Communications Challenges in the Arctic

Course: BiB2003 – Module No.5

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Department of Maritime Transport System

SINTEF Ocean - Trondheim

* This module provides and requires

Providing from the course

- Facts and figures for the movement of major stakeholders to the Arctic and their communications (Voice/Data) demand
- A practical view of existing communications systems and understanding about its challenges in the Arctic
- What are likely sound solutions for Arctic communications?

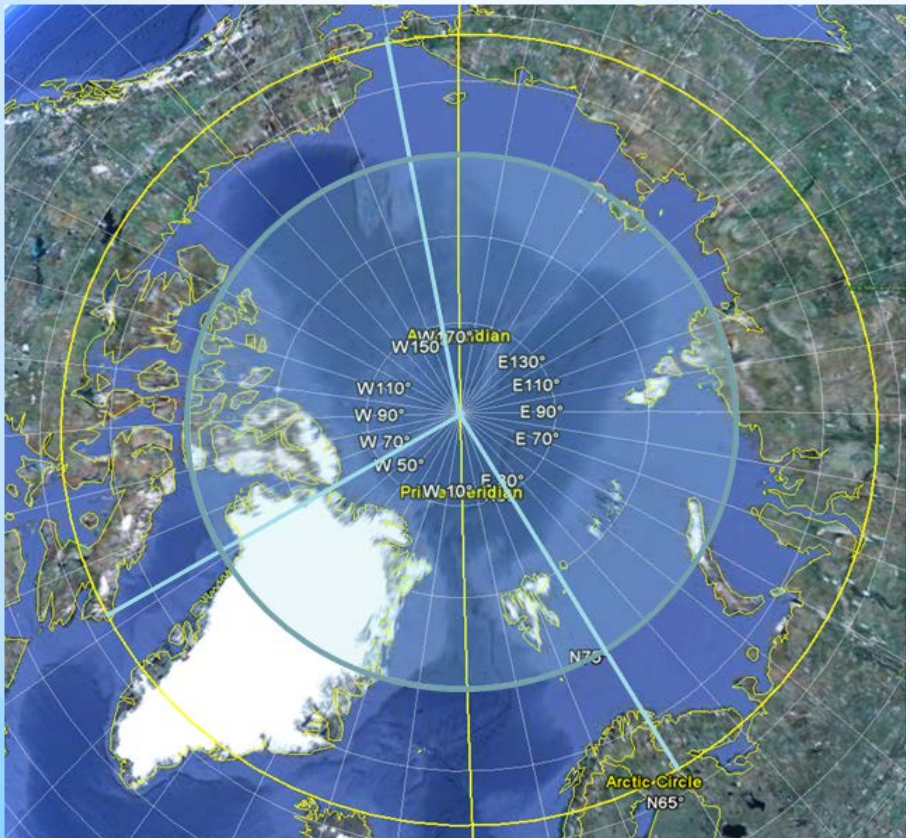
Requirement after this course

- Have a practical and numerical image about the Artic
- Have a general picture about communications conditions and challenges of doing communications over the Artic
- Can apply this knowledge into risk/safety analysis model have been studied in other courses

Part 0: Arctic, location and geography

* It is 14.5 million square km—almost exactly the same size as Antarctica.
* It consists of the ice-covered Arctic Ocean and surrounding land, including all of Greenland and Spitsbergen, and the northern parts of Alaska, Canada, Norway, and Russia.
* Its boundary is defined by either the northern limit of stands of trees on land (the treeline), the line of average July temperature of ~10°C (50°F), or the Arctic Circle, an imaginary line of latitude located at 66 degrees 33 minutes North. North of this line, the sun never sets on the summer solstice (June 21st).
* Some of the land parts of the Arctic, like Greenland, are covered with ice sheets; others, like Alaska, have lush tundra.
* The size and shape of the Arctic Ocean Basins are roughly similar to those of the Antarctic continent, and is 1.5 times the size of the continental US. It is also very deep, reaching more than 4,000 meters in some areas. It is mostly covered by pack ice (frozen seawater) averaging 2-3 meters thick.
* The ice drifts around the polar basin under the influence of winds and currents. When the floes collide, the ice forms a jagged line of ice chunks known as a pressure ridge.

P.0. Arctic Regions

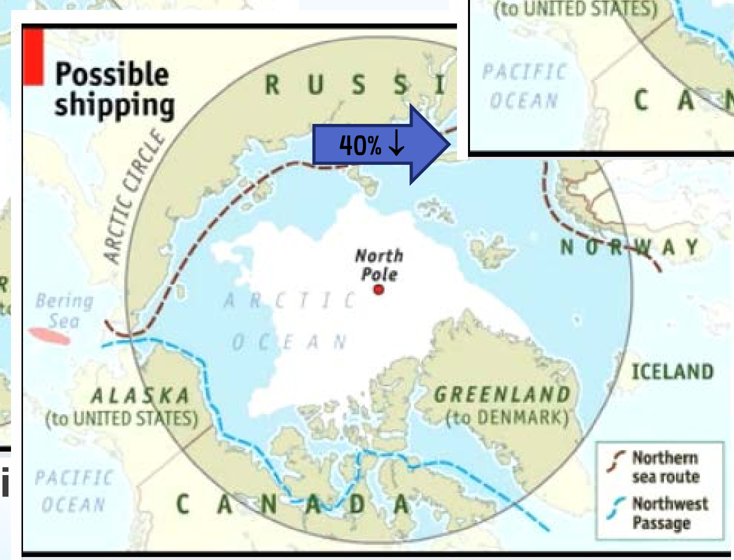


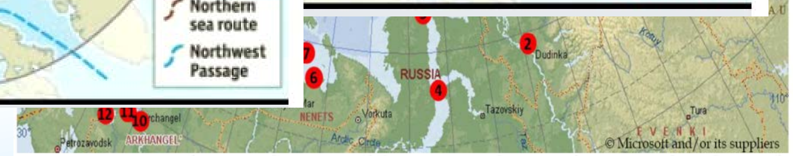
- ❖Europe (Scandinavia): Norway, Denmark, Sweden, Iceland and Finland. Five European countries have territories within the Arctic region.
- ❖North America (Canada and Alaska). In North America the interests in the Arctic are split between Canada and the US, through Alaska.
- ❖Russia has the largest share of all countries in the Arctic, with its Arctic territory reaching from the borders with Norway and Finland in the west, over Siberia and the Bering Sea almost towards Alaska.

P1. General trend of moving to the high North

Introduction - Drivers for increased (maritime) activities in the Arctic

- **Global warming**
  - Arctic region warming is faster than the rest of the plant
  - Open new and efficient shipping routes (Northern sea
- **Glo**
- **Inc**
- **Ava**
  -
- **BUT lots of challenges in thi**





Projects have been executed at SINTEF Ocean

Vessel and operation design
Communication in the High North & Safety
Communication in the High North
Search & Rescue (SAR)

2006

ARCEMOP – Arctic Emergency Operations (2006-2009, MAROFF)

CIVArctic (2008 -2010, MAROFF)

MarCom – Broadband at Sea (2007-2010, MAROFF)

MarSafe North – Maritime Safety Management (2008 -2011, MAROFF)

A Holistic Approach to Safety at Sea (2010, MFN, Kystverket, LN)

A-LEX 1 – "From Hamburg to Yamburg" (2010 – 2012, FRAM-senteret)

ArctiCOM SatCom in the Arctic(2010 -2011, ESA)

ArkKOM (2010 -2011, NRS)

SARiNOR forprosjekt (2012)

BarSek Nor-Russ SAR (2012)

COINOR – Communication in the High North for ConocoPhillips (2012 -2016)

MARENOR – Maritime Radio System Performances in the High North (2012 – 2015, MAROFF)

ArcticSAT (2013-2014) ESA

SARiNOR hovedprosjekt (2013 – 2016, JIP)

A-LEX 2 – "From Hamburg to Yamburg" (2013 – 2016) (UD, NORRUSS)

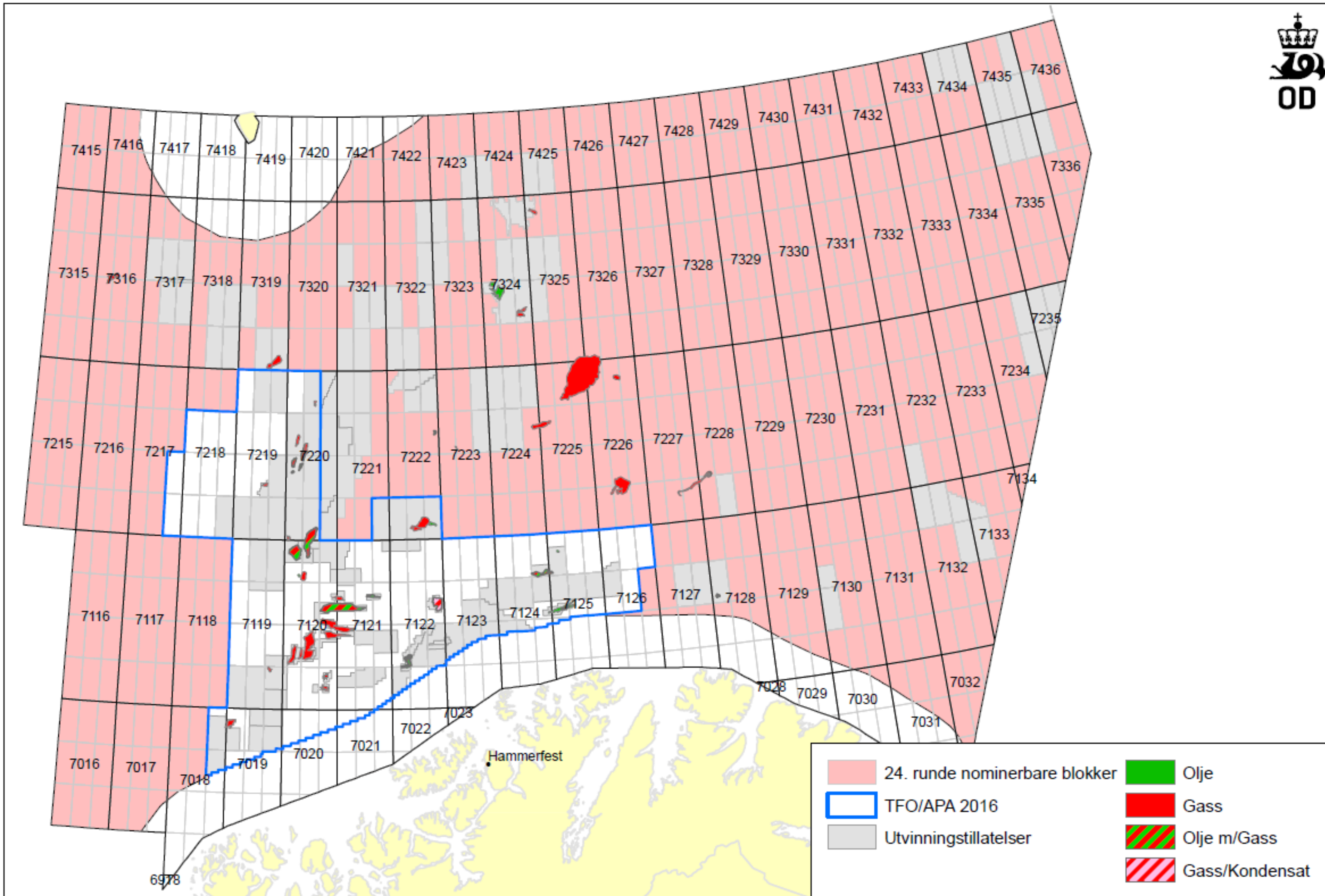
SatCom4Mar (2013-2014) ESA

2016

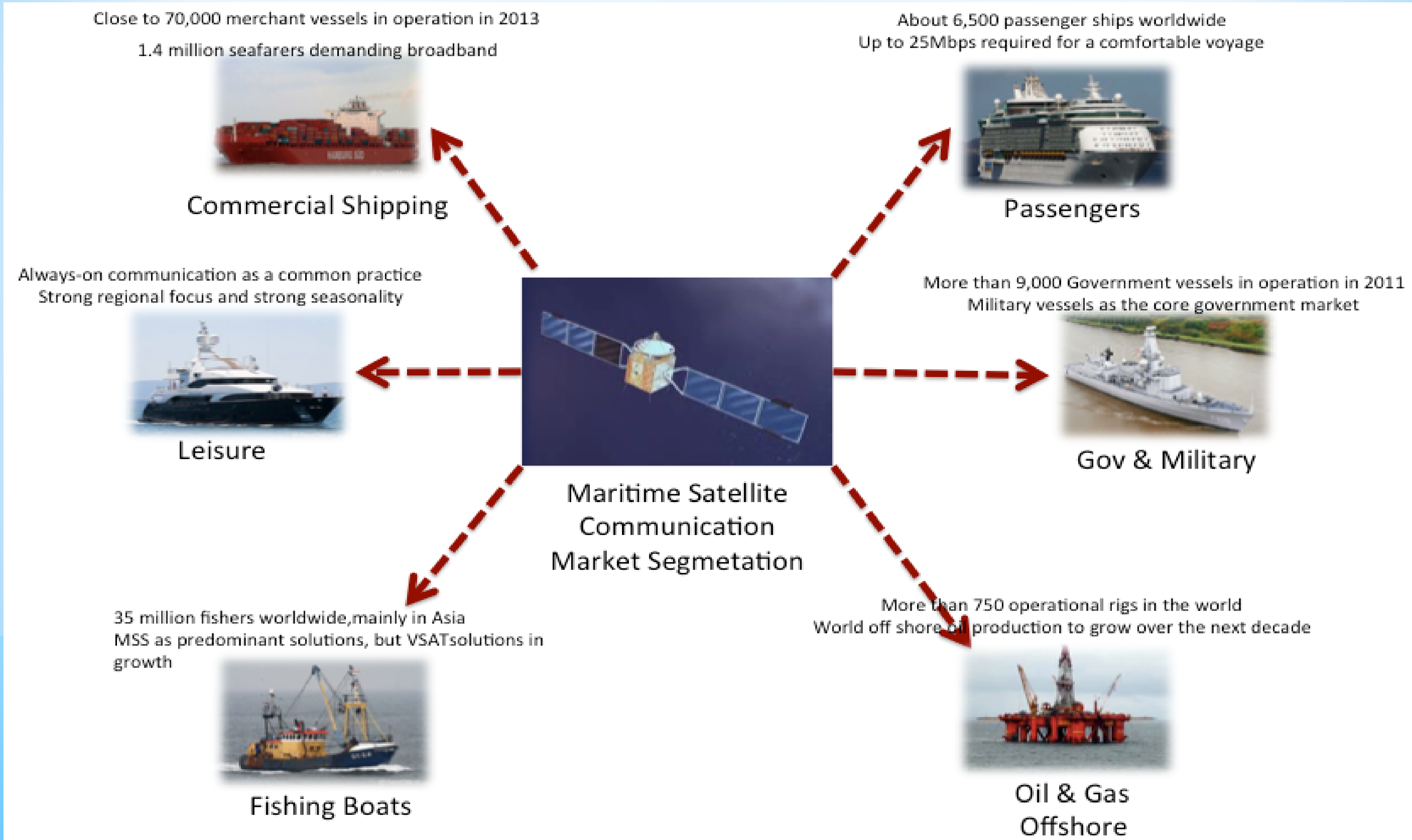
* Main market segments

Segments	Sub-segments	
Energy/ Natural resources	✓ Oil and gas (on shore) ✓ Oil and gas (off shore)	✓ Mining ✓ Utilities
Maritime	✓ Merchant shipping ✓ Fishing	✓ Energy support vessels ✓ Cruise ships
Aeronautical	✓ Commercial airlines passenger ✓ Commercial airlines cargo ✓ Business aviation	✓ Government ✓ General aviation
Government/Authorities	✓ Military ✓ Civilian govt. communications	✓ First responders
Science/Research	✓ Field sites ✓ Tele-education	✓ Education facilities
Local population/Aboriginals	✓ Consumer ✓ Enterprise	✓ Commerce (retail, etc)

* 24th round OG production licience

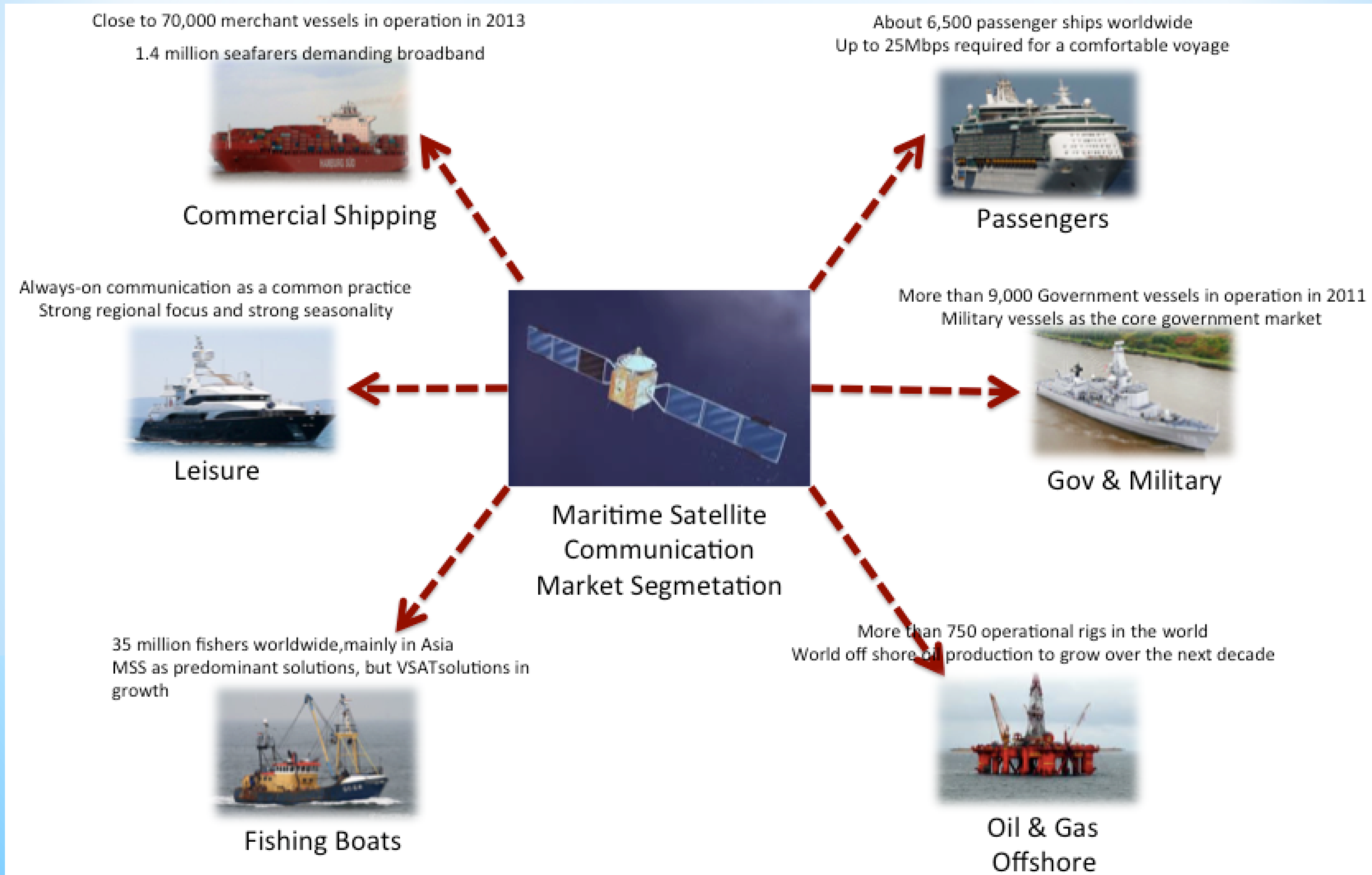


*In Maritime sector

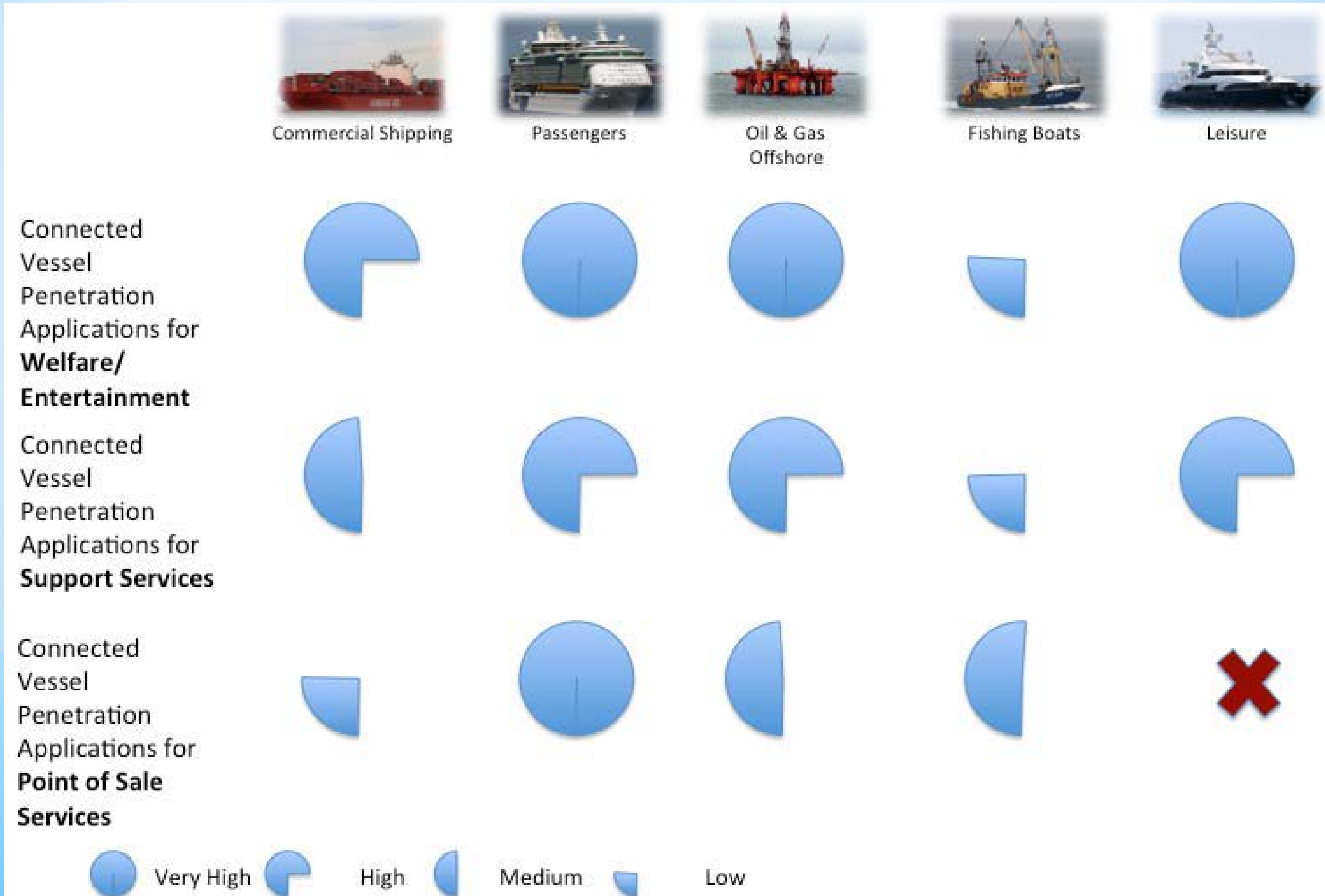


P2. Communications Infrastructures in the Arctic (or high North)

