A Generalized Ray Model of 3-D Propagation on the Continental Shelf Including Shear Wave Effects in an Absorptive Bottom

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Presented at
ICTCA 2014
College Station, Texas A&M University, Texas, USA
10-14 March, 2014

Outline of Presentation

- Overview of Generalized Ray Method Used
  - Wedge Model of the Continental Shelf
  - Integral Representations of Multi-Reflected Wave Fields
  - Propagation Environment
  - Attenuation and Generalized Rays

Outline of Presentation (cont.)

- Application to Large-Range Cross-Slope Propagation
  - Structure of Unattenuated Pressure Response at 40 km
  - Effects of Horizontal Refraction in the Present Environment
  - Analysis of Received Levels (RLs) of Acoustic Tones
- Conclusions

Outline of Presentation (cont.)

- References

- P. Borejko, “An analysis of cross-slope pulse propagation in a shallow water wedge,” in Proceedings of the 10th European Conference on Underwater Acoustics, Edited by Tuncay Akal, Istanbul, Turkey, 785–793 (2010).

- P. Borejko, Modeling of three-dimensional propagation on a coastal wedge with a sediment supporting shear,” in Proceedings of the 1st Underwater Acoustics Conference, Edited by John S. Papadakis and Leif Bjørnø, Corfu Island, Greece, 1541–1546 (2013).

- M. S. Ballard, “Modeling three-dimensional propagation in a continental shelf environmnet,” J. Acoust. Soc. Am., 131, 1969–1977 (2012).

- K. D. Heaney, R. L. Campbell, J. J. Murray, “Comparison of hybrid three-dimensional modeling with measurements on the continental shelf,” J. Acoust. Soc. Am. 131, 1680–1688 (2012).

Acoustic Wave Field in a Wedge

- Wave Equation:

$$c^2\nabla^2 p - \frac{\partial^2 p}{\partial t^2} = -f(t)\delta(x)\delta(y)\delta(z - z_0)$$

- Boundary Conditions:

$$p = 0 \quad \text{at} \quad z = 0$$

$$p = -\tau'_{zz}, \quad v'_z = \frac{\partial u'_z}{\partial t}, \quad \tau'_{zx} = 0 = \tau'_{zy} \quad \text{at} \quad z' = h\cos\alpha$$

- Field Resolution:

$$p = p_0 + \sum_{k=1}^{N} p_{\pm k}, \qquad N = \frac{\pi}{\alpha}$$

Source and Multi-Reflected Wave Fields

- 121 Fields with up to 60 Bottom Reflections in a 3 deg Wedge

- $$p_0 = \frac{p_c}{R} f(t - \frac{R}{c}) = p_c H(t - t_0) \int_{t_0}^{t} \dot{f}(t - \tau) \left[\frac{2}{\pi} \mathrm{Re} \int_0^{q(\tau)} S \frac{dg_0^{-1}}{d\tau} dq \right] d\tau$$

- $$p_{\pm k} = p_c H(t - t_{\pm k}) \int_{t_{\pm k}}^{t} \dot{f}(t - \tau) \left[\frac{1}{2\pi} \mathrm{Re} \int_0^{q(\tau)} S \Pi_{\pm k} \frac{dg_{\pm k}^{-1}}{d\tau} dq \right] d\tau$$

Propagation Environment

Water Wedge	
Slope (deg)	3
Sound speed (m/s)	1500
Density (g/cm^3)	1.0

Seabed (limestone)	
Compressional wave speed (m/s)	3000
Compressional attenuation (dB/λ)	0.10
Shear wave speed (m/s)	1460
Shear attenuation (dB/λ)	0.20
Density (g/cm^3)	2.40

Cross-Slope Propagation	
Water depth (m)	200
Source depth (m)	100
Receiver depth (m)	200
Propagation range (km)	40

Sound-Pressure Level and Attenuation with Distance

- $$L_p = 10 \log \frac{p^2}{p_{\text{ref}}^2}, \qquad p_{\text{ref}} = 1\ \mu\text{Pa}$$

- $$p_{\text{att}} = p\, e^{-\alpha' r}$$

α' = Intrinsic attenuation (Np/m)

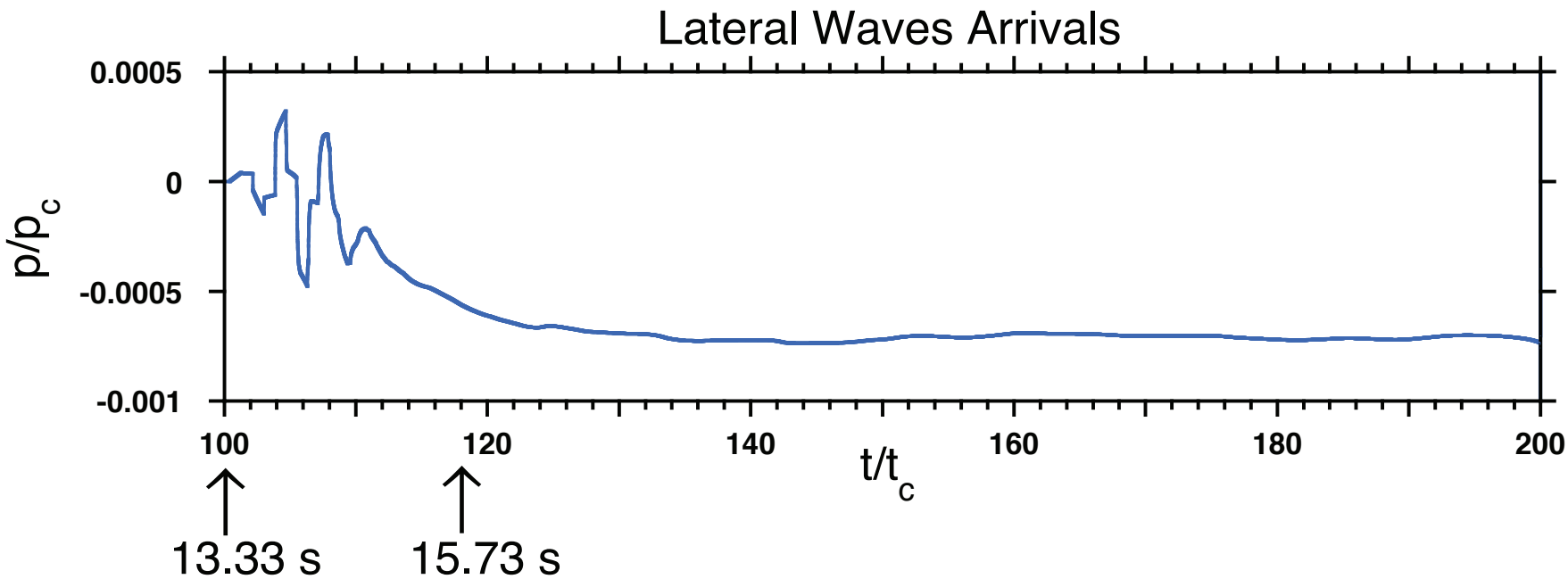
- $$L_p = 10 \log \frac{\left(p\, e^{-\alpha' r}\right)^2}{p_{\text{ref}}^2} = 10 \log \frac{p^2}{p_{\text{ref}}^2} - \alpha\, r$$

α = Intrinsic attenuation (dB/m)

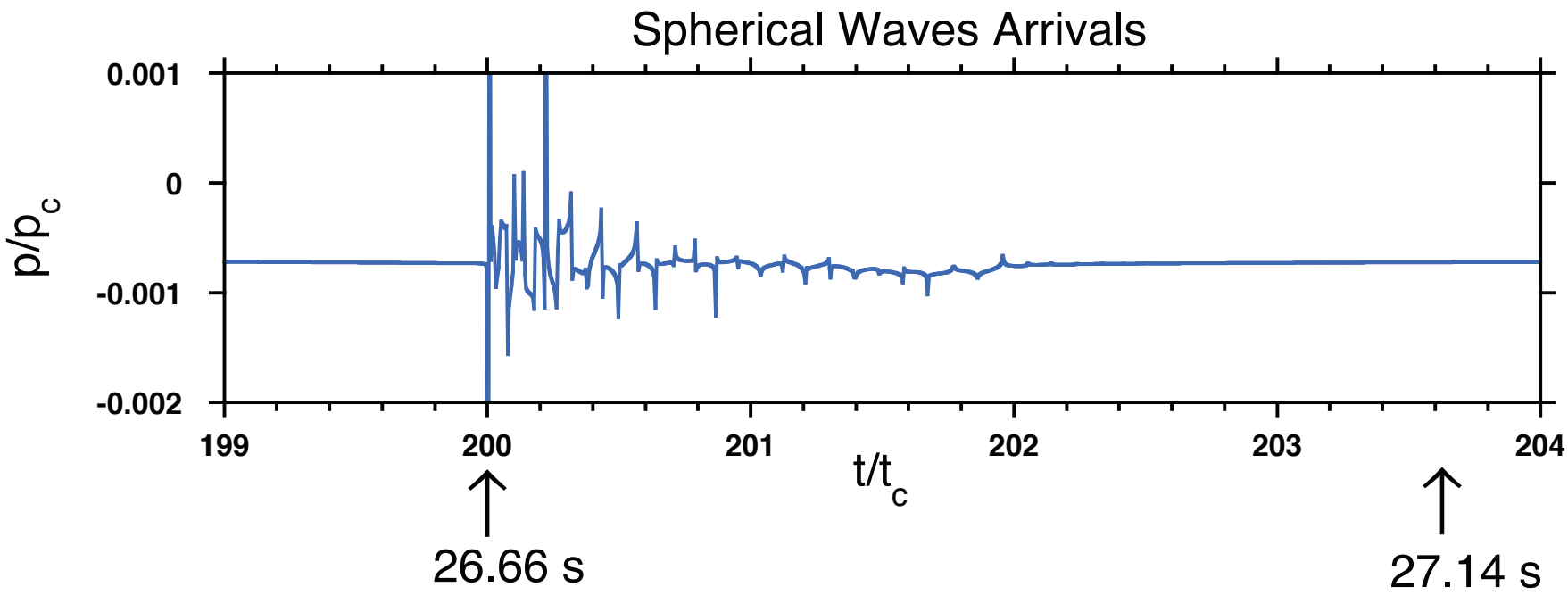
Response at 40 km; Source Pulse of Heaviside Form

- $$p = p_0 + \sum_{k=1}^{N} p_{\pm k}, \qquad N = \frac{\pi}{\alpha} = \frac{180}{3} = 60$$

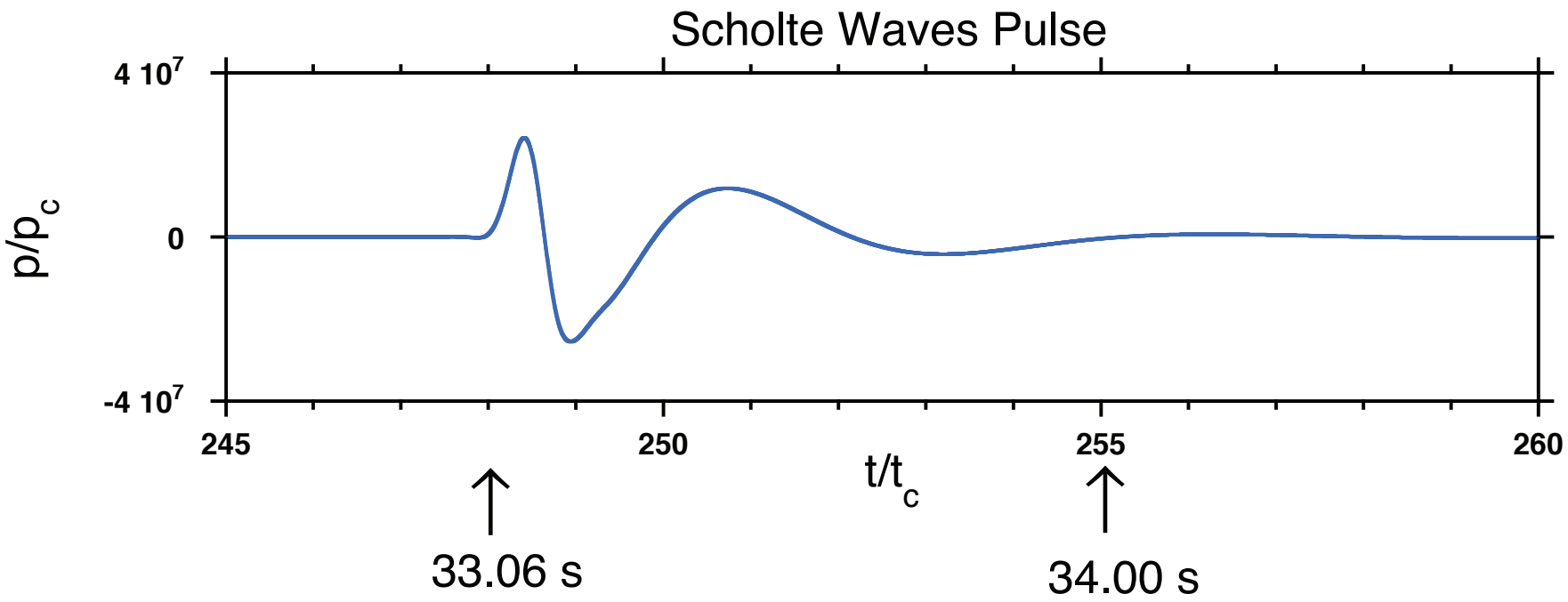
- 121 Pulses with up to 60 Bottom Reflections at 40 km



