Influence of Solar Activity Cycles on Earth's Climate

Task 2 – Identification of Relevant Data

WP203 – Earth's Climate

N. Marsh, H. Svensmark, and F. Christiansen
Danish National Space Center

August 5, 2005

Contents

INTRODUCTION 3

DATA SETS – DESCRIPTIONS 4

- **SURFACE CLIMATE DATA** 4
- **SATELLITE CLIMATE DATA** 8
- **VEGETATION** 12
- **SNOW AND ICE COVER** 13
- **EXTREME WEATHER** 15

CONCLUSIONS 18

REFERENCES 19

DATA SETS – TABLES OF SOURCES AND AVAILABILITY 21

Introduction

The aim of this report is to identify relevant data sets for exploring a possible response in observed climate parameters to solar variability. Task 1 outlined the various routes currently under consideration, which describe how solar variability might influence climate change. Data relevant for exploring the chain of events that are involved in the proposed links between solar driven external forcing and processes in the lower, denser, layers of the atmosphere have previously been identified in WP 201 and WP 202. To avoid too large an overlap, the current report will focus on identifying observations relevant for climate processes at, or near, the Earth's surface.

The data sets need to fulfill similar objectives regarding spatial and temporal coverage as those outlined in WP202. Since the climate response may vary between different geographic zones, high latitude vs. low latitude, oceans vs. land, it is important that the data have a reasonable geographic resolution. The many different time scales in solar activity (see WP101 and WP202) also means that the temporal resolution of the data is important. For this study annual averages are an absolute minimum, but when exploring periods of strong solar variability at short time-scales, e.g., Forbush decreases, then hourly measurements will be necessary.

A large number of land-based stations provide direct observations of various meteorological variables at the surface, with data available at hourly to daily averages over periods of a century or longer. Over the oceans similar observations are provided by ships, however, spatial coverage is limited to the major shipping routes, where often only monthly averages are available. Satellite observations provide a more homogeneous spatial coverage, but are only available for a limited period extending back no more than about 20 years. As a result a combination of surface based and satellite observations have been acquired. The data sets presented in the following report have been sub-divided into three groups, land, ocean and global, depending on their natural geographic distribution, e.g., vegetation, or restrictions in the observing networks coverage, e.g., meteorological stations.

Data Sets – Descriptions

Surface climate data

Climate data measured at Earth's surface, from both meteorological stations or on ships, have both advantages and drawbacks. The foremost advantage is the long time span for which data are available. An analysis of the influence on Earth's climate of the most prominent of the Sun's cycles, the 11-year sunspot cycle, requires data that spans at least 20 years. However, it would be preferable to have considerably longer time series. Surface data with a reasonable geographic coverage extend back more than a hundred years providing the opportunity to analyse several sunspot cycles. There are drawbacks to surface data though. One is the uneven geographical coverage. Western Europe and North America are densely covered with meteorological stations, whereas parts of Africa and South America are only covered sparsely and the large oceans even more so. Perhaps an even more severe drawback that has been raised in discussions on global warming is the temporal inhomogeneity of the observations obtained at each station. Concerns have been raised regarding the positioning of weather stations, which are often placed near cities, and that industrialization in the vicinity of these stations changed the local conditions under which observations were made to such an extent that comparing observations, particularly temperature, over longer time periods is inadvisable. These concerns should be borne in mind when evaluating surface climate data.

A number of gridded climate data sets have been created from surface stations going back more than 100 years at the Climate Research Unit (CRU), University of East Anglia (http://www.cru.uea.ac.uk/cru/cru.htm), and the Hadley Centre for Climate Prediction and Research at the UK Met Office. During the earliest years geographical coverage of surface measurements is very sparse, but during the 20th century regular measurements from 1000s of stations have been available for the construction of the gridded data sets. The gridded data sets from CRU are monthly means. For investigating shorter period variations, e.g. Forbush events, daily or even hourly values are needed. Comprehensive data sets of global hourly observations would be overwhelming to analyse. We have restricted our choice to a single data set of hourly values, a gridded data set of precipitation over the US.

Finally, a number of indices exist that describe large dynamic patterns of the atmosphere, of which we have included the NAO and the SOI indices in our data selection.

Monthly Precipitation over Land (1900-1998)

Dr. Mike Hulme from CRU has constructed an historical monthly precipitation data set for global land areas from 1900 to 1998, gridded at two different resolutions: 2.5° latitude by 3.75° longitude (gu23wld0098) and 5° latitude/longitude (g55wld0098) using more than 11,800 station time series. In the creation of the gridded data set a polygon weight method (Thiessen polygon weights) were used to average gauge data within the grid-boxes. Missing station data were replaced with estimates from surrounding stations using the mean anomaly with respect to a reference period if there were valid station data in the vicinity (less than 600 km). The data are described in Hulme (1992) and are available from http://www.cru.uea.ac.uk/~mikeh/datasets/global/.

Monthly Precipitation over tropics (1972-1994)

Related to the Hulme data set (gu23wld0098), for precipitation over land, Doherty et al. (1999) have created a data set of combined precipitation for land and ocean for the extended tropical region of 30°N to 30°S from 1974 to 1994 (gu23trp7494). This is provided on a 2.5° latitude x 3.75° longitude grid. Here the ocean component is derived from satellite Outgoing Longwave Radiation measurements employing a linear threshold algorithm to convert cloud-top temperatures to precipitation rates. The land and ocean data sets were combined using a Poisson blending technique to produce a continuous merged climatology for the extended tropics. This data set is available from http://www.cru.uea.ac.uk/~mikeh/datasets/global/.

CPC hourly US precipitation data (1948-2002)

This data set is derived from approximately 2,500 US station reports and covers the period 1948-2002 (cpc_us_hourly_prec). The data set is gridded and smoothed on a 2.0° latitude x 2.5° longitude grid using a Cressman scheme with modifications, and covers the area 20N-60.0N, 220.0E-297.5E. It should be noted that any grid boxes falling over the oceans contain data that was derived solely from data obtained over land. The data are provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, USA, and are available from http://www.cdc.noaa.gov/cdc/data.cpc_hour.html. The data set is described in Higgins et al. (1996). Figure 1 shows the mean annual frequency of hourly precipitation over the US derived from these data.

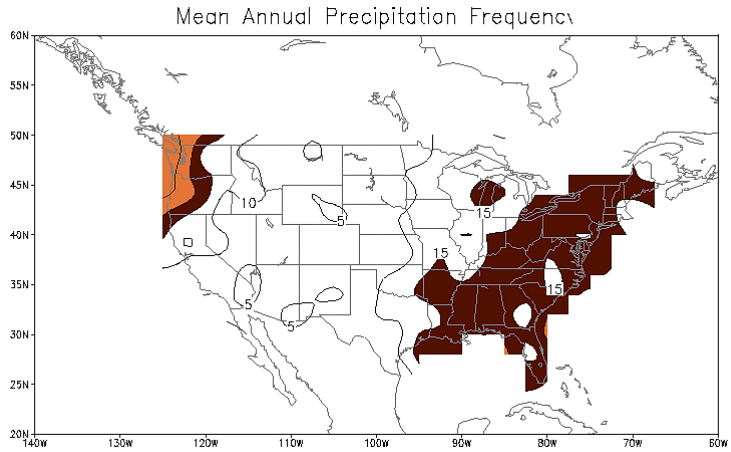


Figure 1: Mean (1963-1993) annual frequency of hourly precipitation expressed as a percentage of the total number of hours in a year. Dark (light) shading denotes regions with frequencies exceeding 15% (20%). From www.cpc.ncep.noaa.gov/research_papers/ncep_cpc_atlas/1/figs.html

Monthly Mean Sea Level Pressure (1873-2000)

Dr. Phil Jones of CRU has created a dataset of monthly mean-sea-level pressure for the northern hemisphere on a 5° latitude x 10° longitude grid for the period 1873-2000 (mslpnh). The sources of the original chart data are given in Jones (1987). The data set is available from http://www.cru.uea.ac.uk/cru/data/pressure.htm.

