Frontogenesis and Langmuir Turbulence in a Hydrostatic Model

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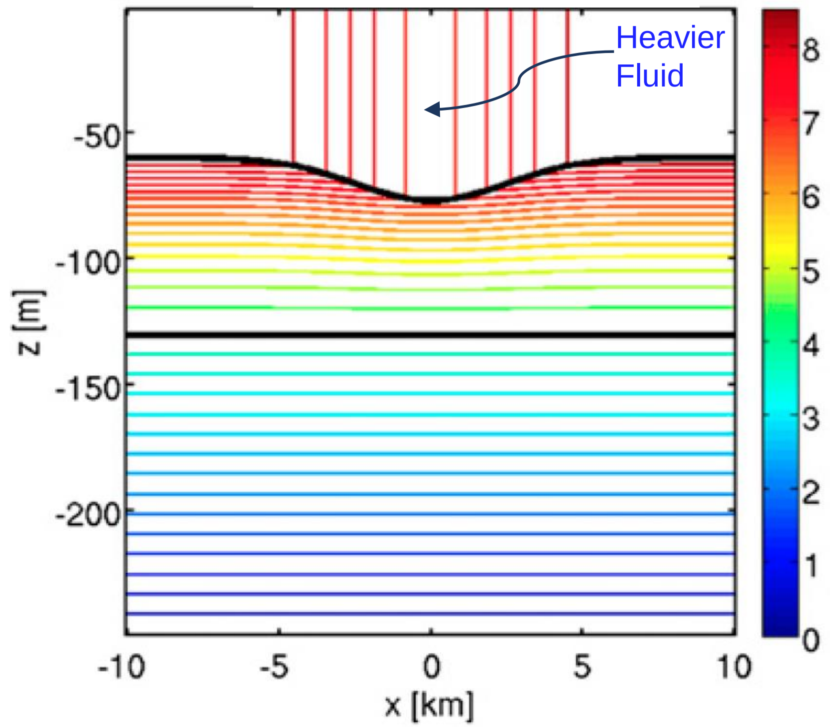
Experiment Design

NCOM –
Navy Coastal Ocean Model

Sullivan & McWilliams 2018 (SM18)

$$\Delta b = g(\rho_0 - \rho)/\rho_0$$

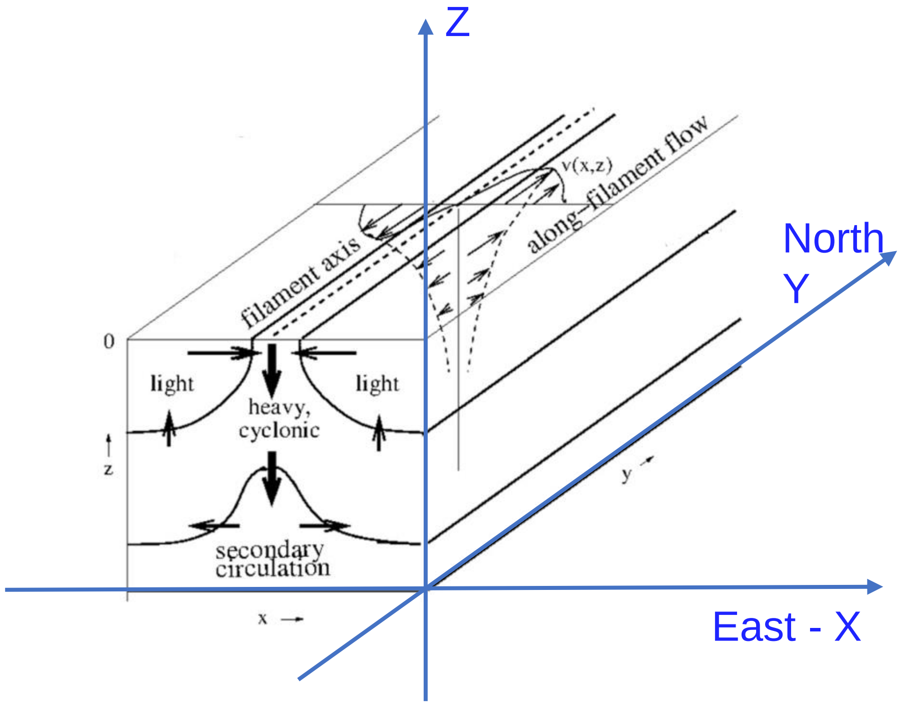


Initial front width: 4km

Surface wind forcing:
U = 8.5m/s ➔ u_*=0.01m/s
with C_d~=1.2 x 10^{-3}
or
Surface cooling:
Q = -100 W/m^2

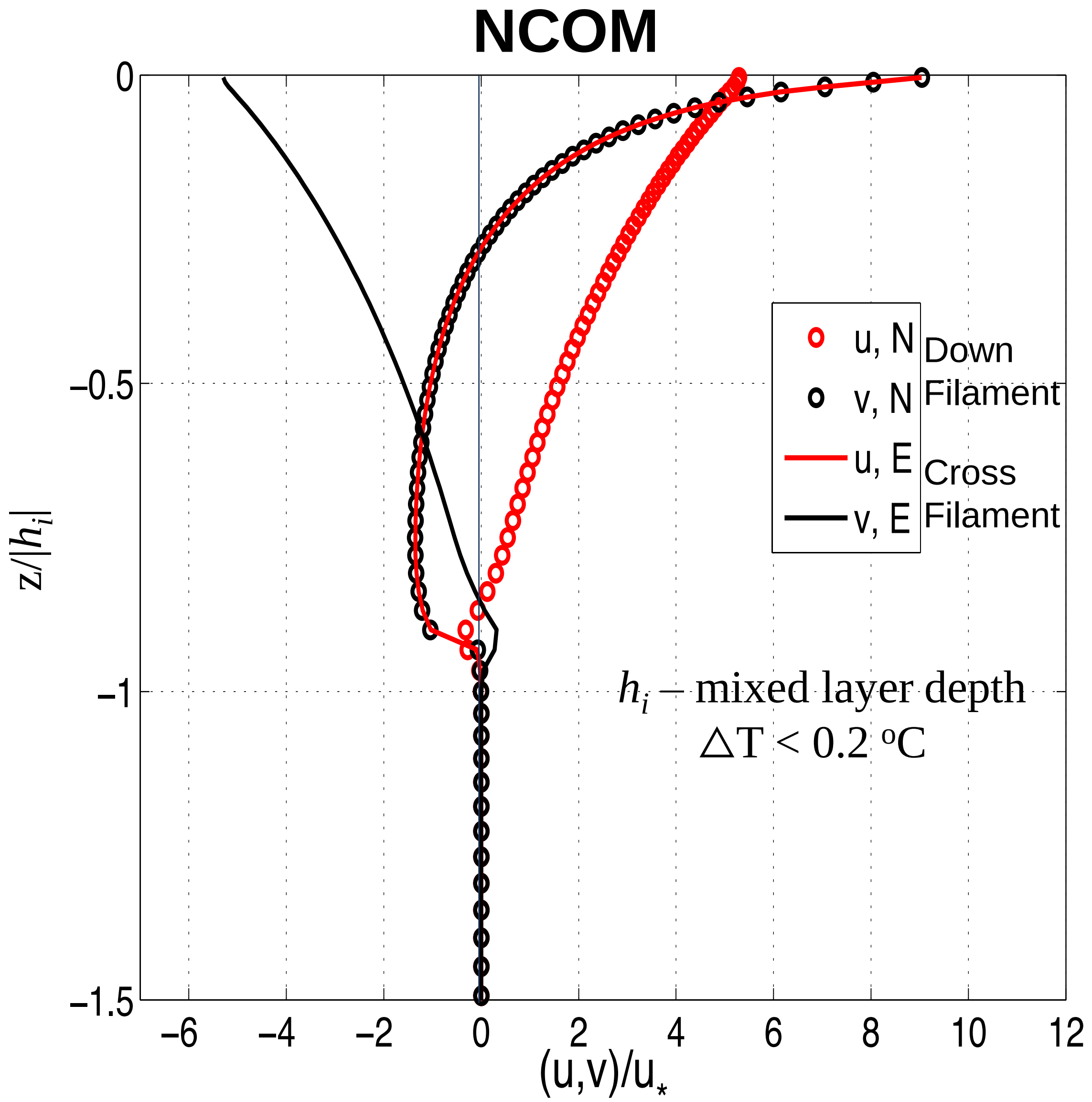
	NCOM	LES (SM18)
Domain size	38km x 5km x 250m	12km x 4.5km x 250m
Vertical levels	101	256
Horizontal resolution	100 m, 50m, 20m	1.46 m
Turbulence	Vert – Kantha & Clayson (2004) Horiz – Smagorinsky (1963)	Solved

