# Svalbard Integrated Arctic Observing System - SIOS

## Anbefalinger fra prioriteringsgruppen for nasjonal forskningsinfrastruktur i SIOS

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# Innhold

# 1. Om rapporten

Denne rapporten beskriver hvordan det norske komplementære infrastrukturturbidraget til SIOS kan se ut og angir prioriteringer for oppgradering av observasjonssystemet under SIOS. Rapporten er utarbeidet av en nasjonal ekspertgruppe og videre kvalitetssikret av Nasjonalkomiteen for Polarforskning. Rapporten er ment å være et underlag for utarbeidelse av en endelig søknad fra forskningsmiljøene, til *Nasjonal satsing på forskningsinfrastruktur (INFRASTRUKTUR)*, om finansiering av ny og oppgradert forskningsinfrastruktur under SIOS. For Forskningsrådet vil rapporten være en rådgivende referanserapport. I denne prosessen har det ikke vært mulig å få på plass kostnadsestimater for alle prioriteringene, dette er derfor utelatt i rapporten. Kostnadsestimater og videre prioriteringer må jobbes videre med i forbindelse med utarbeidelsen av en endelig søknad om ny infrastruktur (se kap 3.6).

Kapitel 2 gir en oppsummering bakgrunnen for rapporten, mens kapitel 3 gir en beskrivelse av arbeidet utført av den nasjonale gruppen.

Kapitel 4 gir en oversikt over den nasjonale gruppens prioriteringer og begrunnelser. Kapittelet er skrevet på engelsk av hensyn til at dette skal presenteres for det internasjonale SIOS-konsortiet.

# 2. Bakgrunn

SIOS Steering Board (SB) sluttet seg i sitt møte 22. april 2012 til en felles visjon for SIOS som innebærer at SIOS skal, basert på en helhetlig, faglig vurdering bli et «regionalt» observasjonsnettverk som muliggjør "Earth System Science" (ESS) studier med reelle muligheter til å prøve ut hypoteser om tverrgående koblinger i systemet. SIOS SB sluttet seg også til å gjennomføre en internasjonal prosess for top-down prioritering av hvilken infrastruktur SIOS må bestå av for å kunne besvare viktige forskningsspørsmål knyttet til globale endringer i et ESS-perspektiv. Den internasjonale ekspertgruppen, ledet av Cynan Ellis-Evans, har gått igjennom den foreliggende brede gapanalysen gjennomført under SIOS (*SIOS Gap-analysis Synthesis Report*) og har levert sin prioriteringsrapport «*Svalbard Infrastructure Optimisation Report ver. 1.8*» til SIOS. Rapporten, ble godt mottatt på SIOS General Assembly i desember 2012 (kap. 3.3).

Nasjonalkomiteen for polarforskning (Polarkomiteen) sluttet i sitt møte 2.-3. mai 2012 seg til et forslag om å foreta en helhetlig vurdering av hvilke prioriteringer Norge skal fremme som sine infrastruktursatsninger i prosjektet, parallelt til den internasjonale prosessen. En arbeidsgruppe ble oppnevnt av Forskningsrådet for å gjennomføre en nasjonal prioriteringsprosess og komme med anbefalinger om prioriteringer av norsk forskningsinfrastruktur under SIOS. Prioriteringsrapporten skal bidra til å gi det norske SIOS-konsortiet og Forskningsrådet best mulig råd om hvordan de norske infrastrukturbehovene bør prioriteres. Gruppens rapport med prioritert forskningsinfrastruktur er kvalitetssikret av Nasjonalkomiteen for polarforskning gjennom en høringsrunde med forskningsmiljøene. Høringsrunden ble utført elektronisk og rettet mot forskningsledere ved institusjonene. Ved høringsfristen 18. mars 2013, kom det inn høringsuttalelser fra 10 institusjoner. I etterkant har relevante innspill blitt innarbeidet i rapporten.

Hensikten med dette prioriteringsarbeidet har vært at et norsk forslag om opprustning av forskningsinfrastruktur på Svalbard under SIOS vil være godt forankret i det norske polarforskningsmiljøet.

**Oppgradering av observasjonssystemet under SIOS**

Det norske SIOS-konsortiet må sende en søknad med fullstendig prosjektbeskrivelse, når tiden er inne, til den nasjonale infrastrukturordningen og vil bli kvalitetssikret der, fortrinnsvis til de fastsatte søknadsfristene under *Nasjonal Satsing på Forskningsinfrastruktur*. Forskningsrådet vil publisere en prosedyre for hvordan SIOS konsortiet skal søke om midler til finansiering av ny og oppgradert infrastruktur, hvordan søknaden vil bli behandlet og hvordan dette skal være koordinert med de internasjonale partnernes planer, i forbindelse med utlysning av midler. Det forventes da at den foreliggende nasjonale prioriteringsrapporten vil inkorporeres i søknaden slik at denne representerer realistiske investeringsplaner, samt at søknaden er i samsvar med den internasjonale SIOS prioriteringsstrategien (*SIOS Research Infrastructure Optimization Report*). Endelig beslutning om hvilken infrastruktur som skal finansieres må gjøres i lys av øvrige lands prioriteringer, slik at alle opplever at deltakelse i prosjektet gir en klart forstått tilleggsverdi, både i form av de enkeltstående investeringer landene bidrar med og i form av en forskningsmessig tilleggsverdi som ikke ville oppnås uten SIOS.

**Etablering av SIOS Kunnskapssenter**
Den norske grunnfinansieringen av Kunnskapssenteret (SIOS KC), som vil være senteret for koordinering av SIOS og ha ansvar for felles tjenester til polarforskere knyttet til å gi bedre tilgang til infrastruktur og data, felles logistikk-tjenester, langsiktig kunnskapsforvaltning, opplærings- og utvekslingsprogrammer og strategiutvikling, behandles separat. Planlegging og implementering av SIOS KC og relaterte tjenester gjøres under SIOS PP, som koordineres av Forskningsrådet og vil være gjenstand for internasjonale forhandlinger. Denne prioriteringsrapporten omhandler ikke etablering av SIOS KC.

# 3. Mandat og oppdrag for den nasjonale gruppen

En arbeidsgruppe ble oppnevnt av Forskningsrådet for å gjennomføre en nasjonal prioriteringsprosess knyttet til SIOS og komme med anbefalinger om prioriteringer av norsk forskningsinfrastruktur under SIOS. Gruppen har bestått av følgende medlemmer:

- Fridtjof Mehlum (leder), Naturhistorisk museum, UiO
- Jøran Moen, Fysisk institutt, UiO
- Eystein Jansen, Bjerknessenteret (BCCR)
- Ole Arve Misund, Universitetssenteret på Svalbard (UNIS)
- Kim Holmén, Norsk Polarinstitutt, (NP)

Gruppen har hatt følgende oppdrag:

- Etablere kriterier for prioritering av norsk infrastruktur som bidraget til observasjons-systemet under SIOS.
- Prioritere infrastruktur på basis av gap-analysen, kriteriene og anbefalingene fra den internasjonale prioriteringsprosessen (ESS Questions).
- Levere sitt prioriteringsforslag til Polarkomiteen som gjennomfører nødvendige høringsmøter og utarbeider endelig forslag.

## 3.1 Gruppens arbeid med prioriteringene

Gruppen har fokusert på det norske bidrag til basis infrastrukturen (SIOS CORE) samt synliggjort den prosessrelaterte forskningsinfrastrukturen (SIOS PROCESS) og hva den gir av merverdi i forhold til internasjonal synergi. Data tilhørende SIOS CORE må være spesielt relevant og tilgjengelig for jordsystemmodellering (ESM) mens SIOS PROCESS skal ha et ESS-perspektiv med fokus på vekselvirkninger mellom «sfærer», tverrfaglighet og koblinger i systemet. Begge er vurdert opp mot kriteriesettet (kap. 3.5) og de internasjonale «key topics» (kap. 3.2) og rangeres i 2 nivåer (1 og 2 prioritet).

Gruppen har i tillegg utført følgende:

- Sammenholdt de nasjonale infrastrukturprioriteringene med den internasjonale prioriteringsrapportens prioriteringer under «key science questions» (kap. 3.4) samt gapanalysens «key research topics» (kap. 3.2).
- Begrunnet hvorfor det spesielt bør være Norge og norske miljøer som tar ansvar for målingene som er prioritert, samt gitt en spesiell begrunnelse der prioriteringene ikke er i samsvar med det den internasjonale rapportens anbefalinger.
- Utarbeidet en felles begrunnelse for prioriteringene under hvert temaområde, på basis av kriteriesettet som er utarbeidet (kap. 3.5).

Gruppen var enig om at de «key research topics» som er nevnt i gapanalysen må sees mer i sammenheng for i større grad å vektlegge grensesnitt og koblingene i systemet. Prioriteringen skal spesielt ta hensyn til at den norske infrastrukturen skal være komplementær og gi merverdi, bl.a. basert på bilaterale forhold og utenlandske prioriteringer, og ta hensyn til norske styrkeområder, synergieffekter osv. Anbefalinger knyttet til eventuelle identifiserte mangler/svakheter i gapanalysen og den internasjonale prioritering rapporten er også tatt med. De enkelte forslag til forskningsinfrastruktur er sortert etter følgende 3 dimensjoner:

- «Key science questions»
- SIOS-CORE og SIOS-PROCESS infrastruktur
- 2 nivåer (1 og 2 prioritet)

Det er 6 hovedtemaer i gapanalysen. Disse er fordelt mellom gruppens medlemmer som hver for seg har utarbeidet et forslag til prioritering.

Ansvarsfordeling:

- Jøran Moen: Magnetosphere – ionosphere/atmosphere
- Eystein Jansen: The coupled arctic geophysical system
- Ole Arve Misund: Environmental change and marine ecosystems
- Fridtjof Mehlum: Environmental change and terrestrial ecosystems
- Kim Holmén: Pollution issues in Svalbard og Solid Earth and long-term processes

## 3.2 Gap Analysis Synthesis Report - Key Research Topics

Det er utarbeidet en synteserapport for å bidra til et bedre overordnet fokus og smelte sammen noen av de i utgangpunktet 30 vitenskapelige nøkkelområder som ble foreslått i gapanalysen. Følgende 12 «key research topics» ble identifisert for SIOS i synteserapporten:

- KT1: Vertical coupling in the arctic atmosphere and coupling to space
- KT2: The Arctic lower atmosphere – boundary layer system: dynamical and radiation feedback processes
- KT3:  Oceanic and sea ice processes

- KT4: Marine transport of energy, nutrients and pollution (horizontally, vertically and through the food chain)
- KT5: Glacier and ice cap mass balance and dynamics
- KT6: Greenhouse gas processes and feedbacks in the Arctic climate system
- KT7: Arctic permafrost, periglacial geomorphological processes including geohazards related to periglacial landscape development
- KT8: Isostasy and changes in Solid Earth's local and regional stress field
- KT9: Direct human impact on the Arctic System
- KT10: Inter-compartmental transition processes related to pollutants and impact of climate change
- KT11: Arctic ecosystem resilience to climate variability and change
- KT12: Overarching issues – Meteorology and hydrology

Denne synteserapporten ble godkjent av SIOS SB som en 0'te versjon av en SIOS «Science and Infrastructure Investment Plan». En egen fjernmålingsstrategi utarbeides for SIOS separat. Dette er et viktig grunnlag også for å utarbeide SIOS sin endelige «Science Plan», eventuelt en «Science and Observational Integration Strategy», som også involverer fullt ut nødvendig infrastruktur for satellittfjernmåling. Det ble imidlertid klart at gapanalysen fortsatt var for bred og at en ytterligere top-down prioritering var nødvendig.

Lenke til *Gap Analysis Synthesis Report*
http://www.sios-svalbard.org/prognett-sios/Project_Documents/1234130481050

## 3.3 Svalbard Infrastructure Optimisation Report ver. 1.8

Den internasjonale prioriteringsrapporten *Svalbard Infrastructure Optimisation Report ver. 1.8* bygger på den eksisterende gapanalysen (*Gap Analysis Synthesis Report*, se kap. 3.2), visjonen inkludert forskningsspørsmålene og dokumentet «*A strategy for prioritization within SIOS*». Rapporten vil fungere som en felles utviklingsplan/strategi for oppgradering og vedlikehold av SIOS infrastrukturen, tilsvarende det andre distribuerte ESFRI infrastrukturer etablerer. Ambisjonene med strategien er å etablere et felles observasjonssystem som prioriterer langsiktige målinger av relevante jordsystemparametere knyttet til horisontal og vertikal transportmekanismer, samtidig som relevante lokasjoner pekes ut. Neste versjon av denne RI-strategien vil ta hensyn til de mange tilbakemeldingene årsmøtet gav til rapporten, blant annet at den må få frem tydeligere sin pan-arktiske rolle (rolle i SAON) og hvordan prioriteringene vil påvirke og spille på lag med nasjonale prioriteringer.

