

A composite image of space. In the upper right, a large, detailed view of the Moon's surface is visible. In the center, a bright comet with a long, glowing tail streaks across the dark sky. In the lower left, the Earth's horizon is shown from space, with a thin blue atmosphere and a view of the planet's surface below.

Atmospheric Impacts of a Close Cometary Encounter

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Wuhu Feng, John Plane



- Introduction
- WACCM Modelling
 - **Run 0 & 1: Meteoric Metal injection**
 - Meteoric Input Function (MIF) development
 - Results: metal layers, sporadic E layers
 - **Run 2: Temperature Perturbation**
 - Calculations
 - Results: temperature and zonal winds
 - **Run 3: MSP and Sulfur injection**
 - MIF details
 - Results:
- Conclusions

Motivation:

- Comet Siding Spring
- Low (?) probability, high impact risk
- 2P/Encke

Research Questions:

CHEMISTRY:

- What atmospheric phenomena would be affected by a close flyby with a comet?
 - Halley encounter at 100,000 km

CLIMATE:

- Could an injection of cometary dust initiate/ contribute to a global cooling event?
 - 6th century 'dark ages'

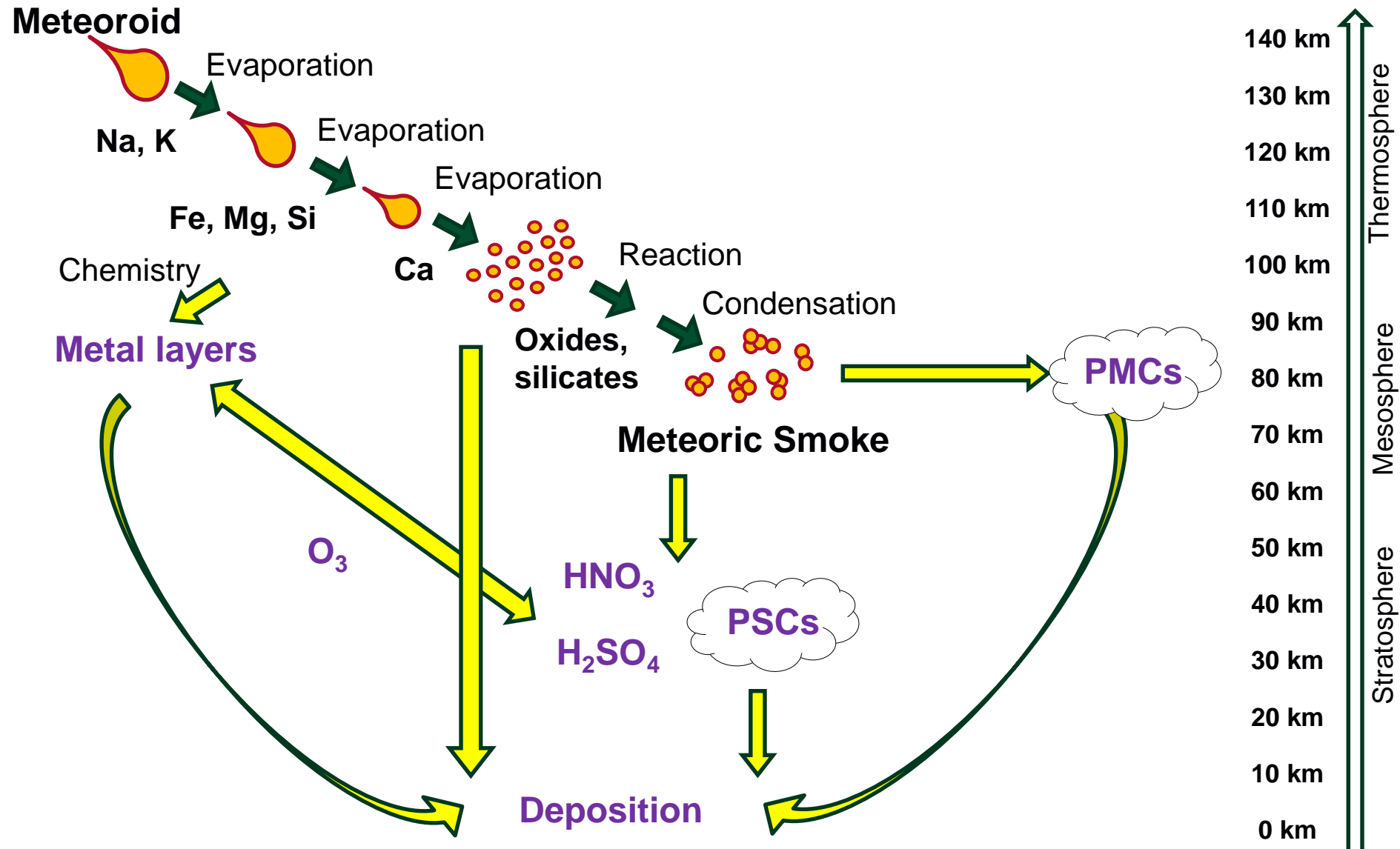
OPTICAL EFFECTS:

- Can the literature refractive indices represent MSPs?
 - Photochemical aerosol flow reactor

Atmospheric Processes



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➤ Mesosphere-lower thermosphere (MLT)

- Metal layers
- Ozone
- Temperature perturbation

➤ Stratosphere

- Sulfate aerosol
- Ozone
- Extinction

➤ Surface

- MSP deposition
- Temperature perturbation

140 km
130 km
120 km
110 km
100 km
90 km
80 km
70 km
60 km
50 km
40 km
30 km
20 km
10 km
0 km

Thermosphere
Mesosphere
Stratosphere

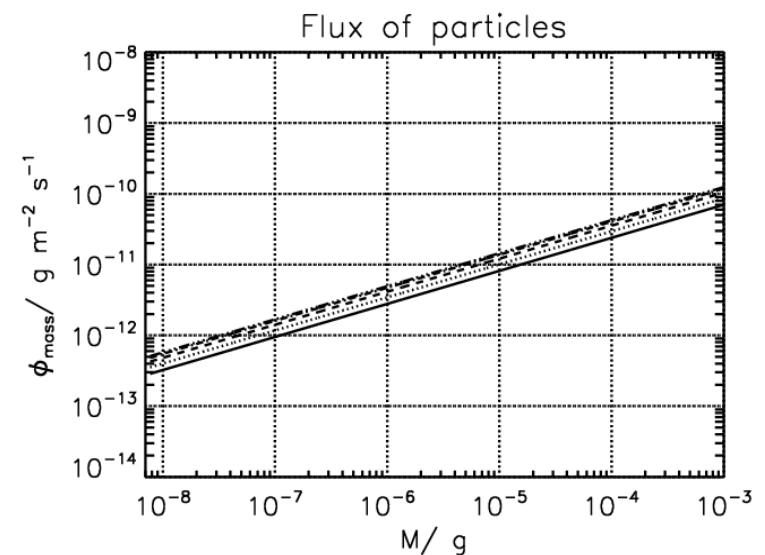
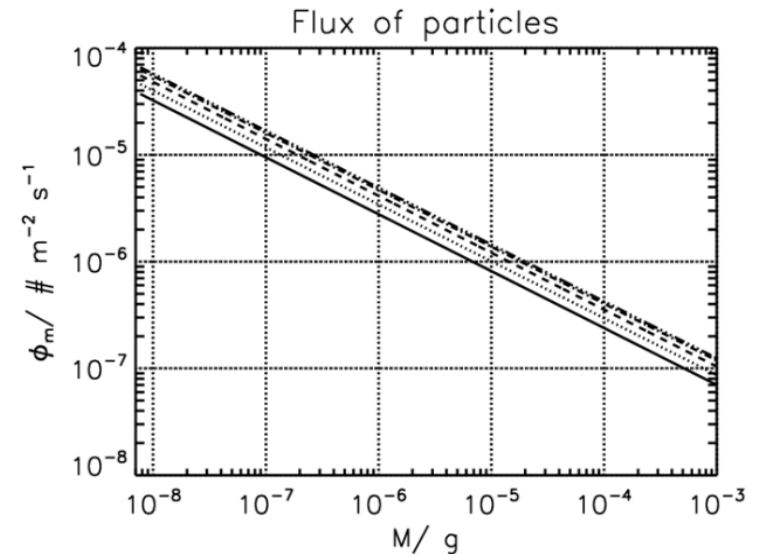
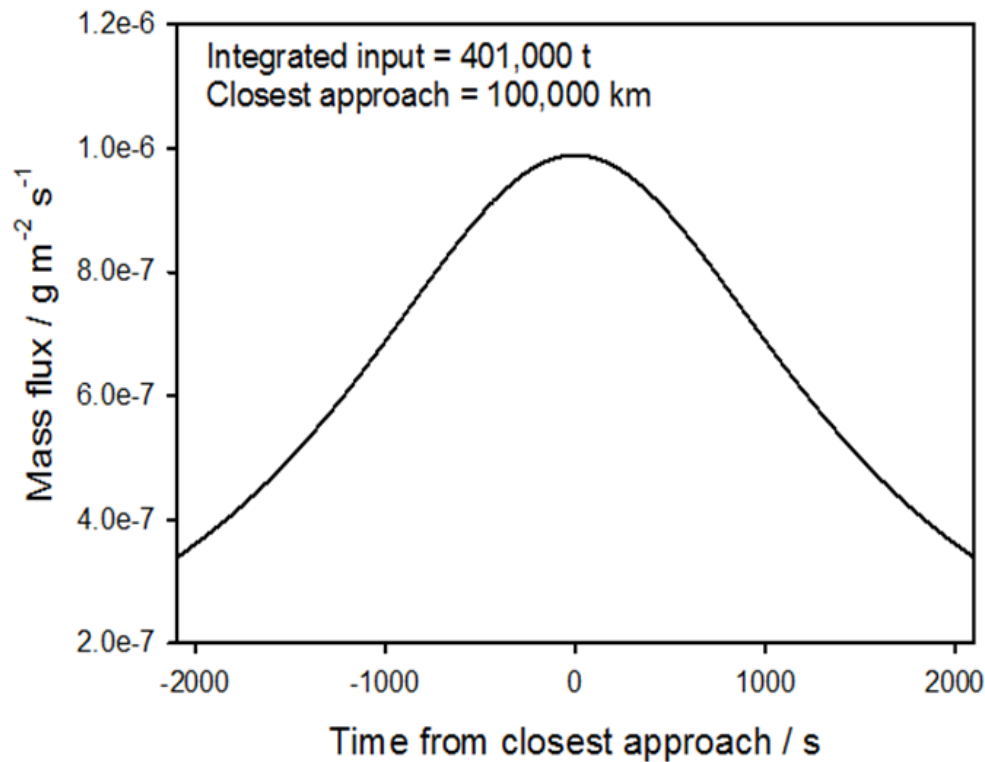
Run 1: Metal Injection

MIF development



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➤ Dust Model - Moorhead et al. 2014



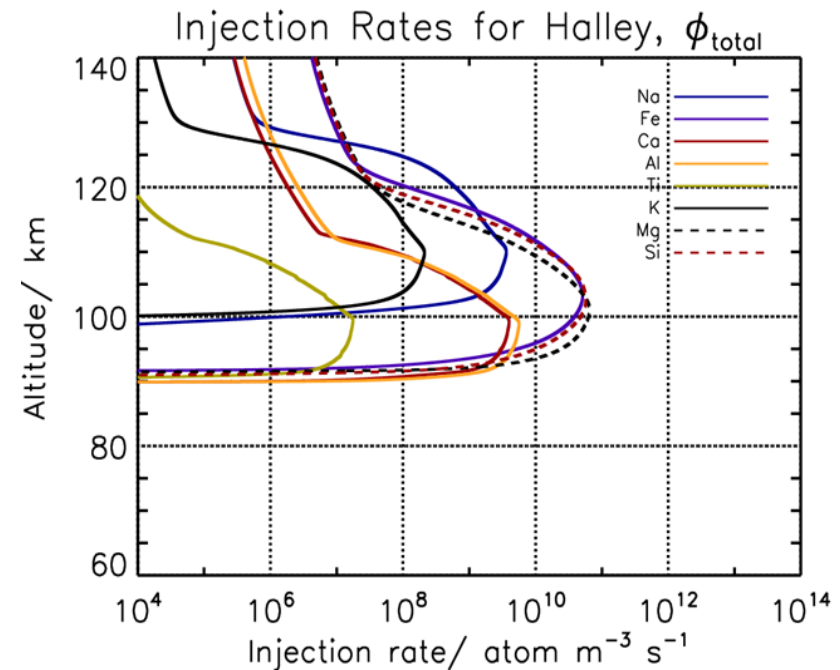
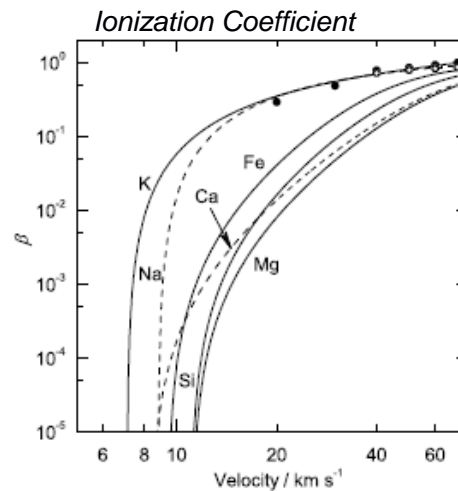
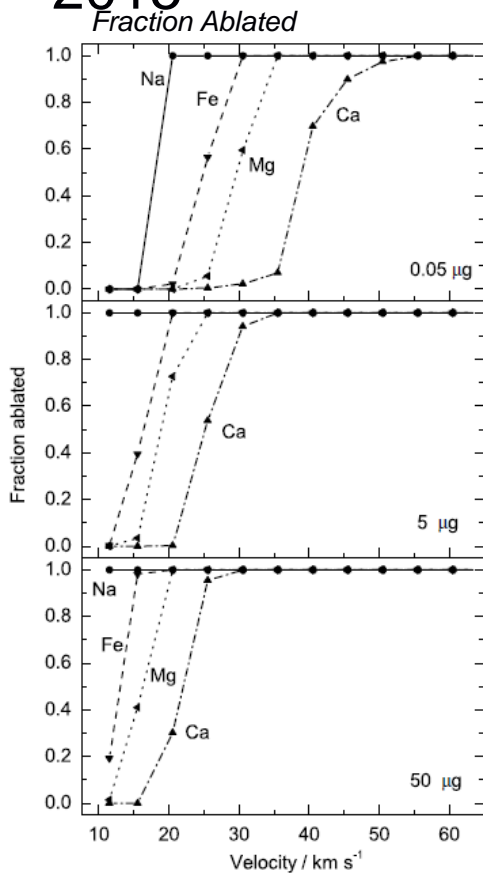
Run 1: Metal Injection

MIF development



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➤ Chemical Ablation Model (CABMOD) – J.D. Carillo-Sánchez et al. 2015



➤ Injection details:

- Scaled to 401,000 tonnes (~100,000 tonnes)
- 2 hours (4 time-steps)
- One hemisphere

