GCAP: Geospatial Center for the Artic and Pacific Tasks: 1, 4, 5, 6

Oregon State University College of Engineering

Oregon State University, College of Engineering,
Department of Geomatics
Hunter D. Mitchell

GCAP: Geospatial Center for the Artic and Pacific

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- **Enhance and extend diverse use** of the National Spatial Reference System (NSRS) **in the specific region of the country where these advances are most needed.**
- Develop future leaders in geodesy and geospatial professions through **new educational opportunities.**
- Provide broader impacts to society and the planet, **including enhanced resilience to coastal and seismic hazards with improved monitoring and modeling capabilities**.
- Enable career advancement and upskilling for a **diverse geodetic science and geomatics workforce** in a currently underserved region.

Source: https://gcapgeospatial.org/

Oregon State to receive $6.5M for federal effort to modernize geospatial coordinate system

November 09, 2023

Source: https://today.oregonstate.edu/news/oregon-state-receive-65m-federal-effort-modernize-geospatial-coordinate-system

UAA UNIVERSITY of ALASKA ANCHORAGE

COASTAL MARGIN OBSERVATION AND PREDICTION CRITFC · CMOP

Yurok Tribe

Oregon State University

GCAP NGS Geospatial Modeling Grant

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8 Tasks (each essentially being its own project), organized into broad themes

1. Research
   - GNSS: RTN, PPP, Multi-GNSS, OPUS
2. Preparing for beneficial use of modernized NSRS by broad geospatial community
3. Education and Outreach

- **Task 1: Real-Time Precise Point Positioning (PPP)**
- **Task 2: Hydrodynamic modeling Columbia and Klamath**
- **Task 3: New Datums in Geospatial Applications**
- **Task 4: Develop and Evaluate OPUS Utilities**
- **Task 5: Develop a National RTN Alignment Service**
- **Task 6: Multi-GNSS**
- **Tasks 7 & 8: Education and Outreach**

NGS Ten-Year Strategic Plan (2013-2023)

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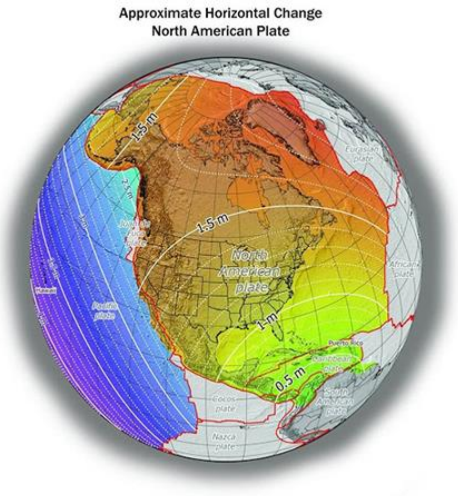
“Modernize and Improve the National Spatial Reference System”



~1 to 1.5 meters North America
~2.5 to 4 meters in Pacific

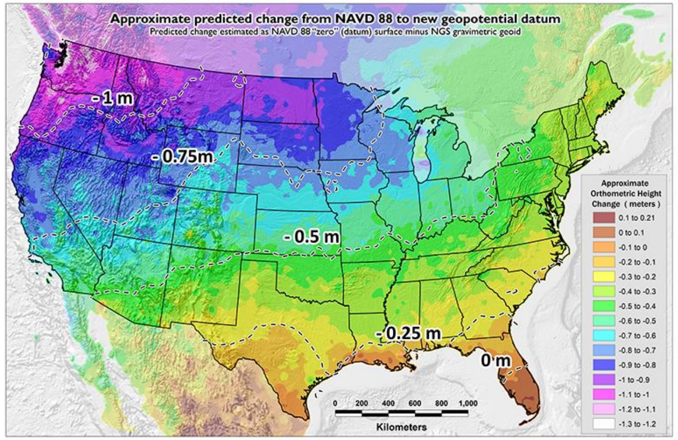
- Objective 1: “Replace NAD 83”

– By 2022, reduce all definitional and access- related errors in the geometric reference frame to 1 centimeter when using 15 minutes of GNSS data.

- Objective 2: “Replace NAVD 88”

– By 2022, reduce all definitional and access- related errors in orthometric heights in the geopotential reference frame to 2 centimeters when using 15 minutes of GNSS data.

- Objective 3: “Re-invent Bluebooking”
- Objective 4: “Fix the Toolkit”
- Objective 5: “Better Surveying”

