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12. A Multi-decadal Daily Sea Surface Temperature and Sea Ice Concentration Data Set for the ERA-40 Reanalysis

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A Multi-decadal Daily Sea Surface Temperature and Sea Ice Concentration Data Set for the ERA-40 Reanalysis

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Abstract

The lower boundary condition of sea surface temperature (SST) and sea-ice concentration (SIC) is a critical forcing of the lower frequencies in multi-decadal global atmospheric reanalyses such as next ECMWF reanalysis ERA-40 (Hurrell and Trenberth 1999). Partly in response to the ERA-40 project, new SST/SIC data sets have been developed that are considerably improved over those available to the first-generation reanalyses (e.g., Kistler et al 2001). This paper documents the input SST/SIC data sets and the processing that created the daily SST/SIC for the ERA-40 period 1957-2002.

The source data are: 1) the monthly mean HadISST data set from the UKMO Hadley Center for 1956-1981; and 2) the weekly NCEP 2DVAR data for 1982-present. Both data sets are reanalyses of satellite and conventional SST/SIC observations. The principal reason for the higher quality of these source data sets is the use of a common consensus SIC and a common SIC-SST relationship in the sea ice margins. The use of a common SIC resulted in a very smooth transition between HadISST and NCEP 2DVAR, despite differences in data assimilation techniques and monthly versus weekly analyses. No special action was required to insure consistency at the transition unlike as was necessary for the AMIP II experiment (Fiorino 1997).

The only special processing was application of the AMIP II mid-month calculation (Taylor et al. 2000) for the interpolation of monthly mean data to daily values. This scheme insures that the monthly mean of the daily-interpolated data is nearly identical to the input monthly mean. Detailed comparisons of the SST and SIC during the HadISST-NCEP transition, and other long time series, are given. We also compare the NCEP 2DVAR (circa 2000) to a newer version of the OISST (V2, circa 2001) and demonstrate that the small differences should have no impact on the ERA-40 atmosphere reanalyses. Finally, we document precisely which data sets were used in ERA-40 production through a comparison of input and ERA-40 post-processed SST/SIC.

1 Introduction

The lower boundary condition of sea surface temperature (SST) and sea-ice concentration (SIC) is a critical source of low frequency (e.g., interannual variability) forcing in multi-decadal global atmospheric reanalyses and climate integrations of atmospheric general circulation models (AGCMs). Further, the analysis of the SST/SIC observations to a grid significantly affects this forcing (Hurrell and Trenberth 1999) so that for the highest quality forcing, SST/SIC input to an AGCM must be updated as the analyses improve.

In this report we describe the SST/SIC data sets used in the second-generation reanalysis of the European Centre for Medium-range Weather Forecasts (ECMWF). This ECMWF ReAnalysis, called ERA-40, was performed for the 40+ year period 1957-2002. Production started in 2000 and finished at the end of March 2003 (200303, year-month time will use the YYYYMM format). Thus, the ERA-40 SST/SIC data set represents the best analysis available at the time the data set was developed circa 1999.

SST/SIC analyses have improved considerably since the first-generation reanalyses of National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR), NASA Global Modeling and Assimilation Office (GMAO) and ERA-15 (ECMWF ReAnalysis) in the early 1990s. The main data set sources were: 1) the Global sea Ice Coverage and Sea Surface Temperature (GISST) data set from the United Kingdom Meteorological Office (UKMO) Hadley Center of monthly mean data before the era of satellite SST/SIC observations (pre 1979/1981) (Rayner et al. 1996); and 2) the weekly (Optimal Interpolation Sea Surface Temperature) OISST Version 1 (V1) (Reynolds and Smith 1994) of NCEP after 198111.

Special adjustments of these two SST/SIC data sets were necessary for application to reanalysis and other global modeling experiments (e.g., AMIP, Gates et al 1999), principally because of the treatment of SIC in the SST analyses. ERA-15 required a SIC mask (SIC = 0,1) and Nomura (1998) painstakingly adjusted both the input SIC data and the thresholds of SIC to define ice versus open ocean appropriate to the ERA-15 global model.

For the AMIP II project (http://www-pcmdi.llnl.gov/amip) climate model intercomparison, Fiorino (1997) had to adjust the SST in the marginal sea ice margins during the transition from the UKMO to the NCEP SST data. This adjustment was necessary because differing SST-SIC relationships led to large (> 1.5 °C) SST differences in the SIC margin. The reasons for these differences were twofold: 1) each center used a different SIC data set; and 2) each center took very different approaches to analyzing SST in and near the ice margins (SIC > 0 and < 1).

To address these deficiencies an international group of SIC experts, under the coordination of Ms. Nick Rayner, UKMO, put together a common and "best" data set for both the UKMO and NCEP in the production of data sets for ERA-40. Furthermore, both centers now explicitly account for SIC during the SST analysis and use a common SST-SIC relationship.

This paper describes the source data sets and processing; and then evaluates the ERA-40 SST/SIC during data set transition. We then compare the new NCEP OISST V2 (available ~ 2001) to the NCEP 2DVAR used in ERA-40 and then document precisely which data sets were used in production.

We need to acknowledge upfront the special efforts of the UKMO and NCEP in producing the data sets used for ERA-40. These centers actually performed an SST/SIC reanalysis so these input data sets represent the best available for atmospheric data assimilation and AGCM integrations in the 1999-2002 era. The ERA-40 project is thankful for the special effort.

1.1 Overview of the Processing

The basic objective of the data processing is to produce daily SST and SIC in ECMWF GRIB format. These steps are:

i) interpolate monthly/weekly to daily values. For monthly mean data (HadISST), calculate mid-month values such that the monthly mean of linearly-interpolated daily values is the same as the observed monthly mean. For weekly data (NCEP 2DVAR), assume that the data are valid at the mid-point of the week and linearly interpolate.

ii) infill SIC over land to 100% using the UKMO land/sea mask so that all points are defined.

iii) infill SST over land using the appropriate land/sea mask and the NCEP "weave" successive scan scheme (used in NCEP 2DVAR/OISST).

iv) convert to the ECMWF GRIB standard

No other adjustments in the daily data were required. Thus, the primary purpose of this report is to analyze the consistency and quality of the data set and document the input data.

