2^{nd} Sonic Boom Prediction Workshop, Jan. 7-8, 2017

Results of *Xnoise* and *IntegRay* for 2^{nd} Sonic Boom Prediction Workshop, Propagation of Sonic Boom

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Outline

- ✓Introduction of Research Activities on Sonic Boom in JAXA
  - ✓ D-SEND project
  - ✓ introduction of prediction tools
- ✓About Cases Analyzed
  - ✓ shaped axi-symmetric body of revolution
  - ✓ Lockheed Martin 1021
- ✓Prediction Results
  - ✓ Ground signatures
  - ✓ Loudness values and their convergence
  - ✓ Lateral cutoff angles and locations along with acoustical rays

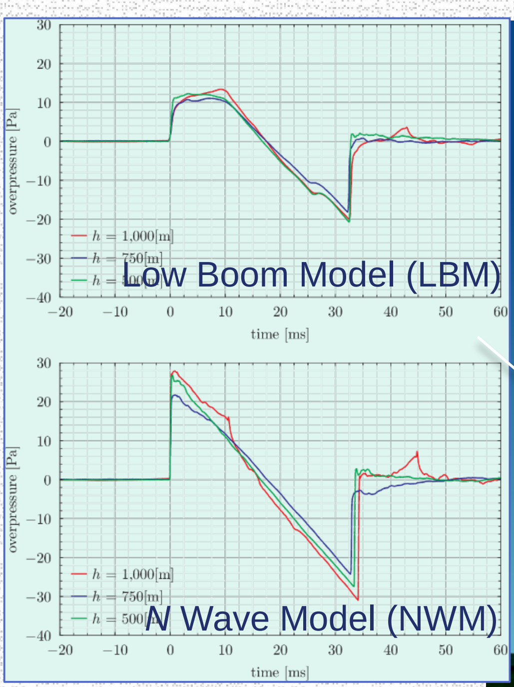
Research Activities on Sonic Boom in JAXA

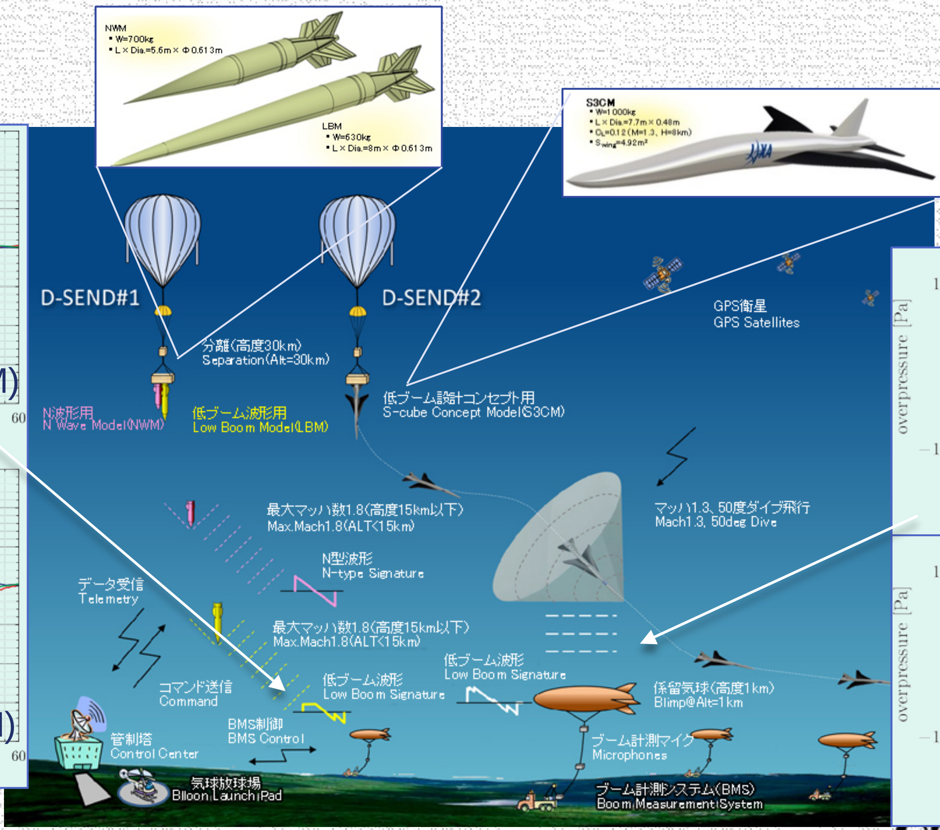
- ✓ JAXA's research activities on sonic boom
  - ✓ propose and demonstrate a low-boom design concept (D-SEND project, 2008-2015)
  - ✓ prepare prediction tools for evaluation, design and optimization of total SST system

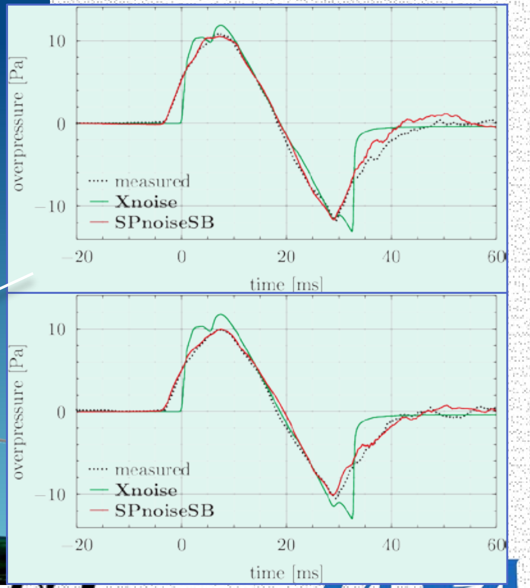
Numerical Simulation Research Unit

D-SEND project in JAXA

- ✓ Demonstration of JAXA's low-boom design concept
- ✓ D-SEND#1 flight test was successfully performed in 2011 (Bottom left)
- ✓ D-SEND#2 flight test demonstrated our design concept (Bottom right)

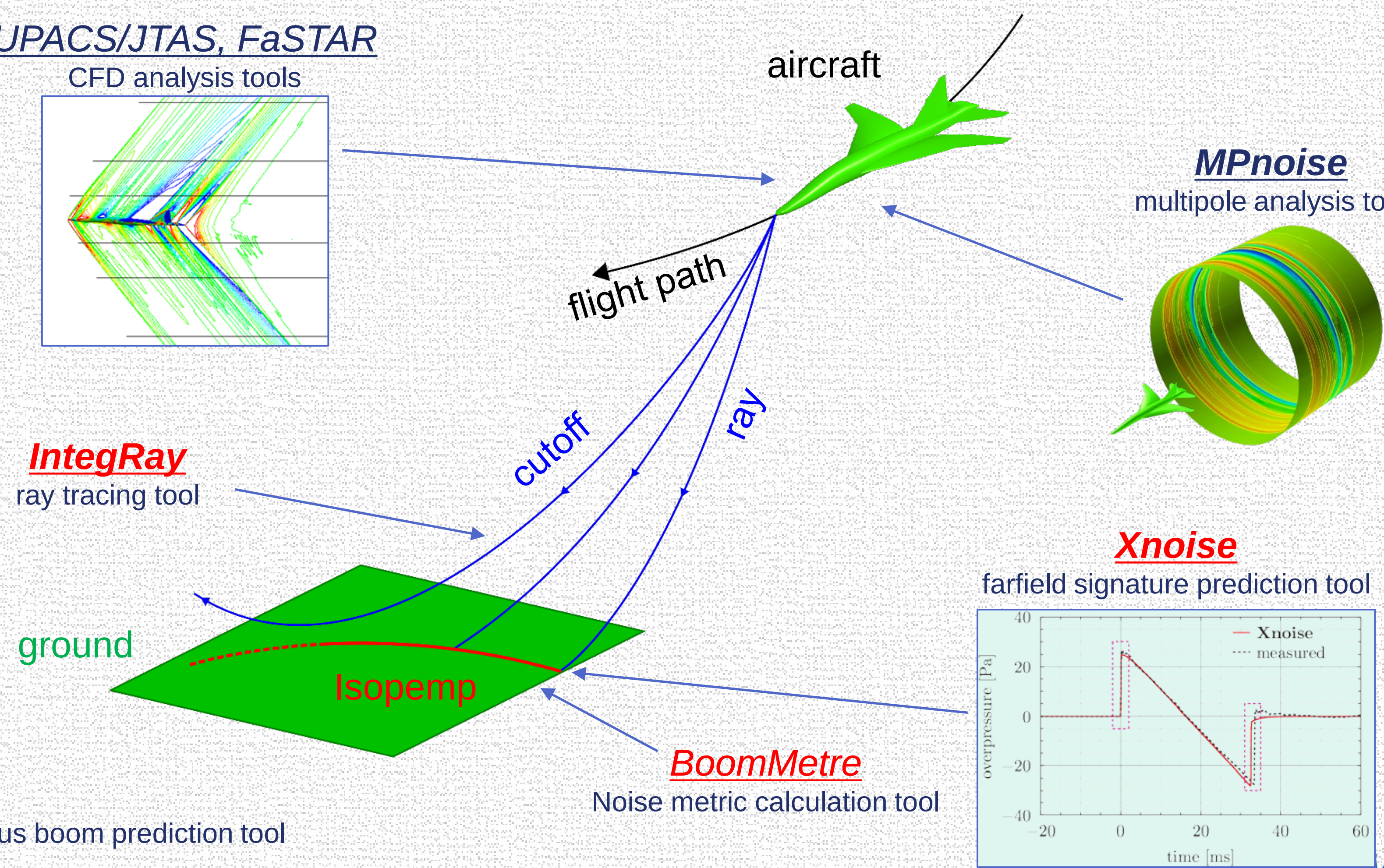






Summary of Boom Prediction Tools in JAXA

✓ Computations from nearfield to farfield are covered



FFnoise focus boom prediction tool

SPnoise for Sonic Boom atmospheric turbulence effect prediction tool

Numerical Simulation Research Unit

Xnoise – Nonlinear Propagation Analysis Tool –

- ✓ solves augmented Burgers equation shown below(Cleveland *et al*, 1995)
- ✓ simulates acoustical effect including nonlinearity, attenuation and dispersion.
  - ✓ All the effects are solved separately in the time domain.
  - ✓ Ray tracing is simultaneously considered in order to evaluate ray tube area.
  - ✓ 3rd order scheme for nonlinearity, 2nd order scheme for attenuation are adopted

◆ Application to D-SEND#1 flight test

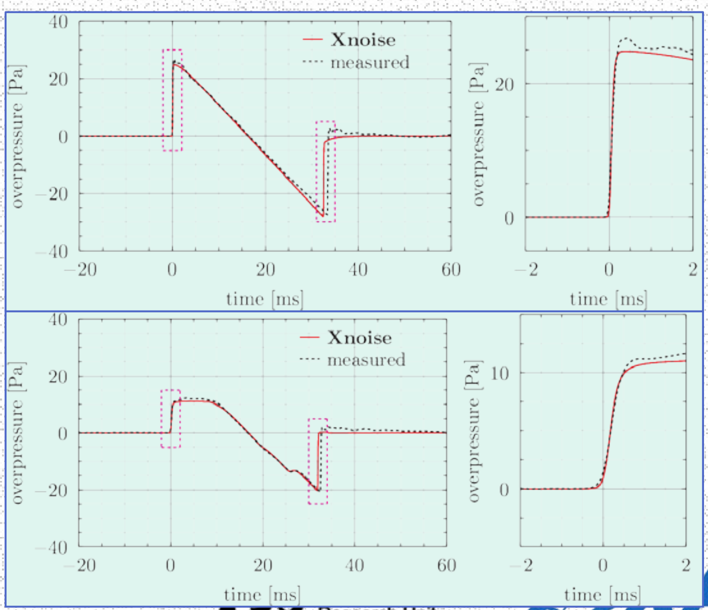
- both *N* wave and flattop signature were tried
- fairly good agreement was achieved including rise time

$$\frac{\partial p}{\partial s} = \frac{\beta}{2\rho_0 c_0^3}\frac{\partial p^2}{\partial \tau}$$: Nonlinearity

$$-\frac{1}{2B}\frac{\partial B}{\partial s}p$$: Blokhintsev Energy Conservation

$$+\frac{\delta}{2c_0^3}\frac{\partial^2 p}{\partial \tau^2}$$: Thermo-Viscous Effect

$$+\sum_{\nu}\frac{(\Delta c)_i \tau_i}{c_0^2}\left(1+\tau_i\frac{\partial}{\partial \tau}\right)^{-1}\frac{\partial^2 p}{\partial \tau^2}$$: Molecular Relaxation Effect



