European Space Policy Institute

Remote Sensing and Regional Climate Change

Report 41
November 2012

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Short title: ESPI Report 41
ISSN: 2076-6688
Published in November 2012
Price: €11

Editor and publisher:
European Space Policy Institute, ESPI
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Tel. +43 1 7181118-0; Fax -99

Design: Panthera.cc

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Foreword

Unprecedented changes in climate are taking place. Overall global warming is now a fact that is not only acknowledged by the overwhelming majority of the scientific community but also by most national and international decision makers and the public. The Intergovernmental Panel on Climate Change (IPCC) is charged by the United Nations with reviewing research in order to create periodic reports on climate risks. In 2007 it attracted worldwide attention by stating that human activity was warming the planet in ways that could greatly disrupt human affairs and nature. Four years later, in November 2011, the IPCC issued a report with another alarming message: Get ready for more dangerous and "unprecedented extreme weather" caused by global warming. After two decades of delivering climate reports to the world without fanfare, climate change is now considered a challenge for humankind and governments around the world. The subject provides fuel for intensive debates at international level and hard negotiations.

The process of increasing global temperature can be slowed down rather than stopped. Ambitious mitigation measures are an effective means to prevent even greater and more rapid warming. According to current climate models, developing countries will be particularly hard hit by changes in temperature and the resulting natural disasters. However, industrial countries also have to develop long-term and sustainable strategies to react appropriately to the effects of climate change. The political and technical debate often focuses on mitigation measures that are globally oriented; whereas the impact of climate change is different at regional levels. In fact, developing a strategic approach at regional level is important for two reasons. Firstly, the severity of the effects of climate change differs greatly from one region to another. Secondly, adaptation measures tailored for a specific region might be relatively easy and quick to implement . The regional perspective should thus be a focus for early action on climate change.

Timely, efficient and specific action requires adequate information on corresponding regional potential and risks of climate change. In recent decades, space systems have contributed to the provision of reliable data in this field through the multi-decade accumulation of vast quantities of scientific data concerning the oceans, the lands and the atmosphere. Remote sensing data can provide actors with the necessary information to detect local and regional risks and with new opportunities such as the mining of natural resources or opening of new transport lines. Geo-information from space has a crucial and leading role to play in this context due to its actuality, its cost-efficiency and its broad accessibility. This is particularly relevant and urgent for many developing countries, which are vulnerable with regard to adverse climate effects. Detection and monitoring of relevant regional climate features on Earth by sophisticated remote sensing from space might thus provide the basis for rational decisions on prudent land use and help therewith. The regional approach should not compete with the global objective of mitigation, control and monitoring. It might be better seen as a complementary element of an overall coherent strategy to tackle the climate problem as a whole.

In this context, the Europäische Akademie zur Erforschung von Folgen wissenschaftlicher-technischer Entwicklungen Bad Neuenahr-Ahrweiler GmbH teamed with ESPI to organize a joint conference on „Remote Sensing Regional Climate Change – Potentials and Options to Adopt". The event was co-funded by the German Aerospace Center (DLR) and supported also by the International Society for Photogrammetry and Remote Sending (ISPRS), the largest professional organisation for research and use in remote sensing. Climate research, policy, ethics and space applications, represented by the three organising institutions, met in a unique setting at the event. During the conference the invited experts touched upon the increasingly important role of remote sensing for the detection, monitoring and management of regional climate change. In the course of the first session addressing the rise of a "climate culture", it was questioned whether complex climate models can tell us who is to be made responsible via detection and attribution of climate change. Furthermore, a more trustworthy use of climate science and its interaction with the public and policy makers with the overall aim of ensuring the implementation of reasonable measures was debated. The second session was devoted to potential and options to adapt to climate change. Large-scale geoengineering concepts go back decades but they appear to be gaining more currency as concerns about global warming heighten. The potential for space contributions to geoengineering therefore formed part of the discussion. In the global context, intensive international coordination in the use of remote sensing has already been implemented to help mitigate and manage climate change and was presented in more detail. The last session then drew the way forward, addressing inter alia the potential policy challenges for Europe. The results of the conference are contained in this publication, encompassing the elaborated presentations together with conclusions and recommendations emanating from the round table discussions.

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Greetings from ISPRS

by Rainer Sandau

Climate change is an ongoing process, and it is widely accepted that this process is caused by human activities as well as by natural fluctuations. The question is: What are the contributions from the two sources qualitatively and quantitatively. The consequences may be good or catastrophic in different regions of our Earth. This leads to the next question: How to avoid or mitigate the consequences coming from human activities, how to determine the natural fluctuation's influences and how to adapt to the resulting changes.

The International Society for Photogrammetry und Remote Sensing (ISPRS), the largest professional association in the field of Earth observation applications, is dealing with all those aspects and questions. ISPRS is also trying to improve the measurement systems and models in order to deliver ever better prediction results which need to be well understood and accepted by the public in large as a basis for appropriate actions.

In this context, ISPRS through its International Policy Advisory Committee (IPAC) is well prepared to co-organise the Conference "Remote Sensing Regional Climate Change – Potentials and Options to Adapt" together with the European Space Policy Institute (ESPI) and the Europäische Akademie zur Erforschung von Folgen wissenschaftlich-technischer Entwicklungen Bad Neuenahr-Ahrweiler (EA). ISPRS is convinced that this conference, hosted by ESPI, and the publication of its proceedings will contribute to an enhanced awareness of the problems and potentials of all those interested in the field and help decision-makers to generate well informed decisions.

Rainer Sandau
Chairman ISPRS-IPAC

1. The Detection, Attribution and Uncertainty of Climate Change: Who Is Responsible?

by Andreas Hense[1]

1.1 Introduction and Statistical Background

The climate system (Figure 1.1) is a stochastic system due to the large number of degrees of freedom within the system, the nonlinear interactions between these degrees of freedom and the fact that the climate system behaves as a system far from thermodynamic equilibrium. The subsystems of atmosphere, hydrosphere, cryosphere and bio-lithosphere exchange energy, matter and momentum on scales between micrometers and the planetary circumference. These exchange cycles are driven by the energy inflow from the sun which has to be compensated by an energy loss through thermal emissions at typical temperatures of the Earth. This indicates a continuous rate of entropy production or a system being not in thermodynamic equilibrium. Due to the fact that the net energy input is at low latitudes and the net loss at high latitudes, energy has to be transported within the systems. Such externally driven non-equilibrium transport systems are known to produce large random fluctuations.[2] All these are indications that the randomness of the climate system is an inherent property arising from the physics of the system. Because complex climate models aim at a simulation of the real system as detailed as possible, it must be recognised that the climate models, although being a crude and low dimensional approximation, are also inherently stochastic. This means that any statement about climate and climate change that addresses observations as well as simulations has to be expressed in probabilistic terms, especially the climate change detection and attribution problem.

[1] Meteorologisches Institut, Bonn University

[2] Dewar, R.C. "Maximum entropy production and the fluctuation theorem." J. Phys. A: Math. Gen. 38 (2005): L371–L381, doi:10.1088/0305-4470/38/21/L01.

1.2 The Detection and Attribution Problem

This can be done e.g. by formulating the detection and attribution problem of climate change as a statistical hypothesis testing with all its consequences. An obvious approach is the formulation of a frequentist hypothesis testing the Null hypothesis that no external forcing is active. If this Null hypothesis is falsified at a specific significance level we speak of *detection*. To avoid circular reasoning, the hypothesis itself has to be formulated without considerations derived from the observations. Therefore climate models are used to prepare hypotheses on the possible changes of climate variables based on external forcing including the special case of applying no external forces. The latter constitutes the Null hypothesis. If the observed spatial-temporal variability does not compare with the simulated one from the no-forcing simulations, in the statistical sense that the probability of erroneously drawing the conclusion from the test is low although the Null hypothesis is true (significance, error of type I), one would reject the Null hypothesis and speak of a *detection*. A detection of a climate change by itself does not mean that a specific forcing (e.g. natural vs. anthropogenic, anthropogenic greenhouse gases vs. anthropogenic aerosol) is causally responsible for the observed change. This is the question of *attribution*. While one standard approach to attribution is through a regression analysis called optimal finger printing, another way is to think about a decision process under uncertainty in favour of one out of a set of alternative hypotheses which can also include the Null hypothesis from above. This can be well formulated by using a Bayesian statistical approach that calculates the conditional probability of a hypothesis given the observations (posterior). The posterior can be derived from the product of the likelihood of the observations given the hypothesis and the prior probability of that specific hypothesis divided by an appropriate normalization. The Bayesian solution of the detection and attribution problem is the decision in favour of the hypothesis with the highest posterior probability. The consequence arising from this statistical approach is such that a classical view of causality („who is responsible“) cannot be made. It would be even preferable in this context to speak of decision or selection of specific scenarios given the data.. The term “attribution” should be avoided because this would imply a causal explanation of the data by the simulations. There is an extensive discussion in statistical literature (e.g. from artificial intelligence, legal reasoning, epidemiology) about which and how causal relations can be deduced from statistical evidence.[3] It has led to the concept of a probability of causation that combines inductive with hypothetic-deductive reasoning.

1.3 Application to Near Surface Temperatures

Application to global and regional averages of mean near surface temperatures observations and simulations from the CMIP3 data base reveals that the hypothesis for the global mean temperature evolution during the 20th century with the highest probability is that which combines natural and anthropogenic forcings The CMIP3 database collects the global climate simulation prepared for the Fourth assessment report of the IPCC under a common experimental protocol. Figure 1.2 shows a smoothed representation of global mean temperature evolution during the 20th century (a) and of the control simulations (b).[4] Grey lines in (a) indicate 48 different model simulations with natural (i.e. solar and volcanic) and anthropogenic (greenhouse gases and sulphur aerosole) forcing while in (b) no external forcing is applied. The continuous black line indicates the observations according to the Climate Research Unit data set (HadCRUT2v, 1900–99), the dashed lines in (a) and (b) are the averages of all model simulations.[5] Application of the Bayesian decision method indicates that the posterior probability of the simulations in Figure 1.2(a) given the observations is much larger than the posterior derived from the data displayed in Figure 1.2 (b). This even holds when a prior probability in favour of the no change hypothesis in Figure 1.2 (b) is as large as 0.99 meaning that there is “decisive” evidence for climate change by natural and anthropogenic forcings/factors during the 20th century at least on the global scale.[6]

Regionally (e.g. Mid-Europe in Winter, December - February) the same method can be applied.[7] In this case the unforced natural climate variability (noise) can be much stronger than on the global scale (Figure 1.3). For low latitude regions similar results as on the global scale are obtained. The cross-hatched boxes in Figure 1.3 over South America and Africa indicate again a “decisive” evidence climate change by natural and anthropogenic (“all”) forcings/factors during the 20th century for the annual mean temperatures. But for Mid-Europe, the cross-hatched area is clearly smaller indicating a weaker signal in the annual mean temperatures of the 20th century due to natural and anthropogenic forcing. In winter and autumn (not shown) the internal variability is even stronger. The result is that the no-change hypothesis has the highest probability even if prior probabilities as low as 0.25–0.3 are attached to the no change Null hypothesis. This means that during the cold season a continental scale climate change signal in the near surface temperature cannot be detected in Mid-Europe at a reasonable level of evidence.

This might not be true for other variables like wind or humidity or even temperatures at higher levels in the atmosphere or in the ocean. Therefore there have been other studies that have similarly analysed mean humidity and precipitation changes over land, extremes in temperature and precipitation over land, surface pressure and sea ice area changes. This has only been possible through increased use of satellite observation. For example, in Santer et al. extensive use is made of atmospheric humidity data derived from the Special Sensor Microwave Imager (SSM/I) on board various polar orbiting satellites in the period 1988–2006.[8] The authors were able to detect a trend structure in the atmospheric water vapour content that is due

[3] Pearl, J. Causality: Models, Reasoning and Inference. Cambridge: Cambridge University Press, 2000; Williamson, J. Bayesian Nets and Causality. Oxford New York: Oxford University Press, 2005.
[4] Min, S.-K., and A.Hense. “A Bayesian Assessment of Climate Change Using Multimodel Ensembles. Part I: Global Mean Surface Temperature.” J. Climate 19 (2006): 3237-3256.
[5] Jones, P. D., and A. Moberg. “Hemispheric and Large-Scale Surface Air Temperature Variations: An Extensive Revision and an Update to 2001.” J. Climate 16 (2003): 206-223.
[6] Kass, R. E., and A. E. Raftery. “Bayes Factors.” J. Amer. Stat. Assoc. 90 (1995): 773-795.
[7] Min, S.-K., and A. Hense. “A Bayesian Assessment of Climate Change Using Multimodel Ensembles. Part II: Regional and Seasonal Mean Surface Temperatures” J. Climate 20 (2007): 2769-2790.
[8] Santer, B. D., C. Mears, F. J. Wentz, K. E. Taylor, P. J. Gleckler, T. M. L. Wigley, T. P. Barnett, J. S. Boyle, W. Brüggemann, N. P. Gillett, S. A. Klein, G. A. Meehl,T. Nozawa, D. W. Pierce, P. A. Stott, W. M. Washington, and M. F. Wehner. “Identification of Human-Induced Changes in Atmospheric Moisture Content.” PNAS 104.39 (2007): 15248-15253, doi:10.1073/pnas.0702872104.

to an anthropogenic forcing. In Min et al. a data set for Arctic sea ice coverage changes is used, which is a data set of ship and station observations merged with estimates from passive microwave satellite imagery for the period 1979–2006.[9] Again the author could detect a sea ice coverage change induced by anthropogenic forcing.

1.4 Regional Climate Change

Besides the above-mentioned global anthropogenic and natural forcings like solar, volcanic and well mixed greenhouse gases (GHG), regional climate change can be influenced by other factors not yet considered in regional detection and attribution studies. Most prominent are land use and cover changes (LUCC) which might be especially relevant in tropical and subtropical regions.[10] [11] Other regional forcing factors are air quality changes through aerosols, mobilization of mineral dust and emissions of reactive gases. The anthropogenic climate change contribution through air quality variations has been studied by detecting weekly cycles in stations observations (e.g. Bäumer and Vogel) but also by using satellite observations (e.g. Beirle et al.).[12] However, a statistically well-defined detection and attribution study combining model studies and observations is not known. For adaptation to and mitigation of climate changes on the regional scale there is a clear need for detection and attribution studies of regional climate change. Otherwise a mitigation of regional climate change has no scientific basis. Satellite observations can play an important role because in most cases they provide the only means for continuous monitoring of the relevant forcings (e.g. concentration distributions of trace reactive trace gases in the atmosphere) as well as of possibly changing climate variables (e.g. cloud coverage or humidity distribution) that are not well represented by standard meteorological networks.

1.5 Future Use of Satellite Data in Climate Change Detection and Attribution

The first steps to establish a more comprehensive use of satellite data in climate research in general have been taken by the ESA Climate Change Initiative. However the retrieval of climate system variables from their electromagnetic signature measured by satellite sensors is in most cases a statistically ill-posed problem. It necessitates additional models and information plus an aggregation model of the spatial-temporal sampling structure to provide homogeneous global coverage in space and time. The possible caveats behind these additional sources can be circumvented by the use of simulated satellite measurements "virtual satellite in model" or "observing system simulation". Instead of comparing the climate model simulation with the retrieved and aggregated satellite climate variables, the simulated variables are used to produce a simulated electromagnetic signature at that point in space and time that has been sampled by a specific satellite/sensor combination. This simulation signal can be compared in statistical terms with the observed one from the real system. First experiences from weather forecasting reveal that observing system simulation is especially useful in regional (climate) models to make efficient use of the valuable information provided by satellites. A possible combination or workflow structure to include satellite observations in a coherent and self-consistent way through observing system simulations into an environmental modeling system is sketched in Figure 1.4. It should be noted that the observing system simulation approach is not restricted to satellite data but may be used also with classical stations observations.

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[9] Min, S.-K., X. Zhang, F.W. Zwiers, and T. Agnew. "Human Influence on Arctic Sea Ice Detectable from Early 1990's Onwards." Geophys. Res. Lett. 35 (2008): L21701, doi:10.1029/2008GL035725; Meier, W. N., J. C. Stroeve, and F. Fetterer. "Whither Arctic Sea Ice? A Clear Signal of Decline Regionally, Seasonally and Extending Beyond the Satellite Record." Ann. Glaciol. 46 (2007): 428-434.

[10] Feddema, J. J., K. W. Oleson, G. B. Bonan, L. O. Mearns, L. E. Buja, G. A. Meehl, and W. M. Washington. "The Importance of Land-Cover Change in Simulating Future Climates." Science 310 (2005): 1674-1678.

[11] Paeth, H., K. Born, R. Girmes, R. Podzun, and D. Jacob. "Regional Climate Change in Tropical and Northern Africa Due to Greenhouse Forcing and Land Use Changes." J. Climate 22 (2009): 114-132, doi: 10.1175/2008JCLI2390.1.

[12] Bäumer, D., and B. Vogel "An Unexpected Pattern of Distinct Weekly Periodicities in Climatological Variables in Germany." Geophys.Res. Lett. 34 (2007): L03819, doi:10.1029/2006GL028559; Beirle, S., U. Platt, M. Wenig, and T. Wagner. "Weekly Cycle of NO2 by GOME Measurements: a Signature of Anthropogenic Sources." Atmos. Chem. Phys. 3 (2003): 2225-2232.

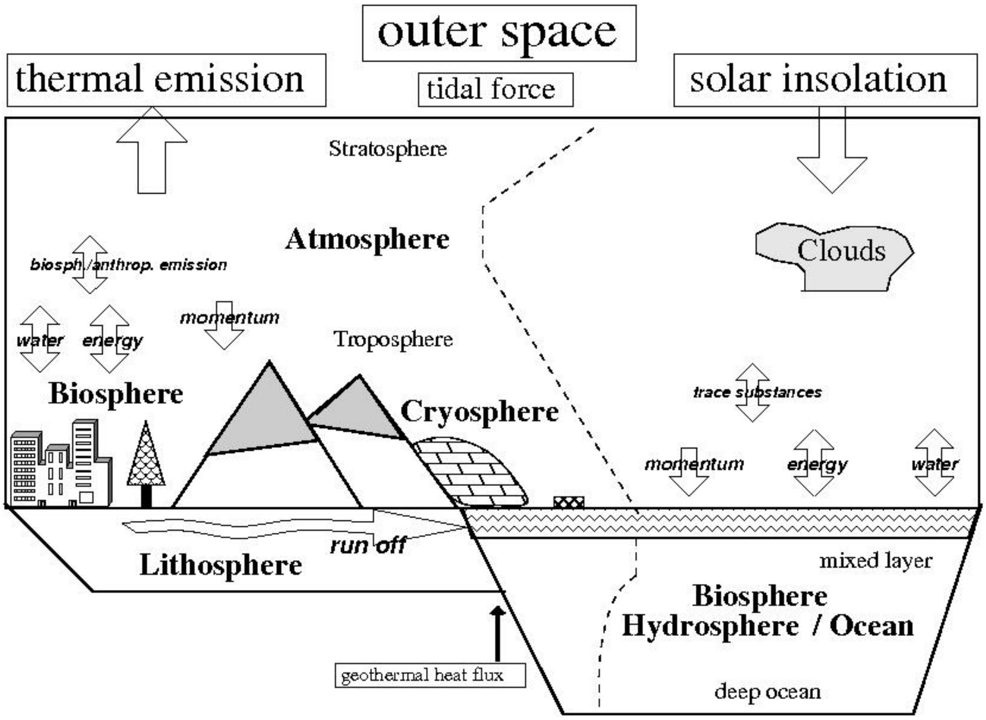

Figure 1.1: The climate system

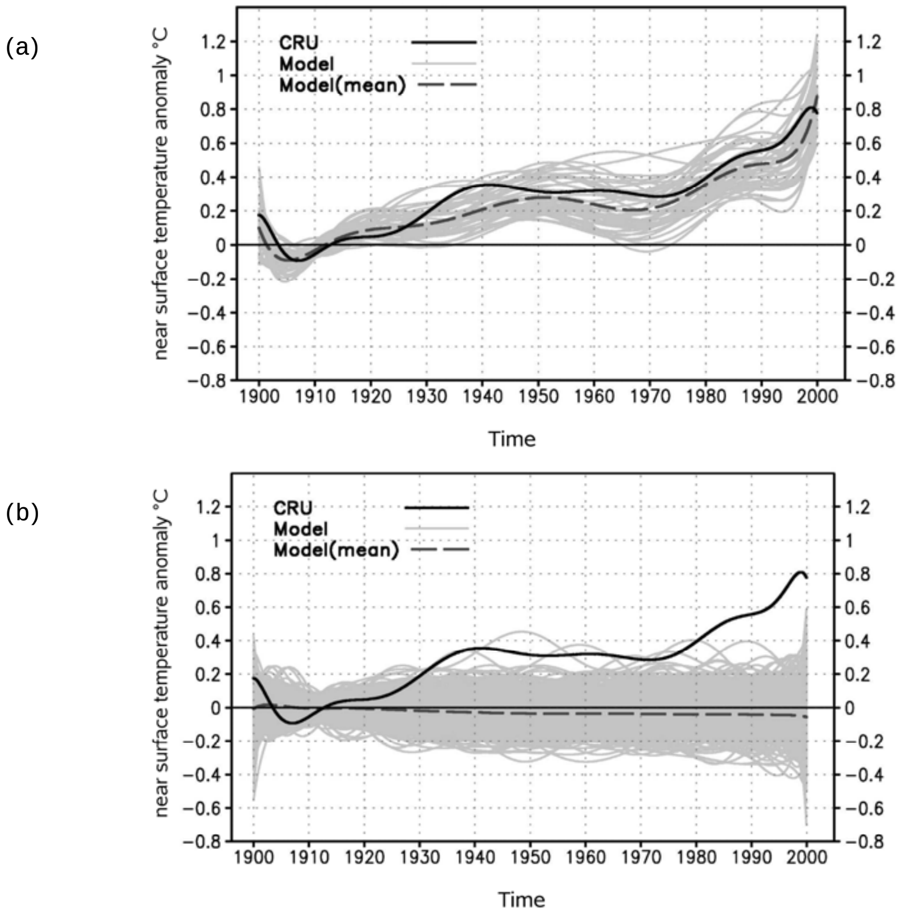

Figure 1.2: A temporally filtered representation of global mean temperature evolution during the 20th century (a) and of the control simulations (b) from CMIP3 global climate model simulations. Grey lines in (a) indicate 48 different model simulations driven by natural and anthropogenic forcing while in (b) no external forcing is applied. The continuous black line indicates the observations acc. to the Climate Research Unit data set (HadCRUT2v, 1900–99), the dashed lines in (a) and (b) are the averages of all model simulations.[5 4]

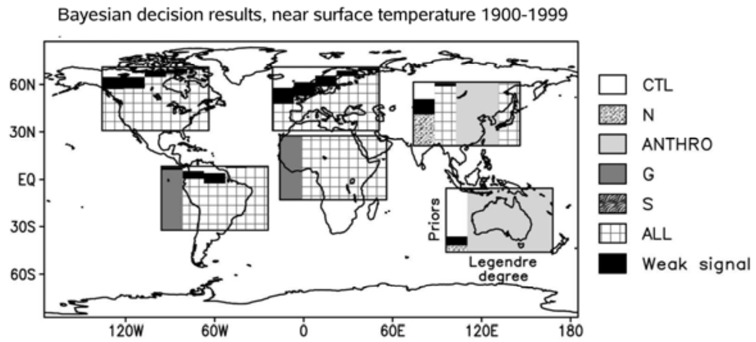

Figure 1.3: Results of the Bayesian decision method for climate change detection and attribution of regional averages of near surface temperatures for the period 1900-1999. The hatched area indicates "decisive" evidence for the simulations driven by natural and anthropogenic forcing (Figure 1.2, left) given the observations, while the white area indicates a decision in favour of the unforced Null hypotheses ("ctl"), after Min and Hense.[4]

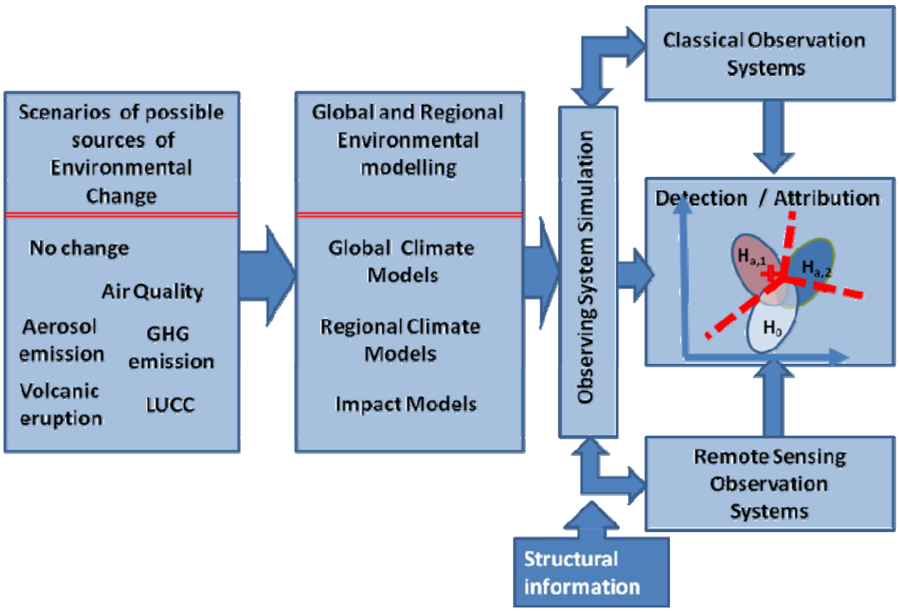

Figure 1.4: Sketch of the workflow of an environmental monitoring system for detecting and attributing global and regional environmental (climate) changes using satellite data and classical observing systems. Structural information is information about the sensor, satellite, orbit etc.