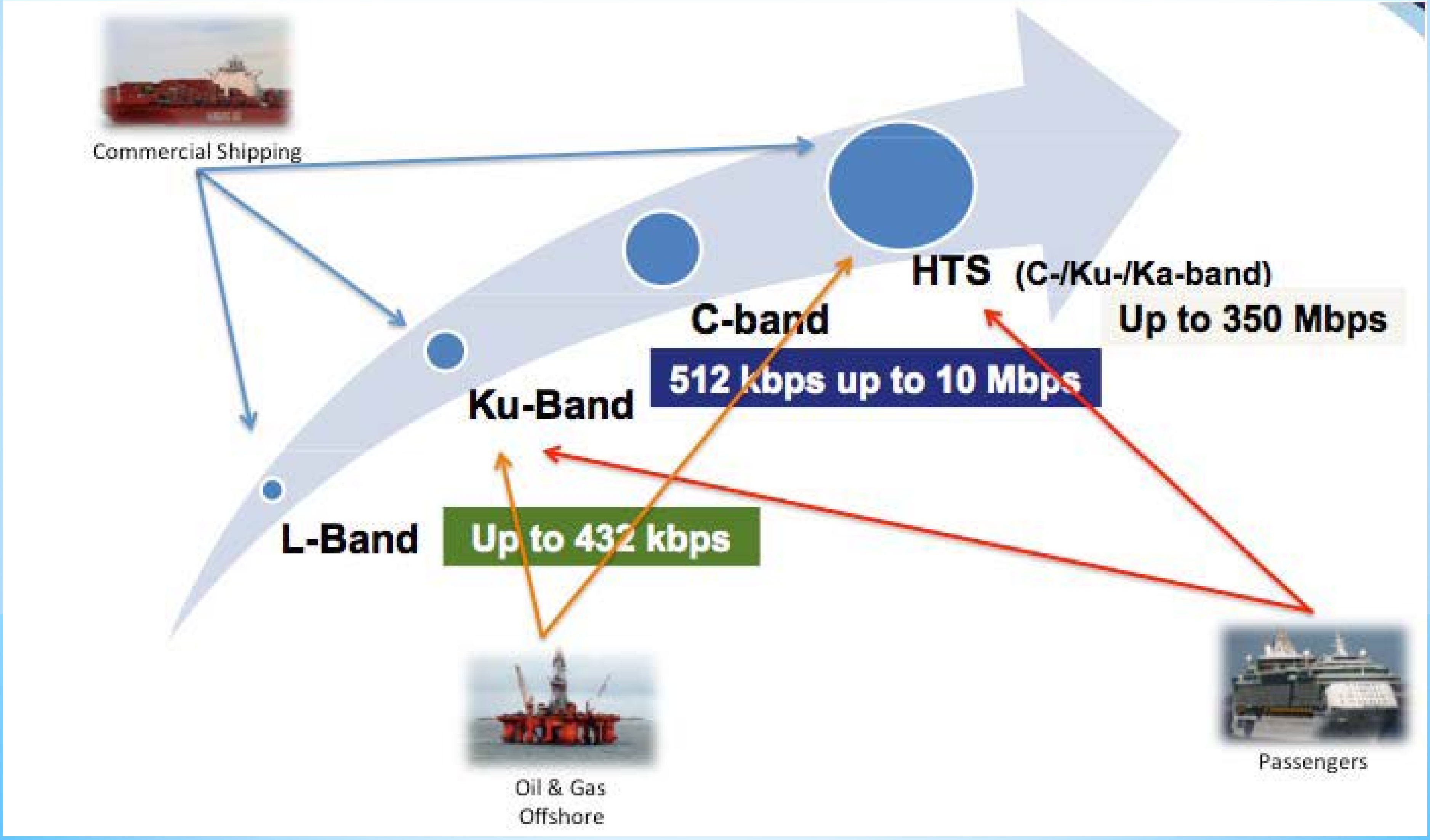
General communications systems and limitations
Then oritented to Arctic conditions


Close to 70,000 merchant vessels in operation in 2013
1.4 million seafarers demanding broadband
Commercial Shipping
About 6,500 passenger ships worldwide
Up to 25Mbps required for a comfortable voyage
Passengers
Always-on communication as a common practice
Strong regional focus and strong seasonality
Leisure
More than 9,000 Government vessels in operation in 2011
Military vessels as the core government market
Gov & Military
Maritime Satellite
Communication
Market Segmetation
35 million fishers worldwide,mainly in Asia
MSS as predominant solutions, but VSATsolutions in growth
Fishing Boats
More than 750 operational rigs in the world
World off shore oil production to grow over the next decade
Oil & Gas
Offshore

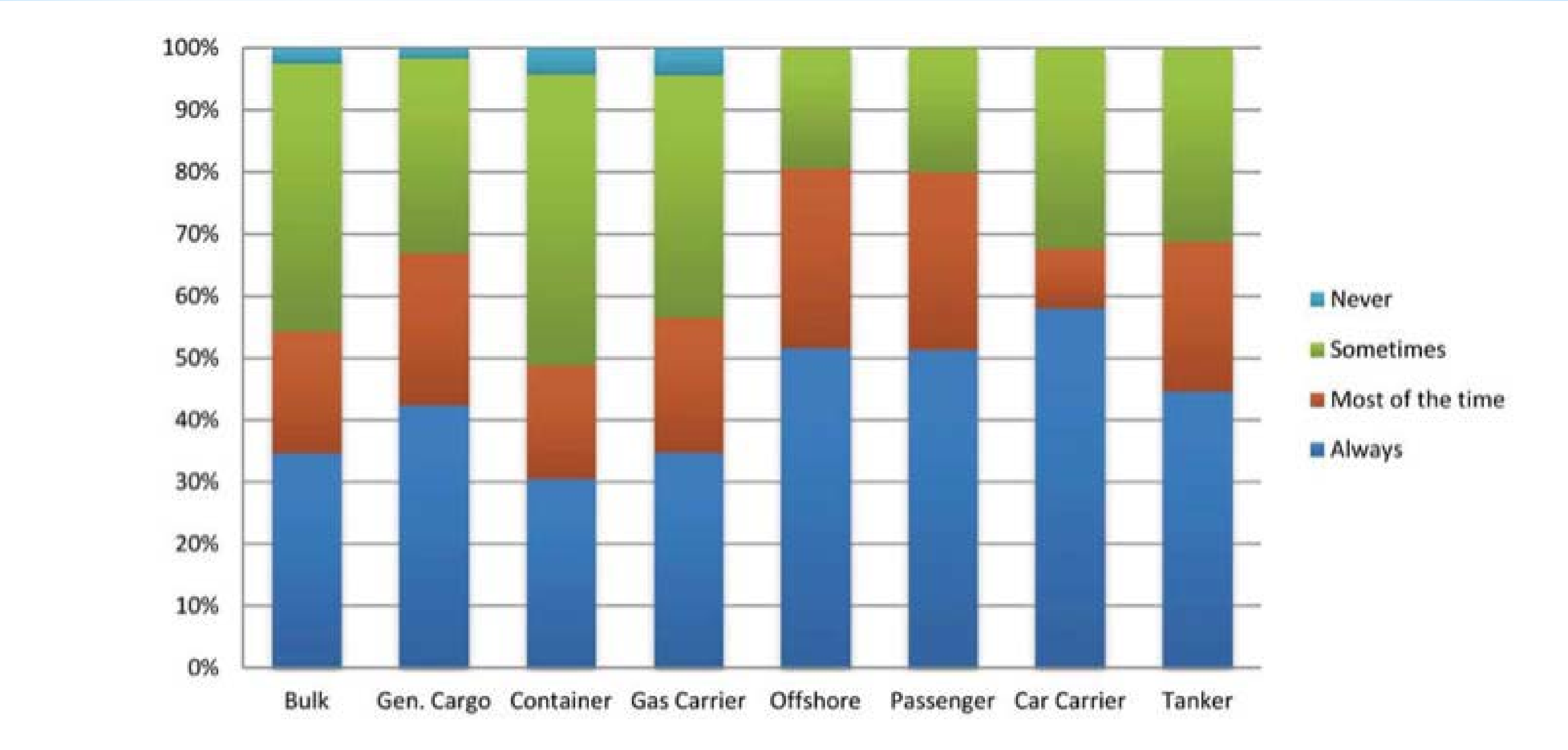
* Developments in the direction of the "connected vessel" in terms of commercial
* services will not be uniform in all market segments, each of which has its own
* specific requirements. However, there will certainly be strong penetration in the
* passenger, offshore petroleum sectors and in some specific sub-groups of the
* commercial segment.


Commercial Shipping
Passengers
Oil & Gas Offshore
Fishing Boats
Leisure
Connected Vessel Penetration Applications for **Welfare/ Entertainment**
Connected Vessel Penetration Applications for **Support Services**
Connected Vessel Penetration Applications for **Point of Sale Services**
Very High
High
Medium
Low

* Technology versus segments



*Access to communication at sea



*Frequency bands being used for military purposes (Source: Euroconsult)

Country	System	User	Frequency band
US	UFO/MUOS	US Navy and other US DoD	UHF
	Milstar	US Navy and other US DoD	UHF
	DSCS	US Navy and other US DoD	X-band
	WGS	US DoD, Australian Navy,	X-band, Ka-band
	AEHF	US Navy and other US DoD	EHF
	TacSat	US Navy and other US DoD	UHF
UK	Skynet	UK Mod; Australian Navy	X-band, UHF
France	Syracuse	French Navy	X-band, EHF
Italy	Sicral	Italian MoD	UHF/SHF, EHF, Ka-band
Germany	Satcom BW	German Bundeswehr	X-band, UHF
UEA	Yahsat	UAE Armed Forces	Ka-band

Source: Euroconsult

* General requirement for military

* Requirements for military application usually includes: high system availability and
* reliability, encryption, security, large capacity, interoperability with government
* systems, global coverage, mobility capability, flexibility and ruggedness.
* According to Euroconsult study, the global military traffic requirements for commercial
* capacity lead to total usage increasing from around 8 Gbps in 2011 to around 22
* Gbps by 2021. This corresponds to a CAGR of 11% over the period.
* Regarding the satellite communication systems there are three key trends:

* Military needs in communications

* **Military Needs**
* □**Tactical communications:** Tactical communications include various applications and account today for the vast majority of capacity usage.
* Commercial capacity is used for secured data communications for fixed and mobile applications with high-capacity needs, but also for tactical voice communications (mainly MSS) and low-data-rate Blue Force Tracking.
* **(Tactical) Voice communication:** The majority of MSS products today are still used for voice communication. As of March 2013, Iridium's handset is currently the only commercially available mobile handheld satellite phone that has Type I encryption accredited by the US DoD.
* **Troop welfare:** Troop welfare has become an increasing drive for satellite capacity as deployed troops demand Internet connectivity. Major applications include e-mail, voice calls, messengers, social websites, downloads, etc. Around 10% of SatCom capacity is estimated to be used for troop welfare today.
* **Broadcasting:** Commercial capacity is also used to broadcast TV and radio channels.
* **Communication-on-the-move (COTM):** COTM solutions are typically deployed on-board land-based vehicles, ships, and aircraft. MSS operators have developed several customized terminal solutions for government and military users in recent years.. In addition, Stratos commercialized Inmarsat's FleetBroadband maritime communications solution with the Royal Netherlands Navy and the US Coast Guard.
* **Blue Force Tracking (BFT):** Situational awareness and networking capabilities are used by the US government to track military assets and to allow search and rescue forces to quickly communicate with at-risk personnel. Commercial SatCom capacity is playing a critical role with MSS, providing sufficient data rates to support most BFT applications. Since April 2012, the US army is using BFT-2, benefitting from higher speeds.
* **M2M for Tracking and monitoring:** Similar to the trend that began in commercial markets several years ago, more and more government users are seeing the necessity to survey, track, and monitor their assets, including at sea. Thus, a trend that is slowly emerging is an increasing use of low-data-rate M2M devices in a government maritime environment to track cargo, to increase safety and situational awareness, and to support logistics.

* Military needs

New applications:

* A main reason why the government's capacity and throughput requirements are increasing rapidly is because of the range of new applications emerging.
* Ships are seen as strategic nodes within the network that basically need
* access to the same information and applications in real-time as their land and aero counterparts. Major new applications include video transmission from ISR vehicles (e.g., UAVs), access to VPNs and databases, real-time access to update maps and images, and applications related to crew welfare. In particular, crew communications are benefitting from commercial VSAT
* solutions, while mission critical strategic and tactical communications still mainly go through proprietary systems.

* Conclusion

Conclusion

* There is clear trend today to move towards higher frequency bands among government maritime users away from legacy L-band systems. Currently, the major effort is put on a migration to Ku-band, but over the long term, a move towards Ka band seems likely.
* As Ka-band should become the dominant frequency band over time, in the long term, Inmarsat might be able to become the dominating provider of commercial SatCom capacity with its Global Xpress service. The uptake of Ka-band should, however, still need some time given the current efforts to equip vessel fleets with new Ku-band solutions and looking at typical replacement cycles of 5-10 years. By 2021, the VSAT terminals are expected to represent about 16% of total active commercial SatCom terminals in the government maritime market, compared to only 10% in 2011. In terms of revenues at the service provider level, as the ARPU of VSAT is higher than the blended ARPU of MSS, VSAT is expected to increase its contribution in total SatCom revenue from 75% in 2011 to 95% in 2021.

Statutory

* International organizations and regional/national agencies have a set of objectives and requirements that include interoperability, reliability, functionality, and security in operation. Considering that the radio communication needs of maritime operators at sea and the infrastructure developed to provide safety and support ashore are growing, future advanced solutions used by the maritime mobile community will require increased global coverage, higher data rates, and possibly video and/or multimedia capability. The satellite communication systems will play a key role in the evolution of maritime services.
* The major requirements that should boost the MSS industry in the maritime market between 2014 and 2020 is for GMDSS, VMS, AIS and LRIT. The modernisation of GMDSS requirements, polar regions coverage, e-Navigation, Satellite AIS, and VDES are also topics under scrutiny by the International Maritime Organisation.
* However the revenue generated by safety service is limited. Indeed, Safety terminals are only used in case of emergency, which limits the volume of data exchanged. Additionally, safety terminals, which report the position of a ship on a regular basis, only require a small amount of bandwidth. However, the development of new regulatory applications should foster a growing competition as new operators with global network capabilities prove their reliability.
* Therefore, the competitive landscape of maritime regulatory communications should continue to expand.

* GMDSS

GMDSS:

* For GMDSS, general maritime distress and safety systems, Inmarsat is today the only satellite provider certified. GMDSS is a SOLAS requirement. However, the International Maritime Organisation (IMO) is likely to certify additional satellite operators. Iridium is positioning itself on this market and intends to compete directly with Inmarsat, particularly with M2M products.

VMS, SSAS:

* Various safety systems are currently operational: vessel-monitoring systems (VMS); ship security alert systems (SSAS); will continue their evolution.

AIS:

* The AIS market, and especially the space-based AIS (S-AIS) market, is easier to penetrate for new entrants that only have one or a few satellites, since real-time is not a regulatory requirement. Orbcomm's network of AIS satellites, for example, does not offer global real-time tracking of all AIS terminals. ComDev, which entered the AIS market through its subsidiary Exact Earth, currently has only one satellite. It collects AIS data (sent on terrestrial radio frequencies) when orbiting over the ships and sends the data to a ground station when it is above Swedish territory. Other players, such as Luxspace or the ESA-financed company Innovative Data Services, are also expected to enter the AIS market.

* GMDSS

LRIT:

* The International Maritime Organisation (IMO) sub-committee called the Maritime Safety Committee (MSC) provided in July 2009 the Long-Range Identification and Tracking (LRIT) requirement.
* This LRIT requirement mandate the automatic reporting of position information for all passenger ships, cargo ships (>300T), and offshore drilling units.
* Today, Inmarsat is the leading provider of LRIT solution (with Inmarsat C and ISAT M2M product range). However, additional satellite providers are expected to compete on this market.
* The license obtained by Iridium for LRIT may pave the way for other applications by MSS operators. However, competition is expected to remain limited for LRIT solutions, since the provision of such services requires a global real-time network.

* E-Navigation

* E-navigation is the future, digital concept for the maritime sector that will have a profound and long-term impact on the way the maritime sector operates. It is foreseen to be supported by many current and future technologies.
* The communications infrastructure should be designed to enable authorized seamless information transfer on board ship, between ships, between ship and shore and between shore authorities and other parties. This infrastructure will have to be capable of not only supporting future e-Navigation applications, but will also have to support legacy applications. It will therefore be bandwidth intensive and possibly rely upon a range of technologies.
* Securing spectrum, or changing the use within existing allocations, is important for e-Navigation due to the planning timescales required to protect or extend the use of the radio spectrum through the ITU WRC.
* In general, there are some concerns relating to spectrum allocation and management for e-Navigation. Protection of the maritime mobile service spectrum allocation needs to continue.
* e-Navigation should develop automated processes for selecting the best communications technology, channel, and characteristics in accordance with the ship's location, and the type of data to be exchanged.
* The e-Navigation concept and future user requirements are rapidly being developed but it is difficult to speculate what specific systems and spectrum will be required to achieve e-Navigation.

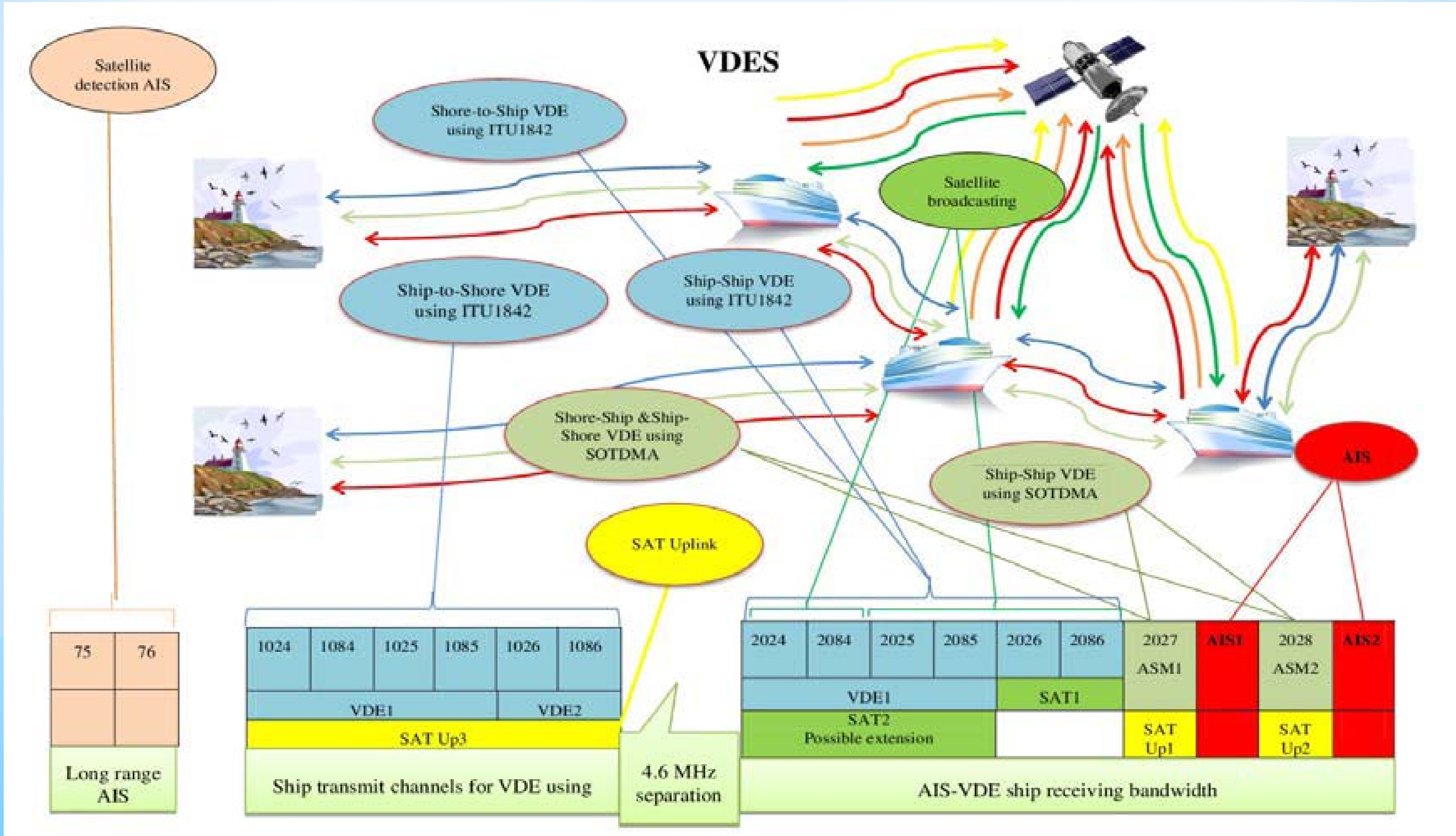
* AIS

* AIS is well recognized and accepted as an important tool for safety of navigation and is a carriage requirement for SOLAS vessels (Class-A). However, because of its effective and useful technology, the use of AIS is expanded to vessels not subject to the SOLAS carriage requirement, and to completely different applications. This expanding use of AIS technology has caused significant increase in VHF Data Link (AIS VDL) loading which has become an active concern in IMO and ITU, and it is considered necessary to urgently allocate new frequencies for new and emerging applications in order to mitigate overloading of AIS VDL.
* Looking further ahead, AIS through satellites (Satellite AIS) may prove to be a reliable and capable of providing MSI.

* VDES

* VHF Data Exchange System (VDES) is a technological concept under development by the IALA e-NAV Committee and now widely discussed at ITU, IMO and other organizations. It is a digital data exchange system envisaged to offer a globally interoperable and commonly available maritime data communication capability for ship/ship and ship/shore safety of navigation communications including an option for global coverage via a satellite component.
* Simultaneously, because of increasing demand on radio spectrum for digital communication such as mobile phone and data, ITU now requests more efficient and effective use of radio spectrum. New techniques providing higher data rates than AIS will become a core element of VDES. Furthermore VDES network protocol should be optimized for data communication so that each VDES message is transmitted with a very high confidence of reception.
* VDES was originally developed to address emerging indications of overload of VHF Data Link (VDL) of AIS and simultaneously enabling a wider seamless data exchange for e-navigation, potentially supporting the modernization of GMDSS.

*VDES



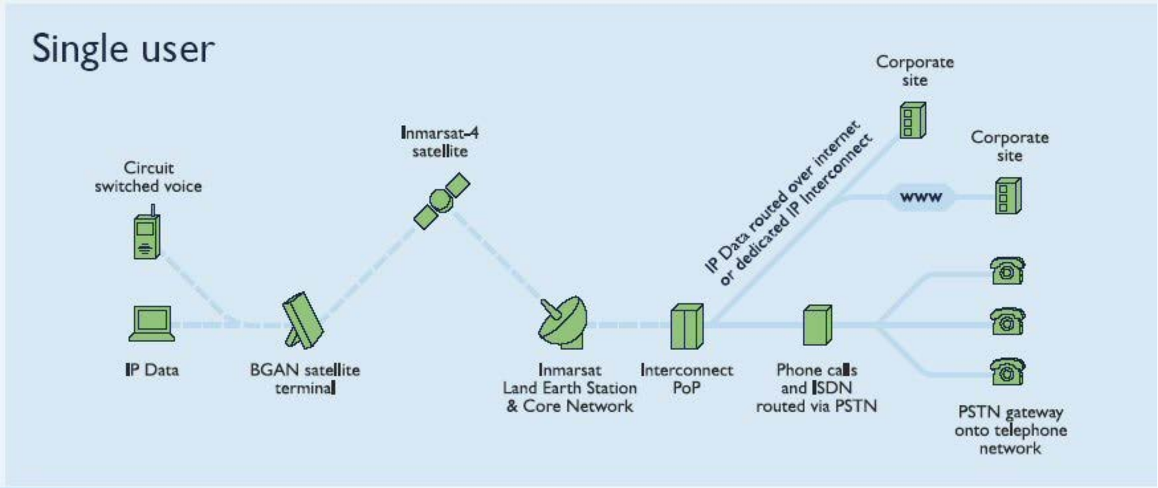
VDES
Satellite detection AIS
Shore-to-Ship VDE using ITU1842
Ship-to-Shore VDE using ITU1842
Ship-Ship VDE using ITU1842
Satellite broadcasting
Shore-Ship &Ship-Shore VDE using SOTDMA
Ship-Ship VDE using SOTDMA
AIS
SAT Uplink
75
76
Long range AIS
1024
1084
1025
1085
1026
1086
VDE1
VDE2
SAT Up3
Ship transmit channels for VDE using
4.6 MHz separation
2024
2084
2025
2085
2026
2086
2027 ASM1
AIS1
2028 ASM2
AIS2
VDE1
SAT1
SAT2 Possible extension
SAT Up1
SAT Up2
AIS-VDE ship receiving bandwidth

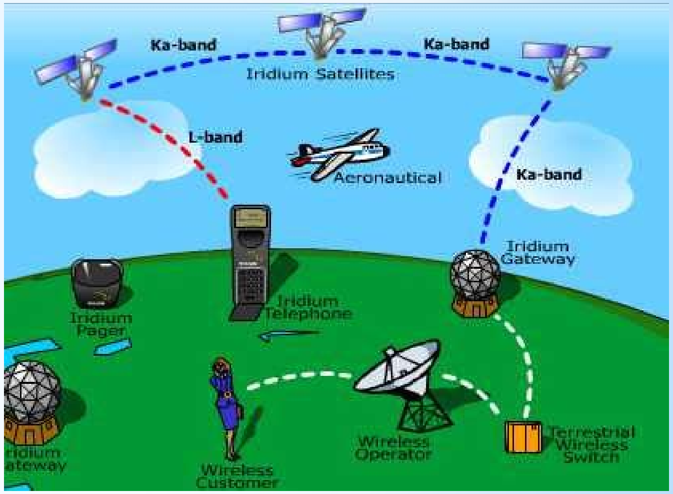
* To facilitate a satellite frequency allocation for the VDES, sharing studies involving land mobile VHF stations are underway in ITU. It is expected that such studies will be completed during the development of the ITU Recommendations for VDES so that final decisions by WRC-18 can facilitate a fully featured VDES including the satellite aspects.
* In order to ensure a coherent and globally interoperable system, comparative studies, field trials involving testbeds and harmonization of the results will be needed to fully develop the system and ensure a safe, efficient and globally interoperable
* implementation.

