Status Report on sea-level data collection and analysis within the EUVN Project

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1 Introduction

1.1. Basic principles on tide gauges

Whatever the technology (acoustic, pressure or floating devices), the basic quantity provided by a tide gauge is an instantaneous height difference between the level of the sea surface and the level of a fixed point on the adjacent land. Tide gauge datum (or reference) can be seen as a conventional local horizontal plane, which is materialized by a set of physical markers. Usually, one of them is arbitrarily called the tide gauge benchmark (TGBM). Sometimes it is the "most" stable, sometimes the most secure, or simply the closest, although all of them are representative of the datum.

The TGBM is extremely important as it serves to build useful long-term sea level time series. Even if parts of the time series were obtained from different gauges and/or with respect to different benchmarks, the measurements may be reduced to a common reference all along the observation period if these benchmarks are geodetically connected. Tide gauge benchmarks are the only guarantee of the long-term coherence of the measurements. It is therefore common sense to preserve the datum by installing and connecting a set of 5 to 10 benchmarks within a few hundred meters of the tide gauge.

Tide gauges not only record ocean tides but also a large variety of sea level signals caused by variations in atmospheric pressure, density, currents or continental ice melt, as well as by vertical motions of the land upon which the measurement instrument is located, due to tectonic changes, isostatic adjustments, volcanism inflation, sediment consolidation, pier subsidence, etc. Therefore, the records of these devices are indicative of so-called "relative" sea level changes.

1.2. Tide gauge and GPS synergy

Periodic or continuous GPS observations may provide the necessary complementary information to separate both long term signals within 10-20 years [Carter et al 1989 and 1994, Neilan et al 1998]. But even one single height determination of the TGBM in the ETRS89 or ITRS may benefit to some applications like for instance the unification of hydrographic chart datums as recommended by the International Hydrographic Organisation. Conversely, tide gauge data may contribute to height system definitions or quality control of levelling results, as most national height systems rely on mean sea level determined over a specific period at one or several sites.

Emphasis has been placed in the 7th EUVN circular letter on collecting all the tide gauge information needed for the complete success of the manifold EUVN objectives. We would like to recall two of them, items (7) and (8) in the initial proposal of EUVN [Ihde et al, 1996] :

7. to provide data to separate the land and sea level components of relative sea level variations, as measured by tide gauges;
8. to provide the basis to express the results of the regional European tide gauge GPS surveys in the EUREF reference system (ETRS89).

2 Tide gauge records : collection and analysis

2.1. EUVN tide gauge selection

The EUVN tide gauge selection was based on the following criteria. We proposed to include :

- tide gauges which were used for the establishment of the national height systems. These tide gauges may no longer be operational. The essential point

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is that a related TGBM still exists and available sea level data can be expressed to this TGBM.

- tide gauges which contribute to the global sea level observing program GLOSS [IOC, 1997].
- and tide gauges which were known for their long term records or for their participation in former GPS campaigns. We also tried to get an homogenous geographical distribution.

The selection led to an initial proposal of about 60 tide gauges. Then after adjustment by the national delegates and participants we came up with the final tide gauge network. This led to a larger number, up to 79 tide gauges. The map in figure 1 shows the distribution of the 79 sites which were observed during the EUVN'97 GPS campaign.

2.2. Collection of tide gauge data

A recent check (June 2000) shows that 57 of the 79 tide gauges have data available in the Permanent Service for Mean Sea Level. The PSMSL is an international service, member of the Federation of Astronomical and Geophysical Data Analysis Services, whose mission is the collection, publication, analysis and interpretation of monthly and annual mean sea level values from any tide gauge in the world. In consequence, the EUVN group agreed to request tide gauge data from its contacts only for stations whose data is not at PSMSL. A sea level form was established for this purpose. It was distributed with recommandations and guidelines through the 7th EUVN Circular Letter in January 1999.

