

Representation of ozone quasi-biennial oscillation (QBO) in JRA-3Q

***Hiroaki Naoe¹, Shoji Hirahara¹,
Makoto Deushi¹, and Kiyotaka
Shibata^{2,1}**

1. Meteorological Research Institute, Japan

2. Independent Researcher, Hidaka, Saitama, Japan

Background

- Ozone used as the boundary in reanalysis.
- Ozone QBO driven by chemistry, dynamics.
- Representation of the ozone QBO remains unclear about how well JRA-3Q aligns with observation and other reanalyses.
- The aim is to quantitatively evaluate the ozone QBO in JRA-3Q in the recent- and pre-satellite eras.

Methods and Datasets

- Noted that JRA-3Q offline ozone chemistry driven by JRA-55 wind.
- Monthly U, T, O₃ in JRA-3Q, JRA-55, ERA5, MERRA-2
- Aura/MLS (AMLS): T, O₃, Z → U using gradient wind, interpolation in tropics.
- Cross-Wavelet analysis. QBO is defined as 20-40 mon.

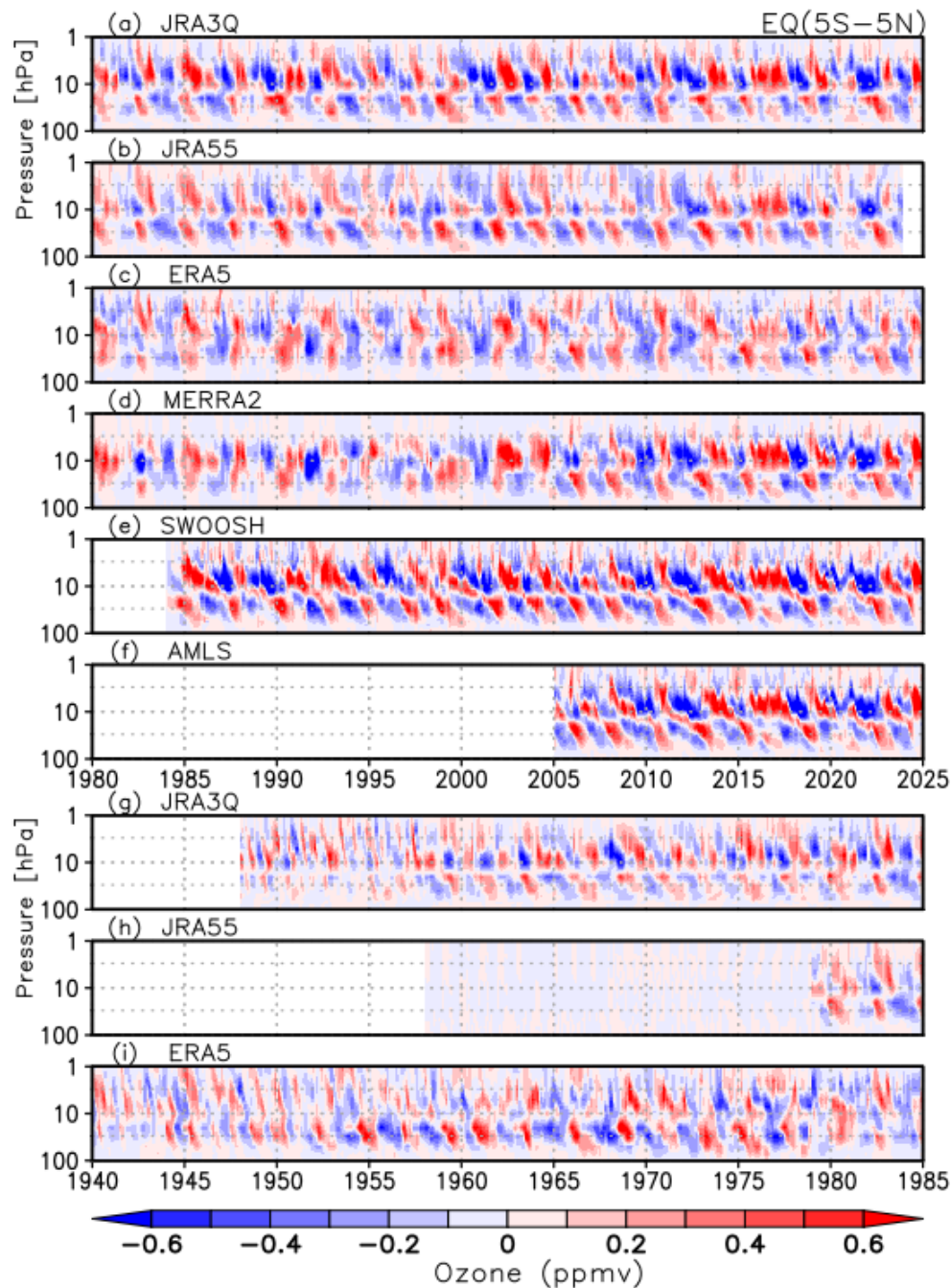


Fig. 1 Time series of monthly zonal-mean deseasonalized ozone mixing ratio anomalies (ppmv) **relative to a 10-year running mean**, averaged over 5° S–5° N, for

- (a) JRA-3Q,
- (b) JRA-55,
- (c) ERA5,
- (d) MERRA-2,
- (e) SWOOSH,
- (f) Aura/MLS (AMLS) for 1980–2025,
- (g) JRA-3Q,
- (h) JRA-55,
- (i) ERA5 for 1940–1985.

