SPARC

Stratosphere-troposphere Processes And their Role in Climate

SRIP –

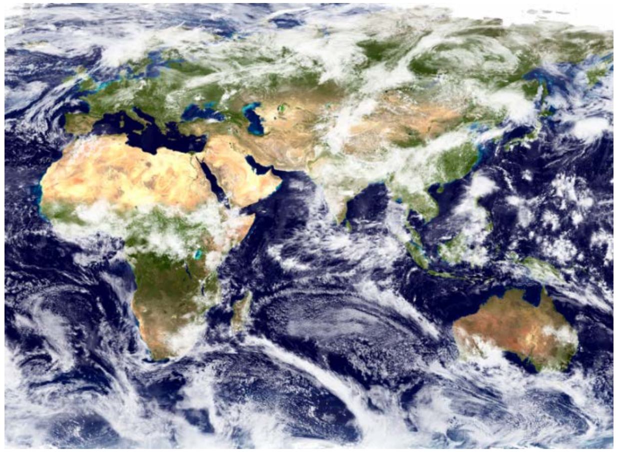
SPARC Reanalysis Intercomparison Project

Susann Tegtmeier

GEOMAR, Kiel, Germany

SPARC themes

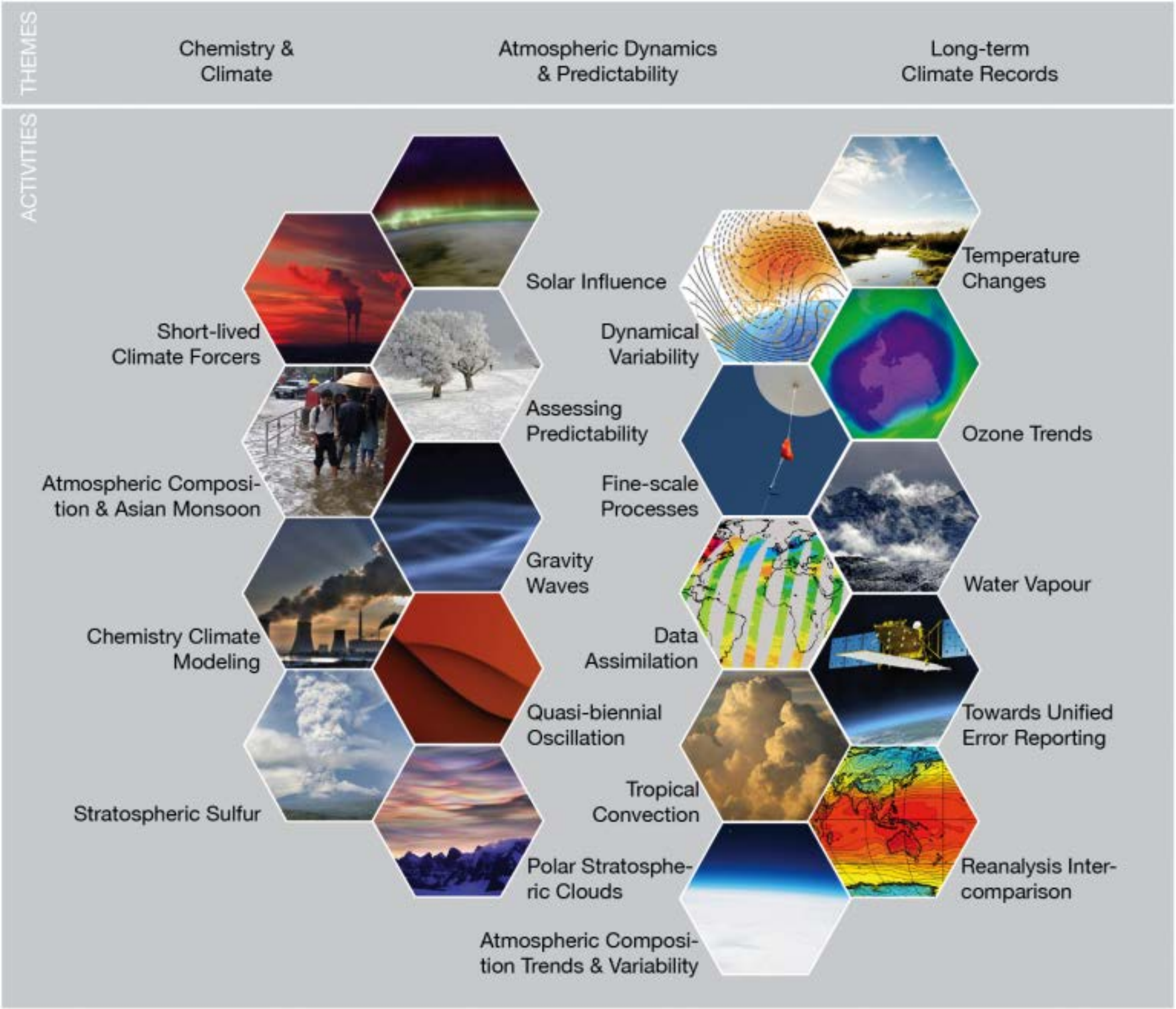
1. Atmospheric Dynamics and Predictability



2. Chemistry and Climate

3. Long-term Records for Climate Understanding

- Vertically and spatially resolved trends in SPARC-relevant ECVs?
- Requirements on observing programmes?
- Species/state variables (resolution, frequency, uncertainty)?
- Evolving atmosphere consistent with our understanding?
- Global and regional forcing of the climate system?


THEMES
Chemistry & Climate
Atmospheric Dynamics & Predictability
Long-term Climate Records
ACTIVITIES
Solar Influence
Short-lived Climate Forcers
Assessing Predictability
Atmospheric Composition & Asian Monsoon
Gravity Waves
Chemistry Climate Modeling
Quasi-biennial Oscillation
Stratospheric Sulfur
Polar Stratospheric Clouds
Dynamical Variability
Fine-scale Processes
Data Assimilation
Tropical Convection
Atmospheric Composition Trends & Variability
Temperature Changes
Ozone Trends
Water Vapour
Towards Unified Error Reporting
Reanalysis Intercomparison

1. Observational requirements

Data continuity

How to ensure consistency in past/on-going records from multiple sensors?

Big issue for SPARC activities focused on long-term data records (e.g. temperature, O_3, H_2O)

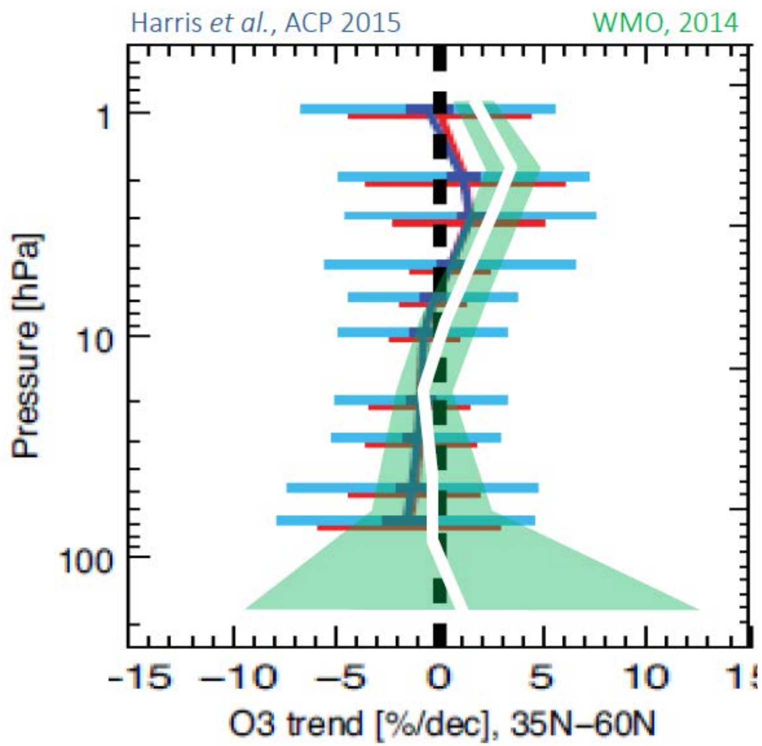
Workshop on ensuring consistency and rigorous uncertainty assessment?

1. Observational requirements

Example: LOTUS – Long-term Ozone Trends and Uncertainties in the Stratosphere

For WMO/UNEP 2018 Ozone Assessment, **a clear understanding of ozone trends and their significance** is needed taking into account errors linked to the sampling and stability of (merged) data sets

- Update and extend stratospheric ozone observations to recent years
- Improve our understanding of crucial yet poorly known sources of uncertainties in trend retrieval
- Investigate how uncertainties interact and propagate through the different stages of analysis chain
- Re-evaluate current best practice(s) and possibly establish more suitable alternatives.



