International Review of the Zackenberg Research Station

Sponsor:

The Danish Environmental Protection Agency

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Summary and Overall Assessment

The Zackenberg Research Station (ZRS) has been an outstanding success in the 10 years since its inception. It is now an established and well-respected institution with perhaps the most comprehensive environmental monitoring programme in the Arctic. It has a vision, and mechanisms, for integrating monitoring output and findings from research. An example of such mechanisms is a 10-year synthesis of research and monitoring at ZRS that is nearing final completion. The Station derives particular importance from its location in a remote region in the high Arctic that is under-represented in monitoring and research activities, yet is particularly vulnerable to environmental and especially climatic change. Further, the Station is strategically located at an important environmental transition zone both on land and in the ocean. There is subsequently a high diversity of environments and biota that differ from other high Arctic locations such as Svalbard. However, the remote location of the Station unfortunately results in high transportation costs that inhibit, to some extent, the use of the Station by some national and international researchers. As should be expected, activities at ZRS are not cost-effective relative to comparable operations in more accessible regions. In high Arctic environments the value of acquiring data and information is simply more costly and must be incorporated in to any comparison of cost effectiveness with stations in more accessible locations.

The Station has designed a monitoring programme that can service important international environmental assessments and has, although to a limited extent so far, developed a mechanism to adjust its monitoring portfolio to implement new activities in line with recommendations from ongoing and new international planning initiatives. The Station is, therefore, poised to play an even greater and internationally significant role in understanding long-term dynamics and change in ecosystem structure and function in the high arctic region. Furthermore, the breadth of monitoring across interacting trophic levels and some degree of integrated monitoring give the potential for a basic science understanding relevant to ecological theory that is important for advancing the biogeosciences at a global scale. Similarly, some of the research and monitoring on feedbacks from the high Arctic to the climate system have potential global relevance and are already acclaimed internationally. Because of the current success of the Station, this report generally offers support for ongoing activities and gives recommendations for the improvement, rather than restructuring, of any major component of the current activities.

The monitoring and research programme at Zackenberg appears to be of high quality and has progressed well since its inception. The reputation of the research programmes at ZRS have been earned through publications in high profile international peer-reviewed journals while the reputation of the monitoring programme has been earned through circulation of informative annual reports, excellent Basic manuals and presentations at international meetings. However, relative to the volume of research and monitoring being conducted, there appears to be a low number of research articles published in high ranking international peer-reviewed scientific journals. For some programmes, many publications appear to be short notes, include somewhat obscure journals and are published in Danish. Further, the publication record for ZRS appears to have been stable or has decreased since 2002. Improving the publication record will be critical for attracting fee-paying international researchers and ensuring the quality, continued success and scientific impact of the research and monitoring programme at ZRS. Although the Station already contributes to international processes and networks, it should develop a more active contribution while increasing the international research component of its field activities. Measures should be taken to attract young and international scientists, for example by holding field courses and seeking funding support for transnational access.

There is a need for a clear procedure for periodically reviewing and improving the monitoring programme. Measurement of glacial mass balance is perhaps the most important element that is currently missing from the ZRS monitoring portfolio. Experimental manipulations operated by researchers are currently lacking from the monitoring programme. These could significantly enhance both the research and monitoring program, as has been demonstrated at numerous research stations around the world. The addition of herbivory exclosures, snow fences, water table and ITEX-accepted warming experiments should be considered even though this might necessitate applications for additional funding from the research community. Also, several baseline datasets such as a specific invertebrate list, soils map and moss flora could enhance the science programme. Although the addition of facilities, infrastructure and logistics is a developing process, there are some key developments that, if implemented, would enhance the Station's achievements. These include lengthening the field season to include at least extended Autumn activities and winter campaigns, the installation of a survey grade differential global positioning system, and establishing a network of '*remote*' field cabins. Many of these recommendations require additional resources, rather than re-allocation within an existing budget. However, securing long term funds for the monitoring programme should be the top priority while some additional resources could be obtained externally, e.g. through IPY funding, or as *'one-off'* commitments through infrastructural or capital equipment awards. Ceasing current monitoring activities should only be done with extreme caution, but new methodologies such as automation of measurements and reduced frequency of observations should be explored in depth where appropriate.

There is a need to remove current uncertainty in the future institutional framework for ZRS. Although the current management system has been effective, particularly with respect to station management, it is complex. Clarification of the overall management system should be sought whenever possible. Similarly, although the integration of the Basic sub-programmes has been explicit and has evolved well during the development of the ZRS, there should be a continuing effort to improve this integration further. On-site station and scientific management during the period of field activities should be provided, and support for data management should be improved. These improvements to data management should include mechanisms for registering data users, as well as tracking data usage, download frequency, and use in publications, models or synthesis efforts. A web-based Map Server, to which the current data archive could be linked would also be a valuable science, logistic and education and outreach tool.

Following publication of the first 10 year synthesis, ZRS staff will be well situated to compile a vision document for the next 10 years. This should incorporate an assessment of the current monitoring programme and mechanisms required to maintain the reputed and high quality scientific programme established over the past 10 years.

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1. Zackenberg Research Station's Setting and Activities

Zackenberg Research Station (ZRS) is situated in the high Arctic at 74°28'N, 20°34'W on the northern side of the fjord, Young Sund. It was established in 1995-96 and is owned and operated by the Danish Polar Centre, and is currently in the process of being handed over to the Greenland Homerule. It consists of a complex of buildings for accommodation as well as laboratories and it is well appointed with infrastructure support and scientific equipment for research and monitoring. Additionally, baseline environmental information and data sets, some of which extend back for 10 years, are available to scientists. A natural runway facilitate access but the Station is staffed only during the summer period. The station is open from May 31st to August 31st each year and can accommodate up to about 25 personnel, which commonly includes logistics staff, monitoring staff and both national (Danish/Greenlandic) and foreign researchers.

Research, monitoring and logistics are operated within the Zackenberg Ecological Research Operations (ZERO) programme. The monitoring programme is called Zackenberg Basic. This relatively long term programme has four sub-programmes: ClimateBasic (monitoring of climate and river water discharge), BioBasic (monitoring of selected ecosystem parameters), GeoBasic (monitoring of the abiotic environment including biogenic trace gases) and MarineBasic (monitoring of selected marine parameters). The Station, its research and monitoring are becoming increasingly recognised internationally, and the research on carbon dynamics is particularly acclaimed (see Section 4.1 below). The ZERO program hosts a comprehensive and well-integrated monitoring programme of about 2,500 variables that is probably the most extensive and best-coordinated environmental monitoring programme in the Arctic. The ZRS has been an ambitious and highly successful venture due to several key factors. These include the vision of the original ZERO design and planning team; the substantial investment that has been made in infrastructure and the ZERO program; the breadth, extent and sustainability of the ZERO program; and the partnering of ZRS to international networks. The ZRS has also been proactive about implementing various monitoring schemes and priorities assessed by international teams of researchers such as the Arctic Council's Arctic Monitoring and Assessment Program (AMAP) and the Arctic Climate Impact Assessment (ACIA).

The importance of the Station is based on its location as well as its activity base. The Station is located in the high Arctic where relatively little is known about ecosystems and the environment compared to the low Arctic. Indeed, the Station is one of only two major observatory platforms in the high Arctic, the second being the combined installations at Ny Ålesund and Longyearbyen on Svalbard. It is debatable if Zackenberg is representative of other high Arctic areas. However, environmental and ecological processes there are representative of other high Arctic areas whereas the local environment has a high intrinsic value. The environment surrounding Zackenberg is remote and relatively undisturbed. Consequently, interactions between ecosystem processes, biota and environment are uncomplicated by humans and are therefore easier to study. Lack of human influence also facilitates the identification of climate impacts on ecosystems and allows fundamental research into the dynamic interactions between

components within ecosystems, thereby advancing ecological theory. There is a great diversity of environments, ecosystems, flora and fauna surrounding ZRS due to the presence of strong altitudinal, continental and oceanographic environmental gradients and proximity to the boundary between low and high Arctic ecosystems. The coastal area of ZRS is close to a critical area of ice export from the Arctic Ocean that is changing dramatically and a reversing point in ocean circulation which is largely driven through thermohaline circulation. As such, ZRS offers the rare ability to study and monitor ocean-land interactions. Many of the ecosystems are particularly sensitive to climatic change, and high Arctic ecosystems are those most likely to diminish in extent during climate warming, making them particularly important ecosystems to monitor.

