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First Steps Toward Adaptive Turbulence Model Corrections

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Motivation

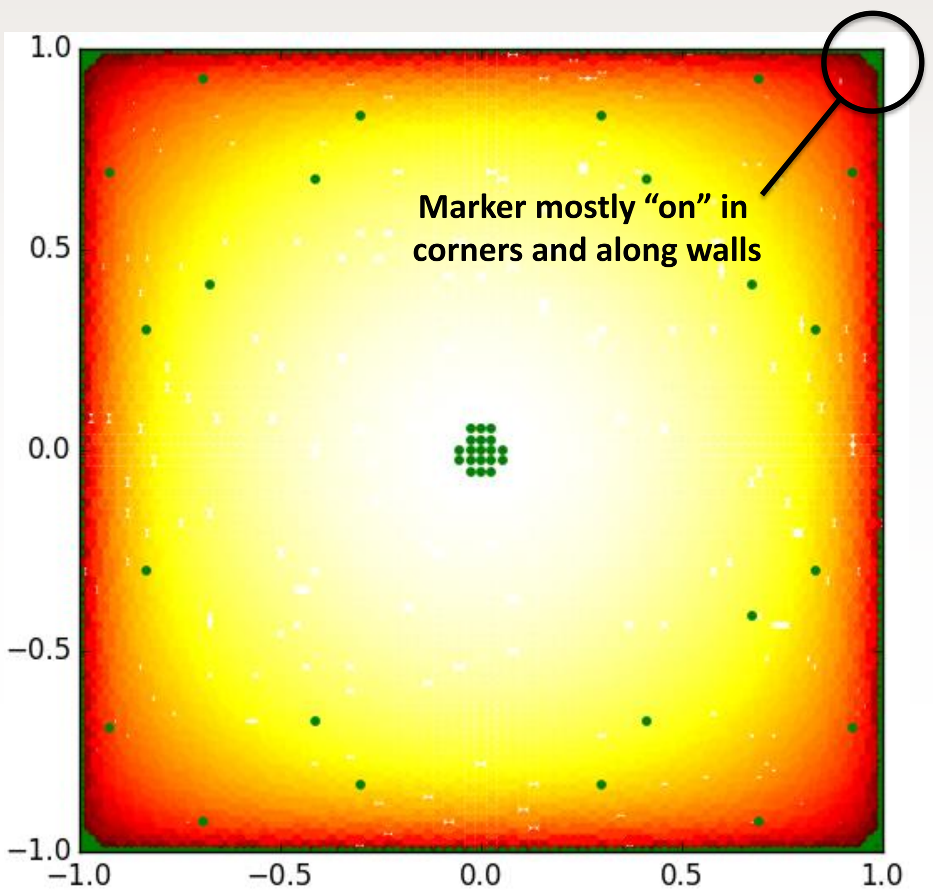

Figure: Contours of velocity magnitude in a turbulent duct flow. Green dots mark places where the machine learning algorithm predicts that the current RANS model will have high uncertainty.

- Turbulence in fluid flows is complex and hard to model
- Reynolds-Averaged Navier-Stokes (RANS) is a popular turbulence model that is computationally efficient but often inaccurate
- Many model corrections exist but are seldom used because it is unclear which situations require corrections
- The long-term goal of this project is to use machine learning techniques to trigger corrections on the fly when/where they are needed

Summer Objectives

- Implement a non-linear correction for an eddy viscosity (ν_t) model (Craft, 1996)
- Boussinesq hypothesis widely used to predict Reynolds stresses: linearity assumption

$$\overline{u_i'u_j'} = \frac{2}{3}k\delta_{ij} - 2\nu_t S_{ij}$$

- This linearity assumption is violated in many flows of engineering relevance
- Cubic eddy viscosity model (CEVM) can improve Reynolds stress predictions
- Summer goal is to implement CEVM in the SIERRA FUEGO computational fluid dynamics code so that it can be triggered by the machine learning algorithm
- Requires code development in C++ and Fortran on in-house simulation package

