Submesoscale eddies along the Mississippi/Atchafalaya plume front

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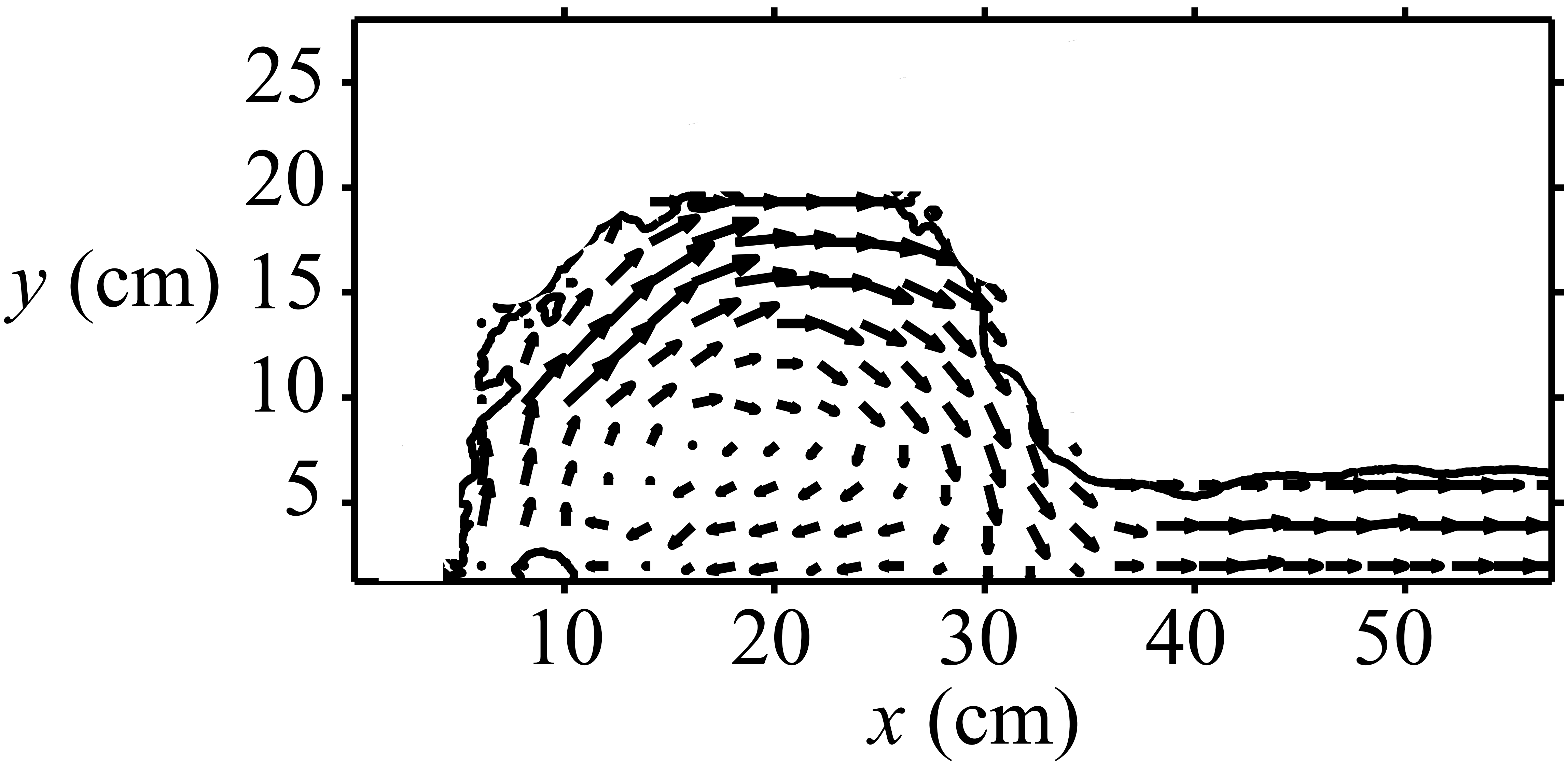
Submesoscale?

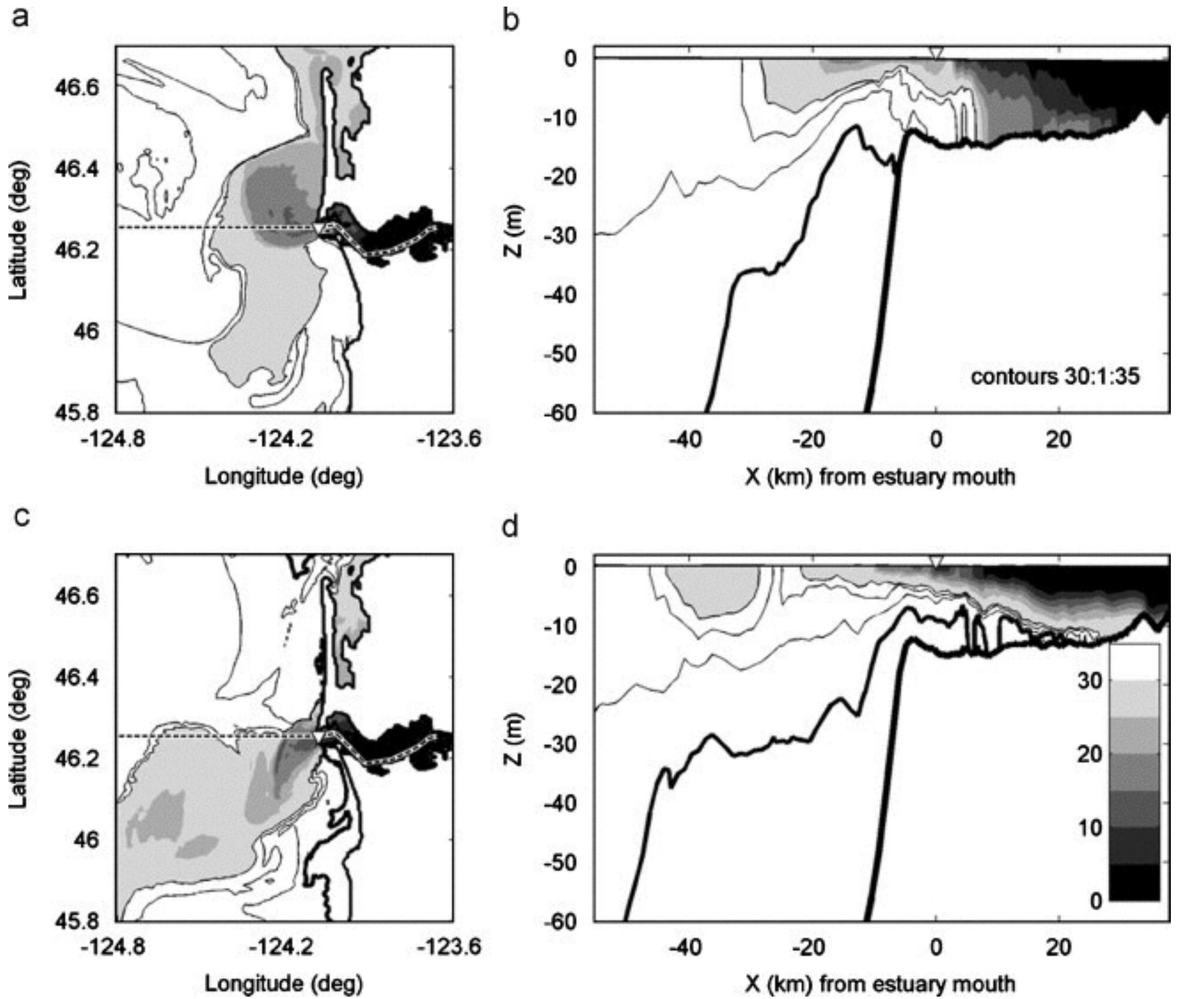
Submesoscale compared to ‘mesoscale’ Loop Current and Loop Current Eddies

Similar to ‘surface mixed layer instabilities’:

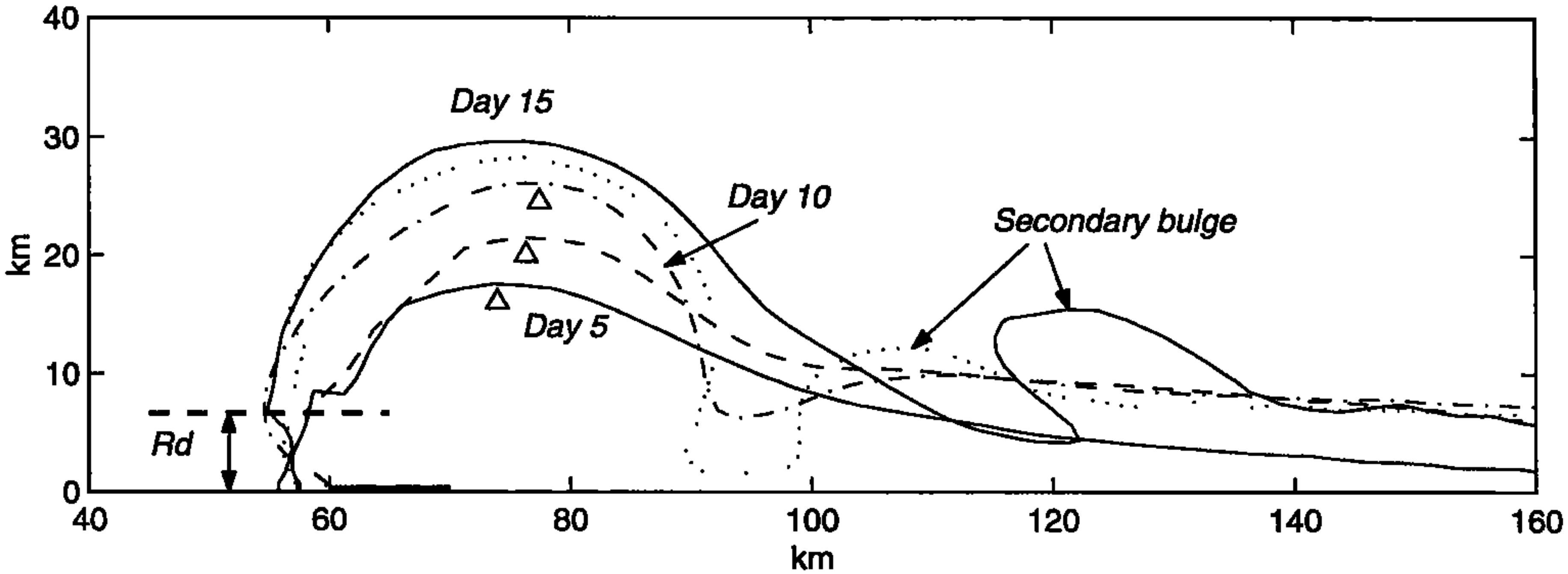
- Similar relevant parameters (Ri ~ 1-10)
- Similar sub-observational scales, O(10 km)



Horner-Devine *et al.* (JFM, 2006)

