School of Chemistry
Faculty of Maths and Physical Sciences

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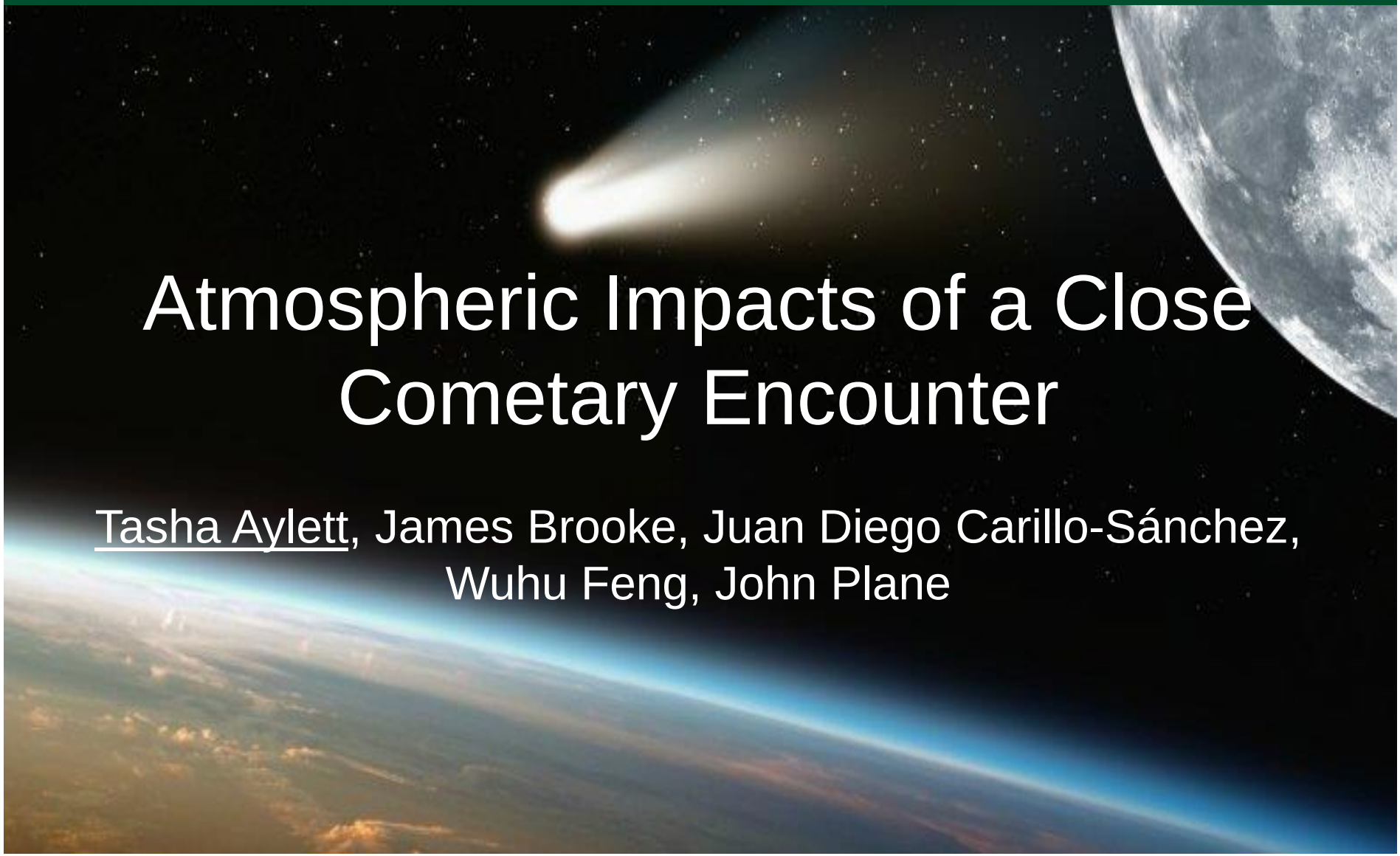

Atmospheric Impacts of a Close Cometary Encounter

Tasha Aylett, James Brooke, Juan Diego Carillo-Sánchez, Wuhu Feng, John Plane

Overview:

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- 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

Project Outline

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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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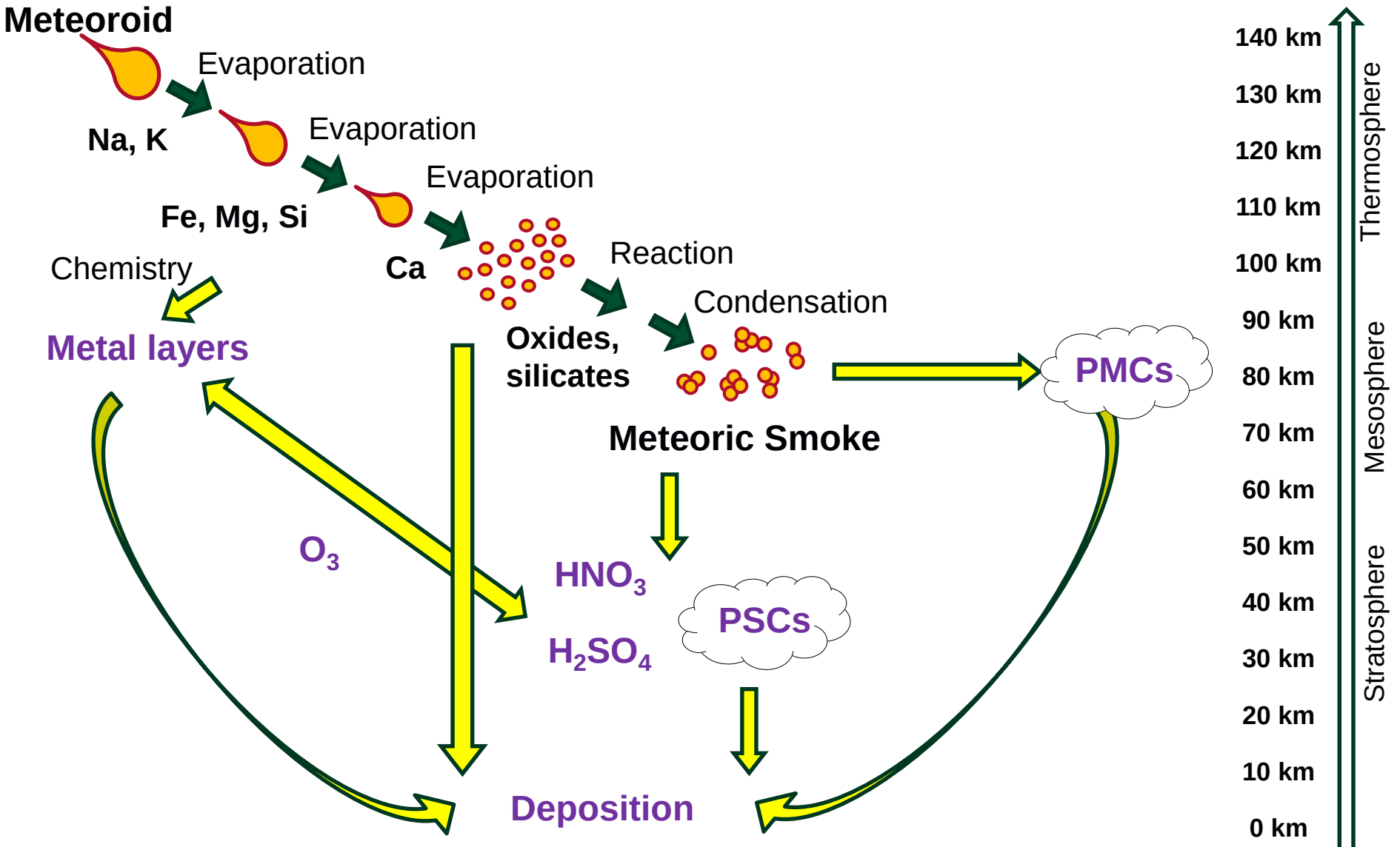

Modelling Strategy

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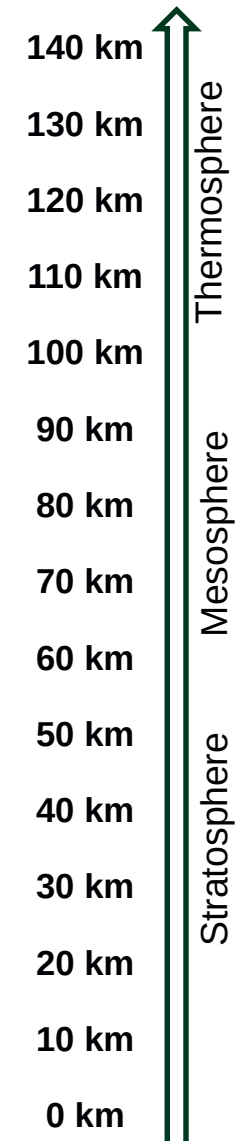
- Mesosphere-lower thermosphere (MLT)
  - Metal layers
  - Ozone
  - Temperature perturbation
- Stratosphere
  - Sulfate aerosol
  - Ozone
  - Extinction
- Surface
  - MSP deposition
  - Temperature perturbation



Run 1: Metal Injection

MIF development

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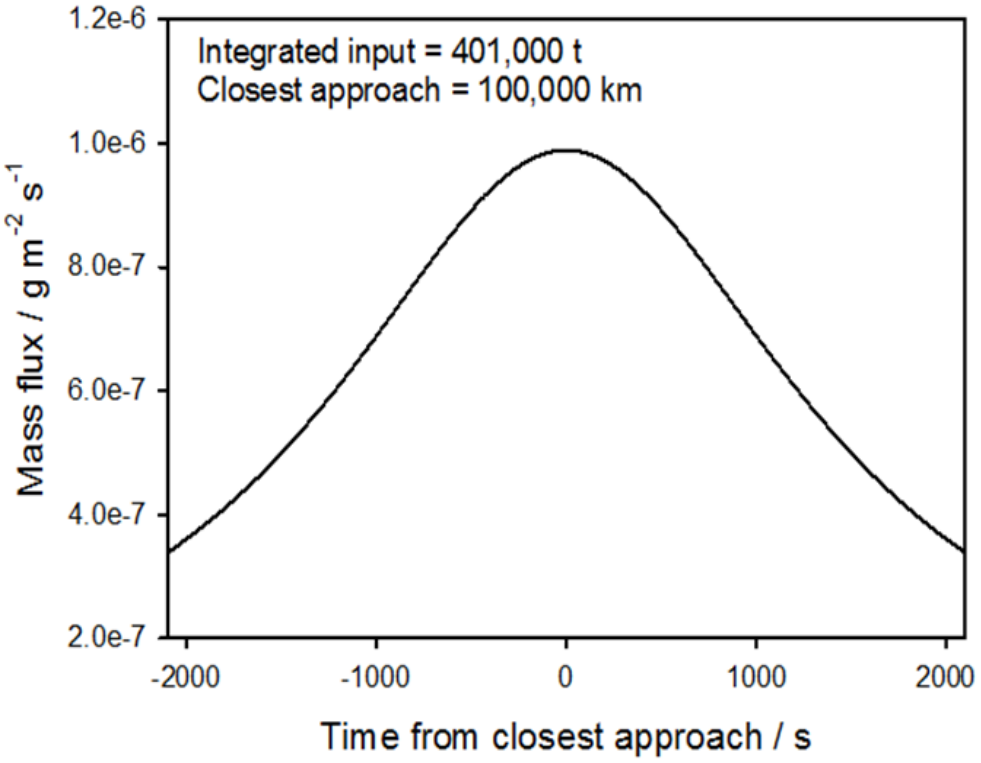
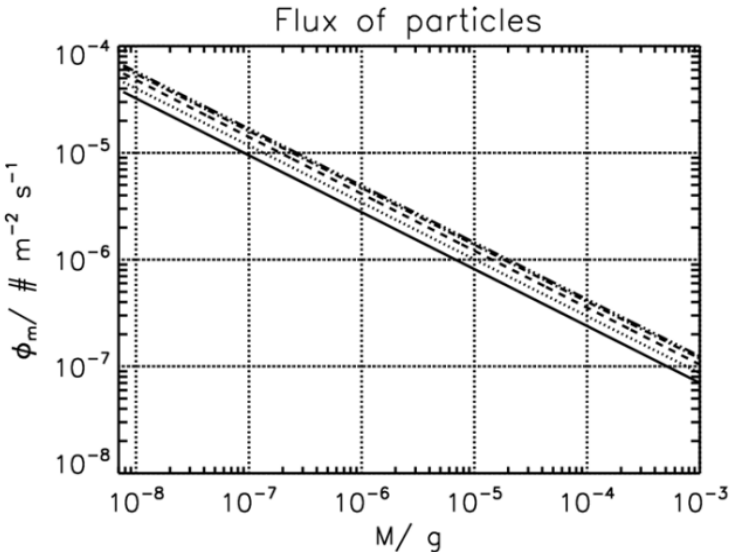
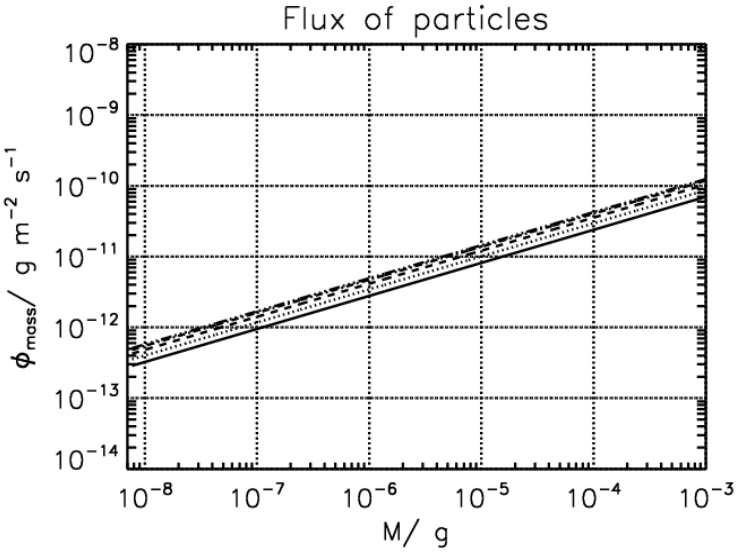
- Dust Model - Moorhead et al. 2014







Run 1: Metal Injection

MIF development

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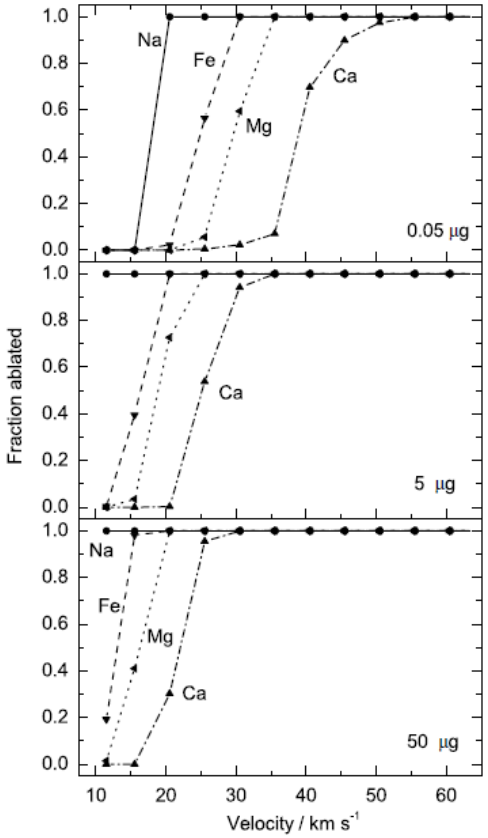
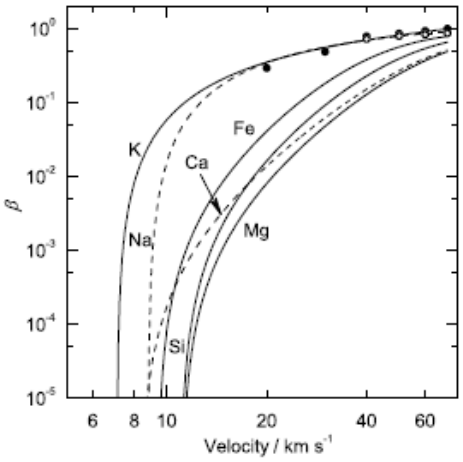
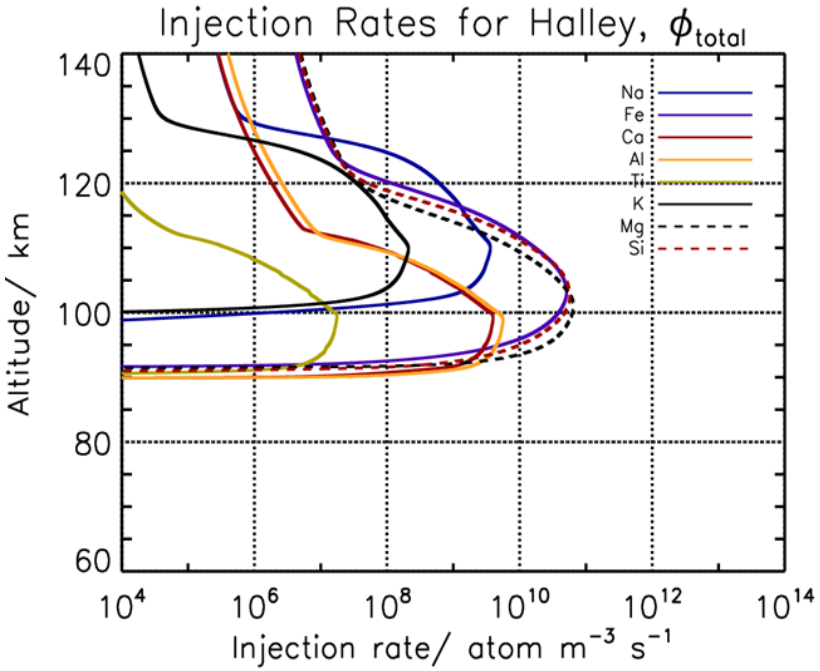
- Chemical Ablation Model (CABMOD) – J.D. Carillo-Sánchez et al. 2015