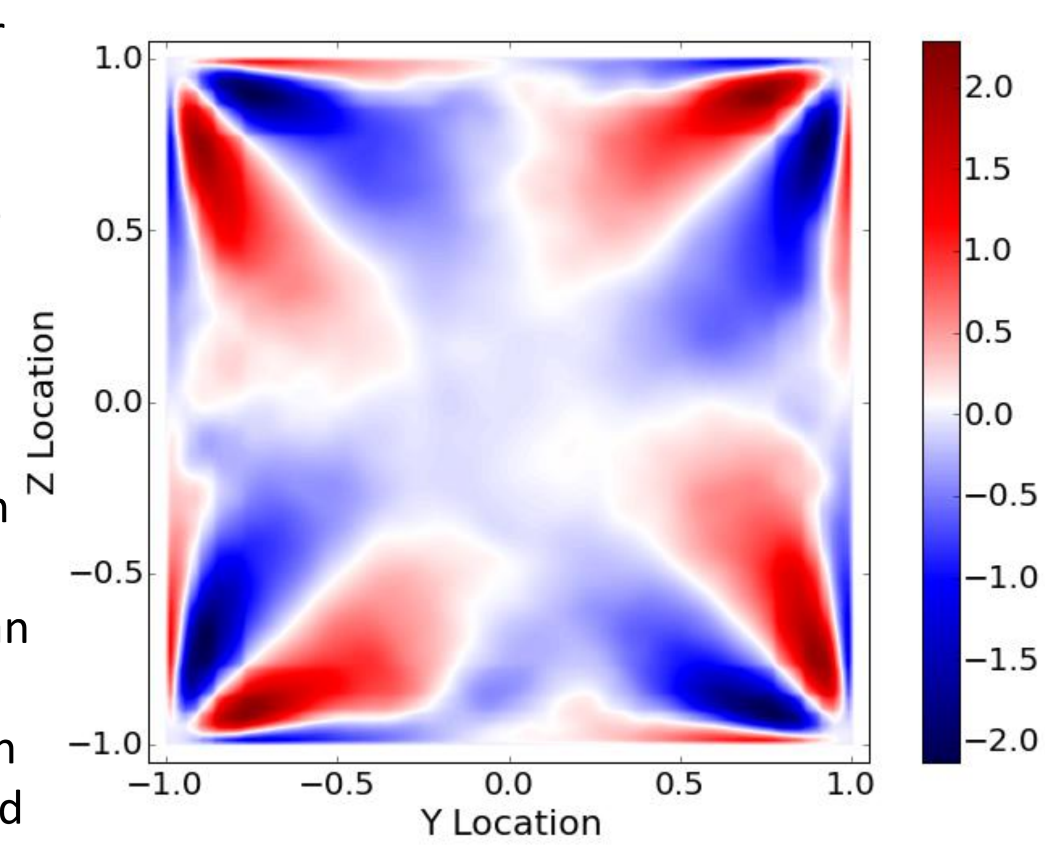

Figure: Contours of streamwise vorticity in a duct flow from Direct Numerical Simulation (DNS) showing corner vortices not present in RANS simulations.

Implementation Roadmap

Stand-alone Code

Write Stand-alone CEVM code → Validate on high-fidelity data →

SIERRA FUEGO

Implement isotropic dissipation → Modify functional turbulence parameters C_μ and f_μ → Add higher order terms from CEVM

References:
Craft, T. J., B. E. Launder, and K. Suga. *International Journal of Heat and Fluid Flow* 17.2 (1996): 108-115.
Jones, W. P., and B.E. Launder. *International journal of heat and mass transfer* 15.2 (1972): 301-314.
Launder, B. E., and B. I. Sharma. *Letters in heat and mass transfer* 1.2 (1974): 131-137.
Ling, J., and J. Templeton. *Physics of Fluids* (2015): *Submitted*