The map in figure 1 summarises the status of the mean sea level data collection. Two types of datasets are available at the PSMSL. The first is called "Metric" and contains data as provided by the organisms. The second is called "RLR" and provides data which has passed through some quality control checks to spot inconsistent or erroneous values. Full TGBM datum history is theoretically available for RLR stations. This information is used to reduce the data to a common local datum, the Revised Local Reference (RLR). Thus, the RLR dataset is the most convenient for long term sea level analysis.

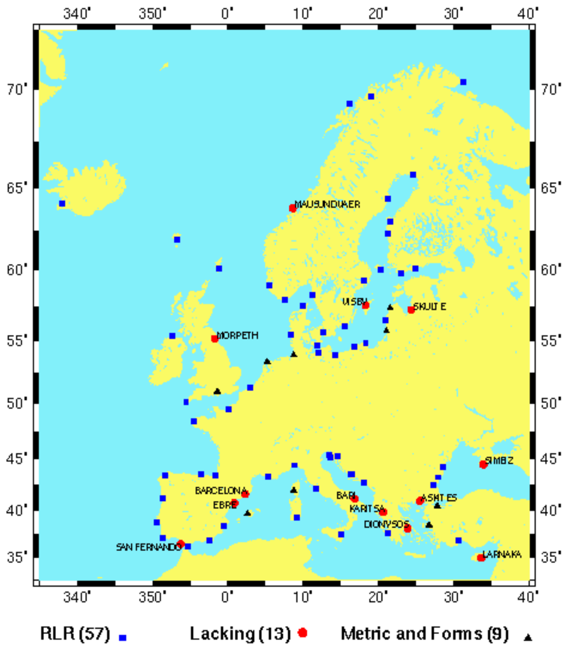

Figure 1: Sea level data collection for the EUVN'97 observed tide gauge sites.

2.3. First analysis of tide gauge data

A few basic data analysis have been performed on the currently available tide gauge data set. In particular, members of the EUVN Working Group expressed their interest in mean sea level values during 1997 which is when the GPS campaign took place, as well as estimations of the mean sea level data precision and the linear trend.

The table in Annex 1 summarises the results for the whole 66 tide gauges for which data is available through EUVN (as of June 2000). The first and third columns are station identification codes, EUVN and PSMSL. The name of the tide gauge station is given in the second column. The fourth column indicates wether the data are of "RLR" (R) or "Metric" (M) type, the number of annual mean sea level values, and the corresponding time span. The trend and standard deviation of the trend are given in the fifth column. These were obtained from the linear regression analysis. Column six shows either the "observed" 1997 annual mean sea level value, or the inter-extrapolated value if no enough observations were available to compute the annual value (11 months at least). Column seven gives the standard deviation of the detrended mean sea level values. The last column informs wether the TGBM connection to the EUVN GPS marker was performed and wether no ambiguity remains concerning the TGBM actually used to perform the link (see section 3).

Figure 2 illustrates the large variety of cases. The trends are quite different from place to place, ranging from few millimetres per year "relative" sea level fall to few millimetres per year "relative" sea level rise. No clear regional pattern emerges from the long tide gauge records, except for the Baltic Sea, where post-glacial rebound dominates the tide gauge signals. This wide range in observed sea level trends is mainly attributed to uplift or subsidence of the land upon which the tide gauges are settled [Woodworth 1993, Pirazzoli 1996].

