How UTLS Processes Can Affect Climate Sensitivity in Global Models Including Interactive Chemistry

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Conceptual Framework

Radiative forcing, radiative feedback, climate sensitivity

The climate sensitivity parameter λ describes the global surface temperature response ΔT_S to a radiative forcing RF:

Non-CO_2 radiative forcings are said to have reduced or enhanced efficacy r, if the surface temperature response per unit radiative forcing (i.e., λ) is smaller or larger than the reference climate sensitivity parameter λ_{CO_2}.

$$\Delta T_S = \lambda \cdot RF = r \cdot \lambda_{CO_2} \cdot RF$$

Variations of the climate sensitivity (among different models, among different forcings, etc.) may be related to distinctive radiative feedbacks α_x.

$$\alpha_{phys} = \sum_x \alpha_x = -\frac{1}{\lambda}$$

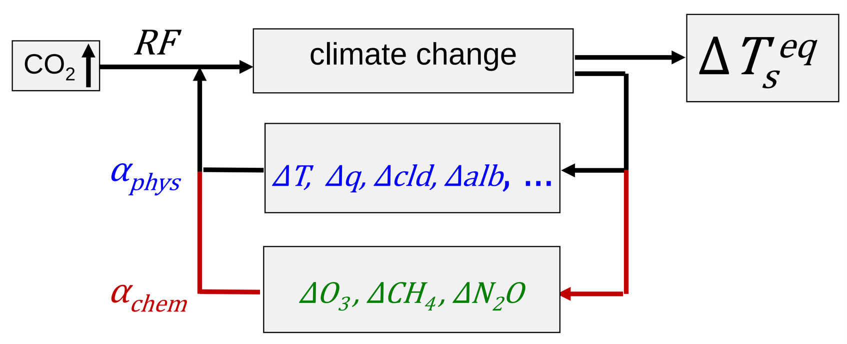
Classical climate models (AOGCMs) include a well defined set of physical feedback processes (x): Planck, water vapor, lapse rate, cloud, and surface albedo feedbacks.

Additional chemical feedback

Chemistry climate models (CCMs) include more feedbacks (y) than AOGCMs due to the presence of additional radiatively active tracers:

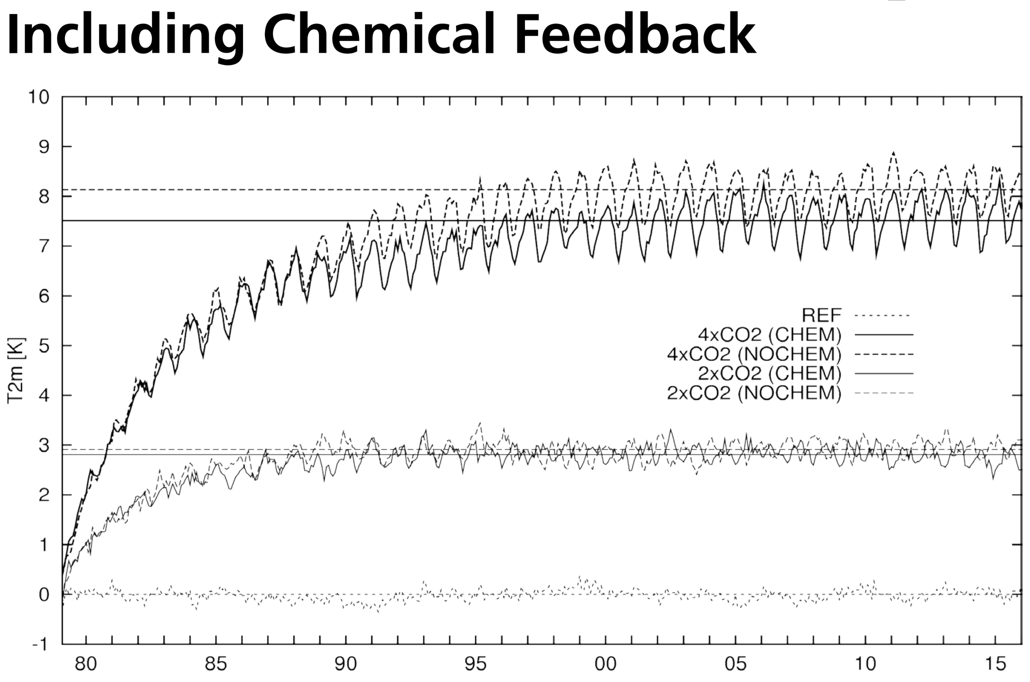
$$\alpha = \sum_y \alpha_y = \alpha_{phys} + \alpha_{chem}$$

Hence, CCMs can be expected to simulate a different climate sensitivity than a equivalent counterpart model without chemical feedback α_{chem}.