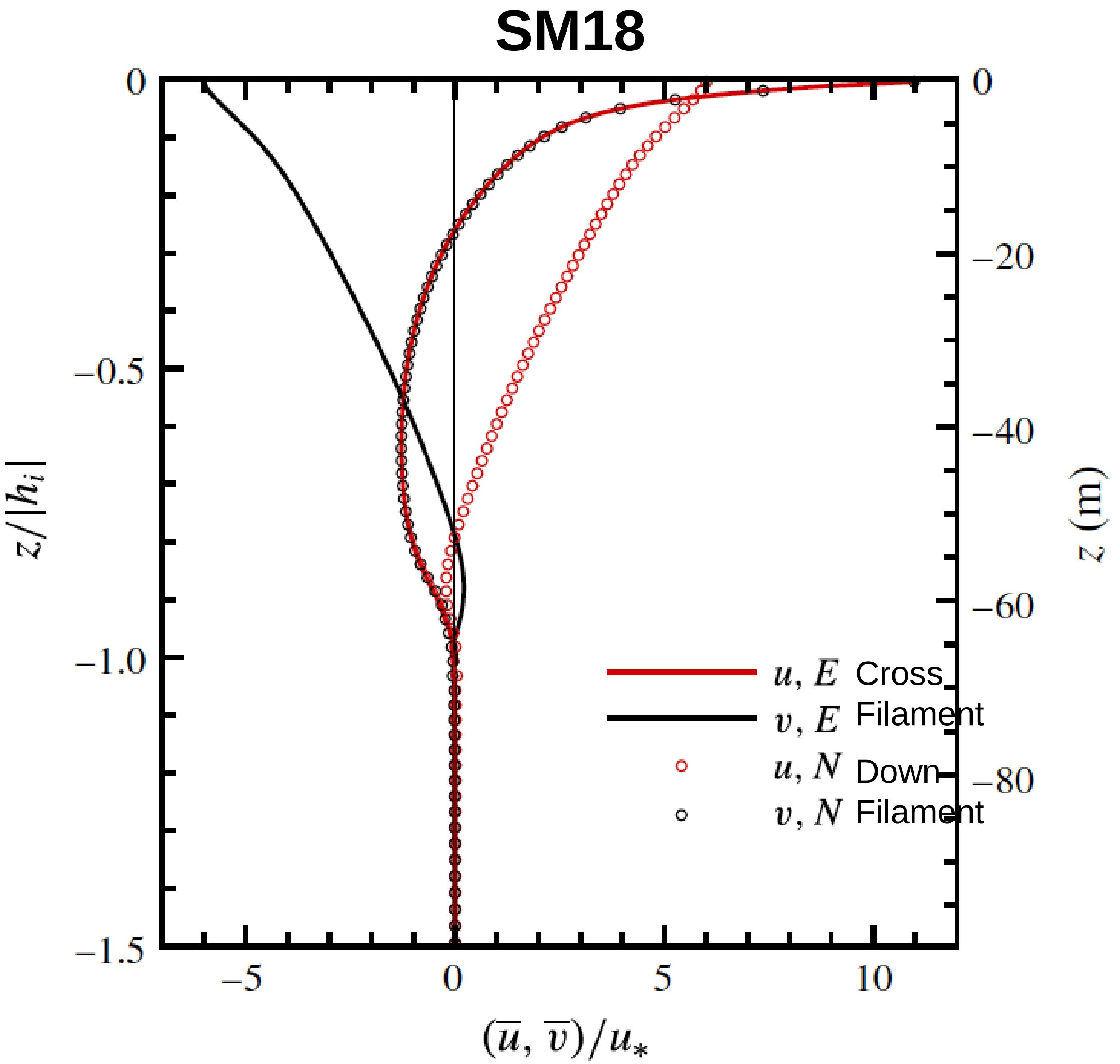
Experiments



	Case	Resolution (m)	C_{smag}	Wave direction
Surface Cooling $Q = -100\ Wm^{-2}$	C100	100	0.1	-
	C50-0	50	0	-
	C50	50	0.1	-
	C50-0.2	50	0.2	-
	C50+n	50	0.1	North
	C50+e	50	0.1	East
	C20	20	0.1	-
Northward / Along Front Wind $WSP = 8.5\ ms^{-1}$ $u_*=0.01 m/s$	N100	100	0.1	-
	N50-0	50	0	-
	N50	50	0.1	-
	N50-0.2	50	0.2	-
	N50+wav	50	0.1	North
	N20	20	0.1	-
Eastward / Cross Front Wind $WSP = 8.5\ ms^{-1}$ $u_*=0.01 m/s$	E100	100	0.1	-
	E50-0	50	0	-
	E50	50	0.1	-
	E50-0.2	50	0.2	-
	E50+wav	50	0.1	East
	E20	20	0.1	-