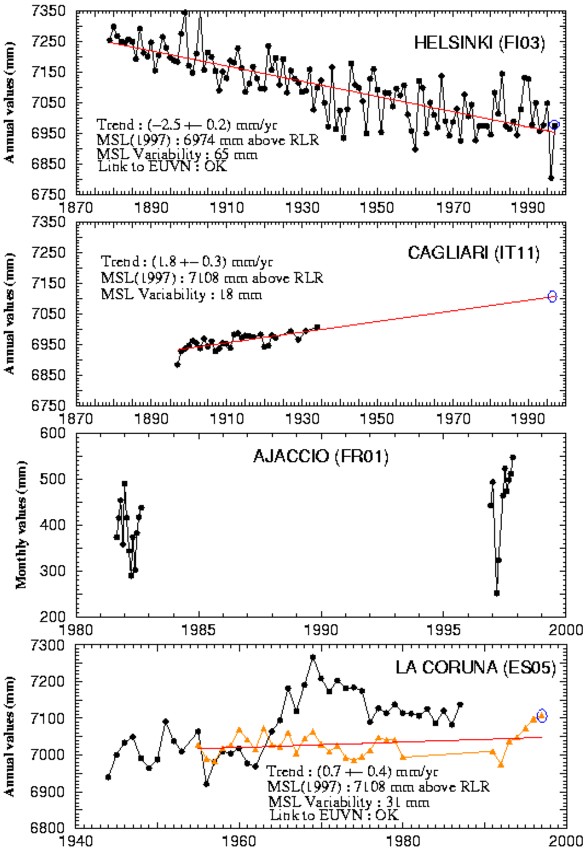

Figure 2: Annual mean sea level time series of some European tide gauge sites and results of the preliminary data analysis.

Tide gauge records also contain a considerable amount of interannual variability, which can affect the determination of long term trends. Atmospheric and oceanographic processes account for a large fraction of the interannual variability : changes in the local surface heating, currents, density, atmospheric pressure, ocean circulation, wind forcing, upwelling processes, etc. This interannual variability is roughly estimated in column seven (Annex 1) by the standard deviation of the detrended annual sea level values. Here again, values are quite different from place to place depending on the physical factors that affect each site and their amplitude. The annual variability is typically less than 10 centimeters whereas monthly variability is higher : 10-20 cm.

Figure 2 shows that an "observed" annual mean sea level value could not be computed for 1997 at every site. A linear regression value is then estimated if enough data is available, although in some cases a filter would be more convenient to approach the real state of the sea. But some stations do not have enough data and no value could be estimated or computed according to the standard and common sense rules of PSMSL. In some places, several gauges are or were operational. Their time series are not always coherent, see Alicante in figure 2 for instance.

2.4. Tide gauges and vertical references

This first analysis also gives an idea of what can be expected from tide gauge data for the definition of the European height system or for the control of the levelling references. Tide gauge data has been used historically - and is still used - for the definition and realisation of vertical reference systems on land and on sea. The belief, about a century ago, that the average level of the sea was constant over long periods of time led to define the concept of geoid and, subsequently, to establish the origin of the levelling networks on "mean sea level". Typically, countries chose one tide gauge station to compute this quantity over an arbitrary time period : in France, for example, the datum was determined at Marseille from continuous tide gauge records performed during the period 1885-1897 ; in Britain, the Ordnance Datum was determined at Newlyn from records extending from May 1915 to April 1921. However, mean sea level varies from place to place and at one specific place over time. Today, the mean sea level at Marseille is about 10 cm above the local 1885-1897 datum, whereas it is about 15 cm above the Ordnance Datum at Newlyn (see figure 3). Thus, the datums no longer represent the "real" average of the sea level at these sites.

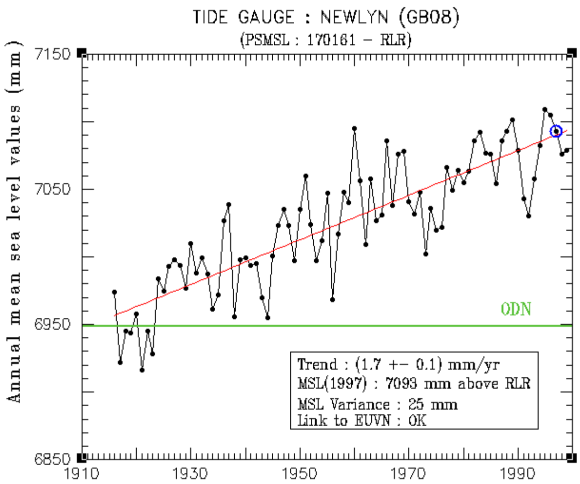

Figure 3: Newlyn tide gauge time series of annual mean sea level values (RLR reference).