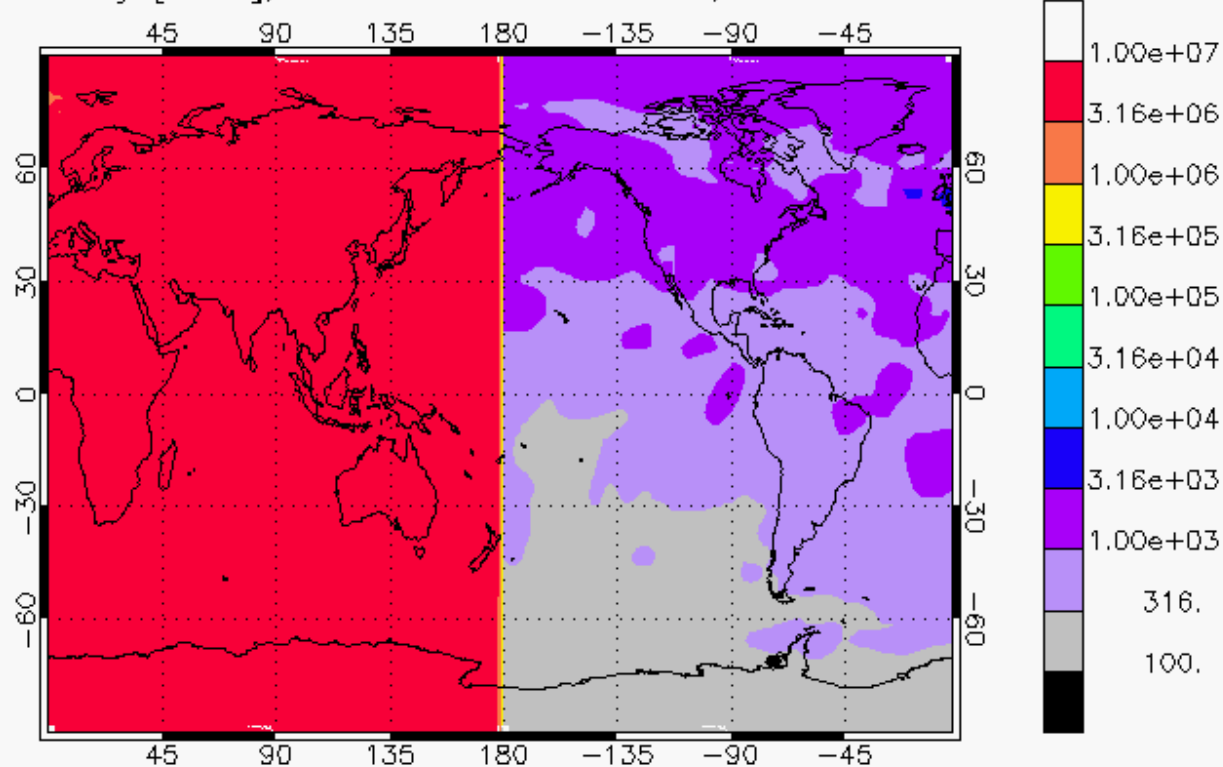
Run 1: Metal Injection

Injection



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Fe Density [cm^{-3}], ca. 0.00011971900 hPa, 02Jan2011 00:00



/codita/cmns/WACCM_run2_final/tasha_halley_4metals/tasha_halley_4metals.cam2.h1.2011-01-02-00000.nc

cmns 10.03.2017 11:04

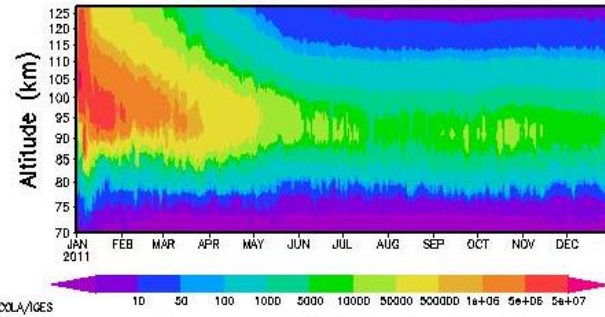
Run 1: Metal Injection

Metal layers

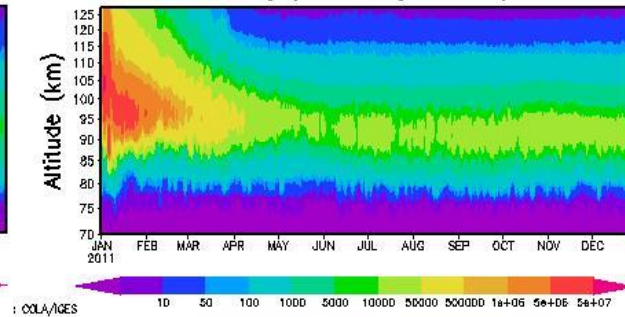


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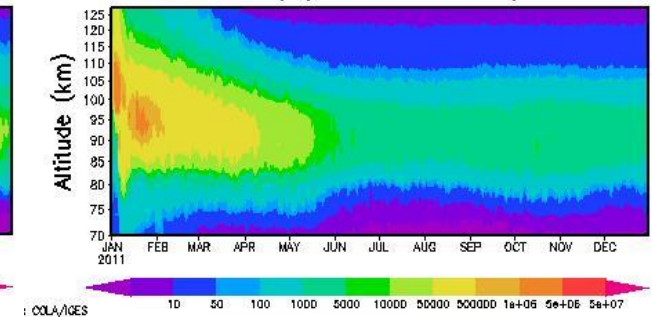
Singapore: Fe Density



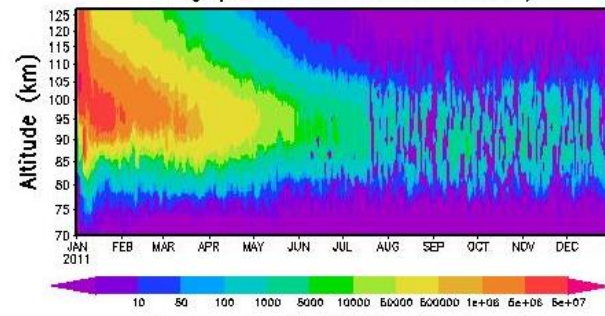
Singapore: Mg Density



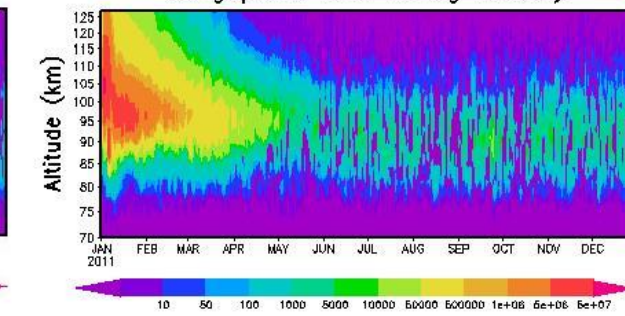
Singapore: Na Density



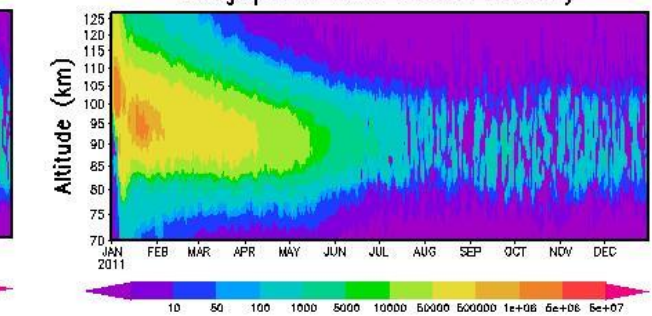
Singapore: Diff. in Fe Density



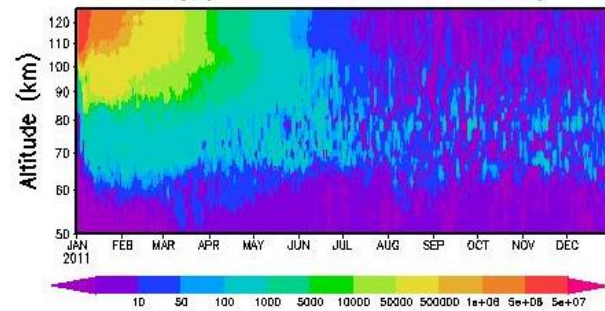
Singapore: Diff. in Mg Density



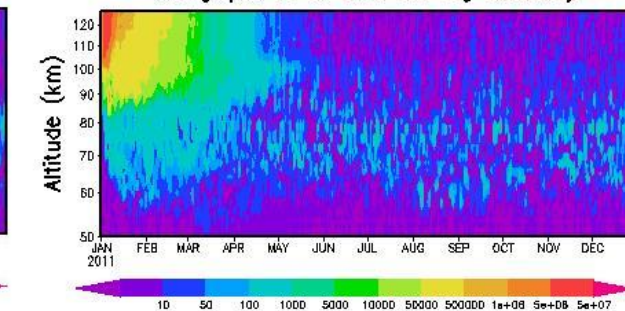
Singapore: Diff. in Na Density



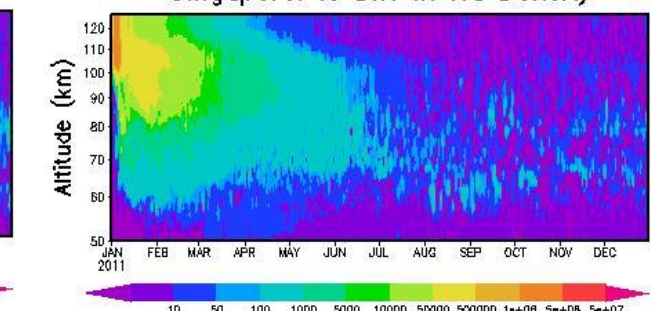
Singapore: % Diff in Fe Density



Singapore: % Diff in Mg Density



Singapore: % Diff in Na Density



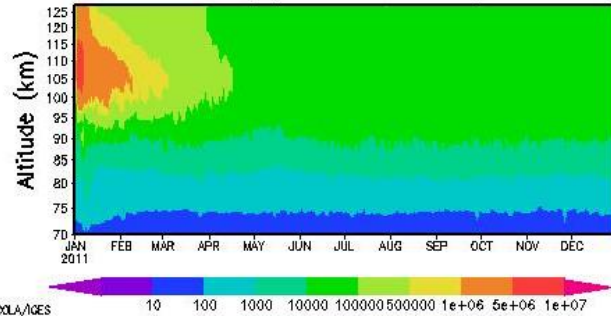
No MSP formation – only sedimentation

Run 1: Metal Injection Ozone

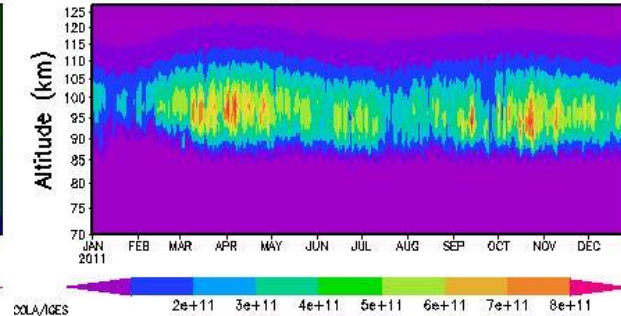


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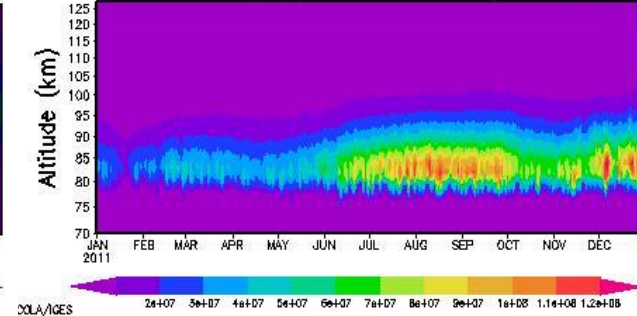
Singapore: e^- Density



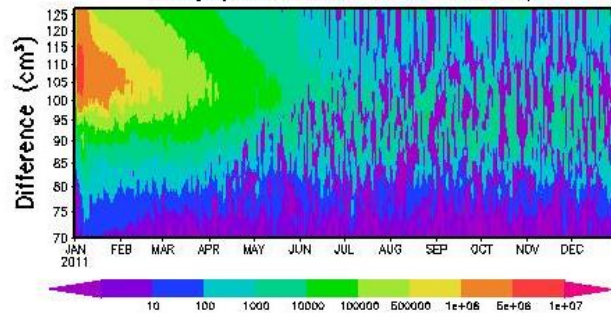
Singapore: O Density



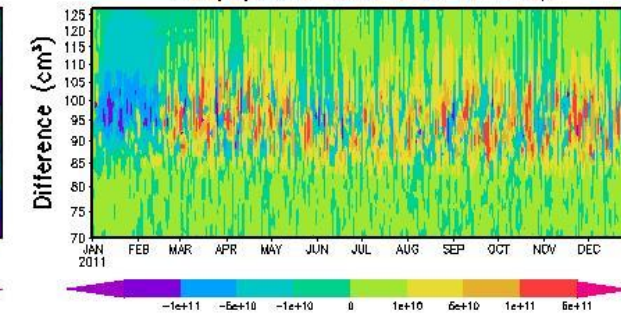
Singapore: H Density



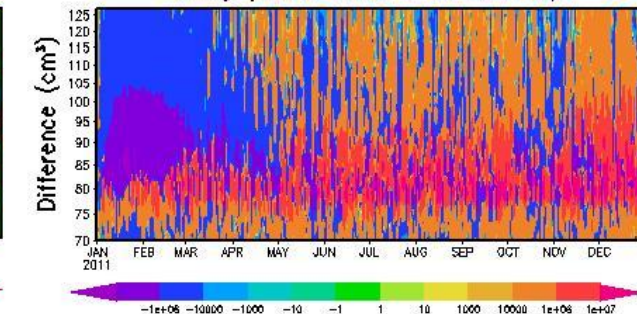
Singapore: Diff. in e^- Density



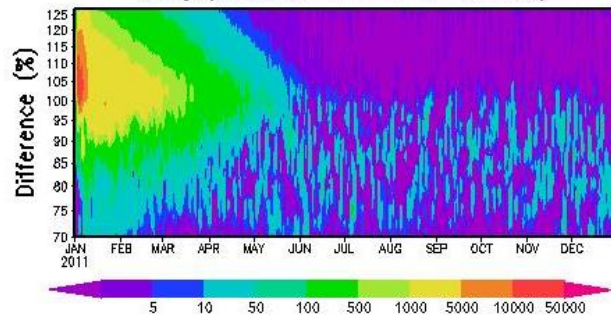
Singapore: Diff. in O Density



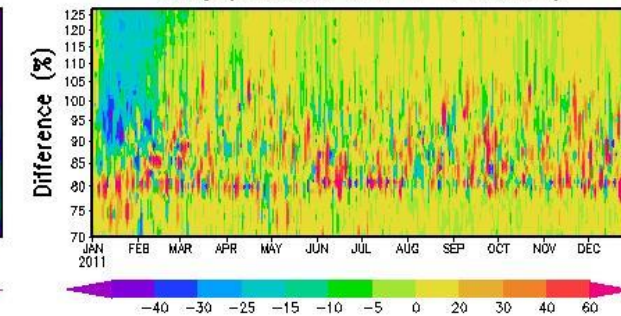
Singapore: Diff. in H Density



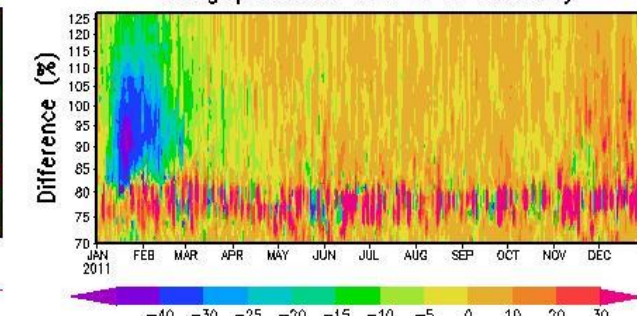
Singapore: % Diff in e^- Density



Singapore: % Diff in O Density



Singapore: % Diff in H Density



Effects on radio communication?