Monthly Mean Surface Temperature over Land (1851-present)

CRU have also generated a 5° x 5°gridded surface temperature data set which is available from CRU for 1851-present over global land areas (CRUTEM2). More than 3000 monthly station temperature time series are used with a dense cover in the more populated parts of the world, particularly, the United States, southern Canada, Europe

and Japan, but a much sparser coverage over the interior of the South American, the African continents, and over the Antarctic. Coverage is extremely sparse in the early years, however, hemisperic averages are available from 1856-present. The data set and a number of references for its use can be found at http://www.cru.uea.ac.uk/cru/data/temperature/. Jones and Moberg (2003) provide a description of the techniques used to derive the gridded data set, and discuss the issue of consistency and homogeneity of the measurements through time and the steps that have made to ensure all non-climatic inhomogeneities have been removed. Folland et al. (2001) describe the extended global hemispheric averages.

Monthly Mean Sea Surface Temperature (1870-present)

Hadley Centre for Climate Prediction and Research at the UK Met Office has constructed a global data set of monthly mean sea surface temperature anomalies, on a 1° latitude x 1° longitude grid, for the period 1870-present (HadISST_1.1_SST). The sea surface temperature measurements were taken on board merchant and some naval vessels. As the majority come from a voluntary observing fleet, coverage is reduced outside of the main shipping lanes, and is minimal over the Southern Oceans. During more recent times satellite AVHHR observations of SST have blended with the in-situ measurements. Included in the data set is also sea ice coverage. The data are described in Rayner et al. (2003) who also discuss the reasons for using sea surface temperatures rather than marine air temperatures and the steps that have been taken to remove spatial and temporal inhomogeneities from the gridded data. The data are available from http://badc.nerc.ac.uk/data/hadisst/.

Global Monthly Surface Temperature (1870-present)

A combination of the ocean (HadISST_1.1_SST) and land (CRUTEM2) surface temperature data sets has been constructed to give a global dataset on a 5° latitude x 5° longitude grid, for the period 1870-present (HadCRU2). This is available from http://www.cru.uea.ac.uk/cru/data/temperature/. Figure 2 shows an example of the global temperature anomalies from August 2000.

Monthly High-resolution gridded data over land (1901-2002)

A 0.5 degree gridded data set over global land areas has been created by Dr. T. D. Mitchell for a number of variables over the period 1901-2002 (CRU_TS_2.1). This includes precipitation, temperature (mean, min., max., and diurnal range), cloud cover, vapour pressure, frost day frequency, and wet day frequency. The data set extends an earlier version created by New et al. (2000). Fields of monthly climate anomalies, relative to the 1961–90 mean, were interpolated from surface climate data. The anomaly grids were then combined with a 1961–90 monthly mean climatology to arrive at grids of monthly climate over the entire period. Precipitation, mean temperature, and diurnal temperature range were interpolated directly from station observations. The remaining parameters were interpolated from merged datasets including station observations and synthetic data estimated using predictive relationships with the primary variables in regions where no station data, was available. Figure 3 shows the precipitation anomalies from August 2000 with respect to 1961-1990. The data are described in Mitchell et al. (2004) and New et al. (2000) and are available from http://www.cru.uea.ac.uk/~timm/grid/CRU_TS_2_0.html.

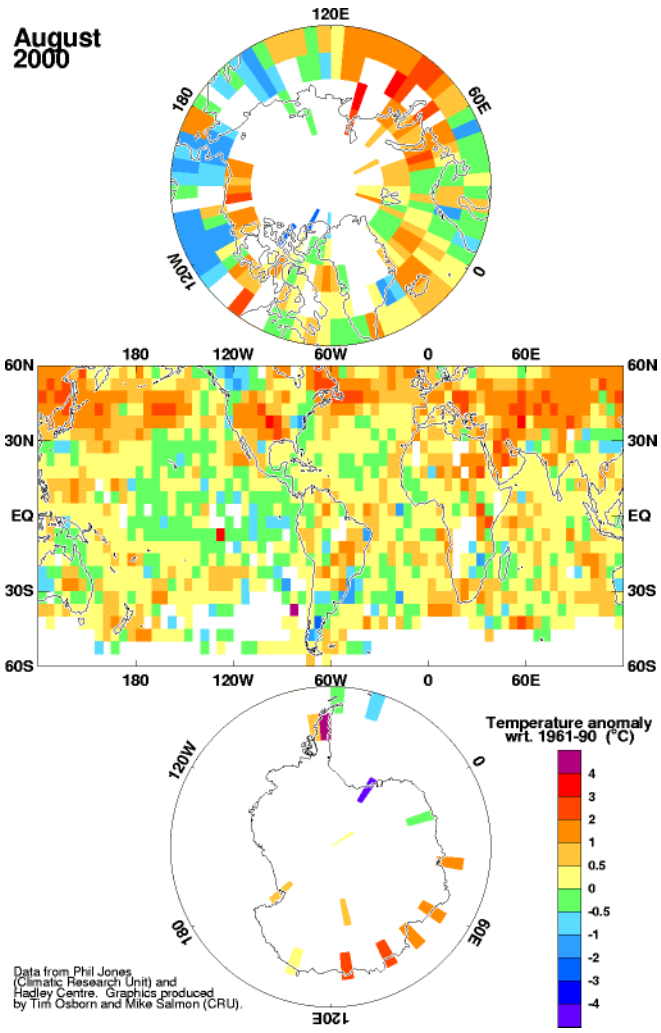


Figure 2: Global temperature anomalies August 2000 with respect to 1961-1990. From http://www.cru.uea.ac.uk/cru/climon/data/tgrid/.

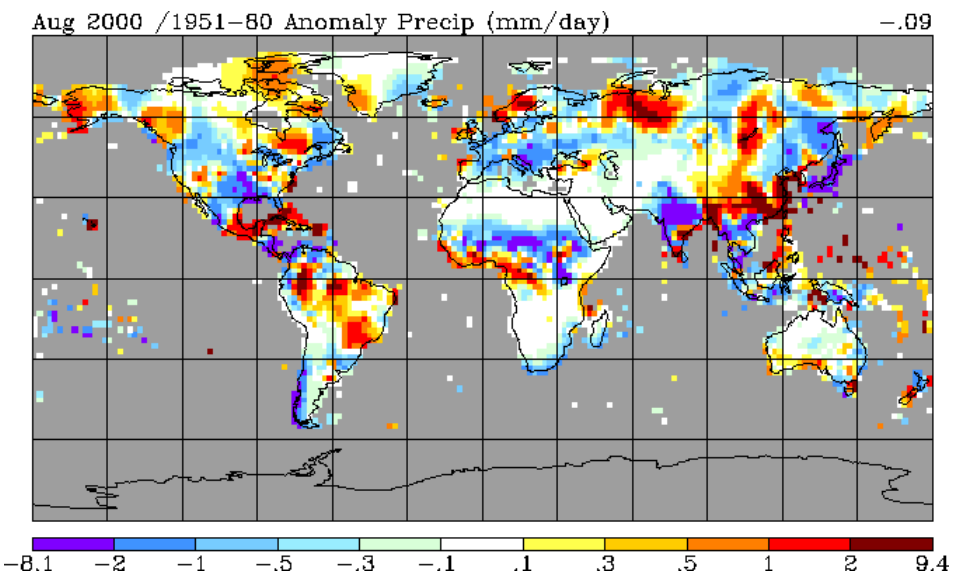


Figure 3: Precipitation anomaly for August 2000. From http://data.giss.nasa.gov/precip_cru/maps.html.

NAO and SOI

The North Atlantic Oscillation (NAO) is one of the major modes of atmospheric variability that is particularly important in winter, when it exerts a strong control on the climate of the Northern Hemisphere. The phase and amplitude of the NAO is traditionally represented by an index defined as the normalized pressure difference between a station on the Azores and one on Iceland. However, for winter Gibraltar data can be used in place of the Azores. Figure 4 shows the NAO for winter which is also the season that exhibits the strongest interdecadal variability. Jones et al. (1997) have used early instrumental data to extend the NAO index back to 1821. Monthly NAO data for the period 1821-2000 can be found at http://www.cru.uea.ac.uk/cru/data/nao.htm.