Fraction Ablated



Ionization Coefficient





- 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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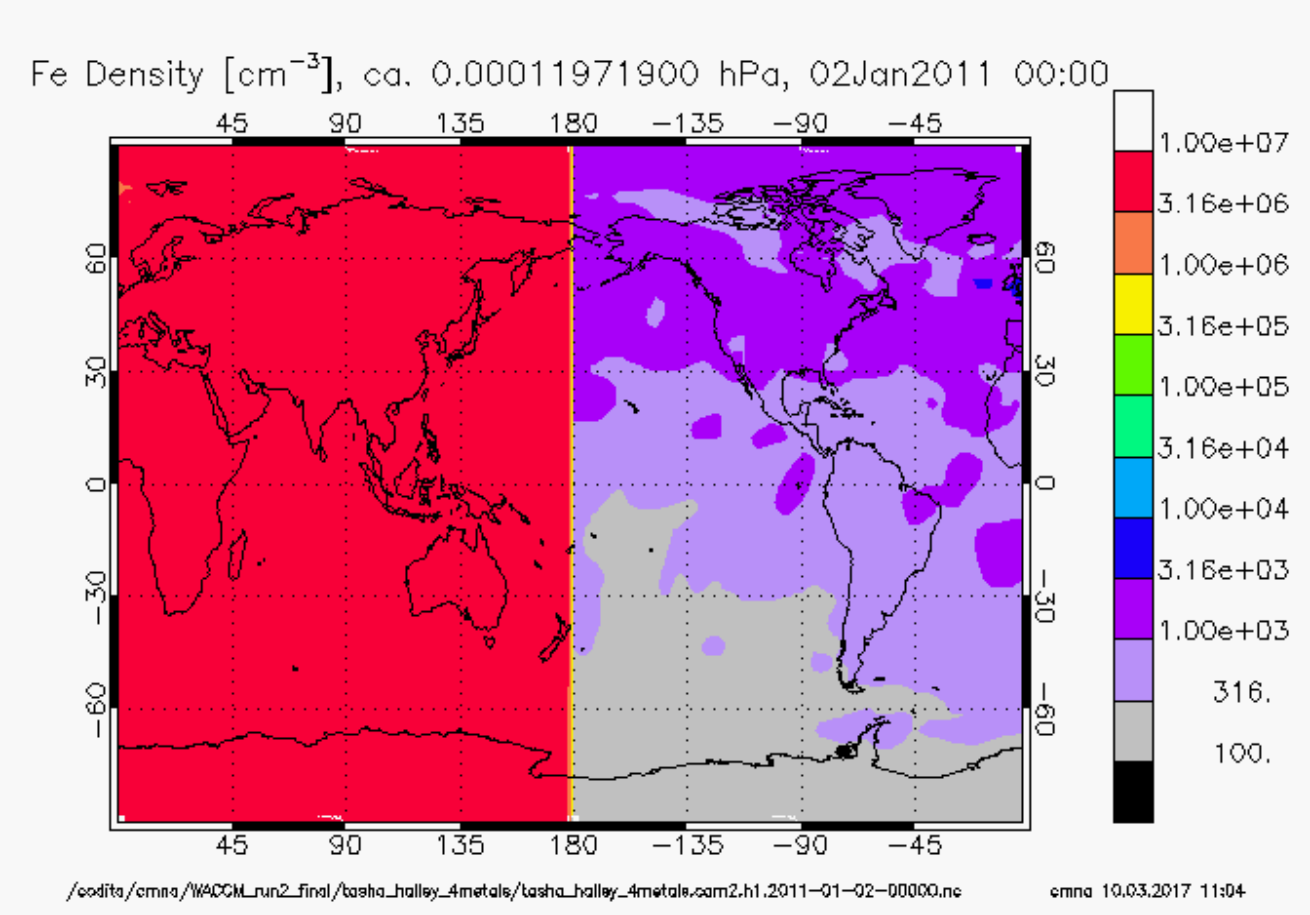

Run 1: Metal Injection

Metal layers

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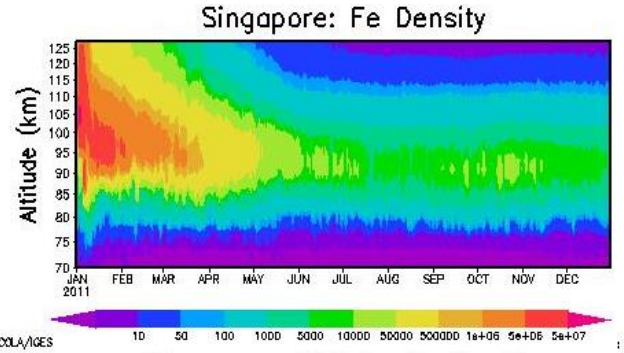

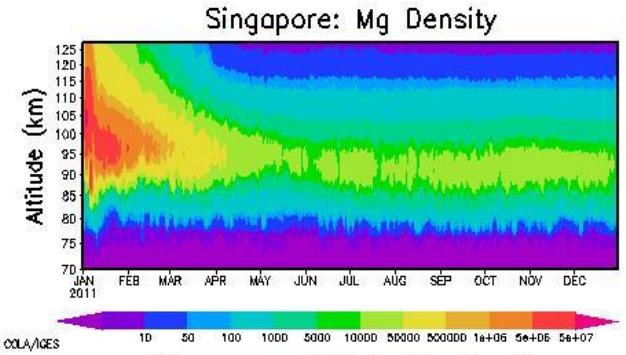

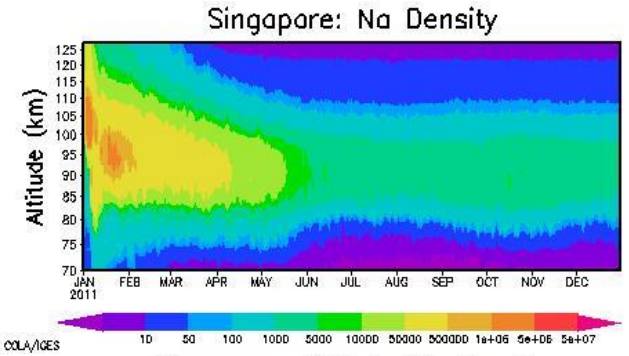

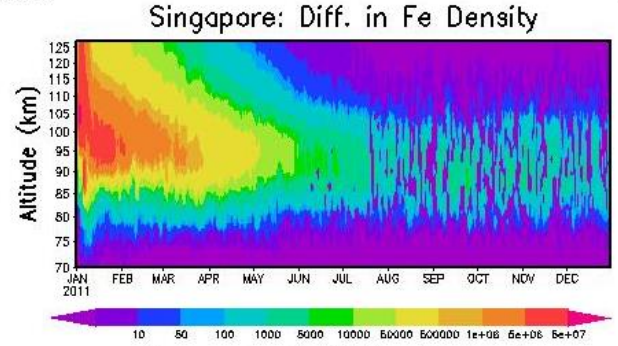

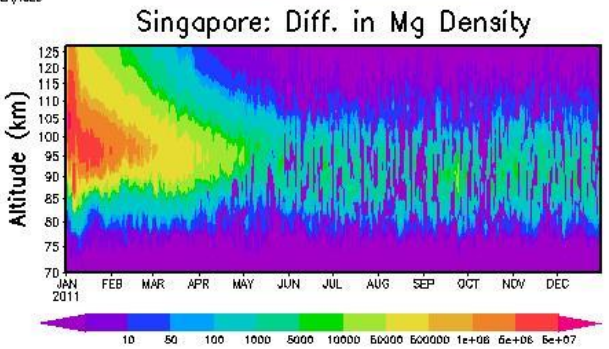

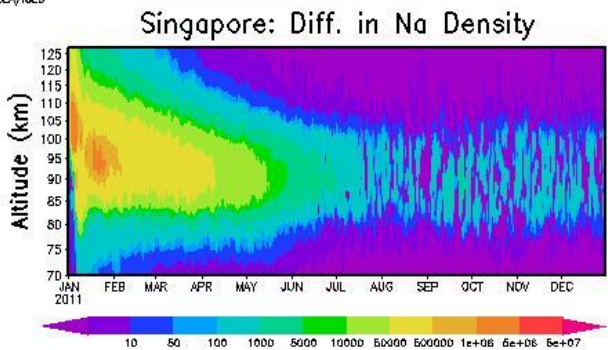

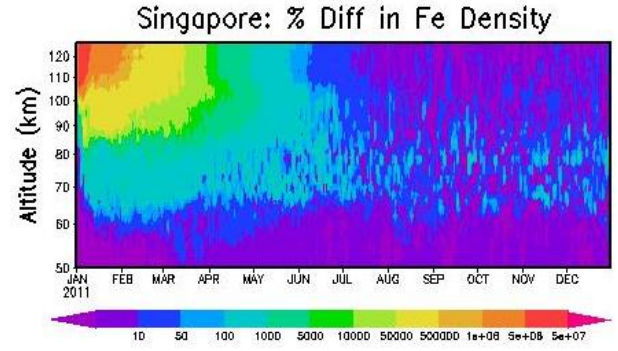

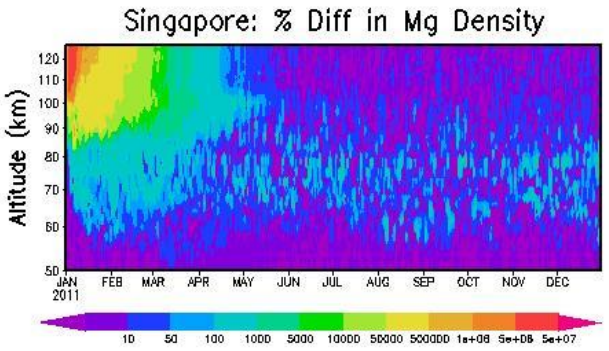

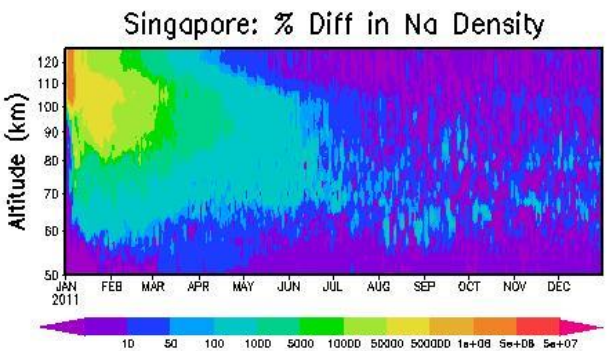

No MSP formation – only sedimentation

Run 1: Metal Injection

Ozone

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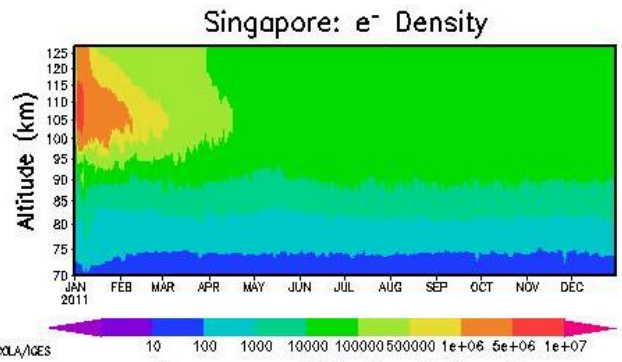

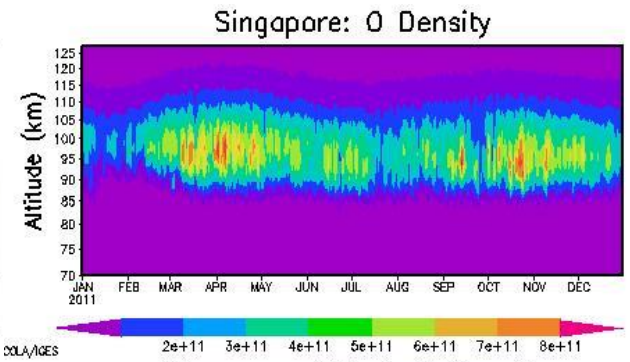

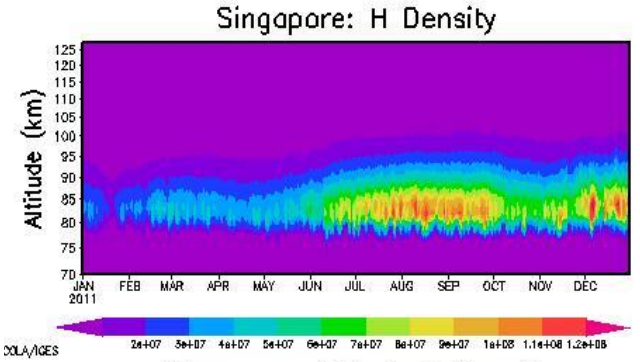

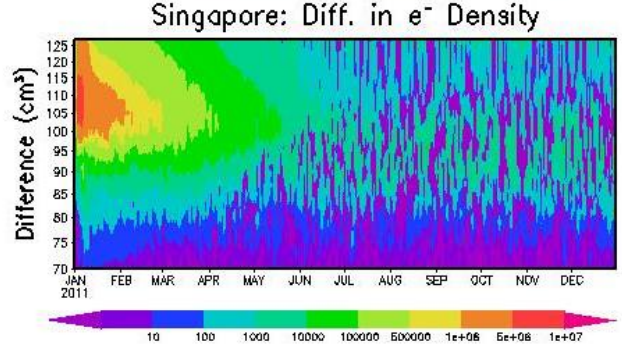

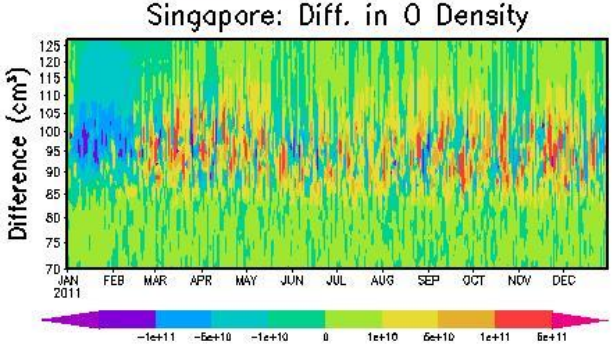

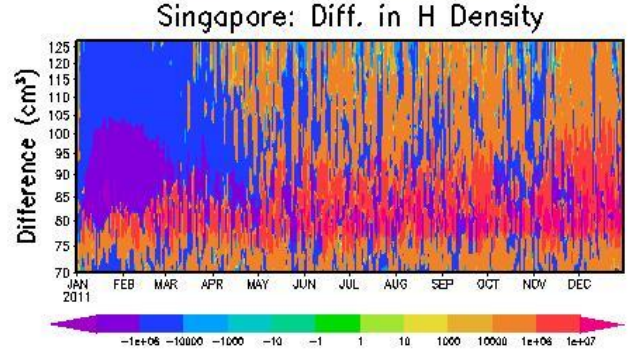

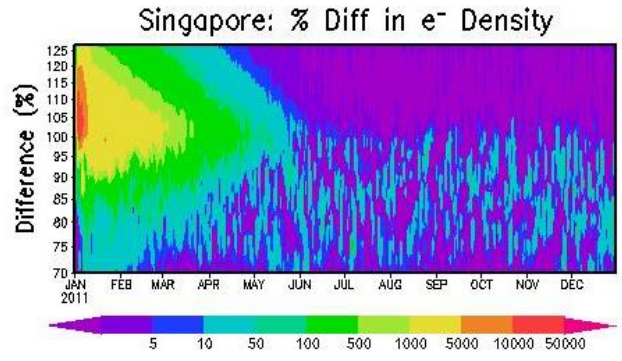

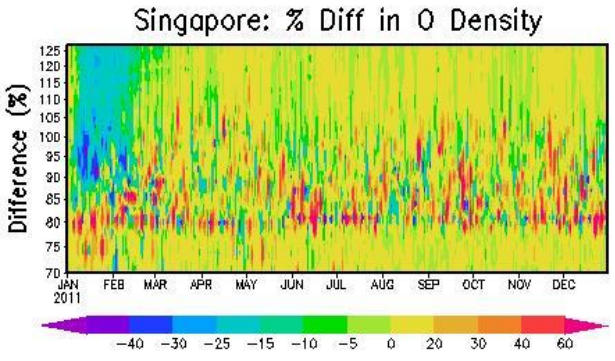

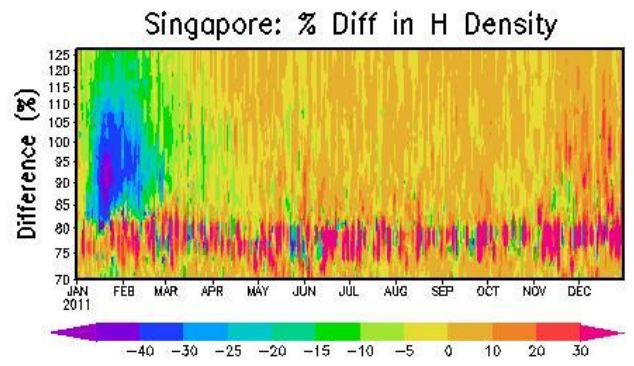

Effects on radio communication?

