From prehistoric ice cores to modern satellite observations - climate data and services from NOAA's National Centers for Environmental Information

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NOAA’s National Centers for Environmental Information

Copernicus Climate Data Store Workshop  3 March 2015
History of NCEI’s Center for Weather and Climate

- **1965**: Environmental Science Services Administration formed under the US Department of Commerce (Weather Bureau dissolved)
- **1970**: NOAA is established under Commerce. NWRC renamed to National Climatic Center (NCC)
- **1984**: NCC renamed National Climatic Data Center (NCDC) to emphasize the importance of the large quantity data
- **2015**: NCDC merges with other NOAA Data Centers to create the National Centers for Environmental Information (NCEI)

### Timeline

- **1950s**: National Weather Records Center (NWRC) established
- **1960s**: 400 million punch cards store NWRC’s data
- **1970s**: Transition to tapes; scientific research growth
- **1980s**: Millions of pieces of microfilm and microfiche store data
- **1990s**: NCDC information used to monitor global weather and climate from the stone age to the space age
- **2000s**: Nation’s first Climate Reference Network station built and operated by NCDC
- **2010s**: Next-generation satellites greatly increase NCDC holdings
MISSION

Steward the United States’ Climate Information

NCEI CWC is responsible for preserving, monitoring, assessing, and providing public access to the Nation’s treasure of climate and historical weather data and information.

VISION

Be the United States’ Trusted Authority on Climate and Historical Weather Information

NCEI CWC will be the most comprehensive, accessible, and trusted source of state-of-the-science climate and historical weather data, information, and climate monitoring.
The United States Has Economic Motivations for Increasing Access to Climate Information Products


170 weather and climate disasters reached or exceeded $1 billion during this period (CPI-adjusted)

Please note that the map reflects a summation of billion-dollar events for each state affected (i.e., it does not mean that each state shown suffered at least $1 billion in losses for each event)

http://www.ncdc.noaa.gov/billions/mapping
### NCEI Products Span from Local to Global on Weekly to Decadal Scales

<table>
<thead>
<tr>
<th>Scale</th>
<th>Weekly</th>
<th>Monthly</th>
<th>Seasonal–Annual</th>
<th>Decadal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local</td>
<td>Snowfall Impact Index – FEMA, disaster response</td>
<td>Heating &amp; Cooling Degree Days – Energy Sector</td>
<td>Temperature &amp; Precipitation Outlooks – Agriculture</td>
<td>Billion $ Disasters, Climate Extremes Index – Insurance</td>
</tr>
</tbody>
</table>

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NCEI Supports the Full Information Lifecycle

- Makes foundational investments in climate information production and preservation.
- Supports others’ application development and policy/decision-making.

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NCEI Begins Definition of the Climate Record with Paleoclimatology

1,700 Years of Northern Hemisphere Temperature Change from Proxy Data
NCEI Operates the U.S. Climate Reference Network (USCRN)

- Follows the GCOS Climate Monitoring Principles
- Three independent measurements of multiple essential climate variables
- Well-calibrated and highly accurate observations
- Pristine, stable environments
- The standard for climate measurements
NCEI Combines Different Data Sources for Climate Records

Example: Global Sea Level Rise

Sea Level Change (feet)

-1 0 1 2 3 4 5 6 7

Year

1800 1850 1900 1950 2000 2050 2100

Proxy Records
Tide Gauge Data
Satellite Data

6.6 ft
4 ft
1 ft
0.66 ft

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NCEI provides national and international leadership in climate data and information, science, stewardship, and service/assessment

- World’s largest archive of climate, weather, and environmental information (>18 PB)
- Multiple “gold standard” datasets, e.g. temperature
- Frequent papers in major scientific journals
- Leadership in WMO, GCOS, GEO, IPCC...
- US National Climate Assessment
- BAMS State of the climate
- US Global Change Research Program leadership since 2010
- Extensive involvement in US national media

NCEI are the United States’ go-to Centers for retrospective weather and climate data
NCEI Produces the Gold-Standard Global Land Surface Temperature Dataset

- NCEI monitors changes in global land surface temperature using the Global Historical Climatology Network-Monthly (GHCN-M) dataset

- This dataset provides monthly average temperatures from over 40,000 stations, some of which contain records back more than 300 years

- Considered the most comprehensive suite of global temperature and precipitation observations in the world
By applying knowledge gathered over time about instruments’ performance and sensor characteristics, environmental data are reprocessed to create consistent and homogenized long-term records.