Lenke til *Svalbard Infrastructure Optimisation Report ver. 1.8*
https://www.dropbox.com/s/rlzw96u69wys88d/SIOS%20infrastructure%20opimisation%20report_1%208.pdf?m

## 3.4 Key Earth System Science Questions

I rapporten *Svalbard Infrastructure Optimisation Report ver. 1.8* har den internasjonale gruppen utarbeidet et sett med «Earth System Science Questions» samt gjennomført en top down analyse og prioritering av hva SIOS som et minimum må inneholde av forskningsinfrastruktur (må ha) for å kunne oppnå de forskningsmessige målene samt andre overordnede behov. I tillegg er det foreslått hva SIOS bør inneholde for å kunne levere forskning i verdensklasse (bør ha) og infrastruktur som i hovedsak kun vil være til nytte innenfor en sfære (fint å ha). Den internasjonale gruppen bringer frem nøkkelspørsmål av mer overordnet karakter og i et Earth System Science perspektiv, som utfyller hovedproblemstillingene fra GAP-analysen der denne var mer måle- og systemorientert. Prioriteringene er således også blitt noe annerledes. Den internasjonale rapporten strukturerer sin rapport etter måleprogram som adresserer vertikale koplingsprosesser og horisontale transportprosesser, relaterer disse til mediene Atmosfære, Hav og sjøis, kryosfære, pedosfære og biosfære, og stiller følgende ESS-relaterte nøkkelspørsmål:

**Vertical Coupling**

- EQ1: "What are the primary coupling processes that connect the troposphere, stratosphere, mesosphere and lower thermosphere and how is this coupling changing over seasonal and multi-year timescales?"
- EQ2: "What controls changes in the vertical structure of the Arctic atmosphere and the ocean?"
- EQ3: "How are changes in the extent of sea-ice cover in the Arctic impacting biogenic emissions from open water, notably in shelf seas, and what are the implications?"
- EQ4: "Is there evidence of change in Arctic marine ecosystem structure through warming, breakdown in vertical mixing and reducing sea-ice extent and age structure?"

**Horizontal Transport**

- EQ5: "What roles do oceanic exchanges of heat between the Arctic and lower latitudes play in Arctic-global climate linkages?"
- EQ6: "To what extent are emissions of short lived greenhouse gases and aerosols (e.g. methane and 'black carbon') outside the Arctic affecting Arctic change?"
- EQ7: "How are the horizontal influxes of sensible heat, nutrients and particulate matter to the Greenland and Barents Seas altering over time and what are the regional consequences?"
- EQ8: "How are the patterns and sources of long-range transported pollutants changing over time and how are these patterns manifested in Arctic ecosystems?"

**Svalbard land mass and biota interactions with changing climate**

- EQ9: "What are the impacts of climate change on Arctic landscape and terrestrial ecosystems?"
- EQ10: "What ecological changes are accelerating?"

**General ESS questions that the SIOS infrastructure can help address include:**

- EQ11: "What is the significance for Arctic climate of the substantial natural variability and feedbacks associated with high latitude winds and ocean currents?"
- EQ12: "What is the relative importance of anthropogenic forcing for Arctic change, especially on the regional and local scales?"
- EQ13: "What is the status of the Arctic water cycle and how are the different components (transport from low latitudes, atmosphere/ocean/sea ice exchange, ice sheets, glaciers, ecosystem exchange) contributing to the budget changing?"

- EQ14: "Why are many aspects of Arctic change amplified with respect to global conditions"
- EQ15: "What are the most important feedback mechanisms for amplification and are they specific to the Arctic System?"
- EQ16: "Will natural variability, particularly the interannual to multi-decadal modes of variability, be affected by anthropogenic forcing in the future?"

Den internasjonale gruppen mener alle disse ESS spørsmålene kan adresseres ved å bruke eksisterende forskningsinfrastruktur på Svalbard. Men, ved å oppgradere observasjonssystemet til å integrere observasjoner av vertikale og horisontale koplingsmekanismer og etablere et koordinert og distribuert nettverk av målestasjoner med tilstrekkelig oppløsning, så vil SIOS kunne gi tilby til det internasjonale polarforskningssamfunnet et detaljert observasjonssystem som her helt unik i Arktis.

## 3.5 Kriteriesettet for prioritering av forskningsinfrastruktur

Kriteriesettet har tatt utgangspunkt i kriteriene som benyttes i Forskningsrådets evaluering av forskningsinfrastruktursøknader.

**Fase 1: Nasjonal prioritering av nøkkelinfrastruktur**

- Forskningsmessig betydning: Excellence i norsk forskning. Infrastruktur som kan bidra til at norske miljøer blir internasjonalt ledende. Unike forskningsmuligheter - støtter forskning som krever regionspesifikk fokus og prosesser som er unike. Bidrag til systemforskning som har global relevans. Adressere key science topics, bredde, koblinger, drivkreftene i systemet.
- Basal-parametere/tidsserier: Fokus på langsiktig overvåkning av basal-parametere i et ESS/ESM perspektiv. Lange tidsserier er en kjerne i SIOS.
- Prosesstudier: Infrastruktur som understøtter prosesstudier som må være oppskalerbare og anvendbare i videreutvikling av bl.a. klimamodeller, spesielt innen mangelfullt forståtte polare prosesser. Vektlegging av observasjoner/data for/fra prosesstudier, feltstudier og grunnforskning, der data vil gjøres tilgjengelig gjennom SIOS.
- Bidrag til et større observasjonssystem: Mulighet for å få tilgang til et større observasjonssystem som norske forskere alene ikke kunne hatt tilgang til. Videreutvikling av eksisterende infrastruktur. Dekke et gap i observasjonssystemet.
- Added value: Infrastruktur som gir merverdi gjennom kobling til SIOS og representerer et bidrag i forhold til komplementaritet, tverrfaglighet, koblinger og grensesnitt.
- Strategisk forankring og betydning: De enkelte delene av observasjonssystemet må være forankret i en norsk vertsinstitusjon og dennes forskningsprioriteringer, enten ved å bygge på eksisterende aktivitet (oppgradering) eller representerer en ny prioritering/satsing.
- Samarbeid og arbeidsdeling: De norske delene av observasjonssystemet skal inngå i en helhet i SIOS) og ha et nasjonalt/internasjonalt brukermiljø. Det norske bidraget til SIOS skal gjøre nytt samarbeid attraktivt og legge til rette for god arbeidsdeling og nettverksbygging mellom norske institusjoner.
- Relevans i forhold til internasjonale programmer: Bidrag til internasjonale programmer, databaser eller nettverk, som for eksempel WCRP, IGBP, SOLAS, IMBER, Future Earth, GEOSS, Global Change Programmene og nasjonale databaser som for eksempel NMDC, NORMAP, EBAS osv.

**Fase 2: Vurdering av langsiktighet og gjennomførbarhet**

- Langsiktig driftssikkerhet: Vurdering av plan for langsiktig finansiering av drift av infrastruktur/observasjonssystemet.

## 3.6 Kommentar til fremdrift og avveininger

Gruppen har brukt en del tid på å diskutere hvordan prioriteringene skulle gjøres og spesielt hvordan infrastrukturen, som identifisert i Gap-analysen og den internasjonale rapporten, burde vektlegges. Spesielt var det mye diskusjon om oppdelingen og vektleggingen av infrastruktur i det som ville kunne tilhøre et «CORE-observing system» og infrastruktur som var mer relatert til «PROCESS-studies». Etablering av en kraftfull SIOS-CORE vil understøtte prosess-studier som benytter SIOS-PROCESS på områder der norske miljøer er ledende. Gruppen var enig om at det må gjennomføres en top-down prioritering som er realistisk med hensyn til investeringsnivå. Det ble påpekt at prioriteringsprosessen også ble vanskeliggjort av mangler i gap-analysen og den internasjonale rapporten, bl.a. som følge av at det er eksperimentalistene som i hovedsak har deltatt i gapanalysen. Det er behov for at modellmiljøene i større grad engasjerer seg i å definere behovene for data og observasjoner under SIOS. Her vil både bedre geografisk dekning av «core observations» (sirkum-arktisk / SAON/ globalt) og økt observasjonsfrekvens fra eksisterende system være relevant.

Det var også enighet om at utgangspunktet må være at det norske bidraget til SIOS bygger videre der vi har eksellente miljøer og eksisterende infrastruktur, nasjonale fortrinn, og der vi ser store synergier med andre land, samtidig som det er behov for å definere et «CORE observing system» som alle kan samle seg om. Her kan en vurdering av samplingsstrategiene og tidsskala dimensjonen være til hjelp. Vurdering av hvordan data tas vare på og tilgjengeliggjøring er likeså helt essensielt.

Prioriteringsgruppen møttes første gang 7. juni 2012 og har hatt 4 møter. Siste møte 10. september 2012. Opprinnelig fremdriftsplanen ble utsatt fra 15. august med ca. 2 uker da det var klart at rapporten fra den internasjonale prioriteringsgruppen måtte foreligge og ville være et viktig premiss for nasjonal prioritering.

Det var enighet om at den norske prioriteringsprosessen ikke skal forskuttere andre lands prioriteringer og slik sett skal rapporten være rådgivende og ikke en endelig beslutning om prioritert infrastruktur.

# 4. SIOS – Proposal for national priorities of research infrastructure in Norway

A national expert group appointed by the Norwegian Research Council was given the task to make a recommendation regarding national Norwegian priorities on research infrastructure that should become a part of SIOS. The task was to prioritize the key topic research infrastructure listed in the Gap analysis synthesis report (chapter 3.2), and to identify important Norwegian infrastructure components to SIOS taking into account a set of selection criteria established for research infrastructure in Norway, as well as the Key Earth System Science Question and recommendation given in the International Prioritisation Report *(Svalbard Infrastructure Optimisation Report, ver 1.8,* chapter 3.3 -3.5).

This reference document does not cover issues concerning the SIOS Knowledge Centre (SIOS KC), it specifically assumes that the SIOS KC exists and functions in its coordinating role and as a data provider.

For each of the thematic areas of the SIOS Gap Analysis the proposal focus on basic (SIOS CORE) or process study related infrastructure (SIOS PROCESS). The proposal is judged on the basis of the criteria agreed, the international key topics, and ranged at 2 levels (1. and 2. priority). Data coming from SIOS CORE shall be especially relevant and be made available for ESM, while SIOS PROCESS will have an ESS – perspective with focus on the interactions between spheres, be relevant cross-disciplinary, and for couplings in the system. The justification of each item suggested and the priority given is similar to the justification given in the national GAP analysis and the International group, which have written quite extensively on this. The infrastructure needs has to a large extent only been classified as belonging to SIOS CORE or SIOS PROCESS, and ranked according to agreed criteria of the national prioritization (Chapter 3.5). The full tables are given in the Annex. For each thematic area a table with the highest priorities are given in the following text for clarity.

No new suggestions are added as the list is rather extensive. For most items suggested, Norway is the main contributor, but there are a few suggestions where other countries also have activities.

The core of SIOS will be integrated ESS-relevant monitoring studies focusing on regional relevant variables that show or facilitate changes over time scales from years to decades. Prioritisation of infrastructure shall reflect this focus. From the Norwegian side the ESS part is essential, we therefore present this first to set the overarching framework for the other priorities.

## 4.1 The coupled arctic geophysical system – ESM perspective priorities

**a. Main motivation, challenges and issues for Norway (Status of current research and infrastructure)**

It is a driving cause for the SIOS infrastructure to be relevant for Earth System Modeling. Hence it is essential that the infrastructures are adequate for this purpose. The Norwegian climate modeling community has developed the Norwegian Earth System Model (NorESM) which has been applied with success to the CMIP5 co-ordinated model simulations in support of IPCC Ar5. Despite major improvements both in this model system and in ESMs in general, Current ESMs display some clear deficiencies and weaknesses, which are important to consider in the SIOS perspective:

- Regional-scale precipitation continues not to be simulated as well as global and continental patterns.
- Assessment of model capabilities remains difficult owing to observational uncertainties.

- CMIP5 models used in IPCC AR5 realistically simulate the annual cycle of Arctic sea- ice extent, and the trend in Arctic sea ice extent over the past decades. Major inter-model differences remain in absolute values of sea ice extent and volume.
- There is large inter- model spread in terms of heat advection and in MOC strength in terms of volumes as well as governing processes, e.g. associated with Arctic shelf processes. There exist large inter-model differences in the model projections for Arctic summer-time sea-ice trends and snow albedo feedback.
- Models have problems simulating clouds and cloud radiative effects. In some cases, model results are in general agreement with observations, but the observational uncertainty precludes definitive statements about model quality.
- The stable atmospheric boundary layer in the arctic poses a challenge to models both due to resolution issues and to scarcity of data for validation and improved parameterizations.
- Observational evidence indicates that coupling between the troposphere and the stratosphere is important for seasonal to decadal variability in the Arctic, yet the observational constraints need improvements if models are to be better predictive tools on seasonal and longer time scales.
- Most CMIP5 ESMs produce global land and ocean carbon sinks over the latter part of the 20th century that fall within the range of observational estimates. The models also reproduce aspects of inter-annual variability and regional patterns of carbon uptake and release. Yet, there is wide difference between models in terms of the future projections of the land-carbon sink in high latitudes.

The strong reductions in summer sea ice cover in recent years have been most manifest in the Barents Sea, and several recent studies suggest that less sea ice has influenced both summer and winter season weather over Europe in recent years. The coupling of atmospheric processes with the ocean has apparently been critical for driving warm water into the Barents Sea and associated heat fluxes apparently strongly influenced the sea ice retreat. In order to test the stability of these inferences and to develop truly predictive systems for decadal scale predictions which assimilates observations into models it is critical to provide high quality measurements of the critical atmosphere, sea ice and ocean components that determine the fluxes of heat and mass into and out of the Arctic around Svalbard.

Current measurement programmes are ad hoc, and not secured on a longer time basis. Measurements in winter time and in the ice covered areas are spotty, and do not implement modern observational techniques such as autonomous systems to the extent required for true progress.

Current generations of Earth System models include comprehensive coupled models for the land surface and ocean carbon cycle. In these models, indications are that both the land and ocean carbon sinks in the high latitudes may reduce in the future, yet major uncertainties remains and the amplitude of this feedback varies substantially between models. Observations already document a lowering of pH in Arctic waters, but observations of relevant processes are scarce, of short duration and form an impediment for constraining models and understanding the large inter-model discrepancies. There is a strong need for a systematic approach for observations of carbon cycle parameters in time and space both on land, in the atmosphere and in the ocean. A number of these requirements have been expressed in the plans for a Norwegian contribution to the pan-European ICOS infrastructure, currently under evaluation in the Research Council.

