Possibility of lightning in the Venusian clouds due to Super-rotation

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Introduction

- This theoretical work proposes the mechanism of lightning is possibly due to the super-rotation of the clouds.
- Excessive amount of atmospheric turbulence and the formation of plumes in the clouds of Venus should possibly lead to the formation of charges in the clouds and thereby trigger lightning.
- The study is conducted using Computational Fluid Dynamics simulation in COMSOL Multiphysics, the flow behavior in the atmospheric layers ranging between 40Km and 70Km corresponding to the cloud layers with respect to it's horizontal distance were analyzed in 2D. The layers have been split with a resolution of 1 Km each and three different simulations were performed for lower, middle and upper cloud decks respectively.

Electrical activity in the cloud region

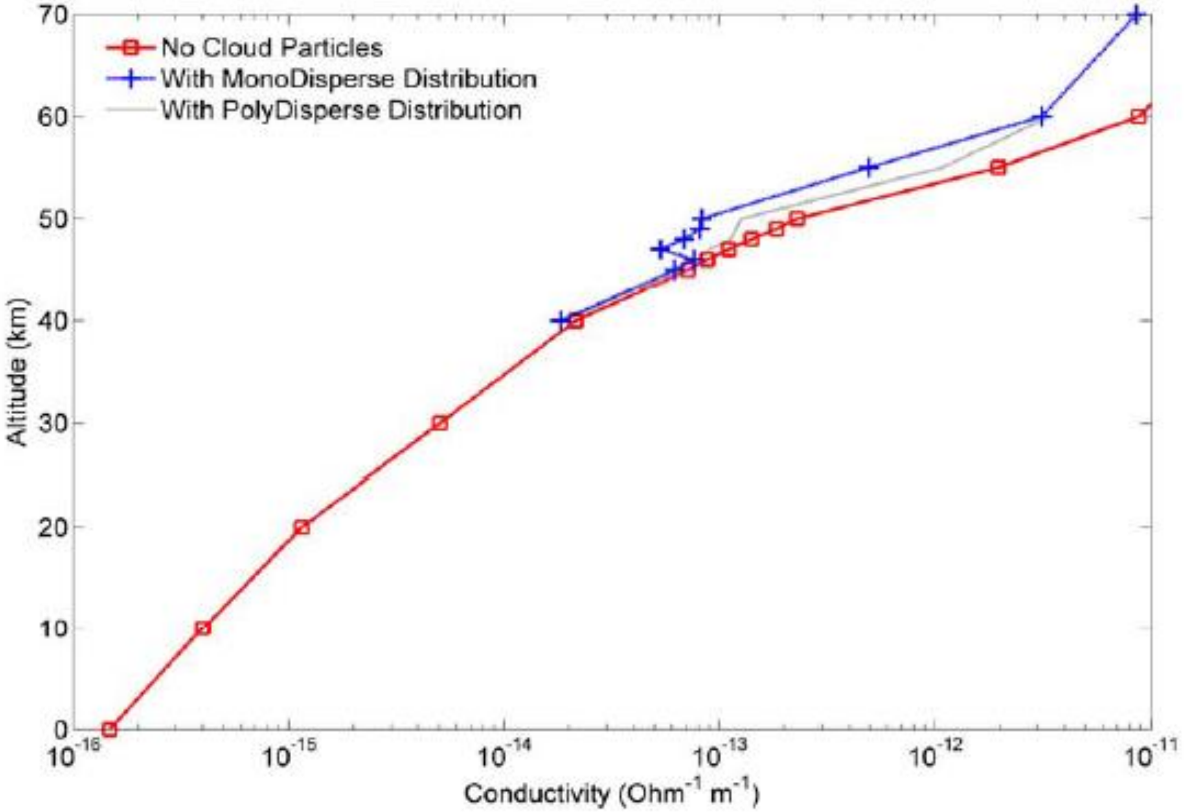

Fig 1: Altitude profile of conductivity for various conditions in the atmosphere of Venus. (extracted from Michael et al., 2009)

- Lightning occurs due to a sudden breakdown in the cloud medium. It is often due to large concentrations of positive and negative charge.
- Cloud lightning is also associated with the convective activity of the atmosphere.
- Cloud formation is associated with condensation of molecules on monodisperse or polydisperse aerosols which act as the nuclei.
- Solar radiation, cosmic rays, atmospheric circulation and heat transport from the solid planet act as some of the factors of ionization of aerosols and charge transport.

