THE Crafoord PRIZE

Crafoord *Days* 2018

22–24 MAY IN LUND AND STOCKHOLM, SWEDEN

The Crafoord Prize in Geosciences

Abstracts and Programmes

PHOTO: JUSTIN KNIGHT, INTERACADEMY COUNCIL

SYUKURO MANABE

PHOTO: JUSTIN KNIGHT

SUSAN SOLOMON

Anna-Greta and Holger Crafoord Fund

THE FUND WAS ESTABLISHED in 1980 by a donation to the Royal Swedish Academy of Sciences from Anna-Greta and Holger Crafoord. The Crafoord Prize was awarded for the first time in 1982. The purpose of the fund is to promote basic scientific research worldwide in the following disciplines:

- Mathematics
- Astronomy
- Geosciences
- Biosciences (with particular emphasis on Ecology)
- Polyarthritis (e.g. rheumatoid arthritis)

Support to research takes the form of an international prize awarded annually to outstanding scientists and of research grants to individuals or institutions in Sweden. Both awards and grants are made according to the following order:

year 1: Mathematics and Astronomy
year 2: Geosciences
year 3: Biosciences (with particular emphasis on Ecology)
year 4: Mathematics and Astronomy
etc.

The Prize in Polyarthritis is awarded only when the Academy's Class for medical sciences has shown that scientific progress in this field has been such that an award is justified.

Part of the fund is reserved for appropriate research projects at the Academy's institutes. The Crafoord Prize presently amounts to 6 million Swedish krona.

The Crafoord Prize is awarded in partnership between the Royal Swedish Academy of Sciences and the Crafoord Foundation in Lund. The Academy is responsible for selecting the Crafoord Laureates.

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The Crafoord Laureates in Geosciences 2018

PHOTO: JUSTIN KNIGHT, INTERACADEMY COUNCIL

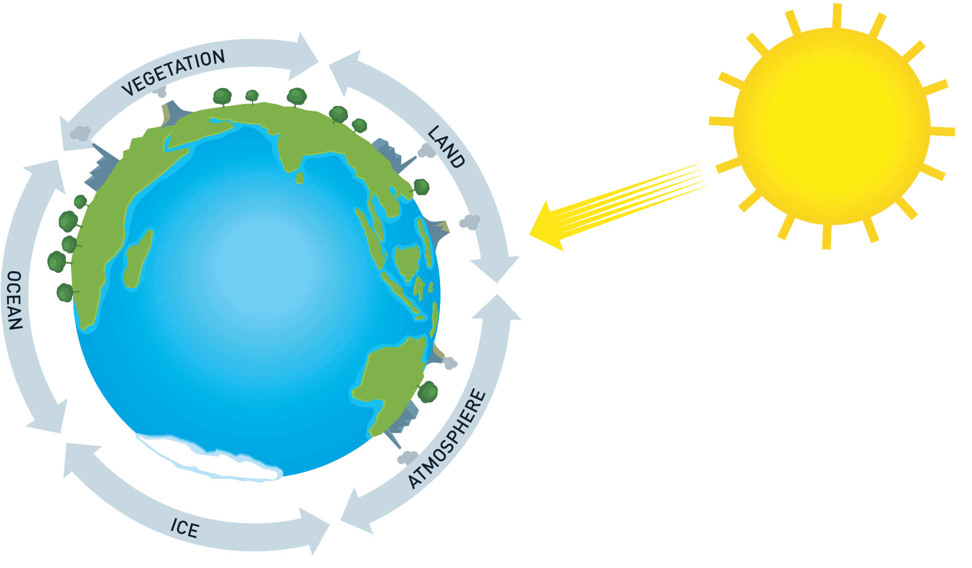
SYUKURO MANABE
PRINCETON UNIVERSITY, NJ, USA

PHOTO: JUSTIN KNIGHT

SUSAN SOLOMON
MASSACHUSETTS INSTITUTE OF TECHNOLOGY, MIT, MA, USA

Syukuro Manabe, Princeton University, NJ, USA and **Susan Solomon**, Massachusetts Institute of Technology, MIT, MA, USA, *"for fundamental contributions to understanding the role of atmospheric trace gases in Earth's climate system"*

The Crafoord *Prize* in Geosciences



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THE ROYAL SWEDISH ACADEMY OF SCIENCES

Atmospheric physicist **Syukoro Manabe** created the first global climate model after his ground-breaking studies of atmospheric dynamics in the 1960s. In this model, he connected the processes that take place in the atmosphere and at ground level with the oceans' movements and their thermal balance. This new way of using large-scale numerical modelling to predict how the Earth's temperature is influenced by atmospheric carbon dioxide levels was a major breakthrough; researchers finally had the powerful tools they required to investigate the Earth's complex climate systems. The basics of his work remain fundamental to contemporary climate models.

