CHASER
Chemistry Climate Model

Changes in tropospheric chemistry and their impacts on climate:

roles of climate change and the stratosphere

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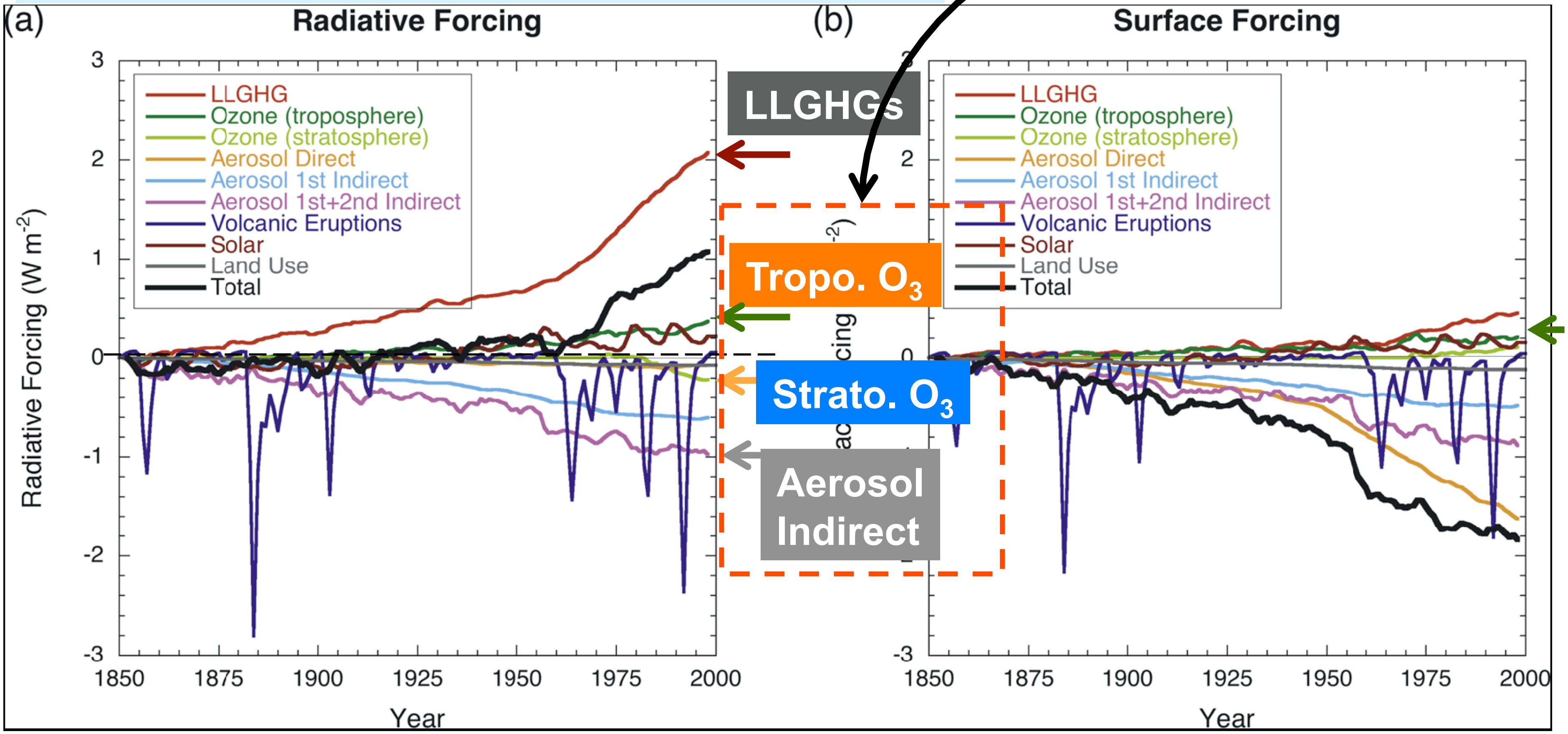
Radiative Forcing in the 20th century

Air pollution / Atmospheric Chem.

IPCC-AR4: CCSR/NIES/FRCGC GCM (MIROC)



LLGHGs

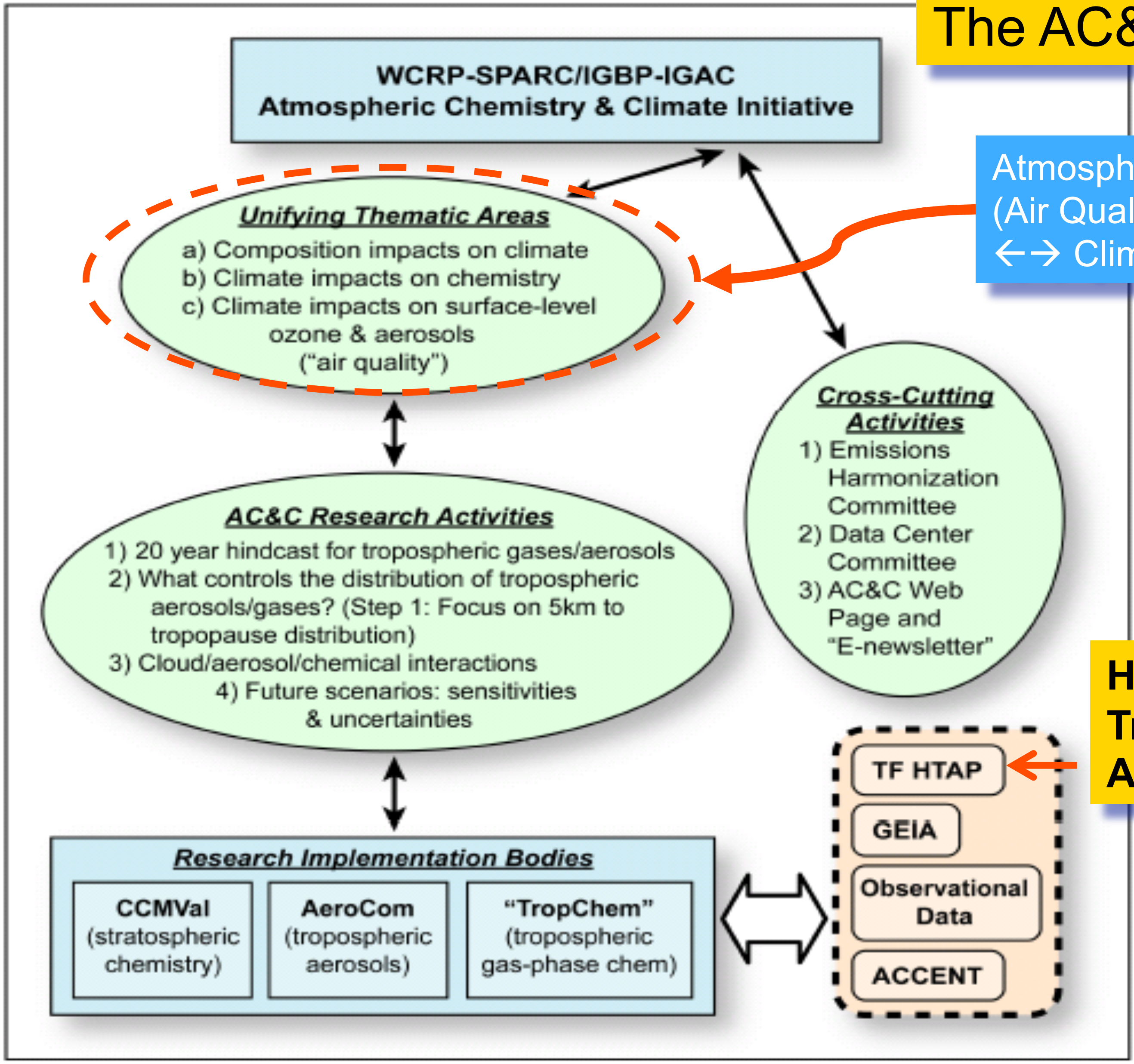
Tropo. O_3

Strato. O_3

Aerosol Indirect

Takemura et al [2006]

The AC&C Initiative



WCRP-SPARC/IGBP-IGAC
Atmospheric Chemistry & Climate Initiative

Unifying Thematic Areas

a) Composition impacts on climate
b) Climate impacts on chemistry
c) Climate impacts on surface-level ozone & aerosols ("air quality")

Cross-Cutting Activities

1) Emissions Harmonization Committee
2) Data Center Committee
3) AC&C Web Page and "E-newsletter"

AC&C Research Activities

1) 20 year hindcast for tropospheric gases/aerosols
2) What controls the distribution of tropospheric aerosols/gases? (Step 1: Focus on 5km to tropopause distribution)
3) Cloud/aerosol/chemical interactions
4) Future scenarios: sensitivities & uncertainties

Research Implementation Bodies

CCMVal (stratospheric chemistry)
AeroCom (tropospheric aerosols)
"TropChem" (tropospheric gas-phase chem)

TF HTAP
GEIA
Observational Data
ACCENT

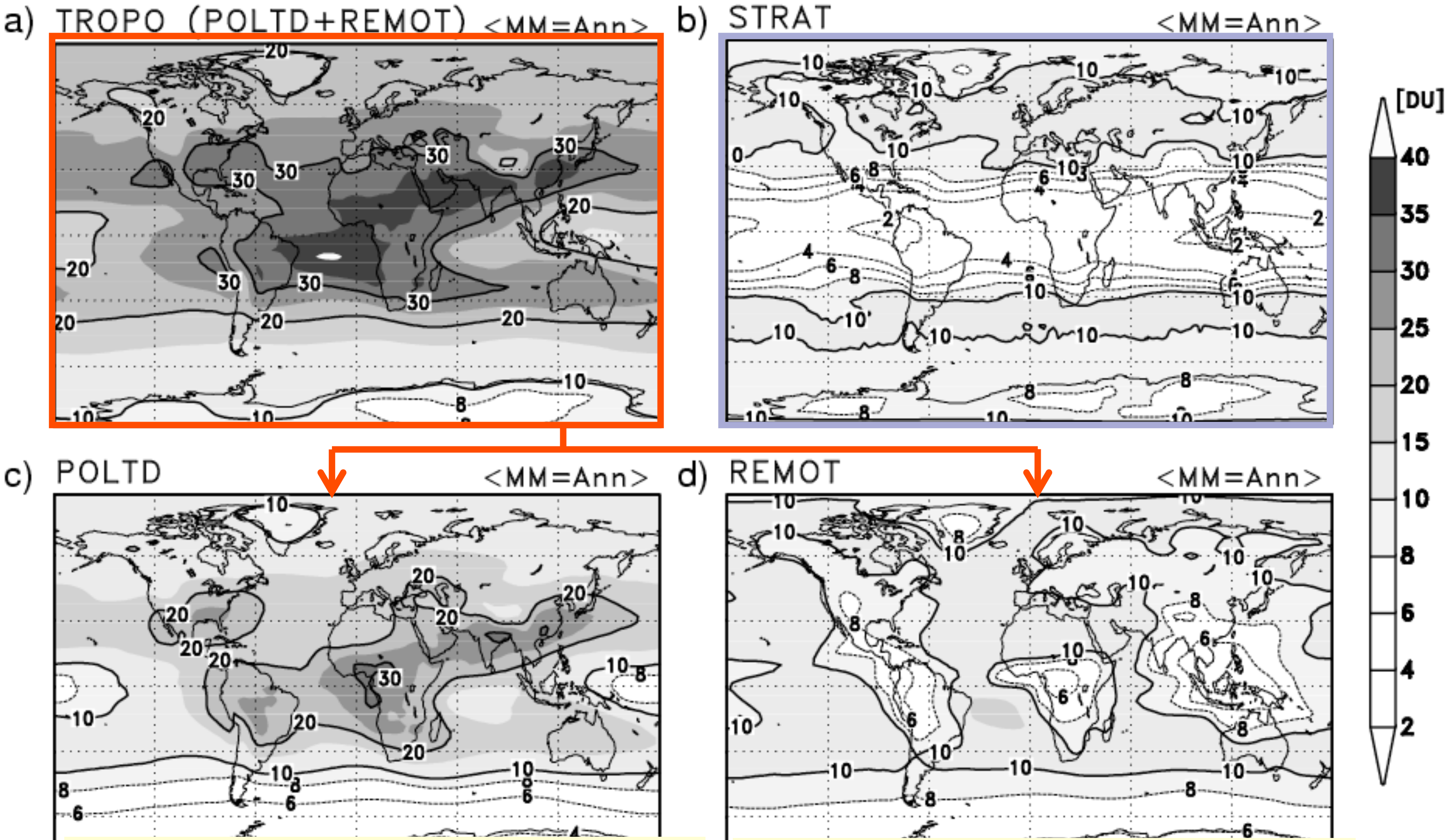
Atmospheric chemistry (Air Quality) ←→ Climate Interaction

