National Aeronautics and Space Administration Goddard Earth Science Data Information and Services Center (GES DISC)

README Document for
GRACE Data Assimilation Version 4 Product

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Revision History

Revision Date	***Changes***	***Author***
01/11/2021	Initial version based on README for GRACE-DA-DM Version 2.0 and information from Hiroko Beaudoing	Hualan Rui
01/12/2021	Add what's new and revision history	Hiroko Beaudoing
01/15/2021	Review and revise	Carlee Loeser
03/01/2021	Update the email address of GES DISC Help Desk	Hualan Rui
10/19/2021	Add a reference for [Getirana et al., 2021]	Hualan Rui

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1.0 Introduction

This document provides basic information for using the Gravity Recovery and Climate Experiment (GRACE) Data Assimilation for Drought Monitoring Version 4.0 product (abbreviated as GRACE-DA-DM V4.0). The GRACE-DA-DM V4.0 data product supersedes the GRACE-DA-DM V2.0 product.

Scientists at NASA's Goddard Space Flight Center generate groundwater and soil moisture drought indicators each week. These indicators are based on terrestrial water storage observations derived from the GRACE satellite data and integrated with other observations, using a sophisticated numerical model of land surface water and energy processes. The data product of **Groundwater and Soil Moisture Conditions from GRACE Data Assimilation** contains a set of drought indicators for the North American Drought Monitor.

1.1 Dataset Basic Characteristics

The GRACE-DA-DM V4.0 data product contains three drought indicators: Groundwater Percentile, Root Zone Soil Moisture Percentile, and Surface Soil Moisture Percentile. These drought indicators express wet or dry conditions as a percentile, indicating the probability of occurrence within the period of record from 1948 to 2014. The drought indicator data are daily, but available only one day (Monday) per week. The data have a spatial resolution of 0.125 x 0.125 degree over North America and range from April 1, 2002 to present (with a 3-6 months latency). The data are archived in netCDF format.

Table 1. Basic characteristics of the GRACE-DA-DM data.

Contents	Drought indicators
Input data	GRACE
Land surface models	Catchment Fortuna 2.5 version
Latitude extent	25 º to 53 º
Longitude extent	-125 º to -67 º
Spatial resolution	0.125 degree
Temporal interval	7-days
Temporal coverage	2002/04/01 ~ present
Dimension	224 (lat) x 464 (lon)
Grid box center points (lat, lon)	Lower left: (25.0625, -124.9375) Upper right: (52.9375, -67.0625)
Format	netCDF

1.2 Digital Object Identifier (DOI) and Citation

A Digital Object Identifier, or DOI, is a unique alphanumeric string used to identify a digital object and provide a permanent link online. DOIs are often used in online publications in citations.

DOI for GRACE-DA-DM V4.0 data product: 10.5067/UH653SEZR9VQ

Citation example: Matthew Rodell and Hiroko Kato Beaudoing, NASA/GSFC/HSL (2021), *Groundwater and Soil Moisture Conditions from GRACE Data Assimilation L4 7-days 0.125 x 0.125 degree Version 4.0*, Greenbelt, Maryland, USA: Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed **[Data Access Date]** 10.5067/UH653SEZR9VQ

Primary Reference:
Houborg, R., M. Rodell, B. Li, R. Reichle, and B. Zaitchik, 2012: Drought indicators based on model assimilated GRACE terrestrial water storage observations, *Wat. Resour. Res.*, 48, W07525, doi:10.1029/2011WR011291

1.3 Contact Information

For information about or assistance in using any GES DISC data, please contact the GES DISC Help Desk at:

GES DISC
Code 610.2
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771
Email: gsfc-dl-help-disc@mail.nasa.gov
301-614-5224 (voice)
301-614-5268 (fax)

For general science questions and comments, please contact:

Matthew Rodell, Ph.D.
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NASA Goddard Space Flight Center
Greenbelt, MD 20771
Email: Matthew.Rodell@nasa.gov
Phone: 301-286-9143

Or

Hiroko Kato Beaudoing, M.S.
Earth System Science Interdisciplinary Center
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Email: Hiroko.Kato-1@nasa.gov
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1.4 What's New?