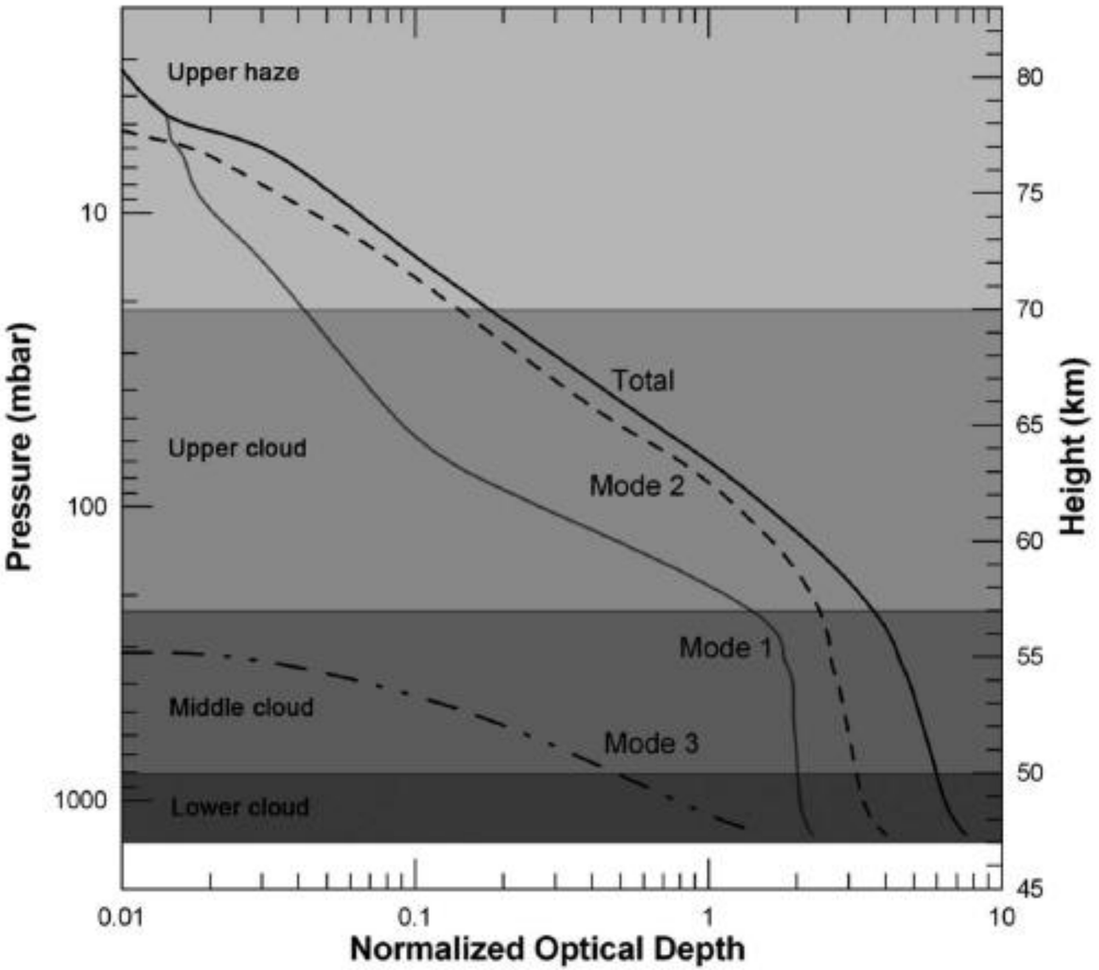

Fig 2: Vertical distribution of particles in Venus atmosphere. Shaded areas mark the extension of the three cloud decks and the haze above. Lines show the contribution to the total optical thickness normalized to the value at 630 nm for an isotropic scatterer. Modes represent different particle sizes. (extracted from Hueso et al., 2008)

Mode 1 (radii around 0.1 µm), Mode 2 (radii ~ 1.0µm) , Mode 3 (radii around 3.0 − 5.0µm).

- The When two particles of a different size collide and rebounce, the larger particle will be negatively charged and the smaller one positively charged.
- charged particles will be separated thereafter by convection and gravitation due to their different masses.
- The ambient field strength and its orientation with respect to the particle affect the magnitude and sign of the charge transfer(*Tokano, T., et al 2001*).
- As the cloud conductivity is less in the bottom cloud region, there is a possibility lightning can be developed in these regions, it is possibly taking place in form of electromagnetic emissions in the ELF and VLF regions as measured by the Venera 11 and 12 landers.

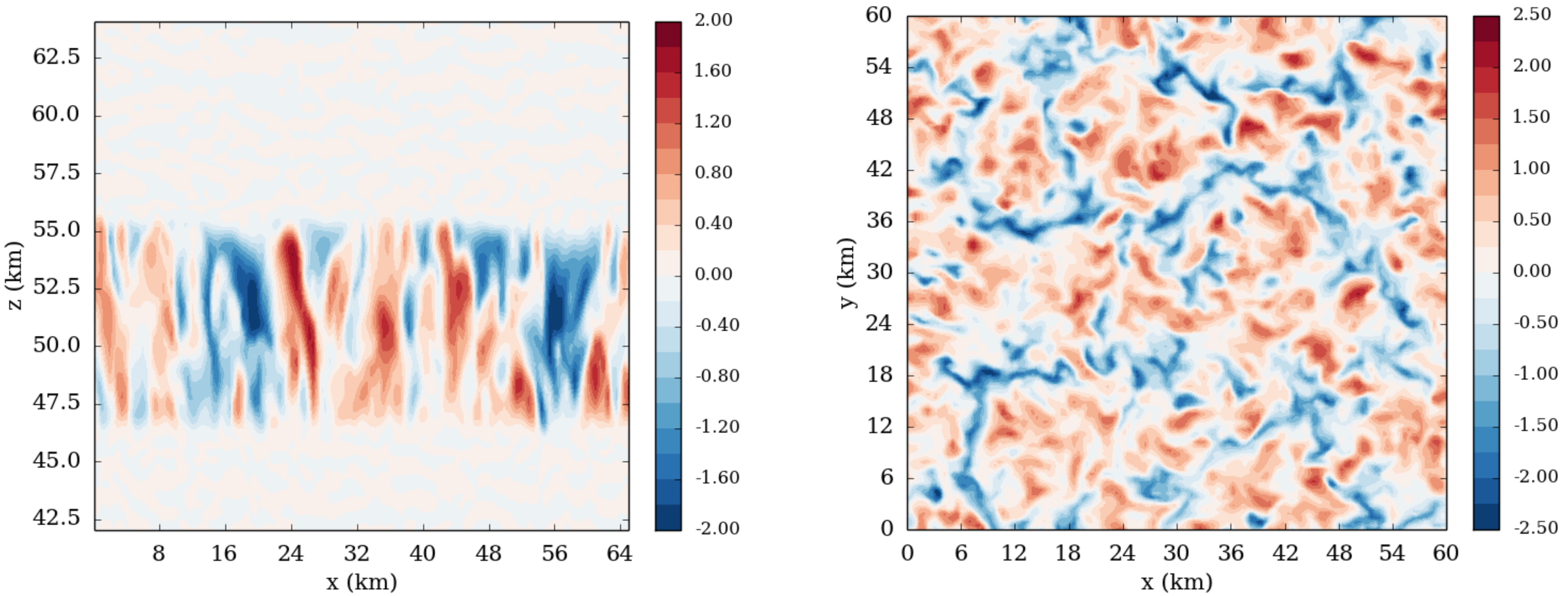

Fig 3: Snapshots of the cloud convective vertical motions : vertical cross-section at y = 20 km between 42 and 65 km of altitude (left) and horizontal cross-section at 51 km of the vertical wind (m/s) (right) at the Equator at noon. (extracted from Lefèvre et al., 2018)

