# SPARC

# Stratosphere-troposphere Processes And their Role in Climate

# SRIP –

# SPARC Reanalysis Intercomparison Project

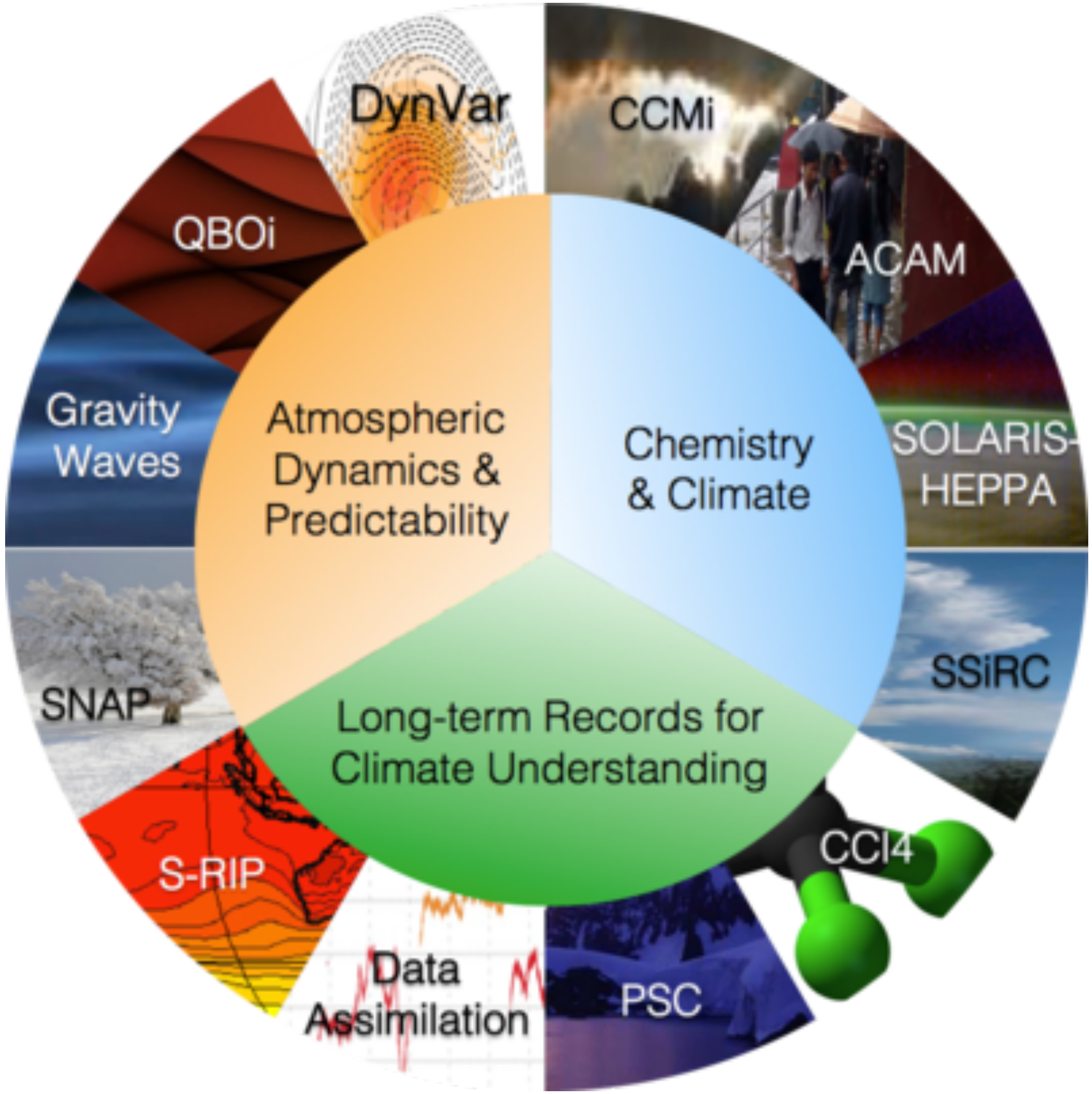
Susann Tegtmeier
*GEOMAR, Kiel, Germany*

# SPARC

- Promotes research on how chemical and physical processes in the atmosphere interact with climate variability and change.
- Historically concentrated on the role of the stratosphere in climate, but now includes foci throughout the atmosphere.

**SPARC Implementation Plan**

- Theme 1. Atmospheric Dynamics and Predictability
- Theme 2. Chemistry and Climate
- **Theme 3. Long-term Records for Climate Understanding**




*New/emerging activities:*

**OCTAV-UTLS – Observed Composition Trends And Variability in the UTLS**

**LOTUS – Ozone Trends**

**Atmospheric Temperature Changes and their Drivers**

# 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

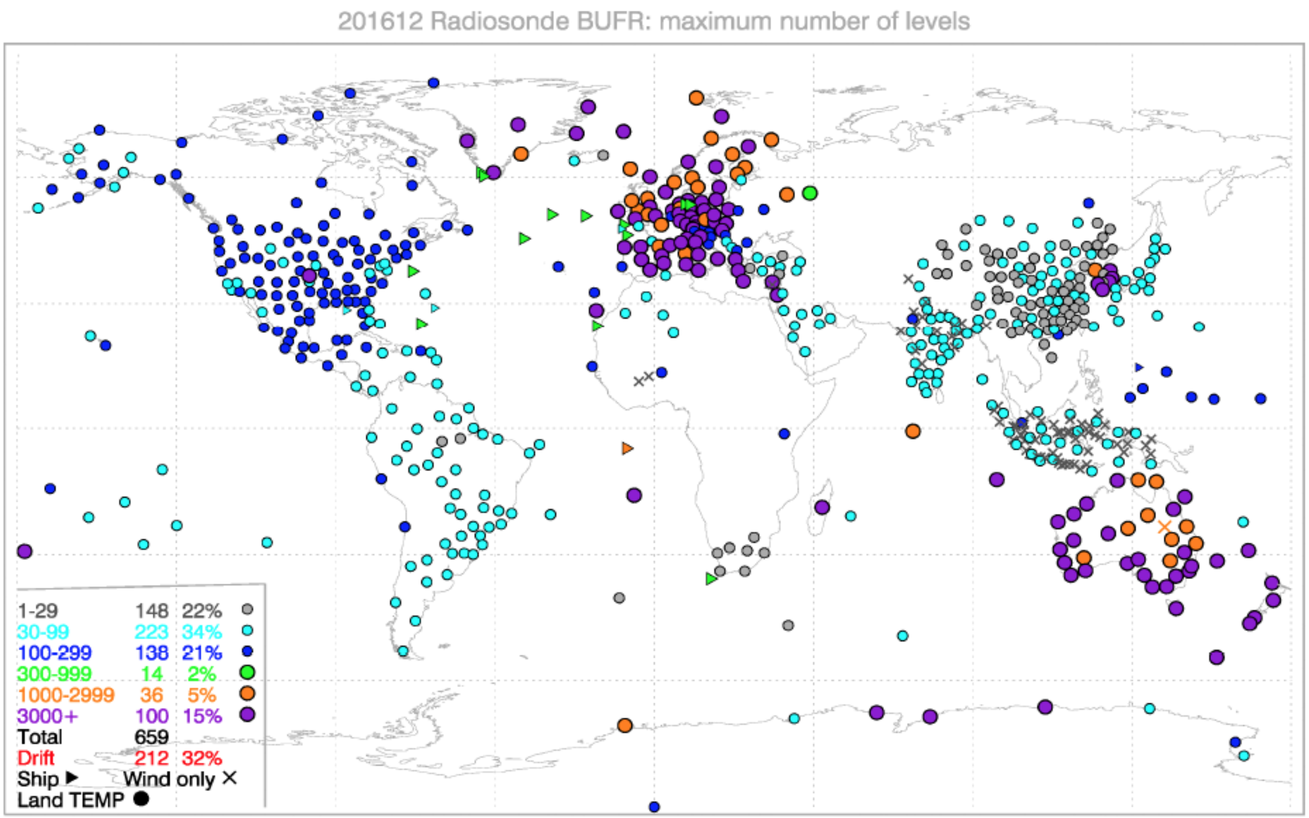
**Regarding the in-situ observing networks at risk it was decided that WDAC will prepare a letter for JSC to WMO.**

