Ensemble Kalman Filter Analysis, and Its Application to Reanalysis Using only Surface Pressure Observations

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With special thanks to: N. Matsui, C. Smith, S. Lubker, S. Woodruff, T. Hamill, and X. Wei

Compo, Whitaker, and Sardeshmukh, 2006, Bull. Am. Met. Soc.
Download from http://www.cdc.noaa.gov/people/gilbert.p.compo/Compoetal2006.pdf

Introduction

1. Prior to 1948, few radiosondes are available for reanalyses, but newly recovered surface pressure observations raise the possibility of generating useful reanalyses of the lower tropospheric circulation.
2. Studies using idealized (*Bengtsson* 1980), ensemble (*Whitaker et al.* 2003, 2004, *Anderson et al.* 2005), and 4D-Var (*Thepaut and Simmons* 2003) data assimilation have suggested that surface pressure observations will produce "good" 6-hourly analyses of Northern Hemisphere SLP and 500 mb heights.
3. *Bengtsson et al.* (2004) and *Kanamitsu and Hwang* (2005) concluded that surface observations are unable to produce reliable fields aloft using ERA-40 and NCEP-DOE 3D-Var systems. Note that the first guess error statistics were assumed to be the same as in the modern era.
4. Need a comprehensive study of feasibility of reanalysis without upper-air data.

Experiment

1. In every 5°×5° degree box, use only surface pressure observations for 2001 at densities typical of 1895, 1905, 1915, and 1935.

   - No aircraft, balloon, satellite, or radiosonde data.
   - ***100 times fewer*** surface observations every 6 hours than currently used.

   Analysis = Background + Weight*(observation – Background)

2. With these reduced observational densities, make 6-hourly assimilations for 2001 using:

   a) The NCEP-NCAR CDAS with ***fixed*** "first-guess" error statistics derived from the NCEP medium range forecast model (MRF) tuned for surface pressure only.

   b) An Ensemble square root filter (EnsFilt) with the mean of a 100 member ensemble from MRF as the first-guess and the ***time-varying*** ensemble covariance as the error in that first-guess (Whitaker and Hamill, 2002).

   c) An Ensemble Climatology Filter (EnsClim) with climatological mean as the first guess and anomaly covariances as the error statistics of that first guess.

3. Compute error relative to the Full NCEP-NCAR reanalysis CDAS (Kalnay et al. 1996) and compare to 1979-2001 MRF re-forecasts (Hamill et al. 2004).

Ensemble Filter Algorithm

$x_j^b = \langle x \rangle^b + x'^b_j =$ first guess jth ensemble member (j=1,…,100)

$y^o =$ 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

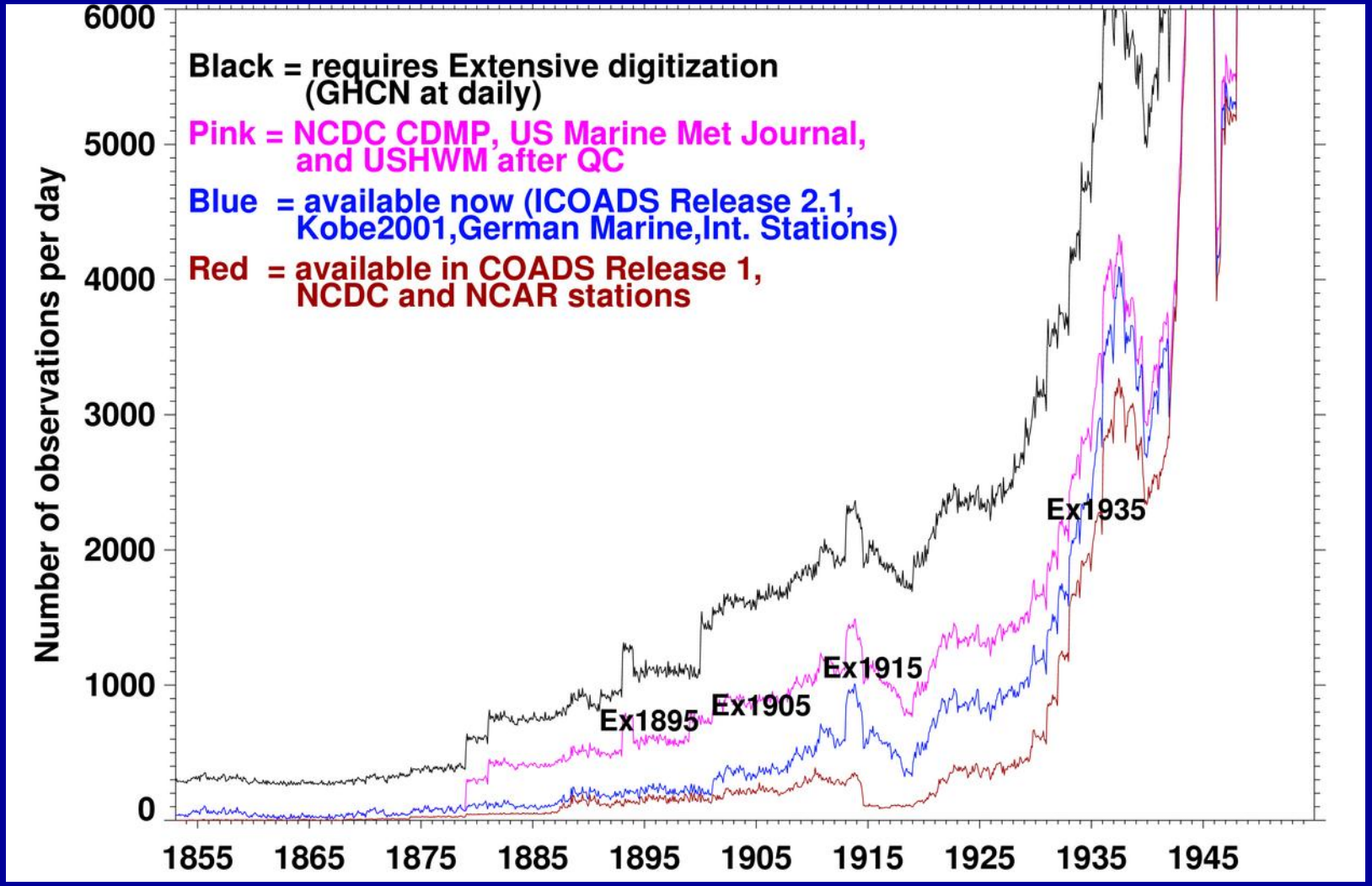
$$K = \Sigma_j x'^b_j y'^b_j (\Sigma_j y'^b_j y'^b_j + R)^{-1}$$ Kalman Gain

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

$(1/(n-1))$ is included in Σ_j

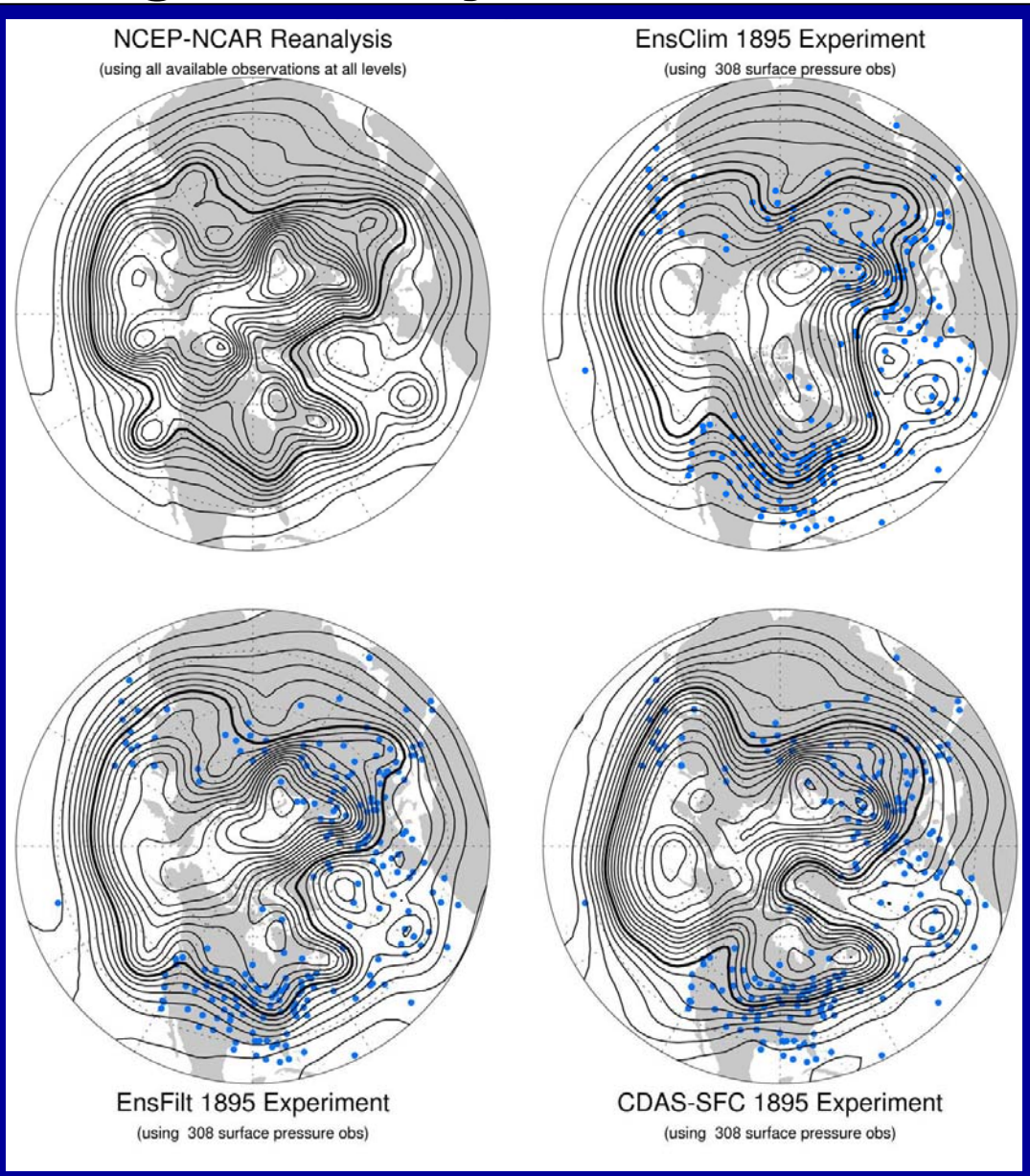
Analysis ensemble becomes first guess ensemble for next observation.