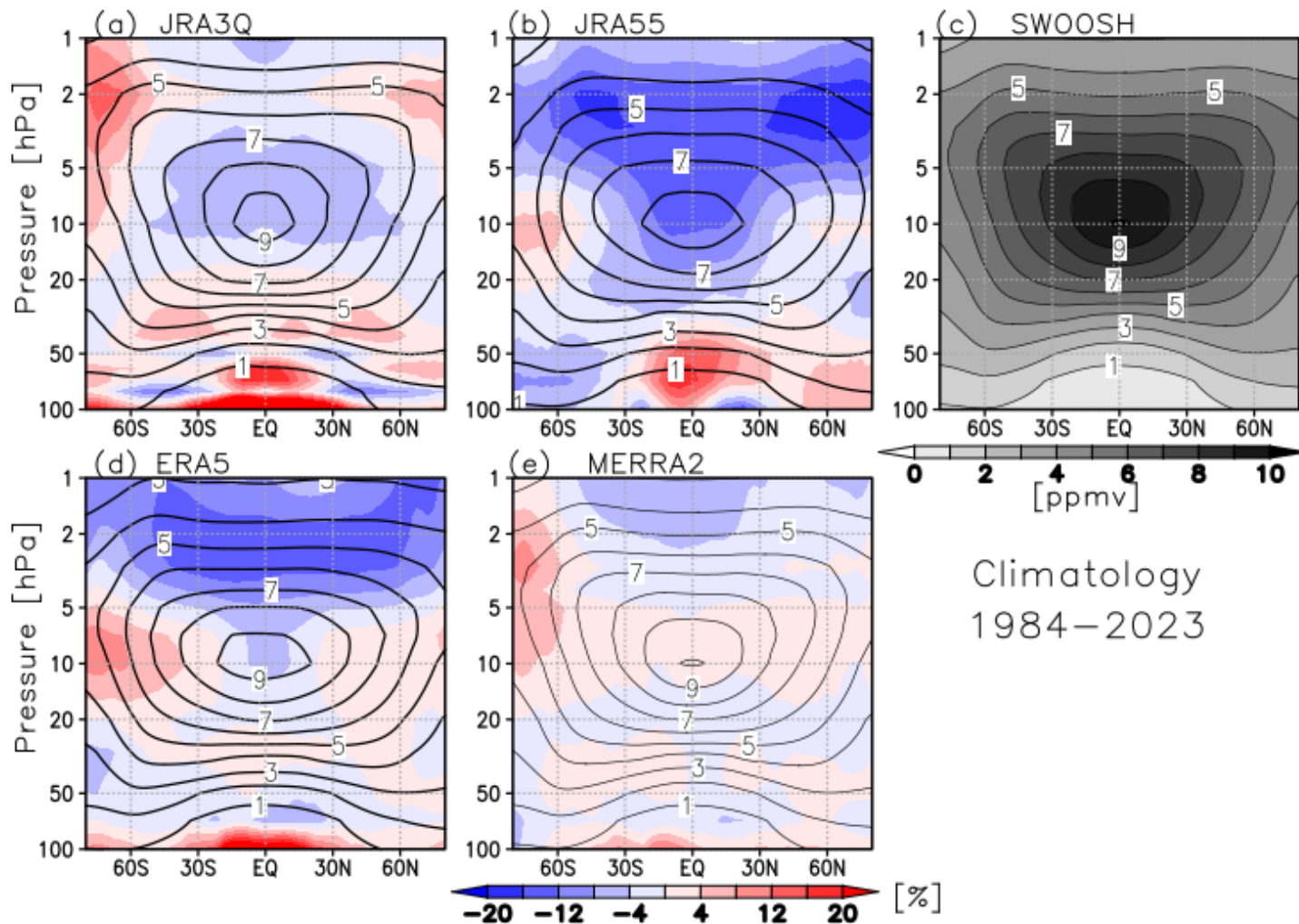
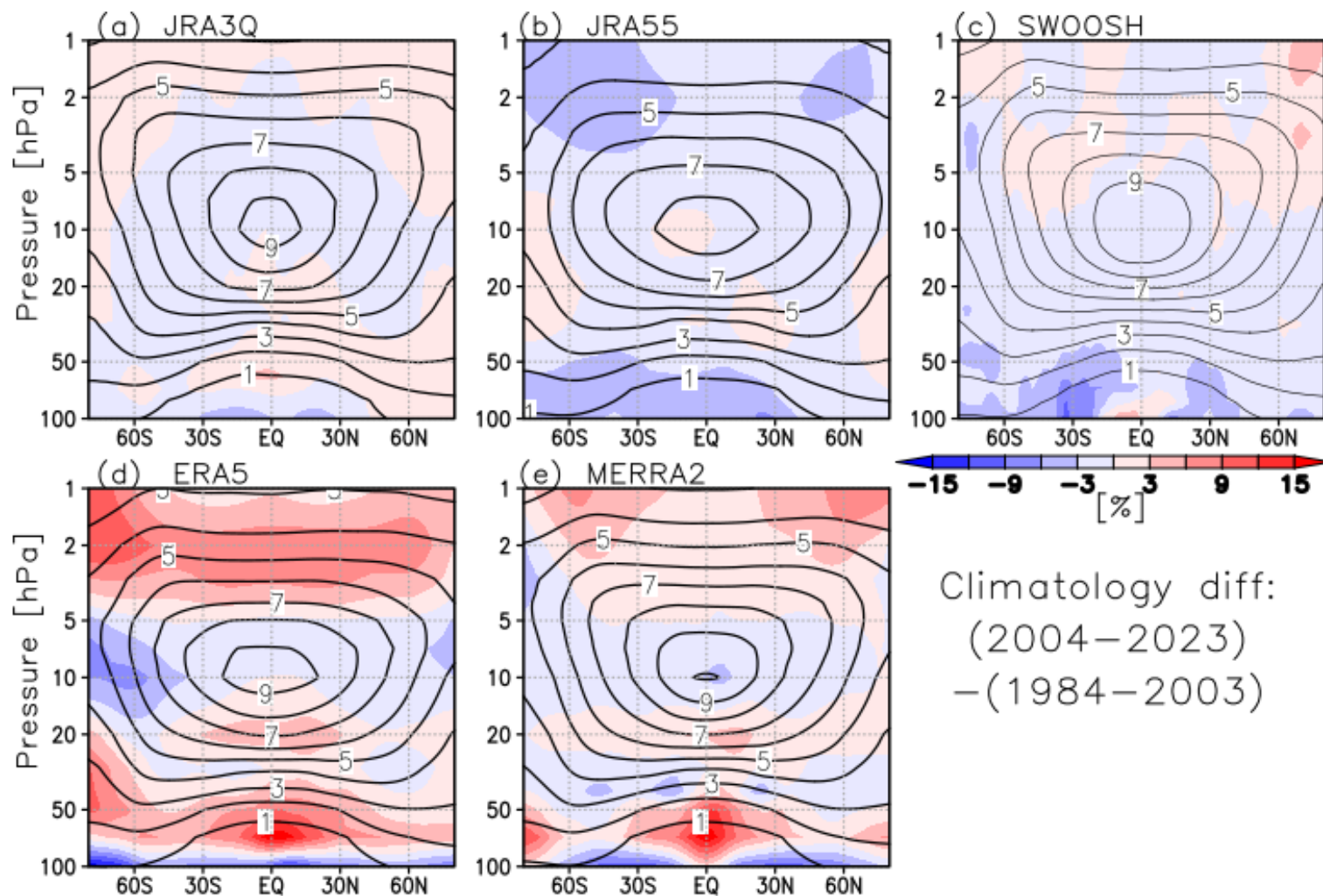


