Resolving the SAI Trilemma: Dolomite–Silica Core–Shell Aerosols for High–Performance, Thermally Neutral, and Ozone–Safe Stratospheric Solar Geoengineering

A 5–Year (1825–Day) Computational Screening Study Using a 1D Vertical Column Model

1. BACKGROUND & THE SAI TRILEMMA

Stratospheric Aerosol Injection (SAI) must balance three competing goals:

High Optical Performance
Maximize shortwave backscatter per mass (cooling per unit mass)

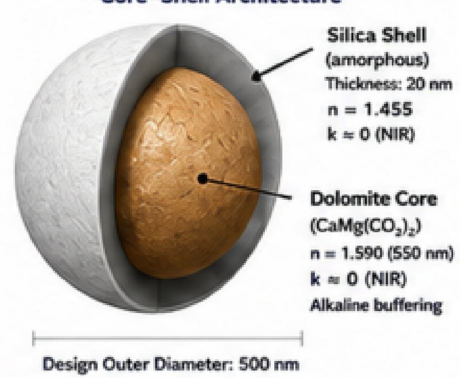
Thermal Neutrality
Minimize near-IR absorption and stratospheric heating

Ozone Safety
Minimize heterogeneous chemistry and ozone depletion

No current material optimizes all three simultaneously. This study introduces a dolomite–silica core–shell aerosol that addresses the Trilemma.

2. CANDIDATE MATERIAL & DESIGN RATIONALE

DoloSil–20: Dolomite–Silica Core–Shell Architecture



Why This Design Works

Optical Advantage
High index contrast + Aden–Kerker resonance → +45.17% backscatter efficiency vs sulfate

Thermal Neutrality
$k_{NIR} \approx 0$ for both core and shell → No near–IR absorption → $\Delta T \approx 0$ K

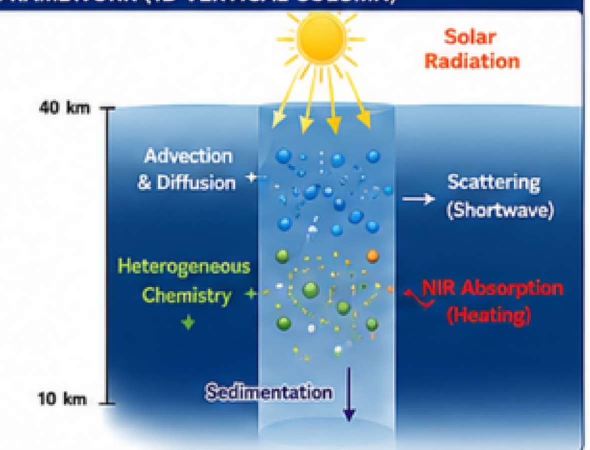
Ozone Safety
Alkaline core neutralizes acids; Silica shell adds pore–diffusion barrier → 10.03% peak ozone depletion

3. MODEL FRAMEWORK (1D VERTICAL COLUMN)

Coupled Processes

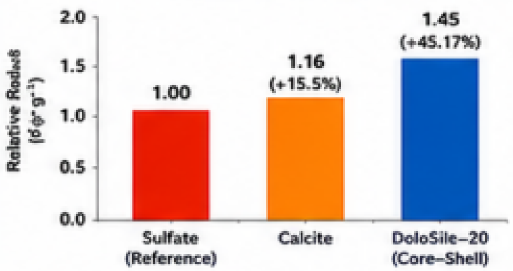
- Advection (upwelling)
- Eddy diffusion
- Coagulation (Brownian)
- Sedimentation (Stokes)
- H_2SO_4 condensation
- Heterogeneous chemistry
- Radiative heating (NIR)
- Ozone loss surrogate

Domain: 10–40 km
120 layers (Δz = 250 m)
Time: 0–1825 days
(Monthly outputs)



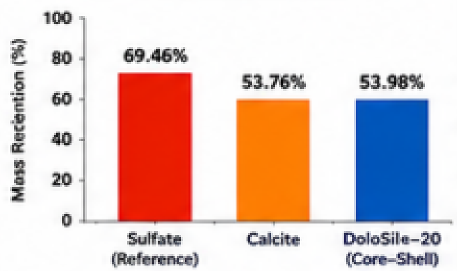
4. KEY RESULTS AT A GLANCE (1825–DAY SIMULATION)

(A) Optical Performance (OPF at 500 nm)
Relative to Sulfate (= 1.00)



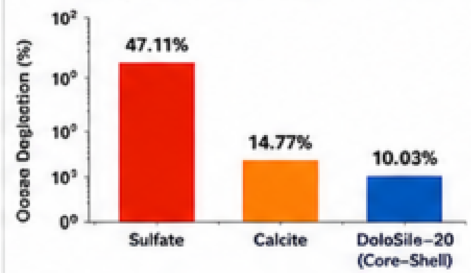
β_{back} = mass–specific backscatter proxy at λ = 550 nm

(B) Mass Retention (Day 1825)
% of Initial Column Mass



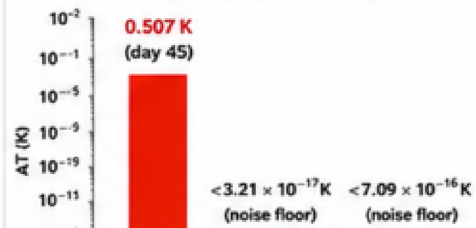
Minerals settle faster due to higher density (–15 percentage–point shortfall vs sulfate)