Research Unit

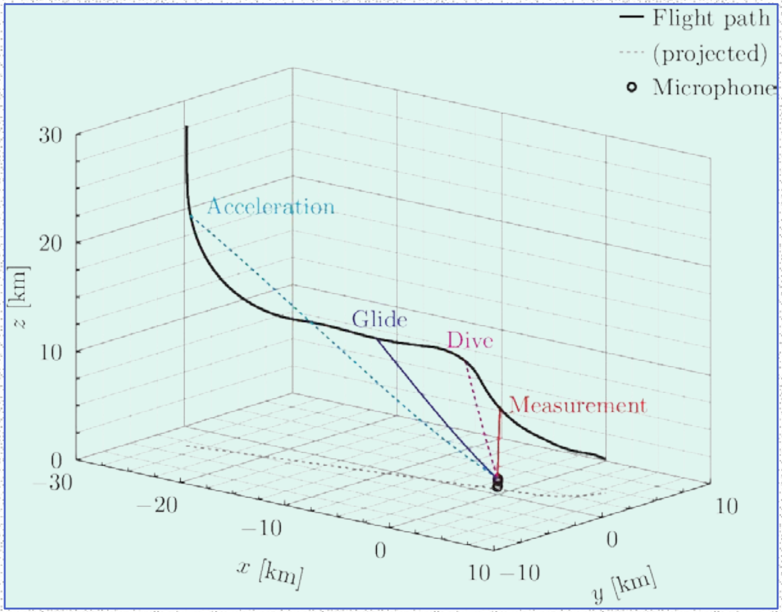
IntegRay – Ray Tracing Tool –

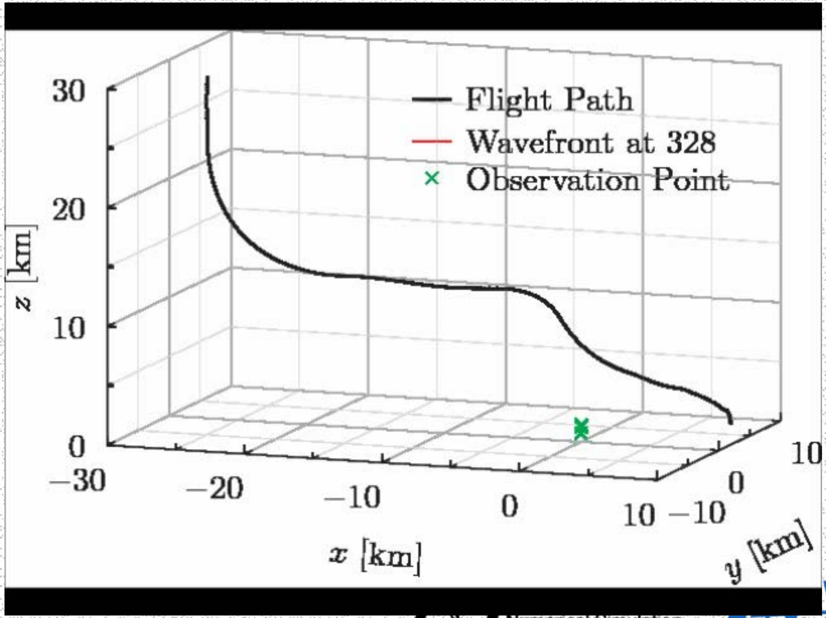
- ✓ calculates acoustical rays by integrating ray path equation
- ✓ specifies the ray starting from a certain point on a flight path and the observation location
- ✓ also computes the cutoff location

$$\frac{d\vec{x}}{dt} = c_0\vec{n} + \vec{v}_0, \frac{d\vec{n}}{dt} = -(I - \vec{n} \otimes \vec{n})(\nabla c_0 + \nabla \vec{v}_0 \cdot \vec{n})$$

◆ Application to D-SEND#2 flight test

- eight rays reached to the microphone (Bottom left)
- progression of wavefront is also shown (Bottom right)





BoomMetre –Loudness Metric Calculation Tool –

- ✓ calculates
  - ✓ Perceived Level(PL) (Stevens, 1972)
  - ✓ A-weighted Sound Exposure Level(ASEL) (ANSI S1.42-2001, 2001)

“Shaped” axi-symmetric body of revolution

Configuration

Parameters	Values	Unit
Mach number	1.6	-
cruise altitude	15,849.6	m
propagation start distance, R	128.93	m
R/L	3.0	-
ground reflection factor	1.9	-
heading	toward east (x direction)	
role angle	-45, 0, 45	deg

Required/Optional Data

Required

- ✓Ground signatures and sampling frequency
- ✓Lateral cut-off angles on both sides of the carpet

Optional

- ✓Ground signatures corresponding to the lateral cut-off
- ✓Loudness metrics (PL, ASEL) corresponding to all the ground signatures
- ✓Loudness convergence history

Numerical Simulation Research Unit

Cases Considered

	Atmospheric Profile	Final Alt., m	Remarks
#1	Profile 3	13	
#2	Standard Atm.	0	NO wind
#3	Profile 4	724	
#4	Standard Atm.	0	NO wind, RH=70% for all alt.

- ✓ Role angles of 0, 45, and -45deg for each case
- ✓ Sampling Frequencies of 2^n $(n = 0, \ldots, 7)$ and $24, 48, 51.2$[kHz]

	Role=0deg	45deg	-45deg
#1	Case1-1	Case1-2	Case1-3
#2	Case2-1	Case2-2	Case2-3
#3	Case3-1	Case3-2	Case3-3
#4	Case4-1	Case4-1	Case4-3

Numerical Simulation Research Unit

Atmospheric Profiles

	Atmospheric Profile	Final Alt., m	Remarks
#1	Profile 3	13	
#2	Standard Atm.	0	NO wind
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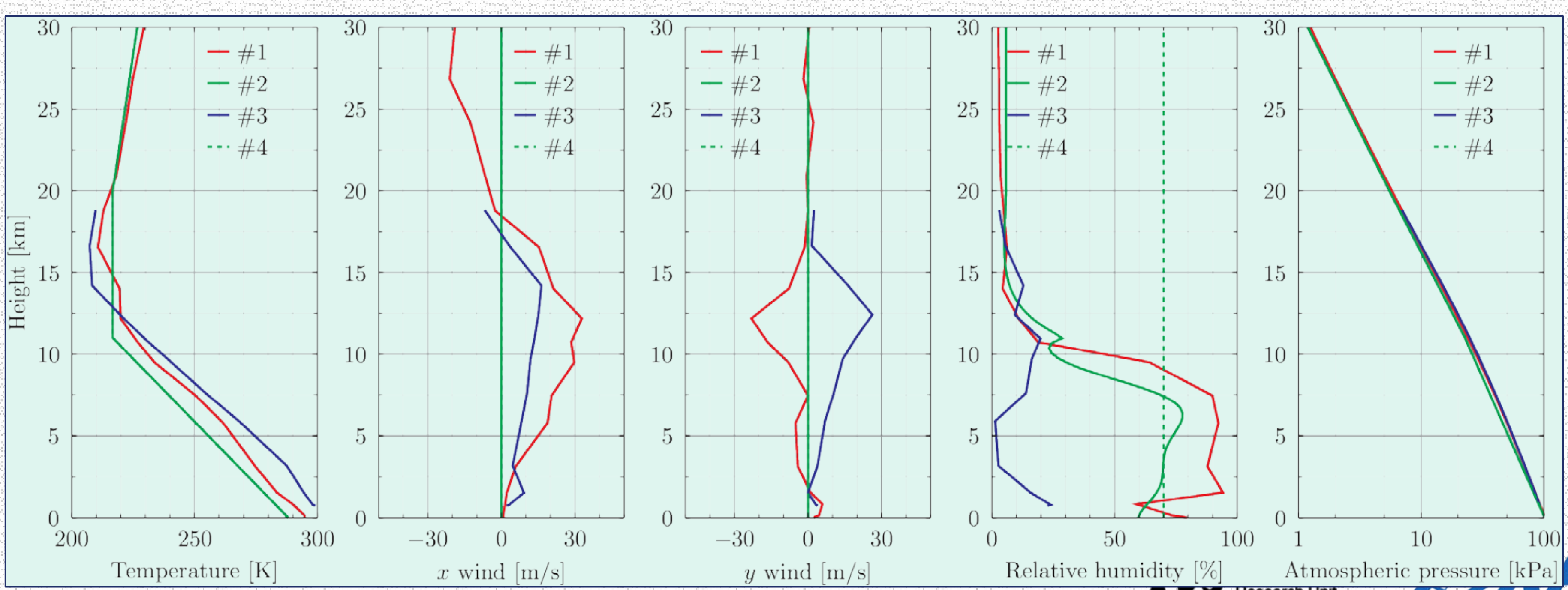
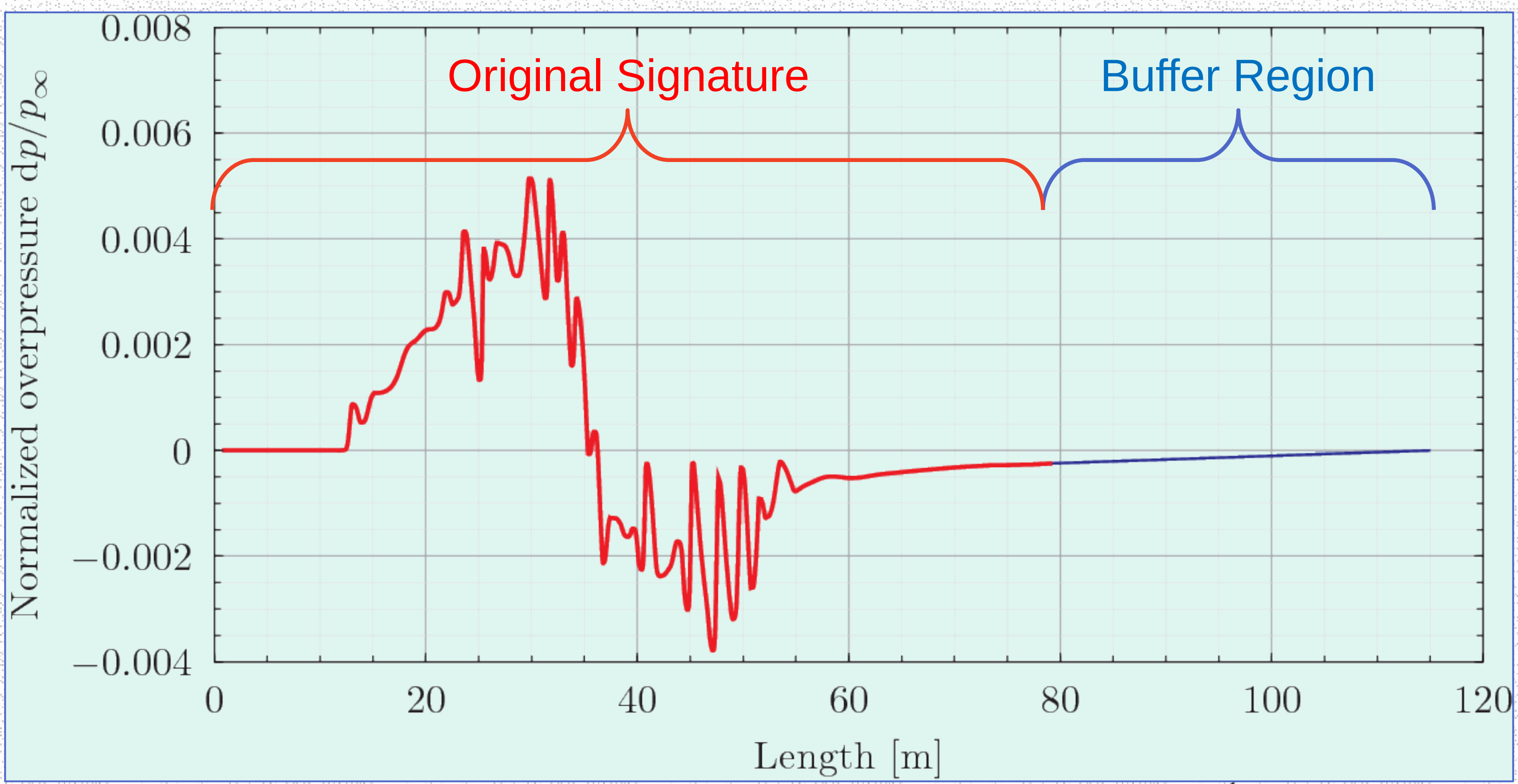
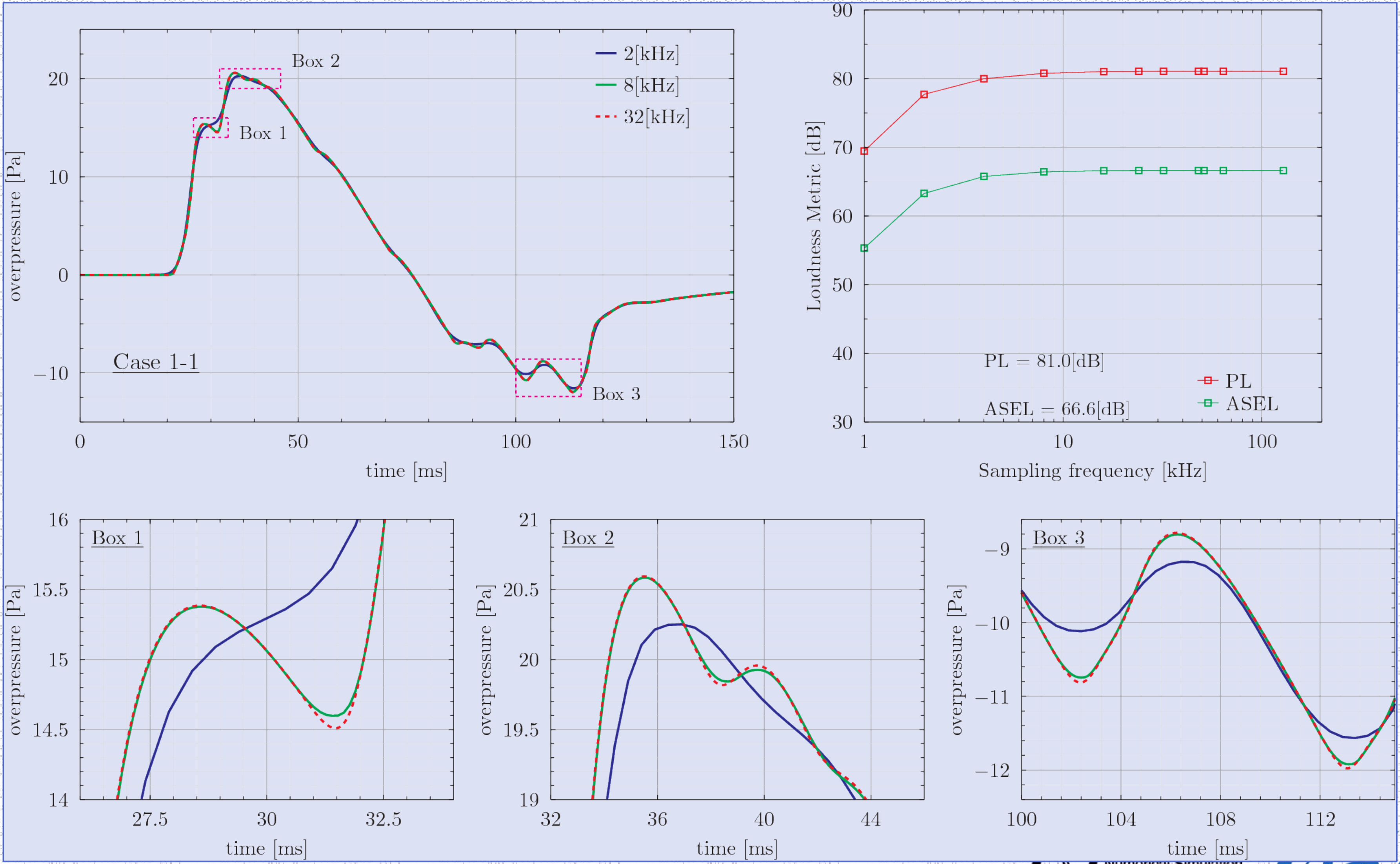


