Modelling of VIRTIS/VEX $O_2(a^1\Delta_g)$ nightglow profiles affected by gravity waves action

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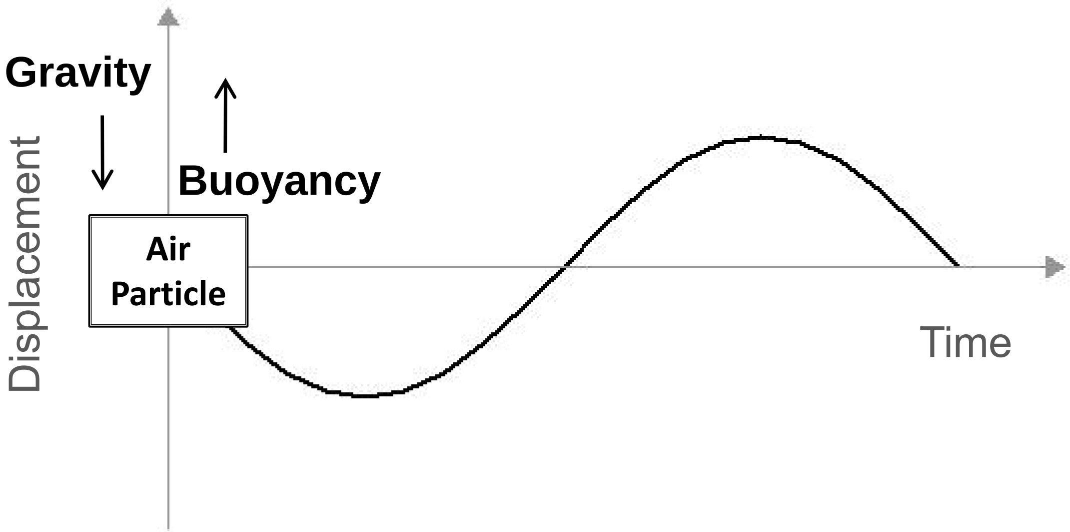
OUTLINE

- Introduction
- Gravity Waves (GWs) propagation in the:
  - ✓ Terrestrial Atmosphere
    - The Swenson and Gardner [1998] analytical model
  - ✓ Venusian Atmosphere
    - GWs detections through the VIRTIS/VEX O_2 nightglow limb profiles
    - Modeling
- Summary and Conclusions

Introduction

GWs are mesoscale atmospheric oscillations related to the buoyancy force, which play a key role in the circulation of planetary atmospheres.
These buoyancy waves can exist whenever an atmosphere is stably stratified (density increase with depth), so that the vertical displacement of air particles produces density changes that cause gravity to act as restoring force [e.g. Nappo, 2002] .



GWs propagate horizontally and vertically. The amplitude of the oscillations they induce grows as they propagate upper ward, transporting momentum and energy.

They induce oscillations in the:

- Temperature field
- Density field
- Airglow intensities (OH*, **O_2* - 1.27 μm**)

Detection methods:

- Vertical profiles
- Airglow & cloud imagery

Terrestrial Atmosphere

Swenson and Gardner [1998] modeled the response of the terrestrial OH airglow emission and Na layers to GWs propagation.

$$\rho_u(z) = \rho_u(0) \times e^{-z/H}$$

Unperturbed density profile for an isothermal atmosphere

$$\frac{\rho}{\rho_u} = 1 + \varepsilon \times e^{\beta(z - z_{HO})} \times \cos[\omega t - kx - m(z - z_{OH})]$$

Relative atmospheric density perturbations; exact solution, starting from the continuity equation, when the mean winds are zero and the wind perturbations are caused by a monochromatic GW

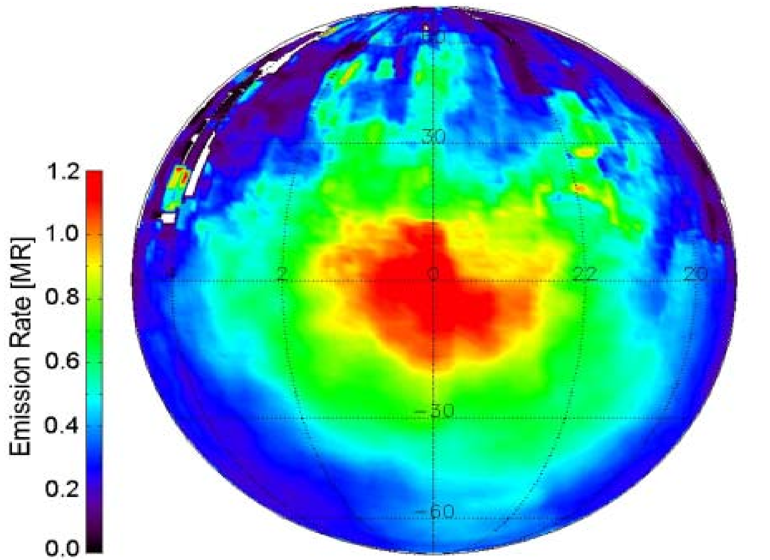
Dispersion relation:

$$m^2 = \frac{(N^2 - \omega^2)}{(\omega^2 - f^2)} k^2$$

N = buoyancy frequency
f = inertial frequency

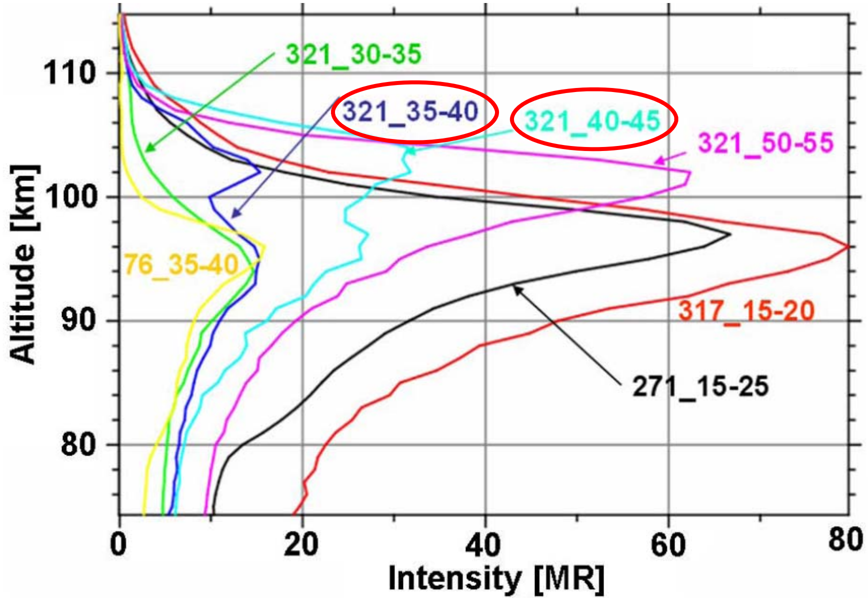
ε = GW amplitude at z_{OH}
z_{OH} = altitude of the peak of the OH layer
$1/\beta$ = amplitude growth length (= 2H for undamped waves)
H = atmospheric scale eight
ω = intrinsic frequency
k = horizontal wave number =$2\pi/\lambda_h$ where λ_h = horizontal wavelength
m = vertical wave number =$2\pi/\lambda_z$ where λ_z = vertical wavelength

Venus Atmosphere



Mean global map of the (0,0) oxygen nightglow

VIRTIS/VEX data



Mechanism to produce excited $O_2(a^1\Delta_g)$ on the night side of Venus:

$$O+O + M \rightarrow O_2(a^1\Delta_g) + M$$
$$O_2(a^1\Delta_g) + M \rightarrow O_2(X^3\Sigma_g) + M$$

$M = CO_2$

which decade from the excited state $O_2(a^1\Delta_g)$, emitting photons around 1.27 µm and 1.58 µm.

Piccioni, Zasova, Migliorini, Drossart, Shakun, Garcıa Munoz, Mills, Cardesin-Moinelo, JGR, 2009

In photochemical equilibrium (condition satisfied below 120 km as verified in Gerard et al. 2009) , a balance is established between

chemical production (three body reaction):

$$O + O + M \rightarrow O_2(^1\Delta_g) + M$$

with an **efficiency $70 < e < 80\%$** (**75 %** in Crisp et al. 1996)

Rate coefficient:

$k\_T = 1.5 \times T^{-2}\ 10^{-27}\ cm^6\ sec^{-1}$

(Krasnopolsky 2010, derived from the value measured by **Campbell and Gray (1973)** with N_2 and O_2 as third body and multiplied by a factor **3.5** to take into account the higher reactivity of CO_2 (Nair et al. 1994, Slarger et al. 2006))

$K\_200 = 2.5 \times 10^{-32}\ cm^6\ sec^{-1}$

(Gerard et al. 2009, derived from the value measured at 200 K by Campbell and Gray (1973) with N_2 and O_2 as third body and multiplied by a factor **2.5** to take into account the higher reactivity of CO_2 (Nair et al. 1994, Slarger et al. 2006))

and **loss:**

- radiative deactivation

$$O_2(^1\Delta_g) \rightarrow O_2(^3\Sigma_g) + 1.27\,\mu m$$

with a **life time $3880 < \tau < 6800$ sec^1 (4300 sec^1** in Miller et al. 2001**)**