Run 2: Temperature Perturbation

Calculations

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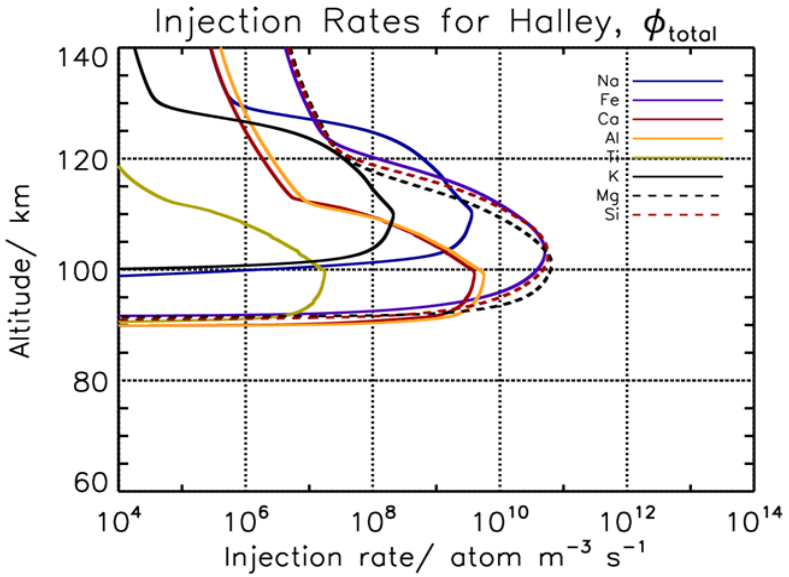
Heat energy ⇨ $mcdT = \frac{1}{2}mv^2$ ⇦ **Kinetic energy**

$$Q = K.E - \Delta H_{fo} - \Delta H_{fu} - \Delta H_{vap} - \Delta H_{at}$$

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_2O_3	2.5	8.50×10^{4}	1.2
CaO	1.9	6.01×10^{4}	8.2×10^{-1}
Na_2O	1.0	5.90×10^{4}	8.0×10^{-1}
K_2O	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:

$$I = \tau \frac{dm}{dt}\frac{v^2}{2} \qquad \tau = 2\times10^{-3} \qquad 0.2\ \% \rightarrow Light\ production$$

Run 2: Temperature Perturbation

Calculations

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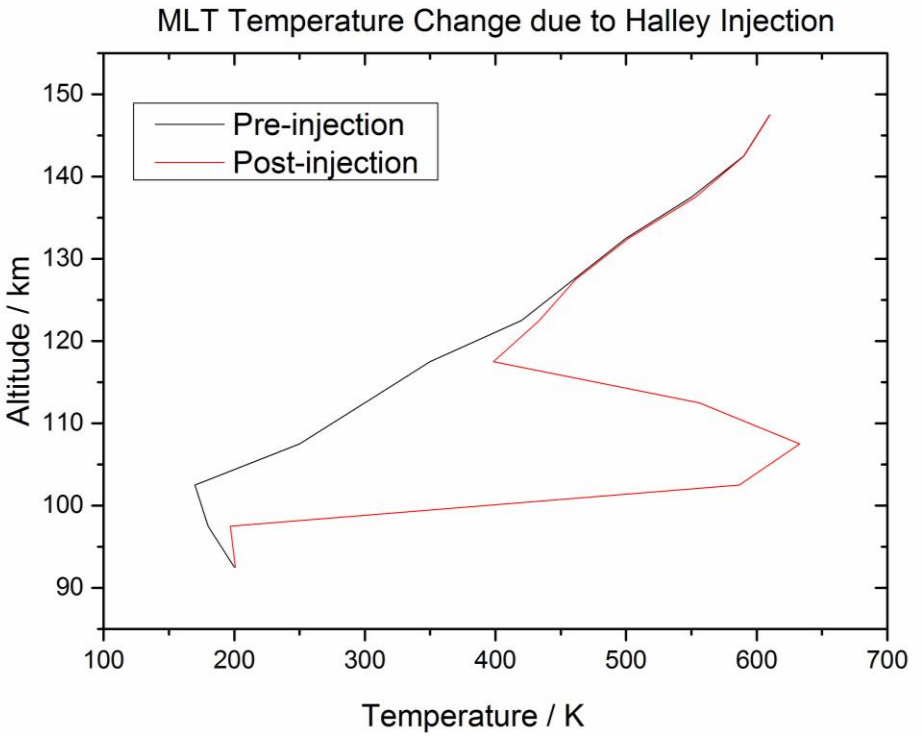
Z range / km	Initial temp / K	ΔT / K	Final temp / K
90-95	200	0.8	200.8
95-100	180	17.1	197.1
100-105	170	416.6	586.6
105-110	250	382.8	632.8
110-115	300	255.9	555.9
115-120	350	48.4	398.4
120-125	420	13.7	433.7
125-130	460	1.4	461.4
130-135	500	2.1	502.1
135-140	550	3.1	553.1
140-145	590	0.4	590.4
145-150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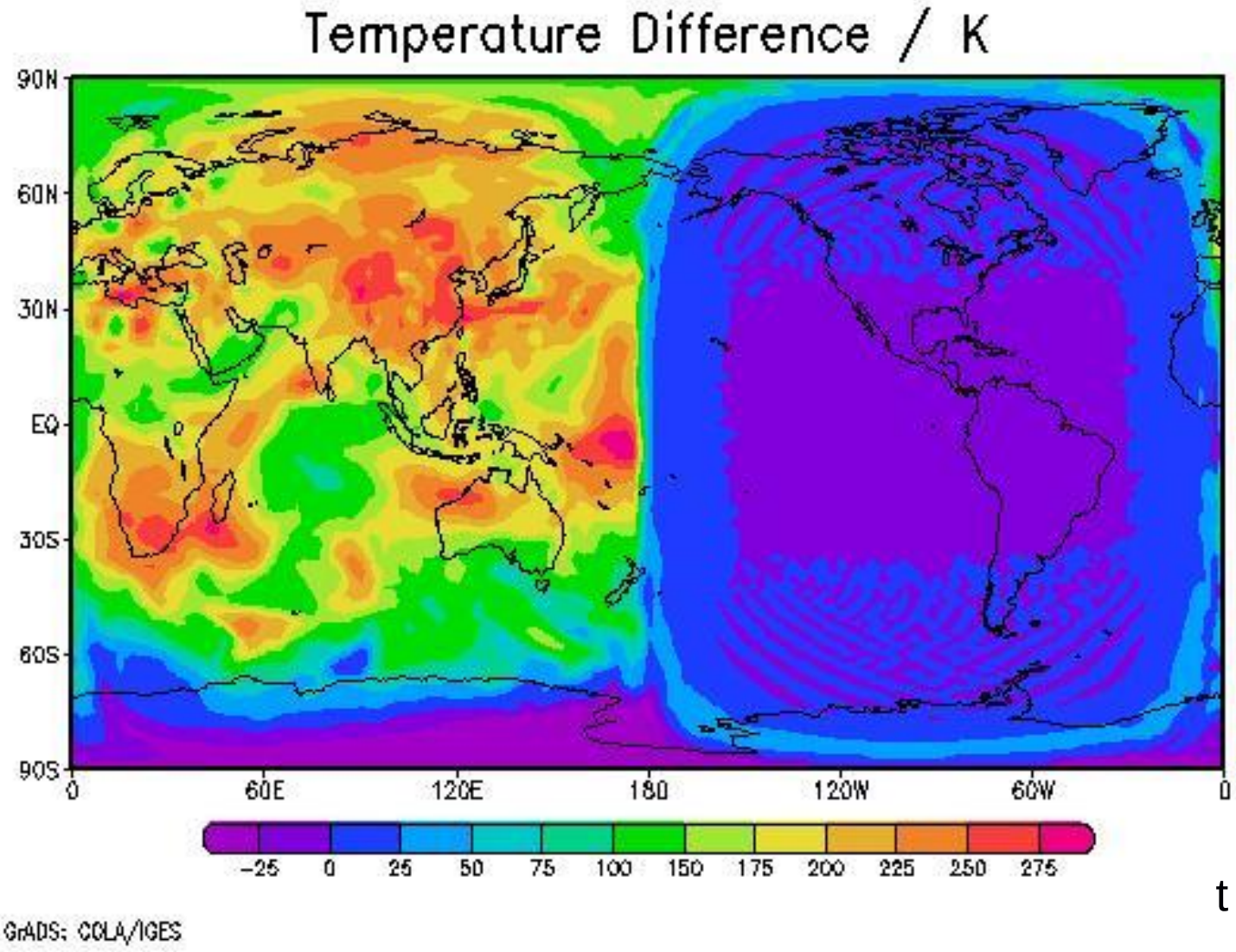
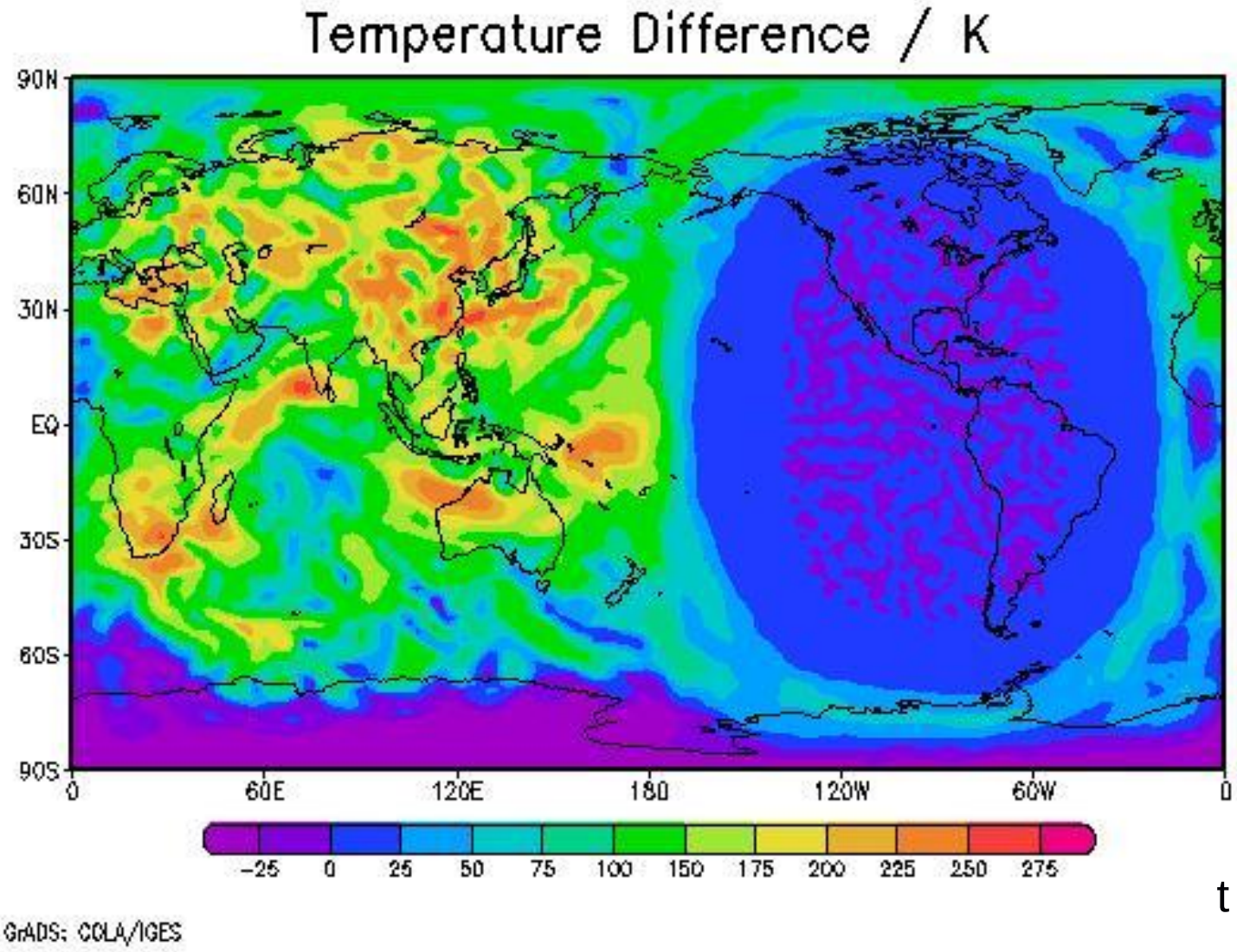


