Chapter 2
Policy and Earth Observation Innovation Cycle (PEOIC) Project (Japan)

Yasuko Kasai, Setsuko Aoki, Akiko Aizawa, Akiko Okamatsu, Tomohiro Sato, Masami Onoda and Brian Alan Johnson

2.1 Assessment Framework of the Policy and Earth Observation Innovation Cycle (PEOIC)

2.1.1 The Policy and Earth Observation Innovation Cycle

Earth observation has the potential to make significant contributions to policy and society, as we discussed in Chap. 1 of this book. In this chapter, we focus on the function of "Inform" and the medium "Atmospheric" as shown in Table 1.1 in Chap. 1. This role generally corresponds to global scale long-term monitoring by low Earth orbit (LEO) satellites. Through such observations, influential scientific findings from satellite data have triggered international debates and helped set the agenda for addressing many environmental problems, including stratospheric ozone depletion and global warming. On the other hand, the policy priorities of national

Y. Kasai (✉)
National Institute of Information and Communications Technology (NICT),
4-2-1, Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan
e-mail: ykasai@nict.go.jp

S. Aoki
Keio University Law School, 2-15-45 Mita, Minato-Ku, Tokyo 108-8345, Japan
e-mail: aosets@sfc.keio.ac.jp

A. Aizawa
National Institute of Informatics (NII), 2-1-2 Hitotsubashi, Chiyoda-Ku,
Tokyo 101-8430, Japan
e-mail: aizawa@nii.ac.jp

A. Okamatsu
Faculty of Sustainability Studies, Hosei University, 2-17-1 Fujimi, Chiyoda,
Tokyo 102-8160, Japan
e-mail: okamatsu@hosei.ac.jp

M. Onoda and O.R. Young (eds.), *Satellite Earth Observations and Their Impact on Society and Policy*, DOI 10.1007/978-981-10-3713-9_2

governments are often the basis of their budgetary allocations to governmental space missions, with the goal being that satellite missions will lead to scientific findings that better inform decision-makers. We know from experience that such cases happen. Our purpose here is to show quantitative evidence of the relationship between observation data and policy.

In Japan, there is a growing demand to set mission goals for publicly funded satellite missions based on societal or policy outcomes. However, at present there are very few studies assessing the actual impacts of satellite Earth observations on policy. The Japanese government typically decides on the funding for satellite Earth observation missions through a one-way planning approach, where the scientific results/advancements from a mission do not fully contribute to the next step of the innovation process. The authors of this chapter think that this lack of analysis—either retrospective or prospective—of the impact of Earth observations on environmental policy is one reason why Japan's Earth observation programs lack consistent and continuous planning.

The goal of this research therefore is to develop methods for quantitative and objective assessment of the impact of satellite Earth observations on environmental policy. For this purpose, the research project members have proposed the concept of a "Policy and Earth Observation Innovation Cycle" (PEOIC). Satellite data are used to produce information and intelligence leading to strategy and the formation of policy. Ultimately, the outcome effect of the policy is monitored and this information feeds into the next cycle of scientific and technological innovation. The immediate goal of the project is to propose methodology options for Japan to perform such an assessment for better system planning in the future. The long-term goal beyond this project is to build a society where there is such a working cycle, which could be a key to developing the road map to Future Earth (2016). Figure 2.1 illustrates the PEOIC concept.

T. Sato
Big Data Analytics Laboratory, Big Data Integration Research Center, National Institute of Information and Communications Technology (NICT), 4-2-1, Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan
e-mail: tosato@nict.go.jp

M. Onoda
International Relations and Research Department, Japan Aerospace Exploration Agency, Ochanomizu Sola City, 4-6, Kanda Surugadai, Chiyoda-Ku, Tokyo 101-8008, Japan
e-mail: onoda.masami@jaxa.jp

B.A. Johnson
Natural Resources and Ecosystem Services, Institute for Global Environmental Strategies, 2108-11, Kamiyamaguchi, Hayama, Kanagawa 240-0115, Japan
e-mail: johnson@iges.or.jp

Fig. 2.1 Proposed "Policy and Earth Observation Innovation Cycle"

2.1.2 Project Outline

There are a number of studies that address the contributions or benefits of satellite remote sensing technologies to society and the relationship with policy (Booz and Company 2011; PricewaterhouseCoopers LLP 2006; Williamson et al. 2002; Macauley 2009; and others). These studies range from public reports to policy or economic analysis. In a broader context, the relationship between science and policy has been an important area of the study on state behaviors, in governance, or in the constructivist approaches in international relations.

We know that publicly funded satellite missions are commonly designed to meet the policy requirements that affect resource allocation. On the other hand, we also know that environmental policy agendas are set by scientific findings. Our investigation on the impact of satellite Earth observations on environmental policy has led us ultimately to the question of the role of science and policy and the interactions between the two, and whether evidence of such interactions could be identified in a quantitative manner. However, the lack of an approach to integrate policy, science, and technology seems to lead to a discrepancy between the two domains, causing inefficiencies in the system. If there is a way to identify and possibly quantify the data and information flow from science to policy, it should be possible to identify the existing gap and analyze the reason for its existence, leading to possible solutions to reconcile this discrepancy.

Based on these hypotheses, the project attempts to develop a tracking technique to link the currently disconnected fields of satellite Earth observation and environmental policy. The project further attempts to bridge the gap between policy and the development of science and technology research.

Our project started by developing a methodology for such an assessment by bringing together groups of specialists in different fields, including space and environmental law and policy, satellite engineering, and informatics. First, different phases of the policy process where satellite observations could have had an impact were identified through a document review; then text mining was performed to quantitatively assess if and how Earth observations had an impact on policy. The project comprises three components: the policy component, led by Prof. Setsuko Aoki of Keio University, the assessment methodology component, led by Dr. Masami Onoda of the Japan Aerospace Exploration Agency (JAXA), and the statistical analysis component led by Prof. Yasuko Kasai of the National Institute of Information and Communications Technology (NICT). The overall project leader is Prof. Kasai of NICT. The project was granted funding for three years (2013–2016) by the Japan Science and Technology Agency (JST) Research Institute for Science and Technology for Society (RISTEX).

2.1.3 Methodology and Results

First, our project conducted a survey to review the relevance of published literature related to each component of the research project, with the objective of developing a method to clarify the extent of the contributions of science, technology, and satellite data to policy through the assessment of literature and documents. The survey included a broad array of studies, from legal and institutional methods to economic methods (cost effectiveness analysis), and other literature on space and remote sensing policy and technology in general. The survey further focused on studies done in the U.S. and Europe that relate to satellite Earth observation and its impact on society in broad terms. The main findings were that: U.S. governmental Earth observation missions are mainly designed based on a survey of scientific requirements [i.e., the decadal survey for Earth science (NRC 2007)] in coordination with budget priorities; the European Global Monitoring for Environment and Security (GMES) program, now called Copernicus, was established based mainly on (operational) end user requirements and a prospective cost–benefit analysis of the program; very few policy documents or literature include specific references to satellite missions, instruments, or other details; existing studies focus on the socioeconomic benefits more than how satellite Earth observation impacts policy; the only closest methodology that used document analysis found during the survey was by Macauley (2009), which comprised an analysis on the use of Landsat data through searches of peer-reviewed scientific papers.

This survey demonstrated the limitations of assessing the impact of satellite data on policy by using data from document analysis, in that there were only a limited number of sample documents that could be used for the analysis. We also found that even if it is possible to analyze the relationship between satellite data and science, the relationship between science and policy is not a straightforward issue and is very difficult to quantify because of the many complicated factors involved.

In parallel, the project analyzed the case of satellite observations and the ozone regime, namely the Convention for the Protection of the Ozone Layer (United Nations 1985) (hereinafter the 'Vienna Convention') and the Protocol on Substances that Deplete the Ozone Layer (United Nations 1987) (hereinafter the 'Montreal Protocol'). The case was chosen because it is a successful example of an environmental agenda where satellite observations are said to have played a major role and was viewed as an ideal case study for retrospective quantitative analysis.

For this effort, Keio University's group researched the impact of satellite data on the amendment processes of the Montreal Protocol, using documents related to the Meeting of the Parties (MOP) and how satellite missions and instruments are mentioned in those documents. A team from the National Institute for Informatics (NII) worked with a team from JAXA and the Institute for Global Environmental Strategies (IGES) to develop a "dictionary" using the database of Earth observation missions developed by the Committee on Earth Observation Satellites (CEOS). The dictionary was then used to analyze how satellite data are being used in scientific papers and the public media (newspapers).

The NII research group worked with the NICT group to develop a document-sharing platform for analyzing the relevance between datasets from policy and from satellite observations. All groups worked together to populate the database for the platform. Using this platform, the case study on ozone gathered a number of policy-related documents, namely those documents from the Conference of Parties to the Vienna Convention and the Meeting of the Parties of the Montreal Protocol, and scientific resources such as the ozone assessments by the World Meteorological Organization (WMO) and the UN Environment Programme (UNEP). The documents were digitized and made available for electronic searching and mining. The details of this work are described in the following sections. This methodology is thought be adaptable to other issues, such as climate change or Arctic ocean navigation, in order to identify the role(s) of satellite data in those policy areas.

