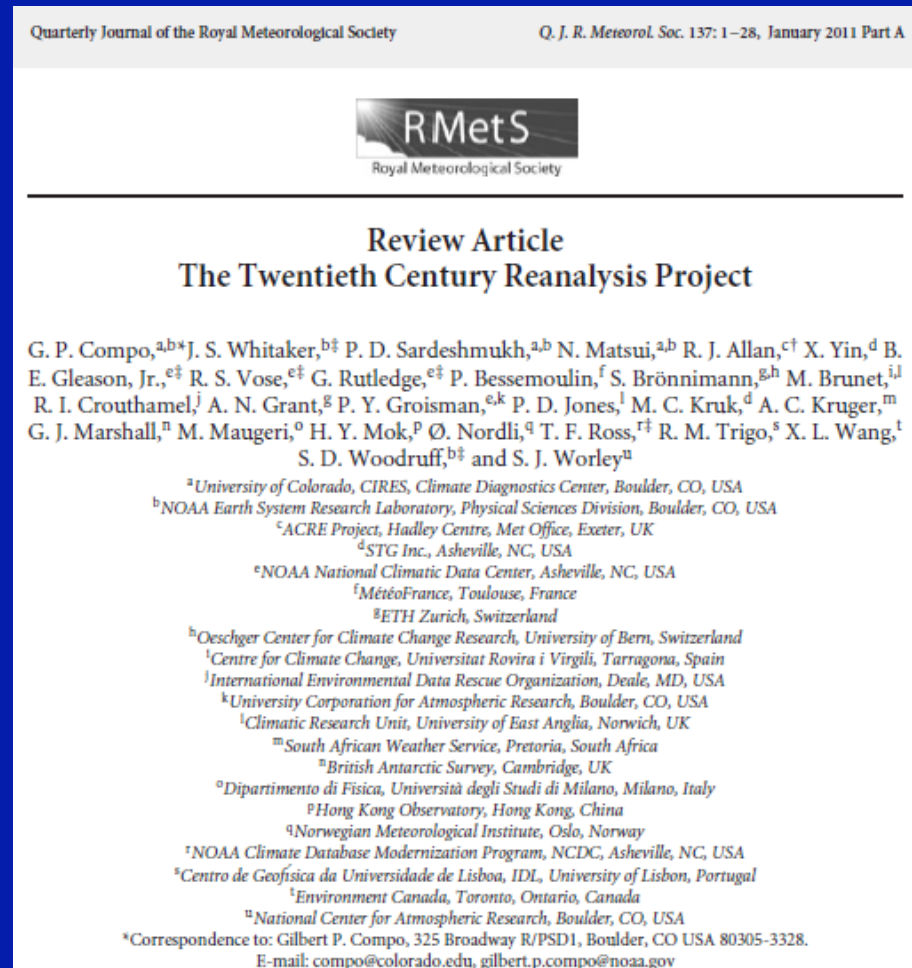


# Developing the Sparse Input Reanalysis for Climate Applications (SIRCA) 1850-2014

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Prashant D. Sardeshmukh, and  
Benjamin Giese

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Univ. of Colorado/CIRES  
Climate Diagnostics Center and  
NOAA Earth System Research  
Laboratory/PSD

Special thanks to **NCEP/EMC, NCDC, Hadley Centre, Chesley McColl, ACRE** partners



Compo et al. 2011, doi:10.1002/qj.776

## US and International calls for historical reanalyses

Reanalysis datasets “spanning the instrumental record”  
(WCRP 3rd conference on reanalysis, Trenberth, EOS, 2008)

- Group on Earth Observations (GEO)/GCOS Task CL-06-01  
**Sustained Reprocessing and Reanalysis Efforts**
- U.S. GCRP Revised Strategic Plan (2008)  
Goal 3 Reduce uncertainty in projections of how the Earth’s climate and environmental systems may change in the future  
Key research topics: **Creating a Historical Reanalysis of the Atmosphere of the 20th Century**
- NOAA Strategic plan (2006-2011) to meet NOAA and GCRP goals calls for integrated observations and analysis with **“quantified uncertainties”**.
- Emphasis on reanalysis improvements for understanding multidecadal variability of **weather extremes** and variations (eg., CCSP, 2008, Weather and Climate Extremes SAP3.3)

# Uses of historical reanalyses

1. Effectively doubling the reanalysis record length for climate change detection and attribution studies 😊
2. Climate model validation dataset for large-scale synoptic anomalies during extreme periods, such as droughts (30's, 50's).
3. Better understand events such as the 1920-1940's Arctic warming.
4. Determining storminess and storm track variations over last 100-150 years.
5. Developing and improving forecasts of subseasonal (e.g., Pacific-North America pattern, North Atlantic Oscillation) atmospheric variations.
6. Understanding changing atmospheric background state associated with interdecadal hurricane activity.
7. Estimating risks of extreme events.

# The Twentieth Century Reanalysis Project

**Summary:** An international collaborative project led by NOAA and CIRES to produce high-quality tropospheric reanalyses for the last 130+ years *using only surface pressure observations (this is not a minus!)*.

The reanalyses provide:

- First-ever estimates of near-surface and tropospheric 6-hourly fields extending back to end of the 19<sup>th</sup> century;
- Estimates of uncertainties in the basic reanalyses;
- Estimates of uncertainties in derived quantities (storm tracks, etc.)

Higher quality in the Northern Hemisphere than in the Southern Hemisphere.

**US Department of Energy INCITE, Office of Science computing awards and NOAA Climate Program Office partnership to produce 1871-2008 and extend to 2010 in fall of 2011.**

# Ensemble Filter Algorithm

(Whitaker and Hamill 2002)

Analysis  $x^a$  is a weighted average of the first guess  $x^b$  and observation  $y^o$

$$x^a = (I-KH)x^b + Ky^o$$

Algorithm uses an ensemble to produce the weight  $K$  that varies with the atmospheric flow and the observation network

$y^o$  is only surface pressure,

$Hx^b$  is guess surface pressure

$x$  is pressure, air temperature, winds, humidity, etc. at all levels and gridpoints.

Using 56 member Ensemble

HadISST monthly boundary conditions (*Rayner et al. 2003*)

Version 2 (1871-2008): T62, 28 level NCEP GFS08ex model

- time-varying CO<sub>2</sub>, solar and volcanic radiative forcing

# International Surface Pressure Databank version 2 (ISPD)

Subdaily observations assembled in partnership with

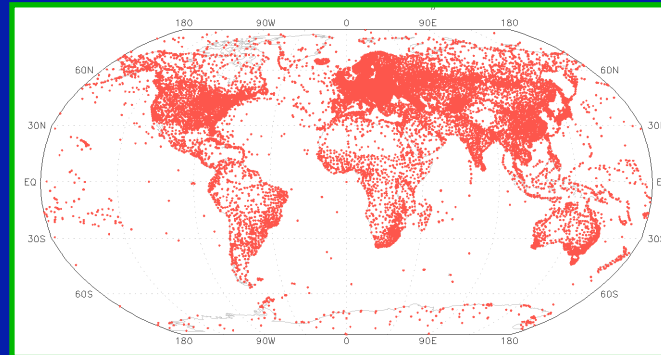
GCOS AOPC/OOPC Working Group on Surface Pressure

GCOS/WCRP Working Group on Observational Data Sets for Reanalysis

Atmospheric Circulation Reconstructions over the Earth (ACRE)

**Land data Component:** merged by NOAA NCDC, NOAA ESRL, and CU/CIRES

- 33 data sources
- 33,653 stations
- 1.7 billion obs
- 1768-2008



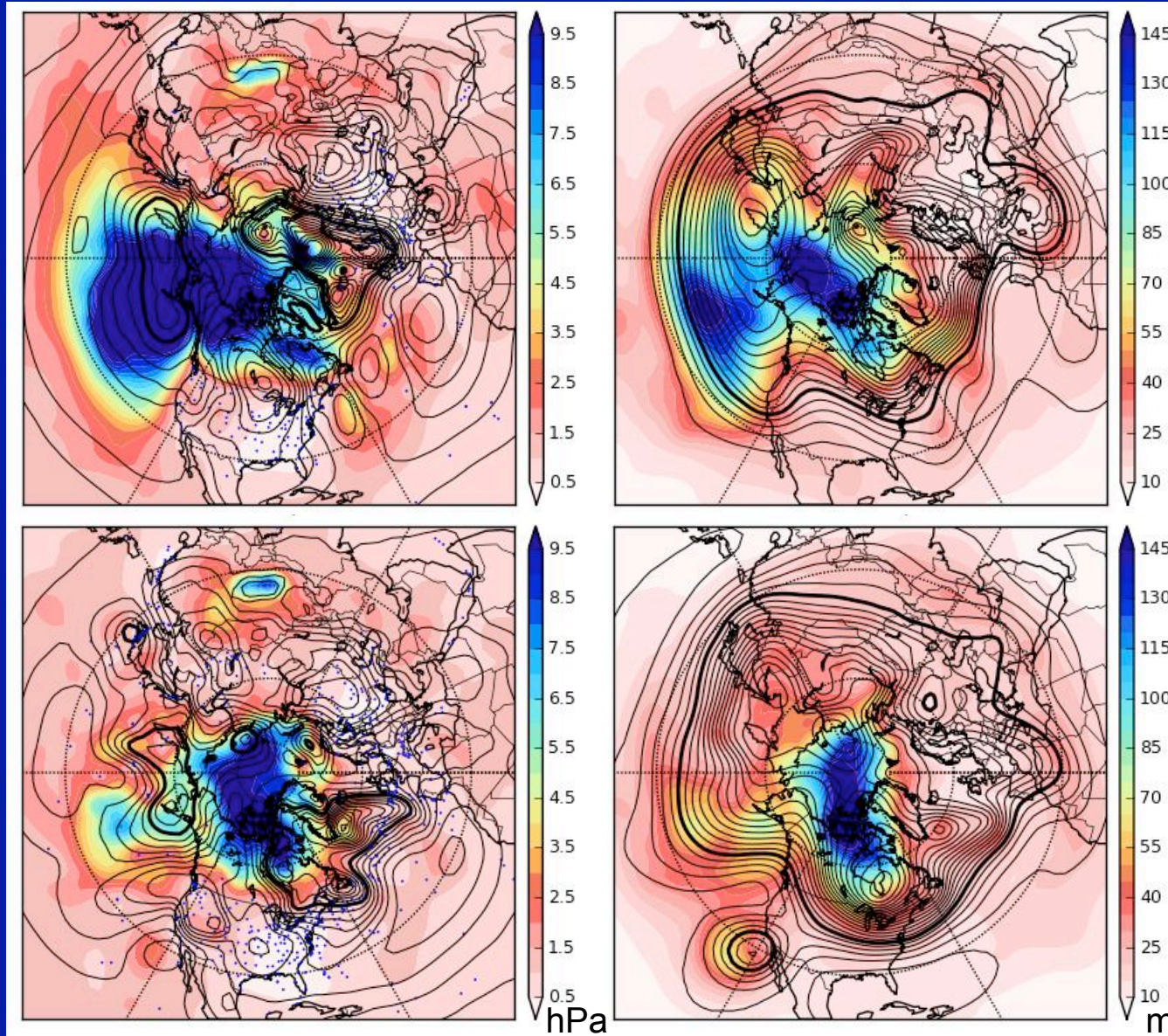
**Marine data component:** **ICOADS** merged by NOAA ESRL and NCAR NOAA

**Tropical Cyclone Best Track data component:** **IBTrACS** merged by NOAA NCDC

See Poster T176A by C. McColl et al.

# Analyses for selected dates in 1894 and 1914

1894



Contours-  
ensemble  
mean

Shading-  
blue: more  
uncertain,  
white: more  
certain

1914

Sea Level Pressure

500 hPa Geopotential Height

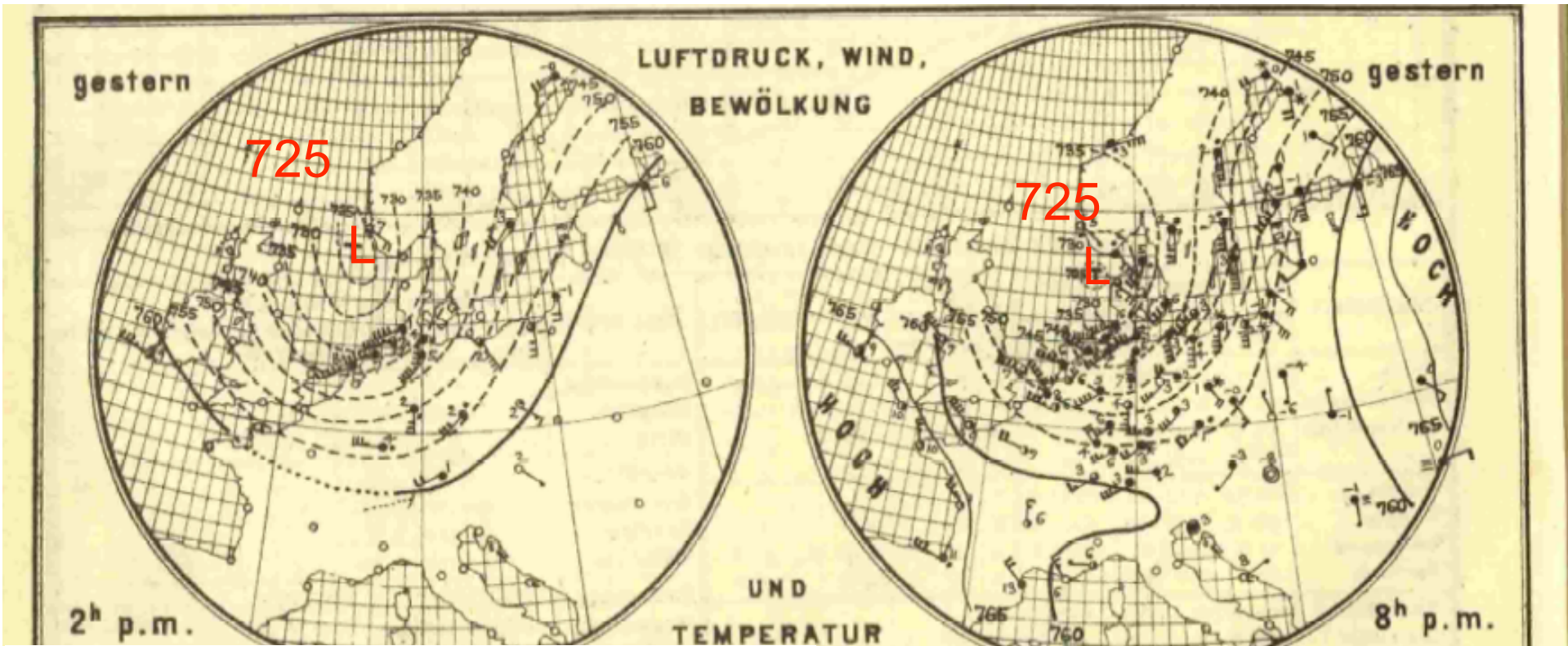


# De Storm van 1894 (Zenit. 2010)

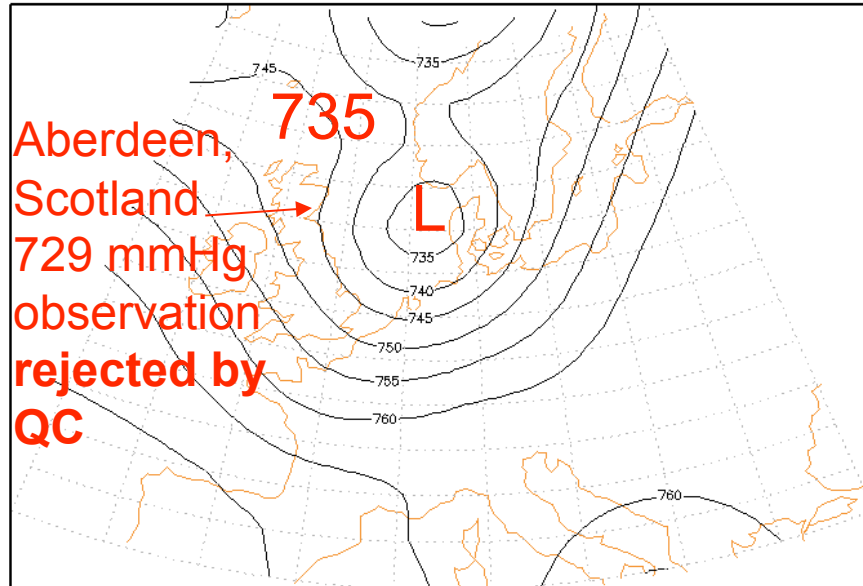
Henk de Bruin and Huug van den Dool

Frank Beyrich and Britta Bolzmann (DWD)  
provided 1894 weather maps of the  
*Seewarte Hamburg*