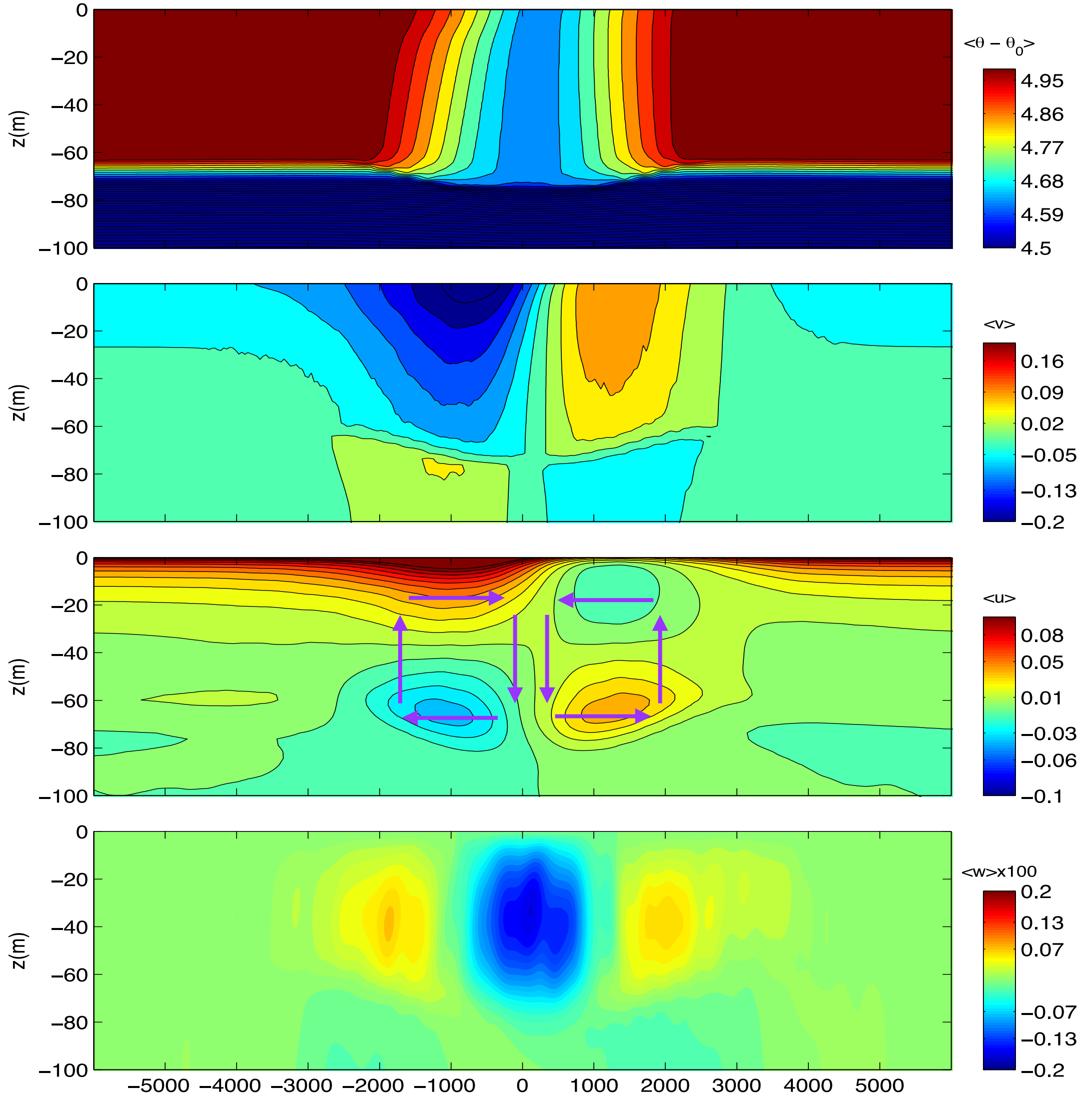
Initial Mean Circulation – step 1



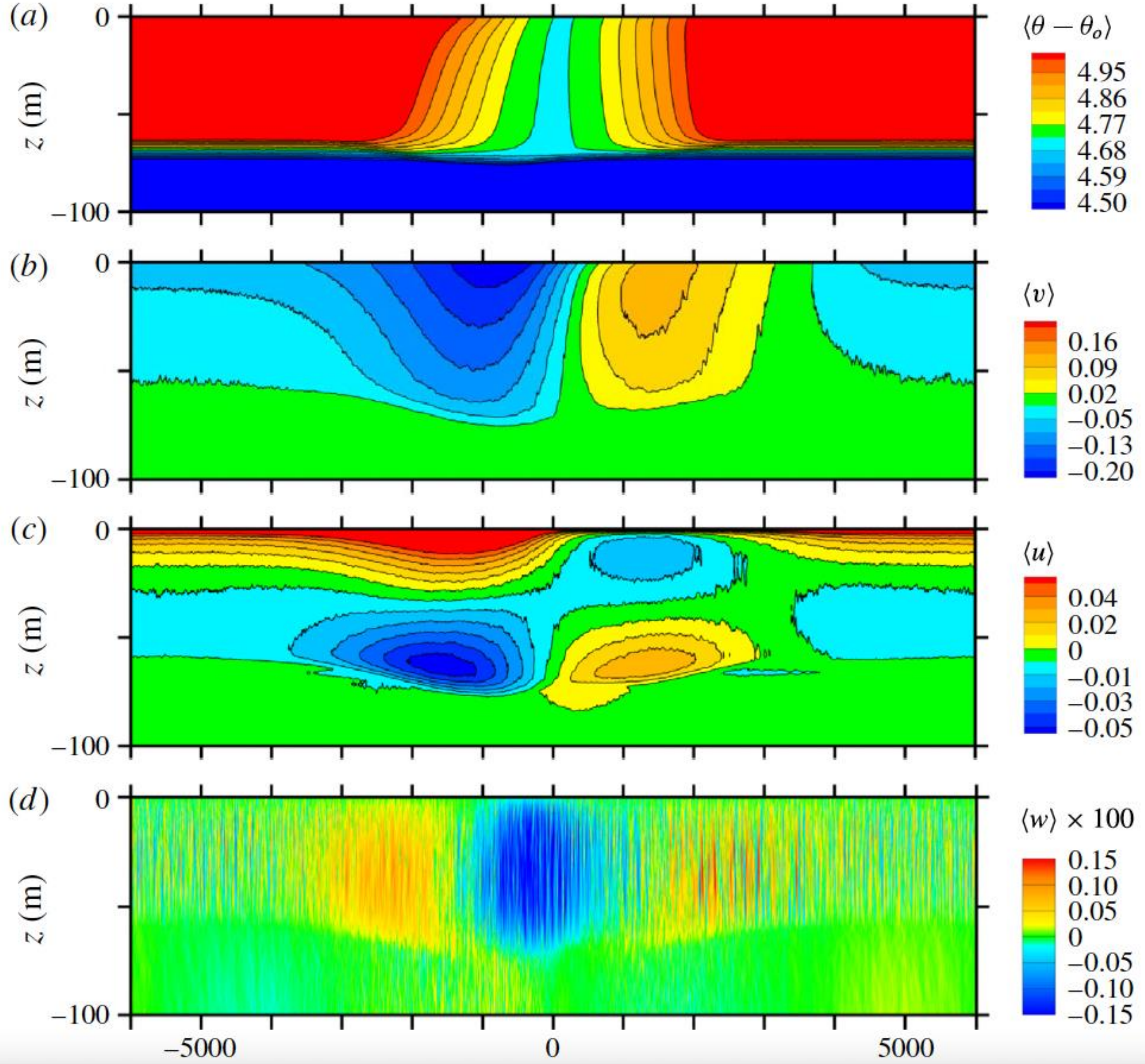


Average Fields at hour = 2 in Cross-Filament Wind Case

E50 / NCOM

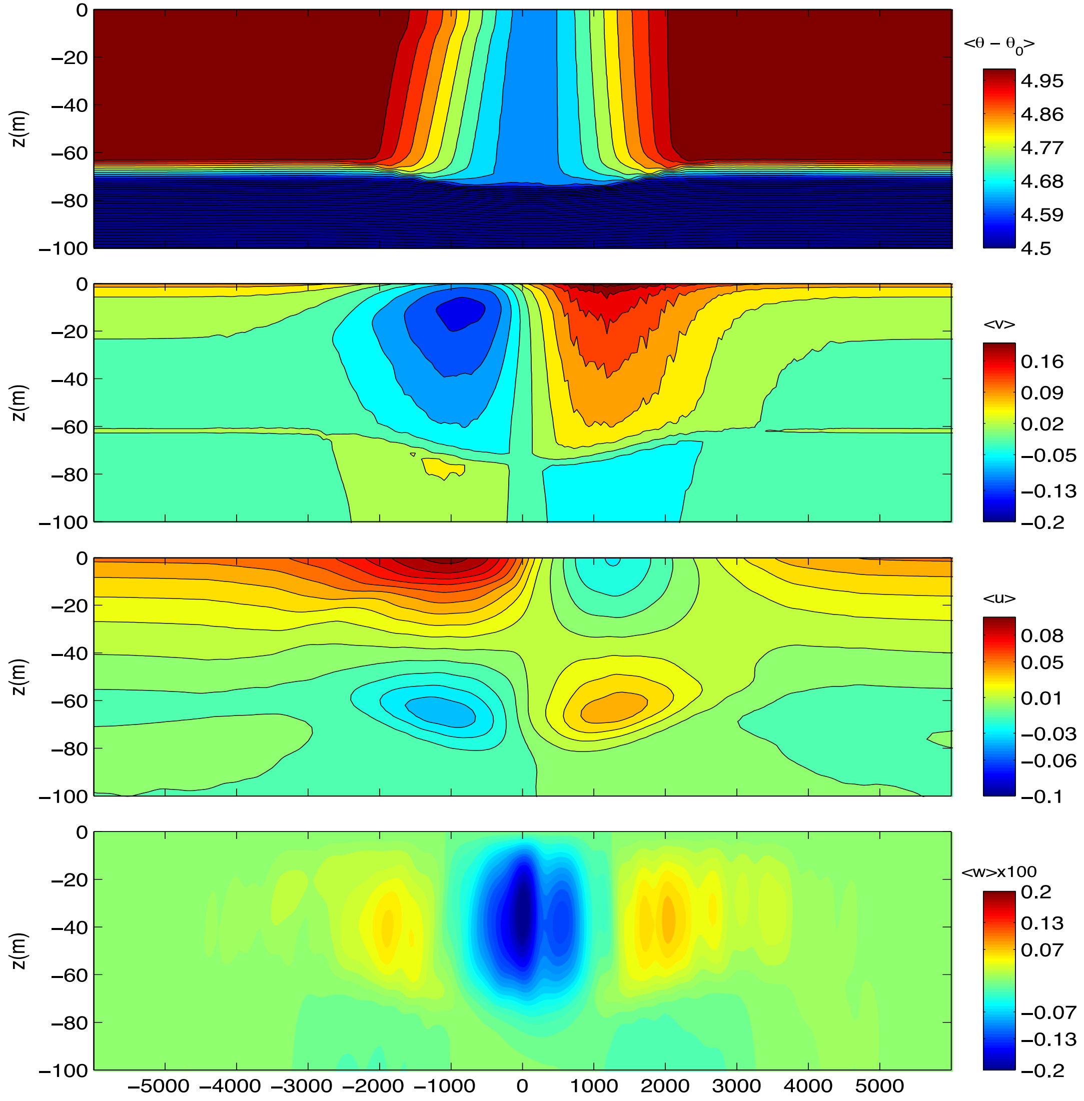


E / SM18

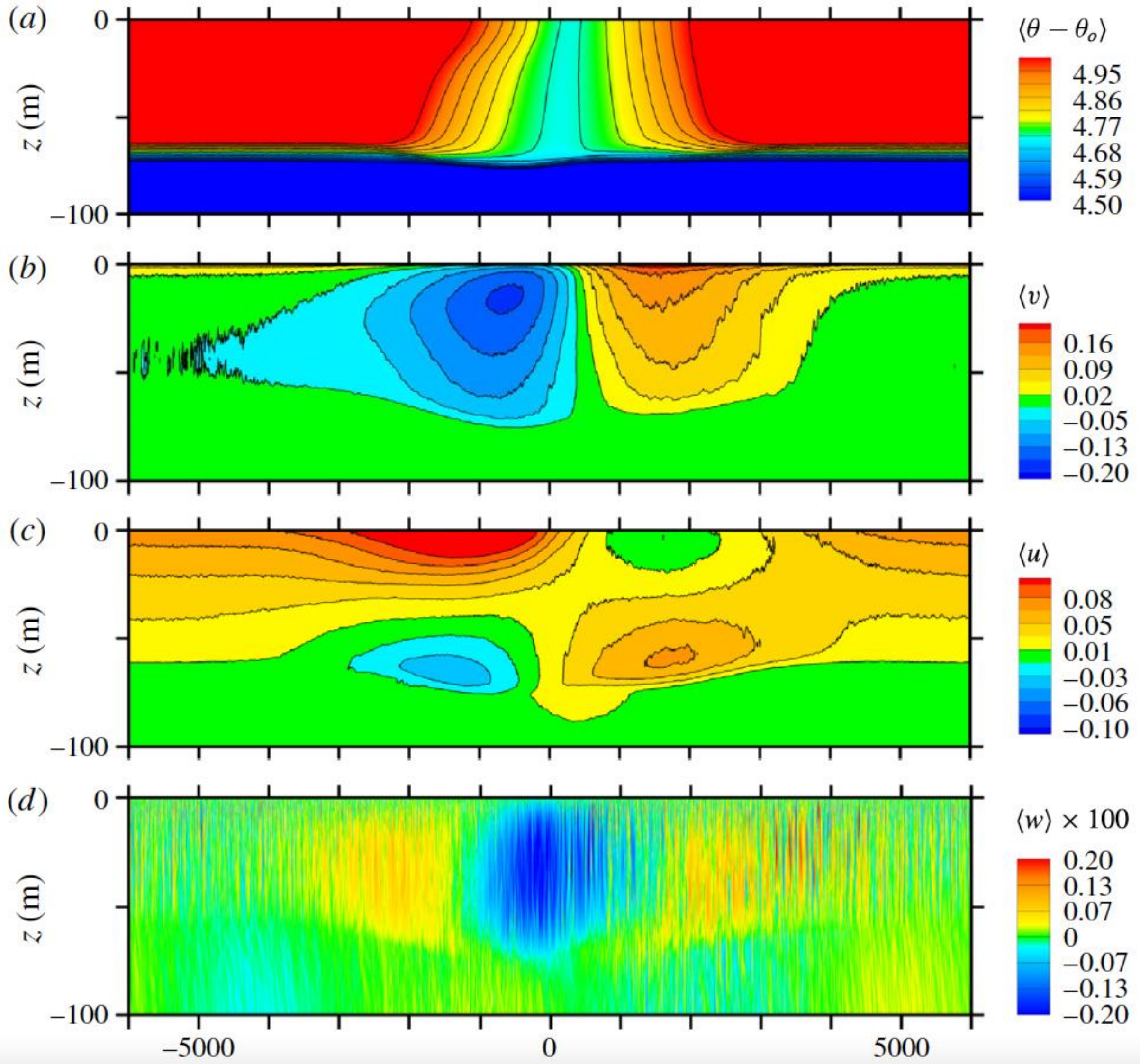