2 HadISST V1.1

The Hadley center sea Ice and Sea Surface Temperature (HadISST) data set is the successor to the GISST (Global sea Ice and SST see http://www.meto.gov.uk/research/hadleycenter/obsdata/GISST.html) data set series V1.0-3.1 (Parker et al. 1999) and is designed to give a "best" representation of lower frequency (climate) variability in the ocean. In contrast, the NCEP operational analyses used by both the NCEP Climate Prediction Center (CPC) and Environmental Modeling Center (EMC) are optimized for higher, synoptic-scale frequencies. It should be mentioned that the UKMO does perform a daily SST analysis for weather forecasting and uses the NCEP operational daily SIC analysis as input. Further, that NCEP now performs a daily high-resolution SST analysis (since 2001, see: http://polar.wwb.noaa.gov/sst/) for use in the EMC numerical weather prediction (NWP) models.

There were two 1.X versions – 1.0 and 1.1, and while officially the data set is 'V1' the final version used for ERA-40 was actually the second or 1.1. Essentially, 1.0 was a "beta" version that was adjusted after initial customer comments. Thus, we will refer to HadISST as HadISST V1.1 in this paper even though the official version is V1.

HadISST is a monthly mean analysis of SST and SIC for the period 1870 – 1999, but in ERA-40 only the period 1957 - 1981 is used – prior to the weekly NCEP 2DVAR reanalyzed SST/SIC. Intercomparison of HadISST and a monthly mean of the NCEP data during the overlap period 1982-1999 showed agreement sufficient to assure no large differences in basic features between the two SST/SIC data. The NCEP data were favored for the modern era (1982-present) because they contain higher-resolution detail and are used in operational NWP at many centers including ECMWF.

2.1 Monthly -> Daily Processing

The traditional method of interpolating monthly data to daily values is to define the monthly mean as being valid at the exact middle of the month and then linearly interpolate in time. The problem with this approach is that the monthly mean of the daily values will not be the same as the original monthly mean, i.e., the procedure smoothes in time and reduces the amplitude of the annual cycle.

A new approach was developed by Taylor et al. (2000) that calculates the mid-month value so that the monthly mean is preserved under interpolation. This approach was applied to the 1956-1999 HadISST data set and daily values produced for the 195601-198111. However, the data were subsequently extended back to 1948 for future pre-ERA-40 period experimentation.

SIC presents a special challenge in that the mid-month values can be non-physical, i.e., < 0 or > 1 when preserving the monthly mean. The daily interpolation process must reset the interpolated SIC back to physical values when the interpolated values go out of bounds.

The implementation code for AMIP II was applied to HadISST at PCMDI. This code performs all processing to output daily values and conversion to ECMWF GRIB.

2.2 Consensus SIC

One of the more significant accomplishments of ERA-40 will be the coordination of sea ice observations and SST-SIC relationships between the two main SST analysis centers of the UKMO and NCEP. While other centers produce SST analyses for operational applications, most notably the U.S. Navy, both the UKMO and NCEP specialize in multi-decadal and inter-annual time scales.

As discussed earlier, merging of previous UKMO and NCEP SST/SIC data sets for AMIP II resulted in huge discontinuities at the data set transition in 198111 for SST in the ice margins (Fiorino 1997). By adopting a single SIC data set at both centers, the AMIP II problem has been eliminated.

The consensus SIC data were derived from a decision tree that selected "best" input data sets as a function of time and ocean. These input data sets were:

1. weekly SIC from the Navy/NOAA National Ice Center (1973-1994), available at NSIDC (http://nsidc.org/index.html)
2. daily SIC from Nomura/Grumbine based SSMR and SSM/I (1979-1997), available at NCEP.

3. daily SIC from NASA Goddard base on SSMR and SSM/I (197810-1996), available from NSIDC
4. daily SIC from Bistol University based on SSM/I for the Antarctic (1987-present)
5. monthly SIC from EMSR data, available from NSIDC
6. monthly SIC from John Walsh in Arctic (1901-1995)
7. 10-day mean SIC from Russian Arctic and Antarctic Research Program (AARI), 1953-1990 in the Russian Arctic, available from NSIDC
8. monthly ice-edge climatology from German and Russian charts in the Antarctic, available from Nick Rayner (1929-1962)
9. half-monthly SIC for U.S. Great Lakes (1960-1979)

Climatologies were used prior to the modern era (1979-present) for the Caspian Sea, Sea of Japan, Gulf of Saint Lawrence for years prior to 1979. These climatologies were constructed from modern-era observations or other data sets.

A common problem in passive microwave satellite data sets is an underestimation of SIC in the Arctic because of the formation of a thin layer of water ("ponding") during the boreal summer. Active microwave measurements (scatterometers) are not sensitive to ponding and so these data were used to bias adjust (increase) the analysis to more realistic 90-100% SIC. This correction is especially important for ERA-40 as the sea ice model does not account for ponding.

The decision tree was developed by leading SIC experts and the resulting consensus data were averaged to monthly means for HadISST SST analysis and weekly for the NCEP SST 2DVAR. Further, the input data sets were inter-calibrated to improve homogeneity prior to going through the decision tree.

2.3 SST-SIC relationship in the ice margins

The UKMO and NCEP had very different approaches to analyzing SST in the ice margins where few *in situ* observations exist (e.g., similar to ship observations in the eye of a tropical cyclone; the ship should not be there). NCEP sets the SST to -2 °C at 85-90 °N/S and lets the analysis scheme fill in the SST between these buffer zones and areas with SST observations. While this approach is not unreasonable from an observational perspective, the impact on atmosphere models is significant. Because one of the purposes of HadISST is to drive climate models, a different approach was taken at the UKMO; namely, to develop a regression-based relationship for SST and SIC, based on the limited observations in the ice margin, and to then set the SST based on the SIC observations.

NCEP tried a similar approach, but found the SST-SIC relationships strongly depended on how the regression was made and which observations were used. The SST-SIC specification also impacted the SST analysis away from the ice margin.

A consensus SST-SIC relationship was agreed to that both fit the observations and helped the fit of the SST analysis to the observations just outside the ice margin. Consequently, a very consistent transition from HadISST to 2DVAR was expected and achieved as will be shown in Section 4.