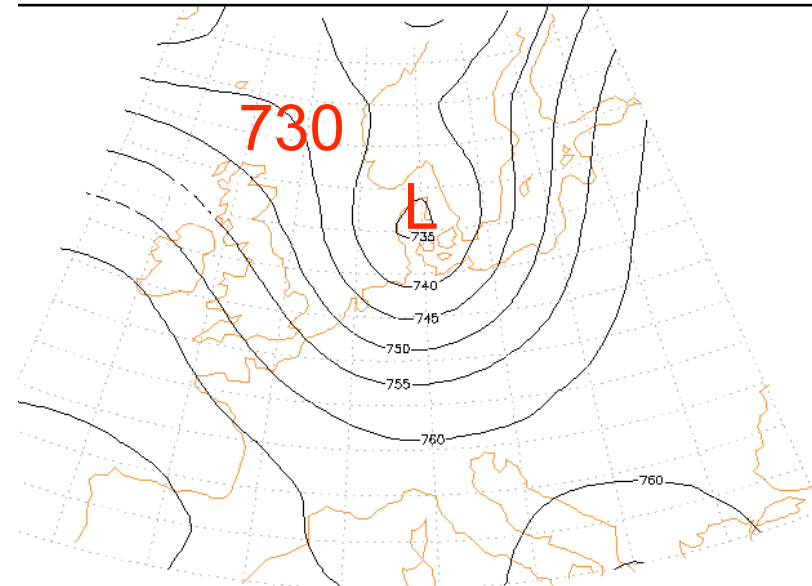




20CR Reanalysis Storm 22 dec 1894 12Z



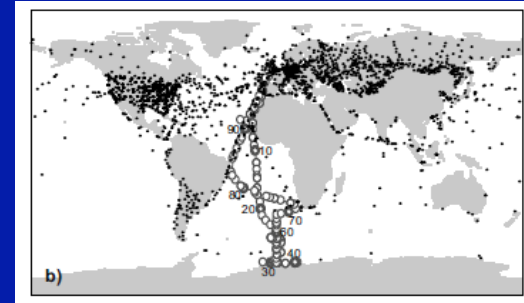
20CR Reanalysis Storm 22 dec 1894 18Z



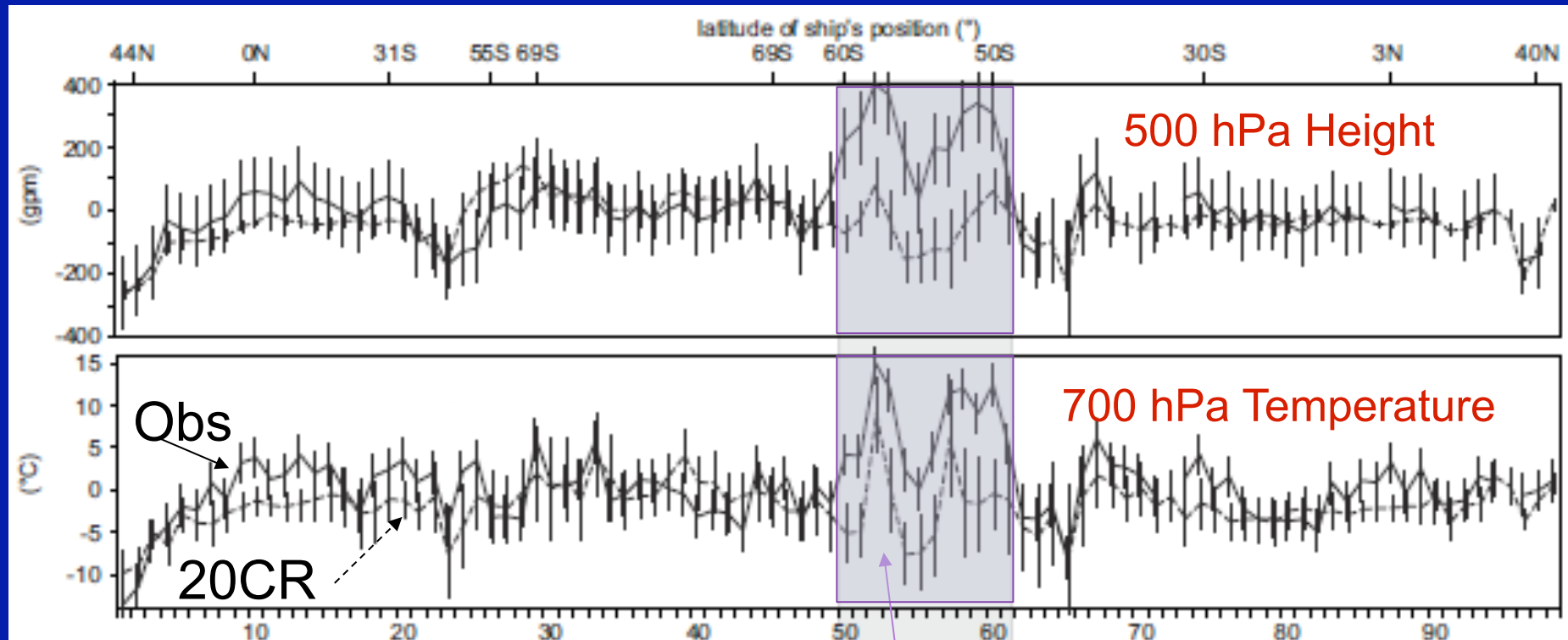
De Bruin and van den Dool (2010)

# Upper-air anomaly data from cruise of MS *Schwabenland* compared to 20CR

(December 1938 to April 1939)



Cruise locations (open circles)



Anomalies are with respect to NCEP-NCAR Reanalyses

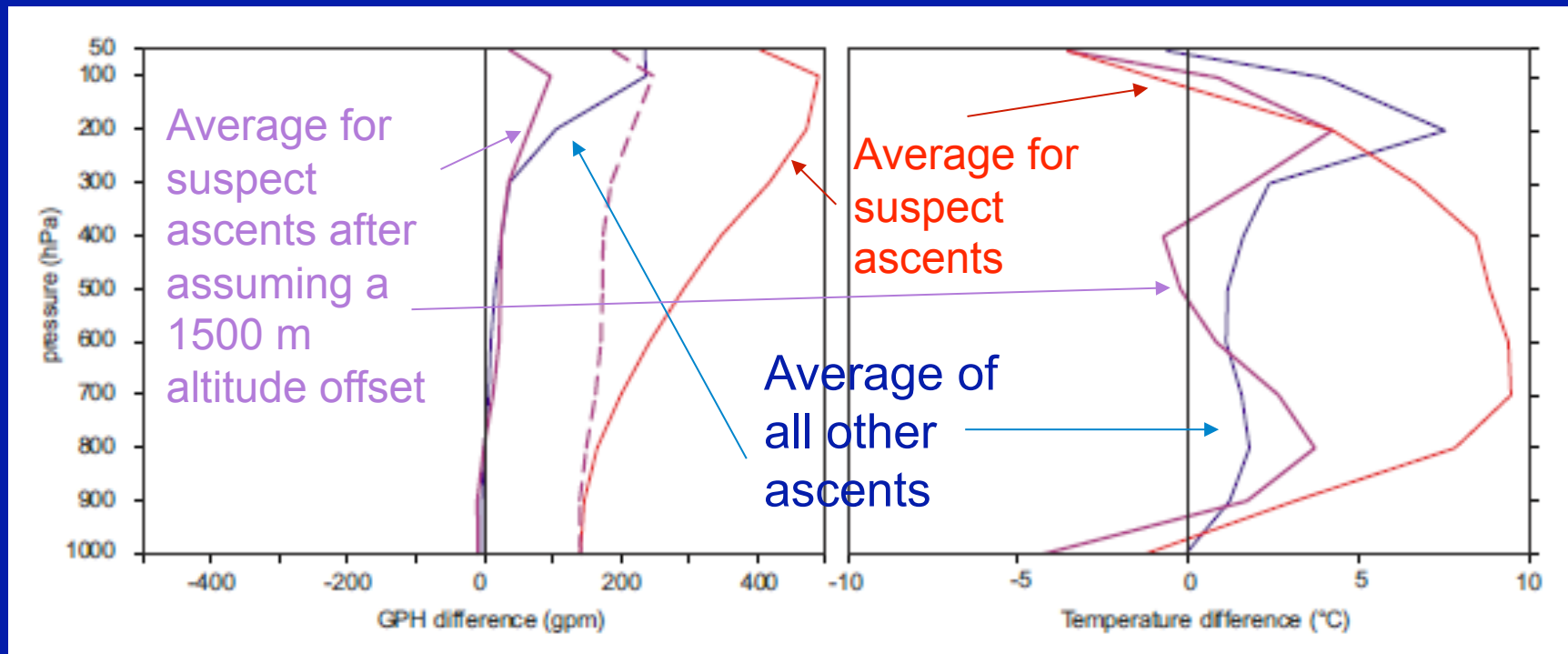
Grey regions shows suspected erroneous data

*Brönnimann et al., Clim. Past (2011)*

# Vertical difference profiles of 20CR and MS Schwabenland geopotential height and temperature soundings

## Geopotential Height

## Temperature

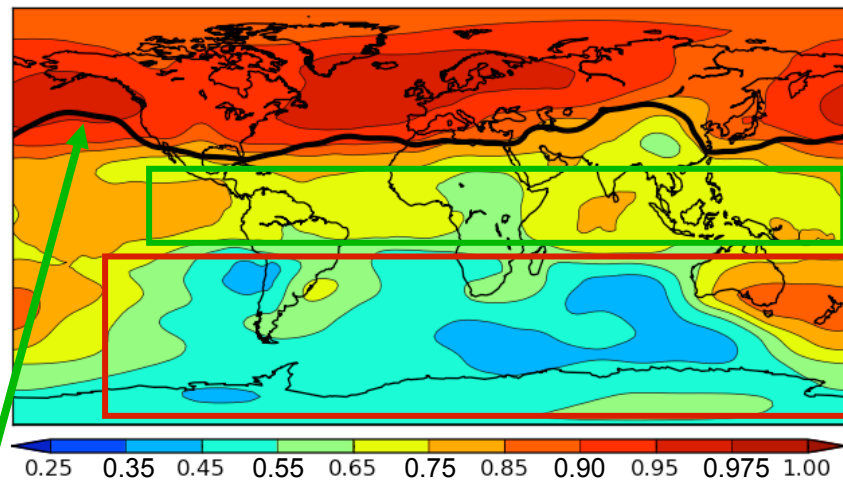


20CR can be used to detect and correct errors in observations

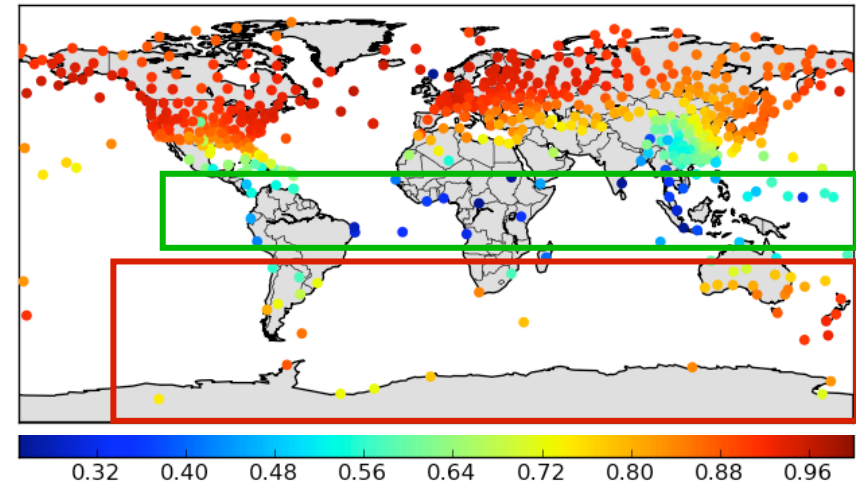
*Brönnimann et al., Clim. Past (2011)*

# Local Anomaly Correlation of 20th Century Reanalysis (20CR), ERA40, and radiosonde 300 hPa geopotential height anomalies (1958 to 1978)

Correlation 20CR vs ERA40 (300 hPa Height 1958-1978)



Correlation of Analyses with Radiosondes (300 hPa Height 1958-1978)



Black curve shows where NCEP-NCAR and ERA40 correlate > 0.975

Northern Hemisphere agreement is excellent where NNR and ERA40 agree.

Tropical agreement is moderate to poor with radiosondes but higher with ERA40.

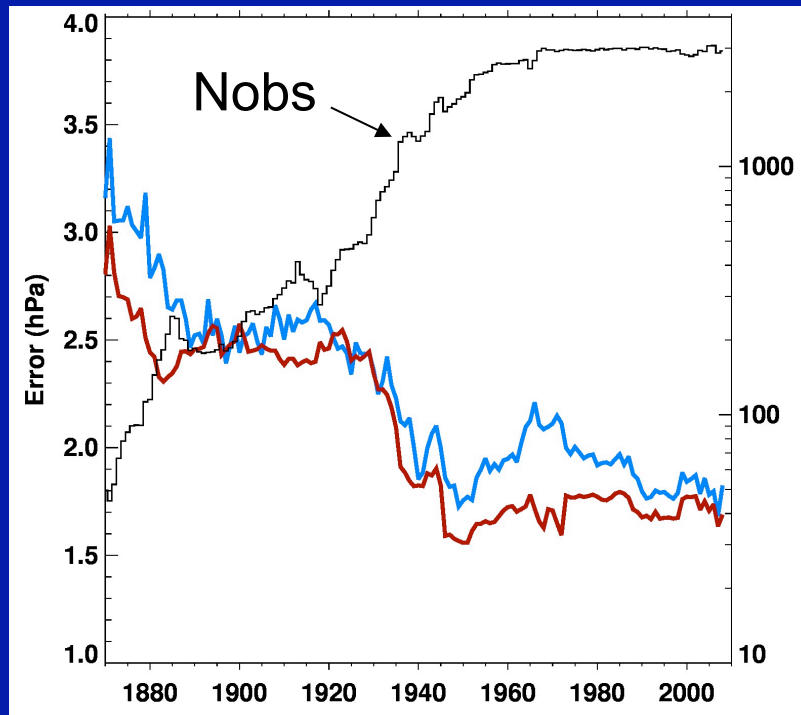
Southern Hemisphere agreement is moderate to poor with ERA40 but higher with radiosondes.