- 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

# FISAPS - Fine Scale Atmospheric Processes and Structures

M. Geller, H. Chun, P. Love

- Focus on atmospheric processes important for large-scale dynamics and chemical composition that occur on vertical scales of less than 1 km
- **Goals: enhance availability of high vertical-resolution radiosonde data (HVRRD)**




Radiosonde reports sorted by vertical levels

Increasing need for research access to HVRRD (currently growing use in real-time forecasting)

Encourage data producers to work towards high resolution BUFR data

Current discussion of availability through IGRA (very preliminary)

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)

## Motivation

- **Multiple studies have identified substantial differences amongst reanalyses with respect to key variables and diagnostics.**

## Objectives

- **Compare** all (or some of the newer) 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 collaborative links** between reanalysis centres and the SPARC community
- **Contribute to future improvements** in reanalysis products

S-RIP focuses on reanalysis outputs in the stratosphere, upper troposphere and lower mesosphere

## Prime Output:

- **S-RIP "interim" Report (2016), four 'basic' chapters**
- **S-RIP "full" Report (2018), twelve chapters in total**

# Global Atmospheric Reanalysis Data Sets

| Reanalysis Centre | Products | Contacts for S-RIP |
|---|---|---|
| ECMWF | ERA-40, ERA-Interim, ERA-20C, [ERA5] | Rossana Dragani |
| JMA (& CRIEPI) | JRA-25/JCDAS, JRA-55 | Yayoi Harada & Kazutoshi Onogi |
| NASA | MERRA, MERRA-2 | Krzysztof Wargan |
| NOAA NCEP | NCEP/NCAR (R-1), NCEP/DOE (R-2), NCEP-CFSR | Craig Long & Wesley Ebisuzaki |
| NOAA & Univ. Colorado | 20CR | Gilbert Compo & Jeffrey S. Whitaker |

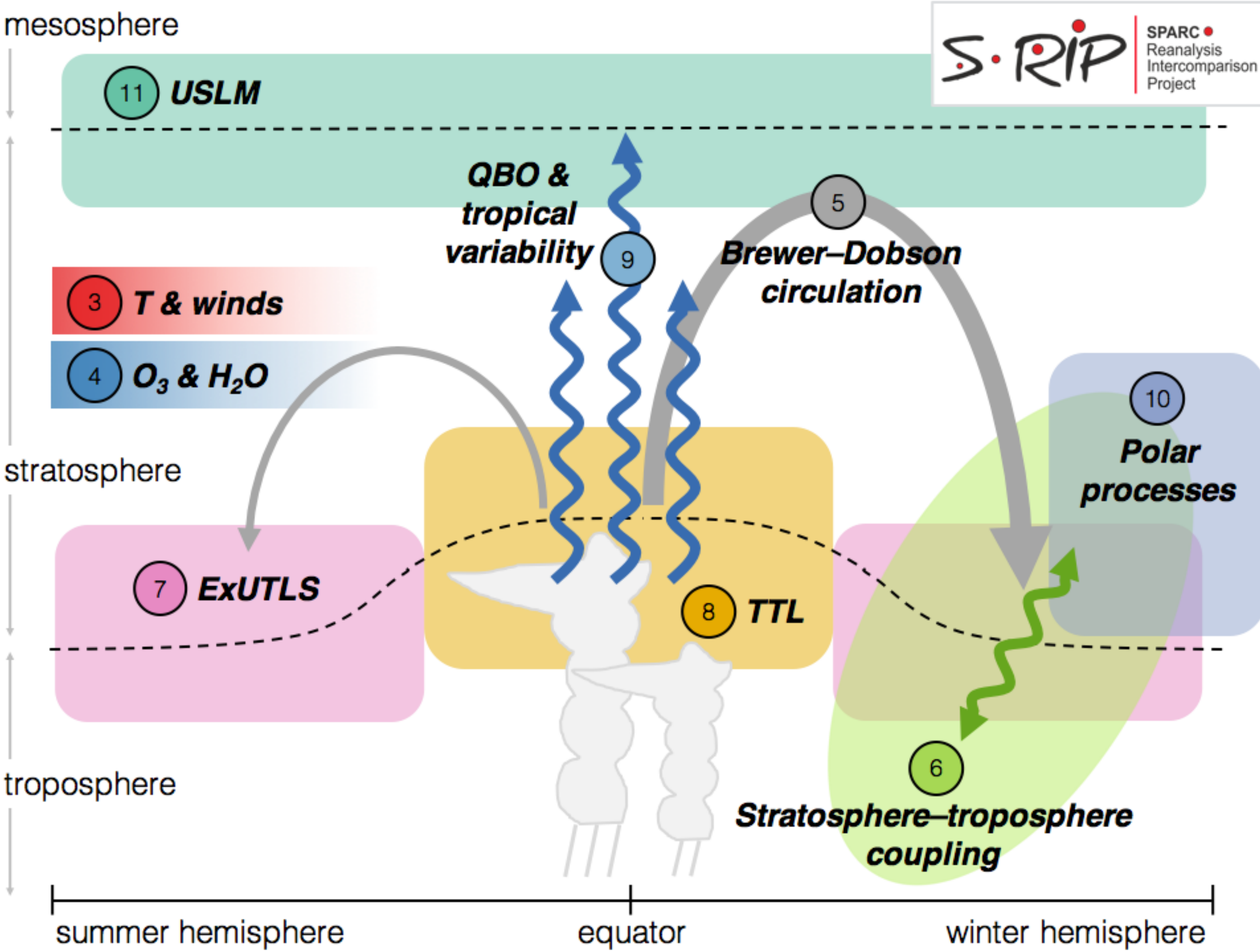
- Focus on newer reanalysis systems that assimilate upper-air measurements (ERA-Interim, JRA-55, MERRA, MERRA-2, CFSR)
- ERA5 will not be included (since time period 1979-2009 not available until 2018)
- Where appropriate, include other reanalyses:
  - Long-term, surface-input reanalyses (e.g. NOAA-CIRES 20CR and ERA-20C)
  - Older reanalyses (NCEP-NCAR R1, NCEP-DOE R2, ERA-40, and JRA-25/JCDAS)
- The intercomparison period common to all chapters: 1979-2012
  - Some chapters will also consider the pre-satellite era and/or include results for recent years.

# Chapters of the S-RIP Report

| | Chapter Title | Chapter Co-leads |
|---|---|---|
| 1 | Introduction | Masatomo Fujiwara, Gloria Manney, Lesley Gray |
| 2 | Description of the Reanalysis Systems | Jonathon Wright, Masatomo Fujiwara, Craig Long |
| 3 | Climatology and Inter-annual Variability of Dynamical Variables | Craig Long, Masatomo Fujiwara |
| 4 | Climatology and Inter-annual Variability of Ozone and Water Vapour | Michaela Hegglin, Sean Davis |
| 5 | Brewer-Dobson Circulation | Thomas Birner, Beatriz Monge-Sanz |
| 6 | Stratosphere-Troposphere Coupling | Edwin Gerber, Patrick Martineau |
| 7 | Extratropical UTLS | Cameron Homeyer, Gloria Manney |
| 8 | Tropical Tropopause Layer | Susann Tegtmeier, Kirstin Krüger |
| 9 | QBO and Tropical Variability | James Anstey, Lesley Gray |
| 10 | Polar Processes | Michelle Santee, Alyn Lambert, Gloria Manney |
| 11 | Upper Strato. Lower Mesosphere | Lynn Harvey, John Knox |
| 12 | Synthesis Summary | Fujiwara, Manney, Gray |

Chapters 1-4: Basic chapters 2016 (now early 2017)

Chapters 5-11: Advanced chapters (end 2018)


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

## S-RIP 2017 Interim SPARC Report (Basic chapters)

- Editors: M. Fujiwara, J. Wright, G. Manney, and L. Gray
- Technical editors: Fiona Tummon and SPARC Office colleagues
- Report status: first revision phase
- Review process is similar to that of journal publications
  - minimum 3-4 reviewers per chapter
  - two rounds of reviews
- Will be published in 2017

## S-RIP 2018 Final SPARC Report (Advanced chapters)

- Zero order drafts of each chapter in October 2016
- Final drafts planned for October 2017
- Beginning of review process end of 2017

# S-RIP 2017 Interim SPARC Report (Basic chapters)

## Chapter 1: Introduction

- Motivation, goals, scope, outline, communication, prospects etc.

