The History and Future of Geoid Modelling at UNB

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Introduction

- The geoid is a reference surface for heights that approximates mean sea level
- It has been a subject of UNB GGE's research since 1973 (37 of the Dept's 50 years! 74%)
- We've gotten pretty good at it
- Errors in geoid results:
  - 1970's: metres
  - 1990's: decimetres
  - 2000's: centimetres

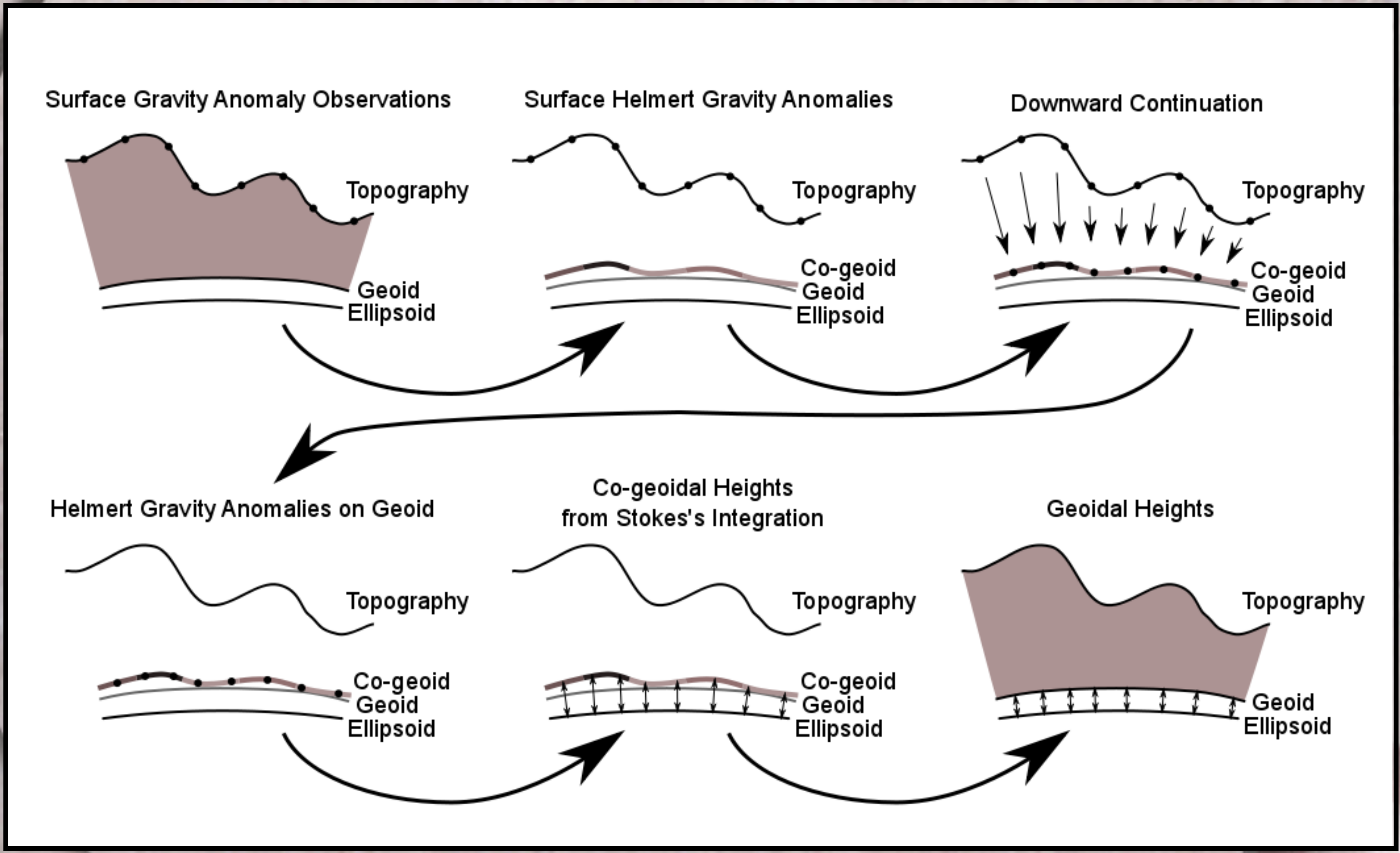
Introduction

1. Why is knowing the geoid important?
2. How do we find out where the geoid is?
3. What has been the historical development of the UNB method?
4. What has been the impact of UNB's geoid determination work?
5. What are the future prospects for UNB's approach?

