Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft
Institut für Physik der Atmosphäre

Stratospheric Change and its Role for Climate Prediction
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Hemispheric differences in the return of midlatitude stratospheric ozone to historical levels

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Why we did this study

- Chemistry-climate models (CCMs) project earlier return of NH mid-latitude total column ozone (TOZ) to 1980 values compared to the southern mid-latitudes.
- The 2010 ozone assessment said: **"The more rapid return to 1980 values in northern mid-latitudes is linked to a more pronounced strengthening of the poleward transport of ozone due to the effects of increased GHG levels, and effects of Antarctic ozone depletion on southern mid-latitudes."**
- We assess the robustness of the return date differences across models and methods for their estimation and assess the relative role of transport and chemistry changes.

How we did it

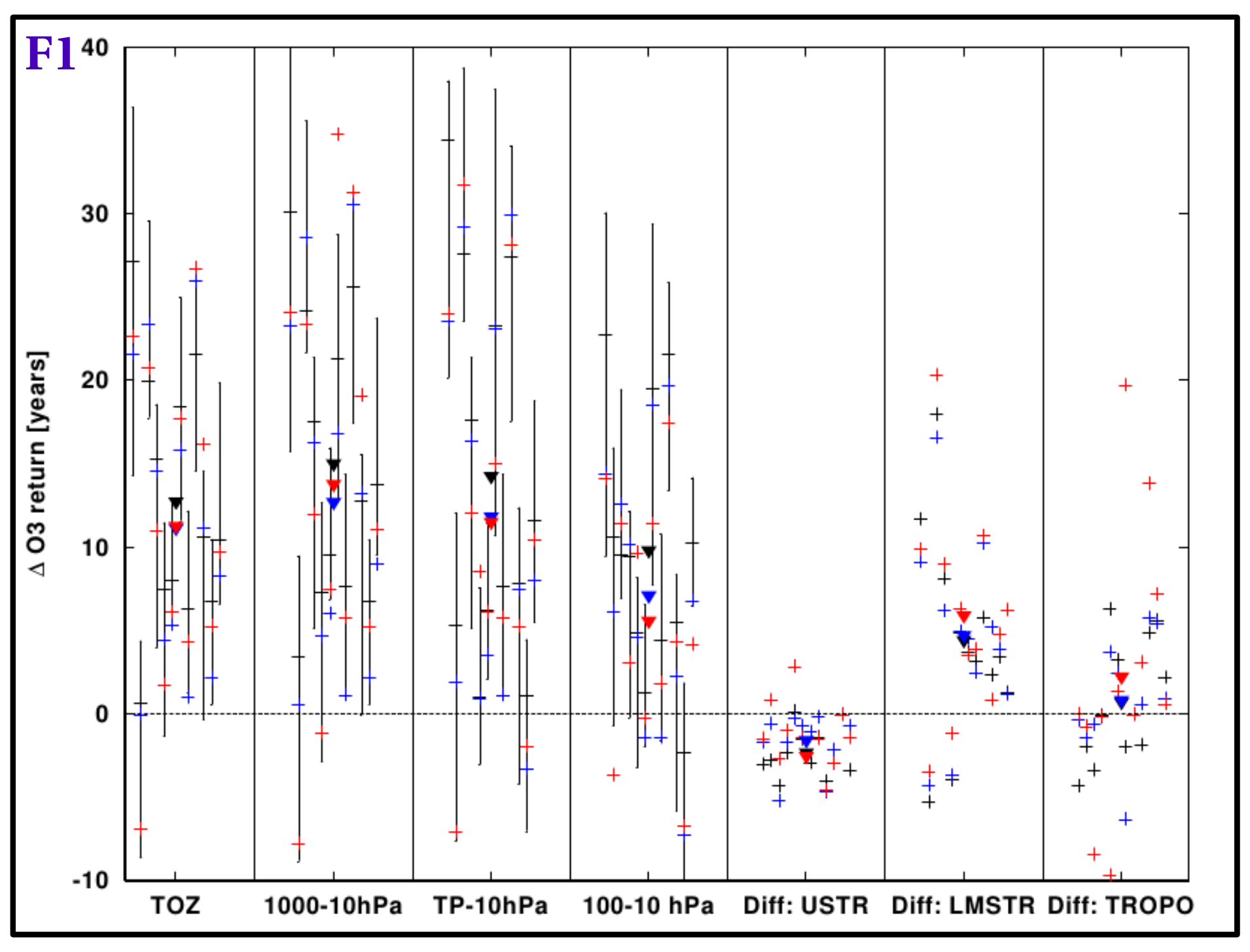
- We use: 1. an ensemble of 12 CCMs from CCMVal2
2. the CCMs NIWA-Socol and E39CA that are equipped with diagnostics to separate effects of chemistry and transport.
- Three different methods of smoothing the time series to estimate the return dates:
  1. simple regression O3(t) = a+b*Cly+c*t
  2. quadratic regression O3(t) = a+b*Cly+c*t+d*Cly^2+e*t^2
  3. simple smoothig: 1:2:1 filter applied 20 times
- Ozone attribution diagnostic (see Garny et al., 2011):

$$\underbrace{\boxed{\frac{O_3^{p2}-O_3^{p1}}{O_3^{p1}}}}_{\text{Relative change in O3 from periods p2 to p1}}=\underbrace{\boxed{\frac{D^{p1}-D^{p2}}{D^{p2}}+\frac{P^{p2}-P^{p1}}{P^{p1}+T^{p1}-\Delta^{p1}}}}_{\text{Relative change in O3 due to chemistry}}+\underbrace{\boxed{\frac{T^{p2}-T^{p1}}{P^{p1}+T^{p1}-\Delta^{p1}}}}_{\text{Relative change in O3 due to transport}}+\underbrace{\delta\Delta+NL}_{\text{Imbalance and Nonlinear terms}}$$