## Chapter 2: Description of the Reanalysis Systems

- Reference for reanalysis users
- Understand how reanalyses work using simple terms
- Compare the structures of two or more reanalyses
- Sources of additional information, extensive use of tables/figures
- Information on potential temporal discontinuities

# Chapter 2: Description of the Reanalysis Systems

J. Wright, M. Fujiwara, C. Long

**2.1 Introduction**

**2.2 Forecast models** (including major physical parametrizations and boundary conditions)

**2.3 Assimilation schemes** (basics and applications in reanalysis systems

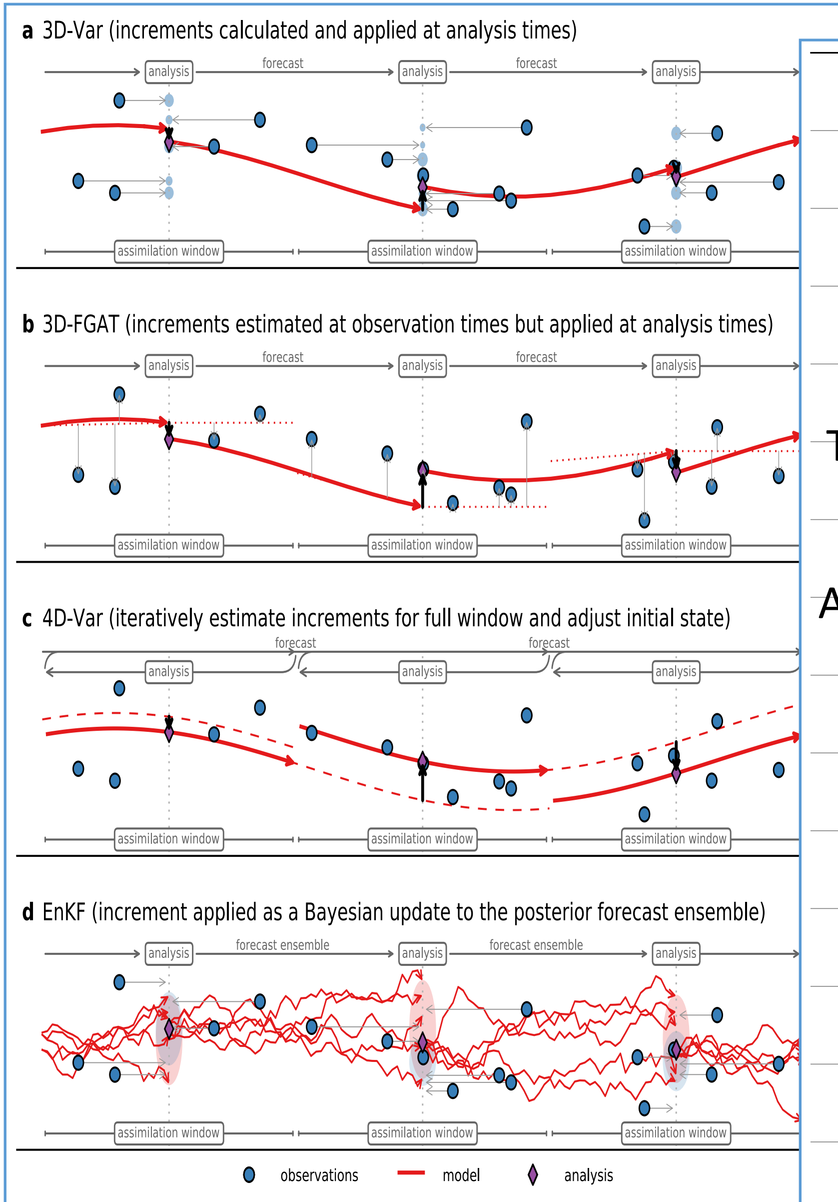
**2.4 Observational data** (including key upper air observations, water vapour)

