Evidence for an OH(v) Excitation Mechanism from CO₂ 4.3 μm Nighttime Measurements taken by the SABER Experiment on the TIMED Mission

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TIMED SWG Meeting, APL, March 15-18 2004
Outline

• Background

• SABER measurements:
  - CO$_2$ 4.3 µm *nighttime quiescent* conditions
  - Correlations between CO$_2$ 4.3 µm and OH 2.0 and 1.6 µm

• Modeling

• Comparison and discussion

• Conclusions
Background

• Accurate knowledge of CO₂ 4.3 µm in nighttime mesosphere:
  - To better understand the upper mesosphere energy balance
  - To allow for accurate retrieval of CO₂ vmr at nighttime

• History:
  - Kumer et al. (1978) proposed the $\text{OH}^*(v) \rightarrow \text{N}_2(1) \rightarrow \text{CO}_2(001)$ mechanism (single ICECAP rocket measurement) to address a model shortfall.
  - Several probes since then (SPIRE, CIRRIS-1A, MSX) showed some evidence of this mechanism $\Rightarrow$ No firm conclusion.
  - Difficulty:
    Need simultaneous $p-T_k$, OH*(v) and 4.3 µm radiance
SABER measurements

• Simultaneous measurements of:
  - CO$_2$ 15 µm (3 channels) $\Rightarrow$ P-T$_k$ (ch. 1-3)
  - CO$_2$ 4.3 µm (ch. 7)
  - OH (2 channels)
    - 2.0 µm $\Rightarrow$ OH* (v=7-9) (ch. 8)
    - 1.6 µm $\Rightarrow$ OH* (v=3-5) (ch. 9)

• Very high S/N ratio

• Correlation between CO$_2$ 4.3 µm and OH channels

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Correlation between 4.3 µm and OH channels

CO₂ 4.3 µm

OH 2.0 µm X 0.01
Correlation between 4.3 $\mu$m and OH channels

![Graph showing correlation between radiance and OH concentration.](image)

- Channel 9
- Channel 8

Correlation coefficients:
- $r=0.851391$
- $r=0.836219$

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Modeling approach

TIME-GCM
N₂, O₂, O(^3P),
p-T_k(z > 85 km)

CO₂ (Rocket)
p-T_k (LTE ret)
(z < 85 km)

CO₂ non-LTE model

CO₂*(v₃) populations

SABER
CO₂ 15 µm

SABER
OH 1.6, 2.0 µm

- Abel Inversion
- OH(v) chemical model

Forward rad. transfer
(KOPRA)

Simulated radiance
CO₂ 4.3 µm
**CO$_2$(v$_3$) non-LTE modeling**

- Whole set of $v_3$ vibrational bands
  [including hot bands (up to third) and 5 major isotopes]

- Vibration-vibration (V-V) collisional coupling
  via CO$_2$(00$v_3$)$\leftrightarrow$N$_2$(1) and CO$_2$(v$_3$)$\leftrightarrow$CO$_2$(v'$_3$)

- Vibrational-thermal (V-T) processes

- Radiative processes
  (exchange between layers, upwelling earthshine boundary flux)

- V-V transfer OH$^*$($v$) + N$_2$→ OH$^*$($v$-1)+ N$_2$(1)

- Thorough intercomparison
  with AFRL (ARC) and NASA codes $\Rightarrow$ $T_{vib}$ differences within 1 K.
Comparison with SABER 4.3 $\mu$m radiance

Day 3 Mar 2002
Orbit #1264

Scaf: 95 Loc: 125

Simulated
CO$_2$ only

Measured
Comparison with SABER 4.3 $\mu$m radiance

CO$_2$+OH($v=7-9$)
Comparison with SABER 4.3 $\mu$m radiance

OH($v=7-9$)+$CO_2$(OH*)
Excitation mechanisms of $CO_2(v_3)$

- Look for potential excitation mechanisms of $CO_2(v_3)$ around 80 km:
  
