Wave activity in the TTL and diurnal tides in the chemistry climate models and reanalyses

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SPARC Data Assimilation Workshop, June 2011

Contents

1. Wave Activity in the Tropical Tropopause Layer (TTL) in 7 Reanalysis and 4 Chemistry Climate Model Data sets (~25 min.)
   - By M. Fujiwara, J. Suzuki, A. Gettelman, M. I. Hegglin, H. Akiyoshi, and K. Shibata

2. Diurnal Migrating Tides in the Troposphere to Lower Mesosphere as Deduced With TIMED/SABER and 6 Reanalysis Data sets (~10 min.)
   - By T. Sakazaki, M. Fujiwara, M. Hagan, X. Zhang, and J. Forbes

- My background and research interests:
  - Balloon measurements of O_3, H_2O, etc. in the tropics
  - TTL dehydration and transport processes (SOWER & SHADOZ)
  - Upper air climate change measurements (GRUAN: GCOS Reference Upper Air Network)

Wave Activity in the Tropical Tropopause Layer in 7 Reanalysis and 4 Chemistry Climate Model Data sets

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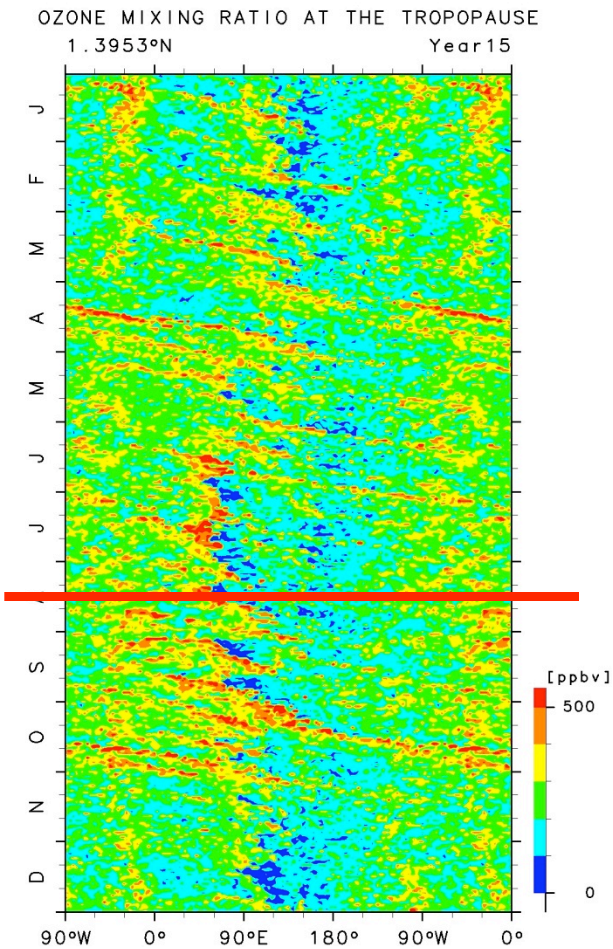
1. Introduction and Motivation

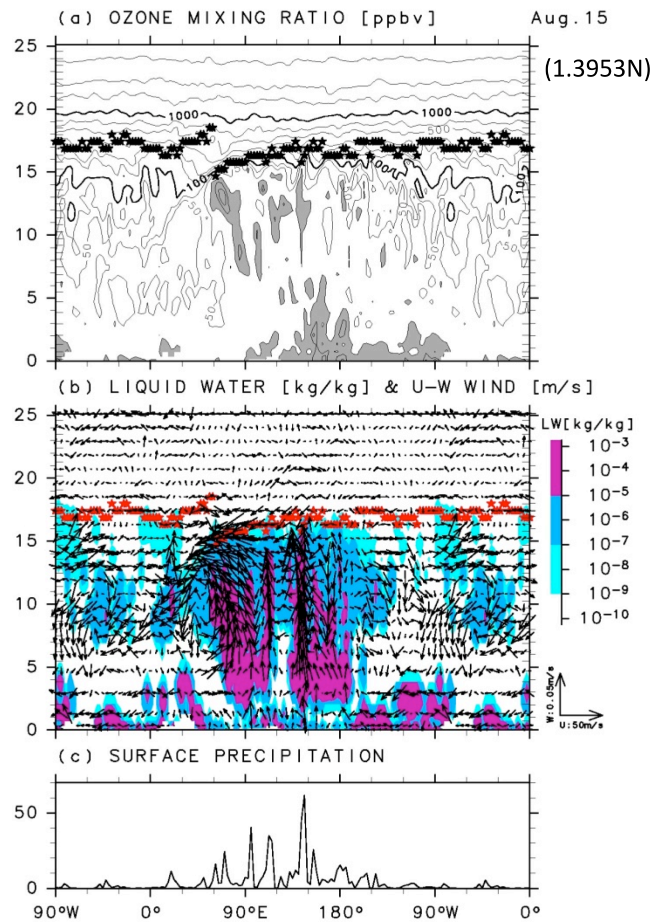
- Dehydration and transport processes in the Tropical Tropopause Layer (TTL) determine the amount of water vapor and other constituents entering the stratosphere

- Large-amplitude, breaking equatorial Kelvin waves in the TTL are known to have various roles in the TTL (as observed with balloons, radar, and lidars)
  - Large temperature changes [Tsuda et al., JGR, 1994]
  - Irreversible ozone transport [Fujiwara et al., JGR, 1998]
  - "Dehydration pump" [Fujiwara et al., GRL, 2001]
  - Turbulence generation [Fujiwara et al., GRL, 2003]
  - Cirrus variations [e.g., Boehm and Verlinde, GRL, 2000; Fujiwara et al., JGR, 2009]

  - A GCM experiment [Fujiwara and Takahashi, JGR, 2001]

Kelvin waves in the TTL in a GCM





- Eastward-moving large-scale disturbances are dominant at the equatorial tropopause
- Most of them are breaking Kelvin waves (based on T & U data analysis)

- In the eastern hemisphere, these waves are often associated with organized convection (ISO, etc.)

- At downward displ. phases, ozone-rich, dry air is transported into TTL
- At upward displ. phases, cold anomalies produce cirrus and prevent TTL from excess water

→ **"Dehydration Pump"**
[Fujiwara et al., GRL, 2001]

CCSRNIES AGCM T42<u>L60</u> (dz~550 m in UT/LS)
+ simplified stratospheric ozone chemistry
[Fujiwara and Takahashi, JGR, 2001]

1. Introduction and Motivation

- Significant sub-seasonal variability is found in temperature, horizontal winds, and other parameters in the TTL. This is due to various types of equatorial waves, and intraseasonal oscillations (ISOs) that are primarily generated by tropical organized convection
- These disturbances largely determine the water vapor amount entering the stratosphere and control the troposphere-stratosphere exchange processes

- Chemistry Climate Models (CCMs) that are used for ozone layer projections need to be validated from the viewpoint of TTL wave activity as well
- Reanalysis data sets (RAs) can be used for the validation of the CCMs
- There is, however, some evidence that different RAs exhibit significantly different tropical tropopause temperature values on various time scales [e.g., Fujiwara et al., 2009; 2010]. Therefore, the comparisons of different RAs are also of great interest

- The activity (variance) of equatorial Kelvin waves, mixed Rossby-gravity (MRG) waves, and ISOs in the TTL is investigated for 7 RAs (NCEP1, NCEP2, ERA40, ERA-Interim, JRA25, MERRA, and CFSR) and 4 CCMs (CCSRNIES, CMAM, MRI, and WACCM)
- The zonal wavenumber-frequency spectral analysis method with equatorially symmetric-antisymmetric decomposition is used

2. Data Description

Table 1. Information on the Space-Time Resolution

Data Set	Model Resolution[a]	Model Top	Model dz in the TTL[b]	Output Grid[c]
Reanalysis				
NCEP1	T62, L28	3 hPa	~1.8 km	2.5°×2.5°, L17, 6 hr
NCEP2	T62, L28	3 hPa	~1.8 km	2.5°×2.5°, L17, 6 hr
ERA40	TL159, L60	0.1 hPa	~1.1 km	2.5°×2.5°, L23, 6 hr
ERA-Interim	TL255, L60	0.1 hPa	~1.1 km	1.5°×1.5°, L37, 6 hr
JRA25	T106, L40	0.4 hPa	~1.3 km	1.25°×1.25°, L23, 6 hr
MERRA	(2/3)° × 0.5°, L72	0.01 hPa	~1.1 km	(2/3)°×0.5°, L42, 6 hr
CFSR	T382, L64	~0.266 hPa	~0.88 km	0.5°×0.5°, L37, 6 hr
Chemistry Climate Models				
CCSRNIES	T42, L34	~0.012 hPa	~1.2 km	~2.8°×~2.8°, L31, 1 dy
CMAM	T31, L71	8.1×10^{-4} hPa	~1.2 km	~5.6°×~5.6°, L63, 6 hr
MRI	T42, L68	0.02 hPa	~0.79 km	~2.8°×~2.8°, L24, 1 dy
WACCM	144×96 grids, L66	4.5×10^{-6} hPa	~1.1 km	2.5°×~1.895°, L66, 6 hr

NOAA OLR data for Outgoing Longwave Radiation (2.5°x2.5°, 1dy)

- Analysis Period: 1990-2000 (~10 years) (Note: No GPS RO data available)
- CCM experiment: The REF-B1 scenario (observed changes in SST, ozone depleting substances, and greenhouse gases)
- Output data analyzed: daily daily-averages for CCSRNIES and MRI, and four-times-daily instantaneous for all the other data sets

3. Some Basic Comparisons – Tropopause Temperature

Temperature at 100 hPa within 10° lat. (monthly & zonal mean)

Anomalies

Climatology

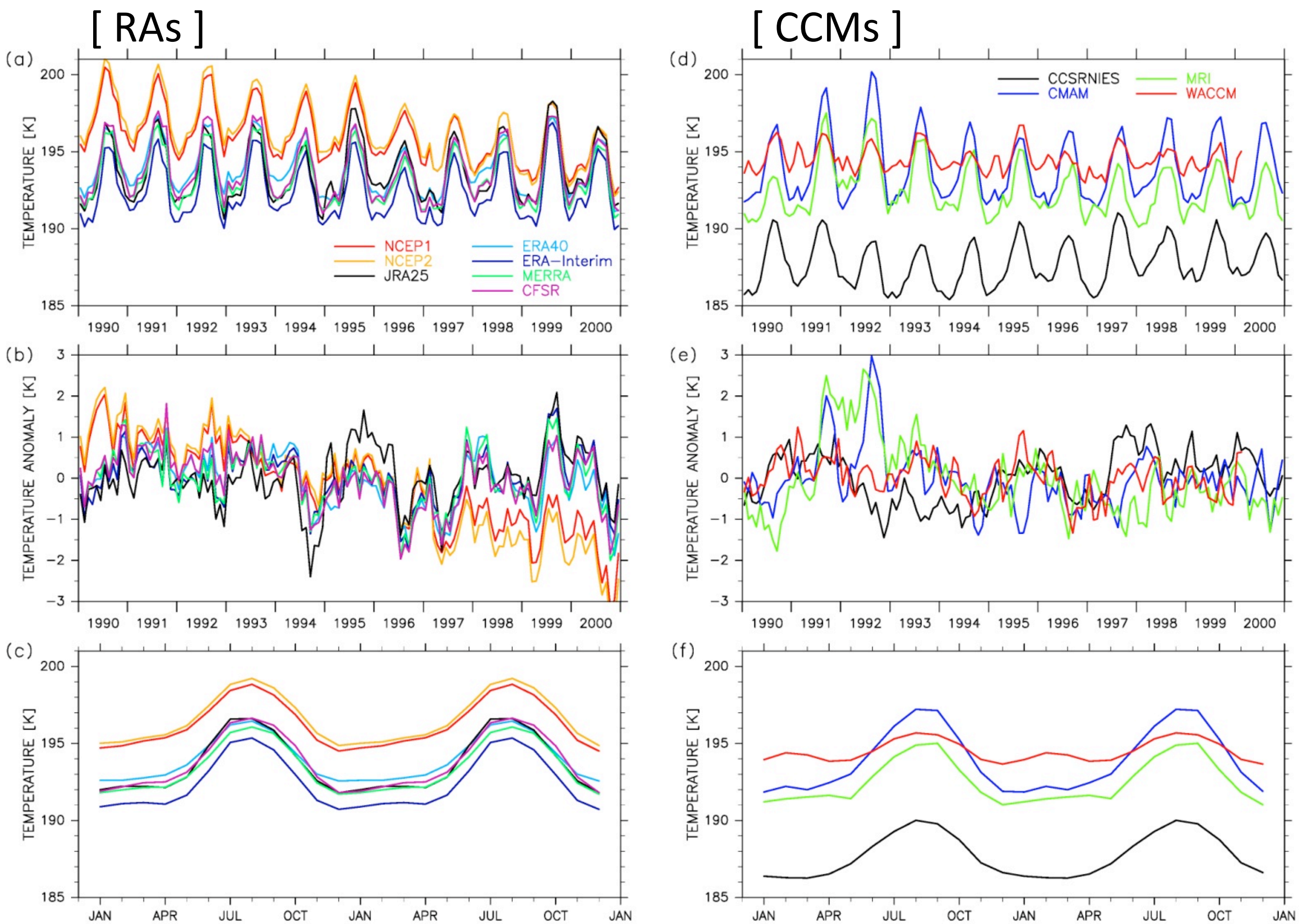


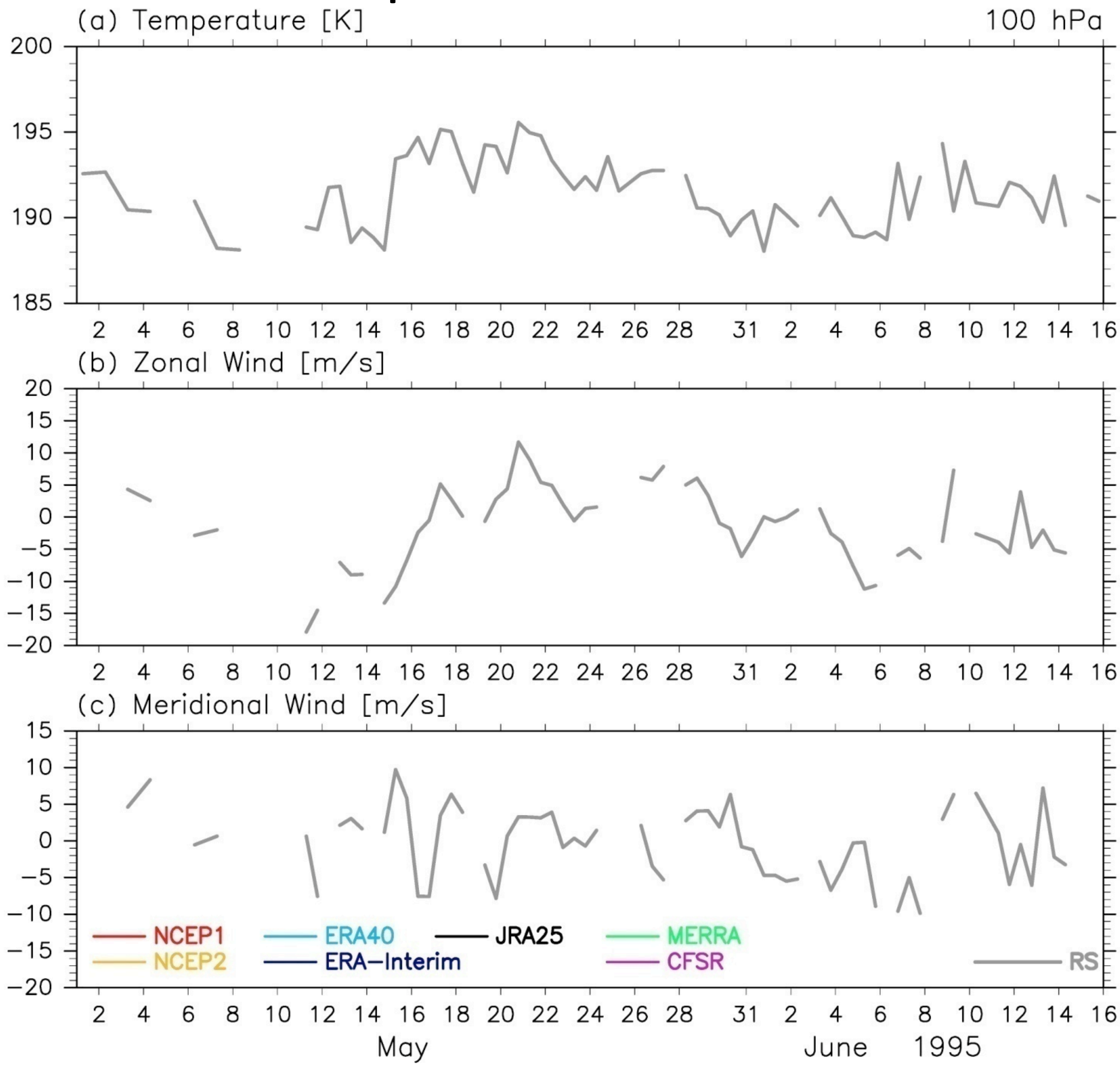
Figure 1. Time series of (a, d) monthly and zonal mean temperature at 100 hPa within ±10° latitudes, (b, e) temperature anomaly with respect to the 1990–1999 climatology, and (c, f) the 1990–1999 climatology (repeated twice), from 7 RAs (a–c) and from 4 CCMs (d–f).