Average Fields at hour = 2 in Down-Filament Wind Case

N50 / NCOM



N / SM18



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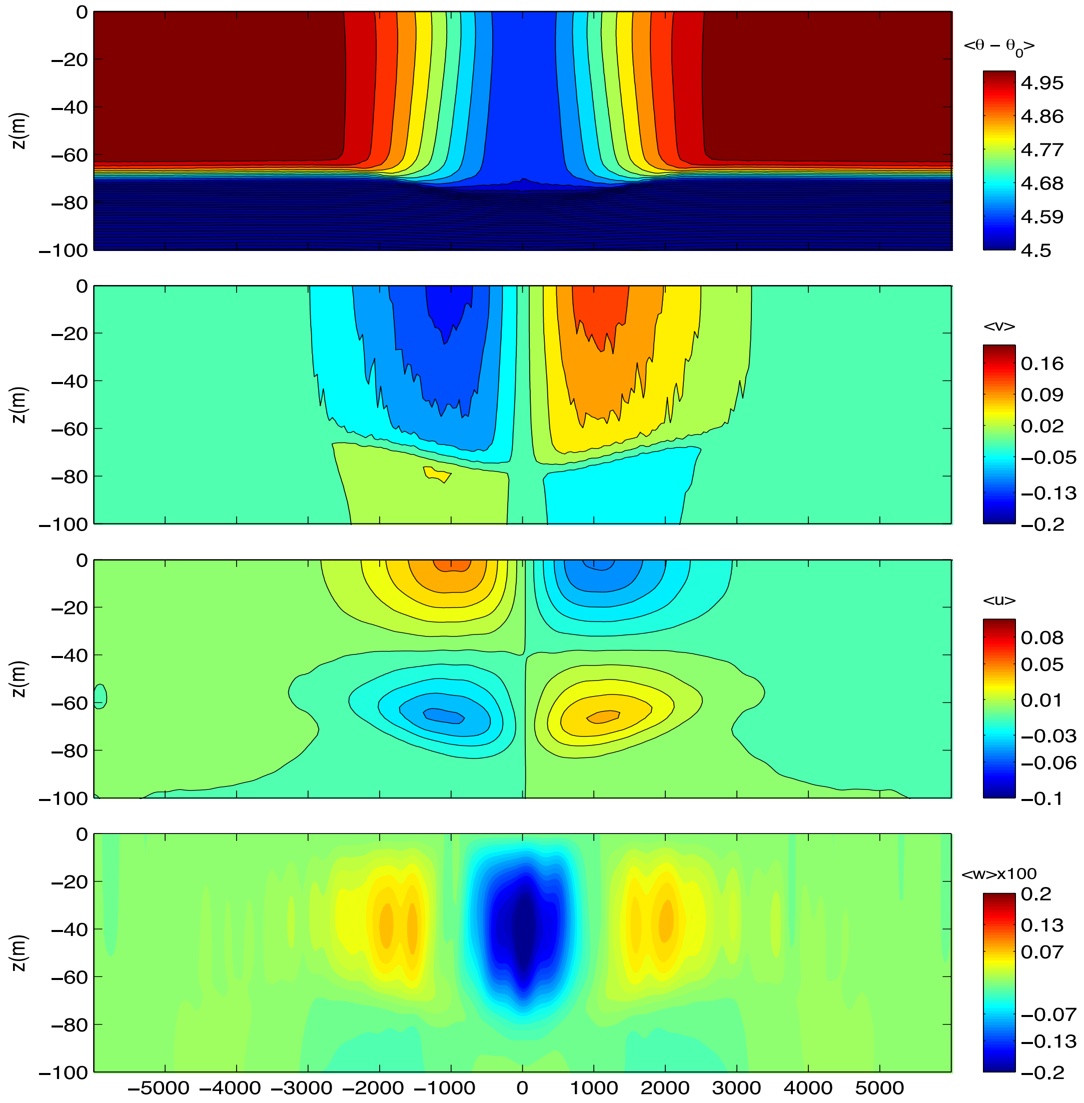
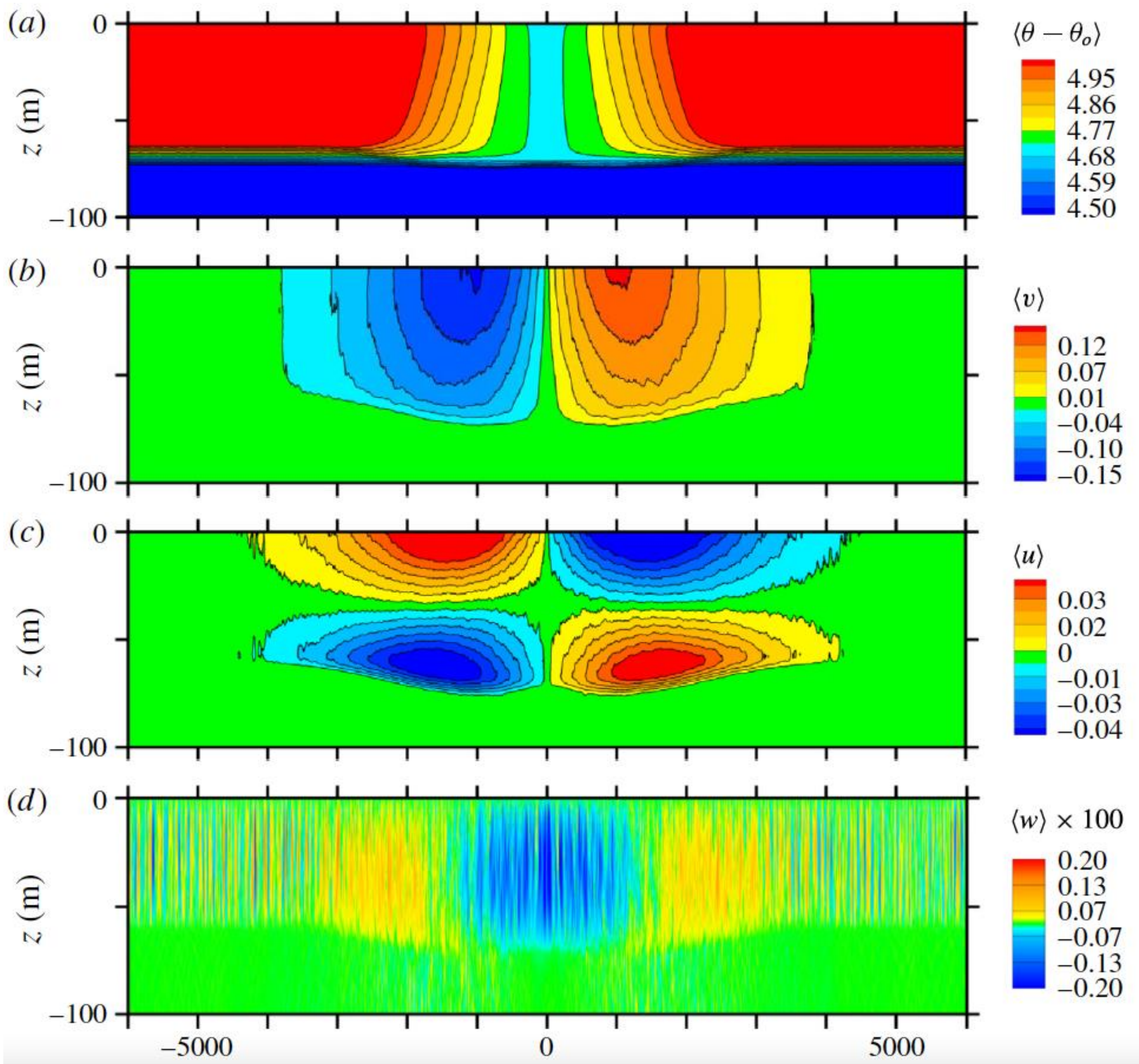
Average Fields at hour = 2 in Surface Cooling Case