Syukoro Manabe has long been a world-leader in physically based numerical climate modelling and his development of the first global climate model is the foundation for all modern climate research.

Atmospheric chemist **Susan Solomon** solved the 1980s' puzzle of the Antarctic ozone hole's appearance, using theoretical and chemical measurement-focused studies in the Antarctic atmosphere. She examined the ice crystals in the stratospheric clouds that form there every year due to the extreme cold. These ice crystals cause the initiation of chemical processes that differ from those that were previously assumed to occur. On this basis, Susan Solomon presented a theory that explained the link between manmade CFC emissions and the chemical processes taking place in the Antarctic stratosphere in the early spring, ones that led to the extensive depletion of its ozone layer. Her theory was verified by the results of the measurements conducted in the stratosphere. Later, Susan Solomon showed how the thickness of the ozone layer in the southern hemisphere affects atmospheric flows and temperatures all the way down to ground level.

For more than 30 years, Susan Solomon's studies have been at the absolute frontline of research into the ozone layer and its role in the Earth's climate systems. The chemical reactions proposed by Susan Solomon are now one of the cornerstones for all modelling of the stratosphere's chemical composition.

Role of greenhouse gas in climate change

CRAFOORD LAUREATE 2018 **SYUKURO MANABE**, PRINCETON UNIVERSITY, NJ, USA

When the concentration of greenhouse gas such as carbon dioxide and water vapor increases in the atmosphere, temperature increases not only at the Earth's surface but also in the troposphere, whereas it decreases in the stratosphere. Meanwhile, the global mean rates of both precipitation and evaporation increase, accelerating the pace of the hydrologic cycle. The geographical distributions of these two variables also change, affecting profoundly the distribution of water availability over continents. For example, precipitation is likely to increase in already water-rich regions, increasing the rate of river discharge and the frequency of floods. In contrast, soil moisture will decrease in the subtropics and other water-poor regions that are already relatively dry, increasing the frequency of drought. The simulated changes described above appear to be broadly consistent with observation. During the last several decades, we have explored the physical mechanism of climate change, using a hierarchy of climate models with increasing complexity. On this occasion, I would like to discuss the role of greenhouse gases in climate change, based upon results of the numerical experiments.

References

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Stouffer, R. J., Manabe, S. and Bryan, K. 1989: Interhemispheric asymmetry in climate response to a gradual increase of atmospheric CO_2. *Nature*, 342, 660–662.

Wetherald, R. T. and Manabe, S. 2002: Simulation of hydrologic changes associated with global warming. *Journal of Geophysical Research*, 107, 4379–4393.

Ozone depletion from pole to pole and its linkages to climate change

CRAFOORD LAUREATE 2018 **SUSAN SOLOMON**, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, MIT, MA, USA

Stratospheric ozone shields Earth from biologically damaging ultraviolet light from the Sun, and is hence essential to life. The possibility that human use of chlorofluorcarbon chemicals (CFCs) could deplete the stratospheric ozone layer was first proposed in the 1970s, based strictly on gas phase chemical reactions. Scientific understanding in the 1970s and early 1980s indicated that use of CFCs could destroy 3–5 percent of the global total ozone by about 2100. The discovery of the Antarctic ozone hole revealed a remarkable ozone decline about ten times larger and a century sooner than anticipated, and in a completely unexpected location. The ozone hole ushered in a transformation of understanding through the recognition that heterogeneous chemistry on the surfaces of stratospheric particles could increase chlorine catalyzed ozone depletion far above that of the gas phase reactions. Campaigns by scientists worldwide in the Antarctic and Arctic measured a range of chemical species including ClO, OClO, and HCl, which demonstrated the effectiveness of surface chemistry at initiating ozone destruction under very cold conditions. While the Arctic is generally warmer than the Antarctic, it is cold enough to exhibit substantial ozone losses in some recent years.