Number of historical surface pressure obs in each month (1855-1954) poleward of 20N



500mb Height Analyses for 0Z 20 Dec 2001

Full CDAS
(120,000+ obs)



EnsClim 1895
(308 surface pressure obs)
RMS = 96 m

EnsFilt 1895
(308 surface pressure obs)
RMS = 49 m

CDAS-SFC 1895
(308 surface pressure obs)
RMS = 96 m

5500 m contour is thickened

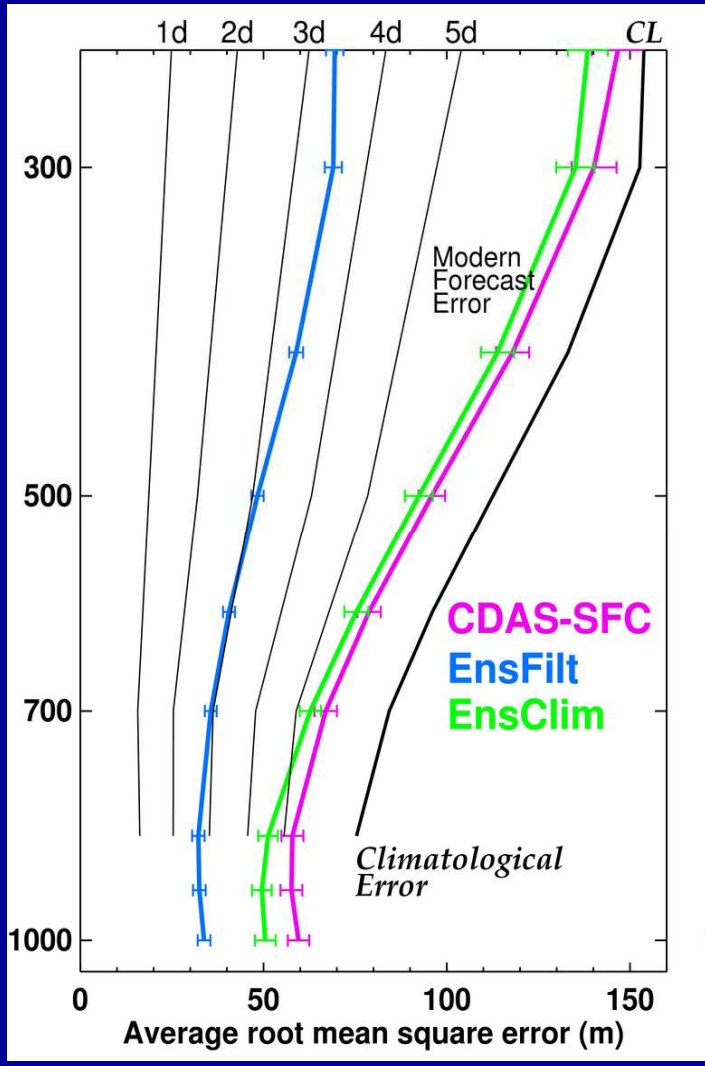
RMS Error and Anomaly Correlation Skill of 6-hourly geopotential height analyses using CDAS-SFC, Ensemble Filter, and Ensemble Climatology Filter
and Surface Pressure Obs at 1895 densities

Surface pressure obs alone produce a good 6-hourly analysis even at 1895 densities.

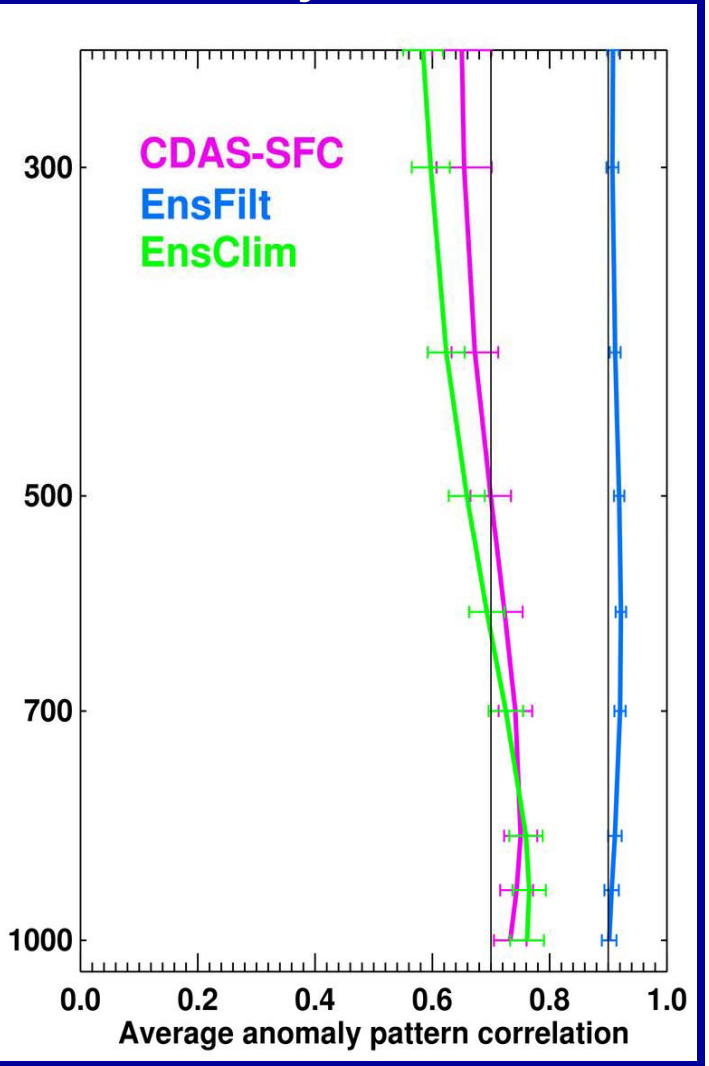
Results obtained using EnsFilt are significantly better than the traditional CDAS-SFC.

Expected error for 1895 circulation is comparable to a 3-day forecast error.

RMS

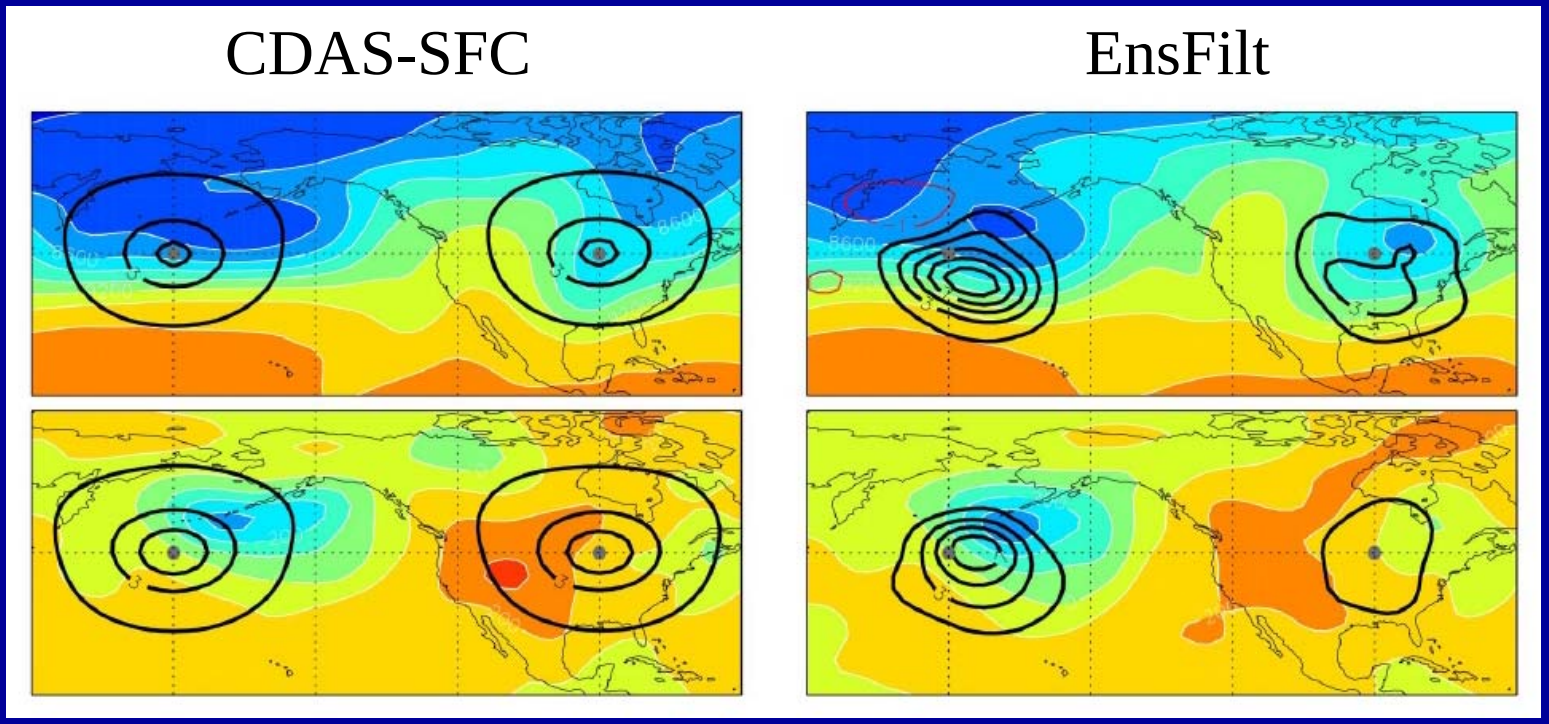


anomaly correlation



Simulating December 2001

Geopotential height first guess (colors) and
analysis minus first guess (lines)
for single pressure observations 1mb greater than first guess