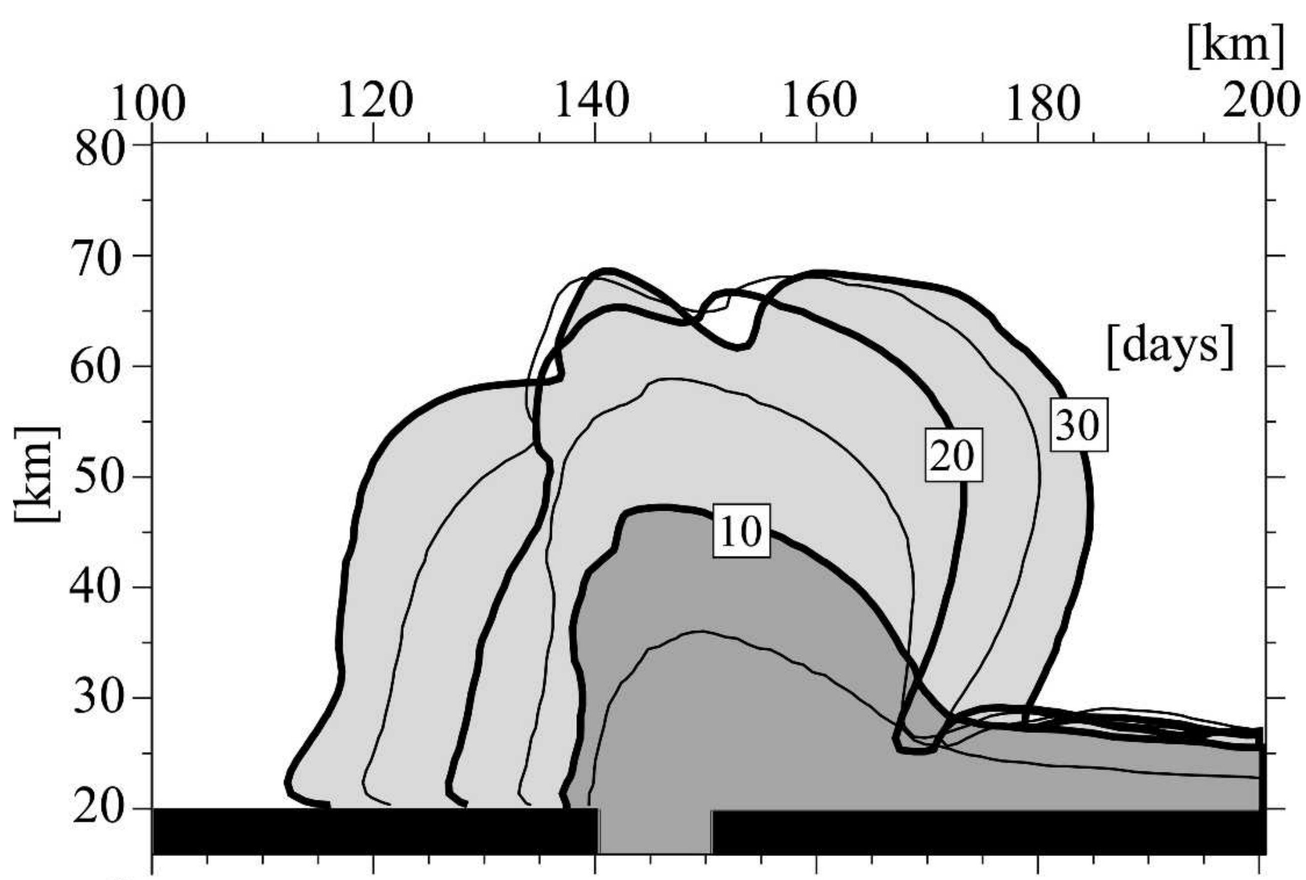


MacCready *et al.* (*CSR*, 2009)



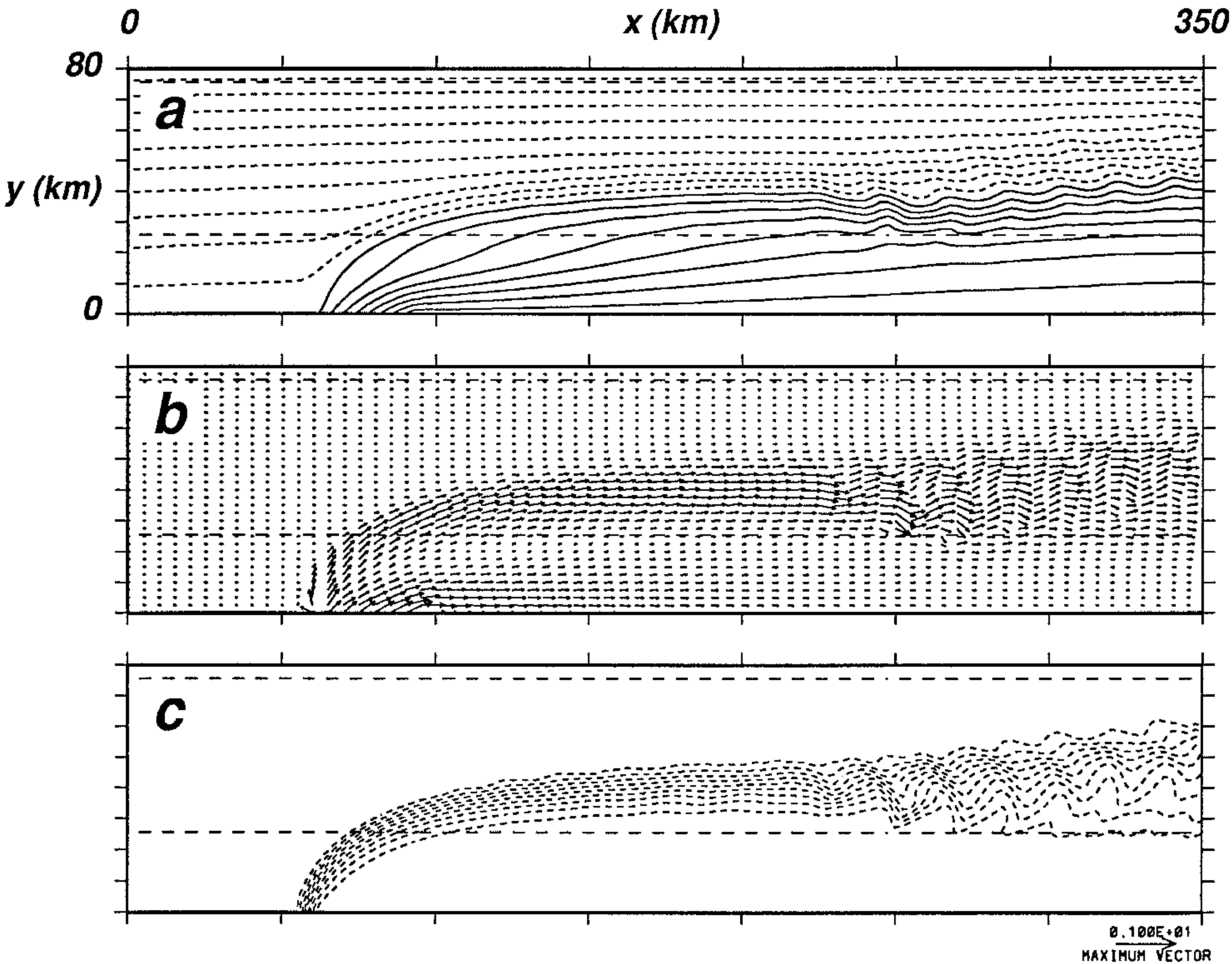
Yankovsky *et al.* (*JGR*, 2001)

Unsteady discharge



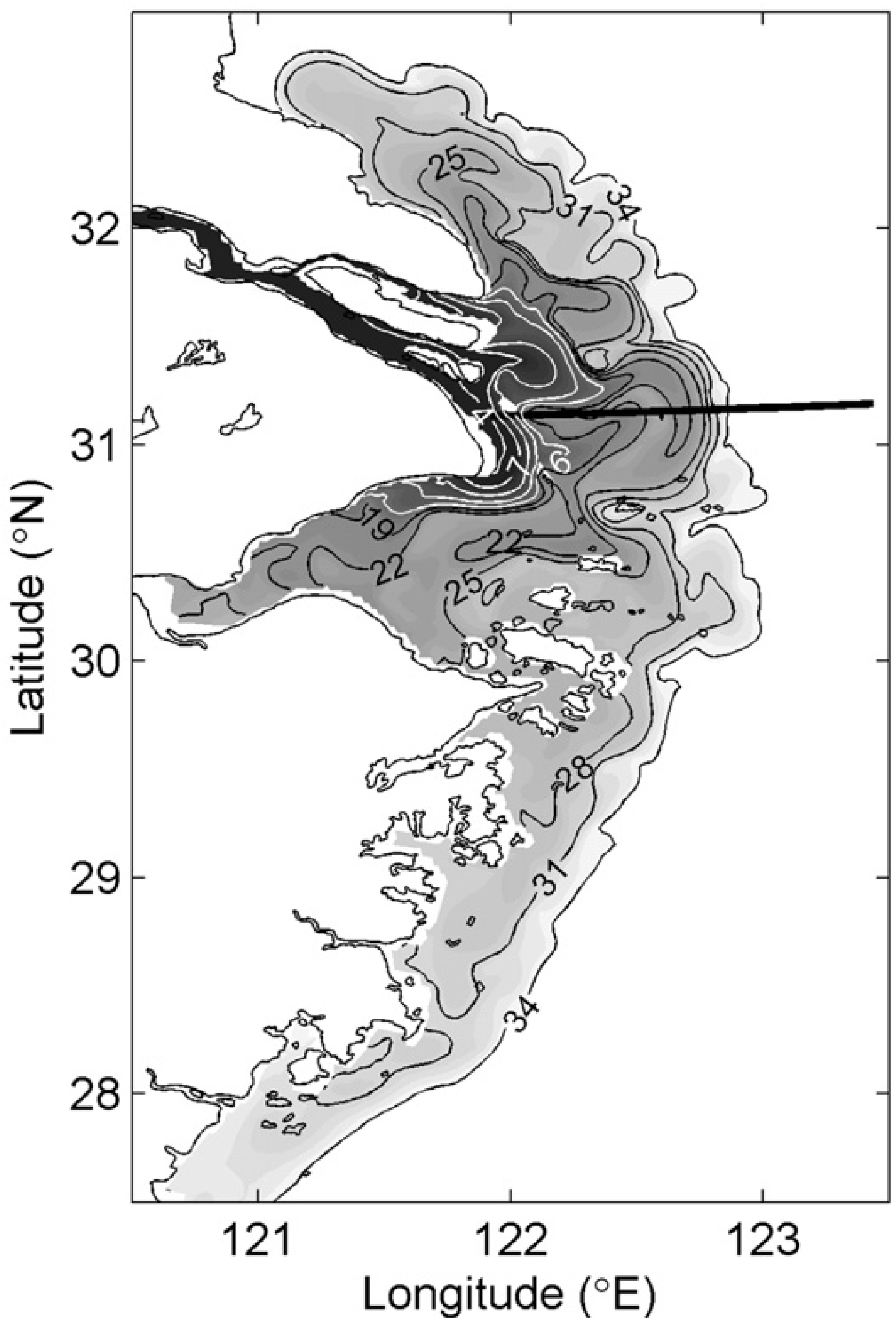
Isobe (*JPO*, 2005)

Inertial instability

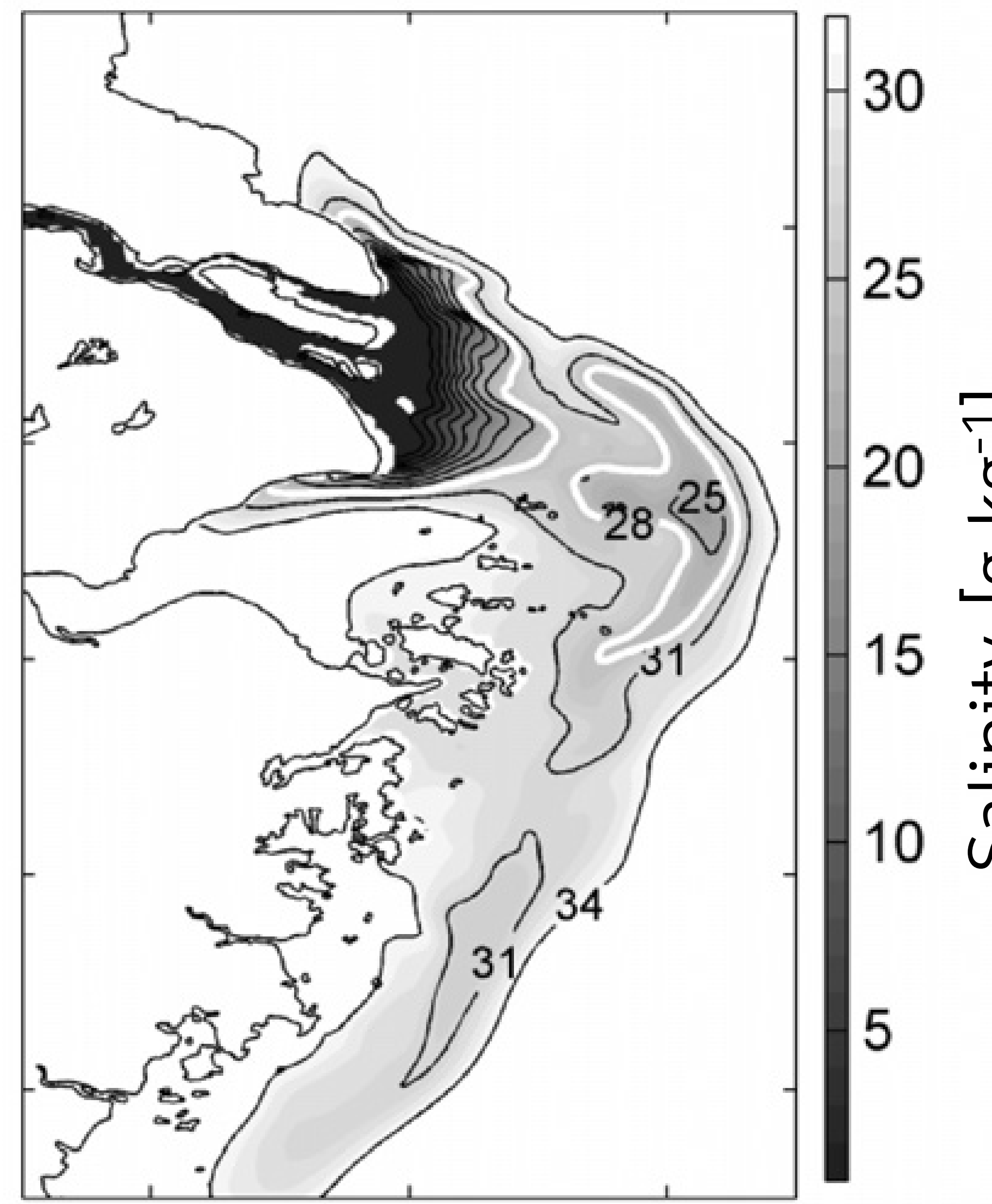


Yankovsky and Chapman (*JPO*, 1997)

