Documentation for the Sudden Stratospheric Warming Compendium data set

User's Guide

Revision 1.0

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Purpose

This document provides a basic user's guide to aspects of the Sudden Stratospheric Warming Compendium (SSWC). Covered topics include the raw inputs utilized, descriptions of the output data and files, instructions for reading the output files, and a brief breakdown of the production techniques.

Overview

Sudden stratospheric warmings (SSWs) are large and rapid temperature increases in the polar stratosphere associated with a complete reversal of the climatological westerly winds in wintertime. These events can have substantial impacts on wintertime surface climate, such as extreme cold air outbreaks over North America and Eurasia, or warming over Greenland.

This compendium of historical SSWs documents the stratospheric, tropospheric, and surface climate impacts of these events, both individually and composited, using a variety of time series, maps, and animations of daily data. Here, we examine only major mid-winter warmings, as defined by a zonal wind reversal between November-March of the 10 hPa and 60N zonal winds from westerly to easterly (Charlton and Polvani 2007). Additional events, such as minor and final warmings, may eventually be included.

Analyses are available from 6 different input reanalyses: MERRA2 (1980-2014), JRA-55 (1958-2014), ERA-interim (1979-2014), ERA-40 (1958-2002), NOAA20CR (1958-2011), and NCEP-NCAR I (1958-2014). Anomaly fields are calculated from smoothed daily climatologies based on the full record of each reanalysis. Data is provided 60 days prior to and after each event.

The Sudden Stratospheric Warming Compendium (SSWC) database provides a simple way to plot and download information on historical SSW events; to consider the development, evolution, and impacts of both individual SSWs and their composite; and to provide a basis for model evaluation and improvement.

Input data description

Reanalysis data

Six different reanalysis data sets are used as inputs to the SSWC. These reanalyses, with brief descriptions and their references, are listed below.

ERA-40

Title	The European Centre for Medium-Range Weather Forecasts' 40 year reanalysis
Time Span	September 1957 – August 2002
Horizontal Resolution	1.1250 x ~1.11209 (Gaussian)
Pressure levels	1, 2, 3, 5, 7, 10, 20, 30, 50, 70, 100, 150, 200, 250, 300, 400, 500, 600, 700, 775, 850, 925, 1000
Theta levels	N/A
Reference	Uppala, S. M., et al. (2005): The ERA-40 re-analysis. *Q. J. R. Meteorol. Soc.*, **131**, 2961-3012, DOI:10.1256/qj.04.176.

ERA-Interim	
Title	The European Centre for Medium-Range Weather Forecasts' Interim reanalysis
Time Span	January 1979 – Present
Horizontal Resolution	0.703125 x ~0.701669 (Gaussian)
Pressure levels	1, 2, 3, 5, 7, 10, 20, 30, 50, 70, 100, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 775, 800, 825, 850, 875, 900, 925, 950, 975, 1000
Theta levels	N/A
Reference	Dee, D. P., et al. (2011): The ERA-Interim reanalysis: configuration and performance of the data assimilation system. *Q. J. R. Meteorol. Soc.*, **137**, 553-597, DOI:10.1002/qj.828.

JRA-55	
Title	The Japanese 55-year Reanalysis
Time Span	January 1958 – Present
Horizontal Resolution	1.25 x 1.25
Pressure levels	1, 2, 3, 5, 7, 10, 20, 30, 50, 70, 100, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 775, 800, 825, 850, 875, 900, 925, 950, 975, 1000
Theta levels	270, 280, 290, 300, 310, 320, 330, 340, 350, 360, 370, 380, 390, 400, 425, 450, 475, 550, 650, 750, 850
Reference	Kobayashi, S., et al. (2015): The JRA-55 Reanalysis: general specifications and basic characteristics. *J. Meteor. Soc. Japan*, **93**, 5-48, DOI:10.2151/jmsj.2015-001.

MERRA2	
Title	NASA Modern-Era Retrospective analysis for Research and Applications, Version 2
Time Span	January 1980 – Present
Horizontal Resolution	0.625 x 0.500
Pressure levels	0.1, 0.3, 0.4, 0.5, 0.7, 1, 2, 3, 4, 5, 7, 10, 20, 30, 40, 50, 70, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 725, 750, 775, 800, 825, 850, 875, 900, 925, 950, 975, 1000
Theta levels	N/A
Reference	Molod, A., et al. (2015): Development of the GEOS-5 atmospheric general circulation model: evolution from MERRA to MERRA2. *Geosci. Model Dev.,* **8,** 1339-1356, DOI:10.5194/gmd-8-1339-2015.

