GEOSA
الهيئة العامة للمساحة والمعلومات الجيومكانية
General Authority for Survey and Geospatial Information

Saudi Arabia National Spatial Reference System Implementation Guidelines

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About the document This document provides practical guidance for the implementation of *Saudi Arabia National Spatial Reference System* (*SANSRS*) components in the everyday activities of users of geospatial and positional data. The user profile of *SANSRS* is very diverse. The users are coming from a variety of sectors including government, academia and science, industry and the public with different application and accuracy requirements. The document will help the users to understand how to integrate the *SANSRS* into their daily operations of surveying and mapping, and to migrate the existing data from old reference frames to the new ones in the *SANSRS*. Appropriate ways and tools for doing that are described. Furthermore, this document may refer the *SANSRS* user to another specific technical manual or guide developed by *GEOSA* for some implementation, and to utilization guidance satisfying specific requirements. The document has four chapters. The first chapter briefly describes the *SANSRS* and its components, areas of it use and explains the necessity of its implementation. The second chapter provides the guidelines for *SANRSR* implementation into the new geospatial activities of the users. The third chapter includes the description of the transformation of already existing geospatial data to *SANSRS* while the fourth Chapter describes SANSRS communication and support.		
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List of Abbreviations

AAA	Ain Al (el) Abd geodetic datum (also called NGN), KSA
ARAMCO	The Saudi Arabian Oil Company, KSA
ASCII	American Standard Code for Information Interchange format
Bernese	Bernese GNSS Software - a scientific, high-precision, multi-GNSS data processing software developed at the Astronomical Institute of the University of Bern Astronomical Institute of the University of Bern (AIUB)
CORS	GNSS Continuously Operating Reference Station
CRS	Coordinate Reference Systems
DGNSS	Differential GNSS
EPSG	European Petroleum Survey Group
FTP	File Transfer Protocol
GASGI	General Authority for Survey and Geospatial Information, KSA (name between Sept, 2020 to Feb, 2023)
GEOSA	General Authority for Survey and Geospatial Information, KSA (former GASGI)
GDMS	General Directorate of Military Survey, KSA
GIS	Geographical Information System
GNSS	Global Navigation Satellite System
GOCE	Gravity field and steady-state Ocean Circulation Explorer satellite
GRAVSOFT	Geoid determination software
GRF	Geodetic Reference Frame
GRS	Geodetic Reference System
GRS 80	The Geodetic Reference System 1980 is a geodetic reference system consisting of a global reference ellipsoid and a gravity field model.
IERS	The International Earth Rotation Service
IGN	Institut Géographique National, Paris, France
ITRF	International Terrestrial Reference Frame
ITRF2014	The latest ITRF
ITRF94	ITRF 1994
ITRS	International Terrestrial Reference System
JED69	Jedda 1969 Vertical Datum
KSA	The Kingdom of Saudi Arabia
KSA-CORS	The National CORS network managed by GEOSA, Riyadh, KSA
KSA-GEOID21	KSA-GEOID 2021: the latest realisation of the KSA National Geoid
KSA-GRF17	KSA GRF 2017: the latest realisation of KSA National GRF
KSA-VRF14	KSA VRF 2014: the latest realisation of KSA National VRF
LMSL	Local Mean Sea Level
LIDAR	Light Detection and Ranging
MOMRA	Ministry of Municipal and Rural Affairs, KSA
NGN	National Geodetic Network
NRTK	Network Real Time Kinematic observation technique
NVN	National Vertical Network
RF	Reference Frame
RINEX	The Receiver Independent Exchange Format
RTCM	The Radio Technical Commission for Maritime Services data standard
RTK	Real Time Kinematic observation technique
SANSRS	Saudi Arabia National Spatial Reference System
SVD78	SVD-1978*:* Saudi ARAMCO Vertical Datum 78
TG	Tide Gauge
TT	Transformation Tool
VRF	Vertical Reference Frame
VRS	Vertical Reference System
WGS 84	World Geodetic System 1984- Earth-centered, Earth-fixed terrestrial reference system and geodetic datum

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1. What is SANSRS

In this paragraph, the SANSRS definition, importance, areas of use, the use policy and maintenance are described.

1.1. SANSRS definition

The *Saudi Arabia National Spatial Reference System (SANSRS)* is a consistent reference system that defines *Cartesian* coordinates, longitude, latitude, height, scale, gravity and orientation throughout the territory of the *Kingdom of Saudi Arabia*.

SANSRS allows users to precisely determine and express locations in the *Kingdom of Saudi Arabia*, as well as to quantify changes of the *Earth's surface* and its gravity field in space and time.

The *SANSRS* consists of the following geodetic components (*Figure 1.1*):

- ***National Geodetic Reference Frame (National GRF)*, known as *KSA-GRF17*** is the latest realization of the *National Geodetic Reference System (National GRS)* developed in 2019. The *KSA-GRF17* is based on the *International Terrestrial Reference Frame 2014* (*ITRF2014*) reference frame, and the epoch of *2017.0* is the epoch when both reference frames coincide. At that epoch, the coordinates are the same in both reference frames, but they diverge with respect to each other at any epoch different from *2017.0* due to the *Arabian* plate rotation. The station position variation with time is expected to be at the level of, or less than *1mm/year* in KSA-GRF17, and at the level *5 cm/year* in ITRF2014.
- ***National Vertical Reference Frame (National VRF)*, known as *KSA-VRF14*** is the latest realization of the *National Vertical Reference System (National VRS)*. The height system that is used in the *KSA-VRF14* is the *Helmert-Orthometric Above Mean Sea Level* at the *JEDDAH Tide Gauge (TG)*. The *KSA-VRF14* has been established on the base of in situ observations from *TG's*, terrestrial national gravity and leveling networks (covering most parts of the *Kingdom*), satellite altimetry and *Gravity field and steady-state Ocean Circulation Explorer* (*GOCE)* satellite data.
- **National Geoid Model (KSA-GEOID21)** is a hybrid geoid model for the Kingdom of Saudi Arabia determined by using land & ship-borne pointwise data together with GEOSA GPS levelling data, airborne gravity and grid data together with satellite data (altimetric & gravity satellite missions data). The KSA-GEOID21 is a major component of KSA-VRF, which allows to compute orthometric heights for the points over KSA different from KSA-NVN benchmarks.