Hemispheric Transport of Air Pollution

Contributions to Annual Mean Tropospheric Column O_3 (TCO)

Tropospheric Origin

Stratospheric Origin

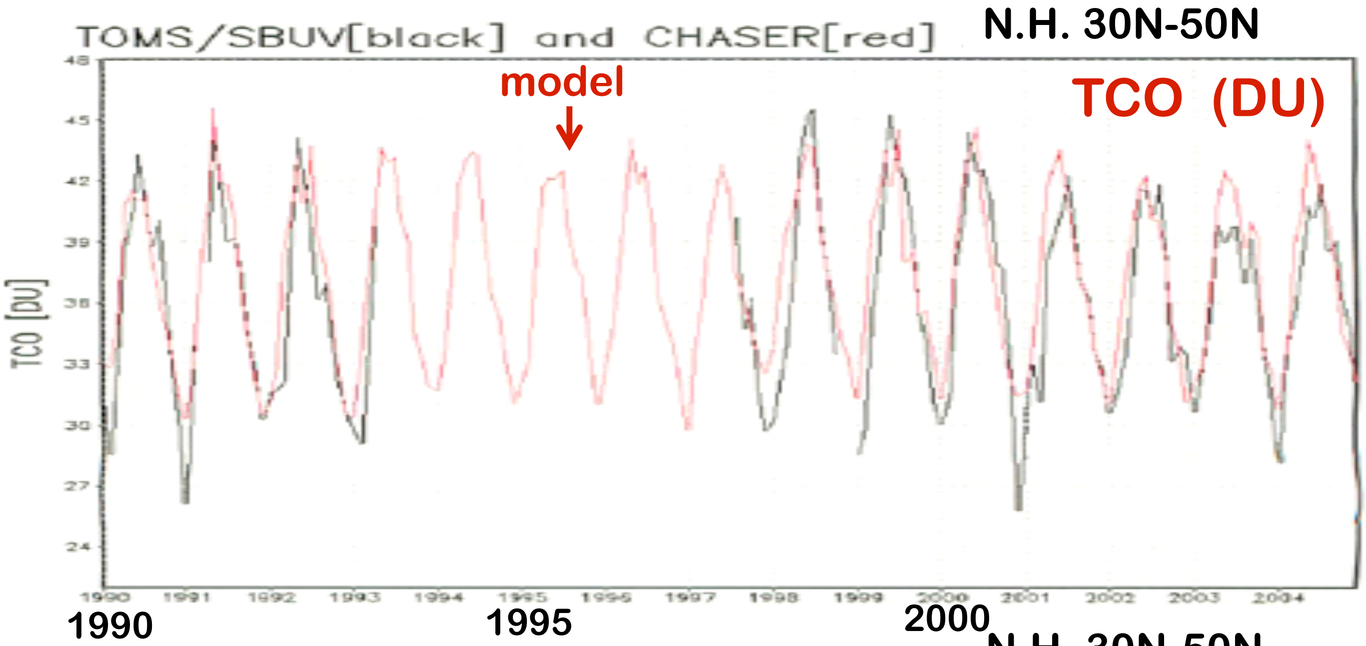


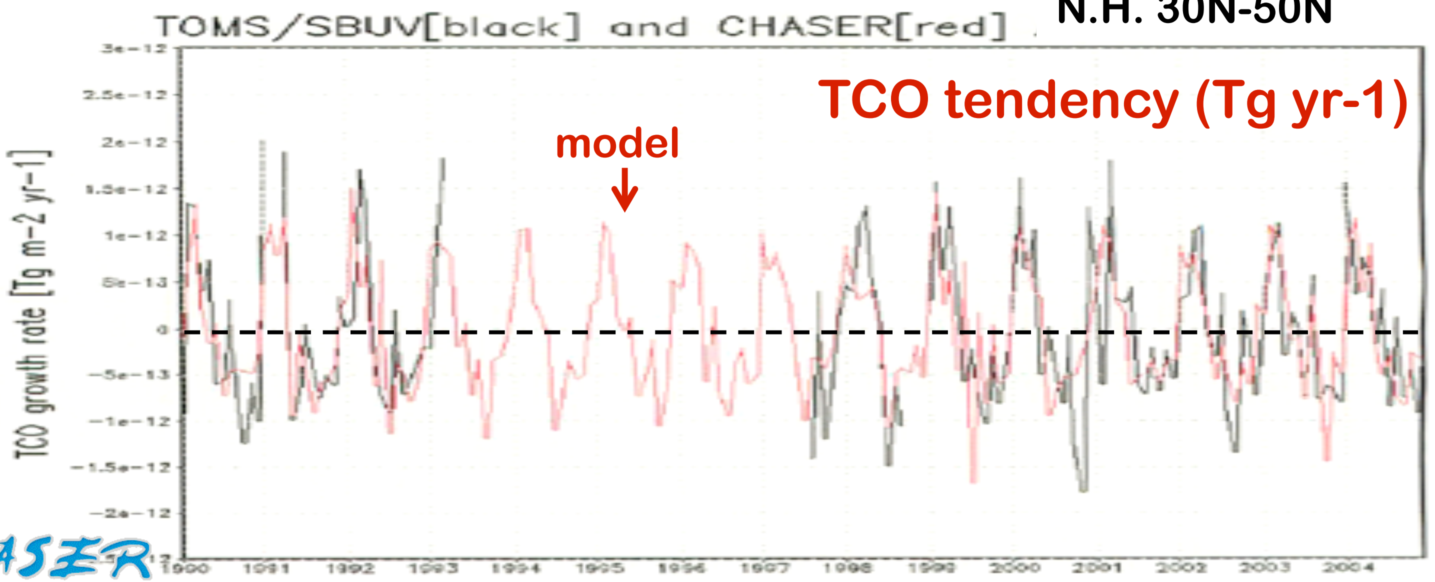
Sudo and Akimoto (2007)

<Production in polluted regions>

<Production in remote regions>

Tropospheric Column Ozone (TCO) seasonal-annual variation





CHASER
Chemistry Climate Model

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Global Budgets of Tropospheric O_3 from Distinct Source Regions

Stratospheric origin

Sudo and Akimoto (2007)

Table 3. Global Budget of Tropospheric O_3 from Distinct Source Regions.

Chem. production

Lifetime(days)

	Tracer ID[a]	P[b]	P−L[c]	Deposition	STE[d]	Tropo. Burden (TgO_3) Global (%)	Tropo. Burden (TgO_3) NH	Chemical	Residential
	O_3-ALL	4744	444.0	-917	472.7	344.6 (100.0%)	187.3	26	22
	STRAT	0	-484.1	-131	615.6	77.9 (22.6%)	38.6	45	37
	REMOT	1735	338.7	-257	-81.7	101.0 (29.3%)	51.1	25	21
	POLTD	3010	589.5	-528	-61.3	165.7 (48.1%)	97.5	23	20
PBL	BL-AMN	162	55.4	-47	-8.1	7.0 (2.0%)	6.8	24	16
	BL-AMM	162	29.8	-30	-0.3	6.6 (1.9%)	5.5	18	15
	BL-AMS	203	49.6	-49	-0.3	7.4 (2.1%)	0.9	18	13
	BL-AFN	166	33.1	-33	-0.2	5.4 (1.6%)	4.0	15	12
	BL-AFS	175	38.8	-38	-0.3	6.6 (1.9%)	0.9	17	14
	BL-EUR	116	49.4	-44	-5.6	4.5 (1.3%)	4.4	27	14
	BL-CEU	76	31.3	-28	-3.7	3.0 (0.9%)	2.9	28	14
	BL-MES	92	22.3	-22	0.0	3.2 (0.9%)	2.9	17	13
	BL-IND	97	20.9	-20	-0.8	3.9 (1.1%)	3.4	18	14
	BL-TLD	50	7.8	-7	-0.4	2.2 (0.6%)	1.7	18	16
	BL-CHN	128	34.6	-34	-1.0	5.9 (1.7%)	5.5	23	17
	BL-JPN	22	6.4	-6	0.0	1.1 (0.3%)	1.1	24	18
	BL-IDN	61	9.7	-9	-0.5	2.8 (0.8%)	0.9	19	17
	BL-AUS	88	19.7	-19	-0.3	3.7 (1.1%)	0.2	20	15
FT	FT-AMN	167	29.6	-19	-10.6	11.9 (3.4%)	10.7	29	26
	FT-AMS	295	32.9	-27	-5.8	21.0 (6.1%)	7.0	27	26
	FT-AFN	203	21.2	-19	-2.2	13.4 (3.9%)	9.1	25	24
	FT-AFS	186	21.6	-18	-3.8	13.1 (3.8%)	2.1	27	25
	FT-EUR	60	15.9	-12	-4.1	4.2 (1.2%)	4.1	34	25
	FT-ASA	325	39.7	-32	-8.0	24.9 (7.2%)	20.5	30	28
	FT-IDN	90	8.9	-7	-2.2	6.9 (2.0%)	2.2	29	28
	FT-AUS	86	11.0	-8	-3.2	6.9 (2.0%)	0.8	31	29

Tropospheric chemistry and its climate impacts
-- roles of climate change and stratosphere ?--

1. The impacts of global ozone changes on climate:

+ Evaluate climate equilibrium response

+ Tropo. O_3 increase and strato. O_3 decrease in the 20th century

2. Long/near term future projection of tropospheric ozone and related species (CH_4 / aerosols):

+ Impacts of climate change

+ Impacts of stratospheric O3 change

3. Summary

Experimental Setup

① **Evaluate climate (equilibrium) responses to changes in "Tropo. O_3", "Strato. O_3", and "LLGHGs" from preindustrial times to the present.**

② **Past O_3 changes are reproduced with a global chemistry climate model CHASER (Sudo et al., 2006); stratospheric O_3 changes are expressed as a function of halogen loading as with the SPARC Ozone Trend Estimate for 1980–2000.**

③ **Run CCSR/NIES/FRCGC climate model (AGCM + simplified ocean model) for 50 years (30 years for analysis) X 6 ensembles.**

