Evaluation of climate models

Per Kållberg

Swedish Meteorological and Hydrological Institute

(ex: ECMWF Re-Analysis team)

with material from

D.Dee, A.Simmons, S.Uppala, S.Kobayashi

and many others at ECMWF

and some pages from the web
• What is a reanalysis - and why?

• ECMWF Re-Analysis ’ERA_Interim’
  - some results – recent trends

• Evaluation of climate models

• ERA_CLIM

• Other reanalyses
Consistent with widespread media reports of extreme heat and adverse impacts in various places, the latest results from ERA-Interim indicate that the average temperature over land areas of the extra-tropical northern hemisphere reached a new high in July 2010.
Global reanalysis projects

- ECMWF FGGE 1979
- NCEP/NCAR 1948-current
- NASA/DAO 1980-1995
- ECMWF ERA-15 1979-1993
- ECMWF ERA-40 1958-2001
- JMA JRA-25 1979-2004
- ECMWF ERA-Interim 1989-2010 and running
- NASA/GMAO MERRA 1979-current (?) (ongoing)
- NOAA/CDC 1892-2007 (20thCentury Reanalysis Project)
- NCEP CFSR 1979-2010 and running
- JMA JRA-55 work in progress
- ECMWF ERA-CLIM work has begun
- EURO4M regional European reanalysis of surface climate
ECMWF Data Coverage (All obs DA) - SYNOP/SHIP
22/FEB/2011; 00 UTC
Total number of obs = 31142
ECMWF Data Coverage (All obs DA) - AMSU-A
22/FEB/2011; 00 UTC
Total number of obs = 596089
Observation minus model differences are computed at the observation time using the full forecast model at T255 (75 km) resolution.

4D-Var finds the 12-hour forecast evolution that optimally fits the available observations. A linearized forecast model is used in the minimization process based on the adjoint method.

It does so by adjusting surface pressure, the upper-air fields of temperature, wind, specific humidity and ozone.

All observations within a 12-hour period (~3,500,000) are used simultaneously in one global (iterative) estimation problem.
Climate reanalysis at ECMWF

Reanalysis is based on analysis methods developed to provide initial states for numerical weather prediction.

It applies a fixed, modern data assimilation system to multi-year sets of observations of different types, resulting in more uniform analysis quality.

Increasing forecast skill is mostly due to improvements in data assimilation, rather than better observing systems.
Reanalysis and “climate quality”

Vertical motion of air during a 15-year period

From archived weather analyses (ECMWF):

From an early reanalysis (ERA-15):

How accurately do modern reanalyses represent climate signals? What about trends? How can we assess uncertainties?
4D-Var analysis of the 500hPa geopotential height surface

0 UTC, 15 February 2005

using all available observations

using surface pressure observations only

- Gridded directly from monthly station anomalies
- CRUTEM3 (Brohan et al., 2006) at all points with <7 months missing per decade

From ERA-Interim reanalysis
Implications of coverage differences on trend

Temperature anomaly (K) relative to 1989-1998, averaged over all land areas

- CRUTEM3
- ERA

**ERA sampled to have same coverage as CRUTEM3**

**ERA-40 for 1973-1988**
**ERA-Interim from 1989**

**Full ERA coverage**

**12m running means**
Global warming

Global average temperature 1850-2009

Temperature difference from 1961-1990 (°C)

The WMO uses three temperature sets - one from the UK Met Office and the University of East Anglia’s Climatic Research Unit (CRU), and two from the US, maintained by the National Oceanic and Atmospheric Administration (Nocaa) and the space agency Nasa.
Global average temperature 1850-2009

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Global temperature anomalies for July 2010

ERA-Interim

NASA/GISS

Hadley Centre

NOAA/NCDC
Comparing ERA precipitation with gridded gauge data

Rain-gauge data provide independent validation of reanalysis products

Global Precipitation Climatology Centre (GPCC) at the German Weather Service collects data and provides a range of gridded products

Version 4 of its “full-data product” was released in September 2008

Location of >50,000 stations used for the GPCC precipitation climatology
Mean precipitation rates (1989-2009)

- **GPCC 1989-2009**
- **ERA-INT 1989-2009**

**Mean precipitation difference ERA-GPCC (mm/day)**
ERA and GPCC precipitation anomalies

**South-east Australia**

**East Africa**

**Number of stations**

- **ERA-Interim**
- **GPCC**

(mm/day; 12m running averages)
Single-level accumulated forecast parameters

Parameter: Total precipitation
Which: Anomaly
Area: 20S-20N
Period: 197901-201012

