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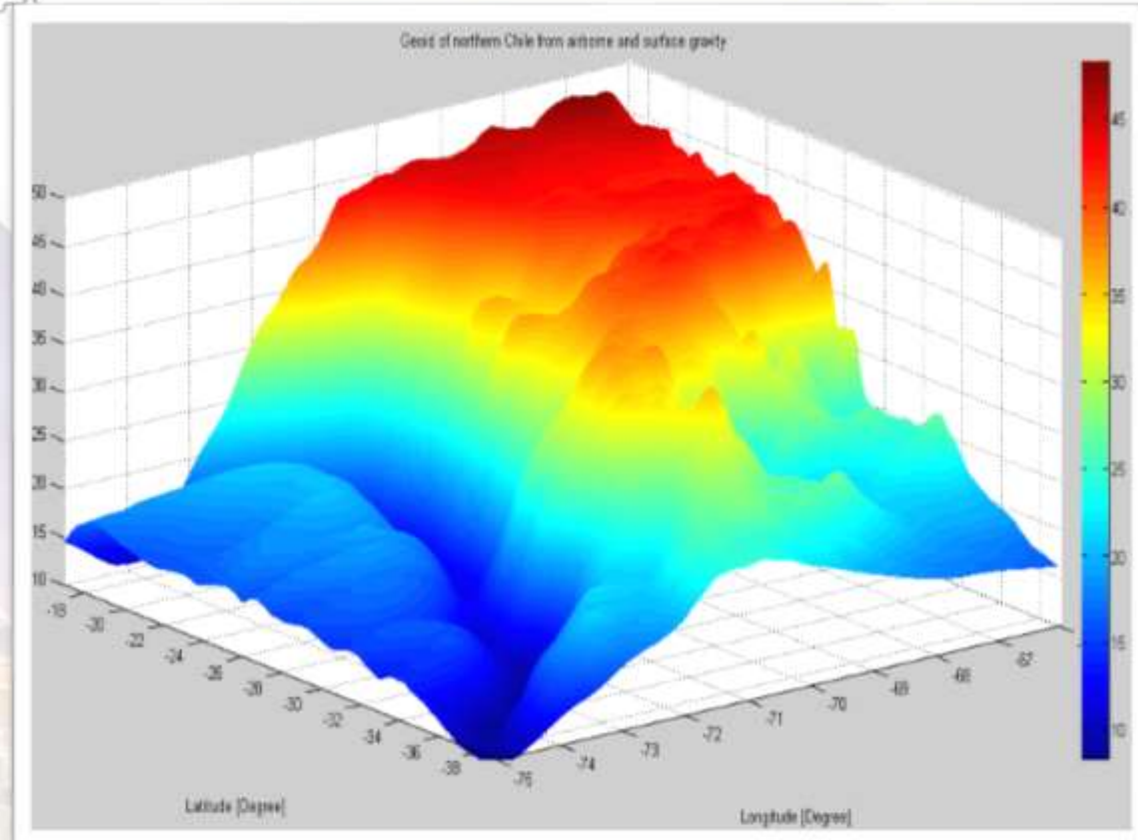
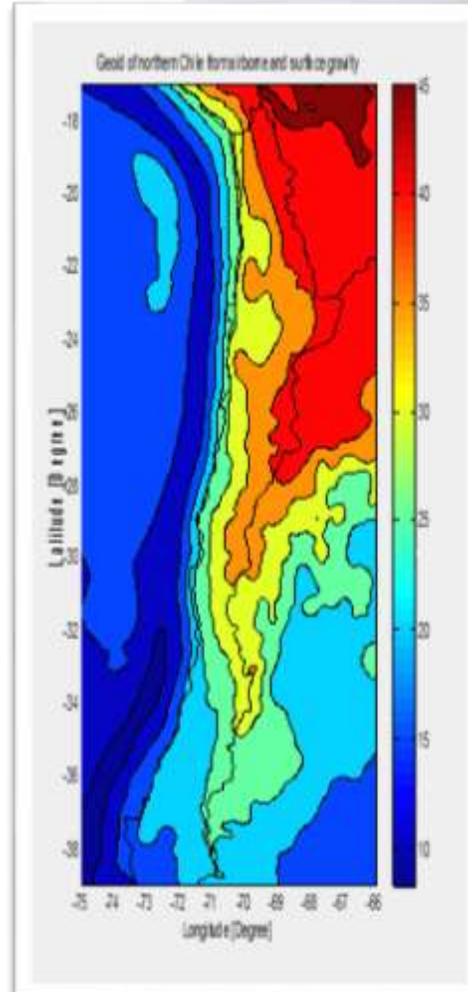
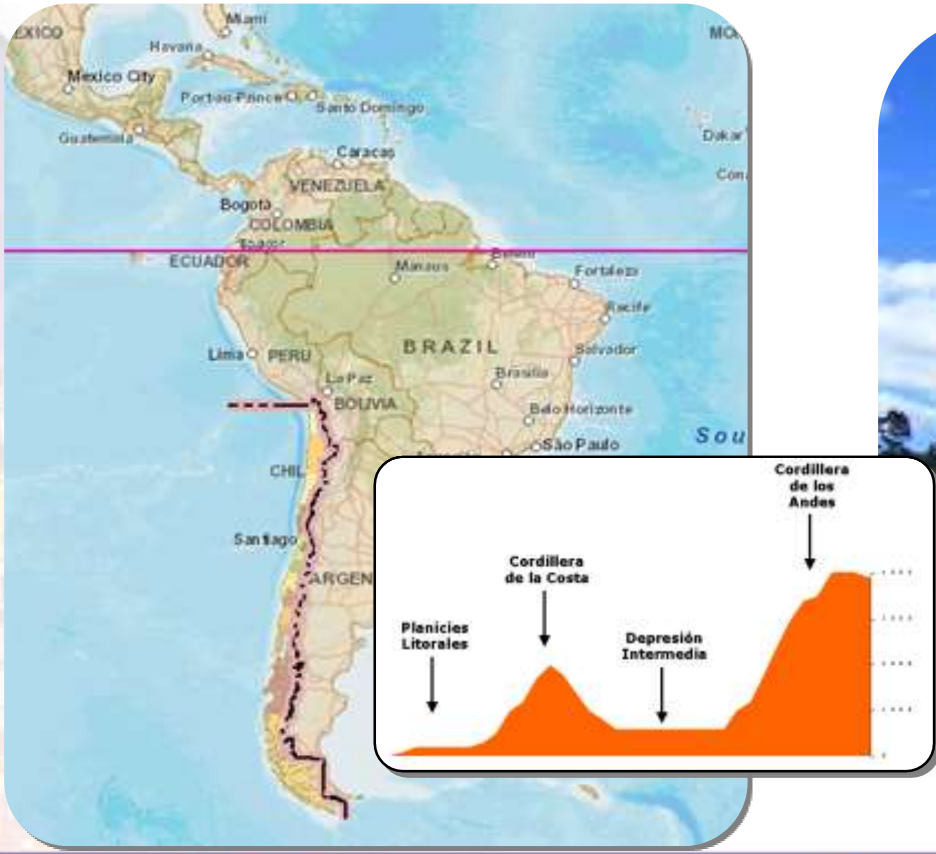