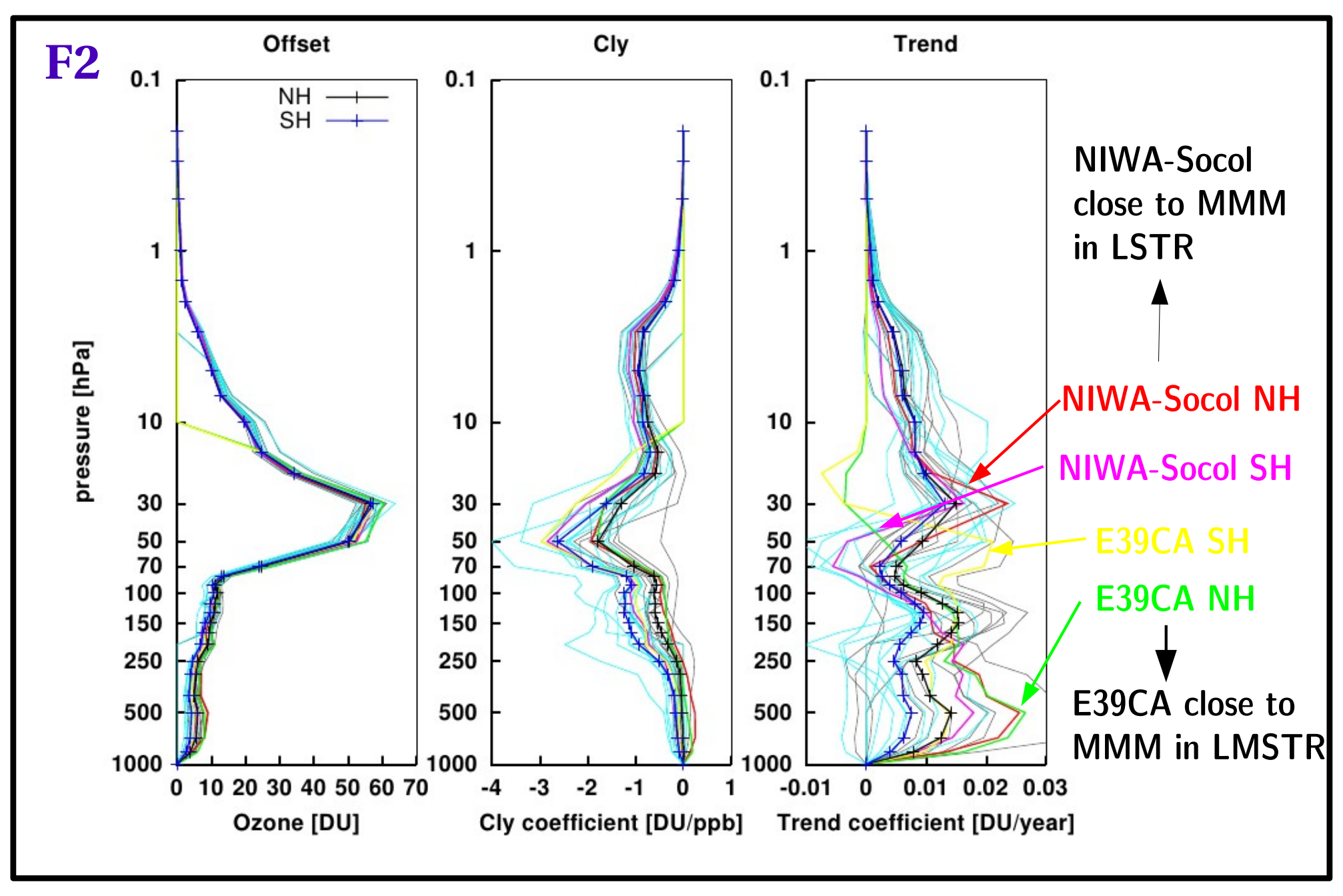
What we find

- Earlier return of TOZ to 1980 values in the NH is a robust result across models and methods, but the return date differences range from 0 to 30 years (Fig. 1).
- Return date differences stem from stronger positive ozone trends in the NH than SH in the LMSTR (tropopause-100hPa) and the LSTR (100-10hPa) (Fig. 1 + 2).
- Spread of hemispheric differences in return dates between models can only in small parts be explained by spread in asymmetric BDC trends (Fig. 3).
- The drivers of asymmetric ozone trends are:
  - → transport differences; important around 100 hPa (Figs. 6+7).
  - → O3 production by NOx in the LMSTR (Figs. 4+5).
  - → O3 loss by NOx in LSTR (Fig. 6+7). Differs between hemispheres due to stronger NOx trends in the SH (Figs. 8+9).
  - → O3 loss by Cly at ~70-50hPa (Fig. 6). Enhanced destruction efficiency in the SH due to heterogeneous ozone depletion (Fig. 10) north of 60°S caused by temperature changes (Fig. 11).