Nearfield (Input) Signature

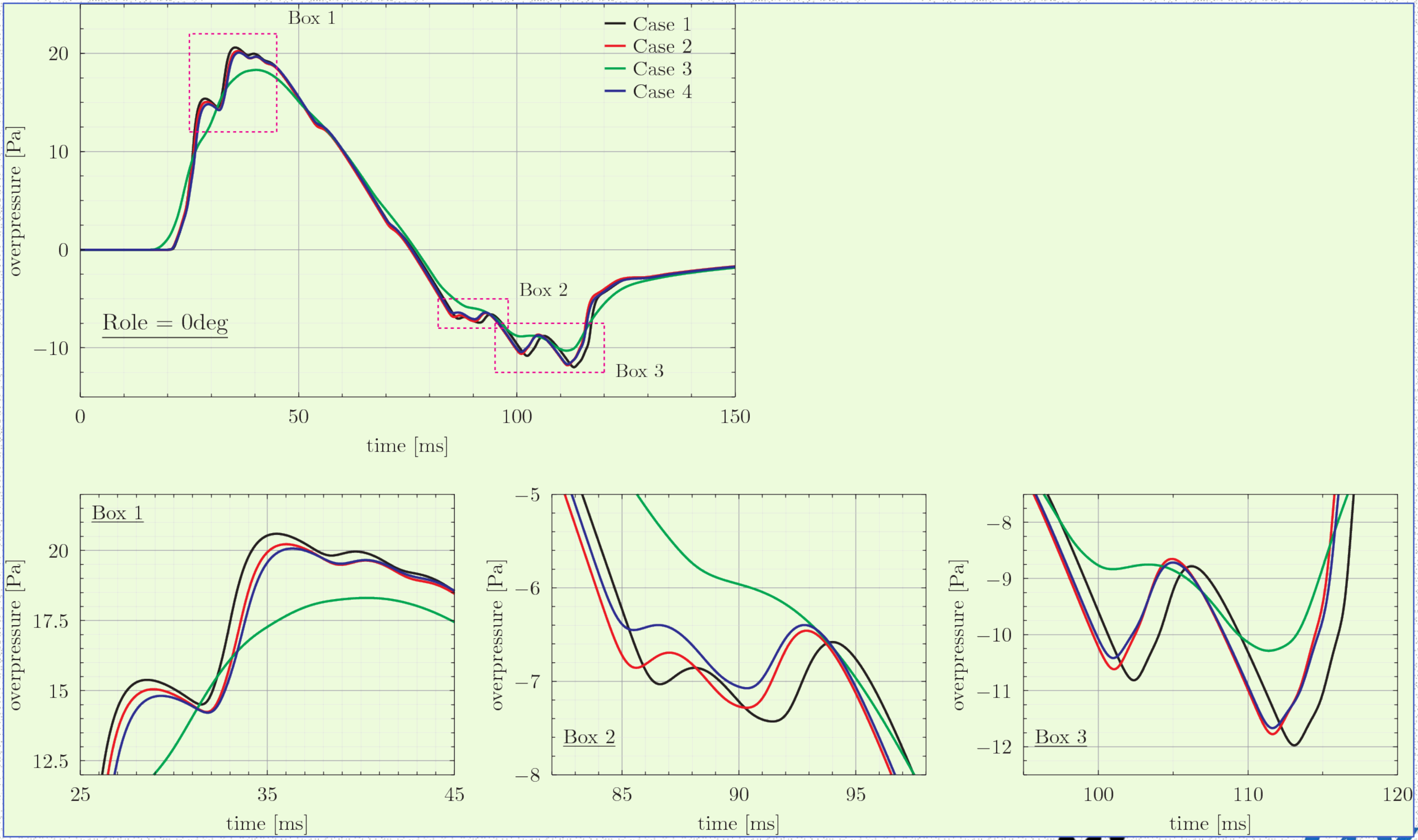
- ✓Only one signature is given (because of axi-symmetricity)
- ✓Buffer region is added to smoothly connect both edges