2. Regional Climate Knowledge for Society

by Hans von Storch[13]

Abstract

The present misconception of climate science and its interaction with the public is addressed. While the knowledge base about the dynamics of climate and its sensitivity to elevated greenhouse gas concentrations has been greatly expanded with broad consensus in the scientific community, the communication with the public and policy makers has not led to the implementation of efficient measures to limit man-made climate change. It is suggested that a different position be adopted, namely the building of a regional climate service, which allows public and stakeholders to consider climate knowledge in the process of dealing with climate-related problems, where this is appropriate. Thus climate science should not be the avant-garde of climate policy but support the political process by providing a knowledge broker service.

2.1 Climate Change and the IPCC

The Intergovernmental Panel on Climate Change, IPCC, documents and assesses scientific knowledge about ongoing climate change and perspectives thereof. The range of issues covered by the IPCC is very broad and the degree of confidence that is met by the reports of the different working groups varies substantially. In particular, the report of Working Group 1, on the "science", enjoys broad acceptance, with a number of key assertions, namely

- strong consensual evidence that the climate system is warming,
- most of this warming cannot be explained without the increase in GHG concentrations – with the present knowledge,
- therefore, because of the ongoing human emissions of greenhouse gases (GHG) in the foreseeable future, the warming of the climate system will continue many decades into the foreseeable future.

The strength of agreement among climate scientists to both the fact that there is global warming ("manifestation") and that its explanation needs the effect of elevated greenhouse gas concentrations ("attribution"), has been determined over the years in a series of surveys, which have been summarized by Bray.[14] While back in 1996, manifestation was accepted by some 62% of all respondents, and attribution only by 38%, both numbers have risen to well above 90% in 2010. Thus, acceptance that warming and greenhouse gases are the major cause is almost universal among climate scientists.

Unfortunately, the IPCC failed to be explicit in documenting, for instance in its "Summary for Policy Makers", consensus on questions *lacking consensus*, such as the fate of ice sheets, sea level projections, present change of hurricanes, present change in different types of extremes. The other two working groups have achieved less scientific authority. The unfortunate und badly managed errors in the AR4 Report of Working Group II, on impacts, as well as the failure of the Chair of Working Group III to rebuke claims of manipulation, have led to less respect among scientists for the work of these two working groups.[15] [16]

2.2 Deciding on Climate Policy

Many, in particular among physical climate scientists, apply the "linear model", according to which knowledge about climate dynamics, in particular the link between greenhouse gas concentration and warming, sea level and other significant state variables, can be translated directly into a set of needed policy

[13] Institute for Coastal Research, Helmholtz-Zentrum Geesthacht

[14] Bray, D. "The Scientific Consensus of Climate Change Revisited." Env. Sci. Pol. 13 (2010): 340-350.

[15] von Storch, H. "Climate Science, IPCC, Postnormality and the Crisis of Trust.", In: N. Roll-Hansen, 2011: *Status i klimaforskningen. Kunnskap og usikkerhet, vitenskapelige og politiske utforderinger*, Det Norske Videnskaps-Akademi, Novus forlag - Oslo, (2011) 151-182.

[16] Klimazwiebel. Still No Reaction to Richard Tol's Assertion About Incorrect Statements by Edenhofer in ZDF. <http://klimazwiebel.blogspot.com/2010/10/still-no-reaction-to-richard-tols.html>.

and market instruments. This set would minimize the sum of adaptation and abatement costs.[17] [18] Indeed, in the public discourse, the impression is raised that after the unequivocal findings of the IPCC – as given above – a mandatory political course would be clear, namely a reduction of greenhouse gas emissions as much as possible, so that temperature increase would peak at 2 degrees or less, and then stabilise.

But, in spite of a massive public campaign based on – what is called, at least in the West: – a scientific consensus and conclusion, concrete and efficient manifestations of such policy remain rare and unconvincing. Obviously, the linear model does not work. One reason is that the world is seen as essentially one-directional, namely that decisions and thus "action" would essentially flow directly from scientific understanding. Also, it is based on a rather idealized understanding of the interaction between science and the public; one idealization is that on the side of the knowledge-providers there are no conflicts about what the "facts" are; science as a knowledge-broker appears monolithic.

In my understanding, the political process does not make use of scientific "truth" – whatever that may be – but on perceptions and on knowledge claims that are the result of a metamorphosis of scientific knowledge. The issue has become an issue of competing knowledge claims, which are by themselves subordinate to certain worldviews and sets of value preferences. Indeed, this had to be expected after climate science found itself in a post-normal situation, where *stakes are high, facts uncertain, decisions urgent and values in dispute*.[19] Interest-led utility is a significant driver in the research area in a post-normal phase, less so "normal" curiosity.

2.3 Different Knowledge Claims

In my understanding, *climate change is a "constructed" issue*. People hardly experience "climate change". There are different classes of *constructions*.[20] One is *scientific*, i.e. an "objective" analysis of observations and interpretation by theories. The other is *cultural*, in particular maintained and transformed by the public media.

The *scientific construction* describes a climate that is subject to the influence of greenhouse gases (GHGs), with the primary effect of higher temperatures and related facets associated with higher GHG concentrations, and secondary effects related to dynamic changes related to cloudiness, circulation etc. In this description, humankind is responsible for the elevated GHG presence, and can limit the effect of man-made climate change by regulating the emissions of greenhouse gases. However, since substantial amounts of GHGs have already been released, the effect cannot be stopped within a few decades or years. Given the inertia of the climate as well as the economic system, the warming will continue for a while. A very substantial effort has to be made to limit the warming to 2 degrees over preindustrial levels, even if there is some doubt that it is possible at all. Thus, not only efforts for reducing the flux of GHGs into the atmosphere have to be explored by science, and possibly implemented by societies, but also measures for dealing with the unavoidable changes of the possibly limited man-made climate change need to be studied and tested.

In the scientific construction, adaptation to climate change and mitigation of man-made climate change are both key aspects of the climate issue.

The *cultural construction* describes a different system, namely a sinful humankind, which is mistreating nature – which eventually strikes back, in an act of global justice. Nature, or more specifically climate, strikes back with all kinds of extremes, prominent among them being storms and hurricanes but also floods and droughts; with rising sea levels, which will in the near future destroy large coastal and island territory. All this can be halted if GHG emissions are dramatically reduced; then, and only then, can the climate crisis, or catastrophe, be managed, and further adaptation measures will not be needed, at least no significant ones.

Of course, the two constructions are not separate; both influence each other – as is common in a post-normal situation.

The present failure of science to really influence policymaking constructively and effectively may be related to the following observations:

[17] Hasselmann, K. "How Well Can We Predict the Climate Crisis?" Environmental Scarcity - the International Dimension. Ed. H. Siebert. Tübingen: JCB Mohr, 1990. 165-183.

[18] Nordhaus, W. D. "To Slow or Not to Slow: the Economy of the Greenhouse Effect." Econ. J. 101 (1991): 920-937.

[19] Funtowicz, S. O., and J. R. Ravetz. "Three Types of Risk Assessment: a Methodological Analysis." Risk Analysis in the Private Sector. Eds. C. Whipple, and V. T. New York: Plenum, 1985: 217-231.

[20] von Storch, H. "Climate Research and Policy Advice: Scientific and Cultural Constructions of Knowledge." Env. Science Pol. 12 (2009): 741-747. <http://dx.doi.org/10.1016/j.envsci.2009.04.008>.

- The science-policy/public interaction is not an issue of the linear model of "knowledge speaks to power".
- The problem is not that the public is stupid or uneducated.
- Science has failed to respond to legitimate public questions and has instead asked: "Trust us, we are scientists".
- The problem is that scientific knowledge is confronted on the "explanation market" with other forms of knowledge. Scientific knowledge does not necessarily "win" this competition.
- The social process "science" is influenced by these other knowledge forms.

I would suggest that this situation should give rise to a change in thinking among scientists, namely to give up plans to persuade societies to implement specific policies, but to support the societal process of finding solutions to the "climate problem" by answering as objectively as possible questions about the consequences of different policies, and options and needs for regional and local adaptation measures. Instead of trying to "solve" political problems on the backstage of scientific debates, science should return to its role of an honest broker (Pielke jr., 2007) and build a dialogue with the public, which goes under the name of *regional climate service*.[21] [22]

2.4 Regional Climate Service

The concept of "climate service" emerged first in North America, with initial publications in governmental documents in the early 1980's and earlier (for a historical perspective, refer to Changnon et al., 1990).[23] Its mission and scope may be summarized as: "A N[ational] C[limate] S[ervice] identifies, produces, and delivers authoritative and timely information about climate variations and trends and their impacts on built and natural systems on regional, national, and global space scales. This information informs and is informed by decision-making, risk management, and resource management concerns for a variety of public and private users acting on regional, national, and international scales. The stakeholders (and the constituency for an NCS) include public and private individuals and organizations at federal, state, and local levels … with sensitivity to and need for climate-related information." (Miles et al., 2006).[24] Stakeholders on different scales take different viewpoints, with national and international actors being more interested in issues related to mitigation of man-made climate change and regional and local actors more engaged in adaptation measures.

The main elements of such a climate service are (Miles et al., 2006): [25]

1. "Serve as a clearinghouse and technical access point to stakeholders for regionally and nationally relevant information on climate, climate impacts, and adaptation; developing comprehensive databases of information relevant to specific regional and national stakeholder needs.
2. Provide education on climate impacts, vulnerabilities, and application of climate information in decision-making
3. Design decision-support tools that facilitate use of climate information in stakeholders' near-term operations and long-term planning
4. Provide user access to climate and climate impacts experts for technical assistance in use of climate information and to inform the climate forecast community of their information needs
5. Provide researcher, modeler, and observations experts access to users to help guide direction of research, modeling, and observation activities
6. Propose and evaluate adaptation strategies for climate variability and change."

This concepts fits well into the linear model discussed above, which stipulates that knowledge about the dynamics in the Earth-society system together with an understanding about the incurred costs for adaptation and mitigation, would "solve" the climate problem, and provide decision makers with directions on how to rationally and cost-effectively respond

[21] Pielke, Jr., R. A., ed. The Honest Broker: Making Sense of Science in Policy and Politics. Cambridge University Press, 2007.

[22] von Storch, H., I. Meinke, N. Stehr, B. Ratter, W. Krauss, R.A. Pielke jr., R. Grundmann, M. Reckermann, and R. Weisse. "Regional Climate Services illustrated with experiences from Northern Europe." Zeitschrift für Umweltpolitik & Umweltrecht 1 (2011): 1-15.

[23] Changnon, S. A., P. J. Lamb, and K. G. Hubbard. "Regional Climate Centers: New Institutions for Climate Services and Climate-Impact Research." Bulletin of the American Meteorological Society 71.4 (1990): 527-537.

[24] Miles, E. L., A. K. Snover, L. C. Whitely Binder, E. S. Sarachik, P. W. Mote and N. Mantua. "An Approach to Designing a National Climate Service." Proceedings of the National Academy of Sciences 103.52 (2006): 19616-19623.

[25] Ibid.

to the perspective of anthropogenic climate change.

As part of the Climate Service data collection, quality control and archival activities, dissemination and guidance for using such data, scenario of climate change and impacts, and links to applied research often are listed.[23] Regional and global data sets, describing recent, ongoing and possible future climate changes and impacts are important elements enabling an efficient climate service.[26]

2.5 Our Activities at the Institute of Coastal Research at the Helmholtz Zentrum Geestacht

The Institute of Coastal Research at the Helmholtz Zentrum Geesthacht (near Hamburg, Germany) describes its mission in this way:

> » Coastal systems are under constant pressure from short and long term natural influences, including erosion or sea level rise due to climate change, and from human endeavours, for example, transportation, land use patterns, tourism, etc. As a means to identify the potential for change, sustainability, and adaptation, coastal research provides the tools, assessments, and scenarios for managing this vulnerable landscape.
> Research activities span both the natural and human dimensions of coastal dynamics, analysing the coastal system in global and regional contexts, conducting assessments of the state and sensitivity of the coastal system to natural and human influences, and developing scenarios of future coastal options.

As such, the Institute claims to generate useful knowledge, which can be used mostly in regional and local contexts for managing coasts, in particular with respect to climate change. Being confronted with the issue discussed above, special efforts were developed and implemented – with partners from the social sciences and humanities.

These efforts comprise:

1. Analysis of the *cultural constructions of climate, climate change and impact*, including common exaggeration in the media (e.g., Neverla and von Storch, 2010).[27]
2. Determination of *response options* on the local and regional scale: mainly adaptation but also regional and local mitigation (e.g., von Storch et al., 2010).[28]
3. *Dialogue* of stakeholders and climate knowledge brokers in “Klimabureaus”.[29] [30]
4. Analysis of *consensus* on relevant issues (climate consensus reports)..[31] [28]
5. Description of *recent and present changes* as well as projection of *possible future* changes, which are dynamically consistent and possible (“scenarios”) (“CoastDat”)[32]
6. Direct exchange and discussion about climate science and climate policy with individuals via a weblog.[33]

2.5.1 North German Climate Office

The North German Climate office was set up in 2006 as an institution that enables communication between science and stakeholders, that is: making sure that:[34] [29]

- science understands the questions and concerns of a variety of stakeholders
- stakeholders understand the scientific assessments and their limits.

The office deals specifically with issues that are covered scientifically by the home institute, i.e., various aspects dealing with climate change and climate impact in the Ger-

[26] von Storch, H., and I. Meinke. “Regional Climate Offices and Regional Assessment Reports needed.” Nature Geosciences 1.2 (2008): 78, doi:10.1038/ngeo111.

[27] Neverla, I., and H. von Storch, eds. Wer den Hype Braucht. Die Presse, 24. Juli 2010.

[28] von Storch, H., M. Claussen, and KlimaCampus Autoren Team, eds. Klimabericht für die Metropolregion Hamburg. Springer Verlag Heidelberg Dordrecht London New York, 2010:321, doi 10.1007/978-3-642-16035-6.

[29] Meinke, I., and H. von Storch. “Regional Cimate Offices as Link Between Climate Research and Decision Makers.” Extended Abstract for International Desaster Reduction Conference (IDRC), Davos, Switzerland, 25-29 August 2008: 938-941.

[30] Schipper, J.W., I. Meinke, S. Zacharias, R. Treffeisen, Ch. Kottmeier, H. von Storch, und P. Lemke. “Regionale Helmholtz Klimabüros bilden bundesweites Netz.“ DMG Nachrichten 1 (2009): 10-12.

[31] BACC author team. Assessment of Climate Change in the Baltic Sea Basin. Springer Verlag Berlin-Heidelberg, 2008: 473.

[32] Weisse, R., H. von Storch, U. Callies, A. Chrastansky, F. Feser, I. Grabemann, H. Günther, A. Plüss, T. Stoye, J. Tellkamp, J. Winterfeldt, and K. Woth. “Regional Meteo-Marine Reanalyses and Climate Change Projections: Results for Northern Europe and Potentials for Coastal and Offshore Applications.” Bull. Amer. Meteor. Soc. 90 (2009): 849-860. <http://dx.doi.org/10.1175/2008BAMS2713.1.>.

[33] <http://klimazwiebel.blogspot.com/).>.

[34] <http://www.norddeutsches-klimabuero.de>.

man coastal regions. As such, typical stakeholders entail representatives and stakeholders in coastal defence, agriculture, offshore activities (energy), tourism, water management, fisheries, and urban planning.

A special product is the North German Climate Atlas (http://www.norddeutscher-klimaatlas.de/), which is available in German language, to meet customers' demands.[35] This web-based atlas describes possible climatic futures, as given by – so far – 12 regional climate projections, for different regions in Northern Germany (plus a region straddling the Polish/German border). Scenarios are described by an ensemble means, but also by minimum and maximum changes in the set of scenarios.

2.5.2 Regional Climate Consensus Reports

In scientifically legitimate knowledge about climate, climate change and climate impacts are screened in an IPCC-like process. All literature, not only in English, is considered as long as it is published in regular scientific journals or by reputable scientific institutions (such as weather services). In a series of chapters, with responsible lead authors, issues like past and ongoing regional change, possible future change, and climate related changes in terrestrial and marine ecosystems are covered. Prior to publication, the reports are anonymously reviewed, and presented to the regional scientific public. Political or management recommendations are not made, but scientifically contested areas are emphasized. The reports are conveyed to political bodies, which use them as a basis for further deliberations.

So far, two such reports have been completed.

- *The Climate Change Assessment: Report for the Baltic Sea Catchment - BACC.* Approximately 80 scientists from 10 countries documented and assessed the published knowledge, which was published in English in 2008.[31] [36] The assessment has been employed by the intergovernmental Helsinki Commission / Baltic Marine Protection Commission HELCOM for the Baltic Sea as a basis for its future deliberations.[37] [38]

  For 2013 the publication of an updated assessment report (BACC II) is presently being prepared. [39]

- *Climate Assessment for the Metropolitan Region of Hamburg.* In 2007-2010 a climate assessment report about the scientifically documented knowledge of climate change in the region of Hamburg was prepared – as an activity of the Climate Centre of Excellence CLISAP at the University of Hamburg, jointly operated with the Helmholtz Zentrum Geesthacht and the Max Planck Institute of Meteorology.[28]

  The Senate of Hamburg and the Environmental Ministry of Schleswig Holstein used the results for climate adaptation planning.

2.5.3 CoastDat. Regional and Local Conditions in the Recent Past and Next Century.

Using a modelling strategy that processes homogeneous multi-decadal analyses of large-scale circulation with a regional climate model (dynamical downscaling), a realistic description of the weather stream since 1948 until (almost) today is constructed. This description is not error free, but the statistics of these errors remain uniform throughout the entire time. In a similar way, scenarios of possible future conditions are generated.

The whole data set, which covers atmospheric and oceanographic data, is named CoastDat (http://www.coastdat.de/index_home.html.en; Weisse et al., 2009).[40] [32] It features long (60 years) and high-resolution reconstructions of recent offshore and coastal conditions mainly in terms of wind, storms, waves, surges and currents and other variables in Northern Europe, and scenarios (100 years) of possible consistent futures of coastal and offshore conditions. Efforts are underway to extend the data set, so as to cover ecological variables, but also other regions such as the Baltic Sea, East Asia and Laptev Sea.

Users of this data are various *governmental/municipal* coastal *agencies* dealing with coastal defence and coastal traffic, *companies* with needs for the assessment of risks (ship and offshore building and operations) and opportunities (wind energy) and finally the *general public / media*, who ask for explanations of causes of change and perspectives and options on how to deal with change.

[35] <http://www.norddeutscher-klimaatlas.de/).>
[36] Reckermann, M., Isemer, H.-J., and von Storch, H. "Climate Change Assessment for the Baltic Sea Basin." EOS Trans. Amer. Geophys. U. 2008: 161-162.
[37] <http://www.helcom.fi/)>.
[38] Helsinki Commission. "Climate Change in the Baltic Sea Area. HELCOM Thematic Assessment in 2007." Baltic Sea Environment Proceedings 111 (2007).

[39] <http://www.baltex-research.eu/organisation/bwg_bacc2.html>.
[40] <http://www.coastdat.de/index_home.html.en>.

The CoastDat-effort is pursued in cooperation with a variety of governmental agencies and also with companies. Applications cover issues such as ship design, navigational safety, assessment of offshore wind potentials, interpretations of measurements, assessments of oil spill risks and chronic oil pollution, assessment of ocean energy perspectives as well as scenarios of possible future surge and wave conditions.

2.6 Concluding Remarks

When discussing the issue "knowledge for society", one has to determine what the task of science should, or could be, when interacting with society. My perspective is that this task is to:

- offer explanations for a complex world, its dynamics, links and dependencies.
- state what can be done, not what needs to be done.
- establish measures to ensure the quality of science by insisting on scientific method (cf. Merton's CUDOS).
- keep in mind that the capital of science is not the utility of the scientific findings but the methodology used to obtain such findings.

Merton CUDOS-norms are repeated here; certainly no strict rules, but a guidance, and with question marks as to what extent these rules are actually applied by wide segments of science.[41] [42]

- **"C**ommunalism: the common ownership of scientific discoveries, according to which scientists give up intellectual property rights in exchange for recognition and esteem.
- **U**niversalism: according to which claims to truth are evaluated in terms of universal or impersonal criteria, and not on the basis of race, class, gender, religion, or nationality.
- **D**isinterestedness: scientists, when presenting their work publicly, should do so without any prejudice or personal values and do so in an impersonal manner.
- **O**rganized **s**kepticism: all ideas must be tested and are subject to rigorous, structured community (peer review) scrutiny."[43]

I suggest using these rules in particular in climate sciences, as this may be a way to leave the swirl of post-normal sciences and help to lead climate science back to normal conditions. In the present situation, the policy making process points to science when decisions are needed, even if there are difficult, value-based problems (*scientising policymaking*)..[21] Science cannot solve these problems. But when it tries it sells out the capital of science, namely the trust of the public that science will deliver in the spirit of Merton's rules. On the other hand, if science openly takes value-based positions in favour of one or other political agenda (*politicising science*), the foundations of good science will be destroyed.

My take-home messages for the reader are:

- The societal service of science is to provide explanation of complex phenomena, using the scientific methodology as per Merton (CUDOS).
- Climate science operates in a post-normal situation, which goes along with a tendency of politicizing science, and scientising politics. Cultural science needs to support climate science to deal with this challenge.
- Climate Science needs to offer "Climate Service", which includes the establishment of a dialogue with the public (direct or via media) and stakeholders – *recognizing the socio-cultural dynamics of the issue*.

[41] Merton, Robert K. "The Normative Structure of Science". The Sociology of Science. Ed. N. W. Storer, Chicago, IL: University of Chicago Press, 1974: 267-273.
[42] Stehr, N. "The Ethos of Science Revisited Social and Cognitive Norms." Sociological Inquiry 48 (1978): 172-196.