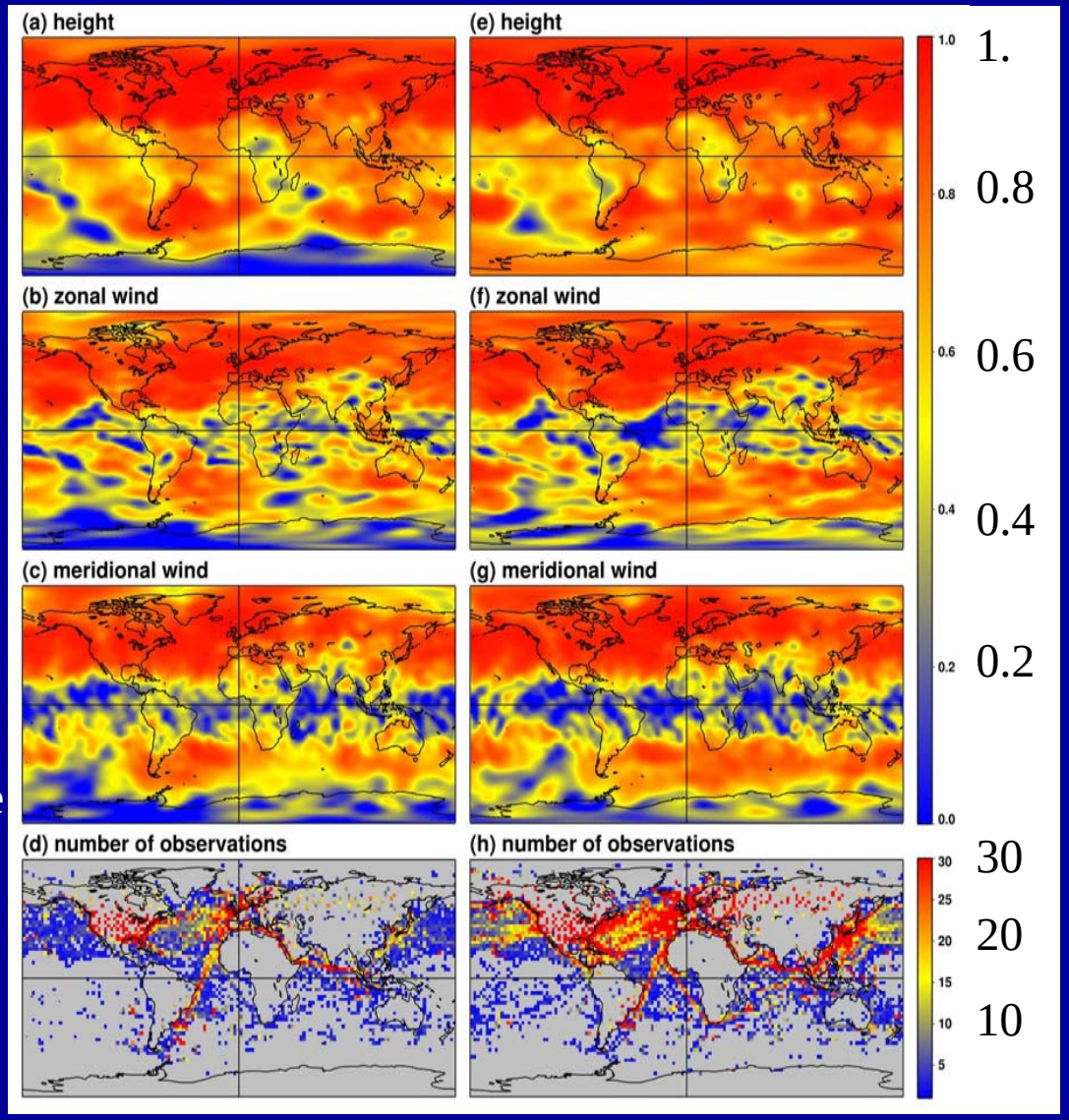
Ensemble filter can extract spatially-varying structures relative to the flow and the previous observational density.

Anomaly correlation skill of 700 hPa analyses using Ensemble Filter and only surface pressure observations

Extratropical Northern Hemisphere mass and wind fields are well-recovered despite inhomogeneous observation network.

Tropical mass field is recovered with the 1935 network, but wind field is not with either network.

More observations help extratropical Southern Hemisphere analyses.

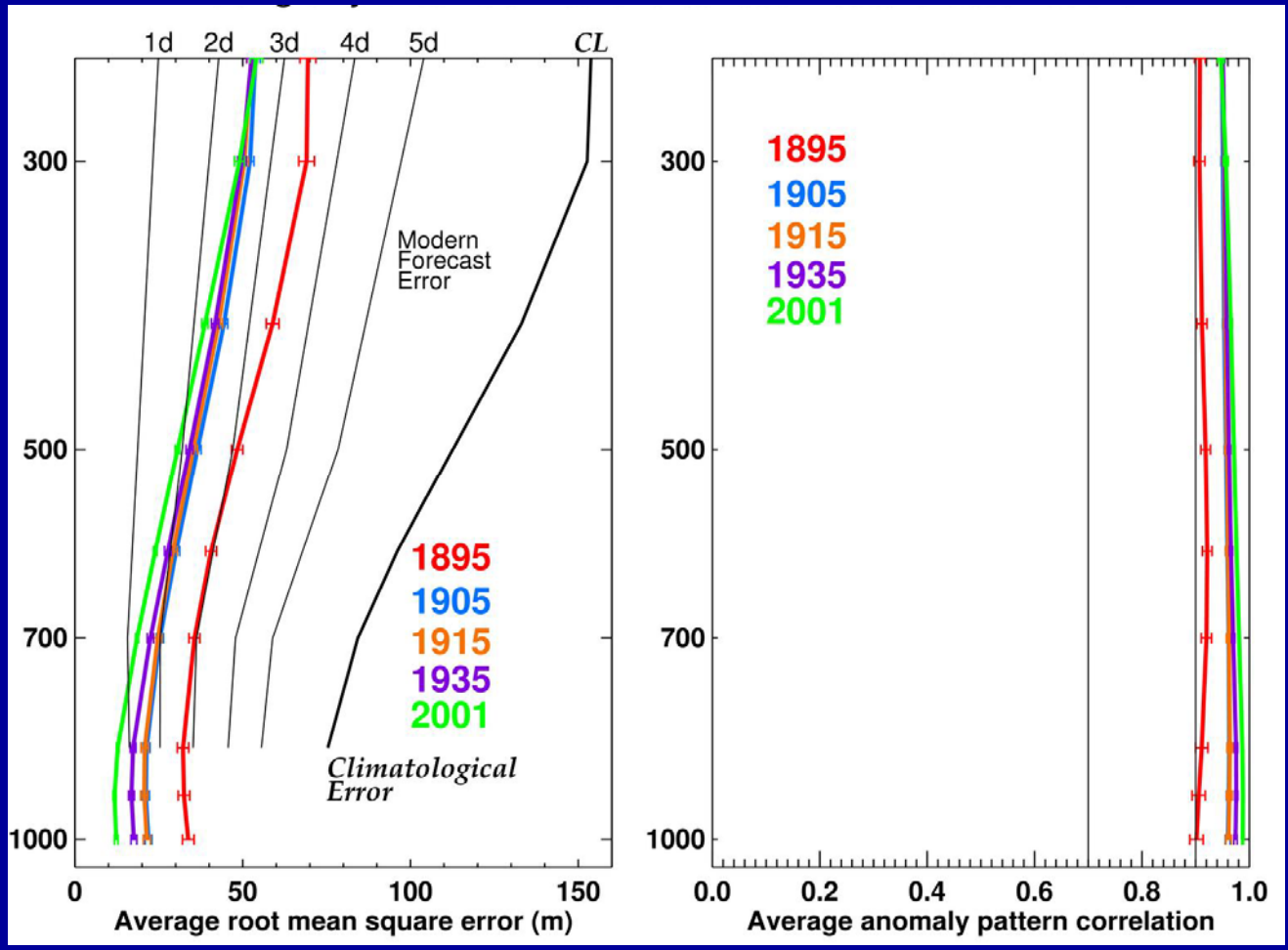


RMS Error and Anomaly Correlation skill of
6-hourly geopotential height analyses using Ensemble Filter and
Only Surface Pressure Obs at 1895, 1905, 1915, 1935, and 2001 densities

RMS anomaly correlation

Increasing number and coverage of observations will help greatly for 1895 period.

1905 only has 30 obs more per analysis, but much better coverage.



Simulating December 2001

The 20th Century Reanalysis Project

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

The reanalyses would provide:

-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;

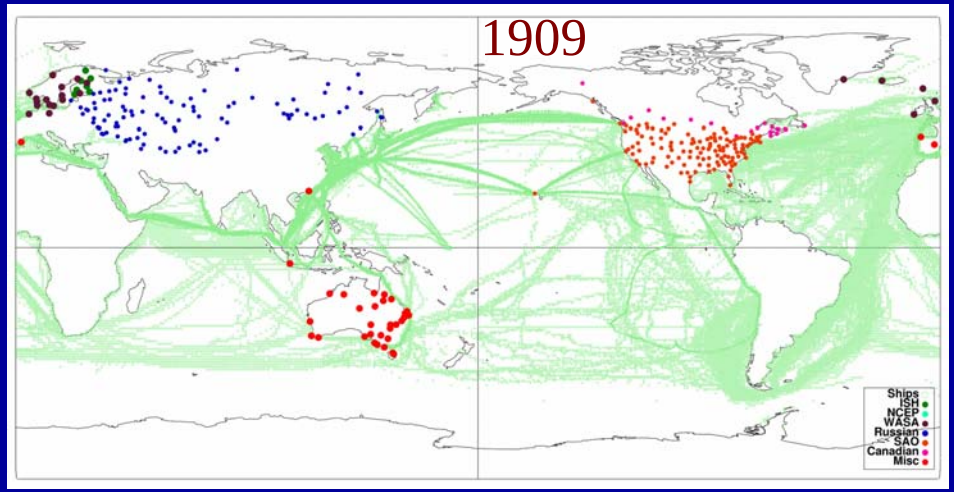
-Estimates of biases and uncertainties in derived quantities (storm tracks, etc.)

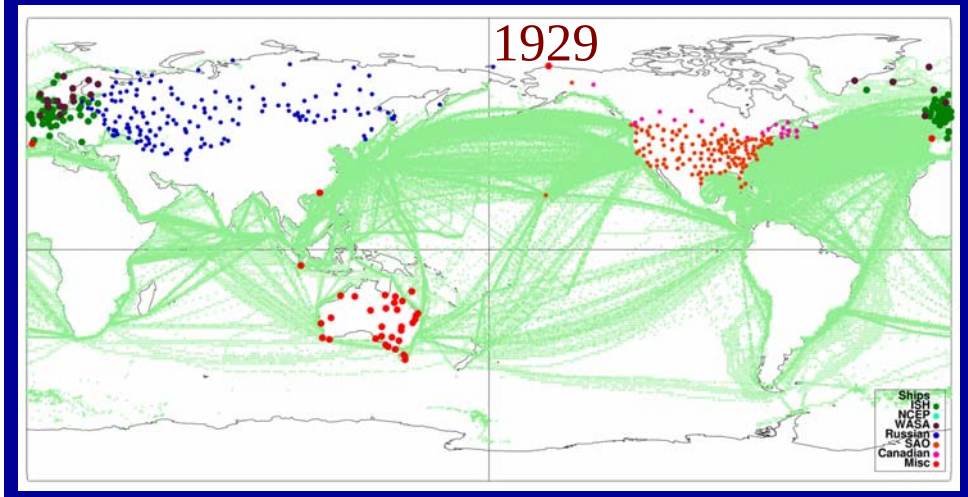
Initial product would have higher quality in the Northern Hemisphere than in the Southern Hemisphere.