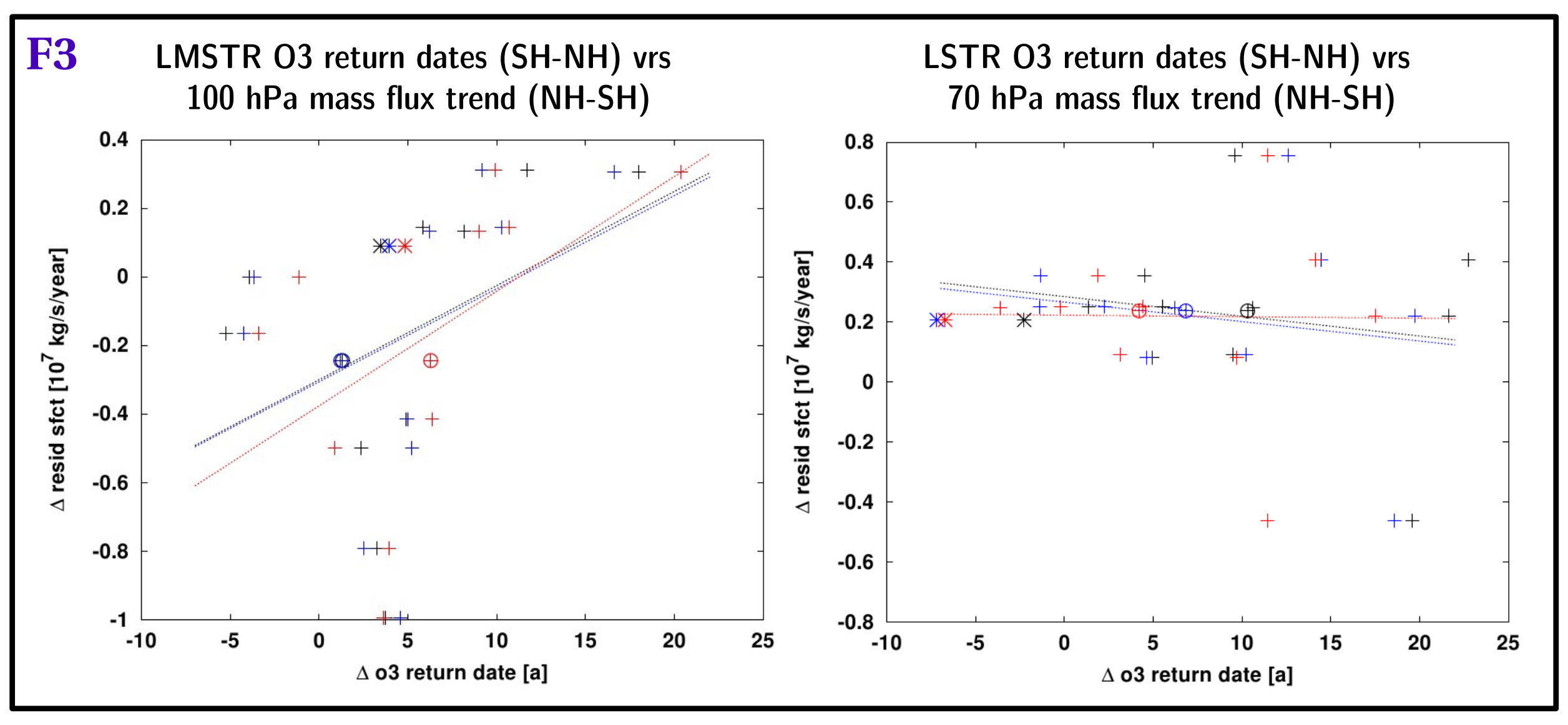
MULTI-MODEL ANALYSIS

F1


Return date difference 45-60°S – 45-60°N from 12 models (crosses) and the mean (triangles) for 3 methods (1:black, 2:blue, 3:red) shown for different altitude regions: The difference in TOZ return dates is due to differences in the LMSTR and LSTR.

F2


Profiles of regression coefficients of contributions to TOZ at each level over the period 1960 to 2049. Individual models in light colors, mean in black and dark blue. Stronger positive trends in O3 in NH in LMSTR and LSTR.

F3


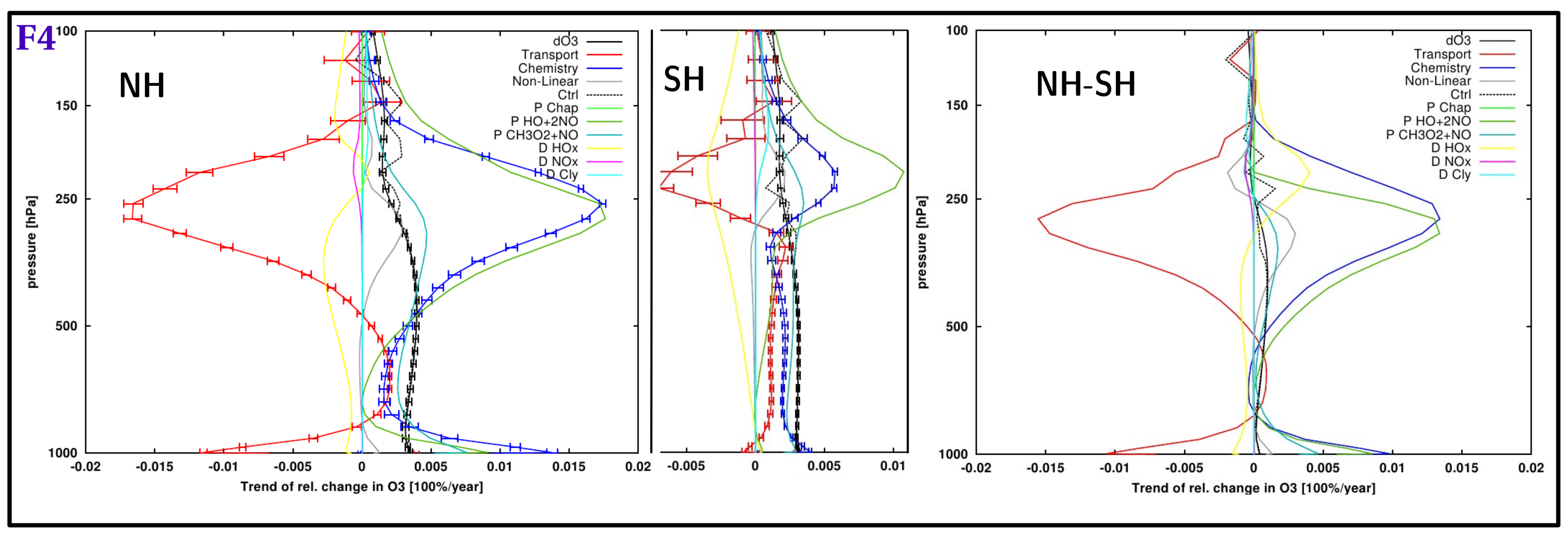
Relation of asymmetric trends in the residual circulation mass flux (NH-SH) to the difference in return dates (SH-NH). Colors as in F1, circle marks NIWA-Socol and star E39CA.
A weak correlation is found in the LMSTR (significant on the 80% level), but none in the LSTR.

