug, J.-S.; Bader, J.; Rolph, R.; Kwon, M. Amplified Arctic warming by phytoplankton under greenhouse warming. Proc. Natl. Acad. Sci. USA 2015, 112, 5921–5926. [CrossRef]
- 19. Eastman, J.L.; Coughenour, M.B.; Pielke, R.A. Does Grazing Affect Regional Climate? J. Hydrometeorol. 2001, 2, 243–253. [CrossRef]
- 20. Lockwood, J.A. Locust: The Devastating Rise and Mysterious Disappearance of the Insect that Shaped the American Frontier; Basic Books: New York, NY, USA, 2004.
- Nemani, R.R.; Running, S.W.; Pielke, R.A.; Chase, T.N. Global vegetation cover changes from coarse resolution satellite data. J. Geophys. Res. Earth Surf. 1996, 101, 7157–7162. [CrossRef]
- Zhu, Z.; Piao, S.; Myneni, R.B.; Huang, M.; Zeng, Z.; Canadell, J.G.; Ciais, P.; Sitch, S.; Friedlingstein, P.; Arneth, A.; et al. Greening of the Earth and its drivers. *Nat. Clim. Change* 2016, *6*, 791–795. [CrossRef]
- 23. Boyaj, A.; Dasari, H.P.; Hoteit, I.; Ashok, K. Increasing heavy rainfall events in south India due to changing land use and land cover. *Q. J. R. Meteorol. Soc.* 2020, *146*, 3064–3085. [CrossRef]
- 24. He, Y.; Lee, E.; Mankin, J.S. Seasonal tropospheric cooling in Northeast China associated with cropland expansion. *Environ. Res. Lett.* **2020**, *15*, 034032. [CrossRef]
- Peters, D.P.C.; Pielke, R.A., Sr.; Bestelmeyer, B.T.; Allen, C.D.; Munson-McGee, S.; Havstad, K.M. Cross-scale interactions, nonlinearities, and forecasting catastrophic events. *Proc. Natl. Acad. Sci. USA* 2004, 101, 15130–15135. [CrossRef] [PubMed]
- 26. Von Stechow, C.; Minx, J.C.; Riahi, K.; Jewell, J.; McCollum, D.; Callaghan, M.W.; Bertram, C.; Luderer, G.; Baiocchi, G. 2 °C and SDGs: United they stand, divided they fall? *Environ. Res. Lett.* **2016**, *11*, 034022. [CrossRef]
- Filho, W.L.; Tripathi, S.K.; Guerra, J.B.S.O.D.A.; Giné-Garriga, R.; Lovren, V.O.; Willats, J. Using the sustainable development goals towards a better understanding of sustainability challenges. *Int. J. Sustain. Dev. World Ecol.* 2019, 26, 179–190. [CrossRef]
- 28. Mensah, J. Sustainable development: Meaning, history, principles, pillars, and implications for human action: Literature review. *Cogent Soc. Sci.* **2019**, *5*, 1653531. [CrossRef]
- Belmonte-Ureña, L.J.; Plaza-Úbeda, J.A.; Vazquez-Brust, D.; Yakovleva, N. Circular economy, degrowth and green growth as pathways for research on sustainable development goals: A global analysis and future agenda. *Ecol. Econ.* 2021, 185, 107050. [CrossRef]
- 30. Pielke, R.A., Sr.; Beven, K.; Brasseur, G.; Calvert, J.; Chahine, M.; Dickerson, R.; Entekhabi, D.; Foufoula-Georgiou, E.; Gupta, H.; Gupta, V.; et al. Climate change: The need to consider human forcings besides greenhouse gases. *EOS* 2009, *90*, 413. [CrossRef]
- National Research Council. Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties; Committee on Radiative Forcing Effects on Climate Change; Climate Research Committee; Board on Atmospheric Sciences and Climate; Division on Earth and Life Studies; The National Academies Press: Washington, DC, USA, 2005; 208p.
- Rial, J.; Pielke, R.A., Sr.; Beniston, M.; Claussen, M.; Canadell, J.; Cox, P.; Held, H.; de Noblet-Ducoudre, N.; Prinn, R.; Reynolds, J.; et al. Nonlinearities, feedbacks and critical thresholds within the Earth's climate system. *Clim. Change* 2004, 65, 11–38. [CrossRef]
- 33. Bonan, G.B.; Doney, S.C. Climate, ecosystems, and planetary futures: The challenge to predict life in Earth system models. *Science* **2018**, *359*, eaam8328. [CrossRef]
- 34. Pielke, R.A., Sr. (Ed.) *Climate Vulnerability, Understanding and Addressing Threats to Essential Resources,* 1st ed.; Academic Press: Cambridge, MA, USA, 2013; 1570p.