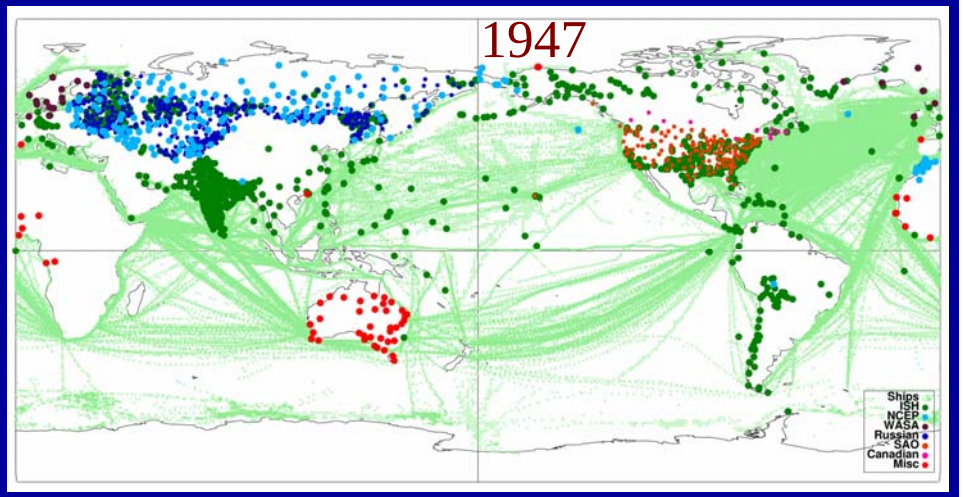
Proof of concept for 1938-1948.
Initially test 1947.

Partners: All Union Research Institute of Hydrometeorological Information - WDC; Australian Bureau of Meteorology; EMULATE; Environment Canada; ETH-Zurich; Hong Kong Observatory; ICOADS; KNMI; MeteoFrance; National Center for Atmospheric Research; NOAA ESRL, NCDC, NCEP, NRCC-Cornell, CDMP; UK Hadley Centre; U. of Colorado-CIRES; U. of East Anglia-CRU; U of Virigilio

GCOS Surface Pressure Working Group
International Surface Pressure Databank

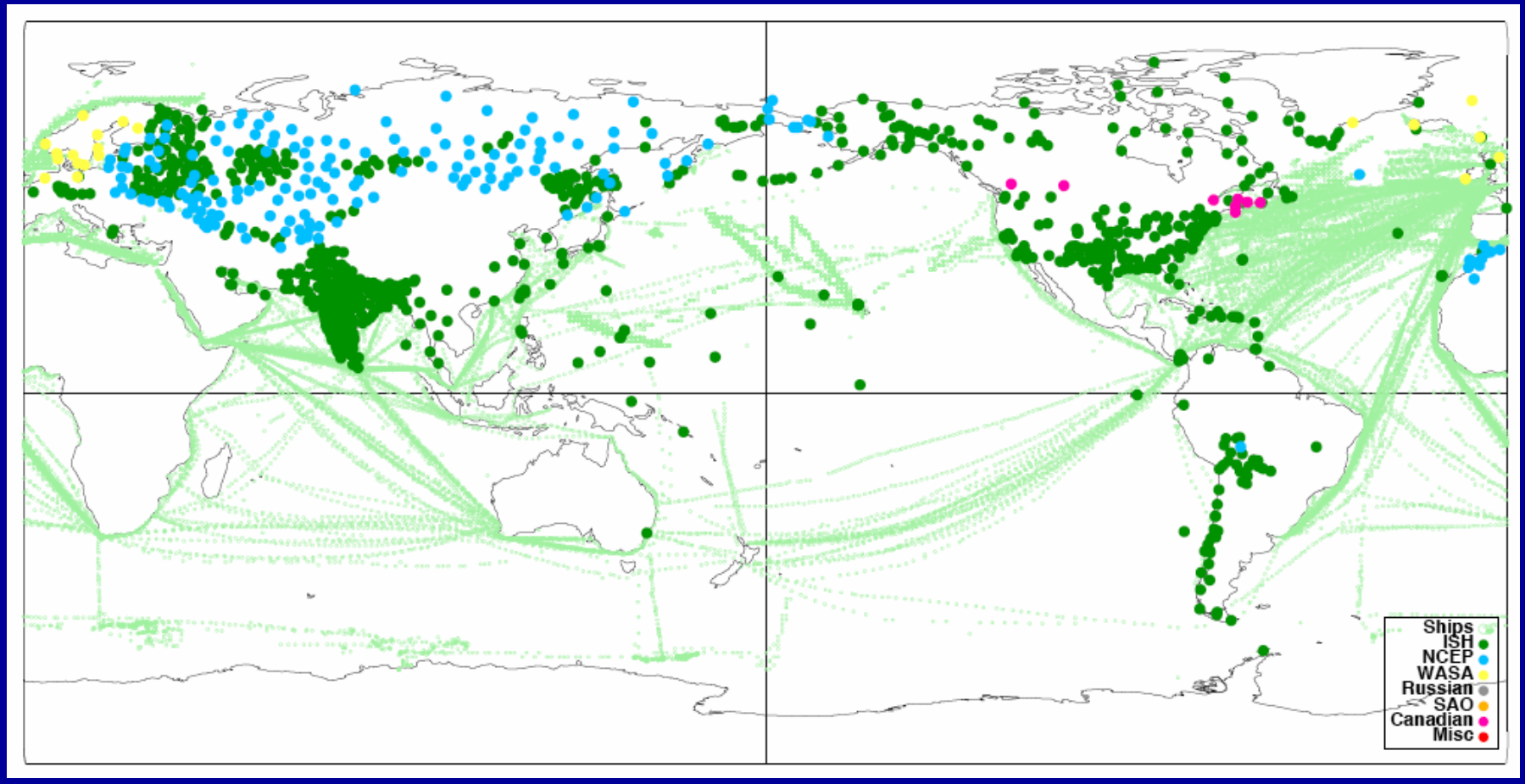






Location of Actual Surface and Sea Level Pressure Observations

Pressure Observation locations Nov-Dec 1947



Pilot reanalysis:

NCEP model: Global Forecast System 2003 T62L28

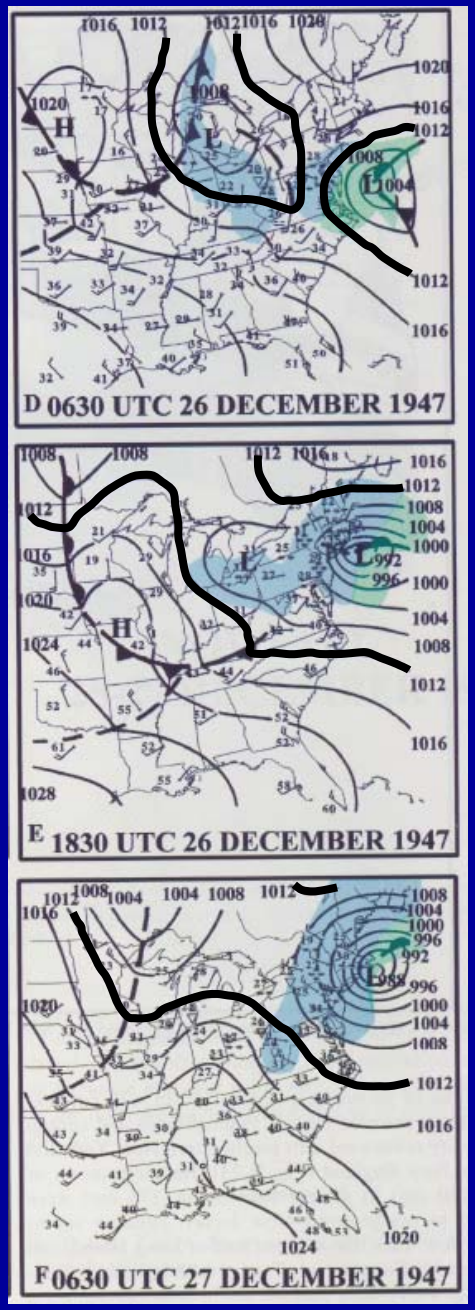
Ensemble Filter with 6-hour window using covariances with correct time (4-D approach)

Sea Level Pressure Analyses
26 - 27 December 1947

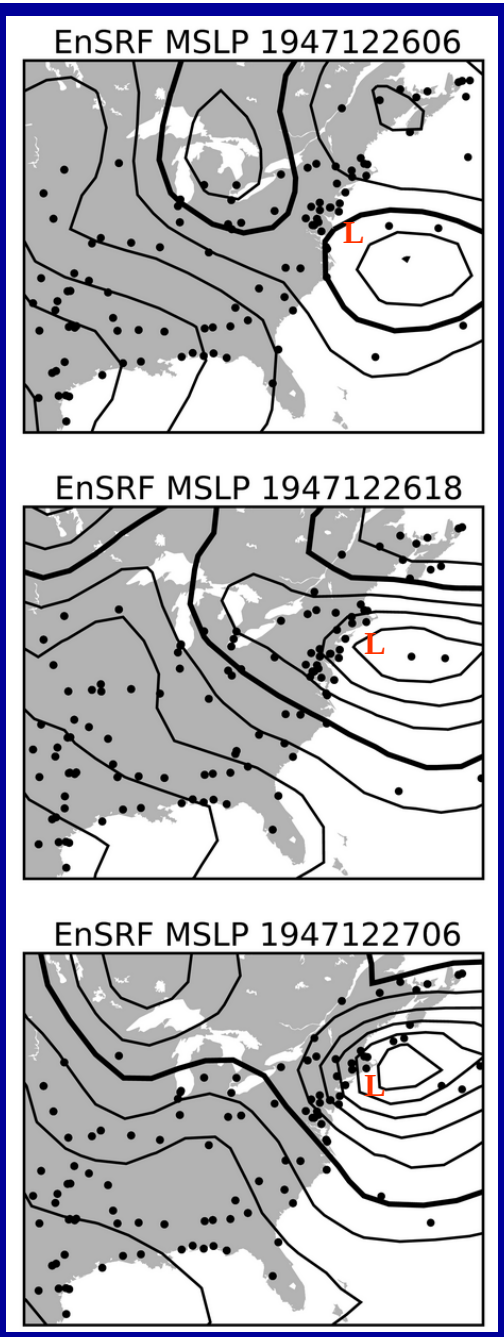
Intensity of East Coast Low is weaker in Ensemble Filter analyses, but major features are present.