For full manuscript : M. Lefèvre, Sébastien Lebonnois, A. Spiga. Three-dimensional turbulence-resolving modeling of the Venusian cloud layer and induced gravity waves. Inclusion of complete radiative transfer and wind shear. Journal of Geophysical Research. Planets, Wiley-Blackwell, 2018, 123 (10), pp.2773-2789. <10.1029/2018JE005679>. <hal-01980130>

As per *Lorenz 2018*, the presence of discharge currents in the lower atmosphere of Venus which has been detected by the Venera 13 and 14 landers. It is also stated that, there exists atmospheric haze or dust which is necessarily charged.

The formation of plumes would initiate the charge generation mechanism in the cloud region which can be inferred from the simulations done by *Lefèvre et al. 2018* using the 3 dimensional turbulence resolving model.

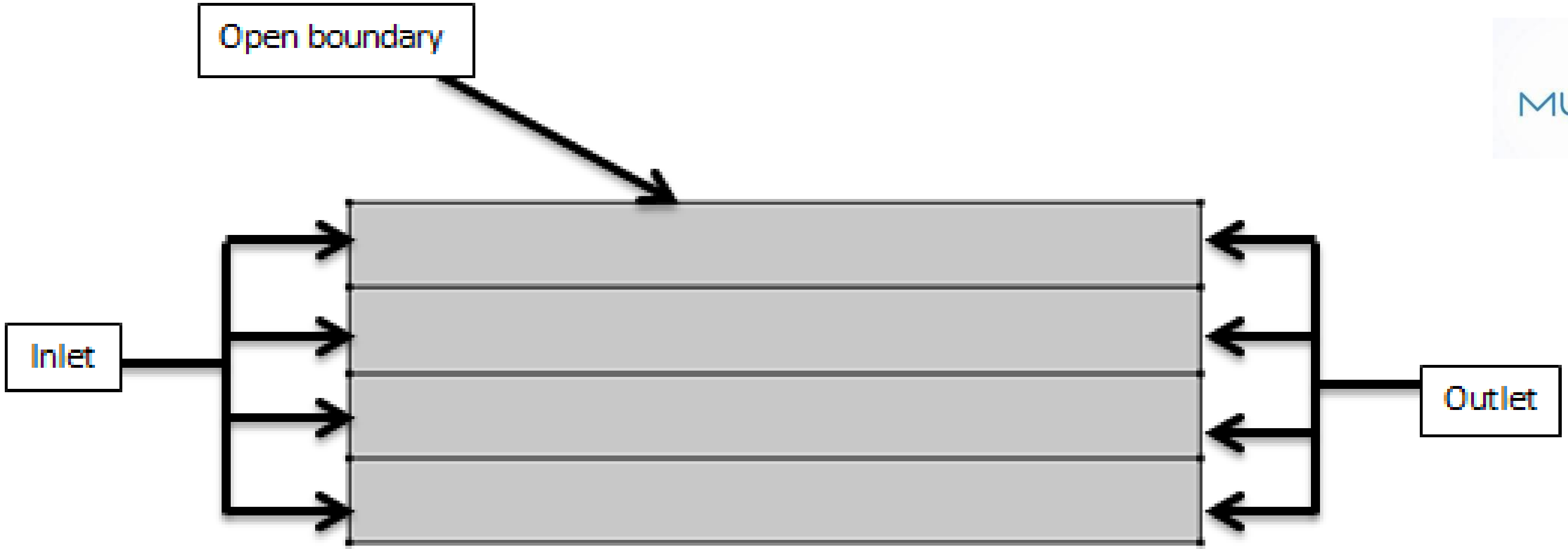

Fig 4: 2D Modelling the cloud layers in COMSOL Mutiphysics

- The 2D mode is done using COMSOL Multiphysics used the atmospheric properties corresponding to VIRA model (*A. Seiff, et al.* 1986).
- Each horizontal layer corresponds to 1 Km of the atmospheric layer with inlet section in the left and outlet section in the right as the boundary conditions for the model. The open boundary in the top is used to simulate the vertical motion of the wind movement.
- The K-omega model that is used here is one of the most commonly used turbulence models. It is a two equation model, that means, it includes two extra transport equations to represent the turbulent properties of the flow. This allows a two equation model to account for history effects like convection and diffusion of turbulent energy. The first transport variable is turbulent kinetic energy (k) determines the scale of turbulence. The second transported variable in this case is the specific dissipation (omega) determines the energy in the turbulence.

