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

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Quarterly Journal of the Royal Meteorological Society Q. J. R. Meteorol. Soc. 137: 1–28, January 2011 Part A

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Review Article
The Twentieth Century Reanalysis Project

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

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

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-01 C1
  Extension and Improvement of the Climate Record, Develop datasets suitable for global climate applications with a focus on the past 100 years, including high-resolution global reanalysis products.

- 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 (2006-2012) 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 or tripling 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). Need to extend to 1850 for full overlap with CMIP5 integrations.
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.

<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 130+ years ***using only surface pressure observations (this is not a minus!)***.

<u>The reanalyses provide</u>:
-First-ever estimates of near-surface and tropospheric 6-hourly fields extending back to end of the 19th 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.

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

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

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

y^o is only surface pressure,

Hx^b is guess surface pressure

Using 56 member Ensemble

HadISST1.1 monthly boundary conditions (*Rayner et al. 2003*)

Version 2 (*1871-2010*): T62, 28 level NCEP GFS08ex model
- time-varying CO_2, solar, and volcanic radiative forcing

International Surface Pressure Databank version 2 (ISPD)

Subdaily observations assembled in partnership with

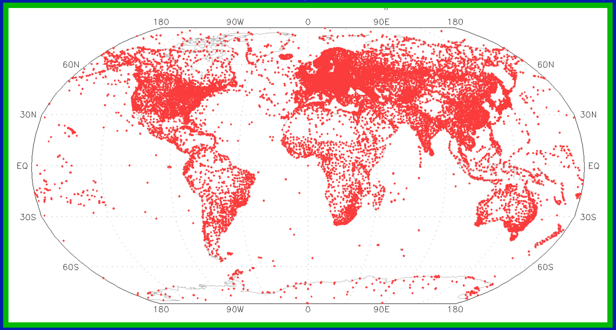
GCOS AOPC/OOPC Working Group on Surface Pressure

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**
- **1768-2010**



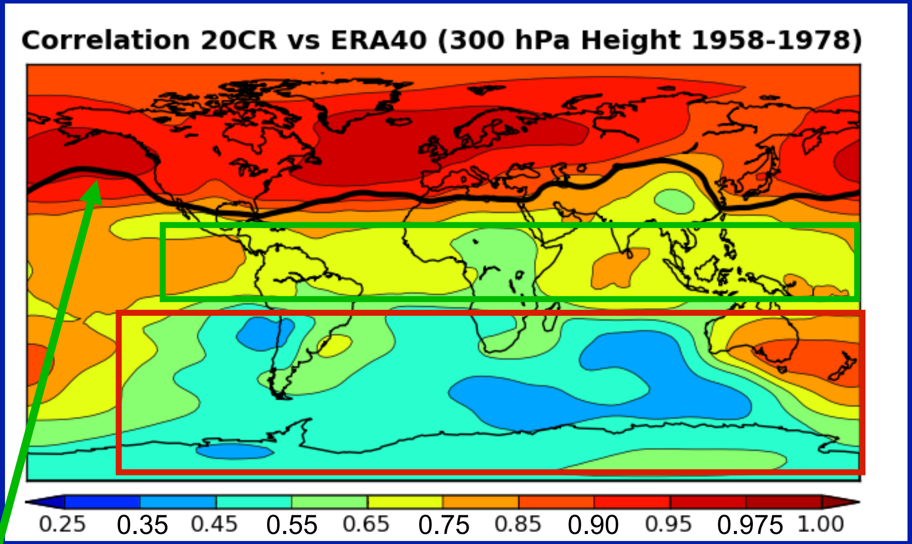
Marine data component: **ICOADS** merged by NOAA ESRL, NCDC, and NCAR

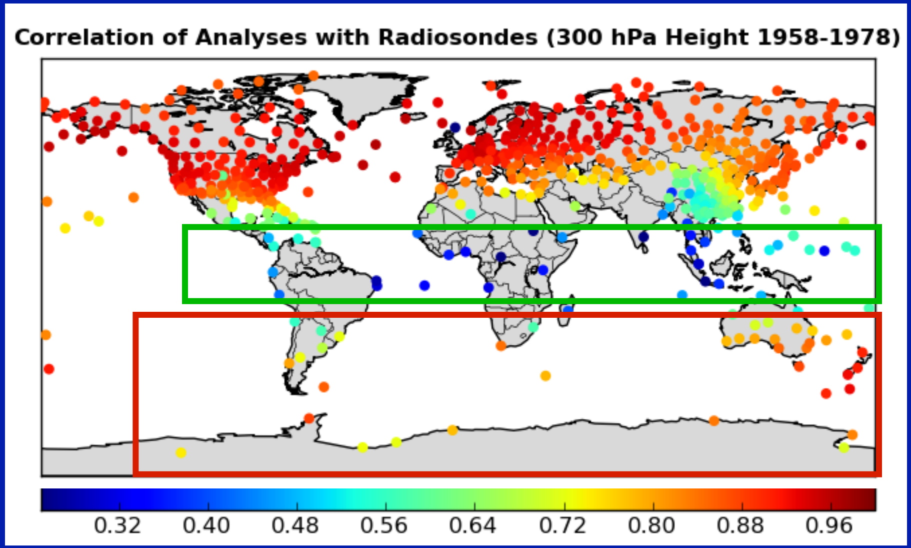
Tropical Cyclone Best Track data component: **IBTrACS** merged by NOAA NCDC

DATA ACCESS rda.ucar.edu/datasets/ds132.0 (T. Cram, NCAR DSS; C. McColl CIRES)

Reanalyses.org/observations/surface

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

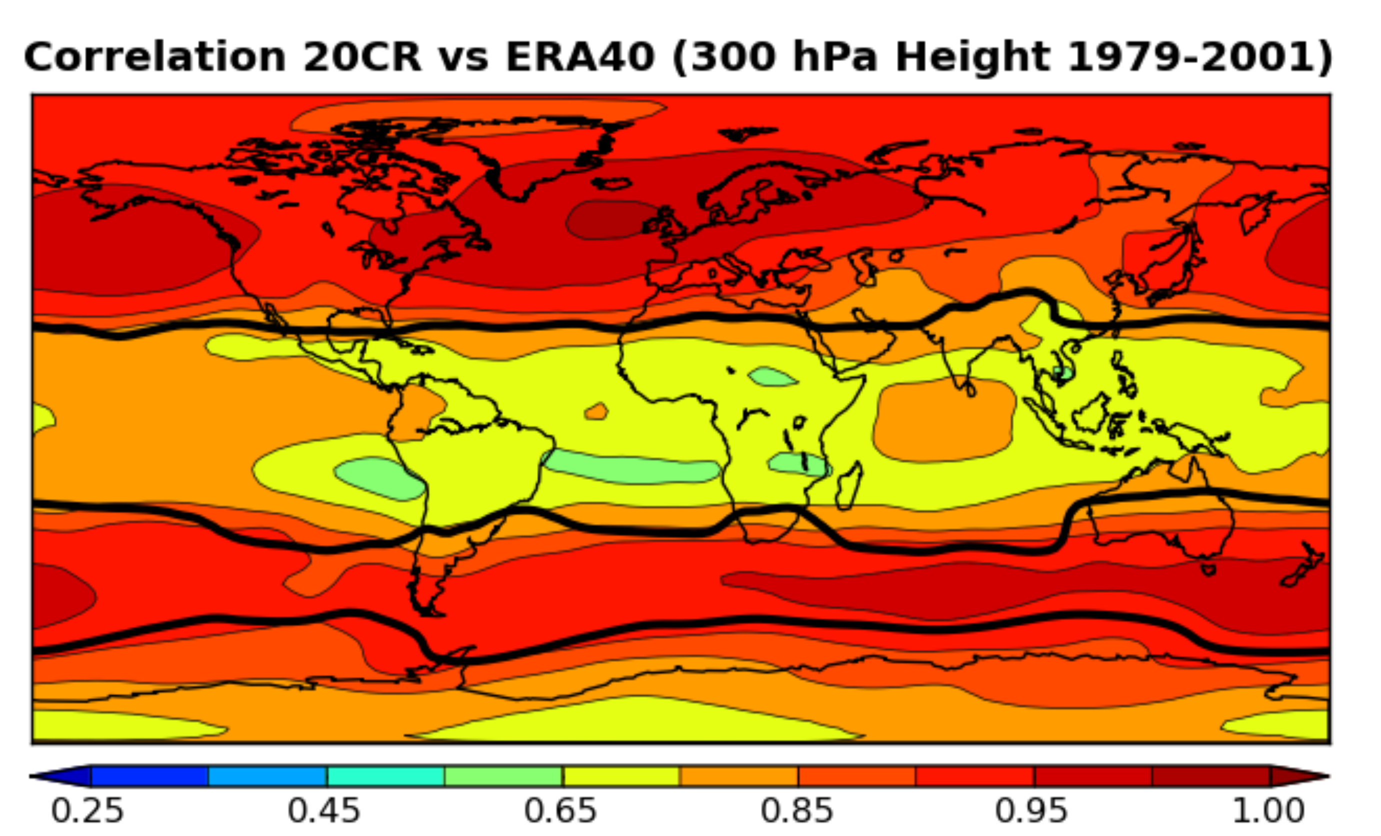
Northern Hemisphere agreement is excellent where NNR and ERA40 agree.

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.

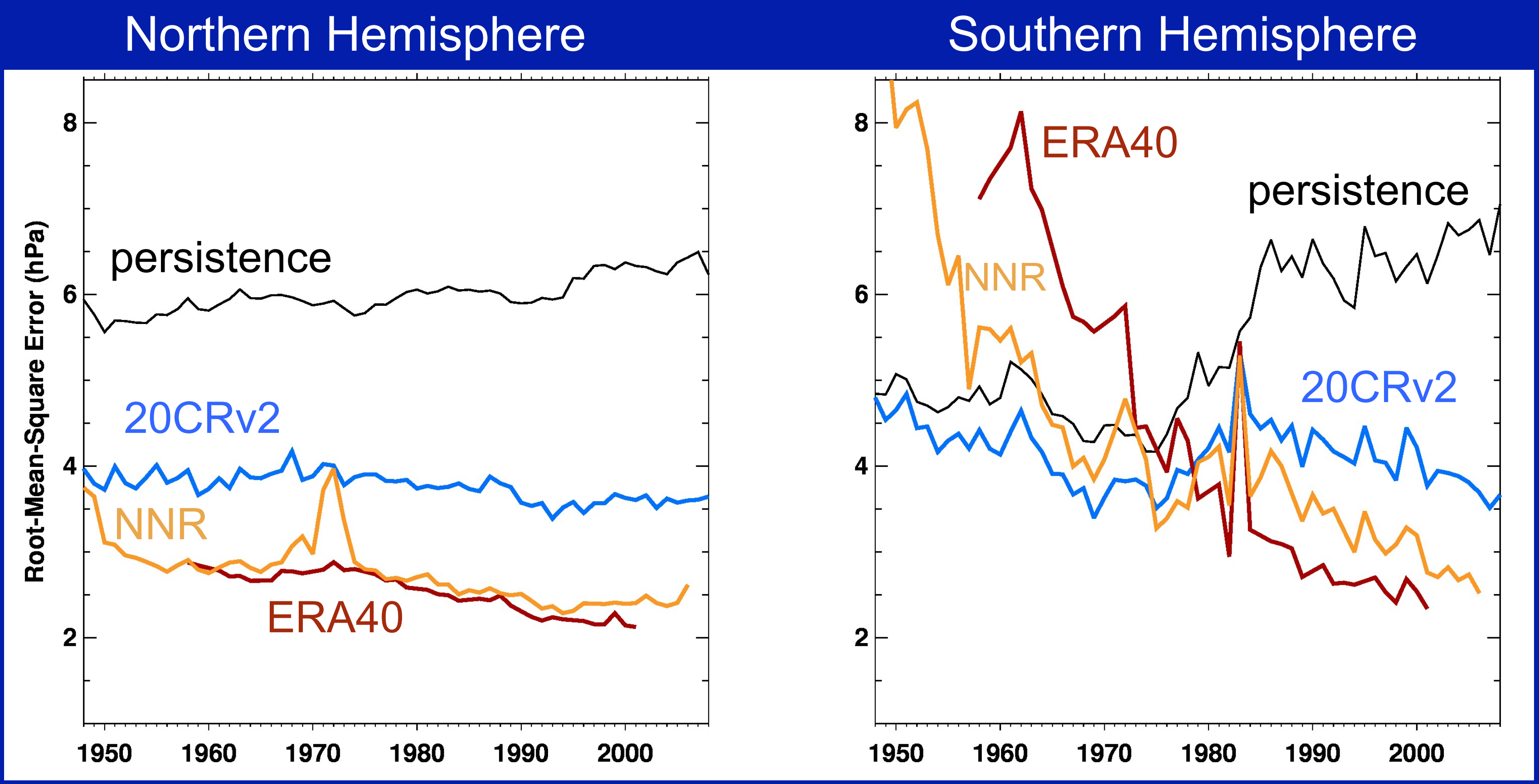
Local Anomaly Correlation of 300 hPa geopotential height anomalies from 20th Century Reanalysis (20CRv2) and ERA40 (1979 to 2001)

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.

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



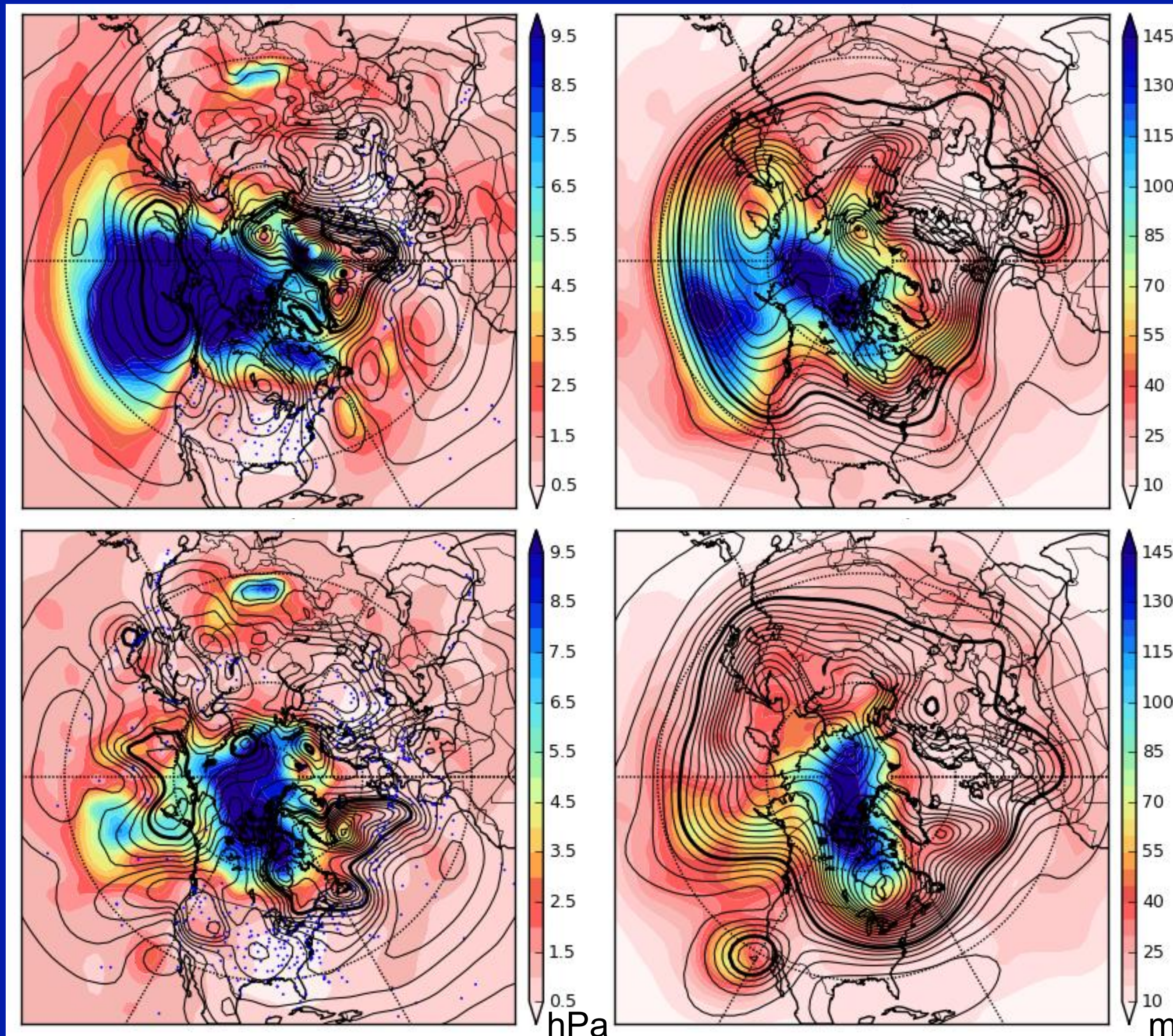
Before the satellite era (1970s), there is ***substantially better skill*** for 20CRv2 than for NCEP-NCAR Reanalysis or ERA40 in the Southern Hemisphere despite the lack of upper-air observations.