A Geoid model of northern Chile from airborne and surface gravity

- **Geographic Description of Chile.**
- **Total Surface: 2,006,096 Km^{2}.**
- **Estimated population 2012 (INE): 17,402,630 inhabitants.**

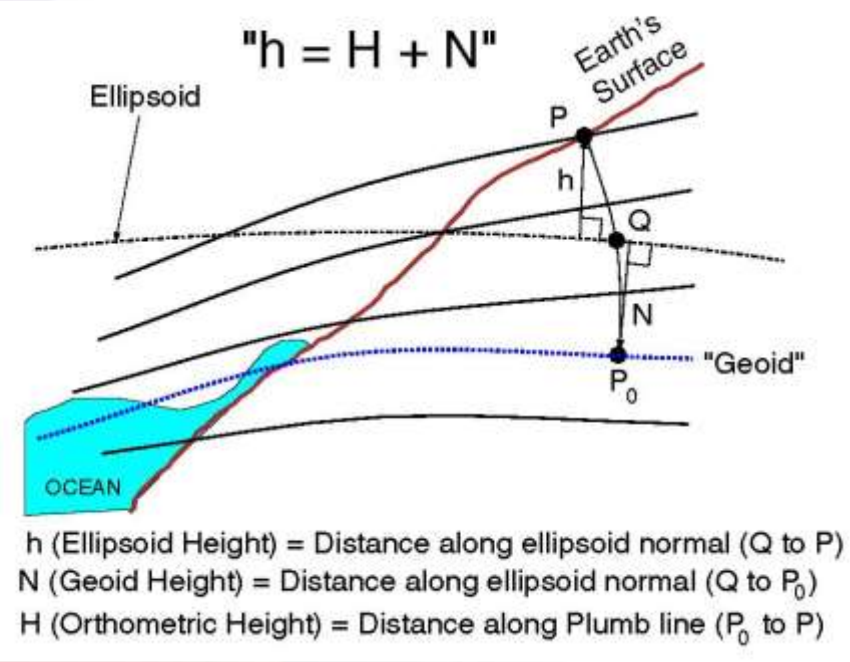


International boundaries:
- **Peru: 180 kms.**
- **Bolivia: 850 kms.**
- **Argentina: 5,600 kms.**

Definitions

Geoid:

The equipotential surface of the Earth's gravity field which best fits, in a least squares sense, global mean sea level.



Source: https://www.ngs.noaa.gov/GEOID/geoid_def.html

The geoid model is a surface (N) which describes the theoretical height of the ocean and the zero level surface on land. The geoid is required to obtain orthometric height H ("height above sea level") from GPS by

$$H = h_{GPS} - N$$

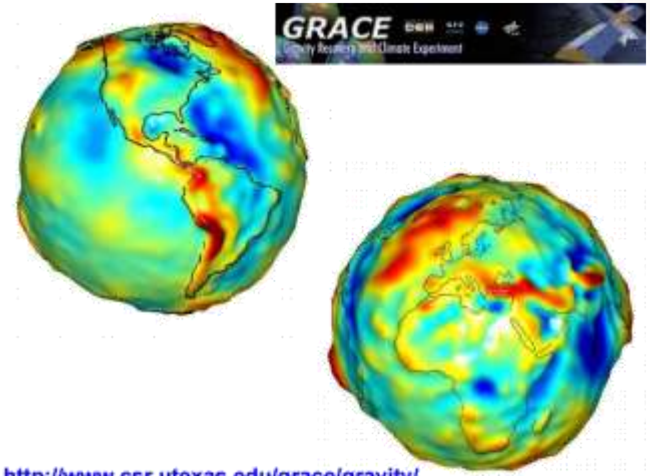
where h_{GPS} is the GPS ellipsoidal height, and H the levelled (orthometric) height.

Definitions

Earth Gravitational Model 2008 (EGM2008)

EGM2008 is a spherical harmonic model of the Earth's gravitational potential, developed by a least squares combination of the ITG-GRACE03S gravitational model

The **GRACE** satellite mission determined a global gravity field model by circling the Earth and tracking the orbital perturbations of the satellite pair.



http://www.csr.utexas.edu/grace/gravity/

Major DTU-Space international aerogravity surveys

Malaysia 2002-3 (*AN38 aircraft*) … *cooperation partners JUPEM/GlobalTrak*
Mongolia 2004-5 (*Twin-Otter and Cessna Caravan) … ALAGaC/MonMap/NGA*
Ethiopia 2006-7 (*Cessna Caravan) … Ethiopian Mapping Agency/NGA/U Edinb.*
Indonesia 2008-.. (*Cessna Caravan) ... Bakosurtanal/NGA*

Major objectives: Geoid in support of national GPS nets + EGM08 (NGA)

Layang-Layang Airways Antonov-38 in Kota Kinabalu, Malasya Sept. 2002

Air Greenland DHC-6 Twin Otter in Ulaanbaatar, Mongolia, October 2004

Abyssian Flight Service Cessna Caravan, Addis Abeba, Etiophia, September 2006

Northern Chile Geoid Model from airborne and surface gravity project

DTU Space
National Space Institute

UNIVERSITY OF COPENHAGEN

UNIVERSITY OF BERGEN

IGM
INSTITUTO GEOGRÁFICO MILITAR

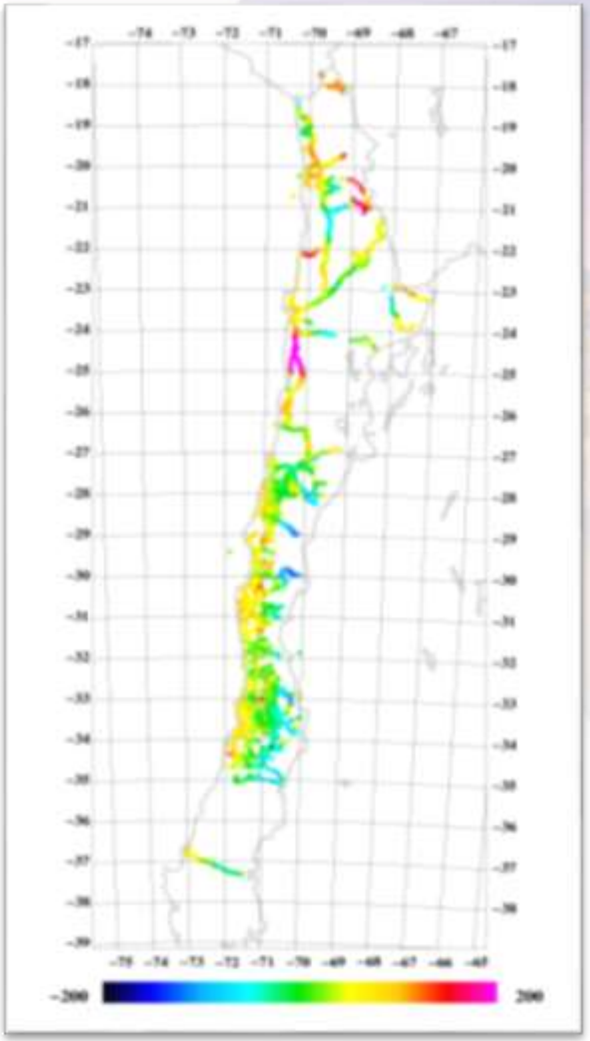
The aircraft used was a Beech King Air 350i aircraft from the Chilean company Aviasur