2.1.4 International Advisory Board and Future Prospects

As the project developed, the members decided that the idea of environmental governance could be a meaningful addition to existing research on Earth observation benefits. Since cost–benefit analysis has been one of the most commonly used methodologies for assessing the benefits of Earth observations in several countries/regions, it was thought that if we couple this with an institutional approach involving the role, rights, and duties of stakeholders, we might be able to establish a working cycle of policy and science.

In order for Earth observations and prediction systems to be used comprehensively for decision-making, a process must be established involving all stakeholders and end users. If we regard Earth observations as a tool to achieve the role of monitoring within the international governance system for the environment, appropriate institutions must be developed to achieve optimum use of Earth observations for environmental monitoring. To pursue this path, the project established an International Advisory Board chaired by Prof. Oran R. Young and composed of experts in socioeconomic studies and Earth and remote sensing sciences from around the world. A workshop was held in November 2015 in Tokyo, inviting the Advisory Board members to speak to the public as well as to participate in a workshop on the experiences of their different countries, regions, or organizations and how Japan could pursue its studies.

Taking into account such developments, the PEOIC project in its last year (2015–2016) started an effort to compile and categorize the present work of Earth observations benefits assessments around the world, and to develop criteria and recommendations for realizing an "Innovation Cycle." The project has asked Advisory Board members to submit contributions based on their own experience, using the template made for this study, and advise on how recommendations could be developed. Further, Profs. Oran R. Young and Olav Schram Stokke added some perspectives on a future "Earth Observation Regime Complex."

The following sections describe in detail the research conducted by each team. Section 2.2 addresses the work on the policy component led by Keio University to analyze the ozone regime and the use and impact of satellite Earth observations on the policy for the protection of the stratospheric ozone layer, extending this to the climate change regime. Section 2.3 by NICT and NII describes how data mining techniques were adopted to track the flow of information from satellite Earth observations to policy. Finally, Sect. 2.4 provides some conclusions for the project.

2.2 Protection of the Ozone Layer and Climate Change

2.2.1 Purpose and Methodology of the Case Study

In 1938, chlorofluorocarbons (CFCs) were discovered to be ideal chemicals for use as refrigerants, propellants and solvents, leading to their widespread use in many applications. However, Molina and Rowland (1974) published findings suggesting that CFCs contribute to ozone depletion in the upper atmosphere, which would result in severe consequences for humans and the Earth's ecosystems if left unchecked. The issue became a controversial topic of intense discussion in the scientific community and the findings were contested by the chemical industry, which denied the relationship between ozone depletion and CFCs. For example, Du Pont's congressional testimony said "The chlorine-ozone hypothesis is at this time purely speculative with no concrete evidence… to support it" and "If creditable scientific data… show that any chlorofluorocarbons cannot be used without a threat to health, Du Pont will stop production of these compounds."

Later it was also found that increased ozone in the troposphere is the third largest cause of global warming, only eclipsed by CO_2 and CH_4. Around the end of the twentieth century, it was also proven that global warming directly increases ozone transport from the stratosphere to troposphere, further increasing total ozone concentration, especially in mid-latitudes (WMO 1988a, b; IPCC 2001). A series of scientific findings suggested that it would not be enough nor efficient just to stop the ozone depletion resulting from human activities, but that an international regime to protect and preserve the appropriate climate status must be carefully constructed and maintained through global cooperation.

Such environmental and climate changes had been studied and supported by model simulations based on laboratory experiments, ground-based observations (especially those of Dobson and Brewer using spectrophotometers), and aircraft and balloon observations. However, satellite data constituted the only direct evidence of ozone layer destruction in the stratosphere as well as the increased transport and circulation of ozone between the stratosphere and upper parts of the troposphere (WMO 1988a, b). Ozone depletion in the stratosphere occurs by recombination with atomic oxygen ($O + O_3 \rightarrow 2O_2$), catalyzed by many atmospheric species such as OH, HO_2, NO and NO_2, or Cl and ClO. Satellite data provide convincing evidence that the international community can use to inform the necessary joint measures required to combat the situation. Data in the form of images are particularly impactful and tend to garner more attention and raise awareness of the international society.

This is evidenced in the confirmation of Molina and Rowland's 1974 hypothesis, which suggested that CFCs were destroying the stratospheric ozone layer. The Total Ozone Mapping Spectrometer (TOMS) on Nimbus-7 and the Solar Backscatter Ultraviolet (SBUV) instrument on NOAA-9 confirmed this hypothesis when they found striking evidence of an Antarctic "ozone hole" phenomenon in 1986 (NASA Ozone Watch 2013).

In 1977, the code of conduct for the ozone layer was adopted and the Coordinating Committee on the Ozone Layer (CCOL) was established. In the late 1970s, the U.S. began to ban the use of CFCs, but European countries opposed similar bans due to the cost of alternatives and a claimed lack of evidence. Many developing countries also opposed such measures, fearing repercussions to their industrial development.

Although industry strongly denied the link between CFCs and ozone depletion, the issue came to be discussed more frequently and Canada, Sweden, and Norway followed the lead of the U.S., enacting national legislations to ban the use of CFCs. In 1980, UNEP recommended that States should freeze or reduce the production and use of CFCs.

Finally, in 1985, the *Vienna Convention* was adopted, acting as a framework for international efforts to protect the ozone layer. However, the Vienna Convention does not include any legally binding reduction goals for CFCs. These targets are instead laid out in the accompanying *Montreal Protocol* adopted in 1987.

Today, the Montreal Protocol is arguably cited as: "the single most successful international agreement to date," as stated by Mr. Kofi Anan, the former Secretary General of the United Nations. This mechanism successfully eliminated the use of human-made ozone depleting substances (ODS) by January 1, 2010. It has been proven that the stratospheric ozone layer is now recovering (United Nations Environment Programme 2010).

While it is difficult to isolate the contribution of satellites, as scientific facts are identified using multiple approaches, this chapter studies whether satellite data had an influence on the decisions made during the implementation of the Montreal Protocol. For this purpose, Sects. 2.2.2 and 2.2.3 present the contents and developing obligations provided for in the Montreal Protocol and its later amendments. Section 2.2.4 explores whether a series of satellite instruments provided substantially important information on which a series of amendments to the Montreal Protocol were made. If this is answered in the affirmative, it would strengthen the basis for accelerating the development of Earth observation satellites through increased international cooperation. Conversely, if the answer is in the negative, it may suggest that there is room to reconsider the role of satellite Earth observations in support of climate policy.

2.2.2 Major Obligations of the Vienna Convention/Montreal Protocol System as an International Regime to Protect the Ozone Layer

The Vienna Convention defines the general obligation of the Parties to take appropriate measures to protect human health and the environment against adverse effects resulting from human activities that have been modifying the ozone layer (United Nations 1985). Parties to the Convention agreed to cooperate by means of systematic observations, research and information exchange, as well as assessment of the effect of human activities on the modification of the ozone layer. The main scientific issues recognized in the Vienna Convention were:

i. the modification of the ozone layer would result in a change in the amount of solar ultraviolet radiation having biological effects (UV-B) that reaches the Earth’s surface and the potential consequences for human health, for organisms, ecosystems, and materials useful to mankind; and,
ii. the modification of the vertical distribution of ozone could change the temperature structure of the atmosphere and the potential consequences for weather and climate.

It was, therefore, specified in Annex I of the Vienna Convention that research into the physics and chemistry of the atmosphere would be conducted by means of not only laboratory studies and field measurements but also “instrument development, including satellite and non-satellite sensors for atmospheric trace constituents, solar flux and meteorological parameters.” Likewise, it was planned that a Global Ozone Observing System of tropospheric and stratospheric concentrations of source gases for the HOx, NOx, ClOx, and carbon families would be constructed as an integration of satellite and ground-based systems. The following gases were specified in Annex I of the Vienna Convention as those to be monitored by the above-mentioned Global Ozone Observing Systems: carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), non-methane hydrocarbon species from carbon substances; nitrous oxide (N_2O) and nitrogen oxides (NO_x) from nitrogen substances; halogenated alkanes including CCl_4, $CFCl_3$ (CFC-11), CF_2Cl_2 (CFC1$_2$), $C_2F_3Cl_3$ (CFC113), $C_2F_4Cl_2$ (CFC114), CH_3Cl, CHF_2Cl (CFC22), CH_3CCl_3, and $CHFCl_2$ (CFC21); CF_3Br (sources of B_rO_x) and hydrogen (H_2) in bromine substances; and hydrogen (H_2) and water (H_2O) in hydrogen substances. Note that the Vienna Convention only determined the kinds of gases to be monitored, not those to be reduced and ultimately eliminated for the consumption for each member state.

The Montreal Protocol explicitly designates the ODS that will be eliminated from production (United Nations 1987). This Protocol also provides for a grace period for developing countries due to the small amounts of ODS they emitted and their low capacity for developing alternatives to ODS. Annex A of the 1987 Montreal Protocol provides for the following substances: Group I chemicals ($CFCl_3$ (CFC-11), CF_2Cl_2 (CFC-12), $C_2F_3Cl_3$ (CFC-113), $C_2F_4Cl_2$ (CFC-114), C_2F_5Cl (CFC-115)), to be eliminated after January 1996; and, Group 2 chemicals (CF_2BrCl (Halon 1211), CF_3Br (Halon-1301) and $C_2F_4Br_2$ (Halon 2402)) to stop after 1 January 1994.

