Causes for Changes in the Brewer-Dobson Circulation derived from Chemistry-Climate Model Simulations

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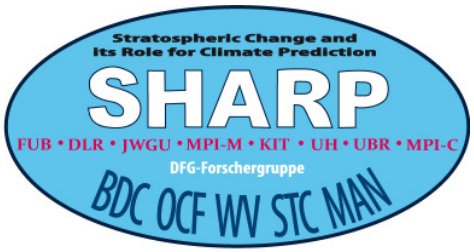
EGU General Assembly
April 26, 2012
Vienna



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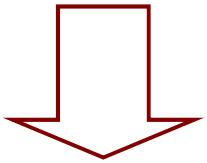
Introduction and Motivation

- Strengthening of the Brewer-Dobson Circulation with climate change is evident from literature
  (e.g. CCMVal, 2010; Butchart et al., 2006/2010)
- **But:** Causes and effects remain uncertain



- Selected sensitivity studies can help to understand mechanisms

Here:

- Chemistry-Climate Model simulations in timeslice mode for past, present and future climate
- Separation of changes due to greenhouse gas (GHG) concentrations, sea surface temperatures (SST) and sea ice concentration (SIC) vs. chlorofluorocarbons (CFC)

Model and Experiments

Model: EMAC (in FUB-configuration)

- ECHAM5/MESSy Atmospheric Chemistry Model *(Jöckel et al., 2006)*
- Chemistry-Climate Model (CCM) with FUBRad-Radiation parameterization *(Nissen et al., 2007)*
- Horizontal resolution: T42 (2.8 x 2.8°)
- Vertical Resolution: L39 (top in 0.01hPa)
- No interactively coupled ocean → SST/SIC prescribed
- Gravity wave parameterization:
    - Non-orographic - NGWD: *Hines, 1997* (→ model output)
    - Orographic - OGWD: *Lott and Miller, 1997* (→ no output)

Model and Experiments

- **Timeslice Simulations:** Integration of at least 20 years under equal boundary conditions, solar mean radiation

Name	Timeslice	GHG	CFC	SST/SIC
2000	**Reference Present**	**2000**	**2000**	**1995-2004** (MPI-OM)
1865	**Reference Past**	**1865**	**1865**	**1860-1869** (MPI-OM)
2095	**Reference Future**	**2095** (A1B-scenario)	**2095** (A1-scenario)	**2090-2099** (MPI-OM)
SEN2095	**Sensitivity Future**	**2095** (A1B-scenario)	**2000**	**2090-2099** (MPI-OM)

2000-1865: Past

2095-2000: Future

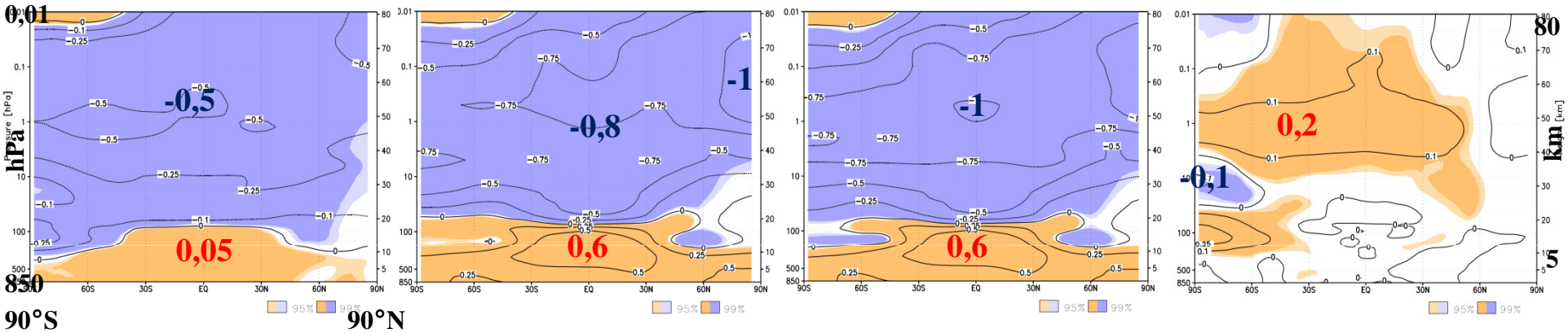
GHG + SST: Future

CFC: Future

Δ Temperature [K/decade] - DJF

→ Strongest dynamical changes in northern hemisphere winter → DJF

2000-1865: Past	2095-2000: Future	GHG + SST: Future	CFC: Future



Slight tropospheric warming ↔ Radiative cooling due to GHGs and less ozone in 2000	Tropospheric warming ↔ Stratospheric cooling	Tropospheric warming ↔ Stratospheric cooling due to GHGs	No tropospheric signal ↔ Stratospheric warming due to future ozone recovery

