ABSTRACTS
Workshop on Advances in the Use of Historical Marine Climate Data
29 January-1 February 2002, Boulder, Colorado, USA

WORKSHOP GOALS

Chris Folland, Hadley Centre, Met Office, Bracknell, UK

The main goals are suggested to be:

1. Create a timetable for enhancing in situ marine datasets, taking account of plans for further digitization of the data. (At a later date, the timetable needs to take account of that for the IPCC Fourth Assessment Report).

2. Develop a strategy for creating alternative SST, sea-ice and marine air temperature analyses, including appropriate satellite data, (i) to test models against the legitimate uncertainties in "reasonable" alternative analysis methods and (ii) to provide estimates of uncertainty in observational analyses of climate variability and change. A set of key diagnostics should be identified like the global sea surface temperature series.

3. Take account of provisional recommendations made by the CLIVAR Climate of the Twentieth Century Project, where a key component involves AGCMs being forced with observed SST and sea-ice extent by around 11 groups.

4. Consider strategies for the joint analysis of surface pressure and wind data, taking account of time-varying biases in the wind data.

5. Make recommendations for blending appropriate marine and land-based data to achieve globally complete surface data sets.

Overview of the International Marine Observational Archive and COADS

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An international marine observational archive for the world ocean will be described, now covering 1784-1997. Data from the Comprehensive Ocean-Atmosphere Data Set (COADS) have been blended with the UK Meteorological Office Main Marine Data Bank (MDB), plus many other sources. Observations from voluntary observing ships extending back for over two centuries have been supplemented since the late 19th century by data from oceanographic research vessels, and in recent decades from moored and drifting environmental buoys. Extensive efforts in data archaeology were required to locate and digitize millions of ship records prior to 1950, never previously available in digital form.

COADS basic monthly summaries based on the observational archive will also be described. These products comprise 10 statistics for each of 22 observed and derived variables, which are available at 2° latitude × 2° longitude resolution, and at 1°×1° resolution for 1960 forward. Ongoing work seeks to increase the usability and scientific value of the data, including improvements in quality controls and additional metadata. Future plans include making available COADS-compatible observational and summary products in near real-time.

The Kobe Collection

Yasuhiro MINAMOTO
Japan Meteorological Agency

The Kobe Collection, consisting of historical marine meteorological data archived at the Kobe Marine Observatory of the Japan Meteorological Agency (JMA), contains over six million observations from Japanese vessels from 1890 through 1961. The observations were mainly in the North Pacific and the Indian Ocean.

After the original log sheet records were microfilmed in 1960/61, the 30 years of data from 1933 onwards, consisting of 2.7 million observations, were digitized by the joint efforts of JMA and US/NOAA and included in COADS.

Two million additional observations, representing about half of the remaining data, have been digitized since 1995 and about half of them were published on CD-ROM in 1999 by the Japan Weather Association under the direction of JMA with financial support of the Nippon Foundation. Applying the WMO Minimum Quality Control Standards after manual tracing of ship cruises enabled 5% of the total data to be corrected or flagged for errors.

In the presentation, together with these accomplishments, future plans will be reported that a further one million observations from the Kobe Collection will be digitized in 2001 and 2002. All of the three million digitized data will be published in 2003 on a final CD-ROM version in the IMMA format, where one third of the total data will include metadata such as the height of the barometer as well as the marine meteorological data themselves. It will also be introduced that long-term variations of marine climate were revealed through statistical studies of the Kobe Collection and COADS data sets such as increasing/warming trends of global average of cloudiness and SST throughout the twentieth century.

International Workshop on Advances in the Use of Historical Marine Climate Data: Boulder, Colorado, USA, January 2002

Marine Data Sets from the UK

David Parker and Simon Tett, Met Office, UK

Abstract

We provide an overview of historical data sets of marine observations provided by the United Kingdom. The largest UK input to the new international marine data base was the Met Office's Marine Data Bank, which has evolved from punch-card data since the 1960s and now includes both logbook and quality-controlled telecommunicated observations from ships. Observations from buoys are not included. A further contribution from the UK was over 450,000 newly-digitized merchant ship observations for 1935-1939. These served to slightly narrow the dip in global coverage of marine data around the second world war, especially in the North Atlantic, South Pacific and southern Indian Ocean. The associated metadata also confirmed previous estimates of ships' decks' elevation used to adjust marine air temperatures. However, an estimated 25 million marine observations made since 1850 remain undigitized in national archives. The CLIWOC project, in which pre-1850 data are being processed, may act as a pilot project for the digitization of this major resource of marine climate information.

Contribution to the "Workshop on Advances in the Use of Historical Marine Climate Data," Boulder
29 January–01 February 2002

The German Historical Marine Archive

Volker Wagner
Deutscher Wetterdienst

Abstract

The transfer of actual and historical marine meteorological ship observations from meteorological journals to media applicable for electronic data processing started in 1940 and has never been interrupted—although the intensity and resources of this process varied. Starting with transfer of these data to punch cards, the procedure in those days suffered from lack of space on the media, so that some organizational information, which appears to be vital today (e.g. logbook numbers) is missing.

This complicates the assessment of which material is already in the archives, which has internationally been exchanged, and where duplicate data have been produced by local data processing.