1. Observational requirements

Example: LOTUS – Long-term Ozone Trends and Uncertainties

Overview of (merged) data sets

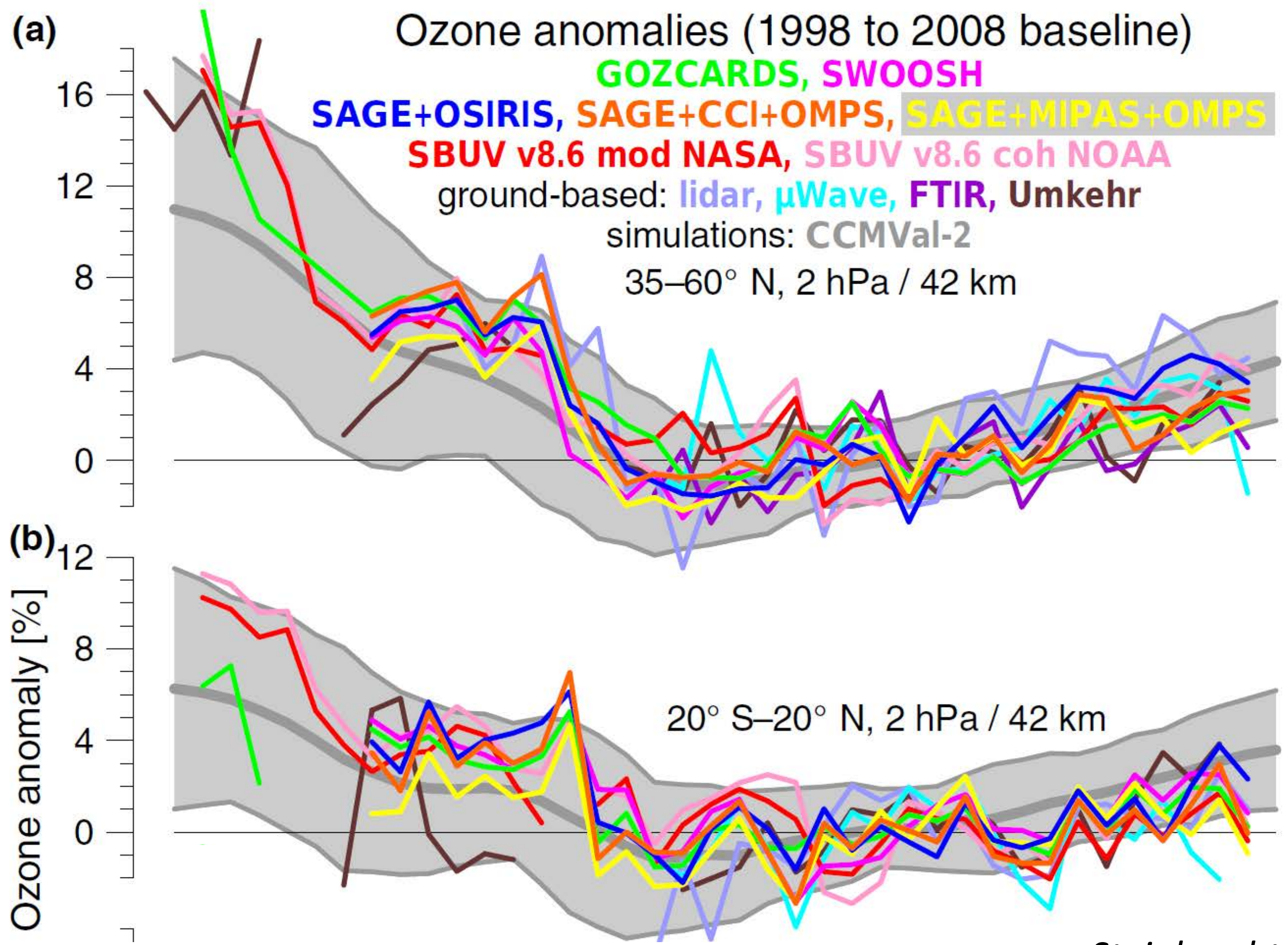
Satellite

- Nadir (pres, vmr)
  - SBUV MOD v8.6 NASA (1970-2016)
  - SBUV COH v8.6 NOAA (1978-2016)
- Limb (alt, ndens)
  - SAGE II–CCI–OMPS (1984-2016)
  - SAGE II–OSIRIS–OMPS (1984-2016)
  - SAGE II–MIPAS–OMPS (1984-2017)
- Limb (pres, vmr)
  - GOZCARDS v2.10 (1991-2016)
- Limb (mixed)
  - GOZCARDS v2.20 (1979-2016)
  - SWOOSH v2.6 (1984-2016)
- BASIC/Particle Filter
  - SBUV NOAA/NASA + GOZCARDS/SWOOSH
  - SAGE-OSIRIS/CCI/MIPAS-OMPS

Ground-based data

Instrument	Station, period since
Lidar	OHP (1986), Hohenpeißenberg (1987), Table Mountain (1988), Mauna Loa (1993), Lauder (1994)
Microwave	Bern (1994), Payerne (2000), Mauna Loa (1995), Lauder (1992)
FTIR	Izana (1999), Lauder (2001), Jungfraujoch (1995), Wollongong (1996)
Umkehr	Mauna Loa (1984), Lauder (1987), Arosa (1956), OHP (1984), Boulder (1984), Fairbanks (1994), Perth (1984)
Ozonesonde	NOAA and SHADOZ datasets + NDACC/WOUDC stations

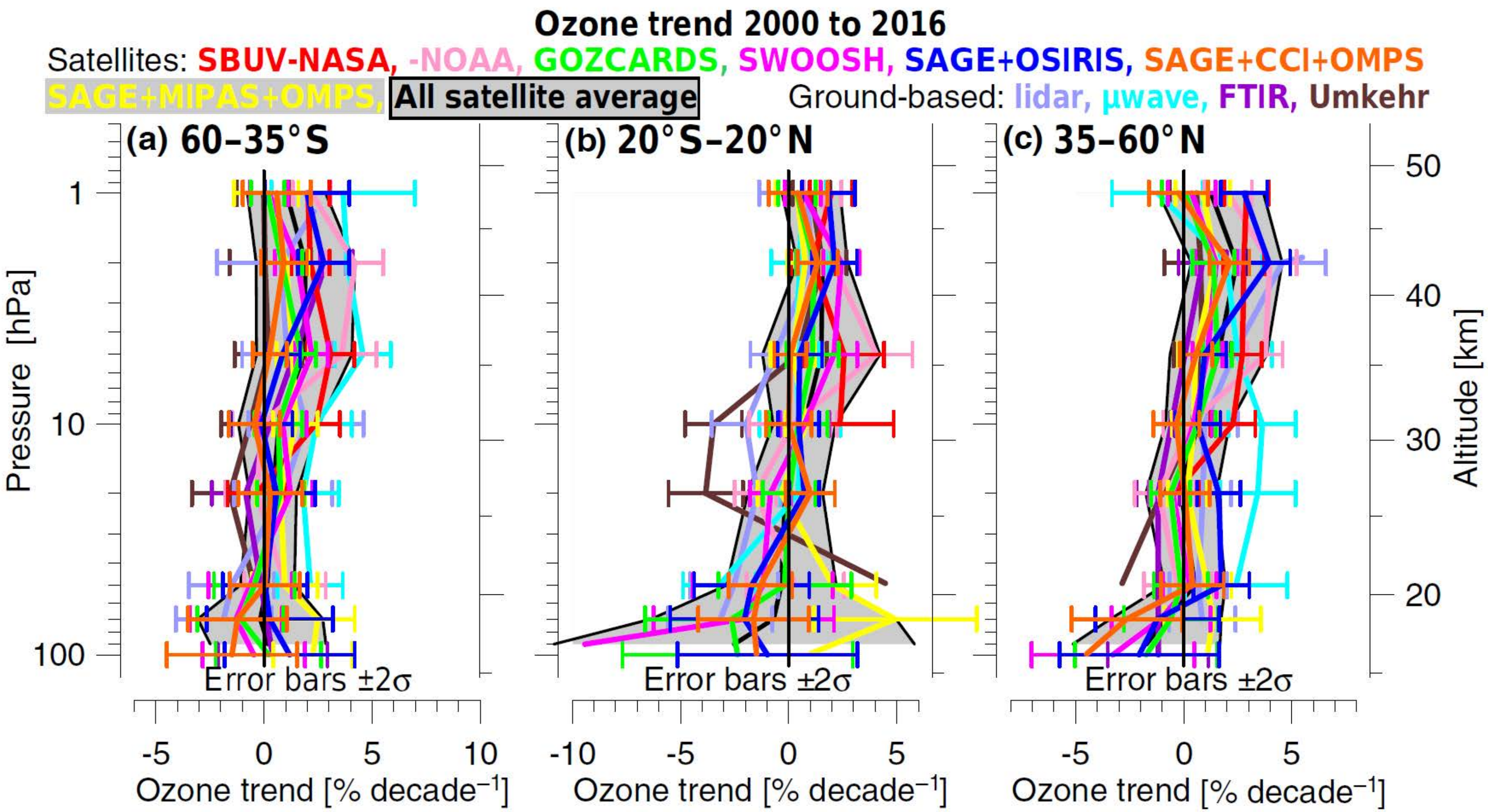
Example: LOTUS – Long-term Ozone Trends and Uncertainties in the Stratosphere



