Detection of Key Atmospheric Features in Reanalysis Data

Phil Arkin, University of Maryland

Randall Dole, NOAA

Siegfried Schubert, NASA

James Carton, University of Maryland

Eugenia Kalnay, University of Maryland

Randal Koster, NASA

What “Key Atmospheric Features” Should We Expect/Attempt to Detect?

- Climatology – the mean seasonal cycle of the atmosphere (e.g. monsoons)
- Changes on times scales long relative to the length of the data set (“trends”).
- Seasonal-to-Interannual Variability – the signatures of coherent patterns of atmospheric variability, such as:
    - El Niño/Southern Oscillation (ENSO)
    - North Atlantic Oscillation (NAO)
    - Pacific-North American (PNA)

Climate Change Science Program
Synthesis and Assessment Product 1.3:

Re-Analysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change

Randall M. Dole, NOAA, Agency Lead and Chair of Author Team
Siegfried Schubert, NASA and Martin Hoerling, NOAA, Convening Lead Authors

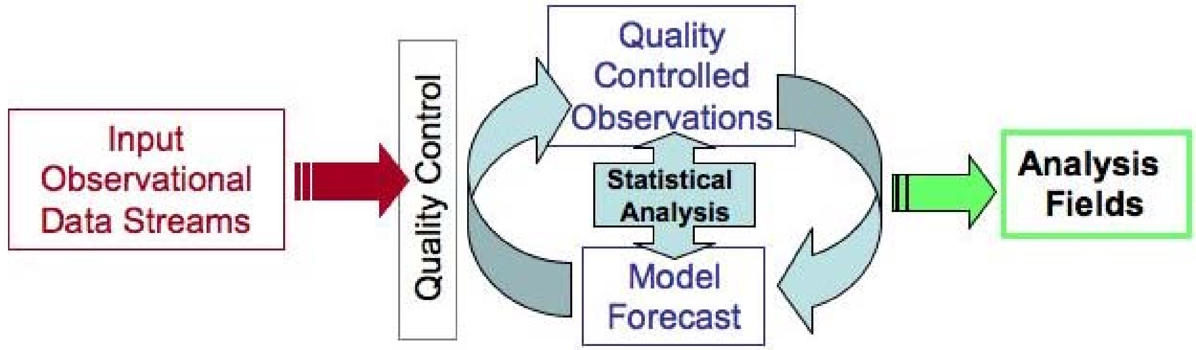
• The U.S. Climate Change Science Program (CCSP) was established in 2002 by President Bush as part of a new cabinet-level management agency to oversee public investments in climate change science.

• The CCSP provides the fundamental, high-level planning and coordination of U.S. activities in climate research. It is supported by 13 federal agencies, and is overseen by the Office of Science and Technology Policy, the Council on Environmental Quality, the National Economic Council, and the Office of Management and Budget.

• An important goal of the CCSP is to prepare scientific syntheses and assessments to support informed discussion of climate variability and change issues by decision-makers, stakeholders, the media, and the general public.

• One of 21 planned Synthesis and Assessment products.

What is climate **reanalysis**?



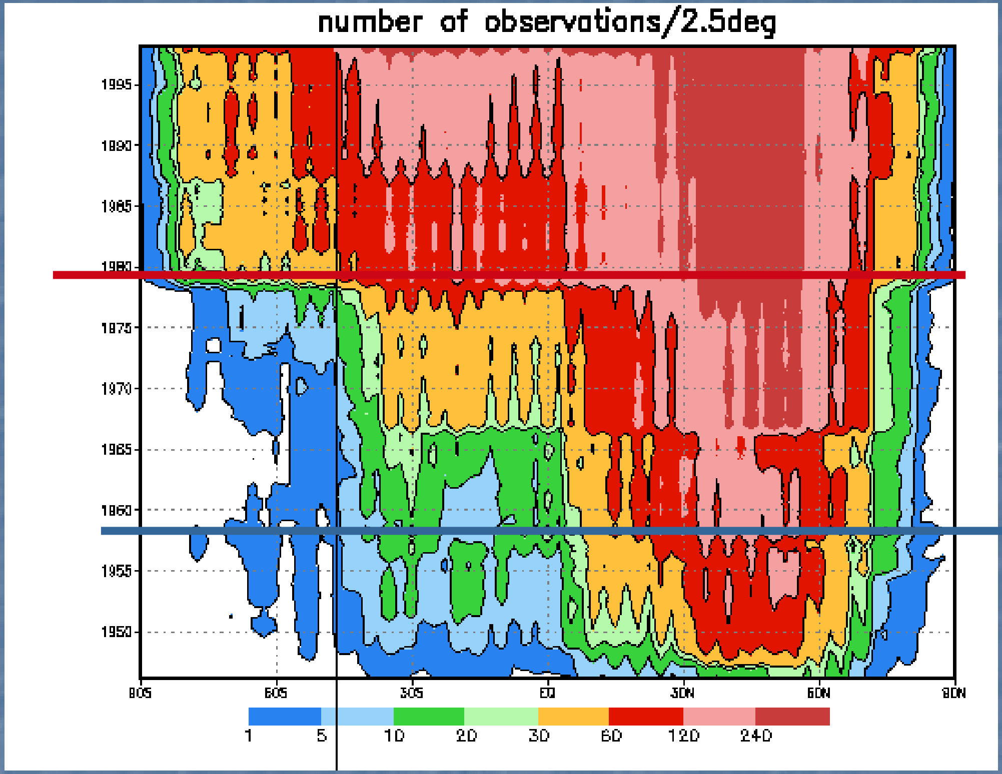
Past observations are reprocessed keeping the model and the statistical analysis unchanged. This creates a relatively self-consistent long analysis.