**b. General description of the research infrastructure given priority:**
The proposed infrastructures that are prioritized have been selected in order to secure existing longer-term observations which are critical for model evaluation and development, to secure completeness in terms of covering the main fluxes into and out of the area, and to secure that the main fluxes in the carbon cycle is covered.

With this in mind, the infrastructures can be grouped into atmosphere, ocean and land surface observation systems.

Atmosphere:

- Automatic meteorological observations with an adequate spatial coverage are a requirement for understanding heat fluxes and the dynamical properties of the atmospheric boundary layer.
- Investigations of upper atmosphere dynamics of relevance for stratosphere/troposphere coupling.
- Aerosol and cloud observations to extend ongoing series are important to create an observational basis for studies of aerosol feedbacks and their influence on cloud formation.
- Greenhouse gas observations in the atmosphere are important to secure critical observations as part of the global observation system for atmospheric greenhouse gas measurements.

Land surface:
Greenhouse gas fluxes. Climate change will influence uptake and degassing of greenhouse gases from the Arctic tundra. This transition needs a strong measurement basis, with state-of-the-art instrumentation in flux towers.

Marine infrastructures:
There is a need for a combination of eulerian systems, i.e. platforms that follow ocean circulation or moorings, with standard sections contained from routine cruises with research vessels. Coverage of the main water mass pathways into and out of the Arctic Ocean on both sides of Svalbard and along the Northern margin is critical for both observing heat and salt fluxes and their variability and for observations of the marine carbon cycle, including the development of ocean acidification. Such data are critical for ecosystem impact studies besides their relevance for the physical and biogeochemical elements of the climate system.

**c. Main recommendation for Norwegian priorities (Impacts of the new RI on research and importance for various user groups):**
Prioritization follows the evaluation criteria listed below, where the impact on larger scale Earth System modeling is the key reference. Some suggested infrastructures have a more local implication, and are thus prioritized lower, although they may be important for disciplinary research in their own right:

- Will observations improve important deficiencies in state-of-the art Earth System Modeling?
- Will it be possible to upscale observations to the spatial scales relevant for Earth System Modeling?
- Are observations part of efforts to compile data sets from in situ measurements to be useful for model evaluation and comparisons.

The following infrastructures are given top priority .

Atmosphere:

- Automatic meteorological observations with an adequate spatial coverage at Ny Ålesund, Bjørnøya, Jan Mayen, Hopen, Edgeøya, Verlegenhuken, Karl XII Land, Svea: Meteorological parameters, radiation and energy balance parameters, including BSRN upgrade.
- Ny Ålesund: Winds in upper troposphere/lower stratosphere and mesosphere, PMSE, PMWE. MST radar and meteor scatter radar.
- Aerosol and cloud observations to extend ongoing series at Zeppelin observatory: Particle density, CCN density, ice nucleus density number, hygroscopicity growth, aerosol mass spectrum, aerosol absorption coefficient.
- Upgrade of greenhouse gas observations in the atmosphere at Zeppelin observatory: Isotopic GHG Monitoring in atmosphere and in precipitation. This will also contribute to ICOS.

Land surface:

- Greenhouse gas fluxes in Adventdalen, Kapp Linné. Proposed station in Rijpfjorden could be added at a later stage when the systems are proven operationally. $CO_2$, $CH_4$, $N_2O$, sensible and latent fluxes. Meteorological flux towers incl. eddy covariance and chambers measurements.

Marine infrastructures:

Eulerian platforms:

- Storfjorden sill and shelf-break off Sørkapp: Bottom frames with acoustic Doppler current profiler and single mooring for Ocean current profiles and water column and bottom temperature and salinity.
- Fram Strait: Mean ocean temperature and currents, acoustic signals for glider navigation. Triangle tomography moorings.
- Fram Strait Mooring: Hydrography, velocity, sedimentation, chlorophyll, oxygen, nutrients. Upgrade of Fram Strait moorings with sediment traps and biological sensors.

Repeat sections:

- Across Fram Strait: Tracers (S, d18O, N:P, alkalinity), revealing the sources of the Arctic Ocean freshwater components. CTD rosette water samples.
- Fram Strait, line along 79 N across the East Greenland Current. Ice thickness and drift velocity across the Transpolar Drift where it exits the Arctic Ocean: Time series. Ice Profiling Sonars and ADCPs.

This is summed up in table 1. For a full overview, see table A1 in the Annex.

**Table 1. Top Earth System Modelling perspective priorities**

| Location/area | Parameters | Infrastructure | Core/ Proc |
|---|---|---|---|
| Ny Ålesund | Winds in upper troposphere/lower stratosphere and mesosphere, PMSE, PMWE | MST radar and meteor scatter radar | P |
| Zeppelin Observatory | Particle density, CCN density, ice nucleus density number, hygroscopicity growth, aerosol mass spectrum, aerosol absorption coefficient | Instrument upgrade to replace above | C |
| All stations | Meteorological parameters, radiation and energy balance parameters, including BSRN upgrade | Meteorological station (upgrade to fully automatic, online) | C |
| Adventdalen, Kap Linné, Rijpfjorden | $CO_2$, $CH_4$, $N_2O$, sensible and latent fluxes | Meteorological flux towers incl. eddy covariance and chambers measurements | C |
| Zeppelin Observatory, Hopen, Ship-board | Isotopic analysis of water vapour and precipitation | Isotopic GHG Monitoring in atmosphere and in precipitation | P |
| Storfjorden sill and shelf-break off Sørkapp | T/S/Currents (profile) | Single Mooring | P |
| Storfjorden sill and shelf-break off Sørkapp | Ocean current profiles and bottom temperature and salinity | Bottom frames with acoustic Doppler current profiler to replace above | P |
| Fram Strait | Mean ocean temperature and currents, acoustic signals for glider navigation | Triangle tomography moorings | C |
| Across Fram Strait | Tracers (S, d18O, N:P, alkalinity), revealing the sources of the Arctic Ocean freshwater components | CTD rosette water samples | C |
| Fram Strait, line along 79 N | Ice thickness and drift velocity across the Transpolar Drift where it exits the Arctic Ocean: Time series | Four Ice Profiling Sonars and four ADCPs | C |

## 4.2 Environmental Change and Marine Ecosystems, Marine Observatories and Ecosystem Time Series

The international prioritization group has structured their analysis along medium (Atmosphere, Ocean&SeaIce, Cryosphere, Pedosphere and Biosphere), listing their key earth system science questions under each field. In order to reach a final national prioritization, the methodological analysis given in table 1 should be compared with the suggestions from the international group.

**a. Main motivation, challenges and issues for Norway (Status of current research and infrastructure):** Most probably, no marine polar region is as well explored and monitored as the Barents Sea and the waters off Svalbard. This is because the North Atlantic Current bring warm Atlantic water masses into the south western and central Barents Sea and west of Svalbard so that these waters are generally ice free and very productive with large, commercially valuable fish stocks. To underpin fisheries exploration and management, repeated transects have been taken the last century, and coordinated Norwegian – Russian surveys have been carried out annually since the early sixties.

However, process-oriented studies have been conducted more sporadically. Likewise, the currents and fluxes in the north eastern Barents Sea are less documented. The ice flow and southbound currents through the Fram Strait between Svalbard and Greenland needs better quantification. Most process studies and monitoring in the marginal ice zones have been conducted in summer – early autumn because of infrastructure limitations (access to ice strengthened research vessels). For proper quantification of the dynamics (EQ2, EQ5, EQ11, EQ12, EQ13) and changes (EQ3, EQ4, EQ7, EQ8, EQ15, EQ16) in the Arctic marine ecosystems, systematic observations must be made throughout the year, and processes must be studied in the cold and dark seasons also.

From about 2016, Norway will operate a new, state of the art ice-going research vessel that will enable scientists at Norwegian directorates (The Norwegian Polar Institute), management advisory institutions (The Institute of Marine Research) and universities to conduct state of the art marine science in Arctic waters, especially in the marginal ice zone. The new ice-going and other Norwegian research vessels can be treated as a Norwegian contribution to the basic SIOS infrastructure (SIOS – CORE). To enable more process oriented studies needed to understand the dynamics in the Arctic marine ecosystems, a suite of instruments for measurements of oceanographic parameters at definite sites in the Fram Strait and in selected Svalbard fjords are proposed. These infrastructure proposals could be the Norwegian contribution to the process related part of the SIOS consortium (SIOS – PROCESS).

**b. General description of the research infrastructure given priority:**

Of the 12 key research topics addressed in the SIOS Gap analysis , at least 4 (KT3: Oceanic and sea ice processes, KT4: Marine transport of energy, nutrients and pollution, KT9: Direct human impact on the Arctic System, and KT11: Arctic ecosystem resilience to climate variability and change) have marine focus or a significant marine component. Through the Gap analysis a wide range of methods and instruments were suggested to become part of a future SIOS infrastructure. Justified by the mandate given for the Norwegian National prioritization group, a “condensed” and more focused proposal for Norwegian marine infrastructure that could become part of SIOS is suggested (Table 2). The priorities suggested therefore rely to a large extent on the ambitious and thoroughly work of the Gap analysis.

To enable quantitative observation of the variations in important parameters and indicators necessary for describing, modeling and understanding the variability and changes in the marine ecosystems in the Svalbard fjords, near shore waters and in the polar offshore waters, a suite of marine infrastructure, both existing and new, are given priority (Table 2). Instruments on moorings, in ferry boxes, and on Eulerian platforms are suggest for continuous measurements of basic parameters as carbon flux, pollutants, temperature, salinity, oxygen, nutrients, and currents. Repeated transects across the Fram Strait to measure basic oceanographic parameters, ice thickness and ice flow out of the Polar Basin are suggested. Several observatories of physical and biological parameters in the Svalbard fjords are proposed to enable observations and quantifications of the impact from run off from land. Existing shelf surveys quantifying distributions and abundance of plankton, nekton and pelagic and demersal fish must continue and become an important, integrated part of the SIOS consortium.

**c. Main recommendation for Norwegian priorities (Impacts of the new RI on research and importance for various user groups):**

As described, there is a suite of existing research infrastructure used for regular marine observations in the Svalbard waters. The new Norwegian ice-going research vessel, supposed to be in operation by about 2016, will strengthen the seasonal regularity of such observations. This will be the case for shelf surveys for quantifying oceanographic parameters, plankton and fish distribution and abundance giving the main priority among the Langrangian and Active Marine Platforms (Table 2). Across the Fram Strait transects for measuring ice flow and ice thickness as well as basic oceanographic parameters will probably also be made more regularly with the new ice-going vessel. Likewise, Repeated Oceanographic Transects and selected Eulerian Marine Platforms are also given top priority (Table 2). Various new instruments and upgrading of moorings are suggested for the Eulerian Marine Platforms and the Repeated Sections (Table 2). The shelf surveys and repeated transects are especially relevant for scientific progress regarding the ESS related questions EQ4, EQ5, EQ11, EQ12, EQ13 and EQ16.

For enabling the marine ambitions of SIOS, new infrastructure is needed for more continuous observations in the fjords of Svalbard. The Eulerian Marine Platforms on sites in Kongsfjorden (the Hausgarten observatory), Billefjorden, Storfjorden sill and off Sørkapp) are proposed (Table 1). On these sites, preliminary investigations and observations have been made, and could form the basis as starting points in valuable time series of important marine parameters. Various new instruments are proposed to realize the ambitions behind these marine platforms. The Eulerian Platforms given priority (Table 1) are relevant to the ESS related questions EQ5, EQ7, EQ8, EQ11, EQ12 and EQ13.

**Table 2. Top Priorities for SIOS Infrastructure on Environmental Change and Marine Ecosystems, Marine Observatories and Ecosystem Time Series.**

| **Location or area** | **Parameters** | **Infrastructure** | **Core/ Proc** |
|---|---|---|---|
| Hausgarten, Kongsfjorden, Ripfjorden | Sedimentation in water column | Automated Sedimentation traps. Links with existing Moorings (see later) | C |
| Mainland/Svalbard-transect | marine pollutants and oceanographic parameters | Ferry Box automated monitoring on "Norbjørn" and other vessels | C |
| Billefjorden | T/S/Currents (profile), sediments, fluorescence, PAR | Single Mooring | C |
| Storfjorden and Sørkapp | T/S/Currents (profile) | Single Mooring | C |
| Eastward extension of the AWI/NPI mooring section in Fram Strait | T/S/Currents | Single Mooring | C |
| Fram Strait | Hydrography, Velocity, sedimentation, Chlorophyll, oxygen, nutrients | Upgrade of Fram Strait moorings with sediment traps and biological sensors | C |
| HAUSGARTEN, Kongsfjorden, Bellsund | Sediment, Meiofauna, Macrofauna | Box corer | C |
| HAUSGARTEN, Kongsfjorden, Bellsund | Sediments, Meiofauna | Multiple Corer | C |
| Isfjorden, Bellsund, off shelf west of Bellsund/Smeeren-burg, off shelf N of | Hydrography, Velocity, zooplankton biomass and vertical distribution, sedimentation, Chlorophyll, sea ice thickness | Moorings: CTD Temperature loggers, ADCP, Sediment traps, Fluorometer - link to Kongsfjorden and Ripfjorden moorings in Section 2 above | P |

| | | | |
|---|---|---|---|
| Rijpfjorden, Grøn-fjorden, Erik Eriksen Strait, Frans-Victoria Trough, N Barents Sea, East Greenland Shelf | | - | |
| Kongsfjorden, (eventually all others) | Hydrography, Velocity, zoo-plankton biomass & vertical distr, sedimentation, Chlorophyll, real time transmission | cabled moorings (additional instruments: MMP profilers, Echo-sounder. Link to Moorings in Section 2 above | P |
| Kongsfjorden, Fram Strait | Zooplankton, fish, hydrography , Chlorophyll div. organic and inorganic compounds Benthic fauna Sedimentation | Benthic lander: Echosounder, CTD, Fluorometer, Chem. sensors, video, ydrophones, sediment traps | P |
| Fram Strait | Hydrography, Velocity, sedimentation, Chlorophyll, oxygen, nutrients | Upgrade of Fram Strait moorings (Section 2) with sediment traps and biological sensors | C |
| Across Fram Strait | Tracers (S, d18O, N:P, alkalinity), revealing the sources of the Arctic Ocean freshwater components | CTD rosette water samples | C |
| Fram Strait, line along 79 N | Ice thickness and drift velocity across the Transpolar Drift where it exits the Arctic Ocean: Time series | Four Ice Profiling Sonars and four ADCPs | C |
| Fram Strait line along 79 N line | Ice thicknesses across the Transpolar Drift where it exits the Arctic Ocean: Snapshots each September | EM bird and EM31 Electromagnetic measures | C |
| Fram Strait, mooring array along 79 N | Arctic Ocean outflow in (EGC) (temperature, salinities, current velocities) | Arctic Ocean Outflow Observatory (AOBS) (16 microcats, 16 RCMs, five ADCPS, one TS string) | C |
| Transects KongHAU, Rijpfjorden, Isfjorden, Hornsund | Mesozoo-, Makrozoo-Ichtyoplankton<br>Water samples<br>Phytoplankton taxonomy<br>Chlorophyll a, fluorescence<br>Photosynthetically Active Radiation<br>Infaunal macrobenthos | WP2, WP3, MIK, Multinet<br>Niskin Bottles<br>Nets<br>Fluorometer<br>Li Cor PAR sensor<br>Van Veen Grab | P<br>C/P<br>P<br>P<br>P<br>P |
| Shelf of Svalbard surveys | Pelagic and demersal fish distribution and abundance | Bottom and pelagic trawl, acoustic instruments (echo sounders sonars) | C |