Concerns about ozone depletion led all the nations of the world to agree upon a Montreal Protocol to phase out production of CFCs. Identification of resulting improvement of the ozone layer has stimulated new directions in stratospheric research, requiring a focus on fingerprinting similar to that of detection/attribution studies for climate science. The first signs of healing of the ozone hole have recently been detected, indicating the success of this landmark environmental treaty. Ozone depletion does not cause global warming, but changes in stratospheric ozone can influence wind patterns both within the stratosphere and at ground level, and thereby change some regional climates. Another important direction of research is to understand how stratospheric wind and temperatures relate to surface climate. Stratospheric harbingers of tropospheric wind changes hold promise for improving not only physical understanding of climate change but also prediction.

References

Solomon, S., Garcia, R. R., Rowland, F. S. and Wuebbles, D. J. On the depletion of Antarctic ozone, *Nature*, 321, 755–758, 1986.

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Climate science: what next?

BJORN STEVENS, MAX PLANCK INSTITUTE FOR METEOROLOGY, GERMANY

Climate science has been exceptionally successful in understanding how human activities can change the mean – globally averaged – state of the climate system. Two profound examples of such changes, the reduction of naturally occurring ozone in the stratosphere and the rise of temperatures at Earth's surface, have been understood in large part through the efforts and creativity of this years' Crafoord Prize Laureates. Now, thanks to the enlightened responses to the advancing science, the ozone hole is on the mend and the causes of surface warming have been accepted, which might prompt the question: what's left for the science to do?

As Earth warms the important question that climate scientists are beginning to grapple with is how warming affects the atmospheric circulation and hence patterns of weather. Particularly in the tropics, there are very large question marks as to how warming will influence circulation patterns and what the implications of these regional changes will be for global circulation systems. In this talk I highlight why the tropics are such a wild-card for a warming world, and introduce a new class of models, designed to exploit the most powerful computers imaginable, and explain why they provide the best chance to gain insight into the shape of a warmer world.

Stratospheric ozone depletion and surface climate

DAVID W. J. THOMPSON, COLORADO STATE UNIVERSITY, CO, USA

The lowermost layers of the atmosphere are markedly different. The troposphere is characterized by robust mixing and contains roughly ~85% of the total mass of the atmosphere; the stratosphere is characterized by relatively quiescent conditions and little mass. Because they comprise very different masses, coupling between variations in the troposphere and stratosphere was long believed to be primarily one-way: i.e., variations in the much denser tropospheric circulation were known to have an important effect on the stratospheric circulation, whereas variations in the stratospheric circulation were thought to be largely unimportant for tropospheric climate.

The widely held view of stratosphere/troposphere coupling changed dramatically in the early 2000s, when both observational and numerical evidence pointed to important effects of variations in the stratospheric flow on surface climate. The discovery that variations in the stratospheric flow do – in fact – influence the circulation of the troposphere paved the way for a more complete understanding of the influence of the ozone hole on Earth's climate system.

Over the past two decades, Professor Susan Solomon and colleagues have used our evolving understanding of stratosphere/troposphere coupling to provide valuable new insights into the effects of the Antarctic ozone hole on surface climate. It is now clear that the societally important effects of stratospheric ozone depletion extend far beyond surface radiation, and include widespread changes in surface weather and climate throughout much of the mid-high latitude Southern Hemisphere, including the Southern Ocean and parts of Australia and South America.

The effects of the ozone hole on surface climate are robust in observations and numerical models. But the mechanisms whereby the ozone hole influences the large-scale circulation of the troposphere remain controversial. I will review our current understanding of the links between the Antarctic ozone hole and surface climate, and discuss the outlook for future research.

The global hydrological cycle and climate change

ISAAC HELD, PRINCETON UNIVERSITY, NJ, USA

This presentation will attempt to provide an overview of current understanding of how the global hydrological cycle is expected to change in a warming climate. Most of the ideas are built upon the foundation laid by Syukuro Manabe, the Crafoord prize recipient. Themes on which the discussion of this topic have focused over the past two decades include 1) the wet-get-wetter/dry-get-drier paradigm for average precipitation, 2) the enhancement of rainfall in extreme weather events, 3) the poleward expansion of the subtropical dry zones, and 4) the shift of the tropical rain belts towards the hemisphere in which the increase in radiative forcing is the strongest. The first two of these changes can be argued from an increase in the amount of water vapor in the atmosphere with warming. The latter two depend on changes in the atmospheric circulation. A brief critical perspective is provided on each of these themes, emphasizing their connection to comprehensive climate simulations and the basic physics of the climate system and significant uncertainties. This global view will be followed by a focus on the forced hydrological response in a few selected regions, such as the Western U.S. and the Sahel.

