Physical sources of sound in laminar and turbulent jets

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Introduction

Aim

To understand the physical sources of jet noise.

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Motivation

- By-pass ratio is limited
- Find alternative strategies

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- Non-radiating base flow sources
- DNS

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Previous work

Single frequency algorithm

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- Non-radiating base flow sources
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Previous work

Single frequency algorithm

Objectives of the presentation

- Multiple frequency algorithm
- Sources in a laminar jet
- Sources in a turbulent jet

Part I

Non-Radiating Base Flow (NRBF) Sources

NRBF sources definition

$$f_i = -\frac{\partial}{\partial x_j}\left(\overline{\rho}\,\widetilde{v}_i\widetilde{v}_j\right)'$$

$$\widetilde{v}_i = \overline{\rho v_i}/\overline{\rho}$$

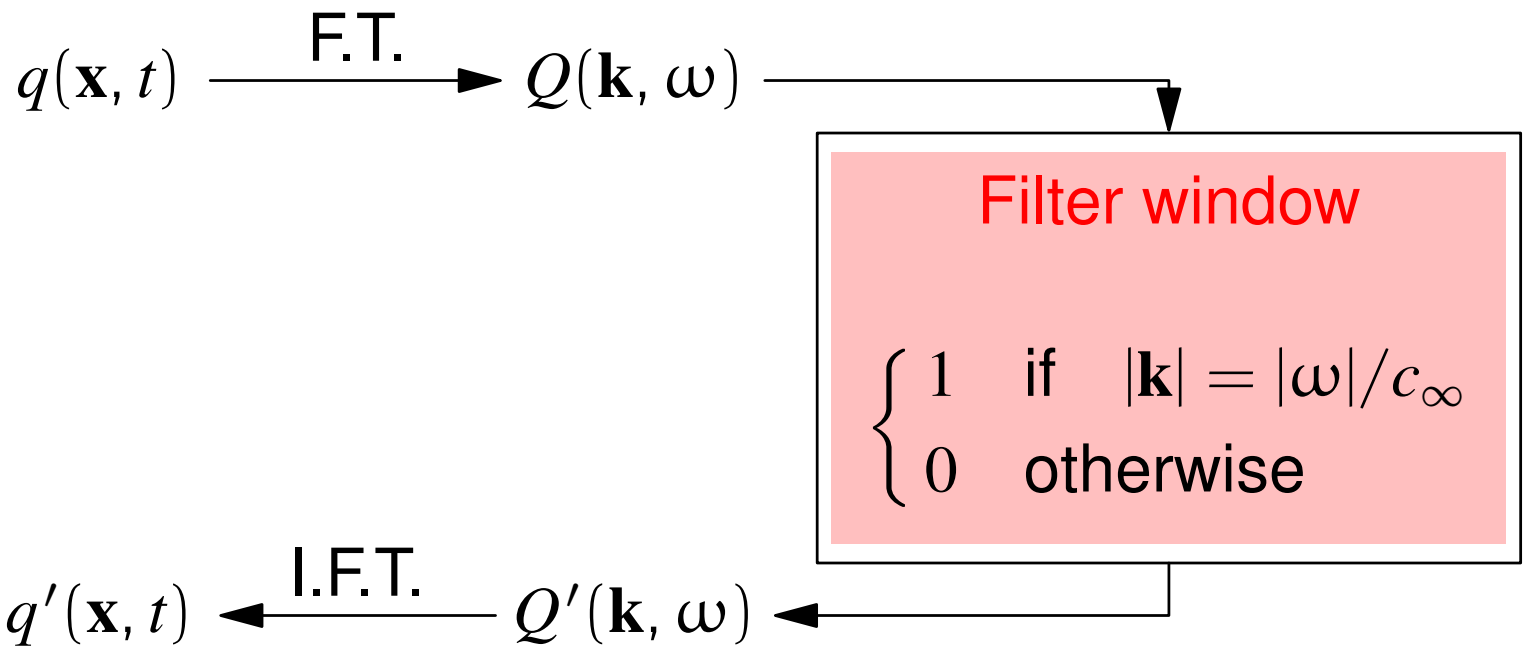
Flow decomposition

Space-time domain

$$q' = w * q$$

Wavenumber-frequency domain

$$Q' = W \times Q$$

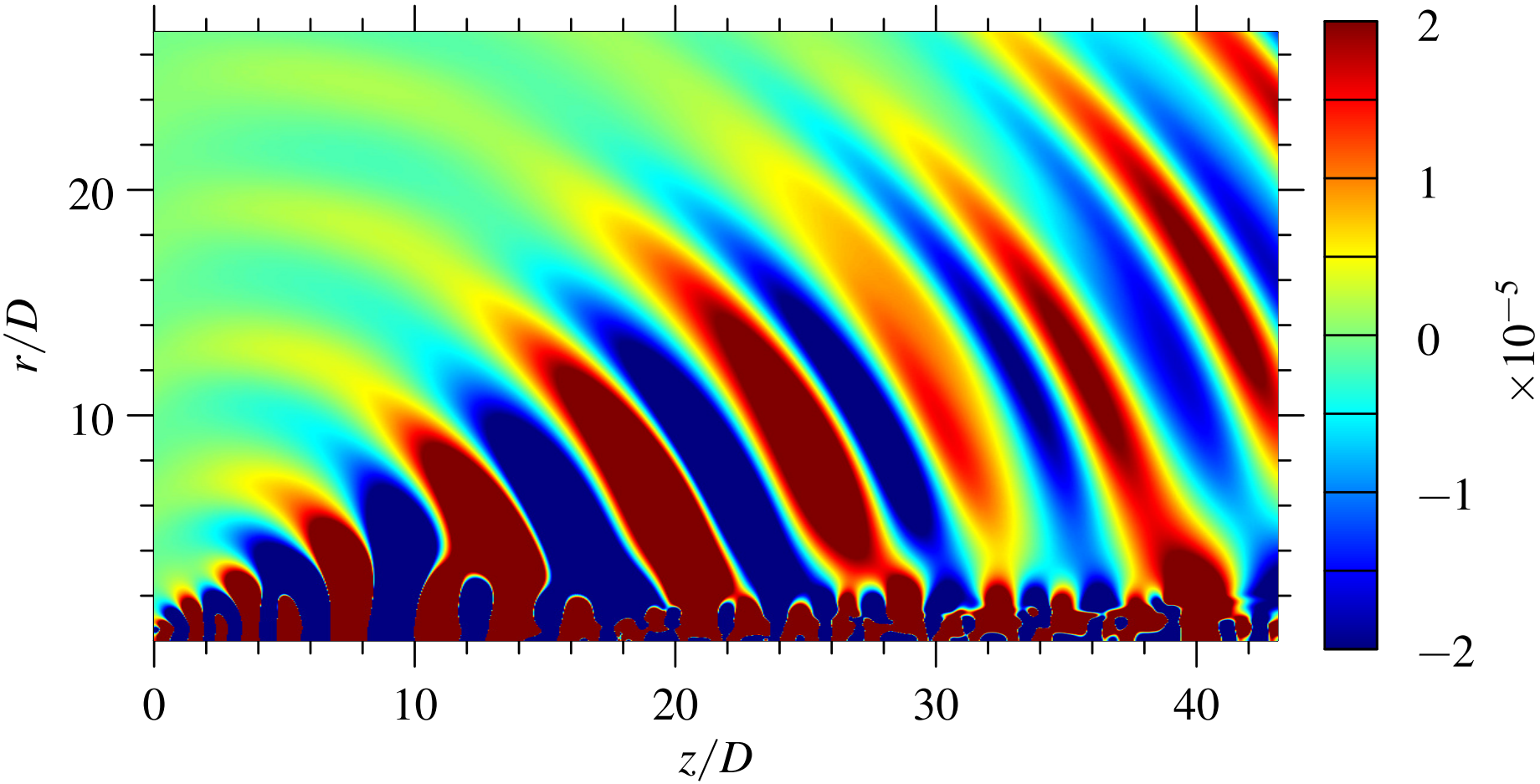


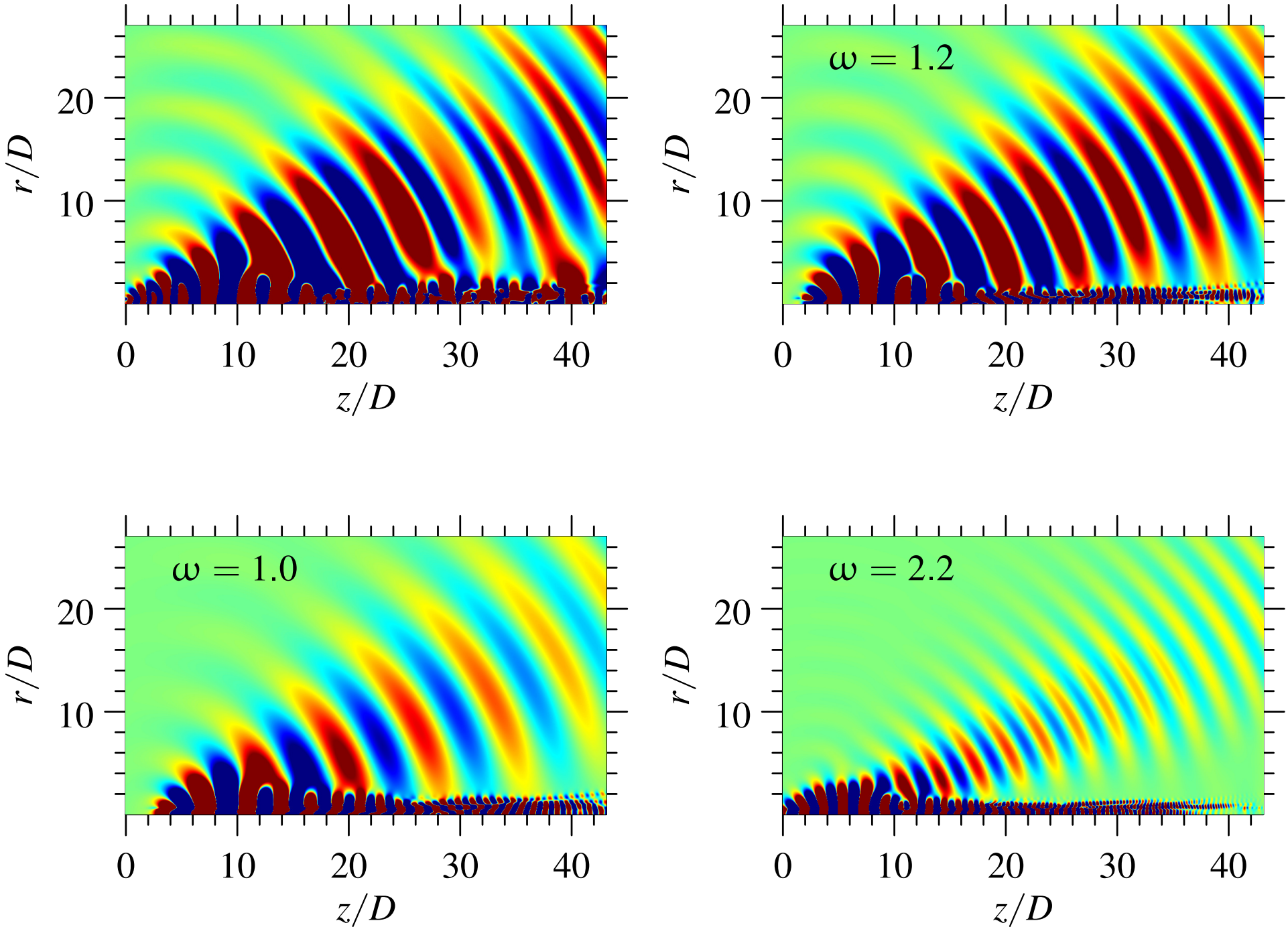
Part II

Sound sources in a laminar jet

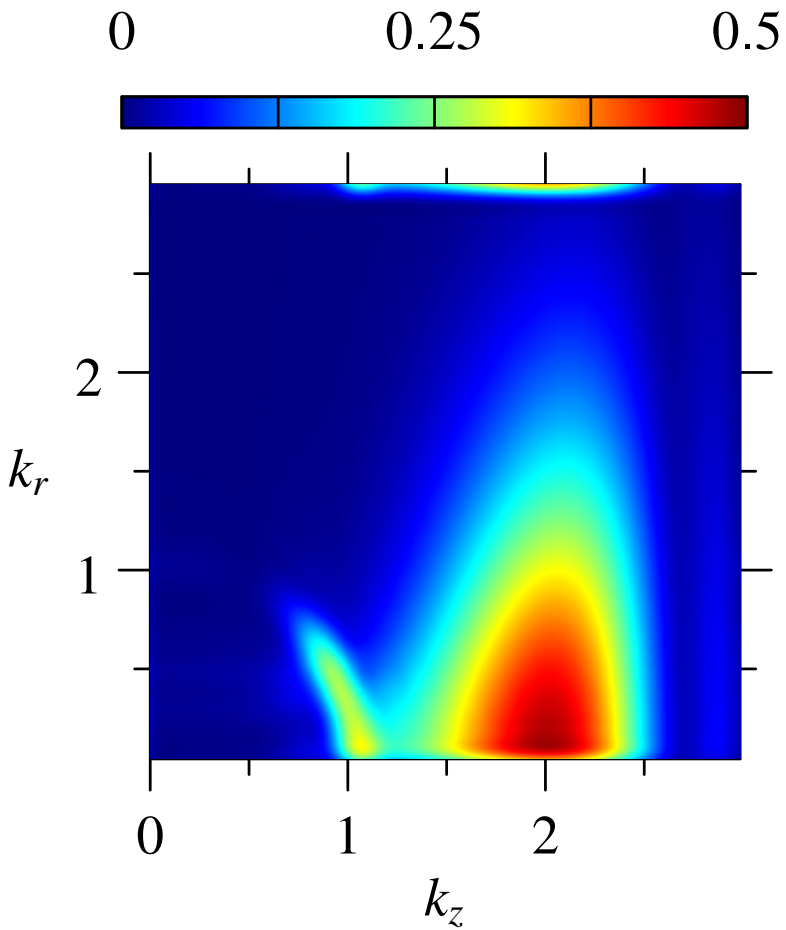
Flow description

Pressure field



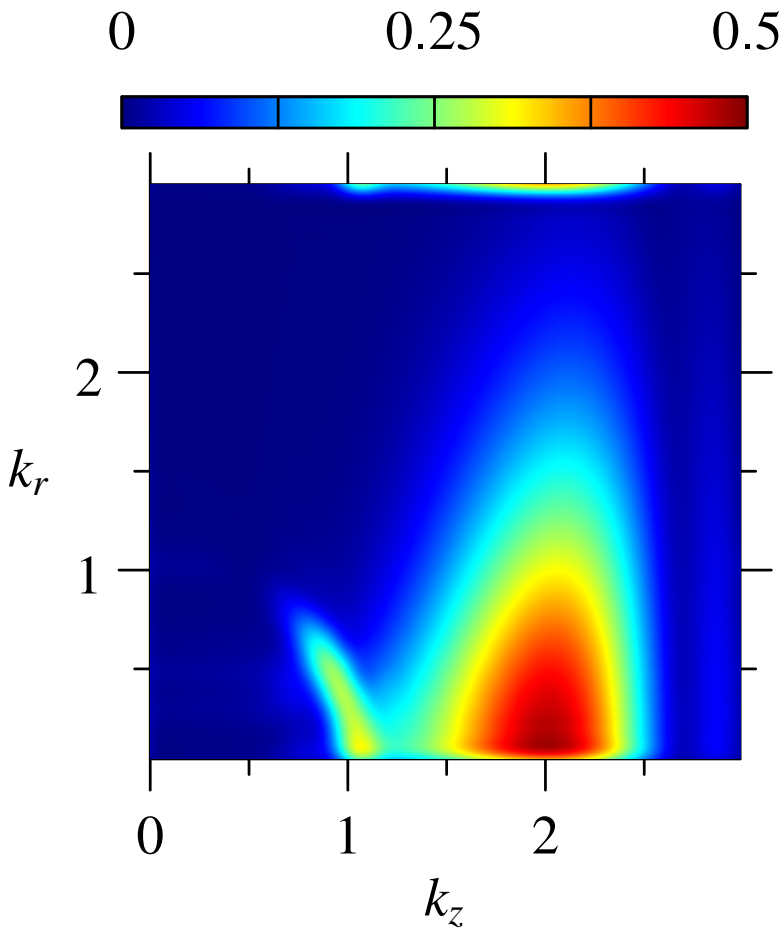

ω = 1.2
ω = 1.0
ω = 2.2
r/D
z/D
0
10
20
30
40

Pressure in Fourier domain ($\omega = 1.2$)

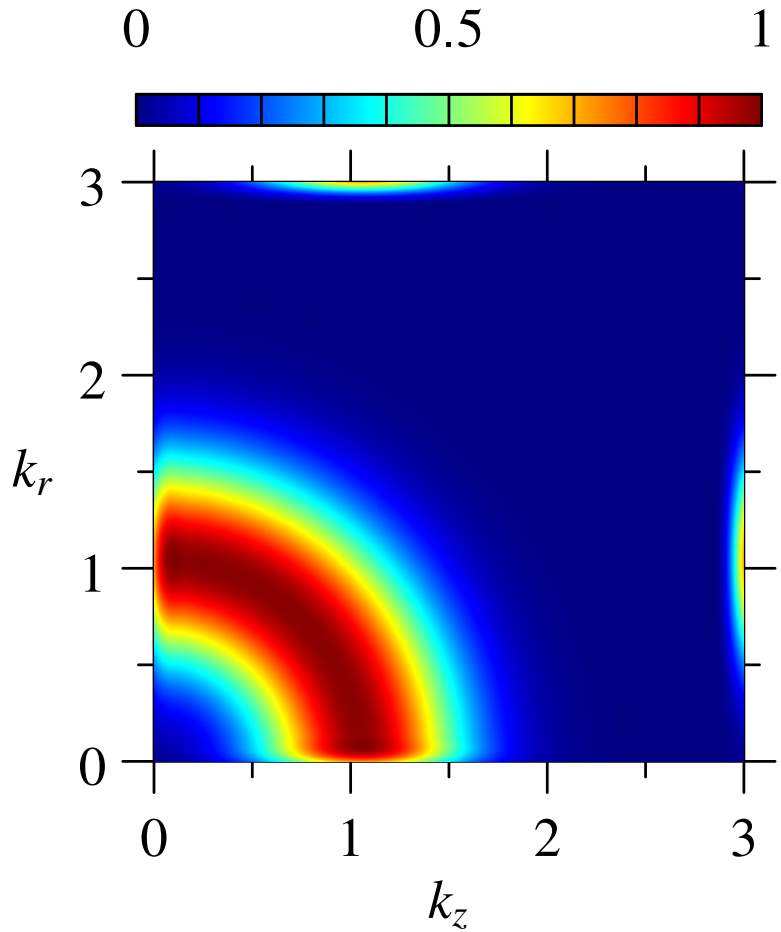


Pressure $P_{1.2}(\mathbf{k})$

Pressure in Fourier domain ($\omega = 1.2$)



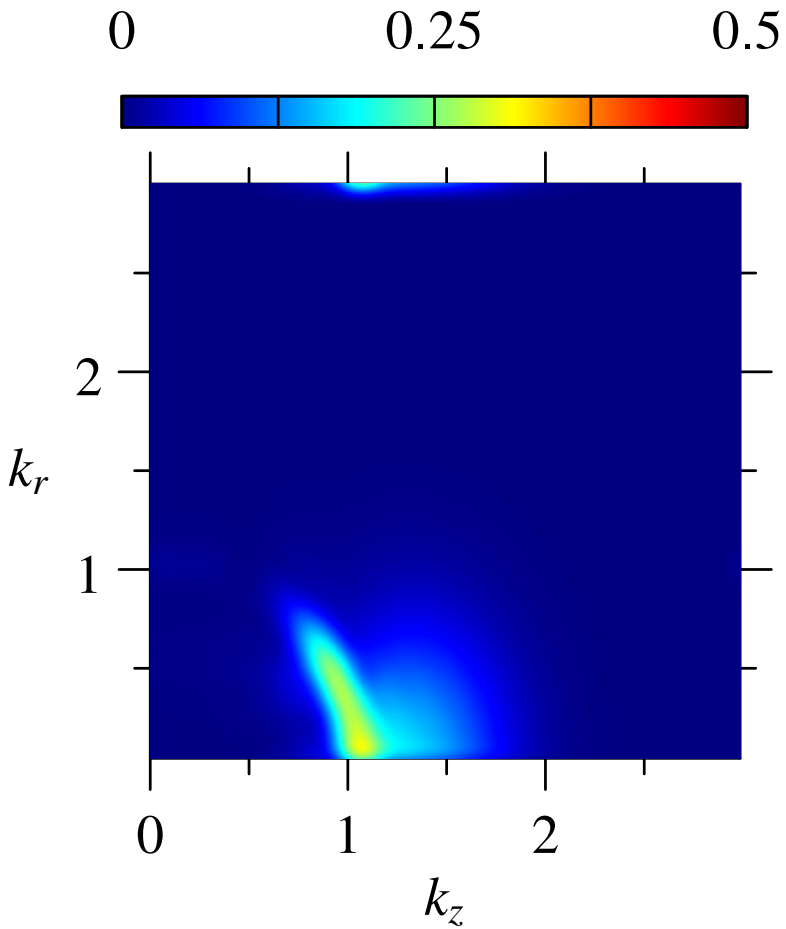
Pressure $P_{1.2}(\mathbf{k})$



Gaussian filter $W(\mathbf{k})$

Pressure in Fourier domain ($\omega = 1.2$)