Compo et al. 2011

Analyses for selected dates in 1894 and 1914

1894

1914



Contours- ensemble mean

Shading- blue: more uncertain, white: more certain

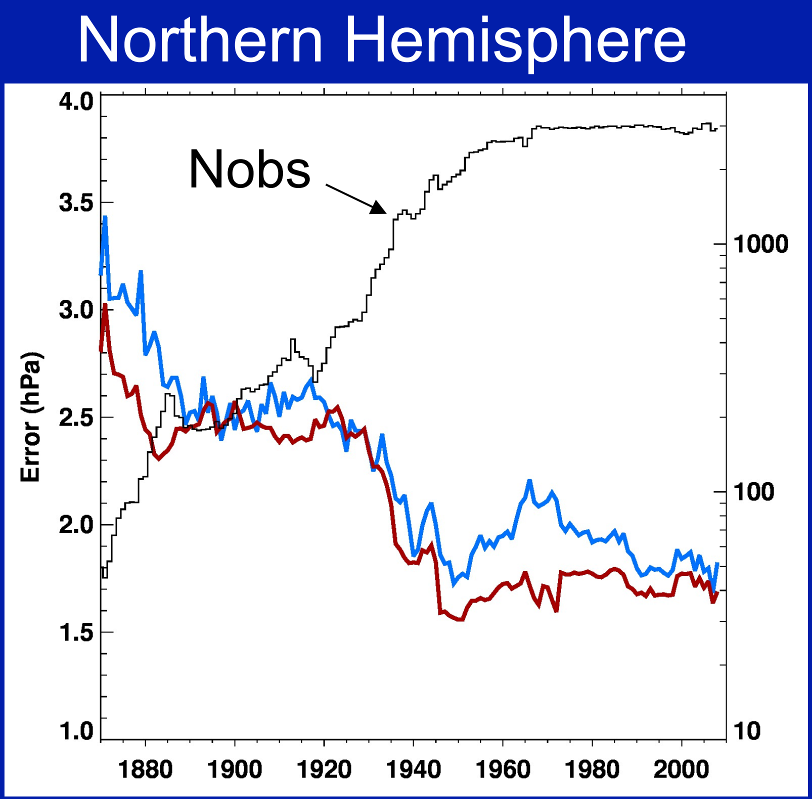
Sea Level Pressure

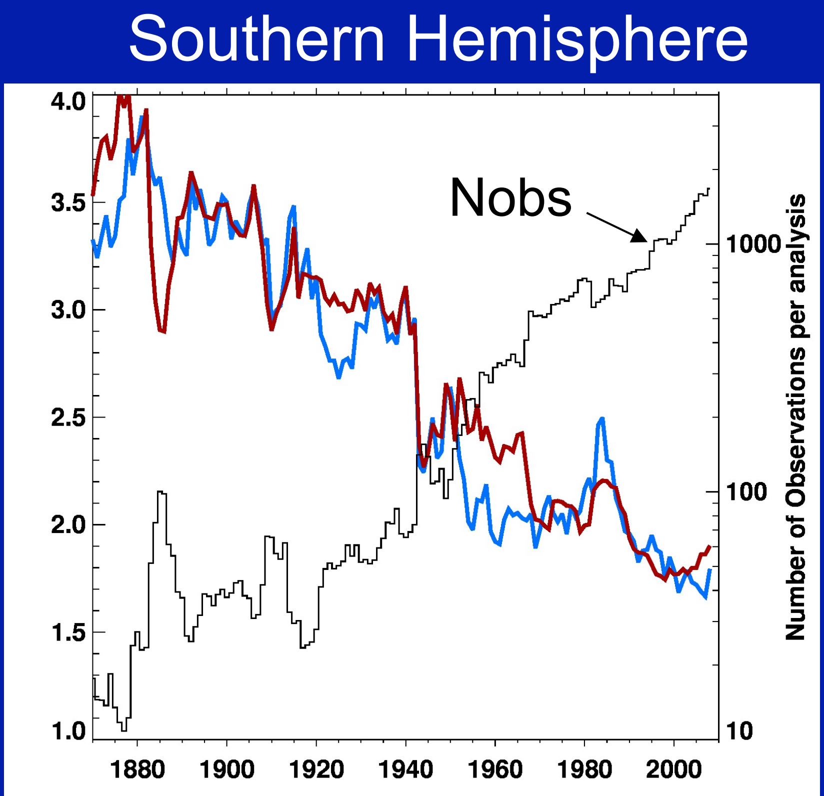
500 hPa Geopotential Height

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

blue actual RMS difference

red expected RMS difference

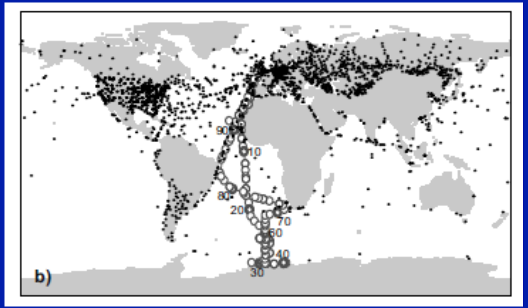




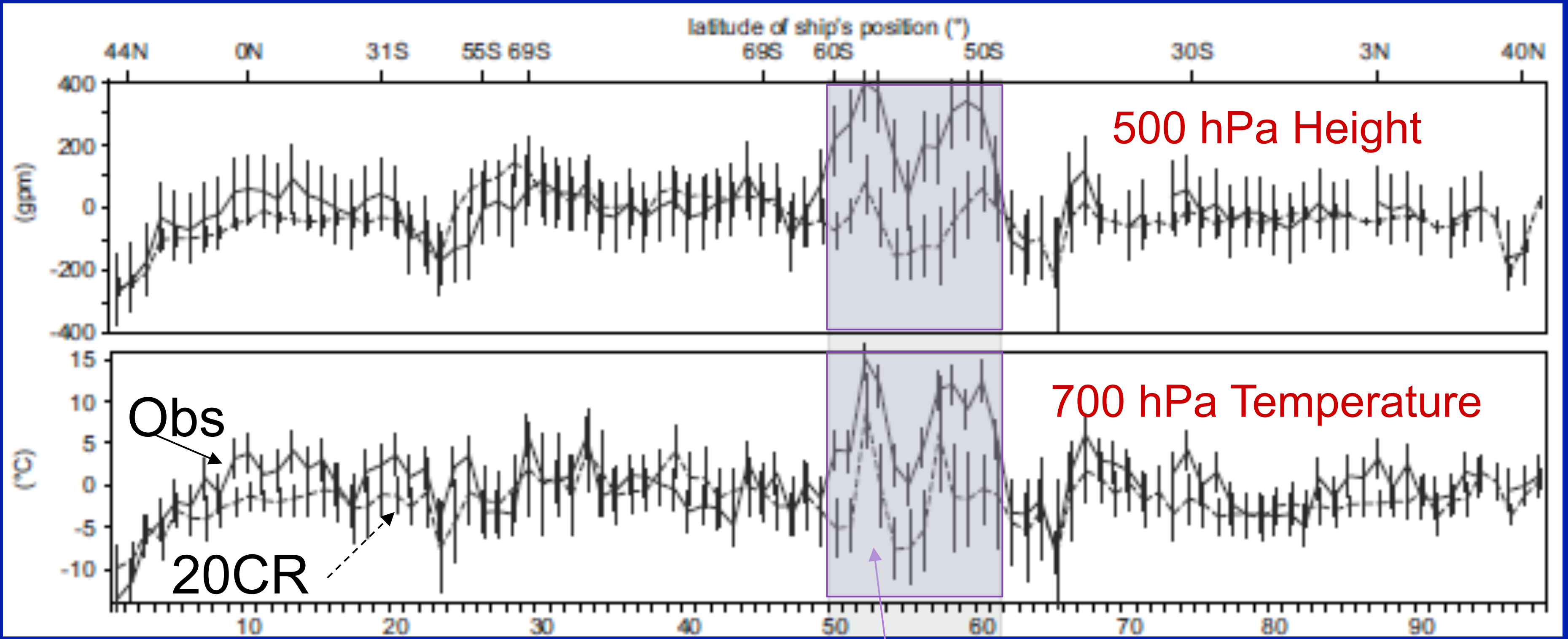
Uncertainty estimates are consistent with actual differences between first guess and pressure observations even as the network changes over more than 100 years!

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

(December 1938 to April 1939)



Cruise locations (open circles)



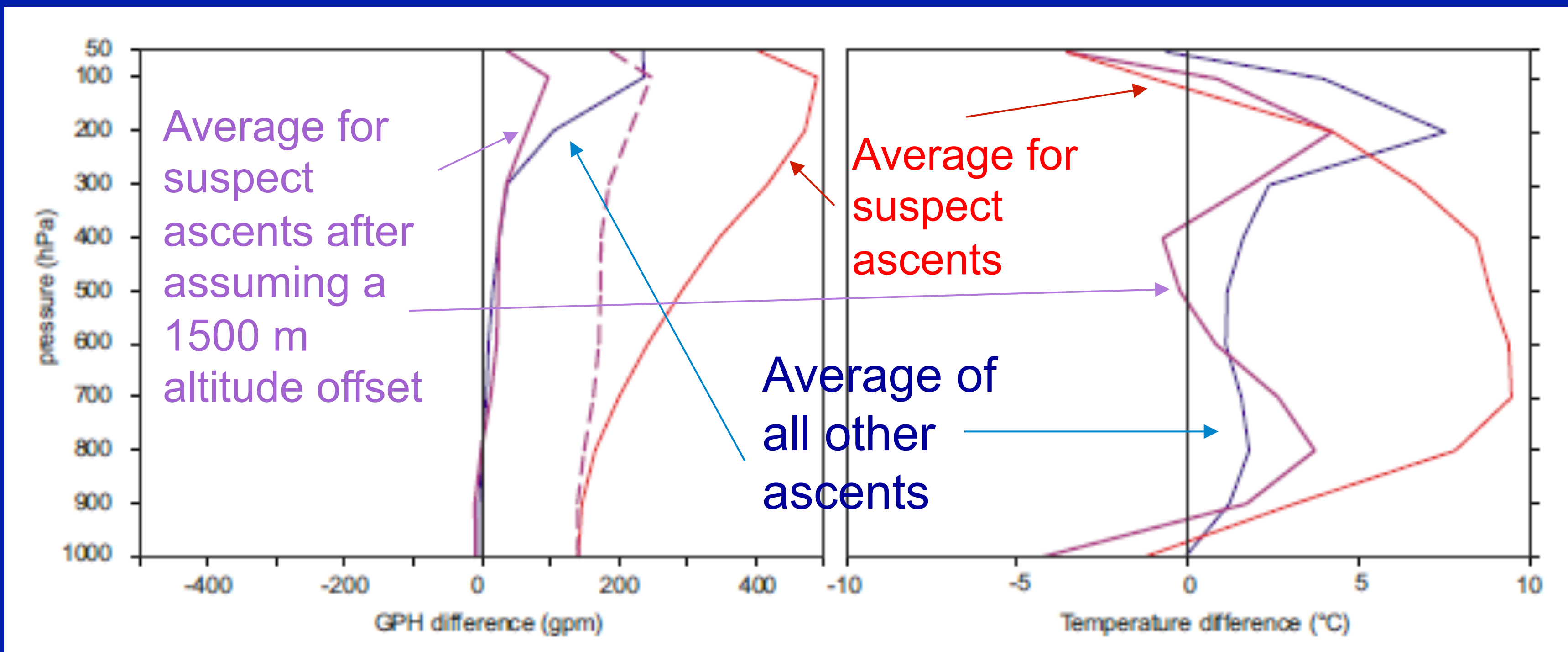
Anomalies are with respect to NCEP-NCAR Reanalyses

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

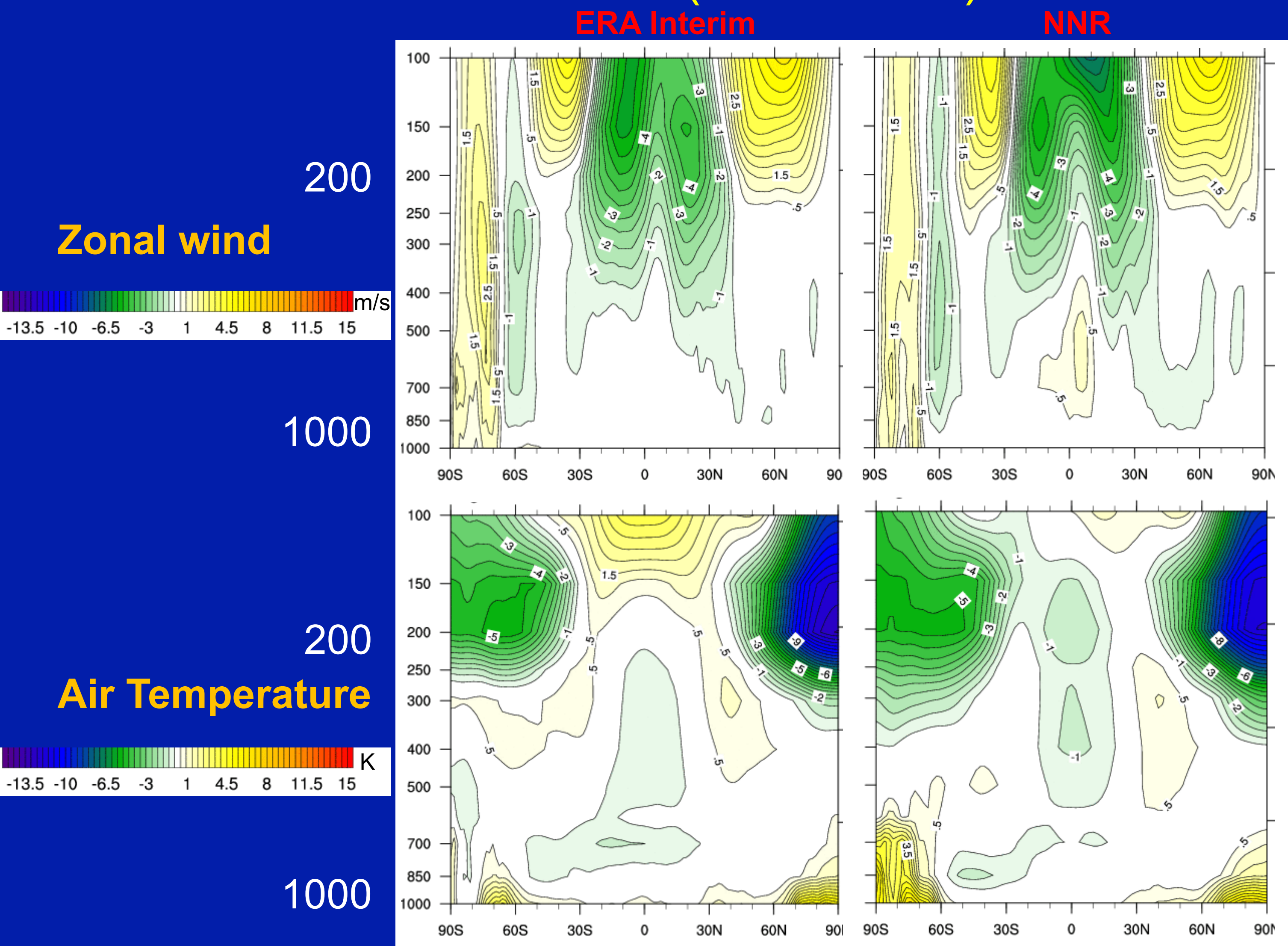
Geopotential Height Temperature



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

Brönnimann et al., Clim. Past (2011)

Zonal mean of annual differences between 20CR, ERA-Interim and NNR (1981-2010)



CI:0.5 m/s

Biases Over Poles and Stratosphere

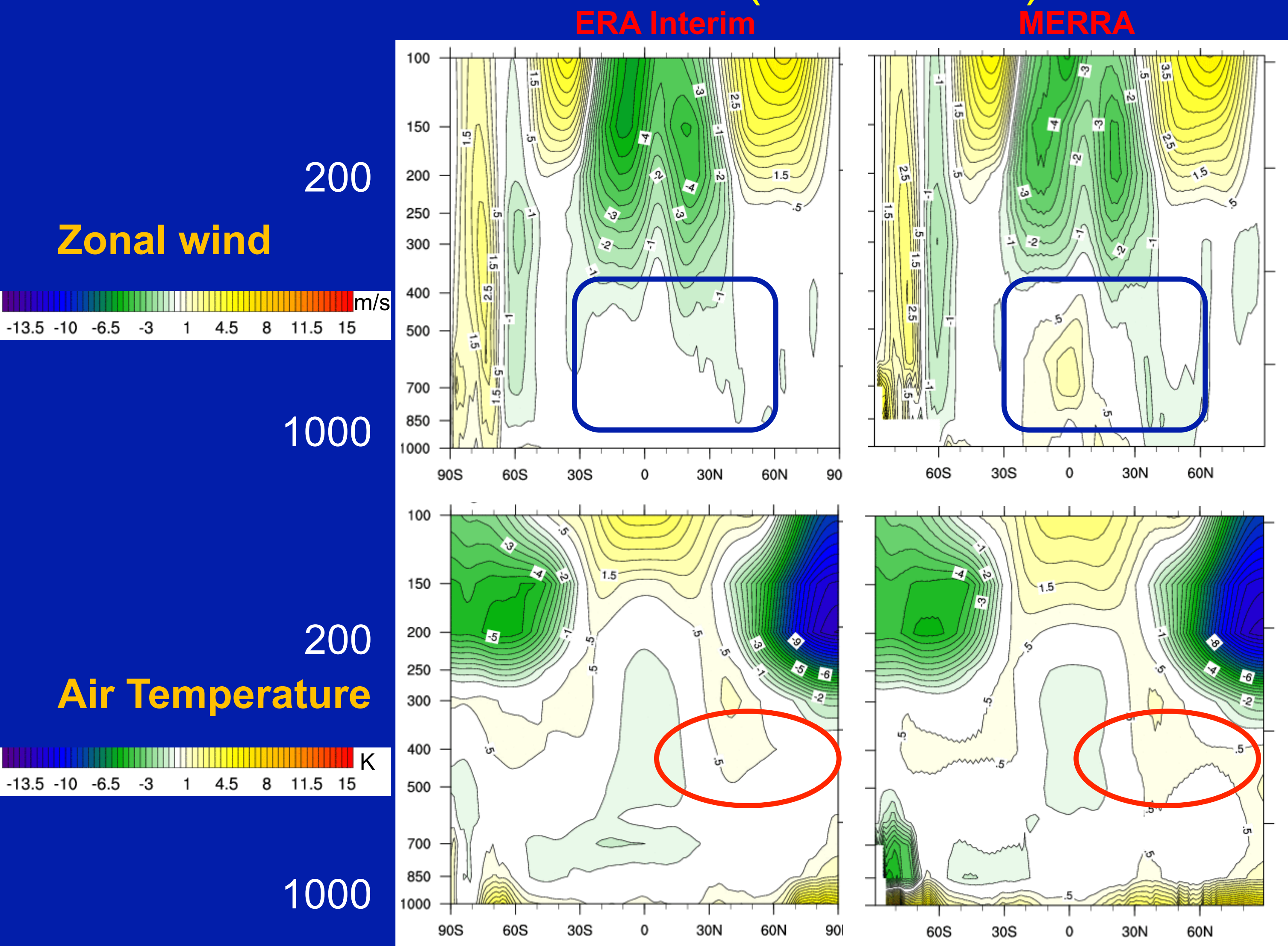
CI:0.5 K

Courtesy of new NOAA-CIRES WRIT tool (C. Smith)

20CR tropospheric biases are low and tend to be closer to ERA-Interim. They are sometimes of opposite sign.

