Stratospheric Observations, Processes, and Reanalysis

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US CLIVAR – Process Study Model Improvement – July 10, 2017 – Baltimore, MD

Outline

- Stratospheric observations
  - A little history
  - Satellite observations
    - Instrument types
    - Past, current, future
- Stratospheric Processes
  - SPARC
  - Stratosphere ↔Troposphere
- Reanalysis
  - S-RIP
- Summary

Stratospheric Observations

- Balloons
  - Radiosonde ~ First developed in 1930
    - Altitude, Pressure, Temperature, Relative Humidity, Wind speed / direction
    - Theodolite / radar / GPS
    - Graph of increase of # reports reaching 10 hPa
    - High vertical resolution (account for thermal lag, radiation corrections)
    - IGY 1958 conformed to 00 and 12Z launch times
  - Ozonesonde ~ 1967
    - Electrochemical Concentration Cell (ECC)
    - Single to several launches per week
    - Can reach 3 hPa with better /more expensive balloon
  - WaterVapor-sonde
    - Frost Point Hygrometers (FPH)
    - 2-28km
- Rocketsonde 1960’s-1990’s
  - Reached 1 hPa
  - Decreasing regularity of launches
- Lidar
  - Shoot at night over several hours
- Satellites
  - Operational
  - Research

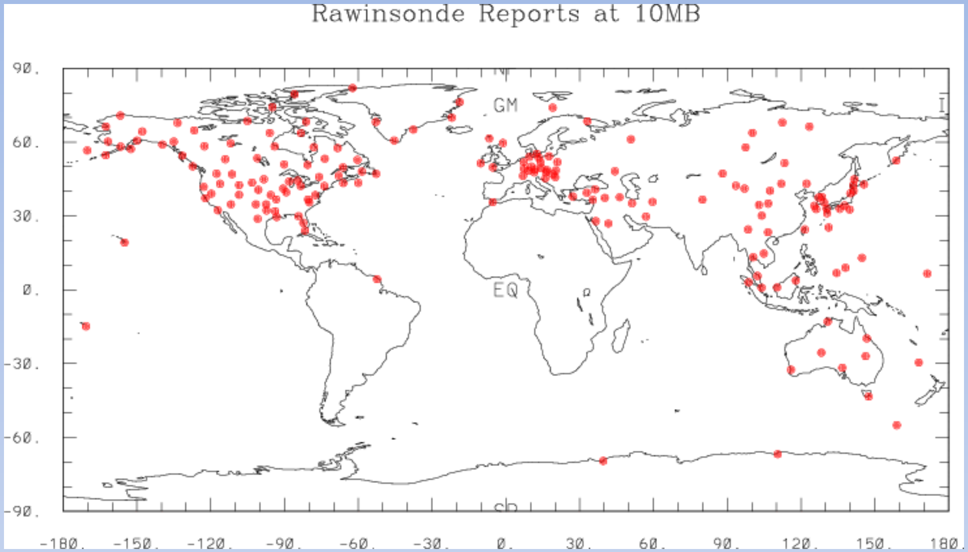
Stratospheric Observations

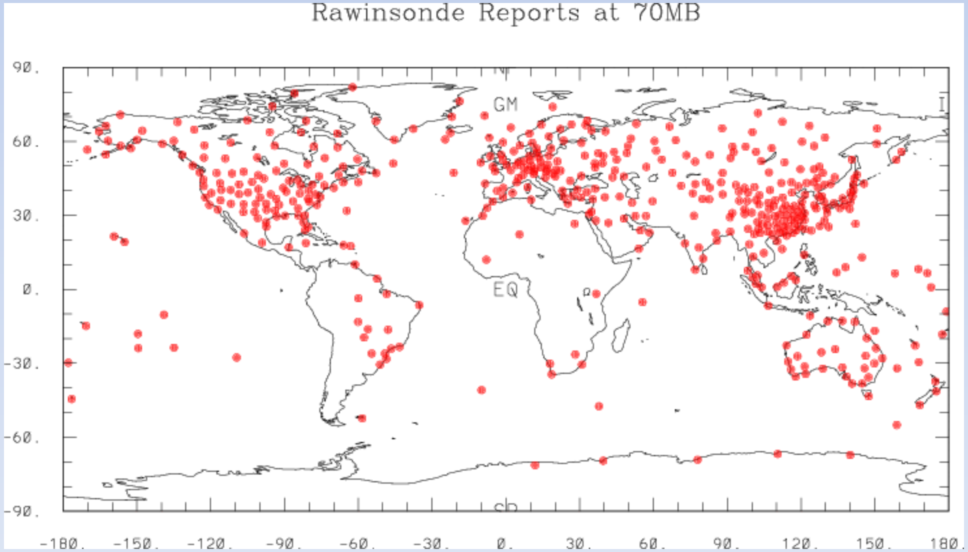
Satellite Instruments observing the stratosphere

- Nadir
  - Mapping
    - VTPR
    - TOMS
    - SSU
    - AMSU
    - ATMS
    - AIRS
    - IASI
    - CrIS
    - DMSP - SSMIS
    - OMPS-NM
    - AURA-OMI
  - Profile
    - BUV
    - SBUV
    - OMPS-NP
    - GOME, GOME-2, GOMOS

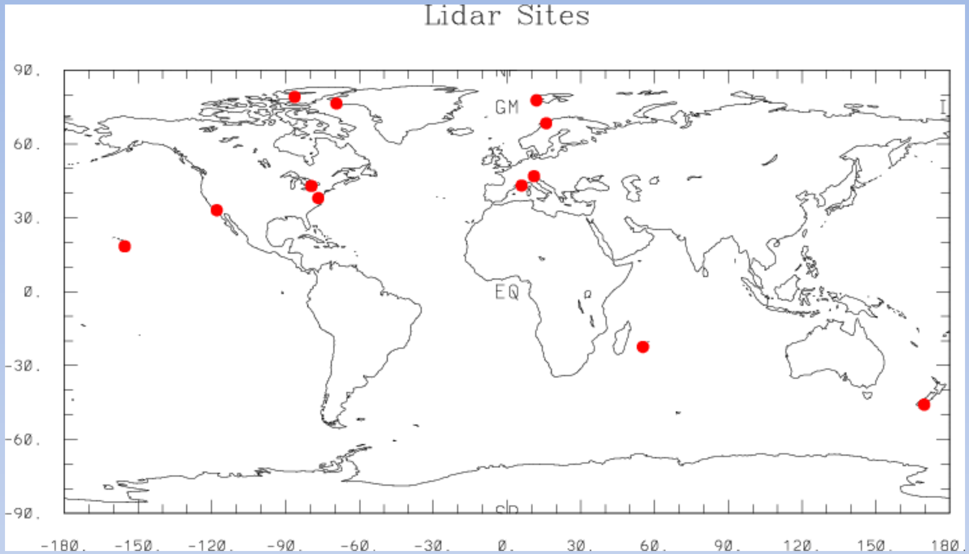
- Limb - Profile
  - NIMBUS-7 - SAMS
  - TIMED-SABER
  - Aura MLS,
  - UARS MLS, HIRDLS
- Occultation - Profile
  - SAGE I, II, III
  - UARS HALOE
  - ACE-FTS
  - GPS-RO
    - GRACE
    - CHAMP
    - COSMIC
    - GRAS (MetOp)