Decomposition

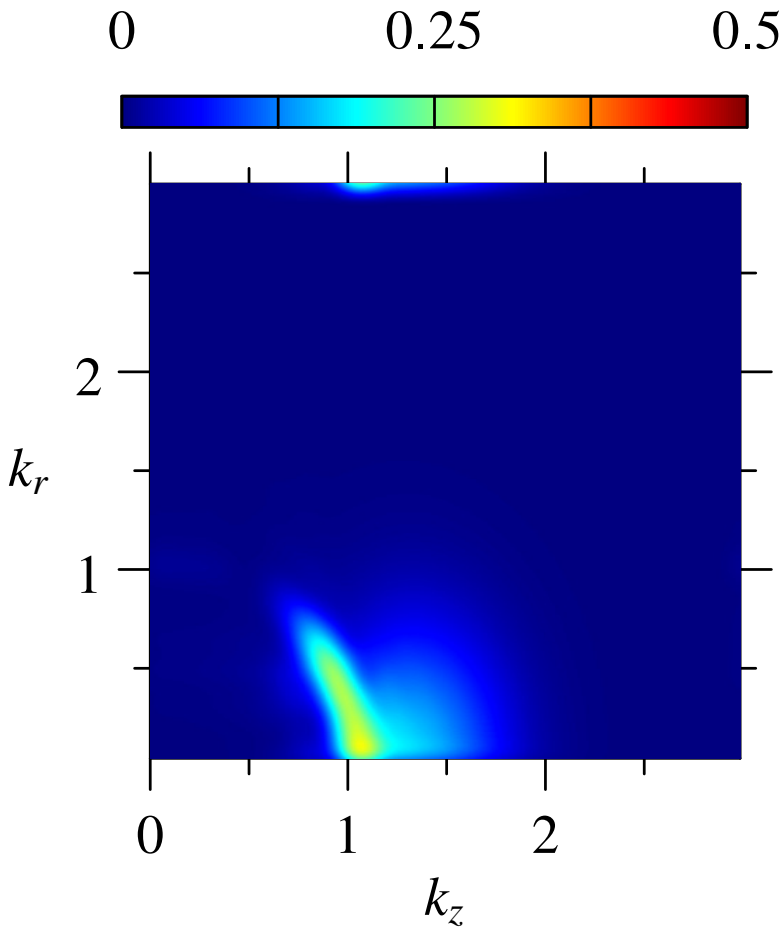


Radiating pressure

$$P'_{1.2} = WP$$

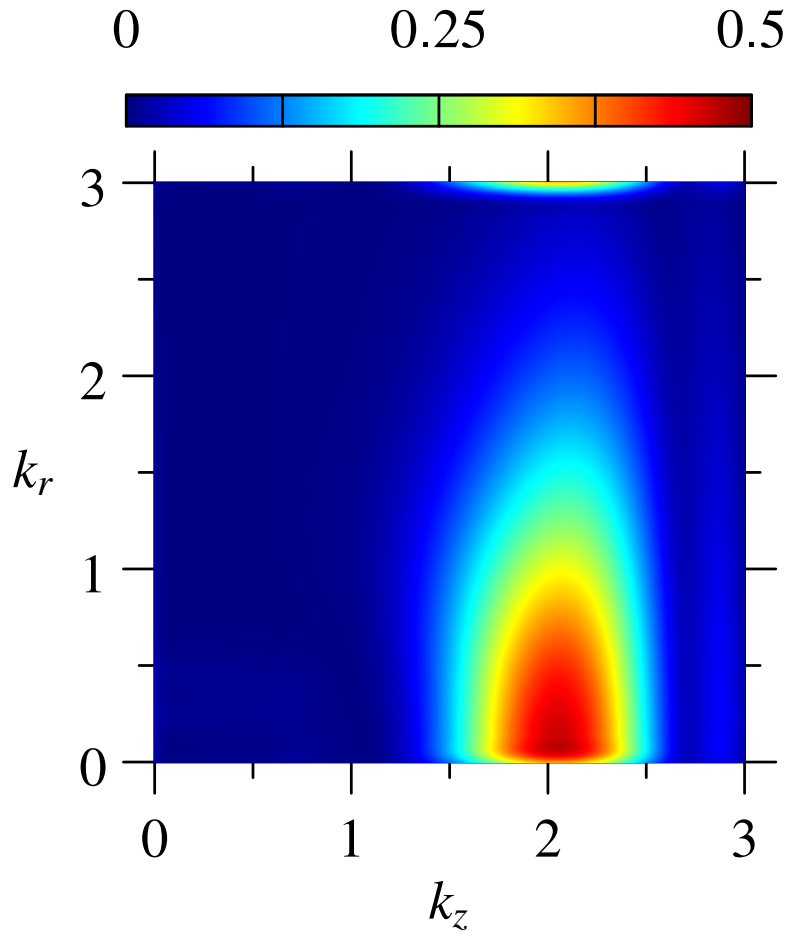
Pressure in Fourier domain ($\omega = 1.2$)