2. Terms of Reference and Scope of this Report

The Primary Objective of this evaluation is to help ensure an efficient, effective and scientifically justified monitoring programme of climate change and climate change effects at ZRS by identifying improvements/adjustments that could be made to the ongoing monitoring programme. Specifically, the Danish Environmental Protection Agency (DEPA) has asked the review panel to address the following questions and offer recommendations for improvement based on existing budgetary constraints. The feasibility and reality of implementing change has weighed heavily on the authors of this report who have been mindful of a limited potential increase in the ZRS budget. DEPA has requested that the review should focus primarily on the DEPA funded monitoring program but also include reference to research, management and logistic issues if these are relevant to the functioning of the DEPA program.

1. To what extent and in what way have the results from Zackenberg contributed to the conclusions of Arctic Climate Impact Assessment (ACIA) and to the fourth IPCC assessment?
2. To what extent are monitoring efforts at Zackenberg in line with recommended AMAP climate effect monitoring and to what extent will continued monitoring be in line with that recommended in the ACIA follow up process.
3. Is the scientific quality of the work at Zackenberg satisfactory?
4. To what extent may the Zackenberg monitoring as it is contribute to monitoring of Arctic Biodiversity?
5. Based on 1-4: Are there elements in the programme, which could be neglected or monitored less frequent?
6. Based on 1-4: Does the programme miss significant elements and/or are there elements which need reinforcing?
7. Which role does Zackenberg play in international monitoring networks such as SCANNET, Arctic Observatory Network (AON), and the Circumarctic Environmental Observatories Network (CEON)?
8. To what extent does Zackenberg duplicate/supplement climate change monitoring at Svalbart (Ny Aalesund)?
9. Are the different Basic-programmes sufficiently integrated.
10. How do you evaluate the Zackenberg Concept?
11. Is the institutional set-up for Zackenberg satisfactory and if not, how could it be improved?

12. Given the strengths and weaknesses of Zackenberg which issues/topics should be prioritised in the next 3-5 years.

3. Evaluation Process

In addition to email and telephone correspondence with parties knowledgeable about ZRS, this evaluation has been compiled following two meetings of the review panel and the ZRS administrative, operational, monitoring and research community. The first of the meetings was convened simultaneously with the 2006 Zackenberg Symposium (Februrary 2-5, 2006) at Menstrup Kro. This opportunity afforded the panel to gain insight in to ZRS through a presentation and overview of the first major book and 10-year synthesis to be generated from the ZERO programme: *The Dynamics of a High Arctic Ecosystem in Relation to Climatic Variability and Change. Ten years of monitoring and research at Zackenberg Research Station, Northeast Greenland*. The second meeting was convened at the Danish Polar Centre (4-6 September, 2006), where interviews with 12 representatives of the ZRS administrative, operational, monitoring and research community were conducted. Several other key people familiar with ZRS were contacted by the review panel via telephone and email to discuss the review questions detailed immediately above. Information provided to the review panel has been treated as confidential and has been detailed synthetically and anonymously in this report accordingly.

4. Evaluation

4.1 To what extent and in what way have the results from Zackenberg contributed to the conclusions of the Arctic Climate Impact Assessment (ACIA) and to the fourth IPCC assessment?

ACIA. Results from research at the Zackenberg Research Station have contributed to the ACIA in several ways, but many of the monitoring activities at Zackenberg were probably established too recently to be incorporated in the ACIA. Input from research at Zackenberg included the following types:

1. Researchers at Zackenberg were contributing or consulting authors of the full technical report. Up to three Greenlandic and five Danish researchers of a total of about 325 lead and contributing authors participated in the assessment. It is unclear to what extent each was associated with Zackenberg, although some were clearly strongly associated with research there.
2. Researchers gave four posters/extended abstracts at the ACIA synthesis meeting in Iceland in November 2004.
3. Research based at Zackenberg was included in the ACIA. At least four, possibly five, chapters contained references to work at Zackenberg.

T.R. Christensen played a direct role in ACIA as a Contributing Author on Chapter 7 '*Arctic tundra and polar desert ecosystems*'. Results from his research group at Zackenberg played a significant role in contributing to our understanding of high Arctic carbon dioxide and methane emissions. The data are one of about only six Arctic-wide

studies of inter-annual carbon fluxes and are an important contribution to our current understanding. This group's work was again referred to in the summary chapter, Chapter 18 '*Summary and synthesis of the ACIA*'. S. Jonasson was a "Consulting" author on Chapter 7. As a researcher from Zackenberg, relevant results from his group's research on plant-soil microbe interactions was included. Chapter 7 also contained references to Heide-Jörgensen and Johnsen's 1998 assessment of climate changes in Greenland and the Faroe Islands and some systematic studies on basidiomycete fungi in Greenland. Chapter 8 that deals with freshwater ecosystems again referred to the important work at Zackenberg on methane emissions by T.R. Chrsitensen's group. Additionally, work on north east Greenland lakes by Jeppesen et al (2003) was included, although it is not clear if this work was located at Zackenberg. Meltofte's 1985 and 2000 work on waders was also referred to. Chapter 11 '*Management and conservation of wildlife in a changing Arctic environment*' was lead by D. Klein who has been involved in research at Zackenberg. Chapter 18 '*Summary and synthesis of the ACIA*' contained a regional analysis of climate changes and their impacts. Region I includes eastern Greenland and the analysis benefited from a review by Callaghan et al., 2004, which was based on the SCANNET network that includes Zackenberg. The review was co-authored by several Zackenberg researchers including T.R. Christensen, H.H. Christiansen, M.C. Forchhammer, T.T. Höye, H. Meltofte and M. Rasch. Consequently, many aspects of research at Zackenberg were included.

During the ACIA synthesis meeting in Iceland in 2004, 4 presentations were made by researchers associated with studies on Zackenberg. These were by Marchand et al, Meltofte, Rasch et al., and Rysgaard.

The Millennium Assessment of Ecosystems. This global assessment included a chapter on polar ecosystems. T.R. Christensen was a contributing author and work on carbon cycling featured strongly.

The Intergovernmental Panel on Climate Change (IPCC). Again, this global assessment, due to be published in 2007, includes a chapter on polar ecosystems. T.R. Christensen is a contributing author and work on carbon cycling at Zackenberg again features strongly. H. Meltofte was a government reviewer of the polar chapter and contributed constructively, with some comments being based on data from Zackenberg. About 10 papers based on research at Zackenberg are cited in the chapter. These papers relate mainly to carbon cycling, and impacts on ecosystems of UV-B radiation. Recent research on impacts of UV-B on ecosystems is also referenced in the United Nations Environment Programme Expert Panel on Ozone Depletion Effects 2007 Assessment.

International Conference for Research Planning II (ICARP II). Science Plan 8, the terrestrial and freshwater ecosystem chapter of this international compilation of research agendas included a co-chair that works at Zackenberg (T.R. Christensen) and a contributing author that is now employed partly to analyse data from Zackenberg (M.C. Forschhammer). Other science plans are not yet available for checking.

4.2 To what extent are monitoring efforts at Zackenberg in line with recommended AMAP climate effects monitoring and to what extent will a continued monitoring be in line with recommended ACIA follow up?

There have been several major initiatives that recommend new monitoring and research activities in the Arctic. Their recommendations range from general concepts (AON – Arctic Observatories Network), through detailed short term recommendations (AMAP climate effects monitoring and ACIA chapter recommendations) to long term goals (ICARP II, 10 years). Some initiatives, such as the ACIA follow-up and AMAP-CAFF joint biodiversity monitoring programme are developing and changing rapidly over time. The ZRS has the potential to implement most of the recommendations made in these processes. An analysis by the Station Manager, Dr Rasch, found that 44 recommendations from the ACIA 2005 technical report were relevant to the Zackenberg's basic programmes. These range from measurements that are easy to implement (e.g. *in situ* measurements of snow water equivalents in high latitude areas) to those that will demand large resources and will be technically difficult and expensive (e.g. long term impact of CO_2 on ecosystems and winter-long measurements). Importantly, the ZRS is *already* monitoring most of the relevant parameters recommended by the ACIA report. Furthermore, the Station has adopted an integrated monitoring programme (although this component could be improved: see Section 4.9) that ACIA failed to recommend, but that is recommended by AON.