2.4 SST analysis

The two main improvements in the HadISST SST analysis is the use of Reduced-Space Optimal Interpolation (Kaplan et al 1998) for reconstructing the global-scale, low frequencies in the ocean (e.g., ENSO) and improved data sources for adding localized detail. Among these data sources are an update to the

Met. Office Historical SST (MOHSST7) and a better bias correction to Advanced Very High Resolution Radiometer (AVHRR) satellite SST anomalies. Further, the gravest temporal mode ("global warming") was removed prior to the RSOI and local detail added to yield a more realistic inter-month correlation. GISST V2.3b had very low month-to-month persistence compared to other SST data sets (Hurrell and Trenberth, 1999)

3 NCEP 2DVAR (V11) Reanalyzed SST

At the time the ERA-40 SST/SIC data set was constructed (1999-2000), the best weekly NCEP SST analysis came from the new 2DVAR scheme (Reynolds et al. 2001). The main motivation for implementing a 2-D variational analysis vice optimum interpolation (OI) was compute intensive, but a secondary consideration was the greater generality and long experience with variational analysis at NCEP[1]. The 2DVAR scheme also features a new bias correction of the satellite-derived SST observations and initial results showed that the combination of 2DVAR and bias correction produced better fits to *in situ* observations compared to the then operational OISST V1.

Beyond technical improvements in the data assimilation system, 2DVAR-analyzed SST in the SIC margin used in the consensus SST-SIC relationship developed jointly with the UKMO. It is this new feature that makes 2DVAR superior to OISST V1 for atmospheric reanalysis vis-à-vis AMIP II (Fiorino 1997).

3.1 Weekly -> Daily Processing

The interpolation from weekly to daily values was linear with no attempt to ensure that the weekly mean of the daily values returned the input mean. While the mid-month scheme could have been applied, PCMDI found that the error (smoothing) was small and that the mid-month scheme was unable to recover lost information for weekly data. Thus, slight smoothing was accepted, particularly as it would give a smoother forcing to the atmospheric model.

The only issue was when NCEP changed the mid-point of the week in 1990. A simple blending of the two possible interpolations was made to insure smoothness.

4 Evaluation of the ERA-40 SST/SIC and comparison to AMIP II

The ERA-40 project plan called for using the monthly mean HadISST1.0 data for 195709 – 19811 and the weekly NCEP 2DVAR reanalysis data for 198112 - present. It was recommended that ERA-40 start with the NCEP data in the month after beginning of data set as a full month for 198111 was not available. As discussed earlier, the monthly HadISST data were interpolated to daily values using the AMIP II scheme.

Because HadISST was available through 199912, we have a long period of overlap to intercompare and to check the transition between the data sets in 198112.

The monthly means from the daily-interpolated data, both NCEP and UKMO, were calculated to check technical soundness (every data point was read) and to concentrate on the lower frequencies. Then, SIC "extent" was calculated as defined by Nomura (1997) for intercomparison with ERA-15 and we found very similar magnitudes. Thus, the SIC should have little or no impact on comparisons of the ERA-15 and ERA-40 atmospheric analyses.

The matching of SIC is demonstrated in Figure 1 where the Arctic sea ice extent for 1979-84 is shown using the shipping threshold of 15% and the meteorological threshold recommended by Nomura of 55%. The differences are very small and on the order of 1% with no trend in the difference. Displays of the SIC maps

[1] NCEP was the first center to run a 3DVAR scheme for the atmosphere starting in 1992.

showed that most of the differences were in the sea ice margin or the area between complete ice and open ocean.

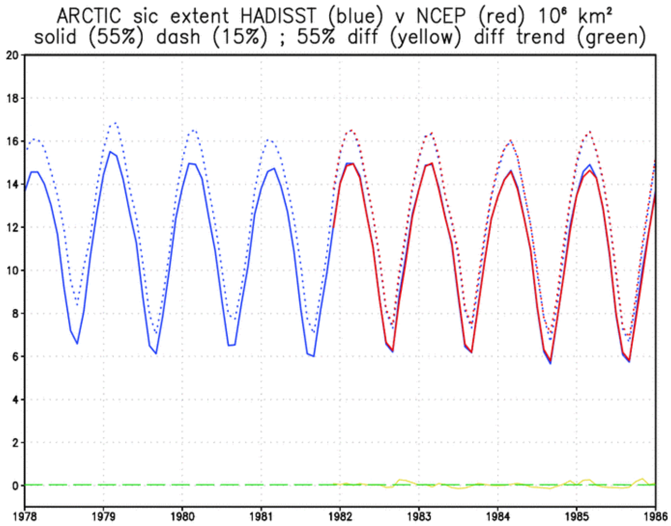

Figure 1. Comparison of Arctic SIC extent [10^6 km^2] in the HadISST (blue-solid: SIC > 55% and blue-dash: SIC > 15%) and in the NCEP (red-solid: SIC>55% and red-dash: SIC>15%) data sets.

In Figure 2 we show the fraction of ocean points in the SIC margin (defined as SIC ≥ 10% and ≤ 80%) during the transition. No jumps are found although there is a suggestion of greater margin in the Antarctic after 1982, but this feature was also seen in the HadISST V1.1 data.

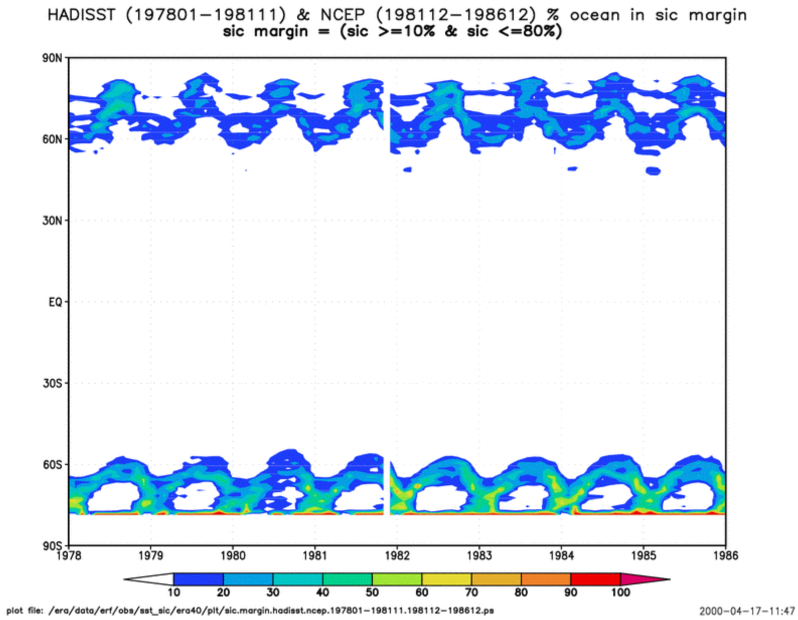

Figure 2. Zonal average of the percentage of the SIC margin (SIC >= 10% and SIC <= 80%) that is open ocean [%].

