Challenges for positioning and navigation in the Arctic

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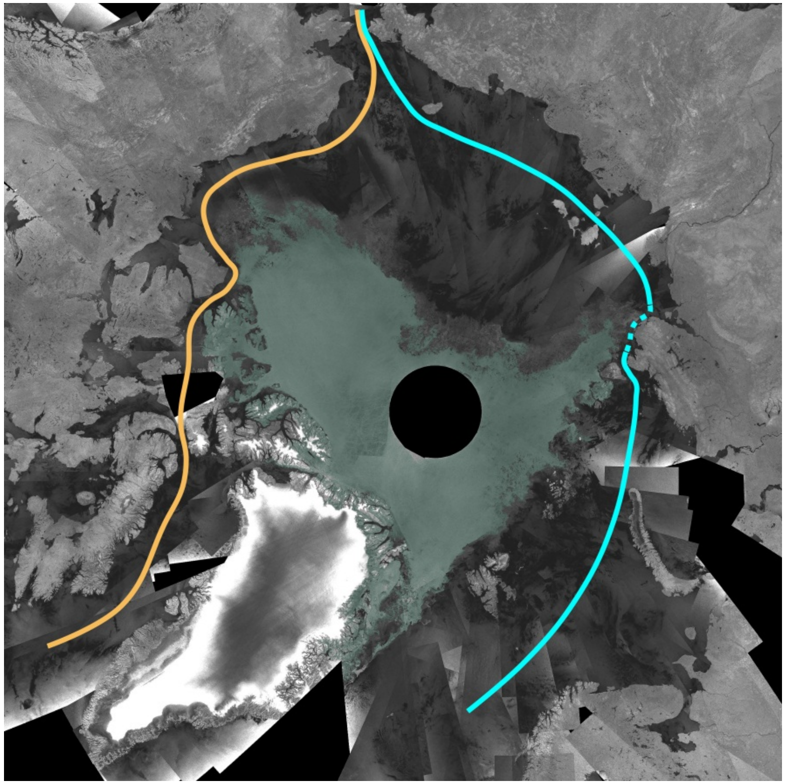
Outline

- Reduction of ice masses in the Arctic
- Increasing activity in the Arctic
- Difficulties with navigation in the Arctic
  - GNSS limitations
  - Ionospheric activity
- Possible solutions

Arctic ice melt

- Arctic ice cap recession is even faster than was predicted
- Consequences at sea
  - North-West & North-East passages open for several months during summer
  - New ice-free shores accessible by ships
  - More drifting ice patches
- Consequences on land
  - New areas accessible for settlement
  - New areas accessible for mineral resources exploitation



http://www.esa.int/esaEO/SEMVLJVH48F_planet_0.html

Increased navigation needs – marine

- More activity
  - Shipping: N-W and N-E passages, access to remote places for logistics
  - Tourism: 250 cruise ship visits in 2007, continuously increasing
  - Fishing: new areas, longer season
- SoL requirements by IMO
  - 1 - 10 meter accuracy, high integrity and availability

www.nytimes.com/2007/11/24/world/americas/24ship.html

Increased navigation needs – survey

- Mapping, surveying, and scientific observations
  - Land and off-shore: seismic surveys, rig positioning etc.
  - Hydrography, marine charts, seabed mapping' etc.

- Requirement is high accuracy at least sub-meter

www.navalhistory.dk/english/photoalbums/2006_SKA11

jdp.ecritel.net/Presentations/documents/Atelier_12

Increased navigation needs – other

- More aircrafts to fly in the Arctic
  - Small aircrafts and helicopters are very important for transportation of goods and people to remote areas
  - Because of climate and large distances, the air is the only access way into the Arctic when the sea is frozen
- Increased en-route traffic in Arctic air space
- Resources exploitation
  - Oil & Gas – 25% world reserves
  - Mineral exploitation
- Environment monitoring
- Political need to enhance sovereignty and security by active presence of defense, coast guards etc.