NCEP1,2: warm bias & negative trends
ERA40 vs. ERA-Interim: 1 K difference
(→ ~1 ppmv saturation wv mr)
WACCM: too small annual amplitude
CCSRNIES: large cold bias

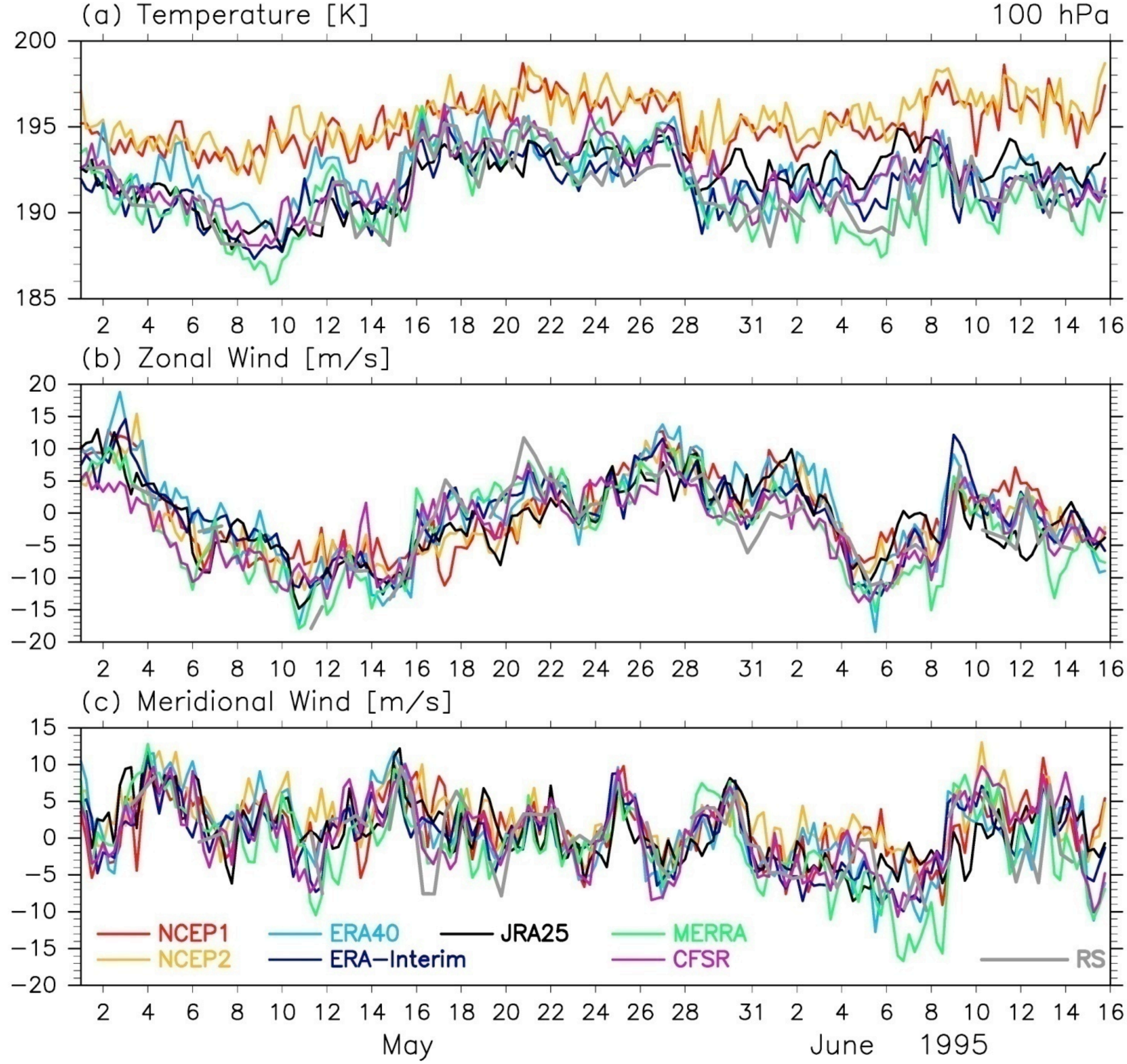
3. Some Basic Comparisons – A Kelvin wave case

Radiosondes in Indonesia during May-June 1995 [Fujiwara et al., JGR, 1998]

… not transmitted over the GTS



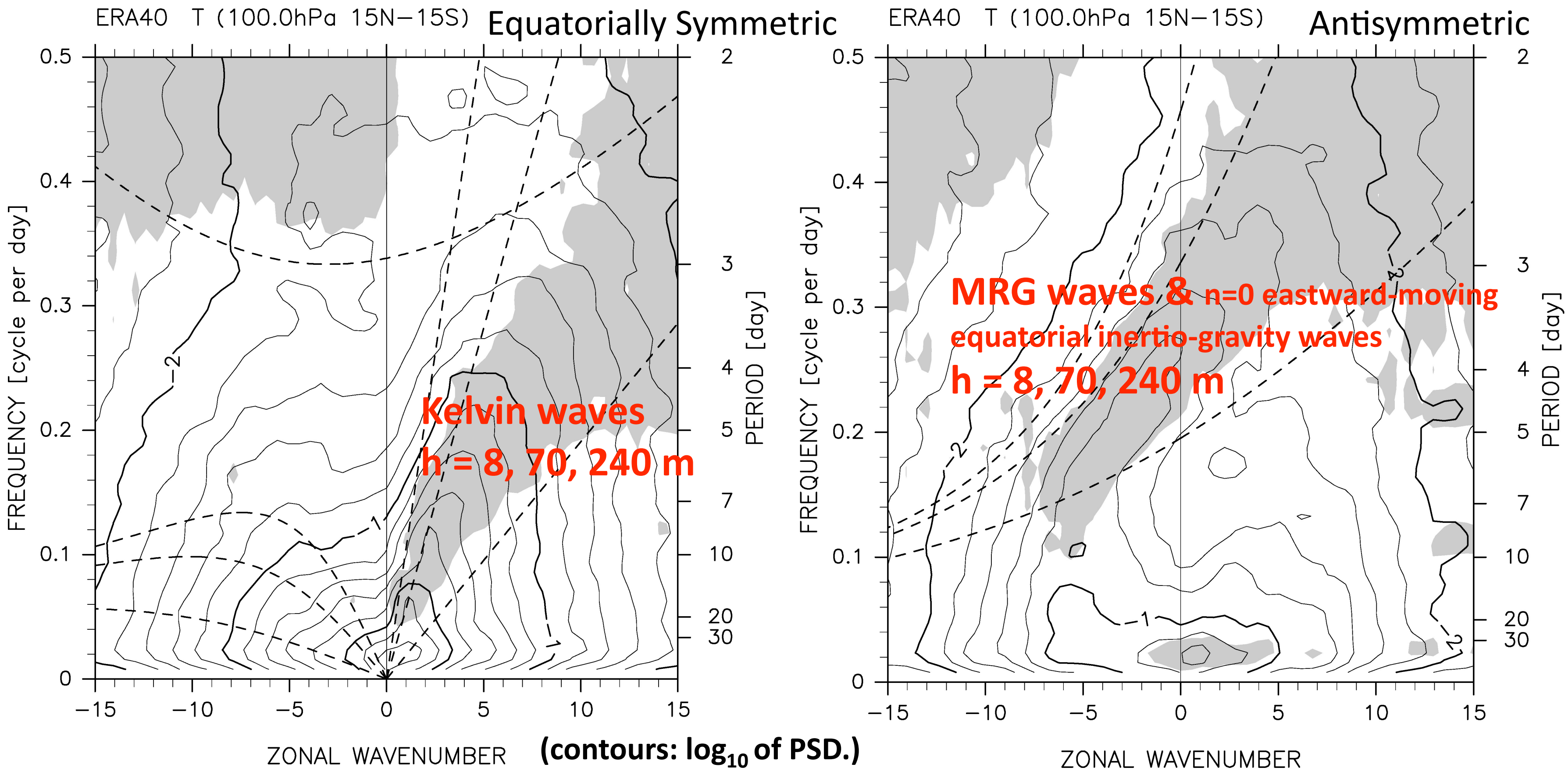
3. Some Basic Comparisons – A Kelvin wave case



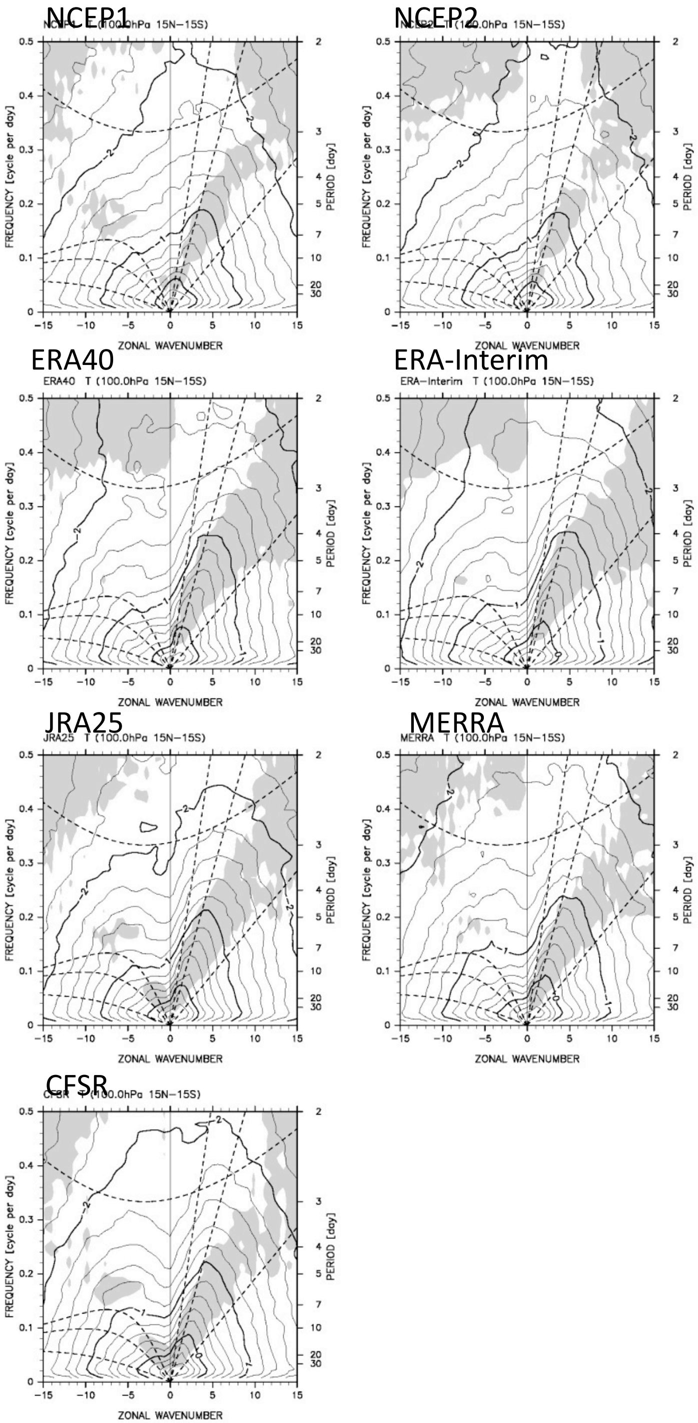
For this particular case, the Kelvin wave temperature amplitude is smaller for NCEP1 and NCEP2 (apart from their warm bias) and somewhat larger for MERRA.

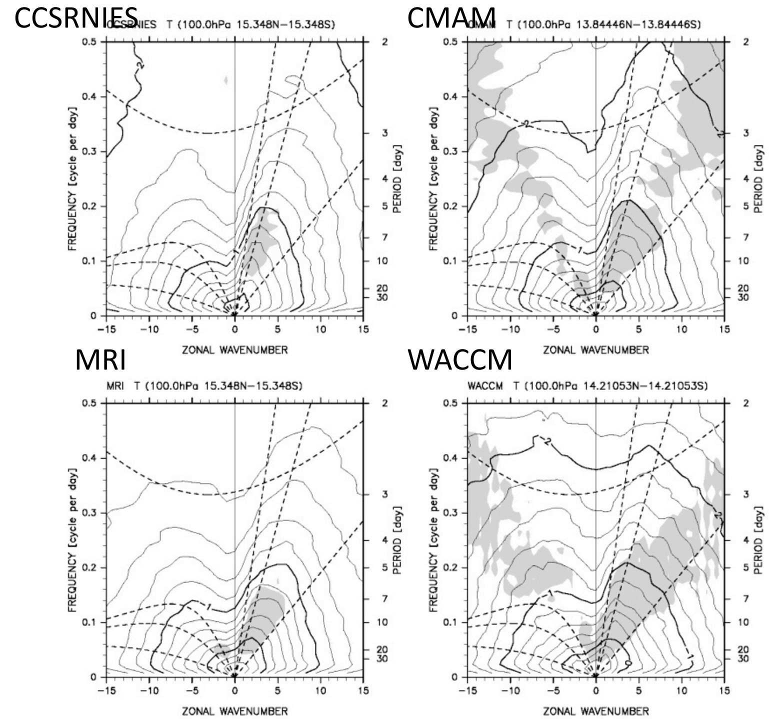
Also, MERRA shows larger amplitudes for shorter-period disturbances.

4. Space-Time Spectral Analysis



- Data within ~15° lat. are decomposed into the equatorially symmetric and antisymmetric components
- Spectral calculations are performed for 92-day segments (2-month overlapping) between Jan. 1990 and Feb. 2000
- Normalized so that the integration in the whole domain equals to the variance of the original time series, and plotted
- Background red-noise spectrum is estimated by the method by **Gilman et al. (1963)** (based on the coefficient of the first-order auto-regressive process, i.e., the lag-one autocorrelation); and the regions with the S/N ratio >1.5 are colored gray
  (Note: the famous method by Wheeler and Kiladis (1999), "1-2-1 filer operated many times", is not good for this study)





Equatorially Symmetric Component

(1) Equatorial Kelvin waves

Among RAs, the gray regions are somewhat smaller in NCEP1 and NCEP2 (the "ridge" is with gentler slopes)

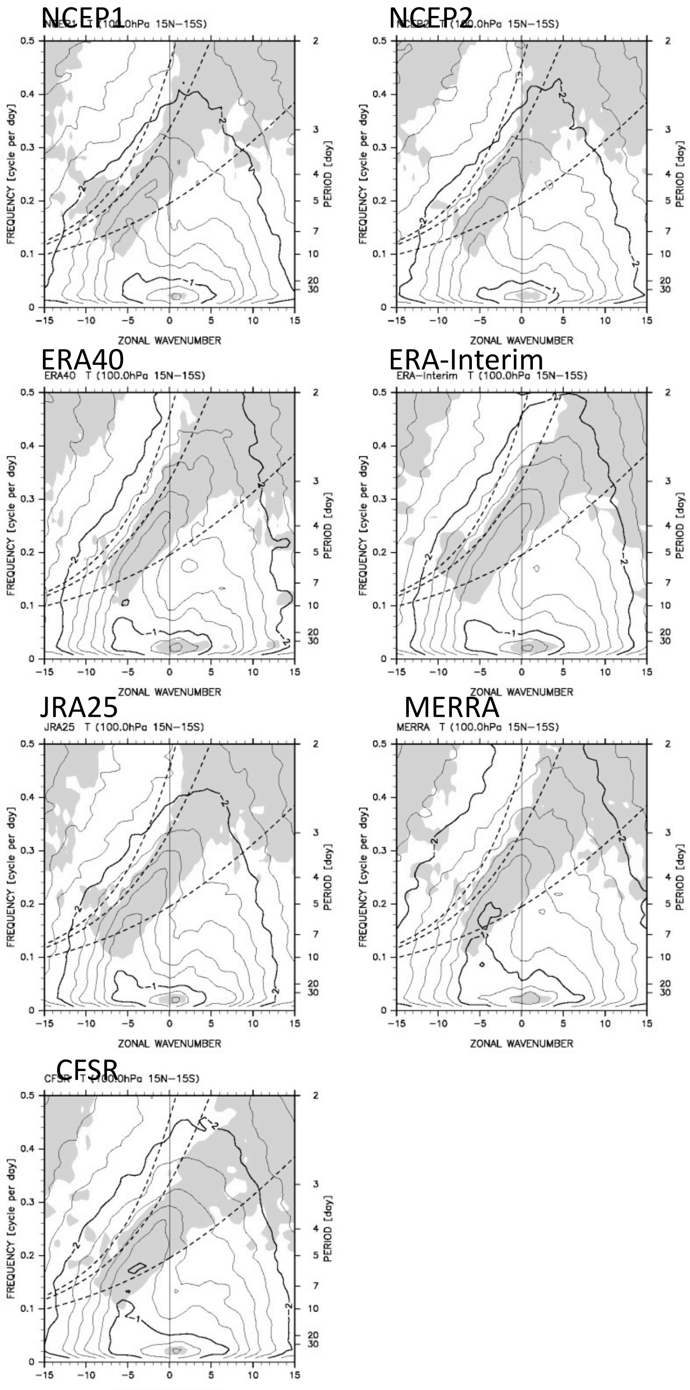
The gray regions are smallest in CCSRNIES and MRI, although the contour distributions are not so different

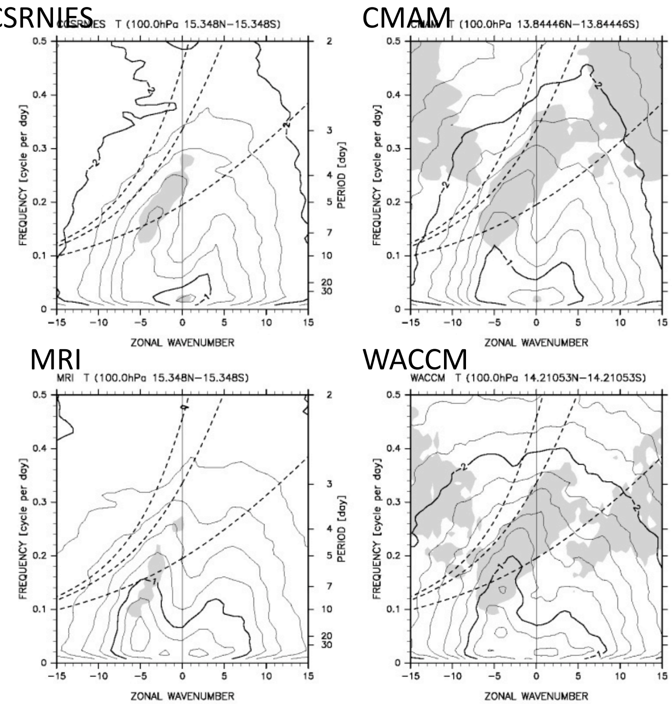
→ due to the difference in the output temporal resolution, (i.e., daily), which results in significantly different estimated background red-noise spectrum.