Fig. 2 **Ozone climatology based on 40 years** of reanalysis data (1984–2023; contours at 1 ppbv intervals) and corresponding biases (shading) relative to SWOOSH observations for (a) JRA-3Q, (b) JRA-55, (d) ERA5, and (e) MERRA-2. (c) SWOOSH ozone climatology averaged over the same period. The contour interval is 1 ppbv.



Climatology diff:
(2004–2023)
–(1984–2003)

Fig. 3 Ozone climatology based on 40 years of data (1984–2023; contours at 1 ppmv intervals) and corresponding **differences** in relative ozone mixing ratio **between 2004–2023 and 1984–2003** (shading; %) for (a) JRA-3Q, (b) JRA-55, (c) SWOOSH, (d) ERA5, and (e) MERRA-2.

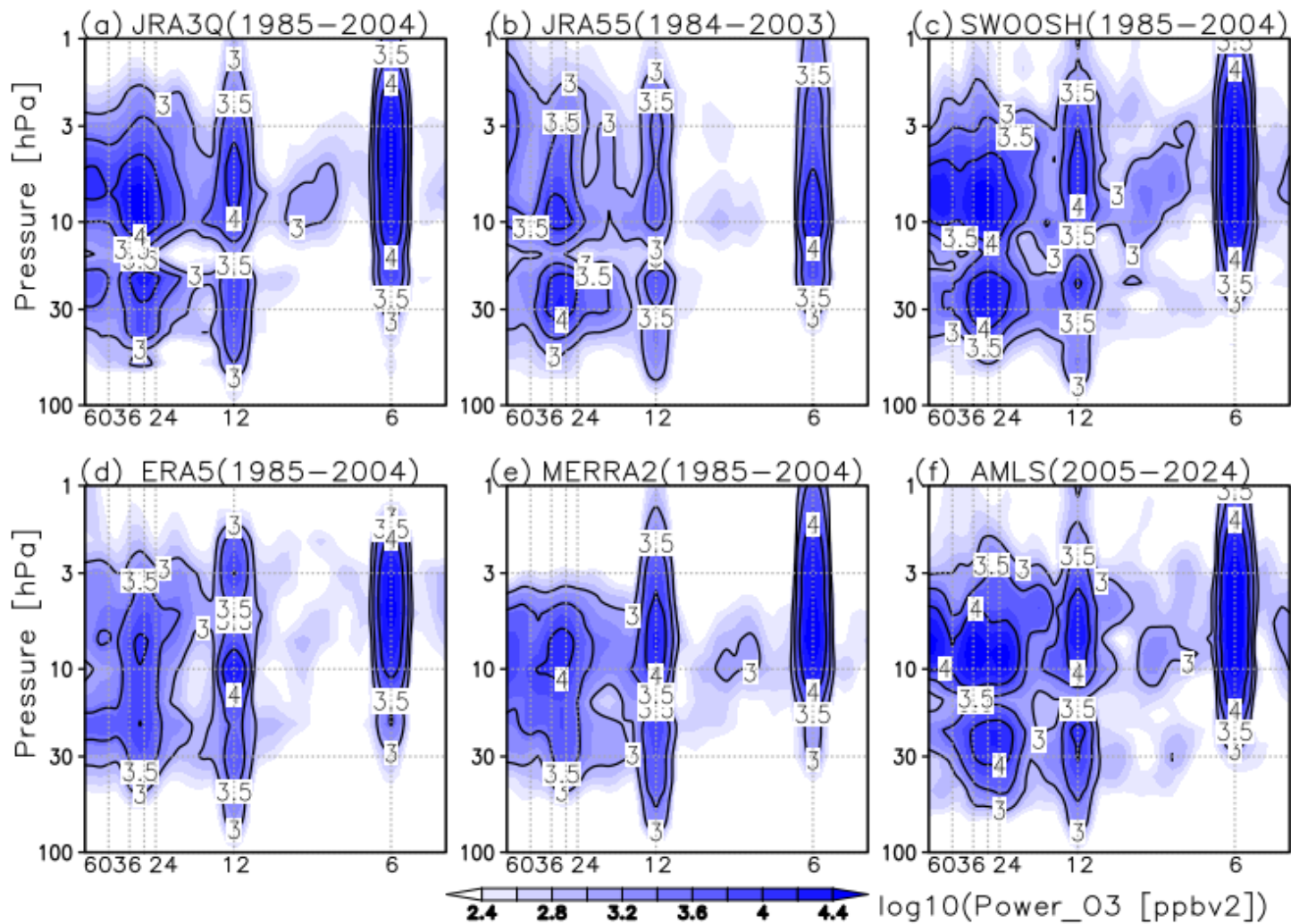


Fig. 4 Power spectra of zonal-mean ozone mixing ratios averaged over 5° S–5° N from 100 to 1 hPa for the 20-year period 1984–2003 for (a) JRA-3Q, (b) JRA-55, (c) SWOOSH, (d) ERA5, and (e) MERRA-2. (f) Same as (a)–(e), but for AMLS observations for the 20-year period 2005–2024. Note that ozone values at 15 hPa in the reanalyses are obtained by linear interpolation between the 10- and 20-hPa standard pressure levels. The resulting minimum in spectral power near 15 hPa represents the transition layer separating the lower- and upper-stratospheric ozone QBO components. Values are shown on a base-10 logarithmic scale (ppbv²), and the contour interval is 0.4.