→ Do transport changes by the asymmetric BDC changes play a smaller role than previously thought?

ATTRIBUTION TO CHEMICAL AND DYNAMICAL DRIVERS

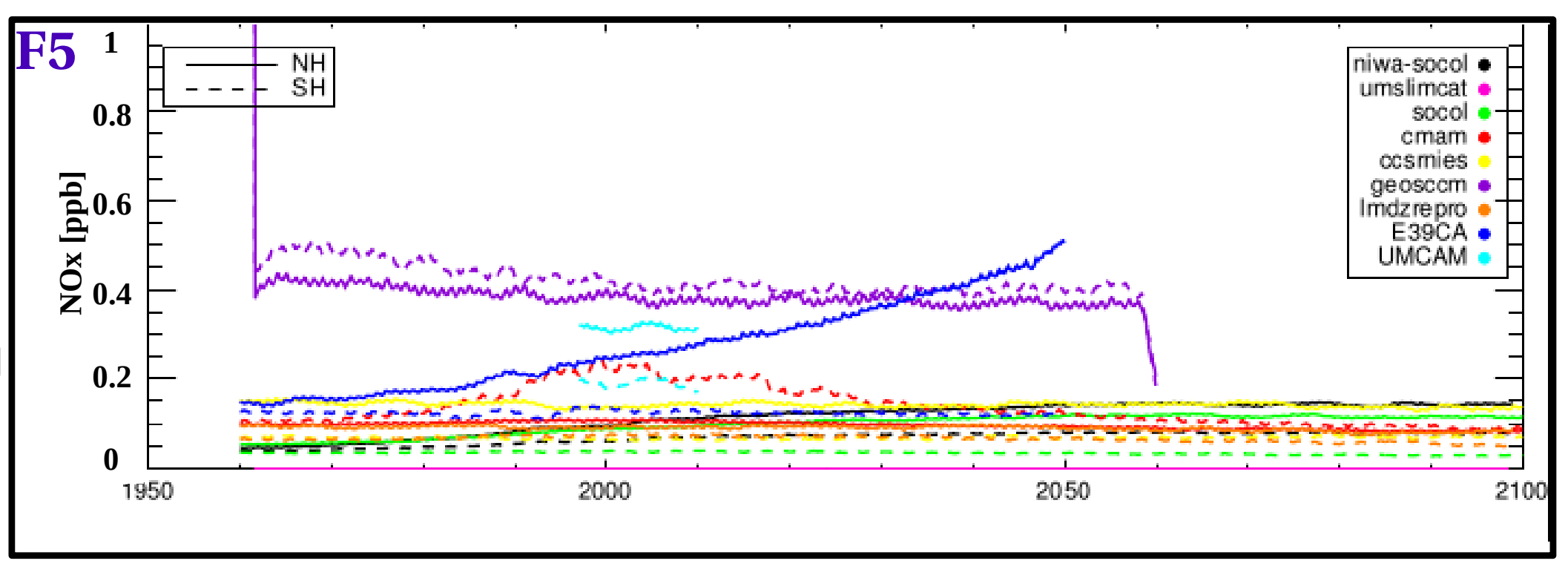
Lowermost Stratosphere (Tropopause to 100 hPa; LMSTR)

→ use E39CA (In NIWA-Socol only stratospheric reaction rates are saved)

