Controls on Plume Heat Flux and Plume Excess temperature

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Plume heat flux and plume excess temperature in the upper mantle inferred from surface ovservations may pose important constraints on the heat flux from the core and mantle internal heating rate. This study examined the relationship between plume heat flux Q_p, core-mantle boundary (CMB) heat flux Q_{cmb} and plume excess temperature ΔT_{plume} in thermal convection using both numerical modeling and theoretical analysis. 3-D regional spherical models of mantle convection were computed with high resolution and for different Rayleigh number, internal heat generation rate, and viscosity structures. An analytic model was developed for variations in Q_p and ΔT_{plume} with depth. The results can be summarized as following. 1) Mantle plumes immediately above the CMB carry nearly 80%-90% of the CMB heat flux. 2) Q_p and ΔT_{plume} decrease by approximately a factor of two for plumes to ascend from near the CMB to the upper mantle depth. 3) Our analytic model indicates that the decrease in Q_p and ΔT_{plume} is mainly controlled by adiabatic cooling and the reduction ratios for Q_p and ΔT_{plume} due to this effect are $exp(\gamma D_i \Delta r)$ for plumes to ascend over a distance Δr, where D_i is the dissipation number and γ is the ratio of the Earth's radius to the mantle thickness. 4) The subadiabatic temperature also contributes to the reduction of Q_p and ΔT_{plume}, but its contribution is only 20% to 30%. Subadiabatic temperature from our models ranges from 70 K to 240 K for CMB temperature of 3400 ^oC. 5) Our results confirms that 60%-70% internal heating rate for the mantle or Q_{cmb} of ~12 TW is required to reproduce the plume-related observations.