Decomposition



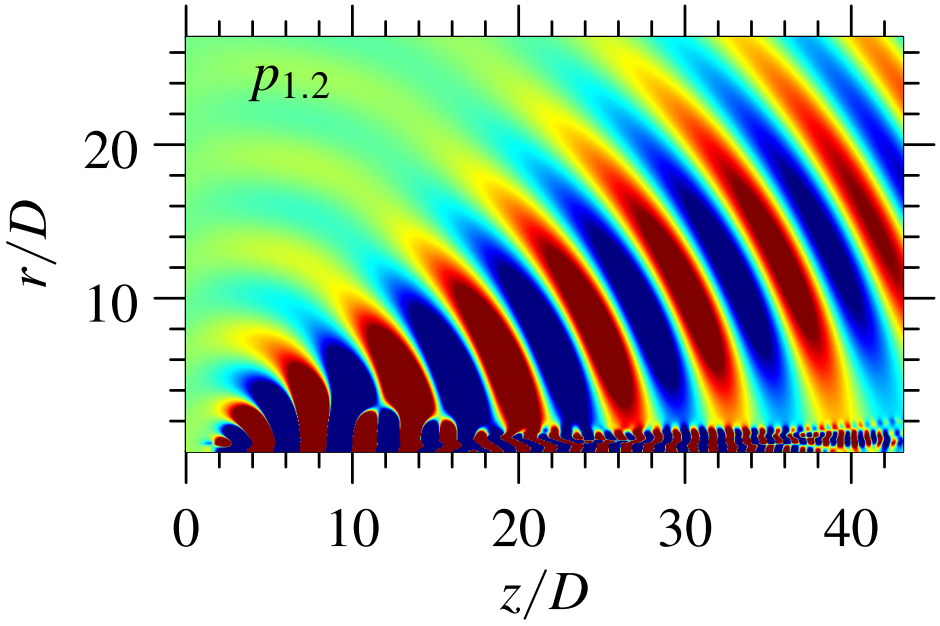
Radiating pressure

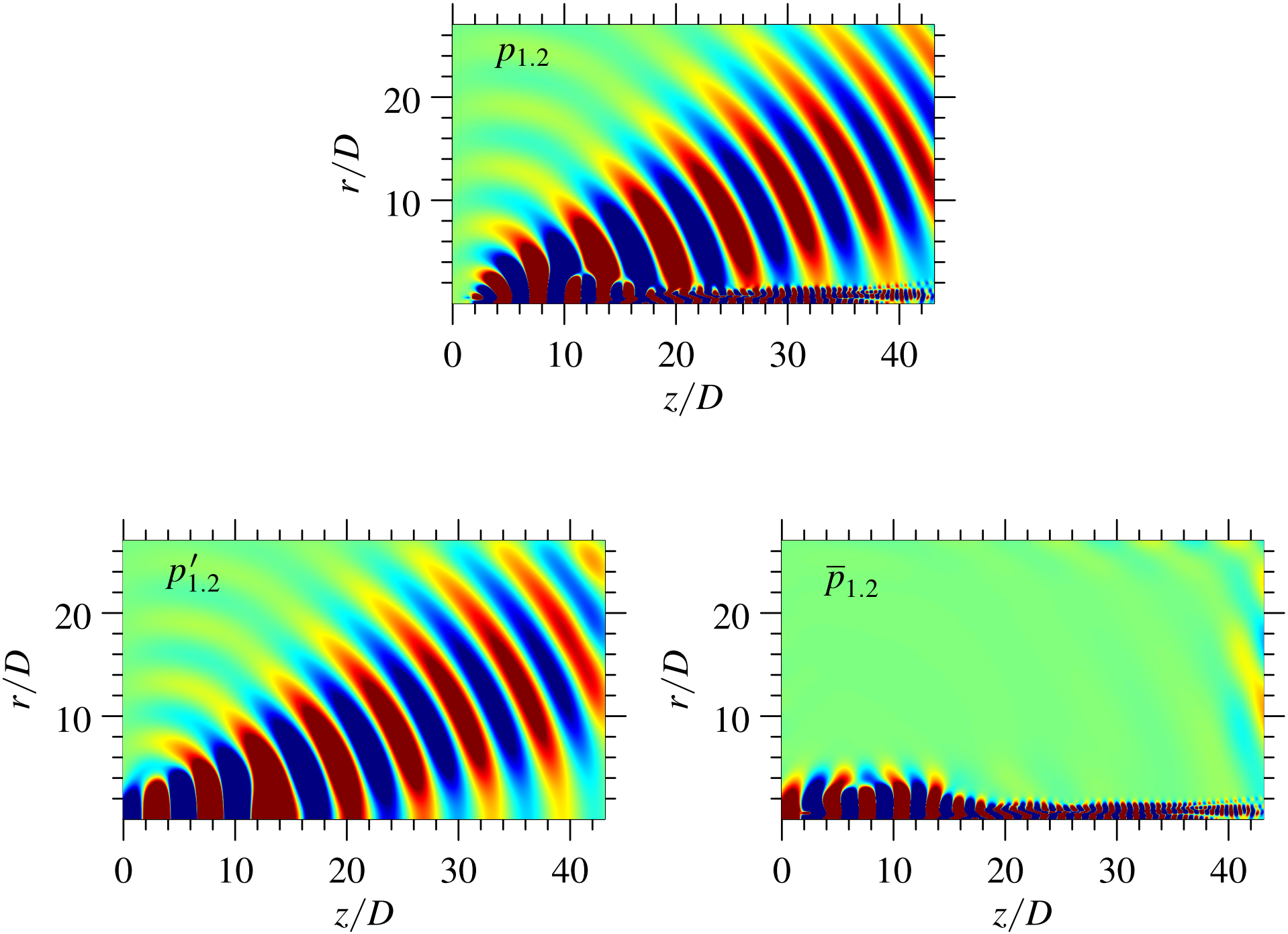
$P'_{1.2} = WP$

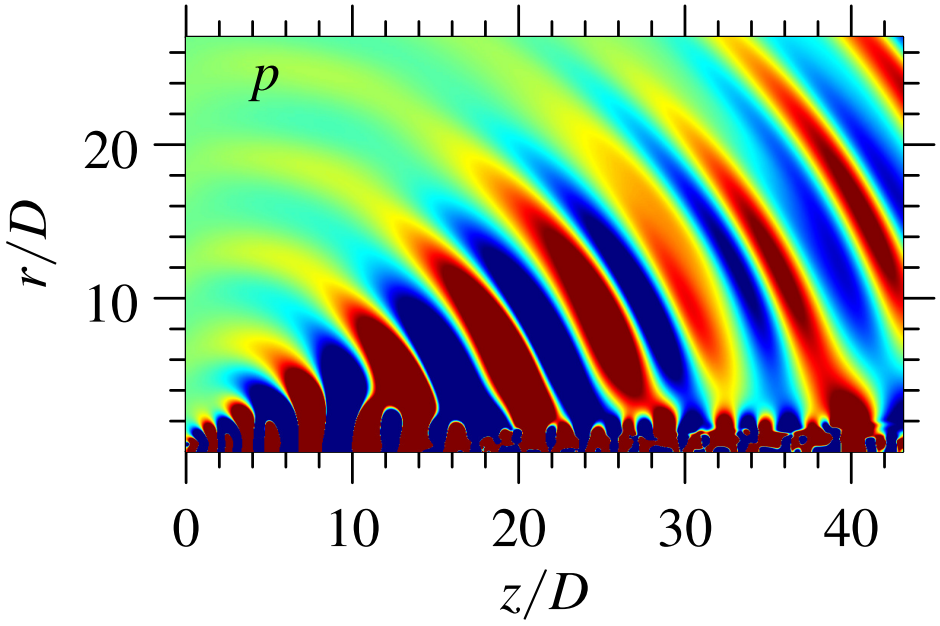


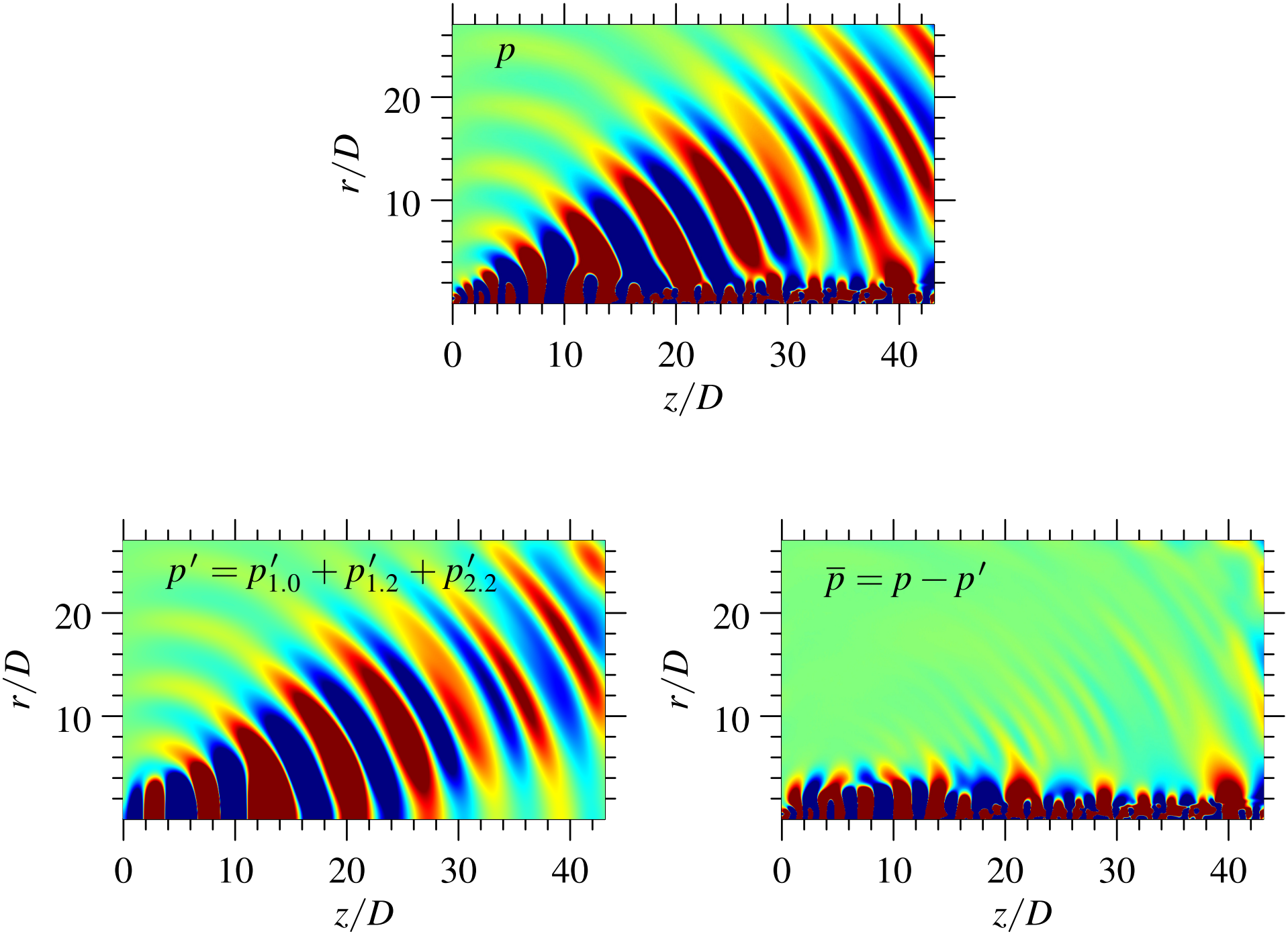
Non-radiating pressure

$\overline{P}_{1.2} = (1 - W)P_{1.2}$


$p_{1.2}$
20
10
r/D
0
10
20
30
40
z/D

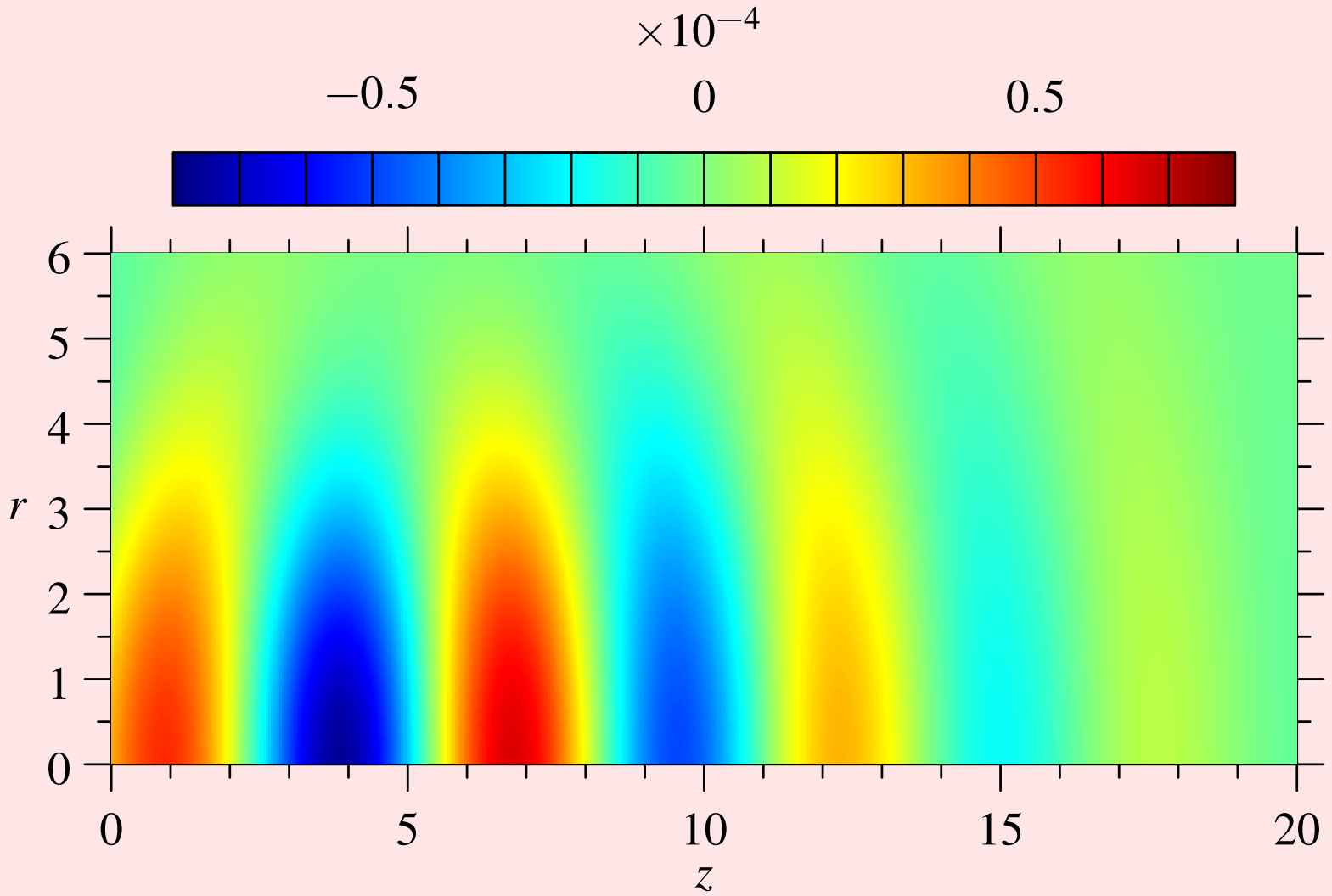

$p_{1.2}$
$p'_{1.2}$
$\overline{p}_{1.2}$
r/D
z/D
0
10
20
30
40


p
20
10
r/D
0
10
20
30
40
z/D


p
r/D
20
10
0
10
20
30
40
z/D
$p' = p'_{1.0} + p'_{1.2} + p'_{2.2}$
r/D
20
10
0
10
20
30
40
z/D
$\overline{p} = p - p'$
r/D
20
10
0
10
20
30
40
z/D