C50 / NCOM

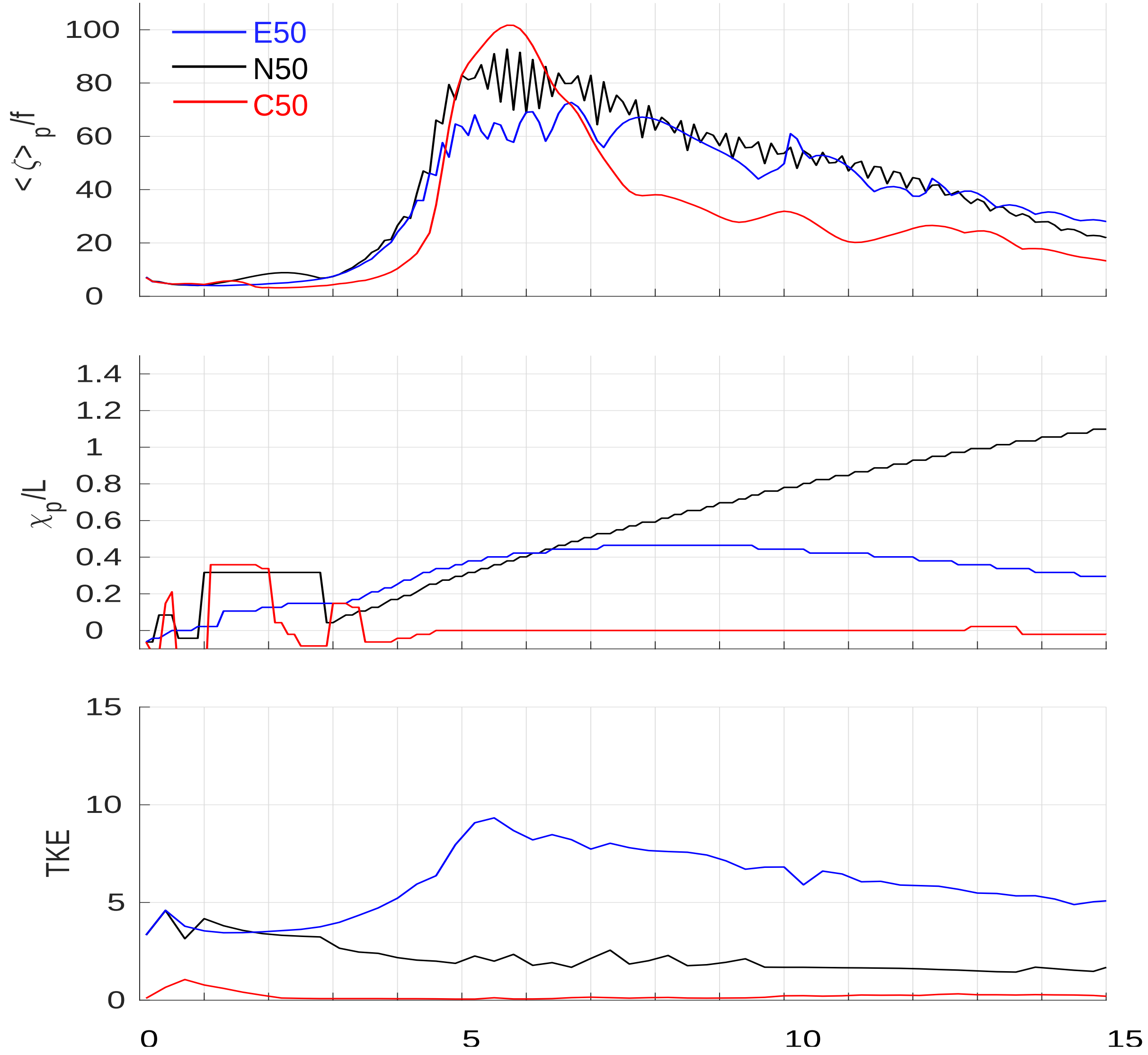


C / SM18

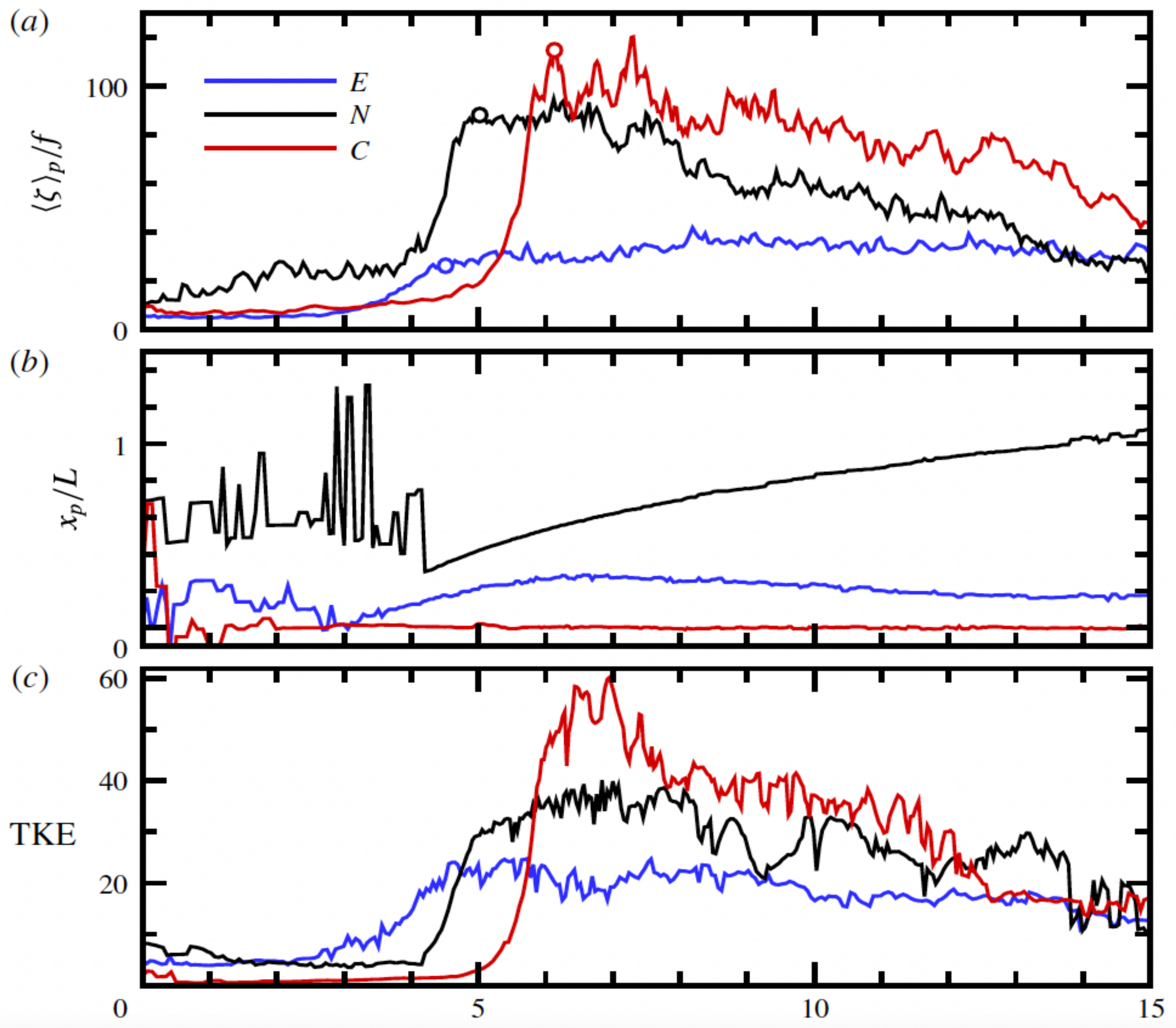


Frontogenetic Progression

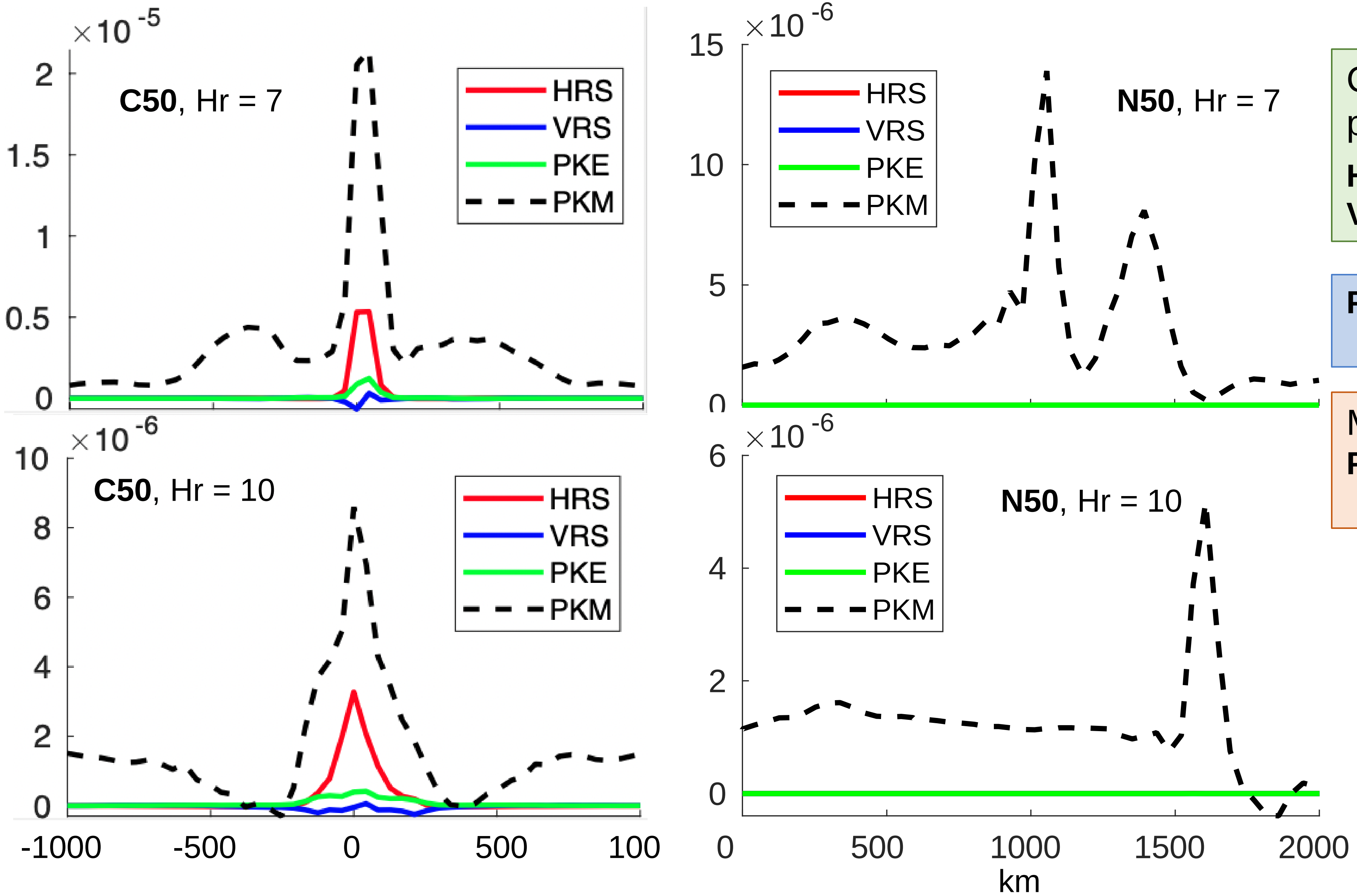
50m Resolution / No wave forcing / C_{smag}=0.1