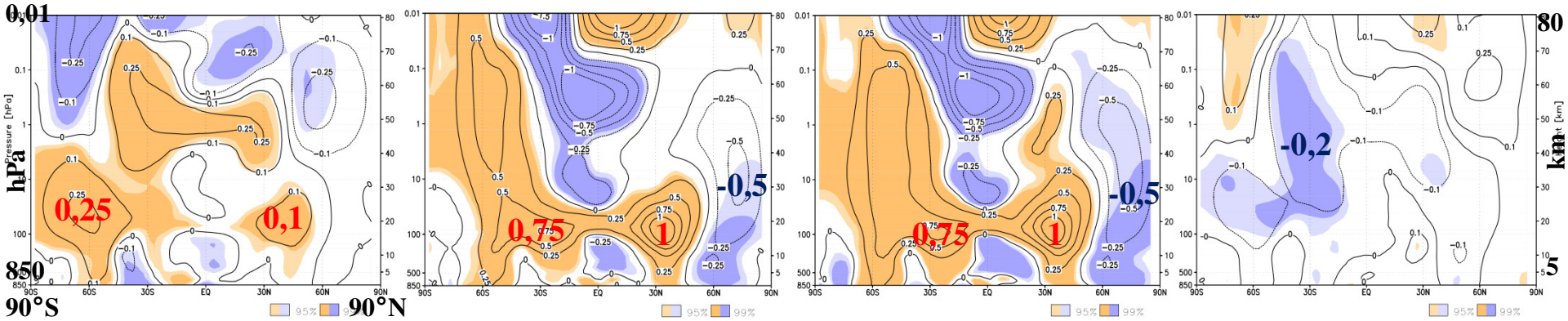
Δ Zonal wind [m/s/decade] - DJF

2000-1865: Past

2095-2000: Future

GHG + SST: Future

CFC: Future

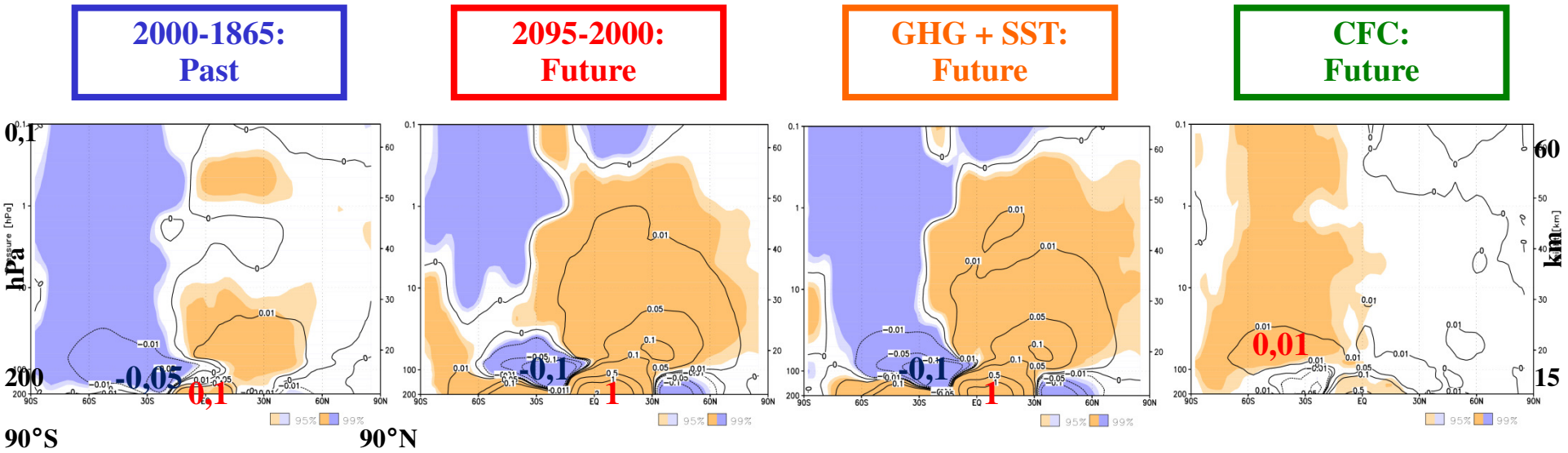


Slight strengthening (NH) and displacement (SH) of subtropical jet

- Strengthening of subtropical jets mainly due to GHG and SST increase
- Deceleration of stratospheric polar night jet