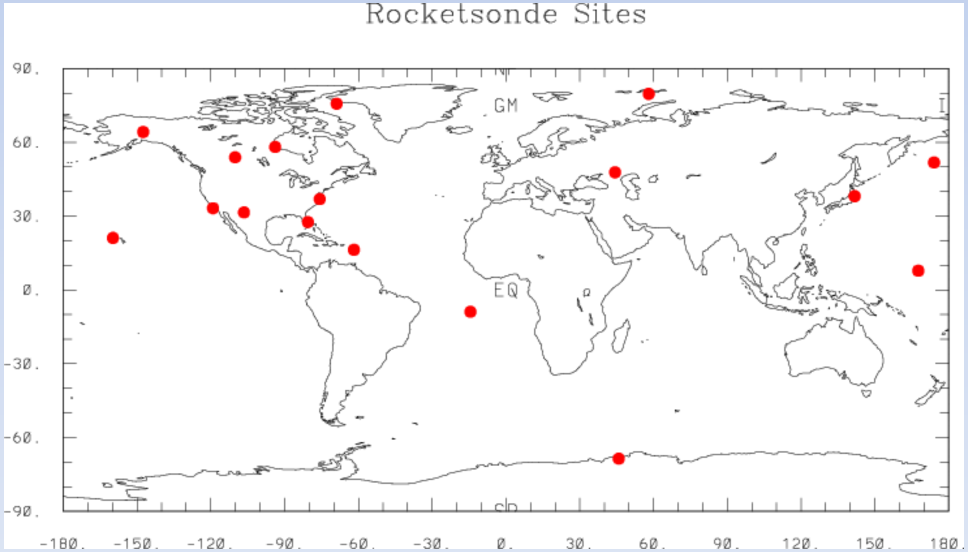
Rawinsonde Sites



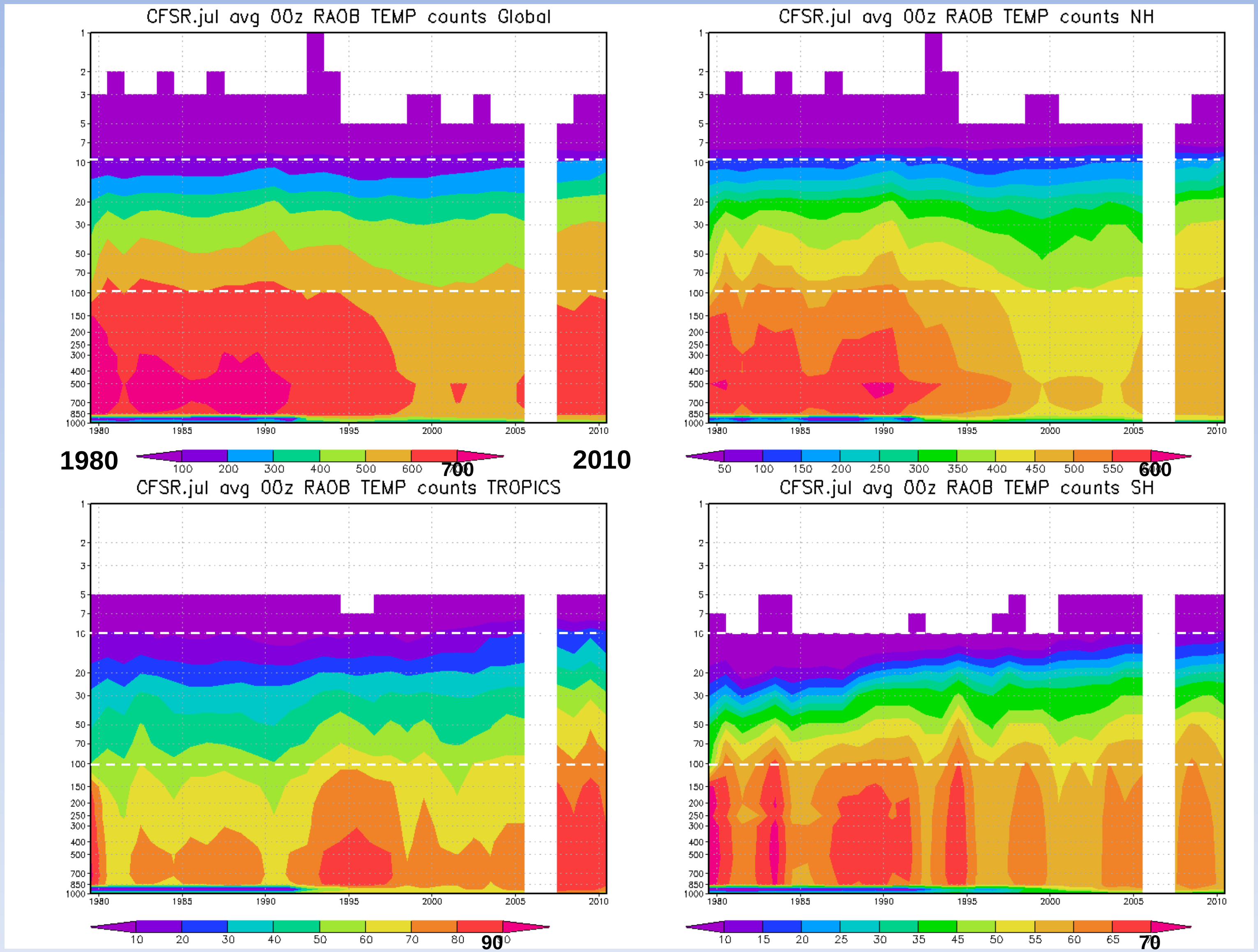


Rocketsonde/Lidar Sites



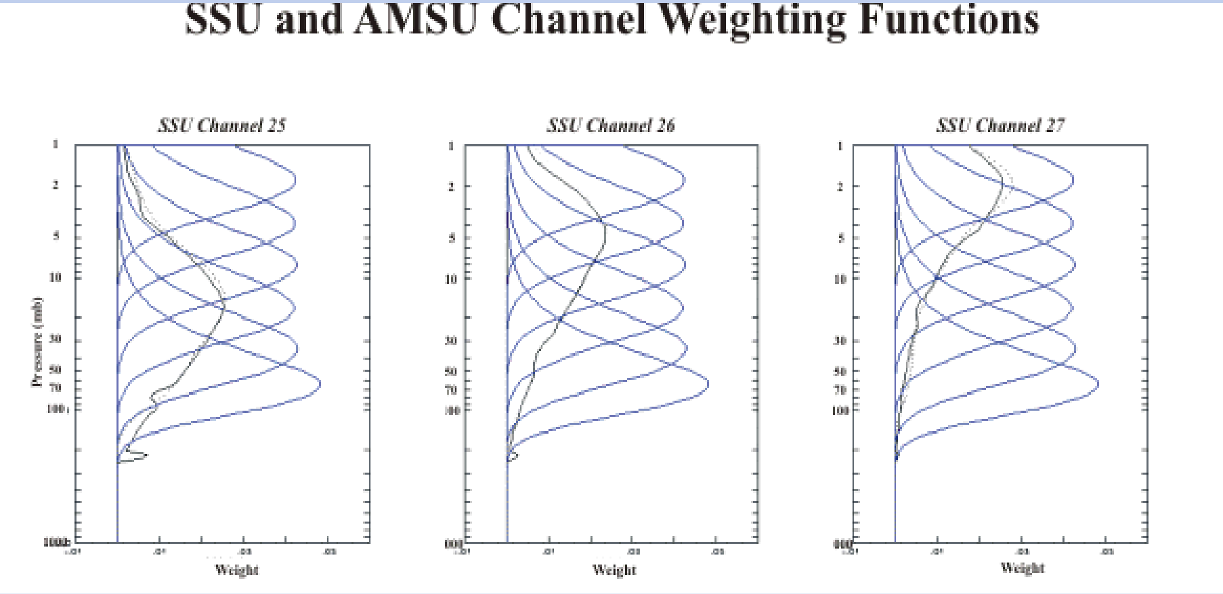


of Radiosondes reaching higher altitudes decreases rapidly



Stratospheric Observations

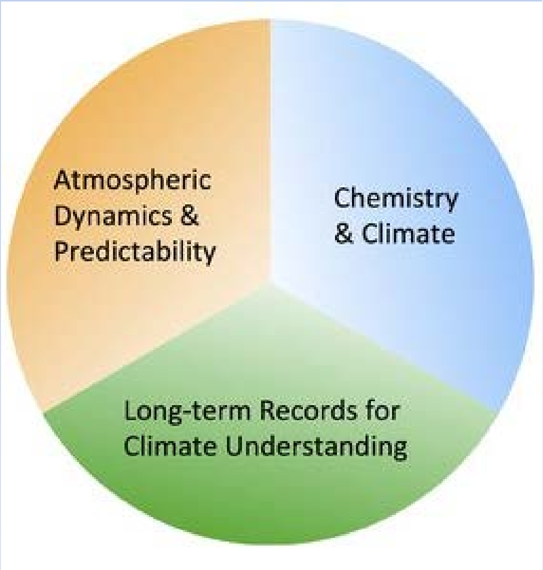
- Satellites
  - Infrared vs microwave
    - SSU vs AMSU
    - SSU - Vertically broad weighting functions
    - AMSU /ATMS – vertically narrower weighting functions
    - Hyperspectral allow choices for channels to be assimilated

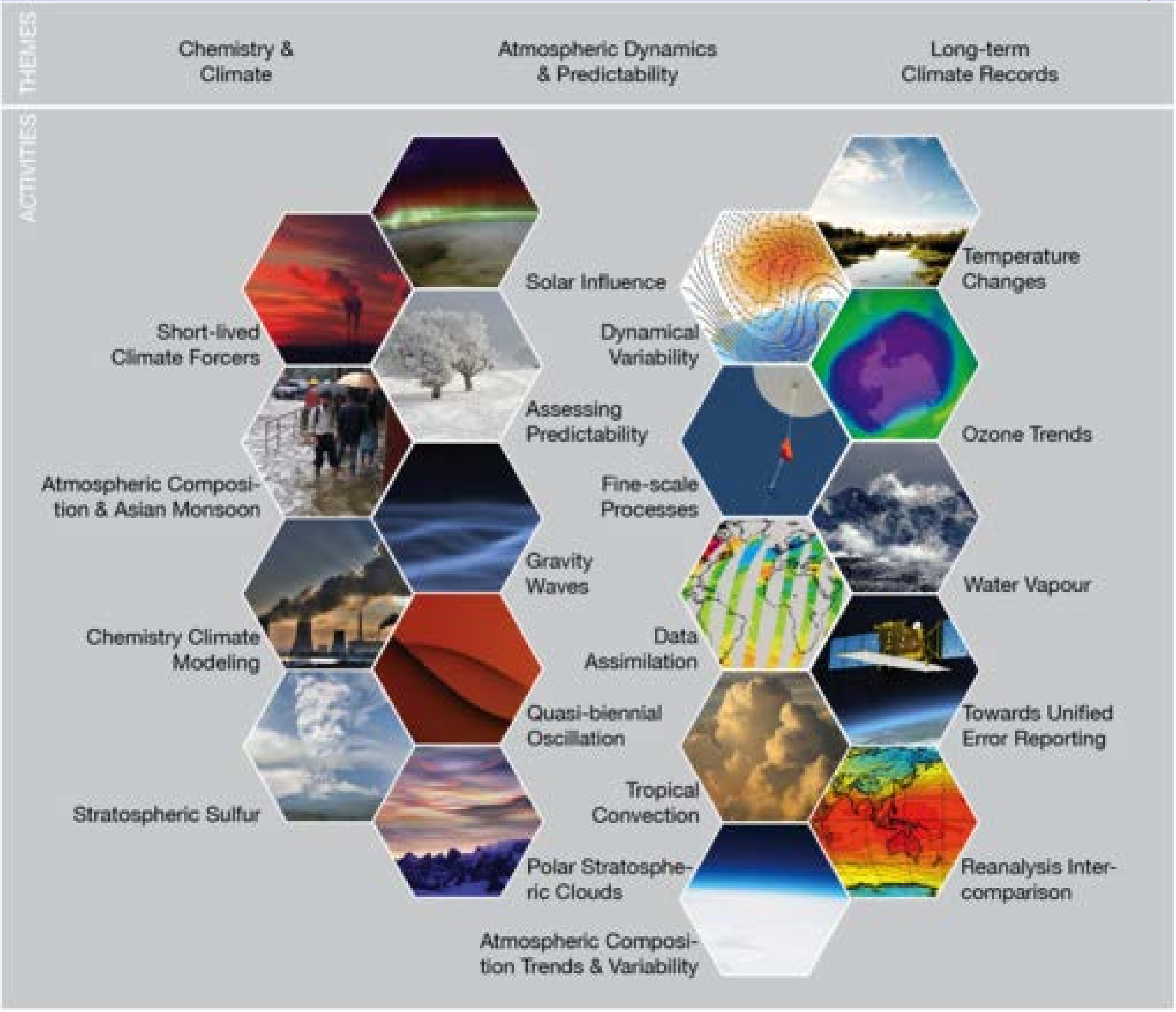


Stratospheric Processes

SPARC: Stratospheric-tropospheric Processes And their Role in Climate

SPARC
Stratosphere-troposphere Processes And their Role in Climate





Atmospheric Dynamics and Predictability

- Climate science community needs to **provide skillful and reliable regional climate predictions** from months to decades ahead.
- **All time scales** need to be addressed for climate prediction
  - Monthly, seasonal, annual, decadal.
- On regional scales **dynamics** determines climate as much as the **thermodynamics**.
- **Regional variations** in atmospheric circulation affect rainfall and circulation-related quantities such as storminess or atmospheric blocking.
- Variations of precipitation and temperature have **crucial socio-economic impacts** and can influence many government and business decisions.
- Seasonal-to-decadal prediction is a challenge of the coupled **troposphere-ocean system.**
- Extra-tropical regions **stratosphere-troposphere coupling** plays an important role, as well.