The Conference of the Parties (COP) held pursuant to the Vienna Convention may adopt additional protocols and any Party may also propose amendments to the Vienna Convention and to future protocols, taking "due account, inter alia, of relevant scientific and technical considerations." The mechanisms to counterattack the abundance of ODS in the atmosphere by the Vienna Convention/Montreal Protocol include a dynamic process to upgrade and modify the Parties' obligations in accordance with new scientific findings. In fact, as portrayed in the next section, the Montreal Protocol has been amended several times in response to the assessment of scientific findings. In addition, further funding mechanisms were introduced to assist developing countries in the process. This chapter will not address the capacity-building aspects of the ODS reduction strategy, but will focus on the relationship between the scientific findings, especially those obtained by satellite monitoring, and the change of obligations imposed on Parties to the Montreal Agreement (197 Parties as of April 2016). Considering the number of United Nations Member States (193 as of April 2016), it can safely be said that the Vienna Convention/Montreal Protocol regime represents one of the most established international regimes today.

2.2.3 Dynamic Obligations of ODS Elimination

2.2.3.1 Amendments and Adjustments of the Montreal Protocol

New scientific findings have led to changes in the obligations of the Montreal Protocol. Since entering into force in 1989, the Montreal Protocol has been amended ten times through two kinds of changes: narrow “amendments” and methodological “adjustments”. The former means adding a new ODS to the list of substances to be eliminated. As this makes the Montreal Protocol more stringent than the original version, financial mechanisms have also been created to alleviate the burden on developing countries. The MOP to the Montreal Protocol adopted amendments to the Protocol four times. They are generally known by the names of the city where the annual MOP was held: the London Amendment (adopted in 1990, entered into force in 1992), the Copenhagen Amendment (1992, 1994), the Montreal Amendment (1997, 1999), and the Beijing Amendment (1999, 2002). As the traditional international technique is applied for the amendment, amended versions of the Montreal Protocol are applicable only to those States that have ratified them. As of April 2016, all 197 member States of the Montreal Protocol have ratified all four amended versions.

“Adjustment” refers to the acceleration of the reduction and elimination schedule in the production, consumption, and transfer of controlled substances that have already been designated in the original Montreal Protocol and its amended versions. Adjustments are possible if a two-thirds majority in the MOP is achieved, unless consensus is reached without a vote, and resulting adjustments are automatically applicable to all Parties. Adjustment becomes effective 6 months from the date of the notification by the Depositary. The Montreal Protocol has been adjusted six times as of April 2016: London (1990, 1991), Copenhagen (1992, 1993), Vienna (1995, 1996), Montreal (1997, 1998), Beijing (1999, 2000), and Montreal (2007, 2008).

2.2.3.2 ODS Added and Accelerated Through Amendments and Adjustments

London Amendment and Adjustment: The first Amendment to the Montreal Protocol was agreed upon by the second MOP held in London. This amendment entered into force 2 years later, in 1992. This amendment required a halt to the consumption or production of chemicals including a variety of CFCs, including carbon tetrachloride (CCl_4) and trichloroethane (methyl chloroform) after January 1, 1996 (United Nations Environment Programme Ozone Secretariat 1990). More specifically, the following ODS were added: F_3Cl (CFC-13), C_2FCl_5 (CFC-111), $C_2F_2Cl_4$ (CFC-112), C_3FCl_7 (CFC-211), $C_3F_2Cl_6$ (CFC-212), $C_3F_3Cl_5$ (CFC-213), $C_3F_4Cl_4$ (CFC-214), $C_3F_5Cl_3$ (CFC-215), $C_3F_6Cl_2$ (CFC-216), C_3F_7Cl (CFC-217), CCl_4, and $C_2H_3Cl_3$ (1,1,1-trichloroethane). The second MOP also adopted an accelerated schedule for the implementation of the CFCs (CFC-11, -12, -113, -114, -115) and Halons (Halon-1211, -1301, -2402), thus replacing Art. 2, paras. 1 and 2 with Art. 2A (CFCs) and Art. 2B (Halons) of the Montreal Protocol.

Copenhagen Amendment and Adjustment: The fourth MOP held in Copenhagen in 1992 added the following controlled substances: Hydrobromofluorocarbons (HBFCs) and CH_3Br (methyl bromide) (United Nations

Environment Programme Ozone Secretariat 1992). The same MOP succeeded in a further adjustment that accelerated the schedule of controlling the following substances: CFCs, Halons, other fully halogenated CFCs, $CCCl_4$ and 1,1,1-Trichloroethane (Methyl Chloroform).

Vienna Adjustment: While no amendment was accomplished in the seventh MOP held in Vienna in 1995, another adjustment was successfully decided, which became effective in 1996. The Vienna Adjustment accelerated the controlling schedule of HCFC and methyl bromide (United Nations Environment Programme Ozone Secretariat 1996a, b). Implementing the reduction ahead of schedule with respect to the following substances was also agreed upon vis-à-vis developing countries: CFC, Halon, Carbon Tetrachloride and 1,1,1-Trichloroethane (Methyl Chloroform) that had been previously only been the obligation of developed countries (United Nations Environment Programme Ozone Secretariat 1996a, b).

Montreal Amendment and Adjustment: The ninth MOP held in Montreal in 1997 did not add new substances to be eliminated; instead, the Amendment banned the trade of methyl bromide between the Parties and non-Parties, as well as providing further trade restrictions on new, used, recycled, and reclaimed controlled substances (United Nations Environment Programme Ozone Secretariat 1997a, b). The Adjustment accelerated the schedule of controlling methyl bromide, etc. (United Nations Environment Programme Ozone Secretariat 1997a, b).

Beijing Amendment and Adjustment: The 11th MOP held in Beijing in 1999a, b agreed that HCFCs and bromochloromethane (CH_2BrCl) would be included as controlled substances (United Nations Environment Programme Ozone Secretariat 1999a, b). It also banned the import and export of CH_2BrCl from and to non-Parties. Another Adjustment agreed in this MOP was the accelerated implementation of the CFCs, Halons, other fully halogenated CFCs and methyl bromide to the level of the basic domestic needs for developing countries (United Nations Environment Programme Ozone Secretariat 1999a, b).

Montreal Adjustment: No further changes to the obligations were decided for an 8-year period, but it was then decided at the 19th MOP in Montreal in 2007 to accelerate the control schedule of HCFCs for developing countries (United Nations Environment Programme Ozone Secretariat 2007).

Efforts for Further Amendments: Since MOP21 (2009), several countries have been proposing a freeze on HFC consumption and production. If adopted, such a freeze would be applicable to developed countries at first and then gradually to developing countries (United Nations Environment Programme 2009). This has been proposed because HFCs, originally developed as alternatives to ODS, have now been demonstrated to have a high global warming potential (United Nations Environment Programme 2015). Ongoing debate has discussed whether this falls under the mandate of the Montreal Protocol, as HFCs are not ODS. Either way, this fact only reinforces the importance of scientific findings and a holistic approach.

2.2.4 Satellite Instruments Used for Ozone Monitoring

2.2.4.1 Satellite Observations Before the Montreal Protocol

We seek to determine if satellite observations since the 1970s have had any influence on the choice of the substances specified in the Montreal Protocol and each amendment or adjustment thereof. The aim of this section is to study if there is a potential link to be found between satellite monitoring and the adoption and changing of international policy instruments.

Satellite measurements of total ozone started when the Infrared Interferometer Spectrometer (IRIS) and Backscatter Ultraviolet (BUV) instruments on Nimbus-4 were launched in 1970 (WMO 1981). Major instruments used in the 1970s included BUV, which continued to monitor for the next 7 years; the previously mentioned SBUV and TOMS, launched in 1978; TIROS Operational Vertical Sounder (TOVS) on TIROS-N; Limb Infrared Monitor of the Stratosphere (LIMS) on Nimbus-6; Stratospheric Aerosol and Gas Experiment (SAGE) on AEM-2; and the Upper Atmosphere Research Satellite (UARS). Most of the instruments/satellites were used to monitor the concentration of CO_2, O_3 and NO_2. SAGE (since 1979) and SAGE-II (since 1984) measured O_3, NO_2 and H_2O; and the Solar Mesospheric Explorer (SME) (launched in 1981) measured O_3, O_3 photodissociation rates, temperature, H_2O, thermal emissions, and NO_2 (WMO 1985a, b).

Until the late 1970s, atmospheric tides were just a theory to be verified by observation. The results of laboratory and ground-based experiments into the concentration of ozone in the middle and upper atmosphere also differed from one experimental technique to another, highlighting the need for direct, consistent, and comparable measurements. The scientific community anticipated the use of satellites for such measurements.[1] Stratospheric circulation and the exchange of constituents between the troposphere and the stratosphere started being measured in the late 1970s.