However, changes in the observing system can still generate some artificial variability in the analysis.

Nevertheless, reanalysis-derived data sets are superior to averages of individual observations or compilations of operational analyses

Major changes in the observing systems through time

FGGE (1979)



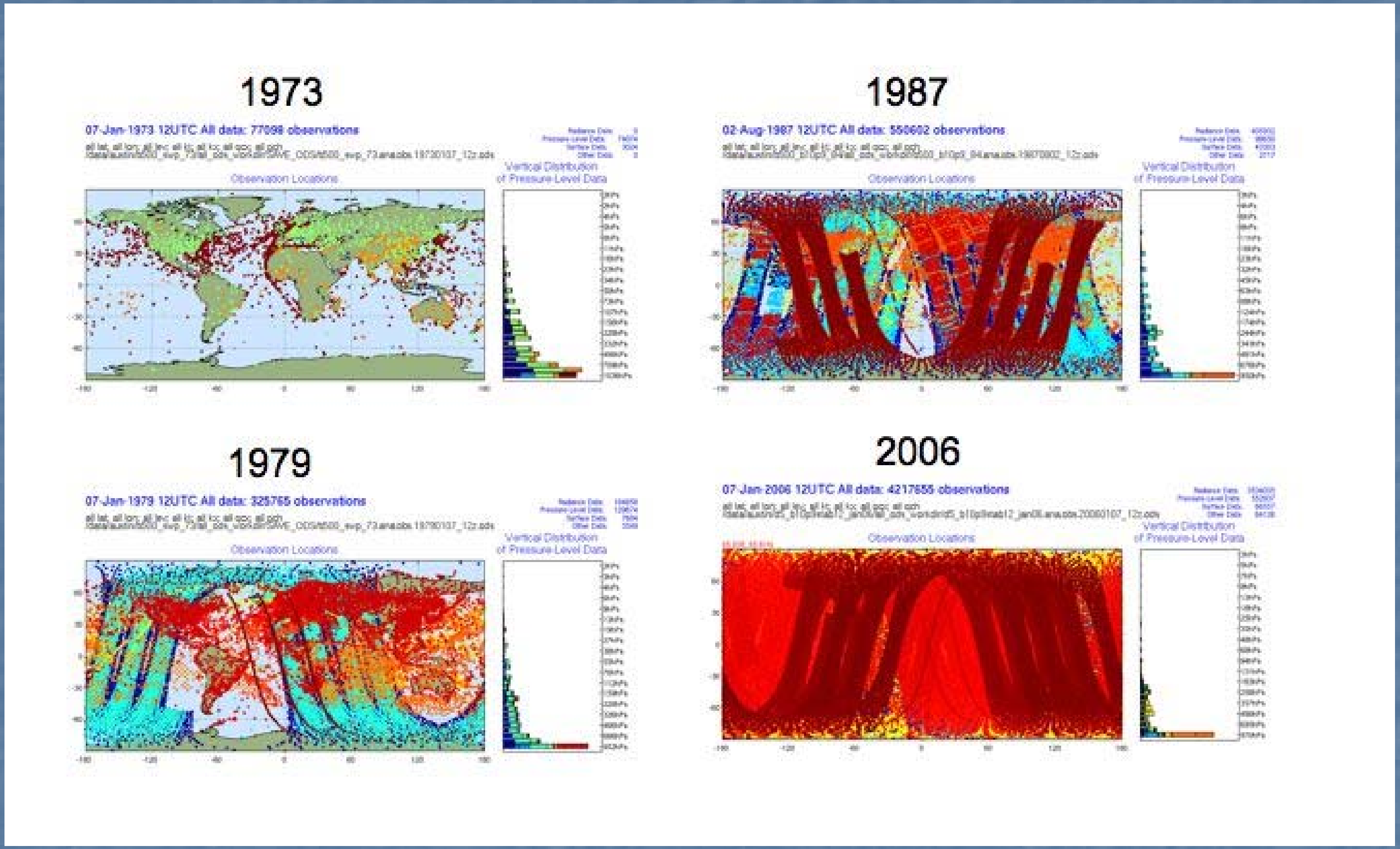
IGY (1958)