NCEP-NCAR I	
Title	NCEP/NCAR Reanalysis I
Time Span	January 1948 – Present
Horizontal Resolution	2.5 x 2.5
Pressure levels	10, 20, 30, 50, 70, 100, 150, 200, 250, 300, 400, 500, 600, 700, 850, 925, 1000
Theta levels	N/A
Reference	Kistler, R., et al. (2001): The NCEP-NCAR 50-Year Reanalysis: monthly means CD-ROM and documentation. Bull. Amer. Meteor. Soc., 82, 247-267, DOI:10.1175/1520-0477(2001)082<0247:TNNYRM>2.3.CO;2.

NOAA20CR	
Title	NOAA-CIRES Twentieth Century Reanalysis
Time Span	January 1958 – Present
Horizontal Resolution	2.5 x 2.5
Pressure levels	10, 20, 30, 50, 70, 100, 150, 200, 250, 300, 400, 500, 600, 700, 850, 925, 1000
Theta levels	N/A
Reference	Compo, G. P., et al. (2011): The Twentieth Century Reanalysis Project. *Q. J. R. Meteorol. Soc.,* **137,** 1-28, DOI:10.1002/qj.776.

Climate Indices

The SSWC also incorporates climate indices to give a fuller picture of the atmospheric state around sudden warming occurrences. These climate indices include diagnostics for the Madden-Julian oscillation (MJO), the quasi-biennial oscillation (QBO), and the El-Niño Southern Oscillation (ENSO). Details of each index are given below.

MEI	
Title	Multivariate ENSO Index
Description	Bimonthly index of ENSO phase based on six observed fields from the tropical Pacific ocean.
Time Span	January 1950 – Present
Source	http://www.esrl.noaa.gov/psd/enso/mei/index.html

ONI	
Title	Oceanic Niño Index
Description	3 month running mean of the Niño 3.4 region sea surface temperature anomalies.
Time Span	January 1950 – Present
Source	http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml

SOI	
Title	Southern Oscillation Index
Description	Monthly mean difference in sea-level pressures between Tahiti and Darwin, Australia.
Time Span	January 1951 – Present
Source	http://www.cpc.ncep.noaa.gov/data/indices/soi

OMI	
Title	The OLR MJO Index
Description	Daily amplitude and phase of first two principal component time series of filtered outgoing longwave radiation.
Time Span	January 1979 – Present
Source	http://www.esrl.noaa.gov/psd/mjo/mjoindex/

QBO	
Title	Quasi-biennial oscillation data
Description	Monthly mean zonal winds from Singapore at 30, 50, and 70 hPa.
Time Span	January 1953 – Present
Source	http://www.geo.fu-berlin.de/en/met/ag/strat/produkte/qbo/

Output data description

There is one intermediate output and two final outputs for the SSWC: field variable data, and climatological statistics and event-based data, respectively.

The field variable data are derived from raw reanalysis input data. To make these data, the raw data are daily averaged and interpolated to a 2.5x2.5 degree horizontal grid. Data are kept on provided pressure levels, and given fields are interpolated to isentropic surfaces. For the latter, unless isentropic-level data is provided, theta values are calculated from temperature data on pressure levels. The data, either on pressure or isentropic levels, are interpolated to the desired theta levels. These field variable data are stored as annual files that span July 01 – June 30 of a given year.

Climatological statistics include the mean and standard deviations of all output fields, and percentiles from the climatological distribution for a selection of surface fields: tsfcMin, tsfcMax, prec. Each output statistic is contained in its own file. The climatological statistics are defined at each spatial point for 366 days. The climatological mean is calculated by retaining the first four Fourier coefficients from the daily-mean climatology. The standard deviation is then calculated from the original data and this smoothed climatological mean. Percentiles are calculated following a method described in Zhang (2005), their Eq. 1. Chosen percentiles are 5, 10, 90, and 95%. These statistics are calculated using the entire data record. As such, when the Compendium is updated with any new data, all these files must also be updated.

