AMENDMENT 1

TO

RTCM STANDARD 10403.1

DIFFERENTIAL GNSS (GLOBAL NAVIGATION SATELLITE SYSTEMS) SERVICES – VERSION 3

DEVELOPED BY
RTCM SPECIAL COMMITTEE NO. 104

MAY 21, 2007

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(GLOBAL NAVIGATION SATELLITE SYSTEMS)
SERVICES – VERSION 3

RTCM Standard 10403.1 - Differential GNSS (Global Navigation Satellite Systems) Services Version 3, dated October 27, 2006 (RTCM Paper 177-2006-SC104-STD)[1] is revised as follows:

1. p. iii: insert new Table of Contents
2. pp. 3-10 and 3-11: replace Section 3.2 and Table 3.2-1 with enclosed Section 3.2 and Table 3.2-1 (pp. 3-10, 3-11, and 3-11-A)
3. pp. 3-12 and 3.13: replace Section 3.3 and Table 3.3-1 with enclosed Section 3.3 and Table 3.3-1 (pp. 3-12, 3-13, and 3-13-A)
4. p. 3-36: add new Data Field entries DF143 through DF217 to Table 3.4-1 (insert pp. 3-36-A through 3-36-M)
5. p. 3-71: add new section 3.5.10 (insert pp. 3-71-A through 3-71-X)

[1] Early editions of this standard were identified only as RTCM Paper 177-2006-SC104-STD, RTCM Recommended Standards for Differential GNSS (Global Navigation Satellite Systems) Services, Version 3.1, dated October 27, 2006.

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3.2 Message Type Summary

The message types shown in Table 3.2-1 support Real-Time Kinematic (RTK) individual and network broadcasts for GPS and GLONASS.

Table 3.2-1. Message Type Table

Message Type	Message Name	No. of Bytes **	Notes
1001	L1-Only GPS RTK Observables	$8.00+7.25*N_s$	N_s = No. of Satellites
1002	Extended L1-Only GPS RTK Observables	$8.00+9.25*N_s$	
1003	L1&L2 GPS RTK Observables	$8.00+12.625*N_s$	
1004	Extended L1&L2 GPS RTK Observables	$8.00+15.625*N_s$	
1005	Stationary RTK Reference Station ARP	19	
1006	Stationary RTK Reference Station ARP with Antenna Height	21	
1007	Antenna Descriptor	5-36	
1008	Antenna Descriptor & Serial Number	6-68	
1009	L1-Only GLONASS RTK Observables	$7.625+8*N_s$	N_s = No. of Satellites
1010	Extended L1-Only GLONASS RTK Observables	$7.625+9.875*N_s$	
1011	L1&L2 GLONASS RTK Observables	$7.625+13.375*N_s$	
1012	Extended L1&L2 GLONASS RTK Observables	$7.625+16.25*N_s$	
1013	System Parameters	$8.75+3.625*N_m$	N_m = Number of Message Types Transmitted

Message Type	Message Name	No. of Bytes **	Notes
1014	Network Auxiliary Station Data	14.625	
1015	GPS Ionospheric Correction Differences	$9+3.75*N_s$	N_s = Number of Satellites
1016	GPS Geometric Correction Differences	$9+4.5*N_s$	N_s = Number of Satellites
1017	GPS Combined Geometric and Ionospheric Correction Differences	$9+6.625*N_s$	N_s = Number of Satellites
1018	RESERVED for Alternative Ionospheric Correction Difference Message		
1019	GPS Ephemerides	62	One message per satellite
1020	GLONASS Ephemerides	45	One message per satellite
1021	Helmert / Abridged Molodenski Transformation Parameters	51.5+N+M	N = Number of characters in Source Name M = Number of characters in Target Name
1022	Molodenski-Badekas Transformation Parameters	64.625+N+M	N = Number of characters in Source Name M = Number of characters in Target Name
1023	Residuals, Ellipsoidal Grid Representation	72.25	
1024	Residuals, Plane Grid Representation	73.75	
1025	Projection Parameters, Projection Types other than Lambert Conic Conformal (2 SP) and Oblique Mercator	24.5	
1026	Projection Parameters, Projection Type LCC2SP (Lambert Conic Conformal (2 SP))	29.25	

Message Type	Message Name	No. of Bytes **	Notes
1027	Projection Parameters, Projection Type OM (Oblique Mercator)	32.25	
1028	*(Reserved for Global to Plate-Fixed Transformation)*		
1029	Unicode Text String	9+N	N = Number of UTF-8 Code Units
4001-4095	Proprietary Messages		These message types are assigned to specific companies for the broadcast of proprietary information. See Section 3.6.

** Fill bits (zeros) must be used to complete the last byte at the end of the message data before the CRC in order to maintain the last byte boundary. Thus the total number of bytes must be the next full integer if fill bits are needed. For example, 55.125 computed bytes means 56 bytes total.

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3.3 DATA TYPES

The data types used are shown in Table 3.3-1. Note that floating point quantities are not used.

Table 3.3-1. Data Type Table

Data Type	Description	Range	Data Type Notes
bit(n)	bit field	0 or 1, each bit	Reserved bits set to “0”
char8(n)	8 bit characters, ISO 8859-1 (not limited to ASCII)	character set	Reserved or unused characters: [0x00]
int8	8 bit 2’s complement integer	± 127	-128 indicates data not available
int9	9 bit 2’s complement integer	± 255	-256 indicates data not available
int10	10 bit 2’s complement integer	± 511	-512 indicates data not available
int14	14 bit 2’s complement integer	± 8191	-8192 indicates data not available
int15	15 bit 2’s complement integer	± 16,383	-16,384 indicates data not available
int16	16 bit 2’s complement integer	± 32,767	-32,768 indicates data not available
int17	17 bit 2’s complement integer	± 65,535	-65,536 indicates data not available
int19	19 bit 2’s complement integer	± 262,143	-262,144 indicates data not available
int20	20 bit 2’s complement integer	± 524, 287	-524,288 indicates data not available
int21	21 bit 2’s complement integer	± 1,048,575	-1,048,576 indicates data not available
int22	22 bit 2’s complement integer	± 2,097,151	-2,097,152 indicates data not available
int23	23 bit 2’s complement integer	± 4,194,303	-4,194,304 indicates data not available
int24	24 bit 2’s complement integer	± 8,388,607	-8,388,608 indicates data not available
int25	25 bit 2’s complement integer	± 16,777,203	-16,777,204 indicates data not available

Data Type	Description	Range	Data Type Notes
int26	26 bit 2's complement integer	± 33,554,407	-33,554,408 indicates data not available
int30	30 bit 2's complement integer	± 536,870,911	-536,870,912 indicates data not available
int32	32 bit 2's complement integer	± 2,147,483,647	-2,147,483,648 indicates data not available
int34	34 bit 2's complement integer	± 8,589,934,591	-8,589,934,592 indicates data not available
int35	35 bit 2's complement integer	± 17,179,869,183	-17,179,869,184 indicates data not available
int38	38 bit 2's complement integer	± 137,438,953,471	-137,438,953,472 indicates data not available
uint2	2 bit unsigned integer	0 to 3	
uint3	3 bit unsigned integer	0 to 7	
uint4	4 bit unsigned integer	0 to 15	
uint5	5 bit unsigned integer	0 to 31	
uint6	6 bit unsigned integer	0 to 63	
uint7	7 bit unsigned integer	0 to 127	
uint8	8 bit unsigned integer	0 to 255	
uint10	10 bit unsigned integer	0 to 1023	
uint11	11 bit unsigned integer	0 to 2047	
uint12	12 bit unsigned integer	0 to 4095	
uint14	14 bit unsigned integer	0 to 8191	
uint16	16 bit unsigned integer	0 to 65,535	
uint17	17 bit unsigned integer	0 to 131,071	
uint18	18 bit unsigned integer	0 to 262,143	

Data Type	Description	Range	Data Type Notes
uint20	20 bit unsigned integer	0 to 1,048,575	
uint23	23 bit unsigned integer	0 to 8,388,607	
uint24	24 bit unsigned integer	0 to 16,777,215	
uint25	25 bit unsigned integer	0 to 33,554,431	
uint26	26 bit unsigned integer	0 to 67,108,863	
uint27	27 bit unsigned integer	0 to 134,217,727	
uint30	30 bit unsigned integer	0 to 1,073,741,823	
uint32	32 bit unsigned integer	0 to 4,294,967,295	
uint35	35 bit unsigned integer	0 to 34,359,738,367	
uint36	36 bit unsigned integer	0 to 68,719,476,735	
intS5	5 bit sign-magnitude integer	± 15	*See Note 1*
intS11	11 bit sign-magnitude integer	± 1023	*See Note 1*
intS22	22 bit sign-magnitude integer	± 2,097,151	*See Note 1*
intS24	24 bit sign-magnitude integer	± 8,388,607	*See Note 1*
intS27	27 bit sign-magnitude integer	± 67,108,863	*See Note 1*
intS32	32 bit sign-magnitude integer	± 2,147,483,647	*See Note 1*
utf8(N)	Unicode UTF-8 Code Unit	00h to FFh	8-bit value that contains all or part of a Unicode UTF-8 encoded character

Note 1. Sign-magnitude representation records the number's sign and magnitude. MSB is 0 for positive numbers and 1 for negative numbers. The rest of the bits are the number's magnitude. For example, for 8-bit words, the representations of the numbers "-5" and "+5" in a binary form are 10000101 and 00000101, respectively. Negative zero is not used.