# Surface Pressure uncertainty estimate poleward of 20(S,N)

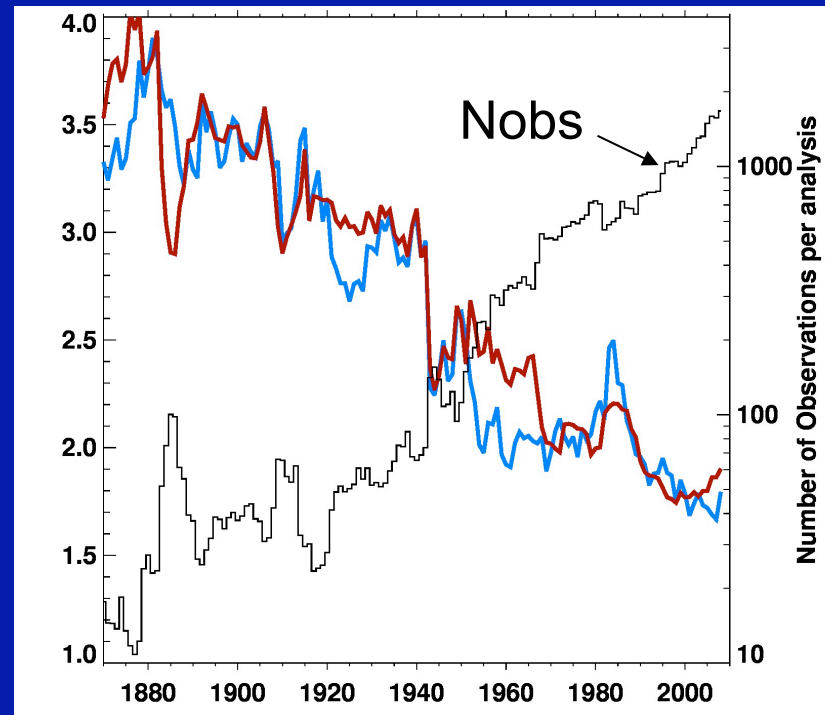
blue actual RMS difference

red expected RMS difference

## Northern Hemisphere

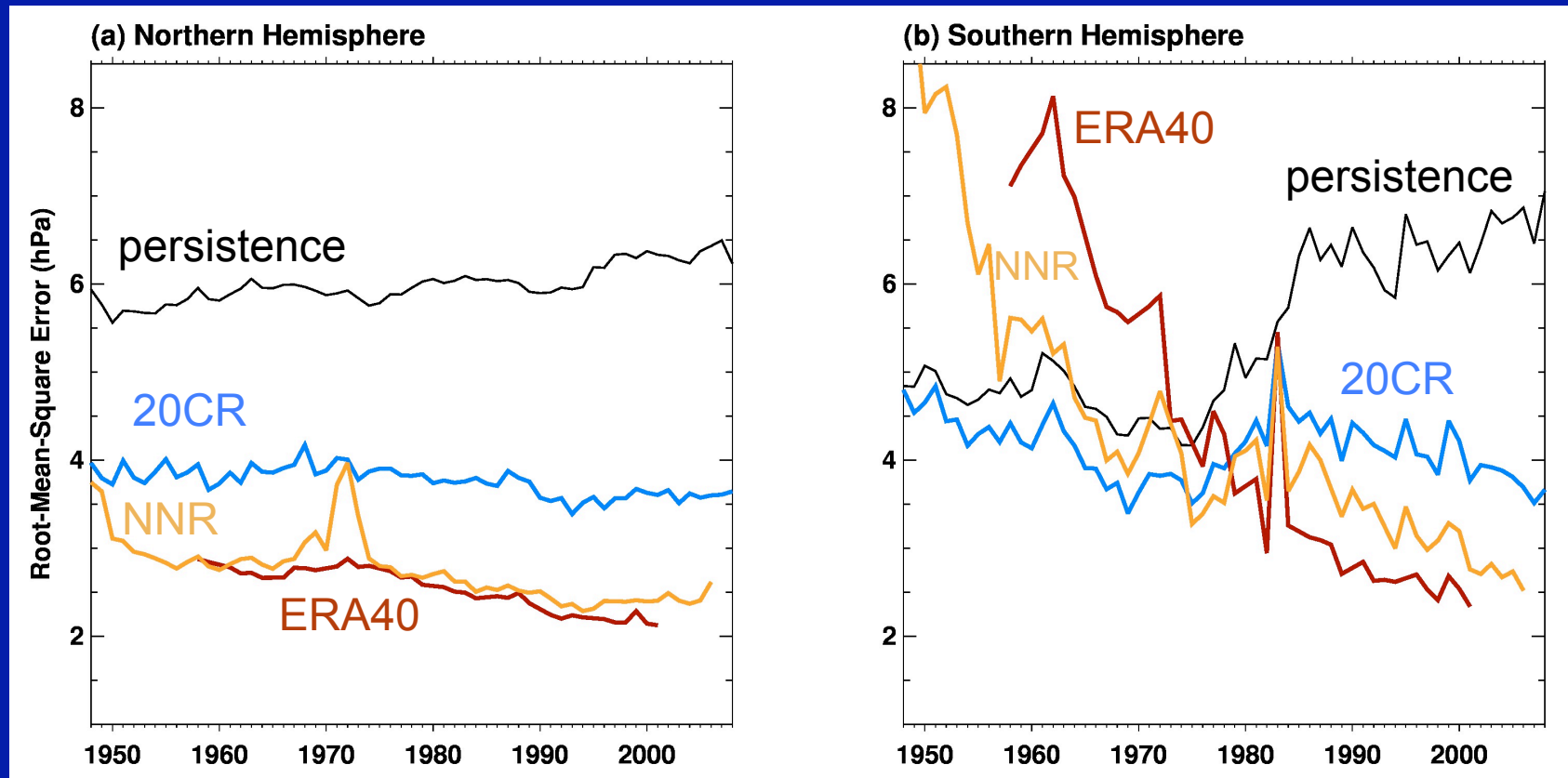


## Southern Hemisphere



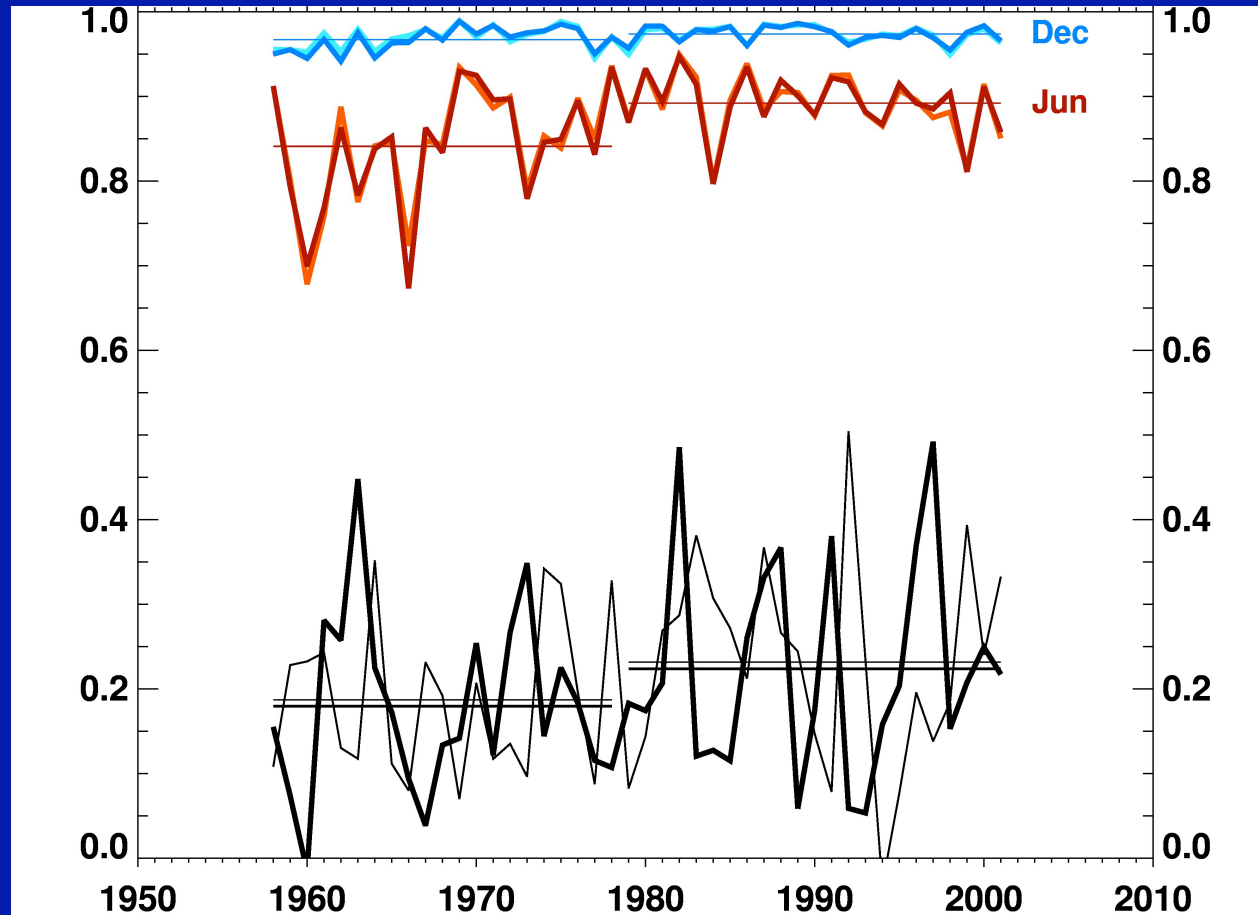
Uncertainty estimates are consistent with actual differences between first guess and pressure observations even as the network changes over more than 100 years!

# RMS Errors of 24 hour forecasts verified against Marine obs for forecasts initialized with NCEP-NCAR Reanalysis, 20CR, and ERA40 (1948-2008)



Before the satellite era (1970s), there is **substantially better skill** for 20CR than for NCEP-NCAR Reanalysis or ERA40 in the Southern Hemisphere despite the lack of upper-air observations.

# Pattern correlation between 20CR and ERA40 and NCEP-NCAR Reanalyses of monthly anomalies of 300 hPa geopotential height



Correlation  
Between  
NNR and  
20CR (and  
ERA-40 and  
20CR)

Correlation  
Between  
NNR and an  
SST-forced  
simulation

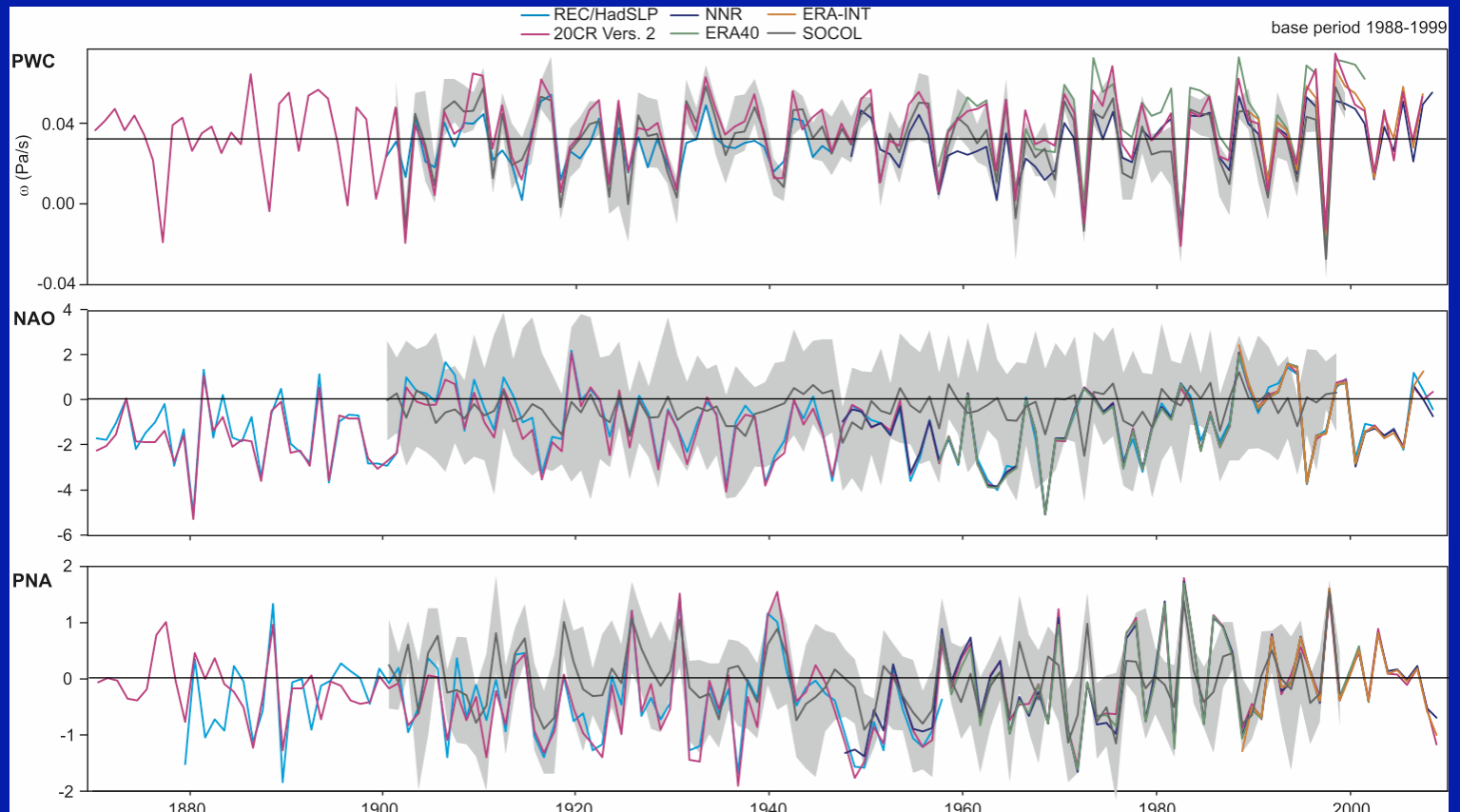
Reanalysis correlations are much higher than for SST-forced simulation.  
1970s change in correlations show satellite data improving NNR and ERA-40.

# Seasonal climate indices from Statistical Reconstructions, SST-forced GCM integrations, and 20<sup>th</sup> Century, ERA-40, NCEP-NCAR, ERA-Interim Reanalyses.

Pacific Walker  
Circulation  
(500 hPa  
vertical velocity,  
SONDJ)

North Atlantic  
Oscillation  
(Sea Level  
Pressure, DJF)

Pacific-North  
America  
Pattern Index  
(500 hPa  
geopotential  
height, DJF)



1870

2008

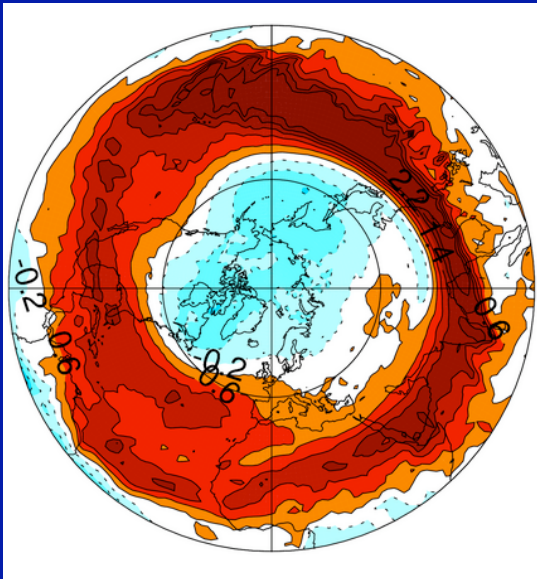
Agreement is high between observation-based estimates  
(correlations between ERA-40 and 20CRv2 > 0.95)

Courtesy S. Bronnimann

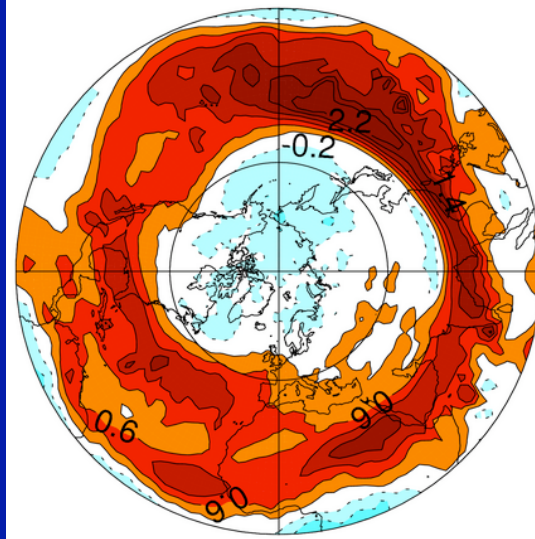


## Storm Track

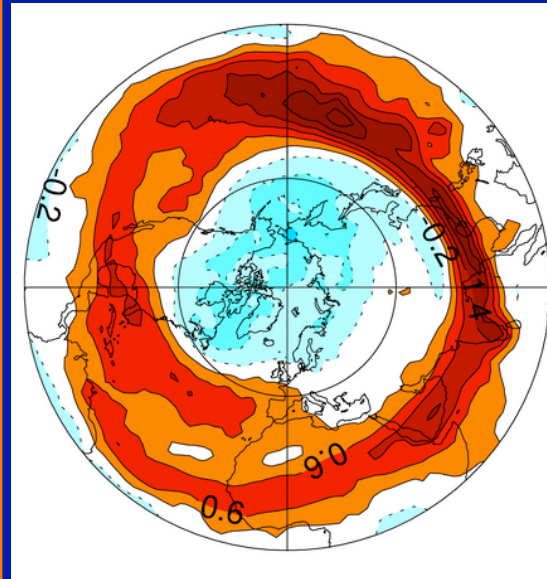
Skewness of Northern Hemisphere 250 hPa *daily* Vorticity  
(Dec-Feb) 1989/90-2005/06



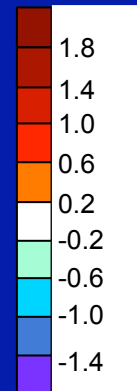
ERA Interim (~50km)  
Uses satellite and  
upper-air data



20CRv2 (~200km)  
**Surface pressure only**

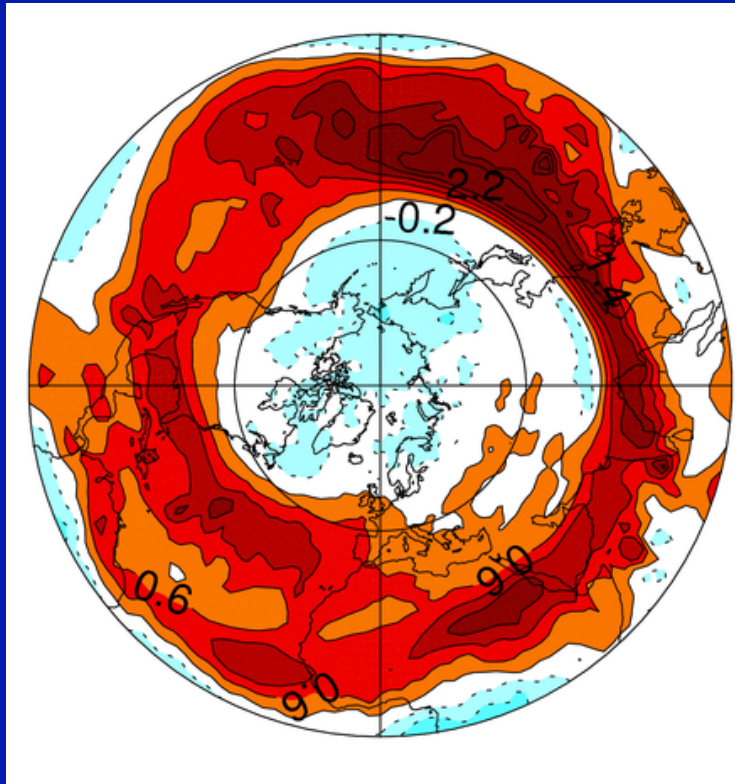


NCEP-NCAR (~200km)  
Uses satellite and  
upper-air data

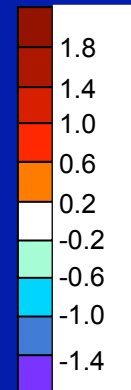
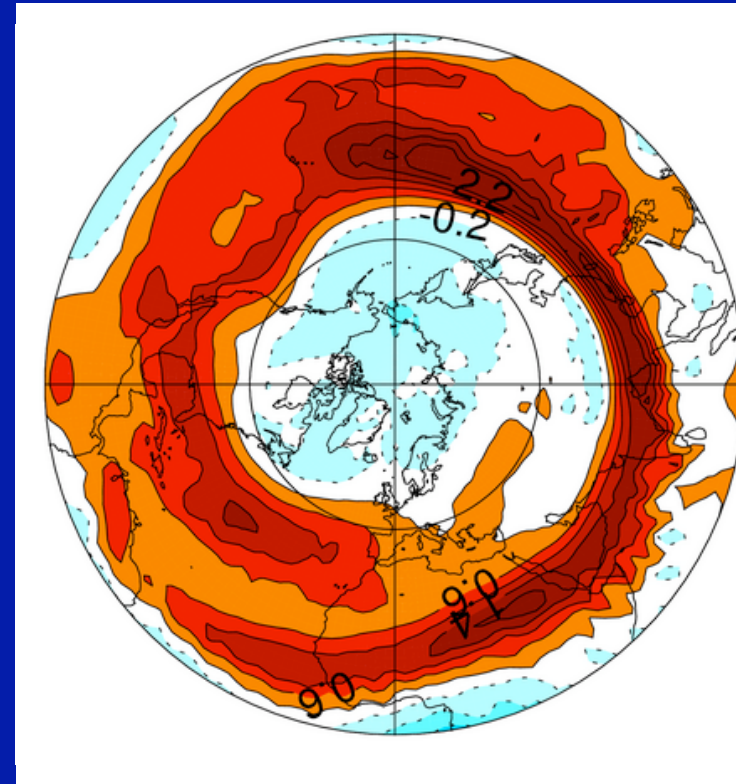


# Skewness of 250 hPa Vorticity from 20<sup>th</sup> Century Reanalyses

DJF 1989/90-2005/06



DJF **1891/92**-2005/06



Storm Track Features are remarkably robust

See Poster TH155B Sardeshmukh, Compo, Penland

# Historical Reanalysis Status and Plans

## 20th Century Reanalysis Project [http://www.esrl.noaa.gov/psd/data/20thC\\_Rean](http://www.esrl.noaa.gov/psd/data/20thC_Rean)

- Data Access: Analyses and ISPD (with feedback) freely available from NCAR, analyses from NOAA/ESRL and DOE NERSC. Coming Soon: NOAA/NCDC.
- **Fall 2011:** 1871-2008, expand to 2010 (includes time-varying CO<sub>2</sub>, volcanic aerosols, GFS from NCEP). **Ensemble mean and spread and some individual member variables online now.**
  - [http://www.esrl.noaa.gov/psd/data/gridded/data.20thC\\_ReanV2.html](http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2.html) (NOAA ESRL)
  - <http://dss.ucar.edu/datasets/ds131.1> (NCAR)
  - [http://portal.neresc.gov/20C\\_Reanalysis](http://portal.neresc.gov/20C_Reanalysis) **Every member** (US Dept of Energy, NERSC)
  - <http://nomads.ncdc.noaa.gov> (NOAA NCDC, coming soon)
  - Coordinate with PCMDI CMIP5 distribution and validation for IPCC AR5

## ECMWF Reanalysis Archive-Climate (ERA-CLIM)

- Series of reanalyses, including Surface-observation based back to 1900 (ERA-20C).
- ERA-20C: T159 spectral (~125km grid spacing)
- **ERA-20C: Available 2012 (previous talk from Dee)**

## Advances and Improvements towards

### ***Sparse Input Reanalysis for Climate Applications (SIRCA)***

spanning 19th-21st centuries over the next 2-10 years

1. More land and marine observations back to early 19th century, especially Southern Hemisphere and Arctic.
2. User requirements for, and applications of, reanalyses
3. Higher resolution, improved methods, possibly other surface variables (e.g., wind, T, Tropical Cyclone position)
4. Uncertainty in forcings (e.g, CO2, solar, SST)
5. Possibly Multi-model (e.g., NASA, NCAR, NCEP, GFDL, ESRL)

