Infrared radiation in the mesosphere and lower thermosphere: energetic effects and coupling with lower atmosphere

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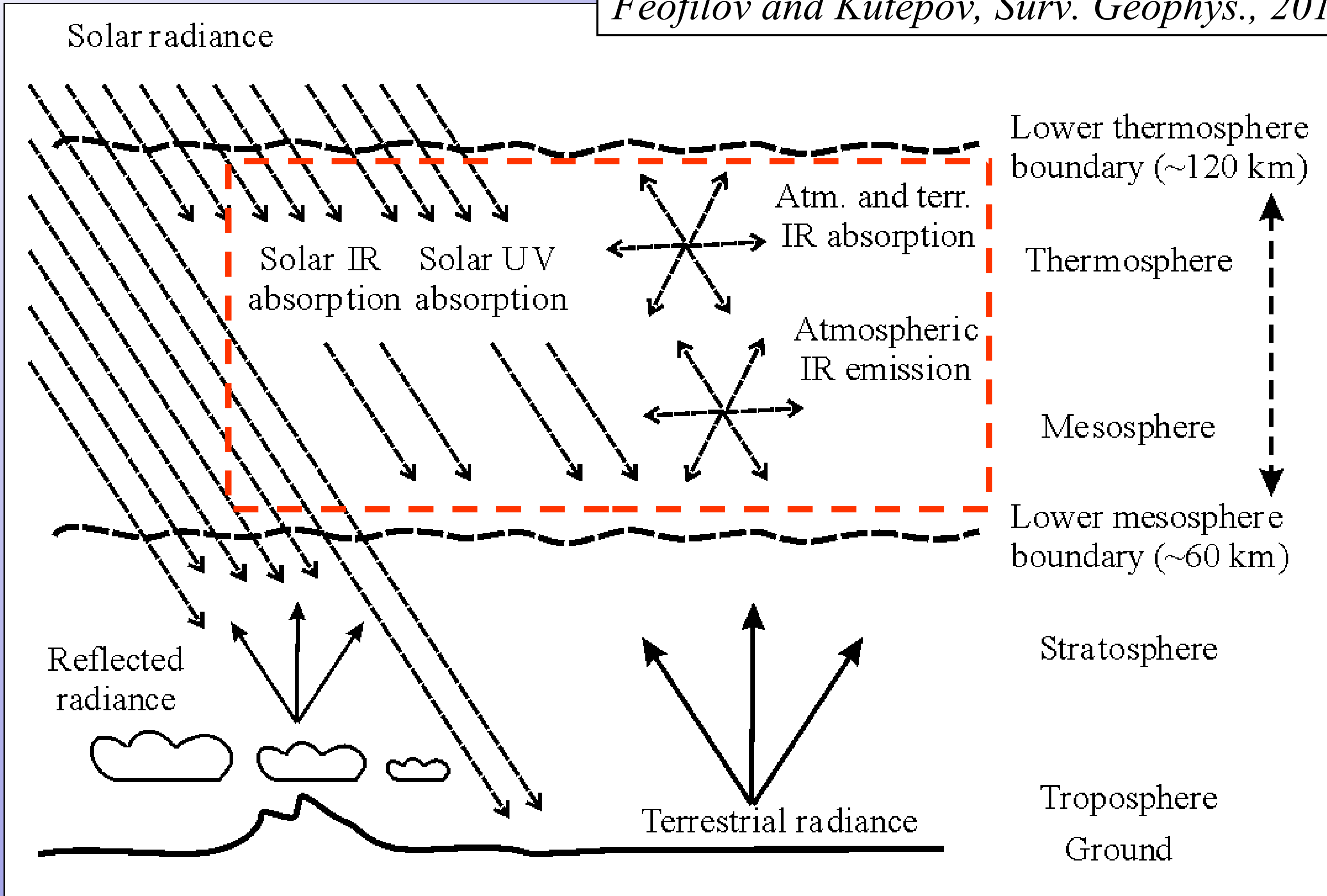
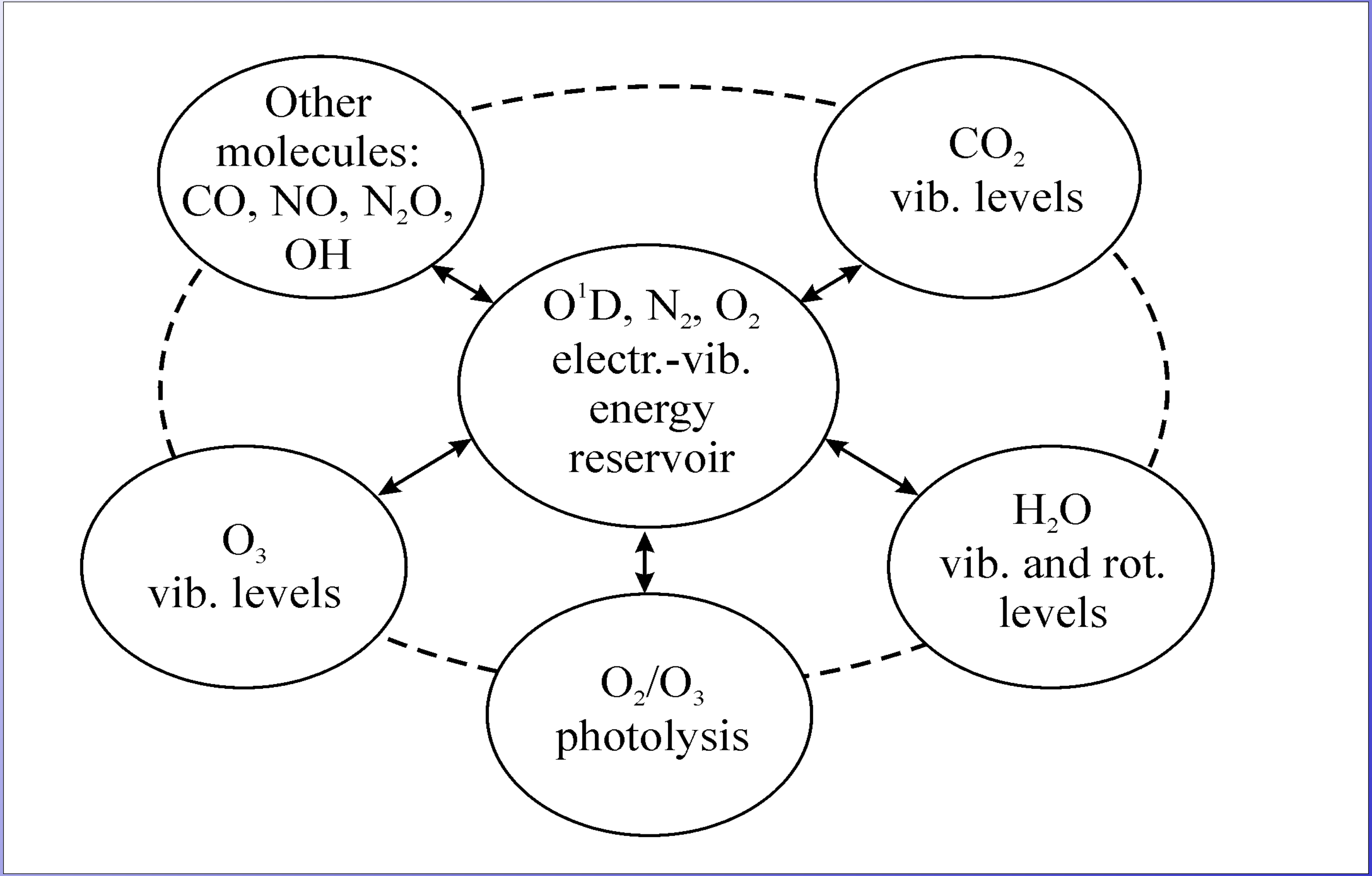
Object of Study: IR radiance in MLT

