Develping the Surface Input Reanalysis for Climate Applications (SIRCA) 1850-2012

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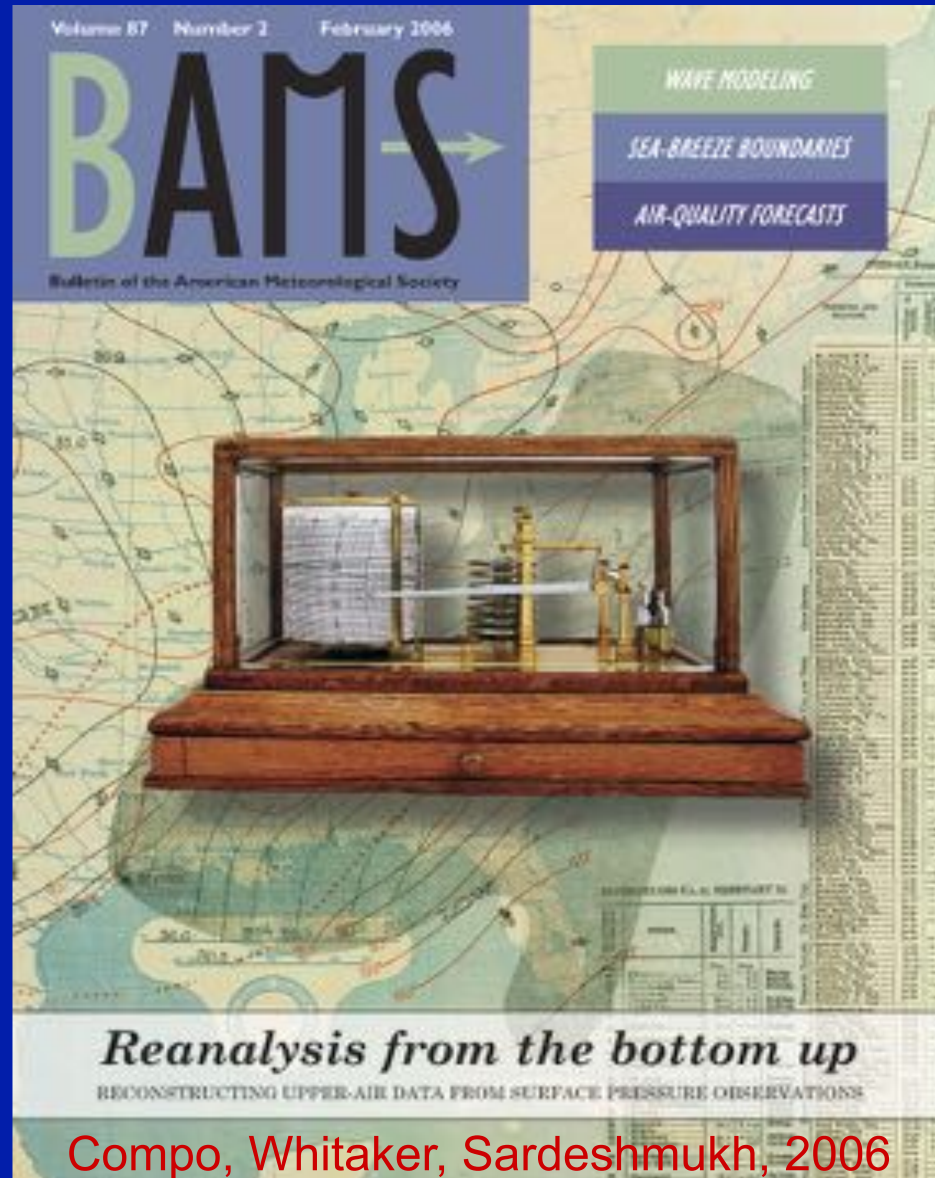
Special thanks to NCEP/EMC



Compo, Whitaker, Sardeshmukh, 2006

<u>The Twentieth Century Reanalysis Project</u>

Summary: An international collaborative project led by NOAA and CIRES to produce high-quality tropospheric reanalyses for the last 100 years ***using only surface observations***.

<u>The reanalyses will provide</u>:

-First-ever estimates of near-surface and tropospheric 6-hourly fields extending back to the beginning of the 20th century;

-Estimates of biases and uncertainties in the basic reanalyses;

-Estimates of biases and uncertainties in derived quantities (storm tracks, etc.)

Initial product will have higher quality in the Northern Hemisphere than in the Southern Hemisphere.

US Department of Energy INCITE computing award and NOAA Climate Program Office support to produce *1871-2008* by Spring 2010 (version 2).

Co-authors on 20th Century Reanalysis Project

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Ensemble Filter Algorithm

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 and sea level pressure observations*,

H$\mathbf{x}^b$ 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 1 (*1908-1958*): T62, 28 level NCEP CFS03 atmospheric model

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

- time-varying CO_2, solar and volcanic radiative forcing
- Note: sea ice concentration low near coasts

International Surface Pressure Databank (ISPD) version 2

Subdaily observations assembled in partnership with

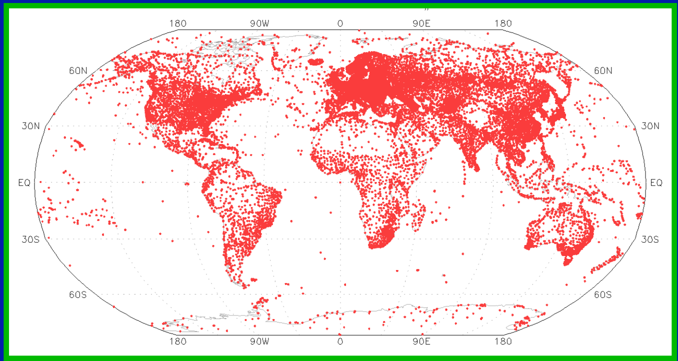
GCOS AOPC/OOPC Working Group on Surface Pressure

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**



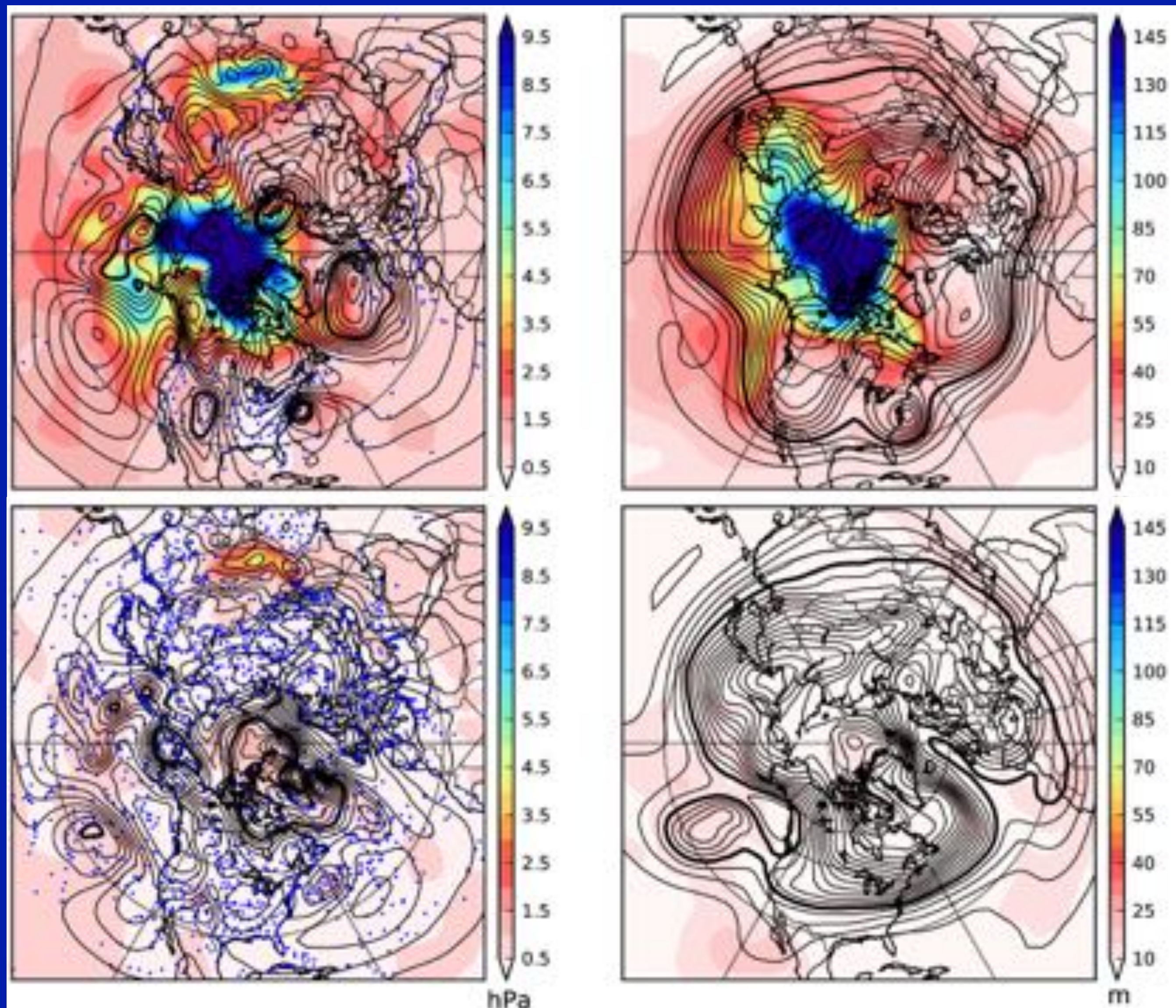
Marine data component: **ICOADS** merged by NOAA ESRL and NCAR NOAA

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

Analyses for selected dates 29 January 1922 and 1972

1922

1972

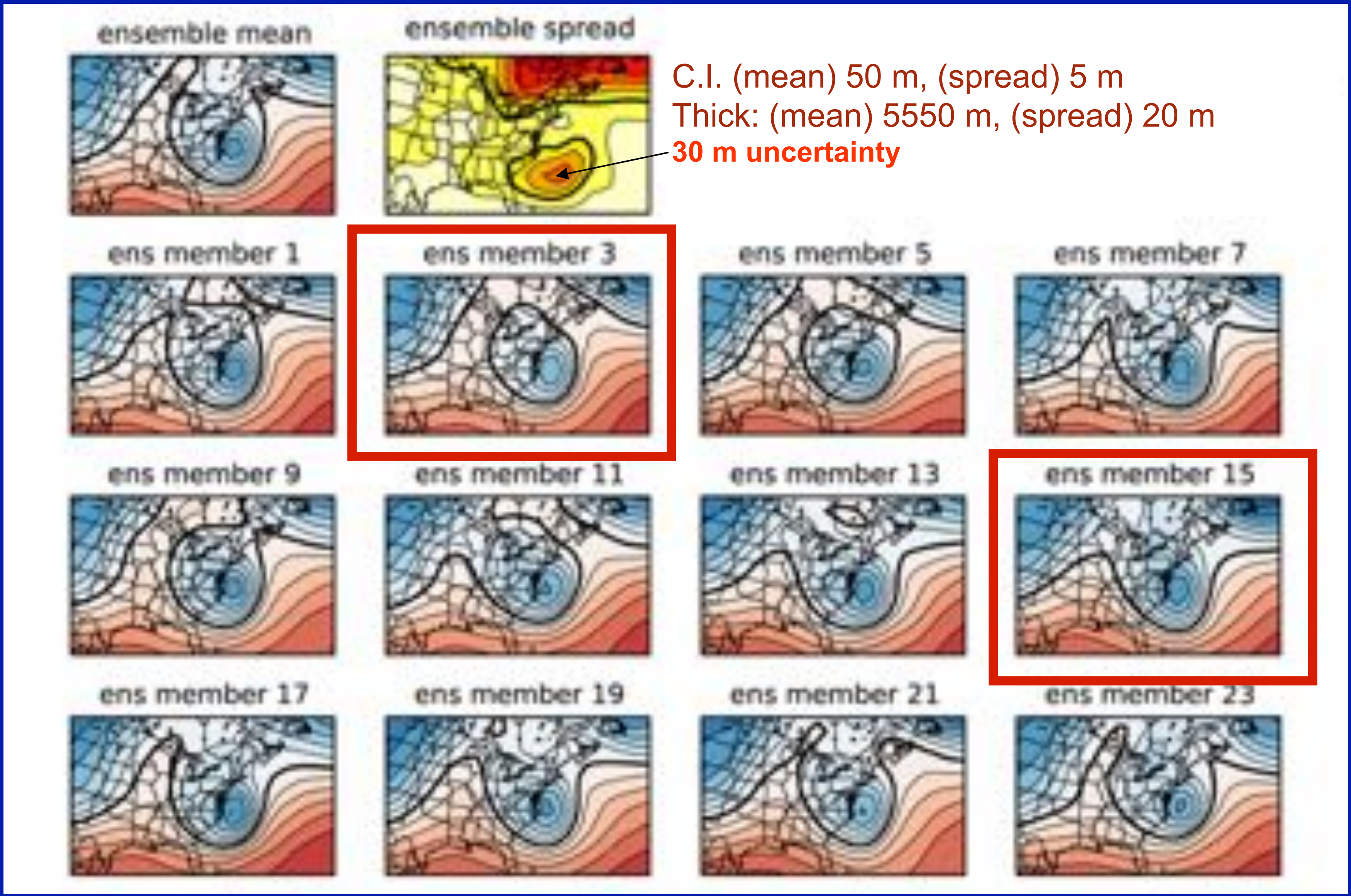


Contours- ensemble mean
Shading- blue: more uncertain, white: more certain

Sea Level Pressure

500 hPa Geopotential Height

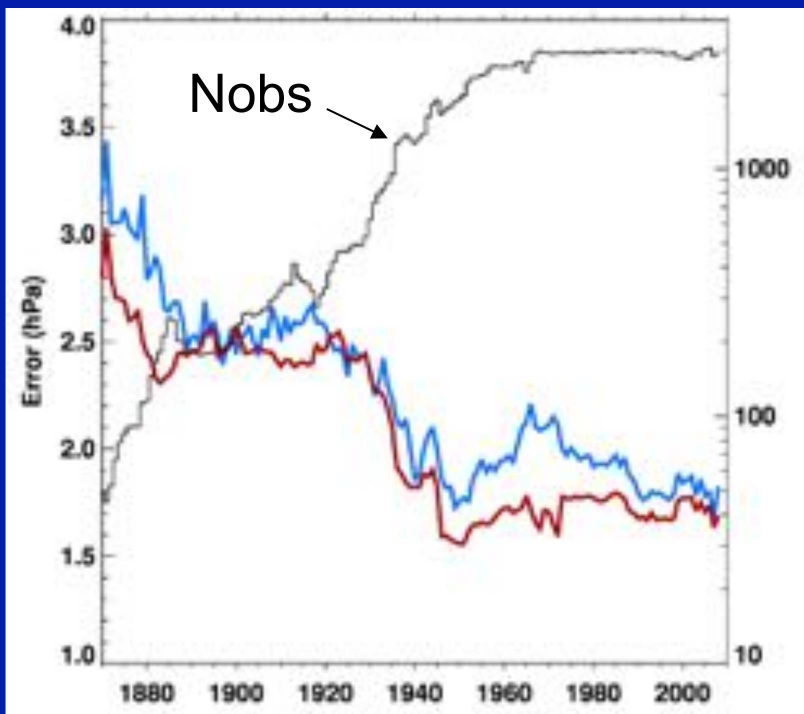
Range of possibilities for 500 hPa Geopotential Height
“Knickerbocker Storm” 29 January 1922 0Z using 12 (of 56) members