Adapted from Compo et al. (2011)

Zonal mean of annual differences between 20CR, ERA-Interim and MERRA (1981-2010)



CI:0.5 m/s

Biases Over Poles and Stratosphere

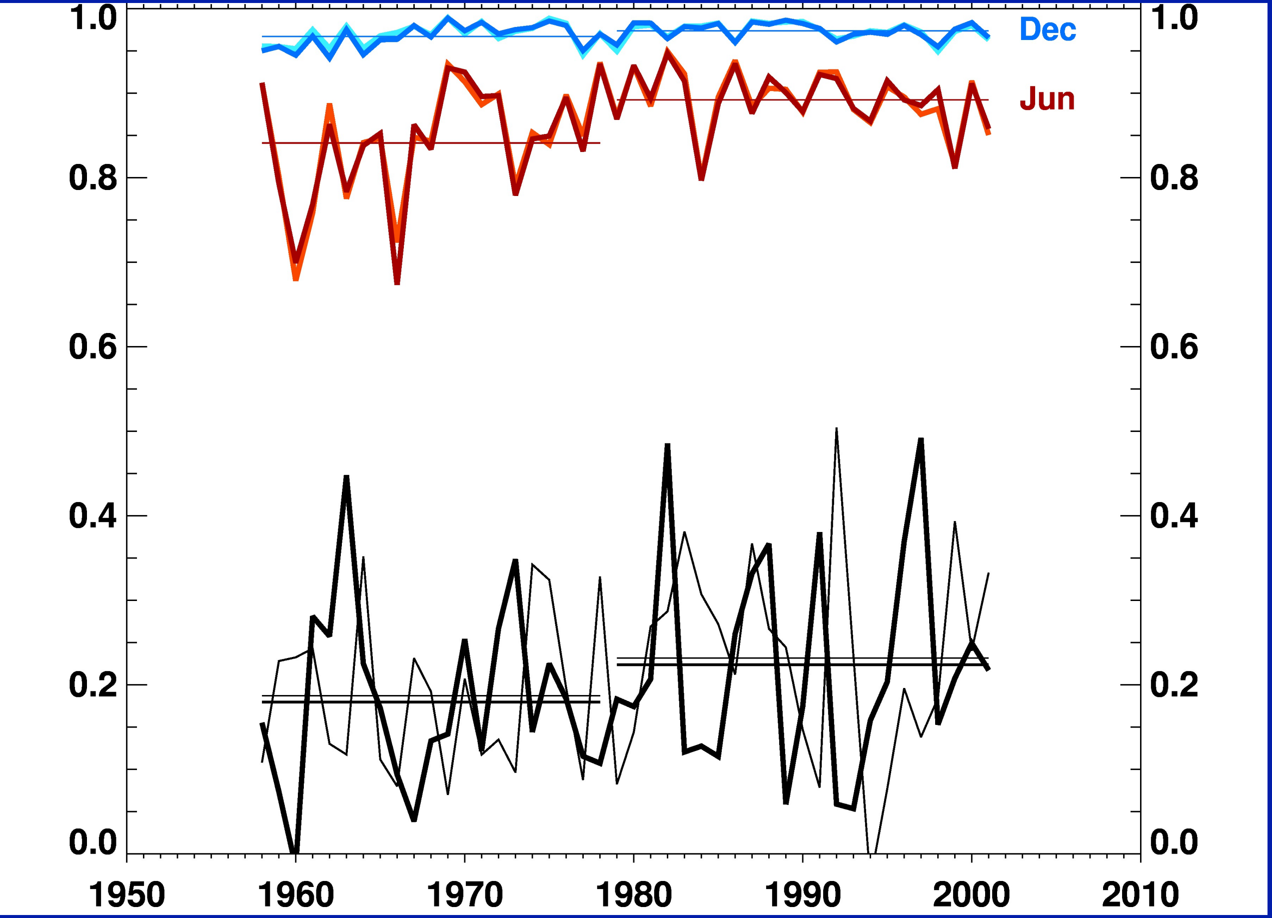
CI:0.5 K

Courtesy of new NOAA-CIRES WRIT tool (C. Smith)

20CR tropospheric biases are low and tend to be slightly closer to ERA-Interim. Sign of biases is similar.

Adapted from Compo et al. (2011)

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

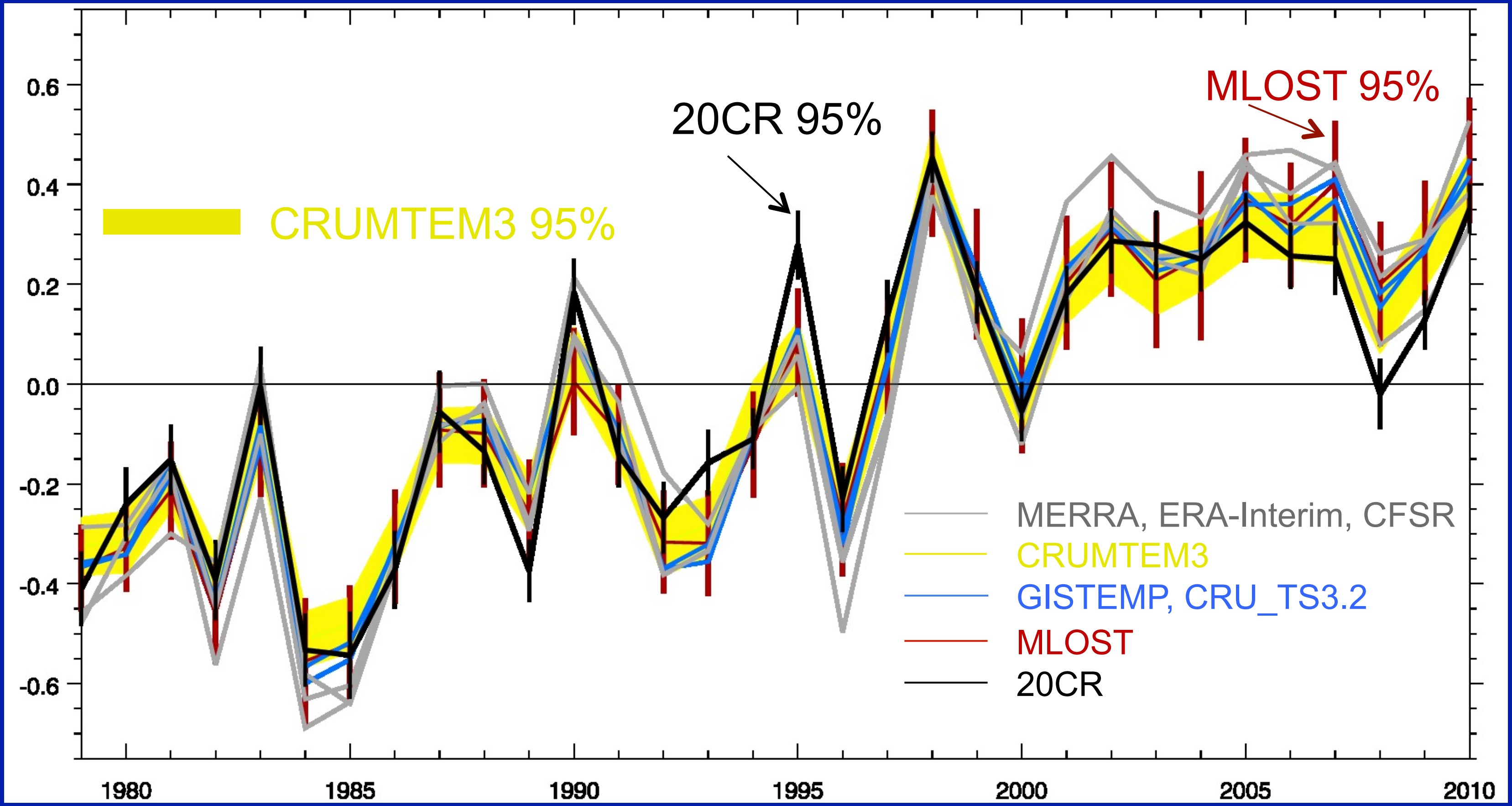


Correlation Between NNR and 20CR (and ERA-40 and 20CR)

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.

Near Surface
Annual Mean Temperature Anomalies
for Land only (60N to 60S) 1979 to 2010

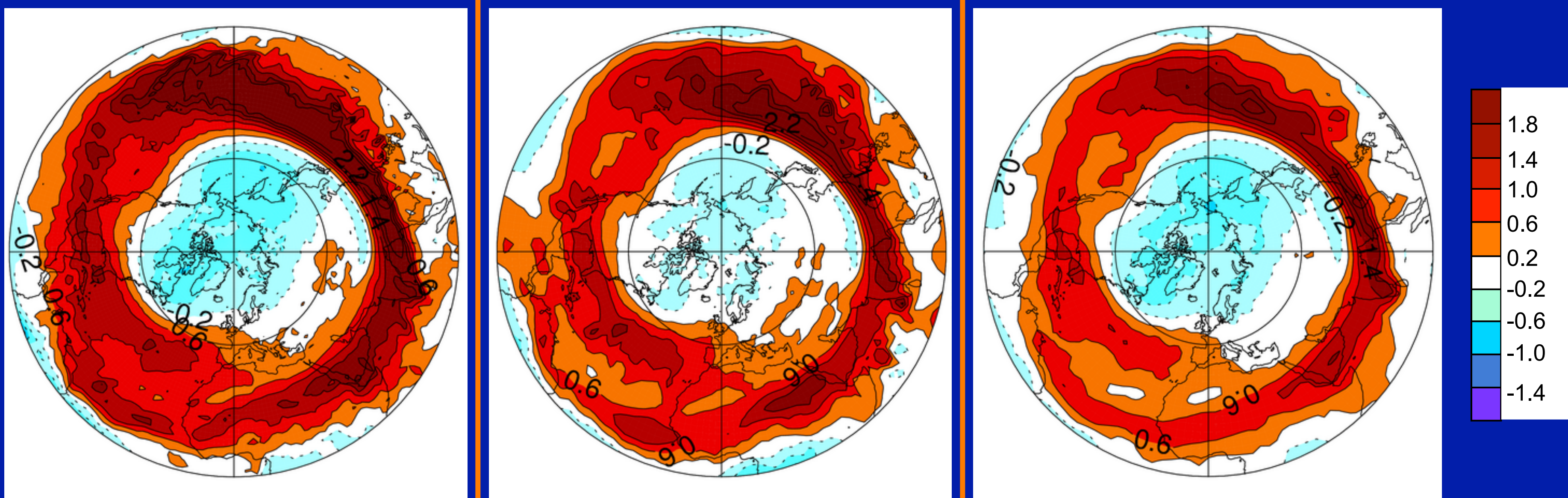


Correlations between 20CR and thermometer-based estimates are relatively high (0.94 to 0.95) [see Parker 2011]. Correlations with upper-air and satellite-based reanalyses also high (0.91 to 0.94). 95% error ranges are largely consistent.

Compo, Sardeshmukh, Whitaker, Jones, Brohan , and McColl (2012)

Storm Track

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



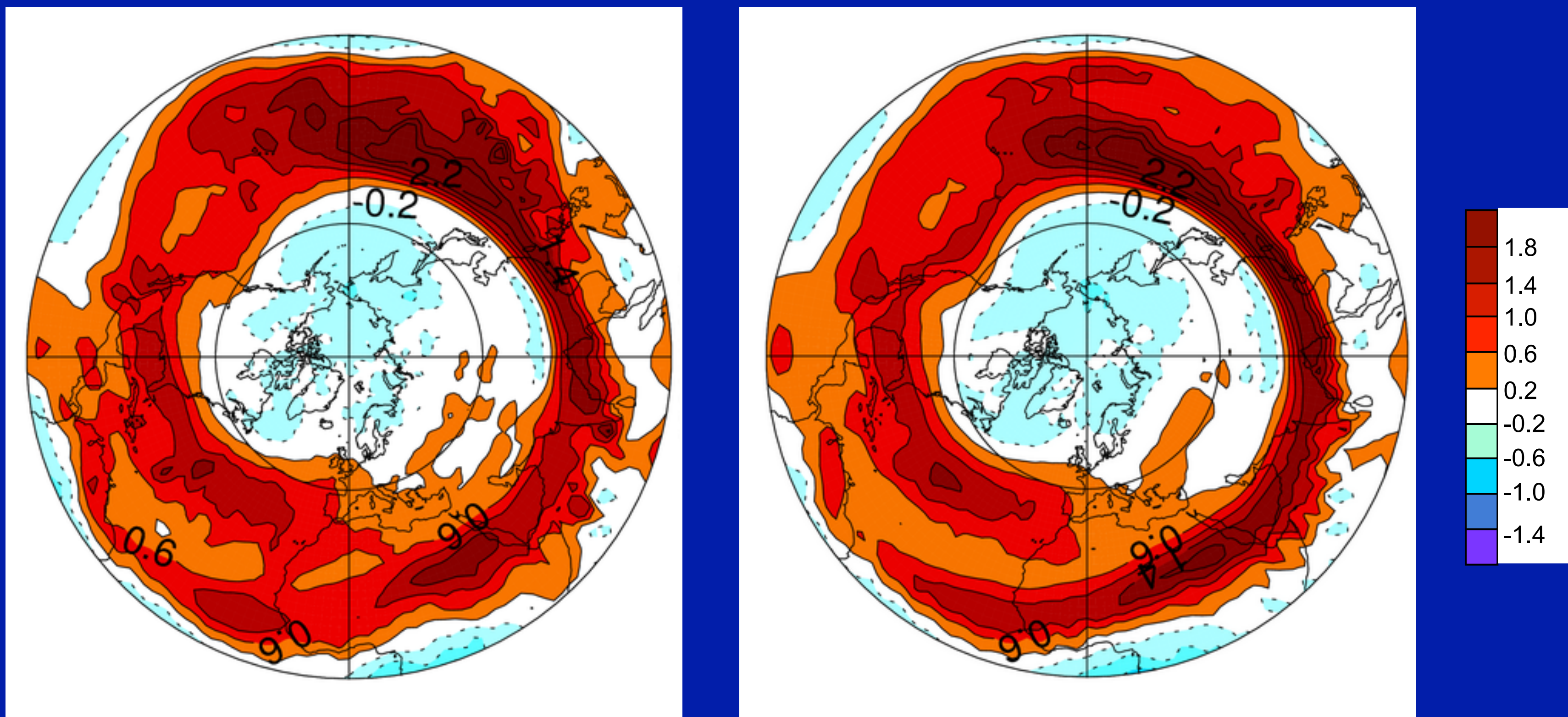
ERA Interim (~50km)
Uses satellite and upper-air data

20CRv2 (~200km)
Surface pressure only

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

Skewness of 250 hPa Vorticity from 20th 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

- Data Access: Analyses and ISPD (with feedback) freely available from NCAR, analyses from NOAA/ESRL and DOE NERSC. Coming Soon: NOAA/NCDC.
- **Fall 2011**: 1871-2-1-(includes time-varying CO2, 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 (NOAA ESRL)
  - http://dss.ucar.edu/datasets/ds131.1 (NCAR)
  - http://portal.nersc.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 -Climate (ERA-CLIM) (upcoming talk from Dee)

- Series of reanalyses, including Surface-observation based back to 1900 (ERA-20C).
- ERA-20C: T159 spectral (~125km grid spacing)

An overview of the proposed NOAA climate reanalysis effort

- NCEP and ESRL will plan to conduct a set of hierarchical climate reanalysis streams.
  - **AMIP: SST and boundary forcing**
  - **Surface data based reanalysis (SIRCA 1850-2014)**
  - **Conventional data based reanalysis**
  - **Satellite era reanalysis**
- The hierarchical aspect involves staggered parallel execution of reanalysis streams in increasing order of complexity
- Results from basic streams may be used to bias correct, detrend, or otherwise adjust inputs into runs at the next higher complexity level

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 (e.g., Hybrid EnKF), possibly other surface variables (e.g., wind)
4. Uncertainty in forcings (e.g, CO2, solar, SST)
5. Possibly Multi-model (e.g., NASA, NCAR, NCEP, GFDL, ESRL)

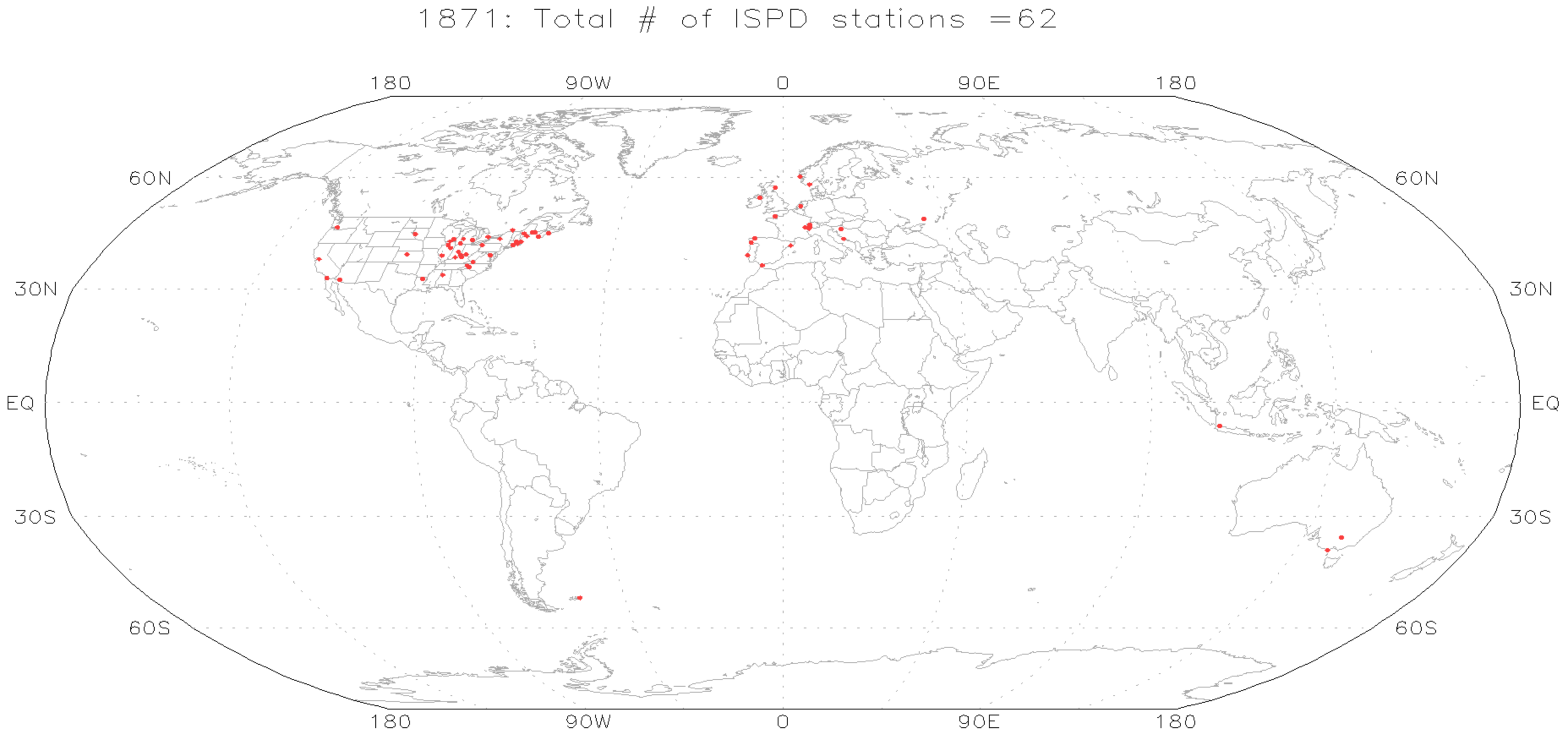
Available 2014 – SIRCA (*1850-2014*)

