North American Geoid Computations

- Greenland
  1996 KMS
- Canada
  1995 GSD/GC
- U.S./Alaska/Hawaii/Puerto Rico
  1996 NGS
- Mexico
  1997 NGS
- Caribbean Sea
  1997 NGS/NIMA
- Central/South America
  1995 EP-USP
GEOID COMPUTATIONS AT NGS

- 2-D FFT for terrain corrections using 30''x30'' DTED
- Downward continuation using normal gravity
- Grid refined Bouguer Anomalies using splines in tension
- Restore Bouguer plate using 2’x2’ mean DTED at grid intersections
- Remove geopotential anomalies
  \[ \Delta g_{0\rightarrow360} = -\partial T/\partial r - 2T/r + 2\delta W/r \]
- 1-D FFT w/ mean removal
- Restore geopotential undulations
  \[ N_{0\rightarrow360} = T/\gamma - \delta W/\gamma \]
- Apply 1st order indirect effect using 2’x2’ mean DTED at grid intersections
GEOID COMPUTATIONS AT GSD/GC

- Terrain corrections pre-computed using templates, and prism integration
- Remove geopotential anomalies at each point.
  \[
  (\Delta g_{0 \rightarrow 360} = -\partial T/\partial r - 2T/r + 2\delta W/r)
  \]
- Downward continuation using normal gravity
- Grid residual refined B.A.'s using collocation to 5'x5' centers of cells.
- Restore Bouguer plate using 5'x5' mean DTED at centers of cells
- 2-D FFT w/ mean removal, 6 band
- Restore geopotential undulations
  \[
  (N_{0 \rightarrow 360} = T/\gamma - \delta W/\gamma)
  \]
- Apply 1st order indirect effect using 5'x5' mean DTED at grid intersections
GEOID COMPUTATIONS AT KMS

- 1 km x 1 km DTED
- Compute and remove gravity RTM signal about mean DTED (100 km resolution)
  (approx. through $2\pi G \rho (h-h_r)-TC$)
- Remove geopotential surface gravity anomalies ($\Delta g^s_{0\rightarrow360} = -\partial T/\partial r - 2T/r$)
- Collocation or FFT to produce gridded residual (quasi-)geoid undulations
- Restore geopotential surface height anomalies ($N_{0\rightarrow360} = T/\gamma$)
- Compute and apply geoid RTM effect to yield (quasi-)geoid undulations
MOLODENSKII METHOD (G9501)

- 30''x30'' DTED, Center of Cell
- 2-D FFT for classical terrain corrections
- Grid refined Bouguer Anomalies using splines in tension
- Restore Bouguer plate using 3’x3’ mean DTED at grid intersections
- **Assume** $\Delta g_{TF} = \Delta g_{surf} + G_1$
- Remove geopotential surface gravity anomalies ($\Delta g^s_{0\rightarrow360} = -\partial T/\partial r - 2T/r$)
- 2-D FFT, $S(\Delta g_{TF}) = S(\Delta g_{surf} + G_1)$
- Restore geopotential surface height anomalies ($\zeta_{0\rightarrow360} = T/\gamma - \delta W/\gamma$)
- Apply height anomaly to geoid undulation correction, using simple Bouguer anomalies and 3’x3’ mean DTED
THEORETICAL ISSUES

• Attempt to write theory at 1 cm level to anticipate future data support.
• Density anomaly data?
• RTM vs. "classical" terrain reductions?
• Spherical Terrain reductions?
• Downward continuation in Helmert Space? Using \( H \)?Using \( g \)? Using \( \gamma \)?
• Gridded vs. pt. gravity values?
• Spectral content of geoid signal to 1 cm (i.e. omission error < 1 cm at 5’’? 2’’?)
• Ellipsoidal Stokes’ Kernel?
• Analytical compatibility of gravity reductions and indirect effect?
MARGIN OF VARIATION

- NGS and GSD/GC have used the same theory.
- Molodenskii method is very similar, under defining assumptions
- KMS uses a modified version of Molodenskii

- Many large (> 10 cm) NGS geoid issues have been data related
- G96SSS vs GSD95 disagreements seem data related (theory is the same).
- G96SSS vs MEXICO97 vs CARIB97 disagreements are data related
CANADIAN TERRAIN CORRECTIONS (Jan 93)
Attempts to reproduce

- 2 DTEDs:
  - TOPO30
  - New Canadian DTED 1995

- 5 Independent TC programs:
  - ftc.f (FFT, Milbert)
  - tc01.f (Flat top Prism, Milbert)
  - tc.f (Flat top Prism, Forsberg)
  - tcpts01.f (Flat top Prism, Veronneau)
  - triter4.f (Inclined top Prism, Rupert/Beach) ***

- 202 points in 50° - 51° N, 235.5° - 237.5°

*** = Not fully tested yet
### TC DIFFERENCES

**Jan93 (Can Database) MINUS Other TCs**

<table>
<thead>
<tr>
<th></th>
<th>TOPO30</th>
<th>1995 Canadian DTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave</td>
<td>12 mgals</td>
<td>14 mgals</td>
</tr>
<tr>
<td>RMS</td>
<td>17 mgals</td>
<td>19 mgals</td>
</tr>
<tr>
<td>Min</td>
<td>-17 mgals</td>
<td>-12 mgals</td>
</tr>
<tr>
<td>Max</td>
<td>+45 mgals</td>
<td>+54 mgals</td>
</tr>
</tbody>
</table>

- 122 non-zero points
- Overall stats for all 4 fully-tested programs
- **Conclusion:** The Jan93 TCs (currently still in the Canadian database) are systematically higher than all 8 TC sets at NGS, by a factor of 1.5 to 1.8
CANADIAN TERRAIN CORRECTIONS (Jan 93)
Preliminary Results

- Unable to reproduce the January 1993 TC's
- Attempts using the old (TOPO30) DTED gave results closer to Jan 1993 than the new DTED
- FFT method agrees to within +/- 1 mgal with prism methods, except for large (>30 mgal) spikes, where the FFT is systematically too low by an average of 8 mgals
- Level 1 DTED (3"x6") unable to get Jan93 TCs!
Pits - 2.16 m
Tilt ≈ 1.25 m E/W
= 0.28 ppm
- 2.2 m in Baja
- 1.5 m in Gulf
80 cm Tx/La till
Menlo edge peak is due to
difficult TC's & Tension
±70 cm about the

Averages:

\[ L = \frac{x}{y} = 36 \text{ cm} / -1.6 \pm 1.5 \text{ m} \]

\[ \sigma = 0.7 \text{ cm} \]

\[ R = \frac{x}{y} = 26 \text{ cm} / -1.8 \pm 2.0 \text{ m} \]

\[ \sigma = 38 \text{ cm} \]
Thinned Bouguer Anomalies (GEOID96)