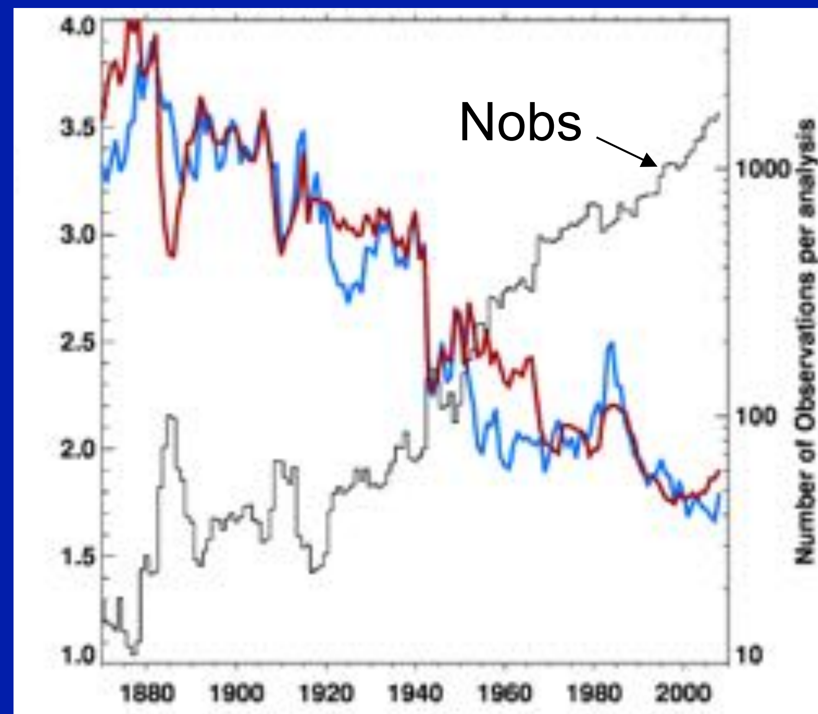
Ensemble of 56 possible realizations consistent with the observations

Surface Pressure uncertainty estimate poleward of 20(S,N)
blue actual RMS difference
red expected RMS difference

Northern Hemisphere



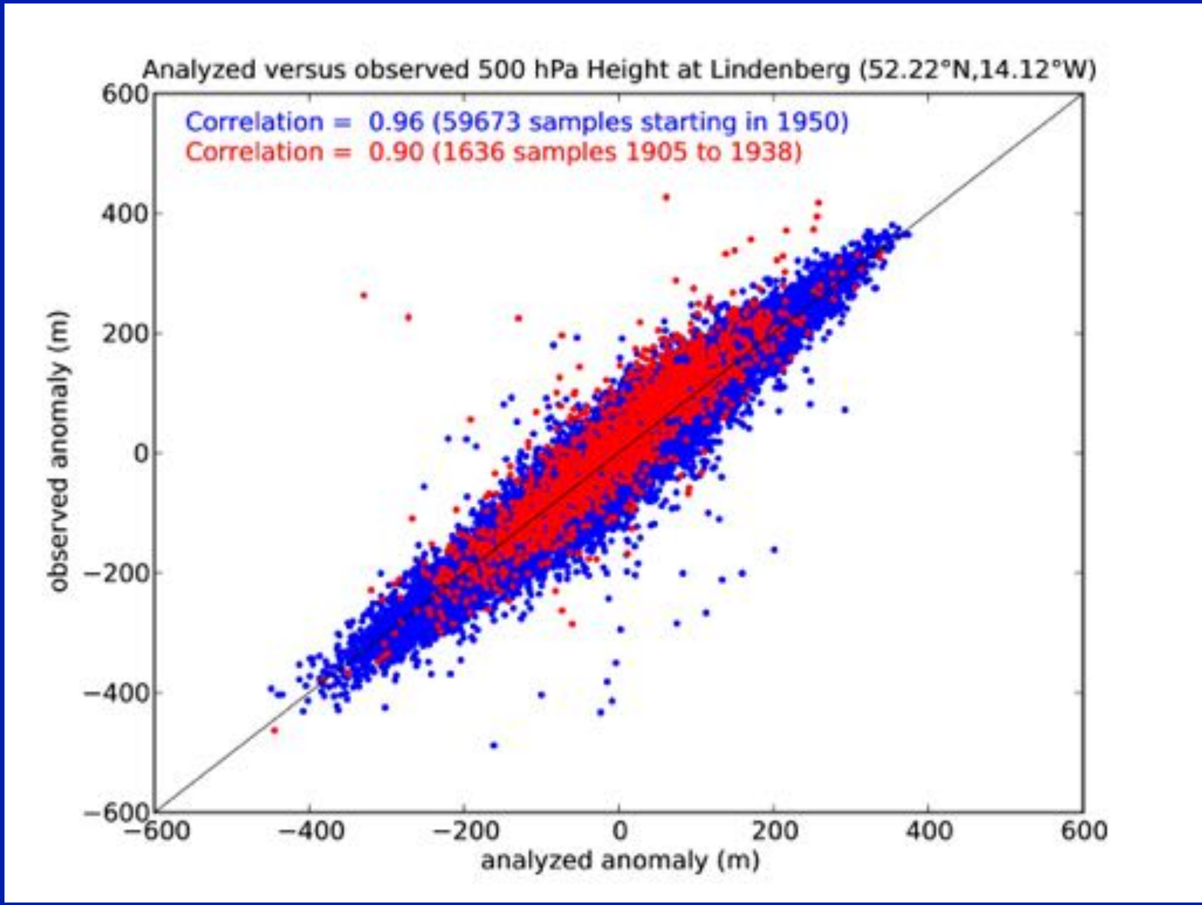
Southern Hemisphere



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

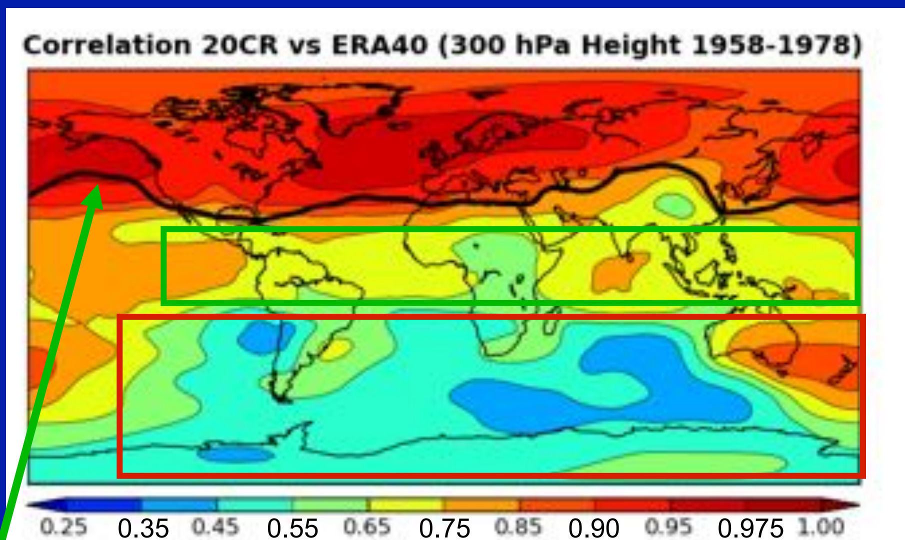
Subdaily 500 hPa Geopotential Height anomalies from observations and 20th Century Reanalysis compare well.

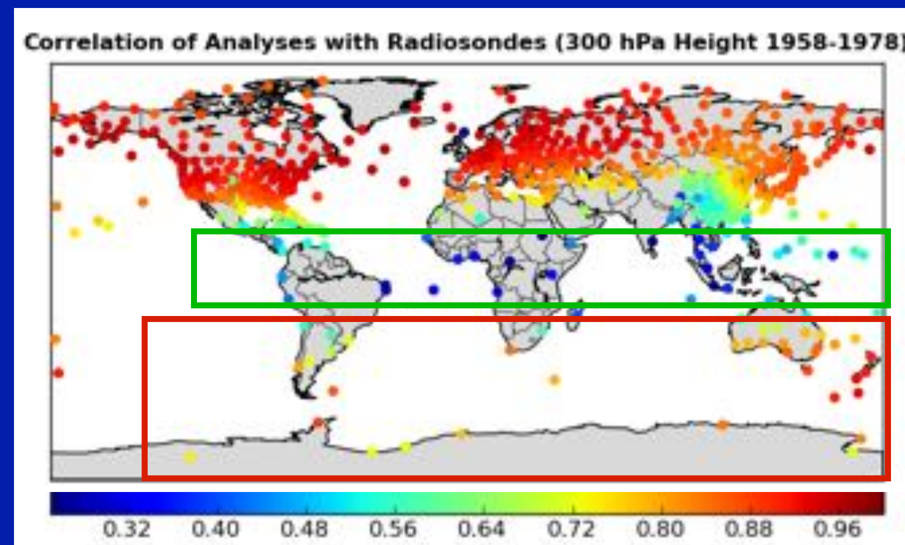
1905-2006
Measurements from kites, aircraft, registering balloon, and radiosondes at Lindenberg, Germany



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

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





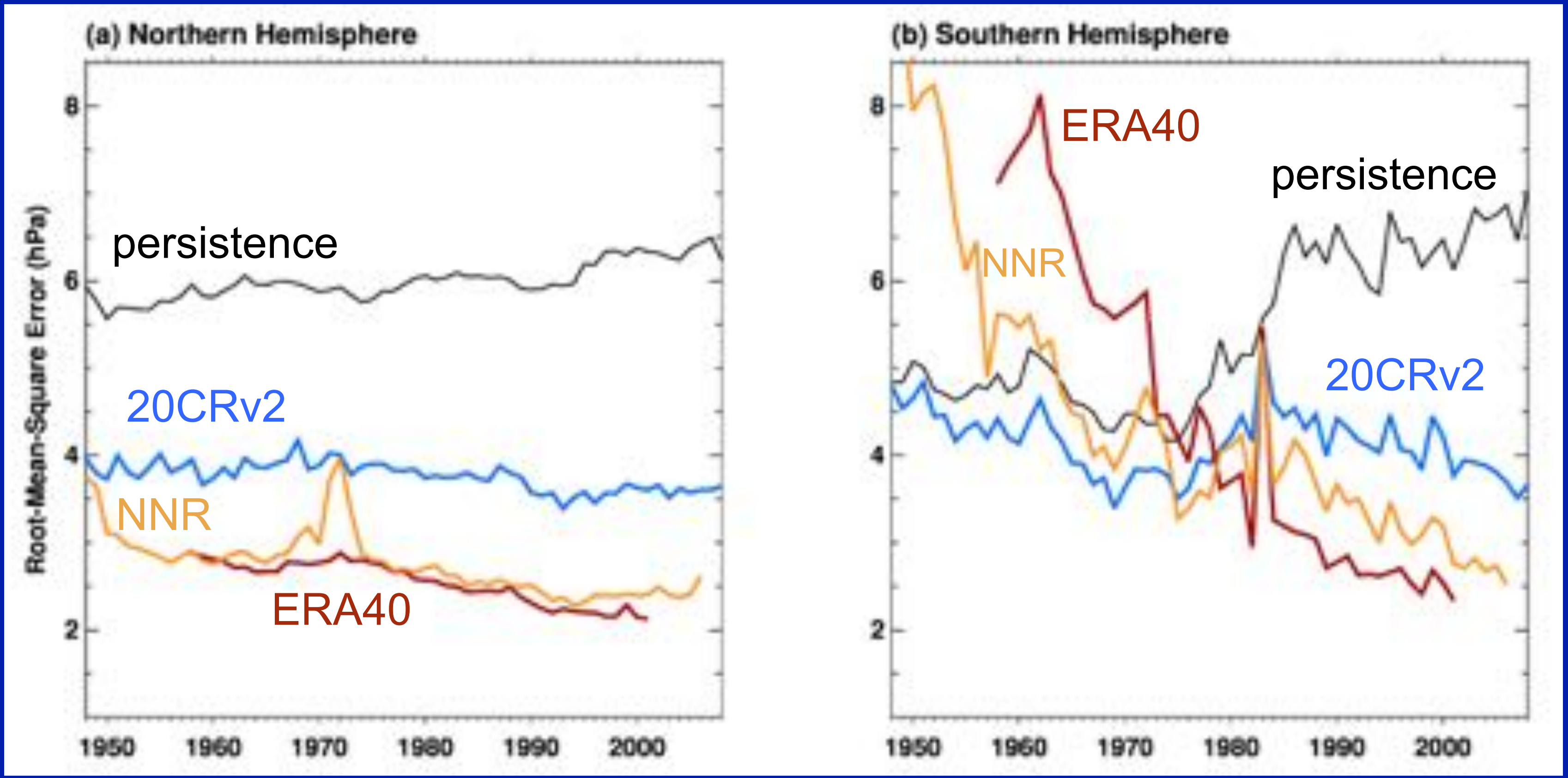
Black curve shows where NCEP-NCAR and ERA40 correlate > 0.975

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.