Discussions with Zackenberg staff revealed that AMAP and ACIA recommendations had already influenced their monitoring programmes, but in an appropriately gradual way rather than a significant leap in vision: some new measurements had been initiated (e.g. methane, CO_2 flux, biomass, NDVI, extended snow measurements, and solutes monitored in the river), while plans existed to initiate others. One view was that the development could have been even greater. In MarineBasic, only one extra variable was added (ocean-air CO_2 flux change). A critically important recent development is the appointment of a most capable research Professor of international standing (Mads Forchhammer) who can provide a conceptual framework for developing the monitoring programme and integrative models to exploit the resulting data, for example, by scaling from plot to landscape. This appointment should meld nicely with the ongoing efforts of many outstanding contributions made in the last 10 years by other Zackenberg researchers of international standing and help to improve the coordination, integration and publication of results from the ZERO program. Another important aspect of the Zackenberg operation is an annual meeting of experts who advise on additional monitoring and cuts to existing monitoring activities. Under the present financing, new measurements are difficult to implement without discontinuing others because of time/staffing constraints, and in some cases finances for instrumentation.

A particularly important requirement from the Arctic monitoring and research community is to make year-round observations because climate models project that warming will be most pronounced during winter. Discussions with Zackenberg staff revealed that there was an awareness that the operations at Zackenberg should be prolonged during the year to include the '*shoulder*' seasons of late winter/spring and autumn/early winter. Although

demanding of resources, an expansion of the period of activities would be more beneficial than taking on more measurements for the summer season only. Any option to develop winter activities during IPY should be exploited fully.

The recommendations from ICARP II are not formally published yet. These have a time horizon of ten years. The Science Plan 8, Terrestrial and Freshwater Ecosystems, has a strong focus on ecosystem function and structure, modeling, scaling-up and remote sensing. The Zackenberg Station could potentially contribute strongly to these recommendations and be at the forefront of observation, research and modeling over the next 10 years. To accomplish this potential, it is important to continue the dialogue between the Basic programmes and the expert groups, and to further develop the links between monitoring programmes, research projects and international modeling exercises.

Almost all of the climate effects monitoring recommended by AMAP have been adopted by the Zackenberg Basic programmes according to the list compiled by Rasch and Canning in the 8th Annual Report (2002). Some of the exceptions are currently being addressed. A major exception that has not yet been addressed, is the recommendation to monitor glacier mass balance. It is somewhat surprising that such measurements have not been made. Indeed, Zackenberg is relatively close to the inland ice, and should consider monitoring the ice edge as a contribution to exceptionally important studies examining the uncertain dynamics of the Greenland Ice Sheet as it responds to global change.

4.3 Is the scientific quality of the work at Zackenberg satisfactory?

The monitoring and research programme at Zackenberg appears to be of high quality and has progressed well since its inception. The monitoring programme is relatively well known in the Arctic terrestrial science community, having recognition as being amongst the most multifaceted and in depth environmental monitoring programme currently active in the Arctic. For some disciplines such as the terrestrial biogeosciences, ZRS holds repute for contributions from a high Arctic site. Recent international interest in ZRS has been spurred on by these research successes in combination with the comprehensive, sustained and relatively long term monitoring programme that is in place.

The reputation of the research programmes at ZRS has been earned through publications in high profile international peer-reviewed journals. The reputation of the monitoring programme, however, has justifiably been earned through circulation of annual reports, presentations at international meetings and workshops and the involvement of ZRS in several international scientific synthesis and planning efforts outlined in 4.1 above and below.

Relative to the volume of research and monitoring being conducted, there appears to be a low number of research articles published in high ranking international peer reviewed scientific journals. Only 31% of publications listed for ZRS appear to be peer reviewed (see Table 4.3.1). For some programmes such as the BioBasic programme publications appear to be mostly short notes, include somewhat obscure journals and are published in Danish. Approximately 7% of published articles are in the form of Masters or Doctoral

theses. Most publications listed for ZRS are best categorized as reports, extended abstracts or general. Further, the publication record for ZRS appears to have been stable or has decreased since 2002. These metrics of success appear to differ greatly by program, and are limited by complete reporting and disciplinary bias. However, they serve as a useful albeit conservative index of scientific productivity, quality and reputability for the ZERO program and ZRS research as a whole.

Importantly, however, some of the published research is of the highest standard, is innovative, and two studies have been acknowledged by publication in the world-leading journal "*Nature*". Although the monetary cost per publication is great, publications from the high Arctic are relatively rare and ZRS is playing an important role in the advancement of science in this region. Based on the 10-year synthesis currently underway, it is likely that many highly referenced and pinnacle journal articles will result. With improved tracking of data users and data use, it is also likely that the traceable publication list for ZRS will grow significantly. Improving the publication record will be critical for attracting fee-paying international researchers and ensuring the quality, continued success and scientific impact of the research and monitoring programme at ZRS.

Table 4.3.1. *Summary of publications generated from research or monitoring activities completed in whole, or part at ZRS. This list excludes publications from the ZRS bibliography that were not obviously based on research there*

Year	Peer-reviewed	Extended abstracts, Newsletters, Bulletins etc	Reports	Theses MSc/PhD	General Information
2006 so far	**4**	**2**	**1**	**4**	**0**
2005	**9**	**1**	**6**	**2**	**11**
2004	**13**	**4**	**3**	**3**	**7**
2003	**11**	**1**	**14**	**2**	**19**
2002	**12**	**4**	**4**	**3**	**24**
2001	**16**	**2**	**4**	**3**	**14**
2000	**13**	**2**	**2**	**3**	**12**
1999	**10**	**5**	**5**	**2**	**13**
1998	**7**	**2**	**4**	**1**	**16**
1997	**4**	**0**	**4**	**1**	**1**
1996	**6**	**1**	**3**	**0**	**2**
1991-1995	**3 (0.7/yr)**	**1**	**12 (2.4 /yr)**	**2 (0.4/yr)**	**2 (0.4/yr)**

At present, ZRS board members (the ZERO Working Group) screen research proposals to gain insight in to planned research endeavors applying to conduct research at ZRS. To date, there appears to have been no proposals rejected and little focus on superior level planning that focuses on building critical momentum to further particular disciplinary

based research and/or move towards answering a large scientific question not able to be addressed at the project level. To improve the representation of some disciplines such as atmospheric science and contaminants research and to provide insight in to such issues as scaling, and linkages between structural and functional studies, some strategic research stimulus will need to be provided. Such studies are well suited to graduate level projects and have the benefit of improving the monitoring programme through validating linkages between parameters that are monitored, testing new technologies and reducing inefficiencies.

4.4 To what extent may the Zackenberg monitoring as it is contribute to monitoring of Arctic Biodiversity?

Understanding how global change impacts arctic wildlife should be an important monitoring component of any large scale environmental observatory in the Arctic. Zackenberg Research Station probably monitors more parameters suitable for assessing change in biodiversity than any other station in the Arctic. It is most certainly the most developed biodiversity monitoring program in the high Arctic and there are sadly few stations with the sustained monitoring program present at ZRS. Compared to its potential, ZRS has contributed relatively little to understanding what factors influence and control biodiversity in the Arctic. This is likely to change significantly, however, when the current synthesis is published and the visions expressed by the leaders of the BioBasic program begin to take effect.

The vision for the BioBasic program expressed by interviewees is noteworthy. Gaining further understanding of inter- or intraspecific population-trophic-climate dynamics using relatively new statistical procedures rarely applied to ecosystems anywhere on the globe will most certainly build on and make full use of the wealth of biological monitoring conducted at ZRS since its inception. Based on the previous publication record of active Zackenberg researchers such as Mads Forchhammer, such analyses are likely to result in several highly cited and noteworthy publications in high profile journals. These will be key metrics to follow in order to properly assess the relative contribution ZRS is making to the monitoring of Arctic biodiversity. Improvements to the registration and tracking system used in the ZRS data archive will also aid this process, as described in 4.6 below.

