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SUPPLEMENTARY INFORMATION

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# The role of satellite remote sensing in climate change studies

Supplementary Information 1

This file contains supplementary tables 1-3 and additional references for tableS1. TableS1 listed varied estimates of mass loss rates of ice sheets. TableS2 listed major time series of ECVs constructed from satellite records. TableS3 listed abbreviations and acronyms used in the article and in supplementary information.

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**Supplemental materials for**

# The Role of Satellite Remote Sensing in Climate Change Studies

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**This file includes:**

Supplementary table 1

References 1-14 for Supplementary table 1

Supplementary table 2

Supplementary table 3

Supplementary table 1. Recent mass loss rates of Antarctica and Greenland ice sheets estimated from satellite observations.

| Region | Data type | Period | Mass loss rate (Gt $yr^{-1}$) | References |
|---|---|---|---|---|
| Antarctica | ICEsat | 2003-2007 | 171±4 | [1] |
| | GRACE | 4/2002-1/2009 | 190±77 | [2] |
| | GRACE | 4/2002-2/2009 | 143±73 | [3] |
| | GRACE | 8/2002-6/2010 | 80 | [4] |
| | GRACE | 5/2002-4/2011 | 104±48 | [5] |
| | GRACE | 1/2003-12/2010 | 165±72 | [6] |
| | MBM[a] | 1/2003-12/2008 | 161±150 | [7] |
| Greenland | ICEsat | 10/2003-3/2008 | 191±23 - 240±28 | [8] |
| | ICEsat | 2003-2008 | 205.4±10.6 | [9] |
| | GRACE | 4/2002-12/2008 | 104±23 | [10] |
| | GRACE | 4/2002-2/2009 | 230±33 | [3] |
| | GRACE | 2/2003-12/2008 | 165±15 | [11] |
| | GRACE | 8/2003-6/2009 | 191.2±20.9 | [9] |
| | GRACE | 8/2003-8/2009 | 195±30 | [12] |
| | GRACE | 3/2003-2/2010 | 201±20 | [13] |
| | MBM | 1/2003-12/2008 | 237±20 | [14] |

a Estimates made using the mass balance model (MBM), listed here as comparison.

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Supplementary table 2. Major data sets of ECVs derived from satellite observations[a]

| ECV | Data set | Spatial coverage | Temporal resolution | Holding agency | Duration | URL |
|---|---|---|---|---|---|---|
| | | | | ***Atmospheric*** | | |
| Precipitation | CMAP[b] | 88.75N-88.75S, 1.25E-358.75E | Monthly, pentad | ESRL/NOAA | 1979-2011 | http://www.esrl.noaa.gov/psd/data/gridded/data.cmap.html#detail |
| | GPCP | 88.75N-88.75S, 1.25E-1.25W; Daily: 89.5N-89.5S, 0.5E-0.5W | Monthly, pentad, daily | GSFC/NASA | 1979-; pentad: 1979-2010 | http://precip.gsfc.nasa.gov/ |
| | TRMM | 49.875N-49.875S, 179.875E-179.875W | Monthly, 3-hourly, near real-time | GSFC/NASA | 1997- | http://precip.gsfc.nasa.gov/ |
| Radiation budget | | | | | | |
| Surface | ERBE data sets | ERBE: 90N-90S, 180E-180W ERBS: 60N-60S, 180E-180W | Monthly, Bi-weekly, daily | LARC/NASA | Varied: earliest[c] 1984; longest set[d] 1984-2003 | https://eosweb.larc.nasa.gov/project/erbe/erbe_table?page=1&qt-erbe_products=0 |
| | CERES data sets | Before 1998: 40N-40S, 180E-180W; After 2000: 90N-90S, 180E-180W | Monthly, daily, hourly | LARC/NASA | Varied: Earliest 1997 longest set 2000- | http://eosweb.larc.nasa.gov/project/ceres/table_ceres.html |
| | ISCCP FD data sets | Global | Monthly, 3-hourly | ISCCP | 1983-2007 | http://isccp.giss.nasa.gov/projects/flux.html |
| Upper-air | AIRS data sets | Global | Twice daily | GES DISC/NASA | 2002- | http://disc.sci.gsfc.nasa.gov/AIRS/data-holdings/by-access-method |
| | ISCCP FD data sets | Global | Monthly,3-hourly | ISCCP | 1983-2007 | http://isccp.giss.nasa.gov/projects/flux.html |
| Upper-air | UAH MSU | Global | Monthly | NCDC/NOAA | 1979- | http://www.ncdc.noaa.gov/temp-and-precip/msu/ |