A short review will be given on:

- the German historical data stock together with an estimate of which material may have been transferred to the US archives by different data exchanges or projects in the past
- data not yet exchanged and/or typed, but potentially available
- an attempt to find original logbooks as trace back of the US 192 deck and some comparisons between the original data, and their appearance in the German archive and in the US 192 deck

International Workshop on Advances in the Use of Historical Marine Climate Data: Boulder, Colorado, USA, January 2002

Climatological Database for the world's oceans 1750-1850 (CLIWOC)

David Parker, Met Office, UK

The immediate purpose of the CLIWOC project is to digitise and quality control data for the period 1750-1850 from ships' logbooks in British, Dutch, French, Spanish and Argentinean archives. Thus, CLIWOC will produce and make freely available for the scientific community a daily oceanic climatological database for that period. Digitisation began in late 2001. It is intended that this information be used to extend and enhance existing oceanic-climatic databases. The ultimate aims of CLIWOC are to realise the potential of the data to provide a better knowledge and understanding of oceanic climate variability. Through the preparation of summaries and derivative diagnostics, it will be possible to determine some characteristics of oceanic climate change and variability at a range of time scales. An attempt will be made to prepare a reliable North Atlantic Oscillation (NAO) index for the period 1750-1850: this will enable assessment of the influence of the NAO on European climate in that period. CLIWOC also aims to stimulate similar data-development projects and research using additional historical marine data not included in the CLIWOC project. CLIWOC ends in November 2003.

CLIWOC is funded under the European Commission Framework 5 initiative. The participants are:

- Universidad Complutense de Madrid, Spain
- University of Sunderland, U.K.
- Royal Netherlands Meteorological Institute
- Incihusa, Mendoza, Argentina
- University of East Anglia, U.K.

The Observers/Reviewers for CLIWOC are Henry Diaz (NOAA, USA) and David Parker (Met Office, U.K.).

World Ocean Database 2001

Sydney Levitus, Margarita Conkright, Timothy P. Boyer, Todd O'Brien, Cathy Stephens, Daphne Johnson, Paulette Murphy, Olga Baranov, Igor Smoylar and John I. Antonov
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World Ocean Database 2001 is scheduled for release during April 2002. Approximately one million additional temperature profiles will become available as part of this release which include a mix of modern as well as historical data. During the past few years The NODC Ocean Climate Laboratory has placed emphasis on acquiring historical data from the southern hemisphere and other data sparse regions in addition to surface data which will improve the comprehensiveness of COADS. Meteorological measurements made during shipboard casts of oceanographic data have been digitized as part of the Global Oceanographic Data Archaeology and Rescue Project. All data will be made available on-line as well as via CD-ROM.

Approximate counts of the additional data expected to be included:

1) 254,343 MBT (Mechanical Bathythermograph Profiles)
2) 142,055 XBT (Expendible Bathythermograph Profiles)
3) 617,626 BD (Bottle Data Casts)
4) 93,023 HCTD (High Resolution CTD Profiles)

The Research Vessel Surface Meteorology Data Center Archive

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Observations of the near-surface atmosphere over the global oceans have evolved rapidly in the past decade. One frequently overlooked source for marine observations is data collected by oceanographic research vessels (RVs). Since 1994, a surface meteorology data center at the Florida State University has been collecting, evaluating, and archiving automated weather station (AWS) observations from select international RVs. AWS data typically include wind, air and sea temperature, pressure, moisture, and radiation data recorded at one to ten minute intervals. Data quality evaluation has revealed some problems with AWS data; however, the overall quality of AWS marine observations is very good and the data have proven useful in validation studies of satellite sensors and global reanalyses.

An overview of our current archive will be provided. Data are available from TOGA-COARE and WOCE and the archive has recently expanded to include historical data from several international and NOAA RVs. Inclusion of these high-quality RV observations into a blended marine dataset is desirable. A discussion of how best to include these RV data will be initiated. One plan is to create hourly 'superobs' from the AWS data. Other discussion topics include how to handle FSU quality flags, metadata, and supplemental (not COADS standard) observations.

Data Access to Marine Surface Observations and Products from COADS

Steven J. Worley, National Center for Atmospheric Research

COADS observations and monthly summary products have been distributed from NCAR since 1983. A review of the distribution characteristics from this starting date to today will highlight the broadening user community, methods of distribution, and set the stage for a description of the various access options currently available. These include online data request forms (with the spatial and temporal limits, selection of summary statistics variables and types, and selection of individual fields from the observed records all user determined) and delivery through network transfers and other media in binary or ASCII file formats. Subset preparation of the observed records also permits the application of the internal QC and data flags. Through this feature a record set can be created that could lead to summary statistics that match the COADS products or a user may customize the QC and flag application so that the record set meets their specific research requirements.

The current system is successful, but more needs to be done. Two centers (NCAR and NOAA/CDC) now serve the data and a third (NOAA/NCDC) is preparing to join this primary service. Other secondary sites also serve the data. If these sites are not kept up to date and complete they can be a disservice to the scientific community. A coordinated metadata site for the three primary centers would help investigators find the best data sources. Such a site would necessarily support the expanding long-term data archive, the products (both statistical summaries and analyses), and the forthcoming real time data products. Currently several different monthly summary data products are offered in an attempt to address the heterogeneities in the archive collection. Allowing investigators some choices to design customized statistics, computed upon request, could augment the standard offerings. The advantages and disadvantages to this approach will be discussed.

Access to Marine Data Sets Over the Web—Requirements to Support Research Users

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Several characteristics of COADS—the large time interval covered, the large number of statistics for each physical parameter and the large number of physical parameters—create special challenges for the would-be designer of an easy-to-use Web interface. Solutions to the problems are restricted by the need for compatibility with an existing general-purpose data delivery system, the Live Access Server (LAS). This presentation will detail some of the interface design choices that were made and the trade-offs between easy-of-use, functionality, and technical expediency that motivated those choices.

Access should include the ability to browse (graphically), zoom into selected regions, request time series and Hofmuller time evolution plots, and obtain subsets of the data (including secondary statistics as well sa monthly means) in a choice of formats. Ideally, the user should be able to compare the same parameter on different months, compare time series at different locations, and compare the COADS estimates with other data products not necessarily defined on the same grids. Methods of comparison might include side-by-side plots, graphical overlays, and computed difference fields. Some of these capabilities will be demonstrated with LAS.

