International Union of Geodesy and Geophysics (IUGG)
National Committee Report

Norway, 2014

Ulf-Peter Hoppe (Editor)

Norwegian National Committee for IUGG

14 October 2014

Contents

1 Introduction

This report by the Norwegian Committee for Geodesy and Geophysics was written by the National Correspondents of the Associations in 2013 and 2014 to briefly describe IUGG-related research in Norway since the General Assembly in 2011 as well as research plans for the near future.

The approximate number of scientists working in IUGG-related fields in Norway is given in the following table, not counting retired scientists or former scientists interested in IUGG, but now working in industry or non-IUGG research (* with personal IAHS membership):

Association	Number of active scientists
IACS	50
IAG	30
IAGA	65 → 76
IAHS	55*
IAMAS	200
IAPSO	100
IASPEI	80
IAVCEI	3-10

1.1 The Norwegian National Committee

ADHERING ORGANIZATION

Den Nasjonale Komite for Geodesi og Geofysikk
Statens Kartverk
3507 Hønefoss

NATIONAL COMMITTEE

Chair: U.-P. HOPPE **Secretary:** O. KRISTIANSEN

National Correspondents of the Associations

IACS:	J.O. HAGEN	**IAG:**	O. KRISTIANSEN	**IAGA:**	U.-P. HOPPE
IAHS:	P. STÅLNACKE	**IAMAS:**	J.E. KRISTJÁNSSON	**IAPSO:**	S.S. HJØLLO
IASPEI:	T. KVAERNA	**IAVCEI:**	R.S. SELBEKK		

HAGEN
Prof. Jon Ove
IACS National Correspondent

Department of Geosciences
Section of Physical Geography
Faculty of Mathematics & Natural Sciences
University of Oslo
PO Box 1047 Blindern
0316 Oslo
NORWAY

T: 47 2285 4038
F: 47 2285 4215
j.o.m.hagen@geo.uio.no

STÅLNACKE
Dr. Per
IAHS National Correspondent

Head of Dept.
Water Quality and Hydrology
Bioforsk – Norwegian Institute for
Agricultural and Environmental Research
Frederik A. Dahls vei 20
1430 Ås
NORWAY

T: 47 9320 2520
Per.Stalnacke@bioforsk.no

HJØLLO
Dr. Solfrid Saetre
IAPSO National Correspondent

Institute of Marine Research
Nordnesgate 50
P.O. Box 1870 Nordnes
5817 Bergen
NORWAY

T: 47 5523 5362
F: 47 5558 4330
solfrid.hjollo@imr.no

HOPPE
Prof. Dr. Ulf-Peter
Chair, National Committee
IAGA National Correspondent

Norwegian Defence Research
Establishment (FFI)
P.O. Box 25
2027 Kjeller
NORWAY

T: 47 6380 7287
T: 47 9909 6494
F: 47 6380 7212
Ulf-Peter.Hoppe@ffi.no

KRISTJÁNSSON
Prof. Jón Egill
IAMAS National Correspondent

University of Oslo
Department of Geosciences
P.O. Box 1022 Blindern
0315 Oslo
NORWAY

T: 47 2285 5813
F: 47 2285 5269
j.e.kristjansson@geo.uio.no

KVAERNA
Dr. Tormod
IASPEI National Correspondent

NORSAR
PO Box 51
2027 Kjeller
NORWAY

T: 47 6380 5941
F: 47 6380 8719
tormod@norsar.no

KRISTIANSEN
Dr. Oddgeir
Secretary, National Committee
IAG National Correspondent

Norwegian Mapping Authority
Geodetic Institute
3507 Hønefoss
NORWAY

T: 47 3211 8299
F: 47 3211 8101
oddgeir.kristiansen@kartverket.no

SELBEKK
Dr. Rune S.
IAVCEI National Correspondent

Curator of Minerals
Natural History Museum
University of Oslo
PO Box 1172 Blindern
0318 Oslo
NORWAY

T: 47 2285 1647
F: 47 2285 1800
r.s.selbekk@nhm.uio.no

2 IACS – International Association of Cryospheric Sciences

2.1 Terrestrial Cryosphere studies in Norway

In a global context the observed climate changes have considerable impact in areas where snow, ice and permafrost dominate. The changes in the cryosphere have both local, regional and global effects and feedbacks. This concerns water balance, glacier and permafrost related hazards, albedo feedback on the global energy balance, release of greenhouse gases from thawing permafrost, glacier melt and sea-level change, geomorphological processes, etc. Cryosphere studies have therefore received increased global attention over the past decade(s). This can be

seen for example by the fact that both the American and European Geophysical Unions (AGU and EGU) during recent years have established large Cryosphere modules at their conferences.

In Norway cryosphere studies related to glaciers, snow and permafrost are integrated parts of the activity both at universities and research institutes. The university studies are mainly at Univ. Oslo, Department of Geosciences, at UNIS and Univ. of Bergen, Dep. of Earth Sciences and the Bjerknes Centre, but also in smaller groups both at NTNU in Trondheim, at UMB in Ås and Univ. in Tromsø. The institute sector has large Cryosphere groups at the Norwegian Polar Institute in Tromsø, at NVE, Norwegian Water resources and Energy Administration, Oslo, at the Nansen Center (NERSC) in Bergen and also some smaller groups at the Meteorological Office (met.no), at NTNU(SINTEF), NGI (Norwegian Geotechnical Institute) and NILU (Norwegian Institute for Air Research).

3 IAG – International Association of Geodesy

3.1 Research in geodesy and Earth science at the Norwegian Mapping Authority

The Norwegian Mapping Authority builds and operates geodetic infrastructure in Norway and Svalbard and has a strong focus on geodetic analysis and interpretation. The goal is to observe and analyse geophysical processes and contribute to a more precise observation of the Earth so that we with greater certainty can measure climate changes such as changes in sea level. To achieve this, the international reference frame has to be improved.

Infrastructure The Norwegian Mapping Authority (NMA) is therefore upgrading the geodetic observatory in Ny-Ålesund in the Arctic to a core network station within the Global Geodetic Observing System (GGOS). The Norwegian government has in 2013 allocated 30 million Euros to the building of the new observatory which will combine all geodetic measurement techniques at one site. NMA will adapt to the VLBI2010 standard and extend the activity to integrate Satellite Laser Ranging (SLR). The NMA's Ny-Ålesund Observatory at 79º N will serve as a keystone for the network of geodetic stations in the northern hemisphere.

Geophysical processes The new geodetic observatory in Ny-Ålesund will fulfill the requirements for a GGOS core station and be an important station for global geodetic reference frames. To fully exploit the station for global geodesy it is mandatory to have control over local and regional geophysical processes that affect the observatory. Processes like plate-tectonics, neo-tectonic, sea-level rise, glacial isostatic adjustment and the elastic response on the ongoing de-glaciation in the area contribute to local deformations in the area. The processes have different temporal and spatial scale, and the Norwegian Mapping Authority will continue the research activities to understand these processes.