Resolution Study for Case1-1



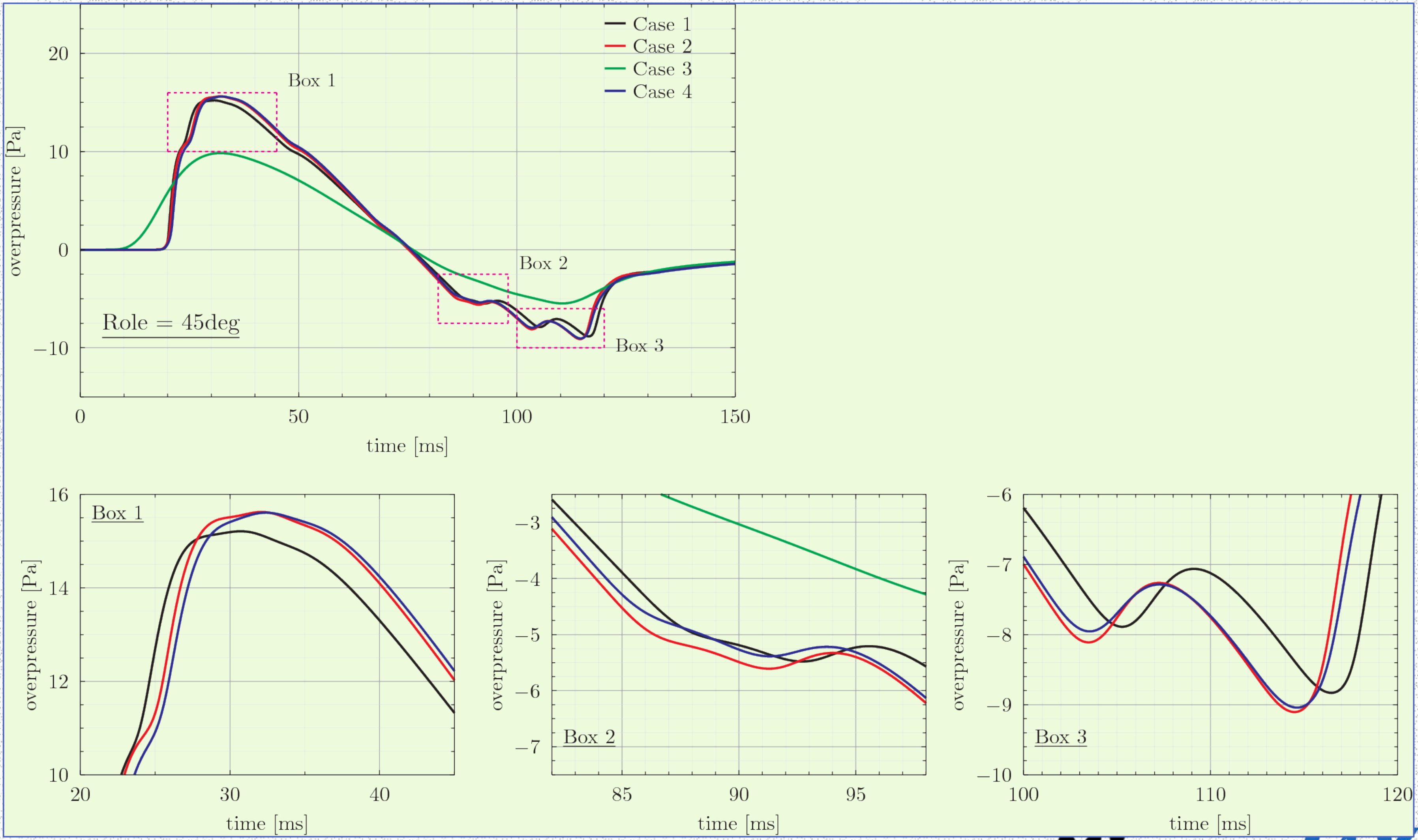
Summary of Role Angle of 0deg



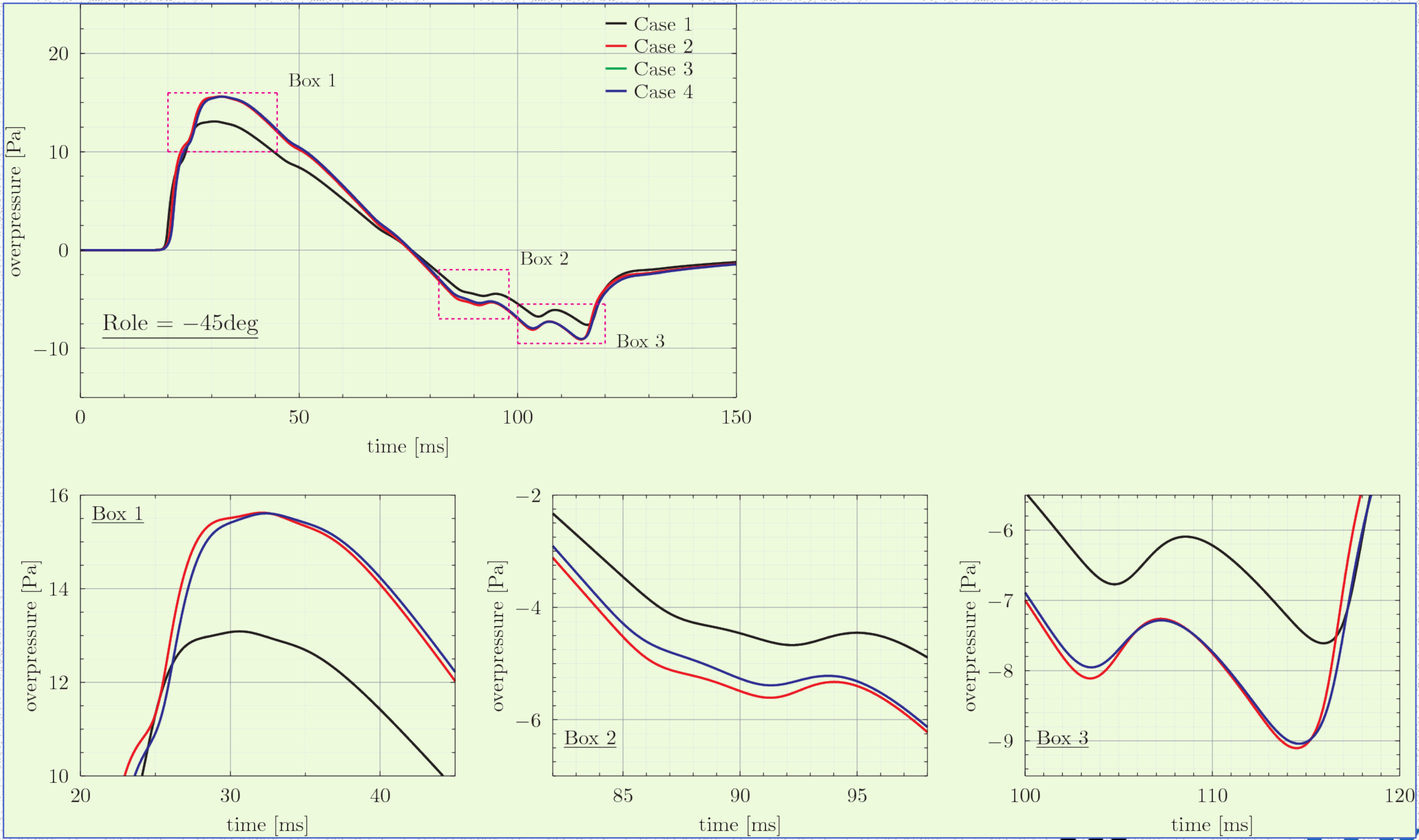
Numerical Simulation Research Unit

JAXA

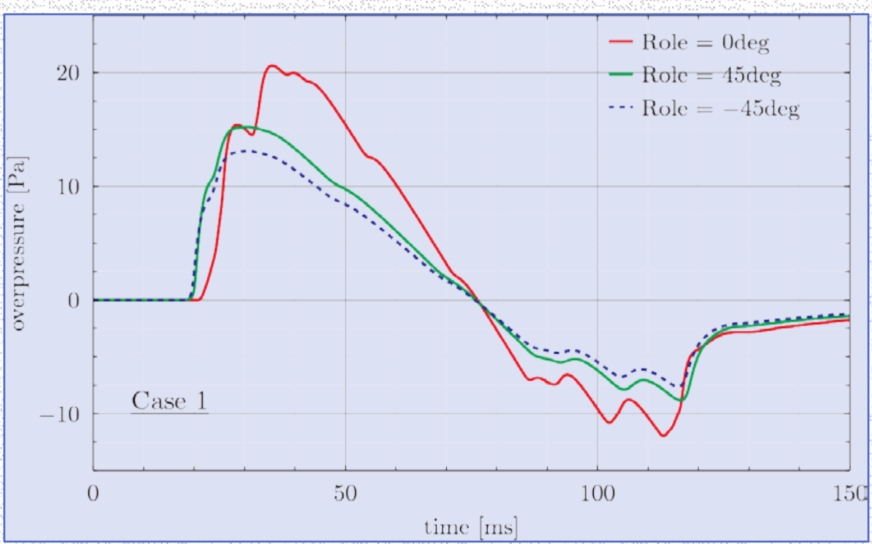
Summary of Role Angle of 45deg

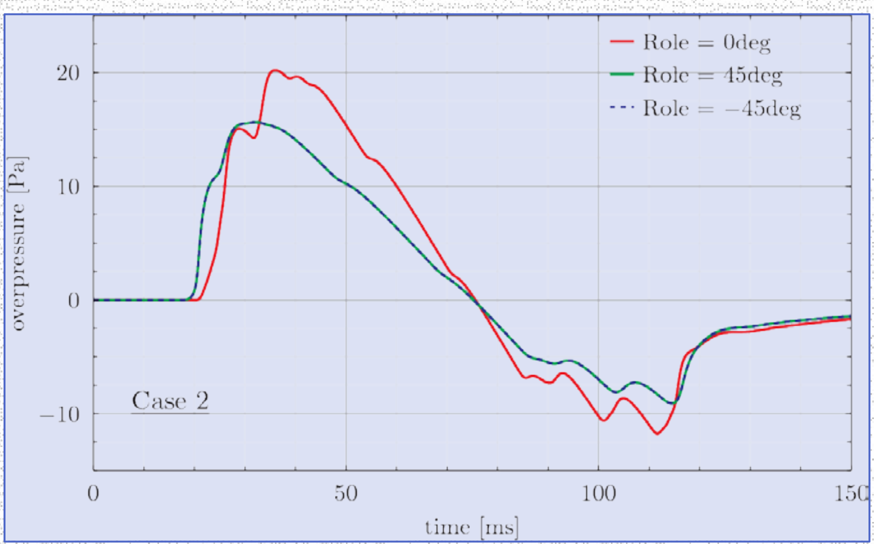


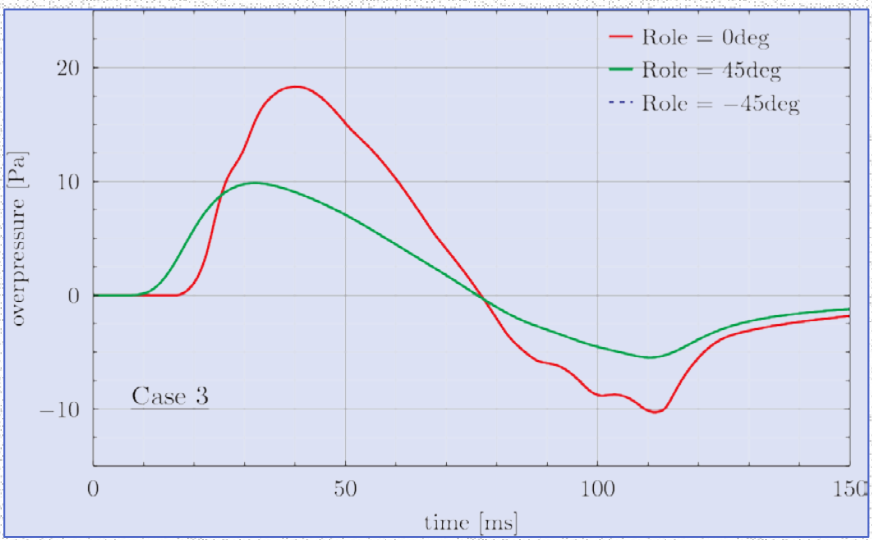
Summary of Role Angle of -45deg

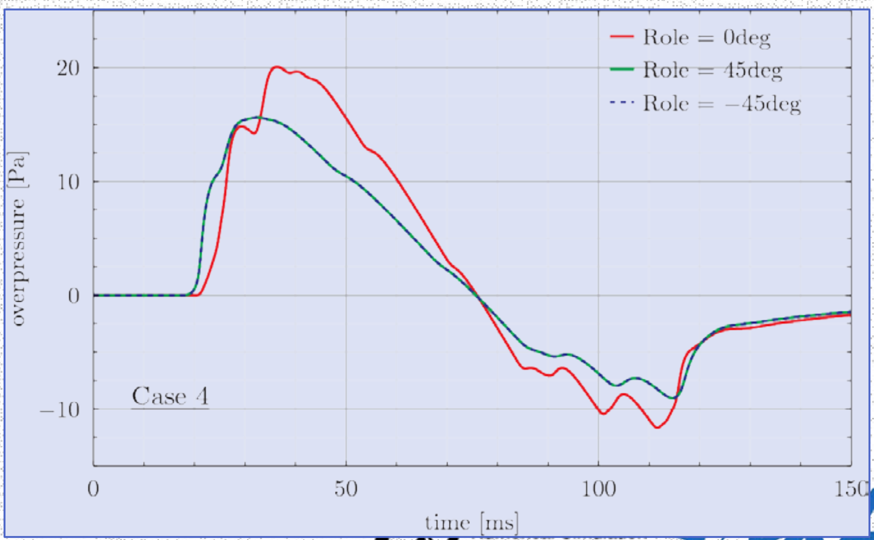


Summary for Each Case



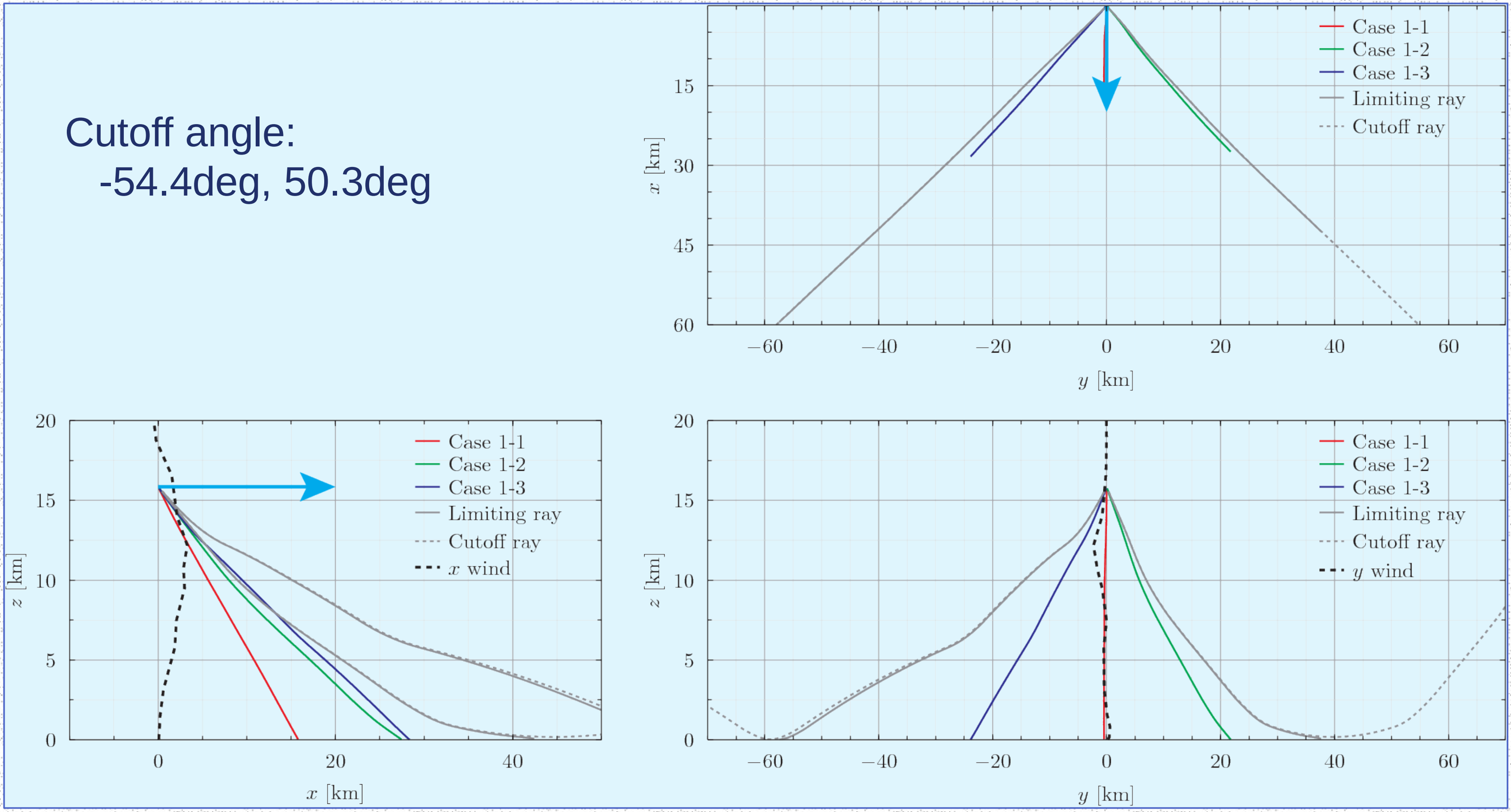






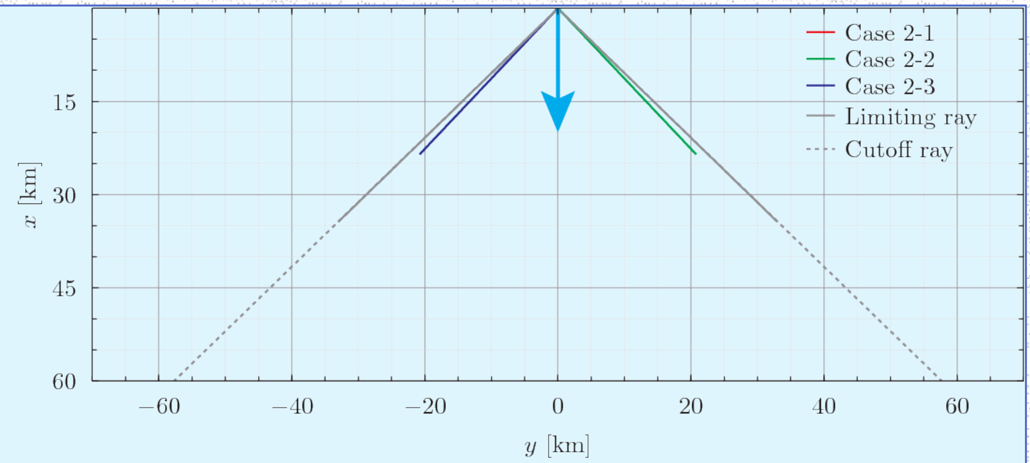
Summary of Rays and Cutoff for Case1

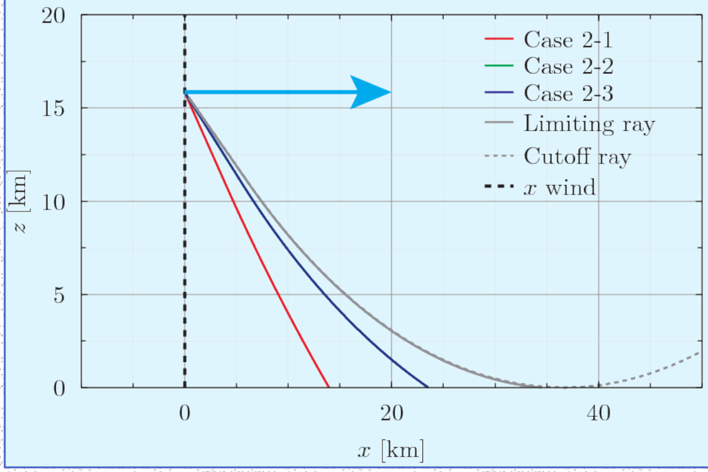
Cutoff angle:
-54.4deg, 50.3deg

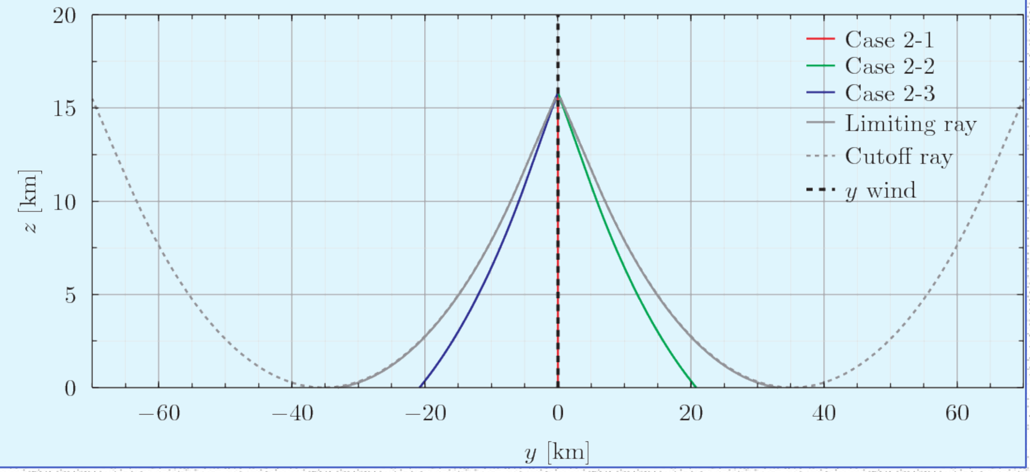


Summary of Rays and Cutoff for Case2

Cutoff angle:
-50.4deg, 50.4deg

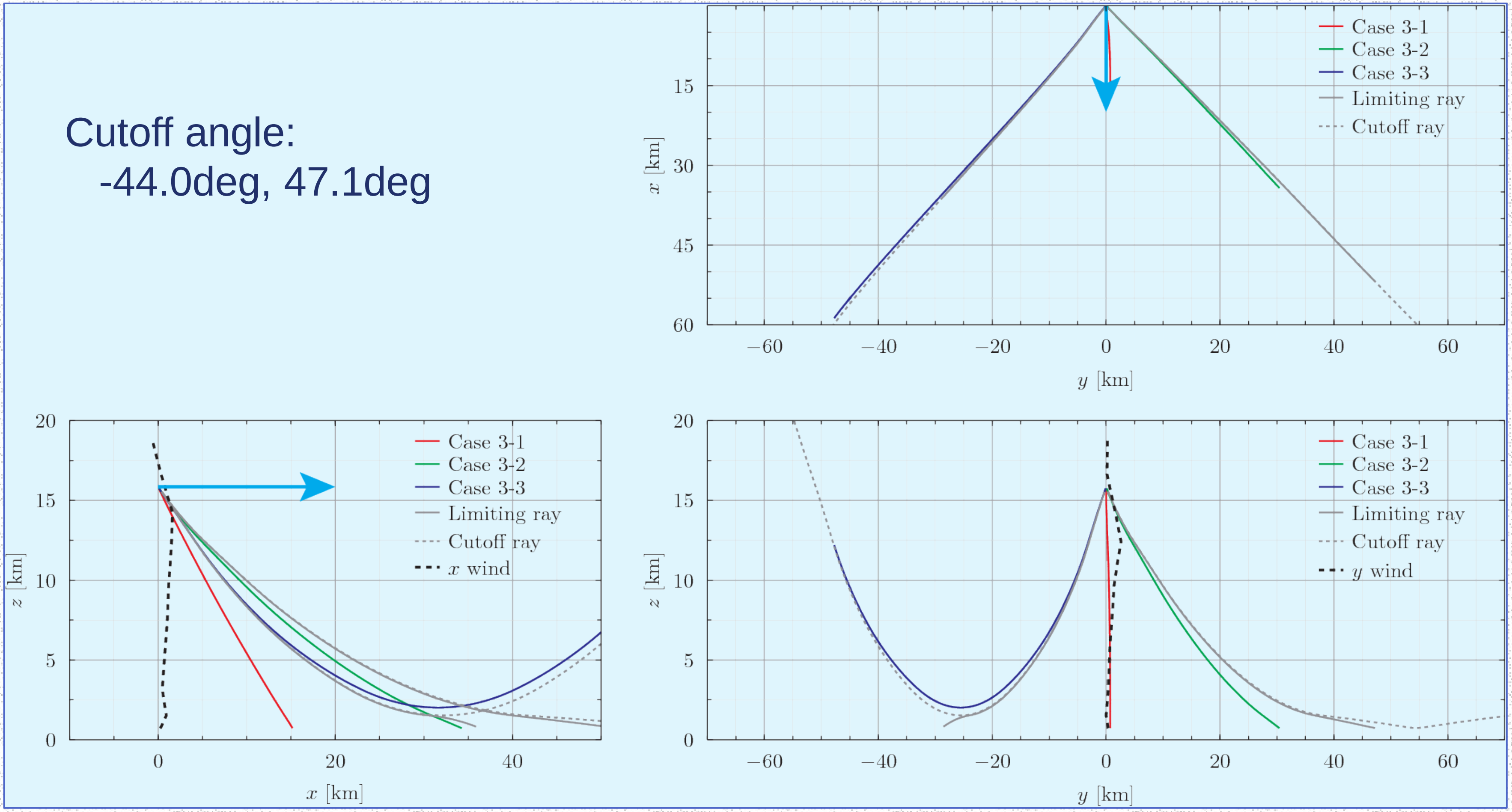






Summary of Rays and Cutoff for Case3

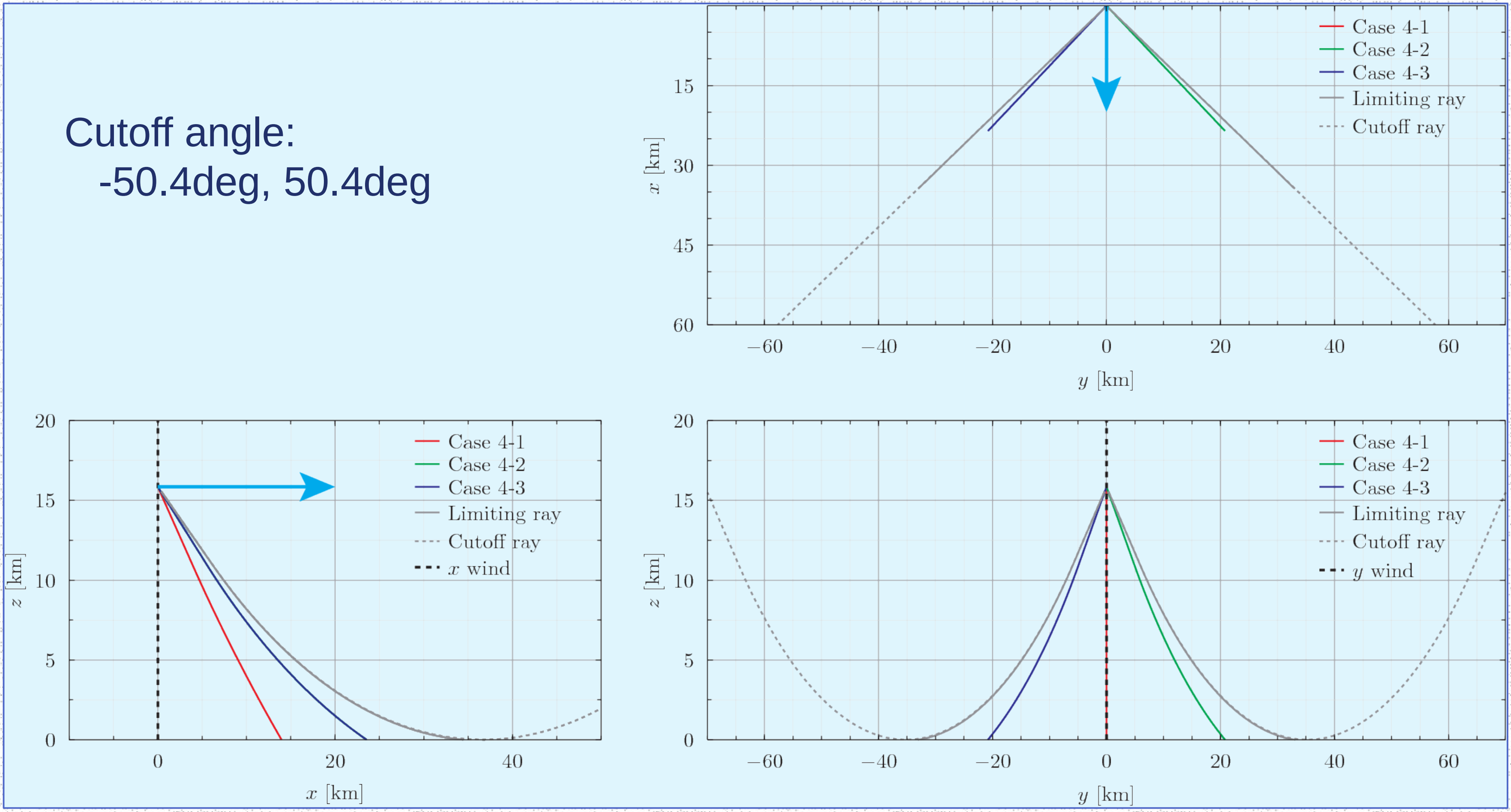
Cutoff angle:
-44.0deg, 47.1deg