Contour interval is 4 hPa in all panels and 1012 hPa contour is thickened.

(Kocin and Uccellini, 2004)



US Weather Bureau

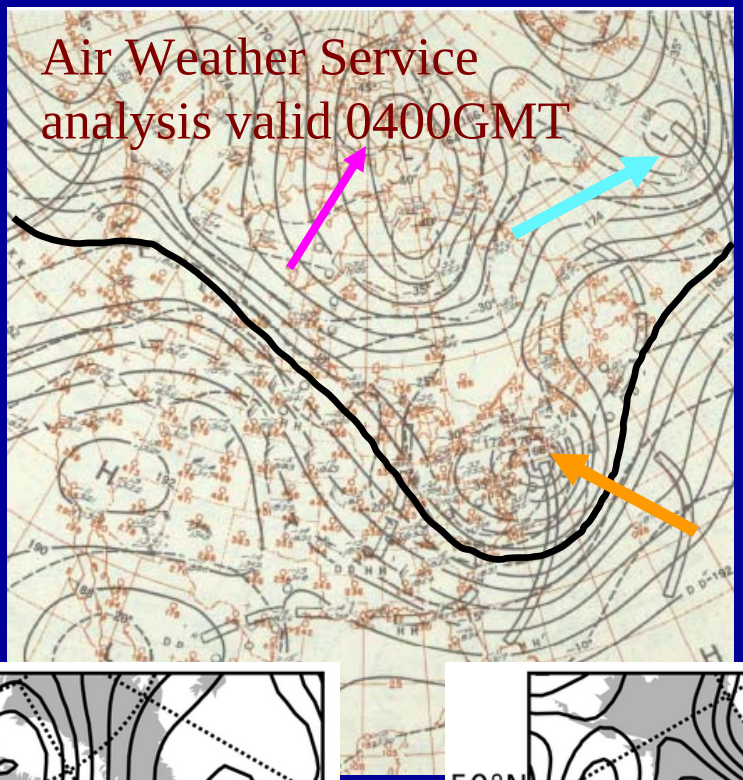


Ensemble Filter

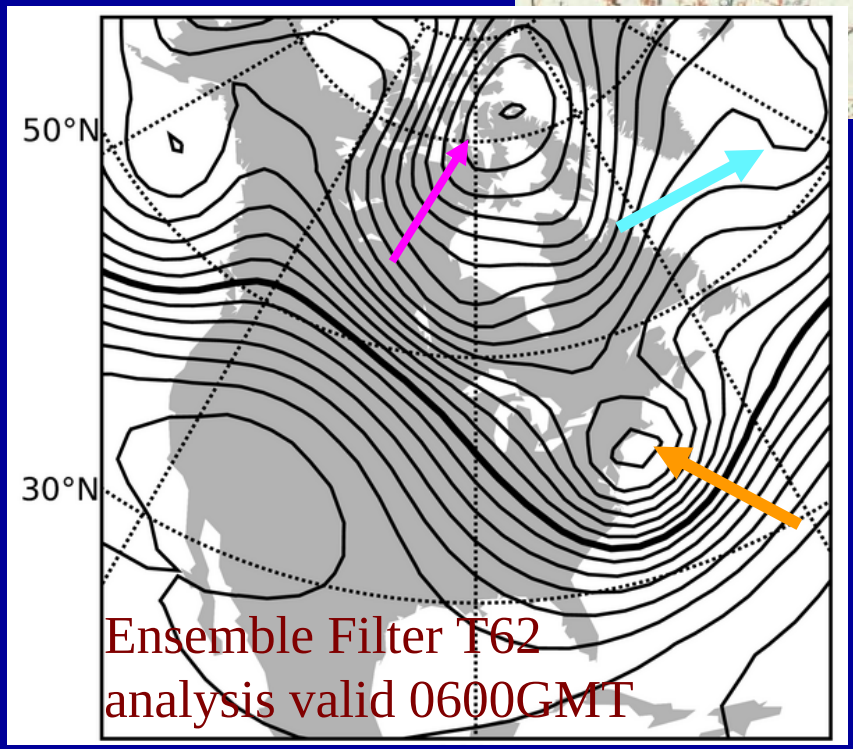
500 hPa
geopotential height

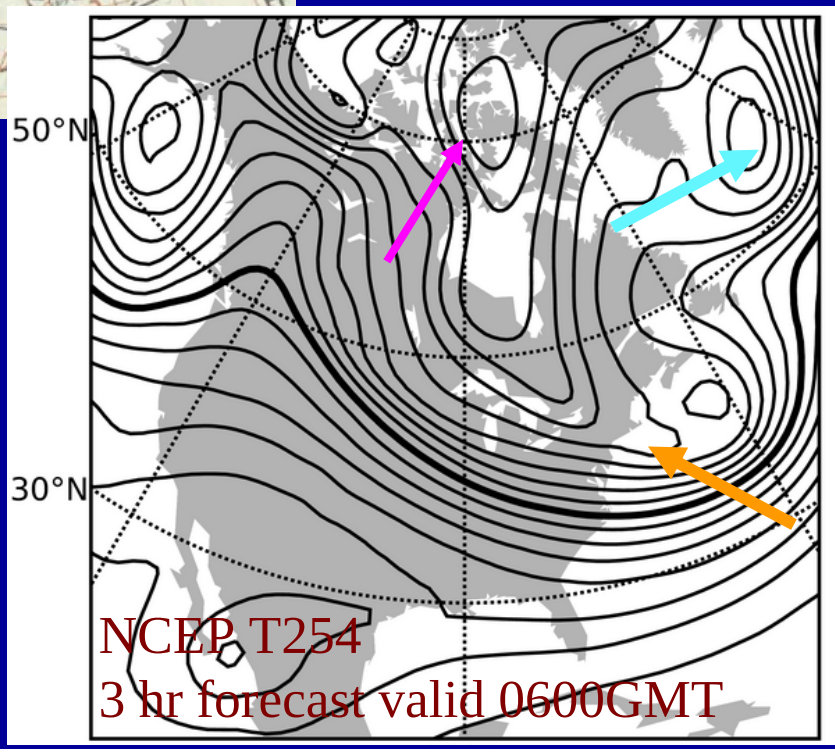
27 December 1947

5500 m (18000 ft)
contour is thickened



Ensemble Filter
analysis has comparable
quality to NCEP 3D-VAR





Conclusion-

The 20th Century Reanalysis Project is Feasible !!

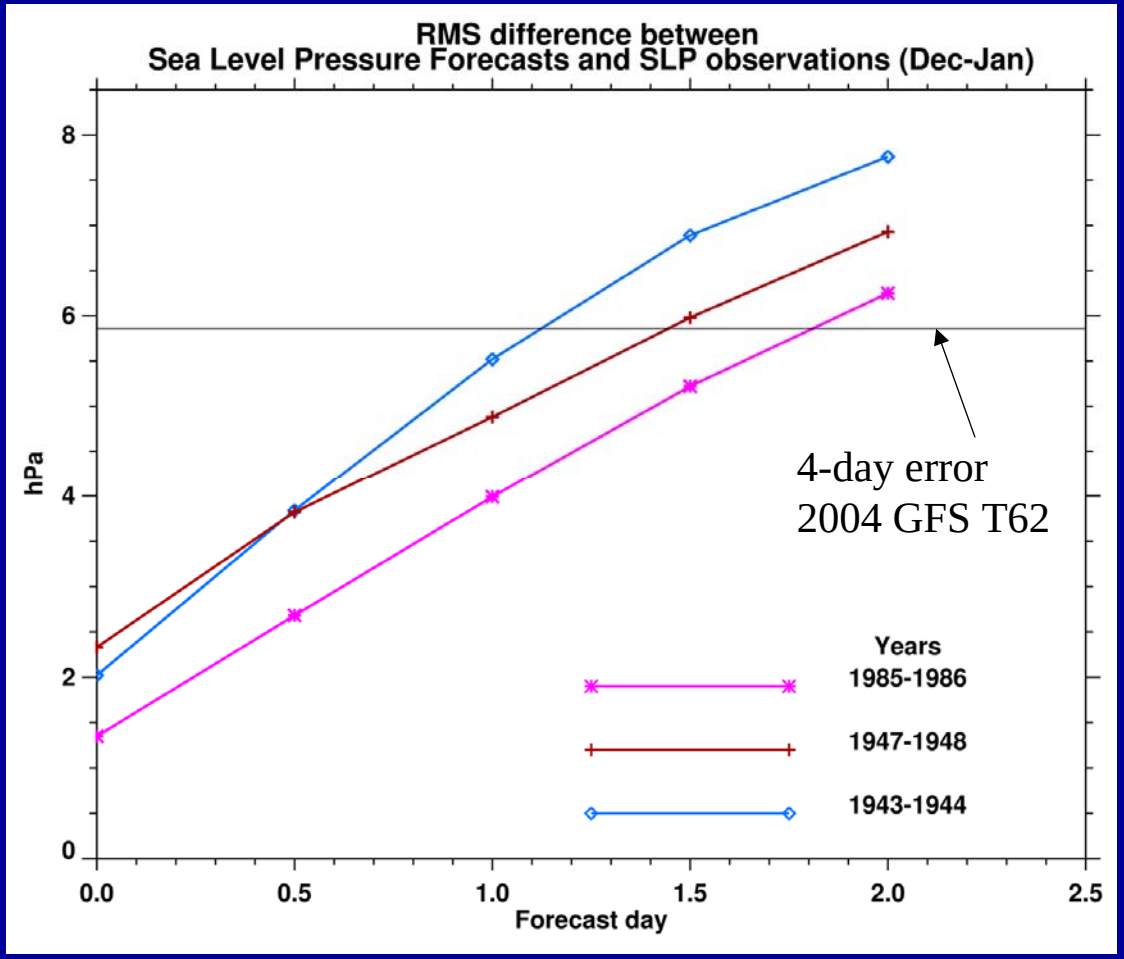
1. Reanalyzing the lower-tropospheric circulation of the entire 20th century is feasible in the Northern Hemisphere ***using just the available surface observations***.