## 4.3 Environmental Change and Terrestrial Ecosystems, Terrestrial Observatories and Time Series

**a. Main motivation, challenges and issues for Norway (Status of current research and infrastructure):**
The basis for the prioritisation of infrastructure related to terrestrial ecosystems is to create an observation network that enables ESS studies with real opportunities to test hypotheses about cross-connections in the system. Here, we also include infrastructure for observations in freshwater ecosystems such as lakes and streams.

Current Norwegian terrestrial ecosystem observation activities in Svalbard are predominantly small-scale, stand-alone studies, which are not integrated into ESS modelling projects. There is a need for the Norwegian terrestrial ecosystem research community to join forces and develop integrated observation programmes as a part of SIOS. The scientific focus of the Norwegian contribution to SIOS will determine the Norwegian final priorities of infrastructure for the observation programme.

The observation system should provide support for on-going and new monitoring programs and related process studies to understand the processes and connections in the system through cross-disciplinary research. The system must therefore have a spatial and temporal resolution of the data collection that provides robustness to answer questions related to the changes and their causes. It is important that data from SIOS can be integrated with corresponding monitoring systems in other parts of the Arctic, and provides complimentary data from the Svalbard region for analyses of Arctic environmental changes.

Several Arctic countries have planned or established comprehensive environmental monitoring programmes in Arctic. The US has been working with the establishment of an "Arctic Observing Network" (AON), which is linked to the research programme "Studies of Environmental Arctic Change" (SEARCH). The US has also developed a science plan for "Regional Arctic System Modeling" (2010).

Of particular interest for terrestrial ecosystems is that the U.S. has recently published a science strategy for enabling continental-scale ecological forecasting called "National Ecological Observatory Network" (NEON, 2012), which includes an Arctic component. The goal of NEON is to understand the effects on ecosystems of changes in climate, land use, and the spread of alien species on a continental scale (North America).

Greenland has also developed a monitoring program called "Greenland Ecosystem Monitoring Programme"(GEM, 2012). The program will provide a platform for cutting-edge inter-disciplinary research on the structure and function of Arctic ecosystems, and contribute significantly to the understanding of their response to variability and climate change, as well as local, regional and global implications of changes in Arctic ecosystems (both terrestrial and marine).

The SIOS International Infrastructure Optimisation Report emphasises the connectivity in the terrestrial biosphere with permafrost, glacial hydrology, the atmosphere and the marine environment (nutrients from seabirds). The report states that in Svalbard, the biodiversity is subjected to significant environmental changes, so it would be a priority for SIOS. The Svalbard archipelago has biogeographical relevance, and inventories of its biodiversity should be updated and referenced against environmental change, colonisation of glacier forelands and the impacts of the invasion of alien species in accordance with appropriate monitoring methodology. The report also suggests phenological studies of migratory birds for comparison with weather pattern and snow cover as input to system modelling. This might be extended by inclusion of the phenology of other organisms such as plants and insects. Data on trends in accumulation of pollutants in the terrestrial biota could be valuable for linking long range transported pollutants and atmospheric processes.

The length of the frost-free and snow-free period on the tundra are major determinants of the biological activity in Arctic terrestrial ecosystems. Earlier springs and changes in the length of the growing season for plants alter the plant productivity as well as species composition of plants and animals. Changes in soil moisture will have similar influences and result in shifts in natural habitats.

**b. General description of the research infrastructure given priority:**

Terrestrial ecosystem observations should include variables that can be used for characterization of the complex interactions that determine the carbon fluxes between Arctic ecosystems and the atmosphere. This will include coupling of biological, geochemical and landscape processes, and their dynamic interplay in space and time. Changes in plant and microbial communities might influence climate at multiple scales. These communities might also show responses to climate changes through changes in species composition and gene frequencies, which might influence carbon and nitrogen fluxes.

In accordance with the design of the US observation network NEON it is important that the core SIOS observations system can facilitate studies and experiments of processes that accelerate physical, biological and chemical drivers of ecological change, to enable parameterization and testing of ecological prediction models and to deepen the understanding of changes in Arctic terrestrial ecosystems.

The terrestrial ecosystem component of SIOS must be based on a combination of intensive sampling of many biotic and non-biotic parameters at single locations, and more extensive measurements of only a few variables by use of other techniques such as remote sensing (satellite- or airborne instrumentation). For up-scaling from local to regional scales, spatio-temporal models can combine data from these different types of observations. The observation system should comprise some core sites that will provide data for the use in different domains within the ESS. For terrestrial ecosystem observations, it will also be necessary with access to relocatable observation sites with instrumentation and proper working space to address question-driven gradient or comparison studies that cannot be fully addressed by the fixed core observation sites. For changes that may occur at faster time scales as f. ex. responses to frequency of extreme events, it may be suitable to use mobile deployment platforms that can be deployed quickly according to demand.

Sampling programmes in observations of terrestrial ecosystems include samples/records of individual organisms and of soil. Much of the sampling methodology does not require large and expensive field instrumentation but may require subsequent labour intensive and instrument-based lab analyses, which could be accommodated in the various research stations in Svalbard or at UNIS.

Key physical and chemical instrument measurements needed for understanding biotic changes in terrestrial ecosystems include (in accordance with NEON): Key climate (weather) and radiation variables, bioclimate (microclimate) variables, chemical climate variables, carbon cycle fluxes, water cycle, hydrology and surface energy balance, soil structure and soil temperature profiles, soil carbon dioxide profiles, and root growth and phenology. Biological measurements of importance for monitoring might include: biomass, productivity, metabolism, species distributions, biodiversity, species community composition, phenology, population dynamics and genetics, demography, microbial diversity (incl. metagenomics) and function, invasive species, infectious diseases and vectors.

c. **Main recommendation for Norwegian priorities (Impacts of the new RI on research and importance for various user groups):**

Table 3 shows the prioritisation made with respect to research infrastructure related to terrestrial and freshwater ecosystems and environmental change. As mentioned above, priorities are dependent on the future scientific focus of the Norwegian terrestrial ecosystem research community. This is particularly relevant for prioritisation of infrastructure related to process studies. The table refers to the 12 key research topics identified by the Gap analysis and the earth system science questions identified by the International Infrastructure Optimisation Report.

Long-term monitoring of key environmental biological and physical (including bioclimatic) parameters is given highest priority. This will be the basis for a range of key biological studies on changes in the arctic terrestrial ecosystem and as input to cross-disciplinary research. The importance of microorganisms in determining carbon and nitrogen fluxes in tundra ecosystems is recognised, as well as their crucial importance in emission of greenhouse gases from soil as input to earth system models.

**Table 3. Top infrastructure priorities for terrestrial and freshwater ecosystem observations**

| Location or area | Parameters | Infrastructure | Core/ Proc |
|---|---|---|---|
| **Terrestrial ecosystems** | | | |
| Adventdalen (Longyearbyen) Ny-Ålesund Smaller systems established in the eastern and northern regions of Svalbard. | Long-term monitoring of key environmental parameters including:- Biological:-Phenology of flora and fauna, activity of fauna, population dynamics, methane fluxes, microbiology, carbon flow and nutrient flux between marine and terrestrial environments | Extensive field instrumentation. (the sampling programme will require analysing, organization and curation of the collections gathered). | C |
| Adventdalen (Longyearbyen) Ny-Ålesund Smaller systems established in the eastern and northern regions of Svalbard. | Long-term monitoring of key environmental parameters including:-Physical:-Duration of snow lie, soil temperatures, surface boundary layer temperatures, precipitation, insolation, wind speeds, direction, influence of sea ice cover on the terrestrial system. | Extensive field instrumentation. (the sampling programme will require analysing of the material and data gathered and combined analyses with biological data). | C |
| Longyearbyen/ Ny-Ålesund | Microbiological analysis. Biodiversity of Arctic microbiological Metagenomics. Role of microorganisms in carbon and nitrogen fluxes. Disease, pollution and immune responses. | Microbiological laboratory (Would need to be equipped to a high standard with up-to-date equipment and apparatus including fume cupboards, extraction hoods, sterilization facilities) | C |

## 4.4 Magnetosphere-Ionosphere/Atmosphere

**a. Main motivation, challenges and issues for Norway (Status of current research and infrastructure):**

Atmospheric models and ionospheric models do not work properly in polar regions. The question is why and how does shortcomings affect ESM, GCM and meteorological models? Even the most modern models use a grid size greater than some important features such as gravity waves and turbulence. Computing power does not increase fast enough to change this limitation soon. Therefore, sub-grid processes are today parameterized in GCM models. A realistic parameterization depending on a physical understanding of small scale physics and chemistry processes. Cutting edge research has revealed the need to understand how the stratosphere is modulated by auroral precipitation (NOx production) in the meteor dust, and how gravity waves break down near the mesopause and drive global convection in the mesosphere. Multi-scale coupling processes are considered to be of critical importance, and the small scale processes needs to be further explored.

Focus areas where Norwegian scientists may have comparative advantages to carry out excellent research within SIOS:

- Multiscale processes in circulation dynamics: In the stratosphere and mesosphere, between 10 - 90 km, we know that the residual meridional circulation is driven by dissipating gravity waves. Gravity wave dissipation at high latitudes in summer and winter force a residual transport from the summer pole to the winter pole as well as adiabatic cooling and heating of the summer and winter polar mesospheres, respectively. The dissipation leads to a momentum flux convergence and an acceleration of the background flow. Gravity wave forcing is included in global (chemical) circulation models (GCM) merely as a factor, but not properly modelled. The factor ("parameterization") is empirically adjusted until the resulting circulation agrees with observation. GCMs are today the most powerful tools for investigating possible climate change. 3D measurements of waves, structures and turbulence are crucial to make progress in the lower thermosphere-mesosphere interaction region.

- The role of mesospheric dust particles on stratosphere and troposphere is another space weather issue to be explored. The dust particles in the mesosphere are most likely mainly formed in its upper parts where the meteoric particles burn up. The motion after formation will be influenced by the local mesospheric winds which sometimes can have velocities up to and above 100 m/s, by gravity, by turbulence and waves and by the slow planetary scale mesospheric wind circulation system. The exact transport pattern of the smoke particles is not well understood but it appears that they spread out throughout all heights of the polar mesosphere region during the winter season, when the wind circulation direction in the polar region is downwards with an average velocity of some cm/s, and hence can be used as a tracer of large scale circulation. How this involves transport into the stratosphere is not known but the smoke particles must eventually enter the stratosphere where they contribute to the chemistry there, also affecting for example the ozone content. Smoke particles as condensation nuclei for polar stratospheric clouds (PSC), influence the ozone layer, influences the temperature structure in the stratosphere, which in turn may influence planetary waves, which in turn often influence troposheric weather. Furthermore, investigations of to what degree the occasional injection of volcanic dust particles in the lower parts of the atmosphere can be transported to and affect the mesosphere is needed. In-situ measurements are crucial in this regard.

- Auroral precipitation impacts on the mesosphere including NOx chemistry which in turn influences the ozone chemistry and hence influences the temperature structure in the stratosphere, which in turn may influence planetary waves which in turn often influence tropospheric weather. Atomic Oxygen is highly reactive, and probably the most important parameter to measure to improve atmospheric models in mesosphere and lower thermosphere. Oxygen profiles by rockets, would give a unique contribution to such studies. This is not captured by the original Gap analysis, but it should be a goal for Norway to bring in measurements of NOx and O profiles into the middle atmosphere rocket program by international collaboration.

- What is the role of turbulence in solar wind-magnetosphere-ionosphere coupling? Plasma turbulence processes represent one of the outstanding major challenges in classical physics, where central problems have not yet been adequately understood. Turbulent, anomalous resistivity is likely to be an essential constituent in the description of the full ionospheric and magnetospheric current circuit, which may have large impact on the energy transfer from the solar wind to the ionosphere/thermosphere. In general, the dynamics of strongly sheared magnetic fields are expected to be influenced, maybe even dominated, by nonlinear effects of turbulent processes.