Sea level changes The NMA has developed software and skills for processing geophysical data records from several altimetry satellites. The data can be combined in order to estimate global and regional sea level changes over the last 20 years.

Troposphere Norwegian Mapping Authority will investigate if the use of dense regional weather models or pressure measurements at ground level, may improve accuracy for network-RTK users. Differences in tropospheric activity between base stations and network-RTK users, such as local weather conditions or larger height variations, may decrease the accuracy at end user level. This may be especially noticeable in Norway with its constantly changing weather conditions which is sweeping across the country, and various topography, where end users may be located at completely different altitudes than the reference stations. The analysis is performed together with NMAs network-RTK provider, Trimble.

Space weather NMA researchers are active in the topic of space physics related to GNSS, as the dynamic ionosphere activities in the auroral and polar regions pose a challenge for GNSS-based systems. The objectives are to understand the impact of space weather on GNSS services, to monitor the active ionosphere, and ultimately to provide some sort of forecast regarding the impact of space weather on GNSS services.
In 2012, NMA established a national ionosphere monitoring service (http://sesolstorm.kartverket.no/), which displays the state of the ionosphere as seen by NMAs receiver network.
In 2013, in an ESA project, NMA developed an expanded version of the ionosphere monitoring service in english, which is to be a part of ESAs space weather portal.
In 2013/14, NMA reached data-sharing agreements with owners of GNSS receiver networks in Denmark and Sweden, allowing additional data input into the ionosphere monitoring.
NMA has also deployed a network of 12 scintillation receivers in Norway, Iceland and the Faroe Islands.
NMA is involved in research projects with both international (e.g. ESA, CNES, DLR) and national (e.g. UiO, UiT) organizations/institutions.
In particular, NMA has an important role in the ESA project "Arctic Testbed", whose objective is to provide recommendations to improve EGNOS performance at high latitudes.
NMA will continue to build competence, monitoring infrastructure and systems, participate in research and development projects and perform studies on space weather and its impacts.

GEOSAT Version 1.0 of our GEOSAT software soon enters it’s final year of development. With the GEOSAT software the individual observations from VLBI, GNSS, SLR and DORIS will be combined epoch-by-epoch in a factorized Kalman filter. During the combination, technique-dependent calibration parameters will be estimated along with parameters of primary interest (orbital parameters, station coordinates, Earth orientation parameters etc). This relative calibration of the techniques is anticipated to increase the consistency between the techniques in scale and orientation of the terrestrial and celestial reference frames and their relative orientations.

Ocean circulation The NMA has studied how geodetic data, such as gravity and geoid, in combination with mean sea level data from altimetry may be used to obtain the ocean circulation in the Norwegian and Greenland sea. It also shows that using geodetic data give a better fit to observation (i.e. mooring) data than oceanographic models.

Reference

Simpson, M., K. Breili, H.P. Kierulf, D. Lysaker, M. Ouassou, and E. Haug, Estimates of Future Sea-Level Changes for Norway, Technical Report of the Norwegian Mapping Authority, March 2012.

3.2 Physical Geodesy at NMBU

The 150 years anniversary of IAG was celebrated at its General Scientific Meeting in Potsdam in September 2013. Norway was one of the founding members. This milestone has been mentioned and highlighted In several papers and talks (Gerlach et al. 2013, Harsson and Pettersen 2014, Pettersen and Harsson 2014).

A project to validate the gravimetric satellite GOCE with ground based data in Norway has been successfully completed. Based on GOCE results, new projects (funding PhD students) have been initiated to re-examine the Norwegian height system in a global context and to investigate methods to combine satellite altimetry and in-situ tide gauge data in the Norwegian coastal zone.

The NMBU absolute gravimeter made extensive observing series at Ny Ålesund, Svalbard in close collaboration with the Norwegian Mapping Authority, who operates a superconducting gravimeter at the same site. The NMBU absolute gravimeter has also made first epoch observations inside the NVE glacial laboratory underneath the Svartisen glacier. The intention is to estimate ice mass changes with time to validate results from other approaches.

References

Gerlach, G., Sprlak, M., Bentel, K., Pettersen, B. R., 2013, Observation, validation, modeling – historical lines and recent results in Norwegian gravity field research. Kart og Plan vol. 73, p. 128-150. ISSN 0047-3278.

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3.3 Research at NTNU-Geomatics

The Geomatics group at the Norwegian University of Science and Technology (NTNU) is placed at the Department of Civil and Transport Engineering. The Department is organized in 4 divisions which contribute to both research and education. The majority of courses support the popular 5 year integrated master's degree program in Civil and Environmental Engineering, which Geomatics is also part of this program. Geomatics research focuses on nearly all aspects of spatial information, from the collection of data to the presentation of the data itself or its derivatives. The

division teaches in all university levels with Geodesy as a special field within Geomatics. Last year, the Department decided, in its strategy program, to prioritize use of satellite technologies in Civil and transport engineering focusing on geodetic and remote sensing satellites. Gravimetry and altimetry satellites, Radar satellites and Positioning satellites are emphasized. The Geomatics group has also defined and registered PhD courses in satellite geodesy. Geomatics group is strongly involved in national and international co-operations within geodesy and Earth sciences.

Recent Research activities

Our recent research activities have been focusing on "Earth Mass Change Tracking using GRACE Satellite Gravity data". The Gravity Recovery and Climate Experiment (GRACE) satellite gravity mission has been providing valuable information regarding Earth's gravity field. GRACE not only maps the Earth's static gravity field but it also measures temporal variation in the Earth's gravity field to a scale of several hundred kilometers and with a period of around one month. GRACE detects changes in the gravity field caused by redistribution of mass within the Earth and on or above the Earth's surface. Due to its global coverage, GRACE provides an excellent tool for mapping the gravity field over large areas.

Our research activities have been dealing with the estimation of present-day Earth's mass transport and its redistribution by using observations from GRACE satellite mission. GRACE measures the gravity fluctuations which are primarily related to redistribution of water around the globe. GRACE data has yield profound new insights into melting rates of ice sheets and mountain glaciers, land hydrology, ocean circulation, and sea level rise. Focus areas of our research have been Greenland (to estimate Ice sheet mass balance), Oceans (to estimate Ocean mass variations), and land (to estimate continental water storage changes).