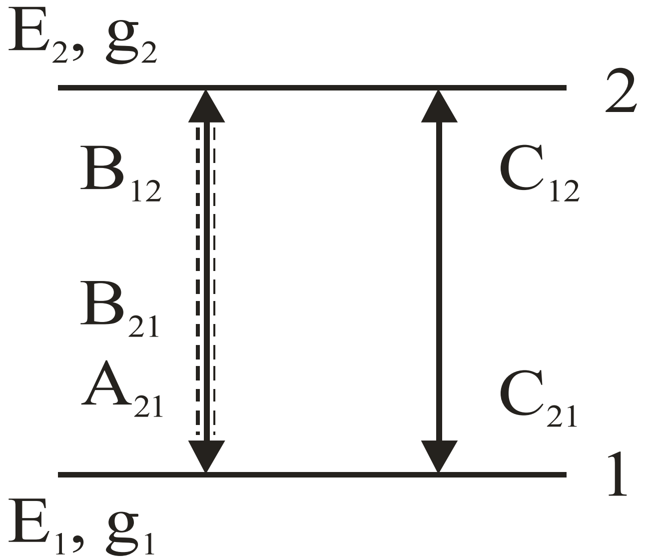
Feofilov and Kutepov, Surv. Geophys., 2012



Energy Exchange Between Atmospheric Molecules

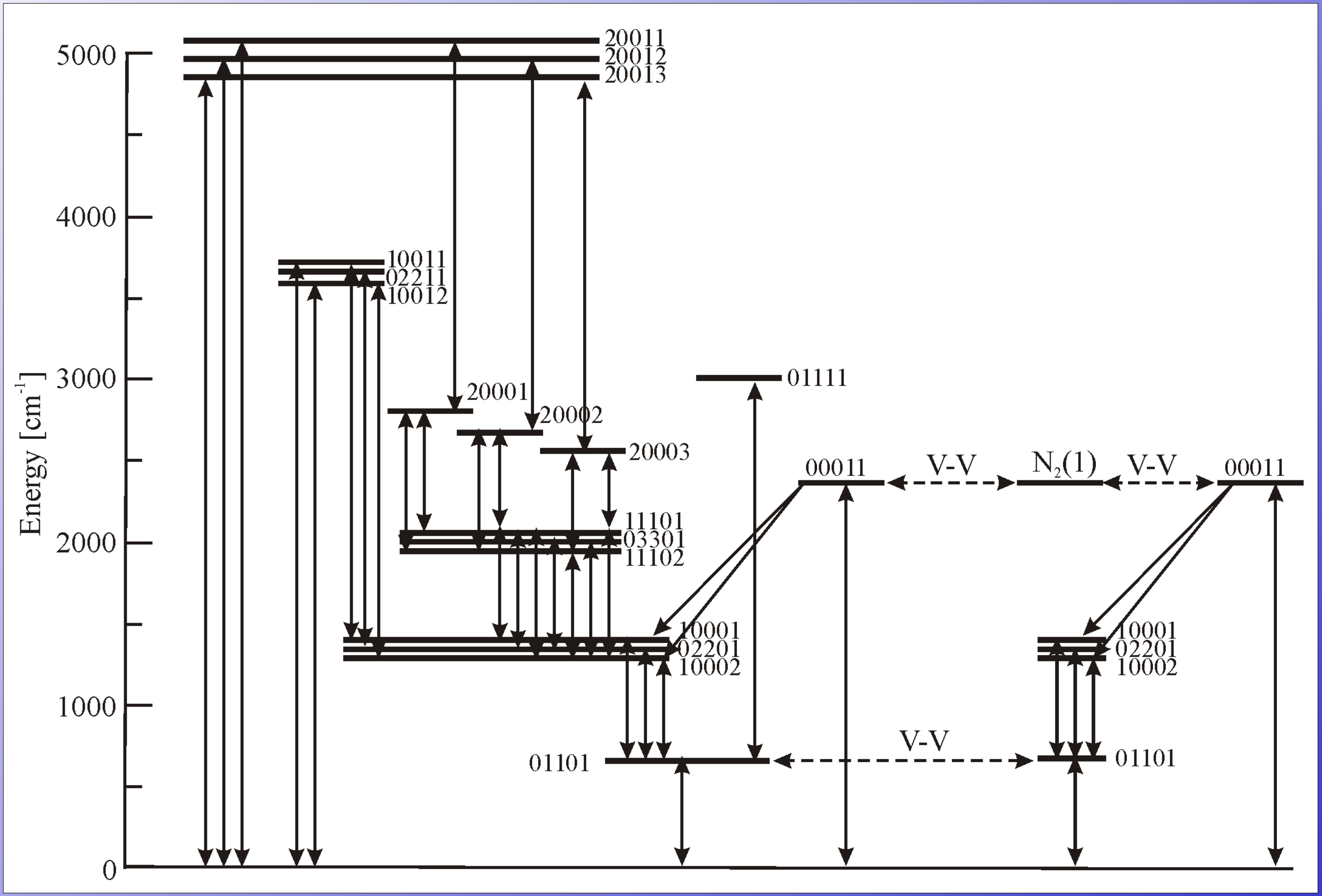


LTE and non-LTE: two-level atom

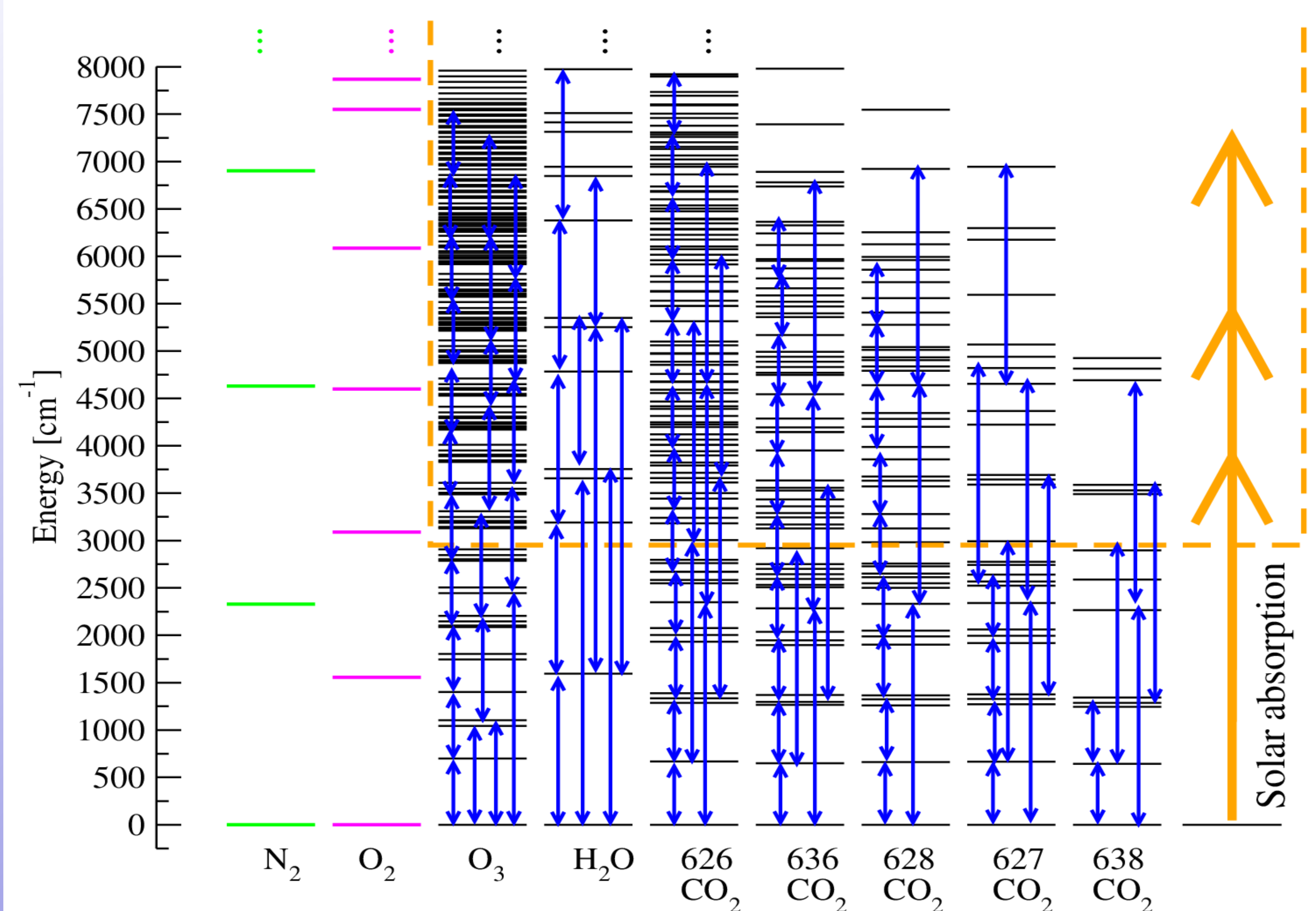


$$
\begin{cases}
(\underbrace{A_{21} + B_{21}\bar{J}}_{R_{21}} + C_{21})\, n_2 = (\underbrace{B_{12}\bar{J}}_{R_{12}} + C_{12})\, n_1 \\