NOAA’s satellite CDRs comprise its longest record of global operational satellite measurements.

NOAA satellite, in situ, and blended CDRs are sustained in an operational environment, which is critical for supporting decision-making in a changing climate, and thus for the world’s resilience to climate variability.
Current NOAA Operational CDR Inventory (>26) Spans the Environment
What is the advantage of using NCEI CDRs?

(High Quality Data: Inter-calibration and Homogenization Reduce Artifacts Imparted by Observing Systems, Facilitating Meaningful Comparisons in Space and Time)

Operational weather products are produced rapidly to potentially save life and property.

Climate Data Records (CDRs) describe climate through rigorous cross-calibration and reprocessing with advanced algorithms, ancillary data and evolved instrument understanding.
NCEI Data Access
Climate Data Online (CDO) System

- [www.ncdc.noaa.gov](http://www.ncdc.noaa.gov)
- Centralized access to numerous US and global datasets and products
- Web Services allow users direct machine-to-machine access for use in applications (WMS, WFS, KML/KMZ, etc.)
- Underlying structure includes Oracle databases with tiered server infrastructure
- Services continue to be built-out for additional datasets and products
“Branded” Data Access Portals
NOAA Climate.gov Portal, Drought Portal, Model Portal

- Ongoing development, integrated to provide one-stop access to widely distributed datasets, products, services
- Drought Portal geared toward providing critical information to decision-makers
- Climate.gov Portal designed to reach a very wide segment of users – scientists, businesses, decision/policy-makers, news media, public, etc
- Model Portal provides access to reanalyses and numerical model output
- Many partners involved across NOAA, other agencies, regional/state level, international
NCEI Is Responding to an Accelerating User Demand

- Now serving over 5 petabytes of climate data annually
- Provide safe storage of over 18 petabytes
- Service over 20,000 personal contacts with users across economic sectors, regions, and societal challenges
## Who Are Our Users?  NCEI’s General User Profile

<table>
<thead>
<tr>
<th>Fraction (%)</th>
<th>Data Expertise</th>
<th>Stereotypical User</th>
<th>Data or Info Need</th>
<th>Preferred Format</th>
<th>Access Volume</th>
<th>Access Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>Low</td>
<td>Business, media, public</td>
<td>Qualitative</td>
<td>Point-and-click, graphics, assessments</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>15</td>
<td>High</td>
<td>Researchers, Climate consultancies</td>
<td>Quantitative</td>
<td>Digital downloads</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>15</td>
<td>High</td>
<td>Value-added Providers (database scrapers)</td>
<td>Quantitative</td>
<td>Digital downloads</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>
Most Users Increasingly Only Want Expert Interpretations

Aspects of Monitoring

- **Average** values (13.3°C)
- Measures of **difference** (+1.8°C above normal)
- Measures of **unusualness** (much above average = top 10%)
- Measures of **trend** (increasing at 0.5°C per century)
- Measures of **impact** (34% of corn reported in poor condition)

Services and Stewardship: NCEI provides authoritative services in climate, science, data, and information preservation.
• Water resource managers rely on the information to help officials and planners make informed decisions about a finite resource

• The American Society of Heating, Refrigerating, and Air Conditioning Engineers uses the data to develop heating/cooling engineering standards

• Insurance and reinsurance companies make use of weather and climate data to calibrate their catastrophe models
National placement of NCEI climate staff to help provide services and gather requirements
NCEI Monitors the State of the Climate

**Global Temperature Trends 1979–2012**

**Statewide Average Temperature Ranks September 2014**

**Decadal Trends in Very Heavy Precipitation**


3/17/2015

Copied by US Climate Data Store Workshop
NCEI Assesses the Earth’s Climate with International, National, and Annual Assessments

International Assessments
- Three NCEI lead authors and review editors on Fourth Assessment Report
- Two NCEI lead authors on Fifth Assessment Report
- Two NCEI lead authors on Special Report on Extremes

National Assessments
- NCEI provides leadership and lead authors for all National Climate Assessments
- NCEI hosts National Assessment’s Technical Support Unit

Annual Assessments
- NCEI coordinates 425 authors from 57 countries
- Covered by all major news networks, briefed to US Congressional staff

