Intercomaparison of reanalyses,
JRA25, NCEP/NCAR and ERA40
with emphasis on their application to driving CTM

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Plan for reanalysis of minor constituents

Ozone reanalysis will be performed with a CTM driven by atmospheric reanalysis. In this system, quality of reanalyzed minor constituents is affected by quality of the atmospheric reanalyses used for driving the CTM.

This work

1. To compare the mean-meridional circulation of three reanalyses, JRA-25, ERA40 and NCEP/NCAR.

2. To compare reanalyzed ozone distributions and their mean and eddy meridional transports.

JAPANESE 25-YEAR REANALYSIS

DATA

JRA-25

ASSIMILATION FORECAST

JMA/CRIEPI

Kazutoshi ONOGI et al. (JMA)

JRA-25 Overview

- Joint research project of JMA and CRIEPI
- Years：1979.1 - 2004.12

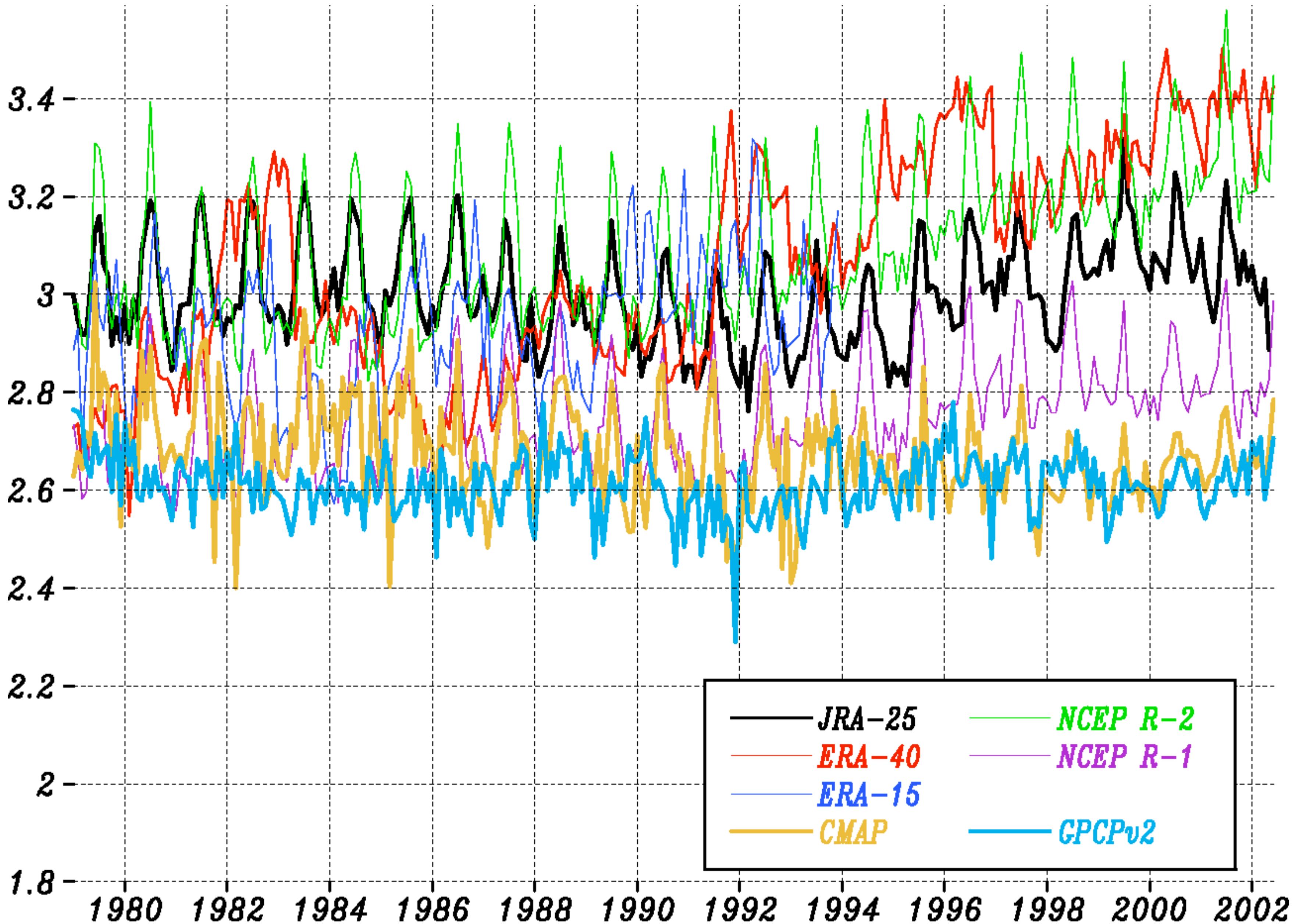
  transitioned to JMA-CDAS (JCDAS) for after 2005
- Resolution : T106L40 with top level at 0.4hPa
- 3D-Var
- Version : JMA operational system as of April 2004

  In addition, SSM/I PW, TOVS radiance level 1c(SSU) and 1d(HIRS, MSU) were assimilated.
- JRA-25 original/firstly used observational data

  TCR, SSM/I snow coverage, digitized Chinese snow depth data, reprocessed GMS-AMV
- JRA-25 original boundary/forcing data

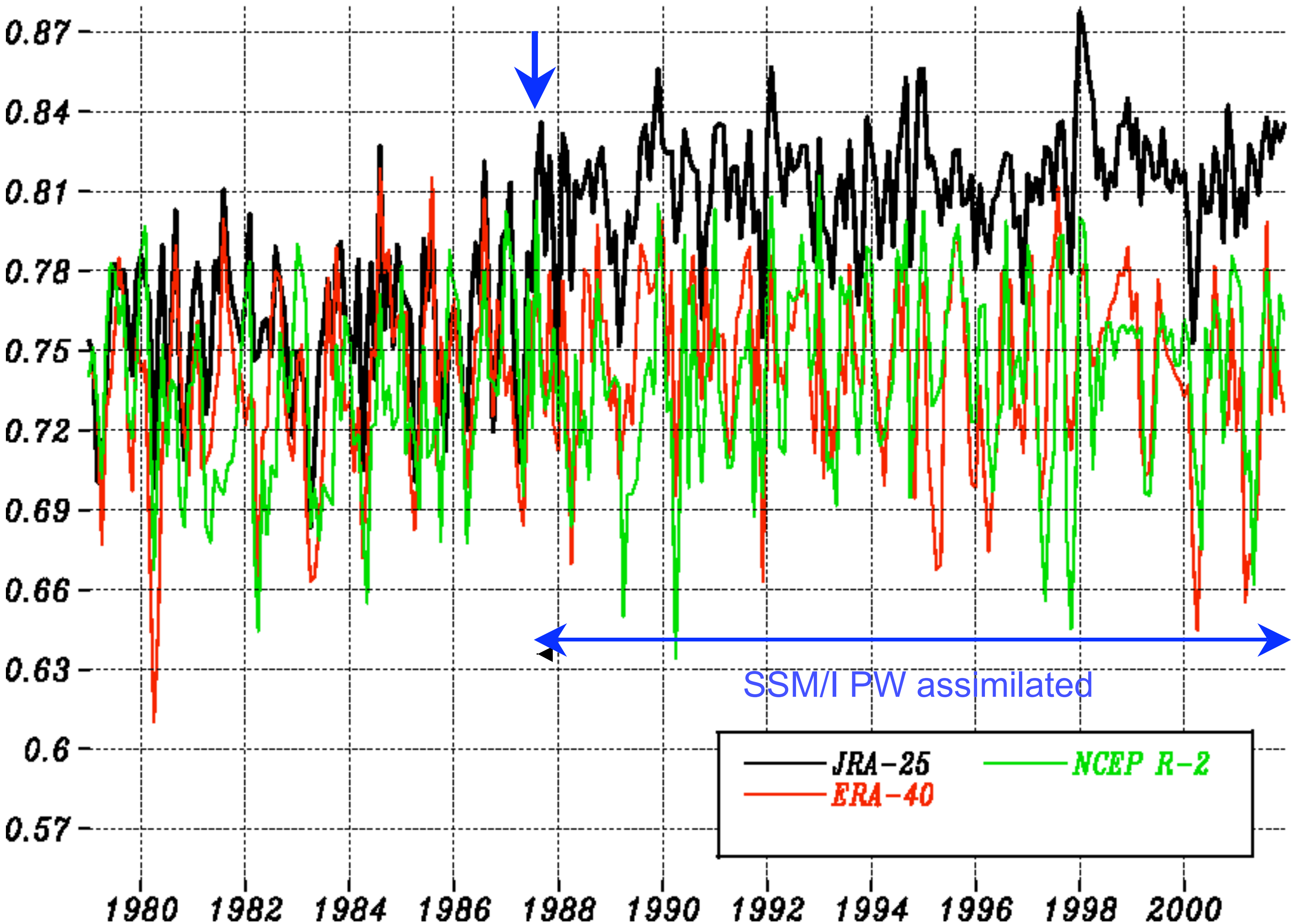
  Daily COBE SST and sea ice (Ishii 2005, IJC), daily 3D-ozone profile

Globally-averaged Monthly Precipitation



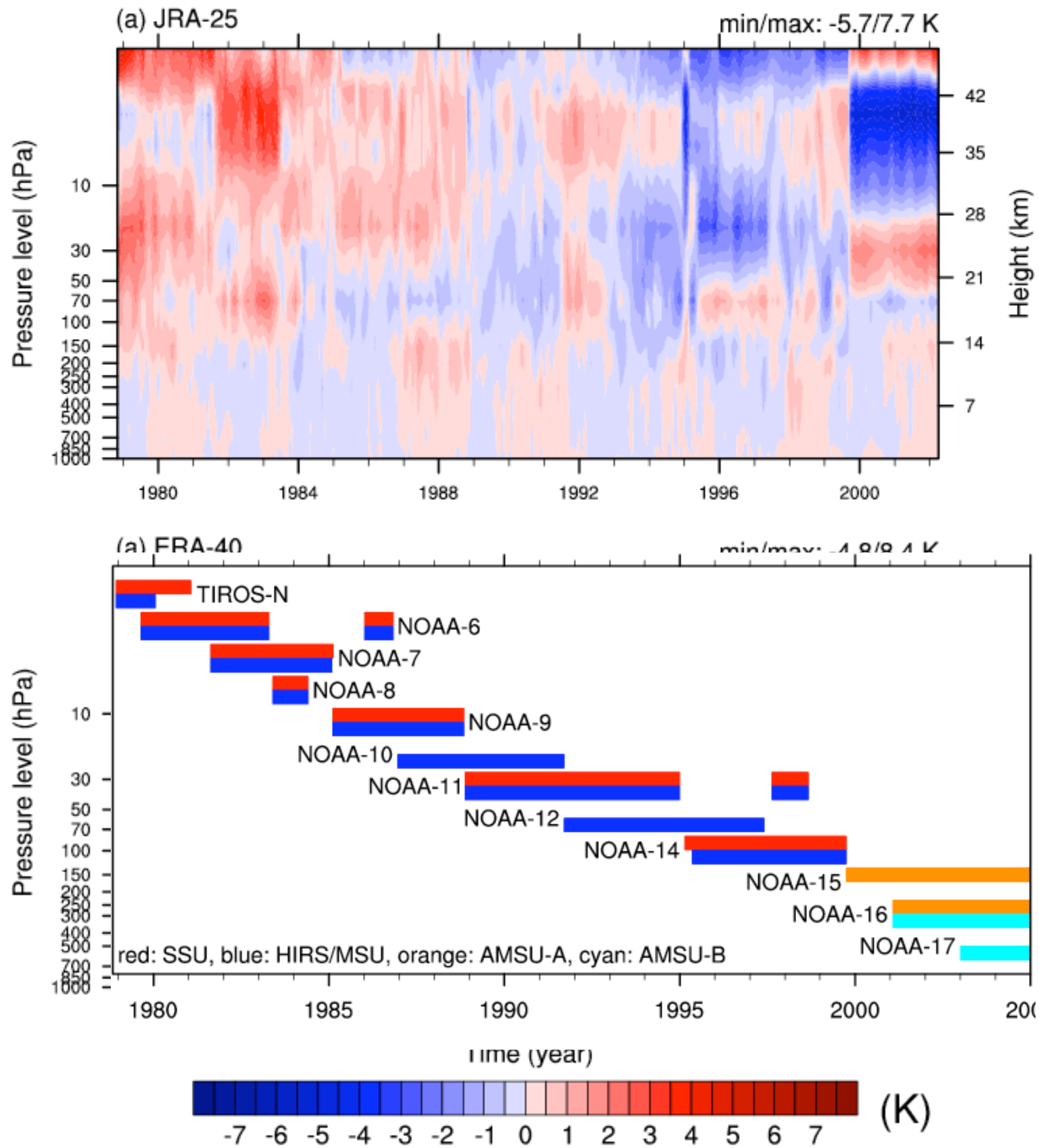
Courtesy: H. Koide

Correlation of Monthly Precipitation with GPCPv2



Courtesy: H. Koide

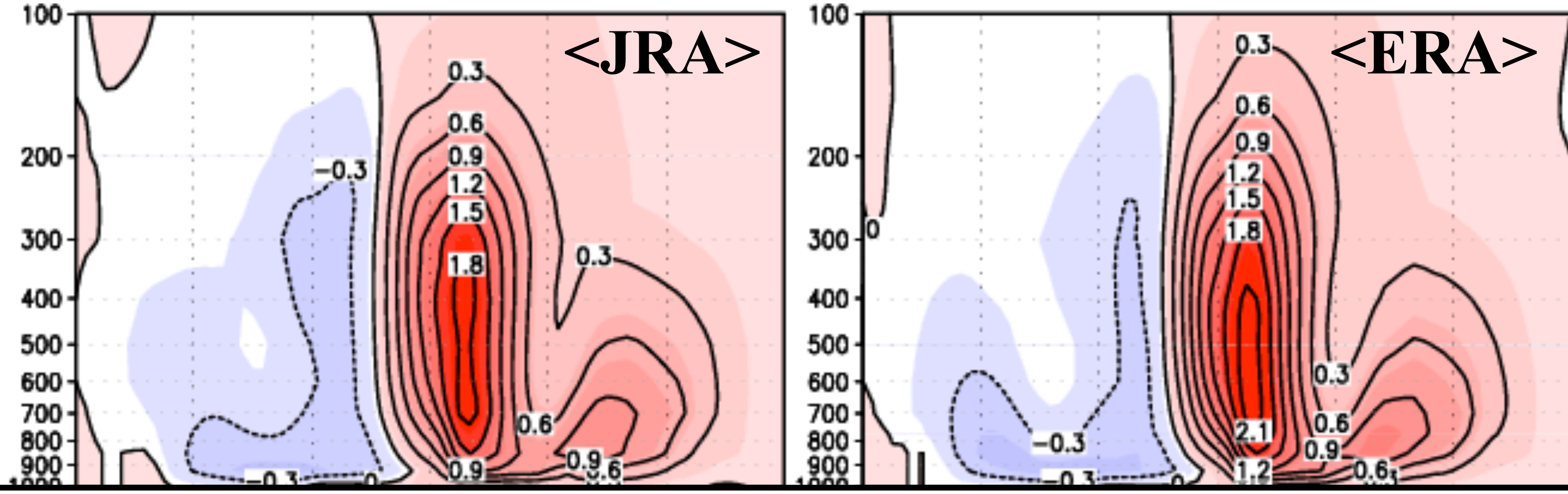
Global Temperature Anomaly



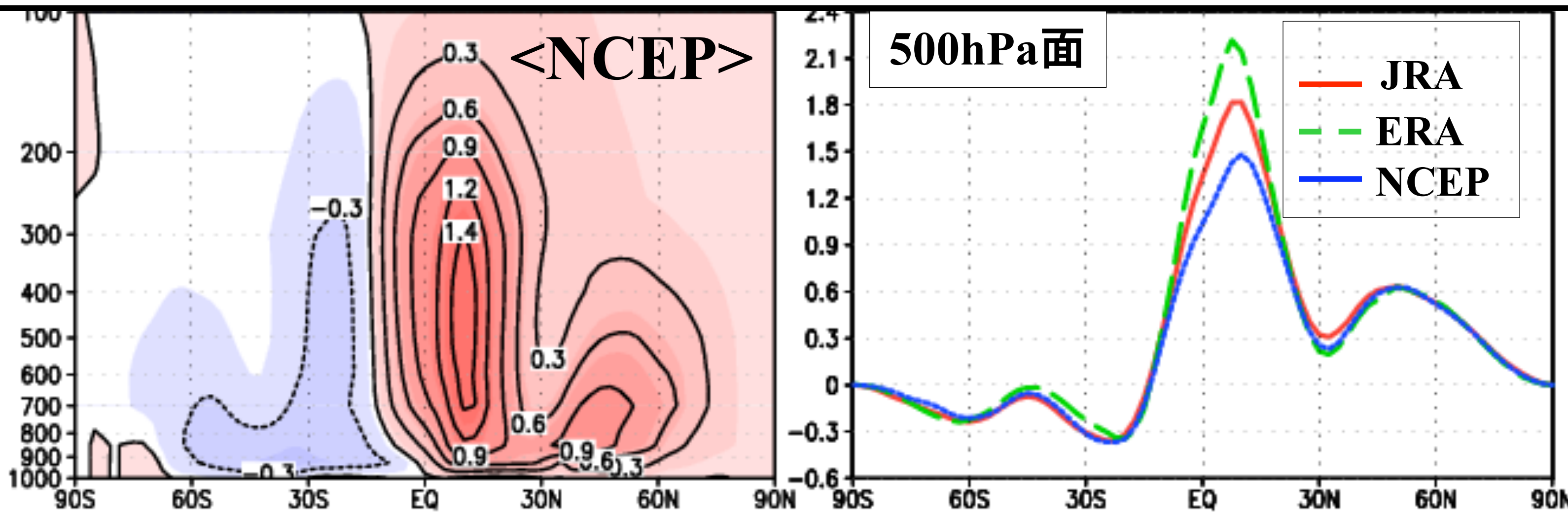
Anomaly from averaged temperature of each level for each reanalysis

Courtesy: J. Tsutsui and M. Sakamoto

DJF Troposphere(1000-100hPa)

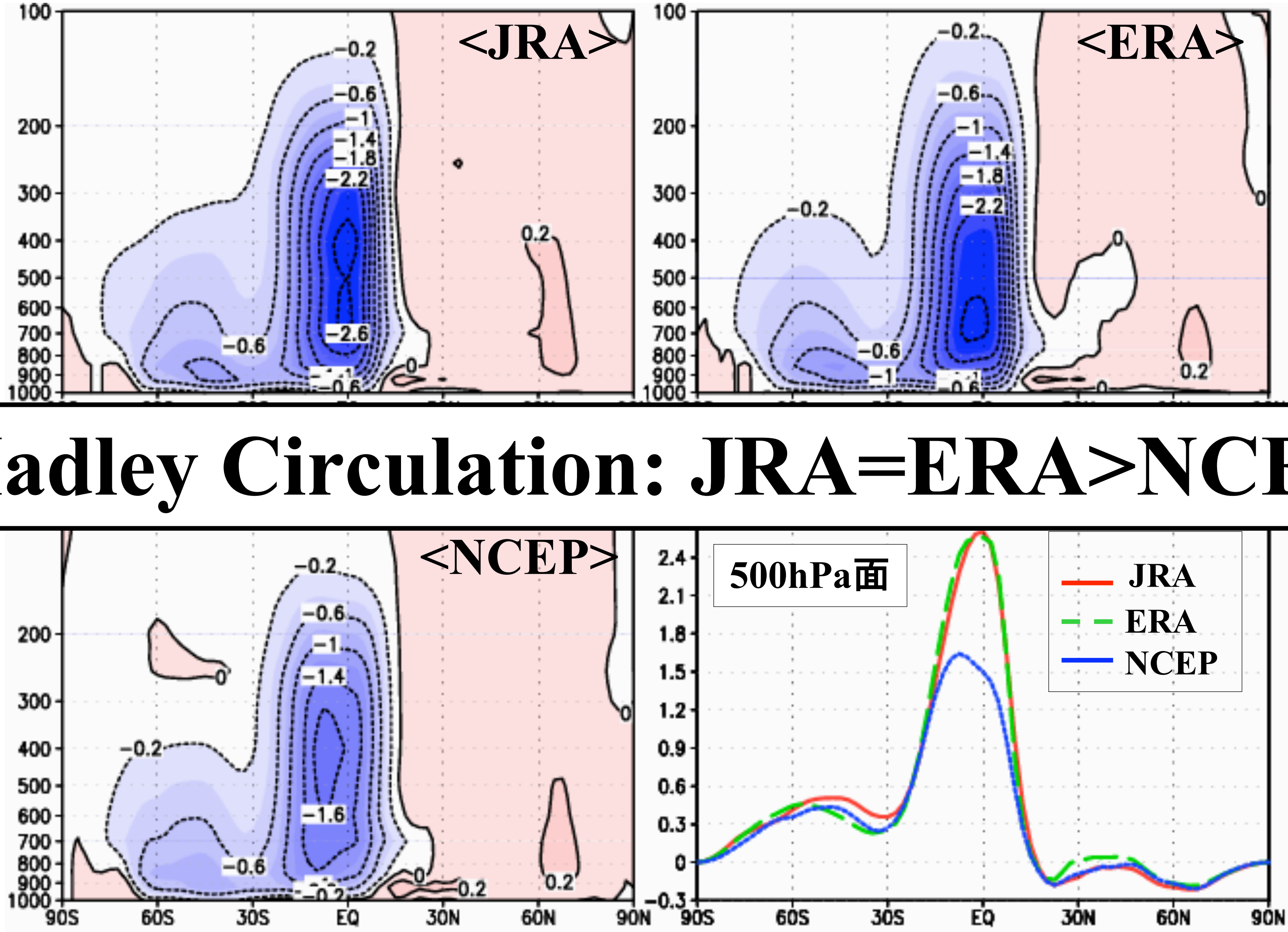


Hadley Cirulation : ERA>JRA>NCEP



Mass stream functions (*1e+11[kg/s])