**Available 2014** – SIRCA (*1850-2014*)

**Available 2017** – include coupling, OARCA (*1800-2016*)

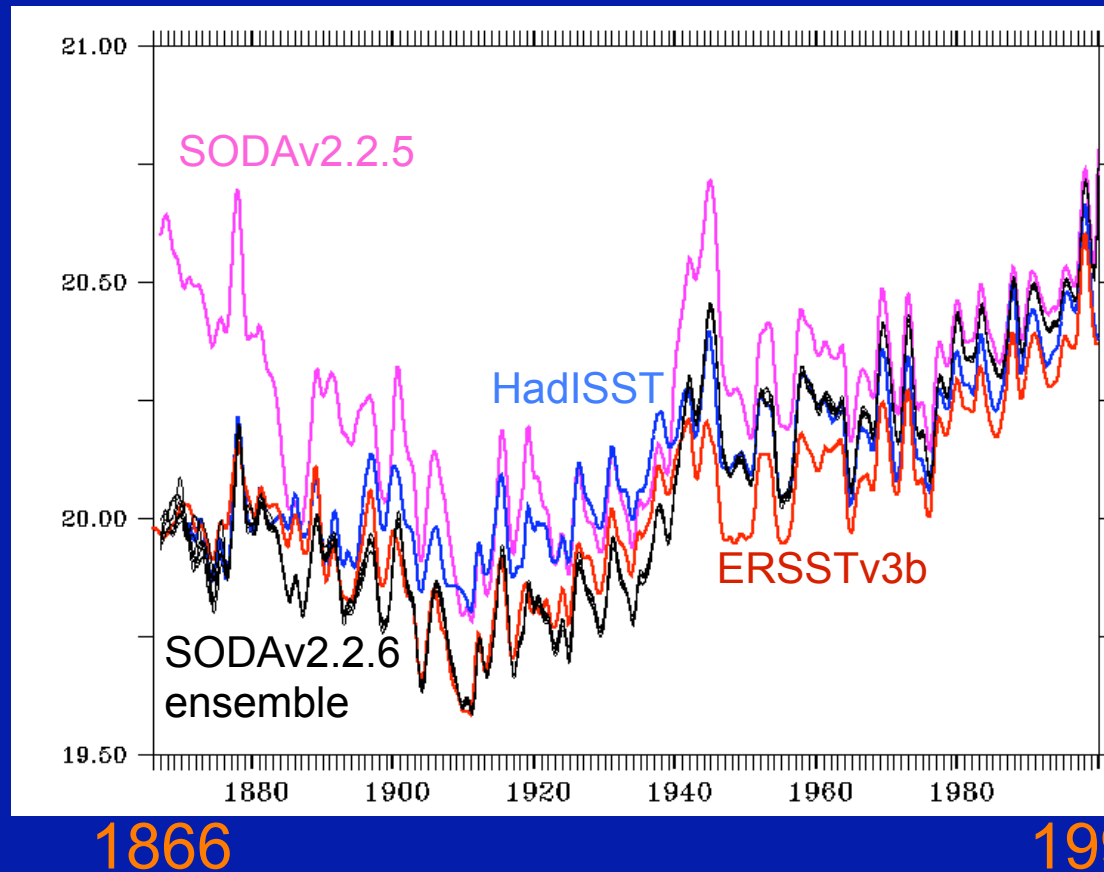
Requires international cooperation, e.g.,

Atmospheric Circulation Reconstruction over the Earth initiative

<http://www.met-acre.org>

Global Ocean Sea Surface Temperature (60N-60S)  
from Simple Ocean Data Assimilation SST *ensemble* (SODAv2.2.6)  
compared to SST reconstructions (HadISST and NOAA ERSST) and  
SODAv2.2.5 using only 20CR ensemble mean

In these,  
SODA  
assimilates  
only SST  
data



SODAv2.2.5  
is too warm  
early in record  
because  
20CR  
ensemble-mean  
wind-stress is  
too weak.

Surprisingly, SODAv2.2.6 ensemble corresponds better to NOAA ERSSTv3b  
at times, despite 20CR having HadISST1.1 as boundary condition.

# Project Status and Plans (con't)

## Surface Input Reanalysis for Climate Applications (SIRCA)

SIRCA 1850-2014

- Higher resolution (T126 ~100km or higher)
- improved methods (e.g., improved quality control, bias correction)
- More input data (e.g., ACRE)
- latest model from NCEP
- Include uncertainty in forcings (e.g., ensemble of SSTs and Sea Ice, CO2, solar)
- **Fall 2014**

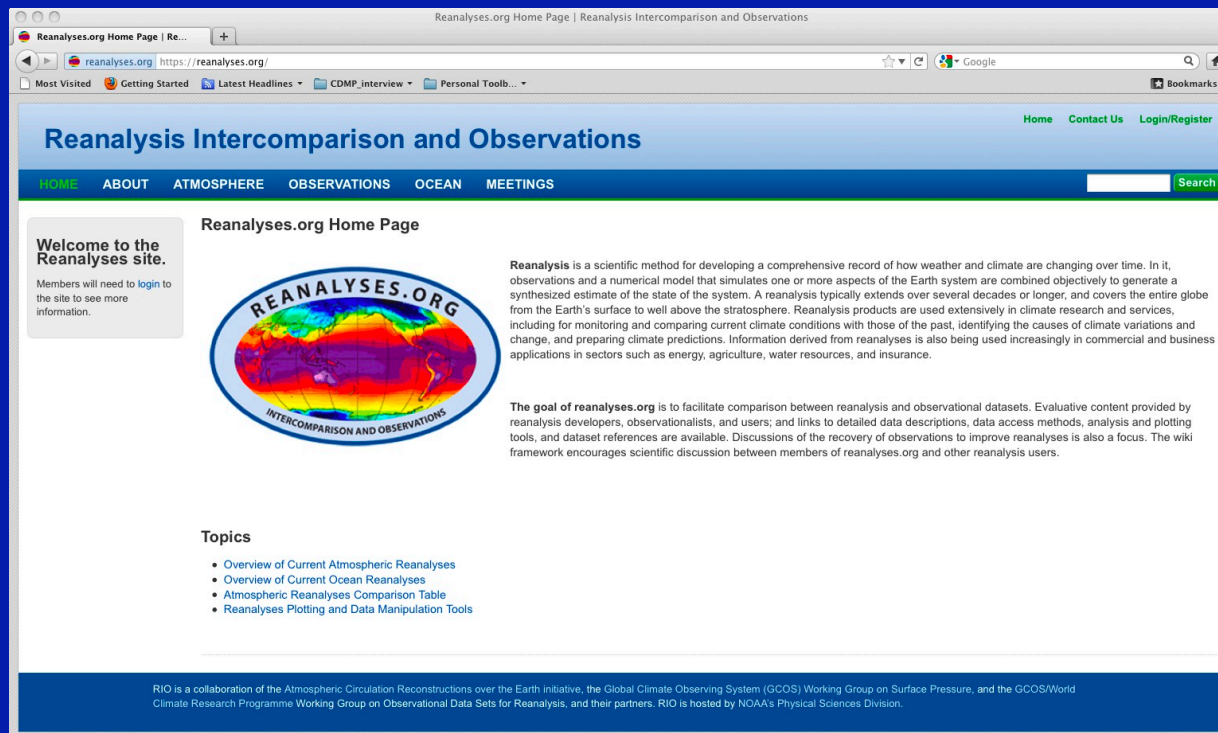
## Ocean Atmosphere Reanalysis for Climate Applications

OARCA 1800?-2017

- Higher resolution (T382 or higher)
- improved methods (e.g., include coupled Cryosphere-Ocean-Land-Atmosphere-Chemistry system, link with SODA advances, possibly NOAA CarbonTracker advances)
- More input data (e.g., ACRE-facilitated, maybe winds and T, storm position, trace gases)
- latest model from NCEP, multi-model with other models (e.g., NASA, NCAR, GFDL, ESRL)
- **Fall 2017**

[www.reanalyses.org](http://www.reanalyses.org)

*Wiki* for comparing Reanalyses with each other  
and with observations



The screenshot shows the homepage of Reanalyses.org. The browser address bar displays "https://reanalyses.org/". The page title is "Reanalysis Intercomparison and Observations". The navigation menu includes "HOME", "ABOUT", "ATMOSPHERE", "OBSERVATIONS", "OCEAN", and "MEETINGS". A search bar is located on the right side of the navigation menu. The main content area features a "Welcome to the Reanalyses site." message, a "Reanalyses.org Home Page" section with a globe logo, and a "Topics" section listing several key areas of interest.

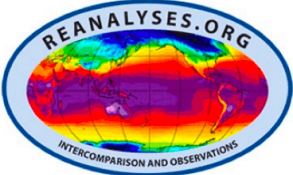
Reanalysis.org Home Page | Reanalysis Intercomparison and Observations

Home Contact Us Login/Register

HOME ABOUT ATMOSPHERE OBSERVATIONS OCEAN MEETINGS Search

Welcome to the Reanalyses site.  
Members will need to login to the site to see more information.

Reanalyses.org Home Page



Reanalysis is a scientific method for developing a comprehensive record of how weather and climate are changing over time. In it, observations and a numerical model that simulates one or more aspects of the Earth system are combined objectively to generate a synthesized estimate of the state of the system. A reanalysis typically extends over several decades or longer, and covers the entire globe from the Earth's surface to well above the stratosphere. Reanalysis products are used extensively in climate research and services, including for monitoring and comparing current climate conditions with those of the past, identifying the causes of climate variations and change, and preparing climate predictions. Information derived from reanalyses is also being used increasingly in commercial and business applications in sectors such as energy, agriculture, water resources, and insurance.

The goal of reanalyses.org is to facilitate comparison between reanalysis and observational datasets. Evaluative content provided by reanalysis developers, observationalists, and users; and links to detailed data descriptions, data access methods, analysis and plotting tools, and dataset references are available. Discussions of the recovery of observations to improve reanalyses is also a focus. The wiki framework encourages scientific discussion between members of reanalyses.org and other reanalysis users.

Topics

- Overview of Current Atmospheric Reanalyses
- Overview of Current Ocean Reanalyses
- Atmospheric Reanalyses Comparison Table
- Reanalyses Plotting and Data Manipulation Tools

RIO is a collaboration of the Atmospheric Circulation Reconstructions over the Earth initiative, the Global Climate Observing System (GCOS) Working Group on Surface Pressure, and the GCOS/World Climate Research Programme Working Group on Observational Data Sets for Reanalysis, and their partners. RIO is hosted by NOAA's Physical Sciences Division.

[http://www.esrl.noaa.gov/psd/data/20thC\\_Rean/](http://www.esrl.noaa.gov/psd/data/20thC_Rean/)

20th Century Reanalysis at PSD

[Physical Sciences Division](#) [About](#) [Contact](#) [Research](#) [Data](#) [Products](#) [Outreach](#) [Intranet](#) [Calendar](#) [People](#) [Publications](#)

We would greatly appreciate feedback on its use; in the classroom, for presentations or for research. Mail to psddata at (esrl.psd.data@noaa.gov).

**Help**

- [20thC at PSD](#)
- [20th dataset details](#)

**Plot/Analysis**

- [Plot 20thC Monthly composites](#)
- [Plot 20thC Daily composites](#)
- [Plot 20thC Monthly composites:Google Earth Search and Plot all 20thC Data](#)

**Background Information**

- [Referencing Plots](#)

**Related Dataset Plotting and Analysis Pages**

- [Plot NCEP/NCAR Reanalysis | 6-hourly composites](#)
- [Plot NCEP/NCAR Reanalysis | daily composites](#)
- [Plot NCEP/NCAR Reanalysis | Monthly composites](#)

**20th Century Reanalysis**

[Dataset Information](#) | [Analysis and Plotting Pages](#) | [Related Links and Datasets](#) | [Feedback](#)

Ensemble Mean SLP and SLP spread (hPa) | Ensemble Mean Z500 and Z500 spread (m)

Ens Mean Pcp (mm, accum over past 6-h) | Ens Mean 2-m Temp (273 K thickened)

**Using a state-of-the-art data assimilation system and surface pressure observations, the Twentieth Century Reanalysis Project is generating a six-hourly, four-dimensional global atmospheric dataset spanning 1871 to present to place current atmospheric circulation patterns into a historical perspective.**

20CR homepage has links for data access and tools for visualizing and analyzing the data.



## *Thank you to 58 organizations contributing observations to ISPD:*

All Russia Research Institute of Hydrometeorological  
Information WDC  
Atmospheric Circulation  
Reconstructions over the Earth (ACRE)  
Australian Bureau of Meteorology  
Australian Meteorological Association, Todd Project Team  
British Antarctic Survey  
Cook Islands Met Service  
Danish Meteorological Institute  
Deutscher Wetterdienst  
EMULATE  
Environment Canada  
ETH-Zurich  
European Reanalysis for Monitoring  
GCOS AOPC/OOPC WG on Surface Pressure  
Hong Kong Observatory  
IBTRACS  
Icelandic Meteorological Office  
ICOADS  
Instituto Geofisico da Universidade do Porto  
IEDRO  
JAMSTEC  
Japan Meteorological Agency  
Jersey Met Dept.  
KNMI  
MeteoFrance  
MeteoFrance – Division of Climate  
Meteorological and Hydrological Service, Croatia  
National Center for Atmospheric Research  
Nicolaus Copernicus University

Niue Met Service  
NIWA  
NOAA Climate Database Modernization Program  
NOAA Earth System Research Laboratory  
NOAA National Climatic Data Center  
NOAA National Centers for Environmental Prediction  
NOAA Northeast Regional Climate Center at Cornell U.  
NOAA Midwest Regional Climate Center at UIUC  
NOAA Pacific Marine Environmental Laboratory  
Norwegian Meteorological Institute  
Oldweather.org  
Ohio State U. – Byrd Polar Research Center  
Portuguese Meteorological Institute (IM)  
Proudman Oceanographic Laboratory  
SIGN - Signatures of environmental change in the  
observations of the Geophysical Institutes  
South African Weather Service  
Univ. of Bern, Switzerland  
UK Met Office Hadley Centre  
U. of Colorado-CIRES/Climate Diagnostics Center  
U. of East Anglia-Climatic Research Unit  
U. of Giessen –Dept. of Geography  
U. of Lisbon-Instituto Geofisico do Infante D. Luiz  
U. of Milan-Dept. of Physics  
U. Rovira i Virgili-CCRG  
U. of South Carolina  
U. of Toronto-Dept of Physics  
U. of Washington  
World Meteorological Organization - MEDARE  
ZAMG (Austrian Weather Service)

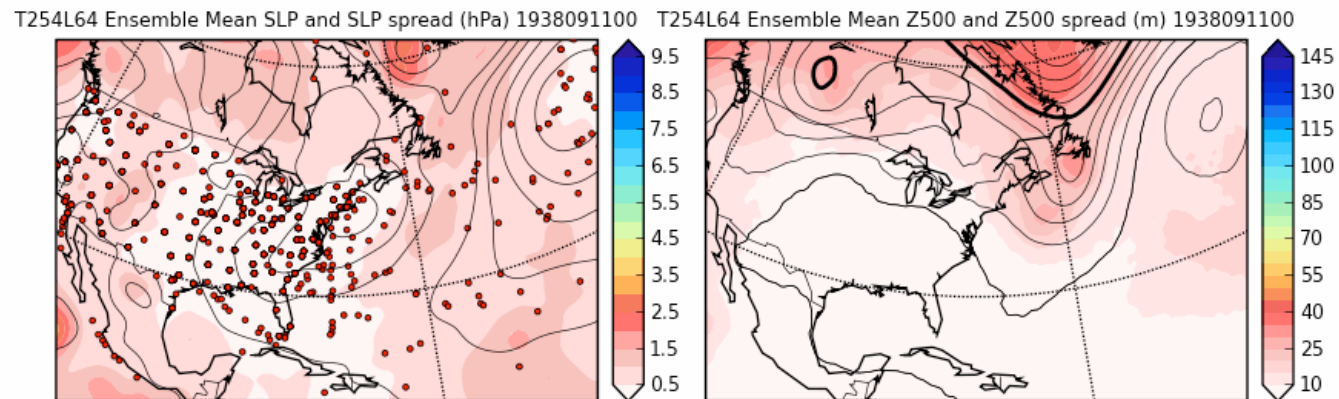
Extra Slides

# Co-authors on 20th Century Reanalysis Project

- **Gilbert P. Compo**, co-Lead Twentieth Century Reanalysis Project, University of Colorado, CIRES, Climate Diagnostics Center & NOAA Earth System Research Laboratory, Physical Sciences Division
- **Jeffrey S. Whitaker**, co-Lead Twentieth Century Reanalysis Project, NOAA Earth System Research Laboratory, Physical Sciences Division
- **Prashant D. Sardeshmukh**, University of Colorado, CIRES, Climate Diagnostics Center & NOAA Earth System Research Laboratory, Physical Sciences Division
- **Nobuki Matsui**, University of Colorado, CIRES, Climate Diagnostics Center & NOAA Earth System Research Laboratory, Physical Sciences Division
- **Robert J. Allan**, ACRE Project Manager, Hadley Centre, Met Office, United Kingdom
- **Xungang Yin**, STG Inc., Asheville, NC
- **Byron E. Gleason, Jr.**, NOAA National Climatic Data Center
- **Russell S. Vose**, NOAA National Climatic Data Center
- **Glenn Rutledge**, NOAA National Climatic Data Center
- **Pierre Bessemoulin**, Meteo-France
- **Stefan Brönnimann**, ETH Zurich
- **Manola Brunet**, Centre on Climate Change (C3), Universitat Rovira i Virgili
- **Richard I. Crouthamel**, International Environmental Data Rescue Organization
- **Andrea N. Grant**, ETH Zurich
- **Pavel Y. Groisman**, University Corporation for Atmospheric Research & NOAA National Climatic Data Center
- **Philip D. Jones**, Climatic Research Unit, University of East Anglia
- **Michael Kruk**, STG Inc., Asheville, NC
- **Andries C. Kruger**, South African Weather Service
- **Gareth J. Marshall**, British Antarctic Survey
- **Maurizio Maugeri**, Dipartimento di Fisica, Università delgi Studi di Milano
- **Hing Y. Mok**, Hong Kong Observatory
- **Øyvind Nordli**, Norwegian Meteorologisk Institutt
- **Thomas F. Ross**, NOAA Climate Database Modernization Program, National Climatic Data Center
- **Ricardo M. Trigo**, Centro de Geofísica da Universidade de Lisboa, IDL, University of Lisbon
- **Xiaolan L. Wang**, Environment Canada
- **Scott D. Woodruff**, NOAA Earth System Research Laboratory, Physical Sciences Division
- **Steven J. Worley**, National Center for Atmospheric Research

# Higher resolution example of Sparse Input Reanalyses for Climate Applications (SIRCA)

# 2008 NCEP GFS at ~50km resolution September 1938 New England (movie)



T254L64 (~50 km)

Is the extraordinary upper-level trough correct?