Significant signal only in southern hemisphere

Δ Mass streamfunction [10^9kg/s/decade] – DJF



Slight intensification in mass streamfunction from past to present

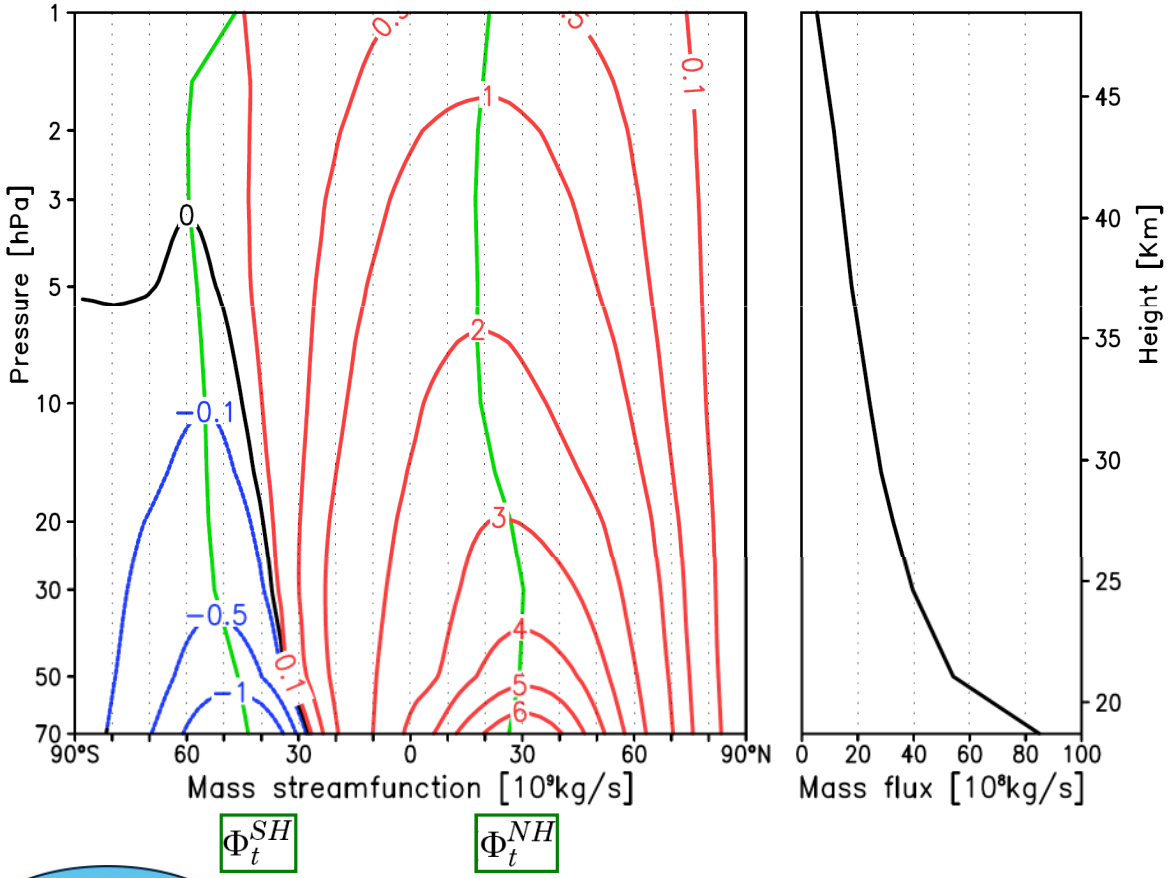
Future intensification in mass streamfunction in both hemispheres

- **GHG+SST**:
  Reason for future intensification in mass streamfunction
  ↕
- **CFC**: small increase in southern hemispheric mass streamfunction

Definition - Tropical upward mass flux [10^9kg/s]

Integration of the mass streamfunction within the turnaround latitudes ↔ BDC-strength

Reference Simulation (2000) - DJF



Tropical upward mass flux:

$$F_{direct}^{total} =$$

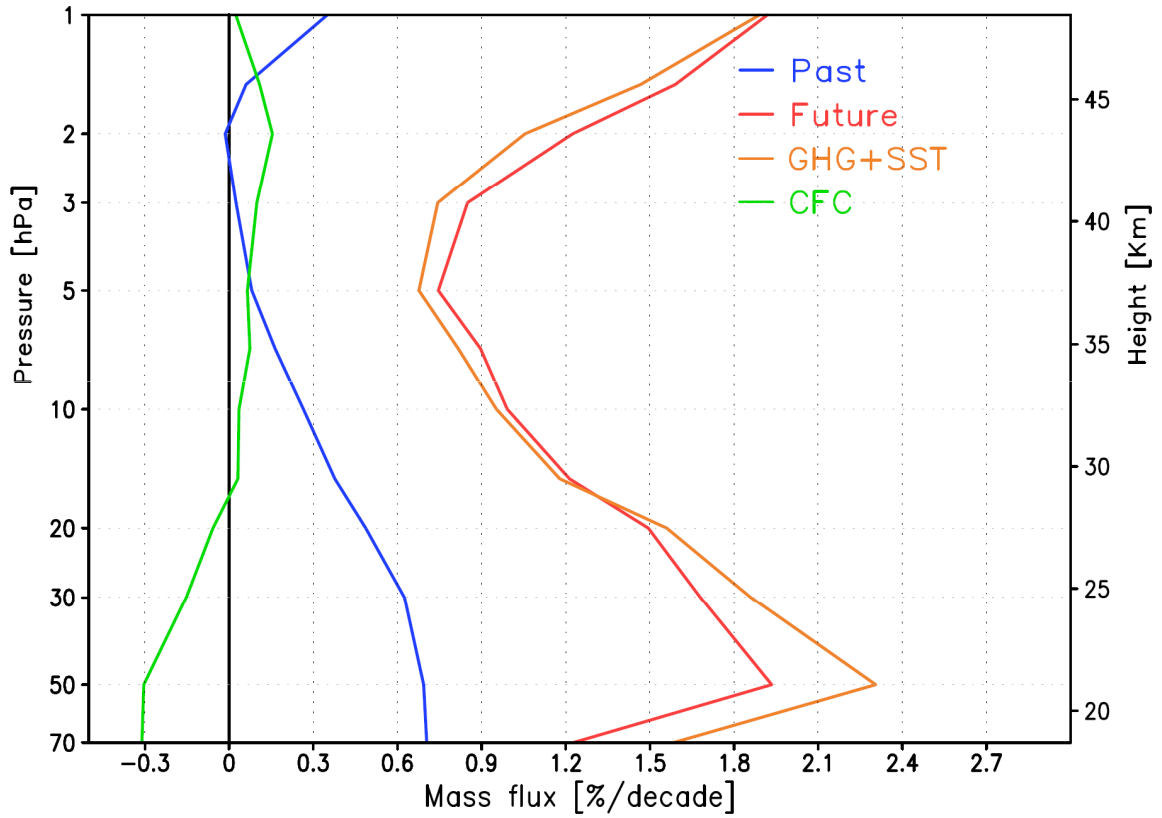
$$-(F_{direct}^{NH} + F_{direct}^{SH})$$

$$= +2\pi a\,[\psi_{direct}(\Phi_t^{NH})$$

$$- \psi_{direct}(\Phi_t^{SH})]$$

Δ Tropical upward mass flux [%/decade] – DJF

2000-1865: Past	2095-2000: Future	GHG + SST: Future	CFC: Future



- **Past:** small mass flux increase (0 - 0.7%)
- **Future:** mass flux increase of less than 1% (upper stratosphere) to 2% (lower stratosphere)
- **GHG+SST** exceed total future effect in lower stratosphere and compensate opposed effect from **CFC**

⇨ **Which waves are responsible for the changes?**

Separation of different scale waves – Application of the downward-control principle to model data

total Forcing:

$$-f\bar{v}* = \frac{1}{\rho_0 cos\phi a}\nabla \cdot \vec{F} + \overline{X} = \mathcal{F}$$

Total forcing
(all waves)

Resolved waves
(EPFlux-divergence)
EPFD

Unresolved waves
Orographic gravity waves
OGWD

Non-Orographic gravity waves
NGWD

mass streamfunction
from direct calculation

$$\psi_{DC} = \psi_{EPFD} + \psi_{GWD} \cong \psi_{direct}$$

$$\Psi(\phi, z) = \int_z^\infty \left\{ \frac{\rho_0 a^2 \overline{\mathcal{F}} cos^2(\phi)}{\overline{m}_\phi} \right\}_{\phi=\phi(z')} dz'$$