Bases at Santiago + Copiapo + Antofagasta

Chilean leveling data

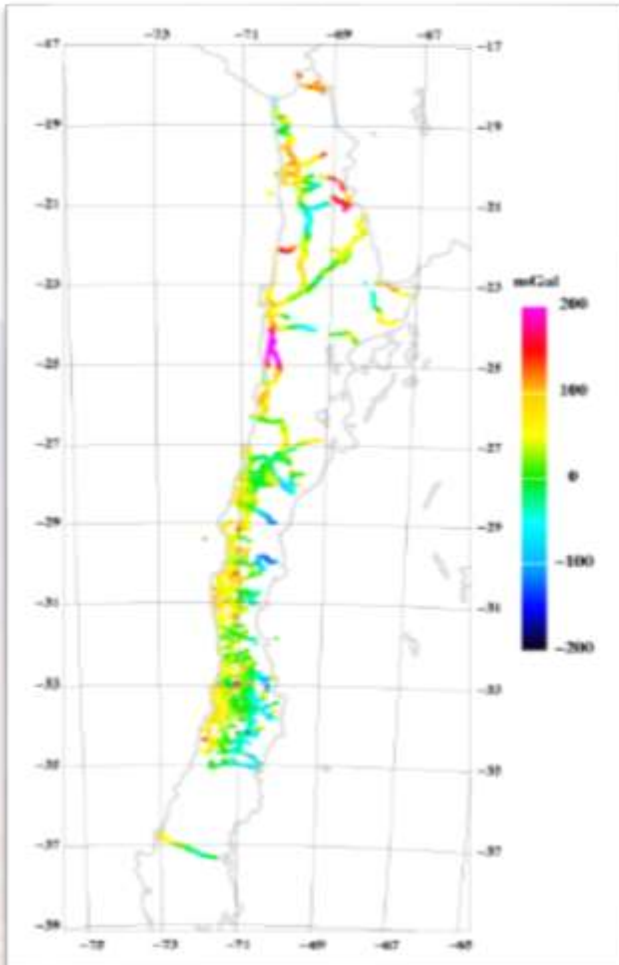
The Chilean geoid was computed in a global vertical reference system, without fits to the Chile GPS-levelling data (due to insufficient and no updated GPS-levelling data available).

The main reason of this, is due to the destruction of the network due to recent earthquakes that have affected the area.



Data for the geoid computation

1. DTU airborne gravity data, augmented with additional IMU data from TU Darmstadt (processed by D. Becker), using a draping technique.
2. Land gravity from IGM compilations.
3. DTU10 global gravity anomalies from multi-mission satellite altimetry. (Only in the open ocean area).
4. SRTM 30” DEM data for the region.
5. EGM08 and GOCE RL4 satellite data.



Data for the geoid computation

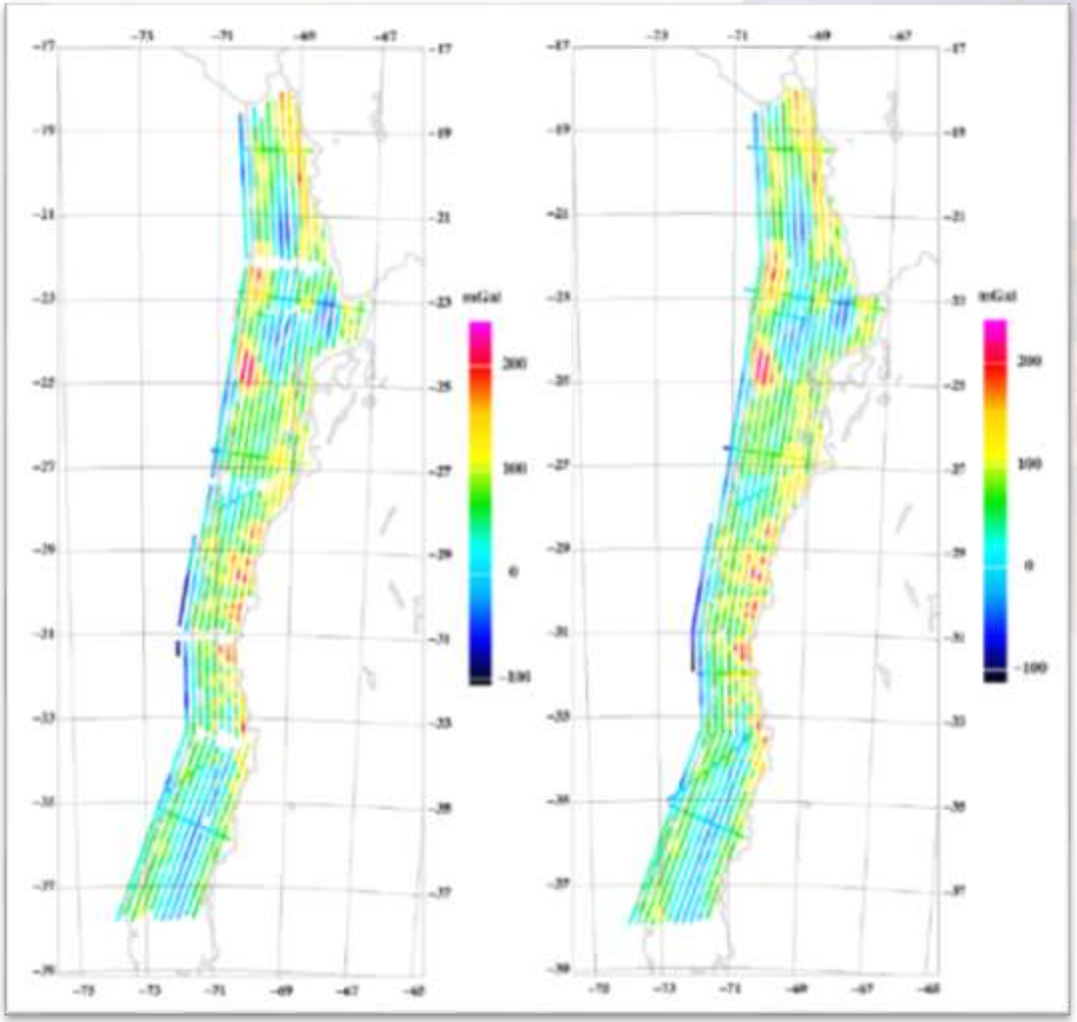
IGM land gravity data used for the geoid determination. Colors show the free-air anomalies.