The VOSClim Project and the WMO Ship Catalogue (WMO-No.47)

Teruko Manabe, Ocean Affairs Division, WMO

The WMO VOSClim project is about to enter into an implementation phase. The primary objective of the project is to provide high quality marine meteorological data and associated metadata, to serve as a reference data set to support global climate studies. It is planned to recruit a total of 200 VOS for this project in the world. A Real Time Monitoring Centre (RTMC), located at Met Office, UK and a Data Assembly Centre (DAC), located at NCDC/NOAA, USA were established to ensure a smooth flow and archival of project data, as well as a real time review of the quality of these data.

WMO has been publishing a catalogue of VOS (WMO-No.47), which provides metedata such as routes and types of meteorological observations on VOS. Details of metadata including instrument exposure and data of any changes are also necessary to achieve the accuracy required by the VOSClim project. Modification of the contents of WMO-No.47 to include such new detailed fields was introduced and an upgraded database has been prepared. The new database will be very shortly available on the WMO web site, for search, downloading and updating. Also, metadata of the project participating VOS will be available in the WMO-No.47 format on the project web site managed by DAC.

BIAS ADJUSTMENTS TO HISTORICAL SST

Chris Folland, Hadley Centre, Met Office, Bracknell, UK

Bias adjustments to historical SST before 1942 are based on the observation that the use of uninsulated or partially insulated buckets to collect sea water creates artificial annual cycles of SST relative to the use of more recent data, away from equatorial regions. The annual cycles are mainly due to cooling of the sea water in the bucket used to collect it, both during hauling and when on deck. Cooling tends to be larger in winter, creating an artificial annual cycle. Models were developed that describe the physics of the cooling of uninsulated canvas and partially insulated wooden buckets. The models can be used to largely remove the artificial annual cycles and create adjustments for the mostly cold biases that are calculated. The models contain information about short and long wave radiation so they can also detect net climatological warm biases in SST collected from buckets in a few areas in summer. Suitably calibrated, the models are used in equatorial regions where there is almost no artificial annual cycle, giving global fields of adjustments.

Tests of the adjustments are described, particularly those using an atmospheric general circulation model forced with adjusted or unadjusted SST to simulate land surface air temperature anomalies. The model only provides satisfactory simulations of global and regional temperature anomalies before 1942 if adjusted SST data are used. Annual mean and seasonally varying adjustments to the imposed SST have been tested in this way. The performance of both annual mean and seasonal corrections will be presented.

Bias Adjustments, Quality Control, and Analyses of Historic SST

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Abstract

Because of changes in SST sampling methods in the 1940s and earlier, there are biases in the earlier period SSTs relative to the most recent fifty years. Published results from the UK Met Office have shown the need for historic bias corrections and developed several correction techniques. An independent bias-correction method is described, based on night marine air temperatures and SST observations from COADS. Because this method is independent from methods proposed by the UK Met Office, the differences indicate uncertainties while similarities indicate where users may have more confidence in the bias correction. The new method gives results which are broadly consistent with the UK Met Office bias-correction estimates. The global and annual average corrections from both are nearly the same. Largest differences occur in the Northern Hemisphere in winter, when our estimates are larger than the Met Office estimates.

Improved quality control (QC) methods are also developed for COADS data and applied to historic SST. The improved QC compares observations with a statistically optimal analysis, discarding values that differ greatly from the analysis. A statistical analysis of QC historic SST data is produced from the 19th century to 1997. The analysis and comparisons with other analyses are discussed. Error estimates for the analysis show that sampling error is greatest before 1880, when analyses may not be reliable for most regions. Between 1880 and 1941, uncertainties in the bias correction are a major part of total uncertainty. Analyses are most reliable beginning in the late 1940s, when sampling is relatively dense and no bias correction is applied.

Improvement of Trimming in COADS

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Abstract

Trimming is an important part of data quality control in the Comprehensive Ocean-Atmosphere Data Set (COADS). The trimming compares each observation with a long-term average and flags it as erroneous if the difference between the data and the average is too large. For COADS Release 1, these rejection limits were set at ±3.5 standard deviations (σ). Later, however, we found that the 3.5σ limits were sometimes too restrictive when applied to data from extreme climate events (e.g., in the eastern tropical Pacific during strong El Niños). The limits were therefore relaxed to 4.5σ for recent updates (Releases 1a, 1b, and 1c). This reduced the amount of incorrectly flagged data, but a new adaptive trimming scheme is under development to provide a more complete solution. The new scheme is based on optimal-interpolation (OI) and is adaptive in two ways: (1) It compares observational data with corresponding year-month means of an OI-analysis, thus adapting to unusual climate events. (2) It uses a linear combination of conventional σ and the difference between the year-month means of the OI-analysis and the raw data, adapting to spatial and temporal variations in the number of observations by weighting the difference more than the σ for better sampled locations/months.

An Integrated Approach to the Production of an Optimal High Resolution Sea Surface Temperature Analysis

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Abstract

Operational oceanography, numerical weather prediction and climate monitoring each have a requirement for sea surface temperature (SST) fields. The differing emphases on accuracy and timeliness, together with a variety of satellite and *in situ* instruments, have led to a plethora of SST analyses. However, there is a growing consensus that a single analysis that makes optimal use of all relevant sources of data is both achievable and desirable for many disciplines, not least in order to eliminate differences between the various datasets that are currently in use. This paper describes the progress being made towards the realization of that goal. Consideration is given to the most appropriate analysis methodology, and the inputs required to ensure optimal results. These include discussion of 4-d variational assimilation techniques, production of error covariances for both background and observation fields, radiative transfer methods for skin SST retrieval and modeling of skin and diurnal thermocline effects. Particular areas of focus include the use of microwave data to not only fill in observations in cloudy areas, but as a means of characterizing the errors resulting from residual cloud contamination of IR SST products, and the geographical, temporal and non-symmetrical nature of the errors.