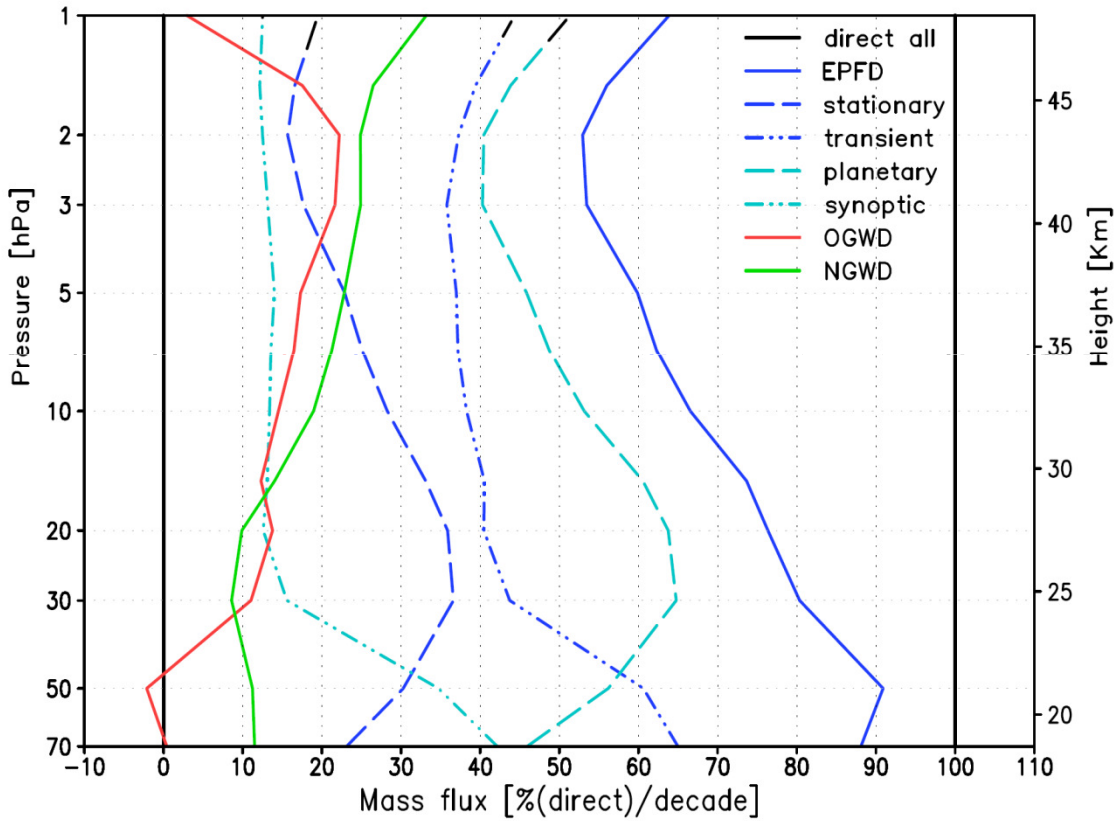
with: $\overline{m} = acos\phi(\overline{u} + a\Omega cos\phi)$

(Haynes et al., 1991)

→ mass streamfunction due to EPFD and NGWD from model data, OGWD as residual

Tropical upward mass flux [% (direct)]

Reference Simulation (2000) - DJF



Resolved waves:

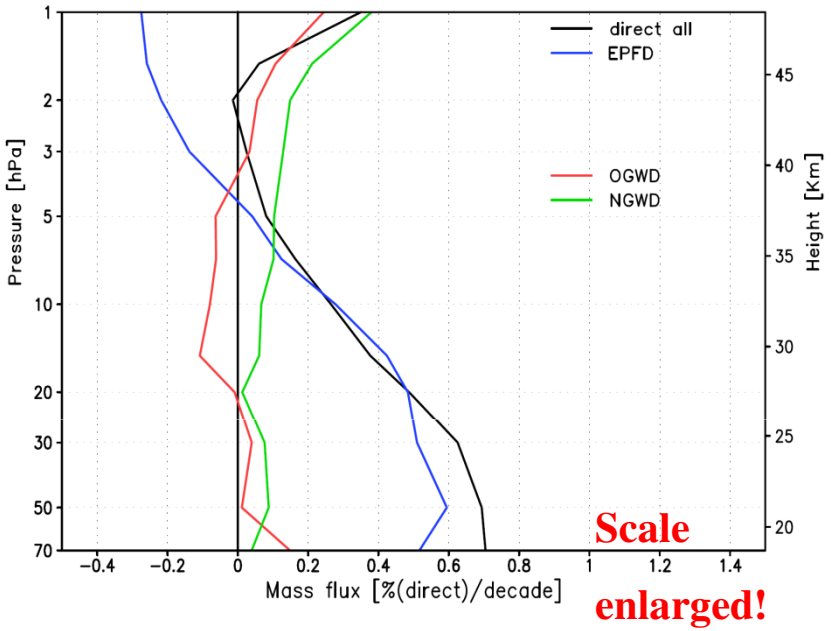
- Account for about 90% in lower and 55% in upper stratosphere
- Largest amount comes from planetary scale, transient waves

