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Global Navigation Satellite Systems (GNSS) serving atmospheric monitoring: A review

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DASP, February 2024

Canada

Introduction

- Global Navigation Satellite Systems (GNSS) are affected by the Earth's atmosphere. While atmospheric effects on GNSS signals are nuisance parameters for positioning and navigation applications, they can provide valuable information on lower and upper parts of the atmosphere.

- Emerging ground and space based GNSS networks have been providing continuous measurements of the Earth atmosphere for few decades; a valuable source of data for atmospheric monitoring.

- Canadian Active Control System operated by NRCan is consist of continuously tracking GNSS stations. In addition to serving positioning, navigation and timing applications, these stations together with other regional networks are used to extract parameters to monitor the atmospheric effects which can serve upper atmosphere, weather and climate studies.

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Global Navigation Satellite Systems (GNSS)

GPS (United States) [Global coverage, ~31 sat.]

GLONASS (Russia) [Global coverage, ~24 sat.]

Galileo (European Union) [Global coverage, ~25 sat.]

BeiDou (China) [Global coverage, ~ 46 sat.]

A total of about 126 satellites in orbit with usually more than 25 of those visible anywhere on Earth at any time, each transmitting signals in 3-5 frequency channels.

Regional systems:

QZSS (Japan) [Service to Japan and the Asia- Oceania region]

NavIC (India) [Service to India and the surrounding area]

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Some of the notable years in GNSS history

1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
First GPS satellite launch				First GLONASS satellite launch						

1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
				GPS fully operational		GLONASS fully operational				

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
First BeiDou satellite launch										QZSS first satellite launch

2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Galileo first “operational” satellite launch		NavIC first satellite launch							Latest operational BeiDou satellite launch	Galileo latest operational satellite launch

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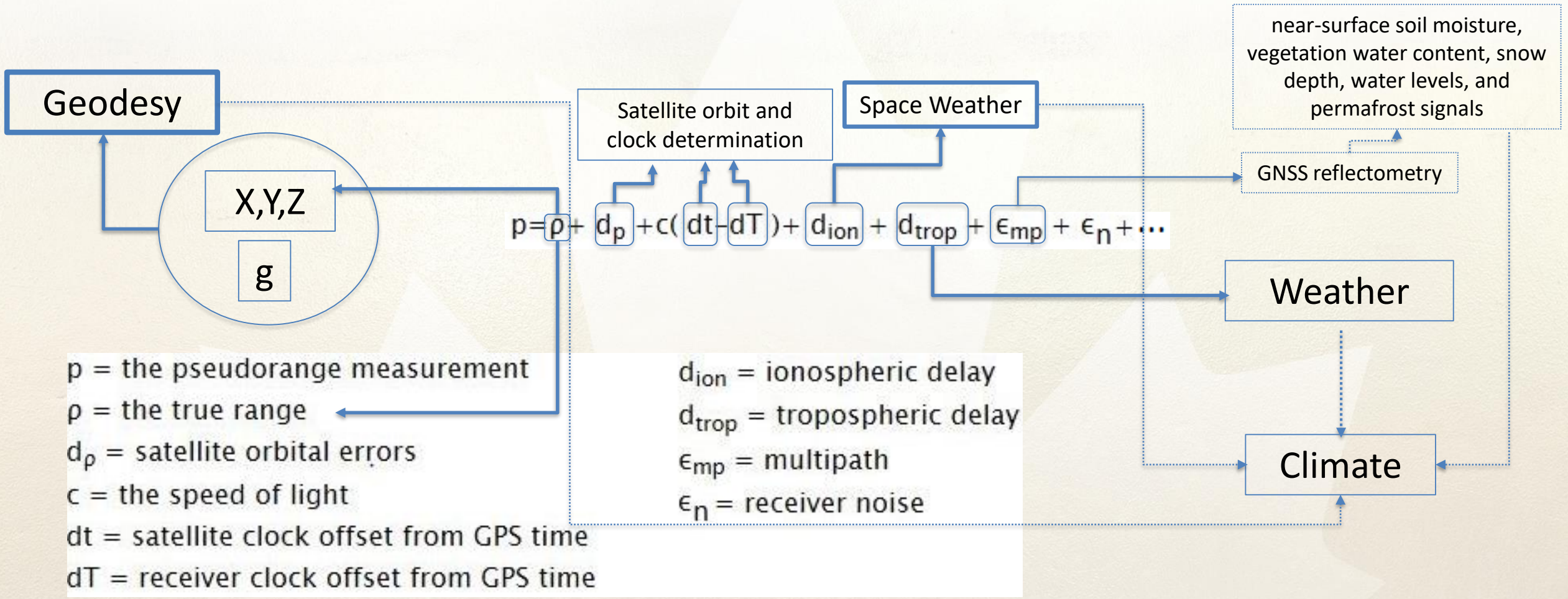
GNSS measurements: a link to monitor climate change and its impact