F4


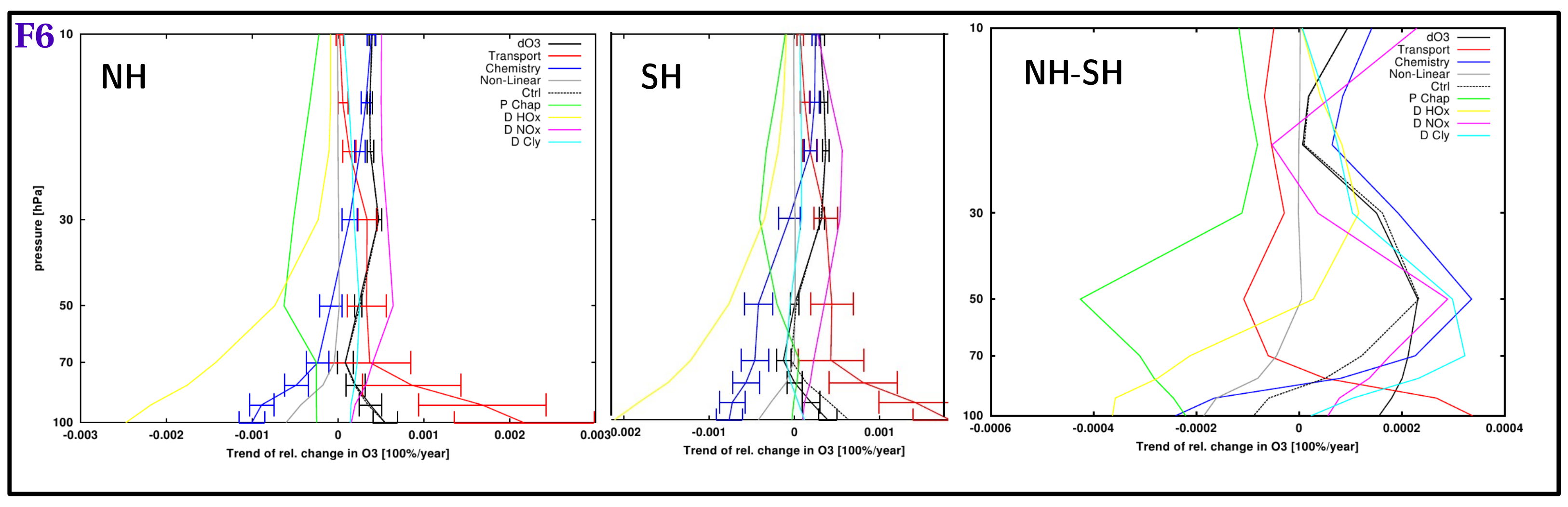
Attribution of ozone trends (1960 - 2049) from the surface to 100 hPa in E39CA: Important contribution from asymmetric NOx induced ozone production.

Timeseries of NOx from various CCMs at 200 hPa and 50°N and S. E39CA has the highest values (but that might be realistic, compared to UMCAM) and a very strong trend. Thus, the NOx production effect might be overestimated in E39CA.

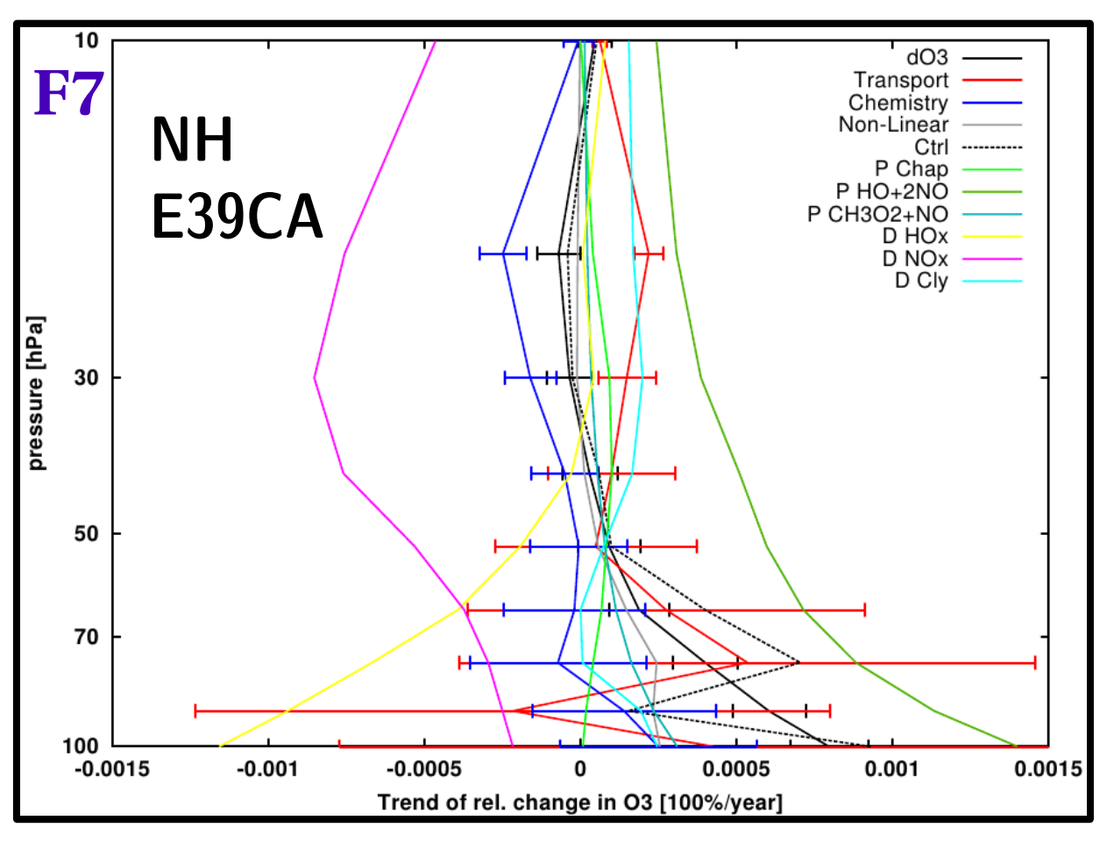
F5


Lower Stratosphere (100 to 10 hPa; LSTR)

→ Use NIWA-Socol (similar to MMM, E39CA is an outlier here)