Why is knowing the geoid important?

- **Conversion of GPS heights to orthometric**
- Reference for vertical benchmarks
- Other geomatics applications:
  - Consistent, intuitive reference for height data
  - Reference for bathymetric observations
  - Datum for vertical deformations and subsidence
- Numerous scientific applications:
  - Ocean circulation/climate change
  - Wetland monitoring (drainage)
  - Sea level rise

The UNB Method



Early History: 1973 to 1986

- Charles Merry's 1973 Geoid
- Followed by:
  - John (1976)
  - Sosa-Torres (1977)

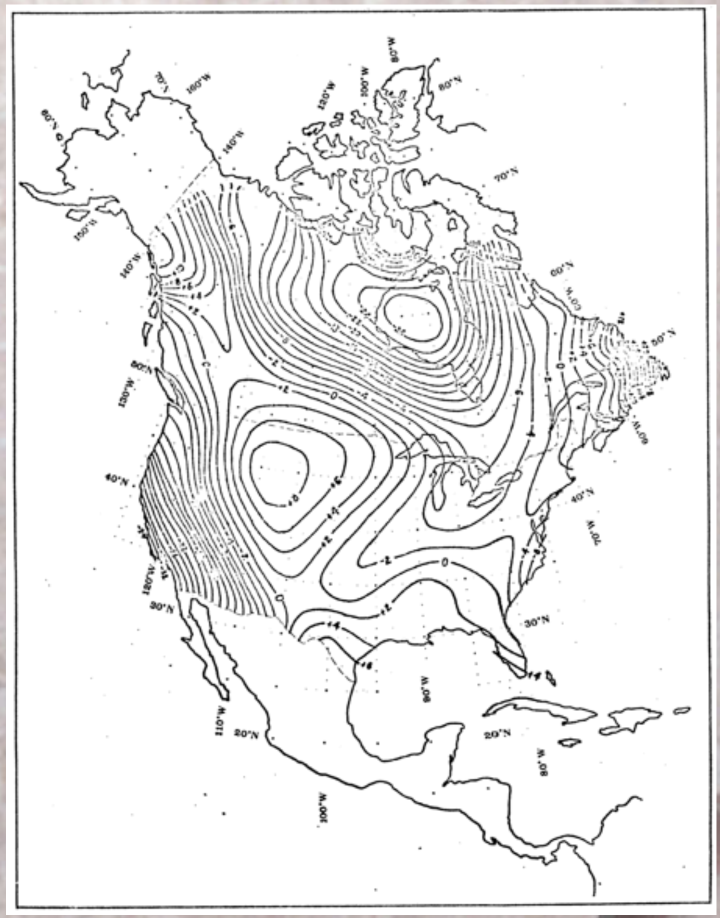


Figure from Merry (*Studies Towards an Astrogravimetric Geoid for Canada*, 1973).