Sea Ice Data: A Review

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A general overview of sea ice data applicable for global analyses will be provided, including basic characteristics of pre- and post-satellite data sets. Emphasis will be placed on ice concentration and ice extent, but with some discussion of issues involved with satellite-derived estimates of ice surface temperatures. Particular issues to be addressed include the effects of errors and biases in the various data sets, consistency among ice mapping methods and satellite algorithms, estimation of trends, and requirements for in situ observations to improve blending of SST and ice data. The potential of new data sets to help quantify errors and biases in the existing time series of ice products will also be considered.

Sea Ice Data Sets Available within the WMO GDSIDB Project and Future Candidates

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The ice cover of the World Ocean is a sensitive indicator of global change climate. So far, accurate temporal sea ice historical data sets most extensive in space and time are valuable for reanalysis of Earth climate and prediction of future ice cover oscillations. Such material prepared by major world sea ice services within the WMO "Global Digital Sea Ice Data Bank" (GDSIDB) project gives a possibility to improve a vision of what variability in ice extent and properties was observed at least during the last 50 years of 20th century. Basic factual data for ice total and partial concentration and stages of sea ice development were prepared and are archived in WMO standard SIGRID format (at the nodes of 15 minutes geographical grid) separately by ice services (from Canada, Russia, USA, etc.) for the Arctic region for period 1950-1994. However, up to now for the region of Eurasian Arctic, the above factual data are still not fully incorporated in reanalysis process. From year 2000, data sets both in SIGRID and EASE grid projections are available online via AARI and NSIDC web sites or in the form of joint "U.S.-Russian Arctic Sea Ice Atlas". Different statistics assessed on the basis on "blended" material (from Canadian, Russian and USA origin) are also available on line and are shown in the report and, we would say, that there is more evidence for long-term oscillations in sea ice variability than for linear trends, or "decrease" in sea ice. So far, it is proposed to more effectively incorporate the proposed sea ice data in climate modeling. Future possible candidates within the WMO GDSIDB project include mapped material for Eurasian Arctic and Northern Atlantic for the first part of the 20th century and regional sea ice material for the Baltic Sea.

International Workshop on Advances in the Use of Historical Marine Climate Data: Boulder, Colorado, USA, January 2002

Creating the HadSST Gridded *in situ* SST Analysis

David Parker, Met Office, UK

Grid-box-average sea surface temperatures are adjusted to compensate for the effects on variance of changing numbers of contributing data. The technique damps monthly average temperature anomalies over a grid box by an amount inversely related to the number of contributing observations. Thus the reduction of variance corrections is greatest over data sparse regions. After adjustment, the data are unaffected by artificial variance changes which might affect, in particular, the results of analyses of the incidence of extreme values. The effects of our procedures on hemispheric temperature anomaly series are small. Our technique is described in detail in Jones *et al*. (*J. Geoph. Res.,* **106**, 3371-3380 (2001)) in which land surface air temperatures are also treated. The improved data were used in an analysis of extremes by Horton *et al.* (*Climatic Change*, 50, 267-295, 2001)) and show little evidence of changes in the incidence of extremes after trends in global-average sea surface temperature have been taken into account.

JMA Gridded SST Analysis

Yasuhiro MINAMOTO
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Among several operational products of the Japan Meteorological Agency for sea surface temperature (SST), the daily SST analysis for 1/4 degree in both latitude and longitude in the seas adjacent to Japan has been objectively conducted not only for monitoring of short-term and small scale oceanic conditions but also as the basis of 10-day and monthly mean products since 1996. Furthermore, the daily product is now expected to serve as a boundary condition for a meso-scale numerical model of the atmosphere.

The daily SST products are derived by optimum interpolation from all of the in-situ data and NOAA/AVHRR data, which are converted to SST with the NESDIS/MCSST method as well as a cloud distinction process developed by the JMA. Furthermore, the bias of satellite derived SSTs is corrected by applying long-term statistical relationships to in-situ SSTs.

The 10-day and monthly SST products, and the arithmetic means of the daily analyses are posted on the North East Asian Regional GOOS (NEAR-GOOS) Regional Real-time Database as charts and grid point values for both operational and research-oriented user communities.

In the presentation, the procedure to prepare the daily SST products will be introduced including characteristics of the bias of satellite derived SST to the in-situ data and the blending method for the two types of SST data.

SST Analysis by Temperature Class

Ken Casey
UCAR-NOAA/NESDIS/NODC

Individual sea surface temperature (SST) anomalies are calculated using a satellite-based climatology and observations from the 1994 World Ocean Atlas (WOA94) and Comprehensive Ocean-Atmosphere Data Set (COADS) to characterize global and regional changes in ocean surface temperature since 1942. For each dataset, anomaly trends are computed using a new method which groups individual anomalies into climatological temperature classes. These temperature class trends are compared with trends estimated using a technique representative of previous studies based on five-degree latitude-longitude bins. The temperature class bins produce similar trends in the recent, relatively well-sampled years. In earlier years when fewer observations are available, the temperature class approach produces similar COADS anomalies but with smaller standard errors. Before about 1960, the temperature class approach extends the more data-limited WOA94 anomalies further back in time than was possible using the five-degree bins. Another advantage of the temperature class approach is its ability to reduce the monthly mean anomaly standard error relative to the five-degree bin technique. This ability is illustrated using a statistical efficiency parameter. Finally, the temperature classes provides a new perspective on warming trends, revealing interesting features like smooth transitions between warming and cooling zones not evident in latitudinal averages.