3 Sea-level connection to EUVN

As explained previously, tide gauge readings {g} are reduced to a common local datum, for instance the PSMSL's Revised Local Reference. The reduction is usually achieved through some calibration constants like {D} and {C_M} in figure 4, leading to a coherent time series of "relative" sea level values {m}.

To express sea level data into the European geocentric reference frame, the EUVN working group has to gather the intermediate data indicated in figure 4. This figure shows the main quantities involved in the geodetic tide gauge connection process.

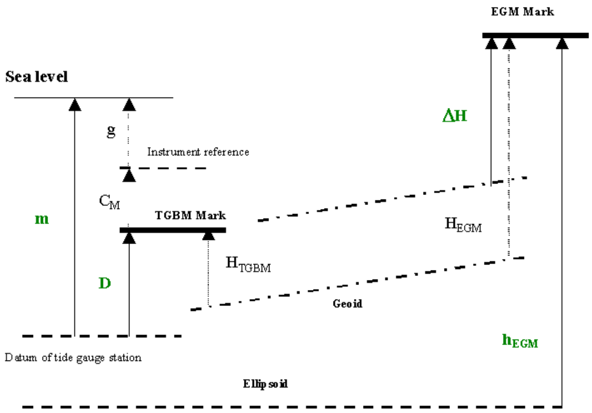

Figure 4: Schematic description of the main quantities involved in the geodetic tide gauge connection process to a geocentric reference frame

- The ellipsoidal height of the EUVN GPS mark {h_{EGM}} near the tide gauge station is already provided by the combined solution [Ineichen et al 1998].
- The height difference between the EGM and the TGBM marks {Δ H}, as well as the mark identifiers, are partly obtained through the levelling forms. 20 levelling forms are still missing.
- The sea level values {m} and the tide gauge datum definition, {D} and TGBM description, are partly collected, either from PSMSL databank, or from the Sea level Forms that we requested in EUVN Circular Letter Nr. 7.

Figure 5 summarises the present situation : 27 tide gauges - out of the 66 for which we have sea level data (see section 2) - can actually be connected to the EUVN solution. For the others, some piece of information is lacking to succeed :

- for 13 tide gauges, we do not have any sea level data (see figure 1) ;
- for 20 tide gauges, the levelling forms have not been received yet ;
- for 19, the TGBM description is ambiguous. The only way to join the sea level data collected at the PSMSL databank to the data provided by the levelling forms is the TGBM mark identifier. When we crosscheck this item, it appears that very few TGBM descriptions are consistent and clearly identified as the same mark in both data sources.

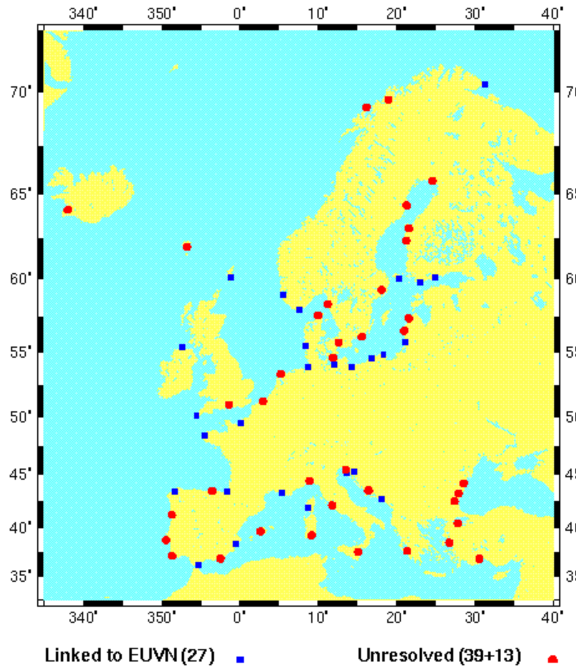

Figure 5: Geodetic connection of tide gauge data into EUVN.