| | | | | | | |
|---|---|---|---|---|---|---|
| temperature | | | | | | |
| | RSS MSU | Global | Monthly | NCDC/NOAA | 1979- | http://www.ncdc.noaa.gov/temp-and-precip/msu/ |
| | UW MSU | Global | Monthly | NCDC/NOAA | 1979- | http://www.ncdc.noaa.gov/temp-and-precip/msu/ |
| | STAR MSU/AMSU | Global | Monthly | STAR/NOAA | 1979- | http://www.star.nesdis.noaa.gov/smcd/emb/mscat/index.php |
| Wind speed and direction | | | | | | |
| Surface air | CCMP ocean surface wind | 89.875N-89.875S, 180E-180W | Monthly, pentad, daily, 12-hourly, 6-hourly, | PO.DAAC/JPL | 1987-2012 | http://podaac.jpl.nasa.gov/datasetlist?search=CCMP |
| | OSWT data sets | 80N-80S, 180E-180W | Daily | STAR/NOAA | Varied : earliest 2003; longest set 2003-2013 | http://manati.star.nesdis.noaa.gov/index.php |
| Upper-air | MTSAT AMV | 60N-60S, 180E-180W | NH: hourly; SH: four times a day | MSC/JMA | 2005- | http://mscweb.kishou.go.jp/product/product/amv/index.htm |
| | AMV-MSG-0 degree | 65N-65S, 65E-65W | Hourly | EUMETSAT | 2004- | http://navigator.eumetsat.int/discovery/Start/Explore/Quick.do |
| | High density winds data sets | Varied in different data sets | 3-hourly, hourly | SSD/NESDIS | Varied: earliest 1994, longest set 1994- | http://www.goes.noaa.gov/WINDS/index.html |
| Water vapor | Atmospheric water vapor products | Varied in different data sets | Monthly, weekly, daily | GES DISC/NASA | Varied: earliest 1978; longest set 1978-1995 | http://disc.sci.gsfc.nasa.gov/data-holdings/PIP/atmospheric_water_vapor_or_humidity.shtml |
| | NVAP-M | Global | Monthly, daily, 6-hourly | LASC/NASA | 1988-2009 | https://eosweb.larc.nasa.gov/project/nvap/nvap-m_table |
| Cloud | ISCCP | Global | Monthly | ISCCP | 1983-2008 | http://isccp.giss.nasa.gov/products/isccpDsets.html |

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|---|---|---|---|---|---|---|
| properties | cloud products | | | | | |
| | CERES cloud products | Global | Monthly 3-hourly, | LASC/NASA | 2000- | https://eosweb.larc.nasa.gov/project/ceres/ceres_table |
| Carbon dioxide | WFM-DOAS X CO2 | Global | Monthly | University of Bremen | 2003-2005 | http://wdc.dlr.de/data_products/projects/promote/ghg_aer/wfm-doas/co2.html |
| | GOSAT CO2 data | Global | Monthly | JAXA | 2009- | https://data.gosat.nies.go.jp/GosatUserInterfaceGateway/guig/GuigPage/open.do |
| | AIRS CO2 data | Global | Monthly, daily | JPL/NASA | 2002- | http://airs.jpl.nasa.gov/data/get_airs_co2_data/ |
| Ozone | Ozone | Global | Daily | WDC-RSA | Varied: earliest 1978; longest set 1978-1993 | http://wdc.dlr.de/data_products/TRACEGASES/ |
| Aerosol properties | GACP | Global | Monthly, Daily | GSFC/NASA | 1981-2006 | http://gacp.giss.nasa.gov/data_sets/ |
| | AOD intercoparison monthly products | Global | Monthly | GES DISC/NASA | Varied: Earliest 1997; longest set 1997-2010 | http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=aerosol_monthly |
| | AERO100 | Global | Weekly | GLASS/NOAA | 1987- | http://www.nsof.class.noaa.gov/saa/products/search?sub_id=0&datatype_family=AERO100&submit.x=20&submit.y=11 |
| | | | | ***Oceanic*** | | |
| Sea surface temperature | GHRSST data sets | Regional, Global | Varied | NODC/NOAA | Varied: earliest 1981; longest set 1981- | http://www.nodc.noaa.gov/sog/ghrsst/accessdata.html |
| Sea level | Global mean sea level | 66N-66S,180E-180W | Monthly | LSA/NOAA | 1992- | http://ibis.grdl.noaa.gov/SAT/SeaLevelRise/LSA_SLR_timeseries_global.php |
| | AVISO sea surface | 85N-85S, 180E-180W | Monthly | AVISO | 1992- | http://www.aviso.oceanobs.com/en/data/products.html |