24 hour Root Mean Square difference of Marine Pressure Observations and Forecasts from NCEP-NCAR Reanalysis, 20th Century Reanalysis v2, and ECMWF Reanalysis 40 (1948-2008)



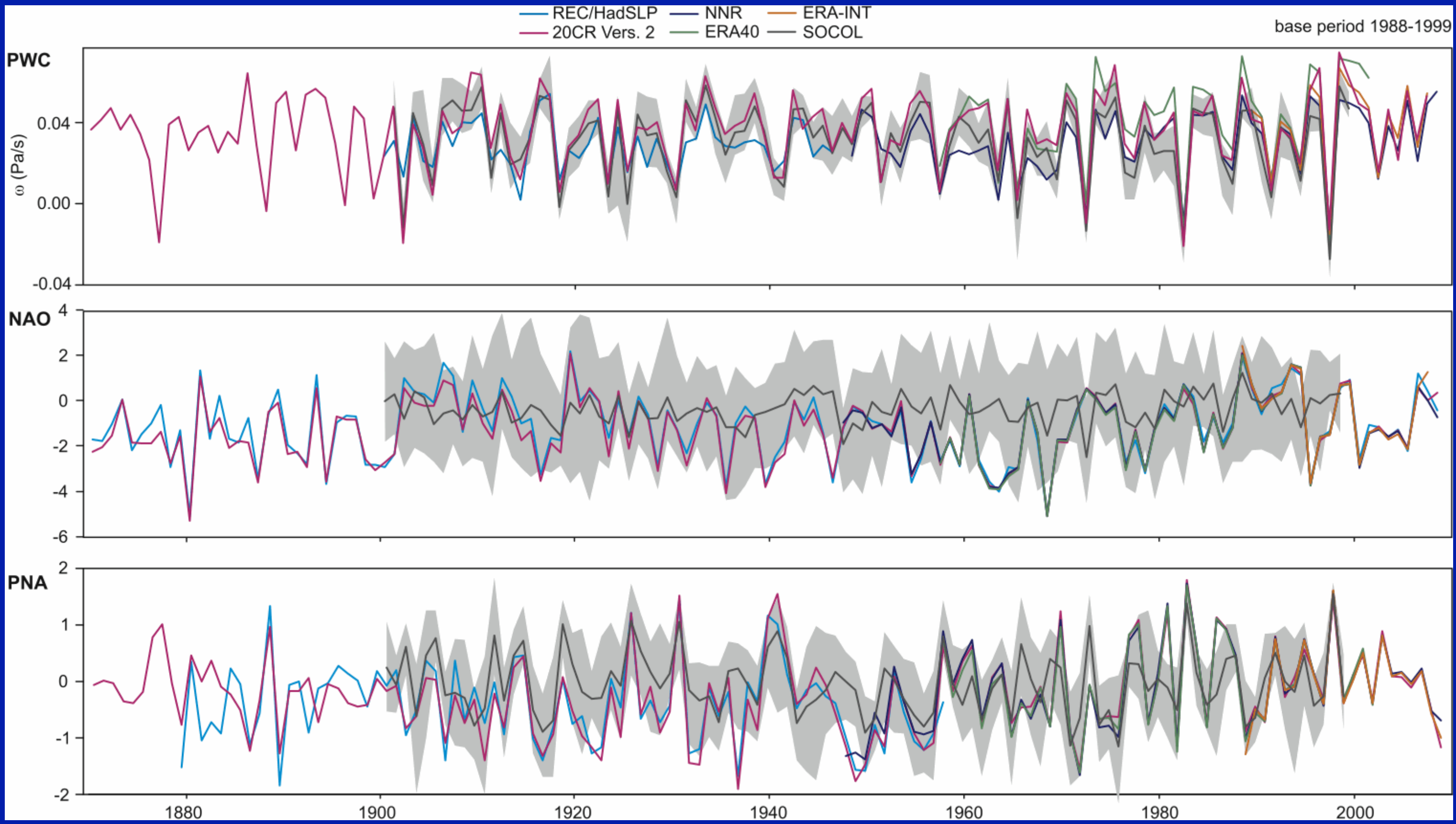
Before the satellite era (1970s), there is ***substantially better skill*** for 20CRv2 than for NCEP-NCAR Reanalysis or ERA40 in the Southern Hemisphere despite the lack of upper-air observations.

Seasonal climate indices from Statistical Reconstructions, SST-forced GCM integrations, and 20th 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

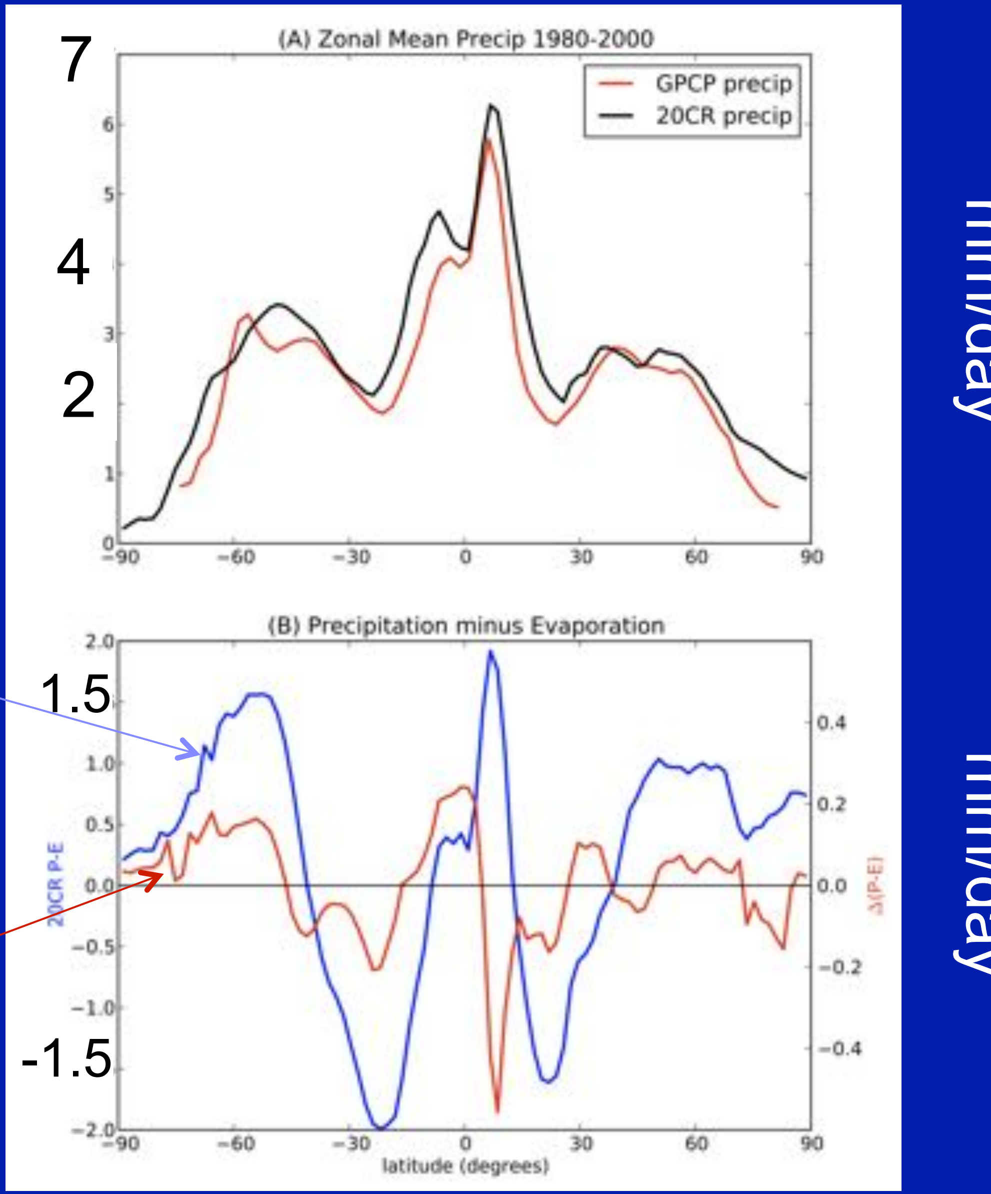
Agreement is high between observation-based estimates (correlations between ERA-40 and 20CRv2 > 0.95)

Courtesy S. Bronnimann

Zonally averaged Precipitation *P* 1980-2000

Precipitation *P* minus Evaporation *E* 1980-2000

Change *Δ(P-E)* 1980-2000 minus 1871-1891



20CR Δ(*P* – *E*) does not resemble Mean *P-E.*
Resemblance was expected from "robust" feature of climate models and simple arguments (Held and Soden, 2006).

Historical Reanalysis Status and Plans

20th Century Reanalysis Project http://www.esrl.noaa.gov/psd/data/20thC_Rean

- Data Access: Analyses and ISPD (with feedback) will be freely available from NCAR, NOAA/ESRL and NOAA/NCDC.
- **Spring 2009**: Version 1, 1908-1958 (complete)
  - http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_Rean.html (NOAA ESRL)
  - http://dss.ucar.edu/datasets/ds131.0 (NCAR)
- **Spring 2010**: Version 2, 1871-2008 (including time-varying CO2, aerosols, upgraded GFS from NCEP). **Ensemble mean and spread online now**.
  - http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2.html (NOAA ESRL)
  - http://dss.ucar.edu/datasets/ds131.1 (NCAR)
  - 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-P1).
- ERA-P1: T159 spectral (~125km grid spacing) 60 layers in the vertical, extending upward to 0.1 hPa (approximately 65km altitude)
- ERA-P1: **Available 2012** (Contingent on EU funding)

Advances and Improvements towards *Surface 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, other surface variables (e.g., wind, T, Tropical Cyclone position)
4. Uncertainty in forcings (e.g, CO_2, solar, SST)
5. Multi-model (e.g., NASA, NCAR, NCEP, GFDL, ESRL)

Available 2014 – SIRCA (*1850-2013*)

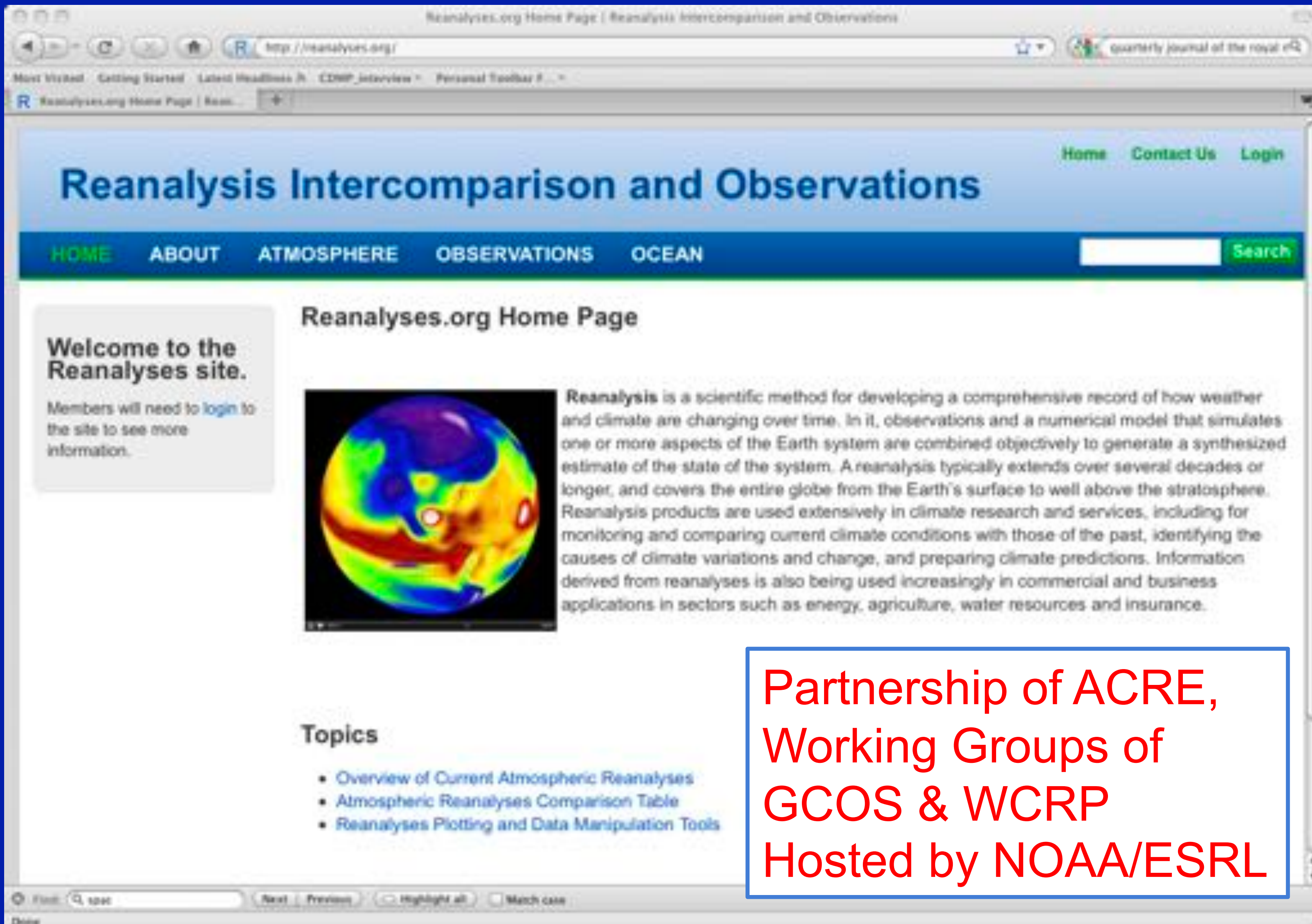
Available 2017 – include chemistry and coupling, CSIRCA (*1800-2016*)