Journal Articles
- NCEI publishes over 50 articles annually in leading scientific journals such as Nature, Science, and BAMS

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NCEI Tracks Drought Through the National Integrated Drought Information System (NIDIS)

- NCEI hosts Drought.gov and tracks state of drought weekly through the U.S. Drought monitor in partnership with other agencies
- Expanded to North America through our international partnerships
NCEI Produces the United State’s Authoritative Climate Normals

- Used extensively by agriculture, engineering, energy planners, and others
- Below: shifts in plant heartiness zones

![Map of zone changes in past 10 years](image1.png)
![Map of zone changes in next 30 years](image2.png)

Average Annual Extreme Minimum Temperature by Climate-Related Planting Zone

- No Change in Zone
- Zone 4 (-29 to -20 °F)
- Zone 5 (-19 to -10 °F)
- Zone 6 (-9 to 0 °F)
- Zone 7 (1 to 10 °F)
- Zone 8 (11 to 20 °F)
- Zone 9 (21 to 30 °F)
- Zone 10 (31 to 40 °F)
Challenges and Opportunities

• How can NCEI best meet the growing demand for data access?
  – Demands are currently overtaxing our personnel and computational capabilities

• How to meet the growing demand for expert monitoring and assessment capabilities
  • President Obama’s Climate Data Initiative
  • Science-certified services for U.S. Government, Industry, and the public

• How does NCEI best identify user requirements in an emerging and evolving community of practice?
  – Climate information industry is growing, but slowly
  – Production of climate information records and summaries
  – Feeding of data-hungry applications
  – Regional and local interest in tailored/downscaled products

• How to best work with our international and national partners on providing climate data and services?
Help coming from emerging climate information platforms?

• Climate information “platforms” are emerging through partnerships between US industry and government to aid in data analysis and distribution. (Some technical advances will be discussed in other US presentations in this workshop.)

• NCEI’s responsibility encompasses the preservation and stewardship of all the algorithms, code, docs involved in a climate data records – and will needed by future climate information platforms.

• While NCEI waits for the infrastructure to be available from/with NOAA and its industry partners, the NCEI is focusing on:
  – Ensuring operational sustainment of its CDRs and information products
  – Making the data ready/portable for dissemination (standards)
  – Describing the data well (documentation, metadata) to enable discovery
  – Preserving and describing the algorithms, workflows, and ancillary data
  – Identifying and supporting uses (user requirements)
Questions?
Backup slides
CDRs Support Decision Support Applications at Time Scales Longer than a Week

Quality (accuracy, completeness, etc.)

- **Operational Weather**
  - (Quick, Robust, Data as-available, Algorithm as-is, Sensor-unique)

- **Interim CDRs** -- Decision Support
  - (Routine, Complete, Timely, Climate processing, Consistent in time/space/resolution over period-of-record)

- **CDRs** -- Research Support
  - (Epoch reprocessing of complete period of record, Complete, State-of-the-art)

Time past observation (logarithmic scale)

Minutes Days Weeks Years Decades

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Example: NVDI Provides historical context for Drought

- 5 km resolution, “wall-to-wall” (globally)
- Historical record from 1981-to current
- Collateral products
  - Surface Reflectance
  - Leaf Area Index (LAI)
  - FPAR

Primary U.S. corn and soybean region

2012 drought depicted by Vegetation Index CDR (July 17)

NDVI time series - example in Kansas
CDRs are being used to improve Monthly to Seasonal forecasts

- NOAA’s Outgoing Longwave Radiation (OLR) CDR is used to measure the Madden-Julian Oscillation (MJO) evolution
- Reanalysis leads to estimates of the future MultiVariate Pacific-North American (MVP) index
- MJO plus MVP provides a useful forecasting tool for future extratropical responses over US

*Courtesy of Dr. Carl Shreck*
Climate Reference Network and Validation/Verification of Climate Data Records

NASA SMAP Satellite

CRN Soil Moisture

% Volumetric Water Content

10/9/14 10/11/14 10/13/14 10/15/14

5 cm 10 cm
20 cm 50 cm
100 cm
Paleo Reanalysis provides a powerful new tool allowing complete climate fields to be reconstructed into the far past – which is not now possible.

A key outcome – such as for the current California drought – is to help ecosystems, communities, and economies become more resilient in the face of change by better knowing the full range of possible climate extremes.