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3.4 Data Fields (Additions)

The data fields used are shown in Table 3.4-1. Each Data Field (DF) uses one of the Data Types of Table 3.3-1. Note that the Data Field ranges may be less than the maximum possible range allowed by the Data Type.

Table 3.4-1. Data Field Table (Additions)

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF143	Source-Name Counter	0 – 31		uint5	The Source-Name Counter defines the number of characters (bytes) to follow in Source-Name
DF144	Source-Name			char8(N)	Alphanumeric characters. Name of Source Coordinate-System. If available, the EPSG identification code for the CRS has to be used. Otherwise, service providers should try to introduce unknown CRS's into the EPSG database or could use other reasonable names.
DF145	Target-Name Counter	0 – 31		uint5	The Target-Name Counter defines the number of characters (bytes) to follow in Target-Name
DF146	Target-Name			char8(N)	Alphanumeric characters. Name of Target Coordinate-System. If available, the EPSG identification code for the CRS has to be used. Otherwise, service providers should try to introduce unknown CRS's into the EPSG database or could use other reasonable names.

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF147	System Identification Number	0 – 255		uint8	A unique system identification number has to be used for all messages related to the same sets of CRS's. This is necessary if transformation information for more than one set of CRS's should be transferred within one data stream.
DF148	Utilized Transformation Message Indicator			bit(10)	This data fields says which are assigned to Transformation messages for the system identification number mentioned under DF147. Bit(n) = 0 : Message not utilized Bit(n) = 1 : Message utilized Bit(1) : 1023 Bit(2) : 1024 Bit(3) : 1025 Bit(4) : 1026 Bit(5) : 1027 Bit(6) : 0 (reserved) Bit(7) : 0 (reserved) Bit(8) : 0 (reserved) Bit(9) : 0 (reserved) Bit(10) : 0 (reserved)

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF149	Plate Number	0 – 31		uint5	0: unknown plate 1: AFRC - Africa 2: ANTA - Antarctica 3: ARAB - Arabia 4: AUST - Australia 5: CARB - Caribbea 6: COCO - Cocos 7: EURA - Eurasia 8: INDI - India 9: NOAM - N. America 10: NAZC - Nazca 11: PCFC - Pacific 12: SOAM - S. America 13: JUFU - Juan de Fuca 14: PHIL - Philippine 15: RIVR - Rivera 16: SCOT - Scotia 17 to 31: Reserved
DF150	Computation Indicator	0 – 15		uint4	Transformation method to be used: 0 = standard seven parameter, approximation 1 = standard seven parameter, strict formula 2 = Molodenski, abridged 3 = Molodenski-Badekas 4 to 15: Reserved
DF151	Height Indicator	0 – 3		uint2	0 = Geometric heights result 1 = Physical heights result If physical heights are derived via Helmert/Molodenski transformation: $H = h_{Target} - (\text{Mean } \Delta H + \Delta H \text{ (Grid interpolation)})$ 2 = Physical heights result Height definition is in Source System for instance if a geoid model is involved: $H = h_{Source} - (\text{Mean } \Delta H + \Delta H \text{ (Grid interpolation)})$ 3= Reserved

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF152	Φ_V	± 324000 [″]	2 [″]	int19	Area of validity (Ref.: Figure 3.5-3) of the Helmert/Molodenski transformation: Latitude of Origin in Degrees Coordinates defined in Source-System
DF153	Λ_V	± 648000 [″]	2 [″]	int20	Area of validity (Ref.: Figure 3.5-3) of the Helmert/Molodenski transformation: Longitude of Origin in Degrees Coordinates defined in Source-System
DF154	$\Delta\Phi_V$	0 – 32766 [″]	2 [″]	uint14	Area of validity (Ref.: Figure 3.5-3) of the Helmert/Molodenski transformation: Area Extension to North and to South in Degrees Delta Coordinates defined in Source-System 0: undefined
DF155	$\Delta\Lambda_V$	0 – 32766 [″]	2 [″]	uint14	Area of validity (Ref.: Figure 3.5-3) of the Helmert/Molodenski transformation: Area Extension to East and to West in Degrees Delta Coordinates defined in Source-System 0: undefined
DF156	*dX*	± 4194.303 m	0.001 m	int23	Translation in X (*dX, dY, dZ*) : Translation vector, to be added to the point's position vector in the source coordinate reference system in order to transform from source coordinate reference system to target coordinate reference system; also: the coordinates of the origin of source coordinate reference system in the target frame.
DF157	*dY*	± 4194.303 m	0.001 m	int23	Translation in Y
DF158	*dZ*	± 4194.303 m	0.001 m	int23	Translation in Z

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF159	R_1	± 42,949.67294 [″]	0.00002 [″]	int32	Rotation around the X-axis in arc seconds (*RX, RY, RZ*): Rotations to be applied to the coordinate reference frame. The sign convention is such that a positive rotation of the frame about an axis is defined as a clockwise rotation of the coordinate reference frame when viewed from the origin of the Cartesian coordinate reference system in the positive direction of that axis, that is a positive rotation about the Z-axis only from source coordinate reference system to target coordinate reference system will result in a smaller longitude value for the point in the target coordinate reference system.
DF160	R_2	± 42,949.67294 [″]	0.00002 [″]	int32	Rotation around the Y-axis in arc seconds
DF161	R_3	± 42,949.67294 [″]	0.00002 [″]	int32	Rotation around the Z-axis in arc seconds
DF162	*dS*	± 167.77215 PPM	0.00001 PPM	int25	dS is the scale correction expressed in parts per million (PPM).
DF163	X_P	± 17,179,869.184 m	0.001 m	int35	X Coordinate for Molodenski-Badekas rotation point (X_P, Y_P, Z_P): Coordinates of the point about which the coordinate reference frame is rotated, given in the source Cartesian coordinate reference system. Must always be the same within the area of a service provider
DF164	Y_P	± 17,179,869.184 m	0.001 m	int35	Y Coordinate for Molodenski-Badekas rotation point Must always be the same within the area of a service provider
DF165	Z_P	± 17,179,869.184 m	0.001 m	int35	Z Coordinate for Molodenski-Badekas rotation point Must always be the same within the area of a service provider
DF166	add a_S	0 – 16,777.215	0.001 m	uint24	Semi-major axis of source system ellipsoid a_S = 6370000 + add a_S 0: undefined If add a_S , add b_S , add a_T or add b_T is 0 (undefined) then only the 7 parameter transformation could be performed. The conversion to ellipsoidal coordinates, the projection and the local transformation (Helmert) have to be omitted.

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF167	add b_S	0 – 33,554.431	0.001 m	uint25	Semi-minor axis of source system ellipsoid b_S = 6350000 + add b_S 0: undefined (see add a_S)
DF168	add a_T	0 – 16,777.215	0.001 m	uint24	Semi-major axis of target system ellipsoid a_T = 6370000 + add a_T 0: undefined (see add a_S)
DF169	add b_T	0 – 33,554.431	0.001 m	uint25	Semi-minor axis of target system ellipsoid b_T = 6350000 + add b_T 0: undefined (see add a_S)

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF170	Projection Type	0 – 63		uint6	**Projection type** **0: unknown projection type** **1: TM - Transverse Mercator** (OGP 1.4.5.1, EPSG dataset coordinate operation method code 9807) **2: TMS - Transverse Mercator (South Orientated)** (OGP 1.4.5.3, EPSG dataset coordinate operation method code 9808) **3: LCC1SP - Lambert Conic Conformal (1SP)** (OGP 1.4.1.2, EPSG dataset coordinate operation method code 9801) **4: LCC2SP - Lambert Conic Conformal (2SP)** (OGP 1.4.1.1, EPSG dataset coordinate operation method code 9802) **5: LCCW - Lambert Conic Conformal (West Orientated)** (OGP 1.4.1.3, EPSG dataset coordinate operation method code 9826) **6: CS - Cassini-Soldner** (OGP 1.4.4, EPSG dataset coordinate operation method code 9806) **7: OM - Oblique Mercator** (OGP 1.4.6, EPSG dataset coordinate operation method code 9815) **8: OS - Oblique Stereographic** (OGP 1.4.7.1, EPSG dataset coordinate operation method code 9809) **9: MC - Mercator** (OGP 1.4.3, EPSG dataset coordinate operation method code 9804 or 9805) **10:PS - Polar Stereographic** (OGP 1.4.7.2, EPSG dataset coordinate operation method code 9810) **11:DS - Double Stereographic** **12 to 63: Reserved** If the Projection type is 0 (unknown) then only the 7 parameter transformation and the interpolations for $\delta\varphi_i$, $\delta\lambda_i$ δh_i (1023) could be performed. The Projection and interpolations for δN_i, δE_i δh_i (1024) have to be omitted.
DF171	LaNO	± 90.0000 [°]	0.000000011 [°]	int34	Latitude of natural origin (TM, TMS, LCC1SP, LCCW, CS, OS, PS, DS)
DF172	LoNO	± 180.0000 [°]	0.000000011 [°]	int35	Longitude of natural origin (TM, TMS, LCC1SP, LCCW, CS, OS, MC, PS, DS)