Data for the geoid computation

Airborne gravity data.

Left: LCR data with gaps at turns, April 2014 version.

Right: new merged LCR/IMU data for final airborne survey results.



Gravimetric geoid computation

The Chile geoid computations was done in connection with a workshop on airborne and strapdown inertial gravity held at the Astronomical Observatory in the city of Porto in Portugal on May 12-15, 2014, with support of prof. Luisa Bastos and with the participation of one Military Geographic Institute team member.

The Chile gravimetric geoid was computed by the use of GRAVSOFT system, which is a set of FORTRAN routines developed through many years of research and project work at DTU-Space and Niels Bohr Institute of the University of Copenhagen

The Chile geoid has been computed by a "remove-restore" technique, where a spherical harmonic earth geopotential model (EGM/GOCE combination) is used as a base, and the geoid is computed from the global contribution N_{EGM}, a local gravity derived component N_2, and a terrain part N_3.

$$N_{grav} = N_{EGM} + N_2 + N_3$$

Steps of the final gravimetric geoid solution

1. Subtraction of EGM08GOCE spatial reference field.
2. Residual Terrain Model (RTM) for terrain reduction of surface gravimetry, after editing for outliers.
3. Residual Terrain Model (RTM) for terrain reduction of airborne gravimetry.
4. Reduction of DTU-10 satellite altimetry in ocean areas away from airborne data.
5. Downward continuation to the terrain level and gridding of all data by least-squares collocation using a 1° x 1° moving-block scheme with 0.6° overlap borders.
6. Spherical Fourier Transformation from gravity to geoid.
7. Restore of RTM and EGM08GOCE effects on the geoid.

The available data from the airborne and surface sources were quality controlled through plotting of the EGM08GOCE and terrain reduction residuals, showing a few (~ 1%) surface gravity outliers, which were deleted in the final geoid processing.

Quality control of the data

	Mean	r.m.s. x-overs	r.m.s. error
LCR free-air anomaly data (April 2014, 57 x-overs)	1.1	5.0	3.4
LCR after terrain and EGM corrections	-1.0	3.6	2.6
LCR after continuation to 5600 m	-0.8	3.5	2.5*
LCR/IMU merged data set (May 2014, 68 x-overs)	0.7	5.2	3.7
LCR/IMU after terrain and EGM corr.	-1.0	3.9	2.8
LCR/IMU after continuation to 5600 m	-0.8	3.5	**2.5**

Estimated errors of the airborne gravity data (Cross-over analysis mGal).

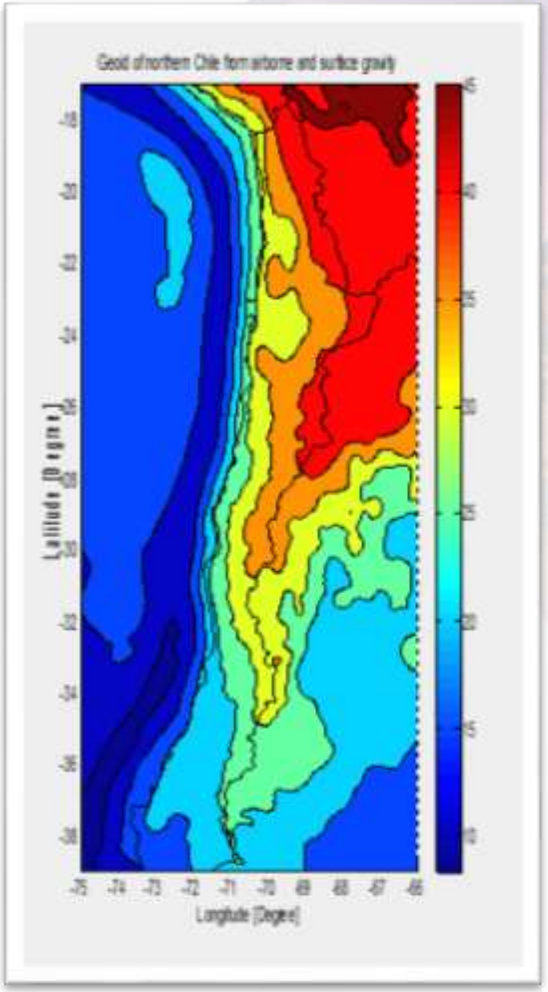
Unit: m	Mean	Std.dev.	Min.	Max.
Reduced geoid (after spherical FFT)	0.00	0.22	-3.36	1.95
RTM restore effects (computed by FFT)	0.00	0.13	-0.64	1.27
Correction quasigeoid to geoid	-0.35	0.57	-2.72	0.14
Final gravimetric geoid statistics	25.43	10.23	8.26	48.32

Statistics of the final Geoid

Use of the final GRID

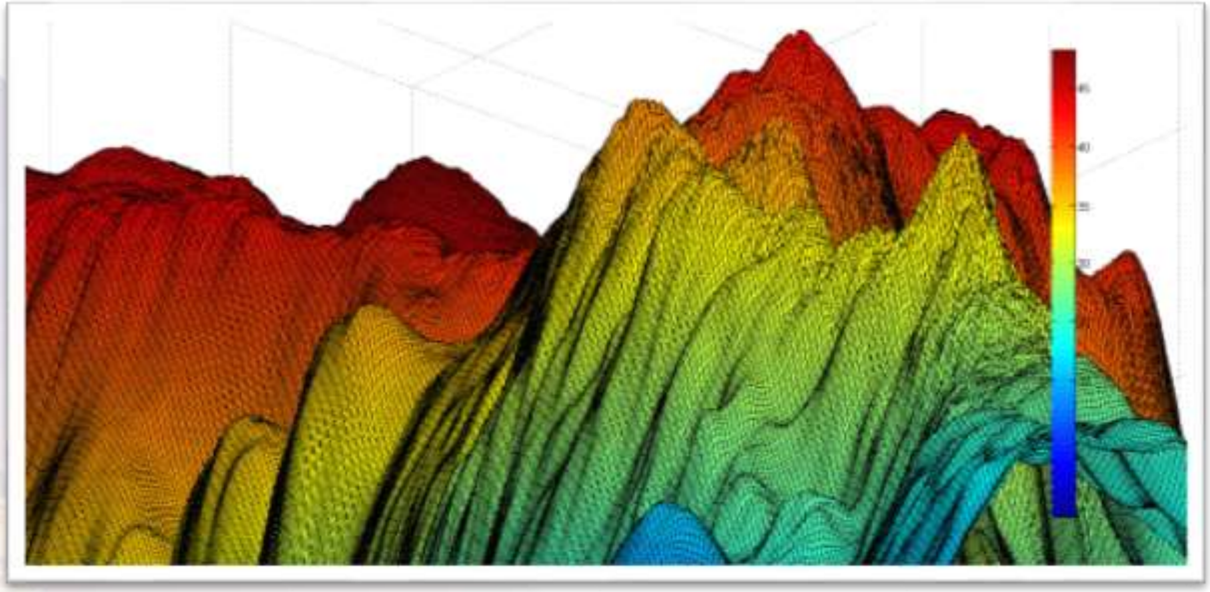
With the data grid provided by the project, and after preparing the data properly, through the use of the software Surfer 8, Global Mapper and Matlab, the author of this technical paper generated different outputs to be use as an input to other products in IGM.