Photo: Anna B.O. Jensen

Difficulties with navigating in the Arctic

- Environment
  - Rough weather
  - Marine navigation: drifting ice patches – more hull-penetrating old ice
- The area is remote and distances are large
  - Very late emergency response
- Poorly mapped areas - both at land and sea
- Higher ecological impact of an accident
- Navigation technologies limitations
  - Poor heading accuracy – both magnetic and inertial
  - Lack of radio-navigation infrastructure
  - Poor GNSS performance

GNSS limitations – geometry

- GPS and Galileo satellite inclination angles of 55º and 56º
  - Low elevation angles in polar areas
  - Good for the HDOP
  - Bad for VDOP – poorer altitude accuracy
  - Higher noise level in observations
  - Larger ionospheric effects at lower elevation angles
  - Slightly better with GLONASS (65º)

- Difficulties with GNSS augmentation
  - Poor visibility of GEO satellites (e.g. EGNOS and WAAS)
  - Sparse infrastructure for GNSS augmentation

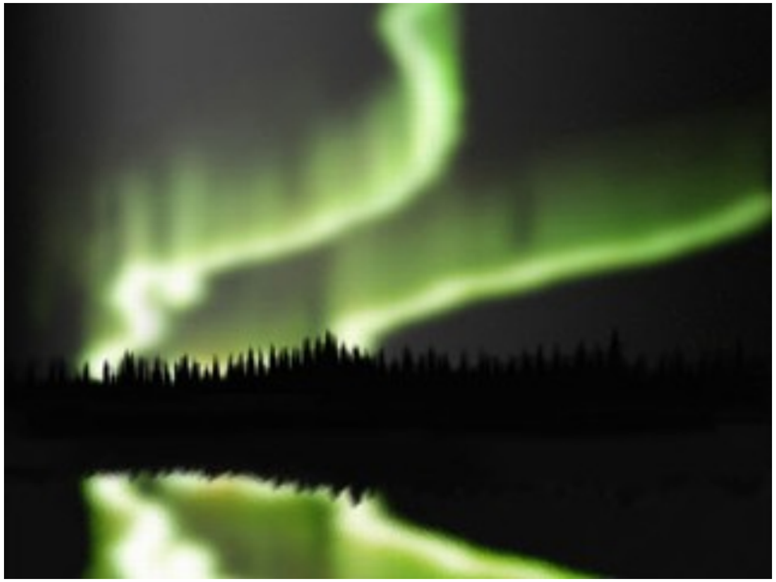
GNSS limitations - ionospheric effects (1)

- In the ionosphere the electro magnetic signals are affected mainly by free negatively charged electrons
- Size of the effect is a function of the amount of electrons encountered by the signal, *total electron content* (TEC)
- The size of the signal delay is dependent on the frequency, i.e. different for GPS L1 and L2 frequencies
- The 'normal' signal delay causes an error on GPS L1 pseudoranges of:
  - 5-15 meters day time, 1-3 meters night
- The ionospheric effect is handled by ionospheric models and linear combinations of observations from different frequencies

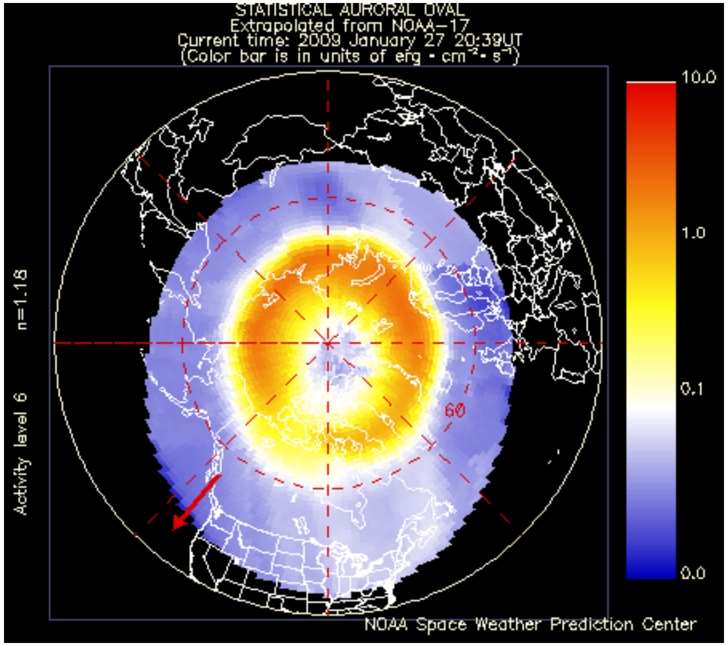
GNSS limitations - ionospheric effects (2)

- In the Arctic the ionosphere is characterized by an enhanced electron precipitation causing an increased ionospheric variability

- Northern light is a visible example of the increased activity at high latitudes