**b. General description of the research infrastructure given priority:**

There is already extensive world class space infrastructure in place in Svalbard, with a large component of international contribution. Norway has already developed key facilities in Longyearbyen and Ny-Ålesund and it is a goal to develop these two sites with identical key instruments for comparative measurements. It is recommended that Norway complement existing instrumentation to open for excellent research on the vertical energy transport through the atmosphere, from the Earth surface to interactions with the space. It is further recommended that new infrastructure investments are constrained to techniques where we already have developed strong expertise, and the efforts are directed to assure that Norwegian scientists become attractive partners in SIOS CORE as well as SIOS PROCESS studies. This can be achieved by for example:

- Continuously monitor by radar upward propagation of gravity waves to where they break near the meospause (core).
- Expand the auroral observations to year-round in order to reveal how the upward energy flows carried by gravity waves are modulated by auroral precipitation (core).
- Develop 3D capabilities for in-situ measurements of turbulence due to breaking gravity waves from below and due to deposition of the solar wind energy from above (process studies).

**c. Main recommendation for Norwegian priorities (Impacts of the new RI on research and importance for various user groups)**

It is recommended that Norway's investments strategy for SIOS space instrumentation is : To enable Norwegian space physicists to become excellent partners in SIOS cross disciplinary research on vertical energy transport dynamics (EQ1), that includes coupling and feedback mechanisms between atmospheric layers and space (EQ2), and trend analysis in ESS questions (EQ11, EQ12, EQ14, EQ15).

The suggested priorities listed in Table 4 comprise: a MST radar in Longyearbyen; an atmospheric airglow imager for Ny-Ålesund identical to the one at the Kjell Henriksen Observatory, Longyearbyen; a daylight auroral imager for Ny-Ålesund identical to the one currently being developed for the Kjell Henriksen Observatory; a sounding rocket program with 3D observation capabilities from SvalRak, Ny-Ålesund.

The MST radars are the key to monitor gravity waves and wind dynamics in the middle atmosphere and lower thermosphere and hence link together dynamic phenomena in several spheres (mesosphere-stratosphere-troposphere). It runs continuously and provides key parameters such as tropospheric structure, PMSE, gravity waves, wind and temperature 80-100 km, which is highly relevant for EQ1&2. Temperature measurements can be provided to current Earth System Models, and it is anticipated that future ESM models will include upward energy transport by gravity waves, and since the MST radar runs continuously, it is regarded as a core instrument. The MST radar data output is relevant for trend studies in general ESS questions (EQ11, EQ12, EQ14, EQ15). We support the International Optimisation Report in that a new MST radar should be explored for Ny-Ålesund (cf. Table 4). However, according to the current research infrastructure policy for Ny-Ålesund, radio wave transmitters are not permitted.

The atmospheric airglow imager is a strong technique to monitor gravity waves, and it provides highly complementary information to the MST radar. The OH airglow imager will give 2-D images of temperatures in the mesosphere with unprecedented resolution and provides continuous imaging of gravity waves gravity waves. There is already such an imager in at the Kjell Henriksen Observatory in Longyearbyen, the proposed imager for Ny-Ålesund will expand the field of view, and increase the amount of data due to variability in local meteorology. The observation period for this technique is constrained to night observations and clear sky conditions, and is categorized as a SIOS PROCESS instrument relevant to advance EQ1,EQ2, EQ11, EQ12, EQ14, EQ15, that includes trend studies.

The daytime auroral imager proposed for Ny-Ålesund will complement the one currently being developed for the Kjell Henriksen Observatory. This additional imager proposed for Ny-Ålesund will increase the number of clear sky days (due to variability in the local meteorology). Ny-Ålesund and Longyearbyen, 110 km apart, are ideal for triangulation of the auroral altitude. This new auroral imaging system opens for year around auroral observations, and hence the first observations of daytime aurora in sunlight conditions. Time and spatial variability in daytime auroras have never been studied. The instruments will provide time series of the auroral activity versus latitude and time over Svalbard which is relevant to study solar wind forcing on the ionosphere/thermosphere and auroral precipitation impacts on NOx in the mesosphere, which in turn influence the ozone layer, which in turn influence the upward energy transport from the Earth's surface (i.e. gravity waves). The observation period for this technique is constrained to clear sky conditions only. The instrument can provide estimates of auroral energy fluxes which are supposed to become a part of future ESM models. However, since it does not proved continuous measurements it is categorized as a SIOS PROCESS instrument to advance research in EQ1,EQ2, EQ11, EQ12, EQ14, EQ15, that includes trend studies.

The sounding rockets are essential to investigate energy deposition processes at the smallest scales. There is a need for in-situ small measurements of 3D measurements of waves, structures and turbulence in the mesosphere, lower thermosphere and the ionosphere by sounding rockets, to make significant progress on the vertical transport dynamics of energy and mass flow dynamics including the compounds of meteors. Ground based observations provide the context for detailed in-situ investigations by rockets. The detailed in-situ measurements with continuous altitude profiles of multi-parameters are crucial to develop a thorough physical description of the coupling mechanism and hence to improve Earth System Models. Atmospheric physics is a mature field, and the missing link in revealing coupling and feedback mechanisms between the spheres are now considered to be hidden in the chemistry and micro-scale physics. The sounding rocket will provide detailed altitude profiles of the key parameters listed in Table 4 and allow deep process studies relevant for (EQ1, EQ2).

Notably, there is a bias between the Norwegian expert panel top priorities and top priorities by the international prioritization group, which has not given top priority (1 - must have) to any of the new space physics instruments. It occurs that instruments providing continuous monitoring to test models (like: temperature and plasma density, ozone profiles) have been ranked on top and there have been less augmentation on the need for process studies to further develop ESM models.  ESM models and most of the weather model do not to our knowledge include the atmosphere above 50 km.  This may be one factor why models do not replicate atmospheric observations at polar latitudes, which have interactions with space. The prioritized Norwegian contribution aligns well with the SCOSTEP Program CAWSES (Climate and Weather of the Sun-Earth System) and to improve atmosphere system models which are numerous. The solar impact on the Earth atmosphere in polar region is now being taken up as a key challenge in the GEM and CEDAR modelling community, where Norwegian participation based on observations has been invited in to put realistic constraints on the modelling efforts.

**Table 4. Top priority for New Magnetosphere-ionosphere/atmosphere infrastructure**

| Location/area | Parameters | Infrastructure | Core/ Proc |
|---|---|---|---|
| SvalRak, Ny-Ålesund | E/B-field waves, electron density, 3D measurements of waves, structures and turbulence, particles (sub-meter resolution), NOx and O-profiles, | 2 middle atm. + 1 upper atm.  rocket per year for 7 years (i.e. 21 rockets) | P |
| Longyear-byen | Winds in upper troposphere/lower stratosphere and mesosphere, PMSE, PMWE | MST radar | C |
| Ny-Ålesund | Measurements of atmospheric airglow (wide FOV) | 1 airglow imagers | P |
| Ny-Ålesund | Measurements of auroral emissions in sunlight (wide FOV) | 1 daylight auroral imagers | P |

## 4.5 Pollution issues in Svalbard

**a. Main motivation, challenges and issues for Norway (Status of current research and infrastructure):**

Pollutants in a regional ESS perspective point towards modeling needs with regional resolution of parameters that influence pollutant distribution and deposition and likewise towards an observational network that resolves variations in space and time within the region. Such capabilities will require investments in new observational sites and methods beyond what is presently included in the tables of infrastructures. The investments will evolve through the types of work that is anticipated to be a primary activity in the SIOS Knowledge Centre. A strong Norwegian participation in the work of the SIOS-KC is of paramount importance to guide SIOS development towards activities were Norway can take on leading roles.

From the International Infrastructure Optimisation Report two bullets are of particular relevance for the pollutant subjects:

1. The problem of effectively quantifying snow and its distribution in the Arctic was recognized as a major shortcoming of current monitoring across the Arctic that could be particularly

usefully addressed in a SIOS monitoring program. Effective monitoring of snow was one obvious target for technological developments.

2. There was a strong case made for the use of distributed observatories to complement and extend the work currently focused at Zeppelin, Longyearbyen, Hornsund and Barentsburg. Where possible these remote observatories would be mobile, use green energy, have a small footprint and satellite communications.

Pollutants are delivered to Svalbard through long range atmosphere and ocean transport. Some local emissions occur (in particular from ships, mainly the fishing fleet but also from tourist ships and transport in general). SIOS should build capacity to separate local and regional sources from the long range transport. For the long range atmospheric transport source attribution is a priority. Sources are presently identified with the aid of models (both mixing models and trajectory models). Norway has state of the art environments for modeling but data for verification in the Svalbard region is scarce and essentially confined to the Ny-Ålesund site and the Zeppelin station in particular. Acquiring data sets for key parameters in a regional grid is a key priority. Utilizing the met.no stations (Hopen, Bjørnøya) is an obvious candidate for such a Norwegian enhancement of the grid (provided that Hornsund and Barentsburg follow suite). Developing a high tech alternative for the North East (e.g. Rijpfjorden) should be considered.

Pollutants enter the food web and these processes need elucidation both on land and in the ocean. Infra-structure that facilitates such studies and monitors such fluxes ascends as a priority. Norway has participated in process studies of this type and monitoring of pollutant levels in some species. There is obvious potential to develop these activities further and accomplish a systematic observational system in Svalbard with a strong Norwegian foundation.

Pollutants are dry and wet deposited from the atmosphere. Deposition processes need to be quantified beyond the single site studies and are to a large extent presently short term process studies or just snapshots based on concentrations in snow at single occasions. Norway has been involved in many snow deposition processes, snow transformation studies and various types of air-snow exchange studies. There is, nevertheless, a pressing need for quantitative knowledge about snow deposition (in space and time). Snow is fundamental for a host of aspects (albedo, habitat, glacier formation, phenology, pollutant release to land etc.). Norway could lead a concerted snow effort and lead a Svalbard wide observational program for snow and its characteristics. Dry deposition is strongly tied to boundary layer meteorology, which is an area with active Norwegian groups; bringing together meteorological infrastructure and deposition work needs attention to enhance the ESS impact of the work and facilities.

Measurements of pollutants, their deposition, transformations, their pathways in the food chain and the effects on organisms and ecosystems are all areas with strong research groups and traditions in Norway. Discovering new pollutants (in particular organic compounds) is likewise a national strength. An emerging ESS challenge is to understand effects of combined perturbations (e.g. interpreting the effects of simultaneous changes in pollutants and climate). Challenges include maintaining an adequate monitoring activity and also, in an ESS perspective, to expand monitoring to systematic coverage in the spheres such that inter-linkages can be elucidated. Few, if any, of these studies can be replaced with remote sensing techniques and one is thus obliged to look at infrastructure on the ground and within the spheres where appropriate. Norwegian infrastructure for long-term programs is concentrated to Ny-Ålesund.

**b. General description of the research infrastructure given priority:**

The expansion of and long term commitments of pollutant measurements in Ny-Ålesund is of highest priority. The Zeppelin station is a well established infrastructure that is a back-bone in our understanding of pollutants in Svalbard. Developing new methods and technology to measure pollutants in remote regions with minimal environmental footprint is a priority that is not identified in the original gap analysis effort. Prioritizing technological development and establishing measurement points on a regional grid is important also to enhance the utility of the existing measurement programs. Such infrastructure is not extensively discussed in the gap analysis but is an area that Norway is well poised to tackle and is recommended to give priority. New technology will need laboratories for developing and testing experiments. Such infrastructure needs to be established/enhanced both in Ny-Ålesund and Longyearbyen but is only cursively presented in the gap analysis documents.

**c. Main recommendation for Norwegian priorities (Impacts of the new RI on research and importance for various user groups):**

The Zeppelin station fulfils all criteria apart from the long term financing plan. It is recommended that this is to be remedied within SIOS. The suggestion for expansion of measurements with new technology would likewise fulfil all the criteria put forth by the national prioritization group. Such steps are important for maintaining a Norwegian leading role in Arctic pollutants research.

The pollution measurements outside Ny-Ålesund should be strongly tied to the recommendations made in section 4.6 (the coupled arctic geophysical system –ESM perspective priorities). The considerations regarding placement of stations should, however, be expanded to also engage in a discussion regarding what resolution of data is necessary for making headway in modeling of pollution distribution in Arctic areas. It is therefore essential to develop an activity within the framework of the SIOS Knowledge Centre that addresses sampling strategies in space and time such that the number of stations and placement of these is coordinated based on scientific, economic and environmental considerations.