The difficulty in attributing observed changes to increasing greenhouse gases, in the presence of natural variability and other forcing agents, such as scattering and absorbing aerosols as well as stratospheric ozone, will also be addressed.

The intricate link between the ocean's deep water formation and climate through the ages

AGATHA DE BOER, STOCKHOLM UNIVERSITY, SWEDEN

The overturning circulation in the ocean replenishes the deep water on time scales of centuries to millennia and affects climate through its role in distributing heat and carbon dioxide across the globe. The stability of the overturning circulation in a changing climate is unclear and remains a subject of active research. Deep water could potentially form in all polar regions where cooling makes the surface water dense, but the global freshwater balance leaves the modern day North Pacific surface water too fresh for sinking. Here we turn to the paleo-record to inform us about the robustness of the overturning circulation as we have it today. During the Eocene warm period (56 Ma–34 Ma), when CO_2 was much higher than today and the continental geography fundamentally different, the deep oceans appear to have been filled with water of southern origin and from the North Pacific. The first signs of North Atlantic deep water formation occurred around the Eocene-Oligocene transition about 34 million years ago which also marks the time when Antarctica developed its first full scale continental ice sheet. We show how this switch from Pacific to Atlantic deep water formation may have been triggered by Atlantic salinification due to the closing of the Arctic Ocean. There is growing evidence that there was again a period of North Pacific deep water formation in the late Pliocene (~3 Ma), just prior to Northern Hemisphere glaciation. Importantly, this period is an analog to modern day warming since it had similar CO_2 concentrations and continental geography to those of today. We suggest and motivate that this may have been the result of the higher mean ocean temperatures during the time, begging the question of if and when deep water may start forming in the Pacific again, as the oceans are warming.

Global warming: on melting ice and glacier engineering

JOHANNES OERLEMANS, UTRECHT UNIVERSITY, THE NETHERLANDS

Glaciers retreat all over the world. An analysis of 500 long records shows that glaciers started to shrink in the middle of the 19th century and have continued to do so ever since. The rate of retreat has varied, but shows unprecedented large values over the past 10 to 15 years. There is very little doubt that this is due to rising temperatures. On the global scale, glaciers contribute significantly to sea-level rise. On a regional scale, glacier fluctuations may affect meltwater supply (reservoirs, irrigation), security of infrastructure and buildings (ice avalanches, outbursts of glacial lakes), and tourist industry (ski areas, attractiveness of alpine scenery).

The rapid loss of glacier ice has stimulated the development of "glacier engineering". This involves protection of glaciers by covering part of melt zones, and by snow farming. Another example is the building of large bodies of ice during cold periods (so-called ice stupa's) for irrigation purposes in spring/summer when conditions are very dry (for instance in Tibet). In this contribution several projects will be presented and the potential of environmentally friendly glacier engineering will be discussed.

Macrobiome: coming soon to an ecosystem near you

MARY SCHOLES, UNIVERSITY OF THE WITWATERSRAND, SOUTH AFRICA

We have moved from the stability of the Holocene into the Anthropocene, where humans are fundamentally and massively altering the planet's systems. Recently a large amount of research has focussed on the "microbiome" in the fields of human health and plant sciences. However, this is expanding into other systems and across systems, and I have coined the word "macrobiome". As the research field grows, the impacts will extend into many of the processes considered as biogeochemical processes occurring in the atmosphere, in the ocean and on land. The expansion of experimental techniques and research platforms is primarily responsible for the new emphasis on microbial processes. Microorganisms responsible for the generation of biogenic trace gases may demonstrate novel attributes that could impact processes and biogeochemical budgets. The new world of "omics", particularly Metagenomics and Volatilomics are just two of the newly applied techniques. Biogenic volatile carbons interact with gas-phase reactions of inorganic O_x, HO_x and NO_x species in the atmosphere. The use of e.g. Proton-transfer reaction time-of-flight mass spectrometry (PTR-TOF-MS) is able to discriminate soils and correlate volatile-organic-carbon (VOC) evolution, microbial biomass and enzyme activities. This has direct application for atmospheric processes. The nitrogen and sulphur cycles involve multiple transfers of various compounds between the atmosphere, ocean and land. Novel soil microbial assemblages may change the amount of substrate (nitrate and nitrite) available for biogenic nitrogen fluxes. Algal-bloom production of dimethyl sulphur (DMS), often mediated by microorganisms, plays a major role in atmospheric transformations. A planetary view of ecosystems and the services they provide are driven by bacterial metabolic processes in addition to physico-chemical processes. The emphasis on the "macrobiome" will grow in the near future.