Greenland: In this part, first, the ice melting rate in the Greenlandic ice sheet is studied. This is done by analyzing the time series of monthly GRACE Level 2 release 05 gravity field solutions from three different data sets, CSR (Center for Space Research), GFZ (Geoforschungszentrum), and JPL (Jet Propulsion Laboratory) with respect to their long-term temporal changes. A method for reducing the leakage effects is developed. As an example, the ice mass balance is estimated to -183 ± 11 Gt/yr based on the CSR release 05 and smoothing by a parameter of during February 2003 to November 2012, corresponding to an equivalent global sea level rise of 0.51 ± 0.05 mm/year. The results also show that the spatial distribution of the ice mass loss is changing with time and the ice mass loss is accelerating. For example, its acceleration is a rate of –32±6 Gt/yr2 during 2002 to 2011. In addition we have estimated Greenland ice-melt spread. Our model shows rapid mass loss of the Greenland icecap is now spreading from southern portions to northwest Greenland coast in 2007-2012. The ice loss rate has doubled over the 9 year period. The summers of 2003, 2005, 2007 and 2008 are observed to be among the warmest years since 1961. Our model reveals large mass losses in these years, indicating strong correlation between summer temperature and the ice loss observed by GRACE. Figure 1 shows our estimation of Greenland Ice mass loss rate in units of cm of equivalent water height change per year, cm/year. The left figure is the rate averaged between 2003 and 2007, the figure in the middle between 2003 and

2010, and the right figure between 2003 and 2012. The ice loss is significant along northwest coast of Greenland.

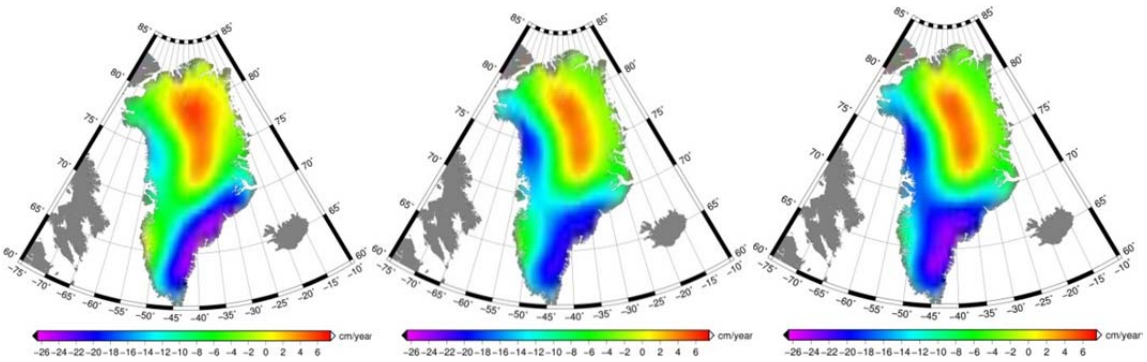

Figure 1: GRACE model estimation of the Greenland Ice mass rate in units of equivalent water height per year (cm/year). The left figure is the averaged rate from February 2003 to December 2007, the figure in the middle is the averaged rate from February 2003 to December 2010, and the right figure is the averaged rate from February 2003 to November 2012.

We have also estimated Greenland monthly mass change shown in Figure 2. For more information see Joodaki and Nahavandchi (2010), (2012a), (2012b), and Nahavandchi and Joodaki (2012).

Figure 2: Estimated Greenland monthly mass change from February 2003 to November 2012. GRACE data sets are from CSR, GFZ and JPL processing centers.

Ocean: In the second focus area, the investigations have been dedicated to the determination of water mass changes in the Nordic Seas. It is determined by analyzing the time series of monthly GRACE level 2 release 04 data from GFZ during October 2002 to October 2010. The striping errors are reduced by using a non-isotropic filter and the data are smoothed by a parameter of

according to Gaussian smoothing radius of 530 km. The time series of water mass changes are used to study the steric sea height variations over the Nordic Seas during the same period of study. This is done by analyzing the time series of monthly sea level anomaly from ENVISAT (Environmental Satellite) altimetry data, cycles 10 to 93, among the time series of water mass changes. The results show that the interdisciplinary nature of the GRACE measurements have opened up the unique opportunity to enhance our knowledge on the interaction between Earth system components and their response to climate variability. Figure 3 shows the variations of the steric sea level anomaly over the Nordic seas during October 2002 to October 2010. For more information see Joodaki et al. (2012).

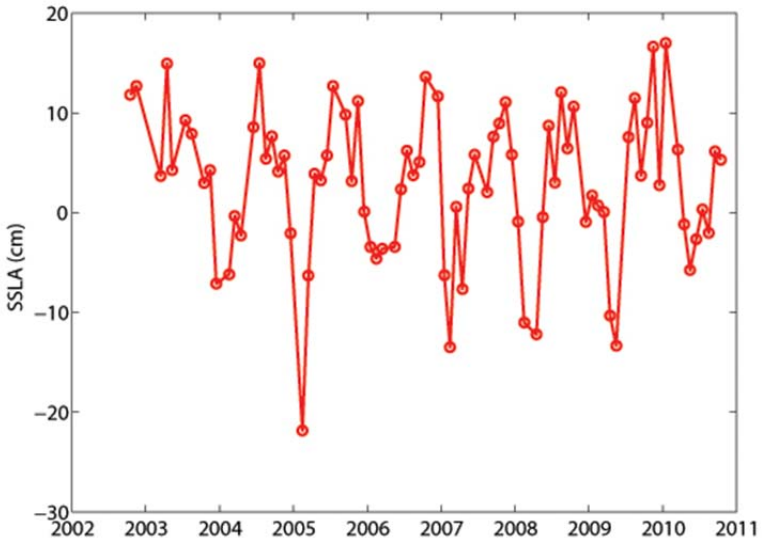

Figure 3: Steric sea level anomaly changes (Sea level changes due to variations in Temperature and salinity) over the Nordic Seas during October 2002 to October 2010.

Land: In the third focus area on land, we have been investigating variations of the continental total water storage, total groundwater storage, and anthropogenic contributions across the Middle East. By using a mascon analysis method and GRACE level 2 release 05 data from CSR during February 2003 to December 2012, the time series of total water storage, total ground water storage and anthropogenic contributions are estimated over this region. The region is subdivided to seven mascons including Iran, Iraq, Syria, eastern Turkey (east of 35o longitude), northern and southern Saudi Arabia (north and south of 25o latitude), and the region immediately west of Caspian Sea. To separate the groundwater variations into naturally occurring and anthropogenic components, we subtract the CLM4.5 (version 4.5 of the Community Land Model) 2003–2012 groundwater trend (which does not include anthropogenic contributions) shown in Figure 4 (left), from the GRACE -minus- SSCR total groundwater trend (Soil moisture + Snow + Canopy + River storage, computed from CLM4.5). The result, shown in Figure 4 (right), represents anthropogenic groundwater variations. The results show that Iran with a rate of 25±6 Gt/yr has the most groundwater loss rate during February 2003 to December 2012 in this region. The Iran's rate of groundwater loss from the GRACE data is supported by an analysis of in situ well data from across Iran. The results also show that the GRACE mission is able to monitor monthly water

storage changes within river basins and aquifers that are 200,000 km2 or larger in area, and, can contribute to water management at regional and national scales, and to international policy discussions as well. For more information see Joodaki et al. (2014).