International Workshop on Advances in the Use of Historical Marine Climate Data: Boulder, Colorado, USA, January 2002

Construction and Testing of the Globally Complete HadISST1 Data Set

Nick Rayner, Met Office, UK

We present the Hadley Centre's sea-Ice and Sea Surface Temperature (HadISST1) data set. HadISST1 replaces the Global sea-Ice and Sea Surface Temperature (GISST) data sets, and consists of monthly globally-complete fields of SST and sea-ice concentration on a 1˚ grid from 1870 to 1999. SST anomaly fields are reconstructed using reduced-space optimal interpolation (RSOI). Satellite-based SSTs are blended smoothly with *in situ* SSTs with the aid of RSOI. As in GISST, we reconstruct the global field of long-term "trend" separately from the remaining SST variability. The local detail of SST is improved by superposing quality-improved gridded SSTs. Satellite microwave-based sea-ice concentrations are compensated for the impact of melt ponds and wet snow, and the historical *in situ* concentrations are made homogeneous with the modified satellite record. The procedure for estimating ice-zone SST has been refined. HadISST1 SSTs are more coherent in time than those in GISST, and are of comparable quality to several shorter published SST analyses. The Antarctic Circumpolar Wave is well reproduced since the 1980s. We verify HadISST1 against other SST data sets and use diagnostics from atmospheric model simulations to show that HadISST1 is an improvement on GISST.

High Resolution Objective Analysis of Historical SSTs:
Small-scale, Long-term, and Sea-ice Aspects

Alexey Kaplan
Lamont-Doherty Earth Observatory of Columbia University

We report on our ongoing methodological developments towards producing an enhanced data set of historical surface temperatures (SST) and sea ice concentrations. We modify the technique of reduced space optimal estimation to produce a globally complete high resolution (1×1 degree for the world ocean) objective analysis of monthly surface temperatures and sea ice concentrations. This analysis is supposed to be accompanied by verifiable error bars. A two-stage procedure is used to account for the long term climate trend and to estimate its uncertainty. The near-complete coverage, high spatial and temporal resolution of remote-sensing data allows us to enhance significantly the quality of pre-satellite period reconstructions. First, through its correlations with in situ observations it provides satellite era resolution and coverage for fields reconstructed for the pre-satellite period. Second, it provides reliable estimates of observational and sampling error for in situ data. These estimates are crucial for the analysis to produce verifiable theoretical error bars for pre-satellite period reconstructions. These error bars might be very large for the places of persistently poor sampling, however the goal of this project is to squeeze all possible information on small scale SST variability out of existing historical data. We attempt to use Multivariate (with SST) reduced space optimal estimation for analysing sea ice concentrations.

Validating Satellite Infrared Sea Surface Temperatures with In Situ VOS Data

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Abstract

Sea surface temperature (SST) is a critical quantity in the study of both the ocean and the atmosphere as it is directly related to and often dictates the exchanges of heat, momentum and gases between the ocean and the atmosphere. As the most widely observed variable in oceanography, SST is used in many different studies of the ocean and its coupling with the atmosphere. We briefly examine the history of this measurement and how this history has led to today's practice of computing SST by regressing satellite infrared measurements against in situ SST observations made by drifting/moored buoys and ships. The fundamental differences between satellite and in situ SST are outlined and recommendations are made for how both data streams should be handled. A comprehensive in situ validation/calibration plan is proposed for the satellite SSTs and the consequences of the suggested measurements are discussed with respect to the role of SST as an integral part of the fluxes between the ocean and the atmosphere. Accuracy improvements in SSTs and related quantities as a consequence of this validation program are discussed.

An Improved In Situ and Satellite SST Analysis for Climate

R. W. Reynolds[1], N. A. Rayner[2], T. M. Smith[1], D. C. Stokes[3], W. Wang[3]

A weekly 1° spatial resolution optimum interpolation (OI) sea surface temperature (SST) analysis has been produced at the National Oceanic and Atmospheric Administration (NOAA) using both in situ and satellite data from November 1981 to present. The weekly product has been available since 1993 and is widely used for weather and climate monitoring and forecasting. We show errors in the satellite bias correction and the sea-ice to SST algorithm and develop an improved version of the OI analysis. The results show that there is a modest reduction in the satellite bias that leaves small global residual biases of roughly -0.05°C. The major improvement in the analysis occurs at high latitudes due to the new sea-ice algorithm where local differences between the old and new analysis can exceed 1°C.

Comparisons with other SST products are needed to determine the accuracy of the OI. These comparisons also show typical differences in the monthly products produced at different centers. The differences are presented to give an estimate of SST analysis accuracy for 1982 to 1999. The results show that these differences occur on large time and space scales with RMS differences exceeding 1°C. Globally averaged SSTs show persistent differences on decadal scales of roughly 0.05°C that can impact climate trends. Decadal-scale differences on smaller spatial scales are larger (greater than 0.25°C) and occur in the middle and high latitude Southern Oceans, and in the Arctic where data are sparse. They also occur in high gradient areas such as the Gulf Stream and Kuroshio where the gradients cannot be properly resolved on a 1° grid. However, smaller differences occur in other regions of the mid-latitude Northern Hemisphere where in situ data should be adequate.

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Summary of Results from High-Resolution SST Workshop

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A three-day workshop was held in November 2000 in Ispra, Italy to discuss the prospects for a new high-resolution sea surface temperature (SST) product in response to improved measurement systems and increasing demands of growing application and user sectors. The invitees were drawn from all fields of SST research and operations and included members from Government research laboratories, university research, private industry, and the Naval sectors. Through the workshop it was decided to pursue the implementation of a Global Ocean Data Assimilation Experiment (GODAE) high-resolution sea surface temperature pilot project (GHRSST-PP). The aim of this project is to provide a new generation of global, multi-sensor, high-resolution SST products for the benefit of the scientific community and those with a potential interest in the products of GODAE.

The meeting consisted first of a series of scientific presentations in the areas of operations and requirements, the physical character of SST, techniques for measuring and estimating SST, and physical processes affecting SST measurements. The focus then turned toward developing a plan for the pilot project and identifying key theme areas. The four themes included testing and refining data sources, data integration and assimilation, users and data products, and research and development.