[43] Grundmann, R., pers. comm.

3. Space and Climate Geoengineering

by Leopold Summerer and Cynthia Maan[44]

Abstract

Global efforts to reduce carbon dioxide emissions have not yet been sufficiently successful to avoid the risk of potentially dangerous effects of climate change; on the contrary, despite these efforts, CO_2 emissions are still rising. If mitigation efforts continue to be delayed or unsuccessful, additional actions to reduce global temperatures might become necessary this century, such as geoengineering; i.e. deliberately influencing Earth's climate system. In 2009, the Royal Society concluded that geoengineering is likely to be technically feasible, and could substantially reduce the costs and risks of climate change.[45] To ensure that geoengineering methods can be adequately evaluated, and applied, the Royal Society recommended internationally coordinated research on the feasibility, benefits, risks and opportunities of geoengineering and on the development of the more promising methods, while not losing the focus on addressing the root causes of global warming by reducing the emissions of CO_2.

The present paper assesses technological aspects of geoengineering in space. There are different ways in which space could possibly play a role in geoengineering, ranging from remote sensing from space to provide insight in the effectiveness and (environmental) impact of (small scale) geoengineering experiments and carbon removal techniques, to actively interfering such as reducing the incoming solar radiation by modifying the albedo/reflectivity of the Earth, i.e. solar radiation management (SRM) techniques. The aim of this paper is to give a first account of the potential of space applications to contribute to geoengineering options and to provide a preliminary assessment of the effectiveness, timeliness/timescales, costs, environmental impacts and technological reversibility of geoengineering methods from space. Given the immaturity of some of the concepts involved, the uncertainties related to space options and the generic approach chosen for this paper, it is also intended to stimulate further interest and discussions on potential space contributions to geoengineering.

3.1 Introduction

Driven by the continuously rising level of anthropogenic greenhouse gasses in the atmosphere, Earth's climate is changing. Climate models show that the consequences could be severe if no drastic actions are taken to stop global warming.[46] According to the fourth and most recent assessment report of the Intergovernmental Panel on Climate Change (IPCC), the global atmospheric temperature rise corresponding to several future trajectories of greenhouse gas emissions lies within a range of 1.1-6.4 degrees Celsius in the 2090's. Furthermore, changes in the climate are expected to occur abruptly and unpredictably.[47] Reducing global greenhouse gas emissions is seen as the most direct and best way to prevent potentially dangerous levels of climate change. However, despite the effort of many countries, emissions are still rising.[48]

If reductions of greenhouse gasses are not achieved in time and severe climate change becomes apparent, other methods to cool the Earth, including geoengineering, might be required. Climate models show that the climate could be brought closer to the pre-industrial climate by applying geoengineering methods to decrease global temperature.[49]

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[44] European Space Agency

[45] Royal Society (Great Britain). Geoengineering the Climate Science, Governance and Uncertainty. London: Royal Society, 2009.

[46] Vaughan, N., and T. Lenton. "Trade-offs Between Geoengineering, Mitigation and Adaptation." (2011); Wigley, T. M. L. "A Combined Mitigation/Geoengineering Approach to Climate Stabilization." Science 314 (2006): 452-454, doi:10.1126/science.1131728.

[47] Ditlevsen, Peter D., and Sigfus J. Johnsen,. "Tipping Points: Early Warning and Wishful Thinking." Geophysical Research Letters 37 (2010), doi:10.1029/2010GL044486.

[48] Intergovernmental Panel on Climate Change, <http://www.ipcc.ch/index.htm>.

[49] see e.g. Govindasamy, B., K. Caldeira, and P. B. Duffy. "Geoengineering Earth's Radiation Balance to Mitigate Climate Change from a Quadrupling of CO2." Global and Planetary Change 37 (2003): 157-168, doi: 10.1016/S0921-8181(02)00195-9; as well as Jones, Andy, Jim Haywood, and Olivier Boucher. "A Comparison of the Climate Impacts of Geoengineering by Stratospheric SO2 Injection and by Brightening of Marine Stratocumulus Cloud." Atmospheric Science Letters (2010), n/a-n/a, doi:10.1002/asl.291; and Keith, D. W. "Photophoretic Levitation of Engineered Aerosols for Geoengineering."

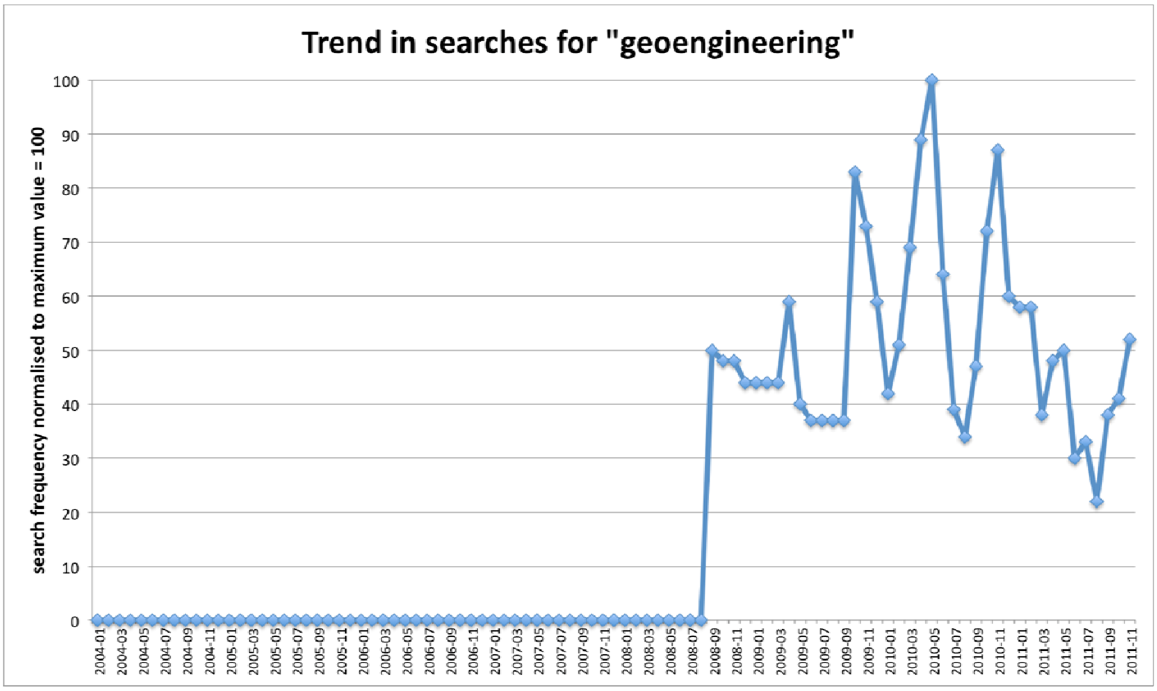

Figure 3.1: Relative frequency of the search term "geoengineering" in Google science searches

Although the deliberate and global manipulation of Earth's climate has long been ignored as a serious option to counteract global warming, in recent years advances in atmospheric science and the understanding of interactions between the main global climate variables and parameters have increased the number of scientists performing serious research on active climate change options. Many new studies have been published on different aspects of geoengineering. Figure 3.1 demonstrates the continued and increasing importance of geoengineering in public searches on the intranet following the publication of the report on the topic by the UK Royal Society. The increasing interest in non-technical and non-scientific aspects of geoengineering might furthermore be seen as a sign of the increasing relevance of this option, including especially questions related to the ethics, governance, politics and economics of climate change.[50]

High profile interventions in the public debate, such as those by former US Vice-President Al Gore, calling climate change "not a political issue. This is a moral issue, one that affects the survival of human civilization" and by James Hansen, from NASA, calling climate change the "predominant moral issue of the 21st century, [...] comparable to Nazism faced by Churchill in the 20th century and slavery faced by Lincoln in the 19th century" contribute to societal and not just scientific and engineering approaches to the discussions on climate change and geoengi-

Proceedings of the National Academy of Sciences 107 (2010): 16428-16431, doi:10.1073/pnas.1009519107; or for a purely space-based concept see e.g. Angel, R. "Feasibility of Cooling the Earth with a Cloud of Small Spacecraft Near the Inner Lagrange Point (L1)." Proceedings of the National Academy of Sciences 103 (2006): 17184-17189, doi:10.1073/pnas.0608163103.; for using aerosols to cool the climate see e.g. Bickel, J. E., and S. Agrawal,. "Reexamining the Economics of Aerosol Geoengineering." Climatic Change (2011); for an assessment of the radiative forcing potential of different concepts see e.g. Lenton, T. M., and N. E. Vaughan. "The Radiative Forcing Potential of Different Climate Geoengineering Options." Atmos. Chem. Phys 9 (2009): 5539-5561; and for a recent analysis based on a global climate model see e.g. Lunt, D. J., and others. "Sunshade World: a Fully Coupled GCM Evaluation of the Climatic Impacts of Geoengineering:" Geophysical Research Letters 35 (2008): L12710, doi:10.1029/2008GL033674.

[50] See e.g. Preston, Christopher J. "Re-Thinking the Unthinkable: Environmental Ethics and the Presumptive Argument Against Geoengineering." Environmental Values 20 (2011): 457-479, doi:10.3197/096327111X13150367351212; Rayner, Steve. "Climate Change and Geoengineering Governance." Presentation. Proceedings Governing Geoengineering in the 21st Century: Asian Perspectives. Signapore. 2011. <http://www.rsis.edu.sg/nts/HTML-Newsletter/Insight/NTS-Insight-jun-1102.html>; Bickel, J. E., and S. Agrawal,. "Reexamining the Economics of Aerosol Geoengineering." Climatic Change (2011)l; Humphreys, D. "Smoke and Mirrors: Some Reflections on the Science and Politics of Geoengineering." The Journal of Environment & Development (2011), doi:10.1177/1070496511405302; Gardiner, Stephen M. "Some Early Ethics of Geoengineering the Climate: A Commentary on the Values of the Royal Society Report." Environmental Values 20 (2011): 163-188, doi:10.3197/096327111X12997574391689; Grasso, M. "The Ethics of Climate Change: With a Little Help from Moral Cognitive Neuroscience." CISEPS Research Paper 7 (2011).

neering.[51] [52]. However, despite the evident advantage of such a holistic approach, it is important to understand that the basic research on geoengineering is still in the germinal stage, with various potential methods being proposed and investigated, and that this process has not yet advanced to the phase that would allow the screening of industrial methods or even representative demonstration experiments.

Methods intended to modify large-scale environment systems and to exert some control over weather and the climate have been proposed since the second world war. These include increasing temperatures in high latitudes, increase precipitation levels, decreasing sea ice levels, creating irrigation opportunities, and counteracting global warming.[53]

Most of the scholarly literature on geoengineering reports from an Earth-scientific or economic point of view. This paper therefore intends to complement and enlarge this discussion by providing an assessment of recent findings on geoengineering from the perspective of potential contributions from space, aiming at the same time to generate more interest on the topic from within the space research community.

Climate change is a global phenomenon with global as well as regional and local effects. Space activities by their very physical nature are global activities. Traditionally, data collected from space has been fundamental in measuring climate change effects in the first place, and in understanding its parameters and interactions. Some climate engineering concepts are entirely space based, taking advantage of the unique properties of space.[54] The space community has however not yet embraced the potential needs to be addressed via space activities for different climate engineering concepts. This paper therefore intends to address this by providing a first iteration of space aspects for different climate engineering concepts.

Section 3.2 provides a summary overview of the different basic physical mechanisms proposed for influencing the Earth's climate. Section 3.3 contains a list of current geoengineering proposals and assesses for each of these potential contributions from space.

3.2 Basic Physics of Climate Engineering

Climate engineering concepts can be put into two broad categories: (1) those approaches trying to reduce the CO_2 content in the atmosphere by actively removing it, and thus increasing the level of outgoing, long-wave radiation leading to overall cooling; and (2) those attempting to directly influence the solar radiation balance of the Earth system. This second approach includes compensating the reduced outgoing, long-wave radiation due to higher levels of greenhouse gases by either increasing the amount of generally short-wave radiation that is reflected back into space or by directly reducing the total amount of sunlight reaching the Earth atmosphere.

The first category is generally viewed as ‘preferable’ since it attempts to restore pre-industrial atmospheric conditions by addressing the cause i.e. the high concentrations of greenhouse gases in the atmosphere. This method therefore seems more “natural”, but reducing greenhouse gas levels is of course subject to the same time scales as increasing them, thus the effects will have delays of decades. When considering time scales, effort and resource levels as parameters, the second approach, influencing directly the solar radiation balance of the Earth to accommodate and compensate for higher concentrations of greenhouse gases, might appear more favourable. The moral dilemma of climate change and the share of the burden of climate change efforts could thus be complemented by the moral dilemma of a choice between a ‘morally superior’ but more difficult and long-term approach in the form of active greenhouse gas extractions, and the more hazardous but potentially faster and cheaper approaches of actively influencing the radiation balance.

The following sections will briefly describe these two approaches, which will then lead to the engineering proposals listed in section 3.3.

[51] Gore, Al. "Moving Beyond Kyoto." (2007). <http://www.nytimes.com/2007/07/01/opinion/01gore.html?pagewanted=print>.

[52] Hansen, James. "Obama’s Second Chance on the Predominant Moral Issue of This Century." Dr. James Hansen: Obama’s Second Chance on the Predominant Moral Issue of This Century (2010). <http://www.huffingtonpost.com/dr-james-hansen/obamas-second-chance-on-c_b_525567.html?>.

[53] an overview is provided by Schneider, S. H. "Geoengineering: Could We or Should We Make It Work?" Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 366 (2008): 3843-3862, doi:10.1098/rsta.2008.0145.

[54] see e.g. Angel, R. "Feasibility of Cooling the Earth with a Cloud of Small Spacecraft Near the Inner Lagrange Point (L1)." Proceedings of the National Academy of Sciences 103 (2006): 17184-17189, doi:10.1073/pnas.0608163103; Or Meulenberg, A., and P. S. Karthik Balaji. "The LEO Archipelago: A System of Earth-rings for Communications, Mass-transport to Space, Solar Power, and Control of Global Warming." Acta Astronautica (2011); As well as Kosugi, T. "Role of Sunshades in Space as a Climate Control Option" Acta Astronautica 67 (2010): 241-253.

3.2.1 Increasing the Level of Outgoing, Long-Wave Radiation Emitted into Space

Concept

Earth surfaces emit about 396 W/m^2 in the form of thermal radiation, of which only a small portion, 40 W/m^2 is emitted directly into space. The remaining 356 W/m^2 are absorbed by greenhouse gases in the atmosphere, of which 199 W/m^2 are then further emitted into space. A further 97 W/m^2 are transferred by evapotranspiration and sensible heat from the Earth surface to the atmosphere.[55] Changes in the levels of greenhouse gases in the atmosphere directly influence the percentage of energy transmitted via thermal radiation through the atmosphere into space (currently 10%). Some of the geoengineering approaches aim to increase the level of outgoing, long-wave radiation re-emitted into space by reducing the level of greenhouse gases in the atmosphere. These include all types of methods to either reduce the source or increase the sinks of greenhouse gases, primarily CO_2.

In 2009, the UK Royal Society subdivided these into the following list of methods:

- Land use management to protect or enhance land carbon sinks;
- The use of biomass for carbon sequestration as well as a carbon neutral energy source;
- Enhancement of natural weathering processes to remove CO_2 from the atmosphere;
- Direct engineered capture of CO_2 from ambient air;
- The enhancement of oceanic uptake of CO_2, for example by fertilisation of the oceans with naturally scarce nutrients, or by increasing upwelling processes.

3.2.2 Increasing the Level of Short-Wave Solar Radiation Reflected into Space

Concept

On average, incoming solar radiation is 341 W/m^2, of which 79 W/m^2 are directly reflected by clouds and an additional 23 W/m^2 are reflected back by the Earth surface cover (essentially snow and ice). The remaining 239 W/m^2 are absorbed either by the earth surface (161 W/m^2) or by the atmosphere (78 W/m^2).

Reducing the average incoming solar radiation of 341 W/m^2 would therefore have an immediate effect on the total amount of energy absorbed by the earth surface and atmosphere, representing 70% of the incoming energy. Thus assuming no changes in the spectral distribution of incoming radiation, every incoming Watt reduced would directly and almost immediately reduce the energy absorbed by 0.7 Watts. This is the basis of concepts placing e.g. sunshades into space between the Earth and the Sun.

Changing the 30:70 ratio of reflected to absorbed energy has a similar immediate and strong effect. This is the basis of concepts aimed at increasing the earth albedo by injecting reflecting aerosols into the atmosphere or increasing the surface albedo.

In its 2009 report, the UK Royal Society included under this category the following specific actions:

- Increasing the surface reflectivity of the planet, by brightening human structures (e.g. by painting them white), planting of crops with a high reflectivity, or covering deserts with reflective material;
- Enhancement of marine cloud reflectivity;
- Mimicking the effects of volcanic eruptions by injecting sulphate aerosols into the lower stratosphere;
- Placing shields or deflectors in space to reduce the amount of solar energy reaching the Earth.

3.2.3 Remaining Climate Change

Solar radiation and greenhouse gas forcing operate in different ways. Because of the different nature of the forcing, solar radiation management methods are unlikely to exactly counteract global warming on global to local scales. Studies on the climate impact of solar radiation management techniques, suggest that regional climate change (compared with the preindustrial climate) remains after applying such methods. However, climate simulations also show that the remaining (local) climate changes after applying solar radiation management, should be relatively small compared with the cases in which no geoengineering is applied.[56]

[55] These numbers are global averages which need to be further decomposed (e.g. land, oceans etc); for the exact energy balance figures, we refer to Trenberth, K. E., J.T. Fasullo, and J. Kiehl. "Earth's Global Energy Budget." Bulletin of the American Meteorological Society 90 (2009): 311-323.

[56] Rasch, Philip J., and others,. "An Overview of Geoengineering of Climate Using Stratospheric Sulphate Aerosols." Phil. Trans. R. Soc. A. 366 (2008): 4007-4037, doi:10.1098/rsta.2008.0131.

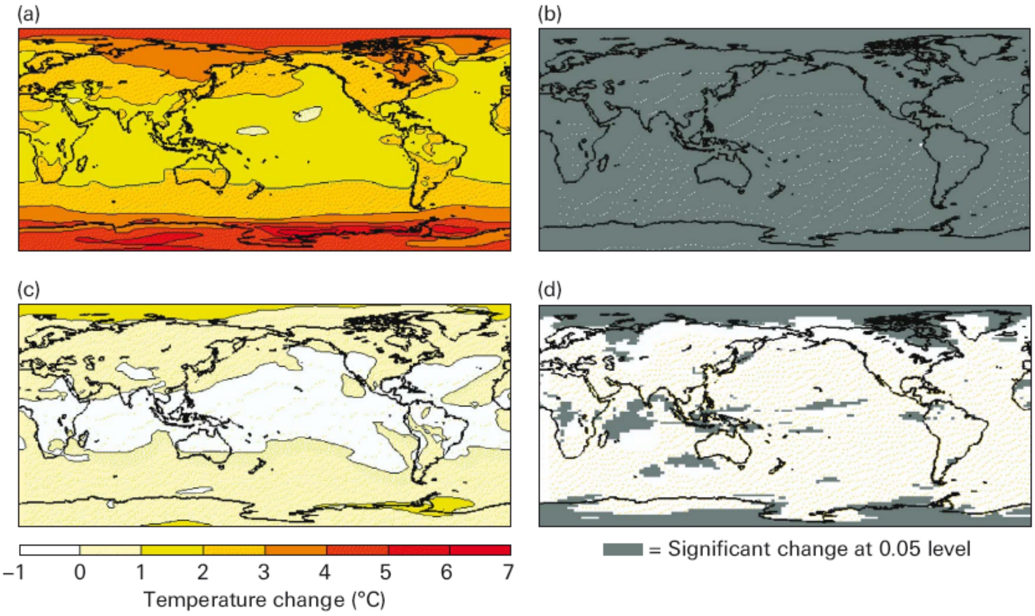

Figure 3.2: Annual mean temperature changes as calculated in GCM studies by Caldeira & Wood (2008) and reproduced by the Royal Society. [57] [58] The model (the National Center for Atmospheric Research Community Atmosphere Model) has been run with 2 times the preindustrial CO_2 concentration and with 2 times the pre-industrial CO_2 combined with a reduction in global mean insolation of 1.84%. Figures (a) & (c) show temperature changes relative to the 1 times CO_2 case. Figures (b) & (d) show areas with significant temperature changes. These figures suggest that climate engineering might be able to reduce temperature changes in most of the world. [59]

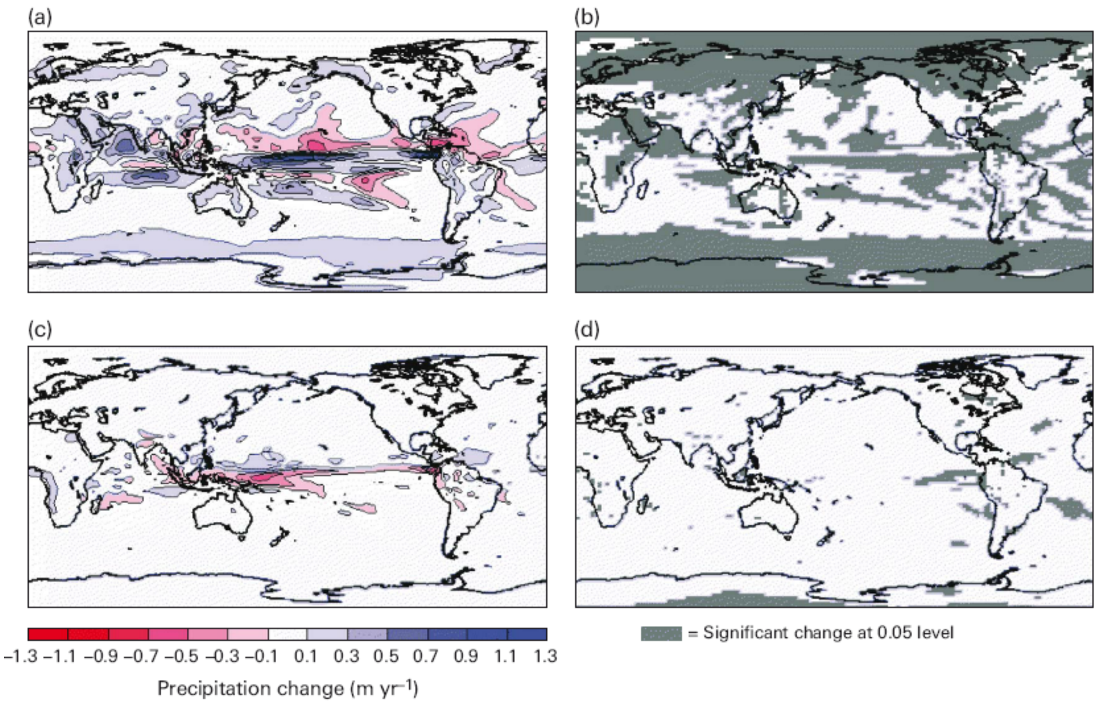

Figure 3.3: Annual mean precipitation changes as calculated in GCM studies by Caldeira & Wood (2008) and reproduced by the Royal Society. [60] [61] (a) & (b) show the result of a run with 2 times CO_2 and (c) & (d) are from an idealised climate engineering experiment with 2 times CO_2 and a global mean insolation of 1.84%. Figures (a) & (c) show precipitation changes from the 1 times CO_2 cases; and (b) & (d) show where the precipitation change is statistically significant at the 0.05 level. The geoengineering simulation indicates that climate engineering might be able to diminish precipitation changes the world.