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|---|---|---|---|---|---|---|
| | height | | | | | |
| | CU sea level data | Global | Monthly | University of Colorado | 1993- | http://sealevel.colorado.edu/ |
| | Combined T/P, J-1, J-2/OSTM sea level fields | 65N-65S, 180E-180W | Monthly | CISRO | 1993- | http://www.cmar.csiro.au/sealevel/sl_data_cmar.html |
| | ECV Sea-level | Global | Monthly | ESA | 1993-2010 | http://www.esa-sealevel-cci.org/node/164 |
| Sea ice | Passive microwave sea ice products | 39.23N-90N, 30.98S-90S, 180E-180W | Daily | NSIDC | 1978- | http://nsidc.org/data/nsidc-0051.html |
| | Visible and infrared sea ice products | Global, NH | Daily | NSIDC | Varied Earliest 1978 longest set 1978-2010 | http://nsidc.org/data/seaice/visible.html |
| Ocean color | GLOB-4km | Global | Monthly, daily | ESA | 1997- | http://www.globcolour.info/data_access_full_prod_set.html |
| | OceanColor data sets | Global | Monthly, daily | GSFC/NASA | Varied: earliest 1997 longest set 1997-2010 | http://oceancolor.gsfc.nasa.gov/ |
| Sea state | Globwave satellite data L2P | Varied in different data sets | Daily, near real-time | Globwave | Varied: earliest 1991 longest set 1996-2011 | http://www.globwave.org/Products/Data-access |
| Ocean salinity | SMOS | Global | Monthly, daily | CATDS | 2010- | http://www.catds.fr/Data/Official-Products-from-CPDC |
| | Aquarius/SAC-D data set | Global | Annual, 3-month, monthly, 7-day, daily | PO.DAAC/JPL | 2011- | http://podaac.jpl.nasa.gov/SeaSurfaceSalinity/Aquarius |
| | | | | ***Terrestrial*** | | |
| Lakes | GLAM lake | 186 lakes | 10-day,35- | FAS/USDA | T/P, J-1,2: | http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/#datasets |

| | | | | | | |
|---|---|---|---|---|---|---|
| | data | | day | | 1992-2012; Envisat: 2003-2012 | |
| | SOLS data | About 100 lakes | 10-day,35-day | LEGOS | 1992-2012 | http://www.legos.obs-mip.fr/en/soa/hydrologie/hydroweb/Page_2.html |
| Snow cover | GSL SCE data set | NH | Monthly, weekly, daily | GSL/Rutgers University | 1966- | http://climate.rutgers.edu/snowcover/index.php |
| | NISE | Global | Daily | NSIDC/University of Colorado at Boulder | 1995- | http://nsidc.org/cgi-bin/get_metadata.pl?id=nise1 |
| Glaciers and ice caps | GLIMS glacier database | Global | Varied, mostly one-time snapshot | NSIDC/University of Colorado at Boulder | 2005- | http://glims.colorado.edu/glacierdata/ |
| Land cover | GLCC 2.0 | Global (1km) | One time | USGS | 1992-1993 | http://edc2.usgs.gov/glcc/glcc.php |
| | MCD12Q1 | Global (500m, 0.05 Dg, 1km) | Yearly | GSFC | 2001-2010 | http://modis-land.gsfc.nasa.gov/landcover.html |
| | Globcover | Global (300m) | Two times | ESA | 2009, 2005-2006 | http://due.esrin.esa.int/globcover/ |
| | FROM-GLC | 30m | Two times | Tsinghua | 2000,2010 | http://data.ess.tsinghua.edu.cn/ |
| fAPAR | AVHRR LAI & fPAR | Global | 10-day | Climate and vegetation research group/Boston University | 1981-2011 | http://cybele.bu.edu/modismisr/index.html |
| | MODIS LAI & fPAR | Global | 4-day;8-day | LP DAAC/USGS | 2002- | https://lpdaac.usgs.gov/products/modis_products_table/mcd15a3 |
| | LAI FAPAR FCOVER NDVI (VITO) | Global | 10-day | Geoland2/EU | 1999- | http://www.geoland2.eu/portal/service/ListService.do?serviceCategoryId=CA80C981 |
| | CYCLOPES fAPAR | Global | 10-day | POSTEL | 1999-2007 | http://toyo.mediasfrance.org/?-Biogeophysical-Products,52- |
| LAI | AVHRR LAI & | Global | 10-day | Climate and vegetation | 1981-2011 | http://cybele.bu.edu/modismisr/index.html |

