**Challenge – Recommendation – how to implement recommendation?**

**WP 2: Existing observing systems**

**Challenges**

Requirements used for gridded satellite data can not be used for in situ observing systems. This makes it difficult to define gaps in the observing system. The heterogeneity of the in situ data sets makes standardization and homogenisation of data and meta data difficult.

INTAROS conducted an extensive assessment of gaps and maturity of in situ observing systems including data collection and distribution to users. While the survey was not covering all Arctic in situ observing systems the assessment showed that s

1. There are significant gaps in the coverage and sustainability of the the in situ observing systems for all spheres in particular in the Arctic Ocean.

standards and requirements for the data delivery chain has several weaknesses, and the data management component was not extensively assessed.

**Assessment of observational gaps:**

* + Requirements for in situ observing systems were (and in big part still are) missing.
	+ There is not any defined metadata standard for observing systems. To make a consistent assessment across different disciplines, we needed to develop an internal “INTAROS” protocol.
	+ The assessment is naturally partial. For completeness, the survey should be extended also to those systems that are currently not included. However, this would require an international interest and commitment that is hard to stimulate without continuation of funding.

**Harmonization of sparse data:**

* + Standard protocols for formatting data and metadata are still missing for many variables. This is a requirement for data interoperability and FAIRness.
	+ There is a knowledge and communication gap between the data providers/curators and the information technology experts who maintain the data repositories.

**Recommendations:**

High sustainability is a proxy for high maturity scores in all assessed aspects. Sustained observing systems result from national, regional or global infrastructures often not specific to the Arctic ⇒

**Integrate Arctic observing in existing national/regional/global program rather than inventing new Arctic specific systems**

Scientific campaigns/expeditions provide the highest quality observations, but are deficient in almost all other aspects, especially on sustainability and data management ⇒

-🡪Revision of funding mechanisms:

* increase coordination/shared funding between operational and scientific driven observations
* involvement of private sector: more observations should be based on ships of opportunity
* a subset of ocean, sea-ice and atmosphere observations should always be made on all research expeditions, regardless of their scientific aim

Dedicated funding should be ensured to the data management (from national or int. bodies)

* Arctic Ocean: A lack of in-situ observing capacity across all disciplines. Almost nothing in the atmosphere; subsurface installations robust but few, and they deliver data in delayed mode ⇒

For the atmosphere: a paradigm shift in system design is needed, where field experiments correspond to the reference system, satellites to baseline and reanalysis replaces the comprehensive level.

For the ocean: increased number of autonomous observing platform and systems is needed, deployed on ice and under ice during field campaigns

* Arctic land: Quality is a larger problem than coverage ⇒

Upgrade and complement existing stations, rather than expanding new networks; invest in new technology (to further automatize the measurements) at existing stations

* Satellites: provides the only data with sufficient spatial and temporal cover, but quality is sometimes lacking ⇒

Invest in in situ Cal/Val multidisciplinary supersites and field campaigns to improve satellite retrievals, models and data assimilation

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Better integration between in situ and satellite observations through:

* + Assessment of spatial representativeness of in situ observations,
	+ deployment of large quantity of cheap, autonomous sensors over the critical gaps in spatial representativeness (e.g GNSS sensors for snow water equivalent, web-cams for snow extent, ice velocity, and coastal sea ice presence/drift).

Better integration between European, American, Canadian, Chinese and Japanese observing programs and infrastructures, through:

* + Shared data portals

Shared use of research icebreakers (as in MOSAiC)

International collaboration and coordination.