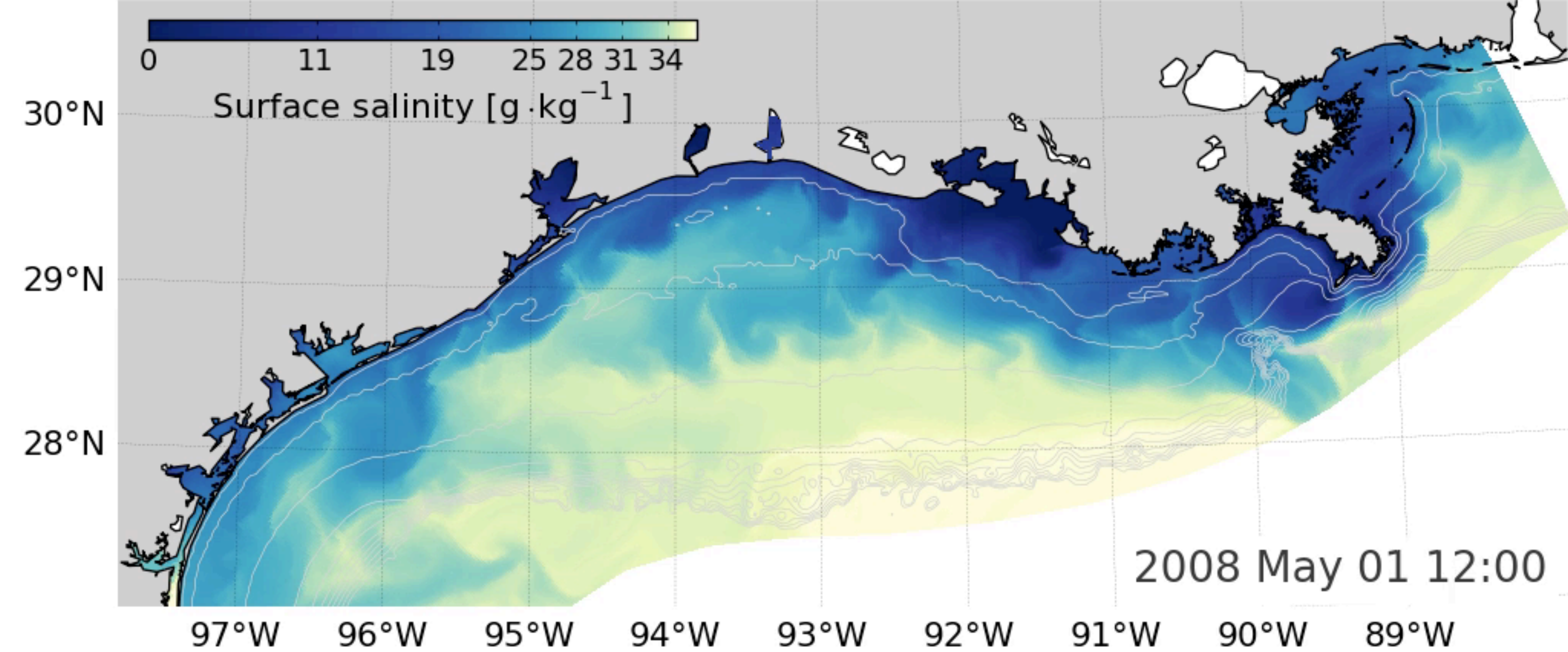
NO TIDE



WITH TIDE



Rong and Li (*ECSS*, 2012)