t = 00h

Run 2: Temperature Perturbation

Results

UNIVERSITY OF LEEDS

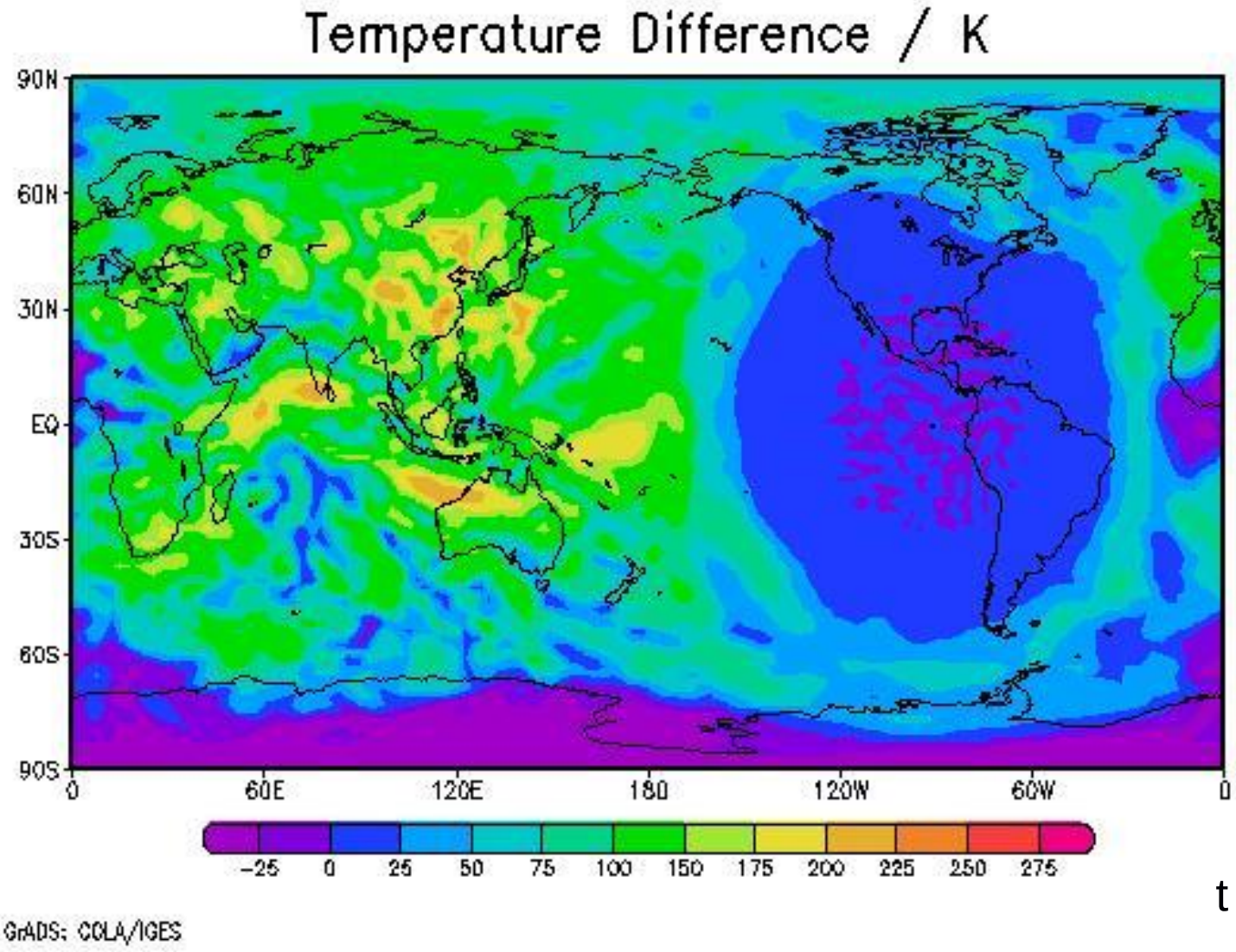


t = +1h

Run 2: Temperature Perturbation

Results

UNIVERSITY OF LEEDS



t = +2h

Run 2: Temperature Perturbation

Results

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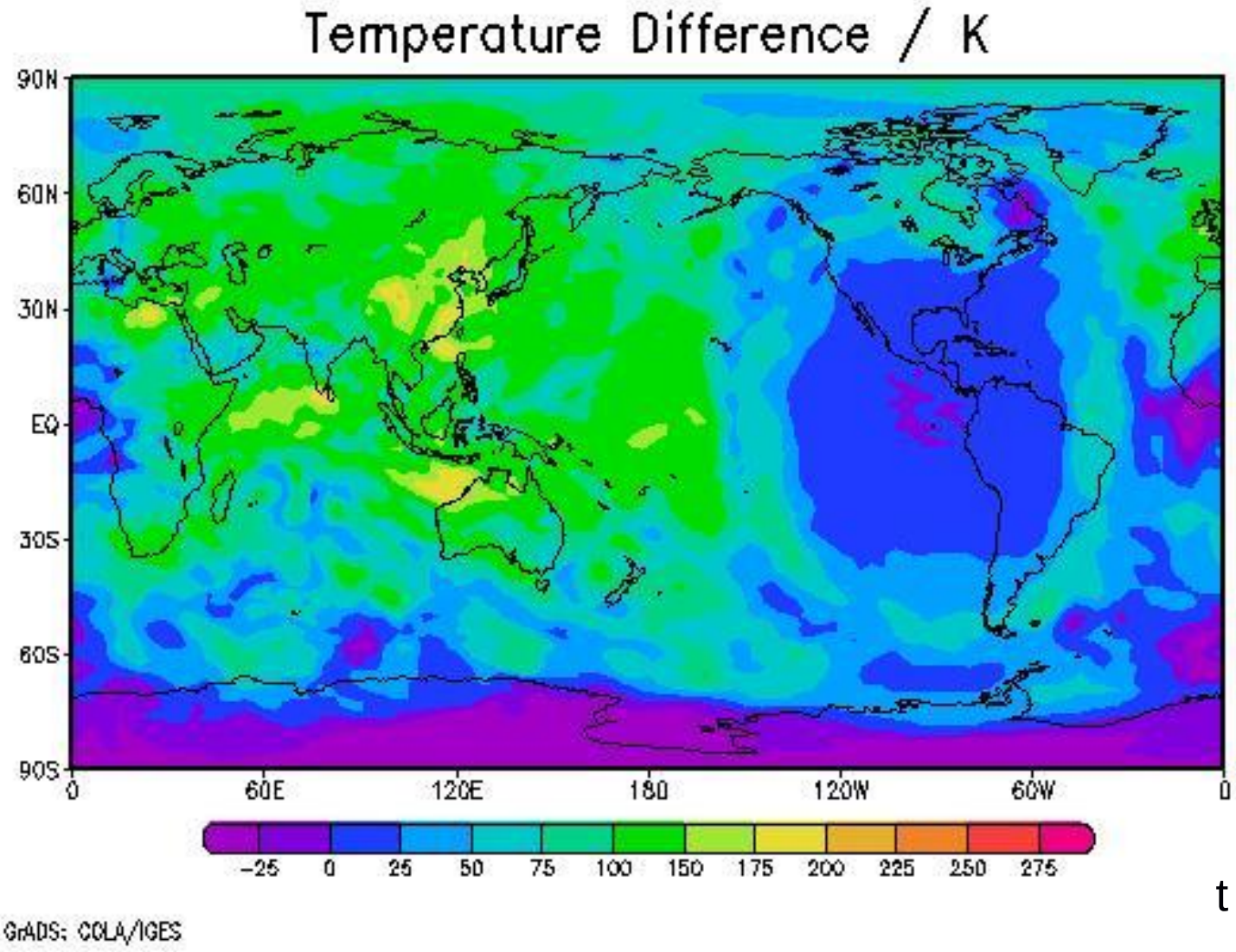

t = +3h

Run 2: Temperature Perturbation

Results

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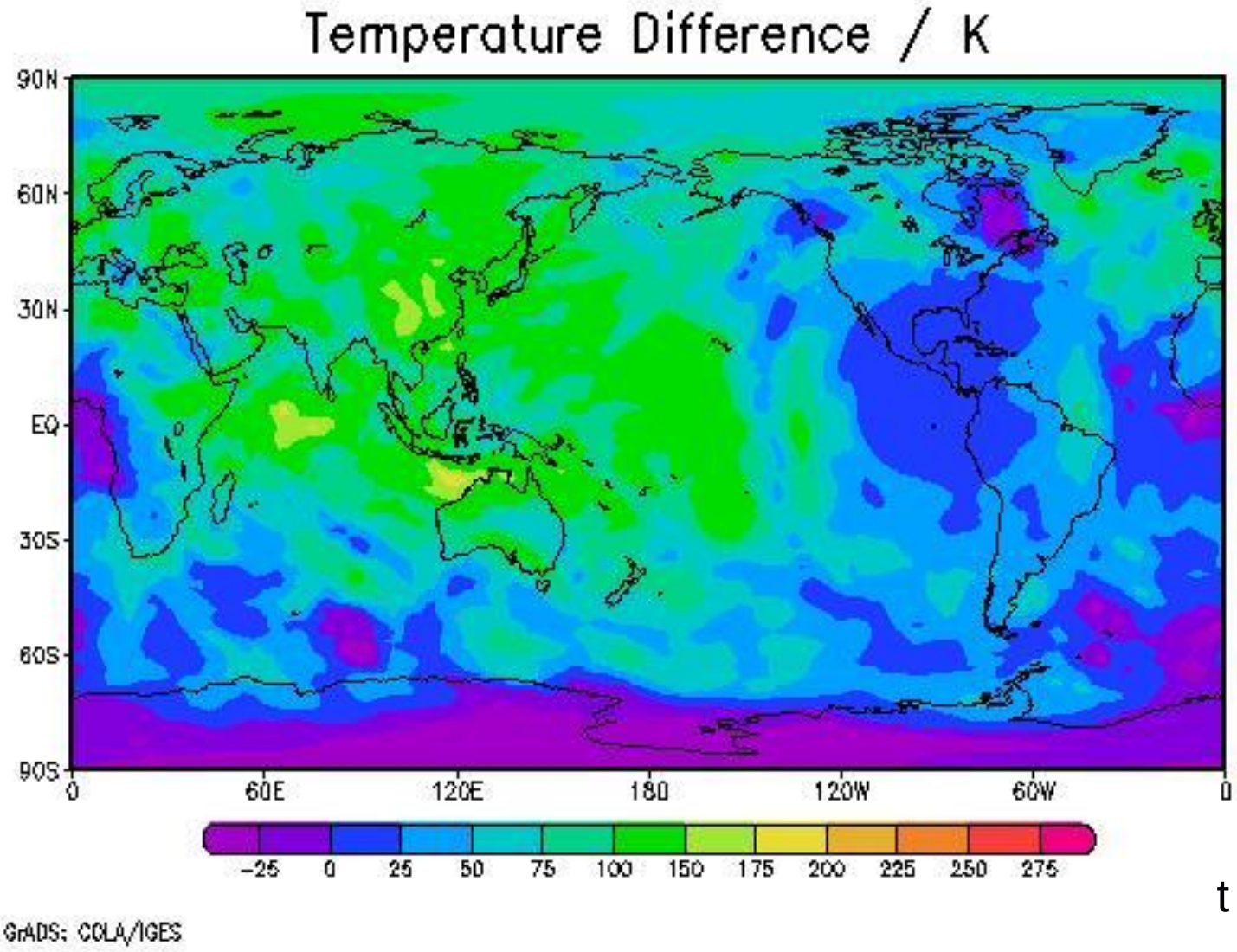

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Run 2: Temperature Perturbation

Results

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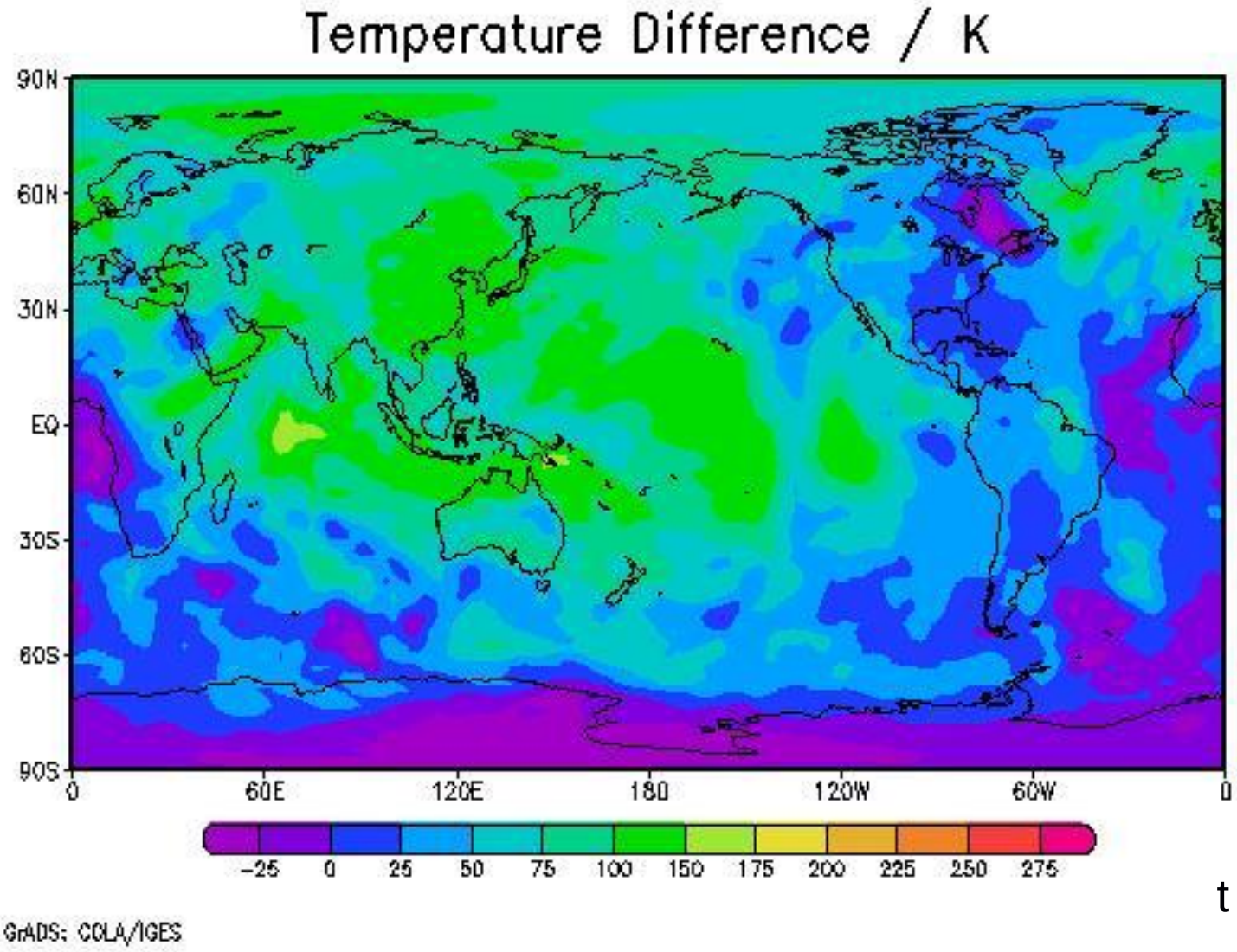
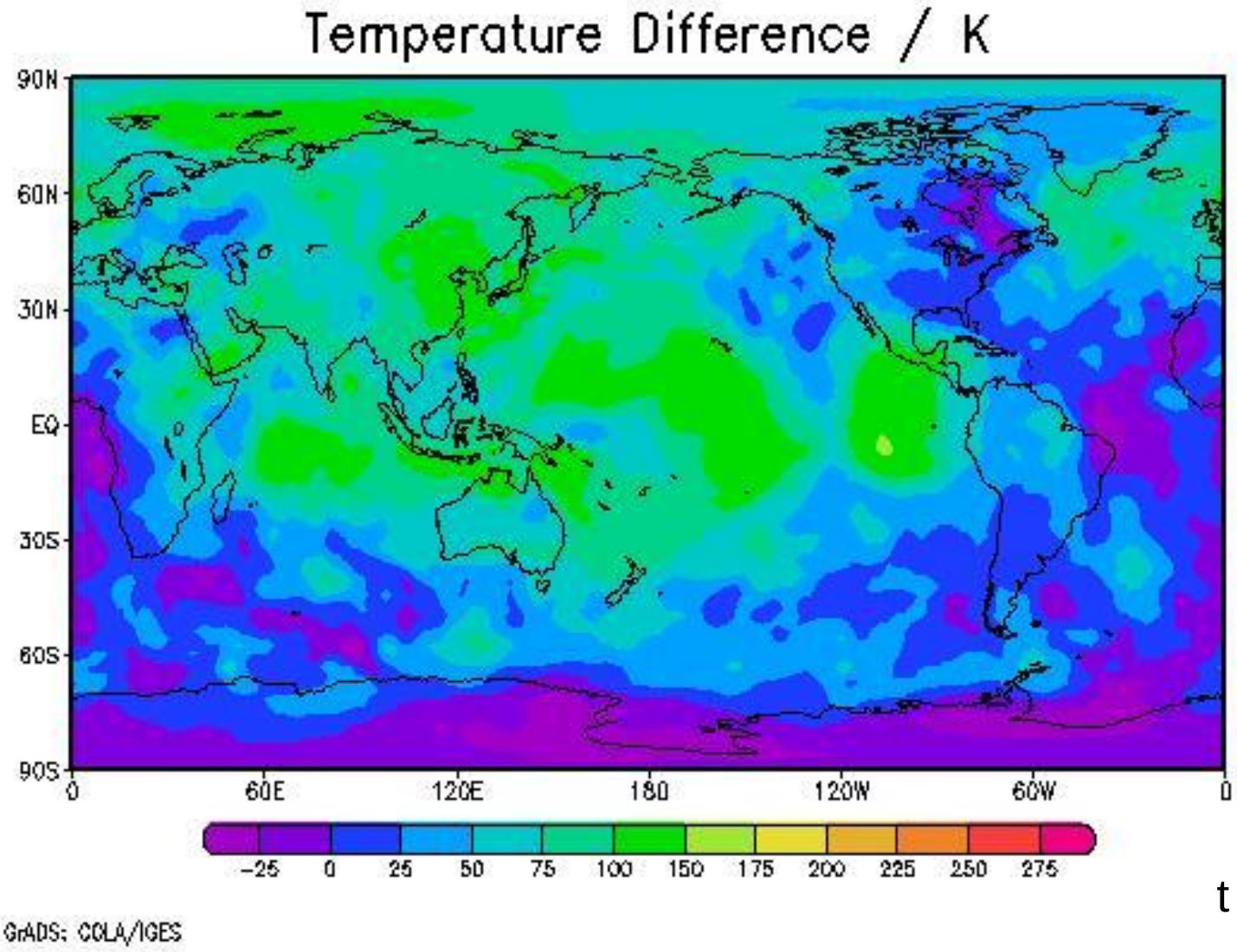