- collisional deactivation with CO_2 molecules (quenching)

$$O_2(^1\Delta_g) + M \rightarrow O_2(^3\Sigma_g) + M$$

quenching coefficient **$C = 2.0 \times 10^{-20}\ cm^3\ sec^{-1}$** (recommended by Sander et al. 2003 and given as upper limit by De More et al. 1997)

$$[O_2(^1\Delta_g)]/\tau = e \cdot k\_T \cdot [CO_2] \cdot [O]^2 - C \cdot [CO_2] \cdot [O_2(^1\Delta_g)]$$

$$M \equiv CO_2$$

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$$[O_2(^1\Delta_g)] = \frac{e \cdot k\_T\,[CO_2] \cdot [O]^2}{(A + C \cdot [CO_2])}$$

$$M \equiv CO_2$$

$$A = 1/\tau$$

Atmospheric response to GW propagation

The density variation for CO_2, O and T can be written (Swenson and Garderner 1998):

$$\frac{[CO_2]_p}{[CO_2]_u} = \frac{\rho_p}{\rho_u}, \quad \frac{[O]_p}{[O]_u} = \left(\frac{\rho_p}{\rho_u}\right)^{g_0(z)}, \quad \frac{T_p}{T_u} = \left(\frac{\rho_p}{\rho_u}\right)^{-1}$$

$$[O]_u = f \times e^{[-(z-z_0)/H_1 - e^{-(z-z_0)/H_2}]} \longrightarrow \quad g_0 = \frac{\gamma H - H_1}{(\gamma-1)H_1} - \frac{\gamma H}{(\gamma-1)H_2} \times e^{-(z-z_0)/H_2}$$

z_0 , H_1, H_2 parameters to fit the O density profile with a layer peaking at z_0

γ = ratio of the specific heats

$$[O_2(^1\Delta_g)] = \frac{e \cdot k\_T \cdot [CO_2] \cdot [O]^2}{(A + C \cdot [CO_2] \cdot)}$$

$$[O_2(^1\Delta_g)]_p = \left(\frac{\rho_p}{\rho_u}\right)^{3+2g_0(z)} \cdot \frac{(A + C \cdot [CO_2]_u)}{(A + C \cdot \left(\frac{\rho_p}{\rho_u}\right) \cdot [CO_2]_u)} \cdot [O_2(^1\Delta_g)]_u$$

$$\frac{\rho_p}{\rho_u} = 1 + \varepsilon \times e^{\beta(z - z_{O2})} \times \cos[\omega t - kx - m(z - z_{O2})]$$

A=1/τ, Eistein coeff.
τ =$O_2(^1\Delta_g)$ life time
C=CO_2 quenching const.
k_T= 3-body r. rate coeff.
e = 3-body r. effic.

Method

Inverted VIRITS O_2 ($a^1\Delta_g$) vertical profile PERTURBED

1. O_2 ($a^1\Delta_g$) initial vertical profile → UNPERTURBED
2. CO_2 initial vertical profile → UNPERTURBED
3. O initial vertical profile → UNPERTURBED
4. GW action → PERTURBED profiles, through Swenson and Garderner (1998) model
5. Playing with free parameters to match the VIRTIS measured profiles showing double (or multiple) peaks,