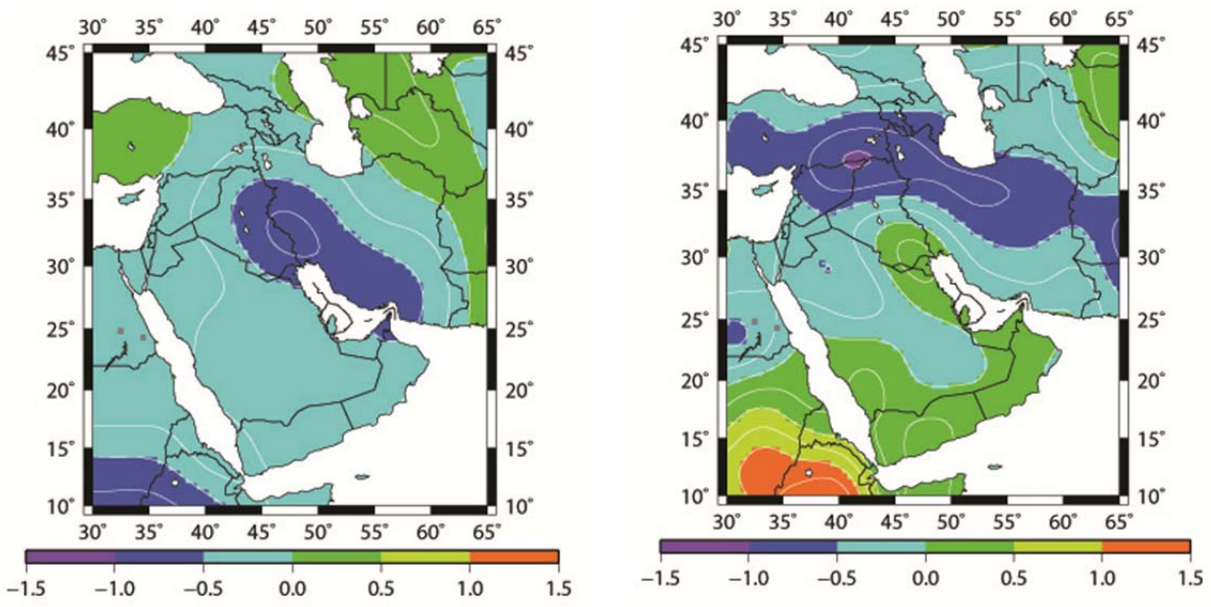

Figure 4: Secular trend (cm/yr) in groundwater during 2003-2012 due to (Left figure) naturally occurring estimated from the CLM4.5 ground water results and (Right figure) Human-made estimated from GRACE data.

References:

G. Joodaki and H. Nahavandchi (2010) Greenland mass balance estimation from satellite gravity measurements, ESA Living Planet Conference, ESA Special Publication SP-686.

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4 IAGA – International Association of Geomagnetism and Aeronomy

- **National Representative**, Prof. Dr. Ulf-Peter Hoppe, Norwegian Defence Research Establishment (FFI) and University of Tromsø (UiT)
- **Deputy national representative**, Dr. Jesper Gjerløv, University of Bergen (UiB)

IAGA-related research in Norway consists of two subject areas, (1) space research including aeronomy, atmosphere, ionosphere, and magnetosphere research, and (2) geomagnetism with emphasis on the solid Earth's magnetism.

4.1 Space research

In 2010 the Research Council of Norway commissioned an evaluation of basic physics research in Norway (Research Council of Norway, 2010). The committee wrote about Space Physics, which is the largest IAGA-related set of research groups: "*The drivers for space physics research in Norway are both scientific and strategic. Both these aspects have a regional/national and an international context.*
Scientifically, Norway is geographically well placed to host ground-based observations of solar-terrestrial coupling. Ground-based incoherent scatter radars at Svalbard (Longyearbyen) and northern Norway (Tromsø) provide observations of the daytime and nighttime aurora respectively, and coupled with optical methods give almost continuous coverage from the middle atmosphere to the ionosphere. These are complemented by rocket-borne payloads which sample the ionospheric plasma in situ. These facilities play pivotal roles in international coordinated campaigns that involve the wider EISCAT (network of incoherent scatter radars) community and in-situ spacecraft observations at low Earth orbit and out to several Earth radii in the magnetosphere. These facilities also satisfy the national commitment to the peaceful exploitation of Svalbard and regional development of the Norwegian mainland. The EISCAT radar facility at Tromsø is nearing the end of its operational life and a next-generation facility – EISCAT 3D – is proposed, based on fields of phased-array dipoles rather than a few high-powered Klystron/dish-based technology. …
There are small but highly effective centers of excellence in space-based instrumentation at UiB and UiO, focusing on X-Ray/gamma detectors and Langmuir probes, respectively. Both these groups have significant international engagement and have competitively achieved selection for, e.g., ISS, and ESA and NASA mission payloads. These groups have benefitted from the availability of rocket programs to develop and demonstrate their detectors to an international audience and thus secure selection for international missions, and a case would need to be made for the future need for rocket programs in this context. As with much of Norwegian physics, these

groups are at marginal or subcritical size due to staff retirements and deliver an impressive level of international impact given the staffing available.
Technology for space exploration traditionally has a security dimension which is also evolving. This has in the past been a driver for the rocket program but this is now regarded as no longer of strategic importance. Science currently funded by RCN includes rocket-borne in-situ ionospheric observations, and these attract international support. Until recently the Norwegian Defence Research Establishment (FFI) has supported the testing and integration of rocket-borne payloads, but this is no longer a strategic priority. If this capability is to be maintained it will need to be picked up by the university sector."

4.1.1 Birkeland Centre for Space Sciences

In 2012 a new Centre of Excellence, The Birkeland Centre for Space Science (BCSS), was awarded to UiB, UNIS and NTNU. It opened in March 2013. Professor Nikolai Østgaard (UiB) is the centre leader. The centre will be funded by the Research Council of Norway (RCN) for ten years. The Birkeland Centre will study how the Earth is coupled to space. and is organized in 4 scientific groups focusing on 4 main questions: 1) When and why is the aurora in the northern and southern hemisphere asymmetric? 2) How do we get beyond the static large-scale picture of the ionosphere? 3) What are the effects of particle precipitation on the atmospheric system? 4) What is the role of energetic particles from thunderstorms in geospace (e.g., terrestrial gamma flashes)? The last question and group is also funded by an ERC Advanced Grant (PI: N. Østgaard). In addition the centre has 2 instrumentation groups (space and ground) and a public outreach and education group. The centre consists of 40 people (staff, postdocs, PhD and engineers) and about 20 Master students. A collaboration with Bjerknes Centre for Climate Research was initiated early 2014 to explore the effects of particle precipitation on climate.
During its first year the centre had more than 30 publications, organized six sessions at EGU and AGU meetings and given many invited talks. The centre is active in international networks (TEA-IS, SCOSTEP, HEPPA) and the Solar System Exploration Working Group, an advisory group for ESA for future space missions. Large instrument projects are ASIM to the International Space Station, where we build the X- and gamma-ray detector and the new SuperDARN radar at Svalbard. One highlight from the first year was the AGU press release in April, 2013 where we showed for the first time the temporal sequence of terrestrial gamma ray flash, optical lightning and their associated radio signals. Another highlight was that a new and innovative experiment was awarded with 24 hour continuous operation of the radar in Aricibo to explore how temporal and spatial scales of ionospheric parameters can be resolved. A third highlight is that the BCSS team at UNIS organized the superDARN international workshop—May 2014.