[57] Caldeira, K., and L. Wood. "Global and Arctic Climate Engineering: Numerical Model Studies." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 366 (2008): 4039-4056, doi:10.1098/rsta.2008.0132.
[58] Shepherd, John, and others. Geoengineering the Climate: Science, Governance and Uncertainty. The Royal Society (2009).
[59] Caldeira, K., and L. Wood. "Global and Arctic Climate Engineering: Numerical Model Studies." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 366 (2008): 4039-4056, doi:10.1098/rsta.2008.0132.
[60] Ibid.
[61] Shepherd, John, and others. "Geoengineering the Climate: Science, Governance and Uncertainty." The Royal Society (2009).

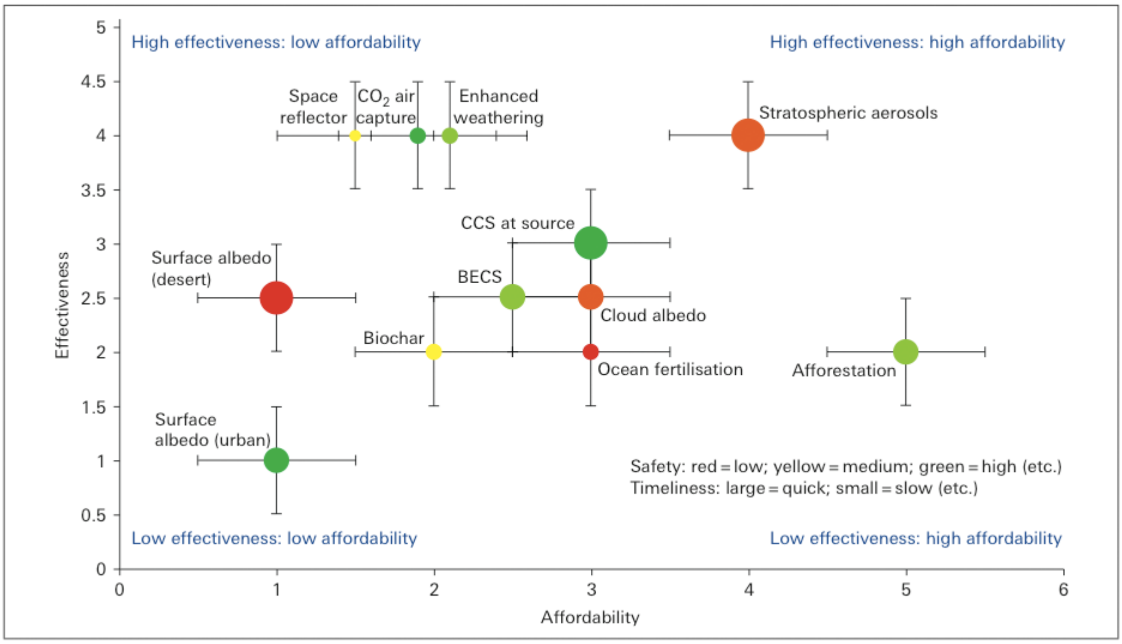

Figure 3.4: Preliminary overall evaluation of the geoengineering techniques.[62]
The numerical ratings are indicated on a scale from ‘very good’ (5) to ‘very poor’ (1).

3.2.4 Costs, Effectiveness and Safety

Uncertainties remain in the estimation of the costs of geoengineering. The costs of geoengineering can best be compared with mitigation, i.e. the costs of reducing CO_2 emissions in order to obtain an equivalent cooling effect and eventually the cost of adapting to a changed climate.[63]

The total costs of solar radiation management methods include costs for technical development, installation and maintenance. The total costs of cloud seeding and stratospheric aerosol injection are estimated to be small relative to mitigation or other climate control options.[64] Space based sunshades appear as one of the most expensive solar radiation management methods, depending strongly on critical parameters such as the continuation of the decline in the cost of access to space.[65] Estimated costs, effectiveness and safety of different geoengineering methods were summarised and compared in the report by the Royal Society (Figure 3.4).

As with all cost estimates based on both highly uncertain market and implementation conditions and immature scientific and technical data, these cost estimates need to be taken with much caution and usually higher than reported error margins. An interesting perspective on this is given by two recent publications related to the economic viability of aerosol-based geoengineering options. Using exactly the same models but just framing the question differently, Goes *et al.* and Bickel *et al* come to exactly opposite conclusions.[66] [67]

One of the potential moral dilemmas caused by these values is that many of them seem at first sight substantially “cheaper” than addressing the root causes of climate change and thus might even be at the reach of individual states and wealthy individuals.

3.2.5Testing Geoengineering

One common technical characteristic of all different geoengineering proposals is the need to verify the method by small scale, ideally reversible and relatively cheap and fast testing of the method, its effectiveness and the validity of the underlying simulation models.

Based on its inherent global reach, space-based verification methods will very likely be central to such a process, ideally made fully independently from the also likely space-

[62] adapted from Shepherd, John, and others. "Geoengineering the Climate: Science, Governance and Uncertainty." The Royal Society (2009).
[63] Keith, D. W. "Geoengineering the Climate: History and Prospect 1."Annual Review of Energy and the Environment 25 (2000): 245-284.
[64] Ibid.
[65] see e.g. Kosugi, T. "Role of Sunshades in Space as a Climate Control Option" Acta Astronautica 67 (2010): 241-253.
[66] see Goes, M., N. Tuana, and K. Keller. "The Economics (or Lack Thereof) of Aerosol Geoengineering." Climate Change (2011).
[67] see Bickel, J. E., and S. Agrawal,. "Reexamining the Economics of Aerosol Geoengineering." Climatic Change (2011)

based data acquisition systems that might be involved in control systems.

3.3 Different Climate Engineering Proposals and their Respective Contributions from Space

In this section different technical proposals for climate engineering are reviewed with the focus on the potential contribution from space that each of these offers. For that purpose a short description of the concept is provided, referring to respective publications for more in-depth information.

3.3.1 Solar Shields

Concept Description

Solar shields belong to the second of the above outlined geoengineering categories. The basic principle is based on reducing the total amount of sunlight reaching the Earth's atmosphere and surfaces. Screens, either a few big ones or many small ones, are placed in space to reflect or deflect solar light at an angle so that it will not reach the Earth's atmosphere.[68] Compared to other geoengineering approaches, an advantage of this method is that the composition of the atmosphere and ocean would not be altered and only one single parameter, the flux of solar radiation, is modified, which promises to make effects easier to model and thus better to predict.

The present status of sunshade research is in the germinal stage, with various potential methods being proposed and investigated, and has not yet converged towards a practical and most favourable method, nor have there yet been any attempts to demonstrate the method. On the other hand, the principle is fairly simple and scholarly work has not yet identified principle engineering or scientific showstoppers to their implementation.

Main Issues

The two main possibilities for the location of the sunshades are either in orbit around Earth or at the Lagrangian L1 point between the sun and the Earth. Angel assessed the approach of placing the shields in the near Earth-Sun inner Lagrange point (L1) in an orbit with the same 1-year period as the Earth.[69] Such shades in L1 could have relatively long lifetimes and the option to control the percentage of blocked or reflected sunlight.[70] The stability of the orbit was mentioned as a major technical hurdle. Possible solutions include the use a cloud of spacecraft holding their orbits by active station-keeping and to use solar radiation pressure as stabilizing force.[71] Baoyin and McInnes demonstrated that constant acceleration from a solar sail could be used to generate artificial libration points in the earth-sun three-body problem.[72]

For their production on Earth, the overall mass of the designed solar shields should be as small as possible. The excessive cost of launching the required mass is reported as one of the most important barriers to implementing solar shields. The development of new light materials and investigation of the most optimal shape and design of the sunshades would be necessary. McInnes concludes that "the shield mass can be minimized if the shield is positioned at an optimum location along the Sun-Earth line, sunward of the classical L1 Lagrange point. The location of the solar shield can be optimized since the solar radiation pressure force exerted on the shield will modify the location of the classical L1 Lagrange point."[73] Angel argues that "sunshades could be built with lower mass if its reflectivity is reduced by applying coatings that absorb light energy on the sunward side and reemit it as heat mostly on the earthward side. The corresponding minimum mass at a distance of 2.5 Gm would be 80 million tonnes".[74]

Early proposed using transparent material to deflect the sunlight, rather than to absorb it.[75] This would minimize the shifting due to radiation pressure. Three advances aimed at practical implementation were proposed by Early:

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[68] see e.g. Kosugi, T. "Role of Sunshades in Space as a Climate Control Option" Acta Astronautica 67 (2010): 241-253.

[69] Angel, R. "Feasibility of Cooling the Earth with a Cloud of Small Spacecraft Near the Inner Lagrange Point (L1)." Proceedings of the National Academy of Sciences 103 (2006): 17184-17189, doi:10.1073/pnas.0608163103

[70] Ibid.

[71] Ibid.

[72] Biggs, James D., and Colin R. McInnes. "Passive Orbit Control for Space-Based Geo-Enginering." Journal of Guidance, Control, and Dynamics 33 (2010); Baoyin, Hexi, and Colin McInnes. "Solar Sail Ortits at Artificial Sun-Eath Libration Points." Journal of Guidance, Control, and Dynamics 28 (2005).

[73] McInnes, C. R. "Minimum Mass Solar Shield for Terrestrial Climate Control." Jbis 55 (2002): 307-311.

[74] Angel, R. "Feasibility of Cooling the Earth with a Cloud of Small Spacecraft Near the Inner Lagrange Point (L1)." Proceedings of the National Academy of Sciences 103 (2006): 17184-17189, doi:10.1073/pnas.0608163103

[75] Early, J. T. "Space-based Solar Shield to Offset Greenhouse Effect." Journal of the British Interplanetary Society 42 (1989): 567-569.

1. A very thin refractive screen with low reflectivity, leading to a total sunshade mass of 22 Tg.
2. A concept aimed at reducing transportation cost to 50 USD/kg by using electromagnetic acceleration to escape Earth's gravity, followed by ion propulsion.
3. The implementation of the sunshade as a cloud of many spacecraft, autonomously stabilized by modulating solar radiation pressure. These meter-sized flyers would be assembled completely before launch, avoiding the need for construction or unfolding in space. They would have a mass of 1g each, be launched in stacks of 800,000, and remain for a projected lifetime of 50 years within a 100,000 km long cloud.

In 1989, Early postulated that given that the concept builds on existing technologies, it would seem feasible to be developed and deployed within 25 years at a cost of a few trillion dollars.[76] Although many proposals and theoretical studies by different scientists are pushing the boundaries of what is possible, the mass and costs involved are still largely considered as major hurdles.

Estimated Costs, Effectiveness and Safety

Kosugi calculated that the total climate control cost is reducible by 240 billion USD compared to the case in which sunshades are unavailable.[77] This is the case if the mass of the sunshade stock required to offset the increase in radiative forcing due to a doubling of the atmospheric CO_2 concentration is lower than 100 Tg/2xCO_2, assuming a continuous decline in the cost of placing (space launching) sunshades from 6000 to 1000 USD/kg over a half-century.[78]

3.3.2 Aerosols

Concept Description

The use of aerosols belongs to the second of the geoengineering categories outlined in section 3.2. The basic principle is based on increasing the total amount of sunlight reflected in the atmosphere by changing its properties slightly and thus reducing the amount of sunlight and energy reaching Earth's lower atmosphere and surfaces. Compared with other geoengineering approaches, an advantage of this method seems to be that it does not seem to require substantial technical advances for its feasibility; it relies on a mechanism that is already working in nature (e.g. volcanic eruptions), and that in principle it could be finely controlled concerning its geographic location and local intensity. Such a concept can additionally be tested on a relatively small scale.

Aerosols could be injected into the upper atmosphere so as to scatter more of the incident sunlight (naturally on average 79 W/m^2 reflected by clouds and the atmosphere) and thus produce a cooling. Most studies on engineered aerosols have focused on sulphate aerosols, which hav a natural equivalent in the form of volcanic eruptions.[79] Keith (2009) examined the possibility of nanoparticles.[80]

Studies suggest that sulphate aerosols can counteract the globally averaged temperature increase associated with increasing greenhouse gases, and reduce changes to some other components of the Earth system.[81] The relative maturity of this approach is also demonstrated by the higher interest in understanding its functioning by comparing different models.[82] It is likely that some regional climate change (compared with the preindustrial climate) remains after applying this method, with some regions experiencing significant changes in temperature or precipitation.[83] Deployment of 3 to 5 Tg a^{-1} of sulphur would be needed to mitigate a doubling of CO_2. This amount is not incompatible with a major reduction in the current atmospheric sulphur pollution of 55 Tg a^{-1} that goes mostly into the troposphere.

Individual volcanic eruptions, such as the 1982 eruption of El Chichon, which is estimated to have released at total 10 Tg of SO_2 (more than 5 Tg in one day), may increase the stratospheric SO_2 mass by over an order

[76] Ibid.
[77] Kosugi, Takanobu. "Role of Sunshades in Space as a Climate Control Option." Acta Astronautica 67 (2010): 241-253.
[78] Ibid.
[79] see e.g. Rasch, Philip J., and others,. "An Overview of Geoengineering of Climate Using Stratospheric Sulphate Aerosols." Phil. Trans. R. Soc. A. 366 (2008): 4007-4037, doi:10.1098/rsta.2008.0131.
[80] see Keith, D. W. "Photophoretic Levitation of Engineered Aerosols for Geoengineering." Proceedings of the National Academy of Sciences 107 (2010): 16428-16431, doi:10.1073/pnas.1009519107.
[81] Rasch, Philip J., and others,. "An Overview of Geoengineering of Climate Using Stratospheric Sulphate Aerosols." Phil. Trans. R. Soc. A. 366 (2008): 4007-4037, doi:10.1098/rsta.2008.0131.
[82] see e.g. the recent interesting intercomparison project described in Kravitz, Ben, and others. "The Geoengineering Model Intercomparison Project (GeoMIP)." Atmospheric Science Letters (2011), n/a-n/a, doi:10.1002/asl.316.
[83] Robock, A., L. Oman, and G.L. Stenchikov. "Regional Climate Responses to Geoengineering with Tropical and Arctic SO2 Injections." J. Geophys. Res 113 (2008): D16101.

of magnitude.[84] The eruption of El Chichon in 1982 is estimated to have emitted a cumulative total of 7.5 Tg. The total sulphur release by the 1991 eruption of the Pinatubo volcano, calculated in the form of SO_2, is estimated between 18 ± 4 Tg 19 ± 4 Tg.[85]

Pyle et al have estimated that the SO_2 flux from explosive volcanic eruptions to the stratosphere is 1 Tg a^{-1}. Historic records derived from residual sulphate peaks in the Greenland ice core suggest that the minimum flux of volcanic sulphur to the stratosphere during the Holocene has varied between 0.5 and 1 Tg SO_2 a^{-1}. The sulphate concentration of the ice cores furthermore places an upper limit on the sulphur flux into the stratosphere of 1.8 Tg a^{-1}.[86]

Main Issues

The comprehensive review of Rasch et al in 2008 concludes that based on best evidence, there are likely to be remaining regional climate changes after sulphur-based geoengineering. Potentially significant side-effects include changes in the natural sulphur cycle in the atmosphere, changes in the ozone levels, with likely depletion of these due to the chemical reactions of sulphur in the atmosphere, and implications related to the change in the frequencies reaching Earth since sulphur would alter the natural frequency spectrum.[87]

Furthermore, technically, there are still a number of open questions related to the delivery of sulphur species to the stratosphere in a way that will produce particles of the right size.

Potential Contributions from Space

This approach relies on a method to continuously inject SO_2 into the lower stratosphere. Furthermore, it will likely require some control on the rate as well as the geographical location and altitude of injection. Different technical solutions are in principle available. Rockets could be an option for aerosol injection into higher atmospheric layers.

[84] Hofmann, D. J. "Increase in the Stratospheric Background Sulfuric Acid Aerosol Mass in the Past 10 Years." Science 248 (1990): 996-1000, doi:10.1126/science.248.4958.996.

[85] Guo, Song. "Re-evaluation of SO2 Release of the 15 June 1991 Pinatubo Eruption Using Ultraviolet and Infrared Satellite Sensors." Geochemistry Geophysics Geosystems 5 (2004), doi:10.1029/2003GC000654.

[86] Pyle, D. M., P.D. Beattie, and G.J.S. Bluth. "Sulphur Emissions to the Stratosphere from Explosive Volcanic Eruptions." Bulletin of Volcanology 57 (1996), 663-671.

[87] Rasch, Philip J., and others,. "An Overview of Geoengineering of Climate Using Stratospheric Sulphate Aerosols." Phil. Trans. R. Soc. A. 366 (2008): 4007-4037, doi:10.1098/rsta.2008.0131.

Space based sensors, including using lidars, could be used to efficiently measure the distribution of injected aerosols, their diffusion rate and patterns as well as their decay. If these are able to measure key parameters in real time, space-based sensors could furthermore be inserted directly into the control loop of the ejection mechanisms.

SO_2 measurements have been successfully performed from space since the early 1980s, when the 1982 eruption of El Chichon inspired a new technique for monitoring volcanic clouds using data from the Total Ozone Mapping Spectrometer (TOMS) instrument[88] on-board of the US Nimbus-7 satellite.[89] It enabled measurement of the sulphur dioxide mass in eruption plumes and tracking them globally as they were carried by winds, thus enabling the distinguishing of magmatic eruptions from phreatic ones.[90]

In 1998 Eisinger and Burrows demonstrated the use of the GOME instrument on-board of ESA's ERS-2 spacecraft, operational from 1995 to 2011, to measure total atmospheric SO_2 columns after volcanic eruptions.[91] The GOME spectrometer, a nadir- looking across-track scanning instrument, has been able to measure the content of a number of minor atmospheric trace constituents including sulphur dioxide with a typical footprint size of about 320 × 40 km^2. It measured the backscattered radiation from the earth-atmosphere system between 240 nm and 790 nm with a moderately high spectral resolution of about 0.2 nm to 0.4 nm.[92]

Recently it has been shown that satellite measurements of volcanic SO_2 emissions can also be used to provide information for aviation hazard mitigation purposes. These uses

[88] McPeters, R. D., and others. Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) Data Products User's Guide. NASA, Scientific and Technical Information Branch (1996).

[89] Krueger, A. J. "Sighting of El Chichon Sulfur Dioxide Clouds with the Nimbus 7 Total Ozone Mapping Spectrometer." Science 220 (1983): 1377.

[90] Krueger, Arlin, Nickolay Krotkov, and Simon Carn. "El Chichon: The Genesis of Volcanic Sulfur Dioxide Monitoring from Space." Journal of Volcanology and Geothermal Research 175 (2008): 408-414, doi:10.1016/j.jvolgeores.2008.02.026; Krueger, Arlin, and others. "TOMS Measurement of the Sulfur Dioxide Emitted During the 1985 Nevado Del Ruiz Eruptions." Journal of Volcanology and Geothermal Research 41 (1990): 7-15, doi:10.1016/0377-0273(90)90081-P; Krueger, A. J. "Sighting of El Chichon Sulfur Dioxide Clouds with the Nimbus 7 Total Ozone Mapping Spectrometer." Science 220 (1983): 1377.

[91] Eisinger, M., and J.P. Burrows. "Tropospheric Sulfur Dioxide Observed by the ERS-2 GOME Instrument." Geophysical Research Letters 25 (1998): 4177-4180.

[92] Thomas, W., and others. "Retrieval of Volcanic Sulfur Dioxide Emissions from GOME Backscatter Measurements." Journal of Atmospheric Chemistry 50 (2005): 295-320.

are potentially interesting also for geoengineering purposes since they tend to require fast revisiting times, regional precision and global range. Simon et al have surveyed such instruments, including the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite. Its high sensitivity to SO_2 permits long-range tracking of volcanic clouds in the upper troposphere and lower stratosphere and accurate mapping of their perimeters.[93] Aerosols and clouds are closely linked since e.g. aerosols control cloud properties. Some of the measurement techniques for aerosols and clouds use the same sensors and spacecraft.[94]

3.3.3 High Reflective Clouds

Concepts Description

The approach of increasing the reflectivity of clouds to influence the energy balance of Earth also belongs to the second of the geoengineering categories outlined in section 3.2. Similar to the use of aerosols, the basic principle is also to increase the total amount of sunlight reflected before reaching the Earth's surface. [95] Clouds are already responsible for reflecting part of the sunlight back to space. Low-level marine clouds contribute especially to this overall cooling, whereas higher, colder clouds have a warming effect due to their reflecting long wave heat radiation back to Earth. Increasing the cloud cover or cloud reflectivity of low-level marine clouds would reduce the amount of sunlight and energy reaching Earth's surface. Compared to other geoengineering approaches, it too enhances and takes advantage of a natural phenomenon.[96] In principle only wind and seawater are needed, and the cooling could be targeted at specific locations and during specific time periods (relying on the relatively small scale of the low-level clouds and the short lifetime of the particles in the clouds). It also offers the potential to be tested first at relatively small scale.

The concept has been proposed in the form of artificially created whitening clouds over parts of the ocean.[97] This could be achieved by seeding low-level maritime clouds with seawater particles, which would increase the cloud condensation nuclei concentration. Due to a higher concentration of condensation nuclei, the average size of the droplets inside a cloud decreases. In a larger reflective surface area, many small cloud micro-droplets reflect more light than a smaller quantity of larger droplets of the same total mass. As such this principle can be used to decrease the incoming solar radiation.[98] Rasch et al calculated that their proposed seeding strategy, consisting of automatic ships seeding clouds over the oceans, could restore global averages of temperature, precipitation and sea ice to present day values, but not simultaneously.[99]

Latham *et al.* and Rasch *et al.* calculated that increasing the reflectivity of clouds is in principle capable of producing short-wave negative forcing of up to about -4 W m^{-2}, which would be sufficient to balance the positive forcing associated with a doubling of present atmospheric CO_2 concentrations.[100]

Main Issues

There are a number of technological and scientific questions that have to be resolved

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[93] Carn, Simon A., and others. "Tracking Volcanic Sulfur Dioxide Clouds for Aviation Hazard Mitigation." Natural Hazards 51 (2008): 325-343, doi:10.1007/s11069-008-9228-4.

[94] For a summary discussion of these sensors readers are referred to the discussion on cloud measurements.

[95] An interesting comparison of these two options if made by Jones, Andy, Jim Haywood, and Olivier Boucher. "A Comparison of the Climate Impacts of Geoengineering by Stratospheric SO2 Injection and by Brightening of Marine Stratocumulus Cloud." Atmospheric Science Letters 12 (2011), 176-183, doi:10.1002/asl.291.

[96] Rossow, W. B., A. Henderson-Sellers, and S.K. Weinreich. "Cloud Feedback: A Stabilizing Effect for the Early Earth?" Science 217 (1982): 1245.

[97] Salter, S., G. Sortino and J. Latham. "Sea-going Hardware for the Cloud Albedo Method of Reversing Global Warming." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 366 (2008): 3989-4006, doi:10.1098/rsta.2008.0136; Rasch, Philip J., John Latham, and Chih-Chieh (Jack) Chen. "Geoengineering by Cloud Seeding: Influence on Sea Ice and Climate System'." Environmental Research Letters 4 (2009): 045112, doi:10.1088/1748-9326/4/4/045112; Jones, Andy, Jim Haywood, and Olivier Boucher. "A Comparison of the Climate Impacts of Geoengineering by Stratospheric SO2 Injection and by Brightening of Marine Stratocumulus Cloud." Atmospheric Science Letters (2010), n/a-n/a, doi:10.1002/asl.291.

[98] Latham, J., and others. "Global Temperature Stabilization via Controlled Albedo Enhancement of Low-level Maritime Clouds." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 366 (2008): 3969-3987, doi:10.1098/rsta.2008.0137; Royal Society (Great Britain). Geoengineering the Climate Science, Governance and Uncertainty. London: Royal Society, 2009..