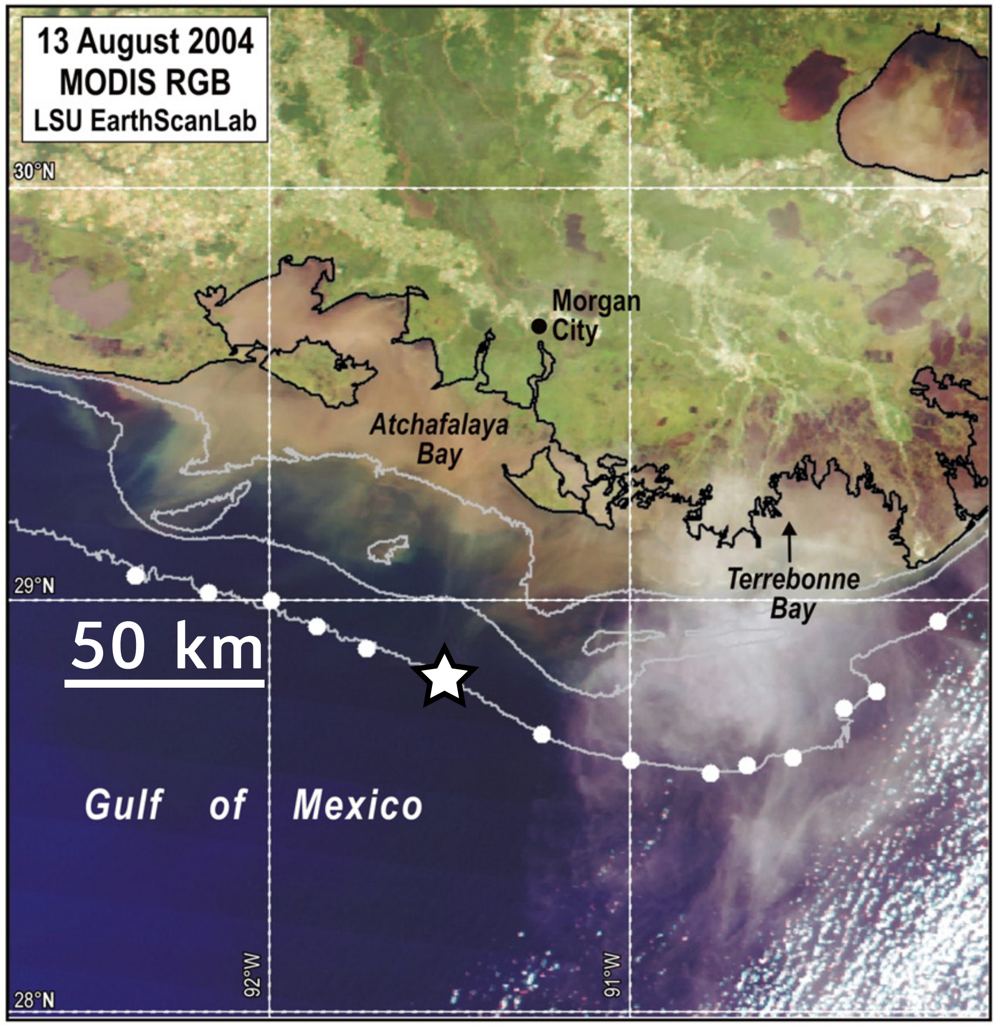


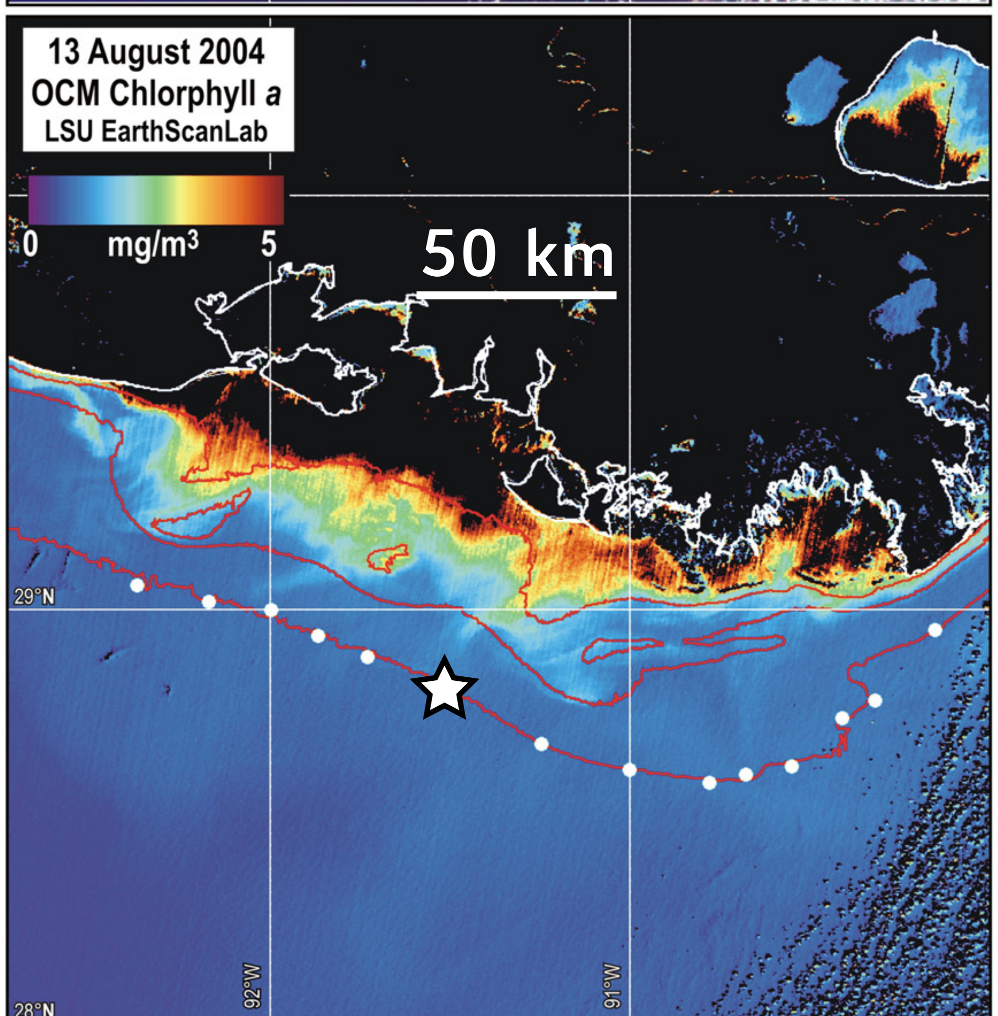
ROMS - TXLA model

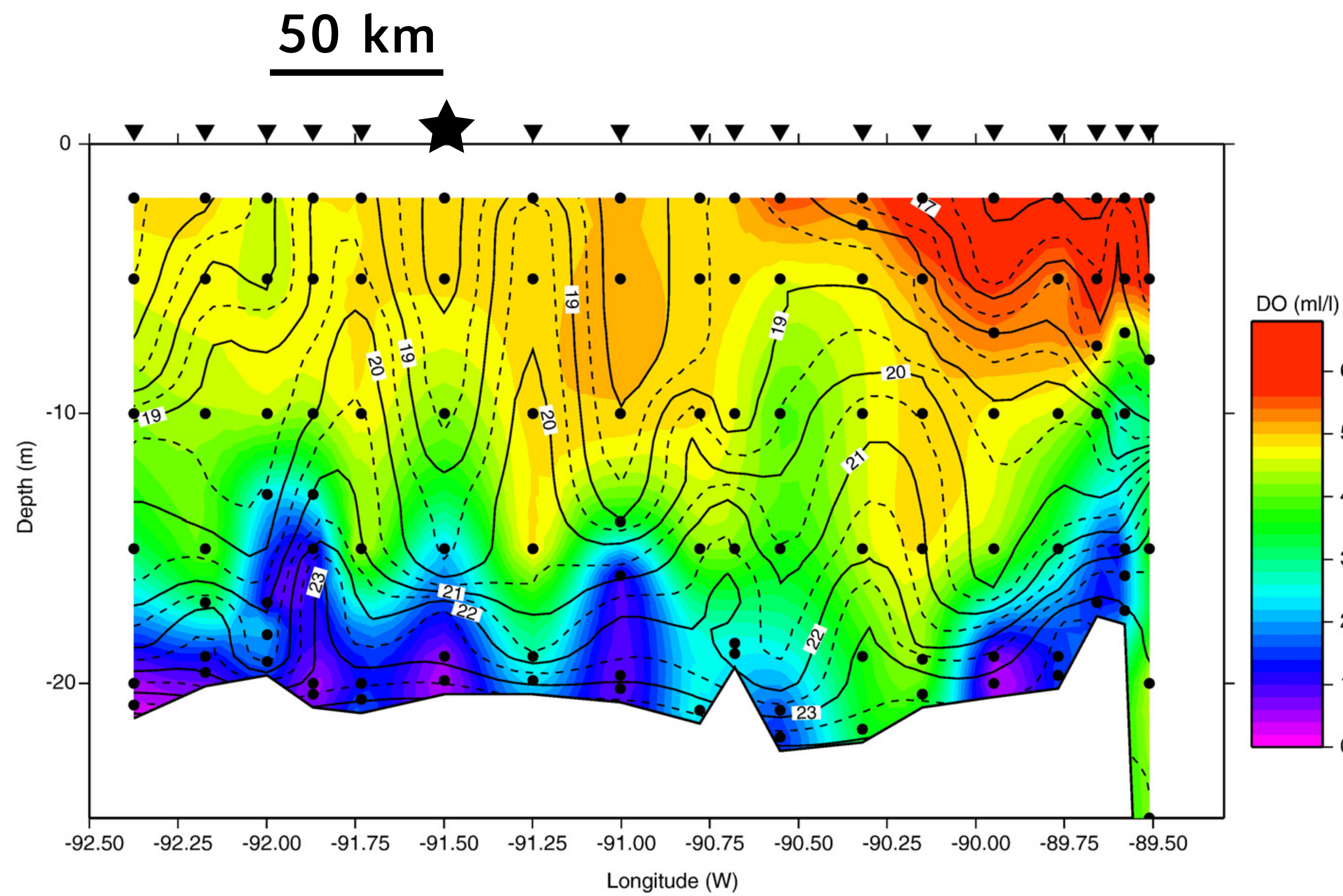
- ~1 km resolution
- Forced with NARR surface fluxes
- All major regional river included
- Nested in GMX HYCOM

X. Zhang *et al.* (*JGR*, 2012)

Topography or instability?







Dimarco et al (2010 JMS)

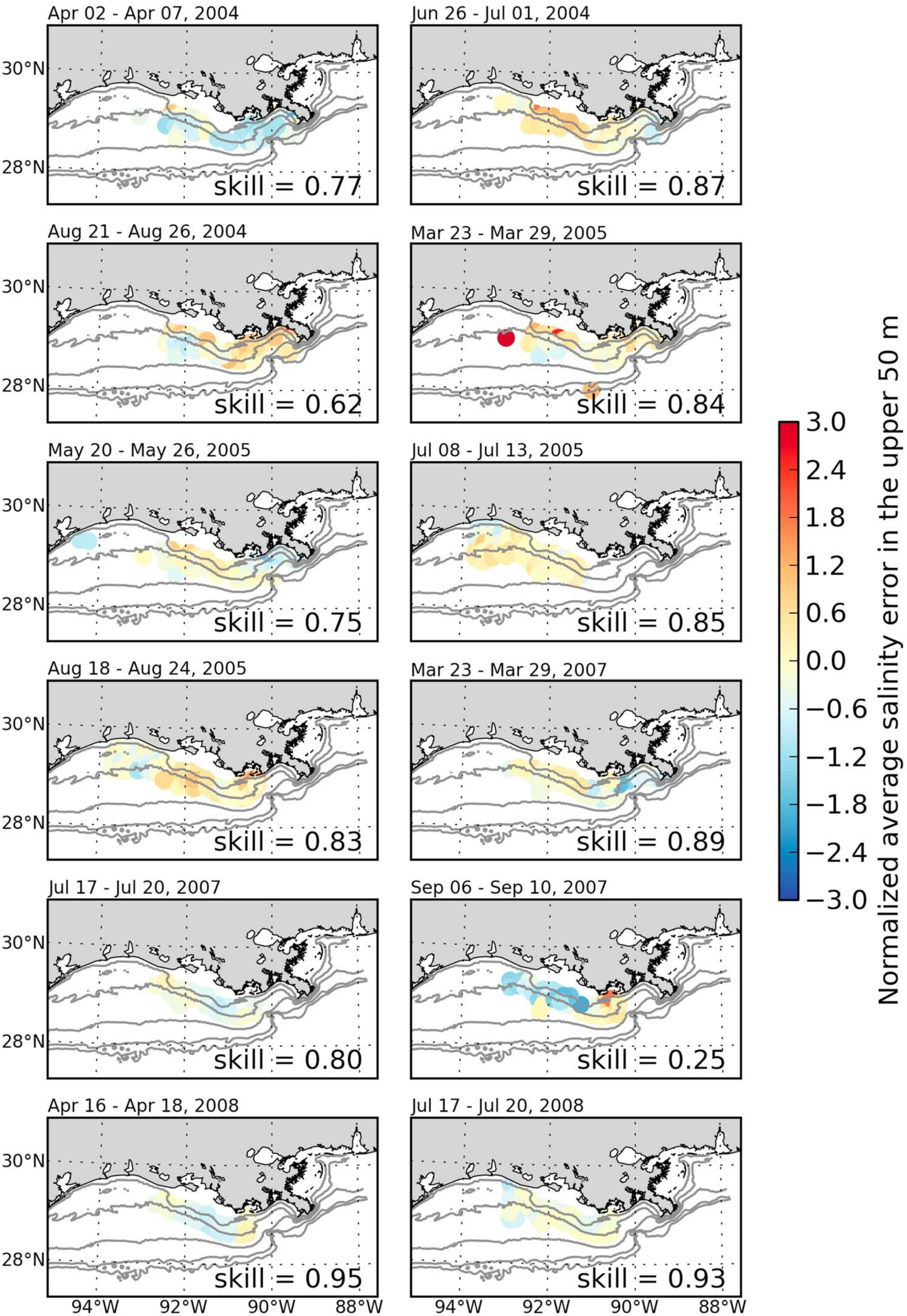


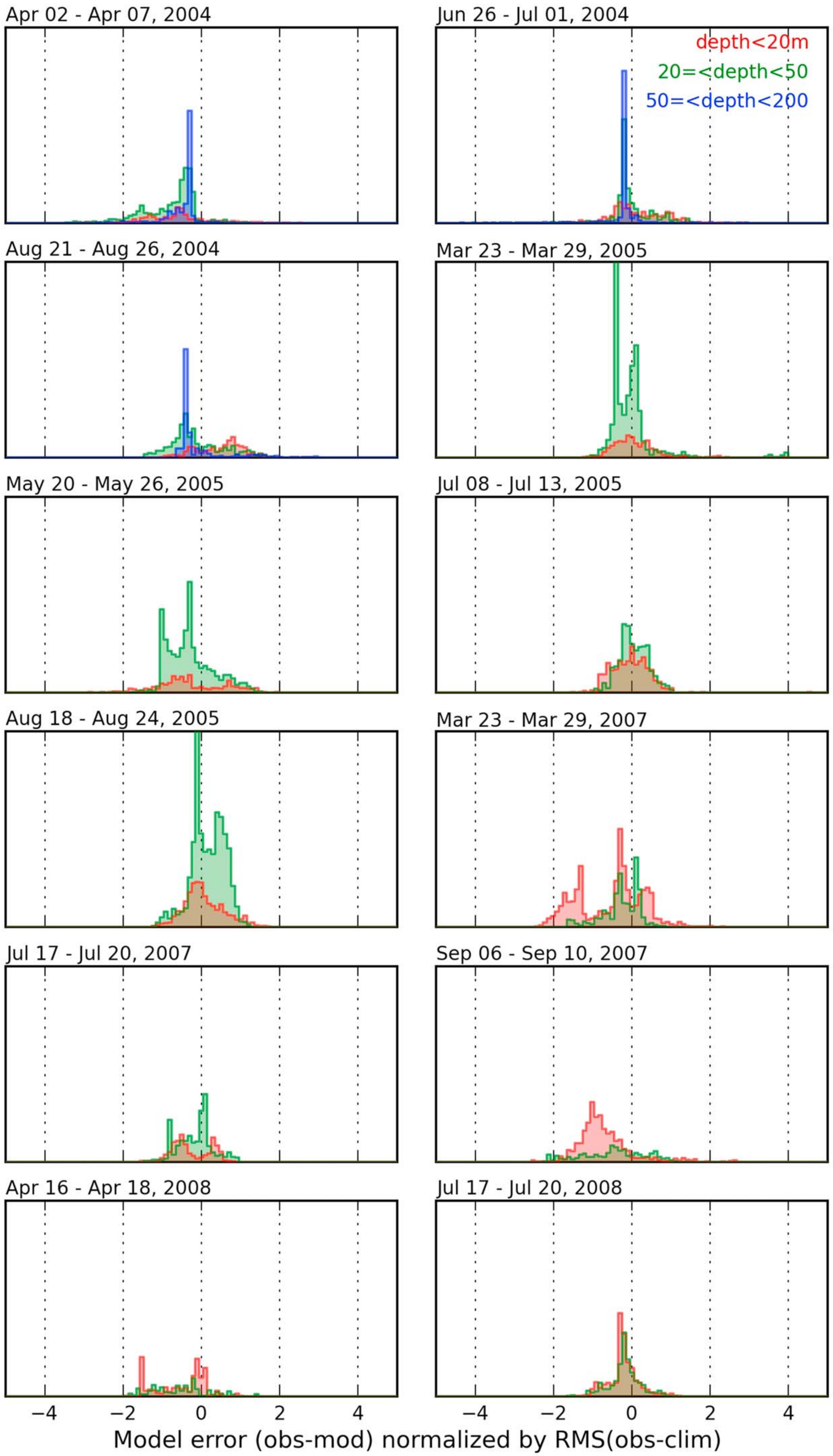
Table 2. Root-Mean-Square (RMS) of the Observed Salinity Relative to Modeled Salinity and Climatological Salinity, Respectively (Equations (2) and (3)) for Each Hypoxia Cruise During Years 2004 to 2008

Hypoxia Cruise	RMS (Obs − Mod)	RMS (Obs − Clim)
2004 MCH01	1.61	3.33
2004 MCH02	1.24	3.38
2004 MCH03	1.52	2.47
2005 MCH04	1.52	3.79
2005 MCH05	1.69	3.42
2005 MCH06	1.29	3.35
2005 MCH07	1.40	3.42
2007 MCH08	1.44	4.38
2007 MCH09	1.56	3.51
2007 MCH10	1.65	1.90
2008 MCH11	1.39	6.13
2008 MCH12	1.36	5.00

Climatology WOA09
1°x1° resolution

$$\text{skill} = \frac{\sum(\text{obs}_i - \text{mod}_i)^2}{\sum(\text{obs}_i - \text{clm}_i)^2}$$