  **Direct excitation of $CO_2(v_3)$ from OH(v)**
  
  **Excitation mechanisms via $O_2(v)$**
  
  **Multiquantum relaxation of OH(v)**
Direct excitation of $CO_2(v_3)$ from $OH(v)$

Current: $k_{N_2}$: $OH^*(v) + N_2 \rightarrow OH^*(v-1)+N_2(1)$

New: $k_{CO_2}$: $OH^*(v) + CO_2 \rightarrow OH^*(v-1)+CO_2(v_3)$

Strong V-V coupling of $CO_2(v_3)$-$N_2(1)$

$\downarrow$

both enhance the $CO_2(v_3)$-$N_2(1)$ reservoir

$$\frac{P_{CO_2}}{P_{N_2}} \approx \frac{k_{CO_2} \times [CO_2]}{k_{N_2} \times [N_2]} \approx 100 \times \frac{3.5 \times 10^{-4}}{0.78} \approx 0.05 \%$$
Excitation of $CO_2(v_3)$ via $O_2(1)$

- From vibrationally excited $O_2(1)$:

$$k_{O_2}: O_2(1) + CO_2(010) \rightarrow O_2 + CO_2(001) \text{ (nearly resonant)}$$

Excitation of $O_2(1)$ at night?

- From $OH(v)$: $OH^*(v) + O_2 \rightarrow OH^*(v-1) + O_2(1)$

$O_2(1)$ $T_{vib}$ increase only by $\sim 10K$ @85km, $T_{vib} \sim 210K$

Test by setting $O_2(1)$ $T_{vib}$ to 250 K 75-95 km
Excitation of $CO_2(v_3)$ via $O_2(1)$
Excitation of $CO_2(v_3)$ via $O_2(2)$

- From vibrationally excited $O_2(2)$:

  $O_2(2) + CO_2 \rightarrow O_2 + CO_2(011)$ (nearly resonant) but

  - needs $OH^*(v) + O_2 \rightarrow OH^*(v') + O_2(2)$ to be fast, and

  - would relax quickly in collisions with $O_2$ and V-V transfer with $H_2O$
Required $\text{OH}(v) \rightarrow \text{N}_2(1)$ efficiency

- $\text{OH}^*(v) + \text{N}_2 \rightarrow \text{OH}^*(v-1) + \text{N}_2(1)$

- Production of $\text{N}_2(1) = k(v) \cdot [\text{OH}(v)] \cdot \text{Eff}$
  
  $\text{Eff} = 2.8 - 3 = \text{no. of N}_2 \text{ vib quanta per OH}(v) \text{ quenched}$

- Also assumes $k(v)$ rate increased by factor of $1.4$ at the low mesospheric temperatures (Adler-Golden)
Efficiency of OH(v) by N₂

Eff=2.8
Efficiency of OH(v) by N$_2$

Eff of 2.8 x 1.4
Comparison at equinox

March 3rd
Orbit 1264
Residual radiances (%) for March 3 2002 #1264
Residual radiances (%) for equinox and solstice
Conclusions

✓ SABER simultaneous measurements of $T_k-p$, OH and CO$_2$ 4.3µm limb radiance offer a good opportunity to better understand the energetics of the nighttime mesosphere.

✓ SABER CO$_2$ 4.3 µm nighttime mesospheric radiance is very large and strongly correlated with OH emission.

✓ An energy transfer for $\text{OH}^* \rightarrow \text{N}_2(v)$ of about 2.8-3 N$_2$(1) molecules per OH(v) molecule is required to explain SABER radiances, i.e., 30% of OH(v) energy needs to be transferred to N$_2$(v).

✓ The mechanism(s) whereby the energy is transferred from OH(v) to N2(v) is (are) still uncertain.

✓ This energy transfer does not affect OH(v) populations since N$_2$ is not a very efficient quencher of OH(v).