The purpose of the generation of this output is allow to non-specialist figured the form of a geoid in a visual form.

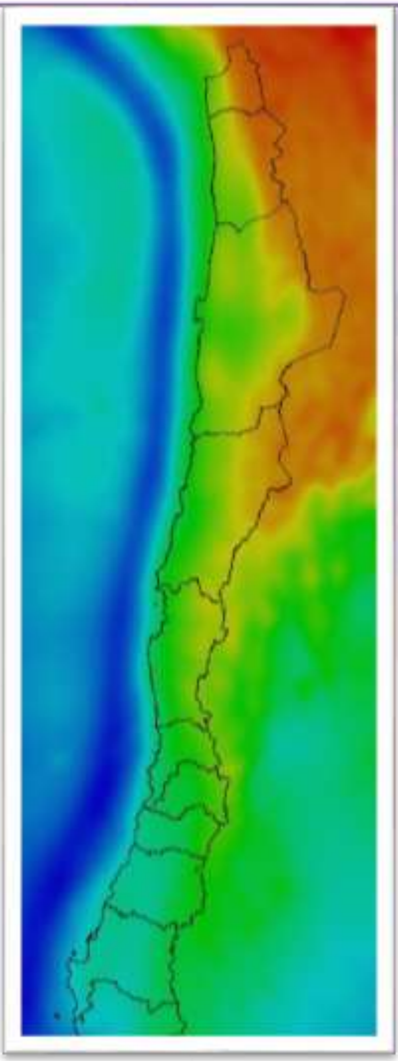


Matlab output

Output in different Software

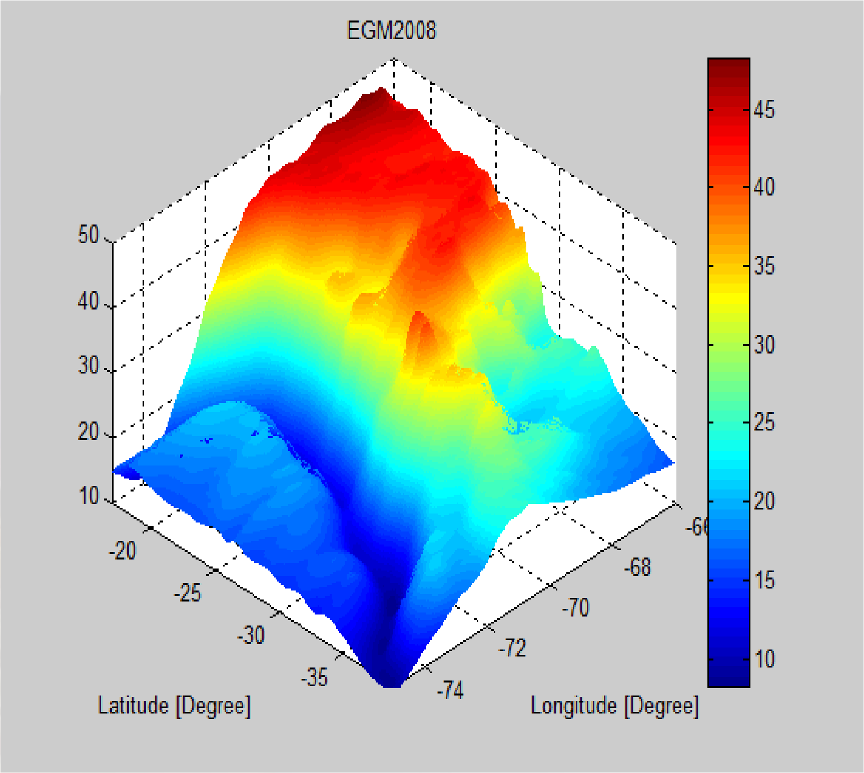


Matlab with function surf

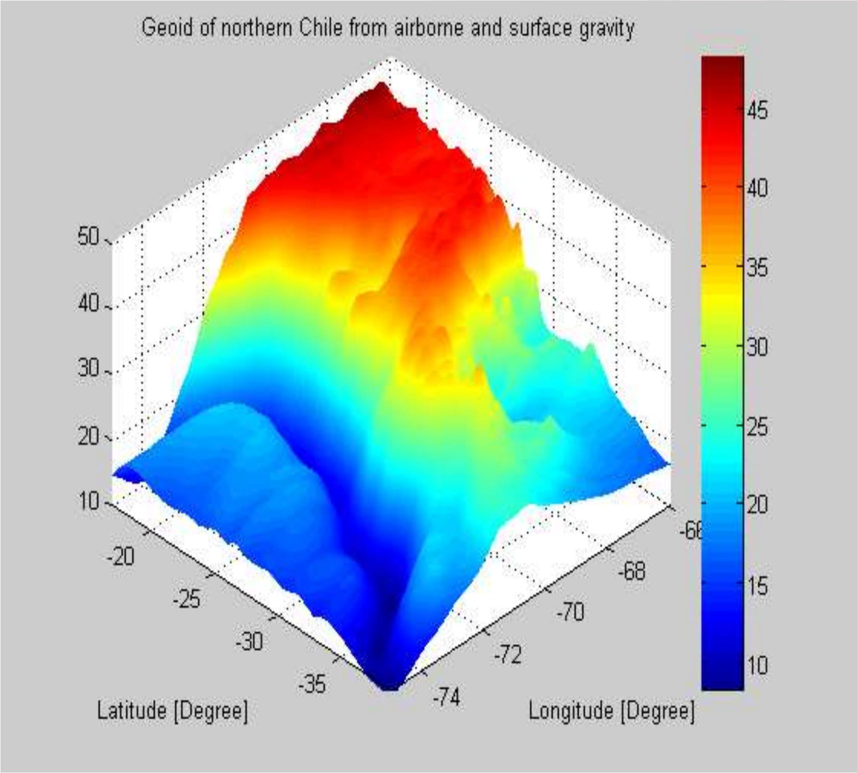


Global Mapper

Comparison of new Chilean geoid to EGM2008



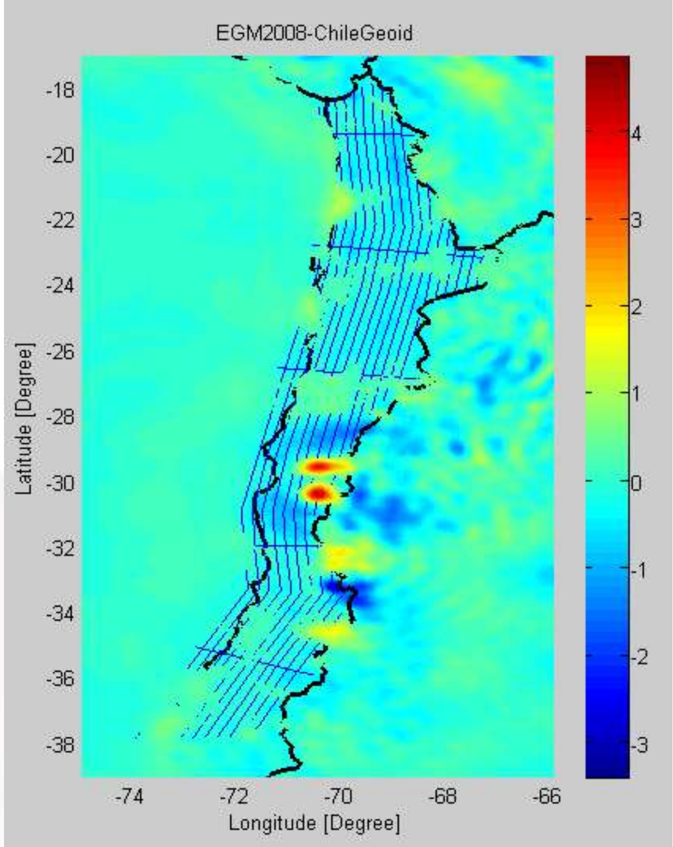