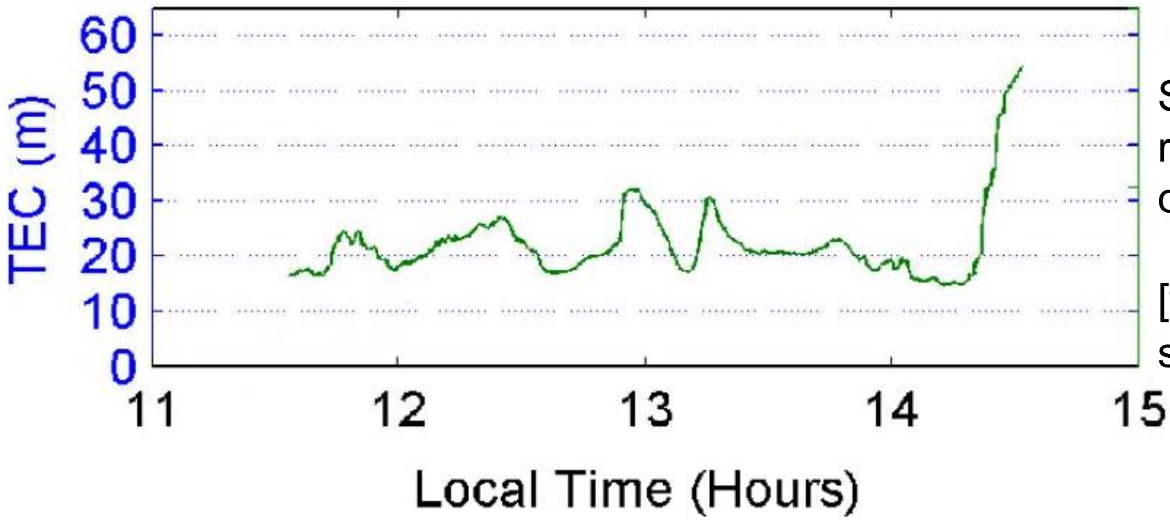
http://abcnews.go.com



http://www.sec.noaa.gov/pmap/pmapN.html

GNSS limitations – ionosphere TEC gradients

- Enhanced electron precipitation causes large gradients of TEC
- Solar activity driven ionospheric storms
  - Ionospheric range error can almost double in less than 10 minutes



Slant TEC on GPS PRN 3, recorded at Thule, Greenland, on Nov. 17th 1989

[from Doherty et al., IEC 2008 symposium]

- Large gradients of ionosphere TEC
  - Affect only some satellites => larger bias on user position
  - Make real-time ambiguity resolution difficult or impossible

GNSS limitations –scintillation

- Scintillation occur when satellite signals experience ‘lumps’ of electrons in the ionosphere causing changes in signal phase and amplitude
- Is highly correlated with auroral activity and large TEC gradients and with the sun spot number
  - Not as strong as in Equatorial areas, but may occur at any time in the day
- Scintillation causes GNSS receivers to loose lock on the satellite signals, limiting positioning and navigation capabilities
- Duration of scintillation events can vary significantly. Often a single signal is only disrupted for a few seconds, but a receiver can be affected by a scintillation event for up to about an hour

GNSS limitations – augmentation systems

- Sparse (lack of) monitoring infrastructure
  - Few GPS monitoring stations
  - Temporarily powered
  - Poor real-time communication links
- Poor visibility of geostationary satellites
  - Arctic area beyond reach of EGNOS and WAAS
  - GEO satellites low on horizon, visible only for brief periods
- No IALA differential beacons (300 kHz)
- No Loran C coverage (100 kHz)
- Most RF communications subject to ionosphere perturbations

