Analysis of Effects of Meander Curvature in Thermally Stratified Turbulent Open-channel Flow

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Abstract

Thermal stratification can lead to the damping of turbulence, which reduces the mixing of solutes in a fluid body, and in turn, affects river health. A series of Direct Numerical Simulation (DNS) solutions sweeping through a range of four different channel radius of curvature is obtained to investigate the effect of curvature on stratification in meandering thermally stratified turbulent open channel flow. This range of radius of curvature will cover a range of the curvature parameter 0.2 < γ <1.5, which is typical of rivers in the sharp to mild curvature range. Here γ = C_fˆ-{1} (H/R_{min} is a dominant control parameter with respect to velocity redistribution in curved open-channel flow, where C_f is the Chezy friction coefficient, R_{min} the minimum radius of curvature, which occurs at the meander apex, H the meander height. An internal heat source models radiative heating from above following an exponential Beer's law profile, which varies with height due to progressive absorption. Based on the DNS results, the present paper addresses two issues. Firstly, the influence of changing curvature on the complex tri-cellular pattern of the secondary flow is investigated, including the distribution of turbulent stresses. Secondly, the effect of changing curvature on the degree of stratification is analysed. Stratification can be characterised by the friction Richardson number Ri_τ = (βgHΔΦ)/uˆ2_τ, and the bulk Richardson number Ri_b = (βgHΔΦ)/uˆ2_{bulk}. Here ΔΦ is the difference between the mean temperature at the top and bottom of the channel, u_τ the mean friction velocity on the solid surfaces bounding the channel, u_{bulk} the domain averaged streamwise velocity, β the volumetric coefficient of expansion and g gravity. Stratification can also be viewed in terms of the transfer of energy from mean flow kinetic energy to potential energy via buoyancy fluxes. We study the effect of curvature on stratification by investigating its effect on the friction and bulk Richardson numbers, the global available, background, total potential energy, and the domain averaged kinetic energy. It is found that with the increase of curvature, Ri_τ and Ri_{bulk} decrease, while available potential energy increases due to increased overturning of the flow, indicating that increasing curvature leads to a decrease in the level of stratification.

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Abstract

Thermal stratification can lead to the damping of turbulence, which reduces the mixing of solutes in a fluid body, and in turn, affects river health. A series of Direct Numerical Simulation (DNS) solutions sweeping through a range of four different channel radius of curvature is obtained to investigate the effect of curvature on stratification in meandering thermally stratified turbulent open channel flow. This range of radius of curvature will cover a range of the curvature parameter $0.2 < \gamma < 1.5$, which is typical of rivers in the sharp to mild curvature range. Here $\gamma = C_f^{-1}(H/R_{min})$ is a dominant control parameter with respect to velocity redistribution in curved open-channel flow, where C_f is the Chézy friction coefficient, R_{min} the minimum radius of curvature, which occurs at the meander apex, H the meander height. An internal heat source models radiative heating from above following an exponential Beer's law profile, which varies with height due to progressive absorption. Based on the DNS results, the present paper addresses two issues. Firstly, the influence of changing curvature on the complex tri-cellular pattern of the secondary flow is investigated, including the distribution of turbulent stresses. Secondly, the effect of changing curvature on the level stratification are analysed. Stratification can be characterised by the friction Richardson number $Ri_\tau = (\beta g H \Delta\phi)/u_\tau^2$, and the bulk Richardson number $Ri_b = (\beta g H \Delta\phi)/u_{bulk}^2$. Here $\Delta\phi$ is the difference be-

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tween the mean temperature at the top and bottom of the channel, u_τ the mean friction velocity on the solid surfaces bounding the channel, u_{bulk} the domain averaged streamwise velocity, β the volumetric coefficient of expansion and g gravity. Stratification can also be viewed in terms of the transfer of energy from mean flow kinetic energy to potential energy via buoyancy fluxes. We study the effect of curvature on stratification by investigating its effect on the friction and bulk Richardson numbers, the global available, background, total potential energy, and the domain averaged kinetic energy. It is found that with the increase of curvature, Ri_τ and Ri_b decrease, indicating that increasing curvature leads to a decrease in the level of stratification.