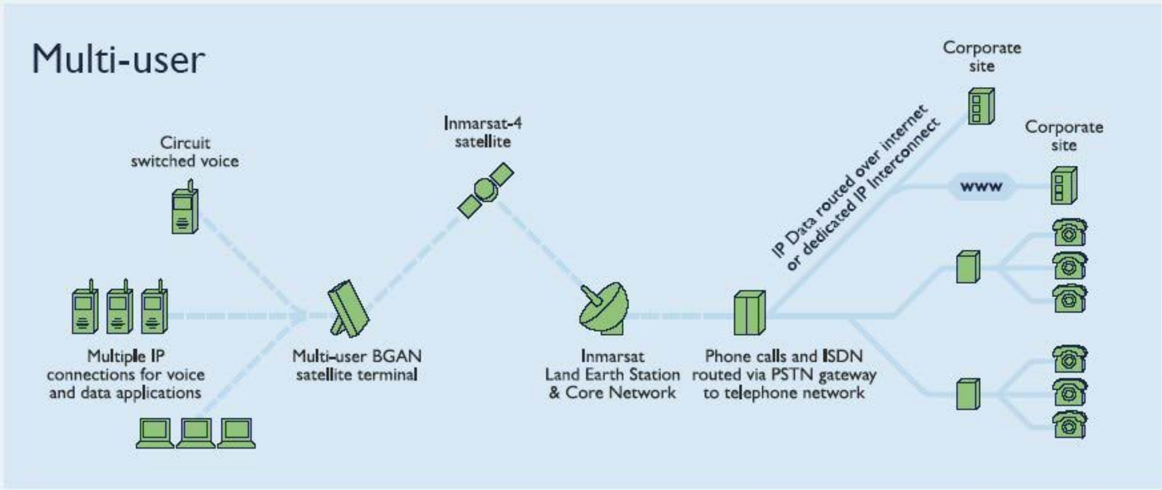
* Roadmap of VDES (KSX)

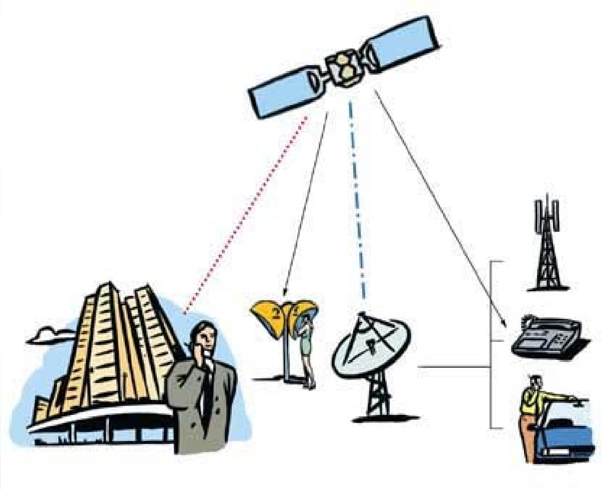
*How to do communications?

* Satellite communications

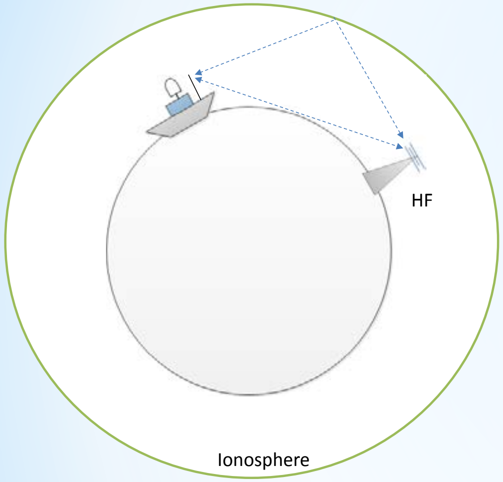








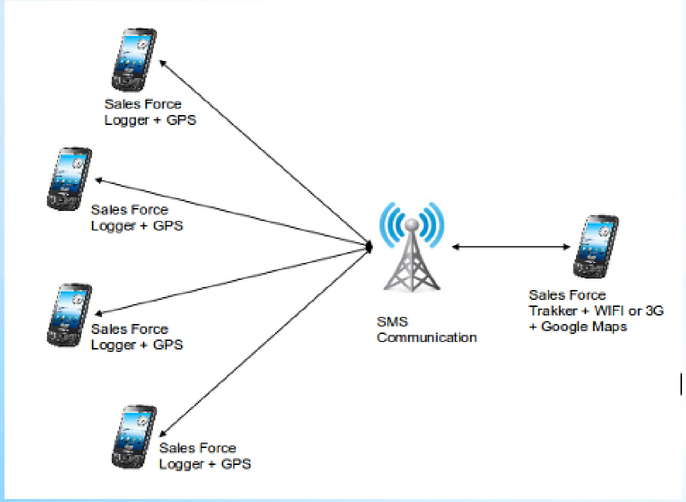
*How to do communication? Cont.



* VHF/HF/MF: Terrestrial radio communications

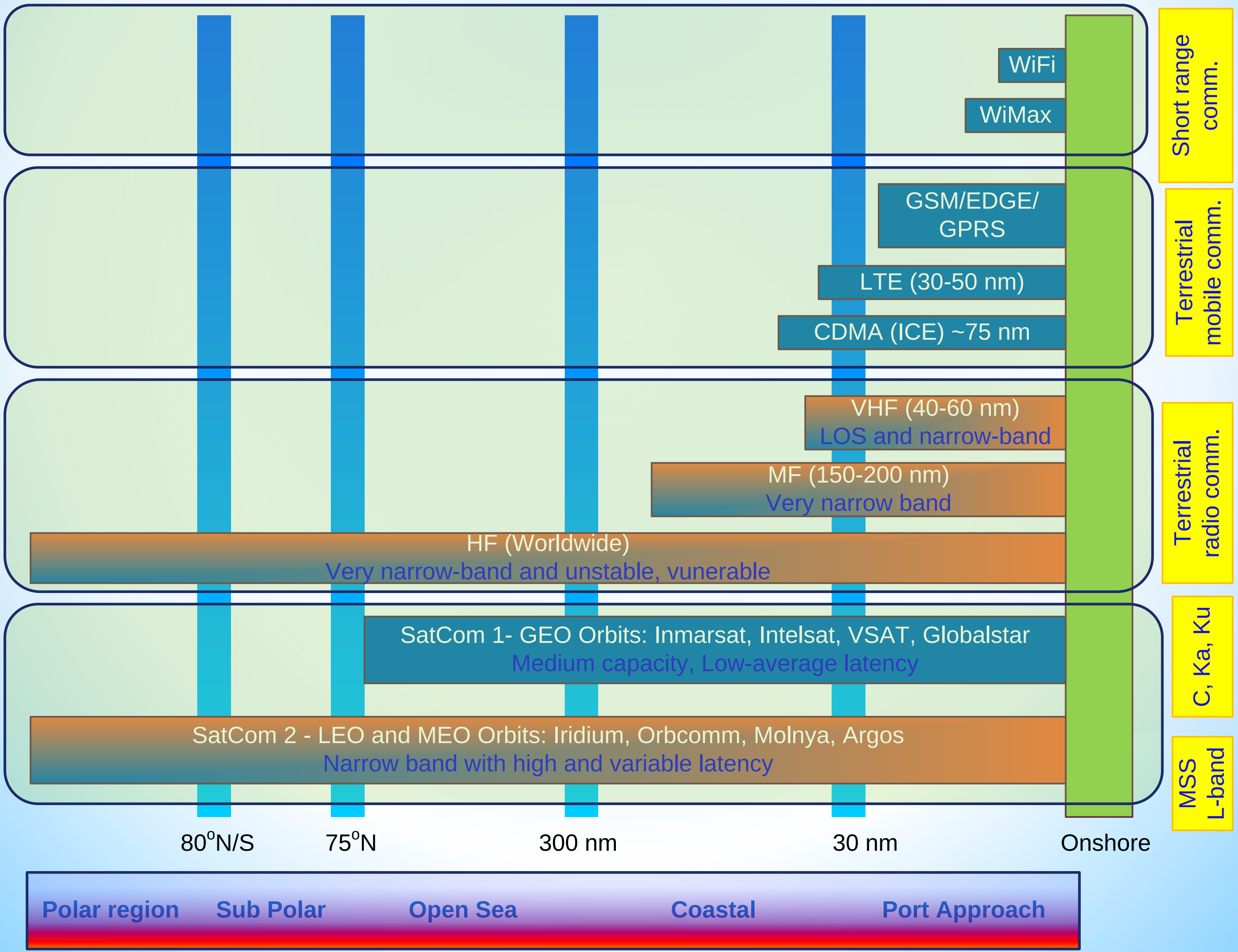
In general, it needs a medium to transmit the electronic signals.

For radio communication, this medium is the airspace (atmosphere and the ones above)

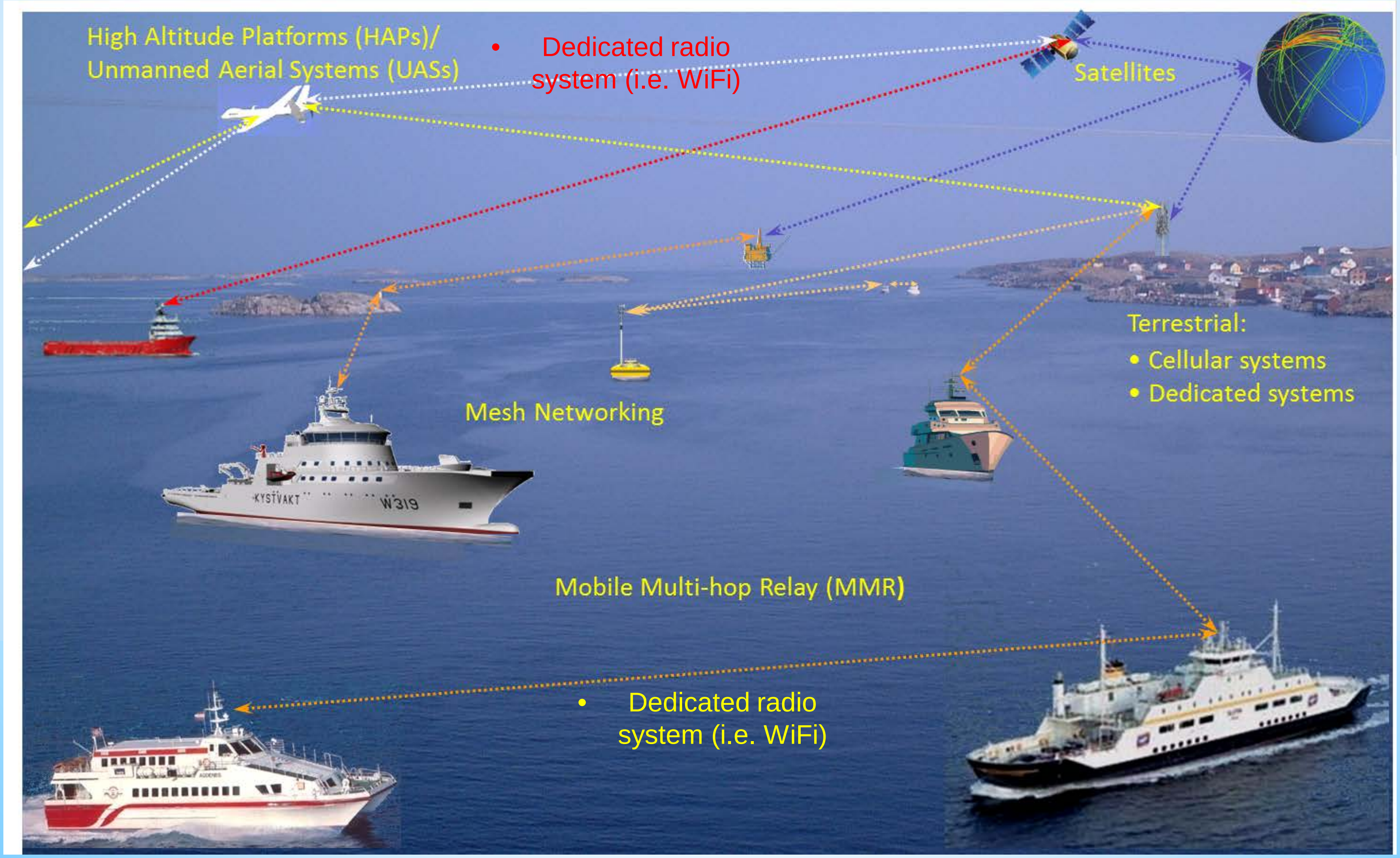


* Terrestrial cellular mobile communications

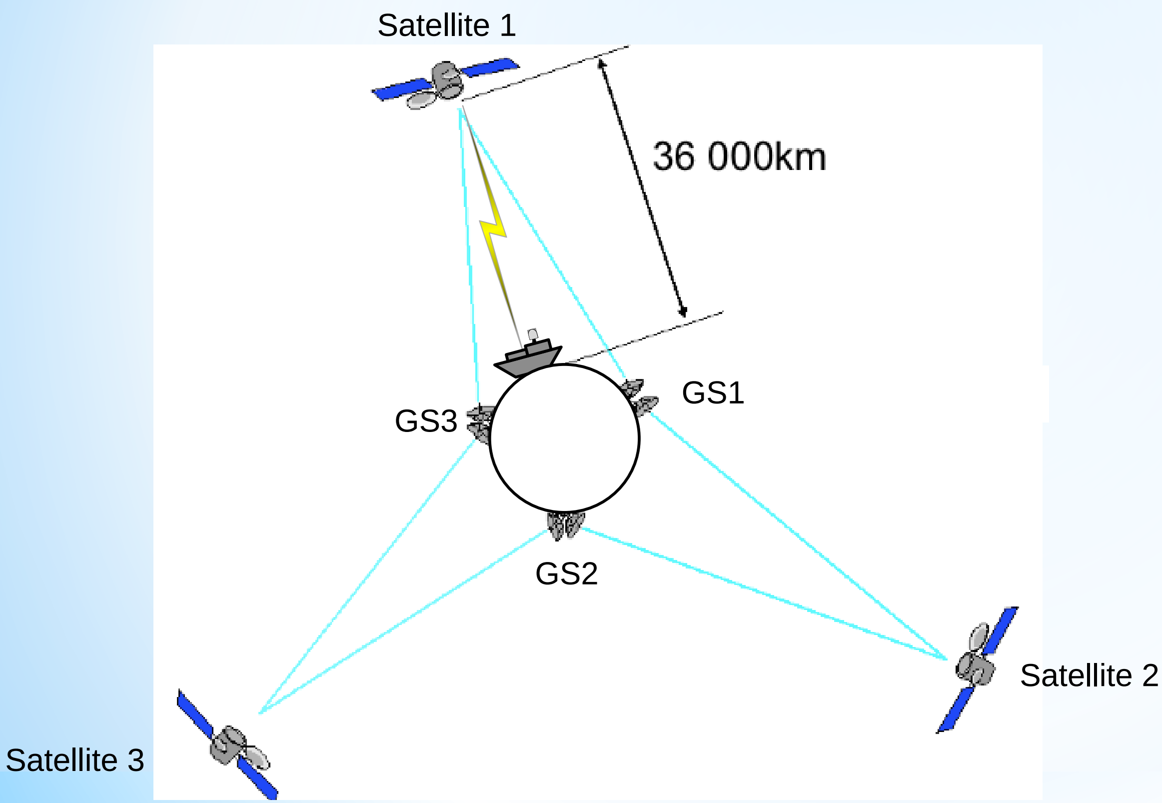
* Radios Coverages and Bandwidths



* Mixed radio communications in maritime sector



* Geostationary Earth Orbit (GEO) satellites



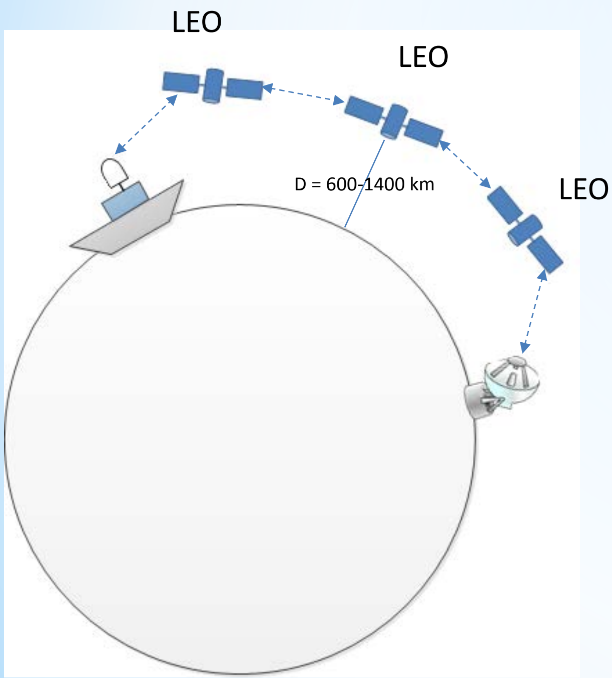
Description of Ship-Shore Communication over GEO Orbit Satellites [Source: MARINTEK]

It usually needs at least three GEO satellites to have a full coverage. These satellites are located at an altitude of 36000 km from the earth in the same plane of the Equator.

*Typical GEO services i.e. in maritime

Inmarsat	Existing and Evolved	Inmarsat-C	Data (600 kbps)
	BGAN Fleet broadband (FB)	FB 150	Voice, Fax, SMS and Data background (up to 432 kbps), Data Streaming
		FB 250	
		FB 500	
	Fleet Phone	Oceana	Voice, Fax, SMS
		Fleet 33	Data (~64 kbps)
		Fleet 55	
		Fleet 77	128 kbps
	Maritime Global Xpress (I-5 F1 (Indian Ocean) and I-5 F2 (Atlantic Ocean) are on services but not included the high North region.	60cm antenna	5 Mbps Uplink 50 Mbps Downlink
		1m antenna	7Mbps Uplink 60 Mbps Downlink
Intelsat	VSAT	60 cm antenna 90 cm antenna	128-4096 kbps (C-band) Up to 50Mbps (K_u-band)
Eutelsat	VSAT	1 m antenna	512 kbps Uplink 1024 kbps Downlink

*Low Earth Orbit (LEO) satellites

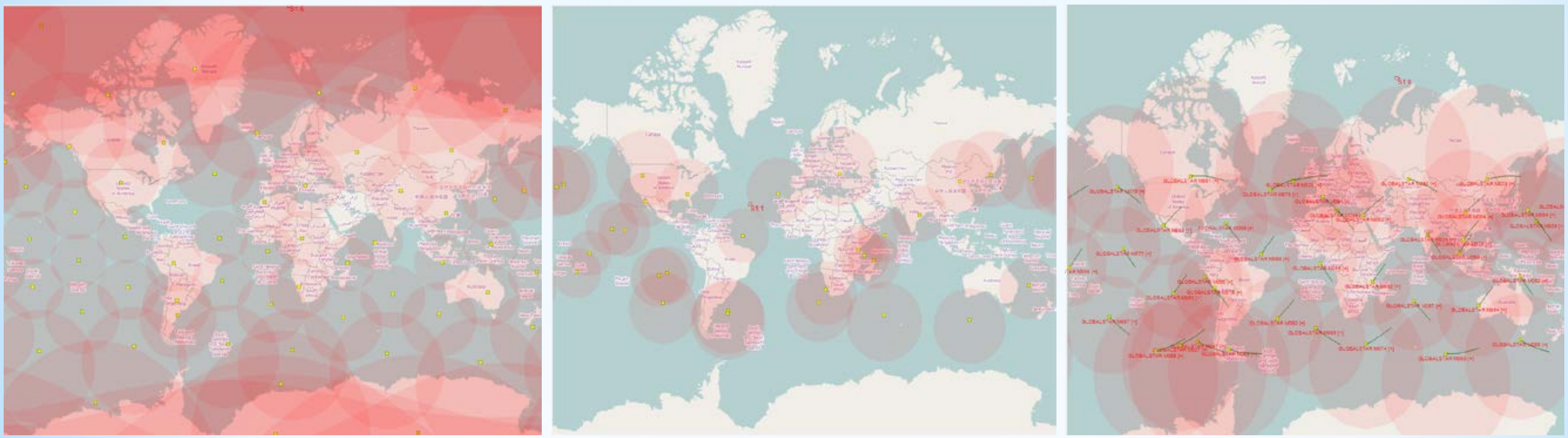


The coverage areas from the different LEO satellite service providers are:

Iridium: global (66 satellites equally located on 6 orbits)
Orbicomm: regional (30 satellites)
Globalstar: +/- 72° nearly global (48 satellites)

SatTracker Tool

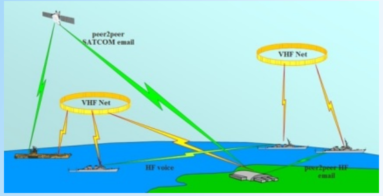
*Typical LEO satellites coverage



Iridium, Orbcomm and Globalstar satellites at elevation angle 10° (Source: MARINTEK)

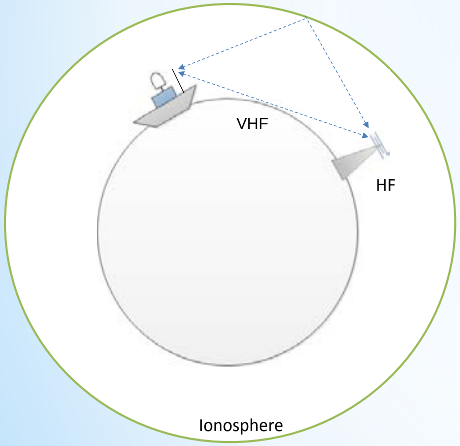
* Bandwidth for LEO orbit satellite services i.e. in maritime

Iridium	Voice	Sailor SC4000	2.4 kbps
	Short Burst Data	-	Low (now)- BW on demand (Future)
	Broadband Openport service	OpenPort	132 kbps (now)-512 (Future)
		Pilot	Up to 512 kbps
	Broadcasting	L band high speed	512kbps(Uplink)/1.5Mbps(Downlink)
Globalstar	-	GSP-1700	9.6kbps
Orbcomm	-	-	2.4-4.8 kbps



*Terrestrial radio MF/HF/VHF

*MF/HF (280-370km/3000km)



- ❑ MF, HF and VHF are three frequency bands extensively used for radio communications in both the maritime and aeronautical sector.
  - ❑ MF: 300 kHz to 3 000 kHz
  - ❑ HF: 3 MHz to 30 MHz
  - ❑ VHF: 30 MHz to 300 MHz

- ❑ The two lowest bands (MF/HF) are primarily used for communications over long distances.
  - ❑ Thanks to special effects in the atmosphere and ionosphere at such low frequencies, a range of 3000km or more is not unusual.
  - ❑ However, the range depends on a number of parameters such as:
    - ❑ Humidity
    - ❑ Temperature
    - ❑ Time of the day and the solar activity.
  - ❑ The vast potential range also makes MF and HF systems highly exposed to interference.

*VHF (75-110km)

It is a Line of sight (LOS) communication

* Svalbard Optical Fiber

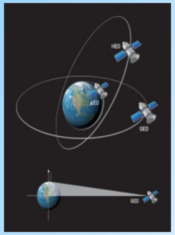
* The Svalbard Undersea Cable System consists of two 1400 km long submarine communications cables from Harstad on the Norwegian mainland to Svalbard. It is owned by the Norwegian government and Kongsberg Gruppen ASA through Norwegian Space Centre and operated by Telenor (officially opened on 1st February 2004). Its capacity is used by such customers as NASA, ESA, meteorology services, UNIS, and many others. Specifically, the cable carries the following traffic: all telecommunication, TV and radio services from Norway to Svalbard; the data from 30+ circumpolar satellites via the SvalSat station in Longyearbyen; research and geodetic data from the Ny-Ålesund research community; and astronomical data from the EISCAT earth station in Adventdalen.