Overview programme Crafoord *Days* 2018

Tuesday 22 May

09:30

Prize Lectures

Held by the Crafoord Laureates **Syukuro Manabe** and **Susan Solomon**.

SKISSERNAS MUSEUM, FINNGATAN 2, LUND

Registration at www.crafoordprize.se or www.kva.se

Wednesday 23 May

09:00

Prize Symposium

Earth's climate system

Lectures by the Crafoord Laureates **Syukuro Manabe** and **Susan Solomon** and invited speakers.

BEIJER HALL, THE ROYAL SWEDISH ACADEMY OF SCIENCES,
LILLA FRESCATIVÄGEN 4A, STOCKHOLM

Registration at www.crafoordprize.se or www.kva.se

Thursday 24 May

16:30

Prize Award Ceremony

In the presence of H.M. King Carl XVI Gustaf and H.M. Queen Silvia of Sweden.

BEIJER HALL, THE ROYAL SWEDISH ACADEMY OF SCIENCES,
LILLA FRESCATIVÄGEN 4A, STOCKHOLM

Detailed programme

THE CRAFOORD PRIZE IN GEOSCIENCES 2018

The Crafoord *Prize* Lectures in Geosciences

09:30

LUND

SKISSERNAS MUSEUM, FINNGATAN 2, LUND

Open to the public and free of charge. Seating is limited.
Registration at www.crafoordprize.se or www.kva.se

Tuesday 22 May

09:30	Welcome remarks	**Svante Björck**, (Chair), the Royal Swedish Academy of Sciences
09:35	Introduction of the Crafoord Laureates	**Martin Jakobsson**, Member of the Crafoord Prize Committee, the Royal Swedish Academy of Sciences
09:45	*Role of greenhouse gas in climate change*	**CRAFOORD LAUREATE 2018** **Syukuro Manabe**, Princeton University, NJ, USA
10:15	Questions from the auditorium	
10:25	*Meeting the challenges of the Antarctic ozone hole: A global science and policy success story*	**CRAFOORD LAUREATE 2018** **Susan Solomon**, Massachusetts Institute of Technology, MIT, MA, USA
10:55	Questions from the auditorium	
11:05	BREAK WITH REFRESHMENTS	
11:35	Panel discussion and questions from the auditorium	**Syukuro Manabe**, Princeton University, USA, **Susan Solomon**, MIT, USA, **Dorthe Dahl-Jensen**, University of Copenhagen, Denmark, **Martin Jakobsson**, the Royal Swedish Academy of Sciences, **Birgitta Svenningsson**, Lund University, Sweden
12:20	Closing remarks	**Svante Björck**, (Chair), the Royal Swedish Academy of Sciences
12:25	LUNCH	Lunch is served outside the lecture hall and is included for registered participants.

Detailed programme

THE CRAFOORD SYMPOSIUM IN GEOSCIENCES 2018

Earth's climate system

09:00

STOCKHOLM
BEIJER HALL, THE ROYAL SWEDISH ACADEMY OF SCIENCES,
LILLA FRESCATIVÄGEN 4A, STOCKHOLM

Wednesday 23 May

Open to the public and free of charge. Seating is limited.
Registration at www.crafoordprize.se or www.kva.se

09:00	Registration	
09:25	Opening address	Göran K. Hansson, Secretary General, the Royal Swedish Academy of Sciences
09:30	Introduction of the Crafoord Laureates	Martin Jakobsson, Member of the Crafoord Prize Committee, the Royal Swedish Academy of Sciences
09:40	*Role of greenhouse gas in climate change*	CRAFOORD LAUREATE 2018 Syukuro Manabe, Princeton University, NJ, USA
10:30	*Ozone depletion from pole to pole and its linkages to climate change*	CRAFOORD LAUREATE 2018 Susan Solomon, Massachusetts Institute of Technology, MIT, MA, USA
11:20	*Climate science: what next?*	Bjorn Stevens, Max Planck Institute for Meteorology, Germany
12:00	LUNCH	(Included for registered participants)
13:20	*Stratospheric ozone depletion and surface climate*	David W. J. Thompson, Colorado State University, CO, USA
14:00	*The global hydrological cycle and climate change*	Isaac Held, Princeton University, NJ, USA
14:40	*The intricate link between the ocean's deep water formation and climate through the ages*	Agatha De Boer, Stockholm University, Sweden
15:20	BREAK WITH REFRESHMENTS	
16:00	*Global warming: on melting ice and glacier engineering*	Johannes Oerlemans, Utrecht University, The Netherlands
16:40	*Macrobiome: coming soon to an ecosystem near you*	Mary Scholes, University of the Witwatersrand, South Africa
17:20	End of symposium	