Steinbrecht et al., 2017

1. Observational requirements

Example: LOTUS – Long-term Ozone Trends and Uncertainties

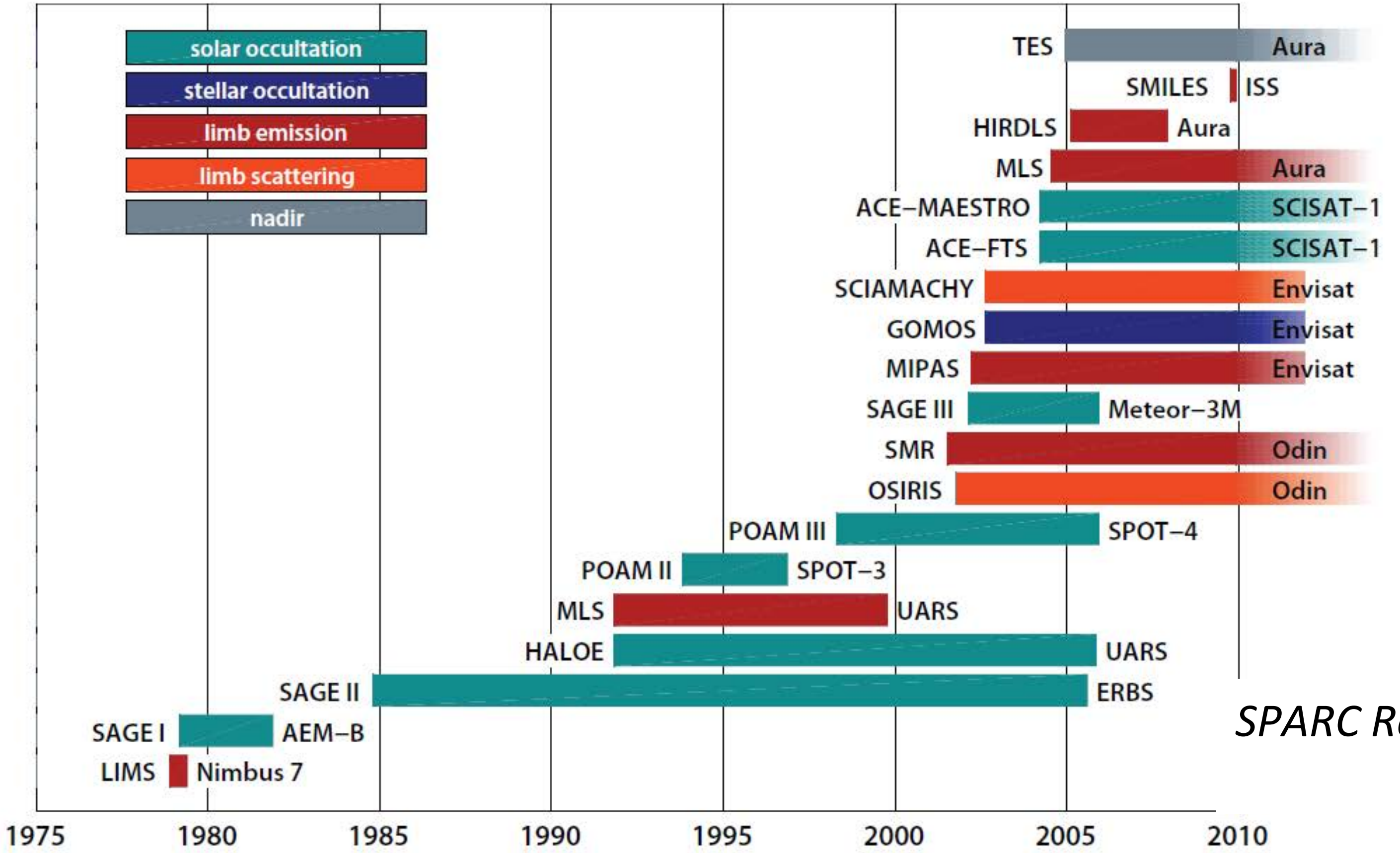


Steinbrecht et al., 2017

2. Assessments

Example: SPARC Data Initiative on stratospheric composition

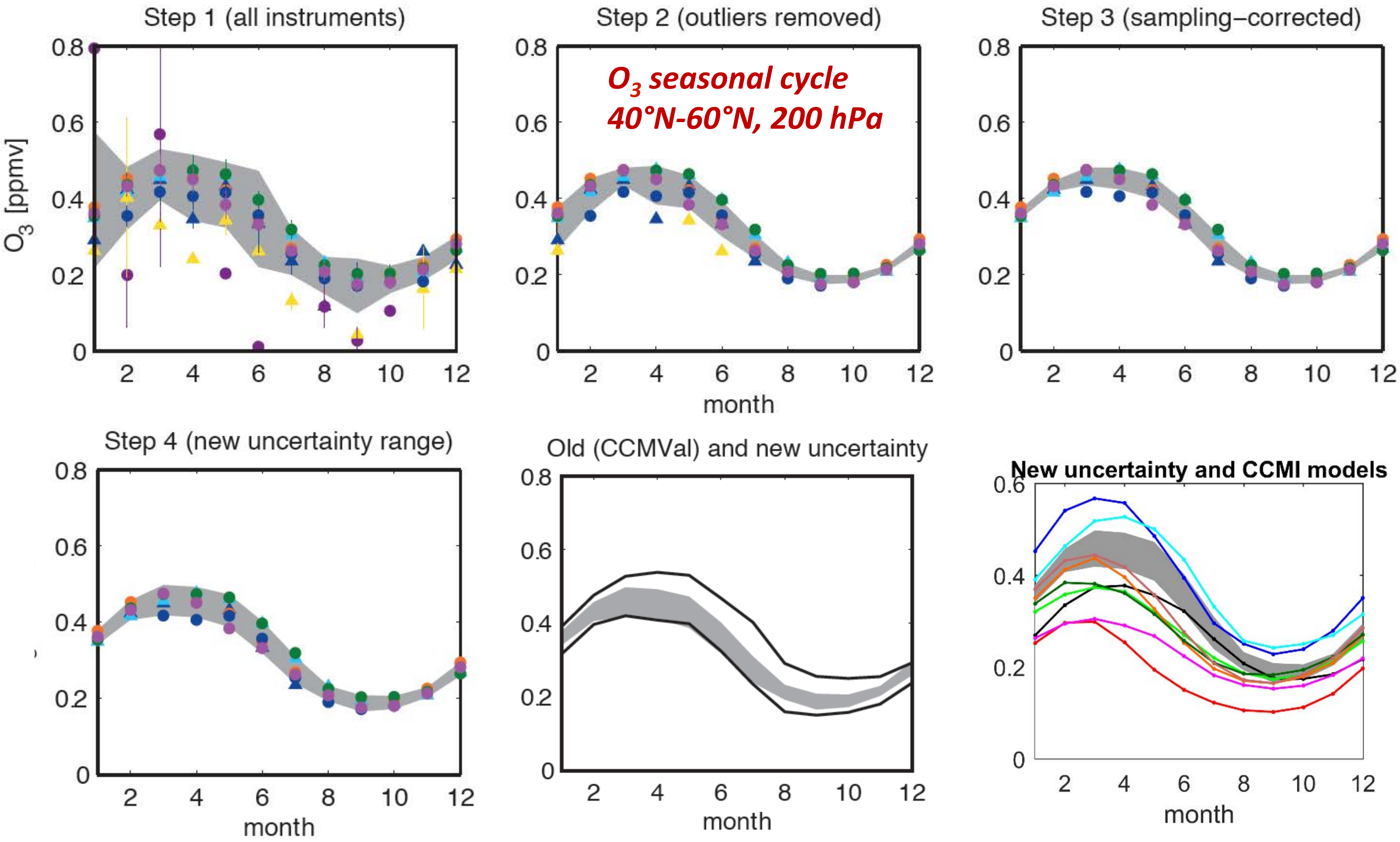
Comprehensive quality assessment of 25 chemical trace gases and aerosol from satellite limb observations



SPARC Report No. 7, 2017

2. Assessments

Derive uncertainty range from all available data sets based on their agreement with the mean state of the atmosphere and on the specific satellite characteristics



http://s-rip.ees.hokudai.ac.jp/

SRIP - SPARC Reanalysis Intercomparison Project

Masatomo Fujiwara (Hokkaido Univ., Japan),

Lesley Gray (Oxford Univ., UK),

Gloria Manney (NWRA, USA)

3. Intercomparisons

Example: SRIP - SPARC Reanalysis Intercomparison Project

- **Compare reanalysis** data sets for key diagnostics
- **Identify and understand** the causes of differences amongst reanalyses
- **Provide guidance** on the appropriate usage of various reanalysis products in scientific studies
- **Establish links** between reanalysis centres and the SPARC community
- **Contribute to future improvements** in reanalysis products

Reanalysis Centre **(Contacts for S-RIP)**	**Reanalysis Product**
ECMWF (R. Dragani)	ERA-40, **ERA-Interim**, (ERA-20C, ERA-20CM, CERA-20C)
JMA (Y. Harada)	JRA-25, **JRA-55**, (JRA-55C, JRA-55AMIP)
NASA (K. Wargan)	**MERRA**, **MERRA-2**
NOAA/NCEP (C. Long, W. Ebisuzaki)	NCEP R-1, NCEP R-2, **CFSR**
NOAA & Univ. Colorado (G. Compo, J. Whitaker)	(20CR)

Prime Output:

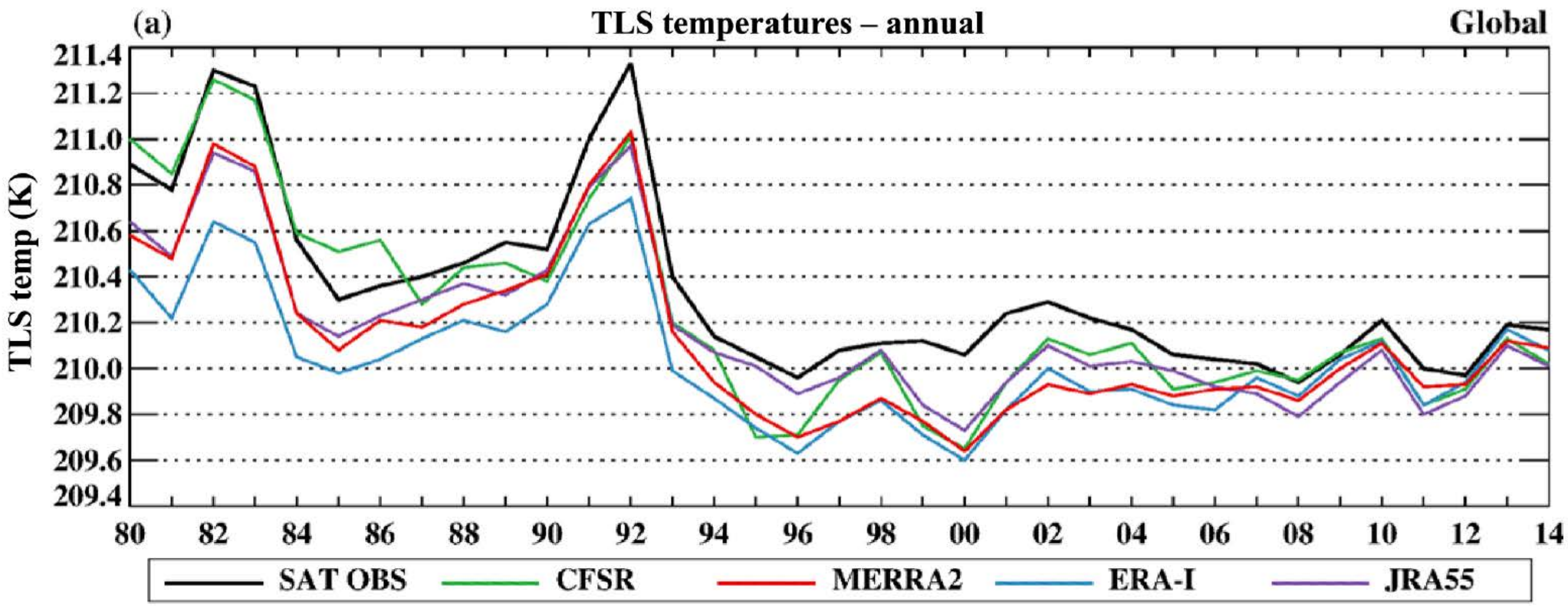
- S-RIP "interim" Report (2017), four 'basic' chapters
- S-RIP "full" Report (2018), twelve chapters in total

	Chapter Title	Chapter Co-leads
1	Introduction	M.Fujiwara, G. Manney, L. Gray
2	Description of the Reanalysis Systems	J. Wright, M. Fujiwara, C. Long
3	Climatology and Interannual Variability of Dynamical Variables	C. Long, M. Fujiwara
4	Climatology and Interannual Variability of O_3 and H_2O	M. Hegglin, S. Davis
5	Brewer-Dobson Circulation	T. Birner, B. Monge-Sanz
6	Stratosphere-Troposphere Coupling	E. Gerber, P. Martineau
7	Extratropical UTLS	C. Homeyer, G. Manney
8	Tropical Tropopause Layer	S. Tegtmeier, K. Krüger
9	QBO and Tropical Variability	J. Anstey, L. Gray
10	Polar Processes	M. Santee, A. Lambert, G. Manney
11	Upper Strato. Lower Mesosphere	L. Harvey, J. Knox
12	Synthesis Summary	M. Fujiwara, G. Manney, L. Gray

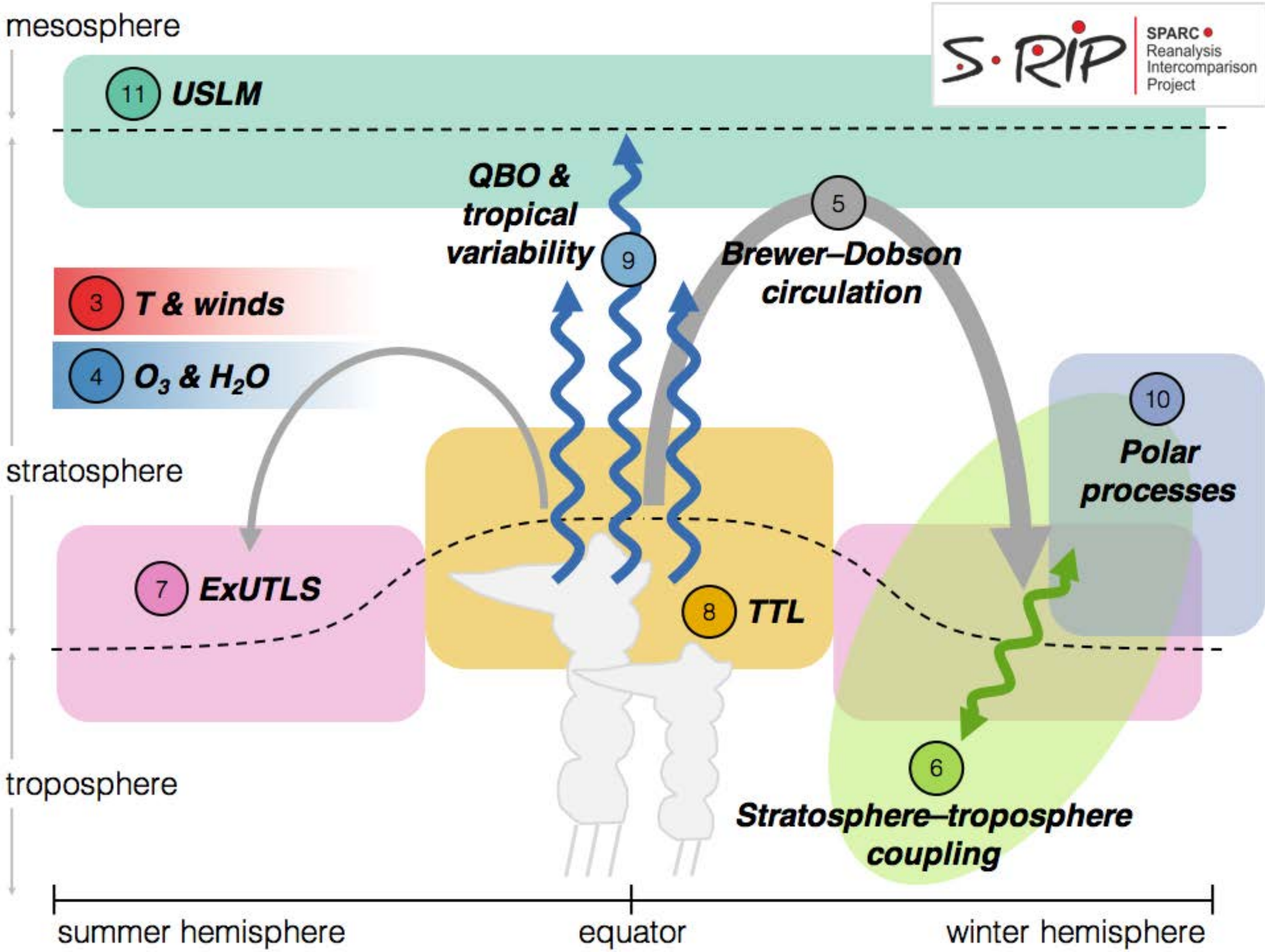
S-RIP 2017 Interim SPARC Report (Basic chapters)