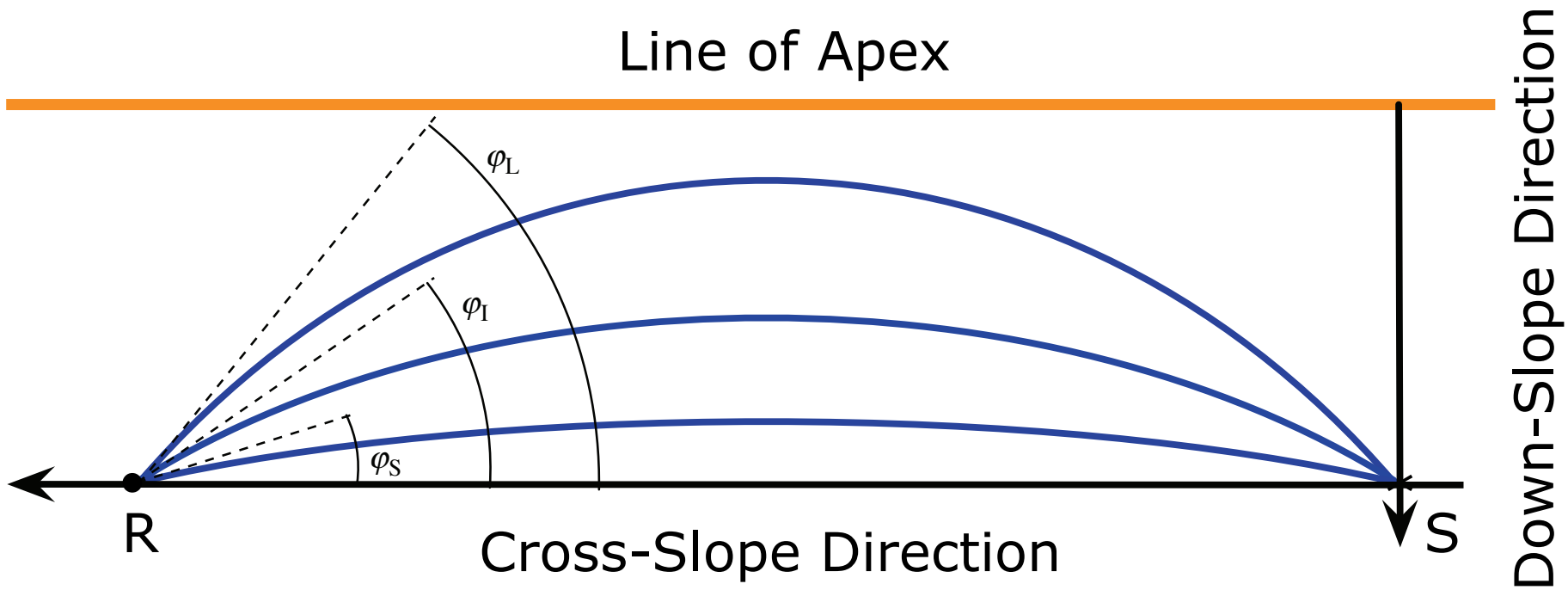
Response at 40 km; Source Pulse of Heaviside Form (cont.)



Response at 40 km; Source Pulse of Heaviside Form (cont.)

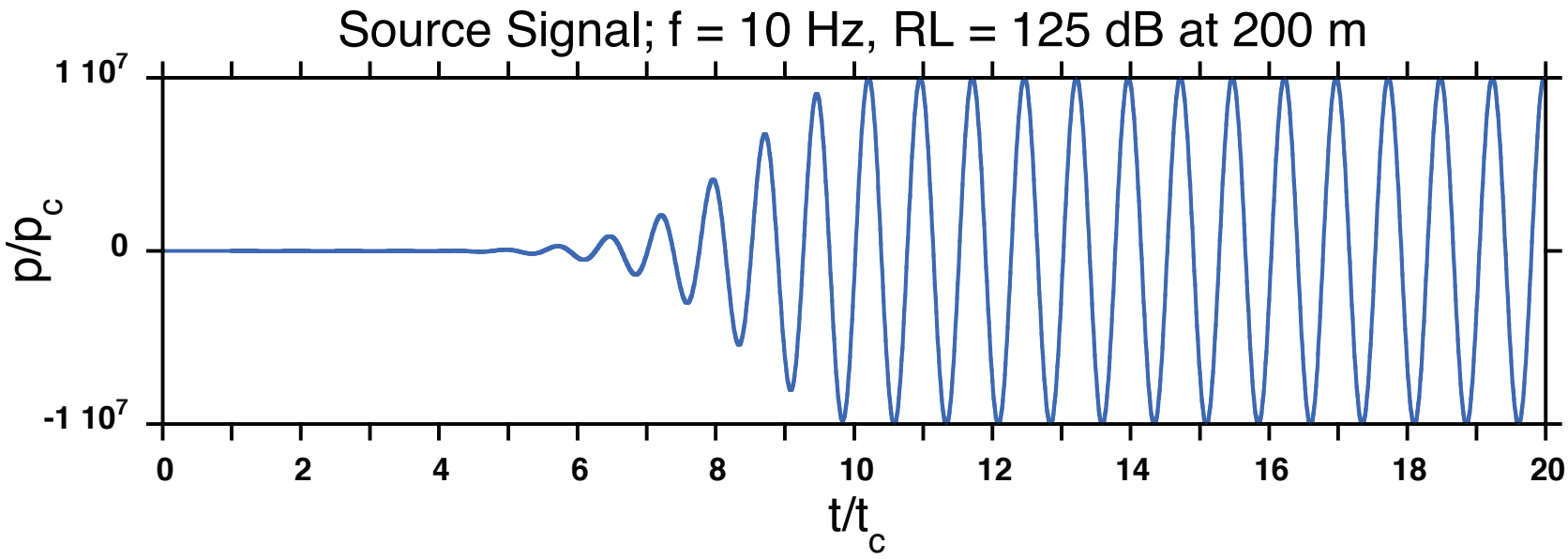


Response at 40 km (cont.); Effects of Horizontal Refraction

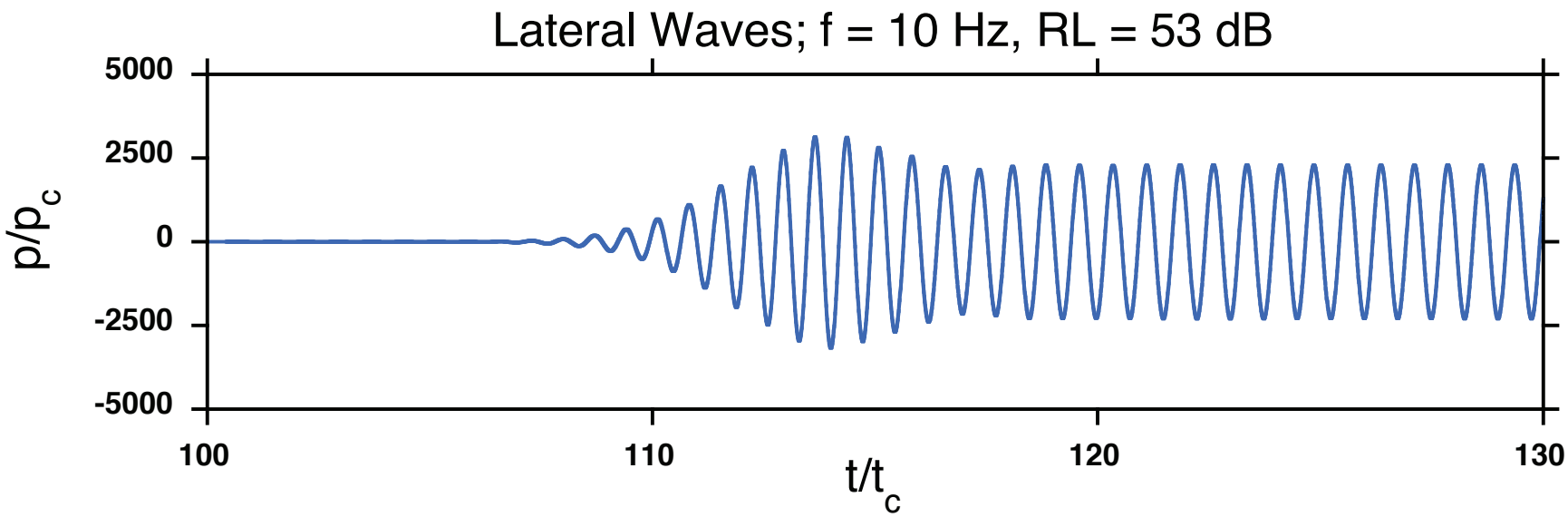


Source Signals

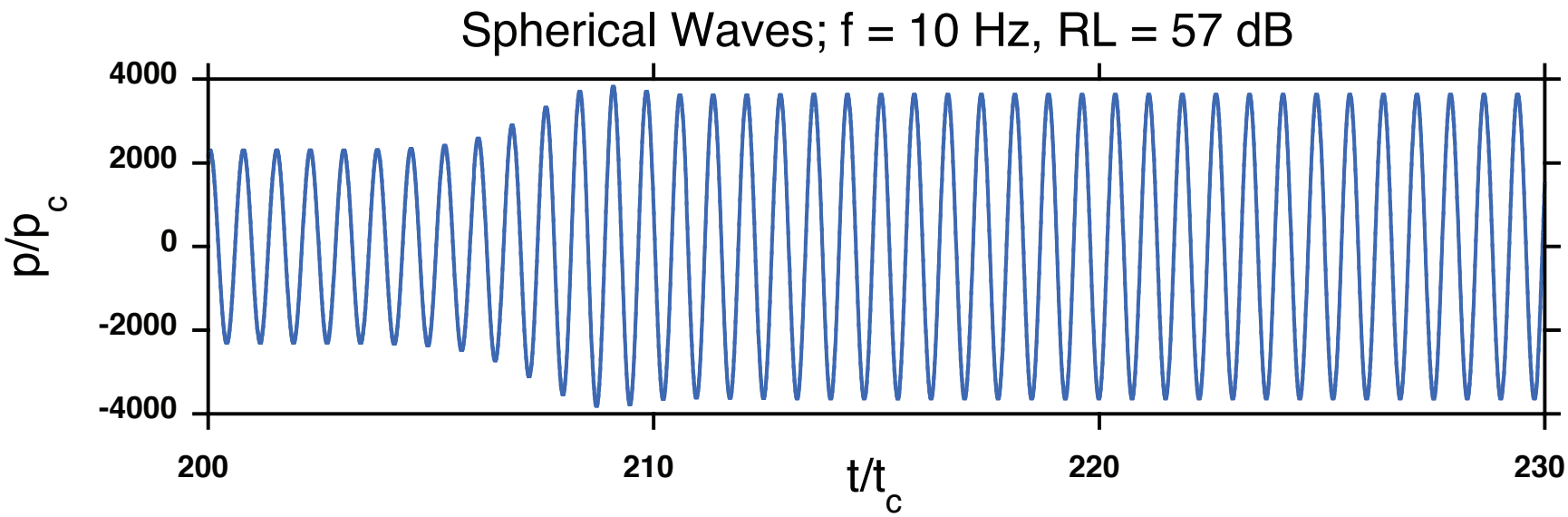
- Source Level of 171 dB re 1 μPa at 1m
- Tones Centered at 10, 15, 20, 25, 30, 35, 40, 45, 50, 52.5 Hz
- Example: Tone Centered at 10 Hz