1. Identify the mean annual climate state from a coupled model ensemble
2. Express the modeled climate state as an expected set of proxy observations (e.g. tree ring widths) using a "forward model" that converts climate parameters into proxy measurements
3. Compare the expected proxy observations derived from the model state with actual proxy data, the difference is information to incorporate (called the "innovation")
4. Incorporate the innovation information to update the mean annual climate (offline)
5. Repeat with proxy data for each year there is appropriate proxy data
GHCN-Daily

- The world’s largest single collection of daily in situ climate data
  - More than 2.3 billion daily observations
  - Earliest value from January 1, 1763
  - Latest value from yesterday
  - ~30,000 temperature stations
  - ~92,500 precipitation stations
  - ~40,000 snowfall or snow depth

Robust global coverage with long periods of record in North America, Europe, Australia, and South Africa

Colors denote number of years of data for each station in GHCN-D mean temperature dataset
GHCN-Monthly (Monitoring and Assessment)

- GHCN-Monthly temperature records are combined with ocean surface temperature data for monitoring climate variability and change.

![Global Land Temperature Anomalies, September](image1)

![Land-Only Temperature Departure from Average Sep 2014](image2)
ISTI Databank Working Group

- Data provided in Stages
  - All data converted to common format in Stage 2
  - ISTI Databank responsibility ends at Stage 3

- Individual institutions can develop their own quality controlled and bias corrected datasets

- NCDC is developing a new version of GHCN-Monthly from the Stage 3 databank release

ICOADS

- Access to 290 ocean data and metadata elements including:
  - Sea Surface Temperature and Measurement method
  - Marine Air Temperature
  - Wind Direction/Speed
  - Sea Level Pressure, Visibility, Clouds
  - Wave and Swell Direction, Period, Height
  - Sea ice concentration
  - Present weather, visibility
Matching Monthly and Daily Normals

Constrained Harmonic Analysis

monthly normals (constraints)
daily normals
raw daily averages
Integrated Global Radiosonde Archive

Version 1

Version 2

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Long-Term Scientific Data Stewardship

- Preservation
  - Product Evaluation
  - Product Acquisition
  - Data Archive
  - Data Governance

- Accessibility Usability
  - Data Search & Discovery
  - Data Availability
  - Data Accessibility
  - Data Usability

- Sustainability
  - Operations & Maintenance
  - Product Update
  - Product Improvement
  - Product Reprocessing

- Data Quality
  - Data Quality Assurance
  - Data Quality Assessment
  - Data Quality Monitoring

- Transparency Traceability Reproducibility
  - Data Provenance
  - Data Reference and Citation

- Information Integrity
  - Information Security
  - Data Integrity

Legend:
- Non-Functional Requirements
- Key Functional Areas
- *Processes/Services*

Data Stewardship:
All activities that preserve and improve the information content, accessibility, and usability of data and metadata (NRC, 2007) and that ensure or improve the quality and usability of environmental data.

Version: 20140226
POC: ge.peng@noaa.gov
What Are CDRs?

• “A Climate Data Record (CDR) is a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change” (US National Academy of Sciences, 2004)

• A relaxed definition: “…sufficient…to have societal value”?

  • **Fundamental CDR (FCDR):** Calibrated observations for a family of sensors together with the ancillary data used to calibrate them (e.g., Brightness Temperatures)

  • **Thematic CDR (TCDR):** Geophysical variables derived from FCDRs; may be generated by blending satellite observations, in-situ data, and model output (e.g., Sea Surface Temperature)
### Sample of NOAA CDR Products

**24 CDRs in Ops as of 2014**

http://www.ncdc.noaa.gov/cdr

#### Sampling of Operational CDRs

<table>
<thead>
<tr>
<th>FCDR</th>
<th>Atmosphere</th>
<th>Ocean</th>
<th>Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVHRR TOA Reflectance</td>
<td>MW Mean Layer Temperature</td>
<td>SST (OISST &amp; Pathfinder)</td>
<td>Surface Reflectance (AVHRR)</td>
</tr>
<tr>
<td></td>
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<tr>
<td>HIRS Brightness</td>
<td>Precipitation (PERSIANN)</td>
<td>Sea Ice Concentration</td>
<td>Northern Hemisphere Snow Cover Extent</td>
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<tr>
<td>Temperature (BT)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>SSMI(S) BT</td>
<td>Cloud (PATMOS-x)</td>
<td></td>
<td>NDVI (AVHRR)</td>
</tr>
<tr>
<td>VIIRS RCDR</td>
<td>OLR (HIRS &amp; GridSat)</td>
<td></td>
<td>LAI/FAPAR (AVHRR)</td>
</tr>
<tr>
<td>MSU/AMSU BT</td>
<td>Aerosol Optical Thickness (AVHRR)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GOES BT (GridSat)</td>
<td></td>
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</tbody>
</table>

