Geodetic Leveling in the Modernized National Spatial Reference System

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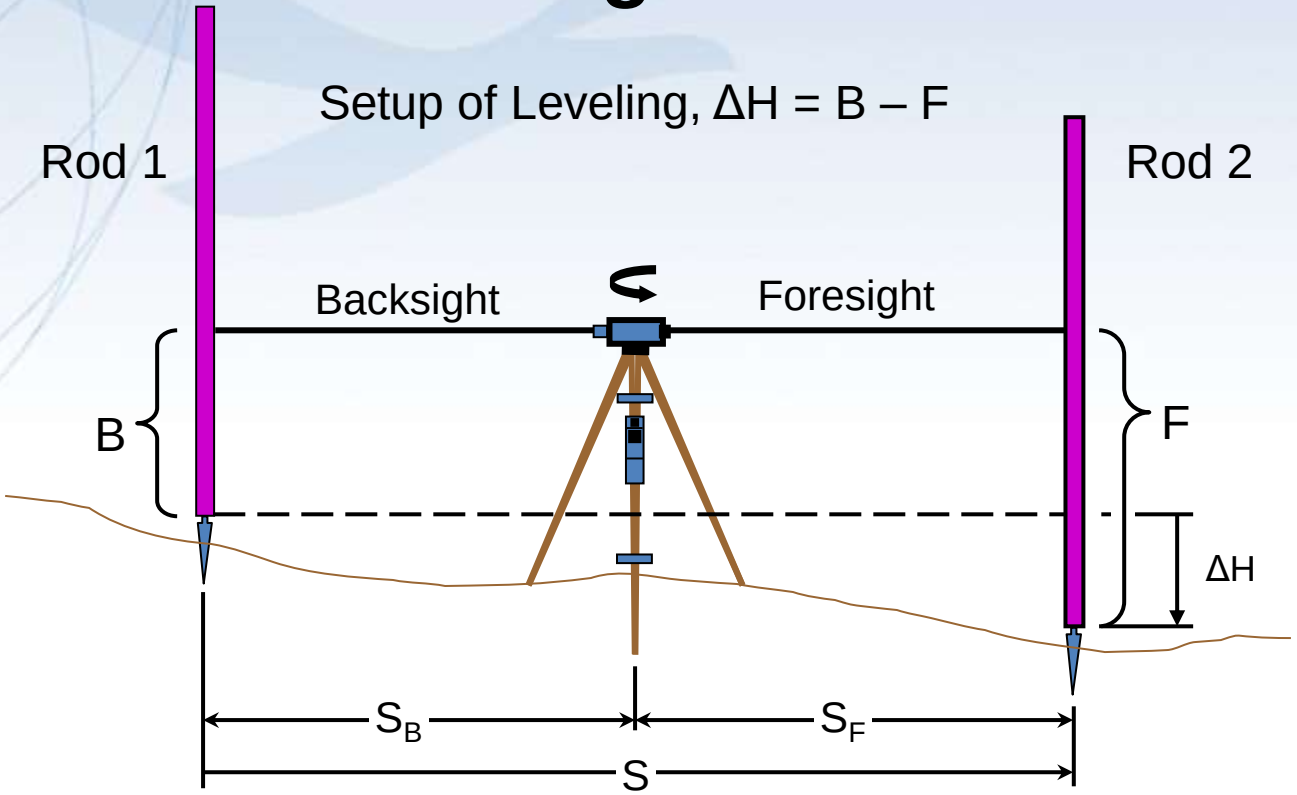
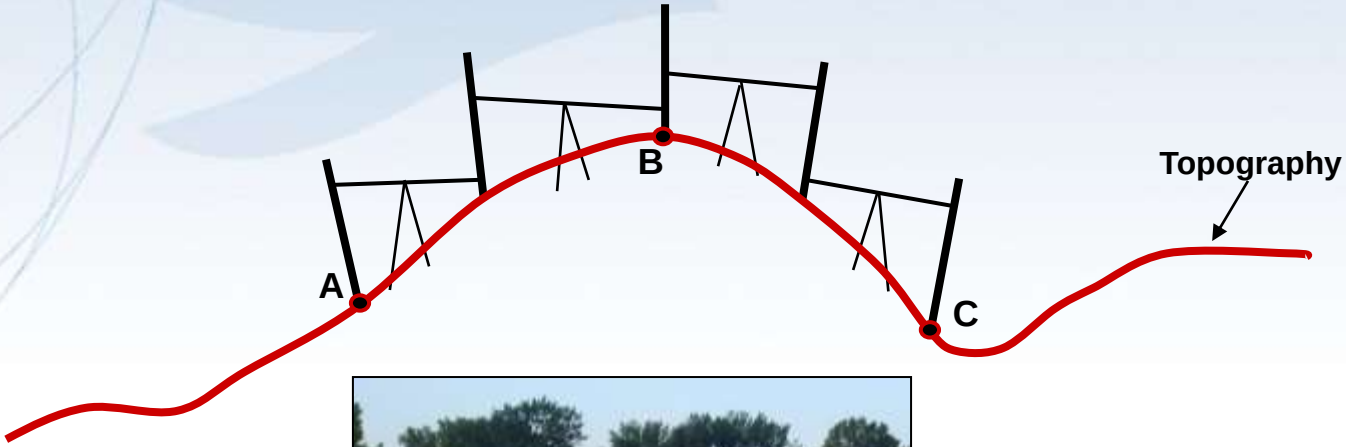
FIG Working Week 2023