Requires international cooperation, e.g.,

Atmospheric Circulation Reconstruction over the Earth initiative

http://www.met-acre.org

Reanalyses.org: comparing Reanalyses with each other and with observations



Partnership of ACRE, Working Groups of GCOS & WCRP
Hosted by NOAA/ESRL

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,
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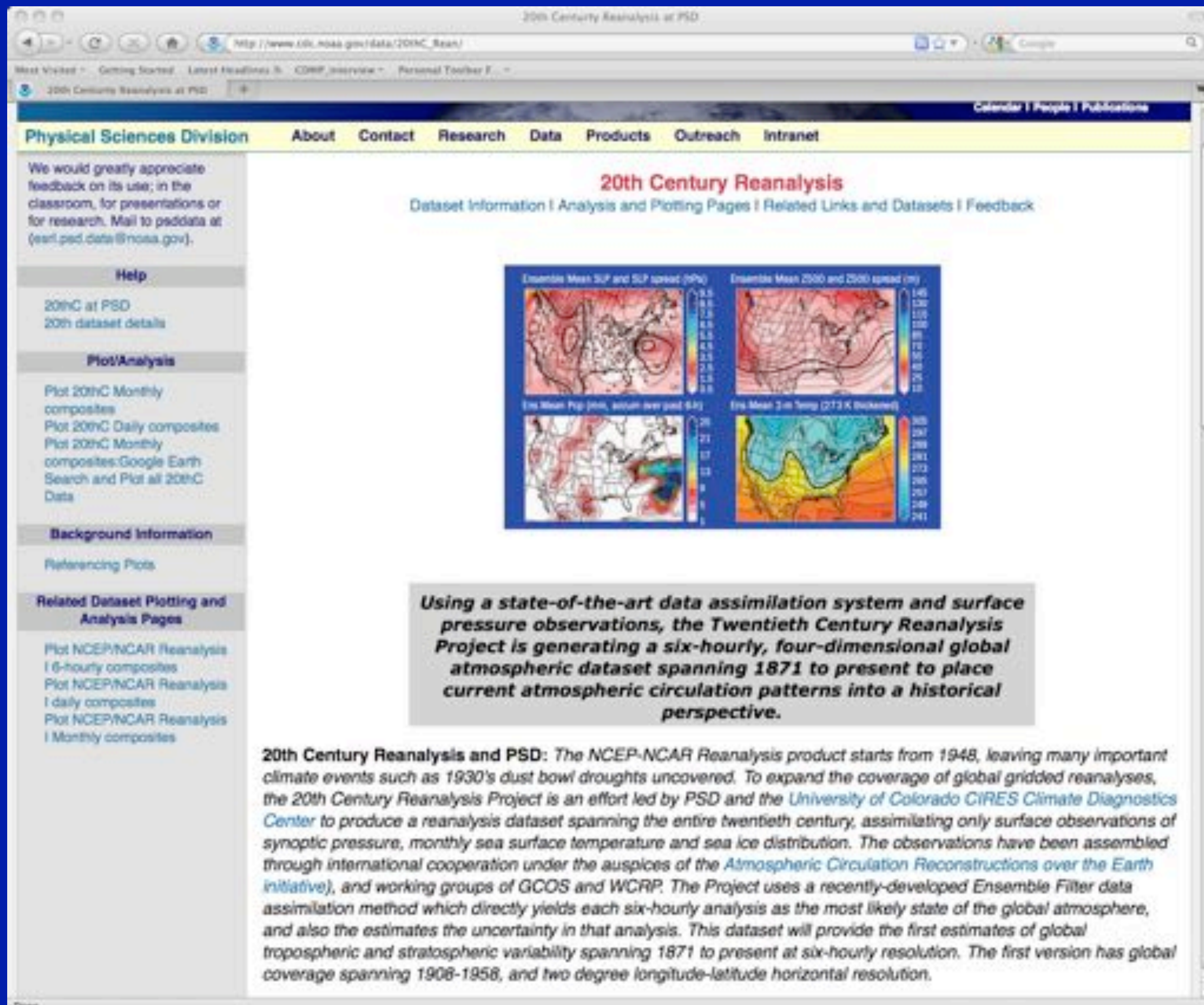
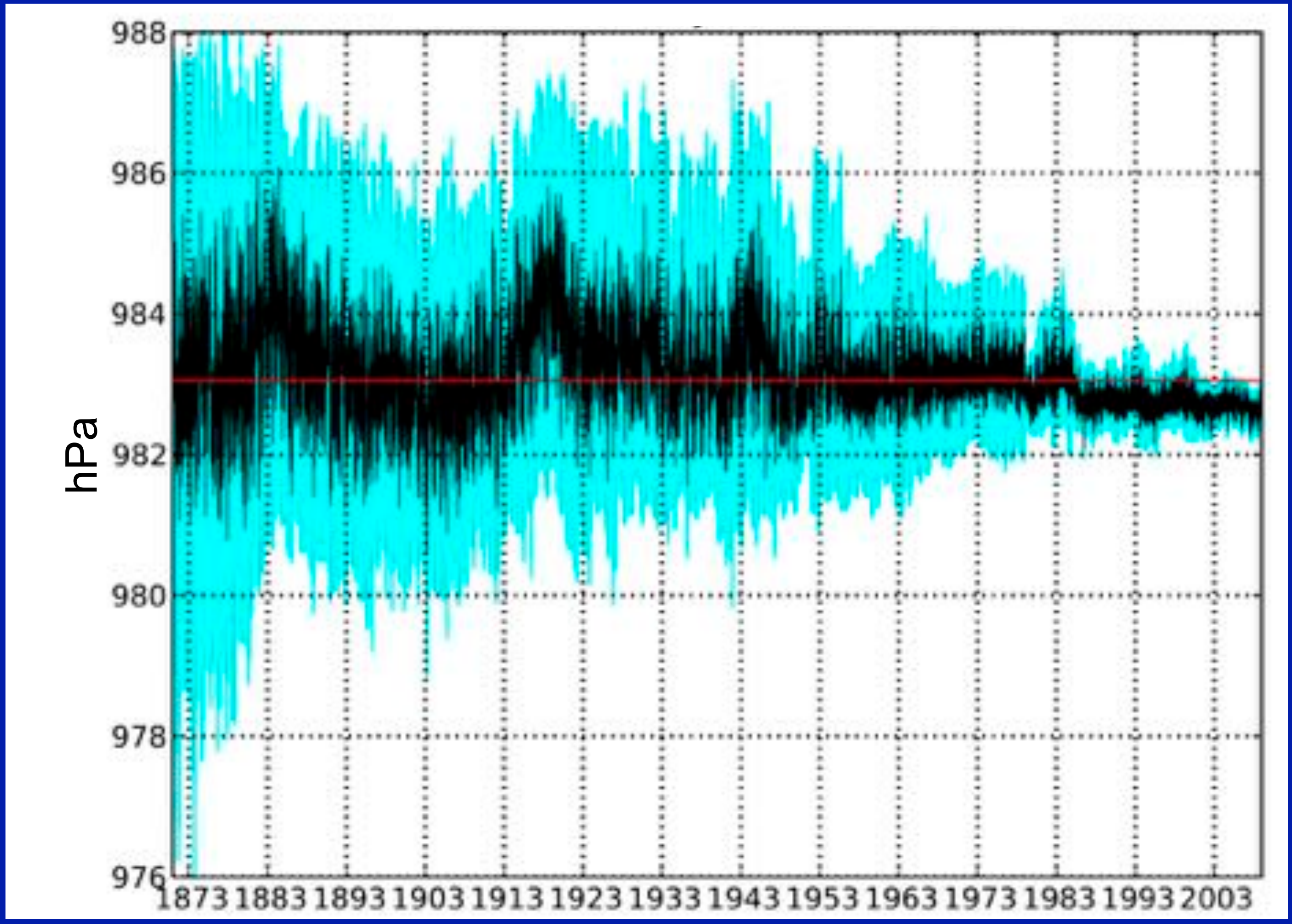
Thank you to organizations contributing observations to ISPD:

All Union Research Institute of Hydrometeorological Information WDC
Atmospheric Circulation Reconstructions over the Earth (ACRE)
Australian Bureau of Meteorology
British Antarctic Survey
Danish Meteorological Institute
Deutscher Wetterdienst
EMULATE
Environment Canada
ETH-Zurich
GCOS AOPC/OOPC WG on Surface Pressure
Hong Kong Observatory
IBTRACS
ICOADS
Instituto Geofisico da Universidade do Porto
IEDRO
Japanese Meteorological Agency
Jersey Met Dept.
KNMI
MeteoFrance
MeteoFrance – Division of Climate
Meteorological and Hydrological Service, Croatia
National Center for Atmospheric Research
Nicolaus Copernicus University
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
Norwegian Meteorological Institute
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
UK Met Office Hadley Centre
U. of Colorado-CIRES/Climate Diagnostics Center
U. of East Anglia-Climatic Research Unit
U. of Lisbon-Instituto Geofisico do Infante D. Luiz
U. of Milan-Dept. of Physics
U. Rovira i Virgili-CCRG
ZAMG

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



20CRv2 Global Mean Dry Surface Pressure
Blue: Max/Min of 20CRv2 Ensemble

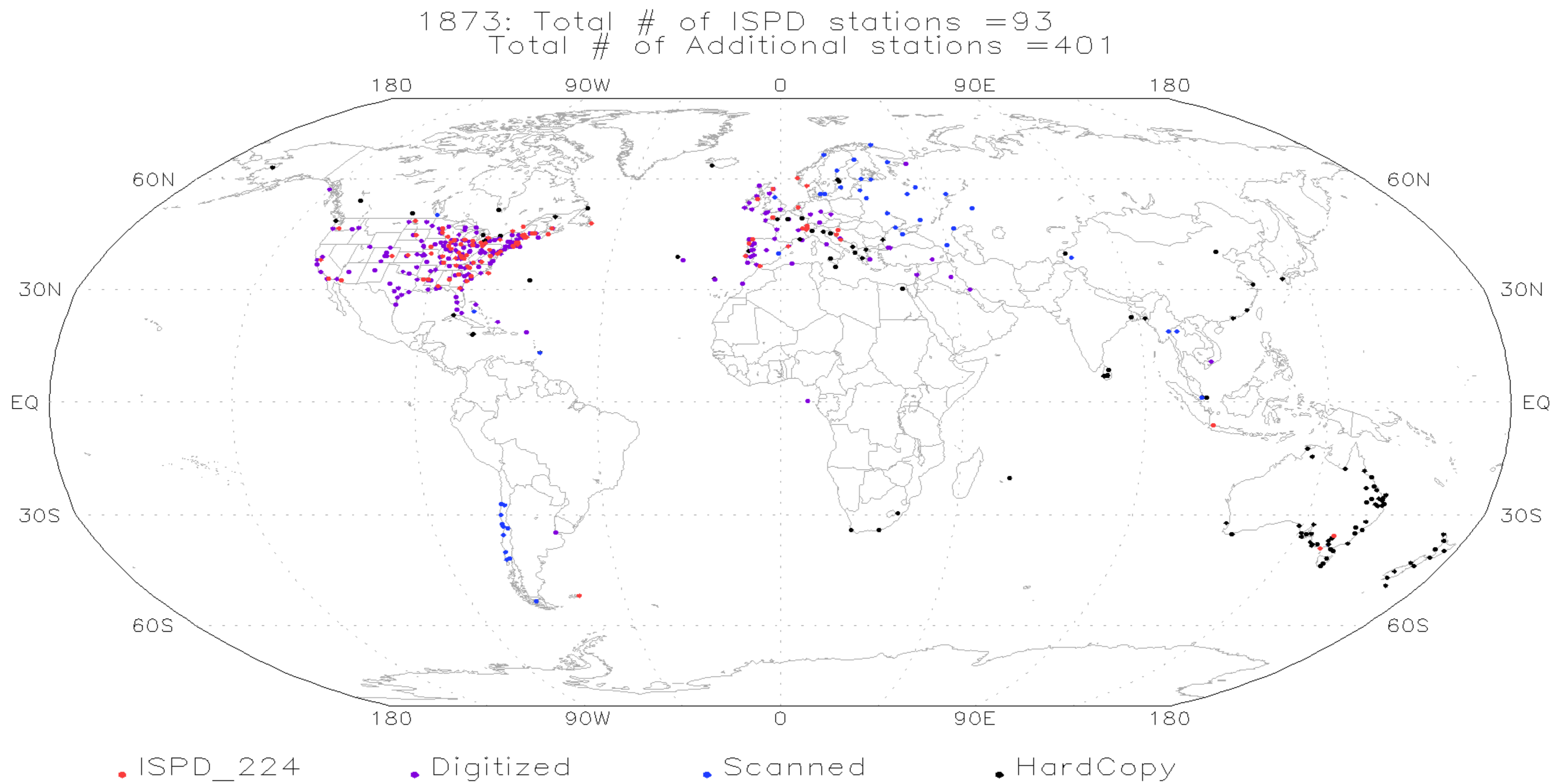


1979-2001
ERA-40
983.05
983.02
CFSR
1979-2009
(*van den Dool, 2010*)

Trenberth & Smith 2005; *van den Dool 2010*

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

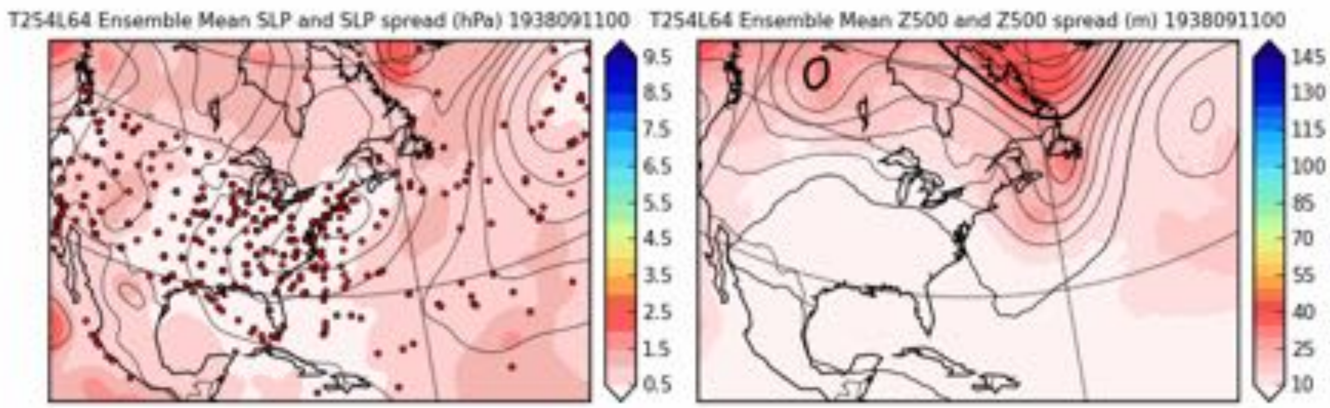
What does the climate community want/need from *long* reanalyses?

1. Climate model validation dataset for large-scale synoptic anomalies during extreme periods, such as droughts (30’s, 50’s).
2. Better understand events such as the 1920-1940’s Arctic warming.
3. Determining storminess and storm track variations over last 100-150 years.
4. Developing new forecast products predicting changes in frequency and intensity of weather extremes, e.g., cold air outbreaks, severe storms.
5. Developing and improving forecasts of low-frequency (e.g., Pacific-North America pattern, North Atlantic Oscillation, ENSO) atmospheric and oceanic variations and their interannual to decadal variability.
6. Understanding changing atmospheric background state associated with interdecadal hurricane activity.
7. Homogenizing upper-air and other independent observations.
8. Estimating historical probability distributions for wind energy.
9. Estimating risks of extreme events for insurance and re-insurance.
10. **Calibrating paleoclimate proxy reconstructions**

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

2008 NCEP GFS at ~50km resolution

September 1938 New England (movie)



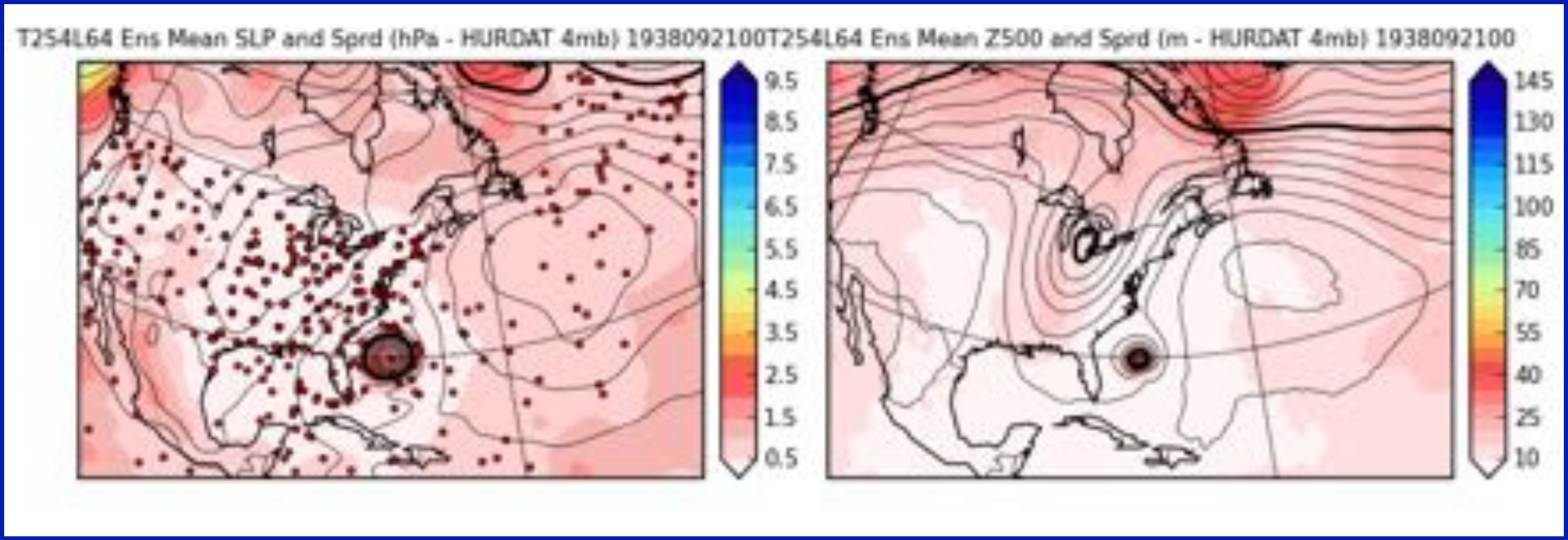
T254L64 (~50 km)

Is the extraordinary upper-level trough correct?