As early as 1981, the scientific community pointed out that newly introduced satellite observations considerably reduced the geographical limitations on measuring total ozone (WMO 1981). Remote sensing by satellite also contributed to recording large-scale, slowly varying disturbances, which provided a picture of the global mean distribution of ozone and its variations with a wide coverage (WMO 1981).

Climatology literature in the early 1980s stated that there was compelling evidence that the composition of the atmosphere was changing and some recent satellite monitoring, e.g., that of the vegetation index of plant activity in 1982, had been effective in precisely identifying the situation (WMO 1985a, b). It was emphasized that the continued development of baseline measurements for CO,

[1]It is stated in one WMO report that "[o]ne of the major difficulties encountered in the literature of estimating global total ozone variations is that there is no unique way to estimate such changes from the given ground-based data set" (WMO 1985a, b).

CH_4, N_2O, CO_2, and halocarbons were vital, and the already accomplished global coverage by Nimbus-7 TOMS ozone column measurements, Stratospheric and Mesospheric Sounder (SAMS) and LIMS data from Nimbus-7, and Stratospheric Sounding Unit (SSU) data from TIRON-N showed promise for the investigation of chemistry exchange processes (WMO 1985a, b). In addition to the SBUV and TOMS measurements, SAGE and SAGE-II measured O_3, NO_2, and H_2O; and the SME measured O_3, O_3 photodissociation rate, temperature, H_2O, thermal emission, and NO_2. For the future, it was proposed that "[a] satellite-borne CO sensor, operating for extended periods ($\sim$years), could help enormously."

By the mid-1980s it was proven that the changing composition of the atmosphere influenced ozone depletion and that continued development of baseline measurements for CO, CH_4, N_2O, CO, and halocarbons (CH-11, CH-12, CCl_4, etc.) was vital to understand future ozone states.

While it may be said that satellite monitoring—in particular the global scale image of the ozone hole—played an important role in advancing ozone management policy to the extent that this helped the adoption of the Vienna Convention, it is fair to conclude that it was one of several techniques used to measure ozone concentration up until the mid-1980s. There is no evidence that satellite data by itself aided the decisions related to the concrete obligations of the Montreal Protocol (e.g., which specific substances to eliminate), though it can be said that scientific assessment by that time was a major source of information on which the drafting of the Montreal Protocol was based.

2.2.4.2 After the Montreal Protocol: Amendments and Adjustments

In 1998, just 1 year after the adoption of the Montreal Protocol, the WMO published another two-volume *Report of the International Ozone Trends Panel 1988* (WMO 1988a, b). The contents of this report differed greatly from the one published 3 years earlier. The most distinguished difference was the increased number of explanations of satellite-borne instruments and their use in measuring aerosol variations. It is even concluded in the report that: "either the ground-based or the satellite system could be assumed to be the standard, and the other system the one of uncertain quality to be tested against it" (WMO 1988a, b). Sensors such as SBUV are less susceptible to aerosol effects from ground-based natural phenomena, such as volcanic eruptions, and are regarded as highly efficient in detecting aerosol abundance (WMO 1988a, b). According to the report, there was extensive observation of trends in source gases including halocarbons such as CCl_3F, CCl_2F_2, CH_3CCl_3, CCl_4, other chlorocarbons, bromocarbon species, NO, CH_4 and trace gases influencing tropospheric ozone and hydroxyl radical concentrations. They were sometimes observed directly and other times indirectly via connected chemical processes. Some of the CFCs and HCFCs were added in the 1990 London Amendment and some of the CFCs and Halons were in the London Adjustment. Comparing the observed gases with those specified in the London Amendment, it can be said that satellite monitoring had an impact on ODS control decisions.

2.2.5 *Circumstantial Evidence? Reports from SAP and ORM*

The Scientific Assessment Panel (SAP), established in accordance with Art. 6 of the Montreal Protocol, assesses the status of the ozone layer and relevant atmospheric science issues. Technical and scientific assessments reported to the Parties at least every 4 years demonstrate:

i. the increased importance of scientific evidence for the amendment and adjustment of the Montreal Protocol; and,
ii. the increased importance of satellite monitoring among observations (WMO/UNEP 2016).

The relationships between scientific assessment and protocol amendment/adjustment are seen in a chart from WMO/UNEP (2010), which is reproduced as Table 2.1. The contents of each Scientific Assessment of Stratospheric Ozone mostly correspond to the subsequent amendment/adjustment of the Montreal Protocol (WMO/UNEP 2014).

Table 2.1 Relationships between scientific assessment and protocol amendment/adjustment (WMO/UNEP 2010)

Year/policy process	Scientific assessment
1981	The stratosphere 1981: theory and measurements
1985 (Vienna convention)	Atmospheric ozone 1985
1987 (Montreal protocol)	
1988	International ozone trends panel report: 1988
1989	Scientific assessment of stratospheric ozone: 1989
1990	London amendment and adjustments
1991	Scientific assessment of ozone depletion: 1991
1992	Methyl bromide: its atmospheric science, technology, and economics (Assessment Supplement)
1992	Copenhagen amendment and adjustments
1994	Scientific assessment of ozone depletion: 1994
1995	Vienna adjustments
1997	Montreal amendment and adjustments
1998	Scientific assessment of ozone depletion: 1998
1999	Beijing amendment and adjustments
2002	Scientific assessment of ozone depletion: 2002
2006	Scientific assessment of ozone depletion: 2006
2007	Montreal adjustments
2010	Scientific assessment of ozone depletion: 2010
2014	Scientific assessment of ozone depletion: 2014

Likewise, as the chart in the executive summary of the *Scientific Assessment of Ozone Depletion: 2010* clearly shows, satellite observations are clearly of increased importance in the total assessment (WMO/UNEP 2010).

In addition to the SAP reports, Ozone Research Managers (ORM), established at the occasion of the first COP of the Vienna Convention in 1989, communicate scientific reports of ozone status every 3 years, 6 months before the respective COP (United Nations Environment Programme Ozone Secretariat 2016). Unlike the SAP reports, ORM reports include national reports. Examinations of each national report from 2002 (fifth meeting) to 2014 (ninth meeting) show that the States have increasingly relied on satellite Earth observation for monitoring the ozone situation.[2] The key sensors used by reporting states include TOMS on Nimbus-7, Meteor-3, ADEOS, and Earth Probe; SBUV on Nimbus-7, -9, -11, -14, -16, -17, -18, -19; SCIAMACHY on Envisat; OMI on EOS-Aura; TES on EOS-Aura; GOME-2 on Metop-A and Metop-B; SAM II on Nimbus-7; SAGE II on AEMB and ERBS; MLS on UARS and EOS-Aura; HALOE on UARS; POAM II on SPOT-3 and POAM III on SPOT-4; OSIRIS and SMR on Odin, SAGE-III on Meteor-3 M; MIPAS and GOMOS on Envisat; ACE on SCISAT; and HIRDLS on EOS-Aura (WMO 2016). Of these, the TOMS instrument is the most frequently cited. All of these sensors can measure O_3, NO_2, SO_2, HCHO, BrO and OCIO, and monitor various areas of the world. The missions are complementary and provide ozone measurement continuity from the initial TOMS/SBUV missions that had a significant impact on the early stages of decision-making in international ozone policy.

Drawing from all the WMO national reports from 2002–2014, the SAP reports, and other ozone monitoring techniques, it is clear that satellite monitoring has played an important role in the amendments and adjustments to the Montreal Protocol (Levelt et al. 2006; Gebhardt et al. 2014).

2.2.6 Tentative Conclusions and Way Forward

As a tentative conclusion, our comparison of the scientific and technical literature with the texts of the Montreal Protocol and subsequent amendments/adjustments suggests that the results of scientific assessments determine the ODS identified in the Montreal Protocol and its amendments/adjustments. Our research also suggests that there is a growing role for satellite observations. Therefore, it seems reasonable to conclude that satellite data, alongside other scientific evidence, have jointly determined the Montreal Protocol obligations.

[2]As archived satellite data has been used by reporting states, satellite instruments referred to by those states could be historical. Examples are the TOMS sensor on Nimbus-7 and Meteor-3 (1978–1994) as well as ADEOS and Earth Probe (1996–2006), which were mentioned even in the ninth ORM report in 2014 by Brazil, Chile, China, Indonesia, Mongolia, Norway, Turkey and USA (UNEP 2014).

Satellite Earth observations may have a long-term role to play in other policy studies. One such example could be the challenges posed by the changing Arctic environment.

Arctic sea ice needs to be monitored for safe ship navigation. Current global warming trends may be causing Arctic sea ice shrinkage, making arctic waterways more easily navigable without icebreaker ships. This could generate new issues related to the exploitation of natural resources in previously pristine areas. However, international and national laws in this area are inconsistent, and the Arctic Council has had to play a primary role in governance in order to establish international policies in areas where natural conditions are rapidly changing. The eight Member States of the Arctic Council are the coastal states of the Arctic. The Member States decide most of the rules. Other states have interests in this area (such as Japan, China, and Korea), but they are only allowed to become Observer States and cannot participate directly in the rule-making process. In this situation, a state with highly advanced technology can contribute to policymaking by providing the scientific data necessary for Arctic research.