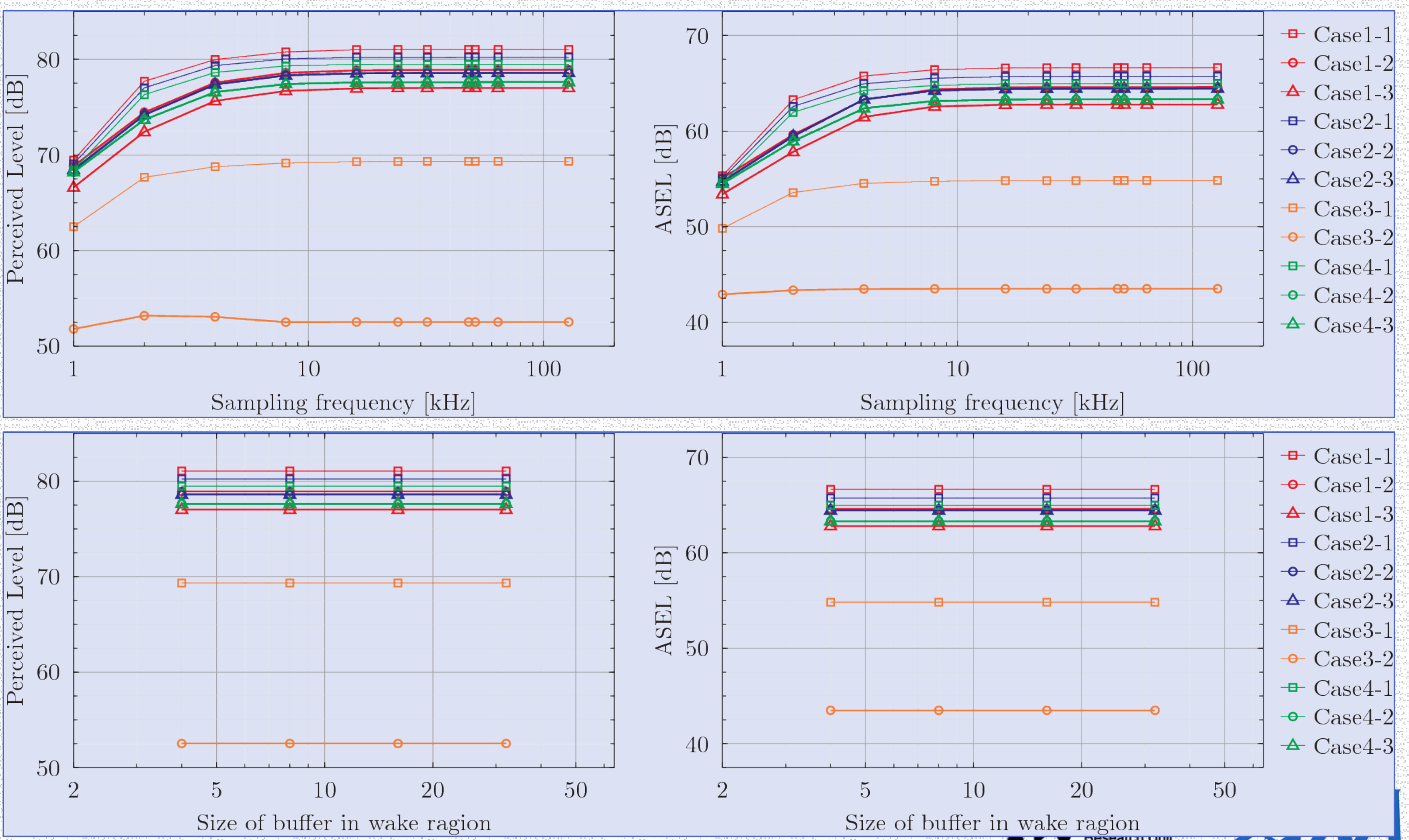
Numerical Simulation Research Unit

Summary of Rays and Cutoff for Case4

Cutoff angle:
-50.4deg, 50.4deg



Histories of Metric Convergence



Lockheed Martin 1021

Configuration

Parameters	Values	Unit
Mach number	1.6	-
cruise altitude	16,764	m
propagation start distance, R	222.59	m
R/L	3.1299	-
ground reflection factor	1.9	-
heading	toward east (x direction)	
role angle	-30, 0, 30	deg

Cases Considered

	Atmospheric Profile	Final Alt., m	Remarks
#1	Profile 1	214	
#2	Standard Atm.	0	NO wind
#3	Profile 2	214	
#4	Standard Atm.	0	NO wind, RH=70% for all alt.

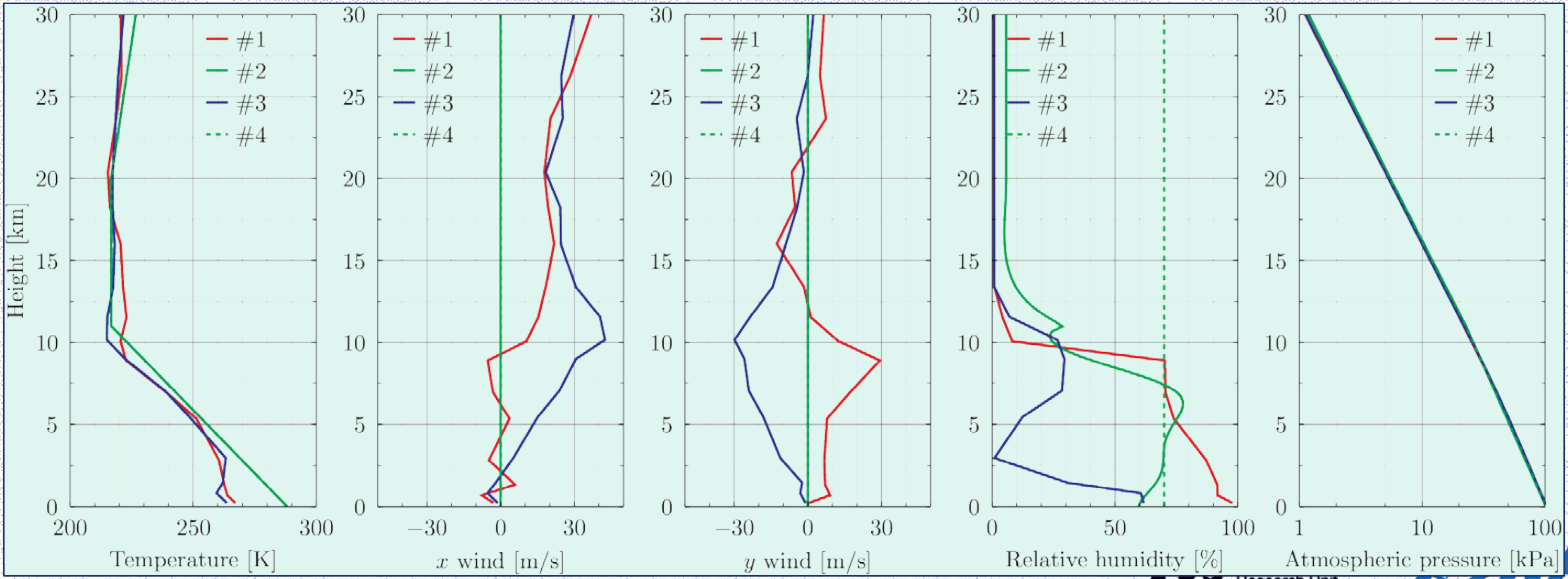
- ✓ Role angles of 0, 30, and -30deg for each case
- ✓ Sampling Frequencies of 2^n $(n = 0, \dots, 7)$ and $24, 48, 51.2$[kHz]

	Role=0deg	30deg	-30deg
#1	Case1-1	Case1-2	Case1-3
#2	Case2-1	Case2-2	Case2-3
#3	Case3-1	Case3-2	Case3-3
#4	Case4-1	Case4-1	Case4-3