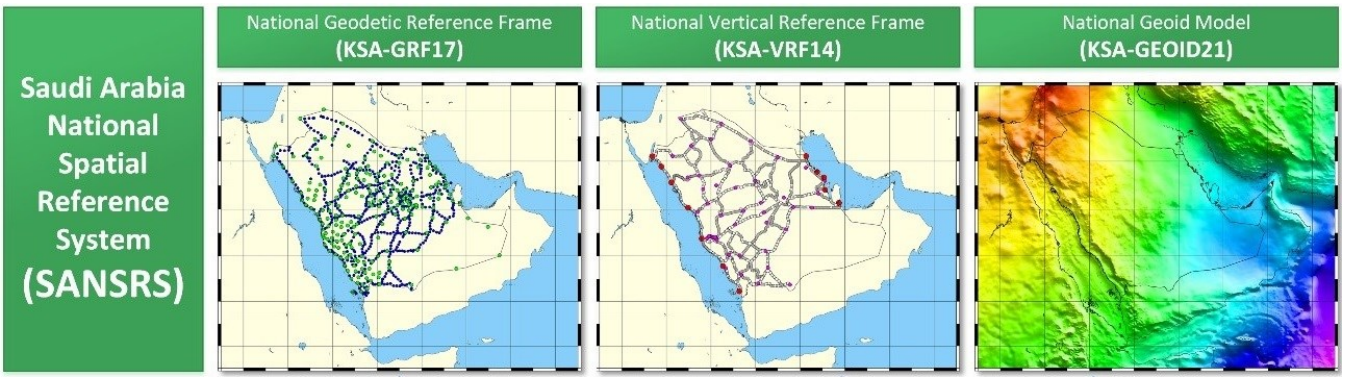


Figure 1.1: SANSRS Components

The *SANSRS* components are described in details in the *Technical Summary for Saudi Arabia National Spatial Reference System (SANSRS)* document.

1.2. Why SANSRS

In the past, different governmental agencies had established their own spatial references to achieve their activities resulting in duplications of references which resulted in spatial activities and maps from different agencies not edge matching properly. *SANSRS* as a single unified framework will ensure the delivery of a seamless *National Spatial Reference System* and will satisfy the requirements of all geospatial and positioning users (surveyors, map makers, *GIS* , etc.) in the *Kingdom*.

The reasons for the necessity of *SANSRS* implementation are as follows:

- **Accuracy:** SANSRS has been developed with the use of state of scientific art methods and technologies what ensured high accuracy of its components.
- **Homogeneity:** SANSRS is homogeneous all over Kingdom and provides uniform accuracy to geospatial and positional users.
- **Consistency:** SANSRS is aligned with a global reference frames as well as with older reference frames of the Kingdom.
- **Access:** SANSRS provides easy access to its components through the *GNSS Continuously Operating Reference Station (CORS)* real-time network *KSA-CORS* and on-line transformation tools.

The *SANSRS* is designed to meet national economic, social and environmental needs and has to be used in all applications & services for positioning in horizontal and vertical directions. In addition, all existing geospatial products & services will be referenced to it.

Implementation of *SANSRS* will ensure all users have confidence in the products and services and their activities are in line with *Vision 2030 Program* requirements. This move will make public spending more efficient by using resources more effectively and by limiting their wastage.

1.3. Areas of SANSRS use

As the *SANSRS* is the national spatial reference for *Saudi Arabia*, it was computed with intention its components have to satisfy the needs of all geospatial information and positioning sectors and users in *KSA*.

The *SANSRS* is expected to be used by a wide range of users according to the following classification.

Governmental organizations

Governmental organization in *KSA* will be a main user of *SANSRS* in its projects and activities, and *SANSRS* will ensure the integrity of all surveying and geospatial data and products between all organizations in the *Kingdom*, costs and time saving, and provision of high accuracy end product.

Educational and scientific organizations

Universities, institutes, and organizations who are conducting scientific research and educational activities in the field of geodesy, surveying and geospatial information.

Private sector

Private sector will be an active user of *SANSRS*, as *SANSRS* is KSA spatial reference system to be used in all surveying and geospatial activities and projects.

Individuals

All individuals in *KSA* will be able to use *SANSRS* in their activities, projects, works and studies.

SANSRS is designed to be used in the position-related activities such as:

- Geodesy and surveying
- Mapping
- Aerial photography and photogrammetry
- Light Detection and Ranging (LIDAR)
- Land management and cadastre
- Constructions
- GIS Hydrography
- Management of national resources
- Navigation
- Machine guidance for precise farming, construction and unmanned vehicles navigation.

1.4. The SANSRS – maintenance and policy of use

Council of Minster's decision No.90 dated (5/2/1442 H) mandates the *General Authority for Survey and Geospatial Information (GEOSA, former GASGI)* to adopt, implement and utilize the *SANSRS* in its activity, and to promote the *SANSRS* use and manage its implementation in the *KSA*.

The *SANSRS* has to become the foundation for all national geospatial products and is to be used for mapping and charting in a wide range of scientific and engineering applications. All surveys in the *Kingdom* are mandated to be linked to the *SANSRS*.

To achieve its mandate as a regulatory organization for the surveying and geospatial information sector in KSA, GEOSA will provide

- Development and maintenance of SANSRS components
- geodetic infrastructure coordinates in *KSA-GRF17*, *KSA-VRF14 and KSA-GEOID21*
- transformation parameters and tools to move the data between legacy references and the adopted reference
- Easy access to the *SANSRS* through *KSA-CORS network* data, *Global Navigation Satellite System (GNSS)* data static-file download for post processing, and on-line user post processing services.
- Recommendations and advices on the use and implementation of *SANSRS*.

2. SANSRS Implementation in New Geospatial Data

2.1. KSA-GRF17 implementation

KSA-GRF17 is used as an official geodetic spatial reference frame for geometric positioning (geodetic latitude, geodetic longitude, ellipsoid height or/and geocentric *Cartesian 3D* coordinates) in the *Kingdom*.

Several methods shall be used to deliver *KSA-GRF17* to users for new activities. The delivery of the frame means, that different types of *GNSS* data and products will be delivered to enable the users to access the *KSA-GRF17*. The next sub-sections describe these different data and products.