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF173	add SNO	0 – 10737.41823 PPM	0.00001 PPM	uint30	Scale factor at natural origin (TM, TMS, LCC1SP, LCCW, OS, PS, DS) SNO = 993000 + add SNO [PPM]
DF174	FE	0 – 68,719,476.735 m	0.001 m	uint36	False Easting (TM, TMS, LCC1SP, LCCW, CS, OS, MC, PS, DS) (Contains zone term if exists)
DF175	FN	± 17,179,869.183 m	0.001 m	int35	False Northing (TM, TMS, LCC1SP, LCCW, CS, OS, MC, PS, DS)
DF176	LaFO	± 90.0000 [°]	0.000000011 [°]	int34	Latitude of false origin (LCC2SP)
DF177	LoFO	± 180.0000 [°]	0.000000011 [°]	int35	Longitude of false origin (LCC2SP)
DF178	LaSP1	± 90.0000 [°]	0.000000011 [°]	int34	Latitude of 1st standard parallel (LCC2SP)
DF179	LaSP2	± 90.0000 [°]	0.000000011 [°]	int34	Latitude of 2^{nd} standard parallel (LCC2SP)
DF180	EFO	0 – 68,719,476.735 m	0.001 m	uint36	Easting of false origin (LCC2SP)
DF181	NFO	± 17,179,869.183 m	0.001 m	int35	Northing of false origin (LCC2SP) (Contains zone term if exists)
DF182	Rectification Flag	0-1		bit(1)	0 = not rectified (OM) 1 = rectified Oblique Mercator projection
DF183	LaPC	± 90.0000 [°]	0.000000011 [°]	int34	Latitude of projection centre (OM)
DF184	LoPC	± 180.0000 [°]	0.000000011 [°]	int35	Longitude of projection centre (OM)

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF185	AzIL	0 – 360 [°]	0.000000011 [°]	uint35	Azimuth of initial line (OM)
DF186	Diff ARSG	± 0.369098741 [°]	0.000000011 [°]	int26	Difference from Azimuth of initial line to Angle from Rectified to Skew Grid ARSG = AzIL + Diff ARSG (OM)
DF187	Add SIL	0 – 10,737.41823 PPM	0.00001 PPM	uint30	Scale factor on initial line (OM) SIL = 993000 + add SIL [PPM]
DF188	EPC	0 – 68,719,476.735 m	0.001 m	uint36	Easting at projection centre (OM) (Contains zone term if exists)
DF189	NPC	± 17,179,869.183 m	0.001 m	int35	Northing at projection centre (OM)
DF190	Horizontal Shift Indicator	0-1		bit(1)	0 = no horizontal shift 1 = apply horizontal shift
DF191	Vertical Shift Indicator	0-1		bit(1)	0 = no vertical shift 1 = apply vertical shift
DF192	Φ_0	± 324000 [″]	0.5 [″]	int21	Latitude of Origin of the grids in Degrees (See Figure 3.5-4) Coordinates defined in Target-System. In this context “Target system” means directly after utilizing Helmert or Molodenski transformation (1021 or 1022).
DF193	Λ_0	± 648000 [″]	0.5 [″]	int22	Longitude of Origin of the grids in Degrees (See Figure 3.5-4) Coordinates defined in Target-System. In this context [“]Target system” means directly after utilizing Helmert or Molodenski transformation (1021 or 1022).
DF194	$\Delta\varphi$	0 – 2047.5 [″]	0.5 [″]	uint12	Grid area extension North to South in Degrees (See Figure 3.5-4) Delta Coordinates defined in Target-System. In this context “Target system” means directly after utilizing Helmert or Molodenski transformation (1021 or 1022). 0: undefined

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF195	$\Delta\lambda$	0 – 2047.5 [″]	0.5 [″]	uint12	Grid area extension East to West in Degrees (See Figure 3.5-4) Delta Coordinates defined in Target-System. In this context [“]Target system” means directly after utilizing Helmert or Molodenski transformation (1021 or 1022). 0: undefined
DF196	Mean $\Delta\varphi$	± 0.127 [″]	0.001 [″]	int8	Mean offset for all 16 grid points.
DF197	Mean $\Delta\lambda$	± 0.127 [″]	0.001 [″]	int8	Mean offset for all 16 grid points.
DF198	Mean ΔH	± 163.84 m	0.01 m	int15	Mean height offset for all 16 grid points to cover all possible geoid heights. If “Height Indicator” = 2 - defined in Source CRS else - defined in Target CRS
DF199	$\delta\varphi_i$	± 0.00765 [″]	0.00003 [″]	int9	Residual in latitude for point i (See Figure 3.5-4) - only for small areas - defined in Target CRS
DF200	$\delta\lambda_i$	± 0.00765 [″]	0.00003 [″]	int9	Residual in longitude for point i (See Figure 3.5-4) - only for small areas - defined in Target CRS
DF201	δh_i	± 0.255 m	0.001 m	int9	Residual in height for point i (See Figure 3.5-4) - only for small areas If “Height Indicator” = 2 - defined in Source CRS else - defined in Target CRS
DF202	N_0	± 167,772,150 m	10 m	int25	Northing of Origin of the grids in meters (See Figure 3.5-4) Coordinates defined in local system after projection

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF203	E_0	0 – 671,088,630 m	10 m	uint26	Easting of Origin of the grids in meters (See Figure 3.5-4) Coordinates defined in local system after projection
DF204	ΔN	0 – 40,950 m	10 m	uint12	Grid area extension North to South in meters (See Figure 3.5-4) Delta Coordinates defined in local system after projection 0: undefined
DF205	ΔE	0 – 40,950 m	10 m	uint12	Grid area extension East to West in meters (See Figure 3.5-4) Delta Coordinates defined in local system after projection 0: undefined
DF206	Mean ΔN	± 5.11 m	0.01 m	int10	Mean local Northing offset for all 16 grid points.
DF207	Mean ΔE	± 5.11 m	0.01 m	int10	Mean local Easting offset for all 16 grid points.
DF208	Mean Δh	± 163.84 m	0.01 m	int15	Mean local height offset for all 16 grid points to cover all possible geoid heights. If "Height Indicator" = 2 - defined in Source CRS else defined in local system after projection
DF209	δN_i	± 0.255 m	0.001 m	int9	Residual in local Northing for point i (See Figure 3.5-4) - only for small areas
DF210	δE_i	± 0.255 m	0.001 m	int9	Residual in local Easting for point i (See Figure 3.5-4) - only for small areas
DF211	δh_i	± 0.255 m	0.001 m	int9	Residual in height for point i (See Figure 3.5-4) - only for small areas
DF212	Horizontal Interpolation Method Indicator	0-3		uint2	Defining horizontal interpolation method to be used (Figures 3.5-5 through 3.5-7) 0 = bi-linear 1 = bi-quadratic 2 = bi-spline 3 = reserved

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF213	Vertical Interpolation Method Indicator	0-3		uint2	Defining vertical interpolation method to be used (Figures 3.5-5 through 3.5-7) 0 = bi-linear 1 = bi-quadratic 2 = bi-spline 3 = reserved
DF214	Horizontal Helmert/Molodenski Quality Indicator	0 – 7		uint3	Maximum approximation error after application of Helmert/Molodenski transformation within the ‘area of validity’. The quality could be further improved by application of information in the residual message (grid residuals). 0 = unknown quality 1 = Quality better 21 Millimeters 2 = Quality 21 to 50 Millimeters 3 = Quality 51 to 200 Millimeters 4 = Quality 201 to 500 Millimeters 5 = Quality 501 to 2000 Millimeters 6 = Quality 2001 to 5000 Millimeters 7 = Quality worse than 5001 Millimeters
DF215	Vertical Helmert/Molodenski Quality Indicator	0 – 7		uint3	Maximum approximation error after application of Helmert/Molodenski transformation within the ‘area of validity’. The quality could be further improved by application of information in the residual message (grid residuals). 0 = unknown quality 1 = Quality better 21 Millimeters 2 = Quality 21 to 50 Millimeters 3 = Quality 51 to 200 Millimeters 4 = Quality 201 to 500 Millimeters 5 = Quality 501 to 2000 Millimeters 6 = Quality 2001 to 5000 Millimeters 7 = Quality worse than 5001 Millimeters

DF #	DF Name	DF Range	DF Resolution	Data Type	Data Field Notes
DF216	Horizontal Grid Quality Indicator	0 – 7		uint3	Maximum horizontal case within the given area after applying the grid residuals. Replaces the Helmert/Molodenski Quality 0 = unknown quality 1 = Quality 0 to 10 Millimeters 2 = Quality 11 to 20 Millimeters 3 = Quality 21 to 50 Millimeters 4 = Quality 51 to 100 Millimeters 5 = Quality 101 to 200 Millimeters 6 = Quality 201 to 500 Millimeters 7 = Quality worse than 501 Millimeters
DF217	Vertical Grid Quality Indicator	0 – 7		uint3	Maximum vertical case within the given area after applying the grid residuals. Replaces the Helmert/Molodenski Quality 0 = unknown quality 1 = Quality 0 to 10 Millimeters 2 = Quality 11 to 20 Millimeters 3 = Quality 21 to 50 Millimeters 4 = Quality 51 to 100 Millimeters 5 = Quality 101 to 200 Millimeters 6 = Quality 201 to 500 Millimeters 7 = Quality worse than 501 Millimeters

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3.5.10 Coordinate Transformation Messages

Further information about coordinate transformations can be found at "OGP Surveying and Positioning Guidance Note Number 7, part 2 - Coordinate Conversions and Transformations including Formulas" (Further on referred to as OGP) and EPSG database Version 6.11_2 (Further on referred to as EPSG) at http://www.epsg.org/ or at the European Coordinate Reference System (CRS) website at http://www.crs.bkg.bund.de/.