Japan carries out many research projects, such as the Green Network of Excellence (GRENE) Arctic Climate Change Research Project and the Arctic Challenge for Sustainability (ArCS) project led by the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

Japan operates two satellites capable of supporting this issue:

i. Ibuki, the Greenhouse gases Observing SATellite (GOSAT) led by JAXA, the Ministry of the Environment (MOE), and the National Institute for Environmental Studies (NIES), is the first satellite designed specifically to observe CO_2, CH_4, and other greenhouse gases to monitor their status/inventory; and,
ii. GCOM-W, led by JAXA, provides unique information for monitoring the size of arctic sea ice.

Another powerful tool would be precise weather forecasting in the Arctic, whereby multiple satellites observe water vapor, clouds, snow, and raindrops with a temporal–spatial resolution of about 1 h and in the order of 1–2 km (not only horizontal but also vertical) using Terahertz (THz) microwave passive sensors. THz technology would enable the use of mini-satellites for these multi-satellite observations. The data resulting from Japanese research would be recognized as important scientific knowledge and might contribute to the protection and effective use of the Arctic.

2.3 A Quantitative Approach for Linking Policy and Satellite Earth Observation Using Text Mining Techniques

2.3.1 Introduction

At first glance, policy or decision-making and satellite Earth observation belong to entirely different fields. However, there is a commonality if we focus on the reports and publications that contain information from both of these areas. This section describes a text mining technique to quantify possible linkages between decision-making and satellite Earth observation.

Text mining retrieves high quality information from text data using statistical and mathematical techniques. In the mid-1980s, labor-intensive manual work was the primary approach to text mining. Advances in computing technology over the past few decades have allowed the automation of text mining methods and the development of many useful computer-coded tools. Text mining is now widely applied in many fields, not only in science but also in marketing, for example for the design of new products using information from customer surveys. Natural language processing (NLP) techniques are essential. NLP is the analysis of human language so that computers can understand natural languages as human do. With the assistance of human experts, NLP techniques are capable of providing a way to verify the detected relationship across different text collections.

Below we describe an investigation into the role of satellite Earth observation in the decision-making process for the Montreal Protocol. A quantitative linkage between the decision-making process and satellite Earth observation is then described.

2.3.2 Role of Satellite Earth Observation in Policy Decisions for the Montreal Protocol

The reports of the MOP to the Montreal Protocol were used as the documents that represent the policy decision-making process. As described above, the Montreal Protocol has been updated through several amendments and adjustments. These amendments and adjustments are discussed and determined by the MOP, whose reports have been published every year from 1990.

One basic and commonly used approach in text mining involves counting the number of times a word occurs. We performed a morphological analysis that assigns a part of speech for all words in 25 MOP reports between 1990 and 2014. Only nouns, verbs, and adjectives were extracted from the MOP reports because other less meaningful words, such as articles "the" or "a", function as noise in this analysis. We used the Stanford Log-Linear Part-Of-Speech Tagger (Toutanova and Manning 2000; Toutanova et al. 2003) for the morphological analysis. Figure 2.2 shows an example result of the morphological analysis in this study. To unify words with different notations, such as "satellite" and "satellites," plural nouns were converted to the singular. Verbs were converted to the base form. Linking verbs, such as "am", "are", and "be", were omitted from the documents. Abbreviations and fully spelled words were also unified into abbreviations. For example, "hydrofluorocarbon (HFC)" was converted to "hfc". All capital letters in the documents were converted to lower case.

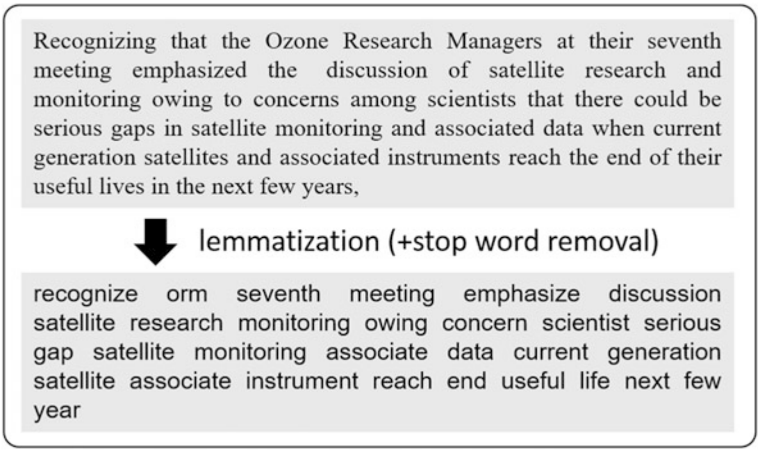


Fig. 2.2 An example of the morphological analysis in this study. The original sentence is quoted from decision VCVIII/2: recommendations Adopted by the Ozone Research Managers at their seventh meeting (United Nations Environment Programme Ozone Secretariat 2008)

We focused on the word “satellite” to investigate how satellite Earth observation is dealt with in the MOP. The word “satellite” appeared 19 times in all of the 25 MOP reports. All of the words “satellite” were used in relation to satellite Earth observation in the MOP reports, so we may take the word “satellite” as being representative of the topic of satellite Earth observation. Figure 2.3 shows the number of occurrences of the word “satellite” in the MOP reports over time. The results showed that the word “satellite” appeared 13 times in 2008, so we focused on this year.

To investigate the topic in which the word “satellite” is used, we selected the sentences that include the word “satellite” and the sentences immediately before and after. We then extracted the words that appeared more than five times in the selected sentences. To extract significant words from those in the selected sentences, we introduced a term frequency-inverse document frequency (*tf-idf*) method to quantify the significance of a word. The basic goal of *tf-idf* is to quantify the significance of each word in a document. In this study, we employed a *tf-idf* defined by Gamon et al. (2005) as follows. Here w and d represent the indexes of the word and document.

$$tf\text{-}idf_{\mathrm{w,d}} = \begin{cases} \left\{1 + \log\left(tf_{\mathrm{w,d}}\right)\right\} \times log\left(N_{\mathrm{doc}}/df_{\mathrm{w}}\right), & tf_{\mathrm{w,d}} \geq 1 \\ 0, & tf_{\mathrm{w,d}} = 0 \end{cases} \tag{2.1}$$

A detailed explanation of *tf-idf* is described below. The simplest approach when assigning the significance of the word w in document d is to count the number of occurrences, which is called term frequency ($tf_{\mathrm{w,d}}$). In this equation, $tf_{\mathrm{w,d}}$ is modified to be $1 + \log(tf_{\mathrm{w,d}})$. However, the raw tf value is not enough to quantify the significance of the words because it is impossible to distinguish those words that

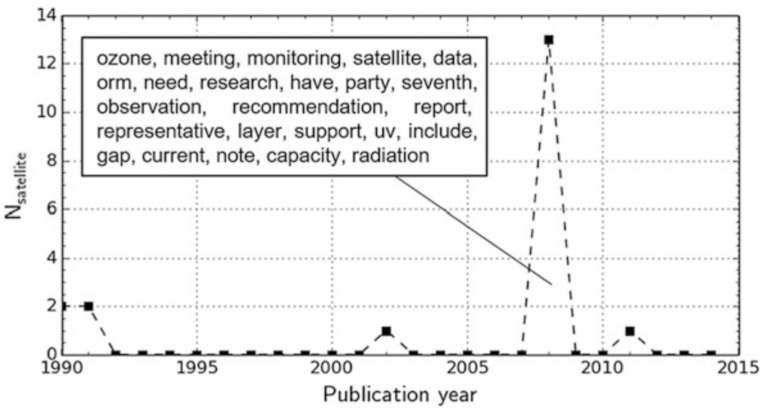


Fig. 2.3 Number of occurrences of the word "satellite" ($N_{satellite}$) in the MOP reports from 1990 to 2014. The words in the *square box* are those that appear more than five times in the selected sentences around the word "satellite"

appear in all documents from those that appear only in a few. If the *tf* values of these words are equal, the significance should be different. For example, the word "meeting" appears many times in the MOP reports but the significance of the word "meeting" should be low. To solve this problem, the idea of document frequency (*df*) is introduced. The document frequency is defined as the number of documents that contain the word *w*. The significance of a word should be high when the *df* value is low, thus the inverse document frequency (*idf*) of a word scaled with the total number of documents N_{doc} is introduced. In this study, the value of *idf* for the word *w* is calculated by $\log(N_{doc}/df_w)$. The value of $tf\text{-}idf_{w,d}$ is calculated by $tf_{w,d} \times idf_w$.

Here each MOP report is treated as one document. The five most significant words determined by *tf-idf* were "satellite", "orm", "gap", "seventh" and "observation". The word "orm" means the Ozone Research Managers (ORM), which include government atmospheric research managers and government managers of research related to health and environmental effects of ozone modifications. The ORM meeting reviews ongoing national and international research and makes recommendations for future research and expanded co-operation between researchers in developed and developing countries for consideration by the Conference of the Parties to the Vienna Convention (Table 2.2).