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|---|---|---|---|---|---|---|
| | fPAR | | | research group/Boston University | | |
| | MODIS LAI & fPAR | Global | 4-day;8-day | LP DAAC/USGS | 2002- | https://lpdaac.usgs.gov/products/modis_products_table/mcd15a3 |
| | LAI FAPAR FCOVER NDVI (VITO) | Global | 10-day | Geoland2/EU | 1999- | http://www.geoland2.eu/portal/service/ListService.do?serviceCategoryId=CA80C981 |
| | CYCLOPES LAI | Global | 10-day | POSTEL | 1999-2007 | http://toyo.mediasfrance.org/?-Biogeophysical-Products,52- |
| Albedo | MODIS albedo | Global (500m, 1km, 0.05 degree) | 16-day | LP DAAC/USGS | 2000- | http://modis-land.gsfc.nasa.gov/brdf.html |
| | MISR albedo | Global | Monthly | ASDC/NASA | 2000- | https://eosweb.larc.nasa.gov/project/misr/misr_table |
| | MSA1 | 65N-65S, 65E-65W | 10-day | EUMETSAT | 1981-2006 | http://www.eumetsat.int/Home/Main/DataProducts/Land/index.htm?l=en |
| | MSA1-IODC | 65N-65C, 128E-2W | 10-day | EUMETSAT | 1998-2007 | http://www.eumetsat.int/Home/Main/DataProducts/Land/index.htm?l=en |
| Biomass | No | | | | | |
| Fire disturbance | ASTER world fire atlas | Global | Monthly | ESA | 1995- | http://dup.esrin.esa.it/wfa/ |
| | MODIS fires | Global | Daily, 8-day, monthly | EOSDIS/NASA | 2000- | http://reverb.echo.nasa.gov/reverb/#utf8=%E2%9C%93&spatial_map=satellite&spatial_type=rectangle |
| Soil moisture | ECV SM | Global, with some gaps | Daily | ESA | 1978-2010 | http://www.esa-soilmoisture-cci.org/node/127 |

a. The table is mainly compiled from the online GCOS ECV data access matrix (http://gosic.org/ios/MATRICES/ECV/ecv-matrix.htm) and the GCOS report *Systematic Observation requirements for satellite-based data products for climate* published in 2011. This list serves as a starting point for readers who are looking for satellite-based climate records. All sources listed here provide free data access to public.

b. Meaning for acronyms and abbreviations are listed in supplementary table 3.

c. The earliest year that the ECV was recorded by satellite-based sensors.

d. The data set which has the longest time duration. If data from several satellite platforms were not integrated into one time series, only the one with the longest duration is shown.

e. All URLs were last checked on April 18, 2013.

Supplementary table 3 Acronyms and Abbreviations used in the article and supplemental materials

| Acronyms & abbreviations | Meaning |
|---|---|
| AVHRR | Advanced Very High Resolution Radiometers |
| AERO100 | Aerosol Optical Thickness (100km) |
| AIRS | Atmospheric Infrared Sounder |
| AMSRE | Advanced Microwave Scanning Radiometer for the Earth Observing System |
| AMV | Atmospheric Motion Vector |
| AOD | Aerosol Optical Depth |
| ASDC | Atmospheric Science Data Center |
| ASTER | Advanced Spaceborne Thermal Emission and Reflection Radiometer |
| AVISO | Archiving, Validation and Interpretation of Satellite Oceanographic Data |
| CATDS | Centre Aval de Traitement des Données SMOS |
| CCI | Climate Change Initiative |
| CCMP | Cross-Calibrated Multi-Platform |
| CERES | Clouds and the Earth's Radiant Energy System |
| CISRO | Commonwealth Scientific and Industrial Research Organization |
| CLARREO | Climate Absolute Radiance and Refractivity Observatory |
| CLASS | Comprehensive Large Array-data Stewardship System |
| CMAP | CPC Merged Analysis of Precipitation |
| CPC | Climate Prediction Center |
| DESDynI | Deformation, Ecosystem Structure and Dynamics of Ice |
| ECMWF | European Center for Medium-Range Weather Forecasts |
| ECV SM | Essential Climate Variables-Soil Moisture |
| ECVs | Essential Climate Variables |
| EOSDIS | Earth Science Data and Information System |
| ERBE | Earth Radiation Budget Experiment |
| ERBS | Earth Radiation Budget Satellite |
| ESA | European Space Agency |
| ESA | European Space Agency |
| ESRL | Earth System Research Laboratory |
| EU | European Union |
| EUMETSAT | European Organization for the Exploitation of Meteorological Satellites |
| FAS | Foreign Agriculture Service |
| fPAR | Fraction of Photosynthetically Active Radiation |