4.1.2 University of Oslo

The Plasma and Space Physics Group at the University of Oslo is active within experimental and theoretical space plasma physics. Scientific objectives include multiscale and multipoint studies of ionospheric phenomena, particle precipitation, instabilities and turbulence, global ionospheric convection and current systems, irregularities and scintillations, instabilities and turbulence, as well as numerical studies of plasma phenomena on kinetic scales. The group has a leading role in the 4DSpace innovation centre at the Faculty of Mathematics and Natural Sciences, University of

Oslo for studies of turbulence in the polar ionosphere. This multidisciplinary centre has been established in January 2014 and is based on the earlier STAR initiative. Under the umbrellas of the 4DSpace and STAR, the group has successfully developed spacecraft instrumentation such as multi-needle-Langmuir probes that will be mounted on several of the QB50 satellites, as well as in the development and launching of sounding rockets (ICI-rocket series for studies of the cusp region irregularities), and nanosatellites for in-situ space weather studies. It also working with development of numerical and analytical studies of plasma turbulence in the context of ionosphere. The group operates instruments for optical studies of the auroral zone and for scintillation monitoring and participates in several ESA projects.

4.1.3 Arctic University of Tromsø

The Space Physics Group at the Department of Physics and Technology of the University of Tromsø has two main activities. One is based on the use of the EISCAT radars on the mainland and on Svalbard and the other is based on the use of instrumented rockets. The first activity is concentrated on the investigation of small-scale plasma irregularities associated with the aurora and in the development of radar interferometric imaging to measure the mentioned irregularities. A five-baseline interferometer (EASI, EISCAT Aperture Synthesis Imaging) has been deployed on Svalbard. Campaigns to measure small-scale irregularities in aurora with EASI and with high-resolution cameras are planned for the winter season 2013/14. The EASI development is associated with the development of imaging technologies for the future EISCAT-3D. – The rocket activity is concentrated on investigations of charged dust particles in the polar mesosphere (ice particles and meteoric smoke). Work is underway to build new rocket probes for a campaign in summer 2014 at Andøya Rocket Range. These investigations are enhanced by the use of the EISCAT HEATING which can artificially modify the charge state of the dust particles. A scientist employed in early 2013 with broad experience in optical techniques will widen the scientific activities to include optics. In late 2012 the group submitted a proposal together with several of the other Norwegian groups to the Research Council of Norway with the aim of building EISCAT-3D.

4.1.4 UNIS

The Space Physics Group at UNIS has its main focus on experimental space physics. The scientific focus at UNIs relates to auroral particle precipitation, ionospheric convection, current systems and gravity wave studies in the mesosphere. UNIS owns and operates the Kjell Henriksen Observatory (KHO) – a world class facility dedicated to optical observations of aurora and airglow. The observatory currently has 27 instruments operated by 18 institutions from eight different countries. Several projects are currently underway to construct a variety of optical instruments, including a hyperspectral auroral imager and a daylight-capable auroral imager. The group owns and operates SPEAR (Space Plasma Exploration by Active Radar) – the northernmost ionospheric heating facility in the world. SPEAR had its last campaign in November 2013, where it supported the new ePOP satellite mission. SPEAR will be decommissioned during 2014. The focus has now turned to a new SuperDARN radar currently being built. It will be part of a global network of upper atmospheric radars. The new radar system will be collocated with KHO and SPEAR. The group provides ground support for sounding

rocket missions launched from Svalbard and northern Norway. The Space Physics Group at UNIS now forms one of the three nodes of the Birkeland Centre of Excellence.

4.1.5 The former Space Physics Group at FFI

The Space Physics Group at the Norwegian Defence Research Establishment (FFI) concluded more than five decades of middle atmosphere research, ionosphere research and space research in December 2010 with a final rocket and ground-based campaign aimed at quantifying the influence of micrometeors and meteoric smoke particles on the middle atmosphere. The programme "Existence and Charge state Of Meteoric smoke particles in the middle Atmosphere" (ECOMA) included nine launches of the dedicated ECOMA payload distributed over the years 2006 to 2010. Until early 2013 Norwegian scientists, together with their close collaborators from Germany and five other countries, published nine papers in a special issue with the results from the 2010 ECOMA campaign. The surprising new results included the fact that even during a major meteor shower such as the Geminids, the sporadic meteors contribute at least as much to meteor smoke as shower meteors (e.g., Hoppe and Rapp, 2013).

4.1.6 Tromsø Geophysical Observatory

Tromsø Geophysical Observatory (TGO) is a unit under the Faculty of Science and Technology at UiT the Arctic University of Norway. TGO has the primary task of maintaining the long time series of geophysical measurements inherited from the Auroral Observatory in Tromsø when the University of Tromsø was established in 1972. TGO's main tasks may be divided into three groups.

4.1.6.1 Geomagnetic measurements

TGO operates a network of 14 magnetometers from Karmøy in southern Norway to Ny-Ålesund on Svalbard. Three of the magnetometer sites have status as Geomagnetic Observatories, namely Dombås, Tromsø and Bjørnøya. This implies that absolute calibrations are performed at these sites regularly and that calibrated data are transferred to the World Data System (world data centers in Edinburgh and Kyoto). The remaining sites are calibrated variometers. Data from TGO observatories are part of the world-spanning effort to monitor the secular variation of the geomagnetic field and to produce international models of the field. As well as providing data for basic research within auroral space sciences, TGO also provides real-time data services for magnetic surveys and for the drilling operations performed by the petroleum industry. TGO has status as Expert Service Centre coordinator for Geomagnetiic conditions in the European Space Agency's Space Situational Awareness Program and is participating in the EU FP-7 project ESPAS. Geomagnetic data from TGO is available through several sources on the internet such as IMAGE, SuperMAG, WDC and TGO's own web pages. Near-future developments will be the establishment of a new Geomagnetic Observatory at Ny-Ålesund and the deployment of magnetometers at several new locations (Jan Mayen during 2014). The geomagnetic observatory in Tromsø must be relocated outside the City of Tromsø because of cultural noise; this will happen within a few years.

4.1.6.2 Vertical electron density soundings

TGO operates an ionosonde at Ramfjordmoen near Tromsø in collaboration with Qinetiq. Vertical ionospheric soundings have been performed continuously in Tromsø since 1932. Thus, the Tromsø ionosonde data set represents one of the longest time series of its kind. Data from the ionsonde is provided to The World Data Centre for Solar-Terrestrial Physics at the Rutherford Appleton Laboratory. Work is in progress to reestablish an ionosonde at Ny-Ålesund where such measurements have been made about half the time since 1972. Data from the Tromsø ionosonde are provided for space weather purposes through portals such as SWACI and GIRO.