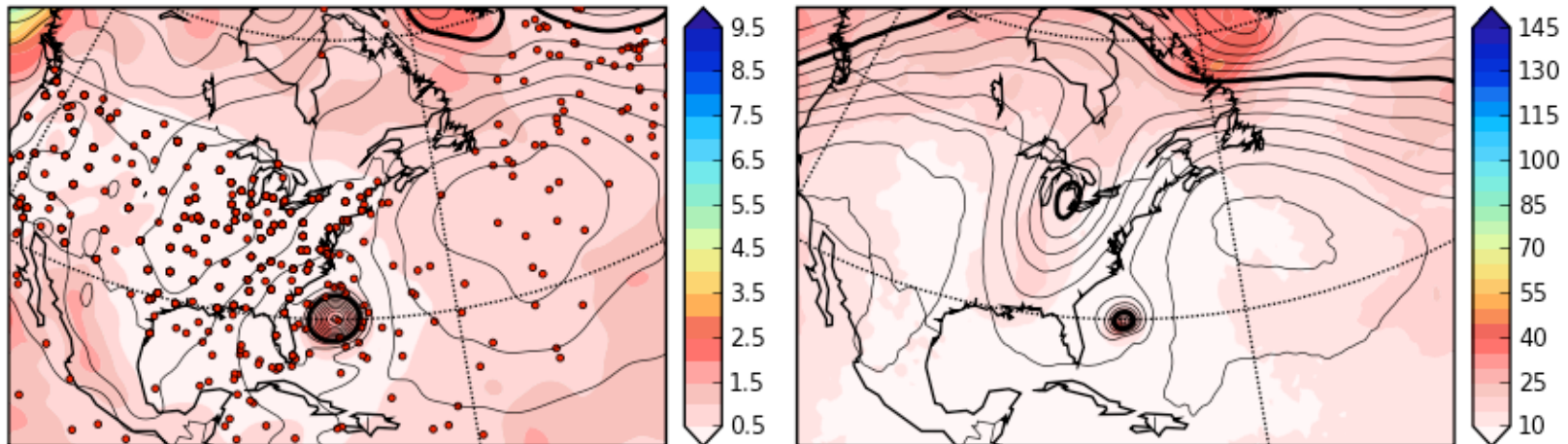
# 2008 NCEP GFS at ~50km resolution

## 21 September 1938 00 UTC

Sea Level Pressure

500 hPa geopotential height

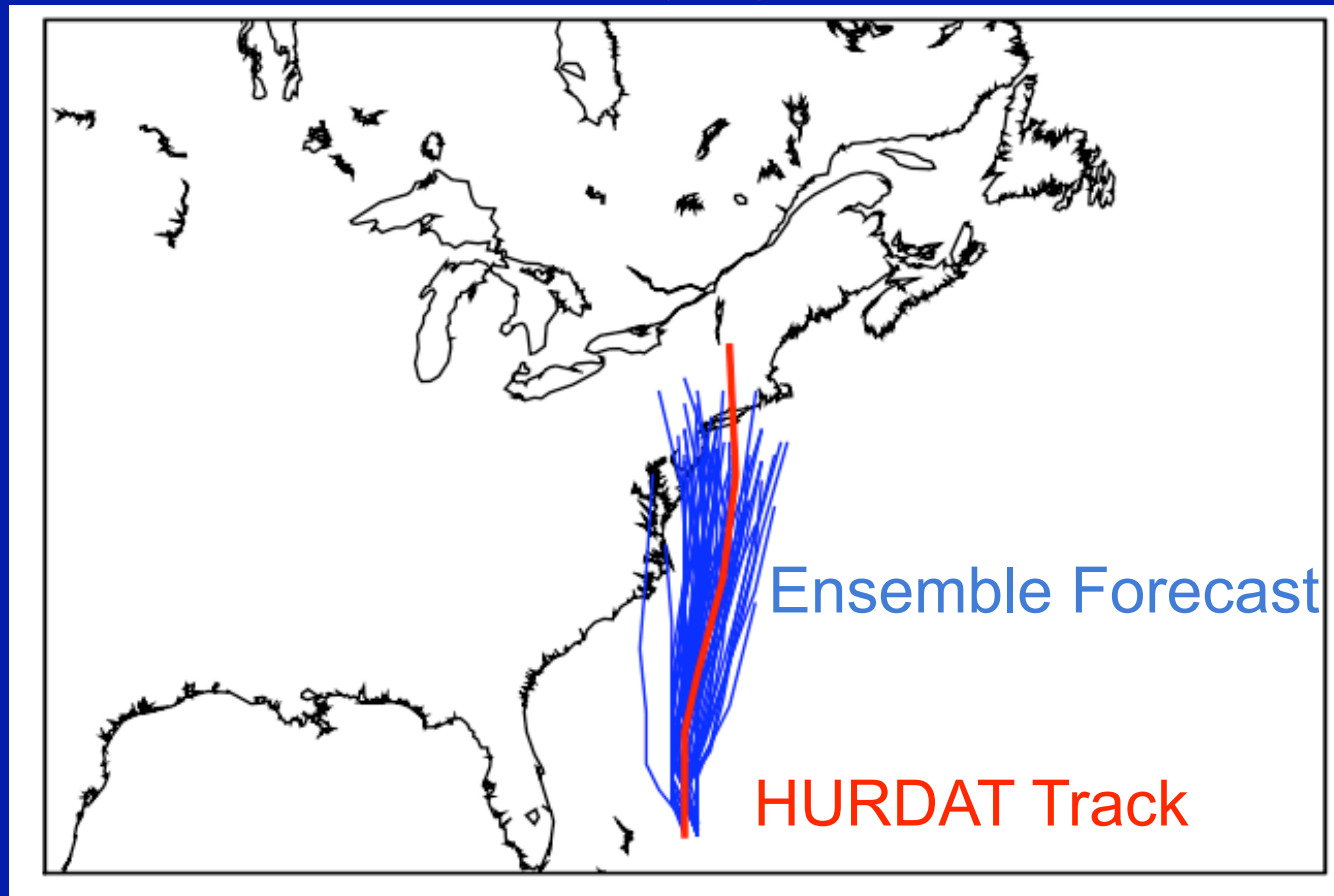
T254L64 Ens Mean SLP and Sprd (hPa - HURDAT 4mb) 1938092100 T254L64 Ens Mean Z500 and Sprd (m - HURDAT 4mb) 1938092100



Is the extraordinary upper-level trough correct?

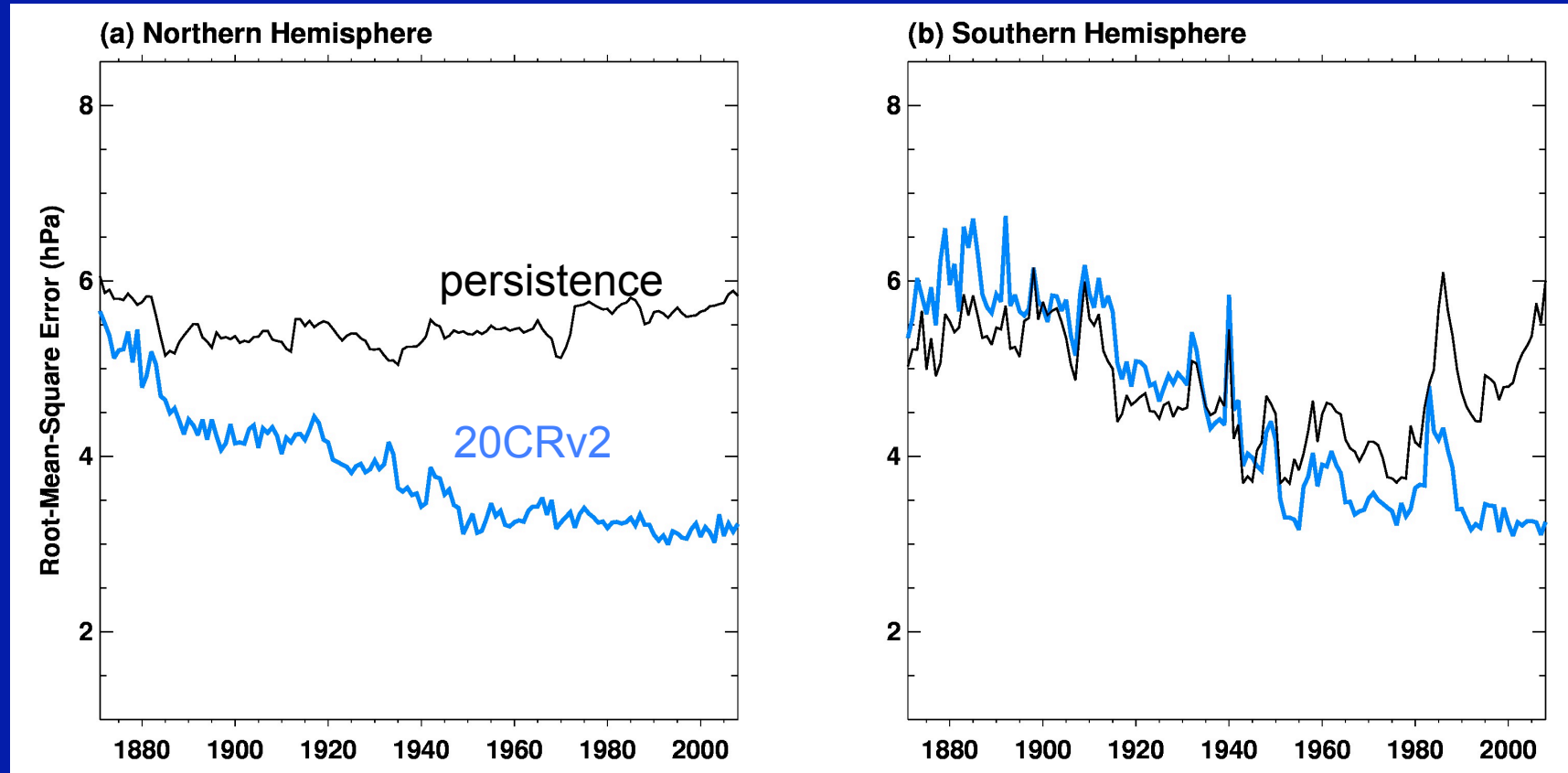
# Any Skill Forecasting the Track?

36 hour forecast verifying 21 Sept 1938 18Z



using 56 ensemble members T254L64 (about 0.5 degree)

# Root Mean Square difference of Surface and Sea Level Pressure Observations and 24 hour Forecasts from 20th Century Reanalysis (1871-2008)

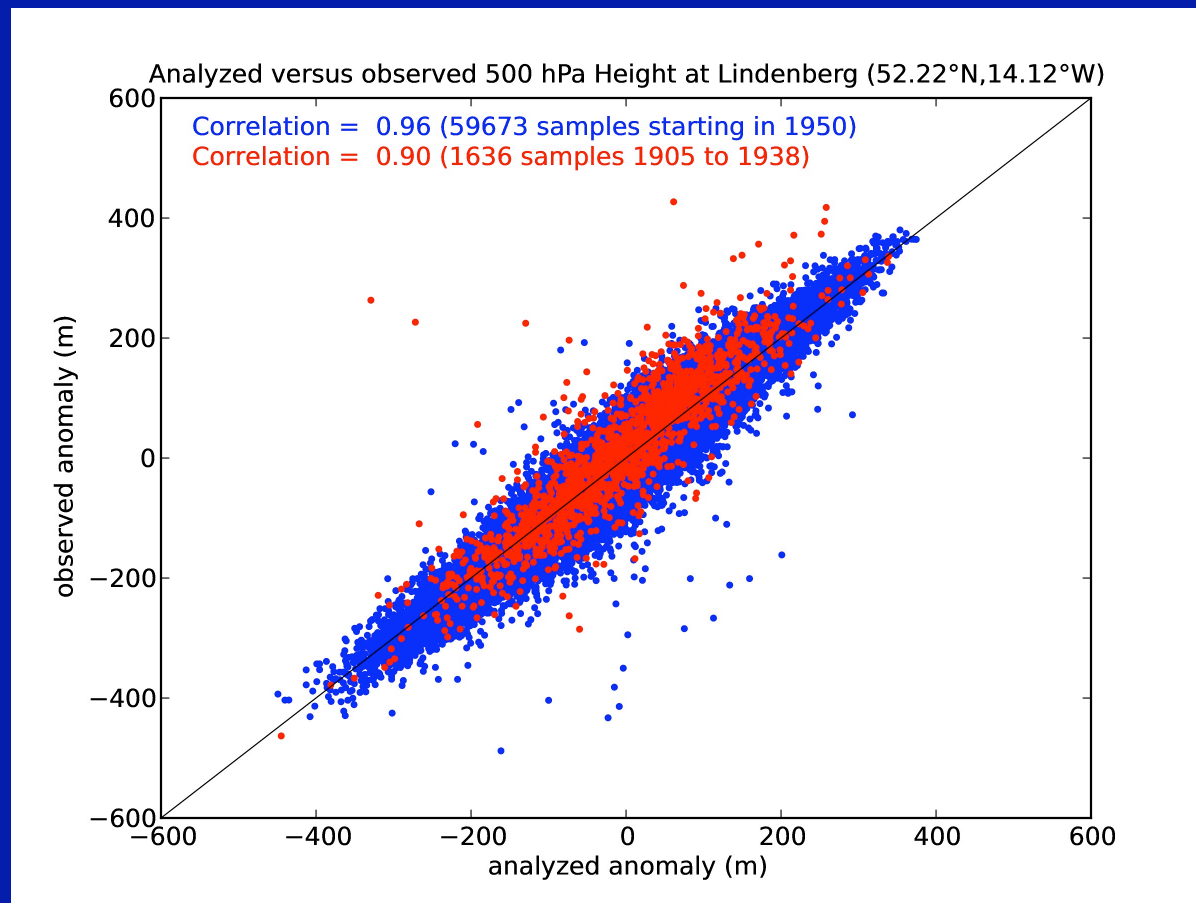


Northern Hemisphere 24 hr forecasts beat persistence even in 1871.  
Southern Hemisphere not better until after 1950.



# Subdaily 500 hPa Geopotential Height anomalies from observations and 20th Century Reanalysis compare well.

1905-2006  
Measurements  
from kites,  
aircraft,  
registering  
balloon, and  
radiosondes  
at Lindenberg,  
Germany

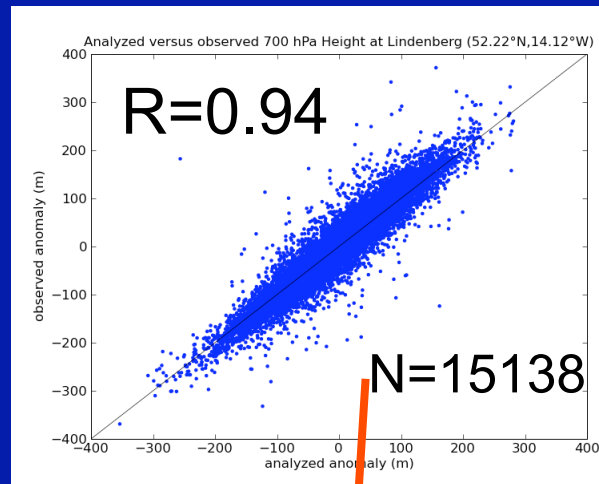


Observations from CHUAN dataset (*Stickler et al. 2010*)

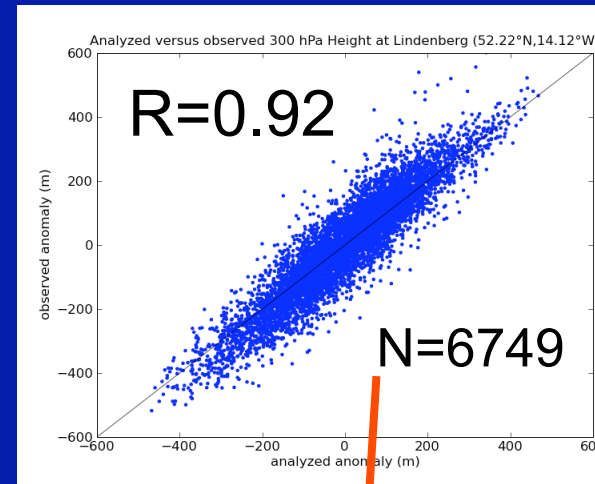
# Local Anomaly Correlation of Twentieth Century Reanalysis and upper-air geopotential height observations from radiosondes and other platforms

1908-1958  
data from kites,  
aircraft,  
radiosondes  
at Lindenberg,  
Germany

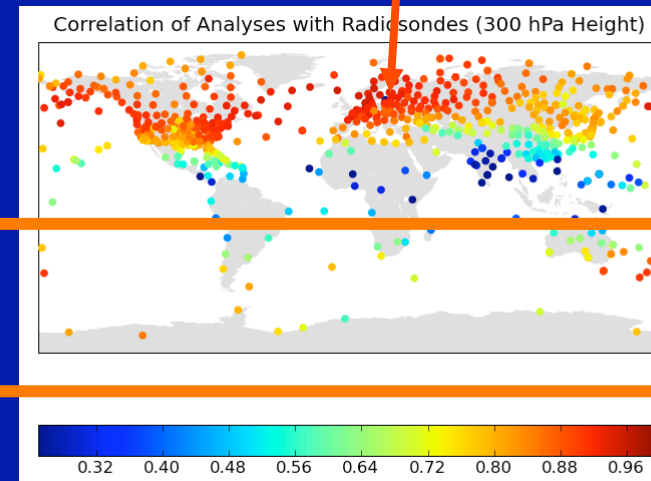
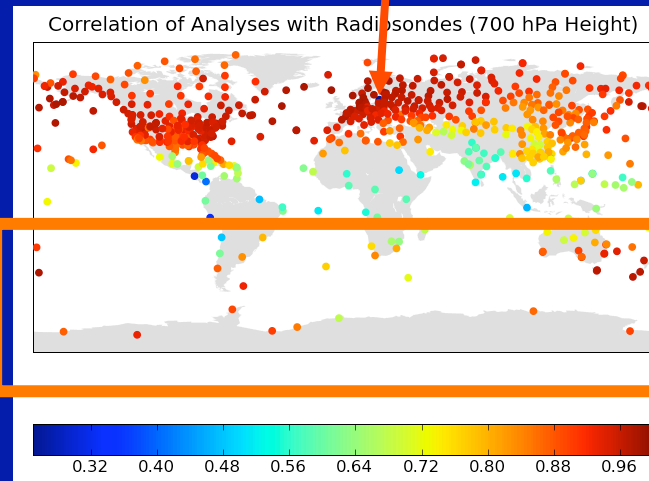
700 hPa