2.1.1. GNSS Raw Observation Files

The *KSA-CORS* network will provide users with *GNSS* data in several formats as required. The *Receiver Independent Exchange Format (RINEX)* formats versions are *2.10*, *2.11*, *3.02* and *3.03*. Other formats include *Trimble raw* data formats such as *T02*, *T01*, *DAT* and *TGD* binary formats. These data can be used for phase differential baseline post-processing by computing with *GNSS raw* data from the user's rover receiver to compute *3D* baseline (*ΔX, ΔY, ΔZ*). The precise coordinates for each *CORS* are available in the downloadable *raw* data file.

2.1.2. KSA-CORS Real-Time Services

The National *KSA-CORS* network is operated by the *GEOSA*. The network consists currently of over *200* active *CORSs* installed according to the international standards. The *KSA-CORS* network provides to users the accurate and reliable *3D* coordinates in the *KSA-GRF17* RF.

Currently, the *KSA-CORS* Network provides three *Real-Time Kinematic* services:

- *Network Real Time Kinematic* (*NRTK*) Service.
- *Differential GNSS* (*DGNSS*) Positioning Service.
- *Single Station RTK*.

The agencies that have already established their *CORS* network and using it in their activities and projects are mandated to use *KSA-GRF17* as a reference frame. Precise coordinates for their *CORS* should be computed by using KSA-CORS network. Furthermore, that agency can submit *GNSS* data of *not less than 2 weeks* long observation period to *GEOSA* for coordinate computation.

2.1.3. Virtual RINEX Files

A *RINEX* file is called *Virtual*, when *raw* data have not been really measured by a receiver but have been computed from a real-time network model. The *Virtual GNSS* files are generated by interpolation of observations made by surrounding *CORSs*. *GNSS* signals could be are generated for any points within *KSA-CORS* real-time network coverage. Therefore, it is possible to simulate a *CORS* right on your working location as long as you are within the network coverage.

2.1.4. Using the KSA-CORS Network Web Viewer

The *KSA-CORS* web sensor map (*Figure 2.1*) or viewer is the certified source for acquiring coordinate values for *SANSRS* active monuments throughout the *Kingdom*. The sensor map can be found on the *GEOSA* website. This service enables users to view *SANSRS* coordinate values, ellipsoidal heights, health status pertaining to each specific *CORS*, and *CORS* pictures.

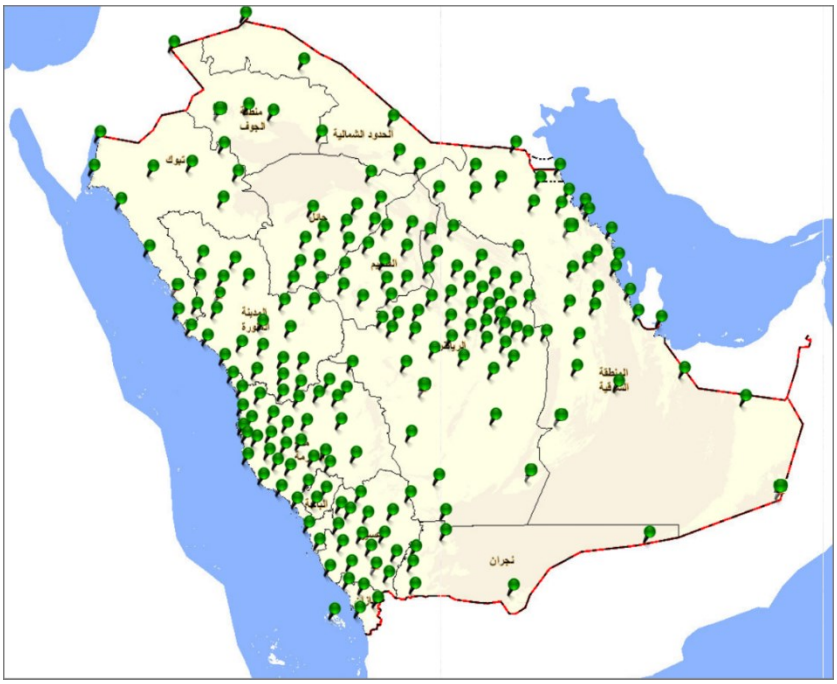


Figure 2.1: KSA-CORS Web Sensor Map

KSA-CORS user registration shall be made using the following procedure:

1. Go to KSACORS website **https://ksacors.geosa.gov.sa/**
2. Select "Register" from the Left hand menu.
3. Download "registration form" from the website.
4. Fill, sign and scan it then send it to **info@geosa.gov.sa**
5. KSACORS team will send you back your username and password
   - You can change your password later when you log in.

For more details/manual regarding downloading of raw *GNSS* data from *KSA-CORS* network, please visit **https://ksacors.geosa.gov.sa/** website.

After registration, a user shall be provided with Login *Username*, *Password and RTK services connection information*, which can be used for accessing the *KSA-CORS* products/services on website or the *KSA-CORS* real-time services using *GNSS* equipment.

Regarding connection to KSA-CORS RTK services, GEOSA recommends the users to contact their receiver's local distributor in Saudi Arabia for receiver configuration support.

2.2. KSA-VRF14 implementation

To implement the *KSA-VRF14* in new activities, orthometric heights from *National Vertical Network (NVN)* should be used as a reference.

NVN includes a set of benchmarks located all around the *Kingdom and its orthometric heights are defined in KSA-VRF14.* To get data from NVN, use the following procedure:

1. Go to National Vertical Network (NVN) web page.
2. Download National Vertical Network (NVN) map in KMZ format.
3. Select required benchmarks.
4. Request the data you need by using the email address: info@geosa.gov.sa using the information described above.

2.3. KSA-GEOID21 implementation

To help the users in calculating Geoid heights in KSA-GEOID21, the *GEOSA* has developed the *Online KSA-GEOID Height Calculator*, which is available under the following link: *https://gds.geoportal.sa/geoidcalculator*.

The ***Calculator*** can be used in both ***Single point*** (one point) and ***MultiPoint*** (when multiple points coordinates are saved in the text file) modes. In the "*Single point*" mode, the user will need to provide the latitude and longitude of the point as input values. In the "*Multipoint*" mode a user will need to store all his input data (*Longitude and Latitude*) in the *ASCII* file and upload this file to the server. The software will generate the result *ASCII* file which will contain both the input data and the output geoid height.

