Project SPR 304-821

Research to Operation

Using the ORGN to Establish Project Control

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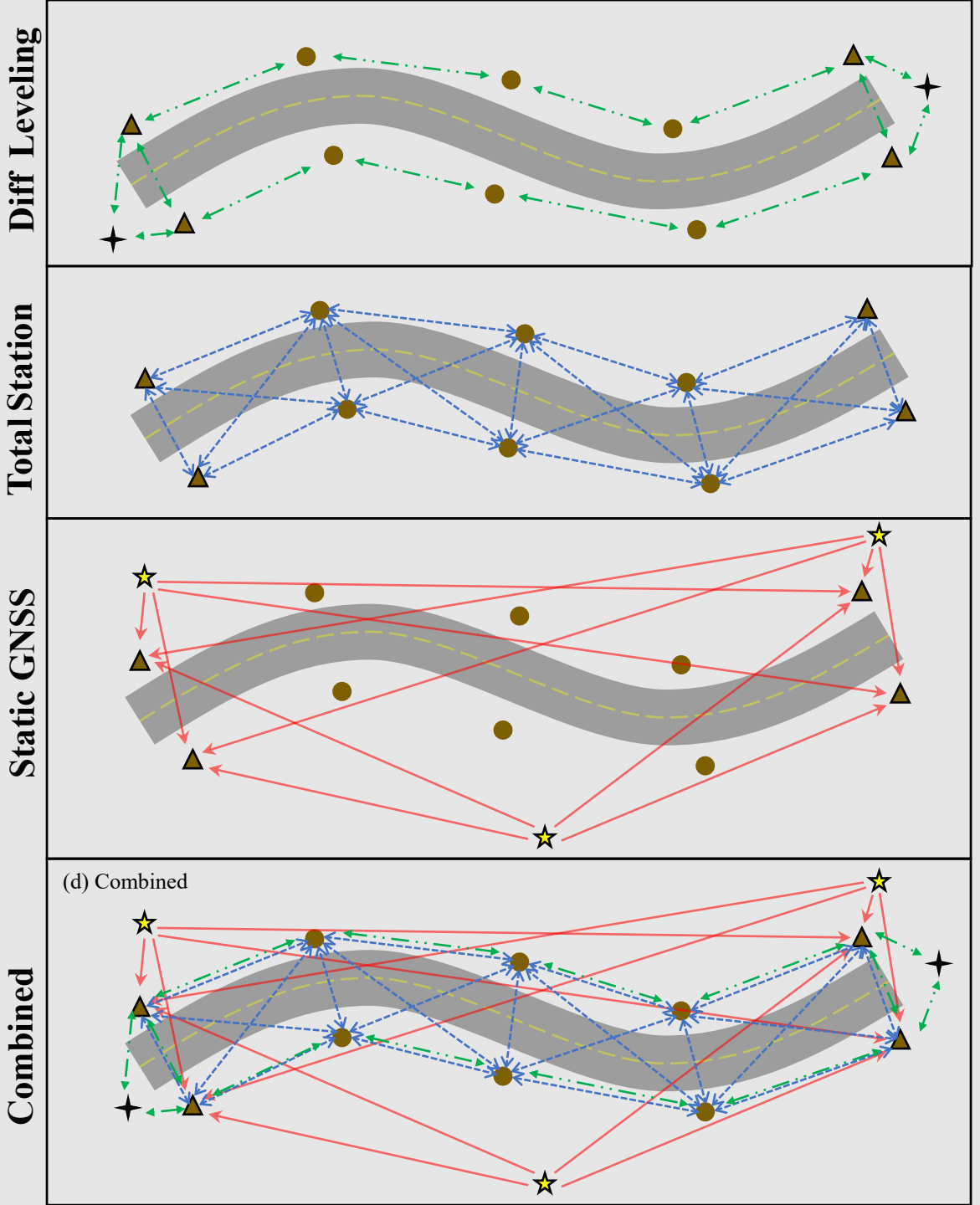
ODOT ENGINEERING AUTOMATION

Oregon State University

Motivation

- Current Procedures for establishing project control require:
  a) Differential Leveling;
  b) Total Station Network; and
  c) Static GNSS
- All combined.. That's a lot of work!



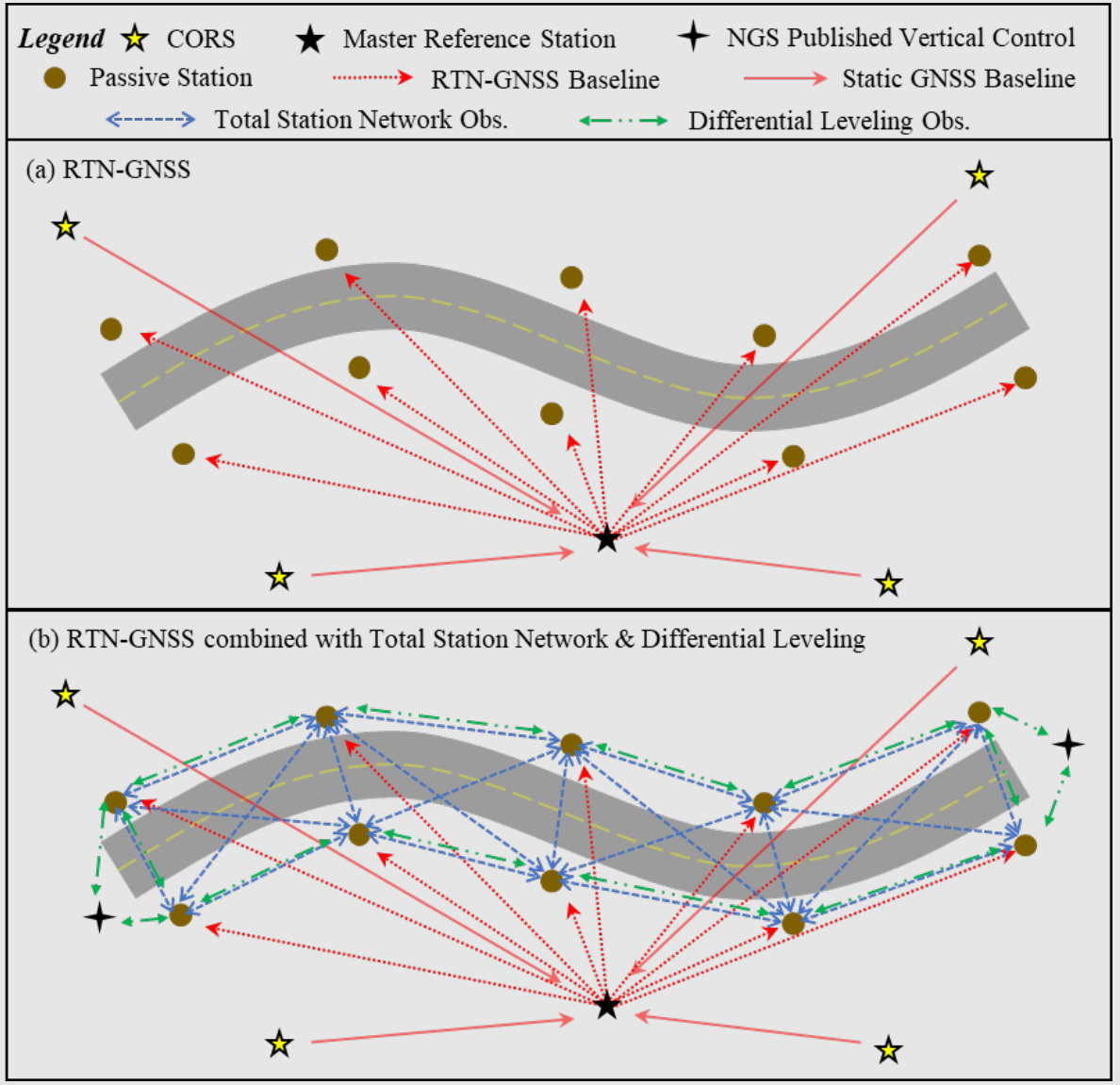
Research Objectives

1. Quantify and document real accuracies using the ORGN
2. Provide guidance for use of RTN GNSS data in Control Networks
3. Create accuracy/procedure matrix for ODOT Survey work

