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The GRAVSOFT package for geoid determination.

by

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Abstract: The GRAVSOFT package of FORTRAN programs has been applied for geoid determination in several countries. We describe the recent developments, which include versions for personal computers and a more user-friendly interactive interface.

The spherical FFT method has been implemented in a new program spfour. The satellite altimetry pre-processing software has been extended to include stacking of repeat tracks, computation of variability, covariance functions and tidal constituents.

A new version of GEOCOL now pages potential coefficients, thereby permitting the use of high order (360) spherical harmonic coefficients on a PC. This program and the program GEOGRID now includes features for gross-error detection.

1. Introduction.

The GRAVSOFT package is described in Tscherning et al.(1991). It includes programs for data handling and presentation:

- SELECT - reformatting and selection of data according to geographical boundaries or error characteristics
- GEOGRID - gridding of randomly distributed data to a geographical or UTM grid
- GEOIP - interpolates in a grid (2D or 3D)
- ALTCORY - bias adjustment and correction of altimeter data
- TRANS12 - geographical coordinates to map-projection or reverse.

Most important are the programs for gravity field modelling:

- GEOCOL - Evaluation of spherical harmonic expansions, modelling using least-squares collocation
- EMPCOV - Estimation of isotropic covariance functions
- COVFIT - Evaluation and fitting of an analytic expression to one or more empirical covariance functions
- GEOFOUR - Fourier modelling of the gravity field
- COVFFT - 1D or 2D empirical covariance functions and power spectra in plane approximation
- TC - Terrain effect computation from prisms
- TCFOUR - Fourier evaluation of terrain effects
- STOKES - Evaluation of Stokes formula using spline densification

and the new programs described below: SPFOUR, ALTSTACK and LOADC.

The package is widely used for scientific and production purposes. It has been used for geoid determination for the Nordic Area (Tscherning & Forsberg, 1986, Forsberg, 1990), parts of UK (Dodson & Gerrard, 1990), Italy (Benciolini et al., 1991), Catalonia (Andreu & Simo, 1990), the Mediterranean Area (Arabelos et al., 1991, Sevilla et al. 1991), Turkey (Ayhan, 1991) and in numerous smaller projects for local detailed geoid determination.

The wide use of the programs gives us a good feed-back, and an inspiration to constantly keep the programs updated. They are also used in the teaching of geodesy at the University of Copenhagen and in 1991 at the Politecnico di Milano. The use of programs in teaching put extra requirements to a clear user interface, which maybe not was the strong point in earlier editions of the package. We will here describe the most important improvements made since the middle of 1991 and which are of importance for geoid determination.

2. Program versions for Personal Computers (PC).

Since personal computers during the last years have been more powerful, and good fortran compilers have been made available, we have decided to prepare the various modules to be run on an IBM-compatible PC. The main change to be made is caused by the fact that the operating system DOS seldom permits the execution of programmes occupying more than 500 KByte. A necessary flexibility is easily introduced by having versions with easily changeable dimensions of arrays, using the PARAMETER statement in FORTRAN.

In geoid modelling it is now standard operating procedures to remove and restore the contribution of a spherical harmonic expansion. In GRAVSOFT this is done using GEOCOL, which until now stored all coefficients in core in double precision. A direct saving is easily made using single precision, except for the C20-term. The method used for evaluation is Clenshaw summation (which despite claims in the recent literature never has shown numerical problems). This method uses the coefficients from the term with maximal degree and order, and then for decreasing order. In order to save space in core, GEOCOL now will expect the coefficients to be stored blockwise in decreasing order and degree. The blocksize may be selected arbitrary small or large.

The storage technique has been tested, and is shows no real delay in the time for the evaluation. A new small program LOADC now converts the coefficients on ASCII character form to the needed binary, single precision form.

The method of collocation requires that a system of equations are solved with as many unknowns as there are observations and parameters. Here from the time of the old IBM mainframe computers (Tscherning, 1974) paging of the normal equations has always been used. So no new implementations have been necessary here. On the other hand, too small pages decreases the speed of the computations considerably.