Editors: M. Fujiwara, J. Wright, G. Manney, and L. Gray

- Introduction
- Description of the Reanalysis Systems (Fujiwara et al., 2017)
- Climatology and Interannual Variability of Dynamical Variables (Long et al., 2017)
- Climatology and Interannual Variability of O_3 and H_2O (Davis et al., 2017)



Long et al., 2017

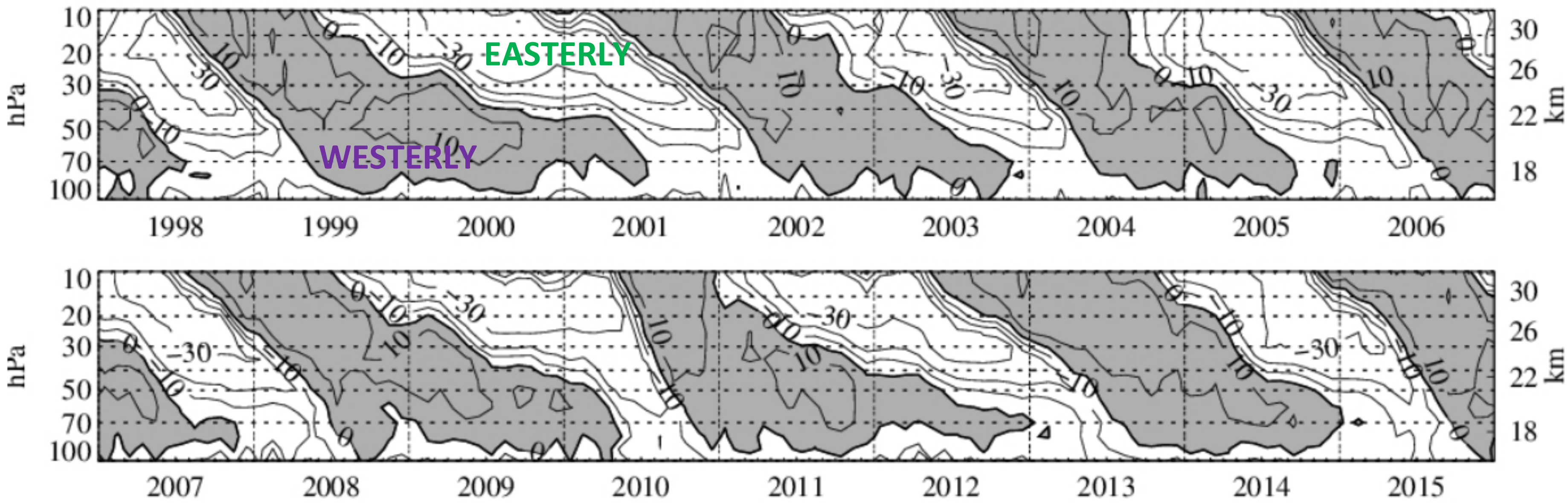


mesosphere
11 USLM
SPARC
Reanalysis
Intercomparison
Project
QBO &
tropical
variability
9
5
Brewer–Dobson
circulation
3 T & winds
4 O_3 & H_2O
10
Polar
processes
stratosphere
7 ExUTLS
8 TTL
6
troposphere
Stratosphere–troposphere
coupling
summer hemisphere
equator
winter hemisphere

Example: Quasi-Biennial Oscillation (QBO)

Period: ~27 months on average
(i.e., slightly longer than 2 years)

MONTHLY MEAN ZONAL WIND AT SINGAPORE



[Based on Meteorological Service Singapore radiosonde observations, Freie Universität Berlin]

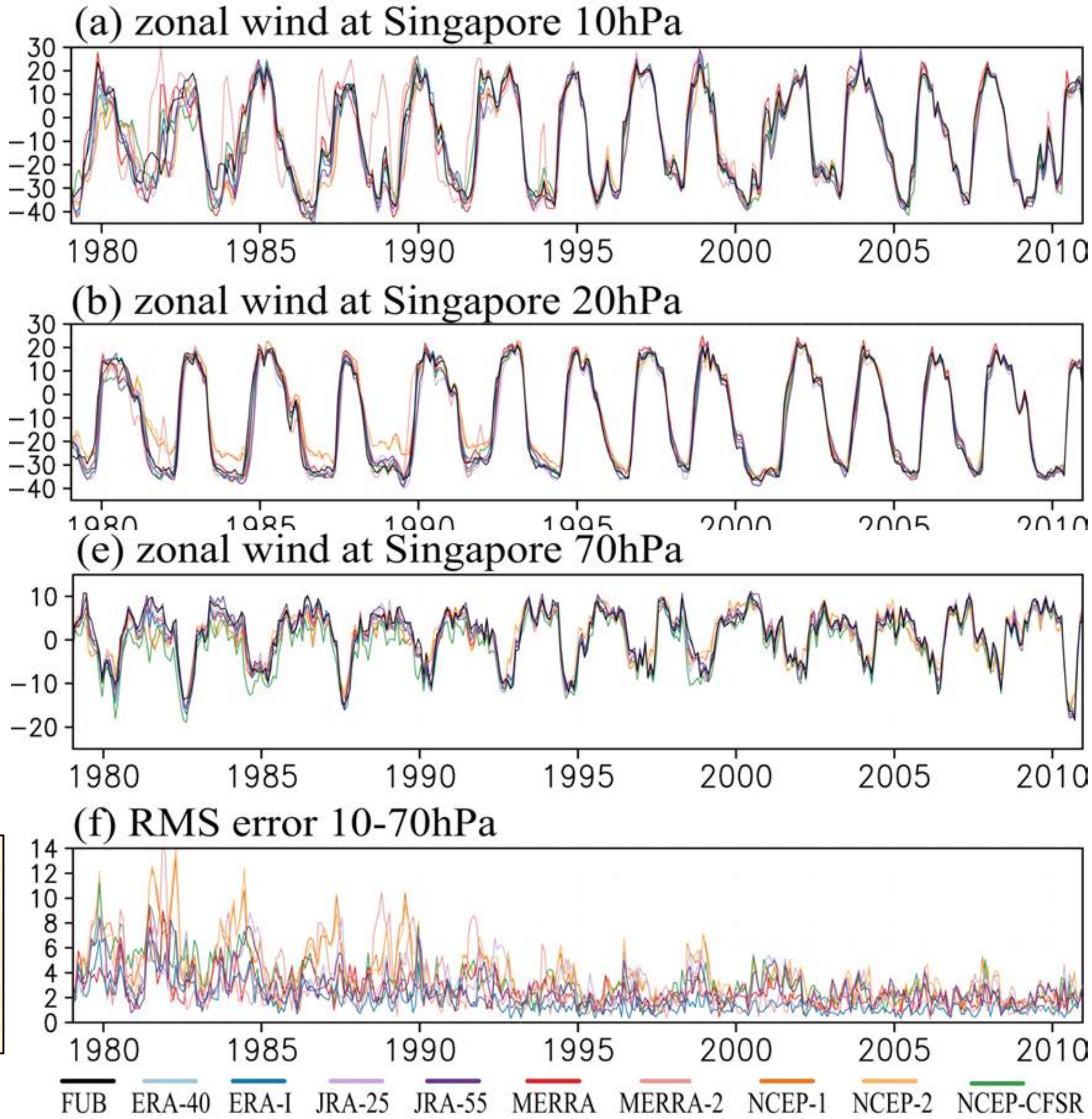
Reanalyses represent the monthly-mean zonal wind over Singapore *reasonably* well

10 hPa

20 hPa

70 hPa

RMS differences with radiosonde data for each reanalysis



MERRA-2 differs much before 1995: over-estimation of the SAO in the upper stratosphere

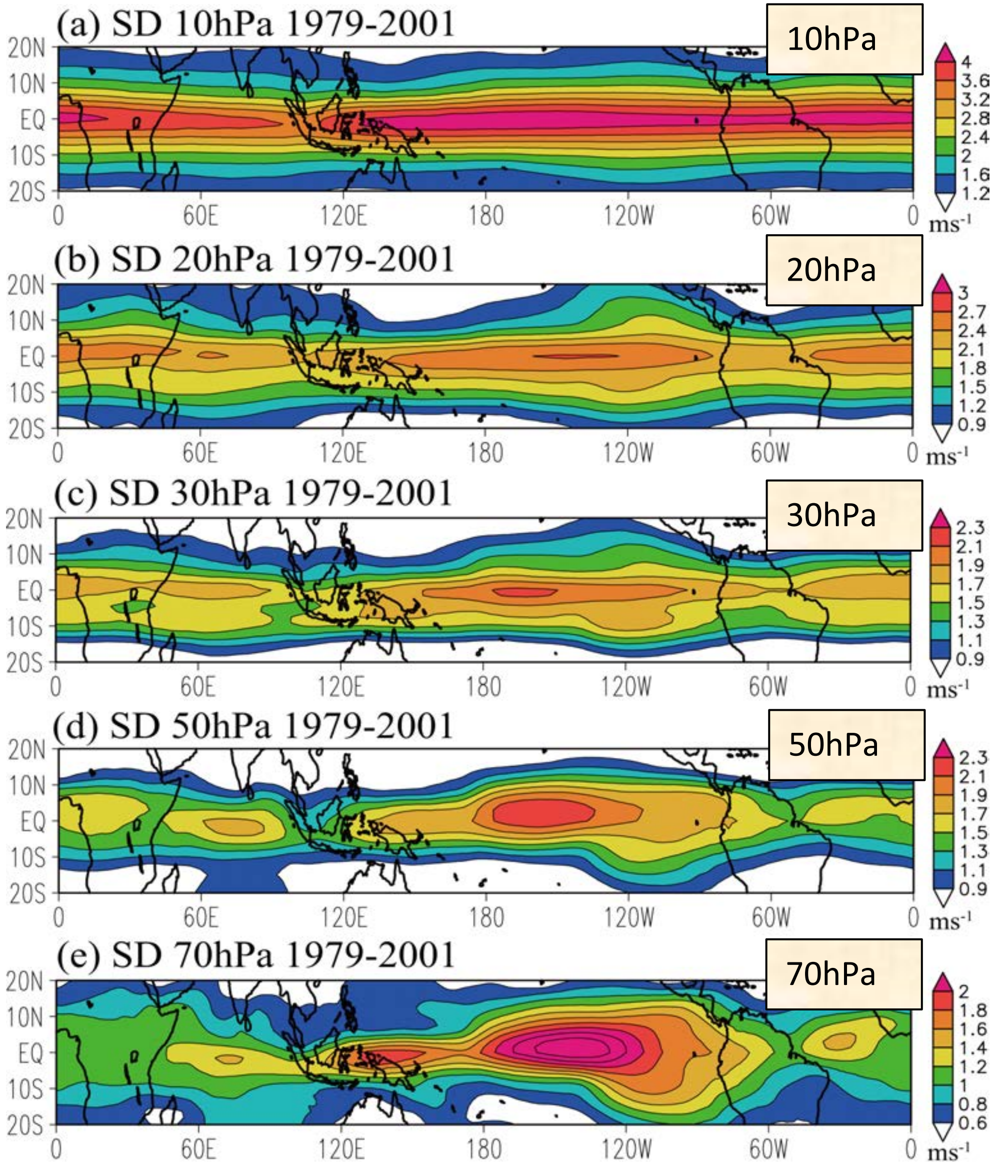
NCEP R-1 and R-2 underestimated QBO in the 1980s, 20 – 50 hPa