Atmospheric Dynamics and Predictability

- **Science questions**:
  - How predictable is the atmosphere across time scales and regions?
  - How is predictability affected by the atmosphere, ocean, sea-ice, and land surface conditions?
  - Do models reproduce the pattern and strength of atmospheric teleconnections?
  - What are the mechanisms of stratosphere-troposphere coupling across time scales?
  - How do external forcings of both natural and anthropogenic origin affect regional climate?
  - How representative is our relatively short sample of observed historical climate variability?
  - What dynamical circumstances are likely to lead to extreme regional events?

Atmospheric Dynamics and Predictability

- **Related SPARC activities:**
  - Assessing predictability (SNAP)
  - Data assimilation
  - Dynamical Variability (DynVar)
  - Gravity waves
  - Polar Climate Predictability Initiative (PCPi) - joint with CliC
  - Quasi-biennial oscillation (QBOi)
  - Solar influence
  - Temperature changes
  - Stratospheric & tropospheric influences on tropical convection

Chemistry and Climate

- Three-way coupling between **chemical**, **dynamical**, and **radiative** processes could have important effects on climate, including modulation of climate sensitivity.
- While stratospheric ozone is expected to recover from the effects of ozone-depleting substances over the coming decades, the **chemical impact of N_2O and CH_4 on stratospheric ozone and water vapor will likely increase**.
- Resulting changes in ozone, water vapor, NO_x, and HO_x will occur **simultaneously** with changes in stratospheric CO_2 and temperature.
- Atmospheric aerosols:
  - The increased stratospheric aerosol following strong volcanic eruptions can influence stratospheric ozone and have a strong impact on tropospheric climate.
  - the simulation of aerosol formation in models is challenging.
  - uncertainty in aerosol concentrations and properties creates uncertainty in aerosol radiative forcing, particularly the indirect aerosol forcing and its effects through cloud feedbacks.
- Radiative forcing from long-lived gases (CO_2, CH_4, N_2O, CFCs, etc.) is well understood.
- The **main uncertainties** are associated with:
  - **future biogeochemical changes** in the carbon cycle;
  - natural and anthropogenic emissions of these gases (CH_4 especially)
  - assessing the **future emission** scenarios of CH_4 and N_2O.

Chemistry and Climate

- **Science questions**
  - **Volcanic eruptions** : how do they affect atmospheric composition, radiation, and dynamics and what are the effects on surface climate?
  - **Tropopause layer cirrus** : how do they and their associated radiative effects change in a warming climate?
  - **Solar UV irradiance** : How much does it vary and influence on decadal-scale climate?
  - **Stratospheric water vapor** : What determines its long-term changes and its feedback on radiative forcing?
  - **Stratosphere-troposphere exchange** : What trends have occurred on hemispheric and regional scales and how robust are projections of future trends?
  - **Stratospheric ozone** : How does climate change affect its transport to the troposphere, and thereby influence tropospheric composition and air quality given expected changes in tropospheric emissions?
  - By what processes, and to what extent, might changes in the chemical composition of the stratosphere influence climate sensitivity?
  - How might coupling between changes in atmospheric dynamics and chemical composition affect future climate?

Chemistry and Climate

- **Related SPARC activities**:
  - Asian monsoon (ACAM) - joint with IGAC
  - CCM initiative (CCMi) - joint with IGAC
  - Data assimilation
  - Polar stratospheric clouds (PSC)
  - Solar influence (SOLARIS-HEPPA)
  - Stratospheric sulfur (SSiRC)
  - Climate response to short-lived climate forcers

Long-term Records for Climate Understanding

- SPARC has a well-established history of assessing the quality and utility of long-term climate records of temperature, water vapor, ozone, and aerosols.
- SPARC promotes the creation, analysis, and interpretation of **climate data records** (CDRs) of a range of **essential climate variables** (ECVs), including temperature, water vapor, ozone, and aerosols.
- In particular, this research provides support to WMO/UNEP scientific assessments of ozone depletion and IPCC assessments of the physical science basis of climate change.
- Ozone CDRs are not only essential for assessing the effectiveness of the Montreal Protocol but are also needed for prescribing forcings in climate model simulations without stratospheric chemistry.
- SPARC promotes activities to guide construction, analysis, and interpretation of CDRs that require international cooperation.

Long-term Records for Climate Understanding

- **Science questions**
  - What are the **vertically and spatially resolved trends** in SPARC-relevant ECVs?
  - What are the **requirements on observing programs**, both in terms of measurement **uncertainties** and measurement sampling regimens, such that these observing programs can reliably detect and quantify trends?
  - Which species and state variables are needed, and with what resolution, frequency, and uncertainty, to better diagnose those changes in atmospheric composition and dynamics relevant to SPARC research?
  - Is the atmosphere, both in terms of chemistry and dynamics, evolving in a way that is consistent with our understanding?
  - To what extent do current observations test our knowledge of atmospheric composition and dynamics? Which observations would provide more robust tests of our current level of understanding?

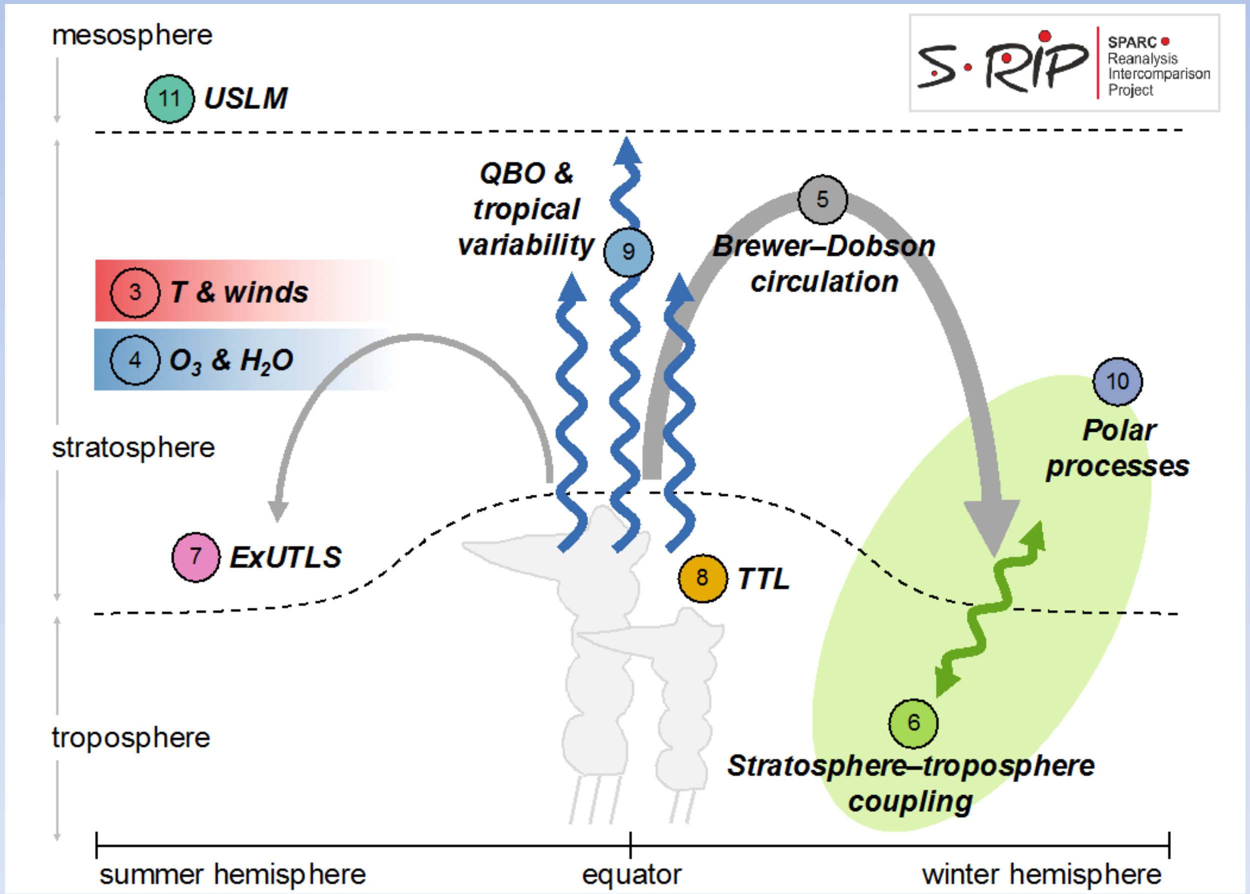
Long-term Records for Climate Understanding