In GEOCOL not only the observation coordinates are stored, but also SIN, COS of the latitude and longitude as well as the observation noise estimate. For each observation are 9 quantities stored in double precision. Here paging will also be used in case the reserved space is not sufficient. This is at this moment (May 92) not fully implemented.

3. Processing of satellite altimeter data.

The earlier used program for simple bias-cross-over adjustment was sufficient for use in smaller areas. Now the use of FFT makes the simultaneous treatment of data from a large area necessary. Also the use of repeat track GEOSAT and ERS-1 data makes the need of stacking necessary if altimeter data are to be used for gravity field modelling.

A new program ALTSTACK has been written (Knudsen, 1992). This program produces stacked data, their mean value and the variability. Power spectrum and covariance functions are produced, and analysis is made for signs of tidal constituents. This is very important, due to the errors found in the currently used tidal models, and the limitation of these models when used in shallow water.

4. Geoid modelling by spherical FFT.

The use of FFT has become widespread, due to its computational efficiency and the excellent results obtained. It is inherent in the method that a plane approximation is used. As shown by Strang van Hess (1990) it is possible to use FFT in a manner, so that the transformation from gravity to geoid is exact along a longitude parallel. A new program SPFOUR has been written implementing this spherical FFT-method (Forsberg, 1992).

The exactness property is used in a manner, so that a FFT solutions is computed for a number of geographical grid parallels. The (residual) geoid height is computed using convolution of the (residual) gravity anomaly multiplied by cosine of the latitude with a properly modified Stokes kernel. When the results for the parallels have been computed, linear interpolation is used to obtain the results for an arbitrary latitude.

The procedure has been implemented very efficiently, so that only two transforms need to be stored at any time.

5. Gross-error detection.

Gross-errors are found in all types of geodetic data. However gravity field data are spatially correlated, at this may be used for error-detection, see (Tscherning, 1990a, 1991a). In the program GEOGRID, one predicts data from the surrounding data. Here a modification has been made, so that it one predicts back in a observation point. then this point is (optionally) left out in the prediction. The observed and the computed value is then compared with the error of prediction, and this relative magnitude is used in order to pinpoint a suspected gross-error. The program permit only the prediction of data of one type.

The general collocation program, GEOCOL, permit the mixing of different data types. Here the same procedure has been implemented. The procedure is difficult to use if the data are biased, as is often found with satellite altimeter data.

6. Interactive execution of the programs.

Earlier the programs were run under operating systems, which did not allow any interference when a run has been submitted for batch processing. Today, using UNIX one may interact easily with a program during on-line execution, or alternatively submit the program for a batch run.

The problem is really in how much detail one should give the instructions to the user. It is still so, that geoid determination is not a routine task, and many functions need detailed explanation and advance study of the literature.

We have chosen a middle way, so that a reasonably experienced user may run the programs in standard situations without too much difficulty, i.e. no need to consult the source-code of the programs. An appendix shows an example of an interactive run using GEOCOL.

A sequence of exercises has also been designed, which leads the user through all steps of gravity field modelling using the programs of the package. (The exercises are available on request from the first author of this paper).

7. Conclusion.

The upgrading of the GRAVSOFT package is done currently, and new modules are added (SPFOUR, ALTSTACK, LOADC). It is prompted by the availability of new data (Arabelos and Tscherning, 1990, Tscherning, 1990, 1991, Knudsen et al., 1992), the interaction with the users and the students using the package.

The package is distributed for free, to users which certify that they will only use it for scientific purposes. It is available commercially, and the charged fee, includes a coverage of the installation at the computer of the costumer, and basic instructions.

In the future the package will also be made available through the new International Geoid Service at Politecnico di Milano, which also plan to organize training courses in geoid modelling.

References.

Andreu, M.A. and C.Simo: El Geoide a Catalunya. Revista Catal-ana de Geografia, Vol. 5, no. 13, pp. 41-56, 1990.