300 hPa



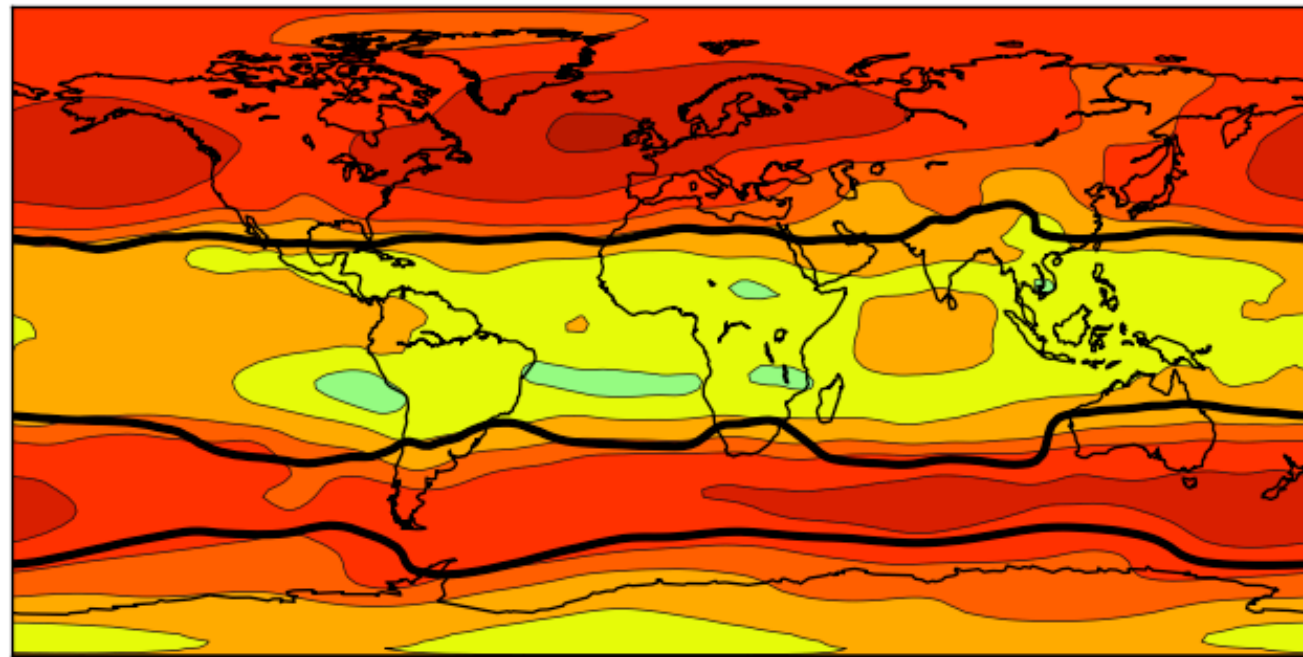
Upper-air  
observations  
with at least  
730 ascents  
*Courtesy  
ETH Zurich*



Agreement with Southern Hemisphere extratropics is good.

# Local Anomaly Correlation of 300 hPa geopotential height anomalies from 20th Century Reanalysis (20CRv2) and ERA40 (1979 to 2001)

**Correlation 20CR vs ERA40 (300 hPa Height 1979-2001)**



Black curves show where NCEP-NCAR and ERA40 correlate > 0.975

0.25 0.45 0.65 0.85 0.95 1.00

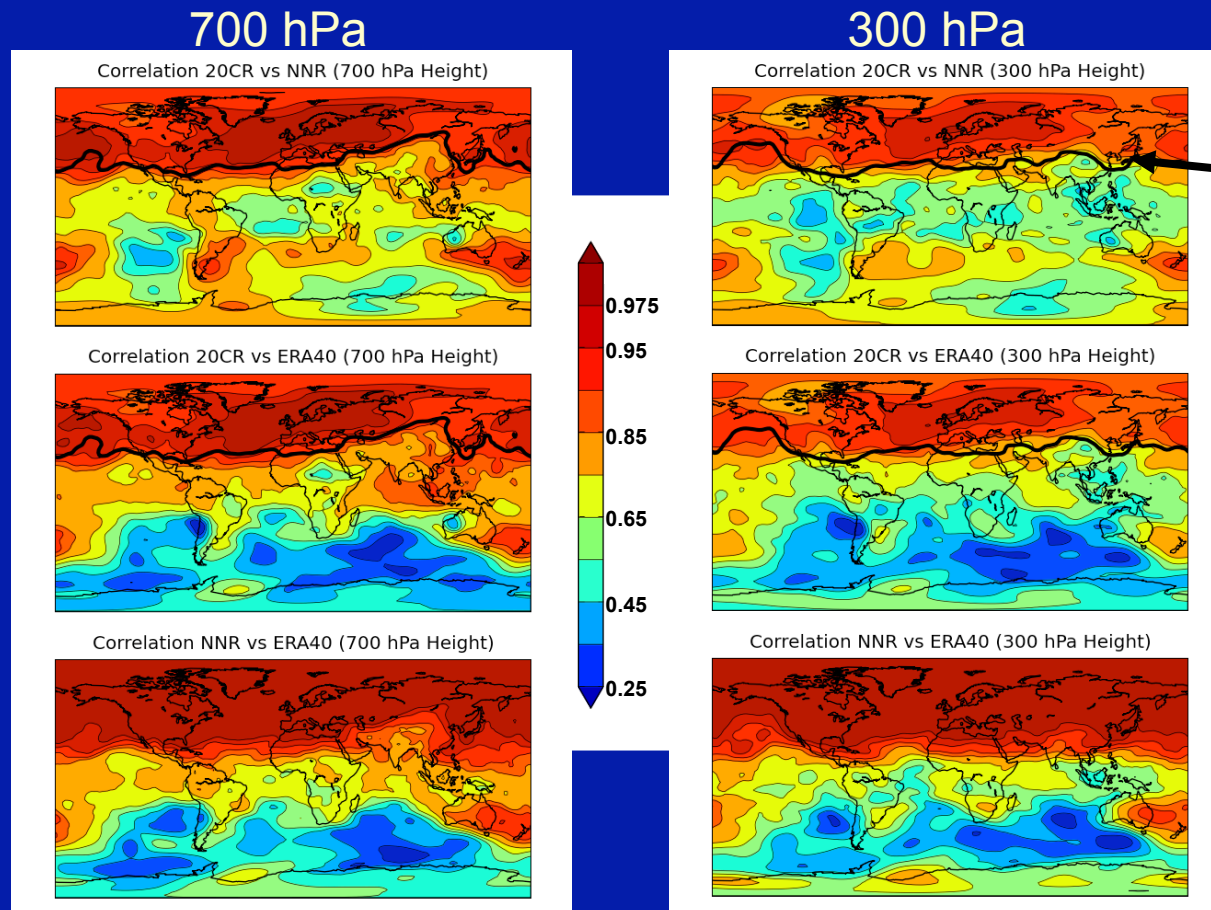
Northern and Southern Hemisphere agreement are excellent between 20CRv2 and ERA40 when ERA40 has satellite observations.

# Local Anomaly Correlation of Twentieth Century Reanalysis (20CR), NCEP-NCAR Reanalysis (NNR), and ERA40 twice-daily geopotential height anomalies (1958)

20CR  
vs. NNR

20CR  
vs. ERA40

NNR  
vs. ERA40



0.975  
correlation  
between  
NNR and  
ERA40

Southern  
Hemisphere  
agreement  
with ERA40  
is poor.

Northern Hemisphere agreement is excellent.  
Southern Hemisphere agreement is moderate to poor.  
Is 20CR useful in Southern Hemisphere?

# Challenges to meeting National and International goals for Historical Reanalyses

- Satellite network only back to 1970's, Upper-air network comprehensive only back to 1940's, scant to non-existent in 19th century
- 3-D Var data assimilation systems such as used in NCEP-NCAR, NCEP-DOE, ERA-40 reanalyses depends on upper-air data for high quality upper-level fields (*Bengtsson et al. 2004, Kanamitsu and Hwang 2005*).
- However, studies using advanced data assimilation methods (e.g., 4D-Var, Ensemble Filter) suggest surface network, especially surface pressure observations, could be used to generate high-quality upper-air fields (*Bengtsson 1980, Thepaut and Simmons 2003, Thepaut 2006, Whitaker et al. 2003, 2004, 2009, Anderson et al. 2005, Compo et al. 2006*).
- Surface Pressure observations are consistent and reliable throughout 20th Century and provide dynamical information about the full atmospheric column.

# Ensemble Filter Algorithm

Whitaker and Hamill (2002)

$x_j^b = \langle x \rangle^b + x_j'^b$  = first guess  $j$ th ensemble member ( $j=1, \dots, 64$ )

$y^o$  = single observation with error variance  $R$

First guess interpolated to observation location:

$$\langle y \rangle^b = H \langle x \rangle^b, \quad y_j'^b = H x_j'^b$$

Form analysis ensemble  $x_j^a = \langle x \rangle^a + x_j'^a$  from

$$\langle x \rangle^a = \langle x \rangle^b + K (y^o - \langle y \rangle^b)$$

$$x_j'^a = x_j'^b + K^M (-y_j'^b) \quad \text{Note the different gain}$$

$$K = \sum_j x_j'^b y_j'^b (\sum_j y_j'^b y_j'^b + R)^{-1} \quad \text{Kalman Gain}$$

$$K^M = (1 + \{R/(\sum_j y_j'^b y_j'^b + R)\}^{-1/2})^{-1} K \quad \text{Modified Kalman Gain}$$

shrinks the ensemble

$(1/(n-1))$  is included in  $\sum_j$

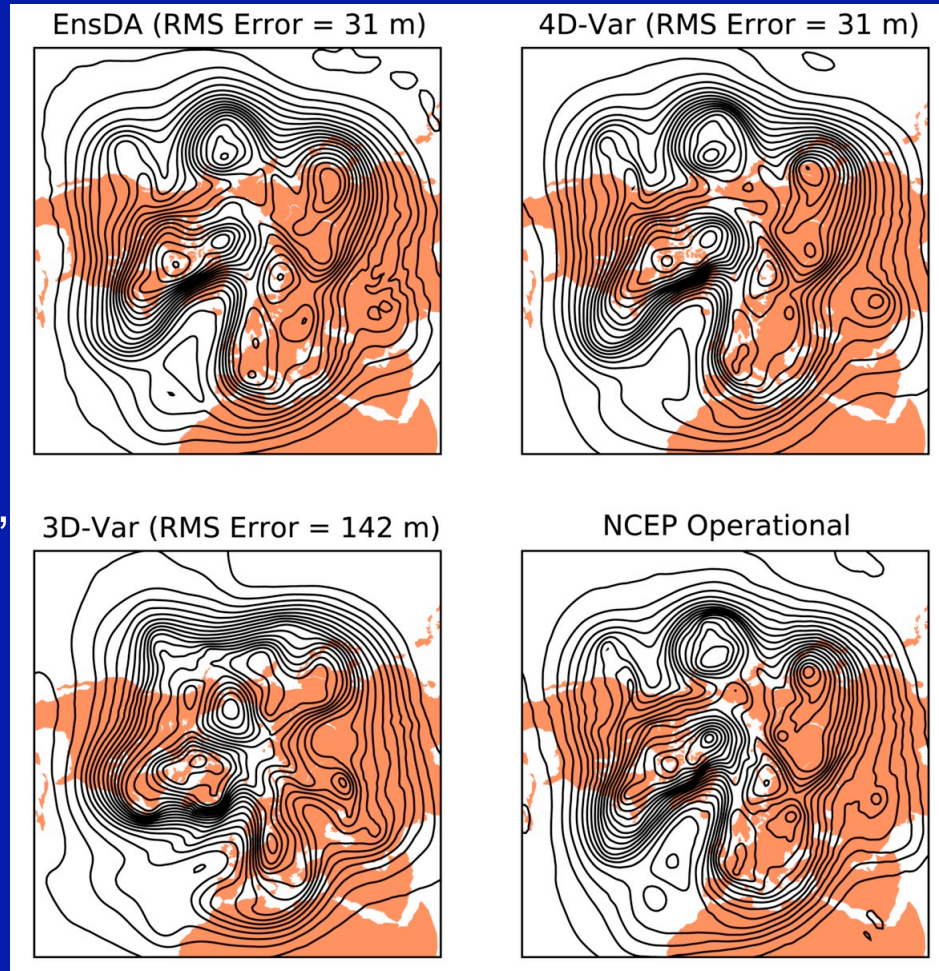
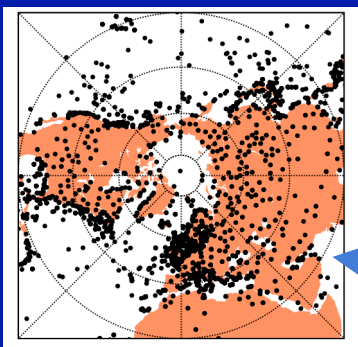
Analysis ensemble becomes first guess ensemble for next observation.

Conduct Observing System Experiments using only surface pressure (e.g., Whitaker et al. 2009).

# 500 hPA Height Analyses for 20 Feb 2005 12Z

Ensemble Filter  
(~3800 surface  
pressure obs)  
RMS = 31 m

ECWMF "Surface"  
3D-Var  
(~3800 surface  
pressure obs)  
RMS = 142 m



ECMWF "Surface"  
4D-Var  
(~3800 surface  
pressure obs)  
RMS = 31 m

Full NCEP  
Operational  
(1,000,000+ obs)

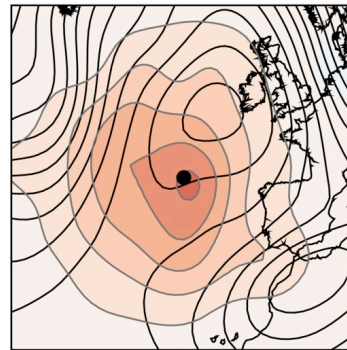
Surface pressure network  
reduced to ~1930's

*Whitaker, Compo, Thepaut (2009)*

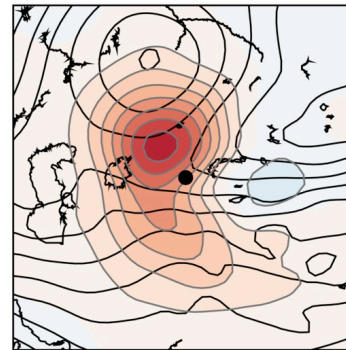
500 hPa Geopotential height first guess (line contours) and analysis minus first guess (shaded) for single pressure observation 1 hPa greater than first guess at selected locations along 45N

Eastern Atlantic

observation at 45°N, 20°W



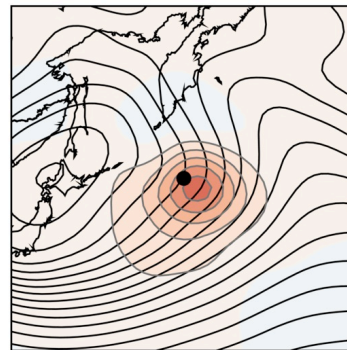
observation at 45°N, 70°E



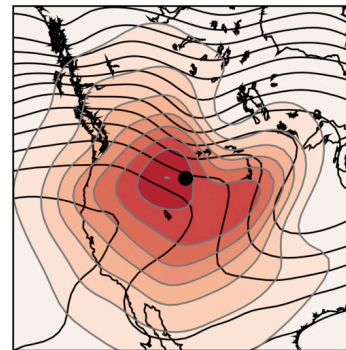
Central Asia

West Pacific

observation at 45°N, 160°E



observation at 45°N, 110°W



North America

Ensemble Filter can extract spatially-varying structures relative to the flow and the previous observational density.

In the 3D-Var used in NCEP-NCAR Reanalyses, all of these structures would be identical and centered on the observation location.