Run Scenarios

	Ctrl	L	LT	LTm	LTS
LLGHGs	PI	PD	PD	PD	PD
Tropo. O_3	PI	PI	PD	PD*	PD
Strato. O_3	PI	PI	PI	PI	PD

*Zonally averaged O_3 increases

(!) LLGHGs = CO_2 + CH_4 + N_2O + CFCs
(!) PI: preindustrial ～1850, PD: present day ～2000

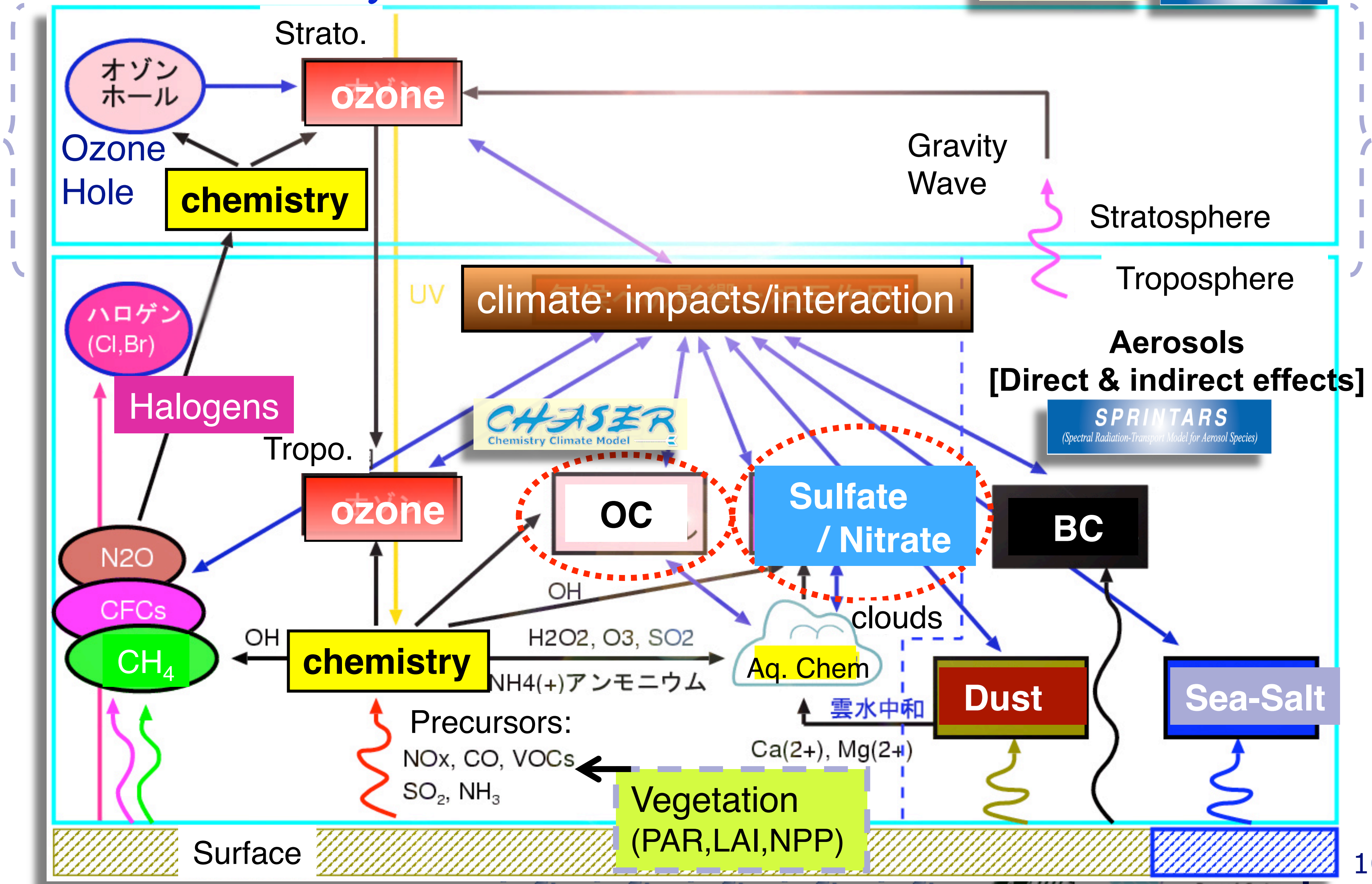
Chemistry-coupled climate model CHASER

Sudo et al. [2002a,b]

Base model	**CCSR/NIES/FRCGC GCM (5.7b)**
Resolution	**horizontal：T42(2.8°x2.8°), vertical：32 layers（surface～40km)**
Transport	**Grid scale（flux-form semi-Lagrangian)** **Sub-grid scale（convection, vertical diffusion）**
Chemistry	**54 chemical species, 152 chemical reactions（gas,liquid,heterogeneous*）** **(1)O_3-HO_x-NO_x-CO-CH_4 , (2)NMHCs oxidation, and (3)SO_2, DMS oxidation** *** heterogeneous reactions are considered for surface of cloud particles, su** **（satellite da** **+ Simplified stratospheric chemistry (no-PSCs)**
Emission	**Industry, biomass burning, vegetation/soil/ocean, lightning NOx** **（NOx, CO, C_2H_6, C_2H_4, C_3H_8, C_3H_6, acetone, isoprene, terpenes, SO_2, DMS)** **Lightning NOx is parameterized in the GCM convection[Price & Rind, 1992]**
Dry deposition	**Function of vegetation type, temperature, solar flux, snow cover [Wesely, 1989]**
Wet deposition	**Rain-out（in-cloud), wash-out （below-cloud), ice-sedimentation**

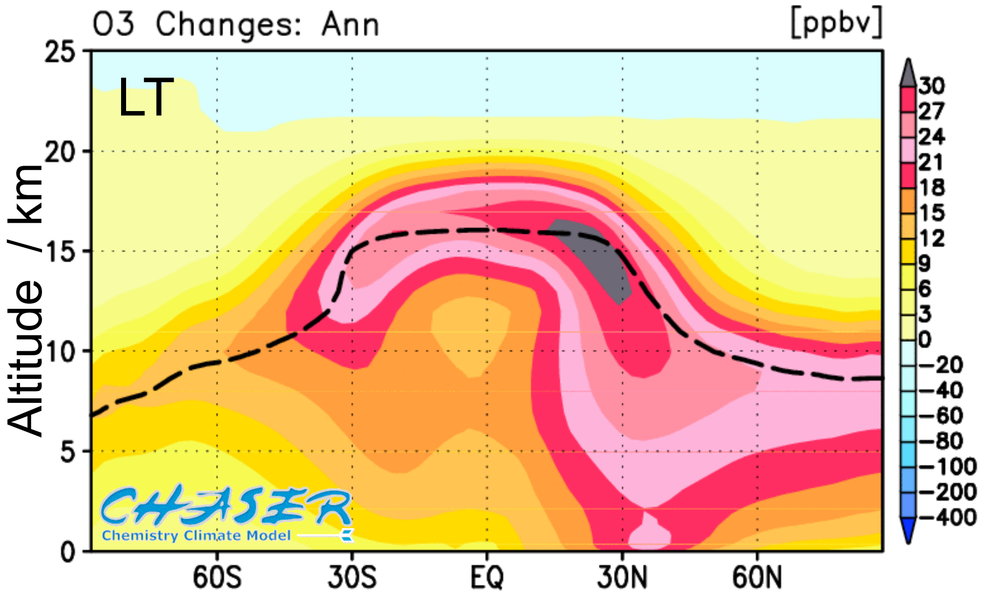
MIROC-SPRINTARS-CHASER: (CCSR/NIES/FRCGC)

Aerosol-Chemistry-Climate Model

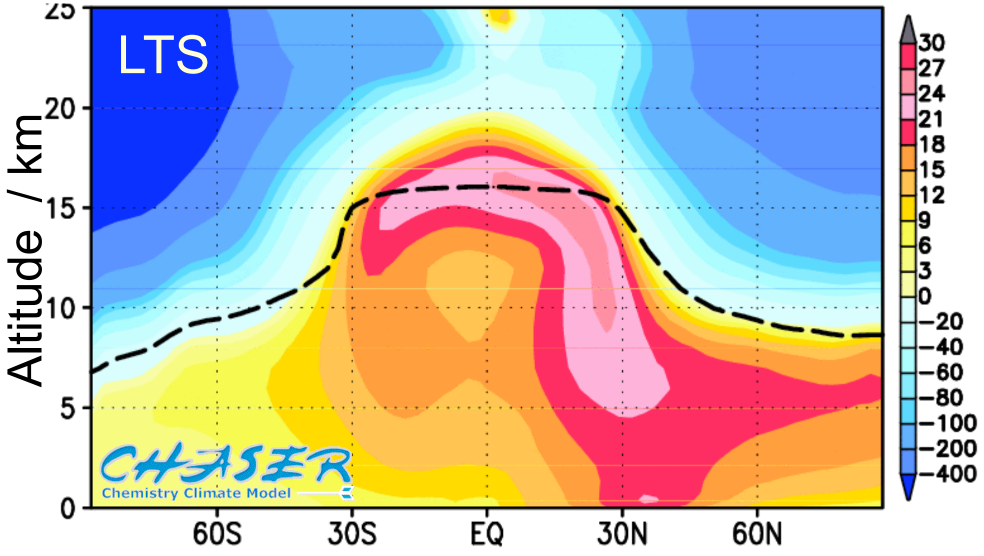


Past Ozone Changes PI(1850) → Present

Tropo. O_3 Increases (only due to emissions increase)



Tropo. O3 Increases + Strato. O3 decreases



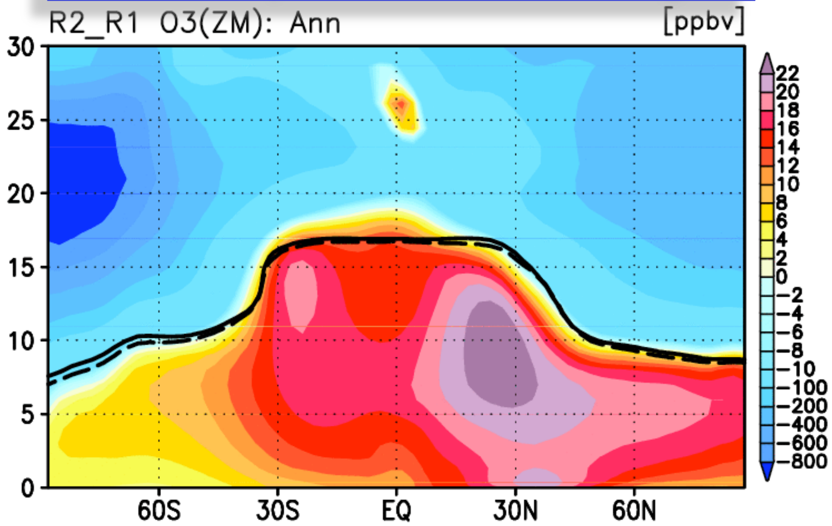
Tropo. Column Ozone Changes（DU）

	global	NH	SH
LT	+10.2	+12.4	+7.9
LTS	+9.2	+11.4	+6.9

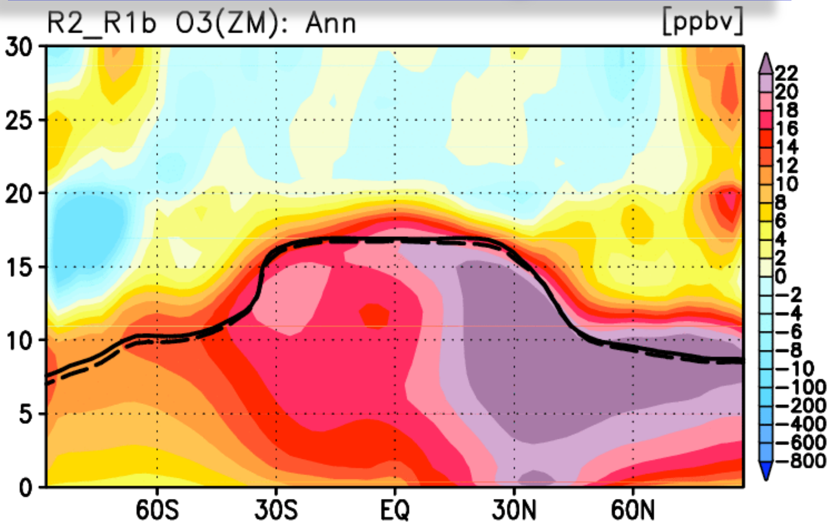
Zonal mean O3 changes: preindustrial → present