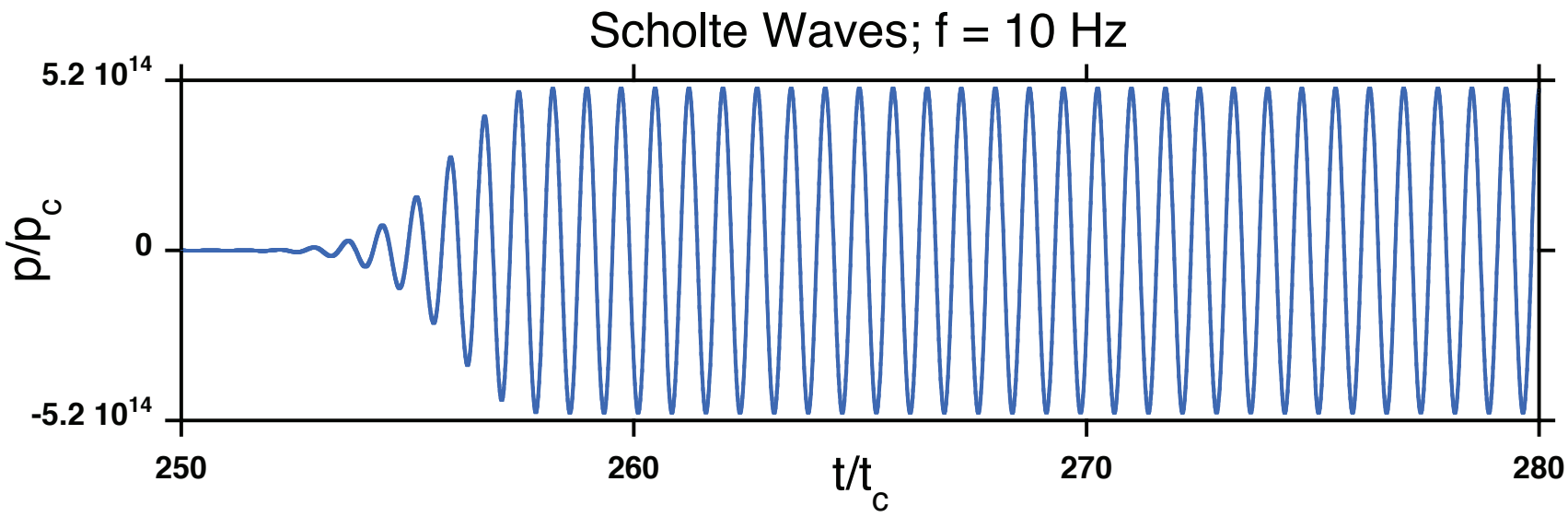
Response at 40 km; f = 10 Hz



Response at 40 km; f = 10 Hz (cont.)

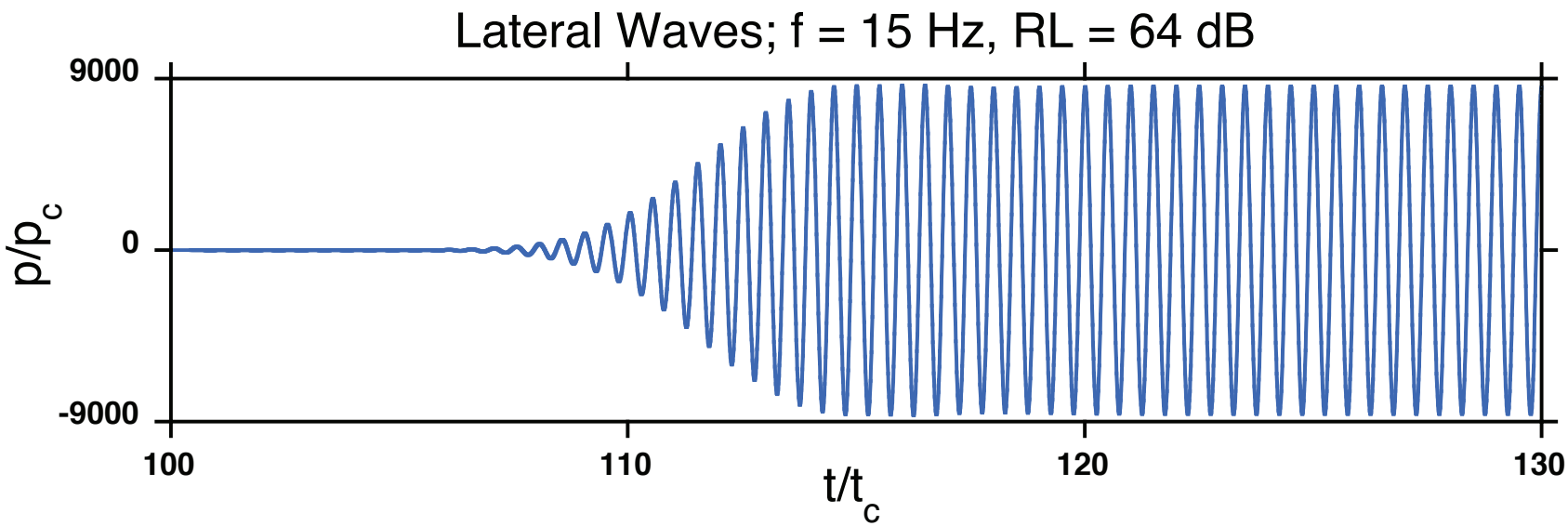


Response at 40 km; f = 10 Hz (cont.)

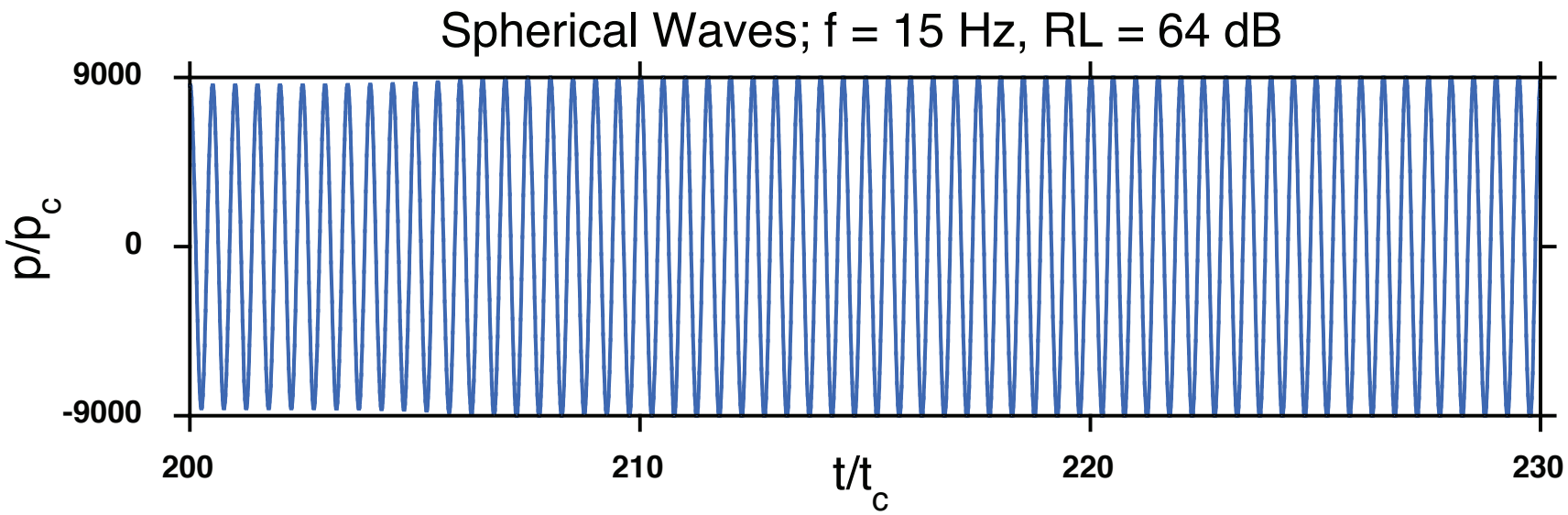


- RL = 279 – 60 = 219 dB

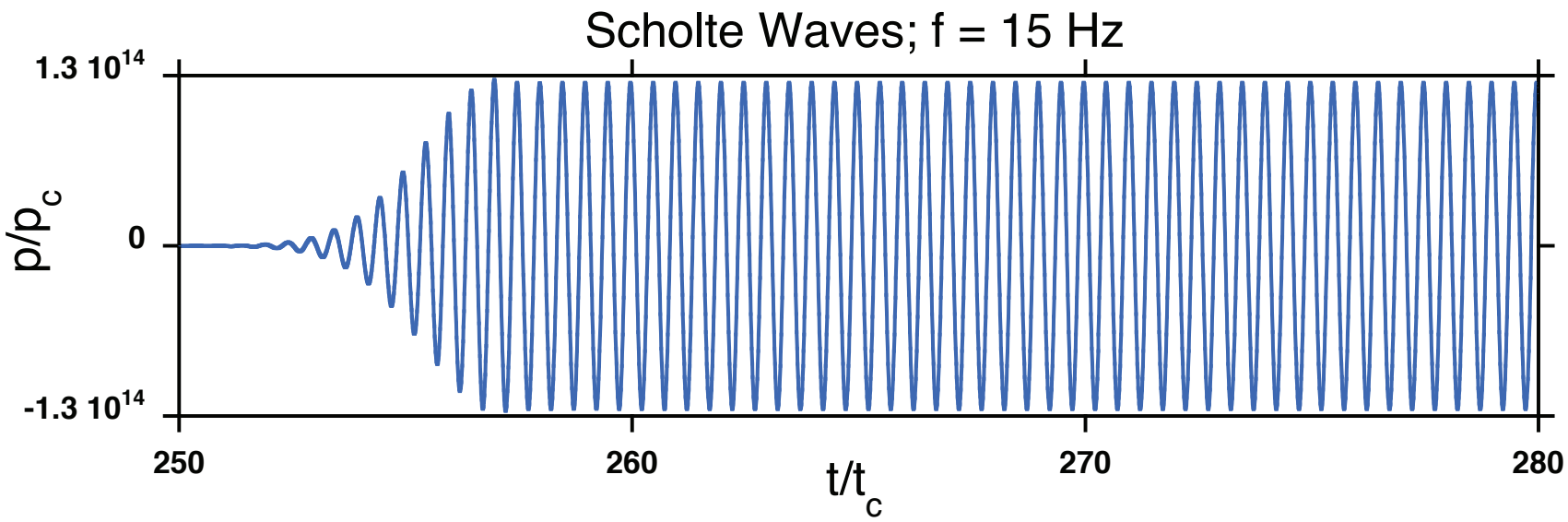
Response at 40 km; f = 15 Hz



Response at 40 km; f = 15 Hz (cont.)

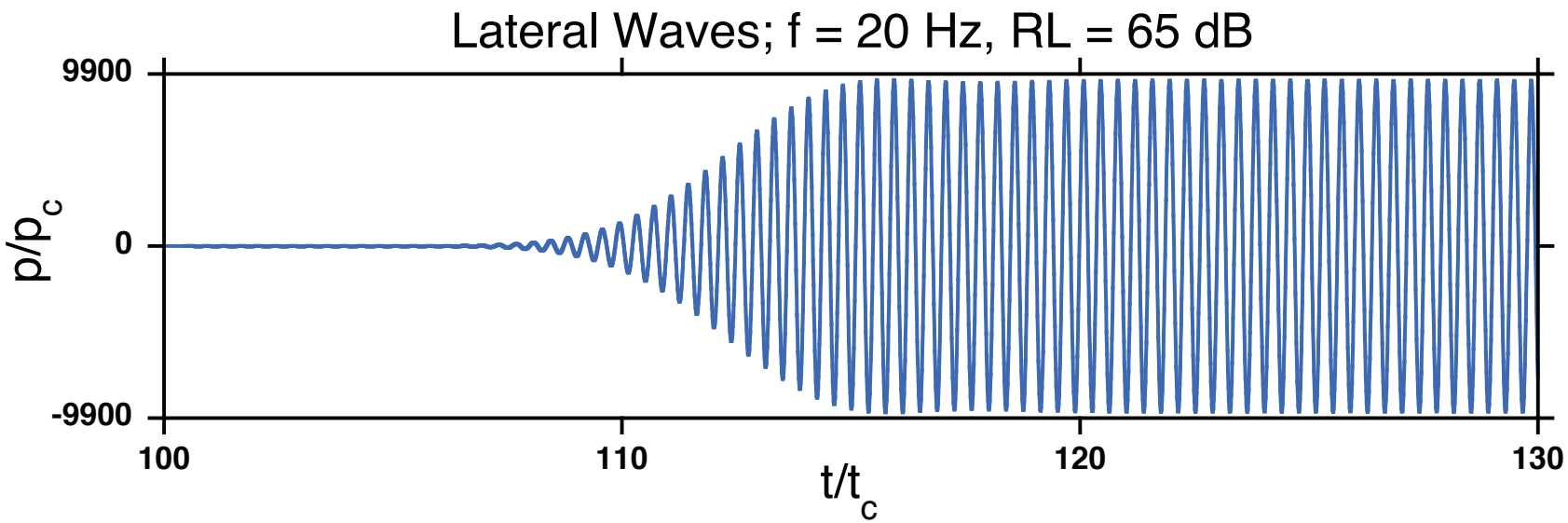


Response at 40 km; f = 15 Hz (cont.)