3.5.10.1 Transformation Information

For RTCM data supporting a RTK service, coordinates are measured within the ITRF or a regional realization. Surveyors and other users of RTK services must normally present their results in the coordinates of local datums. Therefore, coordinate transformations are necessary.

Currently, transformation parameters are calculated and manually transferred to GPS receivers, a process which can be a source of confusion. Another method is to store models on the GPS receivers and to use these for the transformation. However, it often happens that revised models are not available in the GPS receiver, so that users end up utilizing obsolete information.

Users have often expressed their desire to be able to utilize a simpler and more convenient method. By having RTCM messages that contain transformation data and information about the Coordinate Reference Systems, the users of the RTK service can obtain their results in the desired datum without any manual operations. The RTK service providers can then ensure that current information for the computation of the transformations is always used. The convenience of this method will promote the acceptance of RTK services.

3.5.10.2 Concatenated Coordinate Operation (ISO 19111)

The change of coordinates from one coordinate reference system to another coordinate reference system follows from a series of coordinate operations consisting of one or more coordinate transformations and/or one or more coordinate conversions. This is called a concatenated coordinate operation.

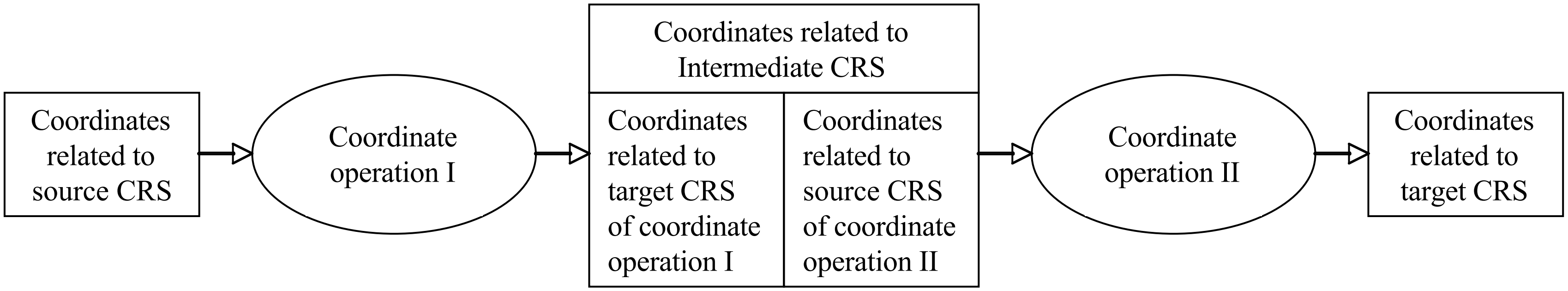

Figure 3.5-1. Steps in the Coordinate Transformation Process

The transformation of coordinates from an ECEF coordinate system to a local coordinate system generally requires several steps, as described in the next few paragraphs.

Datum transformation

The transformation from the global ECEF (ITRF, ETRF, ...) to the local geodetic datum is generally accomplished by means of a 7-*parameter transformation. The ISO19111 specifies the linearized, or approximate, transformation formula. The parameters found in many publications as well as databases like the EPSG or European initiatives, and all the IGS and IERS parameters correspond to this formula. The use of the linearized formula and a respective 7-parameter set is specified by the computation-indicator "0". The strict formula of a 7-parameter transformation is also often used in practice and is related to finite rotations' parameterization. The application of the strict formula and a respective set of 7 parameters is specified by the computation-indicator "1" in data field DF150. The 7 parameters belonging to the indicator "0" and "1"*, respectively are self-consistent also with respect to the given and different inversion formulas, while the different transformation parameterizations and related parameters themselves can not to be interchanged without a loss of transformation correctness and accuracy.

Coordinate conversion from geocentric Cartesian representation to ellipsoidal latitude, longitude and height

This conversion requires the knowledge of the ellipsoidal parameters (a,b).

Coordinate conversion to plane coordinates

This coordinate conversion uses projection formulas like the Transverse Mercator projection (Gauss-Krüger, UTM,..) or other (mostly) conformal projections to obtain 2-D Cartesian plane coordinates (Northing, Easting) and 3.5-D height. The projection step requires the knowledge of the ellipsoidal parameters as well as the parameters for the projection (prime meridian, scale, false northing and easting etc.).

Height transformation

From ellipsoidal heights to the local, leveling-related height system requires the knowledge of the difference between the ellipsoid and the reference surface for the local height system. This reference surface may be the geoid, quasi-geoid or a similar surface. The representation of such a reference surface includes the vertical datum as well as systematic and stochastic effects in the realization of the local height systems. The height surface can be related either to the global datum and ellipsoid, or to the local datum and ellipsoid.

The height transition from ellipsoidal to physical heights can also be accomplished within the 7-parameter transformation, if the area is very small (see DF152, DF153).

Transformation from global ECEF to plate-fixed ECEF coordinates

The dynamic earth causes movements of the tectonic plates on the order of centimeters per year. This means that the transformation parameters are not constant. To account for this, different organizations have established quasi-global coordinate reference systems, which are tied to the tectonic plates (ETRS in Europe). If the starting point for step no. 1 is such a plate-fixed coordinate system, then the transformation parameters may be considered constant for a longer period of time, since only local movements within the plates would be responsible for changes. Since global GNSS (satellite coordinates) are described in a global ECEF coordinate system, an additional transformation step is necessary:

An additional message will be defined for this function in the future. It will be omitted in this document.

3.5.10.3 3-D Coordinate Transformation Formulas

There are four sets of transformations that will be supported in this Standard: (1) the linear form of the Helmert Transformation, (2) the strict form of the Helmert Transformation, (3) the abridged Molodenski Transformation, and (4) the Molodenski-Badekas Transformation. They are described in EPSG Guidance Note 7, which is on the website of the "Surveying and Positioning Committee of the International Association of Oil and Gas Producers (OGP)", the former "European Petroleum Survey Group" (EPSG, http://www.epsg.org). Figure 3.5-2 shows the geometry of the transformation and the senses of rotation used herein.

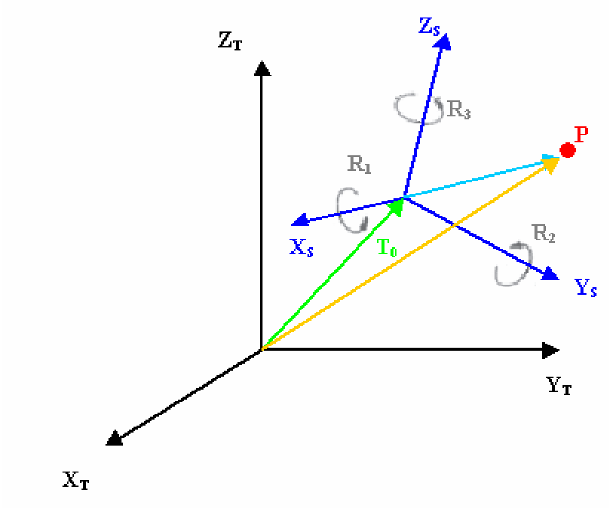

Figure 3.5-2. Definition of Translation and Rotations

3.5.10.3.1 Helmert Transformation, linear expression

(OGP 2.4.3.2.2 Coordinate Frame Rotation, EPSG dataset coordinate operation method code 9607)

Transformation of coordinates from one geographic coordinate reference system into another (also known as a "datum transformation") is usually carried out as an implicit concatenation of three transformations:

[geographical to geocentric >> geocentric to geocentric >> geocentric to geographic]

The middle part of the concatenated transformation, from geocentric to geocentric, is usually described as a simplified 7-parameter Helmert transformation.

The formula is:

$$\begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} = M * \begin{bmatrix} 1 & +R_Z & -R_Y \\ -R_Z & 1 & +R_X \\ +R_Y & -R_X & 1 \end{bmatrix} * \begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix} + \begin{bmatrix} dX \\ dY \\ dZ \end{bmatrix} \tag{3.5-1}$$

and the parameters are defined as:

(R_1, R_2, R_3): Rotations to be applied to the coordinate reference frame. The sign convention is such that a positive rotation of the frame about an axis is defined as a clockwise rotation of the coordinate reference frame when viewed from the origin of the Cartesian coordinate system in the positive direction of that axis, that is a positive rotation about the Z-axis only from source coordinate reference system to target coordinate reference system will result in a smaller longitude value for the point in the target coordinate reference system. Although rotation angles may be quoted in any angular unit of measure, the formula as given here requires the angles to be provided in radians.