   we fit the PERTURBED O_2 ($a^1\Delta_g$) profile

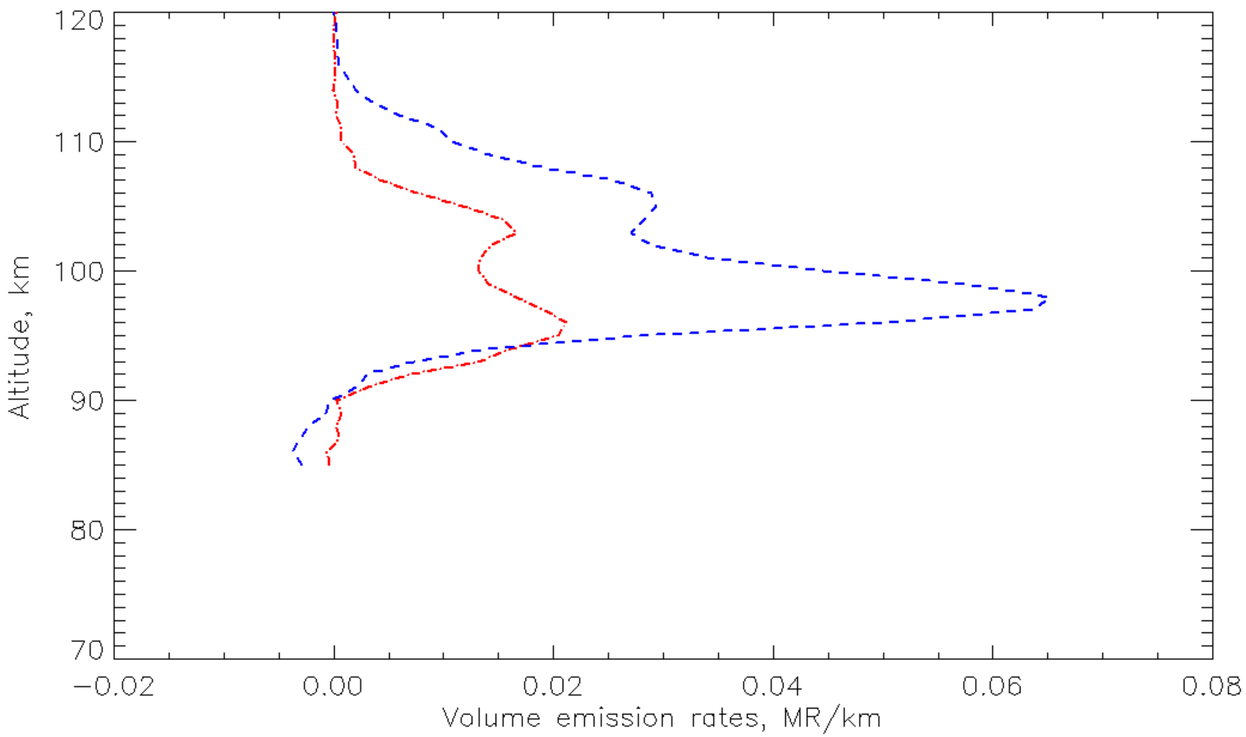
Validation:

Comparison with GW properties as detected by other instrument

Method

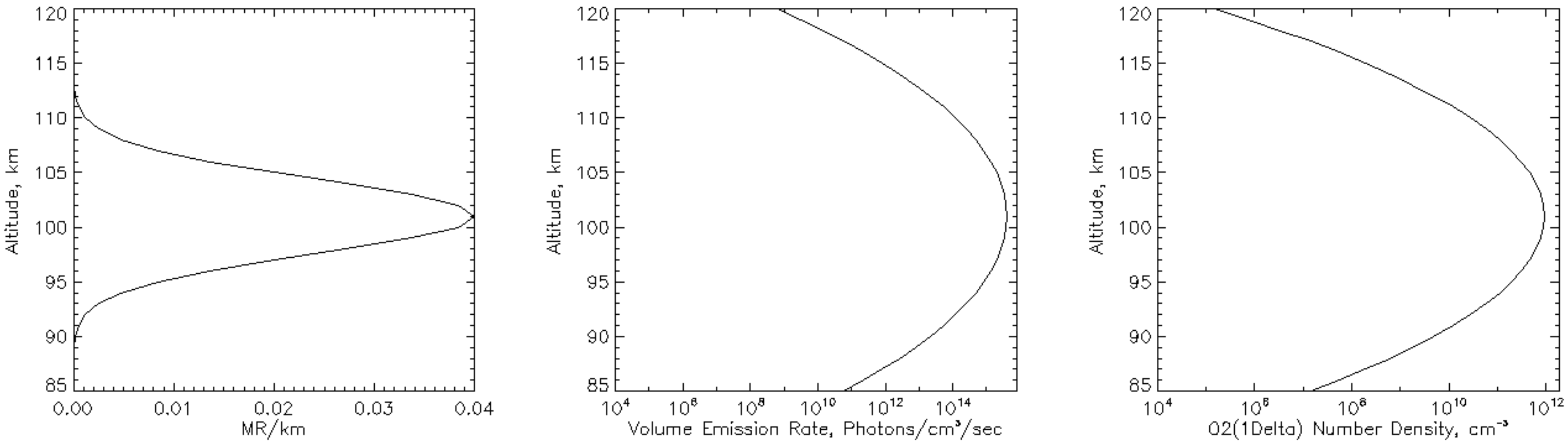
Inverted VIRITS O_2 ($a^1\Delta_g$) vertical profile ⟶ PERTURBED

DATASET : 7800 limb profiles, inversion method: onion peeling (spherically symmetric emission layer)