IPCC-AR4: MIP

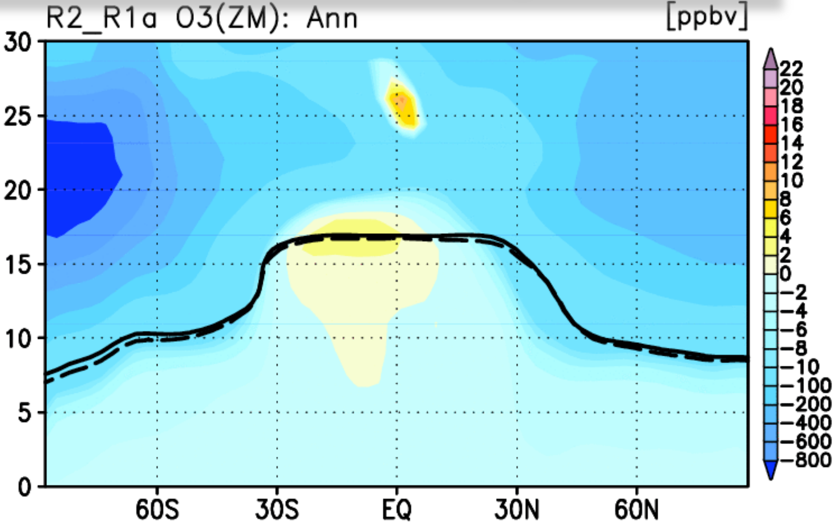
Preind → present: total change



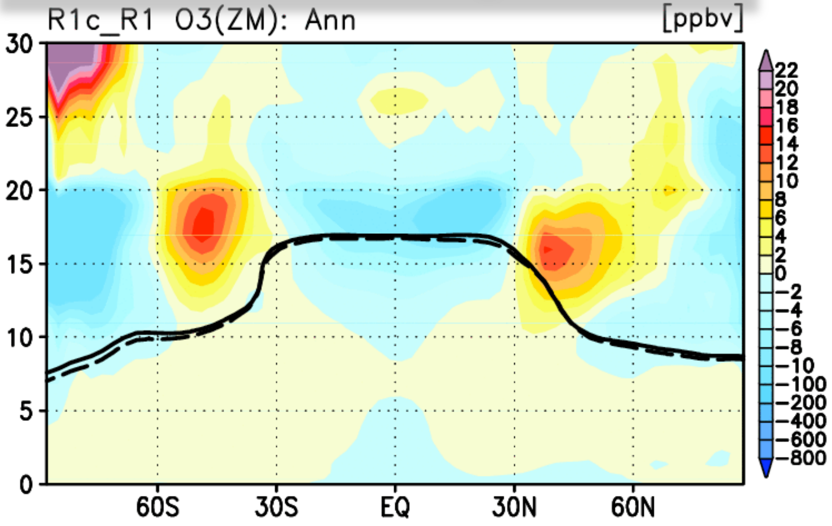
Due to emission change R2-R1b



Due to strato. O3 change R2-R1a

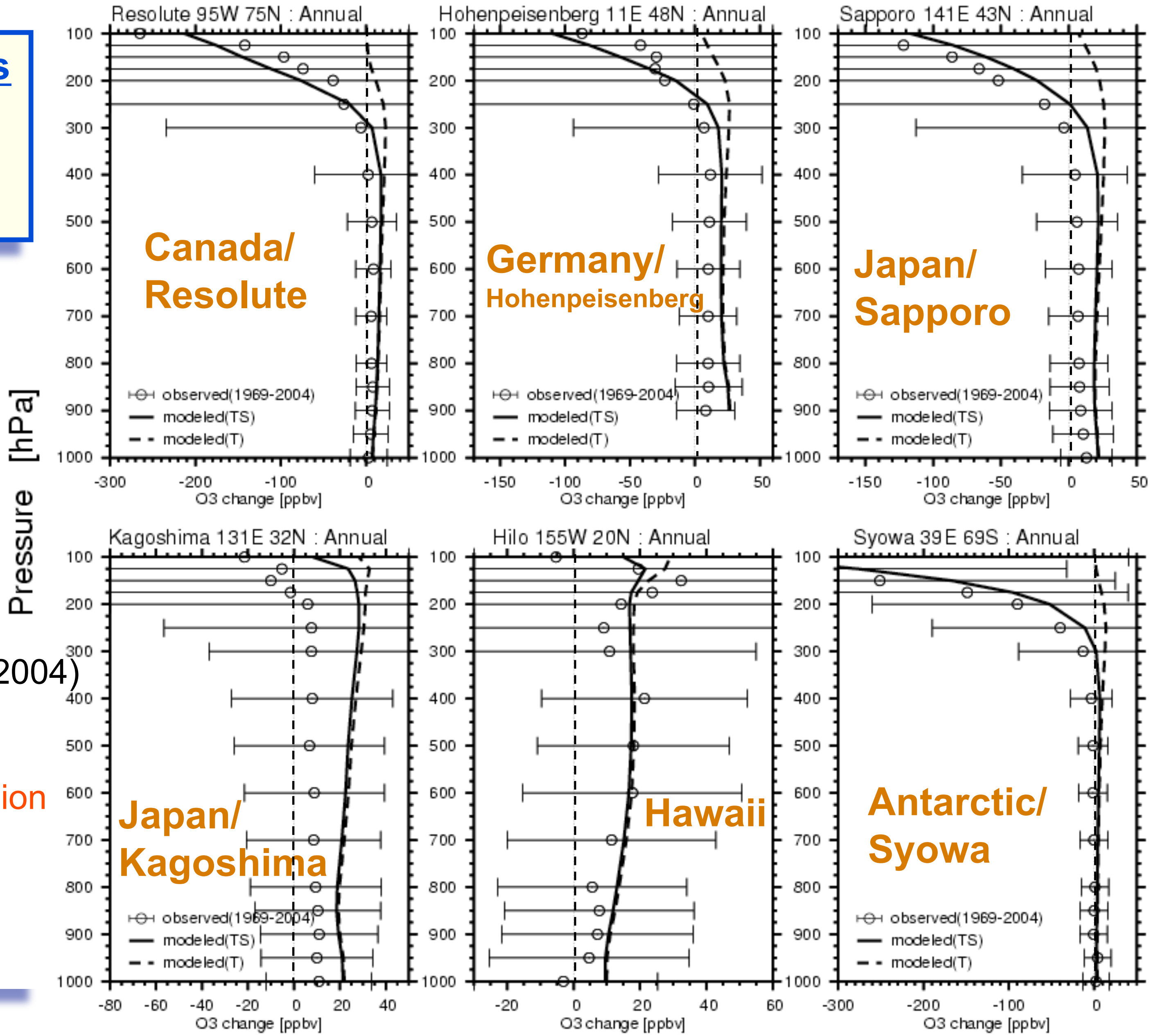


Due to climate change R1c-R1



O_3 Change Profiles

(with sonde obs. for 1970-2004)



observed（1970-2004)

modeled（only with emission increases）

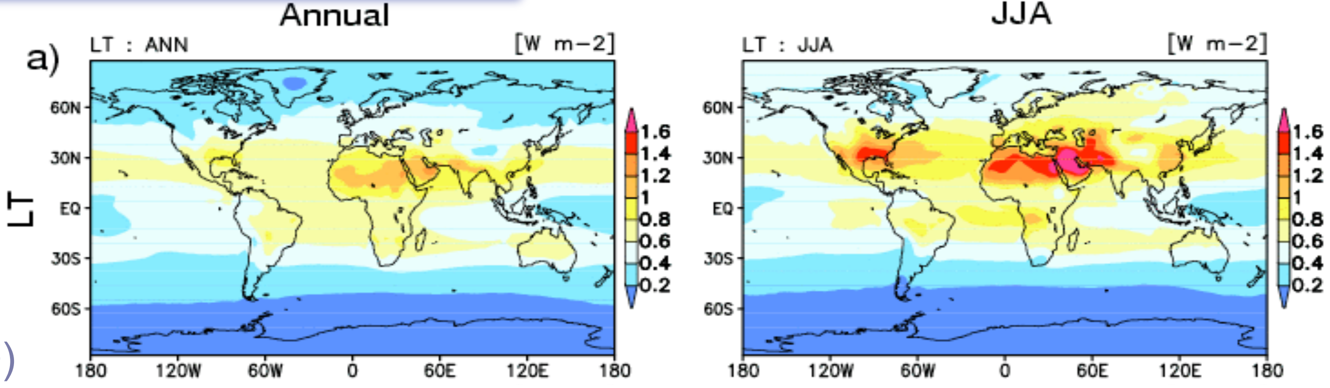
modeled（total changes）

Radiative forcing from tropo. O_3 increases

LT: tropo. O_3 increases

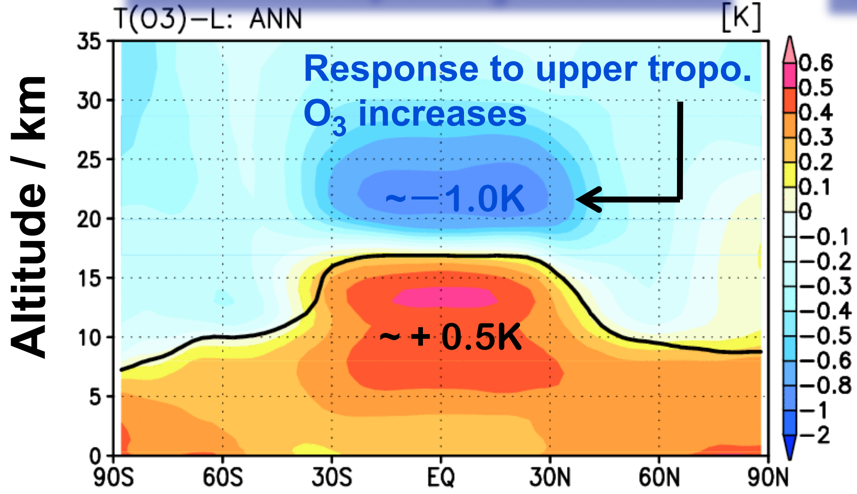
→ +0.49 W m^{-2}

(LLGHGs → +2.38 W m^{-2})



