end-users to understand, value-add and make informed decisions from climate information.

- **Communication Products and Services**
  That a communication protocol be developed and agreed between all stakeholder agencies to ensure consistency and clarity of communication, especially during climatic extremes.
- **Media Interactions**
  Recognise the importance of the Australian mass media as a major channel for distributing climate information to the majority of users, and continue to develop strategies for presentation of this information to best effect.
- **Integration and Value Adding**
  That providers of wholesale climate information proactively seek opportunities to work with intermediaries to provide outputs that are more conducive to value adding through integration with other information that assists decision making.
- **Research and Communication**
  That mechanisms be further enhanced to ensure that end-user needs are communicated to climate information providers and researchers and a scientific review process is undertaken to assist in establishing research priorities.

Addressing recommendations within these areas will require attention and resources from climate information providers, intermediaries and end-users and, most importantly, partnerships between these three groups. The degree to which stakeholder organisations and the wider community adopt these recommendations will significantly help determine the extent to which Australians can develop management practices that factor in climate variability, and especially the extremes such as drought.

Further Information:
http://www.bom.gov.au/climate/droughtcom

Articles

Digital Libraries for Oceans and Climate

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http://www.antcrc.utas.edu.au/tpac/datasets/diglib.htm

A key to understanding earth systems is exploring relationships among the atmosphere, hydrosphere, and geosphere. To do this in a quantitative way requires analysis and comparison of data sets across a variety of disciplines. Much of the challenge in looking for relationships among data sets, or in placing one's own data set in the context of others, currently lies in accessing data from various providers and manipulating data formats to allow comparison. Achieving this frequently entails programming, requiring additional time and/or money, a particular problem for students and others with few resources. Data access and manipulation can form a barrier to achieving the comparisons one would like and become an obstacle to understanding the systems the data sets describe.

Working with data sets in earth systems science can be facilitated by collaboration on standards of data format, description, and access. An ideal model might involve self-describing data, consistently updated by the data provider, which could be accessed in a format readable by the users' preferred

analysis package. Remote access of self-describing data from central locations would ensure data integrity, minimising problems with data storage, version control, and errors generated by intermediate files and data sharing. With greater standardization of access and format, more functions can be performed automatically with scripts and automatically fed into earth system models. Standardized data distribution, accessible in the format required by users' preferred analysis package, would increase the efficiency in working with data sets across disciplines.

The OPeNDAP Data Distribution Framework

The Open Data Access Protocol (OPeNDAP), formerly known as Distributed Oceanographic Data System (DODS), is a distribution framework that provides one answer to the needs of researchers working with oceanographic and climate data. OPeNDAP allows users to access self-describing data via the internet from data servers maintained and consistently updated by the data providers. Data can be delivered from the data server directly to users' preferred analysis application or language, such as Matlab, Fortran, Ferret, IDL, Java and even Excel, ready for further processing. A consistent interface can be used to view the structure and attributes of the data, subsample the data, and access the data itself. Using the client-server model of the world-wide-web, the OPeNDAP distribution framework provides a way to streamline work flow and decrease the resources needed by individual researchers to work with multiple data sets.

Working with OPeNDAP

The OPeNDAP client/server framework

As shown in Figure 1, the OPeNDAP framework uses a client/server model. The client, the user's application program, sends requests for data over the network to an OPeNDAP server. The server takes the request for data and delivers the data directly to the client program in the format needed by that client. The client and server communicate using Uniform Resource Locator (URL) addresses. Any data in the commonly used self-describing formats used by oceanographers such as netCDF can easily be served to client applications via an OPeNDAP server.

OPeNDAP URLs

Each data set on an OPeNDAP server has a unique URL. The URL can be modified to retrieve information about the data set structure, data attributes, and the data itself. Constraint expressions added to the end of the URL allow the user to subsample the data before retrieving the data. A World Wide Web (WWW) interface called the DODS Data Access Form (Figure 2) provides a simple graphical user interface for sampling the data for parameters such as latitude, longitude, and time.

Using the OPeNDAP URL to access data from OPeNDAP-enabled application programs (OPeNDAP clients)

After subsampling the data, the modified URL can be used to access the data from an OPeNDAP-enabled desktop analysis program, or OPeNDAP client. Data can be retrieved in most cases by providing the data set URL instead of a path name in the application's open command. For example, to access a sea