The 1 m Geoid: 1986 to 1993

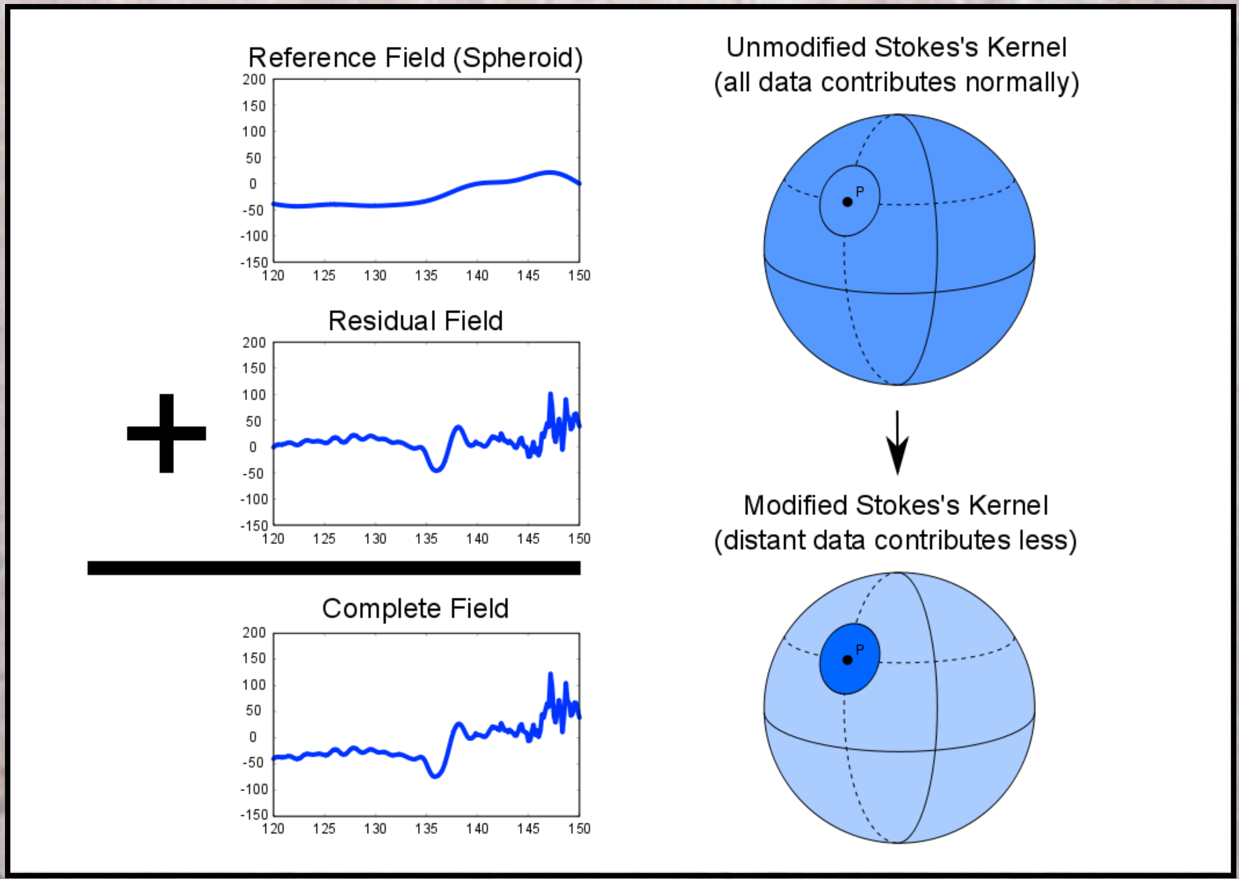
- Early 1980's: considering different data sources
- Theory for 1 m gravity-based geoid developed by Vaníček & Kleusberg (1987)
- UNB '86:
  - UNB's first gravimetric geoid
  - 10 arc-minute resolution, covered (most of) Canada
  - Compared well with Doppler: 1.51 m RMS

The 1 m Geoid: 1986 to 1993

- Features of UNB ‘86:
  - No downward continuation
  - Used modified spheroidal Stokes’s kernel
  - Topography model with constant density
  - Included atmospheric masses in transformation to Helmert space (but not from)
  - Some terms absent from transformations to Helmert space
  - Planar approximation used
- Same for later UNB ‘90 and ‘91 solutions