In the seventh ORM meeting held in 2008, a problem with the NASA Aura satellite mission was discussed. The Aura satellite is equipped with four instruments to observe ozone and ozone-related species in the stratosphere and troposphere. The Aura satellite and its predecessor NASA satellites, such as the Upper Atmosphere Research Satellite (UARS) and Nimbus series, have been continuously observing the Earth's atmosphere. The problem was that some of the instruments might have stopped operating anywhere between 2008 and 2010, resulting in a serious gap in the long-term monitoring of ozone since the 1970s. Fortunately, the Aura satellite is

Table 2.2 Ranking of words with high *tf-idf* values

Word	*tf–idf*	N_{word}
"Satellite"	5.738	13
"Orm"	5.515	11
"Gap"	2.424	8
"Seventh"	1.846	8
"Observation"	1.783	8

orm ozone research managers, N_{word} number of word occurrences

still operational as of July 2016 and other agencies' satellites, such as Odin and SCISAT, also continue to monitor atmospheric ozone. As a consequence, there has been no serious gap in the long-term satellite monitoring of ozone. We emphasize that the MOP in 2008 also raised this problem and mentioned the importance of long-term monitoring using satellites. It is clear that satellite Earth observation plays a role in policy decisions by providing data on long-term trends of atmospheric substances.

2.3.3 Quantifying the Correlation Between Policy and Satellite Earth Observation

The Montreal Protocol has been updated through amendments and adjustments. Any discussion of amendments and adjustments should be based on scientific evidence, such as long-term trends of ozone and species related to ozone. We therefore have focused on the discussion phase for amendments and adjustments to quantify the correlation between policy, or decision-making, and satellite Earth observation.

The MOP has recently focused on hydrofluorocarbons (HFCs), a significant non-ODS alternative to CFCs, which have, however, now been shown to have significant global warming potential. Since the latter half of the 1990s, global warming and climate change have joined ozone depletion as major issues on the global environmental agenda. In 1997, the Kyoto Protocol to the UN Framework Convention on Climate Change (UNFCCC) was adopted and entered into force in 2005. The Protocol aims to provide specific goals for international efforts to reduce the emission of greenhouse gases. The phasing out of HFC production and consumption was first proposed by several countries at MOP21 (2009).

Figure 2.4a shows the number of occurrences of the word "hfc" (N_{HFC}) in the MOP reports over time. The adoption of the Kyoto Protocol in 1997 triggered a rapid increase in N_{HFC} in 1998. After the phasing out of HFCs was proposed in 2009, N_{HFC} rose to over 150 in 2014. The increasing ratio (*IR*) of the word "hfc" was the largest among the substances appearing in the MOP reports.

Table 2.3 shows the five words with the highest *IR* values in the MOP reports. In this study, the value of *IR* for the word w (IR_w) was defined as follows. N_{doc} is the

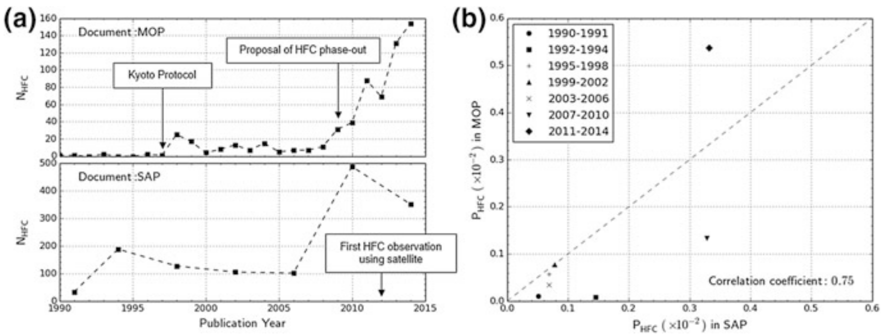


Fig. 2.4 **a** Time trends for the number of occurrences of the word "hfc" (N_{HFC}) in the MOP (*upper panel*) and SAP reports (*lower panel*) from 1990 to 2014, **b** Scatter plot of the probabilities of occurrences (P_{HFC}) in the MOP and SAP reports. The MOP probabilities are averaged for a period corresponding to the time interval of the SAP report publications. The correlation coefficient is estimated to be 0.75

Table 2.3 Ranking of words with high *IR* values among the words of substances

Word	Full Word	*IR*
"hfc"	Hydrofluorocarbon	0.409
"ghg"	Greenhouse gas	0.258
"hfo"	Hydrofluoroolefin	0.239
"h2o"	Water vapor	0.231
"co2"	Carbon dioxide	0.175

total number of documents. N_m is the number of documents to calculate the mean standard of the number of occurrences and was set to four in this analysis, corresponding to the time interval of the publication of the Scientific Assessment of Ozone Depletion prepared by the SAP.

$$IR_w = \text{Mean}\left(ir_{w,N_m}, \ldots, ir_{w,N_{doc}}\right), ir_{w,d} = \frac{N_{w,d} - \text{Mean}\left(N_{w,d-N_m}, \ldots, N_{w,d}\right)}{\text{Mean}\left(N_{w,d-N_m}, \ldots, N_{w,d}\right)} \quad (2.2)$$

The SAP report is used to represent scientific research publications in this study. The SAP reports are prepared every 3–4 years based on a number of scientific papers, pursuant to Article 6 of the Montreal Protocol. The Panel consists of hundreds of top scientists and investigates the status of the depletion of the ozone layer and relevant atmospheric scientific issues. The lower panel of Fig. 2.4a shows the time trend of N_{HFC} in the SAP reports published from 1991 to 2014. In 2010, N_{HFC} increased to about 500, which is consistent in terms of time with the proposal of HFC phase out at MOP21 in 2009. Figure 2.4b shows the correlation between the probabilities of occurrences of the word "hfc" (P_{HFC}) in the MOP and SAP reports. The value of P_{HFC} is calculated by N_{HFC} divided by the total number of words (N_{All}). The value of P_{HFC} was averaged during the time interval of the SAP report publications. This figure shows a positive correlation of P_{HFC} between the MOP and SAP reports, with a correlation coefficient of 0.75. Although we could not identify from this analysis whether science drives policy or vice versa, this does demonstrate a certain connection between policy and science.

As described in Sect. 2.3.2, the role of satellite Earth observation is to provide decision-makers information on the long-term trends of atmospheric substances. Satellite observations of HFCs were first reported in 2012 using the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) onboard the SCISAT-1 satellite (Harrison et al. 2012). The long-term trend of HFCs derived from satellite Earth observations might accelerate further amendments covering HFC production and consumption.

2.3.4 Conclusion

The correlation between policy and satellite Earth observation was investigated for the Montreal Protocol using basic text mining techniques. We utilized several methods and found that correlations by trend analysis with temporal sequences were the best approach to assessing satellite observations and the Montreal Protocol. Tracing the word "satellite" in the MOP reports, our analysis suggested that satellite Earth observation plays a role in policy through the provision of data on long-term trends in atmospheric substances. A certain correlation (correlation coefficient of 0.75) was shown using the word "hfc" for temporal trends in the text from MOP and SAP reports.

To our knowledge, this is the first investigation of whether satellite Earth observations have an impact on policy using text mining techniques. More in-depth investigations are needed to provide a more detailed understanding.

2.4 Conclusions from the Study of the Policy and Earth Observation Innovation Cycle

The research project entitled "Policy and Earth Observation Innovation Cycle" began in November 2013. The objective was to identify why satellite Earth observations are needed in the context of global environmental policymaking.

Satellite Earth observations provide useful information for agriculture, resource exploration, industry, and numerous other applications. Meteorological satellites are perhaps the most prominent, facilitating weather forecasting.

Questions remain over the use of satellites for environmental monitoring—who are the public users other than research scientists and are the data obtained providing societal benefits consistent with the taxpayers' investment? It appears that a quantitative answer has yet to be developed as a rationale to support the use of satellites for environmental observations.

The functions of satellite observations can be categorized according to their spatiotemporal resolutions. Figure 2.5 presents a summary of satellite usage by spatiotemporal scale. It is clear that environmental satellite observations are currently used for long-term trends and global problems. We therefore analyzed global policy in our study.

The purpose of the PEOIC project was to find a method for the quantitative evaluation of the impact of satellite Earth observations on policy. Planning for satellite observations to address environmental issues—such as ozone depletion, global warming, and air quality—has always been part of policy, such as the Montreal Protocol, the UNFCCC and the Climate and Clean Air Coalition. We have attempted to provide quantitative evidence of the effect of satellite observations on policy by using a mathematical method.