F6


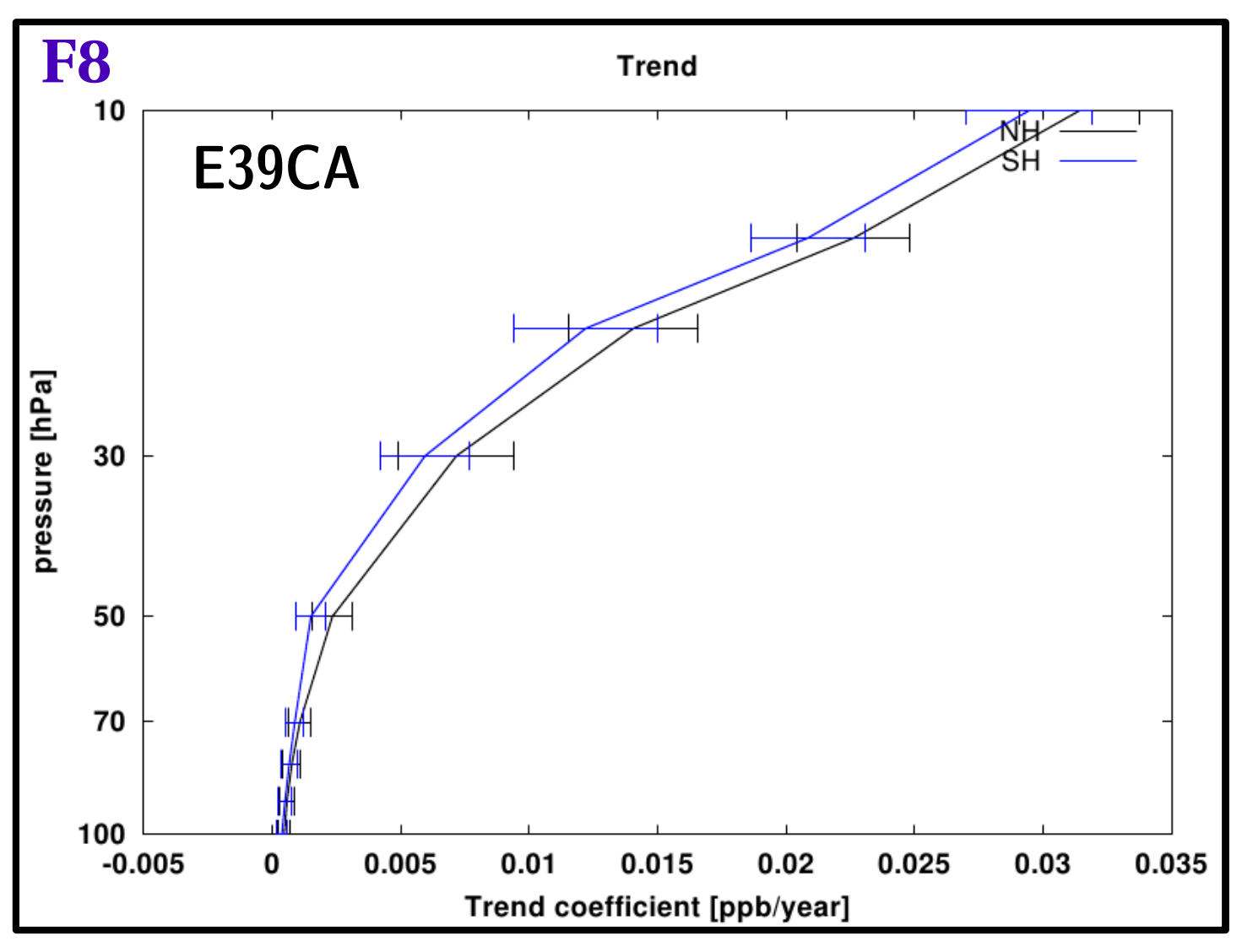
Attribution of ozone trends (1960-2049) from 100 hPa to 10 hPa in NIWA-Socol: Largest hemispheric differences due to chemistry, driven by hemispheric different changes in the NOx and Cly loss cycles.