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

Requires international cooperation, e.g.,
Atmospheric Circulation Reconstruction over the Earth initiative

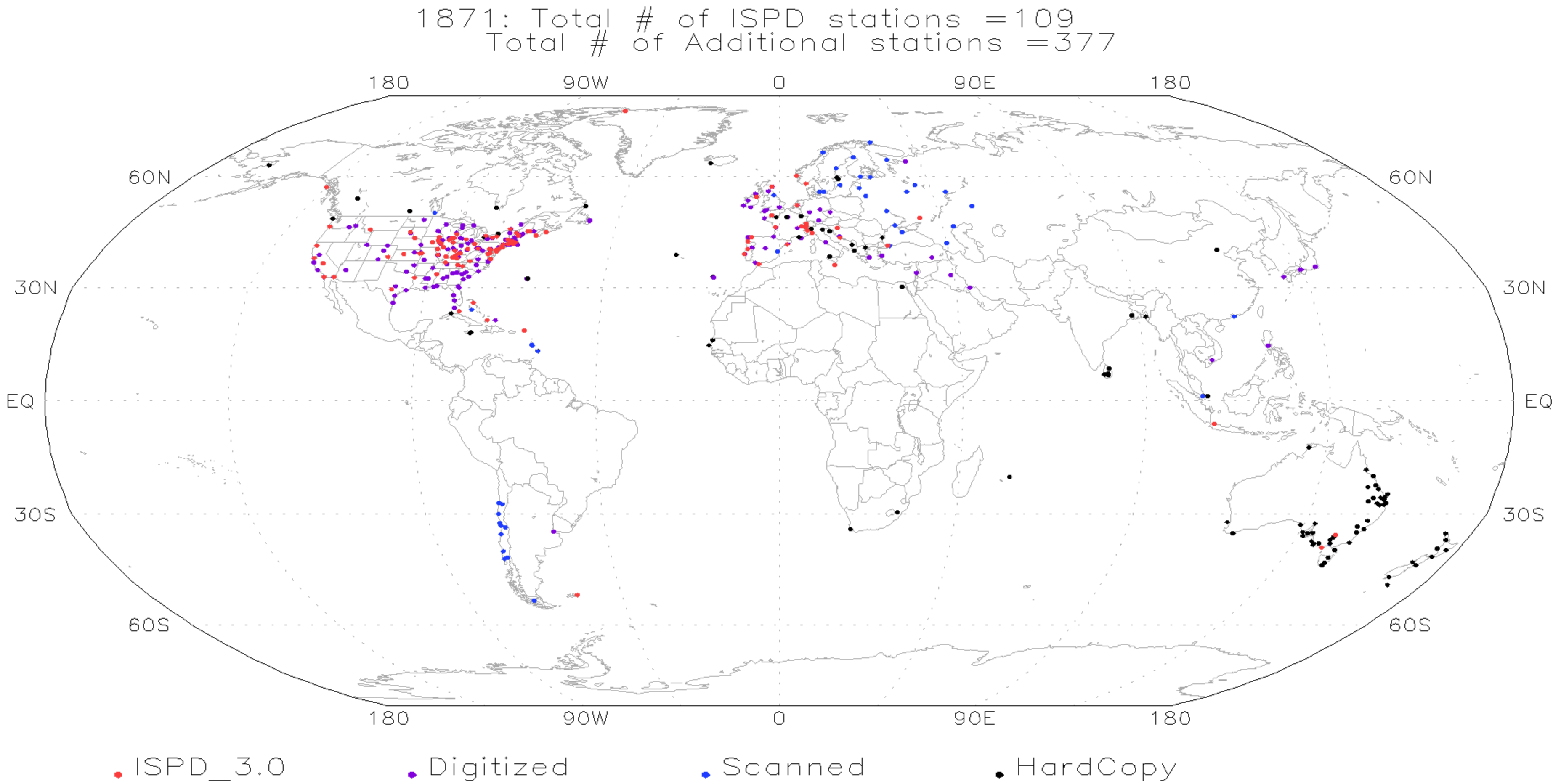
http://www.met-acre.org

Station locations in ISPDv2 (1871)



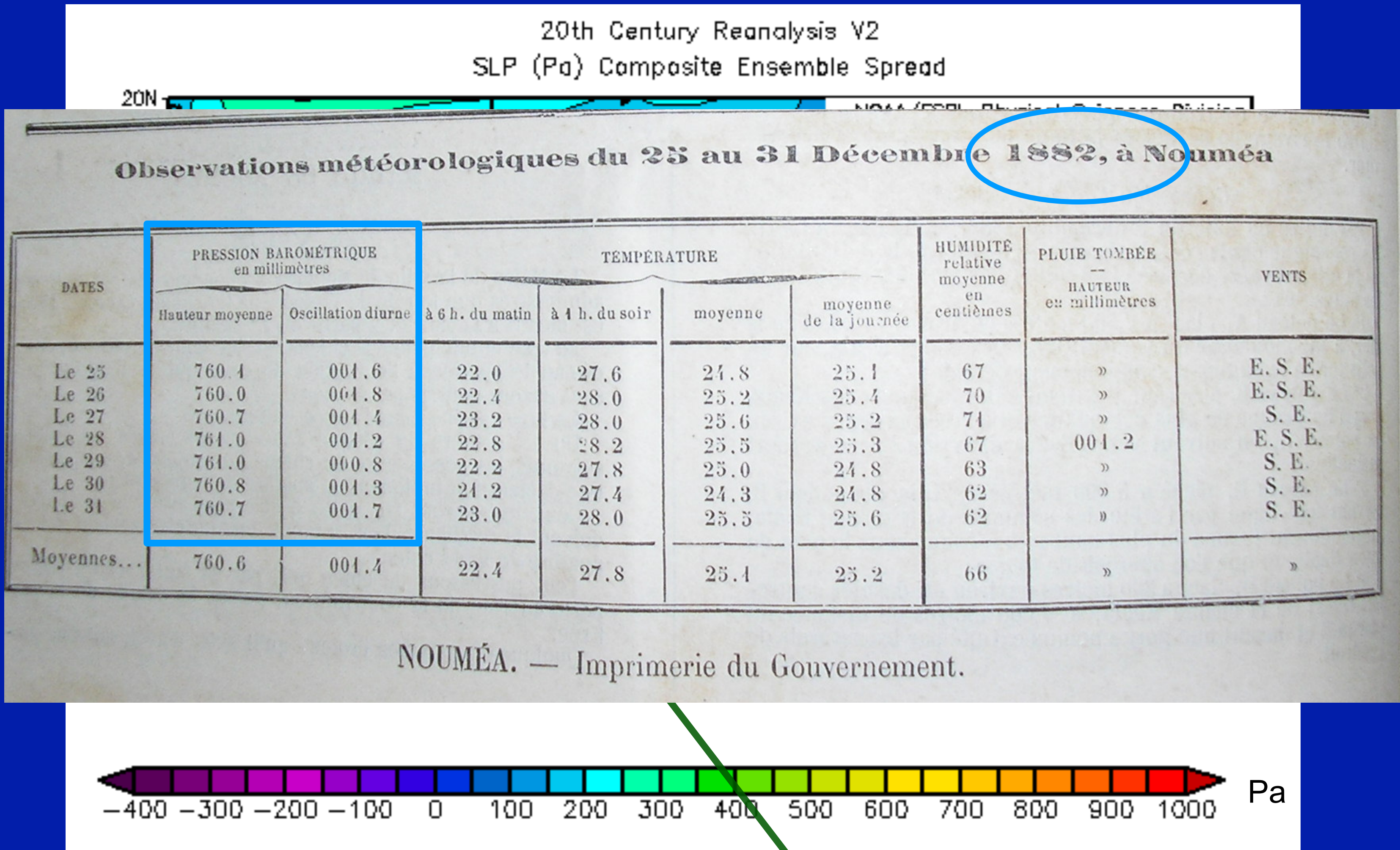
62 stations used in 20CR

Known station locations in ISPDv3 and that could be in future ISPD (1871)



At least 377 stations could be used in SIRCA

Value of additional observations



Observations météorologiques du 25 au 31 Décembre 1882, à Nouméa

DATES	PRESSION BAROMÉTRIQUE en millimètres		TEMPÉRATURE				HUMIDITÉ relative moyenne en centièmes	PLUIE TOMBÉE — HAUTEUR en millimètres	VENTS
	Hauteur moyenne	Oscillation diurne	à 6 h. du matin	à 1 h. du soir	moyenne	moyenne de la journée			
Le 25	760.4	001.6	22.0	27.6	24.8	25.1	67	»	E. S. E.
Le 26	760.0	001.8	22.4	28.0	25.2	25.4	70	»	E. S. E.
Le 27	760.7	001.4	23.2	28.0	25.6	25.2	71	»	S. E.
Le 28	761.0	001.2	22.8	28.2	25.5	25.3	67	001.2	E. S. E.
Le 29	761.0	000.8	22.2	27.8	25.0	24.8	63	»	S. E.
Le 30	760.8	001.3	24.2	27.4	24.3	24.8	62	»	S. E.
Le 31	760.7	001.7	23.0	28.0	25.5	25.6	62	»	S. E.
Moyennes...	760.6	001.4	22.4	27.8	25.4	25.2	66	»	»

NOUMÉA. — Imprimerie du Gouvernement.

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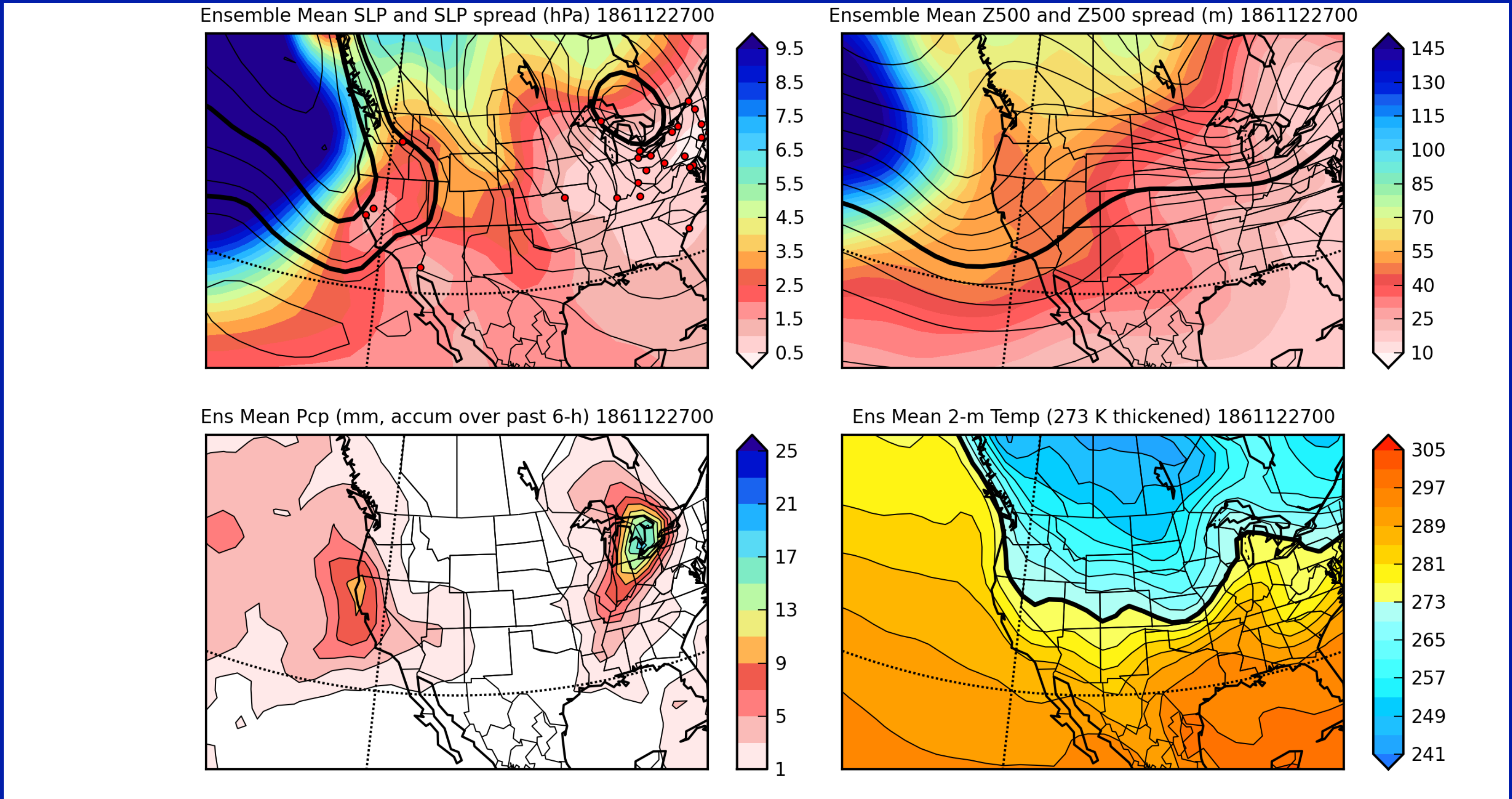
Courtesy A. Peltier of New Caledonia Met Service,
trip to State Archives found New Caledonia SLP data back to 1862

1861/62 Largest flood in California
Series of synoptic extreme rainfall events
(27 to 28 December 1861)

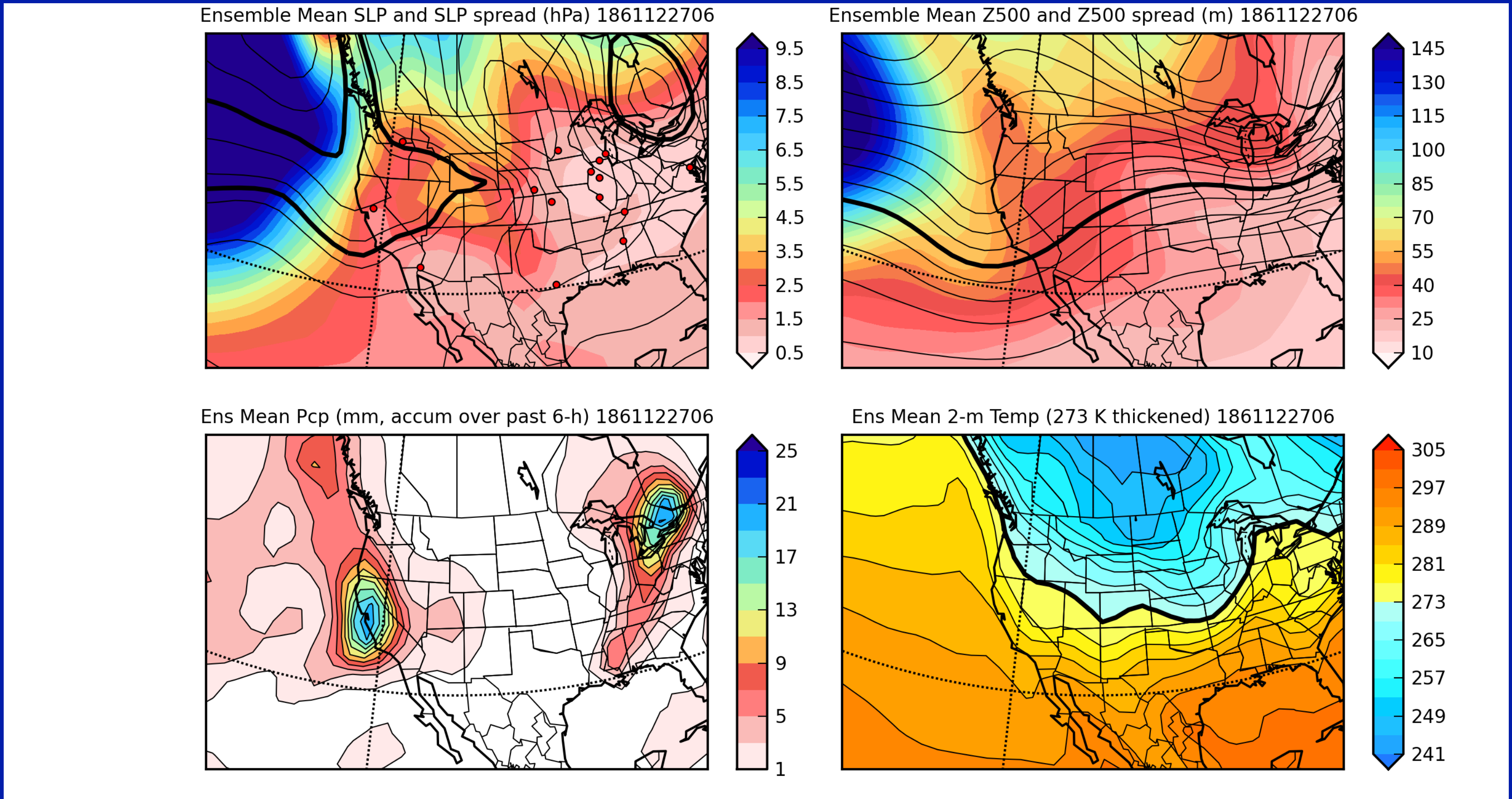


27 December 1861 00UTC

1861/62 Largest flood in California

Series of synoptic extreme rainfall events

(27 to 28 December 1861)