Differential leveling



Differential leveling

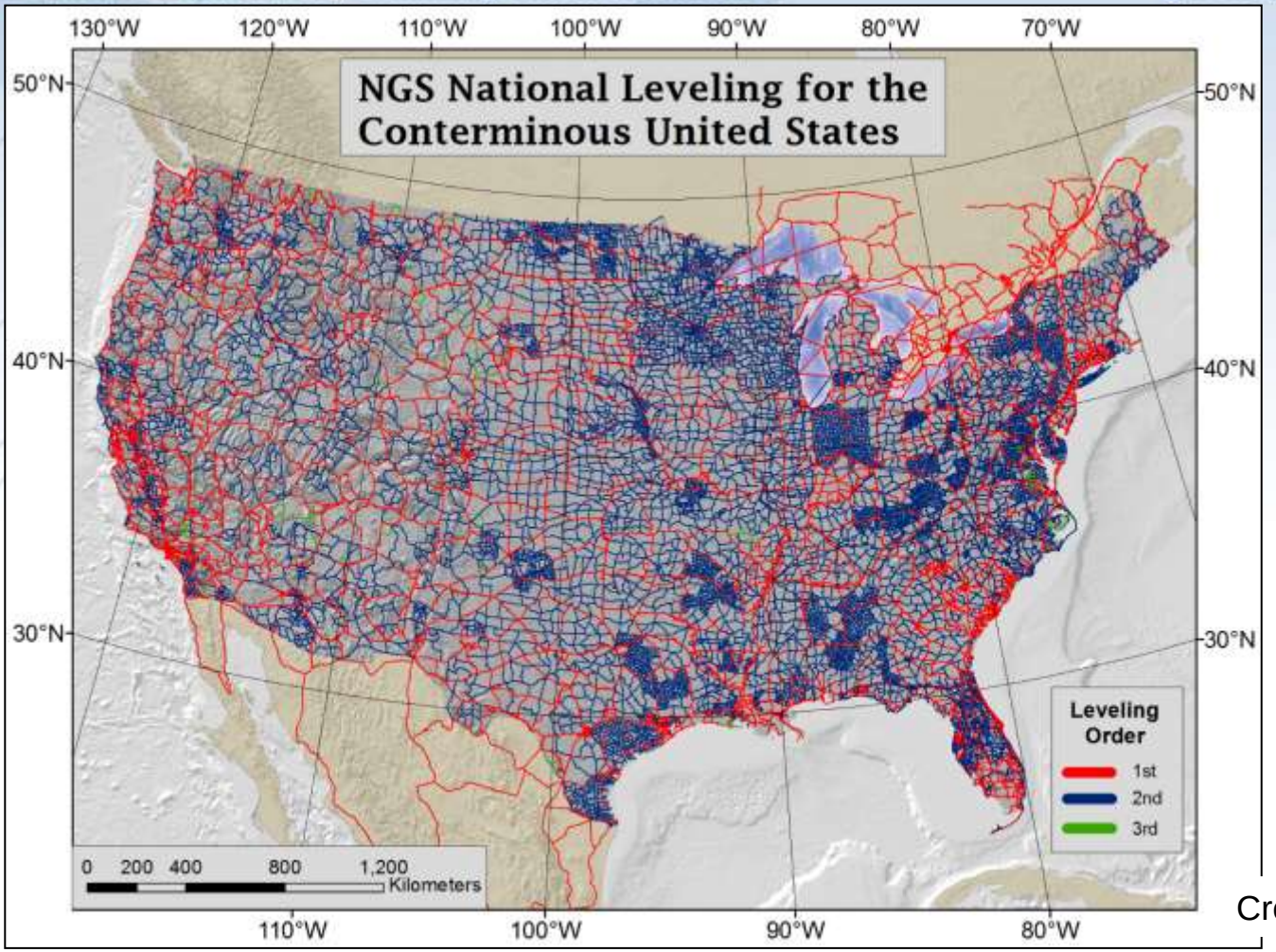


Differential leveling

- Very accurate differential heights. Precision < 1 mm.
- Time consuming, expensive.
- For absolute positioning, starting heights must be known.

Current method:

- Start from passive bench marks with heights published in NGS's vertical datum, NAVD88.
- Establish heights on new marks via leveling.



Credit: Brian Shaw

Ties to Existing Vertical Control

Leveling today: assumptions

- Published marks are available near the project area.
  - Historic level lines must have been previously run.
- Mark still exists and is recoverable.
  - Marks are often lost or destroyed without being replaced.
- Mark has not moved.
  - Stability of setting, damage, subsidence, uplift.
- Published coordinates are accurate & consistent.
  - Coordinates may be “stale”.