Unresolved waves:

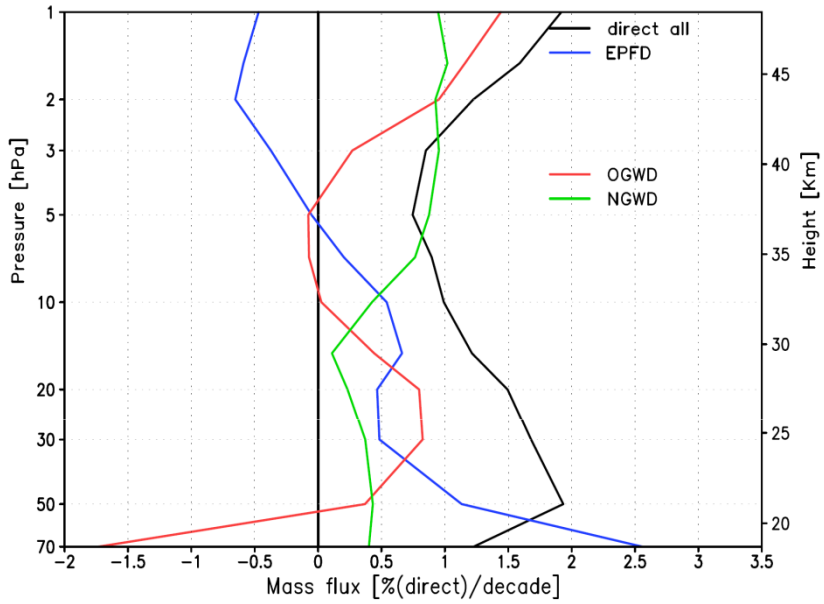
- NGWD: growing influence with height (up to 35% in stratopause region)
- OGWD: important in upper stratosphere

Δ Tropical upward mass flux [% (direct)/decade] - DJF

2000-1865: Past



2095-2000: Future

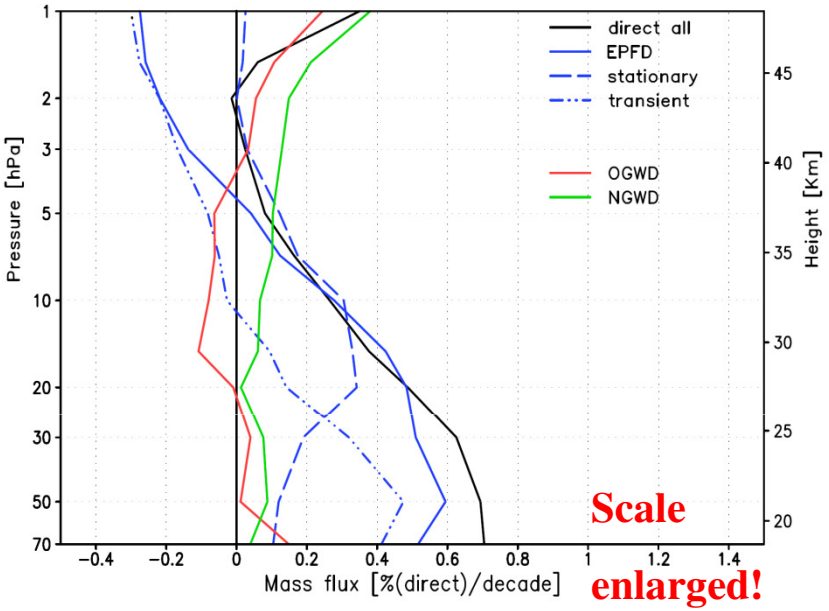


- **Resolved waves:**
  Nearly whole forcing in **lower stratosphere**
- **Gravity waves:**
  Growing importance in **upper stratosphere**