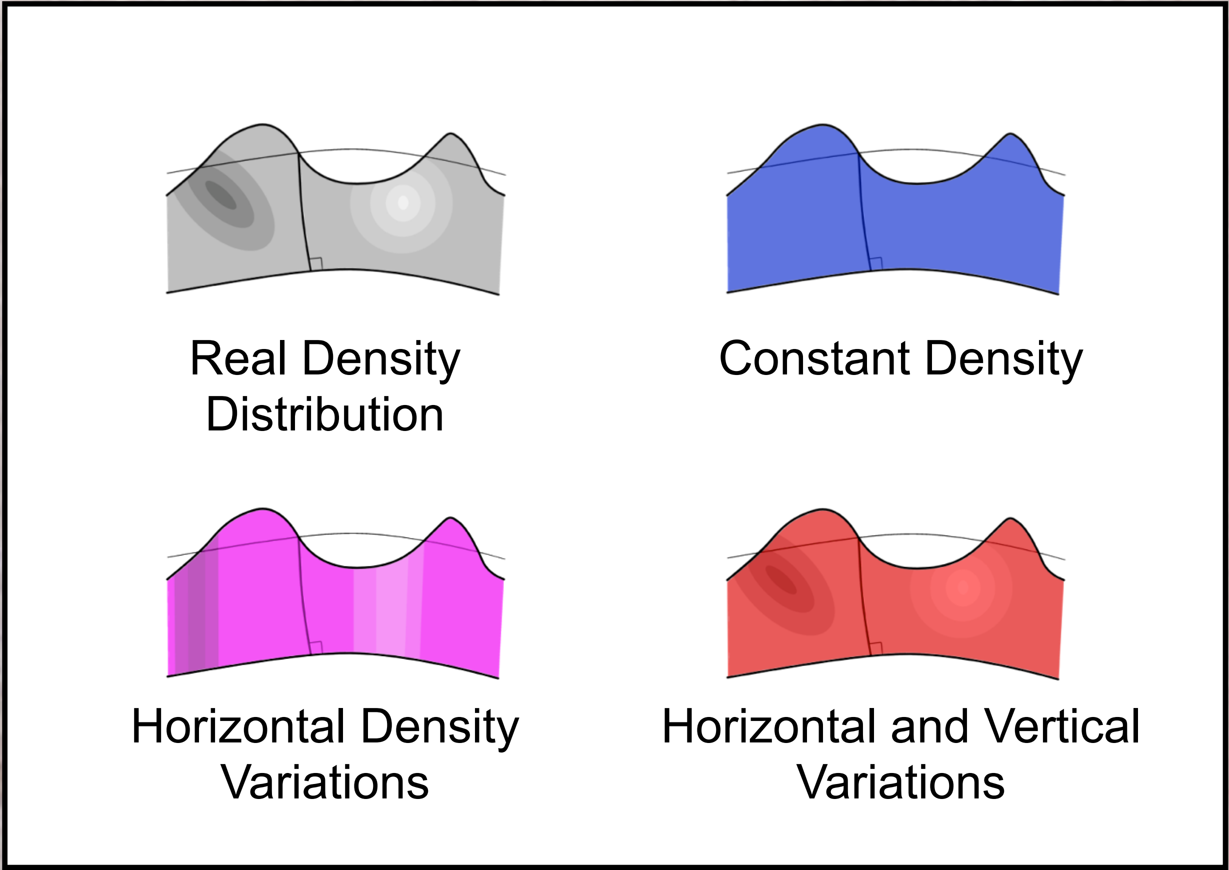
The 1 m Geoid: 1986 to 1993

- Modified spheroidal Stokes's kernel?