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NNSA National Nuclear Security Administration

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Isotropic Dissipation: $\tilde{\epsilon}$

Changing Isotropic Dissipation Source Term (E):

$$E = 2\nu\nu_t\left(\frac{\partial^2 u_i}{\partial x_j \partial x_k}\right)^2 \Longrightarrow E = 0.0022\tilde{S}\nu_t\frac{k^2}{\tilde{\epsilon}}\left(\frac{\partial^2 u_i}{\partial x_j \partial x_k}\right)^2$$

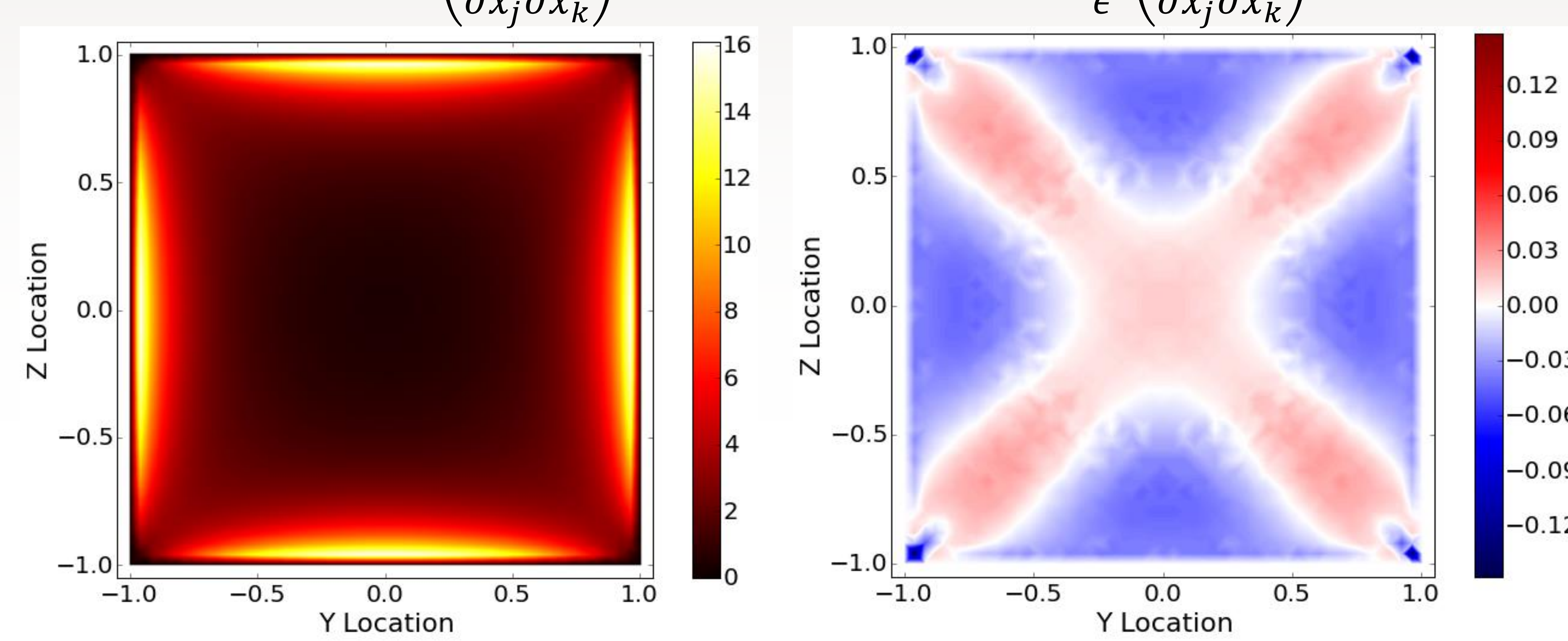

Figure: Contour of $\tilde{\epsilon}$ with the original source term (left) and relative percent change in $\tilde{\epsilon}$ between results with the two different source terms (right).