2008 NCEP GFS at ~50km resolution

21 September 1938 00 UTC

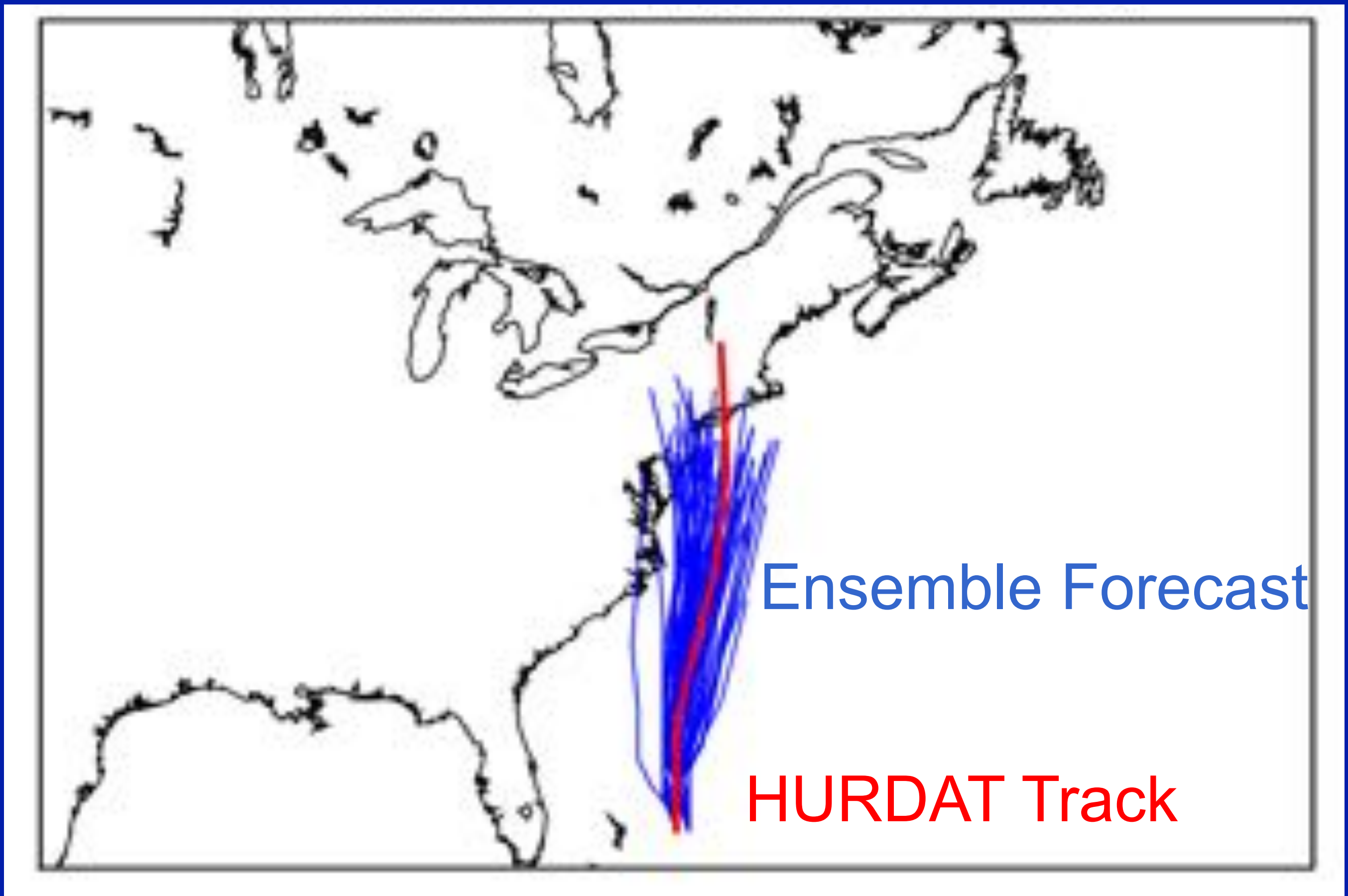
Sea Level Pressure 500 hPa geopotential height



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)

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)

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

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

y^o = single observation with error variance R

First guess interpolated to observation location:
$\langle y \rangle^b = H \langle x \rangle^b$, $y'^b_j = H\, x'^b_j$

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

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

$x'^a_j = x'^b_j + K^M(-y'^b_j)$ Note the different gain

$K = \Sigma_j\, x'^b_j\, y'^b_j\, (\Sigma_j\, y'^b_j\, y'^b_j + R)^{-1}$ Kalman Gain

$K^M = (1 + \{R/(\Sigma_j\, y'^b_j\, y'^b_j + R)\}^{-1/2})^{-1} K$ Modified Kalman Gain shrinks the ensemble

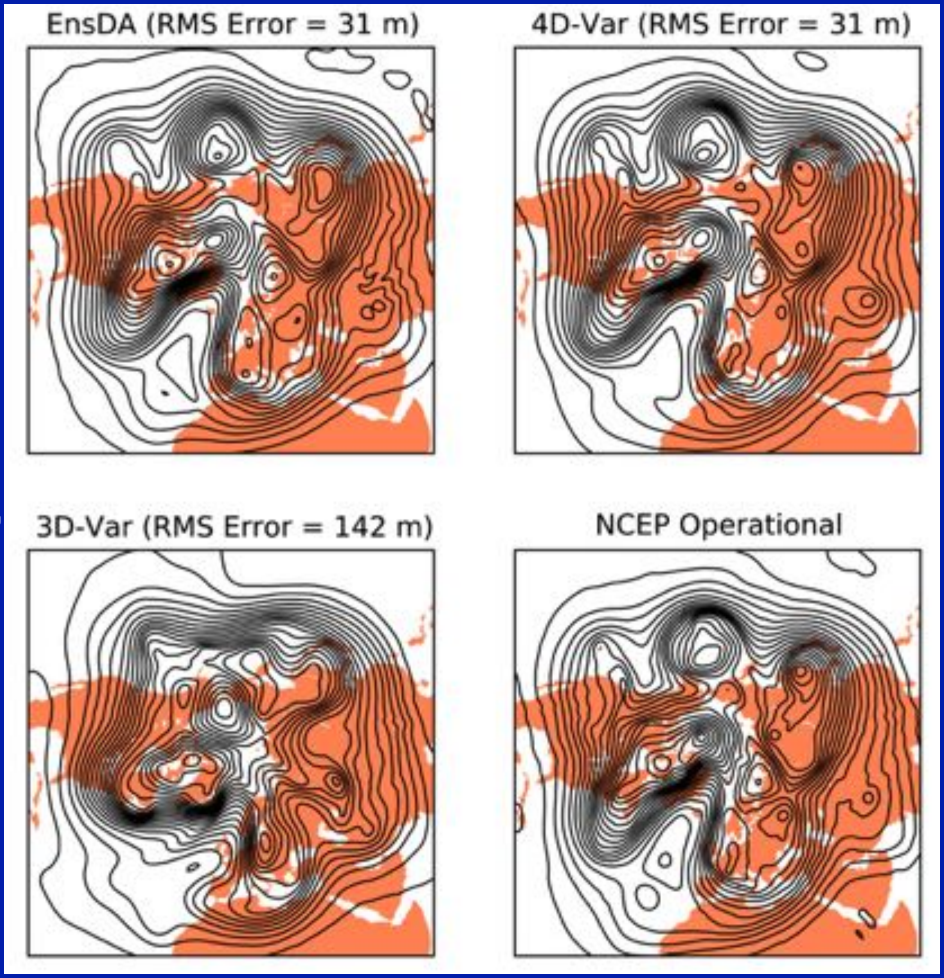
$(1/(n-1))$ is included in Σ_j

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

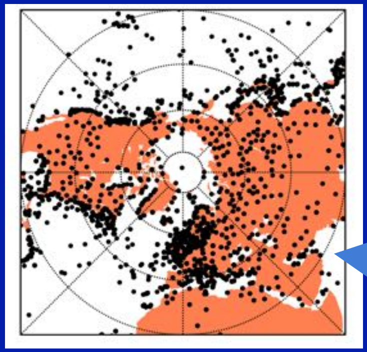
Ensemble Filter
(~3800 surface pressure obs)
RMS = 31 m



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

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

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



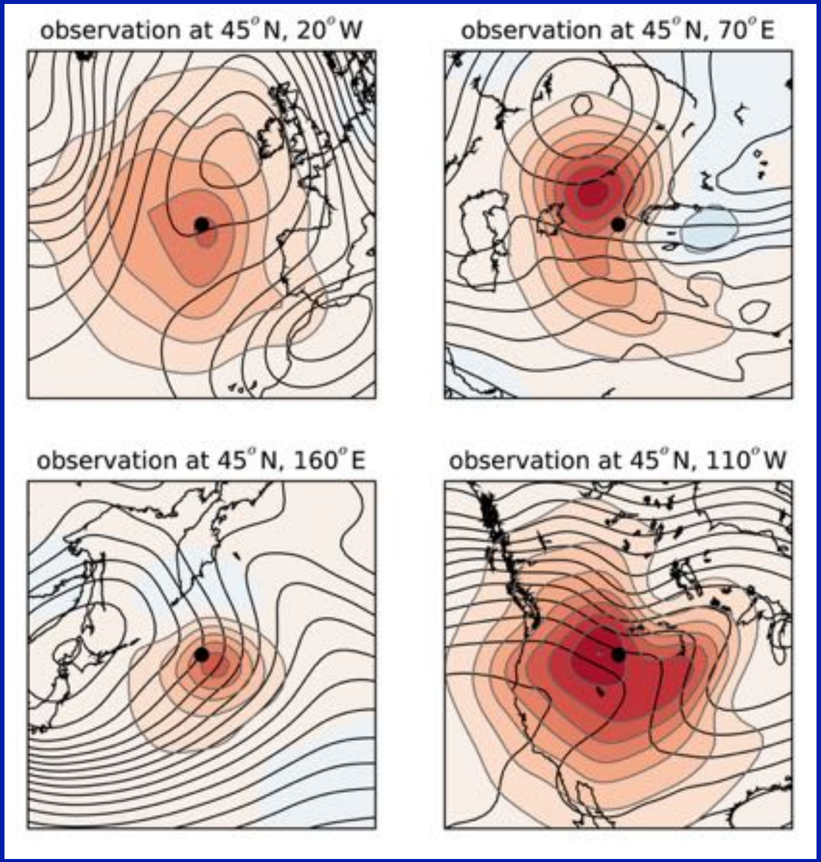
Surface pressure network reduced to ~1930’s

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

Central Asia



West Pacific

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.

Project Status and Plans (con't)

Surface Input Reanalysis for Climate Applications (SIRCA)

SIRCA 1850-2011

- Higher resolution (T126 ~100km or higher)
- improved methods (e.g., Kalman Smoother)
- More input data (e.g., CDMP & ACRE, maybe winds and T, storm position)
- latest model from NCEP
- Include uncertainty in forcings (e.g., ensemble of SSTs and Sea Ice, CO_2, solar)
- Fall 2014

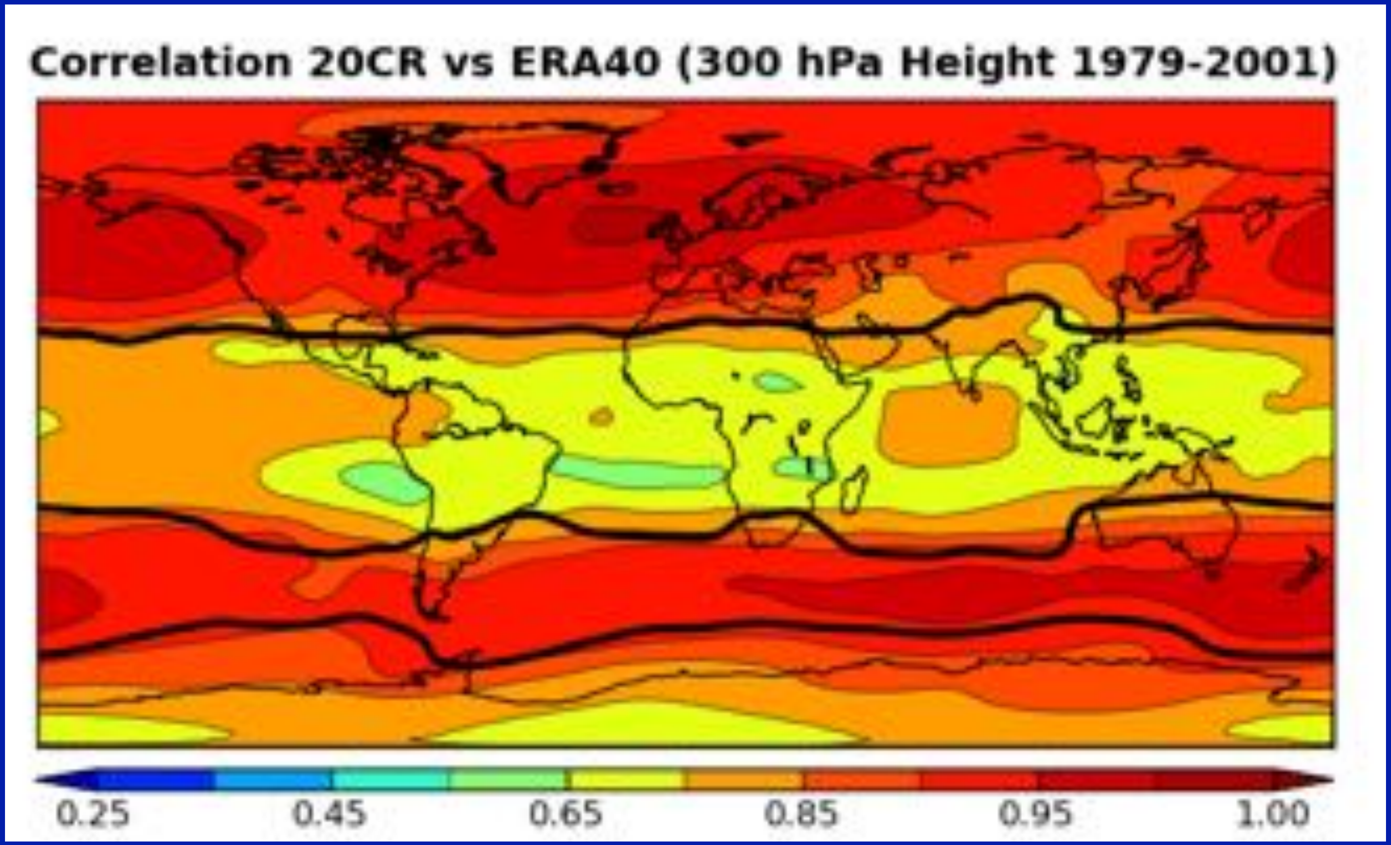
Chemical and Surface Input Reanalysis for Climate Applications

CSIRCA 1800-2016

- Higher resolution (T382 or higher)
- improved methods (e.g., include coupled Cryosphere-Ocean-Land-Atmosphere-Chemistry system, link with 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, GFDL, ESRL)
- Fall 2017

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

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

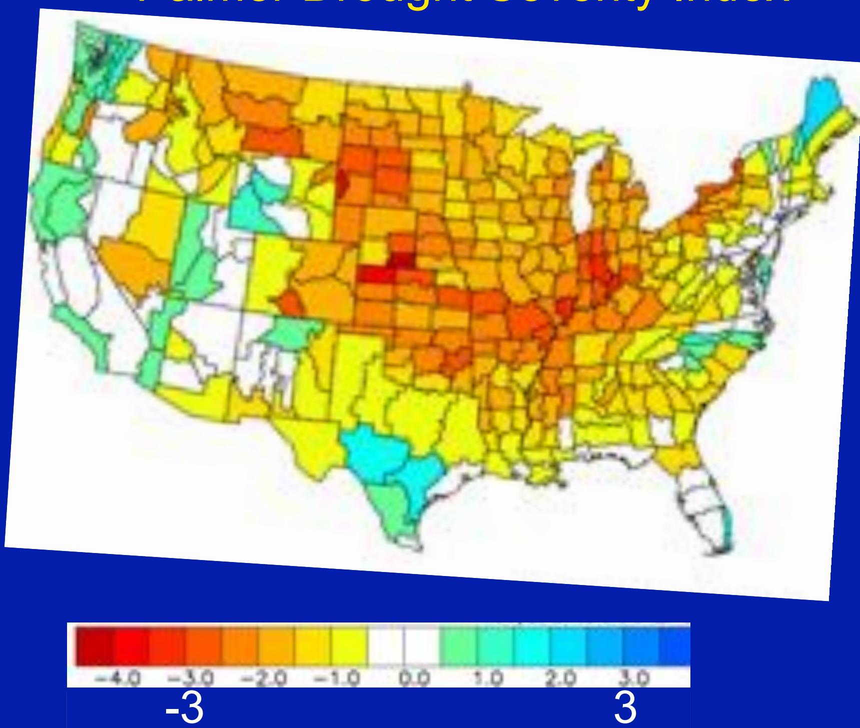


Northern and Southern Hemisphere agreement are excellent between 20CRv2 and ERA40 when ERA40 has satellite observations.