4.1.6.3 Hosting guest instrumentation

TGO is responsible for the Ramfjordmoen Research Station, which is collocated with the EISCAT mainland transmitter site. Here TGO provides facilities for guest research groups to install their instruments for shorter or longer periods. Current instrumentation hosted is: several multispectral imagers, spectrographs, GPS receivers and a LIDAR system.
A small presence has been established in Skibotn in order to provide space for optical instrumentation. UiO is deploying an All-sky Imager there in 2014 and several campaigns are planned for the auroral season 2014/15.

4.1.6.4 Other TGO activities

In addition to the above mentioned activities TGO also operates three meteor radars at Tromsø, Bjørnøya and Longyearbyen in collaboration with the University of Nagoya and NIPR (Japan), an MF radar at Ramfjordmoen in collaboration with the University of Saskatchewan and the University of Nagoya and the SOUSY MST radar at Longyearbyen. The meteor radar at Bjørnøya will be relocated to Alta in Northern Norway during 2014. TGO has during 2013 established single-beam riometers at Ny-Ålesund and Skibotn and more are planned.

4.2 Geomagnetism of the solid Earth

At the Geological Survey of Norway (NGU) there are at least three scientific teams with relation to IAGA:

- Applied geophysics uses aeromagnetic measurements to map geological units and mineral resources. In this connection also satellite data from the ESA SWARM mission will be studied in the coming years.
- Marine geology uses magnetic measurements either for paleomagnetic dating of sediment cores, or to identify environmental changes or climatic variation.
- Geodynamics studies large-scale tectonics based on paleomagnetic measurements. The same data are also used to investigate long-term variability of the Earth's internal magnetic field related to changes of the geodynamo.

Paleomagnetic research at the University of Bergen (Department of Earth Science) focusses on physical factors influencing the fidelity of the paleomagnetic signal in lacustrine, marine and eolian sediments (Løvlie et al., 2011). In addition, enviromagnetic parameters from proglacial

lake sediment systems are applied for high-resolution Holocene paleoclimate reconstructions. Paleoclimate research is in close collaboration with quaternary geologists at the department.

There are small but active research groups at NTNU in Trondheim (Department of Geology and Mineral Resources Engineering) as well as the University of Oslo (Physics of Geological Processes).

4.3 References

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Løvlie, R., R. Wang, and X. Wang, In-situ remagnetization experiments of loess on the Chinese loess plateau: Evidence for localized post-depositional remanent magnetization, Geochem. Geophys. Geosyst., 12, Q12015, doi:10.1029/2011GC003830.
Research Council of Norway, Basic Physics Research in Norway – An evaluation, ISBN 978-82-12-02753-4, 2010.

5 IAHS – International Association of Hydrological Sciences

5.1 IAHS and hydrological sciences in Norway

In 2011 Norway established a national IAHS committee appointing Norwegian representatives and correspondents for all the IAHS commissions and working groups for the period 2011-2015. The names and institutions of the members of the national IAHS committee are listed below:

- **National Representative**, Dr. Per Stålnacke, Bioforsk
  (until Sept. 2014: Dr. Hege Hisdal, the Norwegian Water Resources and Energy Directorate (NVE))
- **Deputy national representative**, Dr. Thomas Skaugen, the Norwegian Water Resources and Energy Directorate (NVE)
- **ICCE** - International Commission on Continental Erosion, Mr. Jim Bogen (NVE)
- **ICCLAS** - International Commission on the Coupled Land - Atmosphere System, Dr. Ingjerd Haddeland (NVE)
- **ICGW** - International Commission on Groundwater, Dr. Bjørn Frengstad (Geological Survey of Norway – NGU)
- **ICRS** - International Commission on Remote Sensing, Dr. Rune Engeset (NVE)
- **ICSH** - International Commission on Statistical Hydrology, Dr. Thomas Skaugen (NVE)
- **ICSIH** - International Commission on Snow and Ice Hydrology, Ass. Professor Thomas Vikhamar Schuler (Department of Geosciences, University of Oslo)
- **ICSW** - International Commission on Surface Water, Dr. Hege Hisdal (NVE)
- **ICT** - International Committee on Tracers, Presently no representative
- **ICWQ** - International Commission on Water Quality, Dr. Brit Lisa Skjelkvåle (Norwegian Institute for Water Research)

- **ICWRS** - International Commission on Water Resource Systems, Professor Knut Alfredsen (Norwegian University of Science and Technology)
- **Working Group on Education in Hydrological Sciences**, Professor Lena M. Tallaksen (Department of Geosciences, University of Oslo)
- **Working Group on Precipitation**, Ms. Torill Engen-Skaugen and Mr. Ole-Einar Tveito (the Norwegian Meteorological Institute)
- **PUB - Prediction in ungauged basins**, Dr. Stein Beldring (NVE)

The national representative and the deputy national representative are both vice-presidents in IAHS commissions and thereby actively take part in organizing symposia and workshops in IAHS conferences, including at the IAHS scientific Assembly to take place in Gothenburg in 2013. They also contribute to the IAHS newsletter and activity reports of their commissions.

Hydrology is a scientific discipline that can be seen as part of the geosciences, but also as an environmental science. In addition hydrology is part of the climate system and hydrological research is therefore also a part of the climate research. This is reflected in the wide spectrum of hydrological research carried out in Norway.

An evaluation committee comprised of leading international experts in a range of Earth Science disciplines reported to the Research Council of Norway (Anon, 2011) that

"Earth Science research in Norway is generally in a state of good health. Very few truly weak research areas were observed and in a number of fields, e.g. climate science, meteorology and atmospheric science, marine science, hydrology, physics of geological processes, and sedimentary basin development in the context of petroleum systems, Norway can be considered to be internationally leading."

The hydrological sciences were also included in an evaluation of Norwegian climate research. An international evaluation committee was appointed by the Norwegian Research Council and their conclusions, including key scientific references related to climate change effects on hydrology, can be found in RCN (2011).

The two reports cover research related to several IAHS commissions. Some examples of focus research areas in 2012 are listed below.

- Hydrological modeling covering physically based models from the global to the local scale, examples:
    - Related to global scale modeling, Norway participates in the ISI-MIP project, a community-driven modeling effort with the goal of providing cross-sectoral global impact assessments, based on the newly developed climate and socio-economic scenarios.
    - At the regional, national and local scale, hydrological models are applied to study climate change effects on hydrology, including floods and droughts.