Radiosonde observations (raobs) started in NH ~ 1948

IGY (1957-58): Improved raob coverage

FGGE (1979): Global satellite coverage

Continuing changes, particularly in the satellite component



Number of remotely sensed observations continues to increase

Describing the mean atmospheric circulation: radiosonde data only

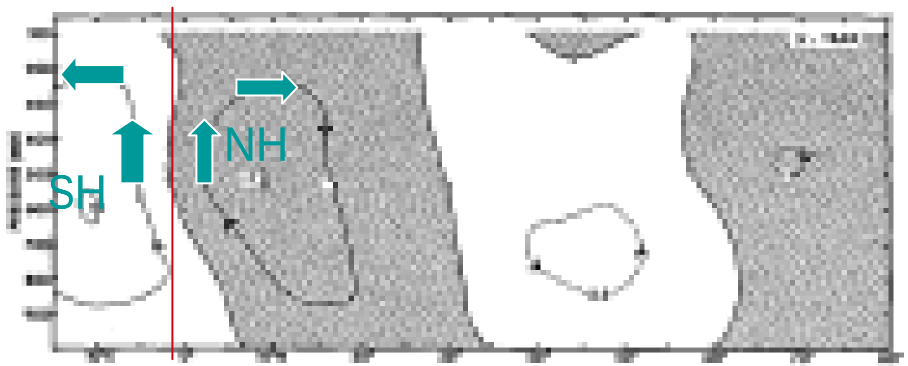
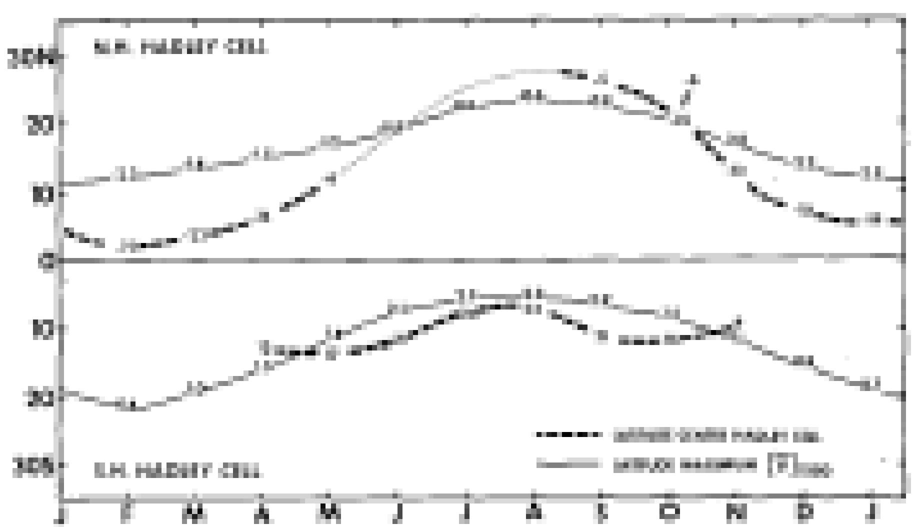


FIGURE 2—Streamlines of the mean meridional circulation for the annual mean conditions. The isolines give the total transport of mass northward below the level considered. Units, 10^{12} gm sec^{-1}.

Mean meridional circulation (Southern and Northern Hemisphere Hadley Cells at the left)



Seasonal migration of Hadley Cells (dashed partial curves) and 1000 mb mean meridional wind