A similar pattern of atmospheric variability can be found in the southern hemisphere. Known as the Southern Oscillation Index (SOI) it is defined as the normalized pressure difference between Tahiti and Darwin. The El-Niño is a major feature of this ocean-atmospheric interaction that leads to a warming of surface waters in the pacific off the coast of the southern Americas. Ropelewski and Jones (1987) have extended the SOI index back to 1866, and monthly data for 1866-2004 is available at http://www.cru.uea.ac.uk/cru/data/soi.htm.

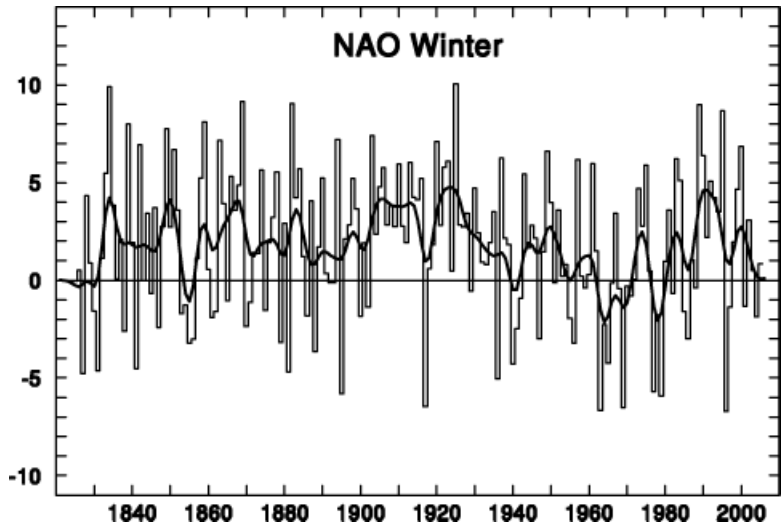


Figure 4: The North Atlantic Oscillation, Winter Conditions. From http://www.cru.uea.ac.uk/cru/climon/data/nao/

Satellite climate data

Satellite data have the opposite advantages and drawbacks to those of surface data. The time period of available data is relatively short, rarely more than a couple of decades. The geographical coverage, however, is considerably improved with no bias towards industrialized areas. A number of satellite data sets were described in WP202, "Possible Interactions and Modifications", that are also highly relevant to this report. Here we reproduce the relevant parts of these sections together with additional satellite climate data. Also included in this section are reanalysis data. These are not satellite data per se, but rather the assimilation of comprehensive sets of meteorological data into physical models of the atmosphere with satellite data included from the time when they became available. However, by their nature the reanalysis data encompasses the largest set of meteorological data available. With an

output 4 times daily and availability over the period 1948-present, they span a number of solar cycles and are as such invaluable to our task.

Reanalysis Data

The aim of a reanalysis project is to assimilate comprehensive sets of historical meteorological data into full physical models of the atmosphere. The models take into account parameterizations of all major physical processes, such as convection, large-scale precipitation, shallow convection, gravity wave drag, etc. Data from two major reanalysis projects are available, the NCEP/NCAR project at the NOAA Climate Diagnostics Center and the ERA-40 project at the European Centre for Medium-Range Weather Forecasts. A schematically is shown in figure 5 of the data input used in the ERA-40 project beginning with surface observations from land stations and ships, and the soundings from radiosonde and pilot balloons. In 1973 the first satellite observations are included; radiances available from the first of the VTPR instruments flown on the early NOAA series of operational polar-orbiting satellites. In 1979 VTPR data were replaced by data from the three (MSU/HIRS/SSU) TOVS instruments on new NOAA platforms and winds became available in significant numbers from geostationary satellites. At this point there were also substantial increases in buoy and aircraft data and ozone data become available from the TOMS and SBUV instruments at about the same time. Newer satellite instruments from which data were assimilated in ERA-40 are SSM/I from 1987 onwards, the ERS altimeter (for the ocean-wave analysis) from 1991, the ERS scatterometer from 1993 and AMSU-A (the MSU/SSU replacement) from 1998.

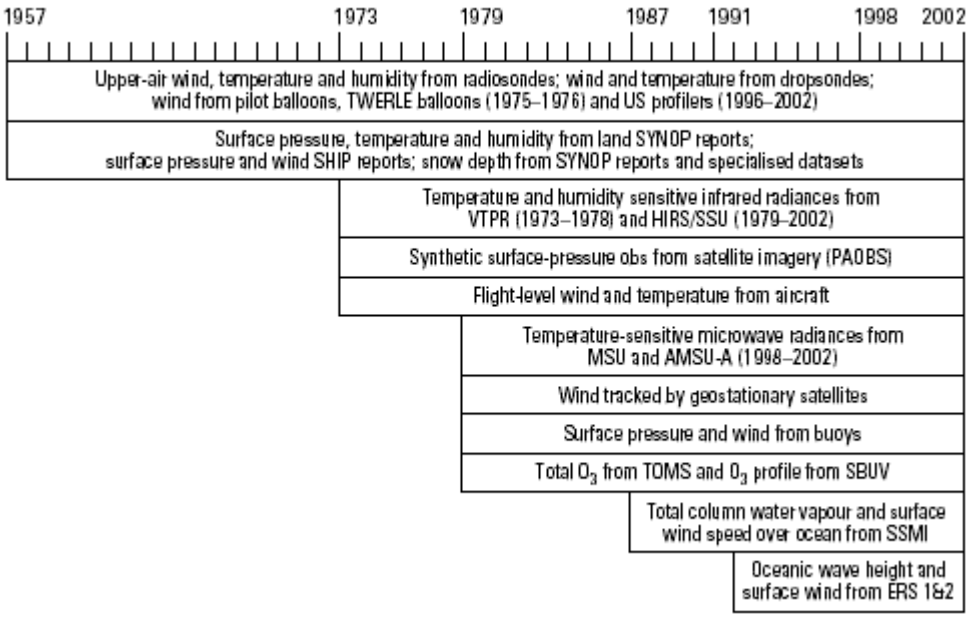


Figure 5: The data input into the ERA-40 project. From the ERA-40 Atlas paper: http://www.ecmwf.int/publications/library/ecpublications/_pdf/era40/ERA40_PRS19.pdf

NCEP/NCAR

The NCEP/NCAR model uses a horizontal resolution of approximately 200 km and vertical resolution at 28 levels from the surface to about 3 hPa. The model assimilates past data from 1948 to the present. Output is 4 times daily. The basic dynamical

weather parameters (temperature, geopotential height, humidity, and winds) are available at 17 pressure levels from 10 hPa down to 1000hPa, as well as at the surface. At the surface various additional parameters are available; pressure, water runoff, soil humidity, temperatures of 0-10 cm layer and 10-200 cm layer, ground heat flux etc. The full data sets can be obtained from http://www.cdc.noaa.gov/cdc/reanalysis/. Figure 6 shows an example of a daily average the mean air temperature (surface) from August 1, 2000.