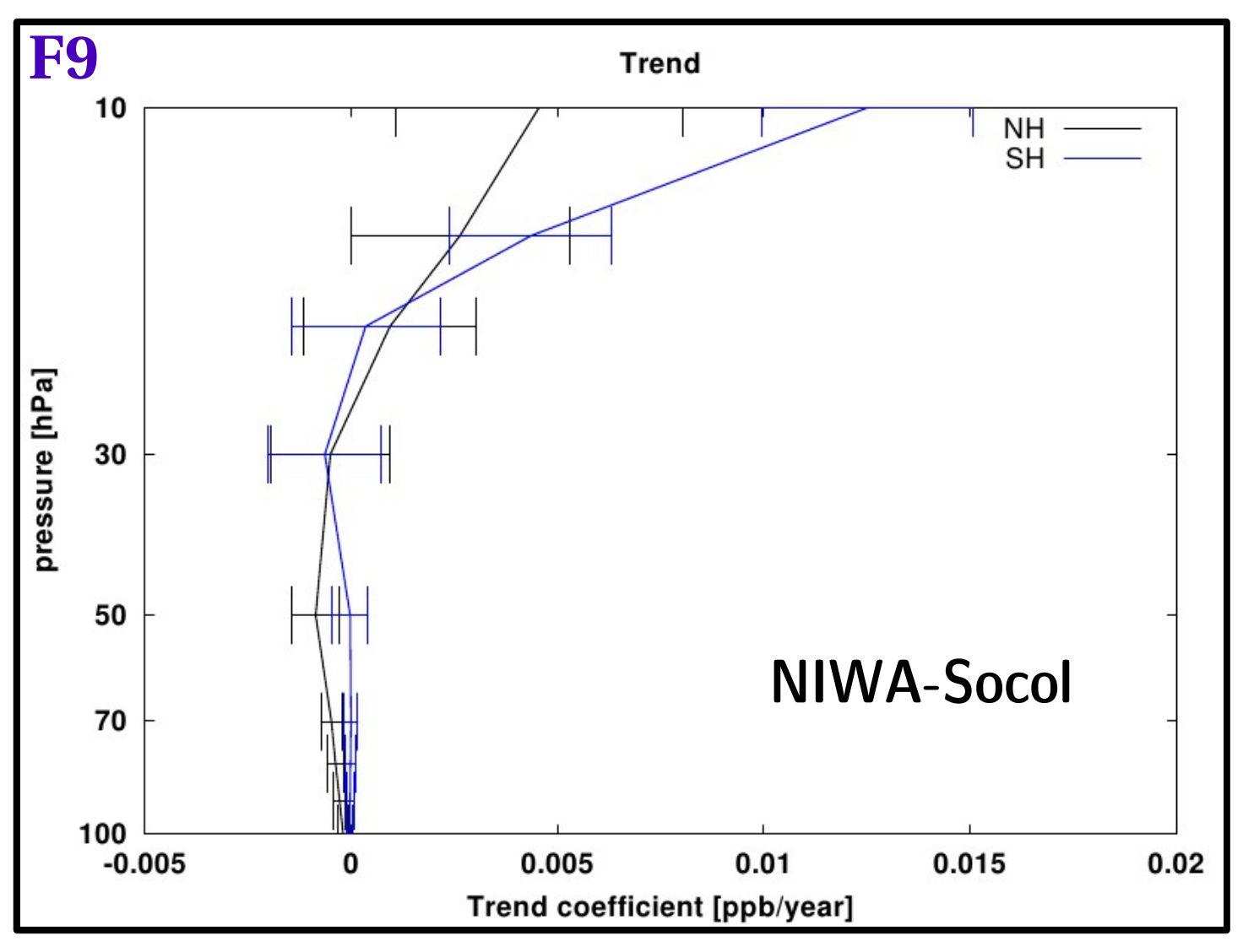
F7


Left: as above but for E39CA (NH only). Here, NOx destruction changes cause a strong negative trend in ozone in the LSTR. Hemispheric differences in ozone return dates in the LSTR are close to zero in E39CA (not shown).

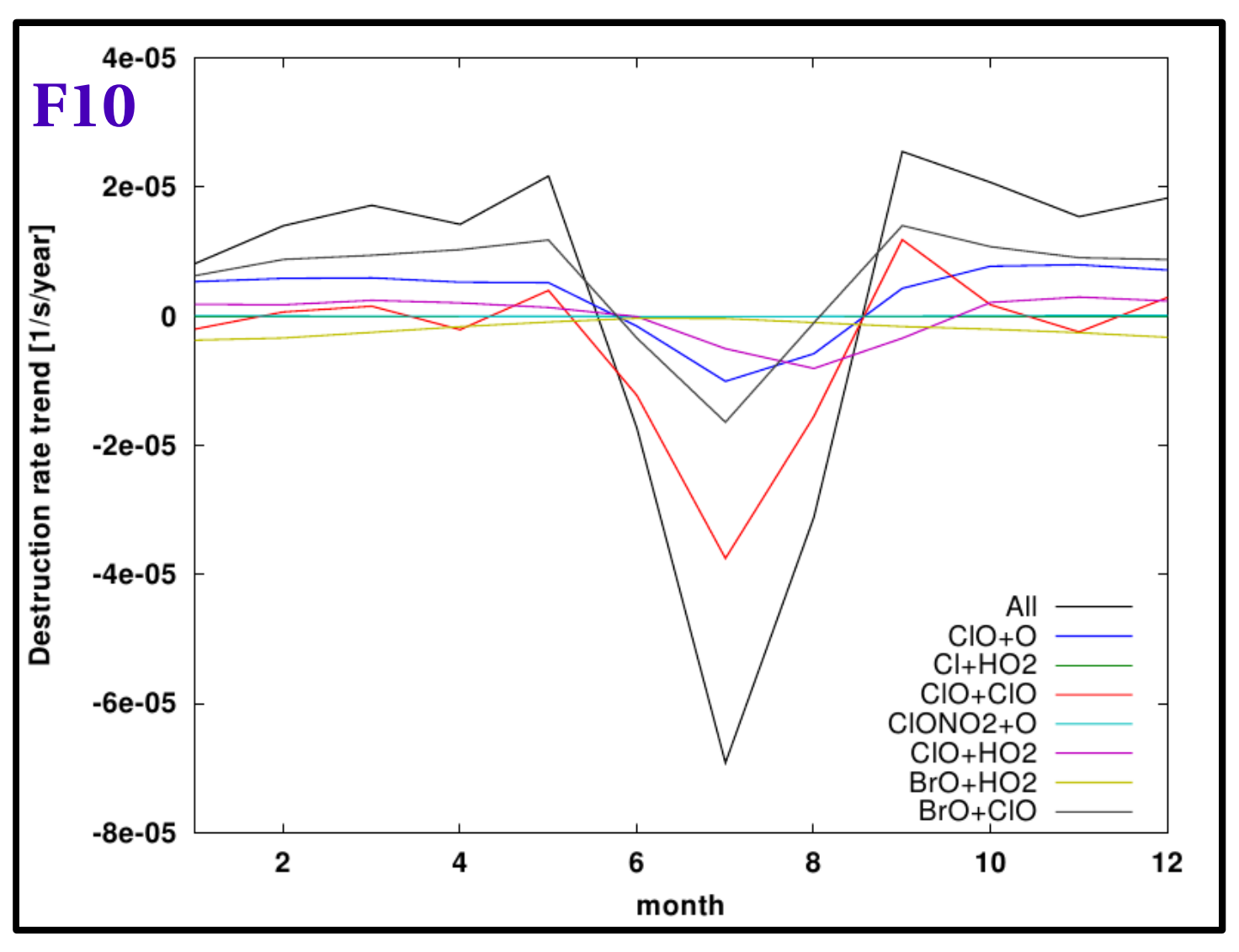
CHANGES IN NOx AND Cly LOSS CYCLES

Linear Trends in NOx (1960 to 2049)