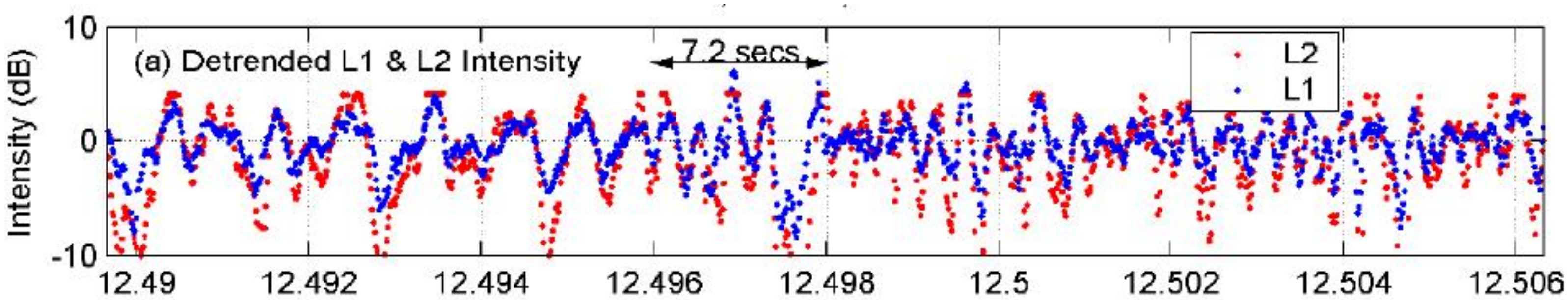
Accidents and consequences

- If an accident does happen in the Arctic the consequences can be serious
- The remoteness, the large distances, and the rough weather cause difficulties for search and rescue (SAR) operations and the nearest airstrip is often very far away
- The Arctic environment is vulnerable and very slow in regeneration after for instance an oil spill

http://www.offshore-mag.com/

Incomplete solutions

- Dual frequency GNSS receivers – iono-free combinations
  - Correlation L1-L2 of scintillation events (Doherty *et al*., IES2008)
  - Under ionospheric perturbations, second-order effects are not corrected



- Galileo, GPS II-F
  - More satellites, more signals, but no improvement on elevation angles
  - Limited additional data broadcast capacity
- Inertial sensors
  - Bridge scintillation events gaps
  - Autonomous integrity monitoring of GNSS

Possible solutions – ionosphere modeling and monitoring

- Improving ionosphere time/spatial variability models
  - With a tracking network features of the ionospheric activity can be detected and followed

- Combination of various types of observations of the ionosphere; for instance GNSS data, magnetometer data, and radar can lead to improved ionosphere models

- Mostly seasonal navigation needs (except aviation)
  - Temporary stations for monitoring might be a solution

- Autonomous portable stations
  - Air-dropped and unattended

www.atairaerospace.com/onyx/hybrid

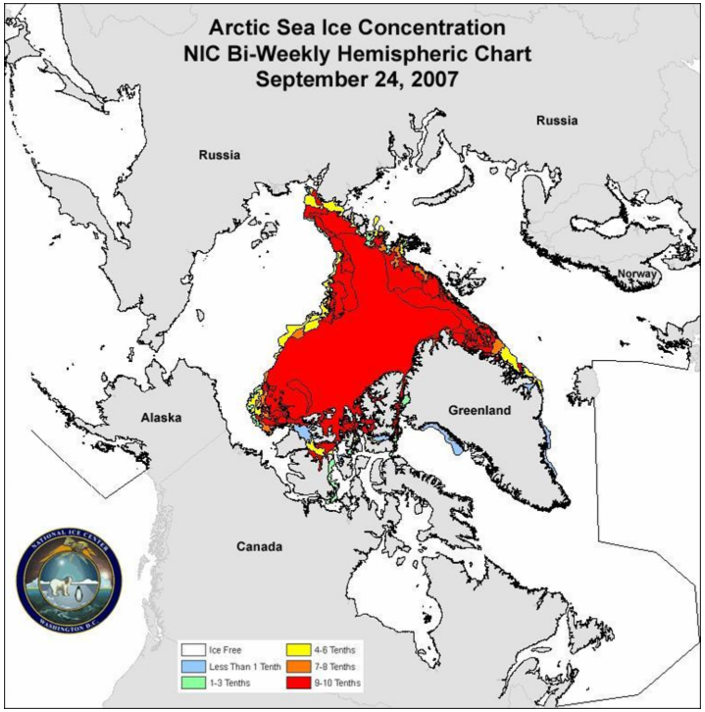
Possible solutions – iono corrections broadcast

- MEO constellation
  - Obvious solution in the long term
  - MRS – limited data channel capacity
- IALA DGNSS beacons
  - Limited range and difficulties with maintenance
- Polar orbiting satellites (Molniya constellation, quasi-GEO…)
  - Expensive (€ billions)
- Long endurance UAVs
  - Seasonal

Conclusions and recommendations

- Urgency
  - Most professionals will not wait to roam the Arctic area
  - Safety of life at stake – no need to wait for a catastrophe before taking action

- Implement denser GNSS observation network to:
  - Support ionospheric modeling studies
  - Support ionospheric monitoring network developments



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