4 Outlooks

As of today this analysis has been carried on over a set of 66 tide gauge time series and the geodetic connection problem has been solved for 27 out of the 79 tide gauges which were actually observed during the EUVN'97 GPS campaign.

For the complete success of the manifold EUVN objectives, sea level data of 13 tide gauges and levelling forms of 20 tide gauges are highly requested. Ambiguities in the TGBM descriptions have also been identified in 19 sites. To solve these problems, the EUVN working group has agreed to individually contact the related national representatives.

Acknowledgements

Thanks are due to the Permanent Service for Mean Sea Level (PSMSL), specially to its Director P. Woodworth. We also thank the EUVN participants, who have already provided the requested information, we hope to thank all of them in the next status report.

5 References

Carter W. E., D.G. Aubrey, T.F. Baker, C. Boucher, C. Le Provost, D.T. Pugh, W.R. Peltier, M. Zumberge, R.H. Rapp, R.E. Schutz, K.O. Emery and D.B. Enfield [1989]: Geodetic fixing of Tide Gauge Bench Marks. Woods Hole Oceanographic Institution Technical Report, WHOI-89-31, CRC-89-5, August 1989.

Carter, W. E. (ed.) [1994]: Report of the Surrey Workshop of the IAPSO Tide Gauge Bench Fixing Committee held 13-15 December 1993 at the Institute of Oceanographic Sciences Deacon Laboratory, Wormley, UK. NOAA Technical Report NOSOES0006, October 1994.

Ihde J., W. Schlüter, W. Gurtner, G. Wöppelmann, B-G. Harsson and J. Adam [1996]: Concept and Status of the European Vertical GPS Reference Network (EUVN). Paper presented at the EUREF Symposium in Ankara, May, 1996, Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung, Astronomisch-Geodätische Arbeiten, Heft Nr. 57, pp. 218-225.

Ineichen D., W. Gurtner, T. Springer, G. Engelhardt, J. Luthardt, J. Ihde [1998]: EUVN97-Combined GPS Solution. Presented at the EUREF-Symposium in Bad Neuenahr-Ahrweiler, June 3-5, 1998.

.

IOC [1997]. Global Sea Level Observing System (GLOSS) Implementation Plan 1997. Intergovernmental Oceanographic Commission, Technical Series No. 50.

Neilan R.E., P.A. Van Scoy and P.L. Woodworth (eds) [1998]. Workshop on methods for monitoring sea level : GPS and tide gauge benchmark monitoring, GPS altimeter calibration. Proceedings of the Workshop organised by the IGS and PSMSL, Pasadena, March 17-18, 1997.

Pirazzoli P.A. [1996]. Sea-Level Changes, The Last 20 000 Years. Chichester : John Wiley & Sons. .

Woodworth P. L. [1993]. A review of recent sea level research. Oceanography and marine biology, An annual review. 31, pp. 87-109, 1993.

Annex 1

Tide gauge data analysis for the EUVN stations and TGBM link (June 20, 2000)