The points' position (*Latitude and Longitude*) in both ***Single point*** and ***Multipoint*** modes should be defined in KSA-GRF17

For more details, please follow the link *https://gds.geoportal.sa/*.

3. Transformation of Existing Geospatial Data to SANSRS

Different organizations in the *KSA* used various reference frames to measure and represent their surveying, maps, and geospatial data. After introduction of the unified *SANSRS*, the stakeholders have to migrate their existing data into it in order to be able to use them in the future.

There are two types of geospatial data – the geodetic points used in geodesy, and *GIS* (Vector & Raster) data.

The following sub-sections describe the common ways of the data transformation, which can be used in the *SANSRS* implementation.

3.1. Points Transformation

3.1.1. Coordinate transformation to KSA-GRF17

In the coordinate transformation, we consider point data only and *3D* & *2D* (horizontal) transformations of *Geodetic Reference Frames*.

3.1.1.1. Theoretical background

Next, two formulas will be presented for two cases of *3D* transformation – with 15 and 7 Helmert parameters.

3.1.1.1.1. Transformation between RFs with epoch consideration. ITRF2014 to KSA-GRF17 transformation

Transformations between different realizations of the *International Terrestrial Reference System (ITRS)* at different epochs (by using 15 parameters) are out of the scope of this document except of the transformation between *KSA-GRF17* (epoch *2017.0*) and *ITRF2014* (epoch *2010.0*). The reader may refer to the official *International Terrestrial Reference Frame (ITRF)* website that contains all relevant formulas and parameters (*http://itrf.ensg.ign.fr/*).

Following the *KSA-GRF17* definition, the general transformation formula linking *KSA-GRF17* to *ITRF2014*, for both station positions and velocities, is given by the following two equations (11 Helmert parameters values are equal to zero, therefore, only 3 rotation rate parameters and the 15th parameter – epoch t, are left of 15 parameters):

For station positions at any epoch t:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{KSA-GRF17}(t) = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{ITRF2014}(t) + \begin{pmatrix} 0 & -\dot{R}_z & \dot{R}_y \\ \dot{R}_z & 0 & -\dot{R}_x \\ -\dot{R}_y & \dot{R}_x & 0 \end{pmatrix} \times \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{ITRF2014}(t).(t - 2017.0) \quad (3.1)$$

and for station velocities:

$$\begin{pmatrix}\dot{X}\\ \dot{Y}\\ \dot{Z}\end{pmatrix}_{KSA-GRF17} = \begin{pmatrix}\dot{X}\\ \dot{Y}\\ \dot{Z}\end{pmatrix}_{ITRF2014} + \begin{pmatrix}0 & -\dot{R}_z & \dot{R}_y\\ \dot{R}_z & 0 & -\dot{R}_x\\ -\dot{R}_y & \dot{R}_x & 0\end{pmatrix} \times \begin{pmatrix}X\\ Y\\ Z\end{pmatrix}_{ITRF2014} \quad (3.2)$$

where three rotation rate parameters $\dot{R}_x, \dot{R}_y, \dot{R}_z$ equal to three opposite signed components of the *Arabian Plate* rotation pole vector (or angular velocity) estimated for *KSA-GRF17*. This way, the station motion due to *Arabian Plate* rotation is removed from coordinates in *ITRF2014*.

The transformation parameters from *ITRF2014* to *KSA-GRF* at epoch *2017.0* are listed in the *Table 3.1* below.

Table 3.1: Transformation parameters from ITRF2014 to KSA-GRF at the epoch 2017.0

Parameters	T_x [m]	T_y [m]	T_z [m]	s [mm/km]	R_x [mas]	R_y [mas]	R_z [mas]
Parameter values	0	0	0	0	0	0	0
Parameter rate (per year) values	0	0	0	0	-1.199	0.107	-1.468

Coordinates of stations in *ITRF2014* reference frame (*ITRF2014@2010.0*) are transformed into *KSA-GRF17* coordinates as follows :

- rotations must be converted from *milliarcseconds* of *degrees* to *radians*:
  R_x, R_y, R_z to be multiplied by π and divided by (*180*3600*1000*);
- rotation rates must be converted from *milliarcseconds* of *degrees*/*year* to *radians*/*year*:
  rates of R_x, R_y, R_z to be multiplied by π and divided by (*180*3600*1000*);
- converted values of rotation parameters are used then in the similarity transformation formula to compute station coordinates (equation 3.1) and velocities (equation *3.2*).

The epoch *2010.0* of station coordinates in *ITRF2014* is denoted by t and has to be expressed in the [*years*].

3.1.1.1.2. Transformation between RFs without epoch consideration

Usually, the transformation parameters can be *Helmert's* set of seven parameters (3 translations, 3 rotations, 1 scale factor). Sometimes, a single set of parameters is not enough to describe accurately enough the distortions between geodetic reference frames: in that case, a grid of parameters (3 translations at each grid node) can be calculated.

The parameters are used in the so-called simplified *7-parameter Helmert* transformation formula, also known as the "*Bursa-Wolf*" formula. It applies only for very small rotation angles (a few arc seconds at most), and describes the shift, the orientation and scale differences between two geodetic reference frames.

Special care must be taken when it comes to the signs of the rotations. *GEOSA* uses the *International Earth Rotation Service (IERS)* convention for the signs of rotation, but the user must be warned that most *GIS* software or *GNSS* receivers use another convention, where the signs of the rotations are reversed.

The *IERS* convention consists in rotating the target geodetic frame axes to bring them parallel to the source geodetic frame axes. In other words, the position vector is rotated in the fixed coordinate frame.