n_1 + n_2 = n
\end{cases}
$$

Vibrational levels and transitions for CO_2



Non-LTE calculations: ALI-ARMS research code



CO_2, O_3, and H_2O: three most "interesting" atmospheric molecules

- The vibrational levels of all 3 molecules are in non-LTE in the MLT.

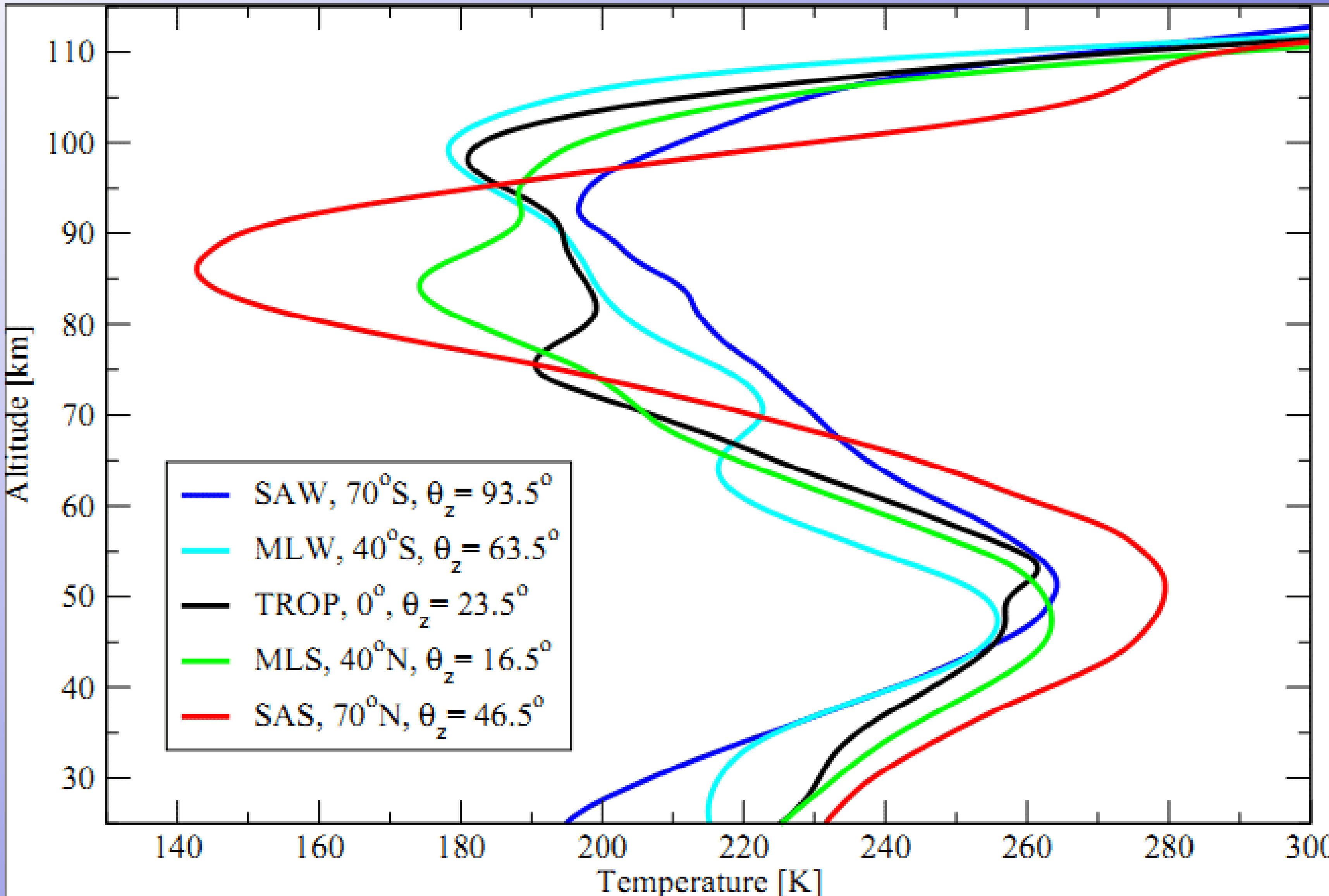
- CO_2(15 μm) is the main cooler in the MLT.

- O_3(9.6 μm) is the second in importance.