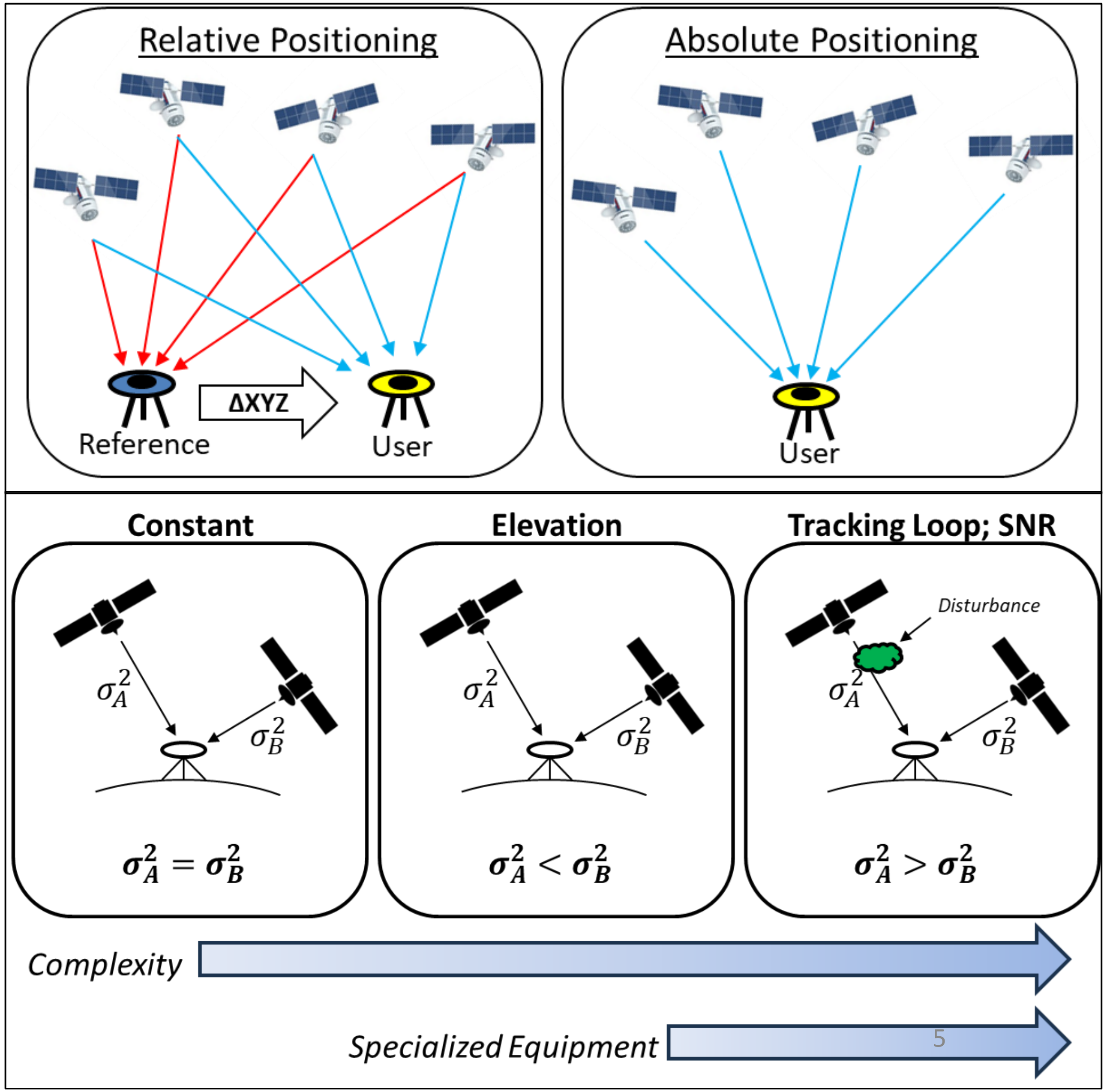


~0 to 1.3 meters CONUS

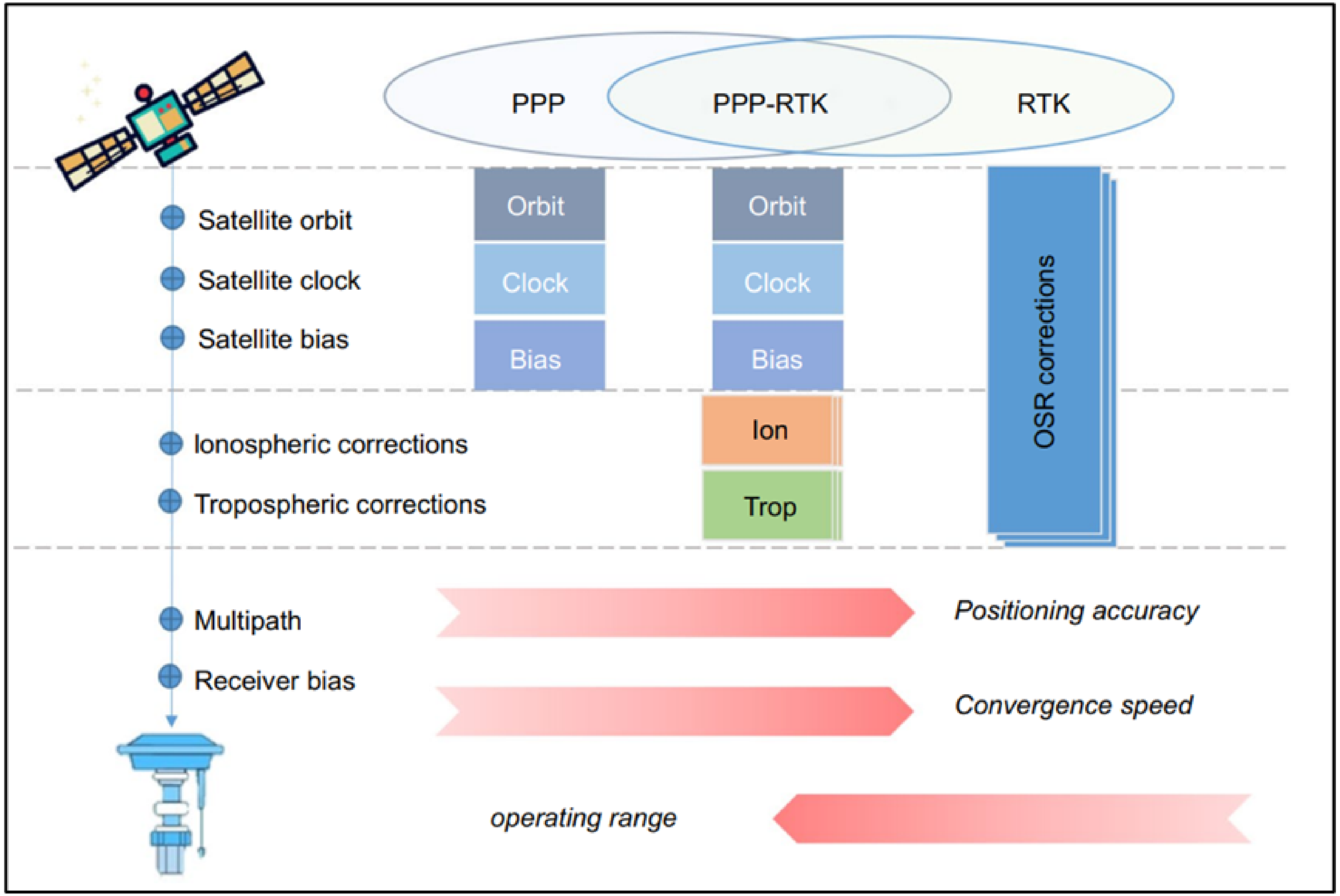
Source: https://geodesy.noaa.gov/datums/newdatums/WhatToExpect.shtml

Task 1: Real-Time Precise Point Positioning (PPP)

- **Objectives:** Develop Accurate and Reliable Real-Time Precise Point Positioning within the NSRS
- **Team:** Brian Weaver (OSU, Lead), Jihye Park (OSU), Chase Simpson (OSU), Muge Albayrak (OSU), Althaf Azeez (OSU), Josh Jones (NGS SME)
- **Current Focus Areas:**
  - Investigating open-source PPP/PPP-AR software
  - Testing new PPP stochastic model
    - Including using data from recent geomagnetic storm
  - Implementing existing real-time PPP-AR products in offline mode
  - Develop/implement PPP-RTK model
    - Multi-station network
    - Single-station user



High-Accuracy Positioning Techniques



Source: Li et al. (2022)

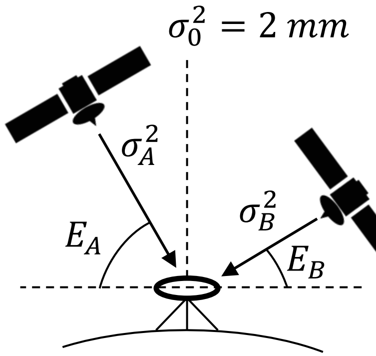
PPP-RTK Developments

- Ionosphere-free → Undifferenced/Uncombined
- Single-system → Multi-system
- Dual-frequency → Multi-frequency
- Float ambiguity → Rapid fixed ambiguity

Stochastic Model Comparison

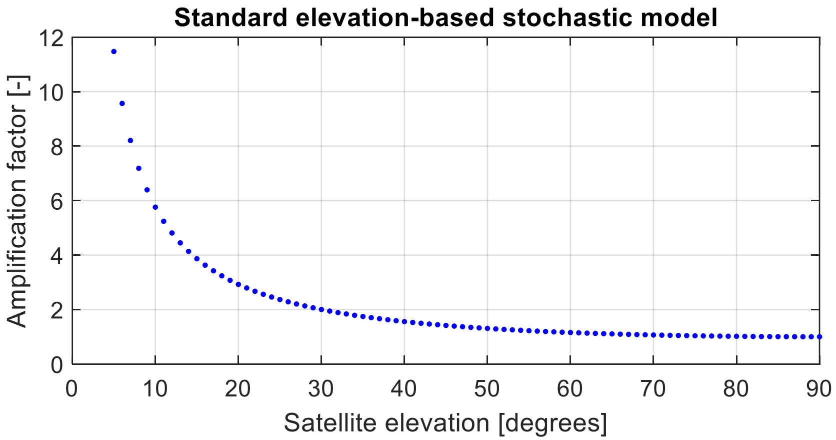
- Standard method limitations

Elevation-Based



$$\boldsymbol{\sigma_A^2} = \boldsymbol{\sigma_0^2} \cdot \left(\mathbf{1}/\boldsymbol{sin(E_A)}\right)^{\mathbf{2}}$$

$$\boldsymbol{\sigma_B^2} = \boldsymbol{\sigma_0^2} \cdot \left(\mathbf{1}/\boldsymbol{sin(E_B)}\right)^{\mathbf{2}}$$



Symmetric model

Limited noise amplification ($5.8 \cdot \sigma_0^2$ at 10-degrees)

σ_0^2 is non-trivial:

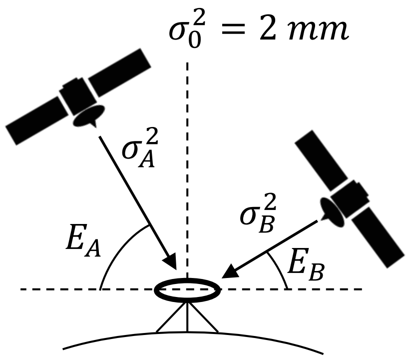
- GNSS constellations: GPS vs. Galileo
- Signals: L2P vs L2C
- Satellite generations: Block II vs. Block III
- Receivers, antennas: Geodetic vs. Low-cost

Stochastic Model Comparison

- Standard vs proposed method

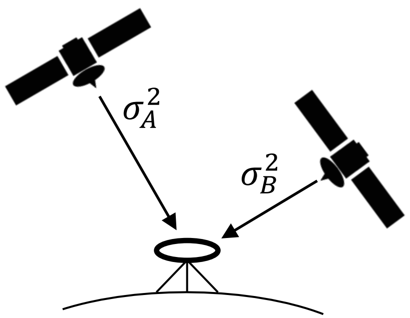
“stochastic models that are unable to adapt to the dynamic nature of GNSS signal propagation conditions can lead to additional inaccuracies that may exacerbate the challenges introduced by cycle slips.”

Elevation-Based



$$\boldsymbol{\sigma_A^2 = \sigma_0^2 \cdot \left({}^{1}/_{sin(E_A)}\right)^2}$$
$$\boldsymbol{\sigma_B^2 = \sigma_0^2 \cdot \left({}^{1}/_{sin(E_B)}\right)^2}$$

Data-Driven



$$\boldsymbol{\sigma_A^2 = f(\sigma_{MWWL}^2, \sigma_{IONO}^2)}$$
$$\boldsymbol{\sigma_B^2 = f(\sigma_{MWWL}^2, \sigma_{IONO}^2)}$$

Next Steps and Outlook

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- Next, validate in positioning domain
  - Static and **kinematic** PPP/PPP-AR performance
  - Implement new algorithms in PPP-ARISEN
- Ongoing research
  - Explore variables that affect the stochastic model: signals, data rate, receiver/antenna type
  - Incorporate in **real-time processing** (high-rate data)

```
> 11580.000 (04/22/2023 03:13:00): GREC = 31, G =  8, R =  9, E =  5, C =  9
```