Run 2: Temperature Perturbation Calculations



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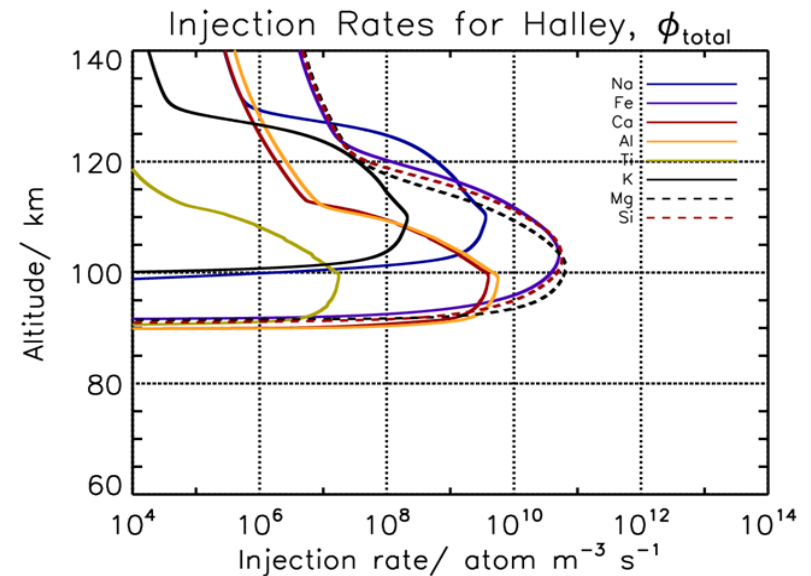
Heat energy \rightarrow $mc\Delta T = \frac{1}{2}mv^2$ \leftarrow Kinetic energy

$$Q = K.E - \underbrace{\Delta H_{fo} - \Delta H_{fu} - \Delta H_{vap} - \Delta H_{at}}_{\text{Phase transitions}}$$

Phase transitions

Initial composition of meteoroids (Vondrak et al 2008)

Oxide	Oxide mass %	Elemental abundance ^a	Elemental atomic %
SiO ₂	34.0	1.00 × 10 ⁶	13.6
MgO	24.2	1.06 × 10 ⁶	14.4
FeO	36.3	8.91 × 10 ⁵	12.1
Al ₂ O ₃	2.5	8.50 × 10 ⁴	1.2
CaO	1.9	6.01 × 10 ⁴	8.2 × 10 ⁻¹
Na ₂ O	1.0	5.90 × 10 ⁴	8.0 × 10 ⁻¹
K ₂ O	0.1	3.77 × 10 ³	5.1 × 10 ⁻²
TiO ₂	0.01	2.65 × 10 ²	3.6 × 10 ⁻³



M. Campbell-Brown 2004:

$$I = \tau \frac{dm}{dt} \frac{v^2}{2} \quad \tau = 2 \times 10^{-3} \quad 0.2 \% \rightarrow \text{Light production}$$

Run 2: Temperature Perturbation Calculations



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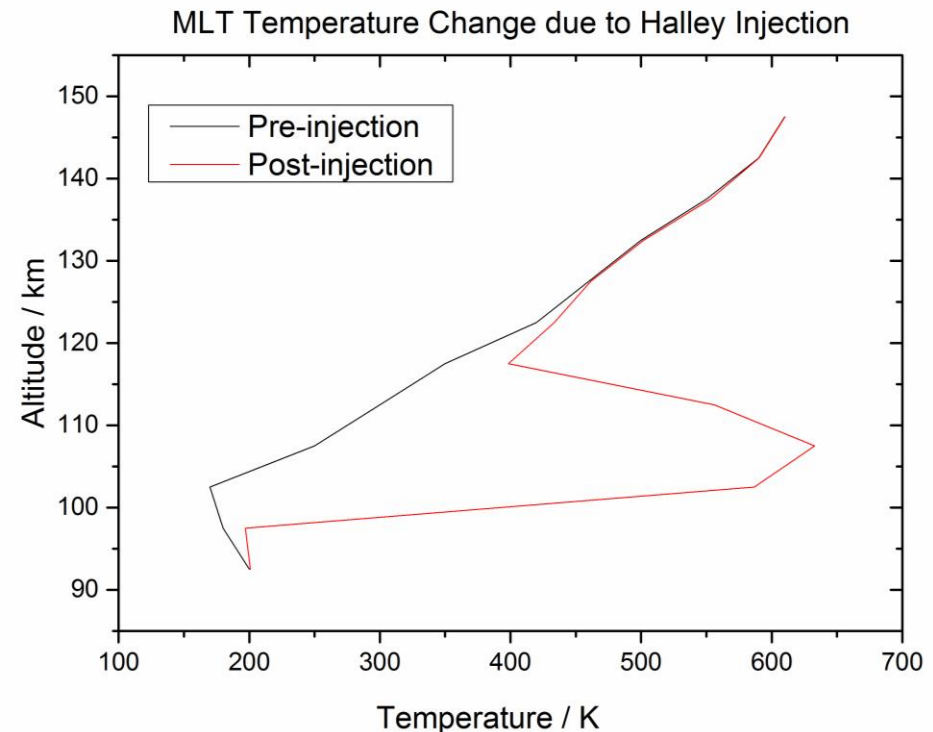
Z range / km	Initial temp / K	ΔT / K	Final temp / K
90-95	200	0.8	200.8
95-100	180	17.1	197.1
100-105	170	416.6	586.6
105-110	250	382.8	632.8
110-115	300	255.9	555.9
115-120	350	48.4	398.4
120-125	420	13.7	433.7
125-130	460	1.4	461.4
130-135	500	2.1	502.1
135-140	550	3.1	553.1
140-145	590	0.4	590.4
145-150	610	0.3	610.3

➤ Simulation details

- ΔT in initialisation file for one time-step (approximation)
- Background MIF – no cometary injection

➤ Atmospheric Feedbacks:

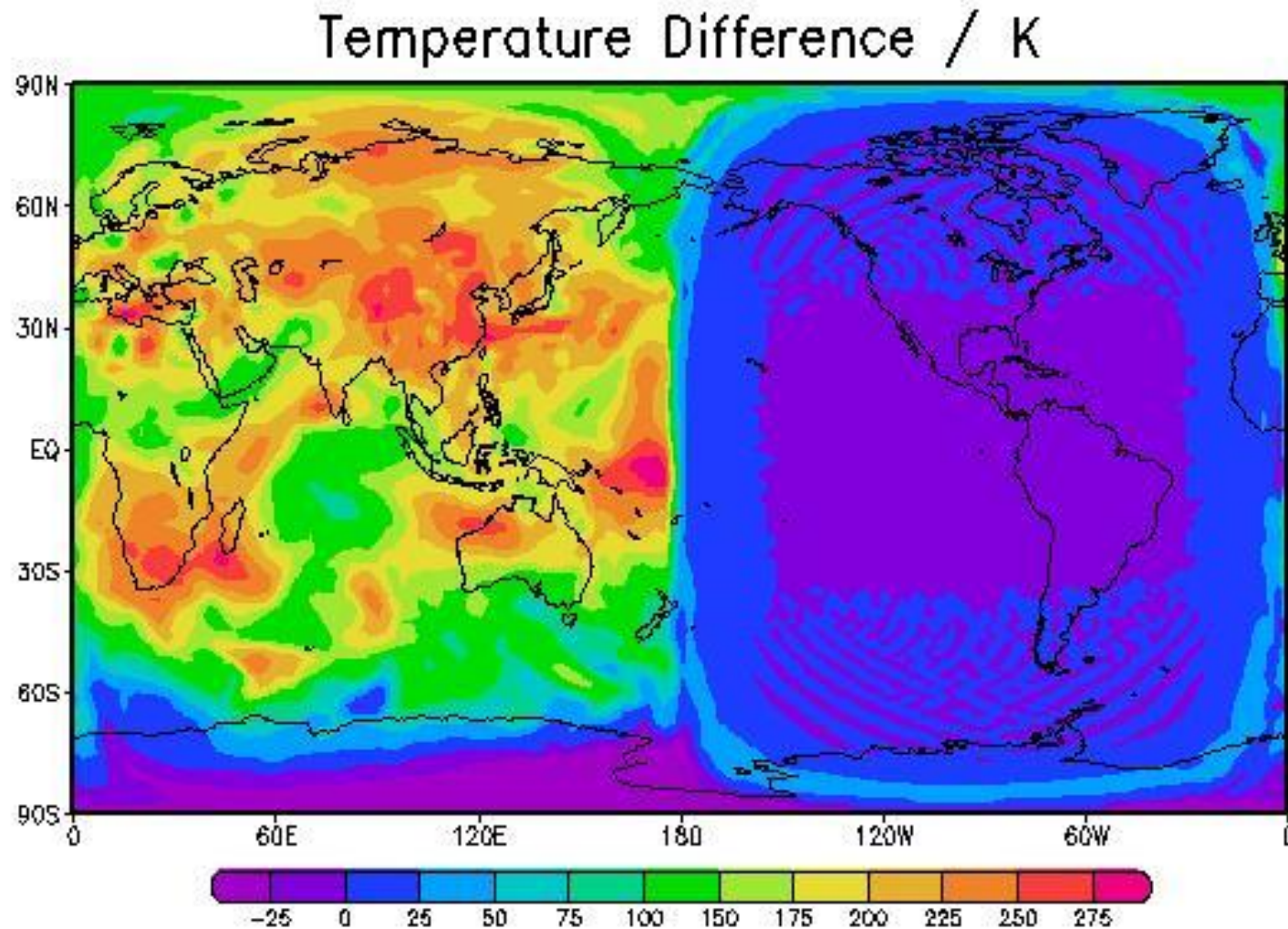
- Ablation rate/height
- Ionization rates
- Metal layers
- Ozone Chemistry



Run 2: Temperature Perturbation Results



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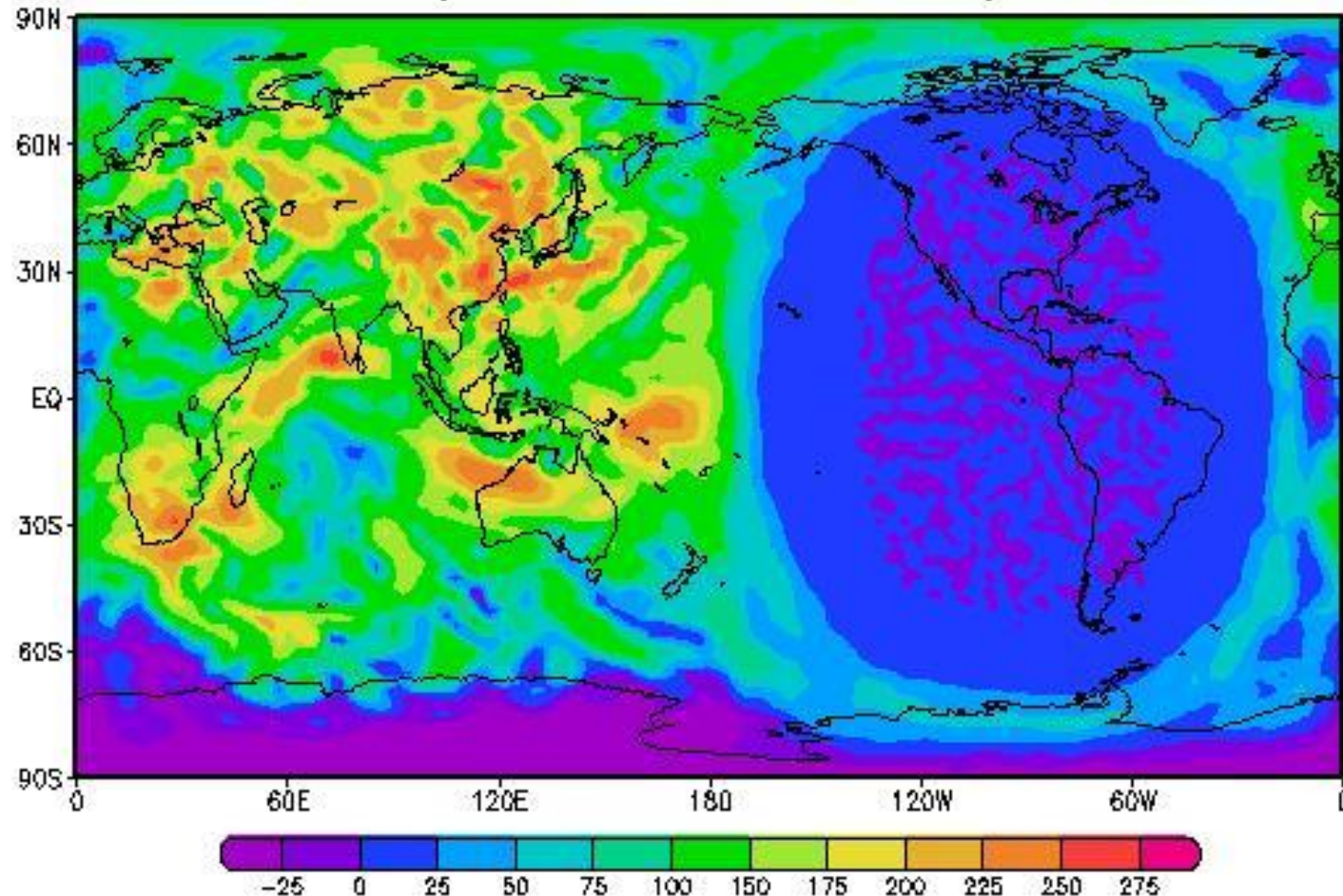
t = 00h