Let's write the position vector (*meters*) in the source geodetic reference frame as $\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$,

the position vector (*meters*) in the target reference frame as $\begin{pmatrix} X_1 \\ Y_1 \\ Z_1 \end{pmatrix}$,

the translation vector (*meters*) as $\begin{pmatrix} T_x \\ T_y \\ T_z \end{pmatrix}$,

the rotation matrix (angles must be provided in *radians*) as $\begin{pmatrix} 0 & -R_z & R_y \\ R_z & 0 & -R_x \\ -R_y & R_x & 0 \end{pmatrix} = R$

and the scale factor (*unitless*[1]) as *s.*

Then we must use the following formulas (similarity transformation formula) to calculate the position vector in the target reference frame:

$$\begin{cases} X_1 = X + T_x + s * X - R_z * Y + R_y * Z \\ Y_1 = Y + T_y + R_z * X + s * Y - R_x * Z \\ Z_1 = Z + T_z - R_y * X + R_x * Y + s * Z \end{cases} \quad (3.3)$$

In matrix mode:

$$\begin{pmatrix} X_1 \\ Y_1 \\ Z_1 \end{pmatrix} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} + \begin{pmatrix} T_x \\ T_y \\ T_z \end{pmatrix} + \begin{pmatrix} s & -R_z & R_y \\ R_Z & s & -R_x \\ -R_y & R_x & s \end{pmatrix} \times \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \quad (3.4)$$

In the *European Petroleum Survey Group* (*EPSG*) *Geodetic Parameter Dataset version 9.4.2*, the corresponding operation method is called the "Position Vector Method" (*EPSG* code *1033*).

3.1.1.2. Description of available geodetic reference frames in KSA

The *KSA* geodetic organizations have been referencing their data in their own reference frames for long years. Two main types of geodetic frames were used before the creation of the *KSA-GRF*.

Before the use of *GPS* technique, the geodetic frames were based on the observation in the *National Geodetic Network* (*NGN*) established in the 1960's, and the resulting frame was called *Ain Al (el) Abd* geodetic datum (*AAA*). Its Reference ellipsoid is *Hayford 1909* (*International 1924*).

With the use of *GPS* and other spatial techniques, and the introduction of the *International Terrestrial Reference System* (*ITRS*), the geodetic frames are national realizations of *ITRS* via global realizations called *International Terrestrial Reference Frames* (*ITRF*) with added the last year of used data ITRFyyyy and fixed at a conventional epoch, calling them ITRFyyyy@epoch. National realizations are biased

[1] If the scale factor is given in parts per million, it must be multiplied by 10^{-6}

relative to ITRFyyyy@epoch so one has to calculate transformations that are slightly (but assumed to be of significant value) different from the official transformations between global realizations of *ITRS*.
The geodetic reference frames, which were used in *KSA* (created by *General Directorate of Military Survey (GDMS)*, The *Ministry of Municipal and Rural Affairs (MOMRA), The Saudi Arabian Oil Company* (*ARAMCO; formerly known as Arabian-American Oil Company*) are listed in the *Table 3.2*.

Table 3.2: Overview of Geodetic Reference Frames

Organization	Reference frame	Ellipsoid	Realization of ITRS (if applicable)
GDMS	ITRF2000@2003.1998	GRS 80	ITRF2000 epoch 2003.1998
MOMRA	MTRF-2000	GRS 80	ITRF2000 epoch 2004.0
Saudi ARAMCO	WGS 84	WGS 84	ITRF94 epoch 1998.0
Saudi ARAMCO	Ain Al Abd 1970	Hayford 1909 (International 1924)	N/A

The *Table 3.3* presents coordinate differences because of translations, rotations and scaling of the listed *KSA RFs* relative to *KSA-GRF17*. The values are substantial not only for geodetic and *GIS* applications, but even for navigation applications.

Table 3.3: A*verage shifts between KSA-GRF17 & other RFs*

Reference System	**Approximate Horizontal shift** [m]
GDMS	0.60
MTRF-2000	0.60
ARAMCO-WGS84	0.80
ARAMCO Ain Al Abd	93

3.1.1.3. Helmert 7-parameter transformation to KSA-GRF17

Helmert transformation parameters have been computed based on the set of common points in *KSA-GRF17* and other *RFs* (except *Ain Al Abd*).

The *Table 3.4* lists computed *Helmert* transformation parameters to transform coordinates from historical *KSA* reference frames to *KSA-GRF17*.

Table 3.4: Helmert transformation parameters

Parameter	GDMS	MTRF-2000	ARAMCO WGS84	ARAMCO Ain Al Abd (with grid)
T_x [m]	-0.0459	0.0469	-0.3192	13.8714
T_y [m]	0.0600	-0.2827	0.3372	-83.9721
T_z [m]	-0.0256	0.0866	0.3495	101.6740
R_x [“]	0.0182	0.0056	0.0185	-
R_y [“]	-0.0014	-0.0050	0.0069	-
R_z [“]	0.0182	0.0231	0.0121	-
s [mm/km]	0.0017	-0.0081	-0.0306	-

When using the transformation parameters from the *Table 3.4*, the coordinates of station in the source reference frame from the *Table 3.2* are transformed into *KSA-GRF17* coordinates X_1, Y_1, Z_1 as follows :

- rotations must be converted from seconds of degrees to radians:
  Rx, Ry, Rz to be multiplied by π and divided by (*180*3600*);
- the scale factor *s* must be converted into $m*m^{-1}$. For that, *s* has to be multiplied by 10^{-6} ;
- converted values are used then in the similarity transformation formula (equations 3.3, 3.4).

3.1.1.4. Transformation from Saudi ARAMCO's Ain Al Abd to KSA-GRF17

There are no ellipsoidal heights in *Ain Al Abd*, which is a *2D* geodetic reference frame. The resulting transformation parameters are valid only to transform the horizontal components (latitude and longitude).

The set of *Helmert* seven parameters was not enough to provide an accuracy of *a few centimeters* for transformation between *Saudi ARAMCO Ain el Abd* and *KSA-GRF17* reference frames. Therefore, the ***grid of transformation parameters*** *ARAMCO_AAA-KSAGRF* has been calculated, and it has an ordered set of regularly spaced nodes, each node having three values for *Tx*, *Ty* and *Tz* (*Helmert* transformation translations).

Next *Figure 3.1* shows the *Ain Al Abd* to *KSA-GRF17* transformation procedure which uses the *ARAMCO_AAA-KSAGRF* grid (it's available in IGN's *.tac* format, and *GRAVSOFT's* (geoid determination software) *.gri* and *.gra* formats and *NTV2* (datum transformation format) *.gsb* format for use in *GIS* tools) of transformation parameters.