t = +5h

Run 2: Temperature Perturbation

Results

UNIVERSITY OF LEEDS



t = +6h

Run 2: Temperature Perturbation

Results

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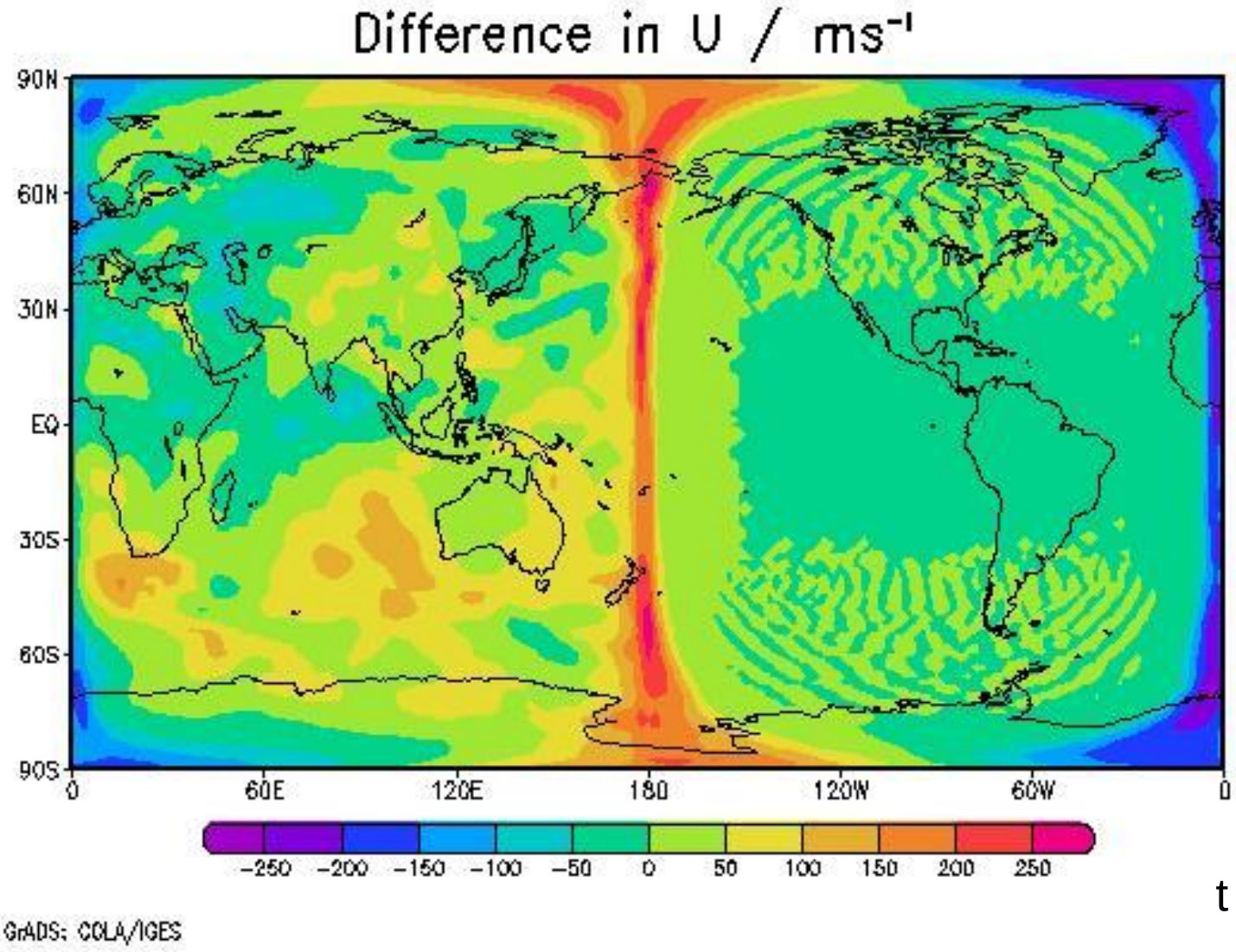

t = 00h

Run 2: Temperature Perturbation

Results

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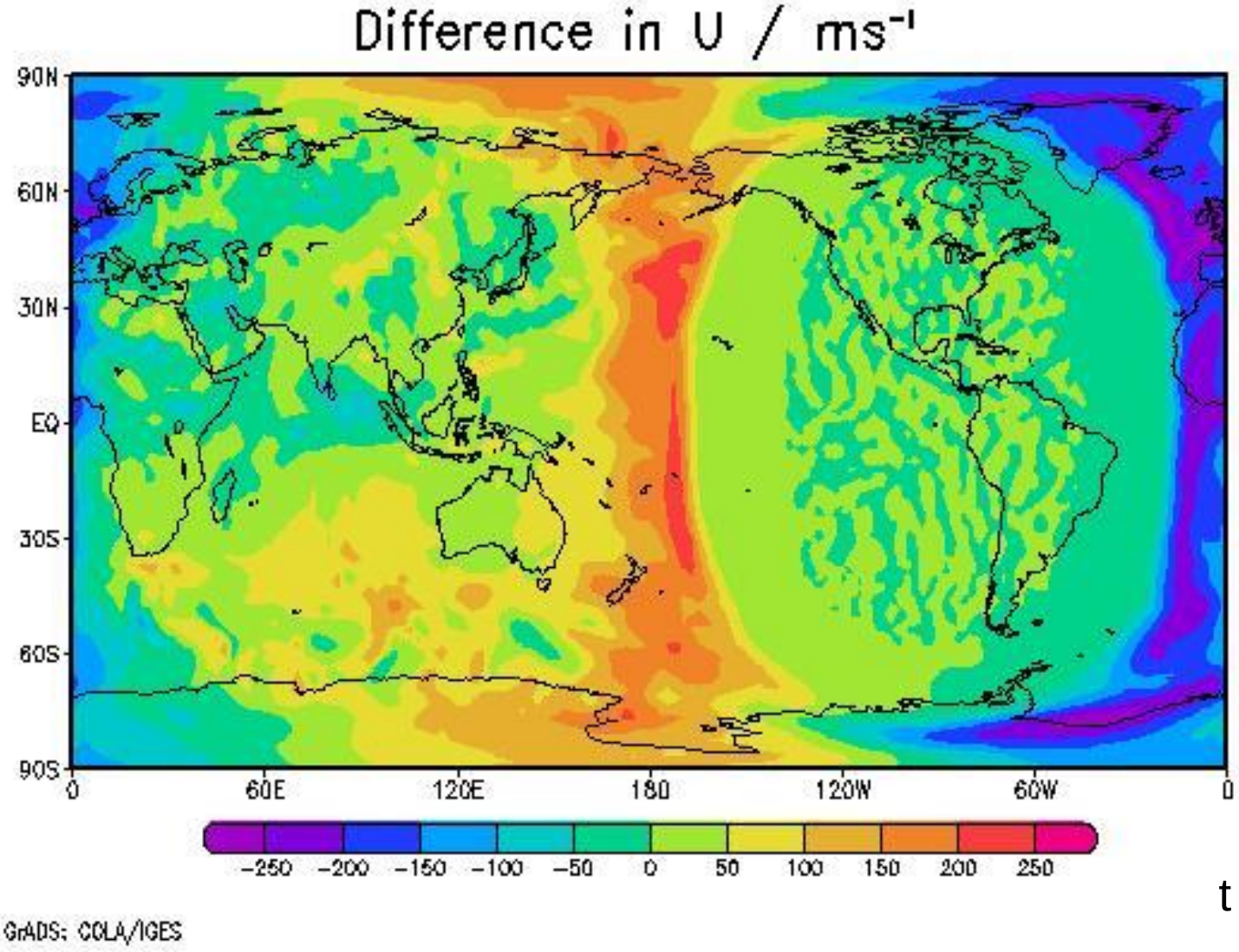

t = +1h

Run 2: Temperature Perturbation

Results

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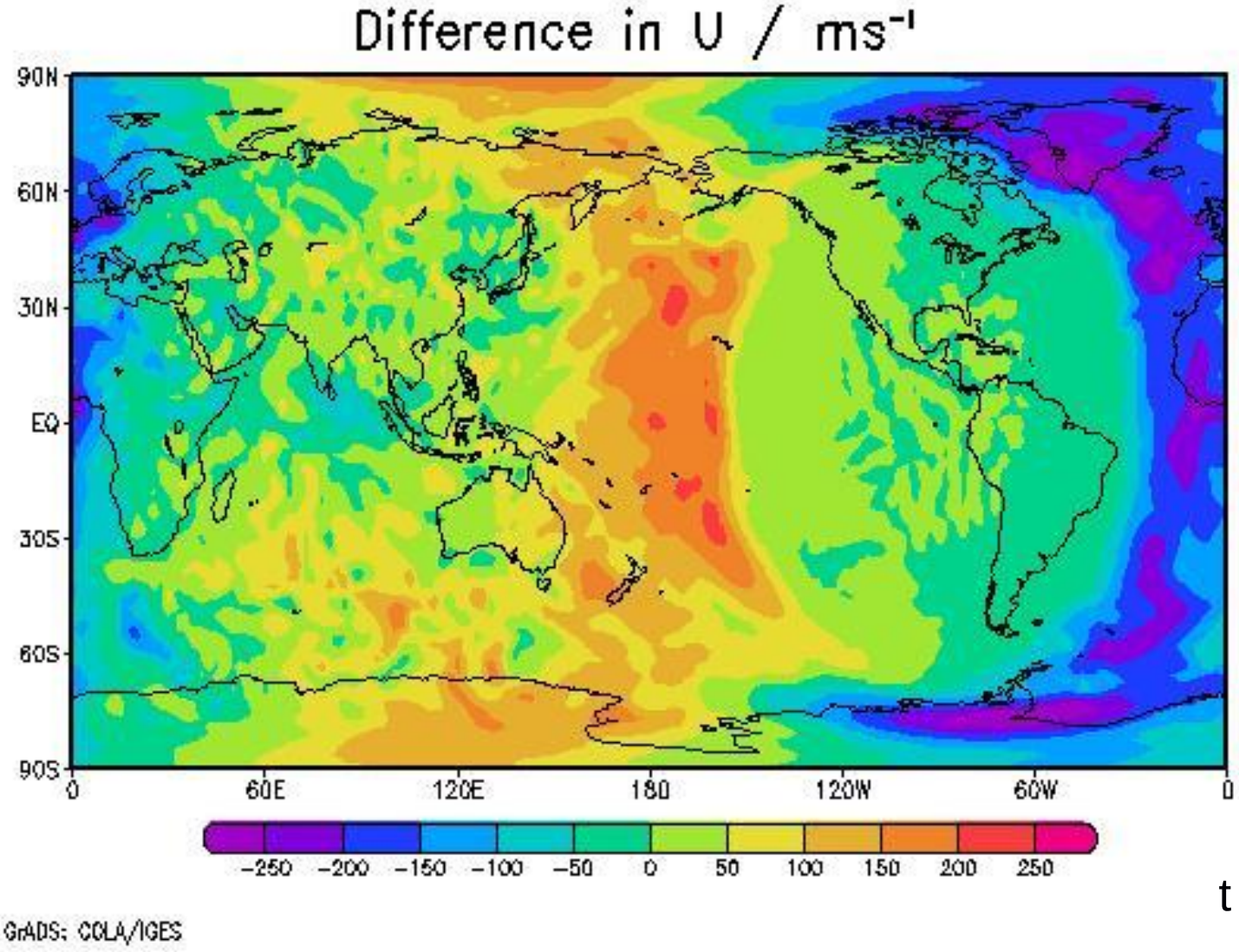
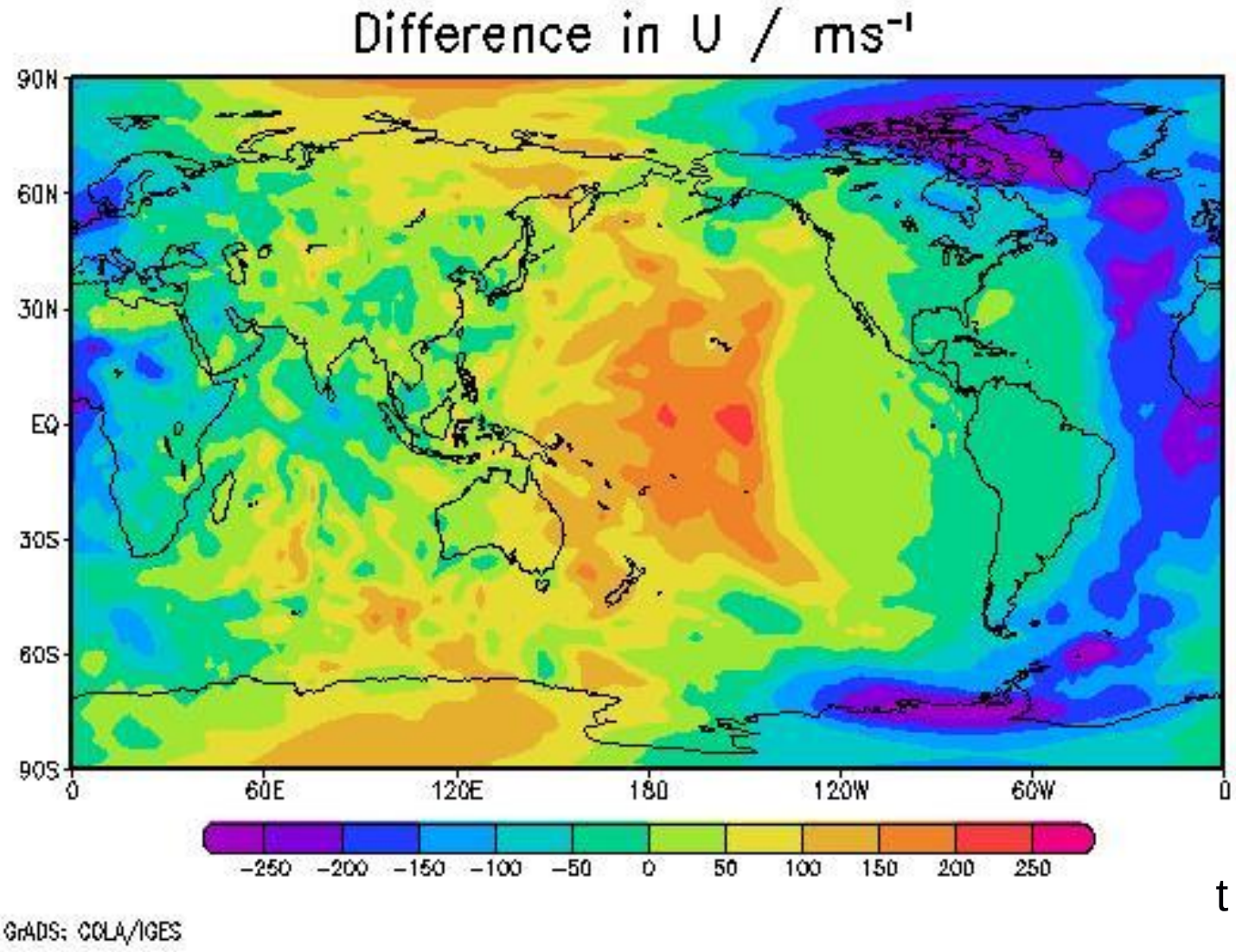