The process of the project was:

1. Define the general system of the PEOIC as shown in Fig. 2.1 in Sect. 2.1 (led by Yasuko Kasai with the assistance of Prof. Yoshifumi Yasuoka).
2. Perform an intensive survey of past evaluation methods for several satellite observations (led by Masami Onoda). The survey identified the limitations of assessing the impact of satellite data on policy using document analysis. Only a limited number of sample documents can be used for such analysis. It was also found that even if it is possible to analyze the relationship between satellite data and science, the relationship between science and policy is not straightforward and is difficult to quantify due to the many complicated factors involved.
3. Select the target policy (all team members). We selected an example of a previously successful policy, namely the Montreal Protocol. Satellite observation is

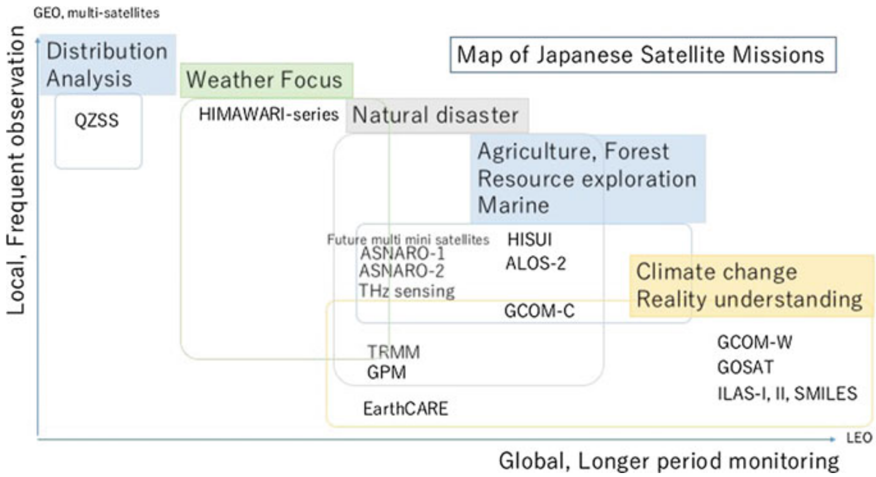


Fig. 2.5 Overview of current Japanese satellite missions according to the spatiotemporal scale of their observations

the only feasible way to monitor the overall size of the ozone hole in the polar regions, and provides scientific evidence of ozone layer recovery.

4. Define the flow between the Montreal Protocol and the scientific data, including satellite Earth observations (all team members). We confirmed that scientific observations, including satellite measurements, have different roles in the policymaking process. There was an increase in the number of scientific papers and satellite operations (as shown in Fig. 2.6) after the Montreal Protocol was agreed in 1987 in a bid to understand the reality and mechanisms of ozone depletion. Our study demonstrated that the agreement of the Montreal Protocol in 1987 resulted in increased satellite launches.
5. Determination of the documentation used in policy and scientific research (all members). This task was very important for our approach and it took more than one year to define the documentation. Figure 2.7 demonstrates the scope of this task with an organizational map of the Vienna Convention and Montreal Protocol (prepared by Setsuko Aoki). WMO/UNEP Scientific Assessments of Ozone Depletion were also used.
6. In-depth evaluation of the policy and scientific documentation, as summarized in Sect. 2.2 (Setsuko Aoki). We conclude that the results from scientific assessments determine the ODS to be eliminated in the Montreal Protocol and its amendments/adjustments. It seems that satellite data alongside other scientific evidence jointly determined the obligations of the Montreal Protocol system.
7. Perform data mining to determine the correlation between scientific input and MOP decisions, as shown in Sect. 2.3 (Tomohiro Sato with Akiko Aizawa, Masami Onoda, Setsuko Aoki, Yasuko Kasai). We tried several methods and found the correlations from trend analysis with temporal sequences to be the

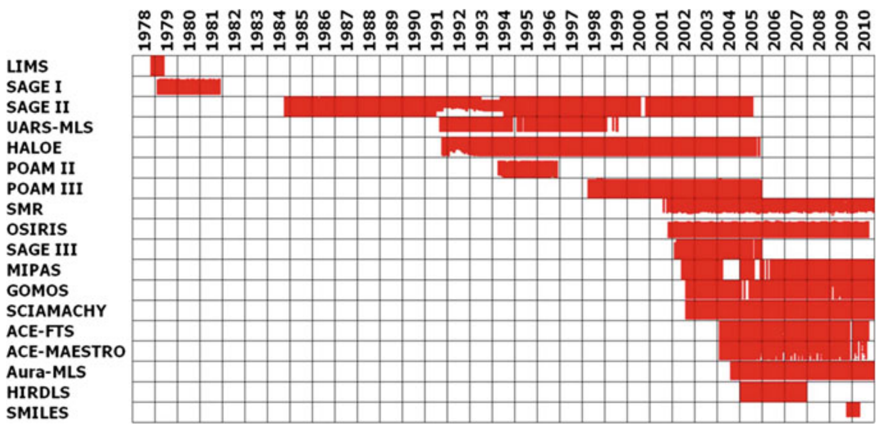


Fig. 2.6 Figure 2.1 from Tegtmeier et al. (2013). The number of limb-sounding satellite instruments used to observe ozone and related species increased after the agreement of the Montreal Protocol in 1987. Note that at that time it took about 10–15 years to develop a new satellite

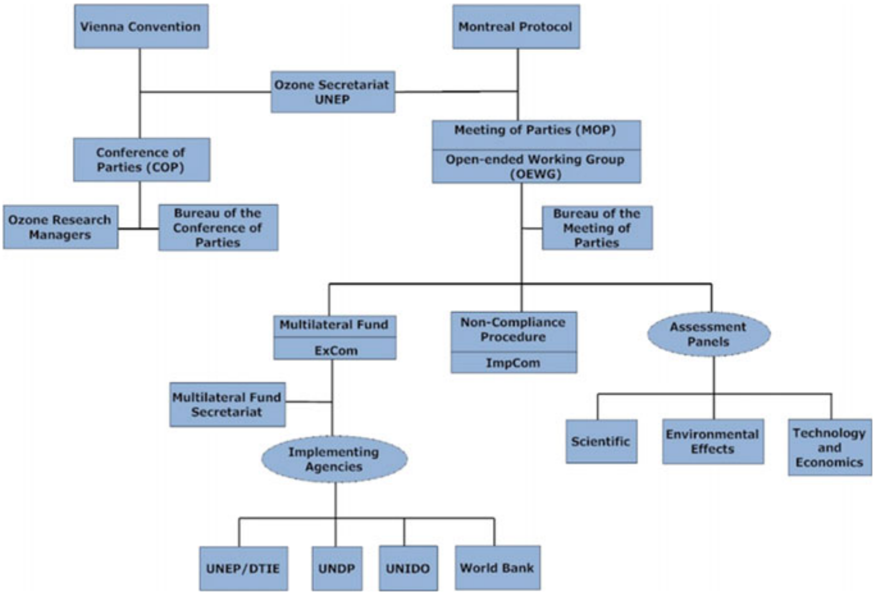


Fig. 2.7 Structure of the Vienna Convention and Montreal Protocol, produced by Setsuko Aoki

best. By tracing the word "satellite" in the MOP reports, the results suggested that satellite Earth observation played a role in policy by providing data on long-term trends in atmospheric substances. A certain correlation (coefficient of 0.75) was shown using the word "hfc" for temporal trends in the text from the MOP and SAP reports.

In conclusion, we have found that satellite monitoring has certainly played an important role in amending/adjusting the Montreal Protocol.

Acknowledgements We are grateful to Prof. Kazuo Matsushita of IGES for guiding the team in initiating and carrying out the project.

References

Booz & Company (2011) Cost-Benefit Analysis for GMES

Future Earth (2016) Home | Future Earth. http://www.futureearth.org/. Accessed 24 Nov 2016

Gamon M et al (2005) Pulse: Mining customer opinions from free text. In: Proceedings of the international symposium on intelligent data analysis, pp 121–132

Gebhardt C et al (2014) Stratospheric ozone trends and variability as seen by SCIAMACHY from 2002 to 2012. Atmos Chem Phys 14(2):831–846

Harrison JJ et al (2012) First remote sensing observations of trifluoromethane (HFC-23) in the upper troposphere and lower stratosphere. J Geophys Res Atmos p 117(D5)

IPCC (2001) Working Report, I. Scientific Basis

Levelt PF et al (2006) Science objectives of the ozone monitoring instrument. IEEE Trans Geosci Remote Sens 44:1199–1206

Macauley MK (2009) Earth observations in social science research for management of natural resources and the environment. Resources for the Future, Washington, DC

Manning CD et al (2008) Introduction to information retrieval. Cambridge University Press, New York

Molina MJ, Rowland FS (1974) Stratospheric sink for chlorofluoromethanes: chlorine atom-catalysed destruction of ozone. Nature 249:810–812

NASA Ozone Watch (2013) Ozone hole watch: facts about ozone hole history. http://ozonewatch.gsfc.nasa.gov/facts/history.html. Accessed 24 Apr 2016

NRC (2007) Earth science and applications from space: national imperatives for the next decade and beyond. National Academies Press, Washington, D.C., USA

PricewaterhouseCoopers LLP (2006) Main report socio-economic benefits analysis of GMES

Tegtmeier S et al (2013) SPARC Data Initiative: a comparison of ozone climatologies from international satellite limb sounders. J Geophys Res Atmos 118(21):12,229–12,247

Toutanova K, Manning CD (2000) Enriching the knowledge sources used in a maximum entropy part-of-speech tagger. http://nlp.stanford.edu/manning/papers/emnlp2000.pdf. Accessed 7 Dec 2016

Toutanova K et al (2003) Feature-rich part-of-speech tagging with a cyclic dependency network. In: Proceedings of HLT-NAACL, Edmonton, pp 252–259

United Nations (1985) Vienna convention for the protection of the ozone layer. United Nations Treaty Series, Vienna