F8


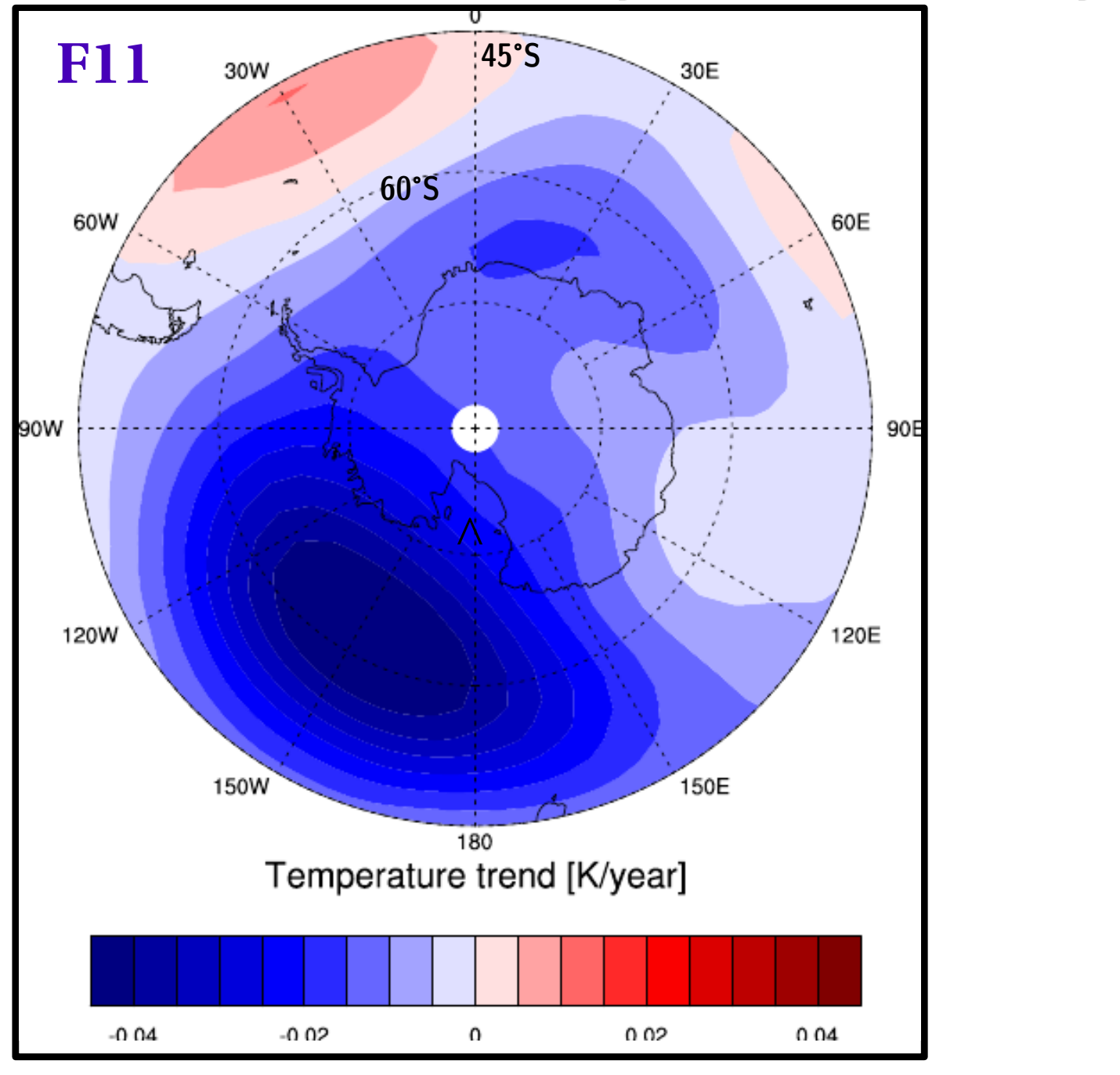
F9


Strong increase of NOx in E39CA. This is due to prescribed values at 10 hPa, with imposed trends following the increase rate of N2O.
Hemispheric differences found in NIWA-Socol that match the differences in the NOx destruction induced ozone trends. The weaker trends in NIWA-Socol and the hemispheric differences indicate an important role of changes in N2O photolysis rates. These might be affected by the increase in the strength of the BDC.

F10


Trends (1960-2049) in Cly destruction rates at 45-60°S, 70 hPa in NIWA-Socol: Strong increase in destruction efficiency in mid-winter due to heterogeneous chemistry (ClO-dimer).

Increase in SH Cly loss efficency

F11


Temperature trends (1960-2049) at 70 hPa in July: decrease in temperature north of 60°S allow for heterogeneous chemistry and thus enhanced ozone loss.

References
Garny, H., Grewe, V., Dameris, M., Bodeker, G. E., and Stenke, A.: Attribution of ozone changes to dynamical and chemical processes in CCMs and CTMs, Geosci. Model Dev., 4, 271–286, 2011.
WMO Scientific Assessment of Ozone Depletion: 2010, Global Ozone Research and Monitoring Project-Report No. 52, 516 pp., Geneva, Switzerland, 2011

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