Arabelos,D., R.Barzaghi, M.Brovelli, R.Forsberg, W.Fuerst, A.Gill, P.Knudsen, J.Otero, M,Poutanen, O.Remmer, G.Rodriquez, F.Sanso, W.-D.Schuh, M.Sevilla, D.Sguerso, H.Suenkel, C.C.Tscherning, I.Tziavos, M.Vermeer: The GEOMED Project. Presented IUGG XX General Assembly, Symp. U 5, Wien, Aug. 1991.

Arabelos,D. and C.C.Tscherning: Simulation of regional gravity field recovery from satellite gravity gradiometer data using collocation and FFT. Bulletin Geodesique, Vol. 64, pp. 363-382, 1990.

Ayhan,E.: Geoid determination using taylored geopotential model and least squares collocation in Turkey. Presented IUGG/IAG General Ass., Vienna, 1991.

Benciolini, B., A.Manzino, F.Sanso and D.Sguerso: ITALGEO'90: the Italian Gravimetric Geoid. Presented IAG/IUGG General Assembly, Vienna, 1991.

Dodson, A. and S.Gerrard: Levelling with GPS. Cahiers du CEGS, Vol. 2, pp. 141-146, 1990.

Forsberg, R.: NKG Nordic Standard Geoid 1989. Proc. 11th General meeting Nordic Geodetic Commission, Copenhagen, May 1990, pp. 472-493, Kort-og Matrikelstyrelsen, Copenhagen, 1990.

Forsberg, R.: Geoid computation by the multi-band spherical FFT approach. Presented 1. Continental Workshop on the Geoid in Europe, Prague, May 11 - 14, 1992.

Knudsen, P.: Separation of residual ocean tide signals in a collinear analysis of GEOSAT altimetry. Presented EGS XVII General Assembly, Edinburgh, April, 1992.

Knudsen, P., O.Ba.Andersen and C.C.Tscherning: A preliminary ERS-1 altimeter data analysis in the Northern North-Atlantic Ocean. Submitted GRL, 1992.

Sevilla, M.J., G.Rodriguez, J.Otero and A.J.Gil: A gravimetric geoid for the Mediterranean Sea. Presented IAG/IUGG General Ass., Vienna, 1991.

Tscherning, C.C.: A FORTRAN IV Program for the Determination of the Anomalous Potential Using Stepwise Least Squares Collocation. Reports of the Department of Geodetic Science No. 212, The Ohio State University, Columbus, Ohio, 1974.

Tscherning, C.C.: GRAVSOFT updates for SSG applications. Final report "Study on Precise gravity field determination methods and mission requirements (Phase 2), ESA contract 8153/88/F/FL, March 1990.

Tscherning, C.C.: A strategy for gross-error detection in satellite altimeter data applied in the Baltic-Sea area for enhanced geoid and gravity determination. Proc. 11th General meeting Nordic Geodetic Commission, Copenhagen, May 1990, pp. 90-106, Kort-og Matrikelstyrelsen, Copenhagen, 1990a.

Tscherning, C.C.: Computation of covariances of derivatives of the anomalous gravity potential in a rotated reference frame. Submitted Manuscripta Geodaetica, June 1991.

Tscherning, C.C.: The use of optimal estimation for gross-error detection in databases of spatially corrlated data. Bulletin d'Information, no. 68, pp.79-89, Bureau Gravimetrique International, 1991a.

Tscherning, C.C., P.Knudsen and R.Forsberg: Description of the GRAVSOFT package. Geophysical Institute, University of Copenhagen, Technical Report, 1991.

Tscherning,C.C. and R.Forsberg: Geoid determination in the Nordic countries from gravity and height data. Boll. di Geodesia e Sc. Aff, Vol. XLVI, pp. 21-43, 1986.

Van Hees, G.S.: Stokes formula using fast Fourier transform techniques. Manus. geodaetica, Vol. 15, pp. 235-239, 1990.

Appendix.