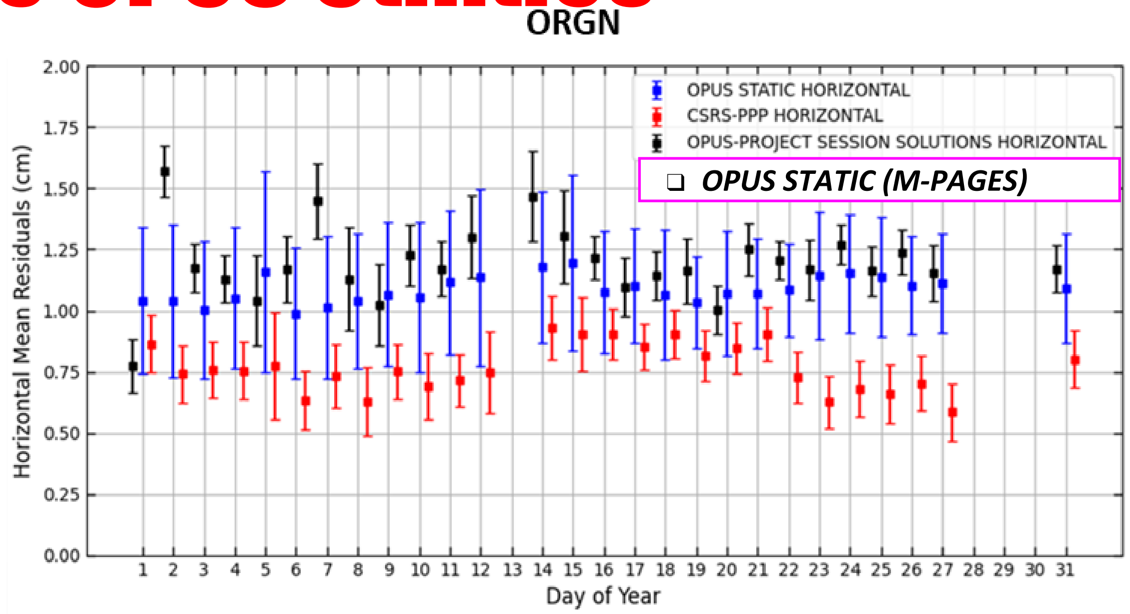
G02,	40.277,	104.501,	34.523,	3.921,	0,	0.496,	0.339,	0.019,	0.314,	0,	0.773,	3.093,	0
G08,	44.609,	287.942,	10.691,	2.784,	0,	-0.062,	0.109,	0.048,	0.223,	0,	0.226,	0.975,	0
G10,	50.021,	183.182,	15.033,	2.527,	0,	0.000,	0.141,	0.032,	0.203,	0,	0.015,	1.353,	0
G15,	30.492,	54.425,	35.343,	12.813,	0,	-0.048,	0.406,	0.136,	1.028,	0,	0.155,	3.285,	0
G16,	20.492,	219.140,	65.921,	3.474,	0,	-0.955,	0.888,	0.018,	0.279,	0,	0.943,	5.886,	0
G18,	37.009,	98.255,	27.027,	6.950,	0,	0.278,	0.357,	0.146,	0.557,	0,	0.029,	2.462,	0
G23,	63.650,	113.936,	10.913,	3.031,	0,	-0.003,	0.125,	0.021,	0.243,	0,	0.205,	0.998,	0
G27,	64.605,	230.771,	9.440,	1.608,	0,	-0.187,	0.155,	0.015,	0.129,	0,	0.082,	0.850,	0

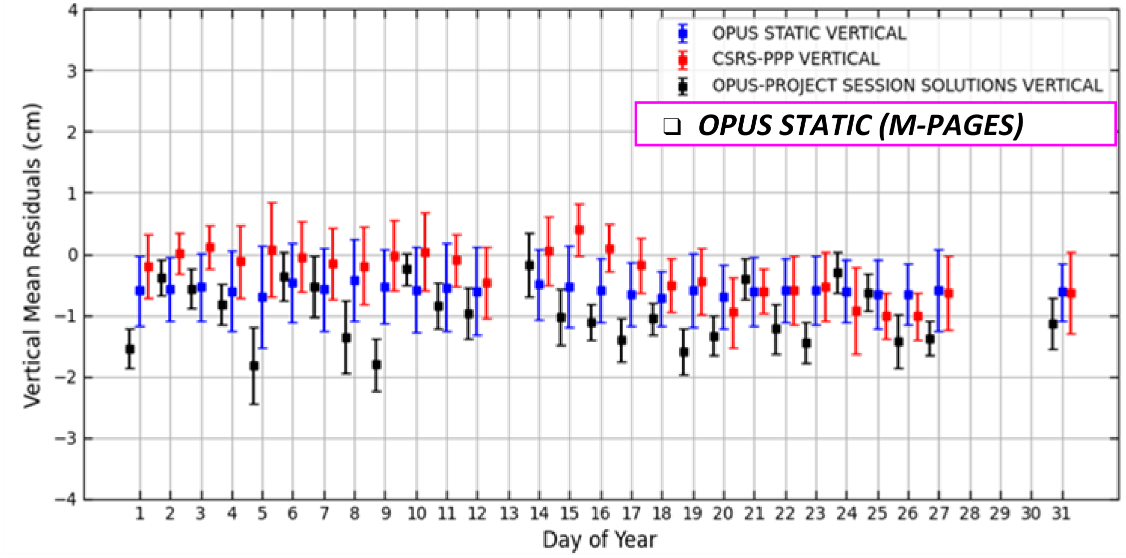
Code noise [cm] *Phase noise [mm]*

PPP-ARISEN

Task 4: Develop and Evaluate OPUS Utilities

- **Objectives:** Evaluate and develop new capabilities in OPUS-related utilities to enhance users' access to GNSS processing tools
- **Team:** Brian Weaver (Lead,OSU), Chase Simpson (co-Lead, OSU), William Ohene (OSU), Ezra Che (OSU), Nick Forfinski-Sarkozi (NGS SME)
- **Current Focus Areas:**
  - Evaluate multi-GNSS M-PAGES software performance via OPUS-Static beta
    - Test challenging test data with known non-ideal conditions
  - Develop optimal constraints for network adjustments
    - Combined GNSS, Total Station, Leveling data
  - Collaborate with OPUS team to implement GCAP outcomes in OPUS/OPUS-Projects





Source: Ohene (2023)
[https://ir.library.oregonstate.edu/]

Multi-GNSS Background

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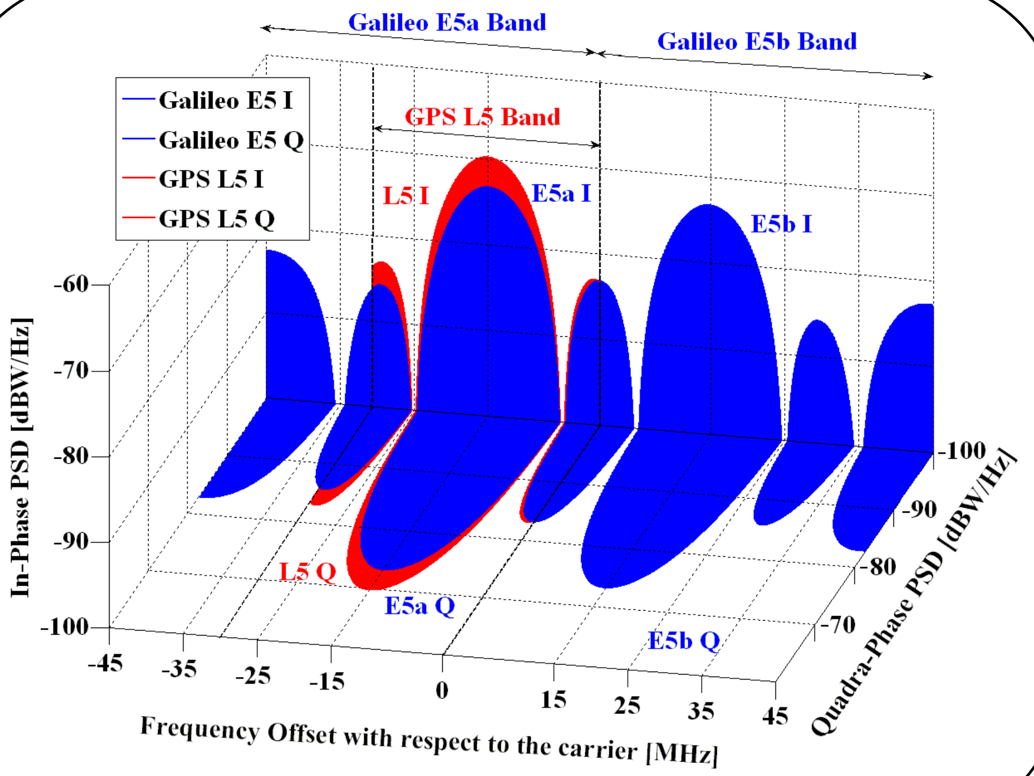
Environment

- Global Positioning System (GPS) (1995)
- GLONASS (1995)
- Galileo (2016)
- BeiDou (2003)

Benefits

- Superior DOP: Daily satellites > 100; Single-epoch > 40
- Reduced noise: ~3x more transmission power
- Enhanced reliability: Access to new signals/frequencies



Source: Navipedia

Processing Combinations

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Evaluations				
Processing engine	PAGES	M-PAGES		
Constellation	GPS (G)	GLONASS (R)	Galileo (E)	BeiDou (C)
Duration	Minutes	Hours	Days	
Network stations	Old CORS selection	New CORS selection		
User stations	ORGN	NCRTN		
Day of year	1-day	7-day	21-day	31-day