X. Zhang *et al.* (*JGR*, 2012)



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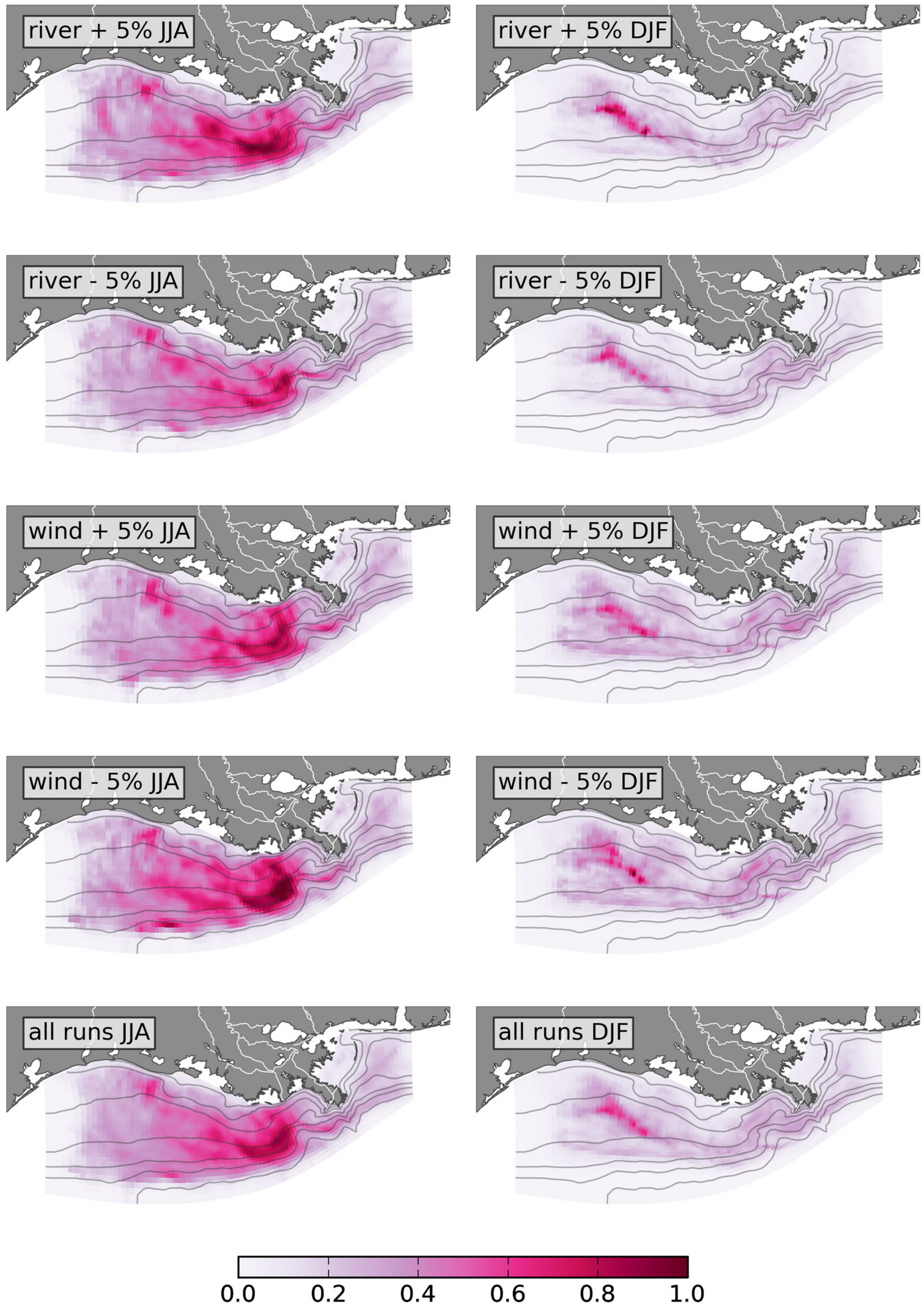
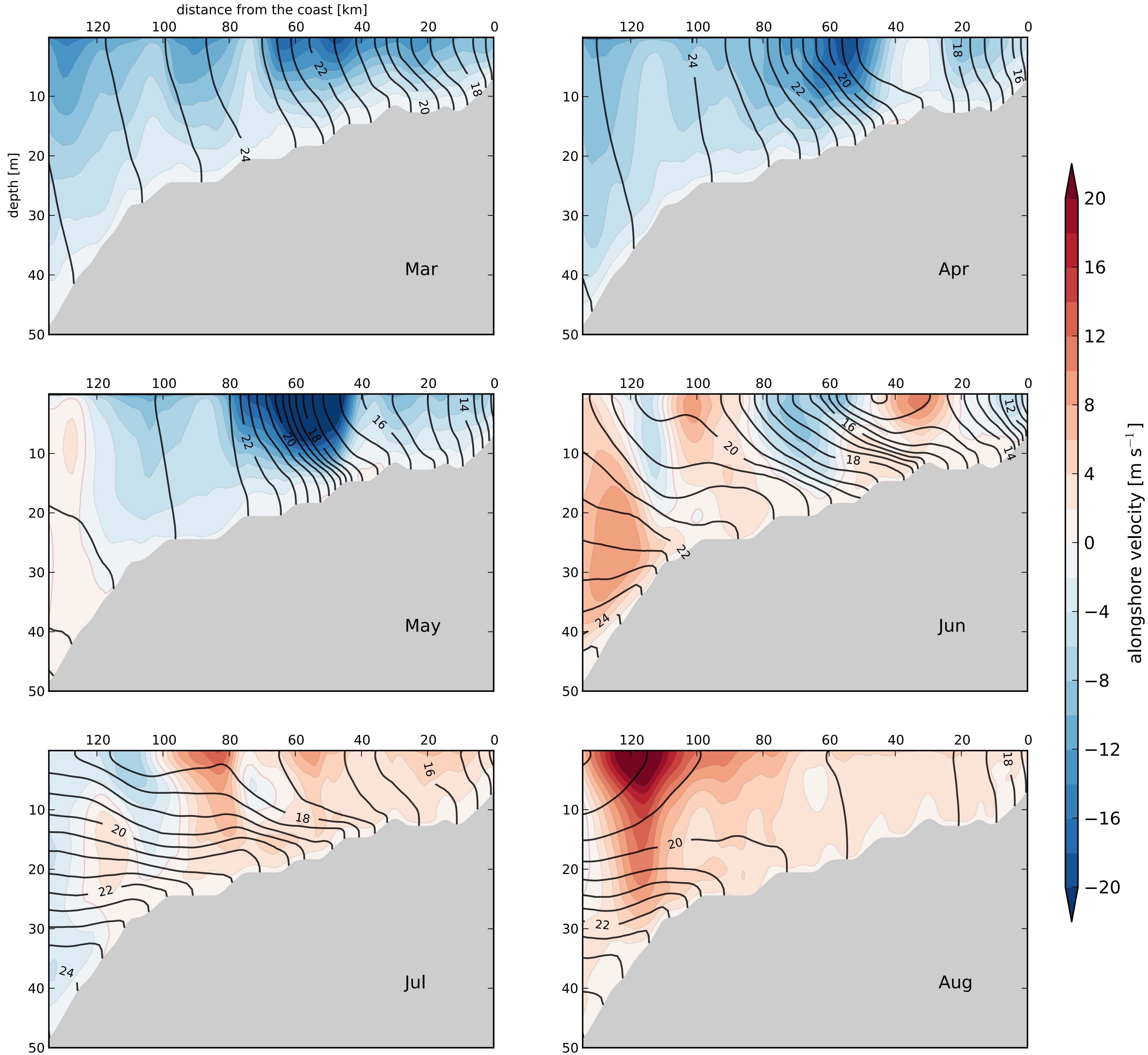
X. Zhang *et al.* (*JGR*, 2012)



Simulations suggest:

- eddy field is chaotic,
- strongest in summer, and
- may be triggered by a variety of processes.

Marta-Almeida *et al.* (*JGR*, 2012)



Z. Zhang and Hetland (*JGR*, submitted)

Base state

Mean state:

$$fU = -\frac{p_y}{\rho_0}$$

$$-b = -\frac{p_z}{\rho_0}$$

so that,

$$U_z = -\frac{b_y}{f} = \frac{M^2}{f}$$

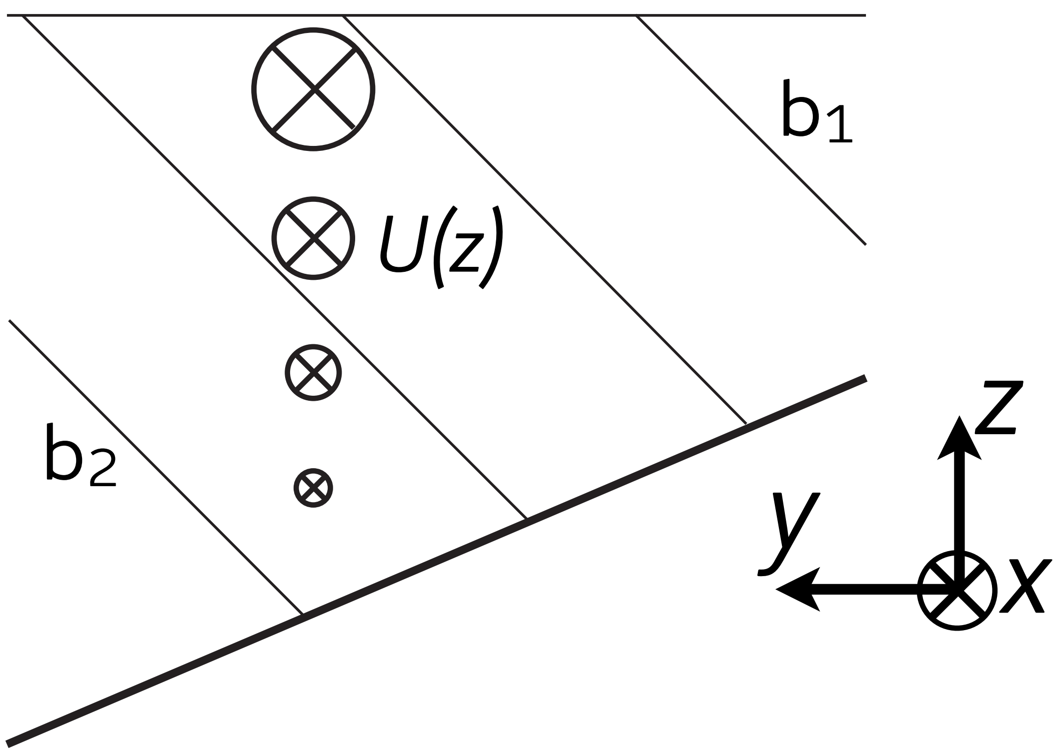
where:

$$N^2 = -b_z$$

$$M^2 = -b_y$$

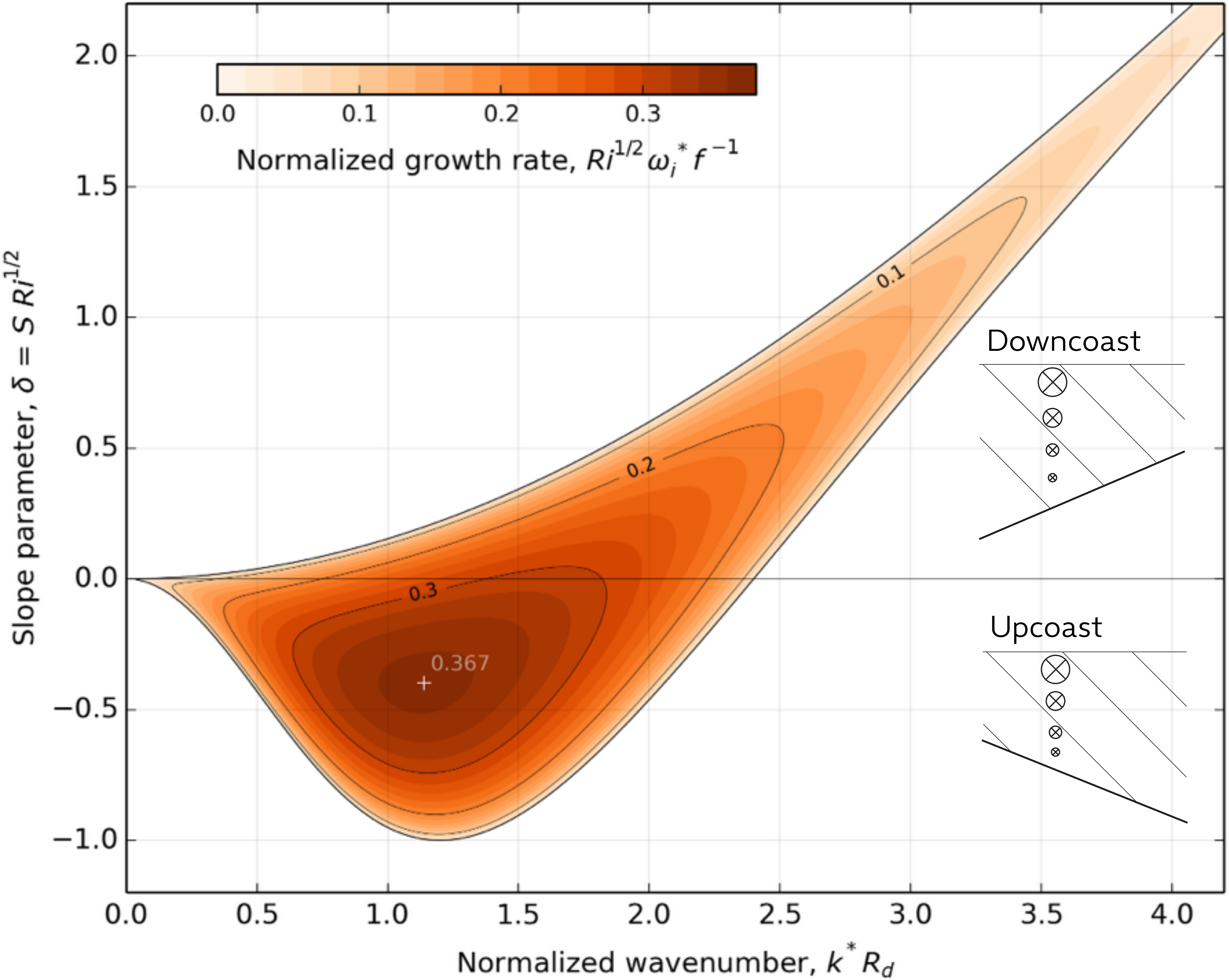
Bouyancy:

$$b = g\left(\frac{\rho_0 - \rho}{\rho_0}\right)$$

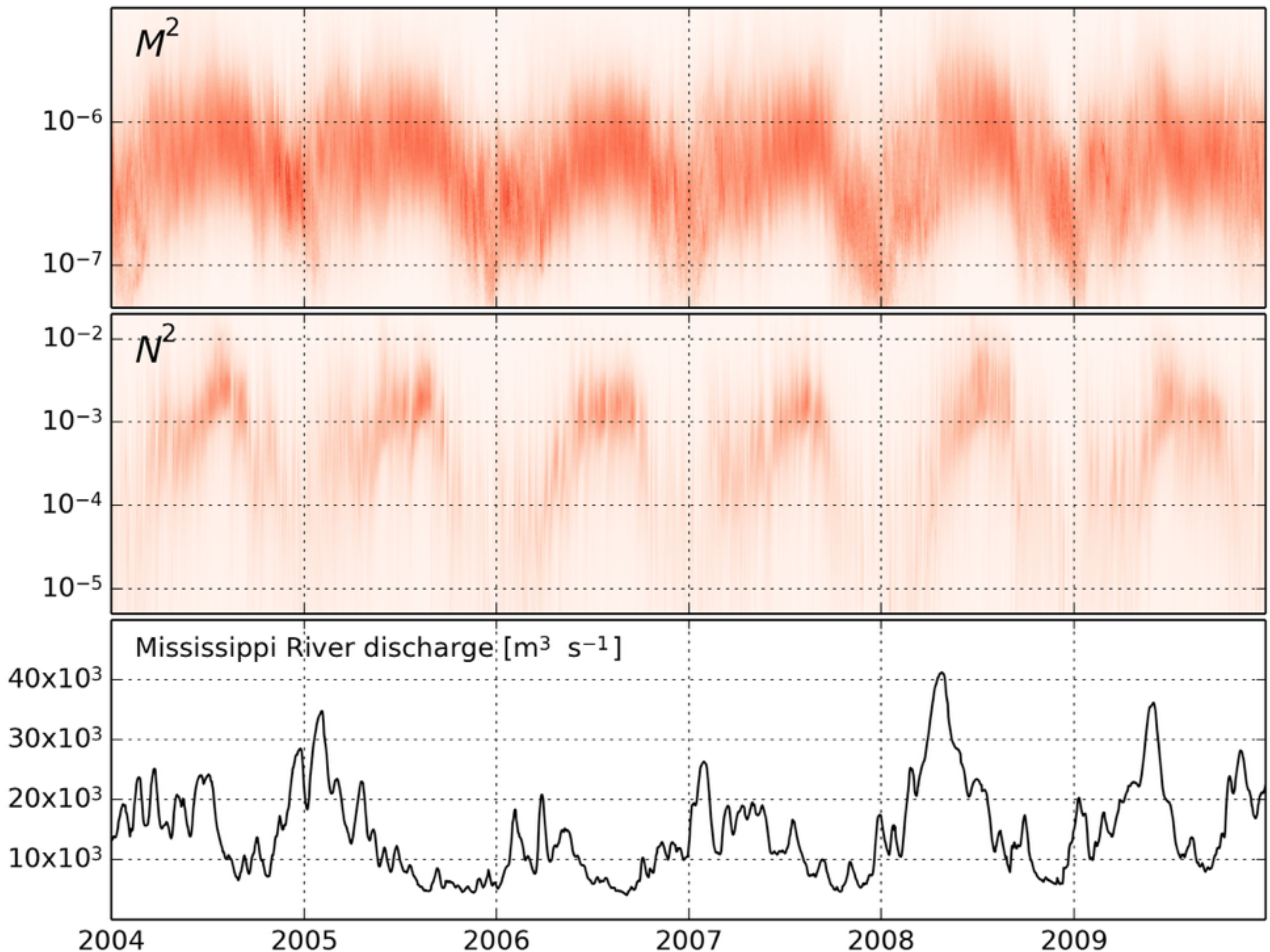


Relevant parameters:

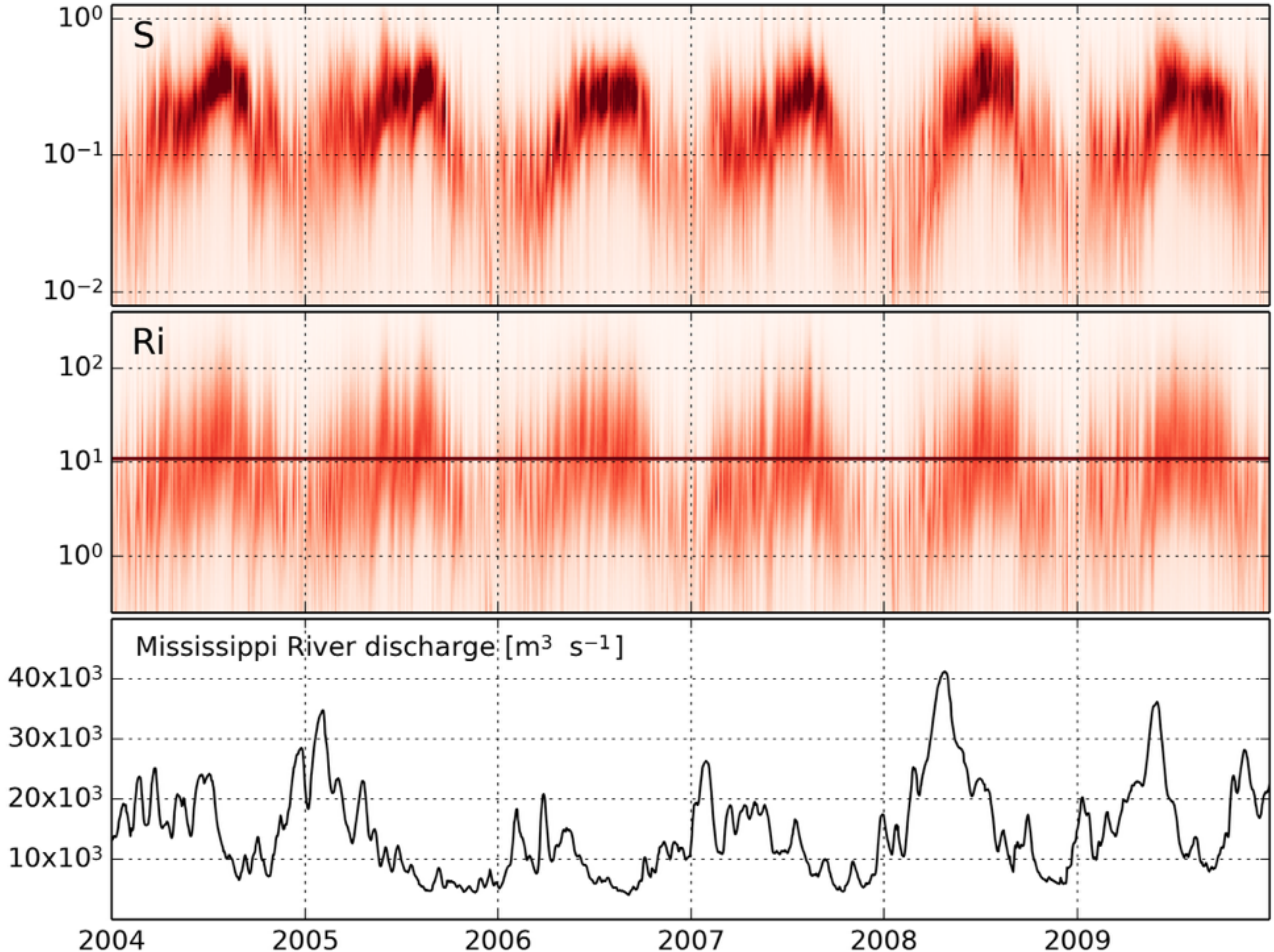
$$Ri = \frac{N^2 f^2}{M^4} \qquad S = \frac{N}{f}\alpha$$



Adapted from Blumsack and Geirasch (*JAS*, 1972)



M^2
10^{-6}
10^{-7}
N^2
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Mississippi River discharge [m^3 s^{-1}]
$40x10^3$
$30x10^3$
$20x10^3$
$10x10^3$
2004
2005
2006
2007
2008
2009

