GNSS in the Arctic
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Outline

• Introduction
• Weather conditions
• Satellite coverage
• Aurora impact
• GNSS corrections
• Test results
• Conclusion
INTRODUCTION
Routes of the Viking Explorers

Viking routes

Sundial: the Viking "sextant"
Monitoring Arctic Navigation from Space

- **AISSat-1** – experimental nano satellite with AIS receiver payload
- Designed for monitoring AIS targets in arctic regions
- Polar orbit, 600 km altitude
- Providing data from July 2010
AIS Vessels in an Arctic Region as of 12 July, 2010

Traffic expected to increase in the years to come
Temperatures in the Arctic

<table>
<thead>
<tr>
<th></th>
<th>°C</th>
<th>°F</th>
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</thead>
<tbody>
<tr>
<td>Average July temperatures</td>
<td>-10 to +10°C</td>
<td>14 to 50°F</td>
</tr>
<tr>
<td>Average January temperatures</td>
<td>-40 to +0°C</td>
<td>-40 to +32°F</td>
</tr>
<tr>
<td>Extreme temperatures</td>
<td>~ -50°C</td>
<td>~ -58°F</td>
</tr>
<tr>
<td>Typical GNSS antenna specifications</td>
<td>-40°C</td>
<td>-40°F</td>
</tr>
</tbody>
</table>

**Conclusion:**
Most GNSS antennas will work fine under almost all temperature conditions in the Arctic

Arctic defined by the 10°C isotherm in July, Wikipedia, 2010-08-25
Iceload on GNSS Antennas

- Surprisingly little is known about the effect of ice-load on a GNSS antenna
- Snow does probably not have any significant effect
- A 1.25 cm wet surface ice loading will (Ref: O’Keefe et al):
  - Reduce the SNR with 3 dB
  - Increase the rms position error of 1 m
  - Increase the number of cycle slips significantly

**Conclusion:**
Ice building up on the GNSS antenna doesn’t make any good!

Ref: http://farm1.static.flickr.com/35/100361821_5d58d82777.jpg
GPS and Glonass

SATELLITE COVERAGE
Significance of the Orbit Inclination Angle

- The highest latitude a satellite can pass zenith is equal to the orbit inclination angle.
- Any GPS or Glonass satellite will eventually be visible from any position in the Arctic.
- A geostationary satellite cannot be observed above a latitude of about 75° with e.g. a 5° elevation mask constraint. The longitude position might reduce this limit.
Observer’s Latitude: 30°N
No GPS satellites observed below a certain elevation in a northern direction leads to less accuracy in North/South direction

Observer’s Latitude: 55°N
The highest latitude where a GPS satellites will pass zenith. Some GPS satellites observed at a very low elevation angle in a northern direction

Observer’s Latitude: 75°N
No GPS satellites observed above a certain elevation angle leads to less accuracy in height

Plots generated by use of GeoSky II (Fugro)
GPS vs. GPS+Glonass Satellite Trajectories

Plots generated by use of GeoSky II (Fugro)
Visible GNSS Satellites at Different Latitudes

- HDOP and number of visible satellites improves at high latitudes
- PDOP peaks at high latitudes because of fewer high elevation satellites and causes some degradation of vertical accuracy

**Conclusion:** Satellite coverage in Arctic is good especially with a combined GPS/Glonass constellation

Plots generated by use of GeoSky II (Fugro)
Availability of Signals from Geo Satellites

- Used for communication and distribution of differential signals

- Some additional margin needed due to
  - roll movement
  - obstructions in a southern direction
  - Signal disturbance caused by high solar activity

**Conclusion:**
Signals from Geo satellites will be less available in Arctic regions
Influence of the Ionosphere

AURORA IMPACT
A Pioneer, Prof. Kristian Birkeland

- An outstanding Norwegian physicist, born in 1867
- Demonstrated artificial polar light in several “terella” experiments as shown on the Norwegian “200 kroner” banknote
- Proved several ionospheric effects that were not verified until about 50 years later
The Sun and the Sunspots