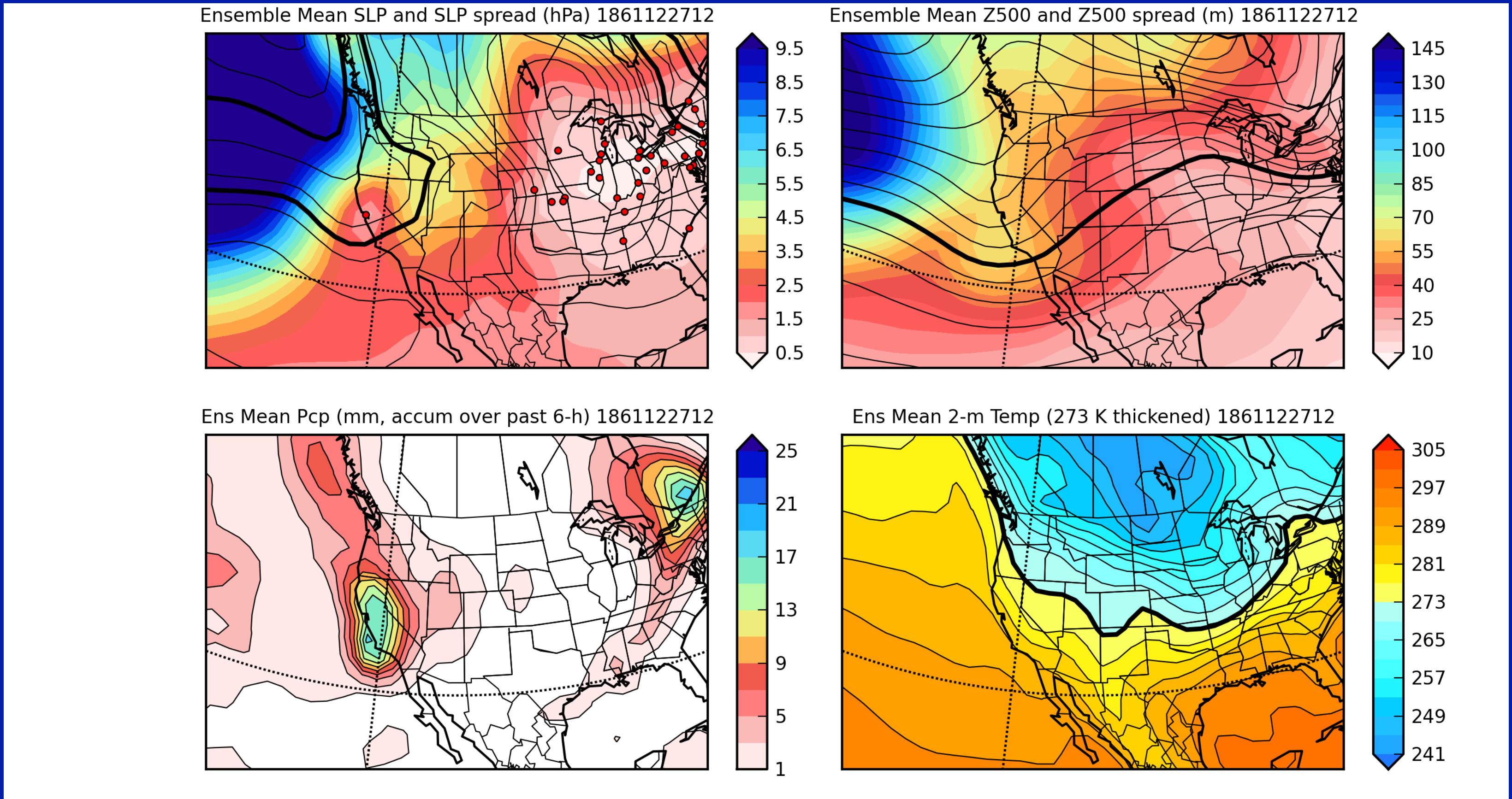


27 December 1861 06UTC

1861/62 Largest flood in California

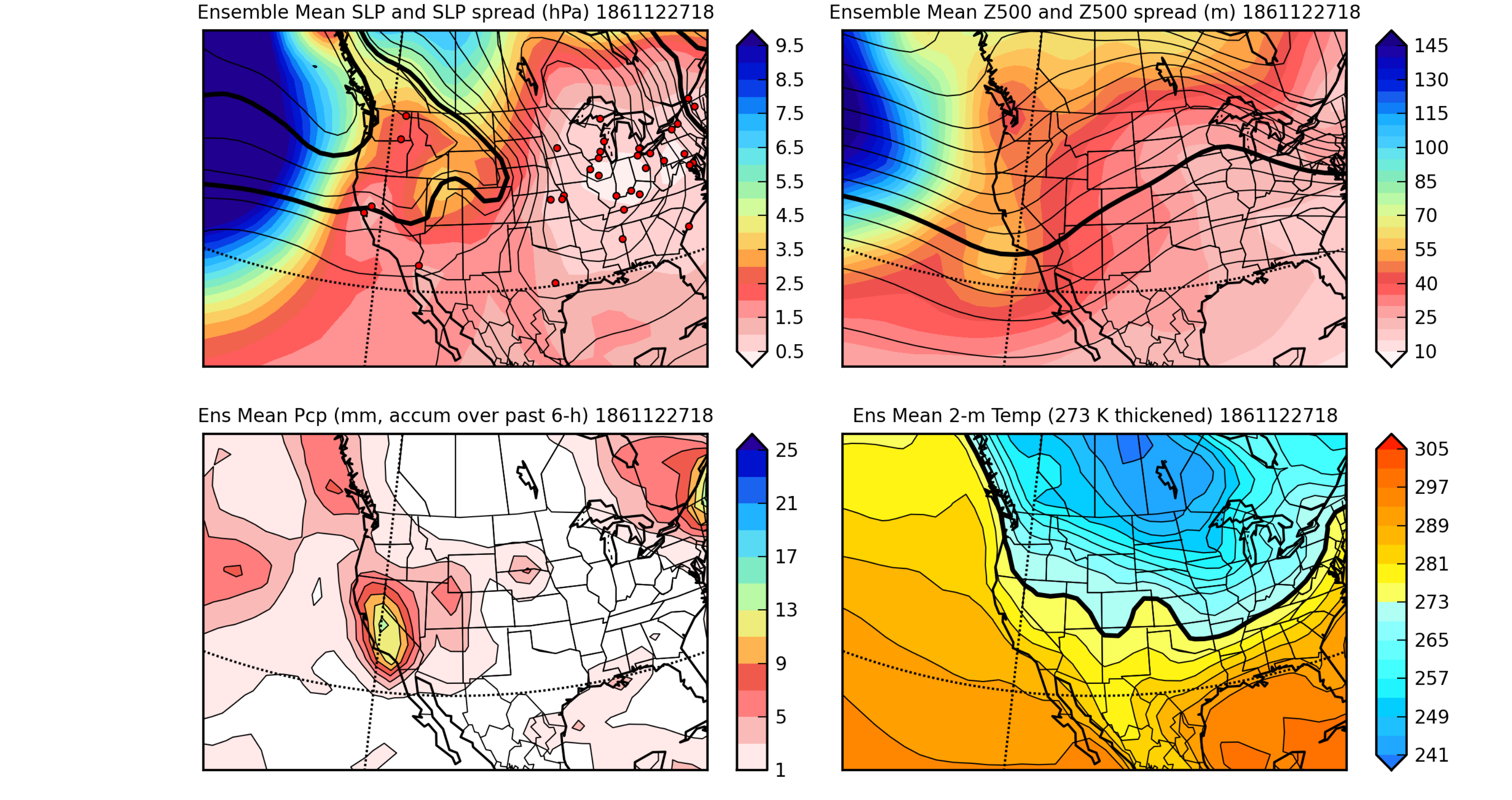
Series of synoptic extreme rainfall events

(27 to 28 December 1861)



27 December 1861 12UTC

1861/62 Largest flood in California
Series of synoptic extreme rainfall events
(27 to 28 December 1861)



27 December 1861 00UTC

Summary

- **Demonstrated that surface-based reanalyses have skill *throughout the troposphere* using advanced data assimilation and surface pressure observations.**

- **Effectively doubling the reanalysis record length from ~70 year to 140 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.**

- **Need to extend back to at least 1850 for full overlap with CMIP5 and other uses. Longest possible reanalysis record is needed for increasing sample size for extremes.**

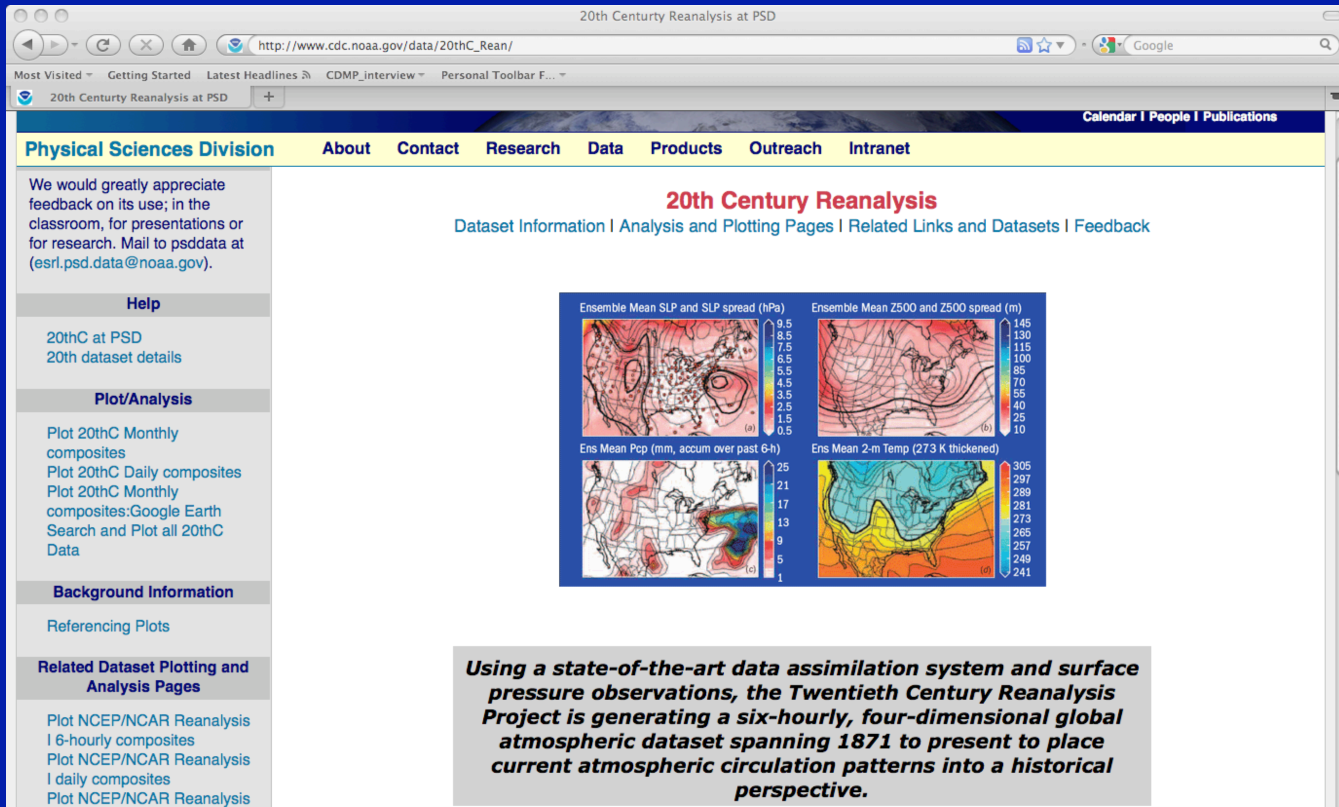
- **Additional observations currently in paper archives will further improve these reanalyses for SIRCA.**

- For additional information, email or go to
  - jeffrey.s.whitaker@noaa.gov,
  - compo@colorado.edu

Thank you to 61 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 and Obs for Monitoring
GCOS AOPC/OOPC WG on Surface Pressure
GCOS/WCRP WG on Obs Data Sets
Hong Kong Observatory
Icelandic Meteorological Office
IBTrACS
ICOADS
IEDRO
JAMSTEC
Japan Meteorological Agency
Jersey Met Dept.
Lamont-Doherty Earth Observatory
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
UK Met Office Hadley Centre
U. of Bern, Switzerland
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 Lisbon-Instituto de Meteorologia
U. of Mebourne
U. of Milan-Dept. of Physics
U. of Porto-Instituto Geofisca
U. Rovira i Virgili-Center for Climate Change
U. of South Carolina
U. of Toronto-Dept of Physics
U. of Washington
World Meteorological Organization - MEDARE
ZAMG (Austrian Weather Service)

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



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

Extra Slides

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

Co-authors on 20th Century Reanalysis Project

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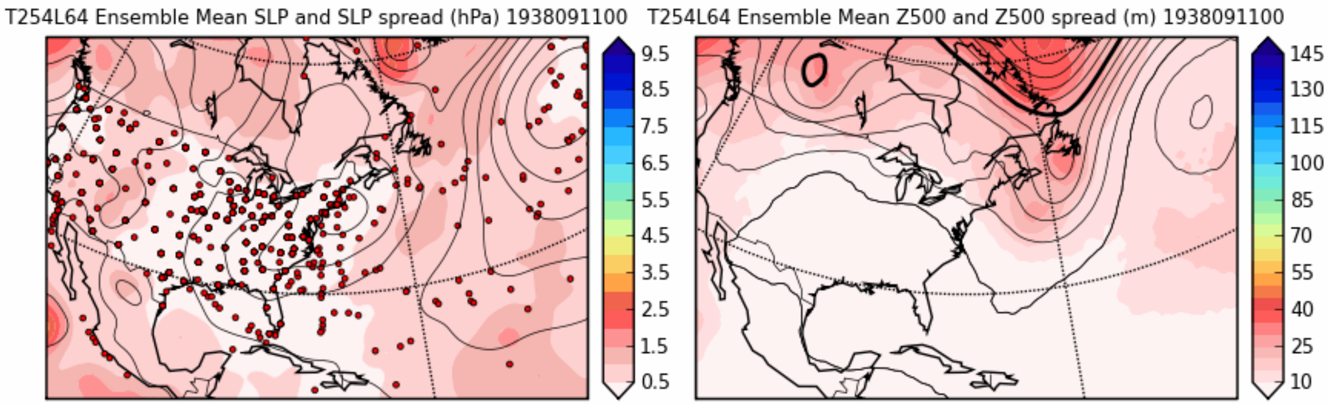
Higher resolution example of Sparse Input Reanalyses for Climate Applications (SIRCA)

2008 NCEP GFS at ~50km resolution

September 1938 New England (movie)



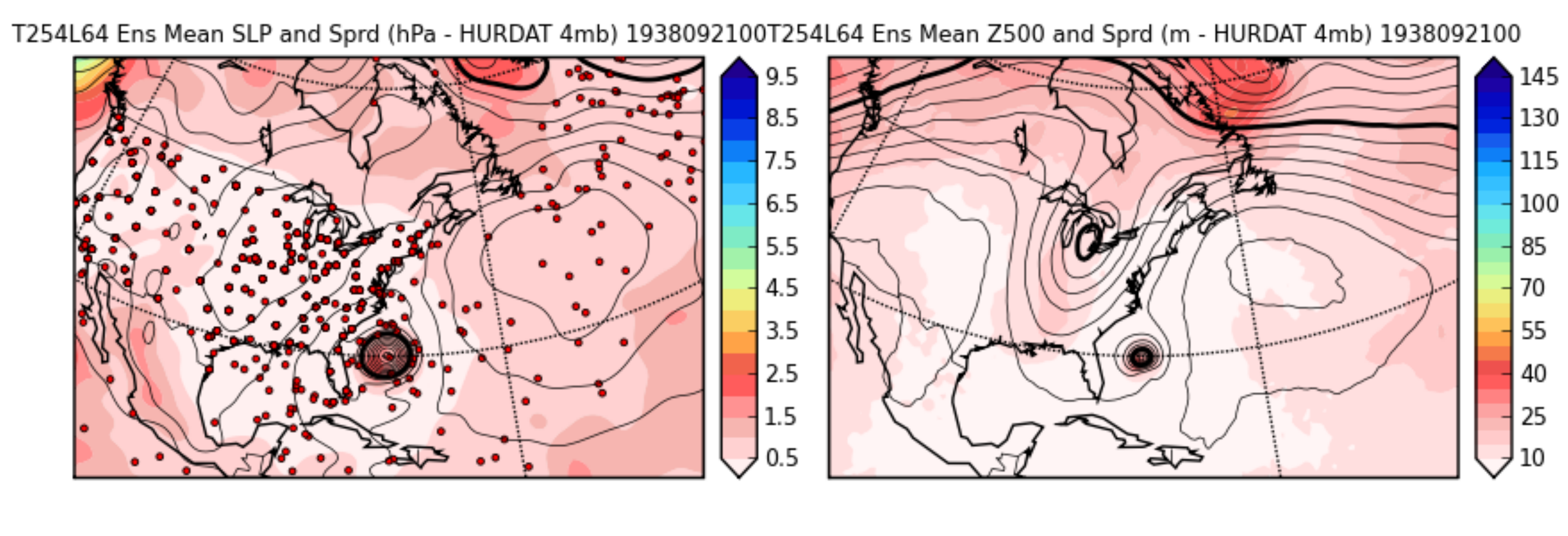
T254L64 (~50 km)

Is the extraordinary upper-level trough correct?

2008 NCEP GFS at ~50km resolution

21 September 1938 00 UTC

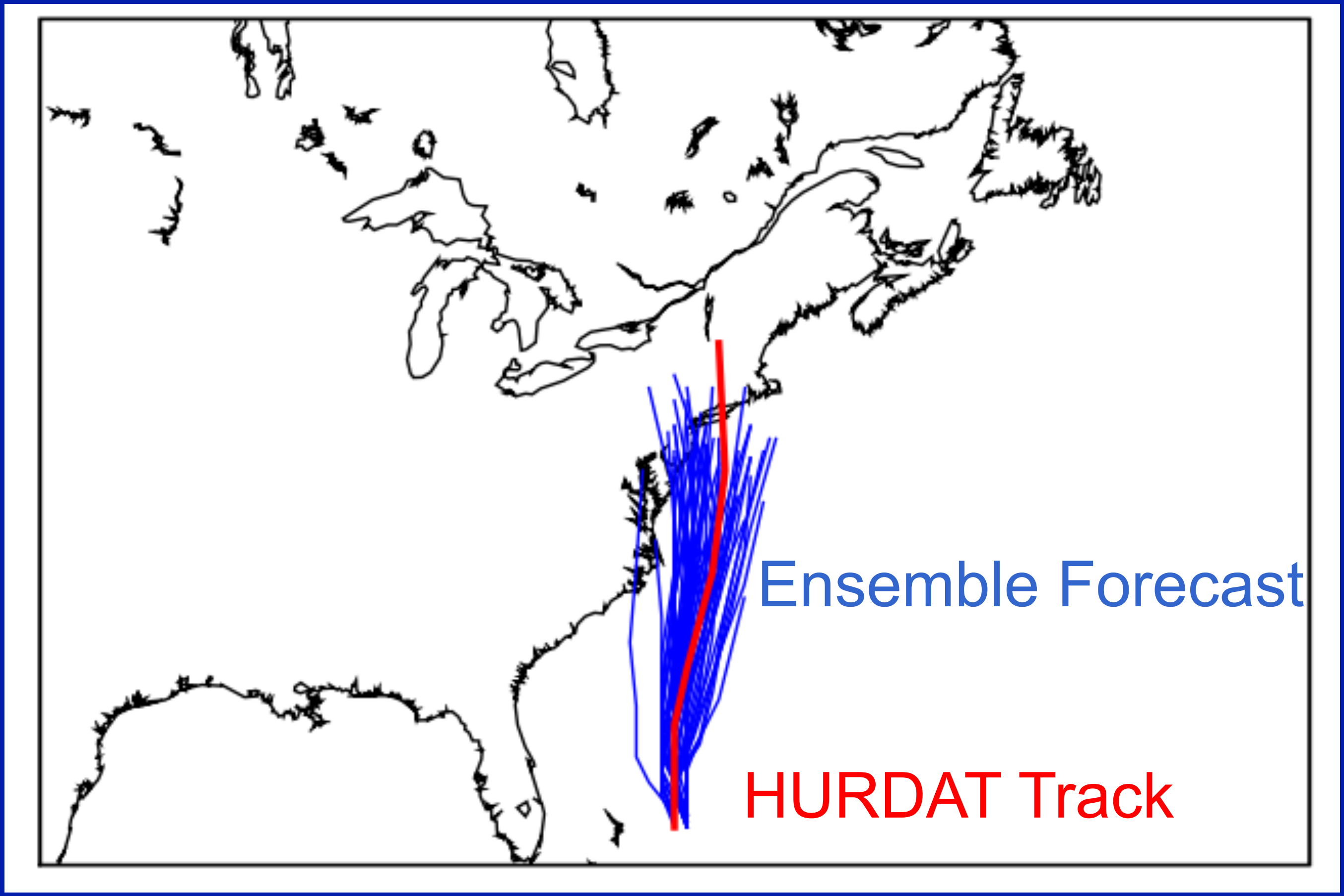
Sea Level Pressure　　500 hPa geopotential height



Is the extraordinary upper-level trough correct?