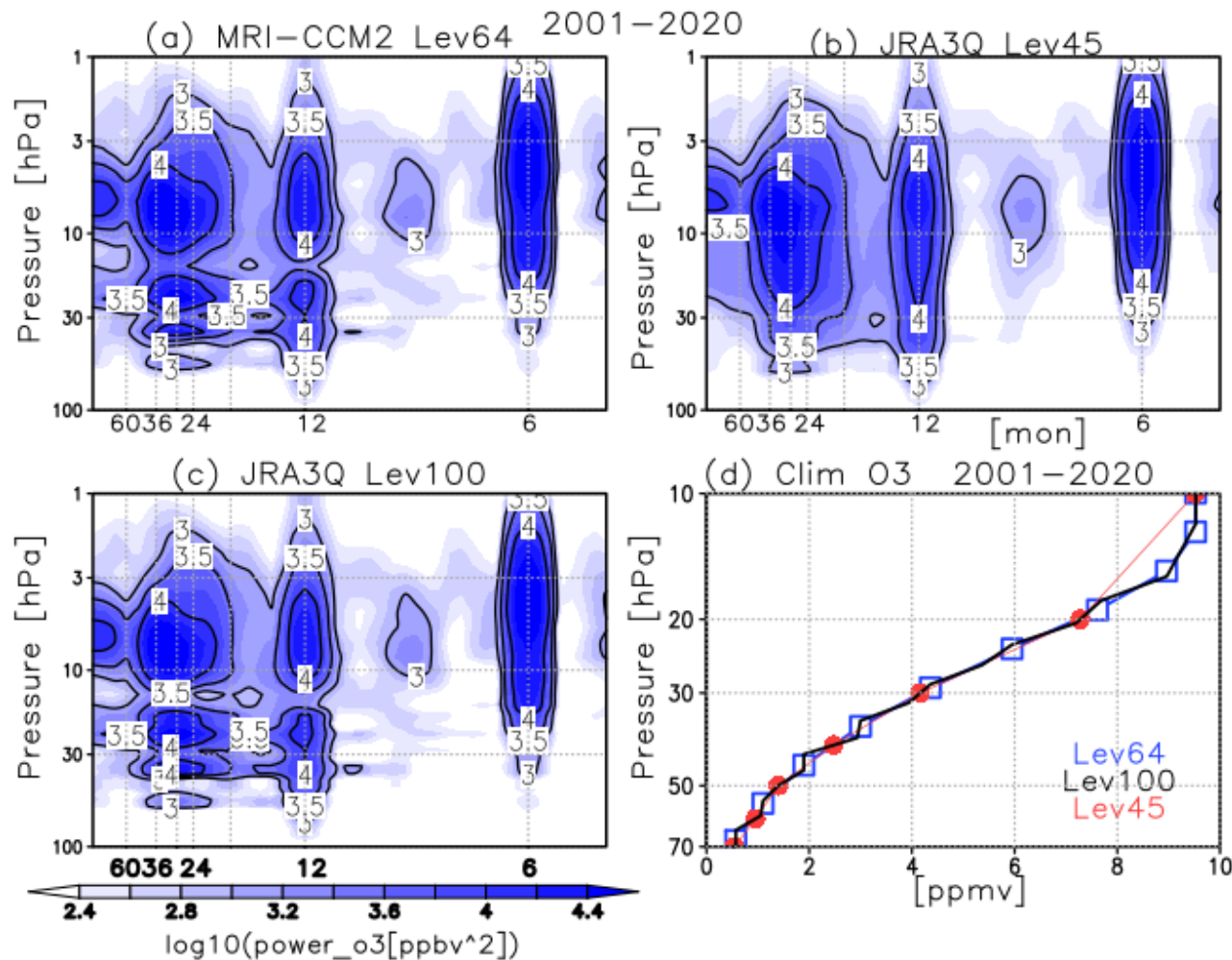


Fig. 5 (a) Power spectra of zonal-mean ozone mixing ratios from 100 to 1 hPa for MRI-CCM2 using model-level data on eta surfaces of a hybrid pressure-based vertical coordinate system with 64 layers. Ozone is averaged over 5° S–5° N for the 20-year period 2001–2020. (b) Same as (a), but for JRA-3Q using standard pressure levels without interpolation at 15 hPa. (c) Same as (a), but using model-level data on eta-surfaces of a hybrid pressure-based vertical coordinate system for a GCM with 100 layers. (d) Climatological ozone profiles averaged over 5° S–5° N and based on the period 2001–2020, shown for JRA-3Q standard pressure levels (red solid line with circles), for the GCM (black solid line), and for MRI-CCM2 (blue solid line with squares).