Current CCMs are mainly suitable to cover the ozone concentration and radiative feedback, extensions are still needed to adequately match CH_4 and N_2O feedbacks as well.

Reduced Climate Sensitivity in CO_2-driven Simulations Including Chemical Feedback



Model: EMAC

ECHAM5/MESSy Atmospheric Chemistry model

ECHAM5 : ECMWF/MPI-HAMburg model, version 5 (Roeckner et al., 2005)

MESSy: Modular Earth Submodel System (Jöckel et al., 2005)

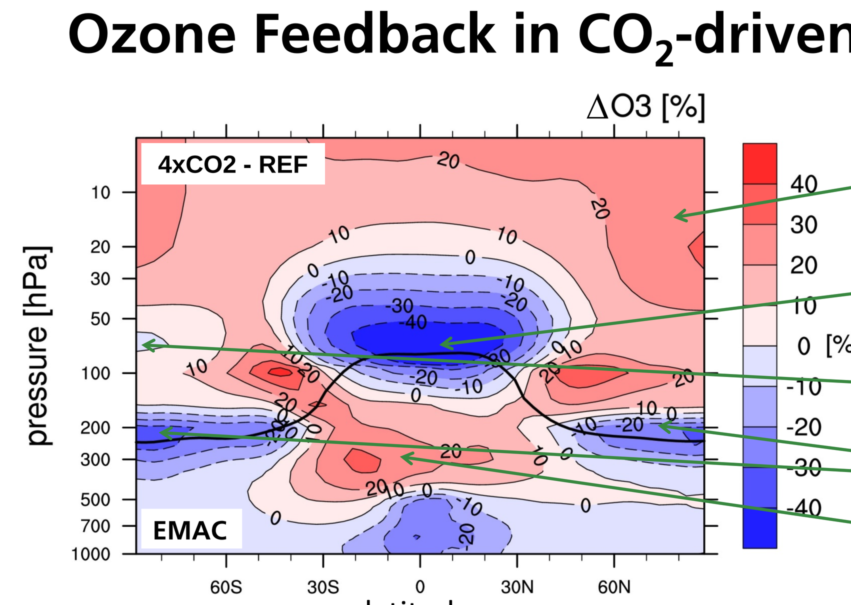
Simulation		RF Wm^{-2}	chemistry	Climate sensitivity λ K/(Wm^{-2}) mean	[95% confi.]
Increase of CO_2 by 75 ppmv	+75CO2	1.06	no **yes**	0.73 **0.63**	[0.67; 0.79] **[0.57; 0.68]**
Doubling of CO_2	2xCO2	4.13	no **yes**	0.70 **0.68**	[0.69; 0.72] **[0.66; 0.69]**
Quadrupling of CO_2	4xCO2	8.93	no **yes**	0.91 **0.84**	[0.90; 0.92] **[0.83; 0.85]**

Simulations:

Dietmüller (2011)
Dietmüller et al. (2014)

Climate sensitivity changes are initiated by the feedback induced by interactive ozone but receive contributions from other feedbacks modified by the presence of interactive chemistry.