Numerical Simulation Research Unit

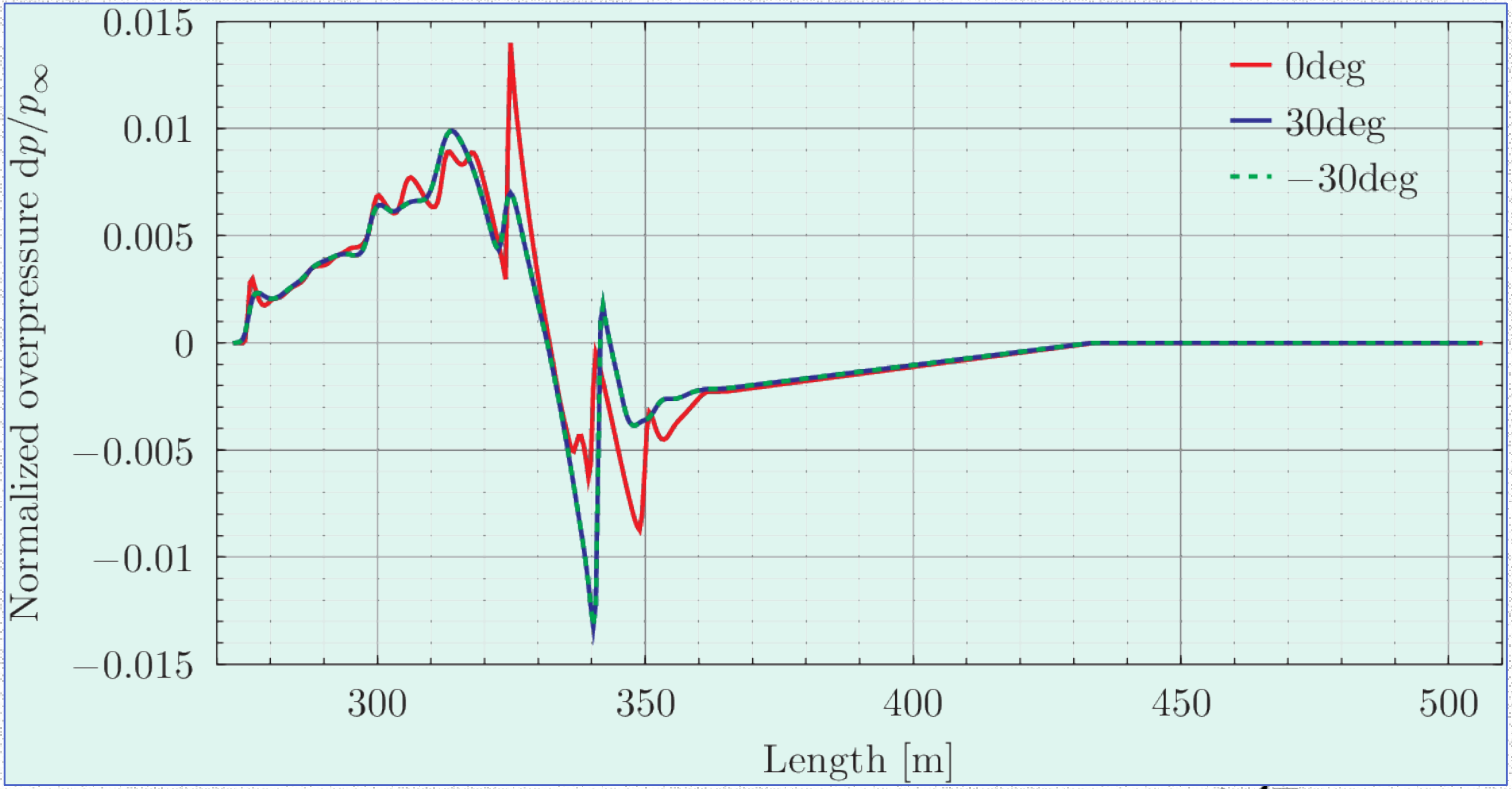
Atmospheric Profiles

	Atmospheric Profile	Final Alt., m	Remarks
#1	Profile 1	214	
#2	Standard Atm.	0	NO wind
#3	Profile 2	214	
#4	Standard Atm.	0	NO wind, RH=70% for all alt.



Nearfield (Input) Signatures

- ✓Three types of signatures (0, 30, -30deg)
- ✓Multipole analysis is not applied
- ✓dp/p is recovered to zero in the wake region



Numerical Simulation Research Unit

Required/Optional Data

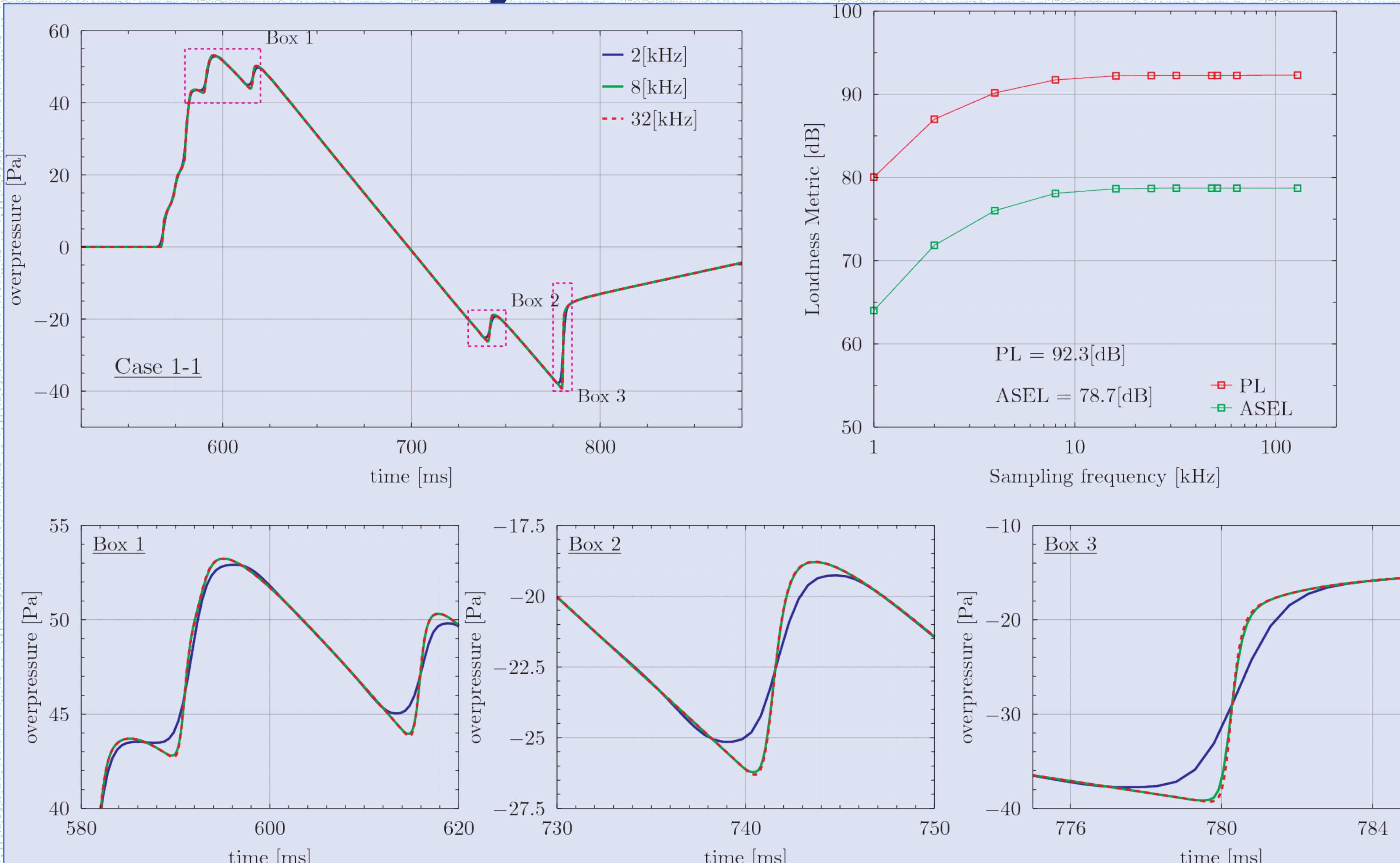
Required

- ✓Ground signatures and sampling frequency
- ✓Lateral cut-off angles on both sides of the carpet

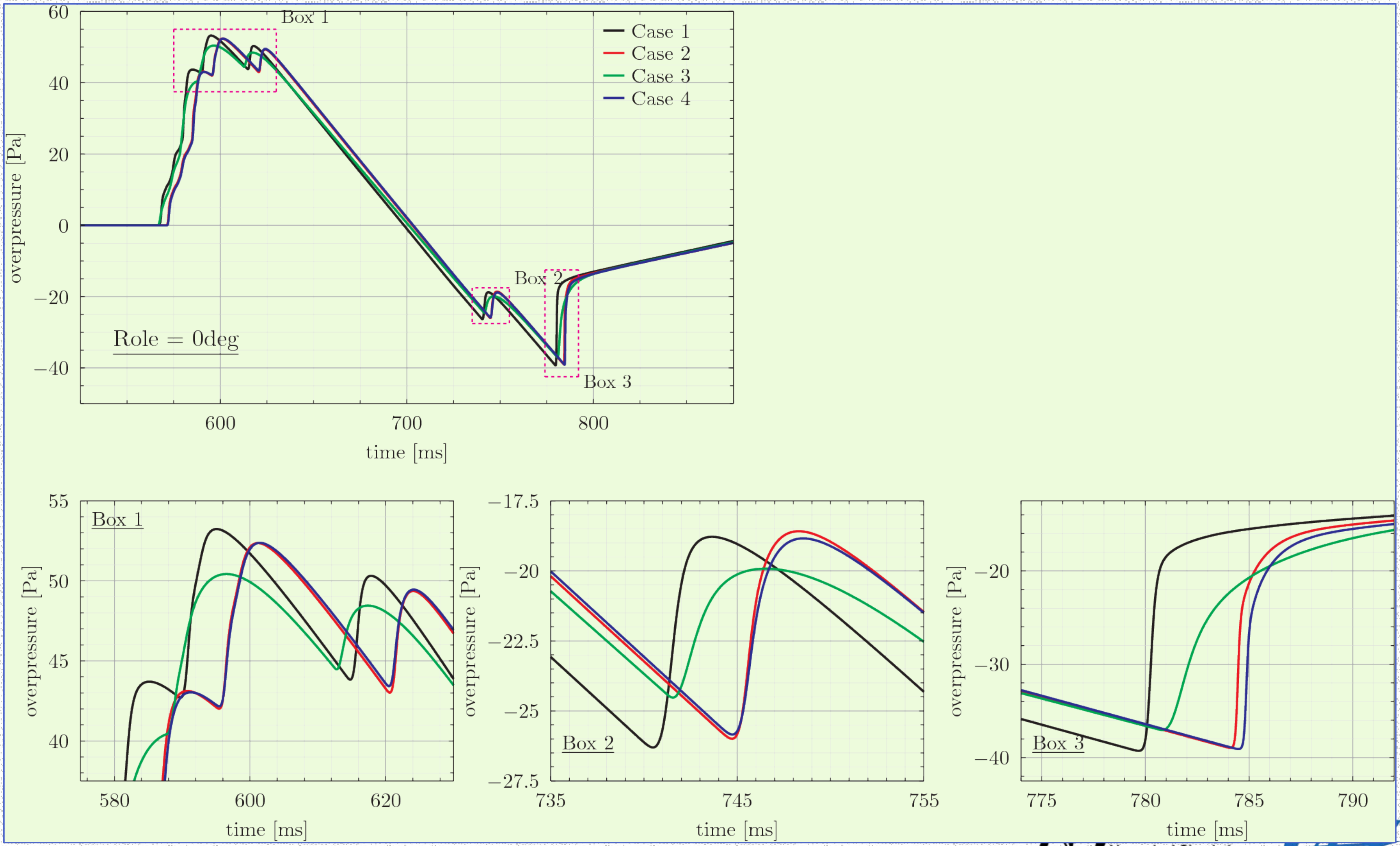
Optional

- ✓Ground signatures corresponding to the lateral cut-off
- ✓Loudness metrics (PL, ASEL) corresponding to all the ground signatures
- ✓Loudness convergence history