Linking site-specific monitoring programs such as that at ZRS to international efforts allows for localized trends or other changes to be put into the perspective of change documented at the regional, circumarctic, or in the case of some migratory birds, for example, the global level. At present, ZRS is partnered to the following international networks or initiatives focused wholly or in part on biodiversity:

- The International Tundra Experiment (ITEX)
- The Arctic Birds Breeding Conditions Survey
- The Committee for Holarctic Shorebird Monitoring
- The Global Runoff Data Centre
- The Arctic Coastal Dynamics (ACD) program
- The Scandinavian / North European Network of Terrestrial Field Bases (SCANNET)

- The European Network of Arctic-Alpine Environmental Research (ENVINET)
- The terrestrial Circumpolar Environmental Observatories Network (CEON)
- In addition, ZRS is partnered to several IPY clusters focused on biodiversity including:
  - The Arctic Diversity Network (ArcDiv)
  - Greening of the Arctic (GOA)
  - Arctic WOLVES

Whilst the partnership of ZRS to the above biodiversity initiatives deserves significant merit, membership of some networks does not involve any specific activity from Zackenberg and there are several factors that limit the capacity of ZRS to contribute to larger scale synthesis efforts. The science program at ZRS does not appear to be partnered to two important and emerging biodiversity initiatives in the Arctic. The first includes the Circumpolar Biodiversity Monitoring Program lead by the Arctic Council's working group on the Conservation of Arctic flora and Fauna (CAFF), and the second includes the Conservation of Arctic Terrestrial Biodiversity (CAT-B) working group of the International Arctic Science Committee (IASC). Both initiatives have been recognized in the ICARP II planning process and have recently attracted financial resources to focus on synthesis activities that build off monitoring and research at field stations like ZRS. It is strongly recommended that program managers at ZRS be advised of these potential linkages and seek support to include ZRS in these developing programs.

Extending resources to the ZERO program leaders and facilitating their involvement in international synthesis and planning activities, and visitation to other leading research infrastructures would especially enhance the biodiversity monitoring effort at ZRS. Such a capacity is timely considering the current synthesis activities underway and the potential to revise the monitoring program following this report and recent change in leadership of the BioBasic program. To date, it seems like few resources have been made available to the BioBasic program leader to travel and build the necessary linkages at the international level that would otherwise permit adequate collaboration and involvement by the ZRS.

4.5 Based on 1-4: Are there elements in the programme, which could be neglected or monitored less frequent?

The monitoring programme at ZRS is amongst the most thorough in the Arctic. This single characteristic underpins the reputation of the Station and to a certain extent, the quality of science performed at ZRS. Altering the monitoring programme through neglecting or monitoring some parameters less frequently should not be taken lightly. Optimally, measurements should only be dropped or monitored less frequently if they require excessive person-power, replacement instrumental technologies can be found, measurements can be interpolated from other parameters being monitored or can be monitored more easily and, the integrity of systems analysis is not jeopardized. Mads Forchhammer and other prominent program leaders are amongst the most qualified of Arctic researchers to conduct such statistical assessments, and throughout the analysis performed for the 10-year synthesis most appear to have considered such actions. The

international community, even beyond the Arctic, has an enormous potential to gain from such analyses and the review panel strongly urges that the results of such analysis and a review of the ZRS monitoring programme based on the current synthesis effort be prepared for publication in journals such as "*Ecological Applications"* and/or "*Global Change Biology*".

Whilst it is outside the scope of this review to assess each and every parameter being measured individually, some interviewees suggested several changes that could focus further consideration. These include reducing the frequency by which large mammalian herbivores and avifauna are being monitored, introducing a greater degree of flexibility to the monitoring programme to allow for change to occur and more measurements from research to be adopted by the monitoring programme, and developing more automated systems for sampling and analysis. Overriding all of these examples is a need for a clear and demonstrated procedure for periodically reviewing and improving the ensuing monitoring programme through the removal of some measurements and or the reduction in frequency by which some parameters are measured.

4.6 Based on 1-4: Does the programme miss significant elements and/or are there elements which need reinforcing?

Zackenberg Research Station hosts a broad based monitoring programme and several focused research projects. To meet the dynamic needs of the global science community, it is important that the ZRS community is open to envelop new elements in to the established science programme. Such critical open mindedness will be essential for ZRS to reach flagship observatory status in the Arctic. Consideration given to such additions should weigh carefully the fine balance between improving the breadth and depth of the monitoring programme whilst not spreading field staff and resources too thin. The latter could otherwise impact the integrity of a greater number of data streams than what is being added. Sometimes these new elements may arise from new findings external to ZRS that have global, Circumarctic, or regional significance, and sometimes they will arise from research or as a need for mechanisms to better understand and or integrate other parameters being measured at the local scale. Programmatic expanses of networks to which ZRS is partnered could also result in the addition of new elements. The ZRS science programme currently has missing elements that fall in to all of these categories.

Measurement of glacial mass balance is perhaps the most important element that is currently missing from the ZRS monitoring portfolio. Future additions of glaciological elements should consider collaborating with established glaciological monitoring programmes focused on the greater Greenland ice cap and meteorological stations located inland and both north and south of ZRS. The distribution of contaminants in Arctic organisms is also missing. To improve scaling in the local area, improved coverage of some parameters such as microclimate could be extended inland. Such extension would require the establishment of satellite huts suitable for short term occupation by field staff. ZRS currently has no boreholes, which when drilled are efficient to operate and could open up capacities to partner to the Global Terrestrial Network on Permafrost (GTN-P). Several additional parameters in line with the developing ICARP II planning process

could be measured to improve carbon balance monitoring and other process level studies. Experimental manipulations operated by researchers are currently lacking from the monitoring programme, despite the proven abilities of such manipulations to further understanding about critical ecological processes in ecosystems world wide. The addition of experimental manipulations in the monitoring programme such as herbivory exclosures, snow fences, water table and ITEX-accepted warming experiments could greatly improve both the monitoring and research programmes at ZRS. Some elements could be made more efficient through automation, including sensing for water quality in the river. Several baseline datasets such as a species-level invertebrate list, and moss flora could enhance the ZRS science programme. Developing capacities for visiting ZRS during the shoulder seasons and in winter will permit critical and understudied winter processes to be included in the science programme. Although the latter is planned for the International Polar Year, extending this capacity in the future so that the ZERO program can benefit directly would be of great and long term scientific merit.

4.7 Which role does Zackenberg play in international monitoring networks such as SCANNET, the Arctic Observatory Network, and the Circumarctic Environmental Observatories Network?

International Tundra Experiment (ITEX). The Zackenberg Station hosts experiments strongly related to ITEX, for example those from the Jonasson group (University of Copenhagen) and earlier work by a Belgian group (the I. Nijs group). Also, phenological measurements at Zackenberg follow the ITEX protocols. Although Zackenberg staff have attended ITEX meetings and contributed to the development of ITEX 2, surprisingly, results from Zackenberg do not seem to appear in the meta-analyses of data from the ITEX community synthesis. Although the experiments at Zackenberg might be too recent for inclusion, it is not clear to what extent a mechanism is in place for Zackenberg's current participation in ITEX.

European Network for Arctic-Alpine Environmental Research (ENVINET). Morten Rasch played an active role throughout ENVINET and particularly as leader of the Station Managers' Forum that discussed best practice among other agenda items.

Scandinavian/North European Network of Terrestrial Field Bases (SCANNET). Zackenberg played several active roles in SCANNET and was a particularly important participant. It provided a model of how a research station and its user community (researchers from the University of Copenhagen) could collaborate to lead a work package on "Species Performance and Phenology in the European North (T.Høye and M.C. Forchhammer). In addition, Zackenberg introduced its technology and methodology for snow monitoring by digital cameras to the SCANNET and wider community. Indeed, cameras were modified and distributed to SCANNET sites by the University of Copenhagen (J. Hinkler).

Circumarctic Environmental Observatories Network (CEON). Zackenberg has been represented at all of the meetings of this network.

Arctic Observatories Network (AON). Zackenberg was unfortunately not represented on the committee selected for this report. However, the report lists the Zackenberg Station.