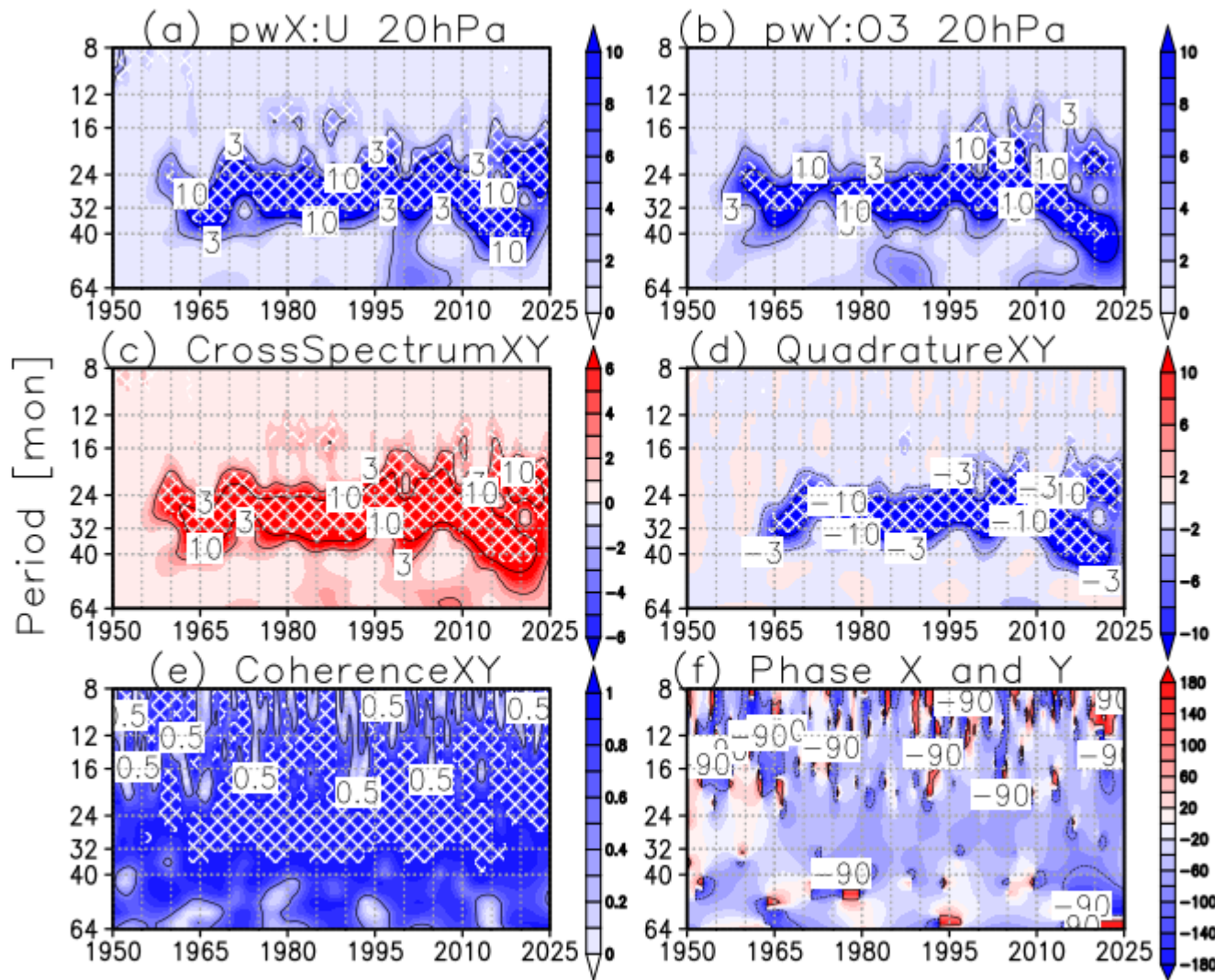


Fig. 6 Time series of wavelet transforms at 20 hPa averaged over 5° S–5° N for JRA-3Q. Panels show (a, b) the [power spectra of zonal-mean zonal wind and ozone](#), respectively, normalized by their variances; (c) [cross-wavelet power](#) normalized by the square root of the product of the variances of zonal wind and ozone; (d) [quadrature-wavelet spectrum between zonal wind and ozone](#), normalized by the square root of the product of the variances of zonal wind and ozone; (e) squared [coherence](#); and (f) phase angle between zonal wind and ozone. Thick contours denote regions exceeding the 95% confidence level.