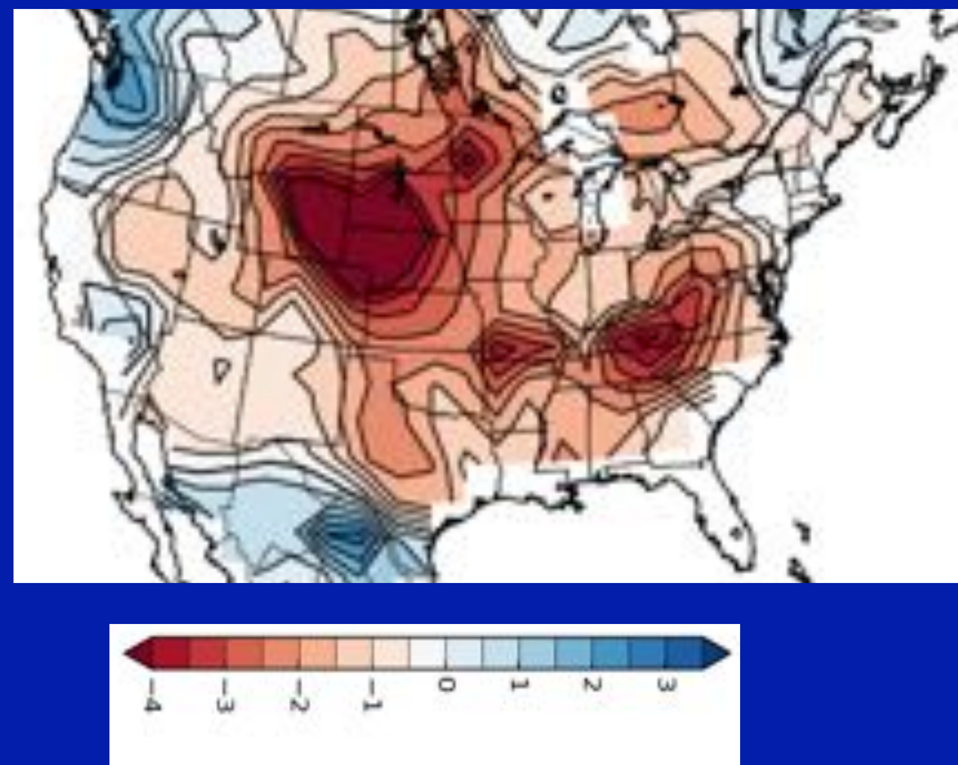
U.S Dust Bowl (July 1936)

Standardized monthly anomalies relative to 1961-1990

US Climate Division
Palmer Drought Severity Index



20CRv2 Soil Moisture 0-200 cm



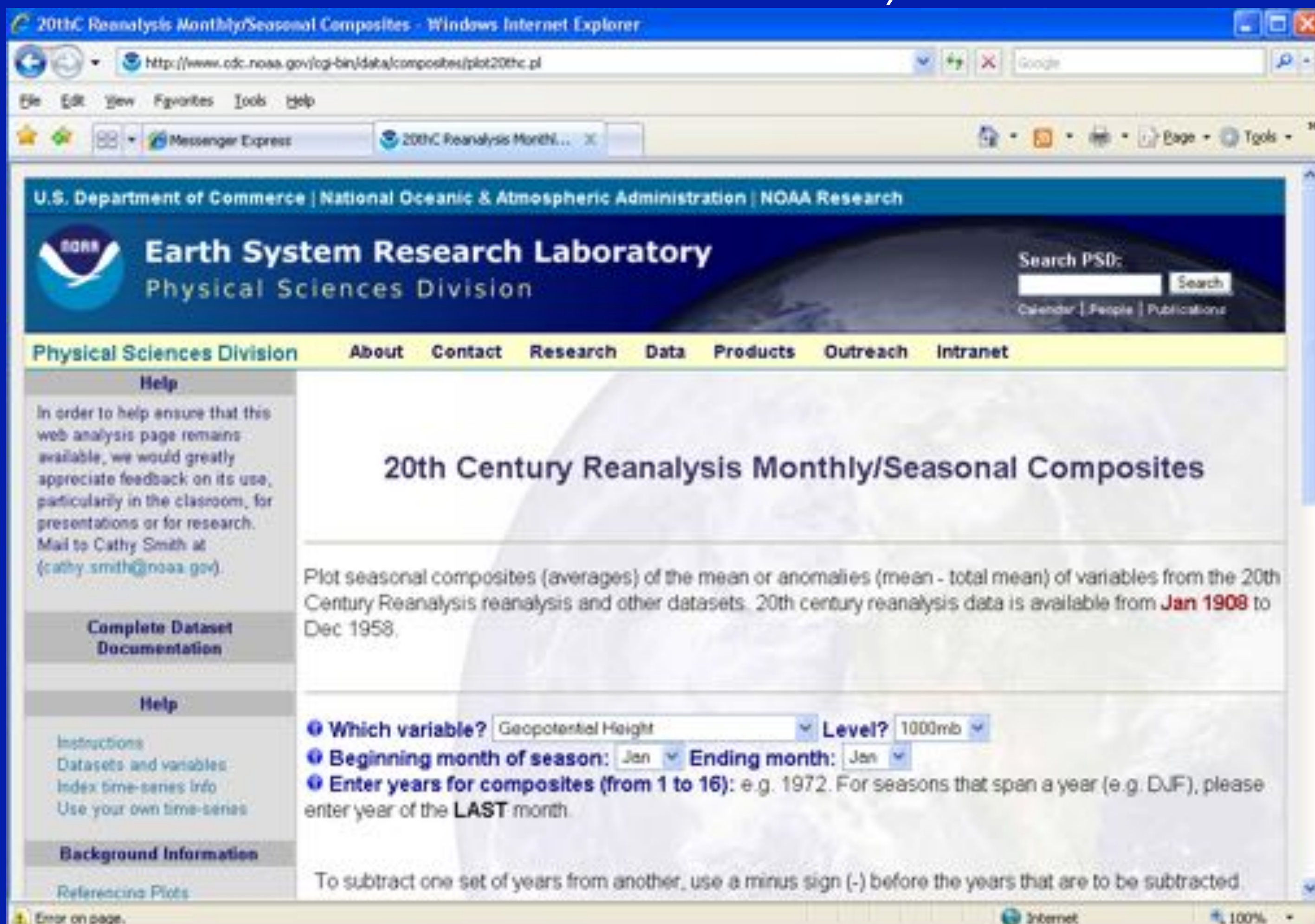
Using only surface pressure, 20CR v2 appears to capture expected features even in derived quantities.

Monthly mean composites (beta)

http://www.cdc.noaa.gov/cgi-bin/data/composites/plot20thc.pl

Plotting page courtesy Cathy Smith

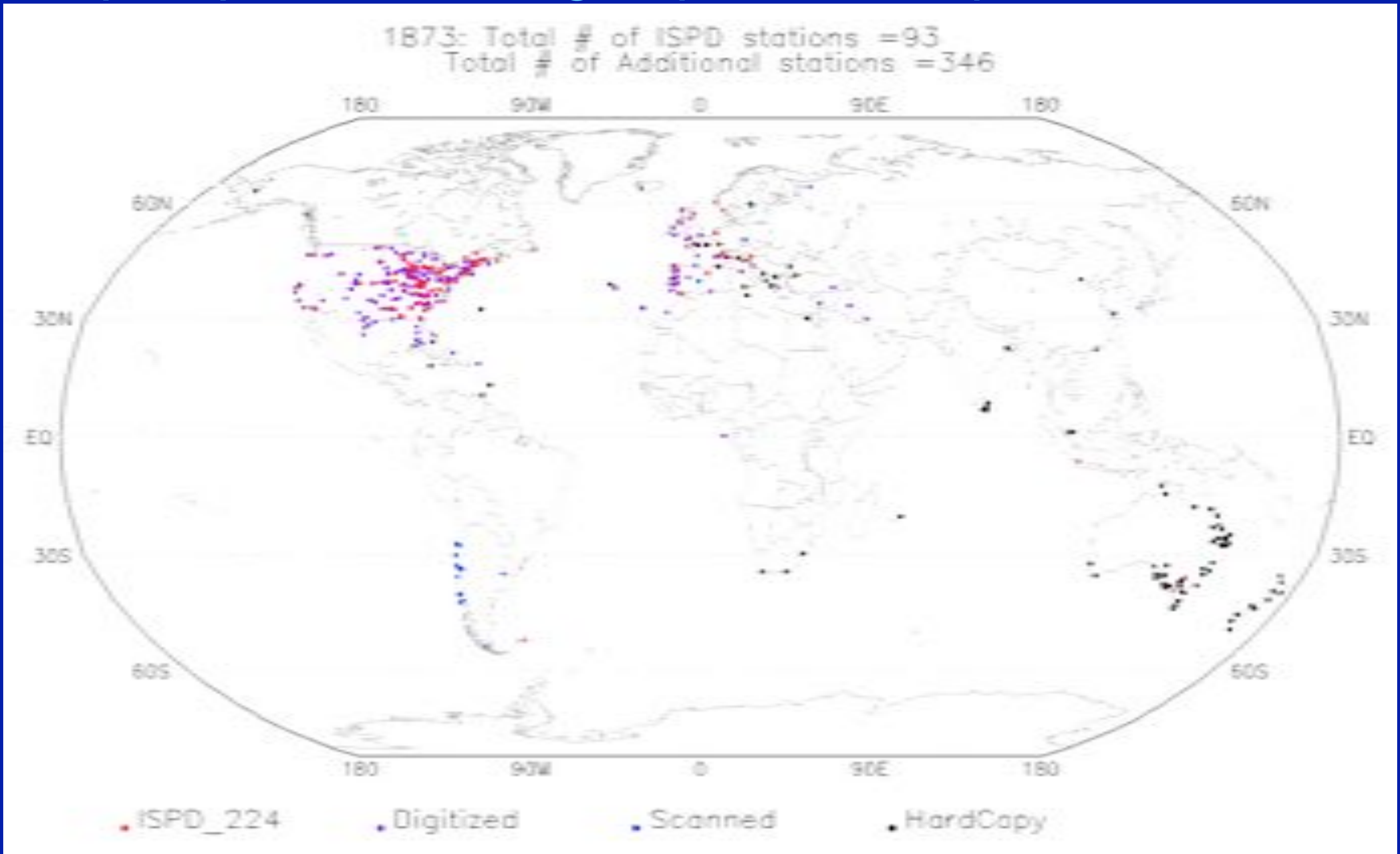
(U. of Colorado CIRES and NOAA ESRL PSD)



Daily means are also planned

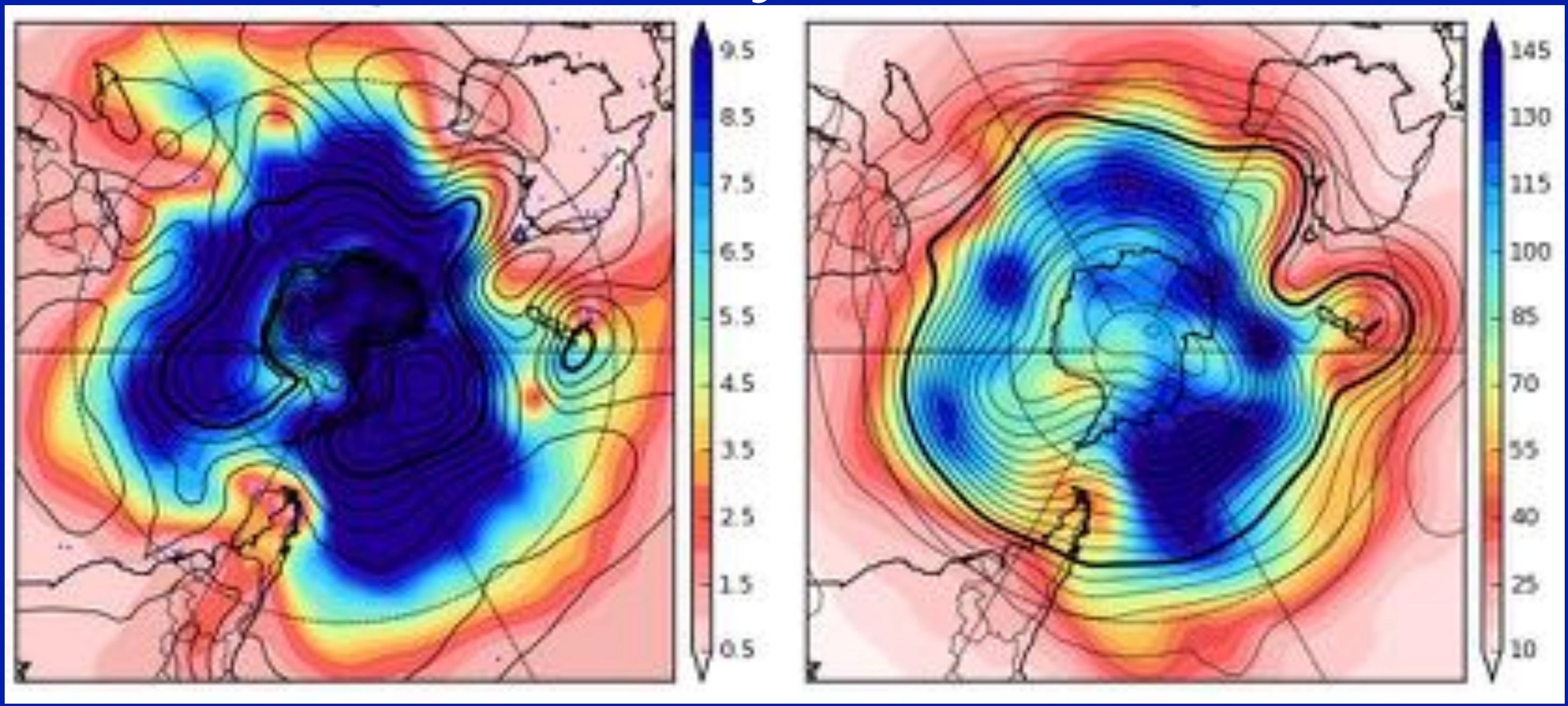
Current and future International Surface Pressure Databank station component
(1670 to 2009)