A more demanding consistency test is to check the SST in the SIC margin. If both centers used the same relationship and the SIC differences were small, then there would be little difference in the SST and no break in continuity. This SIC-margin SST is shown in Figure 3 where we find slightly cooler water in the NCEP data poleward of the winter-time maximum. This cooling is a consequence of the small number of points in the region rather than a systematic difference. In contrast, the difference in AMIP II was on the order of 3 °C.

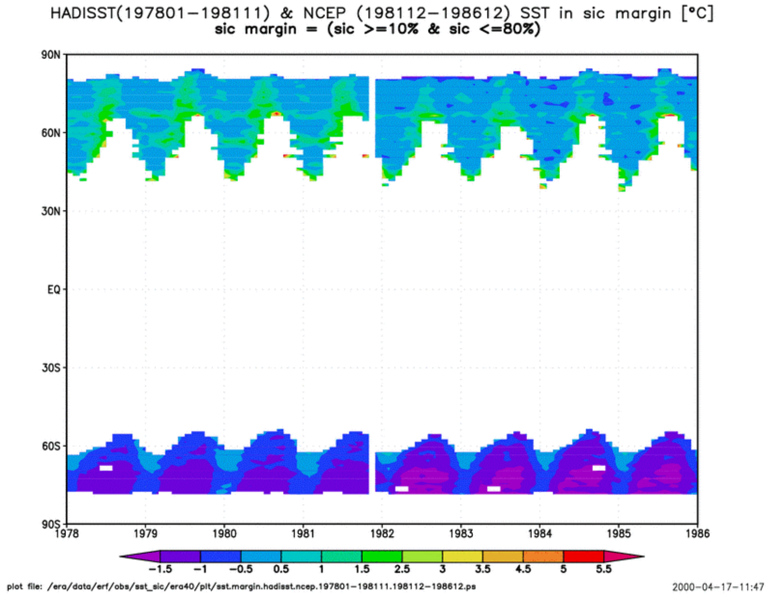

Figure 3. as in Figure 2, except for SST in the SIC margin.

Finally, Figure 4 shows the anomaly of the zonally averaged SST over open ocean during the entire ERA-40 period. Again, no abrupt changes are found at the transition point in 198112, but SST anomalies are greater before about 1978 near the ice margins in the HadISST data. This warming may be reflective of the change in SIC and SST observations, most notably SIC satellite observations starting in 1978. The large El Ninos of the 83, 87 and 97 are clearly seen in the tropics and the warming of the northern Hemisphere mid-latitude oceans from around 1993 is an interesting feature in both the NCEP and HadISST data sets. We also see a general warming of the tropical oceans from 1956 - 2000 – a "global warming" signal.

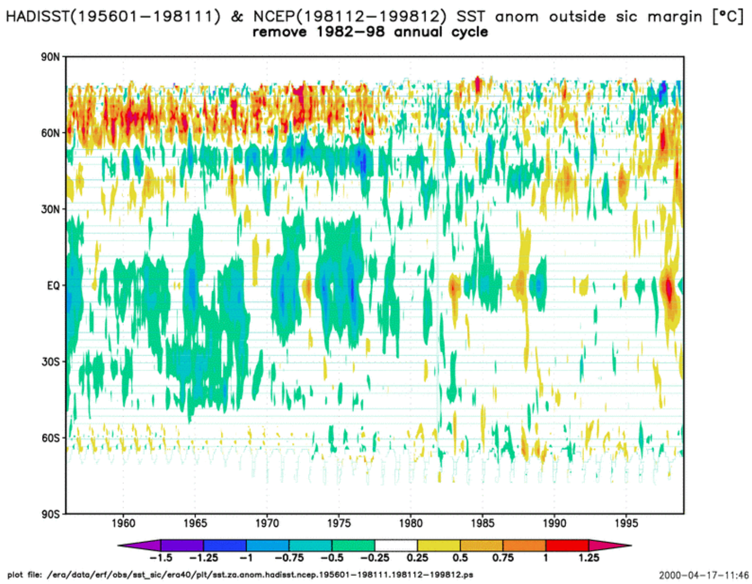

Figure 4 Zonal average of the SST anomaly (from 1982-99 annual cycle) outside SIC margin 1956-2001 [°C].

The seemingly abrupt change in SST anomaly at the high Northern latitudes in the late 1970 was further analyzed at PCMDI and at the UKMO. Figure 5 gives the # of open ocean points and the mean SST in these points for both HadISST and NCEP at 67.5 °N. The number of points increases around 1980, but the temperature decreases. We suspect that the difference is related to how the AVHRR SST data is bias corrected in HadISST since 1982 was when these data were first introduced into the UKMO analysis.

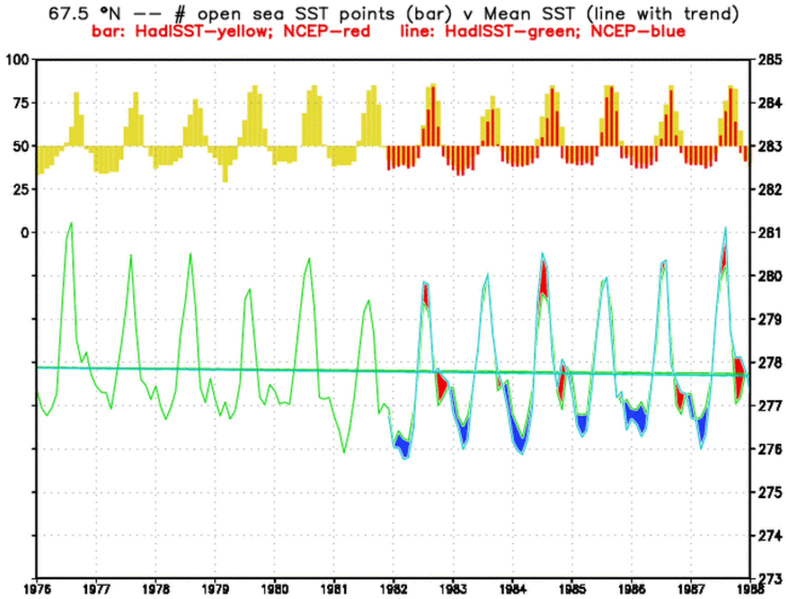

Figure 5. SST [°C] in the SIC margin at 67.5 °N for HadISST (green line) and NCEP (blue line) with NCEP warmer shaded in red and NCEP cooler in blue. The bars compare the # of open ocean (SIC < 10% values on the left) points between HadISST (yellow) and NCEP (red).