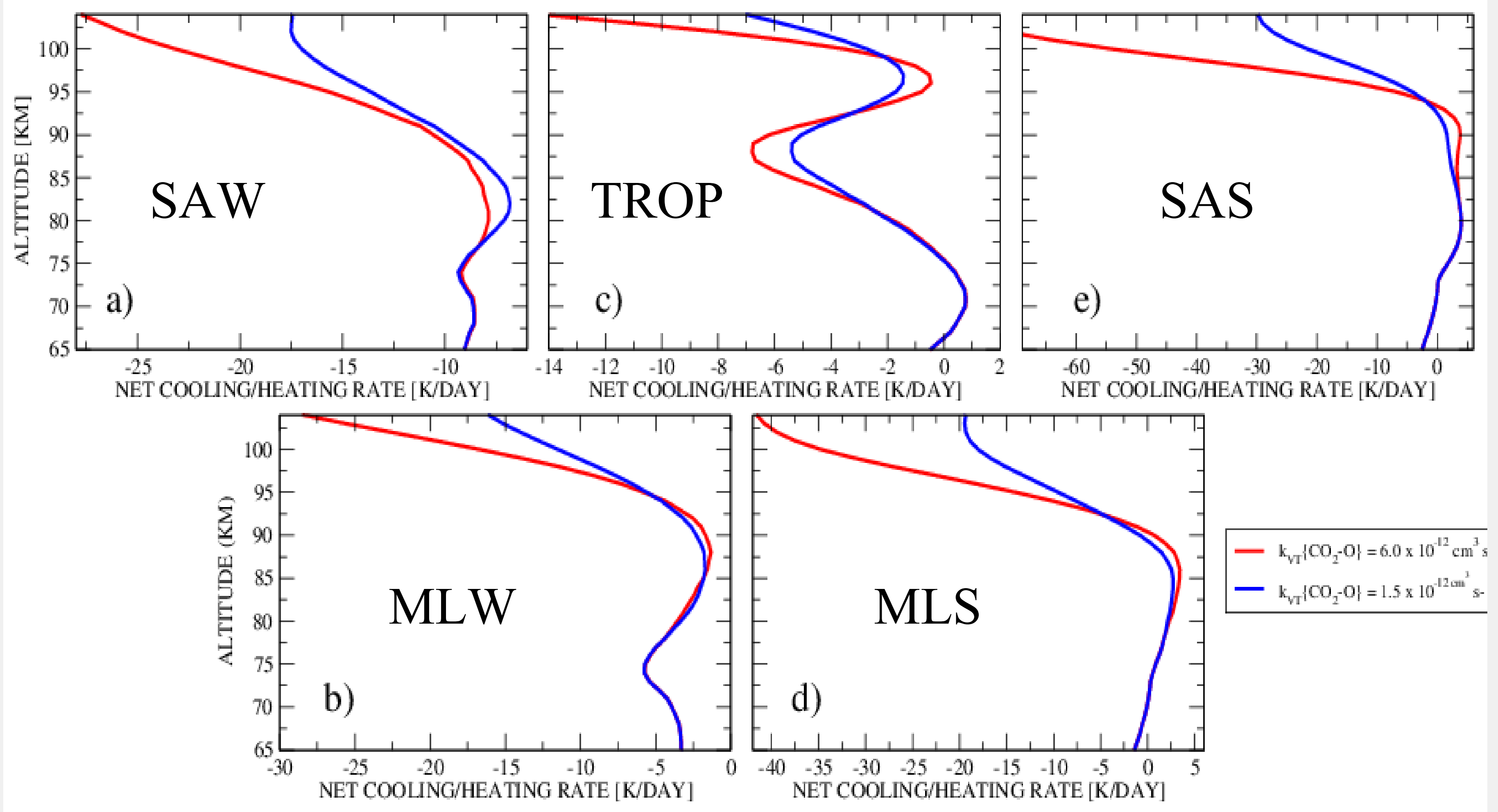
- O_3 and O_2 photolysis in UV forms $O(^1D)$, $O(^3P)$ and electronically and vibrationally excited O_2 coupled with H_2O.

- H_2O **rotational** band is the third in importance. However, the non-LTE model is still required for the H_2O retrievals from the 6.3 μm radiance measurements.