Method

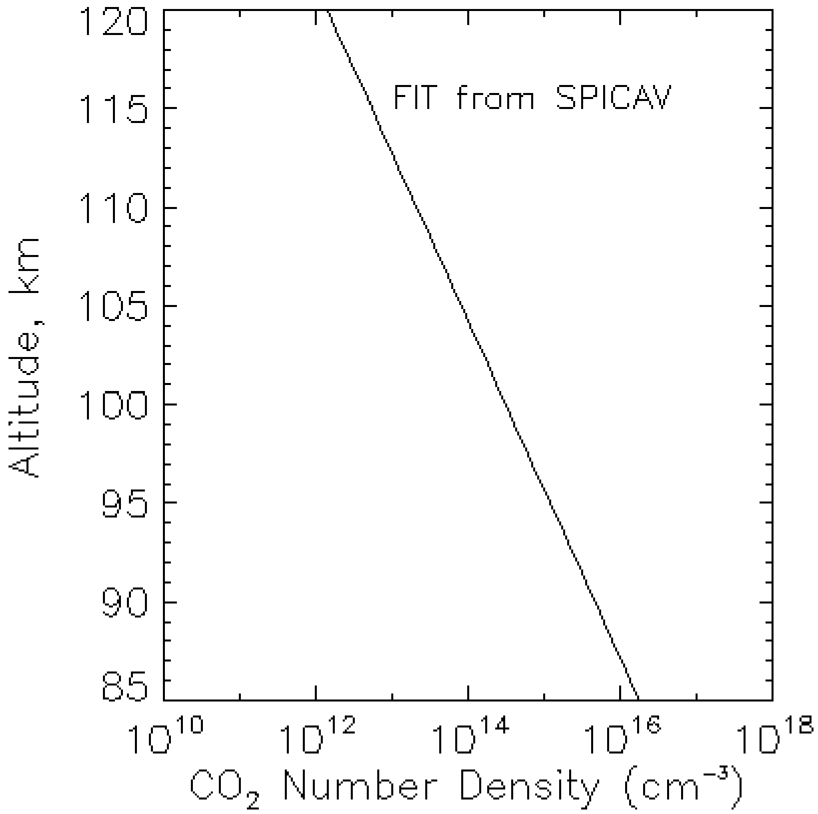
1. O_2 ($a^1\Delta_g$) initial vertical profile → UNPERTURBED