(2) Symmetric eastward-moving ISOs

Not evaluated as significant for all the data sets

→ due to problems in the evaluation method used (cf. Hendon and Wheeler, 2008)





Equatorially Antisymmetric Component

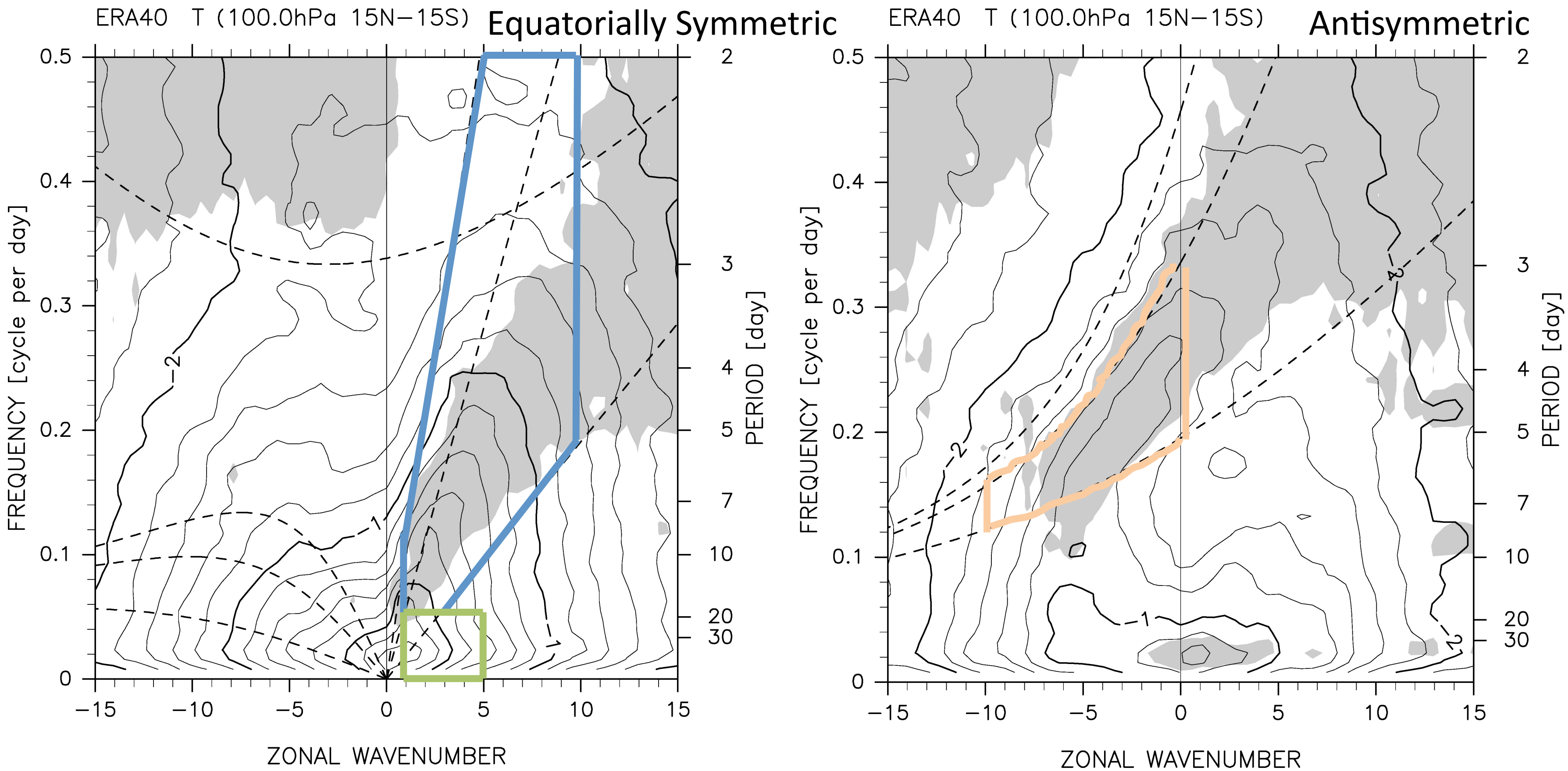
(1) Mixed Rossby-gravity (MRG) waves

As for the Kelvin waves, the gray regions are smallest in CCSRNIES and MRI, although the contour distributions are not so different

→ for the same reason, i.e., difference in the output temporal resolution, which results in significantly different estimated background red-noise spectrum.

→ Need a special treatment for the statistical significance consideration when calculating the wave activity

5. Wave Activity Definition and Comparison



The activity is defined as the variance, i.e., the power spectral density integrated in a particular zwn-frq region

- Kelvin waves: zwn=1 to 10, frq=0.05 to 0.5, and h=8 to 240 (with or without stat. sig. consideration)
- MRG waves : zwn=-10 to 0, h=8 to 70 (with or without stat. sig. consideration)
- Symmetric Eastward-moving ISOs: zwn=1 to 5, frq=0 to 0.05 (no stat. sig. consideration; cf. Hendon and Wheeler, 2008)

→ For Kelvin & MRG waves (as well as ISOs), the activity *without* the stat. sig. considr. will be primarily shown and discussed

(Color: T U V OLR)

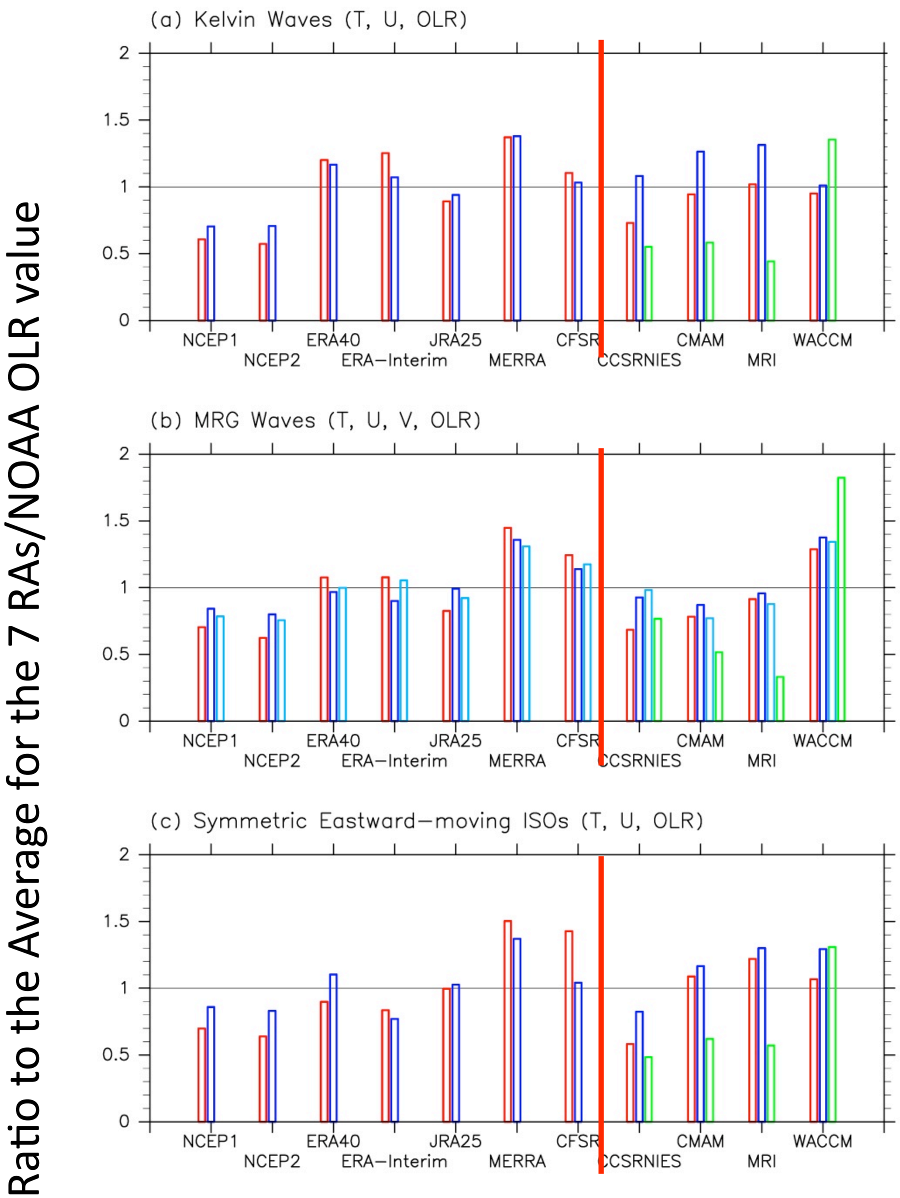


Table 4. Wave Activities[a] Averaged for the 7 RAs and From the NOAAOLR

Parameter	Unit	Kelvin waves	MRG waves	ISO
Temperature (100 hPa)	K^2	0.31	0.039	0.26
Zonal wind (100 hPa)	$(m\ s^{-1})^2$	4.5	0.60	5.4
Meridional wind (100 hPa)	$(m\ s^{-1})^2$	–	1.3	–
OLR (NOAA)	$(W\ m^{-2})^2$	60	16	44

[a] Without the statistical significance consideration.

(→ Kelvin wave and ISO variances are similar; MRG wave variances are fourth to tenth)

(1) Comparisons among the 7 RAs

For all 3 disturbances,

NCEP1&2 < JRA ~ ERAs < CFSR ~ MERRA.

10%-40% diff. in variance even among the RAs other than NCEP1&2.

NOTE: Relative relation among the 7 RAs is almost same for the results *with* the stat. sig. consider. i.e., the above results are robust.

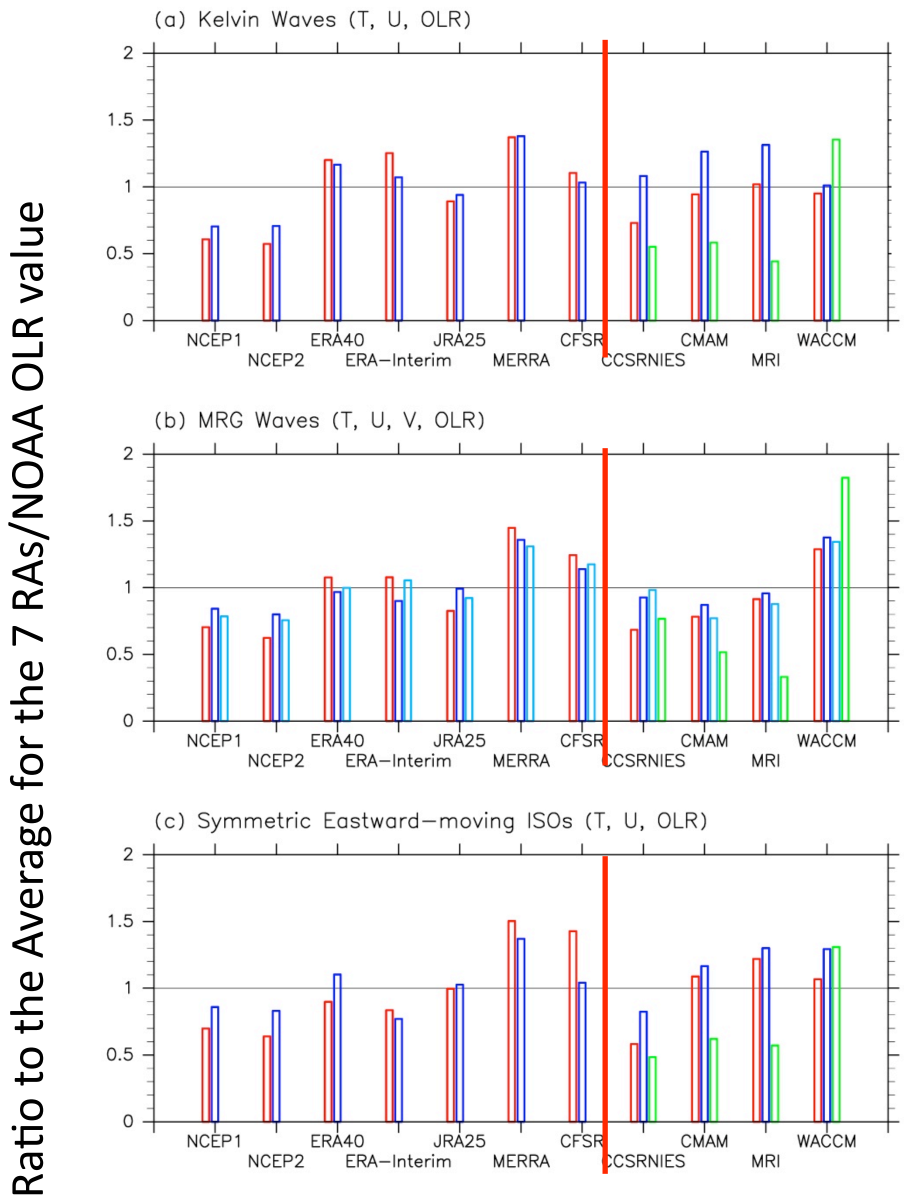
Discussion on the RA results: (please correct me if I am wrong…)

(a) Observations available in the TTL during 1990-2000
- radiosonde data
- satellite radiance-based data
- wind data from tracking of features in geostationary satellite images (for the lower TTL region)
- (GPS RO temperature data NOT available)

(b) Assimilation scheme
- ERA40 (3D-Var) vs. ERA-Interim (4D-Var)
- CFSR and MERRA (Gridded Stat. Interpolation)

(c) Forecast model
- vertical resolution in the TTL: ~2 km for NCEP1&2, and ~1 km for others → the primary cause?

(Color: T U V OLR)



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OLR (NOAA)	$(W\ m^{-2})^2$	60	16	44

[a] Without the statistical significance consideration.

(→ Kelvin wave and ISO variances are similar; MRG wave variances are fourth to tenth)

(2) Comparisons among the 4 CCMs

The results for the parameters at 100 hPa lie
generally within the range of the RAs,
with somewhat smaller in CCSRNIES and
larger in WACCM.

Different tendency for different parameters
(dynamical inconsistency for CCMs? or for RAs?).

Variance in the OLR is too small in CCSRNIES, CMAM, and MRI, and too large in WACCM
for all 3 disturbances.

– All the 4 CCMs have problems in the OLR

Discussion:

The cumulus parameterization scheme is
the Zhang-McFarlane scheme for CMAM and WACCM
the prognostic Arakawa-Schubert scheme for CCSRNIES and MRI.

→ not simply explained by the choice of the scheme

6. Summary and Concluding Remarks

- We investigated the activity of Kelvin waves, MRG waves, and symmetric eastward-moving ISOs in the TTL in 7 RAs (NCEP1, NCEP2, ERA40, ERA-Interim, JRA25, MERRA, and CFSR) and 4 CCMs (CCSRNIES, CMAM, MRI, and WACCM)

- Even the climatology of tropical 100 hPa temperature is quantitatively different in different RAs (significant for the quantitative understanding of the dehydration processes in the TTL)
- There are problems in the method of statistical significance evaluation for the space-time spectral analysis (but, no problem for the comparison of the wave activity in the RAs)

- For RAs, there is a general tendency, NCEP1&2 < JRA ~ ERAs < CFSR ~ MERRA, and we found 10%-40% difference in variance even among the RAs other than NCEP1&2.
- For CCMs, the 100 hPa results lie generally within the range of the RAs, with somewhat smaller in CCSRNIES and larger in WACCM. But, the variance in the OLR is too small in CCSRNIES, CMAM, and MRI, and too large in WACCM
- [Preliminary results in CCMVal Report, UTLS chapter; in prep. for submission to JGR]
- Further studies are necessary to "validate" the RAs by, e.g., statistically comparing with research satellite data sets and research radiosonde data sets

Diurnal migrating tides in the troposphere to lower mesosphere as deduced with TIMED/SABER and six reanalysis data sets

Takatoshi Sakazaki, Masatomo Fujiwara (Hokkaido Univ.),
Maura Hagan (NCAR/HAO),
Xiaoli Zhang, and Jeffrey Forbes (Univ. of Colorado)

SPARC-DA workshop

Introduction

• Atmospheric thermal tides are global-scale waves with periods that are harmonics of a solar day; here, the **diurnal migrating (Sun-synchronous) tides** (**D**iurnal **w**estward propagating zonal wavenumber **1** component; **DW1**) is focused.

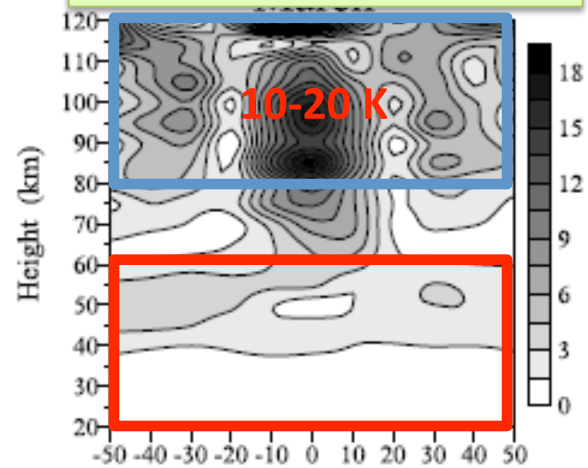
• **DW1 is mainly excited in the troposphere-stratosphere** by **radiative heating by water vapor and ozone**, and propagate upward to the mesosphere-lower thermosphere (MLT) region, where it maximizes.

• Therefore, previous studies mostly focused on the MLT region.

• **DW1 in the troposphsere-stratosphere** has been investigated only recently using satellite (e.g., GPS RO) observations (Zeng et al., 2008; Mukhtarov et al., 2009; Huang et al., 2010; Pirscher et al., 2010; Xie et al., 2010).

• **Reanalysis** data sets are potentially useful for tidal studies in the troposphere-stratosphere because they cover the whole globe at time resolutions of 6 hr or shorter.

DW1 temperature amplitudes with SABER in March



Mukhtarov et al. (2009)

Introduction

- Since 2002, **SABER** (The **S**ounding of the **A**tmosphere using **B**roadband **E**mission **R**adiometry) instrument on the **TIMED** (**T**hermosphere-**I**onosphere-**M**esosphere **E**nergetics and **D**ynamics) spacecraft have been measuring the air temperature from 20 km to 120 km.
- **SABER data is not assimilated, and independent of the reanalyses**.

The purpose of this study is to …

- show that **reanalysis data can be used for tidal studies** by comparing them with TIMED/SABER data, which are independent of reanalyses

- (then, in a separate paper)
  investigate the DW1 (vertical structure, seasonality, dynamics, etc.) in the troposphere-stratosphere using the reanalysis data

Data sets

- Period: 2002-2006 (5 years)
- Altitude: 20-65 km

1. TIMED/SABER data

- Ver. 1.07 kinematic temperature data (Remsberg et al., 2008) in 2002—2006 are used.
- **The region from 52°S to 52°N at 20-120 km** is continuously observed.
  # The latitude coverage on a given day is **(83°N to 52°S)** or **(52°N to 83°S)** according to the yaw mode of the spacecraft, which changes every 60 days.
- The local time of measurements changes 12 min from day to day; **60 days are required to cover a diurnal local time cycle**.
- Data binned in (lat., alt.) = (5°, 2 km) for each ascending/decending orbit is used.