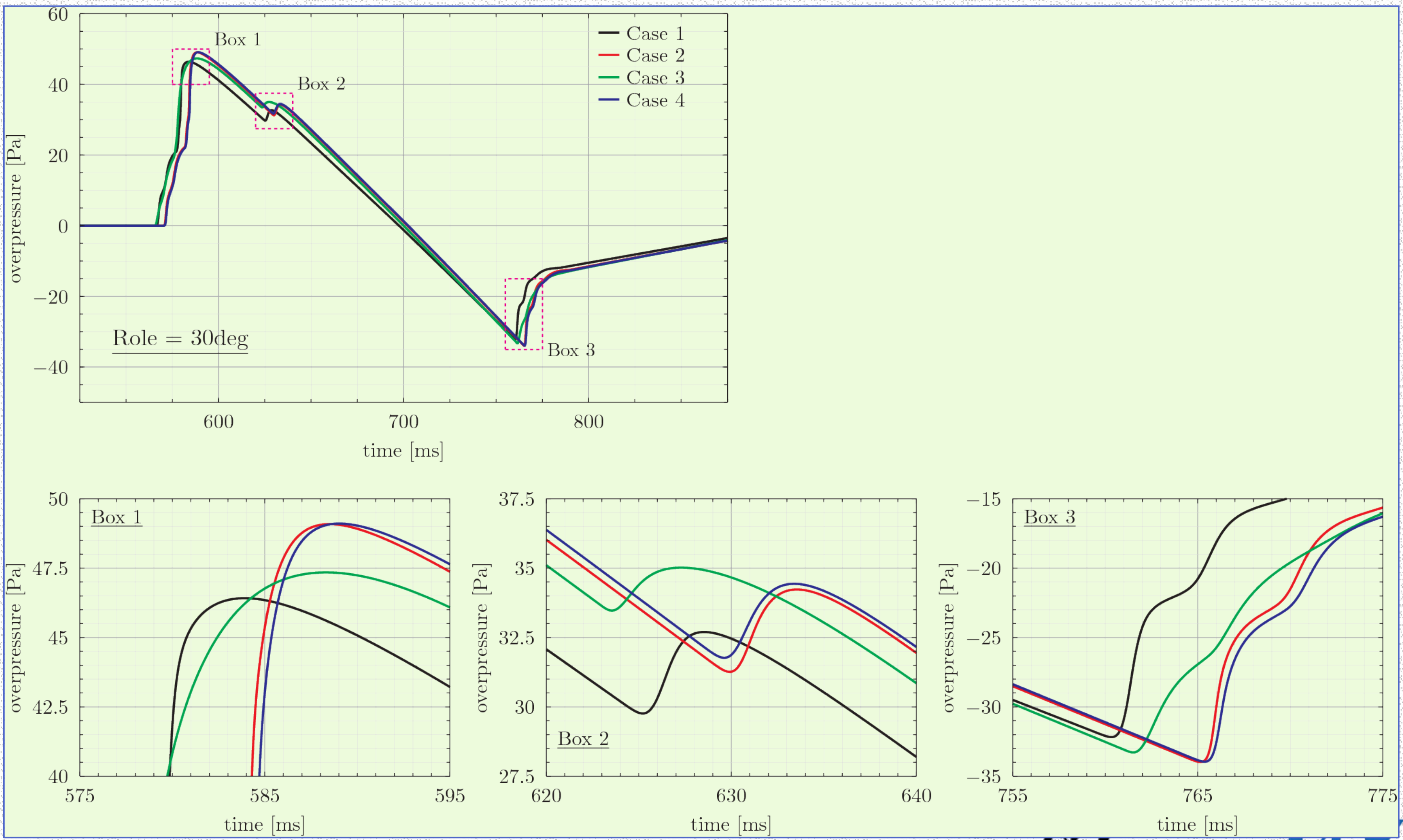
Resolution Study for Case1-1



Summary of Role Angle of 0deg

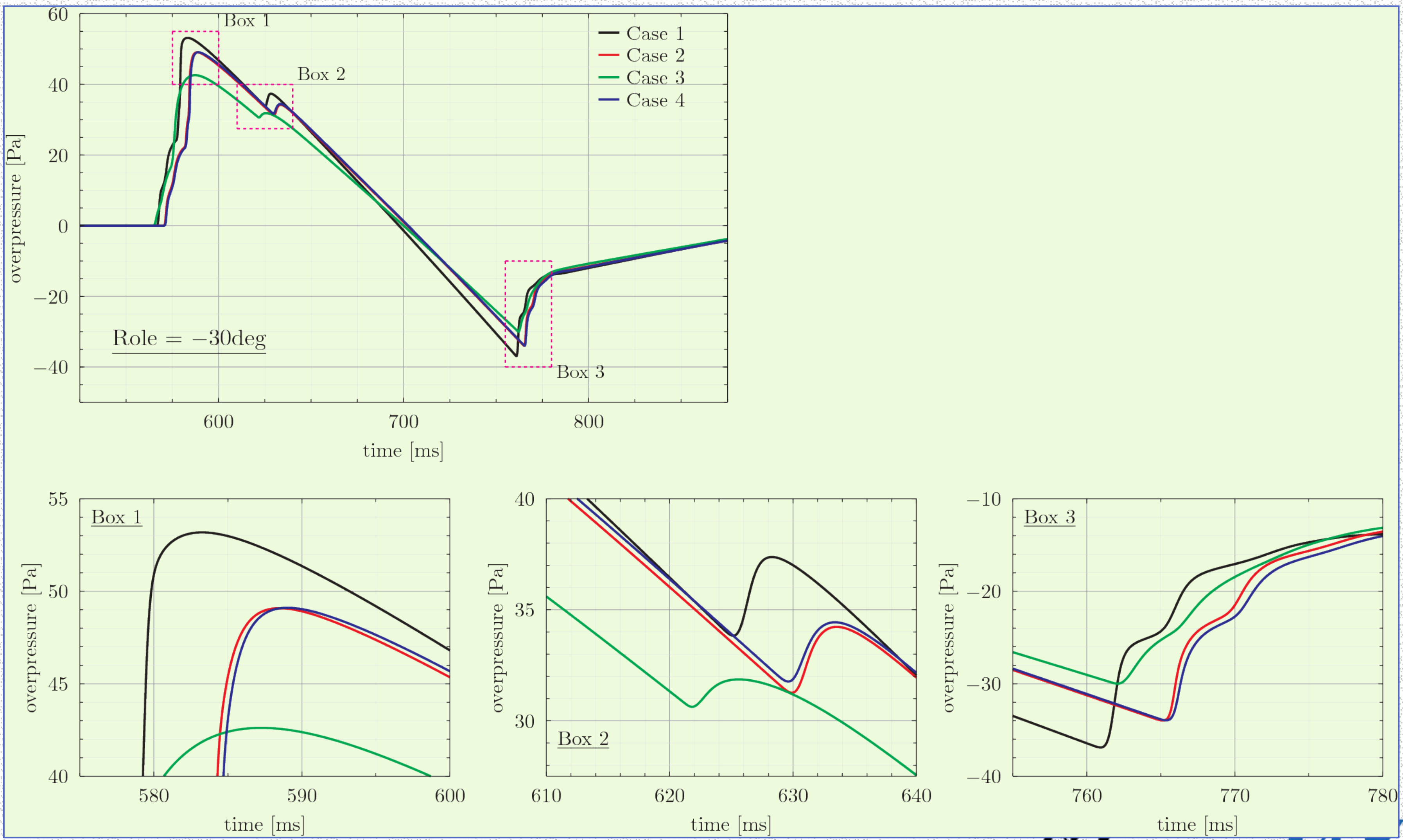


Summary of Role Angle of 30deg

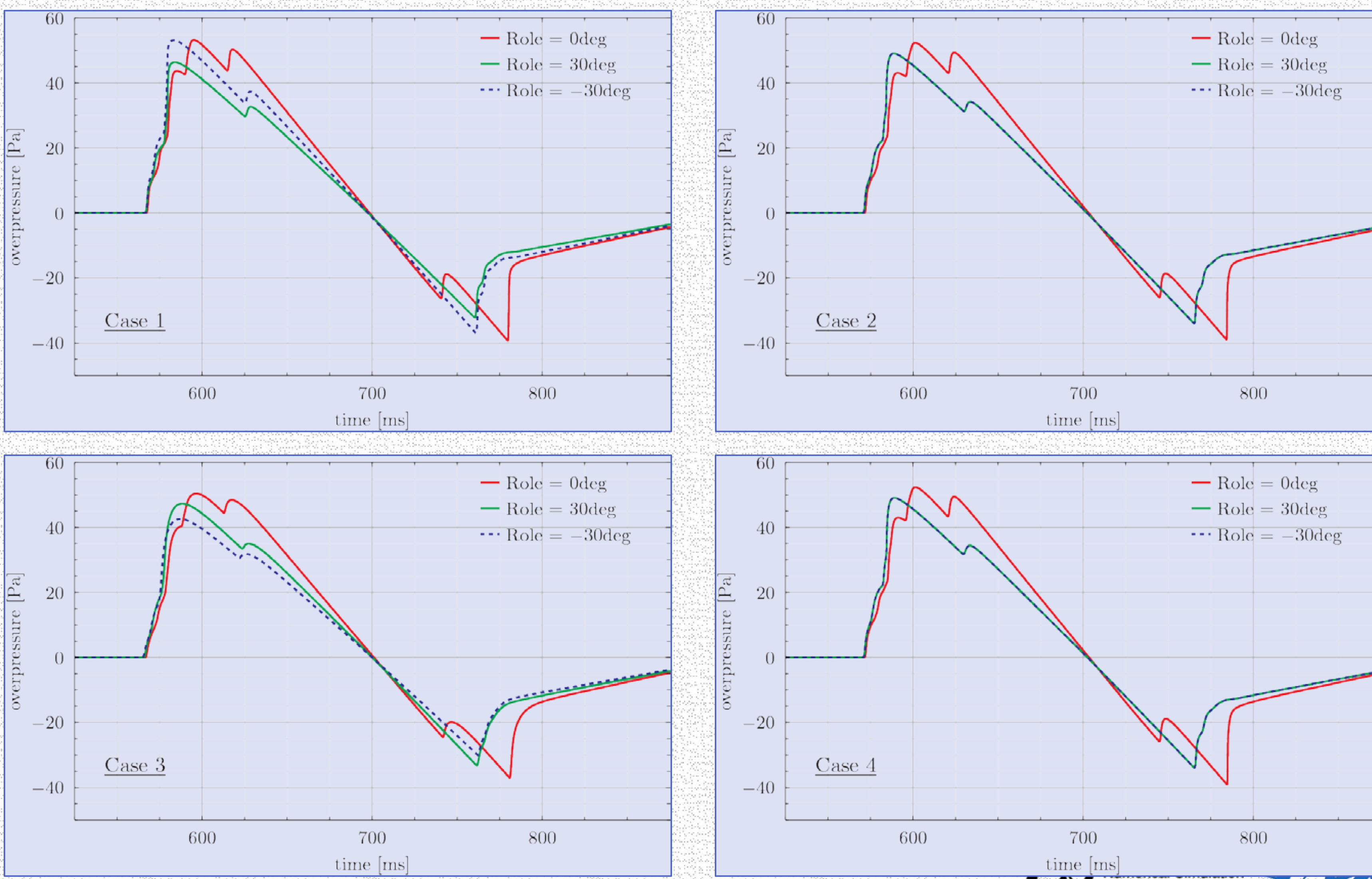


Numerical Simulation Research Unit

Summary of Role Angle of -30deg

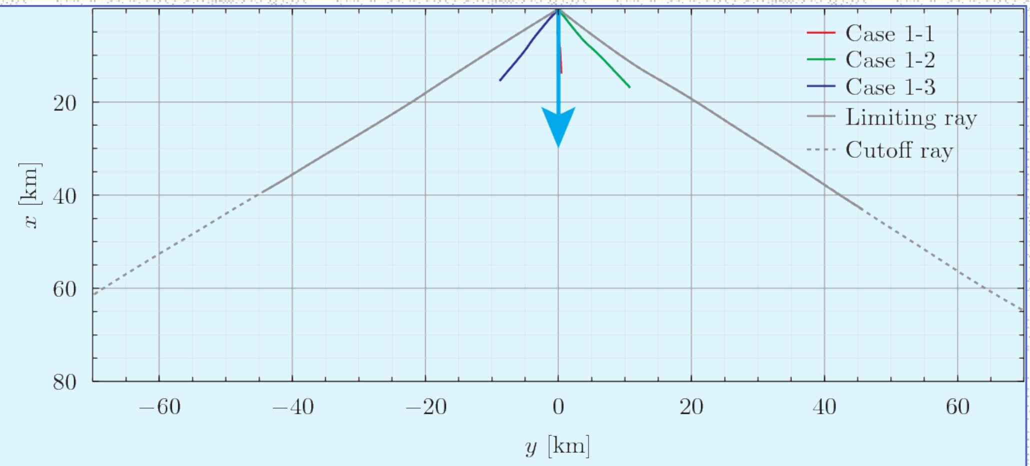


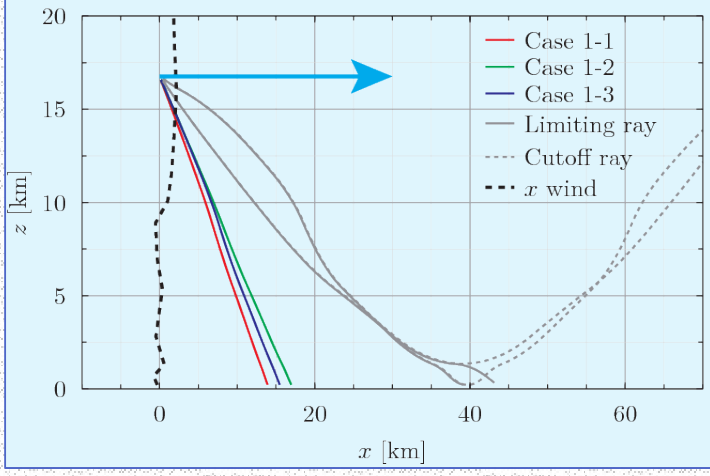
Summary for Each Case

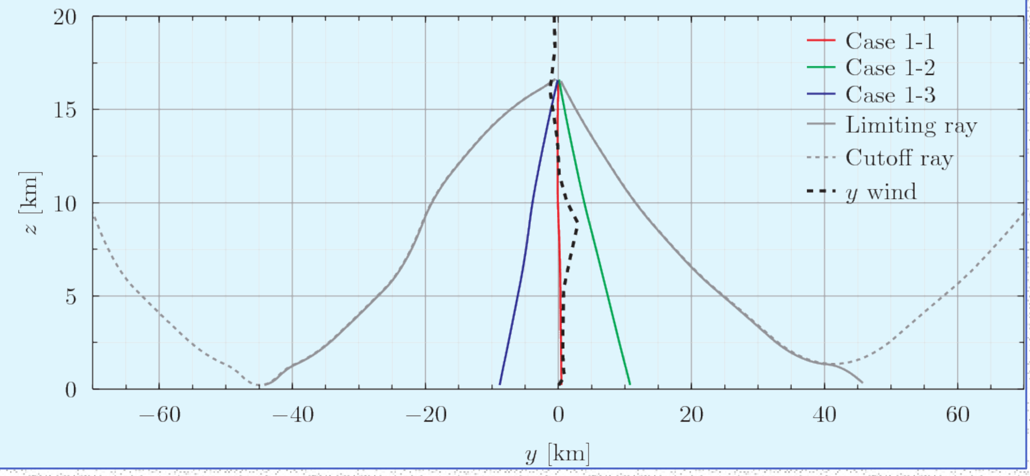


Summary of Rays and Cutoff for Case1

Cutoff angle:
-73.7deg, 57.5deg

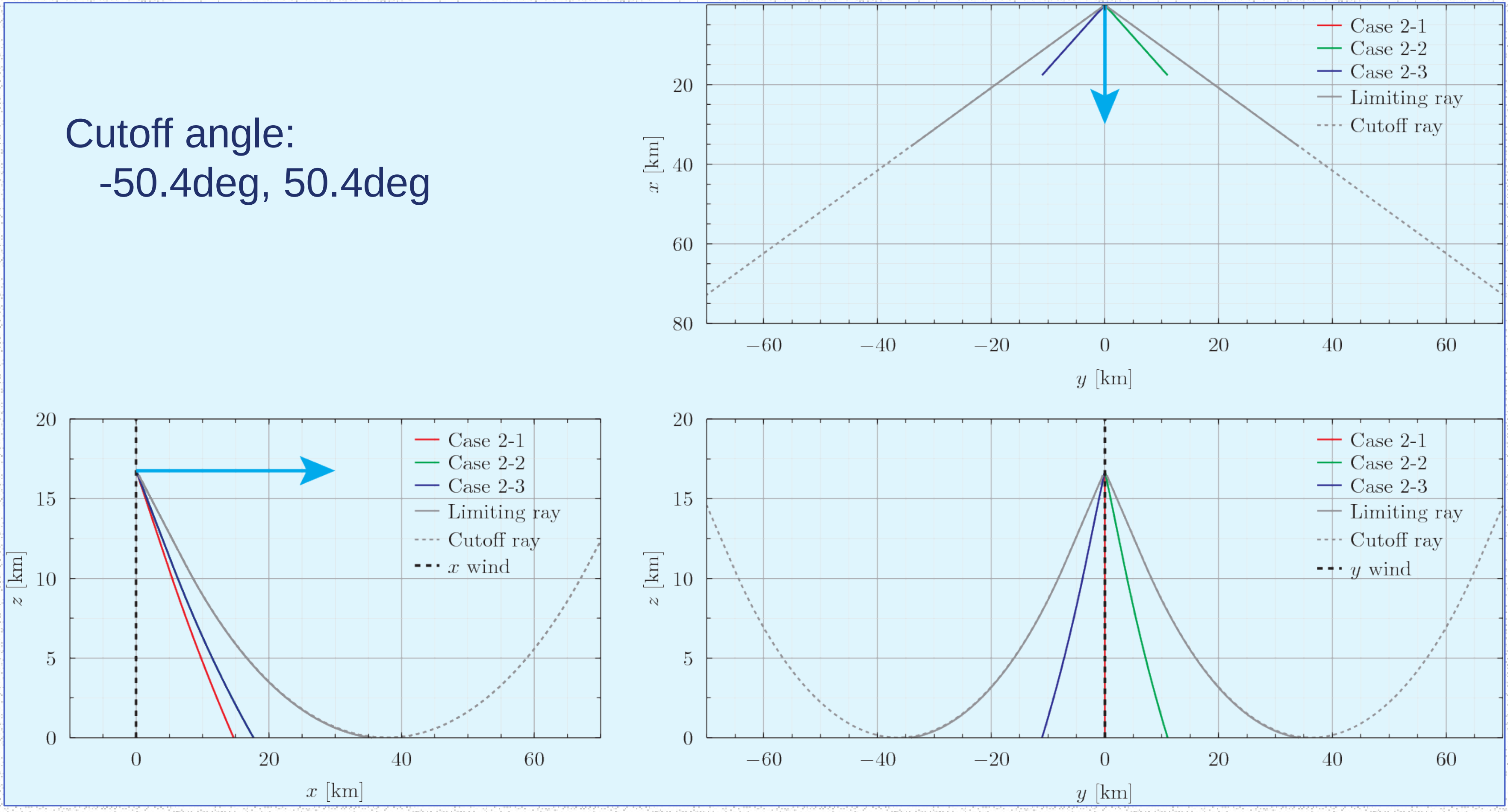






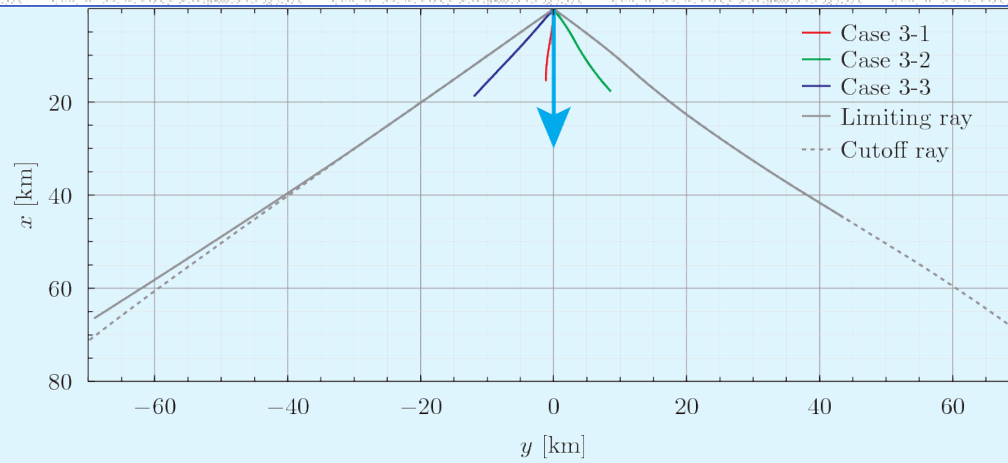
Summary of Rays and Cutoff for Case2

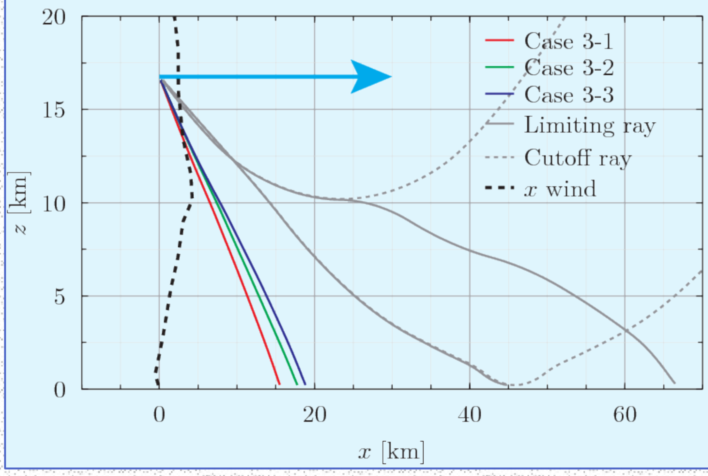
Cutoff angle:
-50.4deg, 50.4deg

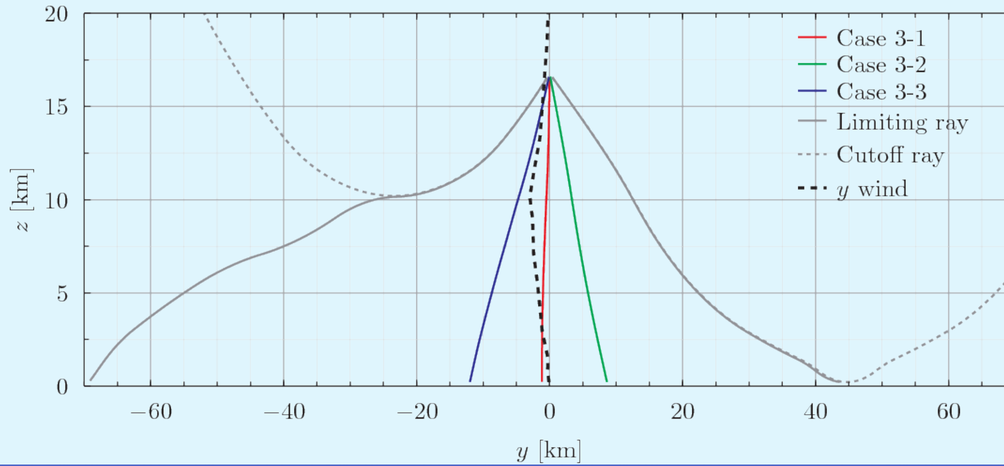