Five test atmospheric models: temperature profiles

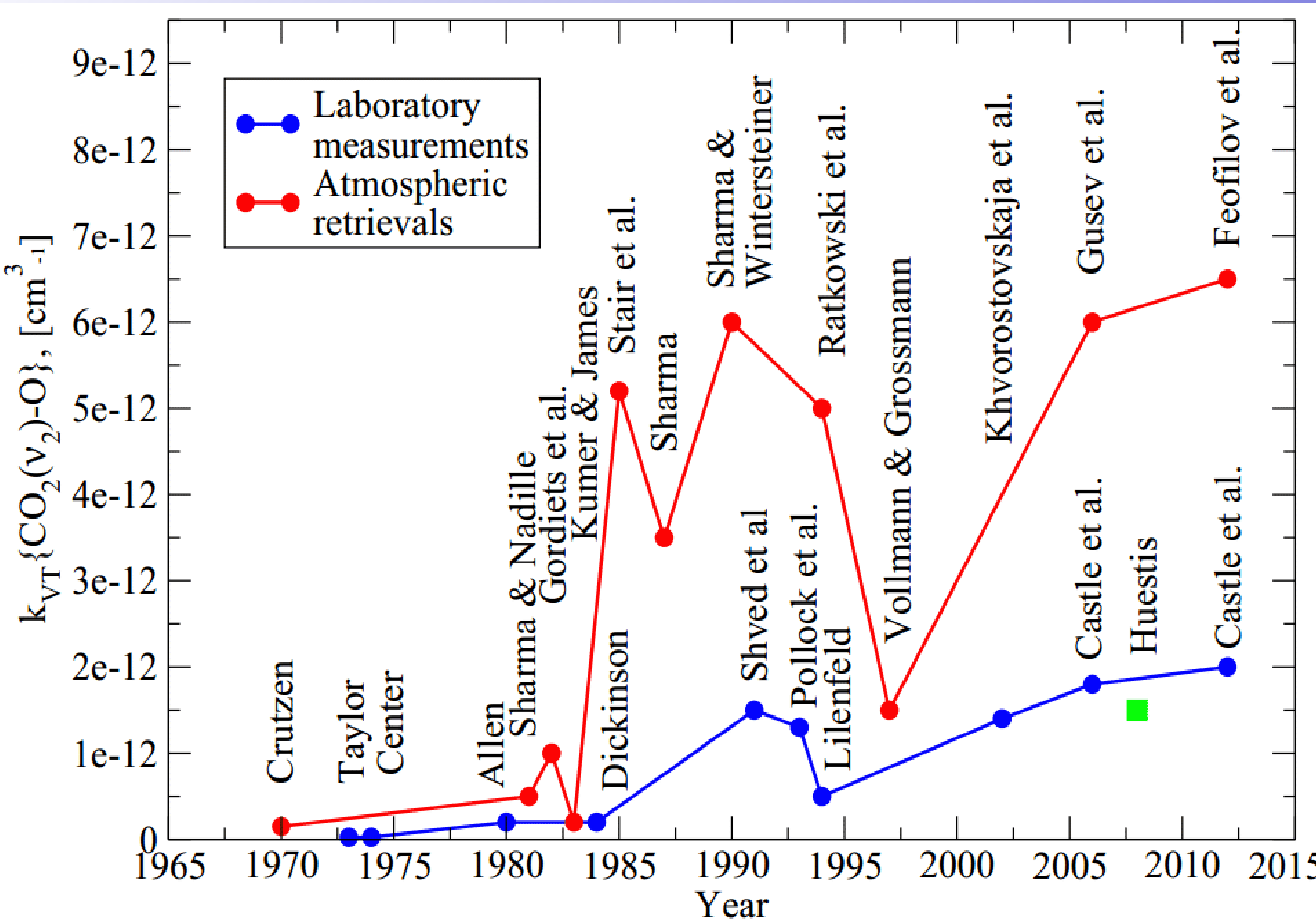


CO_2 cooling/heating rates

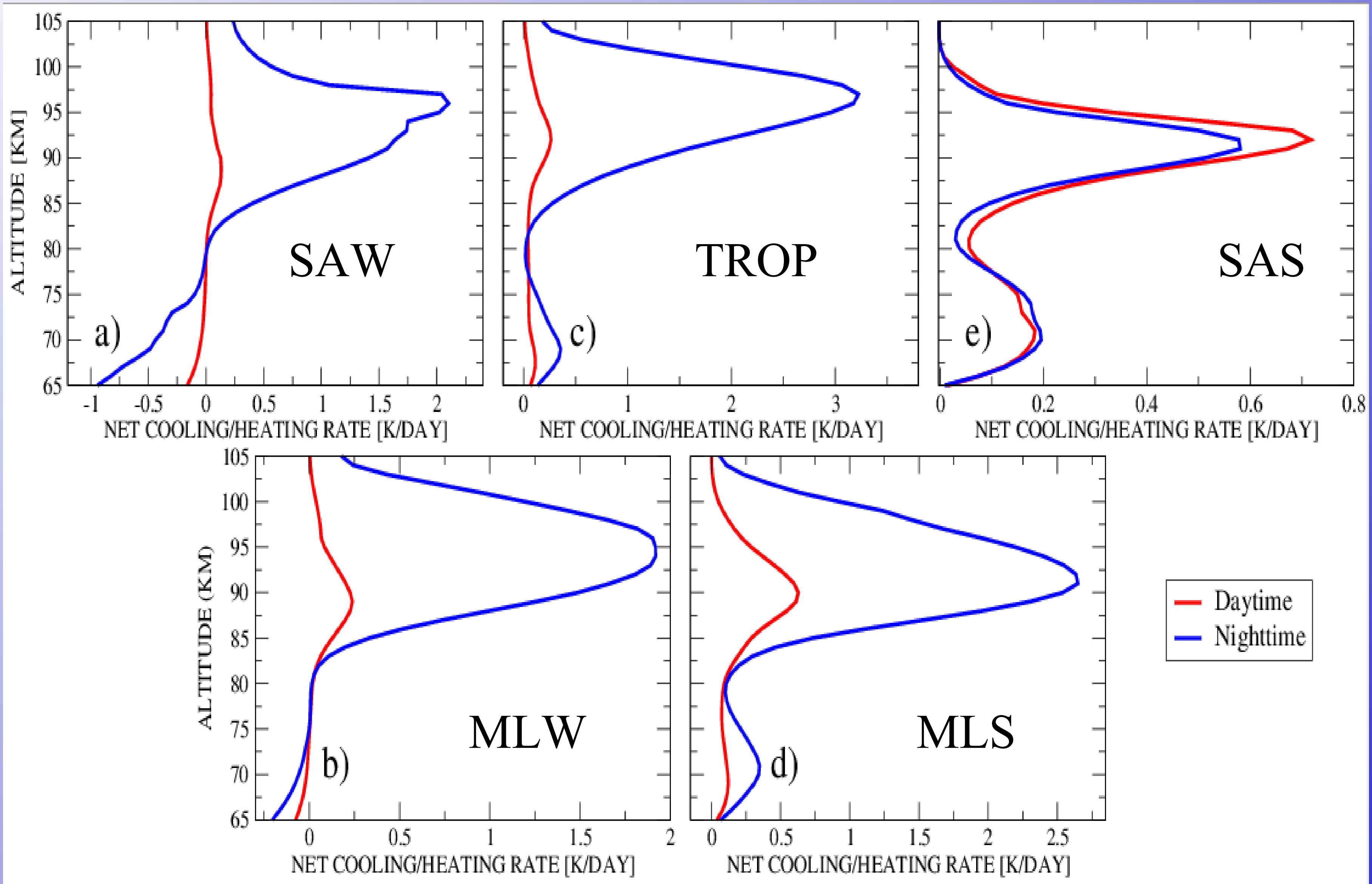


Note two sets of curves calculated for two values of $CO_2(v_2)$-O quenching rate coefficient

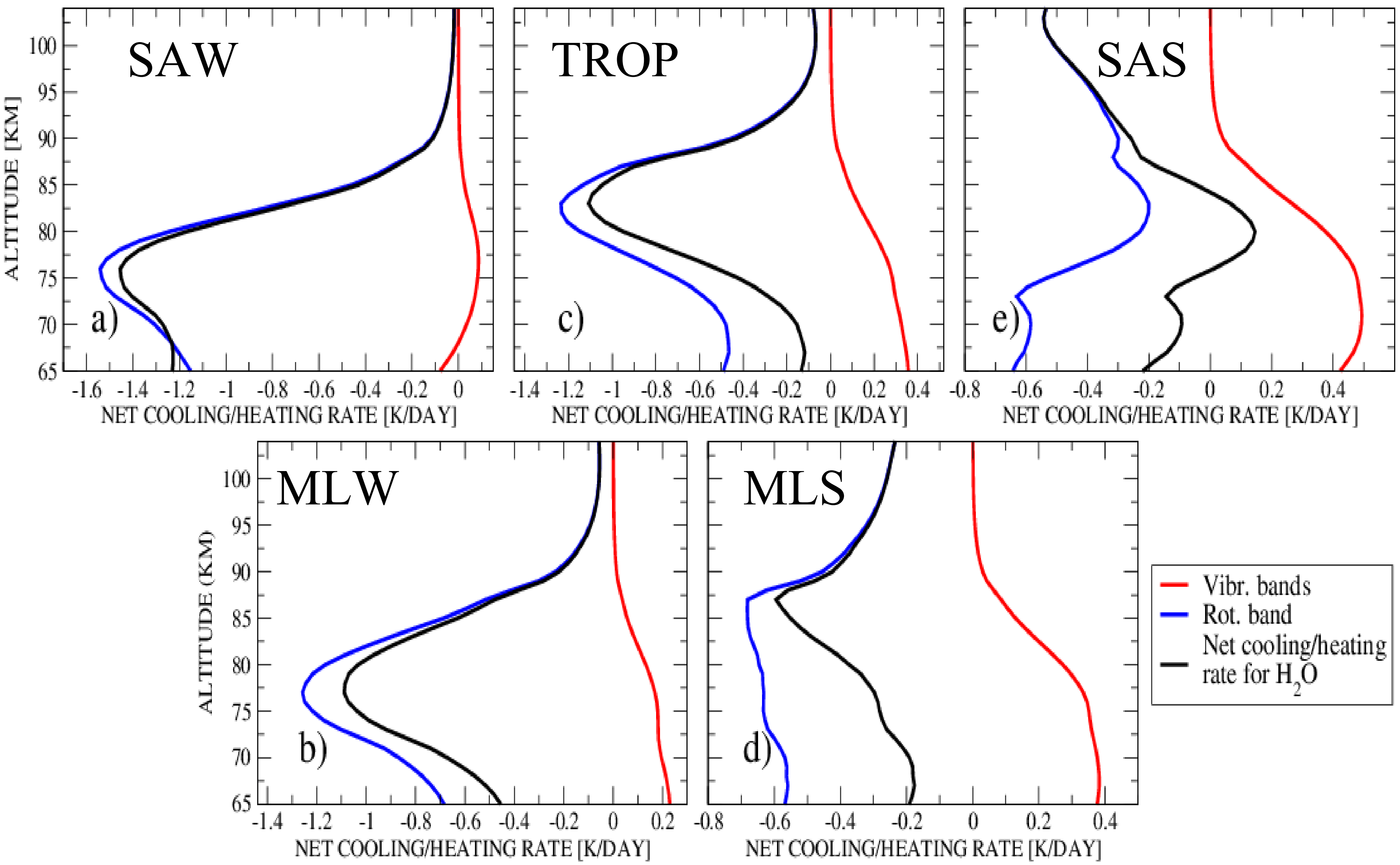
Historical review of $k_{VT}\{CO_2\text{-}O\}$ measurements