Larger differences in NCEP R-1, R-2, and CFSR

RMS differences with radiosonde data decrease with time

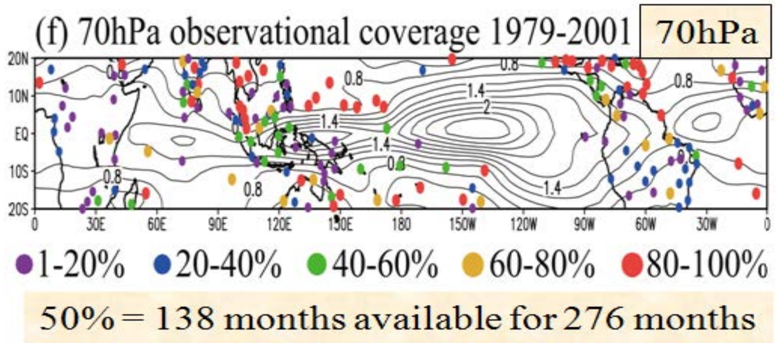
Kawatani et al., 2016

Differences among five reanalyses
(ERA-I, ERA-40, JRA-25, JRA-55, MERRA) for 1979 – 2001

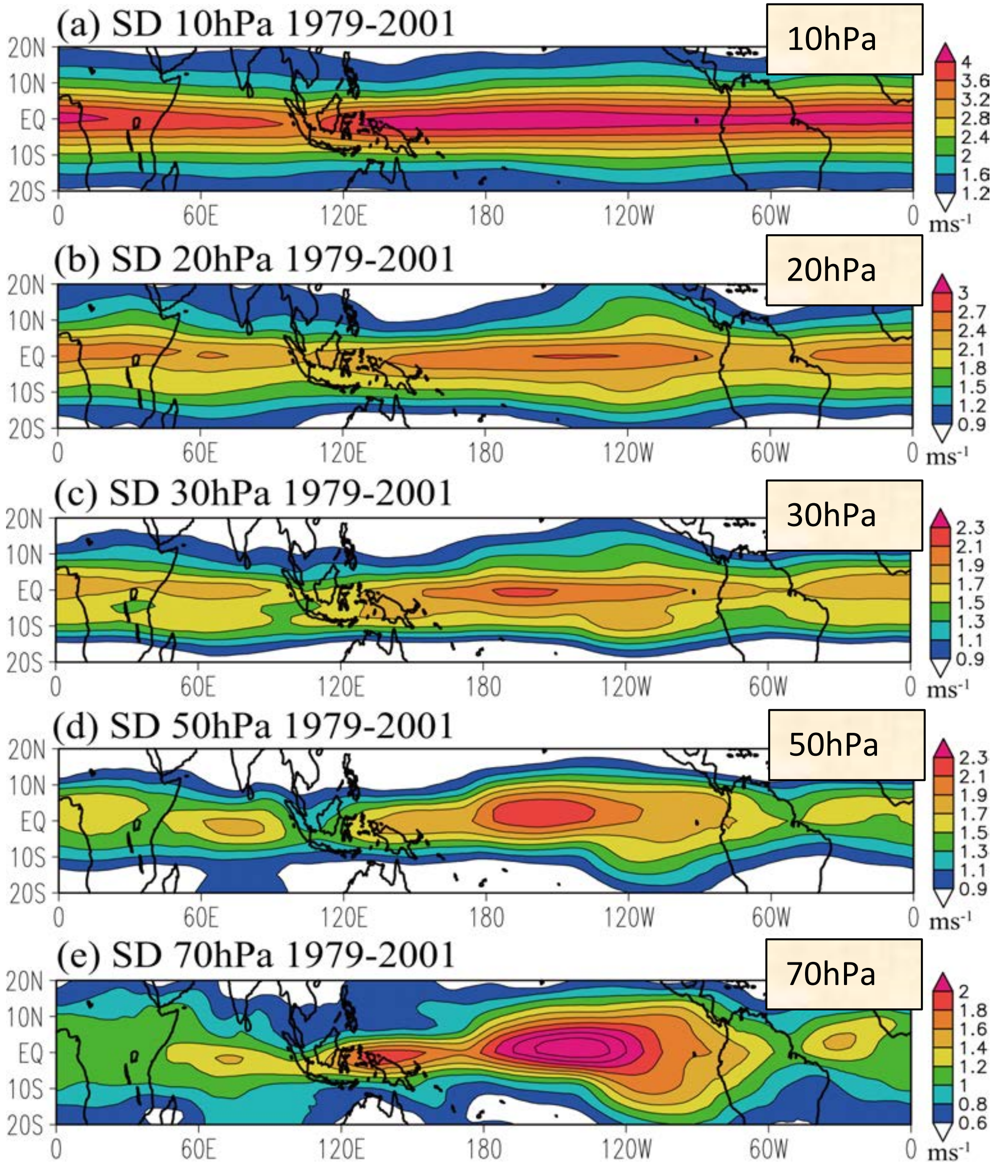


Standard Deviation (SD) at each month

- Differences depend not only on height but also on longitude
- 10 – 30 hPa: more zonally uniform, largest at 10 hPa
- 50 – 70 hPa: zonally non-uniform → distribution of radiosonde measurements!



Conclusions from QBO Study



Reanalysis is particularly challenging in the tropical stratosphere because:

(i) Very limited in situ wind data

(ii) Coriolis parameter is small – Satellite temperature observations do not constrain the winds as strongly as at higher latitudes

(iii) Large vertical shears (~30 m/s over ~3 km)

(iv) Most forecast models used for reanalysis do not simulate a spontaneous QBO – Persistent model bias damp the QBO signals as introduced by data assimilation

SPARC Data needs and requirements

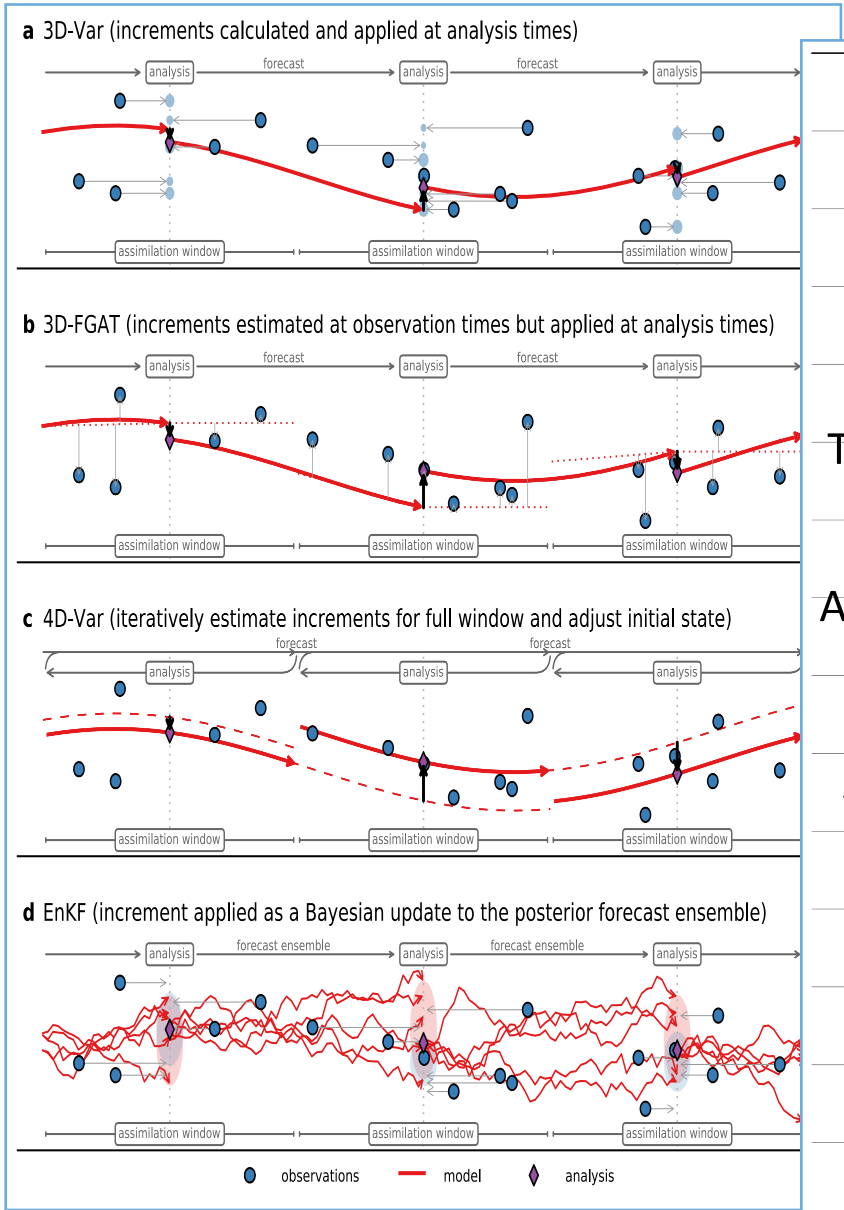
Overall

1. Continued improvement in meteorological reanalyses and past records

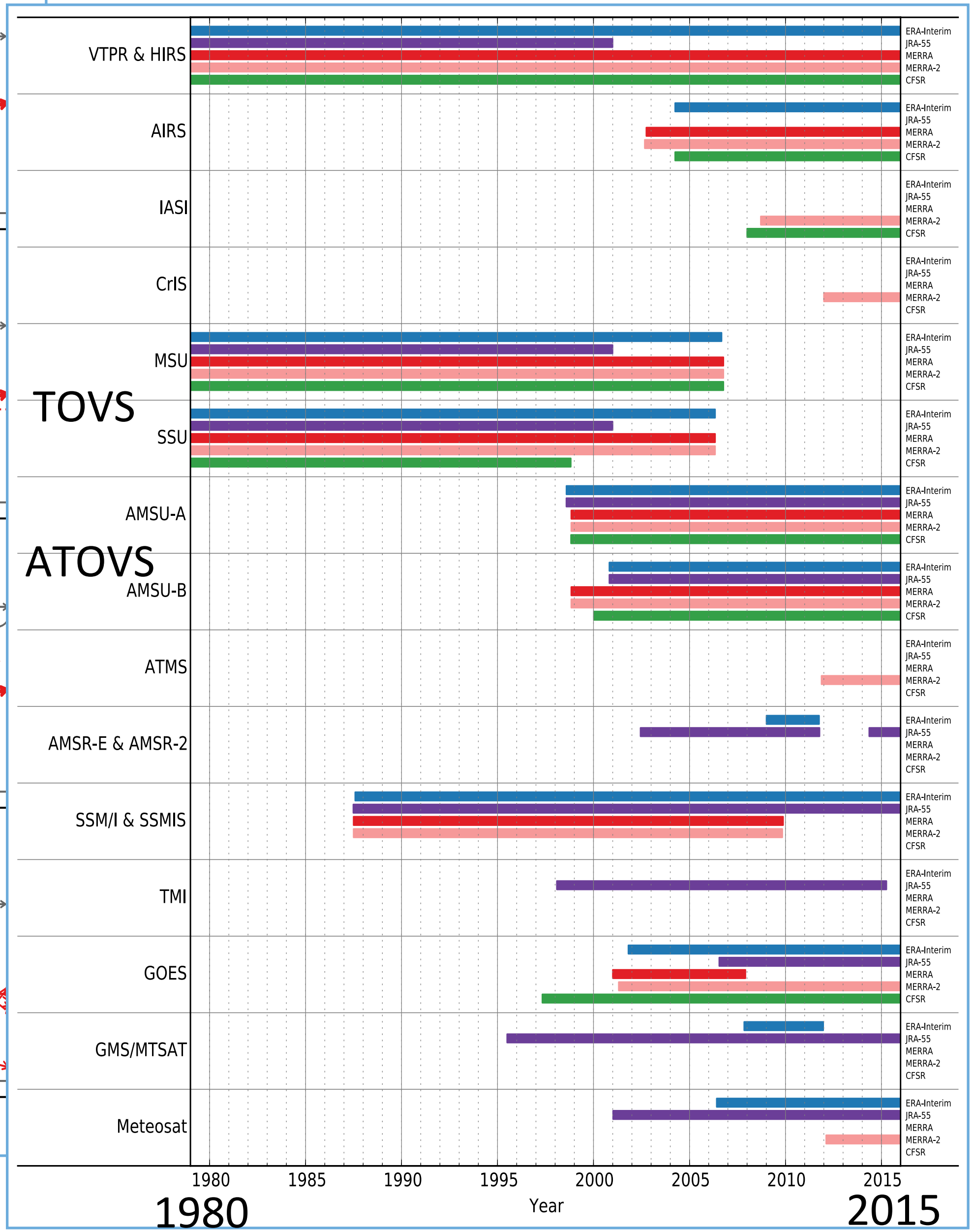
2. Continuation of existing core measurements – real funding pressure