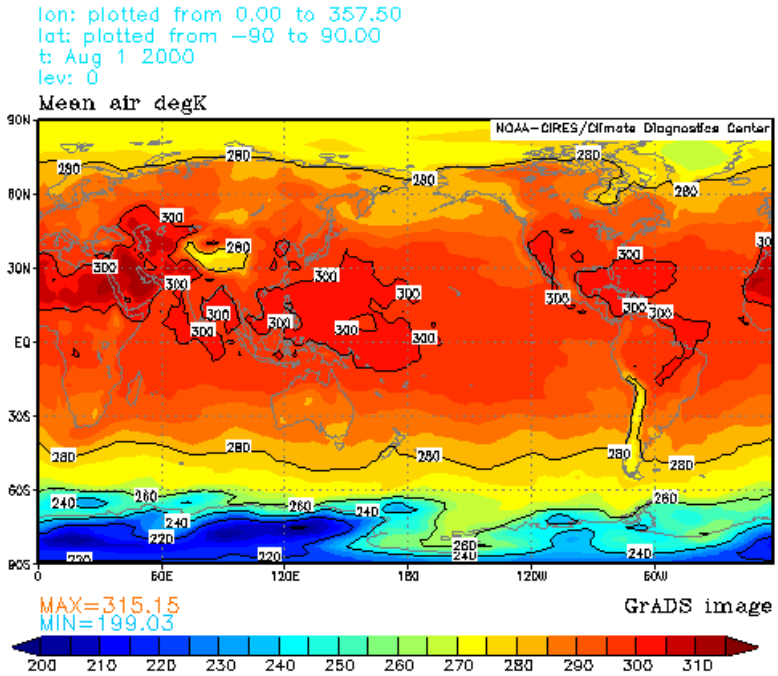


Figure 6: Average surface temperature for August 1, 2000. From http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.html#surface.

ECMWF

The reanalysis project ERA-40 covers the period from mid-1957 to 2001. The reanalysis involves comprehensive use of satellite data, starting from the early Vertical Temperature Profile Radiometer data in 1972. The output is similar to the NCEP/NCAR model with output 4 times daily and a variety of output parameters. The ERA-40 project is described in a series of project reports that maybe found at http://www.ecmwf.int/publications/library/do/references/list/192. Simmons et al. (2004) present a comparison between ERA-40, NCEP/NCAR, and CRU surface air temperatures. Figure 7 shows an example of the surface (2-meter) temperature averaged over August 2000. The ERA-40 data products are available from http://www.ecmwf.int/products/data/index.html.

Temperature - Microwave Sounding Units

Satellite measurements of the Earth's microwave emissions are a crucial element in the development of an accurate system for long-term monitoring of atmospheric temperature. The prime source for satellite temperature profiles is the Microwave Sounding Units (MSU) that have been on board the NOAA polar-orbiting satellites for more than 25 years. The MSUs operate in four channels measuring atmospheric temperature in four thick vertical layers spanning the surface through the stratosphere. Since 1998 the Advanced Microwave Sounding Units (AMSUs) have been in

operation. This makes use of a larger number of channels, thus sampling the vertical temperature profile of the atmosphere with a much higher resolution. The MSU and AMSU instruments are not strictly intended for climate research, but rather for weather forecasting. However, NOAA produces a long-term data set that can be used for climate studies through inter-calibrating the measurements from nine different satellites. For a description of the technique of generating and validating temperature anomalies from MSU measurements, see Spencer and Christy (1992a and 1992b)

The temperature profiles for the lower troposphere and the lower stratosphere for the period 1979-2001 are available at DNSC, present day updates are continuously available from the Global Hydrology and Climate Center http://www.nsstc.uah.edu/data/msu/. Examples of the data available can be seen in Figures 8 and 9.

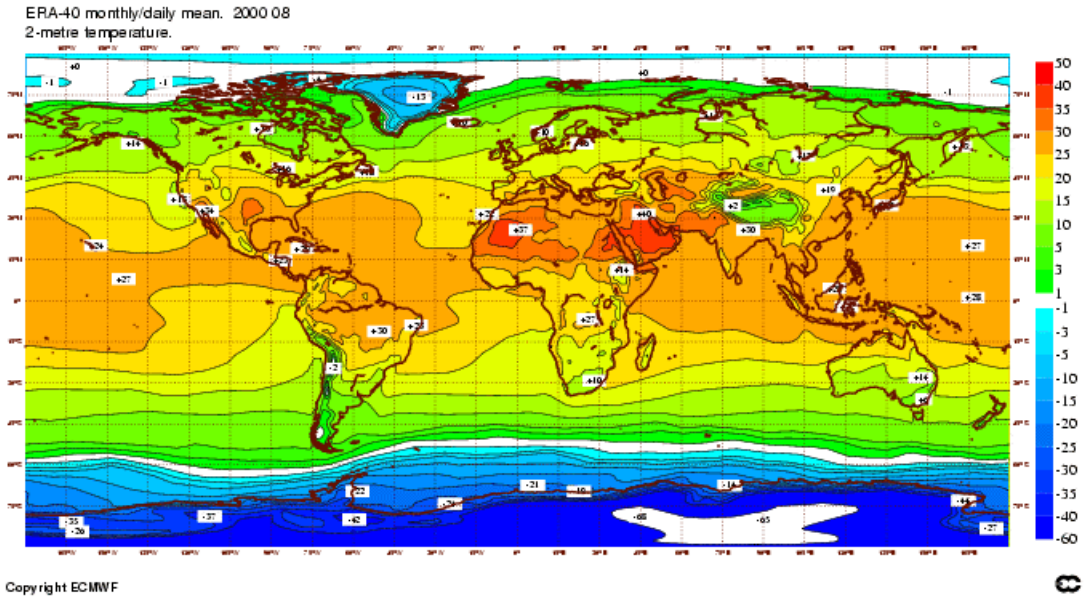


Figure 7:Average 2-meter temperature August 2000. From http://www.ecmwf.int/products/data/index.html.

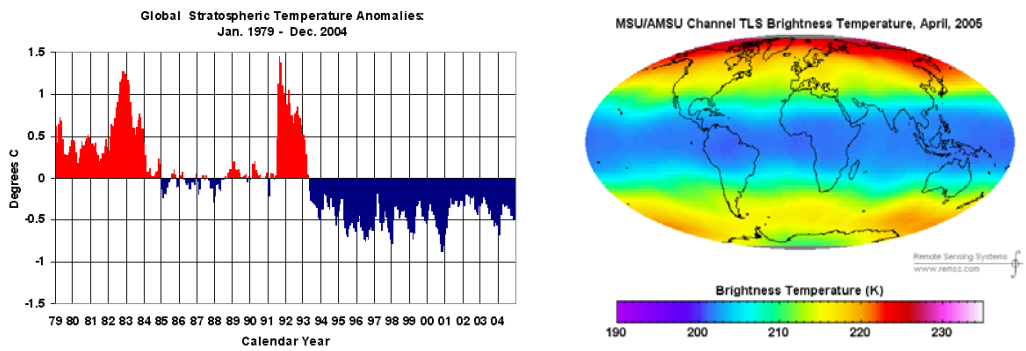


Figure 8: Global temperature average for 1979-present and a global view of the temperature of the lower stratosphere for April 2005. The global average is given as a deviation from a seasonally adjusted average. From http://www.ghcc.msfc.nasa.gov/MSU/msusci.html.

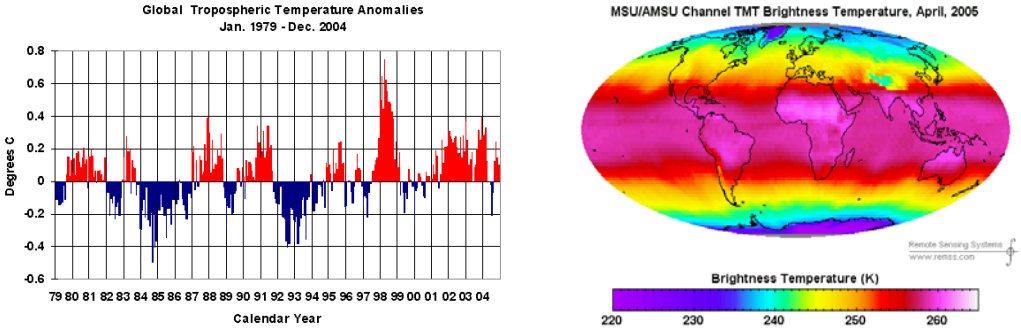


Figure 9: As Figure 8, but for the lower troposphere.