Flagship observatories. Zackenberg was represented in a workshop at the Ecosystems Centre, Woods Hole, MS, that discussed the needs to improve the facilitates for Arctic research and monitoring and particularly the development of research platforms. The meeting defined requirements for research stations to reach "*flagship observatory*" status. Although it concluded that no such flagship observatory currently existed, Zackenberg was recognized as one of a few stations that have that potential.

Other Networks. There are links with other networks including Arctic Birds Breeding Conditions Survey, The Committee for Holarctic Shorebird Monitoring, Global Runoff Data Centre, Circumpolar Active Layer Monitoring Programme (CALM), Arctic Coastal Dynamics (ACD), and the Arctic Monitoring and Assessment Programme (AMAP). However, it is unclear to what extent Zackenberg is active within these networks. For example, activity within AMAP is surprising as no measures of contaminants appear to have been made at Zackenberg. Even though the latter may present some significant logistic challenges, some spot sampling through the collection of biotic samples could benefit AMAP. Also, ZRS is poised to play a greater role as AMAP is widening its role to address ACIA follow-up recommendations, and during the Greenlandic Chairmanship of CAFF.

IPY (International Polar Year). The Zackenberg Research Station is involved in many IPY initiatives including ArcDiv Net (Arctic Diversity Network), Snow Trends from Remote Monitoring, Cold Land Processes in the Northern Hemisphere, Greening of the Arctic, Environmental baselines, processes, changes and Impacts on people in subArctic Sweden and the Nordic Arctic Regions, Cold Land Processes in the Northern Hemisphere and Arctic WOLVES. This demonstrates good international visibility. Although the IPY projects are not yet operational and the extent of Zackenberg's contributions remains to be determined, Zackenberg is poised to rapidly extend its international collaboration.

A perceived problem is how Zackenberg should be represented in international fora. Currently, the Station Manager acts as the main "Ambassador" for Zackenberg. This is a very important activity for the ZRS and the Station Manager is both very active and gives a very competent overview of ZRS activities. However, he cannot provide the required, in-depth scientific expertise across Zackenberg's portfolio of activities. This is most often a difficult task for any one person to accomplish but where possible the various Basic sub-programme managers should represent the Station's activities within their respective fields. At present they have no funding for such international travel and participation in international meetings. The networking is in place for Zackenberg to make major contributions at the international level, but mechanisms need to be enhanced and developed to transform current links into more active participation.

4.8 To what extent does Zackenberg duplicate/supplement climate change monitoring at Svalbard (Ny Ålesund)?

Svalbard and Northeastern Greenland, in spite of their geographical proximity, represent two different regimes of the high Arctic as well as of the Nordic Seas. Svalbard, especially the northwestern part near Ny Ålesund, is strongly influenced by the advection of warm Atlantic water in the West Spitsbergen Current. The ocean is ice-free and the warm, open sea surface sustains, by its heat loss to the atmosphere, advected middle latitude low-pressure systems, thus providing a pathway for warm, moist air into the Arctic. Northeast Greenland, by contrast, is dominated, especially in winter, by the high pressure residing over the Greenland ice sheet and by the southward advection of cold polar water and sea ice from the Arctic Ocean in the East Greenland Current.

The two major ocean currents, the East Greenland Current outside Zackenberg and the east coast of Greenland and the West Spitsbergen Current west of Svalbard accentuate the role of advection in changing the local conditions in Northeast Greenland and on Svalbard, The strength and the characteristics of the advection in these two currents are influenced by variations in the NAO (North Atlantic Oscillation) and AO (Arctic Oscillation) and are also expected to respond to changes in the global climate.

Observations on Svalbard thus primarily monitor the effects of advection from lower latitudes and the changes induced by variations in the northward heat and moisture fluxes. Northeast Greenland (Zackenberg) on the other hand, reflects changes *in* the Arctic, especially the variations in the ice export and the conditions in the Arctic Ocean.

Because of the importance of the advection in the ocean currents, the MarineBasic at Zackenberg in particular has extended its activities from the fjord system to include the waters around Greenland and beyond to the PanArctic domain. This has been done through extensive cooperation. For example, the marine studies at Zackenberg are being integrated with the marine work done at Nuuk and in West Greenland. The area around Ny Ålesund, influenced by the West Spitsbergen Current, and the East Greenland Current dominated area around Zackenberg, are presently studied by projects comparing the conditions in the Young Sound – Tyroler fjord at Zackenberg with those found in Kongsfjorden at Ny Ålesund.

On land, there is also a strong contrast between the environment in Northeast Greenland, that is represented by extensive ice-free landscapes that support large ungulates and a large carnivore, and that on Svalbard dominated by coastal ice-free areas limited in extent, and a limited island mammalian fauna. The extensive and comprehensive BioBasic monitoring programme at Zackenberg is not duplicated on Svalbard, although some of the research activities are similar in theme i.e. impacts of warming and UV-B radiation on ecosystems. However, the main thrusts of environmental monitoring at Zackenberg and on Svalbard should be seen as complementary and not overlapping: Svalbard has considerable strength in monitoring atmospheric chemistry and physics whereas Zackenberg has far greater strength in monitoring ecosystems and terrestrial and freshwater environments.

4.9 Are the different Basic-programmes sufficiently integrated.

The three initial observational and monitoring programmes differ in that ClimateBasic and GeoBasic largely stand on their own, while the BioBasic needs and benefits from the data obtained within the other two programmes. The experience of the scientists working at Zackenberg is that this necessary integration has been slow in coming. The first years were better characterised as consisting of independent programmes. The integration has improved greatly over the years and is now significantly better than in the first few years. ClimateBasic and GeoBasic are also important parts of the climate and geophysical monitoring on Greenland and for the studies of climate-induced changes such as variations in temperature, precipitation, snow cover evolution, discharge from glaciers and sediment transports from rivers.

For measurement of some variables, the different programmes do not use the same plots, which may be an obstacle when addressing integrative questions such as active layer depth and vegetation dynamics, and interactions between cryptogams, higher plants and herbivores. Also, surprisingly, there is an apparent lack of cross calibration of sensors used at the plot scale by the three programmes. The monitoring programmes would also benefit from continuing manipulations initiated by research projects to get longer time series.

The more recently added MarineBasic requires and uses data especially from ClimateBasic and GeoBasic in monitoring the break up of sea ice and the development of the stratification in the Tyroler Fjord – Young Sound system, by direct observations during the field season and by deployed instruments throughout the year. Because of the importance of advection for marine studies, the MarinBasic programme has established strong links with marine research conducted around Greenland and throughout the Arctic Ocean and the Nordic Seas. The marine data are supplied to ICES (International Committee for Exploration of the Sea).

The joint project of producing the book presenting the vision, planning, experiences and the results from the first 10 years at Zackenberg will undoubtedly force the different programmes toward each other, each programme recognising the need and use of the existing data, collected by the other programmes, in presenting and developing its own research. This should work toward a further integration of the different monitoring programmes and between research and monitoring.

4.10 How do you evaluate the Zackenberg Concept?

The decision to establish a station monitoring climatic, geophysical and biological parameters at Zackenberg on the east coast of Greenland has opened the possibilities to obtain sorely needed long-term observation series from the high Arctic region. By combining the monitoring of a wealth of parameters from different but interacting disciplines the station also provides the background data, and thus the possibility, for advanced and cross disciplinary studies, especially within biological research. The most prominent studies have been related to the gas exchange between the high Arctic biotopes and the atmosphere and the importance of the high Arctic tundra as a sink, or a source,

for atmospheric CO_2. The possible effects on the biological processes induced by a warmer and wetter climate and how that might influence the exchanges of CO_2 and CH_4 between land and atmosphere have also been examined. The extensive long-term monitoring also allows for advanced ecological modelling of the high Arctic ecosystem.

The relative remoteness of the ZRS puts strong emphasis on the logistics and the concept brings the logistics into the Zackenberg programme as an equal partner with the monitoring and the research activities. The logistics costs left for the individual research programme to cover by external funding could still constitute an obstacle to increasing the research activity to the level of the monitoring, which presently dominates at Zackenberg. The high costs might also discourage international research from using the ZRS and thus inhibit cooperation between research conducted at Zackenberg and that going on at a pan Arctic scale. This is in contrast to the monitoring, where Zackenberg is well integrated in the Arctic climate monitoring efforts, following the AMAP climate monitoring recommendations almost to the letter.