REQUIRED ORDER OF WORK	STANDARDS	ORGN NRTK RECOMMENDED SURVEY PROCEDURES	
	Horizontal & Vertical	Horizontal	Vertical
0.015 ft (0.005 m)	Network accuracy less than 0.015 feet (0.005m) scaled to a 95% Confidence Level	Not Recommended	Not Recommended
0.030 ft (0.010 m)	Network accuracy less than 0.030 feet (0.010 m) scaled to a 95% Confidence Level	(4) independent 5 minute NRTK observations* on each control station	Not Recommended
0.070 ft (0.020 m)	Network accuracy less than 0.070 feet (0.020 m) scaled to a 95% Confidence Level	(2) independent 5 minute NRTK observations* on each control station	(4) independent 5 minute NRTK observations* on each control station
0.100 ft (0.030 m)	Network accuracy less than 0.100 feet (0.030 m) scaled to a 95% Confidence Level	(2) independent 3 minute^ NRTK observations* on each control station	(2) independent 5 minute NRTK observations* on each control station
0.150 ft (0.040 m)	Network accuracy less than 0.150 feet (0.040 m) scaled to a 95% Confidence Level	(2) independent 1 minute^ NRTK observations* on each control station	(2) independent 3 minute^ NRTK observations* on each control station

Research Objectives

- Use only ORGN to establish control points
  - Most ideal way to increase efficiency
  - Might not be possible depending on spec
- Use ORGN in combination with TS and Leveling
  - Reduces the necessity of static GNSS



Previous Research Investigating the ORGN

- **Allahyari, M.,** Olsen, M.J., Gillins, D.T., Dennis, M.L., 2018. Tale of two RTNs: Rigorous evaluation of real-time network GNSS observations. J. Surv. Eng. 144. https://doi.org/10.1061/(ASCE)SU.1943-5428.0000249

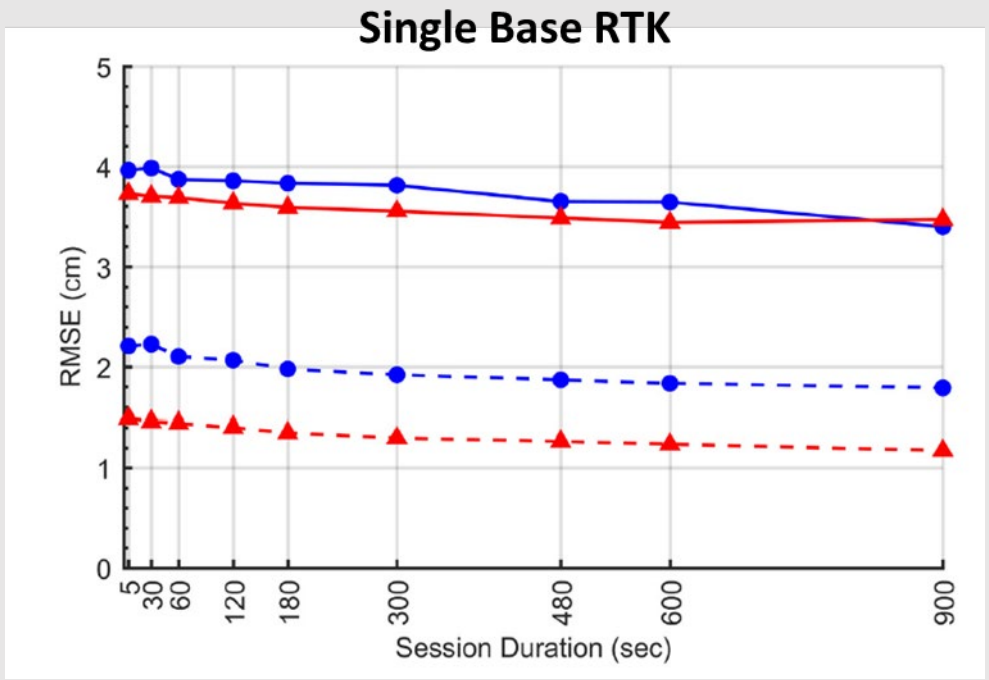
- **Weaver, B.**, Gillins, D.T., Dennis, M., 2018. Hybrid survey networks: Combining real-time and static GNSS observations for optimizing height Modernization. J. Surv. Eng. 144, 1–17. https://doi.org/10.1061/(ASCE)SU.1943-5428.0000244

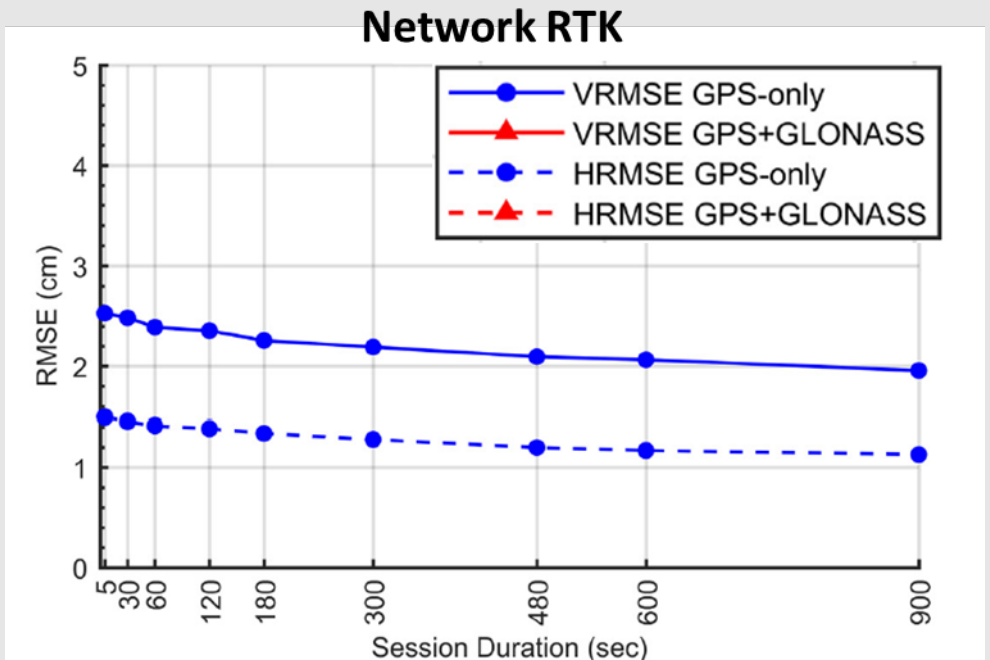
Real-Time Accuracies in Oregon

Single Base vs Network RTK

From work conducted at OSU by:

- **Allahyari, M., Gillins, D.T., Olsen, M.J., and Dennis, M. (2018)**
- Reported RMSE (68% confidence level)
- Assessed the accuracy of NRTK single base RTK as a function of observation duration
- GLONASS improved the accuracy of the observations and helped obtain more fixed solutions at longer baseline lengths.