Selected Combinations

Evaluations				
Processing engine	PAGES	M-PAGES		
Constellation	GPS (G)	GLONASS (R)	Galileo (E)	BeiDou (C)
Duration	Minutes	Hours	Days	
Network stations	Old CORS selection	New CORS selection		
User stations	ORGN	NCRTN		
Day of year	1-day	7-day	21-day	31-day

Selected Combinations

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Variable	Selection	Count
Processing engine	PAGES, MPAGES	2
Constellation(s)	G, GR, GE, GRE	4
Durations	2, 4, 8, 12, 18, 24-hr	6
User stations	ORGN (subset)	59
Day of year	January 2023	31

10,974 combinations

Total files to process: 54,870

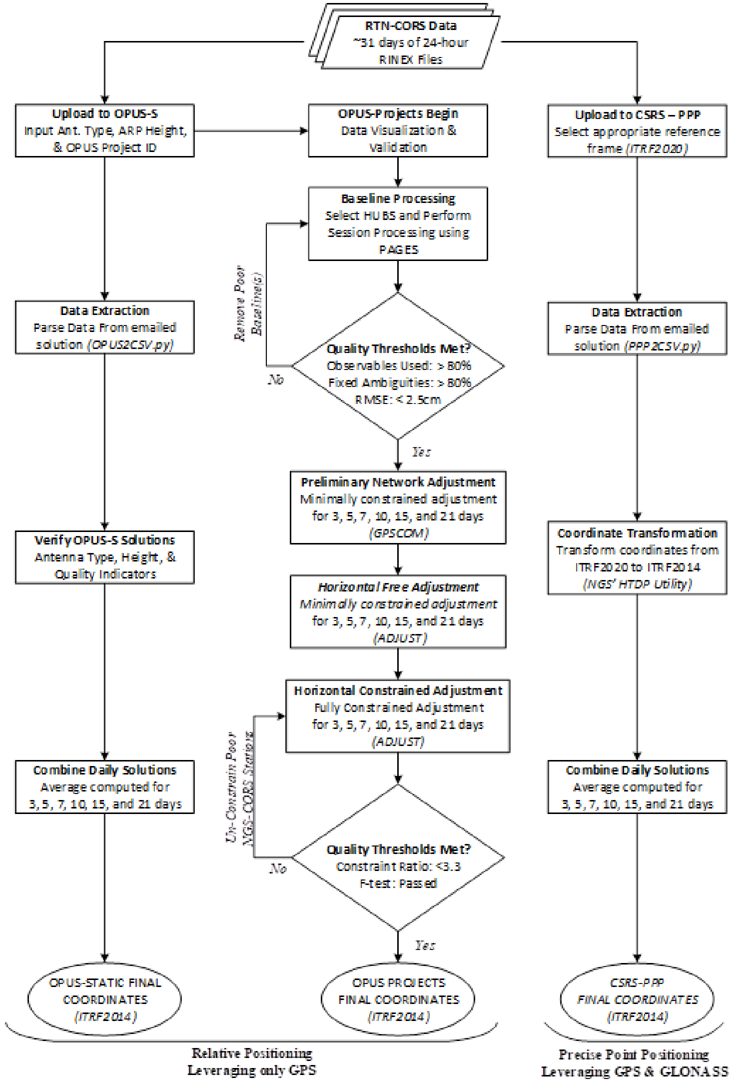
- MPAGES + PAGES: [10,974 * 4 systems] + [10,974 * 1 systems]

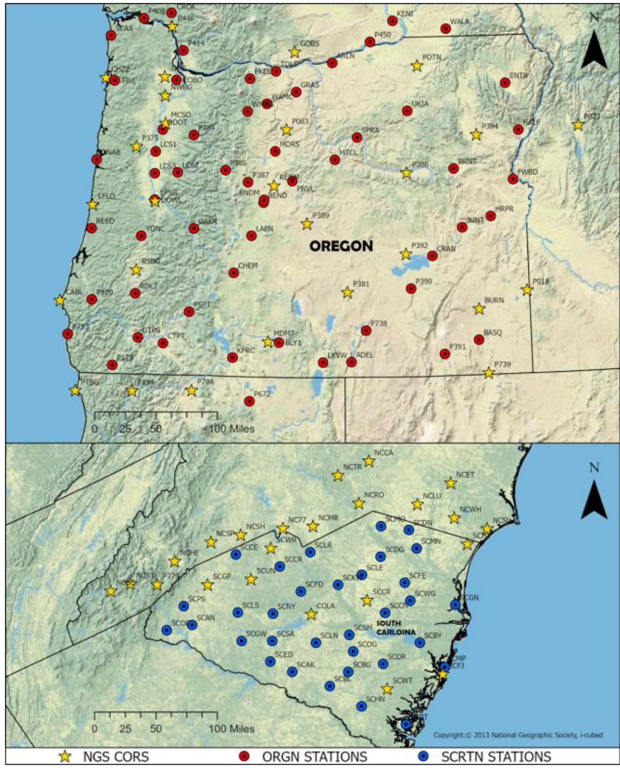
GPS, GLONASS, Galileo, Beidou

GPS Only

Task 5: Develop a National RTN Alignment Service

- **Objectives:** Develop a national service for RTN operators/ managers to utilize to ensure their networks are consistently aligned with the NSRS
  - Support for non-NGS CORS alignment
- **Team:** Chase Simpson (OSU, Lead), Brian Weaver (OSU), Ben Hocker (Yurok), William Ohene (OSU)
  - Dan Gillins (NGS SME)
- **Current Focus Areas:**
  - Exploration of alternative methods to monitor Real-Time Network (RTN) health
  - Develop a semi-automatic workflow for aligning RTNs to the NSRS
  - Create an accessible web-based interface to empower surveying practitioners and RTN managers with real-time network alignment information





Evaluate common methods for Aligning RTN's to the NSRS.

Investigate Methods for Monitoring RTN CORS alignment to the NSRS.

Perform a comprehensive comparison of PPP and relative baseline processing approaches for aligning and monitoring RTN CORS

Provide NOAA NGS with recommendations to assist in the development of a new Tier of CORS (aka "Aligned CORS Network")

Alignment Methods: OPUS & CSRS

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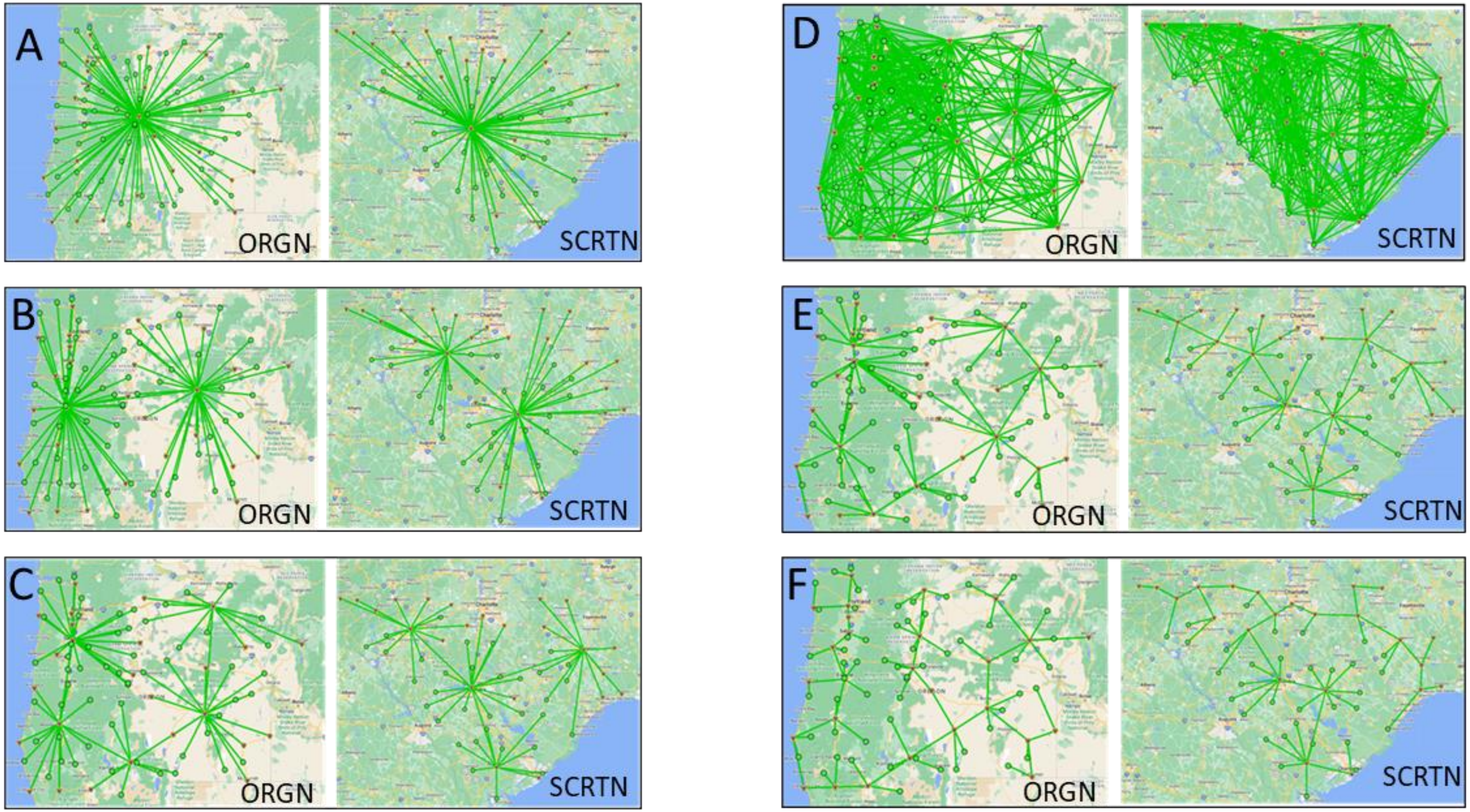
Methods Evaluated:

Service Name	Positioning Technique	Satellites	Elevation Cutoff	Orbit Source	Managed by
OPUS -Static	Relative	GPS only	10°	IGS	NGS
OPUS - Projects	Relative	GPS only	10°	IGS	NGS
CSRS - PPP	PPP	GPS & GLONASS	7.5°	IGS & NRCan	NRCan

- **Number of days**: 3, 5 , 7, 10 ,15 & 21

Network Geometry Evaluation

Workflow: OPUS-Projects Session Network Design



Network Geometry Results

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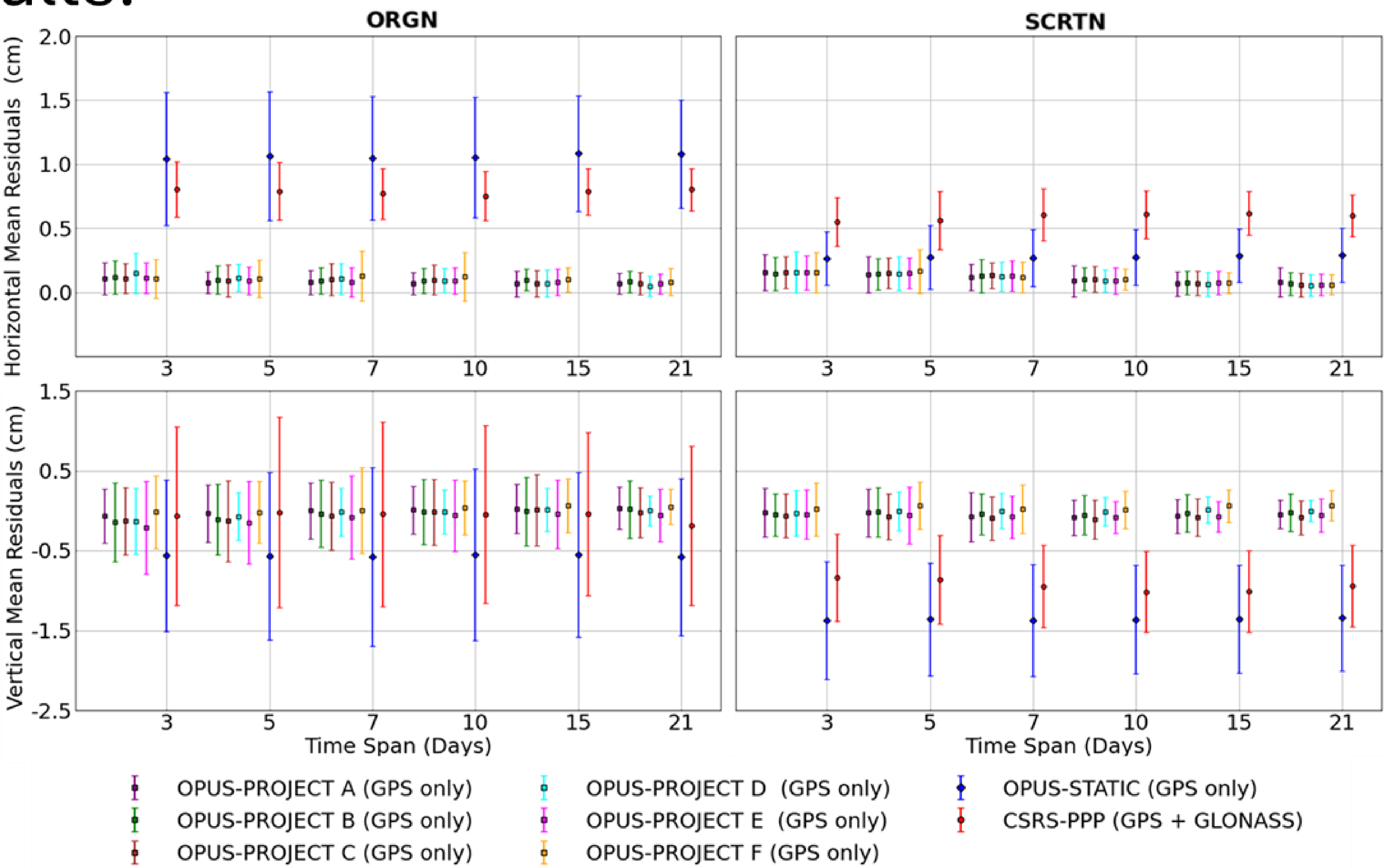
Results:



Time Span Results

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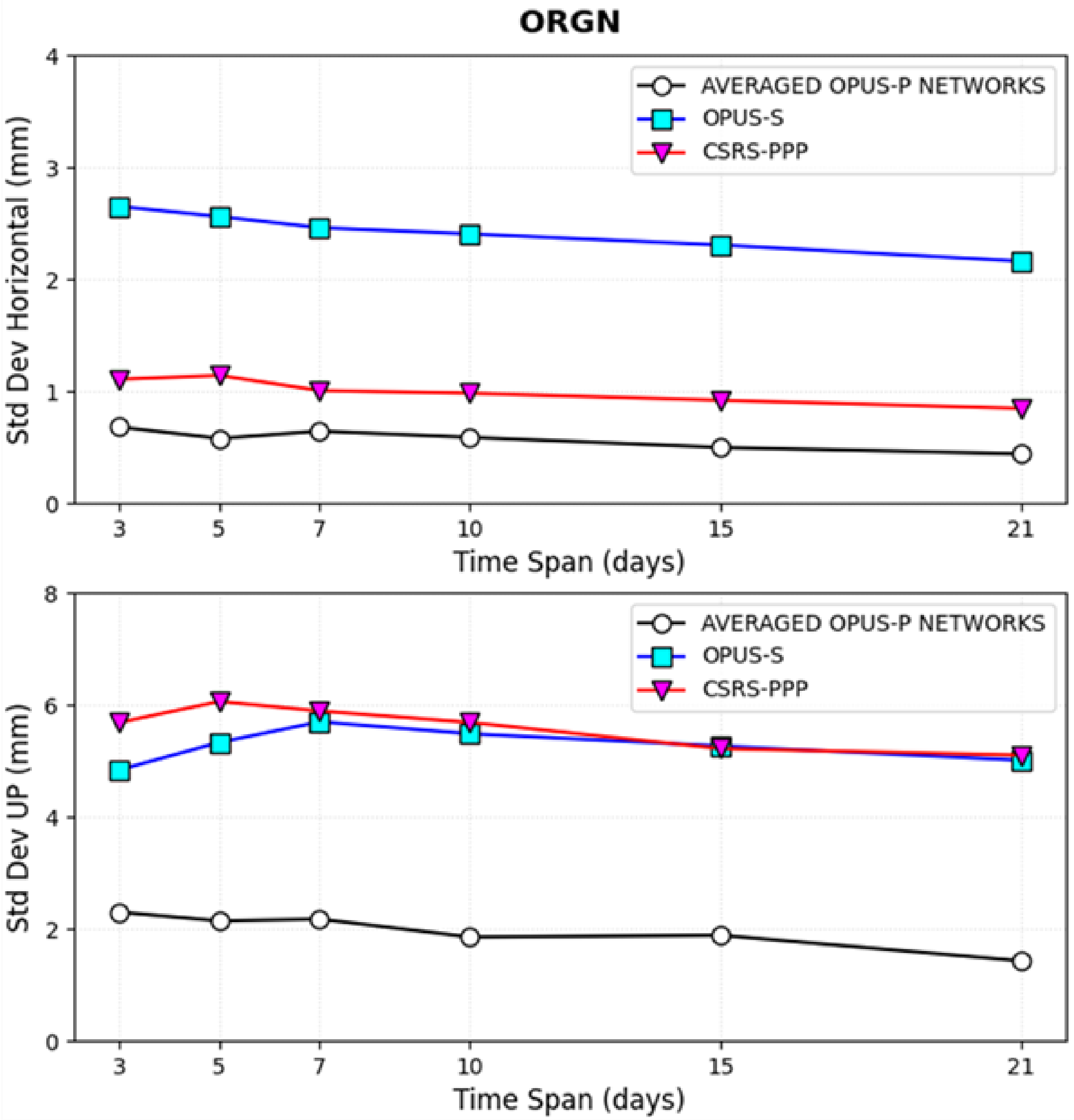
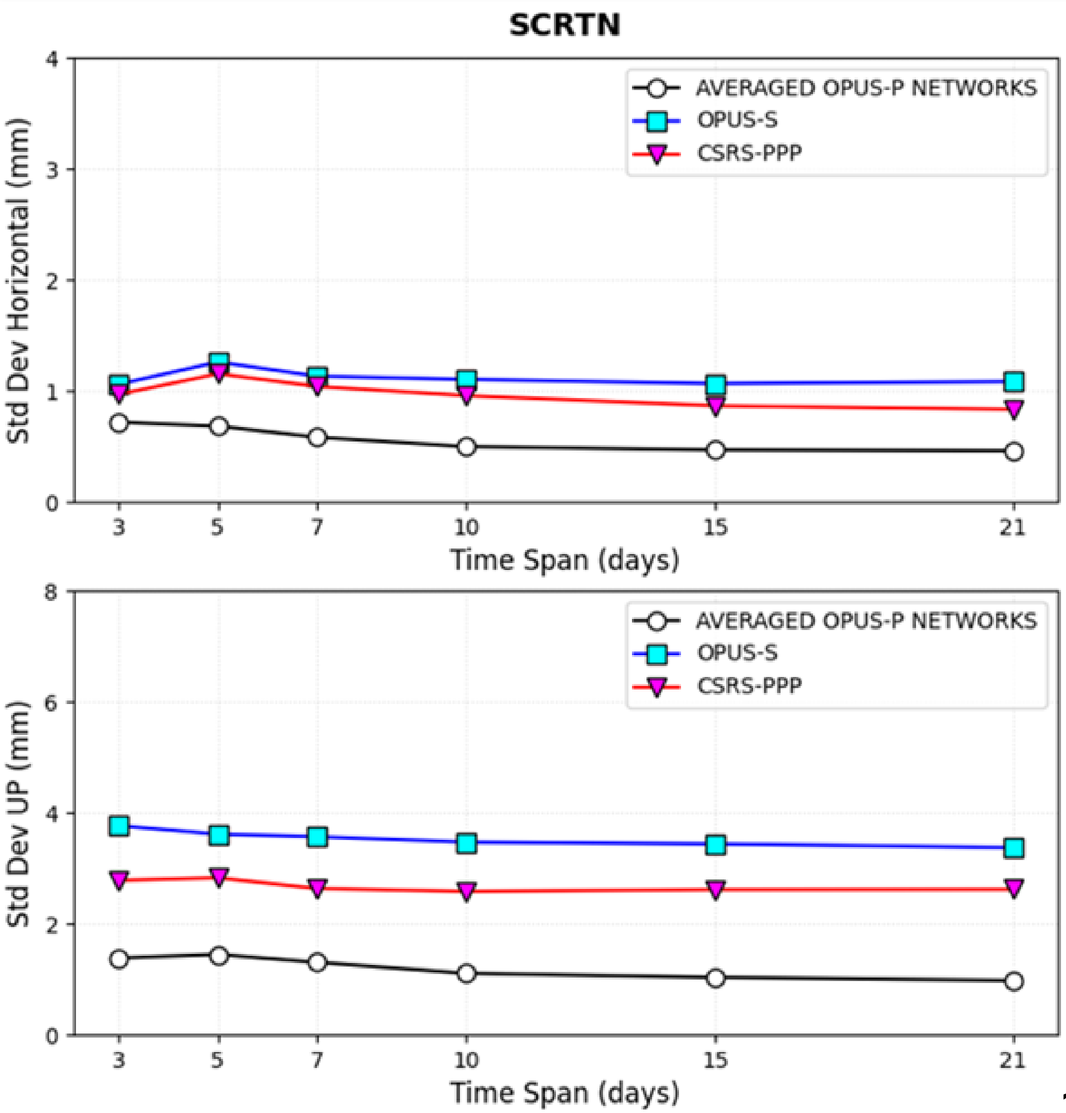
Results:





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Evaluate common methods for Aligning RTN’s to the NSRS.

Investigate Methods for Monitoring RTN CORS alignment to the NSRS.

Perform a comprehensive comparison of PPP and relative baseline processing approaches for aligning and monitoring RTN CORS

Provide NOAA NGS with recommendations to assist in the development of a new Tier of CORS (aka “Aligned CORS Network”)

Tiered CORS & Alignment

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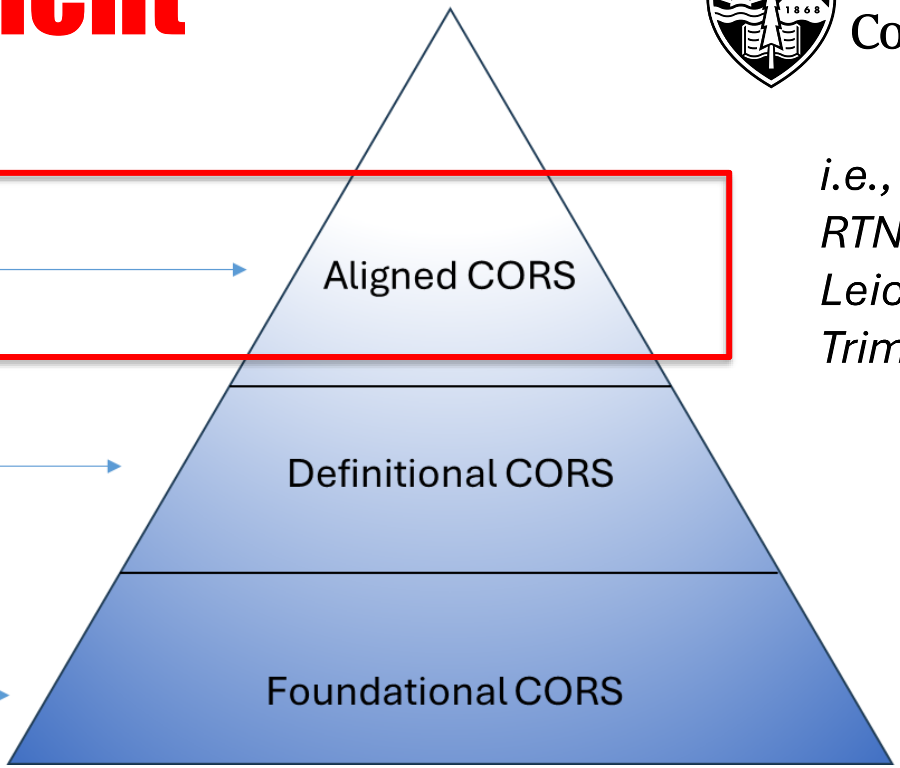
Specifications & Purpose:

Simply process their data; align to NSRS; do not store data or QA/QC

Good stations for defining reference frames; store data; perform QA/QC

Highest quality stations; store data; perform QA/QC; maintain

Courtesy: Dan Gillins



i.e., Earthscope, RTN managers, Leica Smartnet, Trimble VRS, etc.

- Scale-up the semi-automated workflow
- Explore alternative processing methods (OPUS alternatives)
- Establish a recommended CORS data sharing
- Evaluate PPP vs Relative Baseline Processing
- Publish key findings and additional recommendations;

June 2024 **[Proposed Timeline]** **December 2024**

Aligning to the NSRS: Data Sharing Guidelines

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- Adopting standards to maintain consistency of automated alignment workflow
- Utilizing the observation RINEX header to parse all necessary information for alignment
- Consistent and descriptive naming convention & compression scheme
- Positions relative to the Antenna reference Point
- RINEX v3 formatted observation files (enables logging of modern frequencies and observation codes)

Table 1. NGS requirements for station submission to be aligned with the ACORS network.

1.	**Daily (24-hour) observation period**
2.	**30-second observation frequency (data sampling)**
3.	**Antenna header information including:**
i.	**Antenna type**
ii.	**Approximate XYZ location of antenna reference point (ARP)**
iii.	**ARP position offset (Height, Easting, Northing)**
4.	**Hatanaka compressed RINEX *with* additional .gz compression**
5.	**IGS long filename convention**
6.	**Observation file shared to NGS**

```
3.0                 COMPACT RINEX FORMAT                CRINEX VERS   / TYPE
RNX2CRX ver.4.1.0                       08-Apr-24 00:20     CRINEX PROG / DATE
     3.04           OBSERVATION DATA    M                   RINEX VERSION / TYPE
sbf2rin-15.6.1                          20240408 001450 UTC PGM / RUN BY / DATE
USN7                                                        MARKER NAME
404515009                                                   MARKER NUMBER
roof                                                        MARKER TYPE
GGN                 USNO                                    OBSERVER / AGENCY
3013939             SEPT POLARX5TR      5.5.0               REC # / TYPE / VERS
762-11615           TPSCR.G5        TPSH                    ANT # / TYPE
  1112162.1360 -4842854.6620  3985497.0649                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
```

REQUIRED HEADER INFORMATION:
Receiver # / type / version
Antenna # / type
ARP position XYZ
ARP position offset

Figure 5. Receiver and antenna information provided in RINEX v3.xx formatted observation file for station USN7.

1. **24-hours (01 day)** of data from station *CORV*, **January 1st, 2024**, **starting 00:00** (GPS time) **30-second observation frequency** (data sampling rate), **mixed observations**, **Hatanaka compressed RINEX (crx), Gzip compressed (gz)**.