    - At the national and local scale improved modeling for flood forecasting is a core issue. This includes studies of the spatial extreme statistics of areal precipitation based on observations.
    - Recently modeling of the land-atmosphere interactions has become a core research topic.
- Snow and ice:
    - In the field of snow hydrology, research focused on better understanding and description of snow distribution over a range of different scales and different governing processes. Also the study of associated physical snow properties gained enhanced interest due to the implications for a recently established national snow avalanche warning service.
    - Studies of glacier surface mass balance, volume and front changes are of key importance and process studies continued on the linkages between glacier hydrology and atmosphere as well as of hydrology and glacier dynamics including subglacial processes. Progress was made in regional scale modeling of glacier mass balance, with implications both for water resource management as well as for assessing country-wide contribution to sea level changes.
- Water quality:
    - The major research issues related to water quality in Norway is connected to the implementation of the EU Water Framework Directive. In particular to set reference conditions for different types of water and to evaluate what possible effects climate change can have for the chemistry of surface waters.
    - Dissolved organic carbon has shown an increasing trend over the last 15-20 years, and it is still a big question what the drivers for this increase are. The browning of water has implications for drinking water quality and for life conditions for aquatic biota. Increasing levels of mercury in freshwater fish is a major concern in Norway and the increase might be a consequence of the browning of the water. Recovery from acidification of lakes and rivers, and increased eutrophication in many lakes is also important research topics. The fate of both well-known and new recently discovered environmental pollutants (POPs) in aquatic ecosystem is a topic of great concern and also research, in particular because the levels of some POPs are unexpectedly high in some lakes.

5.2 References

Anon (2011): Research in Earth Sciences in Norway. An evaluation. The Research Council of Norway. ISBN 978-82-12-03004-6

RCN (2011) Norwegian climate research. An evaluation. The Research Council of Norway. ISBN 978-82-12-03085-5

6 IAMAS – International Association of Meteorology and Atmospheric Sciences

6.1 Research in meteorology and atmospheric sciences in Norway

Research in meteorology and atmospheric sciences has proud traditions in Norway, having delivered substantial contributions to the understanding of extratropical cyclones and in developing measurement and modeling frameworks to assess transboundary transport of chemical pollutants. Norwegian scientists continue to play an internationally leading role in many areas of atmospheric science and climate science (Wilson et al., 2011), e.g., in connection with IPCC assessments.

Research in atmospheric science in Norway is mainly conducted at the Universities of Bergen (UiB) and Oslo (UiO), at the Norwegian Meteorological Institute (met.no), at the Norwegian Institute for Air Research (NILU) and at the Centre for International Climate and Environmental Research (CICERO), with additionally a small group in Svalbard (UNIS).

The groups are well connected, for instance UiO, met.no, CICERO and NILU have established neighboring office space in the Oslo CIENS building and the UiB group has significant collaboration with met.no as well as with other institutions in the area. The groups are also connected to international activities, e.g. through participation in and leadership of large EU projects.

An area of strong activity includes chemical transport modeling, effects of chemistry on climate - including through aerosols and clouds - and measures of climate forcing due to long-lived and short-lived species and due to emissions from specific sources such as transport, which can be used as a basis for policy discussions and agreements. Another area of activity is dynamical meteorology with a particular emphasis on high-latitude phenomena and small-scale flows. This includes measurement and modeling, having significant practical importance to forecasting and to other areas such as wind energy where connections between research groups and industry have recently been developed.

Norway has developed a new climate model, the Norwegian Earth System Model (NorESM) which has been used for simulations required for the 5th IPCC assessment report. The development of this model has done in collaboration between several Norwegian institutions (BCCR, met.no, UiB, UiO, NERSC, Cicero) and has built on components from major modeling centers in other countries, mainly the U.S.A. Bergen leads in the model development of the ocean and the carbon cycle, whereas the development of components for modeling of radiation, chemistry, aerosols and clouds is carried out in Oslo (UiO, CICERO, met.no). The development of this model has enabled Norway to make a significant independent contribution to the 5th IPCC assessment.

Another activity is the chemistry, dynamics, and remote sensing of the middle atmosphere at NILU, UiO and NTNU.

6.2 Reference

Wilson, B. M., P. Haynes, M. Kendall, J. Kleman, M. Rhein, F. Roure, E. Thomas, and E. Todini, 2011: Research in Earth Sciences in Norway. An evaluation. The Research Council of Norway 2011. ISBN 978-82-12-03004-6, 147 p.

7 IAPSO – International Association for the Physical Sciences of the Ocean

7.1 Research in Physical Sciences of the Ocean in Norway

Physical sciences of the ocean in Norway is concentrated around groups of physical oceanography, climate research groups and marine science groups (main institutions listed in Table 1), and are mainly located in Bergen, Oslo, Tromsø, and Svalbard. The regional foci of research are the coastal areas and fjords of Norway, the Arctic and Antarctic oceans and the Nordic Seas. Norwegian scientists do actively take part in internationally research through participation, leading and coordination of several research programs, and several groups in Norway maintain monitoring programs in the Antarctic, Arctic and the Nordic seas and thus provide a service to the international community. To strengthen the work in ice-covered areas, Norwegian government in 2012 funded a research vessel with ice-breaking capabilities, which is planned to be operative from 2016. Norwegian ocean scientists contribute to the work of the Intergovernmental Panel on Climate Change (IPCC).

Marine research constitutes ~7% of the total research in Norway, and is mainly funded through governmental funding (~60%, directly from Ministries or through the Norwegian Research Council), private funding (trade & industry) (~25%) or from international sources (~5%) (Sarpebakken, 2011). An evaluation committee comprised of leading international experts in a range of Earth Science disciplines, reported to the Research Council of Norway (Anon, 2011) that "*Earth Science research in Norway is generally in a state of good health. Very few truly weak research areas were observed and in a number of fields, e.g. climate science, meteorology and atmospheric science, marine science, hydrology, physics of geological processes, and sedimentary basin development in the context of petroleum systems, Norway can be considered to be internationally leading.*"

Table 1. Main research institutions for physical sciences of the ocean in Norway
University of Oslo, Department of Geosciences
University of Bergen, Department of Earth Science, Geophysical Institute
The University Centre in Svalbard, Department of Arctic Geophysics
Norwegian Meteorological Institute, Oslo
Norwegian Water Resources and Energy Directorate, Oslo
CICERO Center for International Climate and Environmental Research – Oslo
Uni Bjerknes Centre, Bergen
Institute of Marine Research, Bergen
Nansen Environmental and Remote Sensing Center, Bergen
SINTEF Marin modellering, Trondheim
Norwegian Polar Institute, Tromsø

7.2 References

Anon (2011): Research in Earth Sciences in Norway. An evaluation. The Research Council of Norway .ISBN 978-82-12-03004-6

Sarpebakken,B. (2011): Ressursinnsatsen til marin FoU og havbruksforskning i 2009. Rapport 10/2011 (In Norwegian). ISBN 978-82-7218-759-9

8 IASPEI – International Association of Seismology and Physics of the Earth's Interior

8.1 Correspondents and representatives of IASPEI related commissions and working groups:

- **National Representative**, Dr. Tormod Kværna (NORSAR)
- **Deputy national representative**, Professor Valerie Maupin (Department of Geosciences, University of Oslo)
- **ESC** – European Seismological Commission, Professor Kuvvet Atakan (Department of Earth Science, University of Bergen)
- **CoSOI** – Commission on Seismological Observation and Interpretation, Working Group on New Manual of Seismological Observatory Practice, Dr. Johannes Schweitzer (NORSAR)
- FDSN – International Federation of Digital Seismograph Networks, Dr. Johannes Schweitzer (NORSAR)