Notice the higher amplitude of the annual cycle in the NCEP 2DVAR data. This feature is mostly explained by NCEP being a weekly (higher temporal variance) analysis, with more liberal tolerances in the limits for the *in situ* observations and a different AVHRR bias correction.

The provisional conclusion is that the change is a "feature" of the data due primarily to changes in the observing system (e.g., no satellite -> satellite and different SIC data sets).

In summary, the data sets show a great deal of consistency during the overlap period and while some variability due to changes in the observing system is present, the data provide a better boundary condition for ERA-40 and other modeling applications than previously available.

5 NCEP OISST V2 Reanalyzed SST

As the production phase of ERA-40 began in 2000, NCEP continued to develop the 2DVAR scheme and after a detailed and rigorous evaluation concluded that an updated version of the OI scheme produced superior results as measured by the fit to observations. Thus, the operational weekly SST analysis is now OISST V2. The main deficiency in 2DVAR is the isotropic structure functions and bias correction of the satellite observations near the coast. While NCEP expects to correct these problems and implement a 2DVAR scheme at some point in the future, the current OISST V2 system has been judged best for the present.

Although it might have been desirable to switch the ERA-40 SST to OISST V2, the desire for temporal consistency in reanalysis argued against the change and 2DVAR was used during its period of availability 198112-200106. However, the obvious question is how much "error" will be introduced using 2DVAR vice OISST V2.

Using the same software developed for 2DVAR, a parallel OISST V2 data set was produced at ECMWF that is technically identical (the only difference is in file names) to the current 2DVAR data. The intercomparison below shows that the potential error is very small and well below other error sources in the ERA-40 atmospheric reanalyses. The SIC data were absolutely identical and in the following comparison we have masked out both land/glaciers and SST < 273.16 °K (0°C) to focus on the analyses over open ocean.

In Figure 6 we show the global average difference of the monthly means for the 19-year period. This difference is about 0.03 °C, a value close to the numerical precision of the daily GRIB data (0.01) itself.

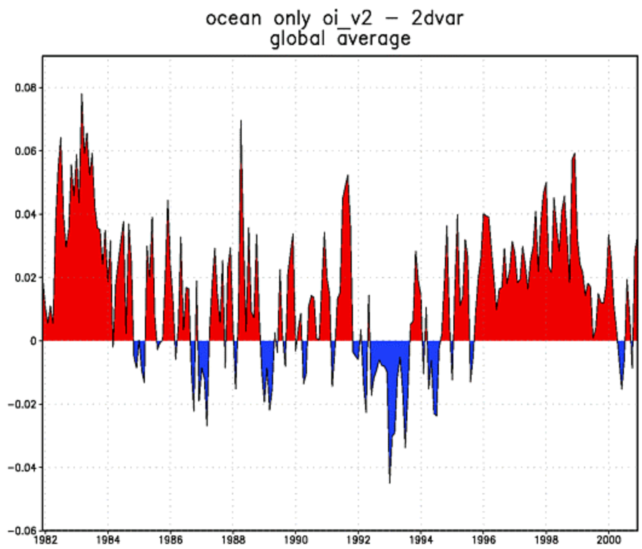

Figure 6. Global average SST difference [°C] between OISST V2 and 2DVAR for the period 1982-2001.

We next look at the distribution of the global differences as a function of latitude in Error! Reference source not found.**.** The largest differences are in the near ice margins, especially Antarctic and OISST V2 is about 0.1 C warmer. The rather abrupt change in 1991 is probably related to the Mount Hudson (Chile) and Mount

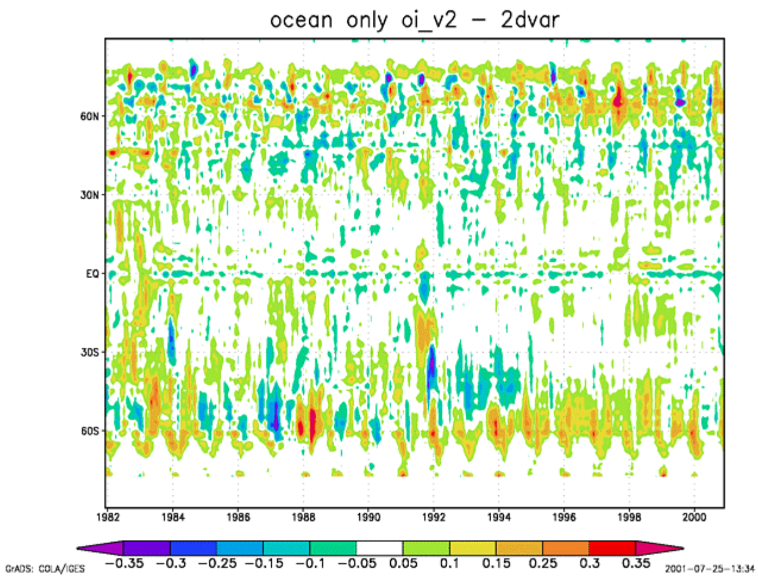

Figure 7. Zonal average SST difference (open ocean only) between OISST V2 and 2DVAR for the period 1982-2001.

Pinatubo (Philippines) volcanic eruptions. The bias correction is different and volcanic eruptions have historically been a large source of bias in the AVHRR SST observations. (See http://vulcan.wr.usgs.gov/Volcanoes/Chile/description_hudson.html and http://vulcan.wr.usgs.gov/LivingWith/VolcanicFacts/volcanic_impact.html).

The differences in bias correction and smoothing between the two analyses may also be seen in the anomaly from the annual cycle of the global mean SST (Figure 8). OISST V2 has slightly higher amplitude (~0.02 °C), but the difference becomes extremely small after 1993.

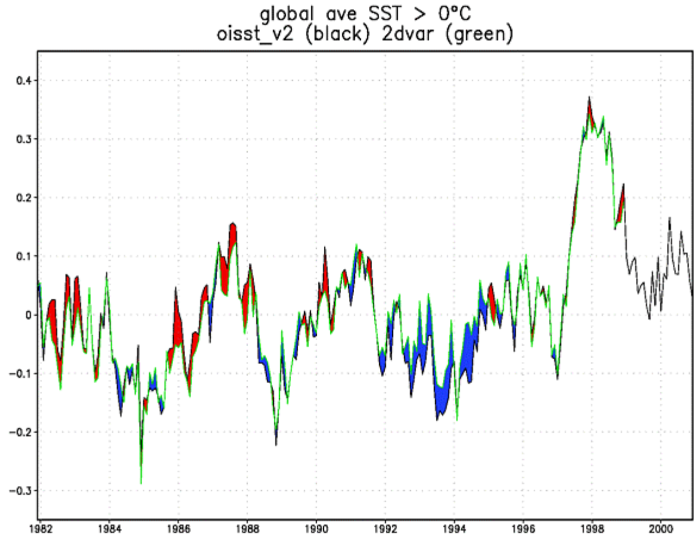

Figure 8. Global average SST anomaly about the annual cycle [°C] (1981-2001) for the period 1982-2001.