2. Reanalysis data (six different reanalyses are analyzed)

(name)	Time Resolution	Horizontal resolution	Vertical Levels	Top level
NCEP1	3 hr	2.5 degs	17	10 hPa (30 km)
NCEP2	6 hr	2.5 degs	17	10 hPa (30 km)
ERA-Interim	6 hr	1.5 degs	37	1 hPa (50 km)
JRA25	6 hr	1.25 degs	23	0.4 hPa (55 km)
MERRA	3 hr	1.25 degs	42	0.1 hPa (65 km)
CFSR	6 hr	0.5 degs	37	1 hPa (50 km)

NOTE: ERA40 (-2002) is not analyzed

Sampling of reanalysis data at SABER grids

- **We prepare the reanalysis data that are sampled when and where SABER measurements are performed.**

✓**Horizontally**, **reanalysis data at the closest grid points to SABER measurements** are used.

✓**Vertically**, **reanalysis data are interpolated to SABER measurement altitude levels** (with a resoluties are converted to geometric altitude levels by using geopotential height data at 12 UTC (Note that SABER altitudes are calculated using geopotential on of 2 km) by using the cubic spline method.
- Pressure levels in reanalysheight at 12 UTC) (Mahoney, 2008).

$$z(H,\theta) = \left(1 + 2.373 \cdot 10^{-3} \cdot \cos(2\theta)\right) H + \left(1 + 8.6476 \cdot 10^{-3} \cdot \cos(2\theta)\right) \frac{H^2}{6356.6818}$$

z: geometric altitude (km), H: geopotential height (km), θ: latitude (rad)

✓**Temporally**, **reanalysis data are interpolated to SABER measurement time** by using the cubic spline method.

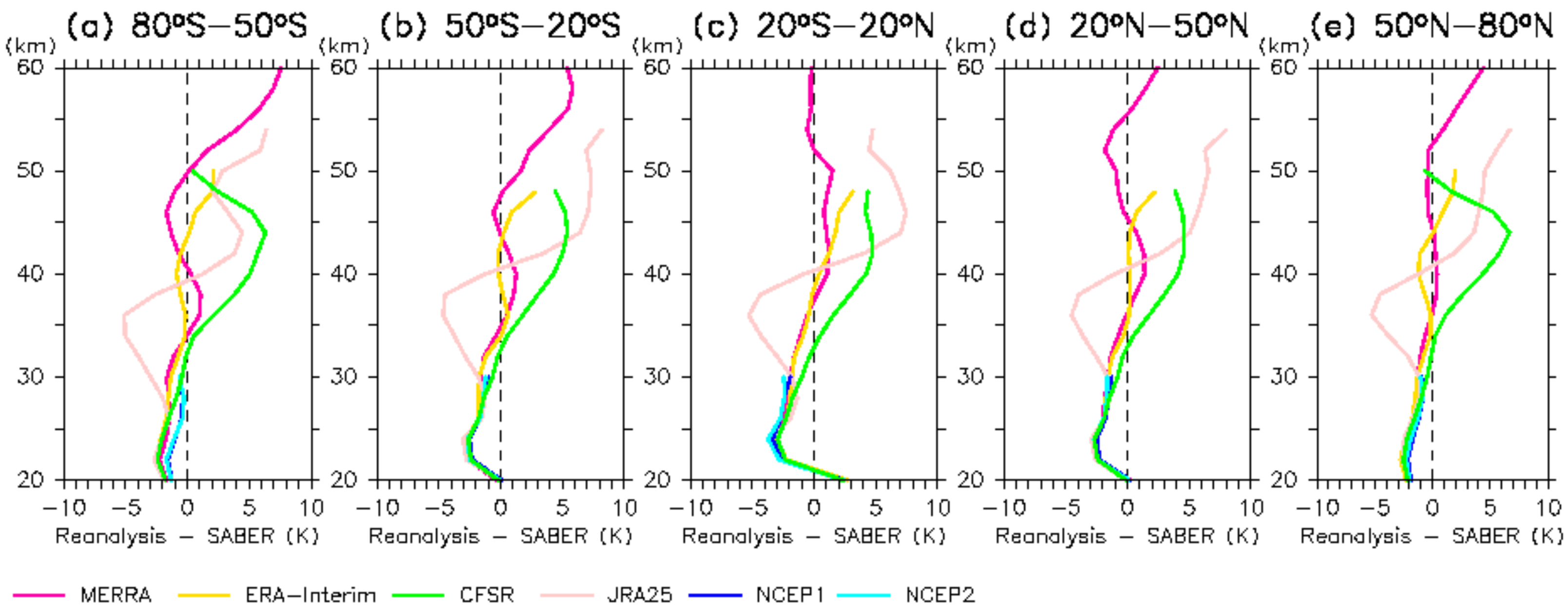
Note that.. **the results do not depend on sampling intervals in reanalyses**.
For MERRA, the difference of the results between 3-hourly sampled data and 6-hourly sampled data was found to be negligible (amp.: <10%, phase: <1 hr) (not shown).

Comparison

1. Daily-means
2. Diurnal migrating component (DW1)

1. Comparison of Daily-means

- **Mean-difference:** $\frac{1}{n}\sum_{n}(T_{\mathrm{Re}\,analysis} - T_{SABER})$ for 2002-2006



- **Bias in SABER** estimated by the comparison with MetO, lidars, ACE, MIPAS, MLS and HALOE (Remsberg et al., 2008):
  - too **high** by 1-3 K **in the lower stratosphere**
  - too **low** by 1-3 K **from the upper stratosphere to lower mesosphere**

- At 20-30 km, all reanalyses show mean diff. of ~-2 K, which is due to the positive bias in SABER.
- **MERRA-SABER** mean diff. is within ~+/-3 K (within the bias of SABER) below 50 km, and +5 to +10 K in mid-high latitudes above 50 km.
- **ERA-Interim-SABER** mean diff. is within ~+/-3 K (within the bias of SABER) below 50 km.
- **CFSR-SABER** mean diff. is within ~+/-2 K below ~35 km, and ~+5 K above 40 km.
- **JRA-25-SABER** mean diff. is ~-5 K at 30-40 km and ~+5 K at 40-50 km.
- The mean diff. in the stratosphere becomes large in the winter hemisphere (not shown).

2. Comparison of DW1 component

Methods for extracting the DW1

1. In time, diurnal harmonic component is extracted.

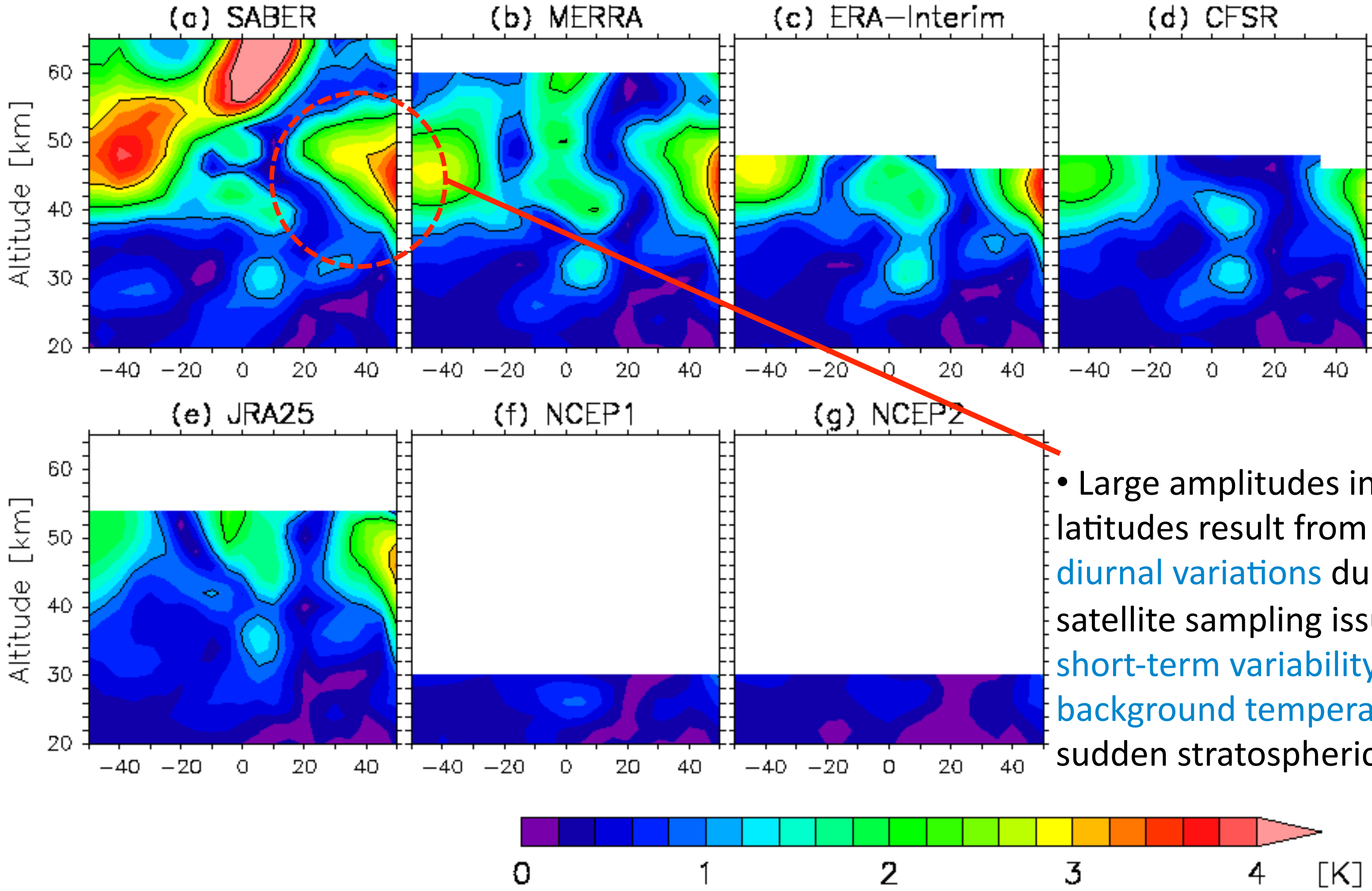
• "Simple local-time composite" suffer from sampling issues (aliasing) due to changes in the background (not diurnal) temperature [Forbes et al., 1997].
• The method proposed by Forbes [2008] (subtracting 60-d mean) is used.

1. Bins with (24°, 15°, 2 km) are prepared.
2. **60-day running mean** is calculated for each day and for each bin.
3. A time series of **residual temperature** is obtained **by subtracting 60-d mean from raw temperature** for each day and for each bin.
4. **Local time composite** is performed **using the residuals**.
5. The diurnal harmonic component is extracted with least-square fitting.

2. In longitude, DW1 is extracted using the Fourier transform.

Amplitude of DW1 in January

- **Latitude-altitude distributions of DW1 temperature amplitude**

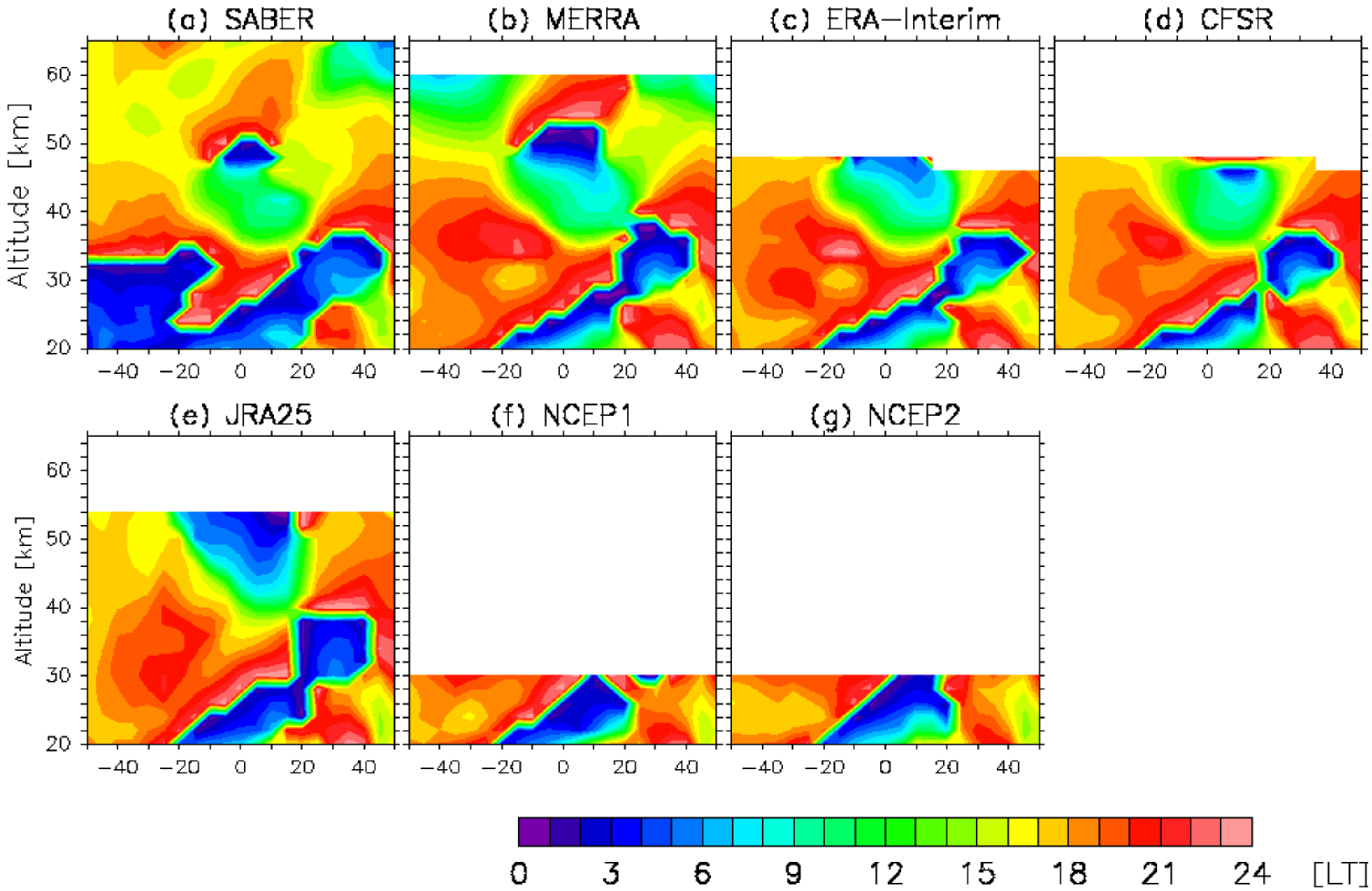


- Large amplitudes in high-latitudes result from "spurious" diurnal variations due to satellite sampling issues, i.e., short-term variability of the background temperature (e.g., sudden stratospheric warming).

- **The distributions of maxima/minima are consistent between SABER and reanalyses**.
- A notable difference is in amplitudes **above ~40 km, where the amplitudes in reanalyses are 30-50% smaller than those in SABER**.

Phase of DW1 in January

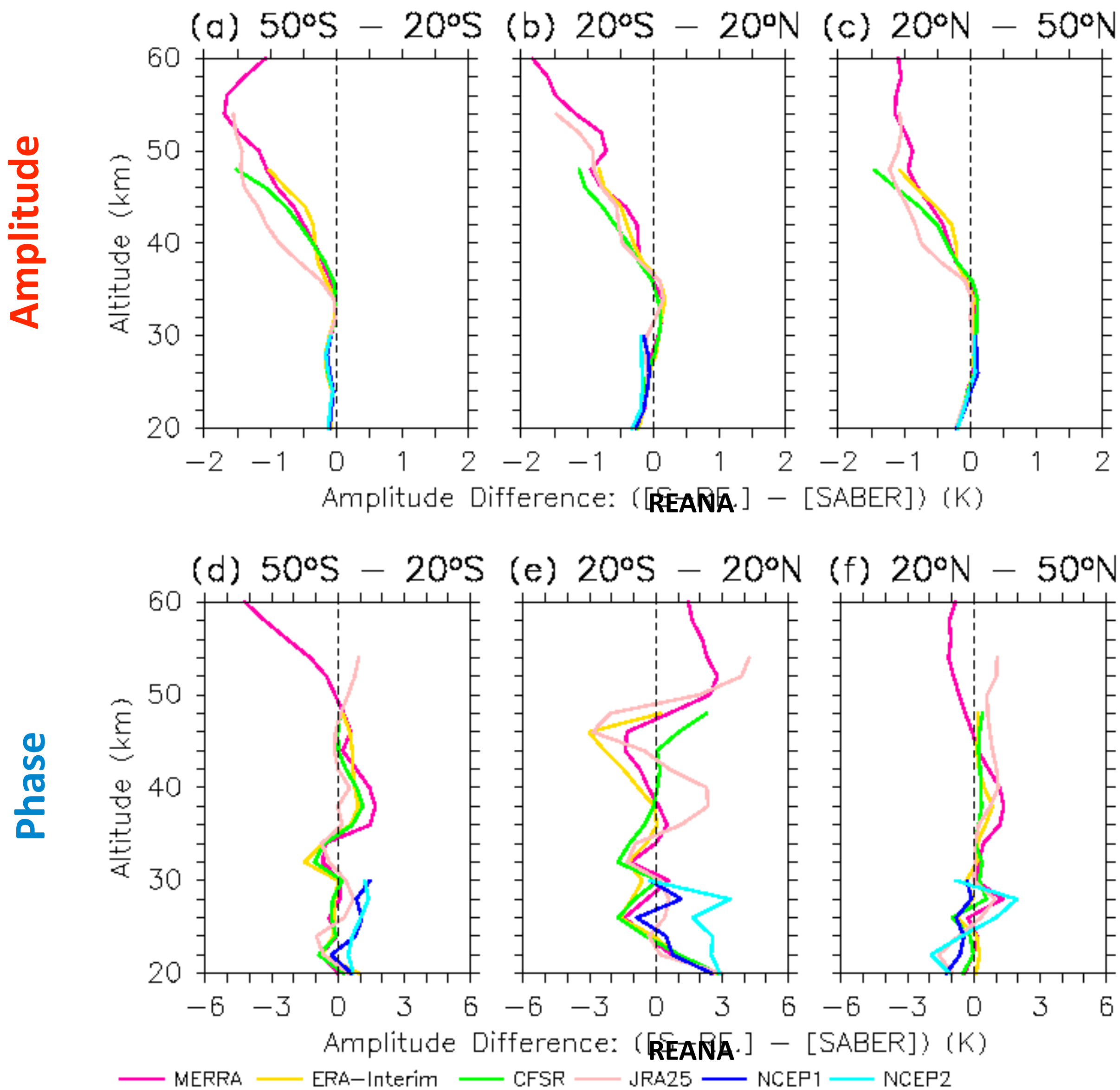
- **Latitude—altitude distributions of DW1 temperature phase**



- Tropics: Propagating Hough mode;   Extratropics: Trapped Hough mode
- The phase distributions are consistent between SABER and reanalyses.