- Sunspots have been observed and counted, more or less systematically, for thousands of years.
- Sunspot activity is known to have an effect on solar wind and conditions in the ionosphere.
- Modern infrastructure is vulnerable to these effects.
Different Scales of Ionospheric Effects

- **Large-scale:**
  - Basically the density of charged particles in the ionosphere

- **Medium-scale:**
  - F-layer patches moving over the auroral oval

- **Small-scale:**
  - Scintillations within the auroral oval causing variations over a few km

The auroral oval (www.mssl.ucl.ac.uk)
"Single frequency users will have to rely on a model of the ionospheric group delay, and the observations made in this trial verifies that this model will have a very poor fit for high latitude data."
The Effect of Cycle 24?

- Degraded GNSS accuracy during "bad ionospheric weather"
- Loss of signals from communication satellites (Geo) during high ionospheric activity
- Increased risk of knock-out of electronics and power due to electromagnetic pulses like in Quebec in 1989

Cycle 24 has started!
GNSS CORRECTIONS
GNSS Correction Main Categories

- Local DGPS L1 Service (e.g. IALA)
- Regional SBAS services (e.g. WAAS, EGNOS, MSAS)
- Global orbit/clock services (e.g. Fugro, Veripos, C&C)
Local DGPS L1 Services

IALA beacon coverage in Europe and North America
Local DGPS Services in the Arctic

- Out of range of local DGPS services in most Arctic areas
- Degraded accuracy caused by ionospheric activity to be expected
- Ionospheric activity might limit GNSS satellite tracking at the reference stations
The SBAS Ionospheric Model

- Calculating Ionospheric Grid Point Delay tables

- The limitations of the method will be density of grid points and ground based monitoring points

- Compensates for large-scale and, to some extent, medium scale effects

- Do not help much for small-scale effects (scintillations)
Regional SBAS Performance

- Most Arctic areas are outside SBAS service area
  - Monitoring stations mostly deployed within service area
  - Ionospheric model

- Availability of correction signals from Geo satellites limited

- Ionospheric scintillations will cause degraded accuracy and integrity
Global Orbit/Clock

- Orbit/clock corrections are global and will not be degraded in the Arctic
- Small 2nd order effects might cause a small accuracy degradation of ionospheric compensation during scintillations
- GPS L2 will be vulnerable to distortion of the satellite signal through an active ionosphere
- Availability of correction signals from Geo satellites will be limited
Coverage of Orbit/Clock Corrections

Fugro Orbit/Clock Service Coverage in Arctic Regions
Communication

TEST RESULTS
Preliminary Results from the MarSafe Project

MarSafe North
Maritime Safety Management in the High North
VSAT Test on KNM Otto Sverdrup

Intelsat IS-1002 coverage, www.intelsat.com

Photo: Beate Kvamstad - MARINTEK
Variations in Communication Performance

1. Unstable VSAT
2. VSAT coverage on the coast line, not inside fjords
3. Unstable HF
4. OK
5. Unstable HF, Unstable VSAT
6. Unstable MF/HF, unstable GSM and mobile (from BS in Svea), unstable VSAT

- Iridium OpenPort had approximately 50% package loss during the observation period
Ionospheric Scintillations

TEST RESULTS
Northern Light, Oslo 3-4 August 2010

Photo: Ole Ørpen - Fugro Seastar

Northern Light prediction (yr.no)
Loosing Lock on GPS L2, Tromsø

Loss of L2 signal for three high elevation GPS satellites (11, 14, 32),
Caused by ionospheric scintillations
Iono Effect on L1 Solution, Tromsø

Time UTC: 4 April 2010

- Height Error
- North Error
- East Error
Iono Effect on GPS Orbit/Clock Solution, Tromsø
Iono Effect on GPS/Glonass Orbit/Clock, Tromsø
CONCLUSION
Conclusion

- GNSS will mostly work fine in Arctic areas.

- Some degradation due to ionospheric scintillations has to be expected but combining GPS and Glonass in orbit/clock solutions will minimise the problem.

- Commercial orbit/clock DGNSS corrections will apply to all Arctic areas but availability of the correction signals is limited.