EGM2008

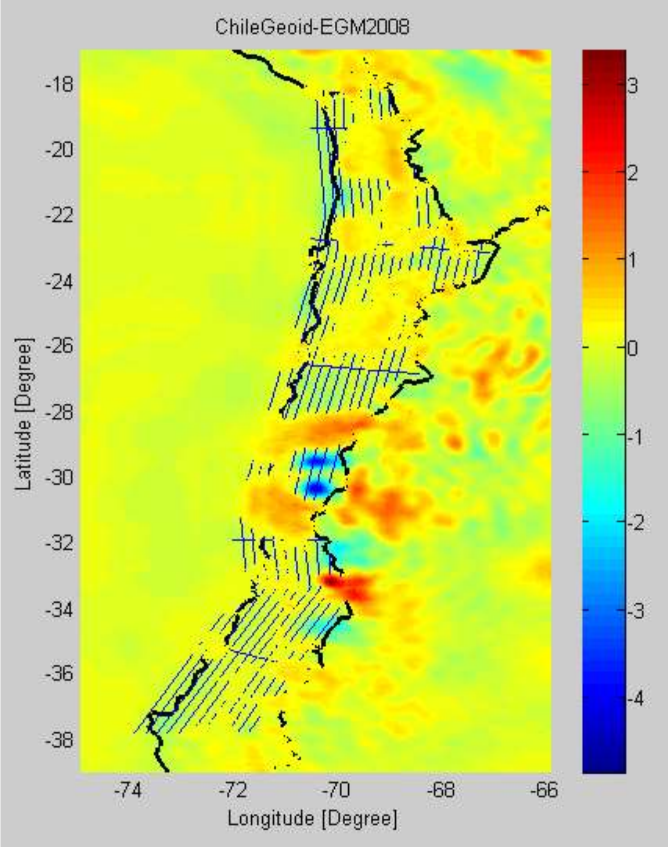


Geoid of Northern Chile

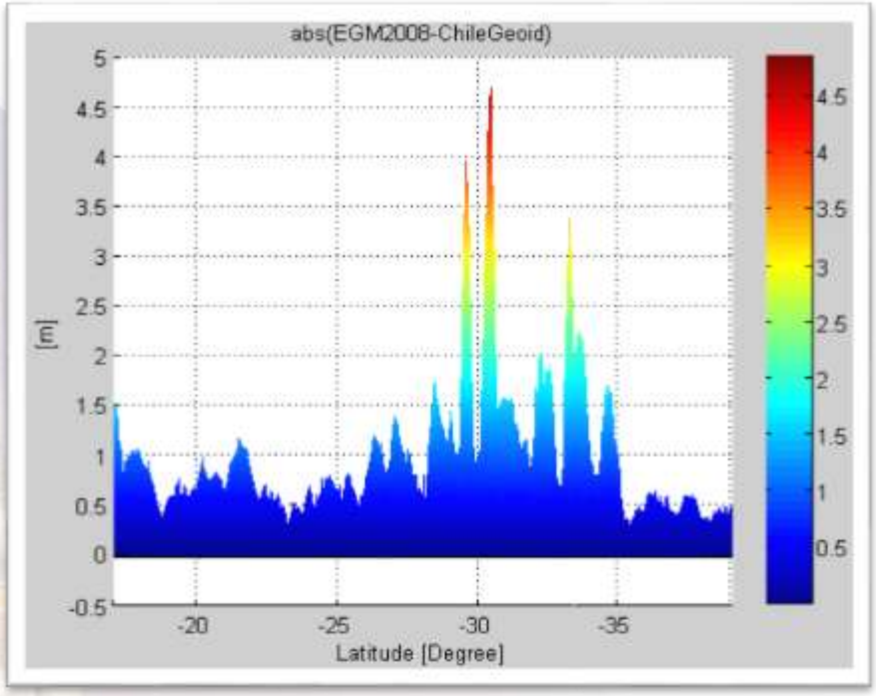
Difference between Chile Geoid and EGM2008.

Closer to the Chilean land borders it is seen large differences to EGM2008, large effects are seen along the border of Argentina, where lack of data will make the geoid uncertain. Large differences are seen especially in the mountains.