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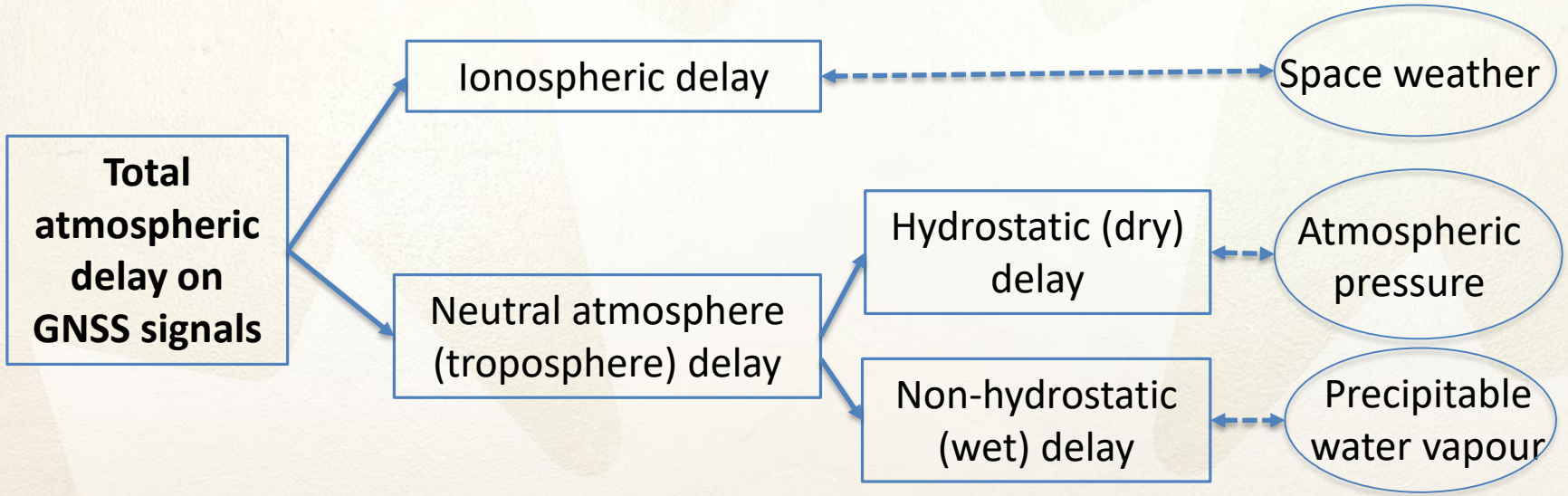
GNSS atmospheric signal delay