1.4.1 What's in GRACE-DA-DM V4.0?

The GRACE-DA-DM V4.0 is based on the Catchment Land Surface Model (CLSM) Fortuna 2.5 version simulation that was created within the Land Information System data assimilation framework (Kumar et al. 2016). This simulation used the latest GRACE RL06 (GRACE; 2002-2017) and GRACE Follow On (GRACE-FO; 2018-present) Mascon solutions version 2, at 0.25 degree resolution, from the University of Texas at Austin (Save et al. 2016; Save 2020). The CLSM soil parameters were updated to address a soil moisture dry limit issue found near Zapata, Texas. Because the root zone soil moisture frequently reaches the dry limit there, drought conditions are often "normal" when the area should be in drought. The new soil parameters resolved the issue, and the root zone soil moisture matches closely with an in-situ observation near Zapata. In the data assimilation, the baseline for Terrestrial Water Storage anomaly computation was updated to 2003-2019 mean whereas previous simulations used 2003-2016 mean. The percentile computation was switched to a 7-day moving average climatology instead of monthly, to improve the temporal transition of drought/wetness conditions.

1.4.2 Revision history of GRACE-DA-DM

The GRACE-DA-DM Version 1.0 was created by the stand alone CLSM (an older version) using the GRACE-Tellus 1 degree data from the Center for Space Research at University of Texas. The GRACE data assimilation (DA) is executed on a grid-to-grid basis in Version 2.0, while a basin scale average was used in Version 1.0 (Zaitchik et al. 2008). The Version 2.0 data were reprocessed (on June 14, 2017), using the GRACE RL05 Mascon solutions version 1 data set from UT CSR, for the entire period from April 1, 2002 to June 5, 2017. The reprocessing included fixes in the DA and increased the bedrock depth by 3 meters to enhance the drought indicator calculations.

The Version 4.0 uses the same configuration as the Version 2.0 for the DA scheme and increased bedrock depth, with the updates previously mentioned, thus supersedes the previous versions.

2.0 Data Organization

2.1 File Naming Convention

GRACE-DA-DM data files are named in accordance with the following convention: GRACEDADM_<Model><Grid spacing><Region>_<Temporal spacing>_.A<Date>.<Product version>.nc4

Attribute	Description
GRACEDADM	GRACE Data Assimilation for Drought Monitoring
<Model>	“CLSM” for the Catchment Land Surface Model
<Grid spacing>	“0125” for 1/8th (0.125) degree
<Region>	"US" for CONUS region
<Temporal spacing>	“7D” for 7-days
<Date>	<YYYYMMDD>
<Product version>	“040” for Version 4.0

Filename example: GRACEDADM_CLSM0125US_7D.A20020401.040.nc4

2.2 File Format and Structure

The GRACE-DA-DM V4.0 files are archived in netCDF format, which is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data, https://www.unidata.ucar.edu/software/netcdf/docs/.

3.0 Data Content

3.1 Products/Parameters

The GRACE-DA-DM V4.0 data product contains three drought indicators: Groundwater Percentile, Root Zone Soil Moisture Percentile, and Surface Soil Moisture Percentile. The drought indicators express wet or dry conditions as a percentile, indicating the probability of occurrence within the period of record from 1948 to 2014. The combination of the GRACE-assimilated drought indicators, the latest GRACE data, the 7-day moving average climatology, and the updated Catchment Model Parameters should provide a comprehensive and objective identification of drought conditions. More information is available at https://nasagrace.unl.edu/.