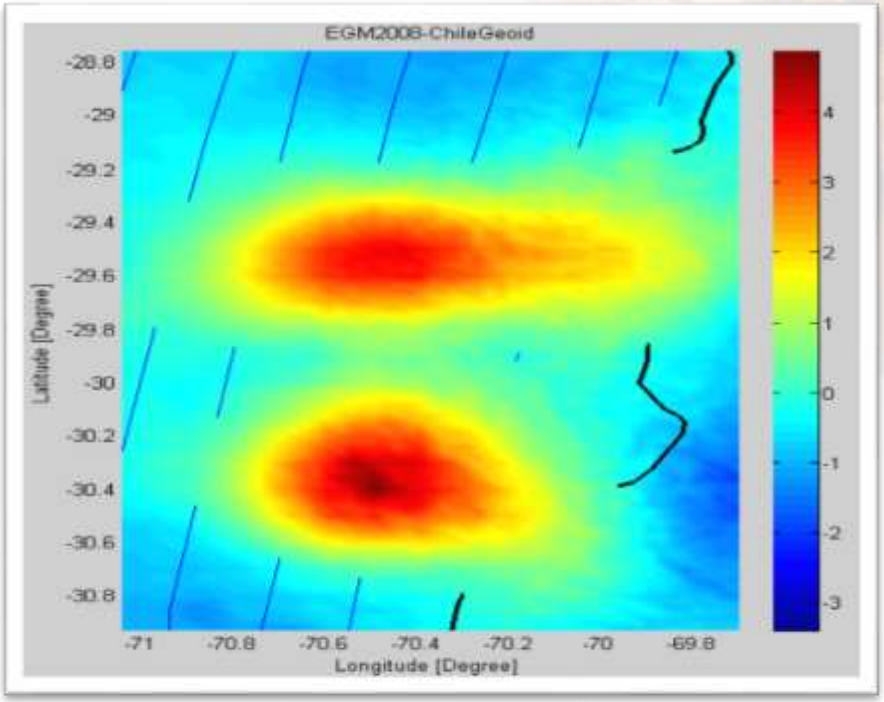




Outliers around 30 S



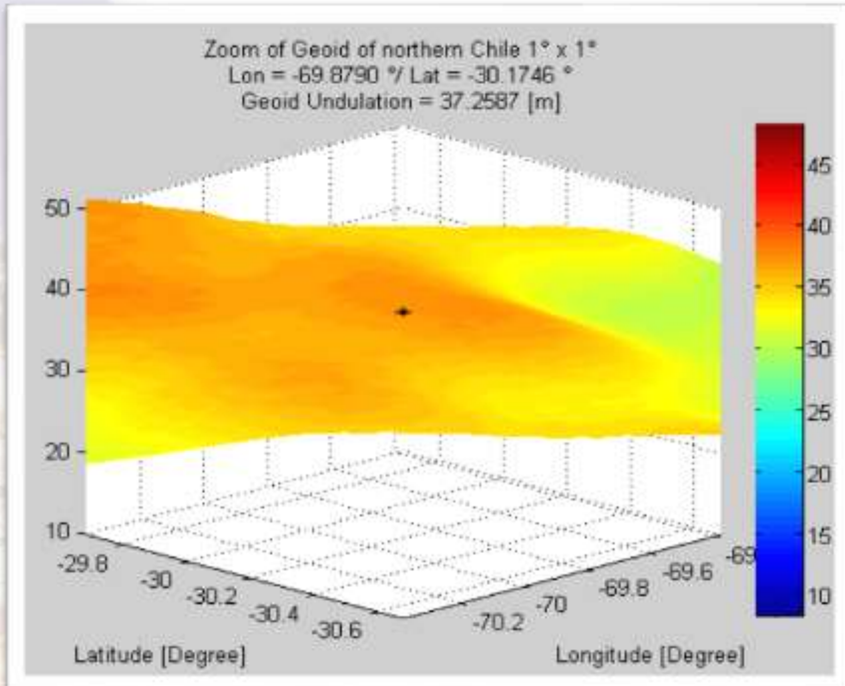
Absolute value of the difference between Chile Geoid and EGM2008.

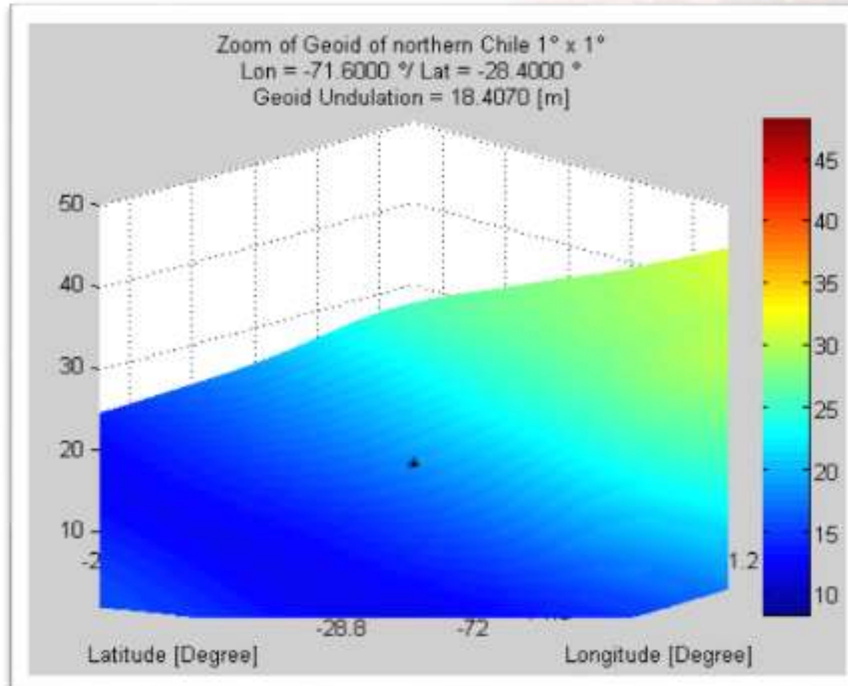


Peaks in the difference between Chile Geoid and EGM2008 and the Flight tracks.

Interpolation function in Matlab for any Latitude and Longitude.

The final geoid "geoid2.gri" can be interpolated with a user-friendly interpolation matlab function. The function shows in 3D a 1° x 1° plot of the Geoid Undulation for the input Latitude and Longitude.