Specific

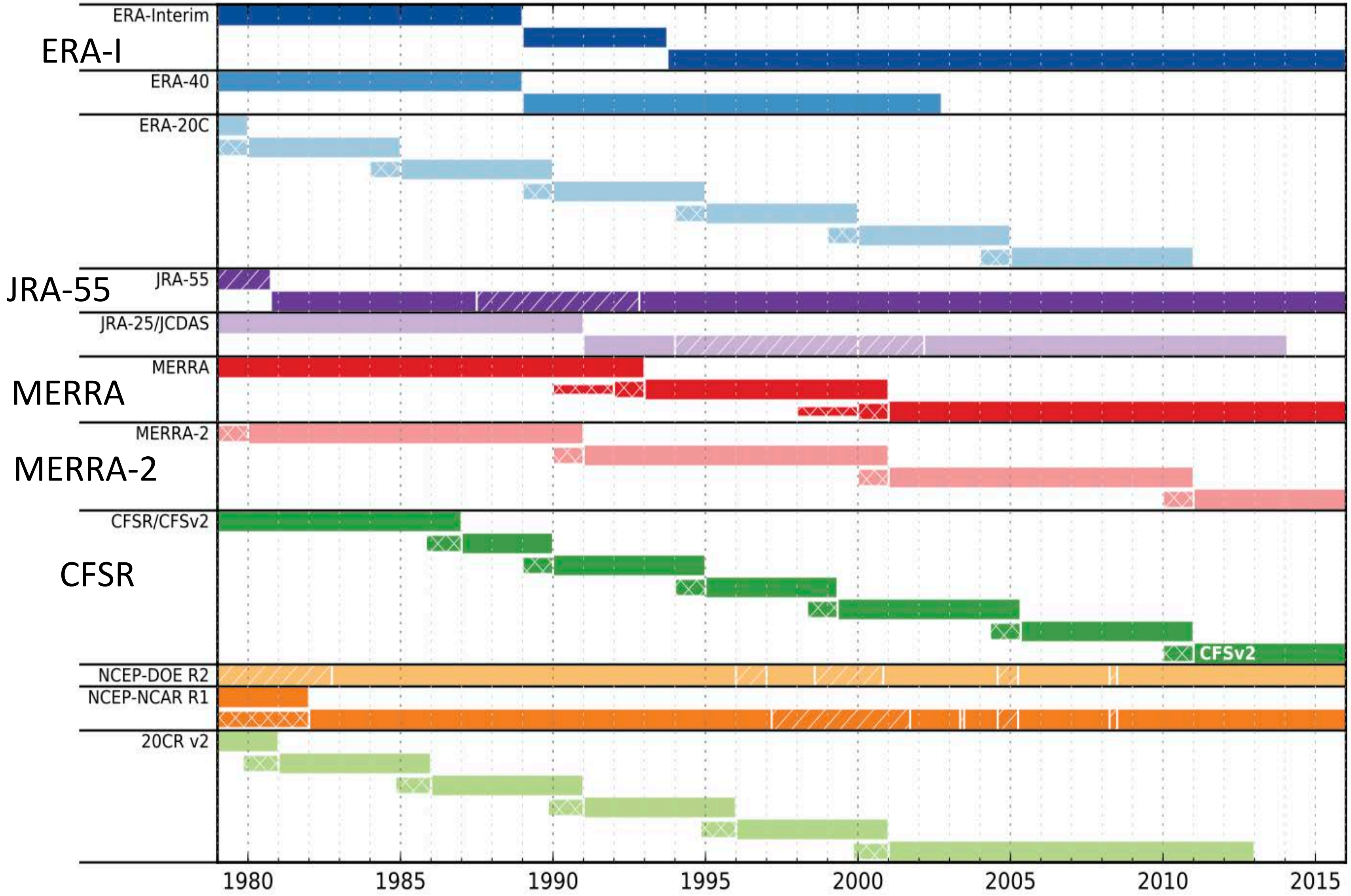
- Lack of planned satellite observations (esp. limb) of UTS composition
- Availability of high vertical-resolution radiosonde data
- Need for more reference-quality global & long-term observations, particularly for reanalysis intercomparisons
- No planned continuation of mesospheric radiance for temperatures
- Need for quick response field campaigns after volcanic eruptions
- Data sharing is a challenge in the 'Asian Monsoon region'



Simplified schematic for data assimilation strategies



Assimilated satellite radiance datasets



Execution 'streams' employed to produce the various reanalysis datasets 1979-2016

Special Issue in the Atmospheric Chemistry and Physics (ACP):

"The SPARC Reanalysis Intercomparison Project (S-RIP)"

Editors: P. Haynes, G. Stiller, and W. Lahoz

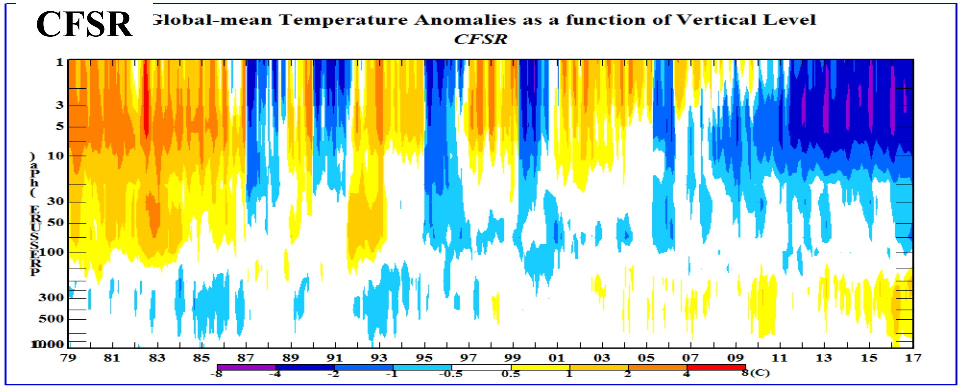
- **Intended to collect research with relevance to S-RIP**
- **Participation in S-RIP is not a prerequisite for submission**
- **10 papers so far, including an S-RIP overview paper, with 8 published and 5 at discussion stage**
- **Fujiwara et al. (ACP, 2017): Introduction S-RIP and overview of the reanalysis systems**
- Hoffmann et al., (ACPD, 2017) Validation of meteorological analyses and trajectories in the Antarctic lower stratosphere using Concordiasi superpressure balloon observations
- Nützel et al., (ACP, 2016) Movement, drivers and bimodality of the South Asian High
- Boothe and Homeyer (ACPD, 2016) Global large-scale stratosphere-troposphere exchange in modern reanalyses
- Kim and Chun, (ACP, 2015) Momentum forcing of the quasi-biennial oscillation by equatorial waves in recent reanalyses
- Fujiwara et al. (ACP, 2015): Global temperature response to the major volcanic eruptions in multiple reanalysis data sets
- Kawatani et al. (ACP, 2016): Representation of the tropical stratospheric zonal wind in global atmospheric reanalyses
- Miyazaki et al. (ACP, 2016): Inter-comparison of stratospheric mean-meridional circulation and eddy mixing among six reanalysis data sets
- Friedrich et al. (ACP, 2017): A comparison of Loon balloon observations and stratospheric reanalyses products
- Wunderlich & Mitchell (ACP, 2017): Revisiting the observed surface climate response to large volcanic eruptions

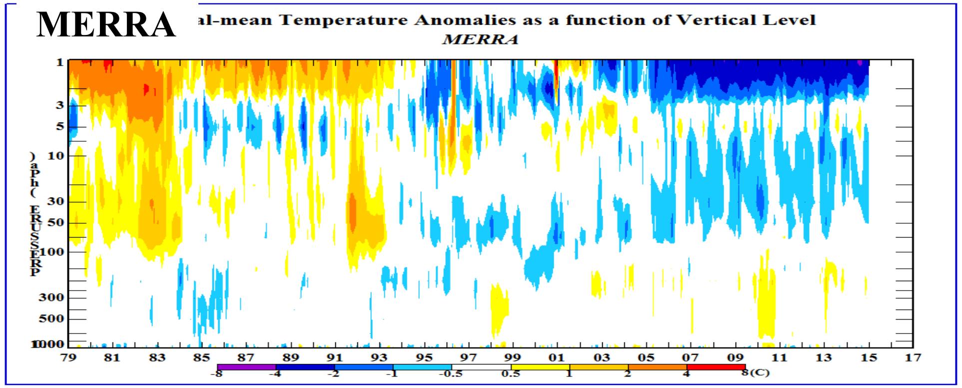
Chapter 3: Climatology and Interannual Variability of Dynamical Variables