Zonal mean temperature changes

Due to tropo. O_3 increase

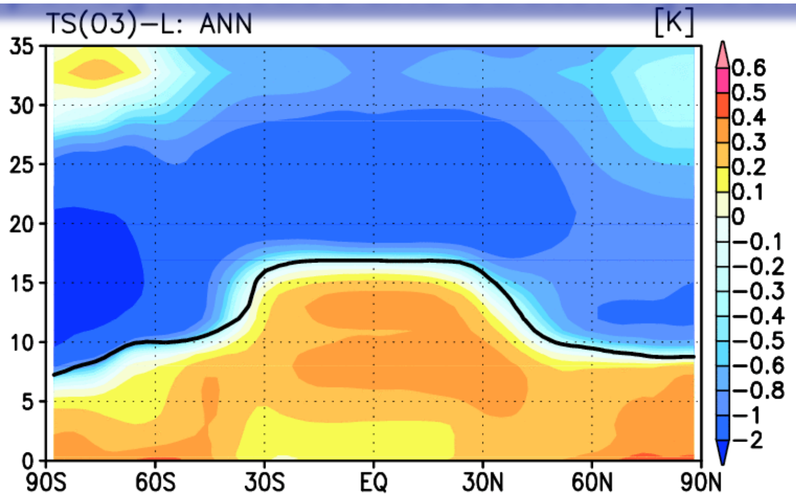


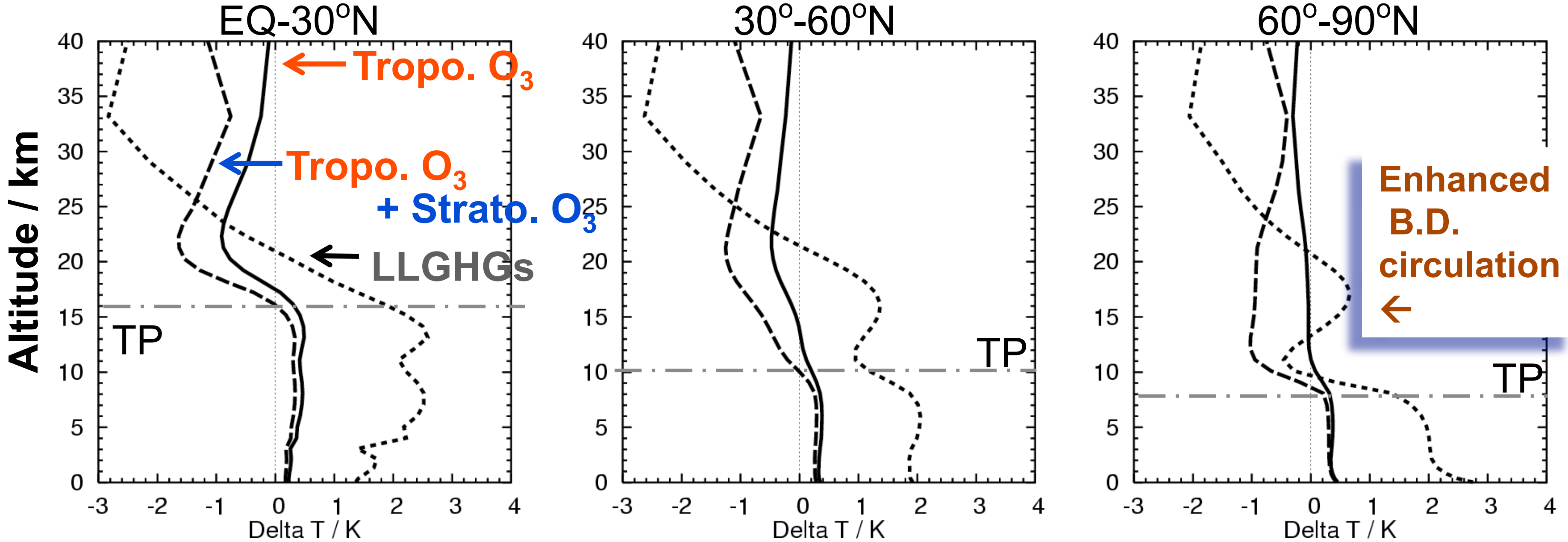
Response to upper tropo. O_3 increases

~−1.0K

~+0.5K

tropo. O_3 increase and strato. O_3 decrease





Tropo. O_3

Tropo. O_3 + Strato. O_3

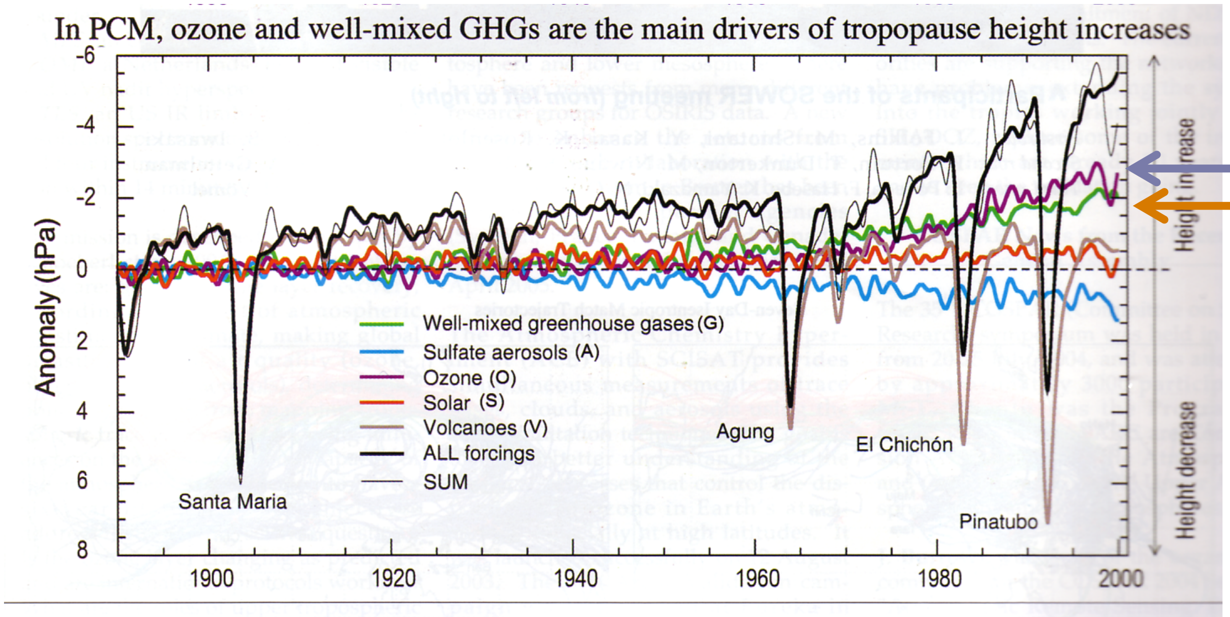
LLGHGs

Enhanced B.D. circulation

Rising tropopause ?

Global average tropopause pressure changes (hPa)

	annual	January	July
LLGHGs	−4.45	−4.05	−4.75
Tropo. O3	−1.31	−1.11	−1.22
Strato. O3	−2.09	−2.70	−1.53
Total	−7.86	−7.86	−7.40



LLGHGs

Ozone

Santer et al. (2003)
Science, *301*, 479-

Impacts of tropo. O_3 increase on surface temperature

Climate Response

	Global	N.H.	S.H.
Tropo. O_3	+0.28 °C	+0.31 °C	+0.25 °C
Strato. O_3	-0.04 °C	-0.04 °C	-0.04 °C
Net O_3	+0.24 °C	+0.2 °C	+0.21 °C
LLGHG	+2.29 °C	+1.78 °C	+2.80 °C

Climate sensitivity to tropospheric O_3 change = 0.57 K m^2 W^{-1}

~ 0.6 K m^2 W^{-1} [Mickley et al., 2004]

Reduced long-wave absorption (~30%)
& decreased O_3 input to the troposphere (~70%)

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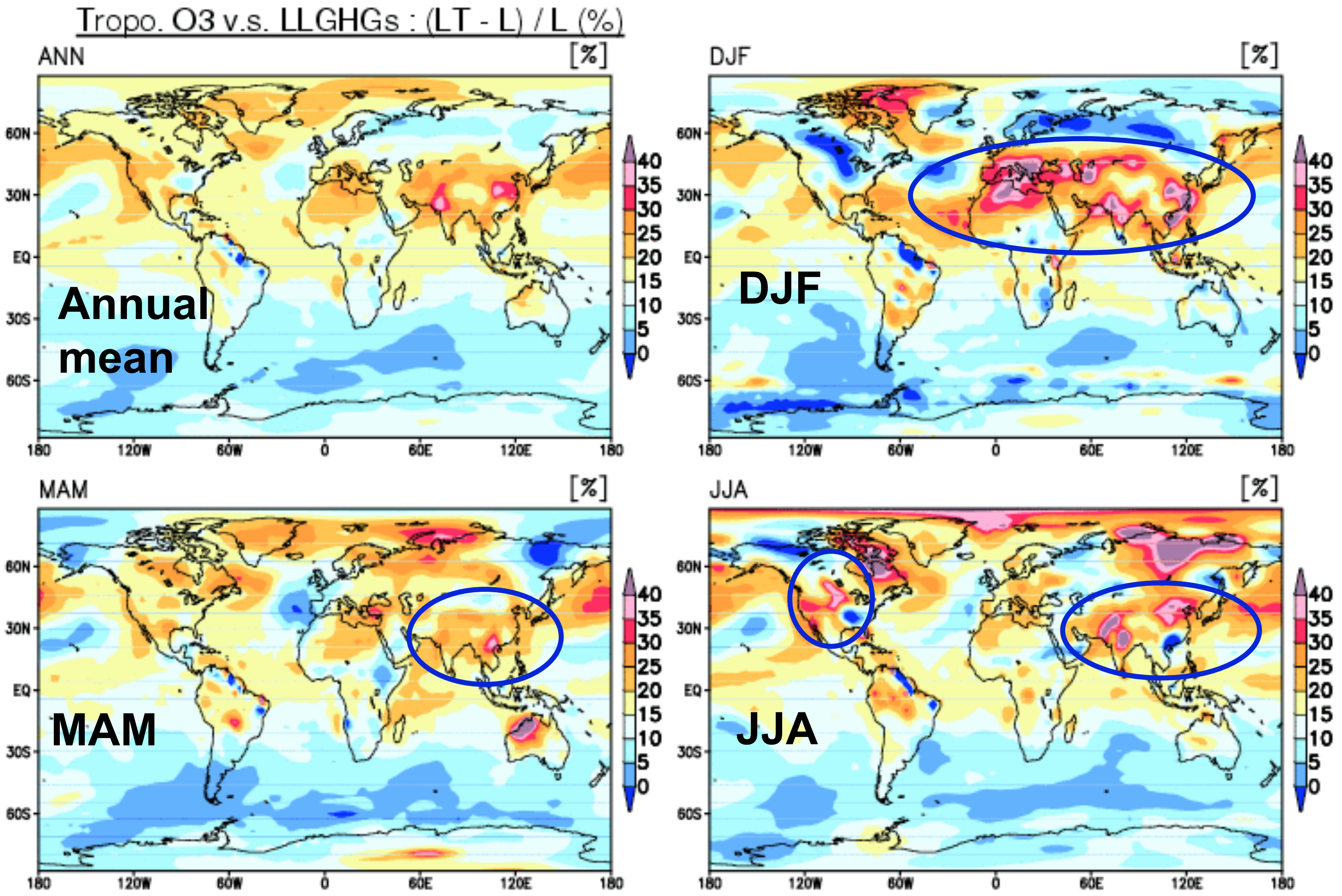
Impacts of tropo. O_3 increase on surface T : (tropo. O3) / (LLGHGs) x 100 (%)



Future Projection of O_3/CH_4/Aerosols

(Chemistry/Climate interaction)

Run Scenarios

	Exp1	Exp2	Exp3
Emission	Future	Future	Future
Climate	Present	Future	Future
Stratospheric O_3	Present	Present	Future

- Emission & climate: Using IPCC SRES-A2, A1, B1 scenarios.
- Runs from 2000 to 2100.
- Simplified stratospheric ozone changes.