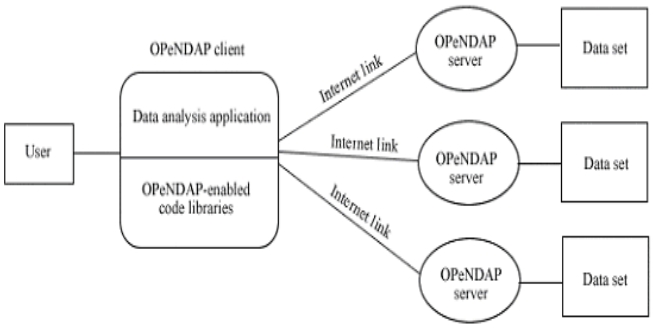

Figure 1 The OPeNDAP client-server model. Figure modified from the DODS web site (2003). Note that the terms OPeNDAP and DODS are often used interchangeably.

surface temperature field in the WOCE Global Data Version 3.0 data set via an OPeNDAP URL in Ferret, the script is simply:

```
yes? use
"http://www.antcrc.utas.edu.au/
dods/nph-dods/dods-
woce3/sat_sst/avhrr/data/10_deg
/sst10d19950107.nc"
yes? shade sst
```

Without the user explicitly downloading any data, the required data has been loaded into Ferret via the internet using a single command. The ease with which data can be loaded into an analysis program opens the way for comparison of data across different data providers and data types. The advantages of self-describing can now easily be seen. Self-describing data files have enough information for programs and applications to automatically read the contents without error. This means applications can load data sets with just the location of the file. With a few command lines, users can load multiple data sets from different sources to then compare, plot, and analyse in their preferred analysis package. The data can also be more traditionally downloaded via ftp in ASCII or binary format.

Converting application programs into OPeNDAP clients

Applications that have OPeNDAP clients (i.e. enabling them to remotely access data from OPeNDAP servers) include the most common data analysis applications and languages, such as Matlab, Ferret, IDL, GrADS, ncBrowse, Fortran, C/C++, Java, and Perl. Free OPeNDAP software transforms these programs into to OPeNDAP clients by re-linking the programs to OPeNDAP-enabled code libraries. This process does not interfere with the programs' other capabilities. Setting up an analysis application to work as an OPeNDAP client is a fairly simple process, but may require assistance from local IT support. The OPeNDAP software can be downloaded from:
http://www.unidata.ucar.edu/packages/dods/home/faq/whatClients.html.

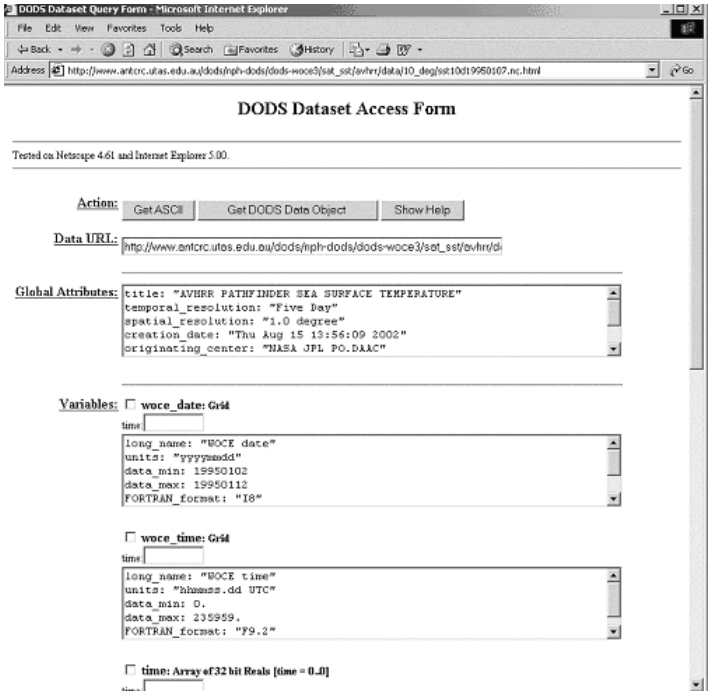

Figure 2 The DODS Data Access Form provides a consistent interface for viewing the structure and attributes of the data, subsampling the data, and accessing the data itself.

Virtual Data Libraries using OPeNDAP

The Tasmanian Partnership for Advanced Computing (TPAC) Digital Library for Oceans and Climate (http://www.antcrc.utas.edu.au/tpac/datasets/diglib.htm)

By presenting data in a consistent format via OPeNDAP servers in different locations, virtual data libraries can be built and provide a powerful research tool. The Tasmanian Partnership for Advanced Computing (TPAC) has created a virtual data library by collaborating with the Bureau of Meteorology Research Centre (BMRC), CSIRO Marine Research, the World Ocean Circulation Experiment (WOCE) (WOCE Data Products Committee (2002); WOCE International Project Office (2002)), and other institutions to facilitate access to data on their OPeNDAP servers or to make their data available via the TPAC OPeNDAP server. In doing so, the TPAC Digital Library for Oceans and Climate makes several data products available to the wider Australian and international research communities for the first time. The Digital Library provides access via OPeNDAP to key global data sets used commonly in oceanographic and climate research and to the unique data resources of the BMRC, CSIRO Marine Research, the University of Tasmania/Antarctic Climate & Ecosystems Cooperative Research Centre (ACE CRC) and the international WOCE program. The data sets currently accessible through the digital library are detailed in Table 1.