Event-based data files contain full field, anomaly, and derived fields for the 60 days on either side of a given event date. These fields constitute a set of data that have been regularly used to study SSWs and their surface impacts[1]. The SSWC field

[1] Our set certainly does not constitute the full range of data that have or will be considered with respect to SSWs. There are notable omissions in the current version, such as the Eliassan-Palm flux vector components.

variable data and climatological statistics are used in generating these data. Climate indices contained in these event-based data files are interpolated to daily values.

All intermediary and final output data produced for the SSWC are stored in CF-compliant netCDF-4 files with standard naming conventions described below. See the section "Reading SSWC output" for details on properly reading these netCDF files.

Field variable data

Standardized name conventions for the climatological statistics contained in the SSWC are given below. These are intermediary data that are used for generating the climatological statistics and event-based data final products.

File name convention

Contents	Convention
Field variable	SSWC_{FIELD}_{RASET}_s{SDATE}_e{EDATE}.nc

File name descriptor

Descriptor	Description
FIELD	Meteorological field short name
RASET	Reanalysis short name
SDATE	Starting date of the climatology (YYYYMMDD)
EDATE	Ending date of the climatology (YYYYMMDD)

Content variables

Contents	Variable Name	Description
Field variable	uwnd	Zonal wind
	vwnd	Meridional wind
	temp	Air temperature
	geop	Geopotential height
	o3	Ozone mixing ratio on pressure surfaces
	o3Theta	Ozone mixing ratio on isentropic surfaces
	tcO3	Total column ozone
	prec	Precipitation
	snow	Snowfall liquid water equivalent
	mslp	Mean sea-level pressure
	psfc	Surface pressure
	tsfc	Daily mean surface temperature
	tsfcMin	Daily minimum surface temperature
	tsfcMax	Daily maximum surface temperature
	epv	Ertel's potential vorticity
	NAMindex	NAM index
	vt	Eddy meridional heat flux
	vt1	Wave 1 eddy meridional heat flux
	vt2	Wave 2 eddy meridional heat flux
	uv	Eddy momentum flux

	uv1	Wave 1 eddy momentum flux
	uv2	Wave 2 eddy momentum flux

Climatological statistics

Standardized name conventions for the climatological statistics contained in the SSWC are given below. Bracketed text in the file name convention indicates file name descriptors that are defined subsequently.

File name convention

Contents	Convention
Mean	SSWC_v{#}_{FIELD}ClimMean_{RASET}_s{SDATE}_e{EDATE}_c{CDATE}.nc
Standard Deviation	SSWC_v{#}_{FIELD}ClimStds_{RASET}_s{SDATE}_e{EDATE}_c{CDATE}.nc
Percentile	SSWC_v{#}_{FIELD}Pct{PNUM}_{RASET}_s{SDATE}_e{EDATE}_c{CDATE}.nc

File name descriptor

Descriptor	Description
#	Version number
FIELD	Meteorological field short name
PNUM	Percentile number
RASET	Reanalysis short name
SDATE	Starting date of the climatology (YYYYMMDD)
EDATE	Ending date of the climatology (YYYYMMDD)
CDATE	Creation date of the file (YYYYMMDD)

Content variables

Contents	Variable Name	Description
Mean	{FIELD}ClimMean	Climatological mean of {FIELD}
Standard Deviation	{FIELD}ClimStds	Standard deviation of {FIELD}
Percentile	{FIELD}Pct{PNUM}	{PNUM}th percentile value of {FIELD}

Event-based data

Standardized name conventions for the climatological statistics contained in the SSWC are given below. Bracketed text in the file name convention indicates file name descriptors that are defined subsequently.