Sullivan & McWilliam 2018



Energy Conversion



Conversion from mean to perturbation kinetic energy

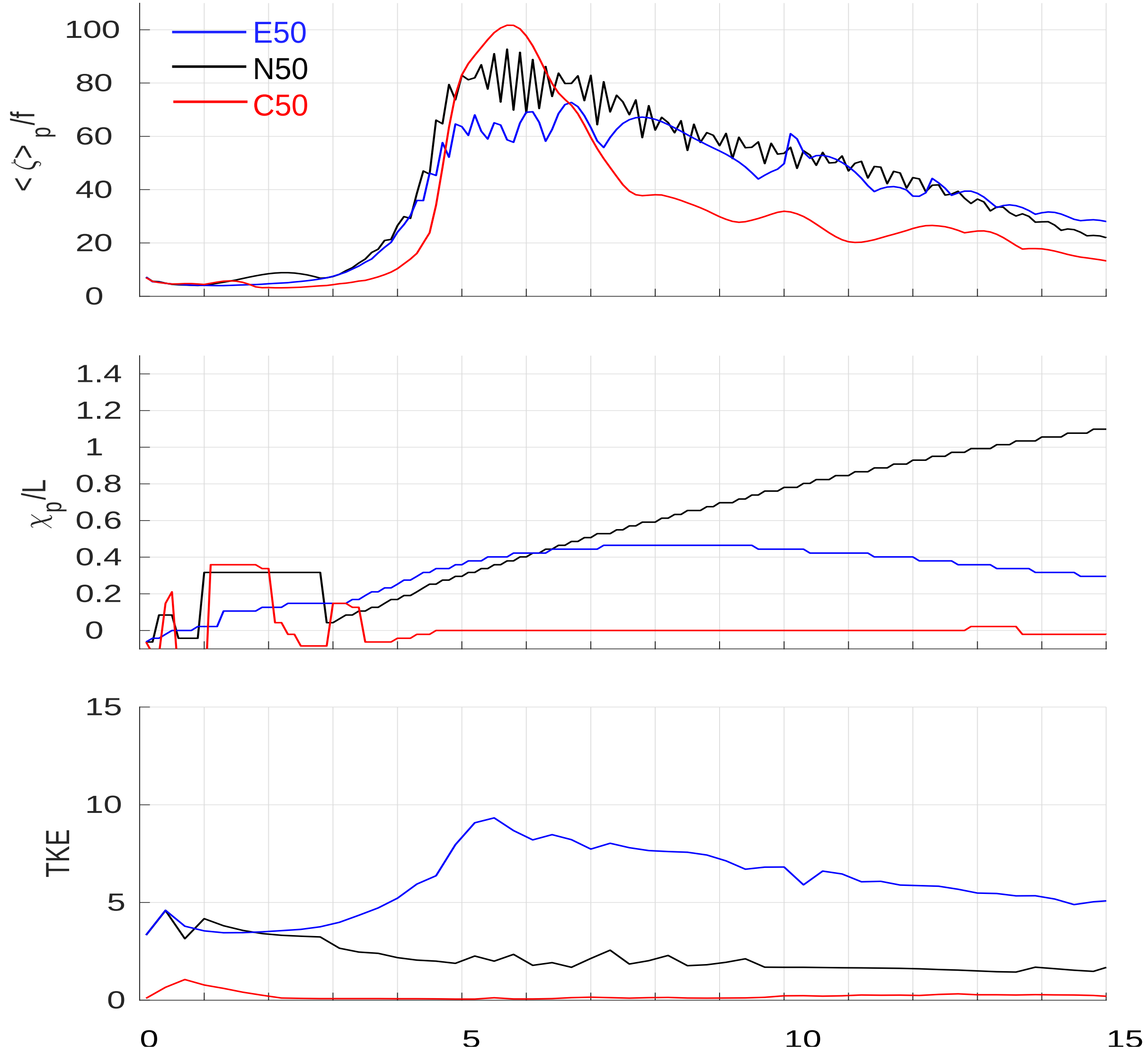
HRS – horizontal shear production
VRS – vertical shear production

PKE – Eddy potential to eddy kinetic energy conversion

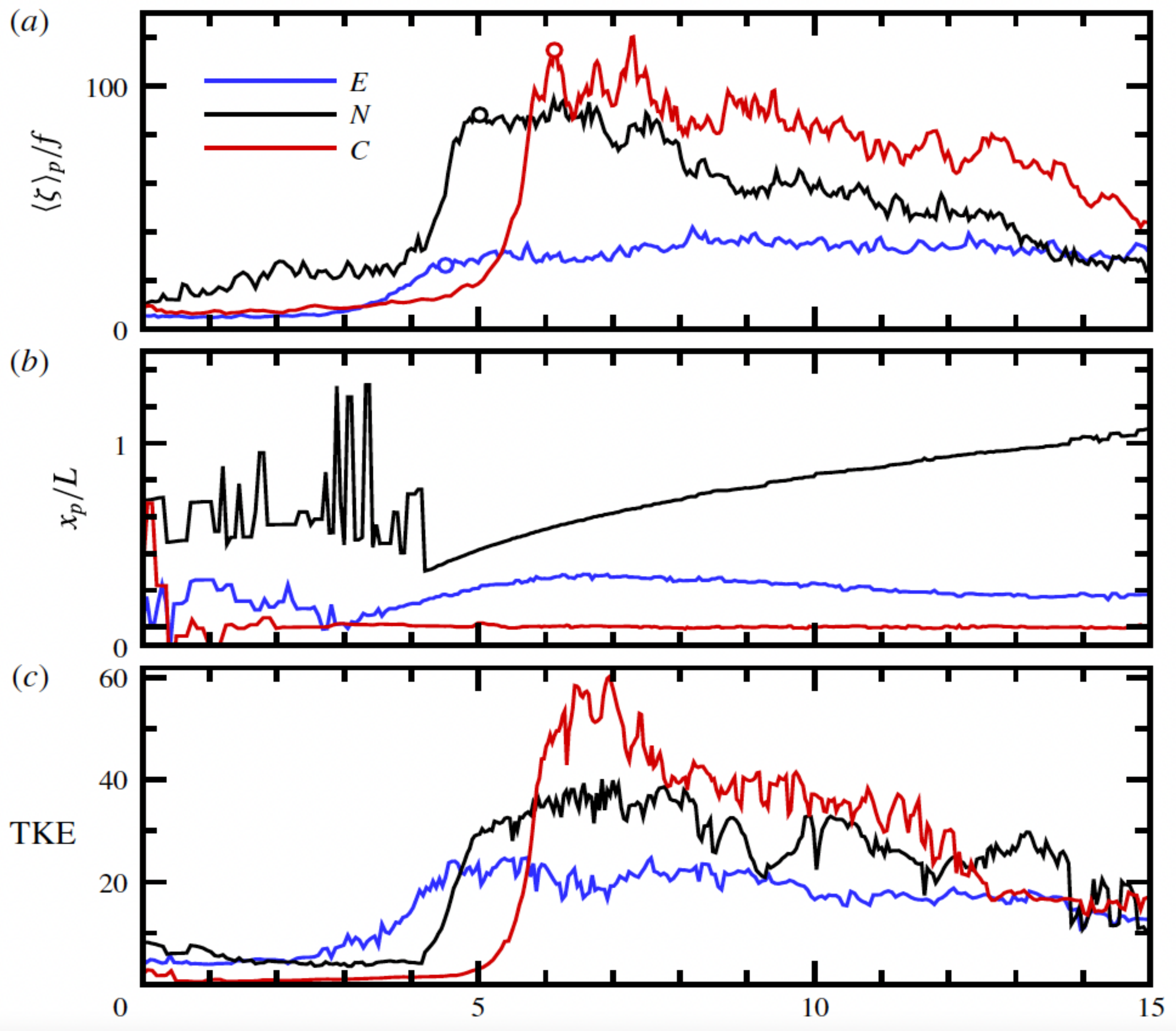
Mean Energy Field
PKM – Mean potential to mean kinetic energy conversion

Frontogenetic Progression

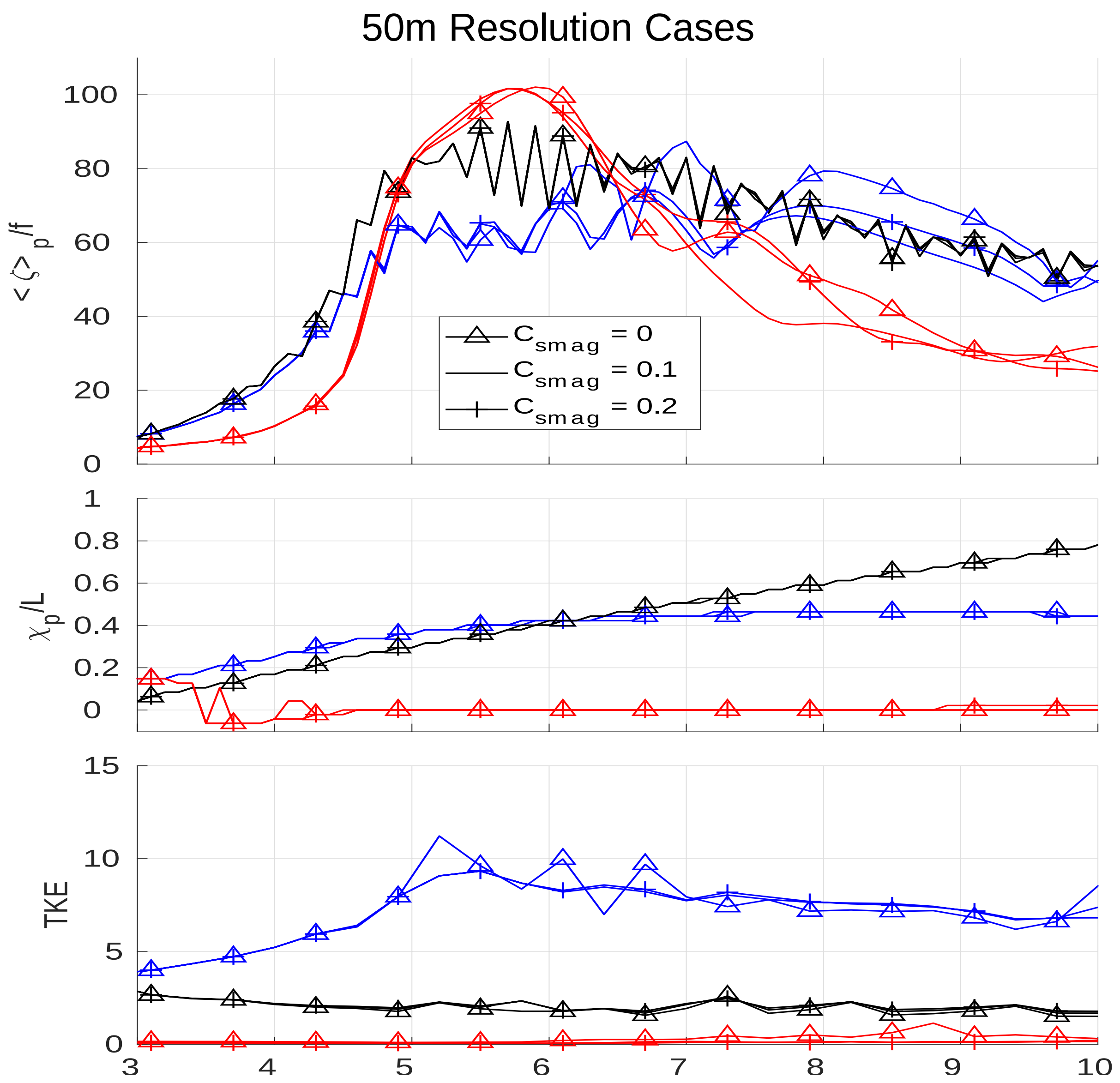
50m Resolution / No wave forcing / C_{smag}=0.1