Advances in Microwave Sea Surface Temperature

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The TRMM Microwave Imager (TMI) has produced passive microwave observations at 10.7, 19.4, 21.3, 37.0, and 85.5 GHz since December 1997. Accurate retrievals of sea surface temperature (SST) can be made in all weather conditions except rain. Microwaves penetrate clouds with little attenuation, giving an uninterrupted view of the ocean surface. This is a distinct advantage over infrared measurements of SST, which are obstructed by clouds. Errors in the microwave SST retrieval are mainly derived from in-accurate parameterization of wind effects. Comparisons with ocean buoys show a root mean square difference of about 0.6ºC, which is partly due to the satellite-buoy spatial-temporal sampling mismatch and the difference between the ocean skin temperature and bulk temperature. The combination of 1-micron (infrared), 1-mm (microwave) and 1-meter (buoy) SSTs is yielding a better understanding of the ocean skin layer. Microwave SST retrievals are of adequate resolution and accuracy for a high-quality, long-term dataset for climate studies.

Towards Improved Validation of Satellite Sea Surface Skin Temperature Measurements for Climate Research

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A poor validation strategy will compromise the quality of satellite-derived sea-surface temperature (SST) products because confidence limits cannot be quantified. This paper addresses the question of how to provide the best operational strategy to validate satellite-derived skin sea-surface temperature (SST_{skin}) measurements. High quality in situ observations obtained using different state-of-the-art infrared radiometer systems are used to characterise the relationship between the SST_{skin}, the subsurface SST at depth (SST_{depth}) and the surface wind speed. Data are presented for different oceans and seasons. These data indicate that above a wind speed of approximately 6 ms^{-1} the relationship between the SST_{skin} and SST_{depth}, is well characterised for both day and night time conditions by a cool bias of 0.17 ±0.07 rms. K. At lower wind speeds, stratification of the upper ocean layers during the day may complicate the relationship while at night a cooler skin is normally observed. Based on these observations, a long-term global satellite SST_{skin} validation strategy is proposed. Emphasis is placed on the use of autonomous, ship of opportunity radiometer systems for areas in areas characterised by prevailing low wind speed conditions. For areas characterised by higher wind speed regimes, well calibrated, quality controlled, ship and buoy SST_{depth} observations, corrected for a cool skin bias should also be used. It is foreseen that SST_{depth} data will provide the majority of in situ validation data required for operational satellite SST validation. We test the strategy using SST_{skin} observations from the Along Track Scanning Radiometer, that are shown to be accurate to ~0.2 K in the tropical Pacific Ocean, and using measurements from the Advanced Very High Resolution Radiometer. We note that this strategy provides for robust retrospective calibration and validation of satellite SST data and a means to compare and compile in a meaningful and consistent fashion similar data sets. A better understanding of the spatial and temporal variability of thermal stratification of the upper ocean layers during low wind speed conditions is fundamental to improvements in SST validation and development of multi-sensor satellite SST products.

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SST, Marine Air and Tropospheric Temperatures

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Since 1979, a curious observational result has confounded climate researchers. The bulk atmospheric temperature over the tropical oceans, as estimated independently by satellites and radiosondes, has shown virtually no trend while SSTs have risen significantly. Consistent with this result is the finding that the trend of the marine air temperatures falls between SST and tropospheric trends for both the ocean-wide Hadley data and groupings of PMEL buoys in the eastern Pacific. This implies a tendency toward a more unstable tropical lapse rate in the past two decades. Climate model simulations indicate bulk tropospheric trends are more positive than those of the SSTs, in contradiction to the observations. This result raises questions about a possible spurious retention of heat in climate model atmospheres.

In a separate study, COADS data of SST, MAT and SLP have been compiled into pentad anomalies (half-degree spatial resolution) for the examination of long-term variations of these quantities. The apparent warming of the SSTs vs. MATs of the past 23 years is not explicitly found in observations prior to the most recent period going back to the late 19th century. In addition, a sea ice algorithm has been applied for SSM/I data for a better determination of the distribution around Antarctica.

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Construction and Testing of the HadMAT Gridded Night Marine Air Temperature Analysis

David Parker and Nick Rayner, Met Office, UK

We review the development of the Hadley Centre night Marine Air Temperature data set HadMAT and assess its quality using comparisons with other temperature data. HadMAT uses data from an hour after sunset to an hour after sunrise, to minimise the effects of solar heating of ships' decks. The bias adjustments used in HadMAT include new allowances for increasing and geographically-varying heights of ships' decks in recent years. HadMAT is not globally complete, but, where data are sufficent for covariance matrices to be constructed, Reduced Space Optimum Interpolation is used to fill gaps. The improved deck-height adjustments give improved overall agreement with trends in collocated sea surface temperatures and land surface air temperatures since the 1980s. Analysis of temperature changes since the late 19th century in the New Zealand - Southwest Pacific region gives more coherent results when HadMAT is used, than using predecessor data sets. Potential future improvements include incorporation of extra data from the international blend, reduction of random and sampling error using statistical techniques similar to those used in HadSST, and further refinements to the adjustments to allow for variations of deck-heights.

Assessing Biases in Recent *in situ* SST and Marine Air Temperature

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The COADS blend with the UK Meteorological Office Marine Databank has been used to assess biases in reports from Voluntary Observing Ships from 1980-1997. Initial focus has been on SST and air temperature. The analysis method chosen uses pairs of co-located reports from ships using different measurement techniques. Metadata from the WMO International List of Selected, Supplementary and Auxiliary Ships were used to identify measurement method. Comparison of reports with climatology was considered but, as the climatologies may themselves be biased, was not taken further.

Analysis of the paired dataset requires careful consideration of random errors. Spurious relationships may result from random errors, so these effects must be assessed and removed before meaningful analysis can proceed. Choosing good quality data with a known error structure to analyse can be problematic. For example, ships reporting engine intake SST give relatively good quality nighttime SST when the ship moves slowly, but the error variance doubles at ship speeds over 4 ms^{-1}. Conversely, the variance of nighttime air temperatures from the same ships increases threefold when the ship speed is less than 4 ms^{-1}. Strong differences in error variance also exist between reports from different countries, at different wind speeds and measurement heights.