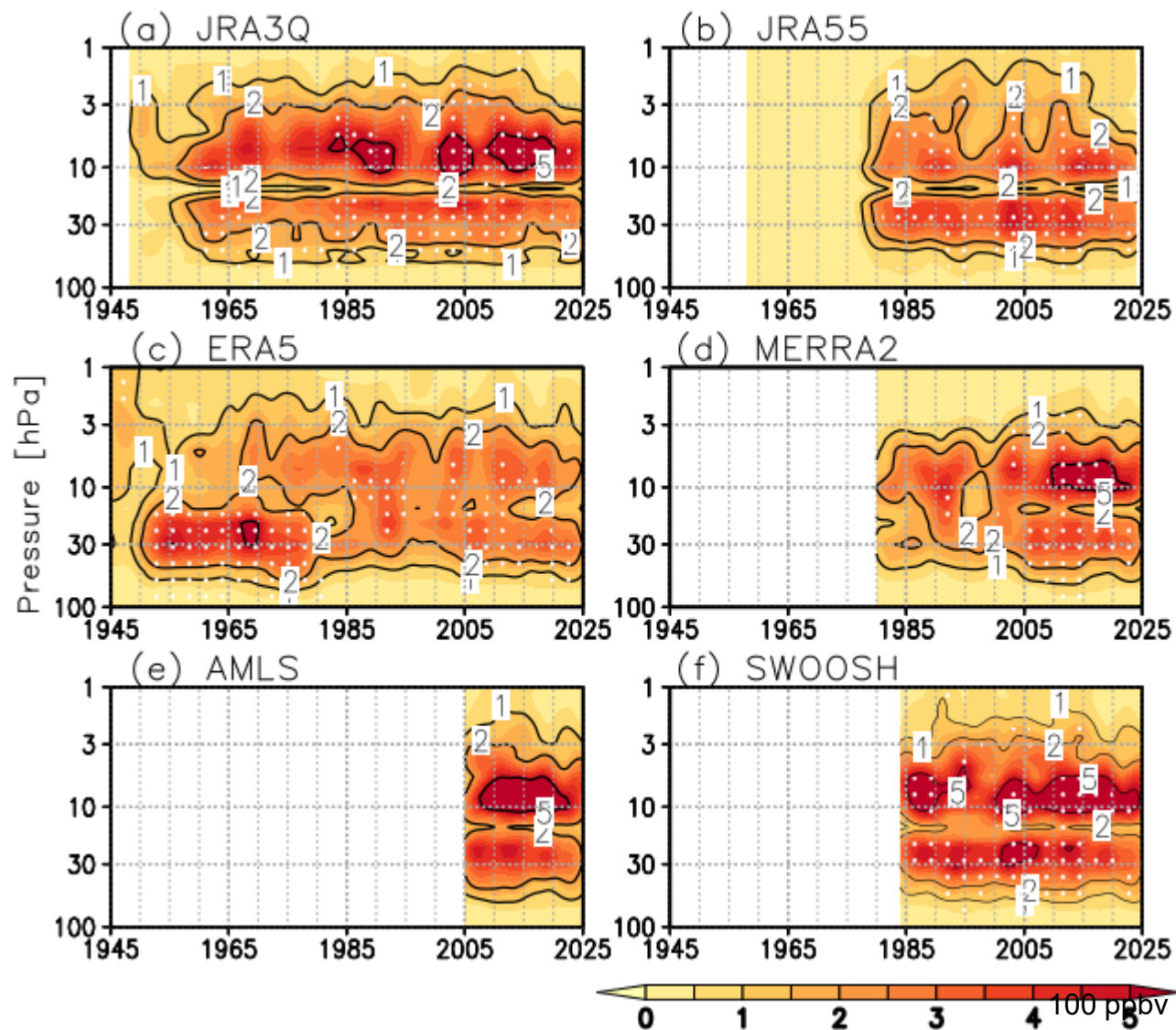


Fig. 7 Time–height cross sections of [the wavelet power amplitude of ozone mixing ratios](#) (in unit of 100 ppbv) for (a) JRA-3Q, (b) JRA-55, (c) ERA5, (d) MERRA-2, (e) AMLS, and (f) SWOOSH. The QBO signal is defined as the wavelet power in the 20–40-month period, corresponding to the ozone QBO separated from the annual and semiannual oscillations. The power amplitude is calculated as the square root of twice the power. Dots indicate regions exceeding the 95% confidence level, based on a background red-noise spectrum estimated from the satellite era (1980–2023). Note that ozone values at 15 hPa in the reanalyses are generated by linear interpolation between the 10 and 20 hPa standard pressure levels.