**Table 5. Top Priority Infrastructure in pollution issues in Svalbard**

| Location/area | Parameters | Infrastructure | Core/ Proc |
|---|---|---|---|
| Sverdrup Station | UV irradiance, total ozone | GUV | C |
| Zeppelin Observatory | Particle density, CCN density, ice nucleus density number, hygroscopicity growth, aerosol mass spectrum, aerosol absorption coefficient | Instrument upgrade to replace above | C |
| Ny-Ålesund, Bjørnøya, Jan Mayen,Hopen, | T, p, wind, RH, prec., snow depth, clouds, visibility | Synoptic met. station (partially automatic) | C |
| Edgeøya, Svea, Verlegenhuken Karl XII Land | T, p, RH, wind, precipitation | meteorological station (automated) | C |
| Ripfjorden, Ny-Ålesund, Kapp Linne,Adventdalen | Snow measurements | Automated snow monitoring – to be developed. | C |

| | | | |
|---|---|---|---|
| Sea-Ice locations, including Fram Strait | Snow measurements | Automated snow monitoring – to be developed. Aircraft,?, UAV's? | C |
| Selected glaciers, rivers, including Ripfjorden area | Freshwater run-off | Runoff monitoring instrumentation | P |
| Zeppelin<br><br>Observatory | Ambient methane<br><br>Nitrous oxide<br><br>GHG concentrations (high time res., precision) | GC-FID<br><br>GC<br><br>High-resolution high-precision GHG monitors | C |
| Adventdalen, Kap Linné, Rijpfjorden | $CO_2$, $CH_4$, $N_2O$, sensible and latent fluxes | Meteorological flux towers incl. eddy covariance and chambers measurements | P |
| Zeppelin Observatory, Ny-Ålesund | Ambient ozone | | C |
| Mainland/Svalbard | Various marine pollutants (+oceanographic parameters) | Ferry Box automated monitoring on "Norbjørn" and other vessels | C |
| Across Fram Strait | Tracers (S, d18O, N:P, alkalinity), revealing the sources of the Arctic Ocean freshwater components | CTD | C |
| Across Fram Strait | Temperature and salinity of Arctic Ocean inflow (WSC) and outflow (EGC): Snapshots each September | Four Ice Profiling Sonars and four ADCPs | P |
| Fram Strait, line along 79 N | Ice thickness and drift velocity across the Transpolar Drift where it exits the Arctic Ocean: Time series | EM bird and EM31<br><br>Electromagnetic measures | P |
| Fram Strait line along the 79 N | Ice thicknesses across the Transpolar Drift where it exits the Arctic Ocean: Snapshots each September | Arctic Ocean Outflow Observatory (AOBS) (16 microcats, 16 RCMs, five ADCPS, one TS string) | P |
| Fram Strait, mooring array across the East Greenland Current at 79 N | Time series of Arctic Ocean outflow in the East Greenland Current (EGC) (temperature, salinities, current velocities) | CTD | C |
| Isfjorden, Rijp-fjorden, Hornsund, Kongsfjorden; Various locations depending on expedition. | Temperature, salinity, div. chemical, biological (acoustic) and optical parameters (PAR, chlorophyll, fluorescence, oxygen, pH) | Autonomous Underwater Vehicle | C |

## 4.6 Solid Earth and long-term processes

**a. Main motivation, challenges and issues for Norway (Status of current research and infrastructure)**

The land mass of Svalbard is on a different scale to the atmosphere and ocean and is subject to the influence of both these spheres, but also impacts on them both to some degree and there can be substantive fluxes at the interfaces. The substantial Svalbard glaciers and ice caps are distributed along significant environmental gradients, east-west and north-south so the archipelago offers an excellent location to study the interaction of cryosphere, geosphere, pedosphere and terrestrial biosphere with atmosphere and ocean along a continuum of change.

To date much of the glaciological studies have been constrained to relatively small glaciers located conveniently close to the main research stations and similarly most hydrological and permafrost studies have been undertaken near to settlements. There needs to be an assessment made of their representativeness for Earth System studies rather than simply continuing with these established studies. There are a number of large tidewater glaciers on Svalbard that have direct linkages with the ocean, as well as very many surge glaciers and some sizeable ice caps, which would likely link more realistically to climate and be more relevant to system modelling. These also need to be assessed as potential locations for core monitoring.

There is currently a lack of information on the total mass of ice across the archipelago, the mass balance components of the large tidewater glaciers, surge glaciers and ice caps and of glacier mass loss through calving. Much of this can be undertaken by satellite remote sensing but ground-based studies provide valuable information at higher resolution for smaller spatial scales which could enhance modelling efforts. This particularly relates to issues such as energy balance and snow cover.

Arguably the most difficult parameter to measure reliably and representatively and therefore incorporate into system models is snow and Svalbard could be a location to develop and refine new and existing methodologies for realistic snow cover estimation. The deployment of sensor systems “tuned” to warm ice and snow on board AV and manned aircraft could provide important data on the temporal and spatial variability of snow cover in relation to atmospheric processes. The same methodologies could also be deployed over sea-ice. There are also opportunities for studying interfaces with different spheres. For example, increased seismic activity observed in recent years seems to coincide with retreat of glaciers and ice caps.

Much of the permafrost research on Svalbard has been undertaken in western Svalbard and close to major settlements and there should really be a site in north/east Svalbard to pick up the patterns of thermal seasonality within permafrost in a true High Arctic site. The scale of much of the current activities does not fit well with existing model scaling but the variety of landscape on Svalbard affords opportunities to develop tools such as inSAR (interferometric Synthetic Aperture Radar) for more widespread use in characterising permafrost studies and scaling up from the site to landscape level. Successful deployment of inSAR in aircraft would ultimately broaden its spatial coverage to relevant ESS scales and provide valuable comparison to existing satellite-based SAR data which is by contrast much coarser.

Solid Earth and long-term processes have fundamental importance for the chemical composition of the Earths’ surface, distribution of land and ocean as well as climate. SIOS has a strategy to focus on processes that influence the System on decadal time-scales up to centuries. The solid Earth processes are intermittent and to an extent stochastic in nature. Such events are, however, often strongly influential on many of the key observational activities proposed for SIOS such that it is relevant to have a background monitoring of solid Earth activity. This poses a dilemma in prioritizing since it is likely that observed changes on decadal time scales (which have been identified as the essential SIOS time-scales) are small whereas the possibility for sudden and significant change remains. The present seismic network is important and probably sufficient to be able to capture spurious events that may have ESS influence.

Climate change and chemical changes in the environment can plausible lead to enhanced weathering of soil and rocks. Climate change is definitely decreasing ice mass on land. These changes can give changed habitats on land and sea and should be monitored in their own right. For solid Earth studies this leads to changes in land rise rates and possible to changes in earthquake frequencies (and strengths). Norway (the Norwegian Mapping Authority) has infrastructure and expertise and could lead an initiative in these areas. Permafrost and permafrost changes are of key importance to follow and understand. Norway has strong groups within permafrost research and it is thus strategic to prioritize the Norwegian contributions to permafrost observations in SIOS

**b. General description of the research infrastructure given priority:**

Observations of changes of the solid Earth system that have influence on the other components of ESM on decadal time scales is the guiding principle for prioritization. Changes in land rise and seismic activities are identified as points of relevance to follow where Norway already is well established.

To the extent permafrost observations are to be included in this section or sections 4.3 be discussed but is an important type of infrastructure that is a solid contribution to SIOS core.

**c. Main recommendation for Norwegian priorities (Impacts of the new RI on research and importance for various user groups):**

Recommendations for new investments needs to be discussed further in an ESM perspective. Were direct links to the international prioritized scientific issues can be identified there should be initiatives taken to play a role where relevant but the time-scale issues make this general field somewhat askew of how the SIOS core is presently understood.

The Norwegian Mapping Authority infrastructure in Ny-Ålesund is an important priority for Norway. Snow, glaciers and permafrost observations are of high Norwegian priority.

**Table 6. Top Priority Infrastructure in Solid Earth and long-term processes, Cryosphere/Geosphere**

| Location or area | Parameters | Infrastructure | Core/ Proc |
|---|---|---|---|
| **Glacial Monitoring and Hydrology** | | | |
| Kongsvegen tidewater glacier | T, H, upward/ downward long-wave /short-wave radiation, wind speed, wind direction | 4 x Automatic Weather Stations (AWS) across glacier | C |
| Holtedahlfonna, | T, H, upward/ downward long-wave /short-wave radiation, wind speed, wind direction | 2 x Automatic Weather Stations (AWS) on ice cap | C |
| Kongsvegen | Meteorological parameters, radiation and energy balance parameters, including BSRN upgrade | Met Station | C |
| Kongsbreen tidewater glacier | Meteorological parameters, radiation and energy balance parameters, including BSRN upgrade | Met Station | C |
| Kongsbreen tidewater glacier | T, H, upward/ downward long-wave /short-wave radiation, wind speed, wind direction | 2 x Automatic Weather Stations (AWS) | C |
| East coast tidewater glacier to be identified | T, H, upward/ downward long-wave /short-wave radiation, wind speed, wind direction | 4 x Automatic Weather Stations (AWS) | C |
| Nordaustlandet, Austfonna, Etonbreen | Global/ reflex radiation, albedo, upward/ downward long-wave radiation, net rad. | Automatic Weather Station (AWS) | C |
| Various sites. See Meteoro-logical Observations earlier | Precipitation measurements | Advanced precipitation gauge network | C |
| Various sites See Meteoro-logical Observations | Snow measurements | Automated snow monitoring – to be developed. | C |
| **Seismicity** | | | |
| Ny-Ålesund | Earth Ground Movement | Seismometer (STS-1 and STS-2) | P |
| Advent-dalen (Jansonhaugen) | Earth Ground Movement | Seismic Array (15 CMG-3T) | P |

| | | | |
|---|---|---|---|
| Hornsund | Earth Ground Movement | Broadband seismometer (STS-2) | P |
| Hopen | Earth Ground Movement | Short period<br><br>Seismometer | P |
| Hopen | Earth Ground Movement | Broadband seismometer (STS-2) | P |
| Bjørnøya | Earth Ground Movement | Broadband<br><br>seismometer (CMG-3T) | P |
| Isfjord Radio | Earth Ground Movement | Seismometer (analog) | P |
| **Deep Permafrost Monitoring** | | | |
| Adventdale n | Deep borehole temperature<br><br>Monitoring. Linked to meteorological station with BSRN upgrade | Permafrost boreholes | C |
| Kapp Linné | Deep borehole temperature<br><br>Monitoring. Linked to meteorological station with BSRN upgrade | Permafrost boreholes | C |
| At sea level and in Svalbard mountains | Permafrost temperature profiles | deep permafrost penetrating boreholes | C |

# Annex

**Table A1. Proposal for new Norwegian infrastructure priorities for Earth System Modelling perspective**

| Location or area | Parameters | Infrastructure | C | Core/ Proc | Prio/ Level | EQ | KT |
|---|---|---|---|---|---|---|---|
| **Radars and Radio Receivers** | | | | | | | |
| Ny Ålesund | Winds in upper troposphere/lower stratosphere and mesosphere, PMSE, PMWE | MST radar and meteor scatter radar | | P | 1 | | 1 |
| **Aerosol and Cloud Observations** | | | | | | | |
| Zeppelin Observatory | Particle density, CCN density, ice nucleus density number, hygroscopicity growth, aerosol mass spectrum, aerosol absorption coefficient | Instrument upgrade to replace above | | C | 1 | | 2 |
| **Meteoro-logical Observations** | | | | | | | |
| All stations<br><br>(Ny Ålesund, Bear Island, Jan Mayen, Hopen, Edgeøya, Verlegenhuken, Karl XII Land, Svea) | Meteorological parameters, radiation and energy balance parameters, including BSRN upgrade | Meteorological station (upgrade to fully automatic, online) | | C, P | 1 | | 2 |
| **Vertical C Transport** | | | | | | | |
| Hausgarten, Kongsfjorden, Ripfjorden | Sedimentation in water column | Automated Sedimentation traps.<br><br>Links with existing<br><br>Moorings (see later) | | P | 2 | | 4, 6 |
| **Greenhouse gases** | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Adventdalen, Kapp Linné, Rijpfjorden | $CO_2$, $CH_4$, $N_2O$, sensible and latent fluxes | Meteorological flux towers incl. eddy covariance and chambers measurements | | C | 1 | | 6 |
| Zeppelin Observatory, Hopen<br><br>Ship-board | Isotopic analysis of water vapour and precipitation | Isotopic GHG Monitoring in atmosphere and in precipitation | | P | 1 | | 2, 3 |
| **Eulerian Marine Platforms** | | | | | | | |
| Storfjorden sill and shelf-break off Sørkapp | T/S/Currents (profile) | Single Mooring | | P | 1 | | 3 |
| Storfjorden sill and shelf-break off Sørkapp | Ocean current profiles and bottom temperature and salinity | Bottom frames with acoustic Doppler current profiler to replace above | | P | 1 | | 3 |
| Eastward extension of the AWI/NPI mooring section in Fram Strait | T/S/Currents | Single Mooring | | C | 2 | | 3, 4 |
| Fram Strait | Mean ocean temperature and currents, acoustic signals for glider navigation | Triangle tomography moorings | | C, P | 1 | | 3, 4 |
| Fram Strait | Hydrography, Velocity, sedimentation, Chlorophyll, oxygen, nutrients | Upgrade of Fram Strait moorings with sediment traps and biological sensors | | C, P | 2 | | 3,4 |
| **Repeat Sections** | | | | | | | |
| Across Fram Strait | Tracers (S, d18O, N:P, alkalinity), revealing the sources of the Arctic Ocean freshwater components | CTD rosette water samples | | Core | 1 | | 3 |
| Fram Strait, line along 79 N across the East Greenland Current | Ice thickness and drift velocity across the Transpolar Drift where it exits the Arctic Ocean: Time series | Four Ice Profiling Sonars and four ADCPs | | C | 1 | | 3 |
| HAUSGARTEN and Kongsfjorden transect | Service cruises – pelagic sampling | | | P | 2 | | 3,4, 6 |
| Transects KongHAU, | Water samples for | Niskin Bottles | | 2 | | | 4, 6 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rijpfjorden, Isfjorden, Hornsund | - nutrient analysis<br><br>- phytoplankton taxonomy, abundance<br><br>- pigment measurements | | | | | | |
| **Glacial Monitoring and Hydrology** | | | | | | | |
| Kongsvegen | Meteorological parameters, radiation and energy balance parameters, including BSRN upgrade | Met Station | | P | 2 | | 5 |
| Kongsbreen tidewater glacier | Meteorological parameters, radiation and energy balance parameters, including BSRN upgrade | Met Station | | P | 2 | | 5 |
| Nordaust-landet, Austfonna, Etonbreen | Global/ reflex radiation, albedo, upward/ downward long-wave radiation, net rad. | Automatic Weather Station (AWS) | | P | 2 | | 5 |
| | | | | | | | |

**Table A2. Proposal for new Norwegian infrastructure priorities for Environmental Change and Marine Ecosystems, Marine Observatories and Ecosystem Time Series**

C: Country where N: Norway, G: Germany, P: Poland, UK: United Kingdom.