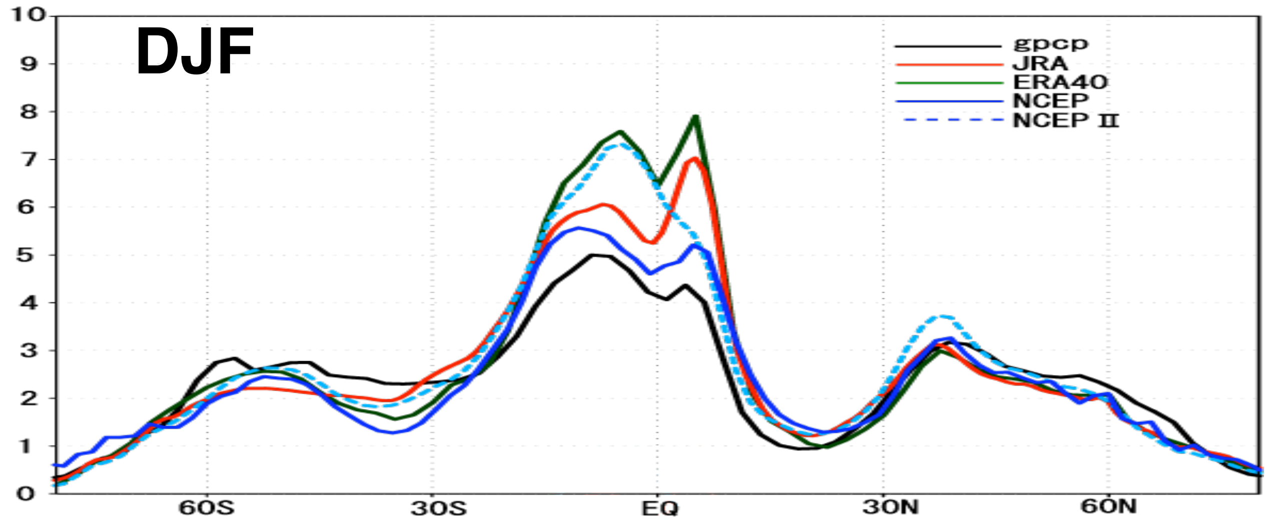
JJA Troposphere(1000-100hPa)

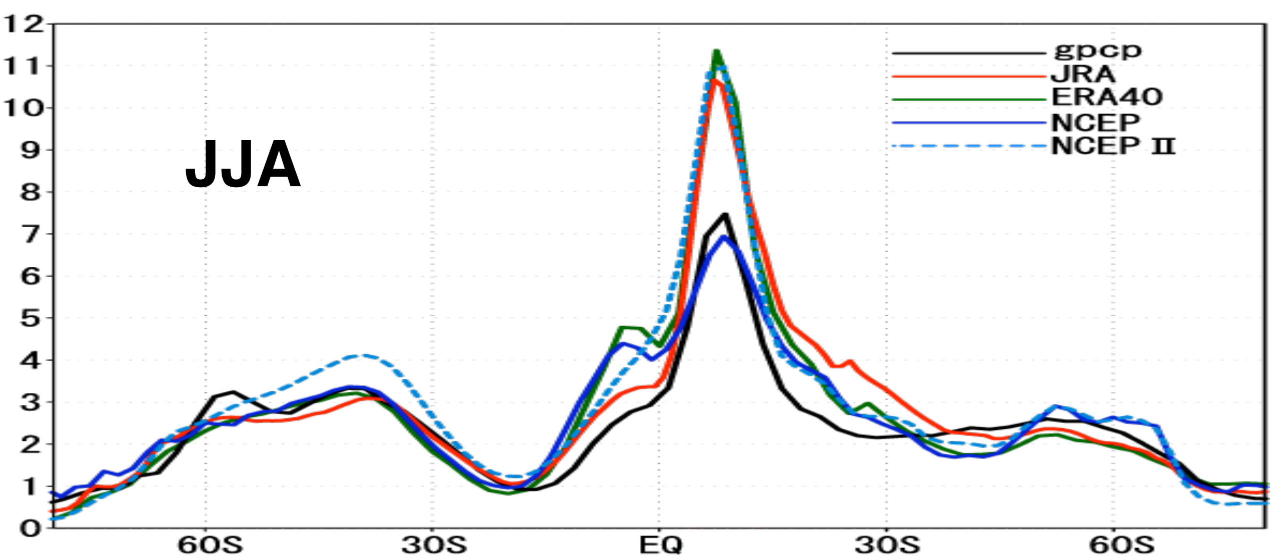


Hadley Circulation: JRA=ERA>NCEP

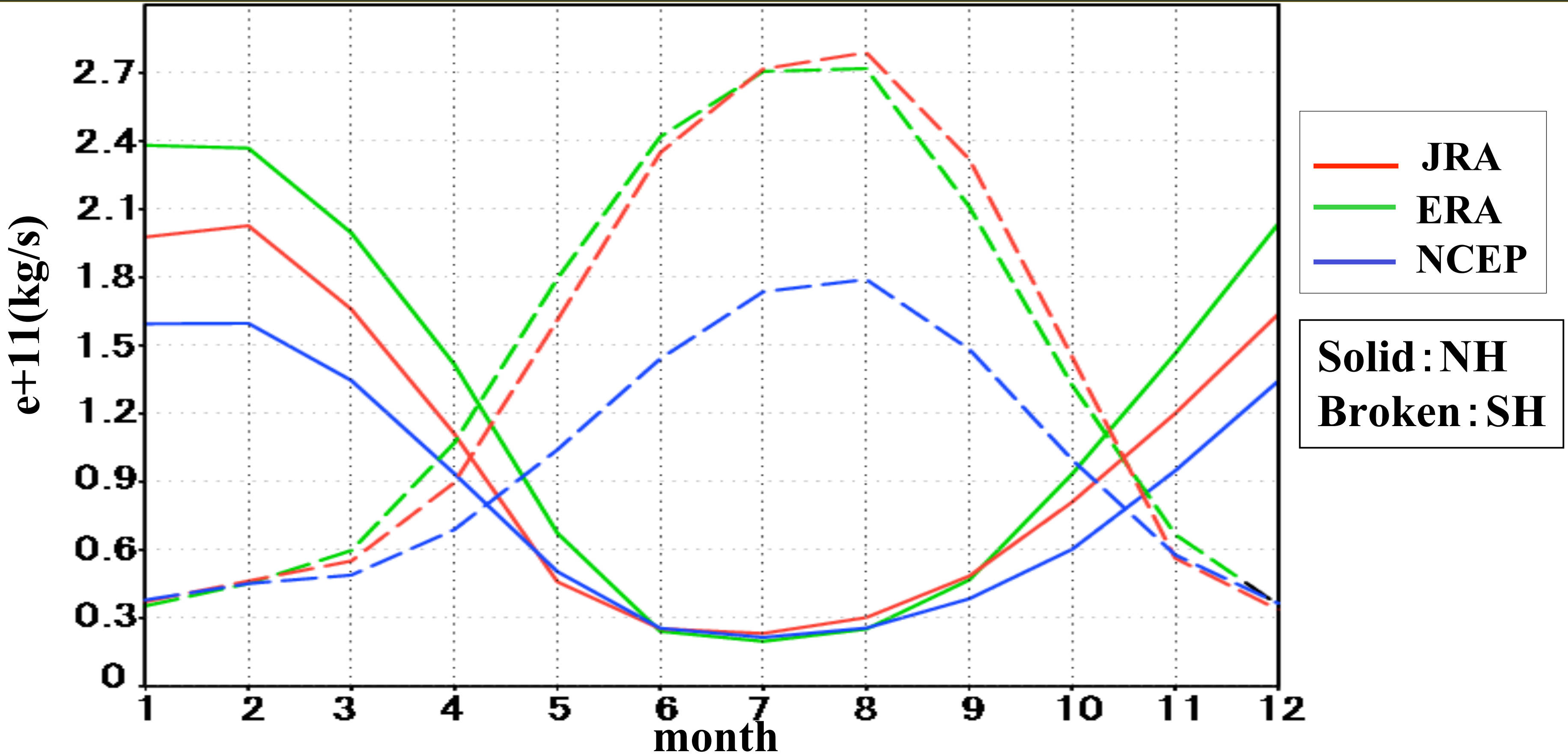
Mass Streamfunction (*1e+11[kg/s])

Precipitation (1979-2001)[mm/day]



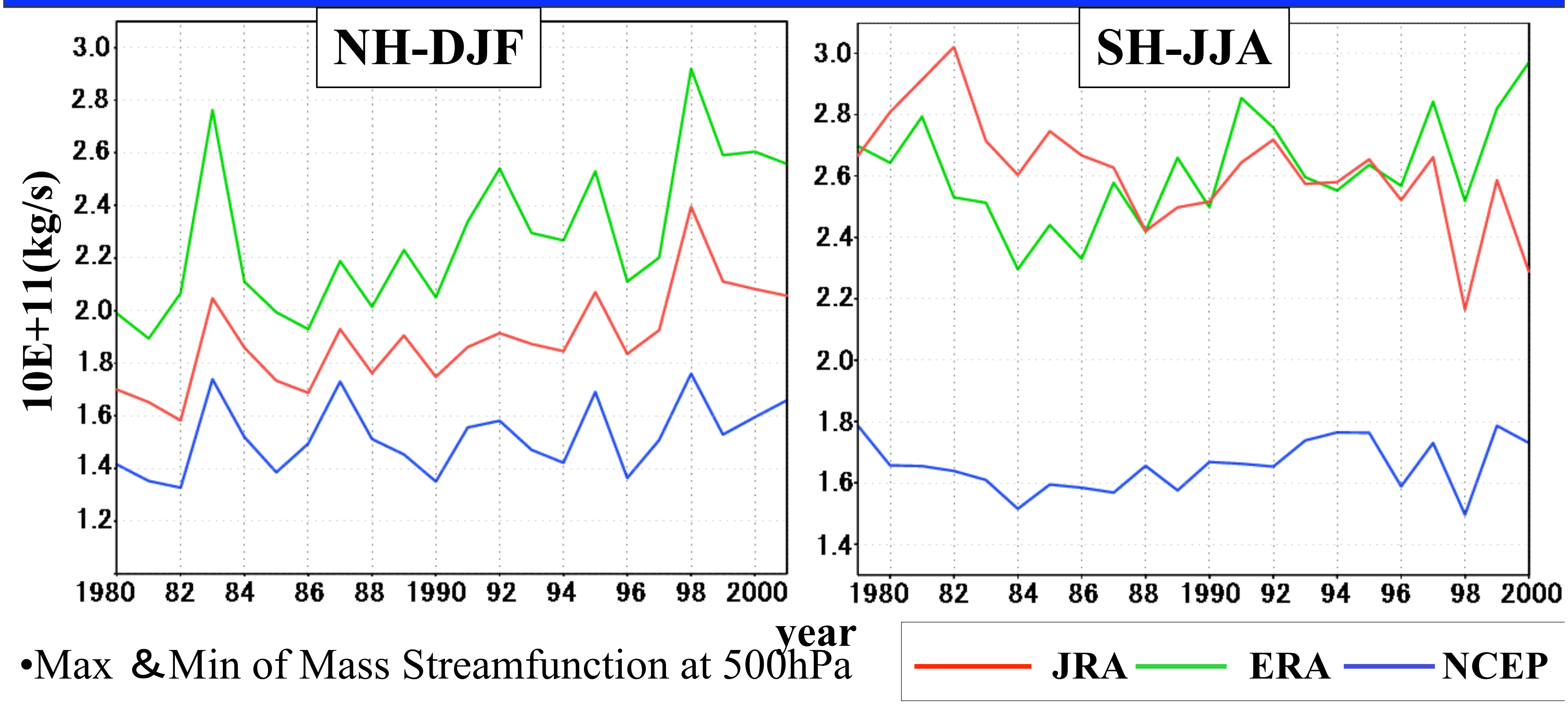


Seasonal Variations
Max and Min of Mass Streamfunction at 500 hPa



- JRA=ERA>NCEP in SH winter
- ERA>JRA>NCEP in NH winter
- SH winter > NH winter

Inter annual variability of Hadley circulation



•Max &Min of Mass Streamfunction at 500hPa

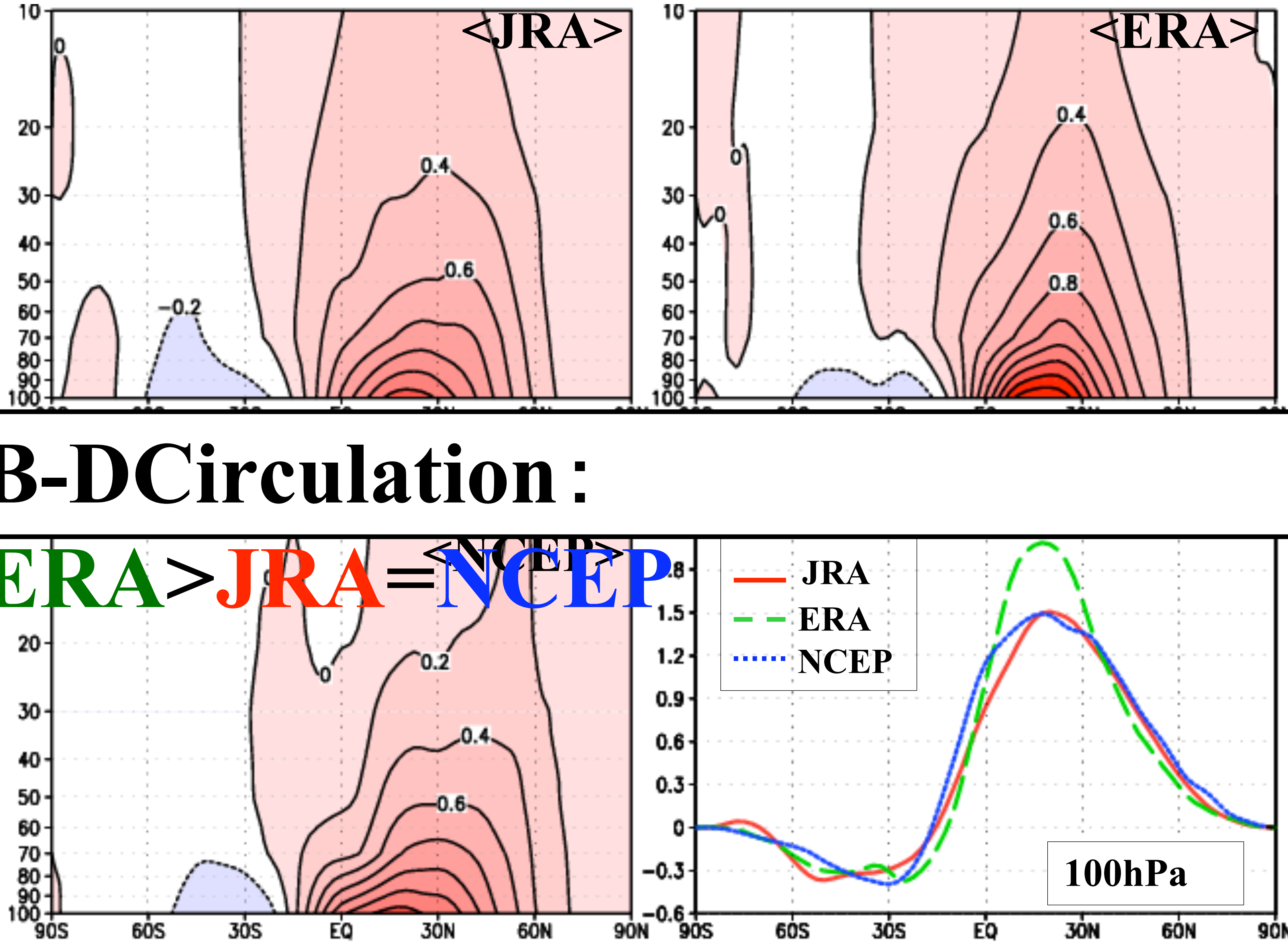
DJF: NH Hadley circulations are gradually strengthened.

Inter-annual variability is strongly correlated among analyses.

JJA: No trend is found in SH winter.

Poor correlation of inter-annual variability among analyses.

DJF: Stratosphere(100-10hPa)

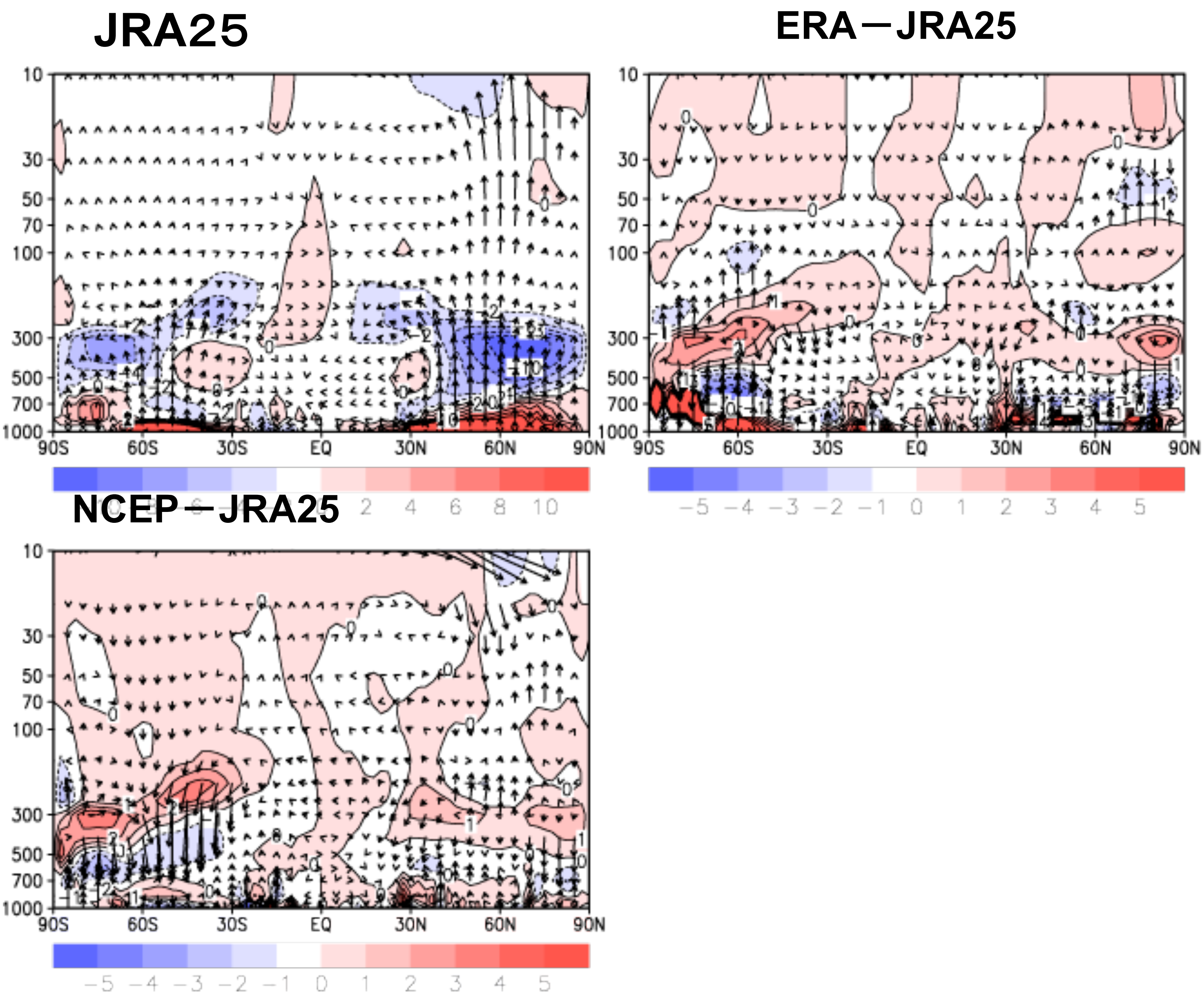


B-DCirculation：

ERA>JRA=NCEP

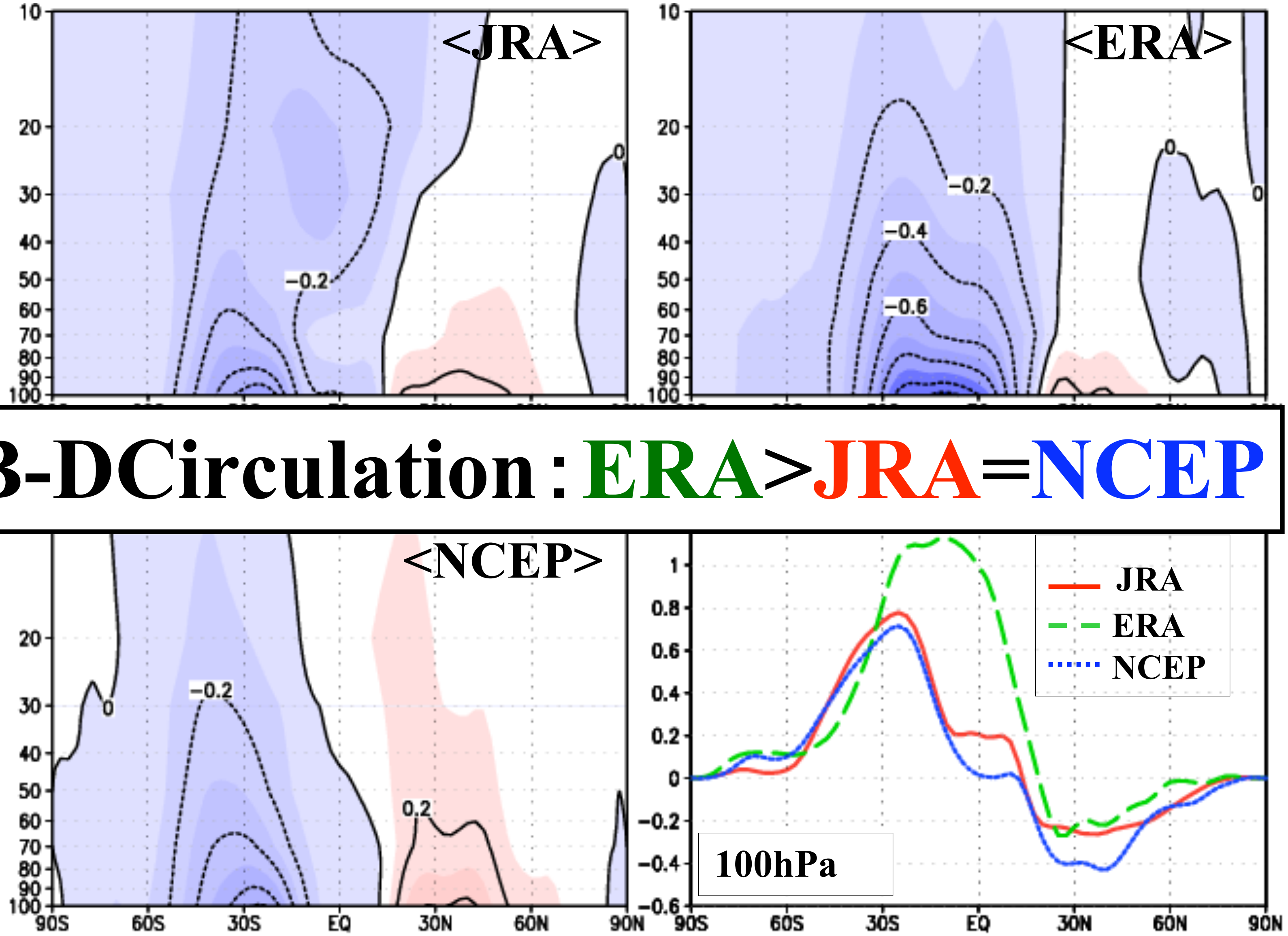
Mass Streamfunction (*1e+10[kg/s])