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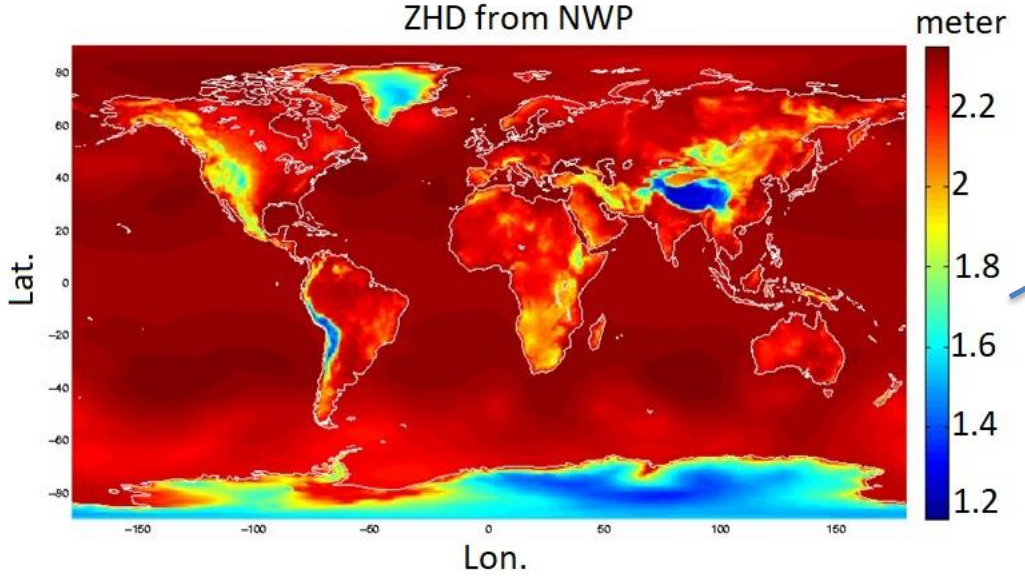
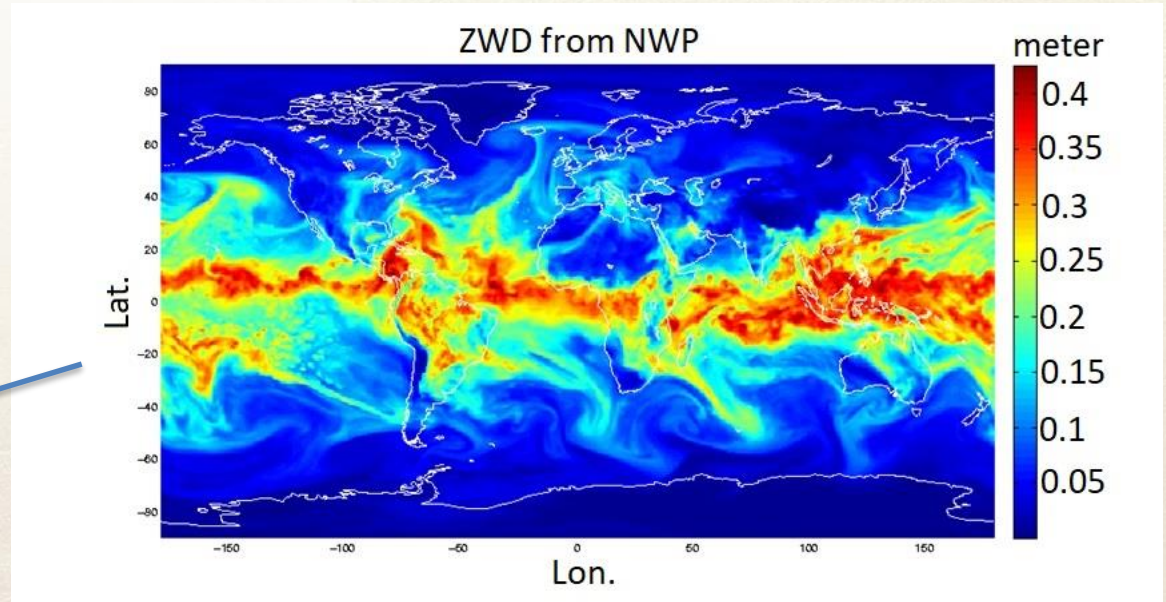
Lower atmosphere effects on GNSS: a link to weather prediction and climatology