Anna-Greta and Holger Crafoord

HOLGER AND ANNA-GRETA CRAFOORD

Holger Crafoord (1908–1982) was prominent in Swedish industry and commerce. He began his career with AB Åkerlund & Rausing and devoted a larger part of his working life to this company. In 1964, Holger Crafoord founded Gambro AB in Lund, Sweden, where the technique of manufacturing the artificial kidney was developed. This remarkable dialyser soon became world famous. Since then, a series of medical instruments has been introduced on the world market by Gambro.

In 1980, Holger Crafoord founded the Crafoord Foundation, which annually contributes greatly to the Anna-Greta and Holger Crafoord Fund.

Holger Crafoord became an honorary doctor of economics in 1972 and in 1976 an honorary doctor of medicine at Lund Univeristy.

Anna-Greta Crafoord (1914–1994) took, as Holger Crafoord's wife, part in the development of Gambro AB. Through generous donations and a strong commitment in the society around her, she contributed to the scientific and cultural life. In 1986 she founded the Anna-Greta Crafoord foundation for rheumatological research and in 1987 Anna-Greta Crafoord became an honorary doctor of medicine at Lund Univeristy.

Over the years, the Crafoords have furthered both science and culture in many ways and it is noteworthy that research in the natural sciences has received an important measure of support from the Anna-Greta and Holger Crafoord Fund.

THE ROYAL SWEDISH ACADEMY OF SCIENCES was founded in 1739 and is an independent non-governmental organisation, whose overall objective is to promote the sciences and strengthen their influence in society. The Academy has a particular responsibility for natural science and mathematics, but its work strives to increase interaction between different disciplines. The activities of the Royal Swedish Academy of Sciences primarily focus on:

- being a voice of science in society and influencing research policy (policy for science)
- providing a scientific basis for public debate and decision-making (science for policy)
- recognizing outstanding contributions to research
- being a meeting place for science, within and across subject boundaries
- providing support for young researchers
- stimulating interest in mathematics and natural science in school
- disseminating knowledge to the public
- mediating international scientific contacts
- preserving scientific heritage

THE ACADEMY has around 460 Swedish and 175 foreign members who are active in classes, committees and working groups. They initiate enquiries, consultation documents, conferences and seminars. The Academy has General Meetings eight times a year. Open lectures are held in association with these (read more at www.kva.se/kalendarium). They can also be watched via www.kva.se/video.

THE ACADEMY´S institutes offer unique research environments in ecological economics, botany, the history of science and mathematics.

Every year, the Academy awards a number of prizes and rewards. The best known are the Nobel Prizes in Physics and Chemistry and the Sveriges Riksbank Prize in Economic Science in Memory of Alfred Nobel (the Prize in Economic Sciences). Other major prizes are the Crafoord Prize, Sjöberg Prize, Göran Gustafsson Prizes, Söderberg Prize and the Tobias Prize. The Göran Gustafsson Prizes are awarded to outstanding young researchers and are a combination of a personal prize and research funding. Since 2012, the Academy of Sciences has been one of the academies involved in implementing the Wallenberg Academy Fellows career programme, which provide long-term funding to the most promising young researchers. As well as a comprehensive range of scholarships, the Academy is also involved in appointments to research posts in a number of programmes funded by external foundations.

Through its working groups and committees, the Academy also works to promote sustainable, science-based societal development in the area of energy and the environment, among others. Issues relating to education and conditions for teachers are another major interest. The Academy organises Science Meetups, holiday schools at which recent arrivals to Sweden and Swedish upper-secondary school pupils learn more about natural science together. In the 1990s, the Academy and the Royal Swedish Academy of Engineering Sciences founded one of Sweden's biggest school development programmes, NTA – Naturvetenskap och teknik för alla (Science and Technology for all).

THE CRAFOORD PRIZE IS AWARDED IN PARTNERSHIP BETWEEN THE ROYAL SWEDISH ACADEMY OF SCIENCES AND THE CRAFOORD FOUNDATION IN LUND. THE ACADEMY IS RESPONSIBLE FOR SELECTING THE CRAFOORD LAUREATES.

WWW.CRAFOORDPRIZE.SE

KUNGL. VETENSKAPS-AKADEMIEN

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