  Distances cover the two segments of Svalbard-Breivika and Breivika-Harstad are:

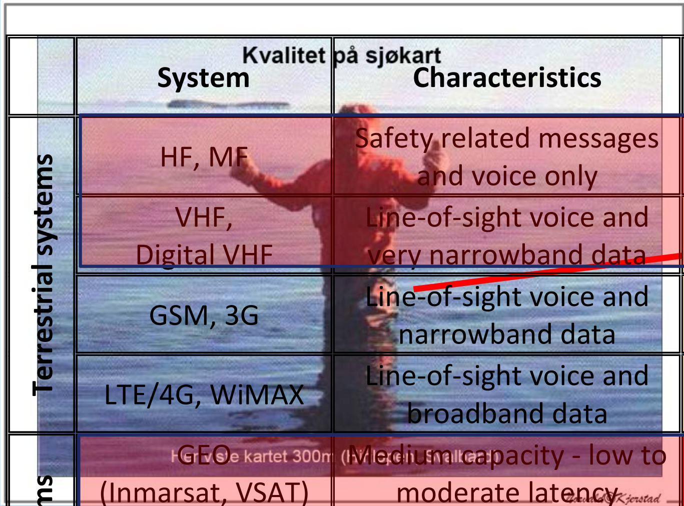
Segment 1: 1375 km (172 km of this buried)	Segment 1a: 61 km
Segment 2: 1339 km (173 km of this buried)	Segment 2a: 74 km

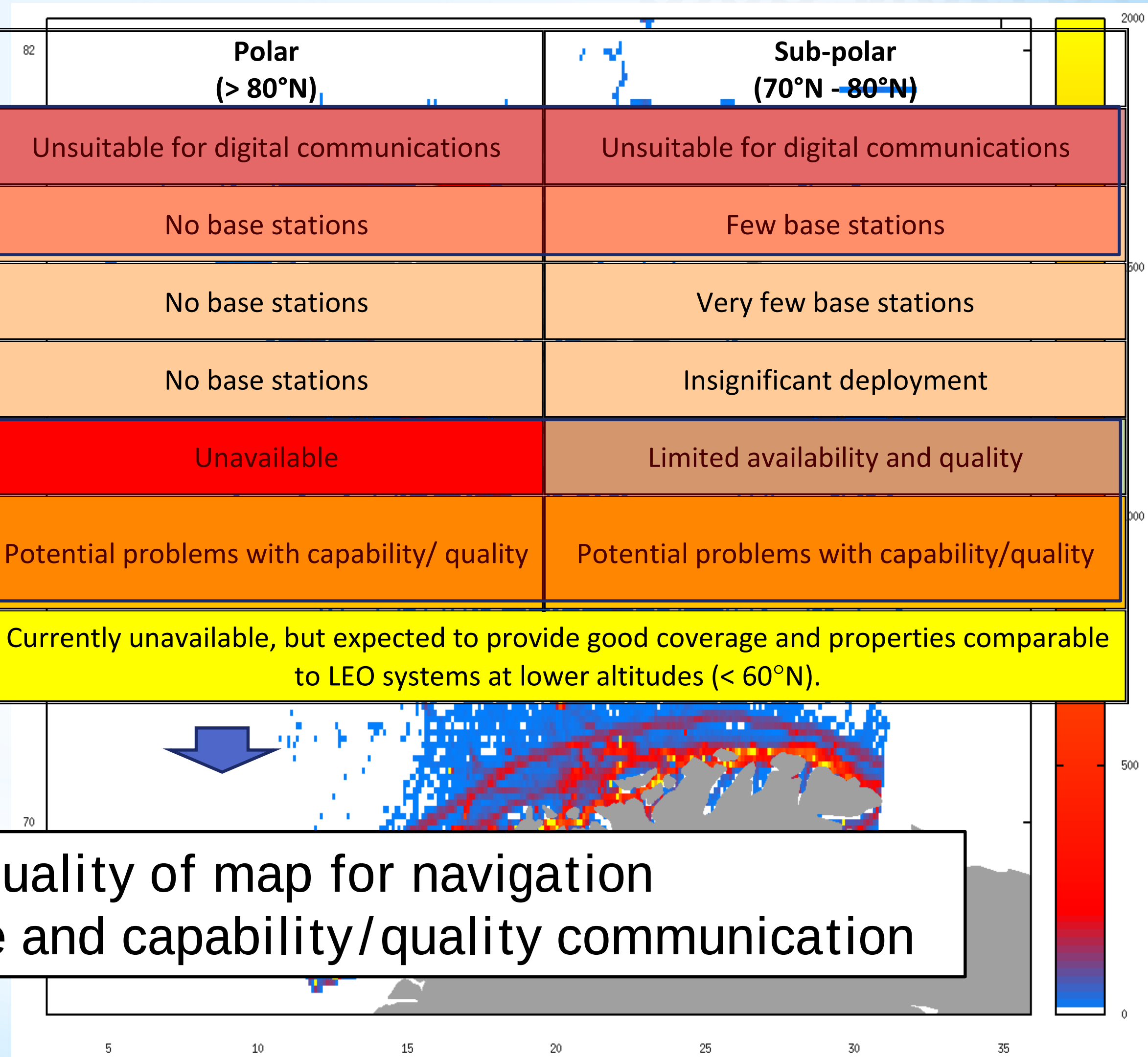
* Currently only one of the 8 optical fiber pairs of each cable is in use, yielding a 10 Gbit/s transmission capacity per cable, with a prospective maximum capacity of 2500 Gbit/s per cable.[2]
* The cable has three landing points located at:
  * Hotellneset, Svalbard, Norway
  * Breivika, Andøy, Nordland, Norway
  * Harstad, Trømso, Norway
* Comparing to wireless communication, optical fibre can provide a **much higher bandwidth**, **smaller delay and higher availability**. However, it still faces to an issue as broken cable under the sea and this might cause serious consequences even though it is rarely happened. So a backup system for fibre cable is always required.

P3. Communication and Navigation Challenges in the high North & what are the key enablers?



* Navigation & communication in the high North?

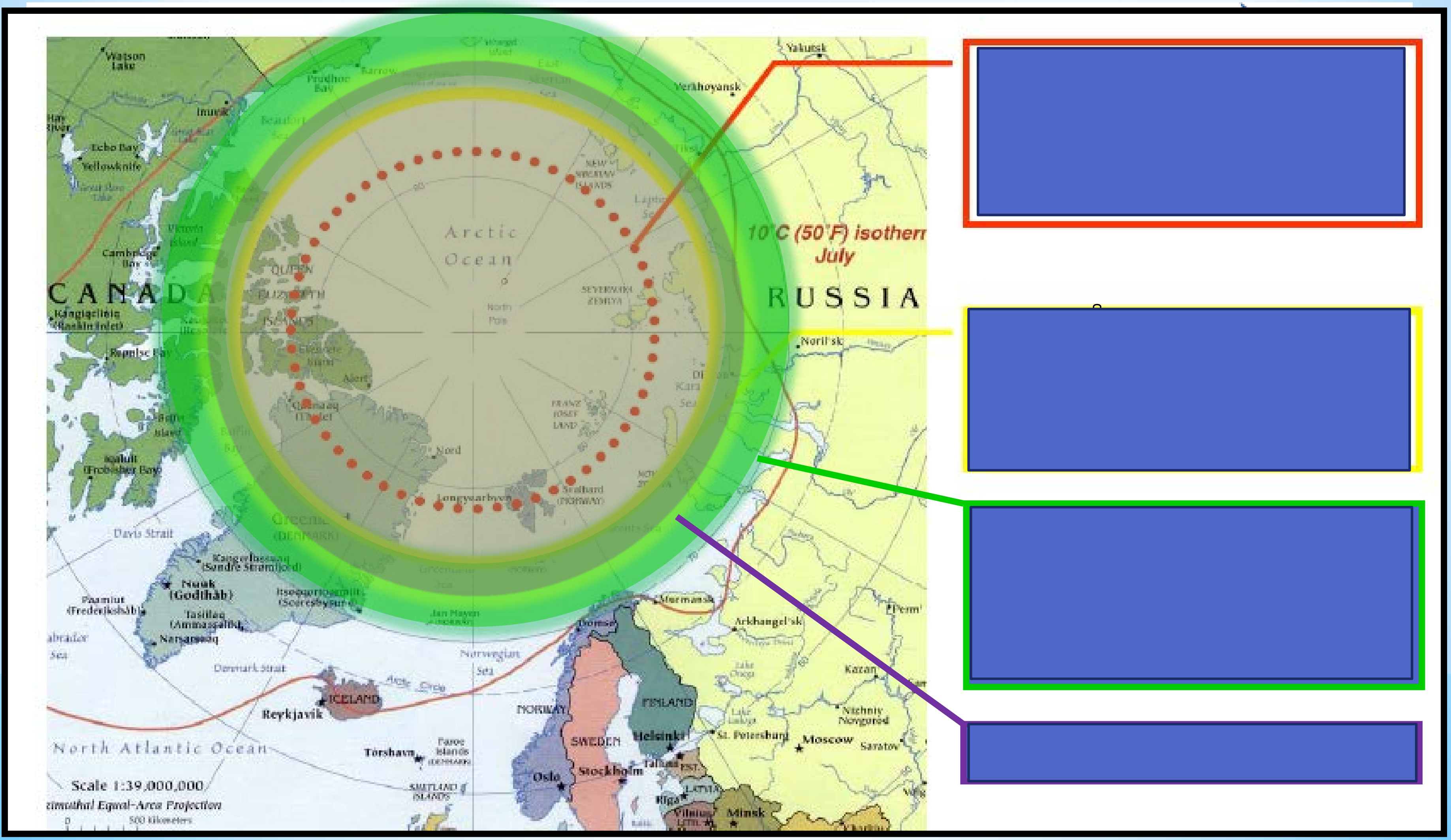




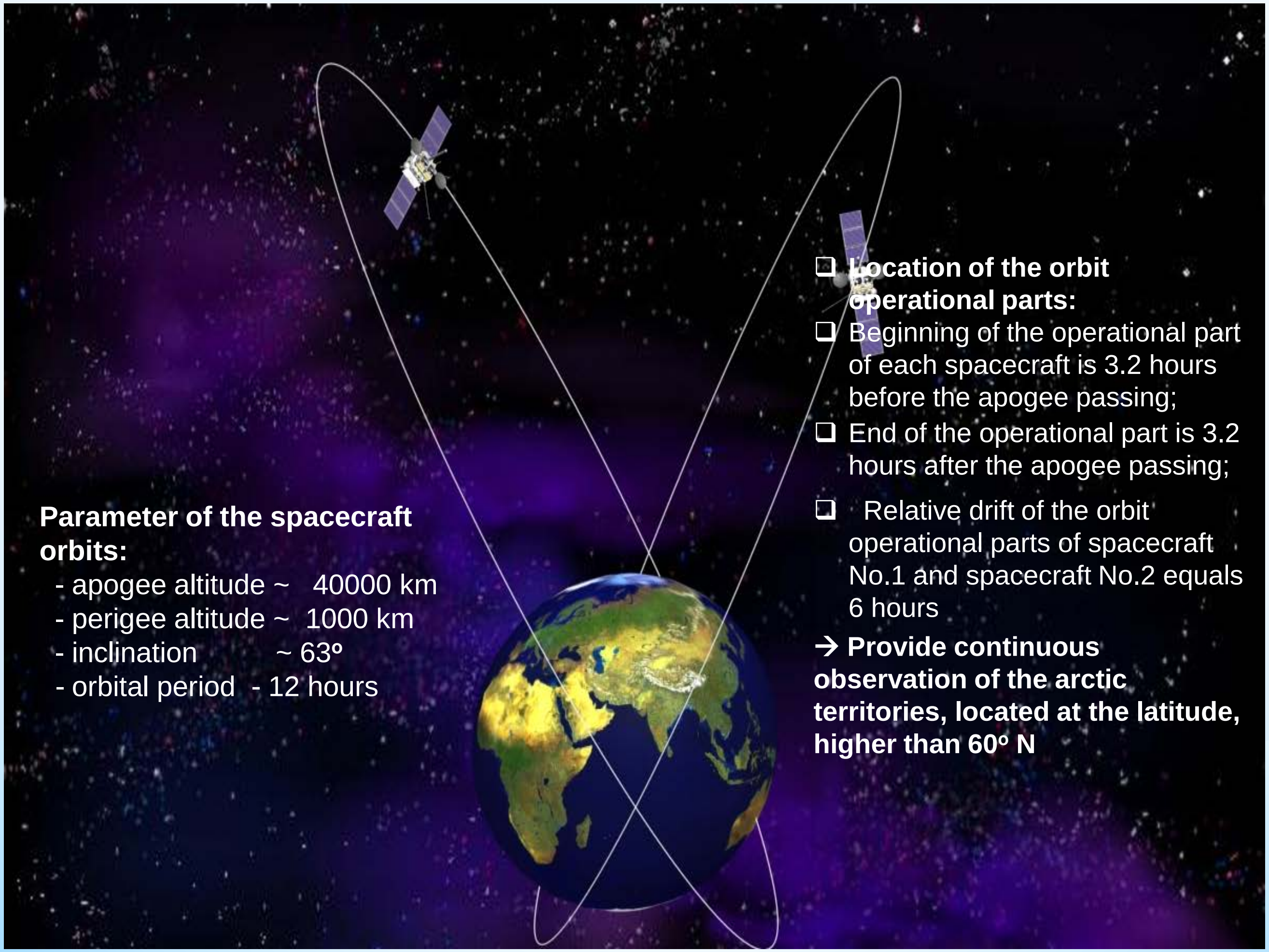
	System	Characteristics	Polar (> 80°N)	Sub-polar (70°N - 80°N)
Terrestrial systems	HF, MF	Safety related messages and voice only	Unsuitable for digital communications	Unsuitable for digital communications
	VHF, Digital VHF	Line-of-sight voice and very narrowband data	No base stations	Few base stations
	GSM, 3G	Line-of-sight voice and narrowband data	No base stations	Very few base stations
	LTE/4G, WiMAX	Line-of-sight voice and broadband data	No base stations	Insignificant deployment
SatCom systems	GEO (Inmarsat, VSAT)	Medium capacity - low to moderate latency	Unavailable	Limited availability and quality
	LEO (Iridium)	Narrowband data communications – high and variable latency	Potential problems with capability/ quality	Potential problems with capability/quality
	HEO	Properties comparable with GEO	Currently unavailable, but expected to provide good coverage and properties comparable to LEO systems at lower altitudes (< 60°N).	

- ✓ Low quality of map for navigation
- ✓ Limited coverage and capability/quality communication

*GEO/LEO Satellite issues in Arctic



* Possibly new options



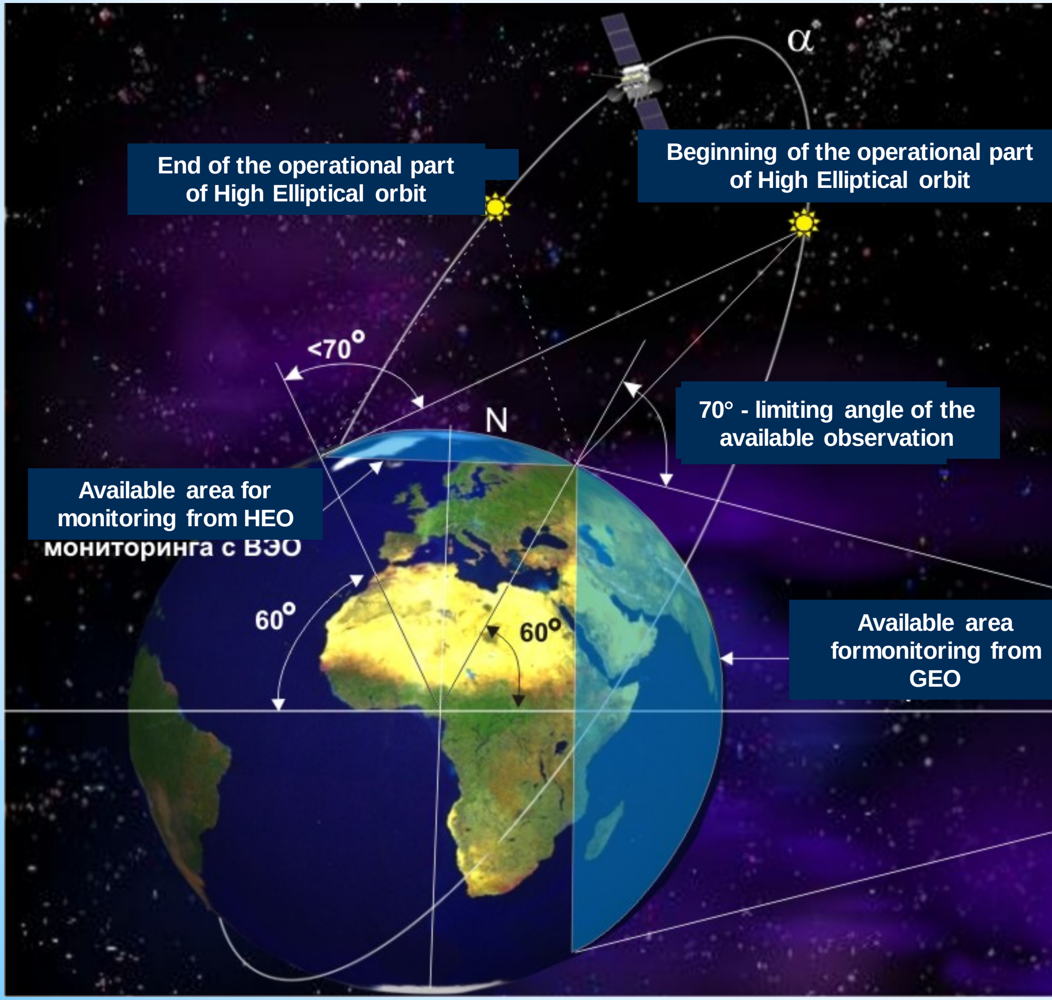
Parameter of the spacecraft orbits:

- apogee altitude ~ 40000 km
- perigee altitude ~ 1000 km
- inclination ~ 63º
- orbital period - 12 hours

- ❑ **Location of the orbit operational parts:**
- ❑ Beginning of the operational part of each spacecraft is 3.2 hours before the apogee passing;
- ❑ End of the operational part is 3.2 hours after the apogee passing;
- ❑ Relative drift of the orbit operational parts of spacecraft No.1 and spacecraft No.2 equals 6 hours

→ Provide continuous observation of the arctic territories, located at the latitude, higher than 60º N

* Benefits of the high- elliptic orbits (HEO) at the Arctic region



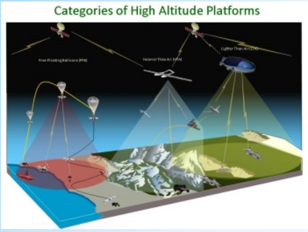
1. Providing the quasi-continuous observations for Arctic region (areas at latitudes higher than 60° N).

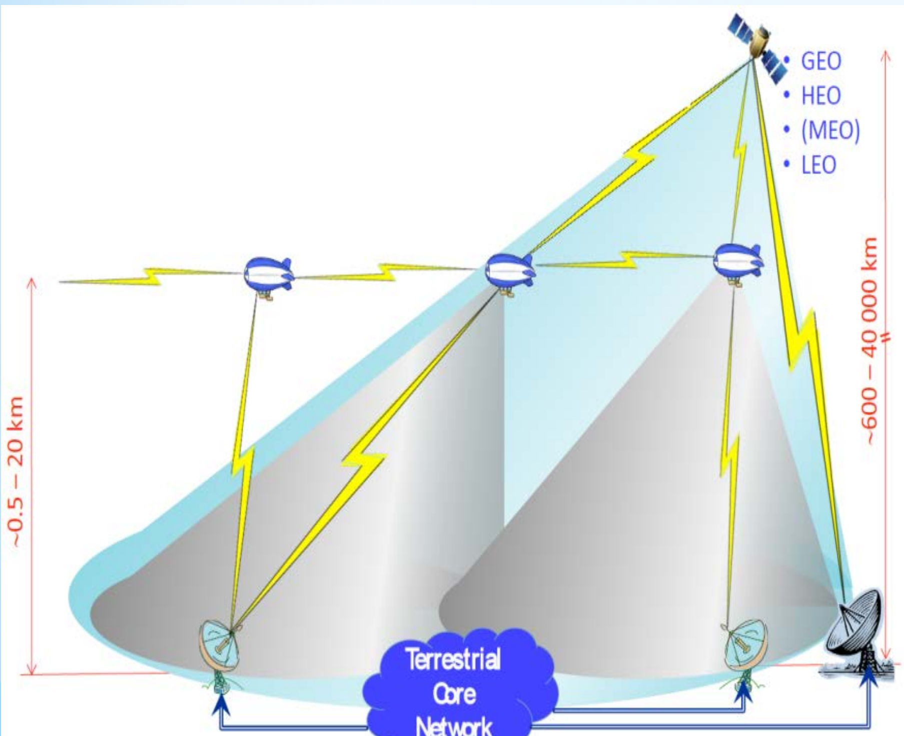
2. The quasi- continuous observations need no more than 2 spacecrafts

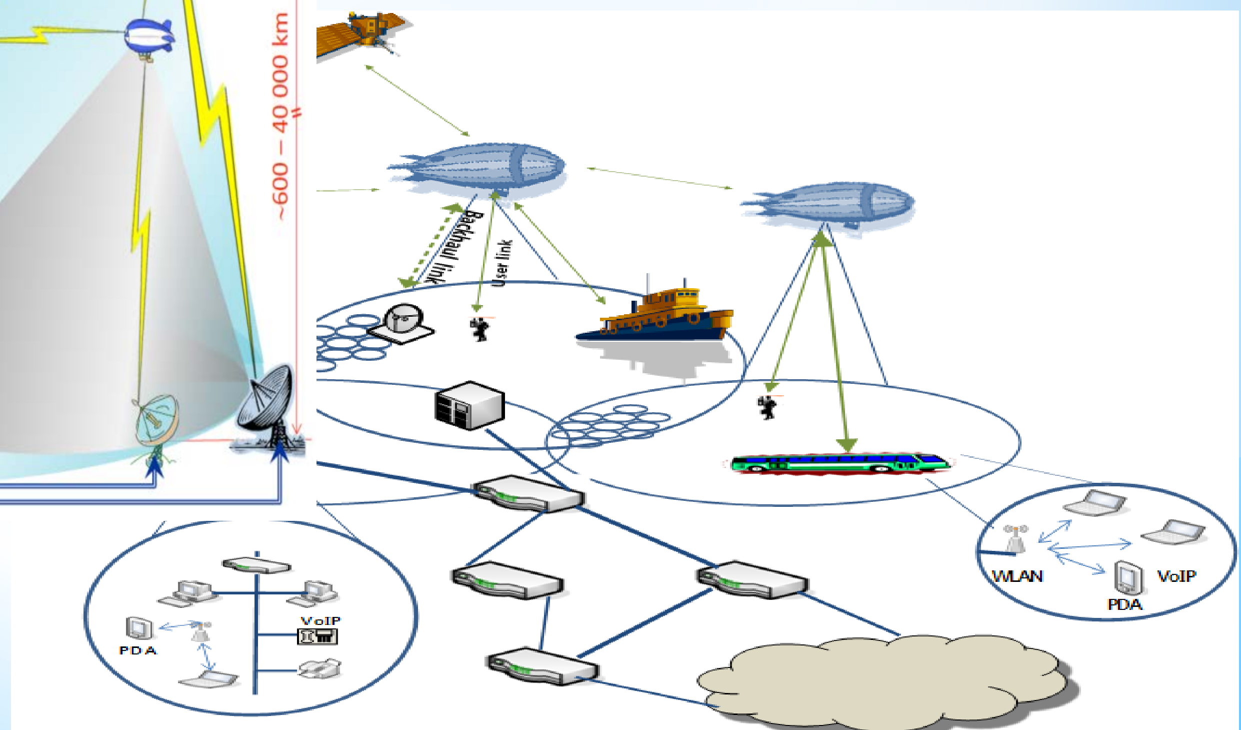
*General satellite orbits

- LEO: Low Earth Orbit (Height: 200 - 2000 km)
- MEO: Medium Elliptical Orbit (Height: 2.000-GEO, normally: 10.000-20.000 km)
- GEO: Geostationary Orbit (Height: 35.786 km)
- HEO: High Elliptical Orbit (Height: 500-50.000 km)

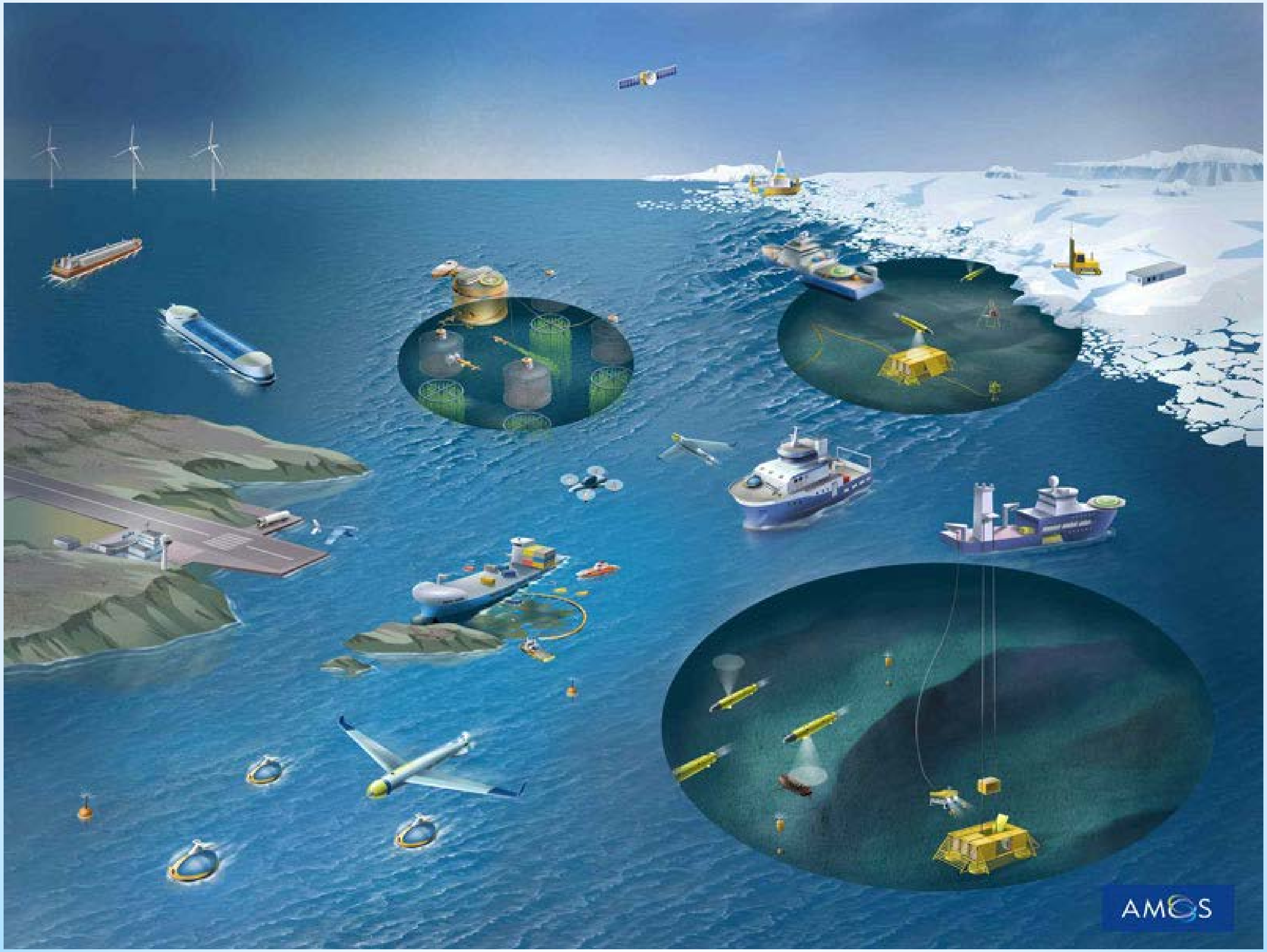
* Combination of High Altitude Platform System (HAPS) and Satellites