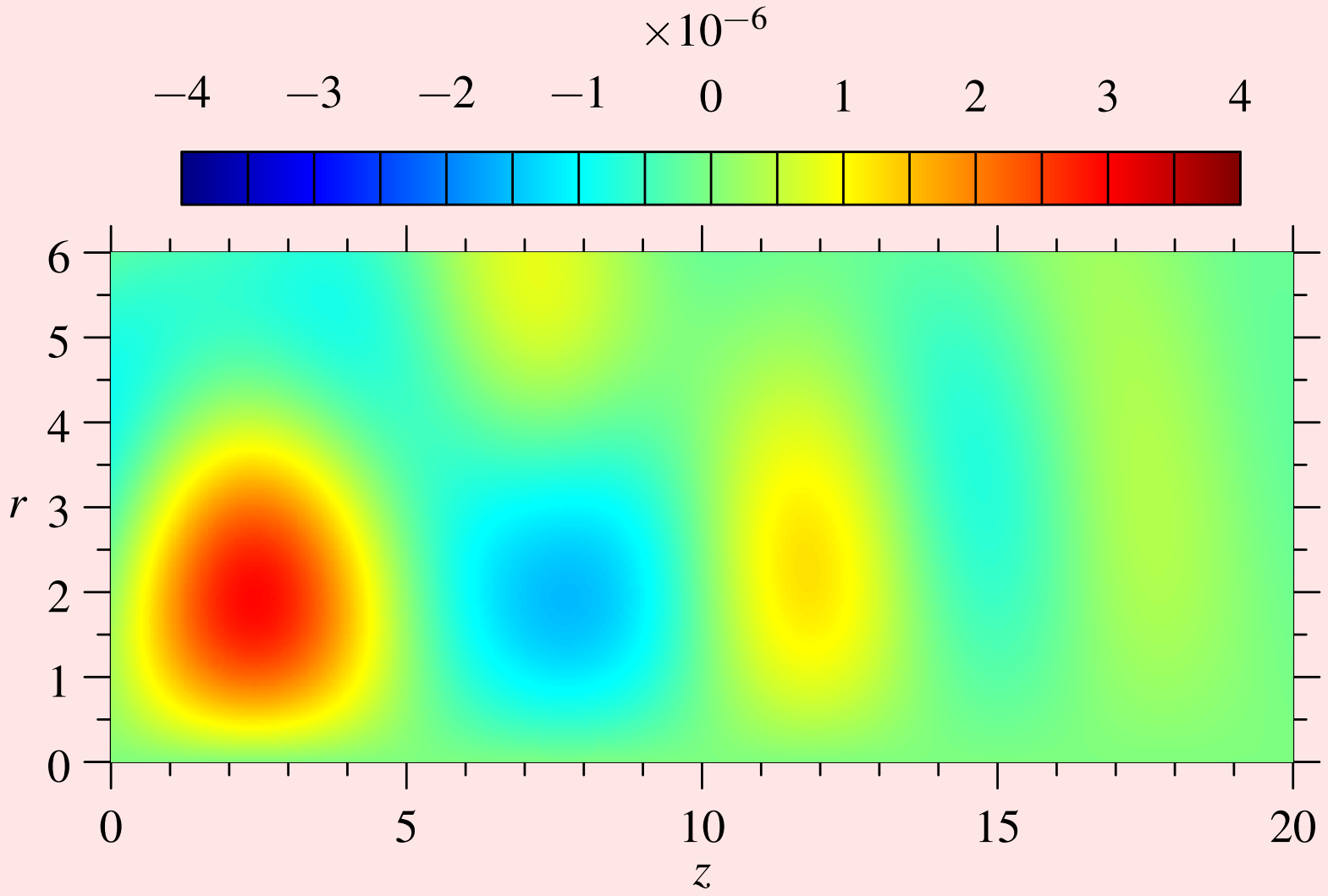
NRBF sources

Axial NRBF source f_z at $\omega = 1.2$

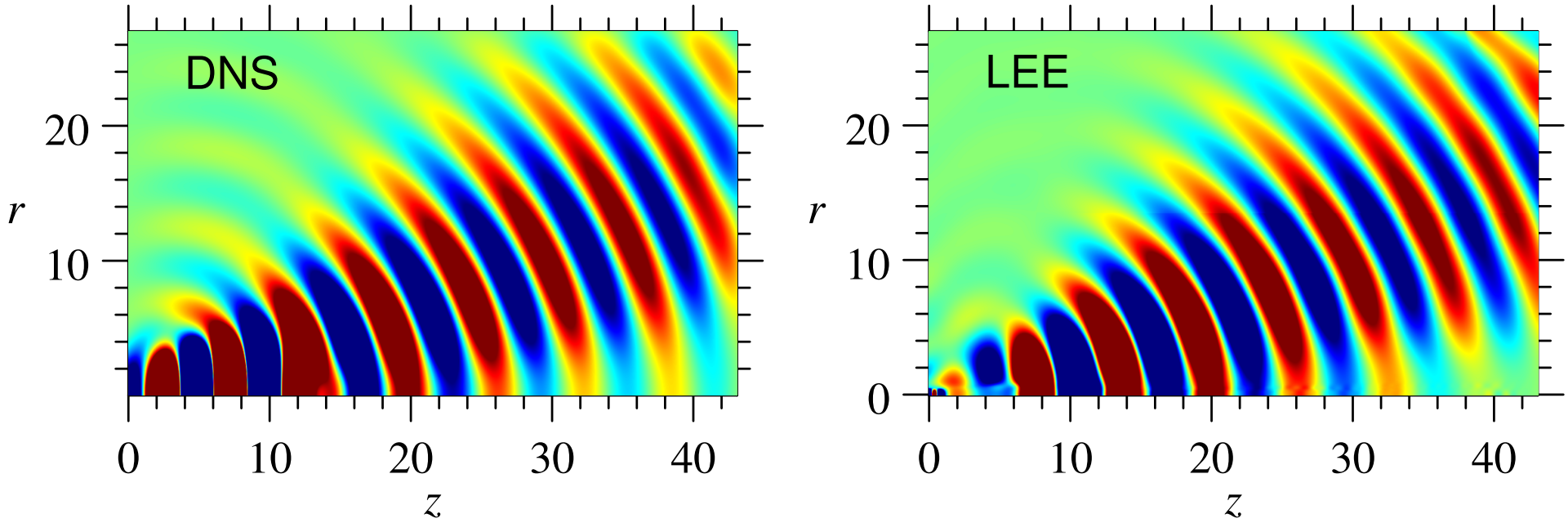


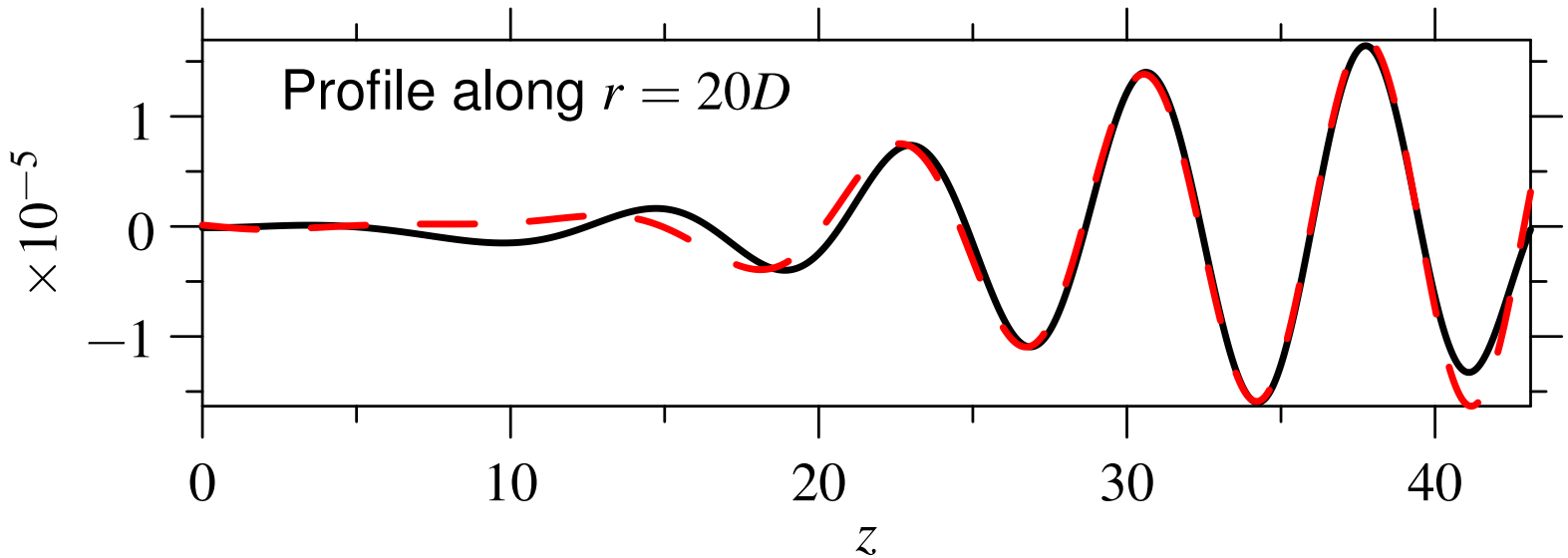
NRBF sources

Radial NRBF source f_r at $\omega = 1.2$



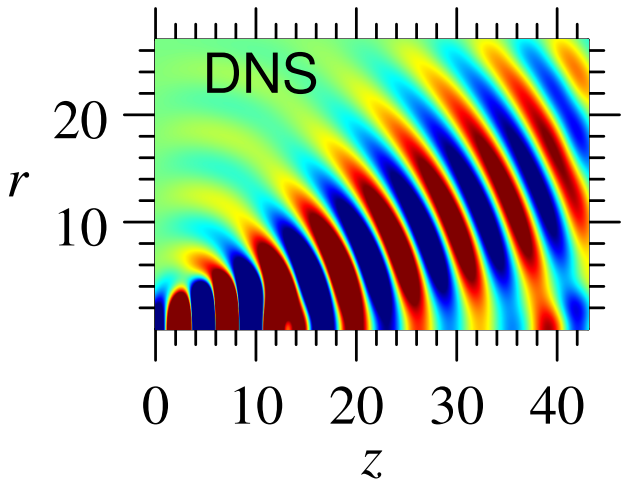
Source validation

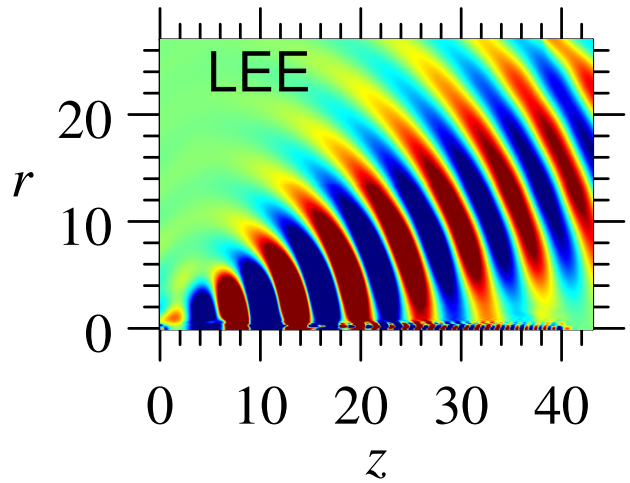


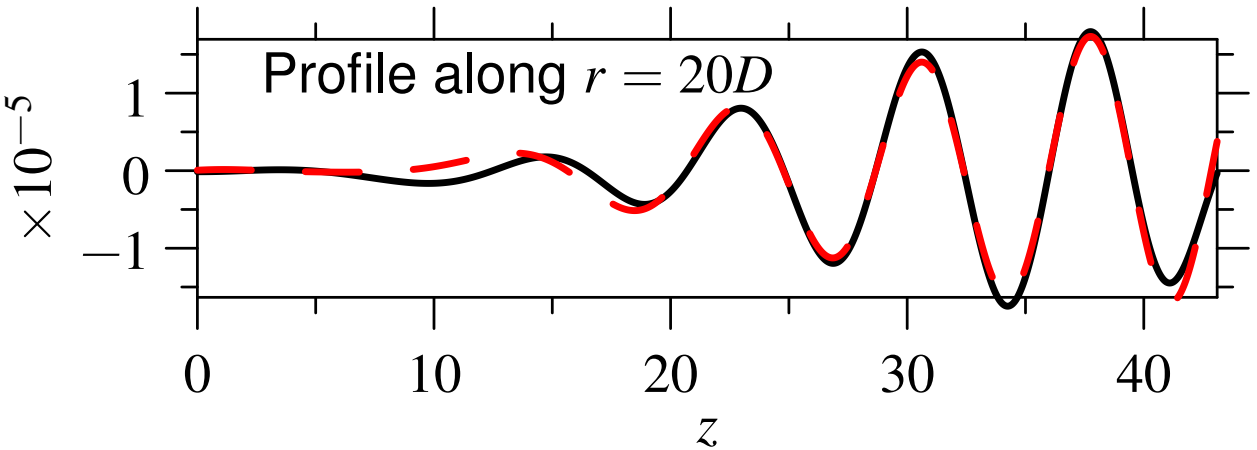


Source identification: shear-noise

$$f_{zz} = -\frac{\partial}{\partial z}\left(\overline{\rho}\widetilde{v_z}\widetilde{v_z}\right)' \approx -2\frac{\partial}{\partial z}\left(\rho_\infty \widetilde{v}_{z0}\widetilde{v_z}''\right)'$$