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



Courtesy X. Yin and R. Allan

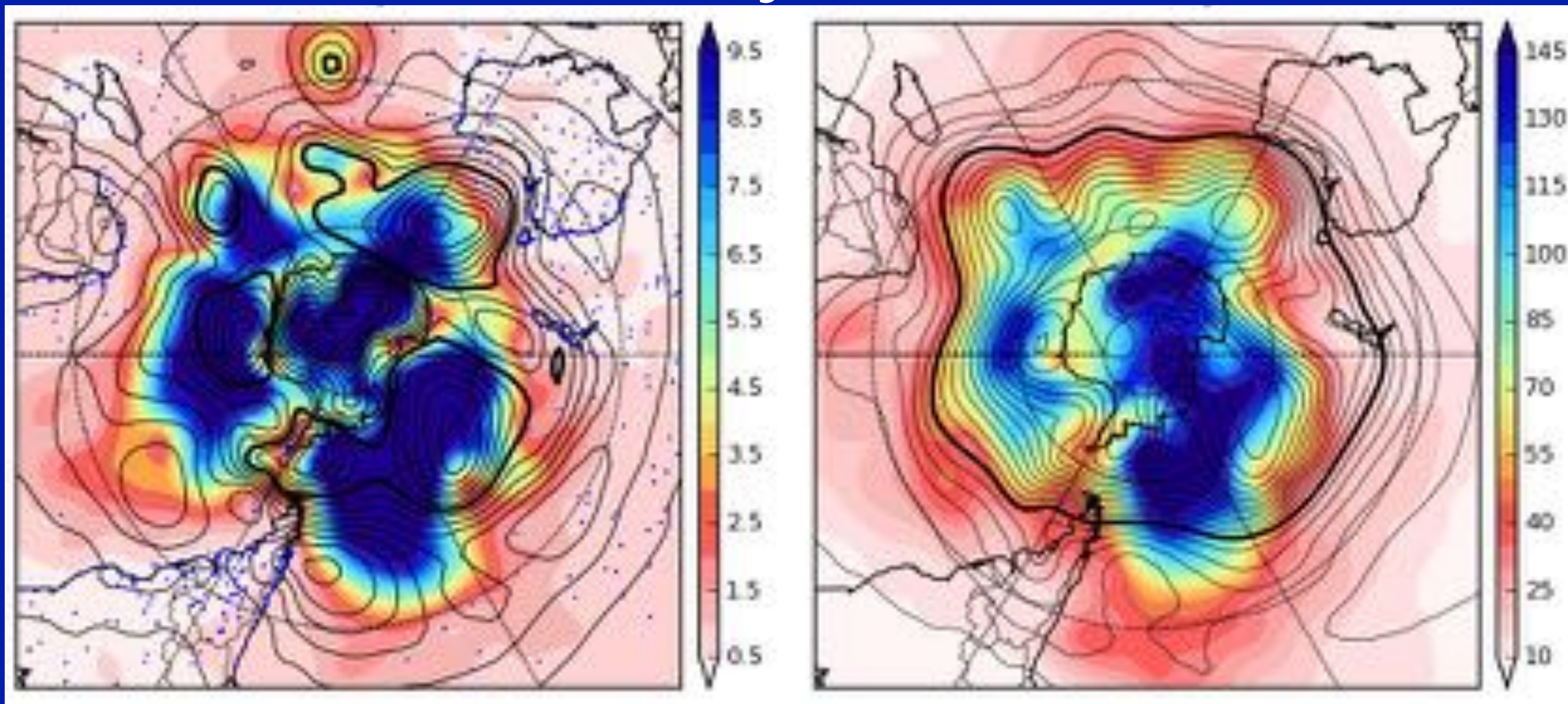
Analyses for selected dates
6 May 1923



Sea Level Pressure (hPa) 500 hPa Geopotential Height (m)

Contours- ensemble mean *(4 hPa, 50 m)*
Shading- blue: more uncertain, white: more certain

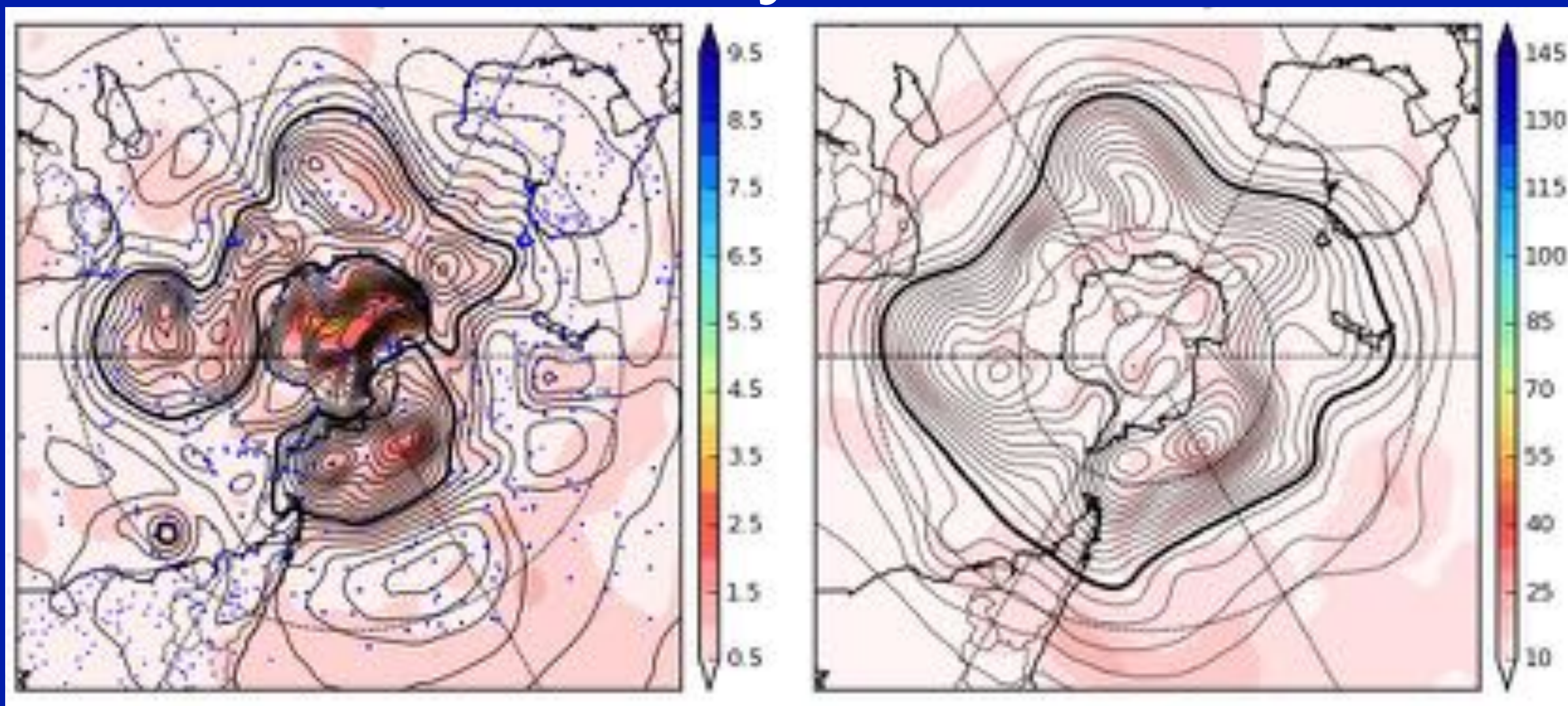
Analyses for selected dates
6 May 1973



Sea Level Pressure (hPa) 500 hPa Geopotential Height (m)

Contours- ensemble mean *(4 hPa, 50 m)*
Shading- blue: more uncertain, white: more certain

Analyses for selected dates
6 May 2008

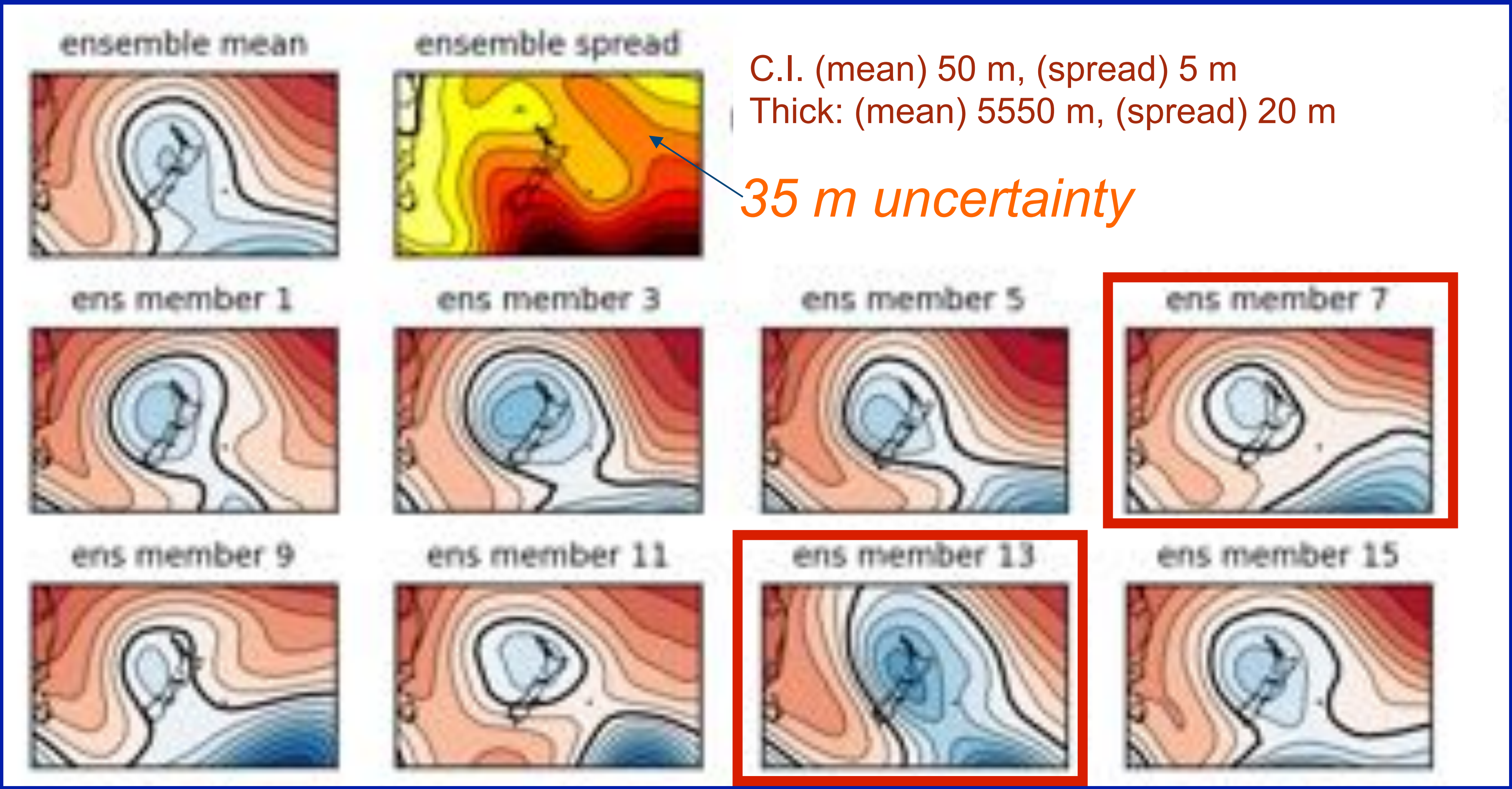


Sea Level Pressure (hPa)　　500 hPa Geopotential Height (m)

Contours-	ensemble mean *(4 hPa, 50 m)*
Shading-	blue: more uncertain, white: more certain

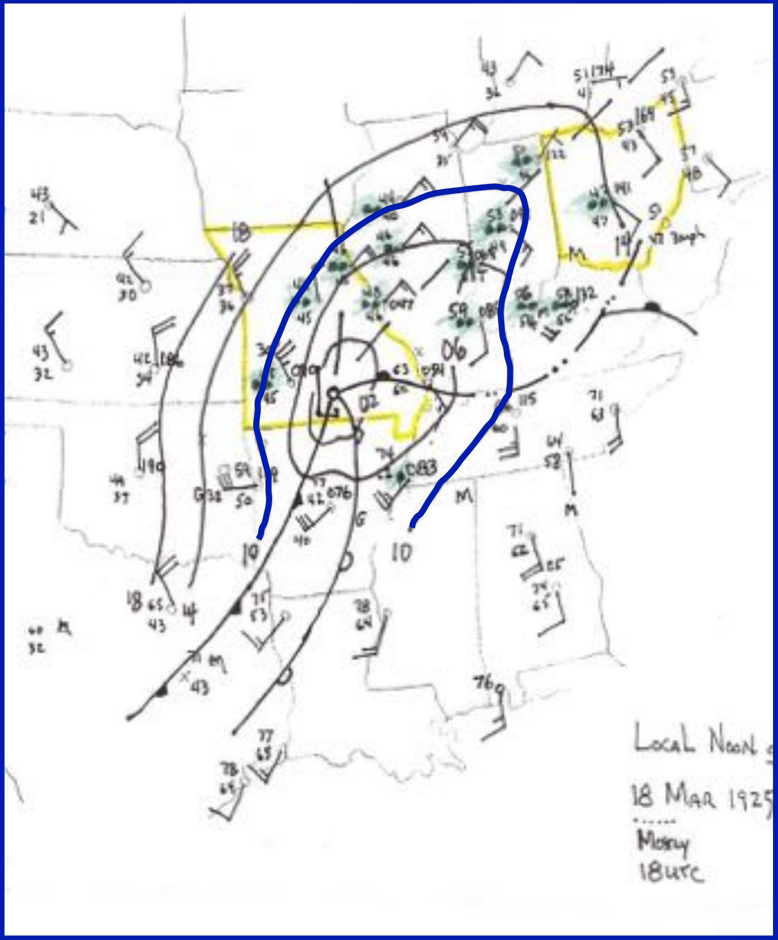
Range of possibilities for 500 hPa Geopotential Height During Severe Flooding Event