Oort and Rasmusson, MWR, 1970

Longitudinal and Seasonal Asymmetries in the Meridional Circulation

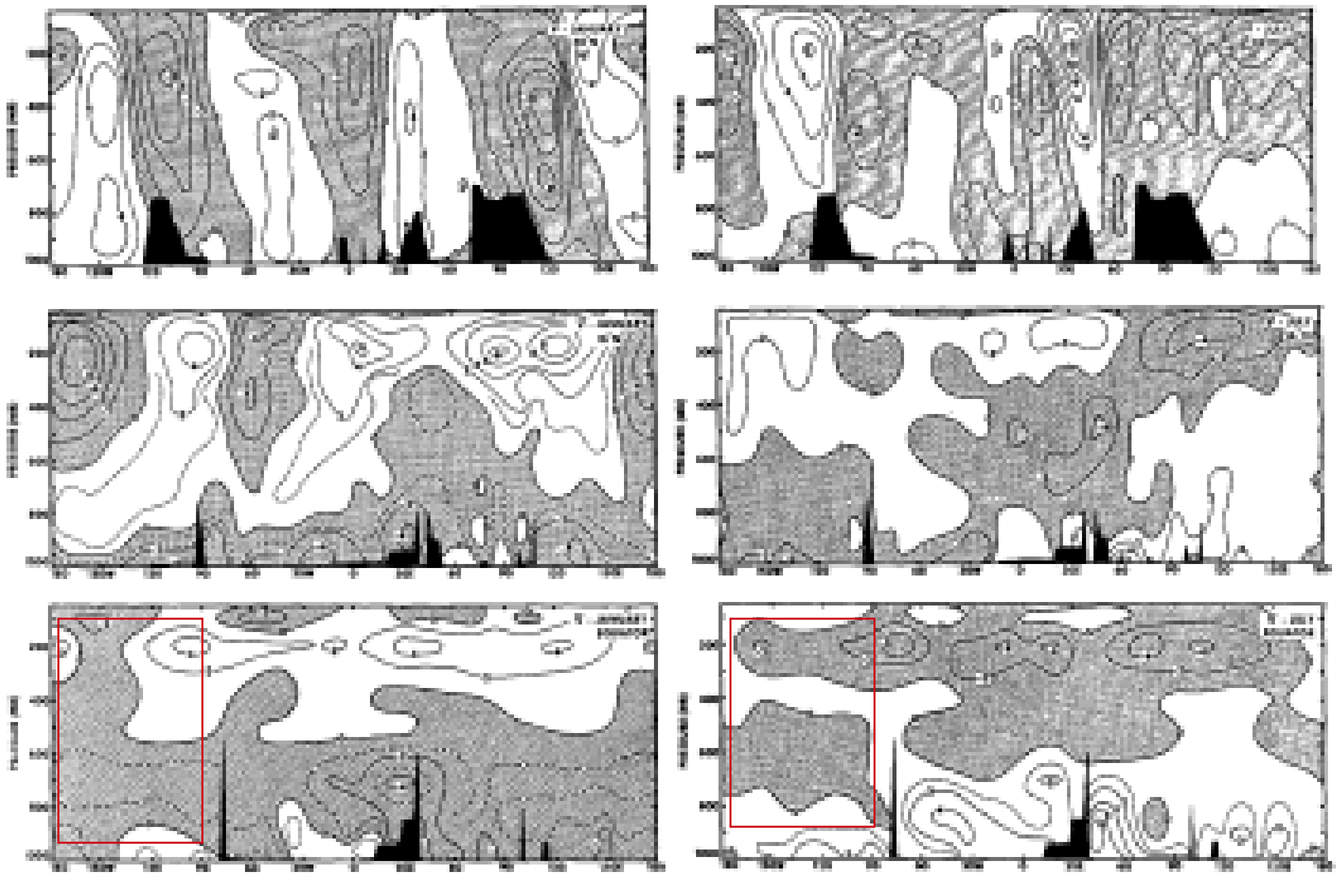


FIGURE 11.—Longitude versus pressure section of the time-mean meridional velocity (positive if northward) for January and July at the Equator, 16° N., and 40° N. Units, m sec⁻¹.

January (left) and July (right) meridional velocity (shaded is southward) at 40° N, 16° N and Equator (top to bottom); Greenwich Meridian in center of each column

Oort and Rasmusson, MWR, 1970

Clearly not uniform around the globe, but the significance of the details (note eastern equatorial Pacific) was impossible to assess

Reanalyses not only permit a much more detailed description of the mean circulation as a function of location and season, but enable diagnostic analyses relating the findings to independent data sets

NCEP 200mb divergent wind and CMAP precipitation – January (top) and July (bottom)