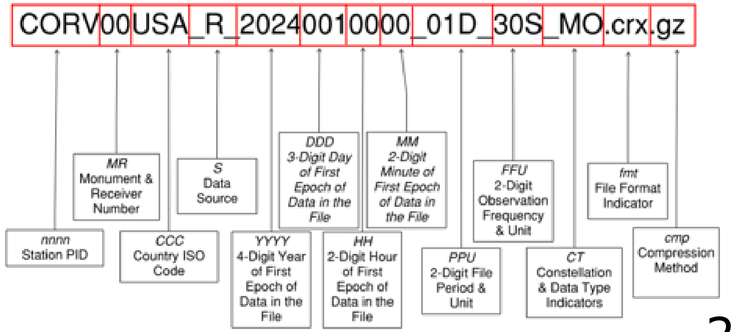

Figure 2. Accepted RINEX formatted observation file for CORS station CORV (located in Corvallis, Oregon).

Aligning to the NSRS: Efficiencies

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- Compression schemes/methods for both consistency and efficiency
- Small directory size *in* and small file size *out*
- Integral for higher-scaled station and network alignment

Table 4. Compression percentages and storage efficiencies of individual or combined compression schemes.

Compression & Data Storage Efficiencies	Total GB	Compression (%)
No Compression (.o)	*13.9*	*N/A*
Hatanaka Only (.crx)	*4.6*	*66.9% decrease*
Gzip Only (.gz)	*4.5*	*67.6% decrease*
Hatanaka & Gzip (.crx.gz)	*1.8*	*87.1% decrease*

Figure 12. Non-compact formatted RINEX observation data section for station AMC4.

Figure 13. Compact formatted RINEX observation data section for station AMC4.

Accuracy & Efficiency: Task 5 Experiment

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- Proposed experiment to further explore accuracy of PPP and relative baseline processing within the modernized NSRS

- Expand study by looking into efficiencies of methodologies for networks comprised of 10,000s of stations

- Efficiencies include time to solution (TTS), computational demand, human involvement w.r.t automation

- ***Purpose is to align networks to accommodate for real-time & close to real-time needs while simultaneously assessing station coordinate accuracy relative to the NSRS)***

Exploring Processing Methods: PPP & Differential

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Courtesy: Brian Weaver

PPP

Single-station

$$\begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix} \quad \begin{bmatrix} \sigma_X^2 & \cdots & \cdots \\ \sigma_{XY}^2 & \sigma_Y^2 & \cdots \\ \sigma_{XZ}^2 & \sigma_{YZ}^2 & \sigma_Z^2 \end{bmatrix}$$

Multi-station

$$\begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix} \quad \begin{bmatrix} \sigma_X^2 & \cdots & \cdots \\ \sigma_{XY}^2 & \sigma_Y^2 & \cdots \\ \sigma_{XZ}^2 & \sigma_{YZ}^2 & \sigma_Z^2 \end{bmatrix}$$

$$\begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix} \quad \begin{bmatrix} \sigma_X^2 & \cdots & \cdots \\ \sigma_{XY}^2 & \sigma_Y^2 & \cdots \\ \sigma_{XZ}^2 & \sigma_{YZ}^2 & \sigma_Z^2 \end{bmatrix}$$

Notes:

- Stations are not correlated (independent)
- Supports parallel processing
- Errors at one station do not affect other stations
- Problem grows linearly with number of stations

Differential

Single-baseline

$$\begin{bmatrix} \Delta X_{AB} \\ \Delta Y_{AB} \\ \Delta Z_{AB} \end{bmatrix} \quad \begin{bmatrix} \sigma_{\Delta X,AB}^2 & \cdots & \cdots \\ \sigma_{\Delta XY,AB}^2 & \sigma_{\Delta Y,AB}^2 & \cdots \\ \sigma_{\Delta XZ,AB}^2 & \sigma_{\Delta YZ,AB}^2 & \sigma_{\Delta Z,AB}^2 \end{bmatrix}$$

Note:

$$\begin{bmatrix} \Delta X_{AB} \\ \Delta Y_{AB} \\ \Delta Z_{AB} \end{bmatrix} = \begin{bmatrix} X_A - X_B \\ Y_A - Y_B \\ Z_A - Z_B \end{bmatrix}$$

Multi-baseline

$$\begin{bmatrix} \Delta X_{AB} \\ \Delta Y_{AB} \\ \Delta Z_{AB} \\ \Delta X_{AC} \\ \Delta Y_{AC} \\ \Delta Z_{AC} \end{bmatrix} \quad \begin{bmatrix} \sigma_{\Delta X,AB}^2 & \sigma_{\Delta YX,AB}^2 & \sigma_{\Delta ZX,AB}^2 & 0 & 0 & 0 \\ \sigma_{\Delta XY,AB}^2 & \sigma_{\Delta Y,AB}^2 & \sigma_{\Delta ZY,AB}^2 & 0 & 0 & 0 \\ \sigma_{\Delta XZ,AB}^2 & \sigma_{\Delta YZ,AB}^2 & \sigma_{\Delta Z,AB}^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sigma_{\Delta X,AC}^2 & \sigma_{\Delta YX,AC}^2 & \sigma_{\Delta ZX,AC}^2 \\ 0 & 0 & 0 & \sigma_{\Delta XY,AC}^2 & \sigma_{\Delta Y,AC}^2 & \sigma_{\Delta ZY,AC}^2 \\ 0 & 0 & 0 & \sigma_{\Delta XZ,AC}^2 & \sigma_{\Delta YZ,AC}^2 & \sigma_{\Delta Y,AC}^2 \end{bmatrix}$$

Notes:

- Stations are correlated (dependent); baselines are independent
- Does not support parallel processing
- Errors at one station affect other stations
- Problem grows as the square of the number of stations

JPL's GIPSYX Processing Software

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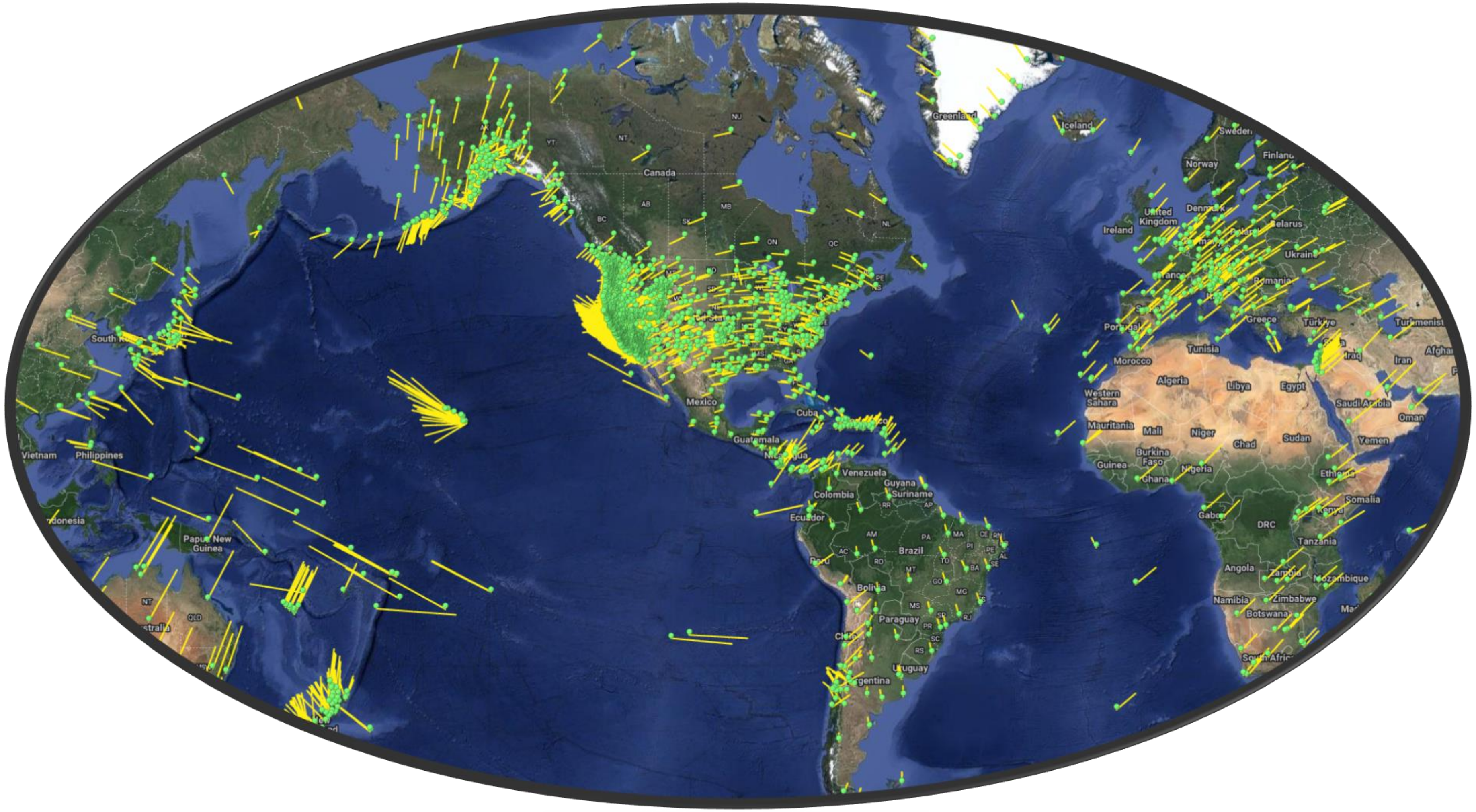
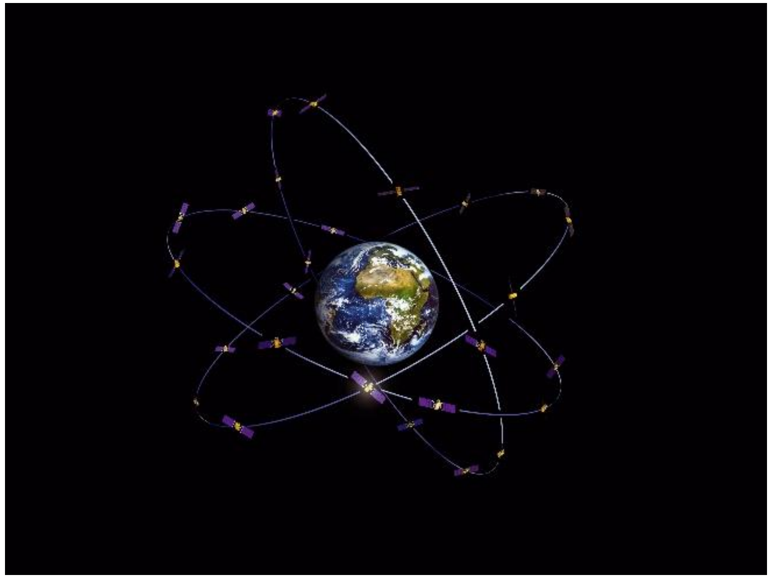
- A potential alternative to NSRS alignment and network solutions
- A QA/QC tool for solutions derived from OPUS
- Existing automated workflows (Network Processor)
- Currently automated to process PPP solutions
- GIPSYX has proven capabilities to process over 2,000 stations to derive network solutions (on a weekly basis)