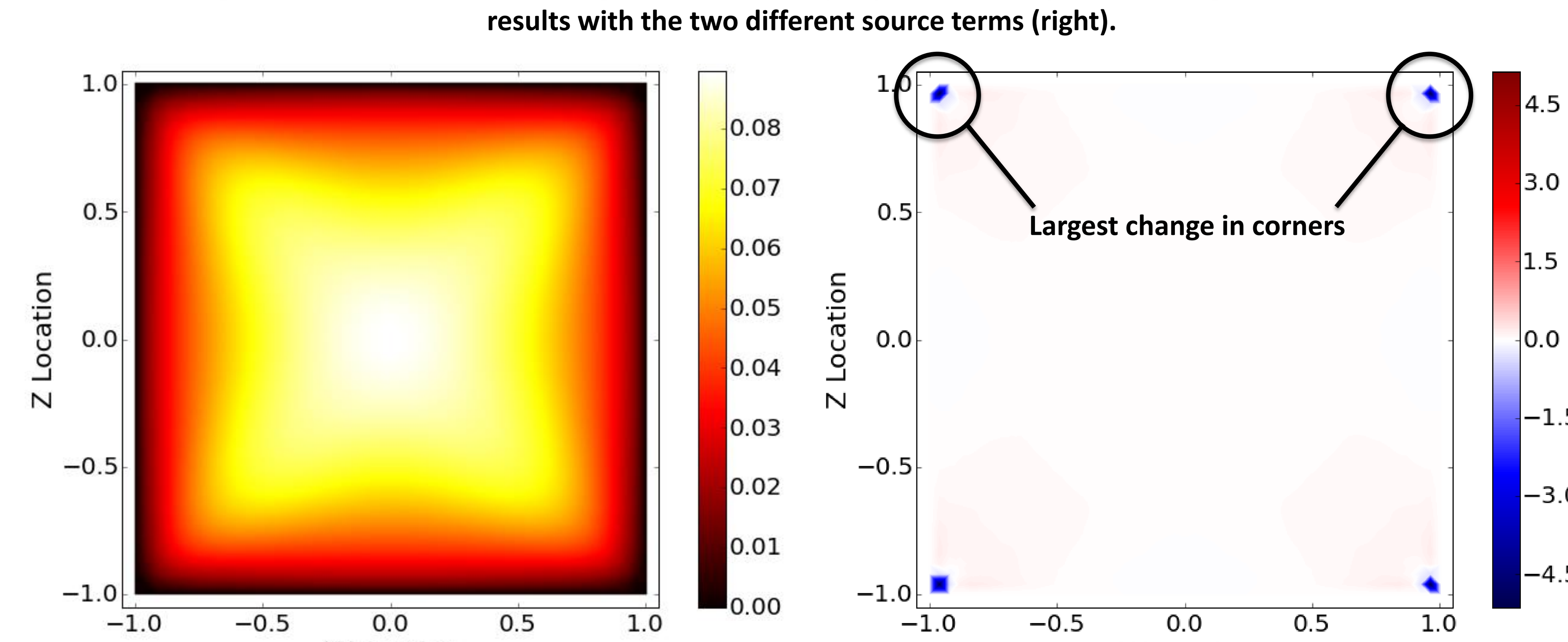

Figure: Contour of ν_t with the original source term (left) and relative percent change in ν_t between results with the two different source terms (right).