Post-Processing Overview for RTN data

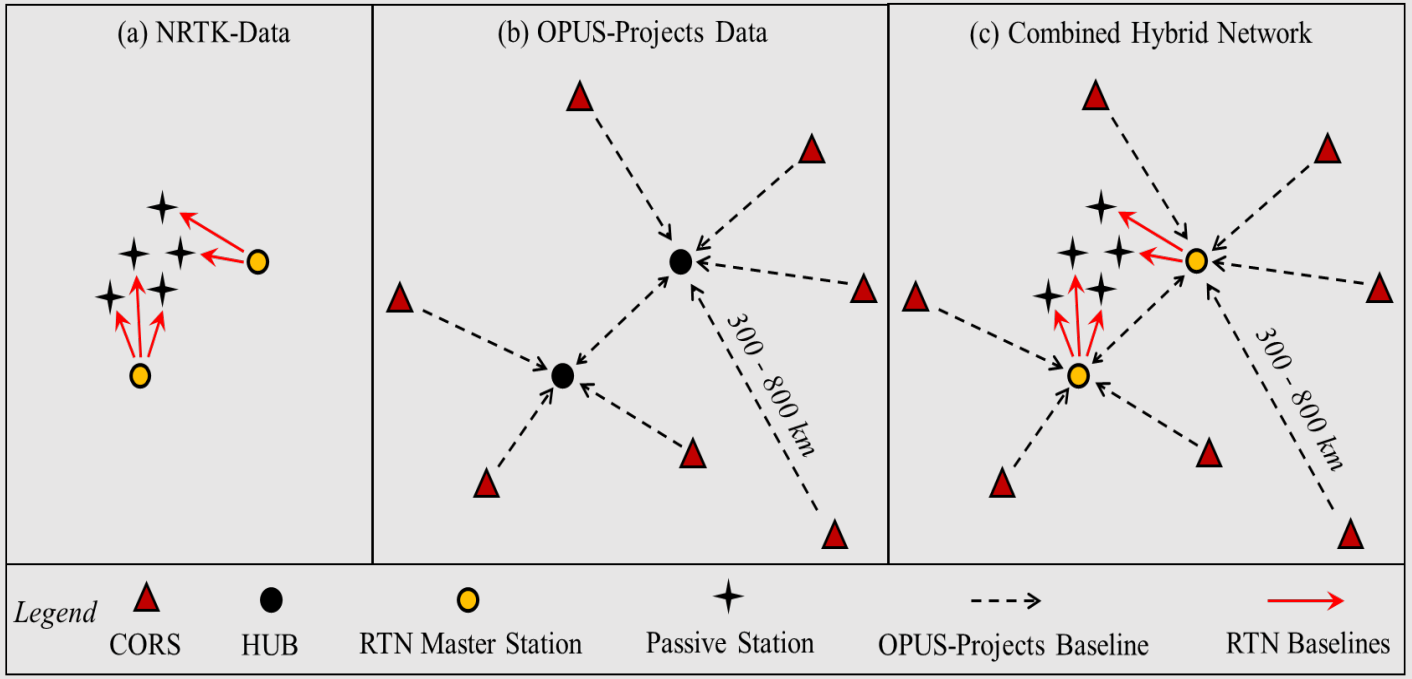
Hybrid GNSS Survey Network

1. Collect RTN Data
   - 5-minute observations per each independent observation
   - Need the baselines from the reference station to the passive marks

2. Align Master Station to NSRS via post-processing
   - Utilizes Static GNSS processing
   - Compute baselines from CORS to the real-time reference station

3. Create the "Hybrid Network"
   - Least squares adjustment
     - Static baselines from CORS to Master station
     - real-time network baselines from master station to survey marks

4. Done!
   - QA/QC the results, ensure everything was properly weighted, no outliers, etc. etc.



See the following articles for more details:

- ***Weaver et al., 2018****. Combining real-time and static GNSS observations for optimizing height Modernization.*
- ***Gillins et al., 2019.*** *Accuracy of GNSS Observations from Three Real-Time Networks in Maryland.*

Project Breakdown

Phase I: Determine capabilities of RTN-GNSS

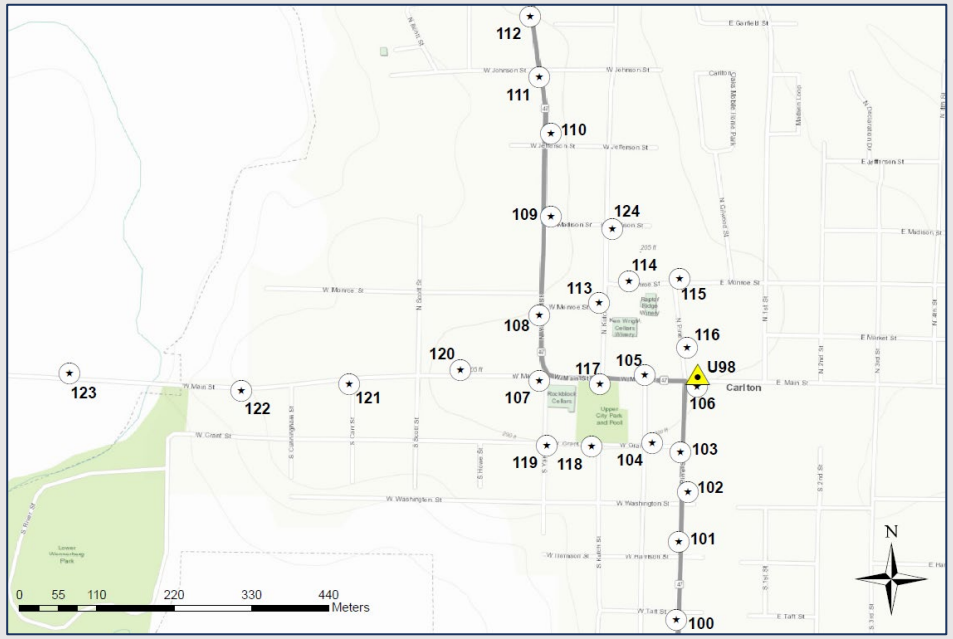
- How can we leverage the ORGN to increase efficiency and still meet our accuracy specs?
- How does the network accuracy vary as more observations are made?
- Does the change in time between repeat observations affect accuracy?

Phase II: Apply/Test accuracy standards from Phase I at a secondary location

- Do the results from Phase I apply to varying control network geometries?
- Can we minimize the amount of total station work required and still achieve our accuracy specs?