The formula as given here requires the angles to be provided in radians - conversion from arc seconds (R_1, R_2, R_3) to radians (R_X, R_Y, R_Z):

$$R_X = R_1 * \left(\frac{\pi}{3600 * 180} \right) \tag{3.5-2}$$

$$R_Y = R_2 * \left(\frac{\pi}{3600 * 180} \right) \tag{3.5-3}$$

$$R_Z = R_3 * \left(\frac{\pi}{3600 * 180} \right) \tag{3.5-4}$$

M : The scale factor to be applied to the position vector in the source coordinate reference system in order to obtain the correct scale of the target coordinate reference system.

$$M = (1 + dS * 10^{-6}) \tag{3.5-5}$$

3.5.10.3.2 Helmert Transformation, Strict formula

$$\begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} = \begin{bmatrix} dX \\ dY \\ dZ \end{bmatrix} + M * \mathbf{R} * \begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix} \qquad (3.5\text{-}6)$$

where **R** is the rotation matrix defined by

$$\mathbf{R} = \mathbf{R}_z \mathbf{R}_y \mathbf{R}_x = \begin{bmatrix} \cos R_3 & \sin R_3 & 0 \\ -\sin R_3 & \cos R_3 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos R_2 & 0 & -\sin R_2 \\ 0 & 1 & 0 \\ \sin R_2 & 0 & \cos R_2 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos R_1 & \sin R_1 \\ 0 & -\sin R_1 & \cos R_1 \end{bmatrix} \qquad (3.5\text{-}7)$$

M : The scale factor to be applied to the position vector in the source coordinate reference system in order to obtain the correct scale of the target coordinate reference system.

$$M = (1+dS*10^{-6}) \qquad (3.5\text{-}8)$$

<u>Inverse formula</u>

To transform in the opposite direction using the same numerical values as for the forward formula use the following strict inverse formula:

$$\begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix} = \frac{\mathbf{R}^{-1}}{M} \left[\begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} - \begin{bmatrix} dX \\ dY \\ dZ \end{bmatrix} \right] \qquad (3.5\text{-}9)$$

where $\mathbf{R}^{-1}$ is the mathematical inverse of the rotation matrix = the transposed matrix $\mathbf{R}^{\mathbf{T}}$.

3.5.10.3.3 Molodenski Transformation, abridged

$$\begin{aligned} \varphi_T &= \varphi_S + d\varphi \\ \lambda_T &= \lambda_S + d\lambda \\ h_T &= h_S + dh \end{aligned} \qquad (3.5\text{-}10)$$

$$d\varphi[rad] = \frac{\left(-dX\cdot\sin\varphi_S\cos\lambda_S - dY\cdot\sin\varphi_S\sin\lambda_S + dZ\cdot\cos\varphi_S + \left[(M\cdot a_s/b_s + N\cdot b_s/a_s)\ \cdot df + (N\cdot e_s^{\,2})/a_s\cdot da\right]\cdot\sin 2\varphi_S/2\right)}{(M+h_S)}$$

$$d\lambda[rad] = \frac{(-dX\cdot\sin\lambda_S + dY\cdot\cos\lambda_S)}{((N+h_S)\cdot\cos\varphi_S)} \qquad (3.5\text{-}11)$$

$$dh = dX\cdot\cos\varphi_S\cdot\cos\lambda_S + dY\cdot\cos\varphi_S\cdot\sin\lambda_S + dZ\cdot\sin\varphi_S + \left(df\cdot N\cdot b_s/a_s\right)\cdot\sin^2\varphi_S - da\cdot a_s/N$$

where M and N are the meridian and prime vertical radii of curvature at the given latitude φ_s,

$$M = \frac{a_S\cdot(1\text{-}e_s^{\,2})}{\left(1\ -\ e_s^{\,2}\ \cdot\ \sin(\varphi_S)^2\right)^{3/2}} \qquad (3.5\text{-}12)$$

$$N = \frac{a_S}{\sqrt{\left(1\ -\ e_s^{\,2}\ \cdot\ \sin(\varphi_S)^2\right)}} \qquad (3.5\text{-}13)$$

$$e_S^{\,2} = (a_s^{\,2} - b_s^{\,2})/a_s^{\,2} \qquad (3.5\text{-}14)$$

da is the difference in the semi-major axes of the target and source ellipsoids [$da = a_T - a_S$] and df is the difference in the flattening of the two ellipsoids [$df = f_t - f_s = 1/(1/f_t) - 1/(1/f_s)$] where $1/f = a/(a - b)$.

The formulas for dφ and dλ indicate changes in φ_S and λ_S in radians. Finally it holds for the translations of the origins: $dX = X_T - X_S$, $dY = Y_T - Y_S$ and $dZ = Z_T - Z_S$

3.5.10.3.4 Molodenski-Badekas Transformation

(OGP 2.4.3.3 Molodensky-Badekas 10-parameter transformation, EPSG dataset coordinate operation method code 9636)

To eliminate high correlation between the translations and rotations in the derivation of parameter values for these Helmert transformation methods, instead of the rotations being derived about the geocentric coordinate reference system origin they may be derived at a location within the points used in the determination. Three additional parameters, the coordinates of the rotation point, are then required. The formula is:

$$\begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} = M * \begin{bmatrix} 1 & +R_Z & -R_Y \\ -R_Z & 1 & +R_X \\ +R_Y & -R_X & 1 \end{bmatrix} * \begin{bmatrix} X_S & -X_P \\ Y_S & -Y_P \\ Z_S & -Z_P \end{bmatrix} + \begin{bmatrix} X_P \\ Y_P \\ Z_P \end{bmatrix} + \begin{bmatrix} dX \\ dY \\ dZ \end{bmatrix} \quad (3.5\text{-}15)$$

and the parameters are defined as:

(R_1, R_2, R_3): Rotations to be applied to the coordinate reference frame. The sign convention is such that a positive rotation of the frame about an axis is defined as a clockwise rotation of the coordinate reference frame when viewed from the origin of the Cartesian coordinate system in the positive direction of that axis, that is a positive rotation about the Z-axis only from source coordinate reference system to target coordinate reference system will result in a smaller longitude value for the point in the target coordinate reference system. Although rotation angles may be quoted in any angular unit of measure, the formula as given here requires the angles to be provided in radians.

(X_P, Y_P, Z_P): Coordinates of the point about which the coordinate reference frame is rotated, given in the source Cartesian coordinate reference system.

The formula as given here requires the angles to be provided in radians - conversion from arc seconds (R_1, R_2, R_3) to radians (R_X, R_Y, R_Z):

$$R_X = R_1 * \left(\frac{\pi}{3600 \quad * \quad 180} \right) \quad (3.5\text{-}16)$$

$$R_Y = R_2 * \left(\frac{\pi}{3600 \quad * \quad 180} \right) \quad (3.5\text{-}17)$$

$$R_Z = R_3 * \left(\frac{\pi}{3600 \quad * \quad 180} \right) \quad (3.5\text{-}18)$$

M : The scale factor to be applied to the position vector in the source coordinate reference system in order to obtain the correct scale of the target coordinate reference system.

$$M = (1 + dS * 10^{-6}) \quad (3.5\text{-}19)$$

Reversibility

The Molodensky-Badekas transformation in a strict mathematical sense is not reversible, i.e. in principle the same parameter values cannot be used to execute the reverse transformation. This is because the evaluation point coordinates are in the forward direction source coordinate reference system and the rotations have been derived about this point. They should not be applied about the point having the same coordinate values in the target coordinate reference system, as is required for the reverse transformation. However, in practical application there are exceptions when applied to the approximation of small differences between the geometry of a set of points in two different coordinate reference systems. The typical vector difference in coordinate values is in the order of $6*10^1$ to $6*10^2$ meters, whereas the evaluation point on or near the surface of the earth is $6.3*10^6$ meters from the origin of the coordinate systems at the Earth's centre. This difference of four or five orders of magnitude allows the transformation in practice to be considered reversible. Note that in the reverse transformation, only the signs of the translations and rotation parameter values are reversed; the coordinates of the evaluation point remain unchanged.

3.5.10.4 Procedures for Utilizing the Messages

Seven message types are defined here in support of the application of coordinate transformations, namely Message Types 1021 through 1027. Message Type 1021 provides the basic transformation parameters for the first three sets, while Message Type 1022 provides the information for the fourth set, the Molodenski-Badekas transformation. Message Types 1023 and 1024 define the residuals for ellipsoidal and plane grid representations, respectively. Message Types 1025, 1026 and 1027 define the parameters that support the Lambert Conic Conformal (LCC2SP) projection, the Oblique Mercator (OM) projection, and others.

At a minimum, the Service Provider should send out either Message Type 1021 or 1022, each of which contains transformation parameters. The other messages provide useful information for many applications. Either Message Type 1023 or 1024 should be utilized, but not both; similarly for Message Types, 1025-1027, only one type should be utilized.

The interval between successive Coordinate Transformation messages is arbitrary, but the following guidelines are provided here. If the communications link is bi-directional,

- 1021 or 1022: Initially send out after 3, 8 and 13 GNSS epochs, each 60 epochs thereafter
- 1023 or 1024: Initially send out after 4, 9 and 14 GNSS epochs, each 60 epochs thereafter
- 1025 *or* 1026 *or* 1027: Initially send out after 5, 10 and 15 GNSS epochs, each 60 epochs thereafter.

For a one-way broadcast link,

- 1021 or 1022: Each 60 epochs
- 1023 or 1024: 10 epochs after 1021 or 1022
- 1025 *or* 1026 *or* 1027: 20 epochs after 1021 or 1022.