Time series of monthly averages – www.ecmwf.int
• Evaluation of climate models
sea surface temperature (SSTK)

tropical oceans - running mean over 12 months

EC_Earth coupled test-simulations
total column water vapour (TCWV) globally

EC_Earth - tests with observed SST
global P-E


EC_Earth - tests with observed SST
• ERA_CLIM
Data requirements for climate services

- Consistent with observations
- Complete (no gaps)
- Comprehensive (Essential Climate Variables)
- Physically coherent
- Timely
- Accurate variability and trends
- Meaningful information about uncertainties

Climate-quality data sets are those where the best possible efforts have been made to identify and remove non-climatic effects that might produce spurious changes over time (US Climate Change Science Program, April 2006)

Climate-quality data sets must have uncertainties demonstrably less than 10% of the expected climate change signal (Thorne and Vose, BAMS, March 2010)

Progress toward climate quality requires open access to all input data
## Progress in key areas

<table>
<thead>
<tr>
<th>ERA-40</th>
<th>ERA-Interim</th>
<th>ERA-20C (targets)</th>
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<tbody>
<tr>
<td>1957–2002</td>
<td>From 1989</td>
<td>From 1900</td>
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<td></td>
<td>Continues in real time</td>
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<tr>
<td>T159L60 (~125km)</td>
<td>T255L60 (~80km)</td>
<td>T511L91 (~40km)</td>
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<td></td>
<td>Improved model physics</td>
<td>Improved land surface model</td>
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<td>Improved boundary and forcing fields (HadISST2, CMIP5)</td>
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<tr>
<td>3D-Var, 6h window</td>
<td>4D-Var, 12h window</td>
<td>Weak-constraint 4D-Var</td>
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<td></td>
<td>Revised humidity analysis</td>
<td>Background errors from Ensemble Data Assimilation</td>
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</tbody>
</table>
## Progress in key areas (contd.)

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<td>Variational bias correction of satellite radiances</td>
<td>VarBC of aircraft temperature data, radiosonde winds, ...</td>
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<tr>
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<td>Revised land-surface analysis</td>
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<td>Newly recovered pre-1957 observations</td>
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<td></td>
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<td>Reprocessed satellite observations</td>
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• Other reanalyses
The Climate Forecast System Reanalysis [1979 - 2010]

A new Reanalysis of the atmosphere, ocean, seaice and land over the 31-year period (1979-2009):

BAMS Vol 91:8 August 2010
• Atmospheric T382L64 (GSI) Analysis at 0, 6, 12 and 18Z, using radiance data from satellites, as well as all conventional data

• GSI => 3D-Var/’FOTO’ and flow-dependent B⁻¹ (Derber)

• Ocean and Sea Ice Analysis (GODAS) at 0, 6, 12 and 18Z

• From each of the 4 cycles, a 9-hour coupled guess forecast (GFS at T382L64) is made with hourly coupling to the ocean (MOM4 at 1/4° equatorial, 1/2° global)

• Land (GLDAS) Analysis using observed precipitation with Noah Land Model at 0Z

• Coupled 2-day forecast from initial conditions from every 0Z cycle, will be made with the T382L64 GFS with hourly coupling to the ocean (MOM4 at 1/4° equatorial, 1/2° global) for sanity check.
CFSR coupled assimilation
JRA-55
the Japanese 55-year reanalysis project
- status and plan -

Ayataka Ebita, Yukinari Ota, Shinya Kobayashi*, Masami Moriya, Ryouji Kumabe, Kiyotoshi Takahashi and Kazutoshi Onogi

Japan Meteorological Agency
Soil wetness in the root layer
(Oct 1990 ~ Sep 1991)
NASA Goddard Space Flight Center
GLOBAL MODELING AND ASSIMILATION OFFICE

MERRA:
MODERN ERA RETROSPECTIVE-ANALYSIS
FOR RESEARCH AND APPLICATIONS
The 20th Century Reanalysis Project

- Gil Compo, Jeff Whittaker, Prashant Sardeshmukh, NOAA/CDC & Univ. of Colorado

- Surface pressure observations only
  - GCOS/WCRP Working Group on Observational Data Sets for Reanalysis
  - Databases hosted by NCDC, Asheville, N.C.

- EnKF 56 members, 6 hour cycling.
  - EnKF yields uncertainty as well.

- First version 1915-1958 is ”Surprisingly good”
  - 98% correlation of 500hPa geopotentials with soundings from Ilmala, Finland 1936-1958 (?)
  - Deadliest tornado event – May 1918

http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_Rean.html
End