Annual-mean difference in DW1 between "SABER" and "Reanalysis"

- **Annual mean of difference (Reanalysis - SABER)**



- All reanalyses show quite similar tendency
- The difference between SABER and reanalyses is large in the middle-upper stratosphere.
  - -**Amplitude**:
    - <20% below ~40km
    - 30-50% at 50-60 km.
  - -**Phase**:
    - <2 hr for almost all levels
- The seasonal variation is small (not shown).

Summary and Conclusions

1. Daily-mean comparisons between SABER and RAs

- Below 30 km, the difference from SABER is <2 K, which is caused by the bias in SABER.
- Above 30 km,
    - **MERRA, ERA-Interim**: the difference from SABER is within +/-3 K (within the bias of SABER) at 30-50 km, and +5 to +10 K in mid-high latitudes above 50 km for MERRA.
    - **CFSR**: There is ~+5 K difference wrt. SABER above 40 km.
    - **JRA25**: There is ~-5 K difference at 30-40 km and ~+5 K difference above 40 km.

2. DW1 comparisons between SABER and RAs

- **DW1 in SABER are reproduced by all reanalyses reasonably well at least qualitatively.**
- The only notable difference is that **the amplitudes in and above the upper stratosphere are (up to 50%) smaller in reanalyses than in SABER**.
- The difference might be caused by the damping effects in the upper part of the model of reanalyses ("sponge layer"), or by bias between assimilated data and model results (Pawson, 2011, personal communication).

Discussion

- How about "SPARC Reanalysis/Analysis Intercomparison Project" focusing on the middle atmosphere?
- Purpose:
  - Understand Reanalysis/Analysis products
  - Understand Reanalysis/Analysis processes/technology/science
- Data:
  - NCEP/NCAR, NCEP/DOE, NCEP-CFSR, CFSR-Lite
  - ERA40, ERA-Interim, ERA-CLIM
  - JRA25, JRA55
  - MERRA
  - NOAA Twentieth Century Reanalysis
  - Others? UKMO?
- Diagnostics:
  - Climatology
  - BD circulation: residual circulation, age of air, tropical pipe, etc.
  - Tropical circulations: QBO and SAO
  - Polar vortex (seasonal progress)
  - Waves: planetary waves, synoptic waves, equatorial waves, ISOs, etc.
  - Climate indices: AO, AAO, ENSO, etc.
  - Solar cycle
  - Events: volcanoes, unstable/stable polar vortex (e.g., 2002, 2011)
  - Other assimilation-scheme-sensitive diagnostics?

- Ask the whole SPARC community for active involvement (there should be some researchers who have already started a part of the intercomparison)
- Close collaboration with Reanalysis/Analysis centers for the interpretation, feedbacks, future technical improvements; DA WG coordinates the whole project , by connecting the SPARC data users and RA centers
- When should we start this project? (e.g., after the release of ERA-CLIM, CFSR-Lite, and JRA55?)

Discussion (older version)

- I have shown the RA intercomparisons for large-scale disturbances in the TTL and diurnal tides in the stratosphere
- Iwasaki et al. (JMSJ, 2009) made the RA intercomparison for the Brewer-Dobson circulation (for NCEP1, NCEP2, ERA40, ERA-Interim, and JRA25)
- Are there any other RA intercomparison studies? (cf. some NOAA groups)

- Is it useful and meaningful to organize a special team for a comprehensive intercomparison/validation of all existing (R)As (like the CCMVal activity for CCMs)?
- Or, does such an activity already exist in, e.g., the tropospheric (and hydrorogical) community?

- Meaningful? What should be the “reference” data sets for the “validation”? Will we be able to identify the cause of the discrepancies and improve the situation?
- What are the key diagnostics (that are, e.g., sensitive to assimilation schemes)?
- How should we define the analysis periods (e.g., 1979- for the satellite era, mid-2000s for GPS RO era, etc.) ?
- Who can become the team members? What is the bonus for the members? Very strong support is necessary from the (R)A centers
- When should we start this project? (e.g., after the release of ERA-CLIM, CFSR-Lite, and JRA55?)

Discussion (oldest version)

- I have shown the RA intercomparisons for large-scale disturbances in the TTL and diurnal tides in the stratosphere (and NH midlatitude troposphere)
- Iwasaki et al. (JMSJ, 2009) made the RA intercomparison for the Brewer-Dobson circulation (for NCEP1, NCEP2, ERA40, ERA-Interim, and JRA25)
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- Meaningful? What should be the "reference" data sets for the "validation"? Will we be able to identify the cause of the discrepancies and improve the situation?
- What are the key diagnostics?
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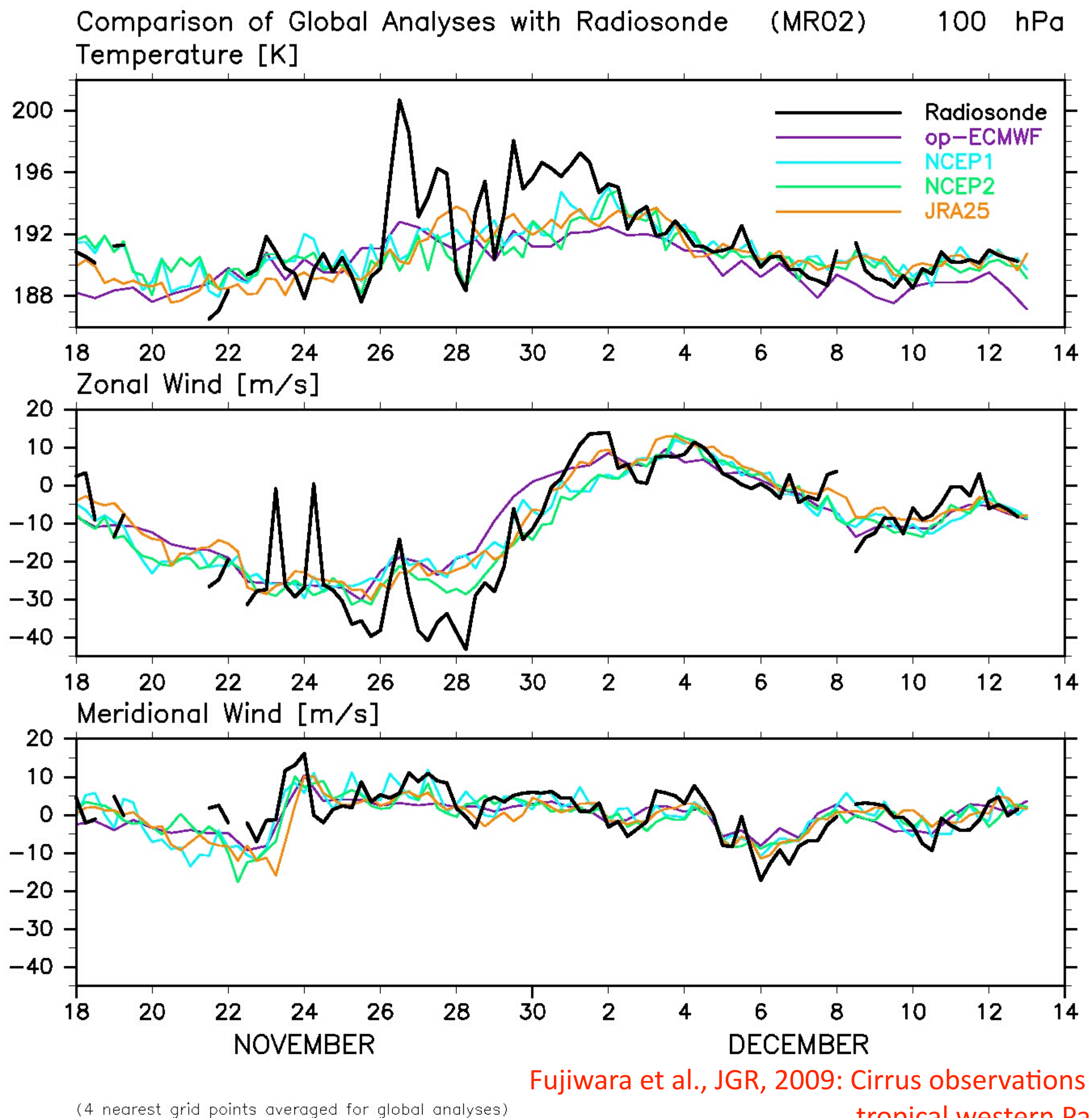
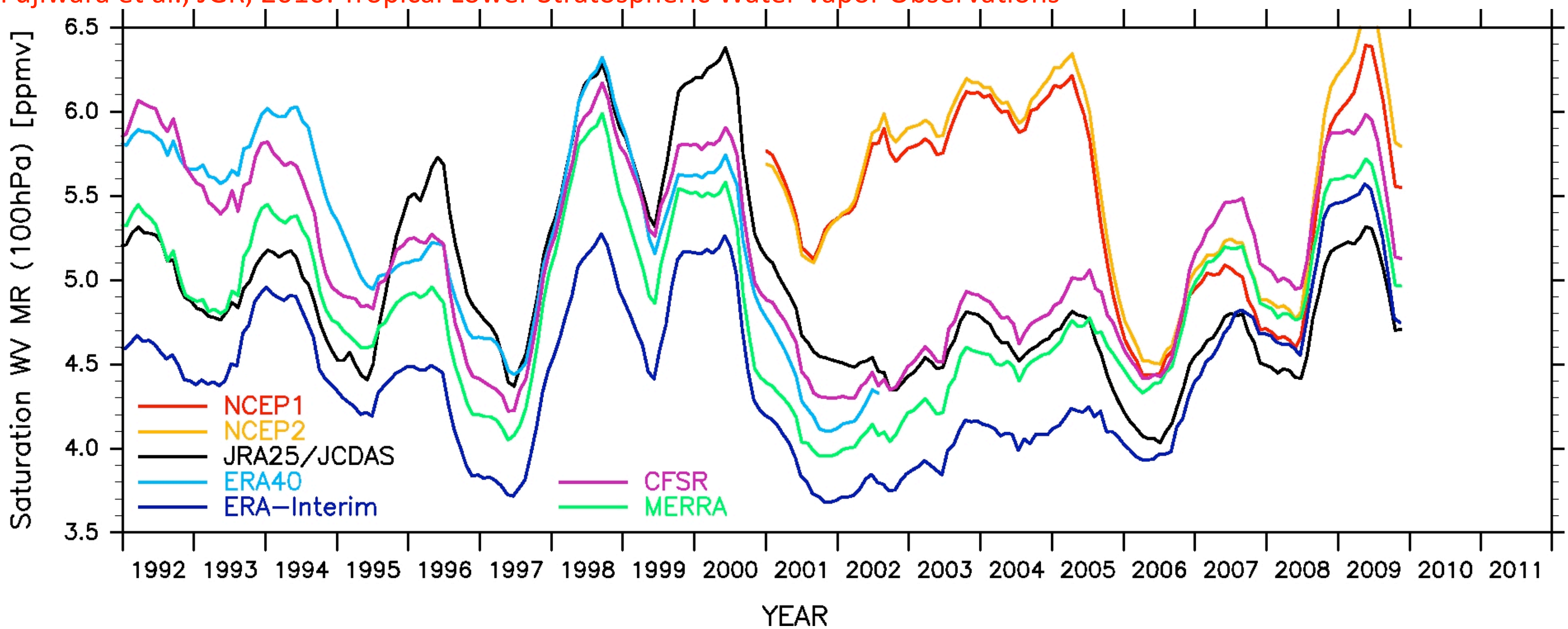
- Who can become the team members? What is the bonus for the members? Very strong support is necessary from the RA centers
- When should we start this project? (e.g., after the new JRA55 release?)



Fujiwara et al., JGR, 2009: Cirrus observations over the tropical western Pacific

Fujiwara et al., JGR, 2010: Tropical Lower Stratospheric Water Vapor Observations

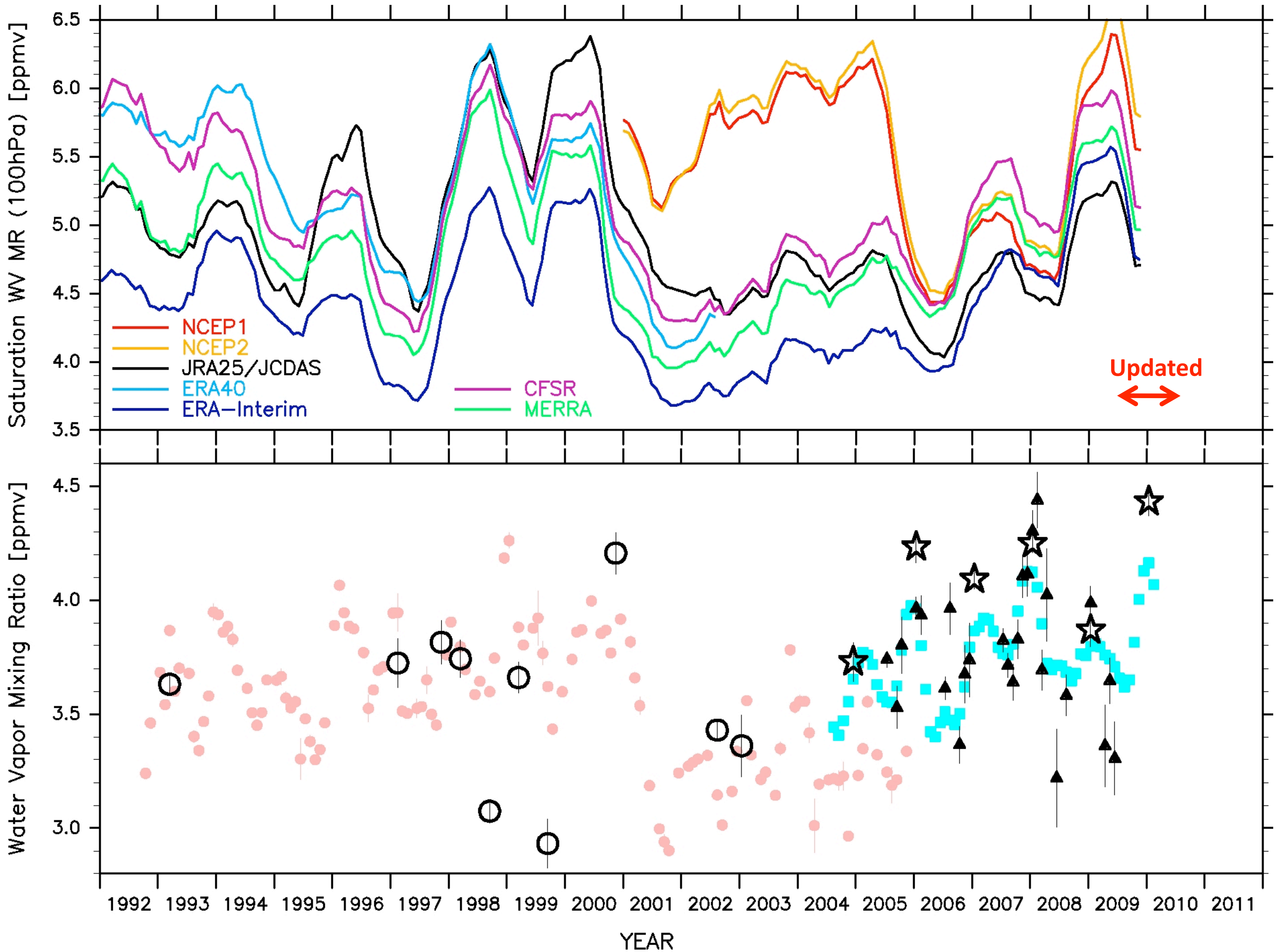


Saturation WVMR at 100 hPa in the Tropical Western Pacific [120E-150W, 10N-10S] calculated using 100 hPa temperature data from 7 re-analyses (NCEPs, JRA, ERAs, MERRA, and NCEP-CFSR) (one-year running averages taken)

NCEP1 and NCEP2 were too high particularly in the 1990s (not shown)

Similar decadal variations (qualitatively) to those in the LS water vapor

(… but … still very different quantitatively … see the range of the Y-axis)


Saturation WV MR (100hPa) [ppmv]
6.5
6.0
5.5
5.0
4.5
4.0
3.5
NCEP1
NCEP2
JRA25/JCDAS
ERA40
ERA–Interim
CFSR
MERRA
Updated
Water Vapor Mixing Ratio [ppmv]
4.5
4.0
3.5
3.0
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
YEAR

Comparisons of Brewer-Dobson Circulations Diagnosed from Reanalyses

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Abstract

A comparison is made of the stratospheric mean-meridional circulations, Brewer-Dobson (B-D) circulations, diagnosed from the reanalyses, JRA-25, ERA-40, ERA-Interim, NCEP/NCAR and NCEP/DOE. The reanalyses coincidently exhibit seasonality of B-D circulation, although considerable discrepancy among the reanalyses is found particularly in low-latitudes. Meridional overturning circulation at 100 hPa in the northern-hemisphere is maximal in winter, while that in the southern hemisphere is maximal in fall and significantly smaller than the northern hemispheric one. Interannual variability of B-D circulation in winter is coincident among the reanalyses, because they may reasonably represent wave-mean flow interactions of planetary waves which drive mean-meridional circulation. Yearly trends are not reliably observed due to large diversity among the reanalyses. Zonal mean vertical velocity becomes very noisy owing to inconsistency between the observation and global numerical weather prediction (NWP) model used in assimilation, except for JRA-25 and ERA-Interim. Further efforts are desired to improve reanalyses mainly through reduction of systematic errors of NWP model and implementation of advanced data assimilation schemes.

For improvement of reanalyses to reproduce BD circulation:

(1) Reduce climate drifts of NWP models implemented into the data assimilation assimilation system. BD circulation is sensitive to radiation schemes, including cloud radiations, and GWD scheme

(2) Refine the assimilation scheme of TOVS and ATOVS data to reduce the discontinuity of stratospheric temperature anomaly caused by instrumental change.

(3) Advanced data assimilation schemes must be introduced to enhance dynamical consistency of the meteorological parameters.