Closely linked to atmospheric pressure



Closely linked to precipitable water vapour

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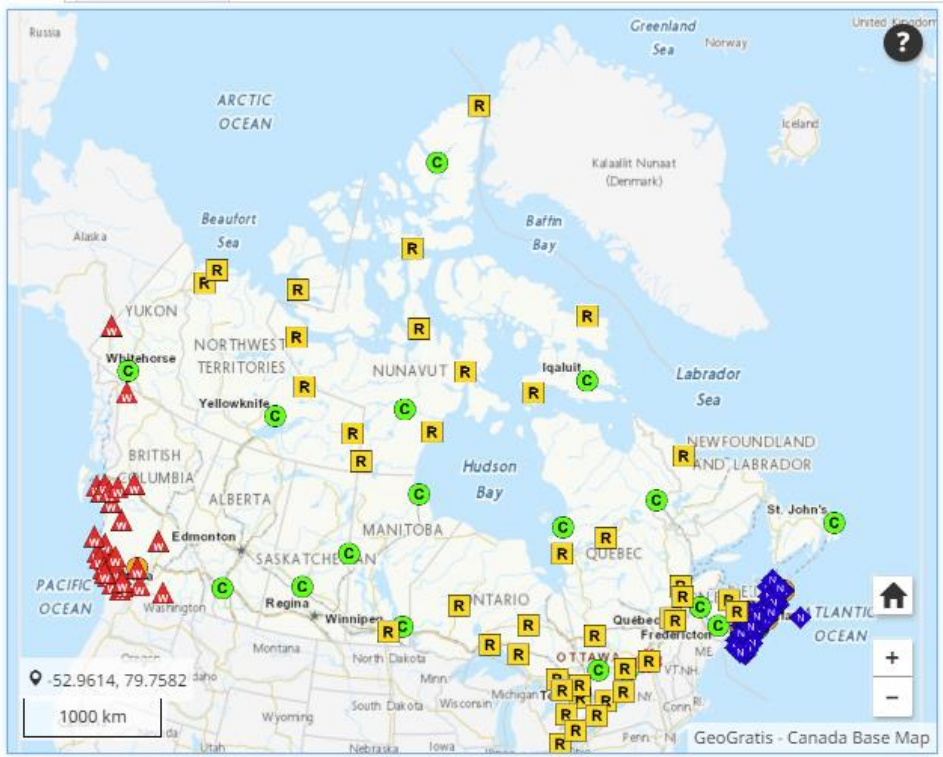
Canadian Active Control System (CACS)

"CACS consists of continuously tracking global navigation satellite system (GNSS) stations, referred to as active control points (ACPs). They're equipped with a high precision, dual frequency GNSS receiver, a geodetic quality antenna, and some also include an atomic frequency standard."

30+ Scintillation receivers are being deployed…

Stations

Map | Stations List



- National Network (19) subject to Open Government Licence – Canada
- Regional Network (41) subject to Open Government Licence – Canada
- Western Canada Deformation Array (31) subject to Open Government Licence – Canada
- Nova Scotia Active Control Network (40) subject to Nova Scotia License
- Discontinued Stations (7) subject to Open Government Licence – Canada
- Montreal Active Control Network (4) subject to Open Government Licence – Canada

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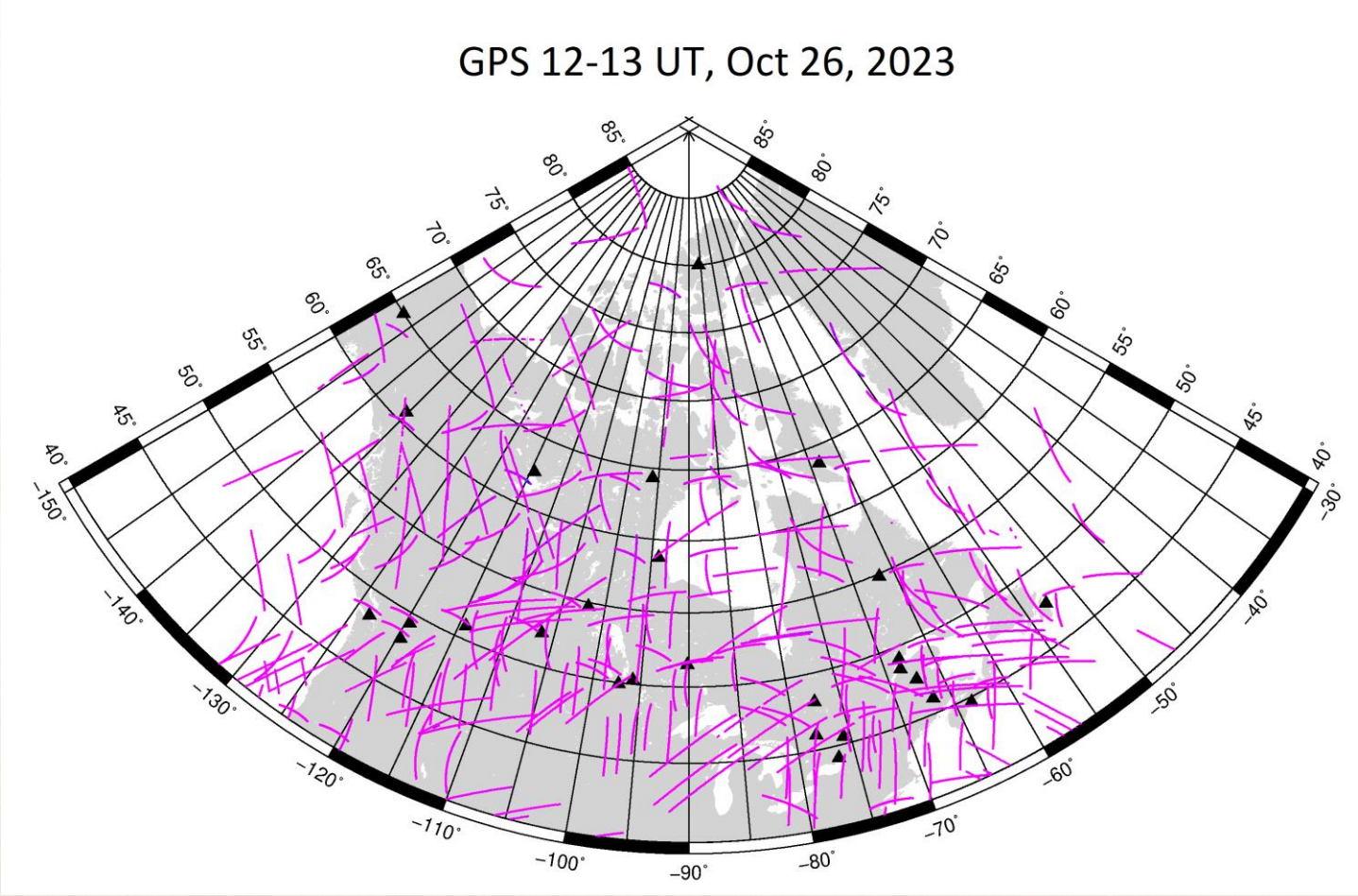
GPS vs GPS+GLONASS vs GPS+GLONASS+Galileo sampling of the atmosphere over 1-hour period using a subset of CACS stations tracking at 1Hz