Hydrology – SSM/I

The Special Sensor Microwave/Imager (SSM/I) has been operating on the DMSP satellites since July 1987, except for a period July 1990 to December 1991 during which no valid SSM/I data was available. It delivers a host of hydrology products made available by NOAA/NESDIS Office of Research & Applications. The products include precipitation related parameters such as rainfall, liquid water path, total precipitable water, and cloud fraction, as well as snow and sea-ice cover, and surface wind speeds. The data are monthly averages and given on a 1-degree grid. Also available are data sets of monthly averages for the entire period of observation given on a 2.5-degree grid. The data sets are described in Ferraro et al. (1996) and are available from http://www.ncdc.noaa.gov/oa/satellite/ssmi/ssmiproducts.html. The rainfall anomaly for January 2004 is shown in Figure 10.

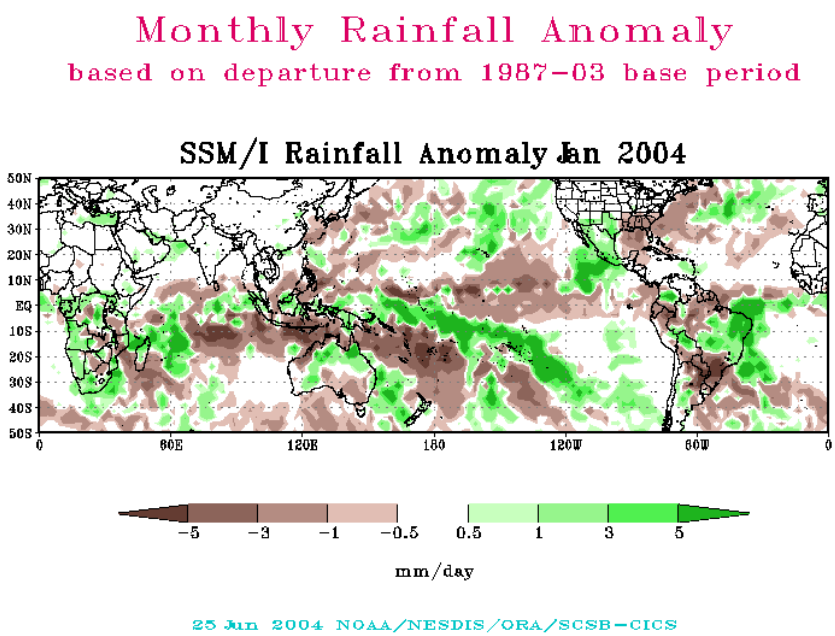


Figure 10: Rainfall anomaly from January, 2004. From http://cics.umd.edu/~rferraro/SSMI_Climate.html.

Vegetation

The effect of possible climate change on vegetation is of strong concern due to its importance for both human society and the biosphere as a whole. Global warming

may increase the extent of arid areas in desert regions, or move boundaries of various types of vegetation, particularly in polar-regions. At the same time vegetation plays an important role in the dynamics of Earth's climate influencing the exchange of CO_2 between the atmosphere and the land surface, land-surface evapotranspiration, and the absorption and release of energy by the land surface. Globally, change in vegetation is best surveyed by satellites registering changes in the reflection of light from Earth's surface.

GIMMS

The Global Inventory Modeling and Mapping Studies (GIMMS) of the University of Maryland provides a normalized difference vegetation index (NDVI) data set, a satellite record of monthly changes in terrestrial vegetation for the period 1981-2003 with a spatial resolution of 8 km derived from NOAA's AVHRR instruments. The NDVI is the difference (in reflectance) between the AVHRR near-infrared and visible bands divided by the sum of these two bands giving a value between -1 and 1. Values around 0 indicate bare soil, while values around 0.7 are a signature of lush vegetation. The data are available at http://glcf.umiacs.umd.edu/data/gimms/ and are described in Tucker et al. (2005). The NDVI for August 2000 is shown in Figure 11.

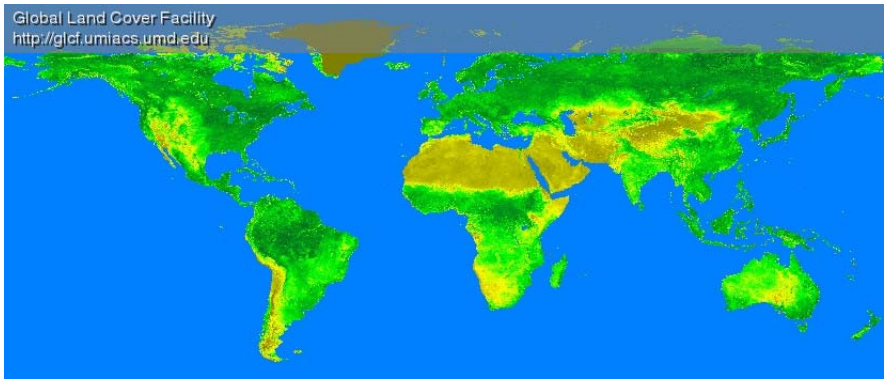


Figure 11: NDVI from August 2000. Brown/yellow is bare soil/sparse vegetation, green is lush vegetation. From http://glcf.umiacs.umd.edu/data/gimms/.

Snow and Ice Cover

Seasonal snow cover is the most rapidly varying natural surface feature. In the northern hemisphere, where 98 percent of the total seasonal snow cover is located, the monthly mean snow cover ranges from 7 to over 40 percent of the land area. This variability means that snow is a sensitive indicator of climate change with its dependence on temperature, precipitation and solar radiation. Each of these climactic factors is in turn influenced by the presence of snow due to changes in albedo and heat transfer between ground and atmosphere. Glaciers and ice sheets cover about 10 percent of the Earth's land area and are a result of accumulating snowfall over long periods of time. Currently two major ice sheets exist on Earth, in Greenland and in Antarctica. All continents, except Australia, bear ice in the form of mountain glaciers, smaller ice sheets, or ice caps.

Floating ice also plays an important role in Earth's climate, e.g., surface albedo, and includes sea ice, frozen lakes, and frozen rivers. Sea ice typically covers 14 to 16 million square kilometres of the Arctic Ocean, and 17 to 20 million square kilometers of the Southern Ocean around Antarctica, during their respective winter seasons.

Since snow and sea ice can influence global climate, and glaciers and ice sheets directly affect sea level, their role within the global climate system should not be underestimated. Satellite data indicate that during the past 30 years, annual snow cover in the Northern Hemisphere and Arctic sea ice extent have decreased at a rate of about 3 percent per decade. The National Snow and Ice Data Center (http://nsidc.org/) at the University of Colorado archives an extensive set of data relating to all forms of snow and ice cover.

Snow Cover and Snow Depth

Snow cover and depth change rapidly over large areas during autumn build-up and spring melt. To understand the heat transfer between atmosphere, snow-pack and ground, the snow depth and snow extent must be known. The Nimbus-7 SMMR Derived Monthly Global Snow Cover and Snow Depth data set consists of monthly global snow cover for the period 1978 through 1987. The SMMR data are interpolated for spatial and temporal gaps, based on six-day average brightness temperature data from the middle week of each month and are provided on a 0.5^{o} grid over land. The data set is described in Chang (1995) and can be found at http://nsidc.org/data/nsidc-0024.html. The full data set is available at DNSC.

Snow Water Equivalent

This data set comprises global, monthly satellite-derived snow water equivalent (SWE) climatologies from November 1978 through June 2003. Global data are gridded to the Northern and Southern 25 km Equal-Area Scalable Earth Grids (EASE-Grids). Global snow water equivalent is derived from Scanning Multichannel Microwave Radiometer (SMMR) and selected Special Sensor Microwave/Imagers (SSM/I). Northern Hemisphere data are enhanced with snow cover frequencies derived from the Northern Hemisphere EASE-Grid Weekly Snow Cover and Sea Ice Extent Version 2 data. The data set is described in Armstrong et al. (2005) and may be found at nsidc.org/data/docs/daac/nsidc0271_ease_grid_swe_climatology.gd.html. The northern hemisphere data are available at DNSC. Figure 12 shows the snow water equivalent for January 2001 as well as the snow extent anomaly for the entire period (inset).