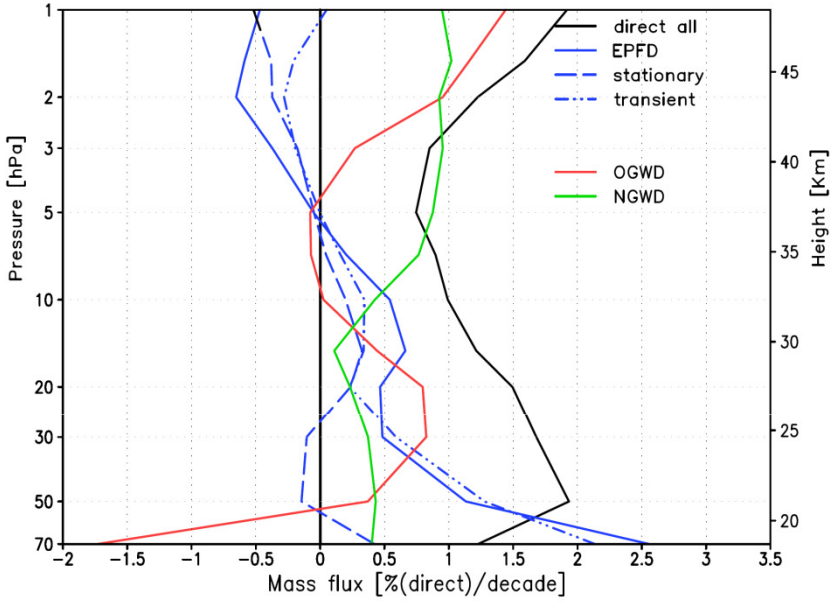
- Comparable with past change pattern, larger signals
- Growing importance of **OGWD** in **middle stratosphere** (**~50%**)
- **NGWD**: nearly total change in **upper stratosphere**

Δ Tropical upward mass flux [% (direct)/decade] - DJF

2000-1865: Past



2095-2000: Future

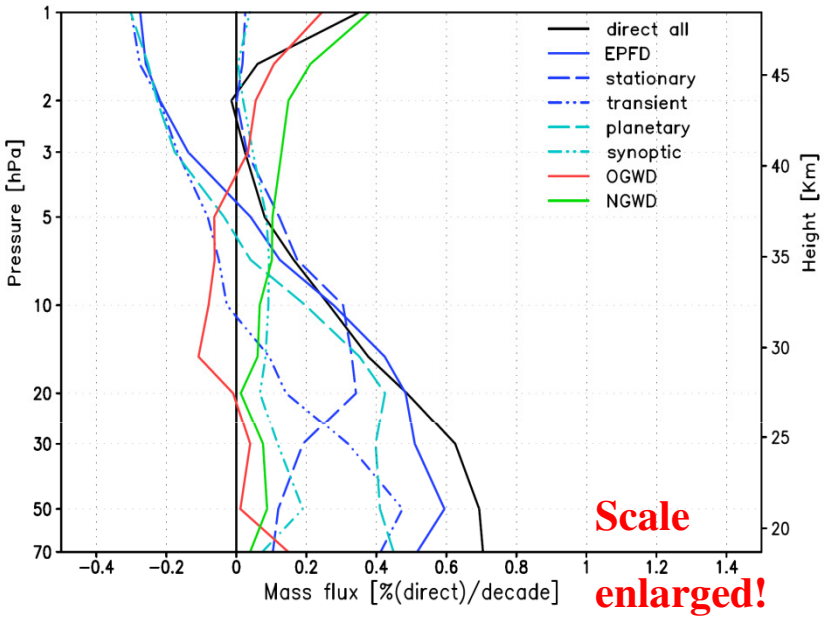


Resolved waves (temporal):

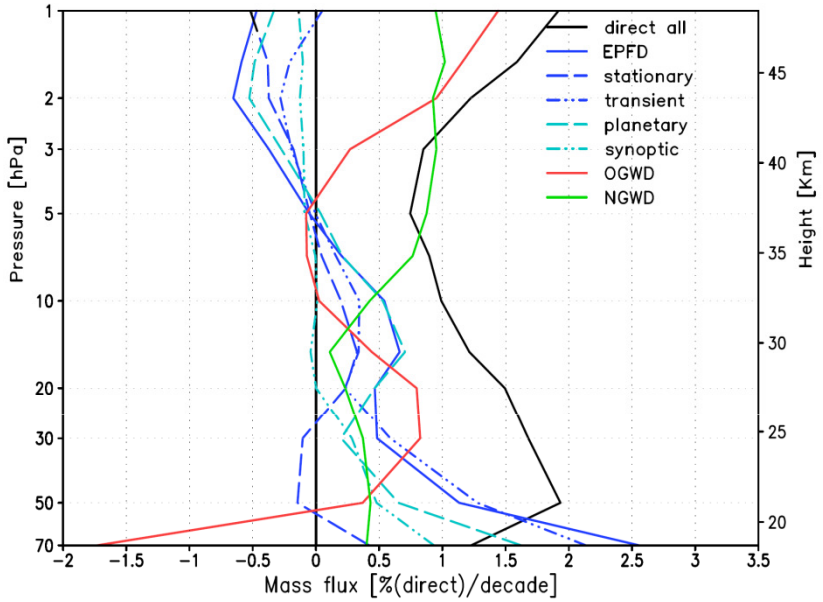
- **Lower stratosphere: Transient waves** dominate, even larger signal for future
- **Middle stratosphere:**
  Stationary waves determine mass flux for past instead of OGWD for future