CHASER

SPRINTARS (Spectral Radiation-Transport Model for Aerosol Species)

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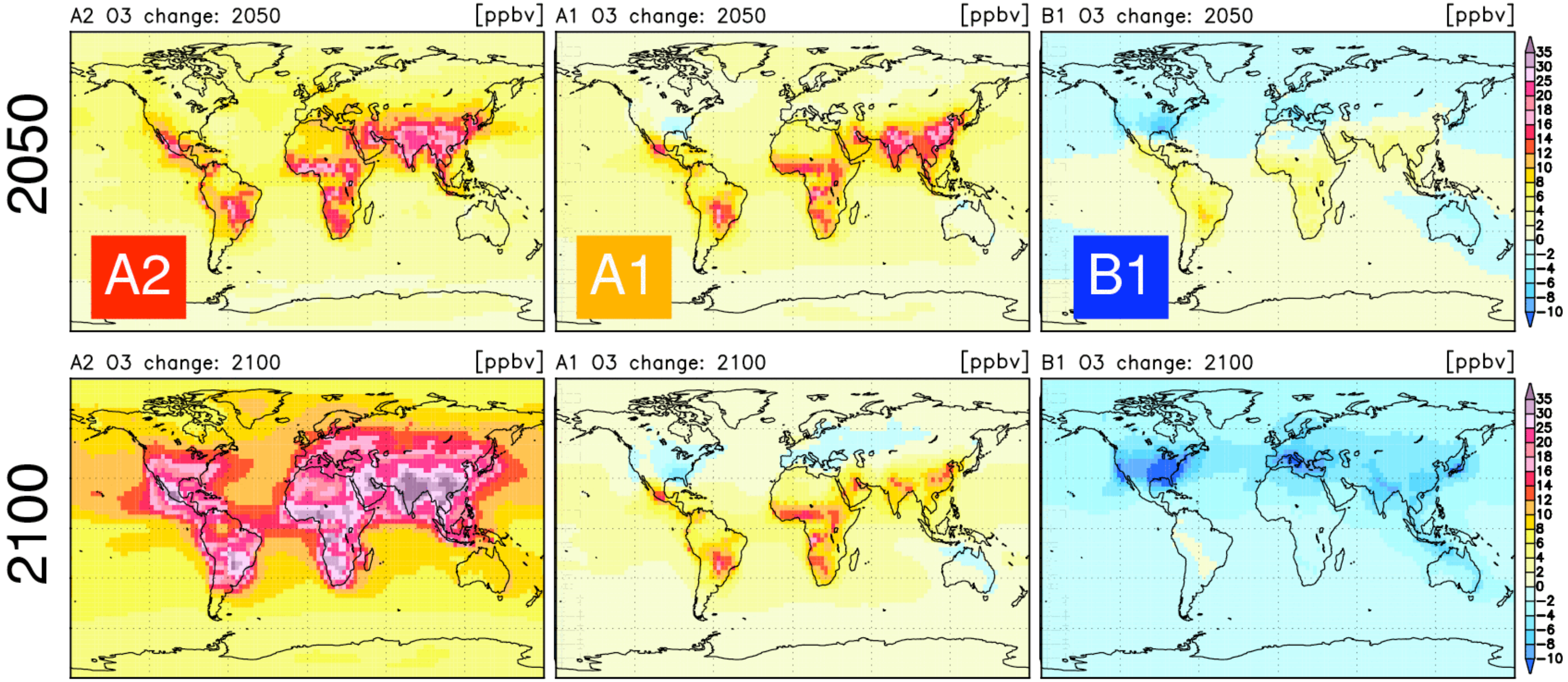
Future Simulation of O_3/ CH_4/ Aerosols

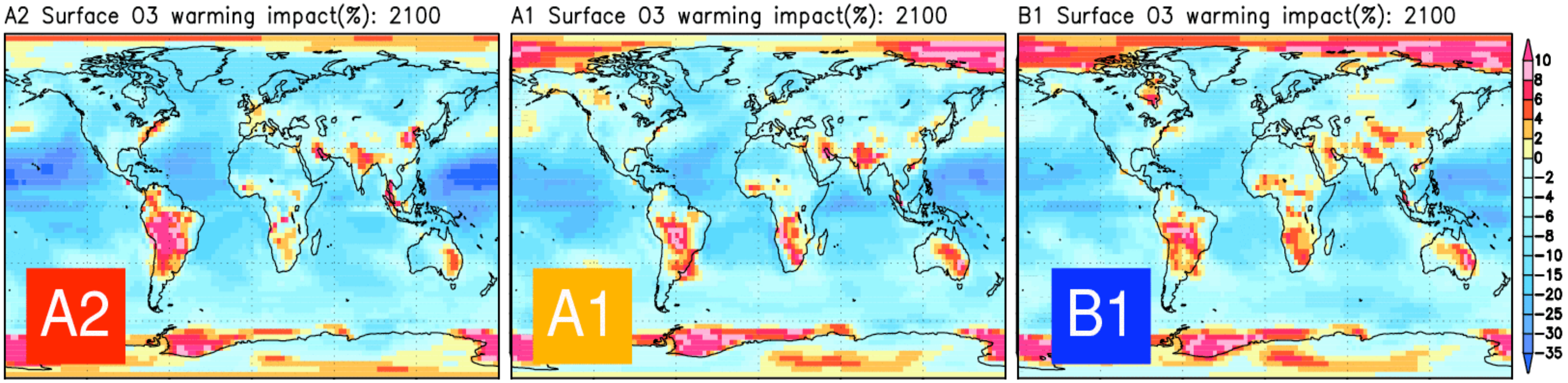
Emission Induced Changes in Surface Ozone ΔO_3 (2050/2100)



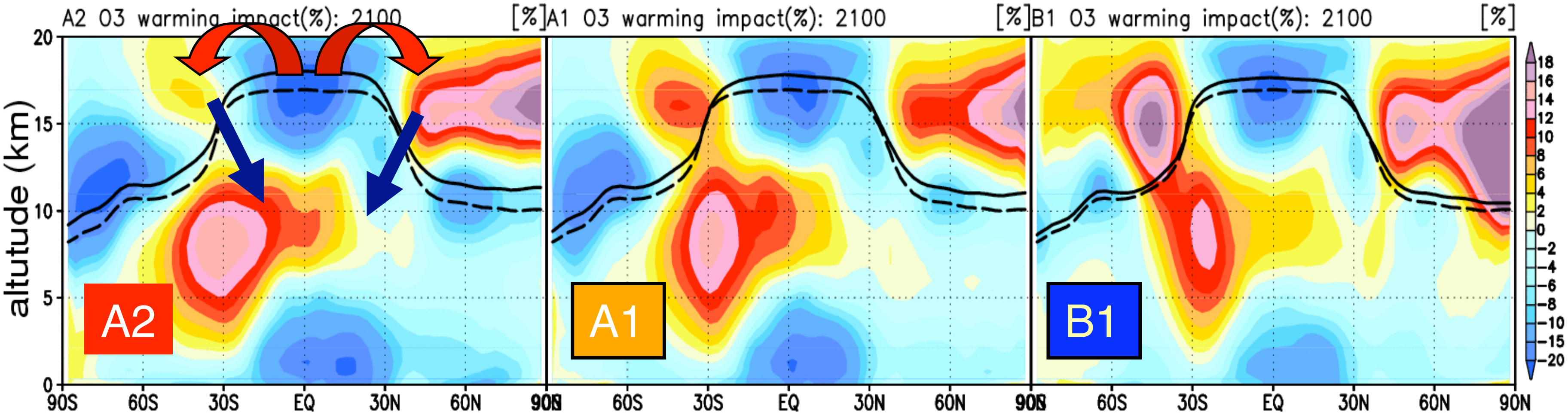
✓Ozone decreases in the US and Europe for A1/B1

Future Simulation of O_3/ CH_4/ Aerosols

Impacts(%) of Climate Change on Surface Ozone (2100)

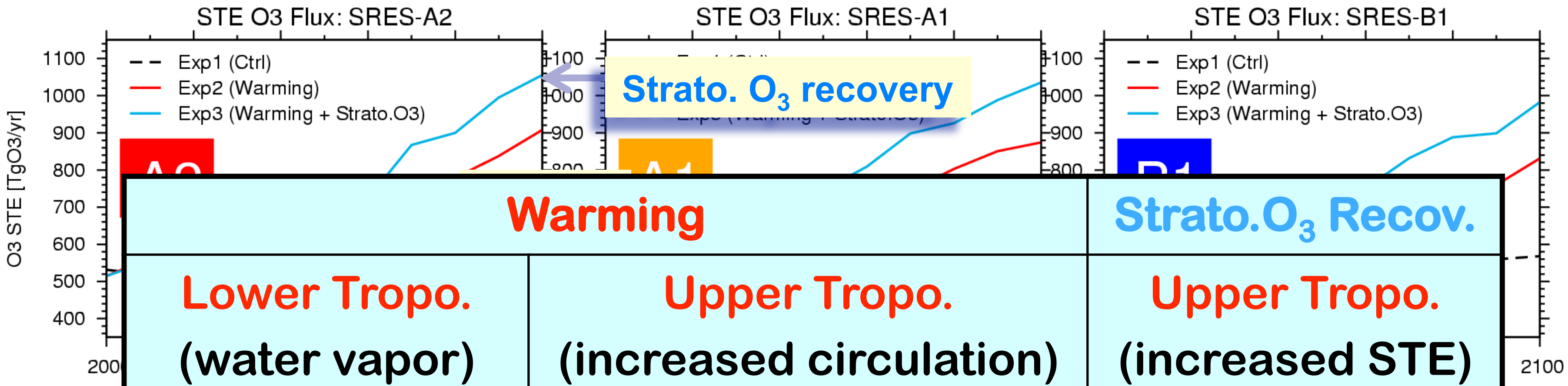


Impacts(%) of Climate Change on Zonal Mean Ozone (2100)