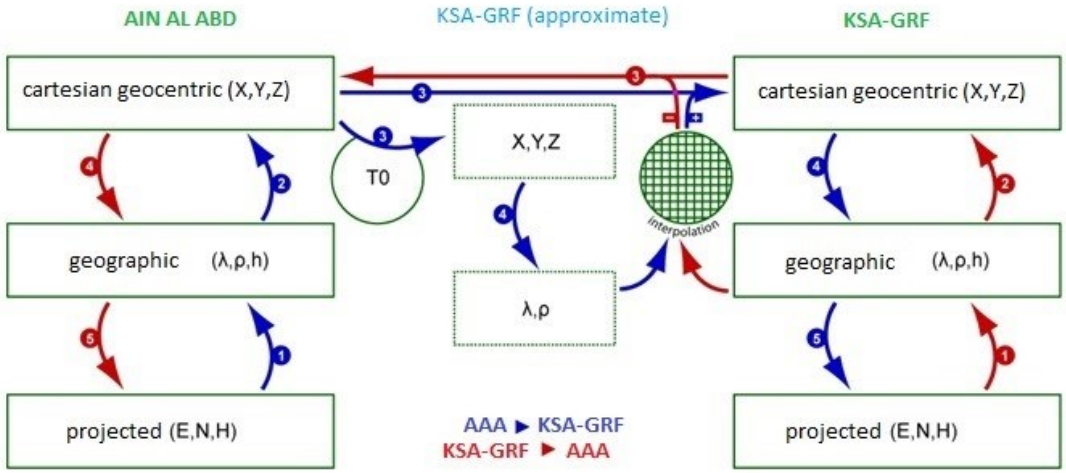


Figure 3.1: Diagram of the transformation procedure using the grid of transformation parameters ARAMCO_AAA-KSAGRF

An initial set of translations is required for the transformation program in order to guarantee a more accurate interpolation in the grid when the source reference frame is Ain Al Abd. The initial translation is represented by T0 in the above diagram. The initial (global) translation parameter values are given in the *Table 3.4*.

The translated *Ain Al Abd* coordinates are used as the first appproach in the iterative procedure of the grid interpolation because the grid nodes are represented by their coordinates in *KSA-GRF17* reference frame.

3.1.1.5. Transformation between WGS84 and KSA-GRF17

The realization of *WGS 84 (G1762,* what corresponds to the introduction of this version on the *GPS Week 1762,* or *13-19 Oct 2013)*, maintained by the *United States National Geospatial-Intelligence Agency (NGA)* is aligned to the *ITRF2008* (epoch *2005*) at the *one centimeter* level (*Department of Defense*. *World Geodetic System 1984. Its Definition and Relationships with Local Geodetic Systems, NGA.STND.0036 1.0.0 WGS84, 2014-07-08, Version 1.0.0, National Geospatial-Intelligence Agency, Arnold, MO, USA*).

The *EPSG* code for coordinate transformation (computed and registered by the *EPSG* itself) from *KSA-GRF17* to *WGS84* can be found in the *Table 3.6*.

3.1.1.6. Workflow of coordinate transformation

Depending on the type of source and target coordinates (*Latitude, Longitude, Ellipsoidal Height* or *X,Y,Z* or projected grid coordinates) the transformation work will be slightly different.

However, the common part of the transformation of different coordinates is that the transformation parameters (*equations 3.3 & 3.4*) have to be applied on geocentric *Cartesian* coordinates (*X, Y, Z*). Due to that, source and target coordinates have to be converted to *Cartesian* coordinates. The most popular case is when a user needs to transform spherical coordinates (*Latitude, Longitude, Ellipsoidal Height*) from one reference frame (source) to another (target). In this case, the transformation procedure is as follows:

- **Step 1.** Convert source coordinates from spherical (*Latitude, Longitude, Ellipsoidal height*) to geocentric (*X, Y, Z*).
- **Step 2.** Transform geocentric coordinates to the target reference frame by using 7 transformation parameters or transformation grid.
- **Step 3.** Convert target coordinates from geocentric to spherical ones.

The *Figure 3.2* illustrates described this workflow.