This shows an interactive run of GEOCOL, where the contribution from OSU91A1F to degree 20 is subtracted from altimeter data stored in a file. Fat text is user input.

```
geocol9

 GEODETIC COLLOCATION, VERSION 1 SEP 1991, RELEASE 2  (UNIX)
 Thu April  5 12:34:28 1992

 NOTE THAT THE FUNCTIONALS ARE IN SPHERICAL APPROXIMATION
 MEAN RADIUS = RE = 6371 KM AND MEAN GRAVITY 981 KGAL USED.
 MAX NUMBER OF OBS= 3200, MAX NUMBER OF PARAMETERS=239
 MAX NUMBER OF OBS IN GIVEN REF. FRAME = 200
 SIZE OF NORMAL EQ. BLOCKS=19800, SIZE OF POT.COFF. BLOCK=
130322
  INTERACTIVE INPUT (T/F) t
 INPUT: LTRAN, TRUE IF NON-STANDARD REF. SYSTEM IS USED
        LPOT,  TRUE IF SPHERICAL HARMONIC EXPANSION IS USED
        LTEST, TRUE IF TEST-OUTPUT IS NEEDED
        LLEG,  TRUE IF LEGEND IS TO BE OUTPUT
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        LPARAM,TRUE IF PARAMETERS ARE TO BE DETERMINED
        LNCOL, TRUE IF COLLOCATION IS NOT USED
        LIOSOL,TRUE IF SOLUTION IS STORED OR RECOVERED
f t f f f t f
  ARE ALL PARAMETERS OK ? t
 INPUT CODE FOR BASIC REFERENCE SYSTEM:
 0: USER DEFINED, 1: ED50 NORTH SEA, 2: ED50/EDOC,
 3: NAD1927 /NEW MEXICO, 4: GRS67, 5:  GRS80, 6: NWL9D,
 7: BEST CURRENT, 8: BEST CUR. FAROE ISL, 9: ED50 FOR SF,
 10: IAG-75, 11: KRASSOWSKY, DDR, 12: GERMAN DHDN, BESS.
 5
 REFERENCE SYSEM:         GRS1980.

 A   = 6378137.00 M
 1/F = 298.2572221
 GM= 0.3986005000E+15
 REF.GRAVITY AT EQUATOR =   978032.6772 MGAL
 POTENTIAL AT REF.ELL.  = 62636860.8500 M**2/SEC**2

  INPUT NAME OF POT.COEFF. SET OSU91A TO DEGREE 20

 SOURCE OF THE POTENTIAL COEFFICIENTS USED:
 OSU91A TO DEGREE 360

 INPUT: GM, SEMI-MAJOR AXIS (M), C(2,0), MAX. DEGREE
  LFM, TRUE IF COEFF. IN INPUT STREEM AND *1.0D6
  LBIN, TRUE IF ON BINARY FORM
  LFORM, TRUE IF FORMAT IS INPUT
  LINT, TRUE IF STORED AS INTEGERS
3.986005D14  6378136.2  0.0  20  f f t f
     GM             A       COFF(5)  MAX.DEGREE
 0.39860050E+15  6378136.2    0.0000 360
  INPUT FORMAT (2I4,2D18.0) F.EX. (2I3,2D19.12)
  INPUT NAME OF FILE HOLDING COEFF.
osu91a1f
 NAME OF FILE HOLDING COEFFICIENTS: osu91a1f
  COEFFICIENTS UP TO N=5
    2   0 -0.484165533E-03  0.000000000E+00
    2   1  0.857179552E-12  0.289607376E-11
    2   2  0.243815798E-05 -0.139990175E-05
    3   0  0.957139401E-06  0.000000000E+00
    3   1  0.202968777E-05  0.249431310E-06
    3   2  0.904648671E-06 -0.620437817E-06
    3   3  0.720295507E-06  0.141470959E-05
    4   0  0.540441630E-06  0.000000000E+00