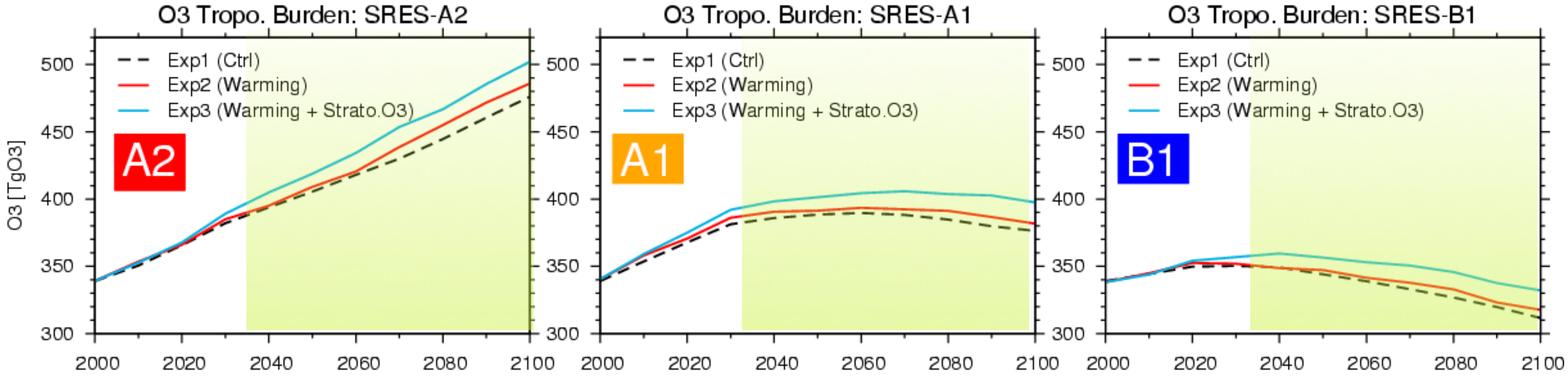
Future Simulation of O_3/ CH_4/ Aerosols

Temporal Evolution : Ozone Strato./Tropo. Exchange（TgO_3/yr)



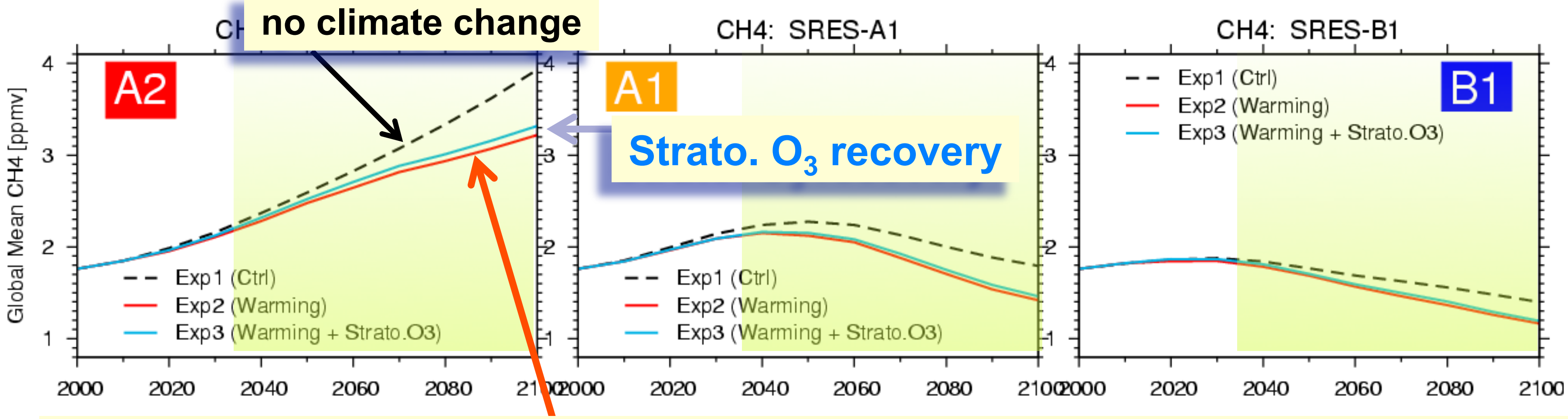
Strato. O_3 recovery

Warming		Strato.O_3 Recov.
Lower Tropo. (water vapor)	Upper Tropo. (increased circulation)	Upper Tropo. (increased STE)
--(negative)	+(positive)	+(positive)



Future Simulation of O_3/ CH_4/ Aerosols

Temporal Evolution : Global Mean Methane CH_4 (ppmv) and SO_4



no climate change

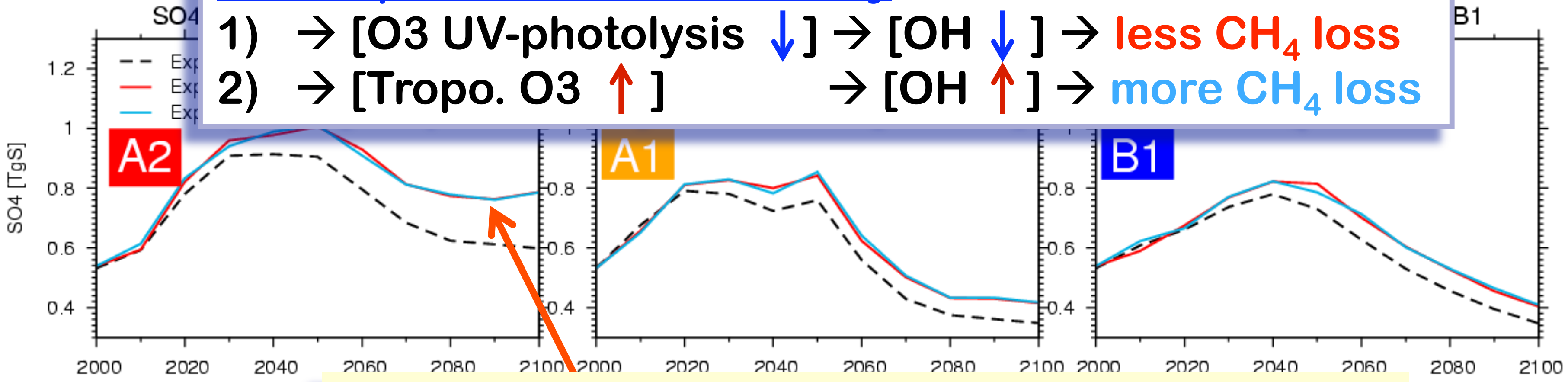
Strato. O_3 recovery

Climate change: Faster destruction of CH_4 (enhanced OH due to water vapor increase)

Stratospheric Ozone Recovery

1) → [O3 UV-photolysis ↓] → [OH ↓] → less CH_4 loss

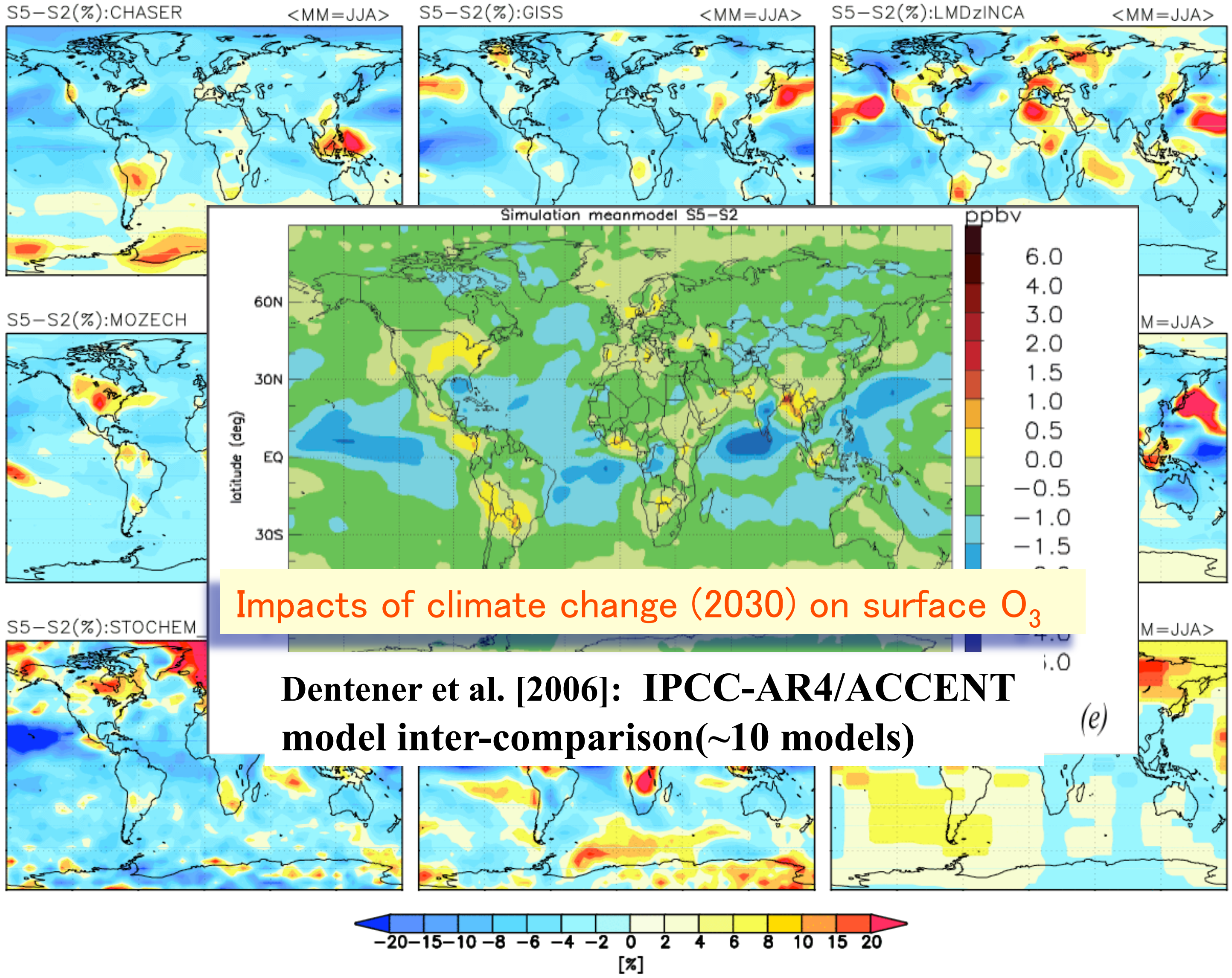
2) → [Tropo. O3 ↑] → [OH ↑] → more CH_4 loss



Climate change: Faster oxidation of SO_2 (increased H_2O_2,etc)