+Unmanned Aerial Vehicle



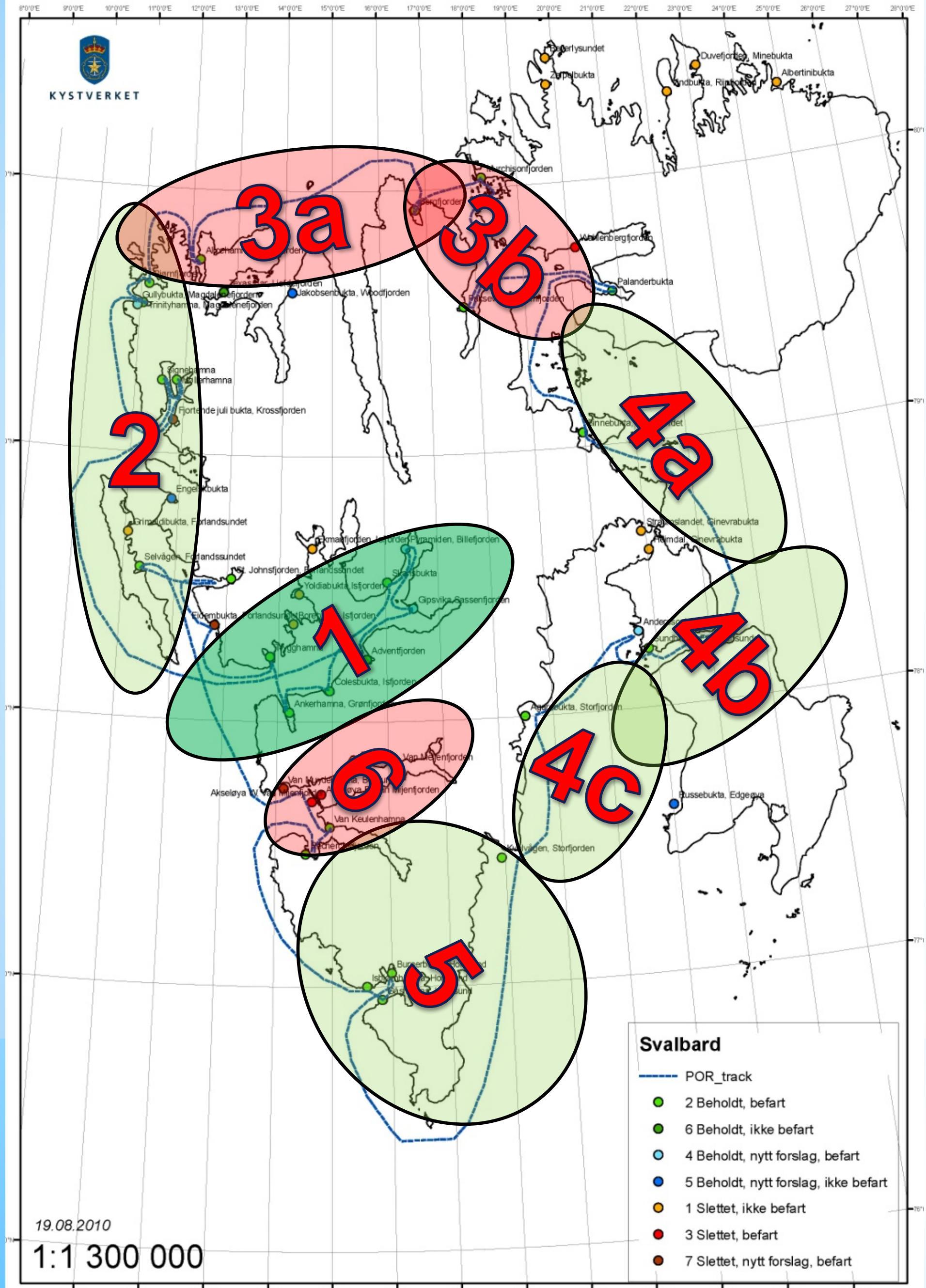
[Source]: https://www.ntnu.edu/amos
Centre for Autonomous Marine Operations and Systems

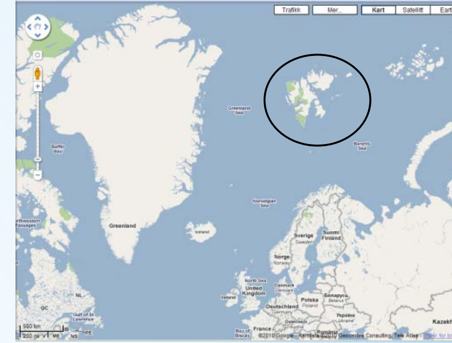
P3. Communications Problems through End-Users

Experiences with Iridium and Terrestrial radio communication (VHF/MH/HF) in Svalbard

* Field test KV Svalbard August 2010

* Testing VHF, MF/HF, GSM, VSAT, Inmarsat and Iridium on KV Svalbard
* Using available communication systems onboard
* Installing Iridium OpenPort, using ping test
* Spot tests on 25-30 locations
* Continuous tests on VSAT to be performed, measuring E_b/N_0 (Signal strength versus noise)

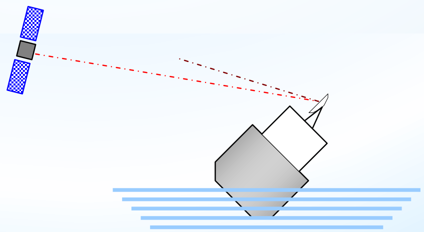


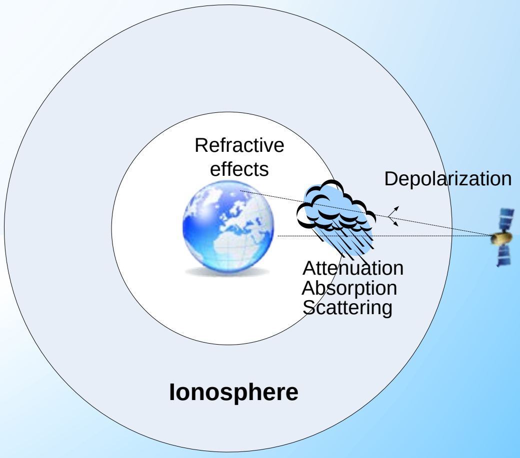


1. VHF, MF/HF o/Svalbard, mobile, ship GSM, unstable VSAT
2. MF/HF o/Svalbard, ship GSM, VSAT coverage on the coast line, not inside fjords
3. MF, unstable HF
4. MF/HF o/Svalbard, VSAT. Inmarsat-C in area 4a.
5. VHF (local station in Hornsund), MF, unstable HF, unstable VSAT. Inmarsat-C.
6. Unstable MF/HF, unstable GSM and mobile (from BS in Svea), unstable VSAT. Inmarsat-C.

General

- Iridium OpenPort had approximately 50% package loss during three days, continuous ping testing (8 bytes, 9 seconds delay)
- Inmarsat-B was tested, but the onboard system is assumed to be out of order.
- Coverage areas for communication systems are dependent on several factors:
  - Weather
  - Frequency
  - Surrounding topography
  - Atmospheric disturbances





Experiences with VSAT (Astra 4A) and Iridium in the high North (up to 81ºN, at LongyearByen (Svalbard), Trondheim and on on Mexico Gulf

* The MARENOR project (Maritime Radio Performance in the high North)

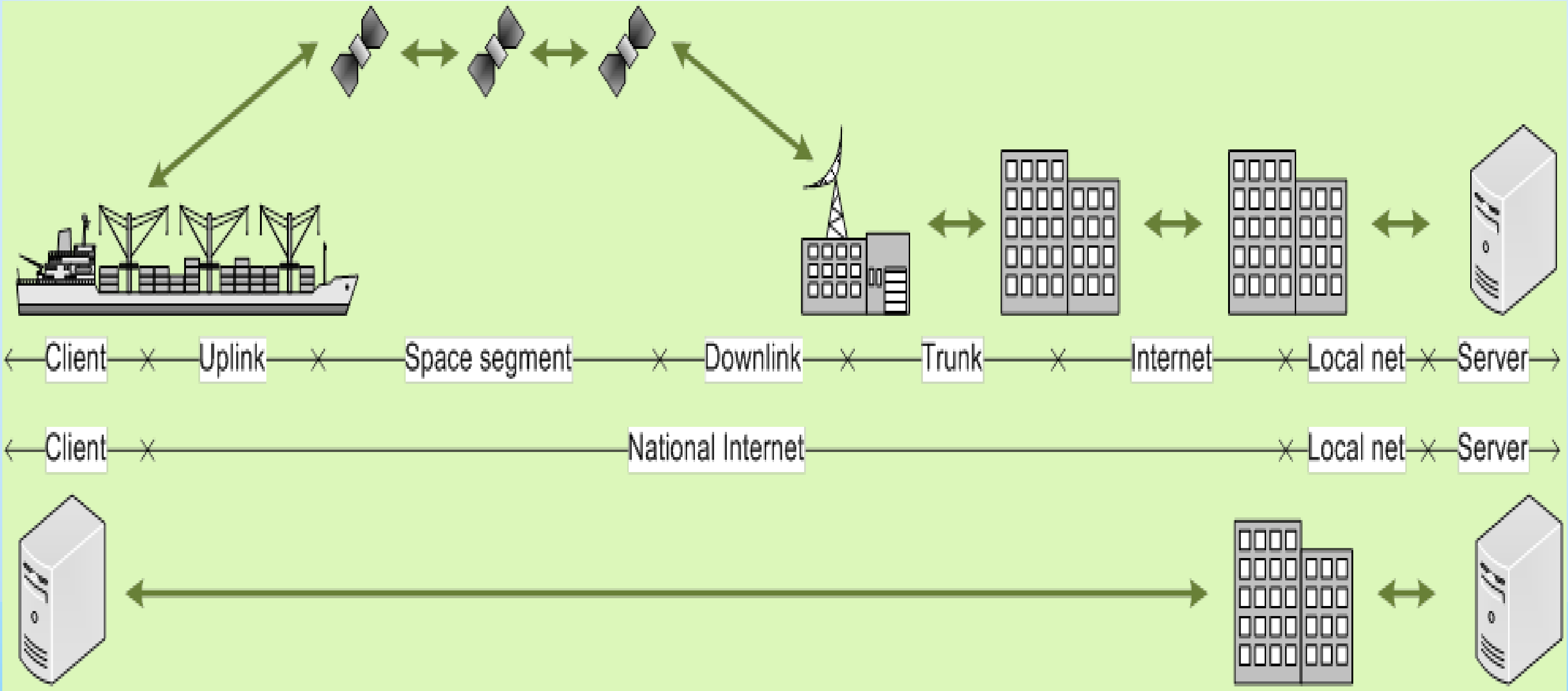
* EMGS – Project Owner
* SINTEF Ocean– Technical Coordinator
* Duration Feb 2012 – Jan 2015
* Supported by NRC

MARENOR will quantify the system performance of the most common navigations and communications systems by maritime users in the Arctic.

emgs MARINTEK
SINTEF Polar Science Guiding DA
KONGSBERG Remøy Havfiske telenor UNIS Politechnika Wrocławska

Measurements for VSAT & Iridium

Svalbard, Mexico and North of Svalbard → 1 year period → Message every 5 minutes → >90 000 exchanges

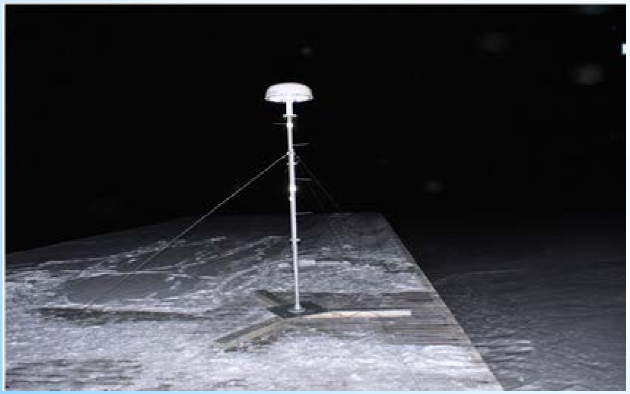


Delays and occasional losses → Prognoses on system failures → Understand and learn weaknesses

* In-situ measurements of satellite performance

MV Atlantic Guardian
Mexican Gulf
Norwegian Sea

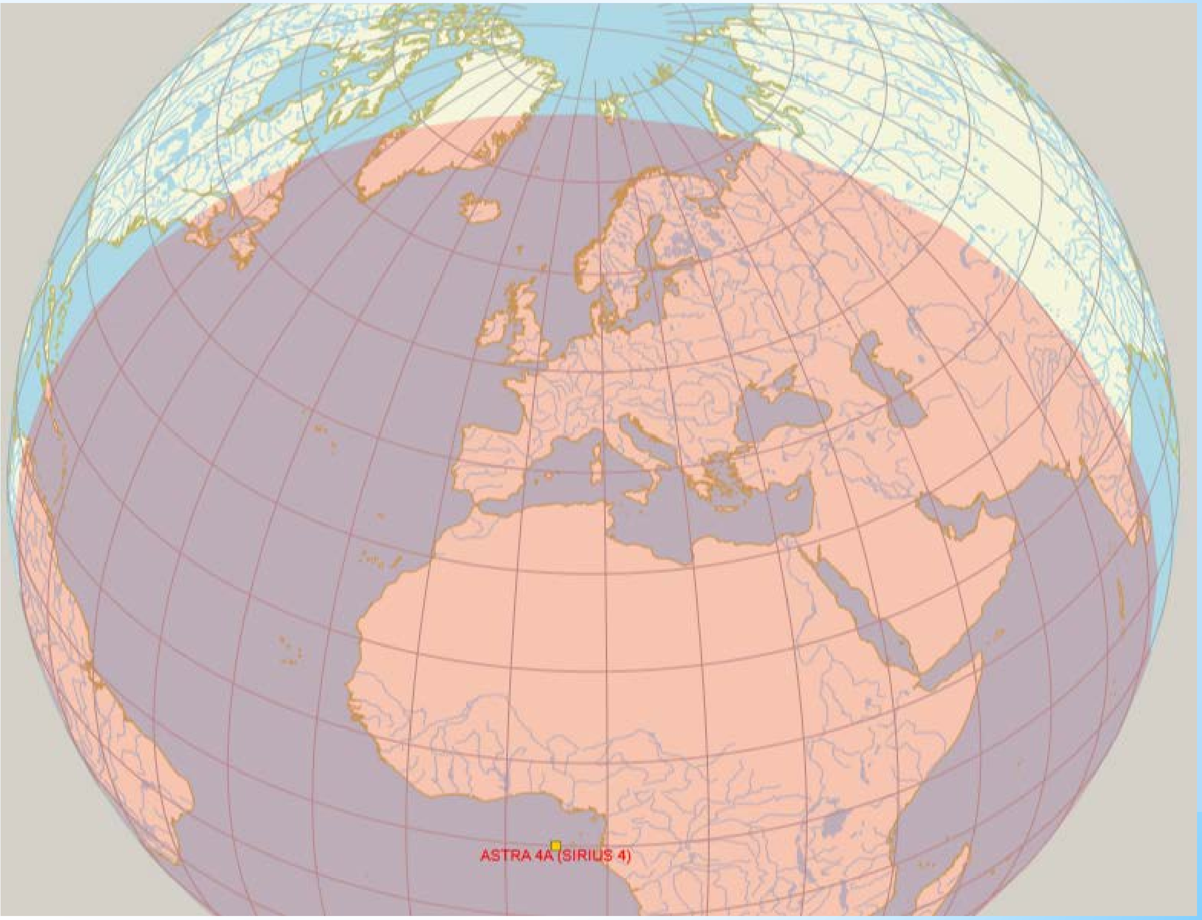
FV Remøy
Greenland Sea
Barents Sea



Kjell Henriksen Observatory
Svalbard

*VSAT Data recorded from Remøy

- Using ASTRA 4A (4.8°E)
- Ku-band (12-14 GHz)

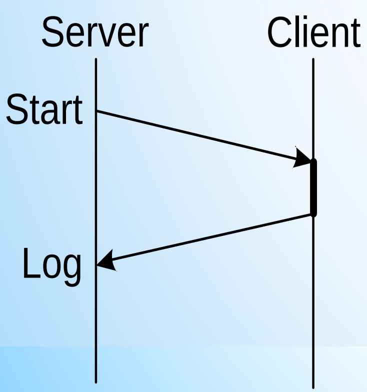


http://www.satbeams.com/footprints

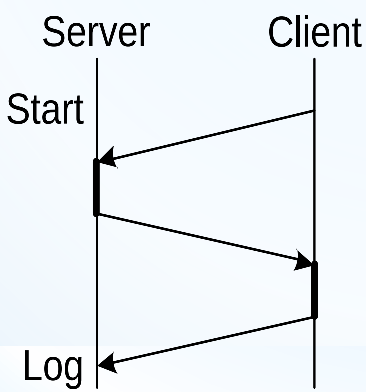
*Round Trip Time Delay (RTT) Measured with VSAT, Iridium satellites

Round Trip Time Delay (RTT), is the elapsed time starting when a message is transmitted from Tx to Rx, and ending when Tx receives a feedback (acknowledgement) from Rx.

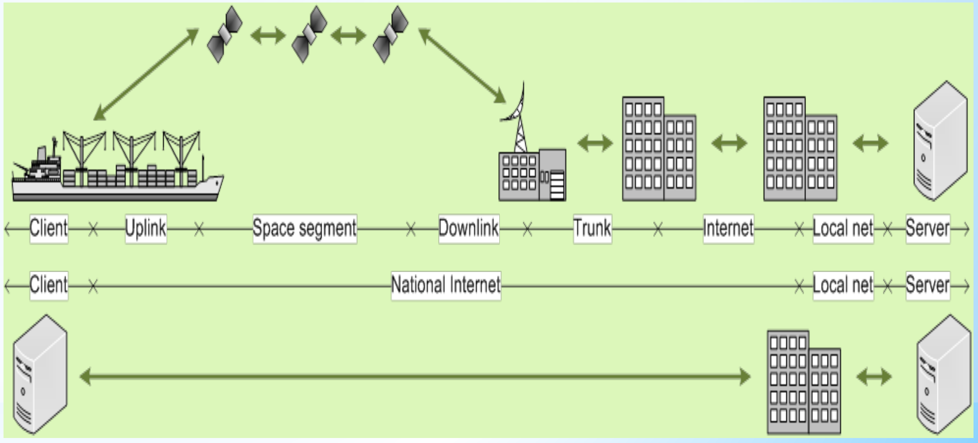
Server-Initiated



Client-Initiated



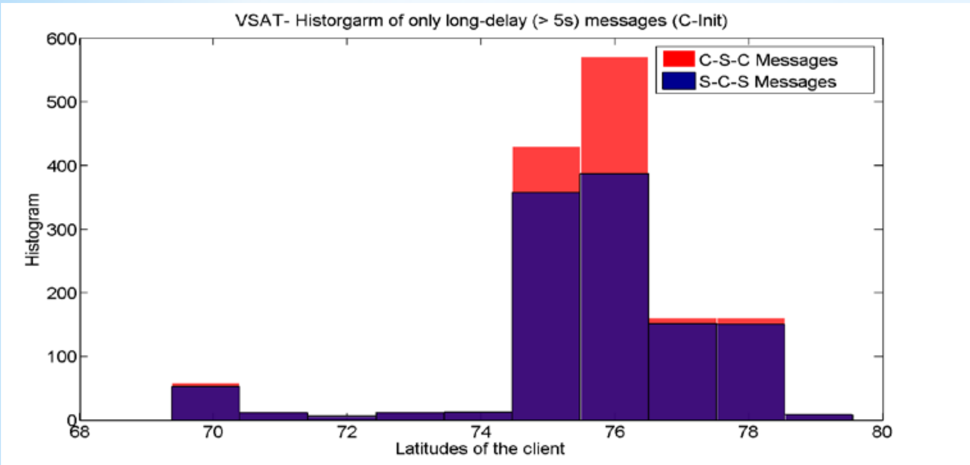
Measurement system



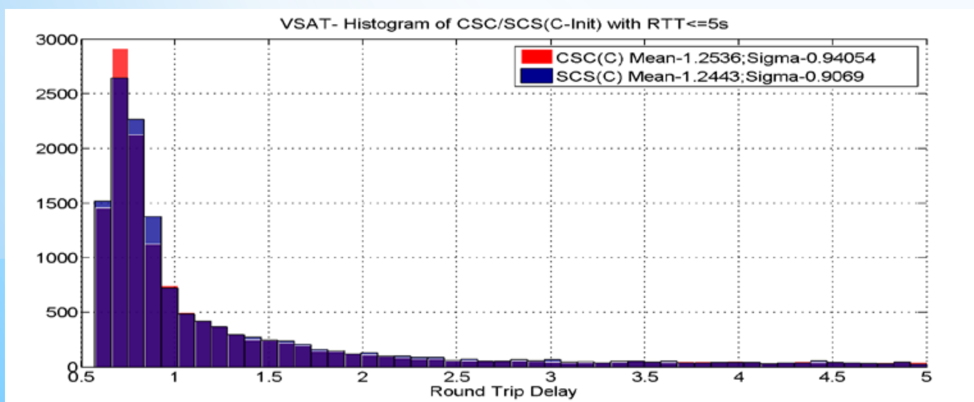
C-S-C: Client (Vessel) →Server (in Trondheim)→Client (Vessel)

S-C-S: Server (TRD)→ Client (Vessel) → Server (TRD)

*Results of measurements

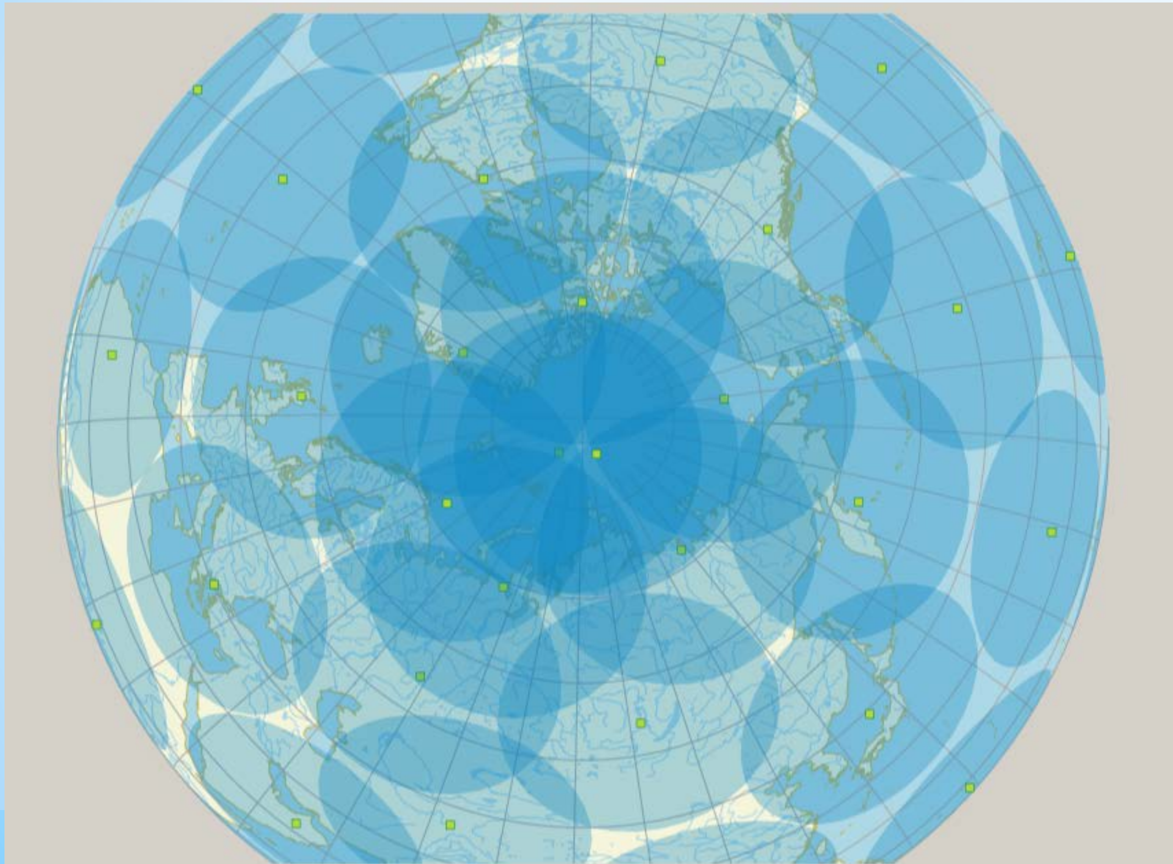


* Good performance up to 78°N
* Intermittent communication breaks above 78°N, sometimes up to 82°N
* No statistically significant degradation below 78°N

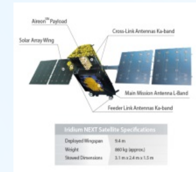


- Expected round-tip time (RTT) is 700ms
- Not significant different between messages initiated from ship or shore?
  - 14% more than 1.4 seconds (2xRTT)
  - 1.4% more than 7 seconds (10xRTT)

* Iridium: Low Earth Orbit System - Global coverage



[Source-MARINTEK]



Current rates

- Voice
  2.4kbps
- Circuit Switched Data
  2.4kbps
- Short Burst Data
  Low
- Iridium OpenPort®
  132kbps
- Iridium OpenPort Aero℠
  132kbps

Iridium NEXT services

- Voice
  2.4kbps (w MOS3.5)
- Circuit Switched Data
  9.6-64kbps
- Short Burst Data
  Bandwidth on Demand
- Iridium OpenPort®
  128-512kbps
- Iridium OpenPort Aero℠
  128-512kbps
- L Band High Speed*
  Up to 512kbps up / 1.5mbs down
- Broadcast*
  64kbps

*New service

LEO satellite altitude at 680 km	
No. Satellite per plane	ISL-time (ms)
4	37,07088
5	29,656704
6	24,71392
7	21,18336
8	18,53544
9	16,47594667
10	14,828352
11	13,48032
12	12,35696
13	11,40642462

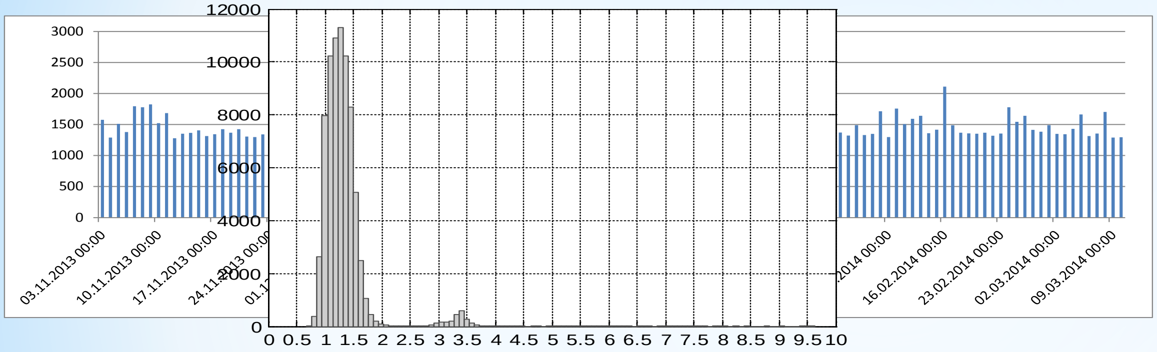
With:
11 LEO orbits
66 satellites (6 per each orbit)

- What are you thinking?
- What might cause the problems and conseuences?
- What is the most possible solution?