| | |
|---|---|
| GACP | Global Aerosol Climatology Project |
| GCOM-W1 | Global Change Observation Mission 1st–water |
| GCOS | Global Climate Observing System |
| GEOSS | Global Earth Observation System of Systems |
| GES DISC | Goddard Earth Sciences Data and Information Services Center |
| GHRSST | Group for High-Resolution Sea Surface Temperature |
| GIA | Glacial Isostatic Adjustment |
| GLAM | Global Agriculture Monitoring |
| GLCC | Global Land Cover Characterization |
| GLIMS | Global Land Ice Measurements from Space |
| GOSIC | Global Observing Systems Information Center |
| GPCP | Global Precipitation Climatology Project |
| GRACE | Gravity Recovery and Climate Experiment |
| GSFC | Goddard Space Flight Center |
| GSL | Global Snow Laboratory |
| | |
| IPCC | Intergovernmental Panel on Climate Change |
| ISCCP | International Satellite Cloud Climatology Project |
| | |
| JAXA | Japan Aerospace Exploration Agency |
| JMA | Japan Meteorological Agency |
| JPL | Jet Propulsion Laboratory |
| | |
| LAI | Leaf Area Index |
| LARC | Langley Atmospheric Science Data Center |
| LECZ | Low Elevation Coastal Zones |
| LEGOS | Laboratoire d'Etude en Géophysique et Océanographie Spatiale |
| LP DAAC | Land Processes Distributed Active Archive Center |
| LSA | Laboratory for Satellite Altimetry |
| | |
| MCD12Q1 | MODIS Landcover Type Product |
| MCD12Q2 | MODIS Landcover Dynamics Product |
| MISR | Multiangle Imaging SpectroRadiometer |
| MSA1 | Meteosat Surface Albedo-MFG-0 degree |
| MSA1-IODC | Meteosat Surface Albedo-MFG-Indian Ocean |
| MSC | Meteorological Satellite Center |
| MSG | Meteosat Second Generation |
| MSU | Microwave Sounding Unit |
| MTSAT | Multifunctional Transport Satellite |
| | |
| NASA | National Aeronautics and Space Administration |
| NCDC | National Climatic Data Center |

| | |
|---|---|
| NCEP | National Centers for Environmental Prediction |
| NCF | The Net Cloud forcing |
| NESDIS | National Environmental Satellite, Data and Information Services |
| NISE | Near-real-time Ice and Snow Extent |
| NOAA | National Oceanic and Atmospheric Administration |
| NODC | National Oceanographic Data Center |
| NPP | NPOESS Preparatory Project |
| NSIDC | National Snow and Ice Data Center |
| NVAP-M | NASA Water Vapor Project |
| OSWT | Ocean Surface Winds Team |
| PO.DAAC | Physical Oceanography Distributed Active Archive Center |
| POSTEL | Pole d'Observation des Surfaces continentales par TELedetection |
| RSS | Remote Sensing Systems |
| SAC-D | Satelite de Aplicaciones Cientificas-D |
| SCE | Snow Cover Extent |
| SIM | Spectral Irradiance Monitor |
| SLR | Sea Level Rise |
| SMOS | Soil Moisture and Ocean Salinity |
| SOLS | Satellite Observations of Lakes |
| SORCE | Solar Radiation and Climate Experiment |
| SPOT | Satellite Pour l' Observation de la Terre |
| SSD | Satellite Services Division |
| SSMI | Special Sensor Microwave Imager |
| SST | Sea Surface Temperature |
| STAR | Center for Satellite Applications and Research |
| TOA | Top of Atmosphere |
| TRMM | Tropical Rainfall Measuring Mission |
| TSI | Total Solar Irradiance |
| UAH | University of Alabama in Huntsville |
| USGS | U.S. Geological Survey |
| WDC-RSA | The World Data Center for Remote Sensing of the Atmosphere |
| WFM-DOAS | Weighting Function Modified Differential Optical Absorption Spectroscopy |