Areas of Interest

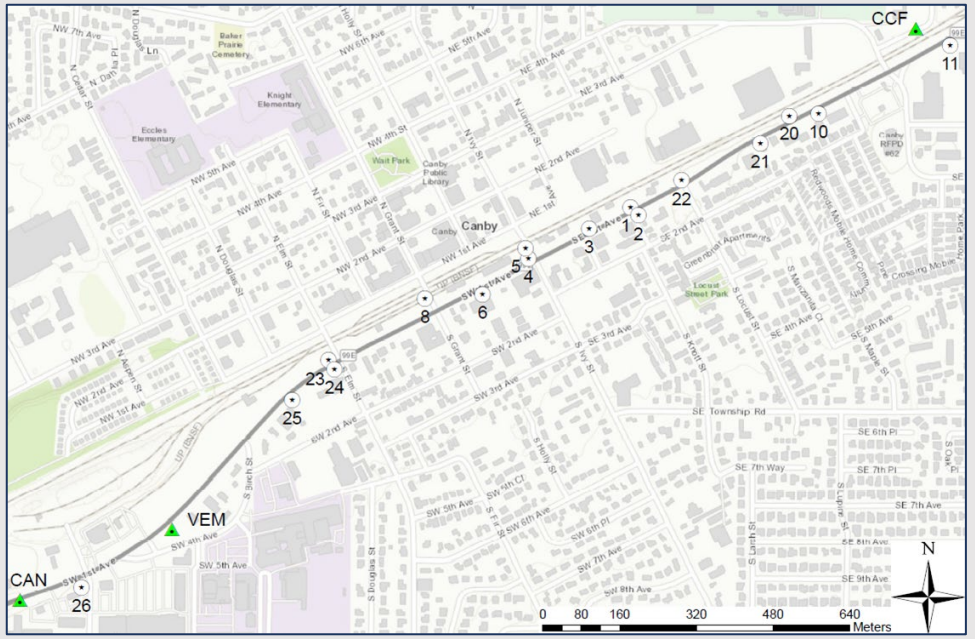
Phase I – Carlton, OR



- OSU acquired Real-time GNSS data on all stations
  - Network Floating Master (GPS+GLO)
  - Each station observed 11-13 times at ~1 hour between repeat observations
  - Observation time 5 minutes each

- ODOT Acquired and provided:
  - Static GNSS data on 4 stations; Total Station Data; Leveling Data

Phase II – Canby, OR



- OSU acquired Real-time GNSS data on all stations
  - Network Floating Master (GPS+GLO)
  - Each station observed 6 times at ~1 hour between repeat observations
  - Observation time 5 minutes each

- ODOT Acquired and provided:
  - 6 sessions of Static GNSS data on 6 stations; Total Station Data; Leveling Data

Adjusting the Data

Processed A LOT of data

136 Least Square adjustments for Phase I

117 Least Square adjustments for Phase II

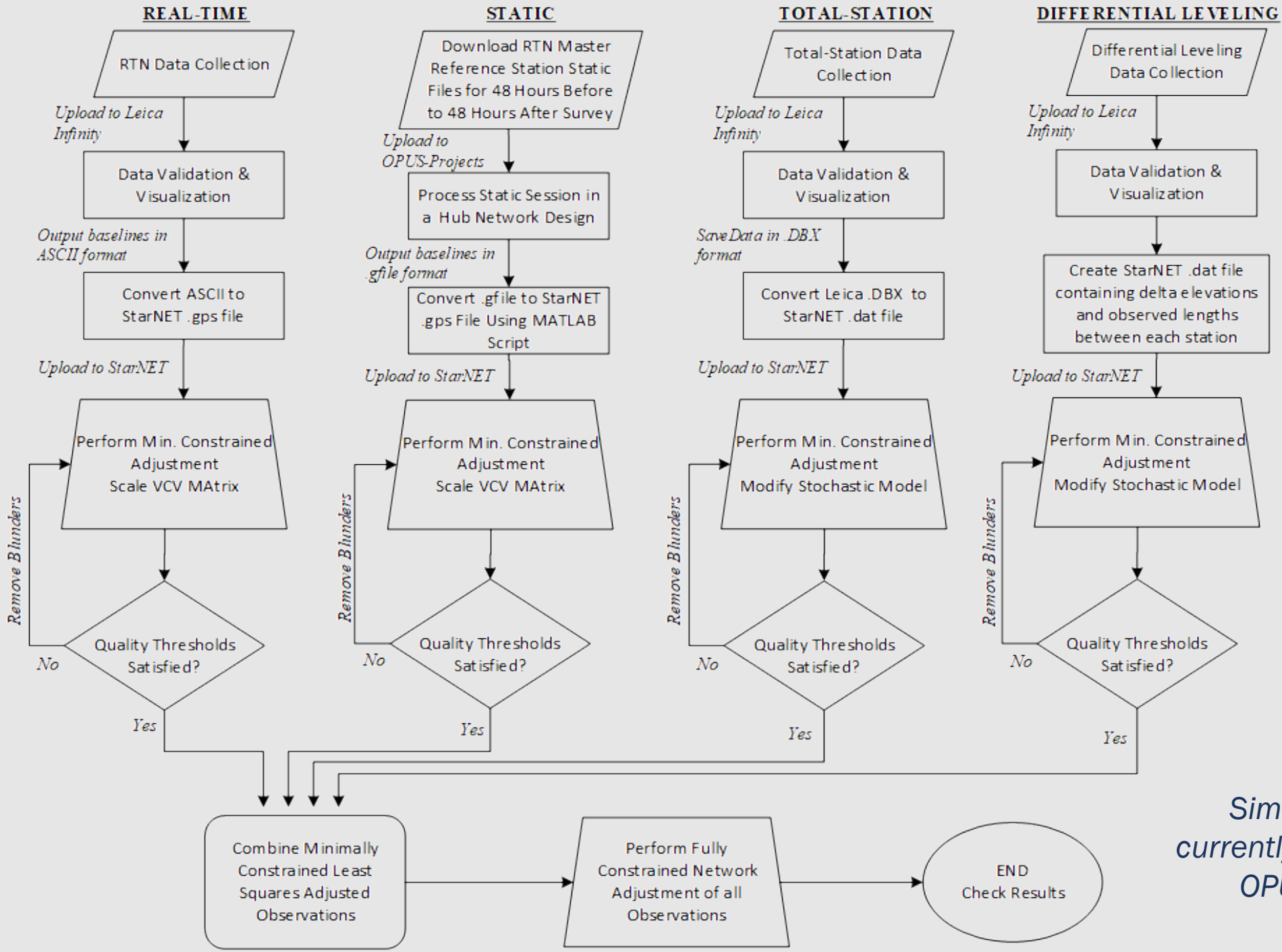
253 NETWORK ADJUSTMENTS!!

Various combinations of RTN data

- Time between repeat observations
  - 1, 2, and 3 hours (Phase I only)
- Total number of repeat observations
  - 1 to 6 repeat observations

Then added in:

- Total Station Data
- Differential Leveling Data



Similar workflow currently being built into OPUS Projects!

Results From Analyzing Real-Time Data Only

How does the accuracy vary as more observations are made?