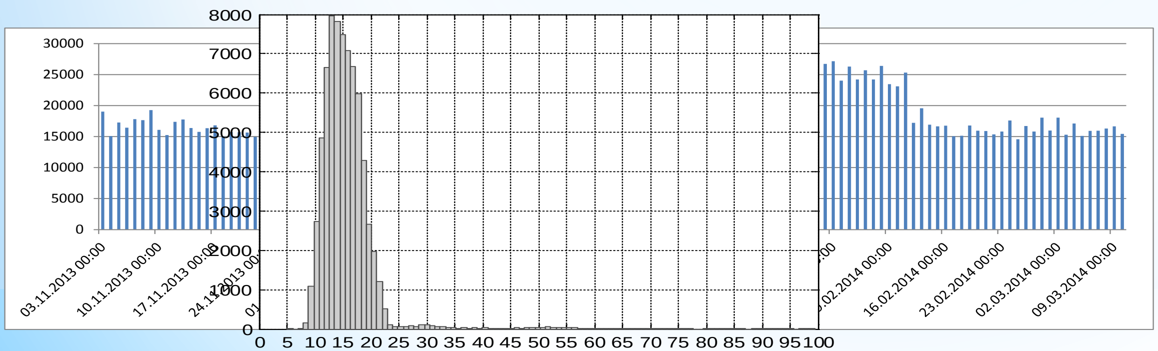
*Main measurements on Svalbard, but also elsewhere

*Results of Iridium measurements (on Svalbard) - 1

Round Trip Time Delay (RTT) (ms)



RTT C-SCS – Client initiated, number of messages vs. RTT

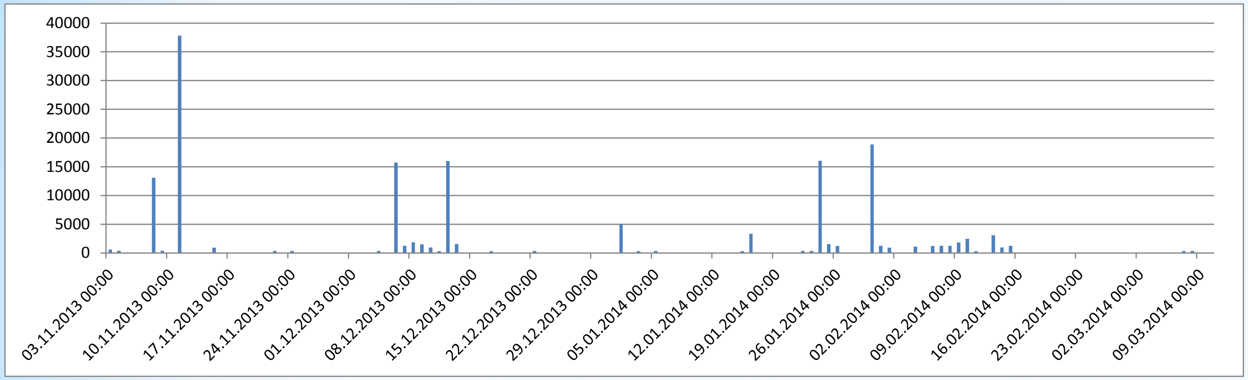


RTT S-SCS – Server initiated: Number of messages vs. RTT

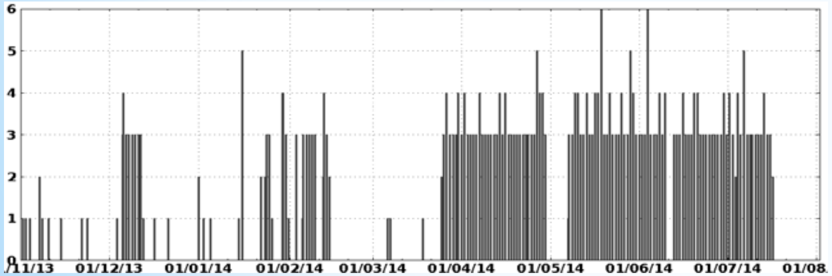
Measurement time scale (t)

* Expected RTT is 1.5s for the messages from the ship
* ... and for the messages from shore, RTT is about 15s

*Results of Iridium measurements (on Svalbard) - 2



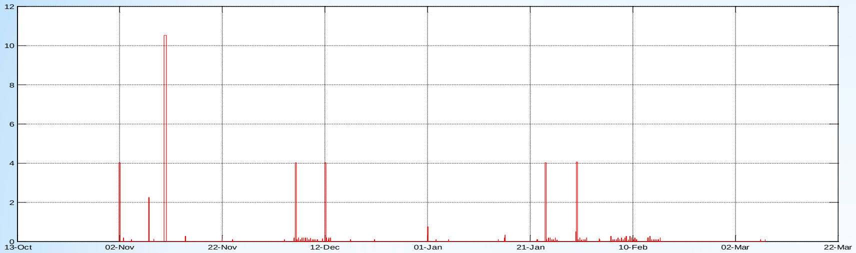
- A relatively high incidence of connection breaks over the four month period.
- On 10.Nov, a break was longer than 10 hours!



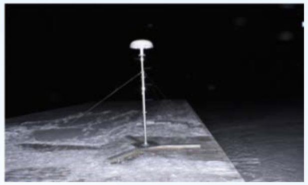
Number of connection breaks per 24 hour period at Svalbard

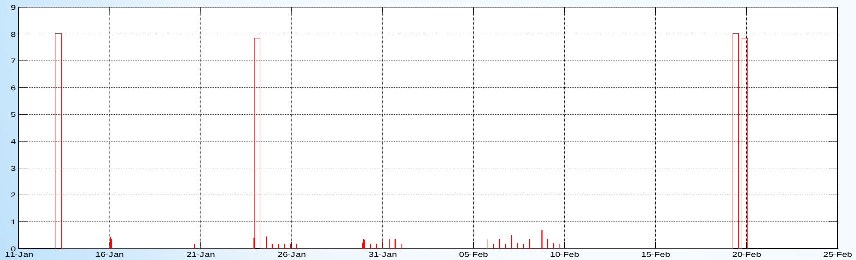
Duration	Number of	Likelihood per day
< 300 s	29	11 %
300 s – 600 s	224	85 %
600 s – 1200 s	197	75 %
1200 s – 3600 s	12	5 %
> 3600 s	12	5 %
All	**474**	**180 %**

* Iridium: Similar results from other areas

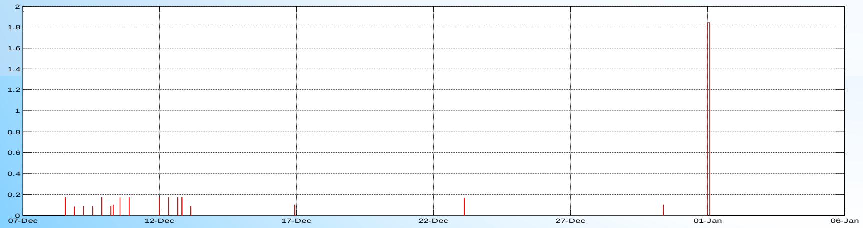


* Svalbard





* Barents Sea



* Mexican Gulf

NOT identical conditions for measurements.

BUT connection breaks were observed at these different places!

* Conclusions for VSAT (GEO) and Iridium (LEO)

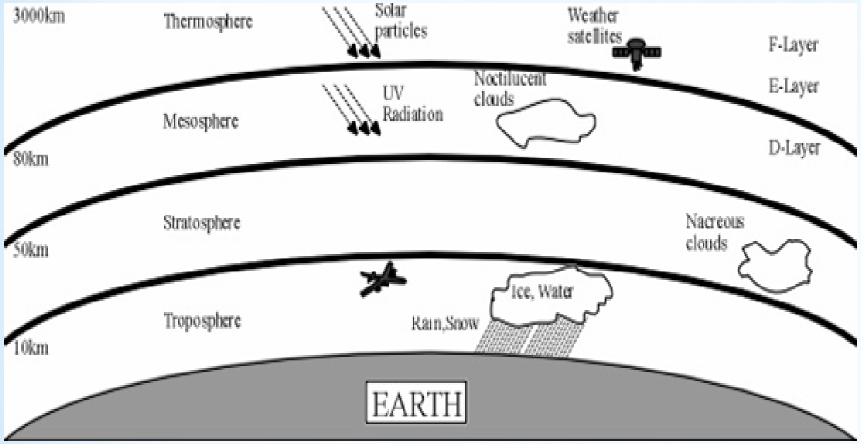
* Navigations in the Arctic mainly rely on general communications due to the limitations of existing ones. In the future, with Galileo satellites, it would be better.
* VSAT over Ku-band works well up to fairly high latitudes
  * Variance in RTT may have an impact on some critical applications
  * East/west shifts will reduce the maximum of workable latitudes
* These characteristics might be varied and needed to examine with each satellite and service provider
* Iridium over L-band works fine in the Arctic region, but with limitations:
  * Limited bandwidth
  * Relatively long RTT
  * Very high variance in RTT
  * Some drop-outs
* These results can be the foundation for further evaluations of different services/applications when operating in the high North

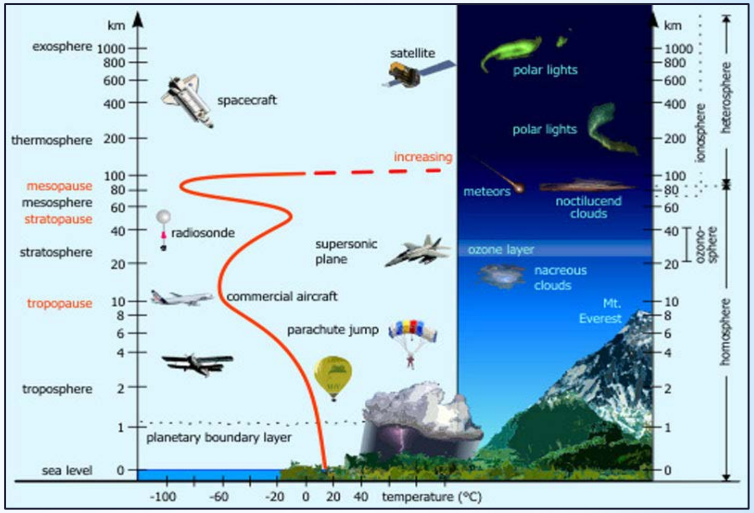
P4. What are the key degradation factors?

What are the possible reasons or technology challenges

* **Satellite communications**
  * GEO
    * Line-of-sight with an angle margin
    * Limited performance at low elevation angles
  * LEO/MEO
    * Complex network amongst the satellites in each orbit and the ones amongst the orbits
    * Doppler effect
  * HEO
    * So costly to launch a new one and currently not available for commercial use
* **Terrestrial communications**
  * VHF
    * Need line of sight (Tx and Rx), limited distance & limited bit rate
  * HF/MF
    * Long distance (HF can be more than 3000km) as it can reflect on ionosphere layer
    * But it is unstable (Depend on the time of the day, require experiences to operate, very low bit-rate)
  * Mobile communication
    * Need ground-based infrastructure (Base stations), so could be close to coastal line
* **Common external degradation factors**
  * Weather (<u>wind/seawave/storm</u>/rain/fog/cloud)
  * Atmosphere (water/oxigen particles)
  * Ionosphere (ionized particles)
* Geographical location & Terrain

Atmosphere



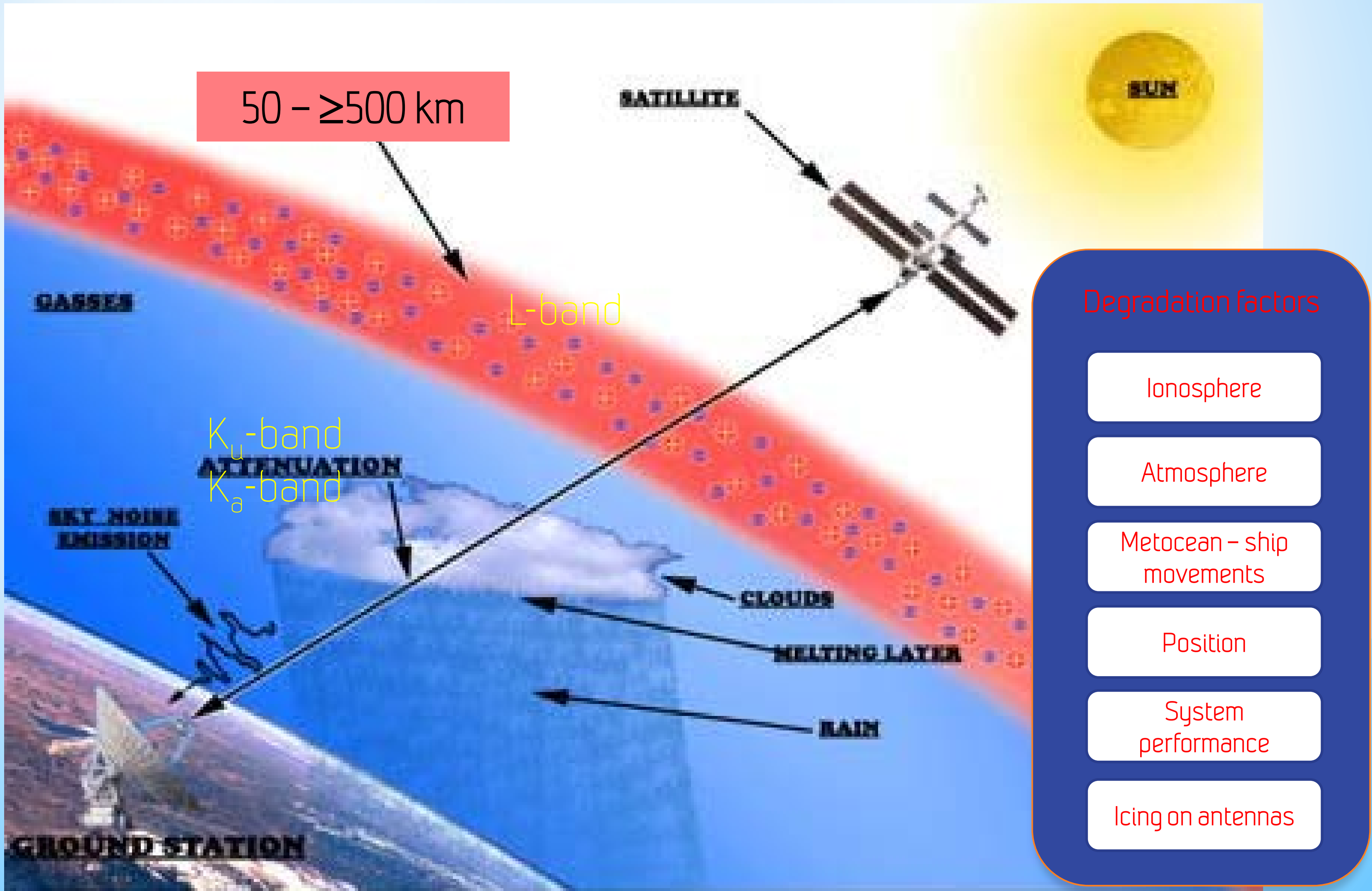


1. **Troposphere**: from the ground up to 7km at the poles and to 17km at the equator with some variation due to weather. It is the thinnest but most dense layer, with 72% of the total mass of the atmosphere is below 10km. The troposphere is well mixed mixing due to the solar heating at the surface. This heat will afterwards warm the air masses near the ground and then rise up as thermals. Averagely, temperature decreases with height.
2. **Stratosphere**: this layer extends from the top of the troposphere (7–17 km) up to around 50 km. In the stratosphere temperature increases with height.
3. **Mesosphere**: This extends from about 50 km to around 80-85 km. Temperature decreases with height.
4. **Thermosphere**: This extends from 80–85 km to in excess of 600km. The temperature increases with height. The Thermosphere is the boundary of the atmosphere, beyond the Thermosphere is the Exosphere, which extends into space.
5. **Ionosphere:** is a layer between Mesophere and Thermosphere where it extends from the altitude of 60 km to around 600 km. The boundaries between the layers are the tropopause, the stratopause, the mesopause and the thermopause

* Non-ionized and Ionospheric losses

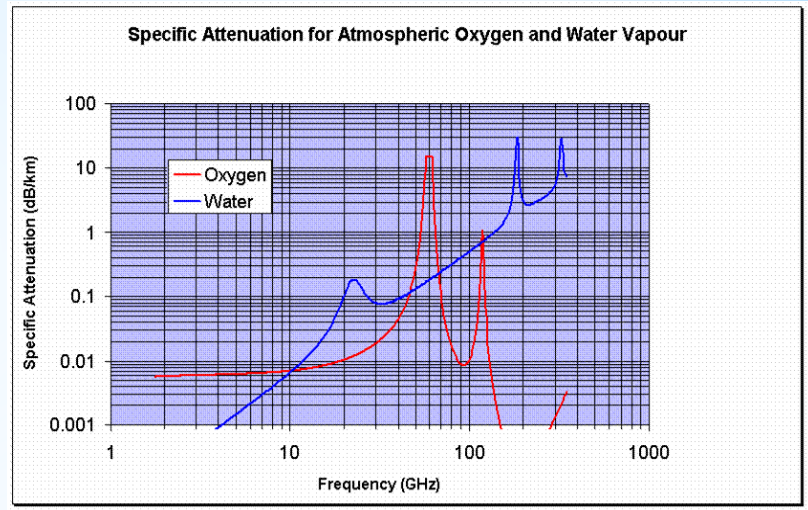
* **Non-ionized atmosphere's loss:**
  * Rain attenuation
  * Gaseous absorption (water and oxygen)
  * Tropospheric scinitillation (loss)
* **Ionospheric effects:**
  * Faraday rotation
  * Group delay
  * These factors are directly linked with the total amount of electrons in the slant path that the radio signal was travelling through.
* **Surface reflection effects** (multipath due to secondary paths arising from the reflection of radio waves from the sea surface).