If it is necessary to cover larger areas with a one-way broadcast link, neighbouring grids - for the 'Area of validity of the Helmert/Molodenski transformation' - can be transmitted with Message Type 1023 or 1024.

The Mobile Receiver must perform the following procedures:

- First, the Mobile Receiver should check which Transformation messages are utilized by inspecting the data field DF148, "Utilized Transformation Message Indicator", which is included in Message Types 1021 and 1022.
- All identified messages should be processed before performing the transformation.
- The Mobile Receiver should process the residual messages using the interpolation technique identified by the Service Provider.
- An estimate of the complete positioning error should be determined using proper error propagation. The contributions of the coordinate transformation are determined by the terms of Helmert/Molodenski error and grid error, respectively.

The Service Provider should observe the following guidelines:

- The Service Provider should utilize a fixed set of Areas of Validity rather than attempt to define the Area of Validity in terms of the location of a particular User.
- If service is provided to a User in the outer 10% of the Area of Validity, as described in Figure 3.5-2, the corresponding messages for the adjacent Area should be sent out (see Figure 3.5-3).
- If the communications link is bi-directional and a User moves into the outer 10% of the Area of Validity, a residual message (1023 or 1024) should be sent out immediately.
    - A new residual message (1023 or 1024) for the neighbouring meshes should be sent out immediately, and repeated 5 and 10 epochs later.
    - Type 1021 (or 1022) and 1025 (or 1026 or 1027) messages should be postponed, if they would normally be sent at the same time.
- The grid extensions should be the same within the area of a Service Provider
- The raster points of the grid should not change and should be independent of the rover position. The Service Provider should determine the origin of the raster according to the rover position and then send the appropriate raster.

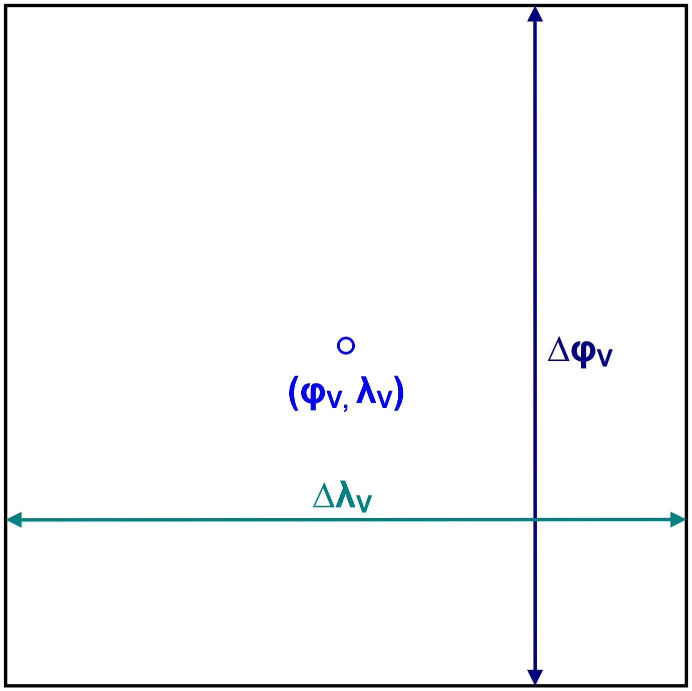

Figure 3.5-3. Area of Validity

Figure 3.5-3 shows the Area of Validity for the Helmert/Molodenski transformation, with the latitude and longitude coordinates of the origin, and the extent of the area in latitude and longitude.

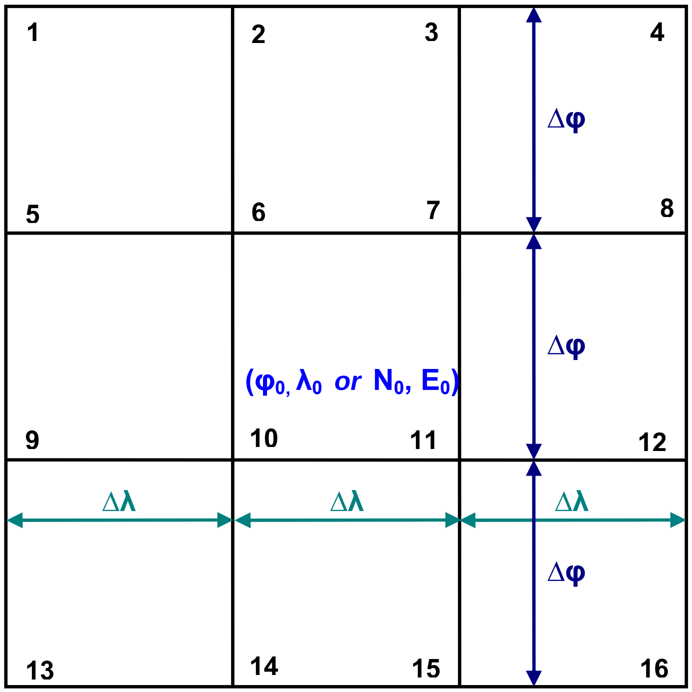

Figure 3.5-4. Grid Definition for Residual Messages

Figure 3.5-4 shows the grid definition for the residual messages, i.e., Message Types 1023 and 1024. The Area of Validity is shown in the center, with the eight adjacent Areas surrounding it. The parameters of Message Type 1023 are defined with respect to longitude and latitude, while the parameters of Message Type 1024 are defined with respect to East and North, respectively. The residual messages define the 3-dimensional shifts for each point number.

The squares are identified in Roman numerals as follows:

I	II	III
IV	V	VI
VII	VIII	IX

Figures 3.5-5 through 3.5-7 show the raster points used for each interpolation method identified in Message Types 1023 and 1024, namely bi-linear, bi-quadratic, and bi-spline, respectively. The mesh points as provided by messages 1023 and 1024 do not have to overlap with neighboring meshes transmitted. For example 4 messages might cover overall 8 by 8 mesh points.

In the bi-linear method, the rover can be located anywhere in the shaded area – not just the location shown in Figure 3.5-5; however, it uses only the four surrounding grid points in the interpolation.

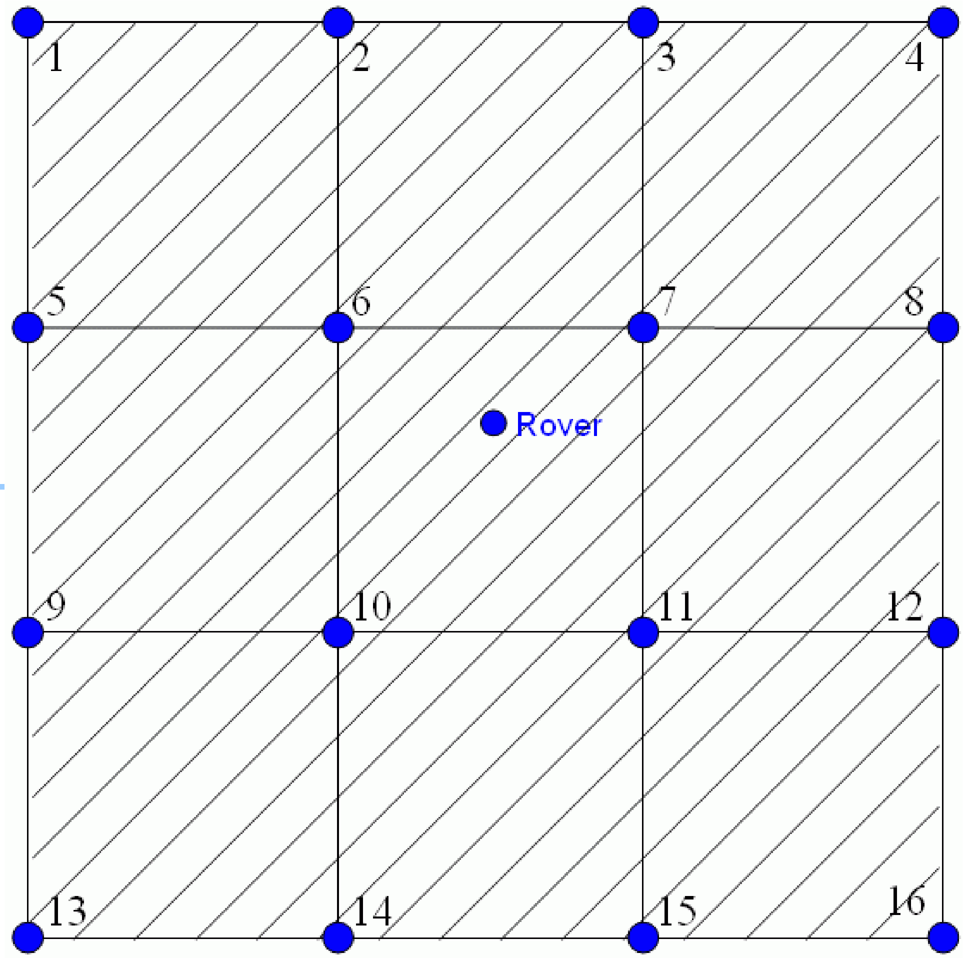

Figure 3.5-5. Raster Points Used for Bi-Linear Interpolation

While it is similar to the bi-linear interpolation, only a section of grid points will be used for the bi-quadratic interpolation. The squares West, North-West and North of the interpolation square are always used for quadratic interpolations. For instance, the grid points in the upper left (1, 2, 3, 5, 6, 7, 9, 10, and 11, squares I, II, IV, and V) are used for interpolation when the rover is within one square, namely the shaded square shown in Figure 3.5-6. For one particular message 1023 or 1024 interpolations can be performed for squares V, VI, VIII, and IX. Note that the squares shown in this example do not necessarily correlate with the content of messages 1023 and 1024.