[99] Salter, S., G. Sortino and J. Latham. "Sea-going Hardware for the Cloud Albedo Method of Reversing Global Warming." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 366 (2008): 3989-4006, doi:10.1098/rsta.2008.0136.

[100] Latham, J. and others. "Global Temperature Stabilization via Controlled Albedo Enhancement of Low-level Maritime Clouds." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 366 (2008): 3969-3987, doi:10.1098/rsta.2008.0137; Rasch, Philip J., John Latham, and Chih-Chieh (Jack) Chen. "Geoengineering by Cloud Seeding: Influence on Sea Ice and Climate System'." Environmental Research Letters 4 (2009): 045112, doi:10.1088/1748-9326/4/4/045112.

before it is clear whether significant negative forcing is achievable.[101]

The main issues for the successful implementation of this strategy are the creation of a supply of particles and the distribution of these particles. The particles need to be of the right diameter and quantity. Most studies on this technique consider the generation of fine particles of sea-salt derived from ocean water, delivered by either ocean-going vessels or aircrafts.[102]

Recently, Korhonen *et al.* presented the so far most detailed model of the efficacy of sea spray geoengineering, including the entire chain from the emissions through to the impact on cloud drop concentrations, taking into account the full aerosol microphysical processes.[103] It concludes that problems are involved in generating uniform cloud drop fields over large regions of the ocean due to the wind speed dependence of the spray emissions, atmospheric transport and particle loss via deposition and precipitation scavenging.[104]

Potential Contributions from Space

Passive imaging radiometers of multiple types have provided observations of global cloud and aerosol layer distributions since the first earth remote sensing instruments were launched into orbit. Such passive instruments however lack accuracy in the observations of height distribution and coverage. Active laser remote sensing of the atmosphere has the major advantage of a direct and unambiguous detection and height measurement of all scattering layers.[105] [106] In 2003, NASA launched the Geoscience Laser Altimeter System (GLAS), the first polar-orbiting satellite lidar instrument.[107]

In June 2006, NASA launched CALIPSO, the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations with the satellite-borne lidar CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) experiment.[108] An interesting capability comparison between active sensor cloud profiles provided by the CALIOP experiment on board the CALIPSO spacecraft with the passive sensor cloud products from MODIS on the Aqua platform is at Holz et al.[109]

CALIOP is able to provide global, 4-dimensional aerosol and cloud data. In 2013, the ESA ADM-Aeolus mission (Atmospheric Dynamics Mission) is going to be launched, with its Aeolus payload, including Aladin, the Atmospheric Laser Doppler-Lidar Instrument, a direct detection Lidar incorporating a fringe-imaging receiver (analysing aerosol and cloud backscatter) and a double-edge receiver (analysing molecular backscatter).[110]

Also in 2013, the 6th of ESA's Earth Explorer missions, called EarthCARE (Earth Clouds, Aerosols, and Radiation Explorer) conducted together with the Japan Aerospace Exploration Agency JAXA will be launched. EarthCARE will address the need for a better understanding of the interactions between cloud, radiative and aerosol processes by acquiring vertical profiles of clouds and aerosols, as well as the radiances at the top of

[101] Rasch, Philip J., John Latham, and Chih-Chieh (Jack) Chen. "Geoengineering by Cloud Seeding: Influence on Sea Ice and Climate System'." Environmental Research Letters 4 (2009): 045112, doi:10.1088/1748-9326/4/4/045112.

[102] see e.g. Latham, J., and others. "Global Temperature Stabilization via Controlled Albedo Enhancement of Low-level Maritime Clouds." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 366 (2008): 3969-3987, doi:10.1098/rsta.2008.0137; Salter, S., G. Sortino, and J. Latham. "Sea-going Hardware for the Cloud Albedo Method of Reversing Global Warming." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 366 (2008): 3989-4006, doi:10.1098/rsta.2008.0136.

[103] Korhonen, H., KS Carslaw, and S. Romakkaniemi. "Enhancement of Marine Cloud Albedo via Controlled Sea Spray Injections: a Global Model Study of the Influence of Emission Rates, Microphysics and Transport." Atmospheric Chemistry and Physics 10 (2010): 4133-4143.

[104] Korhonen, H., KS Carslaw, and S. Romakkaniemi. "Enhancement of Marine Cloud Albedo via Controlled Sea Spray Injections: a Global Model Study of the Influence of Emission Rates, Microphysics and Transport." Atmospheric Chemistry and Physics 10 (2010): 747.

[105] see e.g. Spinhirne, J. D., and others. "Cloud and Aerosol Measurements from GLAS: Overview and Initial Results." Geophys. Res. Lett 32 (2005).

[106] Kokhanovsky, A. A., S. Platnick, and M.D. King. "Remote Sensing of Terrestrial Clouds from Space Using Backscattering and Thermal Emission Techniques." The Remote Sensing of Tropospheric Composition from Space (2011) 231-257.

[107] launched as instrument on board the Ice, Cloud and land Elevation Satellite in January 2003; Spinhirne, J. D., and others. "Cloud and Aerosol Measurements from GLAS: Overview and Initial Results." Geophys. Res. Lett 32 (2005).; Zwally, H. "ICESat's Laser Measurements of Polar Ice, Atmosphere, Ocean, and Land." Journal of Geodynamics 34 (2002): 405-445, doi:10.1016/S0264-3707(02)00042-X.

[108] for an overview of the mission and the instrument, see e.g. Winker,D. M., and others. "Overview of the CALIPSO Mission and CALIOP Data Processing Algorithms." Journal of Atmospheric and Oceanic Technology 26 (2009): 2310-2323.

[109] Holz, R. E., and others. "Global Moderate Resolution Imaging Spectroradiometer (MODIS) Cloud Detection and Height Evaluation Using CALIOP." Journal of Geophysical Research 113 (2008), doi:10.1029/2008JD009837.

[110] "ESA - Living Planet Programme - ADM-Aeolus." "ESA - Living Planet Programme - ADM-Aeolus." (2011). <http://www.esa.int/esaLP/LPadmaeolus.html>.

Figure 3.5: artist representation of the ESA ADM-Aeolus mission to be launched in 2013, including the Aladin instrument. (image credit: ESA)

the atmosphere.[111] EarthCARE will have the ATLID atmospheric lidar on board, further improving the aerosol and cloud data set and our understanding of their influence and role in Earth's climate system.

While CALIOP is a two-wavelength backscatter lidar, which provides aerosol and cloud optical properties at 532 and 1064 nm, these next-generation space-borne lidar missions will operate high-spectral-resolution lidars at 355 nm. In order to relate the measurements at these different wavelengths, extensive calibration campaigns with ground-based multi-wavelength lidars are ongoing (e.g. EARLINET, European Aerosol Research Lidar Network)[112]. Even though the details would need to be looked at with greater care, this data and the combined observation capabilities of these and future space-born sensors, especially active lidar sensors, seem to provide a solid basis for inclusion into a monitoring system for cloud geoengineering validation experiments.

Space-based sensors would be well positioned to measure the immediate effect of these clouds on local atmospheric temperatures at the cloud formation locations. Furthermore, such low-level maritime clouds would likely have effects on the local wind patterns, thus having consequences on the height of waves and eventually on ocean currents and local ocean salinity and water oxygen levels, all of which might be measured from space, via e.g. multi-spectral and infrared sensors for radar distance measurements.

3.3.4 Reflective Mirrors

Concept Description

The reflectivity of the Earth's surface could be altered by albedo modification of desert

[111] for more information see e.g. "ESA - Living Planet Programme - EarthCARE - EarthCARE Satellite Contract Signed." "ESA - Living Planet Programme - EarthCARE - EarthCARE Satellite Contract Signed." (2011). <http://www.esa.int/esaLP/SEMMBQ1YUFF_LPearthcare_0.html>.

[112] see e.g. Giunta, A., and others. "Long-term Aerosol and Cloud Database from Correlative EARLINET-CALIPSO Observations.": 1241-1244. Presentation. 25th International Laser Radar Conference. St. Petersburg. 2010.

grassland, croplands, human settlements and urban areas.[113] [114] [115] [116]

Main Issues

Surface albedo modifications that cover small fractions of the Earth's surface, such as white roof methods in urban areas, need to produce large local albedo changes to produce a significant cooling of the local climate. However, methods that involve smaller changes over larger land areas may potentially be in conflict with other human land-use such as agriculture and forestry.[117] Especially for large scale and very regional forcing methods, such as increasing the reflectivity of desert, there is a risk of changing the atmospheric circulation and other side effects, such as counter-productive reduction in cloud cover and rainfall, could be possible.[118]

To investigate the effect of increased desert reflectivity, we performed an experiment with the Earth system model *LOch–Vecode-Ecbilt-CLio-agIsm Model* (LOVECLIM).[119] Figure 3.6 – Figure 3.9 below show maps of the changes in temperature and precipitation in a climate with 4 times the preindustrial CO_2 concentration with and without high reflective deserts, relative to the current climate. These results demonstrate that applying such a local large negative forcing locally induces relatively big changes in temperature and precipitation. It is noteworthy that the model predicts that increasing the reflectivity of the deserts has a substantial effect on the amount of precipitation in the rainforests (see Figure 3.9).

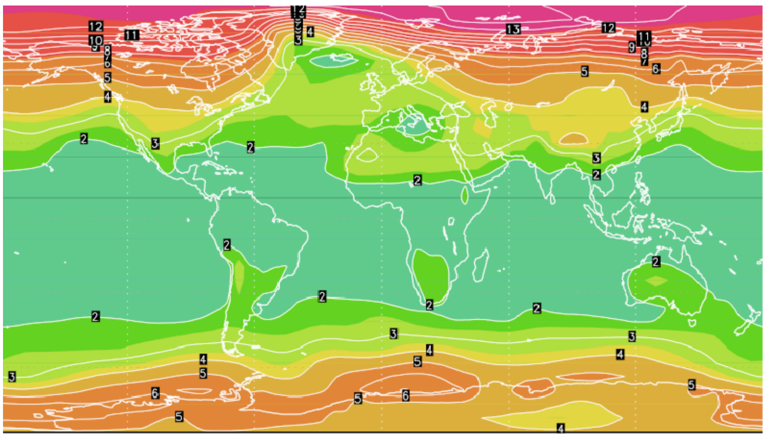

Figure 3.6: Calculated annual mean temperature changes of a 4 times CO_2 climate without highly reflective deserts.

[113] Hamwey, R. M. "Active Amplification of the Terrestrial Albedo to Mitigate Climate Change: An Exploratory Study." Mitigation and Adaptation Strategies for Global Change 12 (2007): 419-439.
[114] Ridgwell, A., and others. "Tackling Regional Climate Change By Leaf Albedo Bio-geoengineering." Current Biology 19 (2009): 146-150, doi:10.1016/j.cub.2008.12.025.
[115] Hamwey, R. M. "Active Amplification of the Terrestrial Albedo to Mitigate Climate Change: An Exploratory Study." Mitigation and Adaptation Strategies for Global Change 12 (2007): 419-439.
[116] Akbari, H., S. Menson, and A. Rosenfield. "Global Cooling: Increasing World-wideUrban Albedos to Offset CO2." Climatic Change 94 (2009): 275-286.
[117] Shepherd, John, and others. "Geoengineering the Climate: Science, Governance and Uncertainty." The Royal Society (2009).
[118] Charney, J. G. "Dynamics of Deserts and Droughts in theSahel." Quarterly Journal of the Royal Meteorological Society 428 (1975): 193–202.
[119] Driesschaert, E., and others: "Modeling the Influence of Greenland Ice Sheet Melting on the Atlantic Meridional Overturning Circulation During the Next Millennia." Geophys. Res. Lett. 34 (2007).

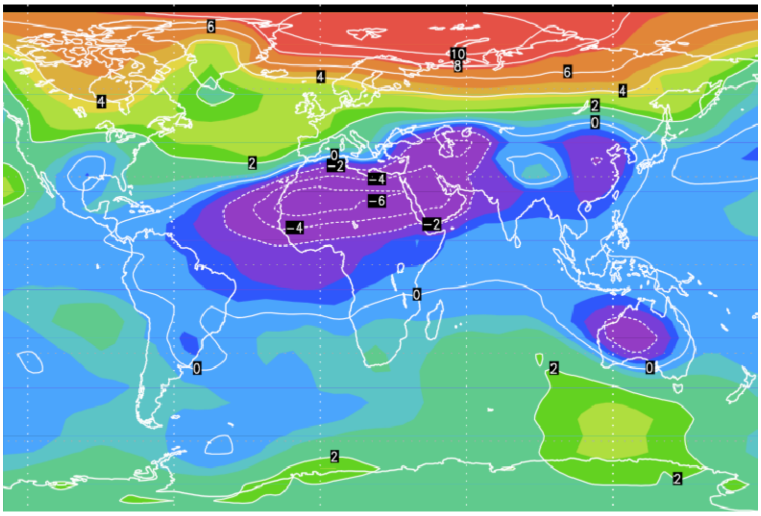

Figure 3.7: Calculated annual mean temperature changes of a 4 times CO_2 climate with highly reflective deserts.

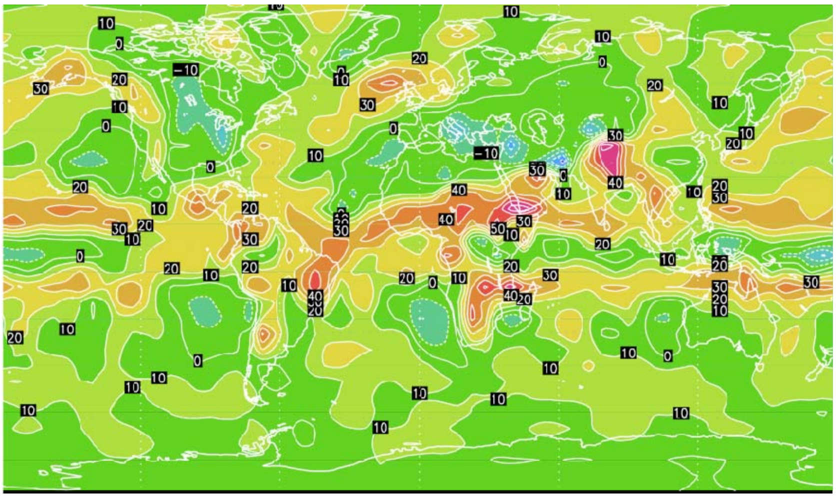

Figure 3.8: Calculated annual mean precipitation changes (in cm/ year) of a 4 times CO_2 climate without highly reflective deserts.

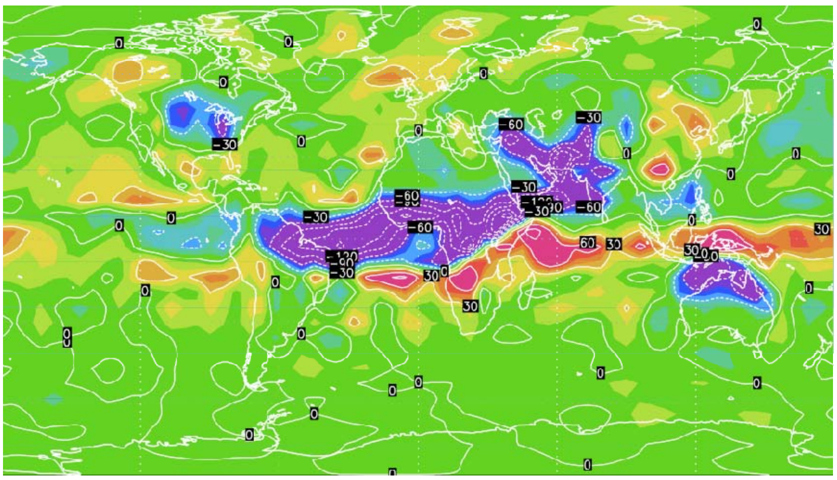

Figure 3.9: Calculated annual mean precipitation changes (in cm/year) of a 4 times CO_2 climate with highly reflective deserts.

Potential Contributions from Space

Earth observation satellites already measure the reflectivity of Earth surface regions.[120] As shown in the previous section, one of the potential impacts of large-scale land cover reflectivity changes might be changes in world-wide precipitation levels. Space instruments are already providing the main data for understanding and measuring precipitation. Given the large variations, such data needs to be collected at local scales over a global domain. Such a comprehensive description of the space and time variability of global precipitation can only be achieved from the vantage point of space.[121] Different observation techniques are currently employed to derive precipitation data, including observations of cloud tops with visible and infrared sensors from geostationary orbits (e.g. Geostationary Operational Environmental Satellites (GOES) spacecraft) can be used to deduce precipitation data, though these are not given on the vertical structure and microphysics of clouds). On the contrary, active radars at Ku, Ka and W band (~14, 35 and 95 GHz, respectively) can measure profiles of precipitating hydrometeor characteristics within clouds. Passive precipitation radiometers (~10–89 GHz) measure the integrated cloud water and ice paths and are used to estimate rain rate.

In 1997 NASA and JAXA launched a combined radar-radiometer system, the Tropical Rainfall Measuring Mission (TRMM), which enables deduction of the rainfall rates especially over the tropics.[122] In 2014, the next dedicated spacecraft, the Global Precipitation Measurement (GPM) Mission, is planned for launch. It is currently designed to provide integrated, uniformly calibrated precipitation measurements at every location around the globe every 2–4 h. While such strong changes in the precipitation levels as suggested by the model runs would probably not be taken as risk, spacecraft might be able to provide timely and detailed enough feedback data on rainfall especially in the tropics.

3.4 Conclusions

The present paper has provided an overview of different technical geoengineering options from the perspective of how space might be involved. These range from actual space-based geoengineering approaches to space applications providing timely data and being possibly part of the control system during both early test phases as well as deployed systems. Most of the paper naturally relies on interpreting and referring to various publications in the fields of geoengineering and different space applications, though some sections required relying on new simulations.

Given the combination of large number of options of using space with the increasing number of climate engineering proposals, the present paper only intends to trigger a wider discussion among the space community on the topic, potentially leading towards a more systematic approach to the uses of space for climate engineering.

[120] Arino, O., and others. "The Most Detailed Portrait of Earth." European Space Agency Bulletin 136 (2008): 25; Kimes, D. S., and P. J. Sellers. "Inferring Hemispherical Reflectance of the Earth's Surface for Global Energy Budgets from Remotely Sensed Nadir or Directional Radiance Values." Remote Sensing of Environment 18 (1985): 205-223.

[121] see e.g. Hou, A. Y., and others. "6 Global Precipitation Measurement." Precipitation: Advances in Measurement, Estimation, and Prediction. Ed. Silas Michaelides. Berlin-Heidelberg: Springer, 2008. And in general Michaelides, Silas, ed. Precipitation: Advances in Measurement, Estimation and Prediction. Berlin-Heidelberg: Springer, 2008.

[122] Kummerow, C., and others. "The Status of the Tropical Rainfall Measuring Mission (TRMM) After Two Years in Orbit." Journal of Applied Meteorology 39 (2000): 1965-1982.

	Geoengineering Concept	Space "Affinity"	Space Contributions
increasing the level of outgoing, long-wave radiation emitted into space	Land use management to protect or enhance land carbon sinks	low	Biomass level measurements from space
	The use of biomass for carbon sequestration as well as a carbon neutral energy source	low	limited
	Enhancement of natural weathering processes to remove CO_2 from the atmosphere	low	limited
	Direct engineered capture of CO_2 from ambient air	low	limited
	The enhancement of oceanic uptake of CO_2, for example by fertilisation of the oceans with naturally scarce nutrients, or by increasing upwelling processes	medium	Indirect measurements from space
increasing the level of reflected, short-wave radiation reflected into space	Increasing the surface reflectivity of the planet, by brightening human structures (e.g. by painting them white), planting of crops with a high reflectivity, or covering deserts with reflective material	medium	Space data providing reflectivity measurements as well as expected precipitation level changes
	Enhancement of marine cloud reflectivity	medium	Space data providing could data measurements; limited alternatives
	Mimicking the effects of volcanic eruptions by injecting sulphate aerosols into the lower stratosphere	low-medium	Aerosol measurements, space data and systems eventually part of active control loop, injection by rockets
	Placing shields or deflectors in space to reduce the amount of solar energy reaching the Earth	high	entirely space-based

Table 3.1

4. International Coordination in the Use of Remote Sensing Data

by Gunther Schreier[123]

Abstract

By definition earth observation from space spans the entire globe from pole to pole. Remote sensing data covers all terrains, all countries and therewith many environmental, ecological and political issues of regional and global interest. This paper focuses on two of these aspects: the use of earth observation data during natural disasters and the use of space borne data to manage the challenges of future sustainable energy supply, namely through solar energy. Using earth observation data for these challenges requires international coordination in the control of the satellite resources, the capturing of data and the sharing of the geo information. Mechanisms, specifically for disaster monitoring, such as the Charter on Space and Global Disasters, are depicted. Global coordination organisations such as GEO and international programs such as GMES are referred to.

4.1 Disaster Monitoring from Space

Natural disasters have happened as long as nature has existed. They have been a threat and a challenge to mankind from the very beginning. Natural disasters such as tsunamis in the aftermath of volcano eruptions and earthquakes gave possible rise to mythological and historic events wiping out entire civilisations, such as the Minoan culture in Crete (also evidencing that tsunamis are not limited to Pacific Ocean coasts). Disasters are believed to now have more effect on humans, first because of population pressure. Settlements are created in disaster prone areas. Living in earthquake or flood endangered areas is not good advice to begin with. Second, electronic global media spread the news about a disaster within minutes and hours. The tsunami reaching the Japanese coast in March 2011 was on TV screens basically in real time. Disasters are now reported from areas of the globe where in former times news would have taken days and weeks to reach Europe. A further topic of new interest in disasters is the monetary loss (thoroughly covered by global re-insurance companies such as the Munich Re, publishing yearly disaster statistics) and the economic impact (also seen in the Japanese events in March 2011).[124]

Space based earth observation is an additional tool for subjective analysis of the impact and aftermaths of regional and global disasters. Remote sensing from space has the advantage of potentially reaching all areas of the globe. In addition, new observation technologies and particularly increased geometrical resolution better than 1 metre, make “bird-like” views of disasters accessible everywhere on the globe. The operations of such earth observation satellites are no longer restricted only to the economic and military super-powers. European systems and those from emerging nations, create a large fleet of missions and sensors. The 2010 CEOS handbook lists 261 earth observation satellite missions in operations or planned.[125]

To some extent these data were used from the very beginning to monitor ecological and natural disasters mainly based on national and governmental programmes[126] An international perspective was introduced with the creation of the “Charter on Space and Major Disasters” (The Charter), in 1999 following the Unispace conference in Vienna with ESA and CNES as the founding members. As the official Charter Website states, the Charter “aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through Authorized Users. Each member agency has committed resources to support the provisions of the Charter and thus is helping to mitigate the effects of disasters on human life and property”.[127]

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[123] German Remote Sensing Data Centre

[124] Munich Re: annual statistics of natural disasters. <http://www.munichre.com/en/reinsurance/business/non-life/georisks/natcatservice/annual_statistics.aspx >.

[125] Committee on Earth Observation Satellites. The Earth Observation Handbook, 2010 update. Tables and details under: <http://database.eohandbook.com>.

[126] Nirupama, Ph.D., Slobodan P. Simonovic, Ph.D., P.Eng. “Role of Remote Sensing in Disaster Management.” ICLR Research Paper Series 21 (2002).

[127] <www.disasterscharter.org>.