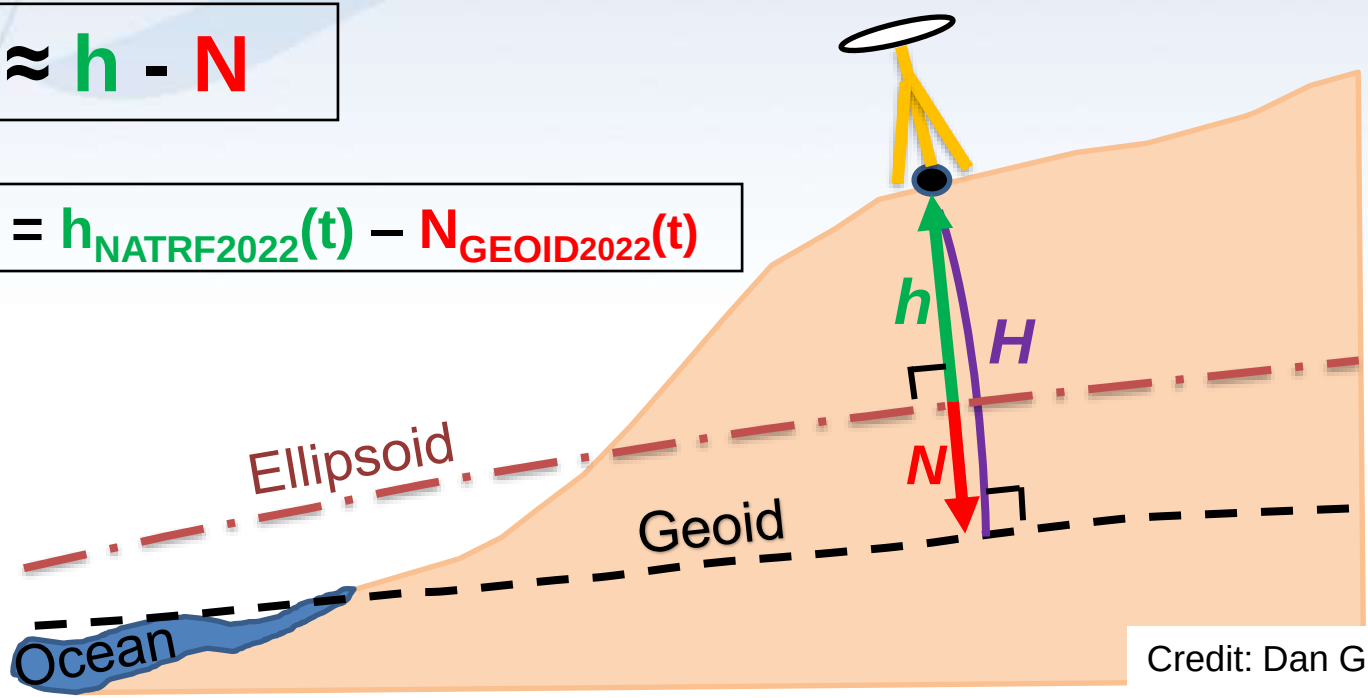
Leveling in the modernized NSRS

- Starting heights need not come from historic level lines.
- Most reliable source will be from new GNSS occupations of ***primary control marks*** included in the level survey.
  - Static, Real-Time Kinematic, Network RTK.
- Obtain orthometric heights from GNSS ellipsoid height and high-resolution geoid model.

GNSS-derived orthometric heights

$$H \approx h - N$$

$$H_{NAPGD2022}(t) = h_{NATRF2022}(t) - N_{GEOID2022}(t)$$



Credit: Dan Gillins

Primary control marks

- 3 marks minimum.
  - Provide access to NAPGD2022 orthometric heights.