Δ Tropical upward mass flux [% (direct)/decade] - DJF

2000-1865: Past



2095-2000: Future



Resolved waves (spatial):

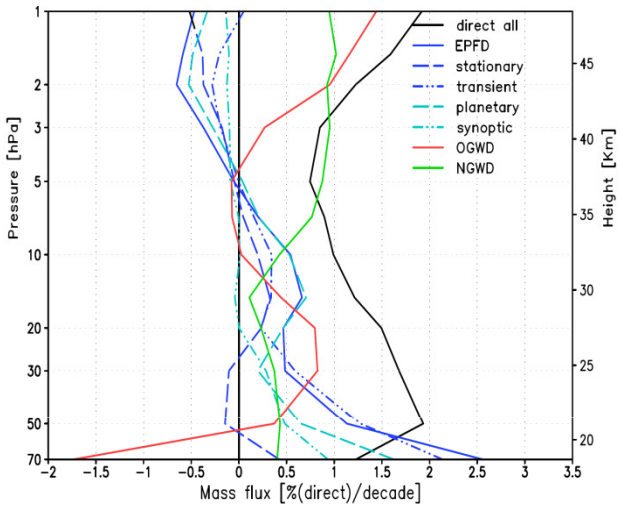
- **Planetary** scale waves more important

Resolved waves (spatial):

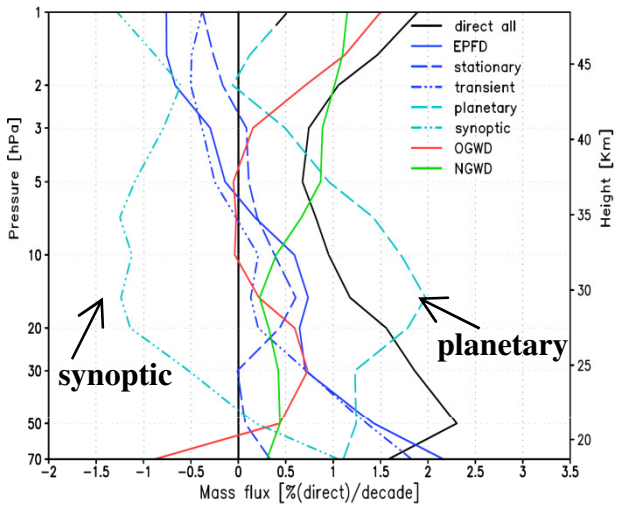
- Nearly equal importance of **planetary and synoptic** scale waves

Δ Tropical upward mass flux [% (direct)/decade] - DJF

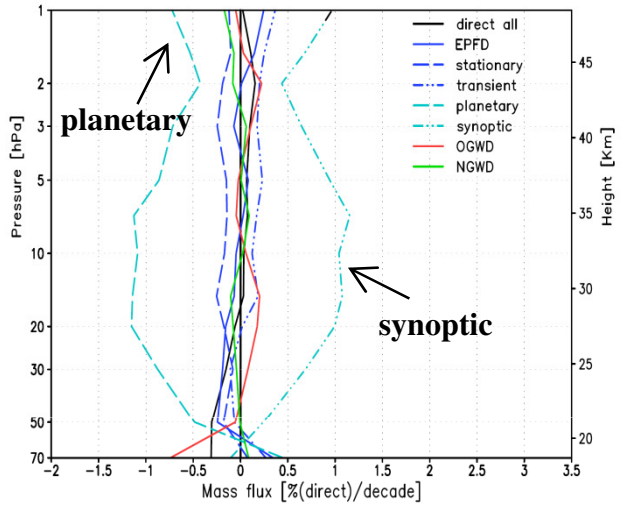
2095-2000: Future



GHG + SST: Future



CFC: Future



- **GHG+SST:** Account for nearly **total future change** in tropical upward mass-flux
- **GHG+SST ↔ CFC: opposed changes in planetary and synoptic scale waves**
  - More planetary scale waves due to (**GHG+SST**)-changes
  - More synoptic scale waves du to **CFC**-changes
  - Nearly no net effect for **Future**

Summary

Increase in GHG+SST:

- Tropospheric warming ↔ stratospheric cooling
- Intensification of subtropical jets
- Enhanced wave generation and propagation → Strengthening of tropical upward mass flux (~BDC)
    - **lower stratosphere:**
      → resolved waves dominate
      → **Future** increase in **transient waves**
    - **middle stratosphere: OGWD** more important for **future**
    - **upper stratosphere:** gravity waves (NGWD+OGWD)

Future CFC-decrease: No significant BDC-change

Thanks for listening!