FWHM = 8km

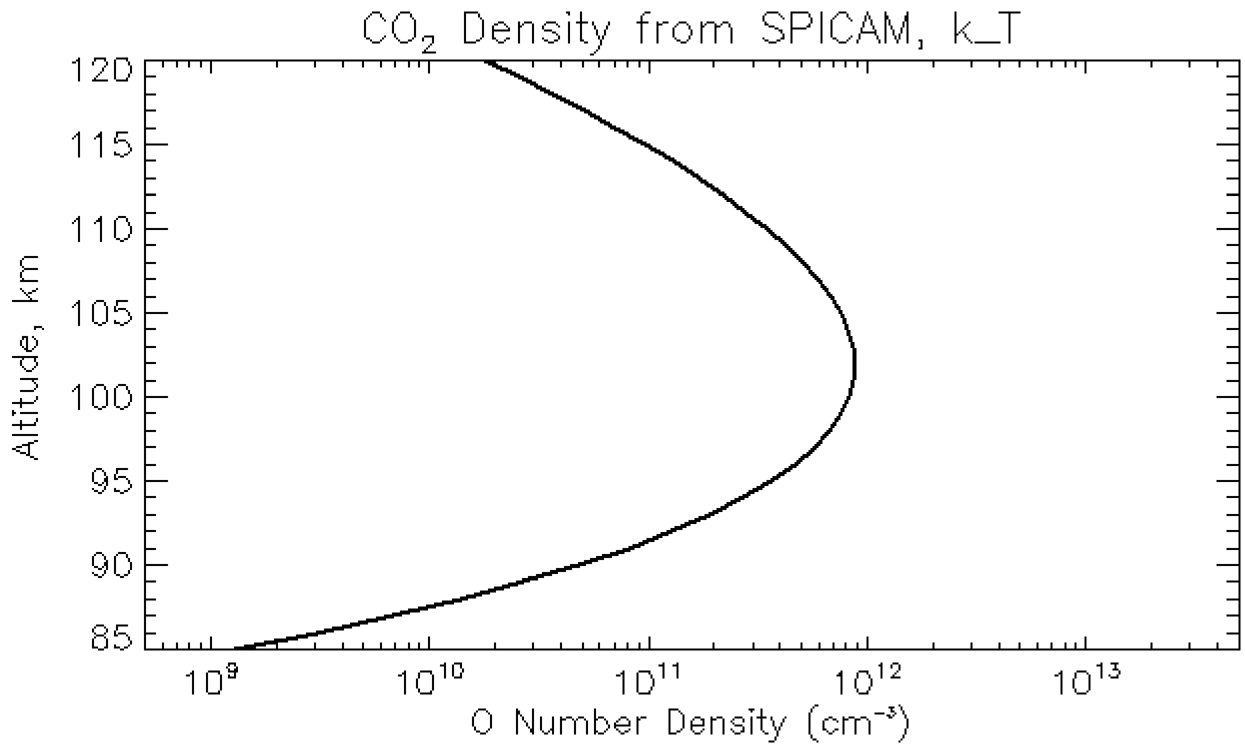
Method

2. CO_2 initial vertical profile (SPICAV data, Bertaux et al. 2007)



Method

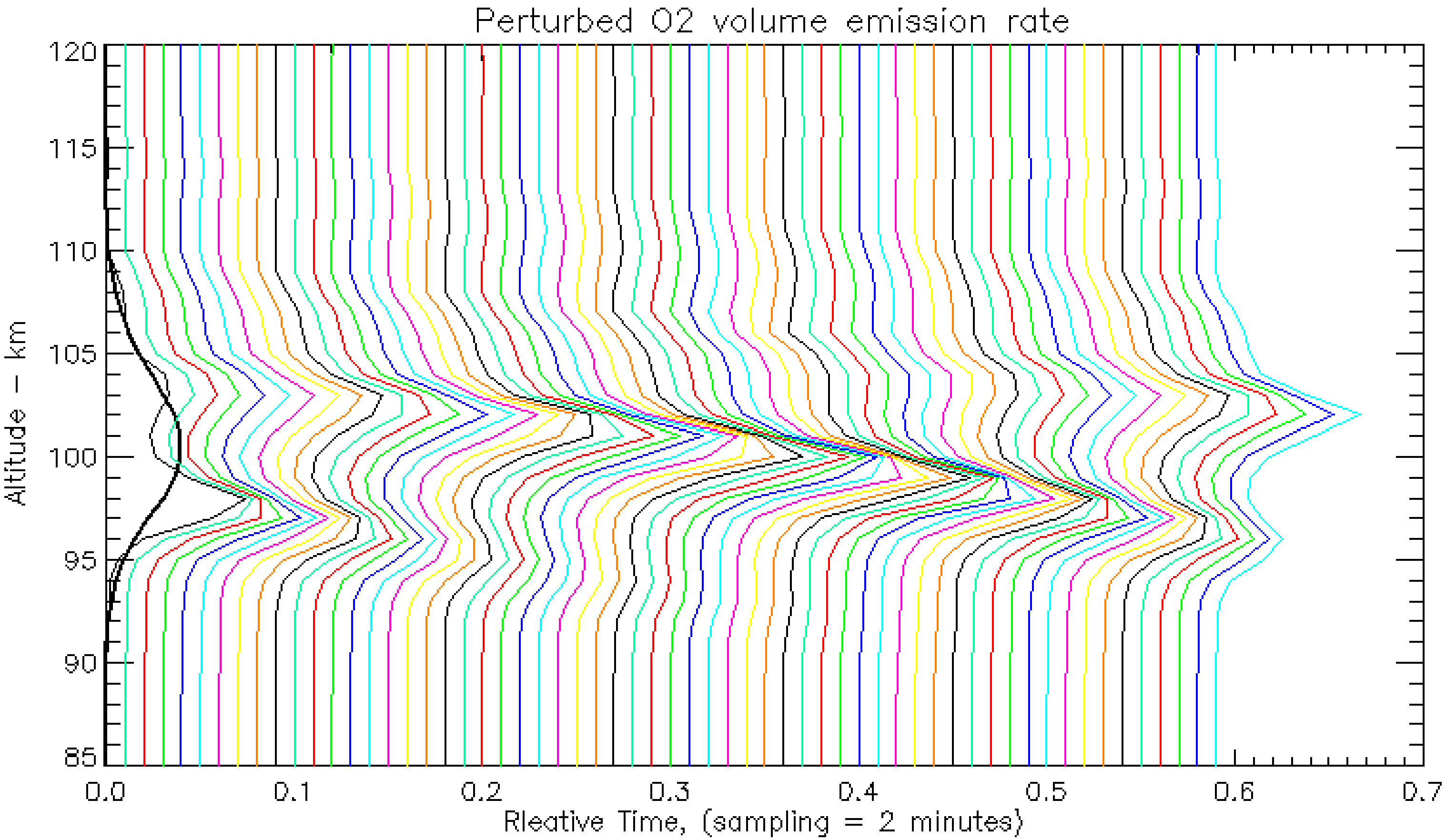
3. O initial vertical profile (Gerard et al. 2009)