Velocity profile for different cloud layers based on the VIRA model

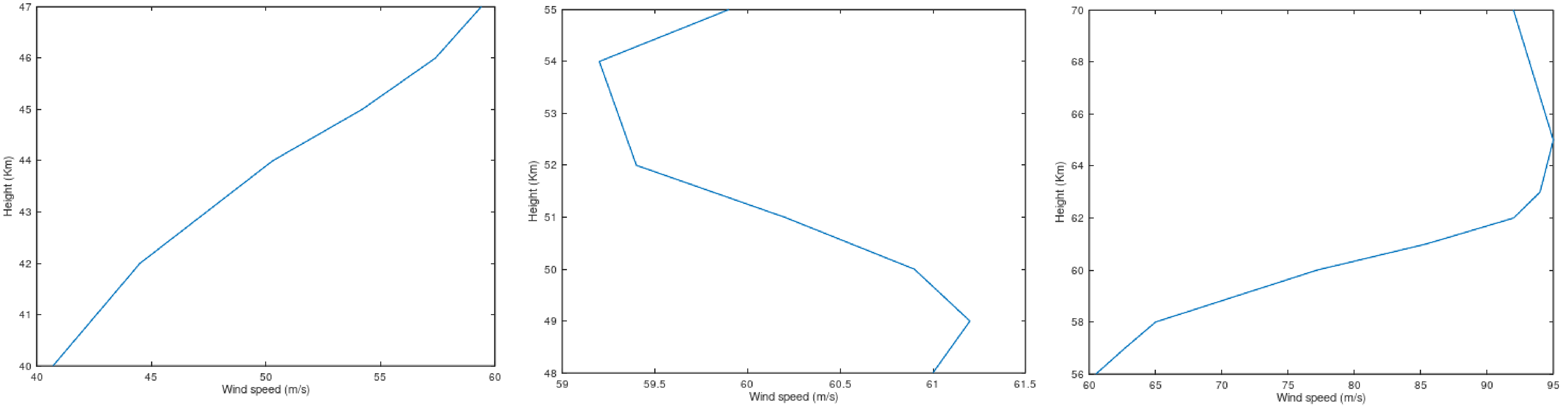

Fig 5: Altitude vs Windspeed for lower cloud deck(left), middle cloud deck(center) and upper cloud deck(right)

Flow simulations in the cloud layers

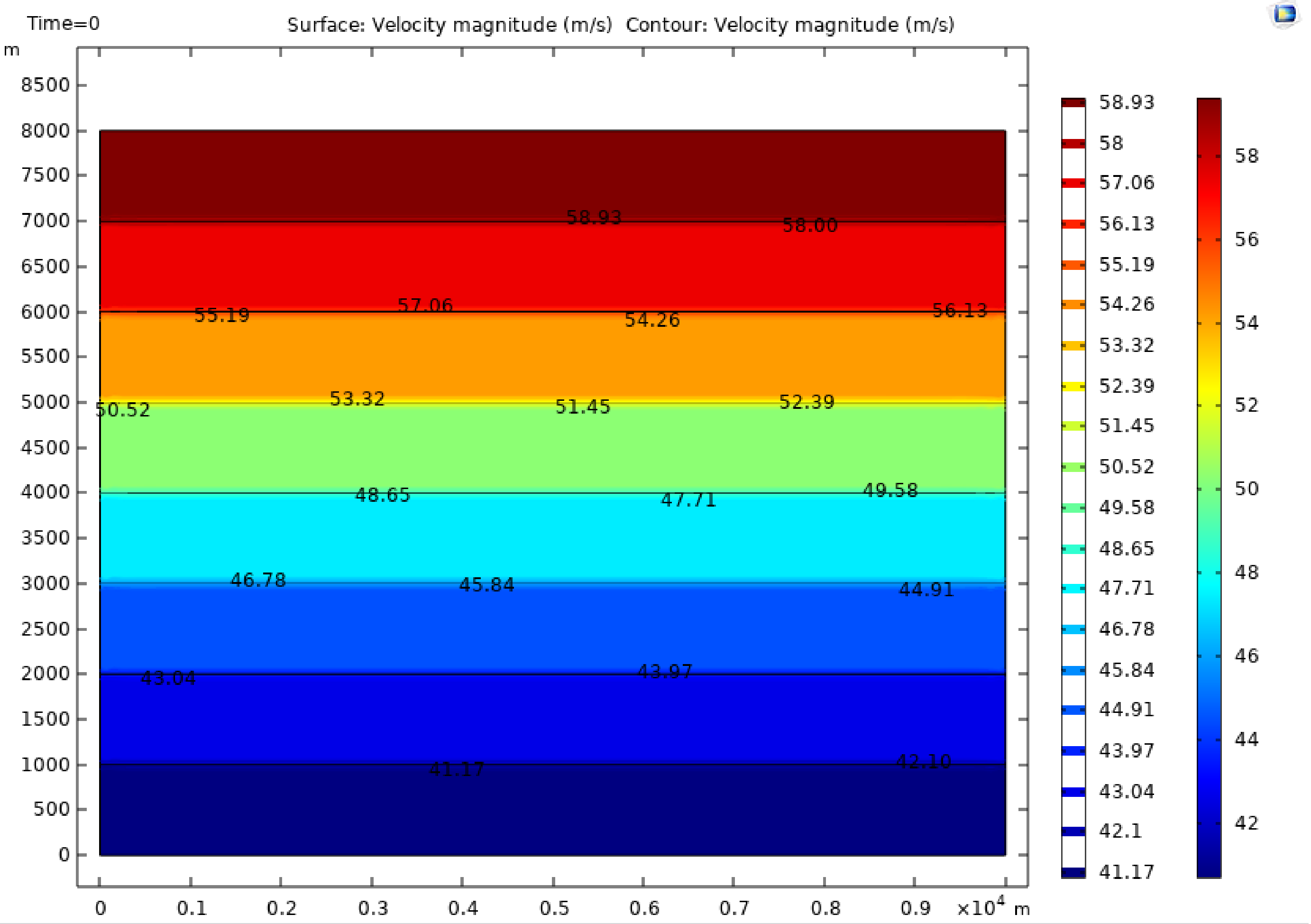

Fig 6: Initial conditions for the lower cloud deck(40-47Km)