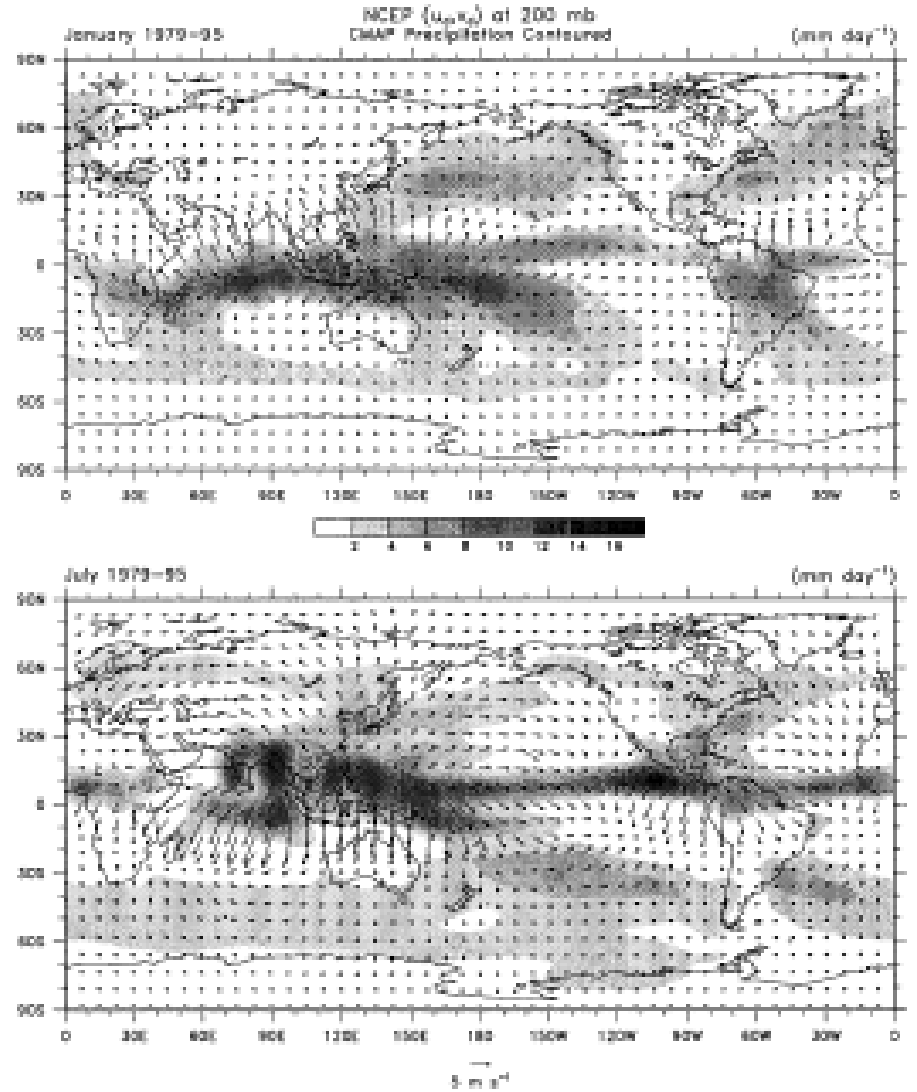
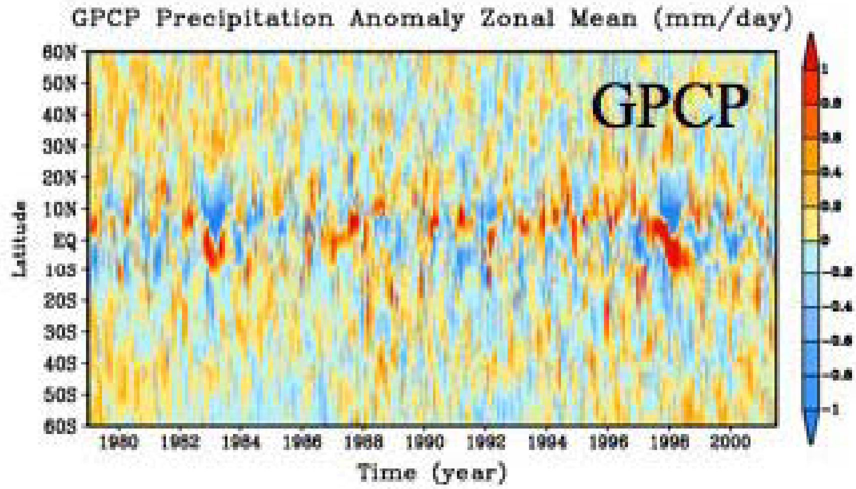
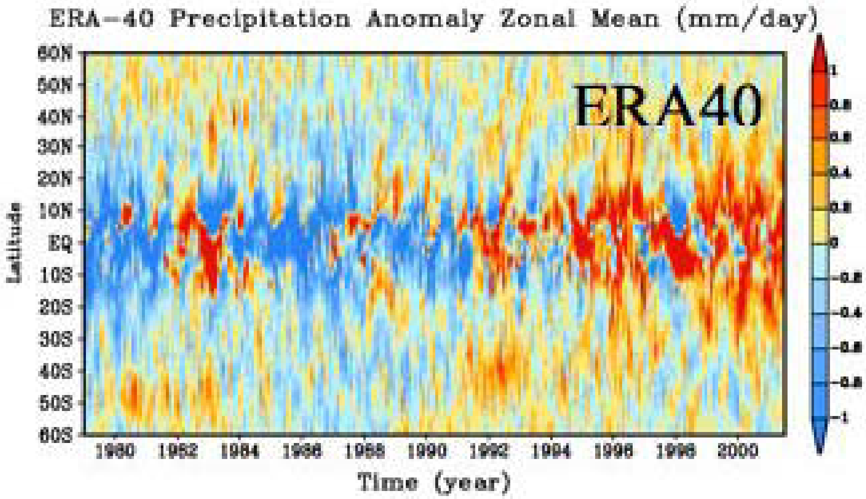


FIG. 1. For 1979–95, mean precipitation in mm day⁻¹ from the CMAP analysis along with the NCEP 200-mb divergent wind component in m s⁻¹, with the scale vector below each plot for Jan and Jul. The grayscale increments in 2 mm day⁻¹ and values less than 2 mm day⁻¹ are left blank.

"The Global Monsoon as Seen through the Divergent Atmospheric Circulation"
Trenberth, Stepaniak and Caron, J. Climate, 2000

While primary fields tend to be quite stable, derived parameters (such as precipitation) exhibit strong dependence on both the model and observations used.