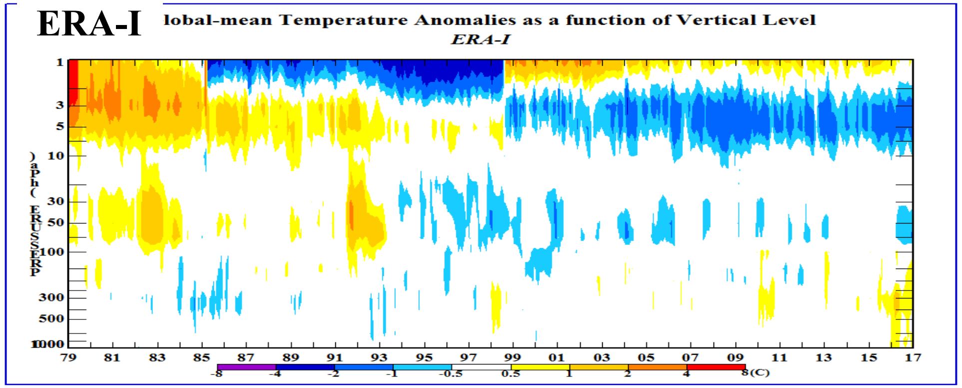
C. Long, M. Fujiwara

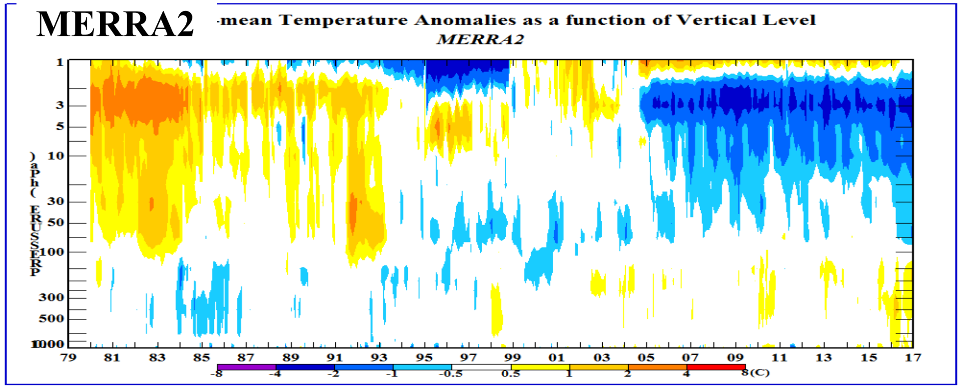
- **Reanalyses temperature variability with time**
- **Reanalyses ensemble mean**
- **Intercomparison of the reanalyses (temperature, zonal wind)**
- **Polar annual temperature cycle**
- **Comparison with independent observations (MLS, HIRLDS, Ozonesondes, Balloons, Rocketsondes)**
- **Effects of volcanic eruptions on reanalyses temperatures and wind**
- **Major conclusions**
  - Reanalyes should NOT be used for trends.
  - There is no one 'perfect' reanalyses. They all have issues.
  - Reanayses have temperature and wind biases in the middle and upper stratosphere with respect to each other. With each generation of reanalyses these biases have been getting smaller.
  - Reanalyses all have 'issues' getting the tropical stratospheric winds correct.

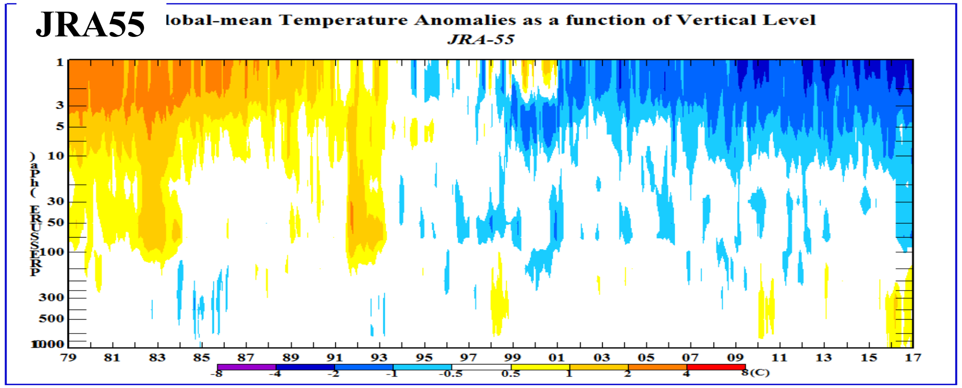
Global Temperature Anomalies
1979-2016







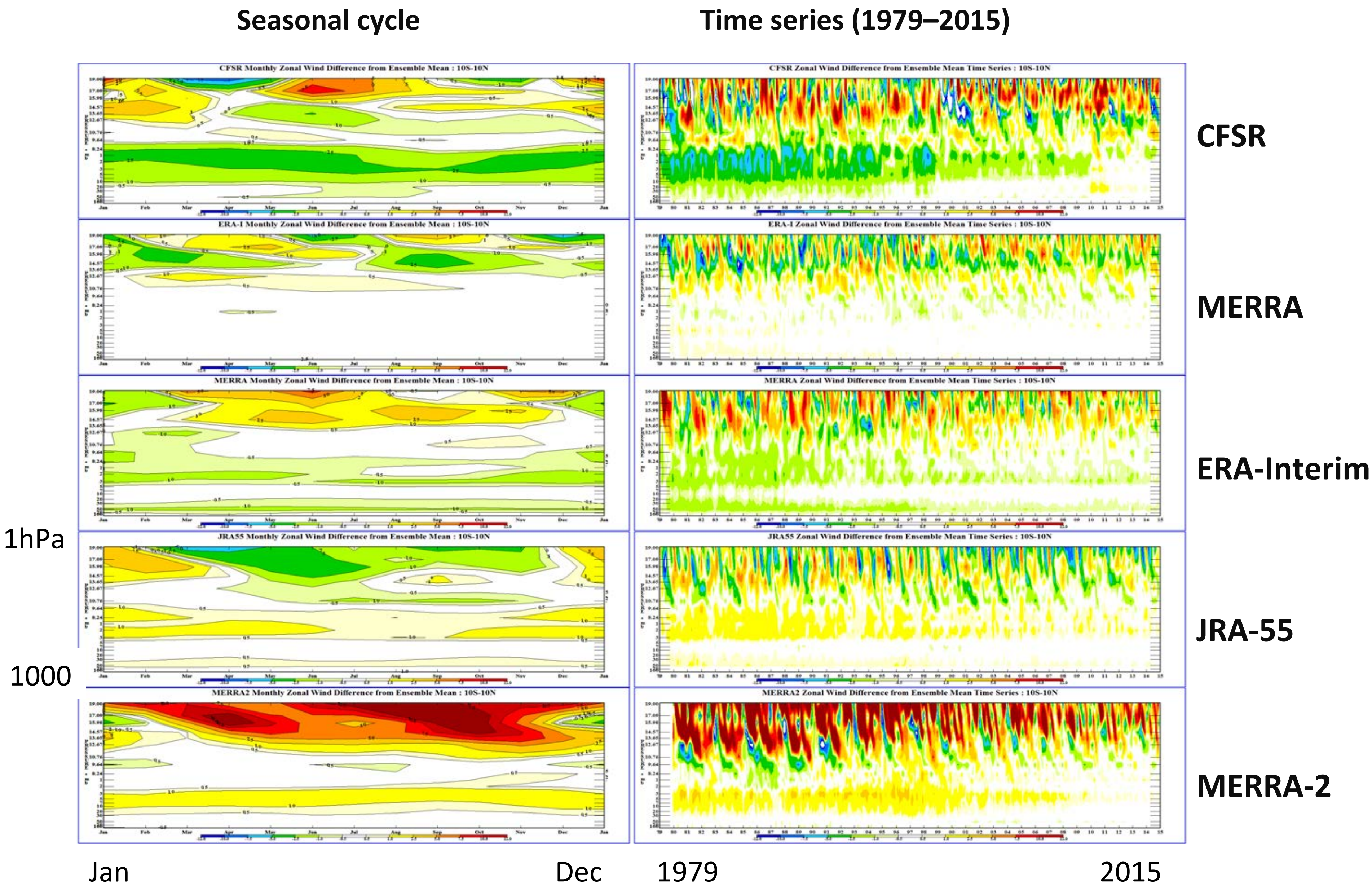




Global temperature anomalies reveal discontinuities in the middle and upper stratosphere due to stream and data transitions. Most notably is the transition from TOVS to ATOVS observations in late 1998. Other features observed are: El Nino warm period in troposphere in 1998, 2010 and 2016, and the lower stratospheric warming due to El Chichón and Mt Pinatubo in 1982 and 1991, respectively.

Equatorial zonal winds (10°S–10°N) and difference from ensemble-mean

(ERA-I+JRA-55+MERRA)



Chapter 4: Climatology and interannual variability of ozone

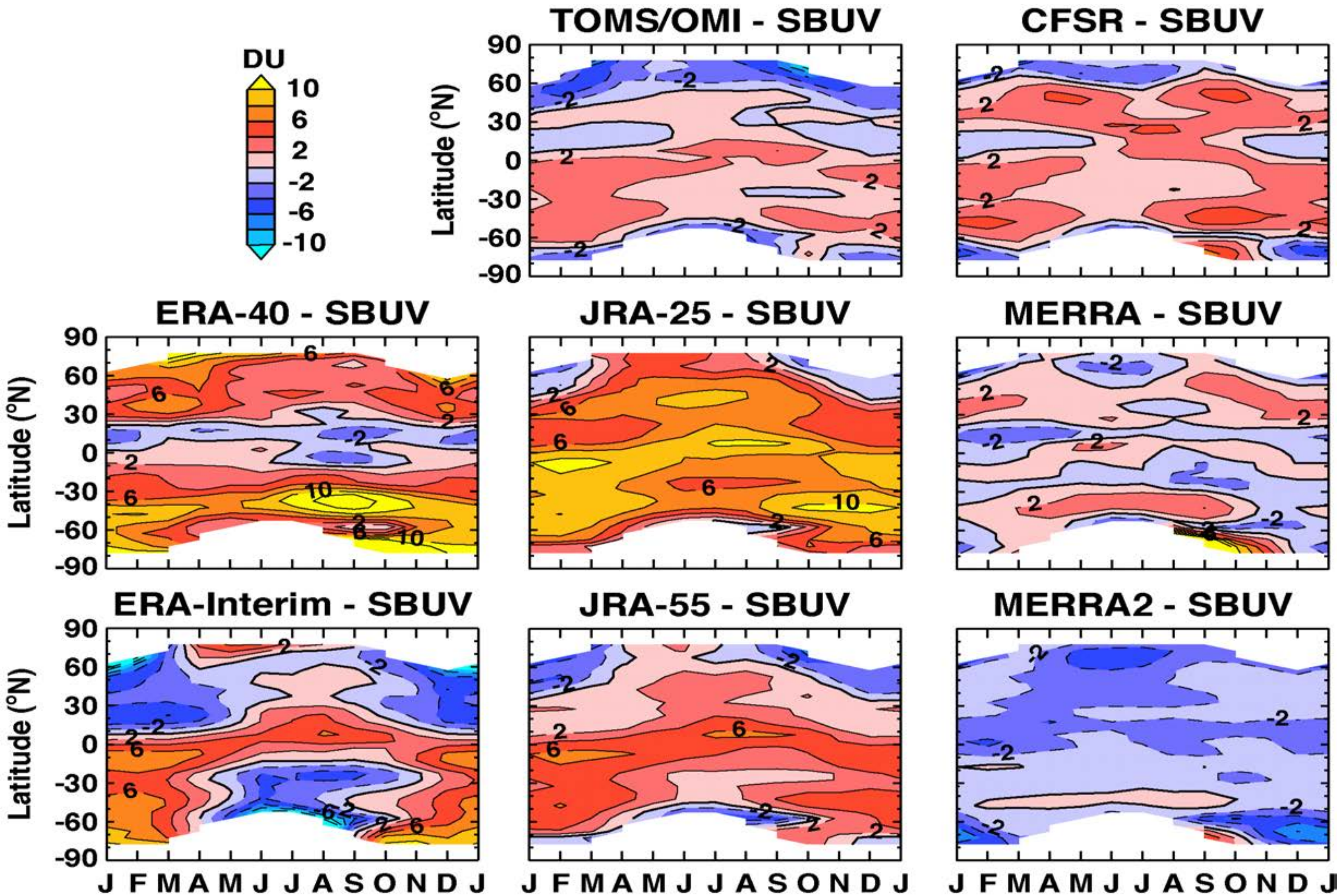
Treatment of ozone

- All of the reanalysis systems except for NCEP R1 and R2 include some form of prognostic ozone parametrization and analysis, but none includes heterogeneous chemistry
- Only satellite ozone retrievals assimilated (no ozonesondes)
- Input observations vary widely, from total column only (JRA-25 and JRA-55) to coarse-resolution profile information (ERA-40, MERRA, CFSR) to a broad selection of satellite products (ERA-Interim)
- ECMWF reanalyses use climatologies rather than analyses for radiation calculations