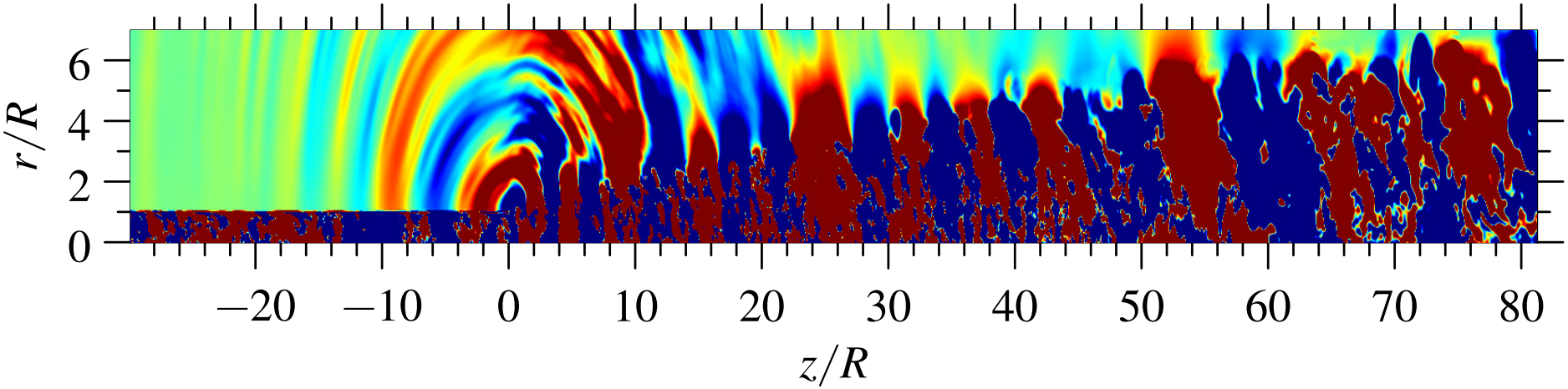


Part III

Sound sources in a turbulent jet

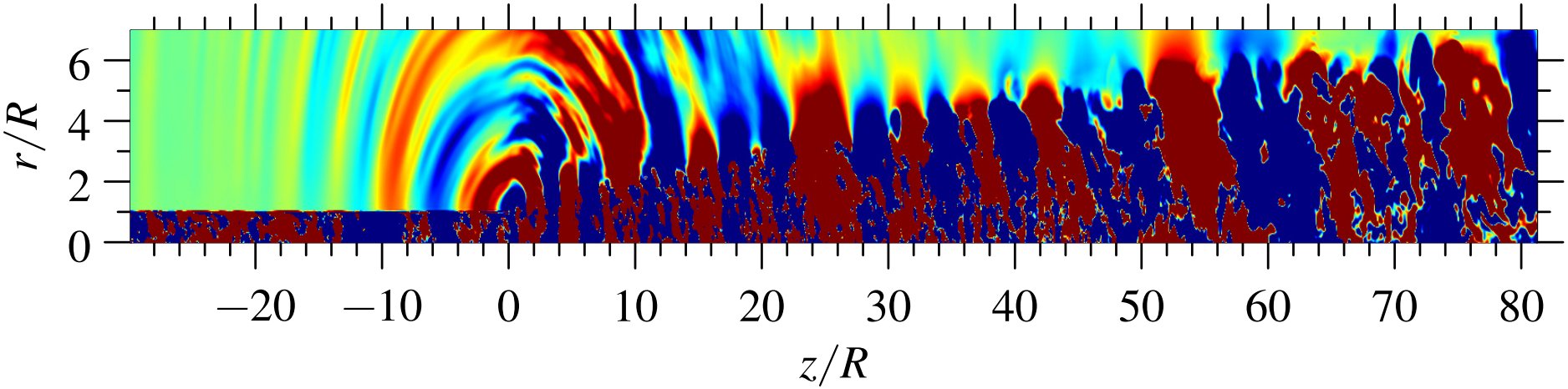
Flow analysis

Full density field

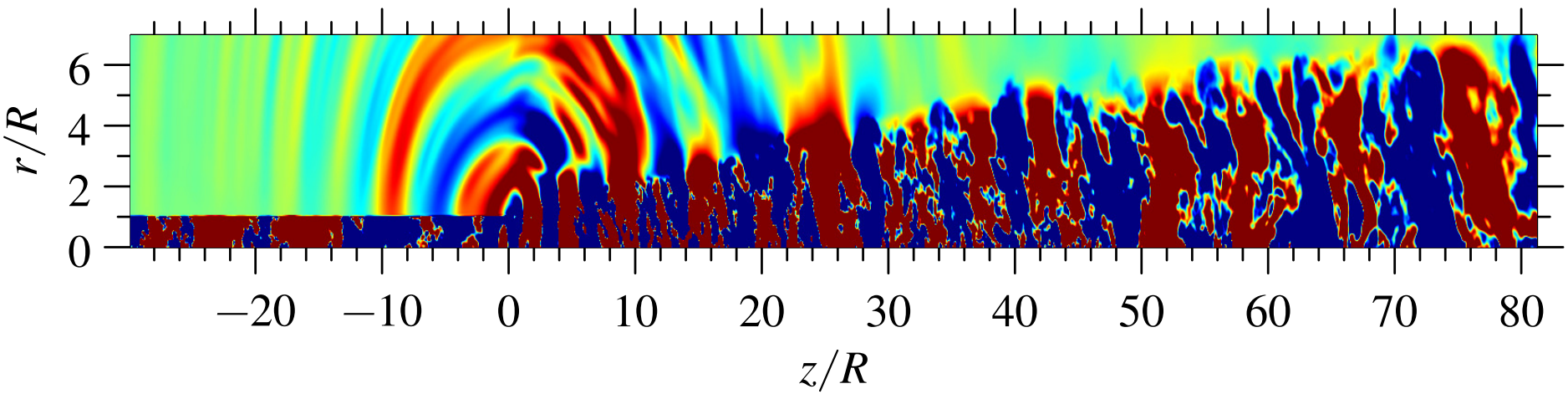


Flow analysis

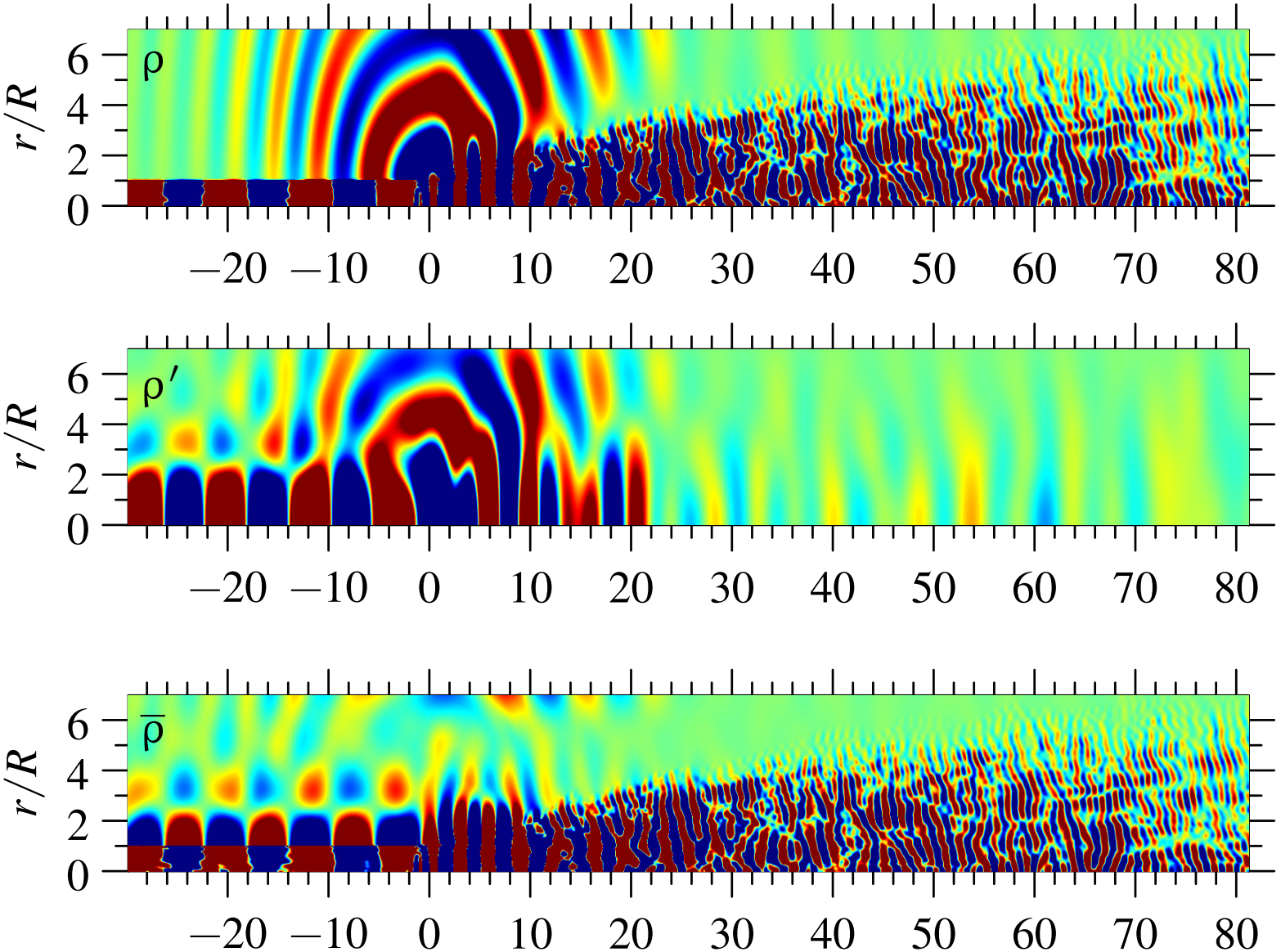
Full density field



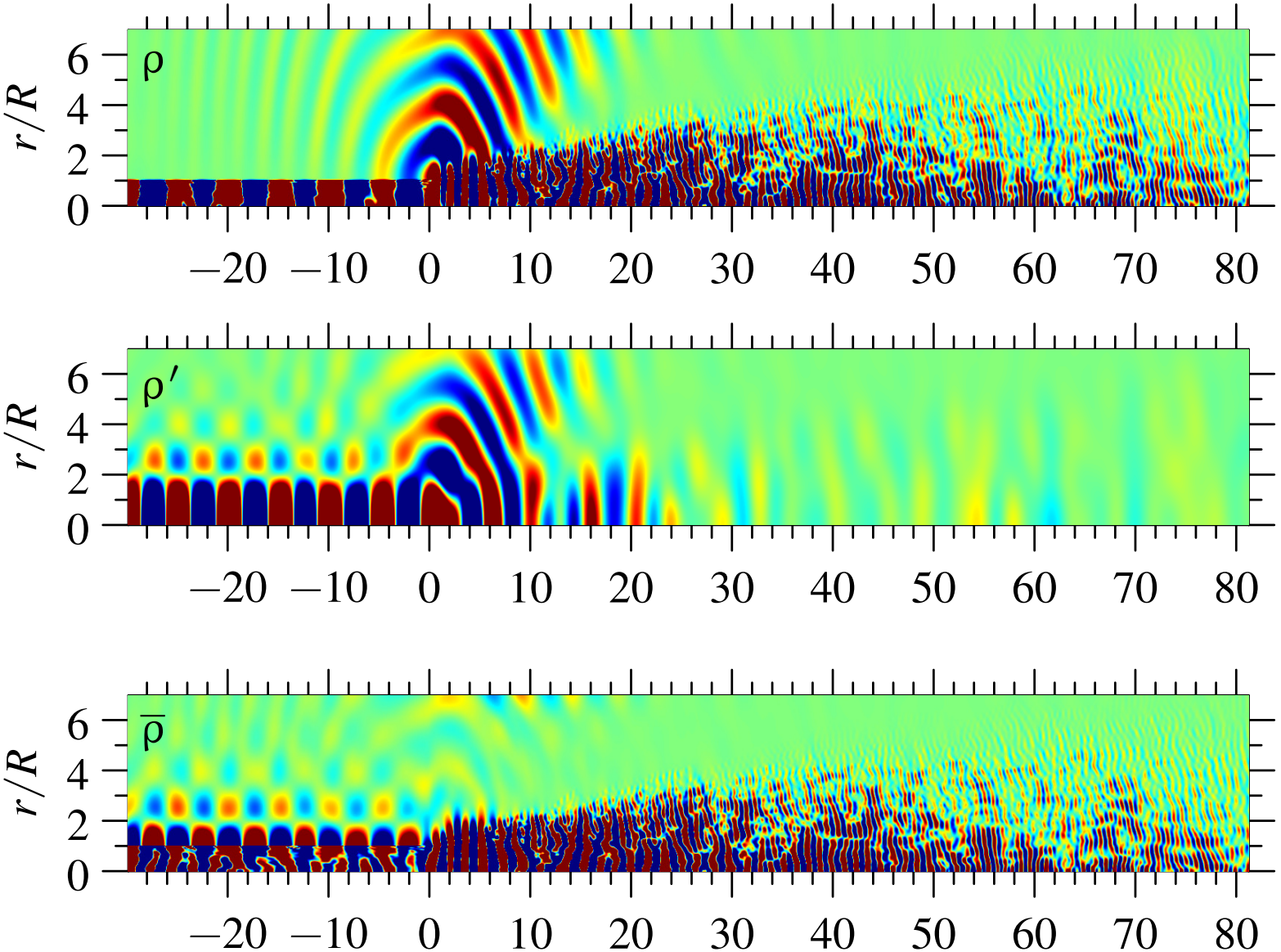
Density field, modes 0 and 1, $|St_D| < 4$



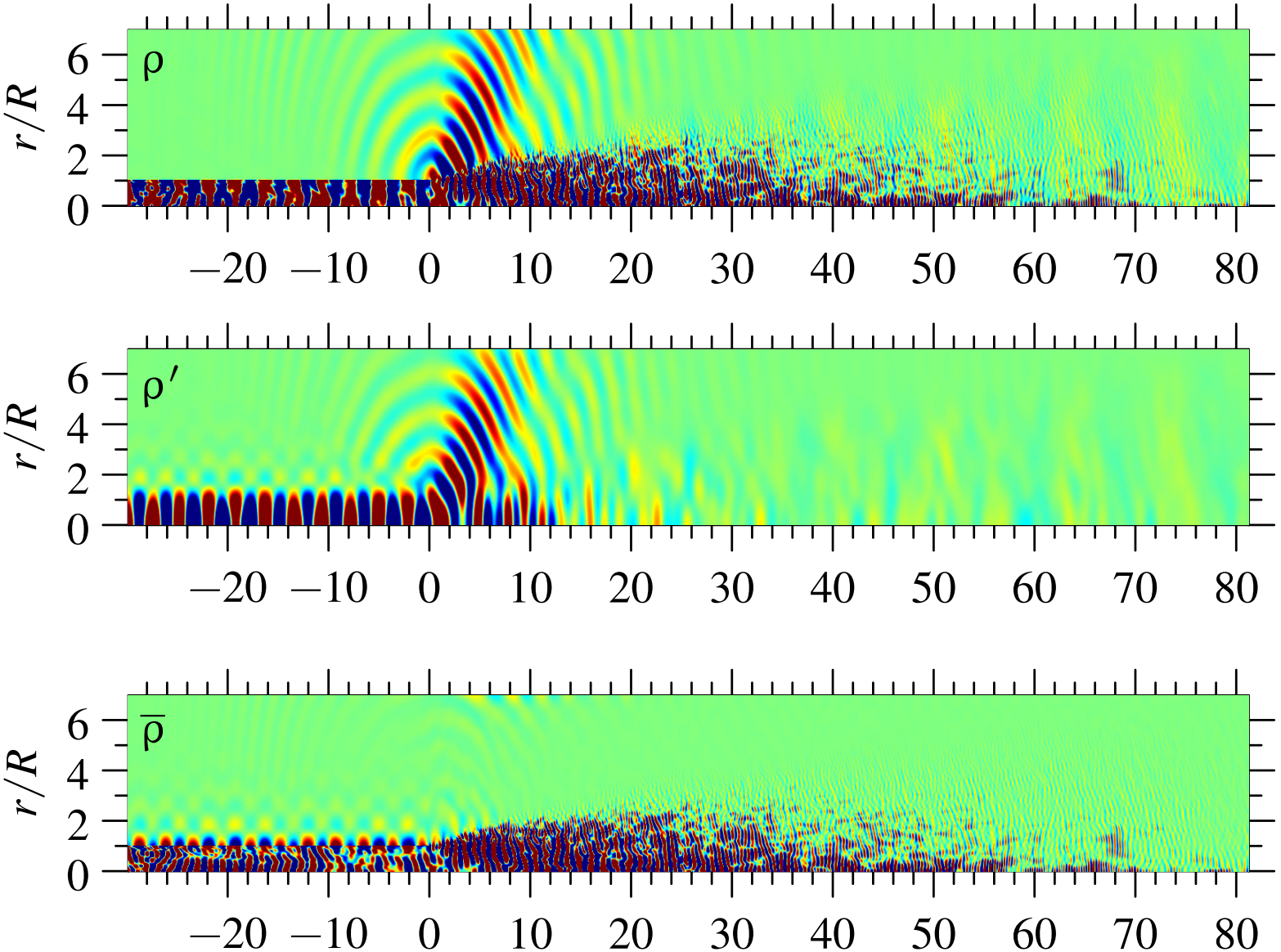
Flow decomposition: $n = 0$, $St_D = 0.5$