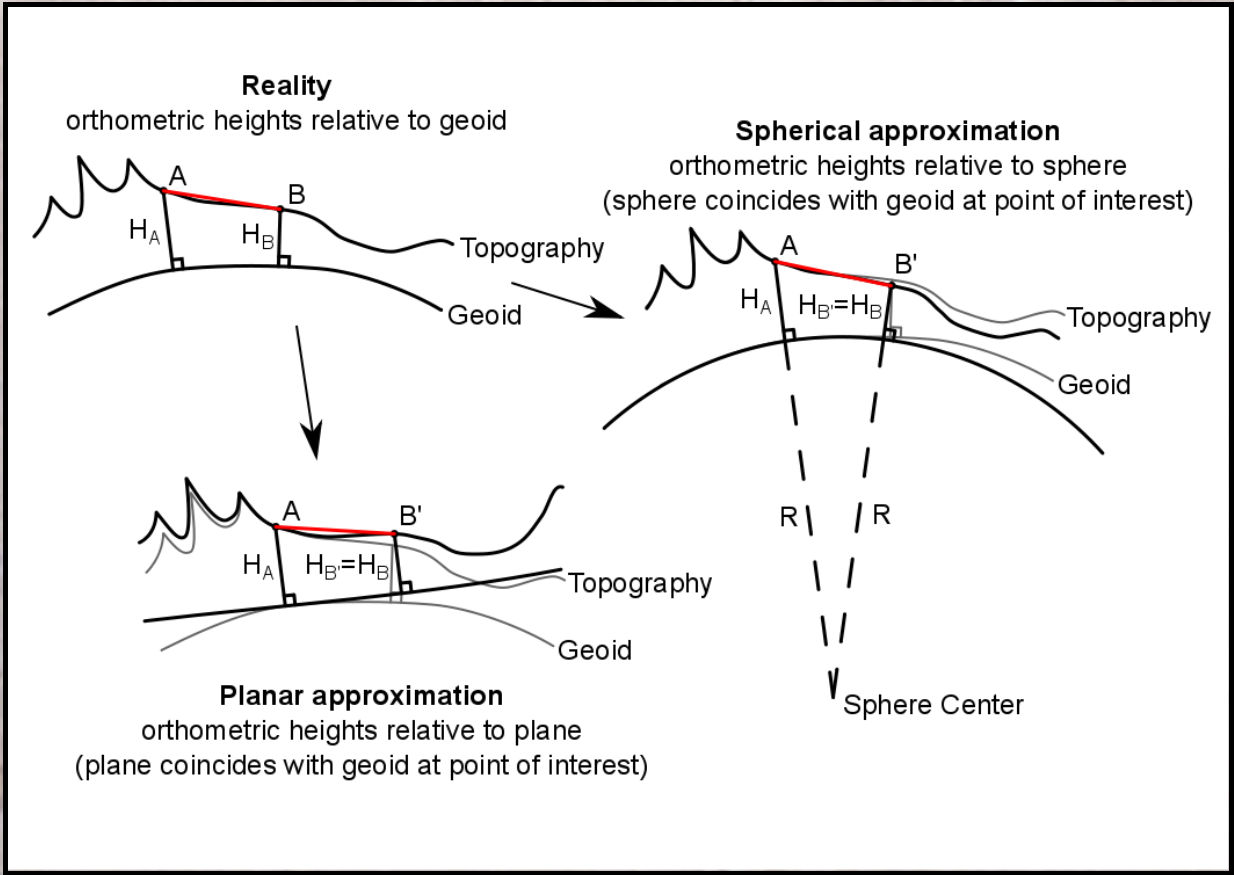
The 1 m Geoid: 1986 to 1993

- Topographical density models



The 1 m Geoid: 1986 to 1993

- Planar vs. spherical approximations



Toward a **1 cm** Geoid: 1993 to 2005

- Early 1990's: discussions about "1 cm" geoid (theory accurate to 1 cm)
- Implemented in SHGeo package
- Changes in theory (and expected benefit):
  - Topographical effects using spherical approximation (50 cm)
  - Downward continuation now included (90 cm)
  - Global Stokes's integration (40 cm)
  - Additional terms in conversion to Helmert space (SITE, ellipsoidal correction) (several decimeters)