Horizontal distribution of the difference is given in Figure 9 for the 20 years. As found in the zonal averages, differences are greatest in the southern oceans, the Gulf Stream and Kuroshio currents and Barents and Norwegian Seas, reflective of slightly greater smoothing in 2DVAR. The pattern in the equatorial eastern Pacific is reflective of smaller N-S gradients in the ENSO region. The magnitude of the difference variability is shown by the root-mean-square in Figure 10. The variability is greatest in the same regions of large mean differences as expected, but the magnitude is about 0.5 °C.

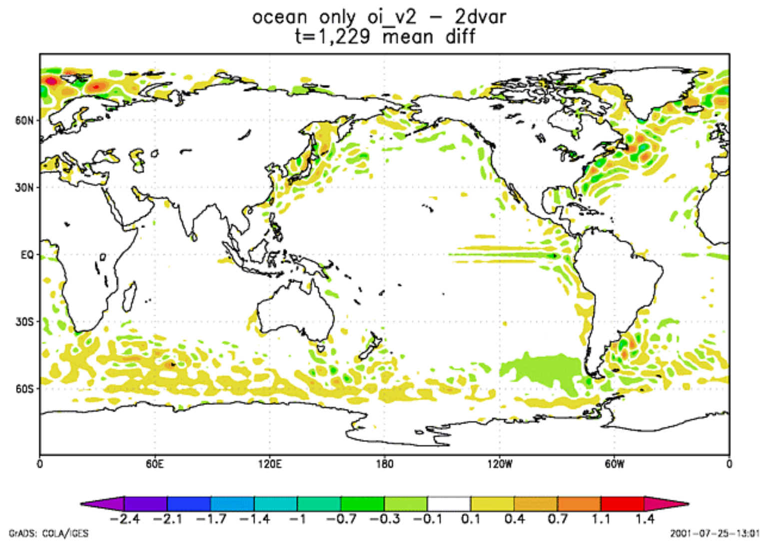

Figure 9. Difference in the 20-year mean (1982-2001) SST between OISST V2 and 2DVAR.

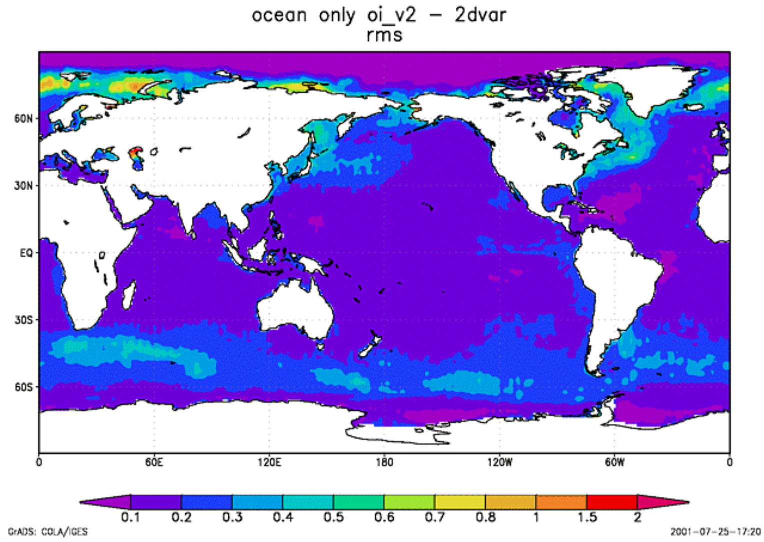

Figure 10. RMS SST difference [°C] of OISST V2 – 2DVAR over the 20-y period 1982-2001.

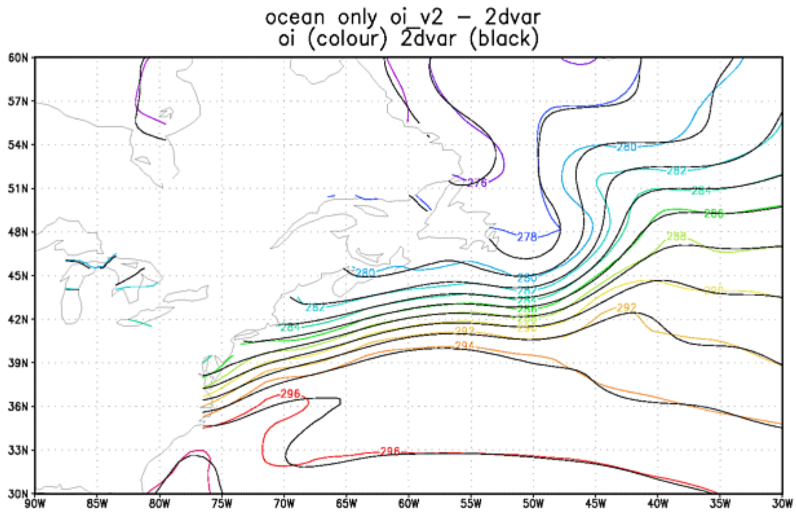

Figure 11. 20-year mean of OISST V2 (color contours) and 2DVAR (black contours) over Gulf Stream.

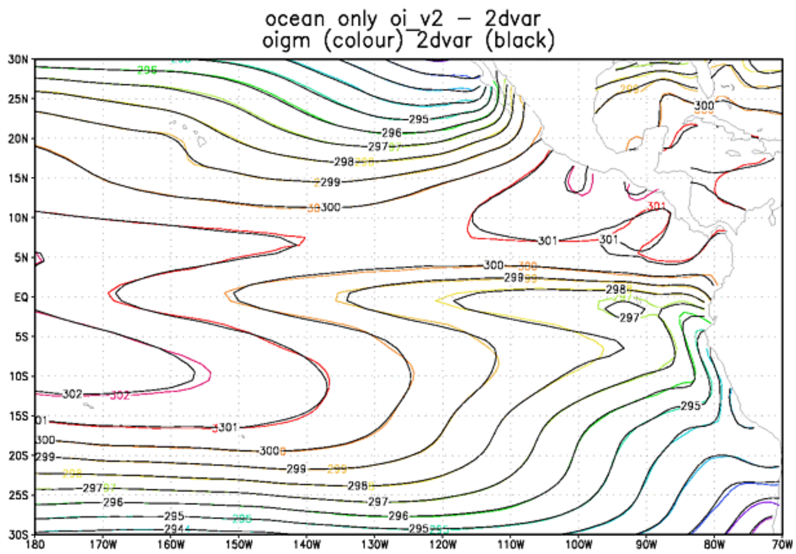

Figure 12. 20-year mean of OISST V2 (color contours) and 2DVAR (black contours) over the equatorial Pacific.