Any Skill Forecasting the Track?

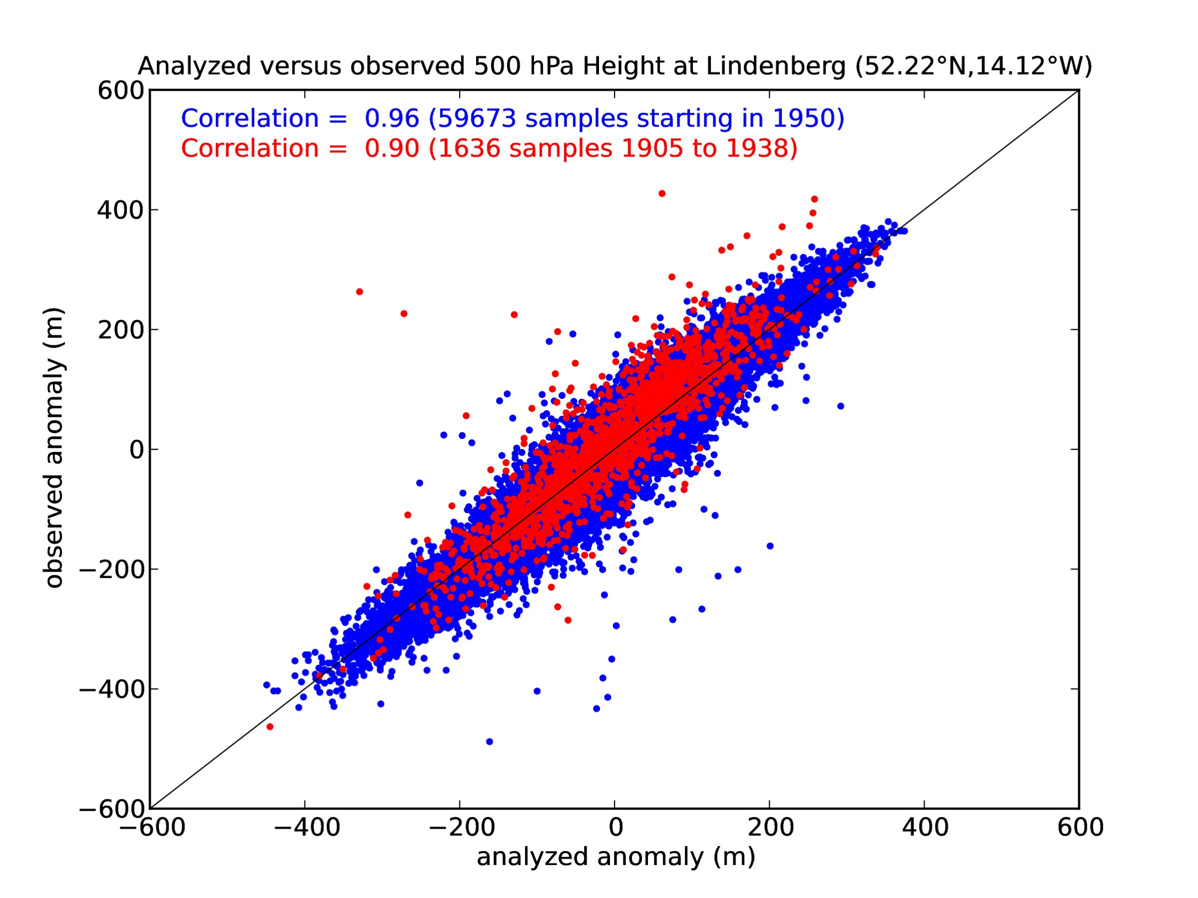
36 hour forecast verifying 21 Sept 1938 18Z



using 56 ensemble members T254L64 (about 0.5 degree)

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

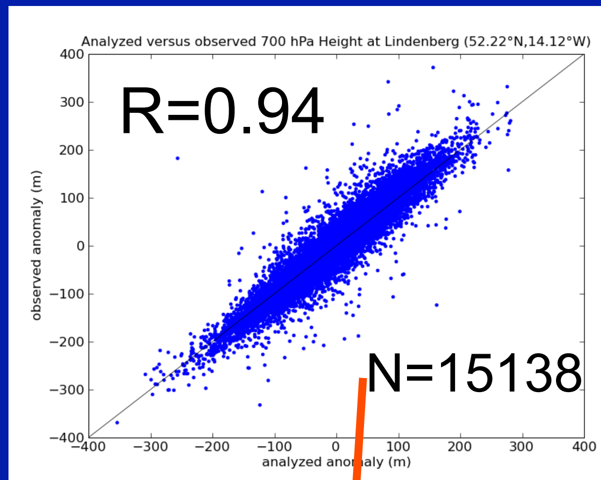


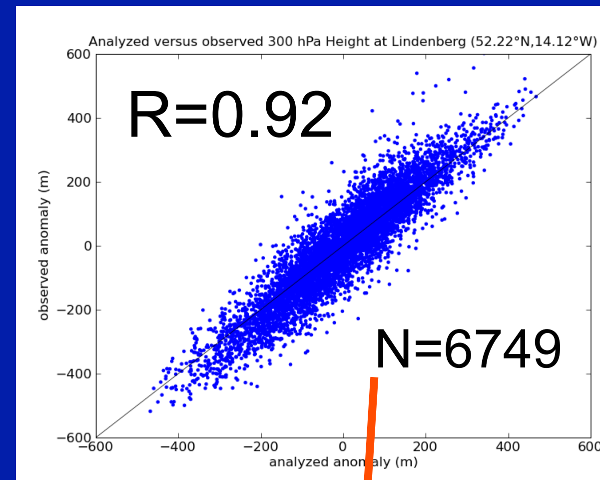
Observations from CHUAN dataset (*Stickler et al. 2010*)

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

700 hPa | **300 hPa**

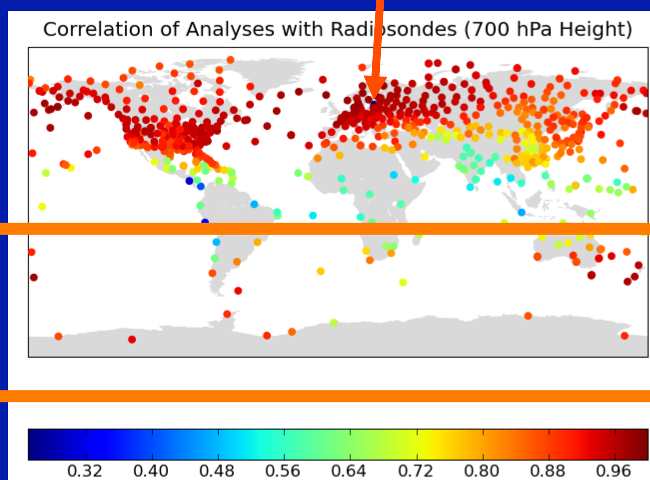
1908-1958
data from kites, aircraft, radiosondes at Lindenberg, Germany

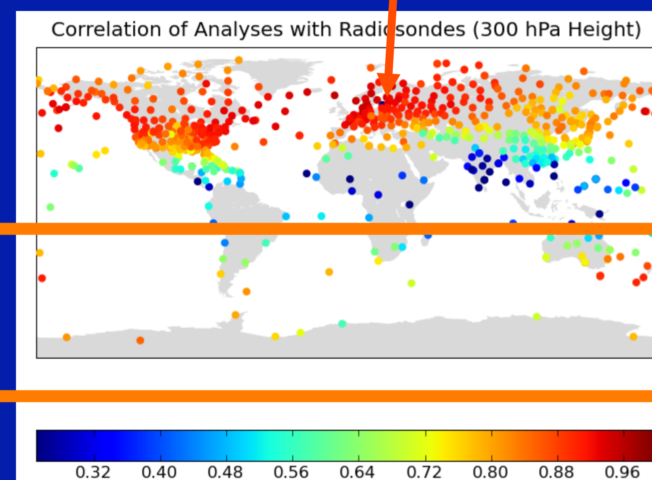




Upper-air observations with at least 730 ascents

Courtesy ETH Zurich





Agreement with Southern Hemisphere extratropics is good.

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

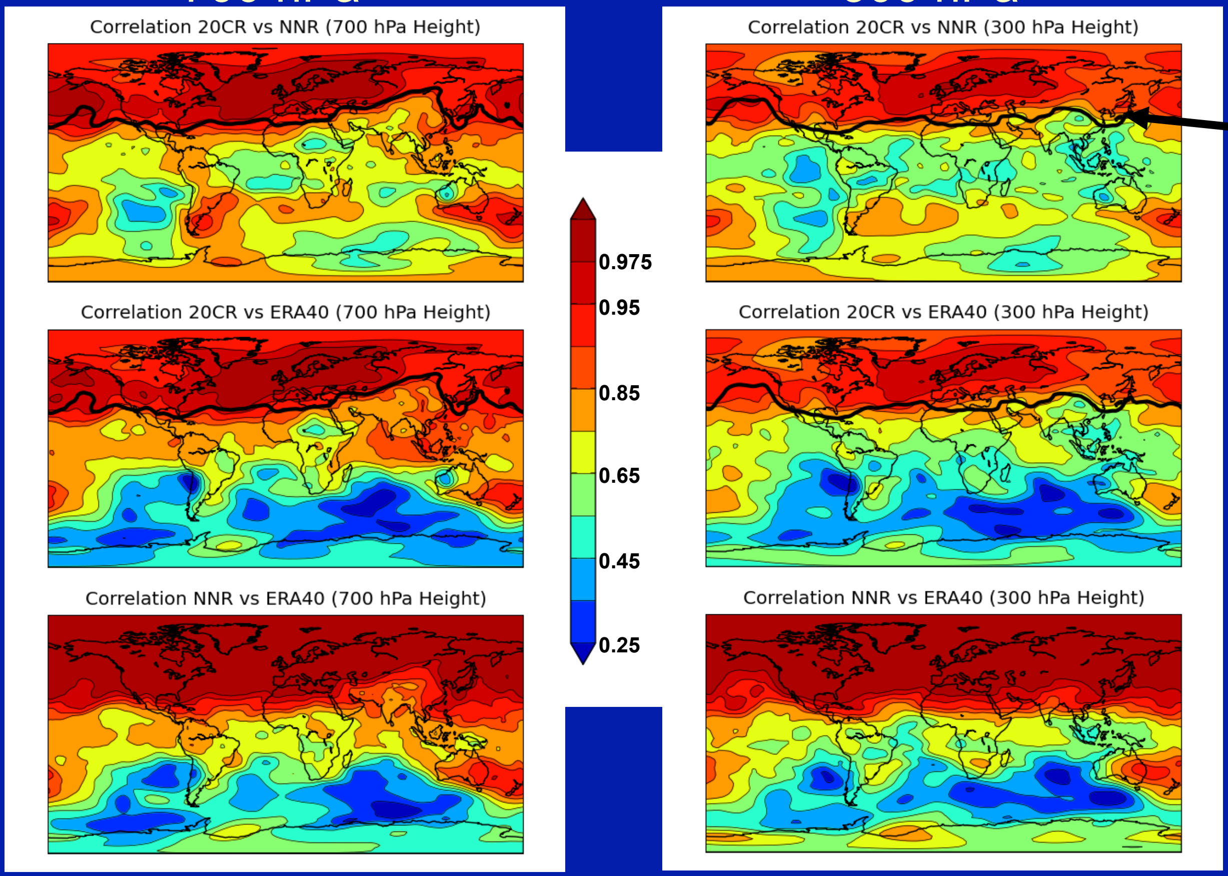
700 hPa

300 hPa

20CR vs. NNR

20CR vs. ERA40

NNR vs. ERA40

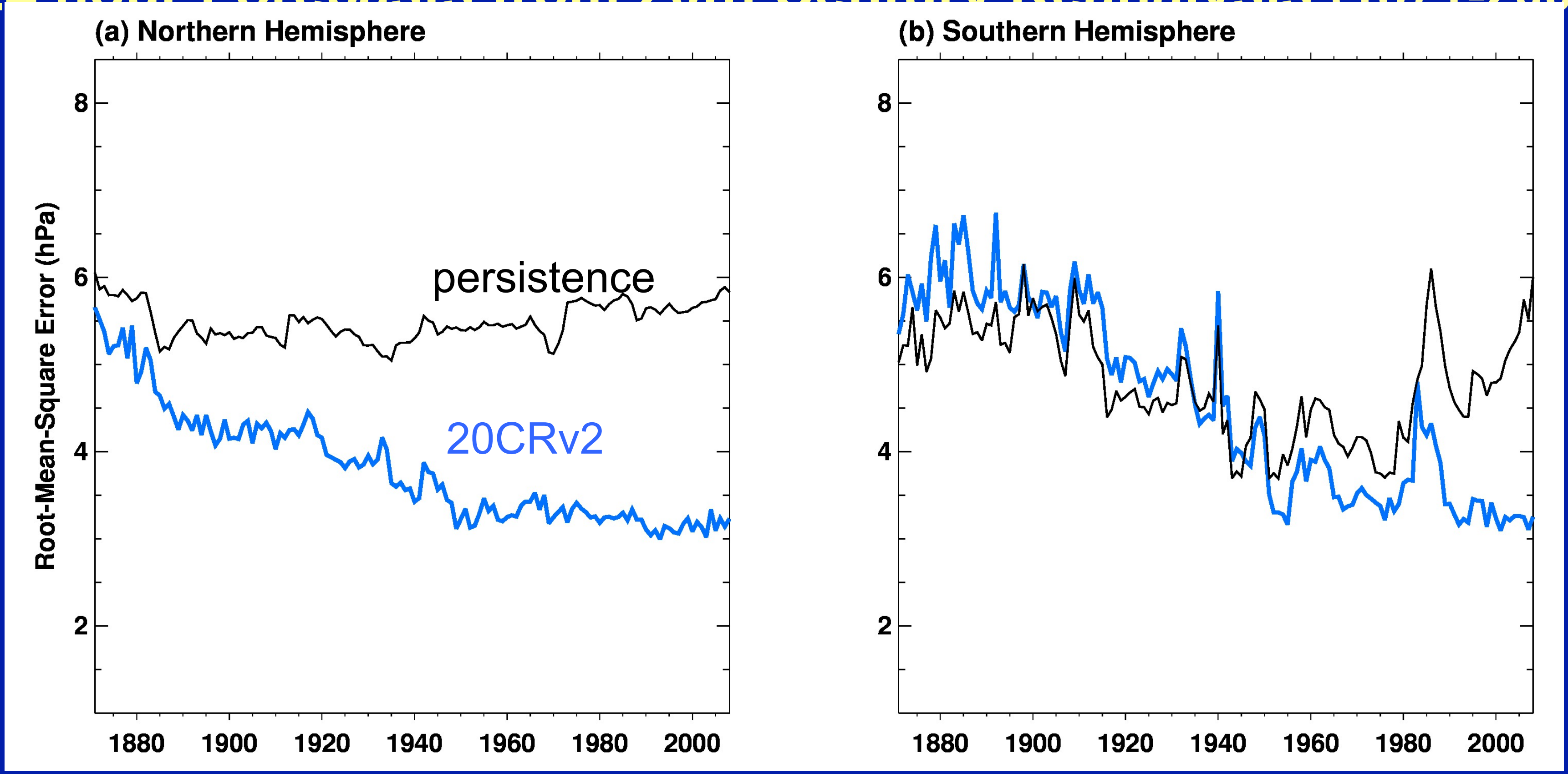


0.975 correlation between NNR and ERA40

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?

(CHANGE TO BACK TO 1850 SIRCA TEST) 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.

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)

$x_j^b = \langle x\rangle^b + x'^b_j$ = 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

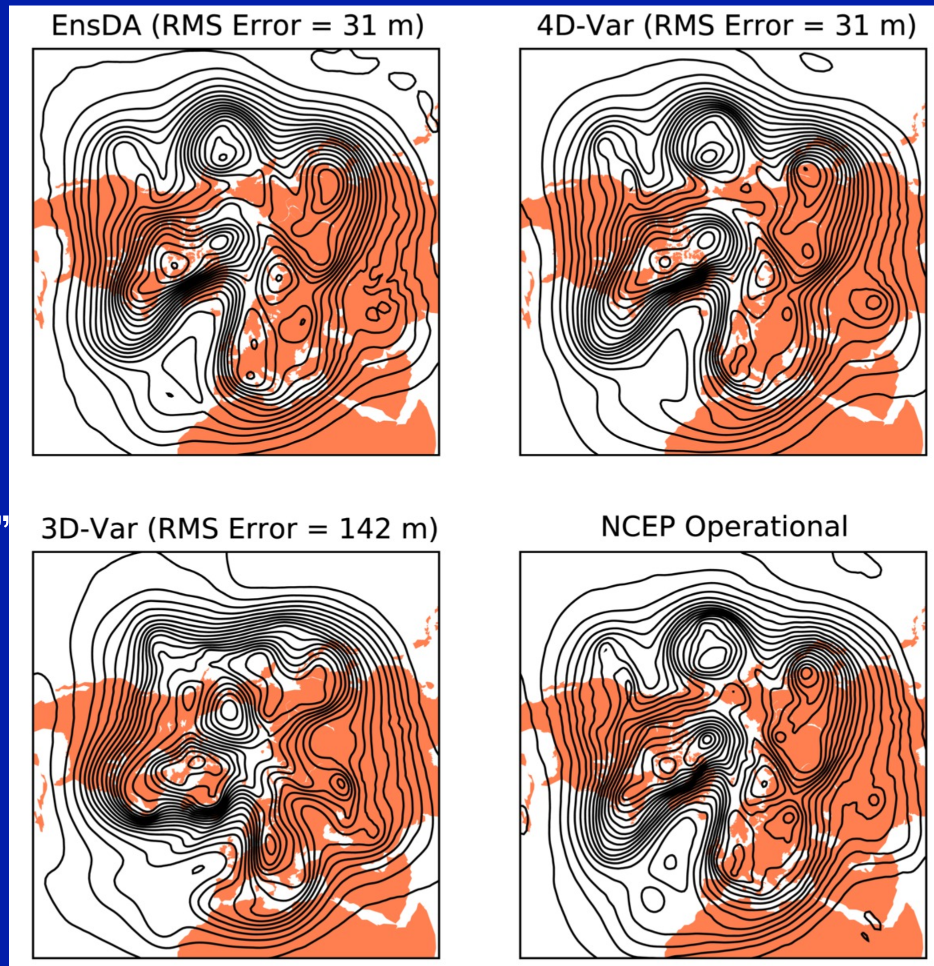
Analysis ensemble becomes first guess ensemble for next observation.