Within the concept is also the idea that the observational work shall have continuity and be independent of changes in personnel between field seasons. This had lead to the creation of extensive, detailed and very useful manuals for the different programmes. These manuals are continuously updated to include the experiences of the observational programmes and to accommodate the needs, developed during the programme and through the experience from the different individual research projects, for monitoring additional parameters. A review of the needs for continuing the measurements of all the initially chosen parameter and the frequency of the observations seems to be lacking. This is largely due to the reluctance to break existing, and now already long, time series. With a limited budget this will be an obstacle to introducing new monitoring parameters.

The annual reports from the Zackenberg campaigns are well produced and informative of the work done at the Station.

4.11 Is the institutional set-up for Zackenberg satisfactory and if not, how could it be improved?

The Zackenberg Research Station was established as a result of a “bottom-up” process. The station and Zackenberg Basic were initially maintained by the Danish Polar Centre as an integrated activity. In 1999 this was changed mainly for economic reasons. The DPC is now responsible only for the running and the logistics of the ZRS, and the operation of the station is the responsibility of the Ministry of Science, Technology and Innovation. Activities at the station are organized through two working groups: the Zackenberg Basic Working Group, responsible for the monitoring, and ZERO Working Group, which coordinates all activities at ZRS, including promoting research and the overall development and relevance of the monitoring programmes.

The Zackenberg Basic programme is run by several different institutions, and the monitoring sub-programmes GeoBasic, BioBasic and MarineBasic are financed by the

Ministry of Environment, while the Greenland Home Rule (Asiaq) supports the ClimateBasic sub-programme. The activities are coordinated within the Zackenberg Basic Working Group. This group includes the leaders responsible for each sub-programme and scientists representing other programmes. The Station Manager acts as executive secretary. The Zackenberg Basic is considered as one large research project at ZRS, and the support it receives from DPC in relation to stays at, and travel to Zackenberg thus is equivalent (in %) to the support given to other projects at Zackenberg.

The ZERO Working Group involves representatives of the institutions operating the Zackenberg Research Station in all its aspects, logistics, monitoring and research, state institutions as well as universities. Finally a ZERO steering Committee, representing the investors of the station has been established. This acts as advisor to the Station Manager. The ZERO working Group meets twice and the ZERO Steering Committee once a year. The station Manager is the secretary in both the Working Group and the Steering Committee.

Presently DPC, especially H. Petersen, Director DPC, and M. Rasch, Station Manager of Zackenberg Research Station, have competence in, and the responsibility for logistic issues. Decisions are, however, normally taken after discussions and agreement with the ZERO working group and the Zackenberg Basic Working Group. In case of disagreement, there is a vote.

M. Rasch as Station Manager is not only responsible for the logistics but is also the overall scientific coordinator and takes an active part in developments of the monitoring and research activities at the station. These efforts range from promoting measurements of new parameters such as CH_4 and CO_2 and introducing new techniques, e.g. for snow monitoring, into the monitoring programme, facilitating the cooperation between different Basic sub-programmes and promoting the introduction of the recent Marine Basic programme, as well as taking part in the development of the Zackenberg Basic/Nuuk Basic. As Station Manager and executive secretary in the Zackenberg Basic Working Group, he has applied for funding for new projects and for the improvement of the facilities at Zackenberg, the most recent being the construction of new buildings at Zackenberg/Daneborg. The Station Manager acts as the "ambassador" for the station internationally and also takes care of the public outreach to secure the visibility of the station on the national scene. These activities have been highly successful and this is a remarkable achievement considering that less than 30% of M. Rasch's time is devoted to Zackenberg.

The current institutional home for the ZRS is appropriate in that it gives stability and commitment to its activities that probably could not be guaranteed in a University setting. Also, Zackenberg has a stronger voice within the international community and can benefit far more easily from Denmark's and Greenland's involvement in Arctic political processes and initiatives such as Arctic Council strategies for research and monitoring.

The existing institutional framework necessitates a well-developed mechanism to be developed for involving the research community, but this has so far been very successful

as evidenced within SCANNET and by the appointment of a Research Professor, especially dedicated to studies based on data from Zackenberg. However, the team, which is running the ZRS, is highly competent and involves several professors. The planned publication of the results from the first 10 years of research and monitoring at Zackenberg will hopefully not only lead a presentation of past achievements but also inspire these researchers to develop and intensify future studies at ZRS, e.g. through the formulation of new themes for Ph.D. and Master studies.

The organization of the DPC is about to change. Currently, its mission is largely based on logistic activities. In the future, it could become part of a Government department focused on research. This is because the DPC is too small at present. Also, it is planned to hand over the ZRS to the Greenland Home Rule, but for the DPC to continue to operate it for 10 years. This is because of increased possibilities of gaining private funding for the Station, if it belongs to Greenland rather than Denmark.

This development accentuates a need to develop a mechanism to facilitate collaboration between Zackenberg and other activities throughout Greenland. This is partly done. The ClimateBasic is presently run by Asiaq and MarineBasic is mainly run by the Greenland Institute of Natural Resources. Furthermore the cooperation between research facilities on Greenland has been formalised by a Letter of Intent. Another important aspect arising from the transfer of the ZRS to Greenland is the maintenance and development of the research potential at Zackenberg. The basic research is normally run by university institutions, which may not yet have open lines of communication and cooperation with the Greenland institutions.

There is the question, if the managing structure can be kept and function after these changes. Although the managing structure looks complex from the outside, it has clearly been functioning well during the first 10 years. This is largely due to the fact that the Station Manager acts as secretary in both working groups and the Steering Committee. With his long experience and seniority M. Rasch will have a strong voice in all three groups and will be able to coordinate the wills and wishes of the groups towards improving the overall concept of the Zackenberg Research Station. The central role of the Station Manager makes it imperative to make sure that dedicated senior scientists with long experience are involved in the work and research at Zackenberg to ensure the continuity of the station and its monitoring and research programme.

Operational aspects of field activities. During the initial 10 years, the seniority and scientific decisions in the field were facilitated by the continuous presence of H. Meltofte, one of the founders of the ZRS, at the station throughout the field season. When, after 2004, this natural authority was no longer present at the station, tensions between the research and logistics communities occasionally developed. To avoid such incidents in the future, the station manager and the leaders of the different Basic programmes should plan their field work so that, at all time, at least one senior, responsible scientific leader is present at the station. This would ensure a smooth running of research projects alongside monitoring activities. Furthermore, it would be beneficial to attract other senior scientists that could supervise younger researchers. One response to the lack of supervision and

continuity of staff undertaking monitoring in the field is the production of excellent Basic manuals that contain detailed protocols for monitoring activities. These manuals are up-dated each year. This process is important and extremely well done and should be applied to produce a MarineBasic manual.

Budget. The logistics at Zackenberg are partly funded by the DPC through an allocation of c. 1.6 million DKK/year and partly by user payment for the travel to, and the stay at Zackenberg. GeoBasic, BioBasic and MarineBasic are funded by the Ministry of Environment, which annually allocates 5 million DKK to Zackenberg. Each sub-programme receives c. 1.5 million and c. 0.5 million DKK are kept for developing new research, buying new instruments etc. ClimateBasic is funded by the Greenland Home Rule with an allocation of c. 0.6 million DKK/year.

The major problems perceived with the current level of funding were that there are insufficient funds devoted to new equipment, foreign travel to disseminate results and interact with the international community, and that new activities could only be accomplished if some exiting activities were discontinued. In addition, there was uncertainty about future levels of funding and how the increased activities at the proposed Nuuk Research Station would affect funding for Zackenberg.

Use of the Station. Research interest at the Station has stabilized, with little recent additional international activity. There is, therefore, a need to heighten the research emphasis at the Station and to increase the international contribution at Zackenberg. The construction of a new building has improved the accommodation capacity to handle this. The establishing of satellite field cabins might also spread the activities, reduce interference among projects, and increase the diversity of systems to be studied. Logistic and economic constraints impose a lack of flexibility in time for importing heavy equipment (only once per year). A general lack of helicopter support during the active season and heavy demands on the logistic personnel in providing ATV support may also occasionally obstruct the field activities.