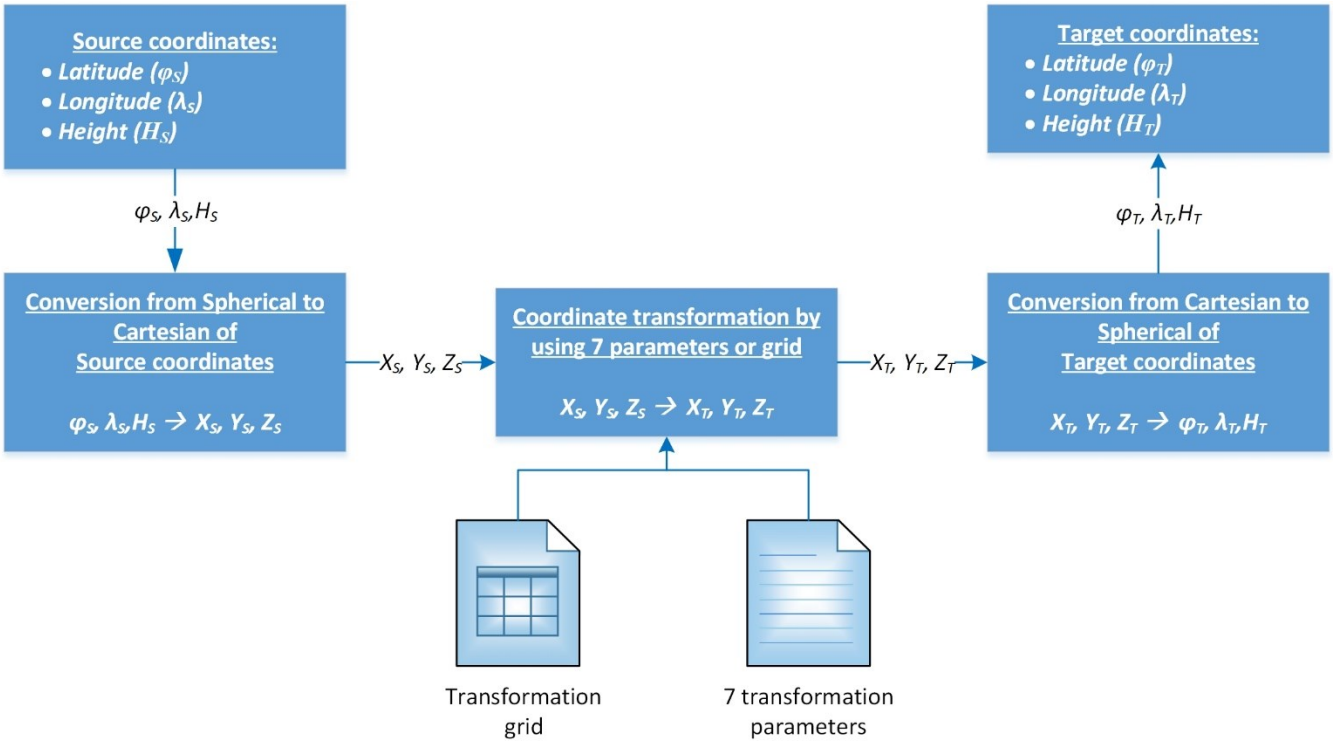


Figure 3.2: Workflow of coordinate transformation

The examples of the same coordinate (values are highlighted) transformation from different source *RFs* to target *KSA-GRF17 RF* are shown in the *Table 3.5* which can be used for checking the correctness of coordinate transformations and conversions.

Table 3.5: Examples of some coordinate transformations to KSA-GRF17 RF

	X [m]	Y [m]	Z [m]	Lon [°]	Lat [°]	Ellipsoidal Height [m]
Source coordinates	4333173.554	3901607.551	2578690.449	42.00000408	24.00000341	999.866
Transformation						
ITRF2014 to KSA-GRF17	4333173.350	3901607.662	2578690.623	42.00000623	24.00000513	999.866
GDMS to KSA-GRF17	4333173.153	3901607.774	2578690.801	42.00000834	24.00000686	999.873
MTRF-2000 to KSA-GRF17	4333173.067	3901607.652	2578690.725	42.00000802	24.00000677	999.709
ARAMCO WGS84 to KSA-GRF17	4333172.961	3901607.791	2578690.924	42.00000973	24.00000836	999.803
ARAMCO Ain Al Abd (ell. Height = 0) to KSA-GRF17	4332697.345	3901068.119	2578417.781	41.99919596	24.00037951	235.921

3.1.1.7. EPSG codes for the GRF datums and transformations

In order to make *SANSRS* available to different geodetic and *GIS* software, the *GEOSA* initiated the procedure of registration of all *SANSRS* components in the *European Petroleum Survey Group* (*EPSG*) registry.

EPSG registry is a global geodetic parameter dataset of definitions of *Coordinate Reference Systems* (*CRS*), transformation parameters and geodetic datums (*http://www.EPSG.org/*). Every *CRS* in the *EPSG* registry is presented by the relevant information describing this *CRS* and by unique code to identify the *CRS*.

The list of *SANSRS GRF* component elements registered by GEOSA (except transformation *9383*) in the *EPSG* database are given in the *Table 3.6*.

Table 3.6: SANSRS GRF component registered in the EPSG database

NAME	CODE	TYPE	Remarks
Kingdom of Saudi Arabia Geodetic Reference Frame 2017	1268	GeodeticDatum	Saudia Arabia – onshore and offshore
KSA-GRF17	9331	GeodeticCRS (geocentric)	
KSA-GRF17	9332	GeodeticCRS (geographic 3D)	
KSA-GRF17	9333	GeodeticCRS (geographic 2D)	
KSA-GRF17 / UTM zone 36N	9356	ProjectedCRS	
KSA-GRF17 / UTM zone 37N	9357	ProjectedCRS	
KSA-GRF17 / UTM zone 38N	9358	ProjectedCRS	
KSA-GRF17 / UTM zone 39N	9359	ProjectedCRS	
KSA-GRF17 / UTM zone 40N	9360	ProjectedCRS	
Ain el Abd to *KSA-GRF17* (1)	9362	CoordinateTransformation	Initial 3-parameters transformation
Ain el Abd to *KSA-GRF17* (2)	9363	CoordinateTransformation	Transformation grid (format: *IGN2009.tac*).
ITRF2014 to *KSA-GRF17* (1)	9334	CoordinateTransformation	15-parameter transformation.
MTRF-2000 to *KSA-GRF17* (1)	9361	CoordinateTransformation	7 parameter transformation.
KSA-GRF17 to *WGS84 (1)*	9383	CoordinateTransformation	7 parameter transformation, accuracy: *1 meter.* Derived by EPSG from ITRF2014 to KSA-GRF17 (1) (CT code 9334). Valid at the epoch 2017.00 and is degrading by approximately 4.5 cm (not 2.5 cm a stated erroneously by EPSG) per year.

3.1.1.8. Online GRF transformation tool (for points)

GEOSA has developed an online tool for points (coordinates) transformation with the name Online GRF-TT Transformation Tool (Online GRF-TT) the software to transform points in 3D and 2D coordinates (*Cartesian*, geographic and *UTM* projected – both for ellipsoid and orthometric heights based on geoid heights of *KSA-GEOID21*) of geodetic points between *KSA-GRF17* and *RF*s listed in the *Table 3.2*. Online GRF-TT is available under the following link: https://gds.geoportal.sa/grf17

For further inquires or requests regarding coordinates transformation, contact *GEOSA* by the e-mail address info@geosa.gov.sa

3.1.2. Height transformation to KSA-VRF14

GEOSA has determined a set of transformation parameters to transform data from the previous *VRF's* and geoid models to the newly developed *KSA-VRF14* & *KSA-GEOID21*.

The main historical *VRFs* that have been used before the development of *KSA-VRF14* are described in the next paragraph.

3.1.2.1. Historical VRF's and geoid model of KSA

SVD78 is the realization of the *Kingdom's VRS* based on a combined network adjustment of all available *ARAMCO Benchmarks (BMs)* with levelled differences. The vertical datum is based on the *Local Mean Sea Level (LMSL)* at the *RasTanura* Tidal benchmark at the east coast of *Saudi Arabia* (i.e. in the *Arabian Gulf*). This vertical datum is known as *Saudi ARAMCO Vertical Datum 78 (SVD-1978).*

SVD70/69 is the realization of the *Kingdom's VRS* based on a combined network adjustment available at that time, but with unknown *BMs* with levelled differences. The vertical datum is based on the *LMSL* at the *Jeddah TG* on the west coast of *Saudi Arabia*.