United Nations (1987) Montreal protocol on substances that deplete the ozone layer. United Nations Treaty Series, Montreal

United Nations Environment Programme (2009) UNEP/OzL. Pro. 21/8

United Nations Environment Programme (2010) Key achievements of the Montreal protocol to date. http://ozone.unep.org/Publications/MP_Key_Achievements-E.pdf. Accessed 24 Apr 2016

United Nations Environment Programme (2014) Report of the ninth meeting of the ozone research managers of the parties to the Vienna convention for the protection of the ozone layer

United Nations Environment Programme (2015) UNEP/OzL. Pro. 27/13

United Nations Environment Programme Ozone Secretariat (1990) The London Amendment (1990): the amendment to the Montreal protocol agreed by the second meeting of the parties

United Nations Environment Programme Ozone Secretariat (1992) The Copenhagen Amendment (1992): the amendment to the Montreal protocol agreed by the fourth meeting of the parties

United Nations Environment Programme Ozone Secretariat (1996a) Adjustments agreed at the seventh meeting of the parties relating to controlled substances in annex B. http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/27599. Accessed 14 Apr 2016

United Nations Environment Programme Ozone Secretariat (1996b) Adjustments agreed at the seventh meeting of the parties relating to controlled substances in annexes C and E. http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/27600. Accessed 14 Apr 2016

United Nations Environment Programme Ozone Secretariat (1997a) Adjustments agreed in 1997 in Montreal at the ninth meeting of the parties. http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/27601. Accessed 14 Apr 2016

United Nations Environment Programme Ozone Secretariat (1997b) The Montreal Amendment (1997): The amendment to the Montreal protocol agreed by the ninth meeting of the parties. http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/27611. Accessed 4 Apr 2016

United Nations Environment Programme Ozone Secretariat (1999a) Adjustments agreed in 1999 in Beijing at the eleventh meeting of the parties. http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/27604. Accessed 14 Apr 2016

United Nations Environment Programme Ozone Secretariat (1999b) The Beijing Amendment (1999): the amendment to the Montreal protocol agreed by the eleventh meeting of the parties.

http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/27612. Accessed 14 Apr 2016
United Nations Environment Programme Ozone Secretariat (2007) Adjustments agreed in 2007 in Montreal at the nineteenth meeting of the parties. http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/27607. Accessed 14 Apr 2016
United Nations Environment Programme Ozone Secretariat (2008) Decision VCVIII/2: recommendations adopted by the ozone research managers at their seventh meeting. http://ozone.unep.org/en/handbook-vienna-convention-protection-ozone-layer/2344. Accessed 4 Apr 2016
United Nations Environment Programme Ozone Secretariat (2016) Institutions | Ozone Secretariat. http://ozone.unep.org/en/institutions. Accessed 25 Apr 2016
Williamson RA et al (2002) The socio-economic value of improved weather and climate information. Space Policy Institute, The George Washington University, Washington, D.C
WMO (1981) The stratosphere 1981: theory and measurements. Geneva, Switzerland
WMO (1985a) Atmospheric ozone 1985: assessment of our understanding of the processes controlling its present distribution and change, vol. 1. Geneva, Switzerland
WMO (1985b) Atmospheric ozone 1985: assessment of our understanding of the processes controlling its present distribution and change, vol. 2. Geneva, Switzerland
WMO (1988a) Report of the international ozone trends Panel-1988, vol.1. Geneva, Switzerland
WMO (1988b) Report of the international ozone trends Panel-1988, vol. 2. Geneva, Switzerland
WMO (2016) WMO global ozone research and monitoring project reports. https://www.wmo.int/pages/prog/arep/gaw/ozone_reports.html. Accessed 25 Apr 2016
WMO/UNEP (2010) Scientific assessment of ozone depletion: 2010. https://www.wmo.int/pages/prog/arep/gaw/ozone_2010/documents/Ozone-Assessment-2010-complete.pdf. Accessed 7 Dec 2016
WMO/UNEP (2014) Assessment for decision-makers: scientific assessment of ozone depletion: 2014. http://www.wmo.int/pages/prog/arep/gaw/ozone_2014/documents/ADM_2014OzoneAssessment_Final.pdf. Accessed 7 Dec 2016
WMO/UNEP (2016) Quadrennial assessment and progress reports. http://ozone.unep.org/en/assessment-panels/scientific-assessment-panel. Accessed 5 May 2016

Author Biographies

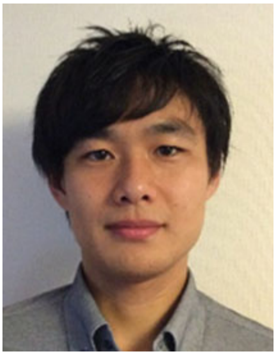
Yasuko Kasai is an executive researcher at the Terahertz Technology Research Center and Big Data Integration Research Center within the National Institute of Information and Communications Technology (NICT), professor at the Tokyo Institute of Technology, and an officer of the Ministry of Internal Affairs and Communications. She previously served as special postdoctoral researcher (SPDR) at RIKEN. She received her Ph. D. from Tokyo Institute of Technology in 1995. Prof. Kasai is a member of the COSPAR Scientific Commission and a commissioner of the International Radiation Commission (IRC). Her research area is terahertz satellite remote sensing of the Earth and other planets.

Setsuko Aoki is professor of international law in the Faculty of Policy Management at Keio University, Japan. Her previous positions include being an associate professor at Keio and associate professor of the School of Social Science, National Defense Academy. She received her Doctor of Civil Law (D.C. L.) from the Institute of Air and Space Law, Faculty of Law, McGill University, Canada, in June 1993; her Master of Laws (LL.M.) from the Graduate School of Law, Keio University, Japan, in March 1985; and a Bachelor of Civil Law (B.C.L.) from the Faculty of Law, Keio University, Japan, in March 1983.

Professor Aoki has served as a member of the Committee on National Space Policy (Cabinet Office) since July 2012, as a legal advisor to the Ministry of Foreign Affairs, and on the Legal Subcommittee of the Committee on the Peaceful Uses of Outer Space (COPUOS) since March 2002. Her area of research is international law and space law.

Akiko Aizawa graduated from the Department of Electronics at The University of Tokyo in 1985 and completed her doctoral studies in electrical engineering in 1990. She was a visiting researcher at the University of Illinois at Urbana-Champaign from 1990 to 1992. At present, she is a professor at the National Institute of Informatics (NII) and also an adjunct professor at the Graduate School of Information Science and Technology (IST) at The University of Tokyo. Her research interests include text-based content and media processing, statistical text analysis, linguistic resource construction, and corpus-based knowledge acquisition.

Akiko Okamatsu is a professor of international law in the Faculty of Sustainability Studies at Hosei University, Japan. She graduated from Jouchi (Sophia) University in Tokyo. She is a member of the Compliance Group of the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972; special advisor to the Ministry of Environment, Japan; and guest researcher at the Research Office of the Standing Committee on Foreign Affairs and Defense, House of Councillors, Japan. She began her career as a research associate at Jouchi University, Faculty of Law, before becoming a postdoctoral fellow at the National Institute for Environmental Studies (NIES) and later assistant professor at Shobi University. She also served as a visiting scholar at Harvard Law School from 2013 to 2014.



Tomohiro Sato is a researcher at the National Institute of Information and Communications Technology (NICT), Japan. His previous positions include teacher of science at Ichikawa Junior High School and High School and research fellow at the Japan Society for the Promotion of Science. His Doctorate of Science, M.Sc., and B.Sc. degrees are from the Tokyo Institute of Technology, Japan. His research interests are Earth observation, atmospheric science, remote sensing, and text mining.

Masami Onoda is currently the U.S. and multilateral relations interface at the International Relations and Research Department of the Japan Aerospace Exploration Agency (JAXA). As an academic, she is fellow of the Institute of Global Environmental Strategies (IGES) and she is also engaged in the private sector as an advisor to the Singapore-based space debris start-up Astroscale Pte. Ltd. since its foundation in 2013. From 2009 to 2012, Dr. Onoda was a scientific and technical officer at the intergovernmental Group on Earth Observations (GEO) Secretariat in Geneva, Switzerland. From 2003 to 2008, while pursuing her graduate studies, she was invited to the JAXA Kansai Satellite Office in Higashiosaka as a space technology coordinator to support technology transfer to SMEs for the small satellite project SOHLA-1. From 1999 to 2003, she worked in the field of Earth observations at JAXA (then NASDA), serving on the Secretariat of the Committee on Earth Observation Satellites (CEOS). In 1999, she was seconded to the UN Office for Outer Space Affairs (UNOOSA) for the organization of the UNISPACE III conference. She holds a Ph.D. in global environmental studies (2009) and a master's degree in environmental management (2005), both from the Kyoto University Graduate School of Global Environmental Studies. Her undergraduate degree is in international relations from The University of Tokyo.

Brian Alan Johnson received his Ph.D. in geosciences from Florida Atlantic University in 2012 and his M.A. in geography from the same university in 2007. He is now a researcher at the Institute for Global Environmental Strategies (IGES) in Hayama, Japan. His research interests in remote sensing are related to land use/land cover mapping, change detection, and data fusion.