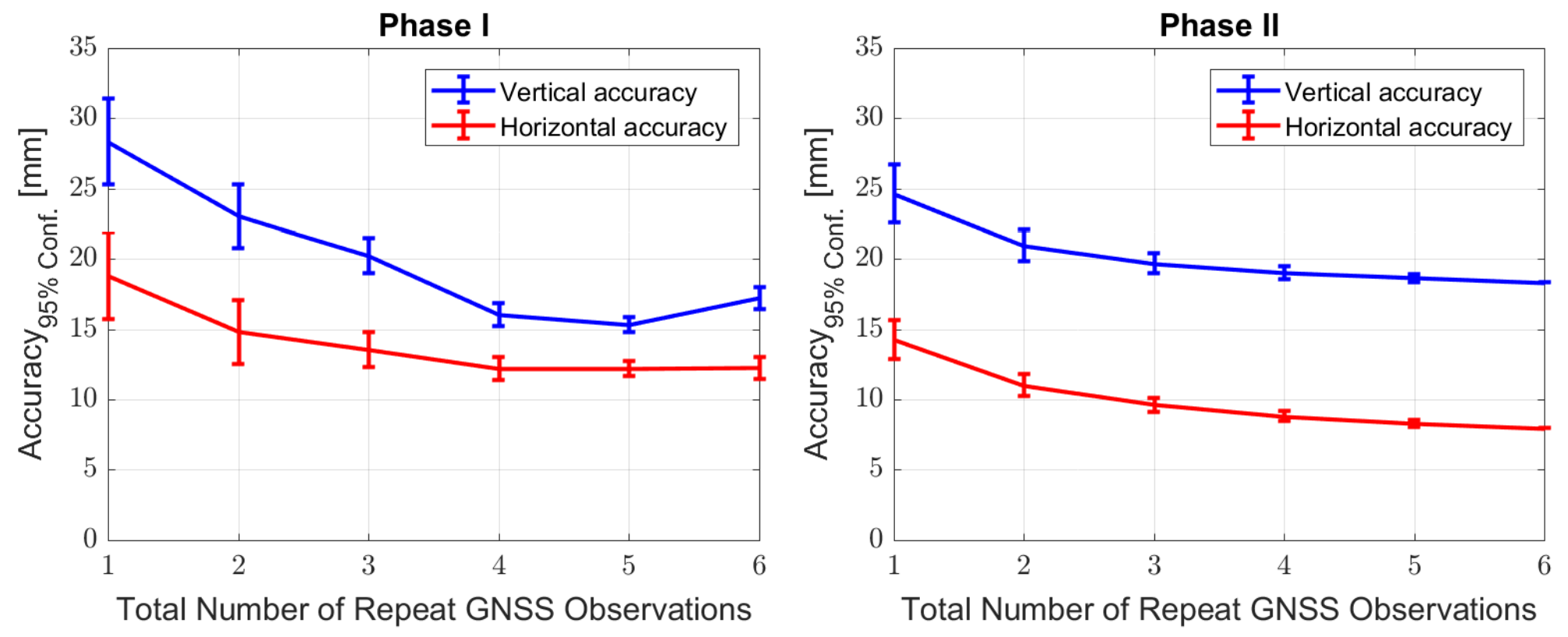
- AND -

Does it matter how long I wait in-between occupations?

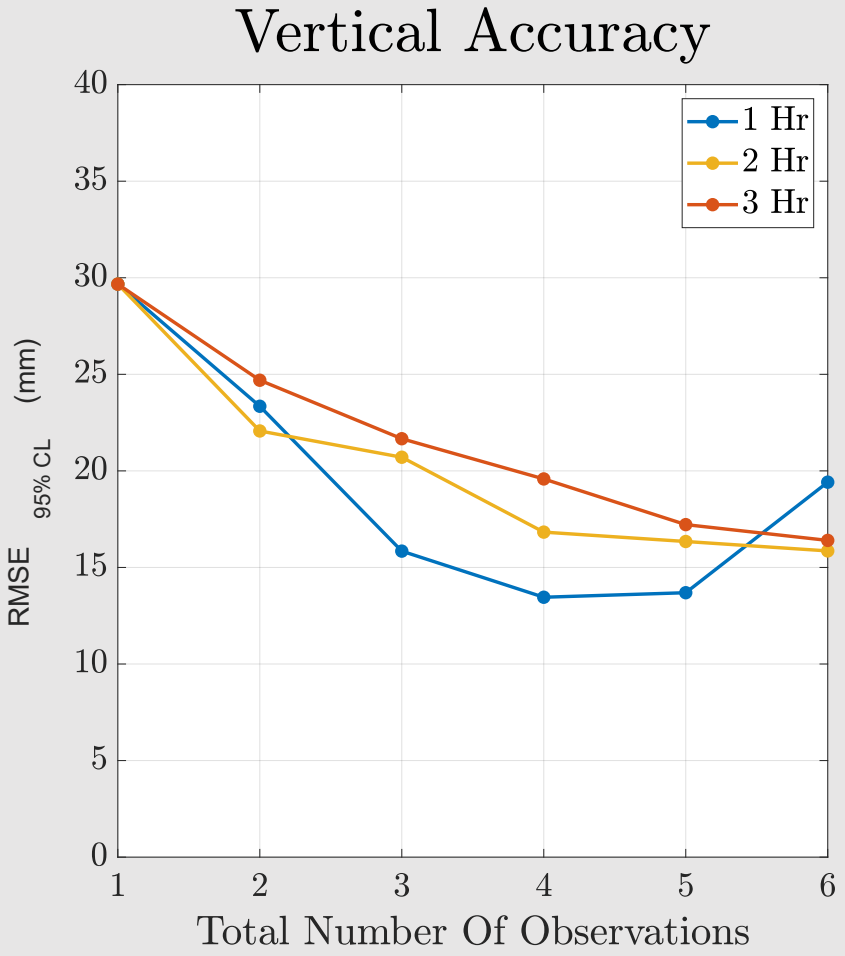
Current NGS Recommendation is **3 hours**!

...BUT time is money...

How Many Observations Should I Make? ..1? ..2? ..4? ..6?



Time Between Occupations...
...Does it matter??



Compared 1hr vs 2hr vs 3hr

2hr and 3hr appear to follow the same trend

1hr appears overly optimistic

Need to perform more research at lower time intervals

(e.g. 15 min, 30 min, 45 min, etc.)

Minimum of 2 hours between repeat observations

Project Control:
Need to include other measurements…

Control from RTN-GNSS alone is NOT typically adequate for project control

Need the control points to be relative within the project!

Current ODOT spec requires:

- Sets of Angles at all stations
- Differential Leveling

What happens if we add Sets of Angles to the network?

RTN-GNSS + Sets of Angles

Horizontal

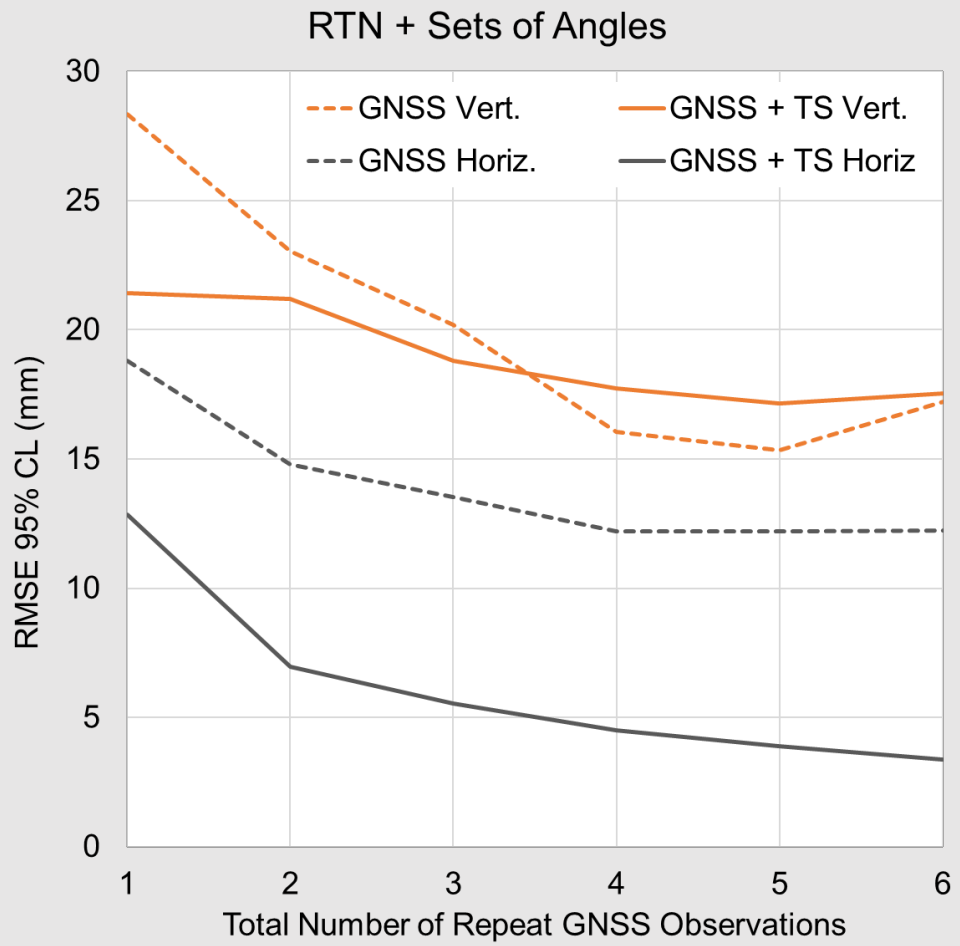
- Big improvement
- ~40% BETTER than current spec with only 2 repeat obs. on all stations