EUVN Code	TIDE GAUGE STATION	PSMSL Code	DATA	TREND (mm/yr)	MSL (1997) (mm)	Variability (mm)	LINK
BE01	OOSTENDE	160021	R 57:1937-1999	1.38 +- 0.20	7018	25	
BG01	BURGAS	295021	R 50:1929-1995	1.51 +- 0.40	7047 (E)	58	
BG04	VARNA	295051	R 58:1929-1996	1.46 +- 0.40	7068 (E)	59	
HR01	BAKAR	280011	R 55:1930-1997	0.64 +- 0.27	7091	37	SOLVED
HR03	DUBROVNIK	280081	R 40:1956-1997	0.15 +- 0.37	7095	27	SOLVED
HR05	SPLIT_HARBOUR	280031	R 43:1955-1997	-0.52 +- 0.34	7082	27	
HR05	SPLIT_RT_MARJANA	280021	R 43:1953-1997	-0.06 +- 0.37	7032	30	
HR07	ROVINJ	280006	R 41:1956-1997	-0.08 +- 0.35	7087	27	SOLVED
CY01	LARNAKA	---	---	---	---	---	
DK01	KOBENHAVN	130021	R 106:1889-1996	0.27 +- 0.11	6995 (E)	35	
DK02	HIRTSHALS	130101	R 94:1892-1997	-0.36 +- 0.15	7061	41	
DK03	ESBJERG	130121	R 105:1890-1997	1.02 +- 0.15	7062	47	OK
DK04	GEDSER	130001	R 97:1898-1996	0.94 +-0.12	6997 (E)	32	
DK05	THORSHAVN	015011	R 27:1957-1997	1.59 +- 0.36	7023	23	
FI01	DEGERBY	060281	R 66:1924-1997	-3.89 +- 0.35	6862	62	SOLVED
FI02	HANKO/HANGO	060331	R 91:1889-1997	-2.74 +- 0.21	6927	62	OK
FI03	HELSINKI	060351	R 119:1879-1997	-2.49 +- 0.17	6974	65	OK
FI05	KASKINEN/KASKO	060071	R 65:1927-1997	-6.84 +- 0.42	6805	69	
FI06	KEMI	060001	R 69:1920-1997	-7.28 +- 0.39	6719	71	
VAAS	VAASA/VASA	060051	R 102:1884-1997	-7.30 +- 0.17	6766	57	
FR01	AJACCIO	---	Few months	---	---	---	SOLVED
FR04	BREST	190091	R 168:1807-1997	0.97 +- 0.05	7113	36	OK
FR05	LE_HAVRE	190051	R 23:1959-1998	2.19 +- 0.60	7031	34	SOLVED
FR06	MARSEILLE	230051	R 106:1885-1996	1.23 +- 0.08	6985 (E)	26	SOLVED
FR09	SOCOA/ST_JEAN_DE_LUZ	190141	29:1966-1996	1.58 +- 0.61	6995 (E)	29	SOLVED
DE03	CUXHAVEN_2	140012	M 156:1843-1998	2.37 +- 0.09	73	50	SOLVED
DE10	WARNEMUNDE_2	120012	R 136:1856-1991	1.17 +- 0.08	7078 (E)	34	SOLVED
GR01	ASKITES	---	---	---	---	---	
DION	DIONYSOS	---	---	---	---	---	
GR02	KARITSA	---	---	---	---	---	
GR03	KATAKOLON	290017	R 25:1969-1999	1.33 +- 0.73	7139	34	
REYK	REYKJAVIK	010001	R 39:1957-1997	2.66 +- 0.59	7085	44	
IE03	MALIN_HEAD	175011	R 36:1959-1997	-0.29 +- 0.50	7129	34	OK