Toward a **1 cm** Geoid: 1993 to 2005

- UNB '95 geoid
  - First attempt with 1-cm theory
  - 5' x 5' result over part of Canadian Rockies
  - Limited by of time and funding
  - Theory not completely implemented
  - Absent were:
    - Effects of atmospheric masses (several centimetres)
    - A model of topography that allowed density variations (up to several decimetres)
    - Geoid-quasigeoid correction (part of transformation to Helmert space)

Toward a **1 cm** Geoid: 1993 to 2005

- UNB '95 geoid
  - Comparison with 13 geoid determinations by GPS/leveling showed differences of up to 1.4 m (largely due to errors in GPS/leveling determinations)
  - Brought to light flaws in:
    - satellite gravity data (several dm diff. between sets)
    - DTM data resolution (100 m or better required)

Toward a **1 cm** Geoid: 1993 to 2005

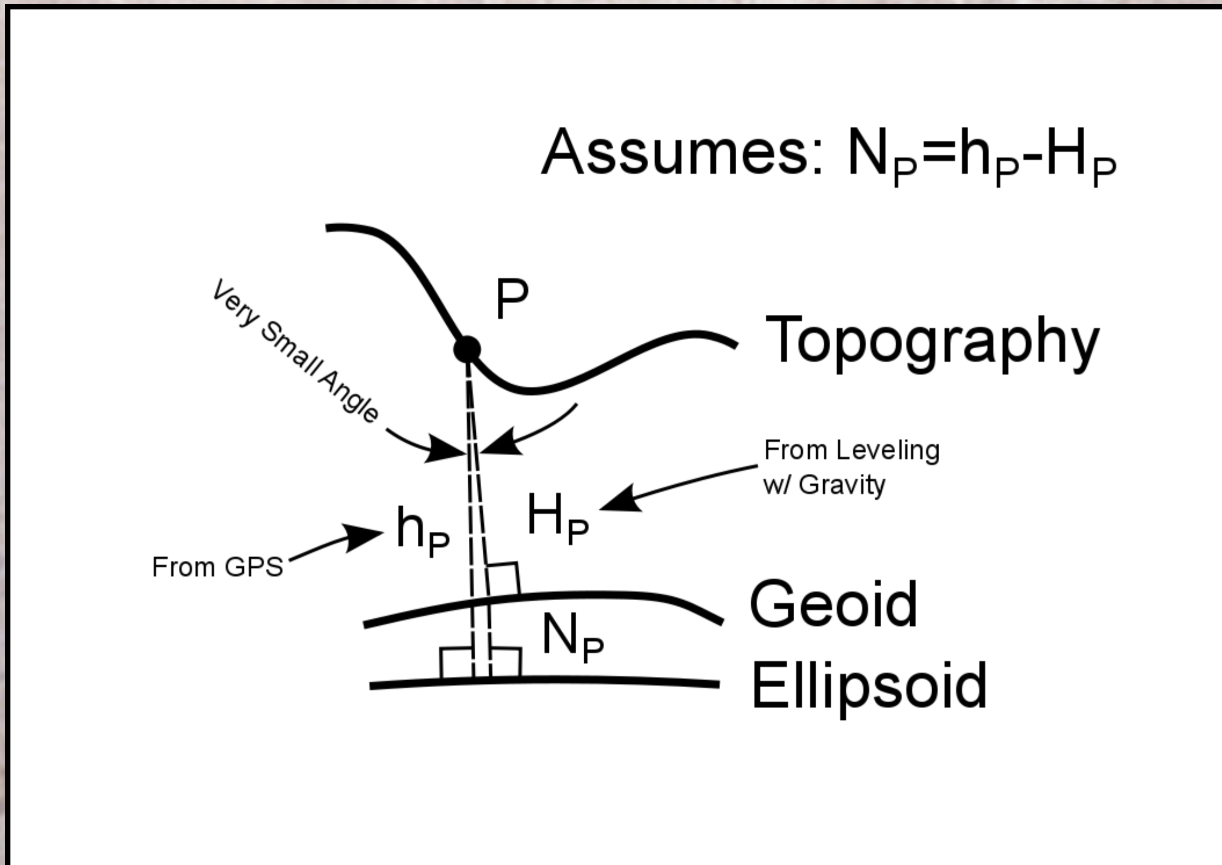
- Since UNB ‘95
  - Improvements in available technology (e.g. ACENet)
  - Improved algorithms (e.g. Huang’s Stokes’s integration better than FFT)
  - Shift toward numerical improvement
  - Atmospheric effect, horizontal density variations, geoid-quasigeoid correction all added
  - New data sources:
    - EGM96 gravity field (1998)
    - GRACE gravity field (2004)
    - Canadain CDED DTM, 100 m resolution (2000)
    - NASA SRTM DTM, 100 m resolution (2003)