t = +2h

Run 2: Temperature Perturbation

Results

UNIVERSITY OF LEEDS

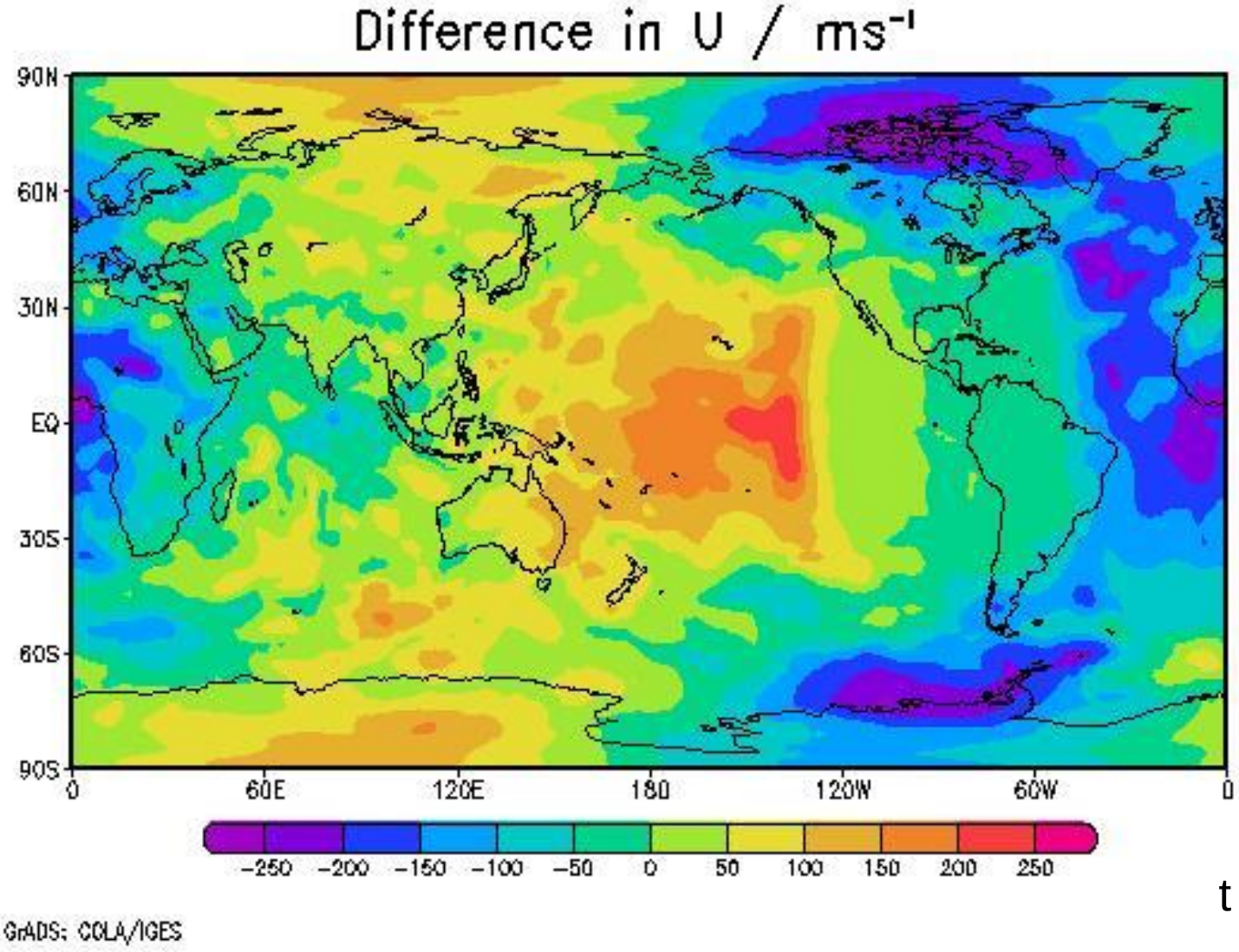


t = +3h

Run 2: Temperature Perturbation

Results

UNIVERSITY OF LEEDS



t = +4h

Run 2: Temperature Perturbation

Results

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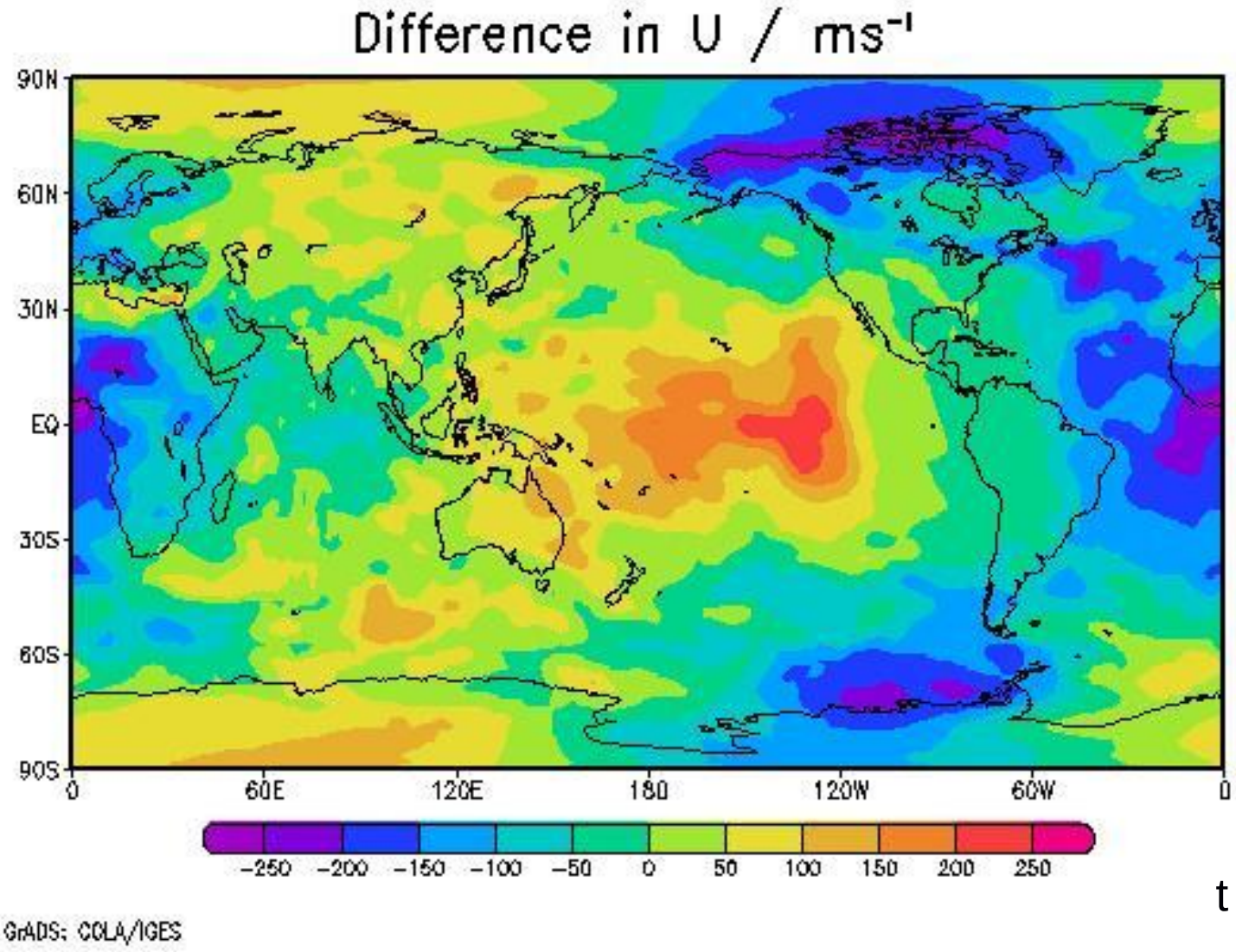

t = +5h

Run 2: Temperature Perturbation

Results

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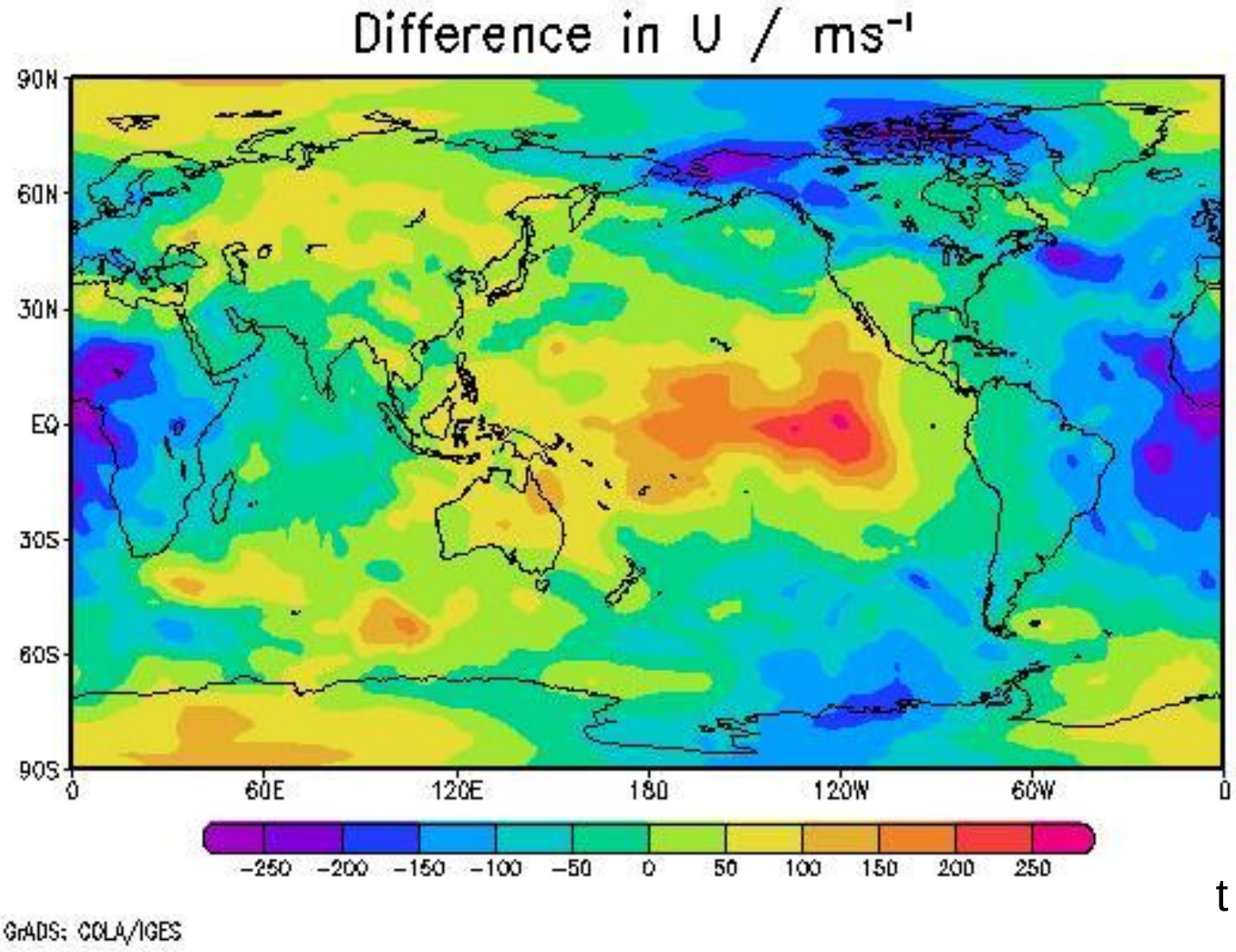
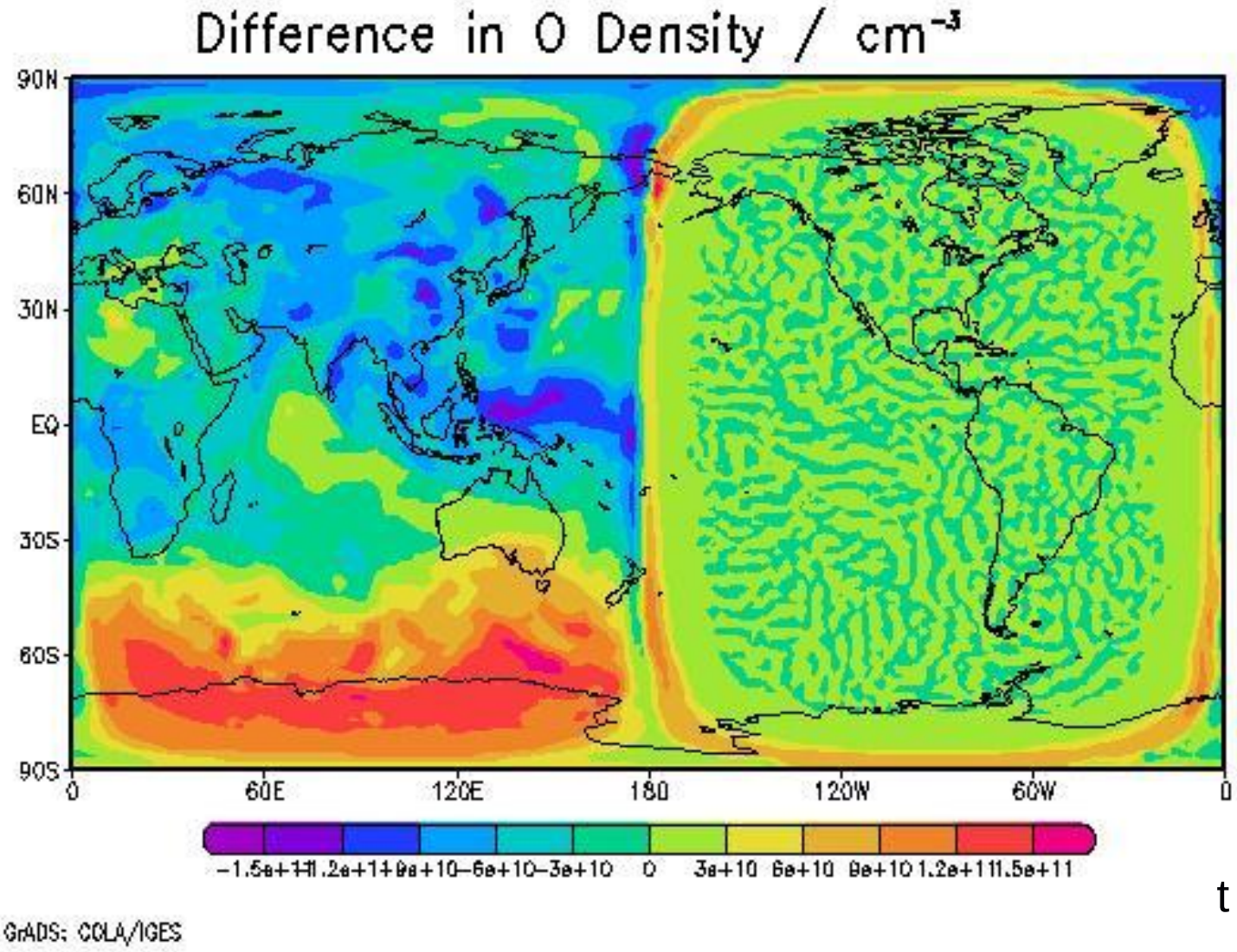