Turbulence Functions: C_μ and f_μ

$$C_\mu = 0.09 \Longrightarrow C_\mu = \left(0.3/\left[1 + 0.35\tilde{S}^{1.5}\right]\right) * \left(1 - \exp\left[-0.36/\exp(-0.75\tilde{S})\right]\right)$$

$$f_\mu = \exp\left[-2.5/(1 + R_t/50)\right] \Longrightarrow f_\mu = 1 - \exp\left[-(R_t/90)^{0.5} - (R_t/400)^2\right]$$

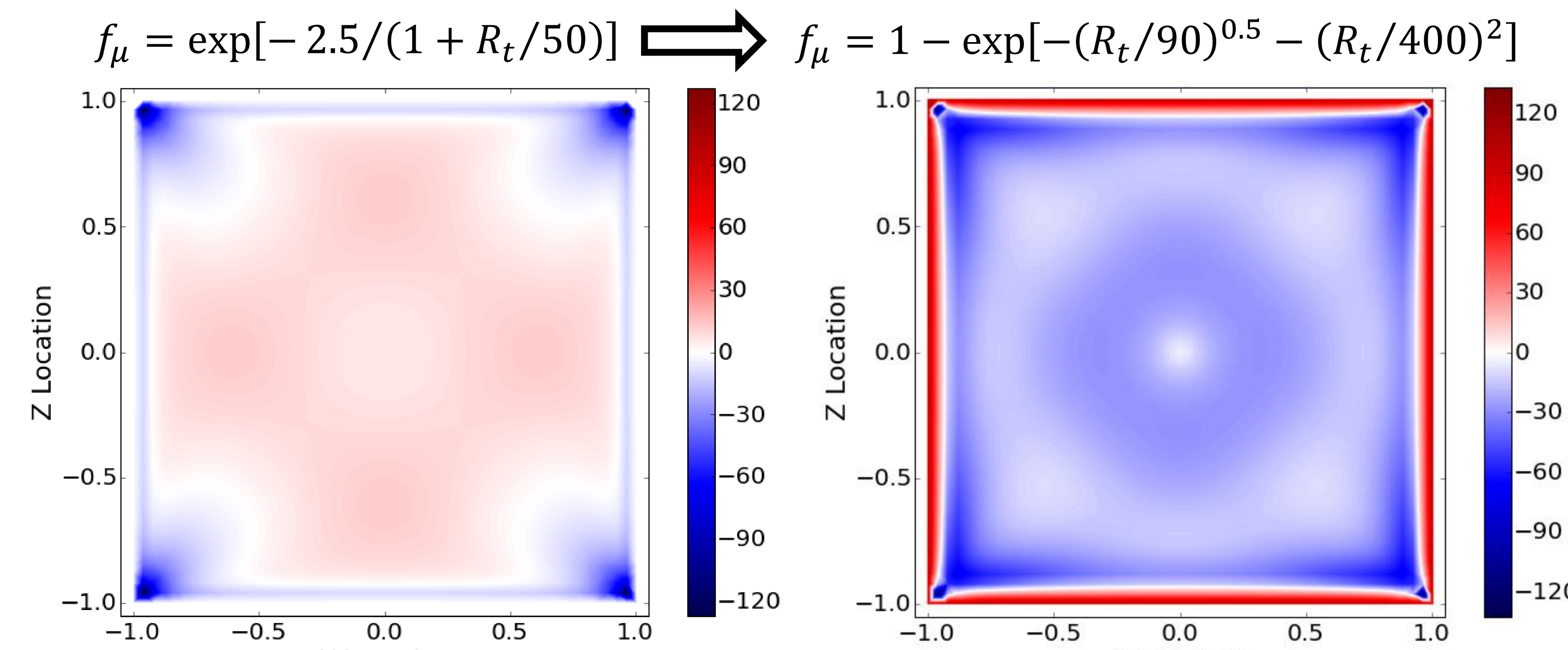

Figure: Contours of relative percent difference from adding C_μ and f_μ to the original model. $\tilde{\epsilon}$ is on the left and ν_t is on the right where $\nu_t = C_\mu f_\mu (k^2/\tilde{\epsilon})$.

Conclusions and Future Work

- Successfully implemented isotropic dissipation source term and turbulence parameter functions from CEVM model
- Achieved convergence on duct flow case with edited model
- Next:
  - Add higher order terms from CEVM
  - Implement zonal model corrections
  - Adaptive zonal corrections based on machine learning algorithm