  Achieved (2obs) = 0.007 m (0.023 ft)

  Current Spec = 0.015 m *(0.05 ft)*
- The more RTN observations the better

Vertical

- More stable vertical results
- Not a significant change when more RTN obs. are made



What happens if we add Leveling to the network?

RTN-GNSS + Leveling

Horizontal

- No change in horizontal (as expected)
- Redundant RTN obs. Improves accuracy

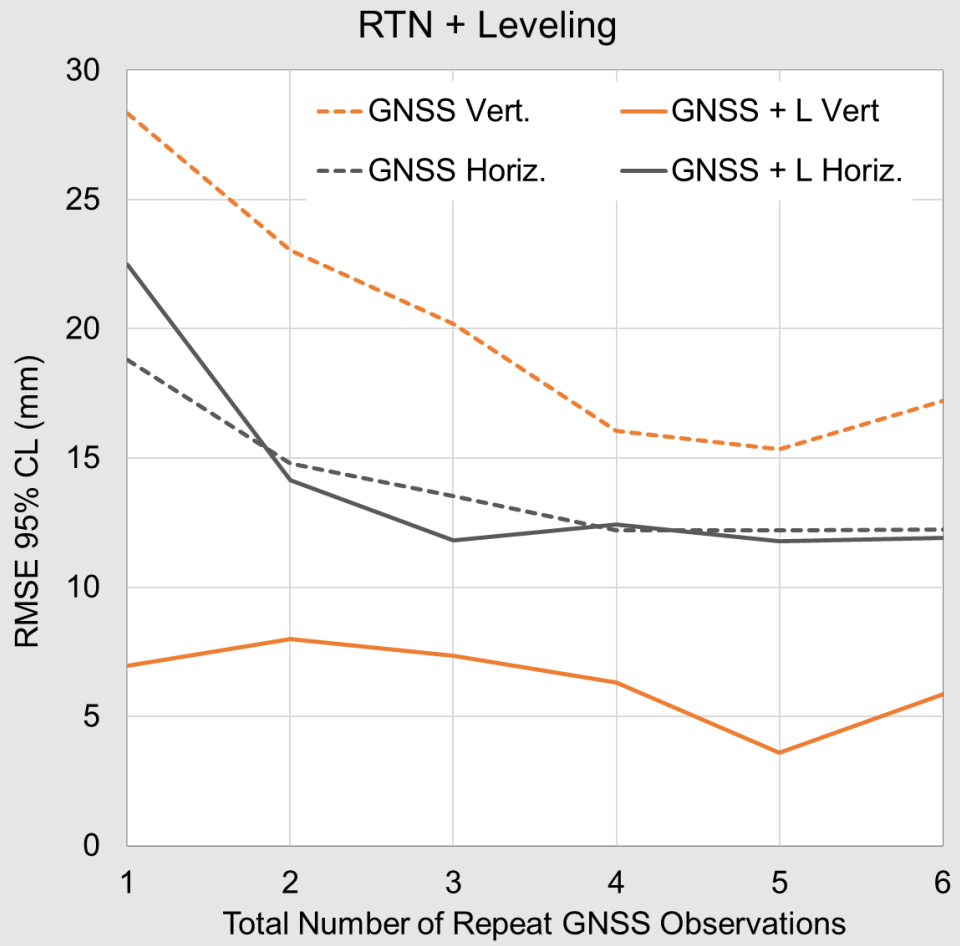
Vertical

- Big improvement in the vertical!
- ~50% BETTER than current spec with only 2 GNSS obs. on all stations

$RMSE_{95\%\ CL}$ = 0.008 m (0.026 ft)

Current Spec = 0.015 m *(0.05 ft)*

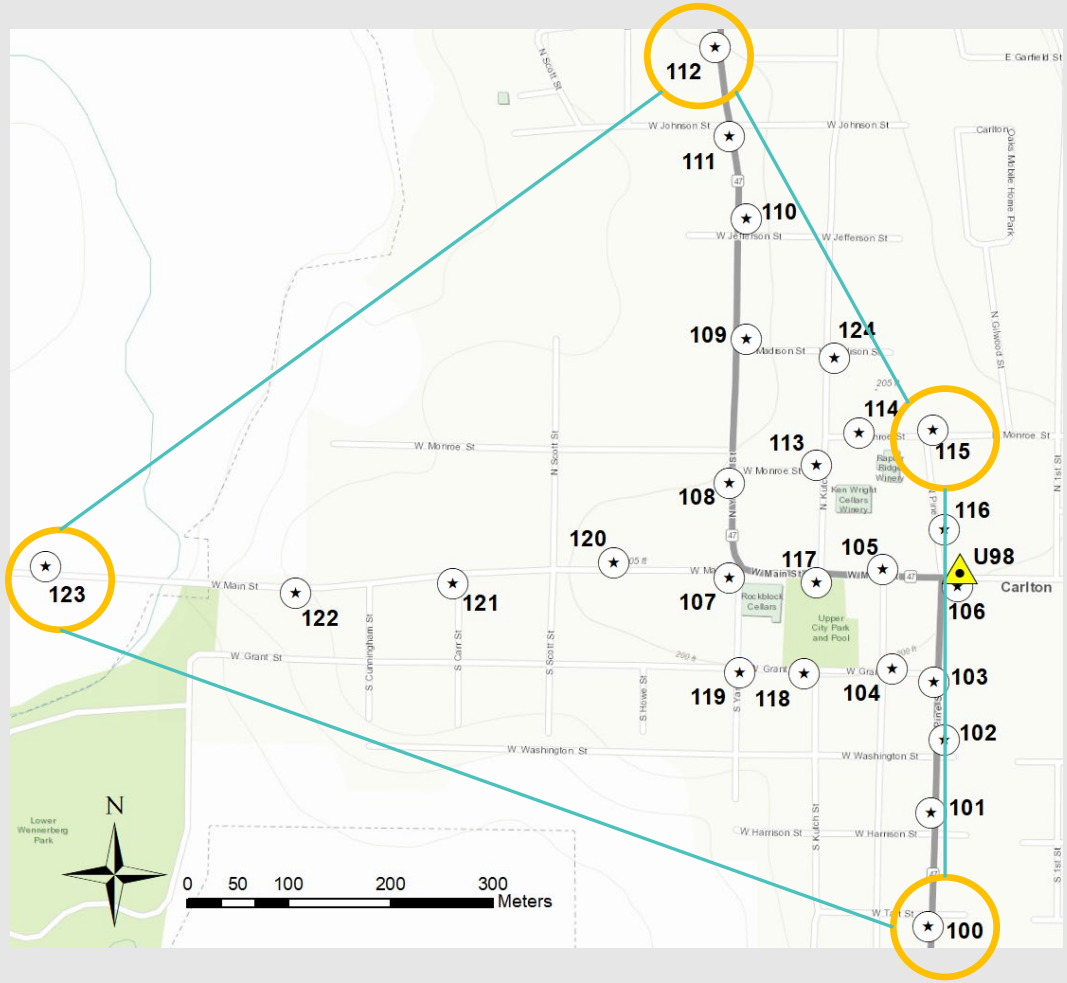
- Redundant RTN observations has little impact
  - Leveling data controls the elevation!