Run 2: Temperature Perturbation Results



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Temperature Difference / K



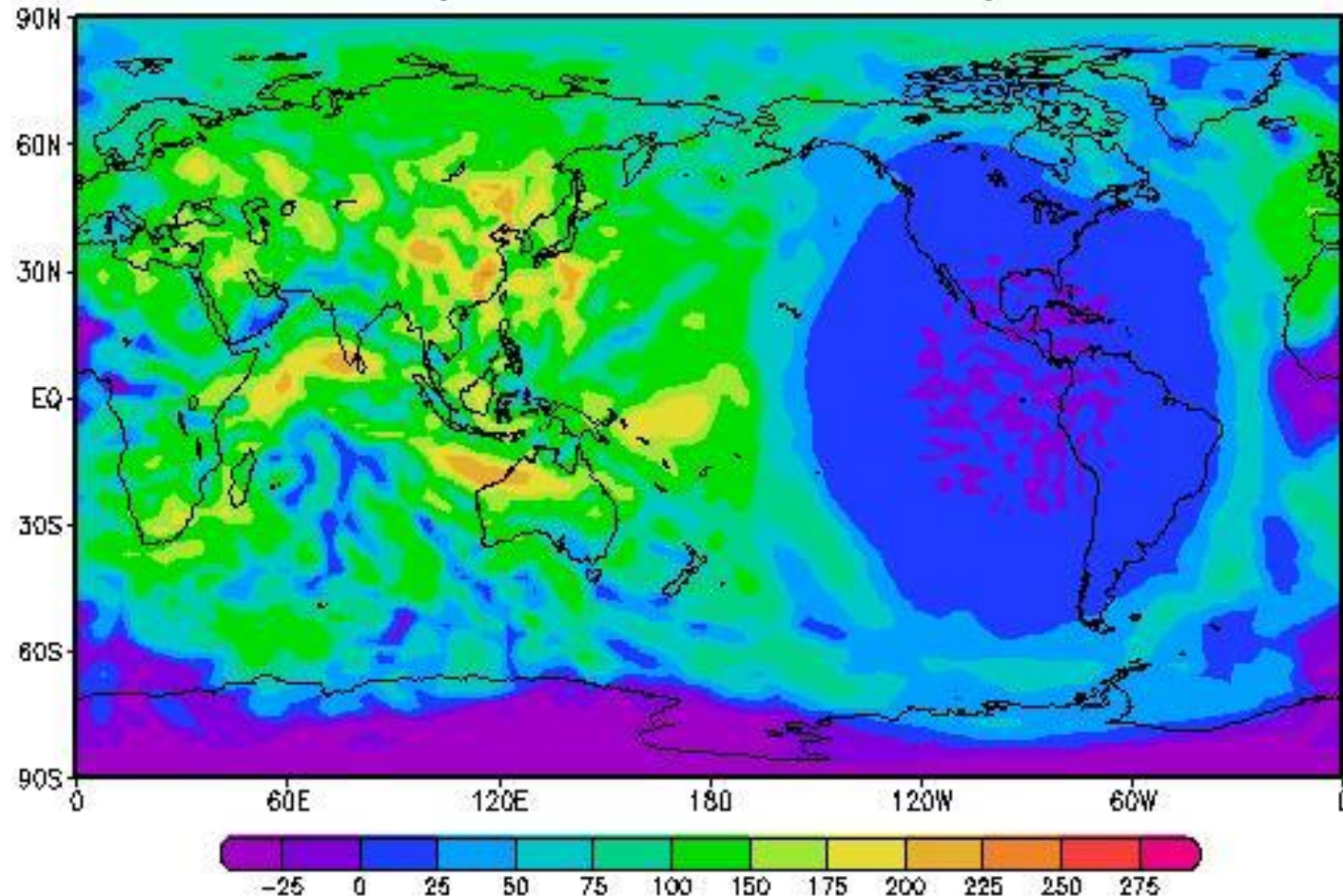
t = +1h

Run 2: Temperature Perturbation Results



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Temperature Difference / K



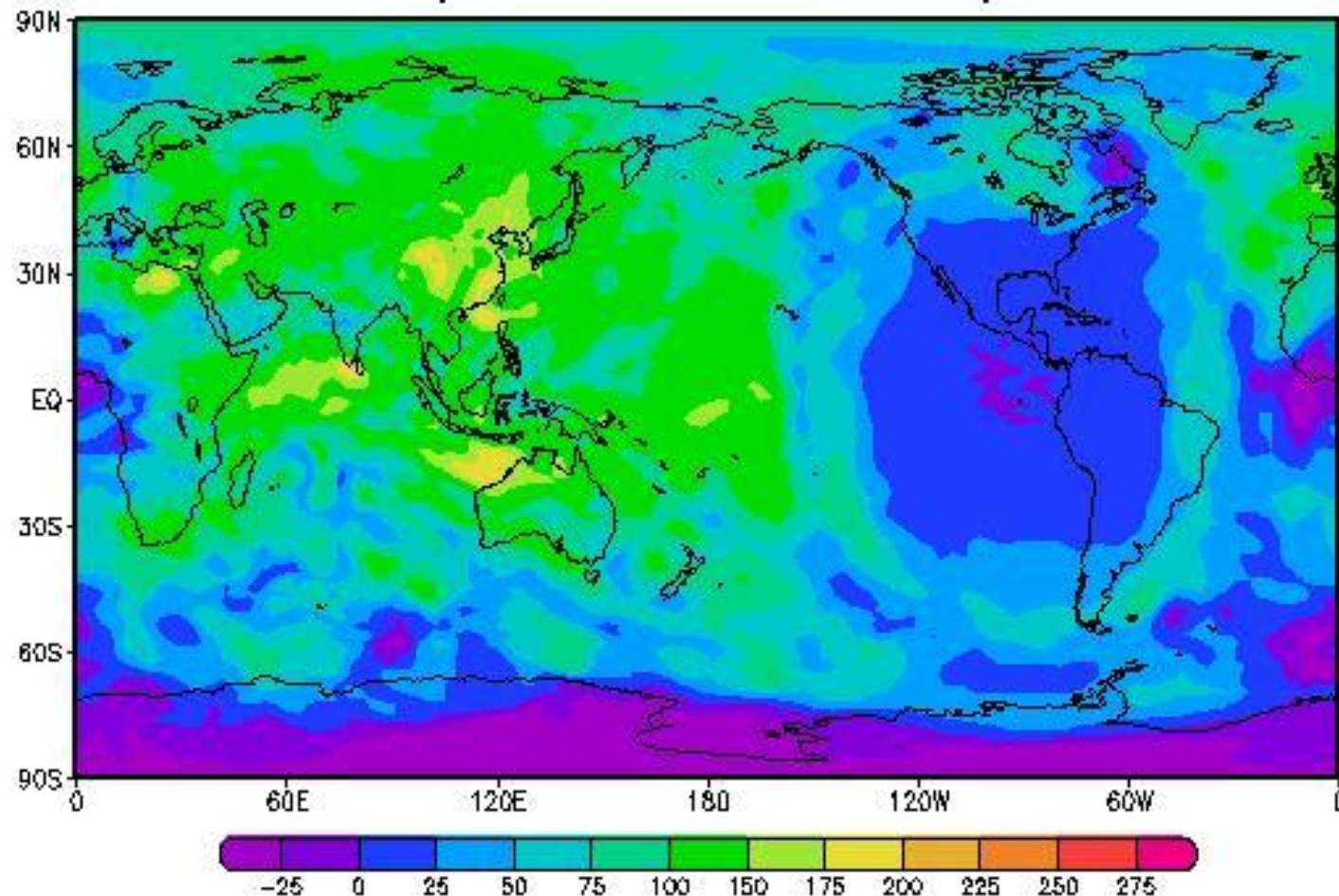
t = +2h

Run 2: Temperature Perturbation Results



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Temperature Difference / K



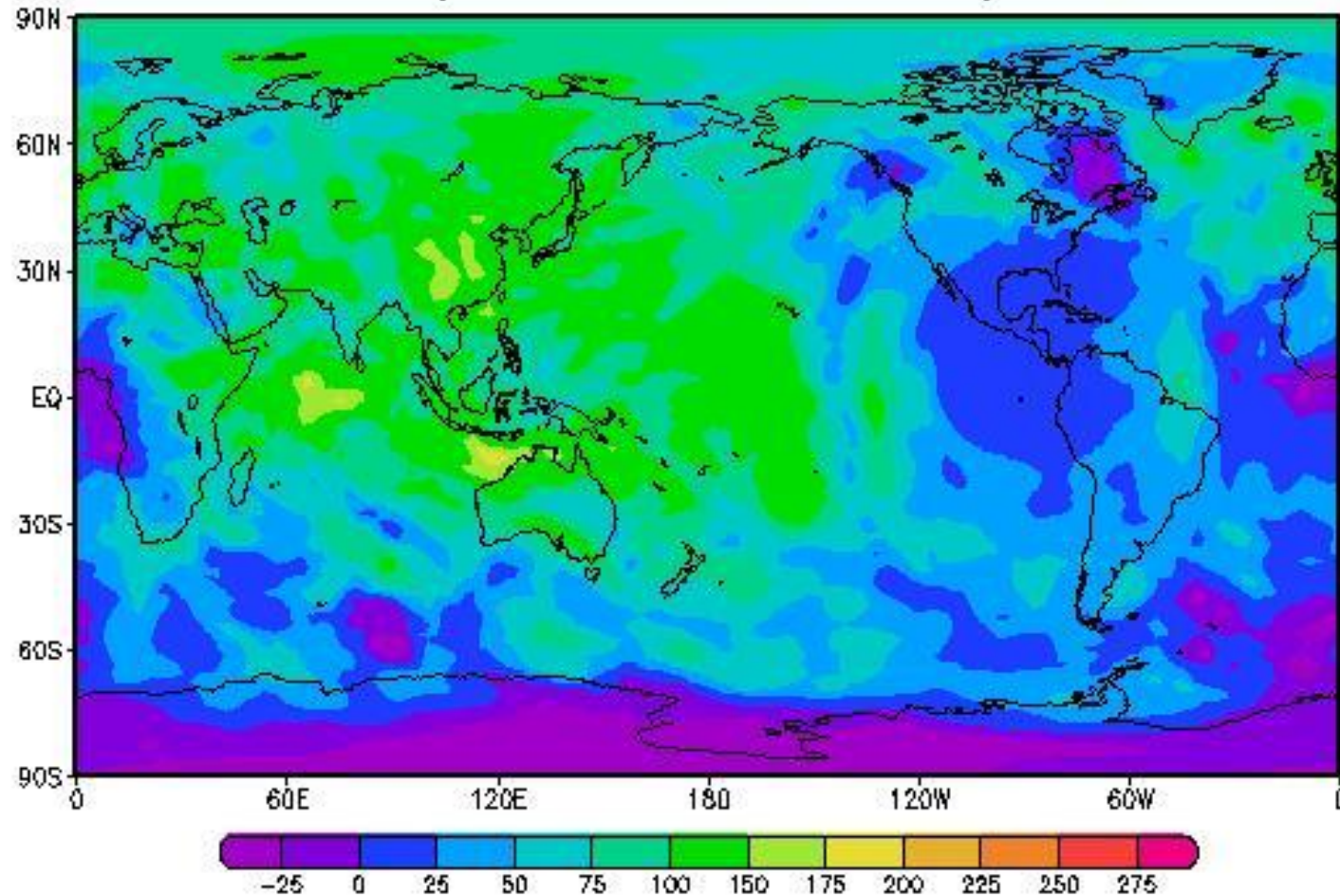
$t = +3h$

Run 2: Temperature Perturbation Results



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Temperature Difference / K



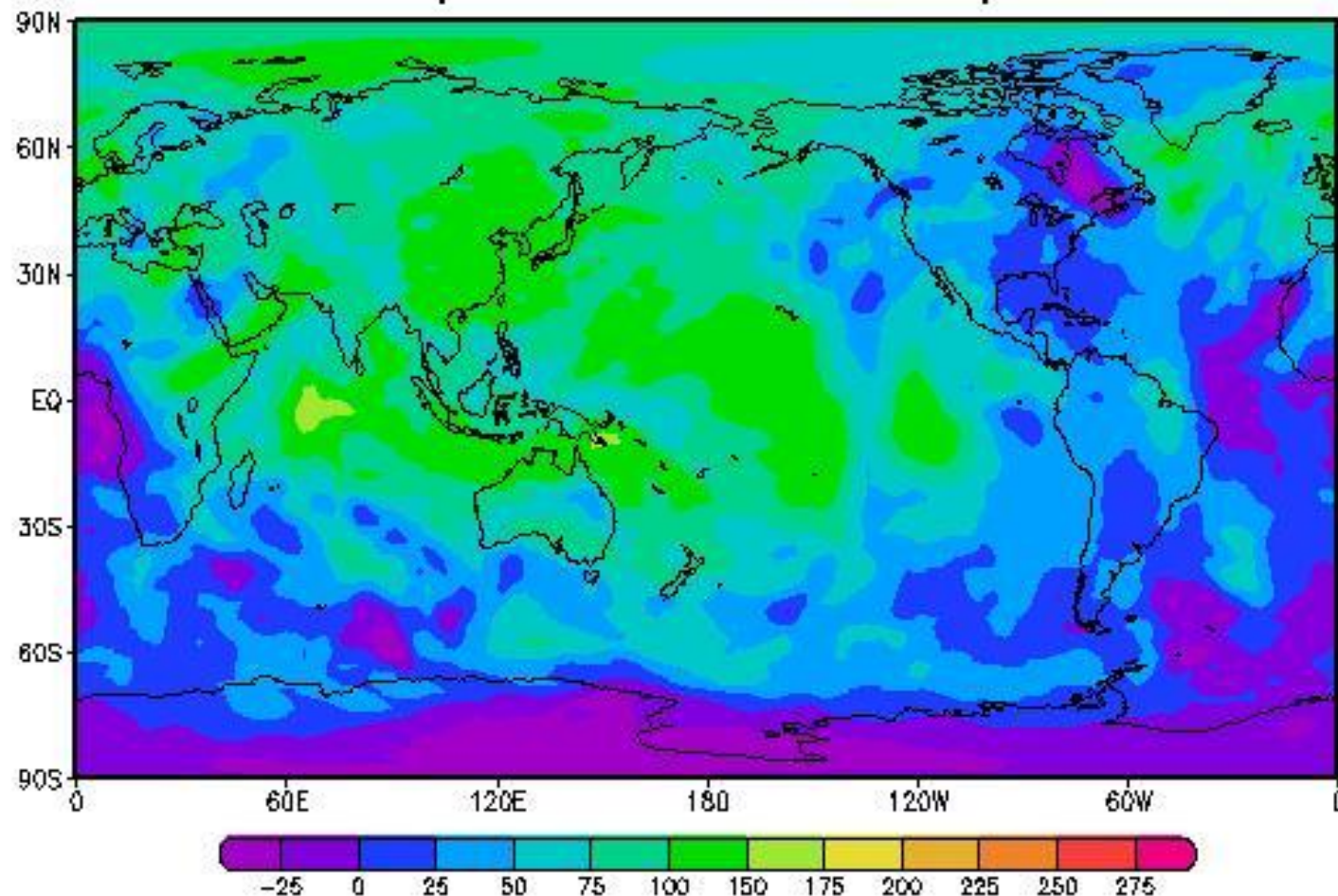
t = +4h

Run 2: Temperature Perturbation Results



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Temperature Difference / K



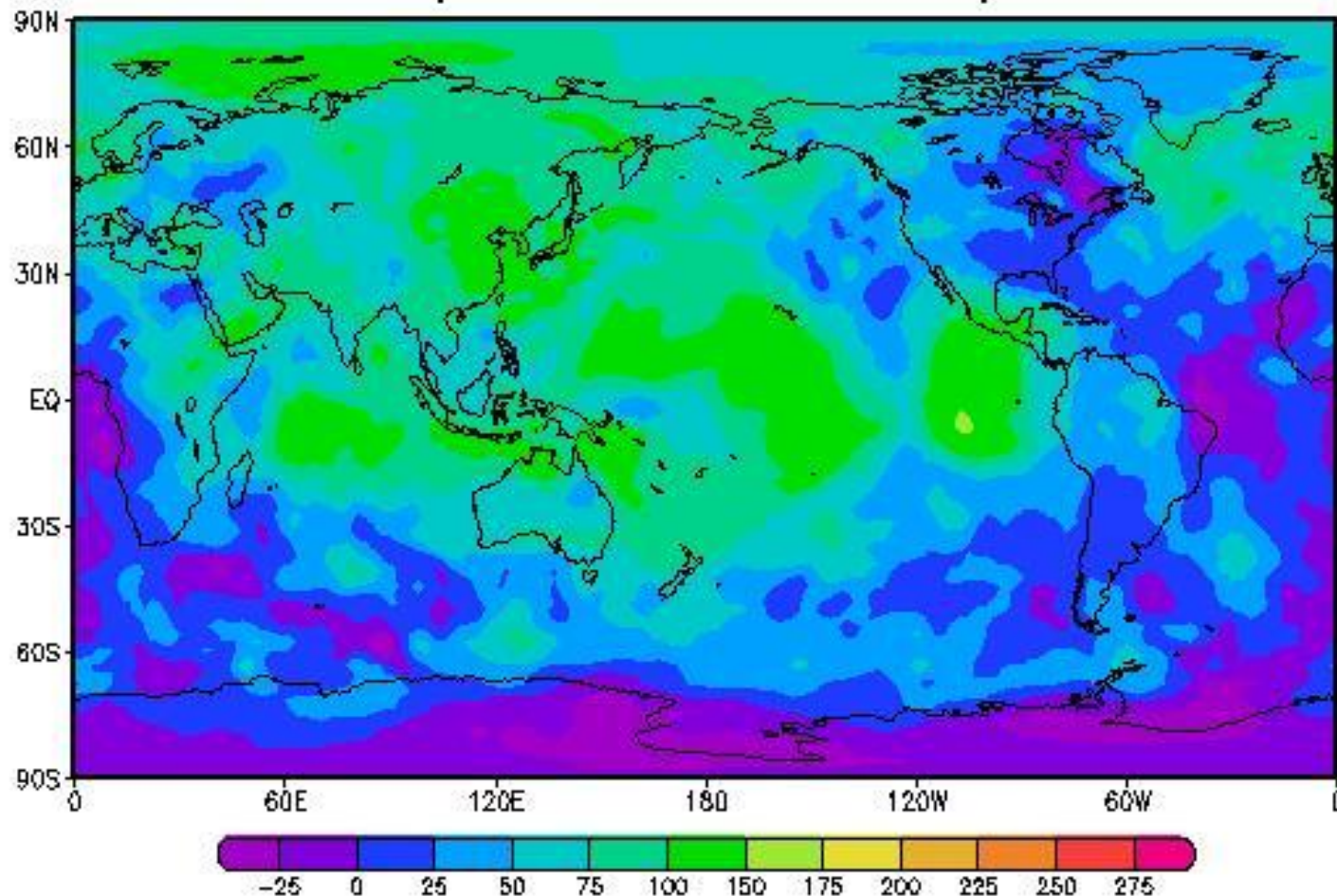
t = +5h