(C) Ozone Depletion (Peak, 10–1825 d)
% Depletion of Partial Column (10–40 km)



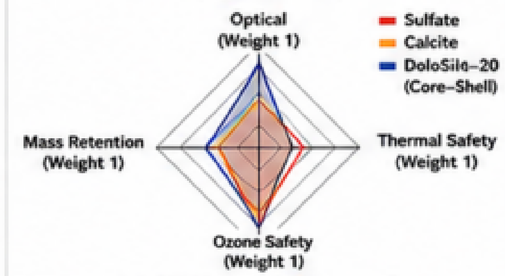
Lowest peak ozone depletion achieved by dolomite–silica core–shell

(D) Thermal Response (Peak ΔT)
Peak Temperature Anomaly (K)



Minerals are thermally neutral ($\Delta T \lesssim 10^{-15}$ K) by construction ($k_{NIR} \approx 0$)

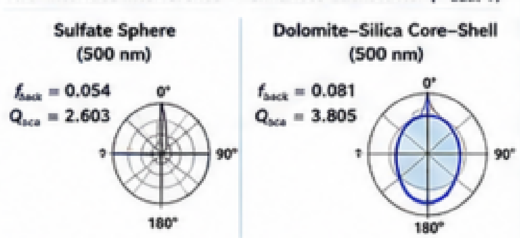
(E) Overall Trilemma Assessment
(Higher is Better)



DoloSile–20 scores highest overall across all three weighted criteria

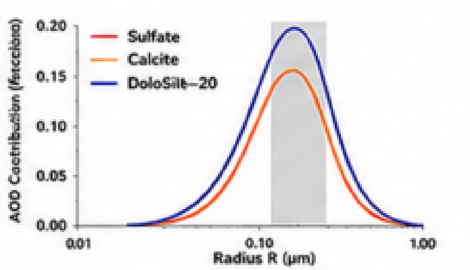
5. OPTICAL MECHANISM: ADEN–KERKER RESONANCE

Higher index contrast + stronger Mie resonance (Q_{sca} ↑)
Two–interface interference → enhances backscatter (f_{back} ↑)



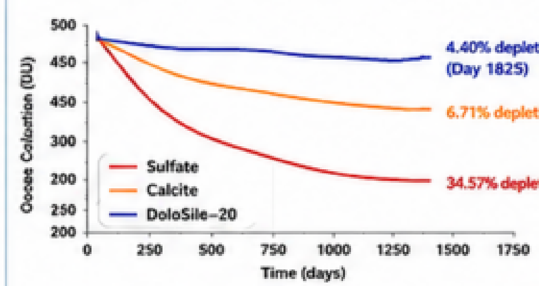
Constructive combination → +45.17% backscatter efficiency (OPF)

6. SIZE–RESOLVED AOD CONTRIBUTION (Day 1825)



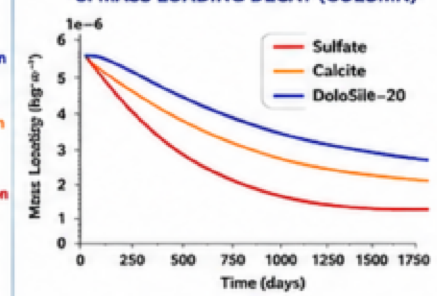
Peak contribution in R ≈ 0.10–0.15 μm range consistent with Mie peak at x ≈ 1–2 (λ = 550 nm). Core–shell distribution is narrower and taller.

7. OZONE COLUMN EVOLUTION (10–40 km)



DoloSile–20 achieves best recovery and lowest peak depletion (10.03% at day ~180).

8. MASS LOADING DECAY (COLUMN)



Mineral candidates start higher (density ↑) but settle faster → ~15% lower retention vs sulfate by day 1825.

9.TRILEMMA SUMMARY

High Optical Performance
+45.17% vs sulfate at 500 nm

Thermal Neutrality
$\Delta T \lesssim 10^{-15}$ K (noise floor) due to $k_{NIR} \approx 0$

Ozone Safety
10.03% peak ozone depletion

Trade–off: Reduced Persistence
~15% lower mass retention vs sulfate due to higher density

10. WHY THIS MATTERS

This is the first computational demonstration of a mineral core–shell aerosol that simultaneously achieves superior optical performance, thermal neutrality, and enhanced ozone safety within a unified framework—resolving the SAI Trilemma at the screening level.

11. LIMITATIONS

- 1D column model (no horizontal transport or dynamics)
- Ozone surrogate with high initial column (DU_0 = 464.85)
- Single–wavelength optical proxy (550 nm only)
- Birefringence approximated as isotropic (~1.8% uncertainty)
- Spherical geometry assumed (upper–bound estimate)

12. PRIORITY FUTURE WORK

1. Measure γ_{O} for DoloSile–20 (flow–tube / Knudsen cell)
2. Measure Hamaker constants (AFM colloidal probe)
3. T–matrix for birefringence & non–sphericity effects
4. 3D chemistry–climate model evaluation

BOTTOM LINE

Dolomite–Silica Core–Shell Aerosols emerge as a promising SAI candidate that best satisfies the Trilemma within a reduced–order framework and warrants evaluation in full 3D climate models.