Summary of Rays and Cutoff for Case3

Cutoff angle:
-59.5deg, 65.1deg

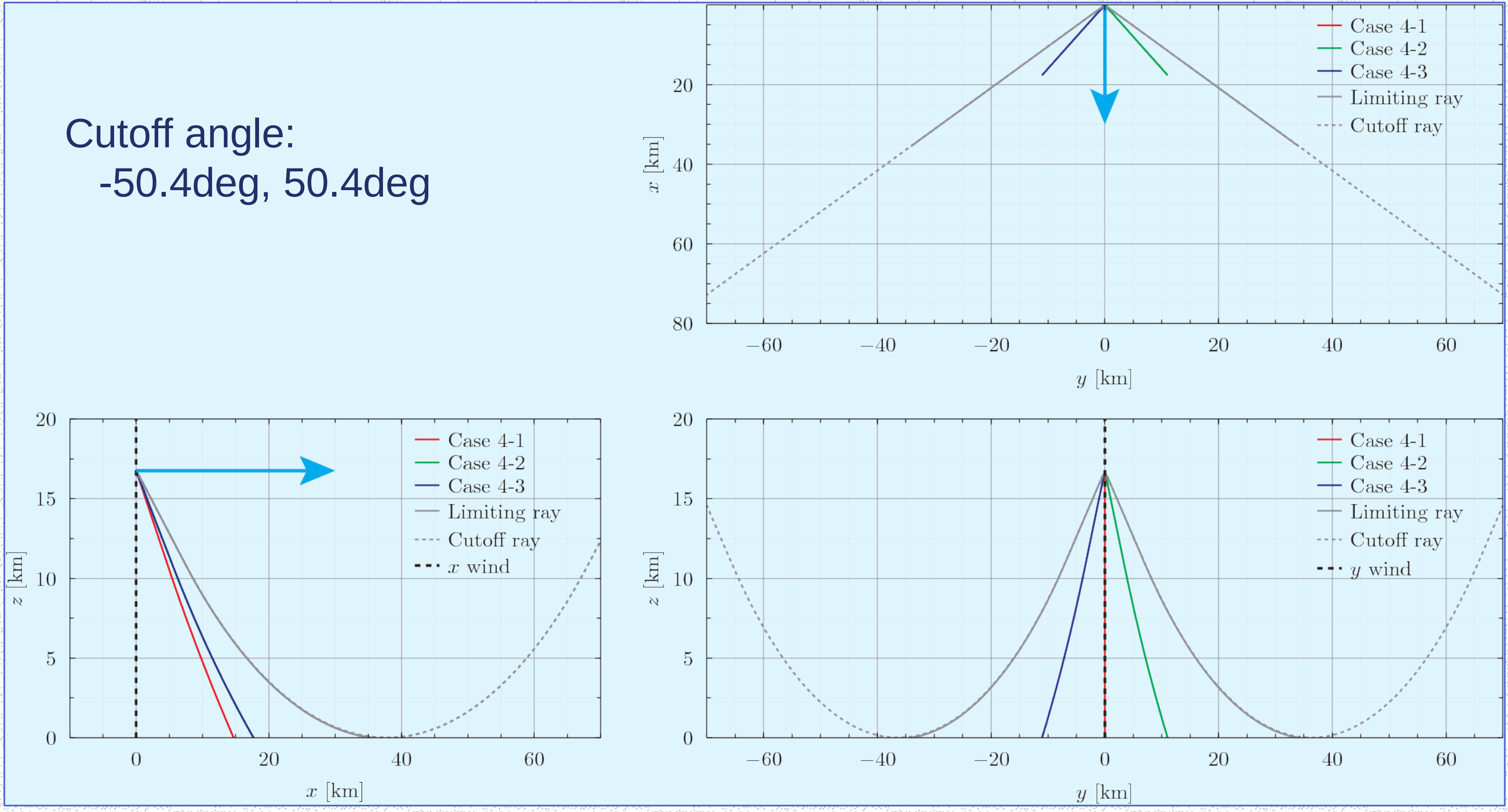




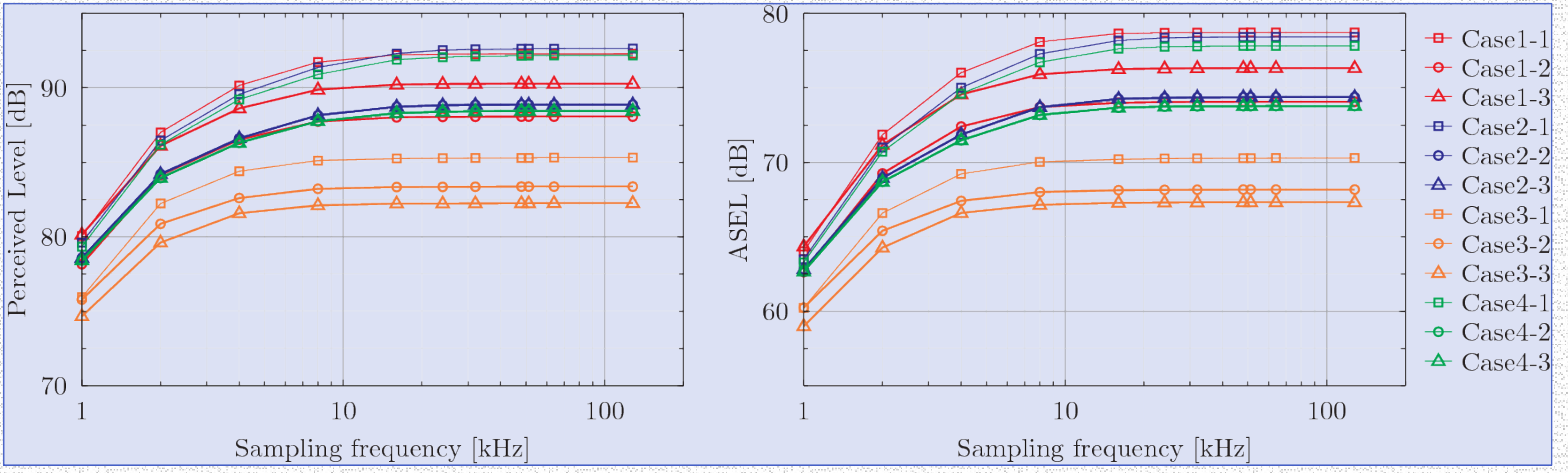


Summary of Rays and Cutoff for Case4

Cutoff angle:
-50.4deg, 50.4deg



Histories of Metric Convergence



Summary

- ✓ Almost all the signatures converge with respect to loudness level for sampling frequency greater than 10[kHz]

- ✓ Deformation of waveform:
  - ✓ relative humidity(RH) has a strong impact; low RH results in more dissipated waveform

- ✓ Variation of ray path:
  - ✓ Cutoff angle changes drastically due to wind and temperature distribution
  - ✓ RH has almost no impact; difference in RH results in the same ray path

Numerical Simulation Research Unit

Thank you for your kind attention!