Ozone Feedback in CO_2-driven Simulations: Robustness



Slower ozone decay rates as the stratosphere cools

Enhanced tropical upwelling as troposphere warms

More polar stratospheric clouds in cooler stratosphere

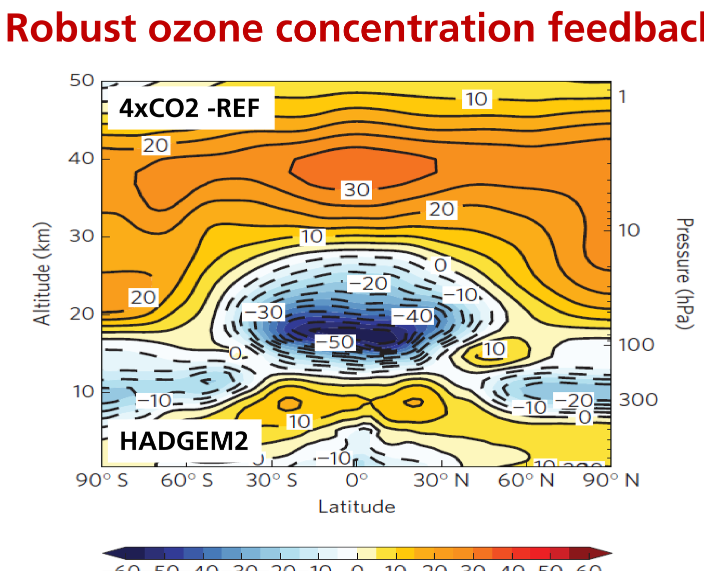
Tropopause lifting

Modified NO_y as transport and lightning NO_x production change

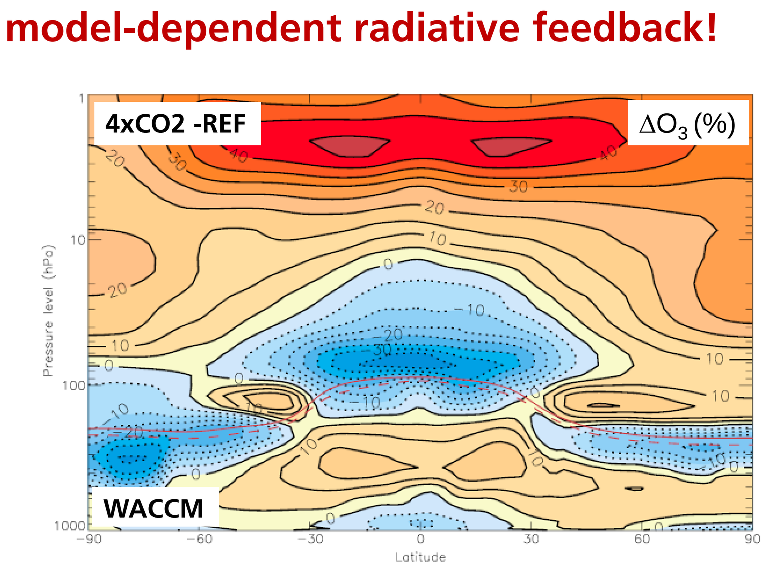
Dietmüller et al. (2014)

$\alpha_{O3} = -0.015$ $Wm^{-2}K^{-1}$

Robust ozone concentration feedback, but model-dependent radiative feedback!



Nowack et al. (2015) $\alpha_{O3} \sim -0.13$ $Wm^{-2}K^{-1}$



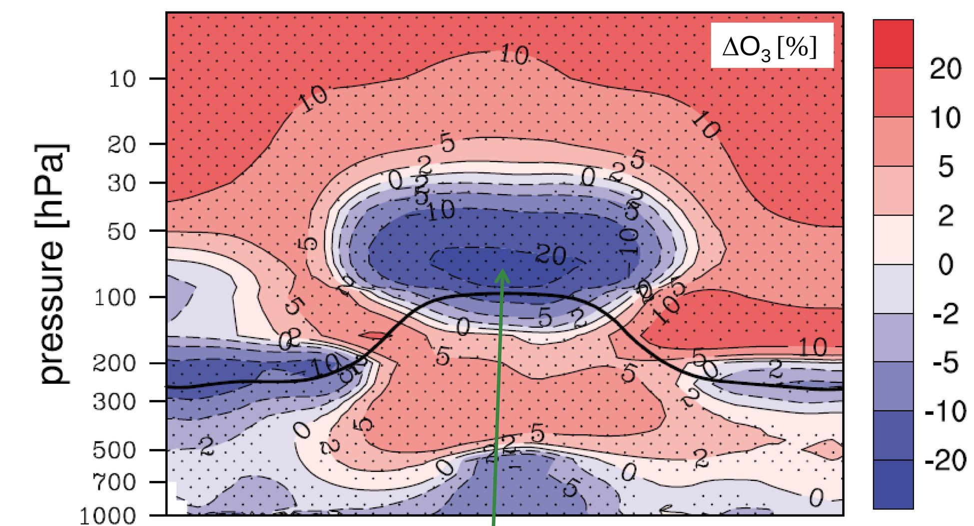
Marsh et al. (2016) $\alpha_{O3} \sim -0.011$ $Wm^{-2}K^{-1}$