DJF



JRA25
ERA－JRA25
NCEP－JRA25
10
30
50
70
100
300
500
700
1000
90S
60S
30S
EQ
30N
60N
90N
2
4
6
8
10
−5 −4 −3 −2 −1 0 1 2 3 4 5

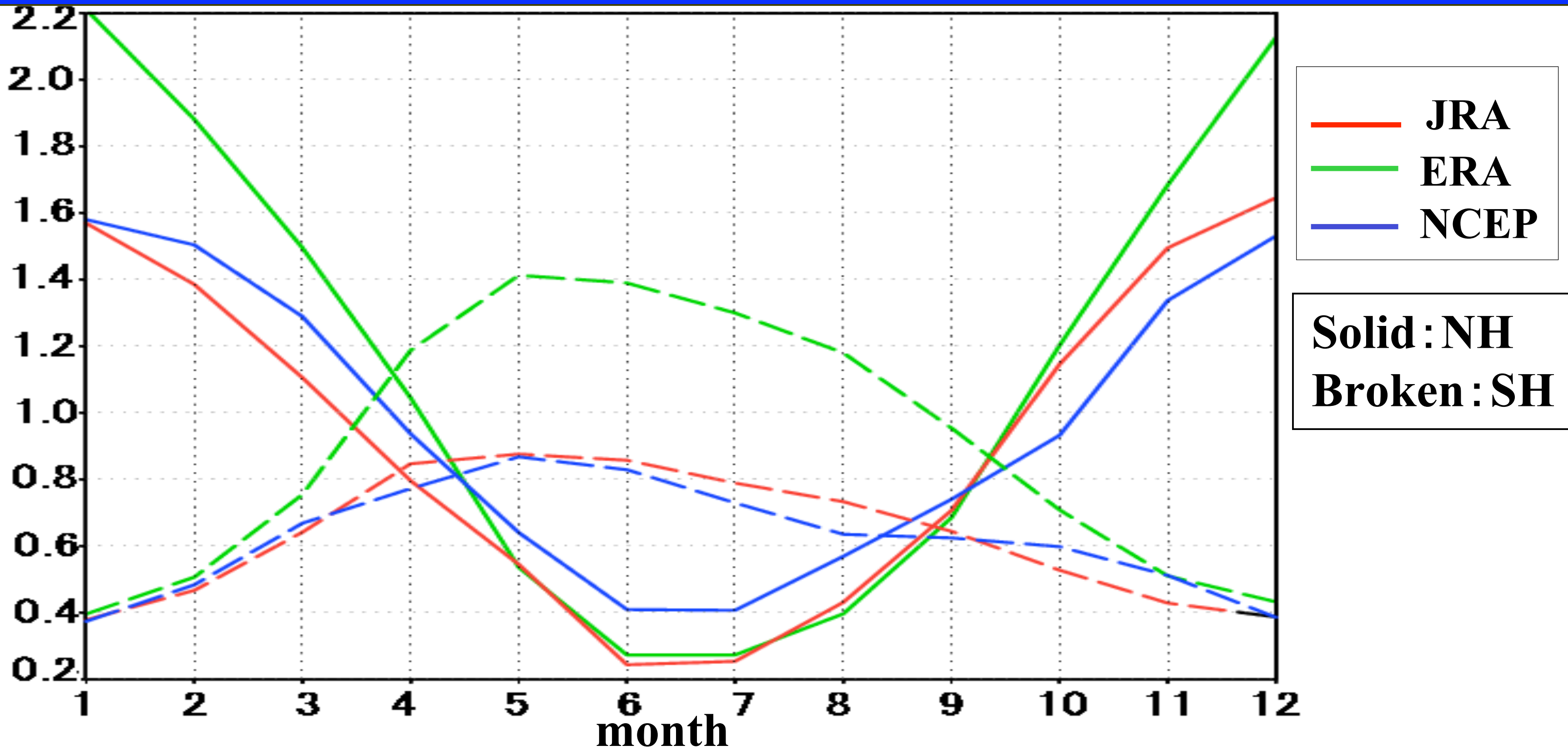
JJA: Stratosphere(100-10hPa)



B-DCirculation：ERA>JRA=NCEP

Mass Streamfunction (*1e+10[kg/s])

Seasonal Variations
Max and Min of Mass Streamfunction at 100 hPa

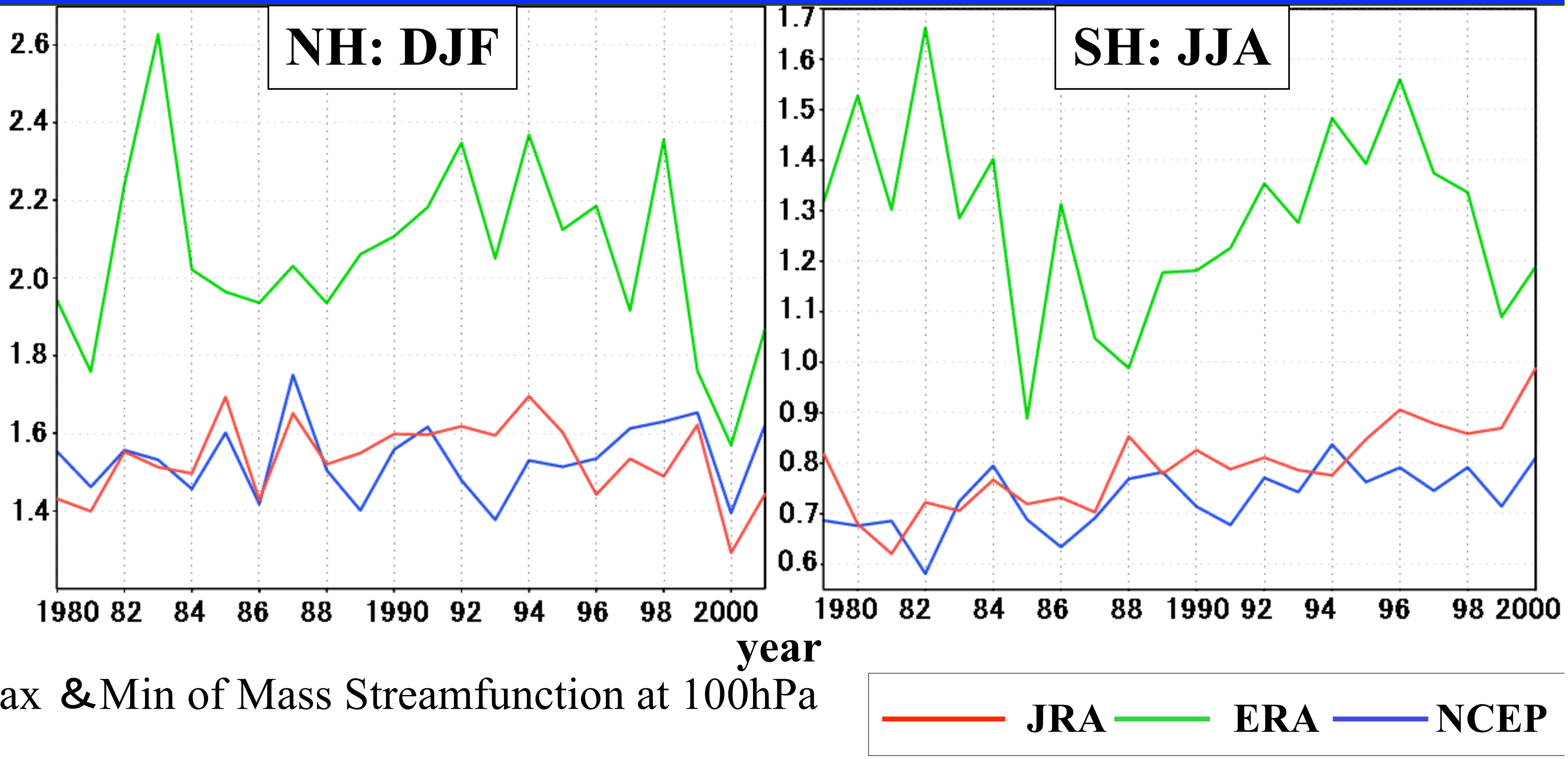


- Downward mass flux integrated over hemispheres at 100 hPa

- Amplitude of Seasonality: ERA>JRA,NCEP

- NH winter ＞SH winter

Inter annual variability of T-S mass exchange



•Max & Min of Mass Streamfunction at 100hPa

No significant trend.

Poor correlation among analyses.

Mean-Meridional Circulation

1. Hadley circulation is: ERA>JRA>NCEP. This may be due to precipitation neat the ITCZ.

2. In NH winter, the Hadley circulation has increasing trends and good correlations among the reanalyses.

3. Midlatitude-tropospheric circulation is almost even in all.

4. BD circulation (downward mass flux at 100hPa) is ERA>JRA>NCEP. But we do not find a strong relationship with EP flux divergence.

5. Stratospheric analysis does not show significant trends or correlations but suffers from biases of satellite data.

Ozone reanalysis
with a CTM driven by the atmospheric reanalysis
(1993-1994)

CTM is driven by T42L68-AGCM and the GCM is nudged to the reanalyses with appropriate relaxation times.

No chemical data is assimilated so as to see the transport characteristics in detail.

Transport diagnosis is made based on mass-weighted isentropic zonal means.

Definition of Zonal Mean State

Mass-weighted isentropic zonal means are taken for all variables, to express the lower boundary conditions and nongeostrophic and finite-amplitude effects of waves.

Zonal Means $$\overline{A(y,\theta,t)}^{*} \equiv \frac{1}{Lx}\int A(x,y,\theta,t)\left(\frac{\partial p}{\partial\theta}\Big/\frac{\partial\overline{p}}{\partial\theta}\right)dx$$

Eddies $A' \equiv A - \overline{A}^{*}$ **Correlations** $\overline{(AB)}^{*} = \overline{A}^{*}\,\overline{B}^{*} + \overline{(A'B')}^{*}$

Isentropic zonal mean pressure is used as the vertical coordinates.
◊ The thermodynamic equation is prognostic while the continuity equation is daignostic.

Vertical Coordinate (isentropic zonal mean pressure) $p_{\dagger} \equiv \overline{p}$

In the zonal averaging, we set $p(x) = p_s(x)$ **for** $\theta_s(x) < \theta$

Logarithmic Pressure Coordinate $z_{\dagger} \equiv -H\log\left(p_{\dagger}/p_{00}\right)$

Formulation of the zonal mean transport equation

The mass-weighting is also considered for the mixing ratio of minor constituent as well as the mean meridional circulation.

The transport equation helps us to express the conservation of minor constituents including the lower boundary condition.

Zonally symmetric transport equation:

$$\frac{\partial \overline{r^*}}{\partial t} = \underbrace{-\frac{\overline{v^*}}{a}\frac{\partial \overline{r^*}}{\partial \phi} - \overline{w^*_\dagger}\frac{\partial \overline{r^*}}{\partial z_\dagger}}_{\text{Mean transport}} \underbrace{- \frac{1}{a\cos\phi}\frac{\partial \overline{(r'v')^* \cos\phi}}{\partial \phi} - \frac{1}{\rho_0}\frac{\partial \rho_0 \overline{(r'w'_\dagger)^*}}{\partial z_\dagger}}_{\text{Eddy transport}} + \overline{Q^*}.$$

Time derivation of mass mixing ratio

Chemical production/loss

Formulation of the zonal mean transport equation

Mean transport flux

$$\mathbf{F}_{mean}(\phi, z_\dagger) = \left[\rho_0 \overline{r^* v^*}, \rho_0 \overline{r^* w_\dagger^*}\right],$$

Eddy transport flux

$$\mathbf{F}_{eddy}(\phi, z_\dagger) = \left[\rho_0 \overline{(r'v')^*}, \rho_0 \overline{(r'w_\dagger')^*}\right].$$

The vertical component of eddy transport term can be separated into the contributions due to adiabatic and diabatic processes.

$$\overline{(r'w_\dagger')^*} = \frac{\overline{(r'v')^*}}{a}\left(\frac{\partial z_\dagger}{\partial \phi}\right)_\theta + \overline{(r'\dot{\theta}')^*}\frac{\partial z_\dagger}{\partial \theta}.$$

For adiabatic processes, the direction of eddy becomes

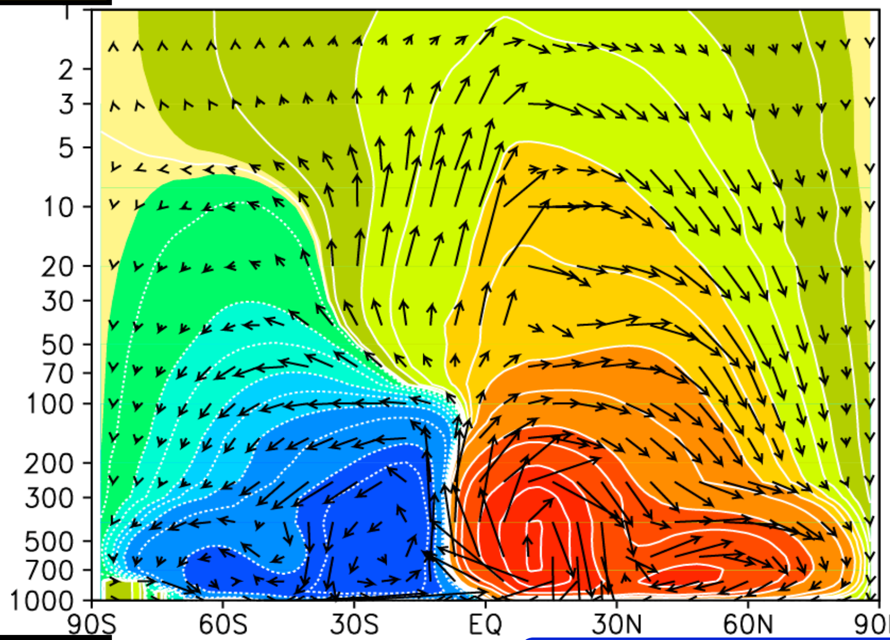
$$\frac{\mathbf{F}_{eddy}(z_\dagger)}{\mathbf{F}_{eddy}(\phi)} = \frac{1}{a}\left(\frac{\partial z_\dagger}{\partial \phi}\right)_\theta.$$

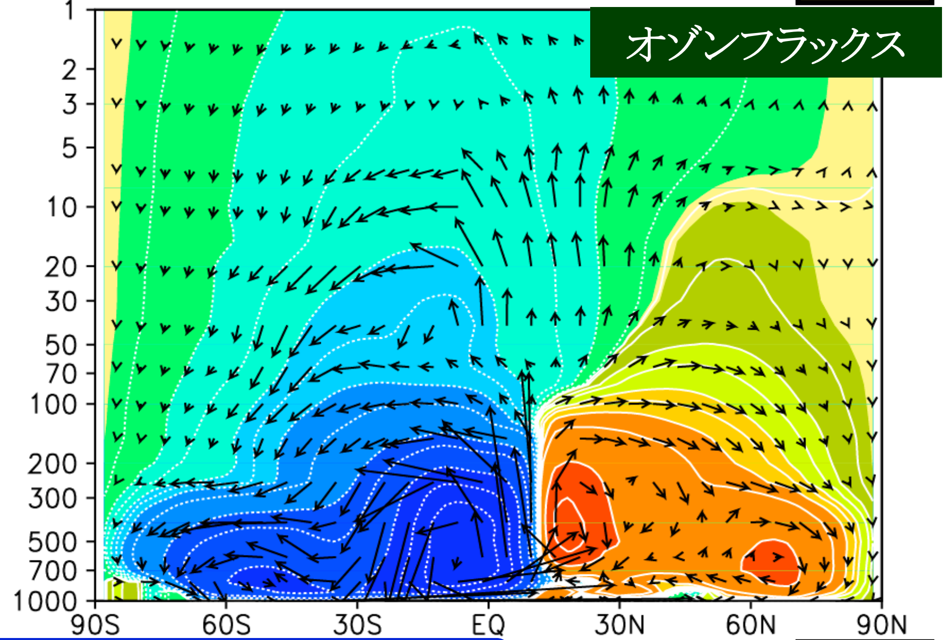
This infers that the eddy flux is parallel to the local isentropic surface for adiabatic processes.