Better integration between European, American, Canadian, Chinese and Japanese observing programs and infrastructures, through:

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**WP 3. In situ observing systems.**

**Environmental challenges:**

* **Low temperatures (freezing conditions), long periods with limited or no daylight, harsh weather (storms, waves)**

**Technical challenges:**

* **Lack of standard instruments, ruggedized for Arctic conditions**
* **Unforgiving operating environment, extended development arc, high sensor/platform costs thus no redundancy**
* **Limited access to critical services (GPS positioning, satellite communication and data transfer), lack of NRT data**
* **Insufficient capacity of power supplies (batteries) for longer/more demanding deployments**
* **Environmental conditions not favorable for windmills or solar panels**
* **Instruments/platforms need evolve with changing environment (e.g. declining sea ice)**

**Logistic challenges:**

* **Difficult access to fieldwork areas (in particular under COVID-19 restriction)**
* **Access to icebreakers/ice capable vessels for marine operations**
* **Long deployment periods (risk for instruments and data recovery)**
* **Cost/scalability – difficult to sustain broad, long‐term activities**
* **High logistic costs and complex operations in remote areas with no regular services**
* **Often limited support by trained technical personnel**

**Better integration between in situ and satellite observations through:**

* + **Assessment of spatial representativeness of in situ observations,**
	+ **deployment of large quantity of cheap, autonomous sensors over the critical gaps in spatial representativeness (e.g GNSS sensors for snow water equivalent, web-cams for snow extent, ice velocity, and coastal sea ice presence/drift).**

**Better integration between European, American, Canadian, Chinese and Japanese observing programs and infrastructures, through:**

* + **Shared data portals**

**Shared use of research icebreakers (as in MOSAiC)**

**Technical recommendations**

1. Facilitate a transition from regional and thematic measurement networks towards a sustained observing system by extending existing components with new instrumentation, to improve present-time measurements and add new observed variables.
2. Support and strengthen implementation of multipurpose observing systems, enabling multidisciplinary observations and providing additional services for different platforms and systems (e.g. acoustic geo-positioning or data telemetry in the ocean).
3. Promote development of relatively simple, low-cost and low-power sensors for measuring essential ocean, atmospheric, and terrestrial variables that could be deployed in larger quantities to improve spatial scales and representativeness of observations and mitigate data gaps.
4. Accelerate a development of robust and reliable sensors for biogeochemistry and biology to be routinely used for ocean observations in the Arctic environment.
5. Encourage development and wider implementation of autonomous systems for untended atmospheric measurements over land, sea ice and ocean, including radiative fluxes, winds, aerosols, and clouds.
6. Improve technical solution for adaptation of standard sensors for operating in the Arctic conditions,
e.g. solutions for deicing of atmospheric and terrestrial instruments or innovative power supplies
for surface instruments operating during polar night.
7. Encourage and promote development of new generation of power sources with high capacity, high performance and improved tolerance for low temperatures, possible also rechargeable, to enable longer and more efficient autonomous measurements in the Arctic.
8. Facilitate availability of reliable, broadband, and cost-efficient services for satellite data transmission and development of robust, low-power hardware for data transfer, in particular with respect to new satellite communication systems coming in near future.
9. Promote using ships of opportunity for autonomous collecting ocean, sea ice, and atmospheric observations
in the Arctic Ocean.
10. Encourage and support development of publicly available best practice documentation for operating different
in situ sensors, platforms and systems in the Arctic and open technical trainings available to professionals from different disciplines involved in Arctic observing.

**The most needed technical developments for building a future sustained Arctic observing system encompass:**

* **s**tandard sensors ruggedized for Arctic conditions and new, low-cost and low-power sensors,
* autonomous observing systems adapted to changing Arctic conditions,
* new generation of improved power sources,
* reliable, high bandwidth, and cost-effective services and hardware for satellite data transfer.

**WP 4:**

**Key challenges**

1. **Insufficient respect among scientists**
2. **Incomplete understanding of how to obtain and use data from different people\* and different knowledge systems in mutually beneficial ways**
3. **Lack of shared protocols enabling cross-weaving, and insufficient dialogue on how to ensure knowledge synthesis**
4. **Lack of enabling government policies**
5. **Asymmetric power relationships (incl. finances)**

**\*With varying beliefs, epistemologies, rationalities and cosmologies**

**Recommendations**

* **Establish an understanding of how to obtain and use data from different people and different knowledge systems**
* **Develop ways to enable knowledge production across scales**
* **Improve coordination of research efforts, mobilize all research results for operational contexts**
* **Develop observing-logistics and research infrastructures for cross-weaving knowledge**