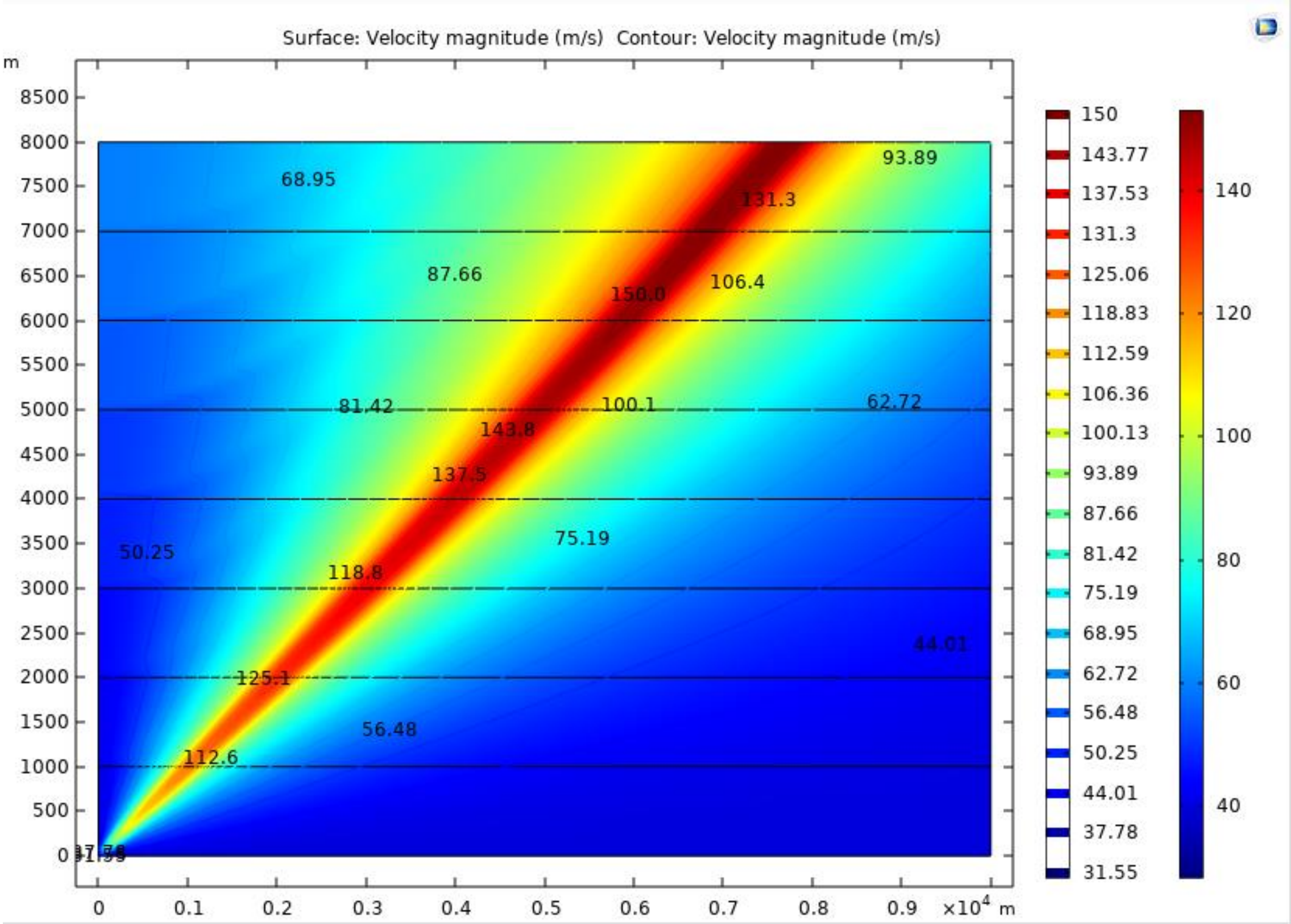

Fig 7: Result at the end of simulation for the flow pattern in the lower cloud deck(40-47Km)