- **Related SPARC activities**:
  - Reanalysis intercomparison (S-RIP)
  - Stratospheric ozone trends (LOTUS)
  - Temperature changes
  - Water vapour (WAVAS-II)
  - Composition and trends in the UTLS (OCTAV-UTLS)
  - Towards unified error reporting (TUNER)

Stratospheric Processes

SPARC – Reanalysis Intercomparison Project (S-RIP)

Evaluated processes and regions



Reanalyses

- **Purpose:**
  - To re-analyize a historic period of time using the latest assimilation, radiative transfer, and forecast models available
  - To provide the best depiction of the atmospheric at any given time.
  - To provide Initial Conditions for climate model hindcasts
    - Used for bias correcting climate S2S forecasts
  - Constraints
    - Horizontal and vertical resolution
    - Available observations to assimilate
  - Issues:
    - Bias correction
    - Transition from similar satellites instruments
    - Transition from dissimilar satellite instruments
    - Accurately modelling (prescribing) processes

Reanalyses

- ERA-15 (1979-1993)
- NCEP/NCAR (R1) (1948-present)
- NCEP/DOE (R2) (1979-present)
- ERA40 (1957-2002)
- JRA-25 (1979-2004)
- CFSR (1979-present) *resolution change in 2010*
- MERRA (1979-2015)
- ERA-Interim (1979-2018)
- JRA-55 (1979-present)
- MERRA-2 (1980-present)
- ERA5 (1979-present) *in production*

Competed Reanalyses
Ongoing Reanalyses

Long term surface obs based reanalyses : 20CR, ERA-20C

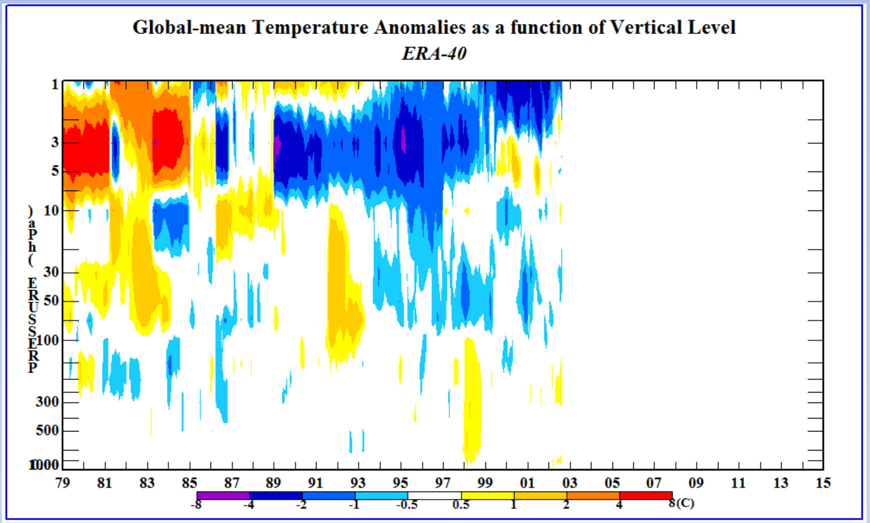
Conventional Reanalyses: JRA-55c, CORe (CPC)

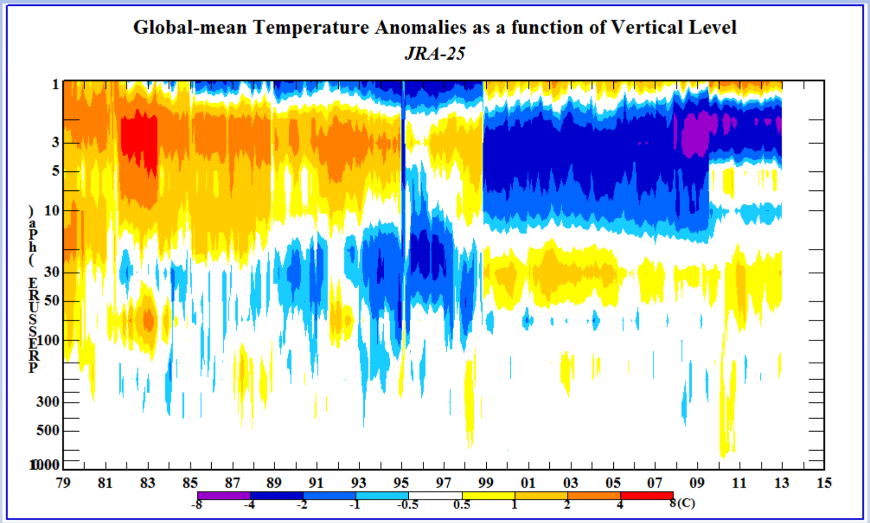
Reanalyses

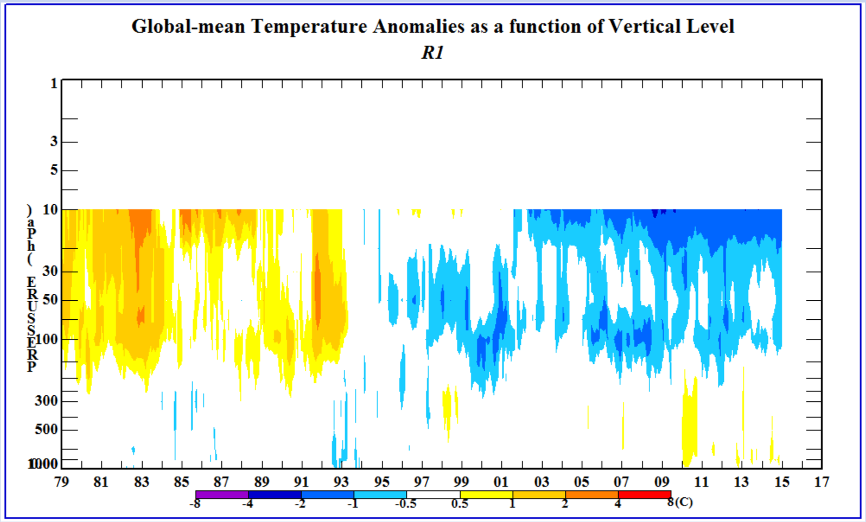
- Qualities – Improvements made over time
  - Radiance Assimilation
  - Model top / vertical and horizontal resolution
  - Radiative Transfer Model
    - CRTM
    - RTTOVS
  - TOVS to ATOVS transition
  - Bias Correction scheme
  - Ozone assimilated
  - Coupled with ocean/ice/land surface
  - GPS-RO assimilated
  - Ability to replicate the QBO