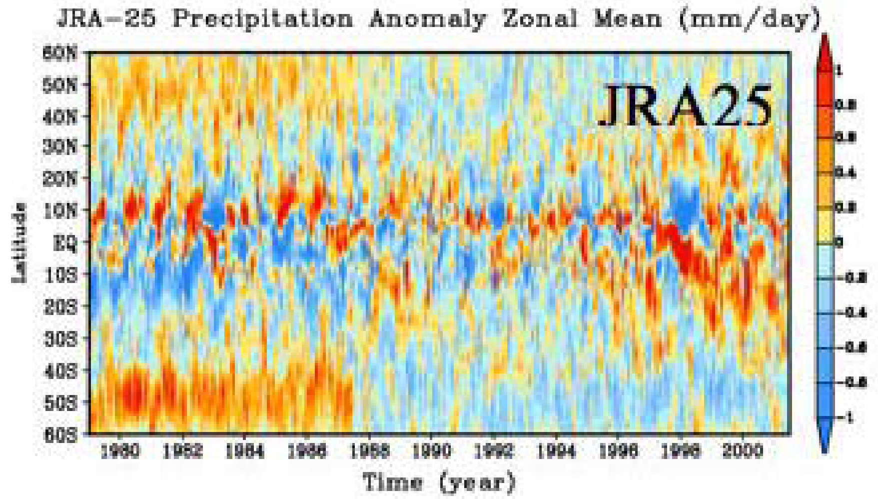


Figure courtesy Junye Chen, ESSIC and Mike Bosilovich, GMAO

The El Niño/Southern Oscillation (ENSO) phenomenon has global manifestations that can only be understood through diagnosis of the global atmospheric circulation. Before the availability of reanalysis data sets, such studies were very challenging (although not impossible).