**2.5 Execution streams**

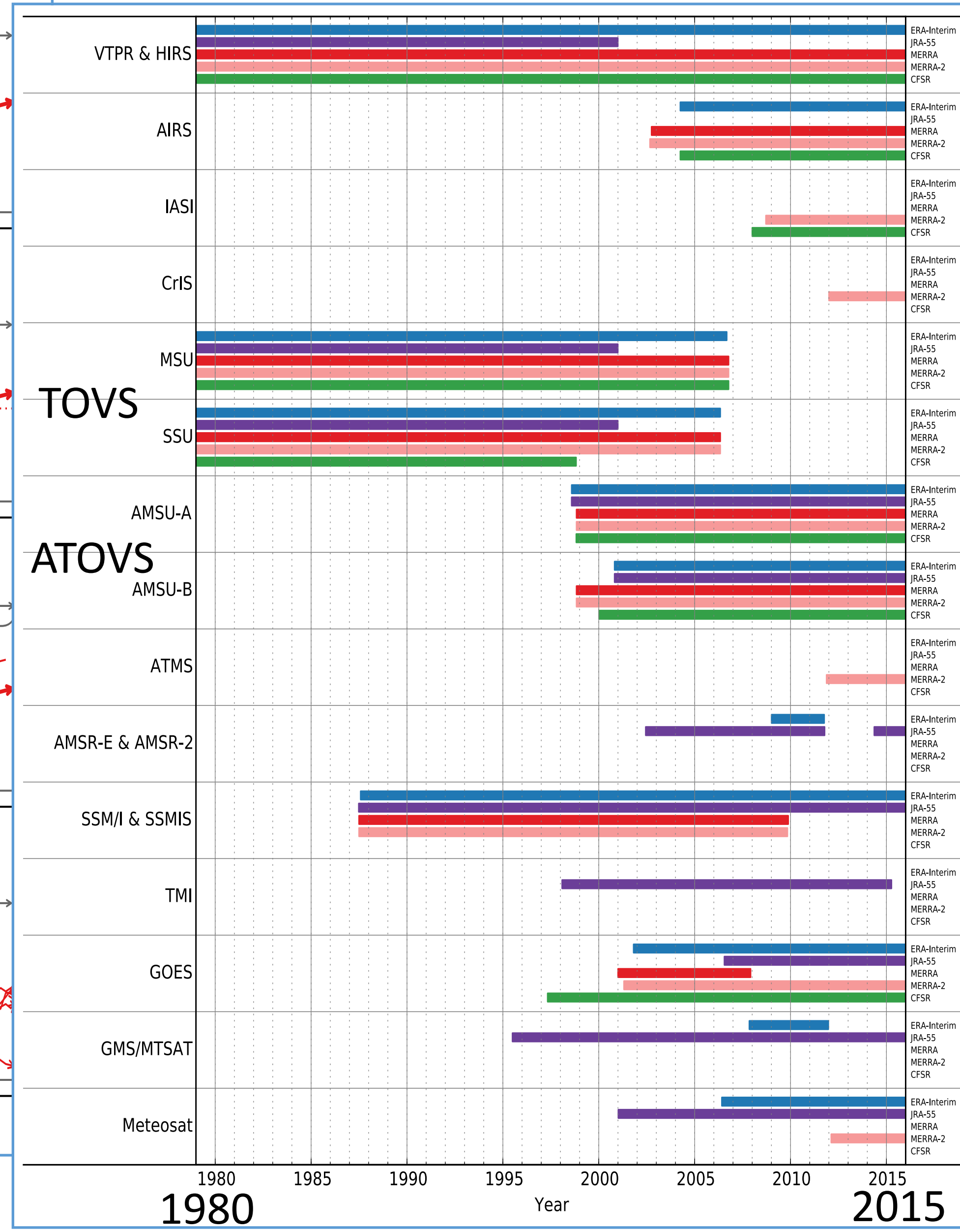
**2.6 Archived data**

## Chapter 2 Tables / Figures

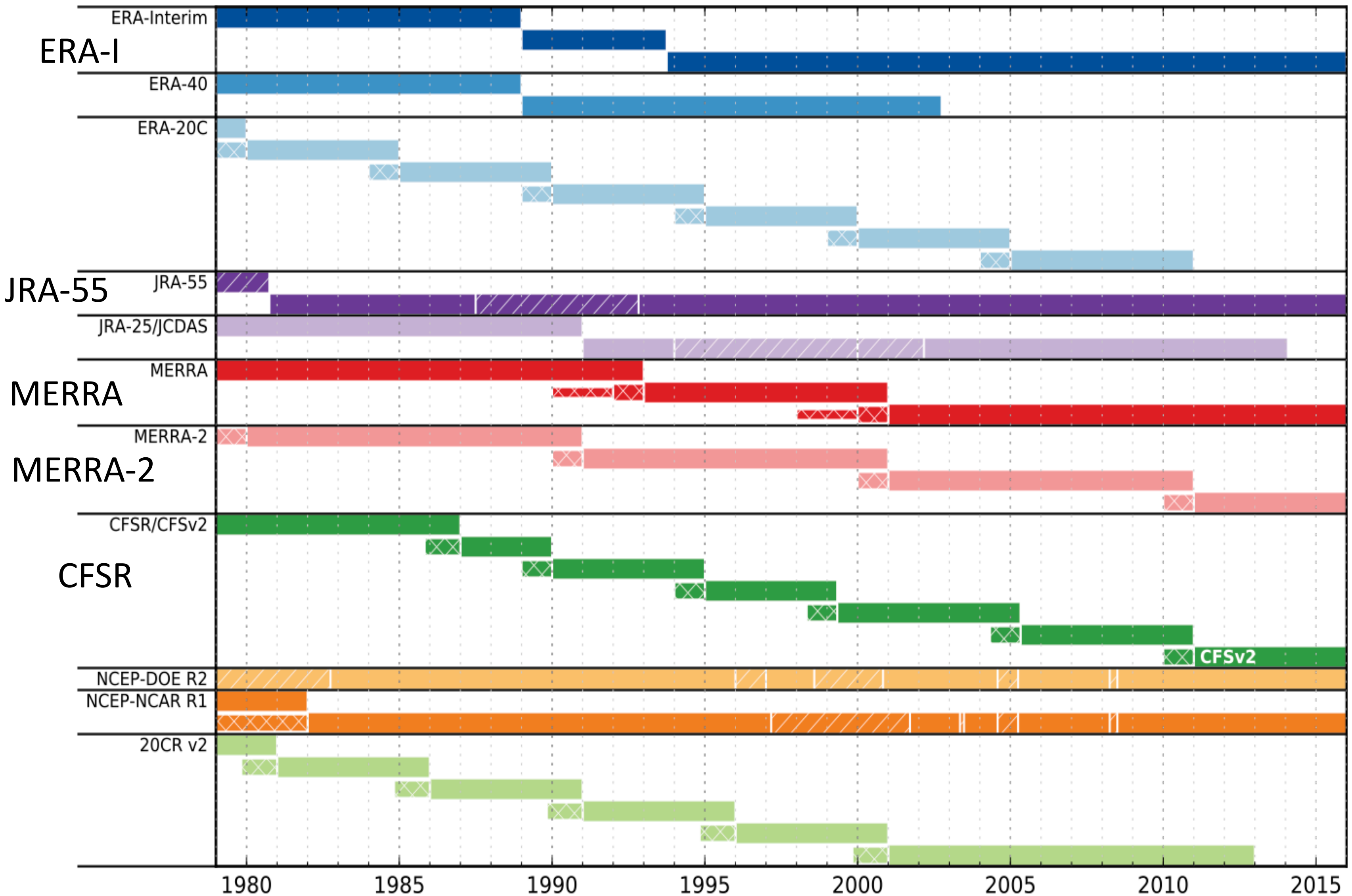
- Reanalysis dataset with dates and journal papers
- Horizontal resolution, vertical levels, model top
- Radiative transfer schemes, cloud scheme, gravity wave scheme
- SST/sea ice treatment, solar variability treatment
- Ozone treatment, aerosol schemes, $CO_2$ + other GHGs treatments
- Assimilation scheme employed, satellite radiance assimilation scheme employed
- Satellite datasets and other datasets (e.g. aircraft) assimilated
- Water vapour treatment




Simplified schematic for data assimilation strategies




Assimilated satellite radiance datasets




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

# S-RIP overview paper in ACP: Introduction to the SPARC Reanalysis Intercomparison Project (SRIP) and Overview of the Reanalysis Systems

**Fujiwara et al.**

- An introduction to S-RIP (motivation, objectives, report structure)
- description of eleven current or recent reanalyses:
  - ERA-40, ERA-Interim, ERA-20C
  - JRA-25/JCDAS, JRA-55
  - MERRA, MERRA-2
  - NCEP-NCAR R1, NCEP-DOE R2, CFSR, NOAA-CIRES 20CRv2
- Forecast model specs (grids, dynamical cores, parametrizations, boundary conditions)
- Data assimilation overview (brief account of methods employed)
- Input observations (conventional and satellite-based, changes in time, key data sources and archives, quality control and bias correction procedures)
- Ozone and water vapour (relevant parametrizations, details of data assimilation)

**Acknowledgements and thanks to the many S-RIP participants who provided input and feedback for this paper — this was truly a collaborative effort**

# 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.

# Chapter 3: Climatology and Interannual Variability of Dynamical Variables

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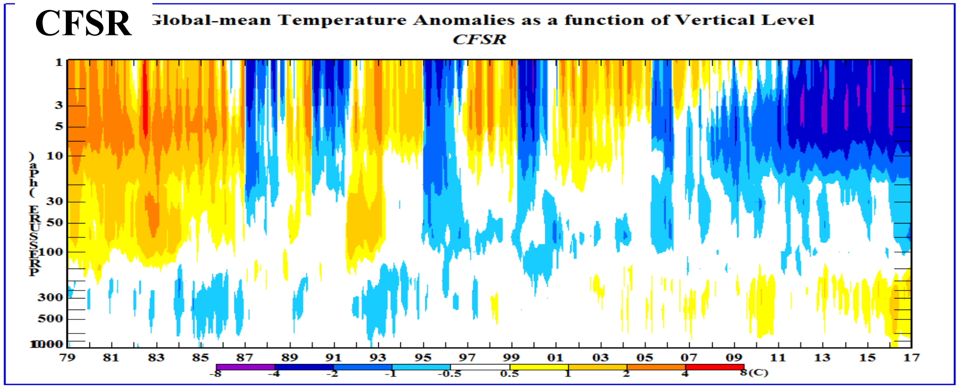
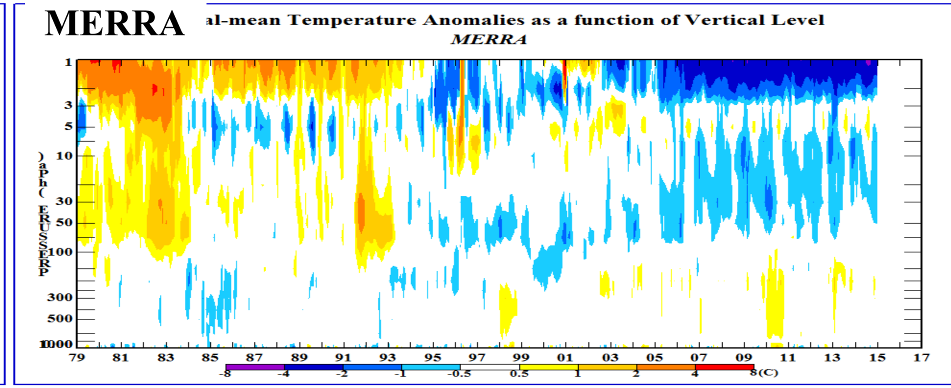
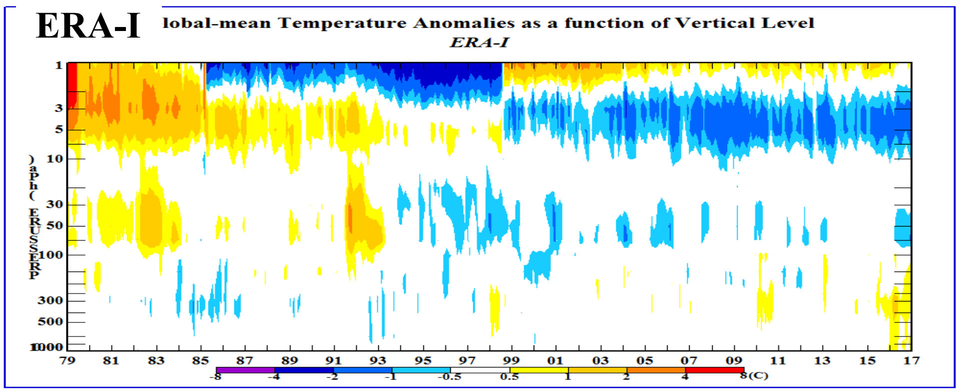
- **Effects of volcanic eruptions on reanalyses temperatures and wind**