t = +6h

Run 2: Temperature Perturbation

Results

UNIVERSITY OF LEEDS



t = 00h

Run 2: Temperature Perturbation

Results

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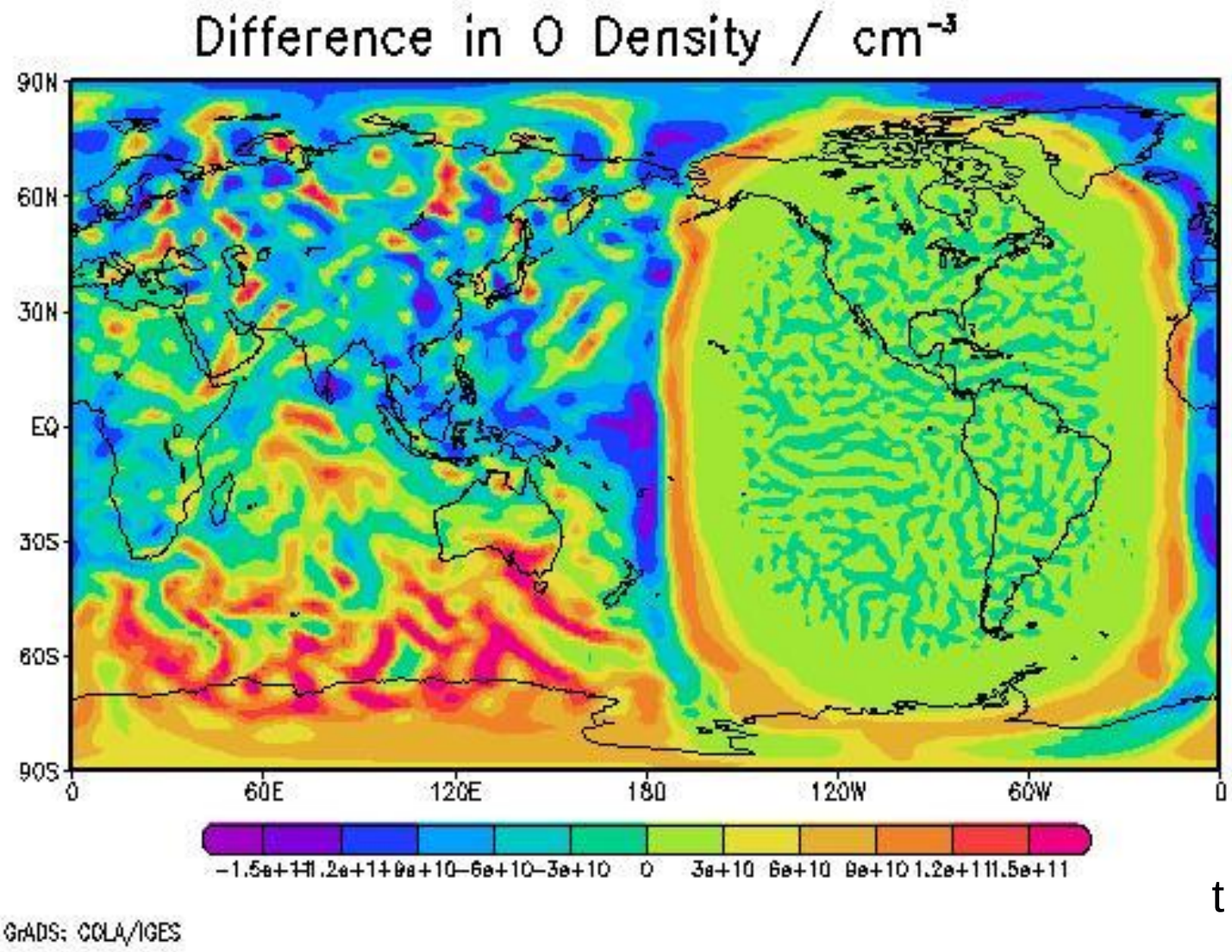

t = +1h

Run 2: Temperature Perturbation

Results

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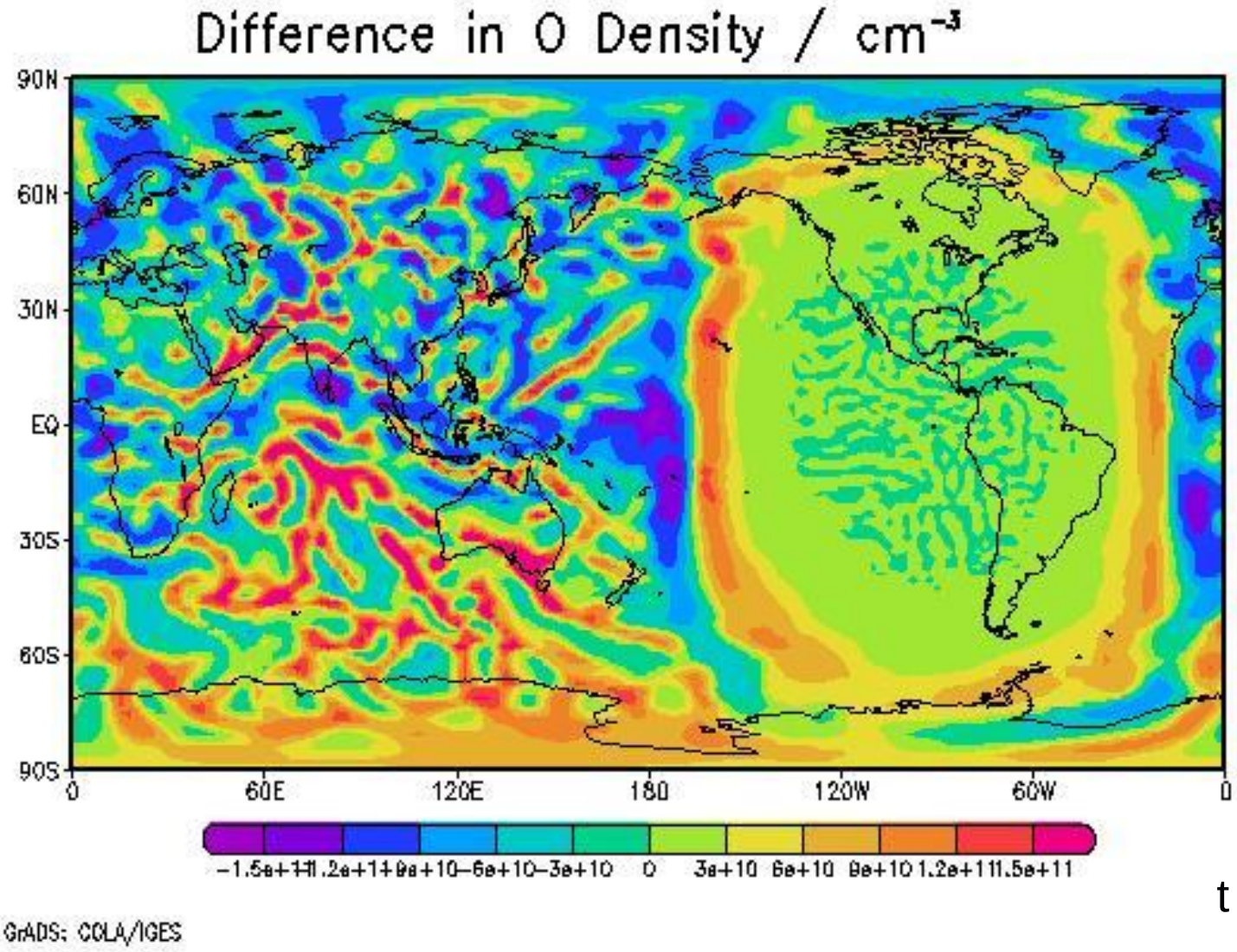

t = +2h

Run 2: Temperature Perturbation

Results

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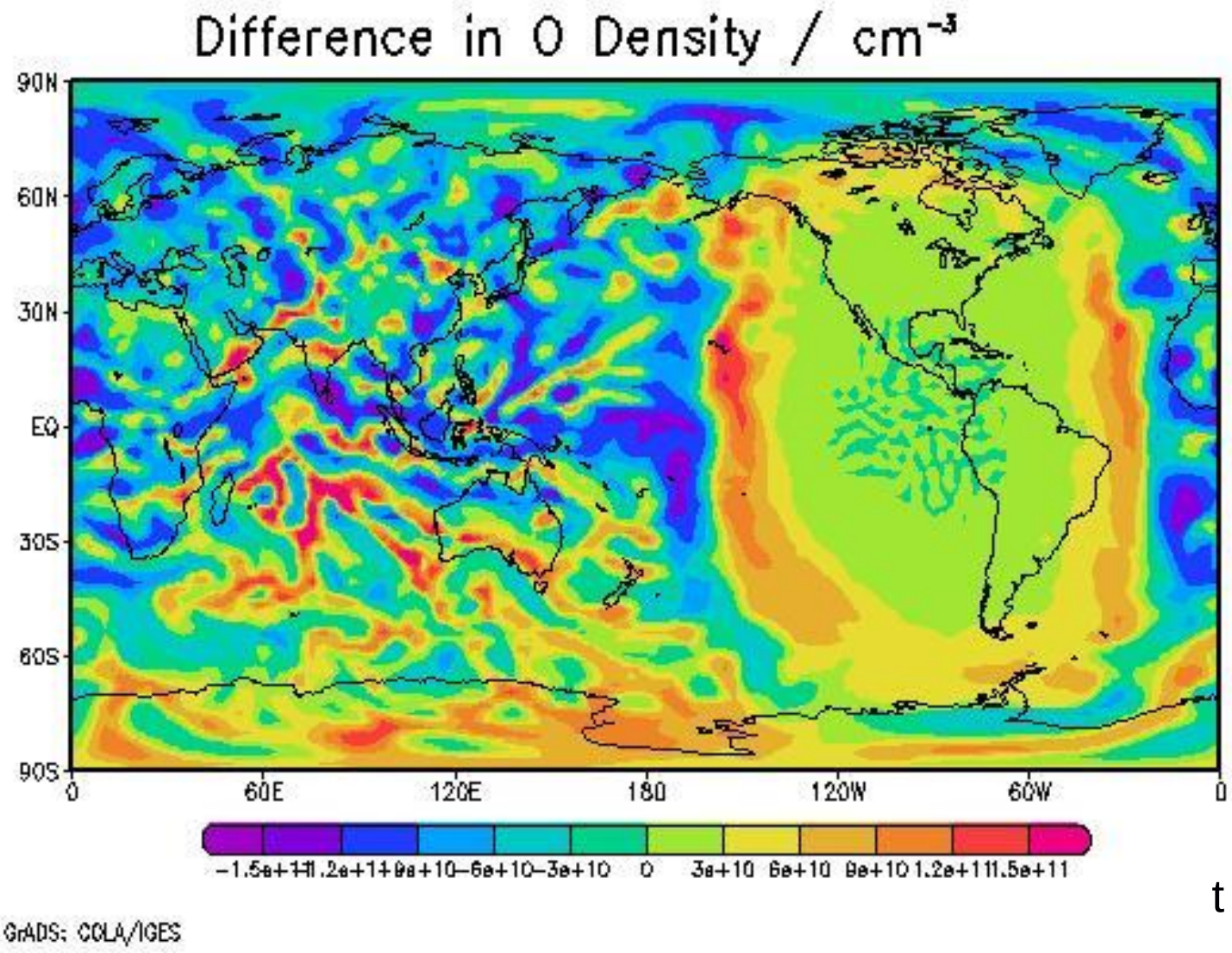

t = +3h

Run 2: Temperature Perturbation

Results

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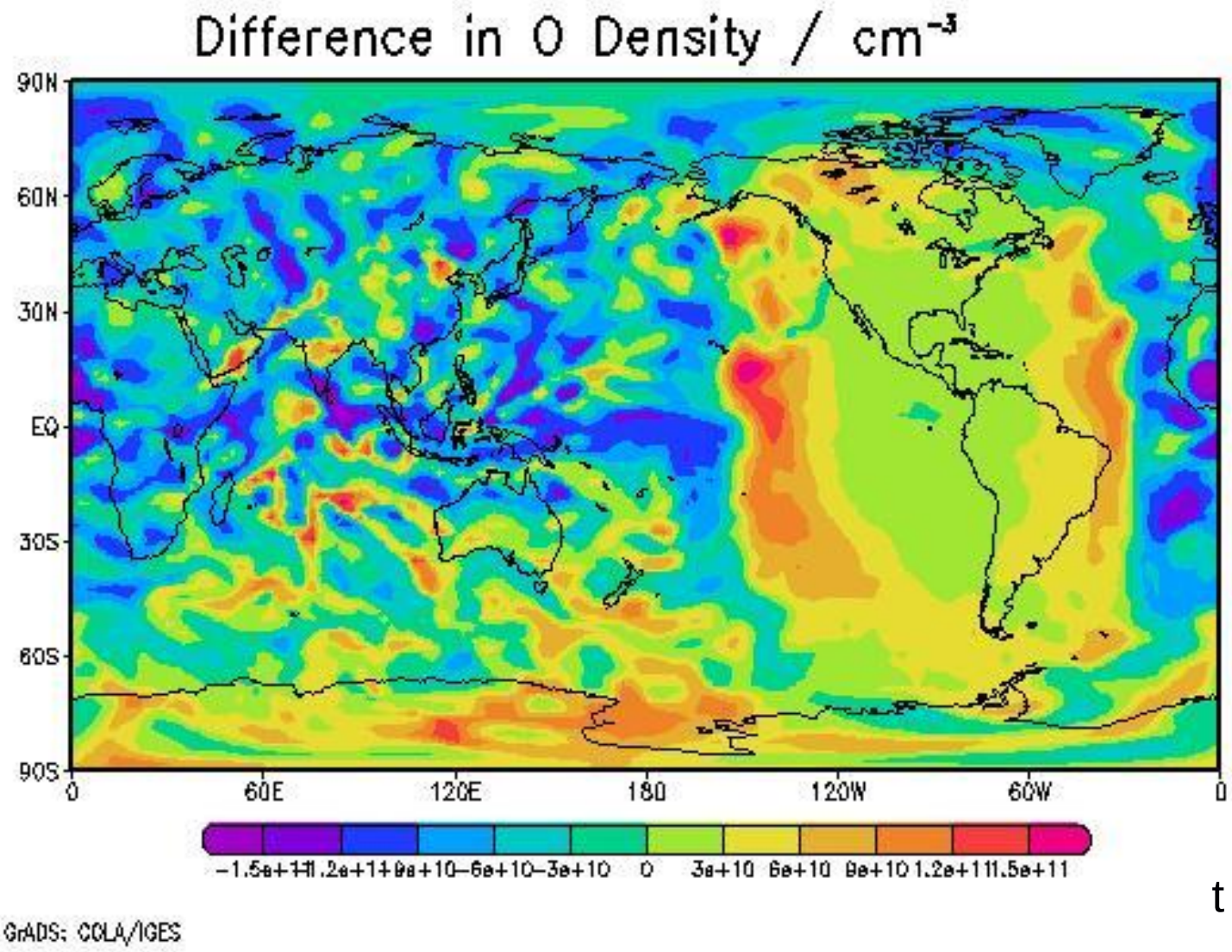

t = +4h

Run 2: Temperature Perturbation

Results

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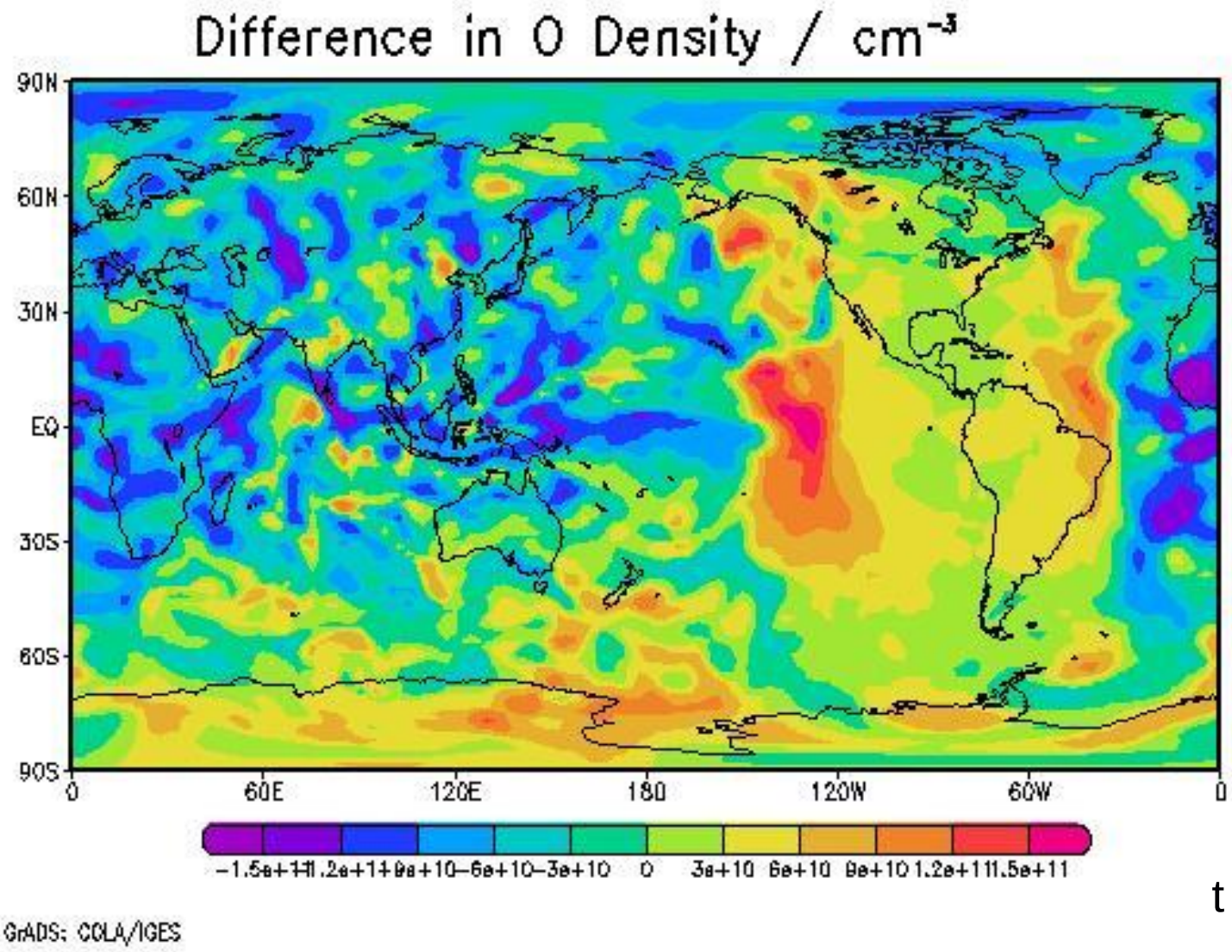