8.2 Main research institutions for IASPEI related sciences in Norway:

- Department of Earth Science, University of Bergen
- Department of Geosciences, University of Oslo
- Geological Survey of Norway
- NORSAR

8.3 Summary of activities in the field of seismology in Norway during the period 2010-2012

8.3.1 Norwegian National Seismic Network (NNSN) – new contract with the Norwegian Oil and Gas Association

The Norwegian National Seismic Network (NNSN) consists of 33 seismic stations with real-time data communication that monitor the seismic activities in Norway and the adjacent offshore areas including the Arctic. The network is operated by the Department of Earth Science at the University of Bergen in collaboration with NORSAR. Historically the first seismograph station was installed in 1905 in Bergen. Since then, the various networks of seismograph stations were operated in the country in the 1970's and 1980's which led to the development of the Norwegian National Seismic Network in the early 1990's. The operational support for the NNSN is provided

by the University of Bergen (UiB) and the Norwegian Oil and Gas Association. Recently the University of Bergen has signed a contract with Norwegian Oil and Gas securing operational funding the NNSN for the next 5 years with an option of extending until 2022, which amounts to more than NOK 60 million. This long-term commitment from the oil and gas industry is unique and provides an important platform for the seismological research and education in Norway.

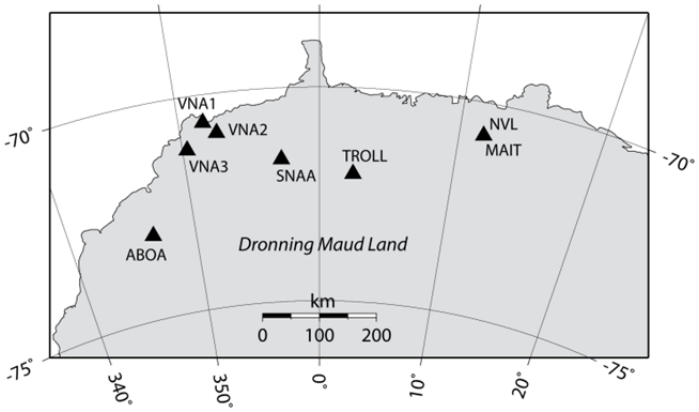
8.3.2 Seismic station TROLL in Antarctica

Seismologists in Norway have for many years wished to install a permanent seismic broadband station at the Norwegian research base Troll in Antarctica. In 2011 NORSAR obtained funding through the NARE (Norwegian Antarctic Research Expedition) program of the Norwegian Polar Institute, and in February 2012 the seismic station was installed.

Seismic stations in Antarctica are often installed on the ice shield. Such installations move with the ice and produce unwanted signal reflections from the bottom of the ice layer. At Troll, the seismic station is installed directly on bedrock, which greatly improves signal quality.

The new station extends the network of permanent seismic recording points in Queen Maud Land. The figure to the right shows seismic stations in Queen Maud Land with their international code names. Only data from TROLL, SNAA and VNA1-3 is available in real time for international research.

The station equipment (a Streckeisen STS-2.5 seismometer and a Quanterra Q330HR digitizer) was purchased in 2011 and tested at NORSAR's test facilities at Løten, Hedmark before being shipped to Antarctica.



The installation at TROLL was completed in February 2012. Our first stored data is from February 5th, 2012 and since then we have recorded, with only minor interruptions, ground motions from Antarctica. The seismic wave field is recorded for all three directions, vertical, north-south and east-west in the very broadband frequency range from below 1 mHz up to 48 Hz with a maximum sampling rate of 100 Hz. Data is continuously transmitted via satellite to NORSAR and then forwarded to the European data center ORFEUS in the Netherlands. From there, all data is freely available to the entire seismological community.

8.3.3 EPOS Project and the Norwegian National EPOS Consortium (NNEC) activities

The University of Bergen participates in the New Large Scale Infrastructure project EPOS (European Plate Observing System – www.epos-eu.org) on behalf of seven institutions in Norway. EPOS is included in the ESFRI (European Strategy Forum Research Infrastructure)

Road Map as the only large scale infrastructure project encompassing solid Earth science. EPOS is now established as Preparatory Phase Project (PPP) with funding from EC-FP7 for the period 2010-2014. The seven institutions participating in the EPOS PPP and constituting the Norwegian National EPOS Consortium (NNEC – www.epos-no.org) are, University of Bergen (UiB – leader of NNEC), NORSAR, Mapping Authority (SK), Geological Survey of Norway (NGU), University of Oslo (UiO), Norwegian Geotechnical Institute (NGI) and the Christian Michelsen Research (CMR). NNEC has recently prepared a White Paper summarizing the main scientific challenges in solid Earth science and outlining the necessity of integration between the various monitoring networks including the seismological, geodetic, as well as the various geological and geophysical databases. Currently the NNEC is in the process of preparing for a large scale infrastructure proposal to be submitted to the Research Council of Norway (RCN) in October 2012.

8.3.4 National pool of mobile broad-band seismic stations

In 2011, the Research Council of Norway (RCN) awarded a consortium of four institutions (NORSAR, UiB, UiO, NGU) 5.1 MNOK for establishing a national pool of broad-band seismograph stations. The national consortium is now in the process of acquiring 30 units, which will be used for portable deployments in various scientific projects. This national pool is expected to be fully operational by summer 2013.

8.3.5 New projects of national character

Recently the solid Earth science community in Norway has established a formal collaboration with India through an agreement at a ministerial level between the two countries. The initiative has started with a joint India-Norway Earth Science Workshop which was held in New Delhi in September 2011 and hosted by the Ministry of Earth Science, Government of India. A number of priority areas of research have been identified during the workshop. New project proposals are underway to cover most of these priority areas. This national initiative is also linked to other bilateral collaborations in the region with Nepal, Bangladesh and Myanmar. Another recent joint project is between NORSAR, UiB and CENAIS in Cuba with focus on earthquake monitoring, seismic hazard and risk issues.

8.3.6 Nordic collaboration in seismology

Collaboration in seismology between the Nordic countries, Norway, Sweden, Denmark, Finland and Iceland has existed more than 40 years through the annual Nordic Seminars on “Detection Seismology”. In recent years these seminars have broaden the perspective both in its scientific content and also in participation including also the neighboring Baltic countries as well as other countries in Northern Europe and now operate under the title “Nordic Seismology Seminars”. In 2012 the Nordic Seminar was held in Tallinn, Estonia, during the period 24-26 October. In 2011 the Nordic collaboration was formalized through a Nordic project with the name “NordQuake”. NordQuake aims to strengthen the collaboration in seismology between the Nordic countries through dedicated meetings, workshops and training sessions. A training course in earthquake data processing was arranged in Bergen at the University of Bergen during the period 11-15 June 2012.