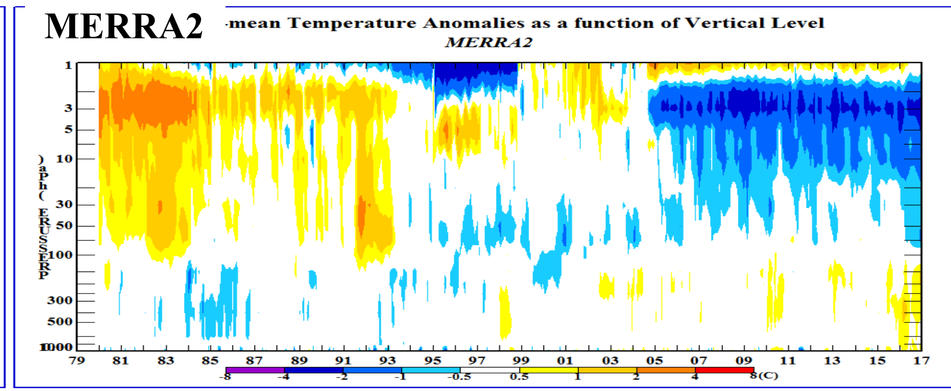
- Reanalysis temperatures agree well below 10 hPa
- Large discontinuities associated with the ~1998 transition from TOVS (SSU+MSU) to ATOVS (AMSU)
- CFSR: several discontinuities associated with production stream changes and the change in model resolution
- CFSR model imparts a warm bias in the upper stratosphere
- JRA-55 contains a year-round cold bias in the upper stratosphere
- ERA-Interim is biased warm in the southern polar vortex near 7~5 hPa
- MERRA contains a slight cold bias at 1 hPa relative to Aura MLS
- Assimilation of Aura MLS temperature retrievals at pressures less than 5 hPa causes a jump in MERRA-2 upper stratospheric temperatures
- Disagreements amongst reanalyses are reduced during the ATOVS period (post-1998) relative to the TOVS period
- Significant biases in earlier reanalyses (JRA-25, ERA-40, NCEP R1/R2) are larger, more persistent, and extend through a deeper vertical layer
- Evaluations against Aura MLS, ozonesondes, long-duration balloon experiments, and un-assimilated radio- and rocketsondes

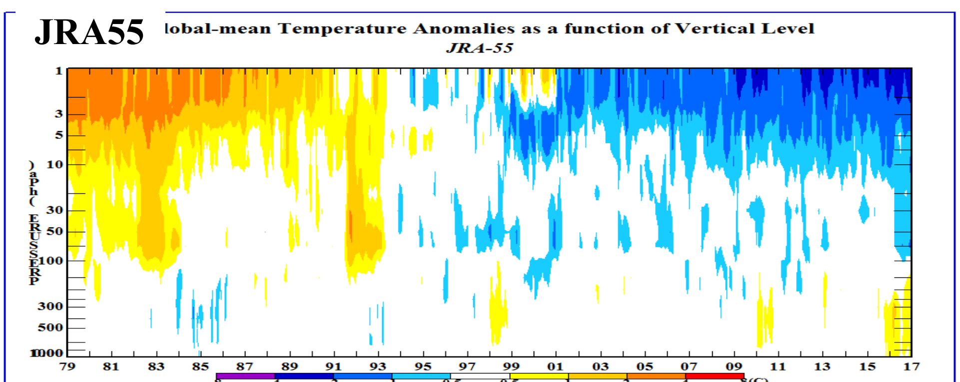
# Global Temperature Anomalies
## *1979-2016*



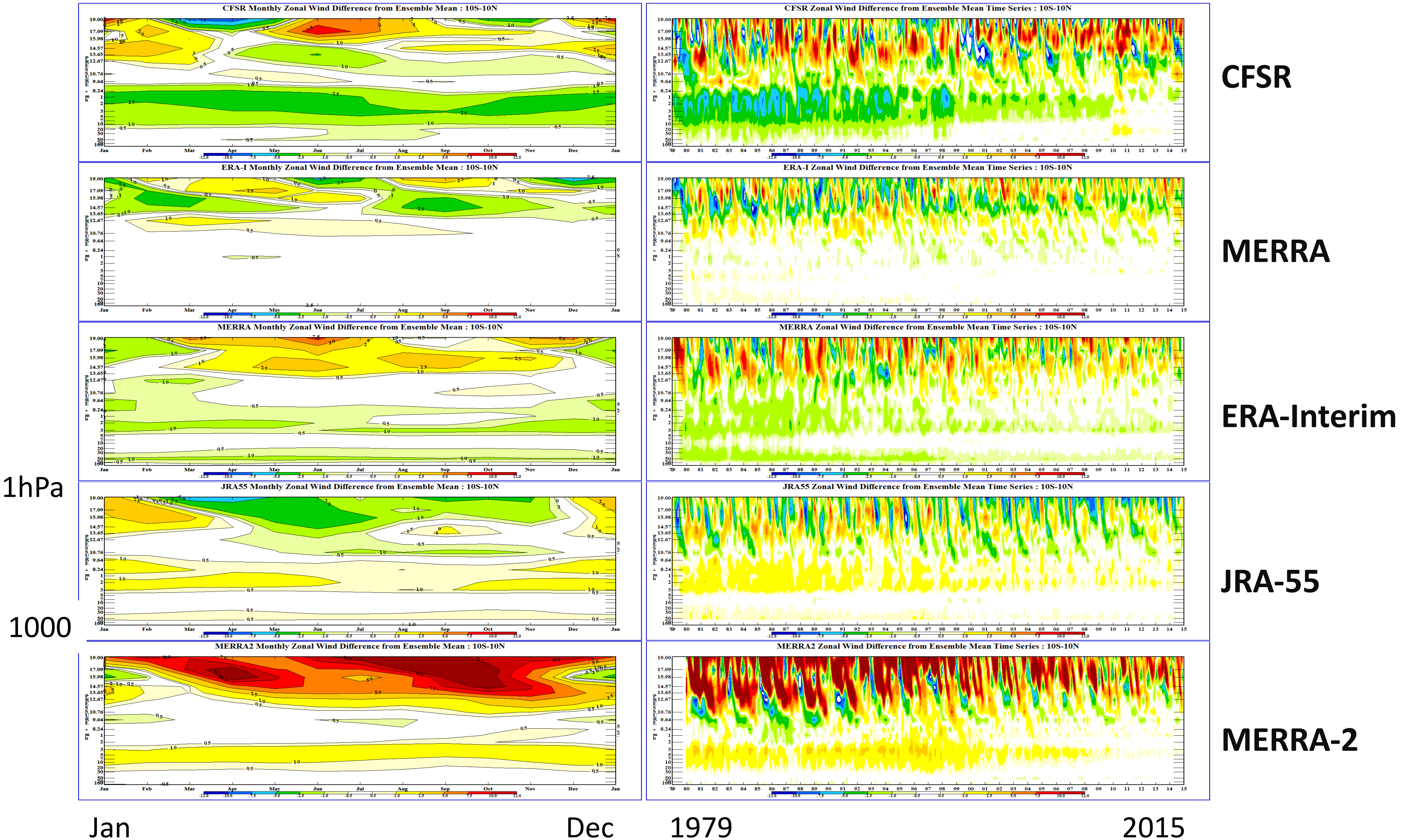




Global temperature anomalies reveal discontinuities in the middle and upper stratosphere due to stream and data transitions. Most notably is the transition from TOVS to ATOVS observations in late 1998. Other features observed are: El Nino warm period in troposphere in 1998, 2010 and 2016, and the lower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