Plans for the AOPC Mean Sea Level Pressure Working Group

Rob Allan

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Abstract

The recovery, quality control, analysis, storage, access and longer term maintenance of historical climatic records has become an essential element supporting ongoing studies of climatic variability and change. Some of the data sets established by the above means, such as those detailing historical land surface air temperature, sea surface temperature, marine nightime air temperature and rainfall, have had considerable attention paid to them, while others, like historical wind, cloudiness and mean sea level pressure (MSLP), have tended to be left in the hands of a few specialised interest groups. Most recently, the emphasis on historical MSLP data sets has reached the stage where considerable advances could be made by more concerted international collaborative efforts.

The AOPC MSLP Working Group has been set up to promote the development of long-term high-quality analyses of atmospheric surface pressure through a more co-ordinated international effort. This presentation will detail the Terms of Reference and Membership of the Working Group, and also illustrate how the Group could work to facilitate progress in historical surface pressure data recovery, and the subsequent construction and archiving of such data.

The Hadley Centre Mean Sea Level Pressure HadSLP Data Set

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Abstract

The Hadley Centre Sea Level Pressure dataset HadSLP is a monthly globally-complete analysis on 5° latitude by 5° longitude resolution for 1871 to 1998. HadSLP is the successor to the Global Mean Sea Level Pressure (GMSLP) series. The advantages of HadSLP over GMSLP are an improved land station data base, a new interpolation scheme - Reduced Space Optimal Interpolation (RSOI), incorporation of original data to provide local detail while safeguarding against random errors, and simpler updating procedures. However, HadSLP requires further refinements. In particular, the analysis has unrealistic negative trends over part of the Southern Ocean. These probably arose because the RSOI used eigenvector patterns partly based on the NCEP Reanalysis which has major negative trends over much of the Southern Ocean . These trends are not supported by available observations. Our observations removed these trends in most, but not all, of the region. Spurious positive trends in the NCEP Reanalysis over parts of North Africa and southern Asia were also removed by the data. By contrast, the negative trends over the high northern latitudes are supported by recent observations and refect a well-known recent strengthening of the Arctic Oscillation and North Atlantic Oscillation. We plan to re-run the RSOI using EOF from the ECMWF Reanalysis which is not affected by the spurious trends.

The FSU Wind Fields

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The Center for Ocean-Atmospheric Prediction Studies at the Florida State University has been producing monthly wind analyses over the tropical Pacific and Ocean since the early 1980s. These subjectively-derived analyses are used worldwide to study ocean-atmosphere interactions in the Pacific and to force ENSO forecast models. Though not as famous, COAPS also produces monthly wind analyses of the tropical Indian ocean and supports the production of tropical Atlantic wind analyses (through French collaborators).

The FSU winds are now moving into a new era where all wind fields (Pacific, Indian, and Atlantic) and turbulent surface fluxes will be produced using a new objective analysis system. A historical look at the current FSU wind products will be presented. Successes include validating the role of equatorial Kelvin waves in the development of El Niño and the expansion to producing operational analyses after the 1982-83 El Niño in support of TOGA. The discussion will also include problems that were overcome through the years. Finally, a brief introduction to the future FSU wind products will be presented (details will follow in Mark Bourassa's talk).

New Objective FSU Wind and Flux Climatologies

Mark Bourassa, COAPS/FSU

An objective technique is used to create a new monthly climatology for surface fluxes and related fields. The wind products are improvements over our previous product (the subjectively analyzed FSU winds). Fields of turbulent surface fluxes and the variables needed to calculate these fluxes are also generated. The new objective method is an extension of a technique used to create daily grid scatterometer vector wind observations obtained a polar-orbiting satellite. The problems related to gridding daily ship and buoy data are analogous to those of gridding daily scatterometer observations. In both cases, there are large gaps in the observational coverage and observational errors and uncertainty should be considered. Furthermore, observational tracks from different times intersect, often with substantial changes in the wind pattern occurring between the observations. Simple averaging would result in spurious wind curl and divergence. Despite these problems, in-situ observations have demonstrated value in producing long time series of monthly products. Our gridding technique deals with these problems more effectively the previous techniques. Our new objective technique also treats various types of data sources (VOS and buoys) as independent. Comparisons are made between the new FSU fields and various other products.

Historical Analysis of Marine Sea Level Pressure and Wind Components: The Good, the Bad, and the Ugly

Alexey Kaplan
Lamont-Doherty Earth Observatory of Columbia University

Least squares procedures of optimal estimation, when applied to gappy and erratic data, result in the solutions which predominantly project on the most energetic patterns of a priori error covariance. This property of the solution allows to combine the classical least squares technique with the approach of a space reduction in order to develop a computationally effective procedure of objective analysis for observed historical climate fields (which are characterized by comparatively precise data and good coverage in the last few decades, and poor observational coverage prior). An application of the procedure to the historical ship-based data set of sea level pressure (SLP) resulted in a near-global monthly reconstruction from 1850s to present along with verified error bars. We now attempt to do the same for zonal and meridional wind components. This happens to be a very difficult task, historical wind observations being plagued with artificial trends, and their variability (particularly that of the meridional component) being of much smaller spatial scale than that of the SLP. Comparison of the tropical Pacific surface zonal windstress from four products for a 30 year period 1964-1993 (da Silva successive correction analysis, our trial reduced space optimal interpolation computed for global surface winds, NCEP-NCAR reanalysis, and FSU subjective analysis) shows completely different trends, poor overall coherency (an area averaged correlation coefficient between any two products does not exceed 0.56), and substantial difference in the degree of the spatial and temporal smoothness. Nevertheless certain large-scale aspects of interannual variability seem to be faithfully reproduced and can be reconstructed on the basis of historical data. We also discuss potential of multivariate analyses with explicit model constraints of local (e.g. geostrophic balance equations) or non-local nature (e.g. dynamical ocean model converting wind stress fields into sea level height observations) for improving analyses quality.