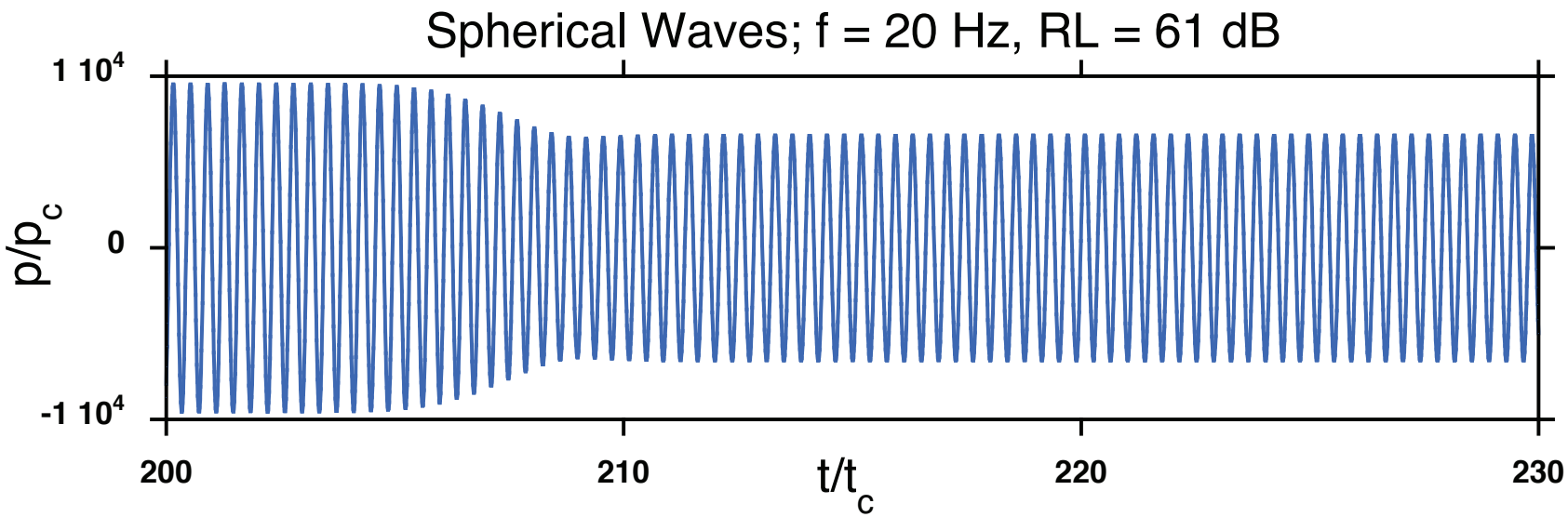


- RL = 267 – 90 = 177 dB

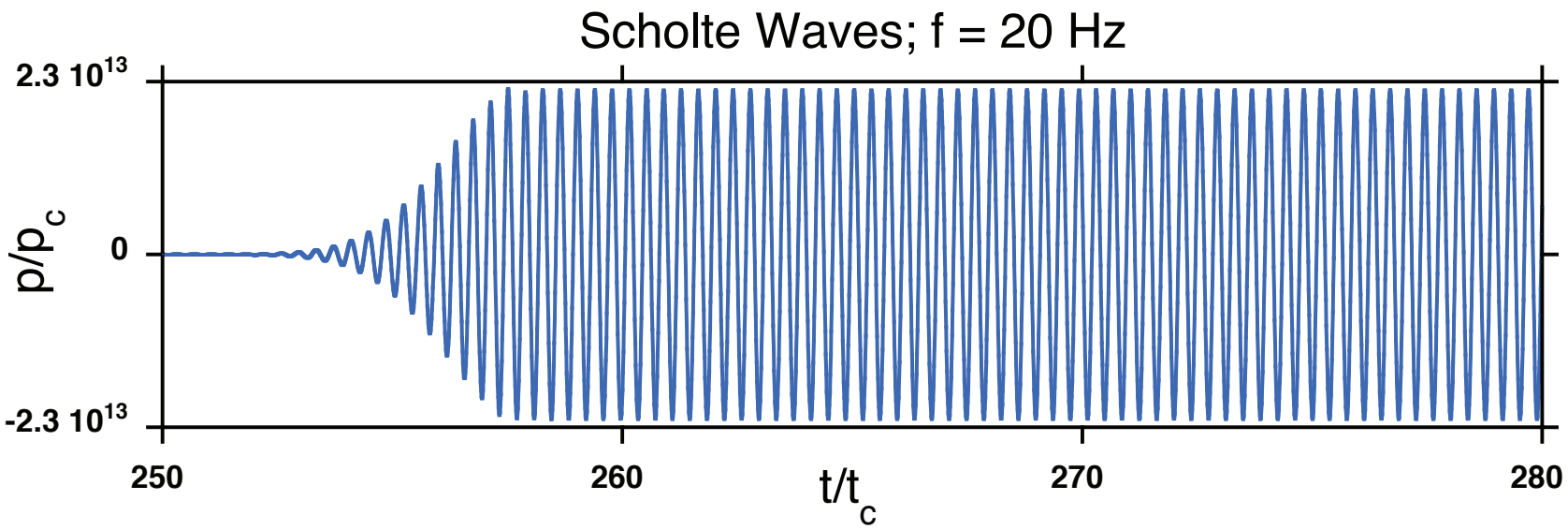
Response at 40 km; f = 20 Hz



Response at 40 km; f = 20 Hz (cont.)

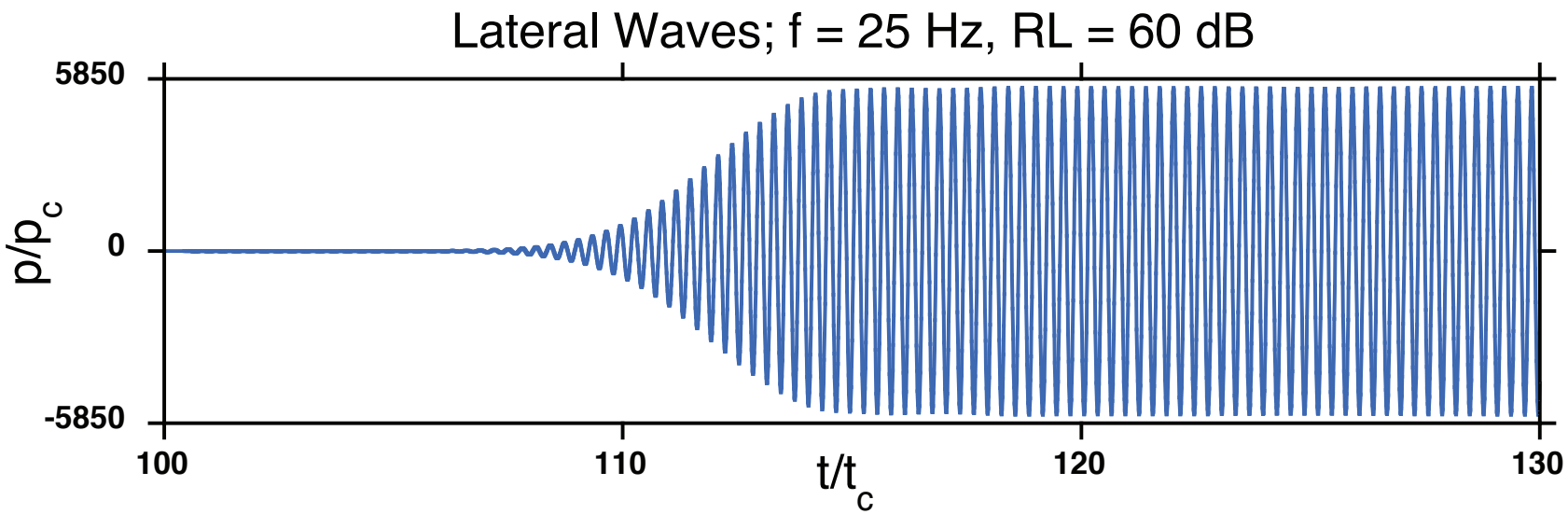


Response at 40 km; f = 20 Hz (cont.)

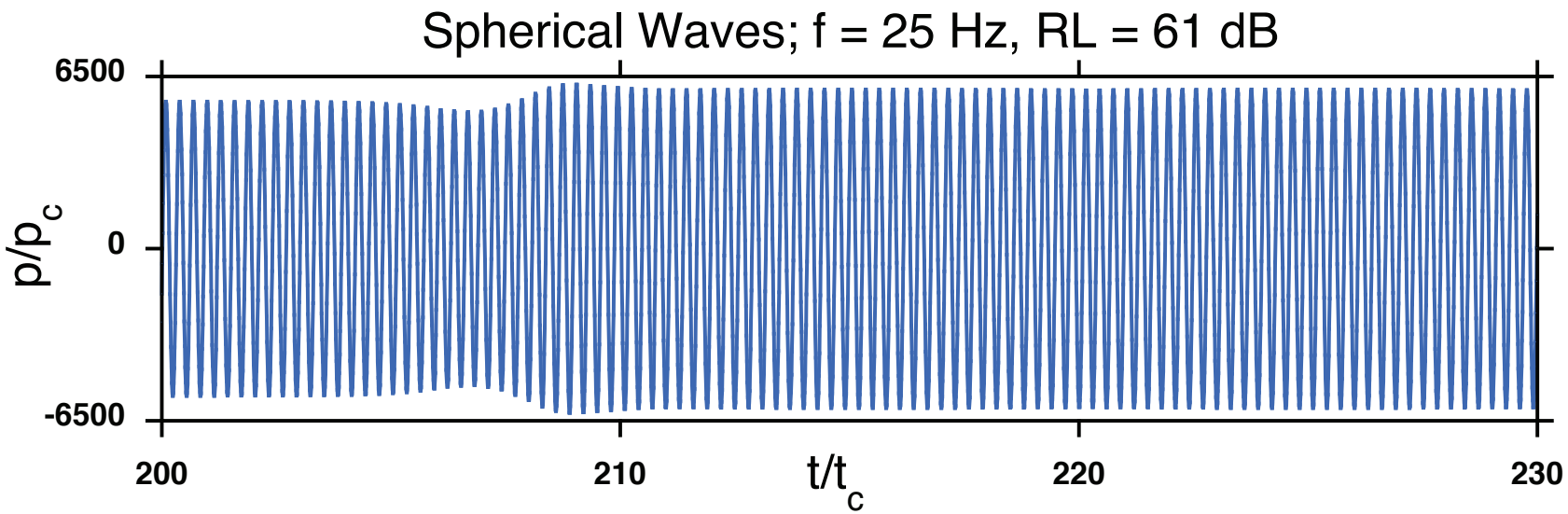


- RL = 252 – 121 = 131 dB

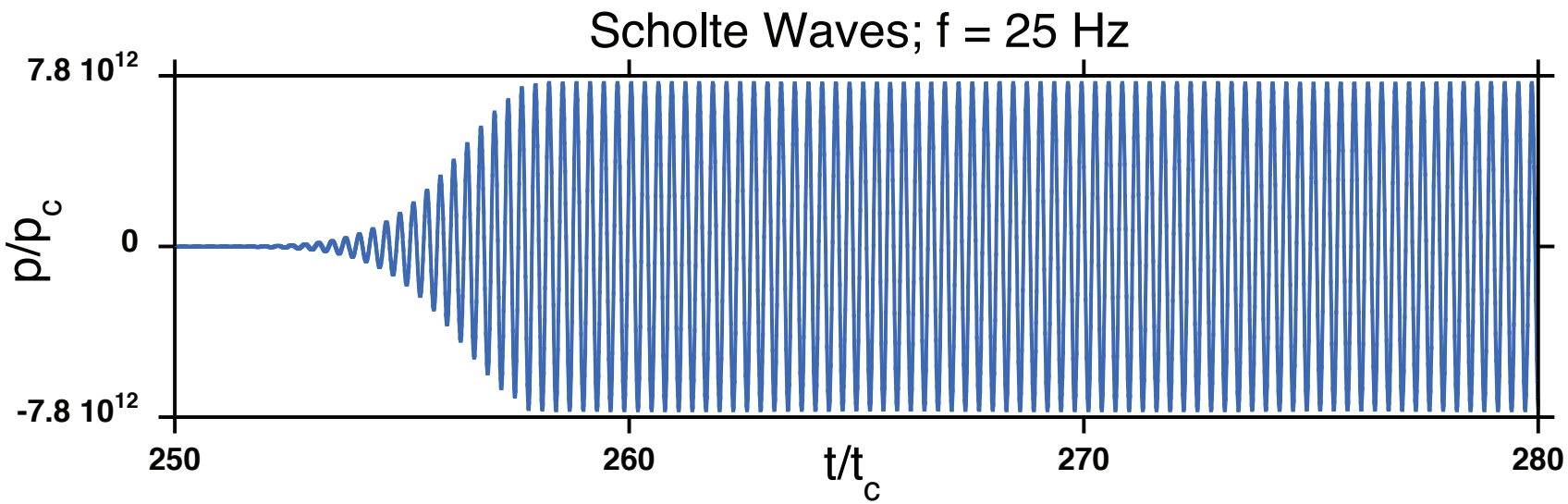
Response at 40 km; f = 25 Hz



Response at 40 km; f = 25 Hz (cont.)