Table 2. Variables in the GRACE-DA-DM Data Product

Short Name	Description	Unit
gws_inst	Groundwater Percentile	%
rtzsm_inst	Root Zone Soil Moisture Percentile	%
sfsm_inst	Surface Soil Moisture Percentile	%

4.0 Options for Reading the Data

4.1 Utilities

GRACE-DA-DM data are archived in the self-describing and machine-independent netCDF format. A Unidata page (http://www.unidata.ucar.edu/software/netcdf/software.html) provides a list of software for manipulating or displaying netCDF Data.

4.2 Panoply

Panoply (https://www.giss.nasa.gov/tools/panoply/) is a cross-platform application that plots geo-referenced and other arrays from netCDF, HDF, GRIB, and other data formats. The HowTo section of NASA GES DISC provides a recipe for Quick View Data with Panoply.

4.3 GrADS

The Grid Analysis and Display System (GrADS) is an interactive desktop tool for easy access, manipulation, and visualization of Earth science data. GrADS supports several data formats, such as binary, netCDF, HDF, and GRIB. The documentation and software for GrADS can be found at http://cola.gmu.edu/grads/grads.php.

Each individual GLDAS-2 netCDF can be opened by the GrADS utility sdfopen directly without a data descriptor file (i.e., a ctl file). After calling sdfopen, GrADS commands, such as “q file”, “d [VariableName]”, etc. can be used to query file information, and read and display the data. An example showing how to use sdfopen to read a GRACE-DA-DM V4.0 netCDF file and query for its dimensions and variables is in Appendix A.

5.0 Data Services

5.1 NASA Earthdata Login System

As of August 1, 2016, access to GES DISC data requires all users to be registered with the Earthdata Login system. Data continue to be free of charge and accessible via HTTPS. As of October 3, 2016, access to data via FTP is no longer available. Detailed instructions on how to register and receive authorization to access GES DISC data are provided at https://disc.gsfc.nasa.gov/data-access.

GES DISC users who deploy scripting methods to list and download data in bulk via anonymous FTP are advised to review the How to Download Data Files from HTTP Service with wget recipe that provides examples of GNU wget commands for listing and downloading data via HTTPS.

If you need assistance or wish to report a problem:

Email: gsfc-dl-help-disc@mail.nasa.gov
Voice: 301-614-5224
Fax: 301-614-5268
Address:
Goddard Earth Sciences Data and Information Services Center
NASA Goddard Space Flight Center
Code 610.2
Greenbelt, MD 20771 USA

5.2 Data Services

The GRACE-DA-DM V4.0 data product landing page provides the product summary, data citation, documentation, and data access methods.

5.2.1 HTTPS

Access the online archive data via HTTPS:
https://hydro1.gesdisc.eosdis.nasa.gov/data/GRACEDA/GRACEDADM_CLSM0125US_7D.4.0.

5.2.2 Earthdata Search

Use Earthdata Search to find and retrieve data sets across multiple data centers:
https://search.earthdata.nasa.gov/search?q=GRACEDADM_CLSM0125US_7D.

5.2.3 OPeNDAP

Access the data via the OPeNDAP protocol for parameter and spatial subsetting:
https://hydro1.gesdisc.eosdis.nasa.gov/opendap/hyrax/GRACEDA/.

5.2.4 Giovanni

The GES-DISC Interactive Online Visualization ANd aNalysis Interface (Giovanni) is a web-based tool that allows users to interactively visualize and analyze data:
https://giovanni.gsfc.nasa.gov/giovanni/#dataKeyword=GRACEDADM_CLSM0125US_7D_4.0

The two sample images below are generated by NASA Giovanni.