Expansion of [ground and space-based] networks capable of tracking multi-GNSS provides enhanced sampling of the atmosphere.



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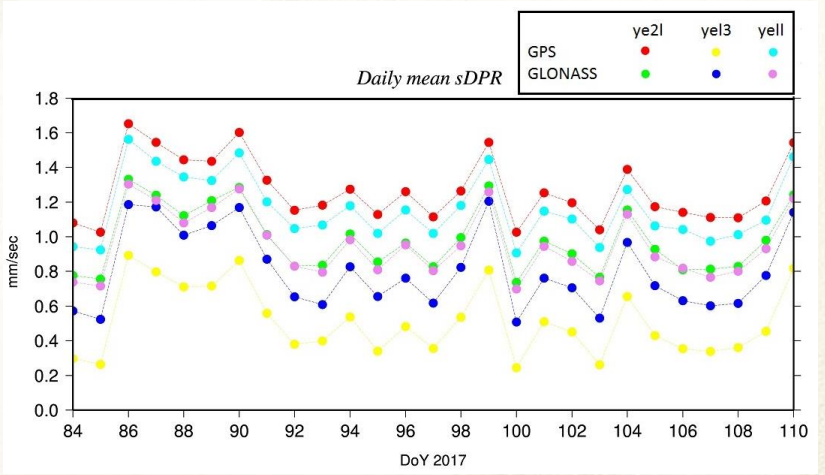
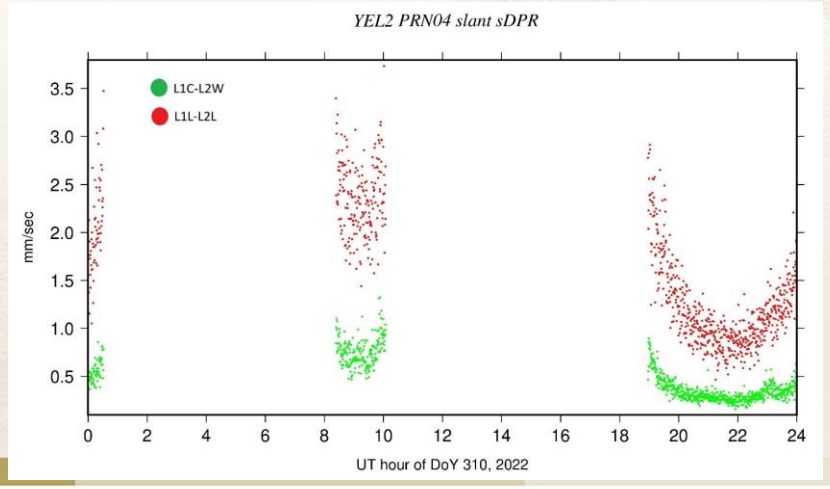
New constellations and new stations: Promising additional data with challenges to consider