Snow Cover and Sea Ice Extent

The Northern Hemisphere EASE-Grid Weekly Snow Cover and Sea Ice Extent Version 2 product combines snow cover and sea ice extent at weekly intervals for October 1978 through June 2001, and snow cover alone for October 1966 through October 1978. (Sea ice data were not available prior to 23 October 1978.) The data set is the first representation of combined snow and sea ice measurements derived from satellite observations for the period of record. Designed to facilitate study of Northern Hemisphere seasonal fluctuations of snow cover and sea ice extent, the data set also includes monthly climatologies describing average extent, probability of occurrence, and variance. Data are provided in the Northern Hemisphere 25-km equal-area grid.

Snow cover extent is based on the digital NOAA-NESDIS Weekly Northern Hemisphere Snow Charts, revised by D. Robinson (Rutgers University) and re-gridded to the EASE-Grid. The original NOAA-NESDIS weekly snow charts are derived from the manual interpretation of AVHRR, GOES, and other visible-band satellite data. Sea ice extent is re-gridded to the EASE-Grid from the NSIDC polar stereographic sea ice concentration grids derived from Scanning Multi-channel Microwave Radiometer (SMMR) and Special Sensor Microwave Imager (SSM/I)

passive microwave brightness temperature data. The data set is described in Armstrong and Brodzik (2002) and is available from http://nsidc.org/data/nsidc-0046.html.

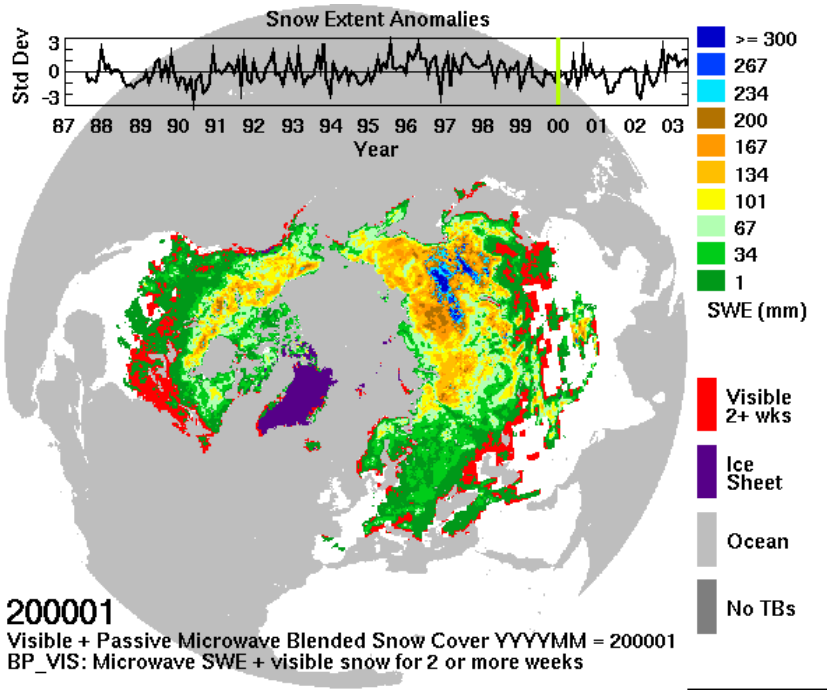


Figure 12: Snow water equivalent for January 2000. Inset: snow extent anomaly 1987-2003. From http://nsidc.org/data/docs/daac/nsidc0271_ease_grid_swe_climatology/browse/viewer.html

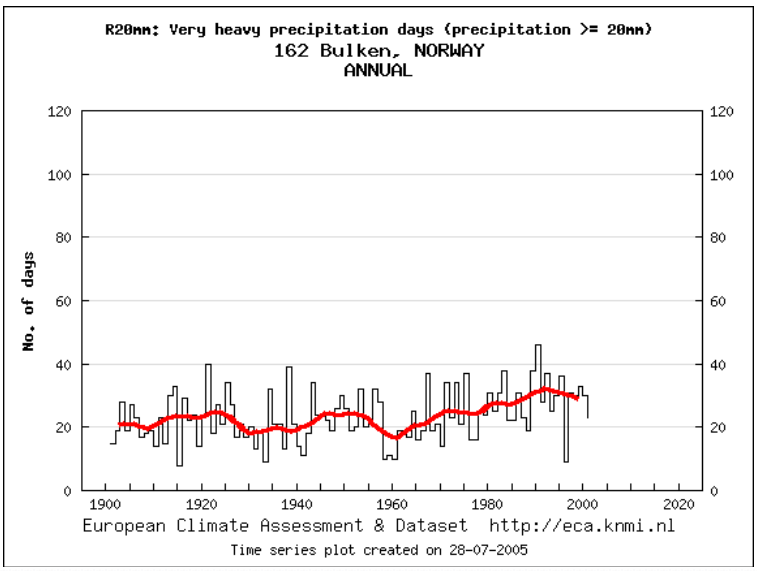
Extreme Weather

One of the possible consequences of climate change is a variation in the occurrence of extreme weather events. According to model simulations climate change may not just occur as a gradual change in climate parameters such as temperature, wind and precipitation, but also as an increase of extreme weather such as hurricanes, draught periods, and heavy precipitation. Due to the huge societal and economic impacts of extreme weather events this area could be of equal importance to any average change in climate.

ECA&D

The European Climate Assessment & Dataset project hosted at the Royal Netherlands Meteorological Institute has constructed a series of indices of climate extremes from 257 stations across Europe (including Greenland, Algeria, and Israel). The indices cover a wide variety of climate parameters that may describe extreme events, such as maximum number of consecutive days of frost, draught, or precipitation, warm periods, cold periods, heavy precipitation, strong variations in weather, length of seasons, etc. In all, more than 40 indices are defined and are available as time series, trends or monitor maps. The indices are constructed annually, semi-annually, and seasonally for the period 1900 (where available) to 2004. Figure 13 shows an example of one extreme index, very heavy precipitation. The top panel is a time series from one of the stations exhibiting a strong trend, while the bottom panel shows the long-term trends, in the number of heavy precipitation days, over Europe for the period 1946-1999. The indices, data sets and the work of ECA&D may be found in a report

series at http://eca.knmi.nl/publications/index.php. The data sets are described in Klein Tank et al. (2002).



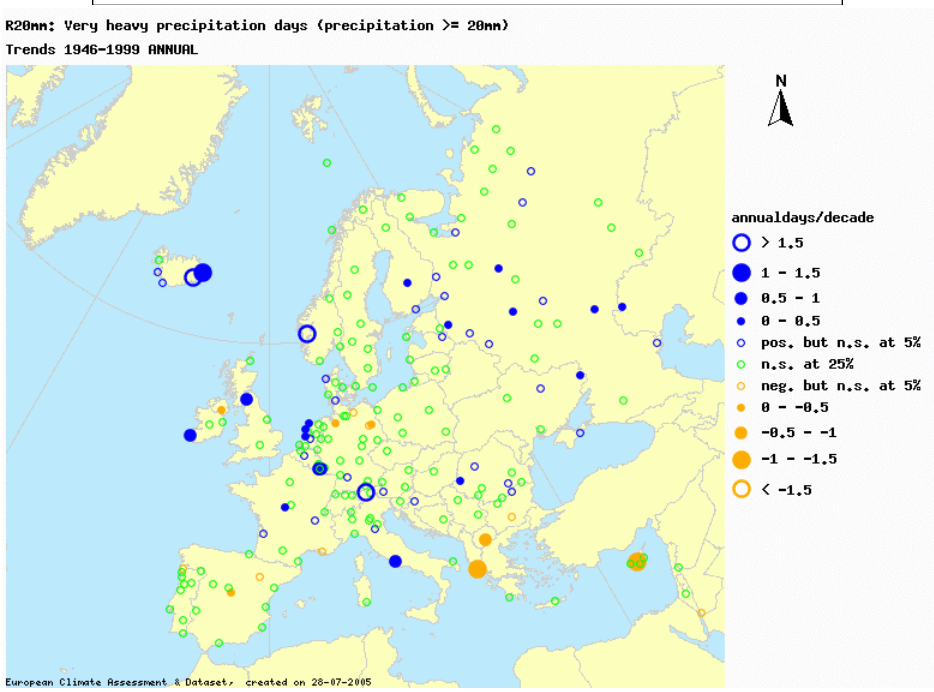


Figure 13: Days of very heavy precipitation is one of the extreme weather indices constructed by ECA&D. Top: Bulken in the west of Norway has seen an increase in heavy precipitation in the past half century. Bottom: European trends in heavy precipitation during the period 1946-1999. From http://eca.knmi.nl/indicesextremes/index.php.