- 30 km max distance.
- GNSS occupations to obtain coordinates at an epoch representative of the survey (e.g., the midpoint date).
  - 2 occupations minimum at the beginning of leveling.
  - 2 occupations minimum at the end of leveling.
  - For projects over 6 months, 2 occupations near the middle of leveling.

Additional marks for leveling

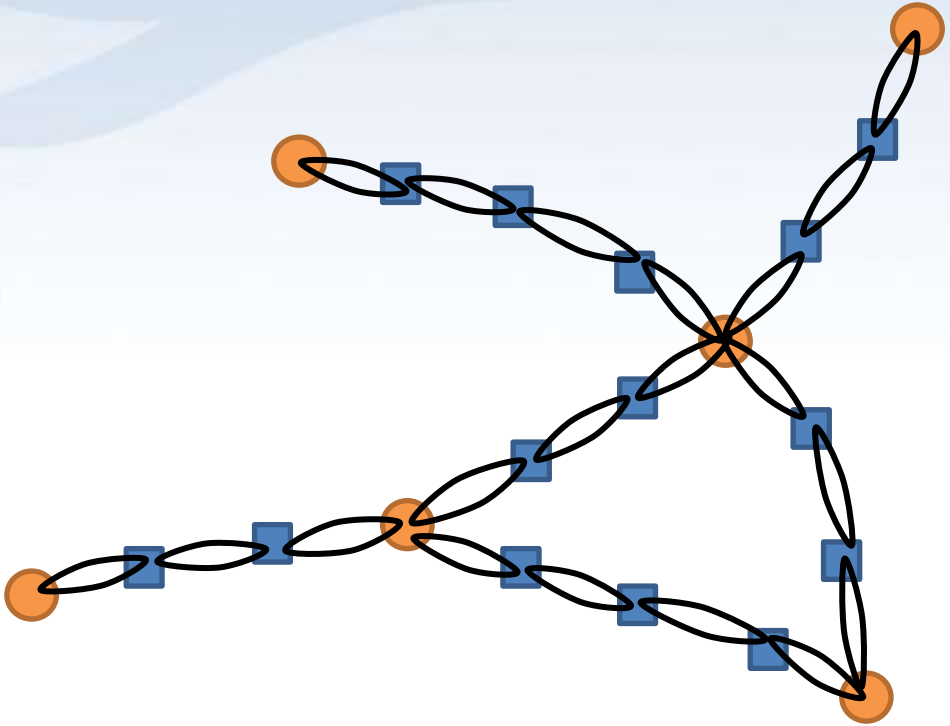
- Leveling-only secondary marks are set as needed for the project.
- Nominal spacing of 1-3 km for level lines.
- Double-run leveling (forward/backward) connects the primary marks to the other marks.