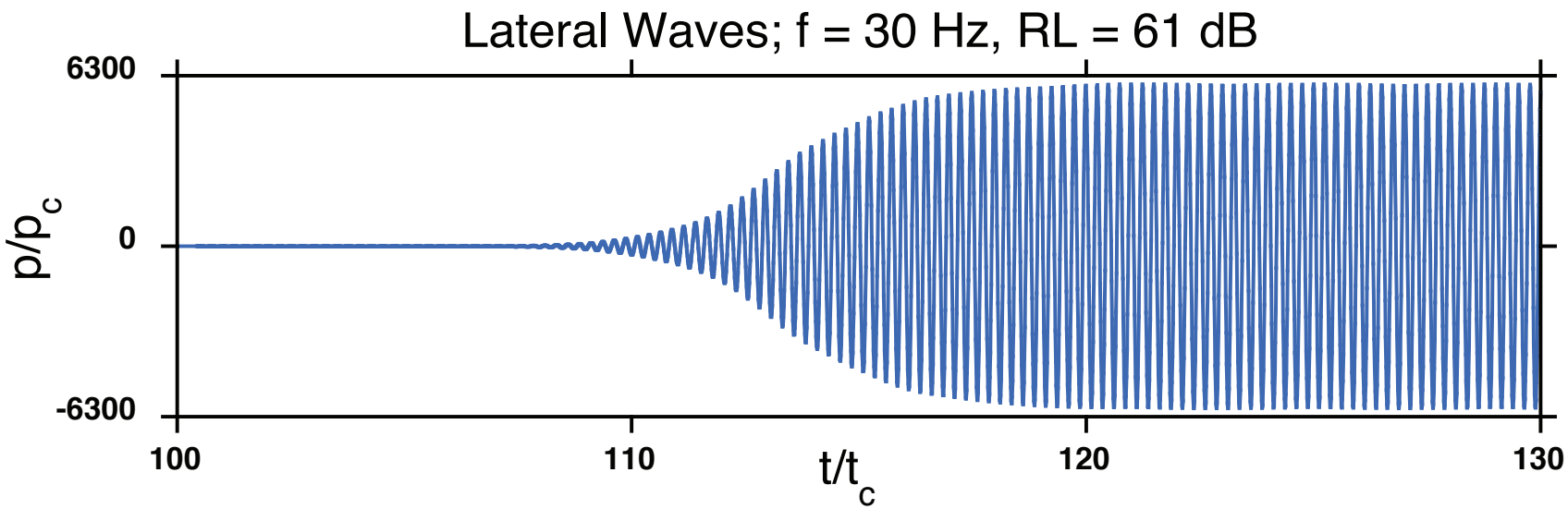


Response at 40 km; f = 25 Hz (cont.)

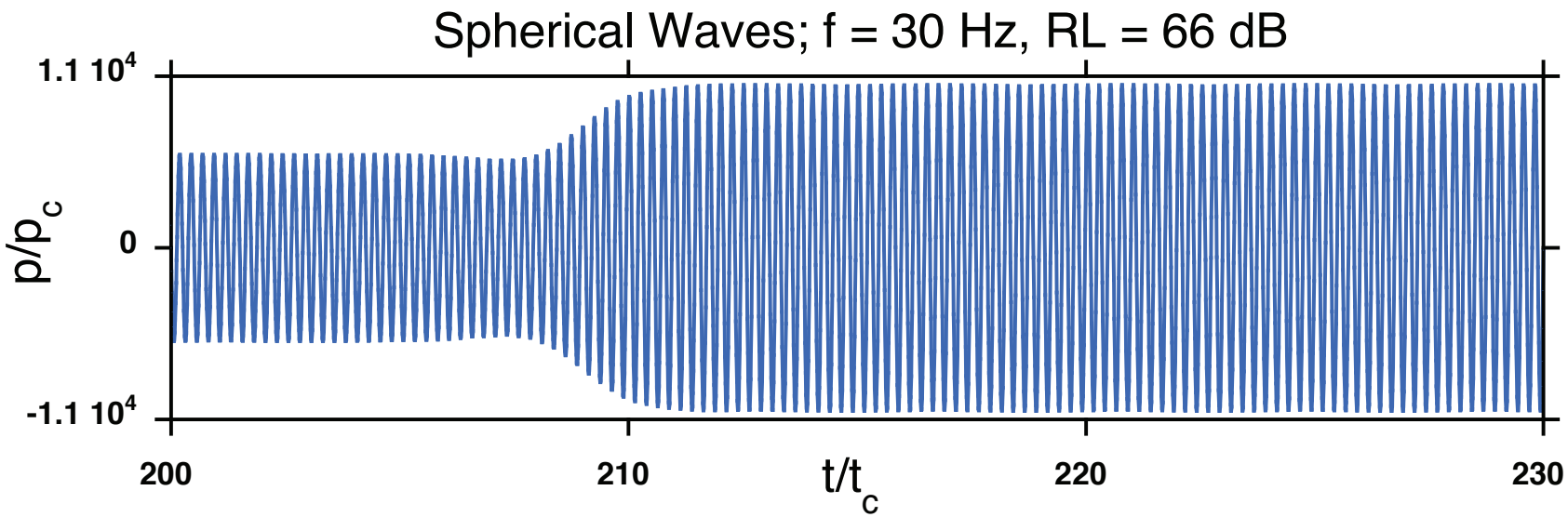


- RL = 243 –151 = 92 dB

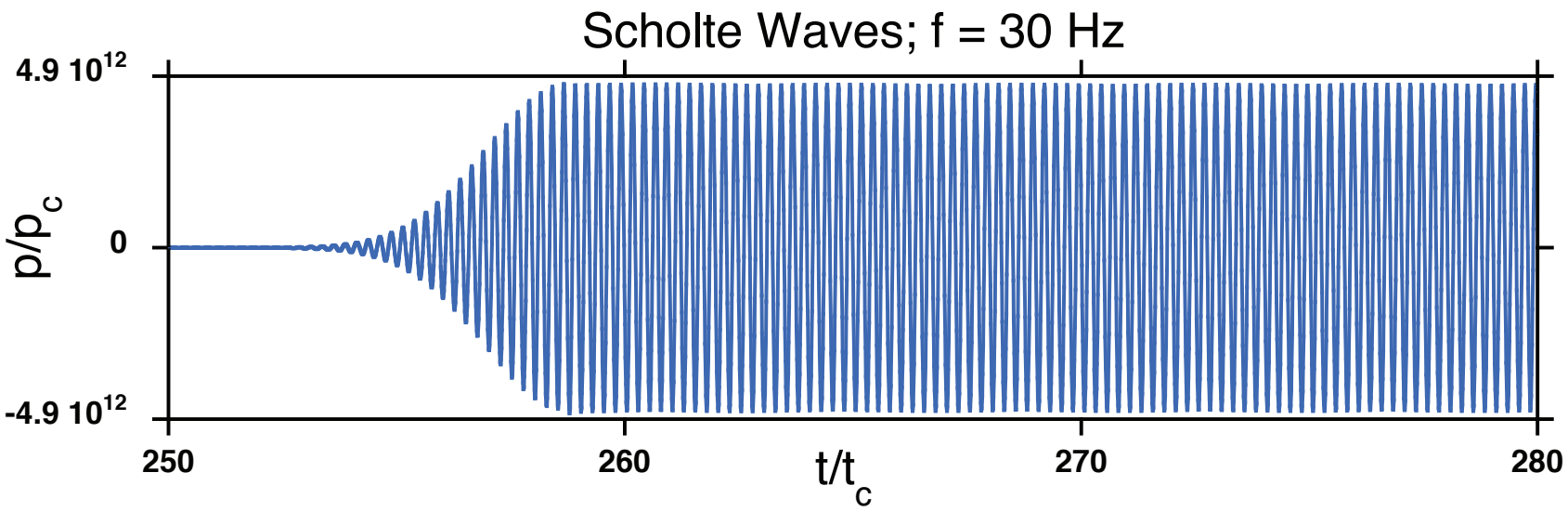
Response at 40 km; f = 30 Hz



Response at 40 km; f = 30 Hz (cont.)

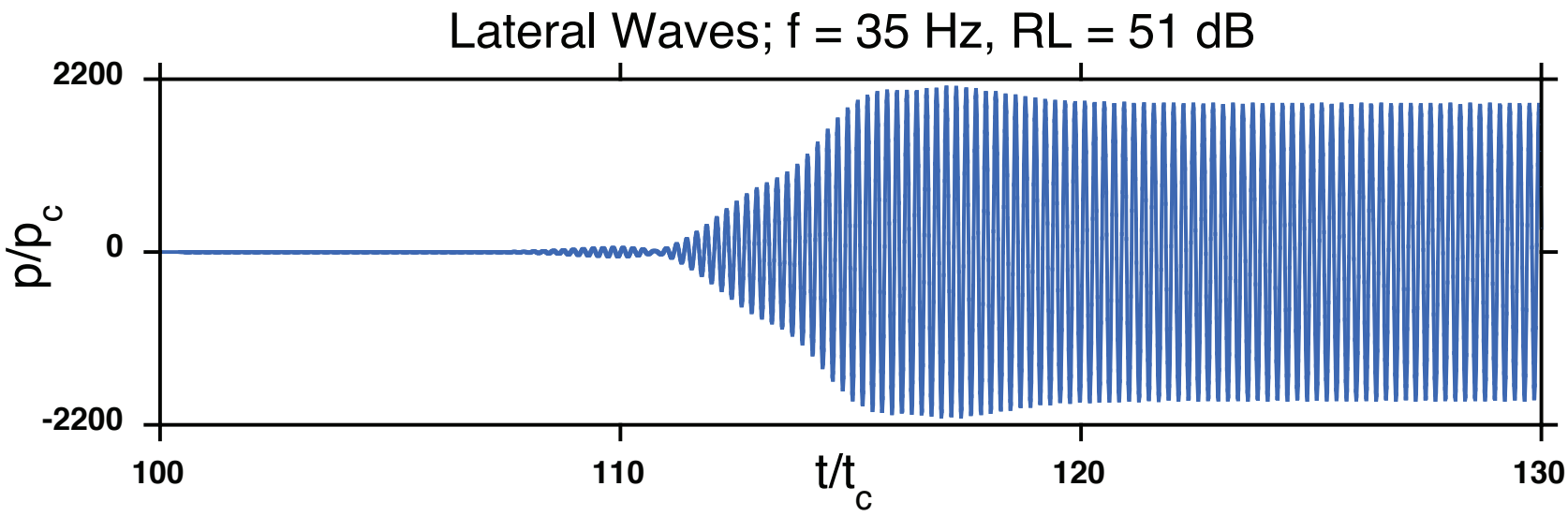


Response at 40 km; f = 30 Hz (cont.)