- Constellation
- Instrumentation (Receiver, antenna ,…)
- Signal frequency and channel (tracking mode)

Co-located GNSS stations at Yellowknife, Canada





Constellation and station (instrumentation and near-field environment) dependent biases.

Ghoddousi-Fard R. (2017). Impact of receiver and constellation on high rate GNSS phase rate measurements to monitor ionospheric irregularities. *Advances in Space Research*, vol. 60, pp. 1968–1977. doi: 10.1016/j.asr.2017.07.039

Signal tracking mode impact on e.g. proxy scintillation indices varies depending on the instrumentation, constellation and signal.

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GNSS atmospheric measurements: A significant source of data for atmospheric monitoring

C National Network (19)

R Regional Network (41)

Considering only the 60 stations over Canadian landmass

✖

2880 satellite to receiver observations per day (considering only the 30 sec interval data)

✖

25 GNSS Satellites

=

4,320,000 sampling point of the atmosphere per day over the Canadian region

At the Canadian Geodetic Survey of NRCan we use this data to monitor the Canadian and global ionosphere, serving space weather and PNT applications. OGD also use this data for weather forecast.

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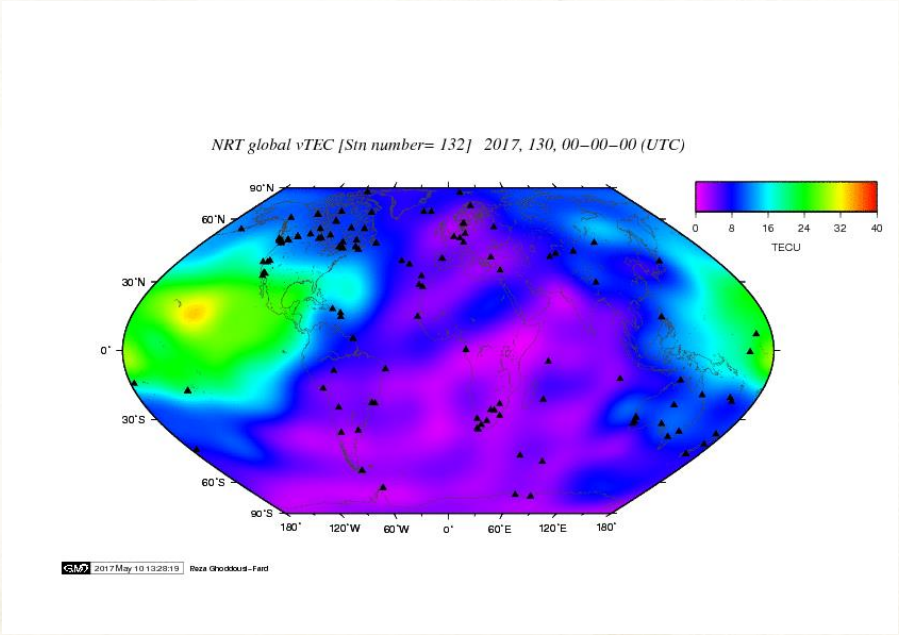
Canadian Geodetic Survey' GNSS ionospheric monitoring

Canadian Geodetic Survey (CGS) near-real-time global TEC maps use high rate real-time IGS stations every 15 minutes. Forecast for up to 24 hours ahead…

Contributing to ICAO through ACFJ aviation space weather advisory service.



CGS global daily TEC maps using about 250 stations, represented using Spherical Harmonics with 1-hour intervals, are submitted to International GNSS Service (IGS) data centers.

CGS processes GPS and GLONASS data from about 130 globally distributed high-rate (1 Hz) stations to monitor ionospheric irregularities in near-real-time as a proxy phase scintillation index. As usage of additional GNSS constellations should allow improved sampling of the ionosphere, high-rate Galileo observations are also being included.

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Thank you!

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