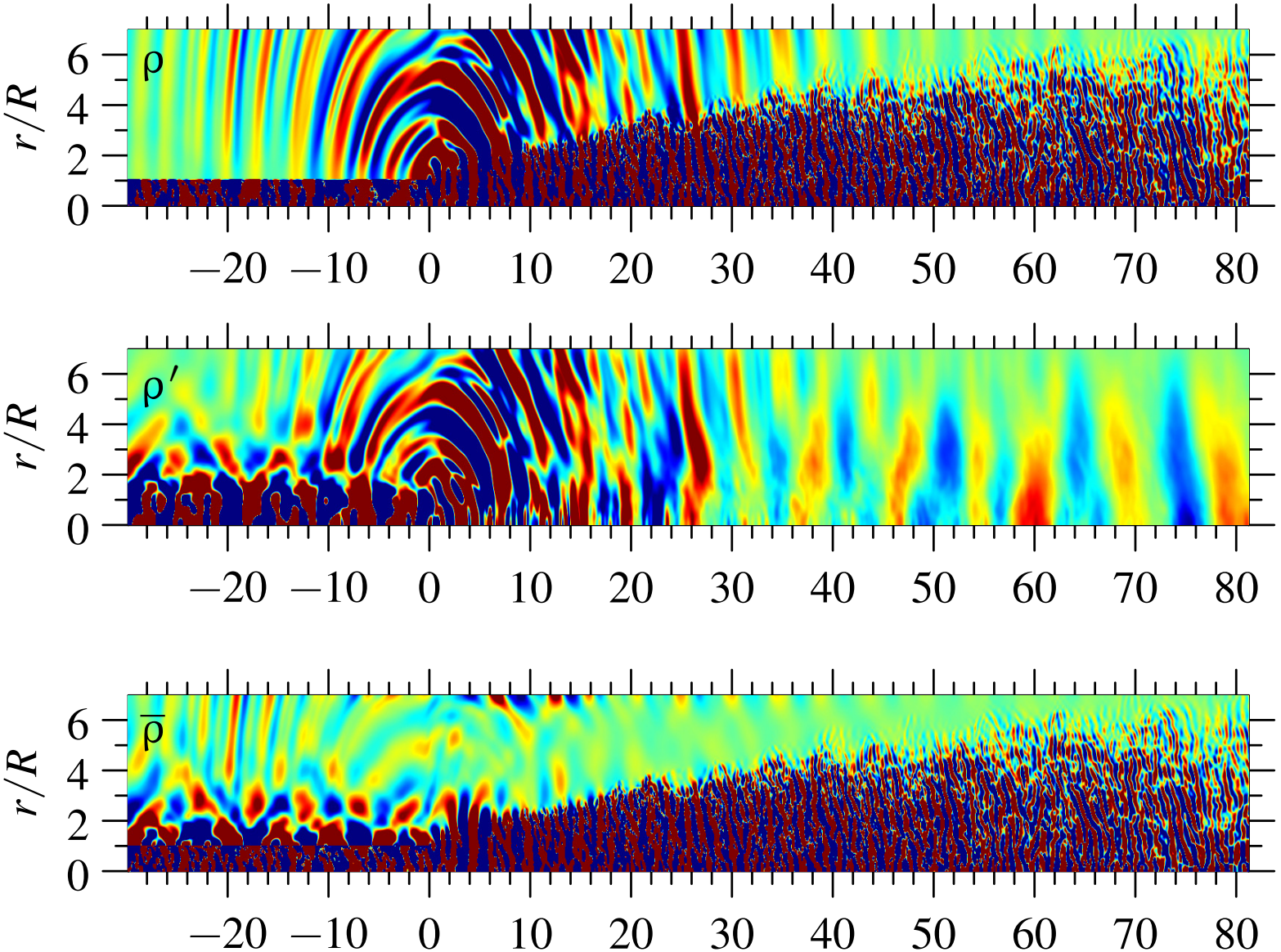
Flow decomposition: $n = 0$, $St_D = 0.8$



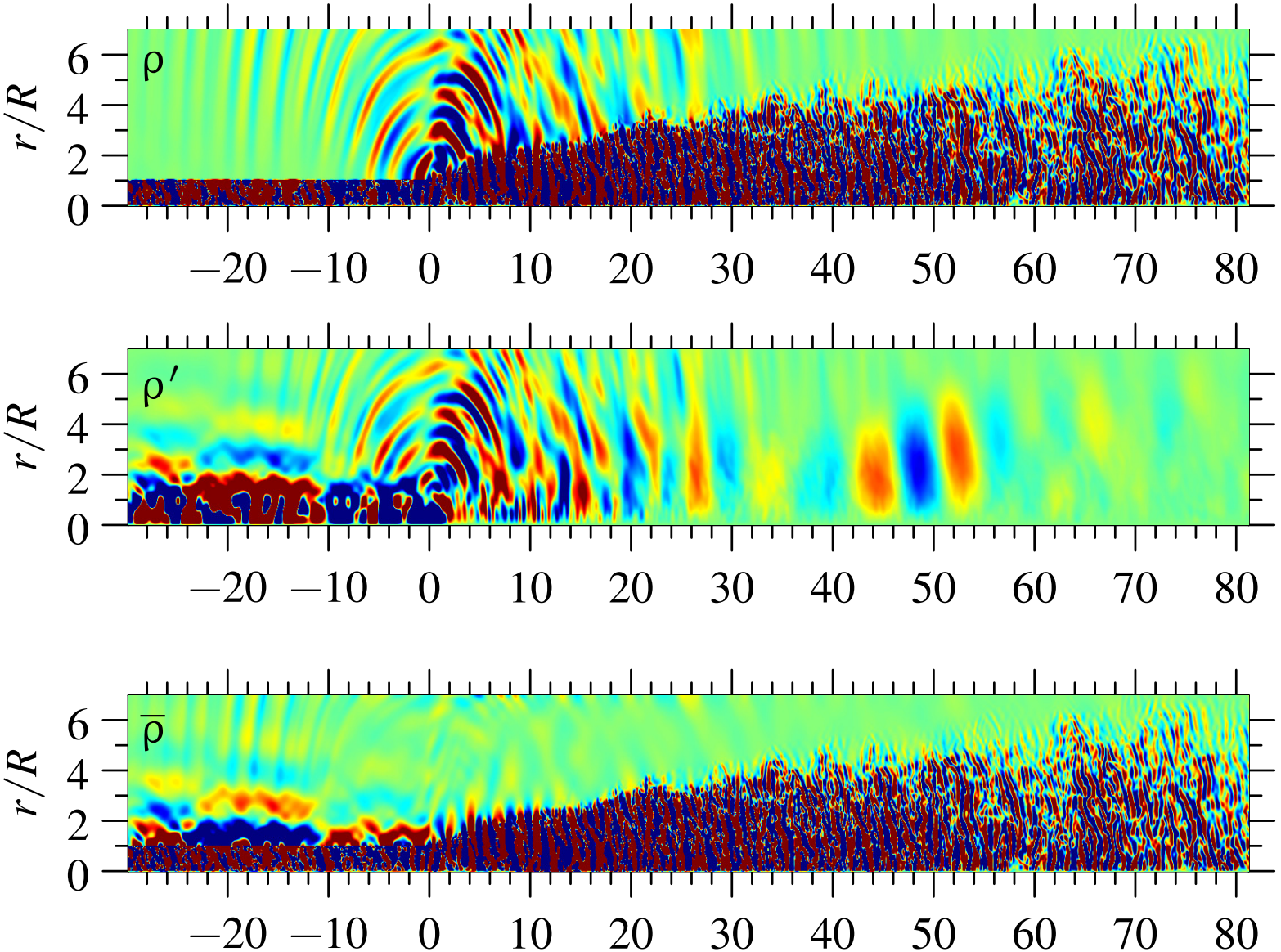
Flow decomposition: $n = 0$, $St_D = 1.45$



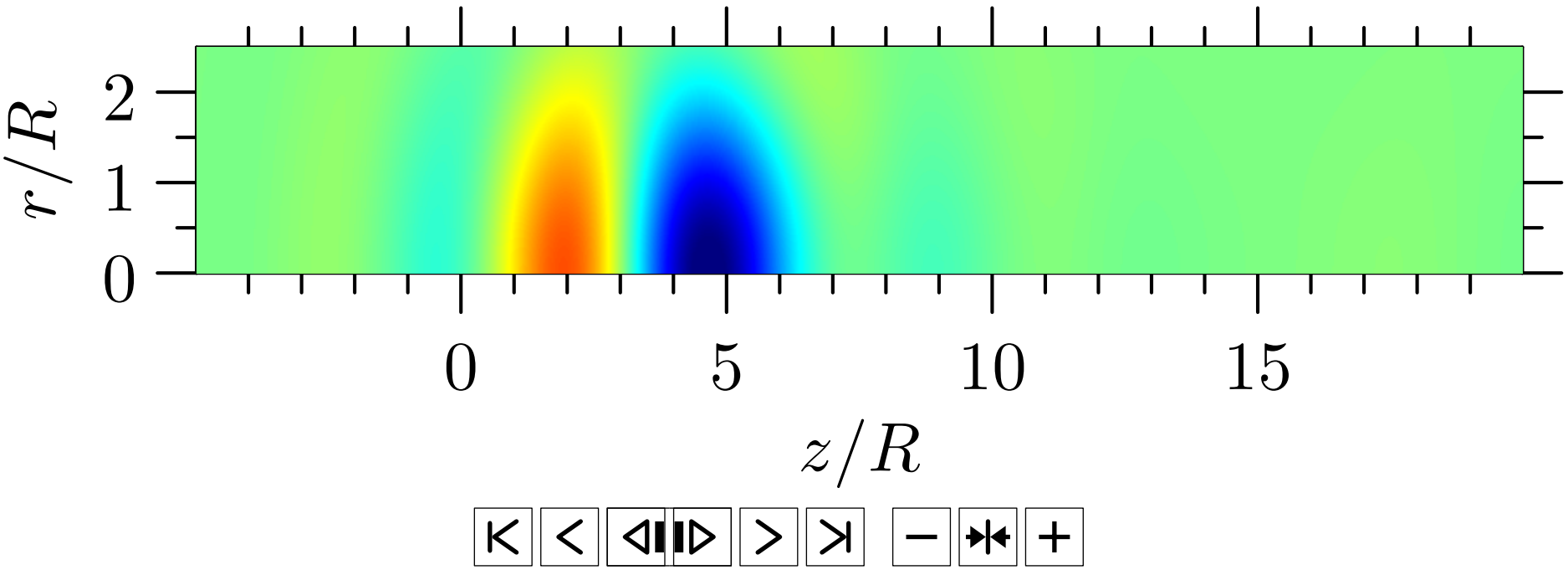
Flow decomposition: $n = 0$, $0.5 \leqslant |St_D| < 4.0$