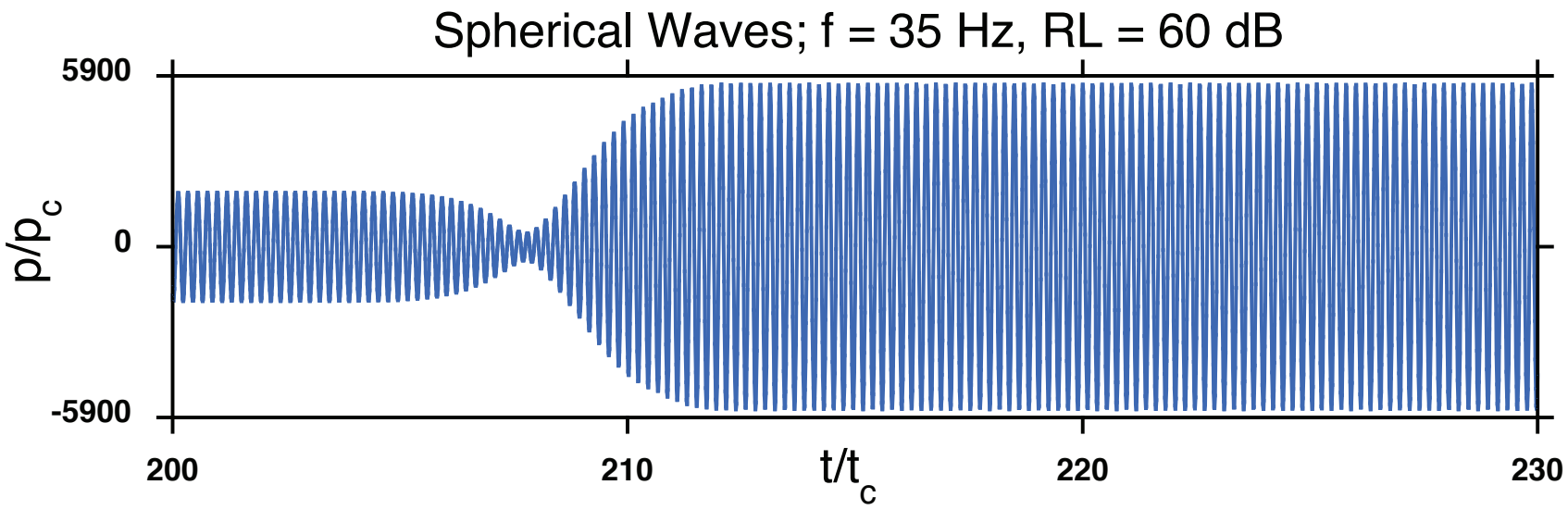


- RL = 239 – 181 = 58 dB

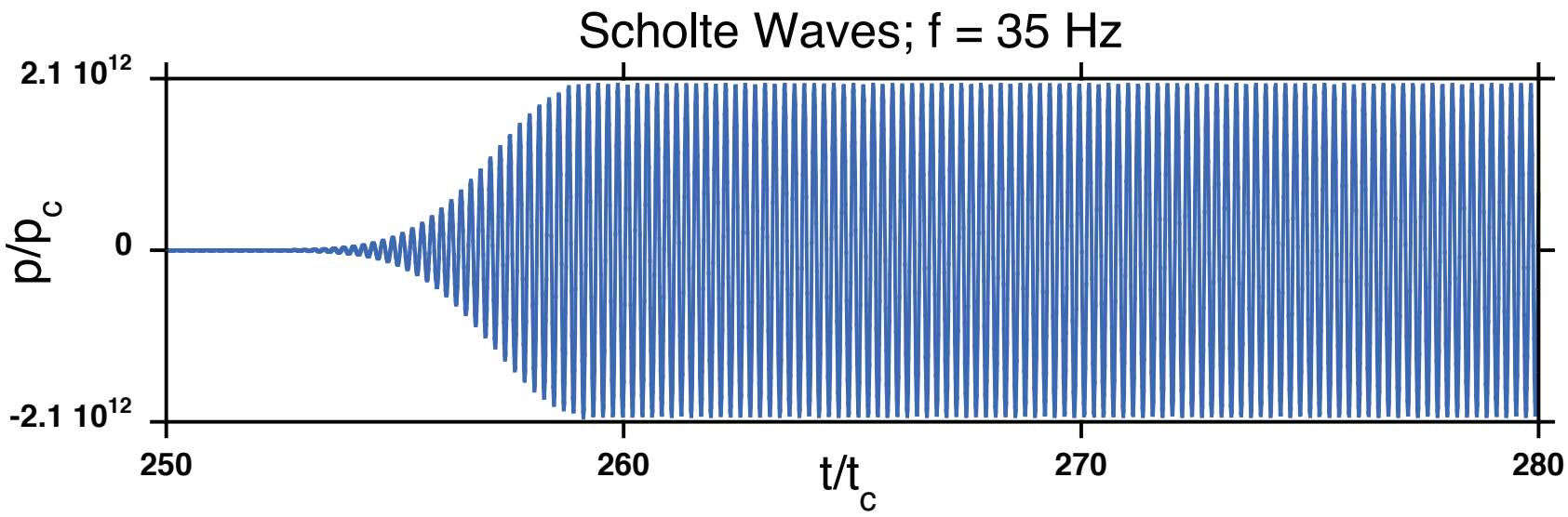
Response at 40 km; f = 35 Hz



Response at 40 km; f = 35 Hz (cont.)

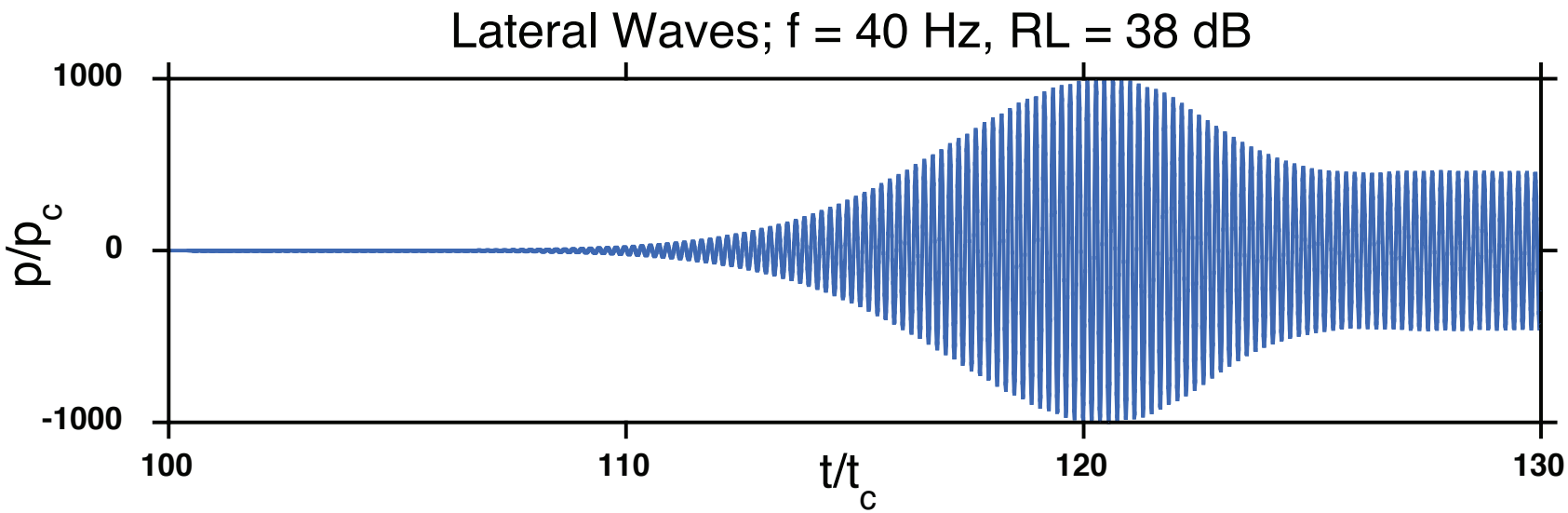


Response at 40 km; f = 35 Hz (cont.)

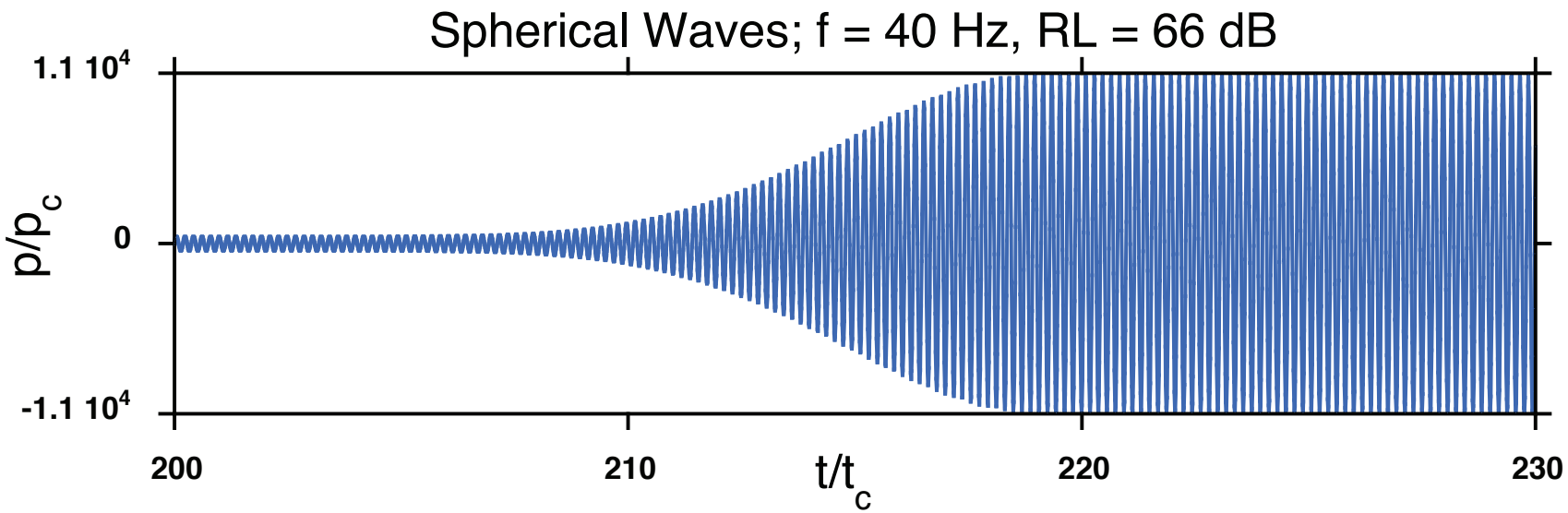


- RL = 231 – 211 = 20 dB

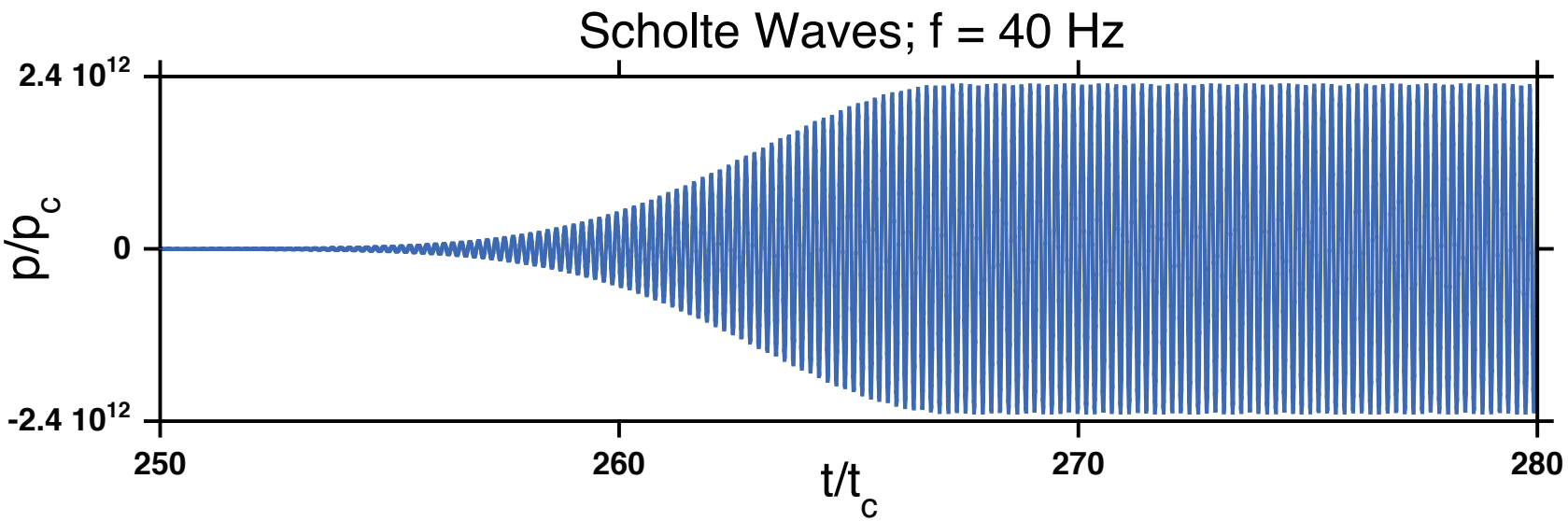
Response at 40 km; f = 40 Hz



Response at 40 km; f = 40 Hz (cont.)