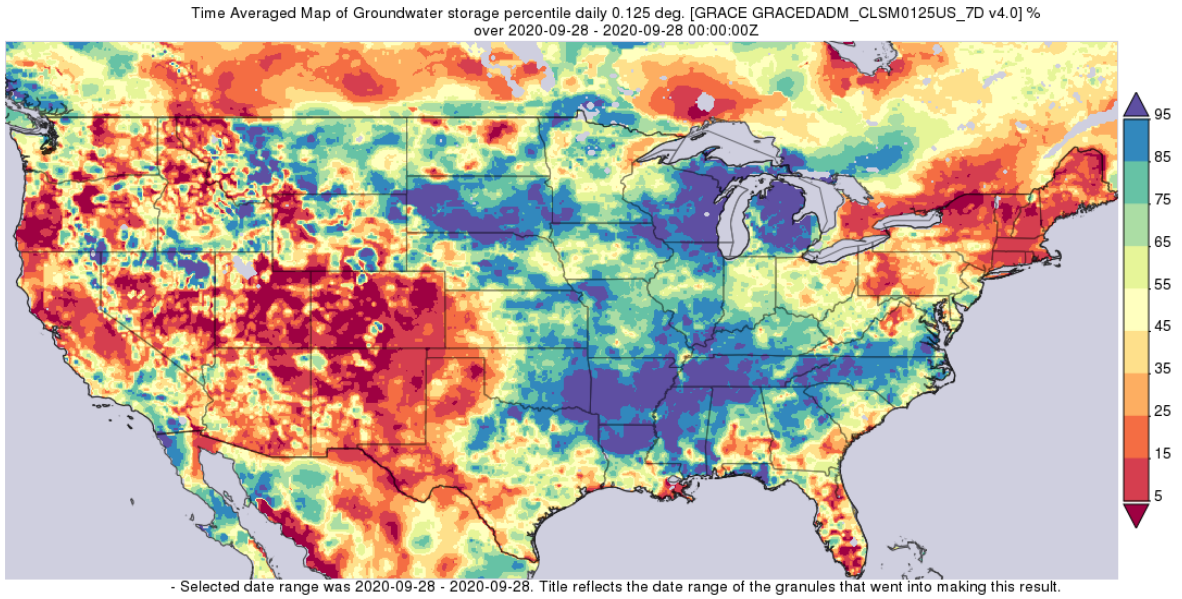

Figure 1. GRACE-assimilated groundwater storage percentile map for September 28, 2020, with lower values (warmer colors) indicating dryer than normal conditions, and higher values (colder colors) indicating wetter than normal conditions. The map was generated by Giovanni.