Occupying ALL the stations with RTN could be pretty time consuming…

If we NEED to perform a total station and leveling survey:

- Do we need to get RTN observations on every station?
- Following the current procedures:
  - ODOT sets GNSS control using ~4-6 Static GPS observations
- Selected 4 stations:
  - Northern most (112)
  - Eastern most (115)
  - Southern most (100)
  - Western most (123)



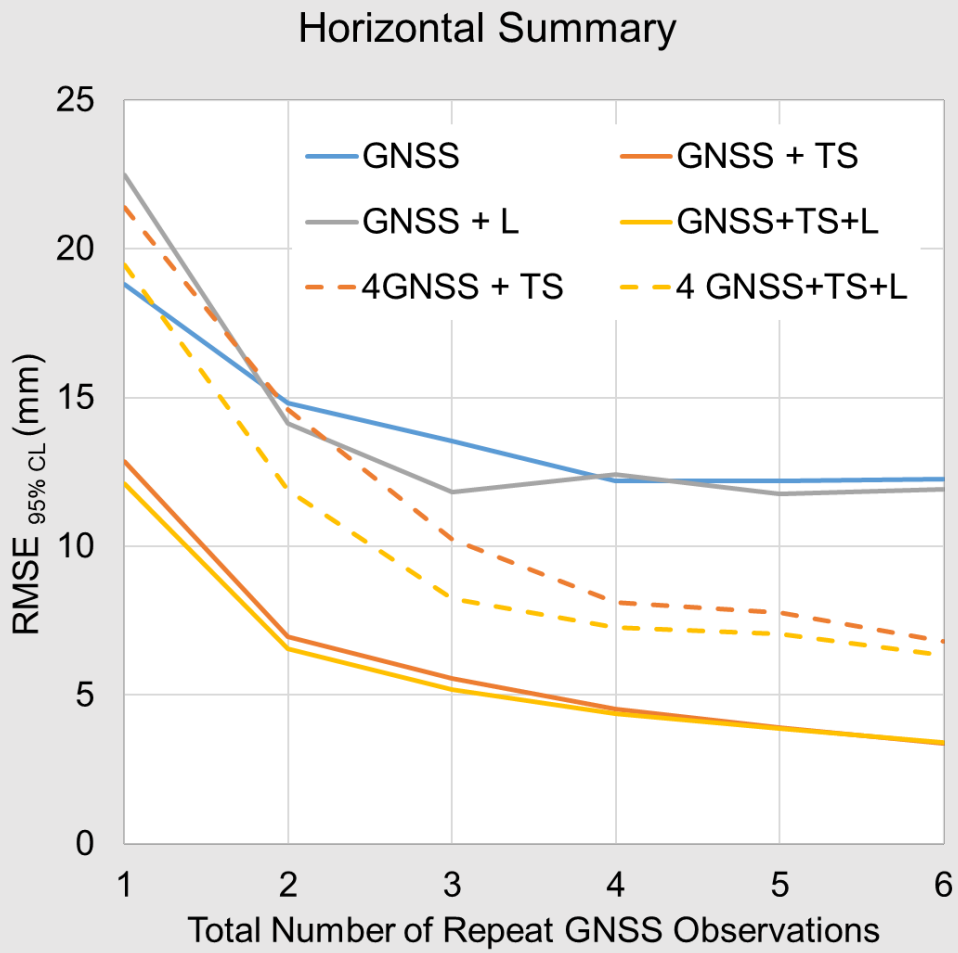
Summary of Results
Horizontal

Sets of Angles survey improves horizontal accuracy of network

- Might not need to occupy ALL stations with GNSS

RTN GNSS:

- The more stations observed the better!
  - ~50% improvement when ALL stations are obs. vs only 4 stations
- Not much benefit beyond 4 observations per station.



Summary of Results
Vertical

If you need the accuracy to be less than 1.5cm (0.05ft) accuracy, **Leveling is required!**

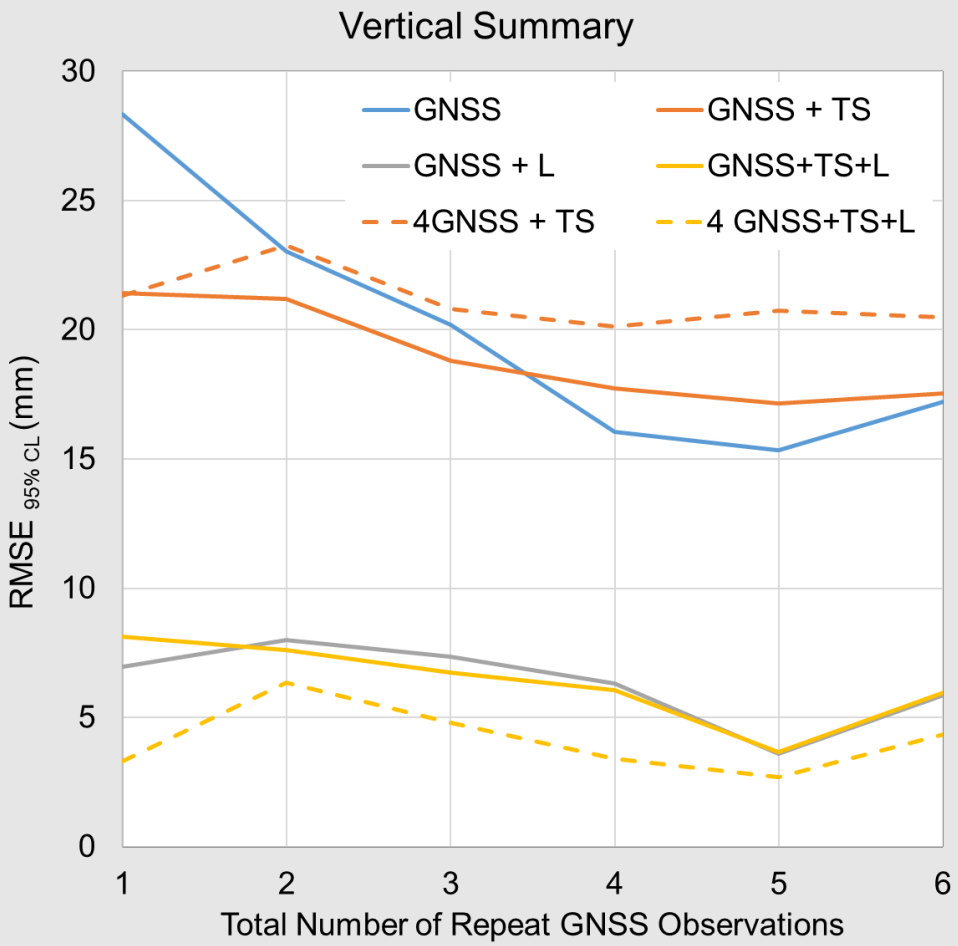
- ~95% improvement when leveling is performed vs when it is not

If sets of angles survey is being completed

- Repeat observations has little affect but are still recommended!