Iwasaki et al., JMSJ, 2009

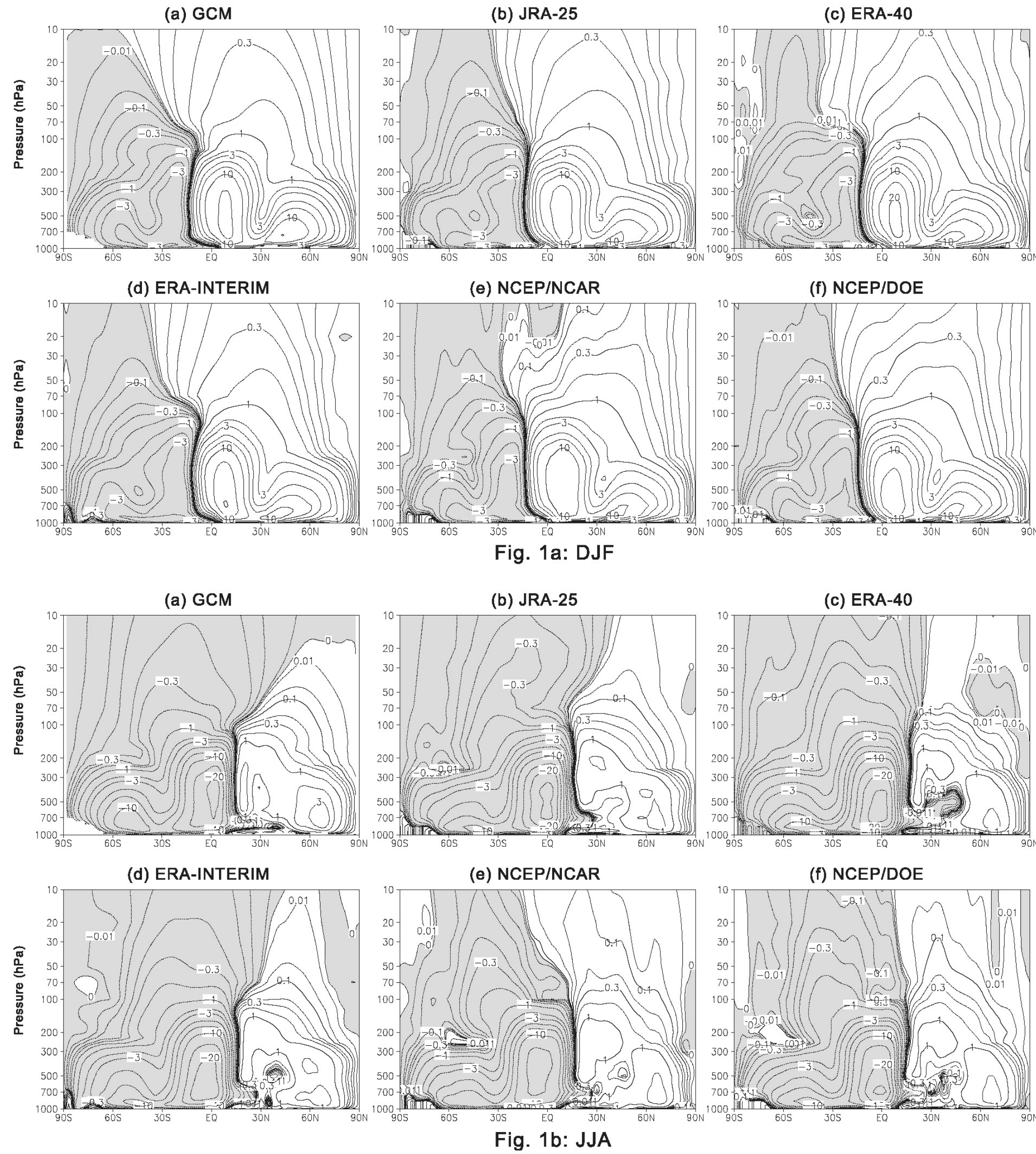
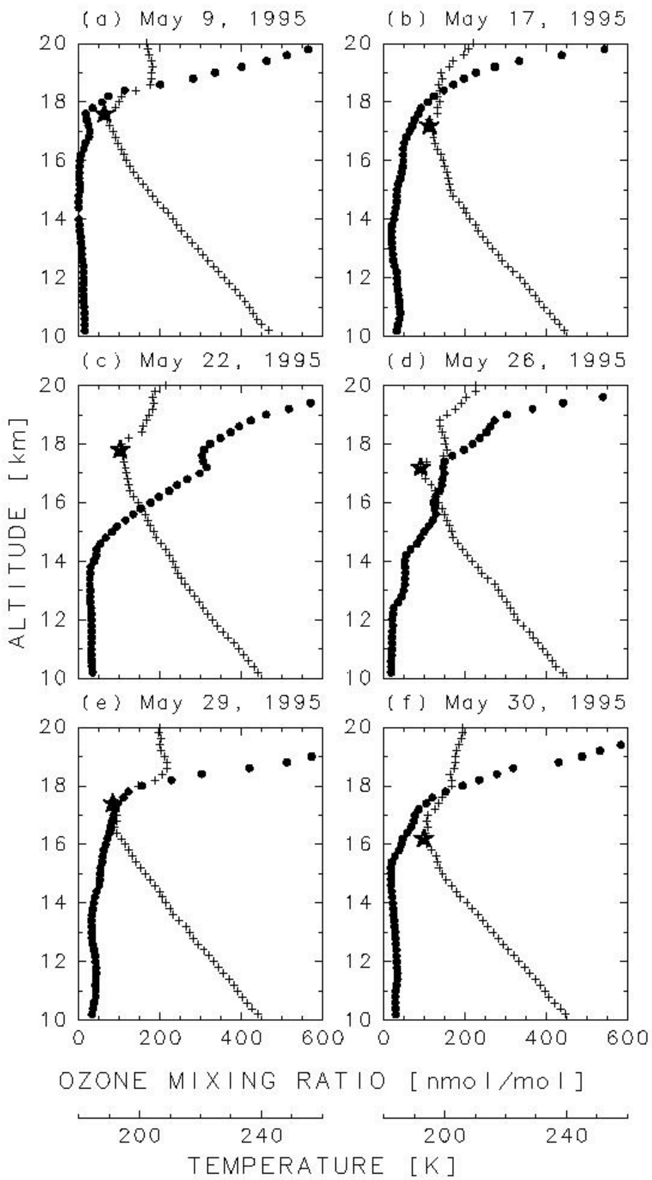
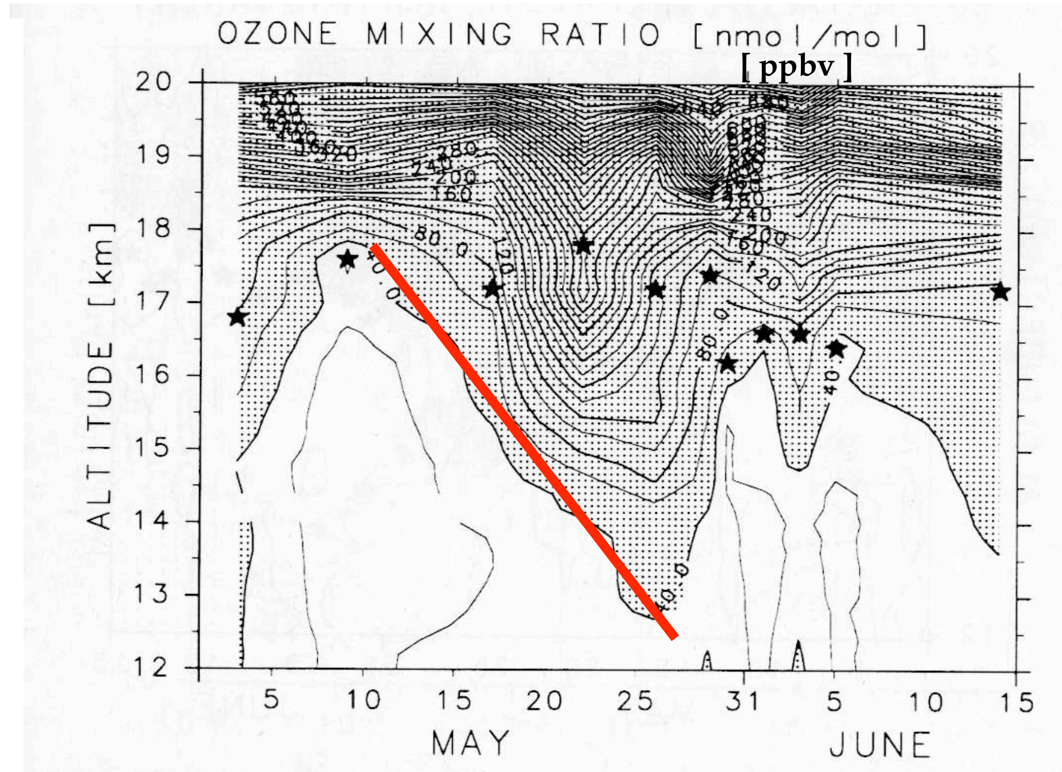


Fig. 1. Mass streamfunctions of a:GCM, b:JRA-25, c:ERA-40, d:ERA-Interim, e:NCEP/NCAR and f:NCEP/DOE averaging during December, January and February (DJF: on the top), and during June, July and August (JJA: on the bottom) 1979–2001 (exception for GCM, 1 year; ERA-Interim, 1989–2001). Contour lines are ±25, ±20, ±15, ±10, ±7, ±5, ±3, ±2, ±1, ±0.5, ±0.3, ±0.2, ±0.1, ±0.05 and ±0.01 (10^{10} kg s^{-1}). Negative values are shaded.

Ozonesondes in Indonesia

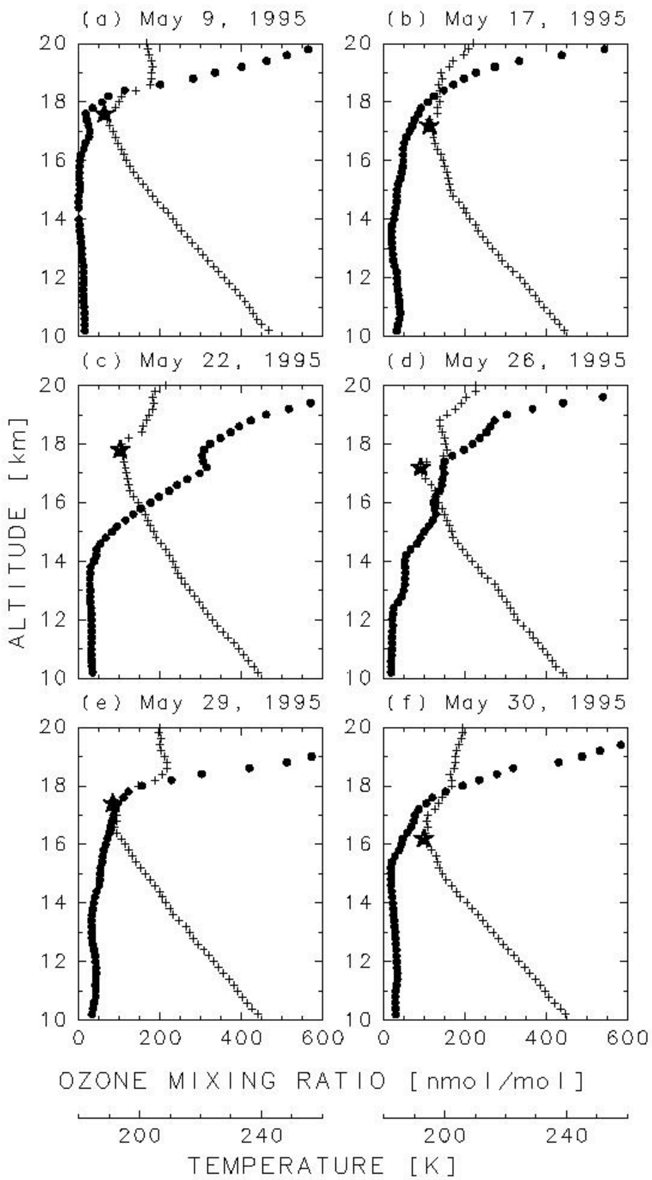


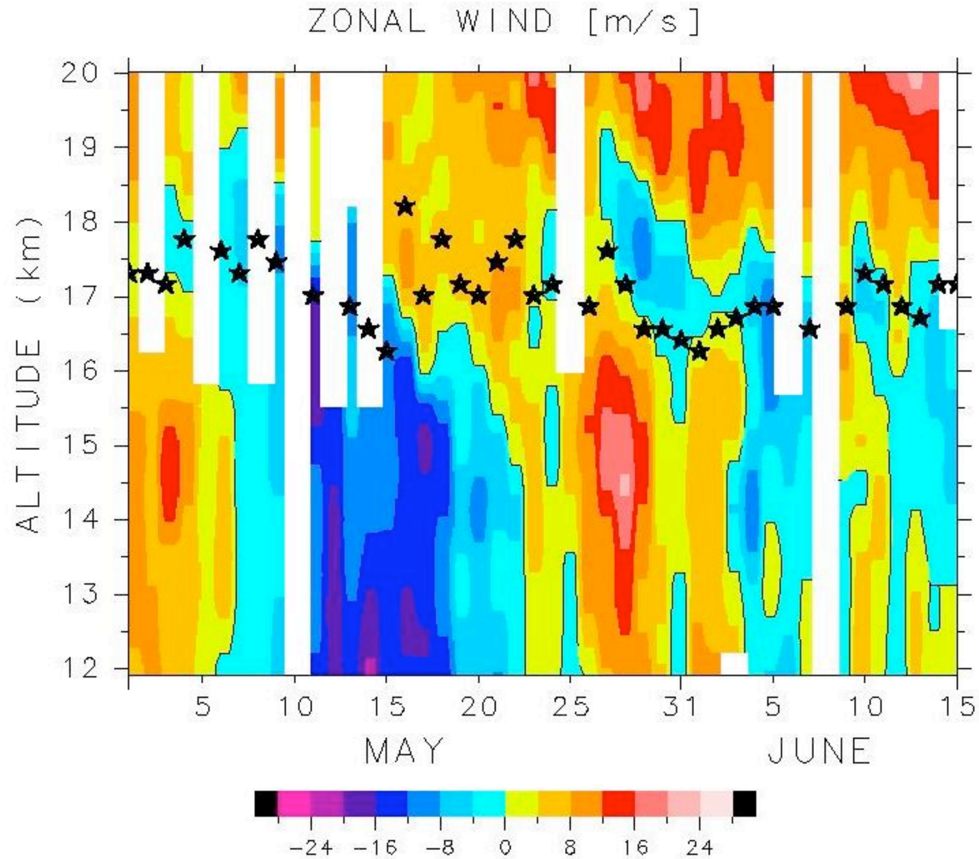


Ozonesondes at Watukosek, Indonesia (1995)

[Fujiwara et al., JGR, 1998]

Ozonesondes in Indonesia

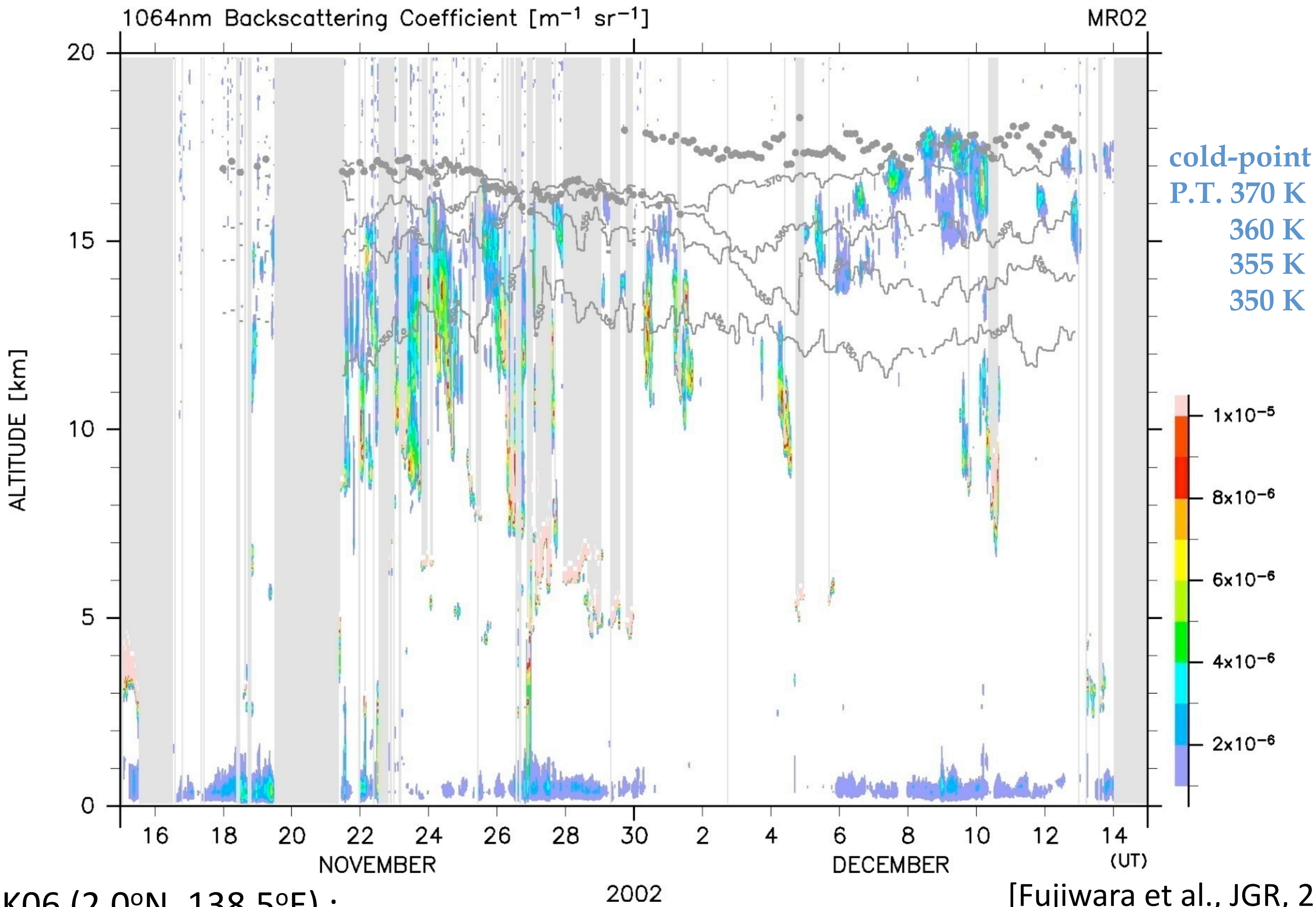




- 20-day oscillation
  TTL: Large-amplitude (breaking) Kelvin waves
  Tropo: Organized convection (ISO)
- Ozone transport at downward displacement phase
- Wave breaking → mixing & irreversible transport