Sullivan & McWilliam 2018



Effect of Horizontal Mixing



Smagorinsky (1963)

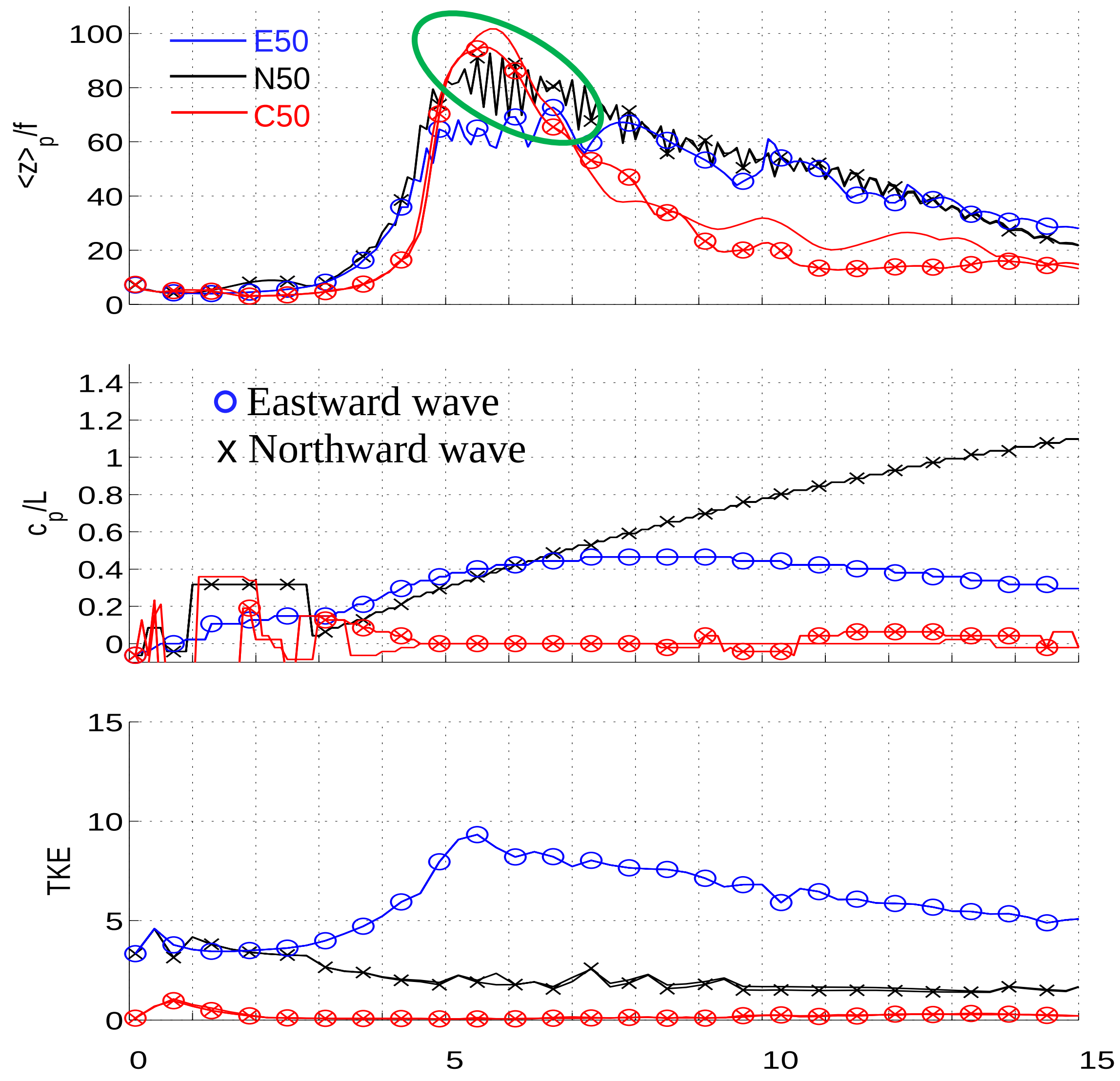
$$\nu_{\perp} = C_{smag}\Delta x \Delta y \left(\left(\frac{\partial u}{\partial x}\right)^2 + \frac{1}{2}\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 \right)^{1/2}$$

	Case	C_{smag}	t_m (hour)	L_w (m)
Surface Cooling	C50-0	0	5.9	110
	C50	0.1	5.7	110
	C50-0.2	0.2	5.7	110
Northward Wind	N50-0	0	5.5	190
	N50	0.1	5.5	190
	N50-0.2	0.2	5.5	190
Eastward Wind	E50-0	0	5.1	250
	E50	0.1	5.1	250
	E50-0.2	0.2	5.1	240

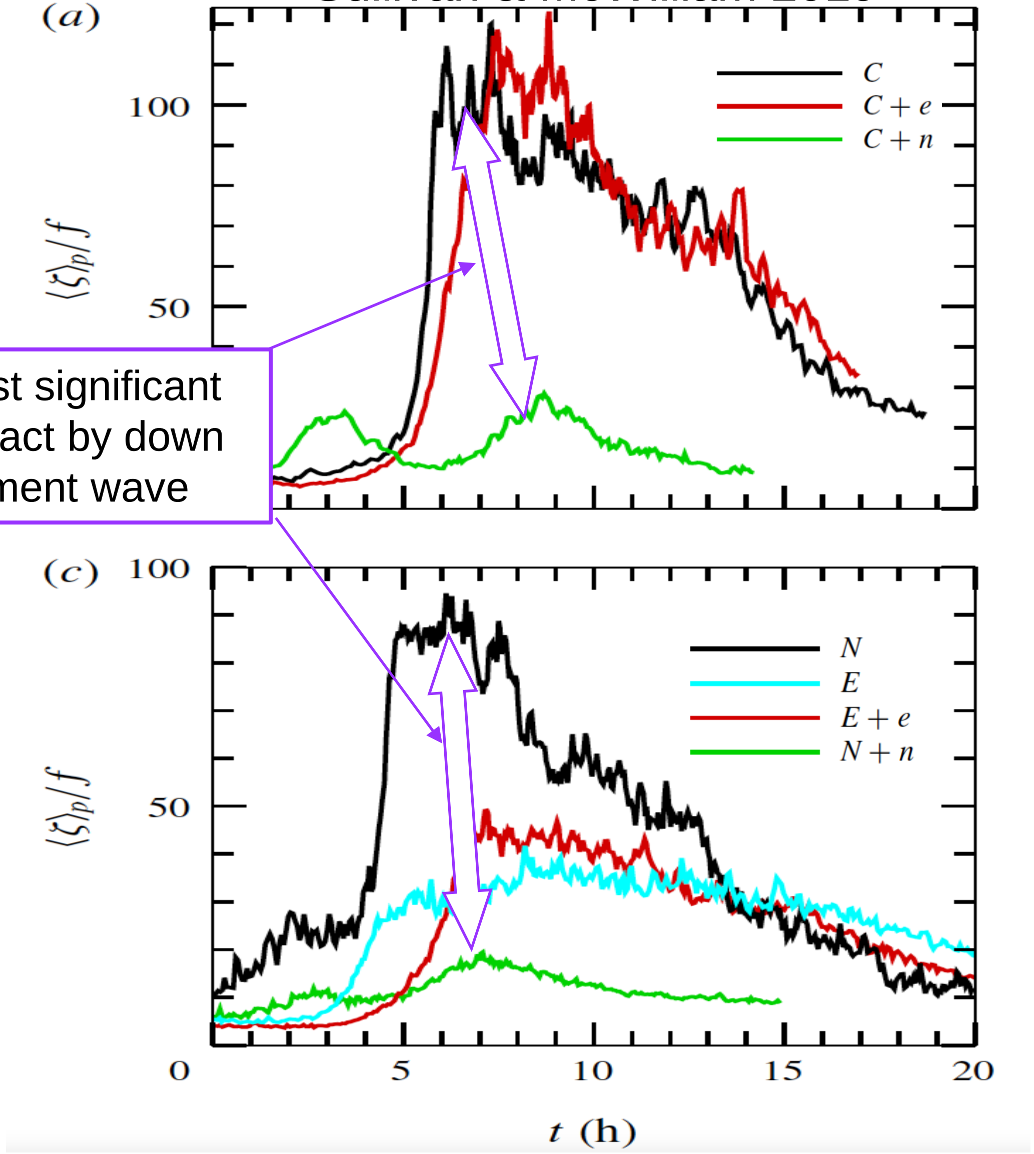
L_w: distance where $\langle u \rangle \partial_x \langle v \rangle$ first falls to zero outside of the filament zone on both side.