Run 2: Temperature Perturbation Results



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Temperature Difference / K



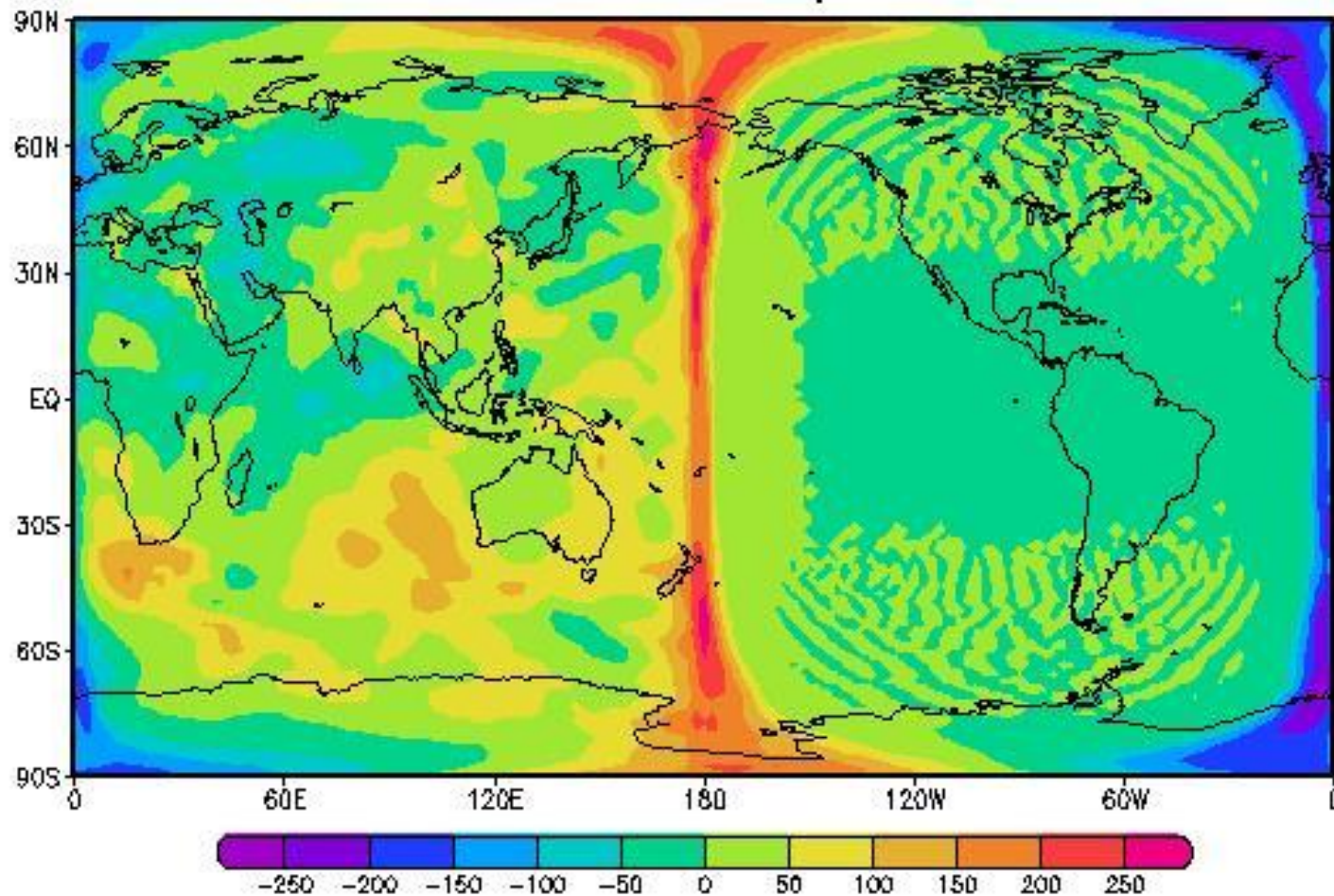
t = +6h

Run 2: Temperature Perturbation Results



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Difference in U / ms^{-1}



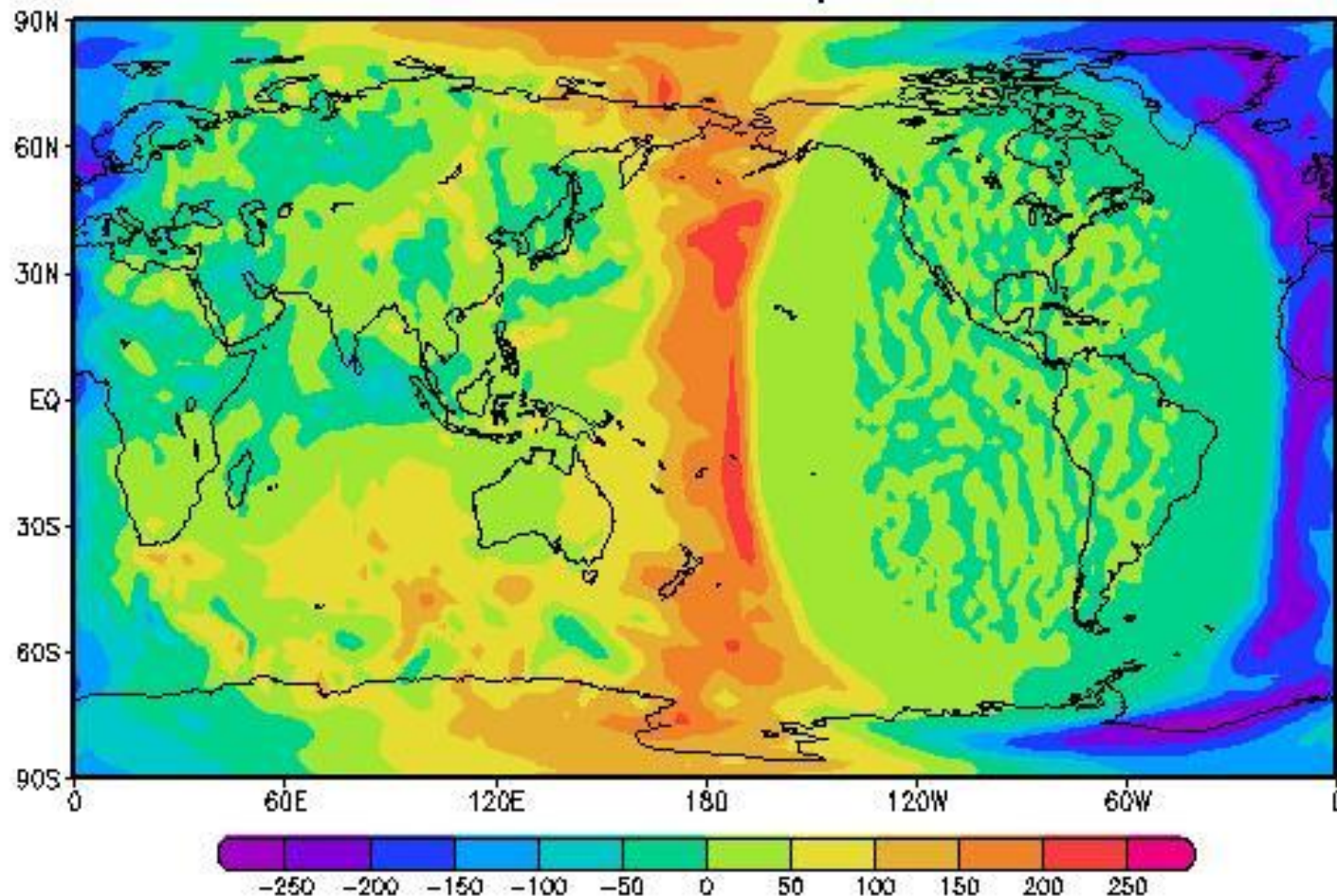
$t = 00\text{h}$

Run 2: Temperature Perturbation Results



UNIVERSITY OF LEEDS

Difference in U / ms^{-1}



$t = +1\text{h}$

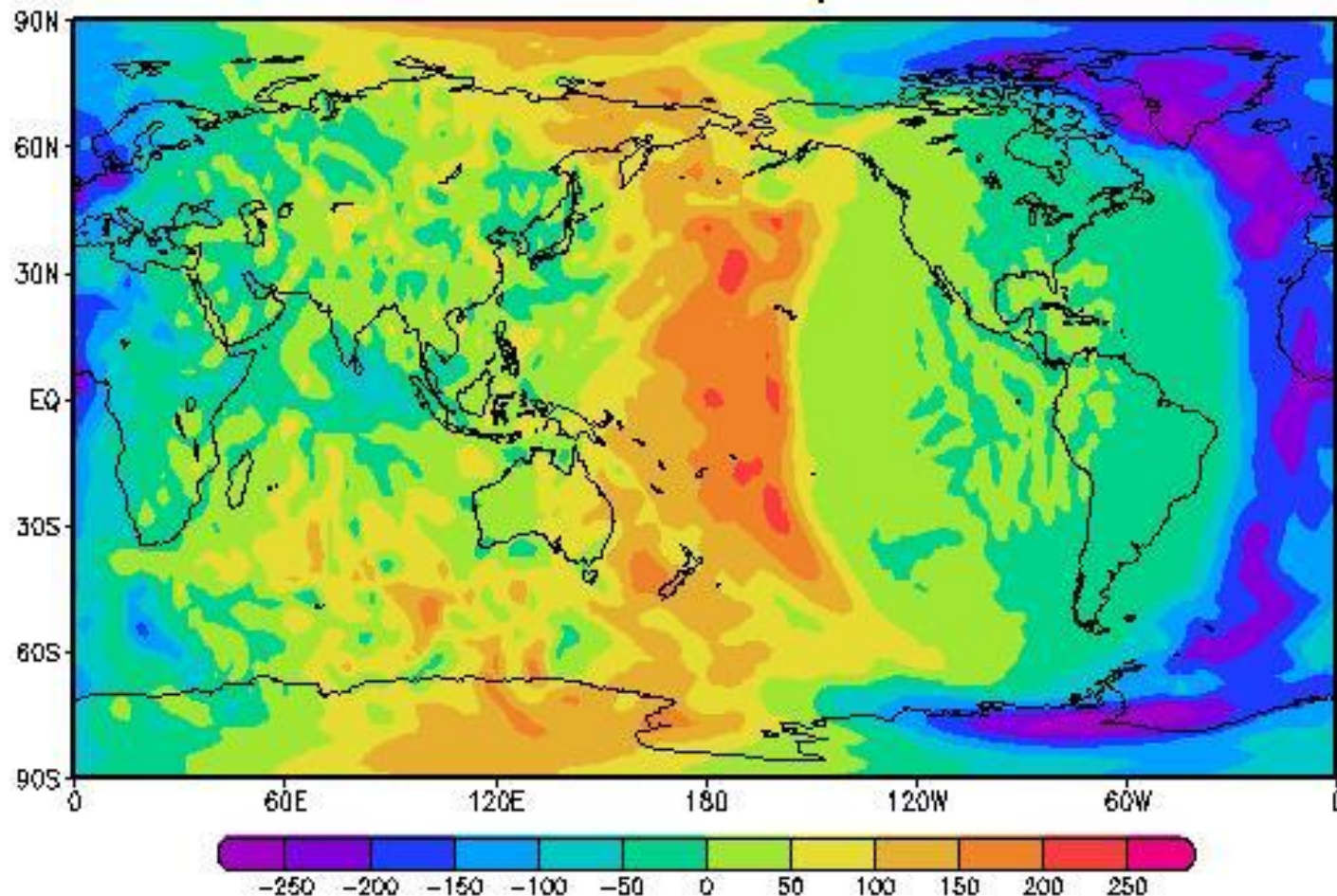
Run 2: Temperature Perturbation

Results



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Difference in U / ms^{-1}



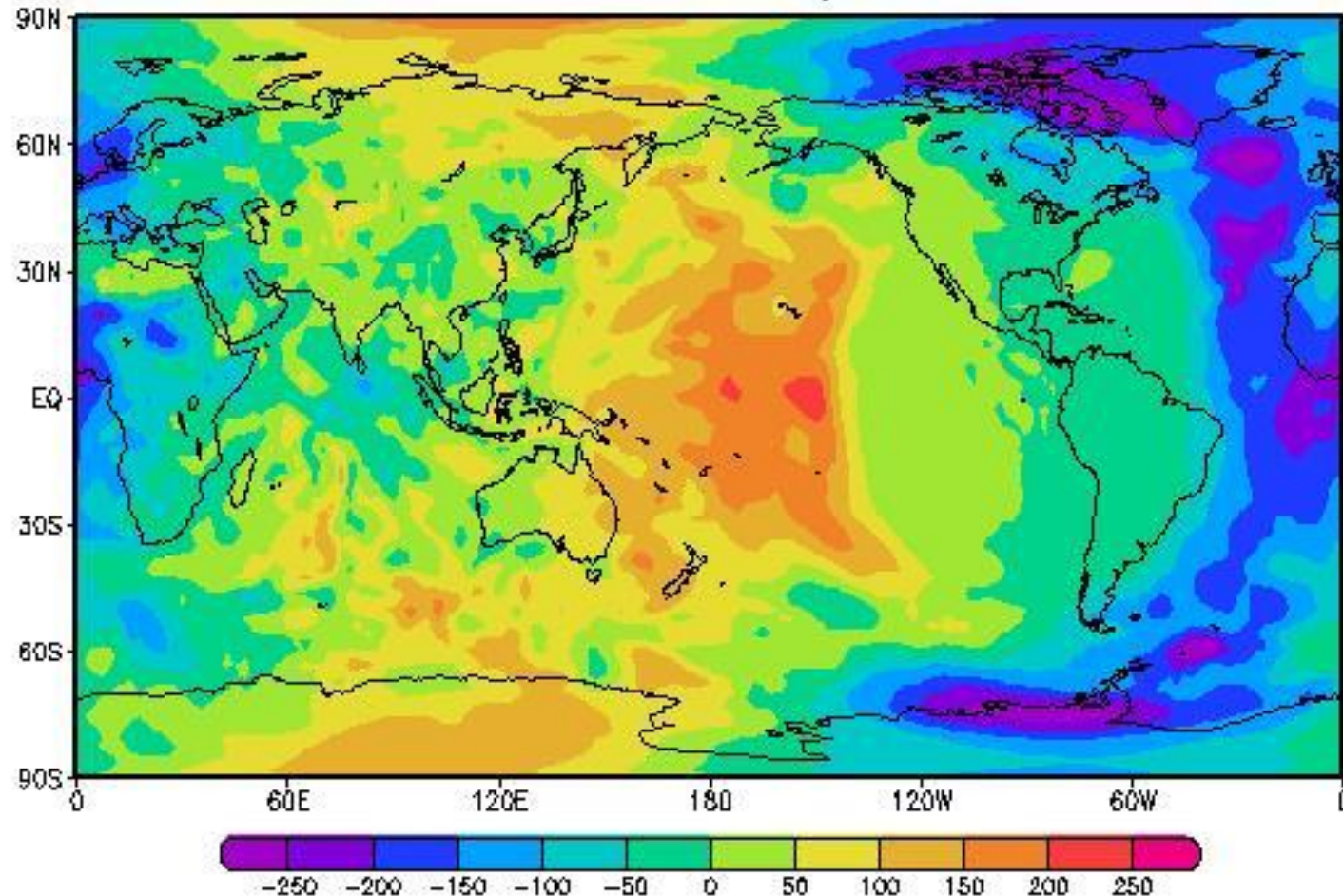
$t = +2\text{h}$

Run 2: Temperature Perturbation Results



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Difference in U / ms^{-1}



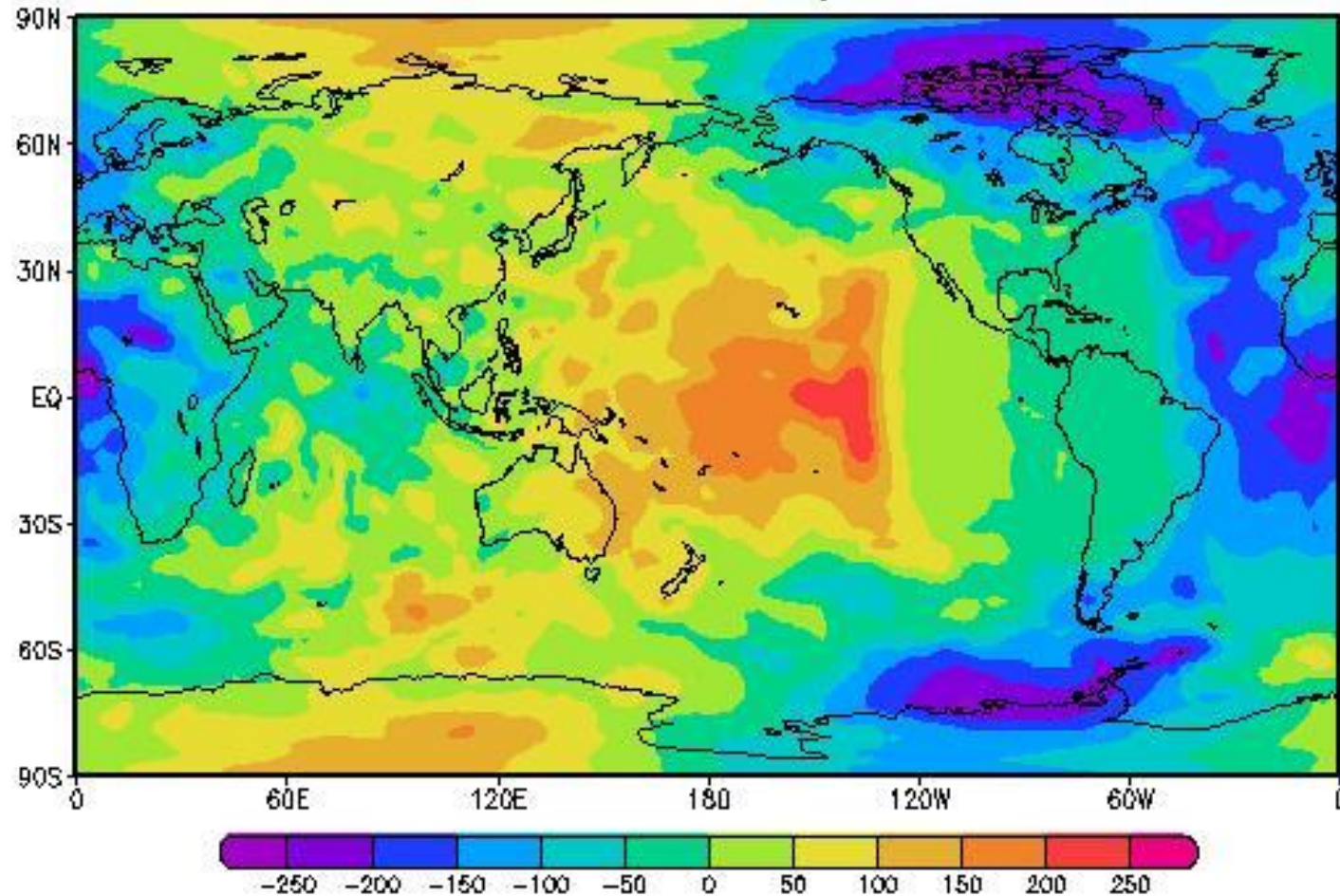
$t = +3\text{h}$