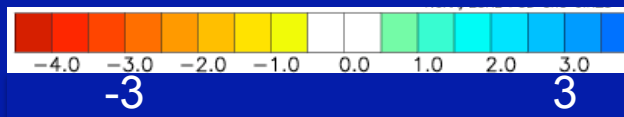
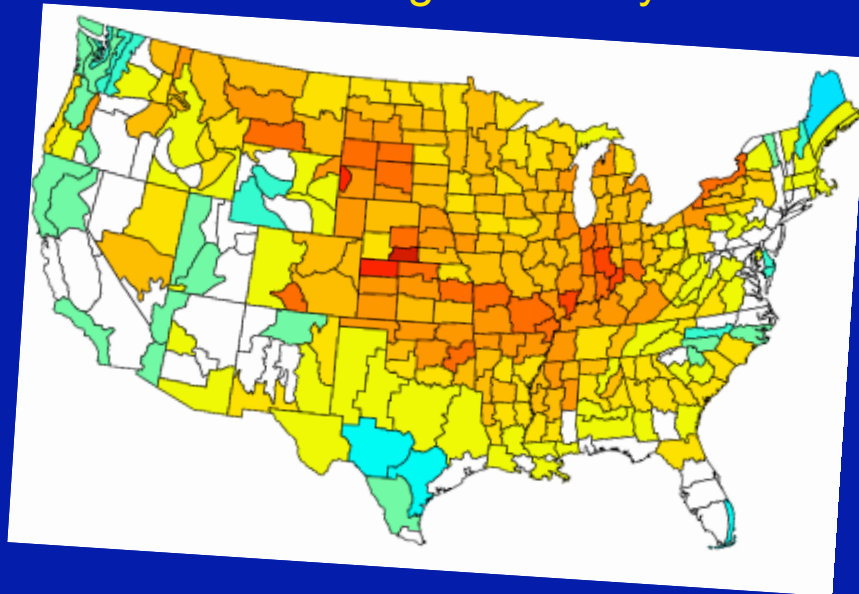
*Whitaker, Compo, Thepaut (2009)*



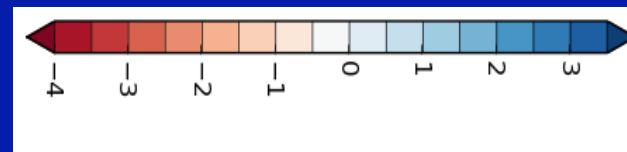
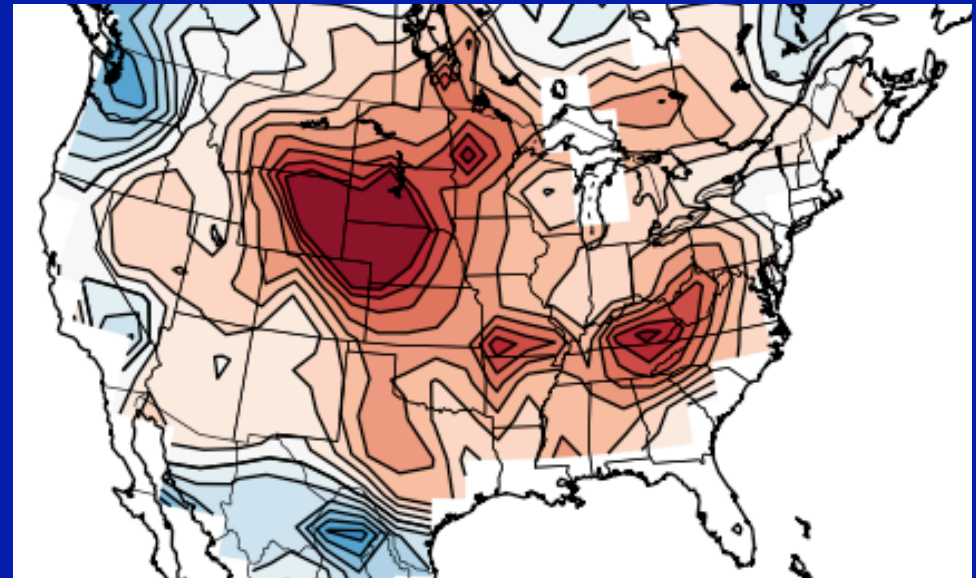
# U.S Dust Bowl (July 1936)

Standardized monthly anomalies relative to 1961-1990

US Climate Division  
Palmer Drought Severity Index

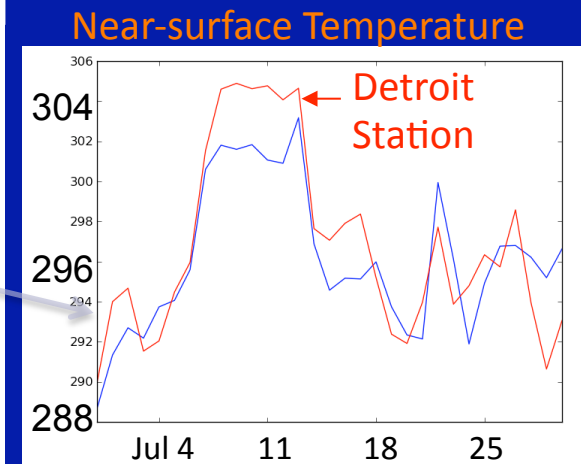
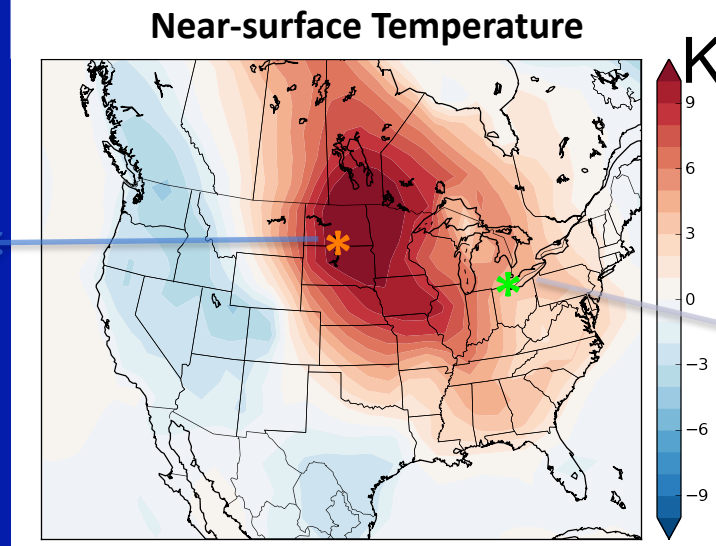
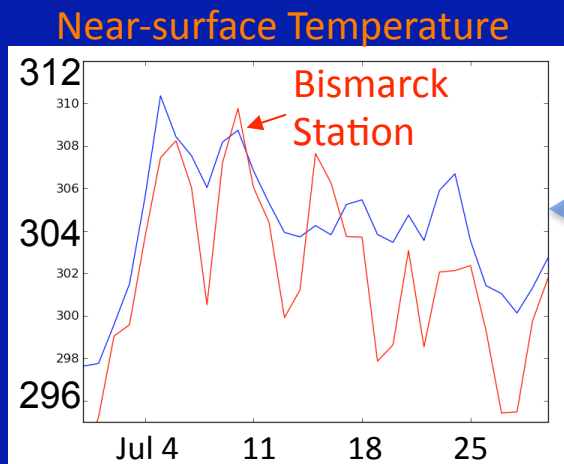
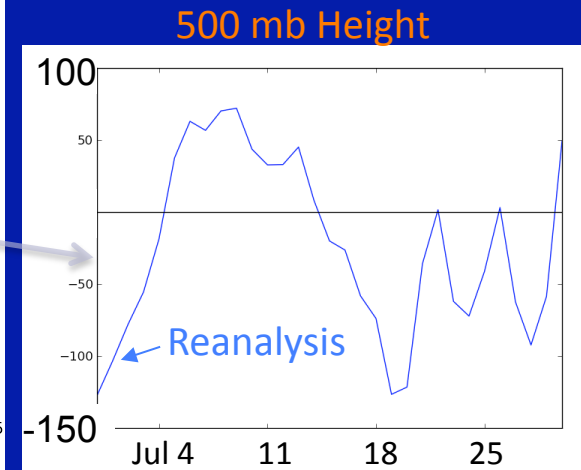
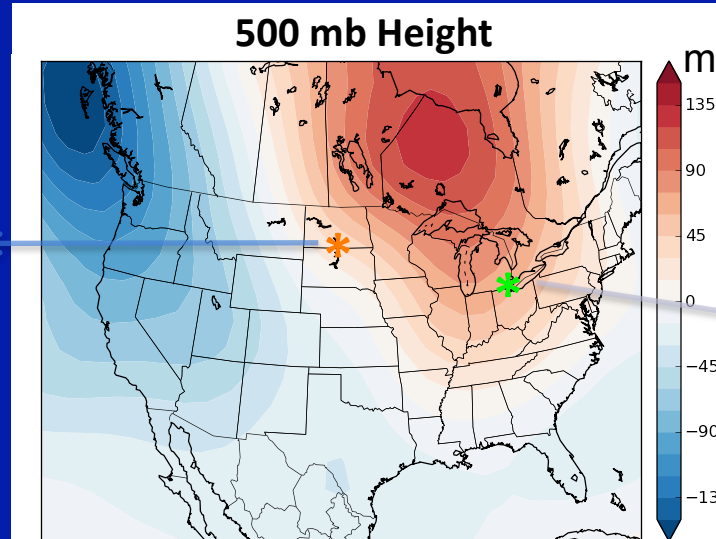
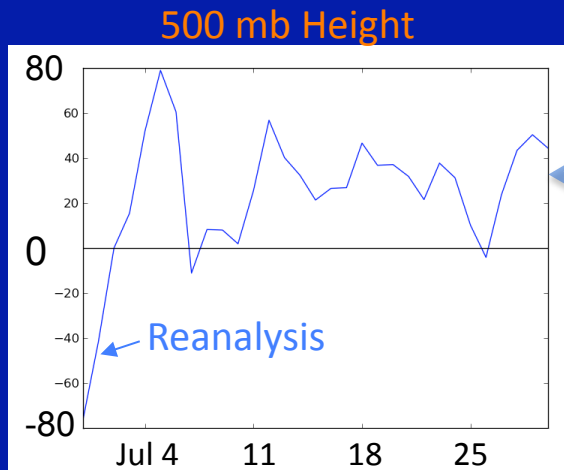


20CRv2 Soil Moisture 0-200 cm



Using only surface pressure, 20CR v2 appears to capture expected features even in derived quantities.

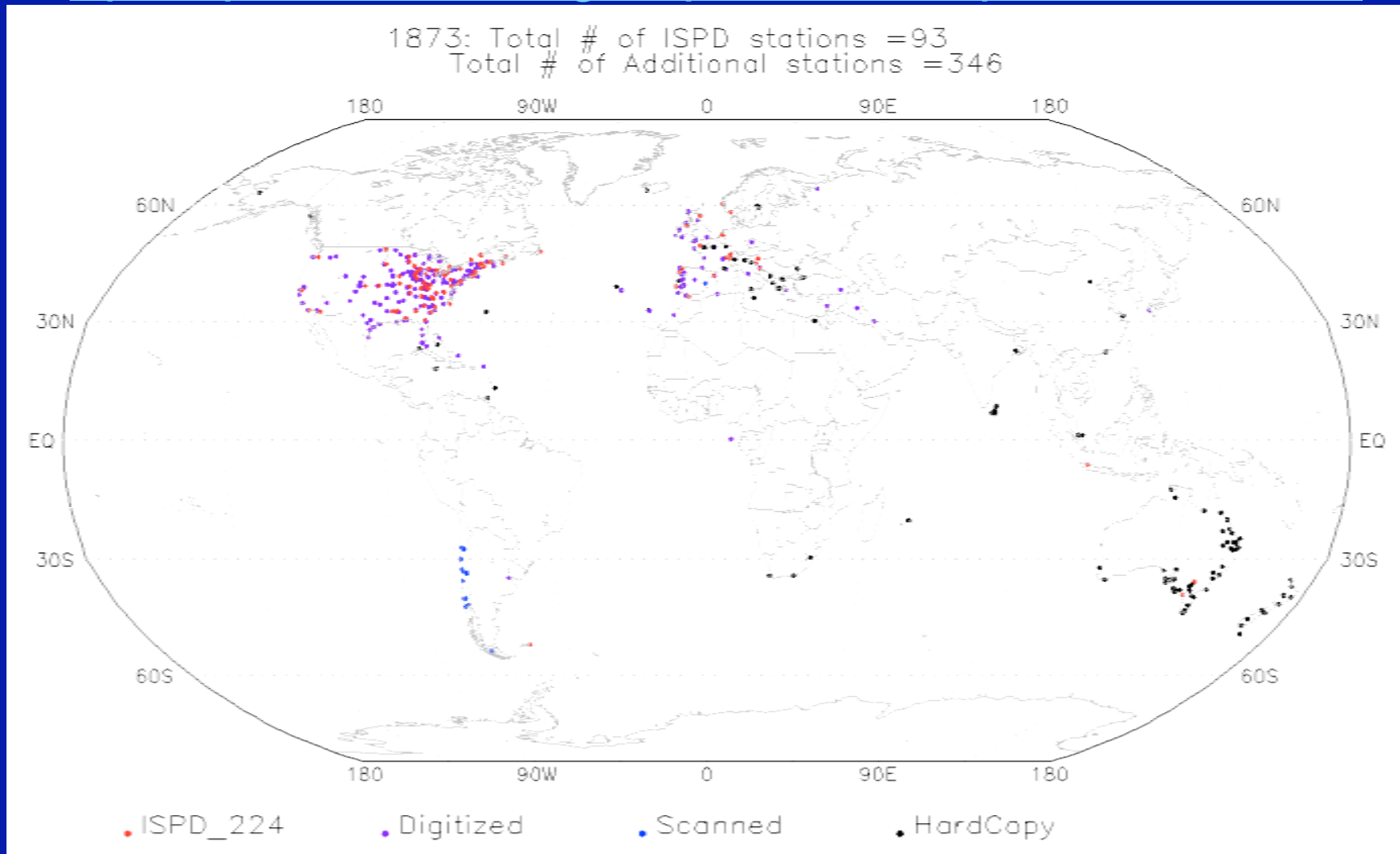
# July 1936 North American Heat Wave (1,000+ US & 1,000+ Canadian deaths during 14-day span)



20<sup>th</sup> Century Reanalysis version 2  
Anomalies July 8 – 14 with respect to 1891-2007