GNSS and leveling

GNSS-derived orthometric heights

Leveling marks

Double-run leveling



Credit: Dan Gillins

Establishing heights

At the primary control marks:

- GNSS occupations are processed into NATRF2022 coordinates at the survey epoch.
- Coordinates combined with GEOID2022 to produce orthometric heights at the survey epoch.
- Orthometric heights used as vertical control for adjustment of the leveling data.

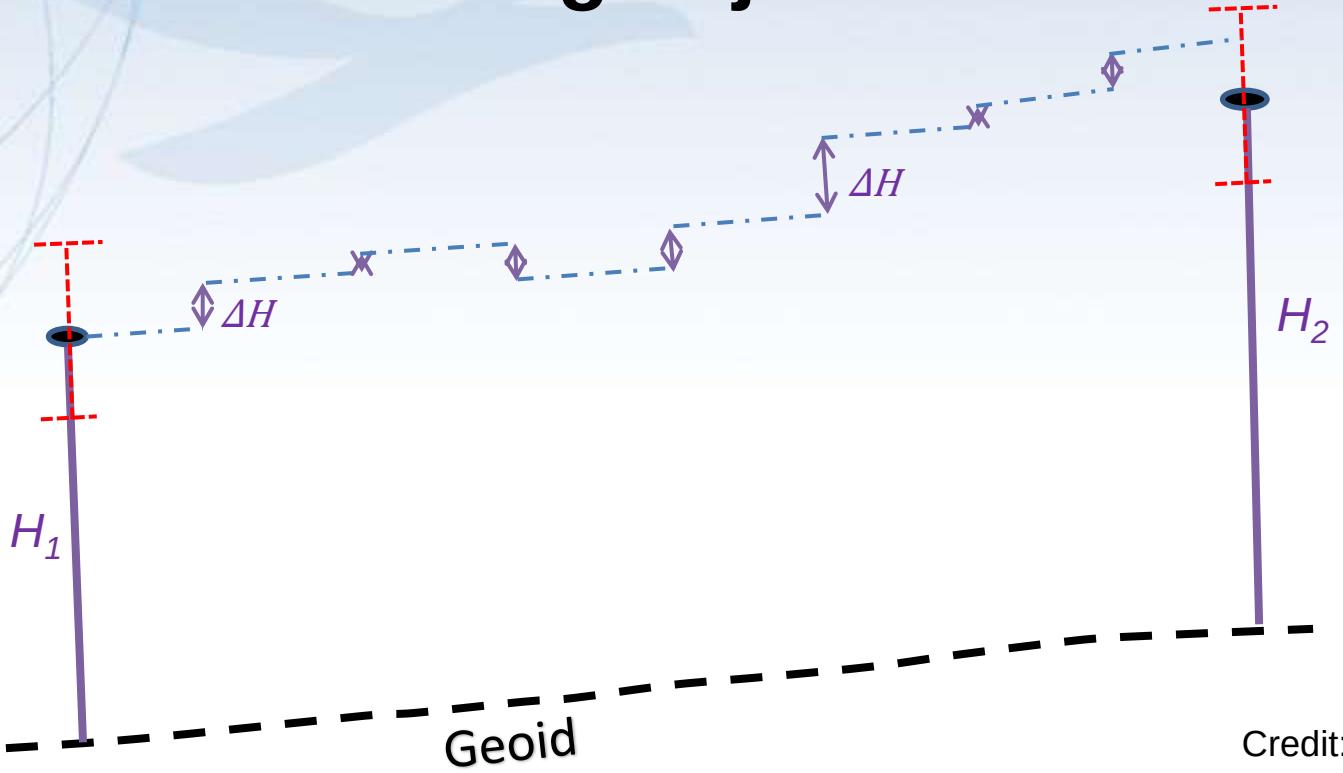
Establishing heights

- Uncertainties will be propagated through the processing sequence. Sources include:
  - σ_h from GNSS observations (cm level).
  - σ_N from GEOID2022 model (cm level).
  - $\sigma_{\Delta H}$ from leveling observations (mm level).
- In the adjustment, the controlling orthometric heights will float according to their uncertainties
  - Variance component model with stochastic constraints.