Run 2: Temperature Perturbation Results



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Difference in U / ms^{-1}



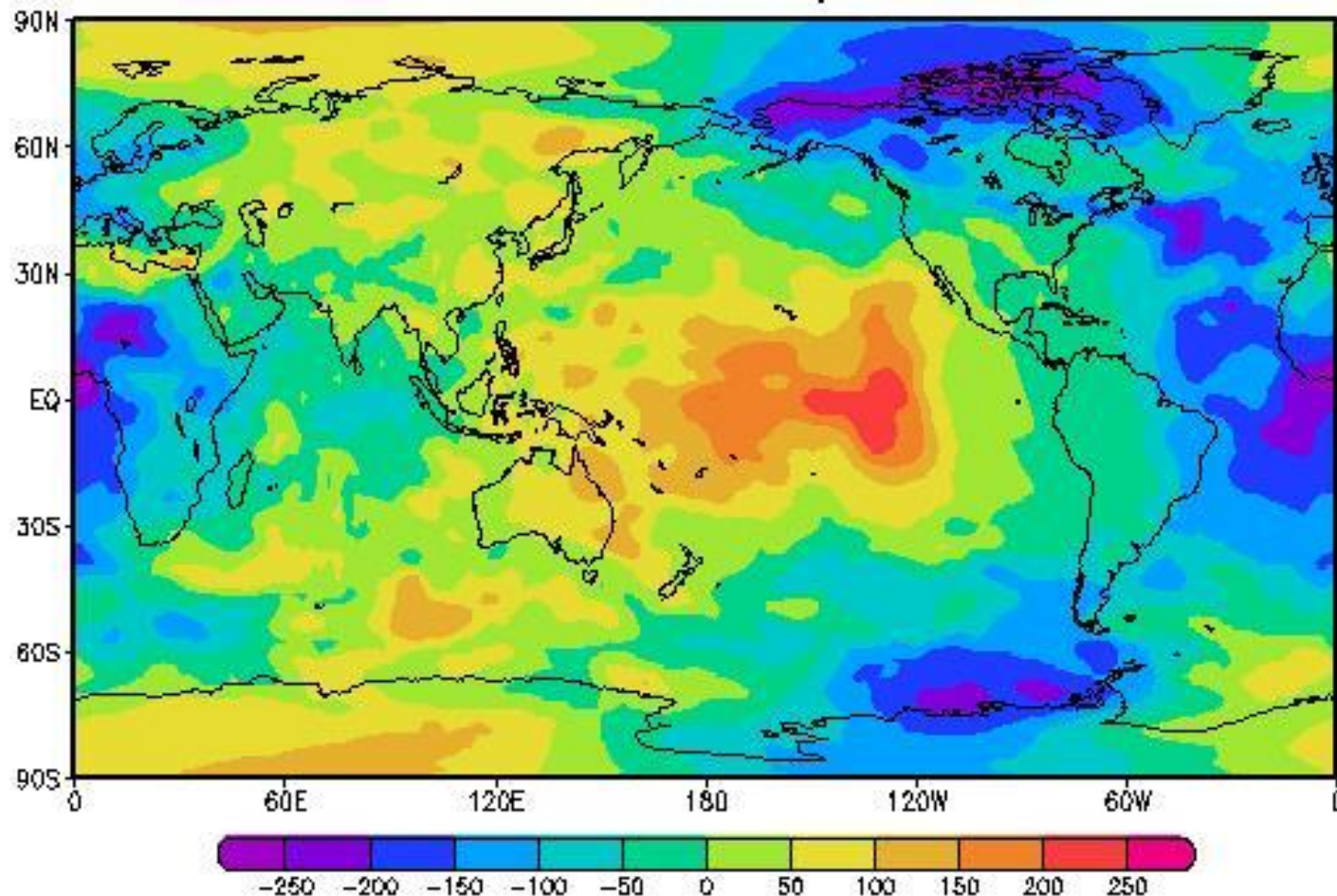
$t = +4\text{h}$

Run 2: Temperature Perturbation Results



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Difference in U / ms^{-1}



$t = +5\text{h}$

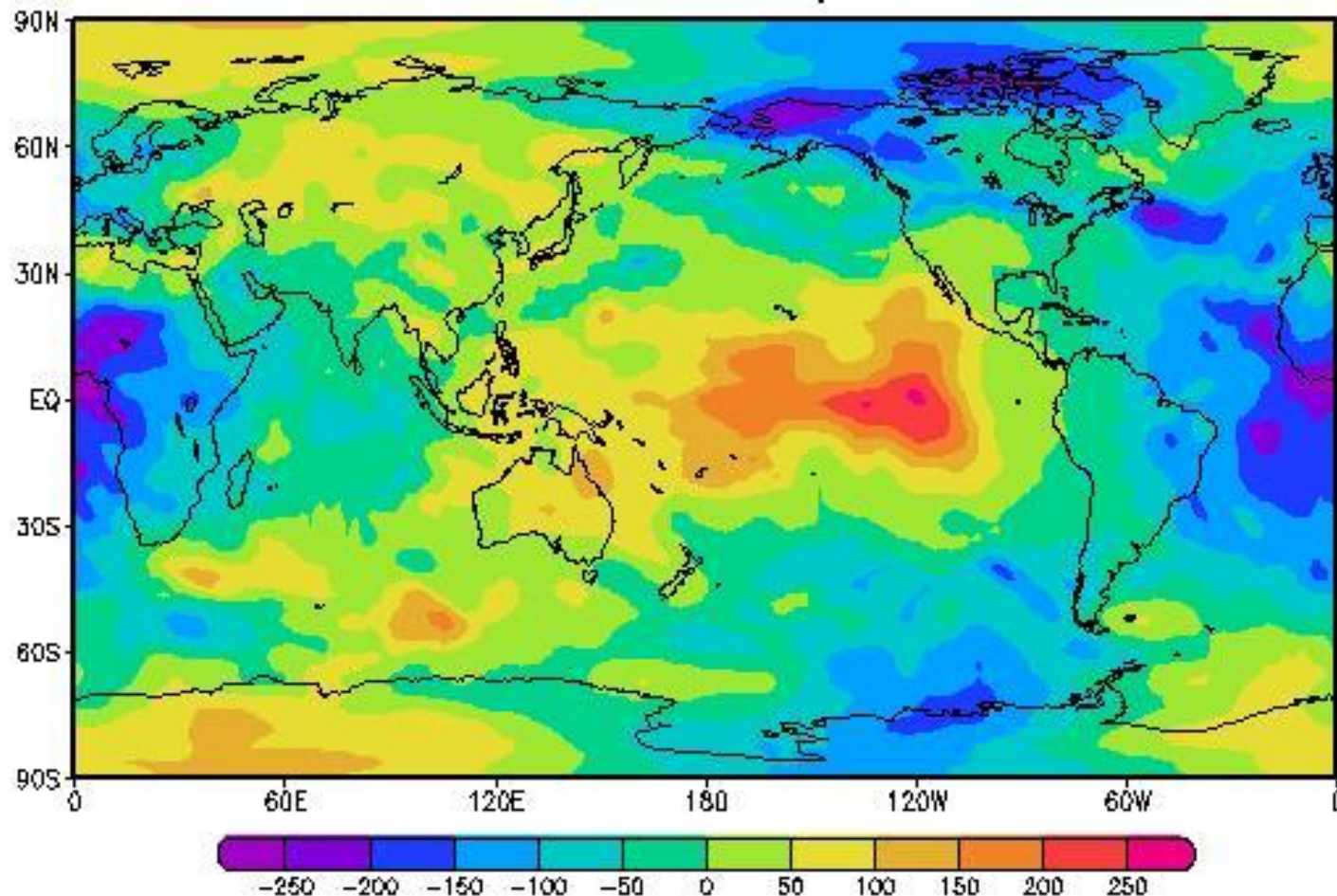
Run 2: Temperature Perturbation

Results



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Difference in U / ms^{-1}



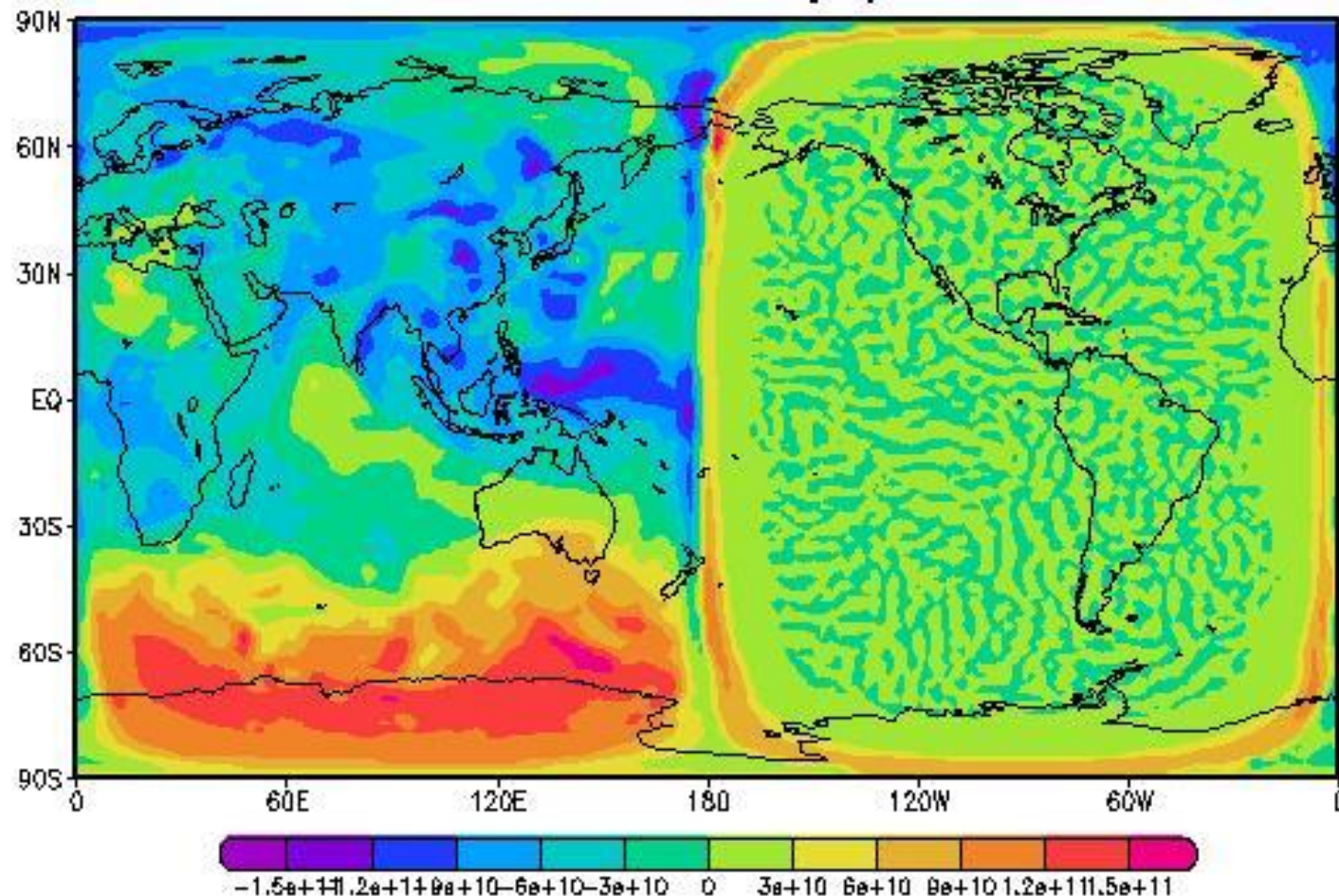
$t = +6\text{h}$

Run 2: Temperature Perturbation Results



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Difference in θ Density / cm^{-3}



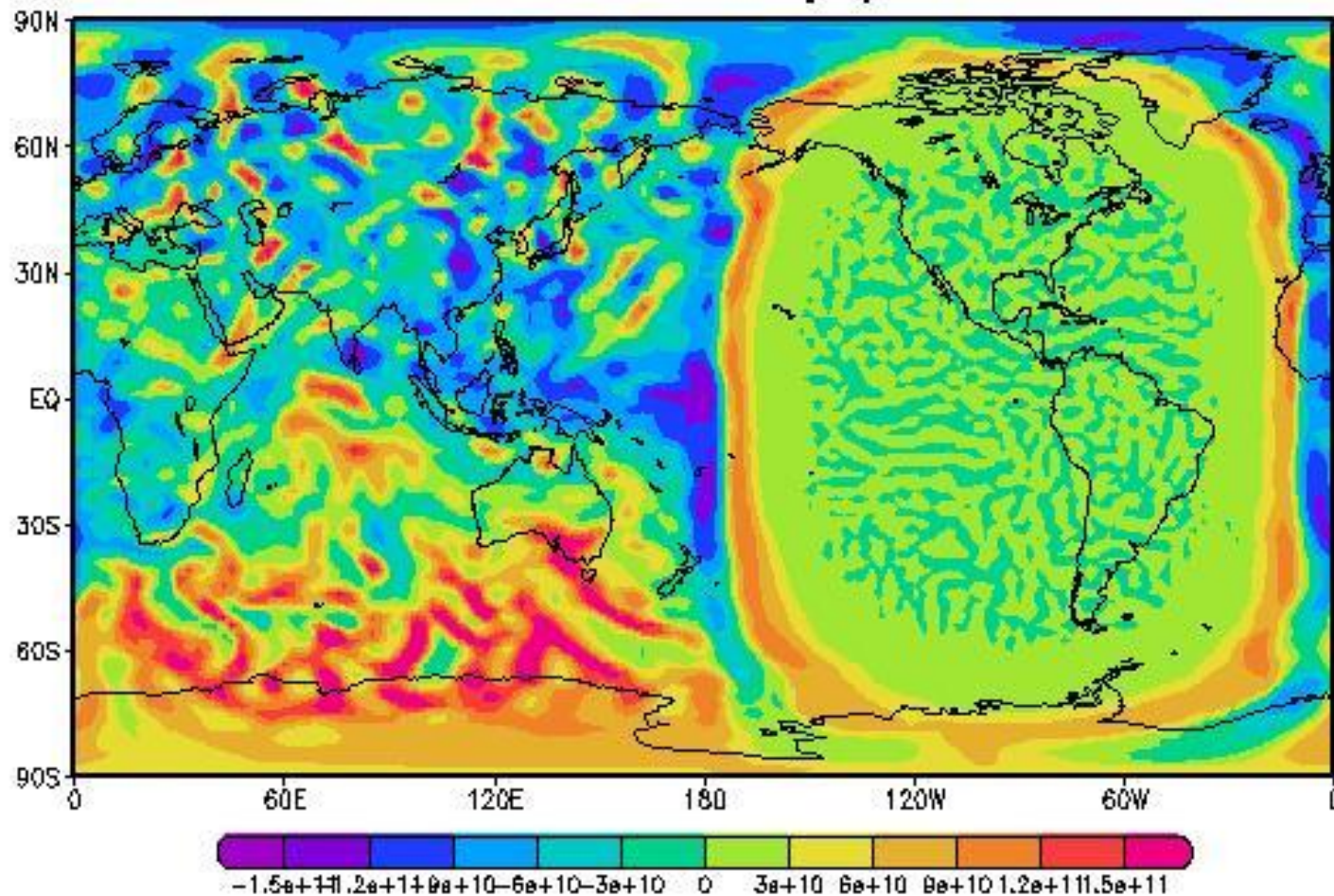
$t = 00\text{h}$

Run 2: Temperature Perturbation Results



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Difference in θ Density / cm^{-3}