Reanalyses

Global Temperature Anomaly Time Series







Reanalyses

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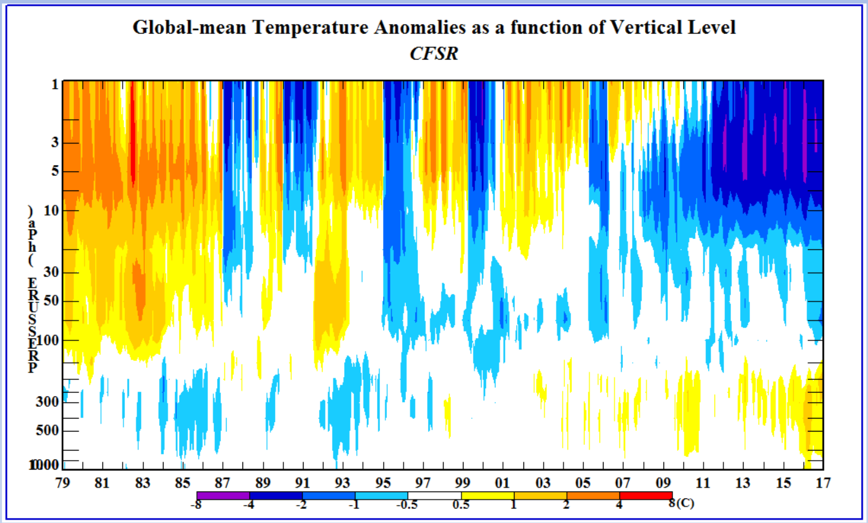
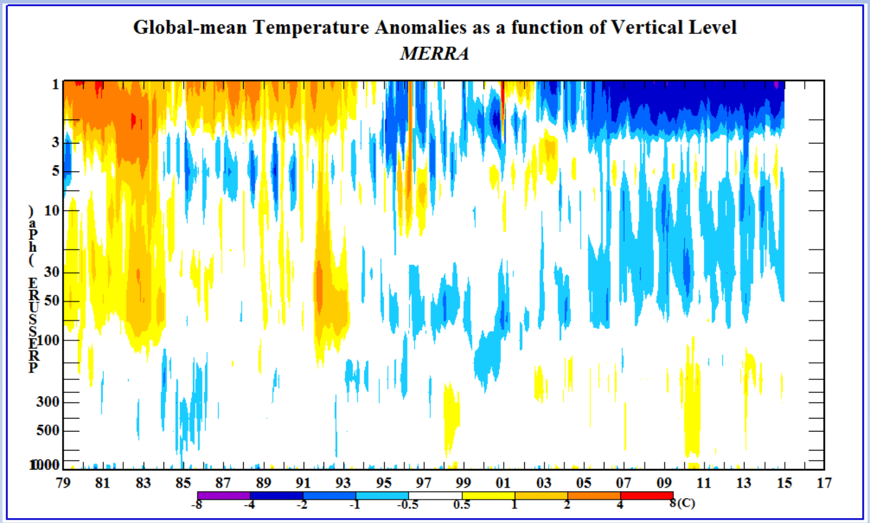
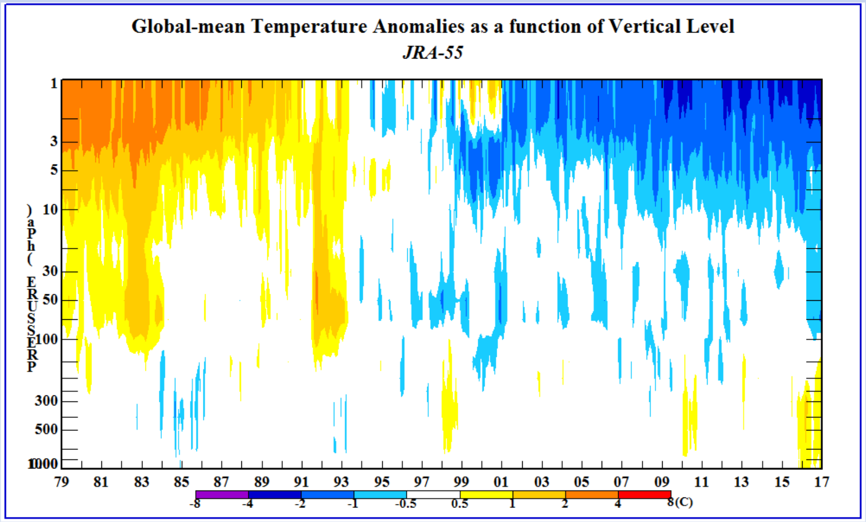
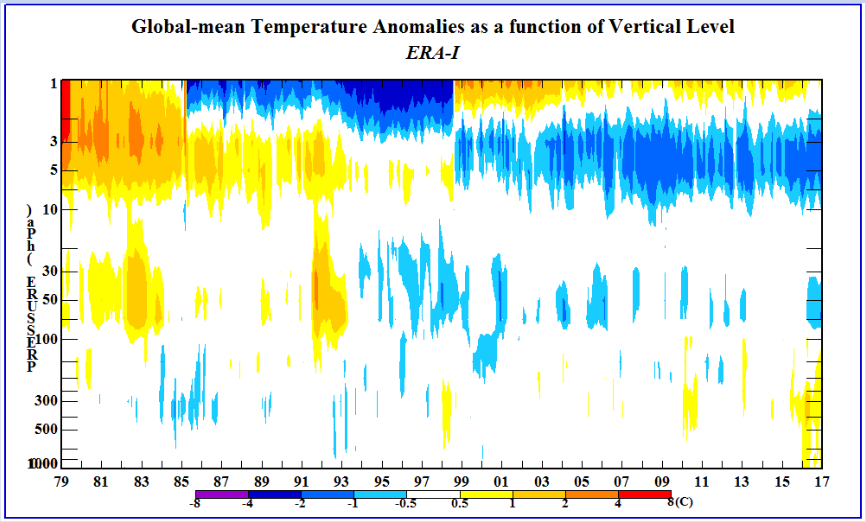