Personnel. As members of the older generation leave their positions at Zackenberg, there is a need to maintain a corporate knowledge. Although there is little problem in recruiting new staff for monitoring work during the field season, a major constraint on the development of the Station was perceived to be the recruitment of a new generation of enthusiastic scientists, who would be prepared to work in the field for relatively long periods during several consecutive summers. New staff and researchers could be recruited more easily if field courses were developed at Zackenberg, or if some programme equivalent to the European Union's transnational access could be arranged. This is particularly important as the cost for travel to, and work at Zackenberg is prohibitively expensive.

Data management. Several improvements could be made to the information and data management of ZRS. This includes the construction of a web-based Mapping Server, to which the current data archive could be linked. The installation of a Differential Global Positioning System (DGPS) would greatly enhance such an initiative. Amongst the

greatest success of the ZRS programme in recent years has been the establishment of an online and interactive data archive. This service was developed at minimal cost and appears to have been extremely effective. Importantly, however, there is currently no way to track data usage, download frequency and/or use of data in publications, models or synthesis efforts. Such metrics are important for assessing the performance of the monitoring programme (as demonstrated in 4.3 above) and reporting to funding bodies. There is also no capacity at present to ingest data from research projects conducted at ZRS. Many modern monitoring programmes dedicate 10-50% of their budget to adequate information and data management. Whilst this might not need to be the case for ZRS, this clearly highlights the importance a mature and reputed observatory should give to information and data management. It also credits the existing data management service, from which future expansion could spawn. Future data management services should consider making spatial data and baseline datasets such as species lists readily available for download online and developing capacities for archiving data from research projects carried out in the ZRS area.

4.12 Given the strengths and weaknesses of Zackenberg which issues/topics should be prioritised in the next 3-5 years.

The future of ZRS is likely to be strong and should be based on an internal reassessment and delineation of goals for the next ~10 year synthesis. Following publication of the first 10 year synthesis, ZRS staff will be well situated to compile this vision document, which should incorporate an assessment of potential elements to cut from the monitoring programme. Given the possibility that funding allocation to the ZRS science program may not grow significantly in the near future, and that most of the recommendations made below in this report will require additional human or financial resources for implementation, the priority for improving efficiencies within ongoing activities at the Station is paramount. One mechanism for improving efficiencies, will be to statistically re-assess the current monitoring program and identify where certain elements could be dropped and or monitoring frequency be reduced, thereby freeing resources to improve the science program within current budgetary constraints. Scientifically, the program could benefit from such a review, in that new possibilities for orienting the monitoring program to a more questions-based approach and improving integration between existing programs could be developed. It is likely that on-site scientific leadership in the form of a field based senior scientist could also greatly improve efficiencies in the field as could additional field staff – particularly those cross-trained between different monitoring programmes.

Of utmost importance to any change at ZRS should be the maintenance of the reputed and high quality scientific programme established over the past 10 years. Continuing to secure funds for the long term monitoring programme will be fundamental. Improving the publication record for ZRS; ground monitoring on key scientific questions; ensuring the involvement of ZRS in international synthesis and planning efforts as well as the IPY; and improving the information and data management of ZRS will be key to acquiring such support. Reducing costs for research projects wishing to utilize ZRS will bolster the stations' reputation and based on the relationship established between research done

monitoring at ZRS to date, will enhance the long term monitoring programme. Efforts that stimulate the involvement of students will also serve this purpose. In some instances careful management of field personnel to reduce long term deployments might be needed to ensure retention of key expertise within the monitoring programme.

The science programme at ZRS should continue to critically review and embrace new measurement parameters and research projects. Initiatives that; enhance the glaciological monitoring programme; monitor contaminants; improve capacities for scaling and integrating datasets in analysis; add experimental manipulations; and span shoulder seasons should receive strong support. Process level studies important for modeling drivers of change and critical feedbacks with the arctic system should be included where possible, as should elements that are critical to international networks, assessments or synthesis efforts, and/or meet the goals and objectives of large scale science initiatives such as those identified in the ICARP II planning process.

It is critical that ZRS improve ties with the international scientific community. Ties have been established to date by the operations/management/scientific leadership sector of ZRS. In some instances, there has been little support for program leaders from each of the monitoring programs to develop international ties and relationships with specialist international initiatives. This appears to have lead to the diminished involvement of ZRS in several large reviews such as the ITEX community change synthesis and scientific planning activities such as the ICARP II planning process. Only one of the ZRS program managers attended the ICARP II planning meeting in Copenhagen in November 2005. The science program at ZRS has the potential to greatly impact and contribute to international Arctic research endeavors. Such involvement will require the availability of funds to committed specialists who can follow-through on such activities, which should also include travel to other research stations around the Arctic. Not only will the reputation and role of ZRS advancing Arctic research improve, so will the attractiveness of ZRS to visiting international researchers. The latter is important for not only advancing the science program at ZRS, but also potentially offsetting some of the operational costs. At present, some researchers appear to be favoring Svalbard to Zackenberg due to the high cost of operating at Zackenberg. Although this might be difficult to overcome, researchers may be able to be convinced the additional cost of ZRS are justifiable based on scientific merit alone if international ties at ZRS are improved. Several promising IPY projects include a focus on ZRS and could be used as a catalyst for improving such linkages.

As the science programme at ZRS grows older, new accommodations will need to be made for changing environmental conditions and pressures from monitoring itself. It should be expected, under current climate change predictions for Northeast Greenland that the Station will need to be open for a longer period of time if the full snow free period is to be studied as in the past 10 years: already there is a need to extend the period of activities into the Autumn. This will present logistic and financial challenges that should be overcome accordingly, but always in response to scientific rationalisation and justification. It is important that science challenges logistics – not the other way around. It is enlightening to see that such considerations are in place and that indeed over the past

few years ZRS management has realized and accommodated the scientific need of opening the station earlier than in previous years. Clear guidelines need to be put in place to regulate field based disturbances and ways to potentially use disturbance to positively reinforce the monitoring programme should be considered – studying the impact of off road vehicle use for example might be useful to land management elsewhere in Greenland or the Arctic. Several interviewees commented on the pressure and possible disturbance that has resulted from the ZRS science programme. Disturbance is already managed but additional disturbance resulting from increasing activities will require continued management, containment and indeed monitoring in order to develop a self-checking mechanism that instills reassurance that long term change documented in experimental plots are just that and not a response to a overly zealous science programme. Excellent examples of human impacts research that may be useful to the ZRS program can be found in Antarctic science literature and it might be that if such accepted programs were implemented at ZRS, bipolar collaborations could be instituted.

5. Recommendations

We recognise the significant achievements of the Zackenberg Station and its staff. The following recommendations are intended to build on these achievements and exploit even further the Station's great potential. The following order of recommendations does not necessarily follow an order of priority.

5.1 Institutional and management arrangements should be stabilised, clarified and simplified

There is a need to remove uncertainty in the future higher-level institutional arrangements for Zackenberg. The current management structure, particularly above the level of the monitoring programmes, is complex and places a large responsibility on the Station Manager. There is a need to ensure clear and adequate science leadership for the duration of the period of activities in the field. The future institutional context for Zackenberg should be decided as soon as possible to reduce uncertainties. While transfer to Greenlandic ownership is politically expedient and can attract funding not available to a Danish-owned institution, care should be taken not to sacrifice the excellent advances made at Zackenberg through its strong connections to Danish institutions. The management system is complex and the Station Manager plays a highly important intermediate role in this complex. Therefore, to maintain the knowledge of how to run and develop the station, it is essential to ensure that highly competent and experienced senior scientists are involved in the research and monitoring at Zackenberg This also applies to the daily running of the station. It is of high priority that clear and supportive science leadership is provided throughout the field season that can integrate the needs of science projects with the monitoring programme. *Such institutional and management changes need not be demanding of resources.*

5.2 Increase the support to the data management system

The data management system should be supported more than at present by allocating adequate support to maintain a free, web based, interactive portal. This portal should include capacities for downloading baseline datasets such as species lists and geospatial data. The data management system should also develop mechanisms that enables registration of users, tracking of downloads and use of data, and a system to inform users of data irregularities should they be identified at a later point in time. Where possible, datasets should be accompanied by metadata that meet international standards and are linked to international metadata search engines. *This recommendation will require additional resources as support for extra staff time. It should be implemented soon, while there is still momentum based on the current database development activities and before the data bases grow even further.*

5.3 Improve the integration of monitoring sub programmes

There should be an improved integration of monitoring sub programmes, and an improved collaboration between monitoring and research that build upon existing integration and collaborative efforts. Integration of monitoring sub-programmes should be achieved by formulating cross-cutting science questions and co-placement of measurements from each of the programmes in the same locations. For example, active layer depth, air and soil temperatures, cryptogam and higher plant monitoring should occur in the same plots. Improvements along these lines have been gradually implemented in recent years but there is further integration to be achieved. Increased collaboration between researchers and the monitoring programme should be a two way interaction in which data from monitoring is made more easily accessible to researchers (this would require more resources for data management) and the research community could develop long-term environmental and ecosystem, manipulation experiments that seek to identify causes of any trends found in the monitoring data. Institutional methods to increase integration and collaboration should also be explored. *This recommendation should be implemented as soon as possible and resources should be sought from the agencies that fund research*.