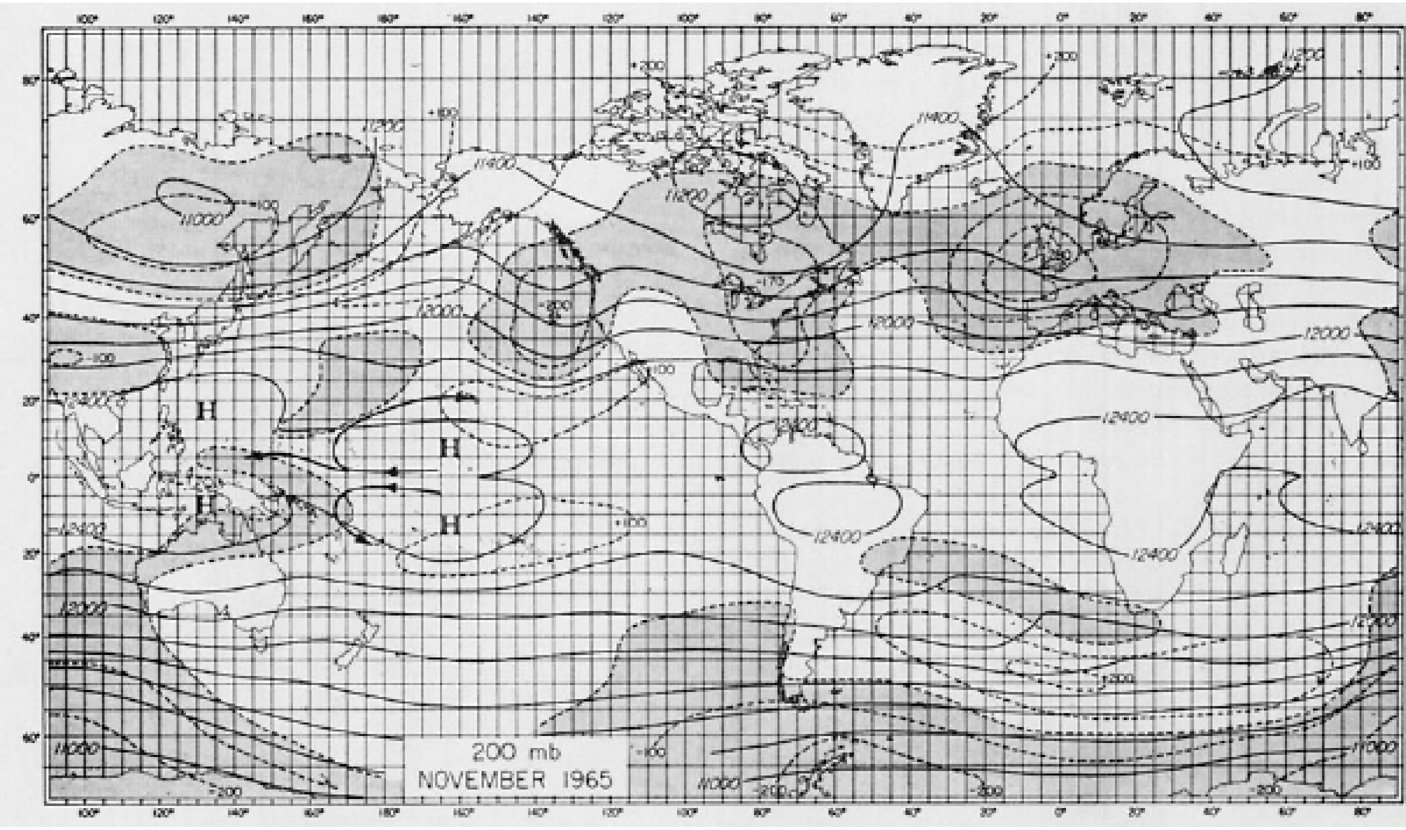


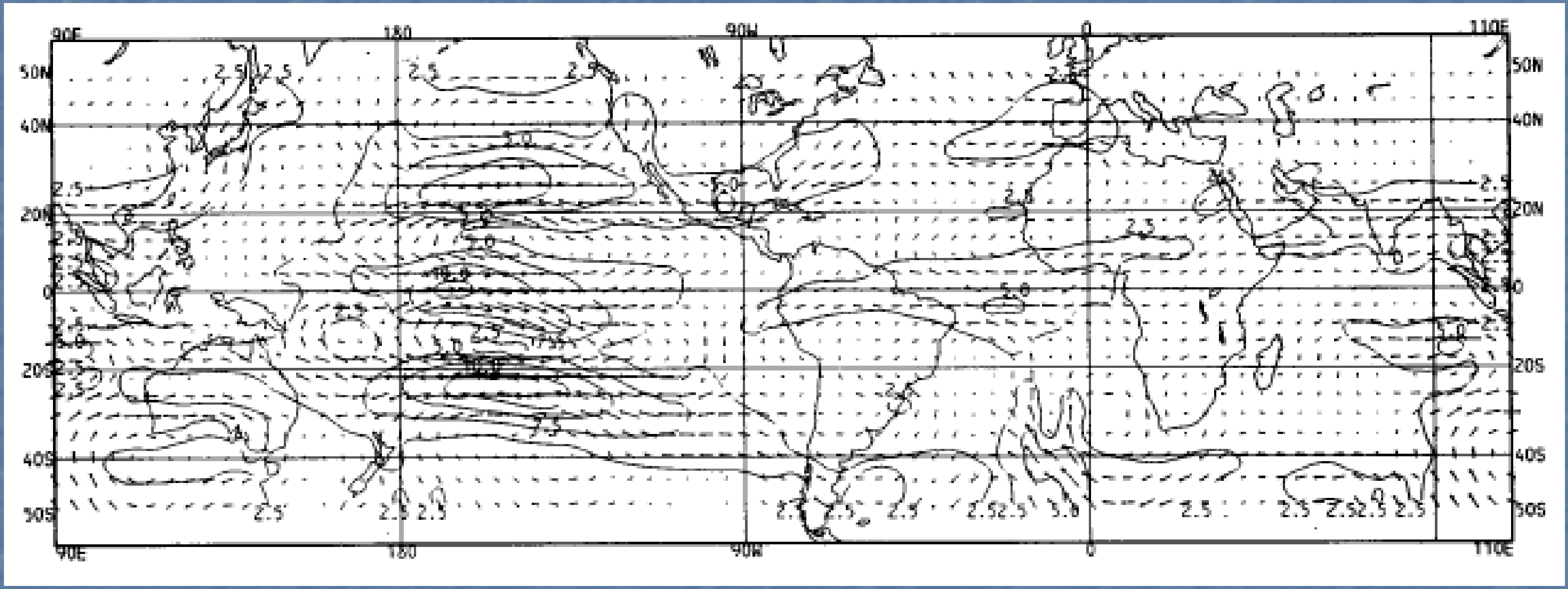
Fig. 4. 200-mb gpm topography for November 1965 and gpm change from November 1964. Negative change areas are shaded.

200 mb height for November 1965 (an El Niño year) and change from previous (neutral) November

Note the dual anticyclones in the tropical Pacific, their anomalous eastward extensions in 1965, and their impact on the subtropical jet streams. (Bjerknes did not discuss the sources for this map – presumably radiosonde observations and graduate students).