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

500 hPA Height Analyses for 20 Feb 2005 12Z

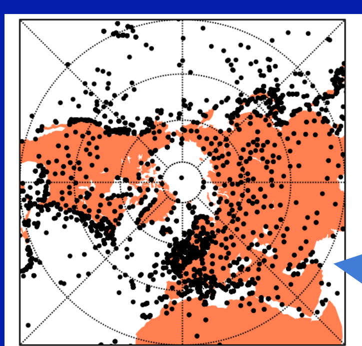
Ensemble Filter
(~3800 surface pressure obs)
RMS = 31 m

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)



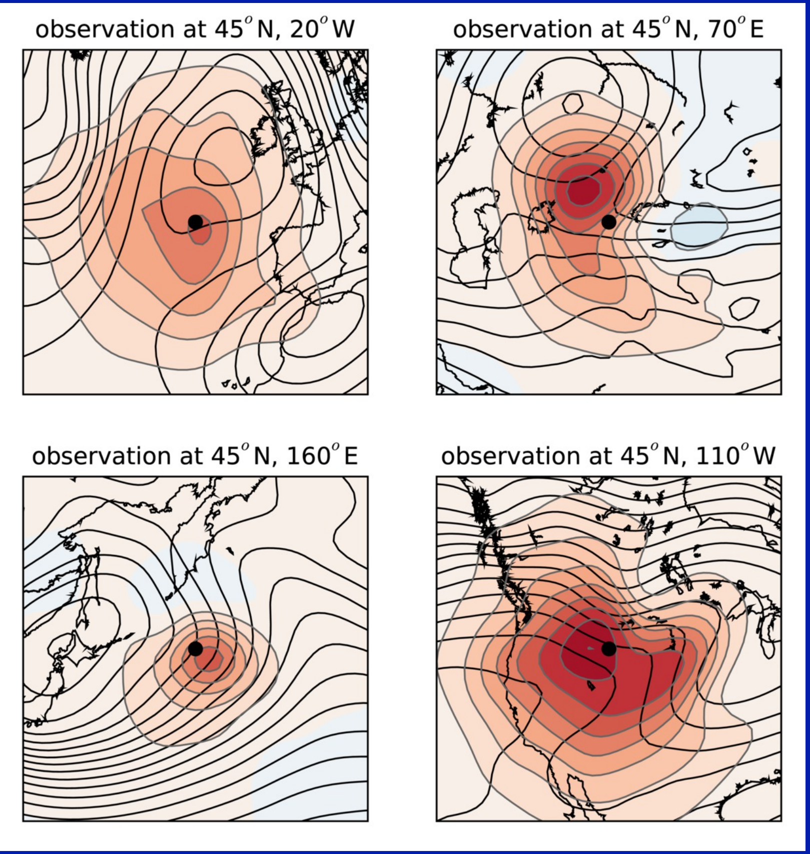
Surface pressure network reduced to ~1930's

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

Central Asia



West Pacific

North America

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

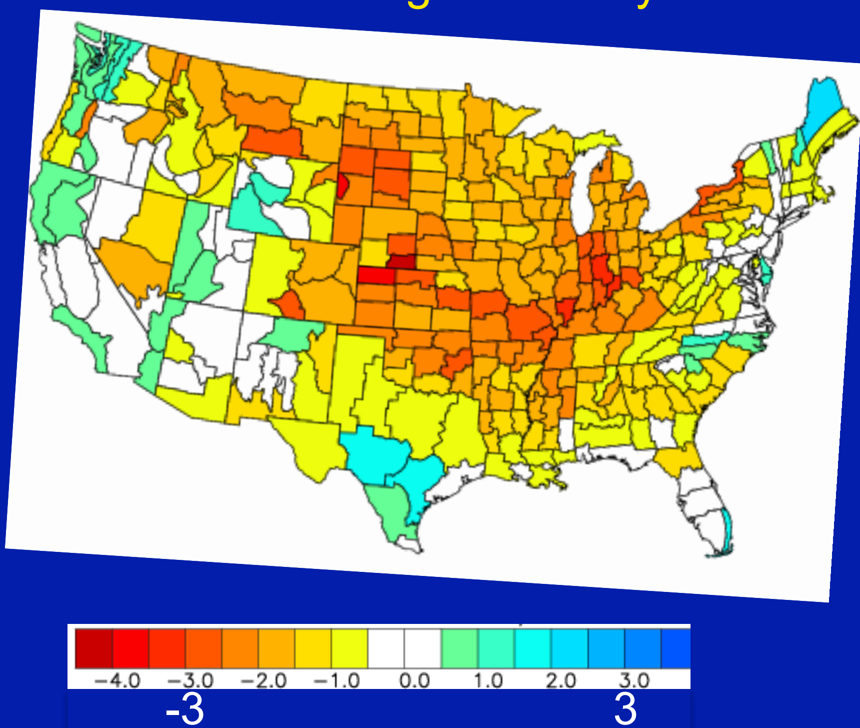
In the 3D-Var used in NCEP-NCAR Reanalyses, all of these structures would be identical and centered on the observation location.

Whitaker, Compo, Thepaut (2009)

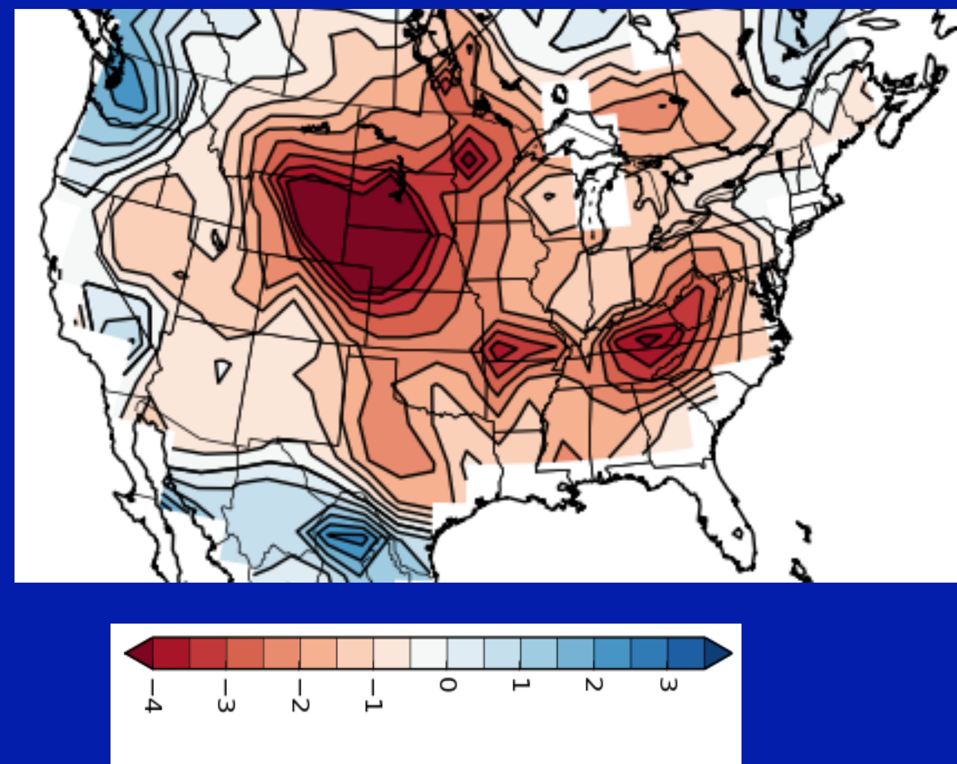
U.S Dust Bowl (July 1936)

Standardized monthly anomalies relative to 1961-1990

US Climate Division
Palmer Drought Severity Index



20CRv2 Soil Moisture 0-200 cm

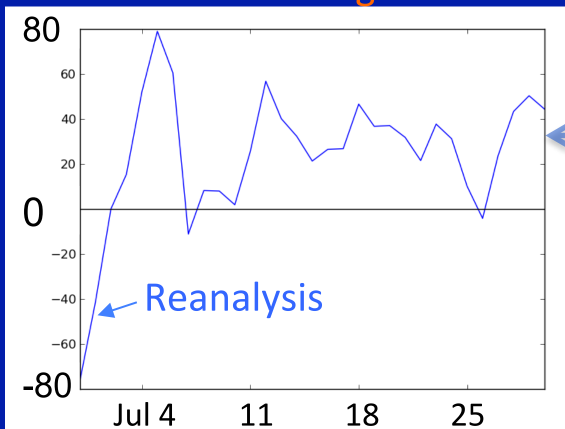


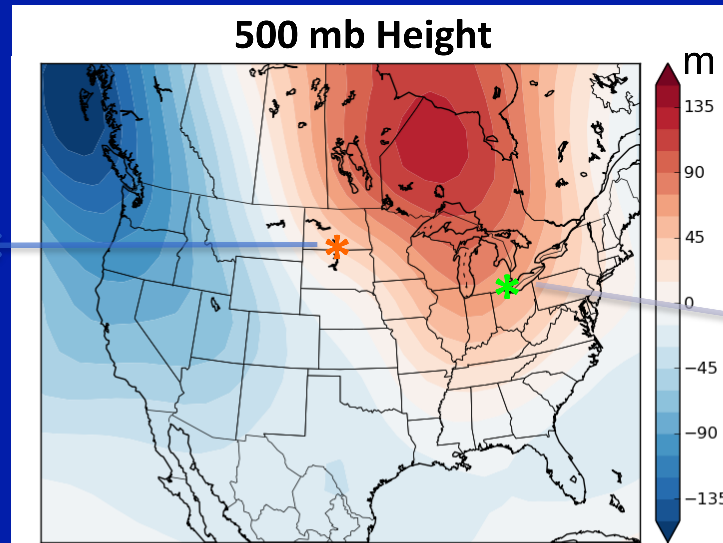
Using only surface pressure, 20CR v2 appears to capture expected features even in derived quantities.

July 1936 North American Heat Wave

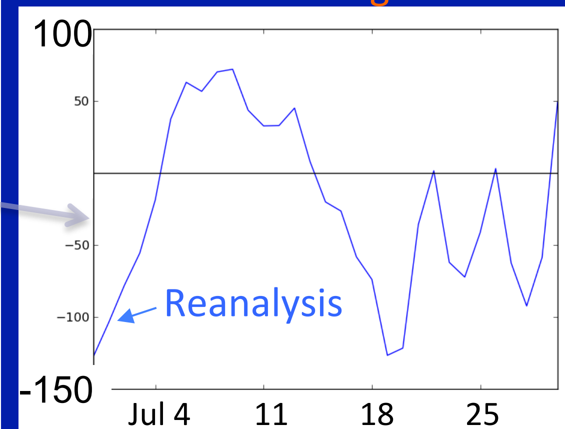
(1,000+ US & 1,000+ Canadian deaths during 14-day span)