6 May 1923 0Z showing 12 (of 56) members

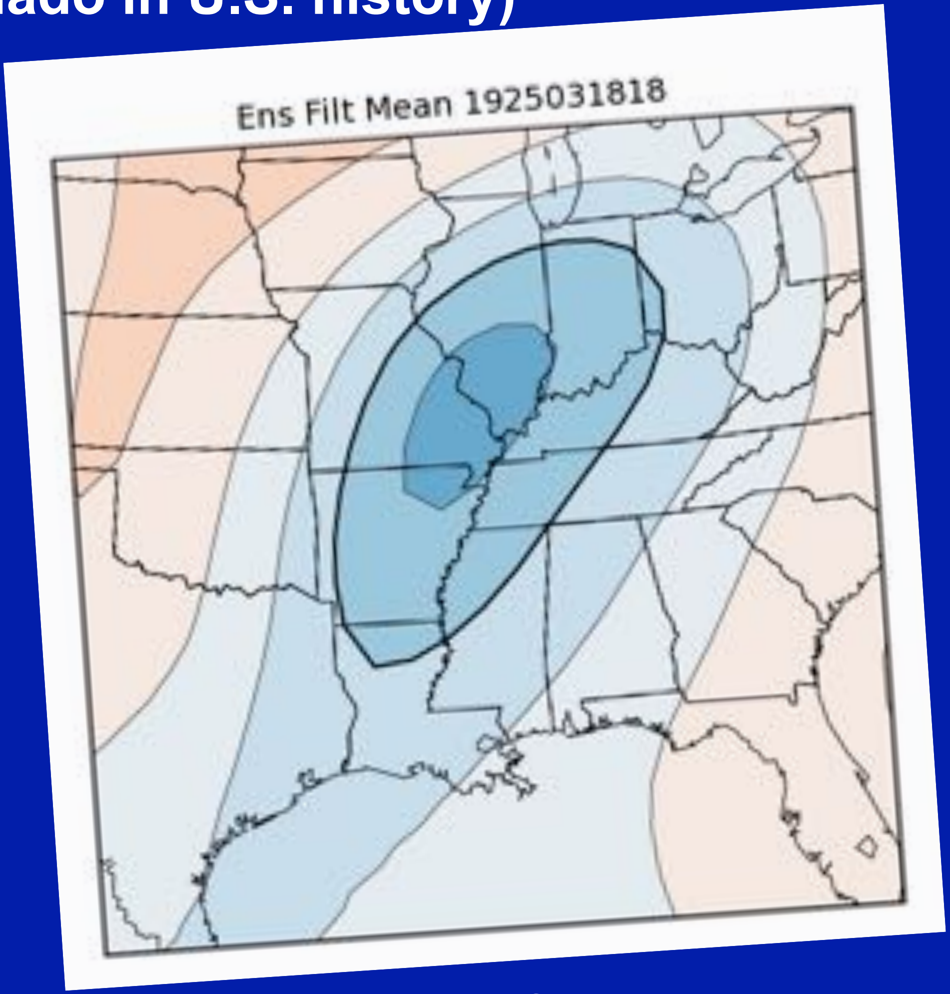


Ensemble of 56 possible realizations consistent with the observations

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



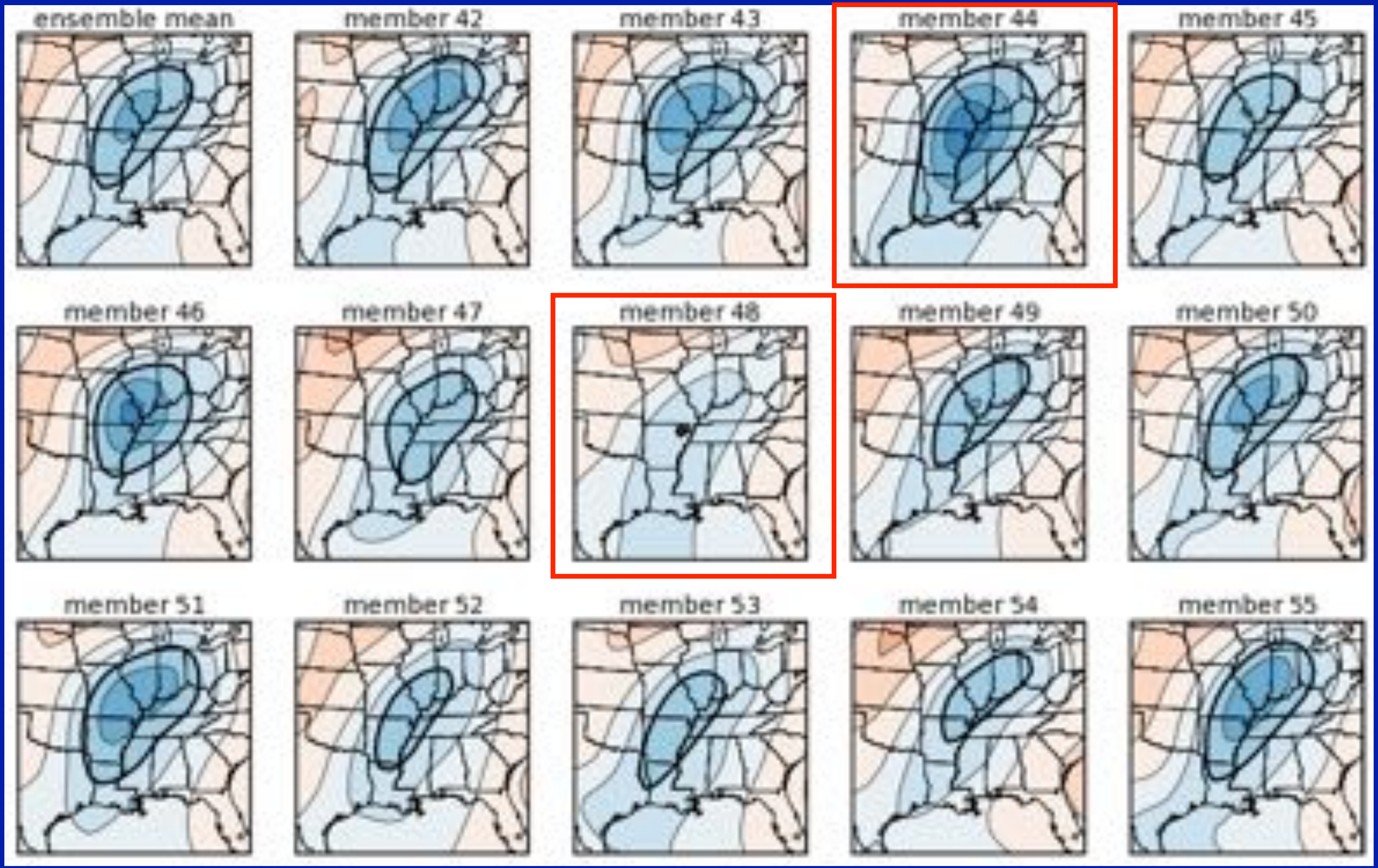
Manual Analysis, courtesy B. Maddox



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.

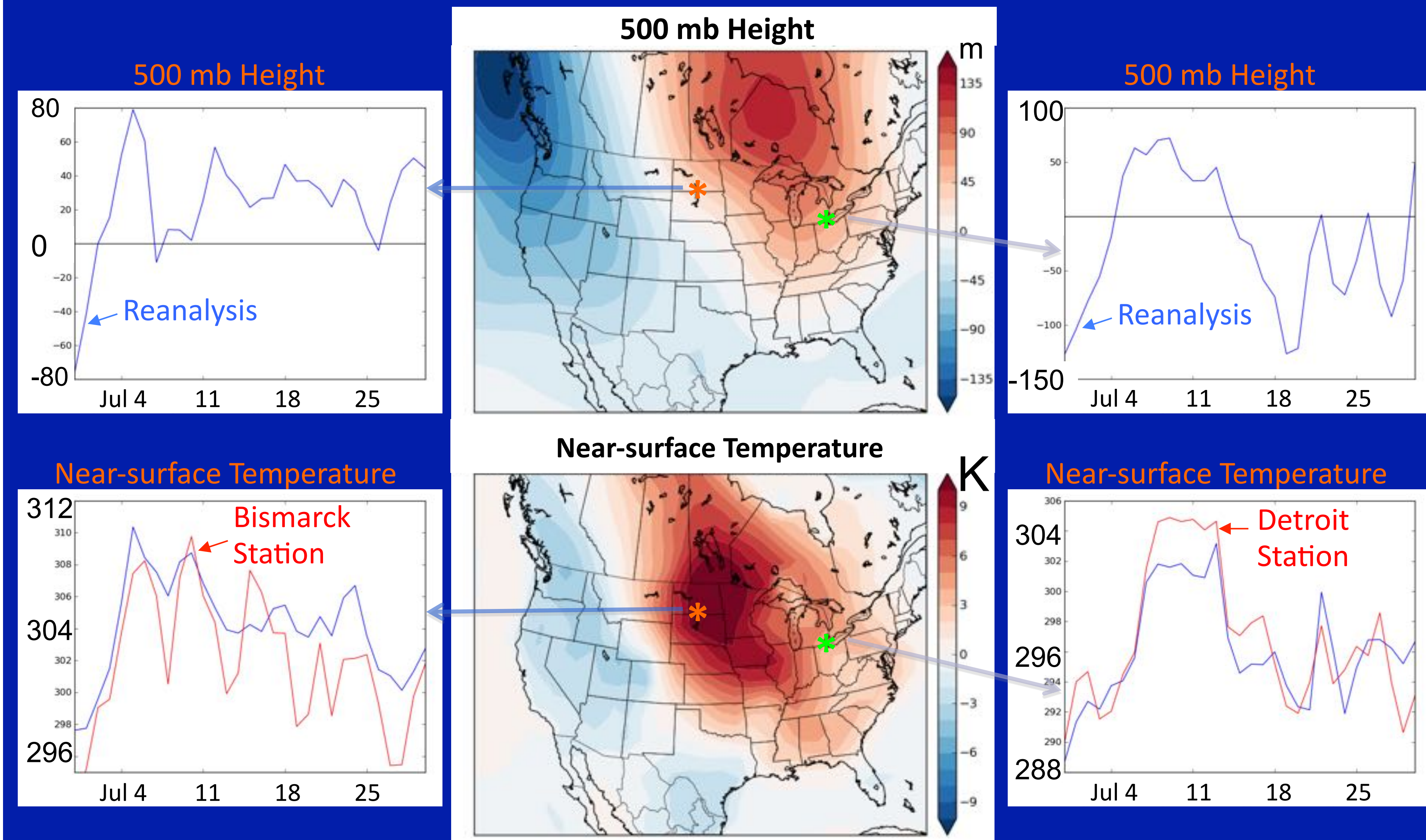
Range of possibilities for Sea Level Pressure
18 March 1925 18Z using 14 (of 56) members



Ensemble of 56 possible realizations consistent with the observations

July 1936 North American Heat Wave

(1,000+ US & 1,000+ Canadian deaths during 14-day span)



20th Century Reanalysis version 2

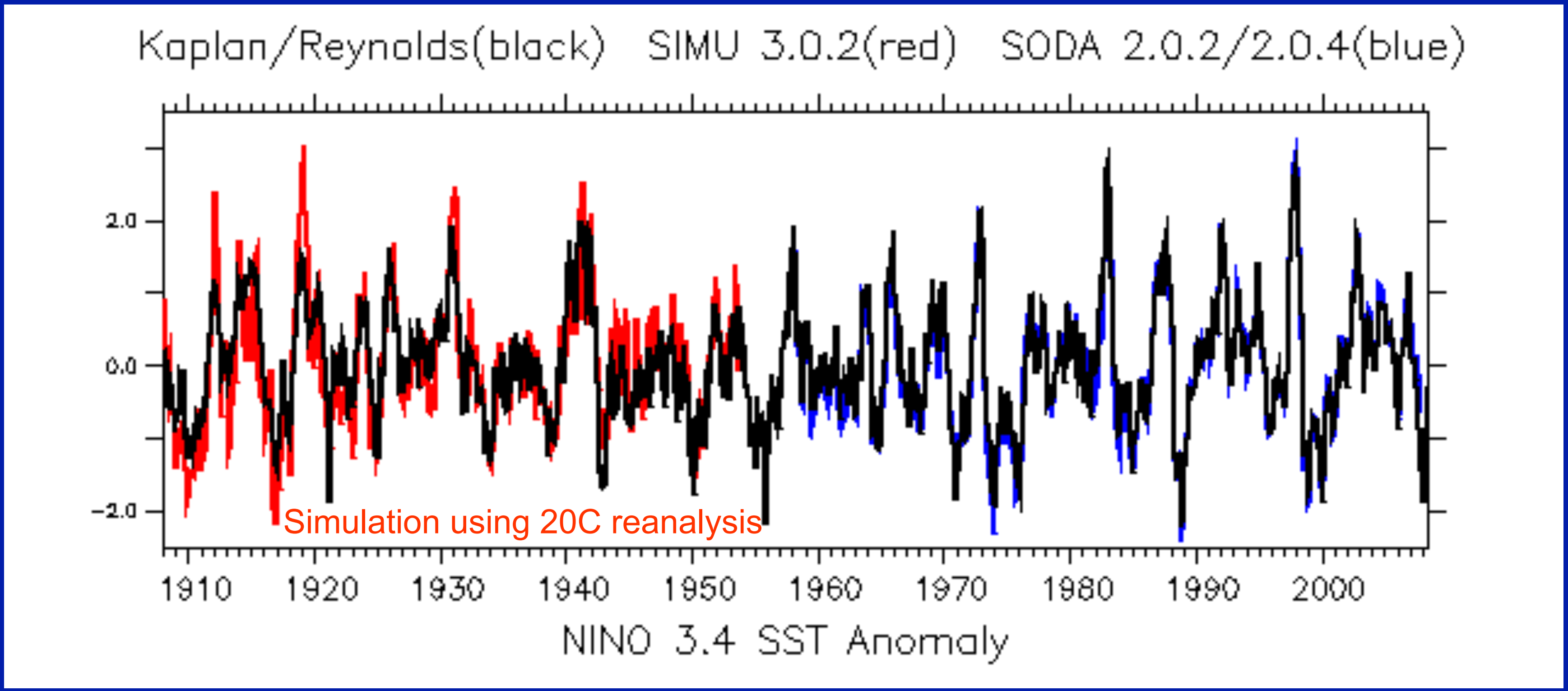
Anomalies July 8 – 14 with respect to 1891-2007

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 2010*)

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

Uses of historical reanalyses

1. Effectively doubling the reanalysis record length ☺
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 new forecast products predicting changes in frequency and intensity of weather extremes, e.g., cold air outbreaks, severe storms.
6. Developing and improving forecasts of low-frequency (e.g., Pacific-North America pattern, North Atlantic Oscillation) atmospheric variations and their interannual to decadal variability.
7. Understanding changing atmospheric background state associated with interdecadal hurricane activity.
8. Homogenizing upper-air and other independent observations.
9. Estimating historical probability distributions for wind energy.
10. Estimating risks of extreme events for insurance and re-insurance.
11. Calibrating paleoclimate proxy reconstructions