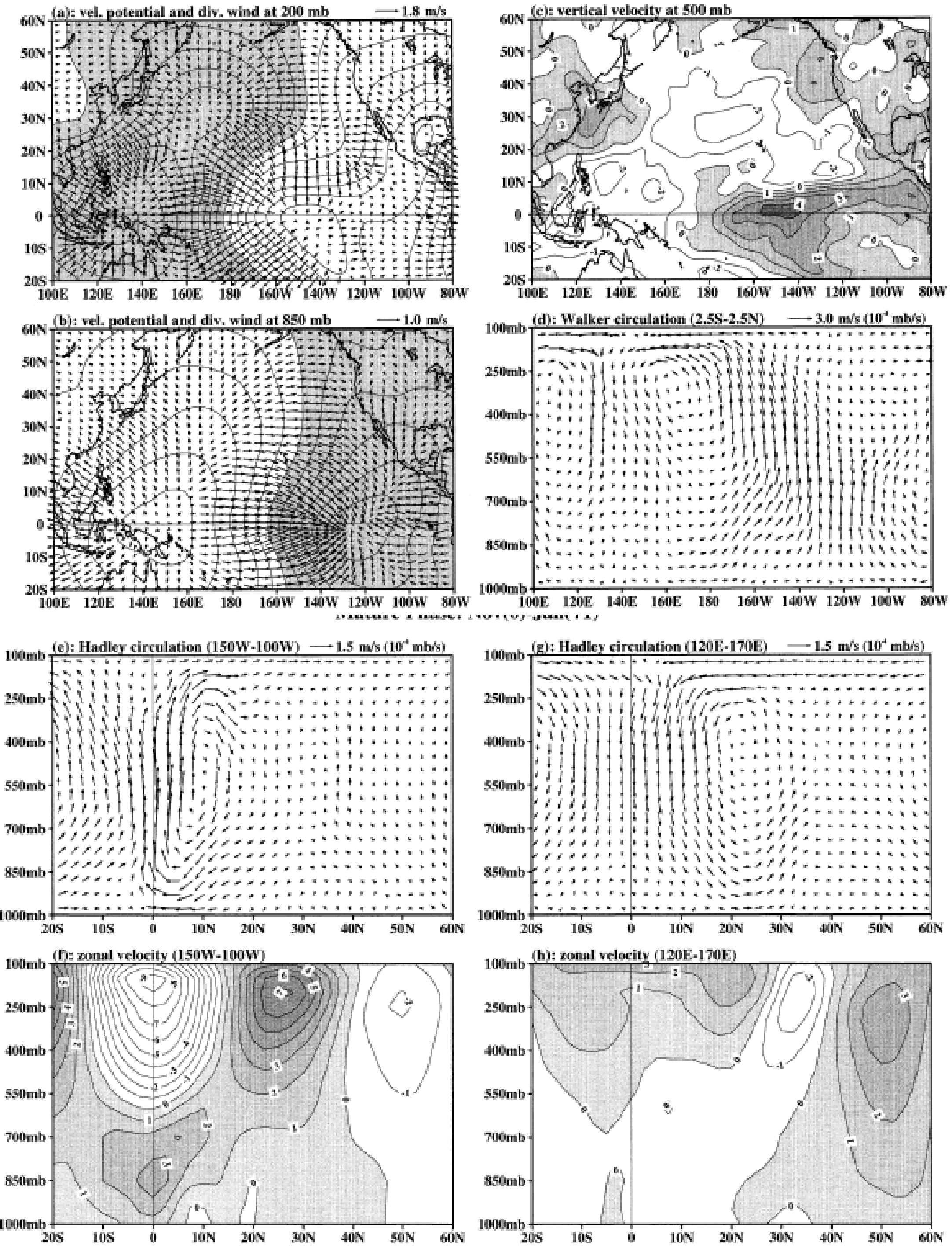
"Large-Scale Atmospheric Response to the 1964-65 Pacific Equatorial Warming", J. Bjerknes, J. Physical Oceanography, 1972

Early operational analyses permitted more complete description of the 200 mb wind field variations associated with ENSO. Where Bjerknes showed the difference between two individual months, here we see the composite difference between all months with high and low Southern Oscillation Index during a 12-year period.



Same kind of findings, but with much more confidence in the signal.

"The Relationship Between Interannual Variability in the 200 mb Tropical Wind Field and the Southern Oscillation", P. Arkin, Monthly Weather Review, 1982



Reanalyses made possible an exhaustive description of the tropospheric circulation features associated with ENSO. This study covered a 50-year period and showed the composite anomalies in divergent circulation (**200/850mb divergent wind/velocity potential; cross sections of Hadley/Walker Circulations**) through the troposphere.

Enormous detail permitting serious study of the coupled physics of ENSO

"Atmospheric Circulation Cells Associated with the El Niño-Southern Oscillation", C. Wang, J. Climate, 2002

Conclusions – 1
(based on findings from the draft report)

- Reanalysis plays a crucial integrating role within a global climate observing system by producing comprehensive long-term, objective, and consistent records of climate system components, including the atmosphere, oceans, and land surface.
- Reanalysis data sets are of particular value in studies of the physical mechanisms that produce high-impact climate anomalies such as droughts and floods, as well as other key atmospheric features that affect the U.S., including climate variations associated with **El Niño-Southern Oscillation** and other major modes of **climate variability**.

Conclusions – 2
(based on findings from the draft report)

- Current global reanalyses are most reliable:
  - in Northern Hemisphere middle latitudes, in the middle to upper troposphere, and on synoptic (weather) and larger spatial scales;
  - on daily to interannual time scales; and
  - for quantities that are most strongly constrained by the observations (e.g., temperature and winds).
- Current global reanalysis data are least reliable:
  - near the surface, in the stratosphere, tropics, and polar regions;
  - in the representation of the diurnal cycle, and in the representation of decadal and longer time scales where they are most impacted by deficiencies in the coverage and quality of observational data and changes in observing systems over time; and
  - for quantities that are highly model dependent, such as evaporation, precipitation, and cloud-related properties.

Conclusions – Outlook
(based on findings from the draft report)

- Reanalyses have already had enormous benefits for climate research and prediction, as well as for a wide range of societal applications.
- Nevertheless, significant future improvements are possible by testing and continue developing new methods able to
  - address observing system inhomogeneities,
  - estimate and correct model biases,
  - estimate reanalysis uncertainties.
- Also, it is essential to continue research towards
  - improving our observational database
  - developing integrated Earth System models and analyses that better represent key climate interactions between the atmosphere, oceans, land and cryosphere,
  - including in the reanalyses, for the first time, an interactive biosphere and carbon cycle.

Thank you for your attention

Arigato Gozaimasu