2. Better methods than 3d-Var will produce better results, especially in the ***upper*** troposphere.

3. Keying or exchanging additional marine observations will greatly increase the fidelity of the reanalysis and give errors comparable to modern 2-3 day forecasts.

4. Results using 1944 and 1947 surface pressure observations suggest that these feasibility conclusions are realistic.

RMS difference of SLP forecasts with SLP observations



1.5-day forecast error for 1947 using only pressure observations is comparable to 4-day error in 2004 using all observations.

Comparison of ICOADS and US Historical Weather Map Feb 1 1899

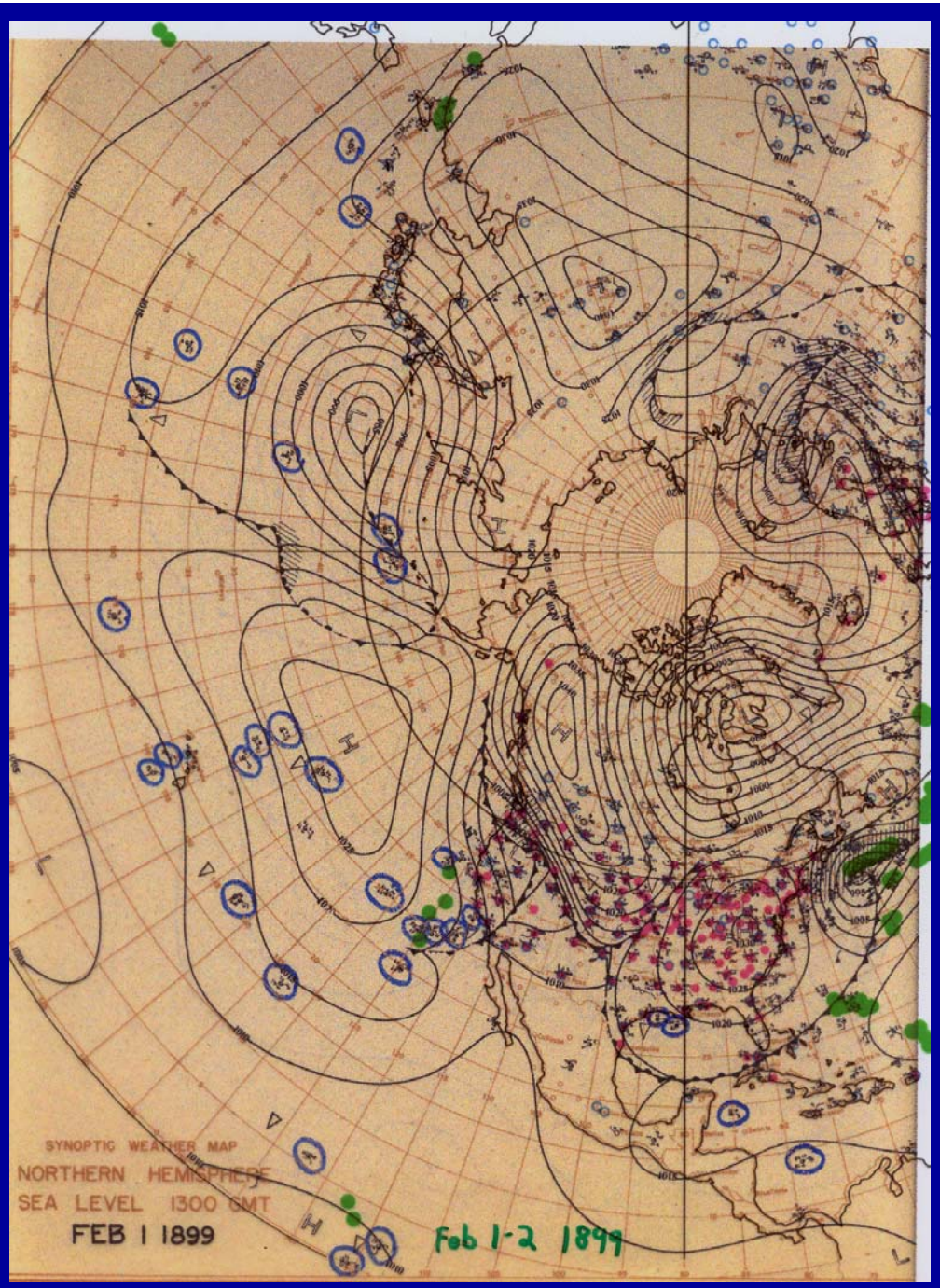
How many observations could be available?

Large open blue circles:

US Merchant Marine obs

Filled green circles:

ICOADS 2.0



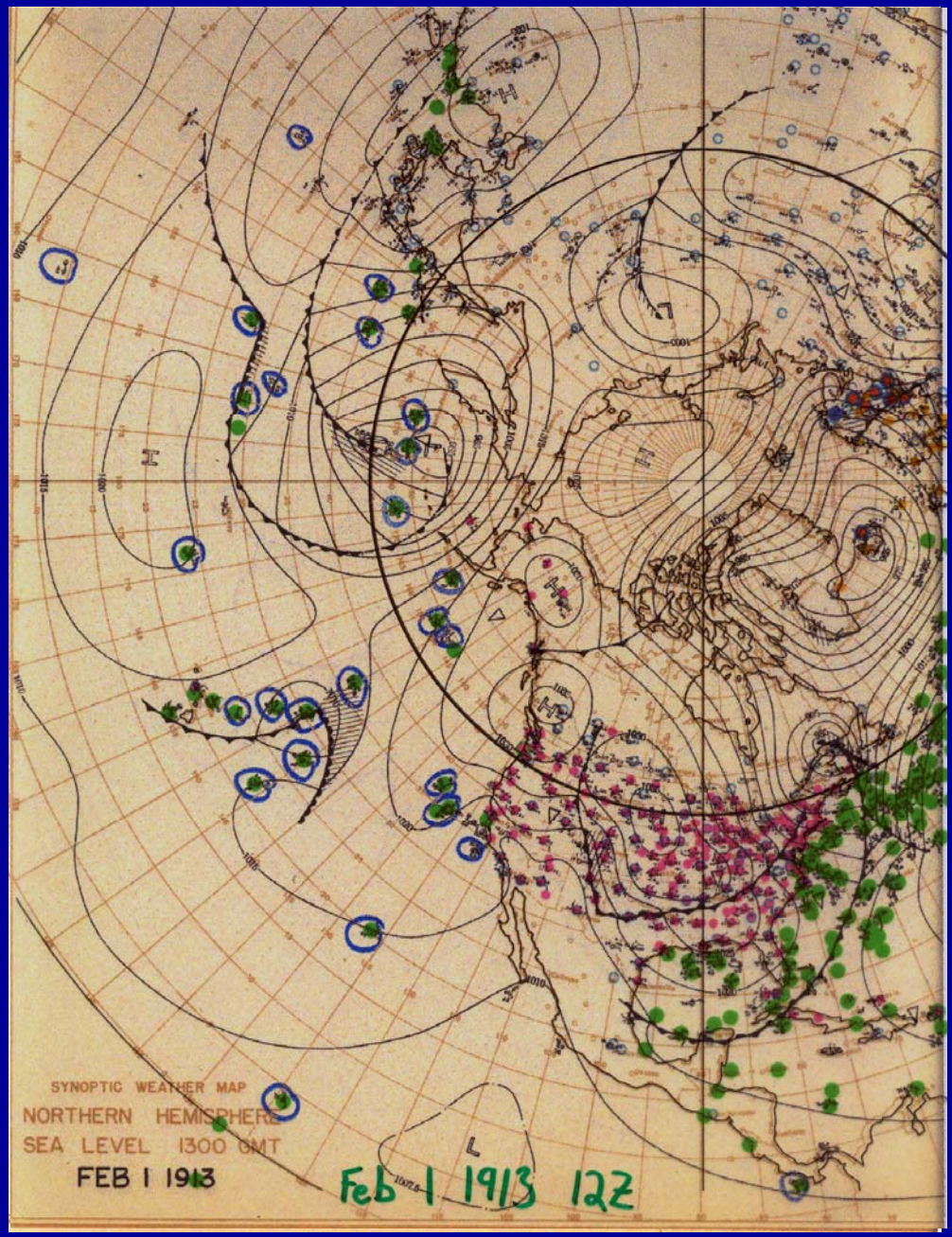
Comparison of ICOADS and US Historical Weather Map Feb 1 1913

Large open blue circles:

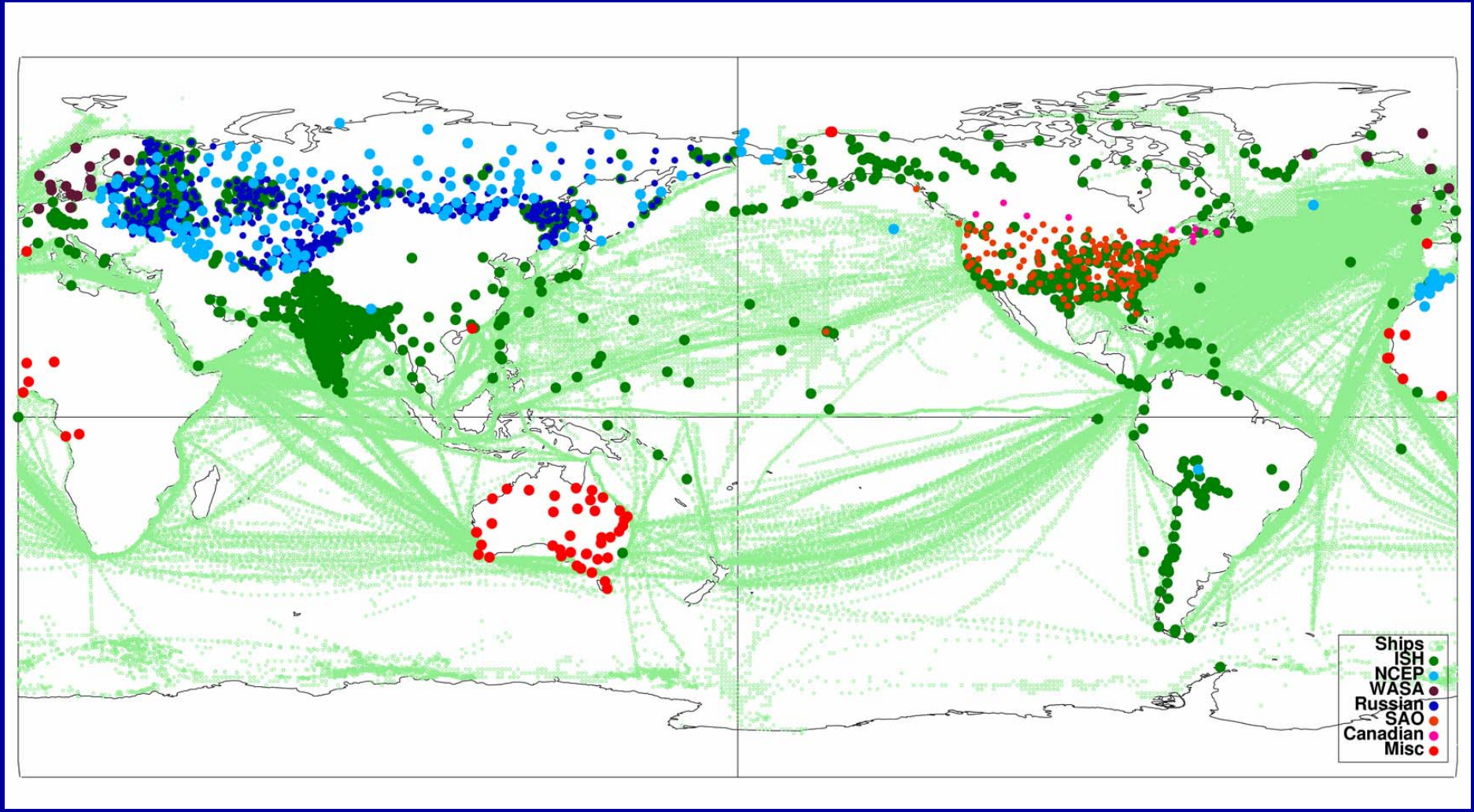
US Merchant Marine obs

Filled green circles:

ICOADS 2.0



Sub-daily Pressure Observation locations Jan-Dec 1947



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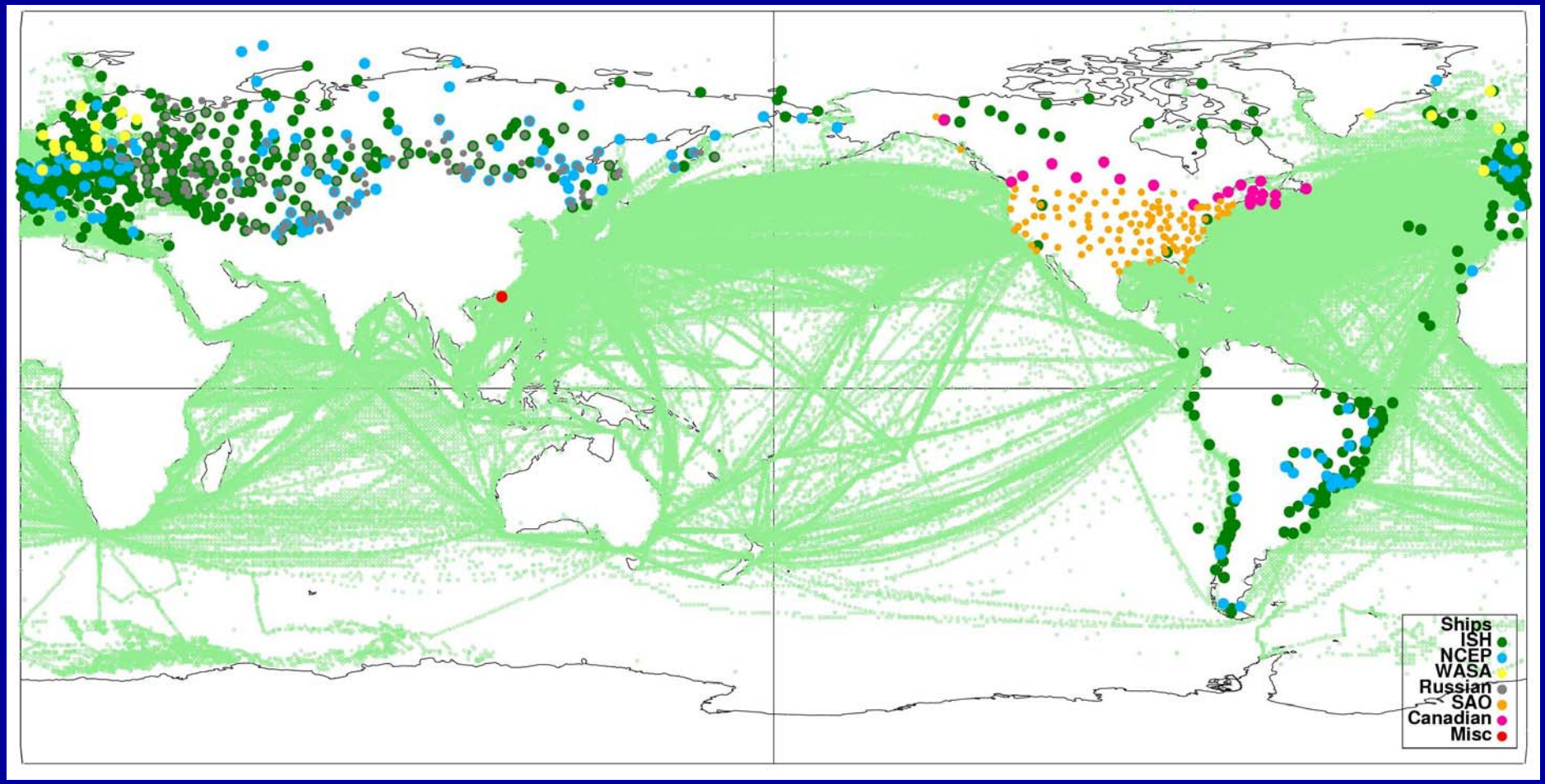
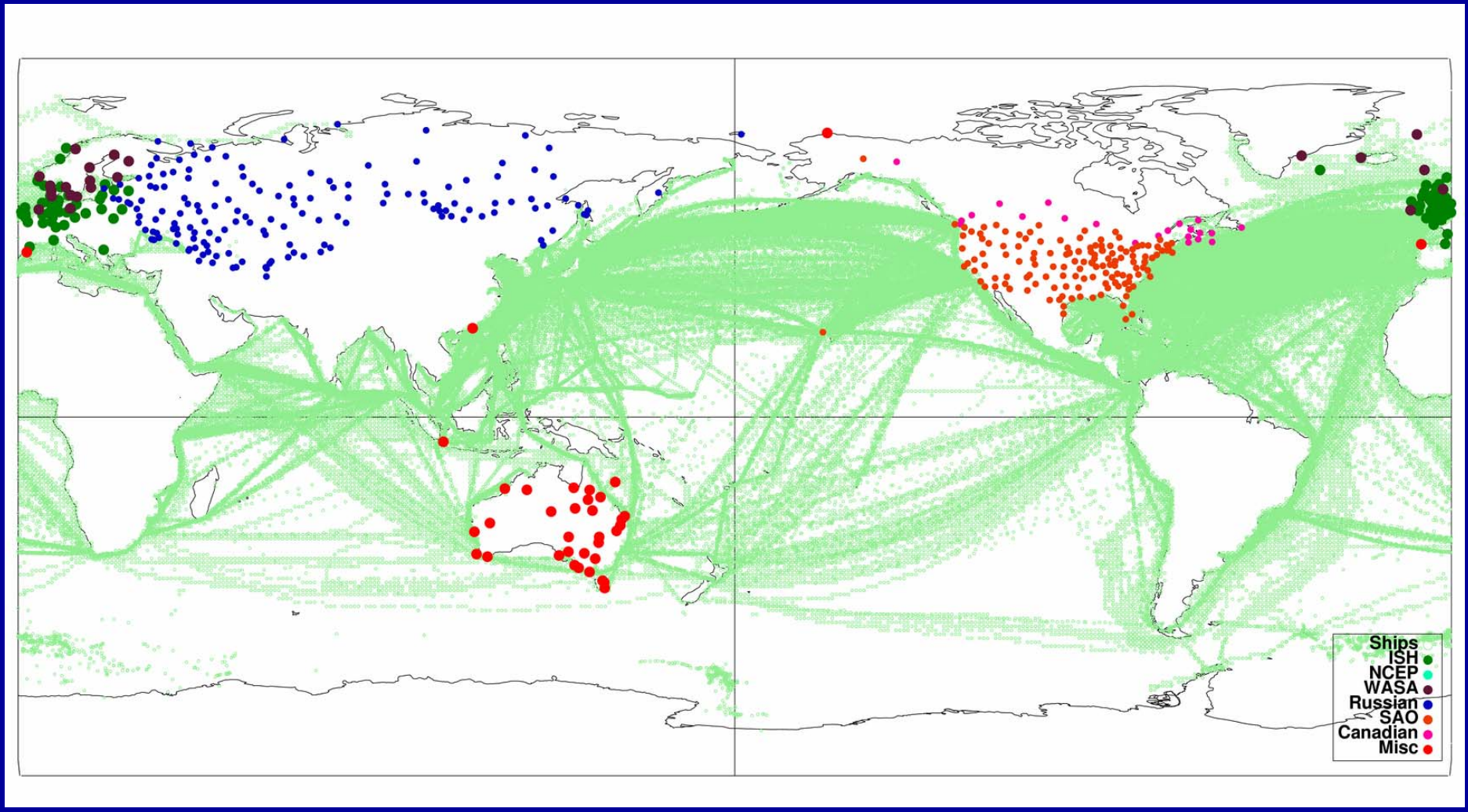
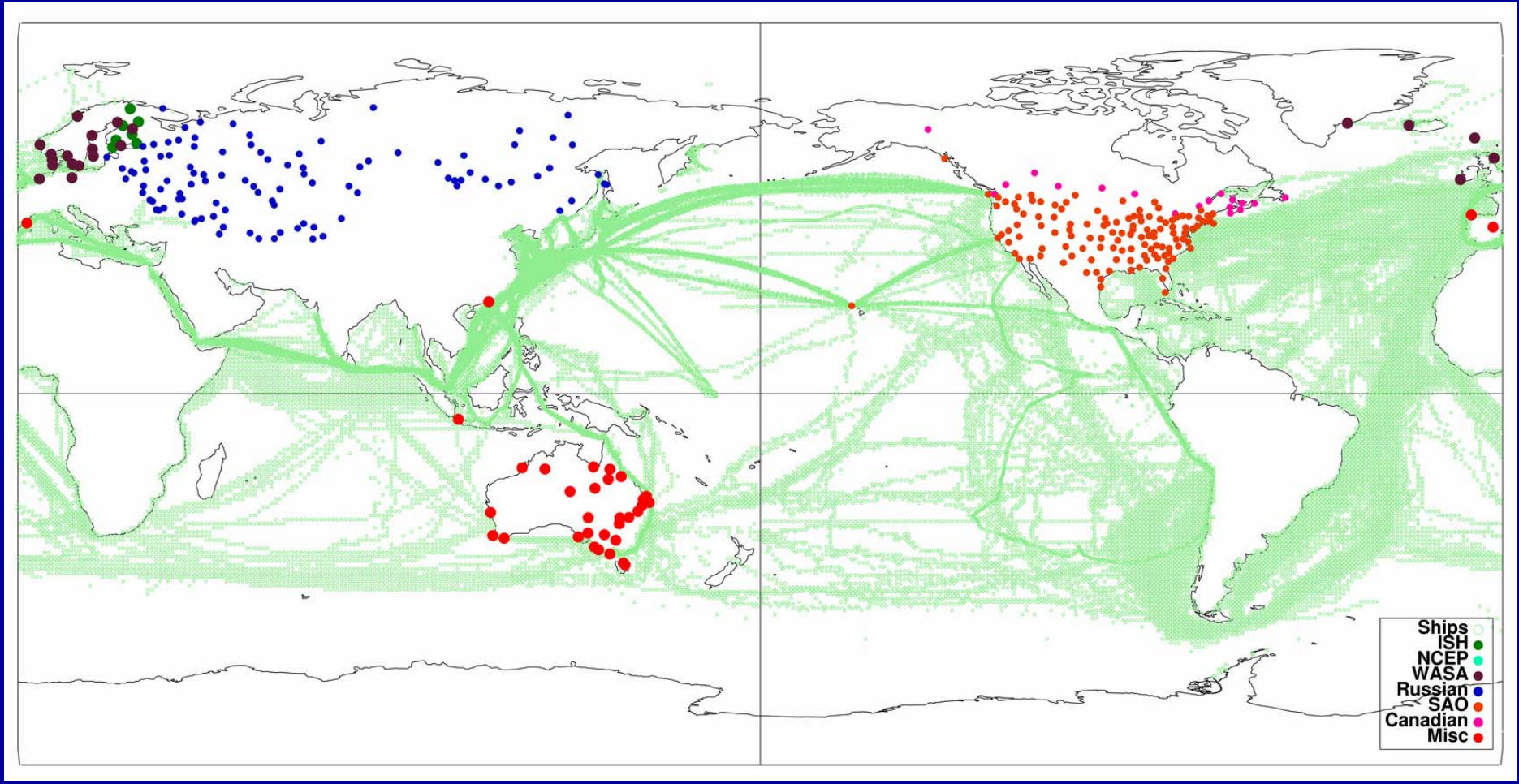
Sub-daily Pressure Observation locations Jan-Dec 1935