EQ: ESS Question from International Report, KT: Key Topic from Gap-analysis

| **Location or area** | **Parameters** | **Infrastructure** | **C** | **Core/ Proc** | **Prio/ Level** | **EQ** | **KT** |
|---|---|---|---|---|---|---|---|
| **Vertical C Transport** | | | | | | | |
| Hausgarten, Kongsfjorden, Ripfjorden | Sedimentation in water column | Automated Sedimentation traps.<br>Links with existing Moorings (see later) | UK, G, N | C | 1 | 2, 7, 8 | 6? |
| **Pollutant Transport** | | | | | | | |
| Longyearbyen-Norwegian mainland transect | various marine pollutants (+oceanographic parameters) | Ferry Box automated monitoring on "Norbjørn" | N | C | 1 | 8 | 4 |
| **Eulerian Marine Platforms** | | | | | | | |
| Kongsfjorden | Temperature, salinity, currents | Multi-parameter mooring (Aanderaa RCM) | N | C | 2 | 5,7 | 3 |
| Billefjorden | T/S/Currents (profile), sediments, fluorescence, PAR | Single Mooring | N | C | 1 | 5,7 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Storfjorden sill and shelf-break off Sørkapp | T/S/Currents (profile) | Single Mooring | N | C | 1 | 5 | 3 |
| Storfjorden sill and shelf-break off Sørkapp | Ocean current profiles and bottom temperature and salinity | Bottom frames with acoustic Doppler current profiler to replace above | N | C | 2 | 5 | 3 |
| Isfjorden mouth, Kapp Linné | Temperature, salinity, currents, turbidity | Multi-parameter mooring (Aanderaa RDCP and SeaGuard, Seabird SBE37) | N | C | 2 | 7 | 3 |
| Eastward extension of the AWI/NPI mooring section in Fram Strait | T/S/Currents | Single Mooring | N | C | 1 | 5,11, 12 | 3 |
| Under-ice boundary layer | High frequency T/S/Currents for ocean microstructure | Sea ice mounted | N | C | 2 | 5 | 3 |
| Oceanic | High frequency T/S/Currents for ocean microstructure profiling | Ship | N | C | 2 | 5 | 3 |
| Fram Strait (Deep) | Ocean acoustic data | Acoustic Arctic Laboratory | N | C | 2 | 5 | 3 |
| Fram Strait (WSC) | Mean temperature from tomography | Mooring | N | C | 2 | 5 | 3 |
| Yermak Branch of WSC (west flank of Yermak Plateau) | Profiles of ocean current, temperature and salinity | Array with 4 moorings | N | C | 2 | 5 | 3 |
| 30 deg E array, north east Svalbard | Temperature, Salinity, currents | Array with 7 moorings | N | C | 2 | 5 | 3 |
| Isfjorden, Bellsund, offshelf west of Bellsund / Smeerenburg, offshelf N of Rijpfjorden, Grønfjorden,Erik Eriksen Strait, Frans-Victoria Trough, NBarents Sea, East Greenland Shelf) | Hydrography, Velocity, zooplankton biomass and vertical distribution, sedimentation, Chlorophyll, sea ice thickness | Moorings: CTD Temperature loggers, ADCP, Sediment traps, Fluorometer | N | C | 2 | 11,12 13 | 3 |
| Fram Strait | Mean ocean temperature and currents, acoustic signals for glider navigation | Triangle tomography moorings | N | C | 2 | 5 | 3 |
| Fram Strait | Hydrography, Velocity, sedimentation, | Upgrade of Fram Strait moorings with | N | C | 1 | 5 | 3,4 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Chlorophyll, oxygen, nutrients | sediment traps and biological sensors | | | | | |
| HAUSGARTEN, Kongsfjorden, Bellsund | Sediment, Meiofauna, Macrofauna | Box corer | G, N | C | 1 | 11,12,13 | 3,4 |
| HAUSGARTEN, Kongsfjorden, Bellsund | Sediments, Meiofauna | Multiple Corer | G, N | C | 1 | 11,12,13 | 3,4 |
| Isfjorden, Bellsund, off shelf west of Bellsund/Smeeren-burg, off shelf N of Rijpfjorden, Grønfjorden, Erik Eriksen Strait, Frans-Victoria Trough, N Barents Sea, East Greenland Shelf | Hydrography, Velocity, zooplankton biomass and vertical distribution, sedimentation, Chlorophyll, sea ice thickness | Moorings: CTD Temperature loggers, ADCP, Sediment traps, Fluorometer - link to Kongsfjorden and Ripfjorden moorings in Section 2 above | N | P | - | 11,12,13 | 3,4 |
| Kongsfjorden, (eventually all others) | Hydrography, Velocity, zoo-plankton biomass & vertical distr, sedimentation, Chlorophyll, real time transmission | cabled moorings (additional instruments: MMP profilers, Echo-sounder. Link to Moorings in Section 2 above | N | P | - | 11,12,13 | 3,4 |
| Kongsfjorden, Fram Strait | Zooplankton, fish, hydrography , Chlorophyll div. organic and inorganic compounds Benthic fauna Sedimentation | Benthic lander: Echosounder, CTD, Fluorometer, Chem. sensors, video, ydrophones, sediment traps | N | P | - | 11,12,13 | 4 |
| Fram Strait | Hydrography, Velocity, sedimentation, Chlorophyll, oxygen, nutrients | Upgrade of Fram Strait moorings (Section 2) with sediment traps and biological sensors | N | C | 1 | 11,12,13 | 4 |
| **Repeat Sections** | | | | | | | |
| Across Fram Strait | Tracers (S, d18O, N:P, alkalinity), revealing the sources of the Arctic Ocean freshwater components | CTD rosette water samples | N | C | 1 | 5 | 3 |
| Across Fram Strait | Temperature and salinity of Arctic Ocean inflow (WSC) and outflow (EGC): Snapshots each September | CTD | N | C/P | 2/1 | 5 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fram Strait, line along 79 N across the East Greenland Current | Ice thickness and drift velocity across the Transpolar Drift where it exits the Arctic Ocean: Time series | Four Ice Profiling Sonars and four ADCPs | N | C | 1 | 5 | 3 |
| Fram Strait along the 79 N line across the EGC and over the East Greenland Shelf | Ice thicknesses across the Transpolar Drift where it exits the Arctic Ocean: Snapshots each September | EM bird and EM31 Electromagnetic measures | N | C | 1 | 5 | 3 |
| Fram Strait, mooring array across the East Greenland Current at 79 N | Time series of Arctic Ocean outflow in the East Greenland Current (EGC) (temperature, salinities, current velocities) | Arctic Ocean Outflow Observatory (AOBS) (16 microcats, 16 RCMs, five ADCPS, one TS string) | N | C | 1 | 5 | 3 |
| Transects KongHAU, Rijpfjorden, Isfjorden, Hornsund | Mesozoo-, Makrozoo-Ichtyoplankton | WP2, WP3, MIK, Multinet | N, G, P | C/P | 2/1 | 11,12 ,13 | 3 |
| Transects KongHAU, Rijpfjorden, Isfjorden, Hornsund | Water samples for<br>- nutrient analysis<br>- phytoplankton taxonomy, abundance<br>- pigment measurements | Niskin Bottles | N | C/P | 1/1 | 11,12 ,13 | 4 |
| Transects KongHAU, Rijpfjorden, Isfjorden, Hornsund | phytoplankton taxonomy | Nets | N, P | C/P | 2/1 | 11,12 ,13 | 4 |
| Transects KongHAU, Rijpfjorden, Isfjorden, Hornsund | Chlorophyll a, fluorescence | Fluorometer | N, G | C/P | 2/1 | 11,12 ,13 | 4 |
| Transects KongHAU, Rijpfjorden, Isfjorden, Hornsund | Light, Photosynthetically Active Radiation (PAR 400-700 nm) | Li Cor PAR sensor | N | C/P | 2/1 | 11,12 ,13 | 4 |
| Kongsfjord, KongHAU, Hornsund, Bellsund | Infaunal macrobenthos (medium size, restricted mobility) | Van Veen Grab | N, G, P | C/P | 2/1 | 11,12 ,13 | 4 |
| Geographically dynamic | Detailed positional information, behavior of top trophics levels on a year-round basis | Top trophic distribution and foraging behaviour | N | C/P | 2/2 | 4 | 4 |
| **Langrangian and Active Marine Platforms** | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Isfjorden, Riipfjorden, Kongsfjorden, Fram Strait, Hornsund and other positions | Temperature, salinity, diversity. chemical, biological and optical parameters (PAR, chlorophyll, fluorescence, oxygen, pH) | Gliders, AUVs with sensors | N | C/P | 2/2 | 11,12 ,13 | 3,4 |
| Marine mammals Svalbard | Hydrography, mammalian distribution, habitat choice | CTD-PPT tags (animal borne tags) | N | C/P | 2-3/1 | 4, 16 | 3,4 |
| Shelf of Svalbard surveys | Pelagic and demersal fish distribution and abundance | Bottom and pelagic trawl, acoustic instruments (echo sounders sonars) | N | C | 1 | 4, 16 | |

**Table A3. Proposal for new Norwegian infrastructure priorities for terrestrial and freshwater ecosystem observations**

| Location or area | Parameters | Infrastructure | C | Core/ Proc | Prio/ Level | EQ | KT |
|---|---|---|---|---|---|---|---|
| **Terrestrial ecosystems** | | | | | | | |
| Advent-dalen (Longyear-byen) Ny-Ålesund Smaller systems established in the eastern and northern regions of Svalbard. | Long-term monitoring of key environmental parameters including:- Biological:-Phenology of flora and fauna, activity of fauna (especially invertebrates), population dynamics (involving marked individuals), methane fluxes, microbiology, carbon flow and nutrient flux from marine to terrestrial environments (and back). | Extensive field instrumen-tation. (the sampling programme will require analysing and curation of the collections gathered and organize the material and data gathered). | N | C | 1 | EQ9, EQ10, EQ12, EQ14, EQ15, EQ16 | 11,6, 10 |
| Advent-dalen (Longyear-byen) Ny-Ålesund Smaller systems established in the eastern and northern regions of | Long-term monitoring of key environmental parameters including:- Physical:-Duration of snow lie, soil temperatures, surface boundary layer temperatures, precipitation, insolation, wind speeds, direction (bioclimatology), effect of changes in the sea ice cover on the terrestrial | Extensive field instrumen-tation. (the sampling programme will require analysing of the material and data gathered and combined analyses with | N | C | 1 | EQ9, EQ10, EQ12, EQ14, EQ15, EQ16 | 2,3,7, 12 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Svalbard. | system. | biological data). | | | | | | |
| Longyear-byen (Ny-Ålesund?) | Microbiological analysis. Biodiversity of Arctic microbiological (characterization, function etc). Metagenomics. Role of microorganisms in carbon and nitrogen fluxes. Disease, pollution and immune responses. | Microbiological laboratory (Would need to be equipped to a high standard with up-to-date equipment and apparatus including fume cupboards, extraction hoods, sterilization facilities) | N | C | 1 | EQ9, EQ10, EQ12, EQ14, EQ15, EQ16 | | |
| Variable, W-E, N-S gradient | Basic fauna and flora parameters, pollution level<br><br>Also suitable for manipulation experiments | Mobile huts with accommodation / working facilities for field workers, with basic lab equipment for sample preparation/ clean-up/ analysis and storage in the field | N | C/P | 2 | EQ8, EQ9, EQ10, | 11 | |
| Longyear-byen | Rapid on-site molecular analysis for DNA-Barcoding, dispersal studies, biodiversity, population dynamics. | DNA sequencing Laboratory | N | C | 2 | EQ9, EQ10 EQ12 EQ14 EQ16 | | |
| Longyear-byen | Sample preparation – dirty samples (soils, biological material). Experiments involving soils /water (marine and freshwater) | Wet laboratory. Minimum size of 20*20m with associated storage rooms. Sinks, wash-down floors and benches. Basic equipment: drying ovens, fume cupboards, fridge and freezers including walk in cold rooms. | N | P | 2 | EQ9, EQ10, EQ14, EQ15, EQ16 | 7 | |
| Longyear-byen / Ny-Ålesund | The adaptation of the flora and fauna to the distinctive Arctic environment including responses to environmental perturbation; cold | Phytotron facilities and Climate Cabinet Laboratory Phytotron:- programmable control of | N | P | 2 | EQ9, EQ10, EQ14, EQ16 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | tolerance, life-cycle synchronisation, consequences of environmental change, projections of species ranges changes/alien invasives. | temperature and photoperiod (daylight bulbs). Climate Cabinet Laboratory 10 cycling incubators e.g. Termaks KB8400 | | | | | |
| Longyear-byen | The adaptive responses of the flora and fauna to Arctic environmental perturbation. Analysis of pollutants and biological effect of pollutants and their break down products. Potential bioassays. | Physiological Laboratory Analytical equipment for detection of pollutants / hormone titres and other metabolic responses; for example, gas chromatograph, high performance liquid chromatograph, differential scanning calorimeter and benchtop freezer/cold box, liquid nitrogen supply, freezer (including biofreezer) gas supply, seawater supply. | N | P | 2 | EQ8, EQ9, EQ10, EQ12, EQ14, EQ15, EQ16 | |
| | | | | | | | |
| Ny-Ålesund (Longyear-byen) | Plant physiology, adaptation and response to environmental variation. | Greenhouse. The greenhouse in Ny-Ålesund requires recommis-sioning with the installation of computer driven climate controls enabling precise manipulation of temperature (and light). | N | P | 2 | EQ9, EQ10, EQ12, EQ14, EQ15, EQ16 | |