File name convention

Contents	Convention
Full fields	SSWC_v{#}_varFull_{RASET}_d{DDATE}_s{SDATE}_e{EDATE}_c{CDATE}.nc
Anomaly fields	SSWC_v{#}_varAnom_{RASET}_d{DDATE}_s{SDATE}_e{EDATE}_c{CDATE}.nc
Derived fields	SSWC_v{#}_varDerive_{RASET}_d{DDATE}_s{SDATE}_e{EDATE}_c{CDATE}.nc

File name descriptor

Descriptor	Description
#	Version number
RASET	Reanalysis short name
DDATE	Event date (YYYYMMDD)

SDATE	Starting date of the event data (YYYYMMDD)
EDATE	Ending date of the event data (YYYYMMDD)
CDATE	Creation date of the file (YYYYMMDD)

Content variables

Contents	Variable Name	Description
Full fields	uwndFull_TS	Zonal wind
	vwndFull_TS	Meridional wind
	tempFull_TS	Air temperature
	geopFull_TS	Geopotential height
	o3Full_TS	Ozone mixing ratio on pressure surfaces
	o3ThetaFull_TS	Ozone mixing ratio on isentropic surfaces
	tcO3Full_TS	Total column ozone
	precFull_TS	Precipitation
	snowFull_TS	Snowfall liquid water equivalent
	mslpFull_TS	Mean sea-level pressure
	psfcFull_TS	Surface pressure
	tsfcFull_TS	Daily mean surface temperature
	tsfcMinFull_TS	Daily minimum surface temperature
	tsfcMaxFull_TS	Daily maximum surface temperature
	epvFull_TS	Ertel's potential vorticity
Anomaly fields	uwndAnom_TS	Zonal wind anomaly
	vwndAnom_TS	Meridional wind anomaly
	tempAnom_TS	Air temperature anomaly
	geopAnom_TS	Geopotential height anomaly
	geopStds_TS	Geopotential height standard deviation
	o3Anom_TS	Ozone mixing ratio anomaly on pressure surfaces
	o3ThetaAnom_TS	Ozone mixing ratio anomaly on isentropic surfaces
	tcO3Anom_TS	Total column ozone anomaly
	precAnom_TS	Precipitation anomaly
	snowAnom_TS	Snowfall liquid water equivalent anomaly
	mslpAnom_TS	Mean sea-level pressure anomaly
	psfcAnom_TS	Surface pressure anomaly
	tsfcAnom_TS	Daily mean surface temperature anomaly
	tsfcMinAnom_TS	Daily minimum surface temperature anomaly
	tsfcMaxAnom_TS	Daily maximum surface temperature anomaly
	epvAnom_TS	Ertel's potential vorticity anomaly
Derived fields	vortFull_TS	Absolute vorticity
	vortFilt_TS	T11 spherical truncated (filtered) absolute vorticity
	NAMindex_TS	NAM index
	vtFull_TS	Eddy meridional heat flux
	vt1Full_TS	Wave 1 eddy meridional heat flux

	vt2Full_TS	Wave 2 eddy meridional heat flux
	uvFull_TS	Eddy momentum flux
	uv1Full_TS	Wave 1 eddy momentum flux
	uv2Full_TS	Wave 2 eddy momentum flux
	vtAnom_TS	Eddy meridional heat flux anomaly
	vt1Anom_TS	Wave 1 eddy meridional heat flux anomaly
	vt2Anom_TS	Wave 2 eddy meridional heat flux anomaly
	uvAnom_TS	Eddy momentum flux anomaly
	uv1Anom_TS	Wave 1 eddy momentum flux anomaly
	uv2Anom_TS	Wave 2 eddy momentum flux anomaly
	uwndAnom_AbsMinVals	Time series of zonal wind anomaly absolute minima
	uwndAnom_AbsMinLons	Longitudes of zonal wind anomaly absolute minima
	uwndAnom_AbsMinLats	Latitudes of zonal wind anomaly absolute minima
	uwndAnom_AbsMinPres	Pressures of zonal wind anomaly absolute minima
	uwndAnom_AbsMinHgts	Heights of zonal wind anomaly absolute minima
	uwnd_RevDate	Days from event date at which zonal wind becomes easterly
	uwnd_RevPres	Pressure levels at which zonal wind becomes easterly
	tempAnom_AbsMaxVals	Time series of temperature anomaly absolute maxima
	tempAnom_AbsMaxLons	Longitudes of temperature anomaly absolute maxima
	tempAnom_AbsMaxLats	Latitudes of temperature anomaly absolute maxima
	tempAnom_AbsMaxPres	Pressures of temperature anomaly absolute maxima
	tempAnom_AbsMaxHgts	Heights of temperature anomaly absolute maxima
	eiTN05P	Boolean for daily minimum temperature $< 5^{th}$ percentile
	eiTN10P	Boolean for daily minimum temperature $< 10^{th}$ percentile
	eiTN90P	Boolean for daily minimum temperature $> 90^{th}$ percentile
	eiTN95P	Boolean for daily minimum temperature $> 95^{th}$ percentile
	eiTX05P	Boolean for daily maximum temperature $< 5^{th}$ percentile
	eiTX10P	Boolean for daily maximum temperature $< 10^{th}$ percentile
	eiTX90P	Boolean for daily maximum temperature $> 90^{th}$ percentile