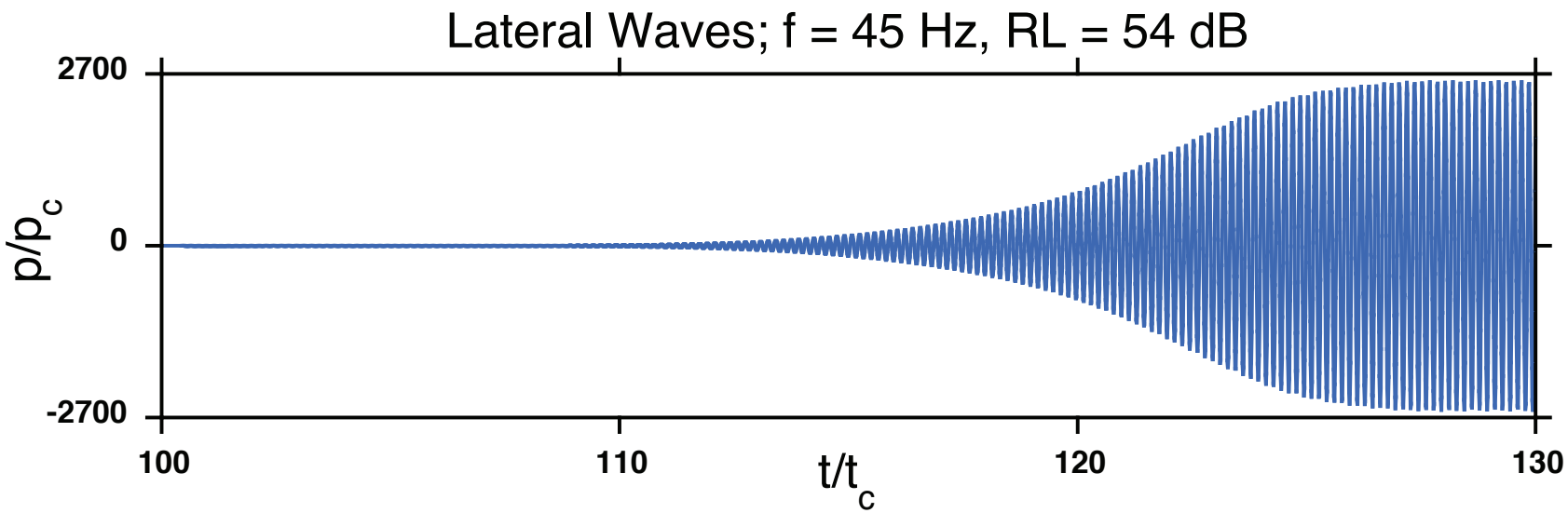


Response at 40 km; f = 40 Hz (cont.)

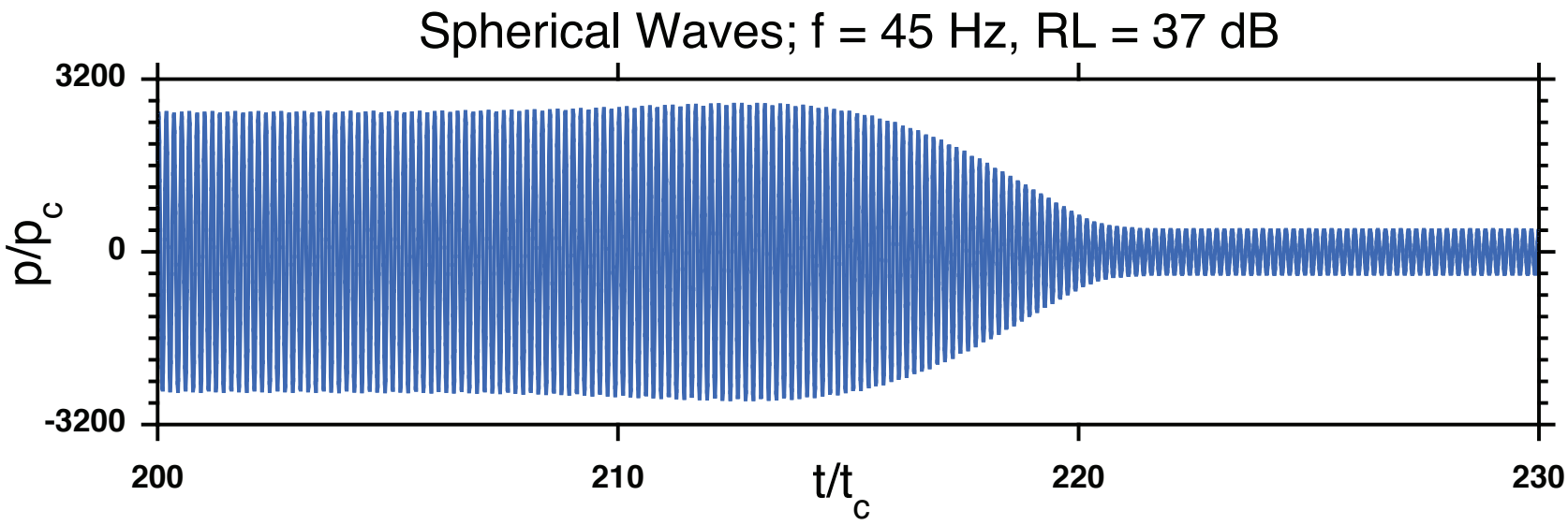


- 233 – 241 < 0 and so RL = 0 dB

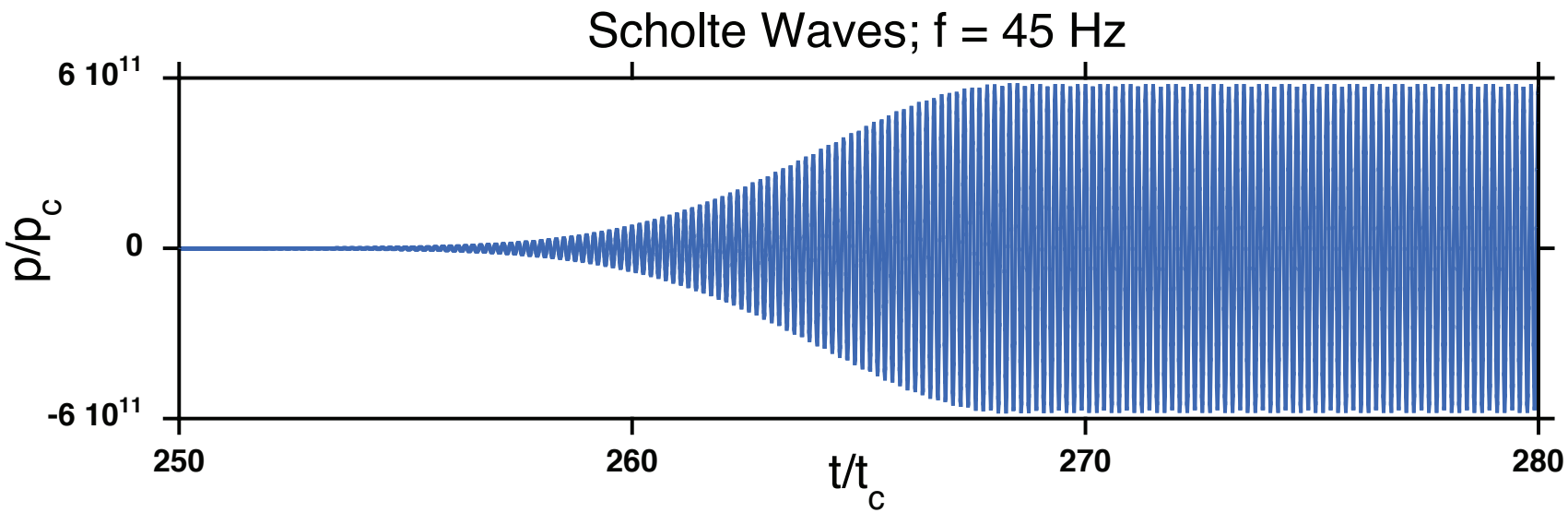
Response at 40 km; f = 45 Hz



Response at 40 km; f = 45 Hz (cont.)

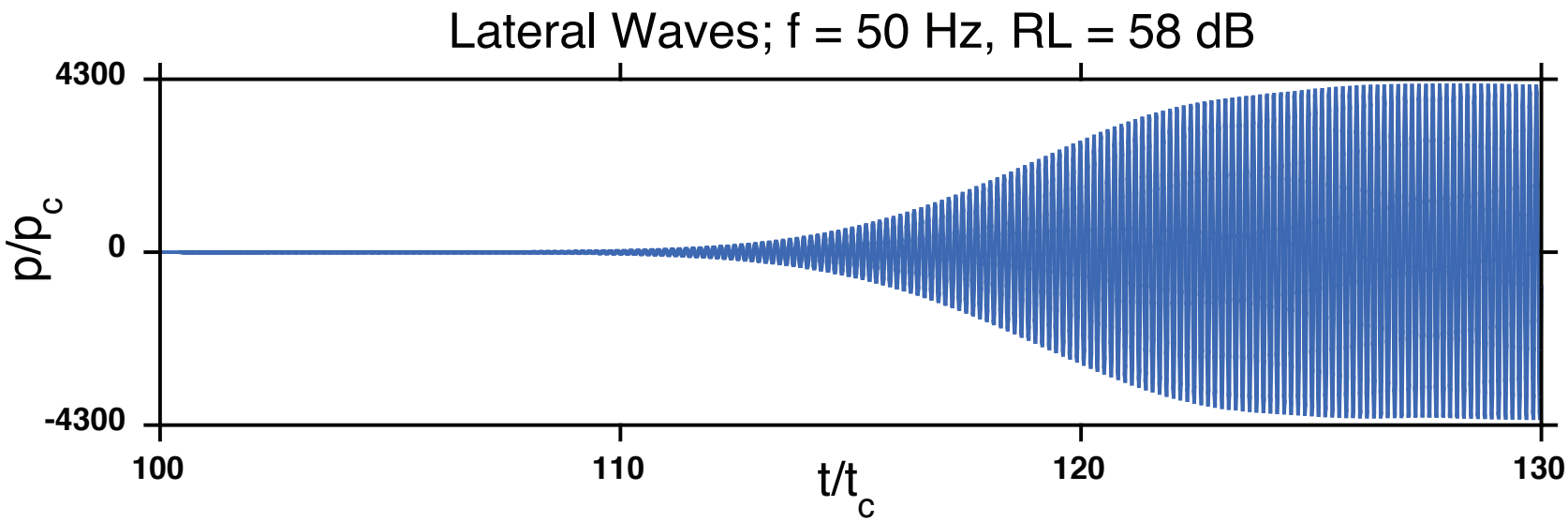


Response at 40 km; f = 45 Hz (cont.)

