Modifications to the Mellor-Yamada-Nakanishi-Niino (MYNN) model for the stable stratification case

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1. Introduction

The Mellor-Yamada-Nakanishi-Niino (hereafter referred to as MYNN) model is a kind of second-order closure model that was proposed by Nakanishi and Niino (Nakanishi 2001; Nakanishi and Niino 2004, 2006, 2009), and is formulated as a modification of the Mellor-Yamada closure model (Mellor and Yamada 1982) However, the MYNN closure model also has some undesirable features in the stable stratification range (Ri > 0).

First, a critical Richardson number exists in which turbulence ceases to occur in the level 2 model. Some previous studies have pointed out that the effect of turbulence is suppressed by increasing the static stability. Despite this, some turbulence remains.

Second, level 2.5 of the MYNN model yields a flux Richardson number Rf over unity at a large gradient Richardson number Ri. Moreover, Rf diverges to infinity at the Ri $\rightarrow \infty$ limit, regardless of the nondimensional velocity shear function G_M. The behavior of the Rf seen in the MYNN level 2.5 model is inconsistent with observations or laboratory experiments, in which Rf converges to a finite value even for large gradient Richardson numbers (Zilitinkevich et al. 2007).

In the present study, we propose a modification of the MYNN model that is based on the concept proposed by Canuto et al. (2008) for the stable stratification case, and we examine whether or not the modified formulation can solve the above problems.

2. Results

Canuto et al. (2008) concluded that a relaxation time scale of temperature-pressure correlation should be inversely proportional to 1 + Ri. The modification by Canuto et al. (2008) can be simply applied to the MYNN model: the closure constant A_2 that was used in the MYNN model is replaced by $A_2/(1 + \mathrm{Ri})$ when the gradient Richardson number Ri takes a positive value. The modified formulation is presented in Kitamura (2010).

Figure 1 indicates the values of the stability functions S_M and S_H calculated from the modified MYNN level 2 model. The adopted closure constants are same as those of Nakanishi and Niino (2009). While S_H tends to zero as the Richardson number increases, S_M converges to a nonzero finite value. However, the behavior of the stability functions is sensitive to the closure constants. In particular, the closure constants C_2 and C_3 should be chosen with special care. The effects of these constants are crucial for the existence of a critical Richardson number.

Figure 2 displays values for S_M, S_H and the flux Richardson number Rf that were calculated with the modified MYNN level 2.5 model. In contrast to the MYNN model, the flux Richardson number converges to a finite value as the gradient Richardson number increases. This is mainly

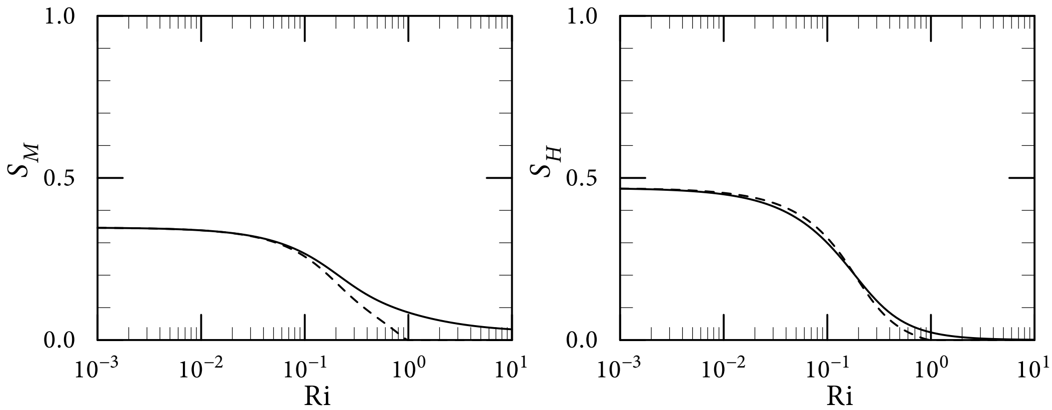

Figure 1: S_M and S_H as a function of the Richardson number in the level 2 model. The solid and dashed lines indicate the results that were obtained from Nakanishi and Niino (2009) and the modified MYNN model, respectively.

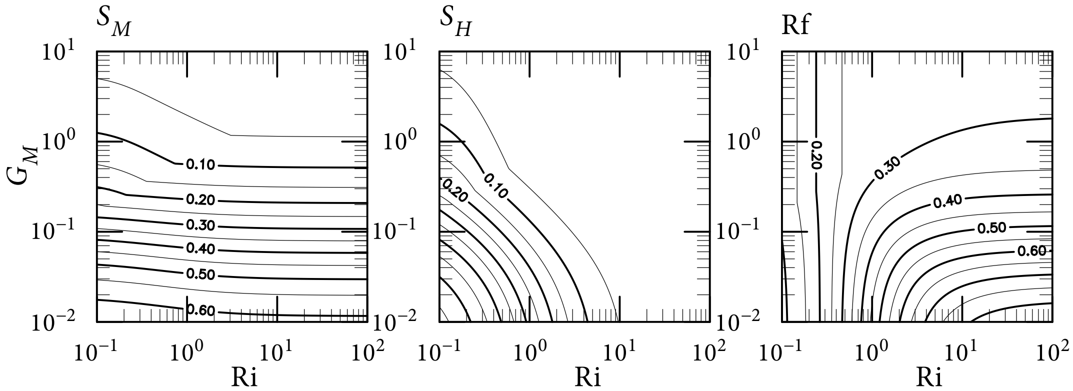

Figure 2: S_M, S_H and the flux Richardson number Rf calculated by the modified MYNN level 2.5 model.

ascribed to the fact that S_M is more insensitive to the gradient Richardson number than that of the MYNN model, whereas S_H tends to decrease as the gradient Richardson number increases. The maximum value of Rf can be analytically calculated as

$$\max(\mathrm{Rf}) = \frac{A_2}{A_1(1 - 3C_1)} \simeq 0.957,$$

using the model constants by Nakanishi and Niino (2009).

Moreover, the modified formulation possesses an advantage even for the level 3 model. While an upper bound for l/q has to be imposed to avoid a singularity appeared in the MYNN level 3 model, this restriction is not necessary for the modified model.

Reference

Kitamura, Y., 2010, Modifications to the Mellor-Yamada-Nakanishi-Niino (MYNN) model for the stable stratification case, *J. Meteorol. Soc. Japan, accepted.*