US Climate Extremes Index (CEI)

The US Climate Extreme Index is the arithmetic average of the following six indicators of the percentage of the conterminous U.S. area:

1) The sum of (a) percentage of the United States with maximum temperatures much below normal and (b) percentage of the United States with maximum temperatures much above normal.
2) The sum of (a) percentage of the United States with minimum temperatures much below normal and (b) percentage of the United States with minimum temperatures much above normal.

3) The sum of (a) percentage of the United States in severe drought (equivalent to the lowest tenth percentile) based on the PDSI and (b) percentage of the United States with severe moisture surplus (equivalent to the highest tenth percentile) based on the PDSI.
4) Twice the value of the percentage of the United States with a much greater than normal proportion of precipitation derived from extreme (equivalent to the highest tenth percentile) 1-day precipitation events.
5) The sum of (a) percentage of the United States with a much greater than normal number of days with precipitation and (b) percentage of the United States with a much greater than normal number of days without precipitation.
6) The sum of squares of U.S. land falling tropical storm and hurricane wind velocities scaled to the mean of the first five indicators.

The definition of much above (below) normal or extreme conditions is conditions falling in the upper (lower) tenth percentile of the local, period of record. The fourth indicator, related to extreme precipitation events, has an opposite phase that cannot be considered extreme: the fraction of the US area with far below normal percentage of annual precipitation derived from extreme (i.e. zero) 1-day precipitation amounts. Hence, the fourth indicator is multiplied by twice its value to give it an expected value comparable to the other indicators. In the case of tropical systems, any land falling system is considered extreme. Since precipitation from such a system is already accounted for in the precipitation steps and can also affect the PDSI, wind velocity at the time of landfall is the focus for this indicator. The square of the wind velocity of each tropical storm and hurricane at the time of landfall is used since a linear increase in wind velocity corresponds more closely to an exponential increase in wind impact and damage. Because this step only accounts for the strength and frequency of tropical systems at landfall (and could not theoretically affect 100% of the US area), this indicator was scaled to make it comparable to the other five indices.

The US CEI as well as each of the 6 individual indices are available on a yearly basis from 1910 to the present and are defined both annually and seasonally (Spring, Summer, Autumn, Winter, cold and warm seasons, and hurricane season). The index and the data involved are described in Karl et al. (1996) and are available from http://www.ncdc.noaa.gov/oa/climate/research/cei/cei.html. Figure 14 shows the annual value of the combined extreme index.

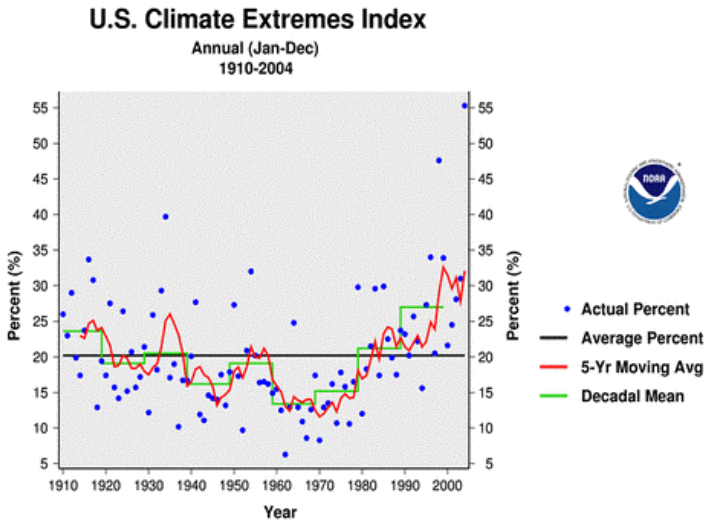


Figure 14: The US Climate Extreme Index – annual value. From http://www.ncdc.noaa.gov/oa/climate/research/cei/cei.html.

Conclusions

In this report we have described the Earth's surface climate data selected for use in the remaining Tasks of the ISAC study. A summary of the spatial and temporal properties of each dataset is included in a Table in the appendix. The majority of the data is available from a database stored at DNSC, however, this is not practical for some of the extremely large datasets, which is indicated in the Table, and a link to the original data source is included.

Both surface data and satellite data have been selected. The satellite data have the advantage of relatively homogeneous global coverage, without bias towards industrialized parts of the world. However, the long observation period of the surface data give them an important role when it comes to analyzing over longer periods that will be necessary for the forthcoming investigation of solar variability. The focus has mainly been on longer time periods, placing an emphasis on monthly mean data which are adequate for analyzing the influence of the slower variations of the Sun, e.g., the 11-year sunspot cycle. The hourly precipitation data over the USA and the 6-hourly outputs from the reanalysis data sets will allow for a detailed investigation of shorter properties of solar variability such as Forbush events.

Our emphasis has naturally been on standard climate parameters such as temperature and precipitation. However, the effects of any possible climate change are likely to be seen as changes in surface features such as vegetation and snow/ice cover. Such changes, for example the spreading of arid areas in desert regions or moving the borders of vegetation in arctic regions, may come to play an important role both for human society and the biosphere as a whole. Therefore these parameters have a place in our analysis of Earth's climate.

The data selected captures changes in surface climate that can be compared directly with solar parameters, or with atmospheric properties that are influenced by solar variability. The intention is that this will complete a possible chain of processes that links solar variability to atmospheric properties to surface climate. If any of the proposed links are confirmed in the subsequent work packages then the data presented in this report can be used to quantify the sensitivity of surface climate to solar variability. Knowledge of such properties can be used to assess the performance of climate models and provide a greater understanding of the role solar activity plays in the Earth's atmosphere.

References

Armstrong, R.L. and M.J. Brodzik, Northern Hemisphere EASE-Grid weekly snow cover and sea ice extent version 2. *Boulder, CO, USA: National Snow and Ice Data Center. CD-ROM,* 2002.

Armstrong, R.L., M.J. Brodzik, K. Knowles, and M. Savoie, Global Monthly EASE-Grid Snow Water Equivalent Climatology. *Boulder, CO: National Snow and Ice Data Center, Digital media*, 2005.

Chang, A., Nimbus-7 SMMR global monthly snow cover and snow depth, *Boulder, CO: National Snow and Ice Data Center. Digital media*, 1995.

Doherty, R.M., M. Hulme, and C. G. Jones, A gridded reconstruction of land and ocean precipitation for the extended tropics from 1974 to 1994, *International Journal of Climatology, 19*, 119-142, 1999.

Ferraro, R., F. Weng, N. Grody, and A. Basist, An Eight Year (1987-1994) Time Series of Rainfall, Clouds, Water Vapor, Snow-cover, and Sea-ice Derived from SSM/I Measurements, *Bulletin of the American Meteorological Society*, 891-905, 1996

Folland, C.K., Rayner, N.A., Brown, S.J., Smith, T.M., Shen, S.S.P., Parker, D.E., Macadam, I., Jones, P.D., Jones, R.N., Nicholls, N. and Sexton, D.M.H., Global temperature change and its uncertainties since 1861, *Geophysical Research Letters 28*, 2621-2624, 2001.