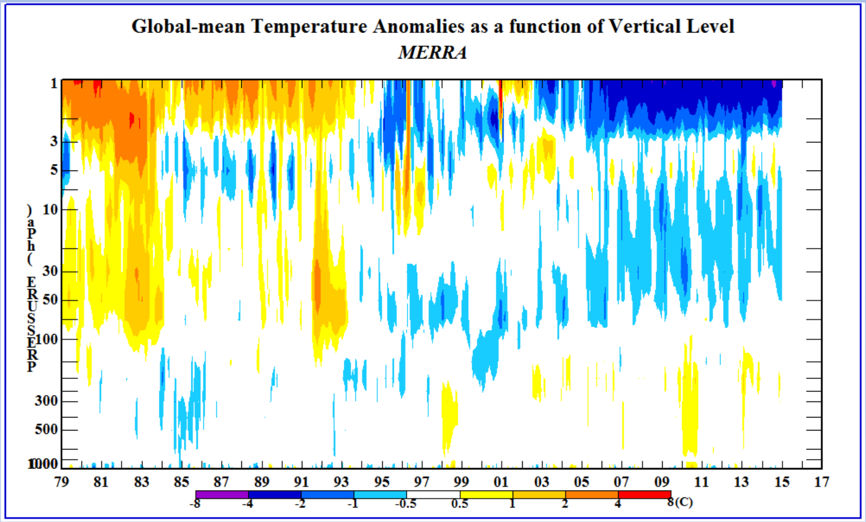


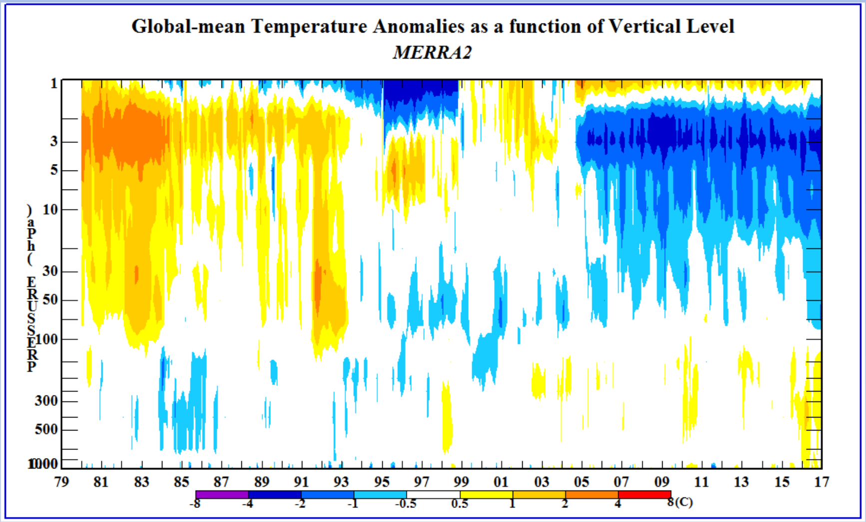




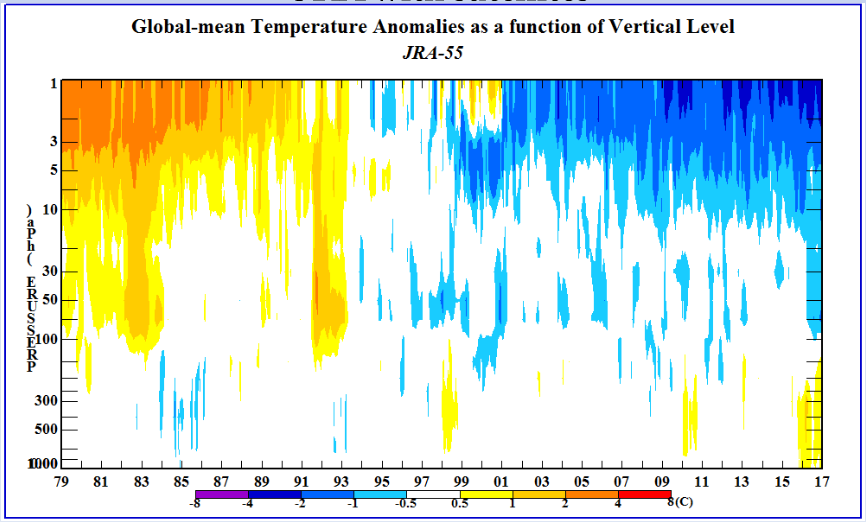
Reanalyses

Global Temperature Anomaly Time Series

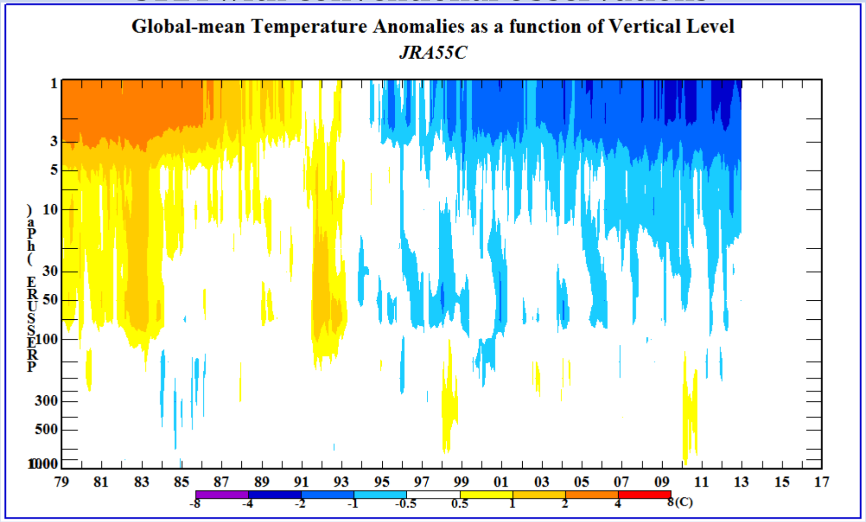




JRA with satellites



JRA with conventional observations

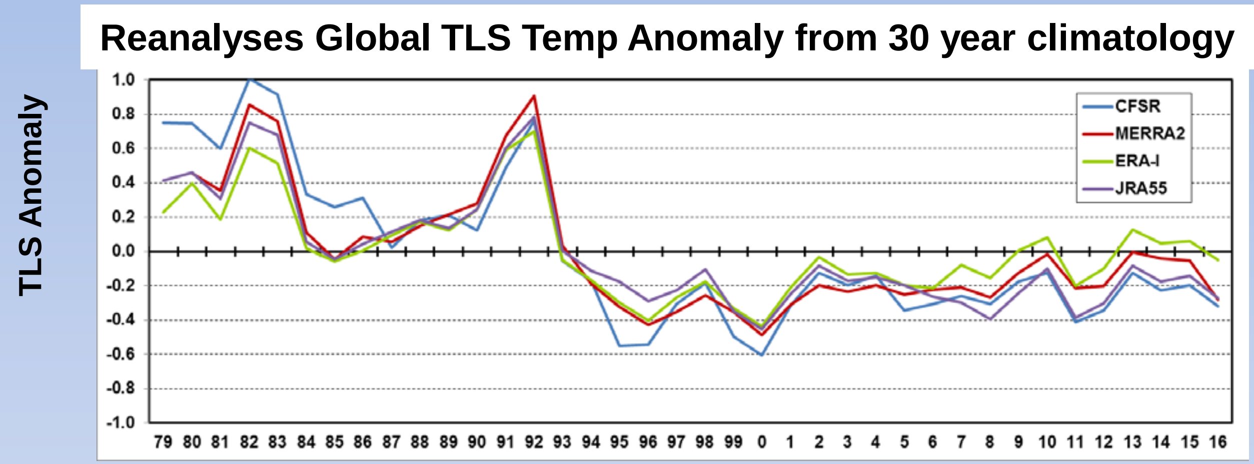


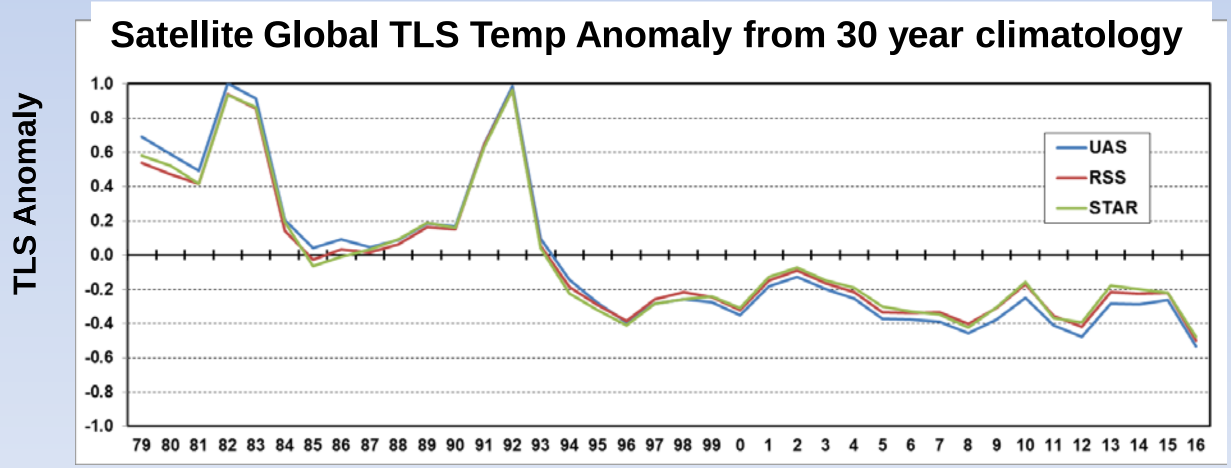
Issues when using Reanalyses

- Reanalyses are not a Climate Data Record
- Reanalyses quality / accuracy varies over time
- Reanalyses utilize multiple & changing sources of information to generate a variable's analysis

Issues when using Reanalyses

Anomalies from 30 year Climatology

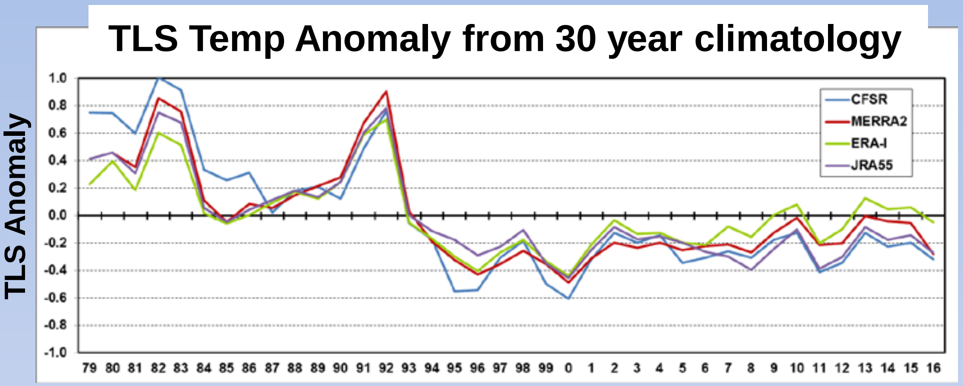


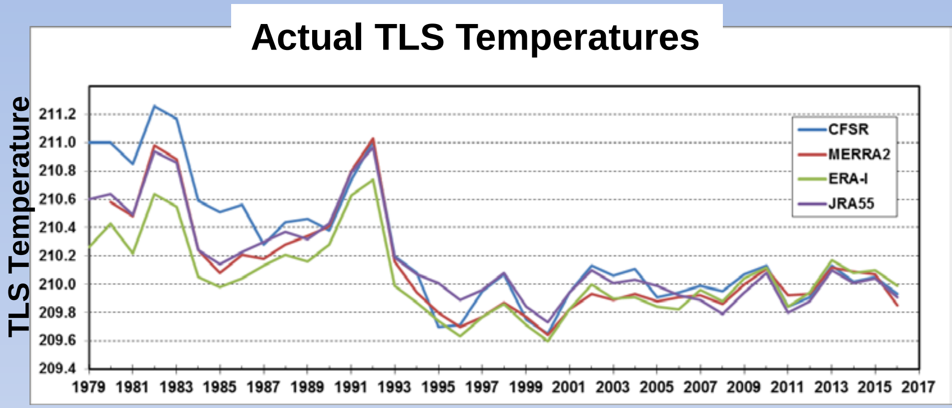


TLS = Temperature Lower Stratosphere = MSU Ch 4 / AMSU ch 9

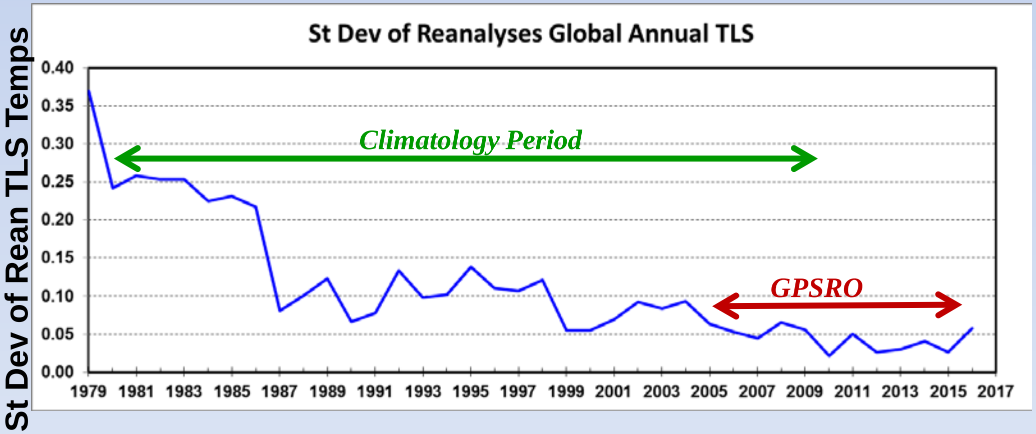
Issues when using Reanalyses

Climatologies assume quality of the variable does not change over time





Reanalyses agree more with each other over time



Summary

- Monitoring the stratosphere has evolved over past several decades
- Satellite observations have increased in quality and variables observed
- Operational vs research missions – follow-ons questionable
- Dynamics, radiation, chemistry processes under investigation by SPARC activities
- As data records are extended and more/different observations are made, more questions about atmospheric processes can be answered and asked.
- S-RIP evaluating reanalyses for dynamic processes
- Reanalyses are best analysis of atmosphere given the observations at that time.
- Quality of reanalysis variables improve with time as more satellite observations are available for assimilation.