While some mean differences seem rather large (~1 °C), they actually represent slight shifts in the contours (less than 10 km) and more variability at higher wave numbers. This is demonstrated for the Gulf Stream in Figure 11 and for the equatorial Pacific in Figure 12. For the equatorial Pacific, note how the equatorial cold tongue extends further west in OISST V2 (color contour) and has more waves (on a scale of several degrees of latitude) relative to the 2DVAR (black) contour. However, the high gradient zone between Hawaii and Baja California is virtually identical.

In conclusion, there are slight differences between OISST V2 and 2DVAR, with 2DVAR somewhat smoother. However, it seems highly unlikely that the ERA-40 atmospheric reanalysis would respond to these SST differences in a detectable way. Thus, we believe the 2DVAR to be of near-equal quality to OISST V2 for the purpose of multi-decadal reanalysis.

6 Application in ERA-40 Production

Since completion of the first draft of this report, ERA-40 production has finished (200303). In this section we summarize precisely which data sets were used through a comparison against the ERA-40 production monthly mean output. If the input daily data were correctly used, then the difference between the input and the post-processed monthly mean output should be very small. However, noticeable differences arise because of interpolation from the uniform 1° latitude/longitude grid of the SST/SIC analyses to the T_L159 reduced Gaussian grid of the model (and *vice versa* when forming differences) , particularly as this interpolation involves a land-sea mask in the ECMWF "interp" software.

Figure 13 demonstrates the interpolation issue where we compare the ERA-40 SST from the "surface analysis" category of the archive (in MARS: expver=1, stream=oper, class=e4, type=an, levtype=sfc) interpolated to the full Gaussian grid (320x160 grid points) and the NCEP 2DVAR input data (in MARS: expver=12, stream=supd, class=e4) for 12z1jan1982 (1982010112).

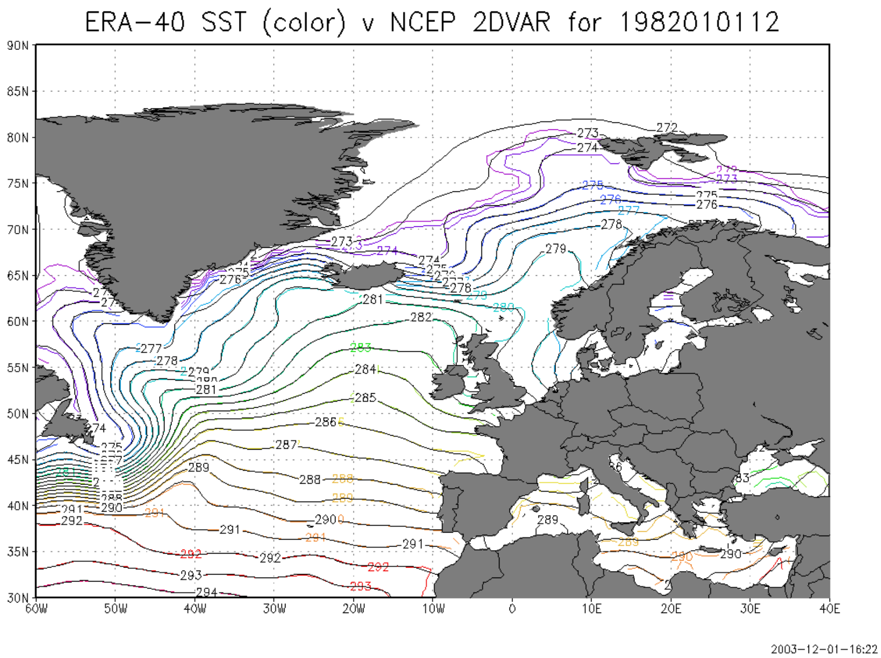

Figure 13. Comparison of SST as represented on the ERA-40 model grid (color contours, full Gaussian, 320x160 grid points) and from the NCEP 2DVAR input grid (black contours, uniform 1° lat/lon, 360x180 grid points) for 12Z 1Jan1982.

The agreement is generally very good, even in the high gradient zone of the Gulf Stream. Note how differences increase with latitude (e.g., between Greenland and Iceland) and in regions of strong land-sea contrasts (e.g., off Norway and in the Mediterranean). Similar interpolation-related differences were found for SIC with the ERA-40 fields smoother in regions of large gradients (fewer longitudinal grid points in the reduced Gaussian grid near the poles). In the global mean, these technical differences are on the order of 2% for SIC and 0.025°C for SST. Thus, global differences exceeding these thresholds indicate a different data set.

We also found large differences (not shown) over large inland lakes (e.g., the Great Lakes) and seas (e.g., the Black Sea). Surface temperature in these bodies of water is handled separately in the land surface hydrology scheme and not by the SST/SIC analyses.

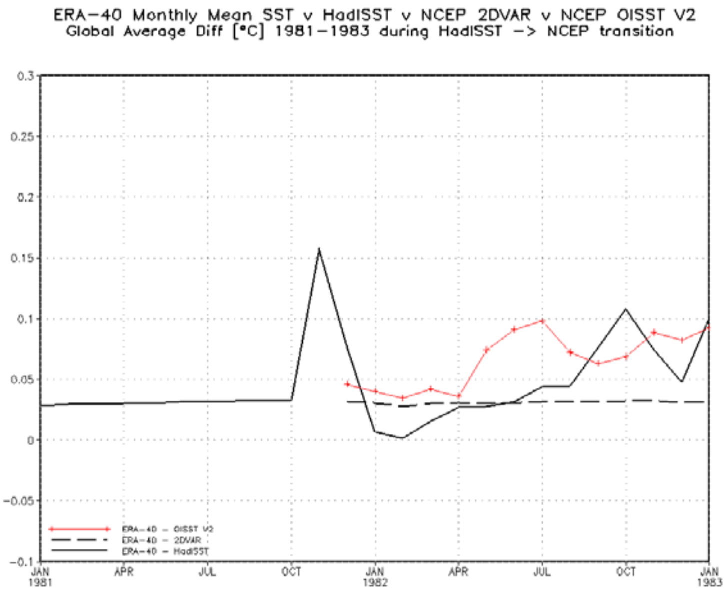

Figure 14. Global mean difference between the postprocessed monthly mean ERA-40 SST and three input data sets interpolated to a common ERA-40 model full Gaussian grid: ERA-40 - HaDISST (solid black); ERA-40 - NCEP 2DVAR (dashed black) and ERA-40 – NCEP OISST V2 (red) for the period January 1981 – December 1983.