Meanwhile 11 space agencies and satellite operators have joined the Charter (as of early 2011), with DLR becoming a full member in October 2010. As defined in the Declaration of the Charter, the purpose of membership is to supply earth observation data from the member missions to those authorized users who need such information during period of crisis, free of charge. Data from the German national remote sensing missions TerraSAR-X, TanDEM-X and RapidEye are the DLR contributions to the Charter. Satellite raw data is seldom useful for end users working in the field to manage support resources and humanitarian aid. Instead these users need analysed geo-information maps, showing the situation on Earth and delivering higher value information for decision making. DLR has therefore created the Center for Satellite Based Crisis Information (Zentrum für satellitenbasierte Kriseninformation, ZKI) as part of the DLR Earth Observation Center (EOC) in Oberpfaffenhofen, Germany. For several years, the ZKI has been involved in rapid disaster mapping activities in the framework of several national and international projects. Of importance is the time delay between the disaster event and the dissemination of the disaster maps to the users. Figure 4.1 depicts the workflow and actions that need to be performed, in the best case, within hours. Critical in the first place is the notification that a disaster has happened and that geo-information support by earth observation data is required.

Other than some satellite operators who monitor the news and geophysical events (e.g. earthquakes) in order to be prepared, the Charter has established a network of "authorized users" who can call the Charter on a 24/7 basis. Authorized users are mostly governmental entities in charge of disaster management. Apart from the countries of the Charter members, other countries have registered authorized users (35%). If not represented, other countries can ask an authorized user to activate the Charter on behalf of the affected country (32%), or international organisations such as the United Nations can contact the Charter (33%). The percentages in brackets denote the activations by this user type in the timeframe 2007–2009 as published on the Charter web page.

The 24/7 on-duty-operator forwards the call to an emergency-on-call-officer (ECO). The ECO identifies the validity of the request and notifies the Charter members to target their earth observation satellites and supply newly acquired data or data from their archives for reference purposes. The further Charter process is managed by the Charter project manager, appointed by the Charter executive secretariat.

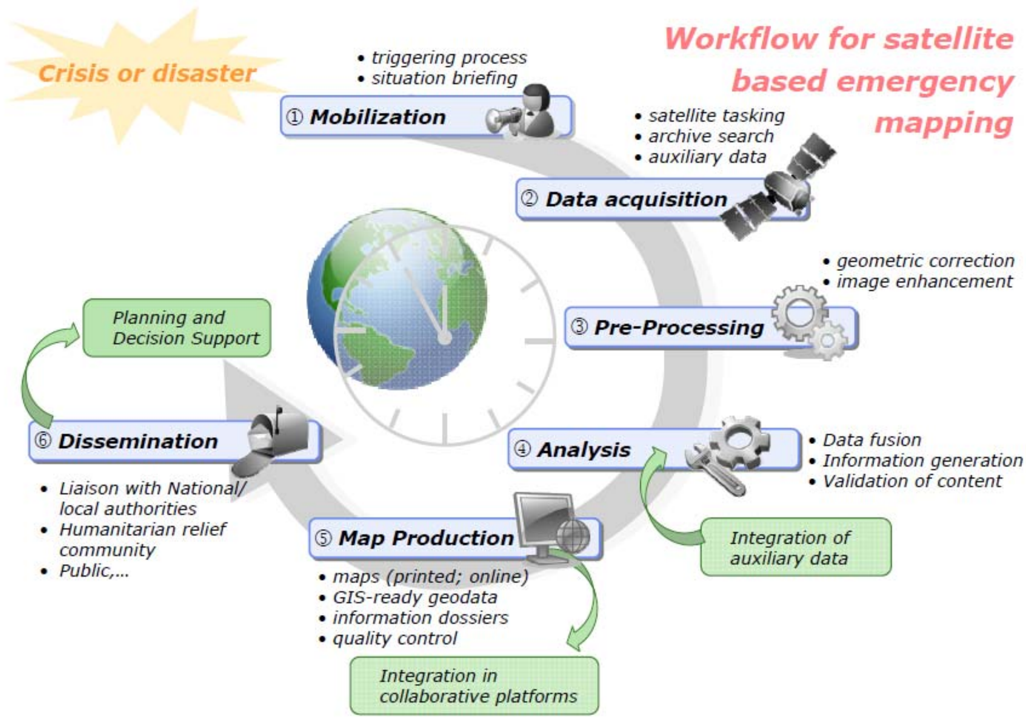

Figure 4.1: Workflow for satellite based emergency/disaster mapping

The project manager also coordinates the various value added entities, which are involved in turning the satellite data into situation maps. Data need to be pre-processed to radiometric and geometric standards (i.e. map projection) and need to be analysed according to the type of disaster. Here, the range of spectrum covered by earth observation sensors and its geometric resolution is critical for the usefulness of the data. Whilst high resolution optical data is good for general and detailed damage assessment, synthetic aperture radar (SAR) delivers imagery during cloud cover and even during the night and is very sensitive to map the extent of water bodies during a flood or following a tsunami.

The Charter was activated for the devastating "triple"-disasters in March 2011 in Japan: an 8.9 magnitude earthquake followed by a tsunami and the breakdown of a nuclear power plant in the aftermaths of these events. The Charter was activated on March 11, 2011 and all remote sensing mission operators targeted their satellites to the tsunami affected area in Japan (see figure 4.2).

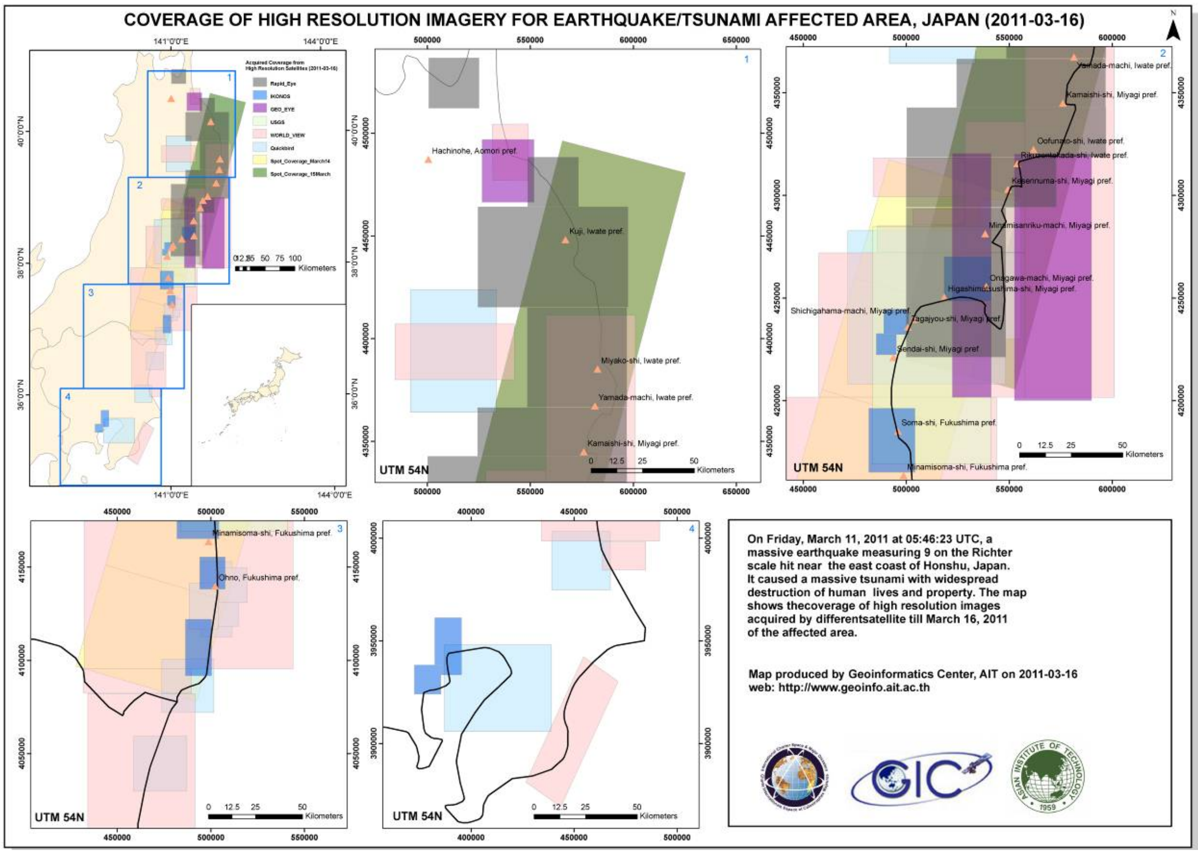

Figure 4.2: Coverage of high resolution imagery for earthquake/tsunami affected area, Japan, Source: AIT, Charter web page

The DLR ZKI was activated, coordinated by the Charter manager, the Asian Institute of Technology (AIT), Bangkok, Thailand, to generate assessment maps of the area affected by the tsunami. Full radar coverage based on TerraSAR-X was acquired and turned into overview and detailed analysis maps. Of primary importance to aid and support teams trying to reach the area was information on the status of major transportation infrastructure such as roads, harbours and airports. With the real time coverage of a news-channel helicopter of the tsunami reaching the Sendai airport, the authorities were eager to learn whether the airport and the surrounding streets could still be used for flying-in support teams. Very high resolution optical and high resolution radar data (figure 4.3) helped to clarify the situation.

The UN Principles Relating to Remote Sensing of the Earth from Space, adopted by the General assembly on 3 December 1986, already stated in Principle XI:

> » Remote sensing shall promote the protection of mankind from natural disasters. To this end, States participating in remote sensing activities that have identified processed data and analysed information in their possession that may be useful to States affected by natural disasters, or likely to be affected by impending natural disasters, shall transmit such data and information to States concerned as promptly as possible.[128]

[128] United Nations General Assembly. Principles Relating to Remote Sensing of the Earth from Space. UN Doc. A/RES/41/65 of 3 December 1986.

To this end, the Charter implements and properly applies this general principle. Since the origin of the principle in 1986, more and more commercial entities operating spacecraft and selling the data have started to appear. These are outsourced governmental operators, public-private-partnership schemes, or commercial entities with a governmental key-client. In fact, both missions that DLR is offering to the Charter, TerraSAR-X and RapidEye, are operated under one of these schemes.

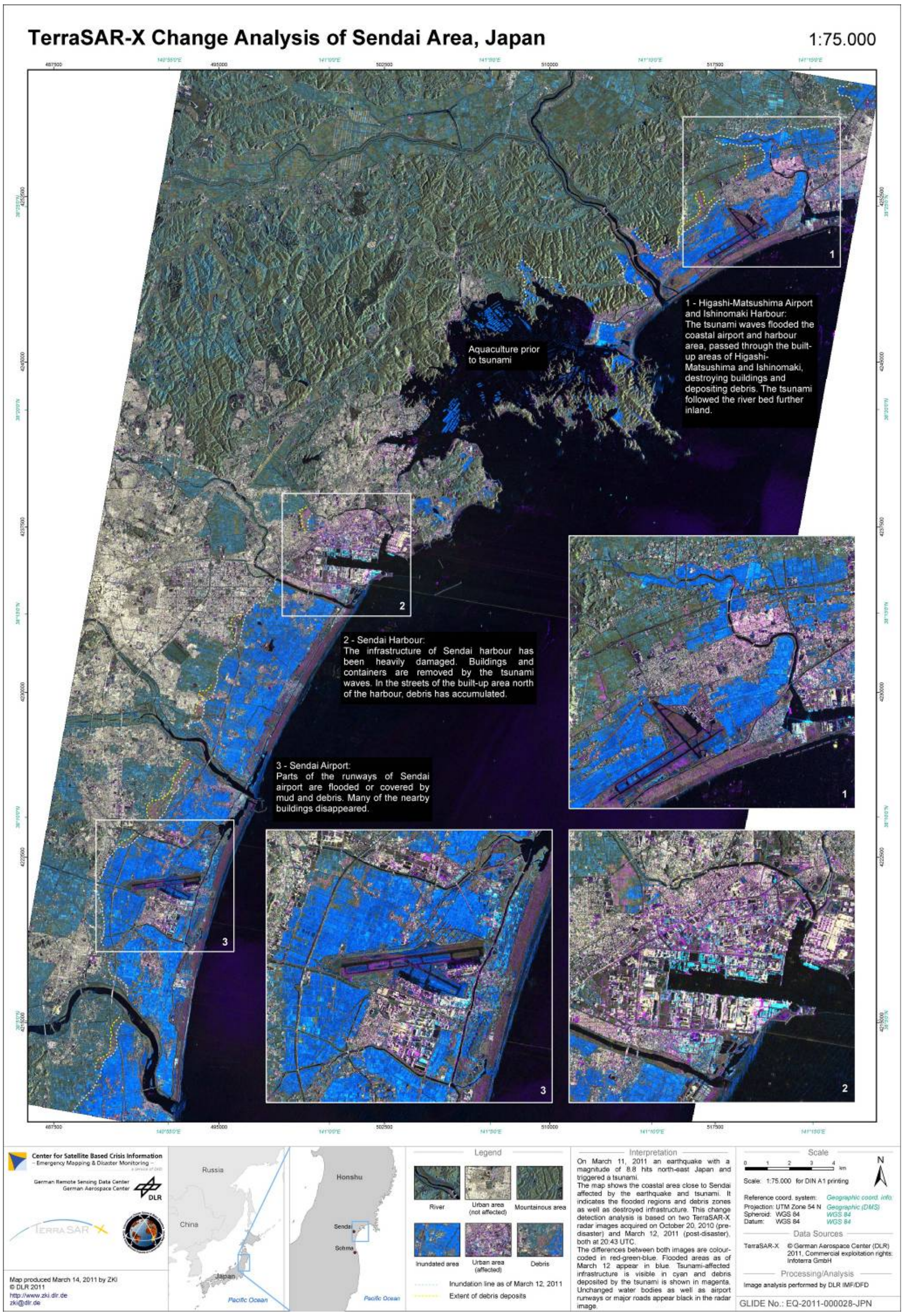

Figure 4.3: One of the maps generated by the ZKI after the Japan earthquake/tsunami in March 2011

This means, in practical terms, the challenge to harmonise the interest of commercial operators and re-sellers with the principles of the UN and the Charter. De facto, every Charter member has found its own way to manage this situation, up to and including full reimbursement of the commercial operator for the data denoted by the Charter member to the international community. This balance between the donation of free data for those in need and safeguarding of commercial interests is also an issue in the European GMES project, as discussed below.

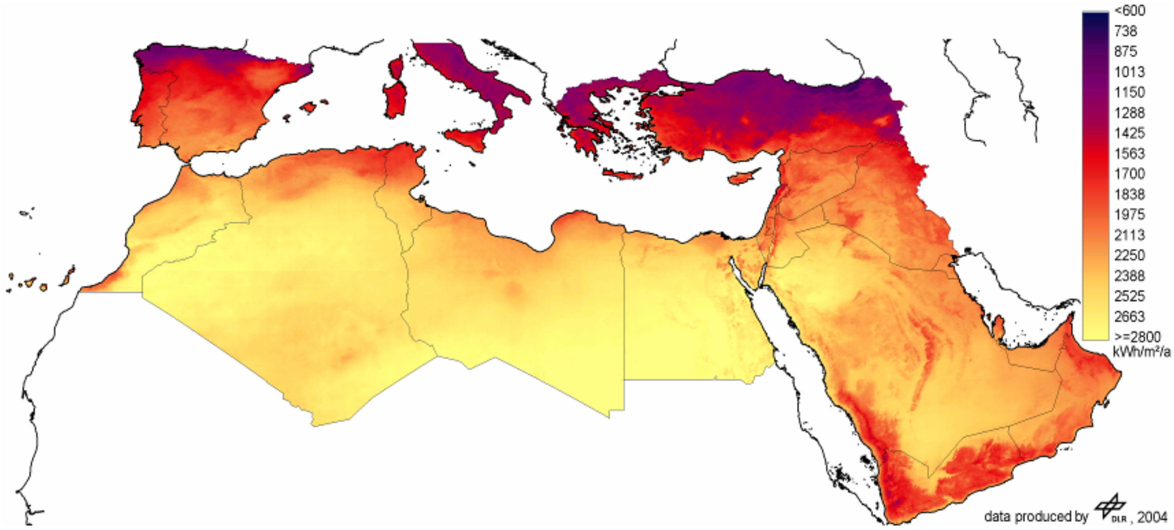

Figure 4.4: Yearly mean solar radiation in the Mediterranean basin

4.2 Atmosphere Monitoring and Solar Energy

The most operational application of remote sensing from space is satellite meteorology. The first operational meteorological satellite, the United States Vanguard-1, was launched in April 1960 and worked for 78 days, monitoring cloud cover from low earth orbit. Knowing and predicting the weather is also of importance for Europe. In 1986, EUMETSAT was founded by European states (not necessarily the same as the membership of the European Union). As of mid-2011, EUMETSAT operated 3 geostationary satellites and 2 polar orbiting monitoring spacecraft. Global cloud parameters are a standard measurement, covered by a multitude of geostationary weather satellites operated by various nations. With the improved understanding of atmospheric physics and chemistry, the constituents of the various layers of the atmosphere came into the focus of environmental science and global climate change research. An icon therefore is the stratospheric ozone. The depletion of the ozone layer over the Antarctic was first measured in – in initially believed erroneous – satellite data in the mid 1980's. Man-made (CFC) is amongst the chemicals causing ozone depletion. The international community reacted in the Montreal Protocol in 1987 (entering into force in 1989) which banned CFCs.[129]

Monitoring these trace gases from space and understanding their global dynamics is a major operational item in satellite remote sensing and global change research. In contrast to high resolution imaging satellite data, this information is believed to be of political importance but not of commercial value. Hence, national space agencies, meteorological and science organisations have come together to create international bodies to foster the management and exchange of such information basically on a free and open basis. The first of these international (in fact supranational) organisations implementing the exchange of data was the system of World Data Centres (WDC). The WDCs were created in the framework of the first international geophysical year 1957/1958, which featured also the launch of the first satellite – meant to support geophysical measurements – SPUTNIK-1 on 4 October 1957. Initiated during the cold war, the World Data Centres were also a form of free and open exchange of scientific data amongst the political blocs, created by the International Council of Scientific Unions (ICSU). Nevertheless, the WDCs were initially organised in WDC-A, -B and -C Centres to reflect the political heritage from these blocs. Universities, state and private research organisations, which host specific science information, have meanwhile applied to become World Data Centres.

Since 2003, the atmosphere applied science group of the German Remote Sensing Data Center has had approval to act as World Data Centre for Remote Sensing of the Atmosphere (WDC-RSAT). This Data Center at DLR host satellite based atmosphere measurements, not only from national and ESA missions, but also from manifold missions from

[129] The Montreal Protocol on Substances that Deplete the Ozone Layer. United Nations Environment Programme. done on 16 September 1987, entered into force on 1 January 1989. <http://ozone.unep.org/Publications/MP_Handbook/Section_1.1_The_Montreal_Protocol/>.

other nations and organisations.[130] Meanwhile, the WDC-RSAT is also a member of the World Meteorological Organisation (WMO) system of World Data Centres.[131]

Reflecting the changed global political situation and the new data distribution mechanisms through the Internet, in 2008 the ISCU changed the World Data Centres into a World Data System (WDS).[132] As the ICSU WDS page states: "The WDS concept aims at a transition from existing stand-alone WDCs and individual Services to a common globally interoperable distributed data system, that incorporates emerging technologies and new scientific data activities.

The new system will build on the potential offered by advanced interconnections between data management components for disciplinary and multidisciplinary applications."

Atmospheric data is not only an essential parameter to understand global change. Atmosphere constituents can also be used to manage actual challenges in global sustainable energy supply. Solar energy is believed to be an important source of such supply. In 2009, the Desertec foundation was created as a global initiative to push the use of solar energy.[133] Also in 2009, industry joined this initiative to create the Desertec industrial initiative GmbH (Dii GmbH) to specifically implement the concept in the Mediterranean region (Europe, Middle East and North Africa = EUMENA). The technical implementation aims at the installation of large area solar thermal power plants in the North African desert. DLR has developed prototypes of this solar power concept and is involved in the Desertec initiative.

Solar energy is not exactly available at places and at times where and when it is needed. Atmosphere conditions, mainly clouds, prevent the harvesting of solar radiation as it reaches the top of the atmosphere. Though clouds are not a major obstacle in the North African desert, aerosols (such as mineral dust and salt from the oceans) as well as certain trace gases can change the harvest of solar radiation at noticeable levels. The DLR WDC-RSAT is therefore involved in projects to collect all atmosphere condition parameters and create current and future forecasts for ground based solar radiation.[134] Figure 4.4 shows a yearly mean solar radiation in the Mediterranean basin calculated on this basis.

4.3 Coordination through GEO

The Group on Earth Observation (GEO) was initiated during the first earth observation summit July 2003 in Washington, USA.[135] It is a voluntary partnership of governments and international organizations. It provides a framework within which these partners can develop new projects and coordinate their strategies and investments in earth observations As of March 2011, GEO's Members include 86 Governments and the European Commission. In addition, 61 intergovernmental, international, and regional organizations with a mandate in Earth observation or related issues have been recognized as Participating Organizations.

GEO is constructing GEOSS on the basis of a 10 year implementation plan during the period 2005 to 2015. The Plan defines a vision statement for GEOSS, its purpose and scope, expected benefits, and the nine "Societal Benefit Areas".[136] (NOTE: link does not work)

Of interest for the topic of this paper are the GEO Data Sharing Principles.

1. There will be full and open exchange of data, metadata, and products shared within GEOSS, recognizing relevant international instruments and national policies and legislation;
2. All shared data, metadata, and products will be made available with minimum time delay and at minimum cost;
3. All shared data, metadata, and products being free of charge or no more than cost of reproduction will be encouraged for research and education

A GEO task team is working to put these principles into practical actions. One of these is the identification of data sets, held by GEO members, which can already be distributed under free and open conditions (GEO-Data CORE).

130 <http://wdc.dlr.de/>
131 <www.wmo.int>
132 <www.icsu-wds.org>
133 <www.desertec.org>
134 Breitkreuz, Hanne, Marion Schroedter-Homscheidt, Thomas Holzer-Popp, and Stefan Dech. "Short Range Direct and Diffuse Irradiance Forecasts for Solar Energy Applications Based on Aerosol Chemical Transport and Numerical Weather Modelling." Journal of Applied Meteorology and Climatology 48.9 (2009): 1766-1779.
135 <www.earthobservations.org>
136 Group on Earth Observations. The Global Earth Observation System of Systems (GEOSS) 10-Year Implementation Plan, adopted 16 February 2005. <http://www.earthobservations.org/ documents/10-Year%20Implementation%20Plan.pdf,>

Figure 4.5: The GEO Global Earth Observation System of Systems and the societal benefit areas

4.4 The European GMES Scenario

The free and open access to data was also adopted by ESA for the data from the Sentinels, the missions specifically operated under the European strategy of “Global Monitoring for Environment and Security” (GMES).[137] These Sentinels comprise:

Sentinel-1: a C-band interferometer radar mission, providing continuity to the ERS and ENVISAT satellites, but with higher ground resolution and more capacity per orbit.

Sentinel-2: a multispectral optical imaging mission, providing improved continuity for SPOT and Landsat kind of multispectral optical data.

Sentinel-3: a mission with a dual band (Ku and C) microwave altimeter, a wide-swath optical imager (OLCI = Ocean Land Color Instrument) with 21 channels and a visible/infrared radiometer for sea/land surface temperature observation.

Sentinel-4, -5: two families of atmospheric chemistry monitoring missions, developed in close cooperation with EUMETSAT and operated as a dedicated payload on EUMETSAT geostationary (Sentinel-4) and polar orbiting (Sentinel-5) satellites.

These SENTINELS will be complemented by additional European national and non-European (3rd party) satellites to fill gaps in the data supply and to deliver information for high resolution mapping and security-relevant tasks. However, these GMES cooperating missions are subject to a different data policy, governed by the GMES data warehouse established by the European Commission. In this data warehouse, national mission data will be supplied from the (often commercial) mission owner, with user licences valid for use by the GMES Services. These services comprise topic areas of the use of earth observation data for the European Union and its member states. In the global context, GMES is the European contribution to GEO/GEOSS.