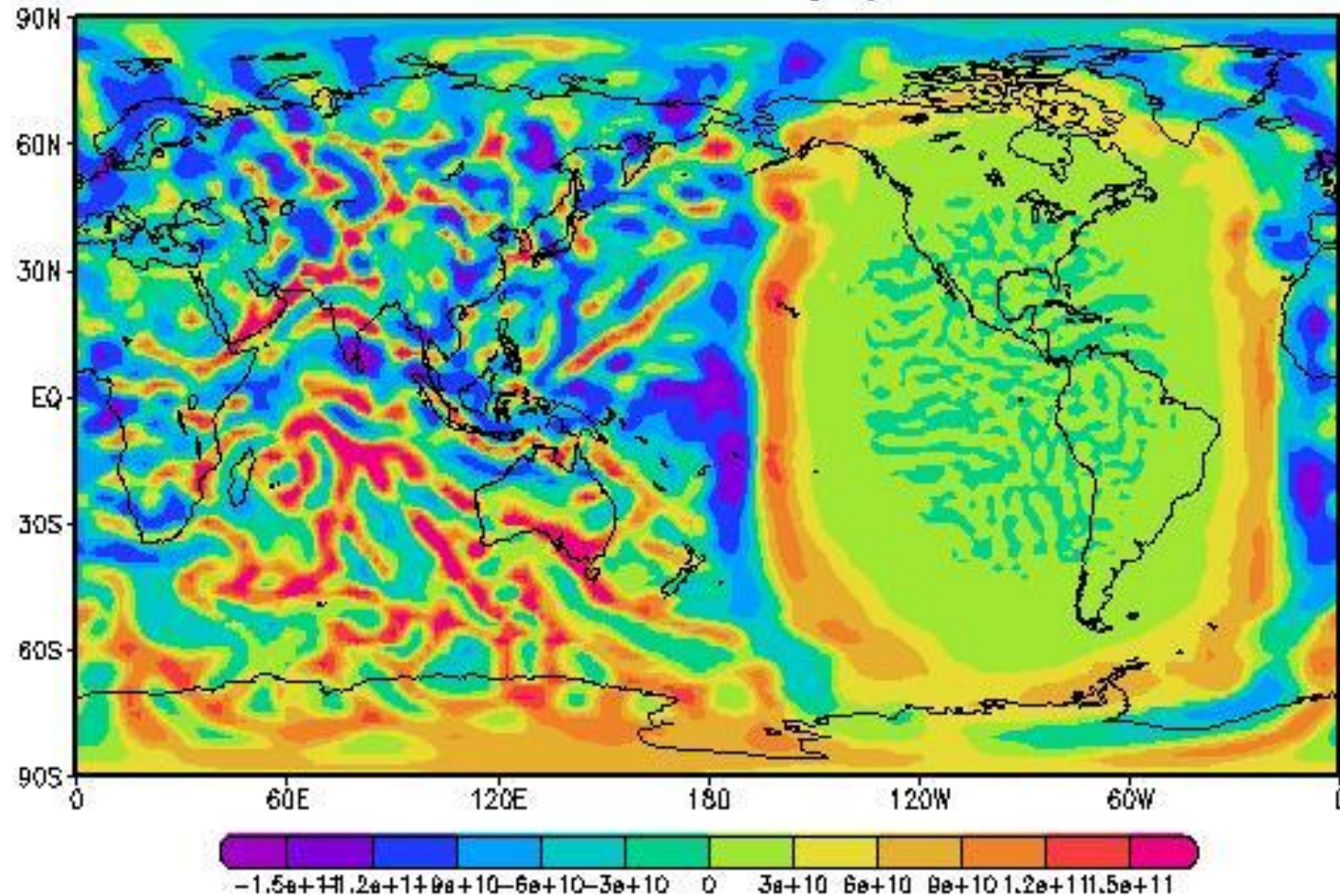
$t = +1\text{h}$

Run 2: Temperature Perturbation Results



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Difference in θ Density / cm^{-3}



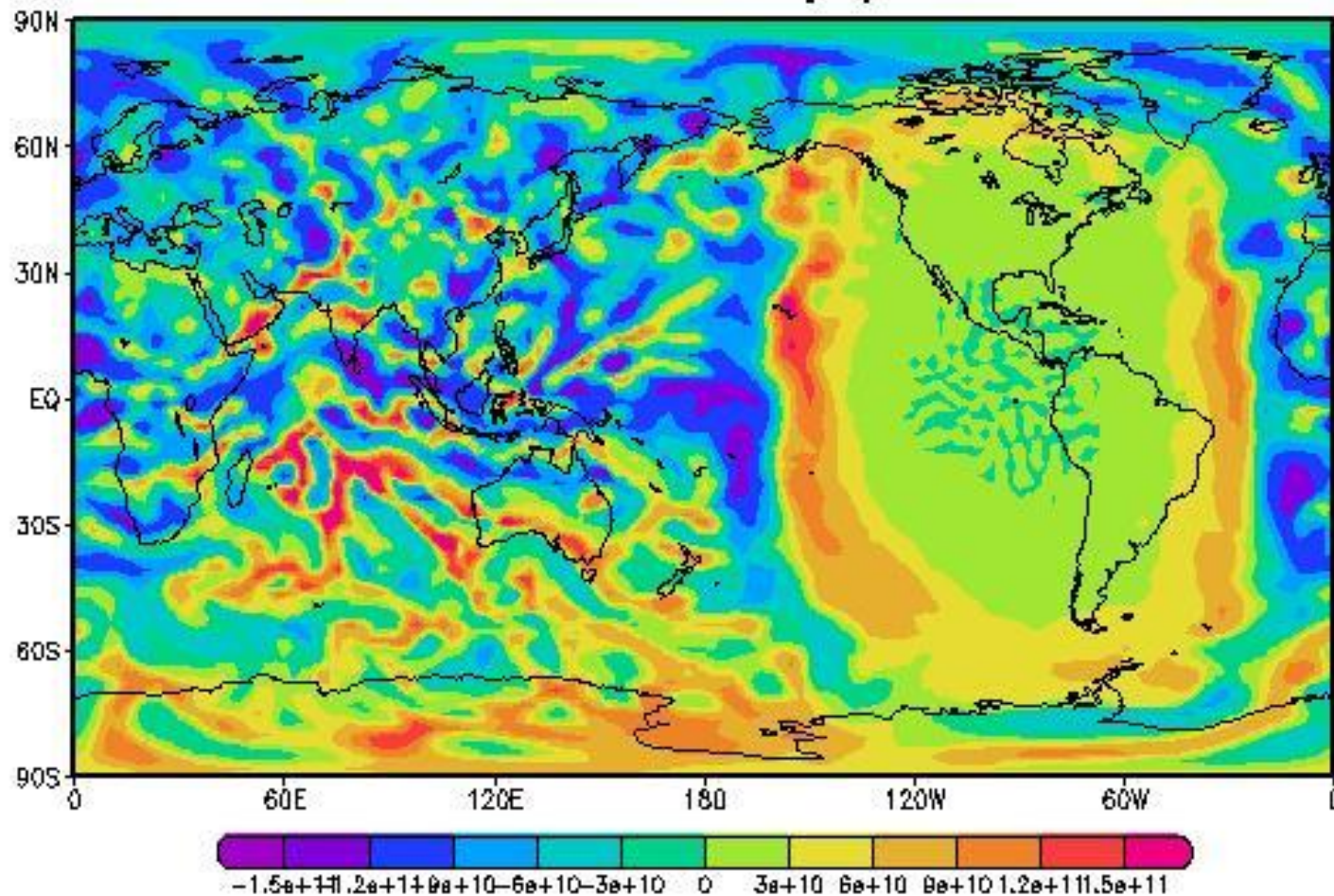
t = +2h

Run 2: Temperature Perturbation Results



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Difference in θ Density / cm^{-3}



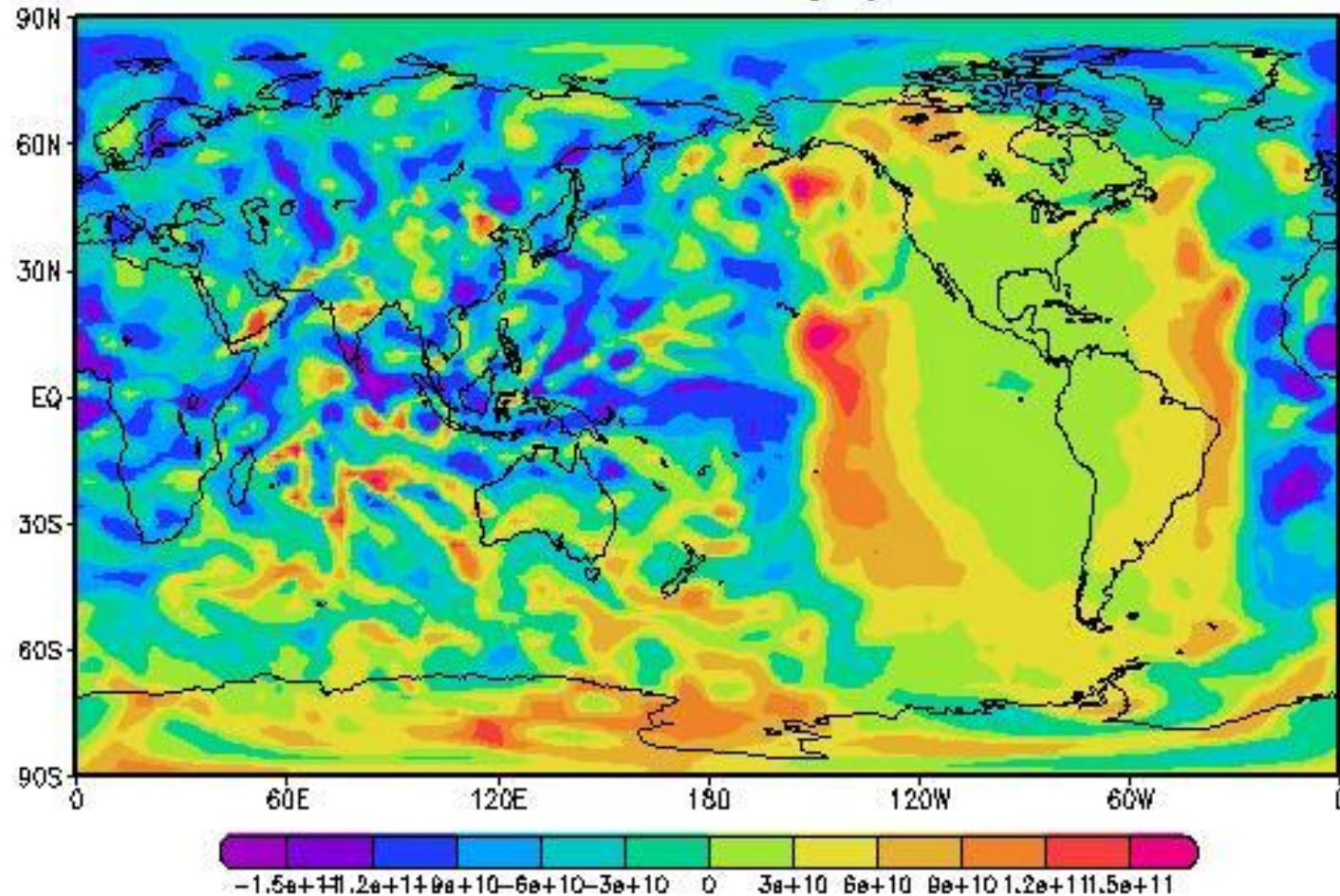
t = +3h

Run 2: Temperature Perturbation Results



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Difference in θ Density / cm^{-3}



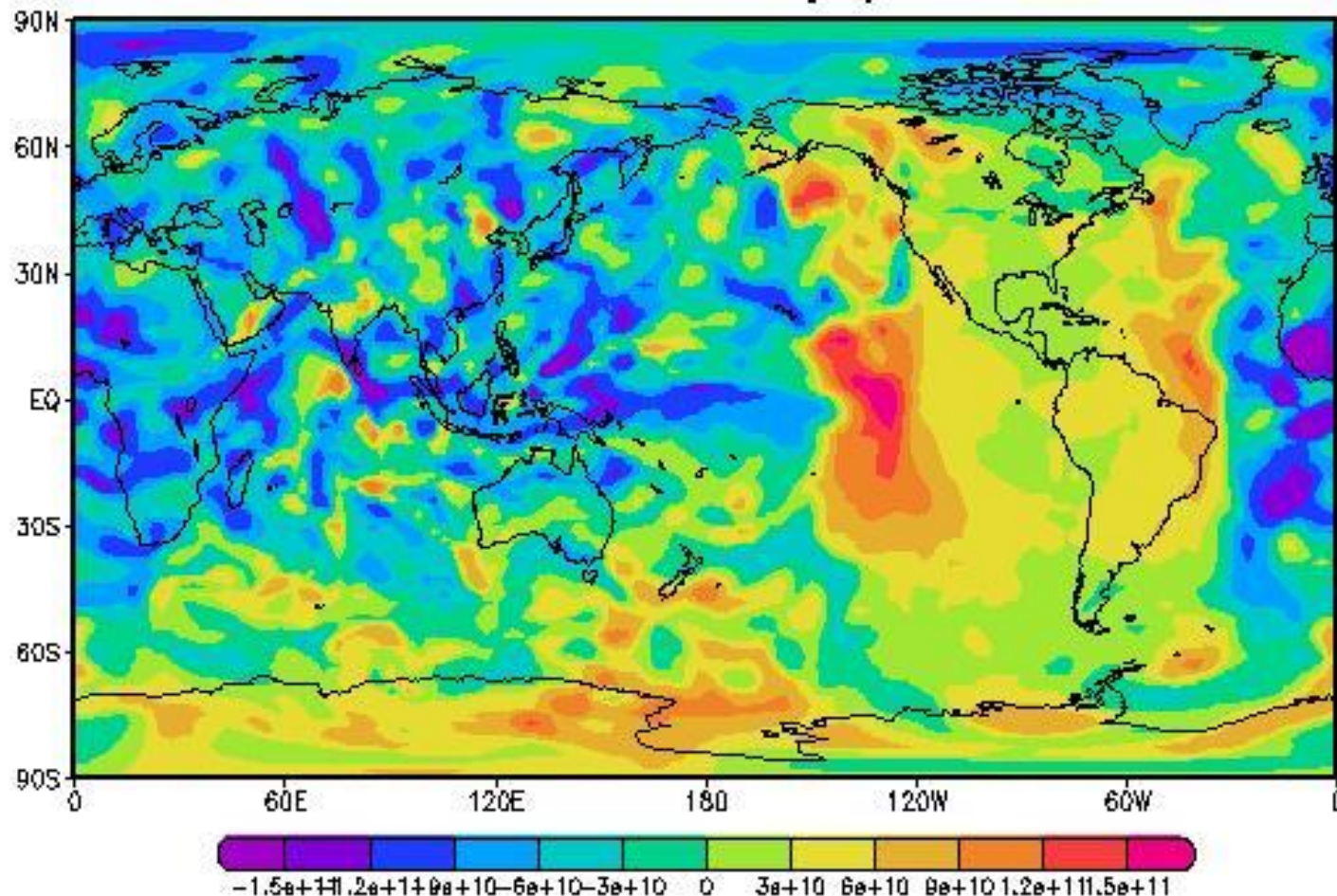
$t = +4\text{h}$

Run 2: Temperature Perturbation Results



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Difference in θ Density / cm^{-3}