Higgins, R. W., J. E. Janowiak, and Y.-P. Yao, A gridded hourly precipitation data base for the United States (1963-1993), NCEP/Climate Prediction Center Atlas 1*, http://www.cpc.ncep.noaa.gov/research_papers/ncep_cpc_atlas/1/,* 1996.

Hulme, M., A 1951-80 global land precipitation climatology for the evaluation of General Circulation Models, *Climate Dynamics, 7*, 57-72, 1992.

Jones, P.D., The early twentieth century Arctic High - fact or fiction?, *Climate Dynamics, 1*, 63-75, 1987.

Jones, P.D., T. Jónsson, and D. Wheeler, Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland, *International Journal of Climatology, 17*, 1433-1450, 1997.

Jones, P.D. and A. Moberg, Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001, *Journal of Climate, 16*, 206-223, 2003.

Karl, T.R., R.W. Knight, D.R. Easterling, R.G. Quayle, Indices of Climate Change for the United States, *Bulletin of the American Meteorological Society,* **77,** 279-292, 1996.

Klein Tank, A.M.G. and Coauthors, Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment, *International Journal of Climatology, 22*, 1441-1453, 2002.

Mitchell, T. D., T. R. Carter, P. D. Jones, M. Hulme, and M. New, A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100), *Tyndall Centre Working Paper No. 55*, 2004

New, M., M. Hulme, and P. D. Jones, Representing twentieth century space-time climate variability. Part 2: development of 1901-96 monthly grids of terrestrial surface climate. *Journal of Climate 13*, 2217-2238, 2000.

Rayner, N.A., D.E. Parker, E.B. Horton, C.K. Folland, L.V. Alexander, D.P. Rowell, E.C. Kent, A. Kaplan, Global analyses of SST, sea ice and night marine air temperature since the late nineteenth century, *Journal of Geophysical Research, 108*, doi:10.1029/2002JD002670, 2003.

Ropelewski, C.F. and P. D. Jones, An extension of the Tahiti-Darwin Southern Oscillation Index, *Monthly Weather Review, 115*, 2161-2165, 1987.

Simmons, A.J., P.D. Jones, V. da Costa Bechtold, A.C.M. Beljaars, P.W. Kållberg, S. Saarinen, S.M. Uppala, P. Viterbo and N. Wedi, Comparison of trends and variability in CRU, ERA-40 and NCEP/NCAR analyses of monthly-mean surface air temperature, *ERA-40 Project Report Series No. 18*, 2004.

Spencer, R.W. and J.R. Christy, Precision and radiosonde validation of satellite gridpoint temperature anomalies, Part I: MSU channel 2*, Journal of Climate, 5,* 847-857, 1992a.

Spencer, R.W. and J.R. Christy, Precision and radiosonde validation of satellite gridpoint temperature anomalies, Part II: A tropospheric retrieval and trends 1979-90, *Journal of Climate, 5,* 858-866, 1992b.

Tucker, C. J., J. E. Pinzon, M. E. Brown, D. Slayback, E. W. Pak, R. Mahoney, E. Vermote and N. El Saleous, An Extended AVHRR 8-km NDVI Data Set Compatible with MODIS and SPOT Vegetation NDVI Data, *International Journal of Remote Sensing (in press)*, 2005.

Data Sets – Tables of Sources and Availability

	Observation	Geographic coverage	Temporal coverage
Surface data			
	Precipitation	Global – over land Gridded (5 degree or 2.5 x 3.75 degree)	1900-1998 Monthly data
	Source: http://www.cru.uea.ac.uk/~mikeh/datasets/global/ Available at DNSC: full data set		
	Precipitation	Tropics – below 30° Gridded (2.5 x 3.75)	1974-1994 Monthly data
	Source: http://www.cru.uea.ac.uk/~mikeh/datasets/global/ Available at DNSC: full data set		
	Precipitation	USA (20N-60N, 220E-297.5E) Gridded (2 x 2.5 degree)	1948-2002 Hourly data
	Source: http://www.cdc.noaa.gov/cdc/data.cpc_hour.html Available at DNSC: full data set		
	Pressure	Northern hemisphere Gridded (5 x 10 degree)	1873-2000 Monthly data
	Source: http://www.cru.uea.ac.uk/cru/data/pressure.htm Available at DNSC: full data set		
	Temperature	Global (1856-1869 only over land) Hemispheric or gridded (5 degree)	1856-present Monthly data
	Source: http://www.cru.uea.ac.uk/cru/data/temperature/ Available at DNSC: full data set		
	Temperature (sea surface), sea ice coverage	Global over oceans Gridded (1 degree)	1870-present Monthly data
	Source: http://badc.nerc.ac.uk/data/hadisst/ Available at DNSC: none		
	Temperature, precipitation, cloud cover, vapour pressure, frost and wet day frequencies	Global over land Gridded (0.5 degree)	1901-2002 Monthly data
	Source: http://www.cru.uea.ac.uk/~timm/grid/CRU_TS_2_0.html Available at DNSC: full data set		
	NAO and SOI	Single index	1821-2000 (NAO)

			1866-2004 (SOI) Monthly data
	Source: http://www.cru.uea.ac.uk/cru/data/nao.htm and http://www.cru.uea.ac.uk/cru/data/soi.htm Available at DNSC: full data set		

	Observation	Geographic coverage	Temporal coverage
Satellite data			
	Reanalysis data, NCEP/NCAR: Meteorological variables	Global Gridded (200 km) 28 vertical layers	1948-present 4 times daily data Monthly means
	Source: http://www.cdc.noaa.gov/cdc/reanalysis/ Available at DNSC: air temperatures and geopotential heights – monthly means		
	Reanalysis data, ECMWF: Meteorological variables	Global Gridded (40 km) 60 vertical levels	1957-2002 4 times daily data Monthly means
	Source: http://www.ecmwf.int/research/era/ Available at DNSC: none		
	Microwave Sounding Units: temperature anomalies	Global Hemispheric, zonal or gridded (2.5 degree) 3 vertical layers	1979-present Daily or monthly data (gridded data only monthly)
	Source: http://www.nsstc.uah.edu/data/msu/ Available at DNSC: monthly hemispheric data 1979-2001		
	SSM/I,hydrology: rainfall, liquid water path, total precipitable water, cloudiness snow and sea-ice cover, surface wind speeds.	Global Gridded (1 or 2.5 degree)	1987-present Monthly data
	Source: www.ncdc.noaa.gov/oa/satellite/ssmi/ssmiproducts.html Available at DNSC: full data set		

	Observation	Geographic coverage	Temporal coverage
Snow and Ice			
	Nimbus-7 snow cover and depth	Global – over land Gridded (0.5 degree)	1978-1987 Monthly data
	Source: http://nsidc.org/data/nsidc-0024.html		

	Available at DNSC: full data set		
	Snow water equivalent	Global – over land Gridded (25 km)	1978-2003 Monthly data
	Source: http://nsidc.org/data/nsidc-0271.html Available at DNSC: northern hemisphere		
	Snow cover and sea ice extent	Northern hemisphere Gridded (25 km)	1966-2001 (snow cover) 1978-2001 (sea ice) Weekly data
	Source: http://nsidc.org/data/nsidc-0046.html Available at DNSC: none		

	Observation	Geographical coverage	Temporal coverage
Vegetation			
	NDVI	Global over land Gridded (8km)	1981-2003 Bi-montly data
	Source: http://glcf.umiacs.umd.edu/data/gimms/ Available at DNSC: none		

	Observation	Geographical coverage	Temporal coverage
Extreme weather			
	40 extreme weather indices – precipitation, temperature, etc.	Europe 257 stations	1901-2004 Annual, semi-annual, and quarterly indices (from daily data)
	Source: http://eca.knmi.nl/indicesextremes/index.php Available at DNSC: none		
	US CEI Temperature, precipitation, tropical storms	USA 6 single indices	1910-present Annual, bi-annual, and quarterly data
	Source: http://www.ncdc.noaa.gov/oa/climate/research/cei/cei.html Available at DNSC: full data set		