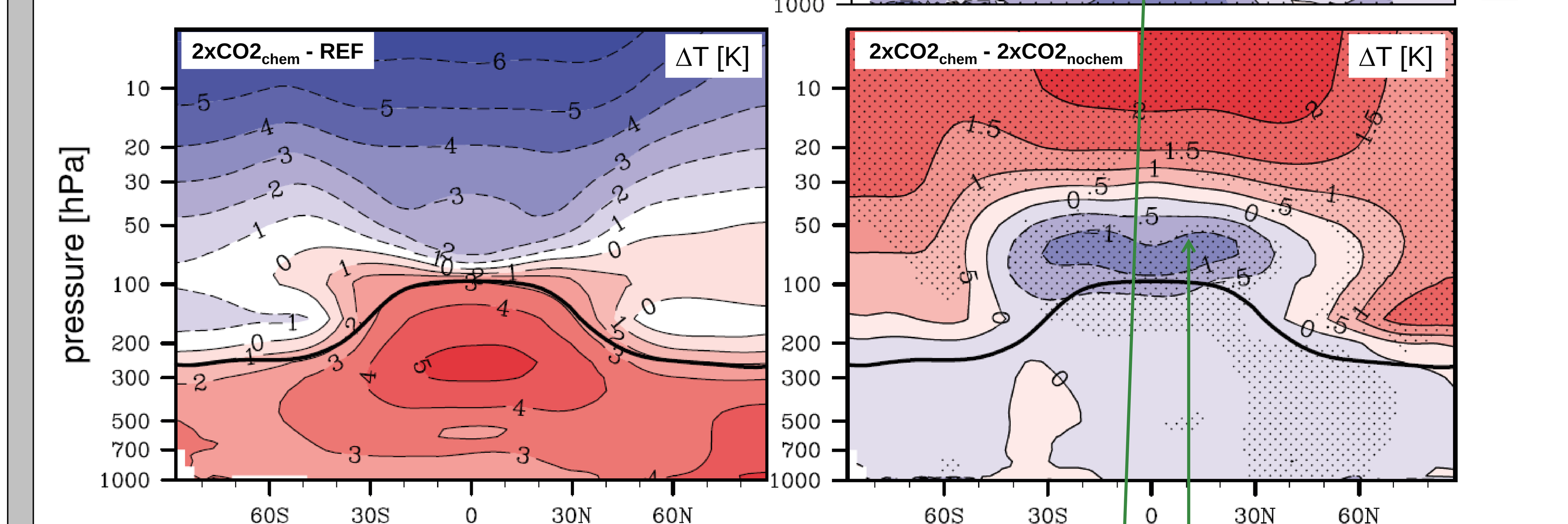
Interaction of Feedbacks and Net Effect: the Key Role of the UTLS