[Fujiwara et al., JGR, 1998]

Ship-borne Lidar & radiosonde over the tropical W. Pacific



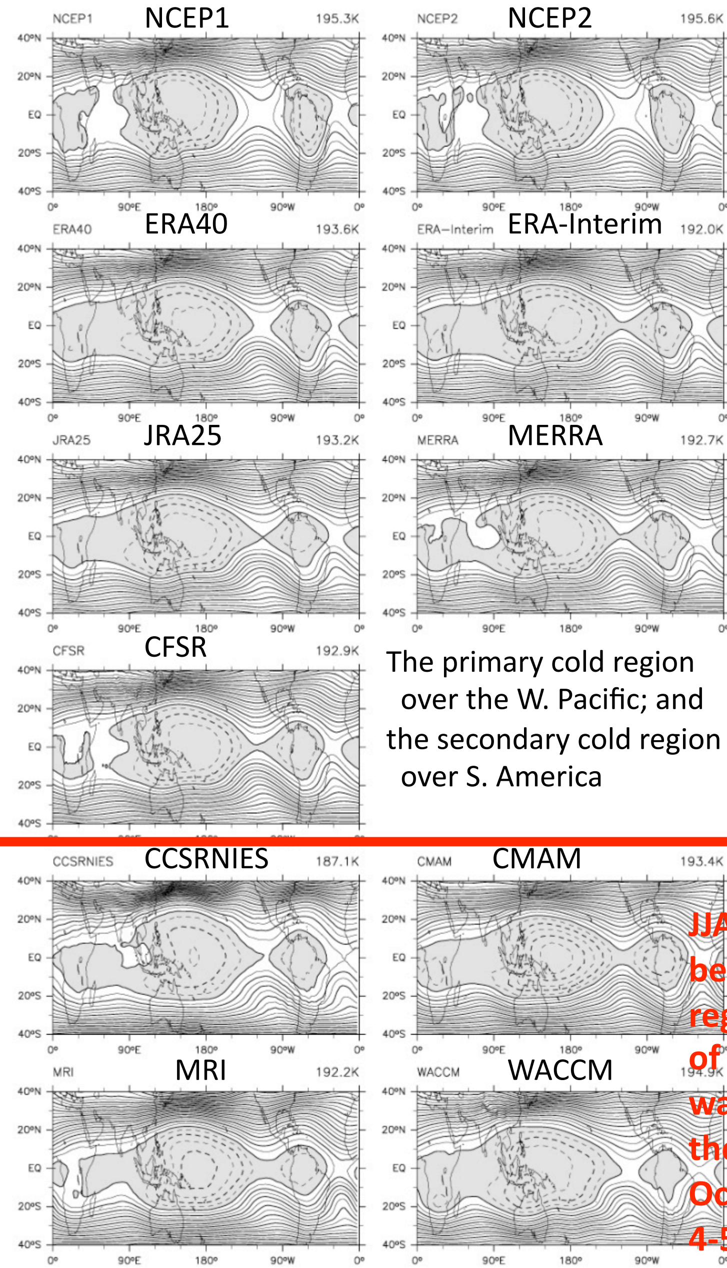
[Fujiwara et al., JGR, 2009]

MR02-K06 (2.0°N, 138.5°E) :

TTL was strongly perturbed (CPT jumped) with a period of ~20 days. → Kelvin wave

Cirrus in the TTL showed corresponding variations to the dynamical variation.

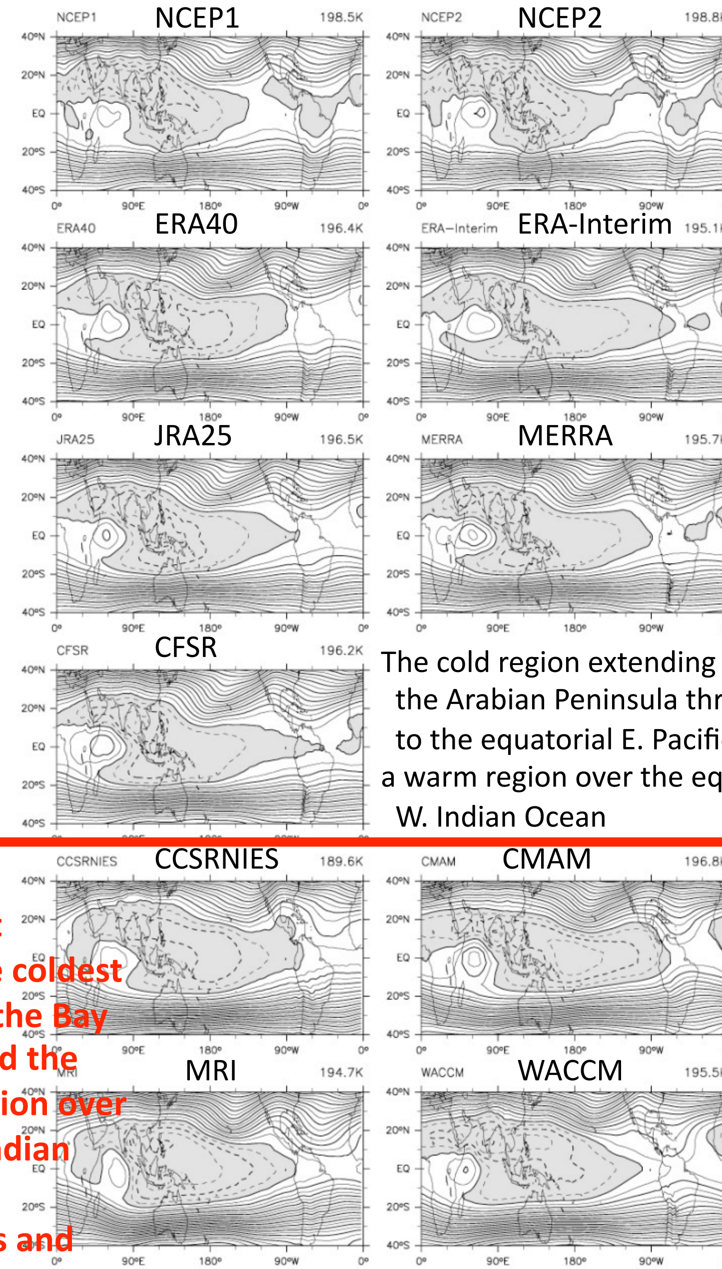
[DJF]



The primary cold region over the W. Pacific; and the secondary cold region over S. America

Figure 2. Distribution of temperature at 100 hPa averaged for December-January-February (DJF) during the period between January 1990 and February 2000 from 7 RAs and 4 CCMs. Anomaly from the 20°N–20°S average for each data set (shown on the top right of each panel) is plotted. The contour interval is 1 K. The regions with negative anomalies are colored gray.

[JJA]



The cold region extending from the Arabian Peninsula through India to the equatorial E. Pacific; and a warm region over the equatorial W. Indian Ocean

JJA: Contrast between the coldest region over the Bay of Bengal and the warmest region over the eq. W. Indian Ocean is: 4-5 K in ERAs and 7-8 K in MERRA.

Figure 3. As for Figure 2, but for June-July-August (JJA).

To remove the bias component, the 20^oN—20^oS average is subtracted for each data set.

3. Some Basic Comparisons – QBO

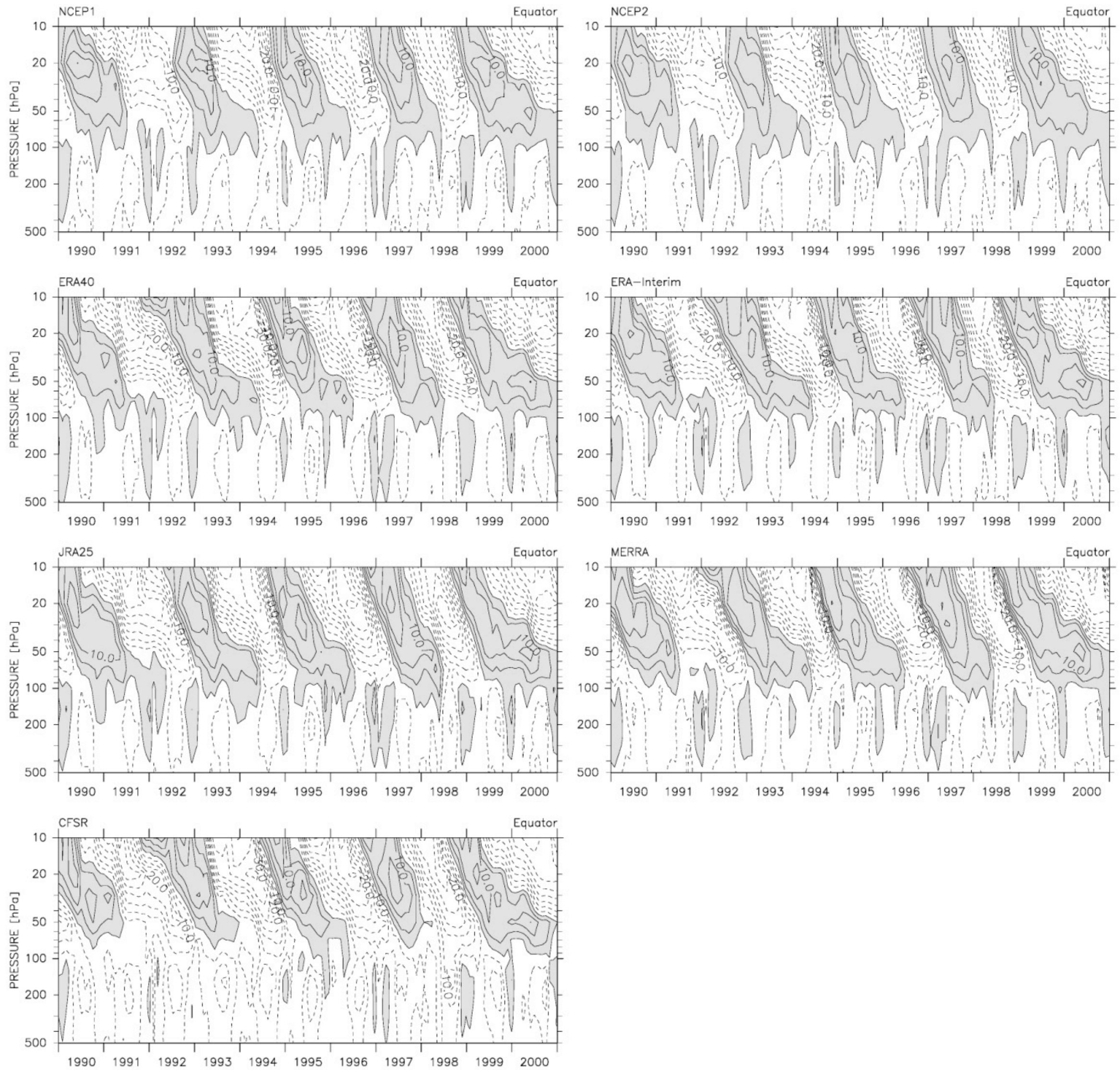


Figure 5. Time-pressure distribution of zonal mean zonal wind at 500–10 hPa at the equator from 7 RAs showing the QBO. The contour interval is 5 m s^{-1}. The regions with eastward winds are colored gray.

CFSR used ERA40 stratospheric winds as bogus observations for the period of 1981--1998, and thus the tropical wind distribution before 1998 above the 20 hPa level is quite similar.

For the other RAs and for the other height regions even in ERA40 and CFSR, the QBO signature is quite different.

One of the major differences is seen at the longer duration of the eastward wind phase at 100--50 hPa; the eastward wind signature is relatively short in duration at this height region for NCEP1, NCEP2, and CFSR.

Also, the upper tropospheric distribution is quite different among the 7 RAs.

→Due to weak mass-wind coupling in the tropics
→ Strong need for enhancing wind measurements in the tropics.

3. Some Basic Comparisons – QBO

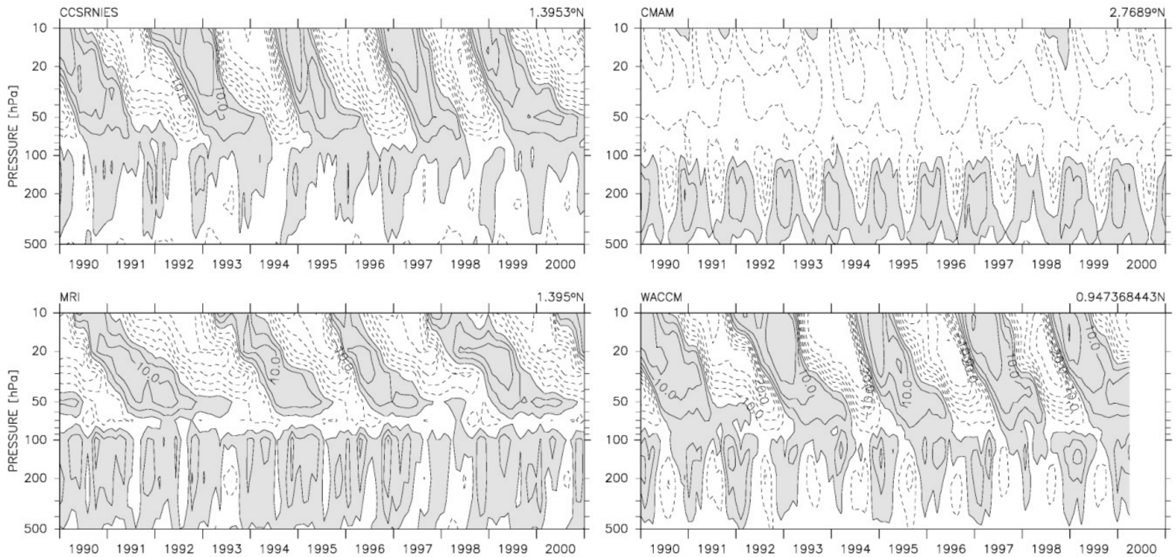


Figure 5b. Time-pressure distribution of zonal mean zonal wind at 500–10 hPa at the equator from 4 CCMs showing the QBO. The contour interval is 5 m s^{-1}. The regions with eastward winds are colored gray.

For CCSRNIES and WACCM, the QBO is simulated through nudging to observations.

For MRI, A QBO-like variation is internally generated by both parameterized and resolved atmospheric waves, with somewhat slower descending signals reaching only the 60--70 hPa level.

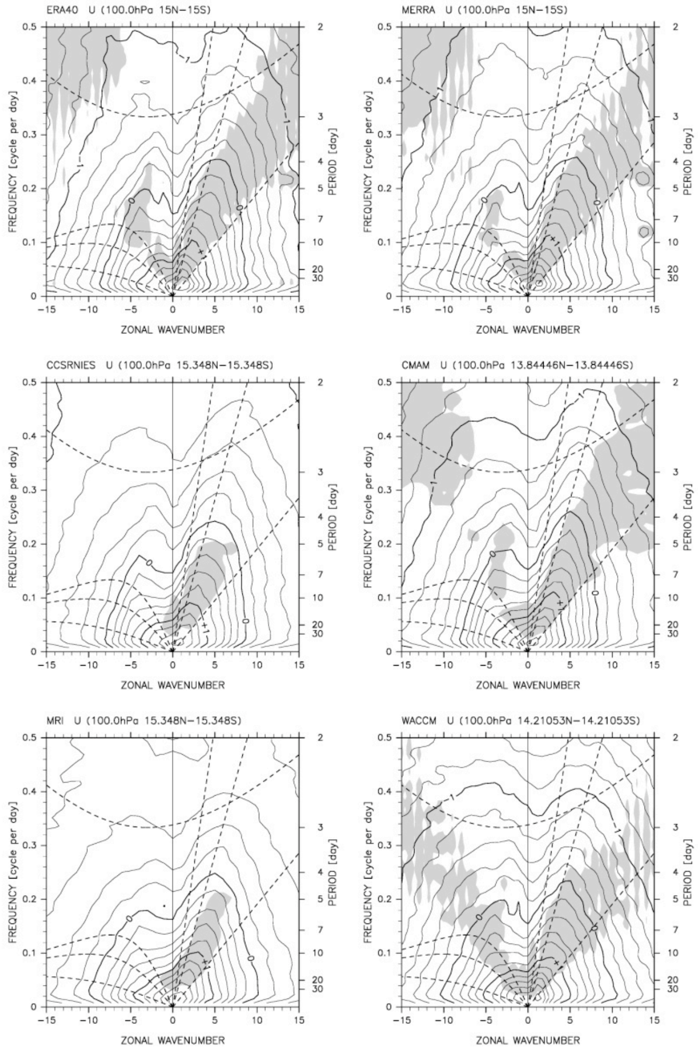


Figure 10. As for Figure 6, but for zonal wind at 100 hPa for 2 RAs (ERA40 and MERRA) and 4 CCMs.

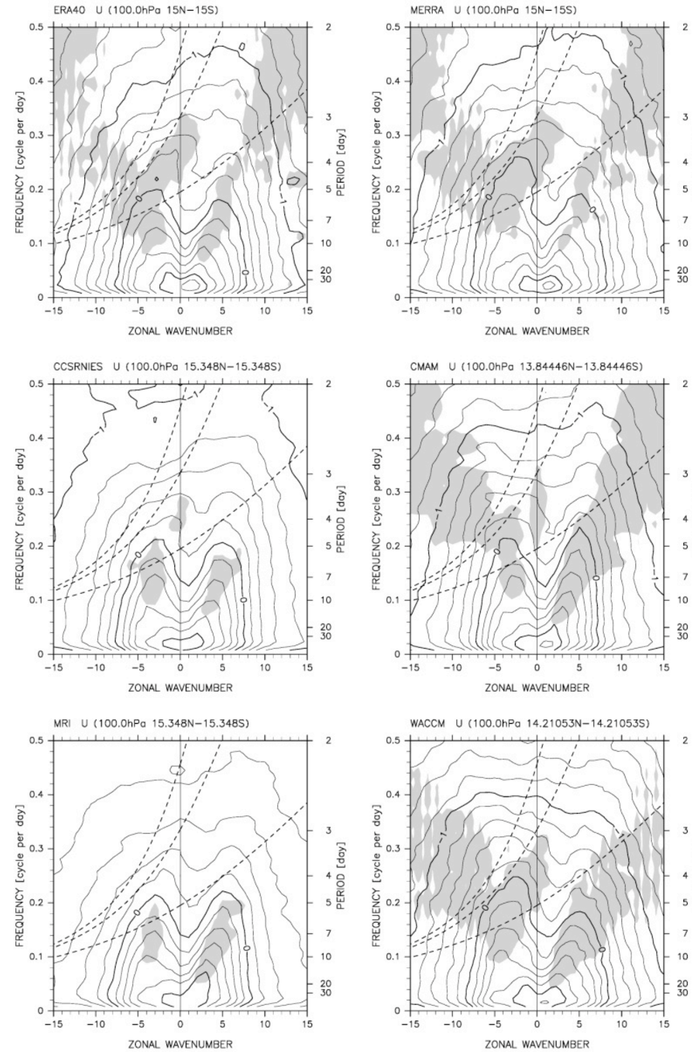


Figure 11. As for Figure 6, but for zonal wind at 100 hPa for 2 RAs (ERA40 and MERRA) and 4 CCMs.