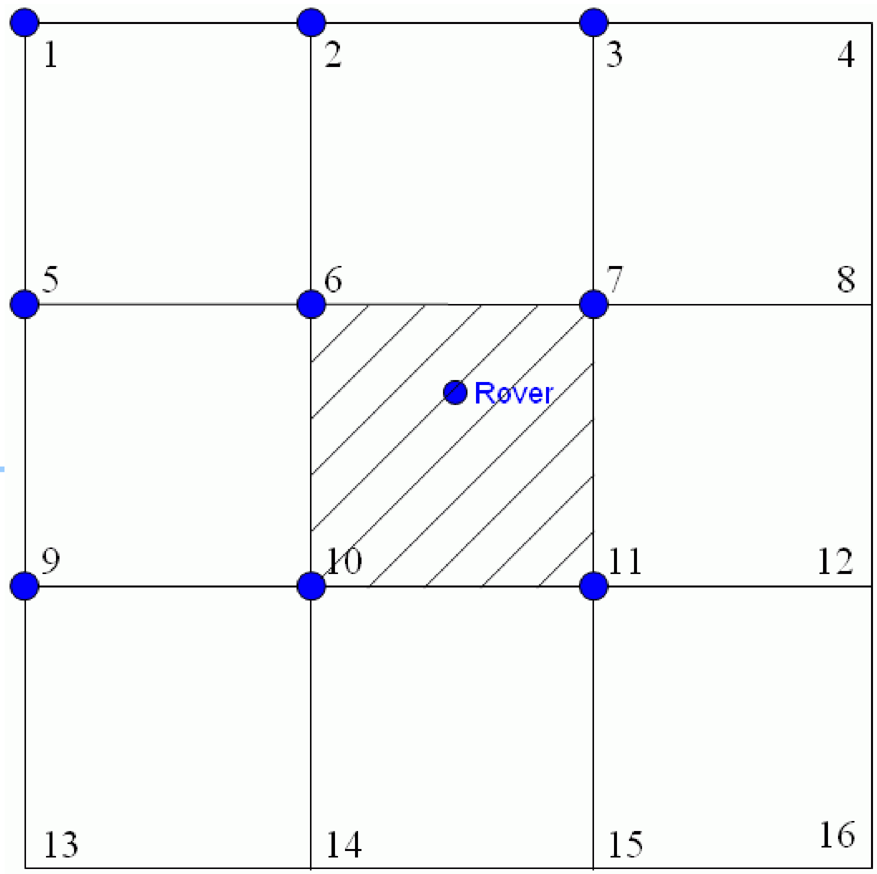

Figure 3.5-6. Raster Points Used for the Bi-quadratic Interpolation.

In the bi-spline method, the rover can be located only in the shaded central square, as indicated in Figure 3.5-7. It uses all 16 grid points in the interpolation.

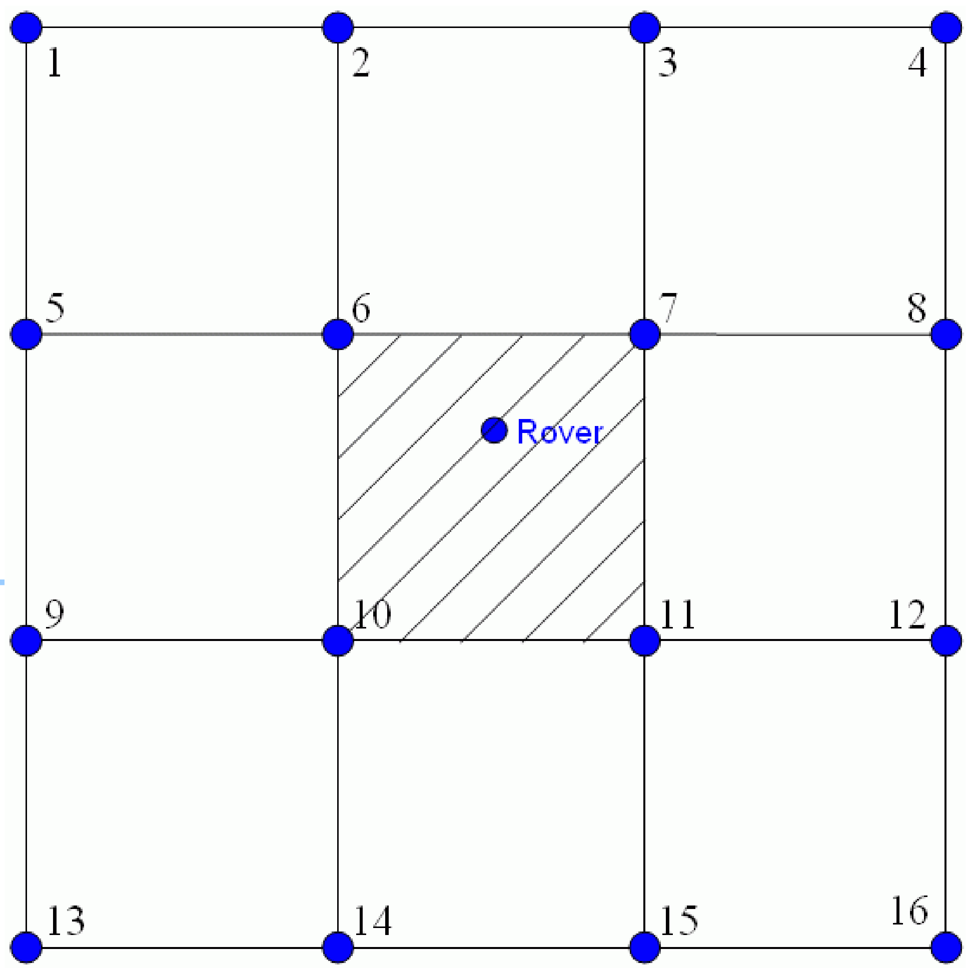

Figure 3.5-7. Raster Points Used for the Bi-Spline Interpolation.

3.5.10.5 Contents of the Coordinate Transformation Messages

Table 3.5-24. Contents of the Helmert / Abridged Molodenski Message Type 1021

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS	NOTES
Message Number	DF002	uint12	12	
Source-Name Counter	DF143	uint5	5	
Source-Name	DF144	char8(N)	8*N	
Target-Name Counter	DF145	uint5	5	
Target-Name	DF146	char8(M)	8*M	
System Identification Number	DF147	uint8	8	
Utilized Transformation Message Indicator	DF148	bit(10)	10	
Plate Number	DF149	uint5	5	
Computation Indicator	DF150	uint4	4	
Height Indicator	DF151	uint2	2	
Φ_V - Latitude of Origin, Area of Validity	DF152	int19	19	See Figure 3.5-3
Λ_V – Longitude of Origin, Area of Validity	DF153	int20	20	See Figure 3.5-3
$\Delta\varphi_V$ – N/S Extension, Area of Validity	DF154	uint14	14	See Figure 3.5-3
$\Delta\lambda_V$ – E/W Extension, Area of Validity	DF155	uint14	14	See Figure 3.5-3
dX – Translation in X-direction	DF156	int23	23	See Equations 3.5-1, 3.5-6, 3.5-9 & 3.5-15
dY – Translation in Y-direction	DF157	int23	23	See notes for *dX*
dZ – Translation in Z-direction	DF158	int23	23	See notes for *dX*

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS	NOTES
R_1 – Rotation Around the X-axis	DF159	int32	32	See Section 3.5.10.3.1, para. 3 and Section 3.5.10.3.4, para. 2, and equations 3.5-2, 3.5-3, 3.5-4, 3.5-7, 3.5-15, 3.5-16, 3.5-17, & 3.5-18
R_2 – Rotation Around the Y-axis	DF160	int32	32	See notes for R_1
R_3 – Rotation Around the Z-axis	DF161	int32	32	See notes for R_1
dS – Scale Correction	DF162	int25	25	See equations 3.5-5, 3.5-8 & 3.5-19
add a_S – Semi-major Axis of Source System Ellipsoid	DF166	uint24	24	See Section 3.5.10.2 and final two para's in Section 3.5.10.3.3, and equations 3.5-11 through 3.5-14.
add b_S – Semi-minor Axis of Source System Ellipsoid	DF167	uint25	25	See notes for add a_S
add a_T – Semi-major Axis of Target System Ellipsoid	DF168	uint24	24	See notes for add a_S
add b_T – Semi-minor Axis of Target System Ellipsoid	DF169	uint25	25	See notes for add a_S
Horizontal Helmert/Molodenski Quality Indicator	DF214	uint3	3	
Vertical Helmert/Molodenski Quality Indicator	DF215	uint3	3	
TOTAL			***412 + 8*N + 8*M***	

Table 3.5-25: Contents of the Molodenski-Badekas Transformation Message Type 1022