To facilitate use of the data sets, TPAC has implemented a web-based search tool on the largest data set and may extend this to other data holdings in the future. The TPAC digital library also provides documentation on using OPeNDAP files within many common analysis programs and on converting existing application programs into OPeNDAP clients (http://www.antcrc.utas.edu.au/tpac/datasets/opendap.htm). All sample scripts and instruction are tested at TPAC and on completion will provide one of the most complete and accurate sets of OPeNDAP documentation currently on the web. In the future, TPAC plans to add model output from key numerical experiments to the digital library, as well as additional key oceanographic and climate data sets.

A major feature of the TPAC digital library is access via OPeNDAP to all of the World Ocean Circulation Experiment data through the web-based WOCE Viewer search tool. TPAC is one of three centres globally to host the entire WOCE Global Data Version 3.0, and the only centre in the Southern Hemisphere. The WOCE Viewer allows the user to conduct progressive searches using the meta-data of each WOCE instrument data set and then link to instrument data via OPeNDAP. The user can acquire a list of multiple data URLs to load, plot, and compare. The Digital Library also provides access to the full set of WOCE Global Data 3.0 data (in netCDF format) and documentation as they appear on the WOCE DVD's.

Additional OPeNDAP data hubs

Additional OPeNDAP data hubs offer access to data from a wide variety of disciplines and data providers. The National Virtual Ocean Data System (NVODS) (http://www.nvods.org) lists data catalogues, collections and individual data provider sites, including the TPAC digital library. The DODS Dataset List (http://www.unidata.ucar.edu/cgi-bin/dods/datasets/datasets.cgi?xmlfilename=datasets.xml) is a major data hub including data from the Center for Ocean Land Atmosphere Studies (COLA), NASA, NCAR, NOAA, Columbia University /LDEO International Research Institute (IRI), MIT, and other institutions. NASA's Global Change Master Directory Portal (http://gcmd.gsfc.nasa.gov/Data/portals/dods/) is a related hub with data sets covering agriculture, the atmosphere, biosphere, hydrosphere and oceans, snow and ice, geology and geophysics, paleoclimatology, and human dimensions of global change.

Summary

The OPeNDAP framework provides one model for facilitating research in ocean and climate sciences. The standardized access, direct delivery to the user's preferred analysis program, and self-describing data format eliminates much of the resource-intensive work involved in conducting research with multiple large data sets. Through OPeNDAP data hubs and digital libraries such as TPAC's Digital Library for Oceans and Climate, researchers can access and compare data across disciplines, critical to the analysis and understanding of the earth system.

References

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WOCE Data Products Committee, 2002. "WOCE Global Data Version 3.0". WOCE International Project Office, WOCE Report No. 180/02, Southampton, UK.

WOCE International Project Office, 2002. "WOCE Observations 1990-1998; a summary of the WOCE global data resource". WOCE International Project Office, WOCE Report No. 179/02., Southhampton, UK.

Data Product	Data Provider	Description
WOCE Global Data Version 3.0	World Ocean Circulation Experiment (hosted at TPAC)	• all WOCE Global Data 3.0 (>2.0 million files) accessible via OPeNDAP
The WOCE Viewer 3.0, navigational front end to the WOCE Global Data Version 3.0	TPAC	• web-based search tool, developed at TPAC, providing a navigational front end to the inventory meta-data of the WOCE Global Data 3.0 data set
NCEP-DOE Reanalysis 2	Climate Diagnostics Center (mirrored at TPAC)	• data provided in its original four-times daily format
Common oceanographic climatologies, focused on the Southern Ocean	CSIRO Marine Research	• extensive data set consisting of historical oceanographic data and atmospheric climatologies • originally provided as a service to CSIRO staff, now accessible to the entire Australian and international communities
Satellite altimetry files	CSIRO Marine Research	• altimeter data sets from the JASON and TOPEX/POSEIDON satellite missions • continually updated in near real time
Bureau of Meteorology Research Centre data products and forecast analyses (not yet available)	Bureau of Meteorology Research Centre (BMRC)	• results from the daily operation of the BMRC forecasting models • near real-time data and analyses
Antarctic Automatic Weather Station Data	Australian Antarctic Division (hosted at TPAC)	• surface meteorological data from a network of Automatic Weather Stations (AWS) at sites in remote regions of East Antarctica • updated in near real time

Table 1. Data available via OPeNDAP through the TPAC Digital Library for Oceans and Climate