Establishing heights

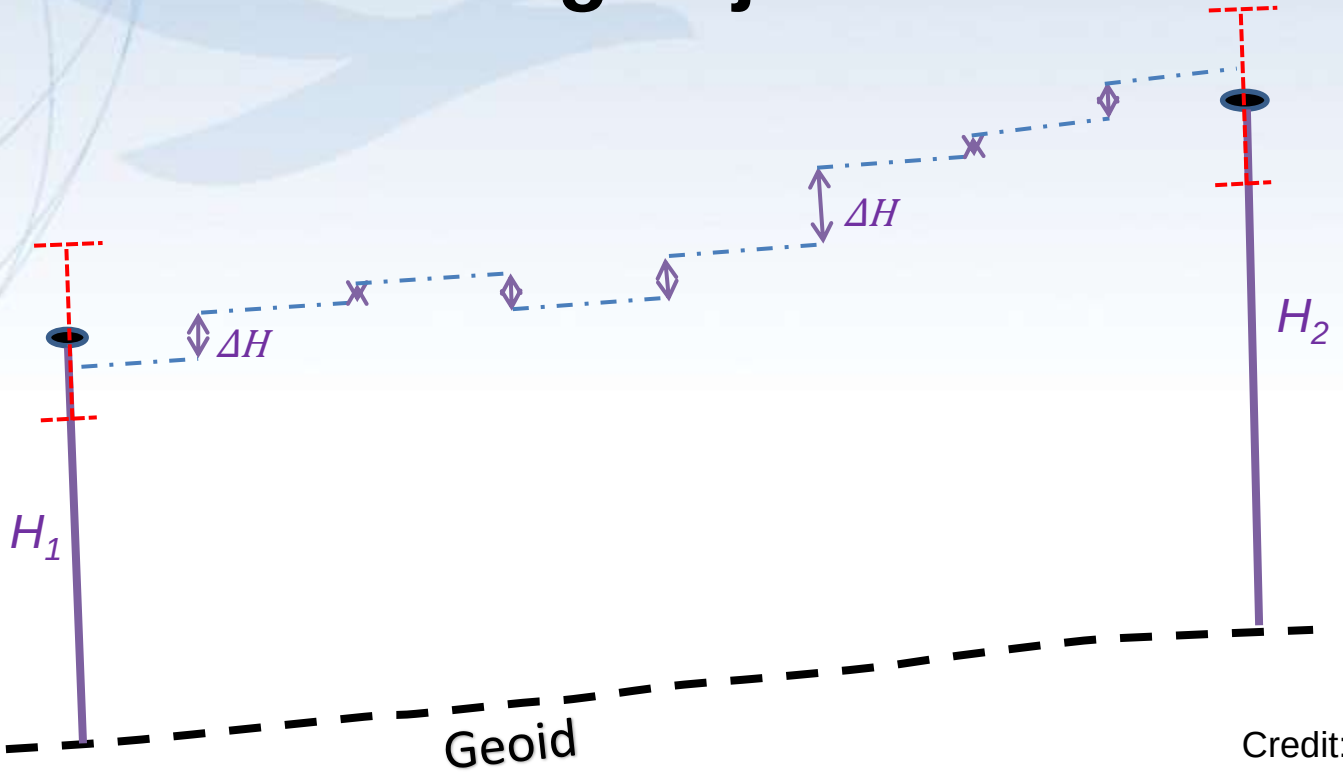
- Per the weighting scheme…
  - Absolute accuracy is determined by the GNSS (network accuracy).
  - Relative precision of the leveling is maintained (local accuracy).
- Corrections are applied to leveling for systematic effects.
  - Astronomic, orthometric, gravity, atmosphere, instrument calibration.
- End result: adjusted orthometric heights for all points in the project at the survey epoch.