IT01	BARI	---	---	---	---	---	
IT02	CATANIA	260031	R 12:1960-1971	1.21 +- 1.60	7052 (E)	15	
IT03	CIVITAVECCHIA	250031	R 23:1897-1921	0.70 +- 0.62	7105 (E)	20	
IT05	GENOVA	250011	R 85:1884-1996	1.22 +- 0.07	7019 (E)	23	
IT10	TRIESTE	270061	R 89:1905-1999	1.13 +- 0.13	7044	34	
IT11	CAGLIARI	240011	R 30:1897-1934	1.75 +- 0.33	7108 (E)	18	
LV01	SKULTE	---	---	---	---	---	
LV02	LIEPAJA	080151	R 63:1865-1936	0.85 +- 0.36	7076 (E)	61	
LV03	VENTSPILS	080121	M 54:1873-1936	1.09 +- 0.37	146 (E)	50	
LT03	MOLAS	---	Few months	---	---	---	SOLVED
TERS	WEST-TERSCHELLING	150011	M 79:1921-1999	0.80 +- 0.19	-49	38	
NO01	TREGDE	040301	R 61:1935-1999	-0.04 +- 0.19	6990	26	OK
NO02	STAVANGER	040261	R 62:1882-1999	0.22 +- 0.14	6973	29	OK
NO08	MAUSUNDVAER	---	---	---	---	---	
NYAL	NY-ALESUND	025021	R 15:1977-1999	-2.48 +- 0.79	6940	23	
NO11	ANDENES	040041	R 29:1938-1999	1.68+-0.41	7169	48	
TROM	TROMSO	040031	R 47:1953-1999	0.05 +- 0.57	6957	52	
NO12	VARDO	040001	R 25:1948-1998	-0.92 +- 0.41	6949	35	OK
PL04	WLADYSLAWOWO	110047	R 47:1951-1997	2.28 +- 0.65	7015	59	SOLVED
PL06	SWINOUJSCIE	110092	R 168:1811-1997	0.82 +- 0.06	6964	44	SOLVED
PL07	USTKA	110057	R 47:1951-1997	1.63 +- 0.59	7002	54	SOLVED
PT02	CASCAIS	210021	R 99:1882-1991	1.19 +- 0.10	7003 (E)	31	
PT04	LEIXOES	210012	R 31:1956-1995	0.47 +- 1.16	7060 (E)	60	
PT05	LAGOS	210031	R 71:1909-1992	1.40 +- 0.15	7094 (E)	29	
RO02	CONSTANTA	297021	R 59:1933-1996	1.19 +- 0.49	6999	67	
ES01	ALICANTE_I	220051	R 28:1952-1996				OK
ES01	ALICANTE_II	220052	R 35:1960-1995	-0.81 +- 0.24	7048 (E)	14	OK
ES02	ALMERIA	220041	R 18:1978-1997	0.30 +- 0.91	7094	21	
ES03	BARCELONA	---	---	---	---	---	
EBRE	EBRE	---	---	---	---	---	
ES05	LA CORUNA_I	200030	R 42:1944-1987				OK
ES05	LA CORUNA_II	200031	R 33:1955-1997	0.73 +- 0.43	7108 7048 (E)	31	OK
ES06	PALMA	225001	M 3:1964-1966	---	---	---	
ES08	SANTANDER_I	200011	R 37:1944-1987	-0.25 +- 0.61	7006 (E)	50	
SFER	SAN FERNANDO	---	---	---	---	---	
SE02	KUNGHOLMSFORT	050081	R 113:1887-1999	-0.09 +- 0.14	7022	48	
SE04	RATAN	050191	R 107:1892-1999	-7.83 +- 0.20	6678	65	
SE06	SMOGEN	050011	R 89:1911-1999	-2.19 +- 0.17	7003	41	
SE07	STOCKHOLM	050141	R 111:1889-1999	-3.89 +- 0.17	6845	57	
VIS0	VISBY	---	---	---	---	---	
TR01	ANTALYA_II	310052	R 9:1986-1997	-1.16 +- 5.44	7084	48	
TR02	ERDEK	310038	M 14:1984-1998	38.60 +- 7.61	1862	106	

TR04	MENTES/IZMIR	310042	M 12:1986-1998	10.86 +- 7.75	1737	85	
UK04	SIMEIZ	---	---	---	---	---	
GB01	MORPETH	---	---	---	---	---	
GB04	GIBRALTAR	215001	R 20:1962-1989	-0.70 +- 0.75	6963	27	SOLVED
GB05	SOUTHAMPTON	170141	M 16:1924-1966	0.32 +- 2.05	2407 (E)	28	
GB06	LERWICK	170001	R 40:1957-1999	-0.81 +- 0.35	7017	27	SOLVED
GB08	NEWLYN	170161	R 84:1916-1999	1.65 +- 0.11	7093	25	SOLVED