Toward a **1 cm** Geoid: 1993 to 2005

- Last attempts with Canadian data:
  - UNB2004 (Canada wide)
    - Last named annual model
    - Used “No Topography” space instead of Helmert space
    - 63 cm RMS difference from GPS/levelling determinations
  - Ellmann et al., 2005 result (over part of Rocky mountains)
    - 60 cm RMS difference from GPS/levelling determinations

Toward a **1 cm** Geoid: 1993 to 2005

- GPS/leveling determinations



Testing with AusSEGM: 2005 to Present

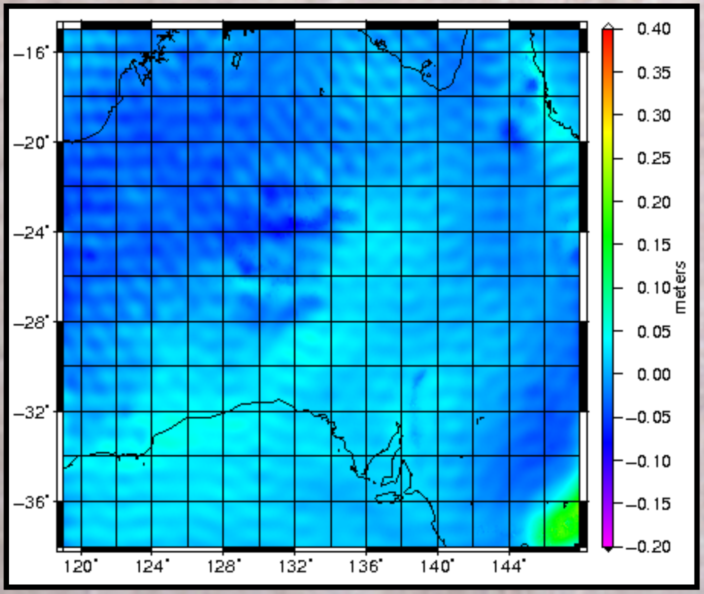
- How to test a geoid?
  - If Earth's mass distribution is known, geoid and gravity can be calculated "perfectly"
  - Researchers at Curtin University (Australia) assumed a mass distribution, and produced a "synthetic" geoid and gravity field (AusSEGM)
  - If we use input gravity data from the synthetic model, and our method is correct, we should arrive at the geoid from the "synthetic" model
  - Any difference represents errors in our method