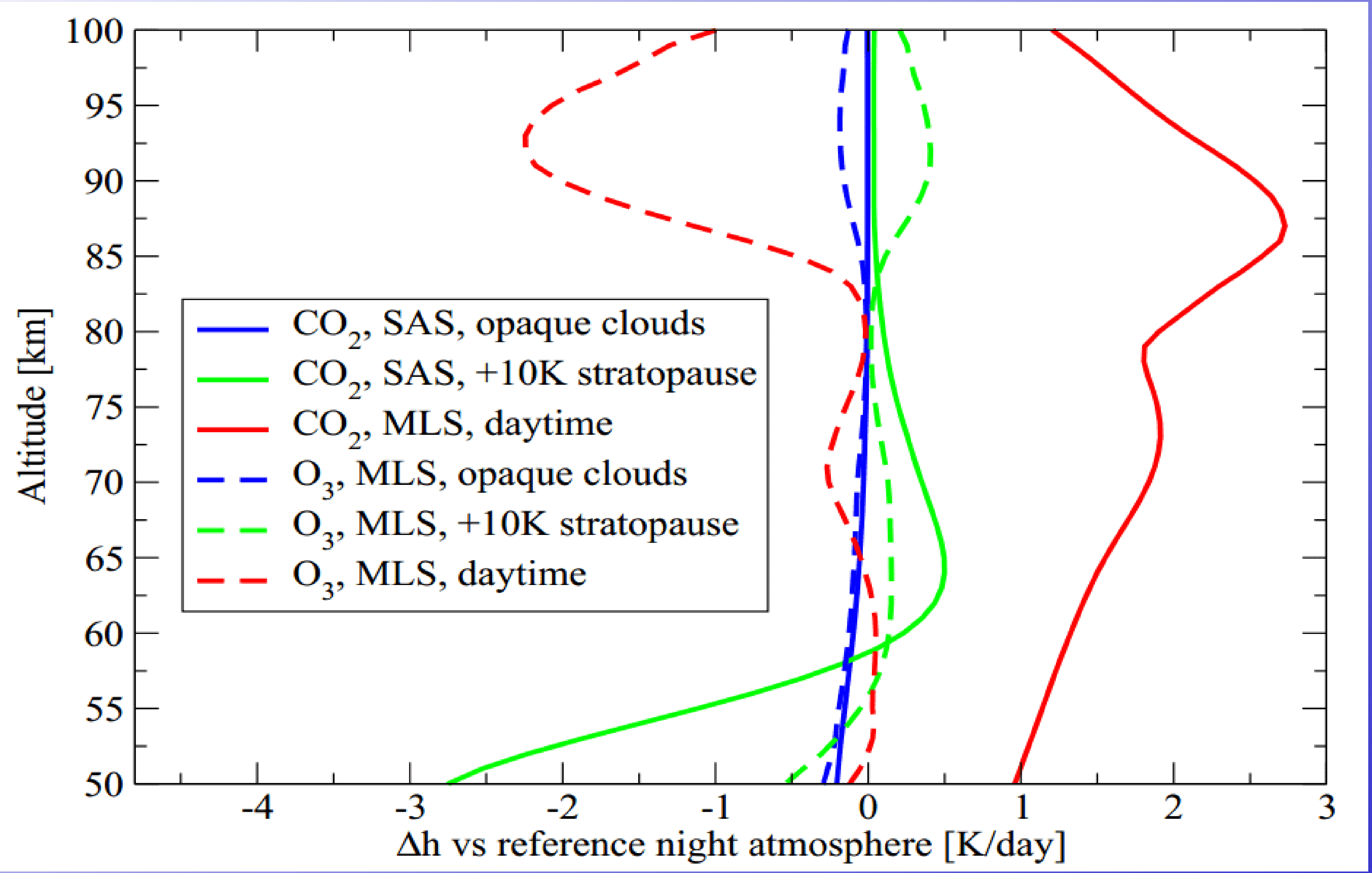
O_3 cooling/heating rates



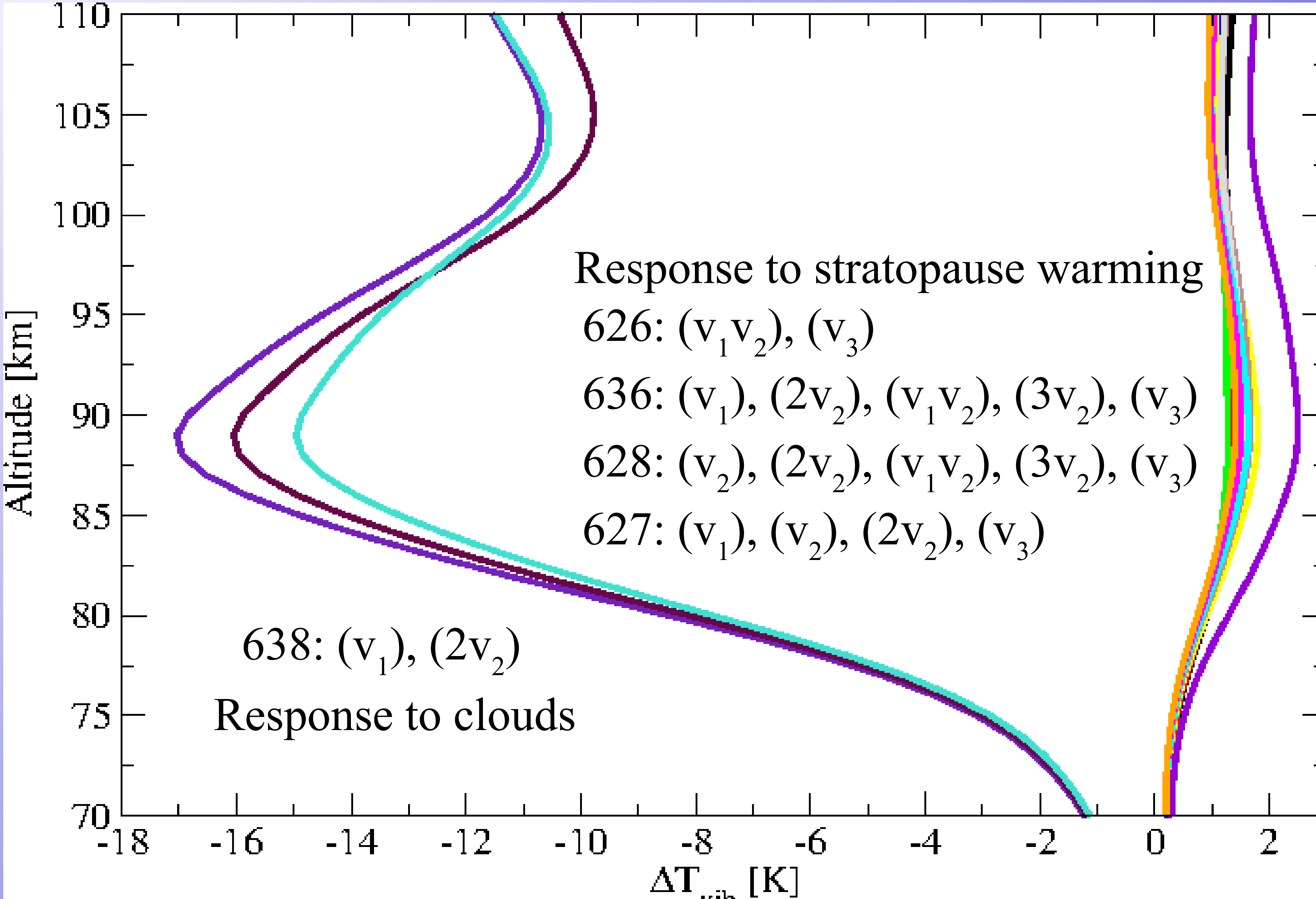
H_2O cooling/heating rates in rotational and vibrational bands