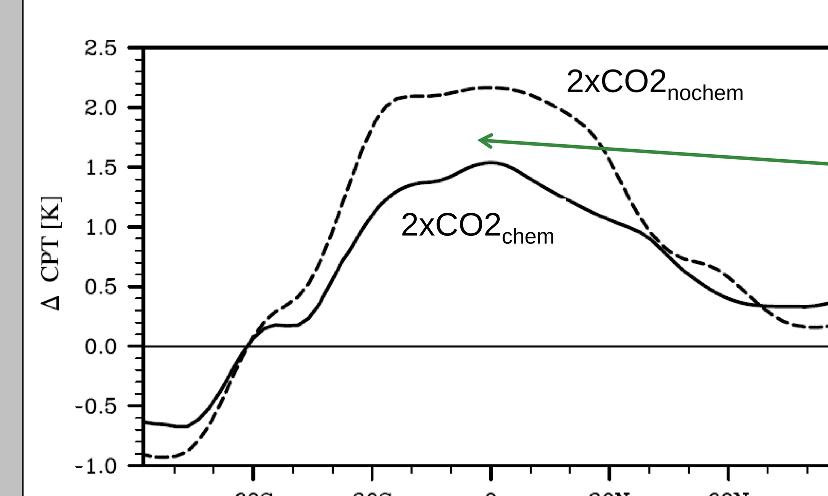
We use 2xCO2 simulations with **EMAC** to demonstrate that interactive chemistry

- introduces an additional negative feedback from stratospheric ozone,
- reduces the increase of tropical cold point temperature as ozone decreases in the UTLS and
- leads to a substantial reduction of the stratospheric water vapor feedback,

eventually causing the climate sensitivity to decrease by ~3.5% (in 4xCO2: by ~8.5%)







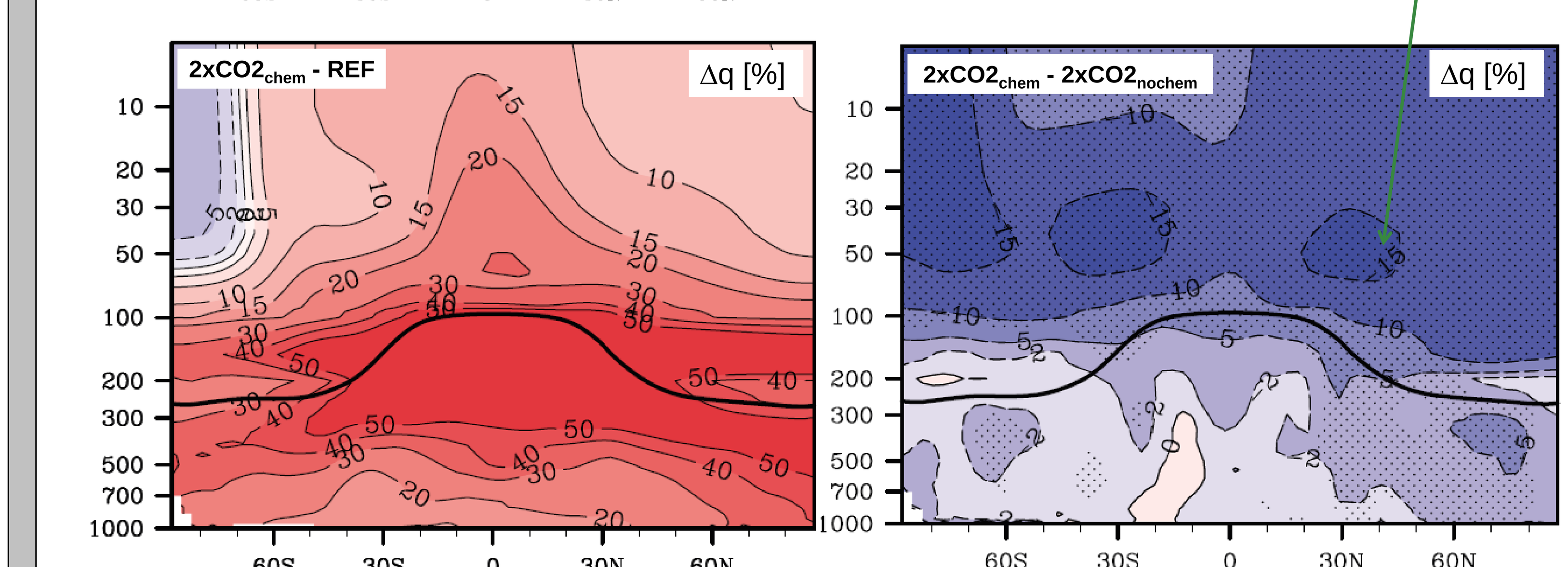
Lower stratospheric ozone concentration (tropics) reduced by enhanced tropical upwelling

Smaller ozone related heating at tropical cold point causes reduced cold point warming

Stratospheric water vapor uptake and the respective radiative feedback decrease, compared to the “nochem” model setup (model dependent!)