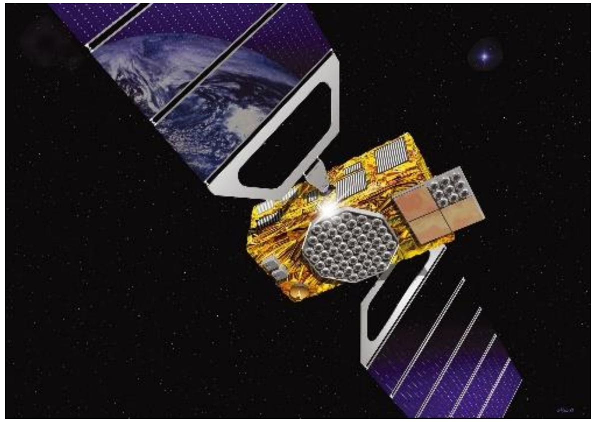


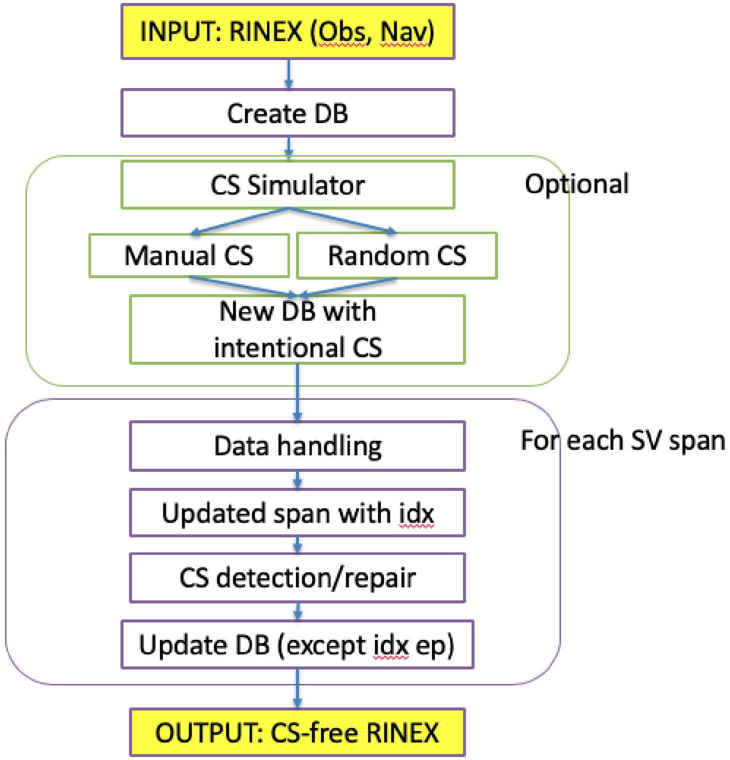
Source: https://sideshow.jpl.nasa.gov/post/series.html

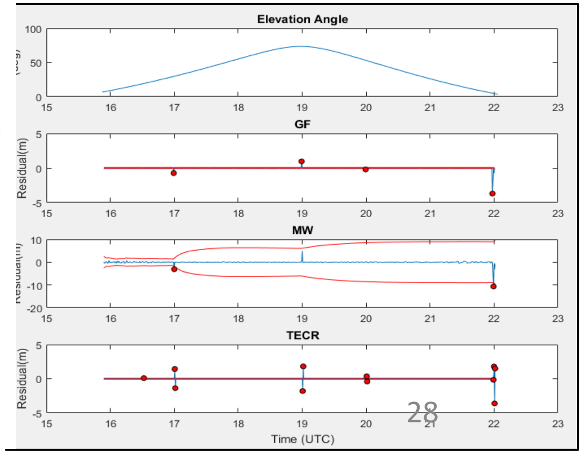
Task 6: Multi-GNSS

- **Objectives:** Assist in the Development and Testing of Multi-GNSS Processing Service
- **Team:** Jihye Park (OSU, Lead),Brian Weaver (OSU), Chase Simpson (OSU), Althaf Azeez (OSU), Mike Olsen (OSU), Muge Albayrak (OSU) Caixia Wang (UAA)
- **Current Focus Areas:**
    - Cycle Slip detection and repair for multi-constellation, multi-frequency GNSS observations
    - To investigate a robust CS algorithm for low sampling rate GNSS preprocessing
    - Outlier detection and support NGS's OPUS-Static pre-processing functionality









Proposed Timeline for Task 6

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- Part A: CS detection and repair (FY24-25)
  - Tuning ORCyder (ORegon state university Cycle slip detection and repair)
- Part B: AR (FY25-26)
  - AR methods for 30 sec and multi-constellation, multi-frequency data
  - Interested in PPP Post-Processing Kinematic performance
- Part C: POD (FY26-27)
  - Overlap with Task 1
- Part D: Atmospheric Correction (FY27-28)
  - Interested in both meteorological and ionospheric corrections for positioning improvement

Task Overlap & Shared Results

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College of Engineering

- All tasks are correlated in one way or another
- Iterative results (used to enhance or enable research within other tasks)
- Findings enable collaborative structure or sub-task re-evaluation (redundancy or diversity of expanding research)
- Several potential studies to emerge from tasks and ultimately support the objectives of GCAP (improve the National Spatial Reference System (NSRS) and to enhance workforce development and geodetic science)

"Standing on the shoulders of giants"

Image Source: Dr. Lim Wee Chai

Acknowledgments

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Task 1:

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Task 4 & 5:

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Questions?

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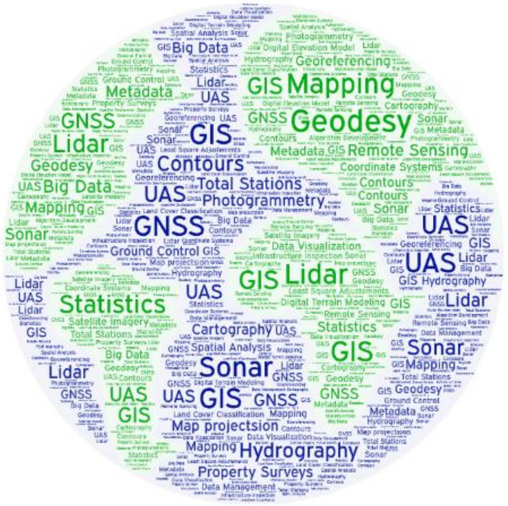
Thank you!

OSU Pursuing New BSc in Geodesy, Geomatics, and Geospatial Engineering (3xGE)



- Currently in the exploratory phase
- Goal: Expand success of OSU's graduate program and undergrad minor in geomatics by adding new BSc program
- Help alleviate shortfall of geospatial professionals and geodesists in the US

Core Curriculum to include:

- Programming
- Reference Frames / Map Projections
- Geodesy
- GNSS
- Uncertainty Analysis
- Least Squares Adjustments
- Inertial Navigation and Timing

Additional Courses in:

- Cadastral Surveying
- Photogrammetry
- 3D Laser Scanning / Reality Capture
- Geodetic Surveying Methods
- Hydrographic Surveying
- GIS
- Electrical & Computer Engineering
- Computer Science