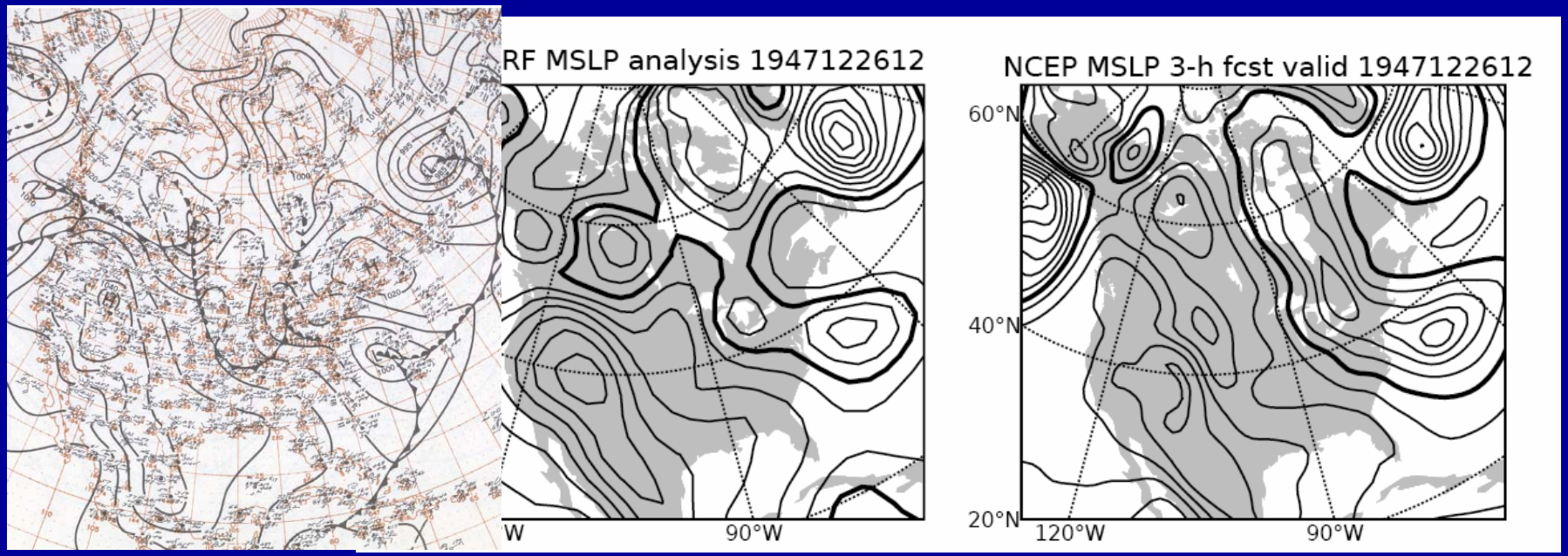
Sub-daily Pressure Observation locations Jan-Dec 1929



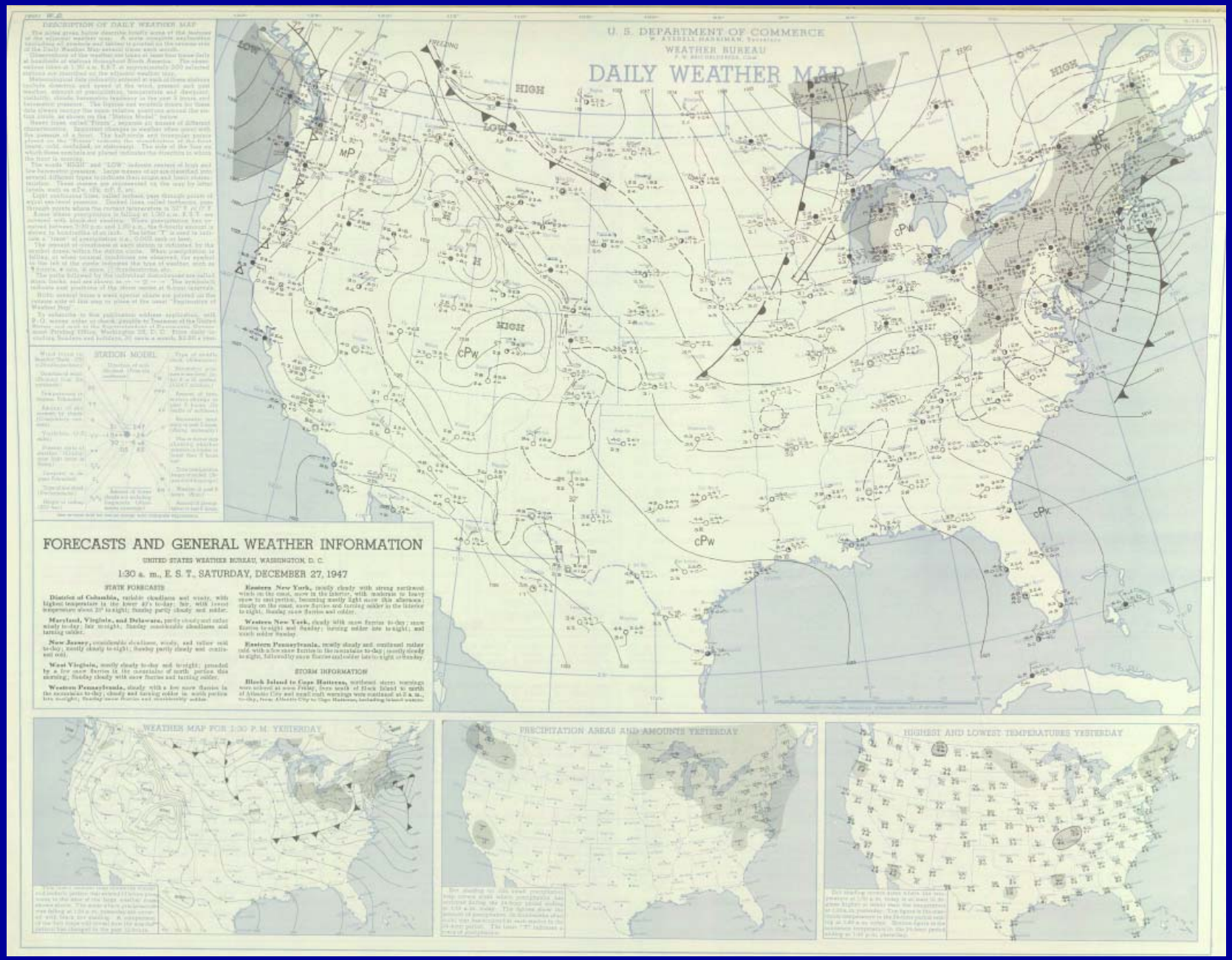
Sub-daily Pressure Observation locations Jan-Dec 1909



SLP 26 Dec 12Z



Sea Level Pressure Analysis 27 December 1947 0630 GMT



RMS Error and Anomaly Correlation skill of 6-hourly geopotential height analyses for Northern Hemisphere June 2001 using Ensemble Filter and Only Surface Pressure Obs at 1905 and 2001 densities

RMS anomaly correlation

Increasing number and coverage of observations will help lower tropospheric analysis of early 20th century.