At the time of writing (July 2011), GMES is challenged by the financial plans of the European Commission for raising the financial resources to bring GMES into operational status beyond 2014. Beyond this challenge, the ESA approved free and open data policy for GMES and the detailed data sharing policy for the data warehouse missions need to be adopted by the European Commission and its Member States.

[137] European Space Agency. Joint Principles for a GMES Sentinel Data Policy, Paris, done 23 October 2009, ESA/PB-EO(2009)98, rev.1.

5. Roundtable Discussion

The conference was closed by two roundtable discussions moderated by Kai-Uwe Schrogl, in which participants Andreas Hense, Gunther Schreier, Stephan Lingner Yves-Louis Desnos and Leen Hordijk elaborated on analysis and assessment of regional climate change. The second round table, comprising Jana Robinson, Herbert Allgeier, Stephan Lingner, Cynthia Maan and Mildred Trögeler, was devoted to the actual management of climate change with satellites as instruments.

During the first round table discussion it was highlighted that there is no lack of data, but the quality of data is a major concern meaning that better accuracy of data is needed. In addition, it is of paramount importance to make sure that corresponding valid data are not only gathered but that they are also used in an effective and useful manner. One way to ensure this is to feed them into existing models.

The question was raised whether free access to data is threatened by the current data policy. On 15 May 2007 the INSPIRE Directive (Infrastructure for Spatial Information in Europe), which requires full implementation by 2019, came into force. The objective of this Directive is to facilitate data exchange, data sharing and data re-use for effective governance and policy-making purposes. EU Member States are obliged to establish and to operate an infrastructure for spatial data in Europe. INSPIRE covers a great variety of spatial data needed for environmental applications and can be considered as an exemplary regulation following a "regional" approach. The wider availability of interoperable datasets will assist decision makers at all levels and will better inform society, which contributes therefore to economic savings and growth. To ensure the required compatibility of spatial data infrastructures, the Directive foresees the adoption of Implementing Rules in the form of binding acts, meaning a Commission Decision or Regulation, in different areas. Even though INSPIRE guarantees in general free and open access to data, it does not cover all areas thus still leaving some restrictions within this field. Another issue to be considered is that the provision of spatial data is determined according to a tripartite distinction: sharing among public bodies for environmental and other policy purposes, public information or access upon request and re-use for commercial and non-commercial purposes based upon the economic value of the data. Participants doubted that this distinction works in practice and holds up against actual demand. At the heart of this issue is the question of who will pay for the data.

Another issue that needs further consideration is the improvement of current cooperation and coordination, in particular for monitoring of climate variables, through various international organizations, such as the Committee on Earth Observation Satellites (CEOS), the Global Climate Observing System (GCOS) and the World Meteorological Organization (WMO), to name a few. It has been recognized that space applications have been less prominent up to now in areas dealing with actual mitigation and adaptation so that in these areas international cooperation is not a top priority. However, the International Charter on Space and Major Disasters (the Charter) is an exception, which serves as a successful tool to provide timely access to images and data acquired by Earth Observation satellites in the event of a major disaster. Each space agency party to the Charter cooperates on a voluntary basis. The Charter has been activated particularly in heavy precipitation events that might occur more often as a consequence of global warming.

In general, satellite data to be used for mitigation and adaptation measures will be needed to respond to the future challenges of climate change, which will increasingly demand cooperation in new areas . In this context, the next step should include the elaboration of complex models to attribute responsibilities with regard to climate change. Earth observation from space can be a useful tool for all aspects of climate change, for instance, by identification and attribution of climate relevant activities. By monitoring changes in land cover and land use, appropriate carbon management measures can be developed and controlled. To take advantage of these opportunities, intensive international coordination and cooperation should be enhanced.

In the course of the second round table discussion, it was stressed that current data policies are not adequate for managing regional climate change. The policies in place are focused on specific fields, but no broad or general approach exists. The role of private satellite operators in the field of management was also debated. On this point it was agreed that the ability to retrieve data from many sources is desirable, but the overall objective is to be able to provide services and to develop tailored products. In this respect, it is important to find the right balance in the development of an effective policy. The advantage of less policy in this field is that it will enable free market growth on its own, whereas too much policy pressure from above into an unknown market will restrict growth and development conditions.

The participants also addressed the question of whether the EU Member States have the right capabilities for managing natural disasters resulting from climate change and whether there is a need to introduce new legal instruments. There was consensus that sufficient capacities exist in most EU Member States, but their efficient use is not always guaranteed. In the field of Earth Observation the International Charter on Space and Major Disasters (the Charter) ensures the provision of timely access to satellite-based data in the event of natural and man-made disasters. The principle underlying the Charter is that images and data acquired by Earth observation satellites should be made available without charge to the authorities responsible for organising relief operations in disaster areas. The Charter creates a unified and coordinated system of image and data acquisition all over the world. Even though the Charter is not a legally binding instrument imposing legal duties and obligations, the fact that it has been relied upon more than 300 times since it was declared operational in November 2000 is a testimony to its success and the willingness of its Member States to commit to it.

Satellite communication (SatCom) also has a vital role in responding to and mitigating disasters in a timely and efficient manner. However, the main reason that restricts its wider use is its inherent unaffordability. One way to overcome the high costs of satellite communication is to share satellite capacities between the civil protection agencies. This approach would lead to the provision of SatCom on a cost-efficient basis, as it would decrease the specific cost of the satellite resource for each civil protection agency thanks to stronger negotiation power and to economies of scale. Unlike the Earth observation sector, where the Charter and associated operational structures already exist, the SatCom sector has only individual, ad-hoc arrangements for the use of space capabilities in response to major disasters. It is therefore important to shape a legal framework that guarantees the availability of satellite capacity on a cost-efficient basis in disaster situations. A respective new legal framework should create mechanisms to coordinate procurement of satellite communication capacity and associated services for civil protection, with the overall intent of securing their rapid and affordable availability during and after disaster events. However, there are also normative issues, like conflicts of interests, distributional fairness and the unwanted access to sensitive data by third parties with military ambitions. Balancing the humanitarian and strategic risks at stake, is a challenging task. Corresponding discussions are still pending.

Regarding the management of regional climate change, the participants discussed what aspects have to be considered in the drafting process of a regional climate change adaptation strategy. During the debate it was emphasized that various areas such as, for example, human health, agriculture, forestry, biodiversity, urban and regional planning have to be taken into account to increase the adaptation capacity of a region. The effective implementation of a strategy requires, among other things, intensive broad-based, regional stakeholder involvement during the drafting process including explanation of the resulting scientific concepts to non-experts. In this way, adaptation measures can be tailored in a way that the needs of the individual stakeholders affected by the consequences of climate change are actually met. The best way to ensure this is thus to choose a bottom-up approach in the process of creating regional climate adaption strategies including the establishment of mechanisms that allow a continuous exchange of information and ideas about favourable adaptation measures. Finally, among the different ideas, space-supported geo-engineering is a recent hotly debated option. The discussion of the panel stressed the unknown risks and non-reversibility of certain geo-engineering concepts. The ethical concern is that uninformed large-scale geoengineering might open a Pandora's box. The panel recommended investing in respective research and small-scale piloting projects, in order to get more risk knowledge and experience before installing larger infrastructures with possibly adverse side-effects.

A closing question centred on priorities for monitoring-based or management-based space activities. This question cannot be answered unambiguously: still unsolved climate research questions and uncharted potential for renewable energy might speak in favour of focussing monitoring activities. On the other hand, evidence of and precaution against pressing climate risks as well as corresponding adaptation needs would also legitimate early action. The problem has to be decided case-to-case, as climate risks have to be assessed against the societal risks of inappropriate or over-action. Disruptions of and irreversible impacts on both societal and environmental systems must be prevented in any case. Therefore, incremental approaches should be aimed at, in order to enable societal learning within this complex and uncertain co-evolution of climate and culture.

6. Remote Sensing – Regional Climate Change

by Herbert Allgeier[138]

The title of our conference is „remote sensing and regional climate change" and you would of course have a session on Climate Change and one on Remote sensing and why not a third one, possibly called "Perspectives", discussing where do we go from here, as it were.

When Kai-Uwe Schrogl asked me if I were prepared to introduce a round table during a conference on Remote Sensing and Climate Change, I said yes without thinking much, but when I found myself as a speaker on the subject "Policy Challenges for Europe" I did ask what more specifically he had in mind and his answer was: "I will send you the references of all the documents and reports we found useful in preparing the conference, but what I suggest is that you tackle the topic against the background of your rich experience". Which – after looking through the some 1000 pages of documents on his list and a few more I got from some friends in Brussels who still remember my name – I will now do.

First a few remarks about my so called rich personal experience relevant to our topic:

I started my professional career as a nuclear engineer working for a German firm who seemed to believe that they would soon again build propulsion units for nuclear submarines, and if not possibly for container ships – remember the Otto Hahn. I soon moved to Euratom exited by forecasts of more than 300 Fast Breeder Reactors by the turn of the century (the last one). You may remember this rather exotic technology: these beasts are fuelled with Plutonium and cooled with liquid sodium and were to breed more fissionable material than they consume. A great idea.

I October 1966 then I was in the control room of the first "commercial" prototype of this technology, the Enrico Fermi Fast Breeder Reactor (FBR) – responsible for the cooling system – when things went terribly wrong and I had the privilege to experience live the first nuclear melt-down.

With that I was done with nuclear and so was soon afterwards Euratom's great idea to develop a truly European reactor type.

I then joined as his assistant the new Director General at the Commission to figure out what could be done at European level in regard to R&D. Indeed following the first energy crisis of 1973, we soon got the (then still 9) Member States to agree on a first programme on renewable energies and another one on environment triggered by the debate on acid rain. Others followed until the Member States thought they needed a "mittelfristige Finanzplanung", leading to the first Framework Program worth 3 Billion Accounting Units (€), which I practically wrote.

During the late 80s, early 90s I became Director of the part of the EU R&D portfolio including Energy. I also was the Commission's Coordinator for Space and Aeronautics and in May 98 called and chaired a meeting which led to the invention of GMES; and, together with Jean-Jacques Dordain, the present DG of ESA we wrote the first joint Commission – ESA communication on a European Space Policy in the year 2000. During that same period I was Director General of the Joint Research Centre (JRC) which then included an Institute for Space Applications (SAI) and still today the JRC is probably the largest user of remote sensing data in support of the development, implementation and control of EU Policies – which is its mission.

Now then let's see.

First some general observations:

Indeed the whole field of Remote Sensing and Climate Change yields a rich harvest of – compared to only a few years ago – excellent documents, analyses and initiatives at European level, i.e. the European Commission and ESA and the consulting landscape surrounding both. All this now embedded in what is – for the remote sensing part – the European Space Policy.

Yet, and this is my first observation, there is precious little concrete stuff about the regional dimension – including in this conference – in spite of the title. This is probably inherent in the nature of both the problem and remote sensing – whereas it is just as obvious that the regional aspects are of vital importance when looking at the down to earth consequences of Climate Change, their mitigation, the information management and the control of eventual policies. At the same

[138] Chairman of ESPI's Advisory Council

time the diversity of regional aspect makes it extremely difficult to be tackled on a conference like this, other than in general terms.

Therefore my first conclusion regarding perspectives is that at some point in time a series of topical and regional events would probably be useful – whereas the definition of region in this context is not straight-forward.

Now to Climate Change, and I will simplify things a little...

Climate Change of course covers many causes from energy to waste management, agriculture and more, but let me for today's debate focus on Carbon Emissions and consequently Energy – surely the most important one.

To start at the top there is the European Economic Recovery Plan providing a stimulus of 400 Billion € which includes a series of initiatives focussing on energy saving and climate change. The Europe 2020 Strategy also supports a resource efficient economy and the proposed flagship initiative "Resource efficient Europe" will require full integration of environmental concerns in many other policy areas assuring internal policy coherence. We also can expect a number of follow-up initiatives.

The Cancun Agreement of 2010 requested developed Countries to provide the UN Framework Convention on Climate Change with details concerning their first start $ 30 Billion contributions of a total of $100 Billion they pledged to deliver between 2010 and 2012.

At EU level there is the 7th Environmental Action Plan in preparation promising an ambitious approach to address environmental issues. The integration of environmental Policy into Energy Policy is summarised in the "2009 Climate and Energy Package", which includes:

- a directive extending the EU Emission Trading system to cover some 45% of total greenhouse gas emissions;
- an "effort sharing" strategy for the period 2012-2020 for emissions from sectors not covered by the ETS;
- a directive setting binding national targets for renewable energy sources in the energy mix, and
- a directive creating a legal framework for the safe and sound environmentally friendly use of carbon capture and storage technologies (CCS).

Finally, and very important, let me mention the INSPIRE directive of 2009 (Infrastructure for Spatial Information in the European Union) addressing the obligation do share data about policies and activities having an impact on the environment. Over the coming years INSPIRE will continue to address the various obstacles which prevent this sharing to happen efficiently.

Coordination of this vital information infrastructure should significantly enhance the Member States' capacity to better plan, implement and monitor environmental, disaster mitigation and climate change measures.

This then could be the cue to go to the second subject of today, because, yes, INSPIRE is an enhancing, enabling contribution to data derived from remote sensing at regional level.

But before doing so let me push my chair back and look at the reality, at what seems to happen in real life in regard to energy in particular, and what experience tells us. Indeed our record of predictions and noble plans vs. reality in regard to energy is not very good:

In the 50ies we predicted some 300 FBRs at the turn of the century (the last one) –no doubt are we glad it did not happen! But we also predicted that nuclear Fusion would be commercial in 20 years – this for many years being the only consistent number in regard to this technology. In the 70s, following the Euratom debacle and the first energy crisis of 73, the Commission started the first renewable energy programme with ambitious targets – and when I became Director of the Energy R&D portfolio in the 90s I discovered that the average R&D contract amounted to some 100,000 €, producing as results little more than paper, and worse, the main actors in the Energy field had only token participations.

I also suspected that little was actually high tech and suggested that further R&D support would only be justified if supported by concrete regional objectives accompanied by normative and fiscal measures. Support of the petroleum industry to improve their drilling technique in order to improve the recovery from wells I suggested to replace by a directive – You guessed right: more of the same was preferred – I changed job.

The picture even gets worse when I look what seems to happen now – not what transpires from documents but what I can see and hear:

In Germany the two visible flagship projects are bio-fuels, increasing the bio fuel content in Super from 5% to 10%, a PR disaster on top of it, and the brand new plan of our Chancellor to have by 2020 1 Million electrical vehicles on the street – out of a present 40 million! At the cost of billions of tax payer's money for R&D, subsidies and other benefits – frankly I see little, if any, reduction of carbon emissions from these measures. Since the events in the Middle East our politicians have also become completely silent about the idea of the century: remember Desert-Tech! The last of the flagships ITER will cost billions in the 2 to 3 decimal range. If it ever works – which I do not believe – it makes the long abandoned FBR like a Lego set in comparison. Not to mention that Tritium is a nasty element and the discovery of other disadvantages may yet come to light. Certainly, since the events in Japan I would not put my money in this technology – actually no industry does. And that is my final remark in regard to energy: This industry is investing a pitiful 1–2 % of its revenues in R&D whereas they normally recover their cost from the consumer with relative ease as we experience every day when we pull up at the petrol station.

Maybe they would spend their money if they would not only be geared to collect subsidies or recover their investment but actually to make money with new technologies! I therefore really believe that in this field directives and clear political guidance will go a lot further than subsidies and tax payers money for R&D. Clear guidance which in the end mobilises market forces – after all the most powerful instrument to achieve objectives.

And of course the guidance will in the end not be effective if based only on rhetoric's by scientists and bureaucrats, it must be firmly embedded in a public perception that our environment is as important as for example health, employment or security, otherwise no chance to reduce greenhouse gas emissions by 80%–95% in 2050 as stated in the Commission's document "Resource efficient Europe", in turn necessary to achieve the 2°C objective.

Coming finally to our second topic: Remote Sensing, it is obvious that a reliable and continuous supply of data – information, is a prerequisite to measure, manage and control change – manage climate change policy. And RS is not all, but an essential, indispensable source of information.

In fact GMES was invented to pass the message that Remote Sensing is not only an interesting gadget but a tool to serve above all two policies of public interest: environment and security. It came in handy that it is not only a respectable a 4-letter word, but one easily pronounceable in most languages and fit to give politicians the immediate feeling that they have understood what Earth Observation or Remote Sensing is all about. Third, it was not intended to be a project, but rather a concept – a new approach – a programme to bring about the resemblance of a system of supply and demand in a complicated and new environment.

Looking at all the documents, programmes and activities it has generated during the last 13 years since, it is obvious that it has worked and is – at a first look well on its way to deliver: to begin, 13 years later those responsible have finally understood that it was not intended as a project, like Galileo, and have therefore abandoned the idea to change the name! Also there is an excellent programme of pilot projects and an effort to structure activities and participation – and, above all money flows through both ESA and the EU.

For the Sentinels 4,2 Bio and 7,3 Bio € are foreseen for the periods 2014–2020 and 2021 and 2030 respectively. In addition national satellite initiatives emerge, like Top Sat, EnMAP, SEOSAT – INGENIO and even the PPP Rapid Eye is up and running. As for the Sentinels at least they are apparently based on a thorough gap analysis of other existing and planned satellite missions. So, I could be tempted to conclude: we are in good shape, let's get on with it.

But I hesitate, and I tell you why:

First, in all the documents – excellent most of them – , I could not find what you could call a real evaluation/assessment of the needs for data based on the operational quality and quantity of information – and how could I, because we are dealing with a moving target. What I mean is analysis of needs based on our understanding of the mechanisms of policy management – and how could I because the policies are still on the drawing board. Moreover who are the actors/institutions at EU, national and regional level? How then will the no doubt excellent pilot and fast track projects executed by a variety of project teams – without a collective memory – lead to a sustainable, reliable mechanism of data collection, analysis and policy management?

The Commission documents talk about the development of a Clearing House Mechanism. Is this something like the US does for its National Spatial Data Infrastructure (NSDI)? I am not quite sure what is meant by this? But yes perhaps we do need some function, entity which acts as a proxy customer for the various policies, a sort of exchange but more maybe clearing house is a good word for it. Some service which centralises or customises and certifies products and services for the policy maker in a world of continuous change?

Let me say it bluntly: I believe what is missing is a European NIMA or NGA (National Geographic intelligence Agency) which it now is called – not a copy, but a European equivalent taking into consideration the regional aspects, Europe's diversity as well as the need for coherence within the EU and the compatibility with international efforts. Not a big bang creation but something that starts modestly but with a clear mission. The mission would not be to do it all – quite the contrary, but to act as a focus for SME's and other participants and to provide a stimulus, an anchor for related RS based commercial activities to develop.

It could easily achieved by for example asking the JRC to host such a service without much ado. Indeed, the JRC is a unique body inside the Commission with the mission to support the development, implementation and control of EU policies. It probably is the most flexible part of the Commission and which is equipped to take on (quasi)operational tasks. In fact it has done so in the past very successfully and then spun off similar activities:

- its European Chemical bureau became the ECHA
- its work on food safety gave birth to the EFSA ,and
- its work in the field of environment laid the ground for the European Environmental Agency, and
- as I already said it also still is the largest European purchaser and user of Remote Sensing data in Europe in support of EU policies.

Perhaps as a joint venture with ESA and the European Satellite Centre?

I ask you, what makes us believe we can remotely do in Europe what the US does with National Geospatial Intelligence Agency (NGA), with a loosely connected and unstructured collaboration of SME's, universities, management consultants, Commission officials or entities like ESA and EUMETSAT who clearly have other missions? Maybe the "Clearing house" idea I found in one of the documents is a step in the right direction, but it can not be all.

7. Climate Change Data – World, Region, Local Community, You!

by Peter Hulsroj[139]

Climate change gives rise to a wide variety of issues, some of which are little discussed and little understood.

In the part of the global population where the Enlightenment did not pass unnoticed, there is a clear understanding that the evidence shows that there is a problem, and that something has to be done about it. As Mr. von Storch points out the scientific evidence will normally not give an unambiguous answer to what should be done, and one fundamental issue is how and by whom the scientific evidence is turned into actionable policy. Mr. Von Storch argues that the scientist should not become a propagandist, which is appealing, even if this would put climate change scientists in a fundamentally different position than, say, economists where in most cases the master of the evidence also considers himself the master of the political process that translates economic evidence into possible remedial policy. The point here is thus that science in this field cannot avoid conjecture, because even if one takes the Caesar's wife position of Mr. von Storch, politicians must ask scientists about the consequences of different policy actions, just like in economics. Will a given action in fact reduce CO2 in a meaningful manner is a question no climate change scientist can escape. As Mr. Allgeier points out a number of alleged climate change mitigations seems to have very questionable climate benefits. Herein lies the rub. How can civil society be 'educated' in such a fashion that eventual action becomes meaningful?

Unfortunately there are far more dilemmas than this. In our 'do good' proactive mode we tend to overlook that there are inherent conflicts between different stakeholder groups all believing that something has to be done and there are terrible conflicts between climate change avoidance and climate change adaptation. The simplest regional contest is the one between the regions to which climate change will bring desertification, and the ones where climate change will suddenly allow vines to grow. Still, here we are still on relatively safe ground, since regions that are benefitting from climate change until now did not argue in favour of it. But take some of the geo-engineering ideas of Cynthia Maan and Leopold Summerer. Some of these approaches would, if feasible, surely bring the world as a whole great benefits. But some persons and some regions would suffer. Take the example of reflectivity clouds. Some regions would presumably be desperately unhappy, because their local climate would be adversely affected. So they would presumably argue for other geo-engineering solutions. Not so easy to do good!

Paralysis in taking action against climate change or its consequences is probably to a large extent introduced by the uncertainty on the boundary conditions. Investment strategists like to measure the soundness of potential investments against a stable investment climate, so to speak. Despite all the good will that undoubtedly exists, there is surely a tendency to hope for the best or to see if somebody else is not solving the problem. And this hope discourages particularly investment in regional mitigation. Climate change is a global phenomenon and hence regions pray that also global remedies will be found. Venice might not want to make a huge investment in flood control if current defences can take care even of the higher sea levels stemming from a 2 degrees climate change. And that is fair enough, but how sure can Venice be that the global community will, in fact, be able to stem climate change at 2 degrees? If Venice invests and global change will be controlled at 2 degrees, Venice will have thrown out a lot of money. If they do not invest and the climate changes by 3 degrees they might be too late and Venice might be gone. The inverse dynamic might be the more relevant, however. The global community might still remain hide-bound, and hope that the consequences of global inaction will not be too severe. Albeit irrational, global decision makers might hope that adequate regional mitigation action is taken.

The lesson of all this pessimism is probably that if regional decision makers try to calibrate their risks then they should not put too great reliance on global action. They should risk the regional investment, simply because

[139] Director, ESPI

it becomes an insurance premium against global inaction.

All politics are local, the popular saying goes. This may be true and what is certainly true is that regional differences in understanding, appreciation and economic interest have blocked most progress on global action against climate change. If one assumes that most political action is a result of a bottom up process, through which engaged stakeholder groups pressure political decision makers, there is a strong impetus to institutionalise regional scientific institutions, as Mr. von Storch suggests. Regional scientific institutions in this field can feed the democratic process, can be close to the citizen and to local groups and authorities, and this should be helpful in replacing belief with fact as the foundation for action.