Propagation impairments over the Earth- satellite slant path



* Atmosphere gases absorption

*Atmosphere gases

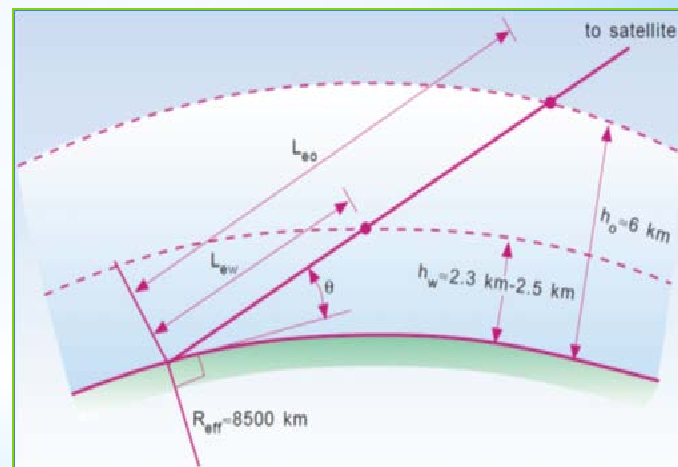


*Water and Oxigen

$$A_{water} = \left\{ 0.050 + 0.0021\,\rho + \frac{3.6}{(f - 22.2)^2 + 8.5} + \frac{10.6}{(f - 183.3)^2 + 9.0} + \frac{8.9}{(f - 325.4)^2 + 26.3} \right\} f^2 \rho\, 10^{-4} \quad \text{dB/km}$$

$$A_{02} = \left(7.19 \times 10^{-3} + \frac{6.09}{f^2 + 0.277} + \frac{4.81}{(f-57)^2 + 1.5} \right) f^2 \times 10^{-3} \qquad f < 57 \text{ GHz}$$

$$A_{02} = \left(3.79 \times 10^{-7} f + \frac{0.265}{(f-63)^2 + 1.59} + \frac{0.028}{(f-118)^2 + 1.47} \right) (f+198)^2 \times 10^{-3} \qquad f > 63 \text{ GHz}$$



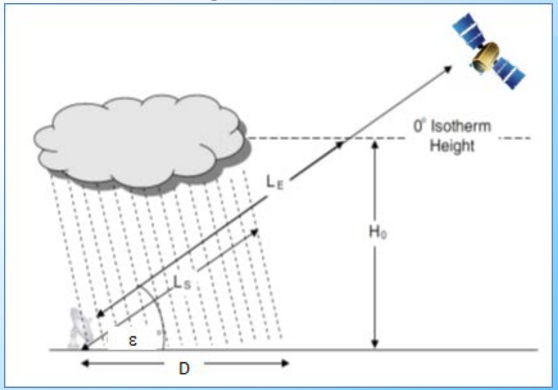
For an example from MARCAD Tool:

Vertical extension of atmosphere (h_A):	12,0 km	
Path Length through the Atmosphere (L_A):		189 km
Vertical extension of the water vapour layer (h_w):	2,5 km	
Path Length through the water vapour layer(L_{ew}):		45 km
Vertical extension of the O_2 layer (h_O):	6,0 km	
Path Length through the O2 Layer (L_{eo}):		103 km

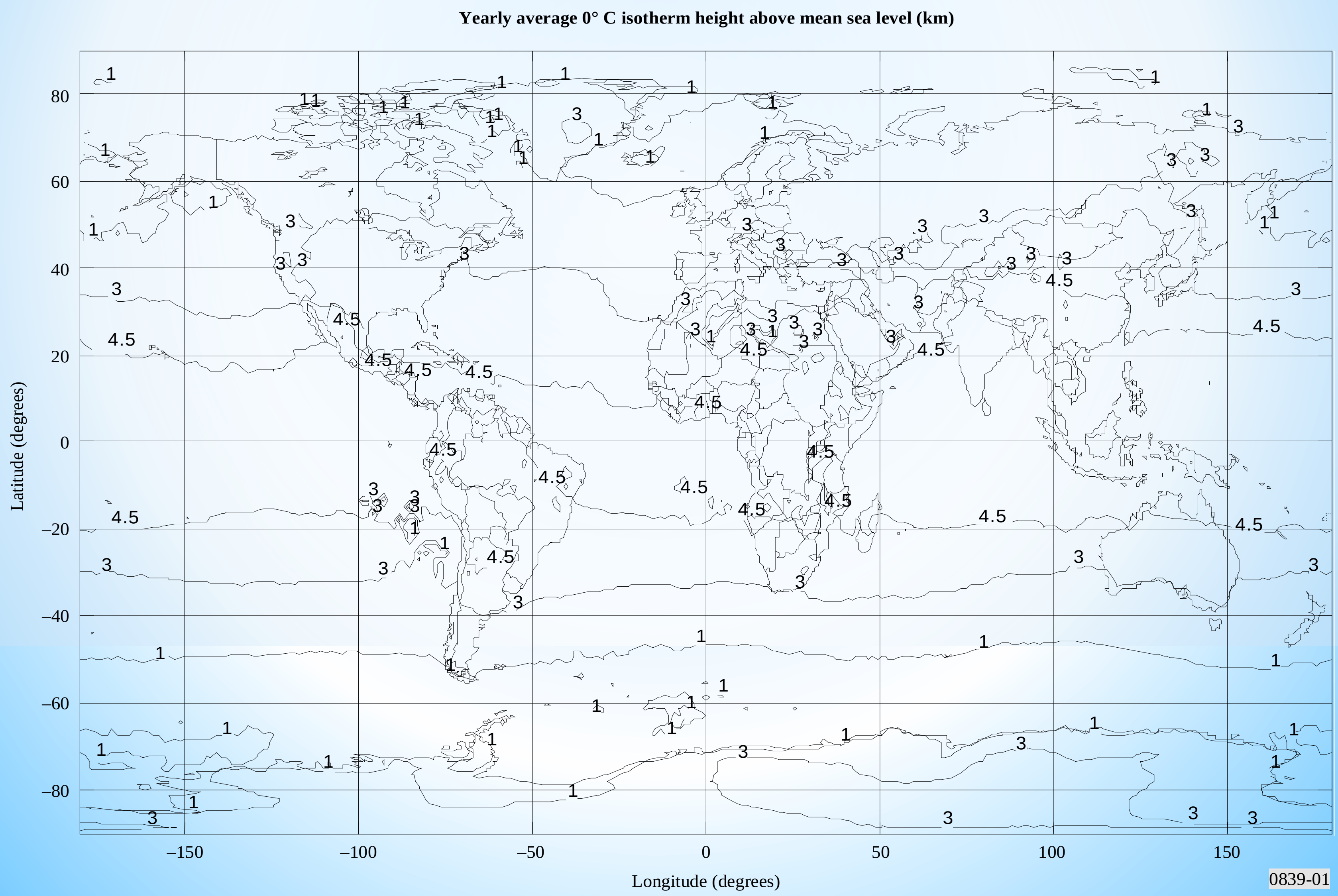
*Rain losses

*Rain, standards and formula

* The ITU-R 618-10 gives summarized procedures for the computation of a satellite path rain attenuation. In order to compute the slant-path rain attenuation using point rainfall rate, the following parameters and assumptions are needed:
  * f: the frequency of operation in GHz
  * µ: the elevation angle to the satellite, in degrees,
  * La: the latitude of the ground station, in degrees N and S,
  * hs: the height of the ground station above sea level, in km
  * Re: effective radius of the Earth (8 500 km)
  * $R_{0.01}$: point rainfall rate for the location of interest at 0.01% over the average value per year (mm/h)
* **Step 1**: Determine the rain height, h_r, as given in by the recommendation from ITU-R P.839
* $h_r = h_0 + 0.36$ (km)
* h_0 could be used from the next Figure.



Rain, the isotherm heights in the planet



Rain, 4 steps to clarify

* **Step 2**: Determine the slant-path length and the horizontal projection. The slant-path length Ls is expressed in km as in the below equation,

$$L_s = \begin{cases} \frac{(h_r - h_s)}{\sin\theta} & \text{for } \theta \geq 5^\circ \\ \frac{2(h_r - h_s)}{\left(\sin^2\theta + \frac{2(h_r - h_s)}{R_e}\right)^{1/2} + \sin\theta} & \text{for } \theta < 5^\circ \end{cases} \quad (\text{km})$$

* **Step 3**: Determine the rain rate at 0.01% for the location of interest over an average year, from the above Figure.

* **Step 4:** The specific attenuation is obtained from the rain rate *R* (mm/h) using the power-law relationship:

$$\gamma_R = kR^{\alpha} \quad (\text{dB/km})$$

* The values for the coefficients k and α are determined as functions of frequency f (GHz) which is ranged from 1 to 1000 GHz are from following equations, which have been developed from curve-fitting to power-law coefficients derived from scattering calculations:

* Rain, k and α parameters

$$\log_{10} k = \sum_{j=1}^{4} a_j \exp\left[-\left(\frac{\log_{10} f - b_j}{c_j}\right)^2\right] + m_k \log_{10} f + c_k$$

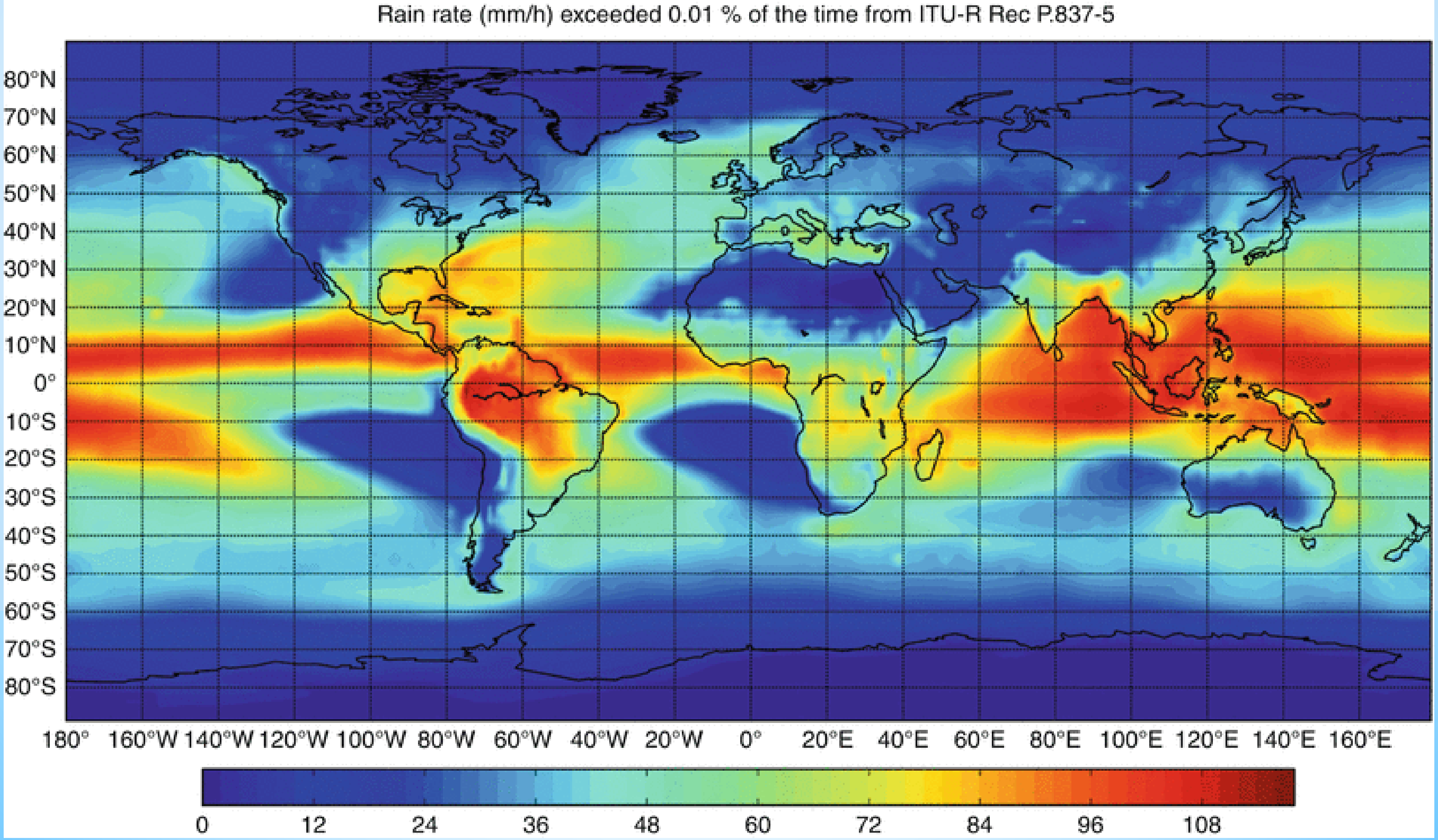
$$\alpha = \sum_{j=1}^{5} a_j \exp\left[-\left(\frac{\log_{10} f - b_j}{c_j}\right)^2\right] + m_\alpha \log_{10} f + c_\alpha$$

f : frequency (GHz)

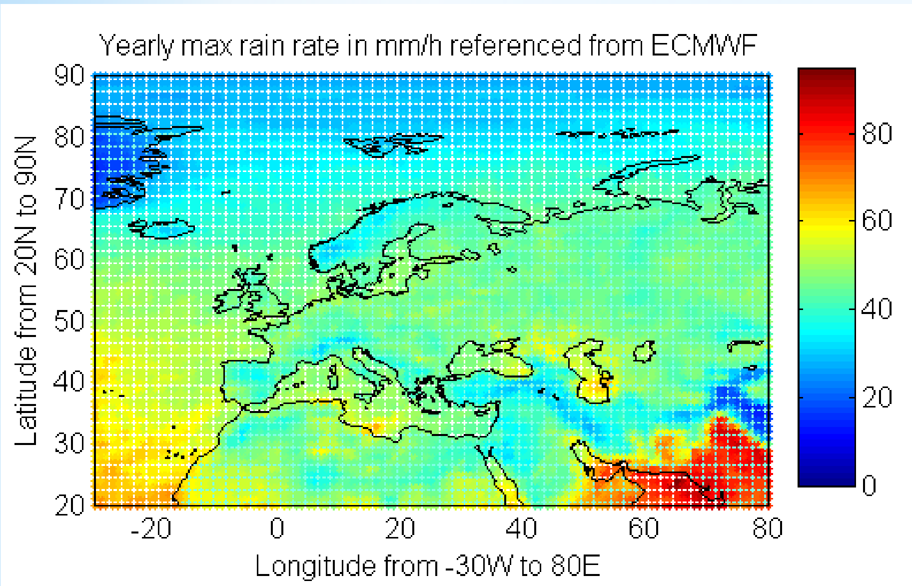
k : either kH or kV

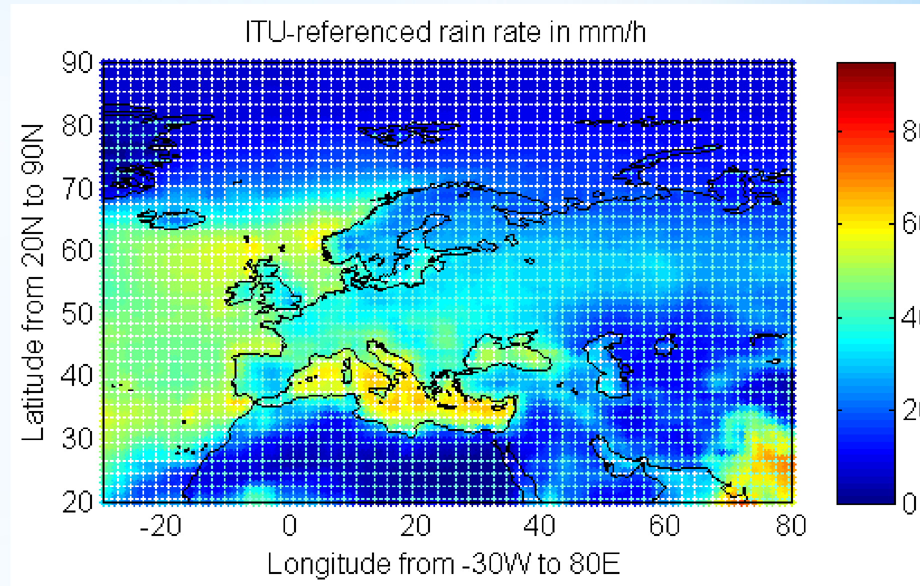
α : either αH or αV.

*Rain, distribution of rainfall rate over Norway [ITU-R P. 837-5]



* Rain, a difference between maximal rain and ITU-R's rain- (90N30W-20N80E)



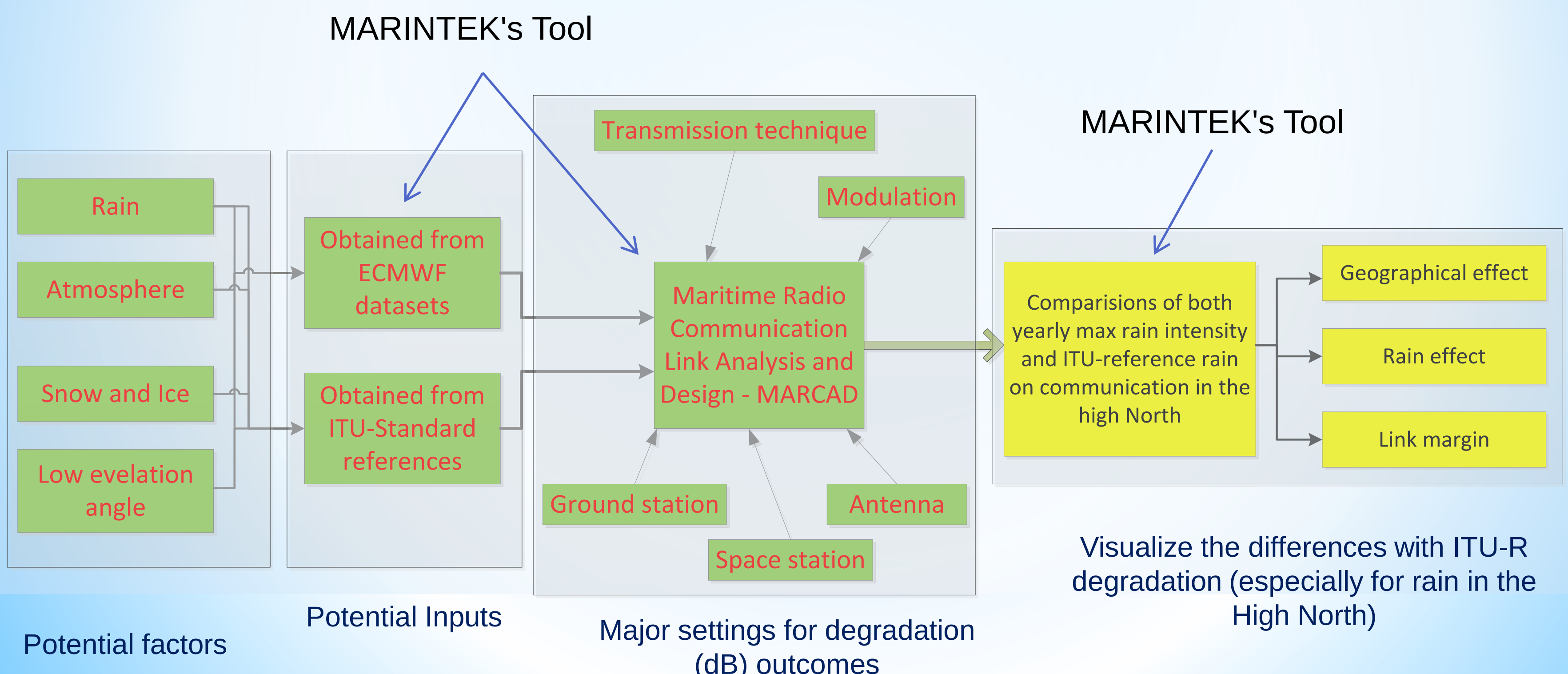


We extract maximum rainfall rate (mm/h) that was stored by ECMWF from 1979 to 2015 (until 3 months before this moment).
[Online]:http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/

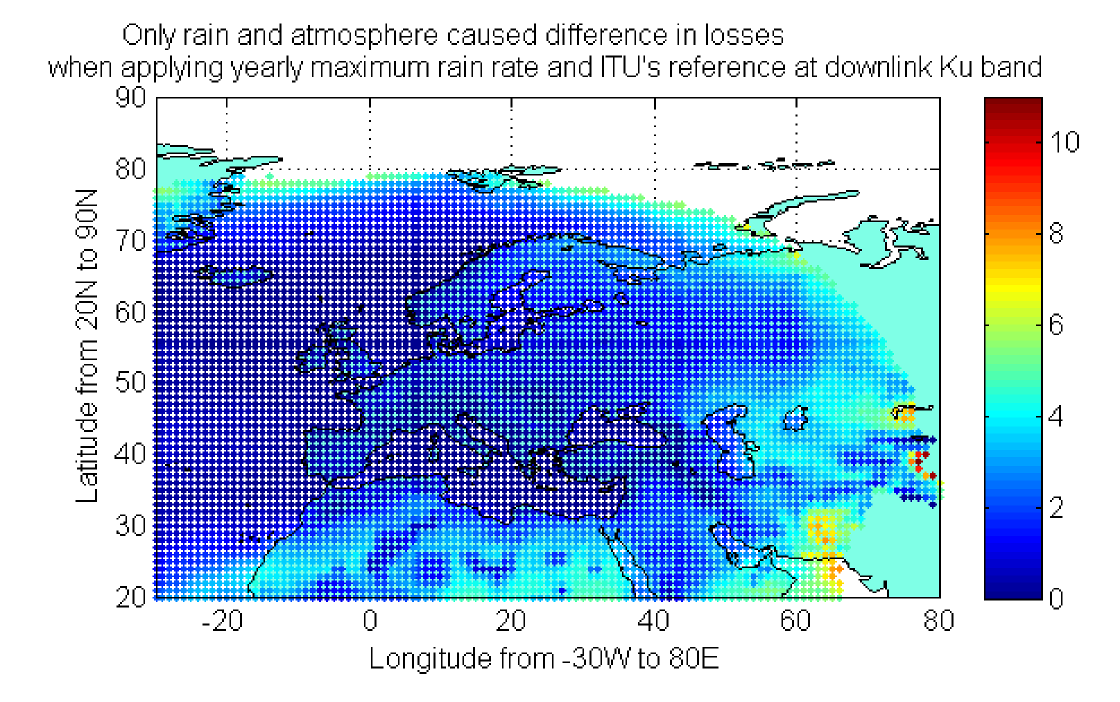
ITU 837-6 selects the rainfall rate (mm/h) that exceeded for 0.01% of the average year. The data was also obtained from ECMWF in 40 years (from middle 1957).
[Online]: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.837-6-201202-I!!PDF-E.pdf

*How all the losses are integrated into a radio link budget

Evaluation the degradation from external factors on Radio Communication in the High North



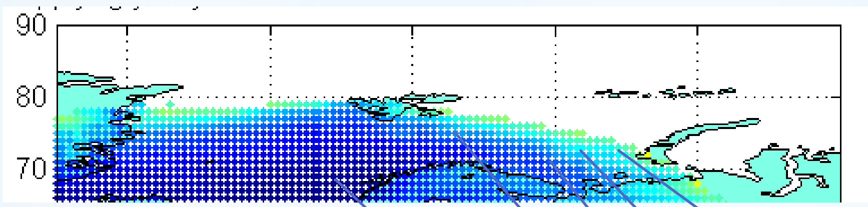
* Difference between yearly max rain rate and ITU-R 837-6 Considering only rain effect

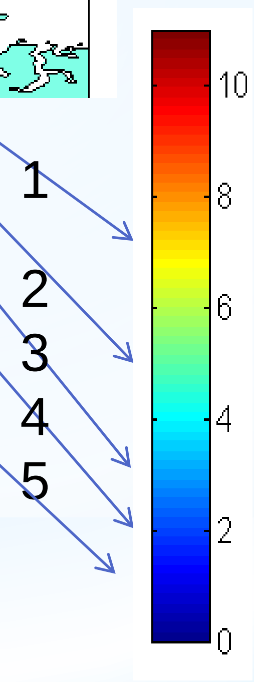


All of the calculations are with GEO Satellite at 4E LON (ASTRA-4)

- The link damping due to rain effect if taking the yearly maximum rain into account is usually larger than the one suggested by ITU-R 837-6 and this difference ranges from 0 to maximum of 11dB.
- Most of the cases was from 1 to 3 dB and some cases close to the outer boundery region in the High North, this value increases to 5-6dB. Som rare cases occured with the maximum difference of 10-11dB

* Difference between yearly max rain rate and ITU-R 839-3 (only rain effect (incl. Atmosphere))



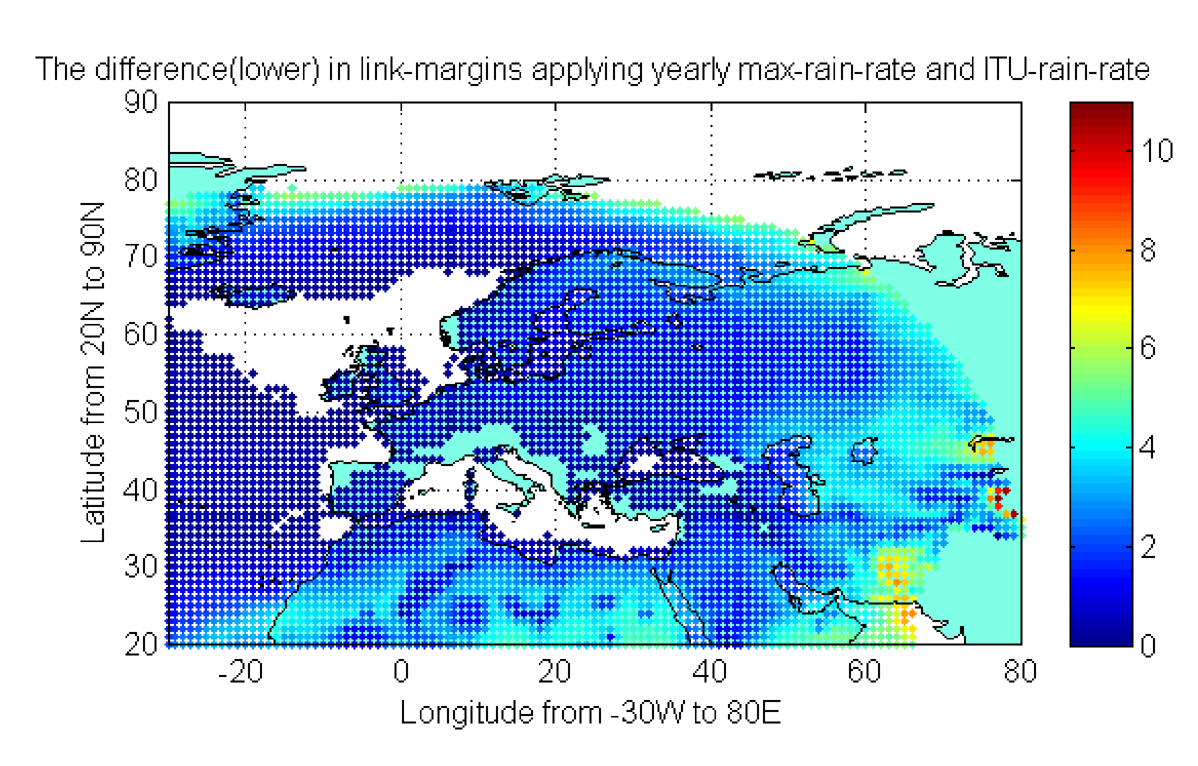


A conversion from damping
to according bandwidth DOWN
or (Tx Power+Antenna gain) compensation for Loss

- Level 1 (7dB) 80%
- Level 2 (5dB) 66%
- Level 3 (3dB) 50%
- Level 4 (2dB) 37%
- Level 5 (1dB) 25%

The link damping due to rain effect if taking the yearly maximum rain into account is usually larger than the one suggested by ITU-R 837-6 and this difference ranges from 0 to maximum of 11dB. Most of the cases were from 1 to 3 dB and some cases close to the outer bounderies this value increases to 5-6dB. Som rare cases occured with the maximum difference of 10-11dB

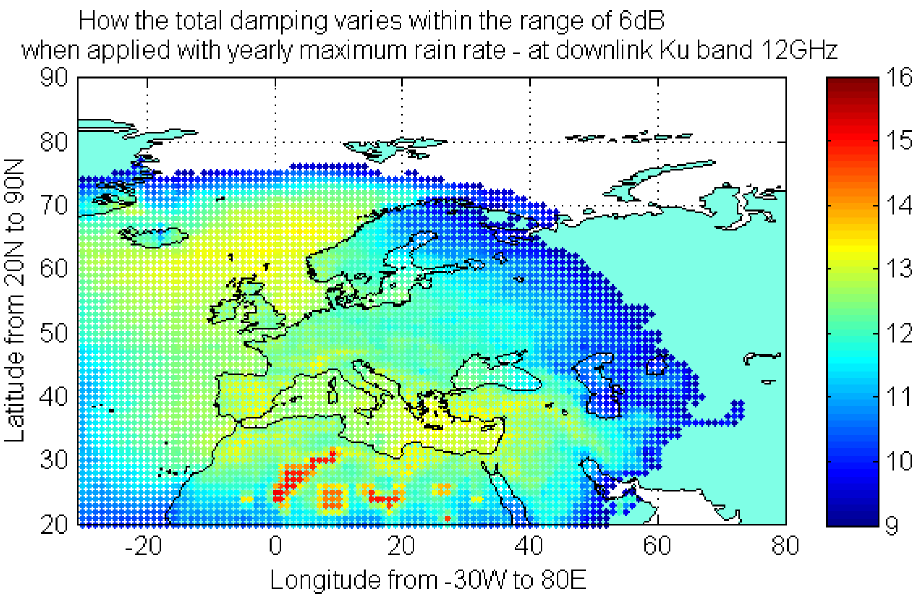
* Difference between yearly max rain rate and ITU-R 837-6 Considering rain and geographic effect

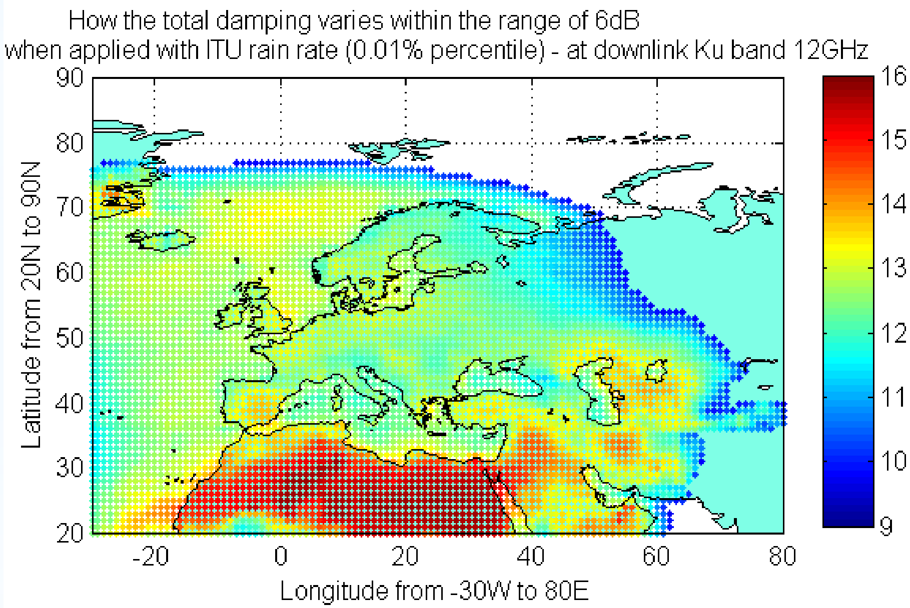


In combination with the previous slide, this Figure shows that the main factor causes the difference between link damping when using yearly maximum rain rate and ITU-R reference is coming from the rain and just less than 1dB difference is due to the geographical location (which make the propagation path longer when moving up to the High North).