Method

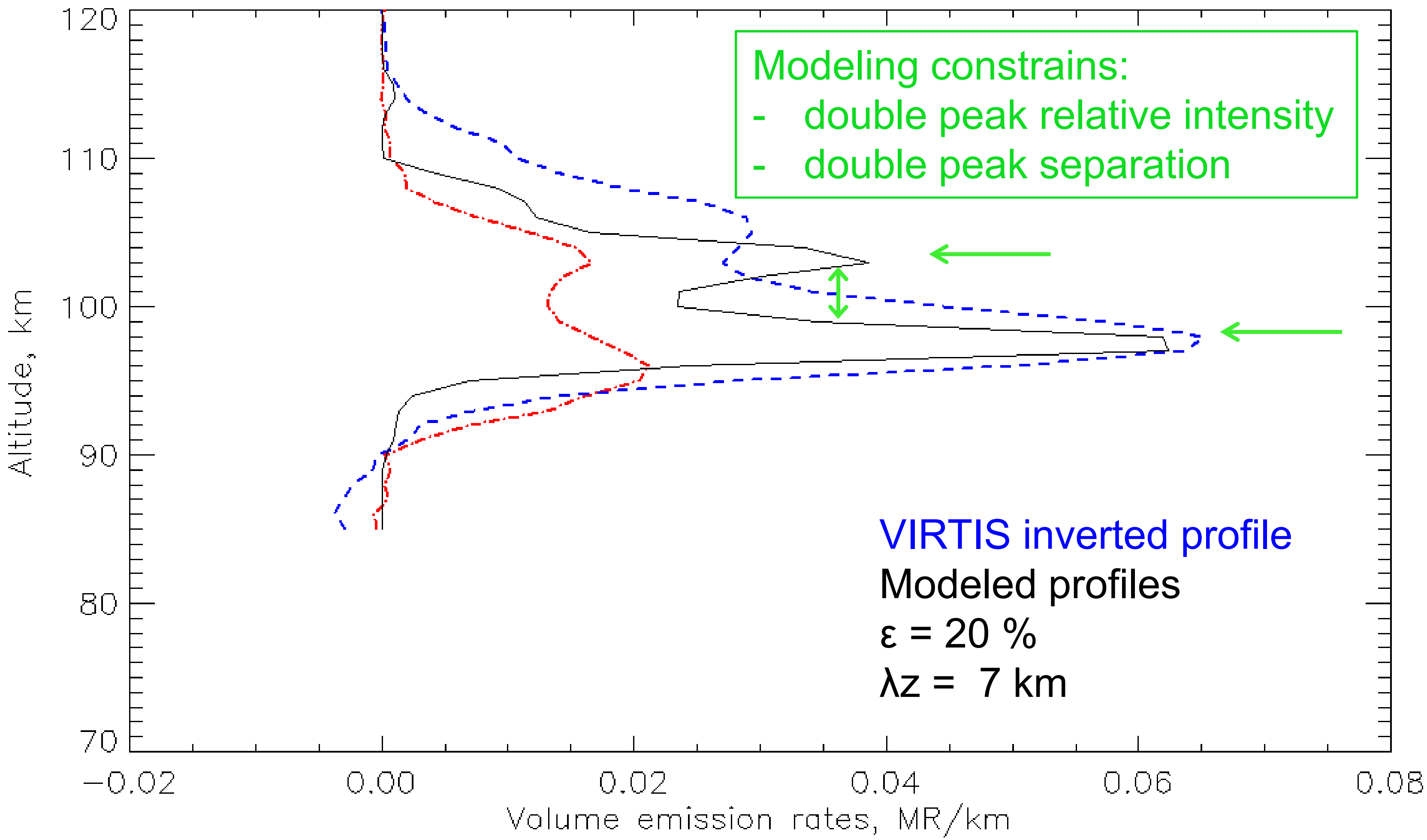
4. GW action as a function of time

ε = 20%, λz = 7 km



Method

5. Fit

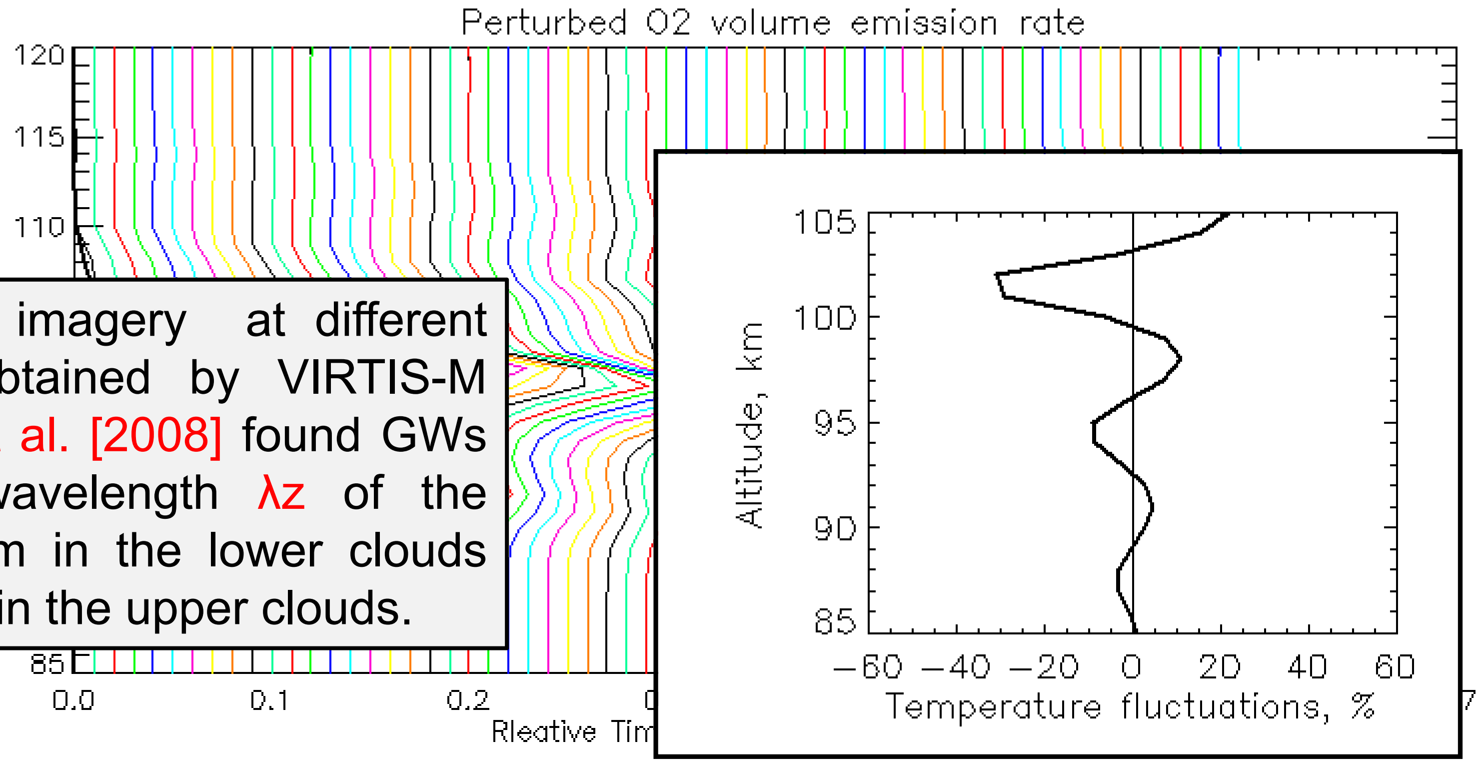


Modeling constrains:
- double peak relative intensity
- double peak separation
VIRTIS inverted profile
Modeled profiles
ε = 20 %
λz = 7 km
Altitude, km
Volume emission rates, MR/km
120
110
100
90
80
70
−0.02
0.00
0.02
0.04
0.06
0.08

Method

GW action as a function of time

ε = 20%, λz = 7



Through could imagery at different wavelengths obtained by VIRTIS-M data, Peralta et al. [2008] found GWs with vertical wavelength λz of the order of 2-5 km in the lower clouds and 5 to 15 km in the upper clouds.

Summary and Conclusions

- GWs are common features in planetary atmospheres.
- O_2 airglow measurements (imagery and limb profiles) are a powerful method to investigate GWs properties.
- In this study for the first time the Swenson and Garderner (1998), used to model GWs propagation in the Terrestial and Martian atmosphere, has been applied to the Venus' case for modeling VIRTIS O_2 nightglow profiles perturbed by GWs action.
- On Venus, oscillations in the O_2 nightglow reveal the occurrence of strong GWs at ~ 100 km with short vertical wavelengths (~ 5-7 km).
- The expected temperatures fluctuations are of the order of 10-20% between 90 – 100 km.

Thank you!