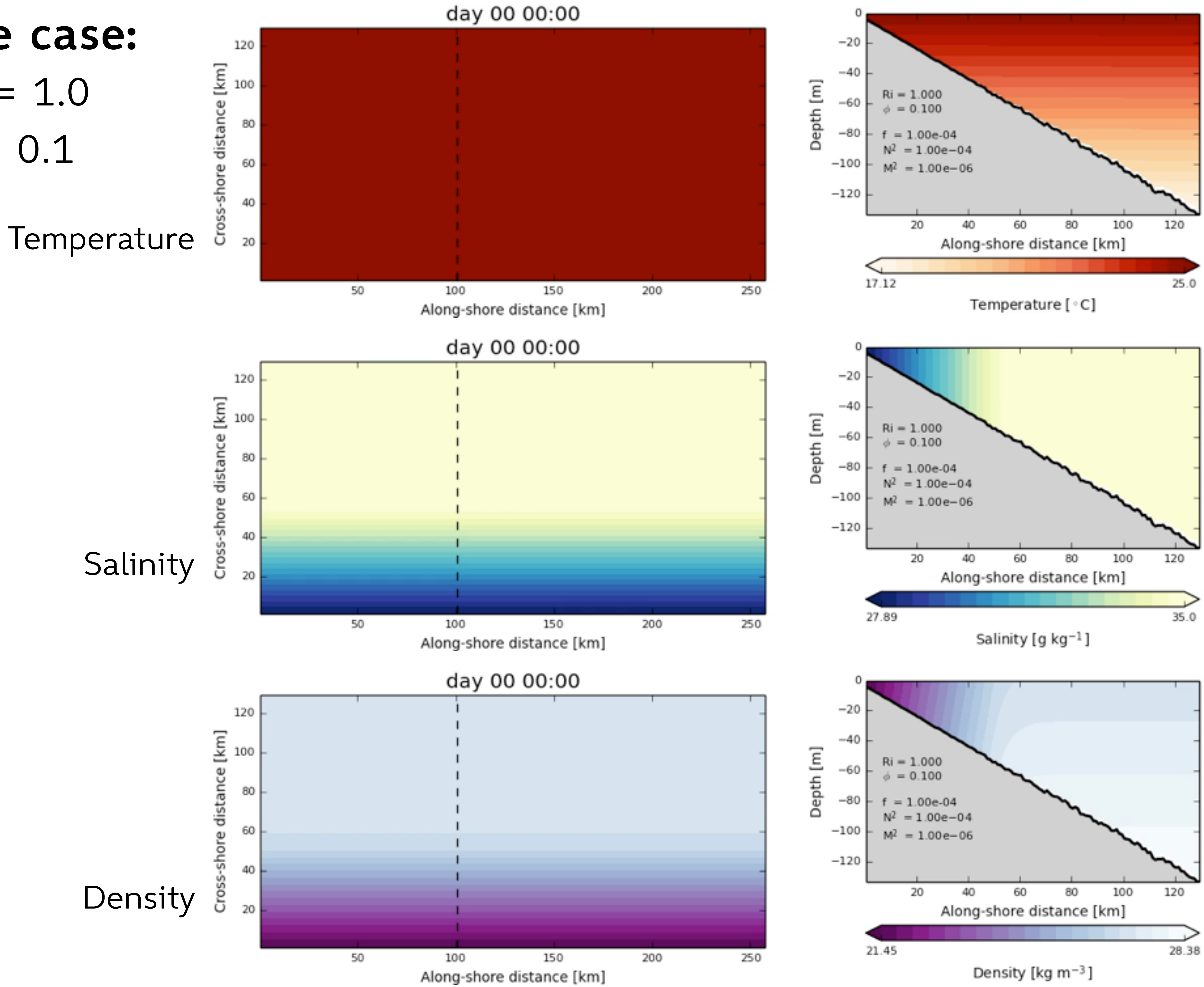


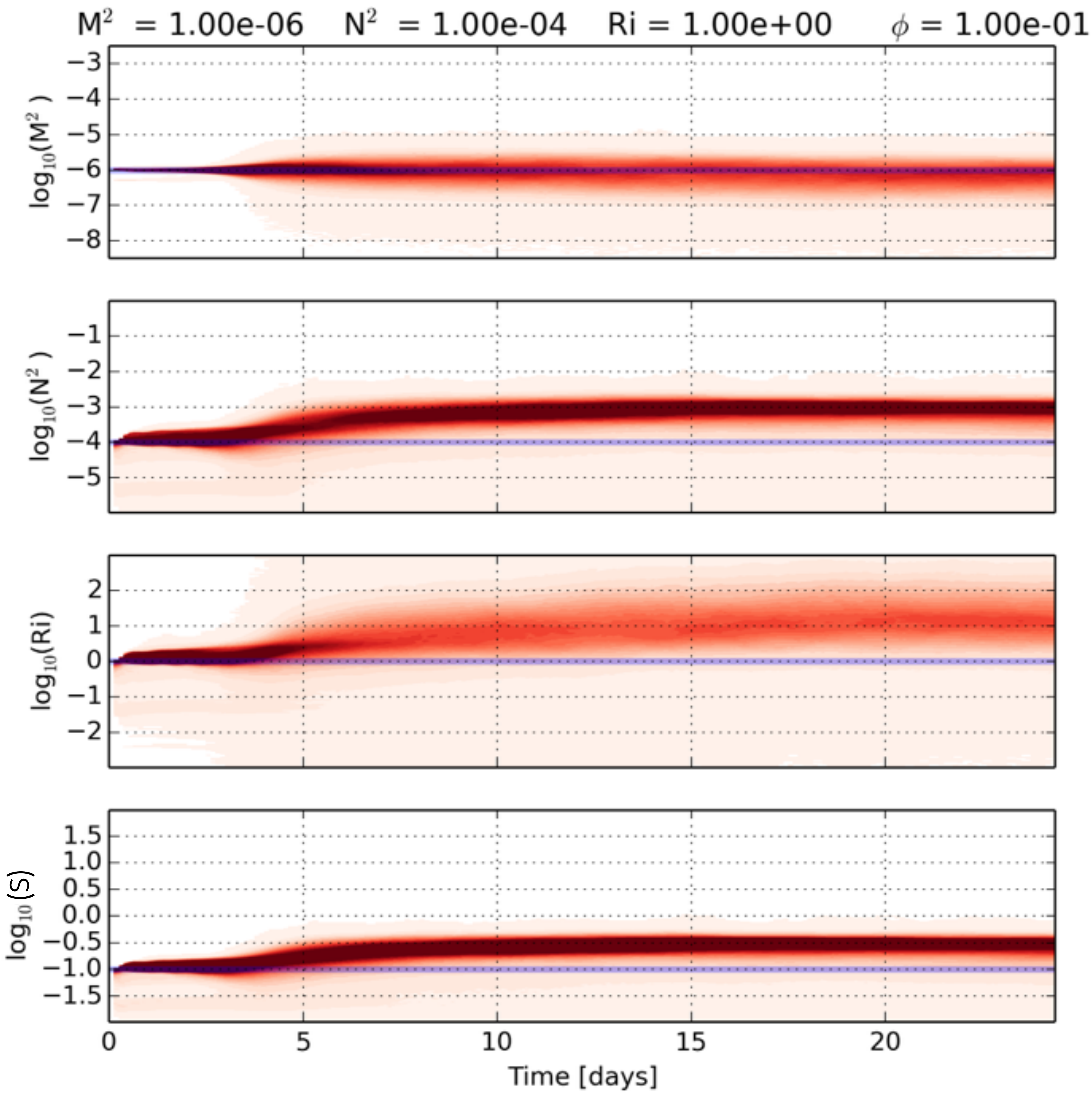
S
Ri
Mississippi River discharge [m³ s⁻¹]
10⁰
10⁻¹
10⁻²
10²
10¹
10⁰
40x10³
30x10³
20x10³
10x10³
2004
2005
2006
2007
2008
2009

Base case:

Ri = 1.0

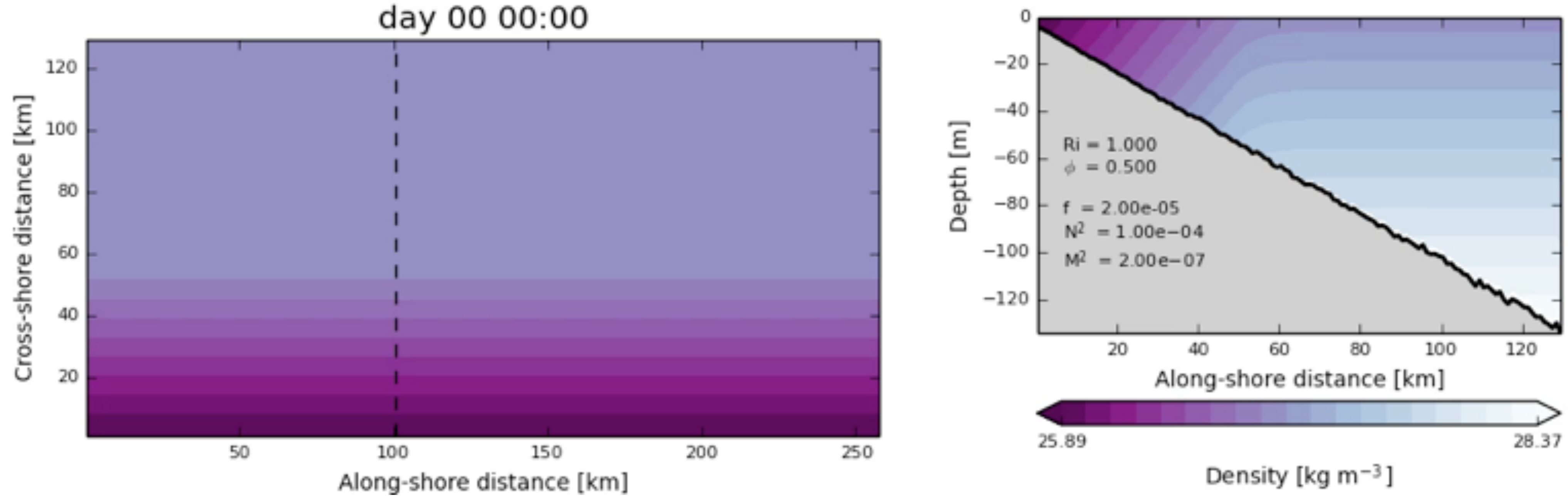
S = 0.1



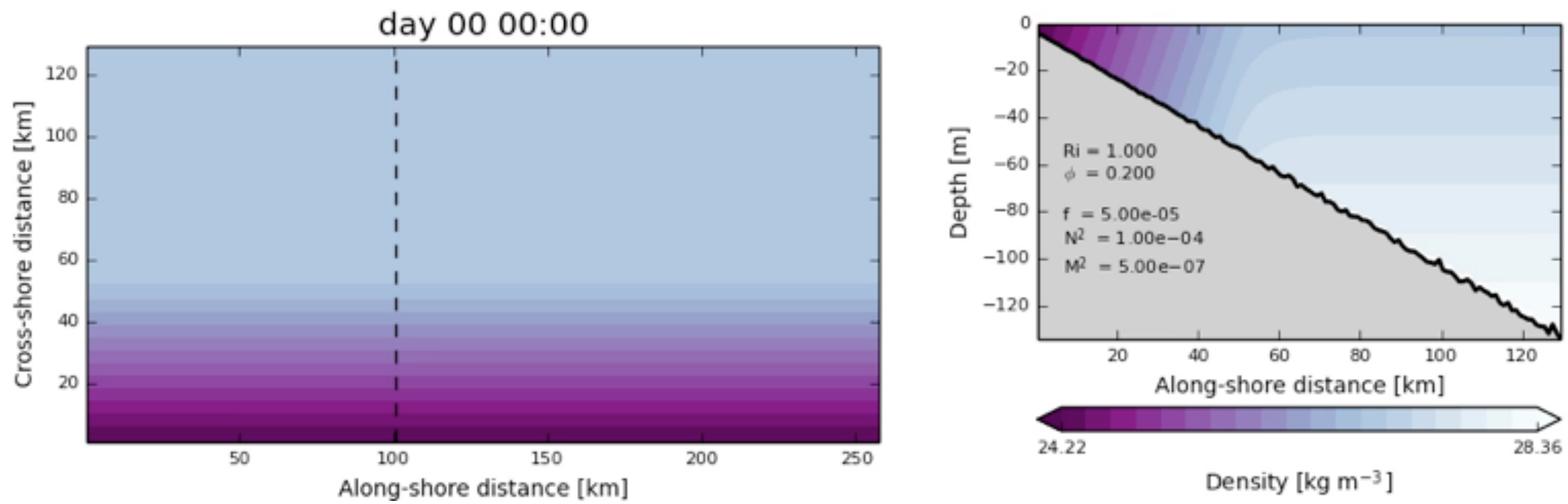


M^2 = 1.00e-06 N^2 = 1.00e-04 Ri = 1.00e+00 ϕ = 1.00e-01
log$_{10}$(M^2)
−3
−4
−5
−6
−7
−8
log$_{10}$(N^2)
−1
−2
−3
−4
−5
log$_{10}$(Ri)
2
1
0
−1
−2
log$_{10}$(S)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
5
10
15
20
Time [days]