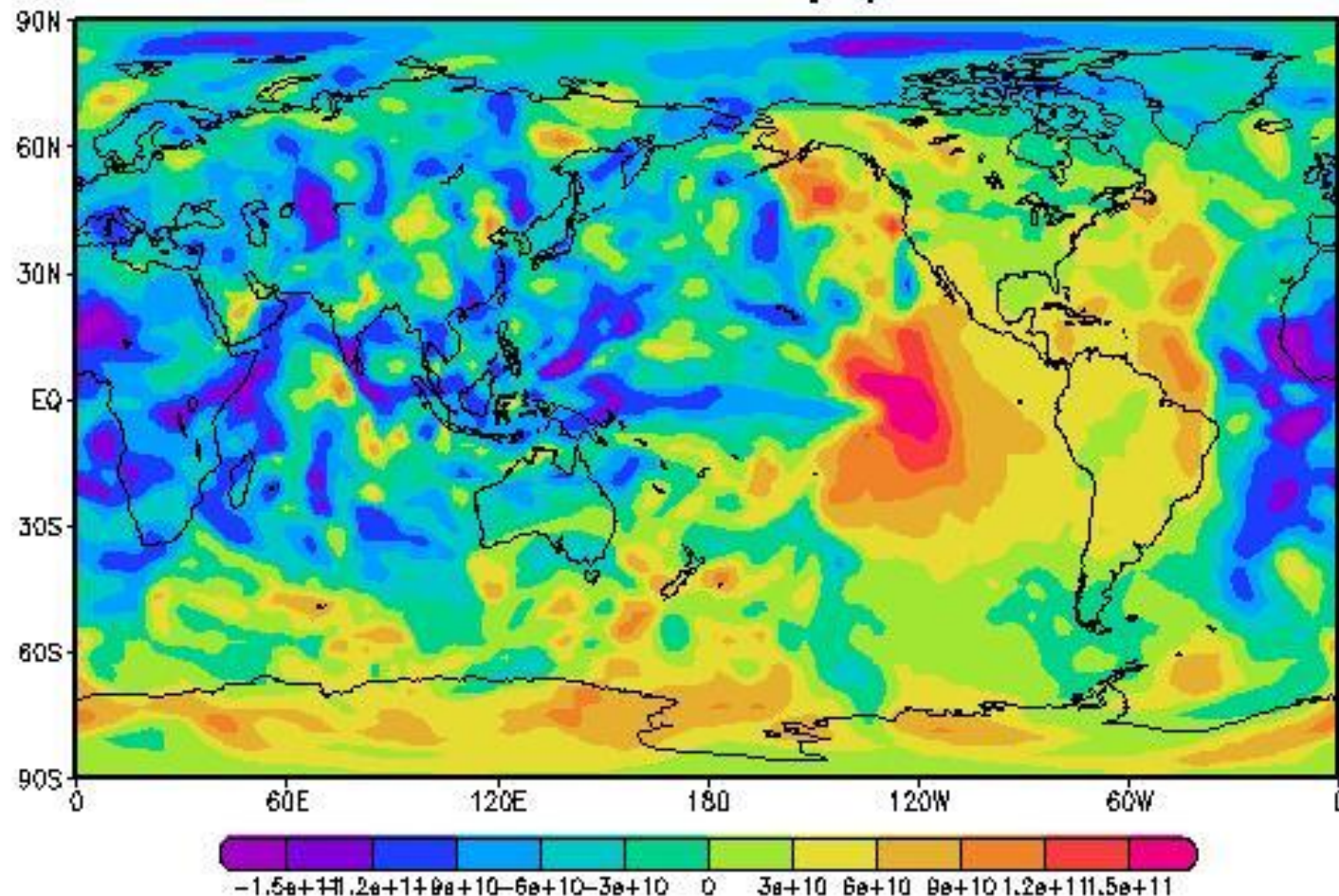
$t = +5\text{h}$

Run 2: Temperature Perturbation Results



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Difference in θ Density / cm^{-3}



$t = +6\text{h}$

Run 3: MSP + Sulfur Injection

Run details



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➤ Sulfur

- 5.425 % Sulfur content in Halley dust (Jessberger et al. 1988)
- 21,755 tonnes injected over 2 hours (4 time-steps)

➤ MSPs

- 401,000 tonnes injected over the course of 1 week
- Assume all ablated material forms MSPs

➤ 5 year Simulation

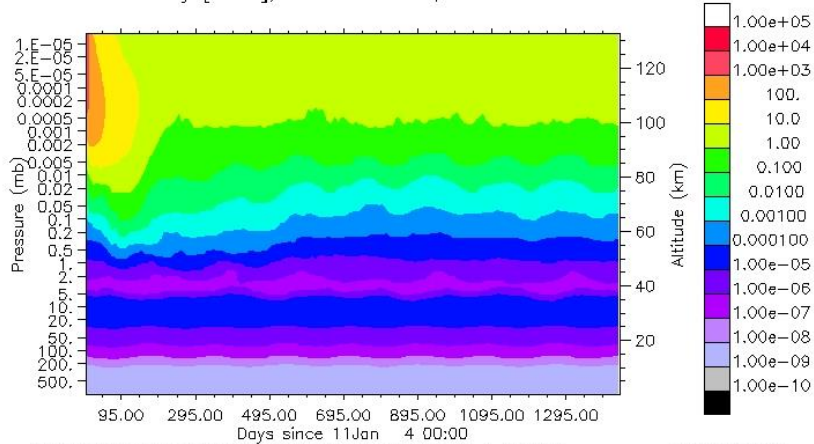
- Free-running
- Pre-industrial emissions, present day S (spin up 5 years)
- MSP deposition pattern
- SO_4 in ice cores?

Run 3: MSP + Sulfur Injection Results

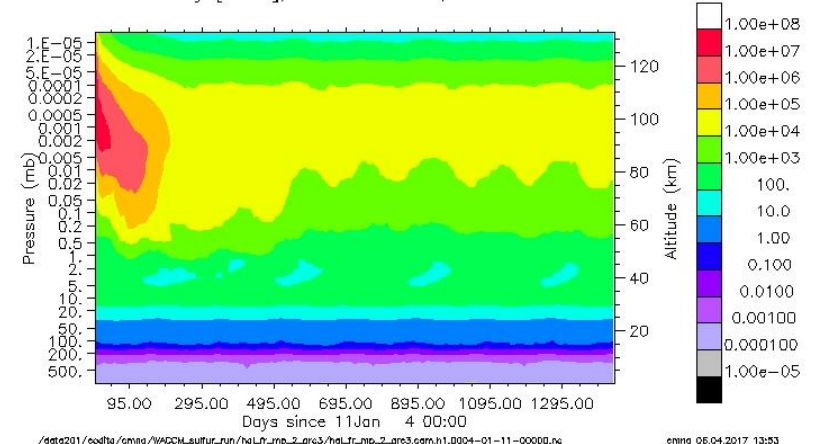


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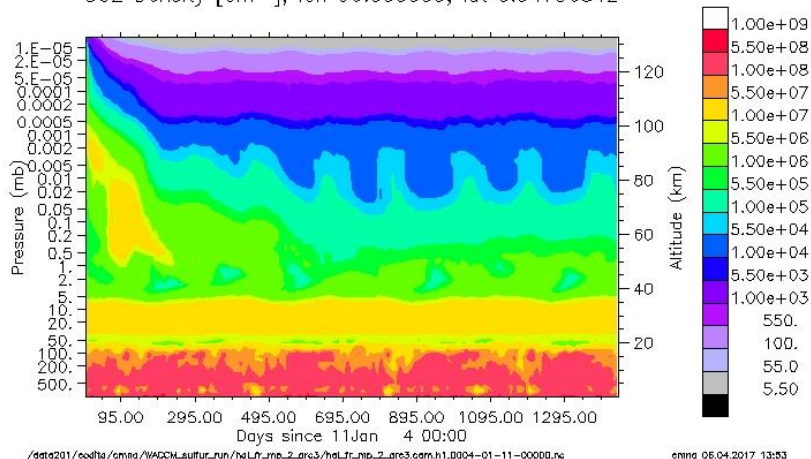
S Density [cm^{-3}], lon 90.000000, lat 0.94736842



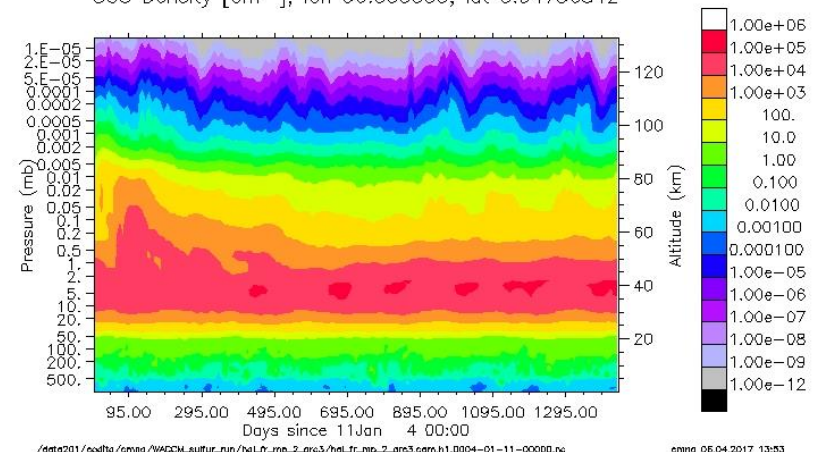
SO Density [cm^{-3}], lon 90.000000, lat 0.94736842



SO2 Density [cm^{-3}], lon 90.000000, lat 0.94736842



SO3 Density [cm^{-3}], lon 90.000000, lat 0.94736842

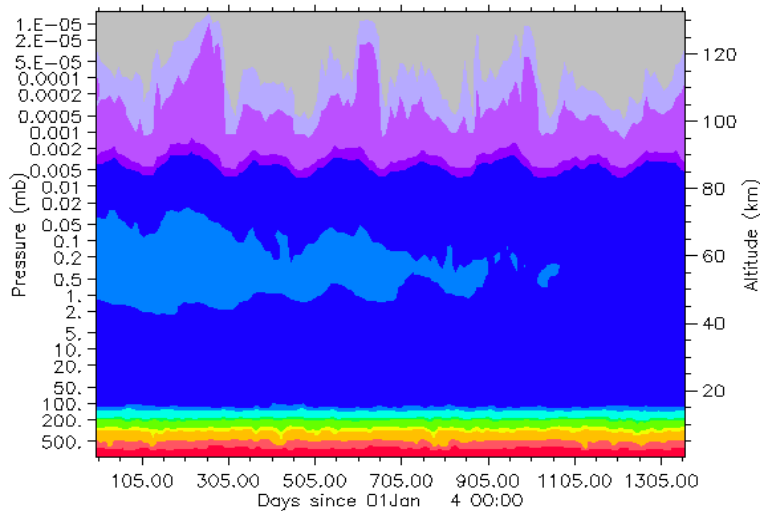


Run 3: MSP + Sulfur Injection Results

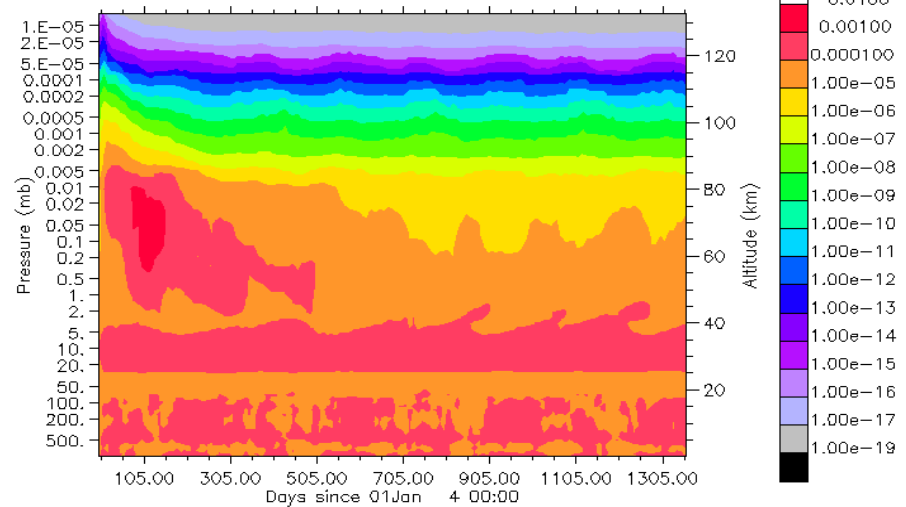


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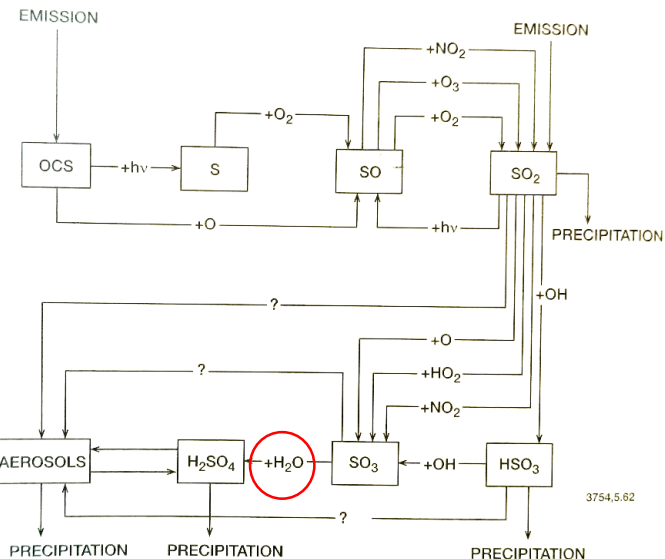
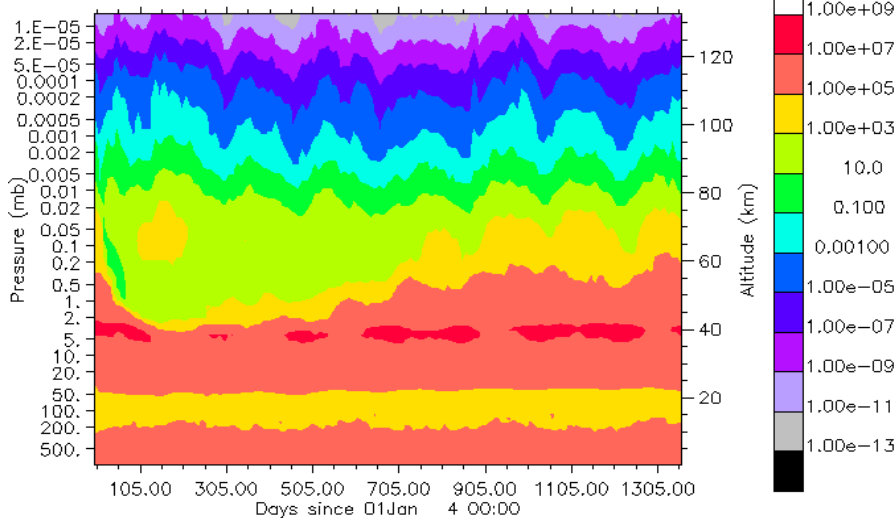
H₂O [mol/mol], lon 90.000000, lat 0.94736842



HSO₃ Density [cm⁻³], lon 90.000000, lat 0.94736842



H₂SO₄ Density [cm⁻³], lon 90.000000, lat 0.94736842



3754.5.62



➤ WACCM Modelling

➤ **Run 1:** Meteoric Metal injection

- Meteoric Input Function (MIF) development
- Results: metal layers, sporadic E layers

➤ **Run 2:** Temperature Perturbation

- Calculations
- Results: temperature and atm. circulation

➤ **Run 3:** MSP and Sulfur injection

- MIF details
- Results: S, SO, SO₂, SO₃, H₂O, HO₂, HSO₃, H₂SO₄ ...

➤ Next Steps

- MSP transport & deposition
- Extinction & radiative forcing