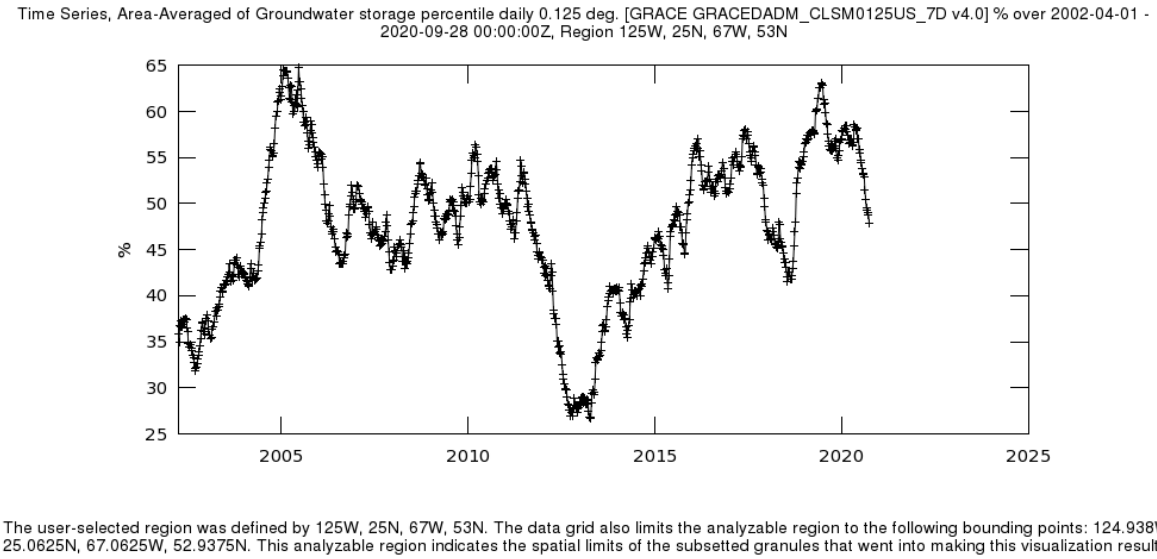

Figure 2. GRACE-assimilated groundwater storage percentile time series, averaged over North America from April 1, 2002 to September 28, 2020. This time series plot was generated by Giovanni (Time Series, Area-Averaged).

6.0 More Information

Groundwater and Soil Moisture Conditions from GRACE Data Assimilation Site: https://nasagrace.unl.edu/

The Land Data Assimilation System (LDAS) Project: https://ldas.gsfc.nasa.gov/

7.0 Acknowledgements

The GRACE-DA-DM V4.0 data are produced by NASA GSFC Hydrological Sciences Laboratory (HSL).

References

Houborg, R., M. Rodell, B. Li, R. Reichle, and B. Zaitchik, 2012: Drought indicators based on model assimilated GRACE terrestrial water storage observations, *Wat. Resour. Res.*, 48, W07525, doi:10.1029/2011WR011291

Getirana, A., M. Rodell, S. Kumar, H.K. Beaudoing, K. Arsenault, B. Zaitchik, H. Save, and S. Bettadpur, 2020: GRACE improves groundwater forecast initialization over the United States, *J. Hydrometeor.*, doi:10.1175/JHM-D-19-0096.1

Save, Himanshu, 2020: CSR GRACE and GRACE-FO RL06 Mascon Solutions v02, doi: 10.15781/cgq9-nh24

Kumar, S. V., B. F. Zaitchik, C. D. Peters-Lidard, et al., 2016: Assimilation of gridded GRACE terrestrial water storage estimates in the North American Land Data Assimilation System, *J. Hydrometeor.,* 17 (7), 1951-1972, doi:10.1175/jhm-d-15-0157.1

Save, H., S. Bettadpur, and B.D. Tapley, 2016: High resolution CSR GRACE RL05 mascons, *J. Geophys. Res. Solid Earth*, 121, doi:10.1002/2016JB013007.

Zaitchik, B.F., M. Rodell, and R.H. Reichle, 2008: Assimilation of GRACE terrestrial water storage data into a land surface model: results for the Mississippi River Basin, *J. Hydrometeor.*, 9 (3), 535-548, doi:10.1175/2007JHM951.1

Acronyms

The following acronyms and abbreviations are used in this document.

GDS	GrADS Data Server
GES DISC	Goddard Earth Sciences Data and Information Services Center
Giovanni	GES-DISC Interactive On-line Visualization and Analysis Infrastructure
GRACE	Gravity Recovery and Climate Experiment
GrADS	Grid Analysis and Display System
GRIB	GRIdded Binary
HDF	Hierarchical Data Format
HSL	Hydrological Sciences Laboratory
LIS	Land Information System
LSM	Land Surface Model
NASA	National Aeronautics and Space Administration
netCDF	network Common Data Form