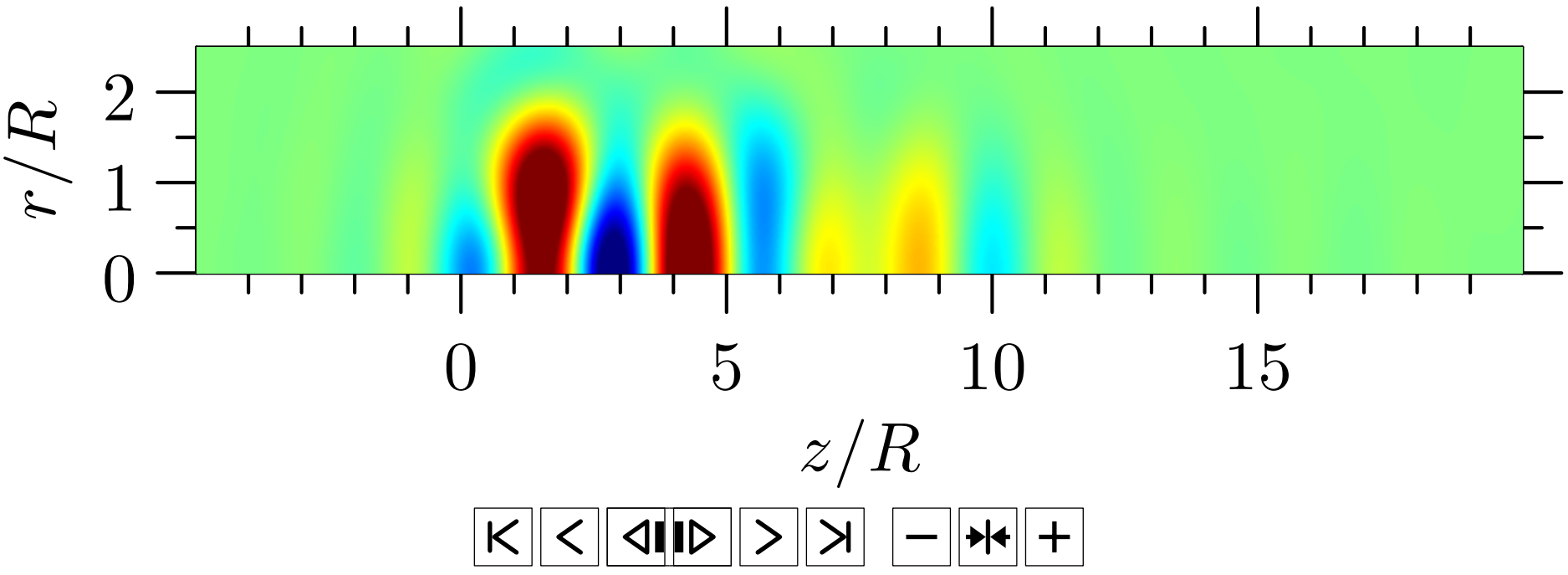
Flow decomposition: $n = 1,\ 0.5 \leqslant |St_D| < 4.0$



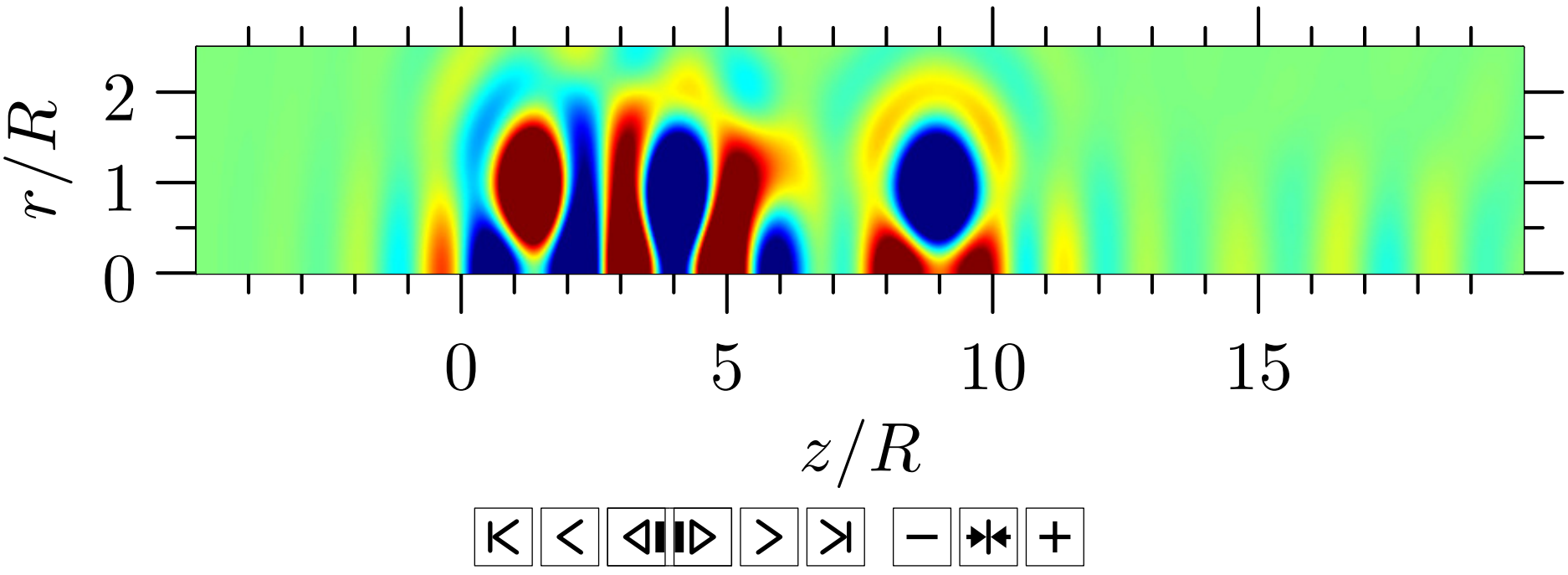
NRBF sources: $St_D = 0.5$



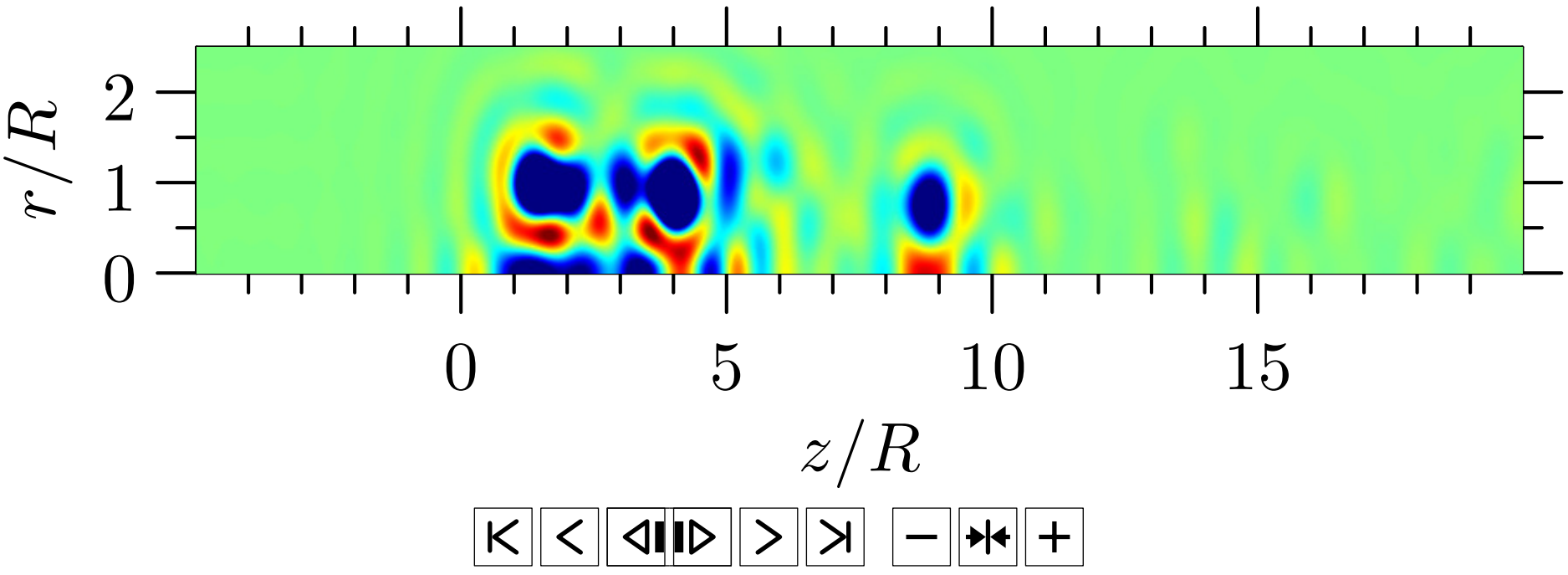
NRBF sources: $St_D = 1.1$



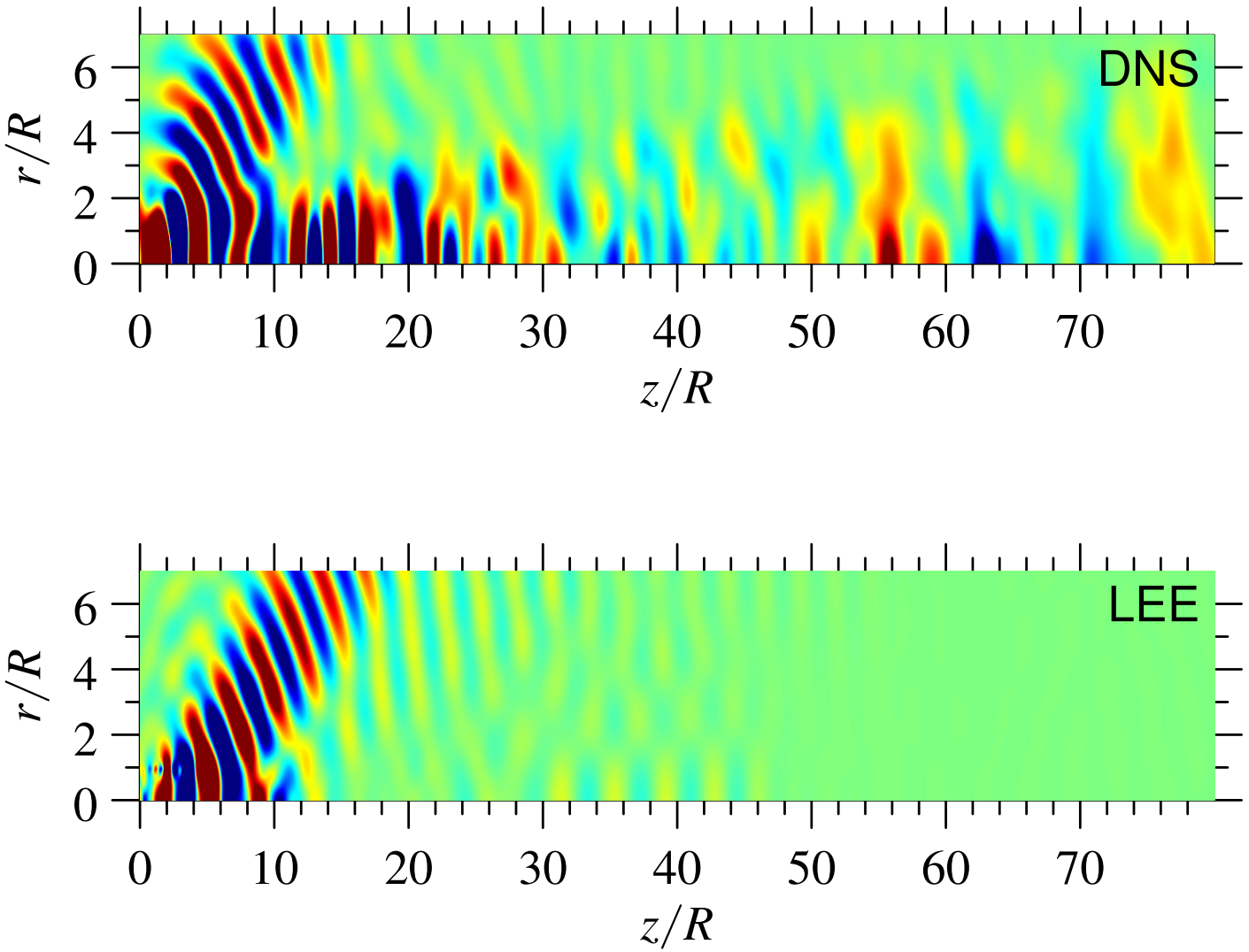
NRBF sources: $St_D = 1.45$



NRBF sources: $St_D = 2.55$



Qualitative validation: $n = 0$, $St_D = 1.1$



Conclusion

1. Algorithm to compute the NRBF sources at multiple frequencies
2. In laminar jet: linear shear noise term is major source
3. NRBF decomposition and sources for a fully turbulent jet
   - wavepackets
   - monopole
   - vortex pairing

Acknowledgements

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Thank you!