DJF

Mean ozone transport

JJA

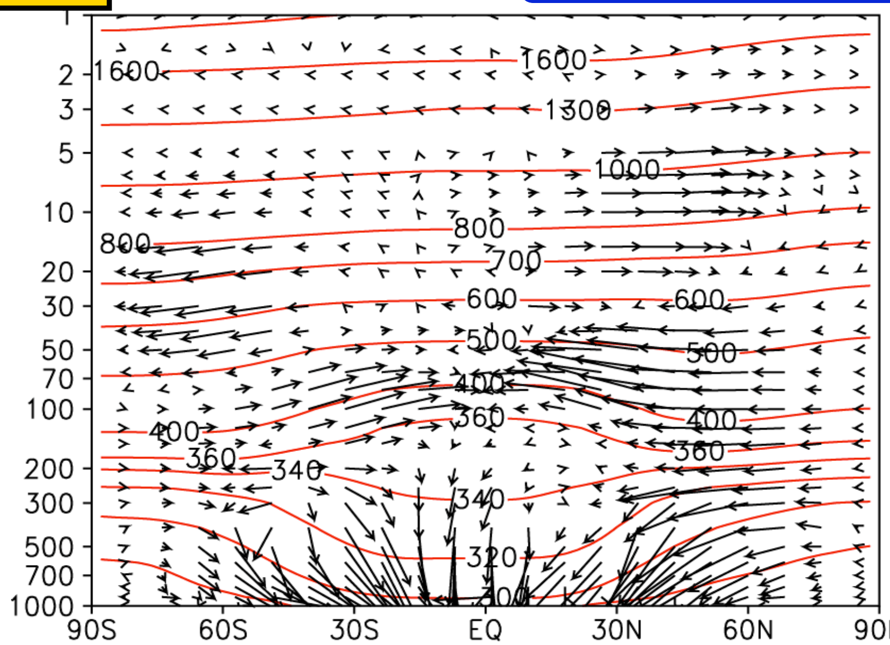


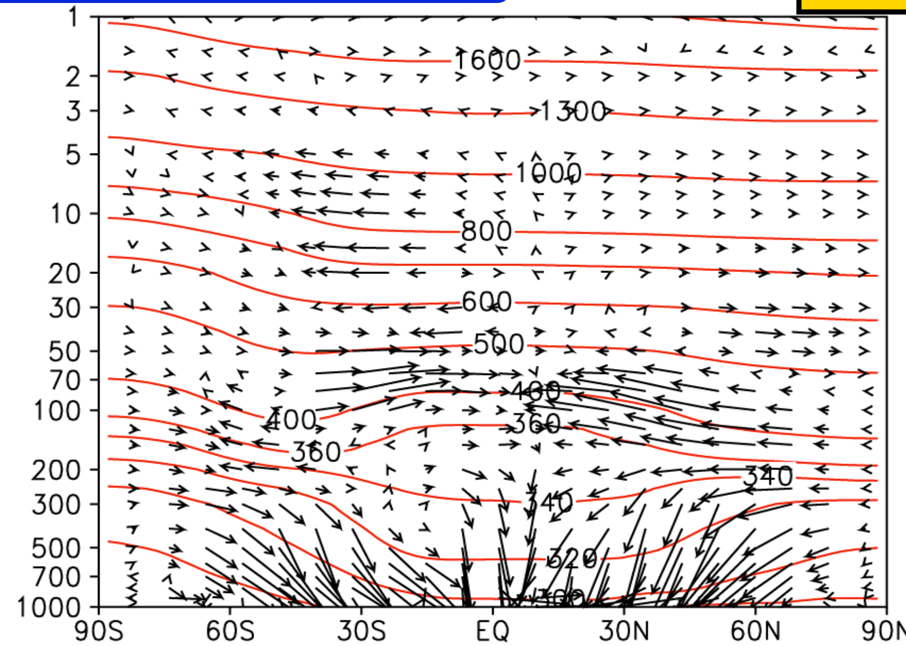


DJF

Eddy ozone transport

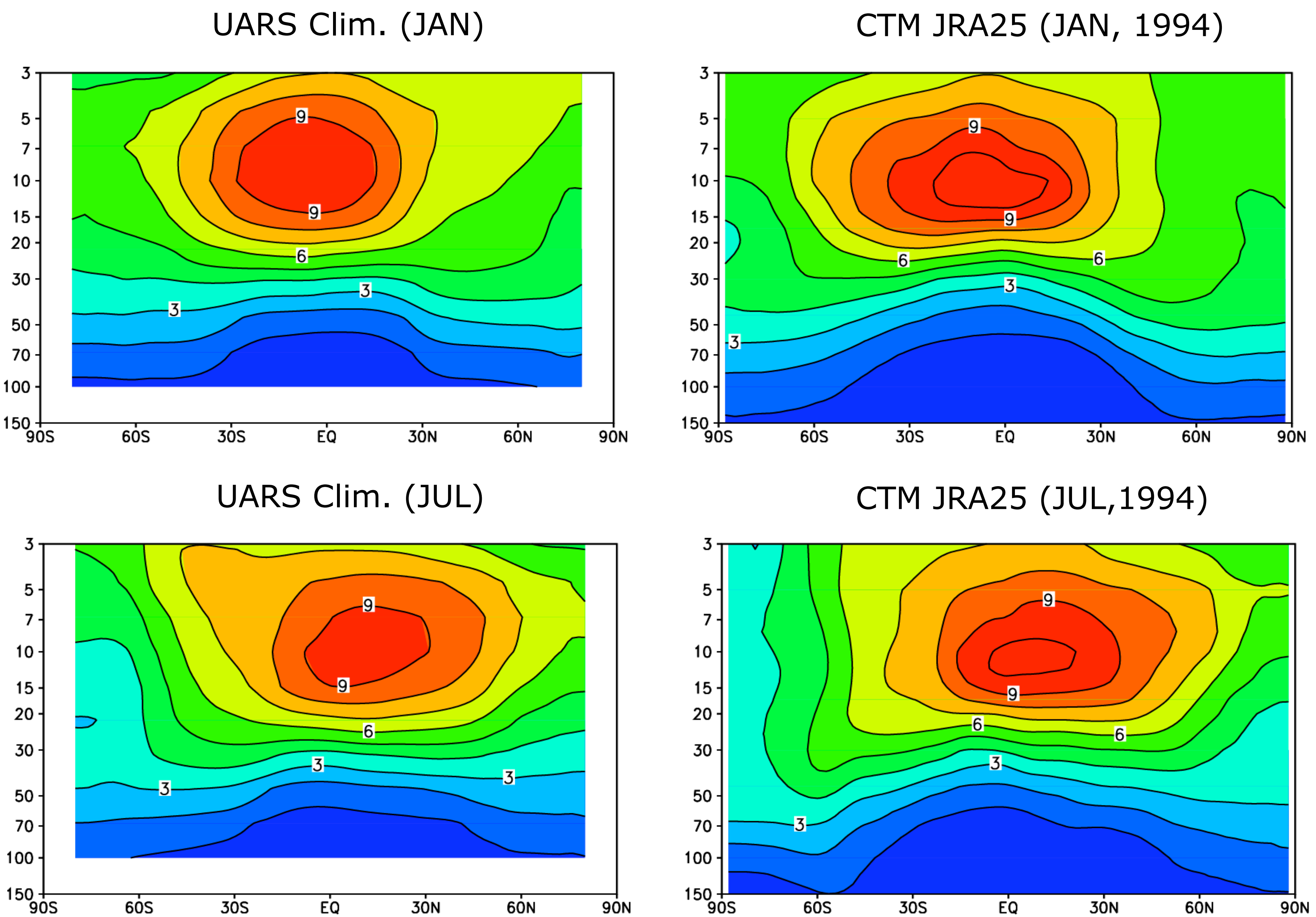
JJA





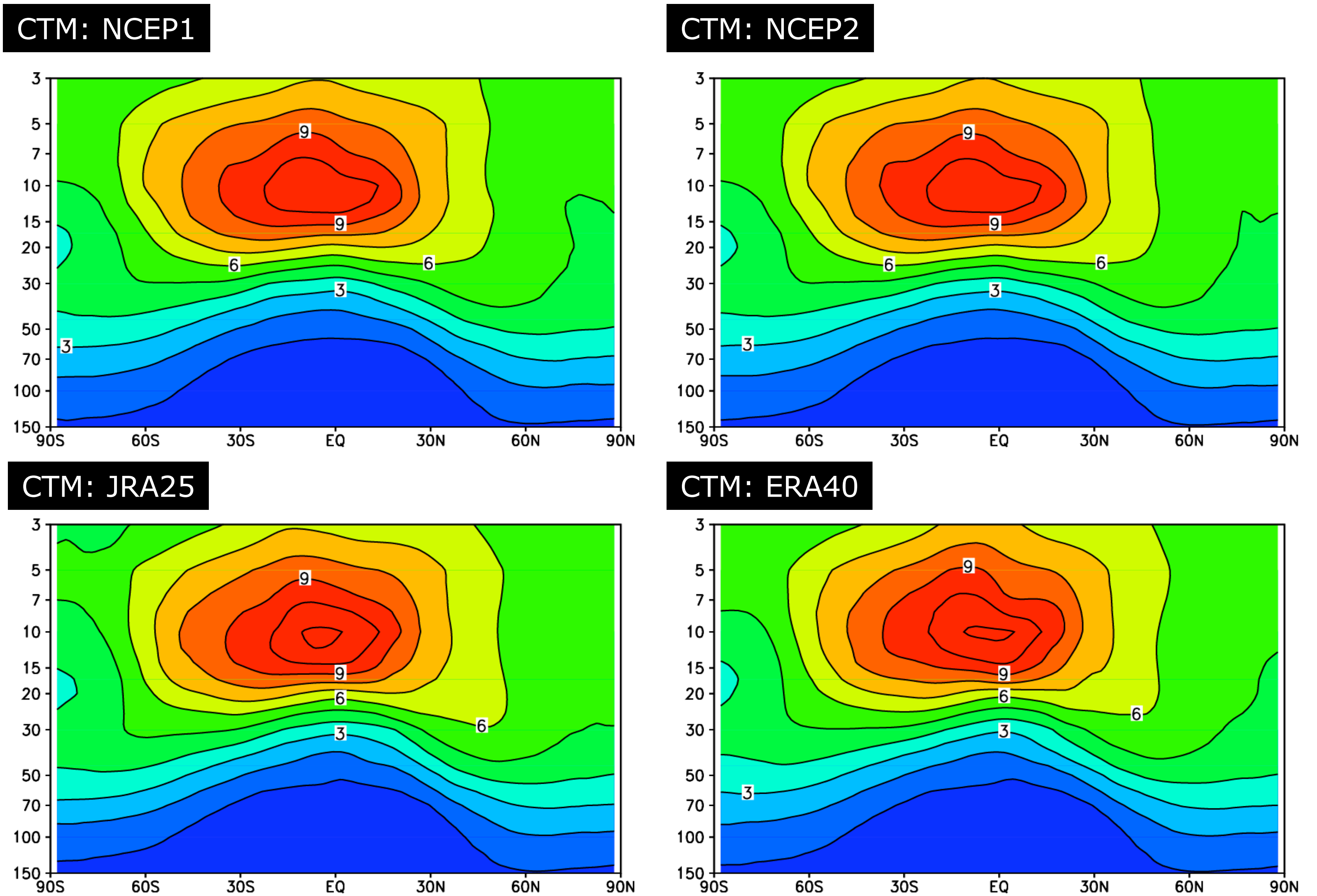
Ozone mixing ratio

Contours int.: 1ppmv



Ozone mixing ratio in Jan. 1994

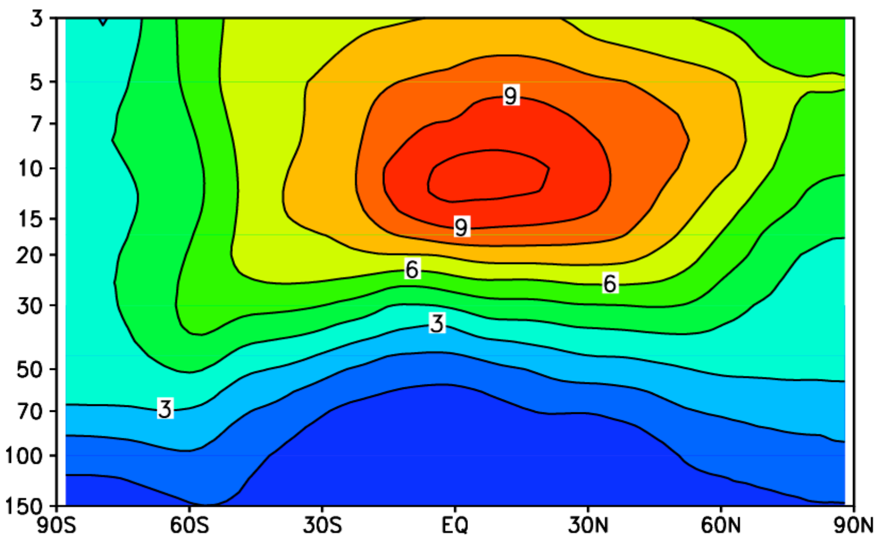
Contours int.: 1ppmv



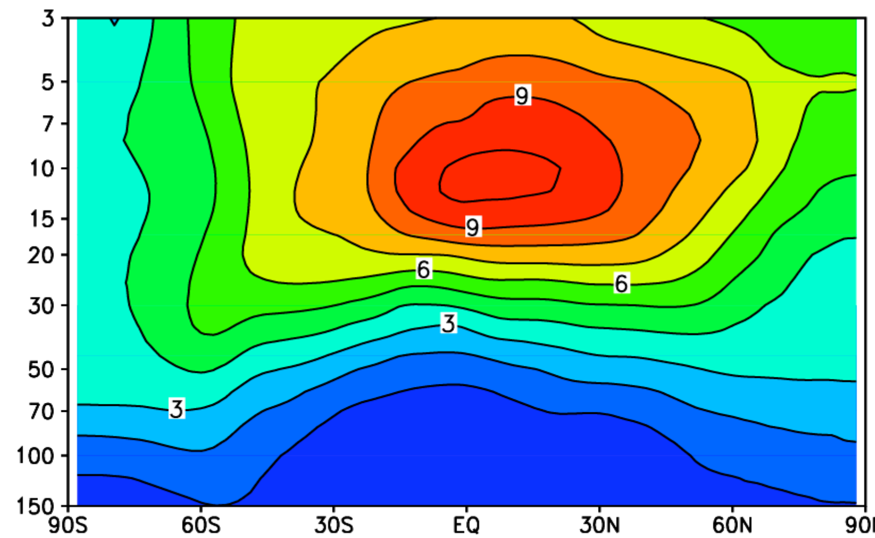
Ozone mixing ratio in Jul. 1994

Contours int.: 1ppmv

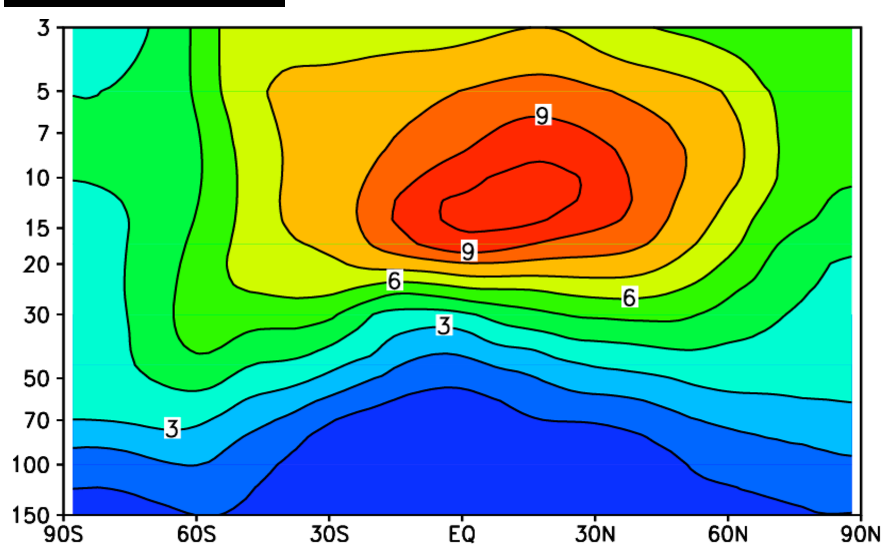
CTM: NCEP1



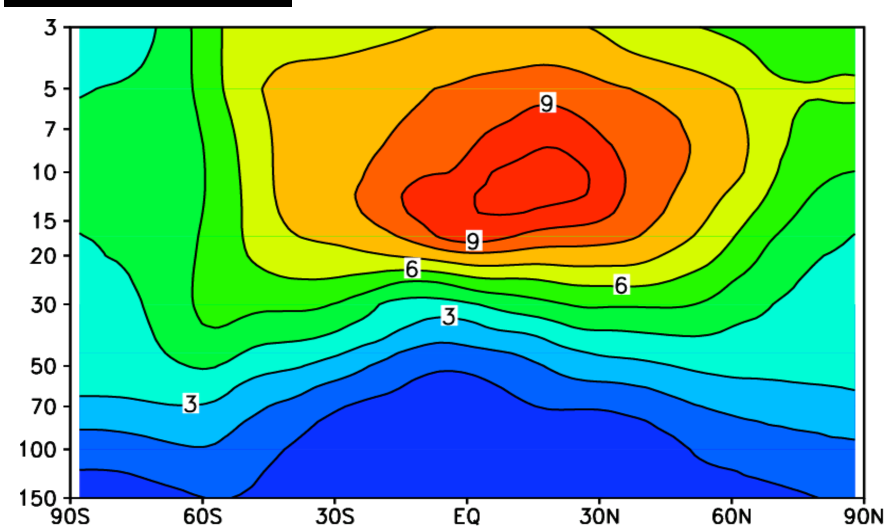
CTM: NCEP2



CTM: JRA25

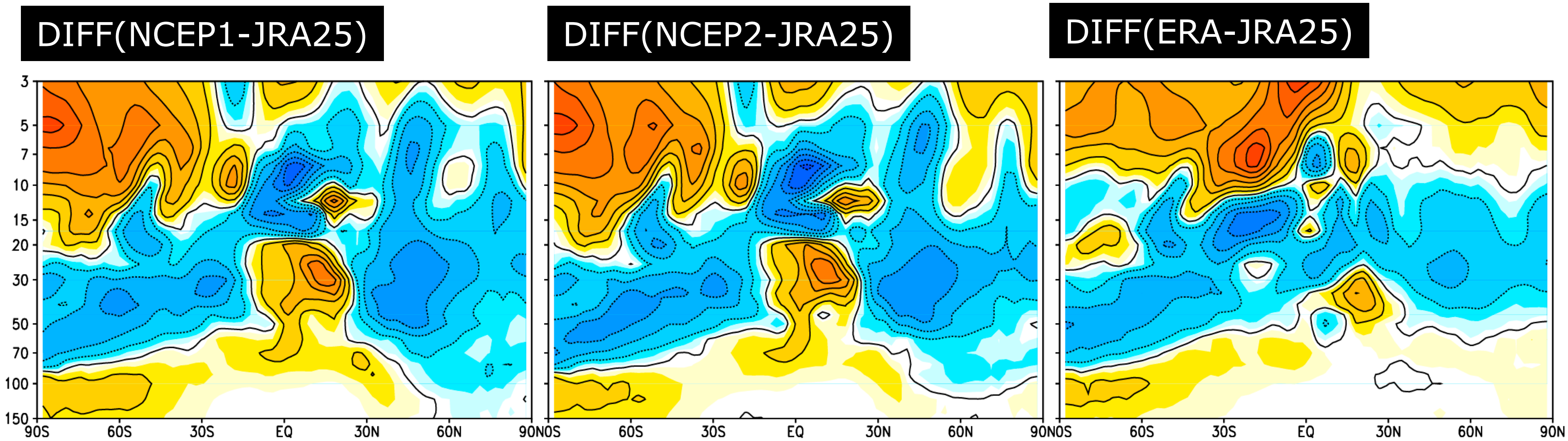


CTM: ERA40

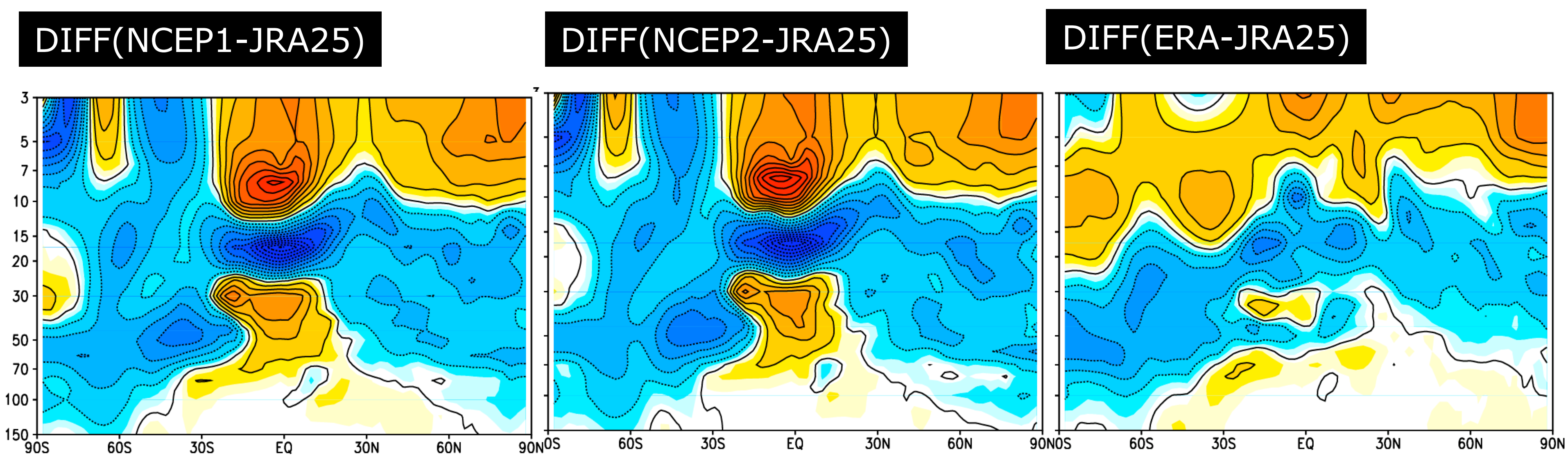


Contours int.: 0.1ppmv

Ozone mixing ratio in Jan. 1994



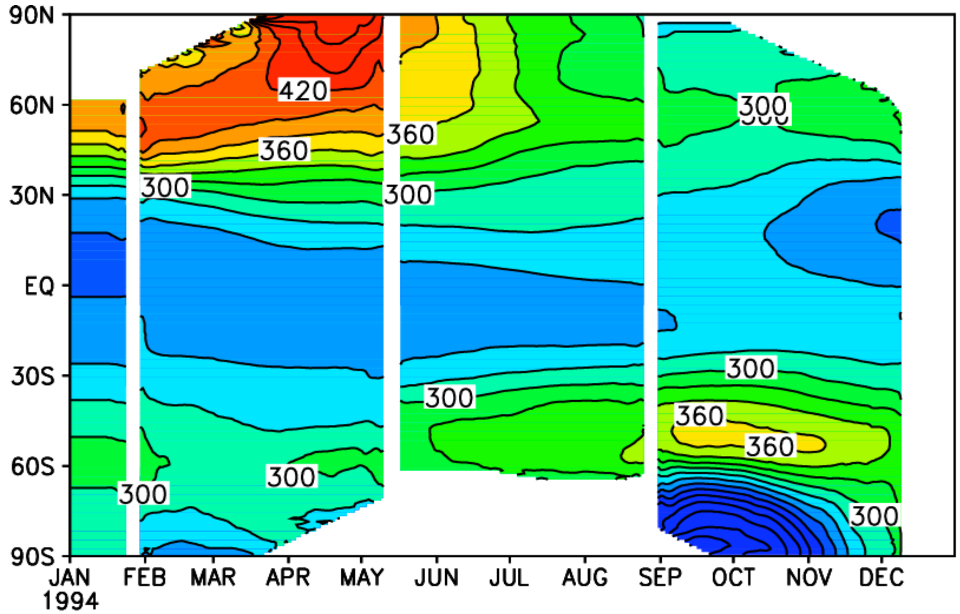
Ozone mixing ratio in Jul. 1994



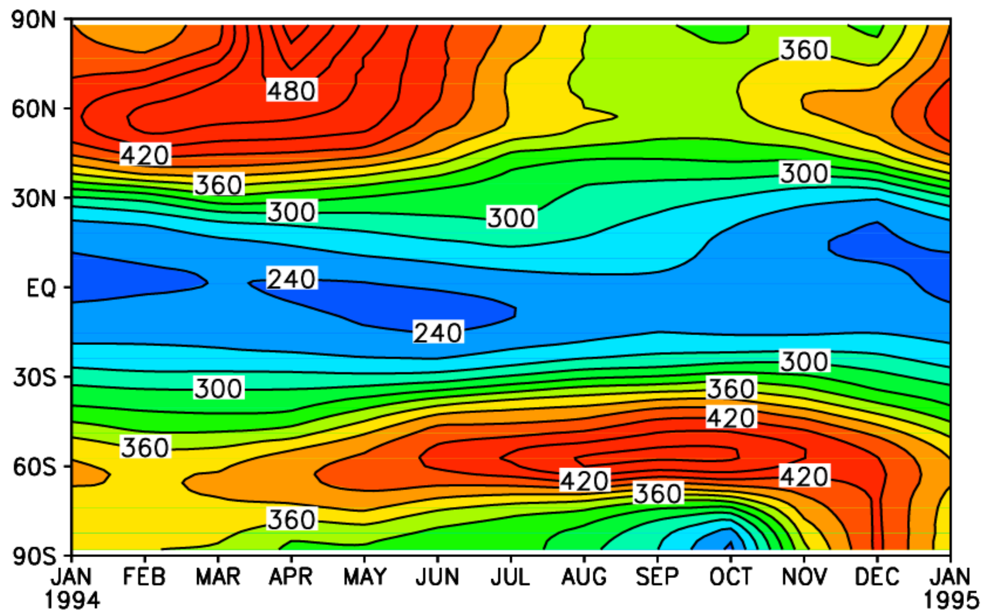
Seasonal variation of Total ozone in 1994