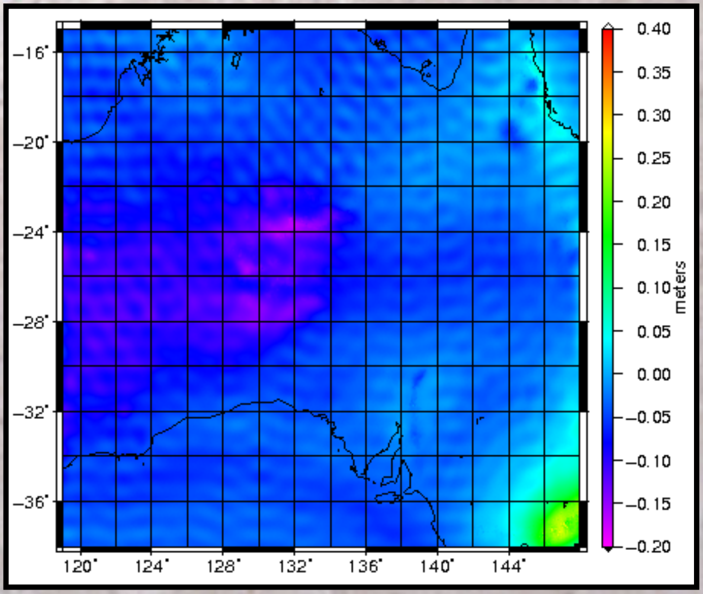
Testing with AusSEGM: 2005 to Present

- AusSEGM comparisons:
  - UNB’s first comparisons (c. 2005) were impressive (8 cm RMS difference from AusSEGM geoid, but range of 70 cm)
  - “No Topography” approach abandoned
  - Several algorithms improved
  - Notably, new method for downward continuation

Current Status

- AusSEGM comparisons:





Best: 2.6 cm RMS,
35 cm range

Worst: 6.1 cm RMS,
50 cm range

Current Status

- UNB's "SHGeo" package gives comparable accuracy to:
  - GRAVSOFT quasigeoid determination package (decimetre level)
  - KTH geoid determination software (several centimeter level)
- Investigations in conjunction with Curtin have shown that some of the apparent "errors" actually come from (cm level) problems with their AusSEGM geoid!

Future Developments

- Using a 3-d model of topographical density
- Eliminating any remaining errors (presumed numerical) in the AusSEGM comparison
- Application of our technique in some real world situations
  - Tweaking according to characteristics of real world gravity data
  - Geoid computations for ____?

Collaboration

- Geodetic Survey Division of NRCan
- National/international computations for:
    - Mexico
    - Israel
    - South America
- FUGRO Airborne Surveys
    - To determine datums for airborne gravity surveys

Contributors to UNB's Approach

- Theory:
  - Petr Vaníček
  - Zdenek Martinec
  - Alfred Kleusberg
  - Lars Sjöberg
  - Will Featherstone
  - Wenke Sun
- Computations:
  - Charles Merry
  - Saburi John
  - Rafael Sosa-Torres
  - Jurai Janák
  - Pavel Novák
  - Mehdi Najafi-Alamdari
  - Jianliang Huang
  - Sander van Eck van der Sluijs
  - Robert Tenzer
  - Artu Ellmann
  - David Avalos
  - Robert Kingdon

Summary

- UNB theory: gravity anomalies -> Helmert space -> downward continue -> geoid solution -> real space
- First geoid: Merry, 1973, astrogeodetic
- UNB ‘86: “1 m” gravimetric geoid; 1.51 m RMS difference from Doppler
- UNB ‘95: “1 cm geoid” w/ spherical formulas, dwnc; max 1.4 m error from GPS/levelling
- 2000’s:
  - Horizontal density variations, atmospheric effects
  - Transition to numerical improvements
  - Canada: 60 cm RMS difference from GPS/leveling

Summary

- Current
  - 3-6 cm RMS difference from AusSEGM geoid
  - Comparable accuracy to GRAVSOFT, KTH approach
- Future:
  - 3D topographical density model, numerical improvements
  - Return to real world application
- Extensive collaboration
  - Other researchers and institutions
  - National and International geoid computations
  - Fugro Airborne Surveys

Thank you for your attention.

Any questions?