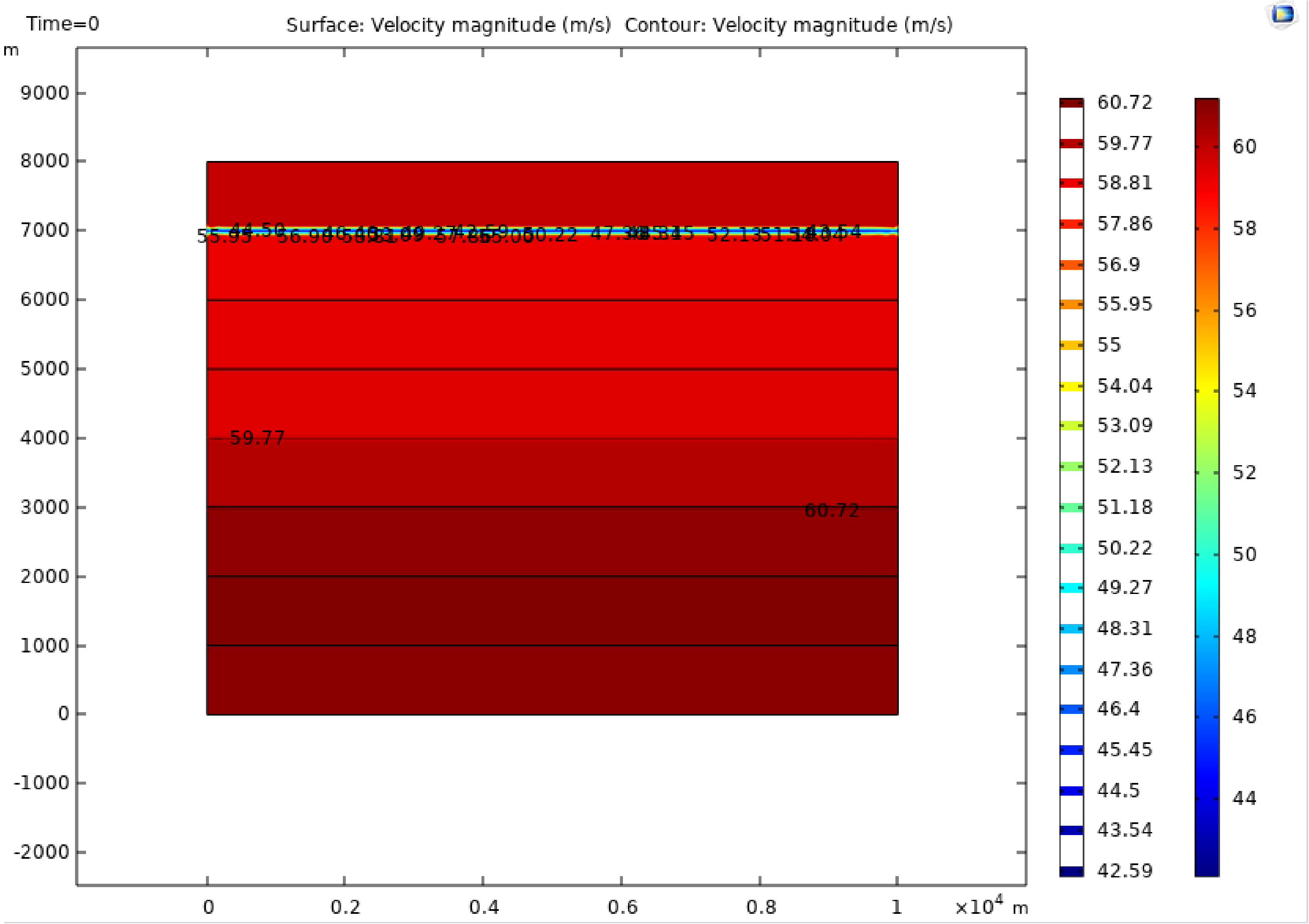

Fig 8: Initial conditions for the middle cloud deck(48-55Km)

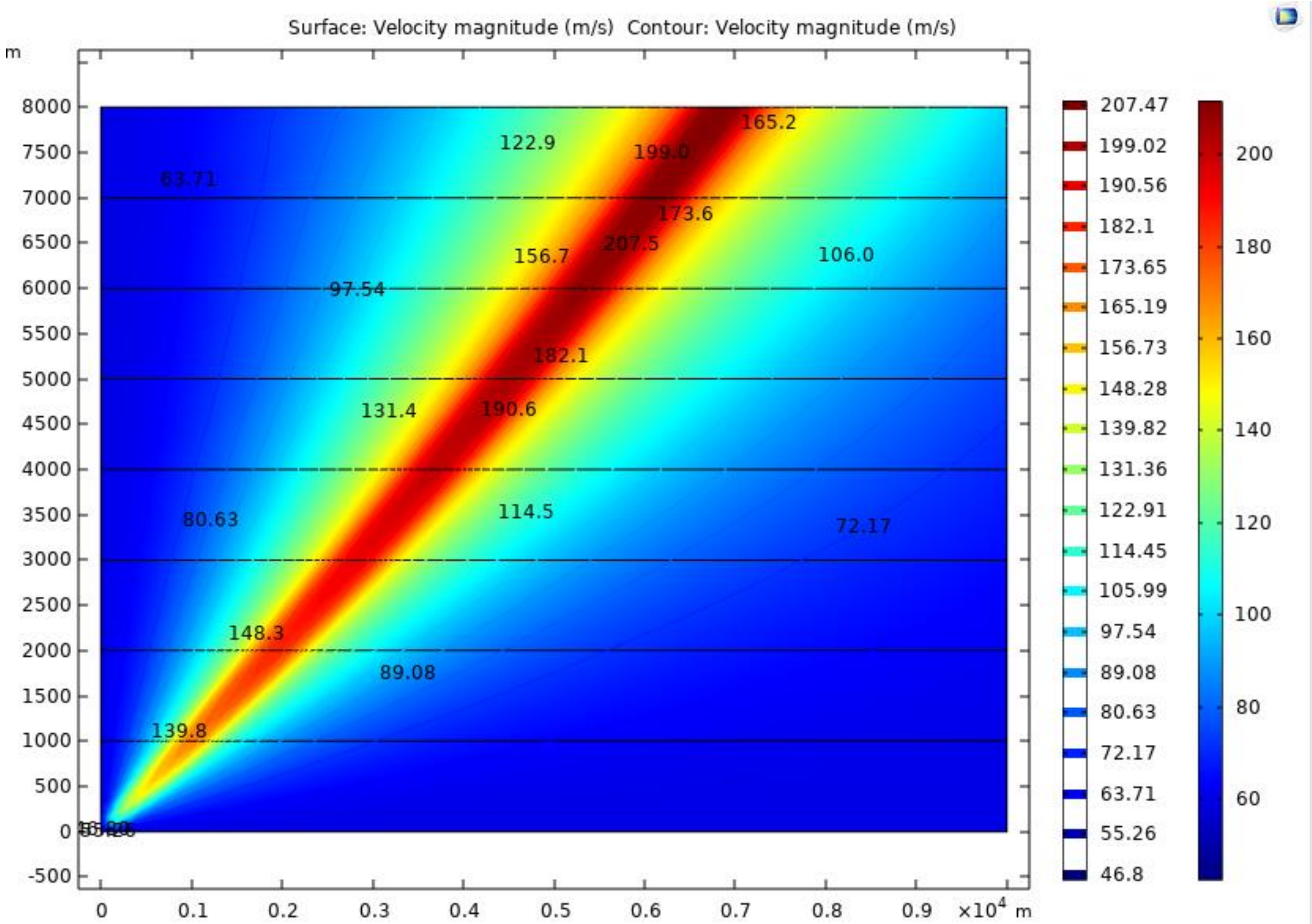

Fig 9: Result at the end of simulation for the flow pattern in the middle cloud deck(48-55Km)