Contours int.: 20DU

OBS: UARS



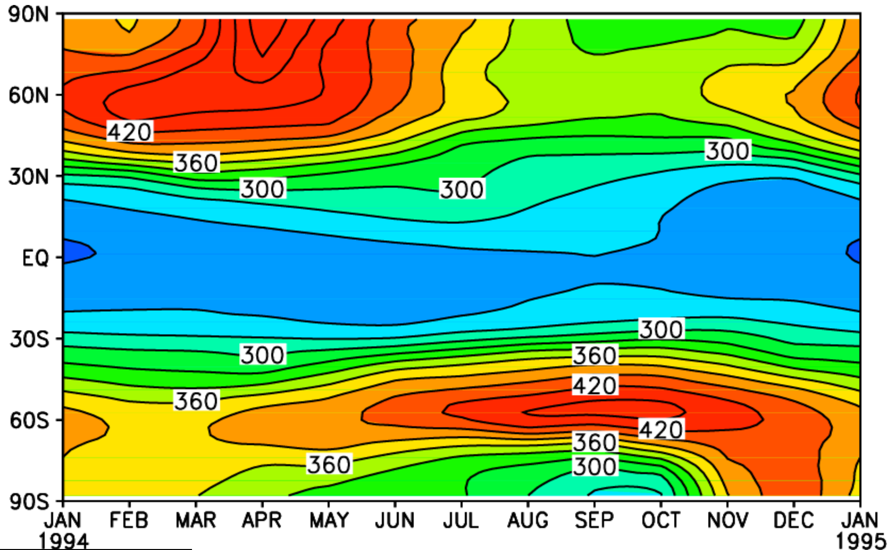
CTM: JRA25



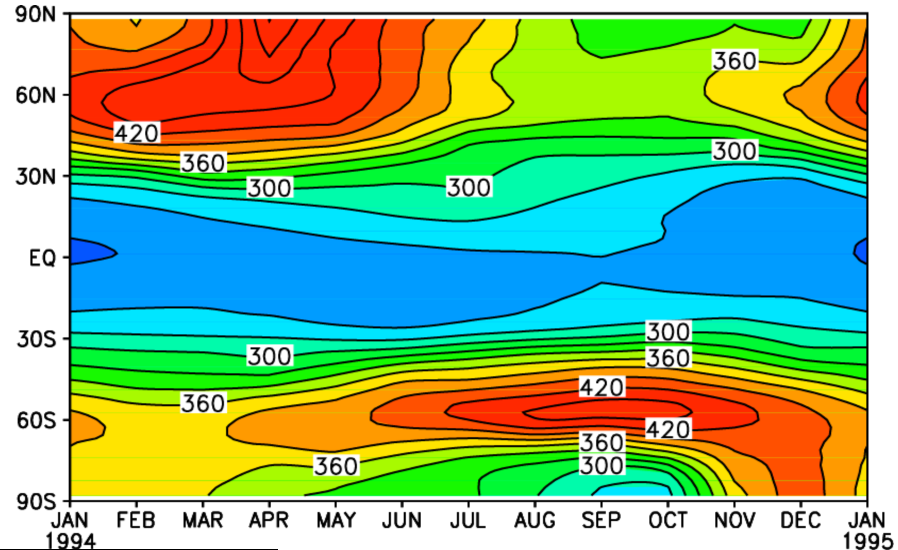
Total ozone in 1994

Contours int.: 20DU

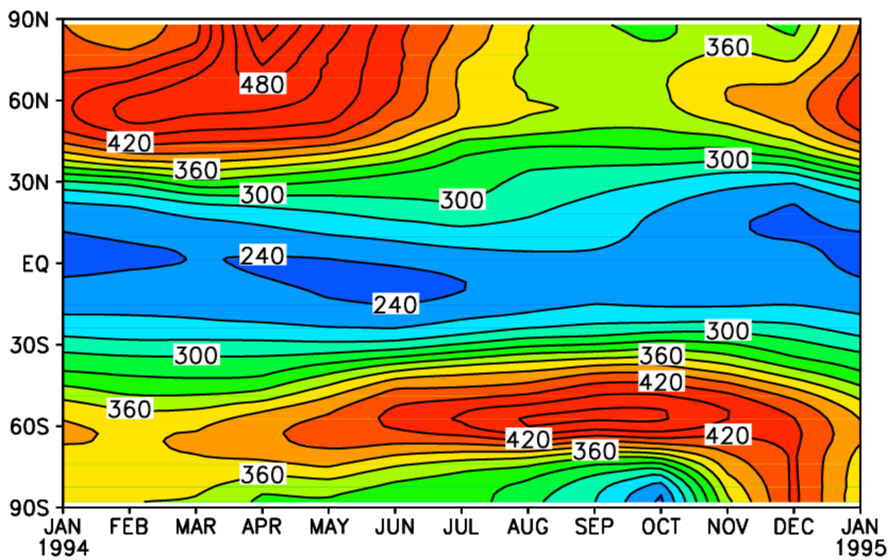
CTM: NCEP1



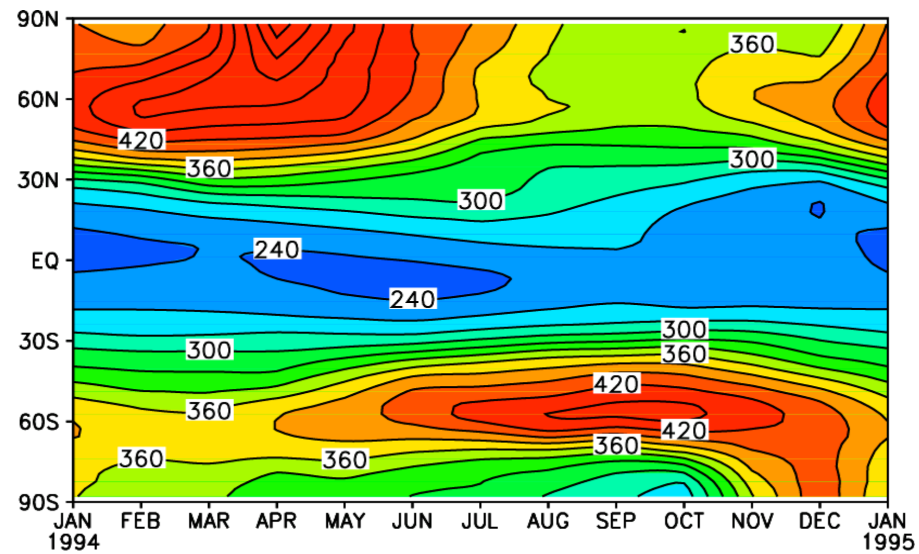
CTM: NCEP2



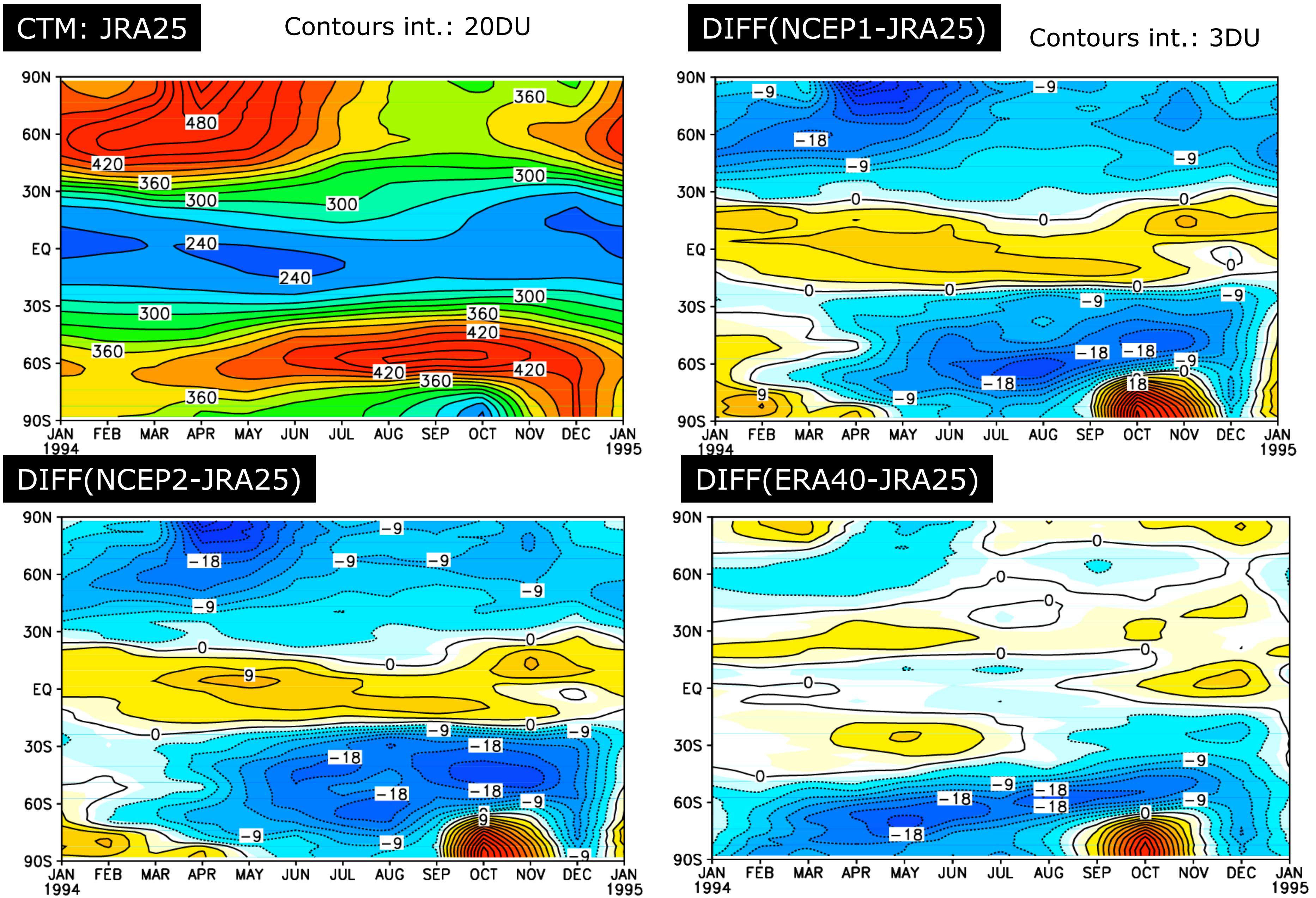
CTM: JRA



CTM: ERA40

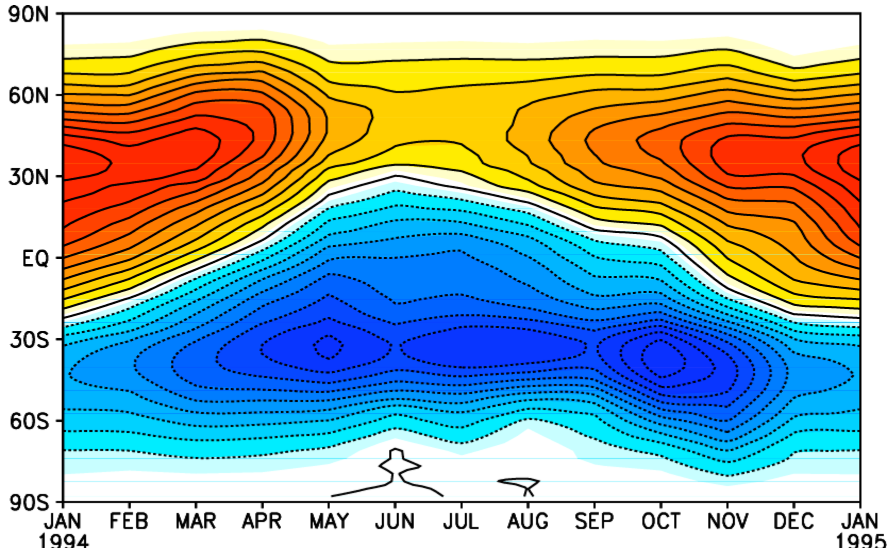


Total ozone in 1994

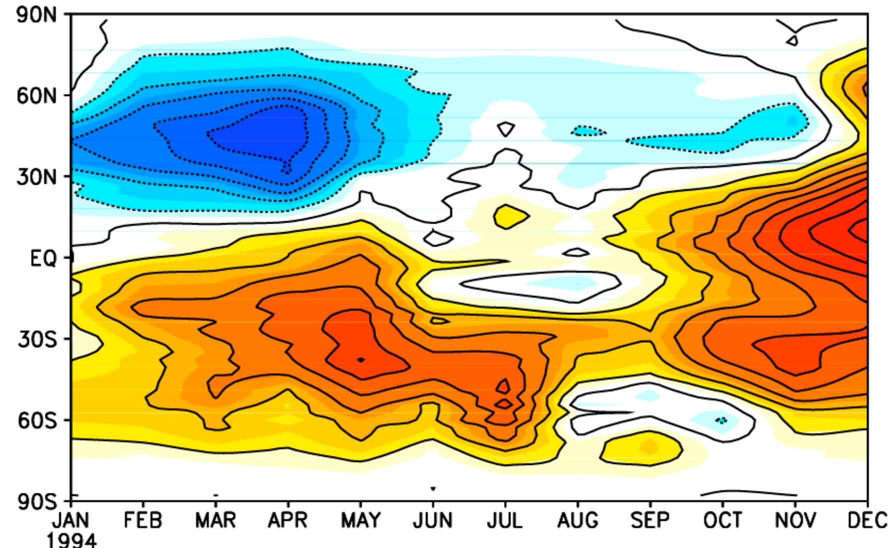


Mean meridional ozone fluxes ingerated through the atmosphere (kg/s)

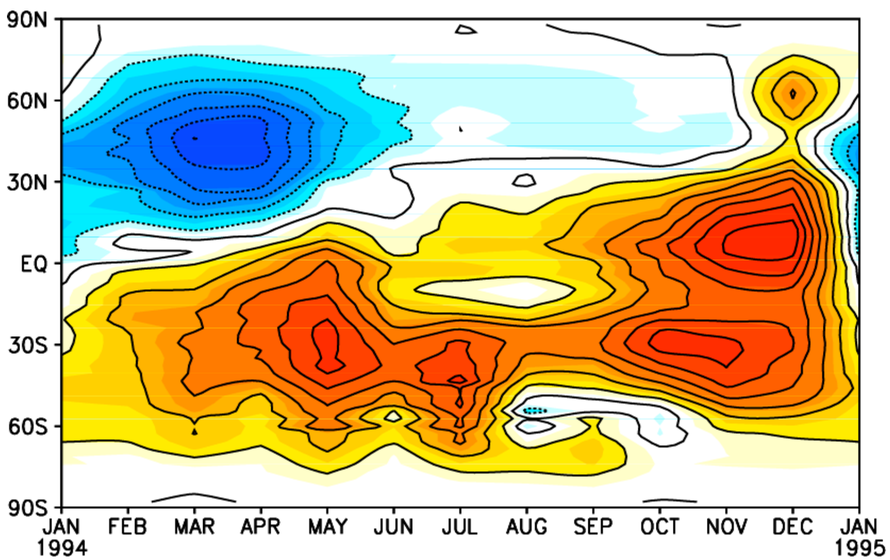
CTM: JRA25 Contours int.: 500



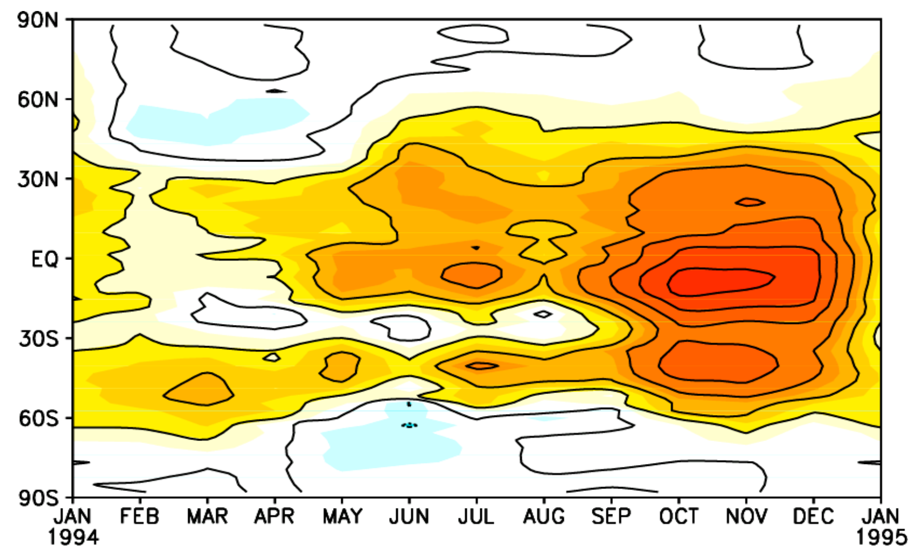
DIFF(NCEP1-JRA25) Contours int.: 100



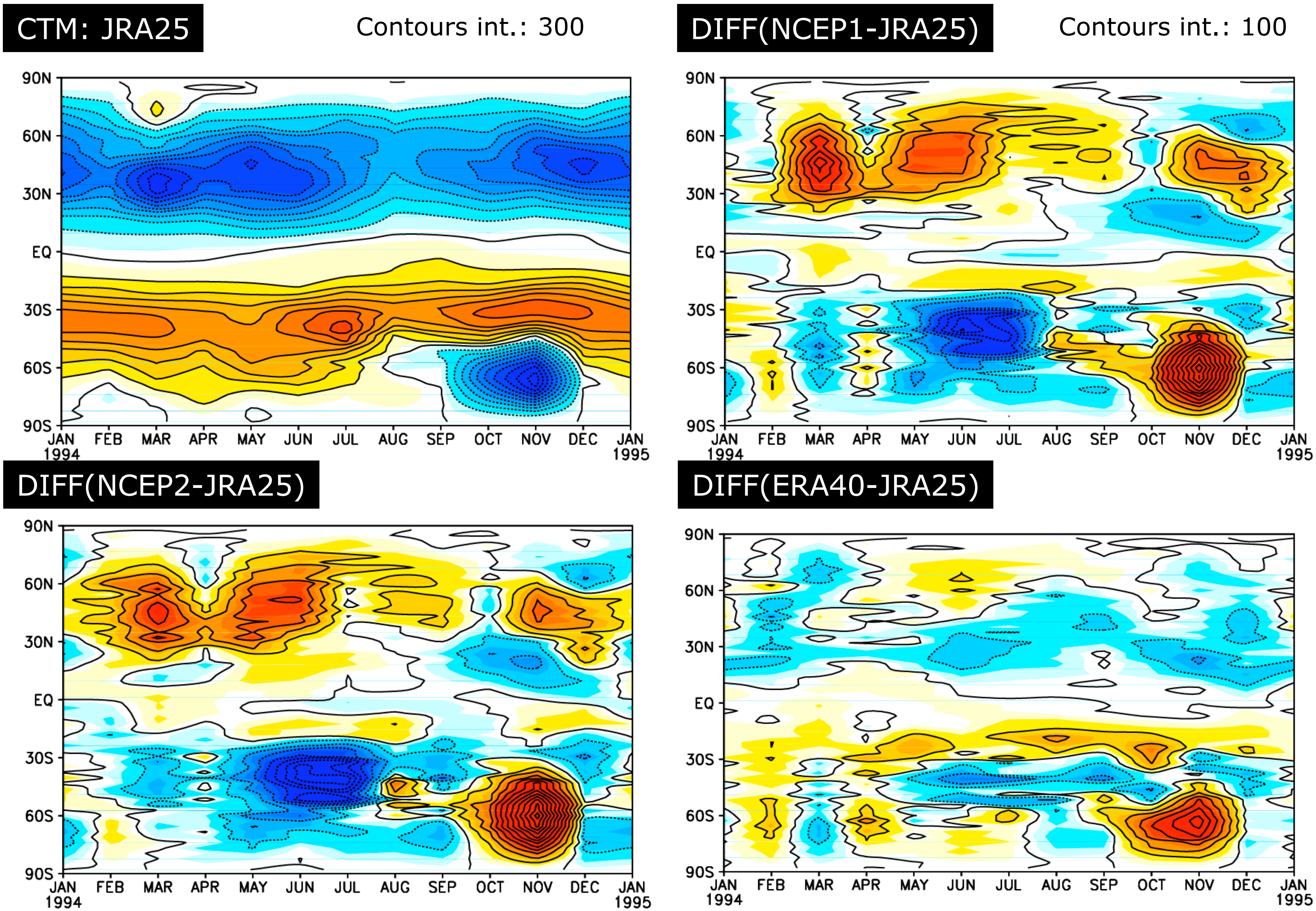
DIFF(NCEP2-JRA25)



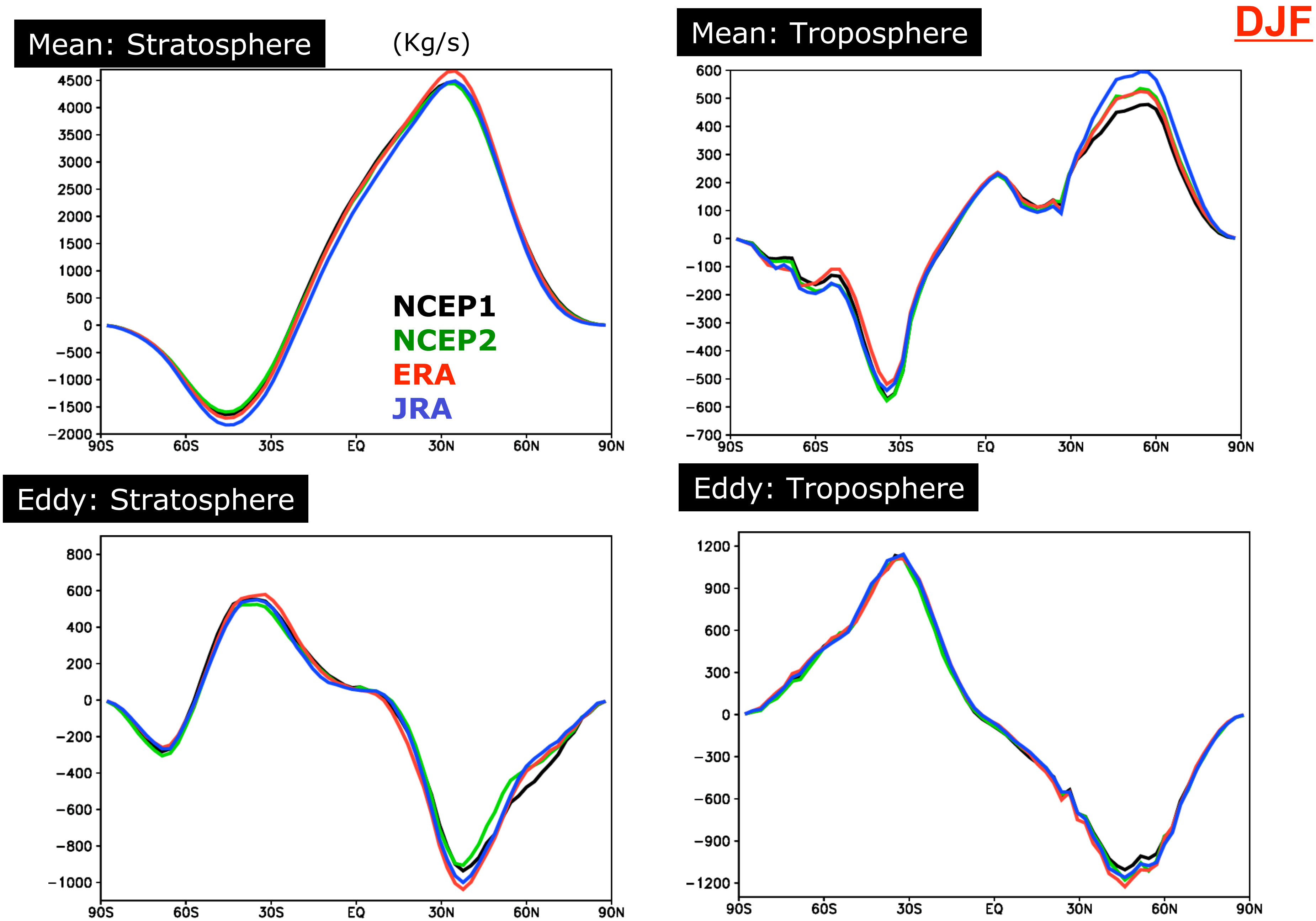
DIFF(ERA40-JRA25)