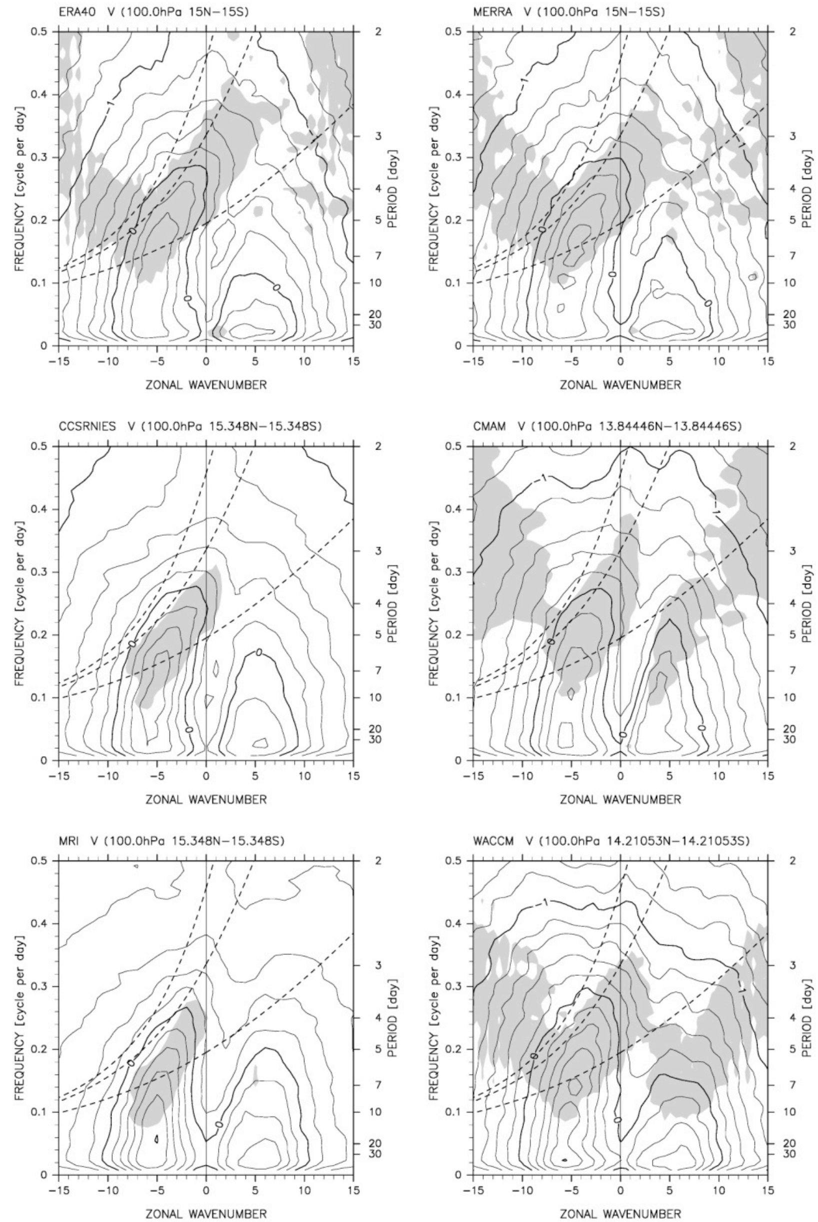


Figure 12. As for Figure 6, but for meridional wind at 100 hPa for 2 RAs (ERA40 and MERRA) and 4 CCMs. Dotted curves show the equatorial-wave dispersion relation at h=8, 70, and 240 m for mixed Rossby gravity waves (negative wavenumbers) and n=0 eastward-moving inertio-gravity waves (positive wavenumbers).

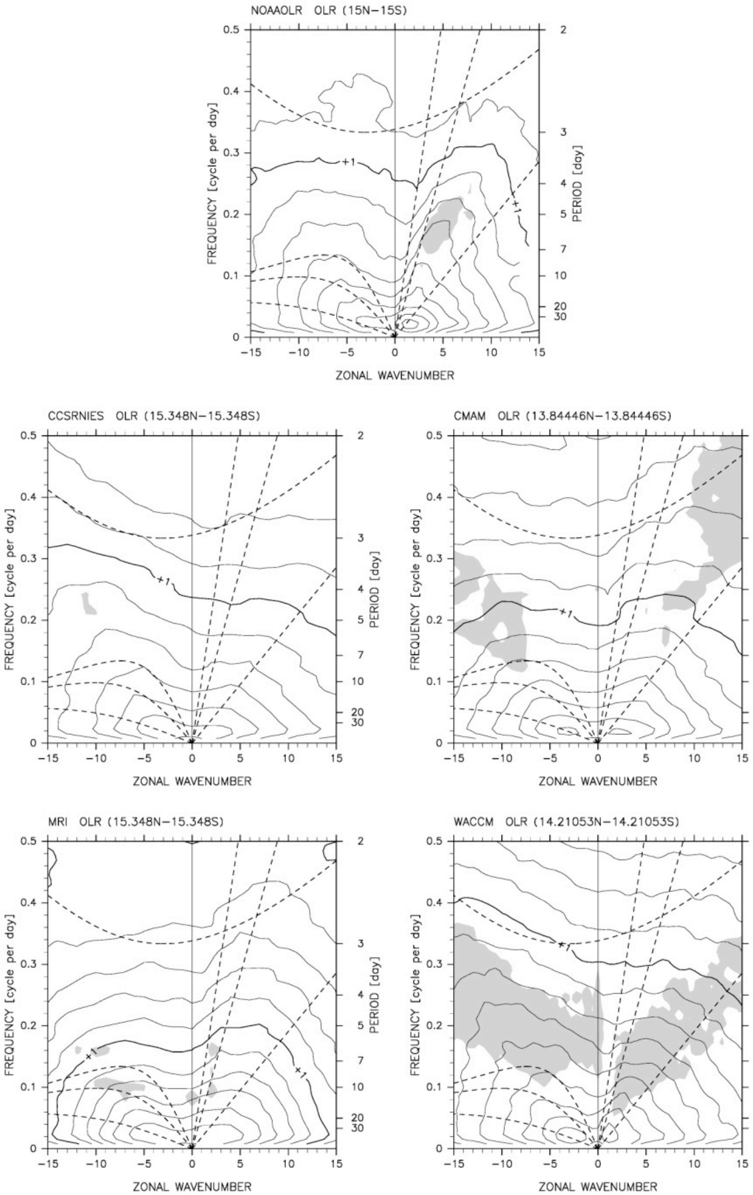


Figure 13. As for Figure 6, but for OLR for NOAAOLR and 4 CCMs.

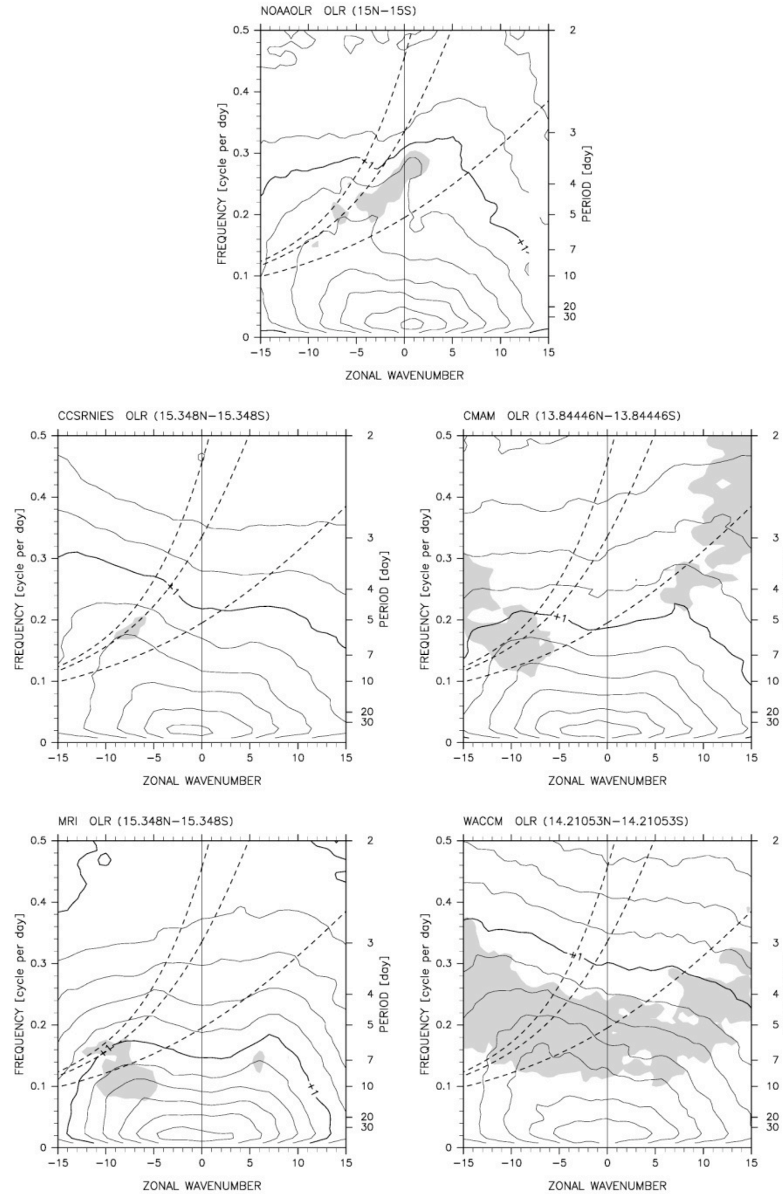


Figure 14. As for Figure 7, but for OLR for NOAAOLR and 4 CCMs.

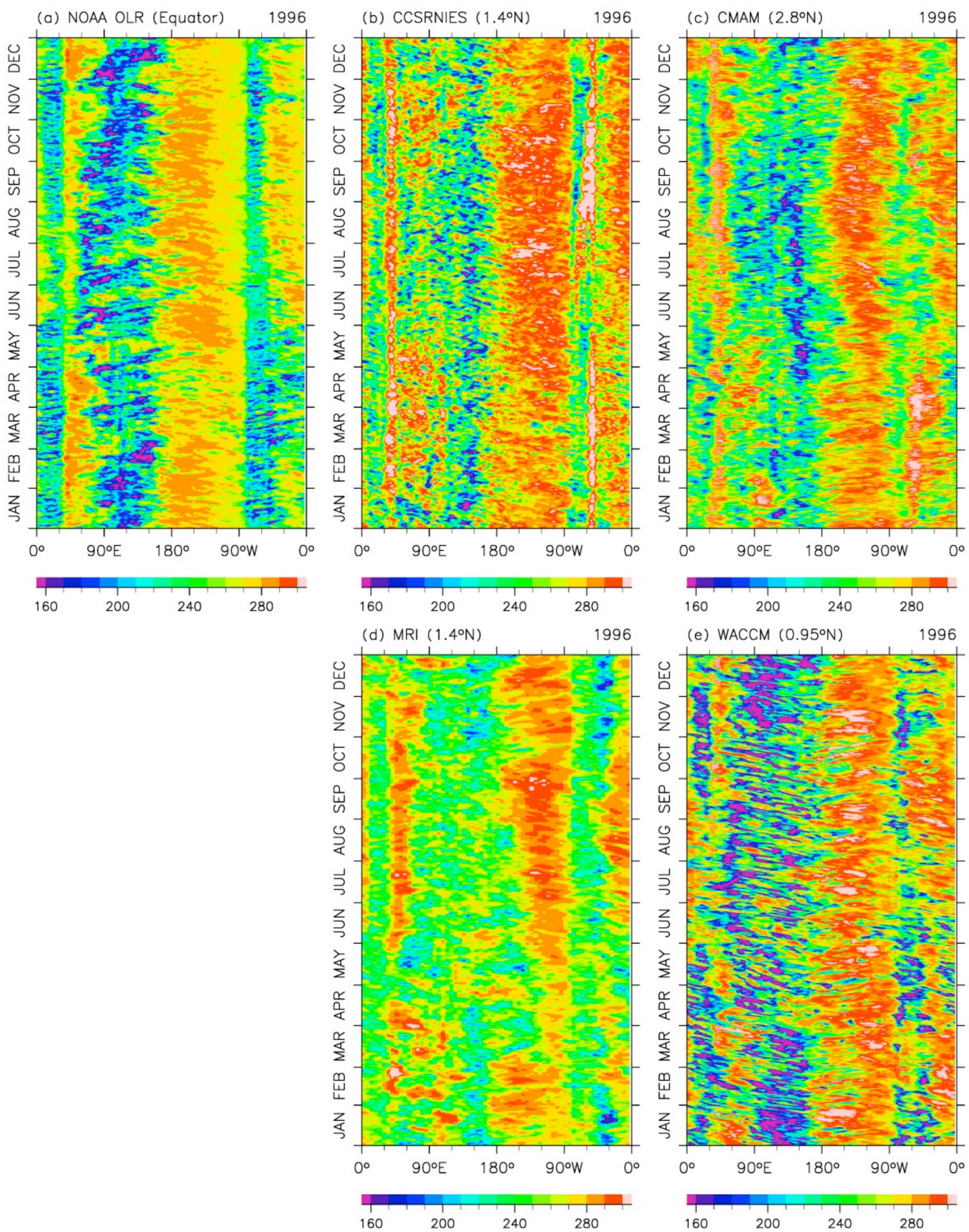


Figure 15. Longitude-time distribution of OLR at/near the equator during 1996 from (a) NOAA OLR (equator), (b) CCSRNIES (1.4°N), (c) CMAM (2.8°N), (d) MRI (1.4°N), and (e) WACCM (0.95°N).

All the CCMs are largely missing eastward-moving large-scale disturbances observed over the Indian Ocean to the tropical western Pacific at 45E-180 longitudes in NOAAOLR data.

WACCM shows strong westward-moving disturbances in the eastern hemisphere, and the other CCMs show smaller-scale less organized convection.

(MRI shows much smoother distributions because of the lower resolution for the radiative calculations (i.e., the fourth of T42).)

… Why does the CCM temperature and horizontal wind fields at 100 hPa show more realistic features for large-scale disturbances while the CCM OLR field does not?

→ For the large-scale disturbances in the TTL, the dynamical constraints in the equatorial region may be more important than the diabatic heating distributions associated with tropical organized convection.

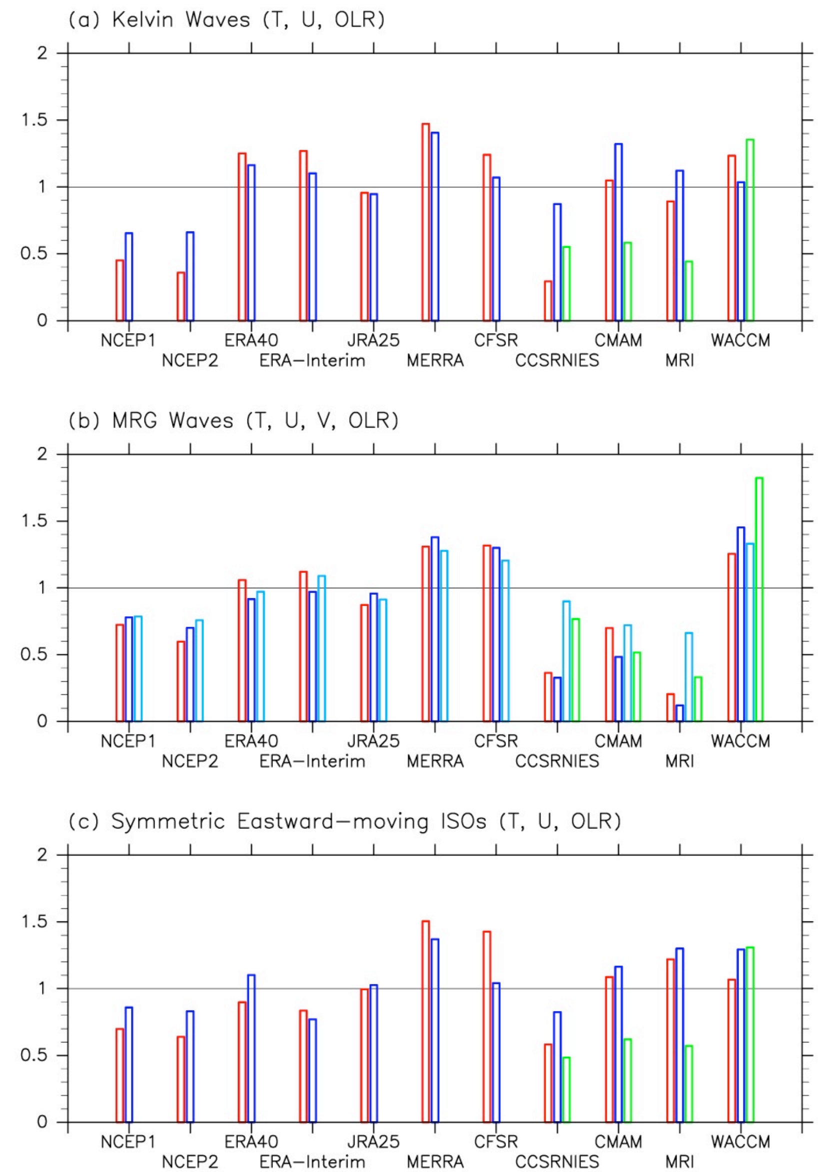


Table 3. Wave Activities[a] Averaged for 7 RAs and From NOAAOLR

Parameter	Unit	Kelvin waves	MRG waves	ISO
Temperature (100 hPa)	K^2	0.21	0.036	0.26
Zonal wind (100 hPa)	$(m\ s^{-1})^2$	3.7	0.49	5.4
Meridional wind (100 hPa)	$(m\ s^{-1})^2$	–	1.3	–
OLR (NOAA)	$(W\ m^{-2})^2$	60	16	44

[a] See text for the definition.