5.4 Review and modify the monitoring programme

An iterative system should be established to review measurements made in the monitoring programme and to assess the optimal frequency at which measurements should be made and alternative, less labour-intensive ways of making measurements. There is also a need top cross calibrate sensors. Although some gaps in monitoring have already been identified during the current process, it is a major task to evaluate each of 2,500 variables currently measured in terms of value, methodology and data quality assessment. Consequently, a review process is needed to optimise the monitoring programme and particularly to reduce unnecessary measurements and labour-intensive ways of making measurements. This task is not trivial. In addition, practices for calibrating sensors between each of the monitoring programmes should be developed. This is currently lacking. Gaps in monitoring perceived by the panel include additional metrics of ecosystem function such as productivity, and monitoring glaciers and possibly

the margin of the inland ice. Such observations could be achieved by the construction of strategically located field cabins. These cabins could help to reduce disturbance around the Station resulting from intensive use while opening up new areas for monitoring and research, thereby increasing the diversity of landscapes and ecosystems currently studied. Field safety could also be improved in this way. Measurements that could be discontinued, or reduced in frequency, include monitoring of some herbivores, river water quality and insect collections. *The review process should seek some balance between additional and reduced monitoring to maximise cost-efficiency of monitoring, and to fund new, important measurements*. *Some "one-off" funding could be obtained for the automation of some currently labour-intensive or high frequency measurements.*

5.5 Add to the baseline data available and extend its presentation

It is recommended to further develop the baseline data available at the Station and the ways in which these data are presented. In particular, it would be beneficial to develop a web based GIS to support science, management, logistics, education and outreach at the Station. This application should include links to monitoring data and project description and/or researcher contact information for mining and management of site-specific information. In addition, the development of current baseline datasets such as species lists, and land cover maps should be encouraged and extended. *All data should include internationally recognized metadata standards for geospatial data. Such developments would require increased support to the data management and should link with initiatives such as CEON (GIS) and CAFF (species lists).*

5.6 Facilitate and increase the impact of research

There should be greater facilitation of research and particularly international research and collaboration at the station. In particular, young scientists who could make prolonged contributions at the Station, should be attracted. The recruitment process could be facilitated by hosting international student courses at Zackenberg, perhaps in collaboration with the proposed facility at Nuuk, joint supervision of research students between supervisors from different countries, and the development of a state-of-the-art research environment with appropriate facilities (that largely exist already). Increased visibility of the Station's activities would be achieved by a shift from publishing in grey literature and producing texts in Danish that are unavailable to a wider audience, to publishing in international, peer-reviewed journals. One publication could be a '*lessons learned*' paper that highlights the Zackenberg monitoring programme and the ways in which the programme has been refined and improved over time. *Such opportunities should be developed gradually over future years. Efforts should be made to reduce the cost of conducting research at Zackenberg to make working there more attractive, but this has budget implications. However, the development of courses could attract funding from higher education sources, rather than research budgets.*

5.7 Increase the international involvement of Zackenberg Staff

There should be greater involvement of Zackenberg Staff, particularly from the basic sub-programmes, in international processes and the international research community that goes beyond belonging to international networks. This could be

achieved by increasing the mobility of programme leaders by providing support to attend international science meetings and to visit other comparable research facilities. There should be an institutional arrangement to ensure that all sub-programme managers have opportunities to present programme activities and to participate in relevant international processes. *This process should start soon. Some funding could come from re-allocation within existing budgets whereas other funding could be applied for from external sources.*

5.8 Improve the Station's infrastructure, facilities and logistics

Although the addition of facilities, infrastructure and logistics will always be a developing process, there are some key developments that, if implemented, would enhance the Station's achievements. The opportunities for lengthening the field season to include at least extended Autumn activities and winter campaigns should be explored. The installation of a differential global positioning system would enhance monitoring, research and the management of field activities, and would improve the long-term archiving of these activities. Continuing to increase the number of possibilities to import equipment during field seasons and establishing a network of "remote" field cabins, are additional important developments. *Most of these developments require a "one-off" investment. The costs of extending the field season and supporting winter campaigns should be funded by IPY activities.*

6. Acknowledgements

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Appendix I: acronyms

ACIA	Arctic Climate Impact Assessment
AMAP	Arctic Monitoring and assessment Programme
ACD	Arctic Coastal Dynamics
AO	Arctic Oscillation
AON	Arctic Observatory Network
ArcDiv	Arctic Diversity Network
Arctic WOLVES	Arctic Wildlife Observatories Linking Vulnerable EcoSystems
ATV	All terrain vehicle
BioBasic	Monitoring of selected ecosystem parameters
CAFF	Conservation of Arctic Flora and Fauna
CALM	Circumpolar Active Layer Monitoring Programme
CAT-B	Conservation of Arctic Terrestrial Biodiversity
CEON	Circumarctic Environmental Observatories Network
CH_4	Methane
ClimateBasic	Monitoring of climate and river water discharge
CO_2	Carbon dioxide
DEPA	Danish Environmental Protection Agency
DGPS	Differential Global Positioning System
DPC	Danish Polar Centre
ENVINET	European Network of Arctic-Alpine Environmental Research
GeoBasic	Monitoring of the abiotic environment including biogenic trace gases
GIS	Geographical Information System
GTN-P	Global Terrestrial Network on Permafrost
GOA	Greening of the Arctic
ICARP II	Second International Conference for Research Planning
ICES	International Committee for Exploration of the Sea
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
IASC	International Arctic Science Committee
ITEX	International Tundra Experiment
MarineBasic	Monitoring of selected marine parameters
M.Sc.	Master of Science Degree
NAO	North Atlantic Oscillation
NDVI	Normalised Vegetation Index
Ph.D.	Doctor of Philosophy Degree
SCANNET	Scandinavian/North European Network of Terrestrial Field Bases
UV-B	Ultraviolet B radiation
Zackenberg Basic.	A long term monitoring programme
ZERO	Zackenberg Ecological Research Operations
ZRS	Zackenberg Research Station

Appendix II: short biographies of the Panel members

Terry V. Callaghan. Professor of Arctic Ecology at the University of Sheffield, UK, Honorary Professor of Arctic Ecology at Lund University, Sweden, and Director of the Royal Swedish Academy of Sciences Abisko Scientific Research Station. Terry Callaghan has spent 40 years in polar research and brings to the Review Panel experience on Arctic terrestrial ecology, international networking, and leadership of a sub-Arctic research station.

Bert Rudels. Senior Scientist at the Finnish Institute of Marine Research. He has been involved in polar marine research since the Ymer-80 expedition, more than 25 years ago. His main research topics are: Arctic Ocean circulation, water mass transformations and thermohaline circulation and the coupling to climate.

Craig E. Tweedie. Assistant Professor at the Department of Biology and the environmental Science and Engineering programme at the University of Texas El Paso, USA. His main research topics are: Climate change, Arctic and Antarctic ecology, desert ecology, biogeochemical cycling, plant phenology and primary productivity, plant-animal interactions, land use and land cover change, biocomplexity, landscape ecology, remote sensing, ecological modeling and disturbance ecology. Dr Tweedie is coordinator of CEON, Circumarctic Observatories Network.