	eiTX95P	Boolean for daily maximum temperature > 95th percentile
	eiR95P	Boolean for daily precipitation > 95th percentile
	meiIndex	Interpolated time series of MEI (Multivariate ENSO Index)
	omiIndex	Time series of OMI (OLR MJO Index) combined amplitude
	omiPhase	Time series of OMI (OLR MJO Index) phase
	oniIndex	Interpolated time series of ONI (Oceanic Nino Index)
	qbo10Vals	Interpolated observed zonal mean zonal winds at 10 hPa
	qbo30Vals	Interpolated observed zonal mean zonal winds at 30 hPa
	qbo50Vals	Interpolated observed zonal mean zonal winds at 50 hPa
	qbo70Vals	Interpolated observed zonal mean zonal winds at 70 hPa
	soiIndex	Interpolated time series of SOI (Southern Oscillation Index)

Reading the SSWC output

All outputs from the SSWC (field variable data, climatological statistics, and event-based data) are packed as short integers into CF-compliant netCDF-4 files. Compliance with CF (Climate and Forecast) metadata standards ensures that the output files themselves contain high detail on the contents of each variable.

Note: NetCDF-4 or greater is required to read the output files. Errors reading the data will be encountered for previous versions of the netCDF libraries.

Short integer packing of the contained variables greatly reduces file sizes of the outputs while adding only a small computational cost during packing and unpacking. Packed data include both an add_offset and $scale\_factor$ attributes so that

$$unpacked\_data = packed\_data * scale\_factor + add\_offset.$$

These attributes are calculated by:

$$scale\_factor = (dataMax - dataMin)/(2^n - 2)$$

$$add\_offset = dataMin + (2^{n-1}) * scale\_factor,$$

where n is the bit resolution of the packed data. Packing the data is then the inverse method to unpacking, but requires rounding to the nearest integer:

$$packed\_data = ROUND((unpacked\_data - add\_offset)/scale\_factor).$$

The denominator of $2^n - 2$ in $scale\_factor$ is used here to scale all values between $-2^n/2$ and $2^n/2 - 2$. This leaves the integer $2^n/2 - 1$ available for missing values.

Note: the SSWC uses 16-bit packing and sets all missing data to 32767. These missing value points must be accounted for prior to unpacking the remainder o f the data. The remainder of the packed data span integers from -32768 to 32766.

Some programming platforms will properly read packed data, unpacking to original data types and accounting for missing values, but not all. Care must be taken while reading packed data else missing values may be unknowingly counted as finite data points.

Production algorithm

An informal description of the SSWC production algorithm follows. This is intended to give an end-user a basic knowledge of how the SSWC is generated from the input data.

Note: more detailed usage and API guides are available for using the Compendium code itself.

Input data spanning the entire desired record are firstly accumulated. The production user then provides overview details of these data, such as time span, directory, and generalized file names, to a userInput script. Details of the individual variables are provided at this time as well. Production users also define an event list giving the dates used for producing the event-based data.

The input data are then read by the Compendium and stored as the field variable data described in "Output data description." In this process, the input data are interpolated to the desired horizontal grid and chunked into yearly segments spanning July 01 through June 30 of the next year. These yearly chunks of data are stored in CF-compliant netCDF-4 files to increase accessibility to production users. This portion of the algorithm also requires some side computations, such as calculation of wave fluxes and interpolation of select fields to isentropic surfaces.

Climatological statistics are then calculated from these field variable data. Any field variables that rely on climatological statistics, such as annular mode indices, are then computed and stored alongside the other field variable data.

The event-based data are then compiled using combinations of the field variable data and the climatological statistics. Climate indices are incorporated here as well. Dates of these events are defined by the event list passed by the production user to the code. Together with the climatological statistics, this constitutes the primary output of the SSWC.

References

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Changelog

v1.0 : First official release.