IPCC-AR4 Model inter-comparison

Climate change impacts (%) on Surface O3 in 2030 for JJA



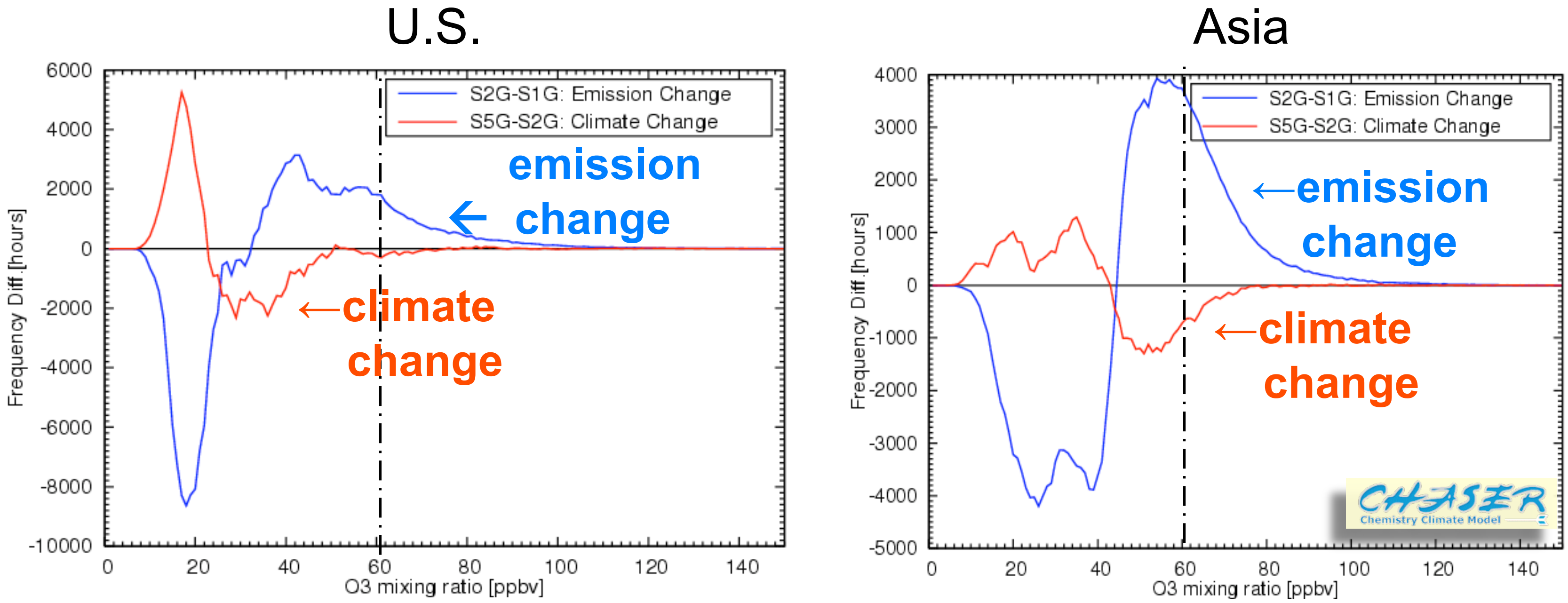
Impacts of climate change (2030) on surface O_3

Dentener et al. [2006]: IPCC-AR4/ACCENT model inter-comparison(~10 models)

IPCC-AR4 Model inter-comparison

Does Climate Change Mitigate/Amplify Air Pollution ?

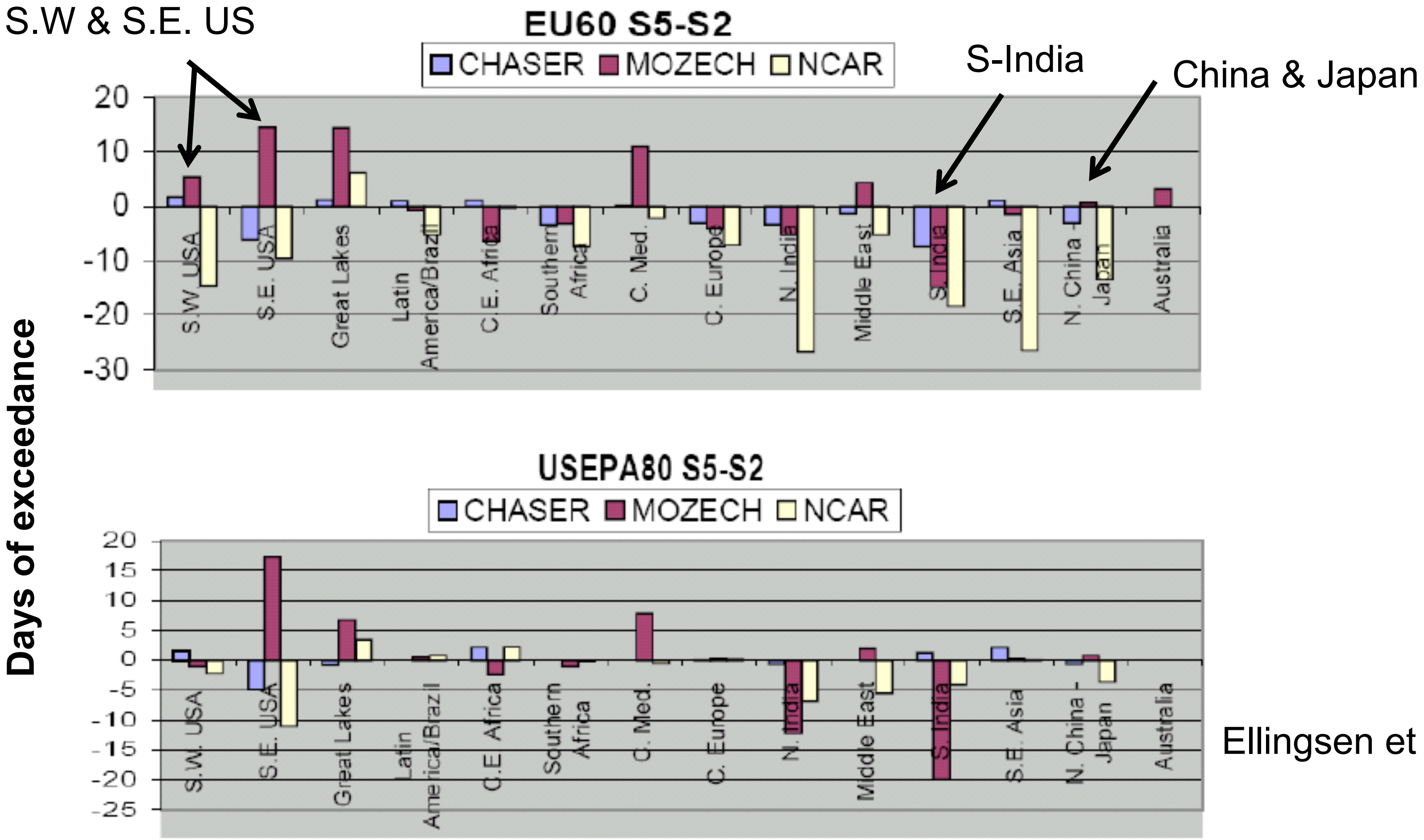
Changes in frequency of surf. O_3 level at 2030



IPCC-AR4 Model inter-comparison

Does Climate Change Mitigate/Amplify Air Pollution ?

Impact of climate change on ozone environmental standards for 2030



S.W & S.E. US

S-India

China & Japan

Ellingsen et al. (2007)

Summary & Conclusions

The past O3 changes:

- The past changes in tropospheric / stratospheric O_3 and LLGHGs differently affect temperature profiles with different mechanisms.
- Tropospheric O_3 increase causes surface warming of ~0.31 °C in NH; especially large impacts are calculated in Asia (~30-40% of the LLGHGs impacts)
- Decreased stratospheric O_3 cools the surface by reducing long-wave absorption and decreasing O_3 input to the troposphere.

Future perspectives:

- Future climate change is likely to modulate atmospheric chemistry.
  + circulation (B.D. & Hadley), lighning NOx, water vapor, …
- Future climate change may affect air quality, but that process has not been clarified yet.

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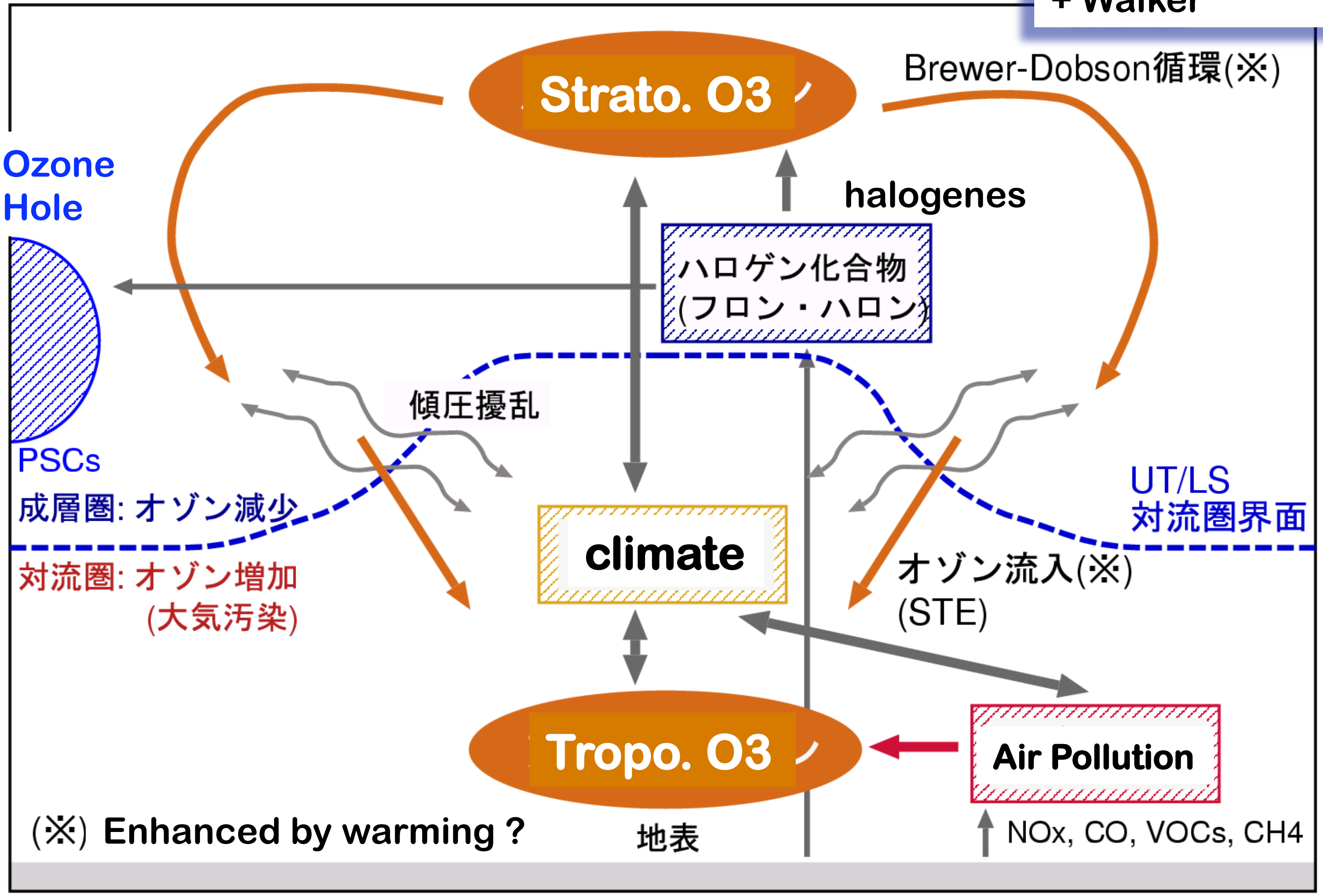
Circulation changes
+ Brewer-Dobson
+ Hadley
+ Walker



Strato. O3

Brewer-Dobson循環(※)

halogenes

Ozone Hole

ハロゲン化合物
(フロン・ハロン)

PSCs

傾圧擾乱

成層圏: オゾン減少

対流圏: オゾン増加
(大気汚染)

climate

UT/LS
対流圏界面

オゾン流入(※)
(STE)

Tropo. O3

Air Pollution

NOx, CO, VOCs, CH4

地表

(※) **Enhanced by warming ?**

Future Plans …

✓ **AC&C related:**

- **AC&C Hindcast Experiments (1980-2009):**
  + trends in O_3, CH_4, related species and aerosols
  + impacts of emissions, climate change, dynamical variation (ENSO/AO..)
- **Future simulations toward IPCC-AR5:**
  + global O_3 fields for new 4 scenarios

✓ **Earth-System perspecitves (long-term prediction ?):**

✓ **Atmospheric chemistry and climate studies need more tight coupling/fusion between modeling and observation**