t = +5h

Run 2: Temperature Perturbation

Results

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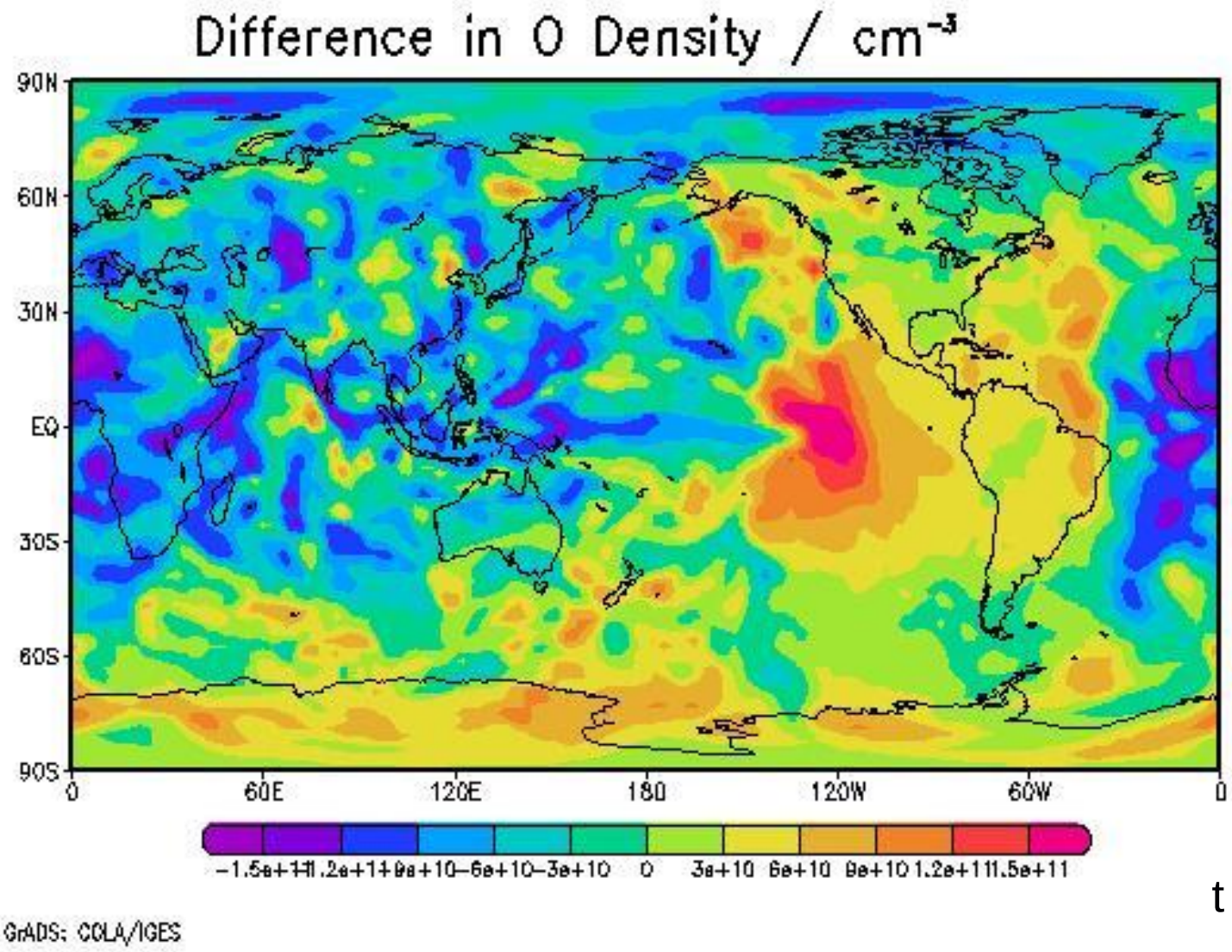

t = +6h

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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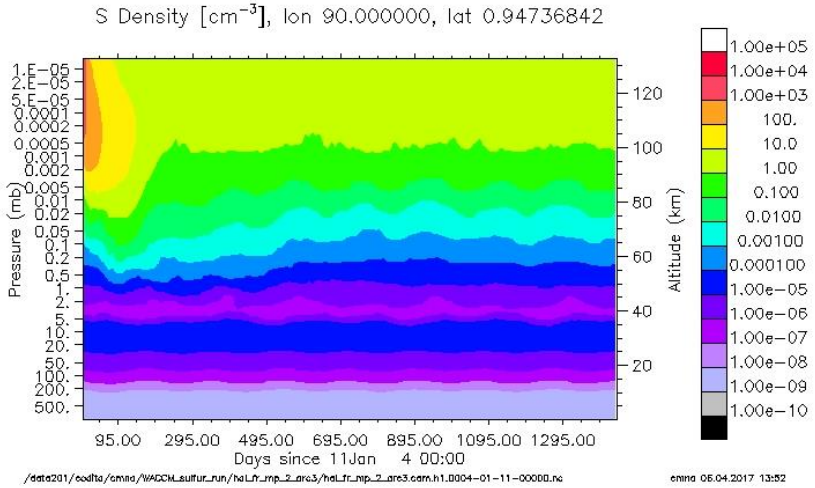

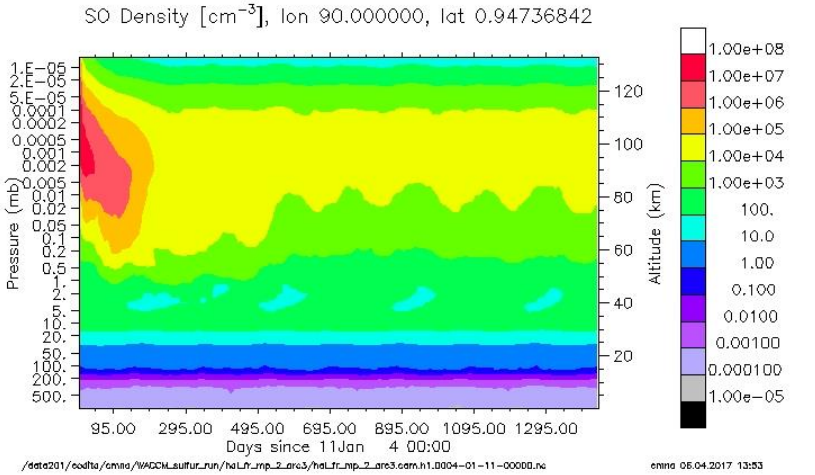

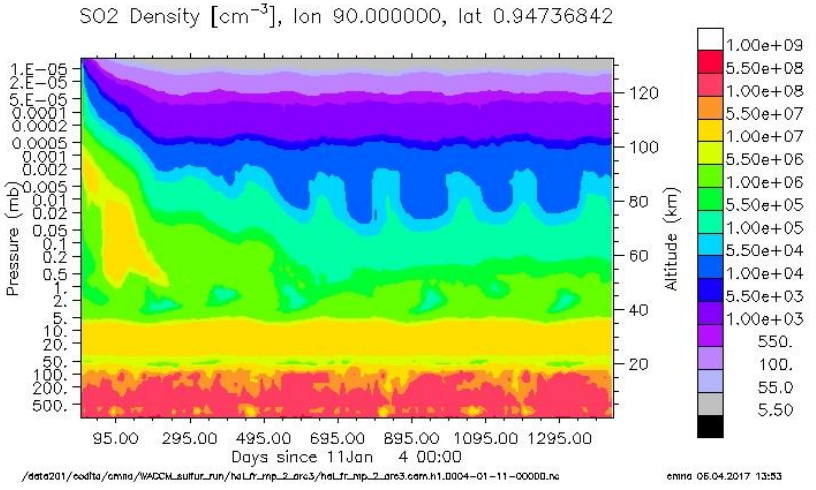

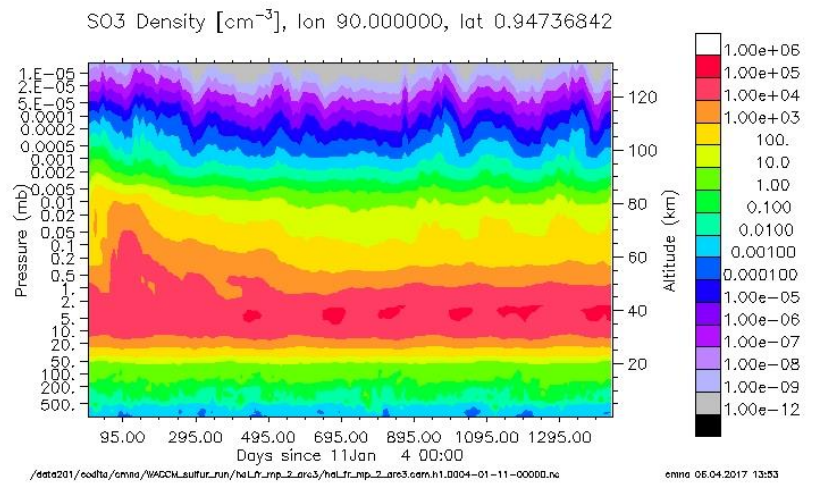

Run 3: MSP + Sulfur Injection

Results

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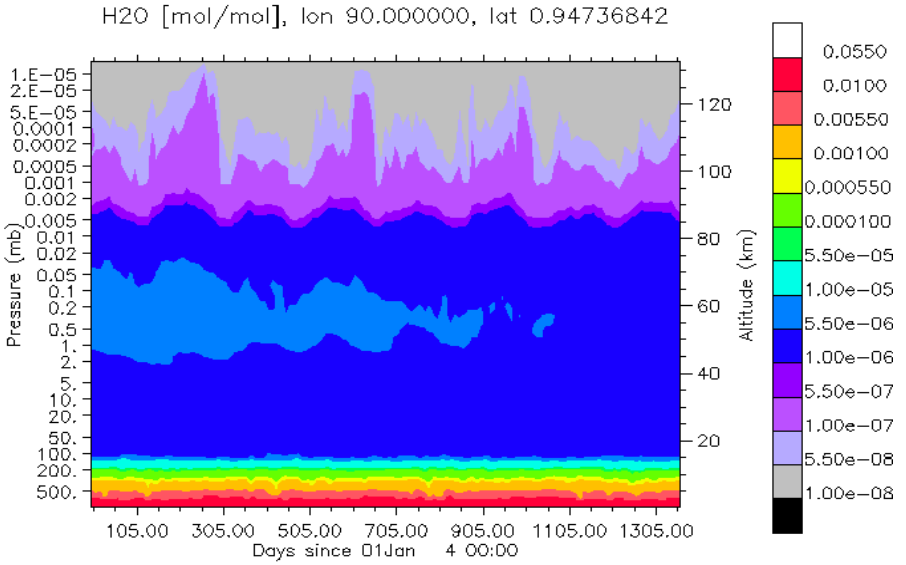

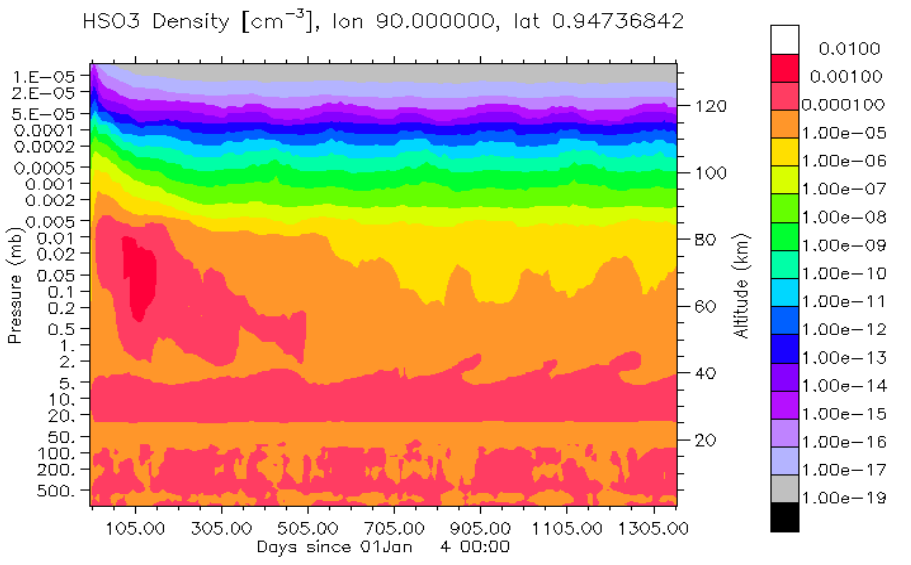

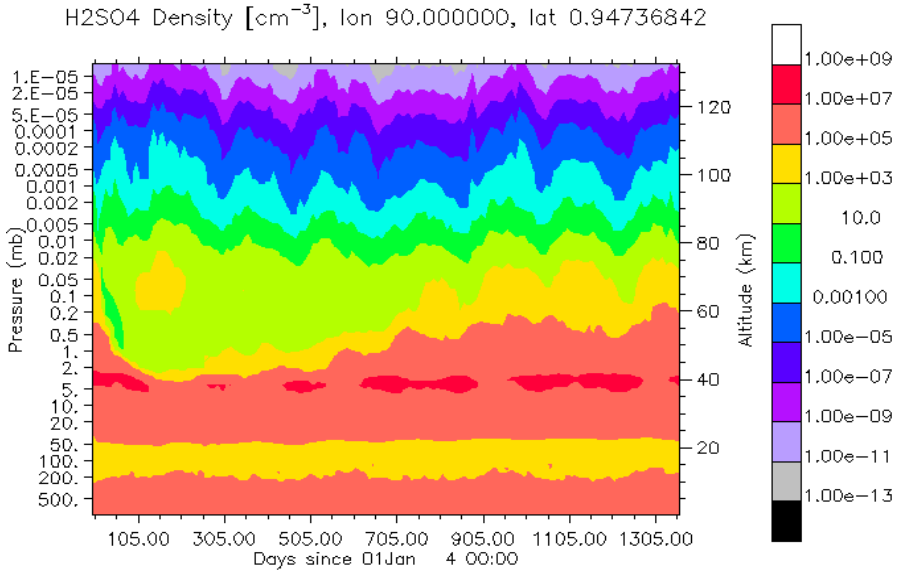

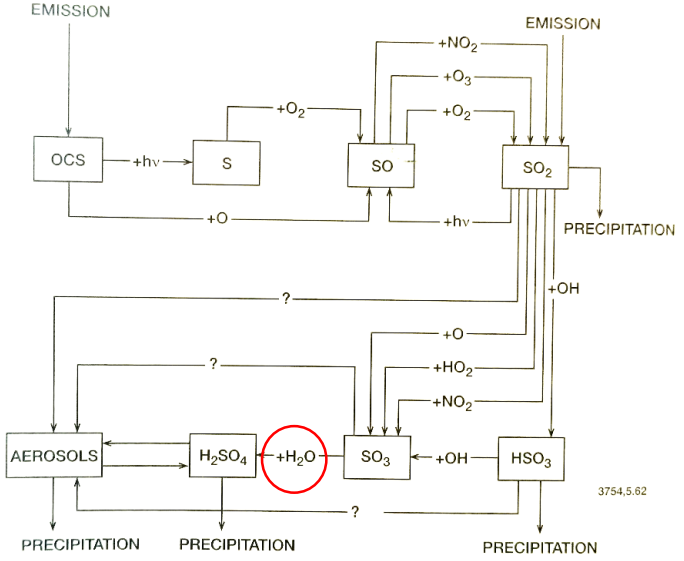

Summary, Conclusions & Further Work

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- 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, SO_2, SO_3, H_2O, HO_2, HSO_3, H_2SO_4 …
- Next Steps
  - MSP transport & deposition
  - Extinction & radiative forcing