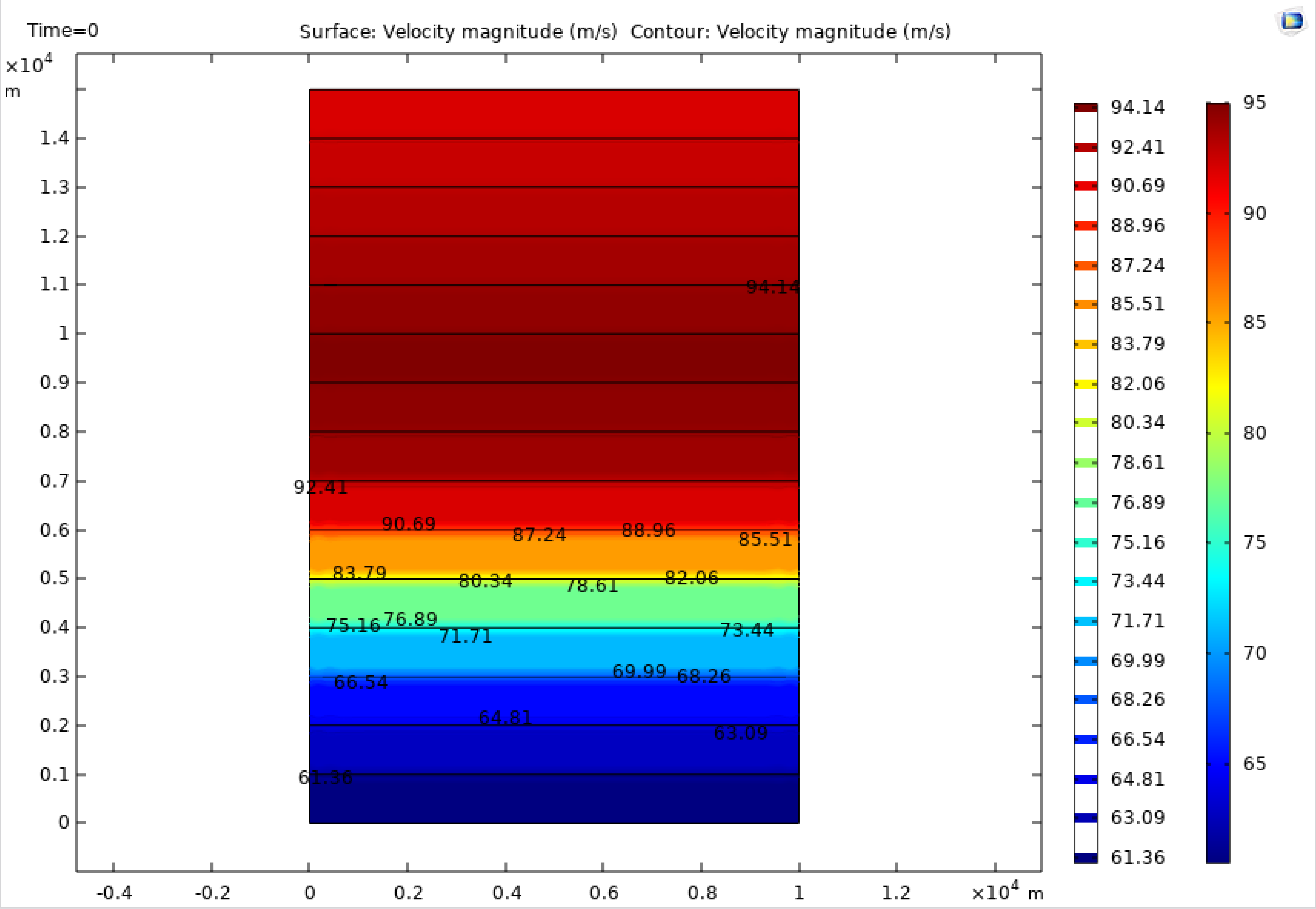

Fig 10: Initial conditions for the upper cloud deck(56-70Km)