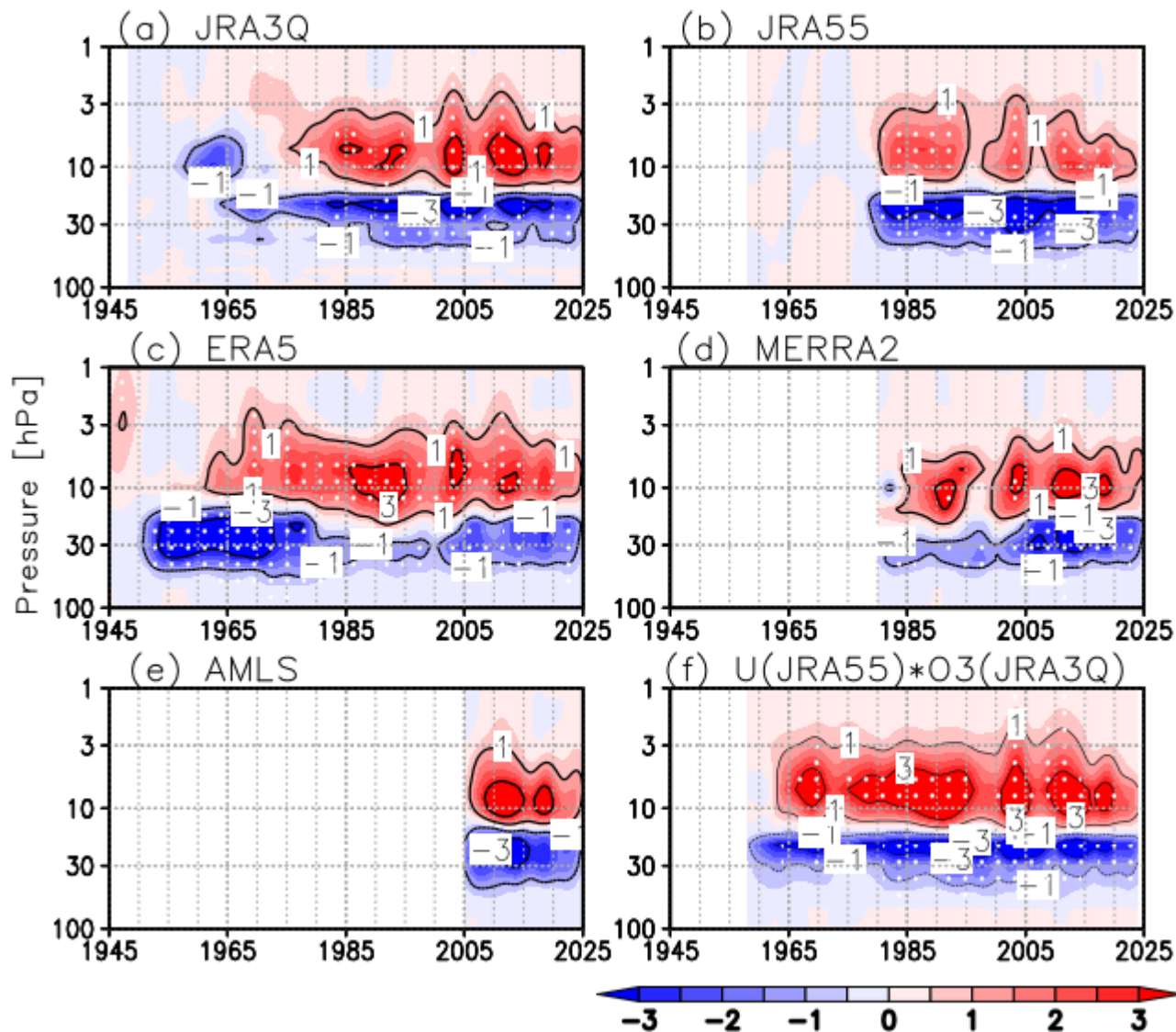


Fig. 8 Time–height cross sections of **quadrature-wavelet power** (the imaginary component of cross-wavelet power) averaged over the 20–40-month QBO frequency band for the relationship between zonal wind and ozone (units: ppbv m s⁻¹) for (a) JRA-3Q, (b) JRA-55, (c) ERA5, (d) MERRA-2, and (e) AMLS. Negative values of the quadrature component indicate that ozone leads zonal wind, while positive values indicate that zonal wind leads ozone. Both zonal wind and ozone are averaged over the equatorial region (5° S–5° N). (f) Same as (a)–(e), but for quadrature-wavelet calculated using zonal wind from JRA-55 and ozone from JRA-3Q.