GNSS and leveling adjustment



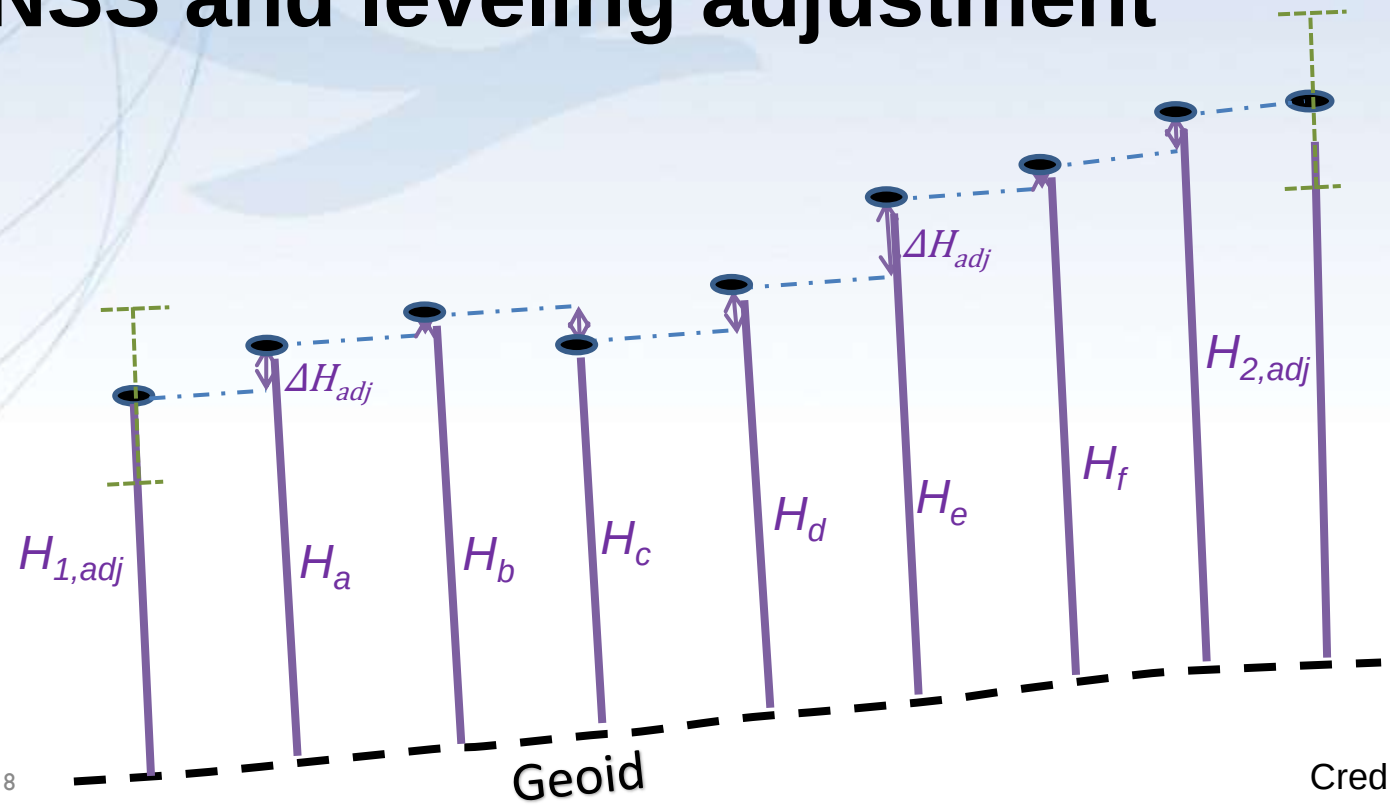
Credit: Dan Gillins

GNSS and leveling adjustment



Credit: Dan Gillins

GNSS and leveling adjustment



Credit: Dan Gillins

Conclusions

In the modernized NSRS:

- Leveling will remain the premier technique for obtaining accurate differential heights.
- Users will longer have to rely on historic passive control with coordinates that may be unsuitable.
- Users can establish new marks and starting coordinates tied to NAPGD2022 via GNSS wherever they like.

Conclusions

In the modernized NSRS:

- High-precision leveling can extend vertical control throughout the project area.
- NGS tools will process and adjust the data, providing orthometric heights, along with estimates of uncertainty.

Under development

- Software and tools for data processing.
- Integrating functionality into the OPUS software suite.
- Making adjacent projects at different epochs consistent.
- Updating formal documentation on leveling methodologies and GNSS control.

Thank you.