**Seasonal cycle** **Time series (1979–2015)**



# 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

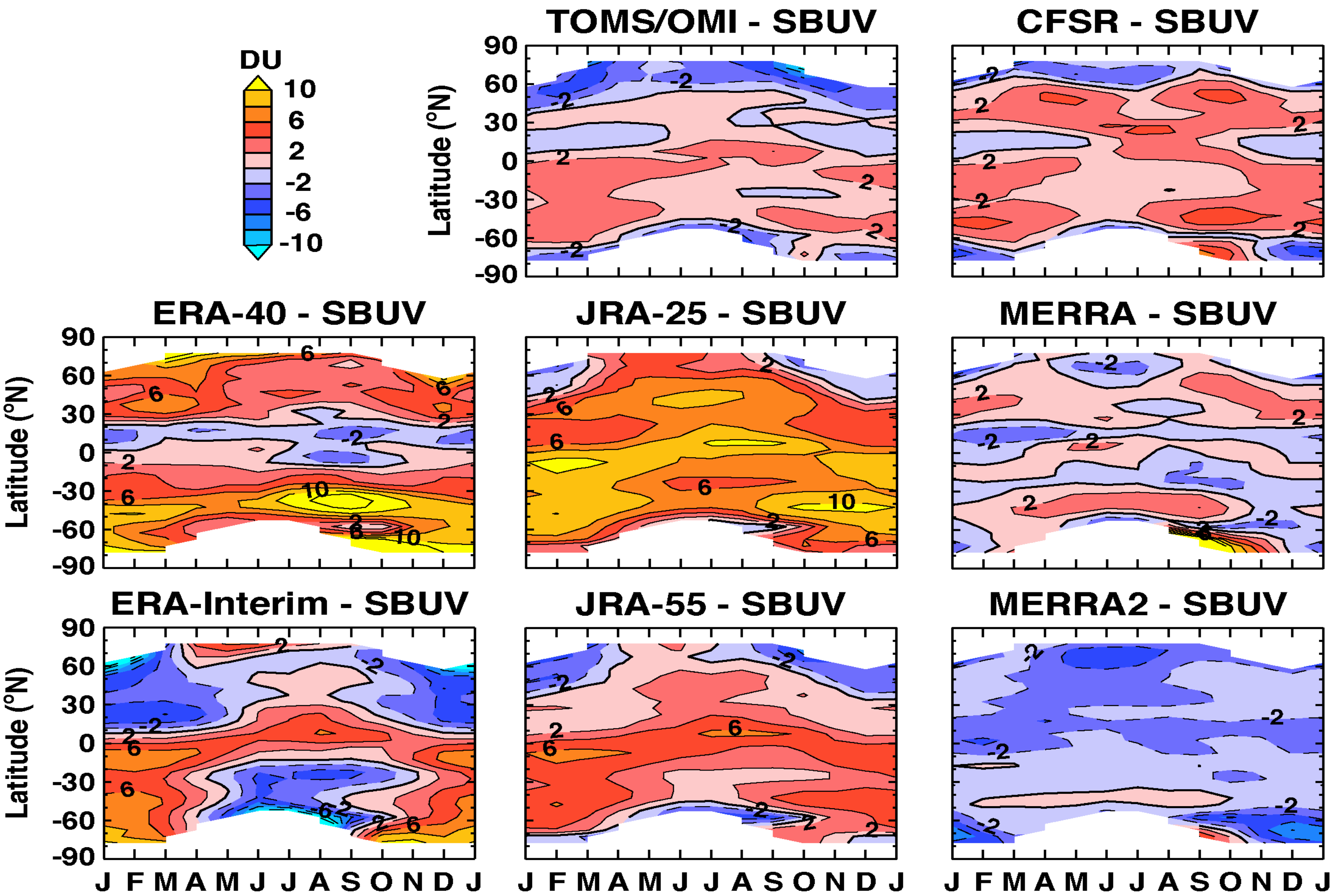
- Lack of planned satellite observations (esp. limb) of UTS composition
- Need up-to-date AMSU and merged SSU-AMSU climate data records
- Availability of high vertical-resolution radiosonde data
- Need for more reference-quality global & long-term observations, particularly for reanalysis intercomparisons
- 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'

# Chapter 4: Climatology and interannual variability of ozone

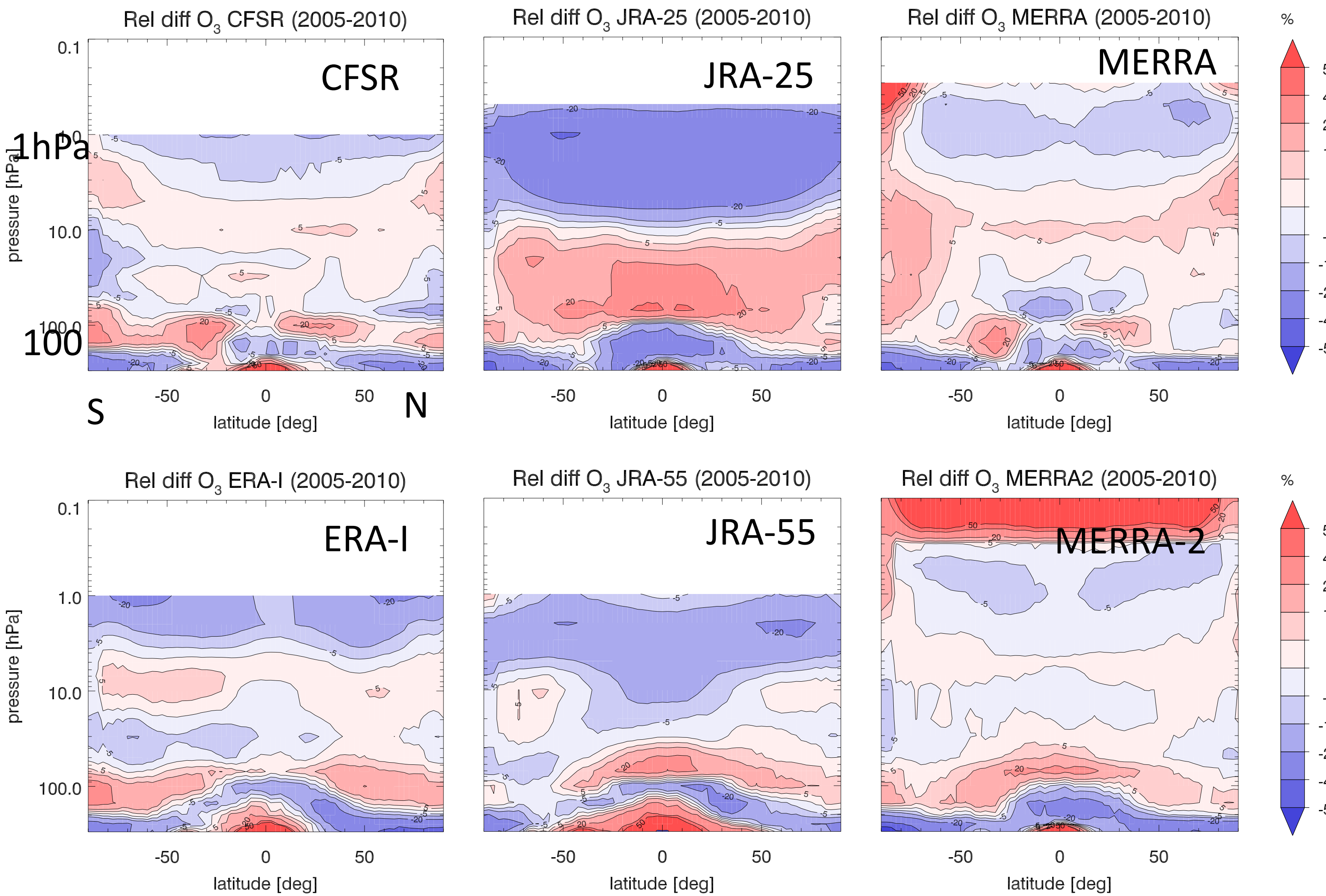
- **Treatment of ozone**
  - All of the reanalysis systems except for NCEP R1 and R2 include some form of prognostic ozone parametrization and analysis, but none of these include heterogeneous chemistry (use with caution for ozone hole studies)
  - To date, only satellite ozone retrievals are assimilated (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, so that mean biases in ozone products vary with height (10~50% in stratosphere)
  - QBO signals are vastly improved in JRA-55 relative to JRA-25
  - All reanalyses fail to capture the “ozone valley” associated with the Asian monsoon anticyclone