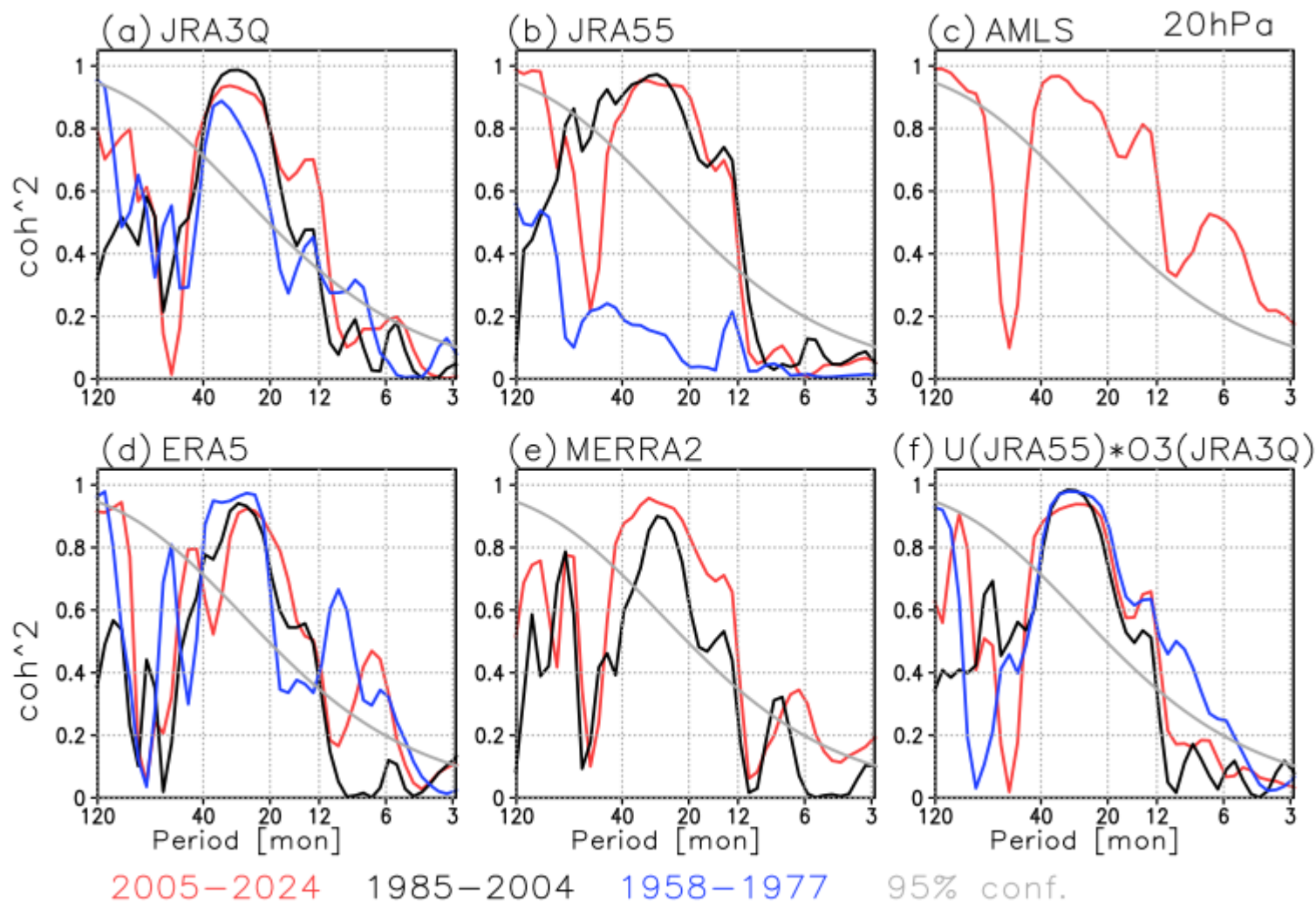


Fig. 9 Squared coherence between zonal wind and ozone at 20 hPa for three 20-year periods, 1958–1977 (blue), 1985–2004 (black), and 2005–2024 (red), for (a) JRA-3Q, (b) JRA-55, (c) AMLS, (d) ERA5, and (e) MERRA-2. The gray line indicates the 95% confidence level. (f) Same as (a)–(e) but for zonal wind from JRA-55 and ozone from JRA-3Q.

Summary of JRA-3Q ozone QBO

- **JRA-3Q ozone QBO reproduces** a vertical structure with **a 15-hPa transition** separating an upper chemistry-regime from a lower dynamics-regime from 1960s onward, through **its realistic zonal-wind QBO driven by JRA-55 wind** and with **a 3-D full-chemistry ozone model**, albeit in an off-line configuration.
- ERA5 and MERRA-2 show less distinct representation of the vertical phase reversal before 2004.
- The ozone QBO power in JRA-55 is generally weaker.