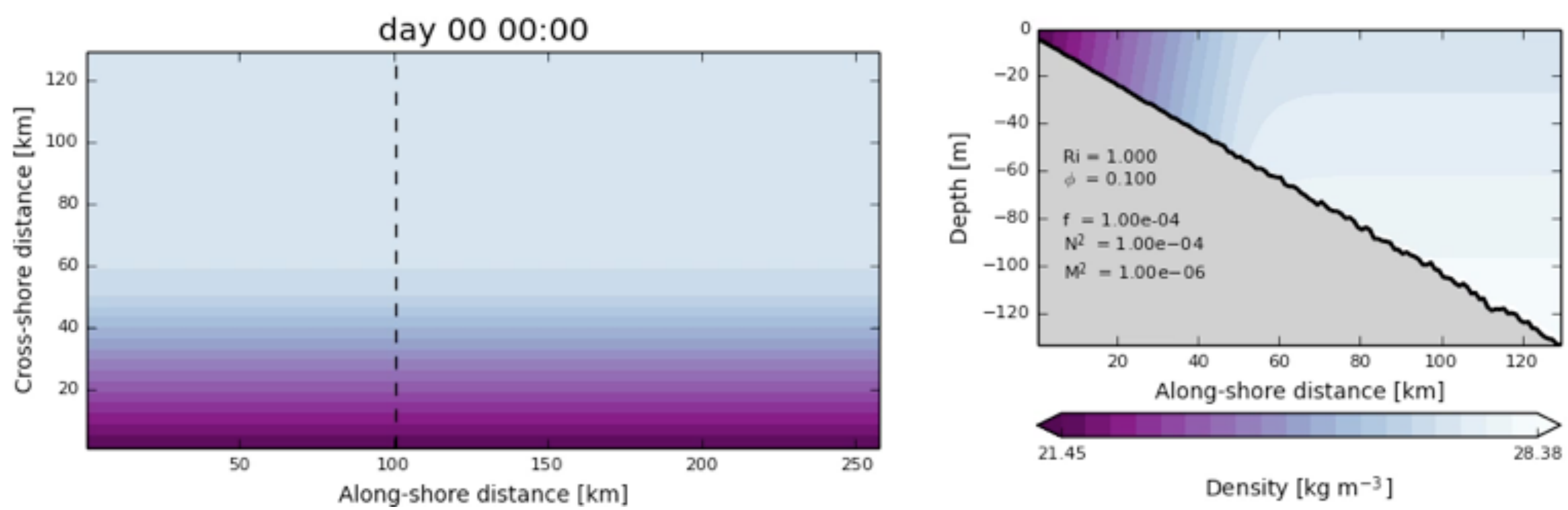
S = 0.5

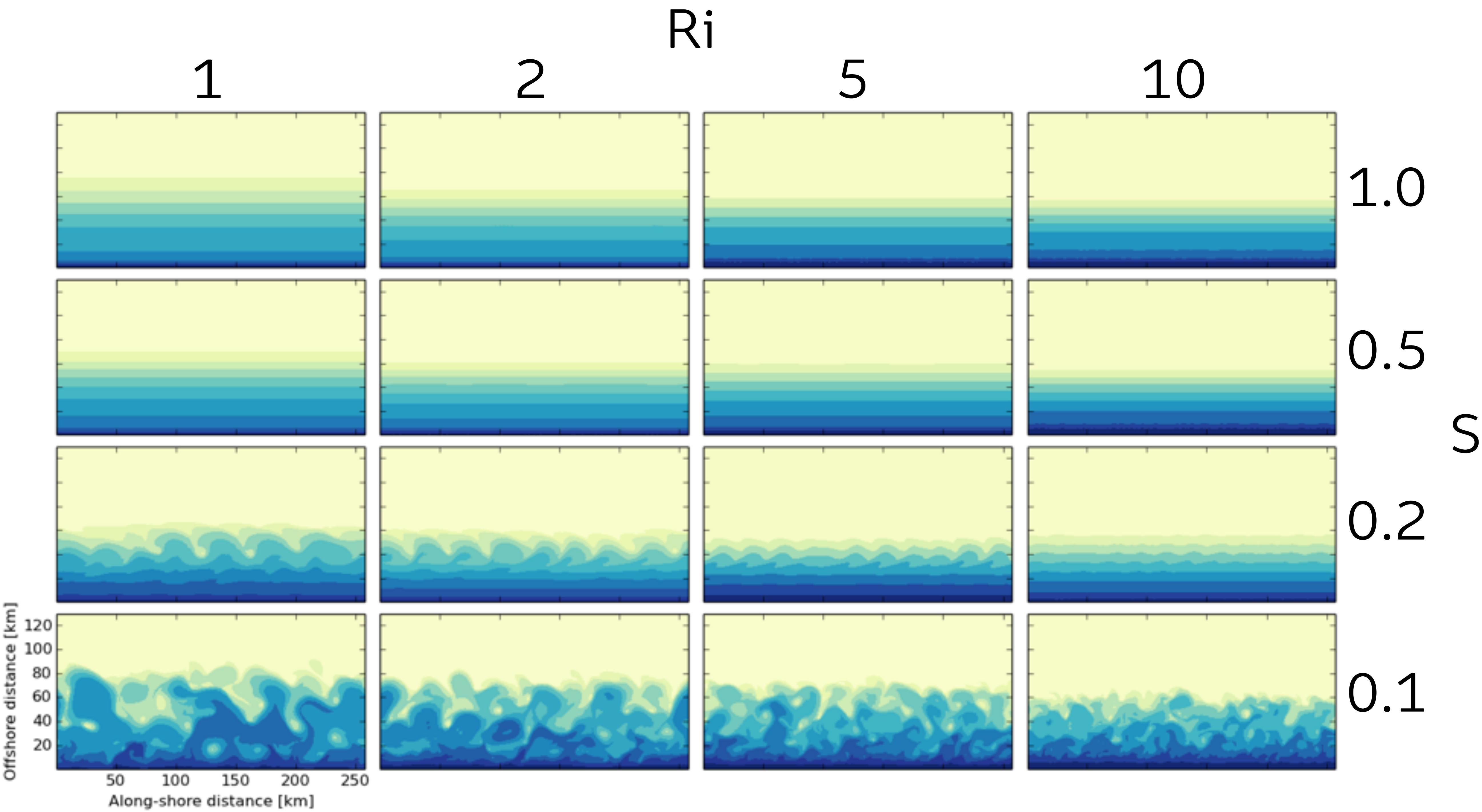

day 00 00:00
Cross-shore distance [km]
Along-shore distance [km]
Depth [m]
Ri = 1.000
ϕ = 0.500
f = 2.00e-05
N² = 1.00e-04
M² = 2.00e-07
Along-shore distance [km]
25.89
28.37
Density [kg m⁻³]

S = 0.2


day 00 00:00
Cross-shore distance [km]
Along-shore distance [km]
Depth [m]
Ri = 1.000
ϕ = 0.200
f = 5.00e-05
N² = 1.00e-04
M² = 5.00e-07
Along-shore distance [km]
24.22
28.36
Density [kg m⁻³]

S = 0.1

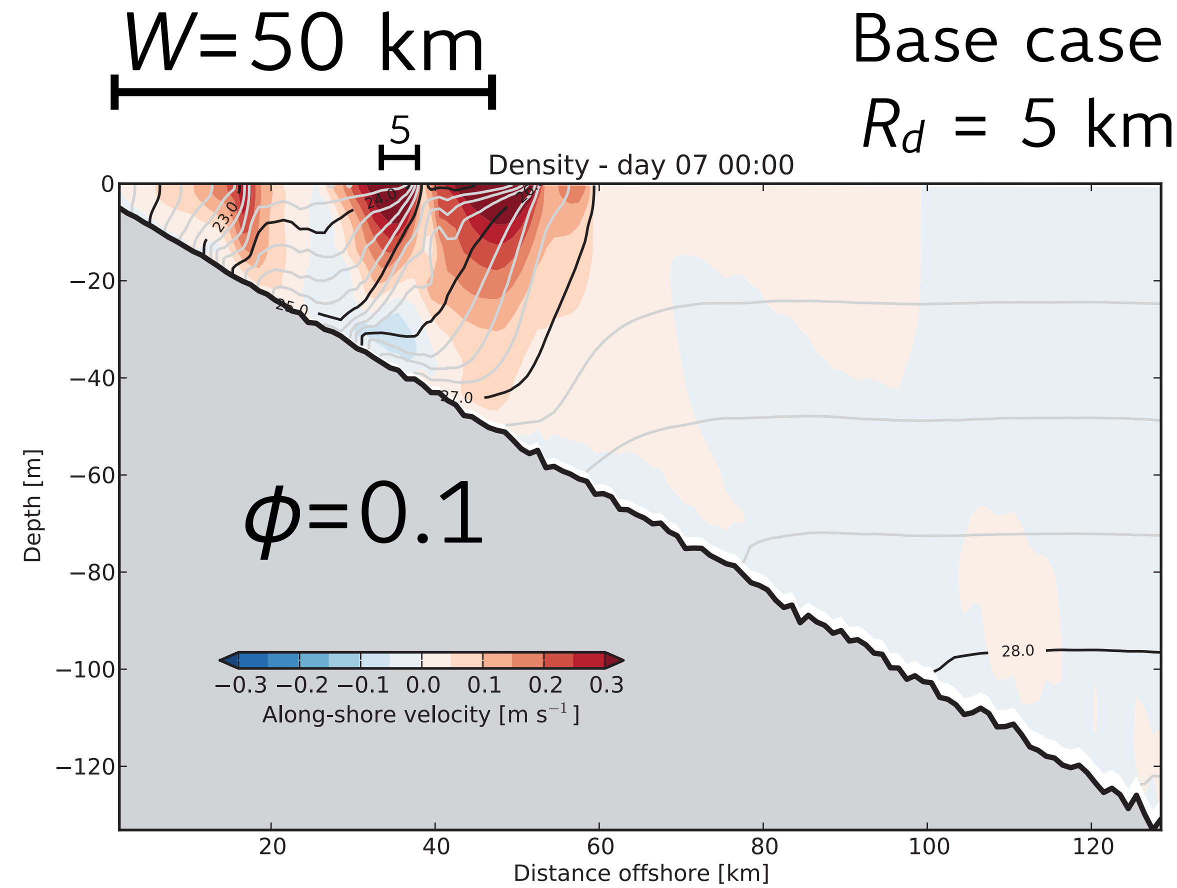

day 00 00:00
Cross-shore distance [km]
Along-shore distance [km]
Depth [m]
Ri = 1.000
ϕ = 0.100
f = 1.00e-04
N² = 1.00e-04
M² = 1.00e-06
Along-shore distance [km]
21.45
28.38
Density [kg m⁻³]



Eddies only form for $S \leq 0.3$, or $3Rd < W$.

In order to form, eddies need to fit.

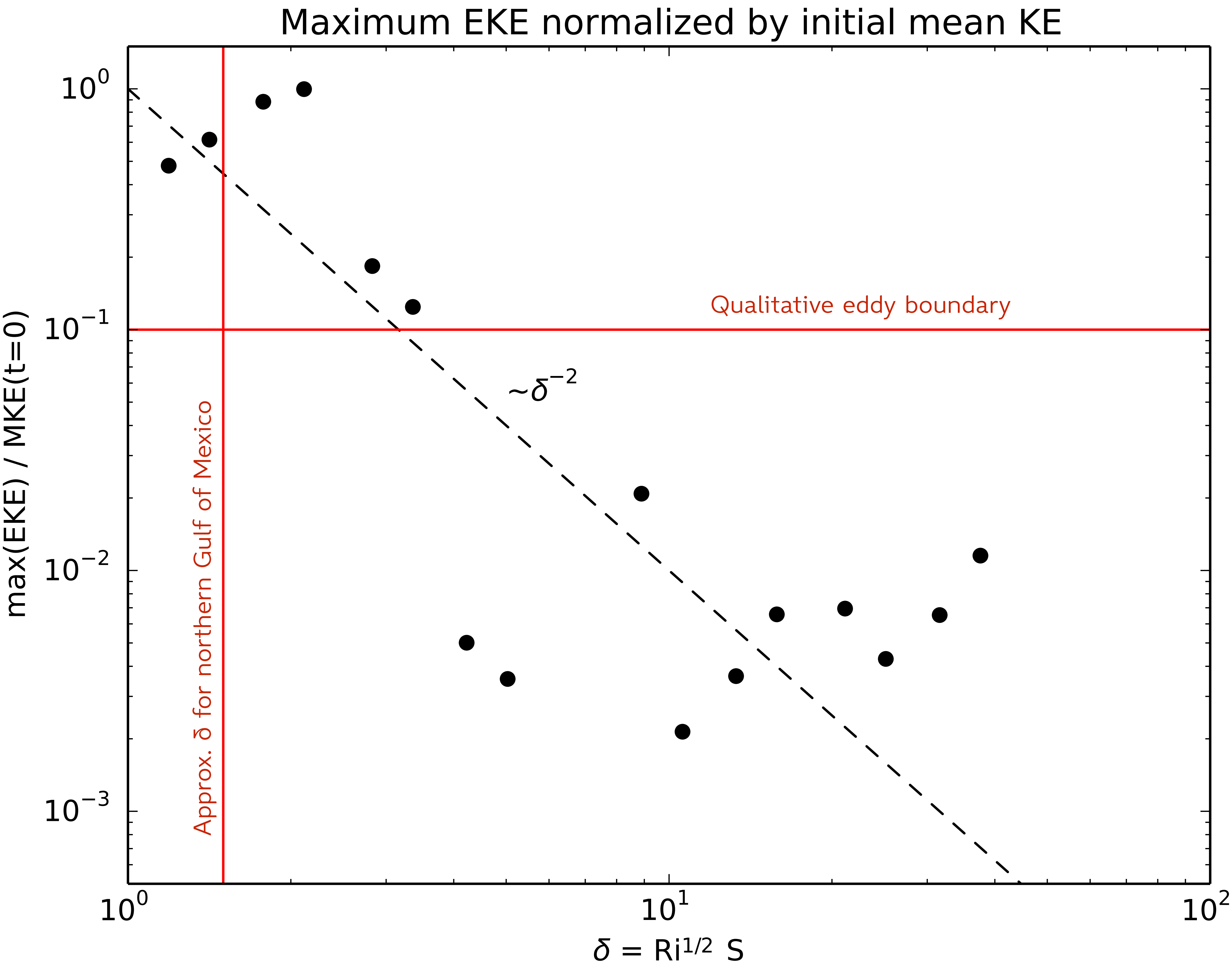
$$W > R_d = \frac{NH}{f}$$



Where the aspect ratio, α, is used to define

$$1 > \frac{N}{f}\frac{H}{W} = \frac{N}{f}\alpha \qquad \text{and using} \quad Ri = \frac{N^2 f^2}{M^4}$$

$$1 > S \equiv \frac{R_d}{W} = \frac{N}{f}\alpha = \frac{M^2}{f^2}\alpha\sqrt{Ri}$$



Maximum EKE normalized by initial mean KE
max(EKE) / MKE(t=0)
δ = Ri$^{1/2}$ S
10^0
10^{-1}
10^{-2}
10^{-3}
10^1
10^2
Qualitative eddy boundary
$\sim\delta^{-2}$
Approx. δ for northern Gulf of Mexico

Conclusions:

Eddies need to fit – S < 0.3.

This may be why baroclinic instabilities are rare in river plumes.

When eddies form, the field evolves to S ~ 0.3.

This suggests that eddies cannot export fresh water from the shelf alone.