We interpolated both the monthly mean ERA-40 data (reduced Gaussian grid) and the monthly means of the input data (1° grid) to the same full Gaussian grid to calculate differences and global means of the differences. Two data set transition periods are considered: 1) HadISST -> NCEP 2DVAR around 198112 (Figure 14); and 2) the end of the NCEP 2DVAR period in 200106 (Figure 15).

Figure 14 confirms that NCEP 2DVAR was used from 198112. However, the jump in 198111 shows that the NCEP data were used in 198111 even though the data were incomplete for that month and the recommendation was to start with the NCEP data in 198112.

The availability of the Fujitsu supercomputer beyond its retirement date allowed production to extend beyond 2001 and up to 200208 so that the final ERA-40 data set consists of 45 full years of reanalyses from 195709 - 200208. However, the observations for the 2002 reanalyses came wholly from the ECMWF operational archives, as might be done if ERA-40 were run an operational climate data assimilation system or CDAS mode. NCEP has continued running their global reanalysis system in CDAS-mode since completion of their first global reanalysis in the late 1990s (Kistler et al. 2001) in which a month of reanalysis is run three days after the end of the month. The three-day delay allows for late-arriving observations, included those used in the weekly SST/SIC analysis, while at the same time insuring timeliness for climate and long-range forecasting applications.

Figure 15 shows the evolution of the difference from 200001 through to the end of ERA-40 period in 200208 and confirms that 2DVAR was used through the 200106 and OISST V2 from 200107 through 200112. However, the big jump in 200201 shows that OISST V2 was not used and that the difference between of ECMWF operational SST/SIC and OISST V2 in 2002 are quite large and 2-3 times greater than in 2DVAR v OISST V2.

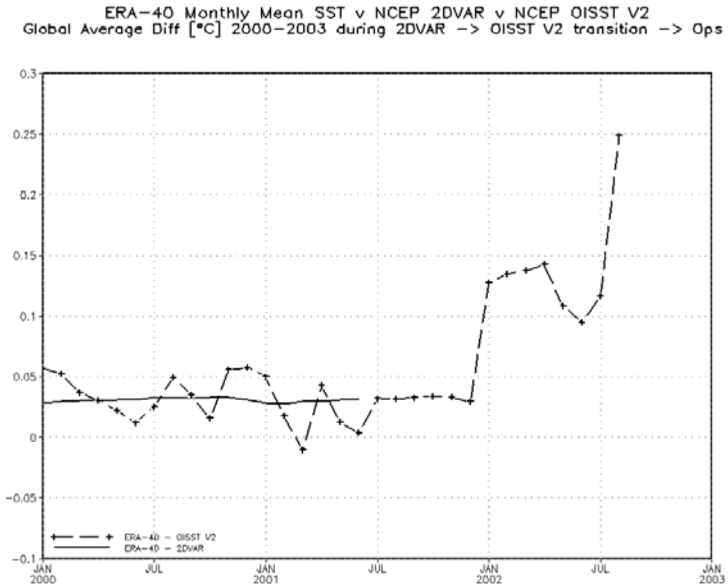

Figure 15. as in Figure 14 except for the period January 2000 through August 2002. The black line is for ERA-40 - NCEP 2DVAR and the dashed for ERA-40 - NCEP OISST V2.

Table 1 below summarizes the ERA-40 SST/SIC data set usage as a function of time. While there are small discrepancies between intended and actual data set usage, the impact will be small since the difference among data sets is small and all are of high quality. However, the impact of using operational SST/SIC in the add-on 2002 period may be more substantial.

TIME PERIOD	**SST**	**SIC**
YYYYMM		**HADISST** AND **NCEP 2DVAR** USE A COMMON SOURCE
195709 – 198110	**HADISST**	**HADISST**
198111	**HADISST** & **NCEP 2DVAR**	**HADISST** & NCEP 2DVAR
198112 – 200106	**NCEP 2DVAR**	**NCEP 2DVAR**
200107 - 200112	**NCEP OISST V2**	**NCEP OISST V2**
200201 – 200208	**ECMWF OPERATIONS**	**ECMWF OPERATIONS**

Table 1. SST/SIC data set usage in ERA-40 Production. Monthly mean: Black ; Weekly: Blue ; Daily: Red.

7 Summary and Recommendations

This report describes the ERA-40 lower boundary conditions of SST and SIC taken from two modern reanalyzed SST/SIC data sets provided by the UKMO and NCEP. The monthly mean UKMO HadISST V1.1 data were used for the period 1957-1981 and the weekly NCEP 2DVAR data for 1982 to present.

The most significant feature of the source data sets is the use of a consensus SIC and SST-SIC relationship in the UKMO and NCEP SST reanalyses. This feature resulted in a near seamless transition between the data sets. We also used a more correct scheme to interpolate the monthly mean data to daily values whereby the monthly mean of the daily-interpolated data is preserved.

Since the beginning of ERA-40 production, NCEP found that an improved OISST V2 produced better SST analyses vis-à-vis the 2DVAR scheme. We processed the new OISST V2 in the same way as 2DVAR and have shown that the differences are small and should have no detectable impact on the quality of the ERA-40 atmospheric reanalyses. However, the SST/SIC from the ECMWF operational archive for the 2002 period is substantially different and could affect temporal continuity.

The relative contribution of SST/SIC and atmospheric observations to low frequency variability in the reanalyzed atmosphere can be assessed through a companion AMIP integration, i.e., to run the ERA-40 AGCM with prescribed SST/SIC. This is equivalent to running the reanalysis with no atmospheric observations. Differences in measures of low-frequency variability, such as an ENSO index, could then be partially attributed to the SST/SIC forcing. Further, an AMIP integration would help define the quality of the ERA-40 SST/SIC data set.

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