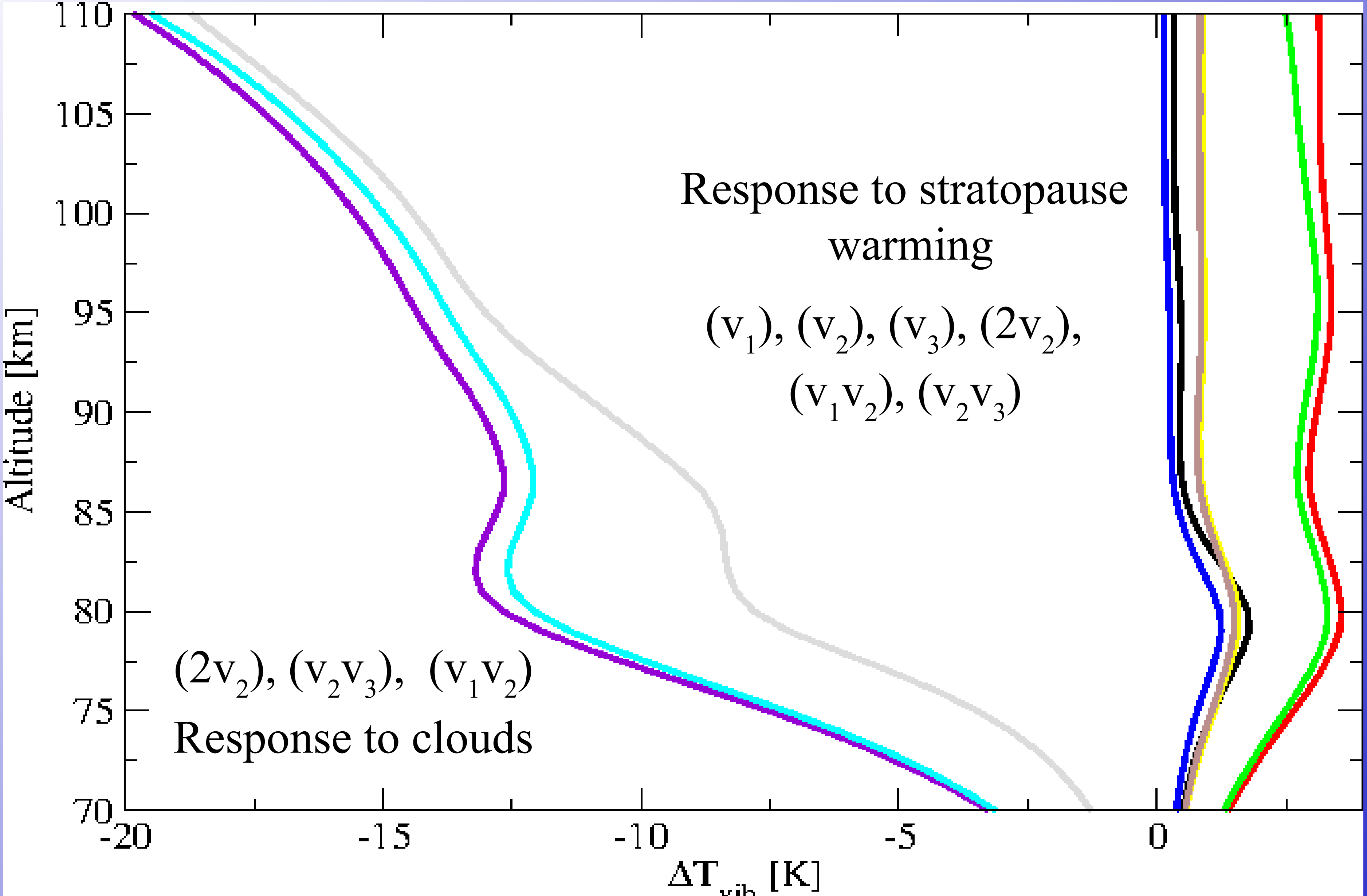
MLT sensitivity to clouds, stratopause T, and solar pumping changes



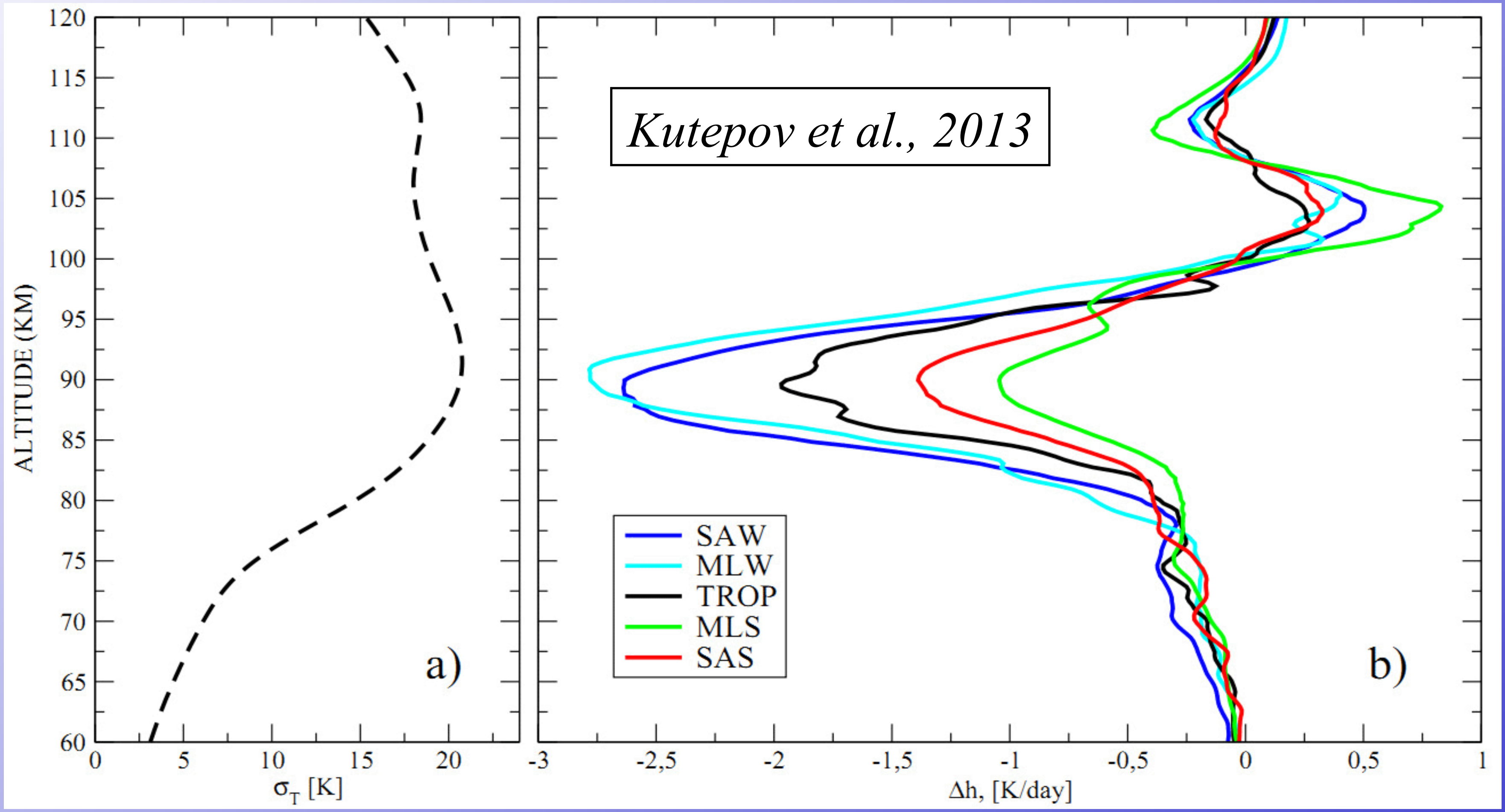
CO_2 vibr. levels, sensitive to changes in other layers