Effect of Surface Gravity Waves

50m Resolution Cases

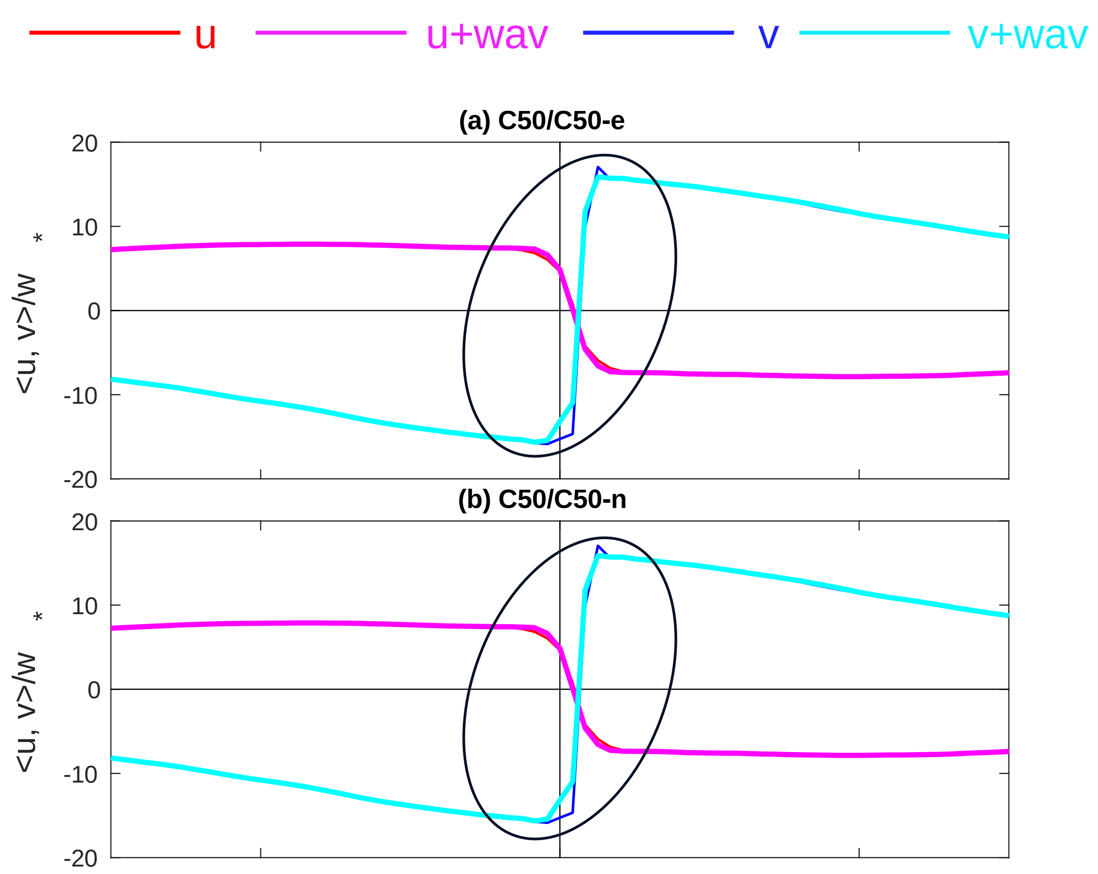


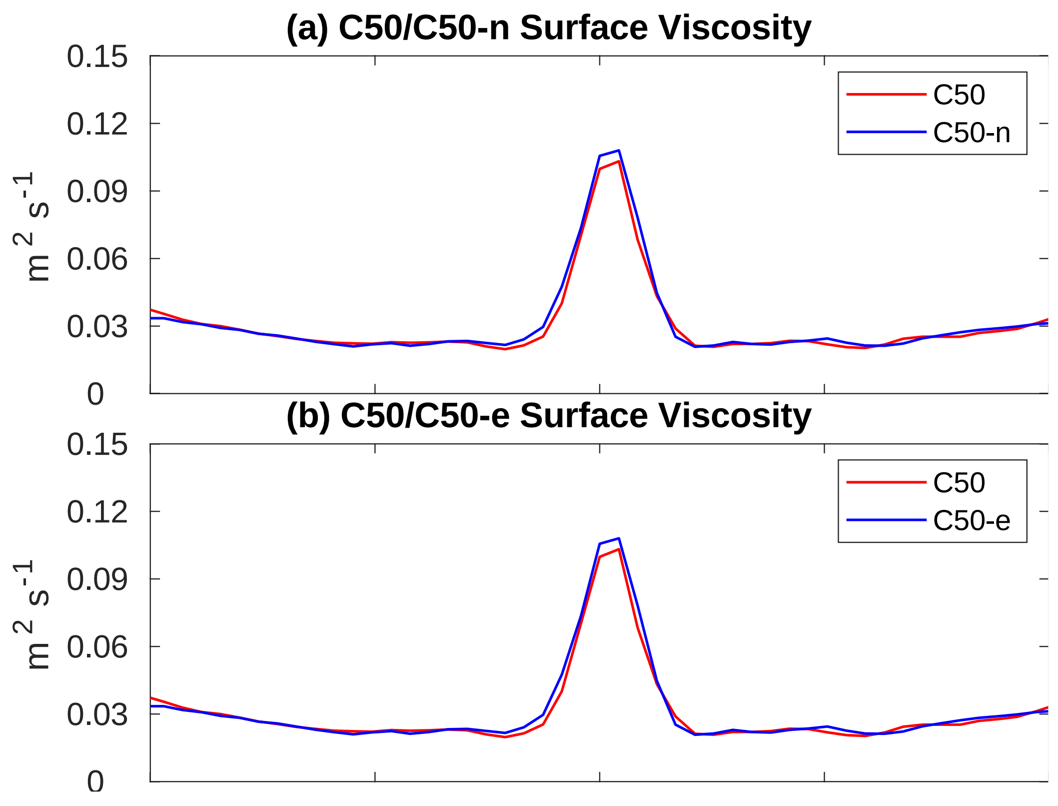
Sullivan & McWilliam 2019



Most significant impact by down filament wave

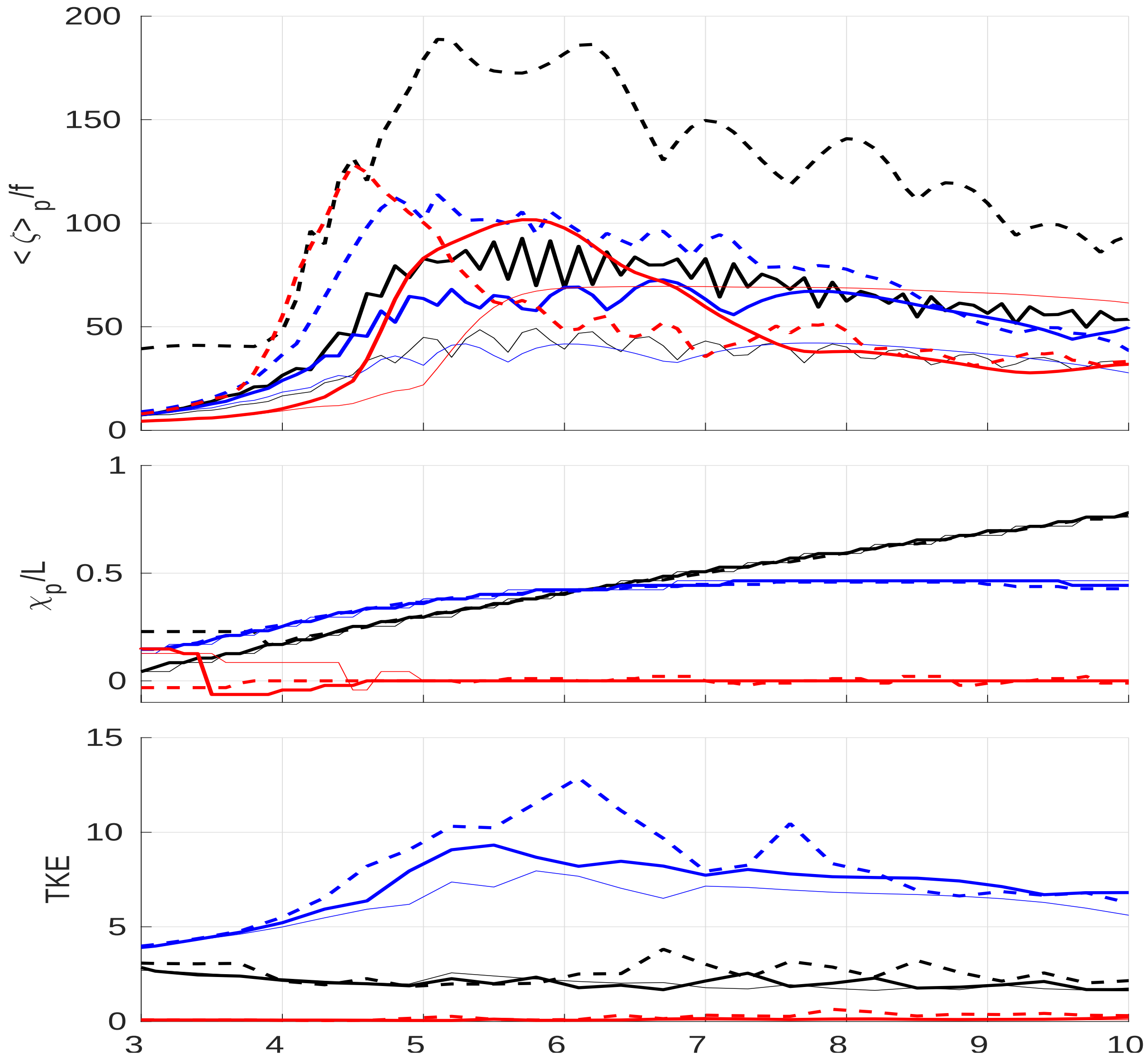
Effect of Surface Gravity Waves





	Case	Wave direction	t_m (hour)	L_w (m)
Surface Cooling	C50	-	5.7	110
	C50+n	North	5.5	120
	C50+e	East	5.5	120

Effect of Horizontal Resolution



	Case	Resolution (m)	t_m (hour)	L_w (m)
Surface Cooling	C100	100	5.9	170
	C50	50	5.7	110
	C20	20	4.5	80
Northward Wind	N100	100	5.8	270
	N50	50	5.5	190
	N20	20	5.1	100
Eastward Wind	E100	100	5.3	300
	E50	50	5.1	250
	E20	20	4.8	180

Most narrow width with Surface Cooling forcing for all resolution

Higher resolution ➔ narrow width at arrest

earlier arrest time

At 50m, 100m resolution, arrest is limited by grid scale

At 20m resolution, horizontal mixing come into play

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Summary

- Hydrostatic Model is able to predict the correct characteristics of filament frontogenesis
- Front arrest is controlled by the model's subgrid-scale artificial regularization procedure. Thus higher resolution is corresponding to stronger frontogenesis in the model
- The effect of horizontal mixing on frontogenesis is very small
- The parameterized effect of surface gravity wave forcing through vertical mixing is negligible on frontogenesis, and can not represent the physics of wave-front interaction

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