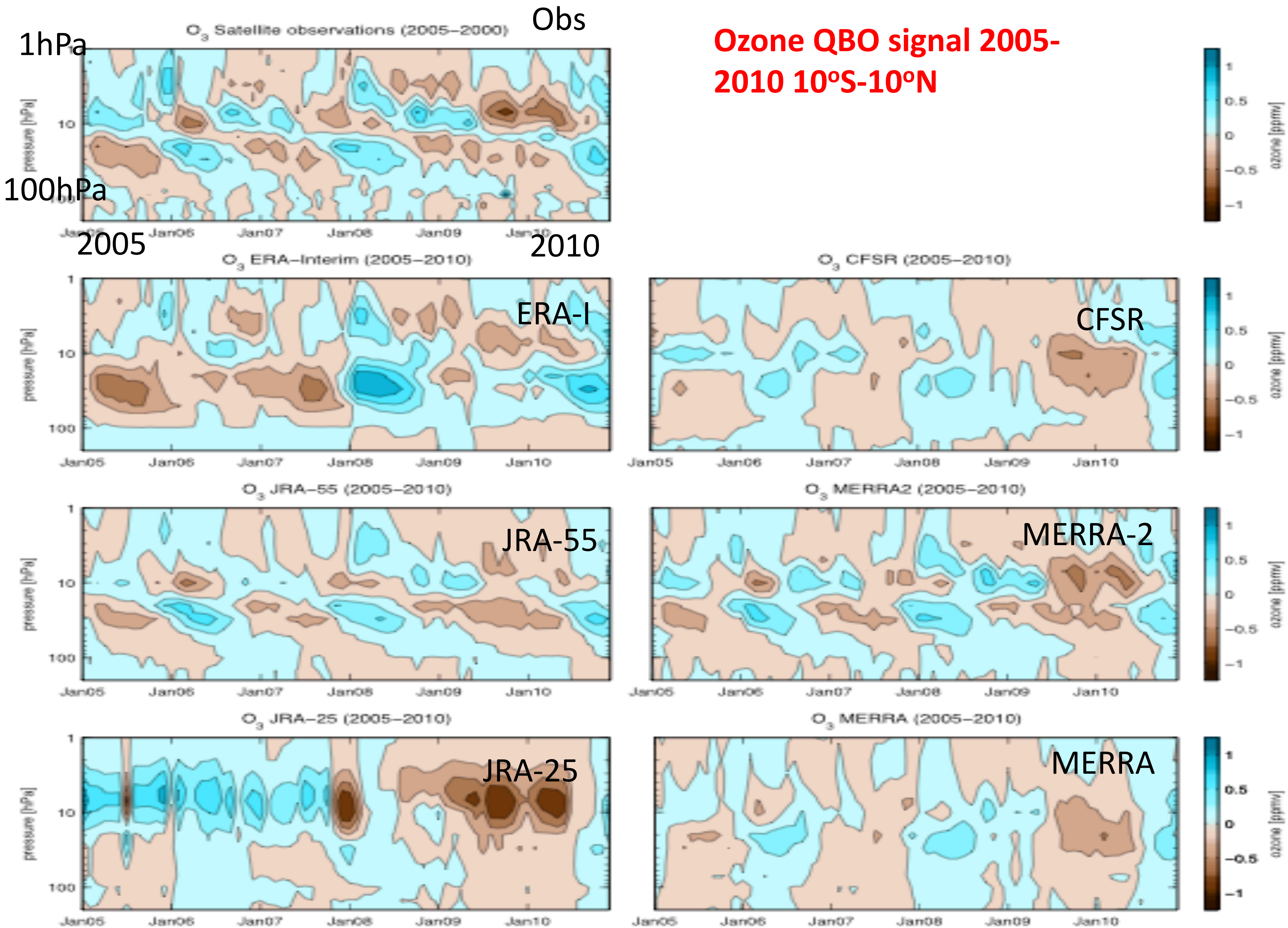
**Height-latitude column ozone climatology: difference from SBUV (DU)**
**Also shown is the TOMS/OMI difference with SBUV.**



**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.)



## Ozone QBO signal 2005-2010 10$^o$S-10$^o$N

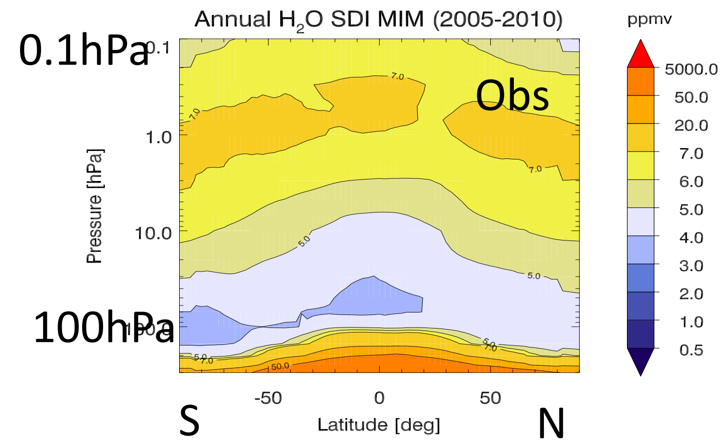


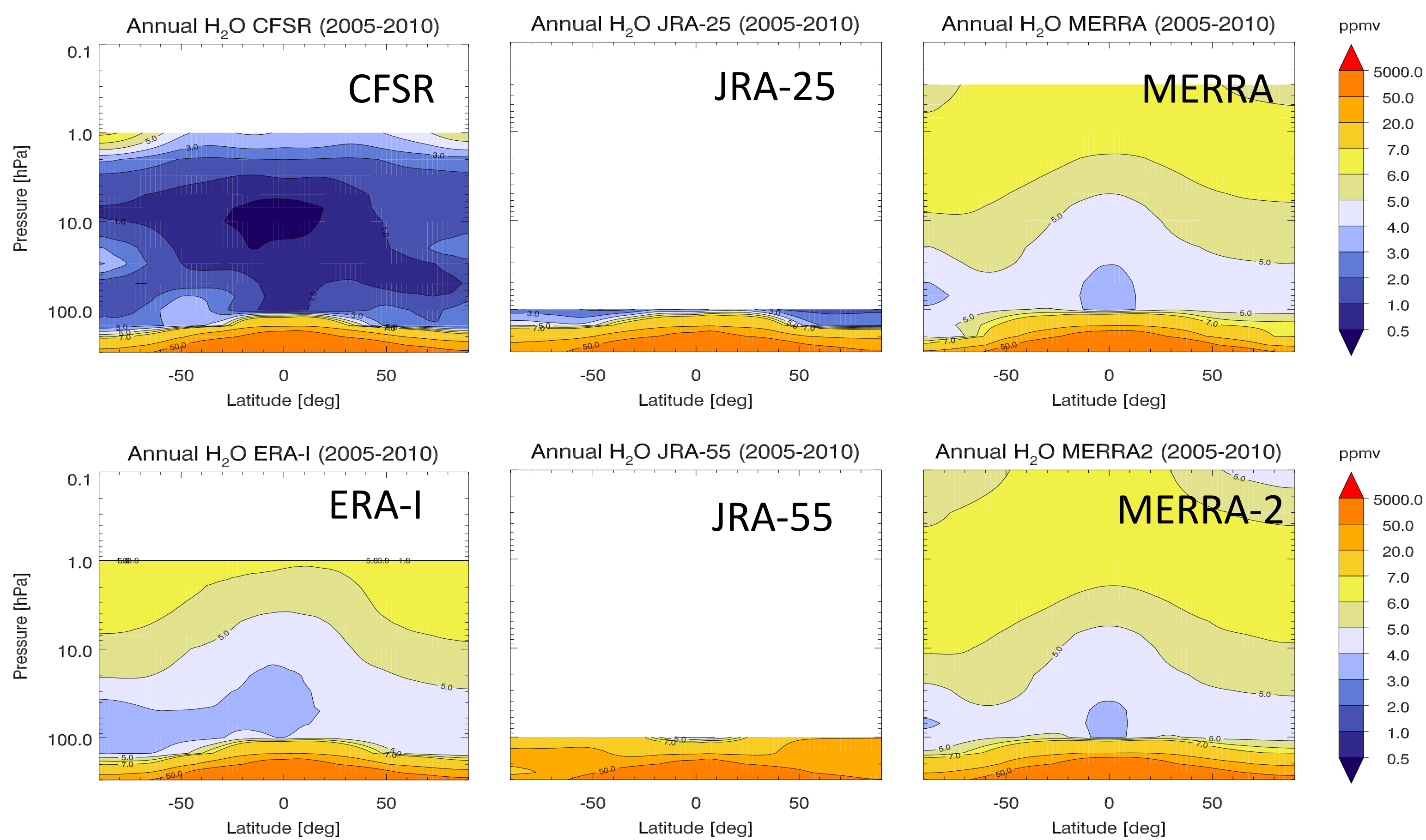
# Chapter 4: Climatology and interannual variability of water vapour