O_3 vibr. levels, sensitive to changes in other layers



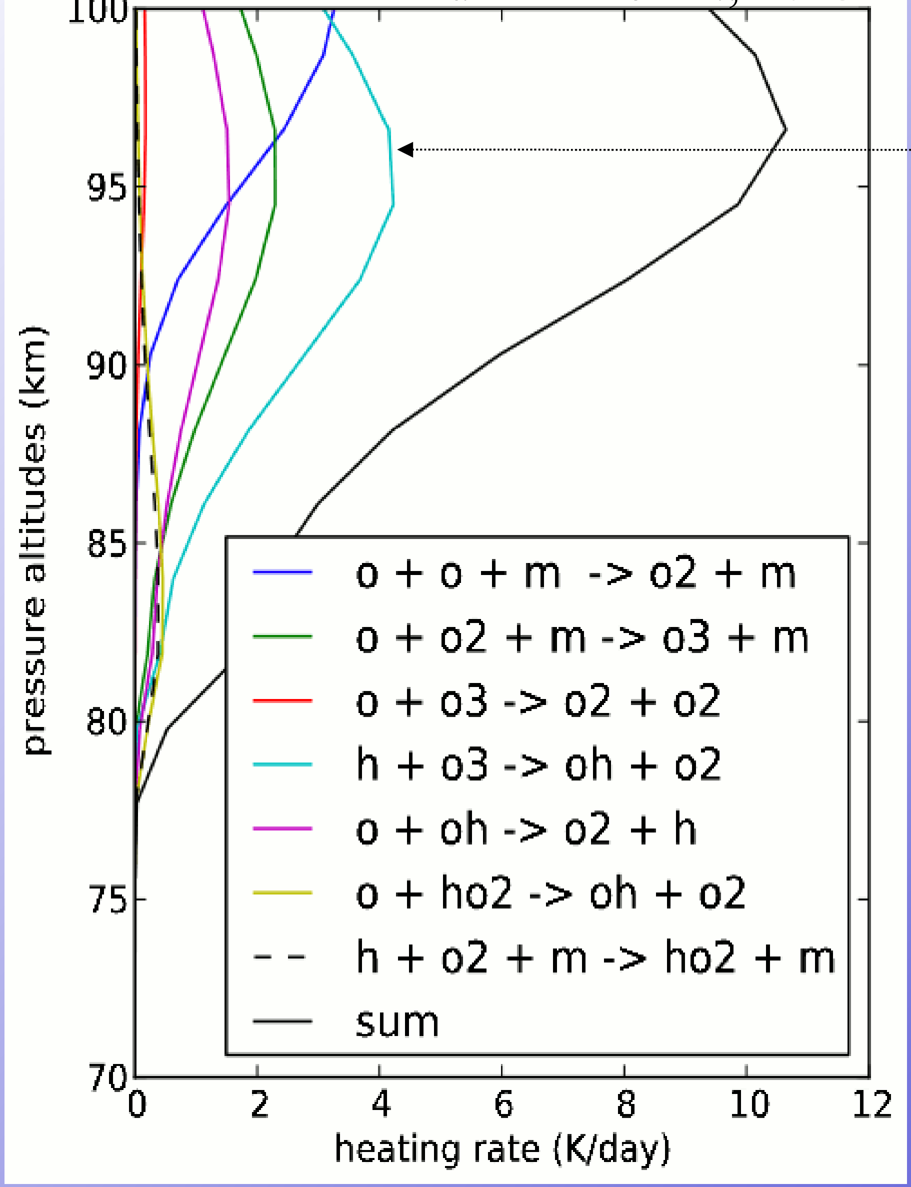
Radiative cooling, associated with GW activity

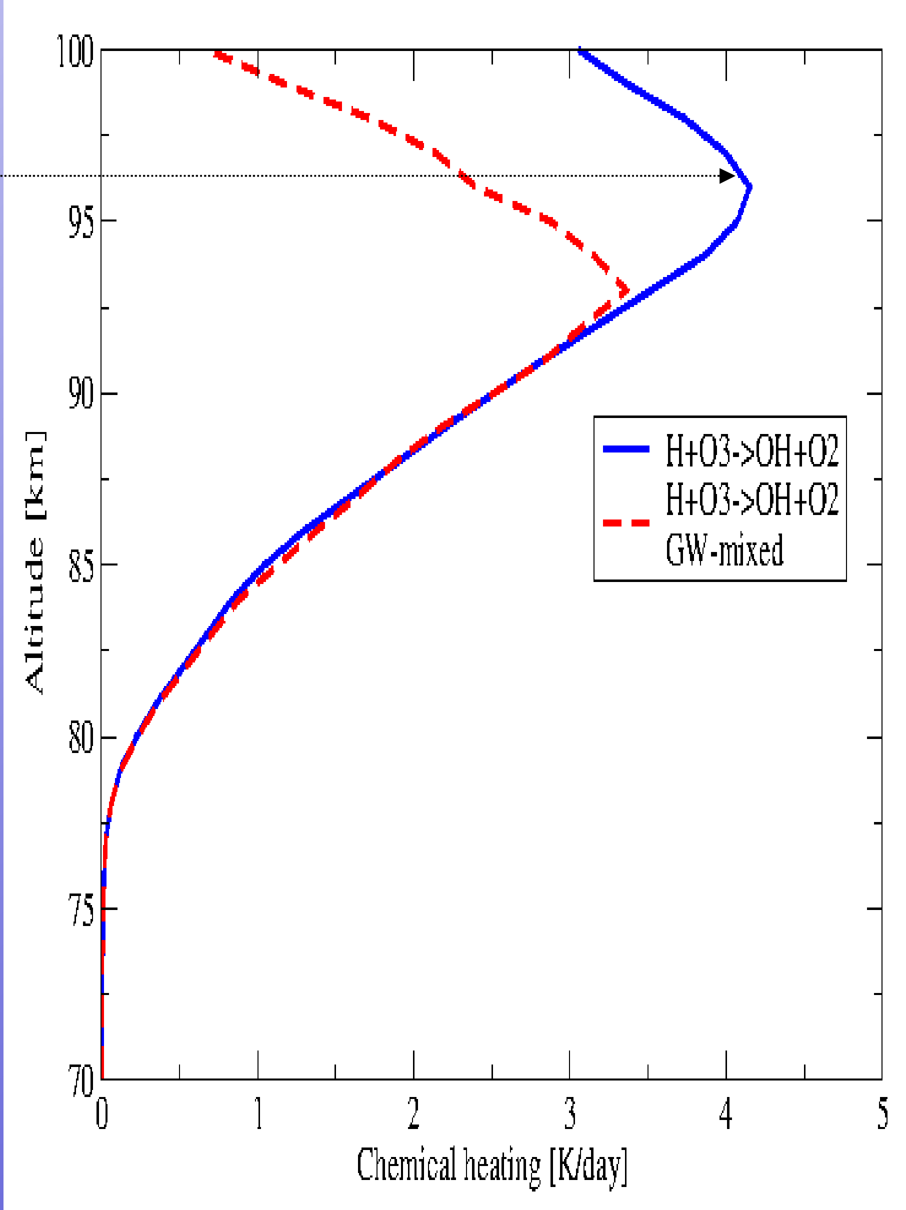


The effect is mainly related to T fluctuations: increased mean local thermal emission vs emission for the non-disturbed T profile (non-linear T dependence of B(v,T))
The magnitude depends on r.m.s. of T variation (left panel) and CO_2(z) and O(z) vertical gradients: CO_2 fluctuations decrease the effect, while O fluctuations increase it.

Gravity wave effects in chemical heating

Kaufmann et al., 2013





Take home messages

- ✓ IR cooling/heating in 65-105 km altitude range:
  CO_2(15µm): -(15-50) K/day, depending on T and k_{VT} rate coeff.
  O_3(9.6µm): -1...+3 K/day
  H_2O(6.3µm vibr. and ~20µm rot. band): -1.5...+0.5 K/day

- ✓ Energetic effects of direct radiative coupling with tropo- and stratosphere are less than 1 K/day

- ✓ Changes in lower atmosphere affect vibrational levels, which are pumped by radiation coming in optically thin lines.

- ✓ Atmospheric fluctuations associated with gravity waves cause additional radiative cooling (up to 3 K/day) and also lead to changes in chemical heating (~ 2 K/day)