Feasibility of Reanalysis Before the Radiosonde Era

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NOAA-CIRES Climate Diagnostics Center

Studies of global climate change, interannual and decadal variability, and their effects on extreme events such as floods, droughts, and heat waves require a detailed, daily circulation dataset for the past 100+ years. While monthly global analyses of sea level pressure (SLP), temperature, and precipitation are commonly available back to 1875, and newly-available NCEP/NCAR four-times daily global reanalyses are available back to 1948, the only daily analyses available before 1948 are hand-drawn northern hemisphere synoptic SLP maps. These maps contain inhomogeneities, discontinuities, and errors, especially during World War I and the 1930's US drought period. While prior to 1948, surface station and marine pressure data are available, there are no radiosondes to provide vertical atmospheric structure information to a modern data assimilation system (DAS). It is widely believed that without upper-air observations, DAS will fail to provide a useful estimate of the synoptic state of the atmosphere. Therefore, 3-dimensional reanalyses of this period have not been attempted. However, surface pressure provides an integrated measure of the atmospheric vertical column and may provide sufficient information for DAS to reanalyze the surface, as well as the lower tropospheric circulation.

We have investigated the feasibility of using surface pressure, together with other available surface variables, to create a homogeneous, high-quality daily analysis of the surface and lower tropospheric circulation back to the late 19th century. We have performed parallel assimilation experiments for November 1999-February 2000 using surface data at observational densities expected for 1900. Two systems were compared, statistical optimal interpolation (OI) and the NCEP operational DAS. We have found that OI, using climatology as first-guess, is extremely competitive with the NCEP operational DAS in the northern hemisphere, with both producing high quality 4-times daily surface pressure fields in our test period. In the Tropics, however, the OI is superior. In addition to surface pressure, the DAS is able to produce realistic lower-tropospheric analyses through the model's dynamics. The results suggest that historical surface and lower tropospheric reanalysis is extremely feasible and may benefit from more advanced data assimilation techniques such as the ensemble Kalman filter and smoother.

HINDCASTING WINDS AND WAVES USING KINEMATIC ANALYSIS

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The Meteorological Service of Canada has recently produced the first 40-year (1958-1997) wind and wave hindcast of the North Atlantic Ocean. The study used the NCEP-NCAR re-analysis products to drive a third-generation wave model adapted to the NA on a high-resolution grid to produce a high-quality, homogeneous, long term wind and wave data base for assessment of the wave climate of the NA, its trend and variability. The most important feature of the hindcast was the rigorous attention devoted to producing the wind fields used to drive the wave model. To remove potential biases in the historical wind fields, all wind observations from ships, buoys and platforms were re-assimilated into the analysis taking account of the method of observation, anemometer height and stability. Wind fields for all significant storms were then painstakingly kinematically reanalyzed manually with the aid of an interactive Wind Workstation. Furthermore, high-resolution surface wind fields for all tropical cyclones, as specified by a proven tropical cyclone boundary layer model, were assimilated into the wind fields to provide greater skill and resolution in the resulting wave hindcasts.

The hindcast compares well against *in situ* and satellite observations in all parts of the North Atlantic, not only in terms of bias and scatter, but over the entire frequency distribution out to and beyond the 99^{th} percentiles of both winds and waves. Monthly, seasonal and annual statistics have been produced for all grid points in the North Atlantic.

On the Pacific Ocean Regime Shift

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Abstract

The temporal variability of Pacific Ocean upper ocean heat content is examined for the 1948-1998 period using gridded, objectively analyzed temperature anomaly fields. Results indicate a "regime shift" in upper ocean temperature structure occurred in conjunction with the atmospheric shift in sea level pressure around 1975 leading to warming (cooling) in the eastern (western) equatorial Pacific. The shift is a basin-wide phenomenon effecting the thermal structure from 60ES to 70EN. EOF analysis of the Pacific Ocean heat content (0-125 m) shows a shift from a relatively cool to a warm state in the equatorial Pacific Ocean during the mid-1970s. Further analysis of the gridded temperature anomaly fields shows equatorial warming to be as much as 1.5EC and a cooling in the North Pacific of 1EC, down to 250 meters depth after the mid-1970s. Overall, the analysis indicates the "regime shift" continues through 1998 with no signs of returning to a cooler phase.

Temporal Variability in Satellite and Analysis SST Data

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The 21-year record of satellite SST measurements from the advanced very high resolution radiometer (AVHRR) are of now sufficient length for use in climate studies and as an adjunct to longer term historical in situ SST data sets. This study builds on an earlier investigation that compared two popular satellite SST data sets, the NOAA operational and the retrospectively processed Pathfinder AVHRR SST data, with analysis SST data sets such as the Reynolds Optimal Interpolation (OI) SST. Results from that study indicate that at a monthly temporal resolution, significant differences exist with respect to the signature of interannual and seasonal variability for each time series when using an independent climatology as a reference. Some of these differences could be explained as noise or algorithm shortcomings in the satellite time series or an over reliance on in situ data in the OI analysis. To separate for these effects, World Ocean Database 1998 (WOD98) in situ and climatological SST values were used to investigate satellite and OI SST trends and variability both globally and in discrete ocean basins. Those SST products that minimized variability with respect to the WOD98 data were assumed to be more consistent.

The Instrumental Record of ENSO Variability: 1840s to Present

Todd Mitchell and John M. Wallace
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Time series of marine and land surface temperatures, sea-level pressure, surface winds, and rainfall are presented to document ENSO variability in the tropics from the 1840s through 2000. The series are derived from area-averages of large regions and emphasize the tropics-scale nature of ENSO-related climate variability. The resultant series are useful indicators of ENSO variability, and corroborate many of the features in the traditional Tahiti-Darwin Southern Oscillation Index (SOI).