**Current** and future International Surface Pressure Databank  
station component  
(1670 to 2009)

<ftp://ftp.ncdc.noaa.gov/pub/data/ispd/add-station>



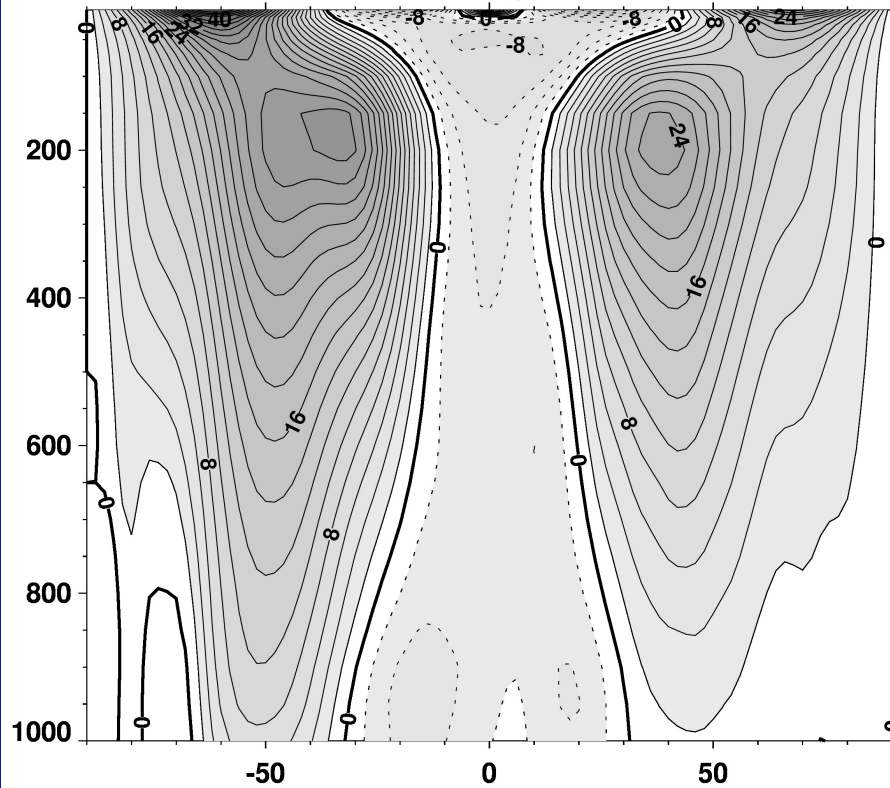
Courtesy X. Yin and R. Allan

# 1871 to 2008 Zonal Means

Zonal wind

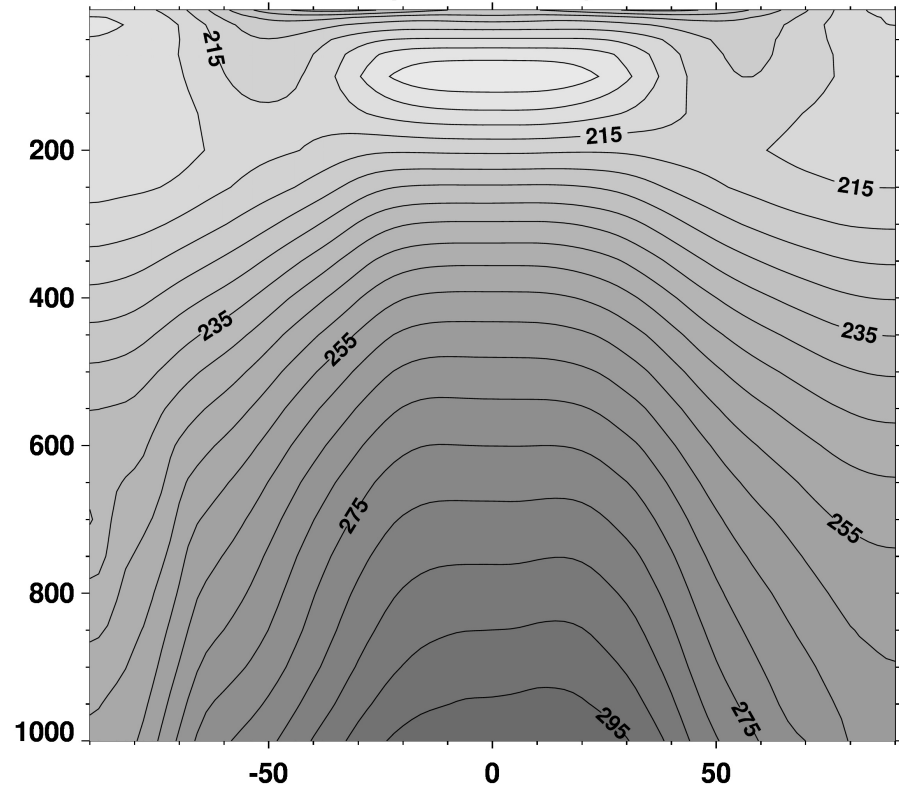
Air Temperature

(a) Zonal Mean Zonal Wind averaged 1871 to 2008



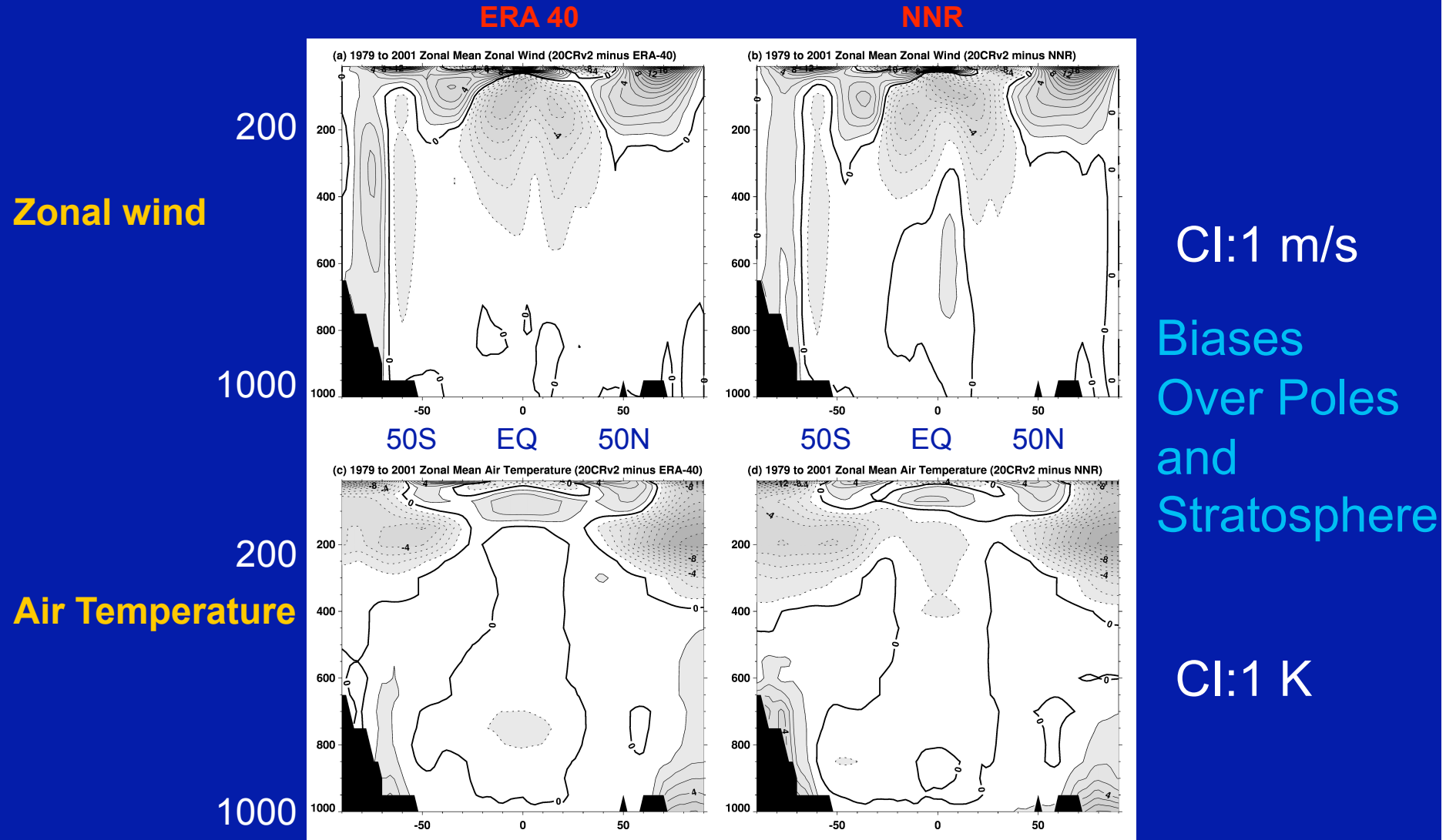
50S EQ 50N

(b) Zonal Mean Air Temperature averaged 1871 to 2008



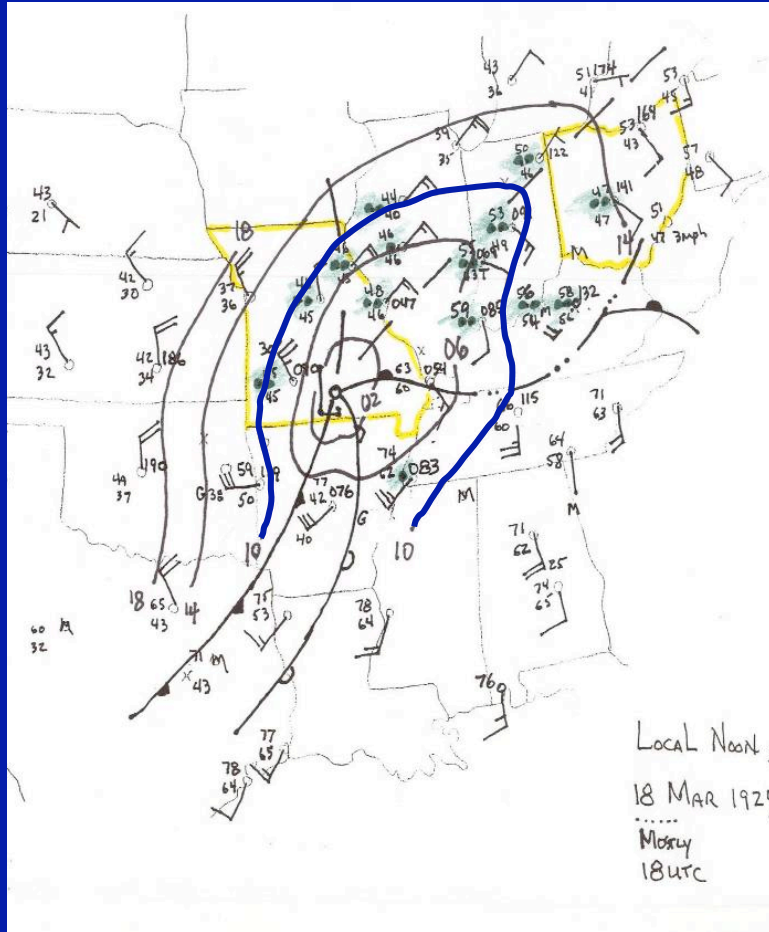
50S EQ 50N

# 20CR zonal mean difference with ERA40 and NNR (1979-2008)

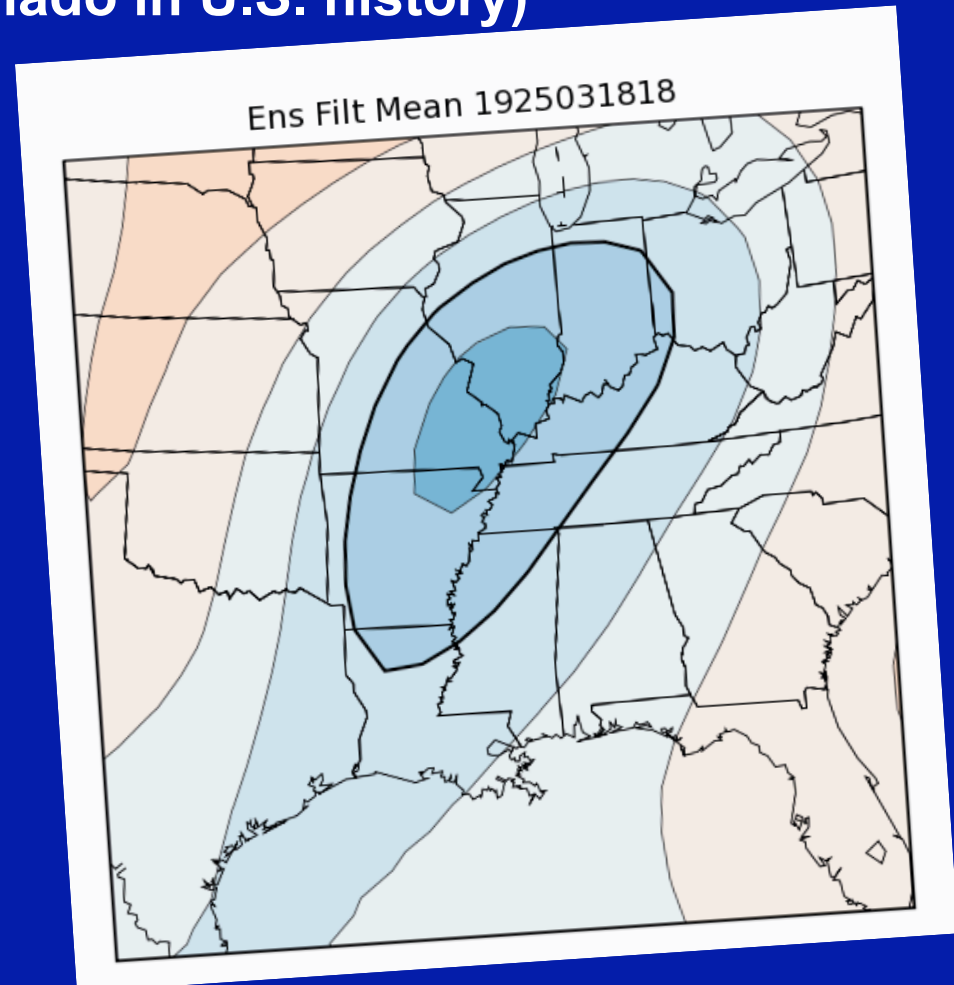


20CR biases are low and sometimes of opposite sign in most of troposphere.

# Sea Level Pressure analyses for Tri-State Tornado Outbreak of 18 March 1925 (deadliest tornado in U.S. history)

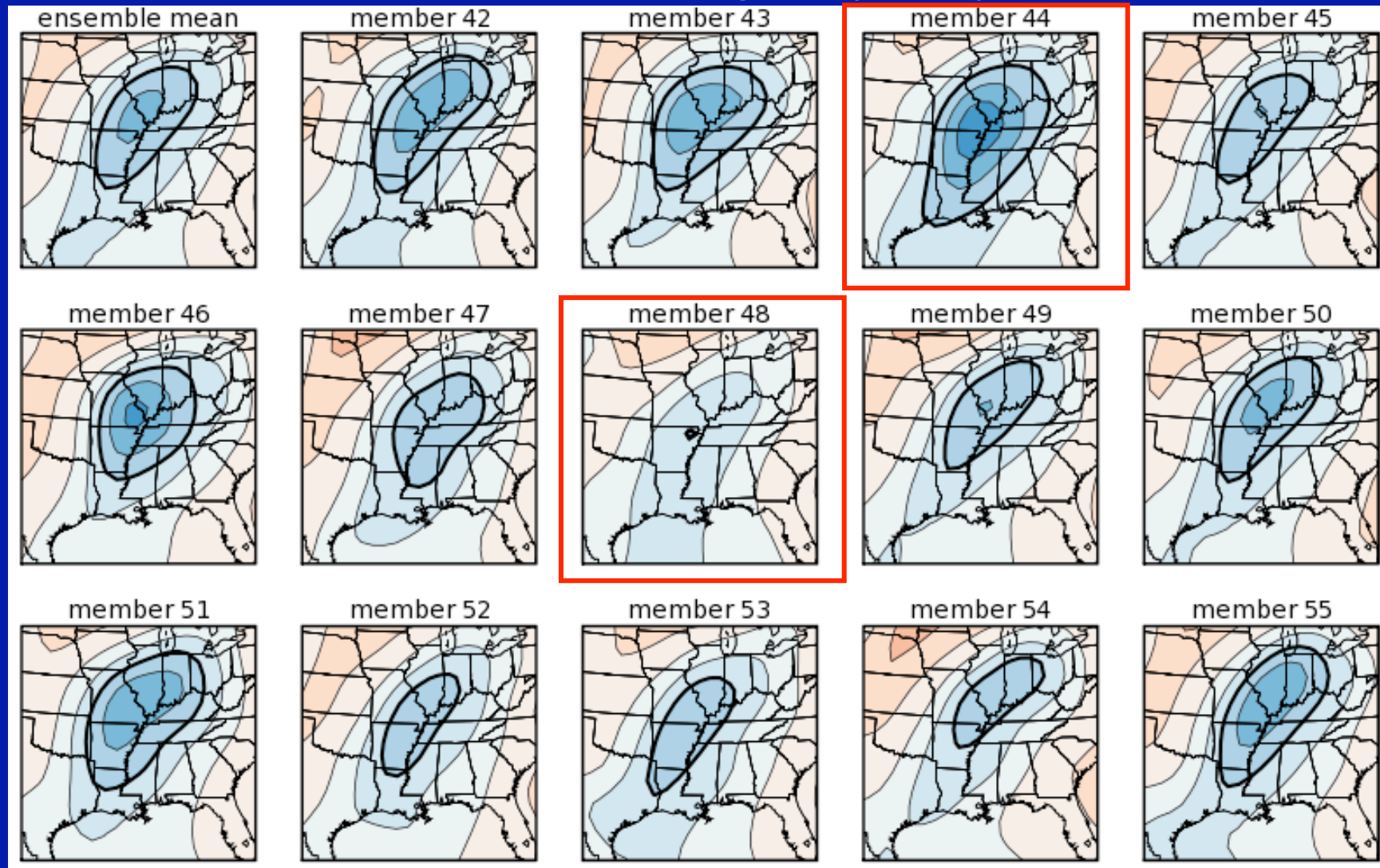


Manual Analysis, courtesy B. Maddox



Ensemble mean from Ensemble Filter  
(4 hPa interval, 1010 hPa thick)  
**NOTE!!!** This analysis did not use ANY  
of the observations shown on the left.

# Range of possibilities for Sea Level Pressure 18 March 1925 18Z using 14 (of 56) members



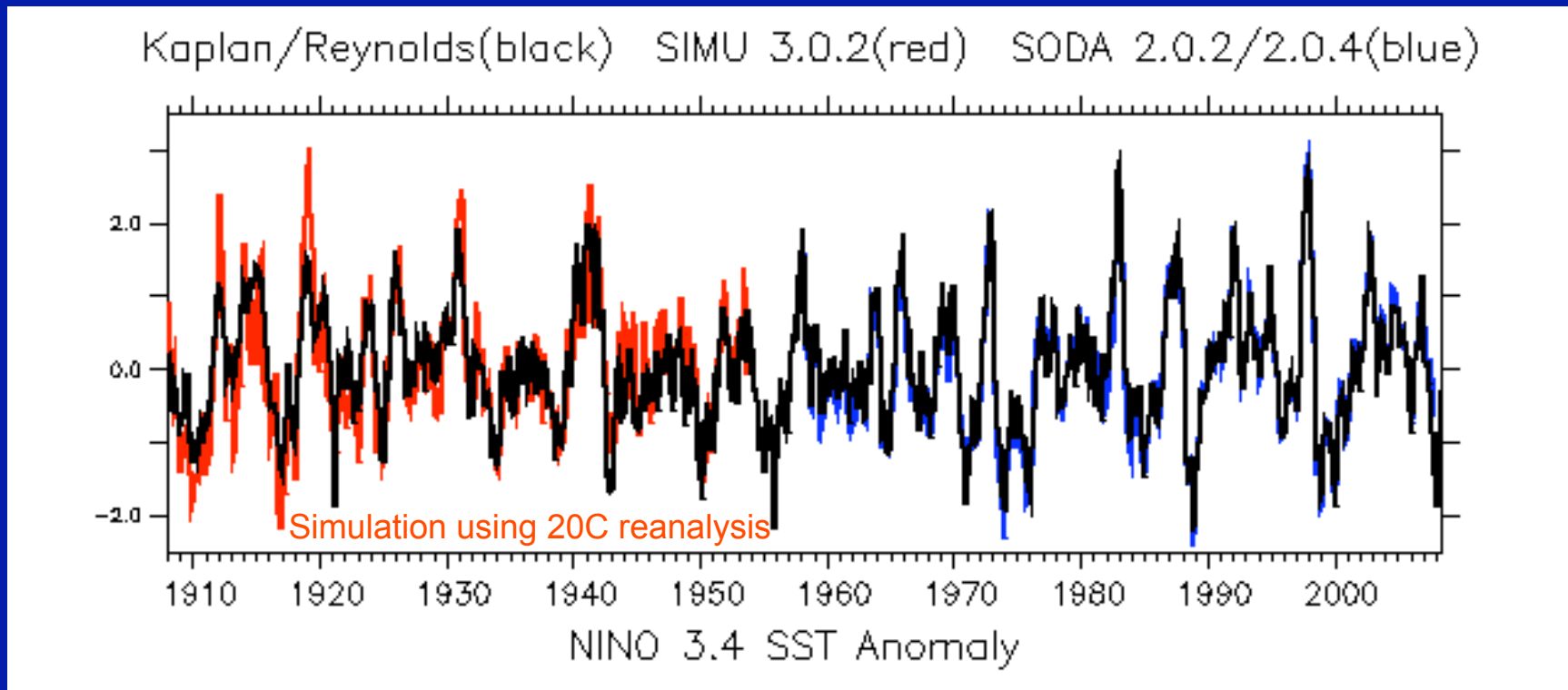
Ensemble of 56 possible realizations consistent with the observations

# Tropical Validation

- Force global Parallel Ocean Program (POP) with daily 20th Century (1908-1956) reanalysis fields
  - 2m Air Temperature
  - 2m Specific Humidity
  - Downwelling Shortwave at Surface
  - Total cloud cover
  - 10 m Wind Speed
  - Precipitation
  - Zonal and Meridional Wind Stress  
(*Giese et al. BAMS 2009*)



# Nino3.4 Time series from Kaplan SST, POP Simulation, SODA Data Assimilation



+20th Century reanalysis forcing fields **with no adjustment**  
generate realistic Nino3.4 variability in simulation  
+Encouraging for Ocean and Coupled Data Assimilation.  
(Giese et al. BAMS 2009)

## Table of correlations of climate indices

PWC	20CR_V2	REC	NNR	ERA40	ERA-INT	SOCOL
20CR_V2	1	0.82	0.91	0.95	0.97	0.93
REC		1	na	na	na	0.83
NNR			1	0.96	0.991	0.89
ERA40				1	0.988	0.93
ERA-INT					1	0.97
SOCOL						1

PNA	20CR_V2	REC	NNR	ERA40	ERA-INT	SOCOL
20CR_V2	1	0.92	0.98	0.991	0.985	0.62
REC		1	na	na	na	0.62
NNR			1	0.987	0.98	0.70
ERA40				1	1.00	0.71
ERA-INT					1	0.90
SOCOL						1

NAO	20CR_V2	HADSLP	NNR	ERA40	ERA-INT	SOCOL
20CR_V2	1	0.98	0.995	0.994	0.997	0.26
HADSLP		1	na	na	na	0.22
NNR			1	0.997	0.998	0.25
ERA40				1	0.997	0.30
ERA-INT					1	0.11
SOCOL						1

# Summary

- Demonstrated that surface-based reanalyses *throughout the troposphere* are feasible using advanced data assimilation and surface pressure observations.
- Effectively doubling the reanalysis record length from ~60 year to more than 120 years, allowing current atmospheric circulation patterns to be placed in a broader historical context. 😊
- Southern Hemisphere fields may be an improvement over first-generation upper-air based reanalyses before the satellite era.
- Challenges: Validating the dataset in regions of sparse observations and rapid change, e.g., the Arctic.
- Higher resolution and additional observations will further improve these reanalyses.
- For status updates, email
  - [jeffrey.s.whitaker@noaa.gov](mailto:jeffrey.s.whitaker@noaa.gov),
  - [compo@colorado.edu](mailto:compo@colorado.edu)