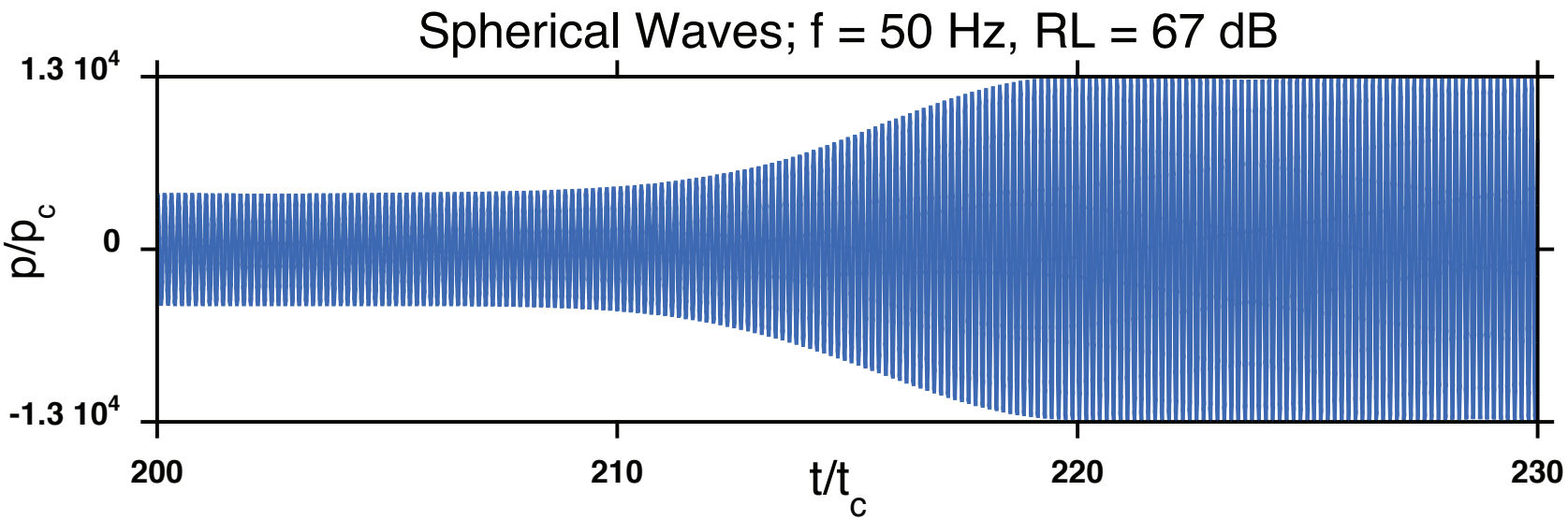


- 221 – 271 < 0 and so RL = 0 dB

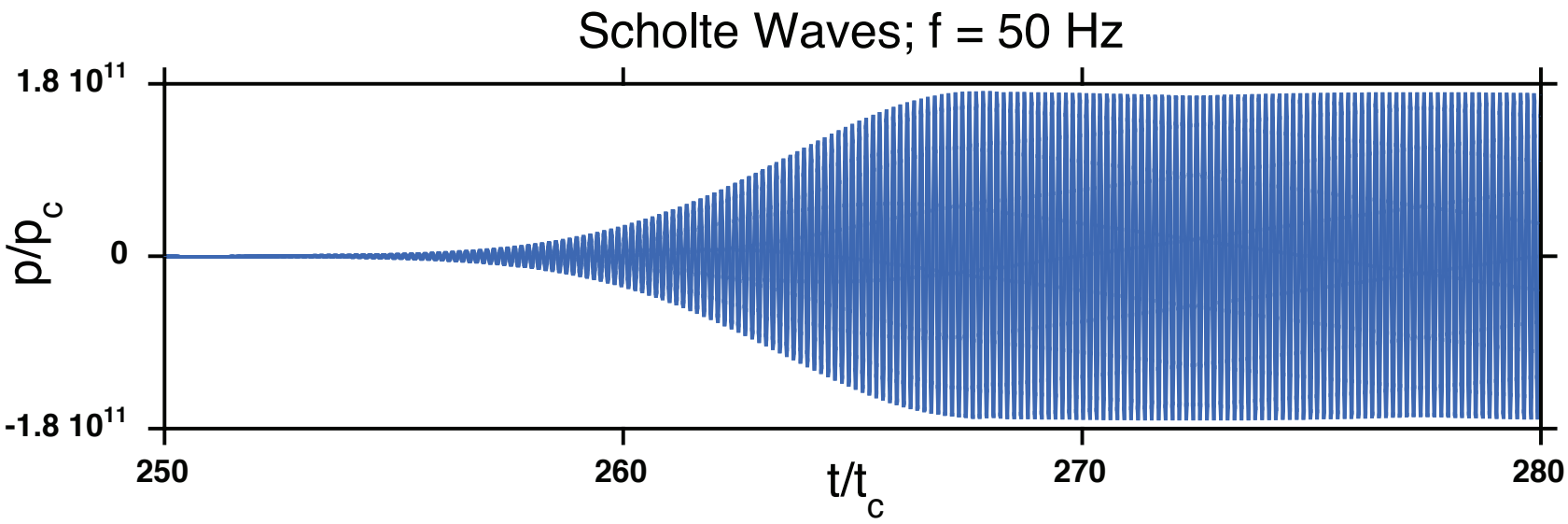
Response at 40 km; f = 50 Hz



Response at 40 km; f = 50 Hz (cont.)

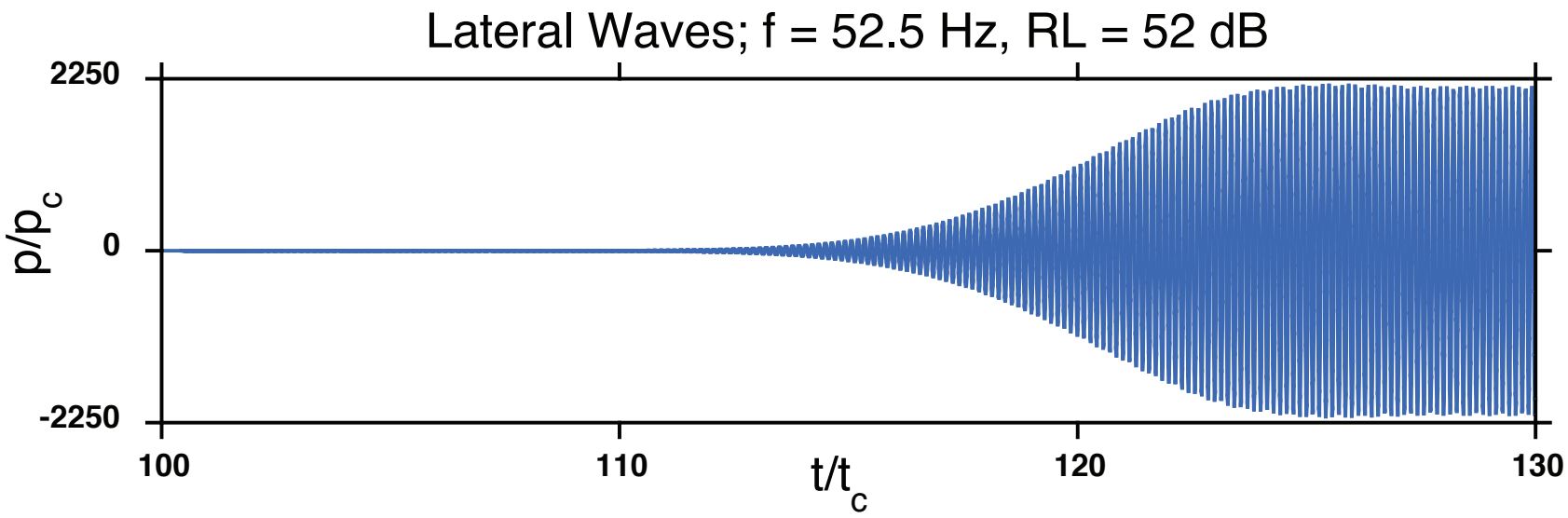


Response at 40 km; f = 50 Hz (cont.)

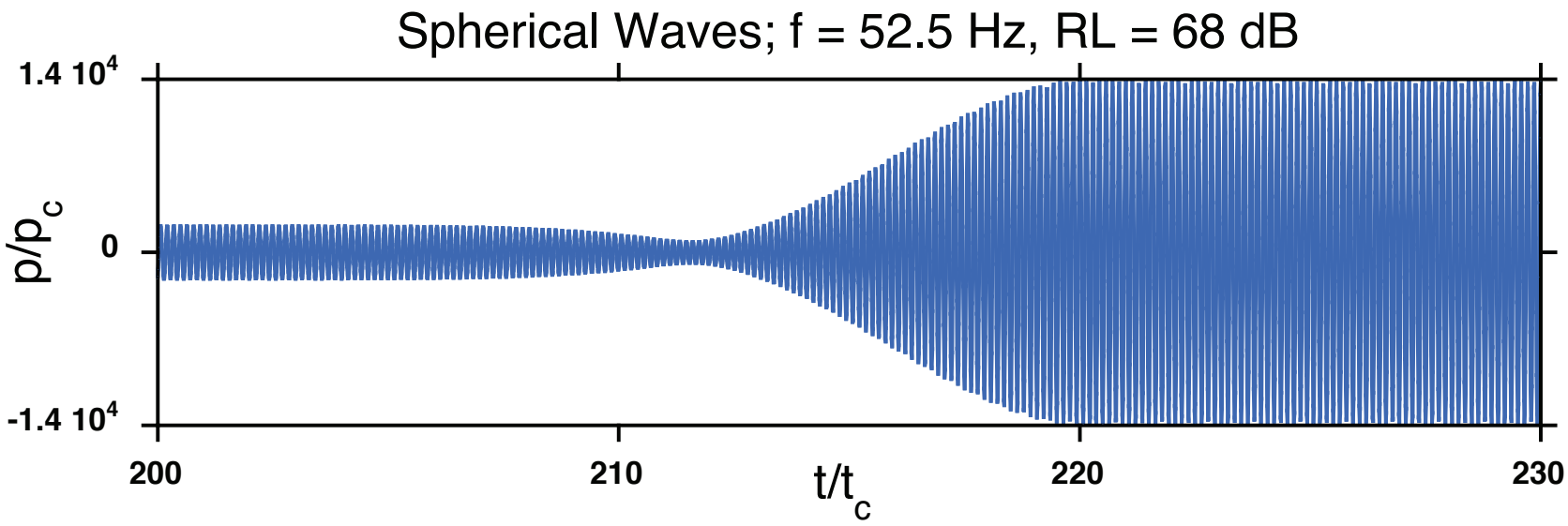


- 210 – 301 < 0 and so RL = 0 dB

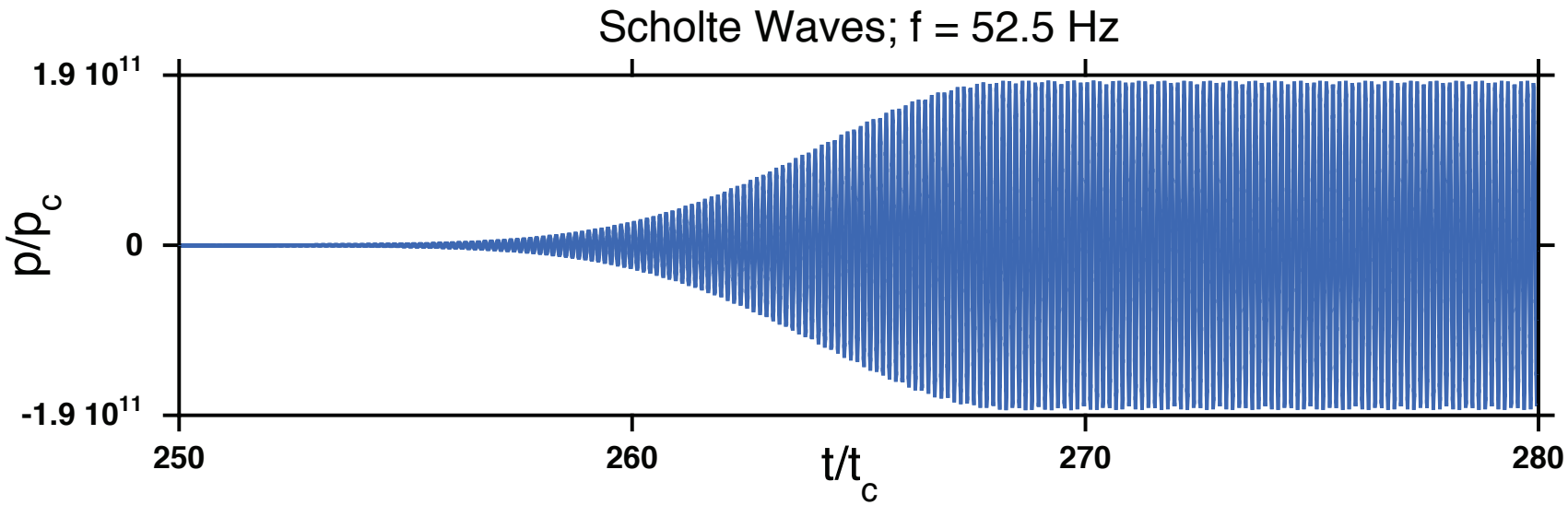
Response at 40 km; f = 52.5 Hz



Response at 40 km; f = 52.5 Hz (cont.)



Response at 40 km; f = 52.5 Hz (cont.)



- 210 – 316 < 0 and so RL = 0 dB

Summary of RLs at r = 40 km, f = 10, 15, 20, . . . , 52.5 Hz

	10 Hz	15 Hz	20 Hz	25 Hz	30 Hz	35 Hz	40 Hz	45 Hz	50 Hz	52.5 Hz
Head Waves	**53 dB**	**64 dB**	**65 dB**	**60 dB**	**61 dB**	**51 dB**	**38 dB**	**54 dB**	**58 dB**	**52 dB**
Spherical Waves	**57 dB**	**64 dB**	**61 dB**	**61 dB**	**66 dB**	**60 dB**	**66 dB**	**37 dB**	**67 dB**	**68 dB**
Scholte Waves	**219 dB**	**177 dB**	**131 dB**	**92 dB**	**58 dB**	**20 dB**	**0 dB**	**0 dB**	**0 dB**	**0 dB**

Conclusions

- Dominant lateral- and spherical-waves arrivals are coming in along "direct paths."
- Dominant Scholte-waves arrivals are due to multi-reflected fields coming in along "in-shore refracted paths."
- RLs of Lateral and Spherical Phases Too High
- RL of Scholte Phase Significant Only for "Low" Frequencies
- Only "low-frequency" cross-slope propagation may indeed be 3-D.