MODELING OF HIGH-PRESSURE TURBULENT MULTI-SPECIES MIXING APPLICABLE TO THE VENUS ATMOSPHERE. J. Bellan, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, MS. 125/109, Pasadena CA 91109 and Mechanical and Civil Engineering Department, California Institute of Technology, Pasadena, CA 91125, Josette.Bellan@jpl.nasa.gov

Introduction: The thermodynamic conditions in the Venus atmosphere, nominally at a pressure of 92 atm, a temperature of 750 K and having a global nominal composition of 96.5% CO2 and 3.5% N2 imply that heat and mass exchange processes in the atmosphere occur under supercritical conditions. In contrast to well-known heat and mass exchange processes at 1 bar, 298 K and Earth atmosphere composition, those on Venus must be described using real-gas thermodynamics, generalized species-mass and heat fluxes based on the formulation of dissipation-fluctuation theory [1] and consistent high-pressure transport properties utilizing high-pressure valid mixing rules [2]. The presence of minor (i.e tracer) species in the Venus atmospherre – 150 ppm SO2, 70 ppm Ar, 20 ppm H2O and 17 ppm CO --- may though introduce some aspects, such as metastable states, that have not been considered so far.

A comprehensive theory of high-pressure multi-species mixing [3] is presented and salient results pertinent to the Venus atmosphere are discussed. Further, using this theory, simulations of CO2 and N2 mixing at high pressure and temperature are discussed and analyzed [4]. The influence of the insights obtained from these results on Venus exploration and planned future studies are addressed.

Turbulent mixing of CO2 and N2:

To evaluate the model, spatial, rather than temporal simulations were performed of a N2 jet at 750 K injected into a chamber pressurized to 60 atm and containing CO2 at 450 K. This configuration represented an experimental configuration used at the University of Southern California (USC). While the experimental data is still forthcoming, the DNS computations revealed that the high density gradients observed in the five-species mixing are still present and are of order 10^4 kg/m^4 as shown in Fig. 1 where the mass fraction of N2 is also plotted showing the mixing with CO2 further downstream and furthermore depicted is the second invariant of the rate of deformation tensor which is indicative of vortical structures in the flow displaying the vortex rings near the inlet and the breakdown of the flow into small turbulent features downstream. Time-averaged results (not shown) reveal a potential core near the inlet downstream of which the density increases due to the mixing of N2 with the heavier CO2.

Summary and conclusions: The studies described above show the intricacies of multi-species mixing under high-pressure high-temperature turbulent conditions. The model can be used to study the time evolution of a three-dimensional vertical slice of the Venus PBL with a domain having non-reflecting boundary conditions (i.e. domain size influence minimized). Since the near-ground Venus atmosphere composition is not known with certainty, additional to CO2/N2, other compositions, i.e. including minor species, can be simulated to determine whether the Venus atmosphere could be in a metastable state in which micro-drops are suspended into a fluid; then the interpretation of signals from probes moving vertically through the Venus atmopshere would require special interpretation, i.e. accounting from scattering from the micro-drops. The near-ground unstable temperature gradient may also be explained by such findings.

References: [1] Keizer J. (1987) *Statistical Thermodynamics of Nonequilibrium Processes,* Springer. [2] Harstad K. G. and Bellan J. (2004) *J. Chem Phys., 120(12),* 5664-5673. [3] Masi E., Bellan, J., Harstad, K. G. and Okong'o N. A. (2013) *J. Fluid Mech., 721,* 578-626. [4] Gnanaskandan A. and Bellan J. (2017) in preparation.

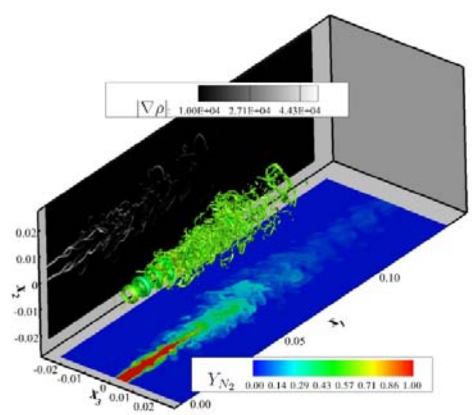

Figure 1 N2 jet (at 750 K) injection into a CO2-filled chamber at 60 atm (and 450 K). Instantaneous snapshot of the vortical jet features, the density gradient magnitude in kg/m^4 and the mass fraction of N2.