Appendix A

Below is an example showing how to use sdfopen to read a GRACE-DA-DM netCDF file and query for its dimensions and variables.

```
hrui@hydro1: $ grads
        Welcome to the OpenGrADS Bundle Distribution
        -------------------------------------------
For additional information enter "grads -h".

Starting "/opt/grads-2.1.a2.oga.1/Linux/Versions/2.1.a2.oga.1/x86_64/grads   " ...

Grid Analysis and Display System (GrADS) Version 2.1.a2.oga.1
Copyright (c) 1988-2013 by the Institute for Global Environment and Society (IGES)
GrADS comes with ABSOLUTELY NO WARRANTY
See file COPYRIGHT for more information

Config: v2.1.a2.oga.1 little-endian readline grib2 netcdf hdf4-sds hdf5 opendap-
grids,stn athena geotiff shapefile cairo
Issue 'q config' command for more detailed configuration information
Loading User Defined Extensions table </opt/grads-
2.1.a2.oga.1/Linux/Versions/2.1.a2.oga.1/x86_64/gex/udxt> ... ok.
Landscape mode? ('n' for portrait):
GX Package Initialization: Size = 11 8.5
ga-> sdfopen  GRACEDADM_CLSM0125US_7D.A20020401.040.nc4
Scanning self-describing file: GRACEDADM_CLSM0125US_7D.A20020401.040.nc4
SDF file GRACEDADM_CLSM0125US_7D.A20020401.040.nc4 is open as file 1
LON set to -124.938 -67.0625
LAT set to 25.0625 52.9375
LEV set to 0 0
Time values set: 2002:4:1:0 2002:4:1:0
E set to 1 1
ga-> q dims
Default file number is: 1
X is varying   Lon = -124.938 to -67.0625   X = 1 to 464
Y is varying   Lat = 25.0625 to 52.9375   Y = 1 to 224
Z is fixed     Lev = 0  Z = 1
T is fixed     Time = 00Z01APR2002  T = 1
E is fixed     Ens = 1  E = 1
```

```
ga-> q file
File 1 : GRACE Data Assimilation Drought Indicator
  Descriptor: /var/tmp/hrui/GRACEDADM_CLSM0125US_7D.A20020401.040.nc4
  Binary: /var/tmp/hrui/GRACEDADM_CLSM0125US_7D.A20020401.040.nc4
  Type = Gridded
  Xsize = 464  Ysize = 224  Zsize = 1  Tsize = 1  Esize = 1
  Number of Variables = 3
    gws_inst  0  t,y,x  Groundwater storage percentile
    rtzsm_inst  0  t,y,x  Root zone soil moisture percentile
    sfsm_inst  0  t,y,x  Surface soil moisture percentile
ga->
```

By using GrADS command xdfopen with a GrADS descriptor file, multiple GRACE-DA-DM netCDF files can be opened, therefore, temporally aggregated visualization and data analysis can be done by GrADS. Below is a GrADS sample descriptor file (GRACEDADM_CLSM0125US_7D.4.0.xdf) for the GRACE-DA-DM files:

```
DSET GRACEDADM_CLSM0125US_7D.A%y4%m2%d2.040.nc4
UNDEF -999.
OPTIONS template
TDEF time  1 LINEAR 01APR2002 7dy
```

An example for using xdfopen to open GRACEDADM_CLSM0125US_7D.4.0.xdf:

```
ga-> xdfopen GRACEDADM_CLSM0125US_7D.4.0.xdf
Scanning Descriptor File:  GRACEDADM_CLSM0125US_7D.4.0.xdf
SDF file /var/tmp/hrui/GRACEDADM_CLSM0125US_7D.A%y4%m2%d2.040.nc4 is
open as file 1
LON set to -124.938 -67.0625
LAT set to 25.0625 52.9375
LEV set to 0 0
Time values set: 2002:4:1:0 2002:4:1:0
E set to 1 1
ga-> q file
File 1 : GRACE Data Assimilation Drought Indicator
  Descriptor: GRACEDADM_CLSM0125US_7D.4.0.xdf
  Binary: /var/tmp/hrui/GRACEDADM_CLSM0125US_7D.A%y4%m2%d2.040.nc4
  Type = Gridded
  Xsize = 464  Ysize = 224  Zsize = 1  Tsize = 1  Esize = 1
  Number of Variables = 3
    gws_inst  0  t,y,x  Groundwater storage percentile
    rtzsm_inst  0  t,y,x  Root zone soil moisture percentile
    sfsm_inst  0  t,y,x  Surface soil moisture percentile
ga->
```