DATA FIELD	DF NO.	DATA TYPE	NO. OF BITS	NOTES
Message Number	DF002	uint12	12	
Source-Name Counter	DF143	uint5	5	
Source-Name	DF144	char8(N)	8*N	
Target-Name Counter	DF145	uint5	5	
Target-Name	DF146	char8(M)	8*M	
System Identification Number	DF147	uint8	8	
Utilized Transformation Message Indicator	DF148	bit(10)	10	
Plate Number	DF149	uint5	5	
Computation Indicator	DF150	uint4	4	
Height Indicator	DF151	uint2	2	
Φ_V - Latitude of Origin, Area of Validity	DF152	int19	19	See Figure 3.5-3
Λ_V - Longitude of Origin, Area of Validity	DF153	int20	20	See Figure 3.5-3
$\Delta\varphi_V$ – N/S Extension, Area of Validity	DF154	uint14	14	See Figure 3.5-3
$\Delta\lambda_V$ – E/W Extension, Area of Validity	DF155	uint14	14	See Figure 3.5-3
dX – Translation in X-direction	DF156	int23	23	See Equations 3.5-1, 3.5-6, 3.5-9 & 3.5-15
dY – Translation in Y-direction	DF157	int23	23	See notes for dX
dZ – Translation in Z-direction	DF158	int23	23	See notes for dX
R_1 – Rotation Around the X-axis	DF159	int32	32	See Section 3.5.10.3.1, para. 3 and Section 3.5.10.3.4, para. 2, and equations 3.5-2, 3.5-3, 3.5-4, 3.5-7, 3.5-15, 3.5-16, 3.5-17, & 3.5-18

DATA FIELD	DF NO.	DATA TYPE	NO. OF BITS	NOTES
R_2 – Rotation Around the Y-axis	DF160	int32	32	See notes for R_1
R_3 – Rotation Around the Z-axis	DF161	int32	32	See notes for R_1
dS – Scale Correction	DF162	int25	25	See equations 3.5-5, 3.5-8 & 3.5-19
X_P – X Coordinate for M-B Rotation Point	DF163	int35	35	See equation 3.5-15
Y_P – Y Coordinate for M-B Rotation Point	DF164	int35	35	See notes for X_P
Z_P – Z Coordinate for M-B Rotation Point	DF165	int35	35	See notes for X_P
add a_S – Semi-major Axis of Source System Ellipsoid	DF166	uint24	24	See Section 3.5.10.2 and final two para's in Section 3.5.10.3.3, and equations 3.5-11 through 3.5-14.
add b_S – Semi-minor Axis of Source System Ellipsoid	DF167	uint25	25	See notes for add a_S
add a_T – Semi-major Axis of Target System Ellipsoid	DF168	uint24	24	See notes for add a_S
add b_T – Semi-minor Axis of Target System Ellipsoid	DF169	uint25	25	See notes for add a_S
Horizontal Helmert/Molodenski Quality Indicator	DF214	uint3	3	
Vertical Helmert/Molodenski Quality Indicator	DF215	uint3	3	
TOTAL			***517 + 8*N + 8*M***	

Table 3.5-26. Contents of the Residual Message, Ellipsoidal Grid Representation, Message Type 1023

DATA FIELD	DF NO.	DATA TYPE	NO. OF BITS	NOTES
Message Number	DF002	uint12	12	
System Identification Number	DF147	uint8	8	
Horizontal Shift Indicator	DF190	bit(1)	1	
Vertical Shift Indicator	DF191	bit(1)	1	
φ_0 – Latitude of Origin of Grids	DF192	int21	21	See Figure 3.5-4
λ_0 – Longitude of Origin of Grids	DF193	int22	22	See Figure 3.5-4
$\Delta\varphi$ – N/S Grid Area Extension	DF194	uint12	12	See Figure 3.5-4
$\Delta\lambda$ – E/W Grid Area Extension	DF195	uint12	12	See Figure 3.5-4
Mean $\Delta\varphi$ – Mean Latitude Offset	DF196	int8	8	
Mean $\Delta\lambda$ – Mean Longitude Offset	DF197	int8	8	
Mean ΔH – Mean Height Offset	DF198	int15	15	
Three shifts for 16 grid points (i=1,16)			**16*(9+9+9)**	
$\delta\varphi_i$ – Latitude Residual	DF199	int9		See Figure 3.5-4
$\delta\lambda_i$ – Longitude Residual	DF200	int9		See Figure 3.5-4
δh_i – Height Residual	DF201	int9		See Figure 3.5-4
Horizontal Interpolation Method Indicator	DF212	uint2	2	See Figures 3.5-5 through 3.5-7
Vertical Interpolation Method Indicator	DF213	uint2	2	See Figures 3.5-5 through 3.5-7
Horizontal Grid Quality Indicator	DF216	uint3	3	
Vertical Grid Quality Indicator	DF217	uint3	3	
Modified Julian Day (MJD) Number	DF051	uint16	16	
TOTAL			***578***	

Table 3.5-27. Contents of the Residual Message, Plane Grid Representation, Message Type 1024

DATA FIELD	DF NO.	DATA TYPE	NO. OF BITS	NOTES
Message Number	DF002	uint12	12	
System Identification Number	DF147	uint8	8	
Horizontal Shift Indicator	DF190	bit(1)	1	
Vertical Shift Indicator	DF191	bit(1)	1	
N_0 – Northing of Origin	DF202	int25	25	See Figure 3.5-4
E_0 – Easting of Origin	DF203	uint26	26	See Figure 3.5-4
ΔN – N/S Grid Area Extension	DF204	uint12	12	See Figure 3.5-4
ΔE – E/W Grid Area Extension	DF205	uint12	12	See Figure 3.5-4
Mean ΔN – Mean Local Northing Offset	DF206	int10	10	
Mean ΔE – Mean Local Easting Offset	DF207	int10	10	
Mean Δh – Mean Local Height Offset	DF208	int15	15	
Three shifts for 16 grid points (i=1,16)			**16*(9+9+9)**	
δN_i – Residual in Local Northing	DF209	int9		See Figure 3.5-4
δE_i – Residual in Local Easting	DF210	int9		See Figure 3.5-4
δh_i – Residual in Local Height	DF211	int9		See Figure 3.5-4
Horizontal Interpolation Method Indicator	DF212	uint2	2	See Figures 3.5-5 through 3.5-7
Vertical Interpolation Method Indicator	DF213	uint2	2	See Figures 3.5-5 through 3.5-7
Horizontal Grid Quality Indicator	DF216	uint3	3	
Vertical Grid Quality Indicator	DF217	uint3	3	
Modified Julian Day (MJD) Number	DF051	uint16	16	
TOTAL			***590***	

Table 3.5-28: Contents of the Projection Message Type 1025 (Projection Types except LCC2SP, OM)

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS	NOTES
Message Number	DF002	uint12	12	
System Identification Number	DF147	uint8	8	
Projection Type	DF170	uint6	6	
LaNO – Latitude of Natural Origin	DF171	int34	34	See EPSG dataset coordinate operation
LoNO – Longitude of Natural Origin	DF172	int35	35	See EPSG dataset coordinate operation
add SNO – Scale Factor at Natural Origin	DF173	uint30	30	See EPSG dataset coordinate operation Ignore if projection = CS
FE – False Easting	DF174	uint36	36	See EPSG dataset coordinate operation
FN – False Northing	DF175	int35	35	See EPSG dataset coordinate operation
TOTAL			***196***	

Table 3.5-29. Contents of the Projection Message 1026 (Projection Type LCC2SP - Lambert Conic Conformal (2 SP))

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS	NOTES
Message Number	DF002	uint12	12	
System Identification Number	DF147	uint8	8	
Projection Type	DF170	uint6	6	
LaFO – Latitude of False Origin	DF176	int34	34	See EPSG dataset coordinate operation
LoFO – Longitude of False Origin	DF177	int35	35	See EPSG dataset coordinate operation
LaSP1 – Latitude of Standard Parallel No. 1	DF178	int34	34	See EPSG dataset coordinate operation
LaSP2 – Latitude of Standard Parallel No. 2	DF179	int34	34	See EPSG dataset coordinate operation
EFO – Easting of False Origin	DF180	uint36	36	See EPSG dataset coordinate operation
NFO – Northing of False Origin	DF181	int35	35	See EPSG dataset coordinate operation
TOTAL			***234***	

Table 3.5-30. Contents of the Projection Message 1027 (Projection Type OM - Oblique Mercator)

DATA FIELD	DF NUMBER	DATA TYPE	NO. OF BITS	NOTES
Message Number	DF002	uint12	12	
System Identification Number	DF147	uint8	8	
Projection Type	DF170	uint6	6	
Rectification Flag	DF182	bit(1)	1	
LaPC – Latitude of Projection Center	DF183	int34	34	See EPSG dataset coordinate operation
LoPC – Longitude of Projection Center	DF184	int35	35	See EPSG dataset coordinate operation
AzIL – Azimuth of Initial Line	DF185	uint35	35	See EPSG dataset coordinate operation
Diff ARSG – Difference, Angle from Rectified to Skew Grid	DF186	int26	26	See EPSG dataset coordinate operation
Add SIL – Scale factor on Initial Line	DF187	uint30	30	See EPSG dataset coordinate operation
EPC – Easting at Projection Center	DF188	uint36	36	See EPSG dataset coordinate operation
NPC – Northing at Projection Center	DF189	int35	35	See EPSG dataset coordinate operation
TOTAL			***258***	