2xCO2 $\Delta\alpha_q = -0.027$ $Wm^{-2}K^{-1}$

4xCO2 $\Delta\alpha_q = -0.047$ $Wm^{-2}K^{-1}$



Dietmüller et al. (2014)

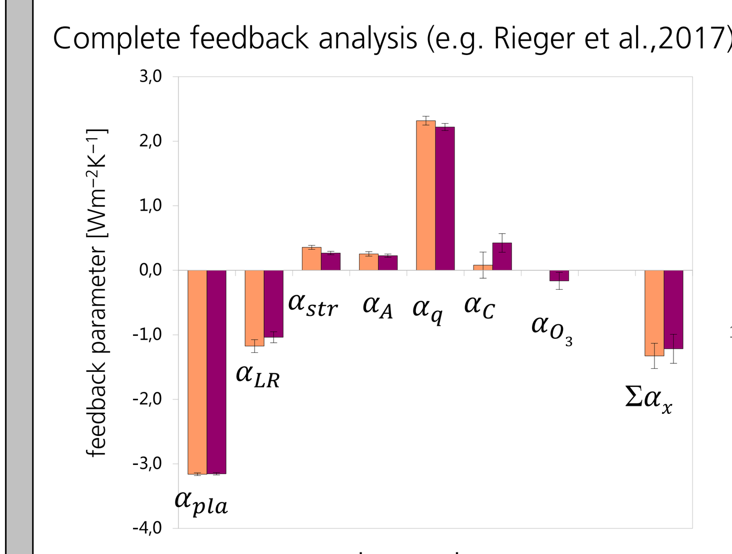
Example of a Non-CO_2 forcing: Enhanced NO_x/CO Surface Emissions Induce Ozone Forcing and Ozone Feedback

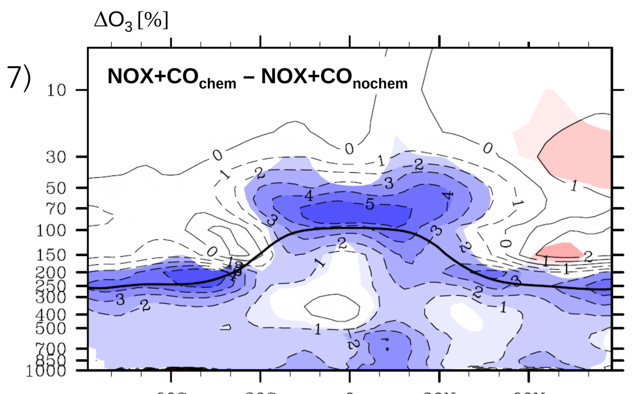
Simulation		RF Wm^{-2}	chemistry	Climate sensitivity λ K/(Wm^{-2}) mean	[95% confi.]
Increase of CO_2 by 75 ppmv	+75CO2	1.06	no **yes**	0.73 **0.63**	[0.67; 0.79] **[0.57; 0.68]**
Ozone change from enhanced NO_x/CO surface emissions	NOX+CO	1.22	no **yes**	0.63 **0.69**	[0.57; 0.69] **[0.65; 0.73]**

Chemistry feedbacks may impact differently on climate sensitivity in case of non-CO_2 forcings!

Stratospheric ozone not always contributes most to the ozone feedback.

Complete feedback analysis (e.g. Rieger et al.,2017)





$\alpha_{O3} = -0.17$ $Wm^{-2}K^{-1}$ (1/3 stratospheric, 2/3 tropospheric)

Dietmüller (2011)

Only a complete feedback analysis ensures consistent process assessment for NOX+CO forcing: Direct effect of chemical feedbacks on the climate sensitivity may be reversed by changes in physical feedbacks (like clouds!).

$$\alpha = \sum_x \alpha_x = \sum_x \frac{\Delta R_x}{\Delta T_S}$$ Partial radiative perturbation (PRP) feedback calculation (e.g., Klocke et al., 2013)

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