#### Research-to-Operation CDRs (works-in-progress)

<table>
<thead>
<tr>
<th>FCDR</th>
<th>Atmosphere</th>
<th>Ocean</th>
<th>Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Irradiance</td>
<td>Earth Radiation Budget (ISCCP-ERB)</td>
<td>Surface Fluxes</td>
<td>Geo-Surface Reflectance</td>
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<tr>
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<tr>
<td></td>
<td>Precipitation (GPCP &amp; CMORPH, NEXRAD NMQ/Q2 Mosaic)</td>
<td>Sea Level Height</td>
<td>Snow Concentration</td>
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<td></td>
<td>Cloud (ISCCP &amp; CERES)</td>
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<td></td>
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<td>Ozone</td>
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### “Maturity Matrix” Defines CDR Product Readiness

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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Research Mission</td>
<td>Significant changes likely</td>
<td>Incomplete</td>
<td>Draft ATBD</td>
<td>Minimal</td>
<td>Limited data availability to develop familiarity</td>
<td>Little or none</td>
</tr>
<tr>
<td>2</td>
<td>Research Mission</td>
<td>Some changes expected</td>
<td>Research grade (extensive)</td>
<td>ATBD Version 1+</td>
<td>Uncertainty estimated for select locations/times</td>
<td>Data available but of unknown accuracy; caveats required for use</td>
<td>Limited or ongoing</td>
</tr>
<tr>
<td>3</td>
<td>Research Missions</td>
<td>Minimal changes expected</td>
<td>Research grade (extensive); Meets international standards</td>
<td>Public ATBD; Peer-reviewed algorithm and product descriptions</td>
<td>Uncertainty estimated over widely distribute times/location by multiple investigators; Differences understood.</td>
<td>Data available but of unknown accuracy; caveats required for use</td>
<td>Provisionally used in applications and assessments demonstrating positive value.</td>
</tr>
<tr>
<td>4 (IOC)</td>
<td>Operational Mission</td>
<td>Minimal changes expected</td>
<td>Stable, Allows provenance tracking and reproducibility; Meets international standards</td>
<td>Public ATBD; Draft Operational Algorithm Description (OAD); Peer-reviewed algorithm and product descriptions</td>
<td>Uncertainty estimated over widely distribute times/location by multiple investigators; Differences understood.</td>
<td>Source code released; Data available but of unknown accuracy; caveats required for use.</td>
<td>Provisionally used in applications and assessments demonstrating positive value.</td>
</tr>
<tr>
<td>5</td>
<td>All relevant research and operational missions; unified and coherent record demonstrated across different sensors</td>
<td>Stable and reproducible</td>
<td>Stable, Allows provenance tracking and reproducibility; Meeting international standards</td>
<td>Public ATBD, Operational Algorithm Description (OAD) and Validation Plan; Peer-reviewed algorithm, product and validation articles</td>
<td>Consistent uncertainties estimated over most environmental conditions by multiple investigators</td>
<td>Source code portable and released; Mission record is publicly available with associated uncertainty estimate</td>
<td>Used in various published applications and assessments by different investigators</td>
</tr>
<tr>
<td>6 (FOC)</td>
<td>All relevant research and operational missions; unified and coherent record over complete series; record is considered scientifically irrefutable following extensive scrutiny</td>
<td>Stable and reproducible, homogeneous and published error budget</td>
<td>Stable, Allows provenance tracking and reproducibility; Meeting international standards</td>
<td>Product, algorithm, validation, processing and metadata described in peer-reviewed literature</td>
<td>Observation strategy designed to reveal systematic errors through independent cross-checks, open inspection, and continuous interrogation</td>
<td>Source code portable and released; Mission record is publicly available from Long-Term archive</td>
<td>Used in various published applications and assessments by different investigators</td>
</tr>
</tbody>
</table>