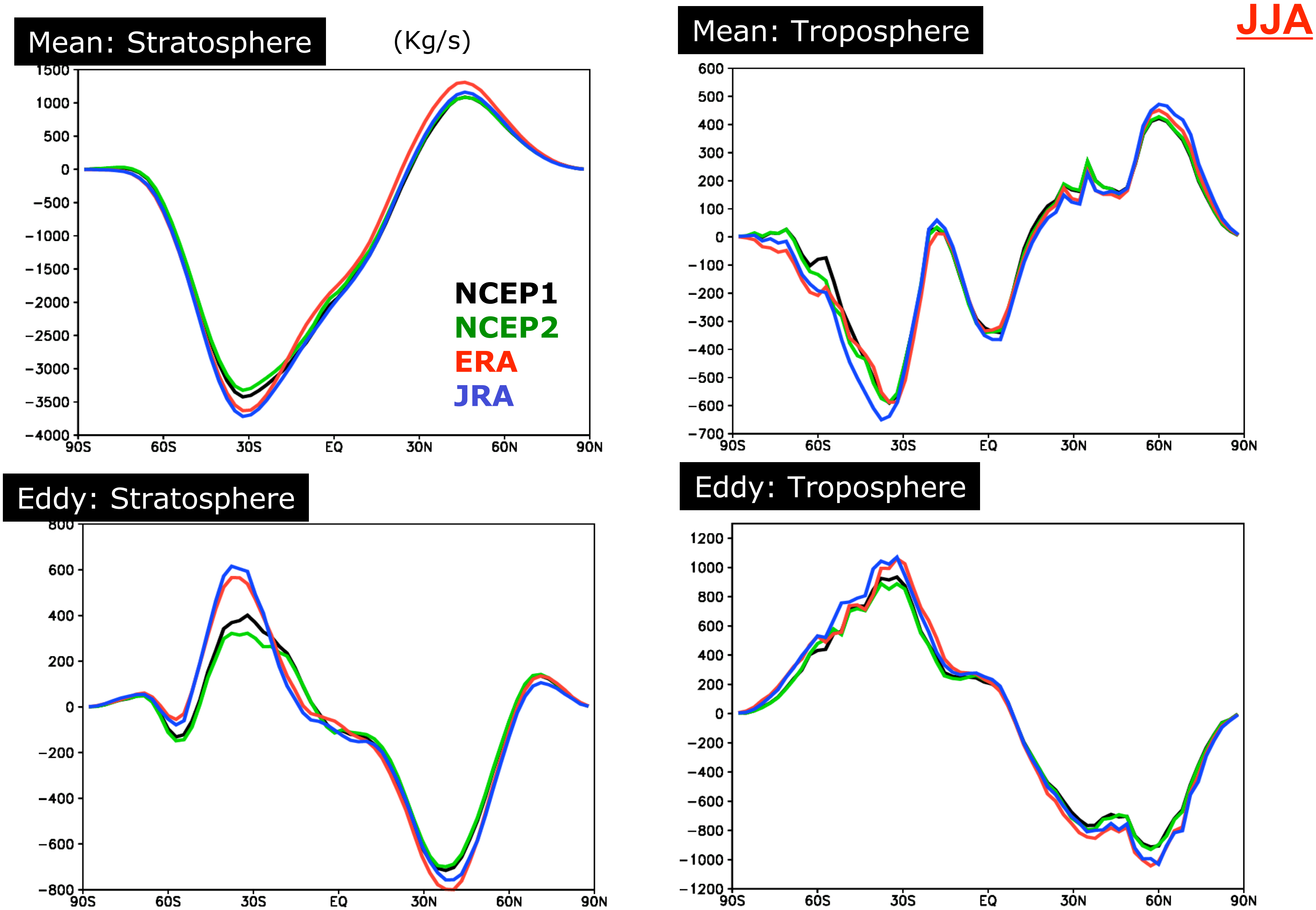
Eddy meridional ozone fluxes ingerated through the atmosphere (kg/s)



Meridional ozone fluxes ingerated in the troposphere and stratosphere (kg/s)



Meridional ozone fluxes ingerated in the troposphere and stratosphere (kg/s)



Summary

1. Ozone mixing ratio obtained with JRA25 is greater than those with ERA and NCEP in the lower stratosphere, while it is less in the middle stratosphere.   The mixing ratio in the lower stratosphere may be the main reason why the extratropical total ozone is the largest when CTM is run with JRA25.

2. Vertically integrated net poleward mean transport with JRA25 is greater than NCEP and a little greater than ERA.

3. Vertically integrated net equatorward eddy transport with JRA25 is greater than NCEP but a little smaller than ERA.

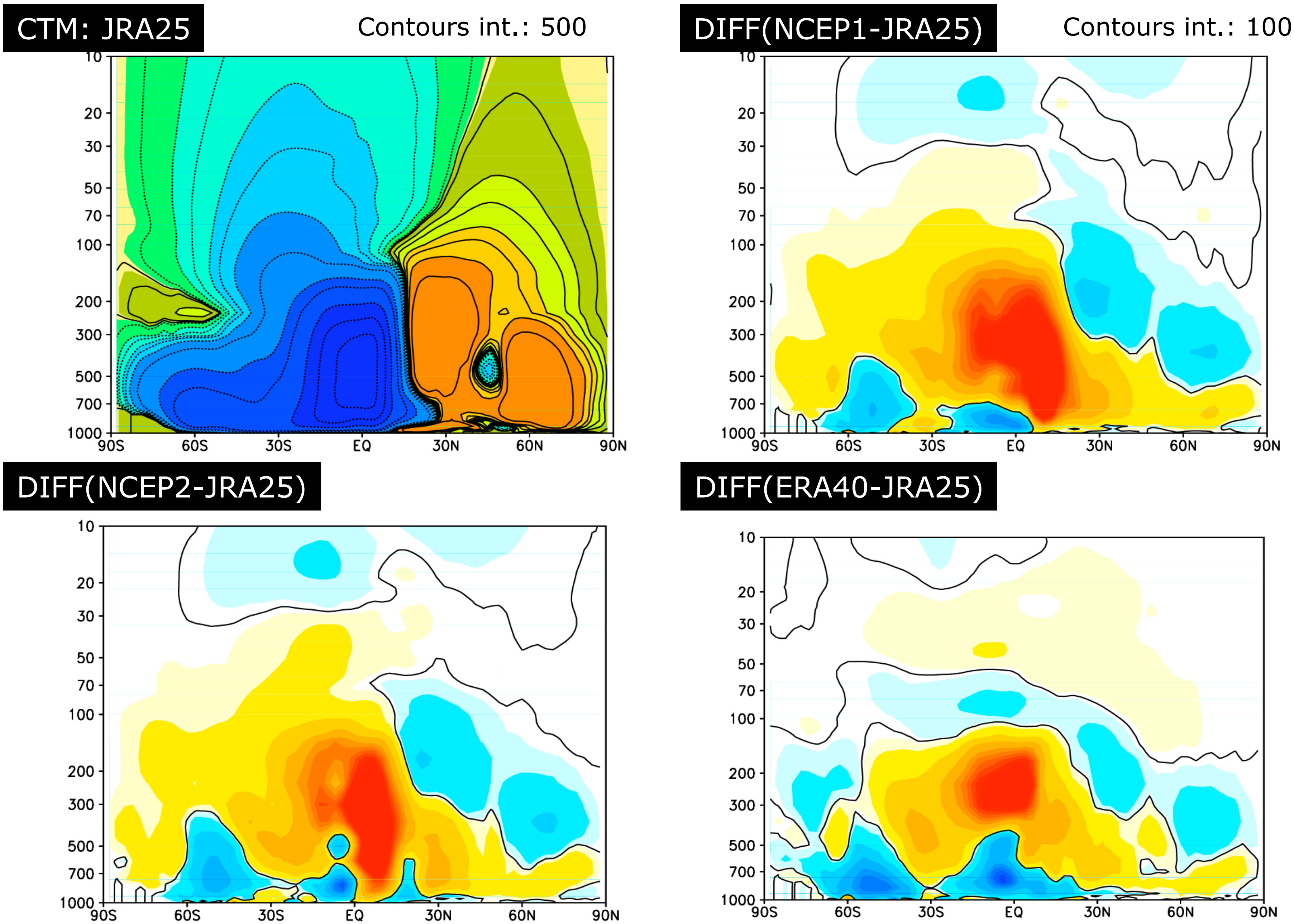
4. Reanalyzed ozone has some biases and requires further improvements of CTM and the atmospheric reanalyses.

Announcement

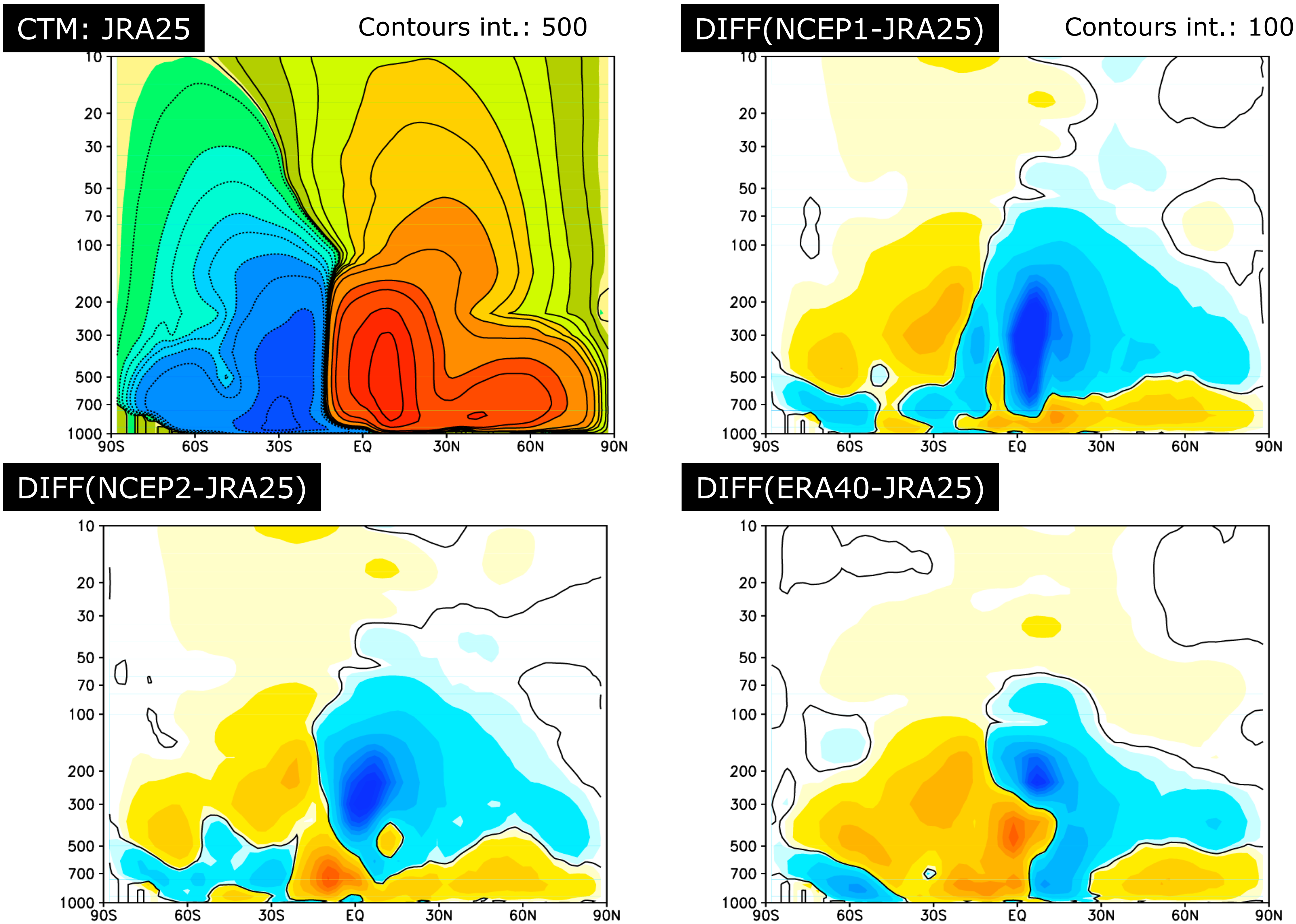
The 3rd WCRP Reanalysis Conference

To be held in Tokyo in January, 2008

Stream function in July & August



Stream function in January & February



Objective Analysis

Analysis

	JRA-25	NCEP/NCAR	ERA-40
Resolution	2.5°×2.5° 23 (upto 0.4hPa)	2.5°×2.5° 17 (upto 10hPa)	2.5°×2.5° 23(upto 1hPa)
Period	**1979～2001**		

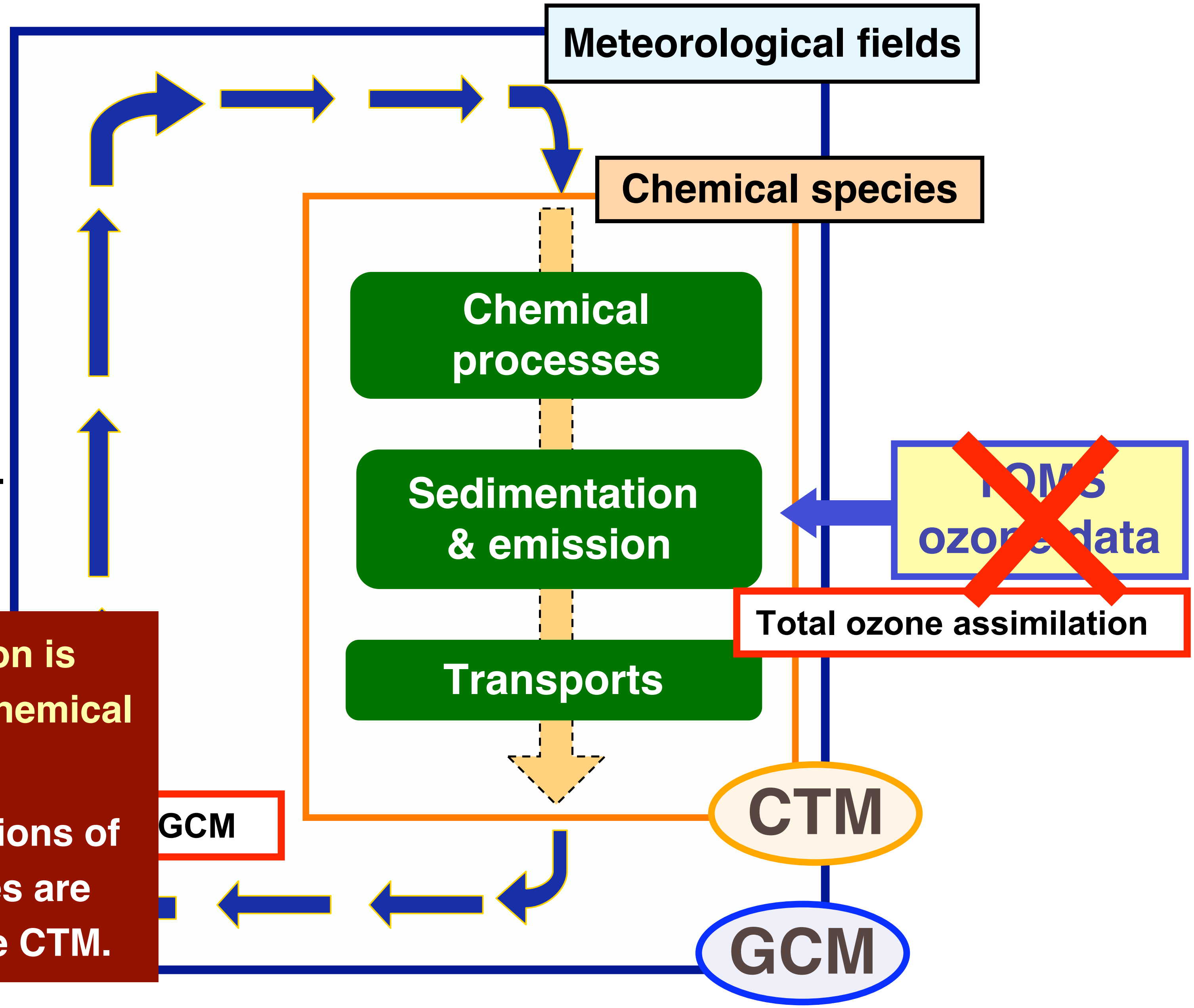
JRA: 23layers: 1000 925 850 700 600 500 400 300 250 200 150 100 70 50 30 20 10 7 5 3 2 1 0.4

NCEP&NCEP2: 17layers: 1000 925 850 700 600 500 400 300 250 200 150 100 70 50 30 20 10

ERA: 23layers: 1000 925 850 775 700 600 500 400 300 250 200 150 100 70 50 30 20 10 7 5 3 2 1

2. MRI/JMA ozone reanalysis system

To reproduce the meteorological field observed, Reanalysis data is assimilated into the GCM with a nudging technique.



Data assimilation is not applied to chemical species.

Thus, distributions of chemical species are calculated in the CTM.

MRI chemical transport model

An ozone reanalysis system is being developed based on the CTM driven by MRI/JMA 98 GCM (Shibata et al., 2005).

- **Long lived chemical species ： 34 species**

  N_2O, Ox, CH_4, H_2O, NO_y, HNO_3, N_2O_5, Cl_y, CO, CO_2, AEROSOLS, HO_2NO_2, NO_x, $ClONO_2$, ClO_x, HOCl, Cl_2, $ClNO_2$, Cl_2O_2, CCl_4, OClO, H_2O_2, HBr, $BrONO_2$, HOBr, HCl, BrO_x, N_2O, $CFCl_3$, CF_2Cl_2, Br_y, CH_3Cl, CH_3Br, CF_2ClBr, CF_3Br,

- **Short lived chemical species ： 15 species**

  $O(^1D)$, $O(^3P)$, O_3, OH, HO_2, H, N, NO, NO_2, NO_3, Cl, ClO, Br, BrO, BrCl

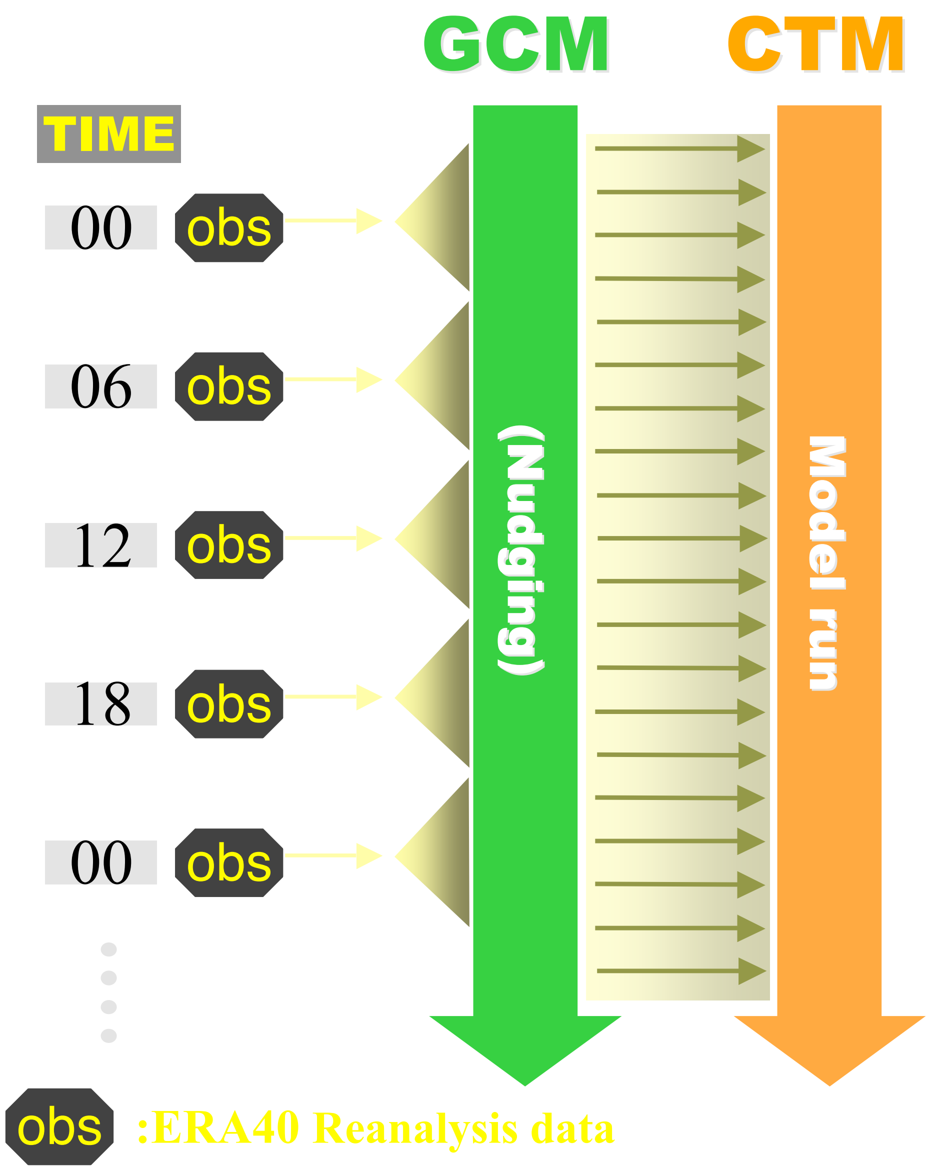
- **Chemical reactions ：**

  Photolysis（23）、Heterogeneous(5:PSC、2:SSA）、

  Gas phase（59）: O_x group(5), HO_x group(12), NO_x group(11),
  Cl_x group(21), Br_x group(9), Hydrocarbon group(1)