All of the calculations are with GEO Satellite at 4E LON (ASTRA-4)

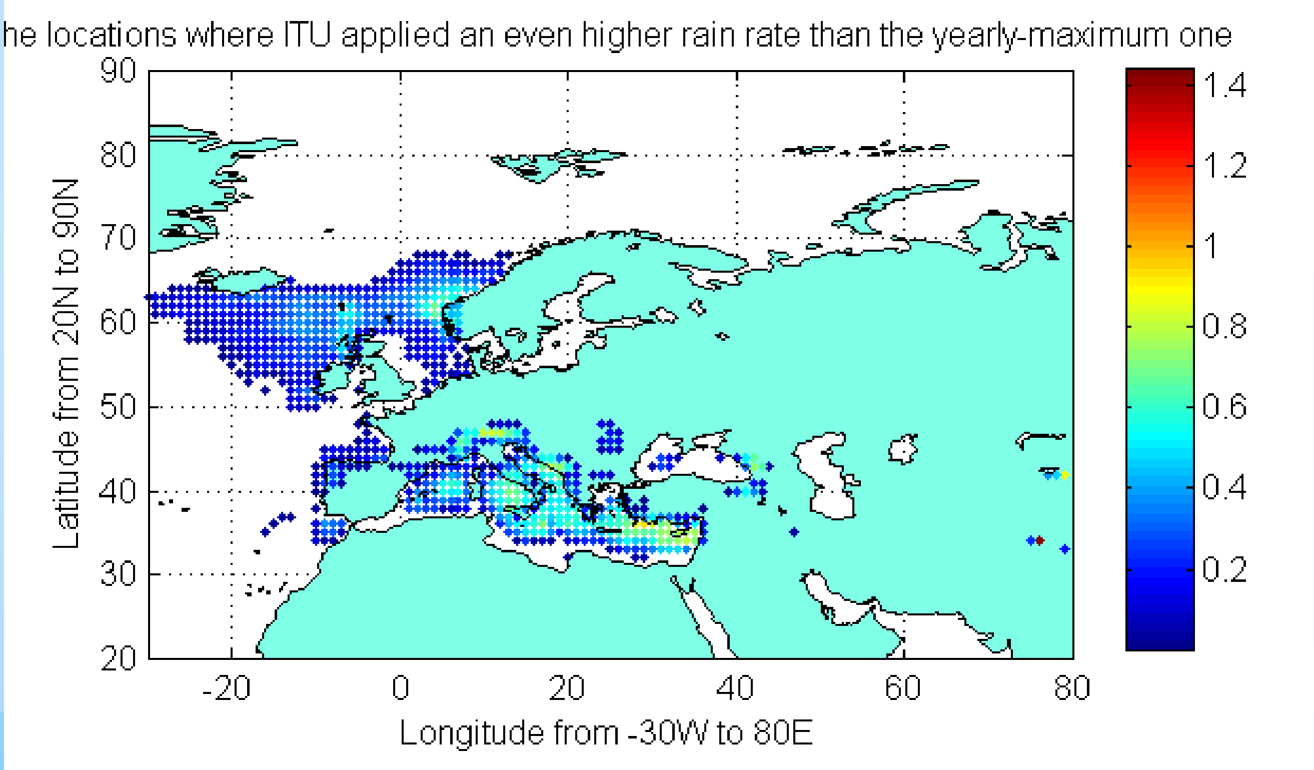
* Relative link margin with 6dB variation region in the two cases of rain rates





All of the calculations are with GEO Satellite at 4E LON (ASTRA-4)

* The areas where ITU-R 837-6 applied good margin on rain damping

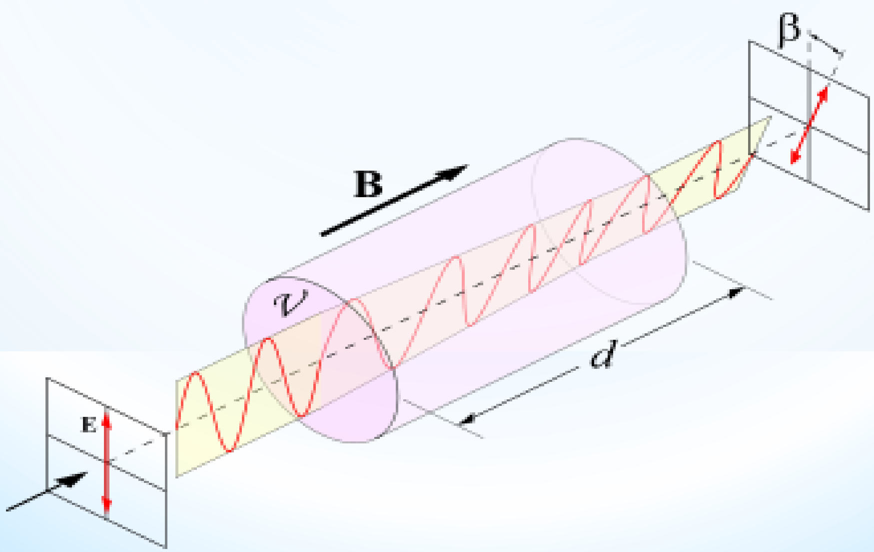


At these areas, the margin applied for rain damping was even better than the one estimated from yearly maximum rate in the past years. This margin ranges from 0 to 1.4 dB; and these regions are not in the High North region.

All of the calculations are with GEO Satellite at 4E LON (ASTRA-4)

* Ionosphere, Faraday rotation

* **Faraday rotation** is a phenomenon that takes place in the ionosphere, at 60 to ≥500 km altitude. When a linearly polarized radio signal passes through an ionized medium where the Earth' s magnetic field has a component aligned with the signal path, the plane of polarization rotates as illustrated.
* The magnitude of rotation depends on the total electron content (TEC), where TEC is defines as the number of electrons present in a column of unit cross sectional area



*Ionosphere, group delay

* Both Faraday rotation and group delay are proportional to $1/f^2$

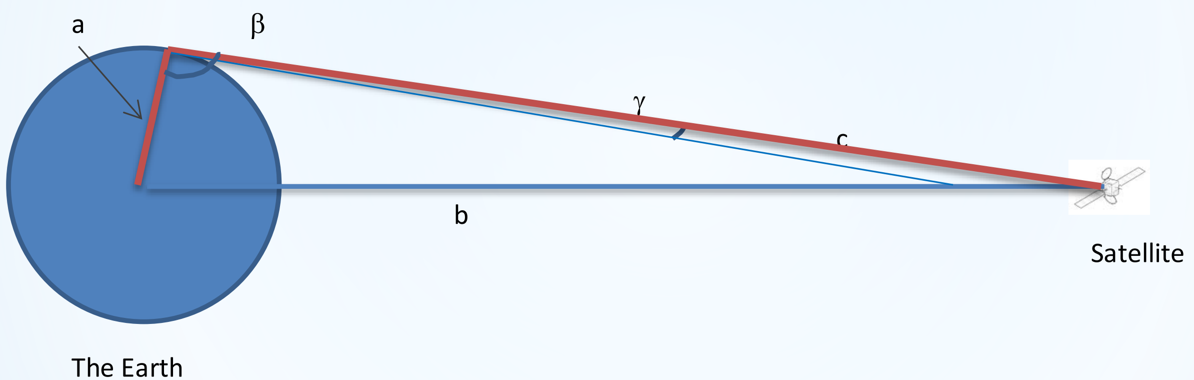
Estimated maximum ionospheric effects at 1 GHz for elevation anglesof about 30° one-way traversal (Rec. ITU-R P.531-12)

Effect	Magnitude	Frequency dependence
Faraday rotation	108°	$1/f^2$
Propagation delay	0.25 μs	$1/f^2$
Refraction	< 0.17 mrad	$1/f^2$
Variation in the direction of arrival	0.2 min of arc	$1/f^2$
Absorption (polar cap absorption)	0.04 dB	$\sim 1/f^2$
Absorption (auroral + polar cap absorption)	0.05 dB	$\sim 1/f^2$
Absorption (mid-latitude)	< 0.01 dB	$1/f^2$
Dispersion	0-4 ns/MHz	$1/f^3$
Scintillation	Above	Above

Problems for low frequencies used in Marine Distress Frequencies (Radio Telephone (R/T) & DSC)

Band	R/T Frequency	DSC Frequency	Day Time Range	Night Time Range
MF	2182 kHz	2187.5 kHz	150 NM	500 NM
HF4	4125 kHz	4207.5 kHz	300 NM	1000 NM
HF6	6215 kHz	6312 kHz	600 NM	1500 NM
HF8	8291 kHz	8414.5 kHz	1000 NM	2000 NM
HF12	12290 kHz	12577 kHz	2500 NM	
HF16	16420 kHz	16804.5 kHz		
VHF	156.800 MHz (Ch16)	156.525 MHz (Ch 70)	30 NM	30 NM

Geographical location and Elevation angle in GEO Orbit



a	b	c
6400	42400	36114,33
6400	42400	41321,01
6400	42400	41766,97
6400	42400	41878,65

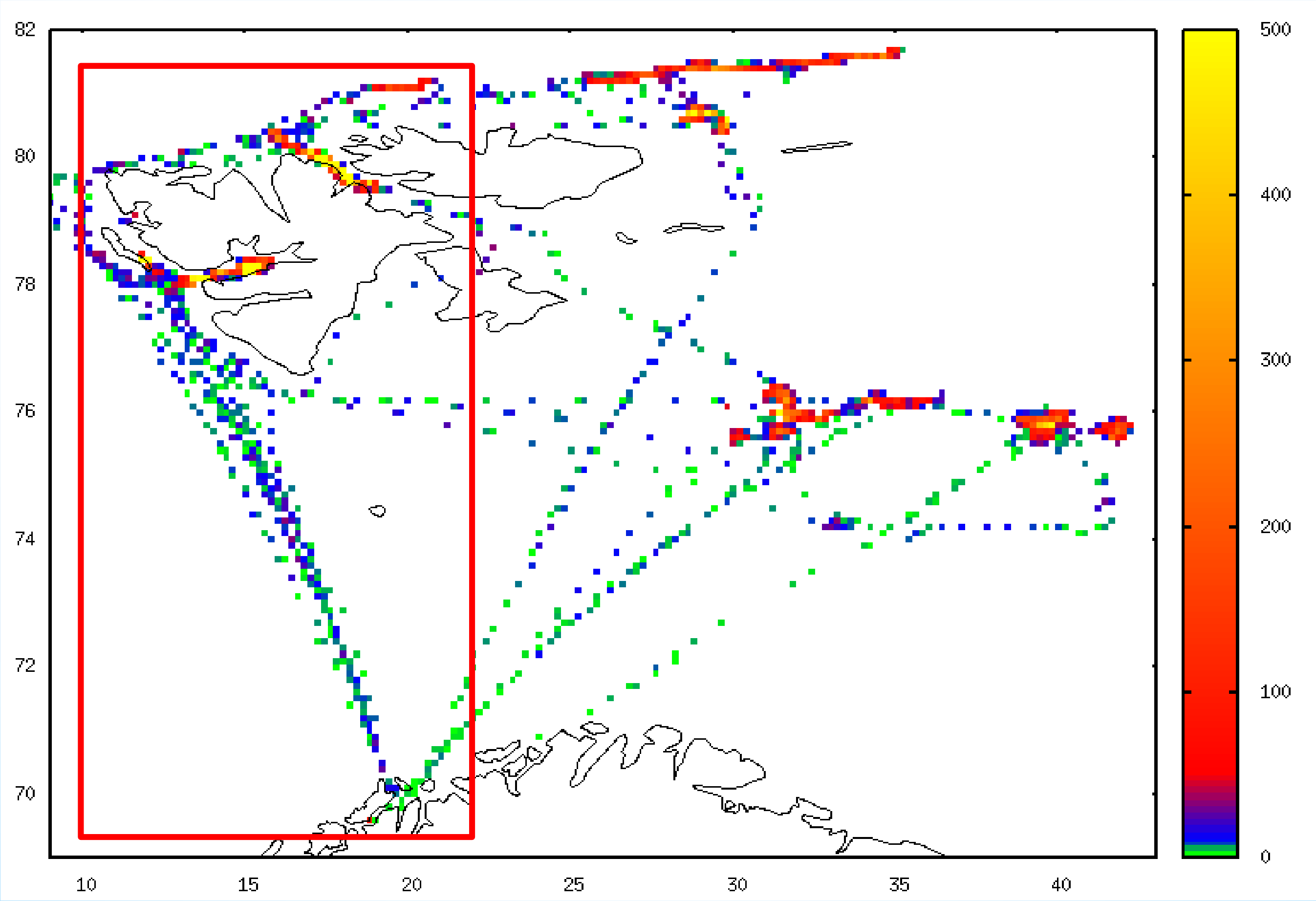
β	γ	Propagation delay	Two-way delay
168,2361	78,23613466	0,120381116	0,240762232
95,3562	5,356198826	0,137736697	0,275473393
91,32032	1,320321196	0,139223218	0,278446437
90,31813	0,318132726	0,139595513	0,279191027

Latitude
10
76
80
81

*Consequences

* System Problematic in Communication
* Accidents due to lacking or poor communication/navigation
* Unsafe or Ineffective Operations
* Search and Rescue Cooperation Issues

*When there are many vessels in the region



Svalbard-Trømsø transit each 6 weeks

* Communication, Navigation and Accident Data analysis

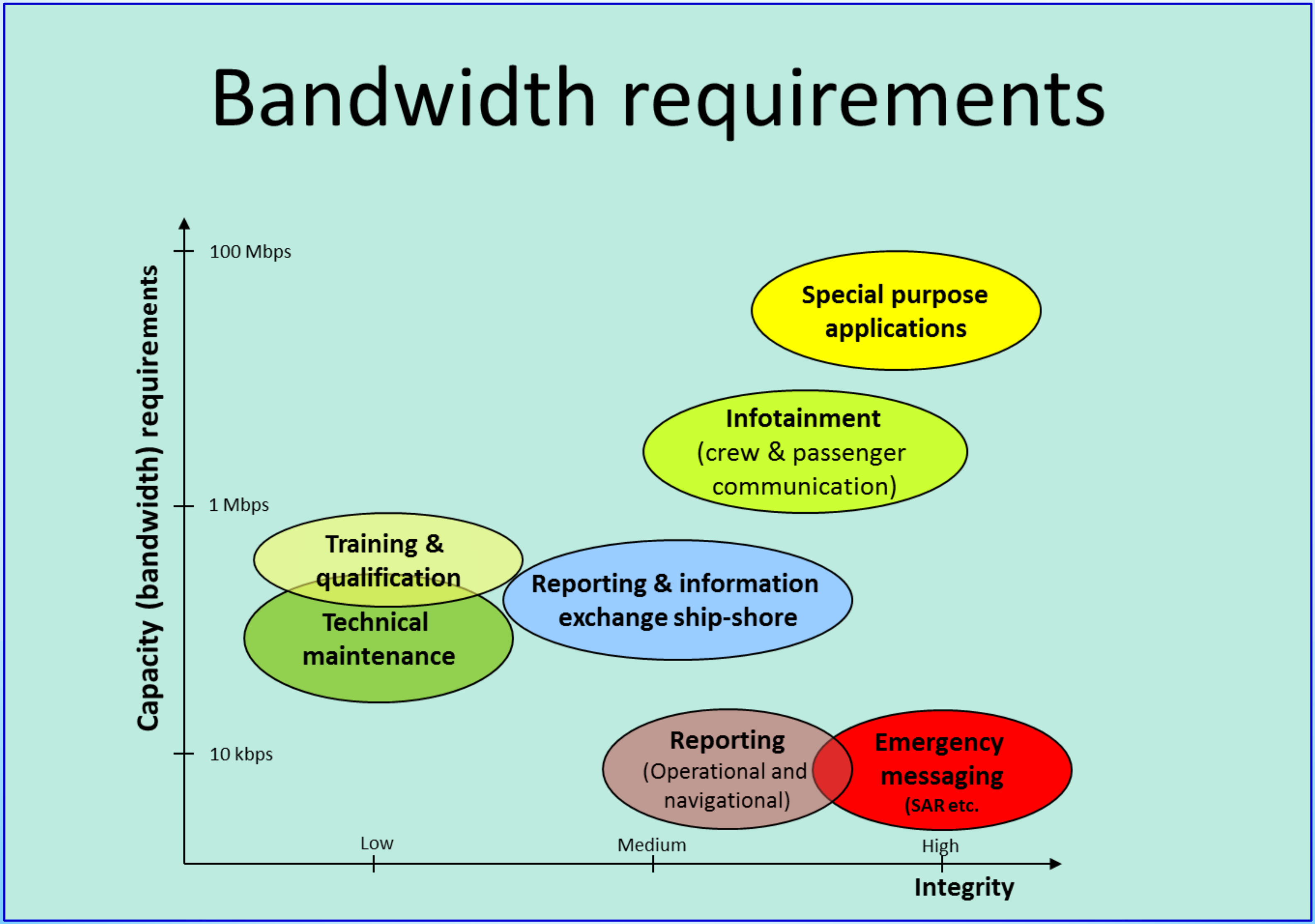
- Basic map
- Radio stations and coverage
  - VHF/MF/HF public
  - DSC watch VHF/MF/HF
  - Coverage DSC VHF/MF
- Navigational aids
  - LORAN-C transmitters
  - CHAYKA transmitters
  - NAVTEX transmitters
- Vessel density
  - Month, type, zone
- Vessel accidents
  - Type, zone
- Combination
- Reports

Stasjon	Assistansetype	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des	Totalt	1.Tert.	2.Tert.	3.Tert.	1.Halvår	2.Halvår
Alle KRS	Brann	1	2	5	6	10	11	17	10	4	3	4	1	74	14	48	12	35	39
	Div. assistanse	14	7	13	23	48	39	64	60	24	41	22	16	371	57	211	103	144	227
	Etterlysning	2		6	4	12	9	11	7	5	7	2	1	66	12	39	15	33	33
	Forlis				3	4	1	1	1	1	1			12	3	7	2	8	4
	Grunnstøting	3	2	11	10	30	49	83	38	25	26	13	13	303	26	200	77	105	198
	Kollisjon	1				1	2	1	1			1		7	1	5	1	4	3
	Lekkasje	1	3	7	5	11	14	25	11	7	7	9	5	105	16	61	28	41	64
	Mann over bord	4	1	2	1	5	5	11	8	5	1	1	1	45	8	29	8	18	27
	Medico	147	218	213	212	173	239	261	287	244	212	256	241	2703	790	960	953	1202	1501
	Motor/gir	29	22	39	42	167	240	412	227	127	76	43	30	1454	132	1046	276	539	915
	Not/bruk/ror	15	12	22	13	28	31	37	27	20	32	23	9	269	62	123	84	121	148
	Sykdom/skade	2	4	4	3	3	8	4	9	4	7	2	5	55	13	24	18	24	31
Alle KRS	Total	219	271	322	322	492	648	927	686	466	413	376	322	5464	1134	2753	1577	2274	3190

Stasjon	Varslingsvei	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des	Totalt	1.Tert.	2.Tert.	3.Tert.	1.Halv	2.Halv
Alle KRS	Annen varsling	142	215	212	208	170	226	247	287	240	205	249	241	2642	777	930	935	1173	1469
	HF/Sat	1										1		2	1		1	1	1
	HRS	15	7	16	20	54	44	36	51	22	35	23	14	337	58	185	94	156	181
	LRS					3					1			4		3	1	3	1
	MF						1	2		5	1	1	3	13		3	10	1	12
	MF m/DSC						1			1	1			3		1	2	1	2
	Telefon	20	8	37	44	207	290	539	272	141	113	59	33	1763	109	1308	346	606	1157
	VHF	38	35	58	48	57	88	103	75	34	55	43	31	665	179	323	163	324	341
	VHF m/DSC		2		1	2		4	1	20	1	1	1	33	3	7	23	5	28
Alle KRS	Total	216	267	323	321	493	650	931	686	463	412	377	323	5462	1127	2760	1575	2270	3192

Alle stasjoner	Type fartøy	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des	Totalt	1.Tert.	2.Tert.	3.Tert.	1. Halvår	2. Halvår
	Fiskefartøy	31	27	46	37	30	26	18	27	29	42	33	19	365	141	101	123	197	168
	Fritidsfartøy	16	17	42	56	265	365	638	332	183	141	57	33	2145	131	1600	414	761	1384
	Yrkesfartøy	160	222	225	226	184	243	256	305	250	219	276	263	2829	833	988	1008	1260	1569
	Annet	12	5	9	3	13	14	15	22	4	11	10	7	125	29	64	32	56	69
Alle KRS	Total	219	271	322	322	492	648	927	686	466	413	376	322	5464	1134	2753	1577	2274	3190

* And the bandwidth, quality requirements are increasing



* In addition, it needs to fulfill the delay requirement (ITU-T G1010)

Error tolerant	Conversational voice and video	Voice/video messaging	Streaming audio and video	Fax
Error intolerant	Command/control (video games, remote control)	Transactions (e-commerce, web browsing, email access)	Messaging, file downloads	Background (e.g., chart and manual updates)
	Interactive Delay << 1 s	**Responsive** Delay ~ 2 s	**Timely** Delay ~ 10 s	**Non-critical** Delay >> 10 s

Conclusion

- The demand for doing communications in the Arctic is increasing
- The quality and bandwidth of currently existing systems are not fully qualified or not available to use
- The quality of maps and navigation in the Artic region is poor
- A harsh weather condition and rain fall in the Arctic could significantly degrade the communication performance
- It would be interesting to have these numerical inputs to a risk analysis for different users groups, geographical areas and time/season
- **Key enablers**
  - HEO satellites & Optical fibers are for a long-term plan
  - Qualified communications solutions in a local area are possible, which helps to improve situational awareness and cooperative work in the area (such as using HAPS, UAV, Drones)
  - Mesh and Ad-hoc networks could be helpful to improve the collaborative tasks, especially in SAR activities.
  - An opportunistic radio communciation with Software-Defined-Radio could be interesting for short and long term phase