KSA-GEOID09 is a gravimetric geoid model, based on terrestrial, ship-borne, satellite altimetry and gravity data, and *Earth Geopotential Model (EGM08)* and *GOCEdird5* global models, and *4195 GPS/BM* geoid height selected points. *KSA-GEOID09* was the first combined geoid ever computed using all available data in the *Kingdom*.

KSA-GEOID17 is a geoid model for the *Kingdom of Saudi Arabia* determined by using land, ship-borne and satellite gravity data, satellite altimetry and *GPS* levelling data. The *KSA-GEOID17* allowed users to compute orthometric heights for the points over *KSA* different from *National Vertical Network* (*NVN*).

Compared to the previous realizations of the *Kingdom's VRS*, the *KSA-VRF14* is modern and precise *VRF* that utilizes ground, precise spirit leveling and gravity data, and its distribution is homogeneous all over the *Kingdom*.

3.1.2.2. Theoretical background of VRF & geoid transformations

Transformation between previous and existing *VRS* realizations is based on the common set of points in order to provide uniform, homogeneous and consistent parameters for the transformations between *Jeddah 1969* (*JED69*) and *KSA-VRF14*, *SVD78* and *KSA VRF14*, and from *KSA-GEOID09* or *KSA-GEOID17* to *KSA-GEOID21*. Transformation parameters were determined by using network adjustment approach based on the set of common points in old and new frames and models.

In general, the transformation between historical *VRF's* and the latest one can be performed by using the following equation:

$$H_{14} = H_{old} + \delta H, \qquad (3.5)$$

where H_{14} – orthometric height in *KSA-VRF14*; H_{old} – orthometric height in *JED69* or *SVD78*; δH – transformation parameters.

For transformation between geoid models *KSA-GEOID09* & *KSA-GEOID17*, next formula was used:

$$N_{21} = N_{old} + \delta N, \qquad (3.6)$$

where N_{21} – geoid height in *KSA-GEOID21*; N_{old} – geoid height in *KSA-GEOID09* or *KSA-GEOID21*; δN – transformation parameters.

As different techniques was used to compute KSA-VRF14 comparing to techniques used in other VRFs in KSA, so the differences between them is not constant all over KSA. In order to achieve homogeneous accuracy, *GEOSA* created transformation grids that cover the territory of the *Saudi Arabia* (*16* ≤ Latitude ≤*32.5* and *34* ≤ Longitude ≤ *55.5*) with the spatial resolution *0.6 arcmin* in latitude and *0.75 arcmin* in longitude (roughly, *500 m*).

3.1.2.3. EPSG codes for the VRF datum and Transformation

The *GEOSA* has registered the *SANSRS VRF* component in the *EPSG* database (*http://www.EPSG.org/*). The *SANSRS VRF* component elements are given in the *Table 3.7*.

Table 3.7: SANSRS VRF component registered in the EPSG database

NAME	CODE	TYPE	Remarks
Kingdom of Saudi Arabia Vertical Reference Frame *Jeddah 2014*	1269	VerticalDatum	Saudia Arabia – onshore
KSA-VRF14 height	9335	VerticalCRS	Saudia Arabia – onshore
KSA-GRF17	9332	GeodeticCRS (geographic 3D)	Saudi Arabia - onshore and offshore
KSA-GRF17 + KSA-VRF14 height	9520	CompoundCRS	Saudia Arabia – onshore
KSA-GRF17 to *KSA-VRF14 height (1)*	9355	CoordinateTransformation	Saudia Arabia – onshore; Transformation grid (formats: *GRAVSOFT .gra*; *IGN2009 .tac*), accuracy: *2-20 cm*
KSA-GRF17 to KSA-GRF17 + KSA-VRF14 height (1)	9620	CoordinateTransformation	Saudia Arabia – onshore

3.1.2.4. Online VRF & GEOID Transformation Tool (for points)

To help the users in transforming their data from old *VRFs and GEOIDs* to *KSA-VRF14 and KSA-GEOID21*, the *GEOSA* has developed the *Online VRF & GEOID -TT Transformation Tool*, which is available under the following link: https://gds.geoportal.sa/vrf

This tool transforms the data in both "*Single point*" (one point) and "*Multi point*" (multiple points saved into text file) modes. In the "*Single point*" mode, a user will be asked to select appropriate transformation (*KSA-JED69 to KSA-VRF14*, *KSA-SVD78 to KSA-VRF14, KSA-2009 to KSA-GEOID21, KSA-GEOID17 to KSA-GEOID21*), to input points coordinates (*Latitude & Longitude*) and height of the point he wants to transform. In the "*Multi point*" mode a user will need to store all his input data (*Longitude, Latitude & Height*) in the *ASCII* file and upload this file to the server. Software will generate the result *ASCII* file which will contain both the input data and the output height.

For more details, please follow the link https://gds.geoportal.sa/

3.2. Transformation of GIS data

To transform the *GIS* data, the *EPSG* registered codes for *KSA-GRF* and *KSA-VRF* (*Table 3.6* and *Table 3.7*) could be used in the *GIS* software. Some *GIS* software manufacturers are working on the integration of the codes into the latest releases of their software. The software users could implement the codes themselves by following the software manufacturer's manuals.

SANSRS relevant EPSG codes are included in the latest versions of the most commonly used GIS software (e.g.: ArcGIS ad QGIS). So, GEOSA recommends updating your GIS software to get SANSRS EPSG codes automatically or to add it manually using your GIS's software manual.

4. Communication & Support

The *GEOSA* shall continuously communicate with users during the implementation and utilization of SANSRS to create awareness, share knowledge about the components of *SANSRS*.

Please, send to *GEOSA* your comments, description of challenges you foresee, and description of any your needs for help and information from us. For that, use the appropriate e-mail addresses of the following:

KSA-CORS related queries: *KSA-CORS@geosa.gov.sa*

KSA-GRF17, *KSA-VRF14* and *KSA-GEOID* related queries: *SANSRS@geosa.gov.sa*

For any requests related to SANSRS: info@geosa.gov.sa