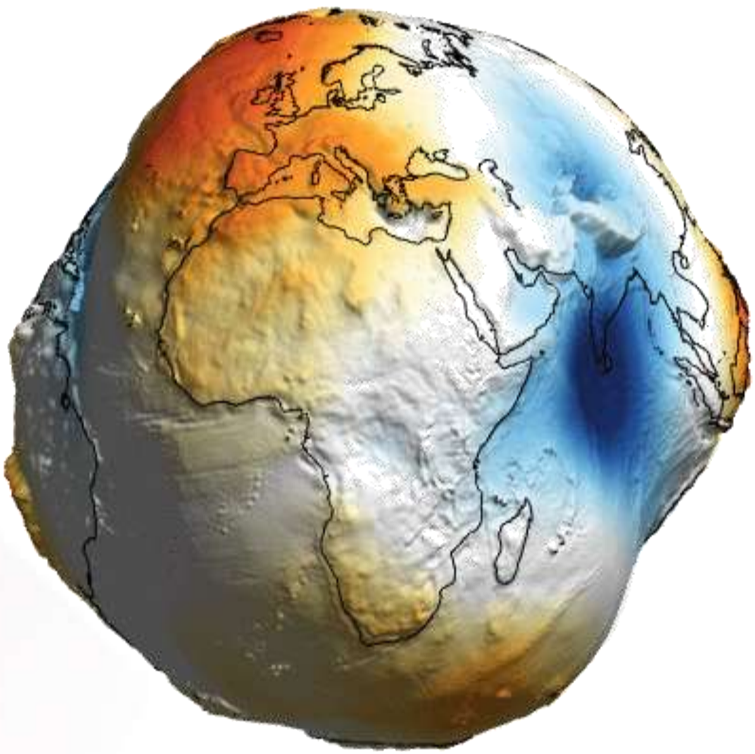


CONCLUSIONS

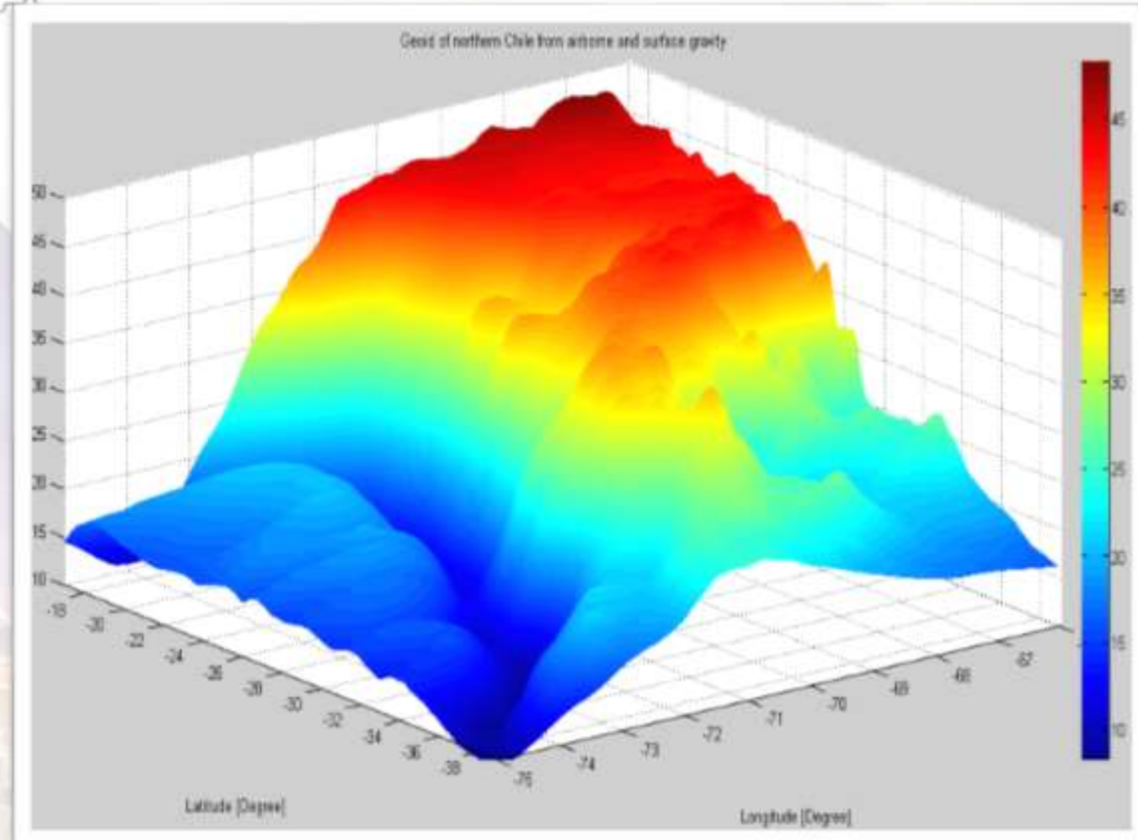
1. Airborne gravity measurements has become essential to determine features of the gravity field, and thus a precise geoid.
2. Airborne gravimetry is an important technique to quickly collect gravity data over large regions, where terrestrial gravity data are sparse and/or of poor quality for use in geoid determination.
3. Airborne measurement of gravity has been a goal for geodesy and geophysics for many years.
4. Airborne measurement provide efficient and economic mapping of gravity anomalies for geophysical exploration.
5. Airborne gravity provide an obvious means of gravity field data over large, inaccessible regions, such as polar and mountainous areas.
6. Satellite gravity missions, such as CHAMP, GRACE and GOCE, and airborne gravity campaigns in areas without ground gravity will enhance the present knowledge of the Earth's gravity field.
7. Many countries have been involved in projects related to the determination of local geoid by combining EGM08 and airborne gravity.

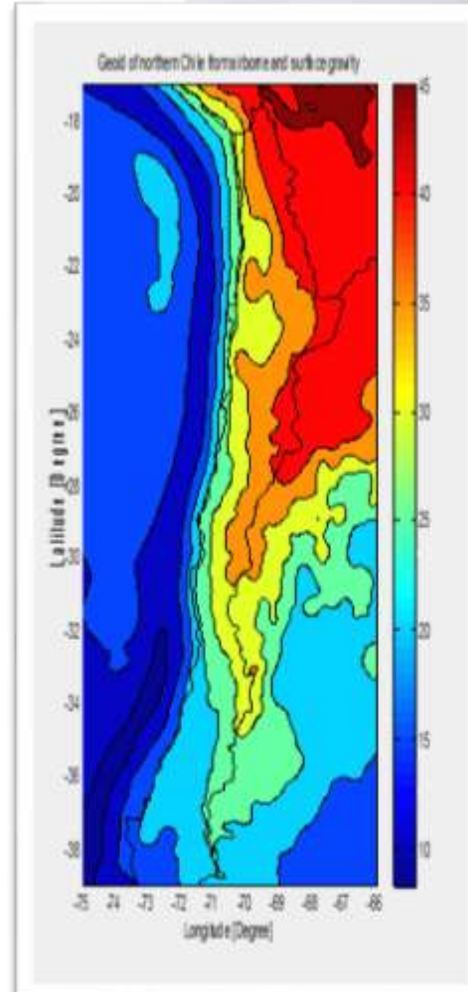
CONCLUSIONS

8. Due to political restrictions the flight tracks did not consider pass the border with Peru, Bolivia and Argentina and is very difficult develop international joint projects.
9. Unfortunately the IGM GPS-levelling data appears to have relatively large errors (due to insufficient and no updated GPS-levelling data available), and it is therefore difficult to use these data.
10. The northern Chile geoid was computed on a grid of 0.02° x 0.025° resolution (corresponding to roughly 2 x 2 km grid).
11. It is seen that large differences to EGM2008 exist in the mountains, in addition, large effects are seen along the border with Argentina, due to the lack of data.
12. The apparent outliers around 30 S appears to be due to errors in EGM2008 and not related to data error of the airborne gravity data used in the Chile Geoid, but can be analyzed in depth in a future study.
13. The cooperation of National Geospatial and Intelligence Agency (NGA), Denmark's National Space Institute (DTU-Space) and University of Bergen has generated the opportunity to give Chile a new geoid model.



Thank You





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