**Table A4. Proposal for new Norwegian infrastructure priorities for Magnetosphere-ionosphere/atmosphere**

| Location or area | Parameters | Infrastructure | C | Core/ Proc | Prio/ Level | EQ | KT |
|---|---|---|---|---|---|---|---|
| **Radars and Radio Receivers** | | | | | | | |
| SvalRak, Ny-Ålesund | E/B-field waves, electron density, 3D measurements of waves, structures and turbulence, particles (sub-meter resolution), NOx and O-profiles, | 2 middle atm. + 1 upper atm. rocket per year for 7 years (i.e. 21 rockets) | N, G, S, JP, US? | P | 1 | 1, 2 | 1 |
| Longyearbyen, SOUSY | Winds in upper troposphere/lower stratosphere and mesosphere, PMSE, PMWE | MST radar | N | C | 1 | 1,2, 11,12 14,15 | 1 |
| | | | | | | | |
| **Optical Instruments** | | | | | | | |
| Ny-Ålesund | Measurements of atmospheric airglow (wide FOV) | 1 airglow imagers | N | P | 1 | 1,2, 11,12 14,15 | 1 |
| Ny-Ålesund | Measurements of auroral emissions in sunlight (wide FOV) | 1 daylight auroral imagers | N | P | 1 | 1,2 | 1 |

## Table A5. Proposal for new Norwegian infrastructure priorities for pollution issues in Svalbard

### 1. Vertical coupling measurements

| Location or area | Parameters | Infrastructure | C | Core/ Proc | Prio/ Level | EQ | KT |
|---|---|---|---|---|---|---|---|
| **Radiation and Atmospheric Chemistry** | | | | | | | |
| Sverdrup Station, Ny-Ålesund | Total ozone, $NO_2$, PSC | SAOZ | N, Fr | C | 2 | 2 | 2,6 |
| Sverdrup Station, Ny-Ålesund | UV irradiance, total ozone | GUV | N | C | 1 | 2 | 2,6 |
| **Aerosol and Cloud Observations** | | | | | | | |
| Zeppelin Observatory | Particle density, CCN density, ice nucleus density number, hygroscopicity growth, aerosol mass spectrum, aerosol absorption coefficient | Instrument upgrade to replace above | N, SW | C | 1 | 7, 9, 13 | 2, 6, 9 |
| Sverdrup Station, Ny-Ålesund | Aerosol optical depth | PFR Sun photometer | N | C | 2 | 6 | |
| **Meteorological Observations** | | | | | | | |
| Ny-Ålesund | T, p, wind, RH, prec., snow depth, clouds, visibility | Synoptic met. station (partially automatic) | N | C | 1 | 2 | 1, 2, 12 |
| Bjørnøya | T, p, RH, prec., snow depth, clouds, visibility, radiosonde | Synoptic met. station (manual) | N | C | 1 | 2 | 1,2, 12 |
| Jan Mayen | T, p, RH, prec., snow depth, clouds, visibility, radiosonde | Synoptic met. station (partially automatic) | N | C | 1 | 2 | 1, 2, 12 |
| Hopen | T, p, RH, prec., snow depth, clouds, visibility, radiosonde | Synoptic met. station (manual) | N | C | 1 | 2 | 1, 2 |
| Edgeøya, | T, p, RH, wind | meteorological station (automated) | N | C | 1 | 2 | 1, 2 |
| Verlegenhuken, | T, p, RH, wind | meteorological station (automated) | N | C | 1 | 2 | 1, 2 |
| Karl XII Land | T, p, RH, wind | meteorological station (automated) | N | C | 1 | 2 | 1, 2 |
| Svea | T, p, RH, wind | meteorological station (automated) | N | C | 1 | 2 | 1, 2 |
| All above | Meteorological | Meteorological | N | C | 1 | 2 | 1, 2, |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| stations | parameters, radiation and energy balance parameters, including BSRN upgrade | station (upgrade to fully automatic, online) | | | | | 12 |
| Isfjorden, Adventalen, Kapp Linne, Ripsfjorden ,Austfonna | As above | Full station as above | N | C | 1 | 2 | 1, 2, 12 |
| All above stations | Precipitation measurements | Advanced precipitation gauge network | N | C | 1 | 2 | |
| Ripsfjorden, Ny-Alesund, Kapp Linne, Adventalen | Snow measurements | Automated snow monitoring – to be developed. | | C | 1 | 2, 7, 10, 11 | 7,12 |
| Sea-Ice locations, including Fram Strait | Snow measurements | Automated snow monitoring – to be developed. Aircraft,?, UAV's? | ? | C | 1 | 2 | 12 |
| Selected glaciers, rivers, including Ripsfjorden area | Freshwater run-off | Runoff monitoring instrumentation | N, Po | P | 1 | 15 | 5 |
| On ice buoys | T, pressure, wind, RH, web cam monitoring | 5 Automatic Weather Stations | G, N | C | 2 | 2 | 1, 2, 12 |
| Zeppelin Observatory , Ny-Ålesund | Wind, temp, RH, | Meteorological observations | N | C | 2 | 2 | 1, 2 |
| **Additional Meteorological Observations** | | | | | | | |
| Svalbard Lufthavn, Longyearbyen | T, pressure, wind, RH, precipitation., snow depth, clouds, visibility, etc. | Synoptic met. station (partially automatic) | N | C | 1 | 2 | 1, 2 |
| | | | | | | | |
| | | | | | | | |

**2. Horizontal transport**

| Location or area | Parameters | Infrastructure | C | Core/ Proc | Prio/ Level | EQ | KT |
|---|---|---|---|---|---|---|---|
| **Greenhouse gases** | | Met Stations providing wind speed and direction data | | | | | 4 |
| Zeppelin Observatory , Ny- | halogenated hydrocarbons | ADS-GCMS | N | C | 2 | 9 | 10 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ålesund | | | | | | | |
| Zeppelin Observatory, Ny-Ålesund | Ambient methane | GC-FID | N | C | 1 | 9 | 6, 10 |
| Zeppelin Observatory, Ny-Ålesund | nitrous oxide | GC | N | C | 1 | 9 | 6, 10 |
| Ny-Ålesund | GHG concentrations (high time res., precision) | High-resolution high-precision GHG monitors | N, SW, UK | C | 1 | 9 | 6, 10 |
| Ny-Ålesund | $CH_4$, $CO_2$ isotope conc. | Isotopic GHG monitoring | N, Sw | P | 2 | 9 | 6, 10 |
| Adventdalen, Kapp Linné, Rijpfjorden | $CO_2$, $CH_4$, $N_2O$, sensible and latent fluxes | Meteorological flux towers incl. eddy covariance and chambers measurements | N, Sw | P | 1 | 9 | 2, 6, 10 |
| Zeppelin Observatory, Hopen Ship-board | Isotopic analysis of water vapour and precipitation | Isotopic GHG Monitoring in atmosphere and in precipitation | ? | P | | | |
| **Pollutant Transport** | | Met Stations providing wind speed and direction data | | | | | |
| Zeppelin Observatory, Ny-Ålesund | Mercury air concentration | Tekran Hg monitor | N | P | 2 | 9 | 9 |
| Zeppelin Observatory, Ny-Ålesund | Ambient ozone | | N | C | 1 | 7, 9 | 9 |
| Zeppelin Observatory, Ny-Ålesund | Ambient Hydrogen | GC-HgO | N | P | 2 | 9 | |
| Zeppelin Observatory, Ny-Ålesund | Aerosol inorganic chemistry | Filterpack | N | C | 2 | 7 | 9 |
| Zeppelin Observatory | CO | CO monitor | N | C | 2 | 9 | 9 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| , Ny-<br>Ålesund | | | | | | | |
| Zeppelin Observatory Ny-Ålesund | Monitoring of organic pollutants (LRT) | DH80 High-Volume Air Sampler | N | C | 2 | 9 | 9 |
| Sverdrup Station, Ny-Ålesund | Inorganic chemistry | Precipitation collector | N | C | 2 | 9 | 9 |
| Longyearbyen, Ny-Ålesund, Svea, Hornsund, Kap Linné | Priority pollutants from settlements (transport, energy production) and ships | Emission monitors in settlements, harbours and research stations | ? | C | 2 | 9 | 9 |
| Longyearbyen-Norwegian mainland transect | various marine pollutants (+oceanographic parameters) | Ferry Box automated monitoring on "Norbjørn" | N | C | 1 | 8, 9 | 9 |
| **Repeat Sections** | | | | | | | |
| Across Fram Strait | Tracers (S, d18O, N:P, alkalinity), revealing the sources of the Arctic Ocean freshwater components | CTD | N | C | 1 | 8 | 3 |
| Across Fram Strait | Temperature and salinity of Arctic Ocean inflow (WSC) and outflow (EGC): Snapshots each September | Four Ice Profiling Sonars and four ADCPs | N | P | 1 | 8 | 3 |
| Fram Strait, line along 79 N across the East Greenland Current | Ice thickness and drift velocity across the Transpolar Drift where it exits the Arctic Ocean: Time series | EM bird and EM31<br><br>Electromagnetic measures | N | P | 1 | 3 | 3 |
| Fram Strait along the 79 N line across the EGC and over the East Greenland Shelf | Ice thicknesses across the Transpolar Drift where it exits the Arctic Ocean: Snapshots each September | Arctic Ocean Outflow Observatory (AOBS) (16 microcats, 16 RCMs, five ADCPS, one TS string) | N | P | 1 | 3 | 3 |
| Fram Strait, mooring array across the East Greenland Current at 79 N | Time series of Arctic Ocean outflow in the East Greenland Current (EGC) (temperature, salinities, current velocities) | CTD | N | C | 1 | 3 | 3 |
| **Langrangian and Active Marine Platforms** | | | | | | | |
| North-Atlantic | ARGO Floats | | | C | 2 | | |
| Isfjorden, Rijpfjorden, | Temperature, salinity, div. chemical, biological | Autonomous Underwater | N | C (if | 1 | 3, 5, 8 | 3, 4 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Hornsund, Kongsfjorden; Various locations depending on expedition. | (acoustic) and optical parameters (PAR, chlorophyll, fluorescence, oxygen, pH) | Vehicle | | systematic) | | | |

**Table A6: Proposal for new Norwegian infrastructure priorities for Solid Earth and long-term processes, Cryosphere/Geosphere interactions and responses to climate change**

| Location or area | Parameters | Infrastructure | C | Core/ Proc | Prio/ Level | EQ | KT |
|---|---|---|---|---|---|---|---|
| **Glacial Monitoring and Hydrology** | | | | | | | |
| Kongsvegen tidewater glacier | T, H, upward/ downward long-wave /short-wave radiation, wind speed, wind direction | 4 x Automatic Weather Stations (AWS) across glacier | N | C | | | 2,5, 12 |
| Holtedahlfonna, | T, H, upward/ downward long-wave /short-wave radiation, wind speed, wind direction | 2 x Automatic Weather Stations (AWS) on ice cap | N | C | | | |
| Kongsvegen | Meteorological parameters, radiation and energy balance parameters, including BSRN upgrade | Met Station | N | C | | | 2,5, 12 |
| Kongsbreen tidewater glacier | Meteorological parameters, radiation and energy balance parameters, including BSRN upgrade | Met Station | N? | C | | | |
| Kongsbreen tidewater glacier | T, H, upward/ downward long-wave /short-wave radiation, wind speed, wind direction | 2 x Automatic Weather Stations (AWS) | N? | C | | | |
| East coast tidewater glacier to be identified | T, H, upward/ downward long-wave /short-wave radiation, wind speed, wind direction | 4 x Automatic Weather Stations (AWS) | ? | C | | | |
| Nordaustlandet, Austfonna, Etonbreen | Global/ reflex radiation, albedo, upward/ downward long-wave radiation, net rad. | Automatic Weather Station (AWS) | N | C | | | |
| Various sites<br>See Meteorological Observations earlier | Precipitation measurements | Advanced precipitation gauge network | N | C | | | |
| Various | Snow measurements | Automated snow | N | C | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| sites<br><br>See Meteorological<br><br>Observations earlier | | monitoring – to be developed. | | | | | |
| **Seismicity** | | | | | | | |
| Ny-Ålesund | Earth Ground Movement | Seismometer (STS-1 and STS-2) | Int. | P | | | 8 |
| Adventdalen (Jansonhaugen) | Earth Ground Movement | Seismic Array (15 CMG-3T) | N | P | | | 8 |
| Hornsund | Earth Ground Movement | Broadband seismometer (STS-2) | Po, N | P | | | |
| Hopen | Earth Ground Movement | Short period<br><br>Seismometer | N | P | | | |
| Hopen | Earth Ground Movement | Broadband seismometer (STS-2) | N | P | | | |
| Bear Island | Earth Ground Movement | Broadband<br><br>seismometer (CMG-3T) | N | P | | | |
| Isfjord Radio | Earth Ground Movement | Seismometer (analog) | N | P | | | |
| **Deep Permafrost Monitoring** | | | | | | | |
| Adventdalen | Deep borehole temperature<br><br>Monitoring. Linked to met station with BSRN upgrade | Permafrost boreholes | N | C | | | 7 |
| Kap Linné | Deep borehole temperature<br><br>Monitoring. Linked to met station with BSRN upgrade | Permafrost boreholes | N | C | | | |
| At sea level and in Svalbard mountains | Permafrost temperature profiles | deep permafrost penetrating boreholes | N | C | | | |
| | | | | | | | |