500 mb Height

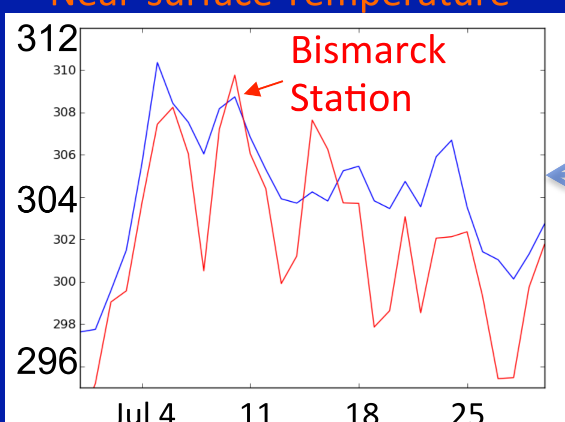


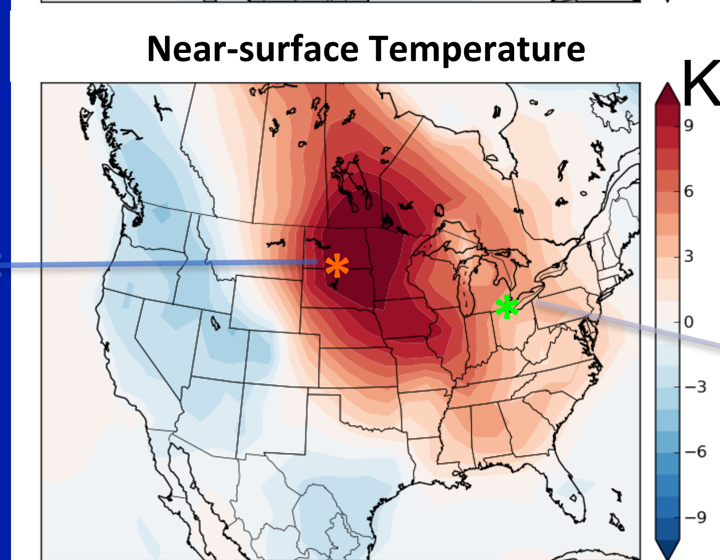


500 mb Height

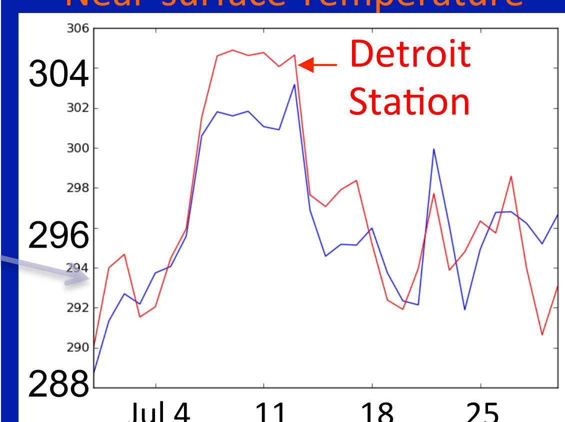


Near-surface Temperature





Near-surface Temperature

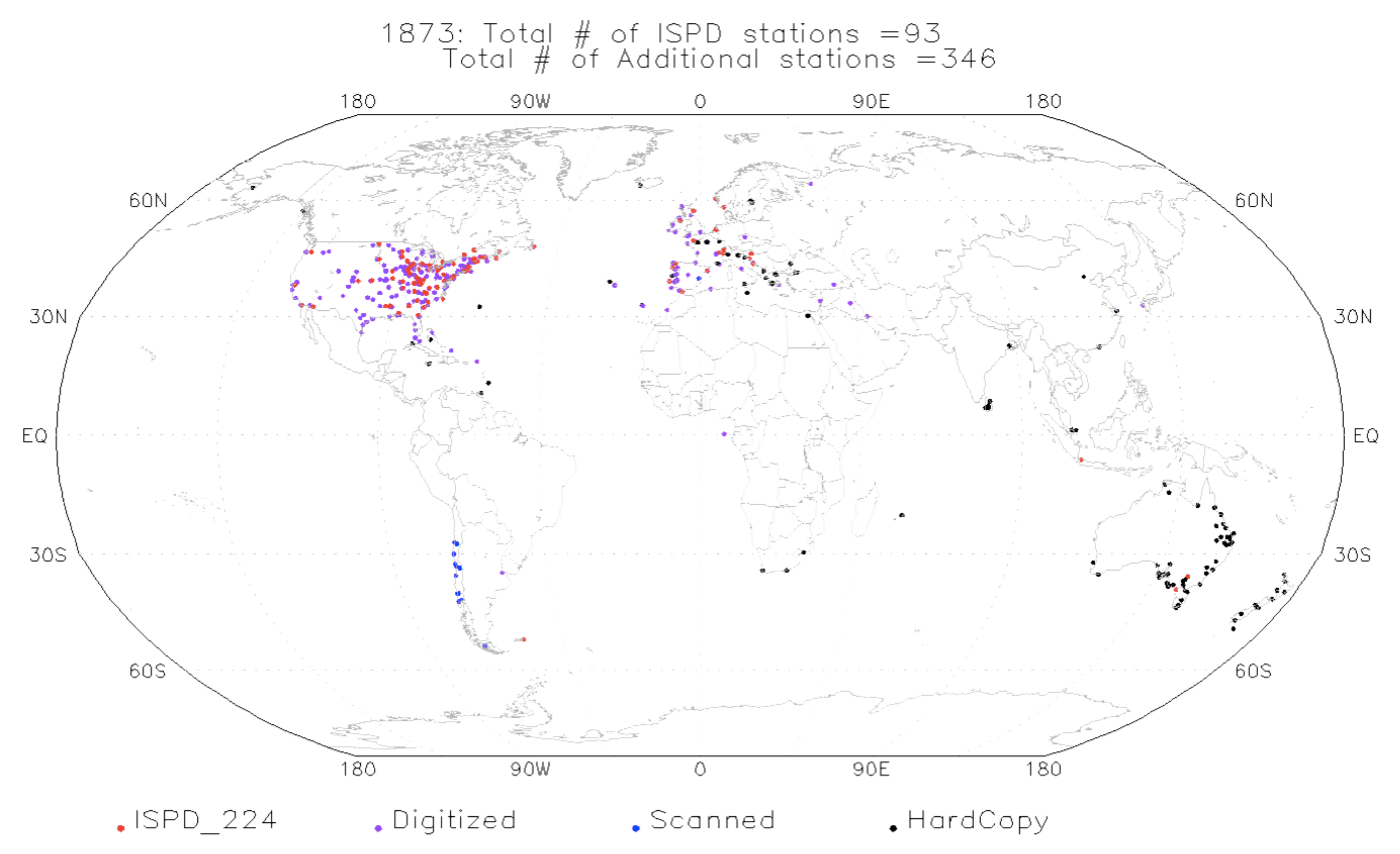


20th Century Reanalysis version 2

Anomalies July 8 – 14 with respect to 1891-2007

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

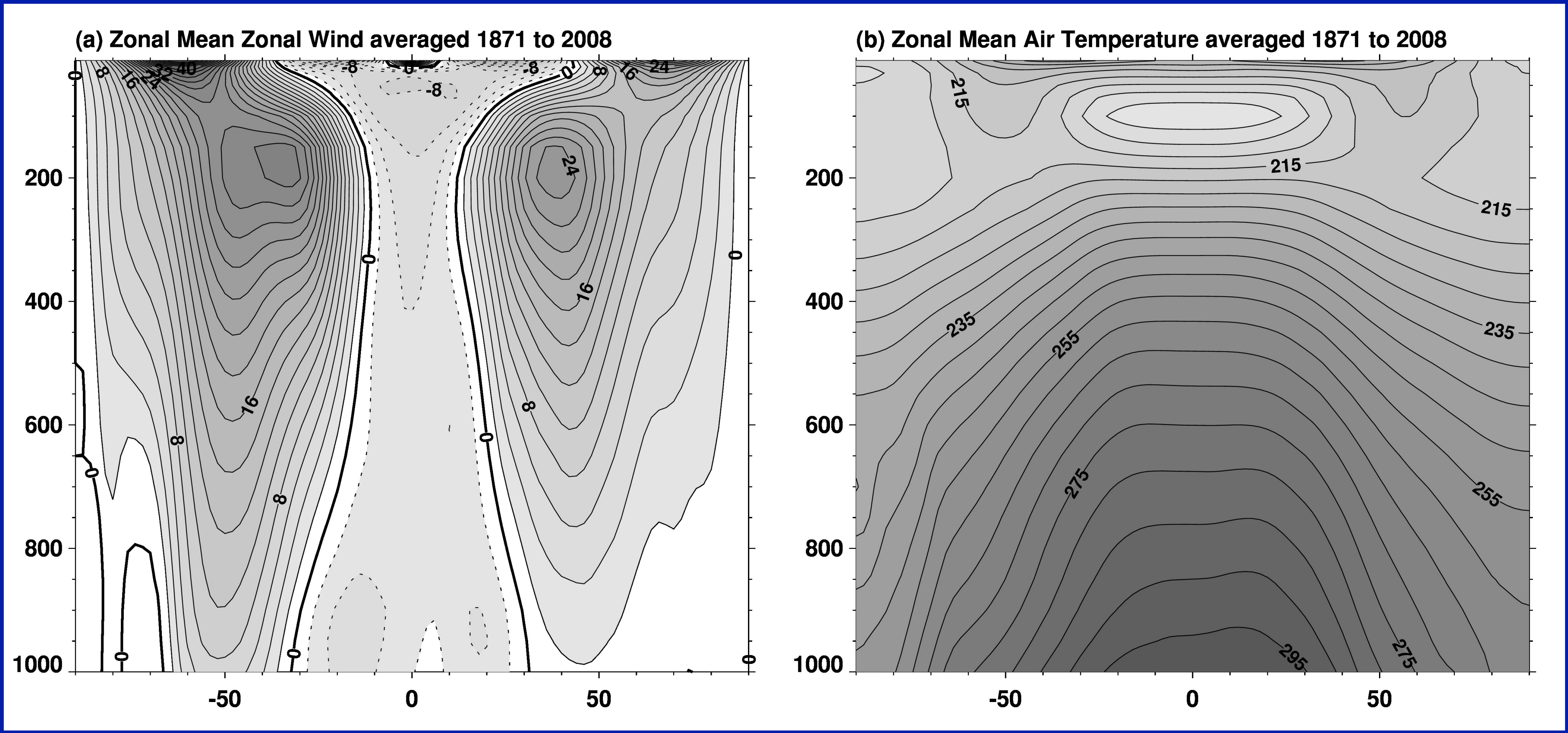
ftp://ftp.ncdc.noaa.gov/pub/data/ispd/add-station



Courtesy X. Yin and R. Allan

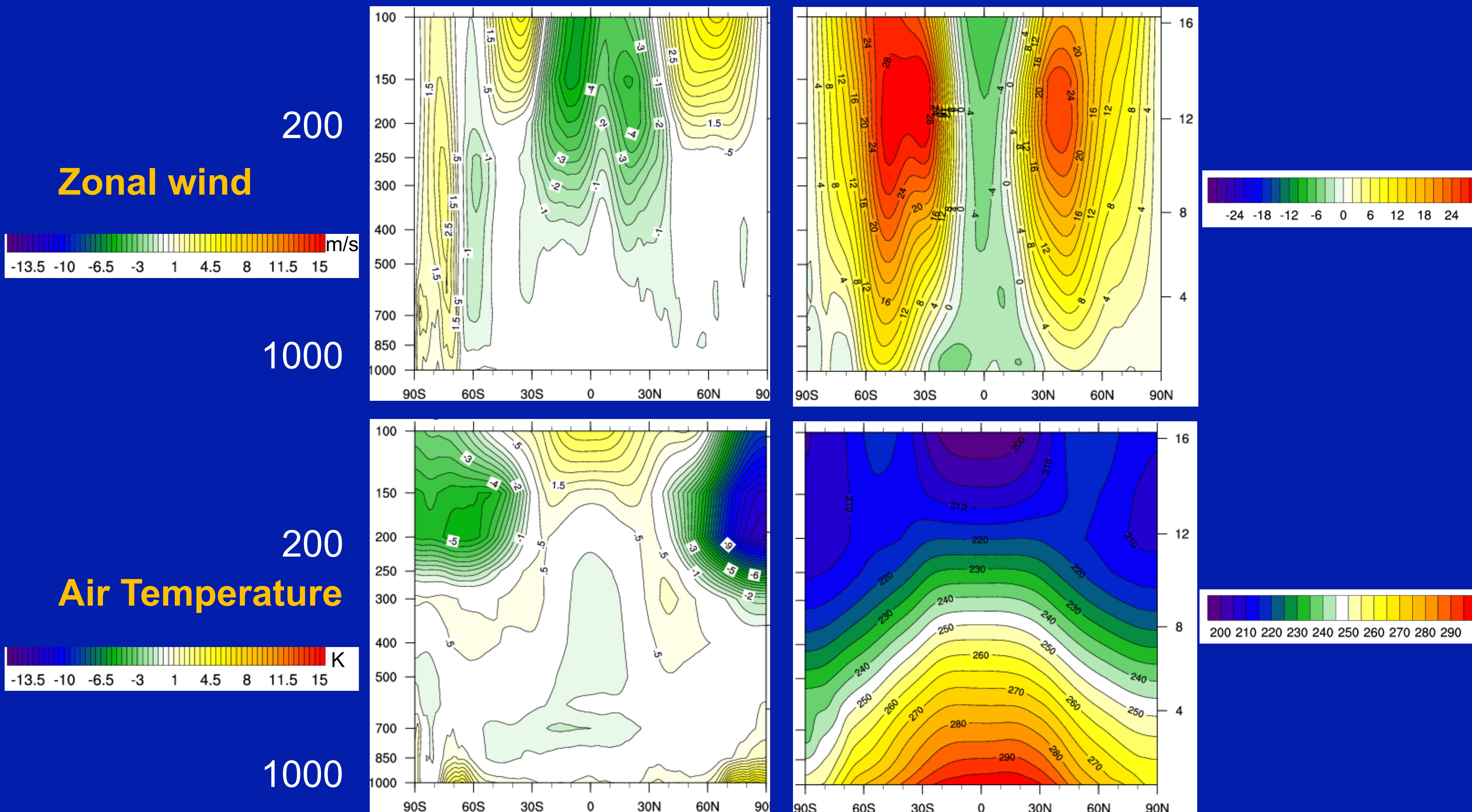
1871 to 2008 Zonal Means

Zonal wind — Air Temperature



50S EQ 50N — 50S EQ 50N

20CR- ERA Interim



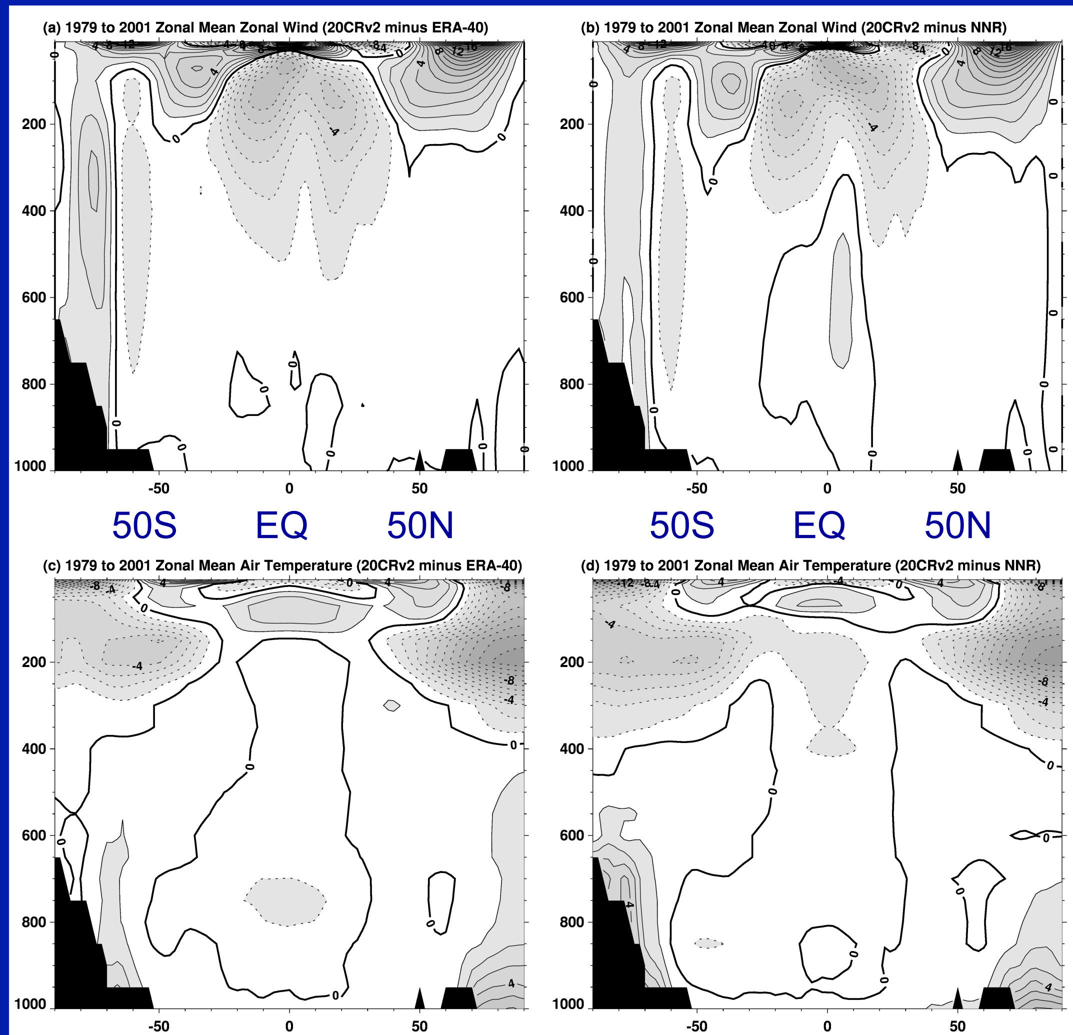
20CR zonal mean difference with ERA40 and NNR (1979-2008)

ERA 40 NNR

Zonal wind

200

1000



Air Temperature

200

1000

CI:1 m/s

Biases Over Poles and Stratosphere

CI:1 K

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

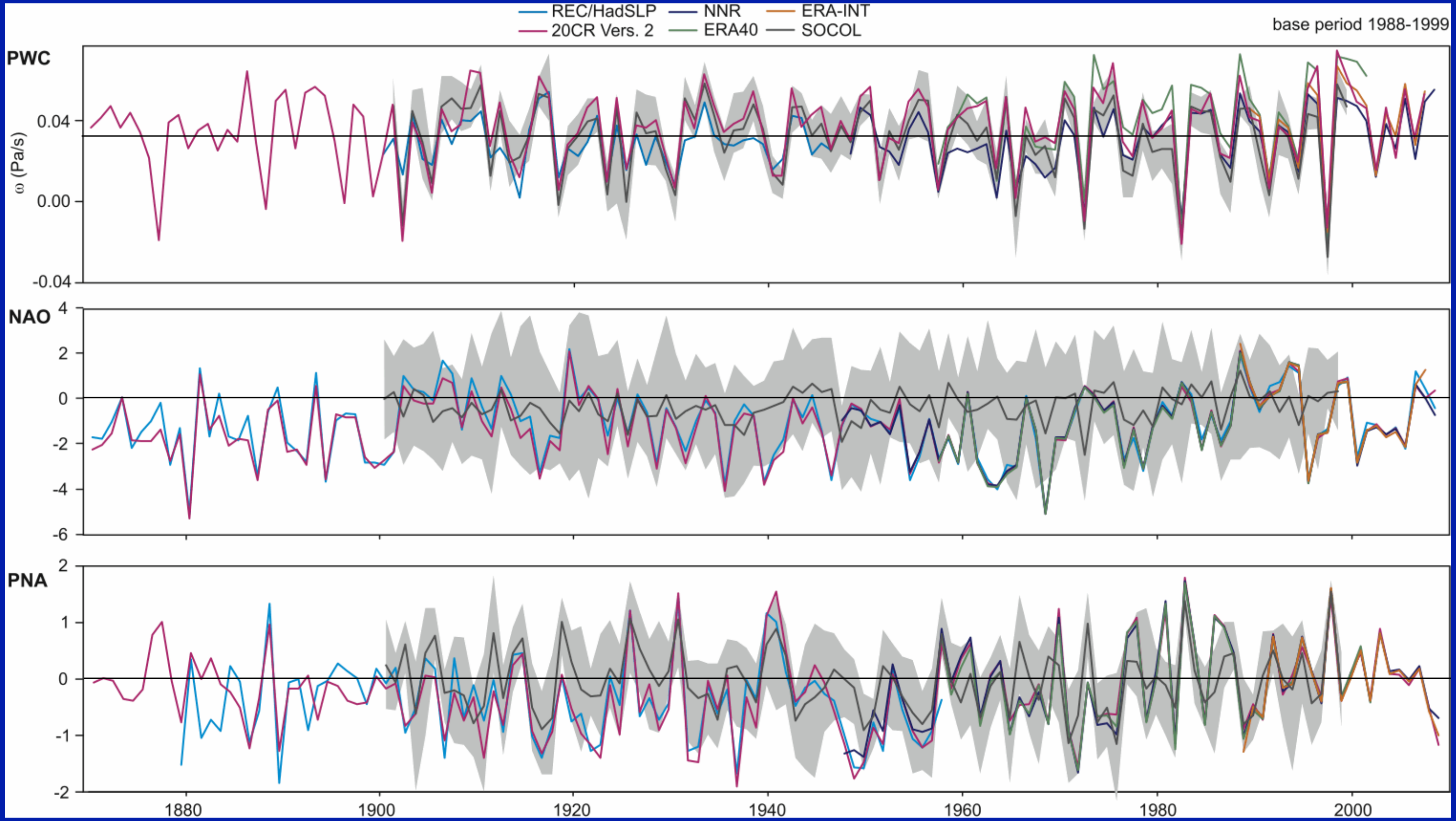
Compo et al. QJRMS (2011)

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

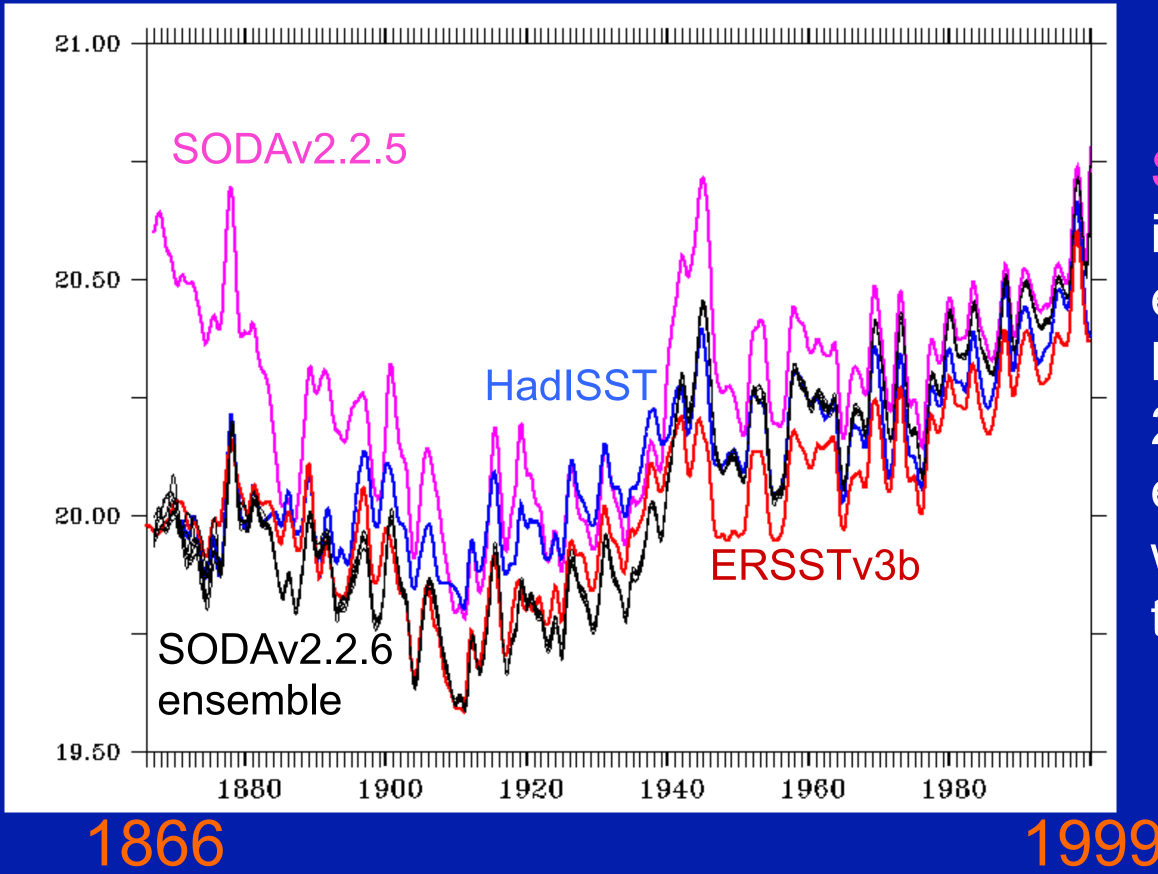
Agreement is high between observation-based estimates (correlations between ERA-40 and 20CRv2 > 0.95)

Courtesy S. Bronnimann

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.