    4   1 -0.535373285E-06 -0.474065010E-06
    4   2  0.350729847E-06  0.663967363E-06
    4   3  0.991080200E-06 -0.202148896E-06
    4   4 -0.190576532E-06  0.309704029E-06

 INPUT: LGRID - TRUE IF COMPUTATIONS IN A GRID
  LERR - TRUE IF ERROR ESTIMATES ARE TO BE COMPUTED
            OR REPRODUCED IN OUTPUT
  LCOMP- TRUE IF COMPUTED VALUES ARE SUBTRACTED FROM OBSERVED
f f t
 INPUT DATA LINE AND OUTPUT SPECIFICATIONS
```

```
 POSITION OF STATION NUMBER (0: NO NUMBER, -1: NO OUTPUT U6)
 POSITION OF LATITUDE AND LONGITUDE (E.G. 2 , 3)
 TYPE OF ANGULAR UNITS USED (1: DD MM SS.S, 2: DD MM.M 3: DD.D)
 POSITION OF HEIGHT (0: NO HEIGHT)
 POSITION OF OBSERVATION 1 AND 2 (0 IF NO OBS. 1 OR 2)
 DATA OR COMPUTATION QUANTITY TYPE CODE (11: GEOID,
   13: GRAVITY, 15: TZZ, 26: (KSI,ETA), NEGATIVE: REF.SUBTR.)
 COORD.SYST. CODE, -1 INDICATE GLOBAL SYSTEM, +100 REVERSE TR.
 HEIGHT (IN M OR KM), ONLY USED IF NO INPUT HEIGHT
 LPUNCH - TRUE IF OUTPUT OF RESULT TO FILE
 LWLONG - TRUE IF LONGITUDE POSITIVE EAST
 LMEAN  - OBS. OR COMPUTED QUANTITY IS A MEAN VALUE
 LSA    - TRUE IF ALL ERROR ESTIMATES ARE IDENTICAL
 LKM    - TRUE IF HEIGHT IN KM
 LADMU  - TRUE IF UNREDUCED OR CONSTANTS * OR +
 STAT   - TRUE IF STATISTICS OF RESULT WANTED
 LAREA  - TRUE IF DATA ONLY INSIDE SPECIFIC AREA ARE USED
 LFORM  - TRUE IF FORMAT OF DATA IS INPUT
 LIN4   - TRUE IF DATA NOT IN INPUT STREAM (FROM FILE)
 LFORM  - TRUE IF FORMAT OF DATA IS INPUT
 LIN4   - TRUE IF DATA NOT IN INPUT STREAM (FROM FILE)
1 2 3 3 4 5 0 11 -1 0.0 t f f f f f t f f t
  INPUT NAME OF FILE HOLDING DATA alt.e12
  INPUT FORTRAN UNIT NUMBER    30

 DATA INPUT FROM UNIT 30, FILE=alt.e12
  INPUT NAME OF FILE TO HOLD RESULT  alt.r20

 SIMULTANEOUS OUTPUT TO FILE: alt.r20
  INPUT SAMPLING INTERVAL SIZE  0.25
  ALL SPECIFICATIONS OK ? t

 SELECTED GEOCENTRIC SYSTEM USED.
   NO    LATITUDE     LONGITUDE   H    ZETA (M)          POT
         DEGREES       DEGREES    M       OBS   DIF
 1970864  39.483500   -64.193100     0.0 -33.38  -2.65  -30.73

    ------ output from other observations not shown. -----
   -1
COMPARISON OF PREDICTIONS AND OBSERVATIONS
DATA TYPE = 11
 NUMBER: 999
         OBSERVATIONS PREDICTIONS DIFFERENCE
 MEAN           -32.22      -31.51       -0.70
 ST.DEV.          0.98        0.80        1.11
DISTRIBUTION OF DIFFERENCES, UNITS:  0.25
  23 58 69 73 78 76 82 71 68 76 61 69 42 33 51 20 20 9 4 1 0 15
 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1  0  1  2  3  4  5  6 7 8 9 10
OUTSIDE

  STOP ? t
```