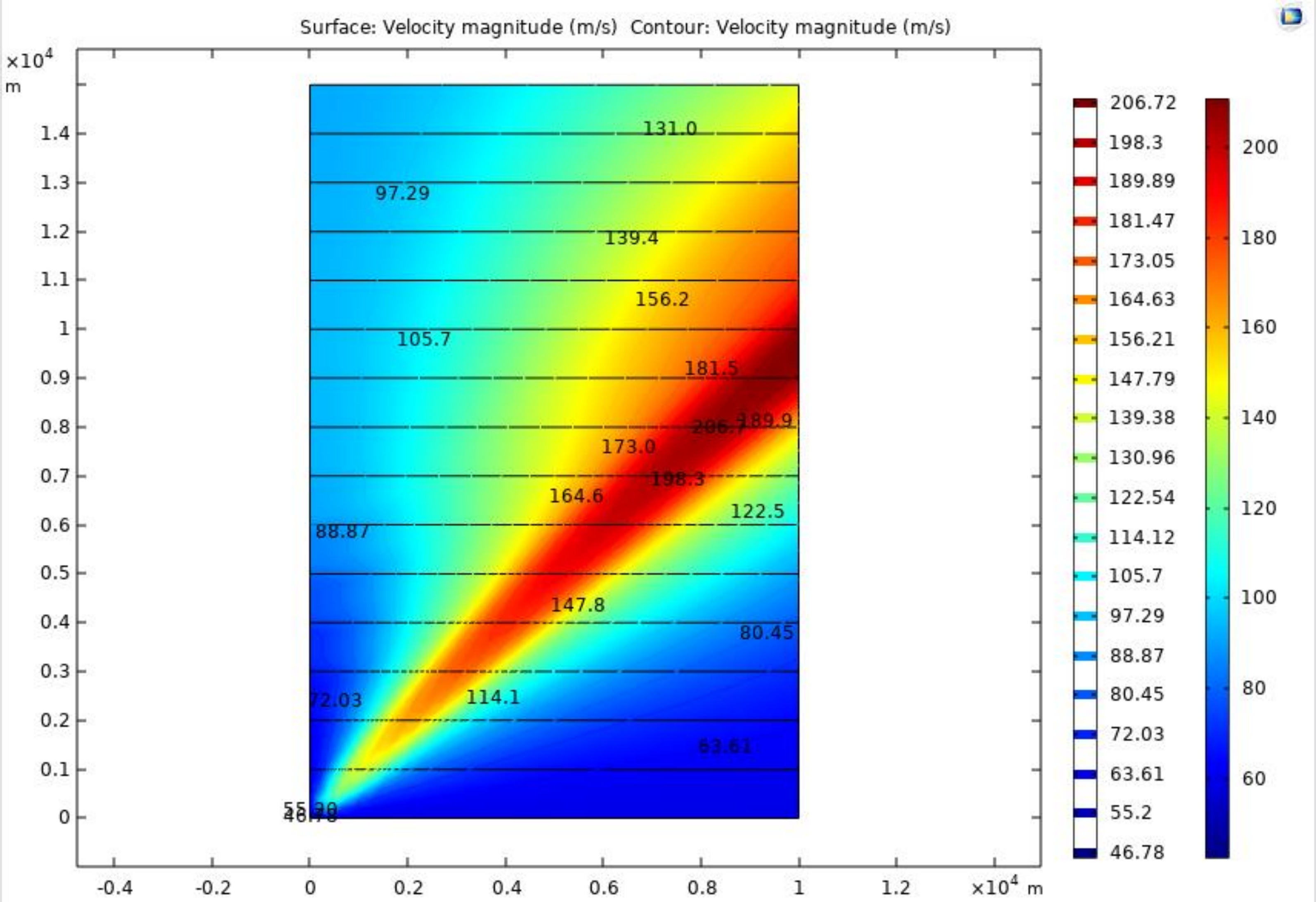

Fig 11: Result at the end of simulation for the flow pattern in the upper cloud deck(56-70Km)

Interpretation of the results

The results obtained from the simulation for the three cloud layers look similar given their respective initial conditions. In general, it is depicting the viscous flow in the clouds and the amount of vertical transport in terms of the increase in the magnitude of the wind velocity. It helps us understand the turbulent kinetic energy and the mixing.

Turbulence in the clouds

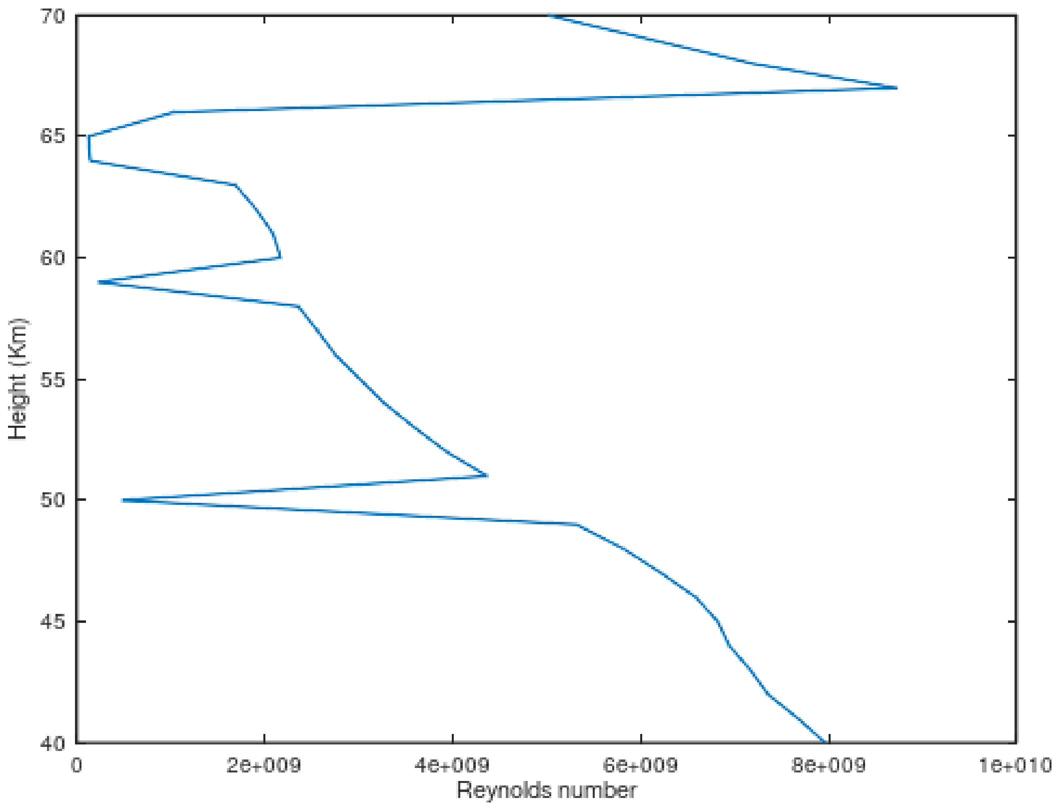

Fig 12: Variation of Reynolds number vs altitude

It can be seen from the graph that there is a high degree of turbulence in the cloud regions. The electrical discharges in the lower cloud regions is possibly due to the formation of ions caused by the rubbing of particles and the discharge occurs as it meets the ambient conditions.

Summary :

- Particles of different sizes are mixed and present in the cloud regions.
- Presence of charged aerosols in the lower cloud region.
- Formation of plumes in the clouds because of the convection especially in the lower to middle cloud regions.
- CFD simulations show that there is vertical transport and friction between the clouds as a result of the viscous flow.
- Higher Reynolds number in the lower cloud region.

Take home message,

Lightning in the cloud regions is possibly due to the integration of the above factors and can be possibly located in the regions of convective clouds along the direction of Super-rotation of the clouds. The charged aerosols can be a trigger to the formation of charges in the lower cloud deck that leads to the formation of charge aggregates and consequently lead to lightning. However, the charge stability is not clearly understood and needs further investigations which would help understand this phenomenon better!

Thank You!