- **Treatment of water vapour**
  - Reanalysis WV is a function of dehydration, transport, and for some reanalyses methane oxidation (ERA-40, ERA-Interim, ERA-20C), ice supersaturation (ERA-Interim and ERA-20C), and/or relaxation to climatology (MERRA and 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 pressures less than 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!

**Multi-annual mean zonal mean cross-sections of water vapour (2005-2010) for SPARC Data Initiative multi-instrument mean (MIM; upper right) and various reanalysis datasets**



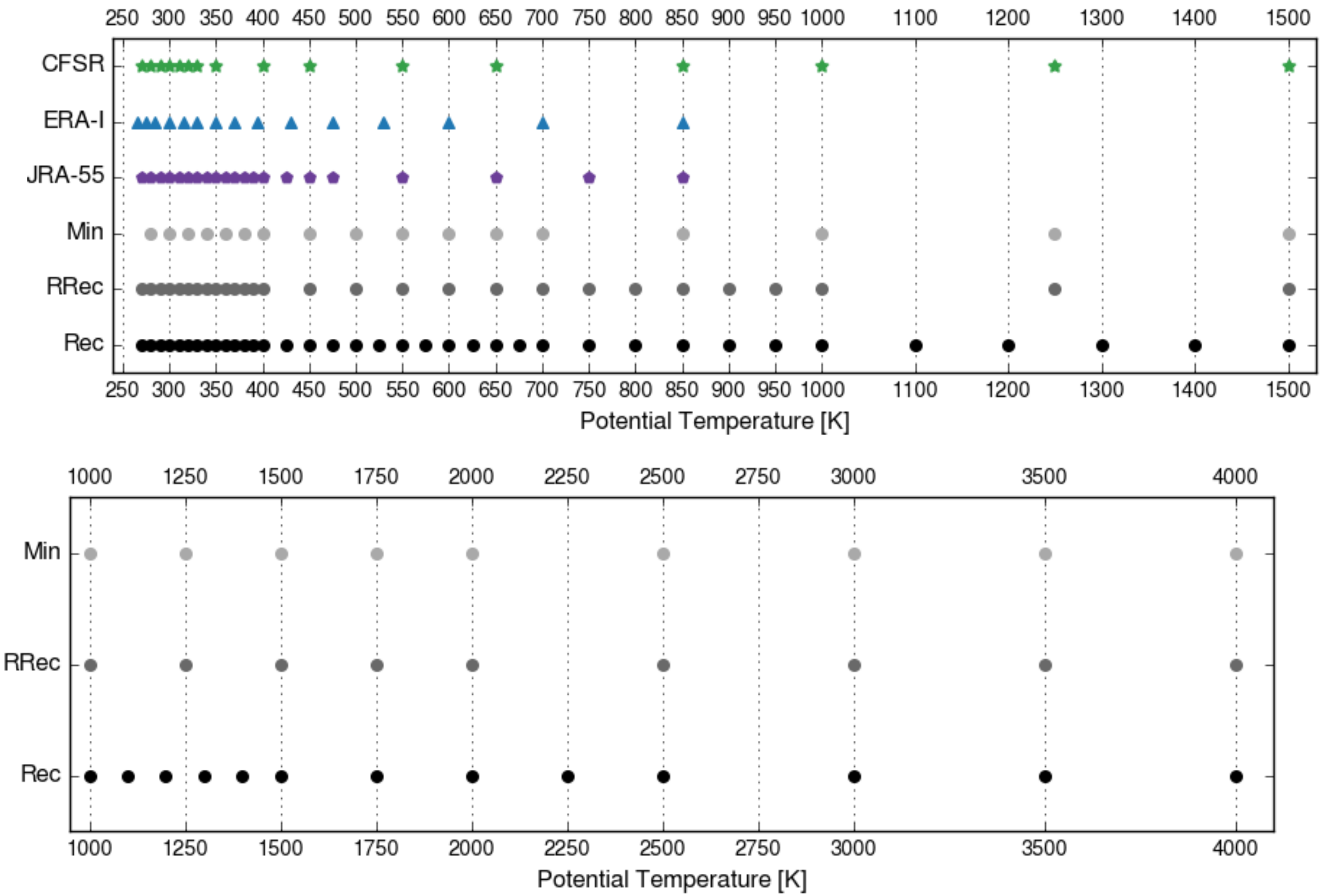



# S-RIP 2017 workshop

- **Place:**
  - **European Centre for Medium-Range Weather Forecasts, ECMWF, U.K.**
- **When** ***(with joint DA workshop)***
  - ***23-27 October 2017***
- **Host: ECMWF**
  - ***Beatriz Monge-Sanz, Rossana Dragani***
- **Facilities**
  - ***Lecture Theatre, meeting rooms, poster boards***
  - ***Wi-Fi, cafeteria, restaurant***
  - ***Parking on site or public transport from town***
  - ***Many hotels in town, offer special ECMWF rates***
  - ***London is reasonably close for "commuting"***
  - ***Two major airports (Heathrow, Gatwick)***

- **Costs estimate**
  - **No cost for meeting rooms and equipment**
  - **Coffee break and lunch at extra cost → registration fee/ small SPARC contribution and self-funded lunch ?**

**Request for PV on Isentropic Surfaces : conduct a quick survey to ascertain that these recommendations will provide what is required by the community?**



# Comments received at the SSG meeting reported by Lesley Gray

- There was some discussion about the relationship between S-RIP and the tropospheric reanalysis inter comparison that might fall under the TIRA initiative.
  - There was great support for the reanalysis inter-comparisons going on within S-RIP and a need to extend them more to direct tropospheric comparisons (e.g. how well do the reanalyses compare with regard to specific tropospheric features such as circulation patterns and features like the monsoons) - and it was felt that this was what TIRA would be planning.

- There was support for the idea of collecting user requirements e.g. PV on isentropic surfaces and feeding them through to the Reanalysis Centres.

- There was strong encouragement for our idea of pulling together the various tables of information on each reanalysis dataset, to encourage the Centres to provide a standard set of information for each future dataset. They helpfully suggested that this might be turned into a 'living document' on a web-site (SPARC? S-RIP?) that could continue to be updated into the future.

- Fiona Tummon said she is happy to be the handling editor, so that reviewers can be anonymous.