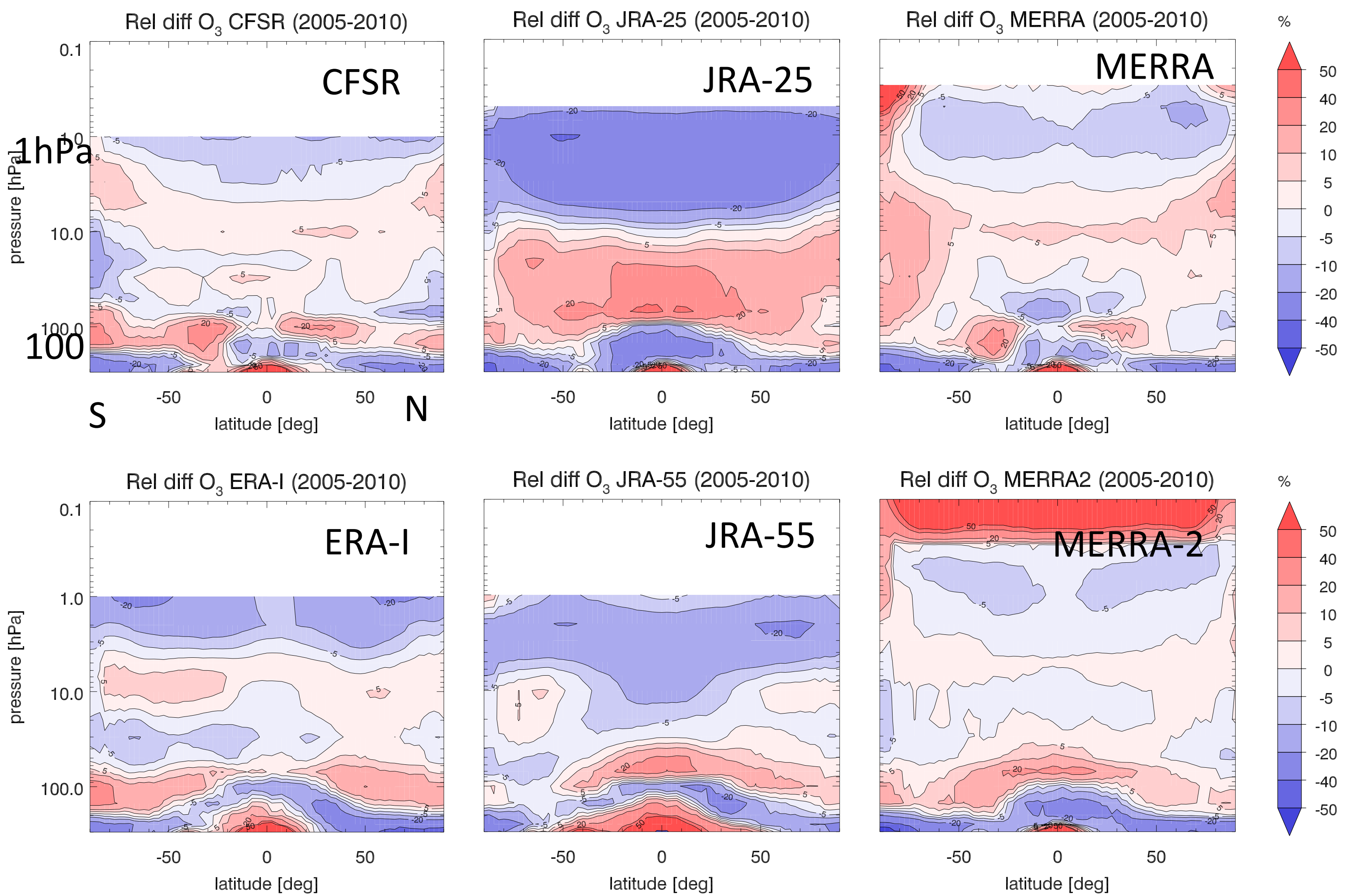
Key conclusions and observational evaluation

- Climatologies, annual cycles and interannual variability generally agree well with observational data, despite some issues in JRA-25 and ERA-40
- Total column ozone is mostly captured by reanalyses, with some limitations (e.g., no Column Ozone data during polar night)
- The ozone vertical distribution is weakly constrained by data assimilation, mean biases in ozone vary with height (10~50% in stratosphere)
- All reanalyses fail to capture the "ozone valley" associated with the Asian monsoon anticyclone

Height-latitude column ozone climatology: difference from SBUV (DU)
Also shown is the TOMS/OMI difference with SBUV.



Ozone vertical distribution: **% differences of annual-av climatology (2005-2010) from the SPARC Data Initiative multi-instrument mean (MIM; i.e. R_i-MIM)/MIM*100.)**



FUB radiosonde

ERA-40

ERA-Interim

JRA-25

JRA-55

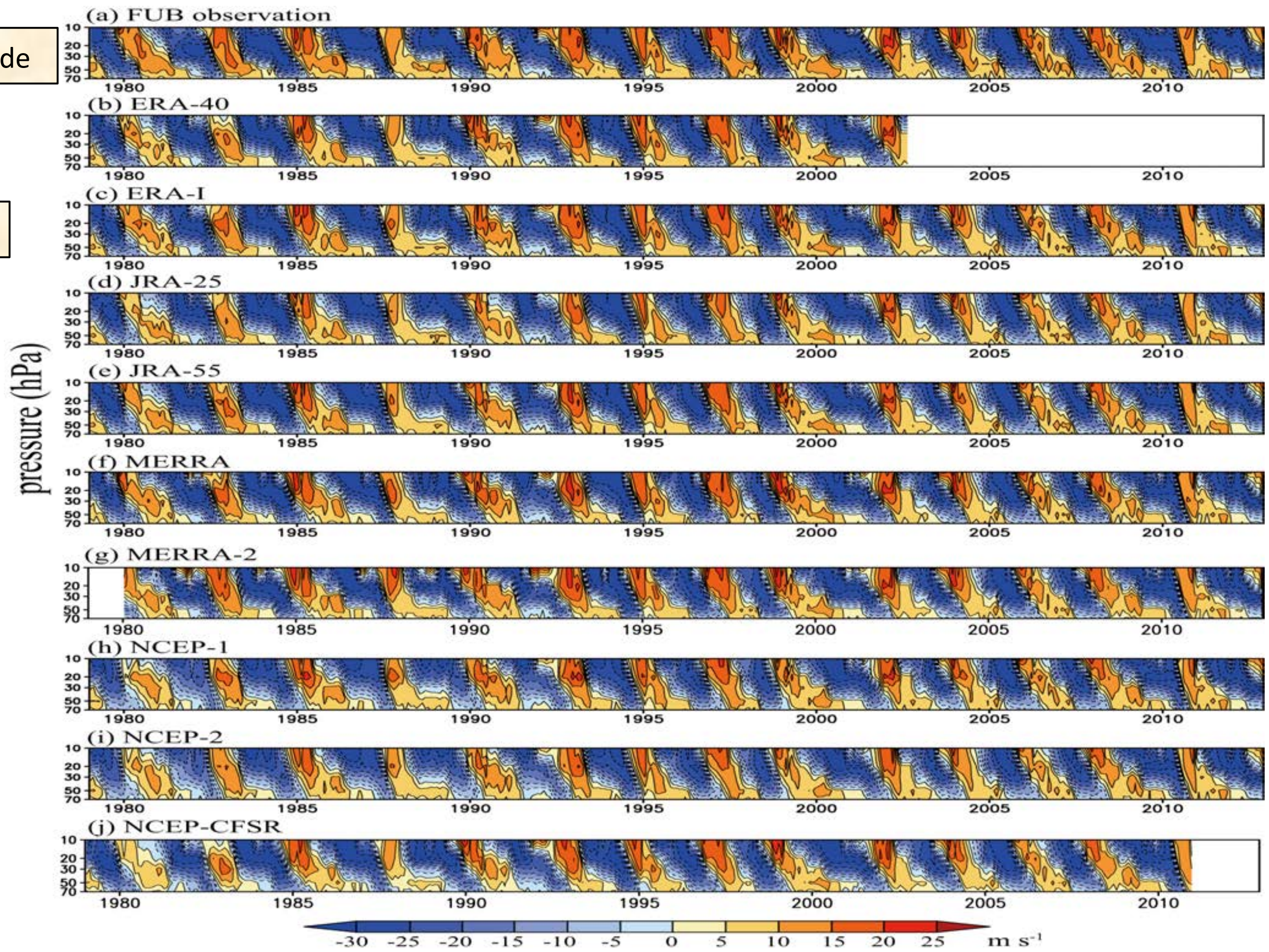
MERRA

MERRA-2

NCEP R-1

NCEP R-2

NCEP CFSR



→ *Represent the monthly-mean zonal wind over Singapore *reasonably* well*

[Kawatani et al., ACP, 2016]

Chapter 4: Climatology and interannual variability of water vapour

Treatment of water vapour

- Reanalysis WV is a function of dehydration, transport, and sometimes methane oxidation (ERA-40, ERA-Interim, ERA-20C), ice supersaturation (ERA-Interim, ERA-20C), and/or relaxation to climatology (MERRA, MERRA-2)
- Data assimilation has limited or no influence in the stratosphere (specification and treatment of the upper bound varies)
- Fields used for radiation calculations in the stratosphere often differ from reanalysis products

Key conclusions and observational evaluation

- Moderate agreement amongst reanalyses in the UTLS
- Major issues in JRA-55 at mid–high latitudes and $p < 200$ hPa
- CFSR is very dry (with some negative mixing ratios) in the stratosphere
- Comparison of transport simulations and tape recorder signals reveals several important discrepancies in circulation and temperatures
- Reanalysis stratospheric WV should not be used in scientific studies!

Future gap in vertically resolved global measurements of stratospheric chemical species (and temperature)

SPARC
Stratosphere-troposphere Processes And their Role in Climate

Limb satellites provide **vertically resolved** information with **good global coverage** of many atmospheric constituents and temperature between 5–140 km.

Problem: There is expected to be a gap after current satellites fail!

Current status:

Lost: SAGE-II (1982-2004), HALOE (1991-2004), GOMOS, MIPAS, SCIAMACHY (2002-2012), HIRDLS (2004-2007)

Working but well over lifetime: OSIRIS, SMR (2001), MLS (2004), ACE-FTS & ACE-MAESTRO (2003), Calipso CALIOP Lidar (2006)

New: NPP (2012, has OMPS limb limited to O3 and aerosol below 60 km)
JPSS-2 (2021) currently will have OMPS-limb (JPSS-1 will not have OMPS-limb)
SAGE-III (2016) limited duration mission, focused on low and middle latitudes

No agencies have current plans for vertical profiling of stratospheric trace gases.

WDAC Actions items from last year

Regarding the satellite mission gap it was decided to send a letter to CEOS/ CGMS Working Group on Climate

- Atmospheric composition: limb sounders

Regarding the in-situ observing networks at risk it was decided that WDAC will prepare a letter for JSC to WMO.

- Continuation of stations with long-term records, especially lidar and ozonesondes
- Homogeneity across the ground networks, e.g. O3S-DQA for ozonesonde, GRUAN.
- Observations in tropics and Southern mid-latitudes