- **Resolution： T42 with 68 levels（Surface ～ 0.01 hPa）**

MRI ozone reanalysis system



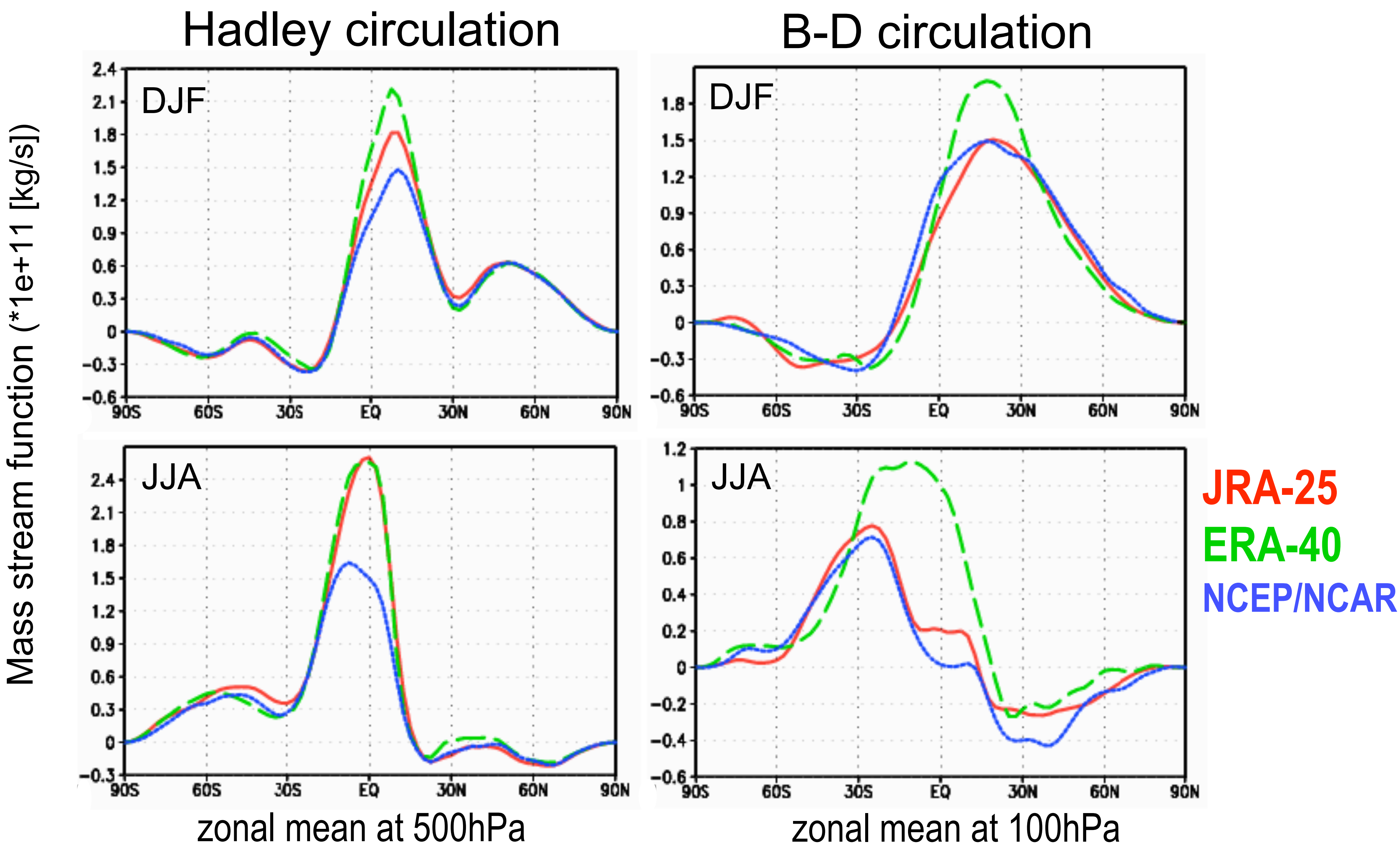
Data assimilation technique

A data assimilation technique based on simple Newtonian relaxation called the nudging technique (Hoke and Anthes, 1976) is used to force the GCM toward the reanalysis data. The prognostic equation is given by

$$\frac{\partial X}{\partial t} = \underbrace{F_m(X)}_{\text{GCM forcing term}} + \underbrace{\frac{X_{obs} - X}{\tau}}_{\text{Relaxation term}}$$

Horizontal and vertical wind
→ Transport
Temperature, humidity
→ Chemistry

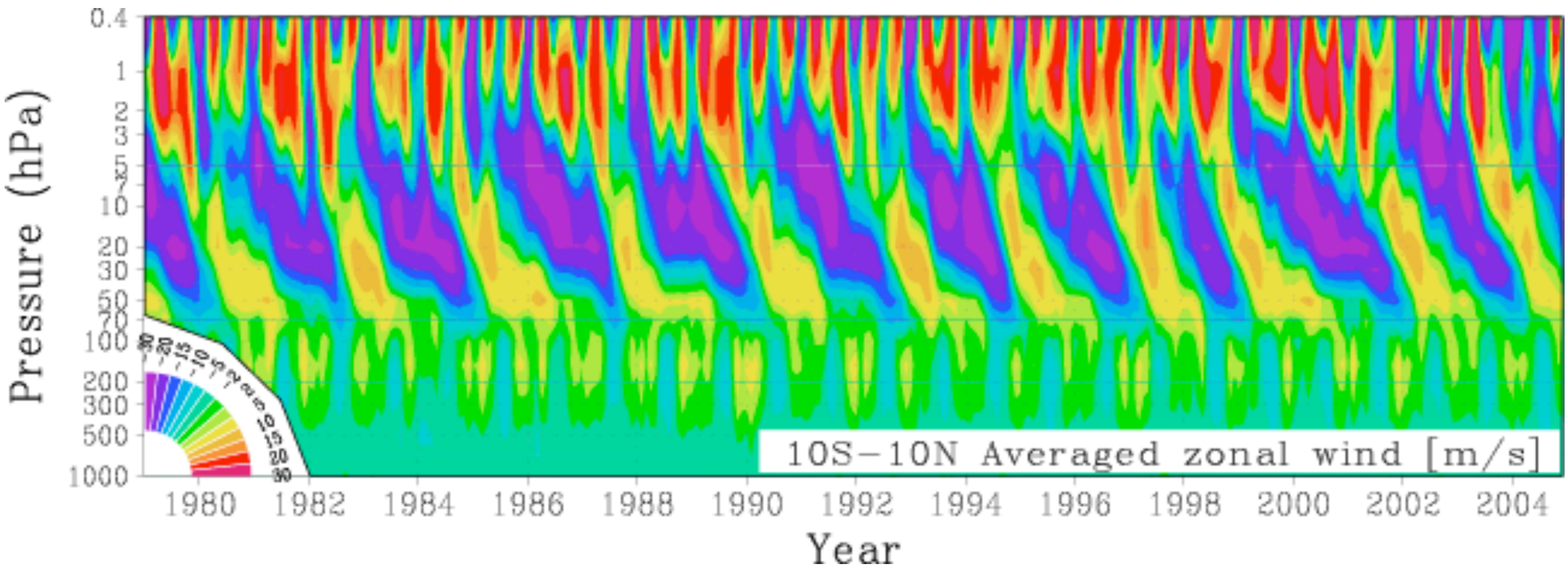
Meridional circulation



Courtesy: H. Hamada & T. Iwasaki (Tohoku Univ.)

QBO and SAO

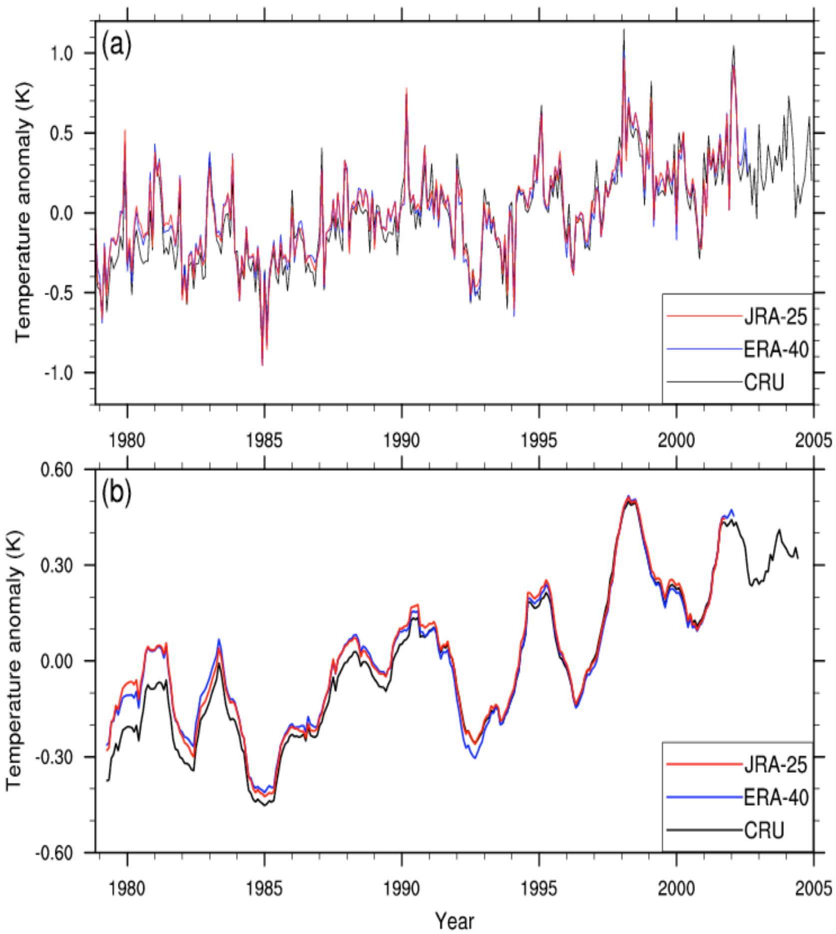
10S-10N averaged zonal wind cross section



Courtesy: H. Hatsushika

Surface temperature Trend

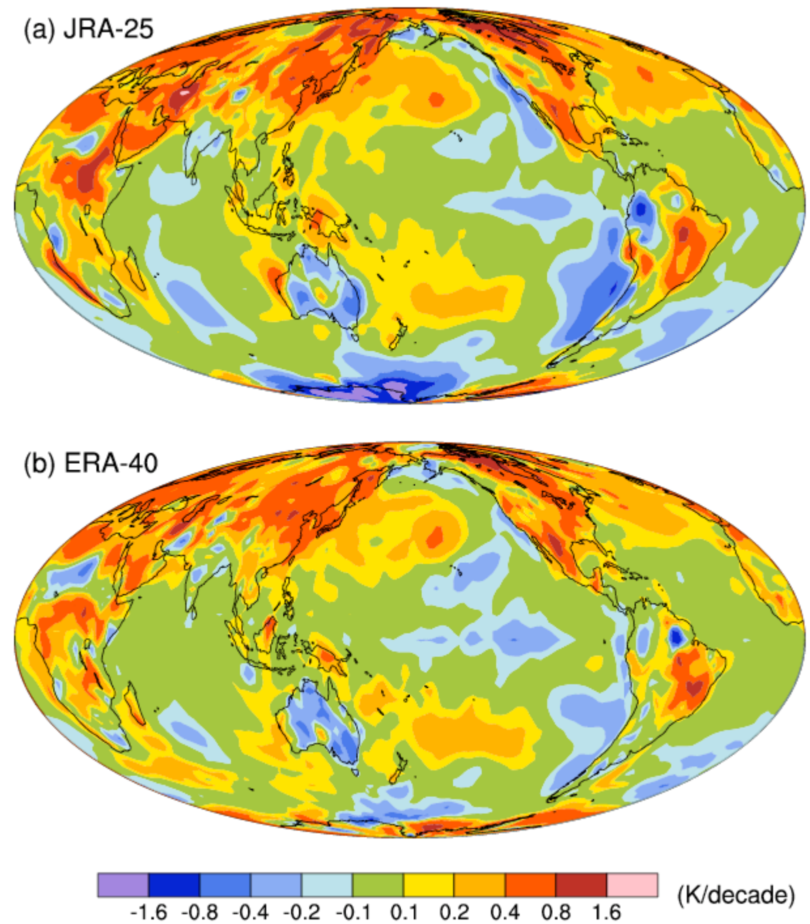
JRA-25 and ERA-40



Global Temperature Anomaly

JRA-25, ERA-40, CRU(Jones)

Top : monthly mean, Bottom : 5-year moving avarage



Distribution of tendency (K/decade)

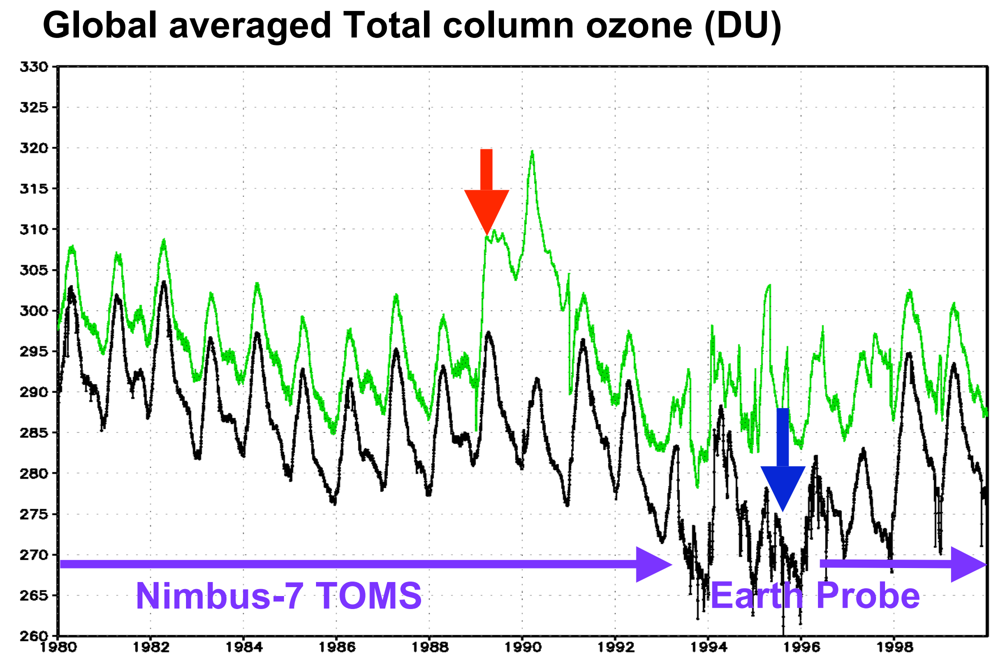
Courtesy: J. Tsutsui

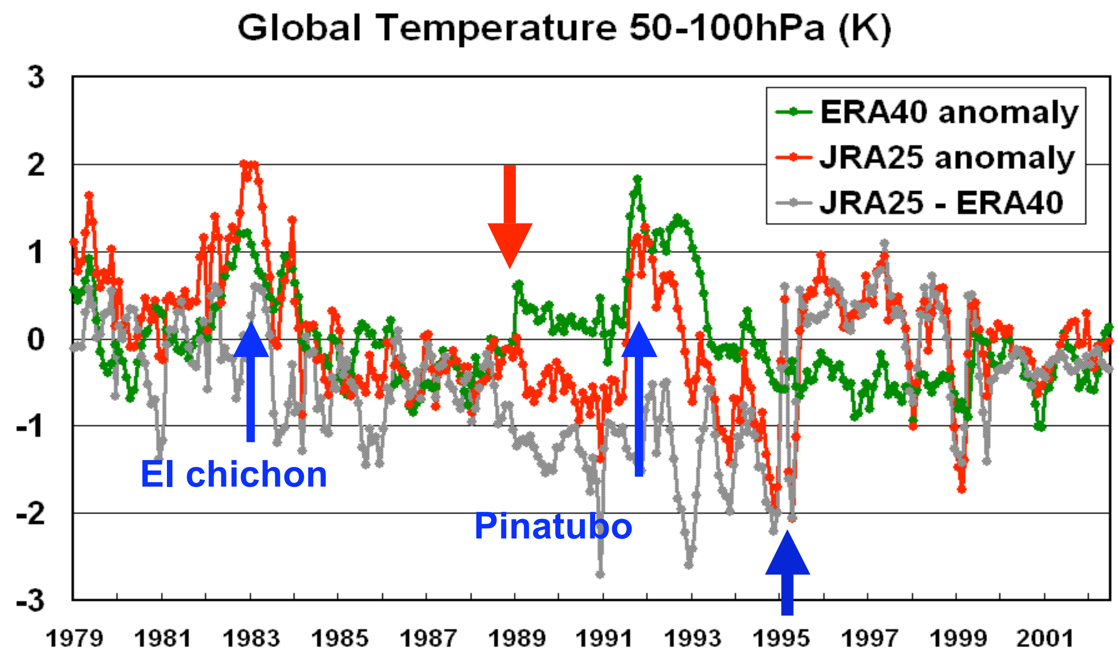
Comparison of ozone and temperature of JRA-25 and ERA-40

Ozone density is dominant for climate in the stratosphere.

Sudden increase from 1989 to 1991 in ERA-40

Ozone in JRA-25 is unstable for the period without TOMS data from May 1993 to July 1996





Courtesy: M. Sakamoto

まとめ

- 今回JRA-25再解析データの子午面循環の比較のため解析に$p_{\dagger}$方程式系を用い、NCEP/NCAR・ERA-40再解析データと比較を行った。

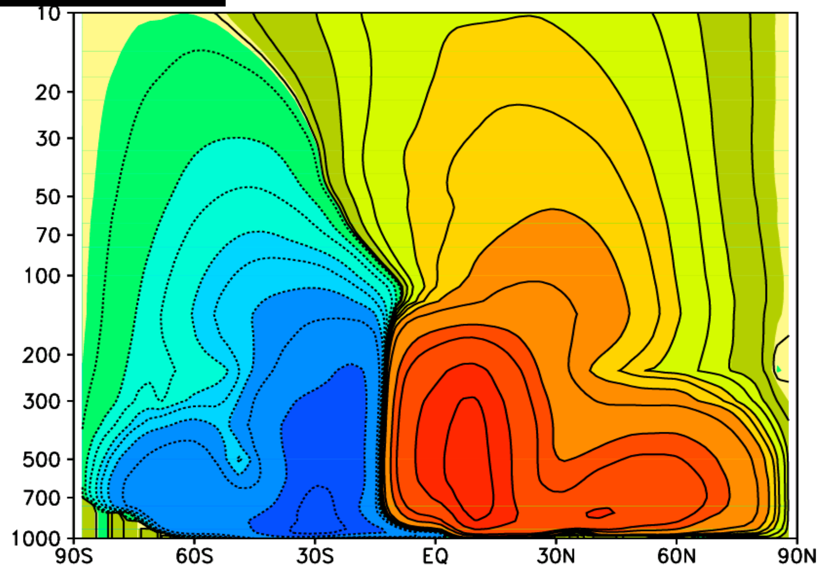
子午面循環の比較

	質量流線関数の強さ	年々変動	季節変動
DJF対流圏 (北・ハドレー循環)	**ERA**>**JRA**>**NCEP**	**相関は高い 強まるトレンド**	**ERA**>**JRA**=**NCEP** ∧
JJA対流圏 (南・ハドレー循環)	**ERA**≒**JRA**>**NCEP**	相関は低くない **JRAのみ弱まるトレンド**	**ERA**>**JRA**=**NCEP**
DJF成層圏 (北・B-D循環)	**ERA**>**JRA**=**NCEP**	相関は低い。はっきりとしたトレンドは見られない	**ERA**≒**JRA**>**NCEP** ∨
JJA成層圏 (南・B-D循環)	**ERA**>**JRA**=**NCEP**	相関は低い。**JRA・NCEPは強まるトレンド**	**ERA**≒**JRA**>**NCEP**