In order to understand the benefits of regional information dissemination and the potential for regional action it is interesting to note that organisations active in the climate change debate are often organisations with a wider environment brief. The fight against climate change is often seen as an integral part of the fight for a better environment in general. Yet, sometimes there may be tension also between general environmental concerns and the specific issues of climate change. Mr. Allgeier has mentioned the issue of nuclear energy. Most environmental groups are dead against nuclear energy for all the reasons we know such as Fukuyama, waste longevity, waste management. Yet, if climate change is the only concern then nuclear energy becomes far more attractive; in a choice only between fossil fuels and nuclear energy the preferred energy source would always be nuclear energy. Still, green concerns led Germany on the path to abandoning nuclear energy entirely, and few if any voices were heard to the effect that this was a bad decision from the point of view of climate change. Germany might be able to replace the fading nuclear energy supply with more expensive energy from renewable energy sources, and that is obviously to be applauded from all environmental points of view, but this is unlikely to be the full story. Germany will also export part of its problem to jurisdictions where both fossil fuels and nuclear energy hold sway, and will probably also domestically rely more on fossil fuels. So perhaps the German approach is a good story for the environment in the wider sense, but a bad story for climate change. A sit-in in front of a nuclear power plant in order to keep it open to protect the climate is more than a stretch of the imagination, but that is only because there is such a strong identification between environmental concerns and climate change concerns, and the tension between them is being ignored.

Nuclear energy is but one example of the possible tension between broad environmental goals and climate change goals. Mr. Allgeier is sceptical about the beneficial effects of bio-fuels for the climate, but even if bio-fuels would be helpful for the climate there would be a conflict between the climate change lobby and the anti-poverty lobby, since we have seen how bio-fuels can increase food prices to the detriment of populations of developing countries. This means that also regionally the tensions can exist, since farming communities might be much in favour of bio-fuels whereas hunger-stricken regions will not.

One of the deficiencies of our societal structure is that we do not have a fully-fledged international clearing house institution which can do the arbitrage between regions benefiting from a certain measure and those being negatively impacted. On the domestic scene the national government might compensate one region losing out by a certain measure in order to harvest the overall benefits for society, and the perhaps disproportional benefit for another region. Internationally, the Kyoto Protocol created the Adaptation Fund, which has as its objective to assist developing countries with the adaptation to global warming. This is certainly a good initiative in arbitrating a bit between the ones mainly creating the climate change and those mainly suffering from it – but it is a drop in the ocean, and is not addressing effectively the wealth disparities created by global warming. The hungry in Africa hit by the increasing price of food is not helped, and the farmer benefiting is to an overwhelming extent left to enjoy the spoils.

It is worth spending a little time considering how lobbying functions operate in the climate change field, because they are highly nonlinear. The reality is that one regionally based group has hijacked the debate by questioning unquestionable evidence and by putting itself in the comfortable position of being credible by doing so, without itself putting up data that could be subjected to equally destructive analysis. Mr. Von Storch is perhaps right when he intimates that the scientists zealously preaching climate change make themselves a target by doing so. But it is astounding that climate change deniers are not being asked to prove their thesis, and are allowed to only punch imaginary holes in the evidence emanating from serious scientific research. From a public debate perspective it is incongruent that climate change deniers have been allowed to define the playing field in this way. The same sort of Tea Party grouping is, by the way, seeking to start the same game with the theory of evolution, seeking to discredit Darwinian evidence without any compulsion to put up facts in support of their own far-fetched ideas. Darwin's thesis was of course subject to similar vehement opposition as climate change evidence is now. Darwin was convincing not only because his evidence was so strong, but also because opponents could not produce any evidence supporting their own hypothesis. It would be salutary if climate change deniers would be required to carry the same burden of proof for their perspective as the one they impose on climate change evidence. Whatever the doubt they might be able to throw on the evidence, the consequence of such doubt is not proof of the opposing thesis that the climate did not change. In criminal law the consequence of doubt is acquittal. Not so in science!

The sad consequence of the dialectic distortion is that the global community wastes its time debating if, rather than what. As was mentioned above there are many potentially conflicting interests between stakeholder groups and regions, even if climate change is assumed, and it is a shame that the debate is not focused on arbitrating between those interests.

Coming full circle it would now be relevant to put the question of the role of the individual in the global warming debate; the question of how the individual interacts with climate change data. The individual might feel lost because the debate appears so specialised and there Mr. von Storch's regional science institutions might be part of the answer, but it cannot be the only answer. It cannot and should not be expected that all citizens become absolute experts on climate change, but short of that it is important that there is more than a superficial understanding of the issue in the general populace, and the route in this respect goes through education. The trickle down of climate change data and understanding cannot only be from scientist to population but must also be from scientist to educator. But there are other possible ways. It is salutary that many airlines notify the passengers when they buy the ticket what the carbon consequence is, and provide passengers with a voluntary mechanism for paying for the off-set, if they so wish. This approach is, of course, easiest for big ticket items, which raise the question why a similar system does not work for other major sources of green house gases. It is true that all sorts of gas guzzler taxes exist, but first of all there is no direct link to the offset, but even if there would these taxes would only fund a partial off-set and for most cars no such tax applies. Since we are indoctrinated to have a bad conscience about owning or using cars it would be helpful that a voluntary mechanism would exist that would allow rich, well meaning people to buy absolution. Would you like this gas with or without carbon off-set, Sir?[140] The voluntary element in this is important, because it draws citizens into the debate in a concrete form. One of the challenges of democracy is always to make voters feel that they are of relevance. In the face of huge problems it is easy to feel disenfranchised. The great advantage of direct democracy is that the voter sees an immediate practical effect of his engagement, where representative democracy per definition introduces a further distance between voter involvement and the solution to concrete problems. When society seeks active involvement of the citizenry it is beneficial when virtuous circles can be introduced. When we separate our waste we are day-by-day reminded of the environment, this makes us more alert to environmental issues, and higher environmental awareness leads us towards the bicycle rather than the car. Making frequent decisions about carbon off-sets will increase our readiness to raise our political voice, and exercising our political rights in aid of the fight against global warming will in turn engage us more in day-to-day climate change correct behaviour.

All politics are not local – all politics are individual. They start with you!

[140] A small step in this direction has been taken by the German company, Arktik, which offers vehicle fleet managers a possibility for voluntary carbon off-set. Yet, the next step must be the prompt to the individual every time he is at the pump, but that, of course, requires a completely different kind of cooperation from oil companies.

8. Concluding Remarks

by Stephan Lingner[141] and Mildred Trögeler[142]

Climate change is a statistical construct that can be discussed on global, regional and local scales. The impacts of climate change already affect societies and individuals on regional to local scales in quite different ways. The regional and local scales seem to be readily accessible for human action and should be therefore considered as one auspicious route for managing climate change. Early action on climate change is necessary and should be directed towards adaptation to changing environmental conditions and even towards emerging new opportunities. Corresponding quick response might thus compensate for the time-delays, which arise due to the time-consuming international negotiations on mitigation of global climate change and due to the inertia of the climate system, which will need decades to react on any mitigation measure.

Nevertheless, timely, efficient and specific action needs adequate information on corresponding local or regional potential and risks. Recent developments in remote sensing from space might provide the actors with a broad range of necessary data. Appropriate geo-information from space stands out due to its cost-efficiency and its quick and broad accessibility – also from remote areas with missing primary data. Detection and monitoring of relevant regional climate features on Earth by sophisticated remote sensing from space might thus provide the basis for rational decisions on prudent land use and relief. However, international coordination and regulation for validation and fair distribution of tailored space-based data is still on the agenda.

8.1 Climate Change and Society

Human societies are sensitive to their climatic environments. Concerns about climate change are therefore also societal concerns and thus give reason for climate research as a scientific endeavour with a clear societal mandate. The societal expectations of climate science are directed towards prognoses of climate change and its attribution to the responsible pollution sources with the goal to prevent further, possibly harmful interference with the climate system.

However, climatology cannot really tell us "inconvenient truths" as some people or media might expect. The contribution of Andreas Hense on the "Detection, Attribution and Uncertainty of Climate Change" points out that the natural forced dynamic of the climate system is beyond thermodynamic equilibrium, thus complicating the detection of climate change. Any scientific statements about future climate as a stochastic ensemble of interrelated variables can only be put and understood in probabilistic terms. The case of human interference with the climate makes the resulting uncertainty even worse. The attribution of the human factor to selected climate signals can only be expressed in terms of conditional probabilities. Therefore, assumed facts and truths about the causal responsibility of human climate impacts turn out to become potentialities or constrained probabilities of the human role in climate change. The observation of the global mean warming of the last century can be attributed to human activity with a very high degree of probability, however. Comparisons of observed and modelled temperature data suggest that human activity have contributed to global warming – but still under *certain* model assumptions. This notwithstanding, global mean warming is a reality, and model assumptions are related to attribution. On balance, this underscores the relevance of local adaptation, since attribution is more uncertain than the warming phenomenon itself.

Corresponding projections for the regional scale or other climate variables (precipitation, wind) – which are specifically relevant for climate effects on societies – are unfortunately also uncertain. This might be in part a problem of the availability of data and sophisticated models, which gives reason for future utilization of satellite data in climate change detection and attribution.

The regional climate impact dimension is the relevant but imperfectly modelled scale on which societies might be affected by natural or human induced climate change. The paper on "Regional climate knowledge for society" by Hans von Storch thus pleads for a re-orientation of the relation of climate science and politics for several reasons:

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- The linear model of policy advice, which simply translates knowledge (about climate change) into action (to mitigate), is not rational, because the scientific uncertainty and plurality of social values, interests and world-views at stake will not allow for non-ambiguous solutions, especially on the relevant impact scales. Natural science should remain the "honest broker" of the necessary knowledge, which has to be reflected within a "broader picture" of politics.
- Mitigation of climate change is therefore not the only solution, because (a) of its uncertain success especially on regional to local scales, (b) of heavily delayed results due to the inertia of the climate system. Adaptation will thus have to be considered, which applies better to both the relevant regional problem scales and to timely action.

However, actors for adaption to regional or local climate change are still in need of more and appropriate knowledge and service with regard to this issue. Corresponding regional capacities and capabilities have to be built up in order to be able to make comparisons with respective institutions on a global scale. Early climate services for exchange of information with the local public and for regional decision support are now already emerging. Further developments might orientate themselves along the activities of the North German Climate Office or the BACC/BALTEX assessments of climate change in the Baltic Sea Basin.

8.2 Space Applications for Climate Change Response

Remote sensing from space and similar services offer new and complementary options for monitoring of climate change variables, for control of climate protection or adaptation measures, for disaster management and even for alternative coping strategies, like geo-engineering. The potential for related space-born services and their utilization is still expandable in favour of consolidation of climate science and management.

The article of Cynthia Maan and Leopold Summerer reflects the options of "Space and Climate Geo-engineering" in some detail. The background for corresponding considerations is that global greenhouse gas emissions are still rising despite international efforts to limit climate active trace gas concentrations in the atmosphere. To date, corresponding negotiations have produced only moderate results and it might be suspected that corresponding international binding and effective commitments will not come into force in time. Therefore, alternatives such as geo-engineering might be considered to counteract global warming in order to reduce related climate risks. The underlying principle relies on solar radiation management by increasing either the outgoing long-wave radiation into space or the reflection of incoming sunlight. The latter is represented by different technical concepts for solar shielding in space, for enhancing reflectivity of clouds and atmospheric aerosol, and for brightening Earth's albedo. The former class of concepts comprises different ideas for immobilization of atmospheric carbon dioxide. However, most of these concepts are still rather immature and far from immediate applicability. Moreover, consideration of geo-engineering might have to deal with moral dilemmas stemming from several consequences like possible second-order risks, their just distribution, residual climate change in certain regions, delays of impacts and limited efficiencies with regards to costs and effects. A preliminary evaluation of the different concepts, weighing their affordability against specific effectiveness, gives the following conclusion: If effectiveness and cost efficiency are set as superior criteria, injecting "cooling" sulfate aerosols into the stratosphere would probably turn out to be the best solution for timely action in the warming "greenhouse". However, this technology might harm the environment and would hardly reach broad acceptance. Safer options of carbon management might be considered instead, but their effects would be much slower and either less intense or more costly. Corresponding contributions from space would be mainly restricted to measurements and control of key-parameters within the specified options. Nevertheless, more research and experience by respective piloting experiments are necessary to be able to give qualified answers on the feasibility and acceptability of the preselected options and geo-engineering as a whole. Depending upon the respective results the affinity of geo-engineering to space operations might even become larger.

Other climate relevant space applications are directed towards disaster monitoring and adequate geo-information for "climate-friendly" energy options. Operational satellite meteorology has developed over several decades. Corresponding data are now distributed by the World Data System (WDS) and are necessary not only for understanding and monitoring global change; the data which reflect for example cloud or aerosol parameters could also be used for forecasting the resulting mean solar radiation on the terrestrial surface, in order to select favourable regions for the efficient conversion of solar energy and its later use. Corresponding space-born services are currently offered to the "Desertec" consortium, which aims at huge solar power stations in North Africa.

Another strand of space-born data utilization is the mapping of natural disasters, which again are often caused by extreme climatological events. Corresponding services are directed towards precaution, impact mapping and emergency support. Therefore, adequate information needs appropriate and problem-specific sensors and respective spatial resolution. The raw data must be processed and distributed in time, which necessitates standardized routines of global data acquisition and analysis as well as efficient international regimes and regulations, which enable the affected users and responsible authorities to get the necessary information without restrictions and needless delay. Within this context, the paper of Gunter Schreier stresses "International Coordination in the Use of Remote Sensing Data". The "Charter on Space and Major Disasters" might serve as a paradigmatic example for the codification of international data access in this respect. Other international organizations such as GEO (Group on Earth Observation) or the European GMES (Global Monitoring for Environment and Security) strategy explicitly comply with the Charter's principles of data sharing and open access. However, the commercial interests of shareholding entities remain to be harmonized within this "low-cost philosophy".

8.3 The Way Forward

- The problem of monitoring regional climate change lies in the quality not in the quantity of remote sensing data; in particular the accuracy of the collected data should be improved. It is of paramount importance to use the collected data in an effective and useful manner. Lessons can be drawn from these data by feeding them into existing models and improved simulations.
- Complex climate change models should be reasonably restricted towards hypothetic reasoning of causation probabilities. The selection of plausible climate change scenarios should be assisted by the use of remote sensing data.
- The INSPIRE Directive covering a great variety of spatial data for environmental applications should serve as a role model for regulation following a regional approach. The wider availability of interoperable datasets will assist decision makers at all levels and better inform society, which contributes therefore to economic savings and growth.
- Cooperation and coordination between actors, particularly in the field of monitoring and managing climate change, should be enhanced and intensified. As space applications have been less significant up to now in areas dealing with actual mitigation and adaptation, the corresponding international cooperation has not yet been a top priority. The International Charter on Space and Major Disasters, which serves as a successful tool to provide timely access to images and data acquired by Earth Observation satellites in the event of extensive disasters, should encourage the actors involved to develop more structured institutional cooperation. Coordination through GEO or GMES already shows the right direction although it is still to be consolidated.
- Geo-engineering is still a theoretical option within the tasks of managing climate change, but it needs further scientific research and societal assessment before it can be considered in practice. Corresponding contributions by space technology might be useful, depending upon the specific approach chosen.
- There is a need to develop an overall and well balanced policy for managing regional climate change, taking into account that too much pressure from policy into an emerging field will restrict growth and development conditions. Furthermore, this policy should follow a bottom-up approach to ensure that the needs of individual stakeholders affected by the consequences of climate change are actually met.

List of Acronyms

Acronym	Explanation
A	
ADM	Atmospheric Dynamics Mission
AIT	Asian Institute of Technology
ALADIN	Atmospheric Laser Doppler Lidar Instrument
AR4	Fourth Assessment Report of the IPCC
ATLID	Atmospheric Lidar
B	
BACC	BALTEX Assessment of Climate Change for the Baltic Basin
BALTEX	Baltic Sea Experiment
C	
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CCS	Carbon Capture and Storage
CEOS	Committee on Earth Observation Satellites
CFC	ChloroFluoroCarbons
CLISAP	Integrated Climate System Analysis and Prediction
CMIP3	Coupled Model Intercomparison Project Phase 3
CNES	Centre National d'Études Spatiales (French Space Agency)
CUDOS Method	Communalism, Universalism, Disinterestedness, Originality and Skepticism
D	
Dii GmbH	Desertec Industrial Initiative GmbH
DG	Director General
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
E	
EA	Europäische Akademie zur Erforschung von Folgen wissenschaftlich-technischer Entwicklungen Bad-Neuenahr-Ahrweiler
EARLINET	European Aerosol Research Lidar Network
EarthCARE	Earth Clouds, Aerosols, and Radiation Explorer
ECHA	European Chemicals Agency
ECO	Emergency-on-call-officer
EFSA	European Food Safety Authority
EOC	Earth Observation Center
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESPI	European Space Policy Institute

Acronym	Explanation
ETS	Emissions Trading System
EU	European Union
EUMETSAT	The European Organisation for the Exploitation of Meteorological Satellites
EUMENA	Europe, Middle East, and North Africa
F	
FBR	Fast Breeder Reactor
G	
GCM	General Circulation Model
GCOS	Global Climate Observing System
GEO	Group on Earth Observations
GEOSS	Global Earth Observing System of Systems
GHG	Greenhouse Gases
GIS	Geoinformationssysteme (Geographic Information Systems)
GLAS	Geoscience Laser Altimeter System
GmbH	Gesellschaft mit beschränkter Haftung (Limited Liability Company)
GMES	Global Monitoring for Environment and Security
GOES	Geostationary Operational Environmental Satellites
GOME	Global Ozone Monitoring Experiment
GPM	Global Precipitation Measurement
H	
HELCOM	Helsinki Commission (The Baltic Marine Environment Protection Commission)
I	
ICSU	International Council of Scientific Unions
INSPIRE	Infrastructure for Spatial Information in Europe
IPAC	International Policy Advisory Committee
IPCC	Intergovernmental Panel on Climate Change
ISPRS	International Society for Photogrammetry and Remote Sensing
ITER	International Thermonuclear Experimental Reactor
J	
JAXA	Japan Aerospace Exploration Agency
JRC	Joint Research Centre
L	
L1	Lagrange Point 1
LOVECLIM	Loch-Vecode-Ecbilt-Clio-Agism Model
LUCC	Land Use and Cover Changes
M	
MODIS	Moderate Resolution Imaging Spectroradiometer
N	
NASA	National Aeronautics and Space Administration
NCS	National Climate Service
NGA	National Geographic Intelligence Agency

Acronym	Explanation
NSDI	National Spatial Data Infrastructure
O	
OLCI	Ocean Land Color Instrument
OMI	Ozone Monitoring Instrument
P	
PPP	Public Private Partnership
PR	Public Relation
R	
R&D	Research and Development
RS	Remote Sensing
S	
SAI	Institute for Space Applications
SAR	Synthetic Aperture Radar
SatCom	Satellite Communication
SMEs	Small and Medium Enterprises
SRM	Solar Radiation Management
SSM/I	Special Sensor Microwave Imager
T	
TOMS	Total Ozone Mapping Spectrometer
TRMM	Tropical Rainfall Measuring Mission
U	
UK	United Kingdom
UN	United Nations
US	United States
W	
WDC	World Data Centres
WDC-RSAT	World Data Centre for Remote Sensing of the Atmosphere
WDS	World Data System
WMO	World Meteorological Organisation
Z	
ZKI	Zentrum für satellitenbasierte Kriseninformation (Centre for Satellite Based Crisis Information)

Conference Programme

REMOTE SENSING REGIONAL CLIMATE CHANGE

POTENTIALS AND OPTIONS TO ADAPT

Climate change is often discussed as a process, which should be mitigated on a global scale – so the broad consensus. However, the international debate on climate protection might be characterized as a culture of postponing, while climate change is already happening, thus affecting individuals and societies.

Moreover, consequences of climate change occur in a quite different manner on regional scales, which seem to be more accessible to human action. The regional perspective might thus be the focus for early action on climate change. This action could be directed towards adaptation to climate change as well as towards utilization of any beneficial climate effects.

Nevertheless, timely, efficient and specific action needs for adequate information on corresponding local or regional potentials and risks. Recent developments of remote sensing from space might provide the actors with necessary data. Appropriate geo-information from space stands out due to its actuality, its cost-efficiency and its broad accessibility – also from remote areas with missing primary data. The latter is especially relevant and urgent for many developing countries, which turn out to be especially vulnerable with regard to adverse climate effects.

Detection and monitoring of regional climate relevant features on Earth by sophisticated remote sensing from space might thus provide the basis for rational decisions on prudent land use and help, thereupon. This regional approach should not compete with the global objective of mitigation control and monitoring. It might be rather seen as a complementary element of an overall coherent strategy to handle the climate problem as a whole.

THURSDAY, 26 MAY 2011

13.00 Registration

14.15 Introduction
Kai-Uwe Schrogl,
European Space Policy Institute (ESPI)
Stephan Lingner,
Europäische Akademie GmbH

SESSION I: TOWARDS A CLIMATE CHANGE CULTURE
Chair: Stephan Lingner,
Europäische Akademie GmbH

14.45 **Detection, attribution and uncertainty of climate change. Who is responsible?**
Andreas Hense,
Meteorologisches Institut, Bonn University

15.45 Break

16.00 **Climate science in society**
Hans von Storch,
Institute for Coastal Research, Helmholtz-Zentrum Geesthacht

17.00 Break

18.00 Keynote address
Klimaforschung und Klima-Engineering. Über den Umgang mit Nichtwissen aus ethischer Sicht
Carl Friedrich Gethmann,
Europäische Akademie GmbH

19.00 Reception

20.00 End of session I

FRIDAY, 27 MAY 2011

SESSION II: REMOTE SENSING ADDRESSING THE POTENTIALS AND OPTIONS TO ADAPT TO THE CLIMATE CHANGE
Chair: Leen Hordijk,
Institute for Environment and Sustainability,
Joint Research Centre, European Commission

9.00 **Space applications for assessing and managing climate change**
Yves-Louis Desnos,
European Space Research Institute (ESRIN),
European Space Agency (ESA)

9.45 **Space and climate geoengineering**
Cynthia Maan/Leopold Summerer,
Advanced Concepts Team, European Space Agency (ESA)

10.30 Break

11.00 **International coordination in the use of remote sensing data**
Gunter Schreier,
International Society for Photogrammetry and Remote Sensing (ISPRS)

11.45 **European Union foreign policy objectives related to climate change and space applications**
Jana Robinson/Christina Giannopapa,
European Space Policy Institute (ESPI)

12.30 Lunch

SESSION III: PERSPECTIVES
Chair: Kai-Uwe Schrogl,
European Space Policy Institute (ESPI)

14.00 **Policy challenges for Europe**
Herbert Allgeier,
Chairman ESPI Advisory Council

14.30 **Round table discussion**
Speakers and chairs

15.30 **Conclusions**

16.00 End of conference

Acknowledgements

The authors would first like to express special thanks to those who stood behind the joint conference on “Remote Sensing and Regional Climate Change- Potentials and Options to Adopt” organised by the Europäische Akademie zur Erforschung von Folgen wissenschaftlich-technischer Entwicklungen Bad Neuenahr-Ahrweiler (EA), the Euopean Space Policy Institute (ESPI), in particular Kai-Uwe Schrogl, Head of ESA Policies Department and former Director of the European Space Policy Institute, and the International Society for Photogrammetry and Remote Sensing (ISPRS), the largest professional organisation for research and use in remote sensing, policy, ethics and applications in Vienna, which served as the foundation for this report. It is likewise important to recognise the general sponsor of the conference: the German Aerospace Center (DLR). Sincere appreciation is extended to those who worked especially hard to organize the conference, especially Friederike Wütscher, EA Conference Coordinator.

The authors are also grateful to the distinguished participants of the Remote Sensing and Regional Climate Change Conference from whom valuable insights were gained both inside and outside the conference proceedings. Finally, the authors wish to acknowledge ESPI’s current Director, Peter Hulsroj, whose fine hands helped improve the quality of this report, and thank ESPI Resident Fellow Erich Klock and ESPI Research Intern Sophie Goemaere for their contributions that proved most helpful to its completion.

Mission Statement of ESPI

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