Again, if doing RTN GNSS only

- Not much benefit beyond 4 observations per station.



Required Order of work	ORGN NRTK RECOMMENDED SURVEY PROCEDURES	
	Horizontal	*Vertical*
0.015 ft (0.005 m)	Not Recommended	Not Recommended
0.030 ft (0.010 m)	(4) independent 5 minute NRTK observations* on each control station	Not Recommended
0.050 ft (0.015 m)	(3) independent 5 minute NRTK observations* on each control station	Not Recommended
0.070 ft (0.020 m)	(2) independent 5 minute NRTK observations* on each control station	(4) independent 5 minute NRTK observations* on each control station
0.100 ft (0.030 m)	(2) independent 3 minute^ NRTK observations* on each control station	(2) independent 5 minute NRTK observations* on each control station
0.150 ft (0.040 m)	(2) independent 1 minute^ NRTK observations* on each control station	(2) independent 3 minute^ NRTK observations* on each control station
0.200 ft (0.050 m)	(2) independent 30 second^ NRTK observations* on each control station	(2) independent 1 minute^ NRTK observations* on each control station
0.300 ft (0.100 m)	(2) independent 5 second^ NRTK observations* on each control station	(2) independent 5 second^ NRTK observations* on each control station
3 ft (1 m)	(1) 3 second^ NRTK observations on each control station	(1) 3 second^ NRTK observations on each control station
33 ft (10 m)	(1) 3 second^ NRTK observations on each control station	(1) 3 second^ NRTK observations on each control station

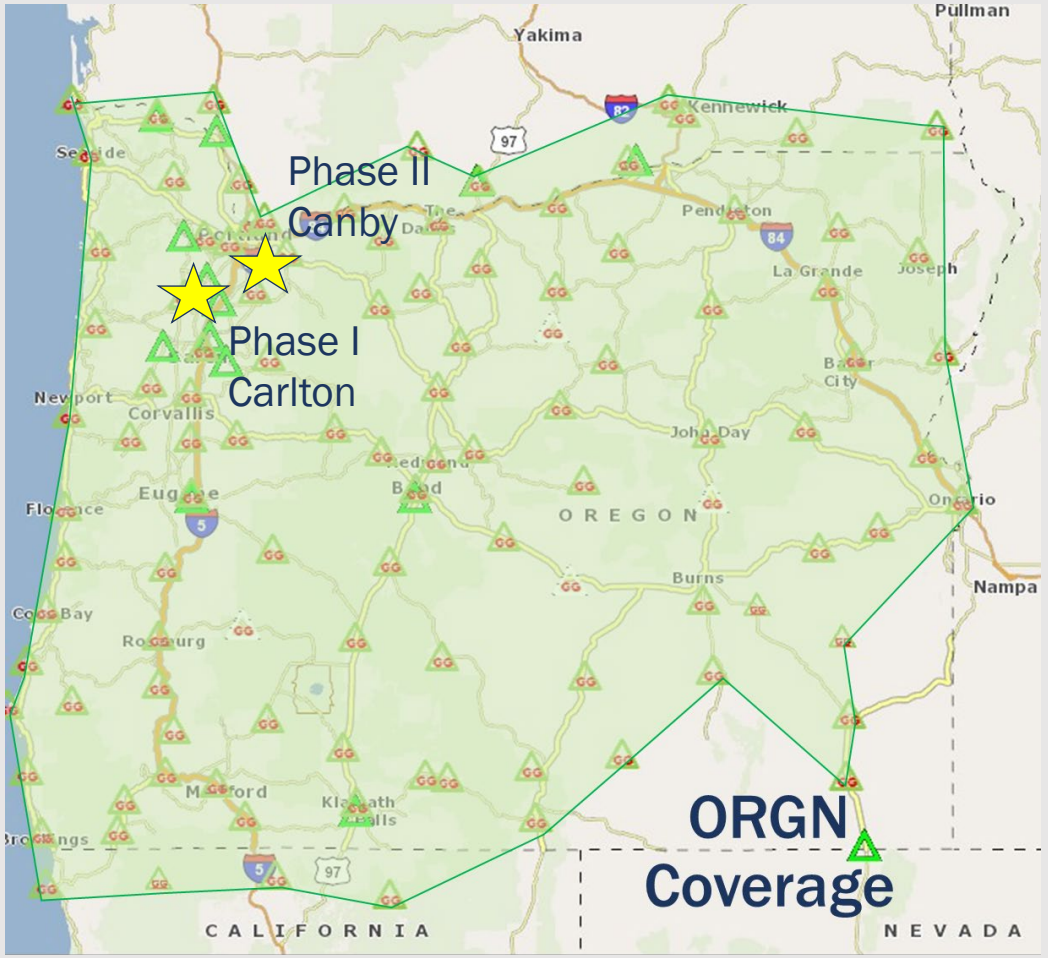
Notes:
* NRTK Observations required to be included in a least squares adjustment using the Hybrid Survey Network methodology proposed by Weaver et. al, (2018).
^ Recommended NRTK occupation times based on findings outlined in Allahyari et. al, (2018).

Required Order of work	RECOMMENDED PROCEDURES LEVERAGING THE ORGN	
	Horizontal	*Vertical*
0.015 ft (0.005 m)	(4) independent 5 minute NRTK observations* on each control station OR Static-GNSS survey following NGS specifications -AND- Total Station Network Survey (reference ODOT SSPM for specific guidelines)	Differential Leveling using NGS first order standards or approved ODOT method, refer to ODOT SPPM for specific guidelines.
0.030 ft (0.010 m)	(2) independent 5 minute NRTK observations* on each control station OR Static-GNSS survey following NGS specifications -AND- Total Station Traverse Survey (reference ODOT SSPM for specific guidelines)	Digital Differential Leveling with bar code rod or approved ODOT alternate, refer to ODOT SPPM for specific guidelines -AND- (4) independent 5 minute NRTK observations* on a subset of the stations
0.050 ft (0.015 m)	(3) independent 5 minute NRTK observations* on each control station	Digital or Optical differential leveling with standard rod -AND- (3) independent 5 minute NRTK observations* on a subset of the stations
0.070 ft (0.020 m)	(2) independent 5 minute NRTK observations* on each control station	(4) independent 5 minute NRTK observations* on each control station -OR- Digital or Optical differential leveling with standard rod AND (2) independent 5 minute NRTK observations on a subset of stations
0.100 ft (0.030 m)	(2) independent 3 minute^ NRTK observations* on each control station	(2) independent 5 minute NRTK observations* on each control station
0.150 ft (0.040 m)	(2) independent 1 minute^ NRTK observations* on each control station	(2) independent 3 minute^ NRTK observations* on each control station
0.200 ft (0.050 m)	(2) independent 30 second^ NRTK observations* on each control station	(2) independent 1 minute^ NRTK observations* on each control station
0.300 ft (0.100 m)	(2) independent 5 second^ NRTK observations* on each control station	(2) independent 5 second^ NRTK observations* on each control station

Remember…
…Results can vary!

Note, your results can vary based on:

- *Sky Visibility*
- *Multipath*
- *PDOP*
- *Ref. Station Health*
- *Network Location*
- *Baseline length*
- *Etc.*



Additional Considerations

- Need to select control station locations to allow for GNSS observations
  - Limit multipath
  - Maximize sky visibility
- Plan your survey such that PDOP is minimized
- Always perform a check on known control before each survey
  - This ensures the ORGN is providing you good corrections
  - Can help catch blunders (e.g. incorrect rod height, network errors)

Question?

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