Stream function in January & February

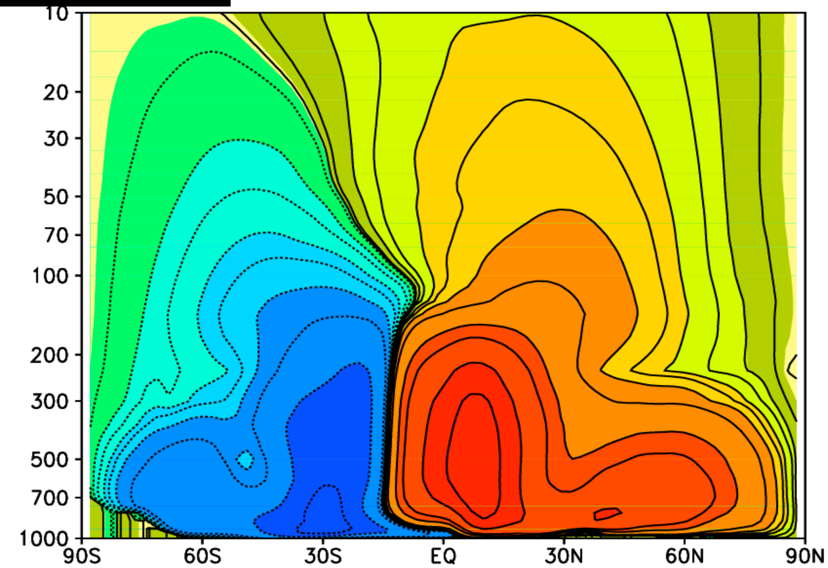
CTM: NCEP1

Contours int.: 20DU

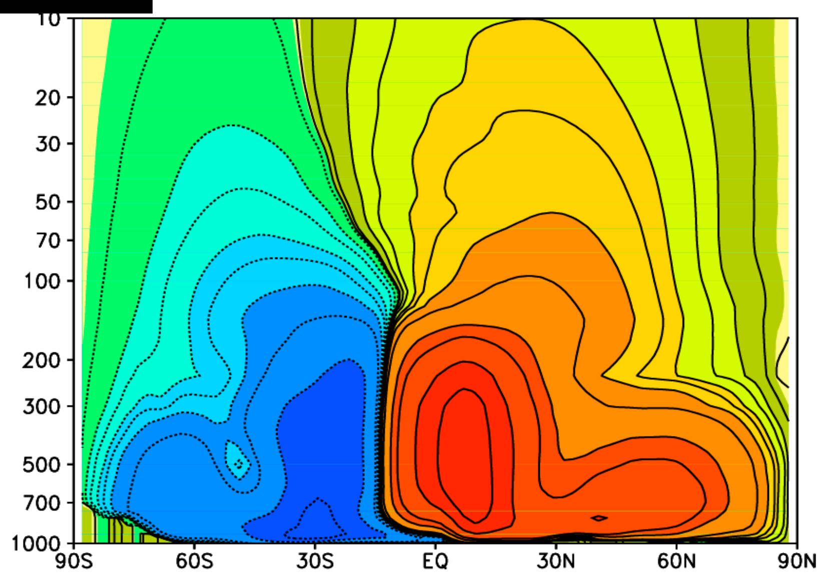


CTM: NCEP2

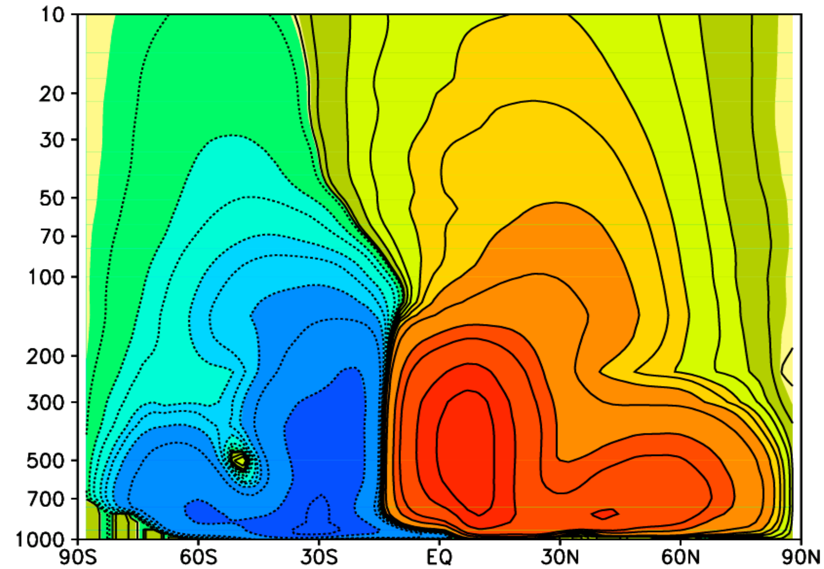
Contours int.: 3DU



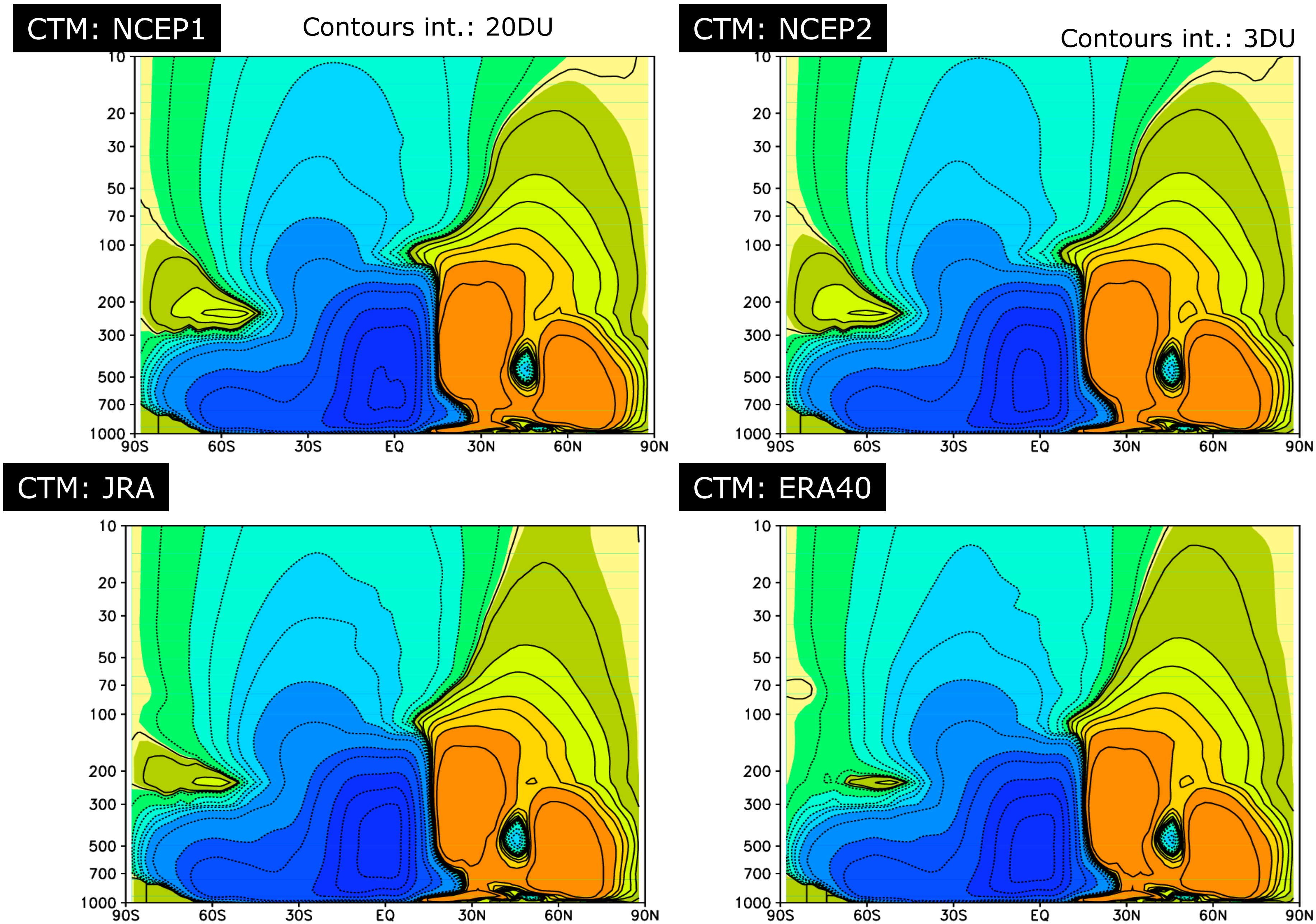
CTM: JRA



CTM: ERA40



Stream function in July & August



帯状平均について

すべての変数に対して質量重み付けした帯状平均をもちいた。帯状平均の定義は

$$\overline{A(y,\theta,t)}^{*} = \frac{1}{L_x}\int A(x,y,\theta,t)\left(\frac{\partial p}{\partial \theta}/\frac{\partial \overline{p}}{\partial \theta}\right)dx$$

のように表される。鉛直面には等温位面に沿って帯状平均した気温を用いる。

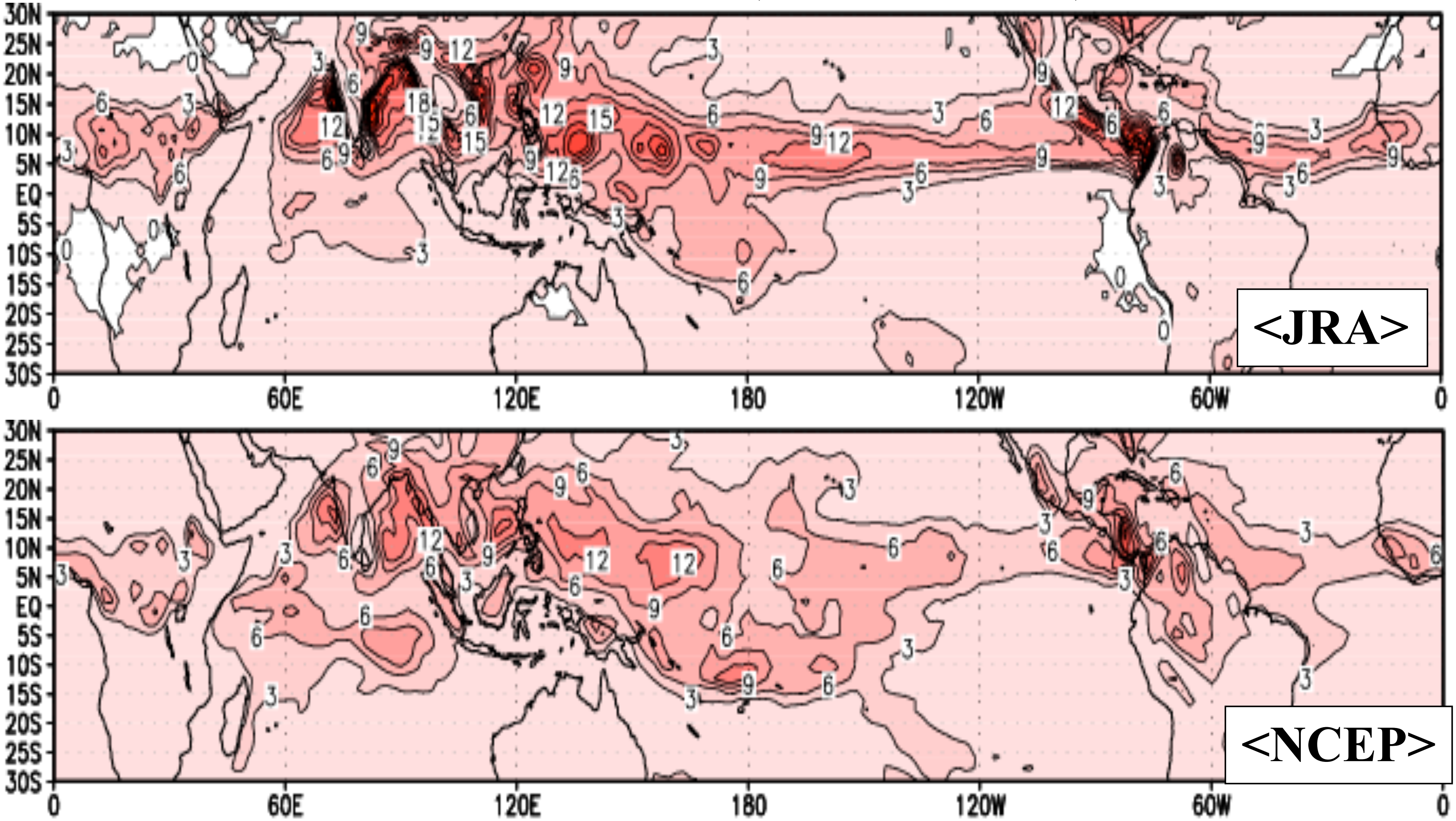
その特徴は地衡風近似を用いないで波動平均流相互作用の表現が可能であり、また下部境界を正しく表現できることである。

・等温位面で東西平均場による子午面循環のメリット

1．ラグランジュ的な子午面循環が得られるため、熱輸送・物質輸送を考える上で有利

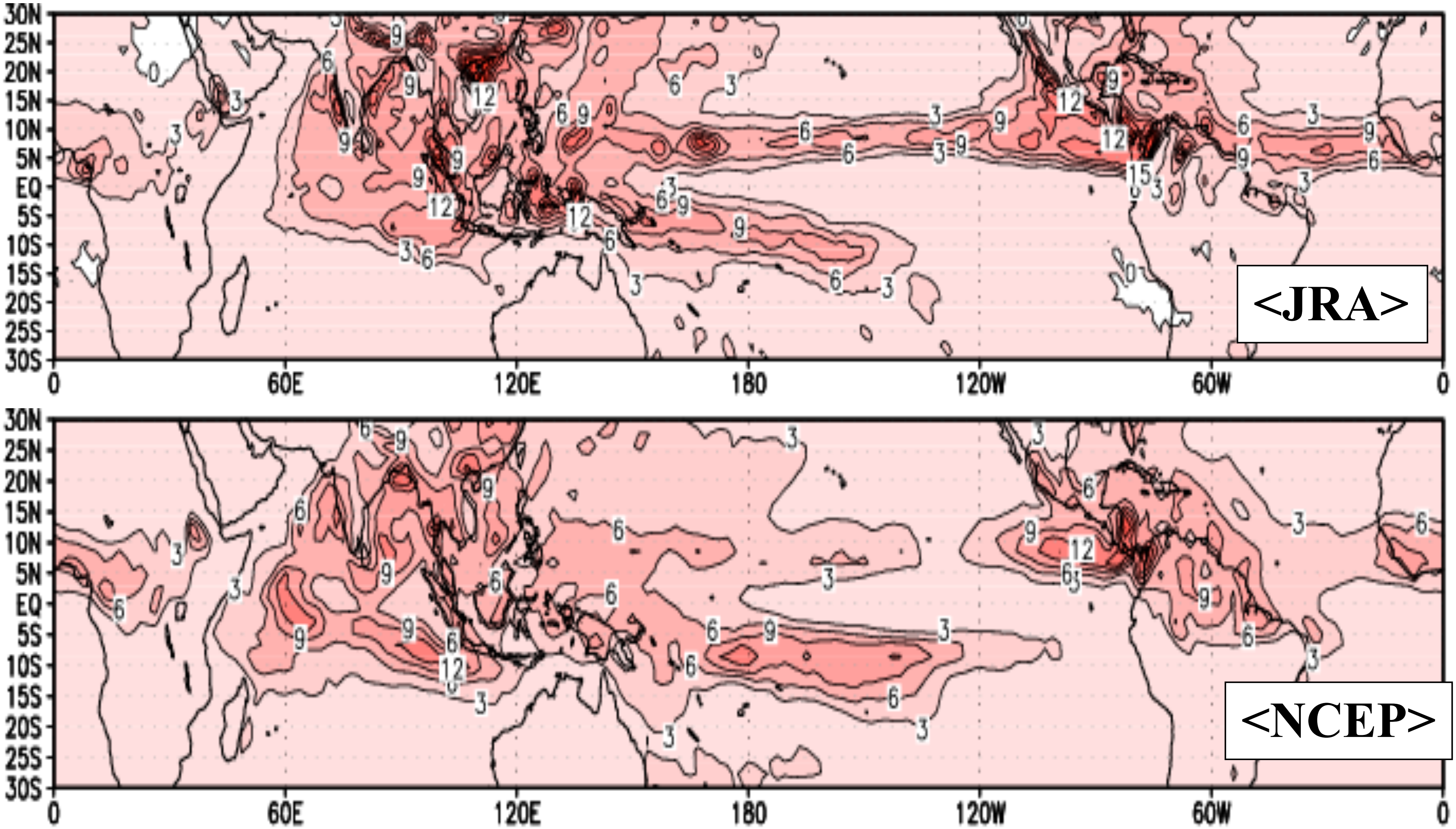
2．波動による運動量輸送の効果を適切に扱える

降水分布(82年JJA)



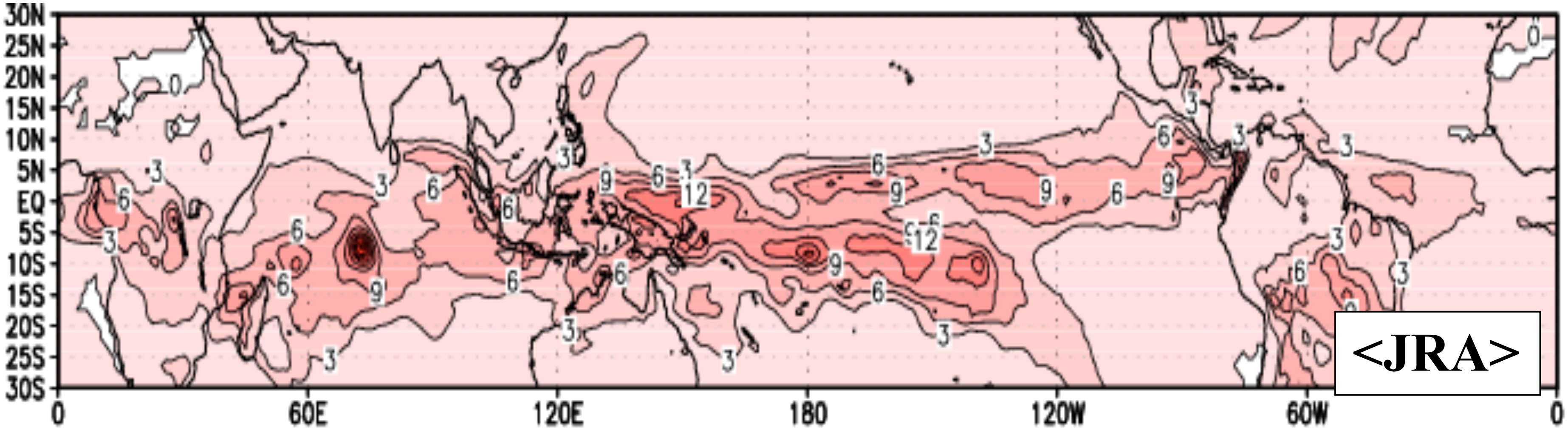
- JRAがNCEPに比べ降水が強く表現され、またITCZが表現されている。

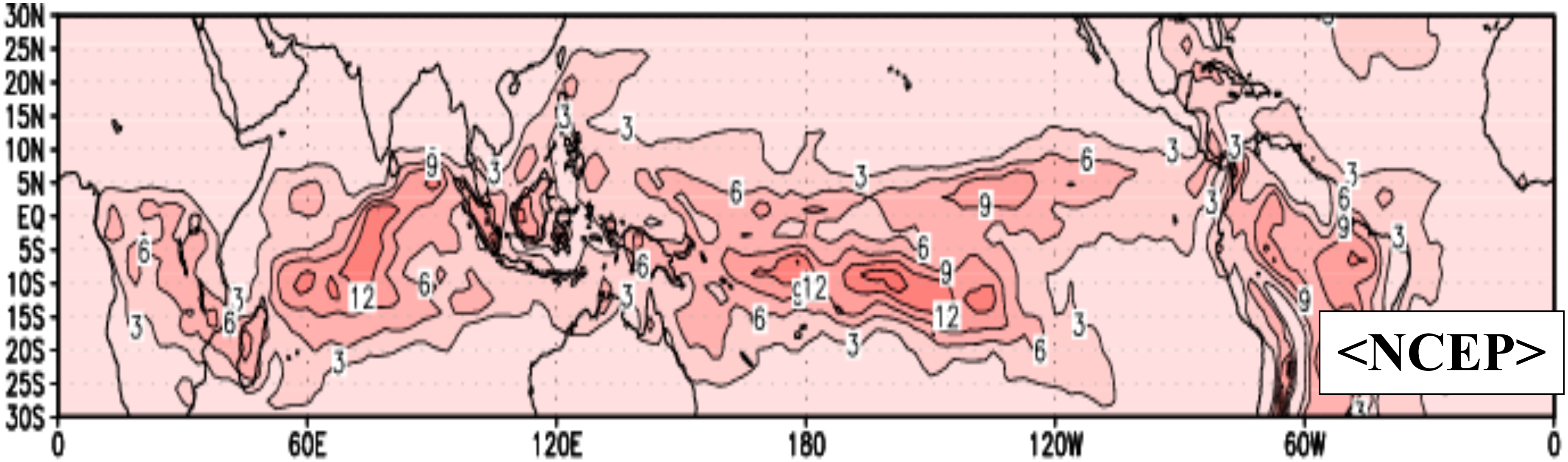
降水分布(98JJA)



- JRAは82年に比べITCZが弱い

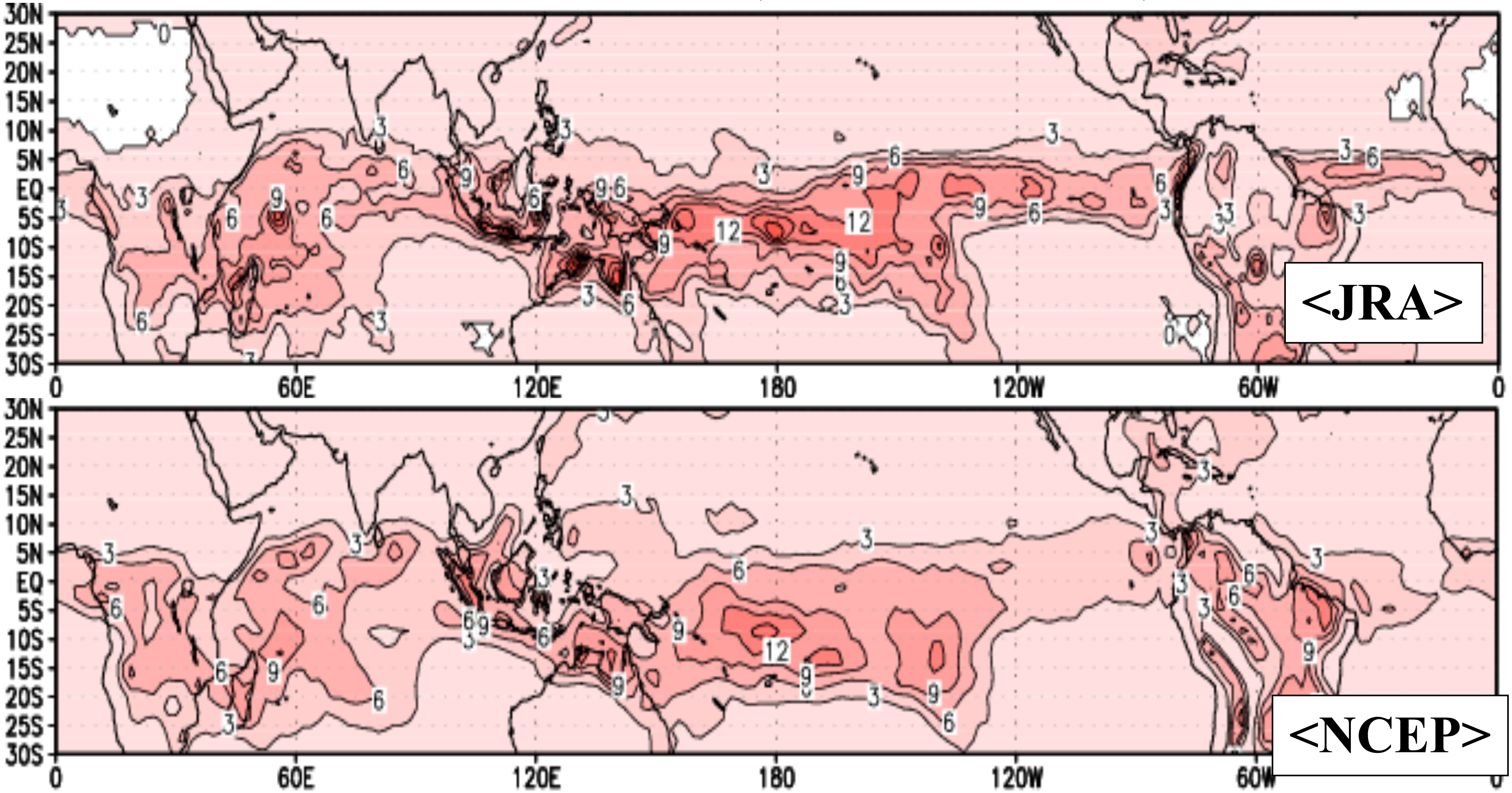
降水分布(82D~83JF)





- JJAに比べ弱い。また分布はJRAとNCEPで似通っている。

降水分布(97D~98JF)



- JRAとNCEPの分布は似通っている。
- 82D~83JFと比べ降水強度が強くなっているとは決して言えないか？

等温位面上での東西平均場

温位θの等温位面上での東西平均場を $\overline{\theta}$ 平均場からの偏差を θ' で表すと $\overline{\theta'} = 0$ で拡散がないので熱力学の式は

$$\frac{\partial \overline{\theta}^*}{\partial t} + \overline{v}^* \frac{\partial \overline{\theta}^*}{\partial y} + \overline{w}^* \frac{\partial \overline{\theta}^*}{\partial z} = \overline{\left(\frac{Q}{\Pi}\right)}^*$$

$$\overline{A}^* = \frac{\overline{\partial p/\partial\theta \, A}}{\partial \overline{p}/\partial\theta}$$

移流（空気塊自身が動く）

凝結、放射等による外部からの加熱、冷却

・等温位面で東西平均場による子午面循環のメリット

1. ラグランジュ的な子午面循環が得られるため、熱輸送物質輸送を考える上で有利
2. 波動による運動量輸送の効果を適切に扱える

中高緯度・成層圏での波動による循環の駆動

EP flux（波動が運ぶ運動量）　$\mathbf{F} \equiv \left(-\overline{(u'v')}^{*}, -\overline{p\left(\frac{\partial \phi}{\partial x}\right)} \right)$

東西方向の運動方程式

$$\frac{\partial \overline{u}^{*}}{\partial t} + \overline{v^{*}}\frac{\partial \overline{u^{*}}}{\partial y} + \overline{w^{*}}\frac{\partial \overline{u^{*}}}{\partial z} - f\overline{v}^{*} = \nabla \cdot \mathbf{F}$$

波が運ぶ運動量の
収束・発散

連続（質量保存）の式

$$\frac{\partial \overline{v}^{*}}{\partial y} + \rho_0^{-1}\frac{\partial \rho_0 \overline{w}^{*}}{\partial z} = 0$$